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PACKARD

HP Fiber Optics Designer's Guide

Fiber Optic Components for Industrial Applications

Hewlett-Packard
A Leader in Components

A Brief Sketch

Founded in 1961, and headquartered in San Jose, California, the Hewlett-Packard Company's Components Group is the world's largest independent supplier of communications components. Today the group has approximately 11,600 employees, and had fiscal 1997 revenues of $1.5 billion (overall HP components revenues).

The Components Group includes four major divisions: Communication Semiconductor Solutions (CSSD), Wireless Infrastructure (WID), Optoelectronics (OED), and Integrated Circuit Business (ICBD), and serves five major markets: communications, networking, industrial, automotive, electronical signs and signalling.

Included in the Components Group's extensive line of more than 9,000 components are visible and infrared LED lamps; visible LED displays; light bars and arrays; Infrared Data Association (IrDA)-compliant infrared transceiver modules; fiber-optic transceivers, transmitters and receivers meeting most of today's industry standards; motion control devices; optocouplers and related optically-isolated control components; bar-code components; RF and microwave semiconductors; and communications amplifiers and assemblies. HP offers the world's brightest LEDs and is a technical leader for visible III-V products.

The Components Group markets products through a sales force of 375 technically-educated sales professionals located in about 45 countries. HP components are also sold through a worldwide distributor network with more than 200 locations. Altogether, 70 percent of sales revenues are from customers external to HP.

The Components Group maintains five marketing centers worldwide in San Jose, California; Boeblingen, Germany; Tokyo, Japan; Pinewood, UK; and Hong Kong. Each is fully staffed with product application and support engineers and each is responsible for regional decision making. A design center in Tokyo is specifically chartered to develop products for the Japanese market.

Local decision-making is central of HP's transnational business strategy which focuses on customer satisfaction. In addition to providing the right product with superior quality and reliability, the Components Group strives to ensure worldwide product availability, accurate ontime delivery and up-to-date technical information for its customers.

Quality and Reliability

Quality and reliability are very important concepts to Hewlett-Packard in maintaining the commitment to product performance.

At Hewlett-Packard, quality is integral to product development, manufacturing, and final introduction. HP's commitment to quality means that there is a continuous process of improvement and tightening of quality standards. Manufacturing quality circles and quality testing programs are important ingredients in HP products.

Reliability testing is also required for the introduction of new HP components. Lifespan calculations in "mean-time-between-failure" (MTBF) terms are published and available as reliability data sheets. HP's stringent reliability testing assures long component lifetimes and consistent product performance.

Information about the Components Group and its products can be found on the World Wide Web at:
www.hp.com/go/components

About This Guide

To help you choose and design with Hewlett-Packard fiber optic components, this guide contains product selection guide, fundamental informations on digital fiber optic links, recommended reference designs, detailed product specifications and application notes.

How to order

To order any component in this guide, call your nearest HP authorized distributor.

A complete listing of HP authorized distributors in Europe is located at the end of this guide. These distributors can offer off-the-shelf delivery for most HP components..

Service and Support

For technical assistance call your nearest HP authorized distributor.

For additional Information

Information regarding Hewlett-Packard fiber optic components is available on the World Wide Web at: **www.hp.com/go/fiber**

Literature is available regarding other HP components Group products not listed in this catalog:

- LED Lamps and Displays
- Infrared Products
- RF and Microwave products
- Optoisolators
- Motion Sensing and Control Products
- Bar Code Components
- High Speed Fiber Optic and Integrated Circuit Components

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Table of Contents

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Fiber Optic Components for Industrial Applications

Introduction

Optical fiber as a transmission medium is gaining acceptance in many areas of technology because of its inherent benefits over copper media, and continuing efforts to reduce the cost of fiber optic links are making them cost competitive with wire assemblies.

In the market for factory automation and industrial control, fiberoptic link assemblies have been found to be cost-comparative with typical grades of twisted pair and coax cable.

Furthermore, fiber provides other advantages to wire such as voltage isolation and electromagnetic immunity, which are common problems in industrial environments.

Benefits of Optical Fiber over Copper Wire

For industrial applications, many problems arise when using copper wire assemblies which can be eliminated with fiber-optic cable. The following is a list of benefits a fiber optic link assembly will provide:

Electromagnetic Immunity/ Transmission

Copper transmission media are susceptible to electromagnetic fields and emit EM noise (which may interfere with other instrumentation.) Fiber optic links neither emit nor receive these signals. Because there is no crosstalk between lines, the signal is clearer and bit error rate (BER) is reduced.

Voltage Isolation

While optocouplers will often isolate high voltage interfaces from delicate CMOS circuitry up to 600 Volts, fiber is needed for higher voltages. Fiber also is used for isolation in longer distance links between equipment where ground loop problems may occur due to differences in potential. Furthermore, fiber provides voltage isolation to the operator and eliminates the risk of I/0 board destruction due to a lightning strike or power surge.

Data Rate/Distance

While copper links perform well at low data rates for industrial applications, some control applications may require higher data rates and longer distances. For instance, a factory PLC might run on an Ethernet LAN (20 MBd). At this data rate, category 5 UTP limits the distance obtainable to 185 meters, but with SpecTran's HCS® (hard clad silica) fiber and 650 nm LED technology, the link can run up to 1 kilometer. If you need even longer distance, 62.5 µm core, graded-index glass fiber and low-cost 820 nm LED technology will run the link up to 2.7 kilometers.

Ease of Handling

Many people have the misconception that fiber is a lot harder to use than wire. In reality, fiber is actually easier to handle. First of all, fiber is a lot lighter than wire, that's a big deal to the workers doing the installation. Also, the bend radius of fiber is tighter than that of wire, giving more flexiblity. These benefits, along with the distance you can achieve with fiber, give the installer a lot of choices. Different rooms, different floors, even different buildings can easily be linked with fiber-optic cable.

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Details of Industrial Fiber
A fiber-optic link assembly consists of an LED transmitter, a PIN photodiode receiver, fiber optic cable and connectors, and related circuitry, integrated or discrete. The LED transmitter has a lens designed to efficiently couple light into the specific fiber you are using. The wavelength of the LED also is optimized for the fiber. Different fibers may give you different data rates and distances, so it is important to choose carefully which fiber to use in order to achieve required performance, while minimizing cost.

Fortunately, for the industrial market, data rates and distances tend to be low compared to the LAN market. Therefore, industrial customers are able to use the lowest cost fiber link available to meet their specifications. The fiber-optic links typically used in these applications fall in the 650 to 665 nm wavelength spectrum, and operate over plastic, 1 mm diameter fiber.

The technology, design, and manufacturing techniques implemented by Hewlett-Packard make their fiber-optic products efficient, durable and low cost. HP has been in the forefront of fiber-optic communications from the very beginning as the largest independent supplier of communication products in the world. We are committed to using our unique combination of in-house. high-technology development along with our high-volume manufacturing processes to meet all of your fiber-optic datacom and telecom needs for data rates from DC to gigabit speeds and distances from 0 to Long-haul telecommunications.*

New Product Offerings!

Crimpless Connectors for Plastic Optical Fiber
The HFBR-453X family of connectors are an enhanced version of the HFBR-450X and HFBR-451X low-cost connectors for plastic optical fiber, which are compatible with HP's Versatile Link family of transmitters and receivers.

The innovative design uses a simple, snap-together concept which eliminates the need for crimping. This connector not only saves the user labor and tool cost, but reduces the yield loss due to installation error. The HFBR-453X family of connectors are available in two styles; latching and non-latching.

10 MBd Versatile Link Fiber-Optic Transmitter and Receiver
The 650 nm HFBR-0508 family consists of a fiber-optic transmitter and receiver. The HFBR-1528 transmitter is an LED in a low-cost housing designed to efficiently couple power into 200 µm diameter hard clad silica (HCS®) fiber and 1 mm diameter plastic optical fiber (POF). The HFBR-2528 receiver incorporates a PIN detector and digital output IC compatible with CMOS and TTL logic families.

The HFBR-0508 links operate from dc to 10 MBd at distances up to 50 meters with 1 mm POF and up to 500 meters with 200 µm HCS®. No minimum link distances are required when using recommended circuits, thus simplifying design.

* Please contact your local sales office for further information on HP's high-performance fiber-optic data communications and telecommunications products to meet any standard.

SMA and ST® Fiber Optic Transmitter and Receiver for Fieldbus Applications
The 650 nm HFBR-0505 Series transmitters and receivers have similar optical and electrical performance with the 10 MBd Versatile Link. Designed for use in optical fieldbus applications as PROFIBUS, INTERBUS-S or SERCOS the transmitters and receivers are housed in a low cost, small footprint 1x4 simplex SMA or ST® port package. These can be used with low-cost plastic optical fiber (POF) or hard clad silica (HCS®) fiber.

125 MBd Versatile Link Fiber-Optic Transmitter and Receiver
The 650 nm HFBR-0507 family is the most cost-effective fiber-optic solution for transmission of 125 MBd data over 100 meters. The data link consists of a 650 nm LED transmitter, HFBR-15X7, and a PIN/preamp receiver, HFBR-25X6. These can be used with low-cost plastic optical fiber (POF) or hard clad silica (HCS®) fiber.

These components can be used for high speed data links without the problems common with copper solutions, at a competitive cost.

125 MBd JIS F07 (PN) Connection Fiber-Optic Transceiver
The 650 nm HFBR-5527 fiber-optic transceiver has compatible optical and electrical performance with the 125 MBd Versatile Link. The transceiver connector is compatible with duplex JIS F07, simplex JIS F05 and PN connectors. PN is an abbreviation for "Premise Networks". The housing design of the PN connector is almost the same as that of the F07 connector.

Product Family Summaries

Versatile Link (650 nm)

The HFBR-0501 Versatile Link is a complete family of fiber-optic link components for applications requiring a low-cost solution. The HFBR-0501 family includes transmitters, receivers, connectors, and cables specified for easy design. This family of components is ideal for solving problems with high-voltage isolation/insulation, EMI/RFI immunity or data security. The optical link design is simplified by the logic compatible receivers and complete specifications for each component. The key optical and electrical parameters of links configured with the HFBR-0501 family are fully guaranteed from 0° to 70°C.

Typical applications for the Versatile Link family include industrial control links, PC-to-peripheral links, local area networks, secure data transmission, and medical equipment.

Fieldbus (650 nm)

This family of 650 nm fiber optic link components is designed for industrial fieldbus applications. The transmitters and receivers comply with the optical specifications of well-known fieldbus standards; SERCOS, PROFIBUS, INTERBUS-S, with the respective ST® or SMA connector style. Plastic optical fiber and HCS® fiber is used with this components.

SERCOS, an acronym for **SE**rial **R**ealtime **CO**mmunication **S**ystem, is a standard digital interface for communication in industrial CNC applications. The standard was formed to allow data transfer between numerical controls and drives via fiber-optic rings. HFBR-1505A and HFBR-0600 series comply with SERCOS specifications for optical characteristics and SMA connector style.

PROFIBUS, an acronym of **PRO**cess **FI**eld **BUS**, is an open fieldbus standard defined for data rates ranging from 9.6 kBd to 12 MBd in selectable steps for wire and optical fiber. The ST® connector is the standard optical port of the PROFIBUS optical fiber version. The HFBR-1515B and HFBR-2515B complies fully to the technical guideline using Plastic Optical Fiber.

INTERBUS-S, a special open Sensor/Actuator Bus, is finding a broad acceptance in the factory automation industry. The HFBR-1505C was specially designed for this application and is recommended as a powerful transmitter for use with 1 mm POF and 200 µm HCS® fiber.

Miniature Link (820 nm)

The HFBR-0400 Miniature Link family of components are designed to provide cost-effective, high-performance fiber-optic communication links. They are widely used in Local Area Network (LAN) systems, Token Ring LAN systems, computers to peripheral links, computer monitor links, digital cross connect links, central office switch/PBX links, video links, modems & multiplexers, and industrial control links with link distances of up to 4 km and data rates up to 175 MBd.

The transmitters and receivers are directly compatible with popular "industry-standard" connectors; ST®, SMA, SC, and FC. To provide you with manufacturing and design flexibility, the transmitters and receivers are auto-insertable and wave-solderable. Also, they are completely specified with multiple fiber sizes;
50/125 µm, 62.5/125 µm,
100/140 µm, and 200 µm.

Miniature Link (1300 nm)

The HFBR-0300 multimode family of components and HFBR-0305 singlemode family of components are designed to provide the most cost-effective 1300 nm fiber optic links for a wide variety of data communication applications. The components are pin-compatible with HFBR-0400 family of components, thus allowing the designers to use a single circuit and board layout for 820 nm multimode fiber links, 1300 nm multimode fiber links, and singlemode fiber links. Upgrading a multimode solution to singlemode solution is as simple as switching components on a board.

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Product Selection Guide and Evaluation Kits

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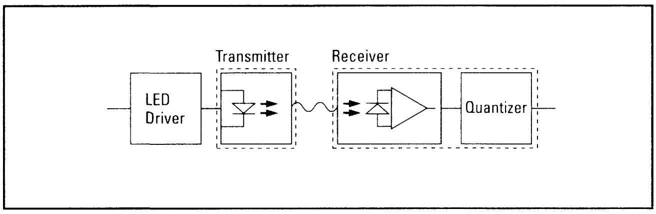
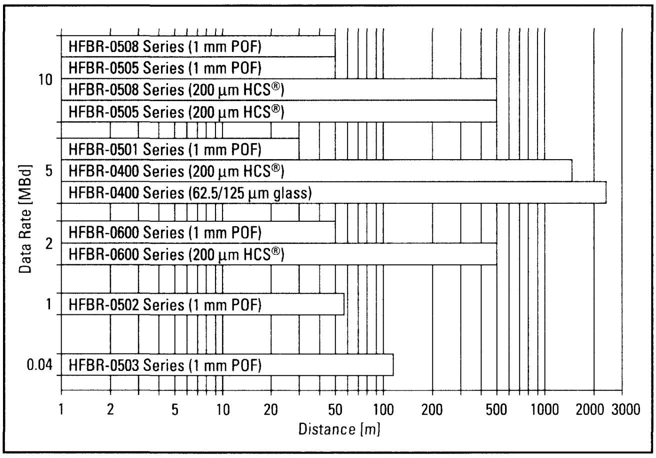
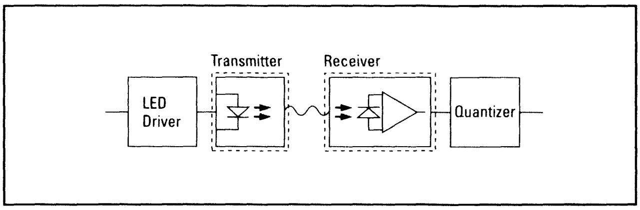
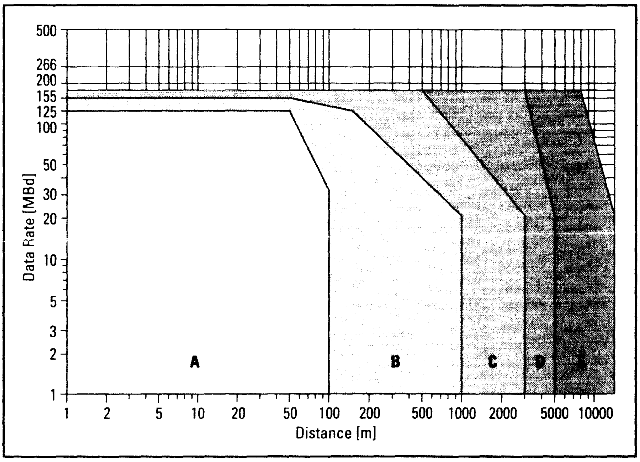
Link Selection from dc to 10 MBd





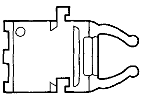
Link Selection from 1 MBd to 175 MBd





A HFBR-0507 Series with 1 mm POF
B HFBR-0507 Series with 200 µm HCS®
C HFBR-0400 Series with 62.5/125 µm glass
D HFBR-0300 Series with 62.5/125 µm glass
E HFBR-0305 Series with 9/125 µm glass

Versatile Link Family (650 nm)

	**Features:** Dual-in-line package, horizontal and vertical PCB mounting, plastic snap-in connectors, specified for 1 mm diameter plastic optical fiber (POF) and 200 µm hard clad silica (HCS®) fiber cables. Auto insertable and wave solderable.	
Product/Part Numbers	**Product Description**	**Page No.**
Evaluation Kits HFBR-0501 (1 MBd)	HFBR-1524 transmitter, HFBR-2524 receiver, polishing tool, 3 styles of plastic connectors, bulkhead feedthrough, 5 meter 1000 µm plastic optical fiber cable, lapping film, grid paper, and literature	41
HFBR-0527H (HCS®, 125 MBd)	HFBR-1527 transmitter, HFBR-2526 receiver, 1x9 + ECL interface demo board, 1 meter of HCS® optical fiber cable with connectors, all interface ICs and literature	59
HFBR-0527P (POF, 125 MBd)	HFBR-1527 transmitter, HFBR-2526 receiver, 1x9 + ECL interface demo board, 1 meter of plastic optical fiber cable with connectors, all interface ICs and literature	59
HFBR-0528 (10 MBd)	Fully assembled Tx board with HFBR-1528 transmitter, fully assembled Rx board with HFBR-2528 receiver, 2 meter connectored plastic optical cable and literature	71

Transmitter/Receiver Pairs					
Horizontal	**Vertical**	**Link Description**	**Data Rate**	**Distance***	
HFBR-1528/2528	N.A.	10-MBd POF Data Link	10 MBd	50 m	71
HFBR-1528/2528	N.A.	10-MBd HCS® Data Link	10 MBd	500 m	
HFBR-1527/2526	HFBR-1537/2536	125-MBd High-Speed POF Link	125 MBd	25 m	59
HFBR-1527/2526	HFBR-1537/2536	125-MBd High-Speed HCS® Link	125 MBd	100 m	
HFBR-1521/2521	HFBR-1531/2531	5-MBd High Performance Link	5 MBd	50 m	41
HFBR-1522/2522	HFBR-1532/2532	1-MBd High Performance Link	1 MBd	73 m	
HFBR-1524/2524	HFBR-1534/2534	1-MBd Standard Performance Link	1 MBd	43 m	
HFBR-1523/2523	HFBR-1533/2533	40-kBd Extended Distance Link	40 kBd	145 m	
HFBR-1523/2523	HFBR-1533/2533	Low-Current Link	40 kBd	45 m	
HFBR-1523/2523	HFBR-1533/2533	Photo Interrupter Link	20 kHz	N.A.	
HFBR-1522/2522	HFBR-1532/2532		500 kHz	N.A.	

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*Link performance at 25°C, improved attenuation cable

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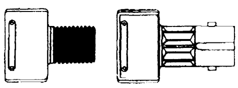
Versatile Link Family (650 nm), continued

Product/Part Numbers			**Product Description**	**Page No.**
Plastic Optical Fiber Cables, Connectors, and Accessories Available in various lengths (yyy meters)				
Attenuation	**Simplex**	**Duplex**		105
Standard	HFBR-RUSyyy	HFBR-RUDyyy	Unconnectored cable	
Standard	HFBR-RNSyyy	HFBR-RNDyyy	Cable with simplex connectors	
Standard	HFBR-RLSyyy	HFBR-RLDyyy	Cable with latching simplex connectors	
Standard	N/A	HFBR-RMDyyy	Duplex connectored cable	
Standard	N/A	HFBR-RTDyyy	Latching duplex connectored cable	
Extra Low Loss	HFBR-EUSyyy	HFBR-EUDyyy	Unconnectored cable	
Extra Low Loss	HFBR-ENSyyy	HFBR-ENDyyy	Cable with simplex connectors	
Extra Low Loss	HFBR-ELSyyy	HFBR-ELDyyy	Cable with latching simplex connectors	
Extra Low Loss	N/A	HFBR-EMDyyy	Duplex connectored cable	
Extra Low Loss	N/A	HFBR-ETDyyy	Latching duplex connectored cable	
Crimpless Connectors				
Non latching		HFBR-4531	Black crimpless connector / simplex or duplex arrangement using 1 or 2 x HFBR-4531	119 Best Buy
Latching		HFBR-4532	Black crimpless latching connector	
Connectors				
Simplex Standard		HFBR-4501	Gray simplex connector/crimp ring	105
		HFBR-4501B	Black simplex connector/crimp ring	
		HFBR-4511	Blue simplex connector/crimp ring	
		HFBR-4531	Crimpless black simplex connector	
Simplex Latching		HFBR-4503	Gray simplex latching connector/crimp ring	
		HFBR-4503B	Black simplex latching connector/crimp ring	
		HFBR-4513	Blue simplex latching connector/crimp ring	
		HFBR-4532	Crimpless black simplex latching connector	
Duplex Standard		HFBR-4506	Parchment duplex connector/crimp ring	
		HFBR-4506B	Black duplex connector/crimp ring	
		HFBR-4531	Crimpless black duplex connector	
Duplex Latching		HFBR-4516	Gray duplex latching connector/crimp ring	
		HFBR-4516B	Black duplex latching connector/crimp ring	
Bulkhead Feedthrough		HFBR-4505	Gray bulkhead feedthrough adapter, simplex	
In-Line Splice		HFBR-4505B	Black bulkhead feedthrough adapter, simplex	
		HFBR-4515	Blue bulkhead feedthrough adapter, simplex	
Accessories		HFBR-4525	1000 simplex crimp rings	
		HFBR-4526	500 duplex crimp rings	
		HFBR-4593	Plastic polishing kits (used for all connectors)	
		HFBR-4597	Plastic fiber crimping tool	
Hard Clad Silica Optical Fiber Cables, Connectors, and Accessories Available in various lengths (yyy meters)				
Rating	**Simplex**	**Duplex**		
Riser Rated	HFBR-HUSyyy	HFBR-HUDyyy	Unconnectored cable	105
Riser Rated	HFBR-HNSyyy	HFBR-HNDyyy	Cable with simplex connectors	
Plenum Rated	HFBR-VUSyyy	HFBR-VUDyyy	Unconnectored cable	
Plenum Rated	HFBR-VNSyyy	HFBR-VNDyyy	Cable with simplex connectors	
Connectors				
HFBR-4521			Black simplex connector/crimp ring	
Accessories				
HFBR-4527			100 simplex crimp rings	
HFBR-4584			Crimp and cleave termination kit	

Fieldbus Family (650 nm)



Features:
Meets 2/4 MBd industrial SERCOS, 1.5 MBd PROFIBUS and INTERBUS-S standard, SMA and ST® ports, specified for use with 1 mm Plastic Optical Fiber and 200 μm Hard Clad Silica, DC to 10 MBd data rate capability, auto-insertable and wave solderable.

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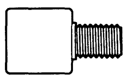
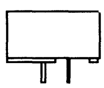
Product / Part Numbers		Product Description			Page No.
Transmitter / Receiver		**Fiber Size**	**Data Rate**	**Distance (typ.)**	
SERCOS	HFBR-1505A/2505A	200 μm HCS® 1 mm POF	2/4/10 MBd	400 m 55 m	79
PROFIBUS	HFBR-1515B/2515B	200 μm HCS® 1 mm POF	1.5/10 MBd	400 m 55 m	
INTERBUS-S	HFBR-1505C/2505A	200 μm HCS® 1 mm POF	0.5/10 MBd	500 m 60 m	



Features:
Dual-in-line package, fully compliant to SERCOS optical specifications, optimized for 1000 mm plastic optical fiber, compatible with SMA connectors, auto-insertable and wave-solderable.

Product/Part Numbers		Product Description		Page No.
Transmitter/Receiver Pairs		**Data Rate**	**Distance (typ.)**	
Standard Link	HFBR-1602/2602	2 MBd	40 m	87
Extended Distance Link	HFBR-1604/2602	2 MBd	55 m	
Evaluation Cable	HFBR-RWS002	Two-meter SMA 1000-mm plastic fiber optic cable		

JIS F07 Connection High Speed Transceiver (650 nm)



Features:
1x8 footprint package style and compatible with duplex JIS F07 simplex JIS F05, and PN connectors. Specified for 1 mm diameter plastic optical fiber (POF) and 200 μm hard clad silica (HCS®) fiber. Auto insertable and wave solderable.

Product/Part Numbers	Product Description			Page No.
Evaluation Kits HFBR-0530	HFBR-5527 transceiver, fully assembled PC board, and literature			93
Transceiver	**Fiber Type**	**Data Rate**	**Distance***	
HFBR-5527	POF	125 MBd	25 m	
	HCS®	125 MBd	100 m	

*Link performance at 0° to 70°C, improved attenuation cable

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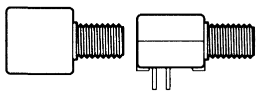
Miniature Link Family (820 nm)

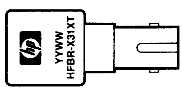


Features:
Dual-in-line package, operates at 820 nm, interfaces directly with ST®, SMA, FC, or SC connectors, specified for used with 50/125-μm, 62.5/125-μm, 100/140-μm and 200-μm hard clad silica (HCS ®) fiber. Auto-insertable, wave solderable, and no mounting hardware required.

Product/Part Numbers	Product Description	Page No.
Evaluation Kits		
HFBR-0410 (ST®, 5 MBd)	HFBR-1412 transmitter, HFBR-2412 receiver, 3-meter connectored 62.5/125-μm fiber cable, and literature	125
HFBR-0414 (ST®, 70 MBd)	HFBR-1414T transmitter, HFBR-2416T receiver, 3-meter 62.5/125-μm fiber cable, PC board, all interface ICs, and literature	
HFBR-0416 (ST®, 155 MBd)	HFBR-1414 transmitter, HFBR-2416 receiver, fully assembled PC board, and literature	
Transmitters/Receivers		
HFBR-14X2 Standard Transmitter	Optimized for large size fiber such as 100/140-μm fiber and 200-μm HCS® fiber	
HFBR-14X4 High Power Transmitter	Optimized for small size fiber such as 50/125-μm or 62.5/125-μm fiber	
HFBR-24X2 5 MBd Receiver	TTL/CMOS compatible receiver with -25.4 dBm sensitivity	
HFBR-24X6 125 MHz Receiver	PIN-preamp receiver for signal rates up to 175 MBd	

Transmitters/Receivers Pairs	Fiber Size	Data Rate	Distance
HFBR-14X2/24X2	200 μm	5 MBd	1500 m
	62.5/125 μm	5 MBd	2000 m
HFBR-14X4/24X6	62.5/125 μm	20 MBd	2700 m
	62.5/125 μm	32 MBd	2200 m
	62.5/125 μm	55 MBd	1400 m
	62.5/125 μm	125 MBd	700 m
	62.5/125 μm	155 MBd	600 m
	62.5/125 μm	175 MBd	500 m

Miniature Link Family (1300 nm)



Features:
Dual-in-line package, operates at 1300 nm wavelength, interfaces directly with ST® connectors, specified for use with 50/125 μm, 62.5/125 μm, and singlemode 8/125 μm fibers.

Product/Part Numbers	Product Description	Page No.
Evaluation Kits		
HFBR-0310 (ST®, 155 MBd)	HFBR-1312T transmitter, HFBR-2316T receiver, fully assembled PC board, and literature	157

Transmitters/Receivers Pairs	Fiber Size	Data Rate	Distance	Page No.
HFBR-1312TM/2316T	62.5/125 μm	55 MBd	4000 m	157
	62.5/125 μm	155 MBd	2700 m	
HFBR-1315TM/2315T	8/125 μm	32 MBd	14000 m	165

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Fiber Optic Components Reference Designs

Table of Contents

Using HP's recommended designs

The logic-compatible circuits shown look deceptively simple, but have been carefully developed to deliver the best performance possible with HP's LED optical transmitter components.

They are based upon proven circuits and techniques that have been demonstrated to work in numerous applications.

To avoid problems, minimize development costs and minimize time-to-market designers are encouraged to imbed the shown circuits.

Fundamentals of Digital Fiber Optic Links

The following reference designs concentrate on links built with the **Versatile Link** and **Miniature Link** family products.

All the optical **transmitters** from these families include an LED without driver circuitry, as shown below in figure 1. But low cost driver ICs are available from many suppliers. The following designs will show easy integration of these ICs into a transmitter circuit.

The optical **receivers** from dc up to 10 MBd include a photodiode, preamp, and quantize circuit, as shown below in figure 1, and have TTL outputs (dc coupled). These receivers can be used with arbitrary timing (no duty factor restriction). Typical applications are RS232, RS485, SERCOS, INTERBUS-S and PROFIBUS protocols.

Typical Link Block Diagram from dc to 10 MBd

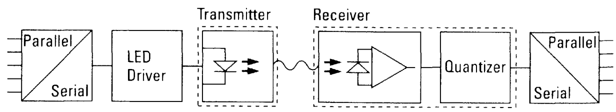


Figure 1

For dc to 40 kBd designs see page 22 and application note AN1035 (page 205)
For dc to 1 MBd designs see page 24 and application note AN1035 (page 205)
For dc to 5 MBd designs see page 26 and application note AN1035 (page 205)
For dc to 10 MBd designs see page 28 and application note AN1080 (page 273)

The **receivers** for data rates from 1 MBd to 175 MBd include a photodiode and preamp with analog outputs. They have to be ac coupled to a comparator or quantizer circuitry to provide the digital logic levels (i.e. ECL, TTL). The ac coupling requires encoding of the serial data (i.e. Manchester, 4B/5B, scrambled coding), but provides better sensitivity than dc coupled receivers.

Typical Link Block Diagram from 1 MBd to 175 MBd

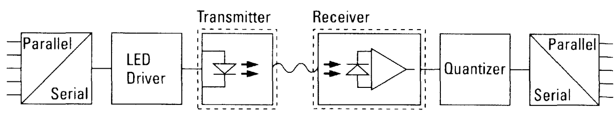


Figure 2

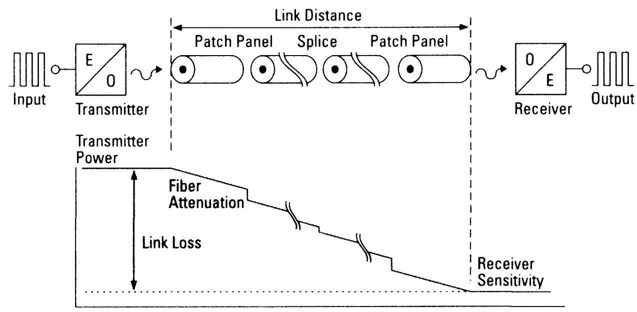
For dc to 32 MBd designs see page 30 and application note AN1121 (page 295)
For 2 to 70 MBd designs see page 34 and application note AN1122 (page 307)
For 20 to 160 MBd designs see page 36 and application note AN1123 (page 319)

Fiber Optic Link Power Budget

When designing fiber optic links it is important to provide to the optical receiver enough optical power for proper operation. Therefore total link loss and optical safety margin should be taken into account when calculating the required transmitter power.

The following worksheet can be used to calculate total link loss, optical link power budget and required optical transmitter power.

Fiber Optic Link Power Budget



Calculations

Fiber Optic Cable

Cable Loss	= Link Distance	km	* Fiber Attenuation	dB/km =	dB
or	= Link Distance	m	* Fiber Attenuation	dB/m =	dB

Splice Requirements

Cable Splice	Qty. of Splices		* Loss per Splice	dB =	dB
Patch Panel	Qty. of Patch Panels		* Loss per Patch Panel	dB =	dB

Link Loss **= Cable Loss + Splice Loss + Patch Panel Loss** **= dB**

Optical Power Budget

Link Power Budget = Link Loss ______ dB + Safety Margin[1] ______ dB = ______ dB

Required Transmitter Power

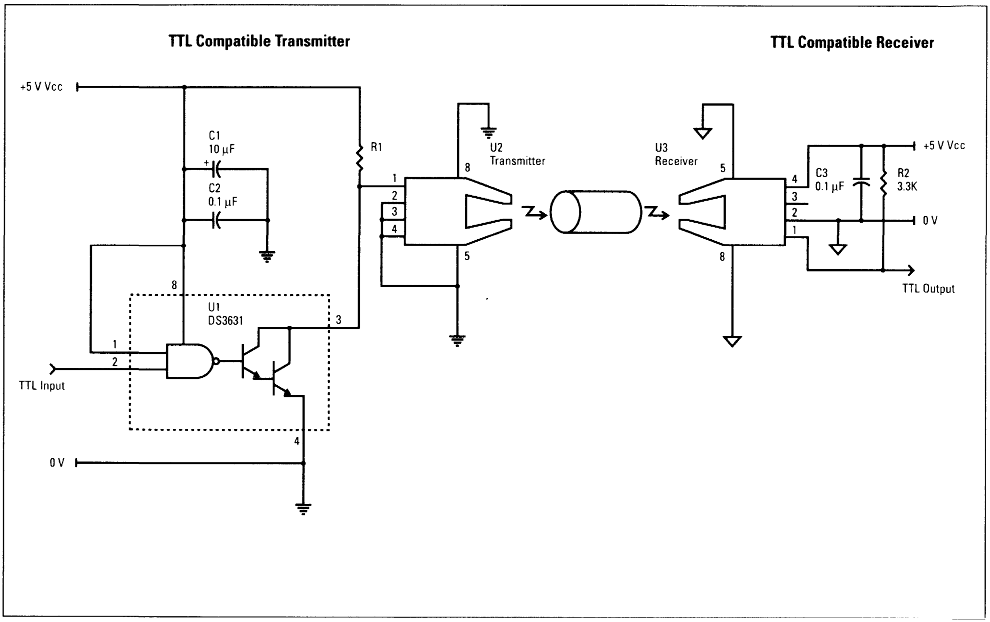
Link Power Budget = Transmitter Power – Receiver Sensitivity

or Transmitter Power = Link Power Budget ______ dB + Receiver Sensitivity ______ dBm = ______ **dBm**

The Transmitter Power can be adjusted via the transmitter forward current limiting resistor to a value equal or greater than the requirement!

[1] A typical Safety Margin is 3 dB and may be required for future splice and aging of the fiber optic transmitter and cable. For further details consult the application notes in this guide.

Reference Design for dc to 40 KBd TTL data at distances between 0 and 1.5 kilometers.



Components values

Distance @ 40 kBd	0 to 53 meters	0 to 1.5 kilometers
Transmitter	HFBR-15X3	HFBR-15X8
Receiver	HFBR-25X3	HFBR-25X3
Fiber Type	1 mm Plastic	200 µm HCS®
R1	340 Ω	150 Ω

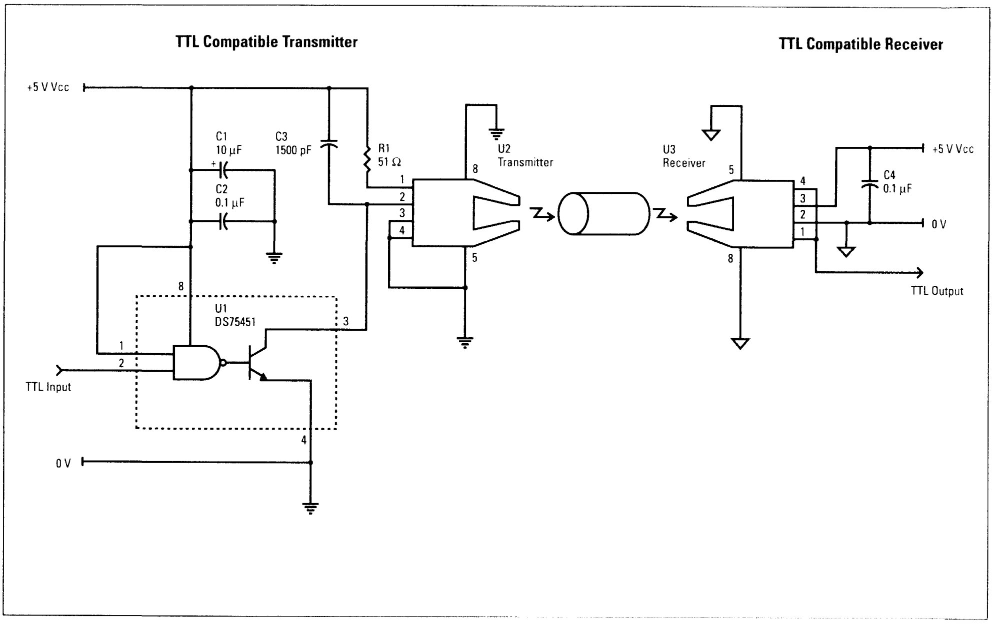
Attributes

1) No adjustments needed.
2) No receiver overdrive with short fiber-optic cables.
3) DS3631 is available from National Semiconductor.
4) Uses 1 mm dia. plastic optical fiber and HFBR-4531 (HFBR-4532) crimpless connector which can be field terminated in less than 1 minute.
5) Uses 200 μm hard clad silica (HCS®) optical fiber and HFBR-4521 crimp and cleave connector.

References

1) HFBR-0501 Series data sheet, HP pub. # 5965-1657E
2) HFBR-4531/4532 Crimpless Connector data sheet, HP pub. # 5965-1659E
3) Application Note 1035 HP pub. # 5964-4027E
4) HFBR-0508 Series data sheet, HP pub. # 5963-3591E
5) Plastic Optical Fiber and HCS fiber cables and connectors, HP pub. # 5963-3711E

Reference Design for dc to 1 MBd TTL data at distances between 0 and 45 meters.



Components values

Distance @ 1 MBd	0 to 10 meters	0 to 45 meters
Transmitter	HFBR-15X4	HFBR-15X2
Receiver	HFBR-25X4	HFBR-25X2
Fiber Type	1 mm Plastic	1 mm Plastic

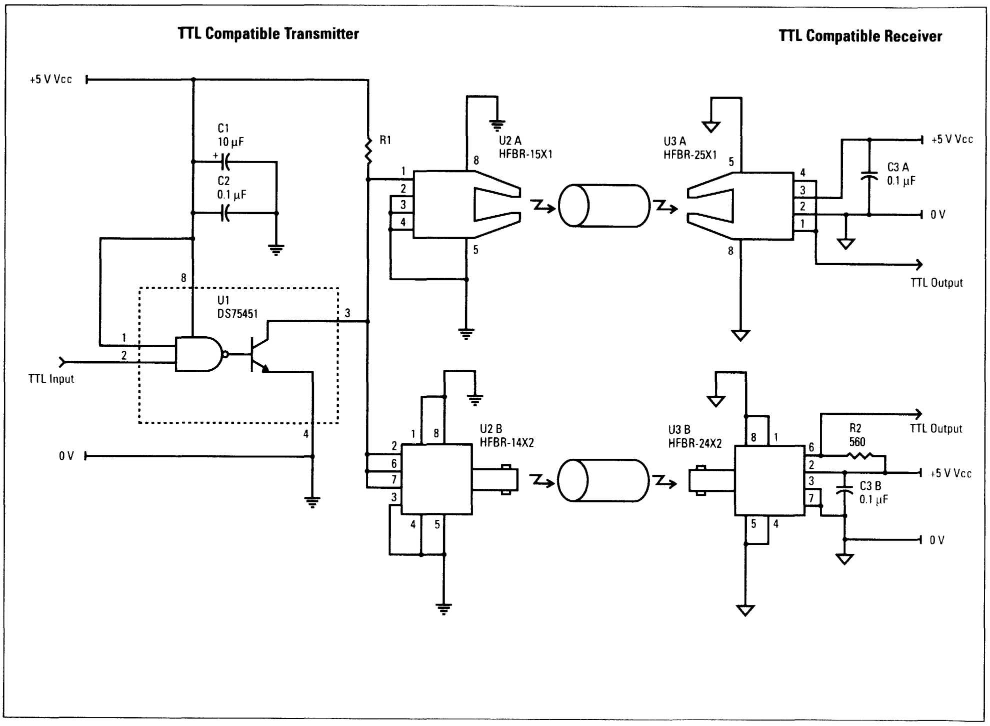
Attributes

1) No adjustments needed.
2) No receiver overdrive with short fiber-optic cables.
3) DS75451 is available from National Semiconductor.
4) Uses 1 mm dia. plastic optical fiber.
5) Uses HP's HFBR-4531 or HFBR-4532 crimpless connector which can be field terminated in less than 1 minute.

References

1) HFBR-0501 Series data sheet HP pub. # 5965-1657E
2) HFBR-4531/4532 Crimpless Connector data sheet, HP pub. # 5965-1659E
3) Application Note 1035 HP pub. # 5964-4027E

Reference Design for dc to 5 MBd TTL data at distances between 0 and 1.7 kilometers.



Components values

Distance @ 5 MBd	0 to 16 meters	0 to 700 meters	0 to 1.7 kilometers
Transmitter	HFBR-15X1	HFBR-14X2	HFBR-14X4
Receiver	HFBR-25X1	HFBR-24X2	HFBR-24X2
Fiber Type	1 mm Plastic	200 µm HCS®	62.5/125 µm
R1	78.7 Ω	174 Ω	69.8 Ω

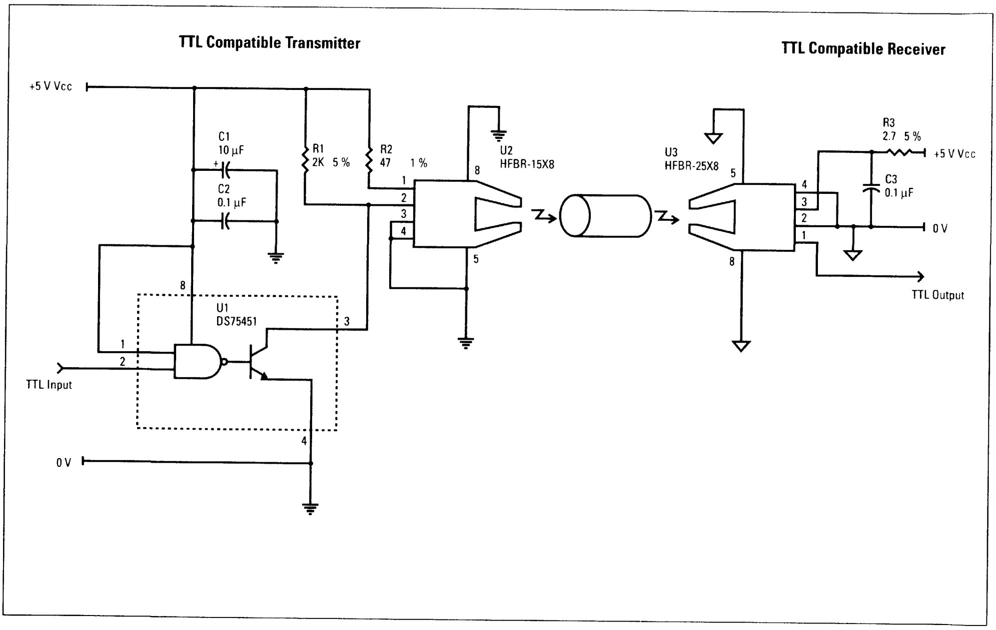
Attributes

1) No adjustments needed.
2) No receiver overdrive with short fiber-optic cables.
3) DS75451 is available from National Semiconductor.
4) Uses 1 mm dia. plastic optical fiber and HFBR-4531 or HFBR-4532 crimpless connector which can be field terminated in less than 1 minute.
5) Uses 200 µm dia. hard clad silica (HCS®) optical fiber and no-epoxy no-polish crimp and cleave ST® or SMA optical connectors available from SpecTran.
6) Uses commonly available 62.5/125 µm dia. glass fiber and ST® or SMA optical connectors.

References

1) HFBR-0501 Series data sheet HP pub. # 5965-1657E
2) HFBR-4531/4532 Crimpless Connector data sheet, HP pub. # 5965-1659E
3) Application Note 1035 HP pub. # 5964-4027E
4) HFBR-0400 Series data sheet HP pub. # 5965-1655E

Reference Design for dc to 10 MBd TTL data at distances between 0 and 300 meters.



Components values

Distance @ 10 MBd	0 to 40 meters	0 to 300 meters
Transmitter	HFBR-1528	HFBR-1528
Receiver	HFBR-2528	HFBR-2528
Fiber Type	1 mm Plastic	200 µm HCS®

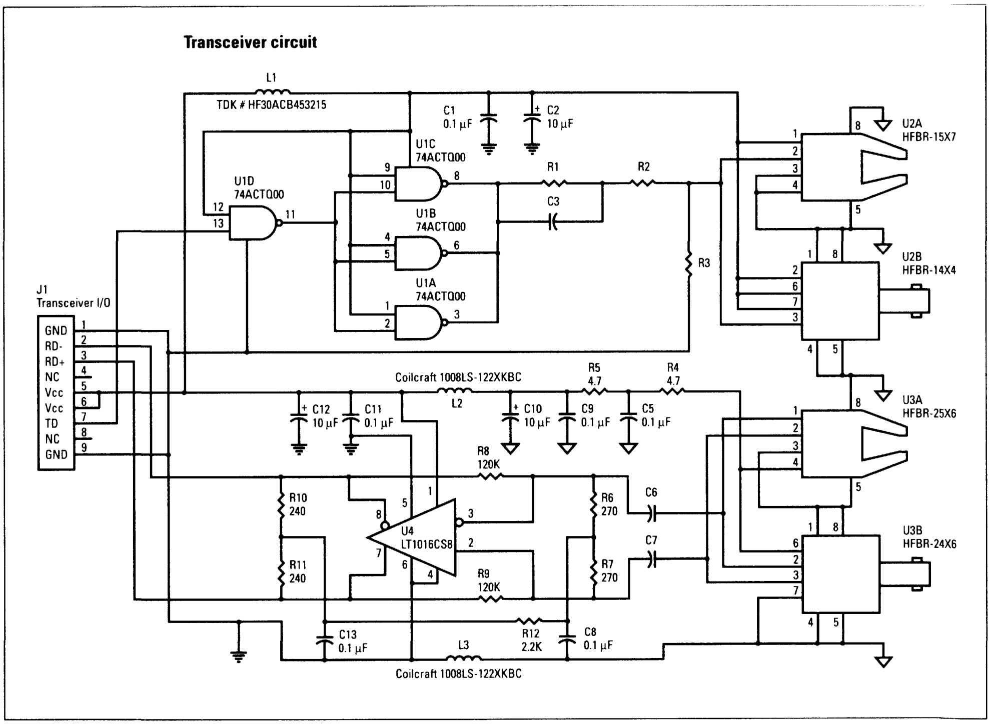
Attributes

1) No adjustments needed.
2) No receiver overdrive with short fiber-optic cables.
3) DS75451 is available from National Semiconductor.
4) Uses 1 mm dia. plastic optical fiber and HFBR-4531 or HFBR-4532 crimpless connector which can be field terminated in less than 1 minute.
5) Uses 200 µm hard clad silica (HCS®) optical fiber and HFBR-4521 crimp and cleave connector.

References

1) HFBR-0508 Series data sheet HP pub. # 5963-3591E
2) HFBR-4531/4532 Crimpless Connector data sheet, HP pub. # 5965-1659E
3) Application Note 1080 HP pub. # 5963-6756E
4) Plastic Optical Fiber and HCS® Fiber Cables and Connectors, HP pub. # 5963-3711E

Reference Design for dc to 32 MBd TTL data at distances between 0 and 1.3 kilometers.



Transceiver component values

Distance @ 32 MBd	0 to 27 meters	0 to 690 meters	0 to 800 meters	0 to 1.3K meters
Transmitter	HFBR-15X7 650 nm LED	HFBR-15X7 650 nm LED	HFBR-14X4 820 nm LED	HFBR-13X2T 1300 nm LED
Receiver	HFBR-25X6	HFBR-25X6	HFBR-24X6	HFBR-23X6
Fiber Type	1 mm Plastic	200 µm HCS®	62.5/125 µm	62.5/125 µm
R1	120 Ω	33 Ω	33 Ω	22 Ω
R2	120 Ω	33 Ω	33 Ω	27 Ω
R3	390 Ω	270 Ω	270 Ω	∞
C3	82 pF	470 pF	75 pF	150 pF

$$C6 = C7 = \frac{2}{(3)\ (R6+R7)\ [\text{Data Rate (Bd)}]}$$

Attributes

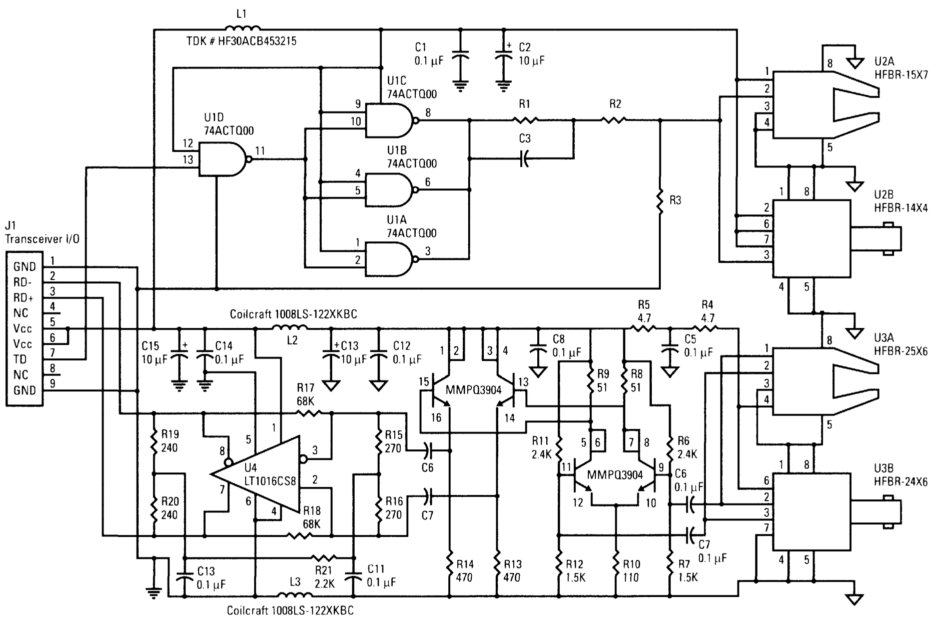
1) Can be used with unencoded data.
2) No analog circuit design needed.
3) No printed circuit design needed.
4) Printed circuit design can be electronically imported from web address http//www.hp.com/HP-COMP/fiber/fiber_index.html#gerber by downloading trans1.exe Electronic files contain:
   a) Transceiver schematic
   b) Printed circuit artwork
   c) Material list
5) No adjustments needed.
6) No receiver overdrive with short fiber-optic cables.
7) Uses low-cost off-the-shelf integrated circuits from Fairchild and Linear Technology.
8) One transceiver design can be used to address a wide range of applications.
9) Can be used with 1 mm dia. POF for lowest cost, 200 µm HCS®, 62.5/125 µm miltimode glass or 9/125 single-mode glass optical fibers for greater distances.
10) POF or HCS® fiber connectors can be field terminated in less than 1 minute. For POF use the HFBR-4531 connector, for HCS® fiber use HFBR-4521 connector.

References

1) HFBR-0507 Series data sheet, HP pub. # 5963-3591E
2) HFBR-0400 Series data sheet, HP pub. # 5965-1655E
3) HFBR-0300 Series data sheet, HP pub. # 5091-7380E
4) HFBR-4531/4532 Crimpless Connector data sheet, HP pub. # 5965-1659E
5) Plastic Optical Fiber and HCS® Fiber Cables and Connectors, HP pub. # 5963-3711E
6) Application Note 1121 HP pub. # 5966-1353E

Reference Design for dc to 32 MBd TTL data at distances between 0 and 4.0 kilometers.

Transceiver circuit



Transceiver component values

Distance @ 32 MBd	0 to 42 meters	0 to 1K meters	0 to 1.6K meters	0 to 3.3K meters	0 to 4.0K meters
Transmitter	HFBR-15X7 650 nm LED	HFBR-15X7 650 nm LED	HFBR-14X4 820 nm LED	HFBR-13X2T 1300 nm LED	HFBR-1315 1300 nm ELED
Receiver	HFBR-25X6	HFBR-25X6	HFBR-24X6	HFBR-23X6	HFBR-2315
Fiber Type	1 mm Plastic	200 µm HCS®	62.5/125 µm	62.5/125 µm	9/125 µm
R1	120 Ω	33 Ω	33 Ω	22 Ω	18 Ω
R2	120 Ω	33 Ω	33 Ω	27 Ω	18 Ω
R3	390 Ω	270 Ω	270 Ω	∞	390 Ω
C3	82 pF	470 pF	75 pF	150 pF	47 pF

$$C9 = C10 = \frac{2}{(3)\,(R15+R16)\,[\text{Data Rate (Bd)}]}$$

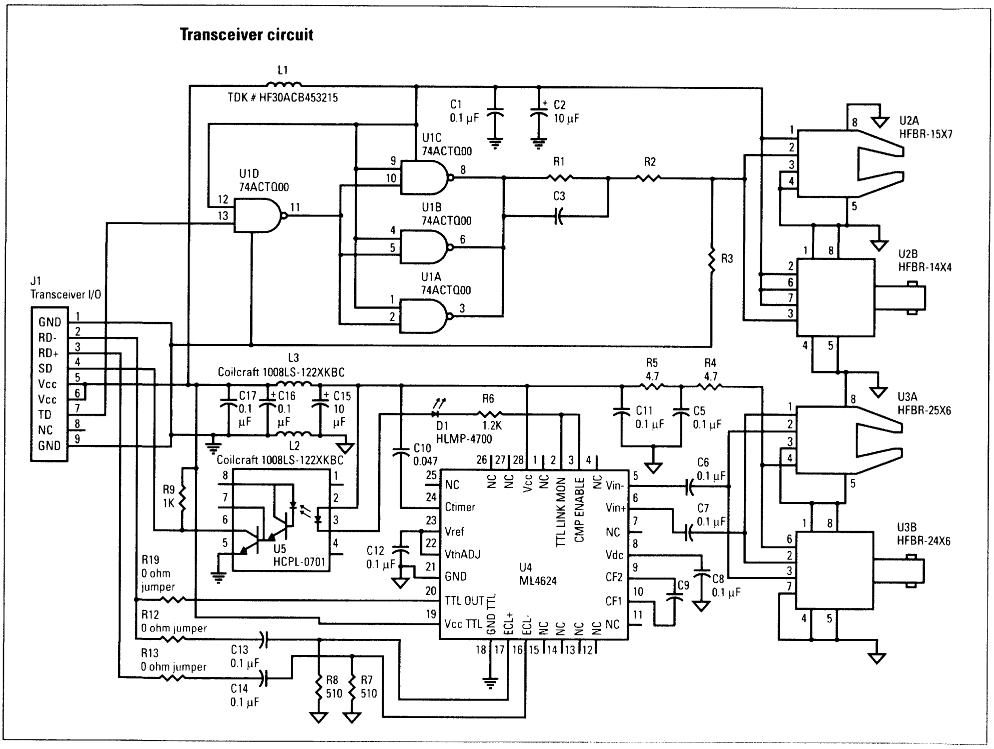
Attributes

1) Can be used with unencoded data.
2) No analog circuit design needed.
3) No printed circuit design needed.
4) Printed circuit design can be electronically imported from web address http://www.hp.com/HP-COMP/fiber/fiber_index.html#gerber by downloading trans2.exe
   Electronic files contain:
   a) Transceiver schematic
   b) Printed circuit artwork
   c) Material list
5) No adjustments needed.
6) No receiver overdrive with short fiber-optic cables.
7) Uses low-cost off-the-shelf integrated circuits from Fairchild, Motorola, and Linear Technology.
8) One transceiver design can be used to address a wide range of applications.
9) Can be used with 1 mm dia. POF for lowest cost, 200 µm HCS®, 62.5/125 µm multimode glass or 9/125 single-mode glass optical fibers for greater distances.
10) POF or HCS® fiber connectors can be field terminated in less than 1 minute. For POF use the HFBR-4531 connector, for HCS® fiber use HFBR-4521 connector.

References

1) HFBR-0507 Series data sheet, HP pub. # 5963-3591E
2) HFBR-0400 Series data sheet, HP pub. # 5965-1655E
3) HFBR-0300 Series data sheet, HP pub. # 5091-7380E
4) HFBR-4531/4532 Crimpless Connector data sheet, HP pub. # 5965-1659E
5) Plastic Optical Fiber and HCS® Fiber Cables and Connectors, HP pub. # 5963-3711E
6) Application Note 1121 HP pub. # 5966-1353E

Reference Design for 2 to 70 MBd TTL data at distances between 0 and 14.0 kilometers.



Transceiver component values

Distance @ 50 MBd	0 to 80 meters	0 to 300 meters	0 to 1.5K meters	0 to 3.8K meters	0 to 14.0K meters
Transmitter	HFBR-15X7 650 nm LED	HFBR-15X7 650 nm LED	HFBR-14X4 820 nm LED	HFBR-13X2T 1300 nm LED	HFBR-1315 1300 nm ELED
Receiver	HFBR-25X6	HFBR-25X6	HFBR-24X6	HFBR-23X6	HFBR-2315
Fiber Type	1 mm Plastic	200 µm HCS®	62.5/125 µm	62.5/125 µm	9/125 µm
R1	120 Ω	33 Ω	33 Ω	22 Ω	18 Ω
R2	120 Ω	33 Ω	33 Ω	27 Ω	18 Ω
R3	390 Ω	270 Ω	270 Ω	∞	390 Ω
C3	82 pF	470 pF	75 pF	150 pF	47 pF

When data rate is ≤ 20 MBd then $C9 = \left[\frac{1}{2\pi\ 800\ (Bd)}\right] - [4(pF)]$

When data rate > 20 MBd delete C9

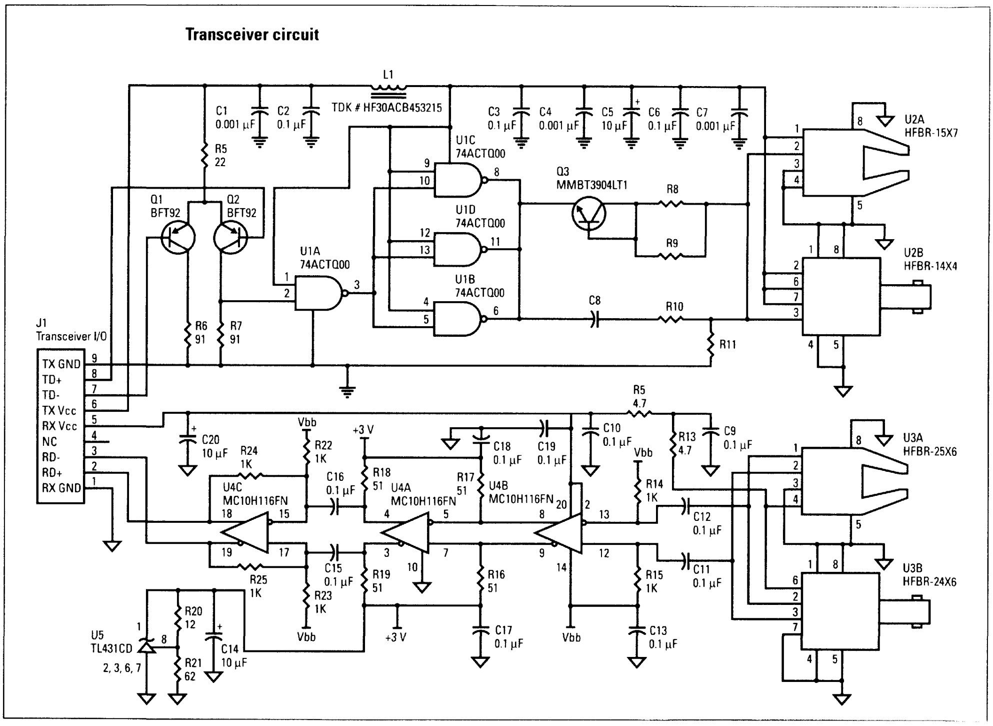
Attributes

1) Intended for applications that use encoded data.
2) No analog circuit design needed.
3) No printed circuit design needed.
4) Printed circuit design can be electronically imported from web address http://www.hp.com/HP-COMP/fiber/fiber_index.html#gerber by downloading rll70.exe Electronic files contain:
   a) Transceiver schematic
   b) Printed circuit artwork
   c) Material list
5) No adjustments needed.
6) No receiver overdrive with short fiber-optic cables.
7) Uses low-cost off-the-shelf integrated circuits from Fairchild and Micro Linear.
8) One transceiver design can be used to address a wide range of applications.
9) Can be used with 1 mm dia. POF for lowest cost, 200 µm HCS®, 62.5/125 µm multimode glass or 9/125 single-mode glass optical fibers for greater distances.
10) POF or HCS® fiber connectors can be field terminated in less than 1 minute. For POF use the HFBR-4531 connector, for HCS® fiber use HFBR-4521 connector.

References

1) HFBR-0507 Series data sheet, HP pub. # 5963-3591E
2) HFBR-0400 Series data sheet, HP pub. # 5965-1655E
3) HFBR-0300 Series data sheet, HP pub. # 5091-7380E
4) HFBR-4531/4532 Crimpless Connector data sheet, HP pub. # 5965-1659E
5) Plastic Optical Fiber and HCS® Fiber Cables and Connectors, HP pub. # 5963-3711E
6) Application Note 1122 HP pub. # 5966-1270E

Reference Design for 20 to 160 MBd +5V ECL (PECL) data at distances between 0 and 6 kilometers.



Transceiver component values

Distance @ 160 MBd	0 to 50 meters	0 to 50 meters	0 to 500 meters	0 to 2K meters	0 to 6K meters
Transmitter	HFBR-15X7 650 nm LED	HFBR-15X7 650 nm LED	HFBR-14X4 820 nm LED	HFBR-13X2T 1300 nm LED	HFBR-1315 1300 nm ELED
Receiver	HFBR-25X6	HFBR-25X6	HFBR-24X6	HFBR-23X6	HFBR-2315
Fiber Type	1 mm Plastic	200 µm HCS®	62.5/125 µm	62.5/125 µm	9/125 µm
R8	310 Ω	82.5 Ω	84.5 Ω	78.7 Ω	53.6 Ω
R9	310 Ω	82.5 Ω	84.5 Ω	78.7 Ω	53.6 Ω
R10	15 Ω	15 Ω	56 Ω	47 Ω	33 Ω
R11	1K Ω	475 Ω	2.2K Ω	∞	1.2K Ω
C8	43 pF	120 pF	33 pF	56 pF	56 pF

Note the transceiver only requires a +5V power supply. The receiver circuit's +3V bus is created using the TL431CD shunt regulator, and Vbb, which equals +3.7V, is a bias source located within the MC10H116FN.

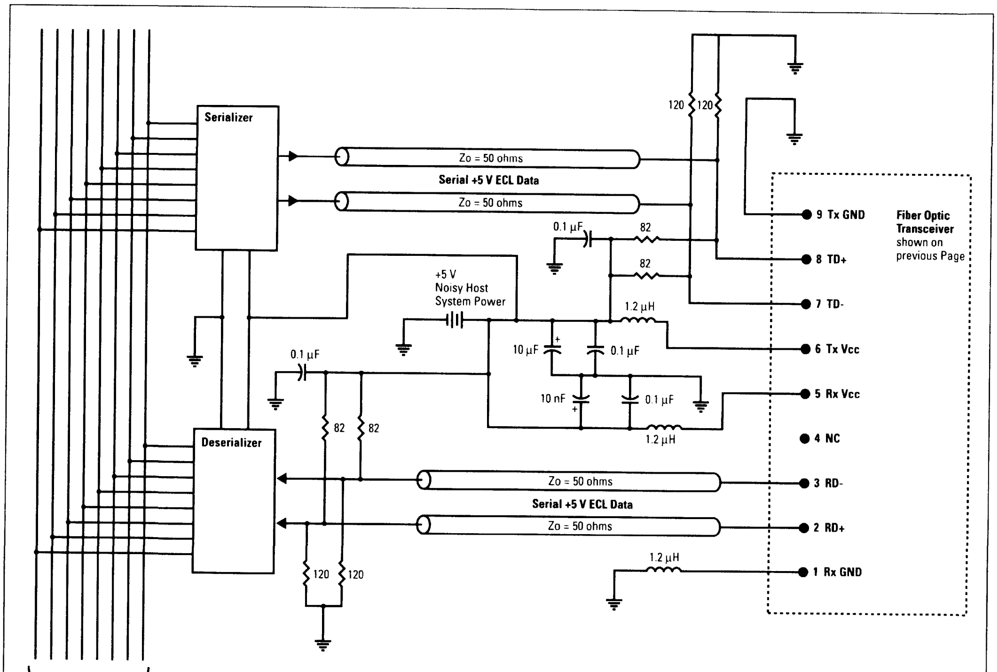
Attributes

1) Intended for applications that use encoded data.
2) Can be used with off-the-shelf physical layer chips such as the AMD TAXIchip' or Cypress HOTLink' to build low-cost byte-to-light protocol-independent data communication links
3) No analog circuit design needed.
4) No printed circuit design needed.
5) Printed circuit design can be electronically imported from web address http://www.hp.com/HP-COMP/ fiber fiber_index.html#gerber by downloading raftv3.exe Electronic files contain:
   a) Transceiver schematic
   b) Printed circuit artwork
   c) Material list
6) No adjustments needed.
7) No receiver overdrive with short fiber-optic cables.
8) Uses low-cost off-the-shelf integrated circuits from Fairchild, Motorola, and Texas Instruments.
9) One transceiver design can be used to address a wide range of applications.
10) Can be used with 1 mm dia. POF for lowest cost, 200 μm HCS®, 62.5/125 μm miltimode glass or 9/125 single-mode glass optical fibers for greater distances.
11) POF or HCS® fiber connectors can be field terminated in less than 1 minute. For POF use the HFBR-4531 connector, for HCS® fiber use HFBR-4521 connector.

References

1) HFBR-0507 Series data sheet, HP pub. # 5963-3591E
2) HFBR-0400 Series data sheet, HP pub. # 5965-1655E
3) HFBR-0300 Series data sheet, HP pub. # 5091-7380E
4) HFBR-4531/4532 Crimpless Connector data sheet, HP pub. # 5965-1659E
5) Plastic Optical Fiber and HCS® Fiber Cables and Connectors, HP pub. # 5963-3711E
6) Application Note 1123 HP pub. # 5966-1269E

Byte-to-light interface between PECL-compatible fiber-optic transceivers and off-the-shelf PHY chips, such as Advanced Micro Device's TAXIchip™ or Cypress Semiconductor's HOTLink™.



Recommended Power Supply Filter and
+5 V ECL (PECL) Signal Terminations
for the AMD TAXIchip and Cypress HOTLink

Technical Data Sheets

Fiber Optic Data Sheet Index

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ST® is a registered trademark of AT&T.

HEWLETT PACKARD

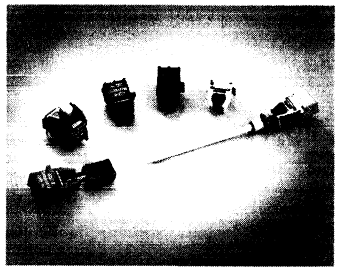
Versatile Link The Versatile Fiber Optic Connection

Technical Data

HFBR-0501 Series

Features
- **Low Cost Fiber Optic Components**
- **Enhanced Digital Links dc-5 MBd**
- **Extended Distance Links up to 120 m at 40 kBd**
- **Low Current Link: 6 mA Peak Supply Current**
- **Horizontal and Vertical Mounting**
- **Interlocking Feature**
- **High Noise Immunity**
- **Easy Connectoring Simplex, Duplex, and Latching Connectors**
- **Flame Retardant**
- **Transmitters Incorporate a 660 nm Red LED for Easy Visibility**
- **Compatible with Standard TTL Circuitry**

Applications
- **Reduction of Lightning/Voltage Transient Susceptibility**
- **Motor Controller Triggering**
- **Data Communications and Local Area Networks**
- **Electromagnetic Compatibility (EMC) for Regulated Systems: FCC, VDE, CSA, etc.**
- **Tempest-Secure Data Processing Equipment**
- **Isolation in Test and Measurement Instruments**
- **Error Free Signalling for Industrial and Manufacturing Equipment**
- **Automotive Communications and Control Networks**
- **Noise Immune Communication in Audio and Video Equipment**



Description
The Versatile Link series is a complete family of fiber optic link components for applications requiring a low cost solution. The HFBR-0501 series includes transmitters, receivers, connectors and cable specified for easy design. This series of components is ideal for solving problems with voltage isolation/insulation, EMI/RFI immunity or data security. The optical link design is simplified by the logic compatible receivers and complete specifications for each component. The key optical and electrical parameters of links configured with the HFBR-0501 family are fully guaranteed from 0° to 70°C.

A wide variety of package configurations and connectors provide the designer with numerous mechanical solutions to meet application requirements. The transmitter and receiver components have been designed for use in high volume/low cost assembly processes such as auto insertion and wave soldering.

Transmitters incorporate a 660 nm LED. Receivers include a monolithic dc coupled, digital IC receiver with open collector Schottky output transistor. An internal pullup resistor is available for use in the HFBR-25X1/2/4 receivers. A shield has been integrated into the receiver IC to provide additional, localized noise immunity.

Internal optics have been optimized for use with 1 mm diameter plastic optical fiber. Versatile Link specifications incorporate all connector interface losses. Therefore, optical calculations for common link applications are simplified.

HFBR-0501 Series Part Number Guide

HFBR X5XX

1 = Transmitter
2 = Receiver

5 = 600 nm Transmitter and Receiver Products

2 = Horizontal Package
3 = Vertical Package

1 = 5 MBd High Performance Link
2 = 1 MBd High Performance Link
3 = 40 kBd Low Current/Extended Distance Link
4 = 1 MBd Standard Link
6 = 155 MBd Receiver
7 = 155 MBd Transmitter
8 = 10 MBd High Performance Link

Link Selection Guide

(Links specified from 0 to 70°C, for plastic optical fiber unless specified.)

Signal Rate	Distance (m) 25°C	Distance (m)	Transmitter	Receiver
40 kBd	120	110	HFBR-1523	HFBR-2523
1 MBd	20	10	HFBR-1524	HFBR-2524
1 MBd	55	45	HFBR-1522	HFBR-2522
5 Mbd	30	20	HFBR-1521	HFBR-2521

Evaluation Kit

HFBR-0501 1 MBd Versatile Link:

This kit contains: HFBR-1524 Tx, HFBR-2524 Rx, polishing kit, 3 styles of plastic connectors, Bulkhead feedthrough, 5 meters of 1 mm diameter plastic cable, lapping film and grit paper, and HFBR-0501 data sheet.

Application Literature

Application Note 1035 (Versatile Link)

Package and Handling Information

The compact Versatilie Link package is made of a flame retardant VALOX® UL V-0 material (UL file # E121562) material and uses the same pad layout as a standard, eight pin dual-in-line package. Vertical and horizontal mountable parts are available. These low profile Versatile Link packages are stackable and are enclosed to provide a dust resistant seal. Snap action simplex, simplex latching, duplex, and duplex latching connectors are offered with simplex or duplex cables.

Package Orientation

Performance and pinouts for the vertical and horizontal packages are identical. To provide additional attachment support for the vertical Versatile Link housing, the designer has the option of using a self-tapping screw through a printed circuit board into a mounting hole at the bottom of the package. For most applications this is not necessary.

Package Housing Color

Versatile Link components and simplex connectors are color coded to eliminate confusion

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when making connections. Receivers are blue and transmitters are gray, except for the HFBR-15X3 transmitter, which is black.

All of the above transmitters and receivers are also available in black versions for applications where improved housing opacity is required due to very bright ambient light or bright flashes of light.

Handling

Versatile Link components are auto-insertable. When wave soldering is performed with Versatile Link components, the optical port plug should be left in to prevent contamination of the port. Water soluble fluxes, not rosin based fluxes, are recommended for use with Versatile Link components.

Versatile Link components are moisture sensitive devices and are shipped in a moisture sealed bag. If the components are exposed to air for an extended period of time, they may require a baking step before the soldering process. Refer to the special labeling on the shipping tube for details.

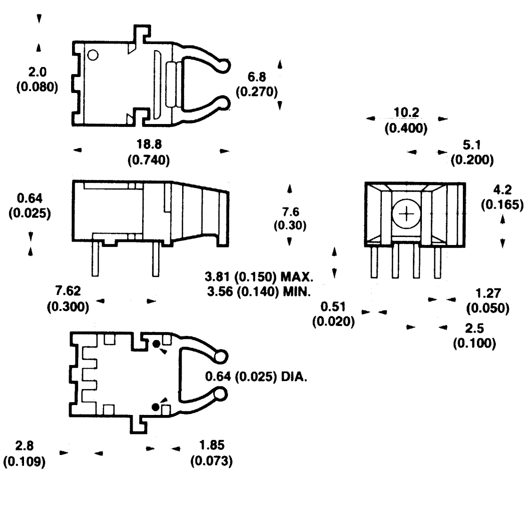
Recommended Chemicals for Cleaning/Degreasing

Alcohols: methyl, isopropyl, isobutyl. *Aliphatics:* hexane, heptane, *Other:* soap solution, naphtha.

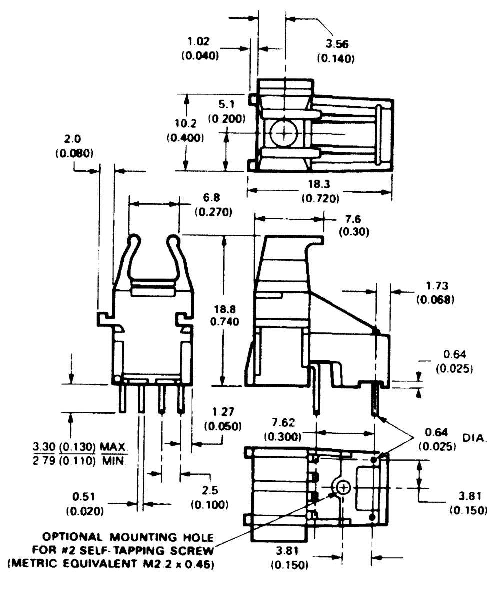
Do not use partially halogenated hydrocarbons such as 1,1.1 trichloroethane, ketones such as MEK, acetone, chloroform, ethyl acetate, methylene dichloride, phenol, methylene chloride, or N-methylpyrolldone. Also, HP does not recommend the use of cleaners that use halogenated hydrocarbons because of their potential environmental harm.

Mechanical Dimensions

Horizontal Modules

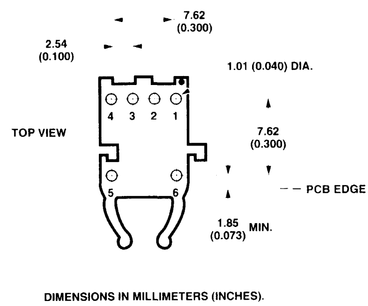


Vertical Modules

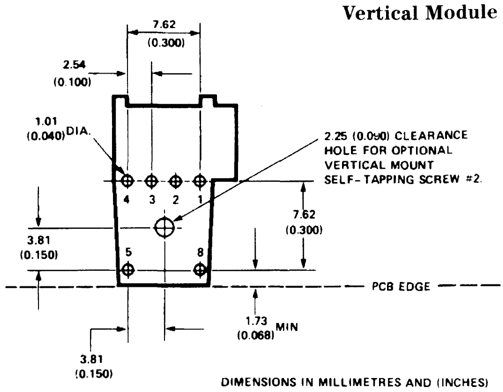


Versatile Link Printed Board Layout Dimensions

Horizontal Module



Vertical Module

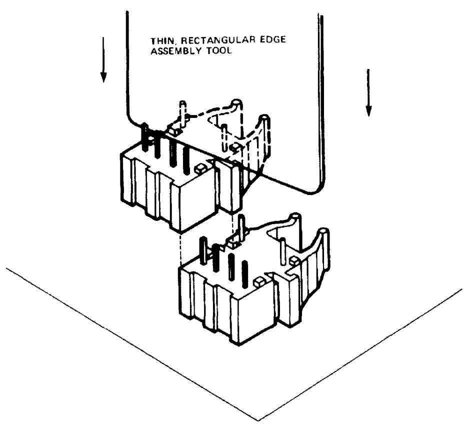


Interlocked (Stacked) Assemblies (refer to Figure 1)

Horizontal packages may be stacked by placing units with pins facing upward. Initially engage the interlocking mechanism by sliding the L bracket body from above into the L slot body of the lower package. Use a straight edge, such as a ruler, to bring all stacked units into uniform alignment. This technique prevents potential harm that could occur to fingers and hands of assemblers from the package pins. Stacked horizontal packages can be disengaged if necessary. Repeated stacking and unstacking causes no damage to individual units.

To stack vertical packages, hold one unit in each hand, with the pins facing away and the optical ports on the bottom. Slide the L bracket unit into the L slot unit. The straight edge used for horizontal package alignment is not needed.

Stacking Horizontal Modules



Stacking Vertical Modules

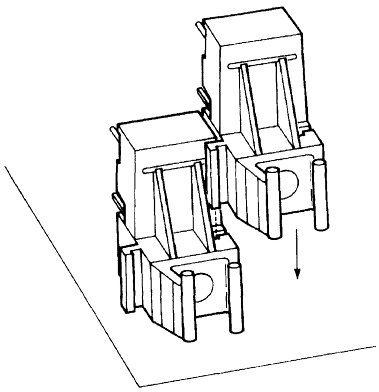


Figure 1. Interlocked (Stacked) Horizontal or Vertical Packages.

5 MBd Link (HFBR-15X1/25X1)

System Performance 0 to 70°C unless otherwise specified.

	Parameter	Symbol	Min.	Typ.	Max.	Units	Conditions	Ref.
High Performance 5 MBd	Data Rate		dc		5	MBd	BER $\leq 10^{-9}$, PRBS:2^7-1	
	Link Distance (Standard Cable)	ℓ	19 27	 48		m m	I_{Fdc} = 60 mA I_{Fdc} = 60 mA, 25°C	Fig. 3 Note 3
	Link Distance (Improved Cable)	ℓ	22 27	 53		m m	I_{Fdc} = 60 mA I_{Fdc} = 60 mA, 25°C	Fig. 4 Note 3
	Propagation Delay	t_{PLH} t_{PHL}		80 50	140 140	ns ns	R_L = 560 Ω, C_L = 30 pF fiber length = 0.5 m $-21.6 \leq P_R \leq -9.5$ dBm	Fig. 5, 8 Notes 1, 2
	Pulse Width Distortion t_{PLH}-t_{PHL}	t_D		30		ns	P_R = -15 dBm R_L = 560 Ω, C_L = 30 pF	Fig. 5, 7

Notes:

1. The propagation delay for one metre of cable is typically 5 ns.
2. Typical propagation delay is measured at P_R = -15 dBm.
3. Estimated typical link life expectancy at 40°C exceeds 10 years at 60 mA.

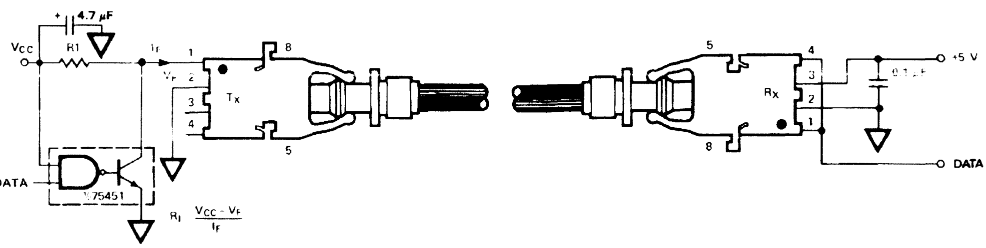


Figure 2. Typical 5 MBd Interface Circuit.

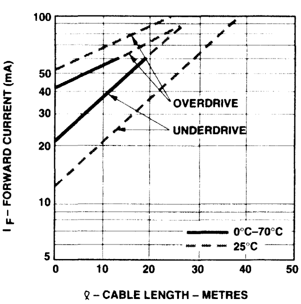


Figure 3. Guaranteed System Performance with Standard Cable (HFBR-15X1/25X1).

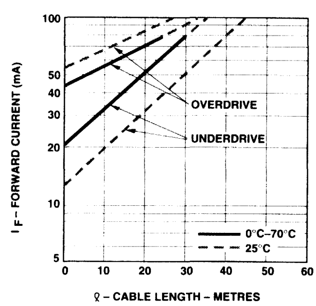


Figure 4. Guaranteed System Performance with Improved Cable (HFBR-15X1/25X1).

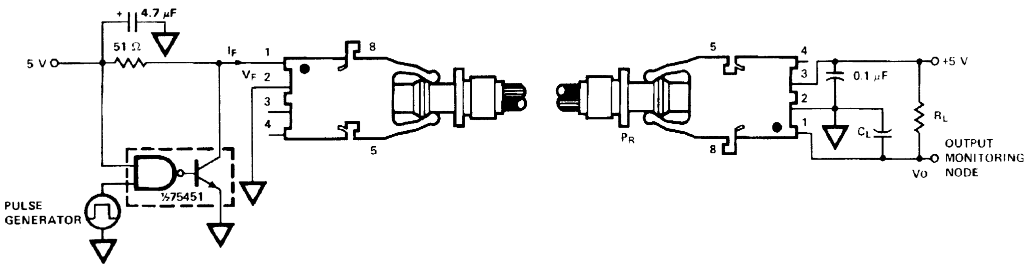


Figure 5. 5 MBd Propagation Delay Test Circuit.

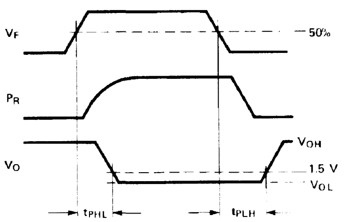


Figure 6. Propagation Delay Test Waveforms.

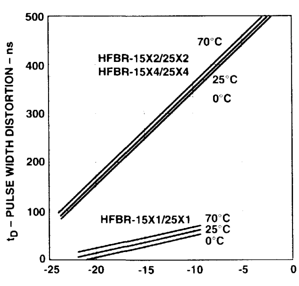


Figure 7. Typical Link Pulse Width Distortion vs. Optical Power.

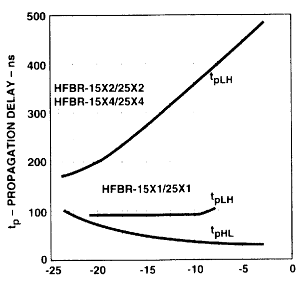
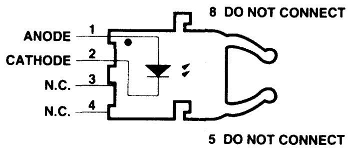


Figure 8. Typical Link Propagation Delay vs. Optical Power.

HFBR-15X1 Transmitter



Pin #	Function
1	Anode
2	Cathode
3	Open
4	Open
5	Do not connect
8	Do not connect

Note: Pins 5 and 8 are for mounting and retaining purposes only. Do not electrically connect these pins.

Absolute Maximum Ratings

Parameter		Symbol	Min.	Max.	Units	Reference
Storage Temperature		T_S	-40	+75	°C	
Operating Temperature		T_A	0	+70	°C	
Lead Soldering Cycle	Temp.			260	°C	Note 1
	Time			10	sec	
Forward Input Current		I_{FPK}		1000	mA	Note 2, 3
		I_{Fdc}		80		
Reverse Input Voltage		V_{BR}		5	V	

Notes:
1. 1.6 mm below seating plane.
2. Recommended operating range between 10 and 750 mA.
3. 1 μs pulse, 20 μs period.

All HFBR-15XX LED transmitters are classified as IEC 825-1 Accessible Emission Limit (AEL) Class 1 based upon the current proposed draft scheduled to go into effect on January 1, 1997. AEL Class 1 LED devices are considered eye safe. Contact your local Hewlett-Packard sales representative for more information.

Transmitter Electrical/Optical Characteristics 0°C to 70°C unless otherwise specified.

Parameter	Symbol	Min.	Typ.[5]	Max.	Units	Conditions	Ref.
Transmitter Output Optical Power	P_T	-16.5		-7.6	dBm	I_{Fdc} = 60 mA	Notes 1, 2
		-14.3		-8.0	dBm	I_{Fdc} = 60 mA, 25°C	
Output Optical Power Temperature Coefficient	$\Delta P_T/\Delta T$		-0.85		%/°C		
Peak Emission Wavelength	λ_{PK}		660		nm		
Forward Voltage	V_F	1.45	1.67	2.02	V	I_{Fdc} = 60 mA	
Forward Voltage Temperature Coefficient	$\Delta V_F/\Delta T$		-1.37		mV/°C		Fig. 9
Effective Diameter	D		1		mm		
Numerical Aperture	NA		0.5				
Reverse Input Breakdown Voltage	V_{BR}	5.0	11.0		V	I_{Fdc} = 10 µA, T_A = 25°C	
Diode Capacitance	C_O		86		pF	V_F = 0, f = MHz	
Rise Time	t_r		80		ns	10% to 90%, I_F = 60 mA	Note 3
Fall Time	t_f		40		ns		

Notes:
1. Measured at the end of 0.5 m standard fiber optic cable with large area detector.
2. Optical power, P (dBm) = 10 Log [P(µW)/1000 µW].
3. Rise and fall times are measured with a voltage pulse driving the transmitter and a series connected 50 Ω load. A wide bandwidth optical to electrical waveform analyzer, terminated to a 50 Ω input of a wide bandwidth oscilloscope, is used for this response time measurement.

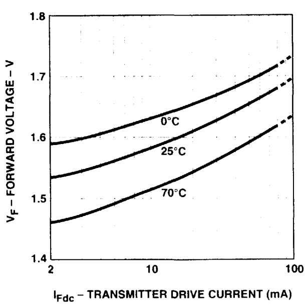


Figure 9. Typical Forward Voltage vs. Drive Current.

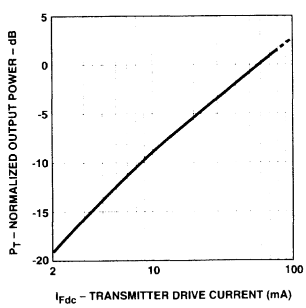
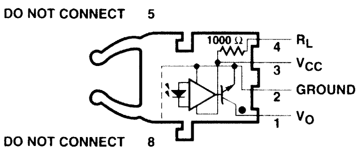


Figure 10. Normalized Typical Output Power vs. Drive Current.

HFBR-25X1 Receiver



Pin #	Function
1	V_O
2	Ground
3	V_{CC}
4	R_L
5	Do not connect
8	Do not connect

Note: Pins 5 and 8 are for mounting and retaining purposes only. Do not electrically connect these pins.

Absolute Maximum Ratings

Parameter		Symbol	Min.	Max.	Units	Reference
Storage Temperature		T_S	-40	+75	°C	
Operating Temperature		T_A	0	+70	°C	
Lead Soldering Cycle	Temp.			260	°C	Note 1
	Time			10	sec	
Supply Voltage		V_{CC}	-0.5	7	V	Note 2
Output Collector Current		I_{OAV}		25	mA	
Output Collector Power Dissipation		P_{OD}		40	mW	
Output Voltage		V_O	-0.5	18	V	
Pull-up Voltage		V_P	-5	V_{CC}	V	
Fan Out (TTL)		N		5		

Notes:
1. 1.6 mm below seating plane.
2. It is essential that a bypass capacitor 0.01 µF be connected from pin 2 to pin 3 of the receiver. Total lead length between both ends of the capacitor and the pins should not exceed 20 mm.

Receiver Electrical/Optical Characteristics

0°C to 70°C, 4.75 V $\leq V_{CC} \leq$ 5.25 V unless otherwise specified

Parameter	Symbol	Min.	Typ.	Max.	Units	Conditions	Ref.
Input Optical Power Level for Logic "0"	$P_{R(L)}$	-21.6		-9.5	dBm	V_{OL} = 0.5 V, I_{OL} = 8 mA	Notes 1, 2, 4
		-21.6		-8.7		V_{OL} = 0.5 V, I_{OL} = 8 mA, 25°C	
Input Optical Power Level for Logic "1"	$P_{R(H)}$			-43	dBm	V_{OL} = 5.25 V, $I_{OH} \leq$ 250 µA	Note 1
High Level Output Current	I_{OH}		5	250	µA	V_O = 18 V, P_R = 0	Note 3
Low Level Output Current	V_{OL}		0.4	0.5	V	I_{OL} = 8 mA, $P_R = P_{R(L)MIN}$	Note 3
High Level Supply Current	I_{CCH}		3.5	6.3	mA	V_{CC} = 5.25 V, P_R = 0	Note 3
Low Level Supply Current	I_{CCL}		6.2	10	mA	V_{CC} = 5.25 V, P_R = -12.5 dBm	Note 3
Effective Diameter	D		1		mm		
Numerical Aperture	NA		0.5				
Internal Pull-up Resistor	R_L	680	1000	1700	Ω		

Notes:
1. Optical flux, P (dBm) = 10 Log [P (µW)/1000 µW].
2. Measured at the end of the fiber optic cable with large area detector.
3. R_L is open.
4. Pulsed LED operation at I_F > 80 mA will cause increased link t_{PLH} propagation delay time. This extended t_{PLH} time contributes to increased pulse width distortion of the receiver output signal.

1 MBd Link

(High Performance HFBR-15X2/25X2, Standard HFBR-15X4/25X4)

System Performance Under recommended operating conditions unless otherwise specified.

	Parameter	Symbol	Min.	Typ.	Max.	Units	Conditions	Ref.
High Performance 1 MBd	Data Rate		dc		1	MBd	BER $\leq 10^{-9}$, PRBS:2^7-1	
	Link Distance (Standard Cable)	ℓ	39 47	 70		m m	I_{Fdc} = 60 mA I_{Fdc} = 60 mA, 25°C	Fig. 14 Notes 1, 3, 4
	Link Distance (Improved Cable)	ℓ	45 56	 78		m m	I_{Fdc} = 60 mA I_{Fdc} = 60 mA, 25°C	Fig. 15 Notes 1, 3, 4
	Propagation Delay	t_{PLH} t_{PHL}		180 100	250 140	ns ns	R_L = 560 Ω, C_L = 30 pF I = 0.5 metre P_R = -24 dBm	Fig. 16, 18 Notes 2, 4
	Pulse Width Distortion t_{PLH}-t_{PHL}	t_D		80		ns	P_R = -24 dBm R_L = 560 Ω, C_L = 30 pF	Fig. 16, 17 Note 4

	Parameter	Symbol	Min.	Typ.	Max.	Units	Conditions	Ref.
Standard 1 MBd	Data Rate		dc		1	MBd	BER $\leq 10^{-9}$, PRBS:2^7-1	
	Link Distance (Standard Cable)	ℓ	8 17	 43		m m	I_{Fdc} = 60 mA I_{Fdc} = 60 mA, 25°C	Fig. 12 Notes 1, 3, 4
	Link Distance (Improved Cable)	ℓ	10 19	 48		m m	I_{Fdc} = 60 mA I_{Fdc} = 60 mA, 25°C	Fig. 13 Notes 1, 3, 4
	Propagation Delay	t_{PLH} t_{PHL}		180 100	250 140	ns ns	R_L = 560 Ω, C_L = 30 pF I = 0.5 metre P_R = -20 dBm	Fig. 16, 18 Notes 2, 4
	Pulse Width Distortion t_{PLH}-t_{PHL}	t_D		80		ns	P_R = -20 dBm R_L = 560 Ω, C_L = 30 pF	Fig. 16, 17 Note 4

Notes:

1. For I_{FPK} > 80 mA, the duty factor must be such as to keep $I_{Fdc} \leq$ 80 mA. In addition, for I_{FPK} > 80 mA, the following rules for pulse width apply:
   $I_{FPK} \leq$ 160 mA: Pulse width $\leq$ 1 ms
   I_{FPK} > 160 mA: Pulse width $\leq$ 1 µS, period $\geq$ 20 µS.
2. The propagation delay for one meter of cable is typically 5 ns.
3. Estimated typical link life expectancy at 40°C exceeds 10 years at 60 mA.
4. Pulsed LED operation at I_{FPK} > 80 mA will cause increased link t_{PLH} propagation delay time. This extended t_{PLH} time contributes to increased pulse width distortion of the receiver output signal.

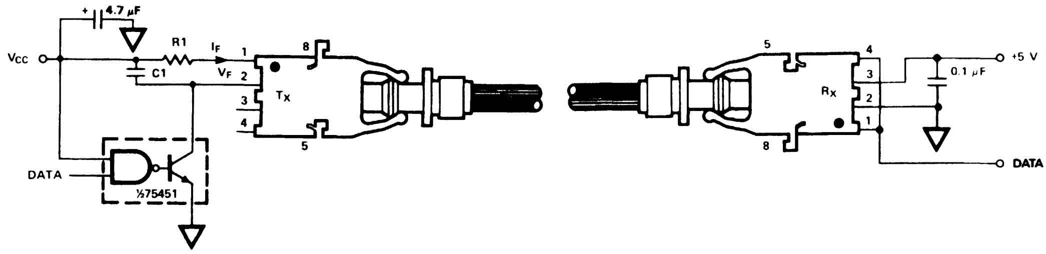


Figure 11. Required 1 MBd Interface Circuit.

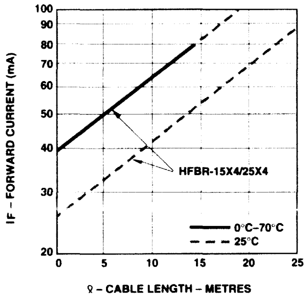


Figure 12. Guaranteed System Performance for the HFBR-15X4/25X4 Link with Standard Cable.

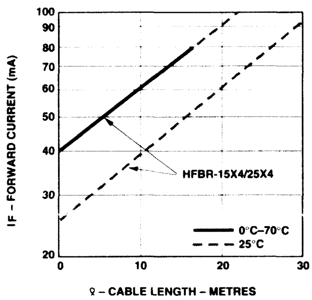


Figure 13. Guaranteed System Performance for the HFBR-15X4/25X4 Link with Improved Cable.

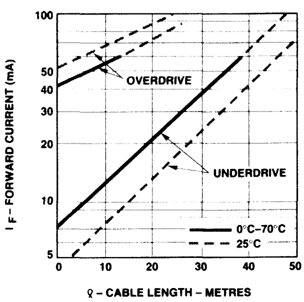


Figure 14. Guaranteed System Performance for the HFBR-15X2/25X2 Link with Standard Cable.

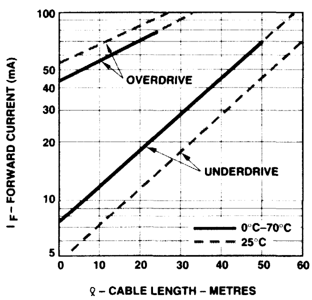


Figure 15. Guaranteed System Performance for the HFBR-15X2/25X2 Link with Improved Cable.

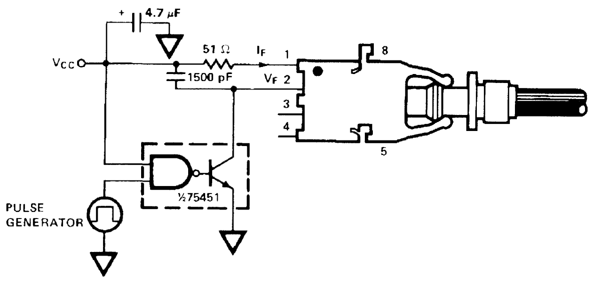


Figure 16. 1 MBd Propagation Delay Test Circuit.

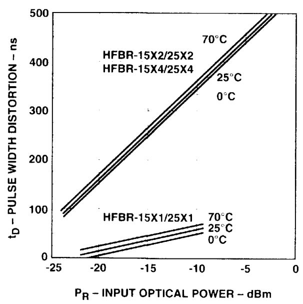


Figure 17. Pulse Width Distortion vs. Optical Power.

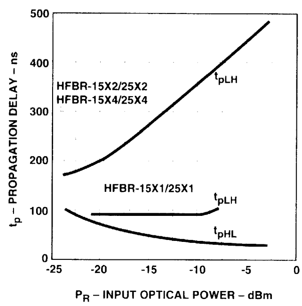


Figure 18. Typical Link Propagation Delay vs. Optical Power.

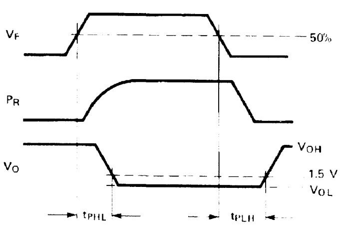
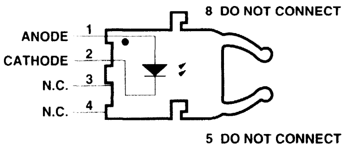


Figure 19. Propagation Delay Test Waveforms.

HFBR-15X2/15X4 Transmitters



Pin #	Function
1	Anode
2	Cathode
3	Open
4	Open
5	Do not connect
8	Do not connect

Note: Pins 5 and 8 are for mounting and retaining purposes only. Do not electrically connect these pins.

Absolute Maximum Ratings

Parameter		Symbol	Min.	Max.	Units	Reference
Storage Temperature		T_S	-40	+75	°C	
Operating Temperature		T_A	0	+70	°C	
Lead Soldering Cycle	Temp.			260	°C	Note 1
	Time			10	sec	
Forward Input Current		I_{FPK}		1000	mA	Note 2, 3
		I_{Fdc}		80		
Reverse Input Voltage		V_{BR}		5	V	

Notes:
1. 1.6 mm below seating plane.
2. Recommended operating range between 10 and 750 mA.
3. 1 µs pulse, 20 µs period.

All HFBR-15XX LED transmitters are classified as IEC 825-1 Accessible Emission Limit (AEL) Class 1 based upon the current proposed draft scheduled to go into effect on January 1, 1997. AEL Class 1 LED devices are considered eye safe. Contact your Hewlett-Packard sales representative for more information.

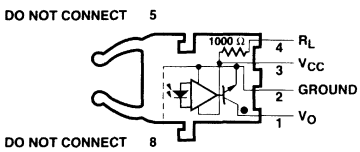
Transmitter Electrical/Optical Characteristics 0°C to 70°C unless otherwise specified.

For forward voltage and output power vs. drive current graphs.

Parameter		Symbol	Min.	Typ.	Max.	Units	Conditions	Ref.
Transmitter Output Optical Power	HFBR-15X2	P_T	-13.6 -11.2		-4.5 -5.1	dBm	I_{Fdc} = 60 mA I_{Fdc} = 60 mA, 25°C	
	HFBR-15X4	P_T	-17.8 -15.5		-4.5 -5.1	dBm	I_{Fdc} = 60 mA I_{Fdc} = 60 mA, 25°C	
Output Optical Power Temperature Coefficient		$\Delta P_T/\Delta T$		-0.85		%/°C		
Peak Emission Wavelength		λ_{PK}		660		nm		
Forward Voltage		V_F	1.45	1.67	2.02	V	I_{Fdc} = 60 mA	
Forward Voltage Temperature Coefficient		$\Delta V_F/\Delta T$		-1.37		mV/°C		Fig. 11
Effective Diameter		D_T		1		mm		
Numerical Aperture		NA		0.5				
Reverse Input Breakdown Voltage		V_{BR}	5.0	11.0		V	I_{Fdc} = 10 µA, T_A = 25°C	
Diode Capacitance		C_O		86		pF	V_F = 0, f = 1 MHz	
Rise Time		t_r		80		ns	10% to 90%, I_F = 60 mA	Note 1
Fall Time		t_f		40		ns		

Note:
1. Rise and fall times are measured with a voltage pulse driving the transmitter and a series connected 50 Ω load. A wide bandwidth optical to electrical waveform analyzer, terminated to a 50 Ω input of a wide bandwidth oscilloscope, is used for this response time measurement.

HFBR-25X2/25X4 Receivers



Pin #	Function
1	V_O
2	Ground
3	V_{CC}
4	R_L
5	Do not connect
8	Do not connect

Note: Pins 5 and 8 are for mounting and retaining purposes only. Do not electrically connect these pins.

Absolute Maximum Ratings

Parameter		Symbol	Min.	Max.	Units	Reference
Storage Temperature		T_S	-40	+75	°C	
Operating Temperature		T_A	0	+70	°C	
Lead Soldering Cycle	Temp.			260	°C	Note 1
	Time			10	sec	
Supply Voltage		V_{CC}	-0.5	7	V	Note 2
Output Collector Current		I_{OAV}		25	mA	
Output Collector Power Dissipation		P_{OD}		40	mW	
Output Voltage		V_O	-0.5	18	V	
Pull-up Voltage		V_P	-5	V_{CC}	V	
Fan Out (TTL)		N		5		

Notes:
1. 1.6 mm below seating plane.
2. It is essential that a bypass capacitor 0.01 µF be connected from pin 2 to pin 3 of the receiver. Total lead length between both ends of the capacitor and the pins should not exceed 20 mm.

Receiver Electrical/Optical Characteristics 0°C to 70°C, 4.75 V ≤ V_{CC} ≤ 5.25 V unless otherwise specified.

Parameter		Symbol	Min.	Typ.	Max.	Units	Conditions	Ref.
Receiver Optical Input Power Level Logic 0	HFBR-2522	$P_{R(L)}$	-24			dBm	V_{OL} = 0 V I_{OL} = 8 mA	Notes 1, 2, 3
	HFBR-2524		-20					Note 4
Optical Input Power Level Logic 1		$P_{R(H)}$			-43	dBm	V_{OH} = 5.25 V I_{OH} = ≤ 250 µA	
High Level Output Current		I_{OH}		5	250	µA	V_O = 18 V, P_R = 0	Note 5
Low Level Output Voltage		V_{OL}		0.4	0.5	V	I_{OL} = 8 mA $P_R = P_{R(L)MIN}$	Note 5
High Level Supply Current		I_{CCH}		3.5	6.3	mA	V_{CC} = 5.25 V, P_R = 0	Note 5
Low Level Supply Current		I_{CCL}		6.2	10	mA	V_{CC} = 5.25 V, P_R = -12.5 dBm	Note 5
Effective Diameter		D		1		mm		
Numerical Aperture		NA		0.5				
Internal Pull-up Resistor		R_L	680	1000	1700	Ω		

Notes:
1. Measured at the end of the fiber optic cable with large area detector.
2. Pulsed LED operation at I_F > 80 mA will cause increased link t_{PLH} propagation delay time. This extended t_{PLH} time contributes to increased pulse width distortion of the receiver output signal.
3. The LED drive circuit of Figure 11 is required for 1 MBd operation of the HFBR-25X2/25X4.
4. Optical flux, P (dBm) = 10 Log [P(µW)/1000 µW].
5. R_L is open.

40 kBd Link

System Performance Under recommended operating conditions unless otherwise specified.

Parameter	Symbol	Min.	Typ.	Max.	Units	Conditions	Ref.
Data Rate		dc		40	kBd	BER ≤ 10^{-9}, PRBS: 2^7 - 1	
Link Distance (Standard Cable)	ℓ	13 94	41 138		m m	I_{Fdc} = 2 mA I_{Fdc} = 60 mA	Fig. 21 Note 1
Link Distance (Improved Cable)	ℓ	15 111	45 154		m m	I_{Fdc} = 2 mA I_{Fdc} = 60 mA	Fig. 22 Note 1
Propagation Delay	t_{PLH} t_{PHL}		4 2.5		µs µs	R_L = 3.3 kΩ, C_L = 30 pF P_R = -25 dBm, 1 m fiber	Fig. 22, 25 Note 2
Pulse Width Distortion t_{PLH}-t_{PHL}	t_D			7	µs	-39 ≤ P_R ≤ - 14 dBm R_L = 3.3 kΩ, C_L = 30 pF	Fig. 23, 24

Notes:

1. Estimated typical link life expectancy at 40°C exceeds 10 years at 60 mA.
2. The propagation delay for one metre of cable is typically 5 ns.

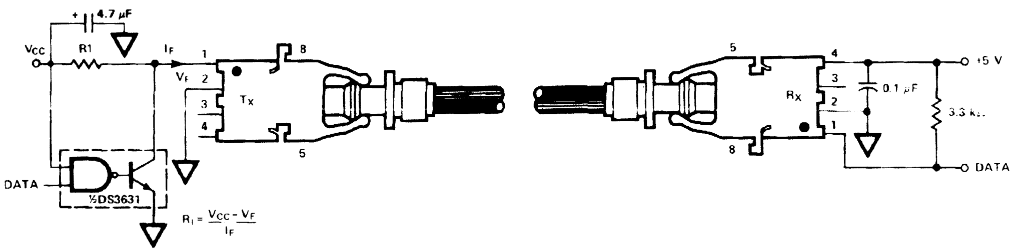


Figure 20. Typical 40 kBd Interface Circuit.

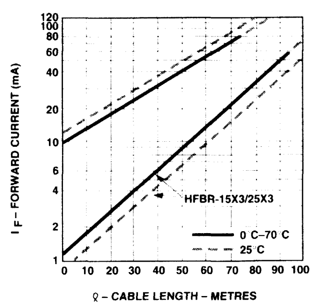


Figure 21. Guaranteed System Performance with Standard Cable.

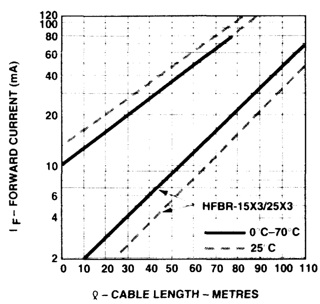


Figure 22. Guaranteed System Performance with Improved Cable.

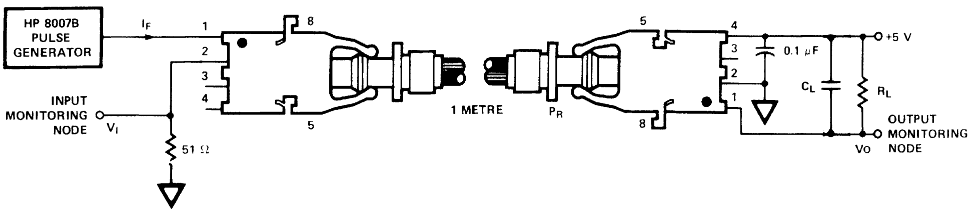


Figure 23. 40 kBd Propagation Delay Test Circuit.

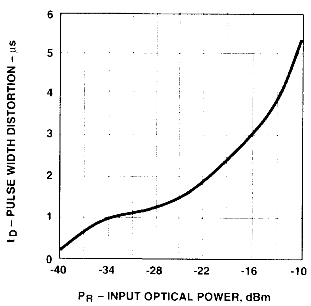


Figure 24. Typical Link Pulse Width Distortion vs. Optical Power.

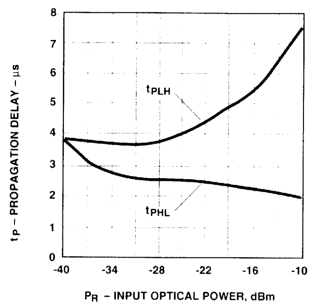


Figure 25. Typical Link Propagation Delay vs. Optical Power.

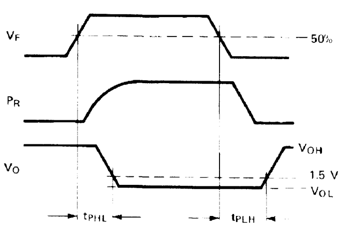
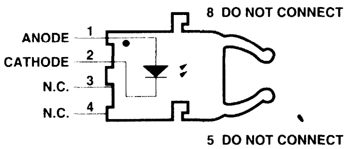


Figure 26. Propagation Delay Test Waveforms.

HFBR-15X3 Transmitter



Pin #	Function
1	Anode
2	Cathode
3	Open
4	Open
5	Do not connect
8	Do not connect

Note: Pins 5 and 8 are for mounting and retaining purposes only. Do not electrically connect these pins.

Absolute Maximum Ratings

Parameter		Symbol	Min.	Max.	Units	Reference
Storage Temperature		T_S	-40	+75	°C	
Operating Temperature		T_A	0	+70	°C	
Lead Soldering Cycle	Temp.			260	°C	Note 1
	Time			10	sec	
Forward Input Current		I_{FPK}		1000	mA	Note 2, 3
		I_{Fdc}		80		
Reverse Input Voltage		V_{BR}		5	V	

Notes:
1. 1.6 mm below seating plane.
2. Recommended operating range between 10 and 750 mA.
3. 1 μs pulse, 20 μs period.

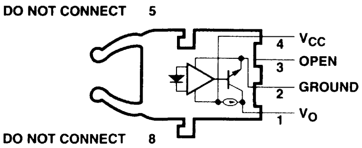
All HFBR-15XX LED transmitters are classified as IEC 825-1 Accessible Emission Limit (AEL) Class 1 based upon the current proposed draft scheduled to go into effect on January 1, 1997. AEL Class 1 LED devices are considered eye safe. Contact your Hewlett-Packard sales representative for more information.

Transmitter Electrical/Optical Characteristics 0°C to 70°C unless otherwise specified.
For forward voltage and output power vs. drive current graphs.

Parameter	Symbol	Min.	Typ.	Max.	Units	Conditions	Ref.
Transmitter Output Optical Power	P_T	-11.2 -13.6 -35.5		-5.1 -4.5	dBm	I_{Fdc} = 60 mA, 25°C I_{Fdc} = 60 mA I_{Fdc} = 2 mA, 0-70°C	Notes 3, 4 Fig. 9, 10
Output Optical Power Temperature Coefficient	$\Delta P_T/\Delta T$		-0.85		%/°C		
Peak Emission Wavelength	λ_{PK}		660		nm		
Forward Voltage	V_F	1.45	1.67	2.02	V	I_{Fdc} = 60 mA	
Forward Voltage Temperature Coefficient	$\Delta V_F/\Delta T$		-1.37		mV/°C		Fig. 18
Effective Diameter	D		1		mm		
Numerical Aperture	NA		0.5				
Reverse Input Breakdown Voltage	V_{BR}	5.0	11.0		V	I_{Fdc} = 10 μA, T_A = 25°C	
Diode Capacitance	C_O		86		pF	V_F = 0, f = 1 MHz	
Rise Time	t_r		80		ns	10% to 90%, I_F = 60 mA	Note 1
Fall Time	t_f		40				

Note:
1. Rise and fall times are measured with a voltage pulse driving the transmitter and a series connected 50 Ω load. A wide bandwidth optical to electrical waveform analyzer, terminated to a 50 Ω input of a wide bandwidth oscilloscope, is used for this response time measurement.

HFBR-25X3 Receiver



Pin #	Function
1	V_O
2	Ground
3	Open
4	V_{CC}
5	Do not connect
8	Do not connect

Note: Pins 5 and 8 are for mounting and retaining purposes only. Do not electrically connect these pins.

Absolute Maximum Ratings

Parameter		Symbol	Min.	Max.	Units	Reference
Storage Temperature		T_S	-40	+75	°C	
Operating Temperature		T_A	0	+70	°C	
Lead Soldering Cycle	Temp.			260	°C	Note 1
	Time			10	sec	
Supply Voltage		V_{CC}	-0.5	7	V	Note 2
Average Output Collector Current		I_O	-1	5	mA	
Output Collector Power Dissipation		P_{OD}		25	mW	
Output Voltage		V_O	-0.5	7	V	

Notes:
1. 1.6 mm below seating plane.
2. It is essential that a bypass capacitor 0.01 µF be connected from pin 2 to pin 3 of the receiver.

Receiver Electrical/Optical Characteristics 0°C to 70°C, 4.5 V ≤ V_{CC} ≤ 5.5 V unless otherwise specified.

Parameter	Symbol	Min.	Typ.	Max.	Units	Conditions	Ref.
Input Optical Power	$P_{R(L)}$	-39		-13.7	dBm	$V_O = V_{OL}$, $I_{OL} = 3.2$ mA	Notes 1, 2, 3
Level Logic 0		-39		-13.3		$V_O = V_{OL}$, $I_{OH} = 8$ mA, 25°C	
Input Optical Power Level Logic 1	$P_{R(H)}$			-53	dBm	$V_{OH} = 5.5$ V, $I_{OH} = \leq 40$ µA	Note 3
High Level Output Voltage	V_{OH}	2.4			V	$I_O = -40$ µA, $P_R = 0$ µW	
Low Level Output Voltage	V_{OL}			0.4	V	$I_{OL} = 3.2$ mA, $P_R = P_{R(L)MIN}$	Note 4
High Level Supply Current	I_{CCH}		1.2	1.9	mA	$V_{CC} = 5.5$ V, $P_R = 0$ µW	
Low Level Supply Current	I_{CCL}		2.9	3.7	mA	$V_{CC} = 5.5$ V, $P_R = P_{RL}$ (MIN)	Note 4
Effective Diameter	D		1		mm		
Numerical Aperture	NA		0.5				

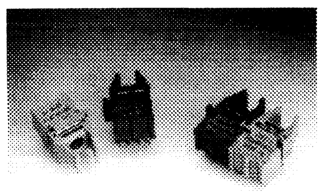
Notes:
1. Measured at the end of the fiber optic cable with large area detector.
2. Optical flux, P (dBm) = 10 Log P(µW)/1000 µW.
3. Because of the very high sensitivity of the HFBR-25X3, the digital output may switch in response to ambient light levels when a cable is not occupying the receiver optical port. The designer should take care to filter out signals from this source if they pose a hazard to the system.
4. Including current in 3.3 k pull-up resistor.

HEWLETT® PACKARD

125 Megabaud Versatile Link The Versatile Fiber Optic Connection

Technical Data

HFBR-0507 Series
HFBR-15X7 Transmitters
HFBR-25X6 Receivers



Features

- **Data Transmission at Signal Rates of 1 to 125 MBd over Distances of 100 Meters**
- **Compatible with Inexpensive, Easily Terminated Plastic Optical Fiber, and with Large Core Silica Fiber**
- **High Voltage Isolation**
- **Transmitter and Receiver Application Circuit Schematics and Recommended Board Layouts Available**
- **Interlocking Feature for Single Channel or Duplex Links, in a Vertical or Horizontal Mount Configuration**
- **Reduction of Lightning and Voltage Transient Susceptibility**

Applications

- **Intra-System Links: Board-to-Board, Rack-to-Rack**
- **Telecommunications Switching Systems**
- **Computer-to-Peripheral Data Links, PC Bus Extension**
- **Industrial Control**
- **Proprietary LANs**
- **Digitized Video**
- **Medical Instruments**

Description

The 125 MBd Versatile Link (HFBR-0507 Series) is the most cost-effective fiber-optic solution for transmission of 125 MBd data over 100 meters. The data link consists of a 650 nm LED transmitter, HFBR-15X7, and a PIN/preamp receiver, HFBR-25X6. These can be used with low-cost plastic or silica fiber. One mm diameter plastic fiber provides the lowest cost solution for distances under 25 meters. The lower attenuation of silica fiber allows data transmission over longer distance, for a small difference in cost. These components can be used for high speed data links without the problems common with copper wire solutions, at a competitive cost.

The HFBR-15X7 transmitter is a high power 650 nm LED in a low cost plastic housing designed to efficiently couple power into 1 mm diameter plastic optical fiber and 200 µm Hard Clad Silica (HCS®) fiber. With the recommended drive circuit, the LED operates at speeds from 1-125 MBd. The HFBR-25X6 is a high bandwidth analog receiver containing a PIN photodiode and internal transimpedance amplifier. With the recommended application circuit for 125 MBd operation, the performance of the complete data link is specified for of 0-25 meters with plastic fiber and 0-100 meters with 200 µm HCS® fiber. A wide variety of other digitizing circuits can be combined with the HFBR-0507 Series to optimize performance and cost at higher and lower data rates.

HCS® is a registered trademark of Spectran Corporation.

HFBR-0507 Series
125 MBd Data Link
Data link operating conditions and performance are specified for the HFBR-15X7 transmitter and HFBR-25X6 receiver in the recommended applications circuits shown in Figure 1. This circuit has been optimized for 125 MBd operation. The Applications Engineering Department in the Hewlett-Packard Optical Communication Division is available to assist in optimizing link performance for higher or lower speed operation.

Recommended Operating Conditions for the Circuits in Figures 1 and 2.

Parameter	Symbol	Min.	Max.	Unit	Reference
Ambient Temperature	T_A	0	70	°C	
Supply Voltage	V_{CC}	+4.75	+5.25	V	
Data Input Voltage – Low	V_{IL}	V_{CC} -1.89	V_{CC} -1.62	V	
Data Input Voltage – High	V_{IH}	V_{CC} -1.06	V_{CC} -0.70	V	
Data Output Load	R_L	45	55	Ω	Note 1
Signaling Rate	f_S	1	125	MBd	
Duty Cycle	D.C.	40	60	%	Note 2

Link Performance: 1-125 MBd, BER ≤ 10^{-9}, under recommended operating conditions with recommended transmit and receive application circuits.

Parameter	Symbol	Min.[3]	Typ.[4]	Max.	Unit	Condition	Reference
Optical Power Budget, 1 m POF	OPB_{POF}	11	16		dB		Note 5,6,7
Optical Power Margin, 20 m Standard POF	$OPM_{POF,20}$	3	6		dB		Note 5,6,7
Link Distance with Standard 1 mm POF	1	20	27		m		
Optical Power Margin, 25 m Low Loss POF	$OPM_{POF,25}$	3	6		dB		Note 5,6,7
Link Distance with Extra Low Loss 1 mm POF	1	25	32		m		
Optical Power Budget, 1 m HCS	OPB_{HCS}	7	12		dB		Note 5,6,7
Optical Power Margin, 100 m HCS	$OPM_{HCS,100}$	3	6		dB		Note 5,6,7
Link Distance with HCS Cable	1	100	125		m		

Notes:
1. If the output of U4C in Figure 1, page 4 is transmitted via coaxial cable, terminate with a 50 Ω resistor to V_{CC} - 2 V.
2. Run length limited code with maximum run length of 10 µs.
3. Minimum link performance is projected based on the worst case specifications of the HFBR-15X7 transmitter, HFBR-25X6 receiver, and POF cable, and the typical performance of other components (e.g. logic gates, transistors, resistors, capacitors, quantizer, HCS cable).
4. Typical performance is at 25°C, 125 MBd, and is measured with typical values of all circuit components.
5. Standard cable is HFBR-RXXYYY plastic optical fiber , with a maximum attenuation of 0.24 dB/m at 650 nm and NA = 0.5. Extra low loss cable is HFBR-EXXYYY plastic optical fiber, with a maximum attenuation of 0.19 dB/m at 650 nm and NA = 0.5. HCS cable is HFBR-H/VXXYYY glass optical fiber, with a maximum attenuation of 10 dB/km at 650 nm and NA = 0.37.
6. Optical Power Budget is the difference between the transmitter output power and the receiver sensitivity, measured after 1 meter of fiber. The minimum OPB is based on the limits of optical component performance over temperature, process, and recommended power supply variation.
7. The Optical Power Margin is the available OPB after including the effects of attenuation and modal dispersion for the minimum link distance: OPM = OPB - (attenuation power loss + modal dispersion power penalty). The minimum OPM is the margin available for longterm LED LOP degradation and additional fixed passive losses (such as in-line connectors) in addition to the minimum specified distance.

Plastic Optical Fiber (1 mm POF) Transmitter Application Circuit:

Performance of the HFBR-15X7 transmitter in the recommended application circuit (Figure 1) for POF; 1-125 MBd, 25°C.

Parameter	Symbol	Typical	Unit	Condition	Note
Average Optical Power 1 mm POF	P_{avg}	-9.7	dBm	50% Duty Cycle	Note 1, Fig 3
Average Modulated Power 1 mm POF	P_{mod}	-11.3	dBm		Note 2, Fig 3
Optical Rise Time (10% to 90%)	t_r	2.1	ns	5 MHz	
Optical Fall Time (90% to 10%)	t_f	2.8	ns	5 MHz	
High Level LED Current (On)	$I_{F,H}$	19	mA		Note 3
Low Level LED Current (Off)	$I_{F,L}$	3	mA		Note 3
Optical Overshoot - 1 mm POF		45	%		
Transmitter Application Circuit Current Consumption - 1 mm POF	I_{CC}	110	mA		Figure 1

Hard Clad Silica Fiber (200 μm HCS) Transmitter Application Circuit:

Performance of the HFBR-15X7 transmitter in the recommended application circuit (Figure 1) for HCS; 1-125 MBd, 25°C.

Parameter	Symbol	Typical	Unit	Condition	Note
Average Optical Power 200 μm HCS	P_{avg}	-14.6	dBm	50% Duty Cycle	Note 1, Fig 3
Average Modulated Power 200 μm HCS	P_{mod}	-16.2	dBm		Note 2, Fig 3
Optical Rise Time (10% to 90%)	t_r	3.1	ns	5 MHz	
Optical Fall Time (90% to 10%)	t_f	3.4	ns	5 MHz	
High Level LED Current (On)	$I_{F,H}$	60	mA		Note 3
Low Level LED Current (Off)	$I_{F,L}$	6	mA		Note 3
Optical Overshoot - 200 μm HCS		30	%		
Transmitter Application Circuit Current Consumption - 200 μm HCS	I_{CC}	130	mA		Figure 1

Notes:

1. Average optical power is measured with an average power meter at 50% duty cycle, after 1 meter of fiber.
2. To allow the LED to switch at high speeds, the recommended drive circuit modulates LED light output between two non-zero power levels. The modulated (useful) power is the difference between the high and low level of light output power (transmitted) or input power (received), which can be measured with an average power meter as a function of duty cycle (see Figure 3). Average Modulated Power is defined as one half the slope of the average power versus duty cycle:

$$\text{Average Modulated Power} = \frac{[P_{avg} @ 80\% \text{ duty cycle} - P_{avg} @ 20\% \text{ duty cycle}]}{(2)\ [0.80 - 0.20]}$$

3. High and low level LED currents refer to the current through the HFBR-15X7 LED. The low level LED "off" current, sometimes referred to as "hold-on" current, is prebias supplied to the LED during the off state to facilitate fast switching speeds.

Plastic and Hard Clad Silica Optical Fiber Receiver Application Circuit:

Performance[4] of the HFBR-25X6 receiver in the recommended application circuit (Figure 1); 1-125 MBd, 25°C unless otherwise stated.

Parameter	Symbol	Typical	Unit	Condition	Note
Data Output Voltage - Low	V_{OL}	V_{CC} -1.7	V	R_L = 50 Ω	Note 5
Data Output Voltage - High	V_{OH}	V_{CC} -0.9	V	R_L = 50 Ω	Note 5
Receiver Sensitivity to Average Modulated Optical Power 1 mm POF	P_{min}	-27.5	dBm	50% eye opening	Note 2
Receiver Sensitivity to Average Modulated Optical Power 200 µm HCS	P_{min}	-28.5	dBm	50% eye opening	Note 2
Receiver Overdrive Level of Average Modulated Optical Power 1 mm POF	P_{max}	-7.5	dBm	50% eye opening	Note 2
Receiver Overdrive Level of Average Modulated Optical Power 200 µm HCS	P_{max}	-10.5	dBm	50% eye opening	Note 2
Receiver Application Circuit Current Consumption	I_{CC}	85	mA	$R_L = \infty$	Figure 1

Notes:

4. Performance in response to a signal from the HFBR-15X7 transmitter driven with the recommended circuit at 1-125 MBd over 1 meter of HFBR-R/EXXYYY plastic optical fiber or 1 meter of HFBR-H/VXXYYY hard clad silica optical fiber.
5. Terminated through a 50 Ω resistor to V_{CC} - 2 V.
6. If there is no input optical power to the receiver, electrical noise can result in false triggering of the receiver. In typical applications, data encoding and error detection prevent random triggering from being interpreted as valid data. Refer to Applications Note 1066 for design guidelines.

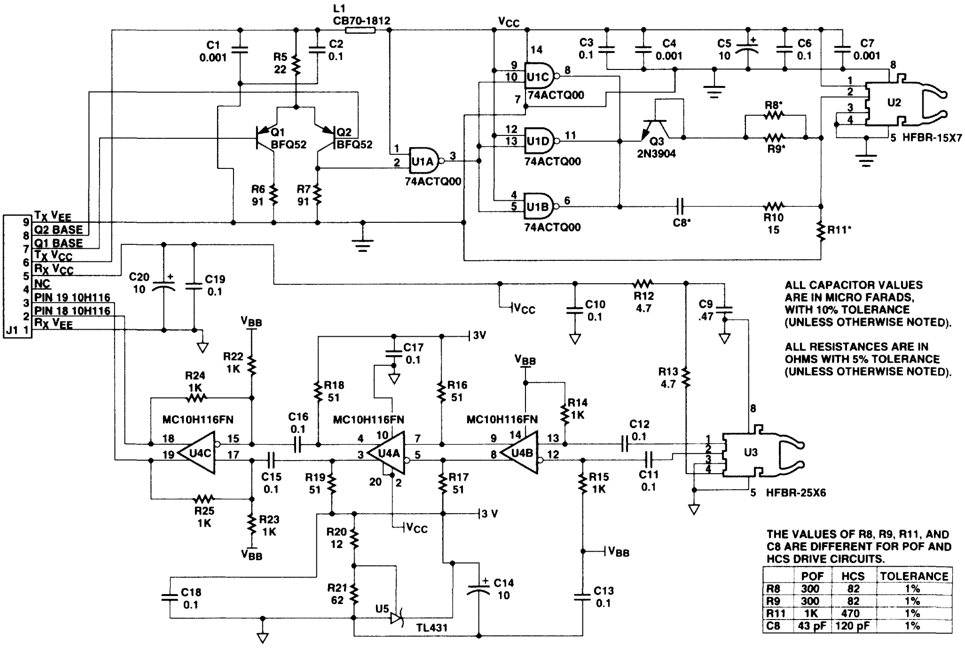


Figure 1. Transmitter and Receiver Application Circuit with +5 V ECL Inputs and Outputs.

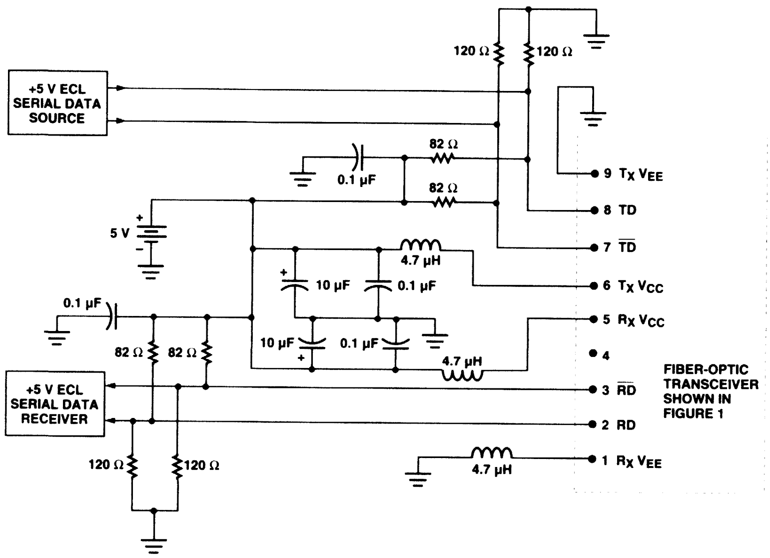


Figure 2. Recommended Power Supply Filter and +5 V ECL Signal Terminations for the Transmitter and Receiver Application Circuit of Figure 1.

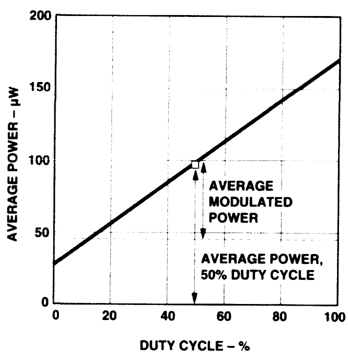


Figure 3. Average Modulated Power.

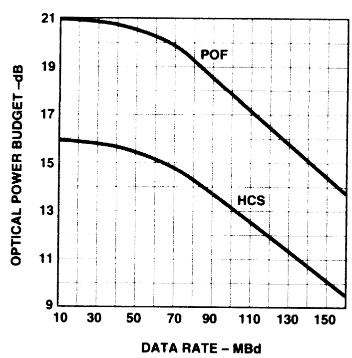


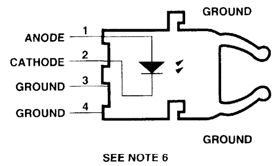
Figure 4. Typical Optical Power Budget vs. Data Rate.

125 Megabaud Versatile Link Transmitter

HFBR-15X7 Series

Description

The HFBR-15X7 transmitters incorporate a 650 nanometer LED in a horizontal (HFBR-1527) or vertical (HFBR-1537) gray housing. The HFBR-15X7 transmitters are suitable for use with current peaking to decrease response time and can be used with HFBR-25X6 receivers in data links operating at signal rates from 1 to 125 megabaud over 1 mm diameter plastic optical fiber or 200 μm diameter hard clad silica glass optical fiber. Refer to Application Note 1066 for details for recommended interface circuits.



Absolute Maximum Ratings

Parameter	Symbol	Min.	Max.	Unit	Reference
Storage Temperature	T_S	-40	85	°C	
Operating Temperature	T_O	-40	70	°C	
Lead Soldering Temperature			260	°C	Note 1
Cycle Time			10	s	
Transmitter High Level Forward Input Current	$I_{F,H}$		120	mA	50% Duty Cycle ≥ 1 MHz
Transmitter Average Forward Input Current	$I_{F,AV}$		60	mA	
Reverse Input Voltage	V_R		3	V	

CAUTION: The small junction sizes inherent to the design of this component increase the component's susceptibility to damage from electrostatic discharge (ESD). It is advised that normal static precautions be taken in handling and assembly of this component to prevent damage and/or degradation which may be induced by ESD.

WARNING: WHEN VIEWED UNDER SOME CONDITIONS, THE OPTICAL PORT MAY EXPOSE THE EYE BEYOND THE MAXIMUM PERMISSIBLE EXPOSURE RECOMMENDED IN ANSI Z136.2, 1993. UNDER MOST VIEWING CONDITIONS THERE IS NO EYE HAZARD.

Electrical/Optical Characteristics 0 to 70°C, unless otherwise stated.

Parameter	Symbol	Min.	Typ.[2]	Max.	Unit	Condition	Note
Transmitter Output Optical Power, 1 mm POF	P_T	-9.5 -10.4	-7.0	-4.8 -4.3	dBm	$I_{F,dc}$ = 20 mA, 25°C 0-70°C	Note 3
Transmitter Output Optical Power, 1 mm POF	P_T	-6.0 -6.9	-3.0	-0.5 -0.0	dBm	$I_{F,dc}$ = 60 mA, 25°C 0-70°C	Note 3
Transmitter Output Optical Power, 200 µm HCS®	P_T	-14.6 -15.5	-13.0	-10.5 -10.0	dBm	$I_{F,dc}$ = 60 mA, 25°C 0-70°C	Note 3
Output Optical Power Temperature Coefficient	$\frac{\Delta P_T}{\Delta T}$		-0.02		dB/°C		
Peak Emission Wavelength	λ_{PK}	640	650	660	nm		
Peak Wavelength Temperature Coefficient	$\frac{\Delta\lambda}{\Delta T}$		0.12		nm/°C		
Spectral Width	FWHM		21		nm	Full Width, Half Maximum	
Forward Voltage	V_F	1.8	2.1	2.4	V	I_F = 60 mA	
Forward Voltage Temperature Coefficient	$\frac{\Delta V_F}{\Delta T}$		-1.8		mV/°C		
Transmitter Numerical Aperture	NA		0.5				
Thermal Resistance, Junction to Case	θ_{jc}		140		°C/W		Note 4
Reverse Input Breakdown Voltage	V_{BR}	3.0	13		V	$I_{F,dc}$ = -10 µA	
Diode Capacitance	C_O		60		pF	V_F = 0 V, f = 1 MHz	
Unpeaked Optical Rise Time, 10% - 90%	t_r		12		ns	I_F = 60 mA f = 100 kHz	Figure 1 Note 5
Unpeaked Optical Fall Time, 90% - 10%	t_f		9		ns	I_F = 60 mA f = 100 kHz	Figure 1 Note 5

Notes:
1. 1.6 mm below seating plane.
2. Typical data is at 25°C.
3. Optical Power measured at the end of 0.5 meter of 1 mm diameter plastic or 200 µm diameter hard clad silica optical fiber with a large area detector.
4. Typical value measured from junction to PC board solder joint for horizontal mount package, HFBR-1527. θ_{jc} is approximately 30°C/W higher for vertical mount package, HFBR-1537.
5. Optical rise and fall times can be reduced with the appropriate driver circuit; refer to Application Note 1066.
6. Pins 5 and 8 are primarily for mounting and retaining purposes, but are electrically connected; pins 3 and 4 are electrically unconnected. It is recommended that pins 3, 4, 5, and 8 all be connected to ground to reduce coupling of electrical noise.
7. Refer to the Versatile Link Family Fiber Optic Cable and Connectors Technical Data Sheet for cable connector options for 1 mm plastic optical fiber and 200 µm HCS fiber.
8. The LED current peaking necessary for high frequency circuit design contributes to electromagnetic interference (EMI). Care must be taken in circuit board layout to minimize emissions for compliance with governmental EMI emissions regulations. Refer to Application Note 1066 for design guidelines.

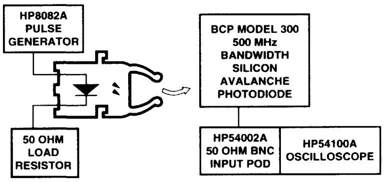


Figure 1. Test Circuit for Measuring Unpeaked Rise and Fall Times.

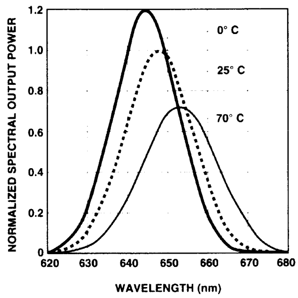


Figure 2. Typical Spectra Normalized to the 25°C Peak.

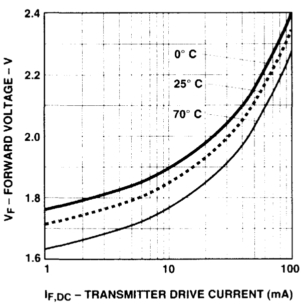


Figure 3. Typical Forward Voltage vs. Drive Current.

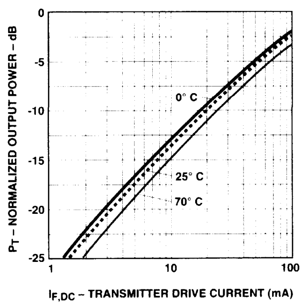


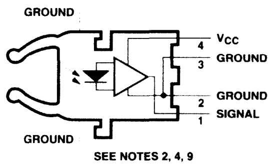
Figure 4. Typical Normalized Output Optical Power vs. Drive Current.

125 Megabaud Versatile Link Receiver

HFBR-25X6 Series

Description

The HFBR-25X6 receivers contain a PIN photodiode and transimpedance pre-amplifier circuit in a horizontal (HFBR-2526) or vertical (HFBR-2536) blue housing, and are designed to interface to 1mm diameter plastic optical fiber or 200 μm hard clad silica glass optical fiber. The receivers convert a received optical signal to an analog output voltage. Follow-on circuitry can optimize link performance for a variety of distance and data rate requirements. Electrical bandwidth greater than 65 MHz allows design of high speed data links with plastic or hard clad silica optical fiber. Refer to Application Note 1066 for details for recommended interface circuits.



Absolute Maximum Ratings

Parameter	Symbol	Min.	Max.	Unit	Reference
Storage Temperature	T_S	-40	+75	°C	
Operating Temperature	T_A	0	+70	°C	
Lead Soldering Temperature			260	°C	Note 1
Cycle Time			10	s	
Signal Pin Voltage	V_O	-0.5	V_{CC}	V	
Supply Voltage	V_{CC}	-0.5	6.0	V	
Output Current	I_O		25	mA	

CAUTION: The small junction sizes inherent to the design of this component increase the component's susceptibility to damage from electrostatic discharge (ESD). It is advised that normal static precautions be taken in handling and assembly of this component to prevent damage and/or degradation which may be induced by ESD.

Electrical/Optical Characteristics 0 to 70°C; 5.25 V ≥ V_{CC} ≥ 4.75 V; power supply must be filtered (see Figure 1, Note 2).

Parameter	Symbol	Min.	Typ.	Max.	Unit	Test Condition	Note
AC Responsivity 1 mm POF	$R_{P,APF}$	1.7	3.9	6.5	mV/μW	650 nm	Note 4
AC Responsivity 200 μm HCS	$R_{P,HCS}$	4.5	7.9	11.5	mV/μW		
RMS Output Noise	V_{NO}		0.46	0.69	mV_{RMS}		Note 5
Equivalent Optical Noise Input Power, RMS - 1 mm POF	$P_{N,RMS}$		- 39	-36	dBm		Note 5
Equivalent Optical Noise Input Power, RMS - 200 μm HCS	$P_{N,RMS}$		-42	-40	dBm		Note 5
Peak Input Optical Power - 1 mm POF	P_R			-5.8 -6.4	dBm dBm	5 ns PWD 2 ns PWD	Note 6
Peak Input Optical Power - 200 μm HCS	P_R			-8.8 -9.4	dBm dBm	5 ns PWD 2 ns PWD	Note 6
Output Impedance	Z_O		30		Ω	50 MHz	Note 4
DC Output Voltage	V_O	0.8	1.8	2.6	V	P_R = 0 μW	
Supply Current	I_{CC}		9	15	mA		
Electrical Bandwidth	BW_E	65	125		MHz	-3 dB electrical	
Bandwidth * Rise Time			0.41		Hz * s		
Electrical Rise Time, 10-90%	t_r		3.3	6.3	ns	P_R = -10 dBm peak	
Electrical Fall Time, 90-10%	t_f		3.3	6.3	ns	P_R = -10 dBm peak	
Pulse Width Distortion	PWD		0.4	1.0	ns	P_R = -10 dBm peak	Note 7
Overshoot			4		%	P_R = -10 dBm peak	Note 8

Notes:

1. 1.6 mm below seating plane.
2. The signal output is an emitter follower, which does not reject noise in the power supply. The power supply must be filtered as in Figure 1.
3. Typical data are at 25°C and V_{CC} = +5 Vdc.
4. Pin 1 should be ac coupled to a load ≥ 510 Ω with load capacitance less than 5 pF.
5. Measured with a 3 pole Bessel filter with a 75 MHz, -3dB bandwidth.
6. The maximum Peak Input Optical Power is the level at which the Pulse Width Distortion is guaranteed to be less than the PWD listed under Test Condition. $P_{R,Max}$ is given for PWD = 5 ns for designing links at ≤ 50 MBd operation, and also for PWD = 2 ns for designing links up to 125 MBd (for both POF and HCS input conditions).
7. 10 ns pulse width, 50% duty cycle, at the 50% amplitude point of the waveform.
8. Percent overshoot is defined at:

$$\frac{(V_{PK} - V_{100\%})}{V_{100\%}} \times 100\%$$

9. Pins 5 and 8 are primarily for mounting and retaining purposes, but are electrically connected. It is recommended that these pins be connected to ground to reduce coupling of electrical noise.
10. If there is no input optical power to the receiver (no transmitted signal) electrical noise can result in false triggering of the receiver. In typical applications, data encoding and error detection prevent random triggering from being interpreted as valid data. Refer to Application Note 1066 for design guidelines.

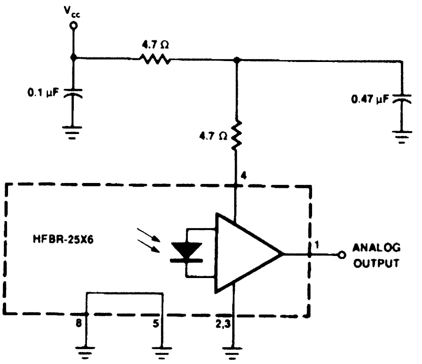


Figure 1. Recommended Power Supply Filter Circuit.

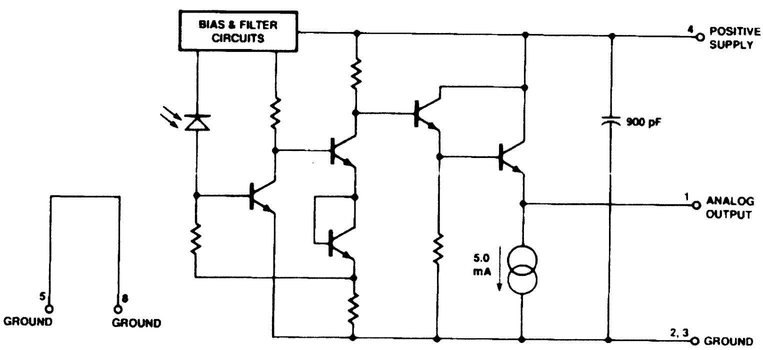


Figure 2. Simplified Receiver Schematic.

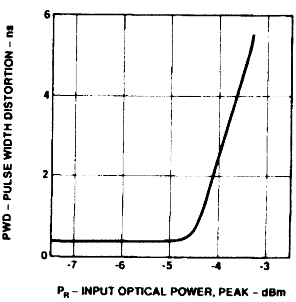


Figure 3. Typical Pulse Width Distortion vs. Peak Input Power.

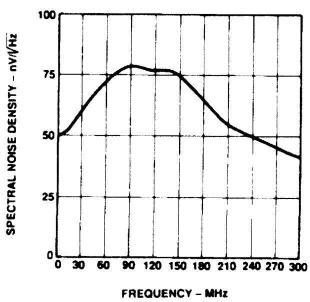


Figure 4. Typical Output Spectral Noise Density vs. Frequency.

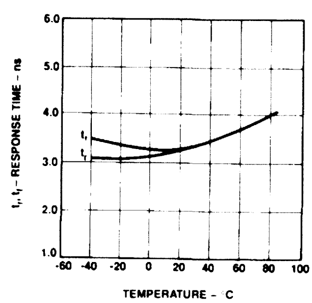
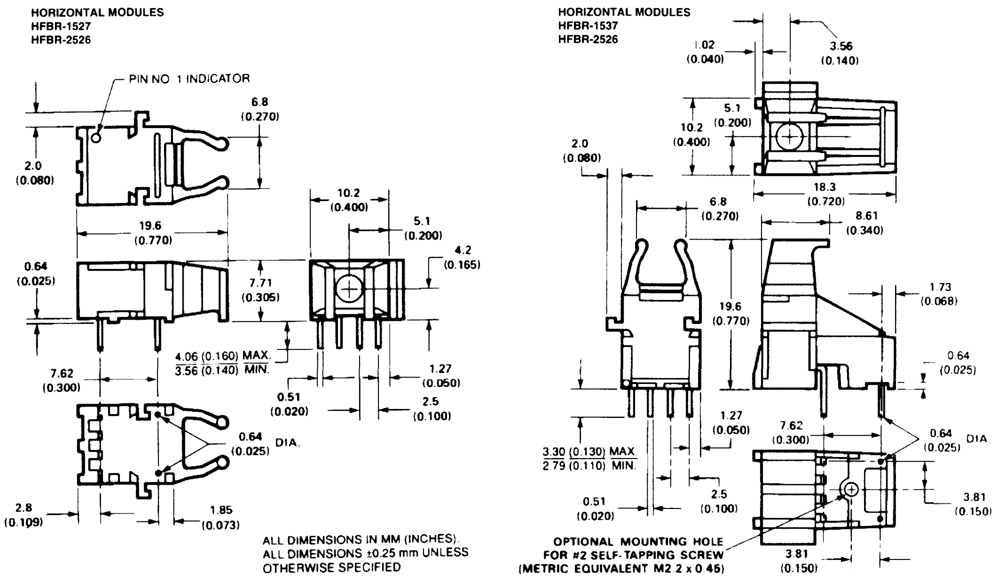
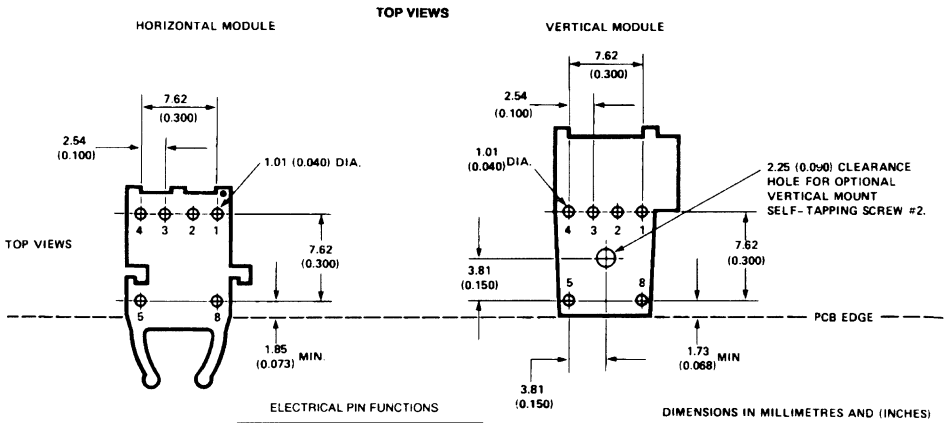


Figure 5. Typical Rise and Fall Time vs. Temperature..

Versatile Link Mechanical Dimensions



Versatile Link Printed Circuit Board Layout Dimensions



ELECTRICAL PIN FUNCTIONS

PIN NO.	TRANSMITTERS HFBR-15X7	RECEIVERS HFBR-25X6
1	ANODE	SIGNAL
2	CATHODE	GROUND
3	GROUND*	GROUND
4	GROUND*	V_{CC} (+5 V)
5	GROUND**	GROUND**
8	GROUND**	GROUND**

*NO INTERNAL CONNECTION.
**PINS 5 AND 8 CONNECTED INTERNALLY TO EACH OTHER ONLY.

HEWLETT® PACKARD

10 Megabaud Versatile Link Fiber Optic Transmitter and Receiver for 1 mm POF and 200 μm HCS®

Technical Data

HFBR-0508 Series
HFBR-1528 Transmitter
HFBR-2528 Receiver

Features

- **Data Transmission at Signal Rates of dc to 10 MBd**
- **Up to 50 Meters Distances with 1 mm Plastic Optical Fiber (POF)**
- **Up to 500 Meters Distances with 200 μm Hard Clad Silica (HCS®)**
- **Wide Dynamic Range Receiver Allows Operation from Zero to Maximum Link Distance with a Single Transmitter Drive Current**
- **Link Distances Specified for Variations in Temperature, Power Supply, and Fiber Attenuation**
- **DC Coupled Receiver with CMOS/TTL Output for Easy Designs: No Data Encoding or Digitizing Circuitry Required**
- **Pulse Width Distortion Controlled to Limit Distortion from Low Duty Cycle or Burst Mode Data**
- **High Noise Immunity**
- **Compatible with HP's Versatile Link Family of Connectors, for Easy Termination of Fiber**

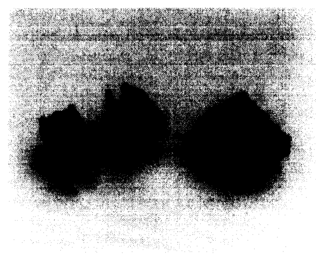
Applications

- **Industrial Control and Factory Automation**
- **Serial Field Buses**
- **Intra-System Links; Board-to-Board, Rack-to-Rack**
- **Extension of RS-232, RS-485**
- **Elimination of Ground Loops**
- **High Voltage Isolation**
- **Reduces Voltage Transient Susceptibility**

Description

The HFBR-0508 Series consists of a fiber-optic transmitter and receiver operating at a 650 nm wavelength (red). The HFBR-1528 transmitter is an LED in a low cost plastic housing designed to efficiently couple power into 200 μm diameter HCS and 1 mm diameter POF. The HFBR-2528 receiver incorporates a PIN detector and digital output IC compatible with CMOS and TTL logic families.

HFBR-0508 links operate from DC to 10 MBd at distances up to 50 meters with 1 mm POF and up to 500 meters with 200 μm HCS®.



No minimum link distances are required when using recommended circuits, simplifying design.

Versatile Link components can be interlocked (N-plexed together) to minimize space and to provide dual connections with the duplex connectors. Up to eight packages can be interlocked and inserted into a printed circuit board.

POF and HCS are available in pre-connectored lengths or can be easily field-terminated. A single transmitter drive current for POF and HCS allows both fibers to be used with a single design.

HCS® is a registered trademark of SpecTran Corporation.

CAUTION:. It is advised that normal static precautions be taken in handling and assembly of these components to prevent damage and/or degradation which may be induced by ESD.

HFBR-0508 Series 10 MBd Data Link

Typical Link Performance, T_A = +25°C

Parameter	Symbol	Typ.[1]	Unit	Condition	Note
Signaling Rate	f_S	15	Mb/s	NRZ	2
Link Distance with Extra Low Loss POF Cable	ℓ	100	m	10 MBd	2, 3, 5
Link Distance with 200 μm HCS Cable	ℓ	900	m	10 MBd	2, 4, 5

Specified Link Performance, T_A = -20° to +85°C, DC to 10 MBd, unless otherwise noted.

Parameter	Symbol	Min.	Max.	Unit	Condition	Note
Signaling Rate	f_S	DC	10	Mb/s	NRZ	2
Link Distance with Extra Low Loss POF Cable	ℓ	0.1 0.1 0.1	50 40 30	m	+25°C 0 to +70°C -20 to +85°C	2, 3, 5
Link Distance with 200 μm HCS Cable	ℓ	0.1 0.1 0.1	500 300 100	m	+25°C 0 to +70°C -20 to +85°C	2, 4, 5
Pulse Width Distortion	PWD	-30	+30	ns	25 – 75% Duty Cycle	2
		-50	+50	ns	Arbitrary Duty Cycle	

Absolute Maximum Ratings

Parameter		Symbol	Min.	Max.	Unit	Note
Storage and Operating Temperature, Transmitter		$T_{S,O}$	-40	+85	°C	
Storage and Operating Temperature, Receiver		$T_{S,O}$	-20	+85	°C	
Receiver Supply Voltage		V_{CC}	-0.5	+5.5	V	
Receiver Average Output Current		$I_{O,AVG}$	-16	+16	mA	
Receiver Output Power Dissipation		P_{OD}		80	mW	
Transmitter Peak Forward Input Current		$I_{F,PK}$		90	mA	6
Transmitter Average Forward Input Current		$I_{F,AVG}$		60	mA	
Transmitter Reverse Input Voltage		V_R		3	V	
Lead Soldering Cycle	Temp	T_{SOL}		+260	°C	7
	Time			10	sec	7

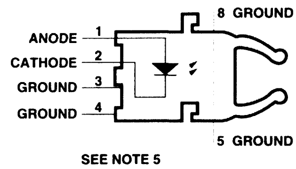
Recommended Operating Conditions

Parameter	Symbol	Min.	Max.	Unit	Condition	Note
Ambient Temperature	T_A	-20	+85	°C		
Power Supply Voltage	V_{CC}	4.75	5.25	V	<100 mV_{p-p} Noise	
Transmitter Peak Forward Current	$I_{F,PK}$	20	90	mA		6
Transmitter Average Forward Current	$I_{F,AV}$		60	mA		
Fanout (7400 Series TTL)	N		1			

Notes:
1. Typical data at +25°C, V_{CC} = 5 V.
2. With recommended transmitter and receiver application circuits (60 mA nominal drive current).
3. POF is HFBR-R/EXXYYY plastic (1 mm) optical fiber. Worst case attenuation used (0.23 dB/m from -40°C to +85°C at 660 nm).
4. HCS is HFBR-H/VXXYYY hard clad silica (200/230 μm) fiber. Worst case attenuation is used (10 dB/km from 0°C to +70°C and 12 dB/km from -40°C to +85°C at 650 nm).
5. BER ≤ 10^{-9}, 2^{23} - 1 PRBS NRZ 10 MBd.
6. For $I_{F,PK}$ > 60 mA, the duty factor must maintain $I_{F,AV}$ ≤ 60 mA and pulse with ≤ 1 μs.
7. 1.6 mm below seating plane.

HFBR-1528 Transmitter

The HFBR-1528 transmitter incorporates a 650 nm LED in a light gray, nonconductive plastic housing. The high light output power enables the use of both plastic optical fiber (POF) and Hard Clad Silica (HCS) fiber. This transmitter can be operated up to 10 MBd using a simple driver circuit. The HFBR-1528 is compatible with all Versatile Link connectors.



HFBR-1528 Transmitter, Top View

Electrical and Optical Characteristics: T_A = -40° to +85°C unless otherwise noted.

Parameter	Symbol	Min.	Typ.[1]	Max.	Units	T_A (°C)	Conditions	Note
Peak Output Power 1 mm POF, 60 mA	P_T	-6.0	-3.5	0.0	dBm	+25	$I_{F,dc}$ = 60 mA	2, 3 Fig. 2
		-6.9		+0.5		0 to +70		
		-7.2		+1.3		-40 to +85		
Peak Output Power 1 mm POF, 20 mA	P_T	-15.6	-9.0	-2.0	dBm	+25	$I_{F,dc}$ = 20 mA	2, 3 Fig. 2
		-16.5		-1.5		0 to +70		
		-16.8		-0.7		-40 to +85		
Peak Output Power 200 µm HCS, 60 mA	P_T	-16.1	-12.5	-8.5	dBm	+25	$I_{F,dc}$ = 60 mA	2, 3 Fig. 2
		-17.0		-8.0		0 to +70		
		-17.3		-7.2		-40 to +85		
Optical Power Temperature Coefficient	$\Delta P_T/\Delta T$		-0.40		%/°C			
			-0.02		dB/°C			
Peak Emission Wavelength	λ_P	640	650	660	nm	0 to +70		Fig. 3
		635		662		-40 to +85		
Peak Wavelength Temperature Coefficient	$\Delta\lambda/\Delta T$		0.12		nm/°C			
Spectral Width	FWHM		21		nm			Fig. 3
Forward Voltage	V_F	1.8	2.1	2.65	V		$I_{F,dc}$ = 60 mA	Fig. 1
Forward Voltage Temperature Coefficient	$\Delta V_F/\Delta T$		-1.8		mV/°C			Fig. 1
Reverse Input Breakdown Voltage	V_{BR}	3.0	13		V		$I_{F,dc}$ = -10 µA	
Diode Capacitance	C_O		60		pF		V_F = 0 V, f = 1 MHz	
Transmitter Numerical Aperture	NA		0.5					
Thermal Resistance, Junction to Case	θ_{jc}		140		°C/W			4
50 Ω Optical Rise Time	t_r		13		ns		10% to 90%, I_F = 60 mA	
50 Ω Optical Fall Time	t_f		10		ns			

Notes:

1. Typical data are at +25°C.
2. Optical power measured at the end of 0.5 meters of 1 mm diameter plastic or 200 µm diameter hard clad silica fiber with a large area detector.
3. Minimum and maximum values for P_T over temperature are based on a fixed drive current. The recommended drive circuit has temperature compensation which reduces the variation in P_T over temperature; refer to Figures 4 and 6.
4. Typical value measured from junction to PC board solder joint for horizontal mount package, HFBR-1528.
5. Pins 5 and 8 are for mounting and retaining purposes, but are electrically connected; pins 3 and 4 are electrically isolated. It is recommended that pins 3, 4, 5 and 8 all be connected to ground to reduce coupling of electrical noise.
6. Refer to the "Plastic Optical Fiber and HCS Fiber Cable and Connectors for Versatile Link" Technical Data Sheet for cable connector options for 1 mm plastic and 200 µm HCS optical fiber.

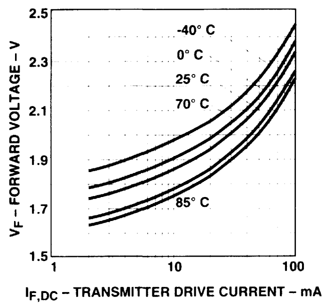


Figure 1. Typical Forward Voltage vs. Drive Current.

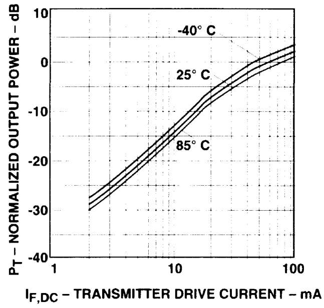


Figure 2. Typical Normalized Optical Power vs. Drive Current.

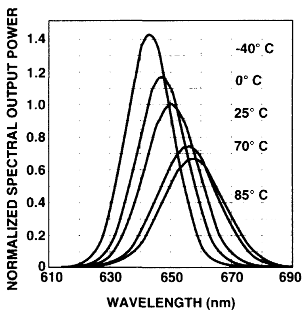


Figure 3. Typical Normalized Optical Spectra.

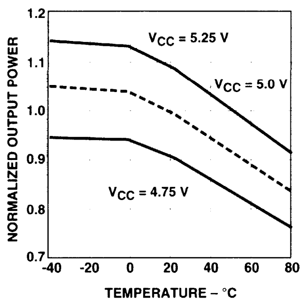


Figure 4. Typical Normalized Optical Power vs. Temperature (in Recommended Drive Circuit).

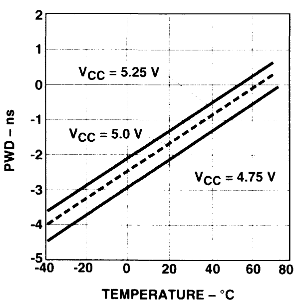
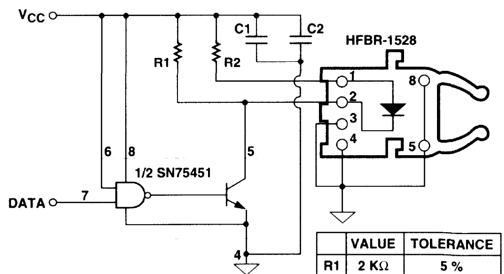


Figure 5. Typical Optical Pulse Width Distortion vs. Temperature and Power Supply Voltage (in Recommended Drive Circuit).



	VALUE	TOLERANCE
R1	2 KΩ	5 %
R2	47 Ω	1 %
C1	0.1 µF	20 %
C2	1.0 µF	20 %

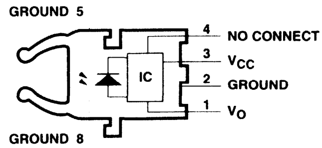
Figure 6. Recommended Transmitter Drive Circuit ($I_{F,on}$ = 60 mA Nominal at T_A = 25°C).

WARNING: WHEN VIEWED UNDER SOME CONDITIONS, THE OPTICAL PORT MAY EXPOSE THE EYE BEYOND THE MAXIMUM PERMISSIBLE EXPOSURE RECOMMENDED IN ANSI Z136.2, 1993. UNDER MOST VIEWING CONDITIONS THERE IS NO EYE HAZARD.

HFBR-2528 Receiver

The HFBR-2528 receiver consists of a silicon PIN photodiode and digitizing IC to produce a logic compatible output. The IC includes a unique circuit to correct the pulse width distortion of the first bit after a long idle period. This enables operation from DC to 10 MBd with low PWD for arbitrary data patterns.

The receiver output is a "push-pull" stage compatible with TTL and CMOS logic. The receiver housing is a dark, conductive plastic, compatible with all Versatile Link connectors.



SEE NOTES 5,7

HFBR-2528 Receiver, Top View

Electrical and Optical Characteristics: T_A = -20° to +85°C, 4.75 V < V_{CC} < 5.25 V, unless otherwise noted.

Parameter	Symbol	Min.	Typ.[1]	Max.	Unit	T_A (°C)	Condition	Note	Fig.
Peak POF Sensitivity: Minimum Input for Logic "0"	$P_{RL,min}$		-23.0	-21.0 -20.0 -19.5	dBm	+25 0 to +70 -20 to +85	1 mm POF, |PWD| < 30 ns	2,6	2,4
Peak POF Overdrive Limit:Maximum Input for Logic "0"	$P_{RL,max}$	+1.0 +0.0 -1.0	+5.0		dBm	+25 0 to +70 -20 to +85	1 mm POF, |PWD| < 30 ns	2,3, 6	1,2, 3
Peak POF Off State Limit: Maximum Input for Logic "1"	$P_{RH,max}$			-42	dBm		1 mm POF	2,6, 8	
Peak HCS Sensitivity: Minimum Input for Logic "0"	$P_{RL,min}$		-25.0	-23.0 -22.0 -21.5	dBm	+25 0 to +70 -20 to +85	200 µm HCS, |PWD| < 30 ns	2,6	
Peak HCS Overdrive Limit: Maximum Input for Logic "0"	$P_{RL,max}$	-1.0 -2.0 -3.0	+3.0		dBm	+25 0 to +70 -20 to +85	200 µm HCS, |PWD| < 30 ns	2,3, 6	
Peak HCS Off State Limit: Maximum Input for Logic "1"	$P_{RH,max}$			-44	dBm		200 µm HCS	2,6, 8	
Supply Current	I_{CC}		27	45	mA		V_O = Open		
High Level Output Voltage	V_{OH}	4.2	4.7		V		I_O = -40 µA		
Low Level Output Voltage	V_{OL}		0.22	0.4	V		I_O = +1.6 mA		
Output Rise Time	t_r		12	30	ns		C_L = 10 pF	6	
Output Fall Time	t_f		10	30	ns		C_L = 10 pF	6	
Thermal Resistance, Junction to Case	θ_{jc}		200		°C/W			4	
Electric Field Immunity	E_{MAX}		8		kV/m		Near Field, Electrical Field Source	5	
Power Supply Noise Immunity	PSNI	0.1	0.4		V_{pp}		Sine Wave DC - 10 MHz	6	

Notes:

1. Typical data are at +25°C, V_{CC} = 5.0 V.
2. Input power levels are for peak (not average) optical input levels. For 50% duty cycle data, peak optical power is twice the average optical power.
3. Receiver overdrive ($P_{RL,max}$) is specified as the limit where |PWD| will not exceed 30 ns. The receiver will be in the correct state (logic "0") for optical powers above $P_{RL,max}$. However, it may not meet a 30% symbol period PWD if the overdrive limit is exceeded. Refer to Figure 2 for PWD performance at high received optical powers.
4. Typical value measured from junction to PC board solder joint for horizontal mount package, HFBR-2528.
5. Pins 5 and 8 are electrically connected to the conductive housing and are also used for mounting and retaining purposes. It is required that pins 5 and 8 be connected to ground to maintain conductive housing shield effectiveness.
6. In recommended receiver circuit, with an optical signal from the recommended transmitter circuit.
7. Pin 4 is electrically isolated internally. Pin 4 may be externally connected to pin 1 for board layout compatibility with HFBR-25X1, HFBR-25X2 and HFBR-25X4. Otherwise it is recommended pin 4 be grounded as in Figure 5.
8. BER ≤ 10E-9, includes a 10.8 dB margin below the receiver switching threshold level (signal to noise ratio = 12).

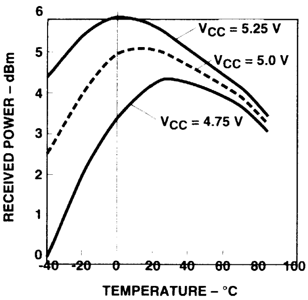


Figure 1. Typical POF Receiver Overdrive, $P_{RL,max}$, at 10 MBd, vs. Temperature and Power Supply Voltage.

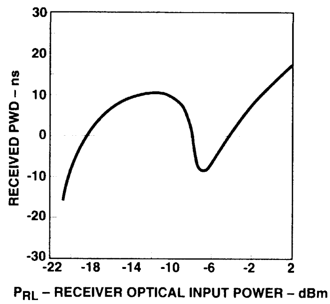


Figure 2. Typical POF Receiver Pulse Width Distortion vs. Optical Power at 10 MBd.

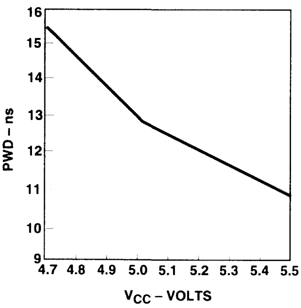


Figure 3. Typical POF Receiver Pulse Width Distortion vs. Power Supply Voltage at High Optical Power (0 dBm,pk, 10 MBd).

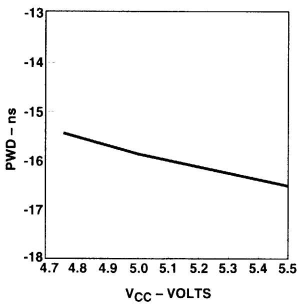
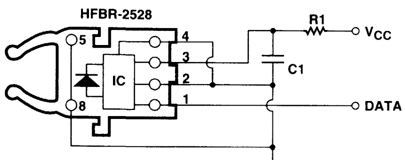


Figure 4. Typical POF Receiver Pulse Width Distortion vs. Power Supply Voltage at Low Optical Power, (-21 dBm,pk, 10 MBd).



	VALUE	TOLERANCE
R1	2.7 Ω	5 %
C1	0.1 µF	20 %

Figure 5. Recommended Receiver Application Circuit.

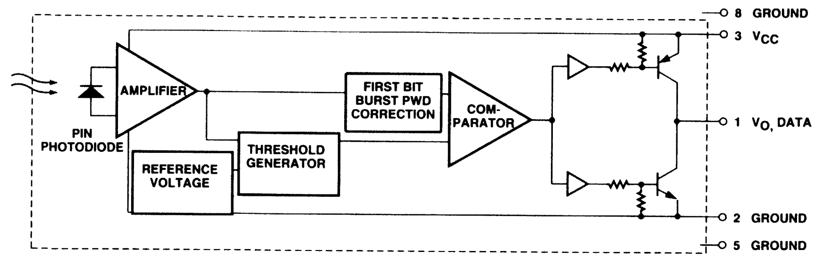
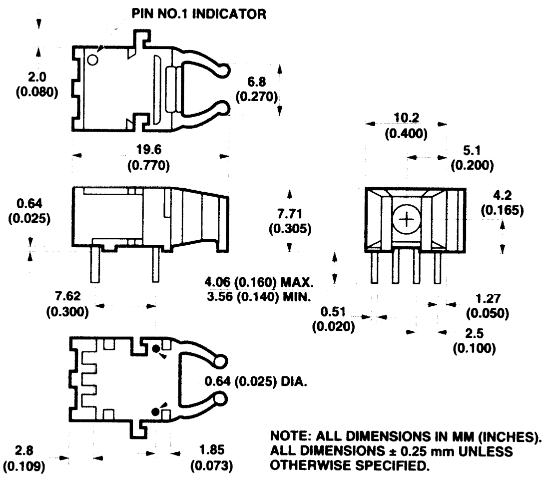
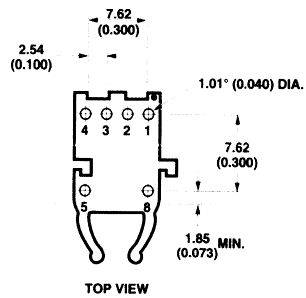


Figure 6. HFBR-2528 Receiver Block Diagram.

Versatile Link Mechanical Dimensions



Versatile Link Printed Circuit Board Layout Dimensions



ELECTRICAL PIN FUNCTIONS

PIN NO.	TRANSMITTER HFBR-1528	RECEIVER HFBR-2528
1	ANODE	SIGNAL, V_O
2	CATHODE	GROUND
3	GROUND*	V_{CC} (+5 V)
4	GROUND*	GROUND*
5	GROUND**	GROUND**
8	GROUND**	GROUND**

* NO INTERNAL CONNECTION, GROUND CONNECTION RECOMMENDED.
** PINS 5 AND 8 CONNECTED INTERNALLY TO EACH OTHER.

Fiber Optic Transmitters and Receivers for Fieldbus Applications

Technical Data

HFBR-1505A/2505A (SMA Tx/Rx for SERCOS)
HFBR-1515B/2515B (ST® Tx/Rx for PROFIBUS)
HFBR-1505C/2505A (SMA Tx/Rx for INTERBUS-S)

Features

- **Meets 2/4 MBd Industrial SERCOS, 1.5 MBd PROFIBUS and INTERBUS-S Standard**
- **SMA and ST® Ports**
- **650 nm Wavelength Technology**
- **Specified for Use with 1 mm Plastic Optical Fiber and 200 µm Hard Clad Silica**
- **Auto-Insertable and Wave Solderable**
- **DC - 10 MBd**

Applications

- **Industrial Control Data Links**
- **Factory Automation Data Links**
- **Voltage Isolation Applications**
- **PLCs**
- **Motor Drives**
- **Automotive**
- **Sensor, Meter and Actuator Interfaces**

ST® is a registered trademark of AT&T.
HCS® is a registered trademark of SpecTran Corporation.

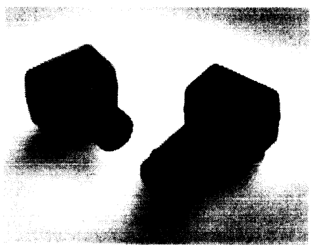
Description

SERCOS

SERCOS, an acronym for **SE**rial **R**ealtime **CO**mmunications **S**ystem, is a standard digital interface for communication in industrial CNC applications. The standard defines two data rates: 2 MBd and 4 MBd and was formed to allow data transfer between numerical controls and drives via fiber-optic rings, with voltage isolation and noise immunity. The HFBR-1505A/2505A products comply with SERCOS specifications for optical characteristics and connector style, and can also be used for data rates up to 10 MBd. The international standard is IEC 1491.

PROFIBUS

PROFIBUS, an acronym of **PRO**cess **FI**eld **BUS**, is an open fieldbus standard defined for data rates ranging from 9.6 kBd to 12 MBd in selectable steps for wire and optical fiber. PROFIBUS is a German national DIN 19245 standard and a European CENELEC standard EN 50170. The ST® connector is the standard optical port of the PROFIBUS optical fiber version. The HFBR-1515B/2515B complies fully to the technical guideline using Plastic Optical Fiber up to 1.5 MBd, and can also



be used for data rates up to 10 MBd. Please contact Hewlett-Packard regarding any future plans for a 12 MBd device.

INTERBUS-S

INTERBUS-S, a special open Sensor/Actuator Bus, is finding a broad acceptance in the factory automation industry. The HFBR-1505C was specially designed for this application and is recommended as a powerful transmitter for use with 1 mm POF and 200 µm HCS® fiber. The optical transmission guideline is a supplement of the German National DIN E 19258 standard draft. On the European level, prEN 50254 is the draft of the INTERBUS-S fieldbus. The HFBR-1505C transmitter can be used in conjunction with the HFBR-2505A receiver.

Package Information

All HFBR-X5X5X series transmitters and receivers are housed in a low-cost, dual-in-line package that is made of high strength, heat resistant, chemically resistant and UL V-O flame retardant plastic. The transmitters are easily identified by the light grey colored connector port. The receivers are easily identified by the dark grey colored connector port. The package is designed for auto-insertion and wave soldering so it is ideal for high volume production applications.

Handling and Design Information
When soldering, it is advisable to leave the protective cap on the unit to keep the optics clean. Good system performance requires clean port optics and cable ferrules to avoid obstructing the optical path. Clean compressed air often is sufficient to remove particles of dirt; methanol on a cotton swab also works well.

Recommended Chemicals for Cleaning/Degreasing X5X5X Products
Alcohols: methyl, isopropyl, isobutyl.
Aliphatics: hexane, heptane.
Other: soap solution, naphtha.

Do not use partially halogenated hydrocarbons such as 1,1,1 trichloroethane, ketones such as MEK, acetone, chloroform, ethyl acetate, methylene dichloride, phenol, methylene chloride or N-methylpyrolldone. Also, HP does not recommend the use of cleaners that use halogenated hydrocarbons because of their potential environmental harm.

CAUTION: The small junction size inherent in the design of these components increases the components' susceptibility to damage from electrostatic discharge (ESD). It is advised that normal static precautions be taken in handling and assembly of these components to prevent damage and/or degradation which may be induced by ESD.

Specified Link Performance

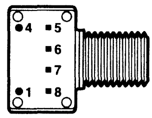
0°C to +70°C, DC to 10 MBd, unless otherwise noted.

Parameter	Symbol	Min.	Max.	Unit	Condition	Reference
Link Distance with HFBR-1505A/2505A or HFBR-1515B/2515B	1	0.1 0.1	40 200	m m	POF HCS®	Notes 1,2,3,4 Notes 1,2,3,5
Link Distance with HFBR-1505C/2505A	1	0.1 0.1	45 300	m m	POF HCS®	Notes 1,2,3,4 Notes 1,2,3,5
Pulse Width Distortion	PWD	-30	+30	ns	25% to 75% duty cycle	Note 1

Notes:
1. With recommended Tx and Rx circuits (60 mA nominal drive current).
2. POF HFBR-Exxyyy 0.23 dB/m worst case attentuation.
3. HCS® HFBR-H/Vxxyyy 10 dB/Rm worst case attenuation.
4. Including a 3 dB optical safety margin accounting for link service lifetime.
5. Including a 2 dB optical safety margin accounting for link service lifetime.

HFBR-15X5X Transmitters

The HFBR-15X5X transmitter incorporates a 650 nm LED in a light gray nonconductive plastic housing. The high light output power enables the use of both plastic optical fiber (POF) and Hard Clad Silica (HCS®). This transmitter can be operated up to 10 MBd using a simple driver circuit. The HFBR-1505X is compatible with SMA connectors, while the HFBR-1515X mates with ST® connectors.



BOTTOM VIEW, HFBR-1505X

SEE NOTE 10

PIN	FUNCTION
1	CONNECTED TO PIN 4
4	CONNECTED TO PIN 1
5	GND
6	GND
7	CATHODE
8	ANODE

Absolute Maximum Ratings

Parameter		Symbol	Min.	Max.	Unit	Reference
Storage and Operating Temperature		$T_{S,O}$	-40	85	°C	
Peak Forward Input Current		$I_{F,PK}$		90	mA	Note 6
Average Forward Input Current		$I_{F,AVG}$		60	mA	
Reverse Input Voltage		V_R		3	V	
Lead Soldering Cycle	Temp	T_{SOL}		260	°C	Note 7
	Time			10	s	

Electrical/Optical Characteristics

0°C to +70°C unless otherwise noted.

Parameter	Symbol	Min.	Typ.[1]	Max.	Unit	Condition	Ref.
Optical Power Temperature Coefficient	$\Delta P_T/\Delta T$		-0.02		dB/°C		
Forward Voltage	V_F	1.8	2.1	2.65	V	$I_{F,\,dc} = 60$ mA	Fig. 1
Forward Voltage Temperature Coefficient	$\Delta V_F/\Delta T$		-1.8		mV/°C		Fig. 1
Breakdown Voltage	V_{BR}	3.0	13		V	$I_{F,\,dc} = -10\ \mu A$	
Peak Emission Wavelength	λ_{PK}	640	650	660	nm		Fig. 3
Full Width Half Max	FWHM		21	30	nm		Fig. 3
Diode Capacitance	C_O		60		pF	$V_F = 0$ V, f = 1 MHz	
Thermal Resistance	θ_{JC}		140		°C/W		Notes 4,5
Rise Time (10% to 90%)	t_r		13		ns	10% to 90%,	
Fall Time (90% to 10%)	t_f		10		ns	$I_F = 60$ mA	

WARNING: When viewed under some conditions, the optical port may expose the eye beyond the maximum permissible exposure recommended in ANSI Z136.2, 1993. Under most viewing conditions, there is no eye hazard.

Peak Output Power

0°C to +70°C unless otherwise noted.

Model Number	Symbol	Min.	Max.	Unit	Condition	Reference
HFBR-1505A	P_T	-10.5	-5.5	dBm	POF, $I_{F, dc}$ = 35 mA	Notes 2,3,11
SERCOS		-7.5	-3.5		POF, $I_{F, dc}$ = 60 mA	Figure 2
		-18.0	-8.5		HCS®, $I_{F, dc}$ = 60 mA	
HFBR-1515B		-10.5	-5.5		POF, $I_{F, dc}$ = 35 mA	Notes 2,3,11
PROFIBUS		-7.5	-3.5		POF, $I_{F, dc}$ = 60 mA	Figure 2
		-18.0	-8.5		HCS®, $I_{F, dc}$ = 60 mA	
HFBR-1505C		-6.2	0.0		POF, $I_{F, dc}$ = 60 mA	Notes 3,8,9
INTERBUS-S		-16.9	-8.5		HCS®, $I_{F, dc}$ = 60 mA	Figure 2

Notes:

1. Typical data at 25°C.
2. Optical power measured at the end of 0.5 meters of 1 mm diameter plastic optical fiber with a large area detector.
3. Minimum and maximum values for P_T over temperature are based on a fixed drive current. The recommended drive circuit has temperature compensation which reduces the variation in P_T over temperature, refer to Figures 4 and 6.
4. Thermal resistance is measured with the transmitter coupled to a connector assembly and fiber, and mounted on a printed circuit board.
5. To further reduce the thermal resistance, the cathode trace should be made as large as is consistent with good RF circuit design.
6. For $I_{F,PK}$ > 60 mA, the duty factor must maintain $I_{F,AVG}$ ≤ 60 mA and pulse width ≤ 1 µs.
7. 1.6 mm below seating plane.
8. Minimum peak output power at 25°C is -5.3 dBm (POF) and -16.0 dBm (HCS®) for 1505C series only.
9. Optical power measured at the end of 1 meter of 1 mm diameter plastic or 200 µm hard clad silica optical fiber with a large area detector.
10. Pins 1 and 4 are for mounting and retaining purposes, but are electrically connected; pins 5 and 6 are electrically isolated. It is recommended that pins 1, 4, 5, and 8 all be connected to ground to reduce coupling of electrical noise.
11. Output power with 200 µm hard clad silica optical fiber assumes a typical -10.5 dB difference compared to 1 mm plastic optical fiber.

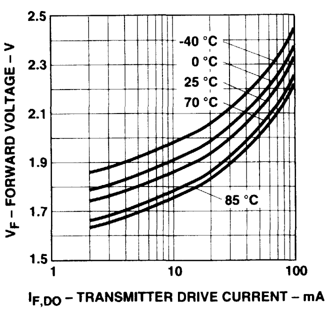


Figure 1. Typical Forward Voltage vs. Drive Current.

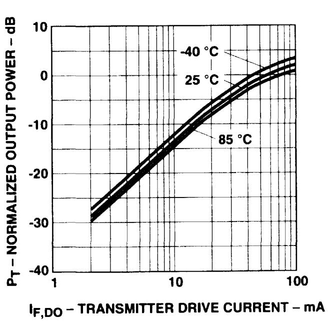


Figure 2. Typical Normalized Optical Power vs. Drive Current.

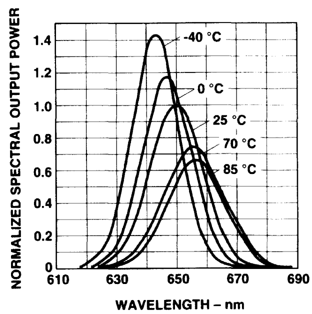


Figure 3. Typical Normalized Optical Spectra.

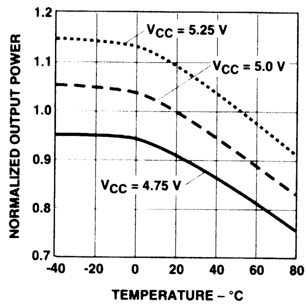


Figure 4. Typical Normalized Optical Power vs. Temperature (in Recommended Drive Circuit).

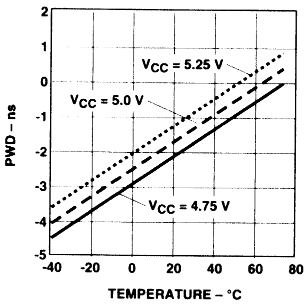
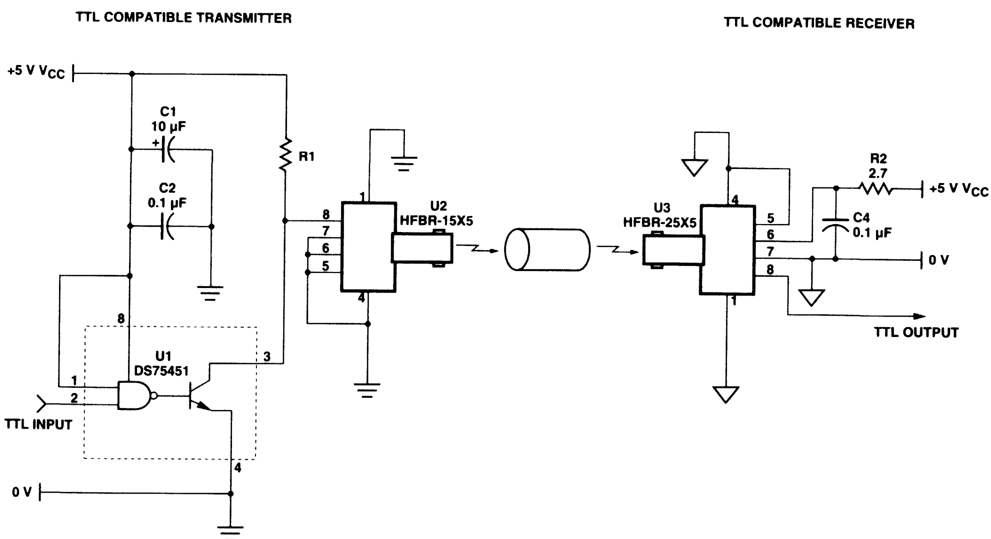


Figure 5. Typical Optical Pulse Width Distortion vs. Temperature and Power Supply Voltage (in Recommended Drive Circuit).

Recommended Drive Circuit for HFBR-15X5X/25X5X

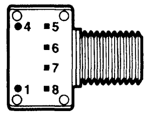


R1	I_F
82.5 Ω	35 mA
47 Ω	60 mA

Figure 6. Recommended Transmitter and Receiver Drive Circuit ($I_{F,\,on}$ = 35 mA or 60 mA Nominal at T_A = 25°C).

HFBR-25X5 Receivers

The HFBR-25X5X receiver consists of a silicon PIN photodiode and digitizing IC to produce a logic compatible output. The IC includes a unique circuit to correct the pulse width distortion of the first bit after a long idle period. This enables operation from DC to 10 MBd with low PWD for arbitrary data patterns. The receiver output is a "push–pull" stage compatible with TTL and CMOS logic. The receiver housing is a dark grey, conductive plastic. The HFBR-2505X is compatible with SMA connectors, while the HFBR-2515X mates with ST® connectors.



BOTTOM VIEW,
HFBR-2505X

SEE NOTE 4

PIN	FUNCTION
1	CONNECTED TO PIN 4
4	CONNECTED TO PIN 1
5	NO CONNECT
6	V_{CC}
7	GND
8	V_O

Absolute Maximum Ratings

Parameter		Symbol	Min.	Max.	Unit	Reference
Storage and Operating Temperature		T_S	-40	85	°C	
Supply Voltage		V_{CC}	-0.5	+5.5	V	
Average Output Current		$I_{O,AVG}$	-16	-16	mA	
Output Power Dissipation		P_{OD}		80	mW	
Lead Soldering Cycle	Temp			260	°C	Note 2
	Time			10	s	

Electrical/Optical Characteristics

0°C to +70°C, 4.75 V < V_{CC} < 5.25 V, V_{P-P} Noise ≤ 100 mV, unless otherwise noted.

Parameter	Symbol	Min.	Typ.[1]	Max.	Unit	Condition	Ref.
Peak Input Power Level Logic HIGH	P_{RH}			-42 -44	dBm	1mm POF 200 µm HCS®	Notes 3,5
Peak Input Power Level Logic LOW	P_{RL}	-20 -22		-0 -2	dBm	1 mm POF, 200 µm HCS® |PWD| < 30 ns	Note 3 Figs. 7,8, 9,10
Supply Current	I_{CC}		27	45	mA	V_O = Open	
High Level Output Voltage	V_{OH}	4.2	4.7		V	I_O = -40 µA	
Low Level Output Voltage	V_{OH}		0.22	0.4	V	I_O = +1.6 mA	
Output Rise Time	t_r		12	30	ns	C_L = 10 pF	Note 3
Output Fall Time	t_f		10	30	ns	CL = 10 pF	Note 3

Notes:

1. Typical data are at 25°C, V_{CC} = 5.0 V.
2. 1.6 mm below seating plane.
3. In recommended receiver circuit, with an optical signal from the recommended transmitter circuit.
4. Pins 1 and 4 are electrically connected to the conductive housing and are also used for mounting and retaining purposes. It is required that pin 1 and 4 be connected to ground to maintain conductive housing shield effectiveness.
5. BER ≤ 10E-9, includes a 10.8 dB margin below the receiver switching threshold level (signal to noise ratio = 12).

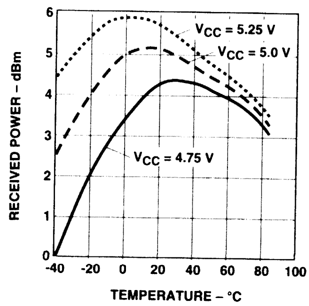


Figure 7. Typical POF Receiver Overdrive $P_{RL,max}$ at 10 MBd vs. Temperature and Power Supply Voltage.

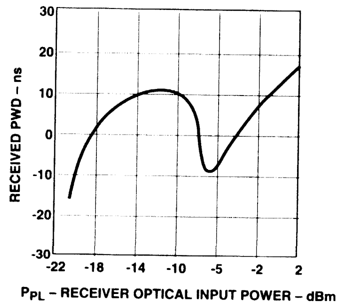


Figure 8. Typical POF Receiver Pulse Width Distortion vs. Optical Power at 10 MBd.

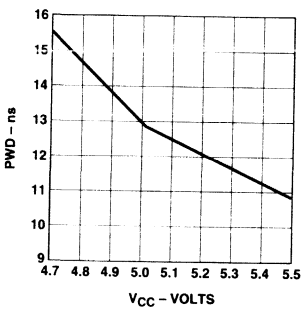


Figure 9. Typical POF Receiver Pulse Width Distortion vs. Power Supply Voltage at High Optical Power, (0 dBm, 10 MBd).

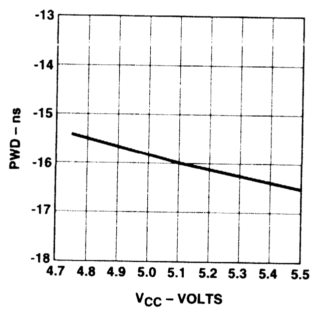
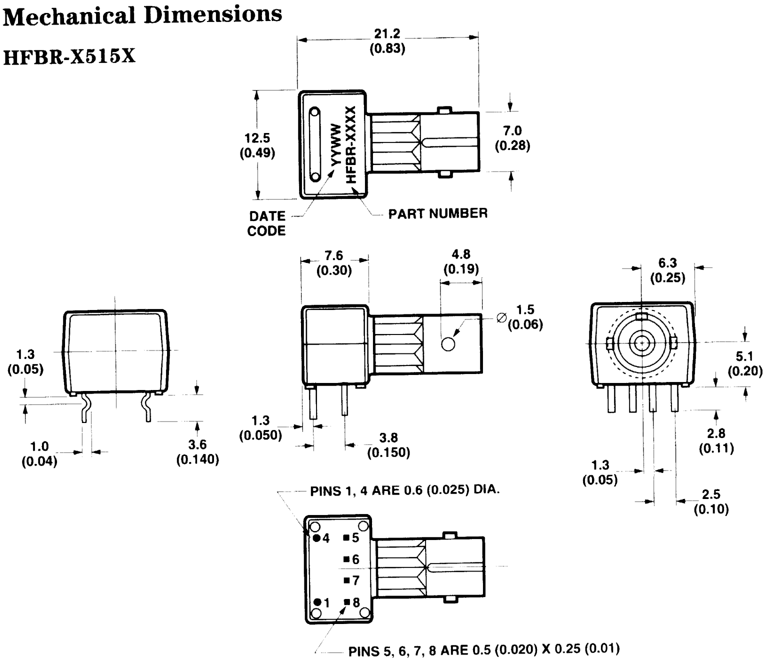


Figure 10. Typical POF Receiver Pulse Width Distortion vs. Power Supply Voltage at Low Optical Power, (-21 dBm, 10 MBd).

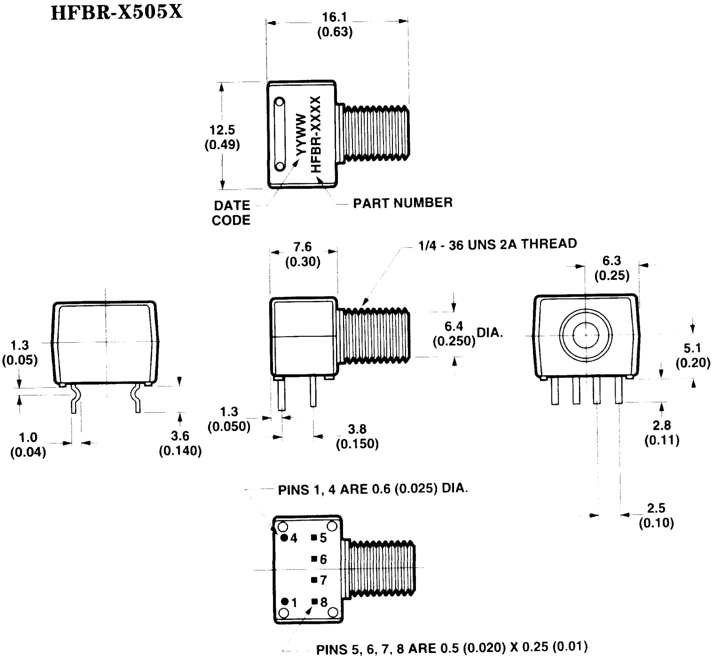
HEWLETT PACKARD

Mechanical Dimensions

HFBR-X515X



HFBR-X505X



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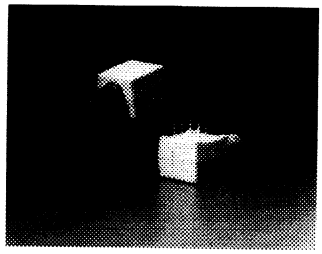
HEWLETT PACKARD

SERCOS Fiber Optic Transmitters and Receiver

Technical Data

HFBR-0600 Series



Features

- **Fully Compliant to SERCOS Optical Specifications**
- **Optimized for 1 mm Plastic Optical Fiber**
- **Compatible with SMA Connectors**
- **Auto-Insertable and Wave Solderable**
- **Data Transmission at Symbol Rates from DC to over 2 MBd for Distances from 0 to over 20 Metres**

Applications

- **Industrial Control Data Links**
- **Reduction of Lightning and Voltage Transient Susceptibility**
- **Tempest-Secure Data Processing Equipment**
- **Isolation in Test and Measurement Instruments**
- **Robotics Communication**

SERCOS

SERCOS is a SErial Realtime COmmunication System, a standard digital interface for communication between controls and drives for numerically controlled machines. The SERCOS interface specification was written by a joint working group of the VDW (German Machine Tool Builders Association) and ZVEI (German Electrical and Electronic Manufacturer's Association) to allow data exchange between NC controls and drives via fiber optic rings, with isolation and noise immunity. The HFBR-0600 family of fiber optic transmitters and receivers comply to the SERCOS specifications for transmitter and receiver optical characteristics and connector style (SMA).

Description

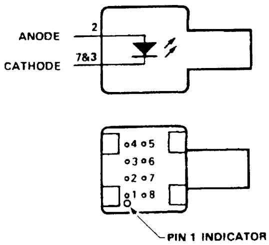
The HFBR-0600 components are capable of operation at symbol rates from DC to over 2 MBd and distances from 0 to over 20 metres. The HFBR-1602 and HFBR-1604 transmitters contain a 655-nm AlGaAs emitter capable of efficiently launching optical power into 1000 μm plastic optical fiber. The optical output is specified at the end of 0.5 m of plastic optical fiber.

The HFBR-1604 is a selected version of the HFBR-1602, with power specified to meet the SERCOS high attenuation specifications.

The HFBR-2602 receiver incorporates an integrated photo IC containing a photodetector and dc amplifier driving an open-collector Schottky output transistor. The HFBR-2602 is designed for direct interfacing to popular logic families. The absence of an internal pull-up resistor allows the open-collector output to be used with logic families such as CMOS requiring voltage excursions higher than V_{CC}. The HFBR-2602 has a dynamic range of 15 dB.

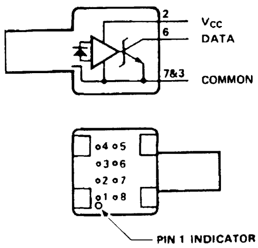
CAUTION: The small junction sizes inherent to the design of this component increase the component's susceptibility to damage from electrostatic discharge (ESD). It is advised that normal static precautions be taken in handling and assembly of this component to prevent damage and/or degradation which may be induced by ESD.

HFBR-160X Transmitters



Pin	Function
1*	N.C.
2	ANODE
3	CATHODE
4*	N.C.
5*	N.C.
6	N.C.
7**	CATHODE
8*	N.C

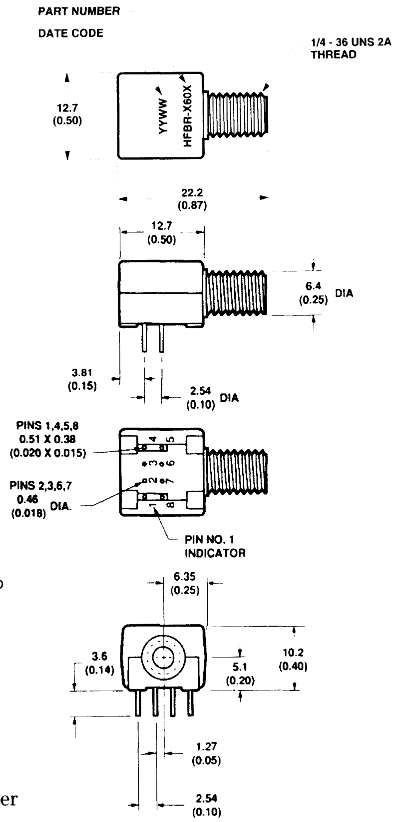
HFBR-2602 Receiver



Pin	Function
1*	N.C.
2	V_{CC} (5 V)
3	COMMON
4*	N.C.
5*	N.C.
6	DATA
7	COMMON
8*	N.C.

*Pins 1, 4, 5, and 8 are isolated from the internal circuitry, but electrically connected to one another.
**Transmitter Pin 7 may be left unconnected if necessary.

HFBR-0600 SMA Series Mechanical Dimensions



In the receiver, both the open-collector "Data" output Pin 6 and V_{CC} Pin 2 are referenced to "Common" Pin 3 and 7. It is essential that a bypass capacitor (0.1 μF ceramic) be connected from Pin 2 (V_{CC}) to Pin 3 (circuit common) of the receiver.

SMA is an industry standard fiber optic connector, available from many fiber optic connector suppliers. HFBR-4401 is a kit consisting of 100 nuts and 100 washers for panel mounting the HFBR-0600 components.

HFBR-1602/1604 Transmitters

Absolute Maximum Ratings

Parameter		Symbol	Min.	Max.	Unit	Reference
Storage Temperature		T_S	-55	85	°C	
Operating Temperature		T_A	-40	85	°C	
Lead Soldering Cycle	Temp.			260	°C	Note 1
	Time			10	s	Note 1
Forward Input Current Peak		I_{FPK}		120	mA	
Forward Input Current Average		I_{Favg}		60	mA	
Reverse Input Voltage		V_{BR}		-5	V	

Electrical/Optical Characteristics 0 to 55°C, unless otherwise stated.

Parameter	Symbol	Min.	Typ.[2]	Max.	Unit	Condition	Reference
Forward Voltage	V_F	1.5	1.9	2.2	V	I_F = 35 mA	
Forward Voltage Temp. Coefficient	$\Delta V_F/\Delta T$		-1.2		mV/°C	I_F = 35 mA	
Reverse Input Voltage	V_{BR}	-5.0	-18		V	I_R = 100 μA	
Peak Emission Wavelength	λ_P	640	655	675	nm		
Full Width Half Maximum	FWHM		20	30	nm	25°C	
Diode Capacitance	C_T		30		pF	V_F = 0 f = 1 MHz	
Optical Power Temp. Coefficient	$\Delta P_T/\Delta T$		-0.01		dBm/°C	I_F = 35 mA	
Thermal Resistance	θ_{JA}		330		°C/W		Notes 3, 4
Peak Optical Output Power of HFBR-1602	P_{T1602}	-10.5		-5.5	dBm	I_F = 35 mA	Notes 5, 6, 11
Peak Optical Output Power of HFBR-1604	P_{T1604}	-7.5 -10.5		-3.5 -5.5	dBm dBm	I_F = 60 mA I_F = 35 mA	Notes 5, 6, 11
Rise Time (10% to 90%)	t_r		57 50		ns ns	I_F = 60 mA I_F = 35 mA	
Fall Time (90% to 10%)	t_f		40 27		ns ns	I_F = 60 mA I_F = 35 mA	

HFBR-2602 Receiver

Absolute Maximum Ratings

Parameter		Symbol	Min.	Max.	Unit	Reference
Storage Temperature		T_S	-55	85	°C	
Operating Temperature		T_A	-40	85	°C	
Lead Soldering Cycle	Temp.			260	°C	Note 1
	Time			10	s	Note 1
Supply Voltage		V_{CC}	-0.5	7.0	V	
Output Current		I_O		25	mA	
Output Voltage		V_O	-0.5	18.0	V	
Output Collector Power Dissipation		$P_{O\ AVG}$		40	mW	
Fan Out (TTL)		N		5		Note 8

Electrical/Optical Characteristics 0 to 55°C;
Fiber core diameter ≤ 1.0 mm, fiber N.A. ≤ 0.5, 4.75 V ≤ V_{CC} ≤ 5.25 V

Parameter	Symbol	Min.	Typ.[2]	Max.	Unit	Condition	Reference
High Level Output Current	I_{OH}		5	250	μA	V_{OH} = 18 V P_R < -31.2 dBm	
Low Level Output Voltage	V_{OL}		0.4	0.5	V	I_{OL} = 8 mA P_R > -20.0 dBm	
High Level Supply Current	I_{CCH}		3.5	6.3	mA	V_{CC} = 5.25 V P_R < -31.2 dBm	
Low Level Supply Current	I_{CCL}		6.2	10	mA	V_{CC} = 5.25 V P_R > -20.0 dBm	

Dynamic Characteristics 0 to 55°C unless otherwise specified; 4.75 V ≤ V_{CC} ≤ 5.25 V; BER ≤ 10^{-9}

Parameter	Symbol	Min.	Typ.[2]	Max.	Unit	Condition	Reference
Peak Input Power Level Logic HIGH	P_{RH}			-31.2	dBm	λ_P = 655 nm	Note 7
Peak Input Power Level Logic LOW	P_{RL}	-20.0		-5.0	dBm	I_{OL} = 8 mA	Note 7
Propagation Delay LOW to HIGH	t_{PLH}		60		ns	P_R = -20 dBm 2 MBd	Note 8, 9
Propagation Delay HIGH to LOW	t_{PHL}		110		ns	P_R = -20 dBm 2 MBd	Note 8, 9
Pulse Width Distortion, t_{PLH} - t_{PHL}	PWD		50 -50		ns ns	P_R = -5 dBm P_R = -20 dBm	Note 10 Figure 6

Notes:

1. 2.0 mm from where leads enter case.
2. Typical data at $T_A = +25°C$.
3. Thermal resistance is measured with the transmitter coupled to a connector assembly and fiber, and mounted on a printed circuit board.
4. Pins 2, 6, and 7 are welded to the cathode header connection to minimize the thermal resistance from junction to ambient. To further reduce the thermal resistance, the cathode trace should be made as large as is consistent with good RF circuit design.
5. P_T is measured with a large area detector at the end of 0.5 metre of plastic optical fiber with 1 mm diameter and numerical aperture of 0.5.
6. When changing μW to dBm, the optical power is referenced to 1 mW (1000 μW). Optical Power P(dBm) = 10 log [P (μW)/1000 μW].
7. Measured at the end of 1mm plastic fiber optic cable with a large area detector.
8. 8 mA load (5 x 1.6 mA), $R_L = 560\ \Omega$.
9. Propagation delay through the system is the result of several sequentially occurring phenomena. Consequently it is a combination of data-rate-limiting effects and of transmission-time effects. Because of this, the data-rate limit of the system must be described in terms of time differentials between delays imposed on falling and rising edges. As the cable length is increased, the propagation delays increase. Data-rate, as limited by pulse width distortion, is not affected by increasing cable length if the optical power level at the receiver is maintained.
10. Pulse width distortion is the difference between the delay of the rising and falling edges.
11. Both HFBR-1602 and HFBR-1604 meet the SERCOS "low attenuation" specifications when operated at 35 mA; only HFBR-1604 meets the SERCOS "high attenuation" limits when operated at 60 mA.

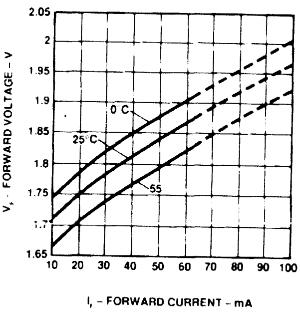


Figure 1. Forward Voltage and Current Characteristics.

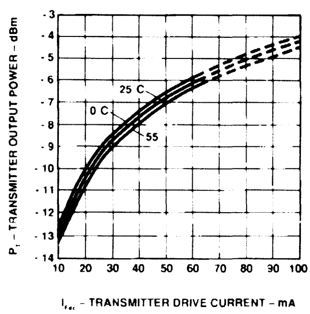


Figure 2. Typical Transmitter Output vs. Forward Current.

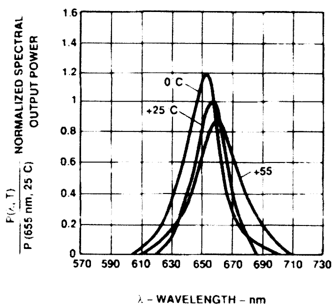


Figure 3. Transmitter Spectrum Normalized to the Peak at 25°C.

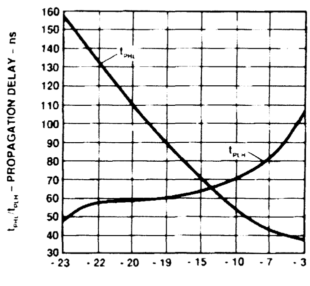


Figure 4. Typical Propagation Delay through System with 0.5 Metre of Cable.

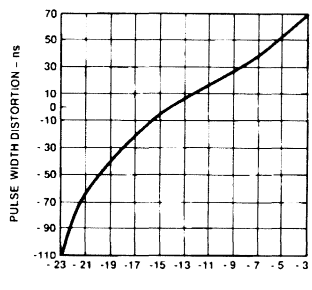


Figure 5. Typical HFBR-160X/2602 Link Pulsewidth Distortion vs. Optical Power.

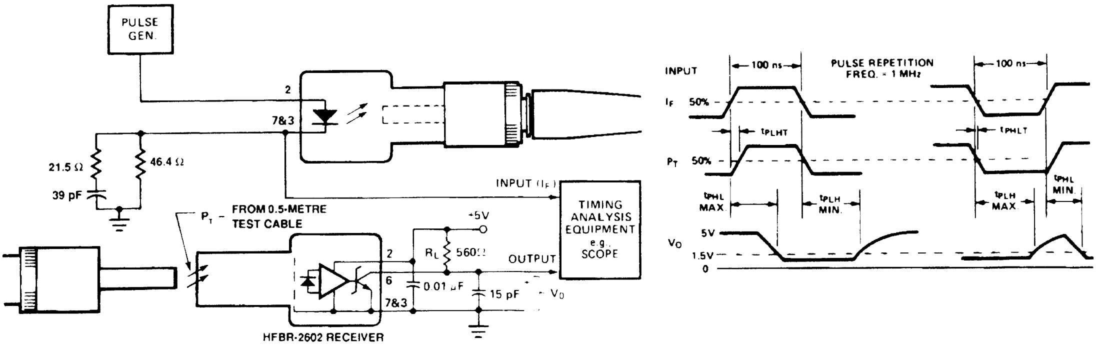


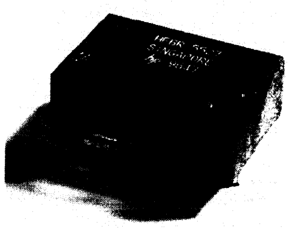
Figure 6. System Propagation Delay Test Circuit and Waveform Timing Definitions.

HEWLETT PACKARD

125 Megabaud Fiber Optic Transceiver JIS FO7 Connection

Technical Data

HFBR-5527



Features

- **Data Transmission at Signal Rates of 1 to 125 MBd over Distances up to 100 Meters**
- **Compatible with Duplex JIS FO7 and Simplex JIS FO5 Connectors**
- **Specified for Use with Plastic Optical Fiber (POF), and with Large Core Silica Fiber (HCS®)**
- **Transmitter and Receiver Application Circuit Schematics Available**
- **Conductive Plastic Housing Provides Electrical Shield**

Applications

- **Intra-System Links: Board-to-Board, Rack-to-Rack**
- **High Voltage Isolation**
- **Telecommunications Switching Systems**
- **Computer-to-Peripheral Data Links, PC Bus Extension**
- **Industrial Control Networks**
- **Proprietary LANs**
- **Digitized Video**
- **Medical Instruments**
- **Immune to Lightning and Voltage Transients**

Description

The 125 MBd transceiver is a cost-effective fiber-optic solution for transmission of 125 MBd data up to 100 meters with HCS® fiber. The data link consists of a 650 nm visible, red LED transmitter and a PIN/preamp receiver. These can be used with low-cost plastic or hard clad silica fiber. One millimeter diameter plastic fiber provides the lowest cost solution for distances under 25 meters. The lower attenuation of HCS® fiber allows data transmission over longer distance. These components can be used for high speed data links without the problems common with copper wire solutions.

The transmitter is a high power 650 nm LED. Both transmitter and receiver are molded in one housing which is compatible with the FO7 connector. This connector is designed to efficiently couple the power into POF or HCS® fiber.

With the recommended drive circuit, the LED operates at speeds from 1-125 MBd. The analog high bandwidth receiver contains a PIN photodiode and internal transimpedance amplifier. With the recommended application circuit for 125 MBd operation, the performance of the complete data link is specified for 0-25 meters with plastic fiber. A wide variety of other digitizing circuits can be combined with the HFBR-5527 Series to optimize performance and cost at higher or lower data rates.

HCS® is a registered trademark of Spectran Corporation.

5965-7092E (5/97)

HFBR-5527
125 MBd Data Link

Data link operating conditions and performance are specified for the transmitter and receiver in the recommended applications circuits shown in Figure 1. This circuit has been optimized for 125 MBd operation. The Applications Engineering Department in the Hewlett-Packard Optical Communication Division is available to assist in optimizing link performance for higher or lower speed operation.

Recommended Operating Conditions for the Circuits in Figures 1 and 2.

Parameter	Symbol	Min.	Max.	Unit	Note
Ambient Temperature	T_A	0	70	°C	
Supply Voltage	V_{CC}	+4.75	+5.25	V	
Data Input Voltage - Low	V_{IL}	V_{CC} - 1.89	V_{CC} - 1.62	V	
Data Input Voltage - High	V_{IH}	V_{CC} - 1.06	V_{CC} -0.70	V	
Data Output Load	R_L	45	55	Ω	1
Signaling Rate	f_S	1	125	MBd	
Duty Cycle	D.C.	40	60	%	2

Link Performance: 1-125 MBd, BER ≤ 10^{-9}, under recommended operating conditions with recommended transmit and receive application circuits.

Parameter	Symbol	Min.[3]	Typ.[4]	Max.	Unit	Condition	Note
Optical Power Budget, 1 m POF	OPB_{POF}	11	16		dB		5, 6, 7
Optical Power Margin, 20 m Standard POF	$OPM_{POF,20}$	3	6		dB		5, 6, 7
Link Distance with Standard 1 mm POF	1	20	27		m		
Optical Power Margin, 25 m Low Loss POF	$OPM_{POF,25}$	3	6		dB		5, 6, 7
Link Distance with Extra Low Loss 1 mm POF	1	25	32		m		
Optical Power Budget, 1 m HCS	OPB_{HCS}		12		dB		5, 6, 7
Optical Power Margin, 100 m HCS	$OPM_{HCS,100}$		6		dB		5, 6, 7
Link Distance with HCS cable	1		125		m		

Notes:
1. If the output of U4C in Figure 1, page 4 is transmitted via coaxial cable, terminate with a 50 Ω resistor to V_{CC} - 2 V.
2. Run length limited code with maximum run length of 10 µs.
3. Minimum link performance is projected based on the worst case specifications of the transmitter, receiver, and POF cable, and the typical performance of other components (e.g., logic gates, transistors, resistors, capacitors, quantizer, HCS cable).
4. Typical performance is at 25°C, 125 MBd, and is measured with typical values of all circuit components.
5. Standard cable is HFBR-RXXYYY plastic optical fiber, with a maximum attenuation of 0.24 dB/m at 650 nm and NA = 0.5. Extra low loss cable is HFBR-EXXYYY plastic optical fiber, with a maximum attenuation of 0.19 dB/m at 650 nm and NA = 0.5. HCS cable is HFBR-H/VXXYYY glass optical fiber, with a maximum attenuation of 10 dB/km at 650 nm and NA = 0.37.
6. Optical Power Budget is the difference between the transmitter output power and the receiver sensitivity, measured after 1 meter of fiber. The minimum OPB is based on the limits of optical component performance over temperature, process, and recommended power supply variation.
7. The Optical Power Margin is the available OPB after including the effects of attenuation and modal dispersion for the minimum link distance: OPM = OPB - (attenuation power loss + modal dispersion power penalty). The minimum OPM is the margin available for long term LED LOP degradation and additional fixed passive losses (such as in-line connectors) in addition to the minimum specified distance.

Plastic Optical Fiber (1 mm POF) Transmitter Application Circuit:
Performance of the transmitter in the recommended application circuit (Figure 1) for POF; 1-125 MBd, 25°C.

Parameter	Symbol	Typical	Unit	Condition	Note
Average Optical Power 1 mm POF	P_{avg}	-9.7	dBm	50% Duty Cycle	Note 1, Fig. 3
Average Modulated Power 1 mm POF	P_{mod}	-11.3	dBm		Note 2, Fig. 3
Optical Rise Time (10% to 90%)	t_r	2.1	ns	5 MHz	
Optical Fall Time (90% to 10%)	t_f	2.8	ns	5 MHz	
High Level LED Current (On)	$I_{F,H}$	30	mA		Note 3
Low Level LED Current (Off)	$I_{F,L}$	3	mA		Note 3
Optical Overshoot - 1 mm POF		45	%		
Transmitter Application Circuit Current Consumption - 1 mm POF	I_{CC}	115	mA		Figure 1

Hard Clad Silica Fiber (200 μm HCS) Transmitter Application Circuit: Performance of the transmitter in the recommended application circuit (Figure 1) for HCS; 1-125 MBd, 25°C.

Parameter	Symbol	Typical	Unit	Condition	Note
Average Optical Power 200 μm HCS	P_{avg}	-14.6	dBm	50% Duty Cycle	Note 1, Fig. 3
Average Modulated Power 200 μm HCS	P_{mod}	-16.2	dBm		Note 2, Fig. 3
Optical Rise Time (10% to 90%)	t_r	3.1	ns	5 MHz	
Optical Fall Time (90% to 10%)	t_f	3.4	ns	5 MHz	
High Level LED Current (On)	$I_{F,H}$	60	mA		Note 3
Low Level LED Current (Off)	$I_{F,L}$	6	mA		Note 3
Optical Overshoot - 200 μm HCS		30	%		
Transmitter Application Circuit Current Consumption - 200 μm HCS	I_{CC}	130	mA		Figure 1

Notes:

1. Average optical power is measured with an average power meter at 50% duty cycle, after 1 meter of fiber.
2. To allow the LED to switch at high speeds, the recommended drive circuit modulates LED light output between two non-zero power levels. The modulated (useful) power is the difference between the high and low level of light output power (transmitted) or input power (received), which can be measured with an average power meter as a function of duty cycle (see Figure 3). Average Modulated Power is defined as one half the slope of the average power versus duty cycle:

$$\text{Average Modulated Power} = \frac{[P_{avg} \text{ @ } 80\% \text{ duty cycle} - P_{avg} \text{ @ } 20\% \text{ duty cycle}]}{(2)\,[0.80 - 0.20]}$$

3. High and low level LED currents refer to the current through the LED. The low level LED "off" current, sometimes referred to as "hold-on" current, is prebias supplied to the LED during the off state to facilitate fast switching speeds.

Plastic and Hard Clad Silica Optical Fiber Receiver Application Circuit:

Performance[4] of the receiver in the recommended application circuit (Figure 1); 1-125 MBd, 25°C unless otherwise stated.

Parameter	Symbol	Typical	Unit	Condition	Note
Data Output Voltage - Low	V_{OL}	V_{CC} -1.7	V	R_L = 50 Ω	Note 5
Data Output Voltage - High	V_{OH}	V_{CC} -0.9	V	R_L = 50 Ω	Note 5
Receiver Sensitivity to Average Modulated Optical Power 1 mm POF	P_{min}	-27.5	dBm	50% eye opening	Note 2
Receiver Sensitivity to Average Modulated Optical Power 200 μm HCS	P_{min}	-28.5	dBm	50% eye opening	Note 2
Receiver Overdrive Level of Average Modulated Optical Power 1 mm POF	P_{max}	-7.5	dBm	50% eye opening	Note 2
Receiver Overdrive Level of Average Modulated Optical Power 200 μm HCS	P_{max}	-10.5	dBm	50% eye opening	Note 2
Receiver Application Circuit Current Consumption	I_{CC}	85	mA	$R_L = \infty$	Figure 1

Notes:

4. Performance in response to a signal from the transmitter driven with the recommended circuit at 1-125 MBd over 1 meter of plastic optical fiber or 1 meter of HCS® fiber with F07 plugs.
5. Terminated through a 50 Ω resistor to V_{CC} - 2 V.
6. If there is no input optical power to the receiver, electrical noise can result in false triggering of the receiver. In typical applications, data encoding and error detection prevent random triggering from being interpreted as valid data.

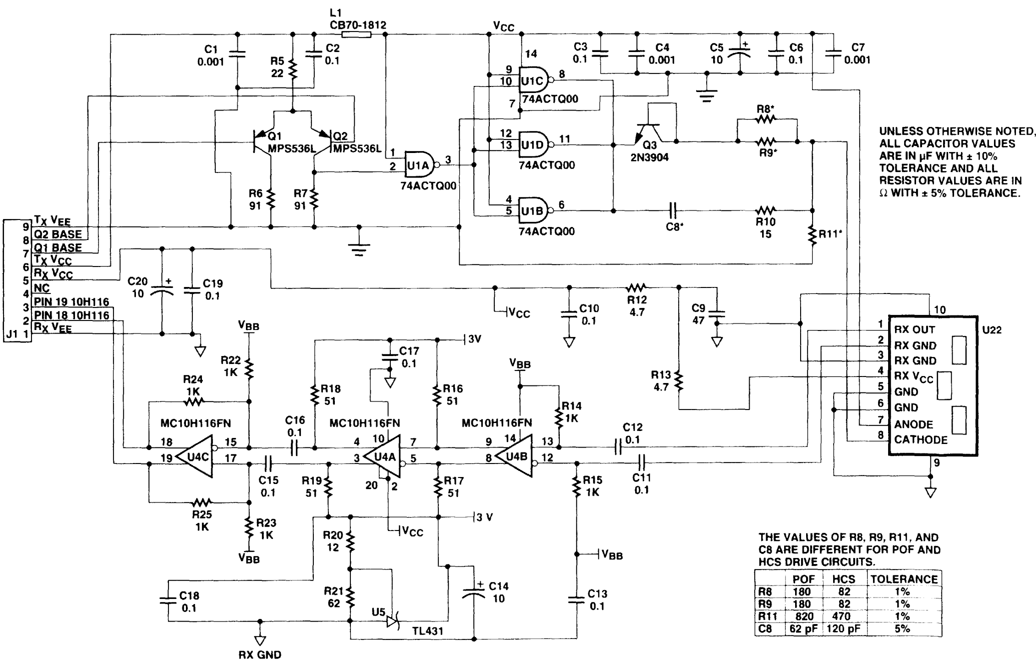


Figure 1. Transmitter and Receiver Application Circuit with +5 V ECL Inputs and Outputs.

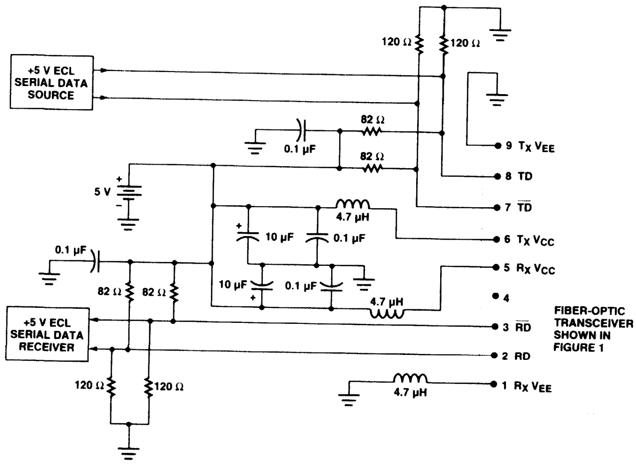


Figure 2. Recommended Power Supply Filter and +5 V ECL Signal Terminations for the Transmitter and Receiver Application Circuit of Figure 1.

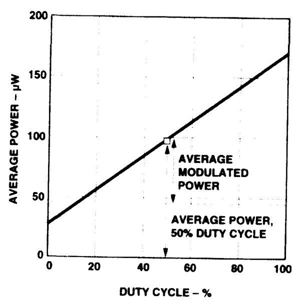


Figure 3. Average Modulated Power.

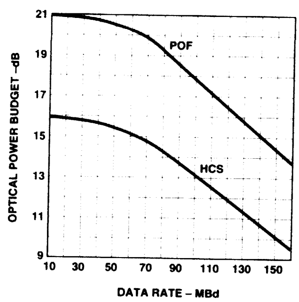
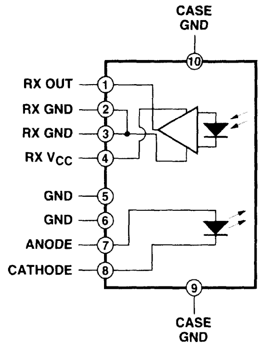


Figure 4. Typical Optical Power Budget vs. Data Rate.

125 Megabaud Fiber Optic Link Transmitter/Receiver



Description

The HFBR-5527 incorporates a 650 nm LED, a PIN photodiode, and transimpedance preamplifier. The 650 nm LED is suitable for use with current peaking to decrease optical response time and can be used with the PIN preamplifier to build an optical transceiver that can be operated at signaling rates from 1 to 125 MBd over POF or HCS® fiber. The receivers convert a received optical signal to an analog output voltage. Follow-on circuitry can optimize link performance for a variety of distance and data rate requirements. Electrical bandwidth greater than 65 MHz allows design of high speed data links with plastic or hard clad silica optical fiber.

Absolute Maximum Ratings

Parameter	Symbol	Min.	Max.	Unit	Reference
Storage Temperature	T_S	-40	+85	°C	
Operating Temperature	T_O	-40	+70	°C	
Lead Soldering Temperature			260	°C	Note 1
Cycle Time			10	s	
Transmitter High Level Forward Input Current	$I_{F,H}$		120	mA	50% Duty Cycle ≥ 1 MHz
Transmitter Average Forward Input Current	$I_{F,AV}$		60	mA	
Transmitter Reverse Input Voltage	V_R		3	V	
Receiver Signal Pin Voltage	V_O	-0.5	V_{CC}	V	
Receiver Supply Voltage	V_{CC}	-0.5	6.0	V	
Receiver Output Current	I_O		25	mA	

CAUTION: The small junction sizes inherent to the design of this component increase the component's susceptibility to damage from electrostatic discharge (ESD). It is advised that normal static precautions be taken in handling and assembly of this component to prevent damage and/or degradation which may be induced by ESD.

WARNING: WHEN VIEWED UNDER SOME CONDITIONS, THE OPTICAL PORT MAY EXPOSE THE EYE BEYOND THE MAXIMUM PERMISSIBLE EXPOSURE RECOMMENDED IN ANSI Z136.2, 1993. UNDER MOST VIEWING CONDITIONS THERE IS NO EYE HAZARD.

HFBR-5527 Transmitter

Electrical/Optical Characteristics 0 to 70°C, unless otherwise stated.

Parameter	Symbol	Min.	Typ.[2]	Max.	Unit	Condition	Note
Transmitter Output Optical Power, 1 mm POF	P_T	-9.5 -10.4	-7.0	-4.8 -4.3	dBm	$I_{F,dc}$ = 30 mA, 25°C 0-70°C	Note 3
Transmitter Output Optical Power, 200 µm HCS®	P_T		-13.0	-10.5 -10.0	dBm	$I_{F,dc}$ = 60 mA, 25°C 0-70°C	Note 3
Output Optical Power Temperature Coefficient	$\frac{\Delta P_T}{\Delta T}$		-0.02		dB/°C		
Peak Emission Wavelength	λ_{PK}	640	650	660	nm		
Peak Wavelength Temperature Coefficient	$\frac{\Delta \lambda}{\Delta T}$		0.12		nm/°C		
Spectral Width	FWHM		21		nm	Full Width, Half Maximum	
Forward Voltage	V_F	1.8	2.0	2.4	V	I_F = 60 mA	
Forward Voltage Temperature Coefficient	$\frac{\Delta V_F}{\Delta T}$		-1.8		mV/°C		
Transmitter Numerical Aperture	NA		0.5				
Thermal Resistance, Junction to Case	θ_{jc}		140		°C/W		Note 4
Reverse Input Breakdown Voltage	V_{BR}	3.0	13		V	$I_{F,dc}$ = -10 µA	
Diode Capacitance	C_O		60		pF	V_F = 0 V, f = 1 MHz	
Unpeaked Optical Rise Time, 10% - 90%	t_r		12		ns	I_F = 60 mA f = 100 kHz	Figure 5 Note 5
Unpeaked Optical Fall Time, 90% - 10%	t_f		9		ns	I_F = 60 mA f = 100 kHz	Figure 5 Note 5

Notes:

1. 1.6 mm below seating plane.
2. Typical data is at 25°C.
3. Optical Power measured at the end of 0.5 meter of 1 mm diameter plastic or 200 µm diameter hard clad silica optical fiber with a large area detector.
4. Typical value measured from junction to PC board solder joint.
5. Optical rise and fall times can be reduced with the appropriate driver circuit.
6. Pins 9 and 10 are primarily for mounting and retaining purposes, but are electrically connected with conductive housing; pins 5 and 6 are electrically unconnected. It is recommended that pins 5, 6, 9, and 10 all be connected to Rx ground to reduce coupling of electrical noise.
7. Refer to the Versatile Link Family Fiber Optic Cable and Connectors Technical Data Sheet for cable connector options for 1 mm plastic optical fiber and 200 µm HCS fiber.
8. The LED current peaking necessary for high frequency circuit design contributes to electromagnetic interference (EMI). Care must be taken in circuit board layout to minimize emissions for compliance with governmental EMI emissions regulations.

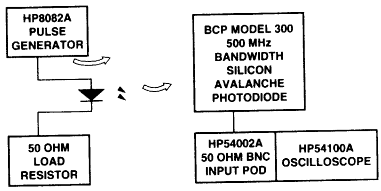


Figure 5. Test Circuit for Measuring Unpeaked Rise and Fall Times.

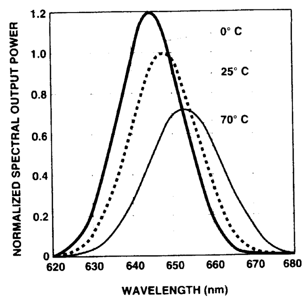


Figure 6. Typical Spectra Normalized to the 25°C Peak.

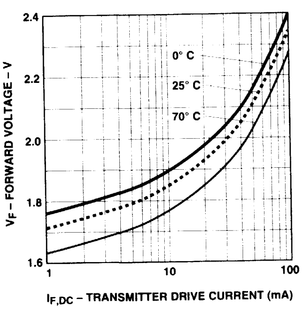


Figure 7. Typical Forward Voltage vs. Drive Current.

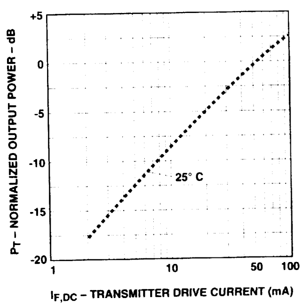


Figure 8. Typical Normalized Output Optical Power vs. Drive Current with the Drive Circuit in Figure 1 Recommended Application Circuit.

HFBR-5527 Receiver

Electrical/Optical Characteristics 0 to 70°C; 5.25 V ≥ V_{CC} ≥ 4.75 V; power supply must be filtered (see Figure 1, Note 2).

Parameter	Symbol	Min.	Typ.	Max.	Unit	Test Condition	Note
AC Responsivity 1 mm POF	$R_{P,POF}$	1.7	3.9	6.5	mV/μW	650 nm	Note 4
AC Responsivity 200 μm HCS	$R_{P,HCS}$	4.5	7.9	11.5	mV/μW		
RMS Output Noise	V_{NO}		0.46	0.69	mV_{RMS}		Note 5
Equivalent Optical Noise Input Power, RMS - 1 mm POF	$P_{N,RMS}$		-39	-36	dBm		Note 5
Equivalent Optical Noise Input Power, RMS - 200 μm HCS	$P_{N,RMS}$		-42	-40	dBm		Note 5
Peak Input Optical Power - 1 mm POF	P_R			-5.8 -6.4	dBm dBm	5 ns PWD 2 ns PWD	Note 6
Peak Input Optical Power - 200 μm HCS	P_R			-8.8 -9.4	dBm dBm	5 ns PWD 2 ns PWD	Note 6
Output Impedance	Z_O		30		Ω	50 MHz	Note 4
DC Output Voltage	V_O	0.8	1.8	2.6	V	P_R = 0 μW	
Supply Current	I_{CC}		9	15	mA		
Electrical Bandwidth	BW_E	65	125		MHz	-3 dB electrical	
Bandwidth * Rise Time			0.41		Hz * s		
Electrical Rise Time, 10-90%	t_r		3.3	6.3	ns	P_R = -10 dBm peak	
Electrical Fall Time, 90-10%	t_f		3.3	6.3	ns	P_R = -10 dBm peak	
Pulse Width Distortion	PWD		0.4	1.0	ns	P_R = -10 dBm peak	Note 7
Overshoot			4		%	P_R = -10 dBm peak	Note 8

Notes:

1. 1.6 mm below seating plane.
2. The signal output is an emitter follower, which does not reject noise in the power supply. The power supply must be filtered as in Figure 9.
3. Typical data are at 25°C and V_{CC} = +5 Vdc.
4. Pin 1 should be ac coupled to a load ≥ 510 Ω with load capacitance less than 5 pF.
5. Measured with a 3 pole Bessel filter with a 75 MHz, -3 dB bandwidth. No modulation appled to Tx.
6. The maximum Peak Input Optical Power is the level at which the Pulse Width Distortion is guaranteed to be less than the PWD listed under Test Condition. $P_{R,Max}$ is given for PWD = 5 ns for designing links at ≤ 50 MBd operation, and also for PWD = 2 ns for designing links up to 125 MBd (for both POF and HCS input conditions).
7. 10 ns pulse width, 50% duty cycle, at the 50% amplitude point of the waveform.
8. Percent overshoot is defined at:

$$\frac{(V_{PK} - V_{100\%})}{V_{100\%}} \times 100\%$$

9. Pins 9 and 10 are primarily for mounting and retaining purposes, but are electrically connected with the conductive housing. Pins 5 and 6 are electrically unconnected. It is recommended that pins 5 and 6 be connected to Rx ground to reduce coupling of electrical noise. Refer to Figure 1. The connections between pins 1 and 2 of the HFBR-5527 and pins 13 and 12 of the MC10H116 should be adjacent and nearly the same length to maximize the common mode rejection of the MC10H116 to eliminate cross talk between the transmitter and receiver.
10. If there is no input optical power to the receiver (no transmitted signal) electrical noise can result in false triggering of the receiver. In typical applications, data encoding and error detection prevent random triggering from being interpreted as valid data.

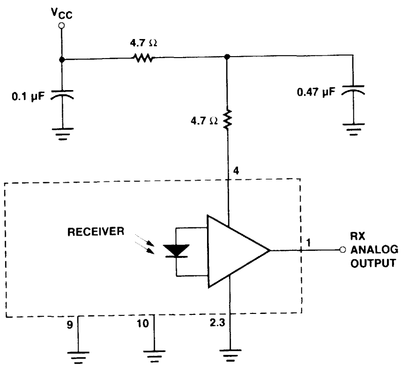


Figure 9. Recommended Power Supply Filter Circuit.

The HFBR-5527 is typically used to construct 125 MBd digital fiber-optic receivers which use the same +5 volt power supply that powers the host system's microprocessors, CMOS logic, or TTL logic. To build a digital receiver, the analog HFBR-5527 component must be connected to a post amplifier and a comparator. This post amplifier plus comparator function is commonly known as a quantizer. The 0 V common and +5 V power supply connections for the HFBR-5527 and quantizer must be isolated from the host system's power and ground planes by a low pass filter. This recommended low pass filter assures that the electrical noise normally present in the host system's digital logic power supply will not reduce the sensitivity of fiber-optic receivers implemented with the HFBR-5527. The quantizer and power supply filter circuits recommended for use with the HFBR-5527 are shown in Figure 7 of HP Application Note 1066. For optimum performance, the HFBR-5527 should be used with the same quantizer and power supply filters recommended for use with HP's HFBR-15X7 and HFBR-25X6 components. To maximize immunity to electrical noise, pins 3, 9, and 10 of the HFBR-5527 should be connected to filtered receiver common. For best common mode noise rejection, the connections between pins 1 and 2 of the HFBR-5527 and the quantizer's differential input should be of equal length, and the components in both traces should be placed to achieve symmetry. The preceding recommendations minimize the cross talk between the fiber-optic transmitter and receiver. These recommendations also improve the fiber-optic receiver's immunity to environmental noise and the host system's electrical noise.

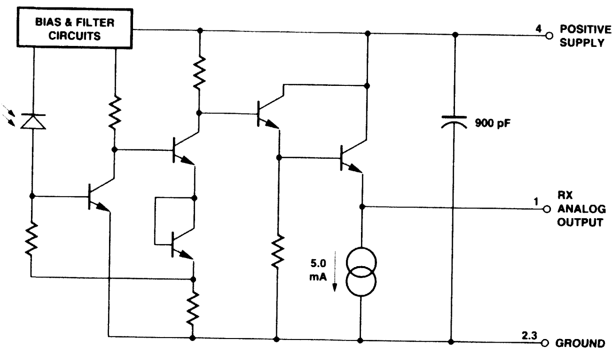


Figure 10. Simplified Receiver Schematic.

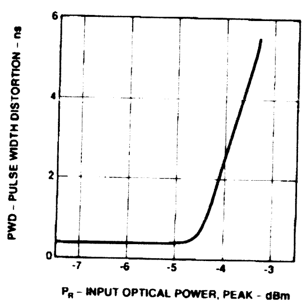


Figure 11. Typical Pulse Width Distortion vs. Peak Input Power.

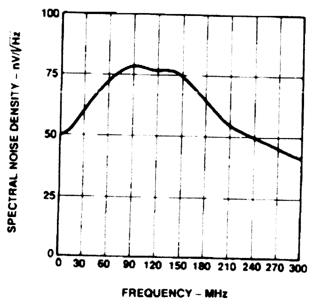


Figure 12. Typical Output Spectral Noise Density vs. Frequency.

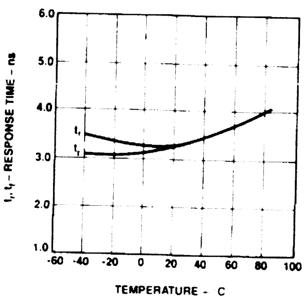
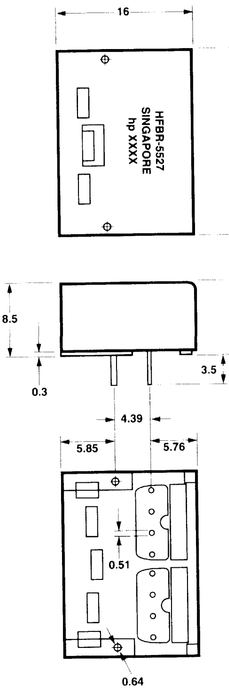
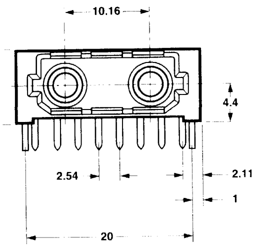


Figure 13. Typical Rise and Fall Time vs. Temperature.

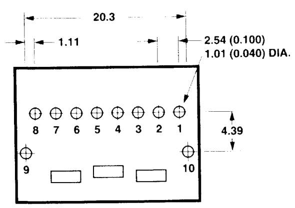
HFBR-5527
Mechanical Dimensions





ALL DIMENSIONS IN MILLIMETERS (INCHES).
ALL DIMENSIONS ± 0.25 mm
UNLESS OTHERWISE SPECIFIED.

Printed Circuit Board Layout Dimensions



TOP VIEW

ELECTRICAL PIN FUNCTIONS

PIN NO.	
1	RX OUT
2	RX GND
3	RX GND
4	RX V_{CC}
5	TX GND*
6	TX GND*
7	ANODE
8	CATHODE
9	CASE GND
10	CASE GND

*NO INTERNAL CONNECTION

CAUTION:
THIS PACKAGE IS MADE OF CONDUCTIVE PLASTIC. PLEASE TAKE THIS INTO ACCOUNT WHEN INCORPORATING THIS PACKAGE INTO INTRINSICALLY SAFE APPLICATIONS.

NOTE:
DIMENSIONS IN MILLIMETERS AND (INCHES).

HEWLETT PACKARD

Plastic Optical Fiber and HCS® Fiber Cable and Connectors for Versatile Link

Technical Data

HFBR-RXXYYY Series (POF)
HFBR-EXXYYY Series (POF)
HFBR-HXXYYY Series (HCS)
HFBR-VXXYYY Series (HCS)

Features

- **Compatible with HP Versatile Link Family of Connectors and Fiber Optic Components**
- **1 mm Diameter Plastic Optical Fiber (POF) in Two Grades: Low Cost Standard POF with 0.22 dB/m Typical Attenuation, or High Performance Extra Low Loss POF with 0.19 dB/m Typical Attenuation**
- **200 μm Diameter Hard Clad Silica (HCS®) Fiber with 8 dB/km Typical Attenuation, Riser or Plenum Rated Jackets, Superior Mechanical Strength**
- **Reduction of Lightning and Voltage Transient Susceptibility**
- **High Voltage Isolation**

Applications

- **Industrial Data Links for Factory Automation and Plant Control**
- **Intra-System Links; Board-to-Board, Rack-to-Rack**
- **Telecommunications Switching Systems**
- **Computer-to-Peripheral Data Links, PC Bus Extension**
- **Proprietary LANs**
- **Digitized Video**
- **Medical Instruments**

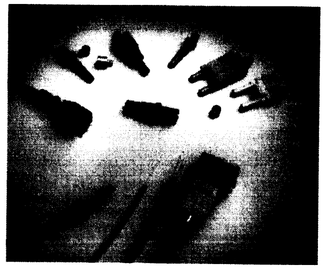
Cable Description

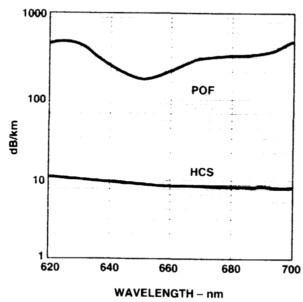
The HFBR-R/EXXYYY series of plastic fiber optic cables are constructed of a single step-index fiber sheathed in a black polyethylene jacket. The duplex fiber consists of two simplex fibers joined with a zipcord web.

Standard attenuation and extra low loss POF cables are identical except for attenuation specifications.

The HFBR-H/VXXYYYY series of hard clad silica fiber optic cables are constructed of a single step index pure silica HCS® fiber sheathed in a blue polyvinyl chloride jacket. The duplex fiber consists of two simplex fibers joined with a zipcord web. Riser and Plenum rated HCS® fiber cables are identical except for jacket materials.

Polyethylene jackets on all plastic fiber cables comply with UL VW-1 flame retardant specifications.





Typical POF and HCS Attenuation

PVC jackets on HCS® cables are either UL Riser rated or UL Plenum rated.

All series of cables are available in unconnectored or connectored options. Refer to the Ordering Guide for part number information.

HCS® is a registered trademark of SpecTran Corporation.

5963-3711E (1/97)

Plastic Optical Fiber Specifications: HFBR-R/EXXYYY

Absolute Maximum Ratings

Parameter		Symbol	Min.	Max.	Unit	Note
Storage and Operating Temperature		$T_{S,O}$	-55	+85	°C	
Recommended Operating Temperature		T_O	-40	+85	°C	
Installation Temperature		T_I	-20	+70	°C	1
Short Term Tensile Force	Single Channel	F_T		50	N	2
	Dual Channel	F_T		100	N	
Short Term Bend Radius		r	25		mm	3, 4
Long Term Bend Radius		r	35		mm	
Long Term Tensile Load		F_T		1	N	
Flexing				1000	Cycles	4

Mechanical/Optical Characteristics, T_A = -40 to +85°C unless otherwise specified.

Parameter		Symbol	Min.	Typ.[5]	Max.	Unit	Condition
Cable Attenuation	Standard Cable, Type "R"	α_O	0.15	0.22	0.27	dB/m	Source is HFBR-15XX (660 mm LED, 0.5 NA)
	Extra Low Loss, Type "E"		0.15	0.19	0.23		ℓ = 50 meters
Reference Attenuation	Standard Cable, Type "R"	α_R	0.12	0.19	0.24	dB/m	Source is 650 nm, 0.5 NA monochrometer,
	Extra Low Loss, Type "E"		0.12	0.16	0.19		ℓ = 50 meters Note 7, Figure 1
Numerical Aperture		NA	0.46	0.47	0.50		>2 meters
Diameter, Core and Cladding		D_C	0.94	1.00	1.06	mm	
Diameter, Jacket		D_J	2.13	2.20	2.27	mm	Simplex Cable
Propagation Delay Constant		l/v		5.0		ns/m	Note 6
Mass per Unit Length/Channel				5.3		g/m	Without Connectors
Cable Leakage Current		I_L		12		nA	50 kV, ℓ = 0.3 meters
Refractive Index	Core	n		1.492			
	Cladding			1.417			

Notes:

1. Installation temperature is the range over which the cable can be bent and pulled without damage. Below -20°C the cable becomes brittle and should not be subjected to mechanical stress.
2. Short Term Tensile Force is for less than 30 minutes.
3. Short Term Bend Radius is for less than 1 hour nonoperating.
4. 90° bend on 25 mm radius mandrel. Bend radius is the radius of the mandrel around which the cable is bent.
5. Typical data are at 25°C.
6. Propagation delay constant is the reciprocal of the group velocity for propagation delay of optical power. Group velocity is v=c/n where c is the velocity of light in free space ($3x10^8$ m/s) and n is the effective core index of refraction.
7. Note that α_R rises at the rate of about 0.0067 dB/°C, where the thermal rise refers to the LED temperature changes above 25°C. Please refer to Figure 1 which shows the typical plastic optical fiber attenuation versus wavelength at 25°C.

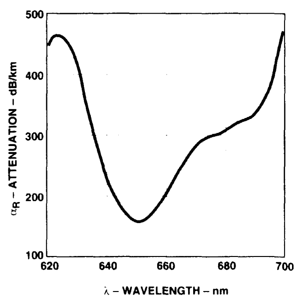


Figure 1. Typical POF Attenuation vs. Wavelength.

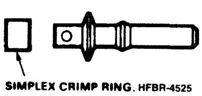
Plastic Fiber Connector Styles

Connector Description

Four connector styles are available for termination of plastic optical fiber: simplex, simplex latching, duplex and duplex latching. All connectors provide a snap-in action when mated to Versatile Link components. Simplex connectors are color coded to facilitate identification of transmitter and receiver connections. Duplex connectors are keyed so that proper orientation is ensured during insertion. If the POF cable/connector will be used at extreme operating temperatures or experience frequent and wide temperature cycling effects, the cable/connector attachment can be strengthened with an RTV adhesive (see Plastic Connectoring Instructions for more detail).

SIMPLEX CONNECTOR STYLES

HFBR-4501/4511/4501B — Simplex



The simplex connector provides a quick and stable connection for applications that require a component-to-connector retention force of 8 Newtons (1.8 lb.). These connectors are available in gray (HFBR-4501), blue (HFBR-4511), or black (HFBR-4501B).

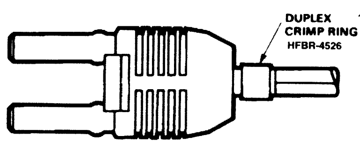
HFBR-4503/4513/4503B — Simplex Latching

The simplex latching connector is designed for rugged applications requiring a greater retention force — 80 Newtons (18 lb.) — than provided by a simplex nonlatching connector. When inserting the simplex latching connector into a module, the connector latch mechanism should be aligned with the top surface of the horizontal modules, or with the tall vertical side of the vertical modules. Misalignment of an inserted latching connector into either module will not result in a positive latch. The connector is released by depressing the rear section of the connector lever, and then pulling the connector assembly away from the module housing.

The simplex latching connector is available in gray (HFBR-4503), blue (HFBR-4513), or black (HFBR-4503B).

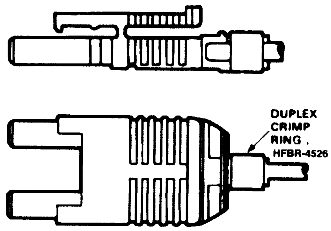
DUPLEX CONNECTOR STYLES

HFBR-4506/4506B — Duplex



Duplex connectors provide convenient duplex cable termination and are keyed to prevent incorrect insertion into duplex configured modules. The duplex connector is compatible with dual combinations of horizontal or vertical Versatile Link components (e.g., two horizontal transmitters, two vertical receivers, a horizontal transmitter with a horizontal receiver, etc.). The duplex nonlatching connector is available in parchment, off-white (HFBR-4506) or black (HFBR-4506B).

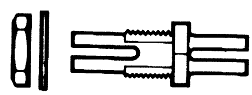
HFBR-4516/4516B — Duplex Latching



The duplex latching connector is designed for rugged applications requiring greater retention force than the nonlatching duplex connector. When inserting the duplex latching connector into a module, the connector latch mechanism should be aligned with the top surface of the dual combination of horizontal or vertical Versatile Link components. The duplex latching connector is available in gray (HFBR-4516) or black (HFBR-4516B).

Feedthrough/Splice

HFBR-4505/4515/4506B Bulkhead Adapter



The HFBR-4505/4515 adapter mates two simplex connectors for panel/bulkhead feedthrough of HFBR-4501/4511 terminated plastic fiber cable. Maximum panel thickness is 4.1 mm (0.16 inch). This adapter can serve as a cable in-line splice using two simplex connectors. The adapters are available in gray (HFBR-4505), blue (HFBR-4515), and black (HFBR-4505B). This adapter is currently not compatible with POF duplex, POF simplex latching, or HCS connectors.

Plastic Optical Fiber Connector Absolute Maximum Ratings

Parameter	Symbol	Min.	Max.	Unit	Note
Storage and Operating Temperature	$T_{S,O}$	-40	85	°C	1
Recommended Operating Temperature	T_O	-40	85	°C	1
Installation Temperature	T_I	0	70	°C	1
Nut Torque HFBR-4505/4515 Adapter	T_N		0.7 100	N-m OzF-in.	2

Notes:
1. Storage and Operating Temperatures refer to the ranges over which the connectors can be used when not subjected to mechanical stress. Installation Temperature refers to the ranges over which connectors may be installed onto the fiber and over which connectors can be connected and disconnected from transmitter and receiver modules.
2. Recommended nut torque is 0.57 N-m.

Plastic Optical Fiber Connector Mechanical/Optical Characteristics

T_A = -40 to +85°C, Unless Otherwise Specified.

Parameter	Part Number	Symbol	Min.	Typ.[1]	Max.	Units	Temp. °C	Note
Retention Force, Connector to Versatile Link Transmitters and Receivers	Simplex, HFBR-4501/4511	F_{R-C}	7 3	8		N	+25 -40 to +85	2
	Simplex Latching, HFBR-4503/4513		47 11	80			+25 -40 to +85	
	Duplex, HFBR-4506		7 4	12			+25 -40 to +85	
	Duplex Latching, HFBR-4516		50 15	80			+25 -40 to +85	
Tensile Force, Connector to Cable	Simplex, HFBR-4501/4511	F_T	8.5	22		N		3
	Simplex Latching, HFBR-4503/4513		8.5	22				
	Duplex, HFBR-4506		14	35				
	Duplex Latching, HFBR-4516		14	35				
Adapter Connector to Connector Loss	HFBR-4505/4515 with HFBR-4501/4511	α_{CC}	0.7	1.5	2.8	dB	25	4, 5
Retention Force Connector to Adapter	HFBR-4505/4515 with HFBR-4501/4511	F_{R-B}	7	8		N		
Insertion Force, Connector to Versatile Link Transmitters and Receivers	Simplex, HFBR-4501/4511	F_I		8	30	N		6
	Simplex Latching, HFBR-4503/4513			16	35			
	Duplex, HFBR-4506			13	46			
	Duplex Latching HFBR-4516			22	51			

Notes:
1. Typical data are at +25°C.
2. No perceivable reduction in retention force was observed after 2000 insertions. Retention force of non-latching connectors is lower at elevated temperatures. Latching connectors are recommended for applications where a high retention force at high temperatures is desired.
3. For applications where frequent temperature cycling over temperature extremes is expected, please contact Hewlett-Packard for alternate connectoring techniques.
4. Minimum and maximum limit for α_{CC} for 0°C to +70°C temperature range. Typical value of α_{CC} is at +25°C.
5. Factory polish or field polish per recommended procedure.
6. Destructive insertion force was typically at 178 N (40 lb.).

Step-by-Step Plastic Cable Connectoring Instructions

The following step-by-step guide describes how to terminate plastic fiber optic cable. It is ideal for both field and factory installation. Connectors can be easily installed on cable ends with wire strippers, cutters and a crimping tool.

Finishing the cable is accomplished with the Hewlett-Packard HFBR-4593 Polishing Kit, consisting of a Polishing Fixture, 600 grit abrasive paper and 3 µm pink lapping film (3M Company, OC3-14). The connector can be used immediately after polishing.

Materials needed for plastic fiber termination are:

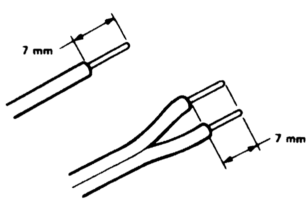
1. Hewlett-Packard Plastic Optical Fiber Cable (Example: HFBR-RUS500, HFBR-RUD500, HFBR-EUS500, or HFBR-EUD500)
2. Industrial Razor Blade or Wire Cutters
3. 16 Gauge Latching Wire Strippers (Example: Ideal Stripmaster™ type 45-092).
4. HFBR-4597 Crimping Tool
5. HFBR-4593 Polishing Kit
6. One of the following connectors:
   a) HFBR-4501/4503 Gray Simplex/Simplex Latching Connector and HFBR-4525 Simplex Crimp Ring
   b) HFBR-4511/4513 Blue Simplex/Simplex Latching Connector and HFBR-4525 Simplex Crimp Ring
   c) HFBR-4506 Parchment (off-white) Duplex Connector and HFBR-4526 Duplex Crimp Ring
   d) HFBR-4516 Gray Latching Duplex Connector and HFBR-4526 Duplex Crimp Ring

Step 1

The zip cord structure of the duplex cable permits easy separation of the channels. The channels should be separated approximately 50 mm (2.0 in) back from the ends to permit connectoring and polishing.

After cutting the cable to the desired length, strip off approximately 7 mm (0.3 in.) of the outer jacket with the 16 gauge wire strippers. Excess webbing on the duplex cable may have to be trimmed to allow the simplex or simplex latching connector to slide over the cable.

When using the duplex connector and duplex cable, the separated duplex cable must be stripped to equal lengths on each cable. This allows easy and proper seating of the cable into the duplex connector.



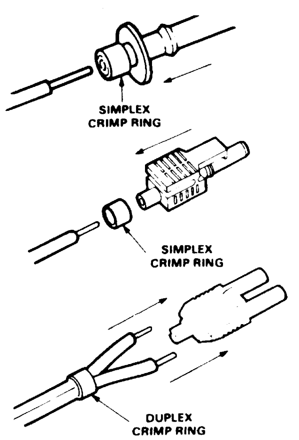
Step 2

Place the crimp ring and connector over the end of the cable; the fiber should protrude about 3 mm (0.12 in.) through the end of the connector. Carefully position the ring so that it is entirely on the connector with the rim of the crimp ring flush with the connector, leaving a small space between the crimp ring and the flange. Then crimp the ring in place with the crimping tool. One crimp tool is used for all POF connector crimping requirements.

For applications with extreme temperature operation or frequent temperature cycling, improved connector to cable attachment can be achieved with the use of an RTV (GE Company, RTV-128 or Dow Corning 3145-RTV) adhesive. The RTV is placed into the connector prior to insertion of the fiber and the fiber is crimped normally. The connector can be polished after the RTV has cured and is then ready for use.

Note: *By convention, place the gray connector on the transmitter cable end and the blue connector on the receiver cable end to maintain color coding (different color connectors are mechanically identical).*

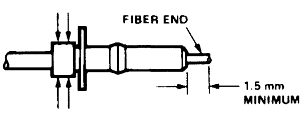
Simplex connector crimp rings cannot be used with duplex connectors and duplex connector crimp rings cannot be used with simplex connectors because of size differences. The simplex crimp has a dull luster appearance; the duplex ring is glossy and has a thinner wall.



Step 3

Any excess fiber protruding from the connector end may be cut off; however, the trimmed fiber should extend at least 1.5 mm (0.06 in) from the connector end.

Insert the connector fully into the polishing fixture with the trimmed fiber protruding from the bottom of the fixture. This plastic polishing fixture can be used to polish two simplex connectors or simplex latching connectors simultaneously, or one duplex connector.



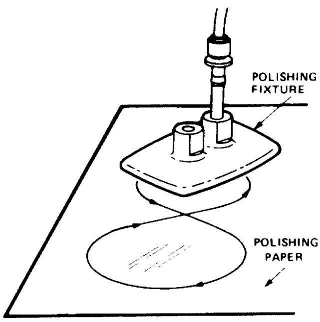
***Note:** The four dots on the bottom of the polishing fixture are wear indicators. Replace the polishing fixture when any dot is no longer visible. Typically, the polishing fixture can be used 10 times; 10 duplex connectors or 20 simplex connectors, two at a time.*

Place the 600 grit abrasive paper on a flat smooth surface, pressing down on the connector, polish the fiber and the connector using a figure eight pattern of strokes until the connector is flush with the bottom of the polishing fixture. Wipe the connector and fixture with a clean cloth or tissue.

Step 4

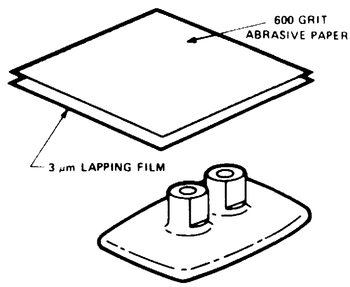
Place the flush connector and polishing fixture on the dull side of the 3 μm pink lapping film and continue to polish the fiber and connector for approximately 25 strokes. The fiber end should be flat, smooth and clean.

This cable is now ready for use.



***Note:** Use of the pink lapping film fine polishing step results in approximately 2 dB improvement in coupling performance of either a transmitter-receiver link or a bulkhead/splice over a 600 grit polish alone. This fine polish is comparable to the Hewlett-Packard factory polish. The fine polishing step may be omitted where an extra 2 dB of optical power is not essential, as with short link lengths. Proper polishing of the tip of the fiber/connector face results in a tip diameter between 2.5 mm (0.098 in.) minimum and 3.2 mm (0.126 in.) maximum..*

HFBR-4593 Polishing Kit



(USED WITH ALL CONNECTOR TYPES)

Hard Clad Silica Fiber Specifications: HFBR-H/VXXYYY

Absolute Maximum Ratings

Parameter		Symbol	Min.	Max.	Unit	Note
Storage/Operating Temperature		$T_{S,O}$	-40	85	°C	
Recommended Operating Temperature		T_O	-40	85	°C	
Installation Temperature		T_I	-20	85	°C	1
Short Term Tensile Force	Single Channel	F_T		101	N	2
	Dual Channel	F_T		202	N	2
Short Term Bend Radius		r	9		mm	3, 4
Long Term Bend Radius		r	15		mm	
Long Term Tensile Load		F_T		21	N	
Flexing				50,000	Cycles	4

Mechanical/Optical Characteristics, T_A = -40 to +85°C

Parameter		Symbol	Min.	Typ.[5]	Max.	Unit	Condition
Cable Attenuation	HCS® Cable	α_O	5	7	10	dB/km	Source is HFBR-15X7 (650 nm LED, 0.5 NA) 0 to +70°C
Cable Attenuation	HCS® Cable	α_O	5	7	12	dB/km	-40 to +85°C
Reference Attenuation	HCS® Cable	α_R	6.0	8.0	10.0	dB/km	Source is 650 nm, 0.37 NA monochrometer -40 to +85°C
Numerical Aperture		NA	0.35	0.37	0.39		ℓ = 2 meters
Diameter, Core		D_{CORE}	196	200	204	μm	
Diameter, Cladding		D_{CLAD}	220	230	230	μm	
Diameter, Buffer		D_{BUFF}	470	500	530	μm	
Diameter, Jacket		D_J	2.1	2.2	2.3	mm	Simplex Cable
Propagation Delay Constant		l/v		4.8		ns/m	Note 6
Mass per Unit Length/Channel				6.1		g/m	Without Connectors
Refractive Index	Core	n		1.457			
	Cladding			1.407			

Notes:

1. Installation temperature is the range over which the cable can be bent and pulled without damage. Below -20°C the cable becomes brittle and should not be subjected to mechanical stress.
2. Less than 1 hour.
3. Less than 1 hour, non-operating.
4. 90° bend on 9 mm radius.
5. Typical data are at +25°C.
6. Propagation delay constant is the reciprocal of the group velocity for propagation delay of optical power. Group velocity is v = c/n, where c is the velocity of light in free space ($3x10^8$ m/s) and n is the effective core index of refraction.

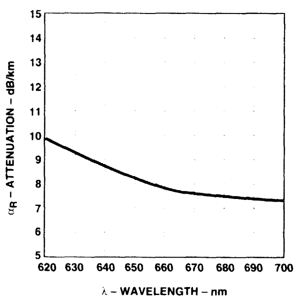


Figure 1. Typical HCS Attenuation vs. Wavelength.

Hard Clad Silica Optical Fiber Connector Styles

Simplex Connector Style, HFBR-4521

The simplex connector provides a quick and stable connection for applications that require a component to provide a retention force of 8 Newtons (1.8 lb.). This connector is available only in black.

Hard Clad Silica Glass Optical Fiber Connector

Absolute Maximum Ratings

Parameter	Symbol	Min.	Max.	Unit	Note
Storage and Operating Temperature	$T_{S,O}$	-40	85	°C	1
Recommended Operating Temperature	T_O	-40	85	°C	
Installation Temperature	T_A	0	85	°C	

Note:

1. Storage and Operating Temperatures refer to the ranges over which the connectors can be used when not subjected to mechanical stress. Installation Temperature refers to the ranges over which connectors may be installed onto the fiber and over which connectors can be connected and disconnected from transmitter and receiver modules.

Hard Clad Silica Glass Optical Fiber Connector

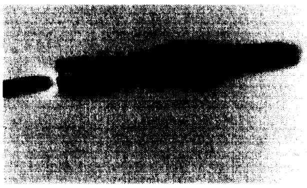
Mechanical/Optical Characteristics; T_A = -40 to +85°C

Parameter	Part Number		Sym.	Min.	Typ.[1]	Max.	Units	Note
Retention Force Connector to Versatile Link Transmitters and Receivers	Simplex	HFBR-4521	F_{R-C}	3	8		N	2
Tensile Force Connector to Cable	Simplex	HFBR-4521	F_T	40	45		N	
Insertion Force Connector to Versatile Link Transmitters and Receivers	Simplex	HFBR-4521	F_I		8	30	N	3

Notes:

1. Typical data are at +25°C.
2. No perceivable reduction in retention force was observed after 2000 insertions.
3. Destructive insertion forces was typically at 178 N (40 lb.).

Instructions for Step-by-Step Connector Installation for HCS® Cable

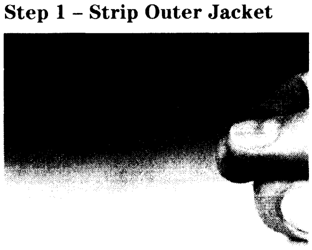


The following step-by-step guide describes how to terminate hard clad silica fiber optic cable. It is ideal for both field and factory installation. Connectoring the cable is accomplished with the Hewlett-Packard HFBR-4521 Crimp and Cleave Kit consisting of a Cable Stripper Tool, Fiber Stripper Tool, Crimp Tool, and Diamond Cleave Tool. No adhesive material is needed to secure the cable in the connector, and the connector can be used immediately after cleaving. Connectors may be easily installed on the cable ends with the Crimp and Cleave Kit.

Materials needed for the terminating procedure are:

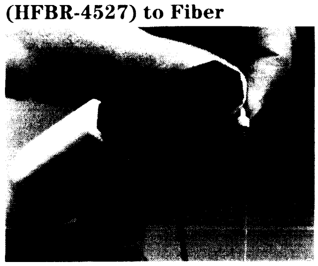
1. Hewlett-Packard HCS® Fiber Optic Cable: (Example: HFBR-HUS500, HFBR-HUD500, HFBR-VUS500)
2. HFBR-4584 Crimp and Cleave Kit
3. HFBR-4521 Black Simplex Connector and Crimp Ring (HFBR-4527)

Step 1 - Strip Outer Jacket



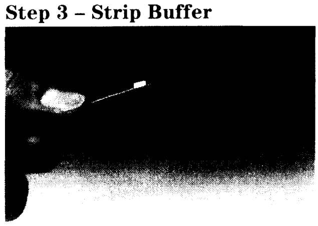
The zipcord structure of the duplex cable permits easy separation of the channels. The channels should be separated approximately 75 mm (3.0 in) back from the ends to permit connectoring and cleaving. After cutting the cable to the desired length, strip off approximately 75 mm (3 in) of the outer jacket with the cable stripper tool, selecting the 1.6 cutting hole labeled on the cable stripper tool. This is done by applying a quick squeezing action to cut the cable jacket. Remove the cut cable jacket portion.

Step 2 - Install Crimp Ring (HFBR-4527) to Fiber



Place the crimp ring over the end of the cable and rest the larger end against the unstripped cable jacket. Selecting the smaller crimp hole (front die nest), align the crimp ring in the crimp tool jaws and fully squeeze the tool handles together and release. This crimps the crimp ring to the fiber buffer.

Step 3 - Strip Buffer



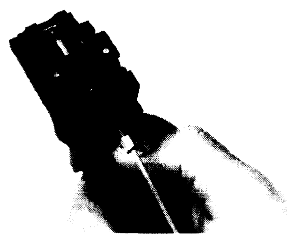
Insert the stripped cable through the guide hole of the fiber stripper tool, inserting the crimp ring until it is fully seated in the guide tube. Holding the unstripped cable securely, squeeze the handles of the fiber stripper to cut the fiber buffer and pull straight to slightly separate the buffer.

Release the fiber stripper handles, remove the tool and carefully slide the buffer off the fiber by hand. Inspect the fiber for cladding damage (i.e., white dusty appearance). If damage has occurred, cut the damaged portion of the fiber and repeat the Strip Outer Jacket procedure. If the fiber stripper tool blade is worn, replace the tool immediately.

Step 4 — Install Ferrule (Connector)

Slide the ferrule onto the fiber and into the crimp ring, carefully aligning the ferrule fully within the crimp ring. The fiber should protrude at least 35 mm (1.4 in) through the end of the ferrule. Selecting the large hole on the crimp tool (rear die nest), crimp the ring to the ferrule by fully squeezing the crimp tool handles together and releasing.

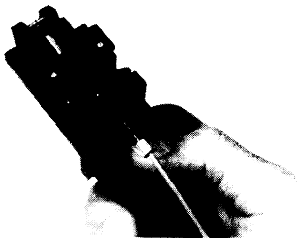
Step 5 - Cleave Fiber



Carefully insert the ferrule into the slot on the diamond cleave tool until the ferrule rests securely in the cleave tool connector adapter.

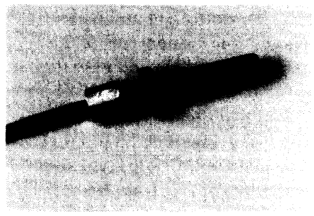
Check to see that the fiber is positioned between the two fiber clamps and that the connector face is in proximity to the cleaving blade. If the ferrule or the fiber is not positioned correctly, remove the cable assembly and reinsert the ferrule.

Holding the cleave tool horizontally, grip the handle, leaving the index finger free. Release the ferrule, and, using the index finger, slowly depress the cleave tool trigger until the trigger is completely down. This motion activates the fiber clamp and the diamond cleave blade to complete the fiber termination; the ferrule will snap back slightly after the cleave process. Remove the cleaved ferrule (connector assembly) from the adapter slot



and release the cleave tool trigger. Remove the fiber remnant from the cleave tool fiber clamps and dispose of properly.

The fiber end should be flat, smooth and clean. Repeat this process for the other end of the cable, and the cable is now ready for use.



Ordering Guide for POF and HCS Connectors and Accessories

Plastic Optical Fiber Connectors

HFBR-4501	Gray Simplex Connector/Crimp Ring
HFBR-4511	Blue Simplex Connector/Crimp Ring
HFBR-4501B	Black Simplex Connector/Crimp Ring
HFBR-4503	Gray Simplex Latching Connector with Crimp Ring
HFBR-4513	Blue Simplex Latching Connector with Crimp Ring
HFBR-4503B	Black Simplex Latching Connector with Crimp Ring
HFBR-4506	Parchment Duplex Connector with Crimp Ring
HFBR-4506B	Black Duplex Connector with Crimp Ring
HFBR-4516	Gray Duplex Latching Connector with Crimp Ring
HFBR-4516B	Black Duplex Latching Connector with Crimp Ring
HFBR-4505	Gray Adapter (Bulkhead/Feedthrough)
HFBR-4515	Blue Adapter (Bulkhead/Feedthrough)
HFBR-4505B	Black Adapter (Bulkhead/Feedthrough)

Plastic Optical Fiber Accessories

HFBR-4525	1000 Simplex Crimp Rings
HFBR-4526	500 Duplex Crimp Rings
HFBR-4593	Polishing Kit (one polishing tool, two pieces 600 grit abrasive paper, and two pieces 3 μm pink lapping film)
HFBR-4597	Plastic Fiber Crimping Tool

HCS® Fiber Connectors

HFBR-4521	Black Simplex Connector/Crimp Ring

HCS® Fiber Accessories

HFBR-4527	100 Simplex Crimp Rings
HFBR-4584	Crimp and Cleave Termination Kit (one Fiber Strip tool, one Cable Strip tool, one Crimp tool, one Scissors and one Diamond Cleave Tool)

Ordering Guide for POF and HCS Cable

Four steps are required to determine the proper part number for a desired cable.

Step 1
Select the cable type.
POF: Standard (**R**) or Extra Low Loss (**E**) Attenuation Cable.

HCS: Riser (**H**) or Plenum (**V**) rated cable.

Step 2
Select the connector style.
POF: Simplex, Simplex Latching, Duplex, or Duplex Latching.

HCS: Simplex only (non-latching).

Step 3
Select Simplex or Duplex cable.

Step 4
Determine the cable length.
To determine the appropriate part number, select the letter corresponding to your selection and fill in the appropriate information, as in the chart below.

For Example:
HFBR-RUD500 is a Standard Attenuation, Unconnectored, Duplex, 500 meter cable.

HFBR-ELS001 is an Extra Low Loss Attenuation, Latching Simplex Connectored, Simplex, 1 meter cable.

HFBR-RMD010 is a Standard Attenuation, Standard Duplex Connectored, Duplex, 10 meter cable.

HFBR-RND100 is a Standard Attenuation, Standard Simplex Connectored, Duplex, 100 meter cable.

Cable Length Tolerances:
The plastic cable length tolerances are: +10%/-0%.

Note: 0.1 meter Standard Attenuation Simplex lengths are available: 0.5 meter Standard Attenuation Simplex and Duplex lengths are also available. The lengths are ordered as HFBR-xxx1DM or HFBR-xxx5DM. Cables of 1 to 10 meter lengths in 1 decimeter increments are also available. This cable is ordered as HFBR-xxxyyD where "yy" is the length of the cable. For example, a 1.5 meter Standard Attenuation, Standard Simplex Connectored, Simplex cable would be ordered as HFBR-RNS15D.

NOTE: By convention, pre-connectored simplex POF cables have gray and blue colored connectors on the opposite ends of the same fiber; although oppositely colored, the connectors are mechanically identical. For duplex POF cables with simplex connectors, the same rule applies to each fiber and adjacent terminations use complimentary colored connectors. For duplex POF cables with duplex connectors similar rules apply using color coded markings on the duplex fiber cable. Pre-connectored simplex HCS cables have identically colored BLACK connectors on both ends of the fiber.

HFBR- □□□□□□

Cable Code
R = Standard Attenuation POF
E = Extra Low Loss POF
H = Riser Rated HCS
V = Plenum Rated HCS

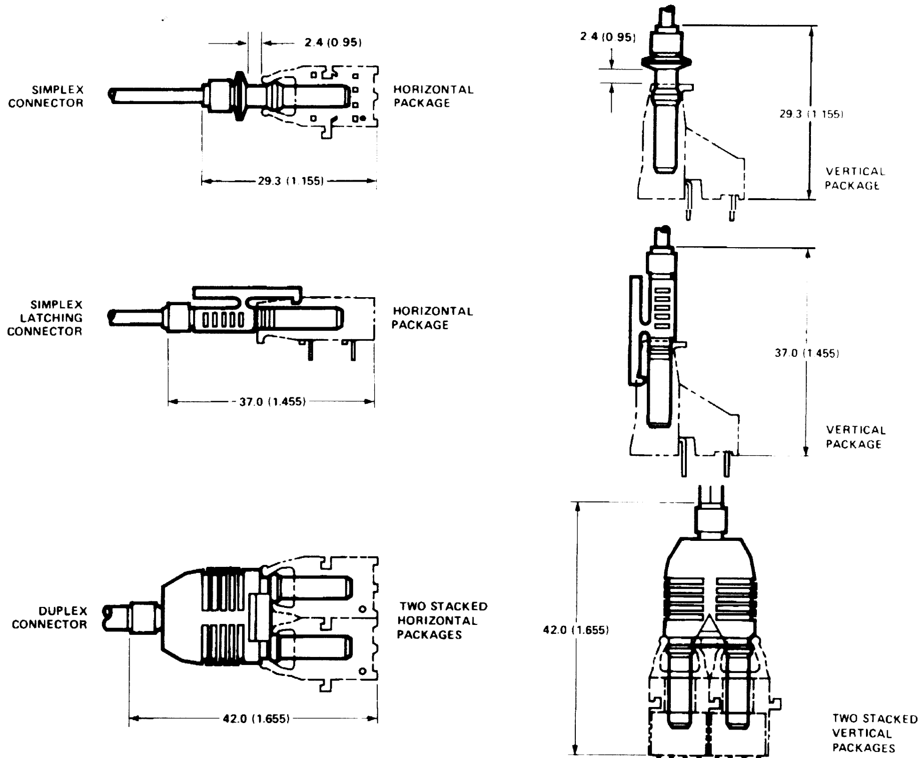
Connector Code
U = Unconnectored
N = Standard Simplex Connectors
L = Latching Simplex Connectors
M = Standard Duplex Connectors
T = Latching Duplex Connectors

Channel Code
S = Simplex Cable
D = Duplex Zipcord Cable

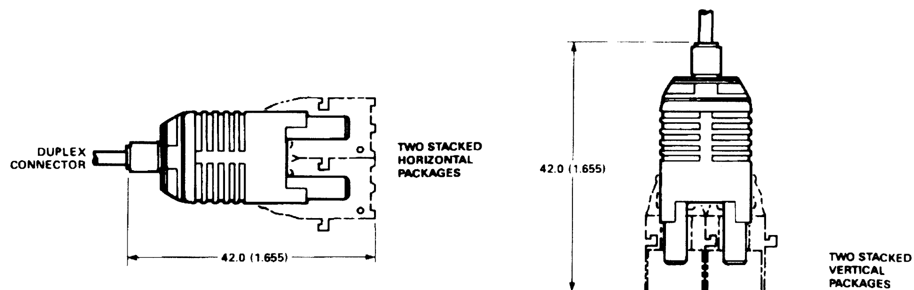
Length Code (measured from tip of connector to tip of connector)
1-500 meters in 1 meter increments
e.g. 015 = 15 meters
1-10 meters in 1 decimeter increments
e.g. 15D = 1.5 meters

Connector Applications

Attachment to Hewlett-Packard Versatile Link Fiber Optic Components

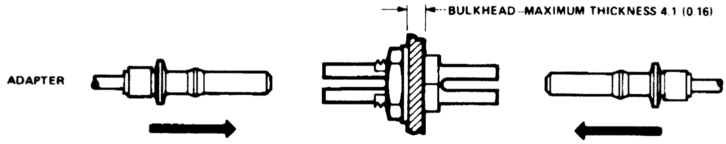


DIMENSIONS IN MILLIMETRES (INCHES)



DIMENSIONS IN MILLIMETRES (INCHES)

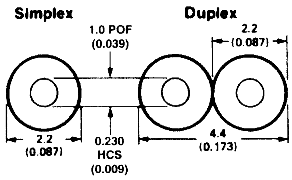
Bulkhead Feedthrough or Panel Mounting for HFBR-4501/4511/4501B Simplex Connectors



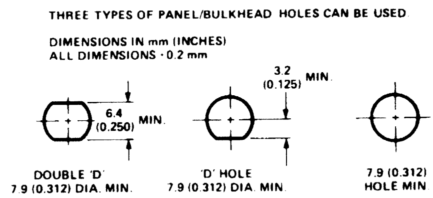
Versatile Link Mechanical Dimensions

All dimensions in mm (inches).
All dimensions ± 0.25 mm unless otherwise specified.

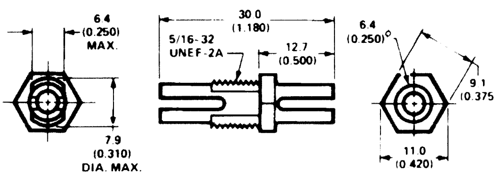
Fiber Optic Cable Dimensions



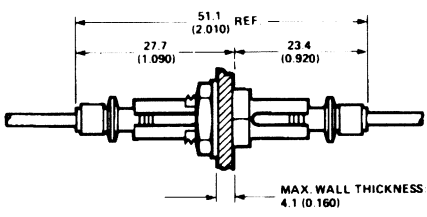
Panel Mounting – Bulkhead Feedthrough



HFBR-4505 (Gray)/4515 (Blue)/4505B (Black) Adapters

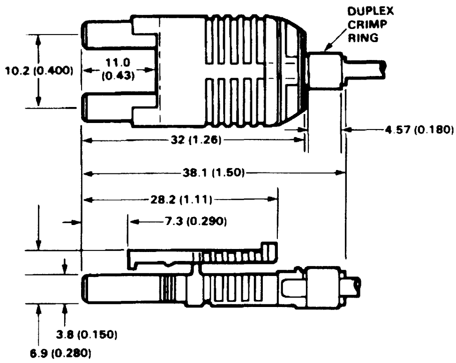


Bulkhead Feedthrough with Two HFBR-4501/ 4511/4501B Connectors

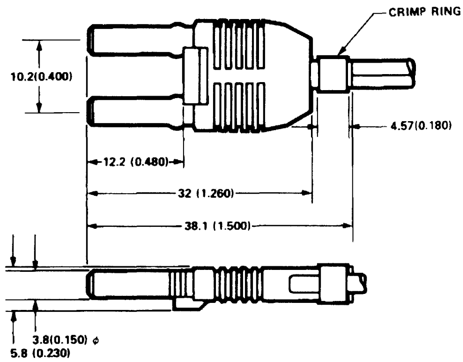


Versatile Link Mechanical Dimensions, continued

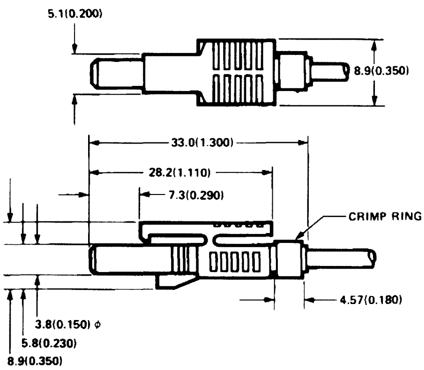
HFBR-4516 (Parchment)/4516B (Black) Duplex Latching Connector



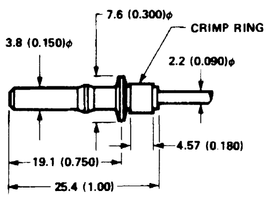
HFBR-4506 (Parchment)/4506B (Black) Duplex Connector



HFBR-4503 (Gray)/4513 (Blue/4503 (Black) Simplex Latching Connector



HFBR-4501 (Gray)/4511 (Blue)/4501 (Black) Simplex Connector



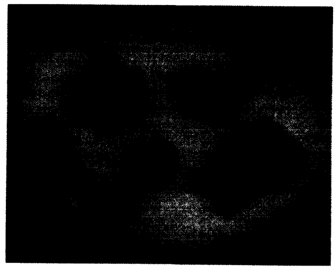
CONNECTORS DIFFER ONLY IN COLOR

HEWLETT® PACKARD

Crimpless Connectors for Plastic Optical Fiber and Versatile Link

Technical Data

HFBR-4531
HFBR-4532



Features

- **Requires No Crimp Ring or Crimping Tool**
- **Durable ULTEM® Plastic Material (UL File #E121562)**
- **Same Low Cost as HFBR-4501/4503 Series Connectors**
- **Excellent Retention Force**
- **Symmetry in Nonlatching Connector Gives Simplex/Duplex Functionality with the Same Part**

Applications

These connectors can be used for any application in which plastic optical fiber is used including:

- **Industrial Control and Voltage Isolation**
- **Automotive Networks**
- **Proprietary System Interconnects**
- **Gaming Equipment**
- **Medical Equipment**
- **Telecommunications**
- **Datacommunications**

Description

The HFBR-453X series connectors are an enhanced version of the HFBR-4501 and HFBR-4503 low-cost connectors for plastic optical fiber, which are compatible with HP's versatile link series transmitters and receivers. The innovative design uses a simple, snap-together concept which eliminates the need for crimping. This connector not only saves the user labor and tool cost, but reduces the yield loss due to installation error.

The HFBR-453X series connectors are available in two styles: latching and non-latching. For a duplex connector, two nonlatching simplex connectors can be snapped together. The connectors are made of a rugged, flame retardant plastic which is good for industrial and other harsh environments. The HFBR-453X series connectors are for use with Plastic Optical Fiber only.

ULTEM® is a registered trademark of the General Electric Corporation.

5965-1659E

Termination Guide

Step-by-Step Plastic Cable Connectoring Instructions

The following step-by-step guide describes how to terminate plastic fiber optic cable. It is ideal for both field and factory installations. Connectors can be easily installed on cable ends with standard tools such as wire strippers and cutters.

Finishing the cable is accomplished with the Hewlett-Packard HFBR-4593 Polishing Kit, consisting of a polishing fixture, 600 grid abrasive paper and 3 µm pink lapping film (3M Company, OC3-14). The connector can be used immediately after polishing.

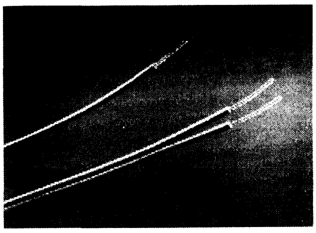
The following materials are needed for plastic fiber termination:

1. Plastic optical fiber cable (Example: HFBR-RUD500)
2. Wire cutters or scissors
3. 16 gauge wire stripper (Example: Ideal Stripmaster type 45-092)
4. HFBR-4593 polishing kit (optional)
5. Crimpless connectors

Step 1: Stripping the Fiber

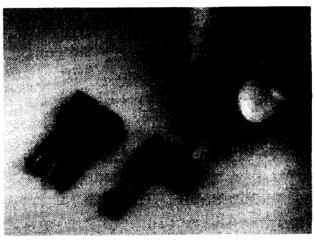
The zip cord structure of the duplex cable permits easy separation of the channels. The channels should be separated a minimum of 100 mm (4 in) to a maximum of 150 mm (6 in) back from the ends to permit connectoring, polishing and cable end flexibility.

After cutting the cable to the desired length, strip off approximately 7 mm (0.3 in) of the outer jacket with the 16 gauge wire strippers.



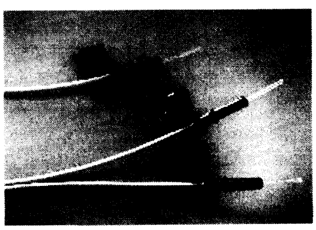
When using the duplex connector arrangement, the separated duplex cable should be stripped to roughly equal lengths on each cable end.

For the non-latching version (HFBR-4531), the same connector is used for simplex and duplex arrangement. No crimping is necessary. The top half of the connector will snap into the ferrule half to secure the fiber.



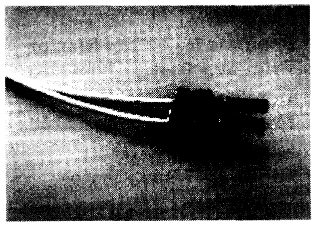
Step 2: Putting on the Connector

Place the connector on each end of the fiber, and slide the connector down until the fiber jacket stops it. The fiber should protrude *no less* than 1.5 mm (0.06 in) from the end of the connector.



To install *simplex* connectors flip the top half of the connector over and snap it into the ferrule half (with your fingers). When the top half latches inside the body of the ferrule half, proper connector-to-cable attachment is achieved.

For *duplex* connector installation place one connector on top of the other, so that the top half of each connector is over the ferrule half of the opposite connector.

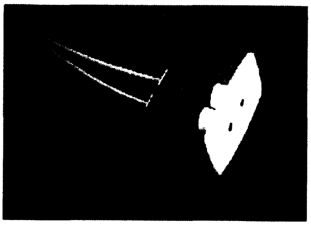


Manually press connectors together in the center of the arrangement. Then latch by pressing on the sides of each connector. As with the simplex version, connectors are secured when top halves latch into the ferrule halves.

Step 3: Trimming and Polishing

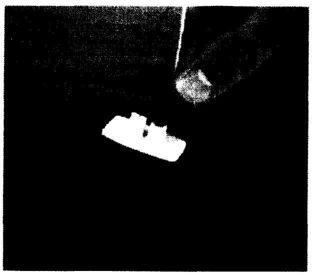
Any fiber in excess of 1.5 mm (0.06 in) protruding from the connector end should be cut off with wire cutters or scissors.

Insert the connector fully into the polishing fixture with the trimmed fiber protruding from the bottom of the fixture. This plastic polishing fixture can be used to polish two simplex connectors simultaneously or one duplex connector.



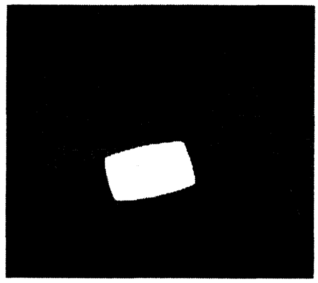
Note: *The four dots on the bottom of the polishing fixture are wear indicators. Replace the polishing fixture when any dot is no longer visible.*

Press the polishing tool down on the 600 grit abrasive paper. Polish the fiber using a figure eight pattern until the connector is flush with the bottom of the polishing fixture. Wipe the connector and fixture with a clean cloth or tissue.



Step 4: Finishing

Place the flush connector and polishing fixture on the dull side of the 3 µm pink lapping film and continue to polish the fiber in the same figure eight pattern for approximately 25 strokes. The fiber end should be flat, smooth and clean.



HFBR-4593 Polishing Kit

Note: *Use of the pink lapping film fine polishing step results in approximately 2 dB improvement in coupling performance of either a transmitter-receiver link or a bulkhead/splice over a 600 grit polish alone. This fine polish is comparable to the Hewlett-Packard factory polish. The fine polishing step may be omitted for short link lengths.*

HFBR-4531/4532
Absolute Maximum Ratings

Parameter	Symbol	Min.	Max.	Unit	Note
Storage Temperature	T_S	-40	85	°C	1
Operating Temperature	T_O	-40	85	°C	1
Installation Temperature	T_I	0	70	°C	1

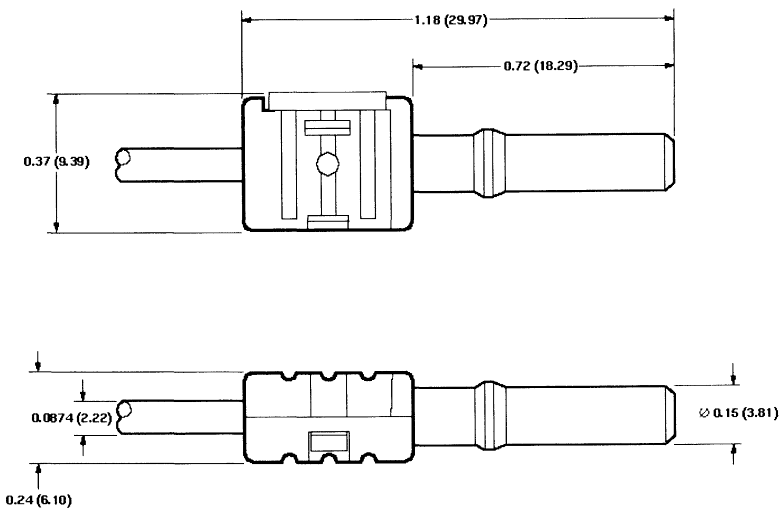
Connector Mechanical Characteristics

Parameter	Part Number	Symbol	Min.	Typ.	Units	Temp (°C)
Retention Force to HFBR-0501 Series	HFBR-4531	F_{R-C}	3	8	N	+25
	HFBR-4532		47	80		
Retention Force to HFBR-0508 Series	HFBR-4531		8	12		
Tensile Force, Connector to Cable	HFBR-4531	F_T	40	50		-40 to +85
	HFBR-4532					

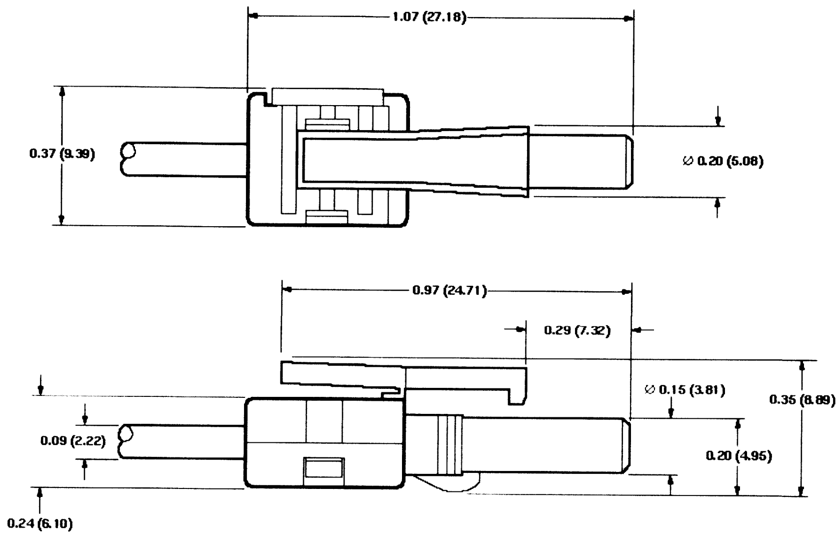
Notes:
1. Storage and operating temperatures refer to the ranges over which the connectors can be used when not subjected to mechanical stress. Installation temperature refers to the ranges over which connectors may be installed onto the fiber and over which connectors can be connected and disconnected from the transmitter and receiver modules.

Mechanical Dimensions
All dimensions are in inches and (millimeters)

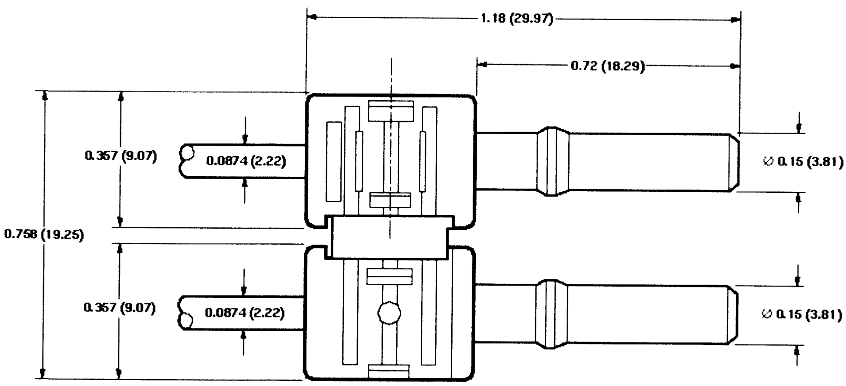
HFBR-4531 (Nonlatching):



HFBR-4532 (Latching):



HFBR-4531 in Duplex Configuration



HEWLETT PACKARD

Low Cost, Miniature Fiber Optic Components with ST®, SMA, SC and FC Ports

Technical Data

HFBR-0400 Series

Features

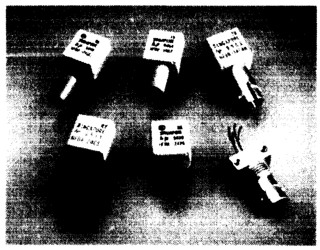
- Meets IEEE 802.3 Ethernet and 802.5 Token Ring Standards
- Low Cost Transmitters and Receivers
- Choice of ST®, SMA, SC or FC Ports
- 820 nm Wavelength Technology
- Signal Rates up to 175 Megabaud
- Link Distances up to 4 km
- Specified with 50/125 μm, 62.5/125 μm, 100/140 μm, and 200 μm HCS® Fiber
- Repeatable ST Connections within 0.2 dB Typical
- Unique Optical Port Design for Efficient Coupling
- Auto-Insertable and Wave Solderable
- No Board Mounting Hardware Required
- Wide Operating Temperature Range -40°C to 85°C
- AlGaAs Emitters 100% Burn-In Ensures High Reliability
- Conductive Port Option with the SMA and ST Threaded Port Styles

Applications

- Local Area Networks
- Computer to Peripheral Links
- Computer Monitor Links
- Digital Cross Connect Links
- Central Office Switch/PBX Links
- Video Links
- Modems and Multiplexers
- Suitable for Tempest Systems
- Industrial Control Links

Description

The HFBR-0400 Series of components is designed to provide cost effective, high performance fiber optic communication links for information systems and industrial applications with link distances of up to 4 kilometers. With the HFBR-24X6, the 125 MHz analog receiver, data rates of up to 175 megabaud are attainable.



Transmitters and receivers are directly compatible with popular "industry-standard" connectors: ST, SMA, SC and FC. They are completely specified with multiple fiber sizes; including 50/125 μm, 62.5/125 μm, 100/140 μm, and 200 μm.

Complete evaluation kits are available for ST and SMA product offerings; including transmitter, receiver, connectored cable, and technical literature. In addition, ST and SMA connectored cables are available for evaluation.

ST® is a registered trademark of AT&T.
HCS® is a registered trademark of the SpecTran Corporation.

HFBR-0400 Series Part Number Guide

HFBR X4XXaa

1 = Transmitter
2 = Receiver

4 = 820 nm Transmitter and
Receiver Products

0 = SMA, Housed
1 = ST, Housed
2 = FC, Housed
E = SC, Housed
3 = SMA Port, 90 deg. Bent Leads
4 = ST Port, 90 deg. Bent Leads
5 = SMA Port, Straight Leads
6 = ST Port, Straight Leads

2 = Tx, Standard Power
4 = Tx, High Power
2 = Rx, 5 MBd, TTL Output
6 = Rx, 125 MHz, Analog Output

Option T (Threaded Port Option)
Option C (Conductive Port Receiver Option)
Option M (Metal Port Option)
Option K (Kinked Lead Option)
TA = Square pinout/straight lead
TB = Square pinout/bent leads
HA = Diamond pinout/straight leads
HB = Diamond pinout/bent leads

LINK SELECTION GUIDE

Data Rate (MBd)	Distance (m)	Transmitter	Receiver	Fiber Size (μm)	Evaluation Kit
5	1500	HFBR-14X2	HFBR-24X2	200 HCS	N/A
5	2000	HFBR-14X4	HFBR-24X2	62.5/125	HFBR-04X0
20	2700	HFBR-14X4	HFBR-24X6	62.5/125	HFBR-0414, HFBR-0463
32	2200	HFBR-14X4	HFBR-24X6	62.5/125	HFBR-0414
55	1400	HFBR-14X4	HFBR-24X6	62.5/125	HFBR-0414
125	700	HFBR-14X4	HFBR-24X6	62.5/125	HFBR-0416
155	600	HFBR-14X4	HFBR-24X6	62.5/125	HFBR-0416
175	500	HFBR-14X4	HFBR-24X6	62.5/125	HFBR-0416

For additional information on specific links see the following individual link descriptions. Distances measured over temperature range from 0 to 70°C.

Applications Support Guide

This section gives the designer information necessary to use the HFBR-0400 series components to make a functional fiber-optic transceiver. HP offers a wide selection of evaluation kits for hands-on experience with fiber-optic products as well as a wide range of application notes complete with circuit diagrams and board layouts. Furthermore, HP's application support group is always ready to assist with any design consideration.

Application Literature

Title	Description
HFBR-0400 Series Reliability Data	Transmitter & Receiver Reliability Data
Application Bulletin 73	Low Cost Fiber Optic Transmitter & Receiver Interface Circuits
Application Bulletin 78	Low Cost Fiber Optic Links for Digital Applications up to 155 MBd
Application Note 1038	Complete Fiber Solutions for IEEE 802.3 FOIRL, 10Base-FB and 10 Base-FL
Application Note 1065	Complete Solutions for IEEE 802.5J Fiber-Optic Token Ring
Application Note 1073	HFBR-0319 Test Fixture for 1X9 Fiber Optic Transceivers
Application Note 1086	Optical Fiber Interconnections in Telecommunication Products

HFBR-0400 Series Evaluation Kits

HFBR-0410 ST Evaluation Kit

Contains the following :

- One HFBR-1412 transmitter
- One HFBR-2412 five megabaud TTL receiver
- Three meters of ST connectored 62.5/125 (µm fiber optic cable with low cost plastic ferrules.
- Related literature

HFBR-0414 ST Evaluation Kit

Includes additional components to interface to the transmitter and receiver as well as the PCB to reduce design time.

Contains the following:

- One HFBR-1414T transmitter
- One HFBR-2416T receiver
- Three meters of ST connectored 62.5/125 µm fiber optic cable
- Printed circuit board
- ML-4622 CP Data Quantizer
- 74ACTllOOON LED Driver
- LT1016CN8 Comparator
- 4.7 µH Inductor
- Related literature

HFBR-0400 SMA Evaluation Kit

Contains the following :

- One HFBR-1402 transmitter
- One HFBR-2402 five megabaud TTL receiver
- Two meters of SMA connectored 1000 µm plastic optical fiber
- Related literature

HFBR-0416 Evaluation Kit

Contains the following:

- One fully assembled 1x9 transceiver board for 155 MBd evaluation including:
  -HFBR-1414 transmitter
  -HFBR-2416 receiver
  -circuitry
- Related literature

HFBR-0463 Ethernet MAU Evaluation Kit

Contains the following:

- One fully assembled Media Attachment Unit (MAU) board which includes:
  -HFBR-1414 transmitter
  -HFBR-2416 receiver
  -HFBR-4663 IC
- Related literature

Note: Cable not included. Order HFBR-BXS010 seperately (2 pieces)

Package and Handling Information

Package Information

All HFBR-0400 Series transmitters and receivers are housed in a low-cost, dual-inline package that is made of high strength, heat resistant, chemically resistant, and UL 94V-O flame retardant ULTEM® (plastic (UL File #E121562). The transmitters are easily identified by the light grey color connector port. The receivers are easily identified by the dark grey color connector port. (Black color for conductive port.) The package is designed for auto-insertion and wave soldering so it is ideal for high volume production applications.

Handling and Design Information

Each part comes with a protective port cap or plug covering the optics. These caps/plugs will vary by port style. When soldering, it is advisable to leave the protective cap on the unit to keep the optics clean. Good system performance requires clean port optics and cable ferrules to avoid obstructing the optical path. Clean compressed air often is sufficient to remove particles of dirt; methanol on a cotton swab also works well.

Recommended Chemicals for Cleaning/Degreasing HFBR-0400 Products

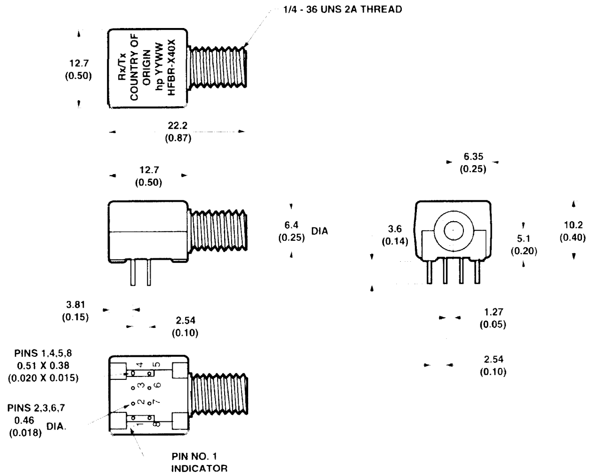
Alcohols: methyl, isopropyl, isobutyl. Aliphatics: hexane, heptane, Other: soap solution, naphtha.

Do not use partially halogenated hydrocarbons such as 1,1.1 trichloroethane, ketones such as MEK, acetone, chloroform, ethyl acetate, methylene dichloride, phenol, methylene chloride, or N-methylpyrolldone. Also, HP does not recommend the use of cleaners that use halogenated hydrocarbons because of their potential environmental harm.

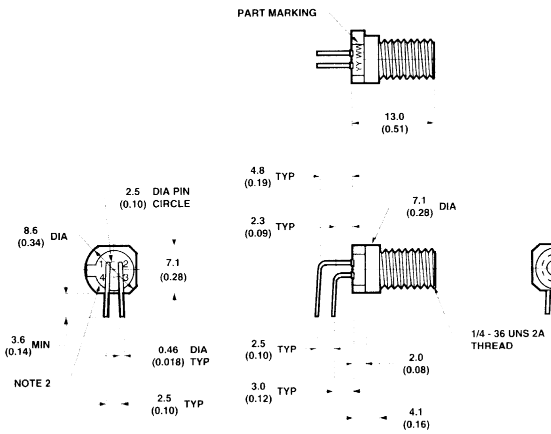
Ultem® is a registered Trademark of the GE corporation.

Mechanical Dimensions HFBR-0400 SMA Series

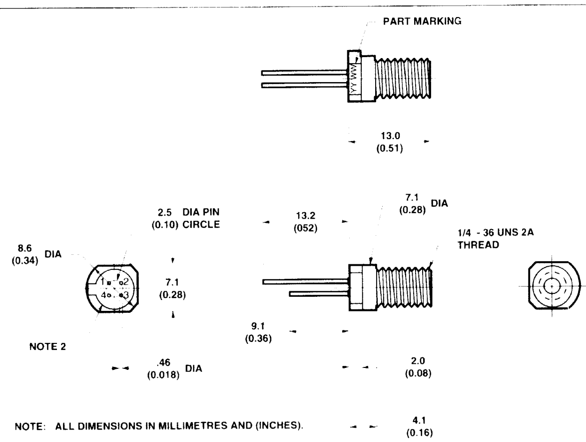
HFBR-X40X



HFBR-X43X



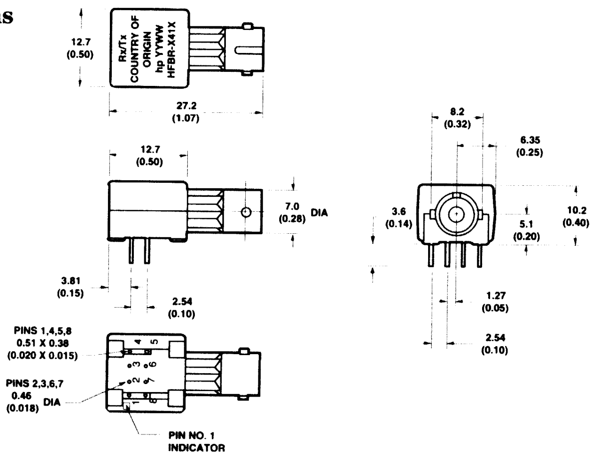
HFBR-X45X



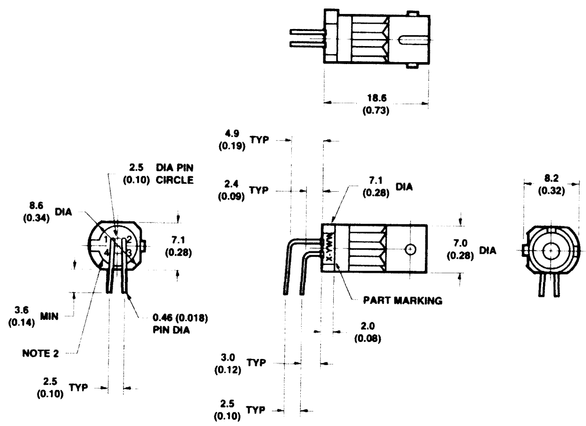
NOTE: ALL DIMENSIONS IN MILLIMETRES AND (INCHES).

Mechanical Dimensions
HFBR-0400 ST Series

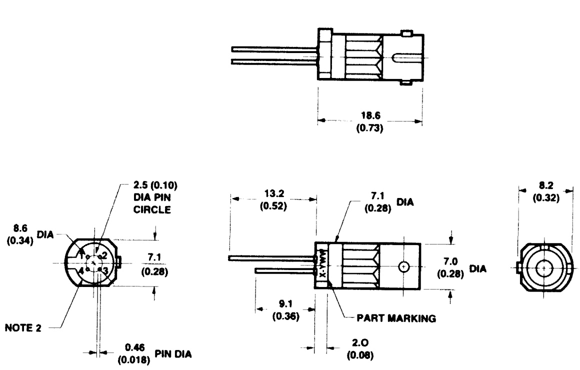
HFBR-X41X



HFBR-X44X



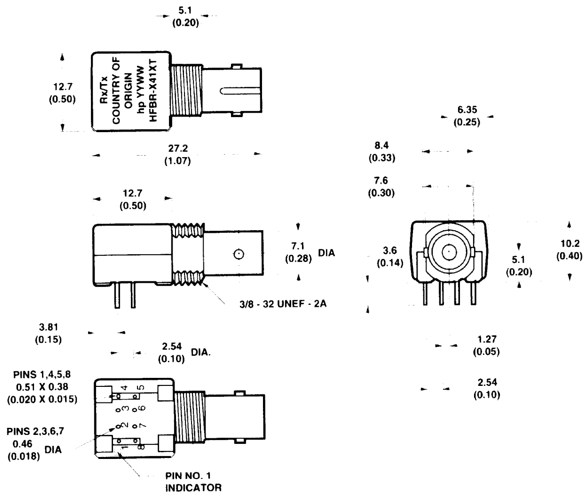
HFBR-X46X



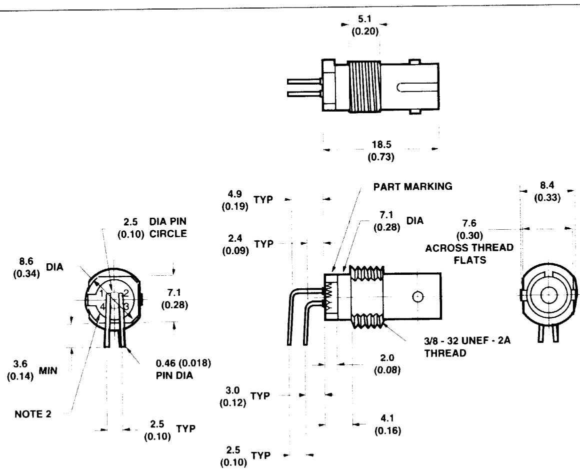
NOTE: ALL DIMENSIONS IN MILLIMETRES AND (INCHES).

Mechanical Dimensions HFBR-0400T Threaded ST Series

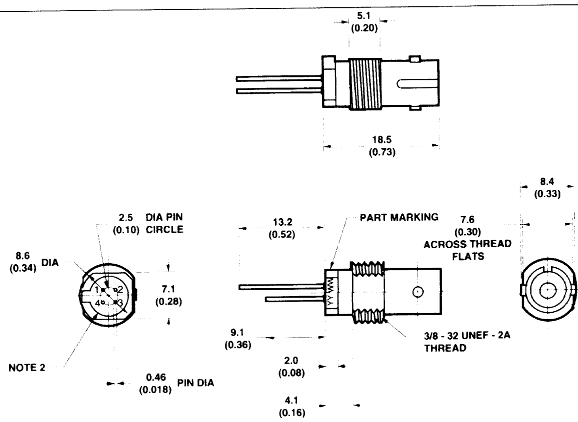
HFBR-X41XT



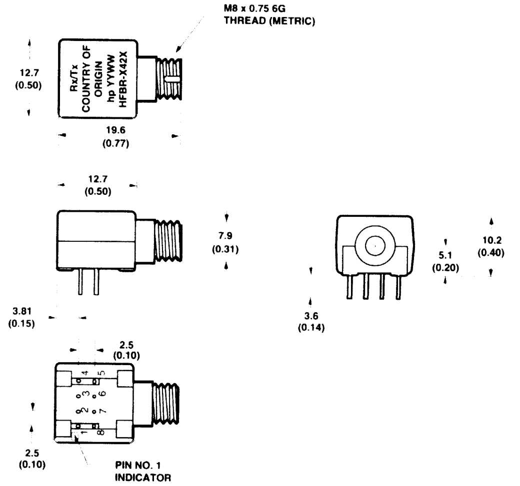
HFBR-X44XT



HFBR-X46XT

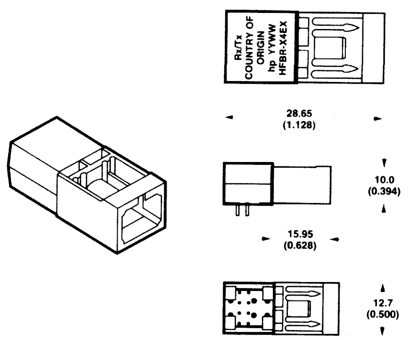


Mechanical Dimensions
HFBR-0400 FC Series



Mechanical Dimensions
HFBR-0400 SC Series

HFBR-X4EX



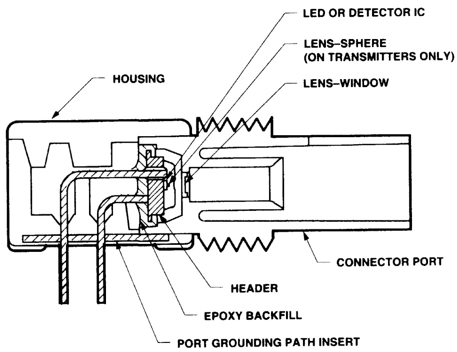
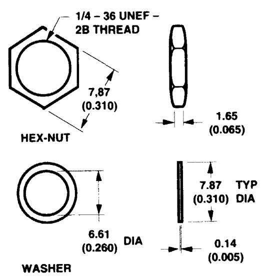


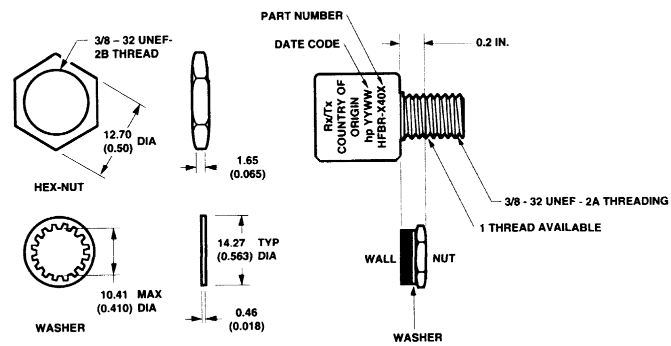
Figure 1. HFBR-0400 ST Series Cross-Sectional View.

Panel Mount Hardware

HFBR-4401: for SMA Ports



HFBR-4411: for ST Ports



(Each HFBR-4401 and HFBR-4411 kit consists of 100 nuts and 100 washers.)

Port Cap Hardware

HFBR-4402: 500 SMA Port Caps
HFBR-4120: 500 ST Port Plugs (120 psi)
HFBR-4412: 500 FC Port Caps
HFBR-4417: 500 SC Port Plugs

Options

In addition to the various port styles available for the HFBR-0400 series products, there are also several extra options that can be ordered. To order an option, simply place the corresponding option number at the end of the part number. For instance, a metal-port option SMA receiver would be HFBR-2406M. You can add any number of options in series at the end of a part number. Please contact your local sales office for further information or browse HP's fiber optics home page at http://www.hp.com/go/fiber

Option T (Threaded Port Option)

- Allows ST style port components to be panel mounted.
- Compatible with all current makes of ST multimode connectors
- Mechanical dimensions are compliant with MIL-STD-83522/13
- Maximum wall thickness when using nuts and washers from the HFBR-4411 hardware kit is 2.8 mm (0.11 inch)
- Available on all ST ports

Option C (Conductive Port Receiver Option)

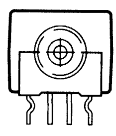
- Designed to withstand electrostatic discharge (ESD) of 25kV to the port
- Significantly reduces effect of electromagnetic interference (EMI) on receiver sensitivity
- Allows designer to separate the signal and conductive port grounds
- Recommended for use in noisy environments
- Available on SMA and threaded ST port style receivers only

Option M (Metal Port Option)

- Nickel plated aluminum connector receptacle
- Designed to withstand electrostatic discharge (ESD) of 15kV to the port
- Significantly reduces effect of electromagnetic interference (EMI) on receiver sensitivity
- Allows designer to separate the signal and metal port grounds
- Recommended for use in very noisy environments
- Available on SMA, FC, ST, and threaded ST ports

Option K (Kinked Lead Option)

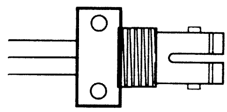
- Grounded outside 4 leads are "kinked"
- Allows components to stay anchored in the PCB during wave solder and aqueous wash processes



Options TA, TB, HA, HB (Active Device Mount Options)

(These options are unrelated to the threaded port option T.)

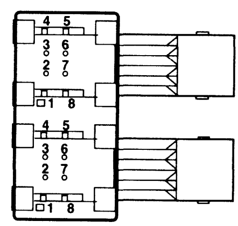
- All metal, panel mountable package with a 3 or 4 pin receptacle end
- Available for HFBR-14X4, 24X2 and 24X6 components
- Choose from diamond or square pinout, straight or bent leads ADM Picture



- TA = Square pinout/straight leads
  TB = Square pinout/bent leads
  HA = Diamond pinout/straight leads
  HB = Diamond pinout/bent leads

Duplex Option

In addition to the standard options, some HFBR-0400 series products come in a duplex configuration with the transmitter on the left and the receiver on the right. This option was designed for ergonomic and efficient manufacturing. The following part numbers are available in the duplex option:
HFBR-5414 (Duplex ST)
HFBR-5414T (Duplex Threaded ST)
HFBR-54E4 (Duplex SC)



Typical Link Data

HFBR-0400 Series

Description

The following technical data is taken from 4 popular links using the HFBR-0400 series: the 5 MBd link, Ethernet 20 MBd link, Token Ring 32 MBd link, and the 155 MBd link. The data given corresponds to transceiver solutions combining the HFBR-0400 series components and various recommended transceiver design circuits using off-the-shelf electrical components. This data is meant to be regarded as an example of typical link performance for a given design and does not call out any link limitations. Please refer to the appropriate application note given for each link to obtain more information.

5 MBd Link (HFBR-14XX/24X2)

Link Performance -40°C to +85°C unless otherwise specified

Parameter	Symbol	Min.	Typ.	Max.	Units	Conditions	Reference
Optical Power Budget with 50/125 μm fiber	OPB_{50}	4.2	9.6		dB	HFBR-14X4/24X2 NA = 0.2	Note 1
Optical Power Budget with 62.5/125 μm fiber	$OPB_{62.5}$	8.0	15		dB	HFBR-14X4/24X2 NA = 0.27	Note 1
Optical Power Budget with 100/140 μm fiber	OPB_{100}	8.0	15		dB	HFBR-14X2/24X2 NA = 0.30	Note 1
Optical Power Budget with 200 μm fiber	OPB_{200}	12	20		dB	HFBR-14X2/24X2 NA = 0.37	Note 1
Date Rate Synchronous		dc		5	MBd		Note 2
Asynchronous		dc		2.5	MBd		Note 3, Fig. 7
Propagation Delay LOW to HIGH	t_{PLH}		72		ns	T_A = 25°C, P_R = -21 dBm Peak	Figs. 6, 7, 8
Propagation Delay HIGH to LOW	t_{PHL}		46		ns		
System Pulse Width Distortion	t_{PLH}-t_{PHL}		26		ns	Fiber cable length = 1 m	
Bit Error Rate	BER			10^{-9}		Data Rate <5 Bd P_R > -24 dBm Peak	

Notes:
1. OPB at T_A = -40 to 85°C, V_{CC} = 5.0 V dc, $I_{F\,ON}$ = 60 mA. P_R = -24 dBm peak.
2. Synchronous data rate limit is based on these assumptions: a) 50% duty factor modulation, e.g., Manchester I or BiPhase Manchester II; b) continuous data; c) PLL Phase Lock Loop demodulation; d) TTL threshold.
3. Asynchronous data rate limit is based on these assumptions: a) NRZ data; b) arbitrary timing-no duty factor restriction; c) TTL threshold.

5 MBd Logic Link Design

If resistor R_1 in Figure 2 is 70.4 Ω, a forward current I_F of 48 mA is applied to the HFBR-14X4 LED transmitter. With I_F = 48 mA the HFBR-14X4/24X2 logic link is guaranteed to work with 62.5/125 µm fiber optic cable over the entire range of 0 to 1750 meters at a data rate of dc to 5 MBd, with arbitrary data format and pulse width distortion typically less than 25%. By setting R_1 = 115 Ω, the transmitter can be driven with I_F = 30 mA, if it is desired to economize on power or achieve lower pulse distortion.

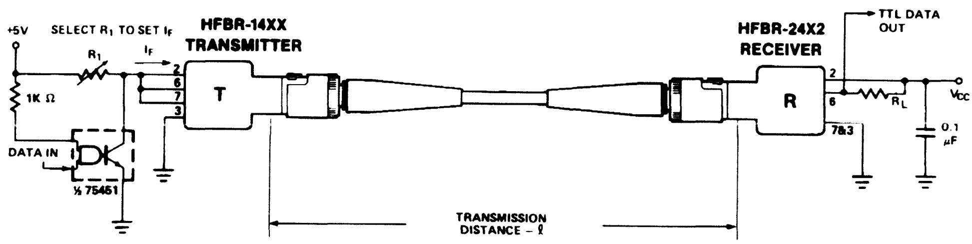
The following example will illustrate the technique for selecting the appropriate value of I_F and R_1.

Maximum distance required = 400 meters. From Figure 3 the drive current should be 15 mA. From the transmitter data V_F = 1.5 V (max.) at I_F = 15 mA as shown in Figure 9.

$$R_1 = \frac{V_{CC} - V_F}{I_F} = \frac{5\text{ V} - 1.5\text{ V}}{15\text{ mA}}$$

$$R_1 = 233\ \Omega$$

The curves in Figures 3, 4, and 5 are constructed assuming no in-line splice or any additional system loss. Should the link consists of any in-line splices, these curves can still be used to calculate link limits provided they are shifted by the additional system loss expressed in dB. For example, Figure 3 indicates that with 48 mA of transmitter drive current, a 1.75 km link distance is achievable with 62.5/125 µm fiber which has a maximum attenuation of 4 dB/km. With 2 dB of additional system loss, a 1.25 km link distance is still achievable.



NOTE:
IT IS ESSENTIAL THAT A BYPASS CAPACITOR (0.01 µF TO 0.1 µF CERAMIC) BE CONNECTED FROM PIN 2 TO PIN 7 OF THE RECEIVER. TOTAL LEAD LENGTH BETWEEN BOTH ENDS OF THE CAPACITOR AND THE PINS SHOULD NOT EXCEED 20 mm.

Figure 2. Typical Circuit Configuration.

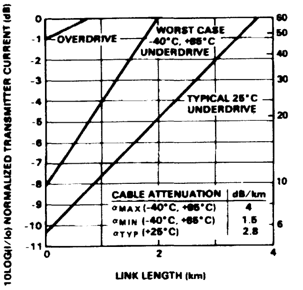


Figure 3. HFBR-1414/HFBR-2412 Link Design Limits with 62.5/125 μm Cable.

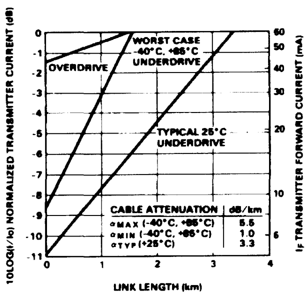


Figure 4. HFBR-14X2/HFBR-24X2 Link Design Limits with 100/140 μm Cable.

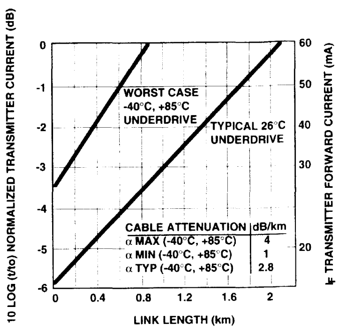


Figure 5. HFBR-14X4/HFBR-24X2 Link Design Limits with 50/125 μm Cable.

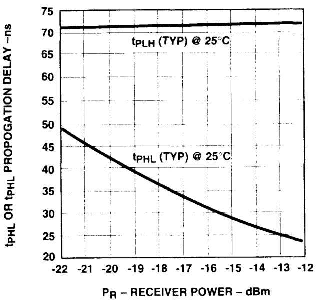


Figure 6. Propagation Delay through System with One Meter of Cable.

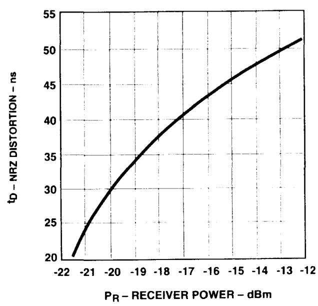


Figure 7. Typical Distortion of Pseudo Random Data at 5 Mb/s.

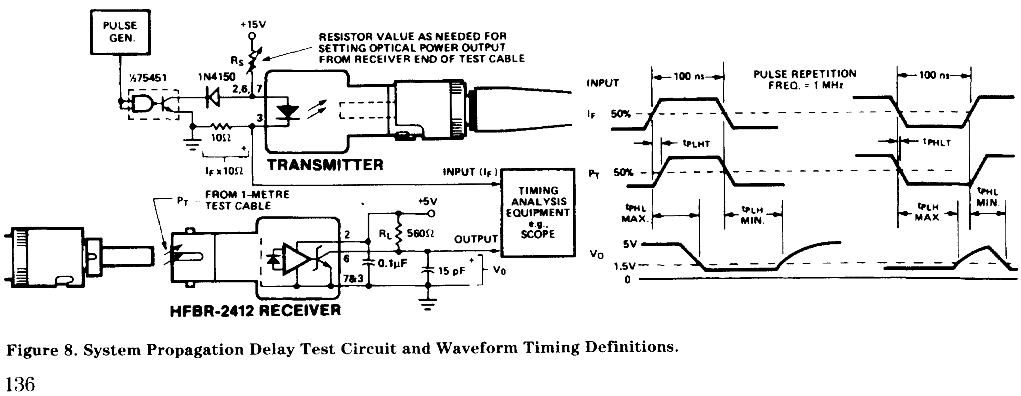


Figure 8. System Propagation Delay Test Circuit and Waveform Timing Definitions.

Ethernet 20 MBd Link (HFBR-14X4/24X6)

(refer to Application Note 1038 for details)

Typical Link Performance

Parameter	Symbol	Typ.[1,2]	Units	Conditions
Receiver Sensitivity		-34.4	dBm average	20 MBd D2D2 Hexadecimal Data 2 km 62.5/125 μm fiber
Link Jitter		7.56	ns pk-pk	ECL Out Receiver
		7.03	ns pk-pk	TTL Out Receiver
Transmitter Jitter		0.763	ns pk-pk	20 MBd D2D2 Hexadecimal Data
Optical Power	P_T	-15.2	dBm average	20 MBd D2D2 Hexadecimal Data Peak $I_{F,ON}$ = 60 mA
LED rise time	t_r	1.30	ns	1 MHz Square Wave Input
LED fall time	t_f	3.08	ns	
Mean difference	$\|t_r - t_f\|$	1.77	ns	
Bit Error Rate	BER	10^{-10}		
Output Eye Opening		36.7	ns	At AUI Receiver Output
Data Format 50% Duty Factor		20	MBd	

Notes:
1. Typical data at T_A = 25°C, V_{CC} = 5.0 V dc.
2. Typical performance of circuits shown in Figure 1 and Figure 3 of AN-1038 (see applications support section).

Token Ring 32 MBd Link (HFBR-14X4/24X6)

(refer to Application Note 1065 for details)

Typical Link Performance

Parameter	Symbol	Typ.[1,2]	Units	Conditions
Receiver Sensitivity		-34.1	dBm average	32 MBd D2D2 Hexadecimal Data 2 km 62.5/125 μm fiber
Link Jitter		6.91	ns pk-pk	ECL Out Receiver
		5.52	ns pk-pk	TTL Out Receiver
Transmitter Jitter		0.823	ns pk-pk	32 MBd D2D2 Hexadecimal Data
Optical Power Logic Level "0"	$P_{T\,ON}$	-12.2	dBm peak	Transmitter TTL in $I_{F\,ON}$ = 60 mA, $I_{F\,OFF}$ = 1 mA
Optical Power Logic Level "1"	$P_{T\,OFF}$	-82.2		
LED Rise Time	t_r	1.3	nsec	1 MHz Square Wave Input
LED Fall Time	t_f	3.08	nsec	
Mean Difference	$\|t_r - t_f\|$	1.77	nsec	
Bit Error Rate	BER	10^{-10}		
Data Format 50% Duty Factor		32	MBd	

Notes:
1. Typical data at T_A = 25°C, V_{CC} = 5.0 V dc.
2. Typical performance of circuits shown in Figure 1 and Figure 3 of AN-1065 (see applications support section)

155 MBd Link (HFBR-14X4/24X6)

(refer to Application Bulletin 78 for details)

Typical Link Performance

Parameter	Symbol	Typ.[1,2]	Units	Max.	Units	Conditions	Ref.
Optical Power Budget with 50/125 µm fiber	OPB_{50}	7.9	13.9		dB	NA = 0.2	Note 2
Optical Power Budget with 62.5/125 µm fiber	OPB_{62}	11.7	17.7		dB	NA = 0.27	
Optical Power Budget with 100/140 µm fiber	OPB_{100}	11.7	17.7		dB	NA = 0.30	
Optical Power Budget with 200 µm HCSfFiber	OPB_{200}	16.0	22.0		dB	NA = 0.35	
Data Format 20% to 80% Duty Factor		1		175	MBd		
System Pulse Width Distortion	$\lvert t_{PLH} - t_{PHL} \rvert$		1		ns	PR = -7 dBm Peak 1 meter 62.5/125 µm fiber	
Bit Error Rate	BER		10^{-9}			Data Rate < 100 MBaud PR >-31 dBm Peak	Note 2

Notes:

1. Typical data at T_A = 25°C, V_{CC} = 5.0 V dc, PECL serial interface.
2. Typical OPB was determined at a probability of error (BER) of 10^{-9}. Lower probabilities of error can be achieved with short fibers that have less optical loss.

HFBR-14X2/14X4 Low-Cost High-Speed Transmitters

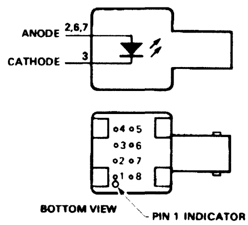
Description

The HFBR-14XX fiber optic transmitter contains an 820 nm AlGaAs emitter capable of efficiently launching optical power into four different optical fiber sizes: 50/125 μm, 62.5/125 μm, 100/140 μm, and 200 μm HCS®. This allows the designer flexibility in choosing the fiber size. The HFBR-14XX is designed to operate with the Hewlett-Packard HFBR-24XX fiber optic receivers.

The HFBR-14XX transmitter's high coupling efficiency allows the emitter to be driven at low current levels resulting in low power consumption and increased reliability of the transmitter. The HFBR-14X4 high power transmitter is optimized for small size fiber and typically can launch -15.8 dBm optical power at 60 mA into 50/125 μm fiber and -12 dBm into 62.5/125 μm fiber. The HFBR-14X2 standard transmitter typically can launch -12 dBm of optical power at 60 mA into 100/140 μm fiber cable. It is ideal for large size fiber such as 100/140 μm. The high launched optical power level is useful for systems where star couplers, taps, or inline connectors create large fixed losses.

Consistent coupling efficiency is assured by the double-lens optical system (Figure 1). Power coupled into any of the three fiber types varies less than 5 dB from part to part at a given drive current and temperature. Consistent coupling efficiency reduces receiver dynamic range requirements which allows for longer link lengths.

Housed Product

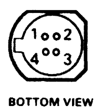


PIN	FUNCTION
1†	N.C.
2	ANODE
3*	CATHODE
4†	N.C.
5†	N.C.
6	ANODE
7*	ANODE
8†	N.C.

*PINS 2,6 AND 7 ARE ELECTRICALLY CONNECTED TO HEADER

†PINS 1, 4, 5, AND 8 ARE ELECTRICALLY CONNECTED

Unhoused Product



PIN	FUNCTION
1	ANODE
2	CATHODE
3	ANODE
4	ANODE

Absolute Maximum Ratings

Parameter		Symbol	Min.	Max.	Units	Reference
Storage Temperature		T_S	-55	+85	°C	
Operating Temperature		T_A	-40	+85	°C	
Lead Soldering Cycle	Temp.			+260	°C	
	Time			10	sec	
Forward Input Current	Peak	I_{FPK}		200	mA	Note 1
	dc	I_{Fdc}		100	mA	
Reverse Input Voltage		V_{BR}		1.8	V	

Electrical/Optical Specifications -40°C to +85°C unless otherwise specified.

Parameter	Symbol	Min.	Typ.[2]	Max.	Units	Conditions	Reference
Forward Voltage	V_F	1.48	1.70	2.09	V	I_F = 60 mA dc	Figure 9
			1.84			I_F = 100 mA dc	
Forward Voltage Temperature Coefficient	$\Delta V_F/\Delta T$		-0.22		mV/°C	I_F = 60 mA dc	Figure 9
			-0.18			I_F = 100 mA dc	
Reverse Input Voltage	V_{BR}	1.8	3.8		V	I_F = 100 µA dc	
Peak Emission Wavelength	λ_P	792	820	865	nm		
Diode Capacitance	C_T		55		pF	V = 0, f = 1 MHz	
Optical Power Temperature Coefficient	$\Delta P_T/\Delta T$		-0.006		dB/°C	I = 60 mA dc	
			-0.010			I = 100 mA dc	
Thermal Resistance	θ_{JA}		260		°C/W		Notes 3, 8
14X2 Numerical Aperture	NA		0.49				
14X4 Numerical Aperture	NA		0.31				
14X2 Optical Port Diameter	D		290		µm		Note 4
14X4 Optical Port Diameter	D		150		µm		Note 4

HFBR-14X2 Output Power Measured Out of 1 Meter of Cable

Parameter	Symbol	Min.	Typ.[2]	Max.	Unit	Conditions		Reference
50/125 µm Fiber Cable NA = 0.2	P_{T50}	-21.8	-18.8	-16.8	dBm peak	T_A = 25°C	I_F = 60 mA dc	Notes 5, 6, 9
		-22.8		-15.8				
		-20.3	-16.8	-14.4		T_A = 25°C	I_F = 100 mA dc	
		-21.9		-13.8				
62.5/125 µm Fiber Cable NA = 0.275	P_{T62}	-19.0	-16.0	-14.0	dBm peak	T_A = 25°C	I_F = 60 mA dc	
		-20.0		-13.0				
		-17.5	-14.0	-11.6		T_A = 25°C	I_F = 100 mA dc	
		-19.1		-11.0				
100/140 µm Fiber Cable NA = 0.3	P_{T100}	-15.0	-12.0	-10.0	dBm peak	T_A = 25°C	I_F = 60 mA dc	
		16.0		-9.0				
		-13.5	-10.0	-7.6		T_A = 25°C	I_F = 100 mA dc	
		-15.1		-7.0				
200 µm HCS Fiber Cable NA = 0.37	P_{T200}	-10.7	-7.1	-4.7	dBm peak	T_A = 25°C	I_F = 60 mA dc	
		-11.7		-3.7				
		-9.2	-5.2	-2.3		T_A = 25°C	I_F = 100 mA dc	
		-10.8		-1.7				

CAUTION: The small junction sizes inherent to the design of these components increase the components' susceptibility to damage from electrostatic discharge (ESD). It is advised that normal static precautions be taken in handling and assembly of these components to prevent damage and/or degradation which may be induced by ESD.

HFBR-14X4 Output Power Measured out of 1 Meter of Cable

Parameter	Symbol	Min.	Typ.[2]	Max.	Unit	Conditions		Reference
50/125 μm Fiber Cable NA = 0.2	PT50	-18.8	-15.8	-13.8	dBm peak	T_A = 25°C	I_F = 60 mA dc	Notes 5, 6, 9
		-19.8		-12.8				
		-17.3	-13.8	-11.4		T_A = 25°C	I_F = 100 mA dc	
		-18.9		-10.8				
62.5/125 μm Fiber Cable NA = 0.275	PT62	-15.0	-12.0	-10.0	dBm peak	T_A = 25°C	I_F = 60 mA dc	
		-16.0		-9.0				
		-13.5	-10.0	-7.6		T_A = 25°C	I_F = 100 mA dc	
		-15.1		-7.0				
100/140 μm Fiber Cable NA = 0.3	PT100	-9.5	-6.5	-4.5	dBm peak	T_A = 25°C	I_F = 60 mA dc	
		-10.5		-3.5				
		-8.0	-4.5	-2.1		T_A = 25°C	I_F = 100 mA dc	
		-9.6		-1.5				
200 μm HCS Fiber Cable NA = 0.37	PT200	-5.2	-3.7	+0.8	dBm peak	T_A = 25°C	I_F = 60 mA dc	
		-6.2		+1.8				
		-3.7	-1.7	+3.2		T_A = 25°C	I_F = 100 mA dc	
		-5.3		+3.8				

14X2/14X4 Dynamic Characteristics

Parameter	Symbol	Min.	Typ.[2]	Max.	Units	Conditions	Reference
Rise Time, Fall Time (10% to 90%)	t_r, t_f		4.0	6.5	nsec No Pre-bias	I_F = 60 mA Figure 12	Note 7,
Rise Time, Fall Time (10% to 90%)	t_r, t_f		3.0		nsec	I_F = 10 to 100 mA	Note 7, Figure 11
Pulse Width Distortion	PWD		0.5		nsec		Figure 11

Notes:
1. For I_{FPK} > 100 mA, the time duration should not exceed 2 ns.
2. Typical data at T_A = 25°C.
3. Thermal resistance is measured with the transmitter coupled to a connector assembly and mounted on a printed circuit board.
4. D is measured at the plane of the fiber face and defines a diameter where the optical power density is within 10 dB of the maximum.
5. P_T is measured with a large area detector at the end of 1 meter of mode stripped cable, with an ST® precision ceramic ferrule (MIL-STD-83522/13) for HFBR-1412/1414, and with an SMA 905 precision ceramic ferrule for HFBR-1402/1404.
6. When changing μW to dBm, the optical power is referenced to 1 mW (1000 μW). Optical Power P (dBm) = 10 log P (μW)/1000 μW.
7. Pre-bias is recommended if signal rate >10 MBd, see recommended drive circuit in Figure 11.
8. Pins 2, 6 and 7 are welded to the anode header connection to minimize the thermal resistance from junction to ambient. To further reduce the thermal resistance, the anode trace should be made as large as is consistent with good RF circuit design.
9. Fiber NA is measured at the end of 2 meters of mode stripped fiber, using the far-field pattern. NA is defined as the sine of the half angle,determined at 5% of the peak intensity point. When using other manufacturer's fiber cable, results will vary due to differing NA values and specification methods.

All HFBR-14XX LED transmitters are classified as IEC 825-1 Accessible Emission Limit (AEL) Class 1 based upon the current proposed draft scheduled to go in to effect on January 1, 1997. AEL Class 1 LED devices are considered eye safe. Contact your Hewlett-Packard sales representative for more information.

CAUTION: The small junction sizes inherent to the design of these components increase the components' susceptibility to damage from electrostatic discharge (ESD). It is advised that normal static precautions be taken in handling and assembly of these components to prevent damage and/or degradation which may be induced by ESD.

Recommended Drive Circuits

The circuit used to supply current to the LED transmitter can significantly influence the optical switching characteristics of the LED. The optical rise/fall times and propagation delays can be improved by using the appropriate circuit techniques. The LED drive circuit shown in Figure 11 uses frequency compensation to reduce the typical rise/fall times of the LED and a small pre-bias voltage to minimize propagation delay differences that cause pulse-width distortion. The circuit will typically produce rise/fall times of 3 ns, and a total jitter including pulse-width distortion of less than 1 ns. This circuit is recommended for applications requiring low edge jitter or high-speed data transmission at signal rates of up to 155 MBd. Component values for this circuit can be calculated for different LED drive currents using the equations shown below. For additional details about LED drive circuits, the reader is encouraged to read Hewlett-Packard Application Bulletin 78 and Application Note 1038.

$$R_y = \frac{(V_{CC} - V_F) + 3.97\,(V_{CC} - V_F - 1.6\text{ V})}{I_{F\,ON}\,(A)}$$

$$R_{X1} = \frac{1}{2}\left(\frac{R_y}{3.97}\right)$$

$$R_{EQ2}(\Omega) = R_{X1} - 1$$

$$R_{X2} = R_{X3} = R_{X4} = 3(R_{EQ2})$$

$$C(pF) = \frac{2000(ps)}{R_{X1}(\Omega)}$$

Example for $I_{F\,ON}$ = 100 mA: V_F can be obtained from Figure 9 (= 1.84 V).

$$R_y = \frac{(5 - 1.84) + 3.97\,(5 - 1.84 - 1.6)}{0.100}$$

$$R_y = \frac{3.16 + 6.19}{0.100} = 93.5\ \Omega$$

$$R_{X1} = \frac{1}{2}\left(\frac{93.5}{3.97}\right) = 11.8\ \Omega$$

$$R_{EQ2} = 11.8 - 1 = 10.8\ \Omega$$

$$R_{X2} = R_{X3} = R_{X4} = 3(10.8) = 32.4\ \Omega$$

$$C = \frac{2000\text{ ps}}{11.8\ \Omega} = 169\text{ pF}$$

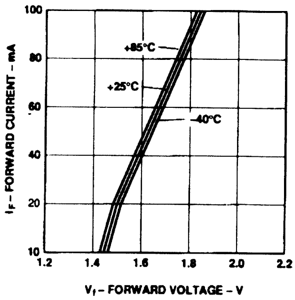


Figure 9. Forward Voltage and Current Characteristics.

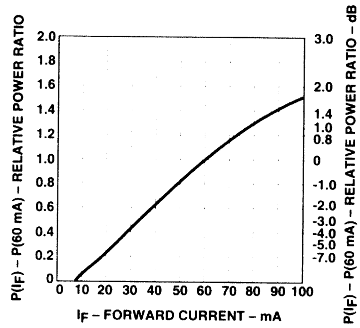


Figure 10. Normalized Transmitter Output vs. Forward Current.

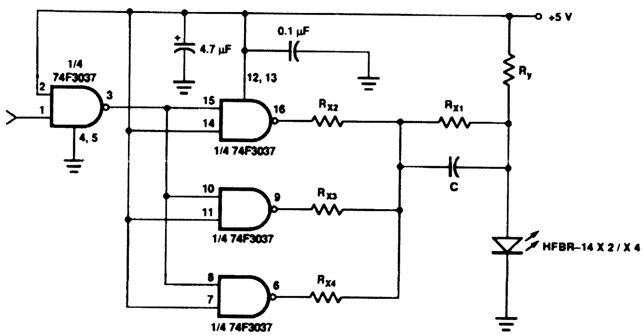


Figure 11. Recommended Drive Circuit.

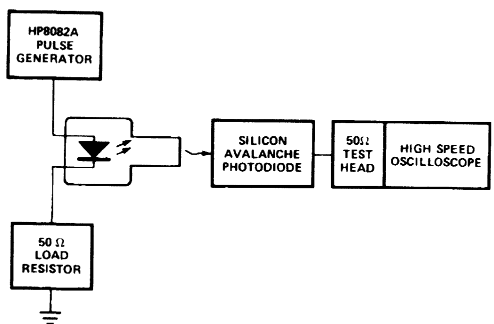


Figure 12. Test Circuit for Measuring t_r, t_f.

HFBR-24X2 Low-Cost 5 MBd Receiver

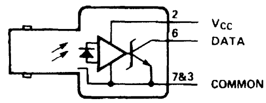
Description

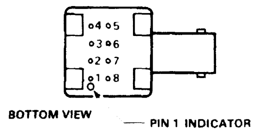
The HFBR-24X2 fiber optic receiver is designed to operate with the Hewlett-Packard HFBR-14XX fiber optic transmitter and 50/125 μm, 62.5/125 μm, 100/140 μm, and 200 μm HCS® fiber optic cable. Consistent coupling into the receiver is assured by the lensed optical system (Figure 1). Response does not vary with fiber size ≤ 0.100 μm.

The HFBR-24X2 receiver incorporates an integrated photo IC containing a photodetector and dc amplifier driving an open-collector Schottky output transistor. The HFBR-24X2 is designed for direct interfacing to popular logic families. The absence of an internal pull-up resistor allows the open-collector output to be used with logic families such as CMOS requiring voltage excursions much higher than V_{CC}.

Both the open-collector "Data" output Pin 6 and V_{CC} Pin 2 are referenced to "Com" Pin 3, 7. The "Data" output allows busing, strobing and wired "OR" circuit configurations. The transmitter is designed to operate from a single +5 V supply. It is essential that a bypass capacitor (0.1 μF ceramic) be connected from Pin 2 (V_{CC}) to Pin 3 (circuit common) of the receiver.

Housed Product

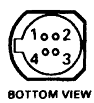




PIN	FUNCTION
1†	N.C.
2	V_{CC} (5 V)
3*	COMMON
4†	N.C.
5†	N.C.
6	DATA
7*	COMMON
8†	N.C.

*PINS 3 AND 7 ARE ELECTRICALLY CONNECTED TO HEADER
†PINS 1, 4, 5, AND 8 ARE ELECTRICALLY CONNECTED

Unhoused Product



PIN	FUNCTION
1	V_{CC} (5 V)
2	COMMON
3	DATA
4	COMMON

Absolute Maximum Ratings

Parameter		Symbol	Min.	Max.	Units	Reference
Storage Temperature		T_S	-55	+85	°C	
Operating Temperature		T_A	-40	+85	°C	
Lead Soldering Cycle	Temp.			+260	°C	Note 1
	Time			10	sec	
Supply Voltage		V_{CC}	-0.5	7.0	V	
Output Current		I_O		25	mA	
Output Voltage		V_O	-0.5	18.0	V	
Output Collector Power Dissipation		$P_{O\,AV}$		40	mW	
Fan Out (TTL)		N		5		Note 2

Electrical/Optical Characteristics -40°C to + 85°C unless otherwise specified

Fiber sizes with core diameter ≤ 100 μm and NA ≤ 0.35, 4.75 V ≤ V_{CC} ≤ 5.25 V

Parameter	Symbol	Min.	Typ.[3]	Max.	Units	Conditions	Reference
High Level Output Current	I_{OH}		5	250	μA	V_O = 18 P_R < -40 dBm	
Low Level Output Voltage	V_{OL}		0.4	0.5	V	I_O = 8 mA P_R > -24 dBm	
High Level Supply Current	I_{CCH}		3.5	6.3	mA	V_{CC} = 5.25 V P_R < -40 dBm	
Low Level Supply Current	I_{CCL}		6.2	10	mA	V_{CC} = 5.25 V P_R > -24 dBm	
Equivalent N.A.	NA		0.50				
Optical Port Diameter	D		400		μm		Note 4

Dynamic Characteristics

-40°C to +85°C unless otherwise specified; 4.75 V ≤ V_{CC} ≤ 5.25 V; BER ≤ 10^{-9}

Parameter	Symbol	Min.	Typ.[3]	Max.	Units	Conditions	Reference
Peak Optical Input Power Logic Level HIGH	P_{RH}			-40	dBm pk	λ_P = 820 nm	Note 5
				0.1	μW pk		
Peak Optical Input Power Logic Level LOW	P_{RL}	-25.4		-9.2	dBm pk	T_A = +25°C, I_{OL} = 8 mA	Note 5
		2.9		120	μW pk		
		-24.0		-10.0	dBm pk	I_{OL} = 8 mA	
		4.0		100	μW pk		
Propagation Delay LOW to HIGH	t_{PLHR}		65		ns	T_A = 25°C, P_R = -21 dBm, Data Rate = 5 MBd	Note 6
Propagation Delay HIGH to LOW	t_{PHLR}		49		ns		

Notes:

1. 2.0 mm from where leads enter case.
2. 8 mA load (5 x 1.6 mA), R_L = 560 Ω.
3. Typical data at T_A = 25°C, V_{CC} = 5.0 Vdc.
4. D is the effective diameter of the detector image on the plane of the fiber face. The numerical value is the product of the actual detector diameter and the lens magnification.
5. Measured at the end of 100/140 μm fiber optic cable with large area detector.
6. Propagation delay through the system is the result of several sequentially-occurring phenomena. Consequently it is a combination of data-rate-limiting effects and of transmission-time effects. Because of this, the data-rate limit of the system must be described in terms of time differentials between delays imposed on falling and rising edges.
7. As the cable length is increased, the propagation delays increase at 5 ns per meter of length. Data rate, as limited by pulse width distortion, is not affected by increasing cable length if the optical power level at the receiver is maintained.

CAUTION: The small junction sizes inherent to the design of these components increase the components' susceptibility to damage from electrostatic discharge (ESD). It is advised that normal static precautions be taken in handling and assembly of these components to prevent damage and/or degradation which may be induced by ESD.

HFBR-24X6 Low-Cost 125 MHz Receiver

Description

The HFBR-24X6 fiber optic receiver is designed to operate with the Hewlett-Packard HFBR-14XX fiber optic transmitters and 50/125 µm, 62.5/125 µm, 100/140 µm and 200 µm HCS® fiber optic cable. Consistent coupling into the receiver is assured by the lensed optical system (Figure 1). Response does not vary with fiber size for core diameters of 100 µm or less.

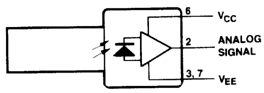
The receiver output is an analog signal which allows follow-on circuitry to be optimized for a variety of distance/data rate requirements. Low-cost external components can be used to convert the analog output to logic compatible signal levels for various data formats and data rates up to 175 MBd. This distance/data rate tradeoff results in increased optical power budget at lower data rates which can be used for additional distance or splices.

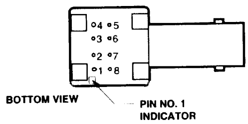
The HFBR-24X6 receiver contains a PIN photodiode and low noise transimpedance pre-amplifier integrated circuit. The HFBR-24X6 receives an optical signal and converts it to an analog voltage. The output is a buffered emitter-follower. Because the signal amplitude from the HFBR-24X6 receiver is much larger than from a simple PIN photodiode, it is less susceptible to EMI, especially at high signaling rates. For very noisy environments, the conductive or metal port option is recommended. A receiver dynamic range of 23 dB over temperature is achievable (assuming 10^{-9} BER).

The frequency response is typically dc to 125 MHz. Although the HFBR-24X6 is an analog receiver, it is compatible with digital systems. Please refer to Application Bulletin 78 for simple and inexpensive circuits that operate at 155 MBd or higher.

The recommended ac coupled receiver circuit is shown in Figure 12. It is essential that a 10 ohm resistor be connected between pin 6 and the power supply, and a 0.1 µF ceramic bypass capacitor be connected between the power supply and ground. In addition, pin 6 should be filtered to protect the receiver from noisy host systems. Refer to AN 1038, 1065, or AB 78 for details.

Housed Product



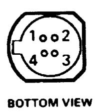


PIN	FUNCTION
1†	N.C.
2	SIGNAL
3*	V_{EE}
4†	N.C.
5†	N.C.
6	V_{CC}
7*	V_{EE}
8†	N.C.

* PINS 3 AND 7 ARE ELECTRICALLY CONNECTED TO THE HEADER.

† PINS 1, 4, 5, AND 8 ARE ISOLATED FROM THE INTERNAL CIRCUITRY, BUT ARE ELECTRICALLY CONNECTED TO EACH OTHER.

Unhoused Product



PIN	FUNCTION
1	SIGNAL
2*	V_{EE}
3	V_{CC}
4*	V_{EE}

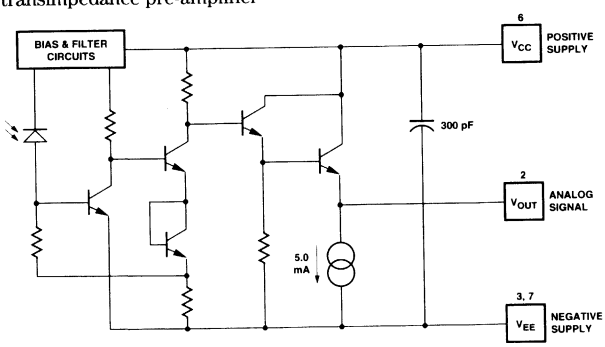


Figure 11. Simplified Schematic Diagram.

CAUTION: The small junction sizes inherent to the design of these components increase the components' susceptibility to damage from electrostatic discharge (ESD). It is advised that normal static precautions be taken in handling and assembly of these components to prevent damage and/or degradation which may be induced by ESD.

Absolute Maximum Ratings

Parameter		Symbol	Min.	Max.	Units	Reference
Storage Temperature		T_S	-55	+85	°C	
Operating Temperature		T_A	-40	+85	°C	
Lead Soldering Cycle	Temp.			+260	°C	Note 1
	Time			10	s	
Supply Voltage		V_{CC}	-0.5	6.0	V	
Output Current		I_O		25	mA	
Signal Pin Voltage		V_{SIG}	-0.5	V_{CC}	V	

Electrical/Optical Characteristics -40°C to +85°C; 4.75 V ≤ Supply Voltage ≤ 5.25 V, R_{LOAD} = 511 Ω, Fiber sizes with core diameter ≤ 100 μm, and N.A. ≤ -0.35 unless otherwise specified

Parameter	Symbol	Min.	Typ.[2]	Max.	Units	Conditions	Reference
Responsivity	R_P	5.3	7	9.6	mV/μW	T_A = 25°C @ 820 nm, 50 MHz	Note 3, 4 Figure 16
		4.5		11.5	mV/μW	@ 820 nm, 50 MHz	
RMS Output Noise Voltage	V_{NO}		0.40	0.59	mV	Bandwidth Filtered @ 75 MHz P_R = 0 μW	Note 5
				0.70	mV	Unfiltered Bandwidth P_R = 0 μW	Figure 13
Equivalent Input Optical Noise Power (RMS)	P_N		-43.0	-41.4	dBm	Bandwidth Filtered @ 75 MHz	
			0.050	0.065	μW		
Optical Input Power (Overdrive)	P_R			-7.6	dBm pk	T_A = 25°C	Figure 14 Note 6
				175	μW pk		
				-8.2	dBm pk		
				150	μW pk		
Output Impedance	Z_o		30		Ω	Test Frequency = 50 MHz	
dc Output Voltage	$V_{o\,dc}$	-4.2	-3.1	-2.4	V	P_R = 0 μW	
Power Supply Current	I_{EE}		9	15	mA	R_{LOAD} = 510 Ω	
Equivalent N.A.	NA		0.35				
Equivalent Diameter	D		324		μm		Note 7

CAUTION: The small junction sizes inherent to the design of these components increase the components' susceptibility to damage from electrostatic discharge (ESD). It is advised that normal static precautions be taken in handling and assembly of these components to prevent damage and/or degradation which may be induced by ESD.

Dynamic Characteristics -40°C to +85°C; 4.75 V ≤ Supply Voltage ≤ 5.25 V; R_{LOAD} = 511 Ω, C_{LOAD} = 5 pF unless otherwise specified

Parameter	Symbol	Min.	Typ.[2]	Max.	Units	Conditions	Reference
Rise/Fall Time 10% to 90%	t_r, t_f		3.3	6.3	ns	P_R = 100 μW peak	Figure 15
Pulse Width Distortion	PWD		0.4	2.5	ns	P_R = 150 μW peak	Note 8, Figure 14
Overshoot			2		%	P_R = 5 μW peak, t_r = 1.5 ns	Note 9
Bandwidth (Electrical)	BW		125		MHz	-3 dB Electrical	
Bandwidth - Rise Time Product			0.41		Hz • s		Note 10

Notes:

1. 2.0 mm from where leads enter case.
2. Typical specifications are for operation at T_A = 25°C and V_{CC} = +5 V dc.
3. For 200 μm HCS fibers, typical responsivity will be 6 mV/μW. Other parameters will change as well.
4. Pin #2 should be ac coupled to a load ≥ 510 ohm. Load capacitance must be less than 5 pF.
5. Measured with a 3 pole Bessel filter with a 75 MHz, -3 dB bandwidth. Recommended receiver filters for various bandwidths are provided in Application Bulletin 78.
6. Overdrive is defined at PWD = 2.5 ns.
7. D is the effective diameter of the detector image on the plane of the fiber face. The numerical value is the product of the actual detector diameter and the lens magnification.
8. Measured with a 10 ns pulse width, 50% duty cycle, at the 50% amplitude point of the waveform.
9. Percent overshoot is defined as:

$$\left(\frac{V_{PK} - V_{100\%}}{V_{100\%}}\right) \times 100\%$$

10. The conversion factor for the rise time to bandwidth is 0.41 since the HFBR-24X6 has a second order bandwidth limiting characteristic.

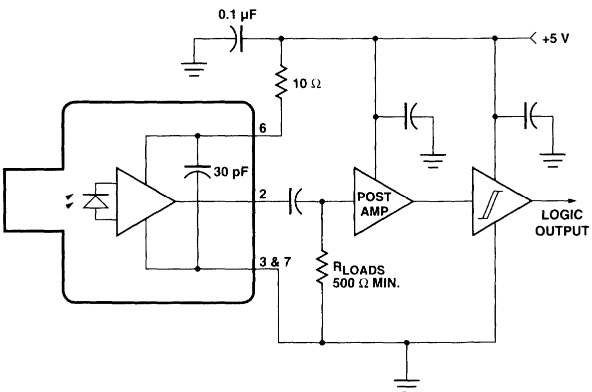
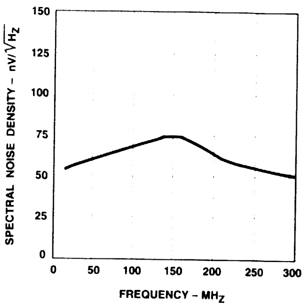
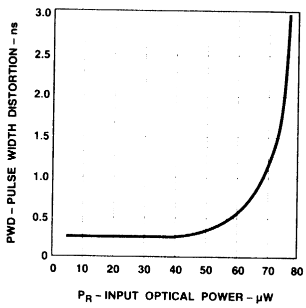


Figure 12. Recommended ac Coupled Receiver Circuit. (See AB 78 and AN 1038 for more information.)

CAUTION: The small junction sizes inherent to the design of these components increase the components' susceptibility to damage from electrostatic discharge (ESD). It is advised that normal static precautions be taken in handling and assembly of these components to prevent damage and/or degradation which may be induced by ESD.





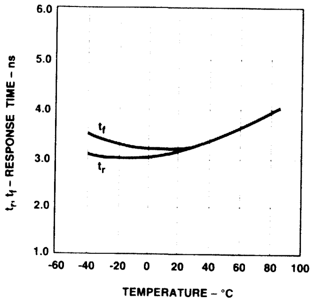


Figure 13. Typical Spectral Noise Distortion vs. Peak Input Power.

Figure 14. Typical Pulse Width Density vs. Frequency.

Figure 15. Typical Rise and Fall Times vs. Temperature.

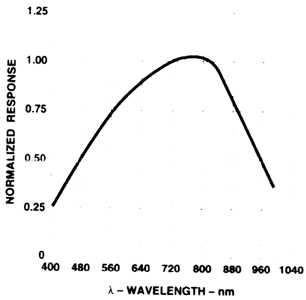


Figure 16. Receiver Spectral Response Normalized to 820 nm.

HEWLETT PACKARD

Conductive Port Option for Low Cost Miniature Link Components

Technical Data

Option C

Features

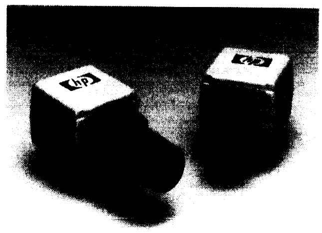
- **Significantly Decreases Effect of Electromagnetic Interference (EMI) on Receiver Sensitivity**
- **Available with Both SMA and Threaded ST Styled Port Receivers**
- **Allows the Designer to Separate the Signal and Conductive Port Grounds**

Description

The conductive port option for the Low Cost Miniature Link component family consists of a grounding path from the conductive port to four grounding pins as shown in the package outline drawing. Signal ground is separate from the four grounding pins to give the designer more flexibility. This option is available with all SMA and ST panel mount styled port receivers. Electrical/optical performance of the receivers is not affected by the conductive port. Refer to the HFBR-0400 data sheets for more information.

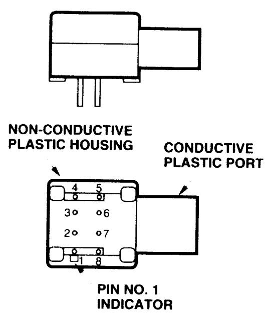
Applications

HP recommends that the designer use separate ground paths for the signal ground and the conductive port ground in order to minimize the effects of coupled noise on the receiver circuitry. If the designer notices that extreme noise is present on the system chassis, care should be taken to electrically isolate the conductive port from the chassis.



In the case of ESD, the conductive port option does not alleviate the need for system recovery procedures. A 15 kV ESD event entering through the port will not cause catastrophic failure for any HFBR-0400 receivers, but may cause soft errors. The conductive port option can reduce the amount of soft errors due to ESD events, but does not guarantee error-free performance.

Package Outline



Pin	Function
1	Port Ground Pin
2	Part Dependent
3	Part Dependent
4	Port Ground Pin
5	Port Ground Pin
6	Part Dependent
7	Part Dependent
8	Port Ground Pin

Reliability Information

Low Cost Miniature Link components with the Conductive Port Option are as reliable as standard HFBR-0400 components. The following tests were performed to verify the mechanical reliability of this option.

Ordering Information

To order the Conductive Port Option with a particular receiver component, place a "C" after the base part number. For example, to order an HFBR-2406 with this option, order an HFBR-2406C. As another example, to order an HFBR-2416T with this option, order an HFBR-2416TC.

This option is available with the following part numbers:

HFBR-2402	HFBR-2442T
HFBR-2404	HFBR-2444T
HFBR-2406	HFBR-2446T
HFBR-2412T	HFBR-2452
HFBR-2414T	HFBR-2454
HFBR-2416T	HFBR-2456
HFBR-2432	HFBR-2462T
HFBR-2434	HFBR-2464T
HFBR-2436	HFBR-2466T

Mechanical and Environmental Tests [1]

Test	MIL-STD-883/ Other Reference	Test Conditions	Units Tested	Total Failed
Temperature Cycling	1010 Condition B	-55°C to +125°C 15 min. dwell/5 min. transfer 100 cycles	70	0
Thermal Shock	1011 Condition B	-55°C to +125°C 5 min. dwell/10 sec. transfer 500 cycles	45	0
High temp. Storage	1008 Condition B	T_A = 125°C 1000 hours	50	0
Mechanical Shock	2002 Condition B	1500 g/0.5 ms 5 impacts each axis	40	0
Port[2] Strength	T_A = 25°C	6 Kg-cm no port damage	20	0
Seal Dye Penetrant (Zyglo)	1014 Condition D	45 psi, 10 hours No leakage into microelectronic cavity	15	0
Solderability	2003	245°C	10	0
Resistance to Solvents	2015	3 one min. immersion brush after solvent	13`	0
Chemical Resistance	-	5 minutes in Acetone, Methanol, Boiling Water	12	0
Temperature-Humidity	-	T_A = 85°C, RH = 85% Biased, 500 hours	30	0
Lead Integrity	2004 Condition B2	8 oz. wt. to each lead tested for three 90° arcs of the case	16	0
Electrostatic Discharge (ESD)	IEC-801-2	Direct contact discharge to port, 0-15 kV [3]	16	0

Notes:

1. Tests were performed on both SMA an ST products with the conductive port option.
2. The Port Strength test was designed to address the concerns with hand tightening the SMA connector to the fiber optic port. The limit is set to a level beyond most reasonable hand fastening loading.
3. HP has previously used an air discharge method to measure ESD; results using this method vary with air temperature and humidity. The direct contact discharge method is perferred due to better repeatability and conformance with IEC procedures. ESD immunity measured with the air discharge method is generally higher than with the direct contact discharge method.

HEWLETT PACKARD

Threaded ST Port Option for Low Cost Miniature Link Components

Technical Data

Option T

Features

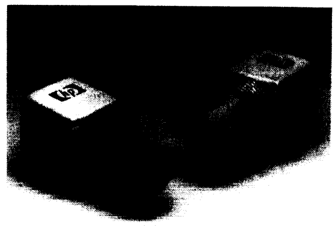
- **Threading Allows ST Styled Port Components to be Panel Mounted**
- **Compatible with all Current Makes of ST Multimode Connectors**
- **Mechanical Dimensions are Compliant with MIL-STD-83522/13**

Description

Low Cost Miniature Link components with the Threaded ST Port Option come with 0.2 inch (5.1 mm) of 3/8-32 UNEF-2A threads on the port. This option is available with all HFBR-0400, ST styled port components. Components with this option retain the same superior electrical/optical and mechanical performance as that of the base HFBR-0400 components. Refer to the HFBR-0400 data sheets for more information on electrical/optical performance and the HFBR-0400 Reliability data sheet for more information on mechanical durability.

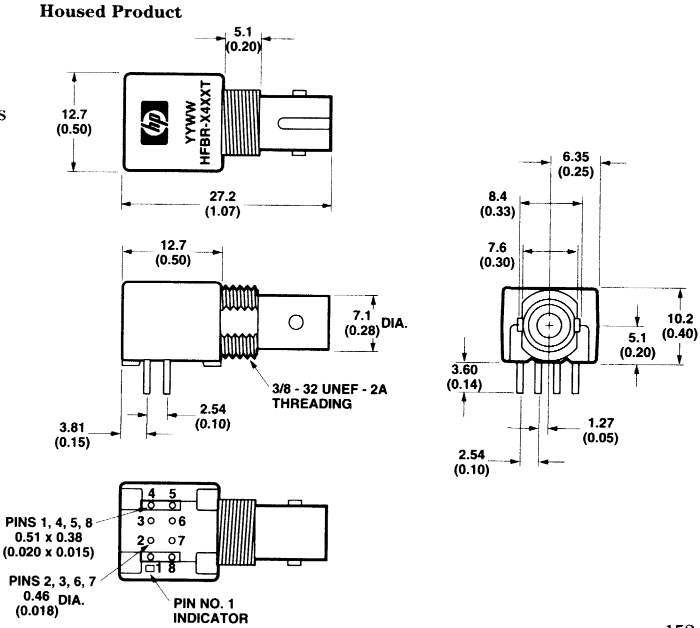
Panel Mounting

Low Cost Miniature Link components with the Threaded ST Port Option are suitable for panel mounting to chassis walls. The maximum wall thickness possible when using nuts and washers from the HFBR-4411 kit is 0.11 inch (2.8 mm).

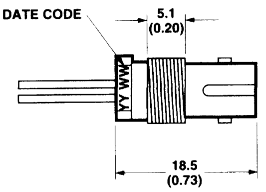


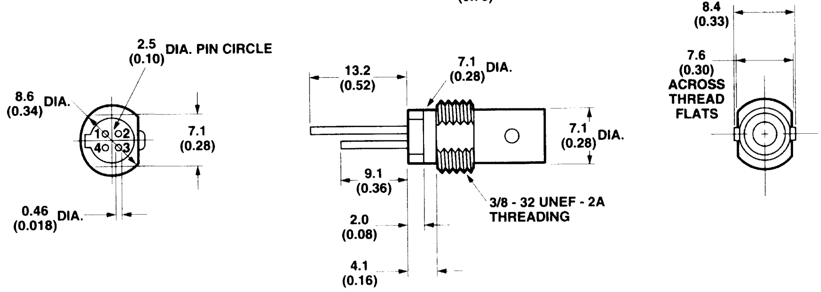
Package Outline

Housed Product



Package Outline
Port Product





ALL DIMENSIONS IN MILLIMETERS AND (INCHES).

The HFBR-4411 kit consists of 100 nuts and 100 washers with dimensions as shown in Figure 1. These kits are available from HP or any authorized distributor. Any standard size nut and washer will work, provided the total thickness of the wall, nut, and washer does not exceed 0.2 inch (5.1mm).

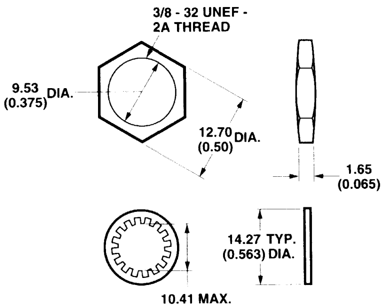
When preparing the chassis wall for panel mounting, use the mounting template in Figure 2. When tightening the nut, torque should not exceed 0.8 N-m (8.0 in-lb).

Ordering Information

To order the Threaded ST Port Option with a particular component, place a "T" after the base part number. For example, to order an HFBR-2416 with this option, order an HFBR-2416T.

This option is available with the following part numbers:

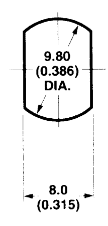
HFBR-1412
HFBR-1414
HFBR-1442
HFBR-1444
HFBR-1462
HFBR-1464
HFBR-2412
HFBR-2414



INTERNAL TOOTH LOCK WASHER

ALL DIMENSIONS IN MILLIMETERS AND (INCHES).

Figure 1. HFBR-4411 Mechanical Dimensions.



ALL DIMENSIONS IN MILLIMETERS AND (INCHES).

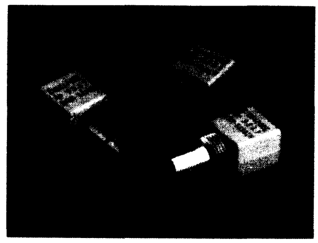
Figure 2. Recommended Cut-out for Panel Mounting.

HEWLETT® PACKARD

Metal Port Option for HFBR-0400 Series Components

Technical Data

Option M



Features

- **Nickel Plated Aluminum Connector Receptacle**
- **Withstands Electro-static Discharge (ESD) of 15 kV to the Port**
- **Significantly Decreases Effect of Electro-magnetic Interference (EMI) on Receiver Sensitivity**
- **Allows Separate Signal and Metal Port Grounds**
- **Available with SMA, ST, Threaded ST, and FC Styled Ports**

Description

The metal port option for the HFBR-0400 Series gives designers the ability to have a metal connector receptacle with the familiar HFBR-0400 dual in-line package (DIP). The metal port option components have an internal electrical connection between the metal port and the four grounding pins, as shown in the package outline drawing. Signal ground is separate from the four grounding pins to give the flexibility in connecting the port to signal or chassis ground. This feature aids in maintaining the integrity of the signal ground if the chassis is exposed to electrical noise. In addition, when the metal port is in good electrical contact with a well-grounded chassis, the metal port provides additional EMI shielding from electrically noisy circuits.

Applications

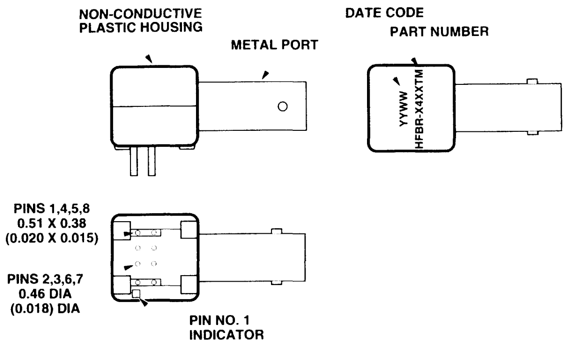
HP recommends that the designer use separate ground paths for the signal ground and the conductive metal port ground in order to minimize the effects of external coupled noise on receiver circuitry. If noise is present on the system chassis, care should be taken to electrically isolate the metal port from the chassis.

In the case of ESD, the metal port option does not alleviate the need for system recovery procedures. A 15 kV ESD event entering through the connector port will not cause catastrophic failure, but the metal port does not guarantee error-free performance during an ESD event.

The Metal Port Option is available with SMA, ST, Threaded ST (panel mount) and FC styled port transmitters and receivers. The electrical/optical specifications, the mechanical dimensions, and the pinouts of the components with metal ports are identical to the standard plastic port products.

5963-5603E (2/95)

Package Outline



Pin	Function
1	Port Ground Pin
2	Part Dependent
3	Part Dependent
4	Port Ground Pin
5	Port Ground Pin
6	Part Dependent
7	Part Dependent
8	Port Ground Pin

Ordering Information

This option will be available with the following part numbers:

Transmitters	Receivers
HFBR-1402	HFBR-2402
HFBR-1412	HFBR-2412
HFBR-1412T	HFBR-2412T
HFBR-1422	HFBR-2422
HFBR-1404	HFBR-2406
HFBR-1414	HFBR-2416
HFBR-1414T	HFBR-2416T
HFBR-1424	HFBR-2426

Refer to the HFBR-14XX and HFBR-24XX data sheeets for electrical/optical/mechanical specifications for each part. To order the Metal Port Option with a particular transmitter or receiver component, simply add the letter "M" to the end of the standard part number. For example, HFBR-1412T with the metal port option is HFBR-1412TM.

Reliability Information

Low Cost Miniature Link Components with the Metal Port Option use the same semiconductor devices and manufacturing processes as standard HFBR-0400 components, so reliability data for the HFBR-0400 Series is directly applicable. The tests listed below demonstrate the mechanical reliability of this package.

Mechanical and Environmental Tests

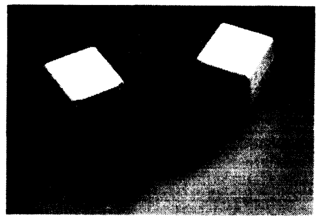
Test	MIL-STD-883 or Other Reference	Test Conditions	Units Tested	Total Failed
Temperature Cycling	1010 Condition B	-55 to +125°C, 15 minutes dwell, 5 minutes transfer, 170 cycles	40	0
Unbiased Pressure Pot Test		121°C, 100% relative humidity, 2 atmospheres, 48 hours	5	0
Mechanical Shock	2002 Condition B	5 blows each X1, X2, Y1, Y2, Z1, Z2 1500 G, 0.5 msec. pulse	40	0
Vibration Variable Frequency	2007 Condition A	50 G, 20 to 2000 Hz. 4, 4 minute cycles each X, Y, Z	40	0

HEWLETT PACKARD

1300 nm Fiber Optic Transmitter and Receiver

Technical Data

HFBR-0300 Series:
HFBR-1312T Transmitter
HFBR-2316T Receiver



Features

- **Low Cost Fiber Optic Link**
- **Signal Rates over 155 Megabaud**
- **1300 nm Wavelength**
- **Link Distances over 5 km**
- **Dual-in-line Package Panel-Mountable ST* and SC Connector Receptacles**
- **Auto-Insertable and Wave-Solderable**
- **Specified with 62.5/125 μm and 50/125 μm Fiber**
- **Compatible with HFBR-0400 Series**

Applications

- **Desktop Links for High Speed LANs**
- **Distance Extension Links**
- **Telecom Switch Systems**
- **TAXIchip® Compatible**

Description

The HFBR-0300 Series is designed to provide the most cost-effective 1300 nm fiber optic links for a wide variety of data communication applications from low-speed distance extenders up to SONET OC-3 signal rates. Pinouts identical to Hewlett-Packard HFBR-0400 Series allow designers to easily upgrade their 820 nm links for farther distance. The transmitter and receiver are compatible with two popular optical fiber sizes: 50/125 μm and 62.5/125 μm diameter. This allows flexibility in choosing a fiber size. The 1300 nm wavelength is in the lower dispersion and attenuation region of fiber, and provides longer distance capabilities than 820 nm LED technology. Typical distance capabilities are 2 km at 125 MBd and 5 km at 32 MBd.

Transmitter

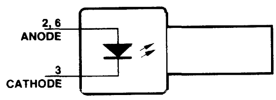
The HFBR-1312T fiber optic transmitter contains a 1300 nm InGaAsP light emitting diode capable of efficiently launching optical power into 50/125 μm and 62.5/125 μm diameter fiber. Converting the interface circuit from a HFBR-14XX 820 nm transmitter to the HFBR-1312T requires only the removal of a few passive components.

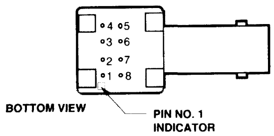
Receiver

The HFBR-2316T receiver contains an InGaAs PIN photodiode and a low-noise transimpedance preamplifier that operate in the 1300 nm wavelength region. The HFBR-2316T receives an optical signal and converts it to an analog voltage. The buffered output is an emitter-follower, with frequency response from DC to typically 125 MHz. Low-cost external components can be used to convert the analog output to logic compatible signal levels for a variety of data formats and data rates. The

*ST is a registered trademark of AT&T Lightguide Cable Connectors

HFBR-1312T Transmitter



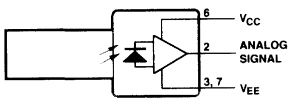


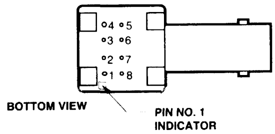
PIN	FUNCTION
1†	N.C.
2	ANODE
3	CATHODE
4†	N.C.
5†	N.C.
6	ANODE
7*	N.C.
8†	N.C.

* PIN 7 IS ELECTRICALLY ISOLATED FROM PINS 1, 4, 5, AND 8, BUT IS CONNECTED TO THE HEADER.

† PINS 1, 4, 5, AND 8 ARE ISOLATED FROM THE INTERNAL CIRCUITRY, BUT ARE ELECTRICALLY CONNECTED TO EACH OTHER.

HFBR-2316T Receiver





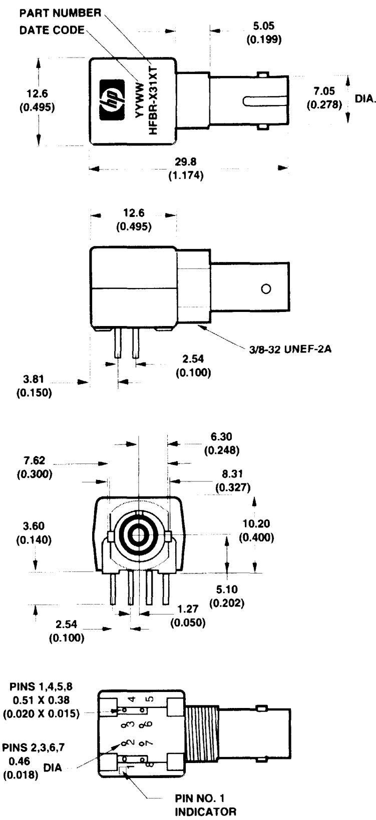
PIN	FUNCTION
1†	N.C.
2	SIGNAL
3*	V_{EE}
4†	N.C.
5†	N.C.
6	V_{CC}
7*	V_{EE}
8†	N.C.

* PINS 3 AND 7 ARE ELECTRICALLY CONNECTED TO THE HEADER.

† PINS 1, 4, 5, AND 8 ARE ISOLATED FROM THE INTERNAL CIRCUITRY, BUT ARE ELECTRICALLY CONNECTED TO EACH OTHER.

HFBR-0300 Series

Mechanical Dimensions



HFBR-2316T is pin compatible with HFBR-24X6 receivers and can be used to extend the distance of an existing application by substituting the HFBR-2316T for the HFBR-2416.

Package Information

HFBR-0300 Series transmitters and receivers are housed is a dual-in-line package made of high strength, heat resistant, chemically resistant, and UL V-0 flame retardant plastic. Transmitters are identified by the brown port color; receivers have black ports. The package is auto-insertable and wave solderable for high volume production applications.

Note: The "T" in the product numbers indicates a Threaded ST connector (panel mountable), for both transmitter and receiver.

Handling and Design Information

When soldering, it is advisable to leave the protective cap on the unit to keep the optics clean. Good system performance requires clean port optics and cable ferrules to avoid obstructing the optical path. Clean compressed air is often sufficient to remove particles of dirt; methanol on a cotton swab also works well.

Panel Mounting Hardware

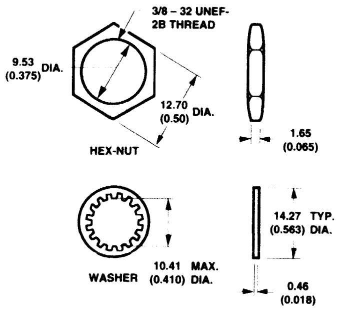
The HFBR-4411 kit consists of 100 nuts and 100 washers with dimensions as shown in Figure 1. These kits are available from HP or any authorized distributor. Any standard size nut and washer will work, provided the total thickness of the wall, nut, and washer does not exceed 0.2 inch (5.1mm).

When preparing the chassis wall for panel mounting, use the mounting template in Figure 2. When tightening the nut, torque should not exceed 0.8 N-m (8.0 in-lb).

Recommended Chemicals for Cleaning/Degreasing HFBR-0300 Products

Alcohols (methyl, isopropyl, isobutyl)
Aliphatics (hexane, heptane)
Other (soap solution, naphtha)

Do not use partially halogenated hydrocarbons (such as 1.1.1 trichloroethane), ketones (such as MEK), acetone, chloroform, ethyl acetate, methylene dichloride, phenol, methylene chloride, or N-methylpyrrolldone. Also, HP does not recommend the use of cleaners that use halogenated hydrocarbons because of their potential environmental harm.



NOTE: ALL DIMENSIONS IN MILLIMETRES AND (INCHES).

INTERNAL TOOTH LOCK WASHER

Figure 1. HFBR-4411 Mechanical Dimensions.

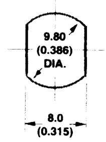


Figure 2. Recommended Cut-out for Panel Mounting.

HFBR-1312T Transmitter Absolute Maximum Ratings

Parameter	Symbol	Min.	Max.	Unit	Reference
Storage Temperature	T_S	-55	85	°C	
Operating Temperature	T_A	-40	85	°C	
Lead Soldering Cycle Temperature			260	°C	Note 8
Lead Soldering Cycle Time			10	sec	
Forward Input Current DC	I_{FDC}		100	mA	
Reverse Input Voltage	V_R		1	V	

CAUTION: The small junction sizes inherent to the design of this bipolar component increase the component's susceptibility to damage from electrostatic discharge (ESD). It is advised that normal static precautions be taken in handling and assembly of this component to prevent damage and/or degradation which may be induced by ESD.

HFBR-1312T Transmitter Electrical/Optical Characteristics

0 to 70°C unless otherwise specified

Parameter	Symbol	Min.	Typ.[1]	Max.	Unit	Condition	Ref.
Forward Voltage	V_F	1.1	1.4	1.7	V	I_F = 75 mA	Fig. 1
			1.5			I_F = 100 mA	
Forward Voltage Temperature Coefficient	$\Delta V_F/\Delta T$		-1.5		mV/°C	I_F = 75 - 100 mA	
Reverse Input Voltage	V_R	1	4		V	I_R = 100 µA	
Center Emission Wavelength	λ_C	1270	1300	1370	nm		
Full Width Half Maximum	FWHM		130	185	nm		
Diode Capacitance	C_T		16		pF	V_F = 0 V, f = 1 MHz	
Optical Power Temperature Coefficient	$\Delta P_T/\Delta T$		-0.03		dB/°C	I_F = 75 - 100 mA DC	
Thermal Resistance	Θ_{JA}		260		°C/W		Note 2

HFBR-1312T Transmitter Output Optical Power and Dynamic Characteristics

						Condition		
Parameter	Symbol	Min.	Typ.[1]	Max.	Unit	T_A	$I_{F,\,peak}$	Ref.
Peak Power 62.5/125 µm NA = 0.275	P_{T62}	-16.0	-14.0	-12.5	dBm	25°C	75 mA	Notes 3, 4, 5
		-17.5		-11.5		0-70°C	75 mA	
		-15.5	-13.5	-12.0		25°C	100 mA	Fig. 2
		-17.0		-11.0		0-70°C	100 mA	
Peak Power 50/125 µm NA = 0.20	P_{T50}	-19.5	-17.0	-14.5	dBm	25°C	75 mA	Notes 3, 4, 5
		-21.0		-13.5		0-70°C	75 mA	
		-19.0	-16.5	-14.0		25°C	100 mA	Fig. 2
		-20.5		-13.0		0-70°C	100 mA	
Optical Overshoot	OS		5	10	%	0-70°C	75 mA	Note 6 Fig. 3
Rise Time	t_r		1.8	4.0	ns	0-70°C	75 mA	Note 7 Fig. 3
Fall Time	t_f		2.2	4.0	ns	0-70°C	75 mA	Note 7 Fig. 3

Notes:

1. Typical data are at $T_A = 25°C$.
2. Thermal resistance is measured with the transmitter coupled to a connector assembly and mounted on a printed circuit board; $\Theta_{JC} < \Theta_{JA}$.
3. Optical power is measured with a large area detector at the end of 1 meter of mode stripped cable, with an ST* precision ceramic ferrule (MIL-STD-83522/13), which approximates a standard test connector. Average power measurements are made at 12.5 MHz with a 50% duty cycle drive current of 0 to $I_{F,peak}$; $I_{F,average} = I_{F,peak}/2$. Peak optical power is 3 dB higher than average optical power.
4. When changing from μW to dBm, the optical power is referenced to 1 mW (1000 μW).
   Optical power P(dBm) = 10*log[P(μW)/1000μW].
5. Fiber NA is measured at the end of 2 meters of mode stripped fiber using the far-field pattern. NA is defined as the sine of the half angle, determined at 5% of the peak intensity point. When using other manufacturer's fiber cable, results will vary due to differing NA values and test methods.
6. Overshoot is measured as a percentage of the peak amplitude of the optical waveform to the 100% amplitude level. The 100% amplitude level is determined at the end of a 40 ns pulse, 50% duty cycle. This will ensure that ringing and other noise sources have been eliminated.
7. Optical rise and fall times are measured from 10% to 90% with 62.5/125 μm fiber. LED response time with recommended test circuit (Figure 3) at 25 MHz, 50% duty cycle.
8. 2.0 mm from where leads enter case.

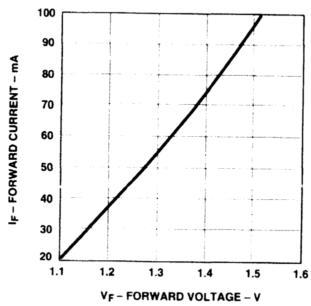


Figure 1. Typical Forward Voltage and Current Characteristics.

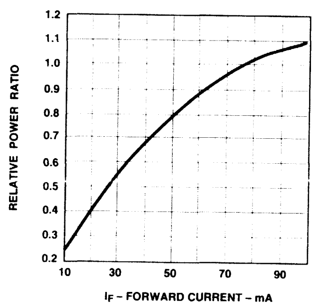


Figure 2. Normalized Transmitter Output Power vs. Forward Current.

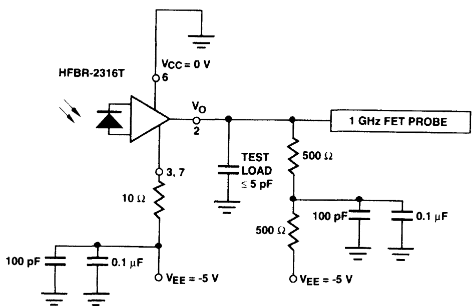


Figure 3. Recommended Transmitter Drive and Test Circuit.

HFBR-2316T Receiver Absolute Maximum Ratings

Parameter	Symbol	Min.	Max.	Unit	Reference
Storage Temperature	T_S	-55	85	°C	
Operating Temperature	T_A	-40	+85	°C	
Lead Soldering Temperature			260	°C	Note 1
Cycle Time			10	s	
Signal Pin Voltage	V_O	-0.5	V_{CC}	V	
Supply Voltage	V_{CC} - V_{EE}	-0.5	6.0	V	Note 2
Output Current	I_O		25	mA	

CAUTION: The small junction sizes inherent to the design of this bipolar component increase the component's susceptibility to damage from electrostatic discharge (ESD). It is advised that normal static precautions be taken in handling and assembly of this component to prevent damage and/or degradation which may be induced by ESD.

HFBR-2316T Receiver Electrical/Optical and Dynamic Characteristics

0 to 70°C; 4.75 V < V_{CC} - V_{EE} < 5.25 V; power supply must be filtered (see note 2).

Parameter	Symbol	Min.	Typ.[3]	Max.	Unit	Condition	Ref.
Responsitivity	R_P	6.5	13	19	mV/µW	λ_p = 1300 nm, 50 MHz	Note 4 Fig. 1, 5
RMS Output Noise Voltage	V_{NO}		0.4	0.59	mV_{RMS}	100 MHz bandwidth, P_R = 0 µW	Note 5 Fig. 2
				1.0	mV_{RMS}	Unfiltered Bandwidth P_R = 0 µW	
Equivalent Optical Noise Input Power (RMS)	$P_{N, RMS}$		-45	-41.5	dBm	@ 100 MHz, P_R = 0 µW	Note 5
			0.032	0.071	µW		
Peak Input Optical Power	P_R			-11.0	dBm	50 MHz, 1 ns PWD	Note 6 Fig. 3
				80	µW		
Output Resistance	R_O		30		Ohm	f = 50 MHz	
DC Output Voltage	$V_{O,DC}$	0.8	1.8	2.6	V	V_{CC} = 5 V, V_{EE} = 0 V P_R = 0 µW	
Supply Current	I_{CC}		9	15	mA	$R_{LOAD} = \infty$	
Electrical Bandwidth	BW_E	75	125		MHz	-3 dB electrical	Note 7
Bandwidth * Rise Time Product			0.41		Hz *s		
Electrical Rise, Fall Times, 10-90%	t_r,t_f		3.3	5.3	ns	P_R = -15 dBm peak, @ 50 MHz	Note 8 Fig. 4
Pulse-Width Distortion	PWD		0.4	1.0	ns	P_R = -11 dBm, peak	Note 6,9 Fig. 3
Overshoot			2		%	P_R = -15 dBm, peak	Note 10

Notes:

1. 2.0 mm from where leads enter case.
2. The signal output is referred to V_{CC}, and does not reject noise from the V_{CC} power supply. Consequently, the V_{CC} power supply must be filtered. The recommended power supply is +5 V on V_{CC} for typical usage with +5 V ECL logic. A -5 V power supply on V_{EE} is used for test purposes to minimize power supply noise.
3. Typical specifications are for operation at $T_A = 25°C$ and $V_{CC} = +5\ V_{DC}$.
4. The test circuit layout should be in accordance with good high frequency circuit design techniques.
5. Measured with a 9-pole "brick wall" low-pass filter [Mini-Circuits™, BLP-100*] with -3 dB bandwidth of 100 MHz.
6. -11.0 dBm is the maximum peak input optical power for which pulse-width distortion is less than 1 ns.
7. Electrical bandwidth is the frequency where the responsivity is -3 dB (electrical) below the responsivity measured at 50 MHz.
8. The specified rise and fall times are referenced to a fast square wave optical source. Rise and fall times measured using an LED optical source with a 2.0 ns rise and fall time (such as the HFBR-1312T) will be approximately 0.6 ns longer than the specified rise and fall times. E.g.: measured $t_{r,f} \simeq [(\text{specified } t_{r,f})^2 + (\text{test source optical } t_{r,f})^2]^{1/2}$.
9. 10 ns pulse width, 50% duty cycle, at the 50% amplitude point of the waveform.
10. Percent overshoot is defined as: $((V_{PK} - V_{100\%})/V_{100\%}) \times 100\%$. The overshoot is typically 2% with an input optical rise time ≤ 1.5 ns.
11. The bandwidth*risetime product is typically 0.41 because the HFBR-2316T has a second-order bandwidth limiting characteristic.

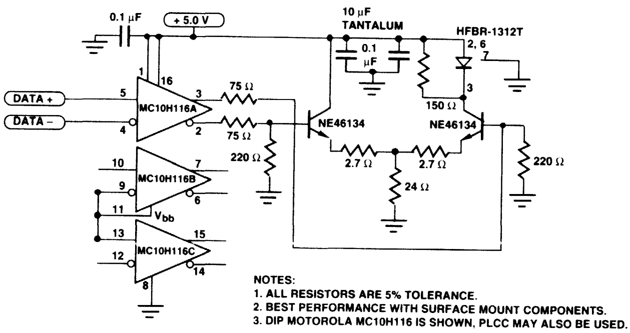


Figure 1. HFBR-2316T Receiver Test Circuit.

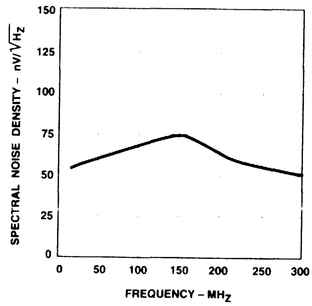


Figure 2. Typical Output Spectral Noise Density vs. Frequency.

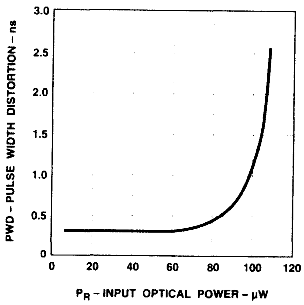


Figure 3. Typical Pulse Width Distortion vs. Peak Input Power.

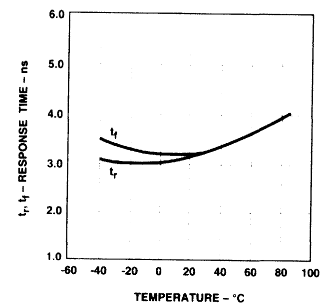


Figure 4. Typical Rise and Fall Times vs. Temperature.

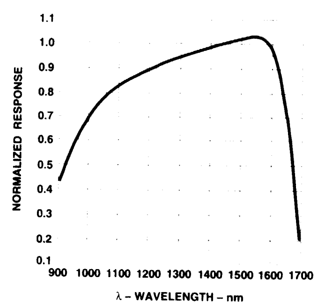


Figure 5. Normalized Receiver Spectral Response.

*Mini-Circuits Division of Components Corporation.

HEWLETT® PACKARD

1300 nm E-LED Transmitter and PIN/Preamp Receiver for Single-Mode Fiber

Technical Data

HFBR-0305 Series

Features

- **Distances up to 14 km at Signal Rates of 20 MBd**
- **Performance Specified with Single-Mode Fiber Cables**
- **Wave Solder and Aqueous Wash Process Compatible**
- **Panel Mount ST Connectors**
- **Pinout Compatible with HFBR-0400 Series Parts**

Applications

- **Single-Mode Extensions to Ethernet (10Base-F) Links**
- **Proprietary Links Using Single-Mode Fiber**

Description

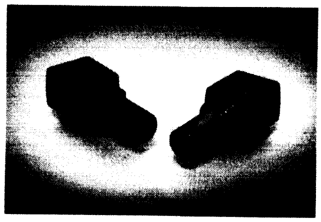
The HFBR-0305 Series is designed to provide the most cost-effective single-mode solution, and is pin-compatible with HP's HFBR-0400 and HFBR-0300 families of 820 and 1300 nm fiber optic links for multi-mode fiber. This allows designers to use a single circuit and board layout for 820 nm multimode fiber links, 1300 nm multimode fiber links, and 1300 nm single-mode fiber links. Upgrading a multimode solution to single-mode fiber is as simple as switching components on a board.

Transmitter

The HFBR-1315TM/1315M single-mode fiber-optic transmitter contains a 1300 nm edge-emitting LED (E-LED) capable of efficiently launching optical power into single-mode fiber. Because it is an LED, and not a laser, the drive circuit is simple and compatible with drive circuits for multimode LED transmitters.

Receiver

The HFBR-2315T/2315M receiver contains an InGaAs PIN photodiode and a low-noise transimpedance preamplifier operating in the 1300 nm wavelength region. The HFBR-2315T/2315M receives an optical signal and converts it to an analog voltage. The buffered output is an emitter-follower, with a frequency response from dc to typically 125 MHz.



Package

HFBR-0305 Series transmitters and receivers are housed in a dual-in-line package made of high strength, heat resistant, chemical resistant, and UL V-0 flame retardant plastic. The HFBR-1315TM/1315M is a stainless steel, threaded ST port (panel mountable); the HFBR-1315M is a stainless steel, unthreaded ST port. The HFBR-2315T is a black, non-conductive plastic threaded ST port (panel mountable); the HFBR-2315M is a stainless steel, unthreaded ST port.

Package Options

	Metal Port	Plastic Port
Transmitter:		
Threaded	HFBR-1315TM	N/A
Unthreaded	HFBR-1315M	N/A
Receiver:		
Threaded	N/A	HFBR-2315T
Unthreaded	HFBR-2315M	N/A

5964-3544E (1/97)

ESD Handling Precautions

The HFBR-0305 Series products are MIL-STD 883C Method 3015.4 Class 1 devices. Normal static precautions should be taken in handling and assembly of this component to prevent damage and/or degradation which may be induced by electrostatic discharge (ESD)

Solder Processing

The HFBR-0305 Series products are compatible with either hand or wave solder processes. When soldering, it is advisable to leave the protective cap on the port to keep the optics clean. Good system performance requires clean port optics and cable ferrules to avoid obstructing the optical path. Clean compressed air is often sufficient to remove particles of dirt; methanol on a cotton swab also works well.

Wash Processing - Chemical Resistance

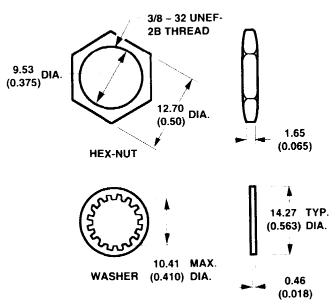
The HFBR-0305 Series package is compatible with the following chemicals for cleaning and degreasing:

- Aqueous Wash
- Naptha
- Alcohol (methyl, isopropyl, isobutyl)
- Aliphatics (hexane, heptane)

The following chemicals are not recommended as they will damage the package: Partially halogenated hydrocarbons such as 1,1,1 Trichloroethane, Ketones such as MEK, Acetone, Chloroform, Ethyl Acetate, Methylene Dichloride and N-methylpyroldone.

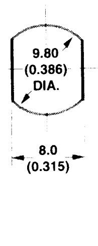
Panel Mounting of Threaded ST Package Style

Any standard 3/8 - 32 UNEF-2B threaded nut and washer can be used to secure the threaded ST receptacle to the chassis wall, provided the overall thickness of the chassis wall, washer and nut are less than 5.1 mm (0.2 inch). Hewlett-Packard supplies the HFBR-4411 kit which consists of 100 each, nuts and washers per the figure below.



NOTE: ALL DIMENSIONS IN MILLIMETRES AND (INCHES).

When preparing the chassis wall for panel mounting, use the mounting template in the figure below. When tightening the nut, torque should not exceed 0.8 N-m (8.0 in-lb). Note that the maximum nut dimension exceeds the width of the port package, so approximately 2 mm of space between device packages is required to allow nuts to be mounted on adjacent ports.



Flame Resistance

The HFBR-0305 Series package is made with UL V-0 flame retardant plastic material.

Electrostatic Discharge (ESD)

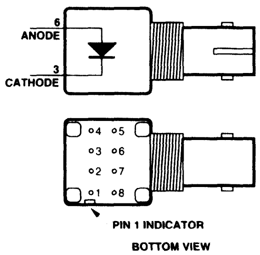
Static discharges can occur to the exterior of the equipment chassis containing the HFBR-0305 Series parts. To the extent that their connector receptacles are exposed to the outside of the equipment chassis, they may be subject to whatever ESD system level test criteria that the equipment is intended to meet.

Radiated Susceptibility

Equipment utilizing these products will be subject to EMI fields in some environments. These HFBR-0305 Series products are expected to withstand fields of up to 10 volts per meter, when tested on a circuit card in free space without an equipment chassis, with no measurable effect on their performance. A suggested test method is based on the equipment procedure specified in IEC 801-3.

Pinout Description

HFBR-1315TM/1315M Transmitters

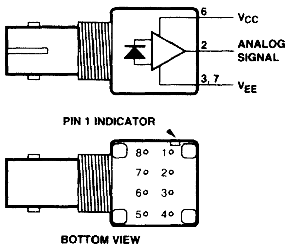


PIN	FUNCTION
1†	N.C.
2*	N.C.
3	CATHODE
4†	N.C.
5†	N.C.
6	ANODE
7	N.C.
8†	N.C.

* THERE IS NO PIN 2. I.E., IN THE NUMBER 2 PIN POSITION, THERE IS NO PHYSICAL PIN.

† PINS 1, 4, 5, AND 8 ARE ISOLATED FROM THE INTERNAL CIRCUITRY, BUT ARE ELECTRICALLY CONNECTED TO EACH OTHER AND TO THE METAL PORT.

HFBR-2315T/2315M Receivers



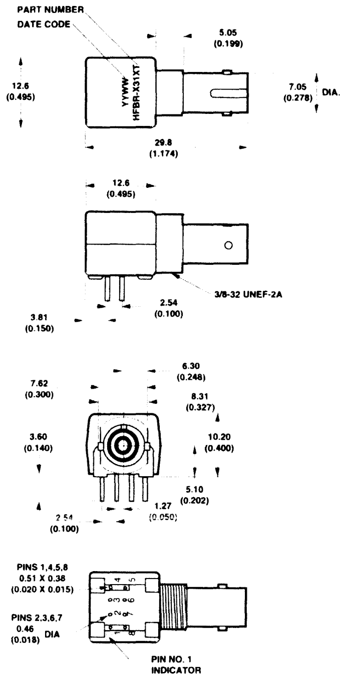
PIN	FUNCTION
1†	N.C.
2	SIGNAL
3*	V_{EE}
4†	N.C.
5†	N.C.
6	V_{CC}
7*	V_{EE}
8†	N.C.

* PINS 3 AND 7 ARE ELECTRICALLY CONNECTED TO THE HEADER.

† PINS 1, 4, 5, AND 8 ARE ISOLATED FROM THE INTERNAL CIRCUITRY, BUT ARE ELECTRICALLY CONNECTED TO EACH OTHER (AND TO THE PORT IF METAL).

Mechanical Dimensions

All dimensions are in millimeters and (inches)



Recommended Operating Conditions for HFBR-0305 Series Products

Parameter	Symbol	Min.	Typ.	Max.	Unit	Reference
Operating Temperature - Ambient	T_A	0		70	°C	
Supply Voltage	V_{CC}	4.75		5.25	V	Note 1

Note:

1. The HFBR-2315T/2315M signal output is referenced to V_{CC}, and does not reject noise from the V_{CC} power supply. Consequently, the V_{CC} power supply must be filtered.

Link Performance: At Data Rates 1-20 MBd

Parameter	Symbol	Min.	Typ.	Max.	Unit	Conditions	Reference
Optical Power Budget with Single-Mode Fiber Cables	OPB	9	18		dB	0 to 70°C	Note 1
Link Distance with Single-Mode Fiber Cables	ℓ	14			km	0 to 70°C	Note 2

Notes:

1. Optical Power Budget applies to HFBR-1315TM/1315M and HFBR-2315T/2315M in the recommended application circuit (Figures 1 and 2). Worst case transmitter coupled power (P_T) is -27 dBm peak, -30 dBm average. Worst case receiver sensitivity is -36 dBm peak, -39 dBm average. Refer to Application Note 1082 for details.
2. Link distance is based on fiber with 0.5 dB/km attenuation, and assumes 1 dB for loss of in-line splices or connectors, and 1 dB margin for LED aging: (9 dB OPB - 1 dB in-line splice loss - 1 dB aging margin)/(0.5 dB/km) = 14 km.

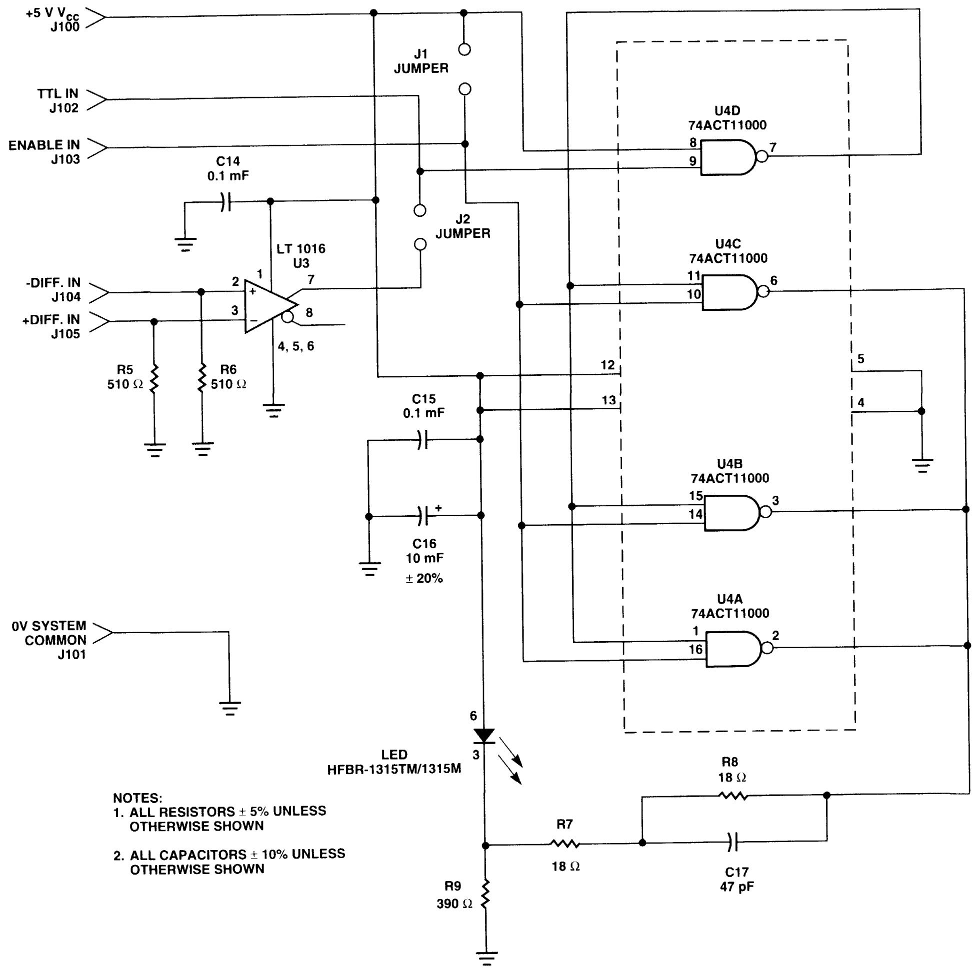
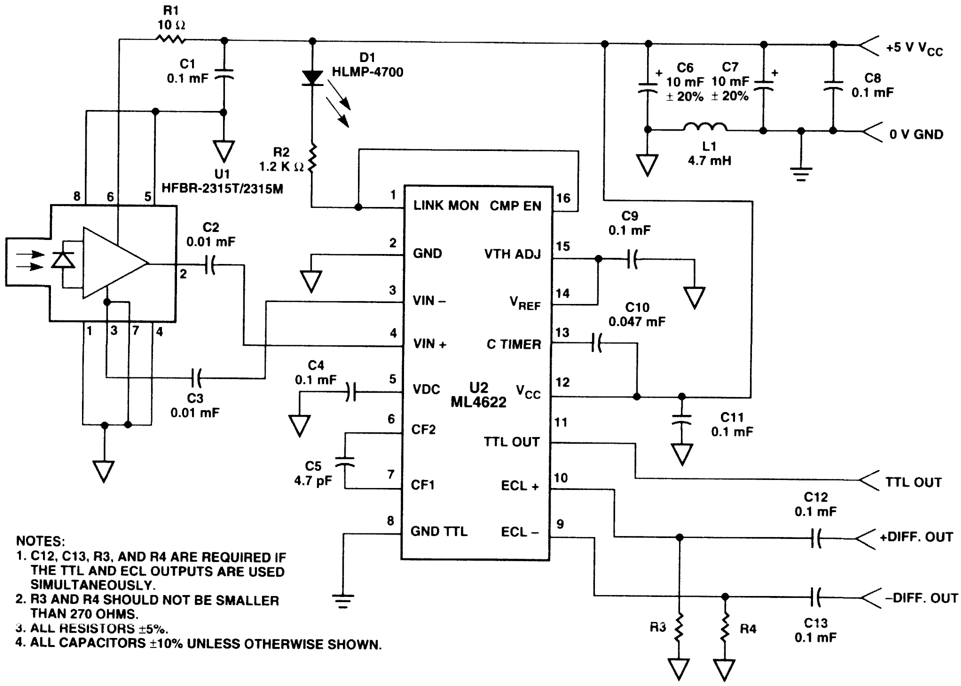


Figure 1. Recommended Transmitter Circuit.



NOTES:
1. C12, C13, R3, AND R4 ARE REQUIRED IF THE TTL AND ECL OUTPUTS ARE USED SIMULTANEOUSLY.
2. R3 AND R4 SHOULD NOT BE SMALLER THAN 270 OHMS.
3. ALL RESISTORS ±5%.
4. ALL CAPACITORS ±10% UNLESS OTHERWISE SHOWN.

Figure 2. Recommended Receiver Circuit.

HFBR-1315TM/1315M - Transmitter Absolute Maximum Ratings

Parameter	Symbol	Min.	Max.	Unit	Condition
Storage Temperature	T_S	-40	85	°C	
Operating Temperature	T_A	-40	85	°C	
Lead Soldering Cycle Temperature			260	°C	Note 1
Lead Soldering Cycle Time			10	sec	
Forward Input Current dc	I_{FDC}		100	mA	
Forward Input Current, Peak	I_{FPK}		175	mA	1 sec pulse
Reverse Input Voltage	V_R		2	V	

Notes:
1. 2.0 mm from where leads enter case.

CAUTION: It is advised that normal static precautions be taken in handling or assembly of these components to prevent damage and/or degradation which may be induced by ESD.

HFBR-1315TM/1315M - Transmitter Electrical/Optical Characteristics

(T_A = 0°C to 70°C, I_F = 100 mA unless otherwise specified)

Parameter	Symbol	Min.	Typ.[1]	Max.	Unit	Condition	Reference
Forward Voltage	V_F	1.1	1.5	1.9	V	T_A = 25°C	Figure 3
		1.0		2.0			
Forward Voltage Temperature Coefficient	$\Delta V_F/\Delta T$		-3.4		mV/°C		
Center Emission Wavelength	λ_C	1265	1310	1380	nm		
Spectral Width - FWHM	$\Delta\lambda$		95	125	nm	T_A = 25°C	
				140			
Optical Power Temperature Coefficient	$\Delta P_T/\Delta T$		-0.07		dB/°C		
Reverse Leakage Current	I_R			200	µA	T_A = 25°C, V_R = -2 V	
Thermal Resistance	θ_{JA}		105		°C/W		Note 2

Notes:
1. Typical data are at T_A = 25°C.
2. Thermal resistance is measured with the transmitter coupled to a connector assembly and mounted on a printed circuit board; $\theta_{JC} < \theta_{JA}$.

HFBR-1315TM/1315M - Transmitter Optical Output Power and Dynamic Characteristics

Parameter	Symbol	Min.	Typ.[1]	Max.	Unit	Conditions T_A	Conditions $I_{F,peak}$	Reference
Peak Power Single-mode	P_T	-23	-21	-17	dBm	25°C	100 mA	Note 2 Figure 4
		-27		-15		0-70°C	100 mA	
Rise, Fall Time (10% to 90%)	t_r, t_f			4.5	ns	0-70°C	100 mA, No Pre-bias	Note 4 Figure 5
Rise, Fall Time (10% to 90%)	t_r, t_f		2.6 1.6		ns	0-70°C	100 mA, With Pre-bias	Note 4 Figure 1

Notes:
1. Typical data are at T_A = 25°C.
2. Optical power is measured with a large area detector at the end of 1 meter of single-mode cable, with an ST* precision ceramic ferrule (MIL-STD-83522/13), which approximates a standard test connector.
3. When changing from μW to dBm, the optical power is referenced to 1 mW (1000 μW). Optical power P(dBm) = 10*log[P(μW)/1000μW].
4. Optical rise and fall times are measured from 10% to 90% with single-mode fiber. The "No Pre-bias" response time is measured in the recommended test circuit (50 ohm load, Figure 5) at 25 MHz, 50% duty cycle. The response time "With Pre-bias" is measured in the recommended application circuit (Figure 1).

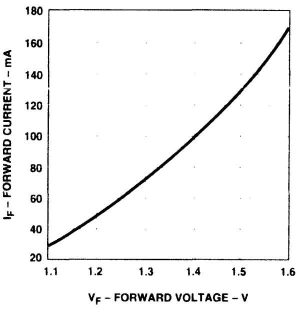


Figure 3. Typical Forward Voltage and Current Characteristics, 25°C.

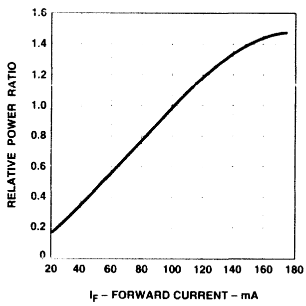


Figure 4. Normalized Transmitter Output Power vs. Forward Current, 25°C.

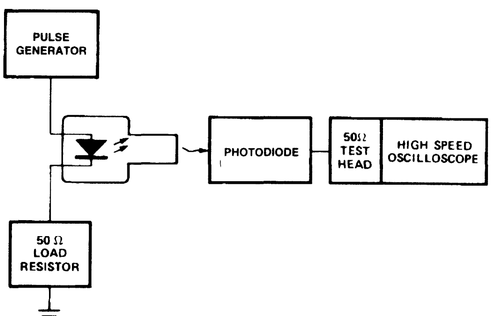


Figure 5. Test Circuit for Measuring t_r, t_f Without Pre-Bias.

HFBR-2315TM/2315M - Receiver Absolute Maximum Ratings

Parameter	Symbol	Min.	Max.	Unit	Condition
Storage Temperature	T_S	-55	85	°C	
Operating Temperature	T_A	-40	+85	°C	
Lead Soldering Cycle Temperature			260	°C	Note 1
Lead Soldering Cycle Time			10	sec	
Signal Pin Voltage	V_O	-0.5	V_{CC}	V	
Supply Voltage	$(V_{CC} - V_{EE})$	-0.5	6.0	V	Note 2
Output Current	I_O		25	mA	

CAUTION: It is advised that normal static precautions be taken in handling or assembly of these components to prevent damage and/or degradation which may be induced by ESD.

HFBR-2315T/2315M - Electrical/Optical and Dynamic Characteristics

(T_A = 0°C to 70°C; 4.75 V < $(V_{CC} - V_{EE})$ < 5.25 V; power supply must be filtered per note 2)

Parameter	Symbol	Min.	Typ.[3]	Max.	Unit	Condition	Reference
Responsivity, Single-Mode Fiber	R_P	8.5	17	24	mV/µW	λ_p = 1300 nm, 50 MHz	Note 4, Figures 6, 10
RMS Output Noise Voltage	V_{NO}		0.4	0.59	mV_{RMS}	@100 MHz, P_R = 0 mW	Note 5 Figure 7
				1.0	mV_{RMS}	Unfiltered Bandwidth P_R = 0 mW	
Equivalent Optical Noise Input Power (RMS)	$P_{N,RMS}$		-45	-41.5	dBm	@100 MHz, P_R = 0 mW	Note 5
			0.032	0.071	µW		
Peak Input Optical Power, Single-Mode	P_R			-14	dBm	50 MHz, 1 ns PWD	Note 6 Figure 8
				40	µW		
Output Impedance	Z_O		30		Ω	f = 50 MHz	
DC Output Voltage	$V_{O,DC}$	0.8	1.8	2.6	V	V_{CC} = 5 V, V_{EE} = 0 V P_R = 0 mW	
Supply Current	I_{CC}		9	15	mA	$R_{LOAD} = \infty$	
Electrical Bandwidth	BW_E	75	125		MHz	-3 dB electrical	Note 7
Bandwidth * Rise Time			0.41		Hz * s		Note 8
Electrical Rise, Fall Times, 10-90%	$t_{r,f}$		3.3	5.3	ns	P_R = -21 dBm Peak, @ 50 MHz	Note 9 Figure 9
Pulse-Width Distortion	PWD		0.4	1.0	ns	P_R = -14 dBm, Peak, Single-Mode Fiber	Note 10 Figure 8
Overshoot			2		%	P_R = -21 dBm, Peak	Note 11

Notes:

1. 2.0 mm from where leads enter case.
2. The signal output is an emitter follower, which does not reject noise from V_{CC}. Consequently, the power supply must be filtered. The recommended supply is +5 V on V_{CC} for typical usage with +5 V ECL logic. A -5 V supply on V_{EE} is used for test purposes to minimize supply noise.
3. Typical specifications are for operation at T_A = 25°C, V_{CC} = +5 V_{DC}, V_{EE} = 0 V.
4. The test circuit layout should be in accordance with good high frequency circuit design techniques.
5. Measured with a Mini-Circuits 9-pole "brick wall" low-pass filter, BLP-100, with -3 dB bandwidth of 100 MHz.
6. -14 dBm is the maximum peak input optical power from single-mode fiber for which pulse-width distortion is less than 1 ns.
7. Electrical bandwidth is the frequency where the responsivity is -3 dB (electrical) below the responsivity measured at 50 MHz.
8. The bandwidth * risetime product is typically 0.41 because the HFBR-2315T/2315M has a second-order bandwidth limiting characteristic.
9. The specified rise and fall times are referenced to a fast square wave optical source. Rise and fall times measured using an LED optical source with a 2.0 ns rise and fall time (such as the HFBR-1315TM/1315M) will be approximately 0.6 ns longer than the specified rise and fall times. E.g.: measured $t_{r,f} \cong [(\text{specified } t_{r,f})^2 + (\text{test source optical } t_{r,f})^2]^{1/2}$
10. 10 ns pulse width, 50% duty cycle, at the 50% amplitude point of the waveform.
11. Percent overshoot is defined as: $((V_{PK} - V_{100\%})/V_{100\%})$ x 100%. The overshoot is typically 2% with an input optical rise time < 1.5 ns.

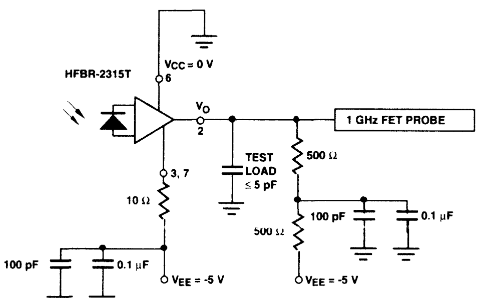


Figure 6. HFBR-2315T/2315M Receiver Test Circuit.

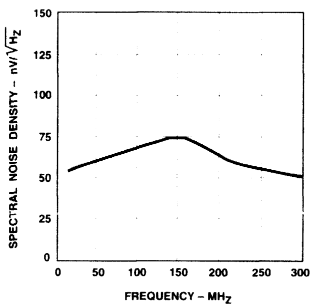


Figure 7. Typical Output Spectral Noise Density vs. Frequency.

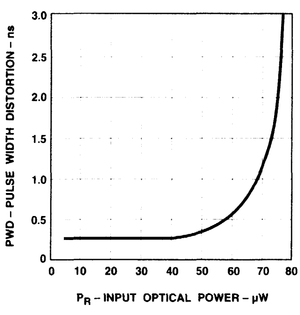


Figure 8. Typical Pulse Width Distortion vs. Peak Input Power.

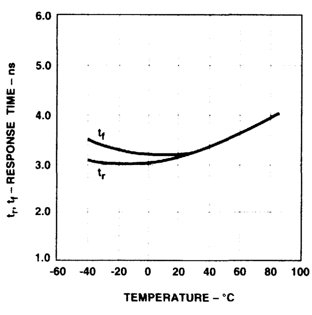


Figure 9. Typical Rise and Fall Times vs. Temperature.

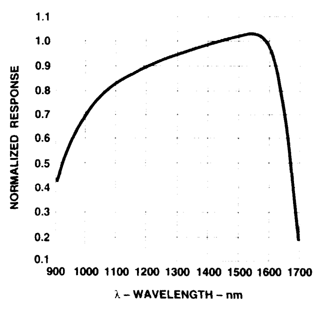


Figure 10. Normalized Receiver Spectral Response.

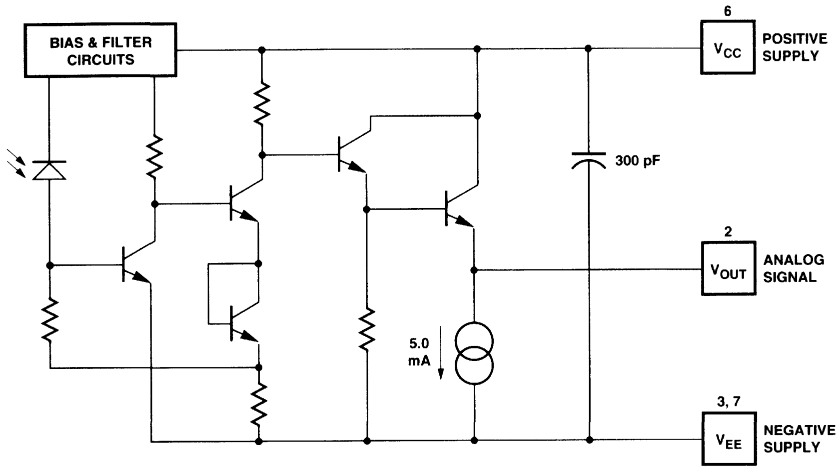


Figure 11. HFBR-2315T Simplified Schematic Diagram.

Applications

Fiber Optic Application Note Index

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Application Note Abstracts

AB 78
Low-Cost Fiber-Optic Links for Digital Applications up to 155 MBd
This application bulletin offers assistance in the transmission of encoded digital signals for HP's HFBR-0400 series components. This is also referred to as run length limited data. The 125 MHz HFBR-24X6 receiver is discussed in full detail in comparison to HP's previous 50 MBd HFBR-24X4 receiver, and design considerations with the HFBR-0400 series components are fully explored.

Design topics discussed include: chromatic and modal dispersion, advantages of data encoding, distance and data rate capabilities, transmitter and receiver design optimization, testing of fiber-optic systems, TTL and ECL transmitter performance, bit error rate versus signal-to-noise ratio, advantages of hysteresis, enhancing receiver sensitivity using low-pass filtering, compromises associated with using high speed 820 nm links, and EMI issues.

Finally, complete recommended drive and receive circuits for high-speed run-length limited data links are presented with TTL or ECL interfaces up to 155 MBd including PCB layout design drawings.

Publication No. 5965-6005E

AN 1035
Versatile Link
This application note describes how fiber optics can be used to solve many different types of application problems, introduces Hewlett Packard's versatile link plastic fiber components, and shows how to design a fiber-optic link using the versatile link. Sections on example applications, versatile link description, system specifications and link design, pulse-width distortion, and additional circuit and recommendations are included. Recommended circuit designs, including design rules and recommended component values are also presented.

Publication No. 5964-4027E

AN 1038
Complete Fiber-Optic Solutions for IEEE 802.3 FOIRL, 10Base-FB and 10Base-FL
This application note explains how to build high-performance ethernet transceivers using Hewlett-Packard's HFBR-0400 series low-cost fiber-optic components and inexpensive off-the- shelf ICs.

The ethernet IEEE 802.3 system specifications are discussed, including the capabilities of the HFBR-0400 series products in relation to this standard.

Complete transmitter and receiver circuit designs for hub, bridge, router, and repeater applications are presented as well as a complete circuit design for fiber-optic Ethernet MAU applications. PCB artwork, layout rules and recommended component values are also provided.

Publication No. 5965-6001E

AN 1057
Conductive Port Receiver
This application note compares the performance of fiber-optic receivers with conductive ports to fiber-optic receivers with non-conductive ports. It explains how conductive port receivers solve specific problems encountered in some applications and how they help to improve the electromagnetic immunity of part number HFBR-24X6XC, required by such standards as MIL 461 and IEC 801-3. This application note also presents test data that shows why HP's low-resistance conductive port has an advantage over the higher-resistance conductive ports of other manufacturers. Test methods are also included.

Publication No. 5091-6001E

AN 1065
Complete Solutions for IEEE 802.5J Fiber-Optic Token Ring
This application note explains how to build high-performance token ring transceivers using Hewlett Packard's HFBR-0400 series low-cost fiber-optic components and inexpensive off-the-shelf ICs.

The token ring IEEE 802.5 system specifications are discussed, including the capabilities of the HFBR-0400 series products in relation to this standard.

Complete transmitter and receiver circuit designs for hub, bridge, router, adapter card and repeater applications are presented as well as measured performance specifications for the HFBR-0400 recommended link. PCB artwork, layout rules and recommended component values are also provided.

Publication No. 5963-9626E

AN 1066
Fiber-Optic Solutions for 125 MBd Data Communication Applications at Copper Wire Prices
This application note demonstrates high-speed fiber-optic links at 125 MBd data rates, while at the same time comparing the costs of wire data communication links to Hewlett Packard's HFBR-0507 series components used with HCS® fiber. A discussion on the benefits of optical fiber over copper wire for communication links appears first. Next, capabilities of the HFBR-0507 series optical components are discussed, including a section on the advantages of data encoding and characteristics of encoders. Complete ECL interface transmitter and receiver circuits are presented, as well as a complete transceiver circuit with a common 1x9 ECL interface. A power supply filter circuit is also presented for this transceiver design. The fourth circuit presented is an interface from the +5 V ECL 1x9 footprint to a common TTL data bus. PCB artwork and component values are also included. Finally, a section on testing digital fiber-optic links is presented with a complete fiber-optic transceiver test fixture recommended.

Publication No. 5965-8542E

AN 1080
DC to 10 MBd Versatile Link with Plastic Optical Fiber or Hard Clad Silica Fiber (HCS®) for Factory Automation and Industrial Control Applications
This application note discusses the functions and features of the 10 MBd HFBR-0508 series components for various industrial applications.

The first section deals with fiber-optic versus electrical link considerations such as interconnects without crosstalk, international EMC regulations, fiber-optic connectors versus electrical connectors, and galvanic insulation.

Section II is the HFBR-0508 series product description, which discusses the housing and optical port, transmitter and receiver technology, and fiber-optic cable types, including plastic and HCS® fiber.

The third section discusses fiber optic link design in full detail. Link length considerations are covered, including optical power budget computation, dynamic range, temperature drift considerations, reliability considerations, and connector and coupling losses. This section also discusses transmitter and receiver interface circuitry in detail including parallel versus serial drive circuits, an example of a series driver circuit using standard TTL buffer ICs, a simple shunt drive circuit diagram, receiver sensitivity discussion, and off-state and overdrive limits on the receiver.

Section IV deals with manufacturing considerations such as handling and assembly guidelines, connectoring guidelines, plastic fiber considerations, 200 μm crimp and cleave termination, and optical port protection.

Next is an application examples section including an introduction to industrial communication networks, and three examples: Interfacing to RS-422 and RS-485, controller area networks, and a gate drive using fiber-optic interfaces.

The last section is an introduction to optical power and loss measurements. In this section you will find recommended equipment and accessories, transmitter output power measurement procedure, receiver sensitivity measurement procedure, and cable attenuation measurement procedure.

Publication No. 5963-6756E

HCS® is a registered trademark of SpecTran Corporation.

AN 1082
Single-Mode Fiber-Optic Solutions for Ethernet LAN Applications

This application note explains how to achieve long-distance Ethernet links using Hewlett-Packard's HFBR-0305 series 1300 nm single-mode family of components. Complete transmitter and receiver circuit designs for single-mode hub, bridge, router, and repeater applications are presented including recommended board layout and component values. A recommended circuit for single-mode Ethernet MAU applications is also presented. These designs are identical to the AN 1038 Ethernet application note recommended circuits except for a few passive component changes. Finally, a fiber-optic link analysis section is included and a note on accounting for fiber repairs and LED aging.

Publication No. 5964-2295E

AN 1121
Inexpensive dc to 32 MBd Fiber-Optic Solutions for Industrial, Medical, Telecom, and Proprietary Data Communication Applications

This application note describes inexpensive solutions for digital fiber-optic data-communication links that are compatible with TTL logic at data-rates between dc and 32 million symbols/second (dc to 32 MBd). When plastic optical fiber is used, the data communication links in AN-1121 can be implemented at costs comparable to copper wire.

AN-1121 provides complete high-performance TTL-compatible digital transceiver solutions which include the schematic, printed circuit artwork, and material lists, so that potential users of this low-cost fiber-optic technology will not need to do any analog design. The fiber-optic transceivers in AN-1121 are able to function with any unencoded arbitrary duty factor or burst-mode protocol commonly used in existing copper wire data communication systems.

Publication No. 5966-1353E

AN 1122
Inexpensive 2 to 70 MBd Fiber-Optic Solutions for Industrial, Medical, Telecom, and Proprietary Data Communication Applications

This application note describes inexpensive solutions for digital fiber-optic data-communication links that are compatible with TTL logic at data-rates between 2 and 70 million symbols/second (2 to 70 MBd). When plastic optical fiber is used, the data communication links in AN-1122 can be implemented at costs comparable to copper wire.

AN-1122 provides complete high-performance TTL-compatible digital transceiver solutions which include the schematic, printed circuit artwork, and material lists, so that potential users of this low-cost fiber-optic technology will not need to do any analog design. The fiber-optic transceivers in AN-1122 are intended for use with encoded data where the duty factor of the data is roughly 50 % and the maximum time interval without a change in logic state (AKA run limit) is less than or equal to 500 ns.

Publication No. 5966-1270E

AN 1123
Inexpensive 20 to 160 MBd Fiber-Optic Solutions for Industrial, Medical, Telecom, and Proprietary Data Communication Applications

This application note describes inexpensive solutions for digital fiber-optic data-communication links that are compatible with +5V ECL (PECL) logic at data-rates between 20 and 160 million symbols/second (20 to 160 MBd). When plastic optical fiber is used the data-communication links in AN-1123 can be implemented at costs comparable to copper wire.

AN-1123 provides complete high-performance PECL-compatible digital transceiver solutions which include the schematic, printed circuit artwork, and material lists, so that potential users of this low-cost fiber-optic technology will not need to do any analog design. The fiber-optic transceivers in AN-1122 are intended for use with encoded data where the duty factor of the data is between 40% to 60% and the maximum time interval without a change in logic state (AKA run limit) is less than or equal to 1 µs.

Publication No. 5966-1269E

AN 1137

Generic printed Circuit Layout Rules for HP's Low-Cost Fiber-Optic Components

Hewlett-Packard's discrete fiber-optic components have been used to construct high-performance optical transmitters and receivers for numerous cost-sensitive LAN, telecom, industrial, and proprietary point-to-point data communication applications. When using discrete fiber-optic components the layout of the printed circuit board will have a significant impact upon the performance of the optical transmitter and receiver. A printed circuit board layout for inexpensive, high-performance fiber-optic transceivers can usually be developed in one design cycle, using the generic rules described in this publication.

Publication No. 5966-2921E

HEWLETT® PACKARD

Low Cost Fiber-Optic Links for Digital Applications up to 155 MBd

Application Bulletin 78

The HFBR-2406/16 High Performance Component

The HFBR-2406 and HFBR-2416 are high-speed, low-cost, linear, light-to-voltage converters with typical bandwidths of 125 MHz. These components can be used to make fiber-optic links for both analog and digital applications. Since the range of possible uses is so varied, this Application Bulletin concentrates on a specific digital application. The application is one of the most prevalent for the HFBR-24X6: the transmission of encoded digital signals, otherwise known as run-length limited* data.

The HFBR-0400 component family's inexpensive, one-piece plastic package allows engineers to construct low-cost high-performance fiber-optic links. All devices in the HFBR-0400 product family, including the HFBR-24X6, are available with optical ports that are compatible with the industry standard SMA and ST** fiber-optic connectors. Components that are compatible with the SMA connector are denoted by a "zero" in the third digit of their part numbers. If the ST connector is to be used, the component part number should contain a "one" in the third digit. For example, the equivalent of the high-performance HFBR-2406 SMA-compatible receiver with the ST connector option is the HFBR-2416.

The addition of the HFBR-24X6 receiver to the low-cost 0400 component family opens new avenues for designers. They can now develop fiber-optic links that meet tough cost and performance objectives. The wide bandwidth of the HFBR-24X6 allows high-speed, fiber-optic links to be built at lower prices than was formerly possible. Engineers can exploit the high performance of the HFBR-24X6 in other ways as well. For instance, the wide bandwidth of the linear light-to-voltage converter can be reduced by a low-pass filter to improve the sensitivity of the fiber-optic receiver in lower-speed applications. The HFBR-24X6 accommodates a larger optical signal than other HFBR-0400 fiber-optic receivers before it begins to overload. This improvement in the overload characteristics of the 24X6 was achieved with no significant reduction in the ultimate sensitivity when compared to the existing HFBR-24X4 receiver. The increased optical input power tolerated by the HFBR-24X6 allows it to function at short fiber lengths with large values of launched optical power. When the receiver can tolerate higher optical power, a longer cable is possible before attenuation reduces the light to the sensitivity limit of the receiver. The increased dynamic range of the HFBR-24X6 will thus permit greater optical link length for any given fiber attenuation.

Applications For 820 nm LED Based Fiber Optic Links

The 820-nm LED technology used in the HFBR-0400 family of components can be used in conjunction with the HFBR-24X6 receiver to construct digital fiber-optic links that transmit data at speeds up to 155 MBd. The length of the fiber cable that can be used with the HFBR-24X6 is restricted by the receiver sensitivity at low data rates. As the data rate is increased a phenomenon known as chromatic dispersion begins to limit the maximum distance. Chromatic dispersion results

* Run length limited means a limit on the number of consecutive symbols in the same state.

** ST is a trademark of AT&T Technologies.

5965-6005E

from the interaction of the 60 nm-wide spectrum emitted by the LED and the propagation velocities of light in silica. Since the velocities of light at various wavelengths near 820 nm are different, the optical pulses sent by the LED are dispersed or spread out in time as they travel down the light guide. A chromatic dispersion null exists at a wavelength of 1300 nm in silica glass. If an LED were operated at the chromatic dispersion null the pulses would experience the minimum broadening as they traveled through the fiber. This is due to the nearly equal propagation velocity for all the wavelengths transmitted through the silica light guide by the long-wavelength emitter. Figure 1 illustrates the effect of the LED center wavelength and spectral width on the chromatic dispersion. An 820 nm LED with a 60 nm emission spectrum is shown to produce a larger change in the arrival time of the light pulses than a 1300 nm LED with a 100 nm spectral width. When selecting a fiber the designer should be aware of how the bandwidth-length product, expressed in MHz/km, was determined. The bandwidth of a fiber measured using a narrow spectrum emitter, such as a laser diode, is related to the various possible modes of light propagation that can exist in a fiber. This is referred to as the fiber's modal bandwidth. The modal bandwidth will be greater than the chromatic bandwidth which dominates when an LED is used. To determine the overall optical bandwidth of a fiber, the modal and chromatic bandwidths must be combined as an rms sum as shown in Equation 1. In LED-based systems the wavelength, spectral width and response time of the emitter used as the fiber-optic transmitter will affect the final system bandwidth. Thus, to understand how a fiber will work with an LED, one must know the type of optical source used to measure the manufacturer's stated bandwidth. HP HFBR-AWSyyy 100/140 µm fiber-optic cable has a typical optical bandwidth-length product of 40 MHz/km. This value represents the performance of the HP fiber with an 820 nm LED emitter that has a 60 nm spectral width. The 40 MHz/km typical bandwidth-length product of HP fiber results from the combination of the modal and chromatic bandwidths.

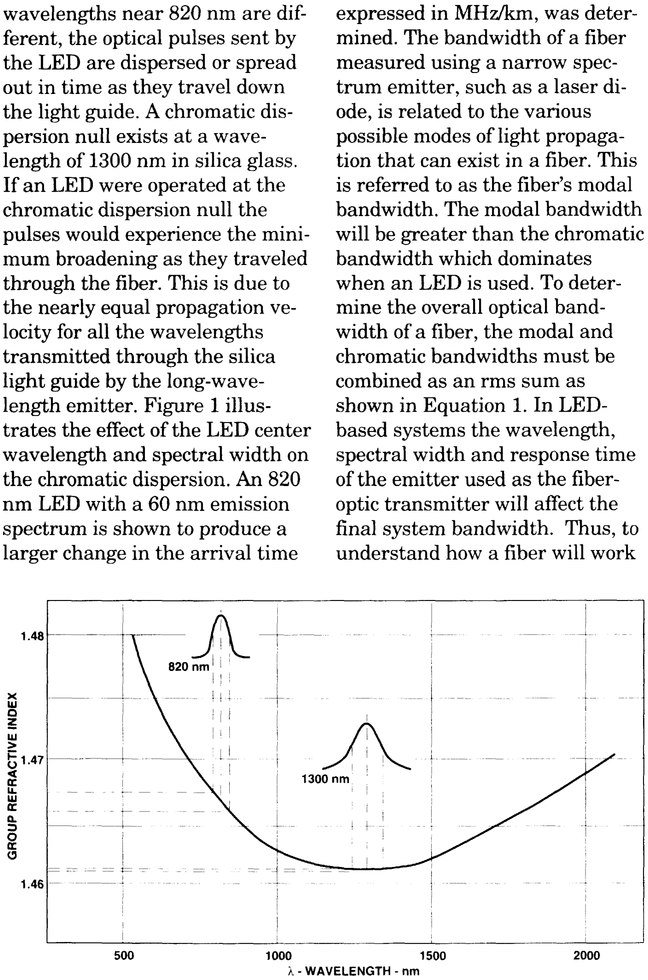


Figure 1. Group Delay vs. Wavelength.

$$\text{B.W.} = \left[\frac{1}{\left(\frac{1}{\text{B.W. modal}}\right)^2 + \left(\frac{1}{\text{B.W. chromatic}}\right)^2} \right]^{1/2}$$

Equation 1.

The typical distances and data rates possible with 820 nm LED emitters and the HFBR-2406/2416 receiver are shown in Figure 2. Note that the data rate versus distance for 100/140 and 62.5/125 µm graded-index fibers are both shown in the figure.[1, 2, 3, 4]

If greater distances or higher speeds are required, other options such as 1300 nm LEDs or laser diodes can meet these objectives. If the system requirements fall to the left of the curves shown in Figure 2 the design goals can be achieved using an 820 nm LED and the HFBR-24X6 for a substantially lower cost than possible with these other technologies. The inexpensive 820 nm LED technology offers the designer a cost-effective solution sufficient for many short-distance applications at data rates in excess of 100 megabaud.

Applications for 820 nm LED Based Systems Using HFBR-2406/2416 Include:

- CPU to disc interface.
- CPU to monitor interface
- CPU to peripheral interface
- Optical data bus applications.

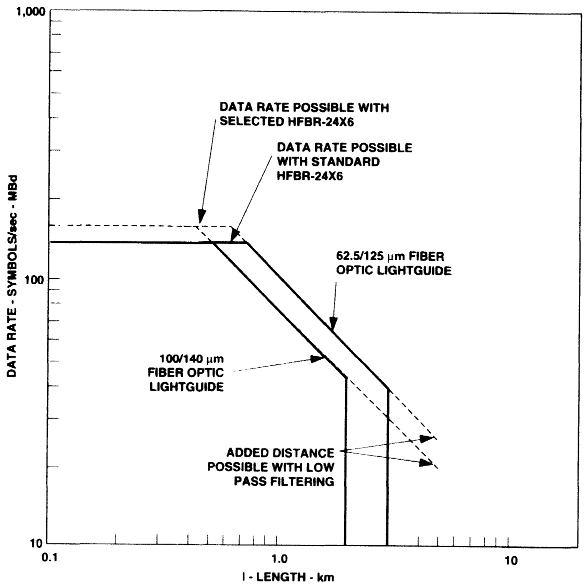


Figure 2. Typical Data Rate and Distance Possible with HFBR-2406/2416.

- Graphics workstation to host computer interface.
- Wide dynamic range, long distance, medium speed LAN applications.
- High-speed, point-to-point data links.
- Security, voltage isolation.

Advantages of Run Limited Code

Data is coded to prevent the digital information from remaining in one of the two possible logic states for an indefinite period of time. The coded data allows the fiber-optic receiver to be ac coupled. Without encoding, the fiber-optic receiver would have to detect dc levels to determine the proper logic state during long periods of inactivity, as when there is no change in the transmitted data. AC-coupled fiber-optic receivers tend to be lower in cost, are much easier to design, and contain fewer components than their dc-coupled counterparts.

Direct coupling decreases the sensitivity of a fiber-optic receiver since it allows the low-frequency flicker noise from the transistor amplifiers to be presented to the comparator input. Any undesired signals coupled to the comparator will reduce the signal-to-noise ratio at this critical point in the circuit, and reduce sensitivity of the fiber-optic receiver.

Another problem associated with direct-coupled receivers is minimizing the accumulation of dc offset. With direct coupling, the gain stages multiply the effects of undesirable amplifier offsets and voltage drifts due to temperature changes, and apply them to the comparator. Increases in the dc offset applied to the comparator result in reduced sensitivity of the fiber-optic receiver. The dc offset at the comparator can be referred to the optical input of the receiver by dividing by the receiver gain. This division refers the dc offset at the comparator to the receiver input where it appears as a change in optical power that must be exceeded before the receiver will switch states.

Another advantage of run-limited coding is related to timing recovery. If NRZ data were transmitted over a serial fiber-optic link the data could be in the logic "1" or logic "0" state for an indefinite period of time. When NRZ data remains in a particular state no transitions occur and the fundamental frequency of the data is dc. This lack of power at the fundamental frequency of the data eliminates the reference signal needed by the timing recovery circuits required to clock the received information. If an optical link is to transmit NRZ data, a clock signal must be sent on a separate fiber-optic link to synchronously detect the incoming serial data.

The particular run-length-limited code chosen must be considered carefully since it will affect the bandwidth required by the serial communication channel. A complete discussion of all run-limited codes is beyond the scope of this publication. If you desire additional information regarding various coding schemes, there are numerous technical papers devoted to this specific topic.[5] Without becoming too involved in the complexity of encoding selection, a quick comparison will now be made between two commonly recognized approaches to this problem.

One of the most familiar run-limited codes is Manchester. Manchester is very popular since it can be encoded and decoded with relatively simple circuits. Manchester works well in ac-coupled systems since it has a 50% duty factor and two pulses or symbols for each bit transmitted. This simplifies the design and implementation of the timing recovery function since Manchester code has only two consecutive symbols without a transition, or a run limit of two. A drawback of Manchester is that two symbols must be sent for each data bit encoded, thus doubling the fundamental frequency that must pass through the information channel. Substitution codes have recently been made available in very large scale integrated (VLSI) circuits. These VLSI circuits function as a general purpose interface between the parallel architecture found in computer-based systems and the serial format required by fiber-optic communication links. The two different substitution codes available in the AMD TAXIchip™ parallel-to-serial encoder are 4B5B and 5B6B. These two codes have an efficiency of 4/5 and 5/6 respectively which compares to an efficiency of 1/2 for Manchester code. The significance of coding efficiency can be illustrated by an example. If an application calls for the transmission of 100 M bits/second, Manchester code requires that the information channel must pass 200 M symbols/second or 200 MBd. If the more efficient 4B5B code were used, 100 M bits/second could be sent at a speed of (5/4)(100 M bit/sec) = 125 MBd. Similarly, use of 5B6B would allow transmission of this data at a speed of (6/5)(100 M bit/sec) = 120 MBd.

Regardless of the particular coding scheme used there will always be two symbols per cycle. This is true because each half cycle of the maximum fundamental frequency that the communications channel must pass is equivalent to a symbol in a binary transmission system.

Designing With Fiber Optic Components

Transmitter Design

Now that the basic issues related to fiber-optic link design have been covered, some specifics related to the design of the optical transmitters and receivers will be discussed in greater detail. To achieve the wide bandwidth performance potential of the fiber-optic medium requires a fast LED and current modulator. The transmitter's pulse-width distortion and optical rise and fall times can be heavily influenced by the driver selected. Readily available off-the-shelf integrated circuit current drivers can be configured with the HFBR-14XX 820 nm LEDs to build high-performance fiber-optic transmitters with a typical pulse-width distortion of 800 psec.

To obtain the best performance from any LED and driver combination, two simple techniques known as prebias and drive current peaking should be employed. Prebias, as its name implies, is a small forward current applied to the LED in the "off" or "low" light state. The prebias current prevents the junction and parasitic capacitances from discharging completely when the LED is in the "off" state, thus reducing the amount of charge that the driver must transfer to turn the emitter back on. Peaking is a momentary increase in LED forward current that is provided by the driver during the rising and falling edges of the current pulses that are used to modulate the emitter. If the time constant of the peaking circuit is approximately equal to the minority carrier lifetime of the emitter, the momentary increase in LED current will transfer charge at a rate that improves the rise or fall time of the light output without causing excessive overshoot of the optical pulses. Problems that can result when excessive peaking is applied to the LED are illustrated in Figure 3. The narrow optical overshoot due to excessive peaking of the transmitter causes a narrow electrical output pulse from the fiber-optic receiver that must now be damped. Even if the receiver amplifiers were critically damped the electrical undershoot resulting from excessive peaking of the emitter can reduce the sensitivity of the fiber-optic link. This electrical undershoot can combine with noise from the amplifiers so that the sum of these two voltages exceeds the decision threshold of the comparator, which converts the low-level analog output of the fiber-optic receiver back to logic-compatible digital signals. Excessive peaking during the turn-off of the emitter can cause additional problems. Too much reverse current during the turn-off transition will reverse-bias the LED, seriously degrading the turn-on time.

A circuit with a low source impedance should be used to drive the LED. This is important because the light output of an LED is proportional to the number of electron hole pairs present in the LED's junction. If high speed operation of the transmitter is desired, a driver with a low source impedance should be used to provide the sudden changes in current required to quickly create and annihilate charge carriers in the LED junction. LEDs are characteristically harder to turn off than to turn on. This difficulty manifests itself as a phenomenon commonly referred to as the long-tailed response. An example of long-tailed response is shown in Figure 4. The long-tailed response is most evident when a simple series switch is used to control the LED drive current as shown in Figure 5. A shunt drive configuration, which turns the LED off when the driver transistor saturates, significantly improves the performance of the LED transmitter. Shunt drive reduces pulse-width distortion and the magnitude of the slow tail by providing a low impedance path for charge stored in the LED junction. Without this low-impedance path the emitter would turn off slowly since the LED would continue to produce light until the diode junction discharges.

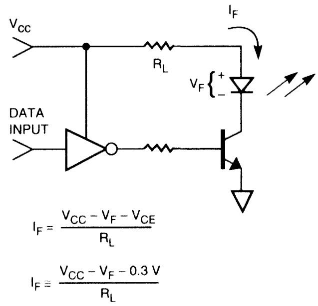


Figure 5. Series Switch LED Driver.

Readily available 74ACT logic gates can be used to implement a shunt drive configuration to current-modulate the LED. A current of 60 mA is typically required to drive the HFBR-14X2/4. Ordinary bipolar TTL gates generally do not have sufficient capability to sink and source 60 mA. A simple high-speed LED driver can be constructed by connecting the active output of 74ACT logic to the HFBR-14X2/4 as shown in Figure 6. In this configuration the pull-up transistor turns the LED off, and the pull-down transistor turns the LED on. The low impedance and high current rating of the MOSFET transistors used in 74ACT output stages allows these gates to quickly inject and remove charge from the LED. The ability of 74ACT gates to quickly move charge is very important as the LED turns off. The dynamic impedance of the LED increases rapidly as forward current decreases at turn off. The LED will continue to emit light as long as the junction contains minority charge carriers. The pull-up transistor of the 74ACT LED driver provides the low impedance discharge path needed to sweep charge from the junction and rapidly quench the light emitted by the LED. The low impedance of the pull-down

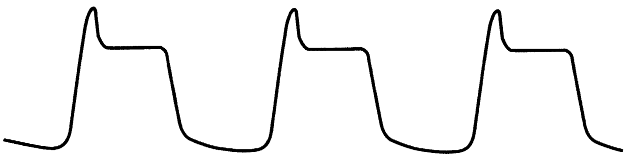


Figure 3a. Optical Overshoot Due to Excessive Peaking of the LED Drive Current.

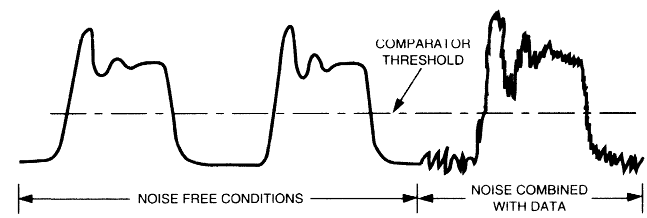


Figure 3b. Response of Optical Receiver to an Excessively Peaked LED Transmitter.

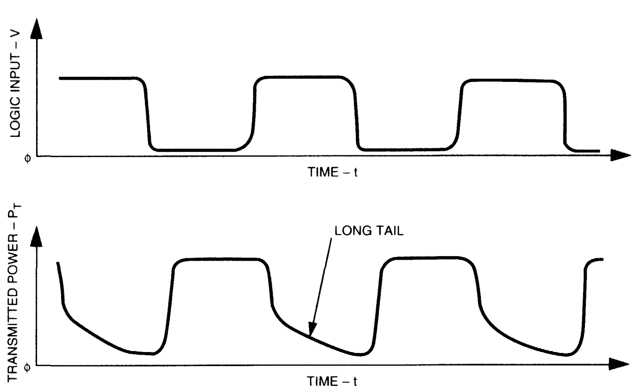


Figure 4. Example of Long-Tailed Response.

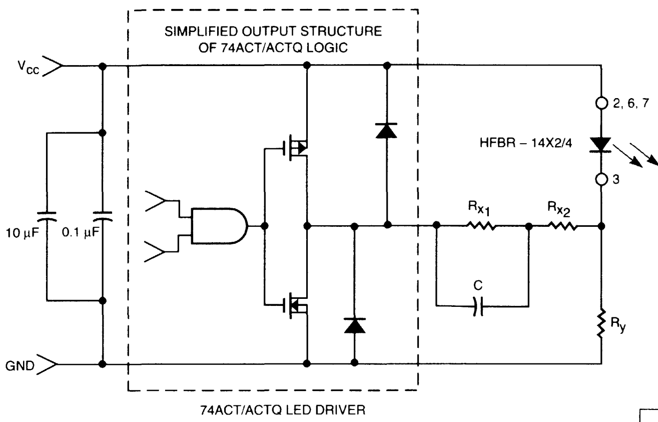


Figure 6. Simple High-Speed Transmitter Circuit.

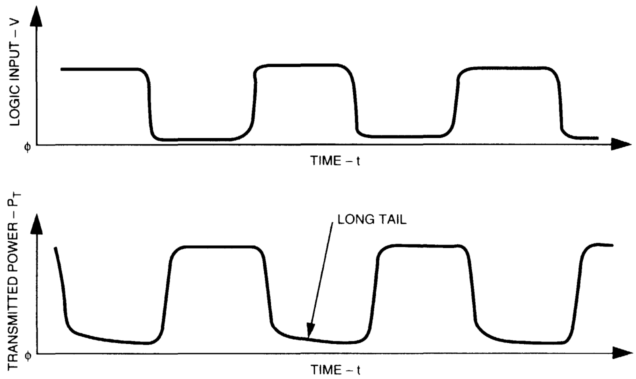


Figure 7. Improved Optical Output Waveform.

Equation 2.

N = The number of 74ACT gates connected in parallel.

B = Is an empirically determined constant which establishes an optimum relationship between prebias and LED forward current.

$$R_y = \frac{(V_{CC} - V_F)(1 + B)}{I_{F\ ON}}$$

$$R_{X_1} = \left(\frac{R_y}{2B}\right)$$

$$R_{X_2} = \left(\frac{R_y}{2B}\right) - \left(\frac{3}{N}\right)$$

$$C = \frac{2.5\ \text{ns}}{R_{X_1}}$$

transistor ensures that the LED turns on quickly by providing the current needed to rapidly charge the junction during the less difficult turn-on transition. When the 74ACT gate and LED are configured as shown by the schematic in Figure 6, the improvement in the optical output waveform is as shown in Figure 7. The high speed capability of 74ACT logic minimizes the difference between high-to-low and low-to-high propagation delays. The variance between t_{PHL} and t_{PLH} of the gate used to drive the LED will affect the pulse-width distortion present in the transmitter's optical waveform. When nand inverters from the same die are connected as shown in Figure 8 the distortion due to gate propagation delay differences is minimized. The transmitter circuit shown in Figure 8 typically has an optical jitter of 800 ps; this excellent transmitter performance can be achieved when an undistorted TTL signal is applied to the 74ACTQ00 quad nand gate used to current modulate the HFBR-14X2/4 LED.

The transmitter shown in Figure 8 is compatible with TTL logic and is suited for data with a maximum fundamental frequency of 78 MHz, which implies a symbol rate of 155 MBd. The design rules for the LED driver shown in Figure 8 are shown in Equation 2. This simple TTL-compatible fiber-optic transmitter has a typical rise/fall time of 3 ns.

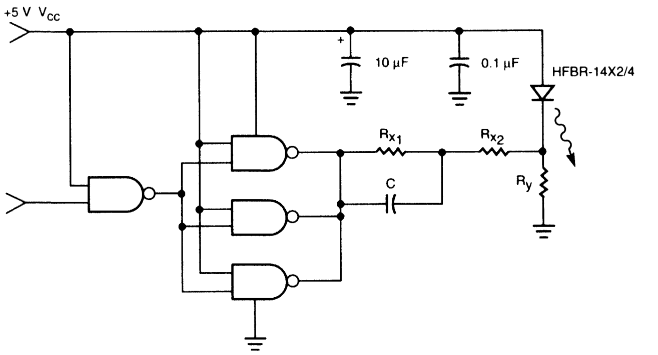


Figure 8. TTL Compatible LED Driver Implemented with 74ACT or 74ACTQ nand Logic.

Testing Fiber Optic Systems

Pseudo-random-bit-sequence (PRBS) generators are very useful for testing the performance of fiber-optic systems. The pseudo-random data pattern contains long periods of inactivity related to the length of the shift register used to build the PRBS generator. A PRBS generator made up of a 23-bit-long shift register could at any given clock time contain one of 8,388,610 possible data patterns. The number of data patterns possible can be calculated as 2^{23}-1 since the state where all shift register stages contain logic zeros is not allowed. These long periods of inactivity in the data pattern produced by the PRBS generator allow time for parasitic capacitances in the transmitter and receiver to charge. The time required to charge and discharge undesired capacitances in the transmitter and receiver result in pulse-width distortion related to the instantaneous duty factor of the data. This phenomenon is known as data dependent jitter or DDJ. If an oscilloscope is clock triggered on the PRBS generator it asynchronously samples the data due to the lack of correlation between the PRBS clock and the time base that generates the horizontal sweep of the scope. When triggered on the PRBS generator's clock the scope will display a signal known as the "eye pattern". The "eye pattern" can be very useful since the width and height of the opening between the data edges defines the time period during which the data is in a valid logic state.

TTL Transmitter Performance

The performance of the circuit shown in Figure 8 was tested using a 2^{23}-1 PRBS data pattern to demonstrate the typical performance of this TTL transmitter. Jitter in the data edges results due to the DDJ induced by the pseudo random bit sequence. The eye pattern shown in Figure 9 reveals that the HFBR-14X2/14X4 LED transmitter had a total data-dependent edge jitter of 800 ps when driven by the 74ACTQ00 gate at a rate of 155 MBd. This data was taken at an ambient temperature of 25°C and represents the typical performance possible with this simple fiber-optic transmitter. The total pulse-width distortion can be further reduced by using a limited-range potentiometer in place of fixed values of R_y for system applications that are extremely intolerant of symbol-width variations. But for most data communications applications, this transmitter performs adequately at speeds up to 155 MBd using fixed component values.

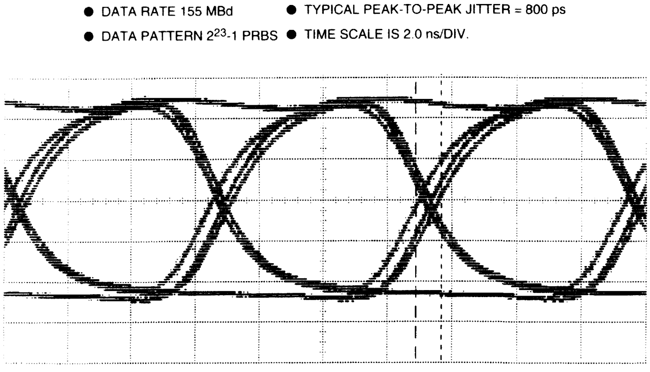


Figure 9. Optical Output of the TTL Transmitter.

ECL Transmitter Performance

If an ECL-compatible fiber-optic transmitter is needed it can be easily built using the circuit shown in Figure 10. The design rules for this high-performance fiber-optic transmitter are given in Equation 3. This particular transmitter uses a simple ECL to TTL converter and 74ACTQ nand logic in conjunction with the HFBR-14X2/X4 LED emitter. It is capable of typical optical rise/fall times of 3 nsec. The performance of the ECL transmitter was measured with a BCP Model 300 Optical Waveform Receiver. Figure 11 shows the optical "eye" pattern when a 155 MBd pseudo-random-bit-sequence of 2^{23}-1 is applied to the ECL transmitter.

Equation 3. Design Rules for 74ACTQ00 LED Driver Circuits.

N = Number of gates connected in parallel.

B = Empirically determined constant for optimum relationship between prebias and LED forward current.

$$R10 = \frac{(V_{CC} - V_F)(1 + B)}{I_{F\ ON}}$$

$$R8 = \frac{R10}{2B}$$

$$R9 = \frac{R10}{2B} - \frac{3}{N}$$

$$C4 = \frac{2.5 \times 10^{-9}}{R8}$$

Recommend B = 3.97

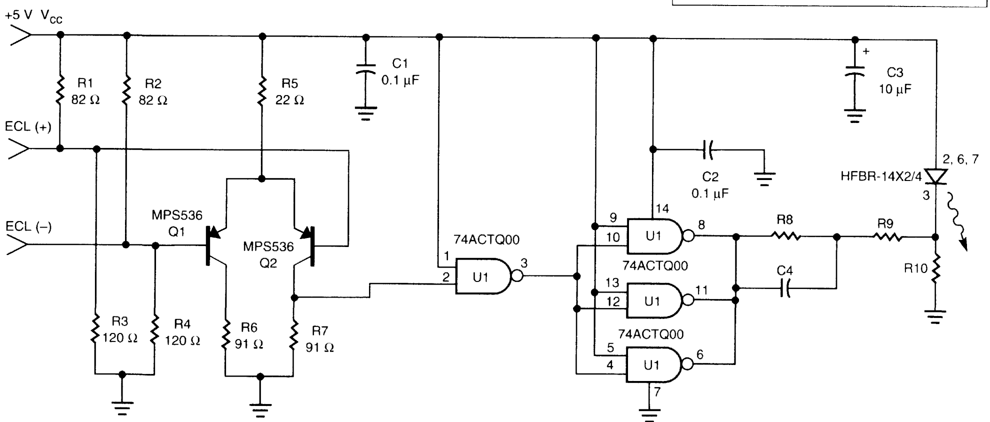


Figure 10. Transmitter with +5 V ECL Interface.

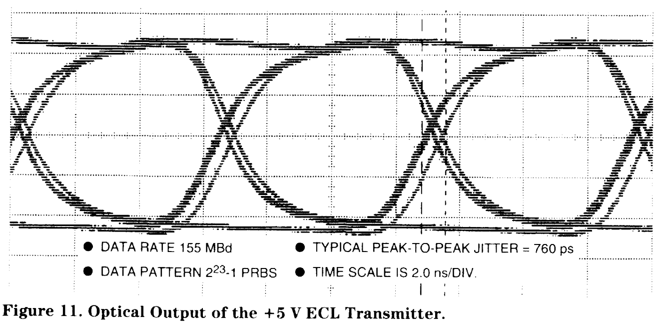


Figure 11. Optical Output of the +5 V ECL Transmitter.

Receiver Design

Now that the techniques required to build high-speed fiber-optic transmitters have been explained, emphasis must be placed on the methods necessary for design and construction of the fiber-optic receiver. Figure 12 shows the functional blocks required to interface the HFBR-24X6 light-to-voltage converter to digital logic. The HFBR-24X6 has a low-level analog output related to the incoming optical power by the 7 mV/µW conversion gain of the light-to-voltage transducer. The HFBR-24X6 needs additional external gain stages to increase the amplitude of its output before it can interface to any of the standard logics like TTL or ECL. The output voltage of the HFBR-24X6 is proportional to the received optical flux. Since the received optical power changes as a function of the fixed optical losses and as a function of fiber-optic link length, some provision must be made to accommodate the change in the output voltage of the light-to-voltage transducer. An amplifier with AGC or a limiting amplifier is needed to accommodate the wide range of output voltages that are possible under various fiber link operating conditions. In the following example, calculations show that the output voltage of the HFBR-24X6 could range from a minimum of 2.9 mV pp to a maximum of 1.74 V pp. This output voltage range is for worst-case conditions at a BER less than or equal to 1×10^{-9} when the component operates between -40 to +85°C.

Calculation of HFBR-24X6 Output Voltage Range

The peak-to-peak signal to rms noise ratio needed at the comparator input for a BER of 1×10^{-9} = 12:1.

This implies an extinction-to-peak (peak-to-peak) change in the received optical flux of (12) (rms noise) will be required. Thus, the peak-to-peak-to-rms-noise ratio required by the fiber-optic receiver for a BER of 1×10^{-9} becomes $(\text{Signal}_{pp}) / (\text{noise}_{rms}) = 12:1$.

The noise floor of the HFBR-24X6 is -43 dBm rms typical.

-43.0 dBm + [10 log (12/1)] = -43.0 dBm + 10.8 dB = -32.2 dBm pk. Thus -32.2 dBm pk is the minimum received optical power that will yield a BER better than or equal to 1×10^{-9}.

-32.2 dBm implies [antilog (-32.2/10)](1,000) = 0.603 µW minimum received optical power for BER better than or equal to 1×10^{-9}.

This minimum power of 0.603 µW implies a change in the receiver input from approximately 0 µW to 0.603 µW or a peak-to-peak change of approximately 0.603 µW pp. The minimum output of the HFBR-24X6 thus becomes (0.603 µW pp)(4.5 mV/µW) = 2.71 mV pp.

The HFBR-24X6 overloads at -8.2 dBm worst-case minimum. Overload is specified as P_r maximum on the data sheet. Overload is defined as the received optical power at which the output pulses from the HFBR-24X6 are distorted 2.5 ns due to saturation of the transimpedance amplifier that converts photo-current to voltage.

-8.2 dBm implies [antilog (-8.2/10)](1,000) = 151 µW. Thus the maximum allowed power of 151 µW implies a change in the receiver input from approximately 0 µW to 151 µW or a peak-to-peak change of approximately 151 µW pp. Thus a maximum received optical power of 151 µW implies a maximum output voltage of (151 µW pp) (11.5 mV/µW) = 1.74 V pp.

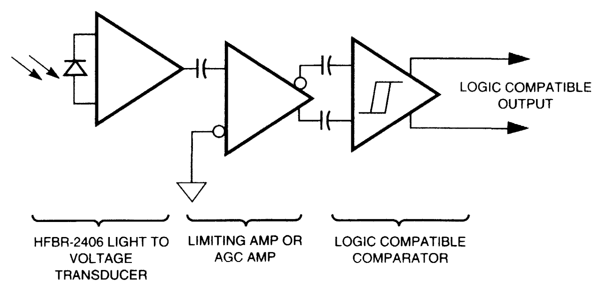


Figure 12. Fiber-Optic Receiver Block Diagram.

Error Rate Versus Signal-to-noise Ratio

The bit error rate (BER) possible with a fiber-optic link is a function of the difference between the peak-to-peak signal and the RMS noise voltages present at the comparator input. A linear relationship exists between optical power entering the HFBR-24X6 and the voltage output of the fiber-optic receiver, provided that interstage coupling and post amplifiers do not introduce significant distortion. This linear relationship implies that if a peak-to-peak signal voltage 12 times larger than the RMS noise voltage is needed at the comparator to ensure a BER of 1 x 10^{-9}, then the same ratio will be required at the receiver input. Thus the difference between the peak-to-peak optical input of light pulses applied to the HFBR-24X6 and the RMS equivalent noise power referred to the optical input must also be 12 to 1. Some confusion exists because changes in the emitter output from extinction to maximum power are often referred to as peak excursions of the transmitter launched power. This confusion results since the transmitter output is varying from zero light to a maximum or peak light output. The extinction-to-on excursion in the optical output of an emitter is actually a peak-to-peak change in intensity. Figure 13 is a graph of receiver signal-to-noise ratio versus BER. The relationship shown in Figure 13 was obtained from extensive reduction of statistical theory that relates the probability of an error to the receiver's signal-to-noise ratio.

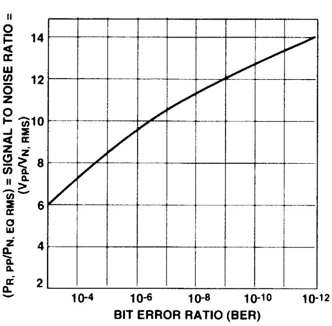


Figure 13. Signal-to-Noise Ratio vs. Probability of Error.

Advantages of Hysteresis

The use of hysteresis in the digitizer will not change the signal-to-noise ratio required at the comparator for a particular BER. Hysteresis will, however, introduce a discontinuous response in the receiver that alters the ratio between peak signal level and the RMS noise in stages prior to the comparator. When dual-threshold detection is used, the signal-to-noise ratio required at the decision circuit for a particular error rate is unaffected but the change in the received power level required to switch the state of the comparator is increased in proportion to the amount of the hysteresis. Dual-threshold receivers experience a reduction in sensitivity proportional to the amount of hysteresis used; however, this type of digitizer offers some interesting advantages. Hysteresis is used in all the receivers shown in this Application Bulletin. Use of hysteresis insures that the logic output of the fiber-optic receiver will not toggle in response to the rms output noise voltage of the HFBR-24X6 when no fiber is connected.

Low-pass Filtering to Enhance Receiver Sensitivity

The importance of filtering to eliminate unnecessary receiver bandwidth becomes apparent by studying Figure 14, which shows the relationship between frequency and the spectral noise density of the HFBR-2406/2416. If the fiber-optic link under consideration were intended for operation at 50 MBd (which implies a fundamental data frequency of 25 MHz) a substantial increase in receiver sensitivity can be realized. This increase in sensitivity is obtained by filtering out the noise peak that occurs in the HFBR-24X6 at higher frequencies than required for this application.

The selection of the low-pass filter corner frequency should be carefully considered since it is affected by the response of the transmitter, fiber, and receiver. To prevent problems that will cause interference between adjacent pulses of data transmitted over the fiber-optic communications channel, the bandwidth of the entire system from transmitter to receiver must be properly specified. A problem known as intersymbol

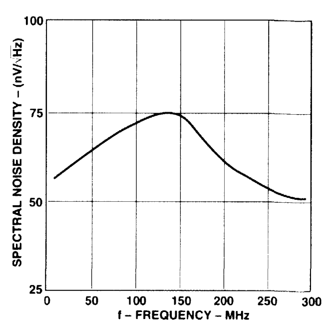
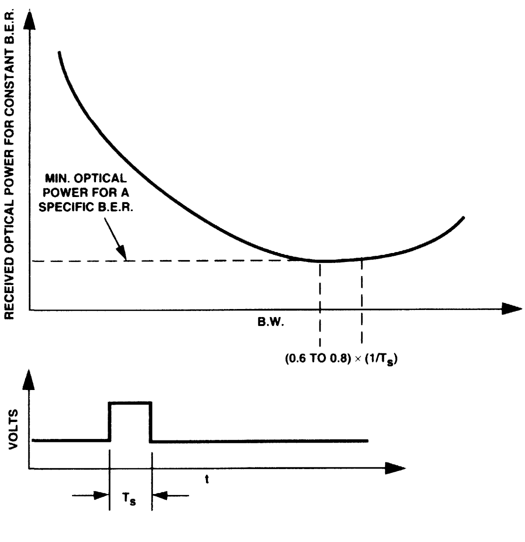


Figure 14. Frequency vs. Spectral Noise Density of the HFBR-2406/2416.

interference develops when the channel bandwidth is not correctly related to the minimum pulse width of the data that is to be transmitted over the communications system. Insufficient system bandwidth manifests itself as distortion in the receiver output signal at time intervals adjacent to the edges of each symbol. This distortion results in interference between adjacent pulses, which can combine with system noise to create errors. Noise is also directly related to bandwidth. Thus, fiber link performance and BER will degrade if system components are excessively fast. For optimum performance that minimizes the amount of optical power required at the receiver for a given BER, the system bandwidth should ideally be constrained to range between 0.6 to 0.8 times the signaling rate in baud, as shown in Figure 15a. If the bandwidth of the fiber-optic communications channel is excessive, a low-pass filter that restricts the system bandwidth to the amount shown in Figure 15a should be constructed in the fiber-optic receiver, at a point ahead of the decision circuit or comparator. For best results the low-pass filter chosen to limit the bandwidth should be a high-order, linear-phase type whenever practical. As the frequency increases, the cost and complexity of a linear-phase high-order filter may become excessive. These higher-speed applications will continue to benefit from a simple first-order or second-order RC low-pass filter that will still be practical to implement.



T_s IS THE MINIMUM PULSE WIDTH OF THE INFORMATION SENT OVER THE COMMUNICATION CHANNEL.

$B.W._{OPTIMUM}$ = [0.6 TO 0.8] (Hz/ baud) × [1/T_s] (SYMBOLS/sec)

$B.W._{OPTIMUM}$ = [0.6 TO 0.8] (Hz/ baud) × [1/T_s] (baud)

Figure 15a. Optimal Relationship Between Fiber-Optic Link Bandwidth and Maximum Receiver Sensitivity.

Compromises Associated With High Speed 820 nm Links

Systems with bandwidths less than (0.6 to 0.8) x (baud) will continue to function since catastrophic failure does not result if these recommendations are violated. Fiber-optic links with bandwidths less than (0.6 to 0.8) x (baud) will have a smaller optical power budget (OPB) than comparable optical links which operate in the flat portion of Figure 15b. This reduction in the OPB is sometimes called the chromatic dispersion power penalty. A decrease in the OPB due to chromatic dispersion is most apparent as an increase in the received power needed to assure a specific BER. The chromatic dispersion power penalty can be directly measured by testing the same transmitter and receiver with both long and short fibers. A fiber-optic link operated beyond the flat portion of Figure 15b requires more received optical power to offset the reduction in signal amplitude due to chromatic bandwidth limitations. Chromatic bandwidth limitations can be overcome if sufficient power is available at the receiver to provide the signal-to-noise ratio necessary for the BER required. The -32 dBm average sensitivity typically obtained when HFBR-24X6 is operated

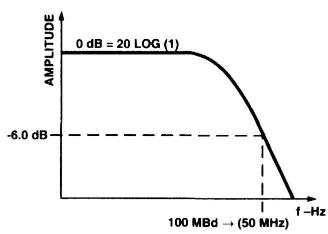


Figure 15b. Optical Link with Normalized Mid-Band Amplitude Response.

with short fibers will allow longer fiber-optic links to operate at frequencies beyond the flat portion of the system's amplitude response. Figure 15b is an example of an optical link whose mid-band amplitude response has been normalized to one. If this hypothetical link were operated at a frequency that reduced the total system output to 6 dB below mid-band amplitude, excess optical power margin (OPM) can still be shown to exist. This excess OPM, as calculated in Equation 4, is sufficient for low-error transmission of 100 MBd data over a 1 km length of 62.5/125 graded index fiber. The HFBR-24X6 receiver has typically demonstrated a BER less than or equal to 1×10^{-9} at received optical powers of -32 dBm average (-29 dBm peak) at 100 MBd with a short 1 m length of fiber. In this somewhat pessimistic example, the link sensitivity was assumed to decrease by 6 dB, due to chromatic dispersion of a 1 km length of 62.5/125 µm fiber. The following calculation shows that an ample 3.25 dB OPM remains to assure that the BER is better than 1×10^{-9} when 100 MBd data is transmitted over a 1 km length of 62.5/125 µm fiber.

High-frequency Circuit Design

The HFBR-24X6 and each of the amplifiers used in the 10H116 are stable gain blocks that have no tendency to oscillate. Although each of these components is individually stable, the combined phase shift and gain that results when they are cascaded might produce oscillation unless proper circuit construction techniques are used. The effect of all the amplifier poles that accumulate as the signal is amplified and digitized by the various gain blocks in the receiver results in a very steep high-order roll-off for the overall input-to-output open-loop receiver gain. In essence, the fiber-optic receiver relies on the fact that it is an open-loop system. It has sufficient gain and phase shift to meet the criteria for oscillation if the loop were to be closed. To assure stability the loop gain must be kept to less than unity; to prevent oscillation the attenuation of parasitic and conductive feedback paths must be greater than the gain of the receiver. Parasitic feedback from the high-level logic-compatible output must be kept to a minimum by layouts that physically separate the receiver inputs and outputs. Filtering must be used to ensure that power supply busses do not provide a metallic feedback path that will degrade the stability of the receiver, and a ground plane is recommended to minimize the inductance of supply commons.

When good layout practices are employed, fiber-optic receivers with 155 MBd data rates can be easily constructed using commonly available breadboarding techniques. A sound breadboard technique suitable for prototyping the HFBR-2406/2416 can be implemented using perforated PC boards with holes on tenth-inch centers and a copper-clad ground plane on one side only. Use a small hand-held twist drill holder (pin vise) and a number 32 drill to clear copper away from holes through which the component leads will pass. Do not clear all the copper away between these holes. This copper provides ground connections between each IC lead, thus reducing ground-loop size and increasing circuit performance. Install the components on the copper foil side using the component leads for point-to-point wiring interconnections on the insulated side of the board. Production fiber-optic systems can

Equation 4.

OPM (dB) = Optical power margin.

P_R (dBm) = Optical power required at HFBR-24X6 receiver for BER $\leq 1 \times 10^{-9}$.

P_T (dBm) = Transmitter launched power

CDP (dB) = The chromatic dispersion power penalty due to fiber bandwidth, response time of the transmitter, and response time of the receiver.

α_o (l) (dB) = fiber loss.

$OPM = -(P_R) + P_T - \alpha_o(l) + CDP$

OPM = - (-29 dBM) + (-16 dBm) - (3.75 dB/km) (1 km) - 6 dB

OPM = 3.25 dB

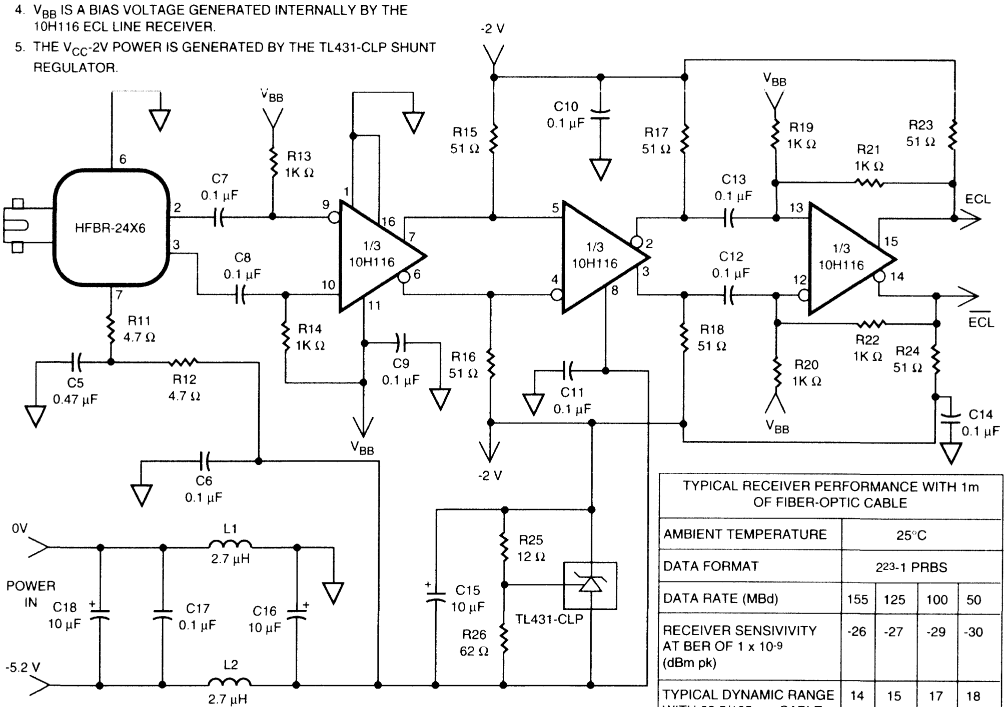
be implemented on ordinary double-sided G-10 printed circuit material or multi-layer boards as long as the layout practices discussed here are observed.

The importance of good construction and layout practices cannot be over-stressed: poor circuit design will seriously degrade system performance. Circuit designs that result in excessive amounts of parasitic inductance or capacitance will degrade the stability and bandwidth of the fiber-optic receiver. Any unintended reduction in the bandwidth or stability of the receiver will result in loss of receiver sensitivity or, in the case where received optical power is held constant, could degrade the BER. It is generally acknowledged that the receiver is the most critical portion of the fiber-optic link electronics. Despite this tendency to focus on the receiver, careful attention must be paid to the transmitter. Care should be taken to keep traces short in the transmitter to minimize inductance of conductors that must carry fast current pulses which can reach momentary peak values as large as 140 mA.

EMI Issues

If a fiber-optic transceiver is to be constructed, additional attention must be paid to minimize crosstalk between a transmitter that is switching hundreds of milliamps and a receiver whose optical detector will have photocurrents as small as hundreds of nanoamps. Individual ground

NOTES:
1. ALL RESISTORS ARE ±5% TOLERANCE.
2. ALL ELECTROLYTIC CAPACITORS ARE ±20% TOLERANCE. ALL OTHER CAPACITORS SHOULD BE RADIAL LEAD MONOLITHIC CERAMIC TYPES WITH ±10% TOLERANCE.
3. L1 AND L2 SHOULD HAVE A ±10% TOLERANCE, SERIES RESISTANCE OF ROUGHLY 0.5 Ω, AND A SELF RESONANT FREQUENCY ≥ 100 MHz.
4. V_{BB} IS A BIAS VOLTAGE GENERATED INTERNALLY BY THE 10H116 ECL LINE RECEIVER.
5. THE V_{CC}-2V POWER IS GENERATED BY THE TL431-CLP SHUNT REGULATOR.



TYPICAL RECEIVER PERFORMANCE WITH 1m OF FIBER-OPTIC CABLE				
AMBIENT TEMPERATURE	25°C			
DATA FORMAT	2^{23}-1 PRBS			
DATA RATE (MBd)	155	125	100	50
RECEIVER SENSIVIVITY AT BER OF 1 x 10^{-9} (dBm pk)	-26	-27	-29	-30
TYPICAL DYNAMIC RANGE WITH 62.5/125 µm CABLE	14	15	17	18

Figure 16a. 155 MBd Fiber-Optic Receiver for -5.2 V ECL Interface.

planes are recommended for the transmitter and the receiver if they are to be laid out next to one another as is typically done in transceivers. The receiver designs shown in Figures 16a, 17a & 18a use a balanced power supply filter that eliminates noise conducted by both the power and common sides of the voltage source used to power the circuit. This filter should be located between the fiber-optic receiver and the noisy voltage source that powers the digital logic to which the fiber-optic receiver must interface. The fiber-optic transmitter can be directly connected to the noisy logic power supply. The transmitter is a large signal device that is not particularly sensitive to digital system noise. Note that when using the balanced power filter a differential interface between the receiver's digital output and the host systems is required.

Another factor that could degrade the performance of a fiber-optic receiver is environmental noise. The HFBR-2406/2416 combines the PIN diode optical detector and the current-to-voltage converter in a small hybrid package. This miniature hybrid package reduces the size of the antenna at the high-impedance input of the transimpedance amplifier that converts the photo-current to a voltage. The small geometry of this hybrid circuit allows the light-to-voltage converter to achieve excellent electro-magnetic interference immunity. Caution must be exercised, however, to ensure that the metal ferrule of the fiber-optic connector does not act as an EMI source by contacting electrically noisy parts of the system in which it is used. Electrostatic shielding should be applied to the receiver if the system using the fiber-optic link is extremely noisy. For noisy system applications the HFBR-2406C or HFBR-2416TC receivers should be specified. The HFBR-2406C and HFBR-2416TC utilize a conductive plastic housing which provides the shielding needed for electrically noisy environments. The conductive plastic receivers can be used in systems that have EMI fields as large as 10 volts/meter (see AN-1057). Another method that improves the EMI

TYPICAL PEAK POWER COUPLED INTO A 1m LENGTH OF FIBER-OPTIC CABLE I_F = 60 mA T_A = 25°C			
FIBER CABLE	NA	HFBR-14X2	HFBR-14X4
100/140 μm	0.3	-12.0	-6.5
62.5/125 μm	0.275	-16.0	-12.0
50/125 μm	0.20	-18.8	-15.8

NOTES:
1. ALL RESISTORS ARE ±5% TOLERANCE.
2. ALL ELECTROLYTIC CAPACITORS ARE ±20% TOLERANCE. ALL OTHER CAPACITORS SHOULD BE RADIAL LEAD MONOLITHIC CERAMIC TYPES WITH ±10% TOLERANCE.

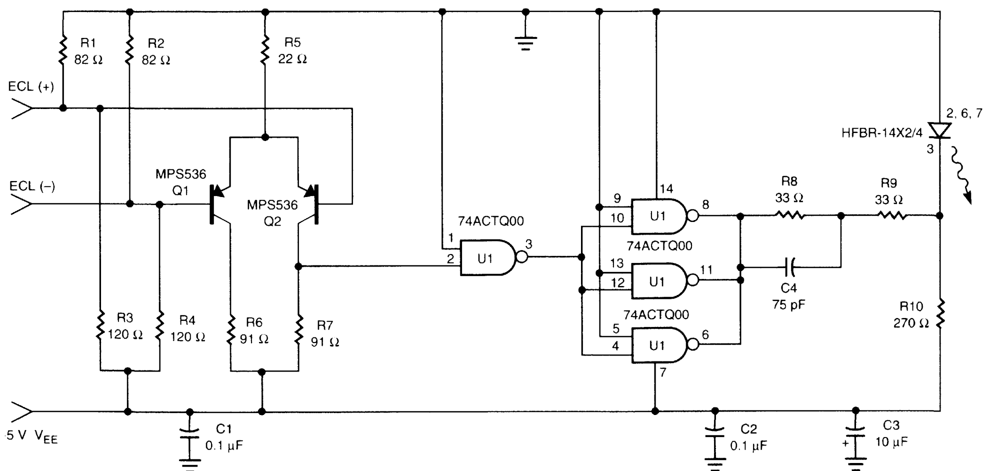


Figure 16b. 155 MBd Fiber-Optic Transmitter for -5.2 V ECL Interface.

TYPICAL RECEIVER PERFORMANCE WITH 1m OF FIBER-OPTIC CABLE				
AMBIENT TEMPERATURE	25°C			
DATA FORMAT	2^{23}-1 PRBS			
DATA RATE (MBd)	155	125	100	50
RECEIVER SENSIVIVITY AT BER OF 1 x 10^{-9} (dBm pk)	-26	-27	-29	-30
TYPICAL DYNAMIC RANGE WITH 62.5/125 μm CABLE	14	15	17	18

NOTES:

1. ALL RESISTORS ARE ±5% TOLERANCE.
2. ALL ELECTROLYTIC CAPACITORS ARE ±20% TOLERANCE. ALL OTHER CAPACITORS SHOULD BE RADIAL LEAD MONOLITHIC CERAMIC TYPES WITH ±10% TOLERANCE.
3. L1 AND L2 SHOULD HAVE A ±10% TOLERANCE, SERIES RESISTANCE OF ROUGHLY 0.5 Ω, AND A SELF RESONANT FREQUENCY ≥ 100 MHz.
4. V_{BB} IS A BIAS VOLTAGE GENERATED INTERNALLY BY THE 10H116 ECL LINE RECEIVER.
5. THE V_{CC}-2V POWER IS GENERATED BY THE TL431-CLP SHUNT REGULATOR.

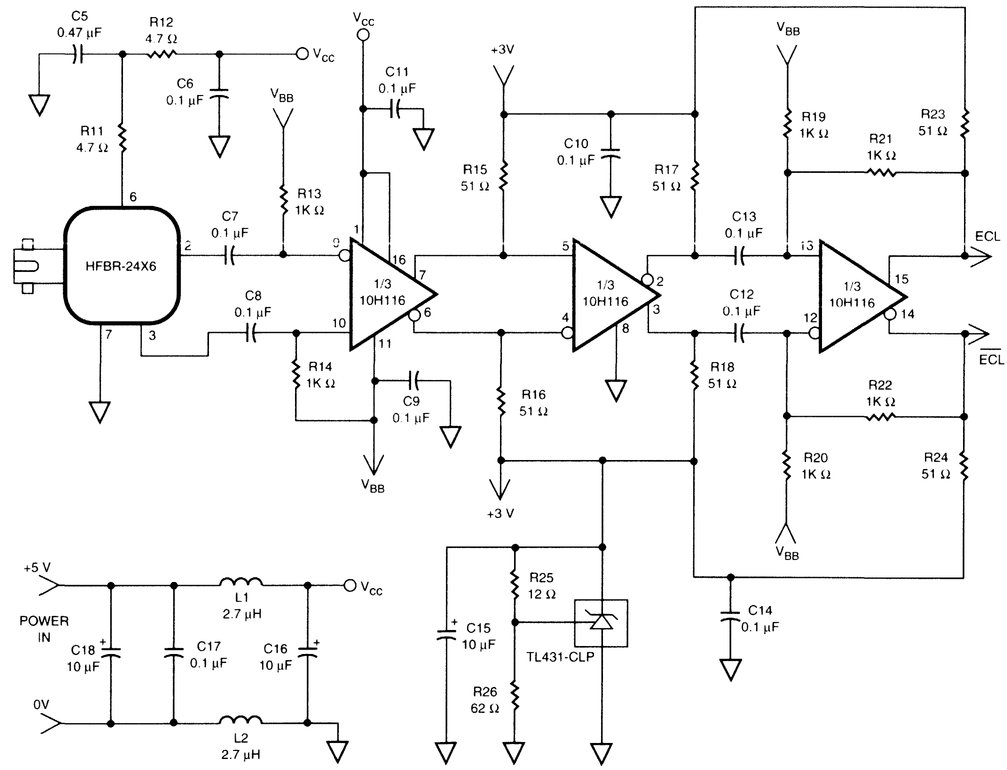


Figure 17a. 155 MBd Fiber-Optic Receiver for +5 V ECL Interface to Am 7969.

immunity of the receiver is to use a connector with a non-conductive plastic or ceramic ferrule. In extremely noisy applications the fiber-optic receiver can be enclosed in a metal box. This box eliminates noise that would otherwise be coupled into the fiber-optic receiver from the system in which it is installed. Systems that require metal shielding have proved to be unusual. Thus, in the majority of applications, the inherent noise immunity of the components combined with the shielding provided by the receiver ground plane have provided sufficient noise immunity.

Applications Support

Some complete designs that allow the use of HFBR-2406/2416 for run-length-limited data applications will now be discussed. Various transceivers have been designed which permit the HFBR-2406/2416 to be interfaced with:

(1) ECL logic operating on -5.2V. (Figure 16)
(2) The AMD TAXIchip™ +5V 100K ECL interface. (Figure 17)
(3) TTL logic operated on +5V. (Figure 18)

At an ambient temperature of 25°C all three interface circuits provided a typical receiver sensitivity of -29 dBm average with a BER of 1 x 10^{-9} at a data rate of 155 MBd. Sensitivity at 125 MBd is typically -30 dBm average at a BER of 1 x 10^{-9}. Figure 19 shows the typical performance of the ECL transmitter/receiver at 25°C. Note that in this test a 2^{23}-1 PRBS pattern at 155 MBd was transmitted over 500 m of 62.5/125 µm graded-index fiber at a BER less than 1 x 10^{-9}. If the low-cost, high-performance fiber-optic links possible with the HFBR-2406/2416 interest you, contact your local HP Field Sales Engineer for additional assistance. Your local HP sales representative can simplify your prototyping task by providing complete artwork for the fiber-optic transmitters and receivers discussed in this Application Bulletin.

*TAXIchip is a registered trademark of Advanced Micro Devices Inc.

TYPICAL PEAK POWER COUPLED INTO A 1m LENGTH OF FIBER-OPTIC CABLE I_F = 60 mA T_A = 25°C			
FIBER CABLE	NA	HFBR-14X2	HFBR-14X4
100/140 µm	0.3	-12.0	-6.5
62.5/125 µm	0.275	-16.0	-12.0
50/125 µm	0.20	-18.8	-15.8

NOTES:
1. ALL RESISTORS ARE ±5% TOLERANCE.
2. ALL ELECTROLYTIC CAPACITORS ARE ±20% TOLERANCE. ALL OTHER CAPACITORS SHOULD BE RADIAL LEAD MONOLITHIC CERAMIC TYPES WITH ±10% TOLERANCE.

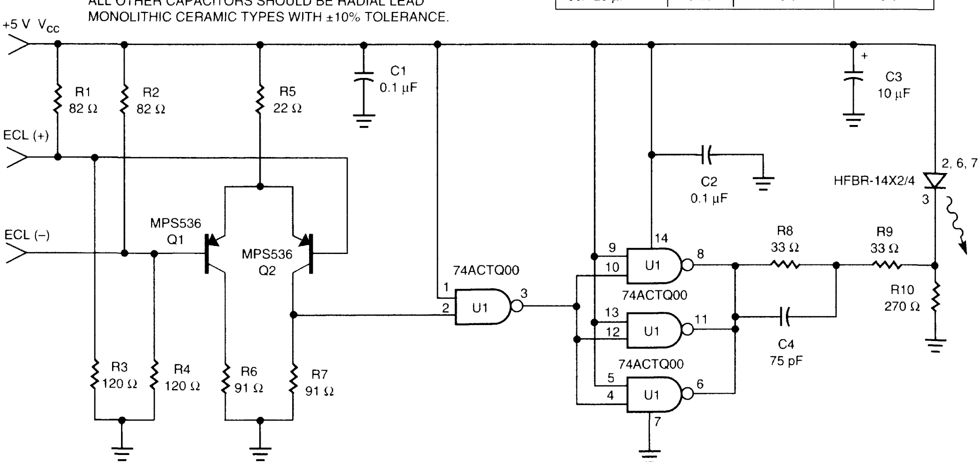
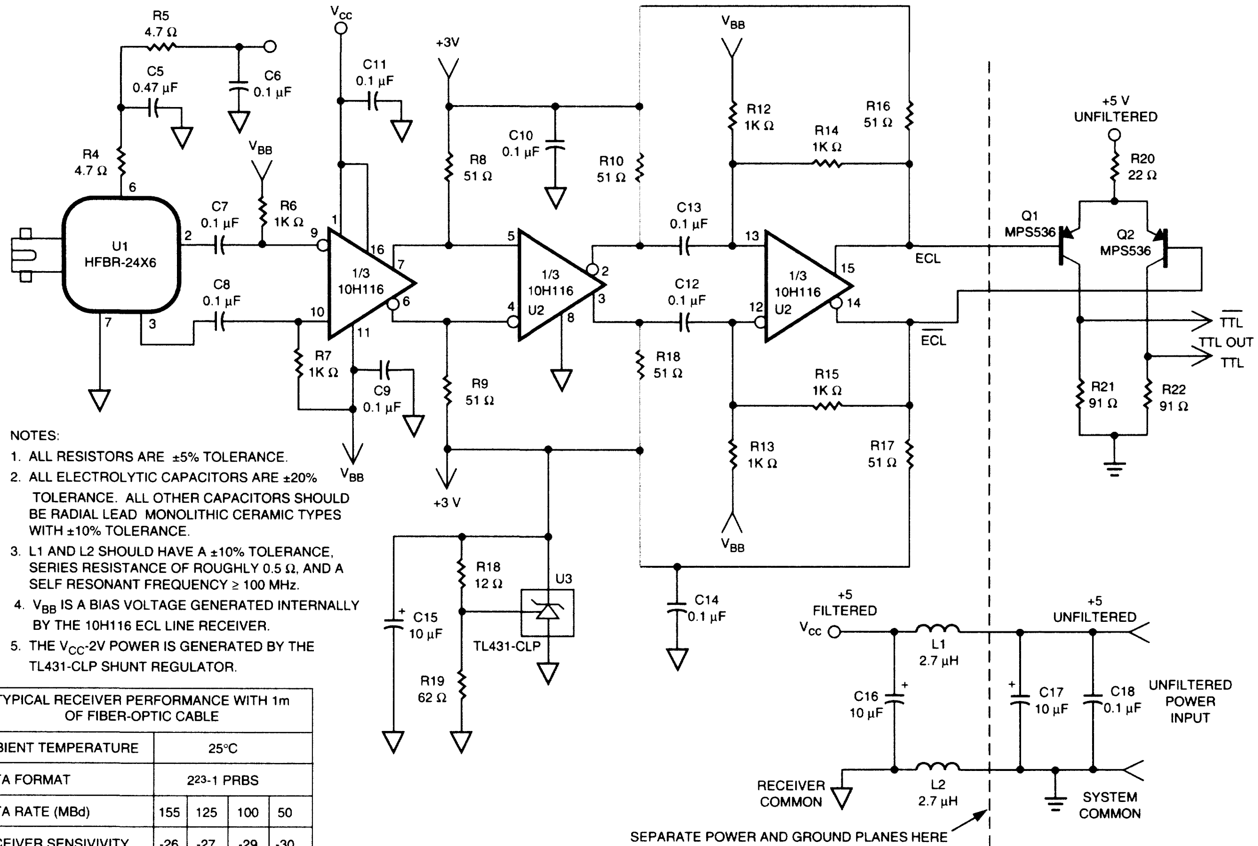


Figure 17b. 155 MBd Transmitter for +5 V ECL Interface to Am 7968.



NOTES:

1. ALL RESISTORS ARE ±5% TOLERANCE.
2. ALL ELECTROLYTIC CAPACITORS ARE ±20% TOLERANCE. ALL OTHER CAPACITORS SHOULD BE RADIAL LEAD MONOLITHIC CERAMIC TYPES WITH ±10% TOLERANCE.
3. L1 AND L2 SHOULD HAVE A ±10% TOLERANCE, SERIES RESISTANCE OF ROUGHLY 0.5 Ω, AND A SELF RESONANT FREQUENCY ≥ 100 MHz.
4. V_{BB} IS A BIAS VOLTAGE GENERATED INTERNALLY BY THE 10H116 ECL LINE RECEIVER.
5. THE V_{CC}-2V POWER IS GENERATED BY THE TL431-CLP SHUNT REGULATOR.

TYPICAL RECEIVER PERFORMANCE WITH 1m OF FIBER-OPTIC CABLE				
AMBIENT TEMPERATURE	25°C			
DATA FORMAT	2^{23}-1 PRBS			
DATA RATE (MBd)	155	125	100	50
RECEIVER SENSIVIVITY AT BER OF 1 x 10^{-9} (dBm pk)	-26	-27	-29	-30
TYPICAL DYNAMIC RANGE WITH 62.5/125 µm CABLE	14	15	17	18

Figure 18a. 155 MBd Fiber-Optic Receiver for TTL Interface.

TYPICAL PEAK POWER COUPLED INTO A 1m LENGTH OF FIBER-OPTIC CABLE I_F = 60 mA T_A = 25°C			
FIBER CABLE	NA	HFBR-14X2	HFBR-14X4
100/140 μm	0.3	-12.0	-6.5
62.5/125 μm	0.275	-16.0	-12.0
50/125 μm	0.20	-18.8	-15.8

NOTES:
1. ALL RESISTORS ARE ±5% TOLERANCE.
2. ALL ELECTROLYTIC CAPACITORS ARE ±20% TOLERANCE. ALL OTHER CAPACITORS SHOULD BE RADIAL LEAD MONOLITHIC CERAMIC TYPES WITH ±10% TOLERANCE.

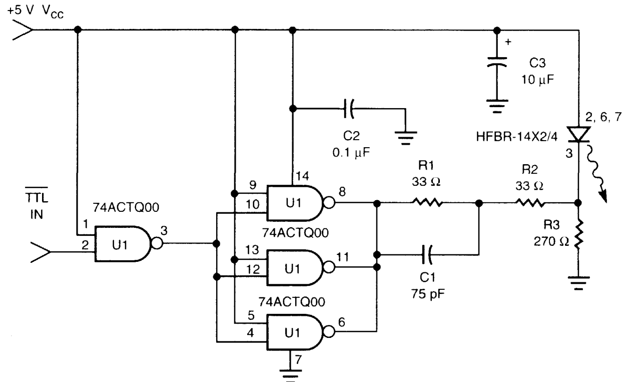


Figure 18b. 155 MBd Fiber-Optic Transmitter for TTL Interface.

- DATA RATE 155 MBd
- DATA PATTERN 2^{23}-1 PRBS
- FIBER TYPE SIECOR 62.5/125 μm
- FIBER LENGTH 500 m
- TYPICAL PEAK-TO-PEAK JITTER = 760 ps
- TIME SCALE IS 2.0 ns/DIV.

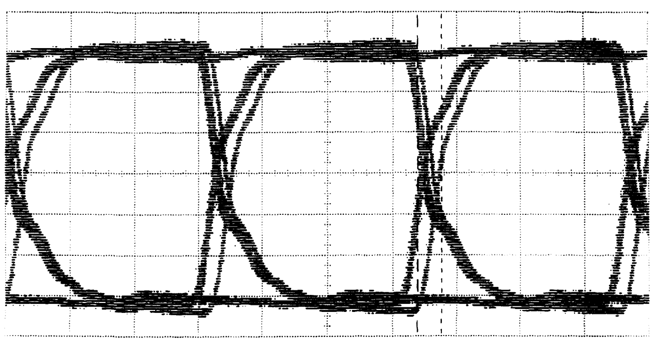


Figure 19. ECL Output of the Transceiver Shown in Figures 17a and 17b.

Complete Transceiver Solution

Figure 21 shows the schematic for a complete fiber-optic transceiver. This transceiver is constructed on a printed circuit, which is 1" wide by 1.78" long, using surface mount components. The transceiver in Figure 21 has an industry standard +5 V ECL (PECL) electrical interface. The transceiver shown in Figure 21 can be populated with HP's HFBR-14X4/24X6 820 nm components or HP's HFBR-1312T/2316T pin compatible 1300 nm components. When the transceiver shown in Figure 21 is populated with 820 nm components, and tested at a data rate of 155.5 MBd, using a 500 m length of 62.5/125 µm fiber, it provides a typical eye opening of 5.2 ns at a BER of 1 x 10^{-9}, as shown in Figure 20.

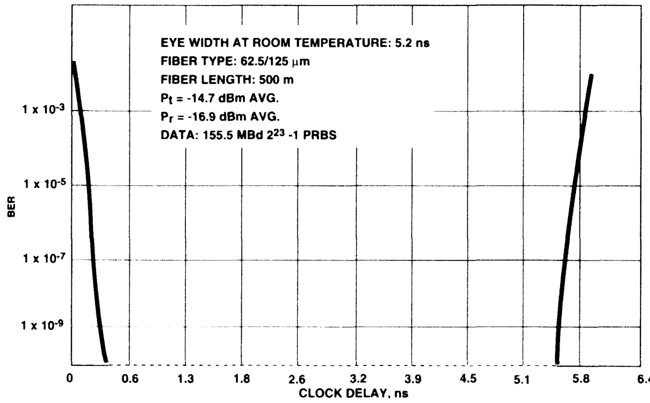


Figure 20. Typical BER vs. Clock Delay at 155.5 MBd.

The power supply filter and ECL terminations shown in Figure 22 are recommended for use with the transceiver shown in Figure 21. The printed circuit artwork for the surface mount transceiver is shown in Figure 23. A complete parts list for the 820 nm transceiver is shown in Table 1, and a complete parts list for the 1300 nm transceiver is shown in Table 2.

Designers interested in inexpensive solutions are encouraged to embed the complete fiber-optic transceiver described in this Application Note into the next generation of their new data communication products. All of the information needed to imbed the transceiver shown in Figure 21 can be obtained by calling the electronic bulletin board at 408-435-6733. Just call the bulletin board, then download the file named FURBALL.EXE to obtain electronic copies of the transceiver's artwork, schematic, and material list. If time to market is critical, the product development cycle can be shortened by ordering a fully assembled HFBR-0416 transceiver demo board from your local HP Field Sales Engineer.

References

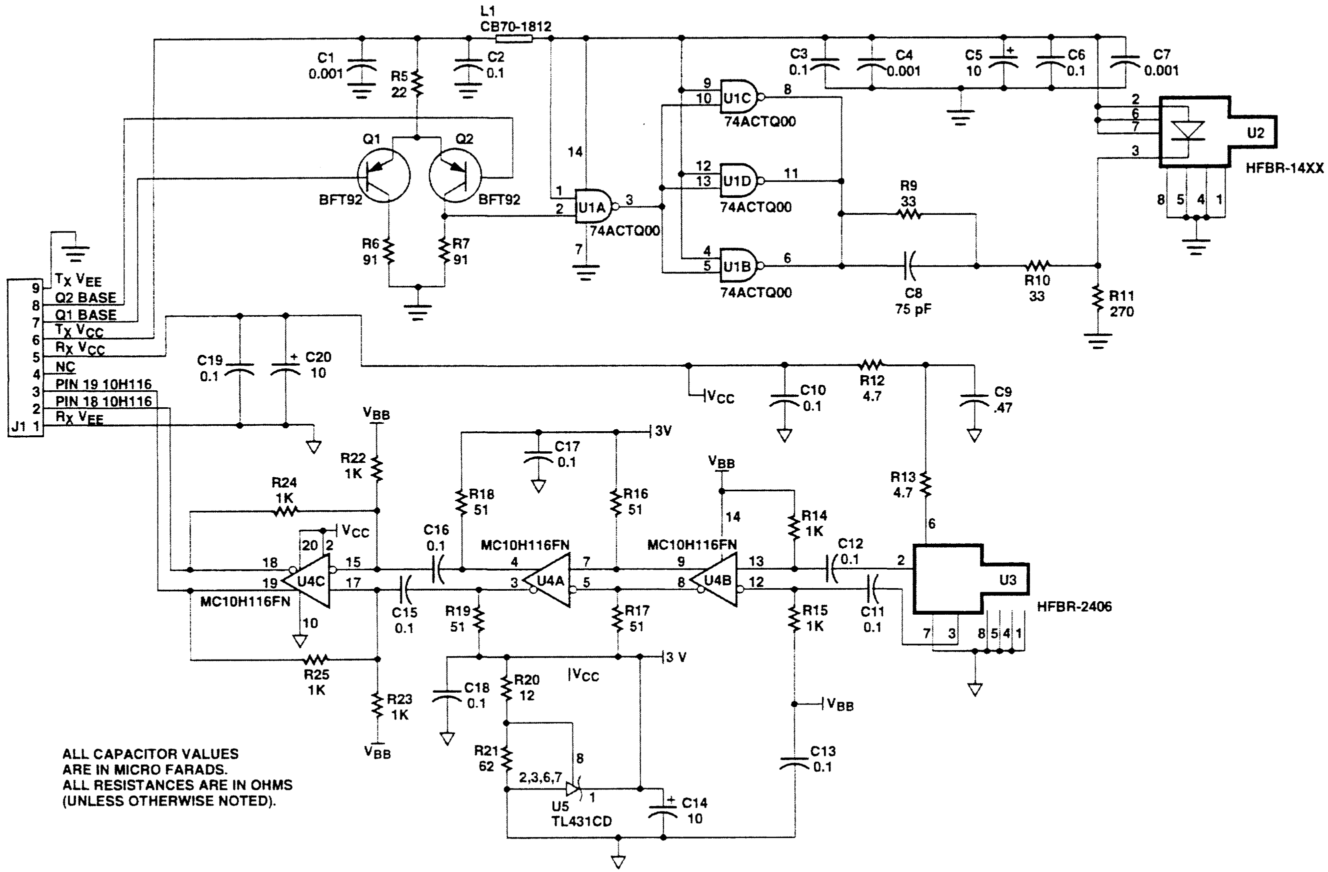
[1] Hewlett-Packard Optoelectronics Designer's Catalog 1988, HFBR-AWSyyy data sheet.

[2] James J. Refi, "LED Bandwidth of Multimode Fibers as a Function of Laser Bandwidth and LED Spectral Characteristics", Journal of Lightwave Technology, Volume LT-4 No. 3, March 1986.

[3] Delon C. Hanson and Jerry Hutchison, "LED Source and Fiber Specification Issues for the FDDI Network", COMPCON Spring '87, IEEE Computer Society, (San Francisco, CA), February 24-26, 1987.

[4] Delon C. Hanson, "Fiber Optic Sub-System for Local Area Networks", OFC '88, (New Orleans, LA), January 24-28, 1988.

[5] Hans O. Sorensen, "Use of Standard Modulation Codes for Fiber Optic Link Optimization", FOC 1984.



ALL CAPACITOR VALUES
ARE IN MICRO FARADS.
ALL RESISTANCES ARE IN OHMS
(UNLESS OTHERWISE NOTED).

Figure 21. 155 MBd 1x9 Transceiver Schematic

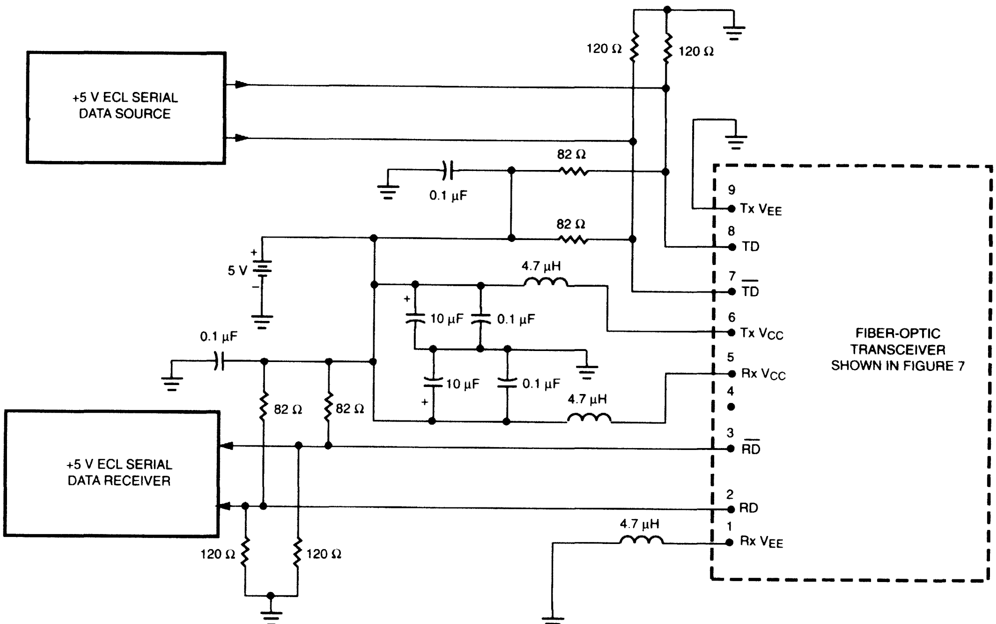


Figure 22. Recommended Power Supply Filter and +5 V ECL Signal Terminations

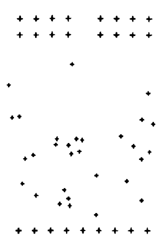


Figure 23a. Drill Drawing

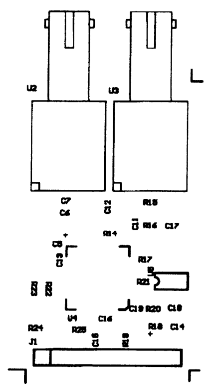


Figure 23b. Top Silkscreen

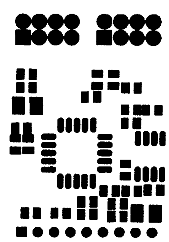


Figure 23c. Top Side Solder Mask

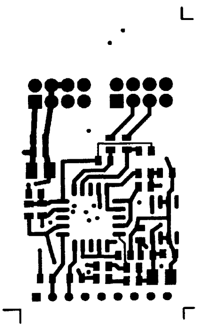


Figure 23d. Top Layer Copper

Figure 23e. Mid Layer (2) Rx GND

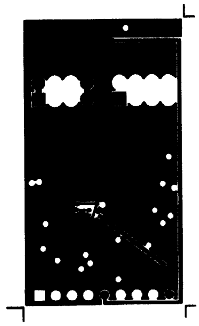


Figure 23f. Mid Layer (3) Ts GND

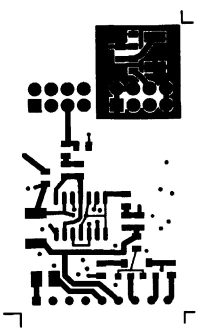


Figure 23g. Bottom Copper

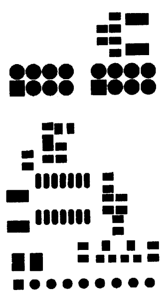


Figure 23h. Bottom Side Solder Mask

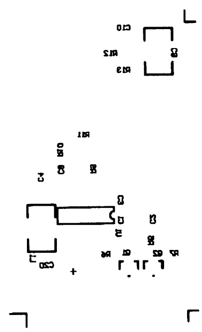


Figure 23i. Bottom Silkscreen

Table 1. Bill of Materials for Multi-Mode 820 nm Fiber-Optic Transceiver

Designator	Part Type	Description	Footprint	Material	Part Number	Quantity	Vendor 1
C1	0.001	Capacitor	805	NPO/COG	C0805NPO500102JNE	3	Venkel
C4	0.001	Capacitor					
C7	0.001	Capacitor					
C10	0.1	Capacitor	805	X7R or better	C0805X7R500104KNE	12	Venkel
C 11	0.1	Capacitor					
C 12	0.1	Capacitor					
C 13	0.1	Capacitor					
C 15	0.1	Capacitor					
C 16	0.1	Capacitor					
C17	0.1	Capacitor					
C 18	0.1	Capacitor					
C 19	0.1	Capacitor					
C2	0.1	Capacitor					
C3	0.1	Capacitor					
C6	0 1	Capacitor					
C9	0.47	Capacitor	1812	X7R or better	C 1812X7R500474KNE	1	Venkel
C14	10	Capacitor	B	Tantalum, 10v	TA010TCM106MBN	3	Venkel
C20	10	Capacitor					
C5	10	Capacitor					
C8	75 pF	Capacitor	805	NPO/COG	C0805COG500750JNE	1	Venkel
U1	I.C.	Nand Gate	S08		74ACTQ00	1	National
U2	Fioer-Optic	Transmitter			HFBR-1414	1	HP
U3	Fiber-Optic	Receiver			HFBR-2416	1	HP
U4	MC10H116FN	IC, ECL line receiver	PLCC20		MC10H116FN	1	Motorola
U5	TL431CD	IC, Voltage Regulator	SO-8		TL431CD	1	T.I.
L1	CB70-1812	Inductor	1812		HF30ACB453215	1	TDK
R12	4.7	Resistor	805	5%	CR080510W4R7JT	2	Venkel
R 13	4.7	Resistor					
R20	12	Resistor	805	5%	CR080510W120JT	1	Venkel
R9	33	Resistor	805	5%	CR080510W330JT	1	Venkel
R10	33	Resistor	805	5%	CR080510W330JT	1	Venkel
R11	270	Resistor	805	5%	CR080510W271JT	1	Venkel
R5	22	Resistor	805	5%	CR080510W220JT	1	Venkel
R16	51	Resistor	805	5%	CR080510W510JT	4	Venkel
R17	51	Resistor					
R18	51	Resistor					
R19	51	Resistor					
R21	62	Resistor	805	5%	CR080510W620JT	1	Venkel
R6	91	Resistor	805	5%	CR080510W910JT	2	Venkel
R7	91	Resistor					
R14	1K	Resistor	805	5%	CR080510W102JT	6	Venkel
R15	1 K	Resistor					
R22	1 K	Resistor					
R23	1 K	Resistor					
R24	1 K	Resistor					
R25	1 K	Resistor					
Q1	BFT92	Transistor	SOT-23		BFT92	2	Philips
Q2	BFT92	Transistor					
J1		Pins			343B	9	McKenzie

Table 2. Bill of Materials for Multi-Mode 1300 nm Fiber-Optic Transceiver

Designator	Part Type	Description	Footprint	Material	Part Number	Quantity	Vendor 1
C1	0.001	Capacitor	805	NPO/COG	C0805NPO500102JNE	3	Venkel
C4	0.001	Capacitor					
C7	0.001	Capacitor					
C10	0.1	Capacitor	805	X7R or better	C0805X7R500104KNE	12	Venkel
C 11	0.1	Capacitor					
C 12	0.1	Capacitor					
C 13	0.1	Capacitor					
C 15	0.1	Capacitor					
C 16	0.1	Capacitor					
C17	0.1	Capacitor					
C 18	0.1	Capacitor					
C 19	0.1	Capacitor					
C2	0.1	Capacitor					
C3	0.1	Capacitor					
C6	0 1	Capacitor					
C9	0.47	Capacitor	1812	X7R or better	C 1812X7R500474KNE	1	Venkel
C14	10	Capacitor	B	Tantalum, 10v	TA010TCM106MBN	3	Venkel
C20	10	Capacitor					
C5	10	Capacitor					
C8	150 pF	Capacitor	805	NPO/COG	C0805COG500151JNE	1	Venkel
U1	I.C.	Nand Gate	S08		74ACTQ00	1	National
U2	Fioer-Optic	Transmitter			HFBR-1312T	1	HP
U3	Fiber-Optic	Receiver			HFBR-2316T	1	HP
U4	MC10H116FN	IC, ECL line receiver	PLCC20		MC10H116FN	1	Motorola
U5	TL431CD	IC, Voltage Regulator	SO-8		TL431CD	1	T.I.
L1	CB70-1812	Inductor	1812		HF30ACB453215	1	TDK
R12	4.7	Resistor	805	5%	CR080510W4R7JT	2	Venkel
R 13	4.7	Resistor					
R20	12	Resistor	805	5%	CR080510W120JT	1	Venkel
R9	22	Resistor	805	5%	CR080510W220JT	1	Venkel
R10	27	Resistor	805	5%	CR080510W270JT	1	Venkel
R5	22	Resistor	805	5%	CR080510W220JT	1	Venkel
R16	51	Resistor	805	5%	CR080510W510JT	4	Venkel
R17	51	Resistor					
R18	51	Resistor					
R19	51	Resistor					
R21	62	Resistor	805	5%	CR080510W620JT	1	Venkel
R6	91	Resistor	805	5%	CR080510W910JT	2	Venkel
R7	91	Resistor					
R14	1 K	Resistor	805	5%	CR080510W102JT	6	Venkel
R15	1 K	Resistor					
R22	1 K	Resistor					
R23	1 K	Resistor					
R24	1 K	Resistor					
R25	1 K	Resistor					
Q1	BFT92	Transistor	SOT-23		BFT92	2	Philips
Q2	BFT92	Transistor					
J1		Pins			343B	9	McKenzie

HEWLETT® PACKARD

Versatile Link

Application Note 1035

Introduction

This application note describes how fiber optics can be used to solve many different types of application problems, introduces Hewlett-Packard's Versatile Link plastic fiber optics, and shows how to design a fiber-optic link using the Versatile Link. Below is an outline of this application note.

I. Introduction
II. Example Applications
III. Versatile Link Description
IV. System Specifications and Link Design
V. Pulse-Width Distortion
VI. Additional Circuit Recommendations
VII. Appendix

Optical fiber is typically made from either plastic or glass. Because both plastic and glass are electrical insulators, there is no direct electrical connection between the transmitter and the receiver of a fiber-optic link. This helps to alleviate ground-loop and common-mode noise problems, as well as to isolate large common-mode voltages. Another useful property of optical fiber is that it does not emit radiation and is not susceptible to electromagnetic interference (EMI). This prevents an optical fiber from interfering with neighboring wires and also gives it inherent immunity to induced or coupled noise from adjacent wires.

Fiber optics can protect equipment from excessive voltages, reduce EMI, increase safety by eliminating the hazard of generating sparks, and ensure data integrity in environments with large amounts of noise or with high common-mode voltages.

Example Applications

Different applications have different requirements and, therefore, different reasons for using fiber optics. The following paragraphs discuss some examples of common fiber-optic applications and why fiber optics are used in those applications.

The first type of application utilizes the EMI immunity of fiber-optics for data transmission in electrically noisy environments. A good example is data transmission between a programmable logic controller (PLC) and the computer that is directing it, illustrated in Figure 1a. The two computers might be in a factory containing machinery that generates large amounts of electrical noise. Data transmission lines commonly run alongside lines that supply power to the machinery. There may be large amounts of electrical noise present on the power lines caused by the machinery. This noise can couple electromagnetically into any adjacent lines. If one of those adjacent lines is a twisted-pair or coax line carrying data, the coupled electrical noise may significantly interfere with the data transmission. The noise may cause only periodic errors, or it might completely corrupt all of the data being sent. Because optical fiber is not susceptible to EMI, it can eliminate the undesirable coupling of noise from the power lines onto the data lines and ensure error-free data transmission.

Figures 1b, 1c and 1d illustrate other applications which utilize the EMI immunity of fiber optics. Figure 1b shows how fiber can connect a robot controller with the cell controller and the robot. The fiber eliminates the large amounts of noise generated by the motors, solenoids, etc. that are part of the robot. Figure 1c illustrates how fiber is used to network point-of-sales terminals (cash registers) in a retail store. Fiber optics ensures that sales information is not corrupted or lost due to noise generated inside the building. Figure 1d shows fiber optics connecting two HPIB (IEEE-488) data buses. The HPIB data bus

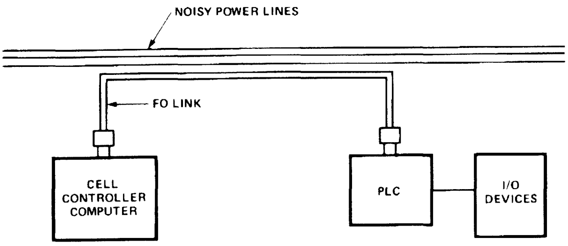


Figure 1a. Programmable Logic Controller.

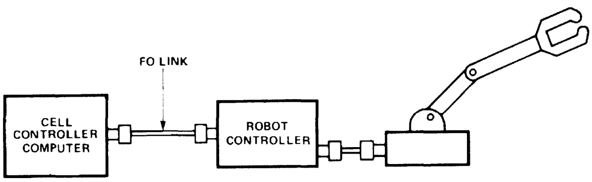


Figure 1b. Robot Controller.

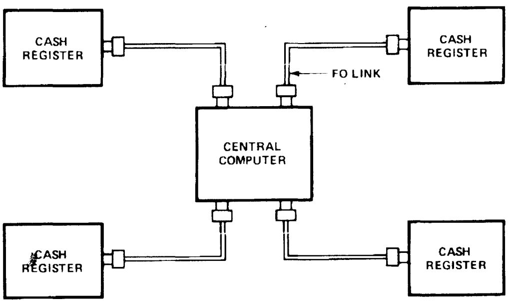


Figure 1c. Point of Sales Terminals

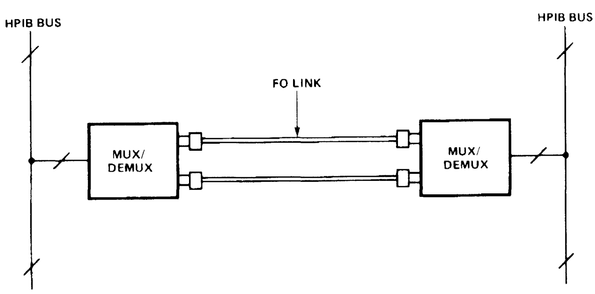


Figure 1d. HPIB (IEEE-488) Bus Extender.

is commonly used to connect test instruments in manufacturing automated test systems. Again, fiber optics eliminates the noise that is commonly present in a factory and ensures that correct test data is transferred to the test system controller.

The second type of application uses fiber-optics for voltage isolation. A digital voltmeter, illustrated in Figure 2a, is a good example. There is typically some circuitry at the input of the voltmeter that converts the analog voltage across the input terminals into a digital signal; this circuitry is called an analog-to-digital converter (ADC). The output of the ADC is then sent to processing circuitry that displays the information on the front panel or, perhaps, sends the information to an external computer. A problem arises, however, when the signal to be measured has a very high common-mode voltage component. An example of this is measuring the difference between two very high voltages. The ADC will also be at the same common-mode voltage, causing a problem in safely sending information from the ADC to the digital control circuitry at ground potential. Because of its insulating properties, an optical fiber is not affected by such high voltages and does not conduct any current that might interfere with or damage the circuitry to which it is connected. Fiber optics allow data to be transmitted and still maintain a high degree of voltage isolation.

Figures 2b, 2c and 2d also illustrate the use of fiber in voltage-isolation applications. Figure 2b is a simple block diagram of an electrocardiograph, which is

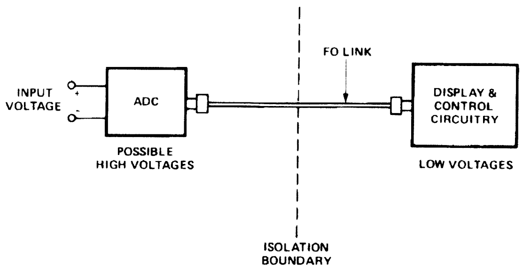


Figure 2a. Digital Voltmeter.

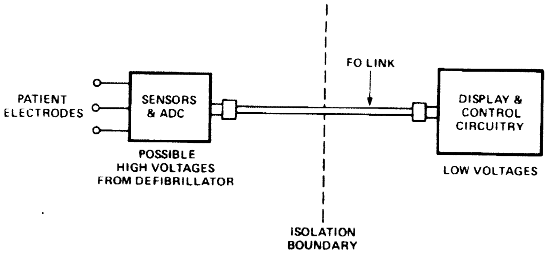


Figure 2b. Medical Equipment – Heart Monitor.

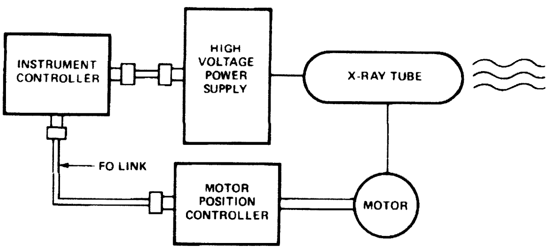


Figure 2c. X-Ray Machine.

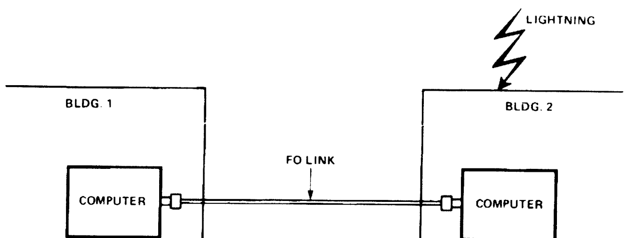


Figure 2d. Lightning Protection.

used to monitor a patient's heart. If the heart were to stop beating, a defibrillator might be used to restart it. The fiber protects the electrocardiograph from the very high voltages that are generated by the defibrillator. Figure 2c shows the use of fiber in a clinical X-ray machine. The fiber isolates the high voltages used to power the X-ray tube and provides EMI immunity from the noise generated by switching high voltages and currents. Figure 2d illustrates how fiber can protect electronic equipment from the high voltages generated by nearby lightning strikes.

Another type of application reduces the amount of unwanted electromagnetic radiation emitted by a transmission line. This type of application is the converse of the first type; the idea is to minimize the amount of EMI that is radiated from the transmission line itself, rather than being concerned with the susceptibility of the transmission line to external interference. An example is high speed video transmission from a workstation computer to a high resolution video monitor, shown in Figure 3a. As the resolution of a video monitor increases, the number of pixels (dots) on the screen also increases. If the computer is updating the screen with the same number of frames per second, the computer must send more pixels per second as the resolution increases. Therefore, the bandwidth of the video transmission link must increase as well. If a coaxial cable is used to transmit the video information, it becomes more and more difficult (and expensive) to shield the cable and reduce unwanted radiation as the frequency of the transmitted information

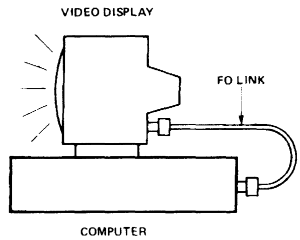


Figure 3a. High Speed Video Transmission.

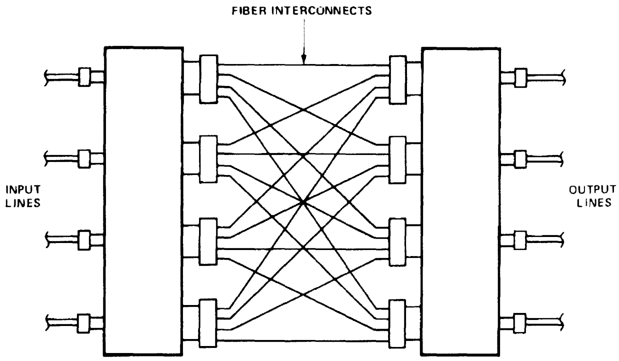


Figure 3b. Telephone Switching Network.

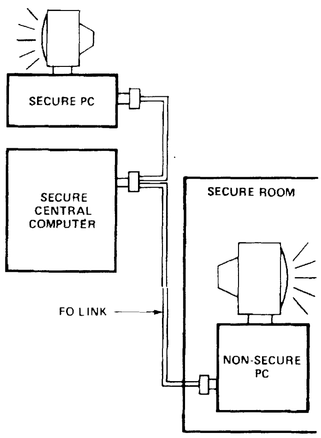


Figure 3c. Tempest Applications.

increases. Because an optical fiber does not emit radiation, it can significantly reduce the amount of EMI generated in transmitting information at very high data rates or when there are many transmission lines.

Figures 3b and 3c show two additional applications that use fiber optics to reduce the amount of unwanted emissions. Figure 3b illustrates the use of fiber in the telephone switching network of a central office switch. Fiber helps to minimize the amount of unwanted radiation generated by the large number of interconnects in the network. Figure 3c illustrates how fiber might be used in Tempest applications. Tempest is a federal government specification that restricts the amount of radiation that can be emitted by "secure" electronic equipment. Because fiber does not emit any radiation, it is well suited for Tempest applications. Figure 3c shows how fiber is used to connect a secure personal

Table 1. Distance and Data Rate Summary

Versatile Link		Guaranteed Minimum Link Length Metres				Typical Link Length Metres	
		0°C - 70°C		25°C		25°C	
		Standard Cable	Improved Cable	Standard Cable	Improved Cable	Standard Cable	Improved Cable
High Performance	5 MBd	12	17	17	24	35	40
High Performance	1 MBd	24	34	30	41	50	65
Low Current Link	40 kBd	8	11	-	-	30	35
Extended Distance Link	40 kBd	60	82	65	90	100	125
Standard	1 MBd	5	7	11	15	30	40
Photo Interrupter	500 kHz	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Evaluation Kit	1 MBd (Standard)	Contents: Horizontal transmitter, horizontal receiver packages; 5 metres of simplex cable with simplex and simplex latching connectors installed; individual connectors: simplex, duplex, simplex latching, bulkhead adapter; polishing tool, abrasive paper, literature.					

computer (i.e., a computer constructed to limit the amount of emissions) with a secure central computer. The fiber also connects the secure central computer with a non-secure personal computer, located inside of a secure room (i.e., a room specifically designed to limit unwanted emissions).

The above examples illustrate how the features of fiber optics can be used to solve problems found in many different types of applications.

Versatile Link Description

The Hewlett-Packard HFBR-0501 series low-cost fiber-optic system, the Versatile Link, was designed for ease of use, versatility, and reliability. Table 1 summarizes the data rate and distance capabilities of the Versatile Link family. Typical distances at room temperature are also shown. The maximum data rates for Versatile Link components range from 40 kBd to 5 MBd, with even higher data rates available in the future.

Hewlett-Packard guarantees minimum and maximum specifications of its components both at room temperature and over the full operating temperature range (0 to 70°C). These guaranteed specifications were obtained from extensive characterizations of the Versatile Link components and cover the full range of manufacturing process variations. This ensures reliable circuit operation and allows HP to guarantee minimum link distances.

The Versatile Link family, shown in Figure 4, is intended

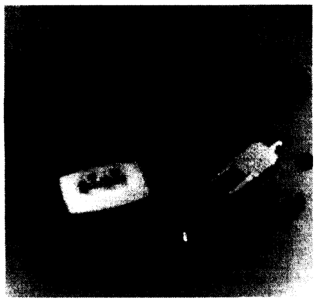


Figure 4. Versatile Link Family.

for use with 1 mm plastic optical fiber. No optical design is required because the specifications include any connector losses at the transmitter and at the receiver. The compact, low-profile package is color coded to distinguish transmitters from receivers; connectors are also color coded. Both horizontal and vertical package styles are available with standard 8-pin DIP pinouts. The packages can also be interlocked or stacked ("n-plexed") to decrease the required amount of PC-board space.

Figure 5 shows an exploded view of the Versatile Link horizontal style package. The package was designed for improved performance and ease of manufacturing. The active components are attached to a lead frame which is then transfer molded with clear plastic to form the insert. A precision lens is molded into the insert to optimize the optical coupling from the package to the fiber. The insert is held in the main part of the housing by a snap-on cap on the back of the package.

The Versatile Link package uses an active optical alignment system to ensure proper coupling between the connector and the package. Figure 6 illustrates

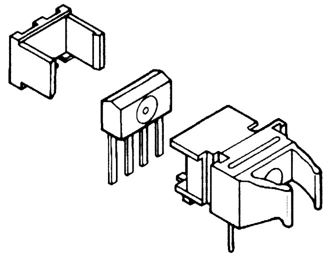


Figure 5. Exploded View.

how the alignment system operates. The precision-molded lens on the insert is located at the bottom of a depression in the shape of a truncated cone. When the connector is inserted into the package, the jaws of the housing force the beveled end of the connector into the cone-shaped depression. This accurately centers the fiber directly above the molded lens on the insert and ensures reliable and repeatable connections.

The gray transmitter modules contain 660 nm large-area LEDs that can be easily interfaced to all standard logic families. The blue receiver modules contain monolithic integrated optical detectors with TTL/CMOS-compatible outputs.

Four connector options are available for use with the Versatile Link:

1. Simplex connector, which is compatible with our previous Snap-In Link family,
2. Latching simplex connector, for applications that require increased connector pullout force,
3. Duplex connector, which incorporates a lockout feature that ensures correct orientation of the connector when used with interlocked packages,
4. Latching duplex connector.

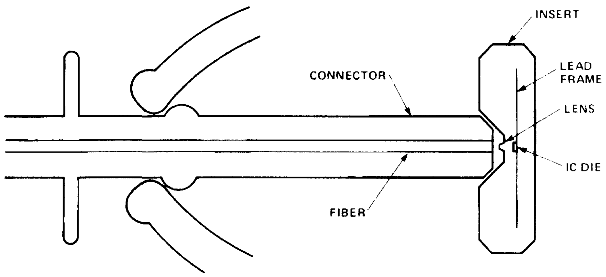


Figure 6. Connector Alignment.

Hewlett-Packard offers simplex and duplex cables with two grades of attenuation, standard and improved. Cable with connectors is offered in one meter increments of length; unconnectored cable is available in lengths of 25, 100, and 500 meters. These cables are UL-recognized and pass UL VW-1 flame-retardancy specifications.

An evaluation kit is available which contains a standard 1 MBd transmitter and receiver, 5 m of connectored cable, individual simplex, simplex latching, and duplex connectors, a bulkhead adapter, polishing tools and literature.

The data sheet for the Versatile Link family contains complete guaranteed specifications for entire links and individual components, electrical pinouts, interface circuits, connectoring information, mechanical dimensions, part number and ordering information.

Reliability Data Sheets are available which provide complete reliability information for all Versatile Link components.

System Specifications and Link Design

To obtain optimum performance under a variety of different conditions, it is helpful to understand some of the basic specifications of the Versatile Link and how to use them in designing a fiber optic link. This section will first discuss how Hewlett-Packard specifies its transmitters, receivers, and plastic fiber-optic cable, then explain how to use those specifications in determining proper operating conditions. This section will also explain what a link operating diagram is and how to use it to quickly determine transmitter drive current or link length.

A basic fiber-optic system is very simple: an LED transmitter couples light into a fiber, the light travels down the fiber to an optical detector, and the detector converts the light into a digital output signal. The important specifications of the fiber-optic data link are:

1. How much light is coupled into the fiber by the transmitter,
2. How much light the receiver needs to function properly,
3. How much light is lost on the way to the receiver.

For a brief explanation of how optical power is specified in "dB" and "dBm", see the Appendix.

Transmitter Specifications

The primary transmitter specification is P_T, the amount of optical power coupled into the fiber at a specified LED drive current. P_T specifies how much power is actually coupled into the fiber; this eliminates the need to calculate the loss in coupling light from the LED to the fiber. Due to normal process variations, HP specifies a range of coupled power for each type of transmitter. Figure 7 shows the coupled power specifications for each of the Versatile Link transmitters. Guaranteed specifications over the full operating range are shown in Figure 7 because these values typically are used in "worst-case" designs and are also used in our examples.

The amount of coupled power can be easily adjusted by changing the LED forward drive current, I_F, as indicated in Figure 8. Notice that the coupled power is normalized to the value at

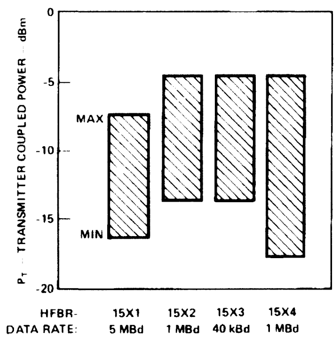


Figure 7. Transmitter Specifications.

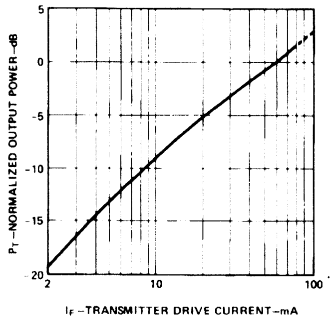


Figure 8. Normalized Typical Output Power vs. Drive Current.

I_F= 60 mA. The graph, therefore, represents the CHANGE in output power for different drive currents. For example, operating the transmitter at a drive current of 20 mA will drop the output power by about 5 dB. There is an approximately linear relationship between drive current and output power; therefore, the output power will drop approximately in half (i.e., about 3 dB) when the drive current is cut in half.

Figure 9 shows the recommended transmitter drive circuits. You should note that for the 5 MBd and 40 kBd drive circuits, an input-high level turns the LED on; for the 1 MBd circuit, an input-high level turns the LED off. The capacitor in the 1 MBd circuit slows the falling edge of the optical waveform and allows the receiver to operate up to the maximum output power of the 1 MBd transmitter. The value of R1 can be determined from the equations in the figure. Typical values for the forward voltage of the LED, V_F, and the output low voltage of the gate, V_{OL}, are 1.6 V and 0.25 V respectively.

Additional transmitter drive circuits will be covered later in the application note.

Receiver Specifications

The Versatile Link receivers function somewhat as optical inverters: high input power causes a low output voltage, and low input power causes a high output voltage.

There are two primary receiver specifications:

1. $P_{R(L)}$ specifies the input power required for a LOW output voltage,

2. $P_{R(H)}$ specifies the input power required for a HIGH output voltage.

Figure 10 shows the ranges of $P_{R(L)}$ and $P_{R(H)}$ for each of the receivers over the full operating temperature range.

Typically, both a minimum and a maximum are specified for $P_{R(L)}$. For proper operation, the received optical power must be between the minimum and the maximum $P_{R(L)}$. If no maximum is specified, the corresponding transmitter (i.e., the HFBR-15X2 transmitter for the HFBR-25X2 receiver) is not capable of overdriving the receiver for drive currents up to the recommended maximum value of 60 mA, and

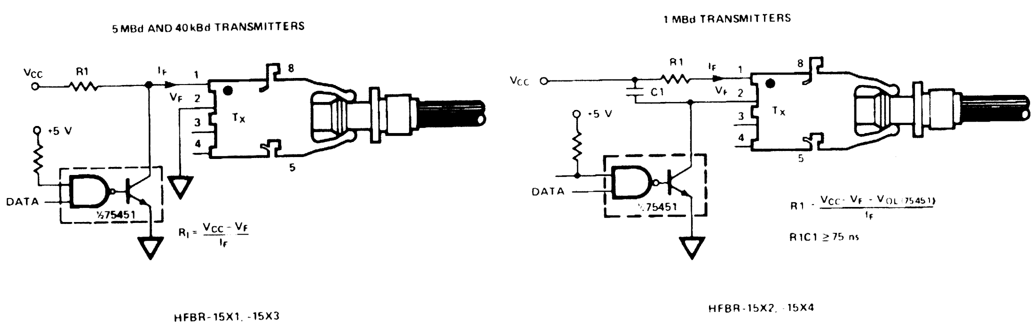


Figure 9. Transmitter Drive Circuits.

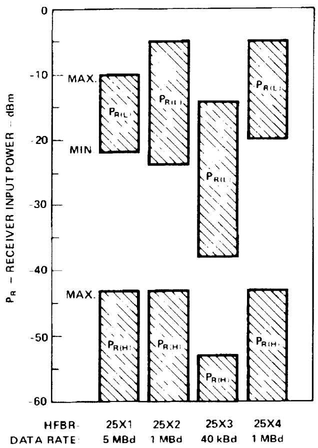


Figure 10. Receiver Specifications.

you need ensure only that the input power is greater than the minimum $P_{R(L)}$. If the maximum $P_{R(L)}$ is exceeded, the receiver may exhibit excessive pulse-width distortion (discussed later) or multiple edge transitions.

Only a maximum $P_{R(H)}$ is specified for each receiver. When the transmitter LED is in the off state, the received optical power must be less than the maximum $P_{R(H)}$ for proper receiver operation.

The minimum $P_{R(L)}$ is called the sensitivity of the receiver. A receiver with good sensitivity (lower minimum $P_{R(L)}$) will allow longer link lengths or lower transmitter drive current. The difference between the minimum and maximum $P_{R(L)}$ is called the dynamic range of the receiver. A receiver with a large dynamic range can handle a wider variation in received power and therefore more variation in the length of the link. Note that the 40 kBd receiver has very good sensitivity and a large dynamic range. The 40 kBd link can therefore handle long link lengths and large variations in the length of the link. Also note that the maximum $P_{R(L)}$ for the 1 MBd receivers is determined by the maximum coupled power of the 1 MBd transmitters.

Because the receiver switching threshold is between the minimum $P_{R(L)}$ and the maximum $P_{R(H)}$, the receiver input power should be within this region only very briefly during signal transitions. Very slow rise or fall times of the input optical waveform may cause multiple transitions on the output of the receiver.

Figure 11 shows how simple the receiver interface circuits are, requiring only one or two external components. The 0.1 μF bypass capacitor is mandatory and must be located close to the receiver; the total lead length between the ends of the capacitor and the receiver power supply pins should not exceed 20 mm. The external pull-up resistor is optional. The 1 MBd and 5 MBd receivers have an internal 1K ohm pull-up resistor, and the 40 kBd receiver has an internal 150 μA pull-up current source. All data sheet specifications for propagation delay and rise/fall time use an external pull-up resistor, a 560 ohm resistor for the 1 MBd and 5 MBd receivers, and a 3.3K ohm resistor for the 40 kBd receiver.

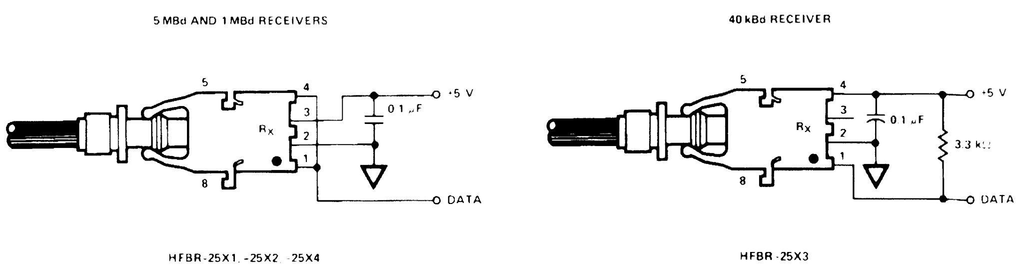


Figure 11. Receiver Interface Circuits.

Optical Losses
There are two primary causes of optical loss in a fiber-optic link: losses due to cable attenuation and connector coupling efficiency.

Attenuation is defined as loss per unit length of fiber, expressed in dB/m. To obtain the optical loss in a fiber, simply multiply the length of the fiber by the attenuation. Figure 12 shows the range of attenuation for the two grades of fiber, standard and improved, that Hewlett-Packard offers.

For a given length and type of fiber, there will be a range of optical loss due to the range of attenuation of the fiber. For our standard fiber, Figure 13 illustrates how the range of loss, as well as the magnitude of the loss, increases as the length of the fiber increases. You can see that for a 40 m length of fiber, the losses due to attenuation will be between 7.6 dB and 17.2 dB, a range of almost 10 dB. A fiber optic receiver must be able to handle the range of loss as well as the magnitude of the loss. Therefore, receivers with both large dynamic range and good sensitivity are required for long link lengths.

Connector losses at the transmitter and receiver are already included in the transmitter and receiver specifications. However, connector losses due to connections through bulkhead adaptors need to be determined. There should be a minimum and a maximum loss specified for the bulkhead connection. Hewlett-Packard specifies the loss of a bulkhead connection as a minimum of 0.7 dB and a maximum of 2.8 dB. As you increase the number of bulkhead connections, the range of loss increases as does the magnitude of the losses. It is important to remember that the range of loss is just as important as the magnitude of the loss.

The total loss in a system is the sum of the individual losses due to attenuation and connectors. It is important to calculate both the minimum and the maximum losses of the system due to attenuation and connectors. A wide range of losses results in a wide range of input power at the receiver. This places greater requirements on the dynamic range of the receiver.

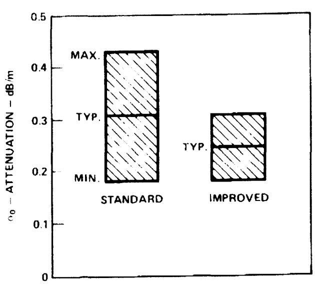


Figure 12. Cable Attenuation.

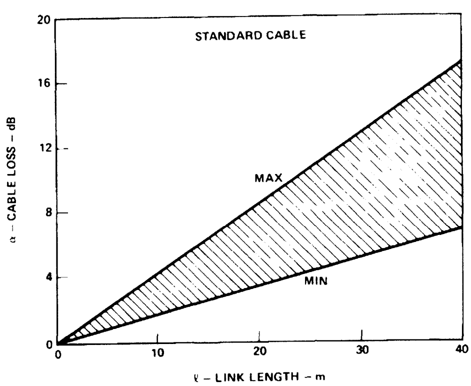


Figure 13. Possible Range of Cable Loss vs. Cable Length.

Table 2. Example Loss Calculation

	min.	max.
Attenuation Loss - dB		
loss/meter	0.19	0.43
total	0.95	2.15
Bulkhead Connection Loss - dB		
loss/bulkhead	0.7	2.8
total	1.4	5.6
System Loss - dB		
total	2.35	7.75
	$= \alpha_{min}$	$= \alpha_{max}$

Table 2 shows the results of calculating the minimum and maximum losses for a 5 m link of standard cable with two bulkhead connections.

You can see that even for this relatively short link, there is over 5 dB difference between the minimum and maximum losses.

Link Design

The fundamental requirement in the design of a fiber-optic link is to ensure that the receiver gets the proper amount of light. As mentioned earlier, this actually places three requirements on the design:

For a high output voltage,

1. input power must be LESS than the maximum $P_{R(H)}$.

For a low output voltage,

2. input power must be GREATER than the minimum $P_{R(L)}$,

3. input power must be LESS than the maximum $P_{R(L)}$.

The first requirement is usually easy to meet: just ensure that the LED drive current is below about 20 μA, or that the forward voltage drop of the LED is less than about 1.0 V.

The second requirement defines the underdrive, or sensitivity, limit of the receiver. You must ensure that the receiver has enough input power. This requires that the minimum transmitter coupled power minus the maximum system losses be GREATER than the minimum $P_{R(L)}$. In equation form:

$$P_{Tmin} - \alpha_{max} > P_{R(L)min}.$$

You should start your design with the transmitter drive current at the maximum recommended current of 60 mA, and decrease it later on in the design if required. Remember to use the maximum link length when calculating the maximum system losses.

Another way of looking at the same requirement is in terms of an optical power budget (OPB). The optical power budget is how much optical power you can "spend" on losses in your system; it is defined as the difference between the minimum transmitted power and the minimum $P_{R(L)}$:

$$OPB = P_{Tmin} - P_{R(L)min}$$

Your total system losses must then be less than the optical power budget:

$$\alpha_{max} < OPB.$$

You may want to include a safety or power margin (PM) in your design. This margin is included to account for any decreases in the received optical power over the lifetime of the link. The received power may decrease over time due to increases in attenuation of the fiber, due to optical contamination of the connectors or active components, or due to a drop in the output power of the transmitter. If you include a power margin in your calculations, your system losses plus the power margin must be less than the optical power budget:

$$\alpha_{max} + PM < OPB.$$

A typical power margin is around 3 dB; choose a larger margin for harsh environments and a smaller margin for more benign environments. For example, if your maximum system losses are 12 dB and you want a power margin of 3 dB, then you must have an optical power budget of greater than 15 dB. As another example, if you have an optical power budget of 10 dB and you want a power margin of 3 dB, then your maximum system losses must be less than 7 dB.

To calculate the minimum allowable transmitter drive current, determine if there is any budget left over after subtracting system losses and the power margin. This is the amount that you can decrease the transmitter output power by decreasing the drive current:

$$\text{Remaining budget} = OPB - (\alpha_{max} + PM).$$

As an example, let's assume we have a 40 kBd 5 m link with standard cable, 2 bulkhead connections, and a power margin of 3 dB. We have already calculated the maximum losses for this system:

Maximum system losses:
α_{max} = 7.75 dB.

With a power margin of 3 dB, the optical power budget, OPB, must be greater than 7.75 dB + 3 dB = 10.75 dB, or

10.75 dB < OPB.

The 40 kBd transmitter can couple a minimum power of -13.6 dBm over temperature at 60 mA, and the receiver has a minimum $P_{R(L)}$ of -39 dBm. Therefore the optical power budget is given by:

OPB = -13.6 dBm - (-39 dBm) = 25.4 dB.

There is plenty of power budget to cover the system losses and power margin. To determine the minimum transmitter drive current, determine the remaining budget:

Remaining budget = 25.4 dB - (7.75 dB + 3 dB) = 14.65 dB.

This is how much we can decrease the transmitter output power and still guarantee that we will not underdrive the receiver. According to Figure 8, decreasing the drive current to about 4 mA will drop the output power by about the right amount. You can see why we call the 40 kBd link a "low-current" link!

So far, we've covered the first two requirements for designing a fiber-optic link. The third requirement defines the overdrive limit of the receiver; you must ensure that the receiver does not get too much power. In other words, the maximum possible received optical power, which equals the maximum transmitter power minus the minimum system losses, must be LESS than the maximum $P_{R(L)}$. In equation form:

$$P_{Tmax} - \alpha_{min} < P_{R(L)max}$$

Remember to use the shortest link length for calculating the minimum system losses.

If the received optical power is too high, then the transmitter coupled power must be decreased by decreasing the drive current. To calculate the maximum allowable transmitter drive current, first determine how far above $P_{R(L)max}$ the received power is, and then decrease the transmitter output power by that much:

Amount of decrease =
$(P_{Tmax} - \alpha_{min}) - P_{R(L)max}$

Let's use our previous example to illustrate. We have already calculated the minimum system losses:

Minimum system losses:
α_{min} = 2.35 dB.

The 40 kBd transmitter can couple a maximum power of -4.5 dBm at 60 mA, and the receivcr has a maximum $P_{R(L)}$ of -13.7 dBm. First determine the maximum possible received power:

-4.5 dBm - 2.35 dB = -6.85 dBm.

This is above the overdrive limit, $P_{R(L)max}$, of -13.7 dBm. Therefore, we must decrease the transmitter drive current to decrease the transmitter coupled power:

Amount of decrease =
-6.85 dBm - (13.7 dBm)
= 6.85 dB.

According to Figure 8, decreasing the transmitter drive current to about 14 mA will ensure that the receiver is not overdriven. For the example link discussed above, the minimum transmitter drive current is about 4 mA, and the maximum current is about 14 mA. Choosing a current between the minimum and maximum currents will provide additional safety or power margin.

After you have determined the minimum transmitter drive current from underdrive considerations and the maximum current from overdrive considerations, it might turn out that the maximum is less than the minimum (this did not happen, however, in the above examples). This occurs when the maximum possible range, or variation, of received power is greater than the dynamic range of the receiver. If this does occur, you can reduce the possible range of received power by doing any or all of the following:

1. Use improved cable. Improved cable has a smaller range of attenuation than standard cable and will therefore reduce the possible range of loss in the link.

2. Reduce the maximum link length.

3. Restrict the allowable variation in the length of the link. A link that is designed to operate from 0 m to 10 m will have

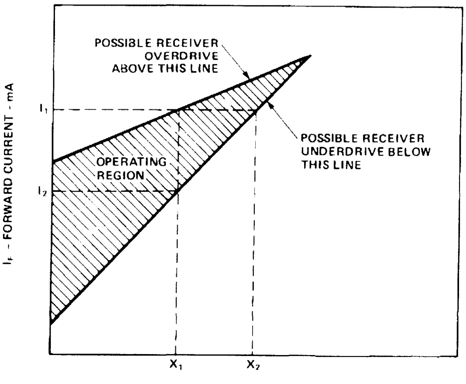


Figure 14. Link Operating Diagram.

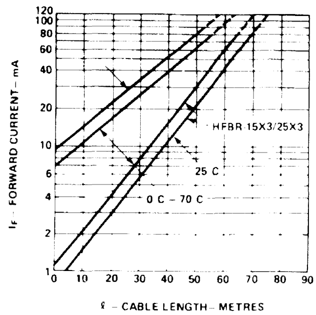


Figure 15. 40 kBd Link Operating Diagram.

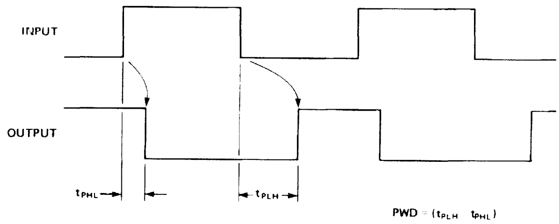


Figure 16. Pulse-Width Distortion.

more possible variation in the received power than a link designed to operate from 8 m to 10 m (the above examples dealt with a fixed link length of 5 m).

4. Reduce the number of bulkhead connections. There is a possible connection loss variation of (2.8 dB - 0.7dB) = 2.1 dB per bulkhead connection.

Link Operating Diagram
A link operating diagram, shown in Figure 14, can simplify the design of a simple point-to-point fiber-optic link, defined as a link with no bulkhead connections and a single length of fiber between the transmitter and the receiver. It illustrates the allowable combinations of link length and transmitter drive current.

The two primary features of the diagram are the overdrive and underdrive lines. If you operate a link in the region above the overdrive line (i.e., a combination of transmitter drive current and link length that lies above the overdrive line), then it is possible that you might overdrive the receiver. Conversely, if you operate the link below the underdrive line, then it is possible that you might underdrive the receiver. Therefore, the region between the two lines defines the valid operating region.

As shown in Figure 14, operating the transmitter at a fixed drive current of I_1 allows link lengths from X_1 to X_2. For a fixed link length of X_1, a drive current of between I_1 and I_2 is required for proper operation.

As an example, Figure 15 shows the link operating diagram for the 40 kBd link with standard cable. Operating the transmitter at 40 mA allows link lengths from about 40 m to 55 m. Or, for a fixed link length of 20 m, a transmitter drive current between about 4 mA and 17 mA is required.

Pulse-Width Distortion

Pulse-width distortion (PWD) is often the limiting factor that determines the maximum data rate of a fiber-optic link. Pulse-width distortion is caused by unequal propagation delays and is defined as the difference between the propagation delays, as shown in Figure 16:

$$PWD = t_{PLH} - t_{PHL}$$

The term t_{PHL} refers to the propagation delay from the input to the high-to-low transition of the OUTPUT, as shown in Figure 16. Pulse-width distortion lengthens or shortens the duration of transmitted pulses, depending on the polarity of the pulse.

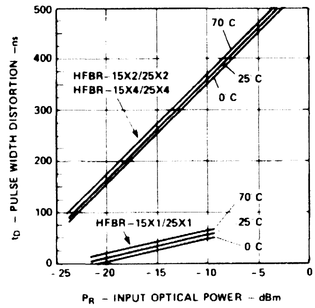


Figure 17. Typical Pulse-Width Distortion vs. Input Power of 5 MBd and 1 MBd Receivers.

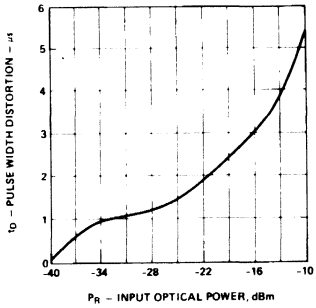


Figure 18. Typical Pulse-Width Distortion vs. Input Power of 40 kBd Receiver.

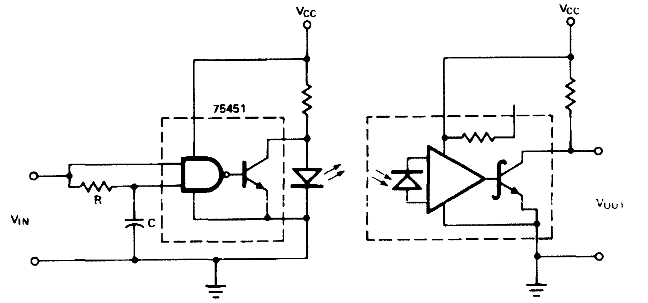


Figure 19. Pre-Correction of PWD.

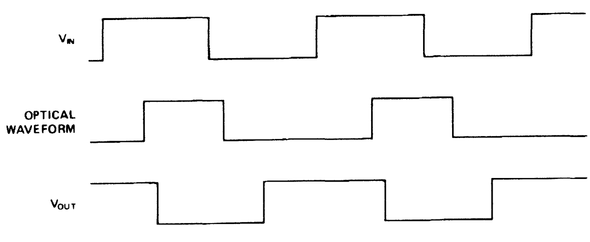


Figure 20. Pre-Correction Timing Diagrams.

Figure 17 shows the pulse-width distortion specifications for the 1 MBd and 5 MBd Versatile Links. Note that the 5 MBd link has significantly less distortion than the 1 MBd link and much less variation in distortion over the full input optical power range. Figure 18 shows the distortion for the 40 kBd link. Notice that the PWD is always positive for all three receiver types (i.e., t_{PLH} is always longer than t_{PHL}). We can utilize this fact to correct or compensate for the PWD by selectively delaying one of the transmitted edges.

Figure 19 illustrates how to implement a "pre-correction" circuit, which corrects for distortion at the transmitter. The circuit is almost the same as our recommended 5 Mbd transmitter circuit, except for the RC network at the input of the gate. The RC network delays the turn-on of the LED, but not the turn-off. Both inputs must be high for the LED to turn on; the RC network delays one of the inputs and, therefore, delays the turn-on of the LED. However, only one of the inputs needs to go low for the LED to turn off. Figure 20 is a timing diagram which illustrates the operation of the correction circuit. Note how the turn-on of the LED is delayed and how the distortion is reduced. It is possible to calculate the required values for R and C to achieve the desired amount of correction; however, it is usually just as easy to experimentally determine their values. For the 5 MBd link, start with R = 100 ohms and C = 390 pF and adjust the values to obtain the desired amount of correction.

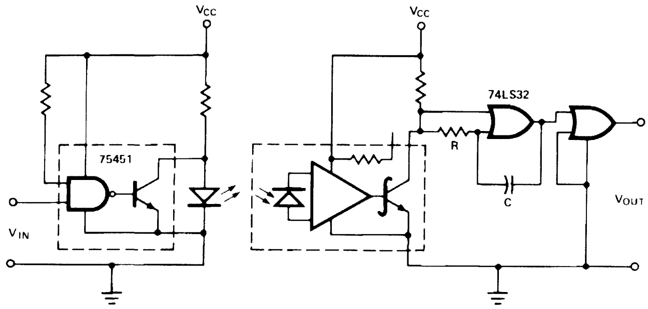


Figure 21. Post-Correction of PWD.

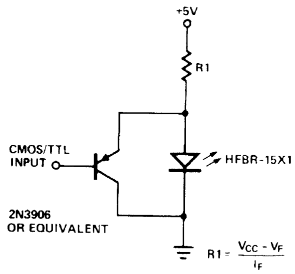


Figure 23. Simple 5 MBd PNP Transmitter Circuit.

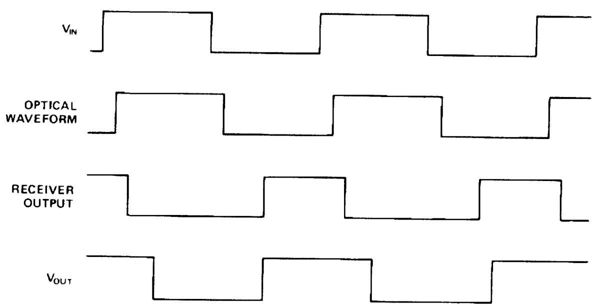


Figure 22. Post-Correction Timing Diagrams.

It is also possible to correct the distortion at the receiver using "post-correction". Figure 21 shows a post-correction circuit. It works on the same principle of delaying one of the edges. Again, it is similar to the recommended circuit, except for the addition of a delay circuit on the output of the receiver. The RC network delays the falling edge of the receiver output. Both of the inputs to the OR gate must go low for the output to go low; the RC network delays one of the inputs and, therefore, delays the falling edge. Connecting the capacitor to the output provides positive feedback to ensure rapid switching of the output. Only one of the OR gate inputs needs to go high for the output to go high; therefore, there is no delay of the rising edge.

Figure 22 is a timing diagram illustrating the operation of the circuit. Notice the distortion of the receiver output and how the post-correction circuit delays the falling edge to reduce the amount of distortion. Again, it is easiest to experimentally determine the values of R and C to achieve the desired amount of correction. For the 5 MBd link, start with R = 330 ohms and C = 39 pF and adjust the values to get the desired amount of correction.

Although it is possible to use pre-correction and post-correction in the same link, there is no need to incorporate both, and we recommend using only one type of correction. The choice of which circuit to use depends on external system constraints, such as a limit on the total number of system components, or other constraints on the transmitter or receiver circuitry.

Additional Circuit Recommendations

This section presents several additional circuits that can be used with the Versatile Link. The transmitter circuits discussed below should be used only with the 5 MBd and 40 kBd links; the 1 MBd link requires the transmitter circuit shown in Figure 9 for proper operation.

The first circuit, shown in Figure 23, is a simple PNP transmitter circuit. The primary feature of the circuit is its simplicity: only two components are required other than the transmitter. It uses an inexpensive PNP transistor in a shunt drive configuration; when the input (i.e. the base of the transistor) is high, the transistor is cut off and the LED is on.

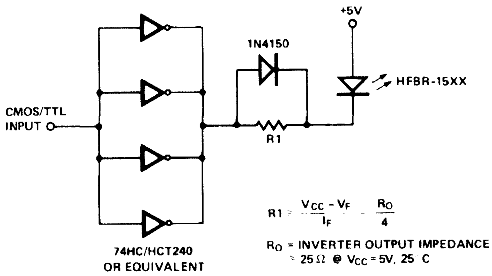


Figure 24. Low-Current CMOS Transmitter Circuit.

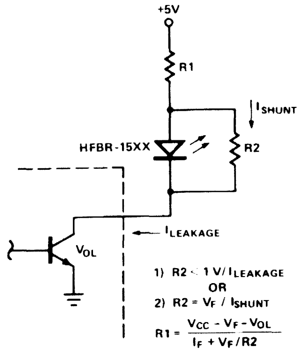


Figure 25. LED Shunt Resistor for Open Collector Drive.

When the input is low, the transistor turns on and shunts current away from the LED, turning the LED off.

The circuit is very fast for several reasons. The transistor allernates between the cutoff and active regions of operation and, therefore, never saturates. The circuit presents a very low impedance during turn-off of the LED, which helps to turn off the LED more rapidly. And finally, the emitter base junction voltage of the transistor "pre-charges" the junction capacitance of the LED to about 700 mV, which helps to turn on the LED more rapidly. The "pre-charge" eliminates the time that would otherwise be required to charge the LED capacitance from 0 V to the pre-charge voltage of 700 mV during turn-on of the LED.

The circuit has a high input impedance because the input source need supply only the base current of the transistor; the large LED drive current is handled by the transistor. This allows the circuit to be driven directly from low-current outputs, such as CMOS. Choose the value of R1 according to the equation in Figure 23.

Figure 24 is the schematic of a low-current CMOS-compatible transmitter circuit. The circuit operation is straightforward. The outputs of four CMOS buffers are arranged in parallel to ensure adequate drive capability for large LED currents. For smaller LED currents, fewer buffers can be used. The circuit has a very high input impedance, is CMOS compatible, and draws essentially no quiescent current when the LED is off. The diode helps to speed up the circuit. The capacitance of the diode provides additional current during the turn-on transition to help turn on the LED more rapidly. It also provides a low impedance during turn-off, which helps to turn the LED off more quickly. Choose the value of R1 according to the equation in Figure 24. If fewer buffers are used, divide R_O by the number of buffers in the circuit, instead of the four shown in the figure.

If an open-collector output is used to drive the LED, a shunt resistor in parallel with the LED, shown in Figure 25, can improve the performance of the transmitter. The shunt resistor R2 serves two purposes:

1. It shunts any output leakage current around the LED, ensuring that the LED is off when it is supposed to be off. The leakage current will cause a voltage drop across R2; as long as the voltage drop is less than about 1 V, the LED will not turn on. Equation No. 1 in the figure can be used to determine the value of R2 in this case.

2. It also helps turn the LED off more quickly by discharging the stored charge in the junction of the LED. Smaller resistors will shunt more current and will turn the LED off more rapidly, at the expense of more overall drive current. Equation No. 2 in the figure can be used to determine the value of R2 in this case.

In either case, select R1 according to the equation in Figure 25.

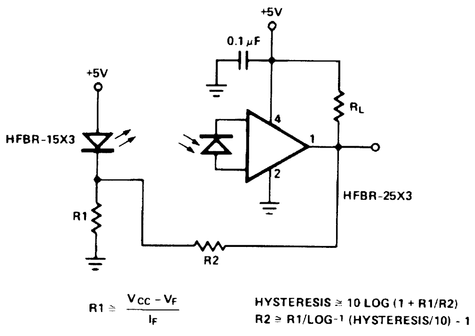


Figure 26. Photo Interrupter Hysteresis Circuit.

The final application circuit is used in photo-interrupter applications. A photo-interrupter is comprised of a transmitter and a receiver connected by two lengths of fiber. The ends of the fibers are not connected directly together, but have a small separation between them. This allows small objects to pass between them and interrupt the light from the transmitter. The Versatile Link data sheet discusses how to use Versatile Link components in photo-interrupter applications. The circuit shown in Figure 26 illustrates how to add hysteresis to the recommended photo-interrupter circuit shown in the data sheet. Hysteresis may be required because it is possible that the received optical power may occasionally be at the threshold of the receiver. This could cause multiple transitions on the output and lead to improper circuit operation. It is common in this application for the transmitter and the receiver to be located next to each other. This allows a small amount of positive feedback to be applied from the receiver to the transmitter, resulting in hysteresis.

The hysteresis will rapidly switch the output and eliminate the problem mentioned above. The amount of hysteresis is determined by the values of R1 and R2. Choose R1 to achieve the desired drive current according to the equation in Figure 26. The amount of hysteresis, expressed in dB, is given approximately by the following equation:

$$\text{Hysteresis} = 10 \log (1 + R1/R2).$$

Solving for the value of R2 yields:

$$R2 = R1/ [\log^{-1} (\text{Hysteresis}/10)-1]$$

Values of hysteresis from 0.25 to 1 dB should be sufficient for most applications. As an example, for hysteresis of 0.25 dB, R2 should be about 17 times the value of R1.

For additional information regarding the photo-interrupter application, please refer to the Versatile Link data sheet.

Summary

The Versatile Link low-cost fiber optic components were designed and specified for easy design. Guaranterd electrical and optical parameters ensure reliable system performance. The wide variety of package configurations and connector types allow maximum flexibility to meet application requirements. The Hewlett-Packard HFBR-0501 series of fiber optic components offer guaranteed performance, quality, and reliability.

For more information, please call your local Hewlett-Packard Components Sales Office or authorized HP Components Distributor.

Appendix

We quantify the amount of light by measuring its power. Optical power is measured in watts or, more commonly in fiber optics, in microwatts (μW). Optical power is also commonly expressed in dBm. dBm is a logarithmic measure of power relative to 1 milliwatt (mW), as explained below.

The ratio of two powers, P1 and P2, can be expressed in dB as follows:

$$\text{dB} = 10 \log (P1/P2).$$

A positive number indicates that P1 is greater than P2, and a negative number indicates that P1 is less than P2. Remember, dB is a relative measure of two powers.

The ratio of a power, P1, to 1 mW is expressed in dBm as follows:

$$\text{dBm} = 10 \log (P1/1\text{ mW}) \text{ or } 10 \log (P1/1000\ \mu\text{W}).$$

Negative numbers do not indicate negative power, only power less than 1 mW. Remember, dBm is an absolute measure of power because it references the measured power to 1 mW.

To convert from dBm to mW or μW, use the following equations:

$mW = \log^{-1} (dBm/10)$, or ,
$\mu W = 1000 \log^{-1} (dBm/10)$.

As an example, to convert 150 μW to dBm:

$$dBm = 10 \log^{-1} (150\ \mu W / 1000\ \mu W) = -8.24.$$

To convert -24 dBm to μW:

$$\mu W = 1000 \log^{-1} (-24/10) = 3.98.$$

If optical power is lost in the fiber, the loss can be expressed in dB as the ratio of output power to input power as follows:

$$\text{loss (dB)} = 10 \log (P_{out} P_{in}).$$

Expressing power loss in dB allows the different losses in a system to be added together to determine the total loss. Therefore, the output power can be determined simply by subtracting the total system losses, expressed in dB, from the input power, expressed in dBm:

$$P_{out}\ (dBm) = P_{in}\ (dBm) - \text{losses (dB)}.$$

As an example, if the input power to the system is -10 dBm and the total system losses are 12 dB, then the output power is:

$$P_{out}\ (dBm) = -10\ dBm - 12\ dB = -22\ dBm.$$

HEWLETT PACKARD

Complete Fiber-Optic Solutions for IEEE 802.3 FOIRL, 10Base-FB, and 10Base-FL

Application Note 1038

Introduction

Hewlett-Packard's HFBR-0400 fiber-optic components are widely used in Ethernet LAN systems. These 820 nm wavelength components were first used in 802.3 FOIRL applications. The same low-cost HFBR-0400 components have subsequently been used in systems which comply with the IEEE 802.3 10Base-FB, and 10Base-FL standards. Several integrated circuits are now available which make it easier to use HFBR-0400 components in fiber-optic Ethernet applications. This Application Note shows how easy it is to build high-performance Ethernet transceivers using inexpensive, off-the-shelf, integrated circuits and HP's low-cost HFBR-14X4 and HFBR-24X6 short-wavelength fiber-optic components.

Two categories of fiber-optic Ethernet applications will be discussed in this Application Note. The first category addresses fiber-optic transmitters and receivers suited for use in LAN equipment such as hubs, bridges, routers, and repeaters. The second category addresses Medium Attachment Unit (MAU) applications that convert standard Attachment Unit Interface (AUI) Ethernet connections to optical fiber. The MAU circuits recommended in this Application Note use the HFBR-4663 transceiver IC with low-cost HFBR-0400 fiber-optic components. The HFBR-4663 allows fiber-optic MAU transceivers which meet IEEE standards to be implemented with a single integrated circuit.

IEEE 802.3 System Specifications

Tables 1 and 2 provide a brief listing of some key parameters specified in the 802.3 FOIRL, 10Base-FB, and 10Base-FL standards.

Capabilities of HFBR-0400 Components

The transmitter and receiver circuits recommended in this Application Note characteristically exceed the limits called for in IEEE 802.3 by a comfortable margin. The optical power launched into 62.5/125 µm fiber by the HFBR-14X4 LED is typically -12 dBm peak at a dc forward current of 60 mA. When Manchester encoded data with a 50% duty factor is applied to the LED transmitter the HFBR-14X4 LED can typically launch -15 dBm average into the core of a 1m length of 62.5/125 µm fiber with a numerical-aperture of 0.275. This 3 dB difference between peak and average power is due to the 50% duty factor of Manchester data and the averaging response of most optical-power meters. The HFBR-24X6 is a simple hybrid component that contains a silicon PIN detector and a transimpedance amplifier. The HFBR-24X6 can be combined with simple inexpensive integrated circuits to build digital receivers that have an optical dynamic range and sensitivity greater than called for in the IEEE 802.3 specifications.

Recommended Transmitters for Hub, Bridge, Router, and Repeater Applications.

Two different techniques have commonly been used to drive the HFBR-1414 LED in Ethernet applications. Both of the LED drivers recommended in this Application Note will address the requirements called out in the IEEE 802.3 LAN specifications. The HFBR-14X4 LED has typical rise/fall times of less than 4 ns when used in the circuits recommended in Figure 1 or Figure 2. Transmitter jitter and

Table 1. Key IEEE 802.3 LED Transmitter Specifications

Parameter	Symbol	802.3 FOIRL Limits	802.3 10Base-FB Limits	802.3 10Base-FL Limits	Units
Launched Optical Power Over Life	P_T on	-12 to -20	-12 to -20	-12 to -20	dBm avg
Extinction	P_T off	13 dB less than P_T on	13 dB less than P_T on	13 dB less than P_T on	–
Maximum Optical Rise Time	t_r	10	10	10	ns
Maximum Optical Fall Time	t_f	10	10	10	ns
Maximum Difference Between Optical Rise & Fall Times	$\lvert t_r - t_f \rvert$	3	3	3	ns
Maximum Jitter at Optical Output	–	±2	±2	±4	ns
Maximum Duty Cycle Distortion	–	Not Specified	±2.5	±2.5	ns
Min. Eye Opening	–	46	41	37	ns

Table 2. Key IEEE 802.3 Fiber-Optic Link Specifications

Receiver Input Conditions			Required Link Performance		
IEEE 802.3 STANDARD	**Maximum Rise/Fall Time of Received Optical Pulse (ns)**	**Received Optical Power (dBm avg)**	**802.3 FOIRL Maximum Jitter (ns)**	**802.3 10Base-FB Maximum Jitter (ns)**	**802.3 10Base-FL Maximum Jitter (ns)**
FOIRL 10Base-FB 10Base-FL	10 with 1 m of 62.5/125 μm fiber	-12 max.	±6	±6.5	±15
10Base-FB 10Base-FL	31.5 with 2 km of 62.5/125 μm fiber	-32.5 min.	–	±6.5	±15
FOIRL	Not Specified	-30.0 min.	±6	–	–
IEEE 802.3 STANDARD	**Maximum Rise/Fall Time of Received Optical Pulse (ns)**	**Received Optical Power (dBm avg)**	**802.3 FOIRL Minimum Eye Opening (ns)**	**802.3 10Base-FB Minimum Eye Opening (ns)**	**802.3 10Base-FL Minimum Eye Opening (ns)**
FOIRL 10Base-FB 10Base-FL	10 with 1m of 62.5/125 μm fiber	-12 max.	38	37	20
10Base-FB 10Base-FL	31.5 with 2 km of 62.5/125 μm fiber	-32.5 min.	–	37	20
FOIRL	Not Specified	-30.0 min.	38	–	–

duty-cycle distortion are normally less than 1 ns when using either of the recommended LED drivers. The cost complexity and performance tradeoffs associated with these two different LED drivers will now be discussed in greater detail.

The LED forward current (I_F) supplied by the simple voltage-source driver shown in Figure 1 will change with variations in V_{CC} and LED forward voltage (V_F). The tolerance of resistors R7, R8, and R9 will also effect the magnitude of I_F. Deviations in I_F due to the 74ACT11000 nand-gate voltage-source are insignificant. The typical output impedance of the three parallel connected nand gates is only 1 ohm and the external resistors R7 and R8 which limit the LED current total to 66 ohms. This large difference between the source-impedance of the nand-gate voltage-source and the sum of R7 and R8 makes it improbable that changes in LED I_F will result due to process variations in the 74ACT11000.

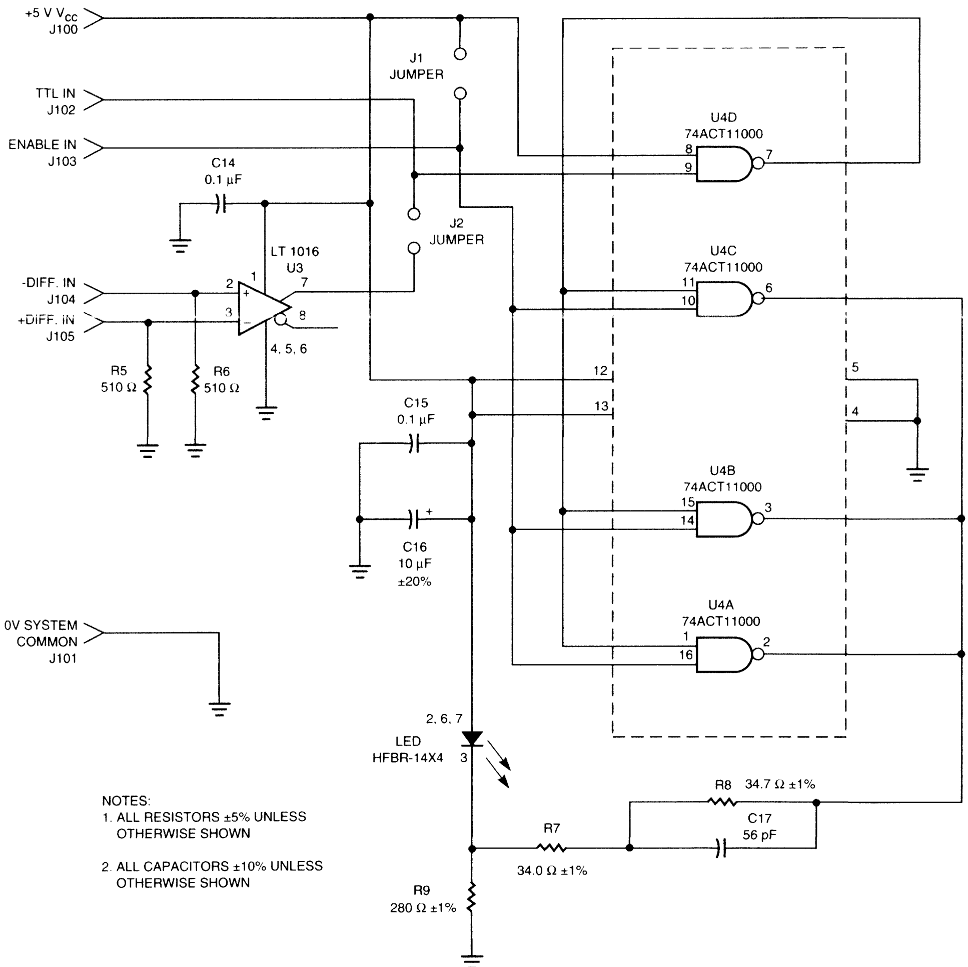


Figure 1. Voltage Source Transmitter for Hub, Bridge, Router, and Repeater Applications.

A voltage-source drive-circuit suited for 802.3 applications is shown in Figure 1. This simple drive-circuit has an LED forward current (I_F) that varies from the nominal 60 mA peak value desired for fiber-optic Ethernet applications. This variation in I_F causes a small decrease in the power coupled into 62.5/125 µm fiber. When using the circuit shown in Figure 1, the launched power will be 1 dB less than specified in the HFBR-14X4 data sheet, under worst-case conditions. The worst-case occurs when V_{CC} is low and LED forward voltage (V_F) and resistor tolerance are high. The HFBR-1414 data sheet specifies launched power at I_F = 60 mA, and assumes that LED forward current is constant. Normal tolerances of the voltage-source LED driver will cause variations in LED I_F that lower the minimum power launched into the fiber. This reduction in launched power relative to the P_{t62} specification given in the HFBR-14X4 data sheet is expected. Voltage-source drive-circuit tolerances will lower LED forward current and the amount of light coupled into the fiber-optic cable is directly proportional to I_F.

For applications that require tighter control over LED I_F, and less variation in launched optical power, the current-source transmitter shown in Figure 2 is recommended. Figure 2 shows an LED drive-circuit which provides a forward current that is independent of V_{CC} and LED forward voltage. The LED current provided by this driver is primarily determined by the tolerance of the bandgap reference U3, and the tolerance of resistors R5 and R6. The -2 mV/°C temperature coefficient of the base-emitter junction of Q3 or Q4 increases the voltage applied to R5 and R6 as ambient temperature rises. The temperature coefficient of NPN transistor base-emitter voltage is thus used to increase the magnitude of the current applied to the LED as temperature rises. This technique prevents LED light output from decreasing as temperature rises by compensating for changes in the LED quantum efficiency.

Either of the LED drivers shown in this Application Note will address the requirements called out in the IEEE 802.3 specifications. The design rules for the LED driver shown in Figure 1 are given in Equation 1 and the design rules for the LED driver shown in Figure 2 are provided in Equation 2.

When choosing the driver the designer should consider the fol-

Equation 1

Design rules for voltage source LED driver circuits.

N = Number of gates connected in parallel.

B = Empirically determined constant for optimum relationship between prebias and LED forward current.

$$R9 = \frac{(V_{CC} - V_F)(1 + B)}{I_{FON}}$$

$$R8 = \frac{R9}{2B}$$

$$R7 = \frac{R9}{2B} - \frac{3}{N}$$

$$C = \frac{2.0 \times 10^{-9}}{R8}$$

Recommend B = 3.97

Equation 2

Design rules for temperature compensated current source LED driver circuit.

$$I_F = \frac{\Delta V_{U3} - V_{BE_{Q3}}}{R5} + \frac{\Delta V_{U3} - V_{BE_{Q4}}}{R6}$$

$$I_F = \frac{1.24 - 0.7}{R5} + \frac{1.24 - 0.7}{R6}$$

$$I_F = (1.24 - 0.7)\left(\frac{1}{R5} + \frac{1}{R6}\right)$$

$$R3 = \frac{V_{OH} - V_{OL}}{I_F} = \frac{5V}{I_F}$$

$$C4 = \frac{2.0\ \text{ns}}{R3}$$

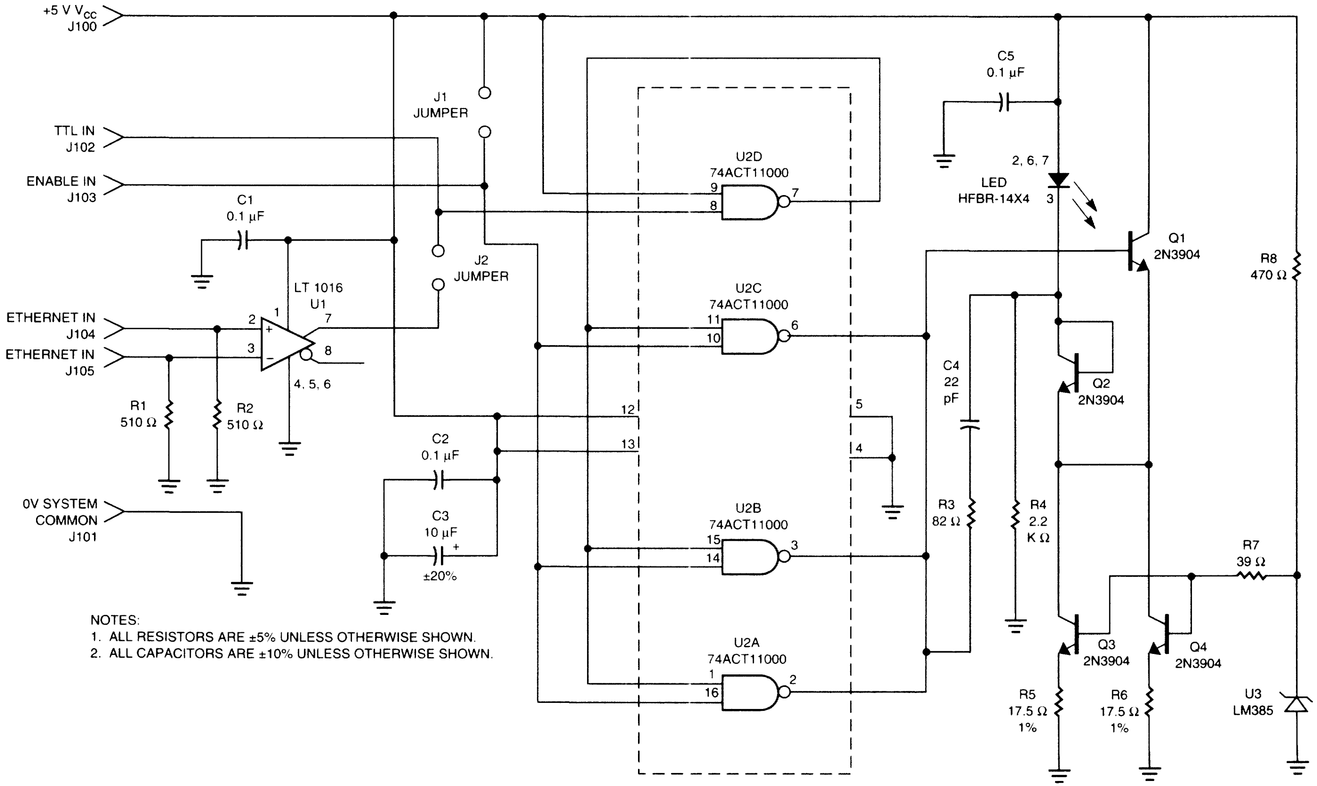


Figure 2. Current Source Transmitter for Hub, Bridge, Router, and Repeater Applications.

lowing factors. The LED driver shown in Figure 1 is simple but has a larger variation in the power coupled from the LED to the fiber. The circuit shown in Figure 2 is more complex, but offers tighter control over variations in launched optical power. System designers are encouraged to choose the LED driver which best meets their requirements. If cost and board space are of greater concern than variations in launched optical power then the voltage-source transmitter circuit shown in Figure 1 makes the most sense. If the designer desires to maximize the optical power budget of the fiber-optic link then the transmitter circuit shown in Figure 2 is a better choice.

Recommended Receiver for Hub, Bridge, Router, and Repeater Applications.

A simple receiver which complies with IEEE 802.3 specifications is shown in Figure 3. The post-amplifier comparator function used to convert the analog output of the HFBR-24X6 to digital data is generally referred to as a quantizer. The ML-4622 quantizer shown in Figure 3 also contains a link-monitor which inhibits the data output when the optical power drops below the minimum level needed to ensure that the receiver's output is error free.

The receiver recommended in Figure 3 has a typical sensitivity of -36 dBm average at a Bit-Error-Rate (BER) of $1x10^{-10}$ when receiving 20 MBd Manchester encoded data. This receiver performance was measured using 2 km of 62.5/125 µm fiber with the BER tester's clock centered in the middle of the received 20 MBd Manchester symbols. The link-monitor function must be disabled by grounding pin 15 of the ML-4622 quantizer in order to measure the ultimate sensitivity of the receiver. In normal operating mode the ML-4622's link monitor disables the data output of the fiber-optic receiver before the probability of an error exceeds 1 in 10^{10} bits.

When receiving a repetitive 20 MBd D2D2 hexadecimal word the total peak-to-peak jitter at the data output of the circuit shown in Figure 3 is typically

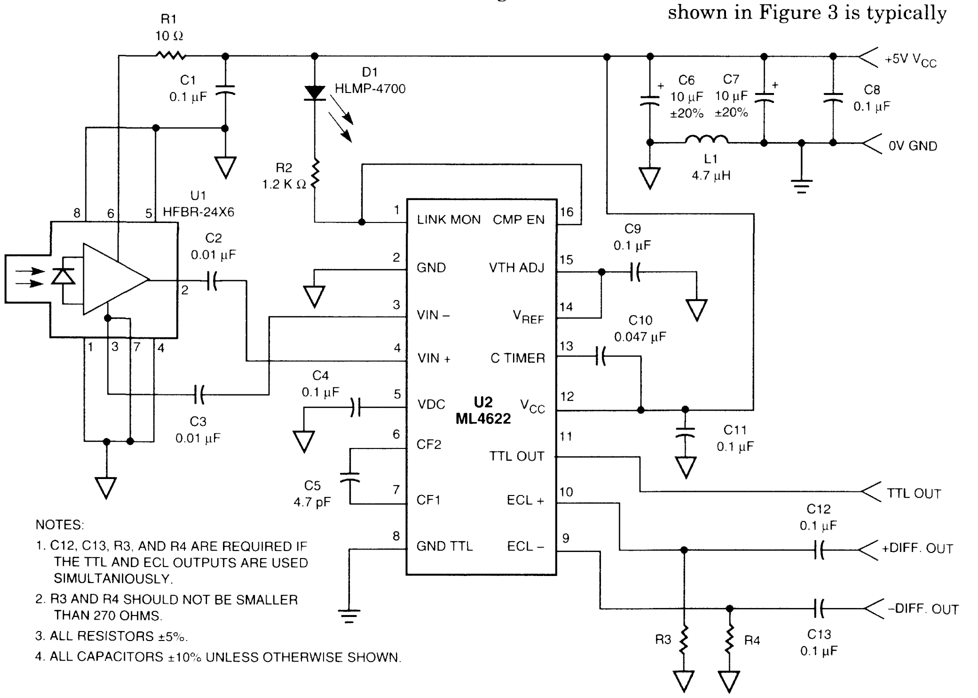


Figure 3. Receiver for Hub, Bridge, Router, and Repeater Applications.

less than 10 ns. A D2D2 Hexadecimal pattern was used to test the complete fiber-optic link because it emulates the worst stress possible with Manchester encoding. The excellent performance of the circuits recommended in this Application Note allows low jitter to be achieved when data is transmitted over a 2 km segment of 62.5/125 μm fiber with a received optical power of -32.5 dBm average. The low jitter attained at the receiver's output corresponds to a 40 ns clear eye-opening between the edges of the data symbols. A wide eye-opening is desirable because this minimizes the accumulation of jitter when active star hubs are cascaded.

Demo Kit For Fiber-Ethernet

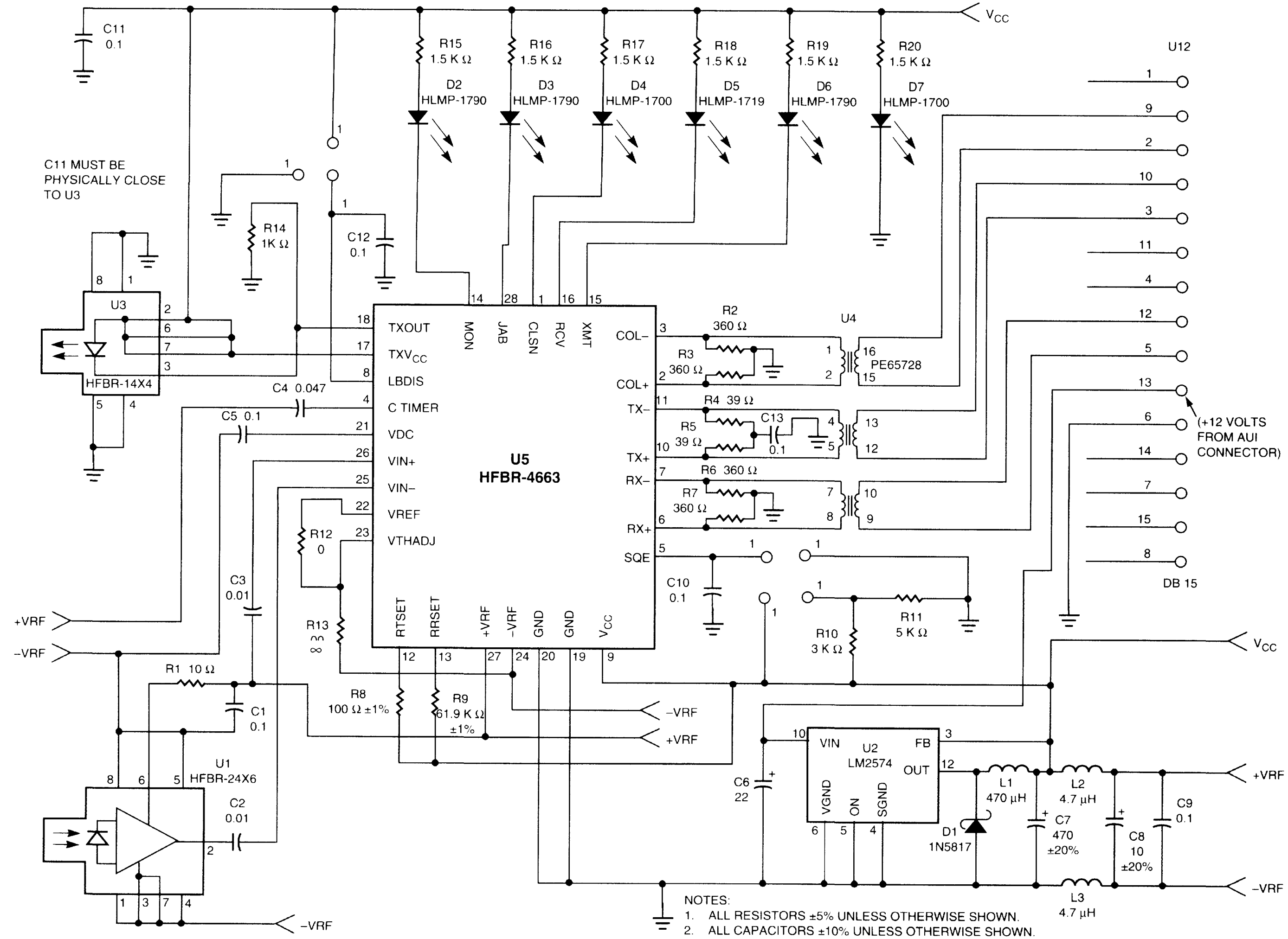
The transceiver circuits shown in Figures 1, 2, and 3 are suited for use in fiber-optic hubs, bridges, routers, and repeaters. This recommended transceiver can easily be compared to the IEEE specifications listed in Tables 1 and 2 by ordering the HFBR-0414 demo kit. The HFBR-0414 kit contains a small 2 3/4 by 1 3/4 inch through-hole printed circuit board and all of the active devices needed to build the circuits shown in Figures 1 and 3. This inexpensive kit can be completed using readily-available passive components such as radial-lead monolithic ceramic capacitors, radial-lead epoxy-dipped tantalum capacitors, and axial-lead 1/4 W resistors. The passive components needed to assemble this fiber-optic demo are available in most engineering stock rooms. The HFBR-0414 demo kit minimizes the engineering cost of building the fiber-optic transceiver recommended in this Application Note, reduces time-to-market by minimizing the effort required to construct working prototypes, and enables designers to quickly determine that Hewlett-Packard's HFBR-0400 fiber-optic components can meet Ethernet LAN requirements. The measured performance of the circuits used in the HFBR-0414 demo can be found in Tables 3 and 4. Table 3 shows the measured performance of the transmitter recommended in Figure 1. Table 4 shows the measured performance of an entire fiber-optic link which uses the circuits recommended in Figures 1 and 3.

Recommended Circuit for Ethernet Fiber-Optic MAU Applications

Circuits recommended for use in Medium-Attachment-Unit (MAU) applications will now be discussed. Figure 4 shows a MAU transceiver using the HFBR-4663 single-chip transceiver IC. The HFBR-4663 provides all of the circuit elements needed to build a complete fiber-optic transmitter and receiver which complies with the 802.3 10Base-FL standards. The HFBR-4663 provides every function needed to make HFBR-0400 fiber-optic components compatible with a standard Ethernet AU interface. This single IC also provides all necessary network and status indicators needed by a fiber-optic MAU. The HFBR-4663 replaces two-chip solutions that were formerly needed to construct fiber-optic MAUs. A highly efficient switching power-supply that allows the MAU transceiver to operate from the +12 V power available at the AUI is also included in Figure 4. The measured performance of the transmitter portion of the MAU is shown in Table 5.

Table 3. Measured Performance of the Transmitter shown in Figure 1
Mean Performance of Five Transmitters Tested at Room Temperature

Parameter	Measured Typical Performance	Test Conditions
P_t On	-12.2 dBm pk.	Logic "0" at Transmitter TTL Input, I_f dc = 60 mA
P_t Off	-82.2 dBm pk.	Logic "1" at Transmitter TTL In
LED t_r	1.30 ns	1 MHz Square Wave Input
LED t_f	3.08 ns	1 MHz Square Wave Input
$\lvert t_r - t_f \rvert$	1.77 ns	1 MHz Square Wave Input
Tx jitter	0.763 ns pp	20 MBd D2D2 Hexadecimal Input



NOTES:
1. ALL RESISTORS ±5% UNLESS OTHERWISE SHOWN.
2. ALL CAPACITORS ±10% UNLESS OTHERWISE SHOWN.
3. THE HFBR-4663 DATA SHEET (PUBLICATION #5091-7391E 4/93) CONTAINS ERRORS THAT HAVE SUBSEQUENTLY BEEN CORRECTED IN THIS SCHEMATIC.
4. ALL CAPACITORS ARE IN µF.

Figure 4. Ethernet Fiber-Optic MAU Transceiver.

Table 4. Measured Performance of the Transceiver Shown in Figures 1 and 3

Mean Jitter of 5 Transceivers at Maximum Received Optical Power at Room Temperature

Parameter	**Measured Typical Performance**	**Test Conditions**
1 m Link Jitter at Rx ECL Output	3.07 ns pp	P_r = -11.4 dBm avg. with 20 MBd D2D2 Hexadecimal Data
1 m Link Jitter at Rx TTL Output	2.73 ns pp	P_r = -11.7 dBm avg. with 20 MBd D2D2 Hexadecimal Data

Mean Performance of 5 Receivers with 1 m of 62.5/125 mm fiber at Room Temperature

Parameter	**Measured Typical Performance**	**Test Conditions**
Mid Bit Rx Sensitivity	-36.5 dBm avg. at BER of $1x10^{-10}$	20 MBd D2D2 Hexadecimal Data
Link Monitor Assert Threshold	-35.4 dBm avg.	20 MBd D2D2 Hexadecimal Data

Mean Performance of 5 Links with 2 km of 62.5/125 mm Fiber at Room Temperature

Parameter	**Measured Typical Performance**	**Test Conditions**
Mid Bit Rx Sensitivity	-34.4 dBm avg. at BER of $1x10^{-10}$	20 MBd D2D2 Hexadecimal Data
Link Jitter at Rx ECL out	7.56 ns pp	P_r = -32.5 dBm avg. with 20 MBd D2D2 Hexadecimal Data
Link Jitter at Rx TTL out	7.03 ns pp	P_r = -32.5 dBm avg. with 20 MBd D2D2 Hexadecimal Data

The complete performance of a fiber-optic link which uses the HFBR-4663 is shown in Table 6. A long length of 62.5/125 μm fiber was used to slow the response time of the light pulses applied to the receiver. The test results shown in Table 6 were obtained by adjusting the length of the optical cable until the 90% to 10% fall-time of the light pulses exiting the fiber slowed to 31 ns. The 10% to 90% optical rise-time at the end of the 2.5 km fiber was 28 ns. The dispersion in the 2.5 km test fiber approaches the maximum 31.5 ns exit response time limit given in the IEEE 802.3 specifications. Table 6 shows how well the MAU transceiver recommended in this Application Note functions as fiber dispersion approaches the maximum limits allowed in the 10Base-FB and 10Base-FL specifications.

Table 7 shows how to select the functions listed in the HFBR-4663 data sheet. The MAU implemented with the HFBR-4663 can be connected directly to data terminal equipment (DTE) through an Ethernet adapter card with an AUI connection. The SQEN, JABD, LBDIS, and COLL functions should be enabled when the MAU shown in Figure 4 is connected to DTE. When the fiber-optic MAU is connected to an Ethernet hub the SQEN, LBDIS, and COLL functions should be disabled.

The HFBR-4663 data sheet can be used in conjunction with Table 7 to determine if functions should be enabled or disabled when evaluating fiber-optic MAU performance. When measuring the performance of the MAU it is usually necessary to disable JABD so that the fiber-optic transmitter will remain active for more than the 1024 byte limit allowed by Ethernet protocol. When JABD is disabled the rise/fall time, jitter, and launched power of the fiber-optic transmitter can easily be measured.

The JABD function should also be disabled when determining the bit error rate (BER) versus receiver sensitivity of MAUs constructed with the HFBR-4663. A D2D2 hexadecimal test pattern should be used to measure the BER of fiber-optic transceivers used in Ethernet

Table 5. Measured Performance of the MAU Transceiver Shown in Figure 4

Mean Performance of 14 Transmitters. All Tests done at Room Temperature.

Parameter	**Measured Typical Performance**	**Test Conditions**
P_t avg	-17.1 dBm avg.	5 MHz Square Wave Input $I_f$pk = 56 mA
LED t_r	2.88 ns	5 MHz Square Wave Input
LED t_f	3.34 ns	5 MHz Square Wave Input
$\lvert t_r - t_f \rvert$	0.46 ns	5 MHz Square Wave Input
Tx jitter	1.64 ns pp	20 MBd D2D2 Hexadecimal Input

Table 6. Typical Performance of a Complete Fiber-Optic Link Which Uses the MAU Transceiver Shown in Figure 4

**All results measured at a received power of -32.5 dBm avg. with fiber dispersion ≅ to max. limits called out in the IEEE 802.3 Specifications.

Eye Opening at the AUI output of the Receiver	V_{CC}	**Temperature**
32.8 ns	4.75 V	0°C
36.9 ns	5.00 V	0°C
32.2 ns	5.25 V	0°C
33.7 ns	4.75 V	25°C
36.7 ns	5.00 V	25°C
33.5 ns	5.25 V	25°C
37.2 ns	4.75 V	70°C
36.7 ns	5.00 V	70°C
36.7 ns	5.25 V	70°C

**Measured Results for a Solitary MAU Transceiver.

Table 6. HFBR-4663 Functions vs. Input Conditions

Input Conditions		**Status of HFBR-4663 Functions**			
HFBR-4663 Pin #	**Voltage at Pin**	**SQEN**	**JABD**	**LBDIS**	**COLL**
5	+5V	EN	EN	–	–
5	V_{CC}-2	DIS	DIS	–	–
5	0V GND	DIS	EN	–	–
8	+5V	–	–	DIS	DIS
8	0V GND	–	–	EN	EN

Notes:
1. DIS = Disabled
2. EN = Enabled

applications. The D2D2 test pattern is equivalent to the worst data induced stress that will occur when sending Manchester encoded data. The JABD function must be disabled when measuring BER because this test is certain to exceed the 1024 byte limit allowed for normal Ethernet traffic.

Printed Circuit Layout Techniques

The circuits given in this Application Note are recommended for use in any system which addresses the requirements specified in the IEEE 802.3 draft standard. HP encourages customers that want to use HFBR-0400 components in fiber-optic Ethernet applications to utilize these circuits in their products. The performance of the fiber-optic transceivers shown in this publication is partially dependent on the layout of the printed circuit board on which these recommended circuits are constructed.

The following simple rules should be followed if you desire to lay out a unique printed circuit (PC) board for the fiber-optic transceivers recommended in this publication.

1) Design the PC board with a ground plane. Use a ground and a power plane if possible. This minimizes the inductance of the ground and power leads connected to the transceiver.

2) Minimize the size of cuts or openings in the ground and power planes. This minimizes the parasitic inductance and improves the dampening of both the transmitter and receiver circuits.

3) The two circuit traces connected between the HFBR-24X6 and the differential input of the receiver's quantizer should be of equal length, and the components in both traces should be placed to achieve symmetry. This minimizes the cross-talk between the fiber-optic transmitter and receiver and improves the receiver's immunity to environmental noise.

4) Connections between the drive circuit and the LED should be of minimum length. This minimizes the noise emitted by the transmitter and improves the optical rise/fall time of the LED.

5) A large 10 μF electrolytic capacitor and a 0.1 μF monolithic-ceramic capacitor should be located as close to the signal source which drives (current-modulates) the LED. This minimizes the noise emitted by the transmitter and improves the optical response time of the LED.

6) The low-pass filters shown on the recommended schematics must be used to protect the fiber-optic receiver from noise that is present in the V_{CC} power supply.

7) If an inductor is used in series with the receiver's V_{CC} and V_{ee} connections the receiver should be referenced to V_{CC} and V_{ee} islands that are isolated from the remainder of the transceiver's power planes. A differential interface at the receiver's output is required if inductors are used in series with V_{CC} and V_{ee}. This dual-inductor filter is recommended if the receiver is connected to an AUI interface or operated in a noisy environment.

Printed Circuit Artwork

Variations in transceiver performance due to circuit layout can be avoided by using the artwork shown in Figures 5 through 7. Designers that would like to use the artwork provided by HP are encouraged to embed the PC artwork shown in this Application Note into their systems. The PC art shown here is available from an electronic bulletin board that can be down loaded using a 2.4 kBd telephone modem. If you desire an electronic copy of this PC art call 408-435-6733 in the continental USA and Canada. The Orcad file for the through-hole transceiver shown in Figures 1 and 3 is 802KITP.EXE. The through-hole transceiver is also available as a Gerber file under the file name 802KITG.EXE. The file name for the current-source LED driver shown in Figure 2 is IDRIVE.EXE. The artwork for the surface-mount MAU transceiver shown in Figure 4 is available in the file called 802MAU.EXE.

Designers should note that printed circuits for the fiber-optic solutions recommended in this Application Note are not difficult to create. If your product requires a unique printed circuit this can easily be accomplished by following the 7 layout rules previously discussed. The printed circuit art provided in this Application Note was developed in one design cycle using these PC design rules.

System designers that want to quickly evaluate the transceiver recommended for hub, bridge, router, and repeater applications should order the HFBR-0414 demo kit. The HFBR-0414 contains a printed circuit board and

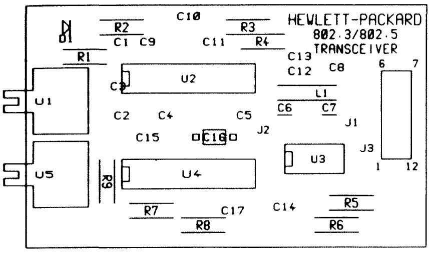


Figure 5a. Silkscreen artwork for the HFBR-0414 Demo Kit. Transmitter per Figure 1. Receiver per Figure 3.

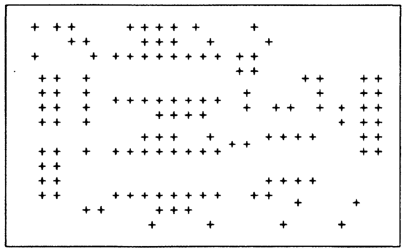


Figure 5b. Drill.

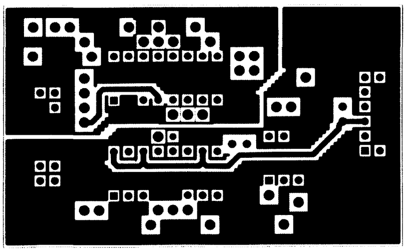


Figure 5c. Layer 1 Component Side.

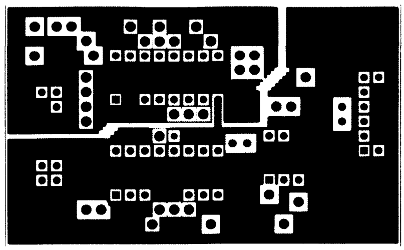


Figure 5d. Layer 2.

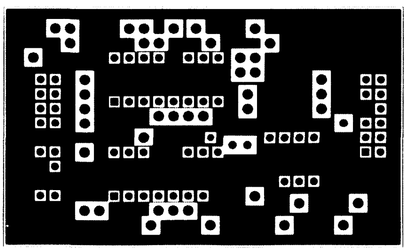


Figure 5e. Layer 3.

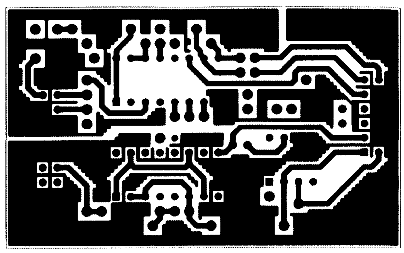


Figure 5f. Layer 4.

WARNING: DO NOT USE PHOTOCOPIES OR FAX COPIES OF THIS ARTWORK TO FABRICATE PRINTED CIRCUITS.

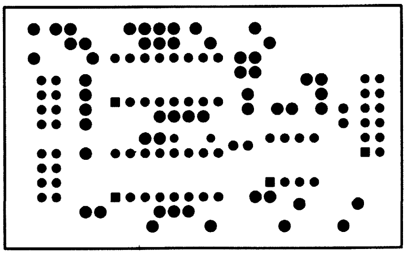


Figure 5g. Solder Mask.

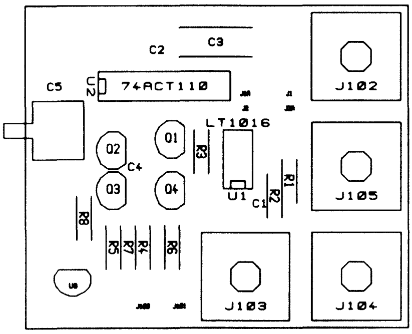


Figure 6a. Silkscreen artwork for the Constant Current Transmitter per Figure 2.

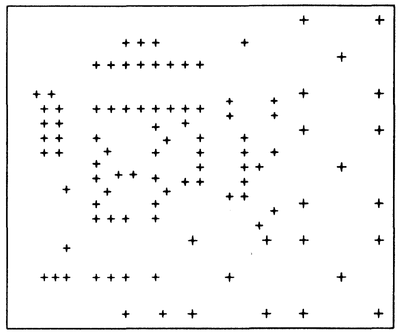


Figure 6b. Drill.

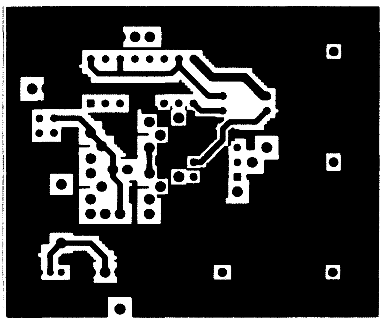


Figure 6c. Layer 1 Component Side.

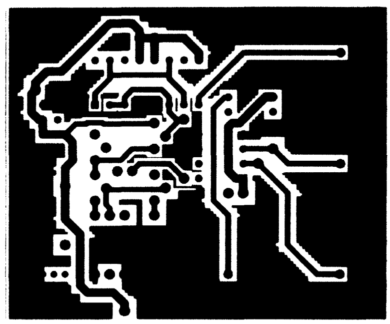


Figure 6d. Layer 2.

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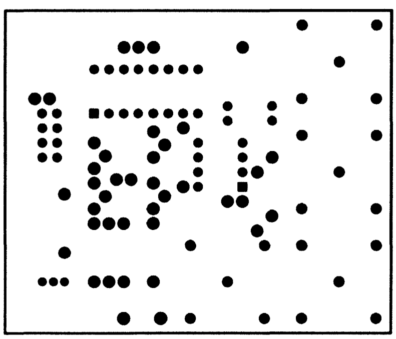

Figure 6e. Solder Mask.

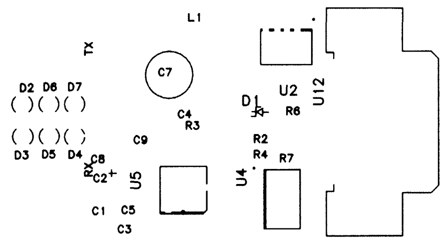

Figure 7a. Top side silkscreen artwork for the Fiber-Optic MAU Transceiver.

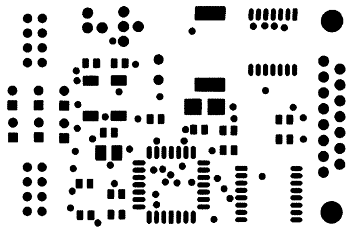

Figure 7b. Top Side Solder Mask.

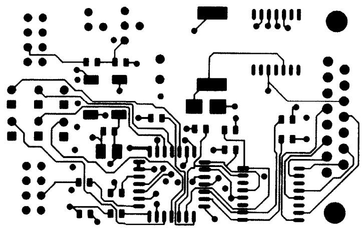

Figure 7c. Top Layer.

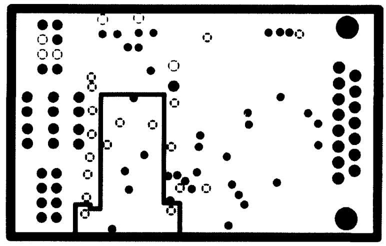

Figure 7d. Layer 2.

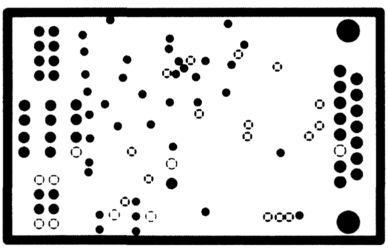

Figure 7e. Layer 3.

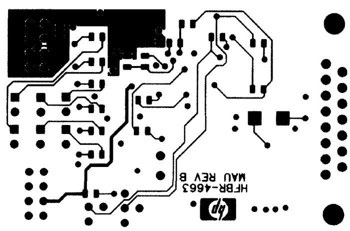

Figure 7f. Bottom Layer.

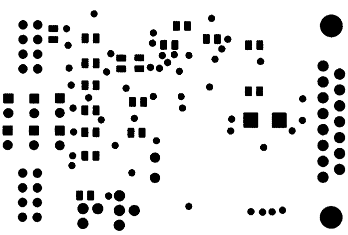

Figure 7g. Bottom Side Solder Mask.

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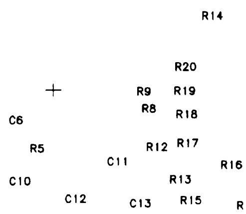

Figure 7h. Bottom Side Silkscreen.

all of the active devices needed to build the transceiver shown in Figures 1 and 3 of this Application Note. A list of the components needed to construct the transceiver shown in Figures 1 and 3 is shown in Table 8. Designers can also quickly determine how well the HFBR-4663 works with HFBR-0400 components in fiber-optic MAU applications by ordering the HFBR-0463. The HFBR-0463 is a fully assembled surface-mount fiber-optic MAU that is implemented using the circuit shown in Figure 4 of this Application Note. A list of the components needed to construct the MAU in Figure 4 is shown in Table 9.

The HFBR-0414 and HFBR-0463 evaluation kits minimize the design effort needed to implement fiber-optic systems that comply with IEEE 802.3 standards and reduce the time needed to bring these new Ethernet LAN products to the market.

Conclusion

The transmitters and receivers shown in this Application Note are an excellent starting point for engineers interested in fiber-optic Ethernet applications. Designers that are planning to build products which address the specifications called for in IEEE 802.3 are encouraged to evaluate these recommendations and determine how well HP's HFBR-0400 fiber-optic components can address their Ethernet LAN application.

Note: The data sheet for the HFBR-4663 (Publication #5091-7391E 4/93) contains errors that have subsequently been corrected in Figure 4 of this Application Note.

Table 8. Bill of Materials for Circuits in Figures 1 and 3.

Item #	Ref. Desig.	Qty. Each	Description	Vendor	Vendor Part Number
1	R1	1	Axial lead resistor 10 Ω ±5% 1/8W		
2	R2	1	Axial lead resistor 1.2K Ω ±5% 1/8W		
3	R3, R4, R5, R6	4	Axial lead resistor 510 Ω ±5% 1/8W		
4	R7	1	Axial lead resistor 34.0 Ω ±1% 1/8W		
5	R8	1	Axial lead resistor 34.7 Ω ±1% 1/8W		
6	R9	1	Axial lead resistor 280 Ω ±1% 1/8W		
7	C1, C4, C8, C9, C11 C12, C13, C14, C15	9	Monolithic ceramic radial lead capacitor 0.1µF ±10% 50V X7R		
8	C2, C3	2	Monolithic ceramic radial lead capacitor 0.01µF ±10% 50V X7R		
9	C5	1	Monolithic ceramic radial lead capacitor 4.7pF ±10% 50V COG		
10	C10	1	Monolithic ceramic radial lead capacitor 0.047µF ±10% 50V X7R		
11	C17	1	Monolithic ceramic radial lead capacitor 56pF ±10% 50V COG		
12	C6, C7, C16	3	Tantalum radial lead capacitor 10µF ±20% 10V		
13	L1	1	Axial lead molded inductor 4.7µH ±10%, Resonant Freq. 75MHz, 1.2 Ω DC res.	Delevan	1025-36K
14	U1	1	125 MHz low cost miniature fiber-optic PIN-amplifier receiver	HP	HFBR-2416
15	U2	1	Integrated post amplifier/comparator (quantizer)	Micro Linear	ML-4622
16	U3	1	Comparator	Linear Tech.	LT-1016
17	U4	1	Quad two input NAND gate NI barrier, SN or SN/PB plated	Texas Instr.	74ACT11000
18	U5	1	820 nm LED transmitter	HP	HFBR-1414
19	D1	1	Low current LED lamp	HP	HLMP-4700

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Table 9. Bill of Materials for the Circuit in Figure 4

Item #	Ref. Desig.	Qty. Each	Description	Vendor	Vendor Part Number
1	R1	1	Res, 0805 10 Ω ±5% ni barrier, sn or sn/pb plated	Venkel	CR0805-10W-100JT
2	R2, R3, R6, R7	4	Res, 0805 360 Ω ±5% ni barrier, sn or sn/pb plated	Venkel	CR0805-10W-361JT
3	R4, R5	2	Res, 0805 39 Ω ±1% ni barrier, sn or sn/pb plated	Venkel	CR0805-10W-390FT
4	R8	1	Res, 0805 100 Ω ±1% ni barrier, sn or sn/pb plated	Venkel	CR0805-10W-1400FT
5	R9	1	Res, 0805 61.9K Ω ±1% ni barrier, sn or sn/pb plated	Venkel	CR0805-10W-6192FT
6	R10	1	Res, 0805 3K Ω ±5% ni barrier, sn or sn/pb plated	Venkel	CR0805-10W-302JT
7	R11	1	Res, 0805 2K Ω ±5% ni barrier, sn or sn/pb plated	Venkel	CR0805-10W-202JT
8	R12	1	Res, 0805 0 Ω ±5% ni barrier, sn or sn/pb plated	Venkel	CR0805-10W-000JT
9	R13	1	Res, 0805 select Ω ±5% ni barrier, sn or sn/pb plated	Venkel	CR0805-10W-XXXJT
10	R14	1	Res, 0805 1K Ω ±5% ni barrier, sn or sn/pb plated	Venkel	CR0805-10W-102JT
11	R15, R16, R17 R18, R19, R20	6	Res, 0805 1.5K Ω ±5% ni barrier, sn or sn/pb plated	Venkel	CR0805-10W-152JT
12	C1, C5, C9 C10, C11, C12	6	Cap 0805, .1μF, Z5U, 25V, +80/-20% ni barrier, sn or sn/pb plated	Venkel	C0805Z5U250-104ZNE
13	C2, C3	2	Cap, 0805, .01μF,X7R, 25V, ±20% ni barrier, sn or sn/pb plated	Venkel	C0805X7R250-103MNE
14	C4	1	Cap 0805, .047μF, Z5U,25V, ±20% ni barrier, sn or sn/pb plated	Venkel	C0805Z5U250-473MNE
15	C6	1	Cap case size C (.236" x .126"), 22μF, tant, 16V, ±20% ni barrier, sn or sn/pb plated	AVX	TAJC226M016R
16	C7	1	Cap aluminum, radial lead, 470μF (.315" dia x .450" long), 10V ±-20%	Sprague	515D477M010BB6A
17	C8	1	Cap case size B (.138" x .110"),10μF, tant, 16V, ±20% ni barrier, sn or sn/pb plated	AVX	TAJB106M010R
18	L1	1	Inductor, DT series, (.510" x .365"), 560 μH ±20% molybdenum/ manganese base metal, sn or sn/pb plated	Coilcraft	DT3316-554XM3C
19	L2, L3	2	Inductor, DT series, (.260" x .175"), 4.7 μH ±20% molybdenum/ manganese base metal, sn or sn/pb plated	Coilcraft	DT1608-472XMBC
20	D1	1	Schottky power rectifier, surface mount MBRS120T3, case 403A-01, (.213" x .140")	Motorola	MBRS120T3
21	U1	1	125 MHz low cost miniature fiber optic PIN-amplifier Receiver	HP	HFBR-2416(ST)
22	U2	1	Simple switcher, 0.5A step-down voltage regulator LM2574, 14 lead surface, (.354" x .406")	National	LM2574M-5.0
23	U3	1	125 MHz low cost miniature fiber optic transmitter	HP	HFBR-1414(ST)
24	U4	1	10base-t transformer, 16 pin, (.500" x .370")	Pulse	PE-65728
25	U5	1	Ethernet transceiver, package: Q28, 28 pin molded leaded PCC, .490'" sq	HP	HFBR-4663
26	D2, D3, D6	3	LED green T1	HP	HLMP-1790
27	D4, D7	2	LED red T1	HP	HLMP-1700
28	D5	1	LED yellow T1	HP	HLMP-1719
30	N/A		Solder paste, SN63		
31	N/A		SN63 RMA core solder		
32	U12		15 pin right-angle posted D connector, 318 mount	AMP	747841-4

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Conductive Port Receiver

Application Note 1057

Introduction

This application note compares the performance of fiber optic receivers with conductive ports to fiber optic receivers with non-conductive ports (Figure 1). It explains how conductive port receivers solve specific problems encountered in some applications and how they help to improve the electromagnetic immunity of part number HFBR-24X6 XC, required by such standards as MIL 461 and IEC 801-3. The application note also presents test data that shows why HP's low-resistance conductive port has an advantage over the higher-resistance conductive ports of other manufacturers.

This application note focuses specifically on the receiver preamplifier, because it is a crucial electronic element in the optical link. The preamplifier must process input signals as low as or lower than -30 dBm and must also have a wide bandwidth to accommodate high data rates. The preamplifier's high gain and wide bandwidth make it sensitive to electromagnetic interference (EMI). Small-junction devices used in its construction may make it inherently sensitive to electrostatic discharge (ESD). Exposure to either of these phenomena, especially to EMI, can affect the overall performance of the receiver.

Background

Pulses of EMI with large electric field strengths can induce currents to flow in the input circuitry of the fiber optic receiver. These currents can interfere with the photocurrent generated by the desired optical signals and can prevent the receiver from faithfully reproducing an electrical signal based on the received optical input. This condition degrades the bit-error ratio (BER), the ratio of the number of erroneous bits at the output of the optical receiver to the total number of received bits. Modern transmission systems routinely require a BER better than 1×10^{-9} and very often require a BER better than 1×10^{-12}.

In some systems the degraded BER can result in either correction of the data by error-correction software or frequent re-transmission of data. Thus, the system appears much slower than normal. This condition is known as a detectable error. By contrast, high BER can overwhelm the error correction software or hardware. Errors of this type prevent proper operation of the system.

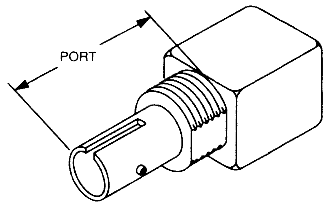


Figure 1. Fiber Optic Receiver.

In systems using fiber optic components, errors can garble the data as long as an excessive electromagnetic field exists. If the system is removed from the field or the field is eliminated the data will once again be valid.

EMI is generated by radio transmitters, transients from electrical equipment switching on and off, test equipment, and so forth. ESD can also generate electromagnetic fields (more will be said about this mechanism later).

Conductive Port Receivers

The main benefit of a fiber optic receiver with a conductive port is that it reduces coupling of external fields by partially shielding the very sensitive input node of the fiber optic receiver. The shield is not complete, however; the field can propagate through the hole in the center of the port, but it is greatly attenuated.

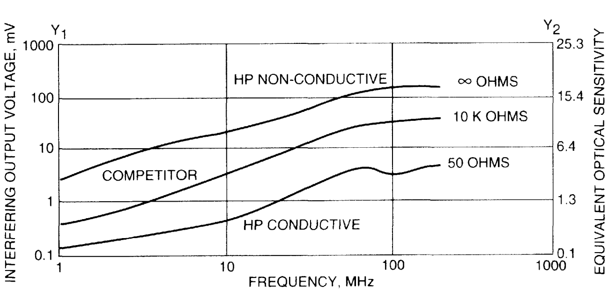
A metal-ferrule connector can degrade the sensitivity of a receiver with a non-conductive port in an electromagnetic field by about a factor of four. The electric field couples to the metal connector and ferrule, which act as a receiving antenna. Because the end of the metal ferrule is close to the amplifier IC, the field easily capacitively couples to the input of the amplifier, inducing an interfering current. The coupling capacitance is several femtofarads. In the case of the conductive port, a low-impedance path to ground, provided by pins 1, 4, 5, and 8, reduces the potential on the ferrule. So, in terms of coupling from the external field, the ferrule then becomes a poorer antenna.

HP's conductive port uses a low-resistance (50 ohm) material[1] for a very low impedance to ground. Measurements on a sample of conductive ports from a competitor showed higher resistance (of about 10,000 ohms). A lower resistance port material could be expected to provide lower coupling from an electric field to the output of the receiver and improved immunity to EMI.

Hewlett-Parkard Optical Communication Division has tested the EMI immunity of the HFBR-24X6 family (see Figure 2 and 3) and found less than 2 dB degradation of receiver sensitivity in a 10-volt-per-meter field for HP's conductive port. This value compares favorably with an average value of 9 dB sensitivity degradation for HP's non-conductive port. HP OCD also tested the EMI immunity of competitor's conductive ports, which had approximately 10,000 ohms resistance from the port to ground. These ports had an average sensitivity loss of 5 dB in a 10 volt-per-meter field, measured under conditions identical to the HP product measurements (see Figure 2). For all types of ports measured, the performance depends on the frequency of the field; measured between 10 kHz and 300 MHz, the worst values are between 100 and 200 MHz.

In cases where customers must meet specifications for fields of this strength or similar levels of strength, they should use HP's conductive port. With the conductive port, the receiver will tolerate a field strength roughly 30 times greater than with the non-conductive port before losing sensitivity. Some additional benefit is gained by running the port through a hole in a metal chassis. With this arrangement, the field strength experienced by part of the fiber optic receiver is reduced.

In applications where the received optical power is 20 dB or more above the equivalent optical noise input power, however, electric fields up to 10 volts per meter should not affect the performance of the receiver. For short links, enough signal strength is available for the receiver to function. Whether or not an application requires a conductive port depends on a number of factors, including field strength expectations, link performance expectations, bandwidth of the signal processing and digitizing, and so forth. For low data rates, high-frequency interference can be filtered.



NOTE: RELATIONSHIP BETWEEN Y AXES: $Y_2 = 10 \text{ LOG} \frac{12.07 \text{ mV} + 2\sqrt{2}\, Y_1}{12.07 \text{ mV}}$

Figure 2. Typical Output Signal Due to 10 V/m Field with Metal Ferrule.

[1]Hewlett-Packard's conductive ports have a resistance that is typically 5 to 15 ohms and always less than 50 ohms (measured from the port tip to ground pin 1, 4, 5 or 8) at the beginning of life. Long-term exposure to heat and humidity increases this resistance. After 168 hours at 121°C and 100 percent relative humidity, the typical resistance increases to 50 to 60 ohms, but may go as high as several hundred ohms. This level of resistance is still much lower than competitive parts and offers significant immunity to EMI. In a 10 V/m field, however, receiver sensitivity may be degraded 1 to 3 dB relative to a conductive port with resistance less than 50 ohms.

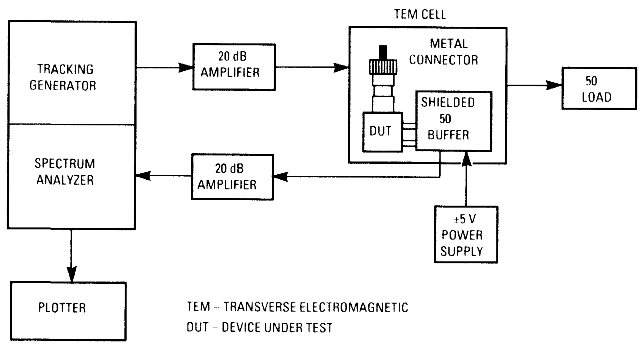


Figure 3. Block Diagram of Test Setup for Electromagnetic Susceptibility.

In those cases where the bandwidth is substantially narrowed to lower the data rates, as in applications of IEEE 802.3 and 802.5, insignificant changes in sensitivity are expected when the non-conductive fiber optic receiver is exposed to a 10-volt-per-meter field.

Although Europe will soon have requirements for EMI immunity (for example, IEC 801-3), as of the date of this document, products in the U.S. are usually not required to meet EMI immunity standards. For this reason, engineers must often design their products to either certain military or European standards, as in the case of products intended for worldwide markets.

ESD can also cause problems. Under conditions of low humidity we can accumulate a considerable amount of stored charge on clothing and skin surfaces merely by shifting position in a chair or walking across a carpet. Our bodies then become high-voltage, static-charge generators with voltages up to about 15 kV. If we touch a grounded electronic device or component we can produce an arc due to the voltage differences.

ESD most often affects a fiber optic receiver by either or both of two mechanisms. In one mechanism, ESD current entering electronic equipment through the fiber optic receiver port generates thousands of volts per meter of instantaneous electric field strength surrounding the discharge. This field can momentarily disrupt recovery of data from the fiber optic link and introduce errors. Generally, these errors can be corrected by error correction software within the system.

In the other mechanism, catastrophic failure, a very large electrostatic potential difference suddenly discharged onto the transmitter port, receiver port or any other entry point, such as switches or connectors in an improperly grounded metal cabinet, rapidly distributes itself on the printed circuit board (PCB). This potential difference may adversely affect susceptible electronic components mounted on the PCB and can melt bond wires, damage IC metalization traces or destroy junctions.

ESD-related component failures can occur during PCB assembly also. The operators can prevent it by wearing static-grounding wrist straps and taking all ESD handling precautions, including proper packing materials, work surfaces, and so forth. ESD can occur, however, in the end user's environment.

Catastrophic failures from ESD can be avoided by using a metal chassis and either a ground plane or wide ground trace. The wide ground trace extends to the edge of the printed circuit board and so is closer to the user's fingers than the leads of the receiver housing. This creates a low-inductance path to ground and the current is directed away from sensitive components. This is especially important if the system's enclosure is not metal.

For systems designed without a true earth ground, a low-impedance path to a large area such as a ground plane or metal chassis is recommended. A low-impedance path will help divert the current away from the internal components.

HP recommends that pins 1, 4, 5, and 8 of the conductive receiver ports, HFBR-24OXC and HFBR-241XTC be connected to circuit ground, as shown in Figure 4. ESD will then follow this predefined, low-resistance path, preventing the possibility of internal discharge.

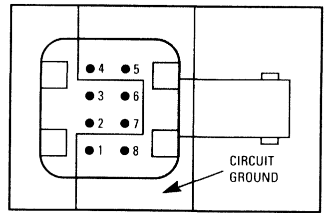


Figure 4. Bottom View.

Test Methods

HP has tested the ESD susceptibility of its HFBR-141X transmitter and HFBR-241X receiver fiber optic components per the IEC 801-2 contact discharge method. This test method was chosen for the more repeatable measurements of contact discharge as opposed to air discharge. Both the conductive port and the non-conductive port experienced discharges but survived 15 kV of ESD to or around the connector. Discharges flowed either along the surface of or through the air near the non-conductive port to the edges of the printed circuit board. With the conductive port discharges flowed through the port to the PC board. The HP conductive and non-conductive ports both withstood 15 kV electrostatic discharges, a value well above the requirements of 801-2.

No catastrophic damage occurred during HP's tests, although there were errors at very low levels of ESD. These errors resulted whenever a discharge occurred anywhere in the vicinity of the protruding fiber optic connector. A conductive port receiver improves the immunity to errors caused by electromagnetic fields (please see previous section for approximate values) but does not eliminate them. HP's conductive and non-conductive ports passed tests 15 kV for ESD immunity.

The IEC 801-2 ESD regulations are in effect only in Europe. The U.S. has no regulations of this type, although various U.S. companies have their own requirements.

In reliability testing, the mechanical strength of the conductive port has been shown to be similar to the mechanical strength of the non-conductive port. Both the conductive and non-conductive port have many features. They include high reliability, resistance to solvents and some other chemicals (please see data sheet), and resistance to thermal and mechanical shock. In addition, they are inexpensive.

Tests show that HP's non-conductive and conductive port receivers both have excellent immunity to ESD, so conductive ports offer little ESD performance improvement over non-conductive ports. Only users with exceptional ESD environments will benefit from conductive ports for ESD protection.

Conclusion

For applications at higher speeds and higher levels of electric field strength, a receiver with a conductive port has significantly better EMI immunity than a non-conductive port receiver. HP's low-resistance conductive port receivers have demonstrated superior EMI performance relative to receivers with higher-resistance ports. If your application requires an extra margin of protection against EMI, HP's conductive port receivers are recommended.

HEWLETT PACKARD

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HEWLETT PACKARD

Complete Solutions for IEEE 802.5J Fiber-Optic Token Ring

Application Note 1065

Introduction

Hewlett-Packard's HFBR-0400 fiber-optic components are widely used in Ethernet LAN systems. These same 820 nm wavelength components are also used in Token Ring LAN systems. The HFBR-14X4, and HFBR-24X6, comply with the IEEE 802.5J Trial-Use Standard for both 4 and 16 M bit/s transmission rates. Distances that range from 1 meter to 2 k meters can easily be achieved when Hewlett-Packard's inexpensive short wavelength components are used with the circuits recommended in this publication. Several integrated circuits that work well with the HFBR-14X4, and the HFBR-24X6, are discussed in the following text. These integrated circuits reduce the amount of board space required and lower the number of components needed to build the fiber-optic transceiver. The objective of this application note is to make it simple for designers to use HP's HFBR-0400 components in LAN equipment such as multi-station access units (MAUs), bridges, fiber-optic media converters, repeaters, and adapter cards that are used in Token Ring LANs. The following text will show that it is easy to build high-performance Token Ring transceivers, when using inexpensive off-the-shelf integrated circuits, with HP's low-cost HFBR-14X4, and HFBR-24X6 fiber-optic components.

IEEE 802.5 System Specifications

Tables 1 and 2 provide a brief listing of some key parameters specified in the 802.5J Trial-Use Standard.

Capabilities of HFBR-0400 Components

The transmitter and receiver circuits recommended in this Application Note characteristically exceed the performance called for in IEEE 802.5J by a comfortable margin. The optical power launched into 62.5/125 µm fiber by the HFBR-14X4 LED is typically -12 dBm peak at a dc forward current of 60 mA. When Manchester encoded data with a 50% duty factor is applied to the LED transmitter the HFBR-14X4 LED can typically launch -15 dBm average into the core of a 1 meter length of 62.5/125 µm fiber with a numerical-aperture of 0.275. This 3 dB difference between peak and average power is due to the 50% duty factor of Manchester data and the averaging response of most optical-power meters. The HFBR-24X6 is a simple hybrid component that contains a silicon PIN detector and a transimpedance amplifier. The HFBR-24X6 can be combined with simple, inexpensive integrated circuits to build digital receivers that have an optical dynamic range and sensitivity greater than called for in the IEEE 802.5J specifications.

Recommended Transmitter Designs For Token Ring.

Two different techniques have commonly been used to drive the HFBR-1414 LED in Token Ring applications. Both of the LED drivers recommended in this Application Note will address the requirements called out in the IEEE 802.5J Token Ring specification. The HFBR-14X4 LED has typical rise/fall times of less than 4 ns when used in the circuits recommended in Figure 1 or Figure 2. Transmitter jitter and duty-cycle distortion are normally less than 1 ns when using either of the recommended LED drivers. The cost complexity and performance tradeoffs associated with these two different LED drivers will now be discussed in greater detail.

Table 1. Key IEEE 802.5 LED Transmitter Specifications

Parameter	Symbol	802.5J Limits @ 8 MBd	802.5J Limits @ 32 MBd	Units
Launched Optical Power Over Life	P_T on	-12 to -19	-12 to -19	dBm avg
Extinction	P_T extinct	13 dB less than P_T on	13 dB less than P_T on	
Average Power Transmitter Disabled	P_T off	-38	-38	dBm avg
Maximum Optical Rise Time	t_r	25	6.0	ns
Maximum Optical Fall Time	t_f	25	6.0	ns
Maximum Difference Between Optical Rise and Fall Times	$\lvert t_r - t_f \rvert$	12	3	ns
Maximum Symbol Width Distortion (OTA)		±4.0	±1.5	ns

Table 2. Key IEEE 802.5 Fiber-Optic Link Specifications

Test Conditions	Receiver Input Conditions			Required Link Performance	
Length of 62.5/125 μm Fiber-Optic Cable (meters)	**Maximum Rise/Fall Time of Received Optical Pulse at 8 MBd (ns)**	**Maximum Rise/Fall Time of Received Optical Pulse at 32 MBd (ns)**	**Received Optical Power (dBm avg.)**	**Maximum Jitter at 8 MBd (nspp)**	**Maximum Jitter at 32 MBd (nspp)**
10	25	6.0	- 12 max.	9.9	5.8
2 k	60	27	- 32 min.	18.3	9.2
Length of 62.5/125 μm Fiber-Optic Cable (meters)	**Maximum Rise/Fall Time of Received Optical Pulse at 8 MBd (ns)**	**Maximum Rise/Fall Time of Received Optical Pulse at 32 MBd (ns)**	**Received Optical Power (dBm avg.)**	**Minimum Eye Opening at 8 MBd (ns)**	**Minimum Eye Opening at 32 MBd (ns)**
10	25	6.0	- 12 max.	115	25.5
2 k	60	27	- 32 min.	107	22.1

The LED forward current (I_F) supplied by the simple voltage-source driver shown in Figure 1 will change with variations in V_{CC} and LED forward voltage (V_F). The tolerance of resistors R7, R8, and R9 will also effect the magnitude of I_F. Deviations in I_F due to the 74ACT11000 nand-gate voltage-source are insignificant. The typical output impedance of the three parallel connected nand gates is only 1 ohm and the external resistors R7 and R8 which limit the LED current total to 66 ohms. This large difference between the source-impedance of the nand-gate voltage-source and the sum of R7 and R8 makes it improbable that changes in LED I_F will result due to process variations in the 74ACT11000.

A voltage-source drive-circuit suited for Token Ring applications is shown in Figure 1. This simple circuit is designed to nominally drive the LED at a forward current (I_F) of 60 mA dc, when logic "0" is applied to pin 9 of U4D. Normal tolerances of the circuit cause the LED current to be greater or less than the 60 mA forward current recommended for the HFBR-14X4. Since the

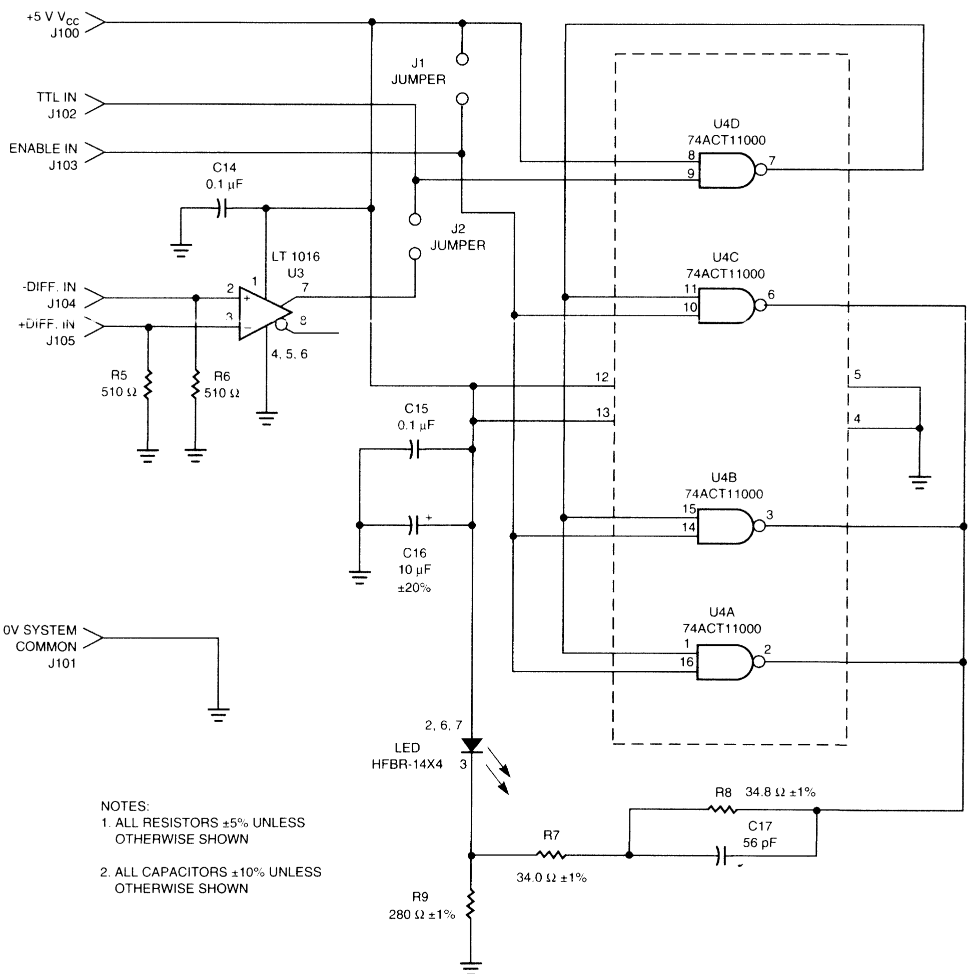

Figure 1. Voltage Source Transmitter for Token Ring LAN applications.

light output of the LED is proportional to the forward current, this variation in I_F causes changes in the optical power coupled into the fiber. The elements contributing to the variations in forward current are LED forward voltage (V_F), tolerance of the resistors which set the drive current, and variations in V_{CC}. When tolerances of the circuit add up to increase the forward current of the LED, about a 0.8 dB increase in the light output can be expected. This light output level is well within the limits of the IEEE 802.5J standard, and is less than the saturation point of the recommended receiver. Decreases in LED forward current due to circuit tolerances cause a 1.0 dB drop in the light coupled into the fiber under worst-case conditions. The worst-case condition occurs when V_{CC} is low, LED forward voltage (V_F) is high, and resistor tolerance is high.

The HFBR-14X4 data sheet specifies launched power at I_F = 60 mA, and assumes that LED forward current is constant. Normal tolerances of the voltage-source LED driver will cause variations in LED I_F that lower the minimum power launched into the fiber. This reduction in launched power relative to the P_{t62} specification given in the HFBR-14X4 data sheet is expected. Voltage-source drive-circuit tolerances will lower LED forward current and the amount of light coupled into the fiber-optic cable is directly proportional to I_F.

For applications that require tighter control of the launched optical power, the current-source transmitter shown in Figure 2 is recommended. Figure 2 shows an LED drive-circuit which provides a forward current that is independent of V_{CC}, and LED forward voltage. The LED current provided by this driver is primarily determined by the tolerance of the bandgap reference U3, and the tolerance of resistors R5 and R6. The -2 mV/°C temperature coefficient of the base-emitter junction of Q3 or Q4 increases the voltage applied to R5 and R6 as ambient temperature rises. The temperature coefficient of NPN transistor base-emitter voltage is thus used to increase the magnitude of the current applied to the LED as temperature rises. This technique prevents LED light output from decreasing as temperature rises by compensating for changes in the LED quantum efficiency.

Either of the LED drivers shown in this Application Note will address the requirements called out in the IEEE 802.5J specifications. The design rules for the LED driver shown in Figure 1 are given in Equation 1 and the design rules for the LED driver shown in Figure 2 are provided in Equation 2.

When choosing the driver, the designer should consider the following factors. The LED driver shown in Figure 1 is simple, but has a slight variation in the power coupled from the LED to the fiber. The circuit shown in Figure 2 is more complex, but offers tighter control over variations in launched optical power. System designers are encouraged to choose the LED driver which best meets their requirements. If cost and board space are of greater concern than variations in launched optical power then the voltage-source

Equation 1
Design rules for voltage source LED driver circuits.

N = Number of gates connected in parallel.
B = Empirically determined constant for optimum relationship between prebias and LED forward current.

$$R9 = \frac{(V_{cc} - V_F)(1 + B)}{I_{F_{ON}}}$$

$$R8 = \frac{R9}{2B}$$

$$R7 = \frac{R9}{2B} - \frac{3}{N}$$

$$C = \frac{2.0 \times 10^{-9}}{R8}$$

Recommend B = 3.97

Equation 2
Design rules for temperature compensated current source LED driver circuit.

$$I_F = \frac{\Delta V_{U3} - V_{BE_{Q3}}}{R5} + \frac{\Delta V_{U3} - V_{BE_{Q4}}}{R6}$$

$$I_F = \frac{1.24 - 0.7}{R5} + \frac{1.24 - 0.7}{R6}$$

$$I_F = (1.24 - 0.7)\left(\frac{1}{R5} + \frac{1}{R6}\right)$$

$$R3 = \frac{V_{OH} - V_{OL}}{I_F} = \frac{5V}{I_F}$$

$$C4 = \frac{2.0 \text{ ns}}{R3}$$

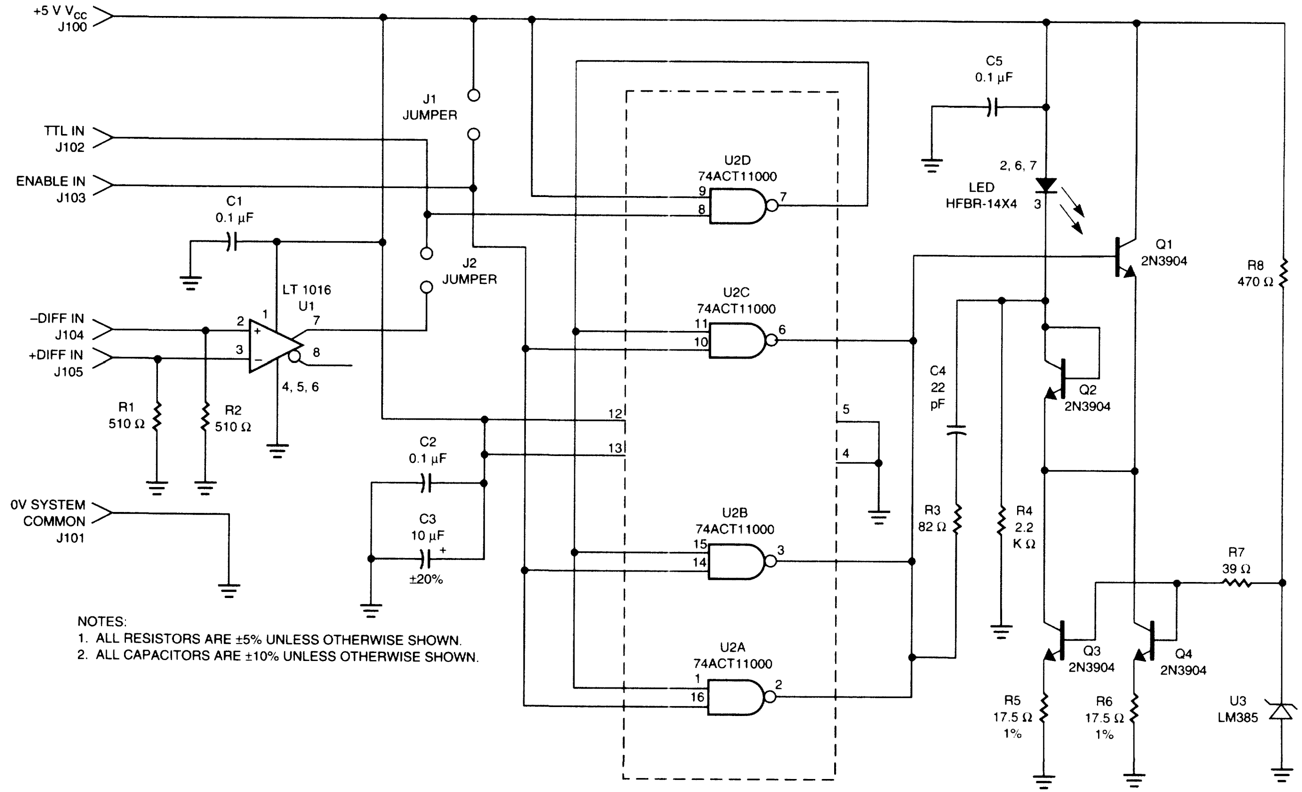

Figure 2. Current Source Transmitter for Token Ring LAN Applications.

transmitter circuit shown in Figure 1 makes the most sense. If the designer desires to maximize the optical power budget of the fiber-optic link then the transmitter circuit shown in Figure 2 is a better choice.

Recommended Receiver Designs For Token Ring

A simple receiver which complies with IEEE 802.5J specifications is shown in Figure 3. The post-amplifier comparator function used to convert the analog output of the HFBR-24X6 to digital data is generally referred to as a quantizer. Micro Linear's ML-4622 quantizer also contains a link-monitor function. The link monitor inhibits the data output when optical power drops below the minimum level needed to ensure that the receiver's output is error free.

The receiver recommended in Figure 3 has a typical sensitivity of -34 dBm average at a Bit-Error-Rate (BER) of 1×10^{-10} when receiving 32 MBd Manchester encoded data. This receiver performance was measured using 2 km of 62.5/125 µm fiber with the BER tester's clock centered in the middle of the received 32 MBd Manchester symbols. The link-monitor function must be disabled by grounding pin 15 of the ML-4622 quantizer in order to measure the ultimate sensitivity of the receiver. In normal operating mode, the ML-4622's link monitor disables the data output of the fiber-optic receiver before the probability of an error exceeds 1 in 10^{10} bits.

When receiving a repetitive 32 MBd D2D2 hexadecimal word, the total peak-to-peak jitter at the data output of the circuit shown in Figure 3 is typically less than 7 ns. A D2D2 hexadecimal pattern was used to test the complete fiber-optic link because it emulates the worst data dependent stress possible with Manchester encoding. The excellent performance of the circuits recommended in this Application Note allows low jitter to be achieved when data is transmitted over a 2 km segment of 62.5/125 µm fiber with a received optical power of -32.0 dBm average. The low jitter attained at the receiver's output corresponds to a clear eye-opening which is typically > 24 ns. A wide eye-opening is desirable because this minimizes the accumulation of

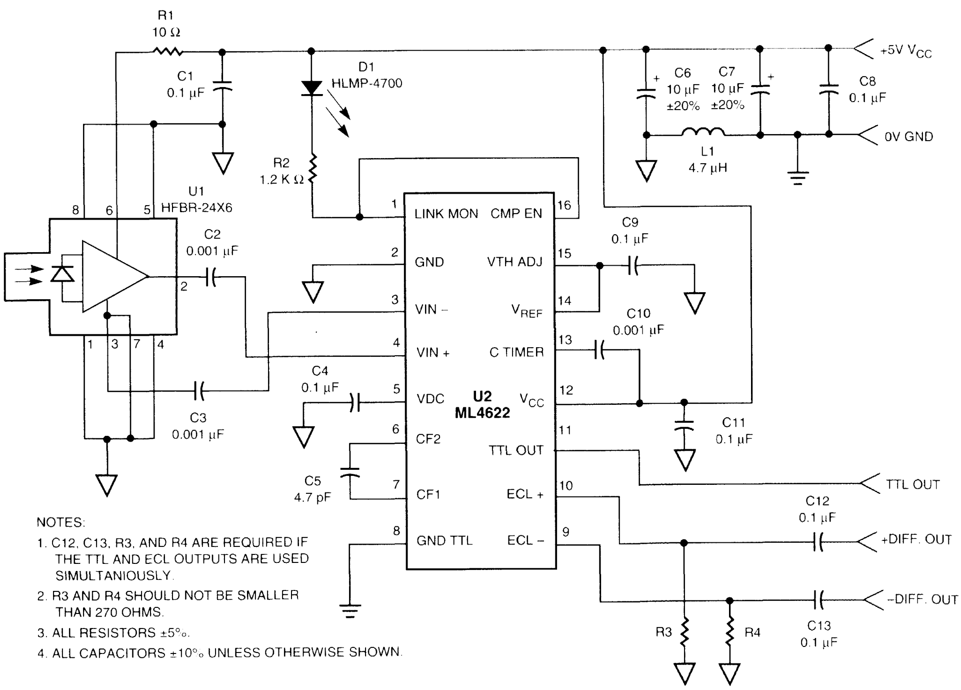

Figure 3. Receiver for Token Ring LAN Applications.

jitter when data is passed from station-to-station in the Token Ring LAN.

Demo Kit For Fiber-Optic Token Ring

The transceiver circuits shown in Figures 1, 2, and 3 are suited for use in fiber-optic multi-station access units (MAUs), bridges, fiber optic media converters, repeaters, and adapter cards. This recommended transceiver can easily be compared to the IEEE specifications listed in Tables 1 and 2 by ordering the HFBR-0414 demo kit. The HFBR-0414 kit contains a small 2 3/4 by 1 3/4 inch through-hole printed circuit board and all of the active devices needed to build the circuits shown in Figures 1 and 3. This inexpensive kit can be completed using readily-available passive components such as radial-lead monolithic ceramic capacitors, radial-lead epoxy-dipped tantalum capacitors, and axial-lead 1/4 W resistors. The passive components needed to assemble this fiber-optic demo are available in most engineering stock rooms. The HFBR-0414 demo kit minimizes the engineering cost of building the fiber-optic transceiver recommended in this Application Note, reduces time-to-market by minimizing the effort required to construct working prototypes, and enables designers to quickly confirm that Hewlett-Packard's HFBR-0400 fiber-optic components can meet Token Ring LAN requirements. The measured performance of the circuits used in the HFBR-0414 demo can be found in Tables 3 and 4. Table 3 shows the measured performance of the transmitter recommended in Figure 1. Table 4 shows the measured performance of an entire fiber-optic link which uses the circuits recommended in Figures 1 and 3.

Measured Performance Of The Complete Fiber-Optic Link

Figure 4 shows the TTL output of a fiber-optic transceiver constructed using HFBR-14X4 and HFBR-24X6 components. The results shown in Figure 4 were obtained at room temperature when 32 MBd data is transmitted through 3.32 km length of 62.5/125 µm fiber terminated with ST connectors. Figure 4 shows that average jitter is approximately 7 ns and that the eye opening is roughly 24 ns when an optical attenuator is used to adjust received power to -32 dBm average. Figure 4 was measured using a D2D2 hexadecimal test pattern that simulates the worst stress possible with Manchester encoded data. The waveform shown in Figure 4 was obtained by connecting an HP 54100A Digitizing Oscilloscope to the receiver's TTL output. The infinite persistence mode of the HP 54100A Digitizing Oscilloscope was used to determine the peak-to-peak jitter and eye opening. Figure 5 shows that the receiver does not overload when a short 1 m length of 62.5/125 µm fiber is substituted for the long cable.

A more accurate method of determining the performance of a complete fiber-optic link is to use a computer controlled delay line and a BER test set. The computer is used to adjust the position of the BER test set's clock so

Table 3. Measured Performance of the Transmitter Shown in Figure 1
Mean Performance of Five Transmitters Tested at Room Temperature

Parameter	Measured Typical Performance	Test Conditions
P_t On	-12.2 dBm pk.	Logic "0" at Transmitter TTL Input, I_f dc = 60 mA
P_t Off	-82.2 dBm pk.	Logic "1" at Transmitter TTL In
LED t_r	1.30 ns	1 MHz Square Wave Input
LED t_f	3.08 ns	1 MHz Square Wave Input
$\lvert t_r - t_f \rvert$	1.77 ns	1 MHz Square Wave Input
Tx jitter	0.823 ns pp	32 MBd D2D2 Hexadecimal Input

Table 4. Measured Performance of the Transceiver Shown in Figures 1 and 3

Mean Jitter of 5 Transceivers at Maximum Received Optical Power at Room Temperature

Parameter	Measured Typical Performance	Test Conditions
1 m Link Jitter @ Rx ECL Output	3.04 ns pp	P_r = -11.3 dBm avg. with 32 MBd D2D2 Hexadecimal Data
1 m Link Jitter @ Rx TTL Output	2.18 ns pp	P_r = -11.5 dBm avg. with 32 MBd D2D2 Hexadecimal Data

Mean Performance of 5 Receivers with 1 m of 62.5/125 µm Fiber at Room Temperature

Parameter	Measured Typical Performance	Test Conditions
Mid Bit Rx Sensitivity	-36.1 dBm avg. @ BER of 1×10^{-10}	32 MBd D2D2 Hexadecimal Data
Link Monitor Assert Threshold	-34.4 dBm avg.	32 MBd D2D2 Hexadecimal Data

Mean Performance of 5 Links with 2 km of 62.5/125 µm Fiber at Room Temperature

Parameter	Measured Typical Performance	Test Conditions
Mid Bit Rx Sensitivity	-34.1 dBm avg. @ BER of 1×10^{-10}	32 MBd D2D2 Hexadecimal Data
Link Jitter @ Rx ECL Output	6.91 ns pp	P_r = -32.0 dBm avg. with 32 MBd D2D2 Hexadecimal Data
Link Jitter @ Rx TTL Output	5.52 ns pp	P_r = -32.0 dBm avg. with 32 MBd D2D2 Hexadecimal Data

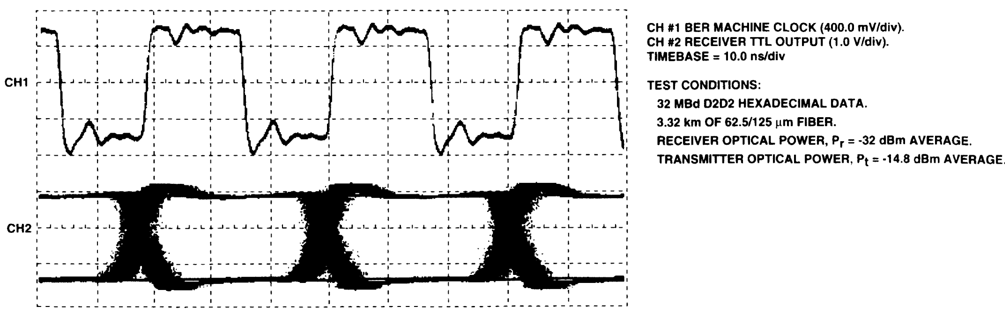

Figure 4. Receiver Output vs. Clock with Long Fiber.

that the probability of error is measured in 1.5 ns steps through the entire 31.25 ns period of every 32 MBd symbol. This technique was used to create the plot of BER versus clock delay. Figure 6 shows that BER is $\leq 1.1 \times 10^{-10}$ for 24.9 ns of each symbol transmitted through the 2 km length of 62.5/125 µm fiber. This performance was obtained when using the transmitter and receiver shown in Figures 1 and 3. The measured results shown in Figure 6 were obtained by using an optical attenuator at the end of the 2 km fiber. For these tests the attenuator was adjusted so that the optical power applied to the receiver was -32.0 dBm avg.

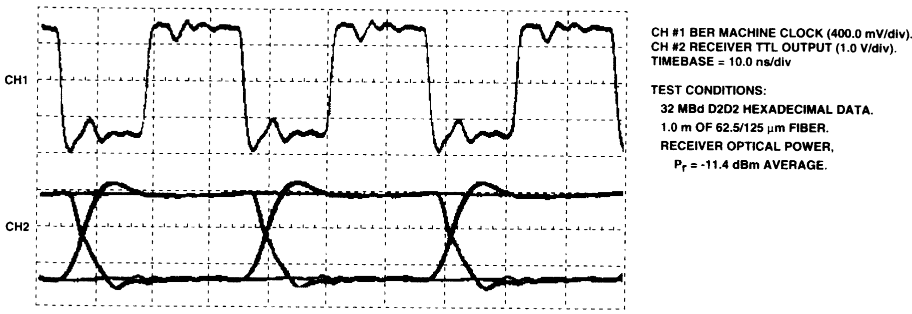

Figure 5. Receiver Output vs. Clock with Short Fiber

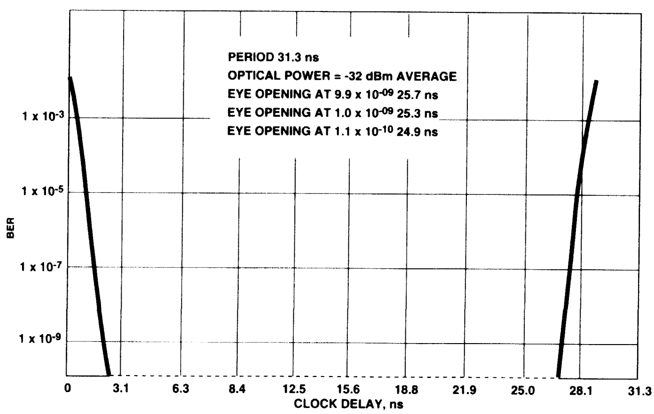

Figure 6. BER vs. Clock Delay

Insert and Bypass Key Timing Requirements

Another important characteristic that must be measured is the response of the complete fiber-optic link to the insert and bypass keys used in Token Ring applications. The insert key is the most critical of these two functions because it interrupts the Manchester encoded data at the transmitter for a time interval that is much shorter than the bypass key. Stations will fail to insert into the ring if the pulse width of the insert key is altered by the fiber-optic transceiver. The insert key must remain undistorted while received optical power changes from a minimum of -32 dBm average to a maximum of -12 dBm average. Figures 7 and 8 show that the pulse width of the insert key does not change as received optical power and fiber-optic cable length vary over the ranges defined by the 802.5J Trial Use Standard.

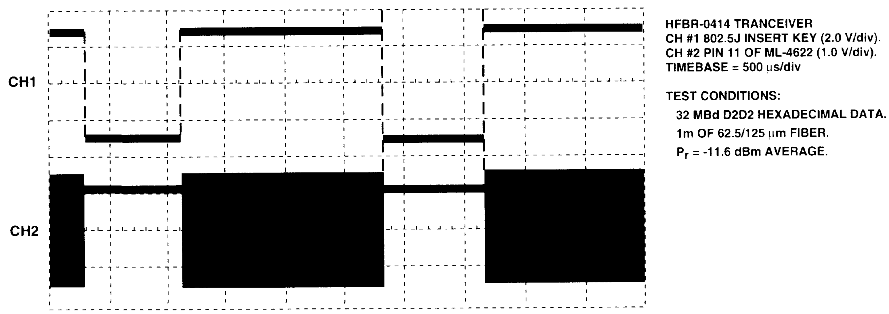

Figure 7. Insert Key Response with Short Fiber.

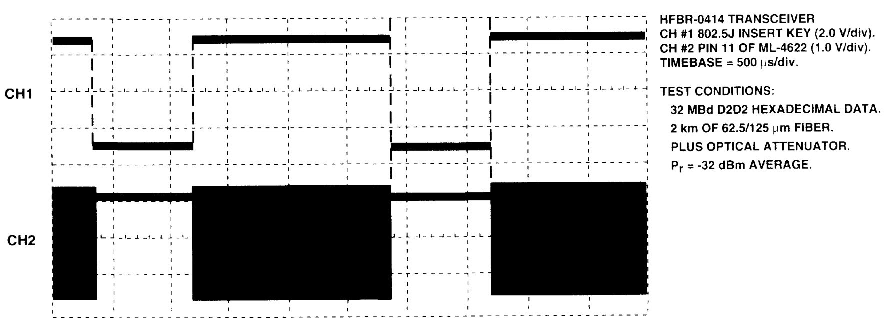

Figure 8. Insert Key Response with Long Fiber.

Printed Circuit Layout Techniques

The circuits given in this Application Note are recommended for use in any system which addresses the requirements specified in the IEEE 802.5J Trial-Use standard. HP encourages customers that want to use HFBR-0400 components in fiber-optic Token Ring applications to utilize these circuits in their products. The performance of the fiber-optic transceiver shown in this publication is partially dependent on the layout of the printed circuit board on which this recommended circuit is constructed.

The following simple rules should be followed if you desire to layout a unique printed circuit (PC) board for the fiber-optic transceiver recommended in this publication.

1) Design the PC board with a ground plane. Use a ground and a power plane if possible. This minimizes the inductance of the ground and power leads connected to the transceiver.

2) Minimize the size of cuts or openings in the ground and power planes. This minimizes the parasitic inductance and improves the dampening of both the transmitter and receiver circuits.

3) The two circuit traces connected between the HFBR-24X6 and the differential input of the receiver's quantizer should be of equal length, and the components in both traces should be placed to achieve symmetry. This minimizes the cross-talk between the fiber-optic transmitter and receiver and improves the receiver's immunity to environmental noise.

4) Connections between the drive circuit and the LED should be of minimum length. This minimizes the noise emitted by the transmitter and improves the optical rise/fall time of the LED.

5) A large 10 µF electrolytic capacitor and a 0.1 µF monolithic-ceramic capacitor should be located as close to the signal source which drives (current-modulates) the LED. This minimizes the noise emitted by the transmitter and improves the optical response time of the LED.

6) The low-pass filters shown on the recommended schematics must be used to protect the fiber-optic receiver from noise that is present in the V_{CC} power supply.

7) If an inductor is used in series with the receiver's V_{CC} and V_{ee} connections the receiver should be referenced to V_{CC} and V_{ee} islands that are isolated from the remainder of the transceiver's power planes. A differential interface at the receiver's output is required if inductors are used in series with V_{CC} and V_{ee}. This dual-inductor filter is recommended if the receiver is operated in a noisy environment.

Printed Circuit Artwork

Variations in transceiver performance due to circuit layout can be avoided by using the artwork shown in Figure 9. Designers that would like to use the artwork provided by HP are encouraged to embed the PC artwork shown in this Application Note into their systems. The PC art shown here is available from an electronic bulletin board that can be down loaded using a 2.4 kBd telephone modem. If you desire an electronic copy of this PC art call 408-435-6733 in the continental USA and Canada. The Orcad file for the through-hole transceiver shown in Figures 1 and 3 is 802KITP.EXE. The through-hole transceiver is also available as a Gerber file under the file name 802KITG.EXE. The file name for the current-source LED driver shown in Figure 2 is IDRIVE.EXE.

Designers should note that printed circuits for the fiber-optic solutions recommended in this Application Note are not difficult to create. If your product requires a unique printed circuit this can easily be accomplished by following the 7 layout rules previously discussed. The printed circuit art provided in this Application Note was developed in one design cycle using these PC design rules.

System designers that want to quickly evaluate the transceiver recommended in this application note should order the HFBR-0414 demo kit. The HFBR-0414 contains a printed circuit board and all of the active devices needed to build the transceiver shown in Figures 1 and 3 of this Application Note. A list of the components needed to construct the transceiver shown in Figures 1 and 3 is shown in Table 5. The HFBR-0414 evaluation kit minimizes the design effort needed to implement fiber-optic systems that comply with IEEE 802.5J standards and reduces the time needed to bring new Token Ring LAN products to market.

Conclusion

The transmitters and receivers shown in this Application Note have excellent performance. Engineers designing systems for use in fiber-optic Token Ring applications can save a considerable amount of time and effort by utilizing the circuits recommended in this publication. Designers that are planning to build products which address the specifications called for in IEEE 802.5J are encouraged to evaluate these recommendations and determine how well Hewlett-Packard's HFBR-0400 fiber-optic components can address their Token Ring applications.

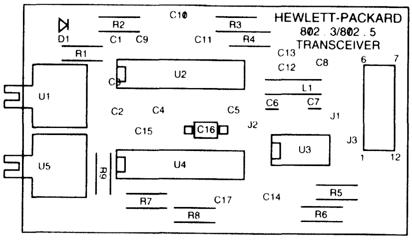

Figure 19a. Silkscreen artwork for the HFBR-0414 Demo Kit. Transmitter per Figure 1. Receiver per Figure 3.

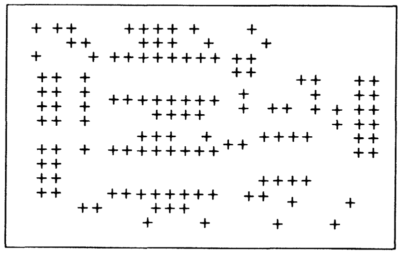

Figure 9b. Drill.

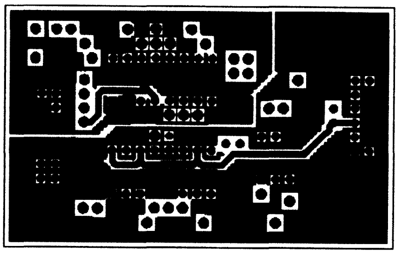

Figure 9c. Layer 1 Component Side.

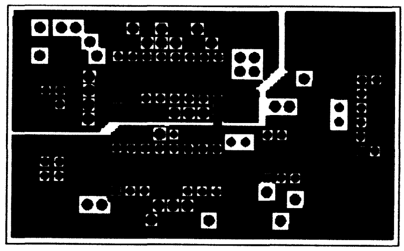

Figure 9d Layer 2.

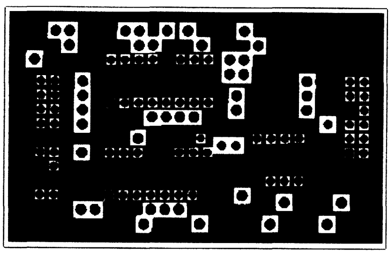

Figure 9e. Layer 3.

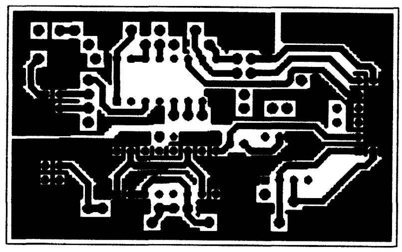

Figure 9f. Layer 4.

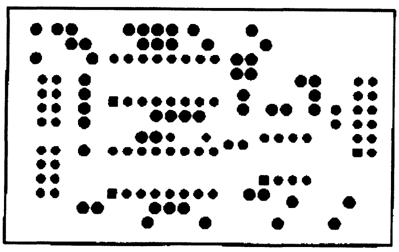

Figure 9g. Solder Mask.

WARNING: DO NOT USE PHOTOCOPIES OR FAX COPIES OF THIS ARTWORK TO FABRICATE PRINTED CIRCUITS.

Table 5. Bill of Materials for the Circuits in Figures 1 and 3.

Item #	Ref. Desig.	Qty. Each	Description	Vendor	Vendor Part Number
1	R1	1	Axial lead resistor 10 Ω, ±5% 1/8 W		
2	R2	1	Axial lead resistor 1.2 K Ω, ±5% 1/8 W		
3	R3, R4, R5, R6	4	Axial lead resistor 510 Ω, ±5% 1/8 W		
4	R7	1	Axial lead resistor 34.0 Ω, ±1% 1/8 W		
5	R8	1	Axial lead resistor 34.8 Ω, ±1% 1/8 W		
6	R9	1	Axial lead resistor 280 Ω, ±1% 1/8 W		
7	C1, C4, C8, C9, C11, C12, C13, C14, C15	9	Monolithic Ceramic Radial Lead Capacitor 0.1 μF ±10% 50 V X7R		
8	C2, C3, C10	3	Monolithic Ceramic Radial Lead Capacitor 0.001 μF ±10% 50 V X7R		
9	C5	1	Monolithic Ceramic Radial Lead Capacitor 4.7 pF ±10% 50 V COG		
10	C17	1	Monolithic Ceramic Radial Lead Capacitor 56 pF ±10% 50 V COG		
11	C6, C7, C16	3	Tantalum Radial Lead Capacitor 10 μF ±20% 10 V		
12	L1	1	Axial Lead Molded Inductor 4.7 μH ±10%, Resonant Freq. 75 MHz, 1.2 Ω dc Res.	Delevan	1025-36K
13	U1	1	125 MHz Low Cost Miniature Fiber-Optic PIN-Amplifier Receiver	HP	HFBR-2416
14	U2	1	Integrated Post Amplifier/Comparator (Quantizer)	Micro Linear	ML-4622
15	U3	1	Comparator	Linear Tech.	LT-1016
16	U4	1	Quad Two Input NAND Gate, Ni Barrier, Sn or Sn/Pb Plated	Texas Instr.	74ACT11000
17	U5	1	820 nm LED Transmitter	HP	HFBR-1414
18	D1	1	Low Current LED Lamp	HP	HLMP-4700

HEWLETT® PACKARD

Fiber-Optic Solutions for 125 MBd Data Communication Applications at Copper Wire Prices

Application Note 1066

Introduction

Fiber-optic cables have historically been used when the distance is too long, or the data rate is too high, for the limited bandwidth of wire. Optical communication links are also favored when the environment through which the data will pass is elec-trically noisy, or when electro-magnetic radiation from wire cables is a concern. Optical fibers have numerous technical advantages over conventional wire alternatives, but the cost of fiber-optic solutions has always been higher until now.

The Inherent Disadvantages Of Wire

Systems which must communicate are often connected to different reference potentials which are not necessarily zero volts, or in other situations ground references that are thought to be 0 V are electrically noisy. Metallic connections between systems with different ground potentials can be implemented by using the proper isolation and grounding techniques, but if these techniques are not strictly adhered to conductive cables will introduce conflicts between systems operating at different ground potentials. Data communication system designers must exercise caution to ensure that conductive cables do not exceed radiated noise limits established by the FCC, and cable installers need to route wire cables away from other power conductors that might couple electrical noise into the data by magnetic induction. Conventional wire transmission lines must also be terminated using a load resistor equal to the characteristic impedance of the metallic cable. This termination resistor must always be connect-ed to the receiving end of every wire cable to ensure that pulses are not reflected back toward the data source causing interference with the transmitted data.

Fundamental Advantages Of Optical Communication

Non-conductive optical cables have none of the traditional problems associated with wire. When using a fiber-optic solution, system designers do not need to be concerned about environmental noise coupling into cables, or worry about whether there is a termination resistor at the end of the cable. Conflicts between systems with different reference potentials do not happen when using insulating fiber-optic media because optical cables do not have conductors or shields that can be improperly grounded when the cables are installed or maintained. The fiber-optic receiver is the only portion of the optical link which is sensitive to noise, and it can easily be protected because it is contained within the host system which is receiving the data. A simple power supply filter is usually sufficient to protect the fiber-optic receiver from the host system's electrical noise. Electrostatic shielding can be applied to the receiver if the host system is particularly noisy, but electrostatic shields are not needed in most applications if the circuit techniques recommended in this application note are used.

A Fiber-Optic Solution At Wire Prices

The traditional argument for using copper wire has always been that fiber-optic solutions cost more, but Hewlett-Packard's Versatile Link components now enable system designers to overcome cost barriers that have historically prevented the use of fiber-optic cables in short distance applications. The HFBR-15X7 LED transmitter, and the HFBR-25X6 receiver, can be used with large diameter 1 mm plastic, or 200 µm Hard Clad Silica

(HCS TM) step index fibers to build unusually low cost data communication equipment. The fiber-optic solution described in this application note can transmit data at rates up to 12 5 MBd for the same price as shielded twisted pair wire, but this unusually low cost optical data link has none of the disadvantages that are inherent to wire cables.

Distances and Data Rate Capabilities of HFBR-15X7/25X6

Various distances and data rates are possible when the HFBR-15X7 and HFBR-25X6 components are used with large core step index fibers. At low data rates, the distances achievable are determined by the sensitivity of the receiver, cable attenuation, and the amount of light which the LED can launch into the fiber core. As data rate increases, fiber bandwidth will begin to influence how long the optical data link can be, and how fast the data can be transmitted. A plastic fiber with a 1 mm core diameter will couple more light from the LED than a composite fiber with a 200 m m diameter silica glass core and plastic cladding, but greater distances are achievable with the composite fiber since it has significantly lower attenuation than possible with an all-plastic fiber.

The distance data rate curves shown in Figures 1 and 2 are provided to allow designers to quickly determine if HFBR-15X7 and HFBR-25X6 can be used with large core optical fibers to meet their system requirements. Figure 1 shows the distances and data rates that can be achieved with HP's 1 mm plastic fibers and Figure 2 shows what can be accomplished when using HP's 200 mm hard clad silica fibers. If designers utilize the

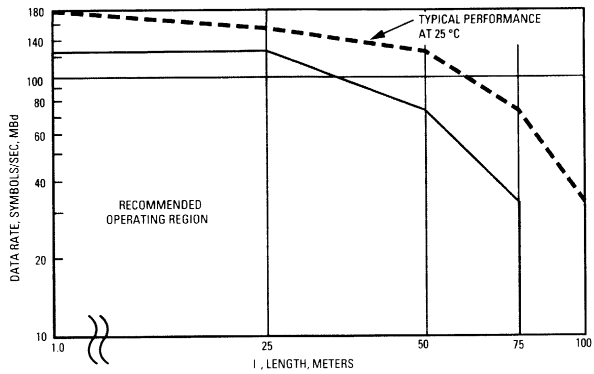

Figure 1. Distances and Data Rates Possible with 1 mm Plastic Fiber.

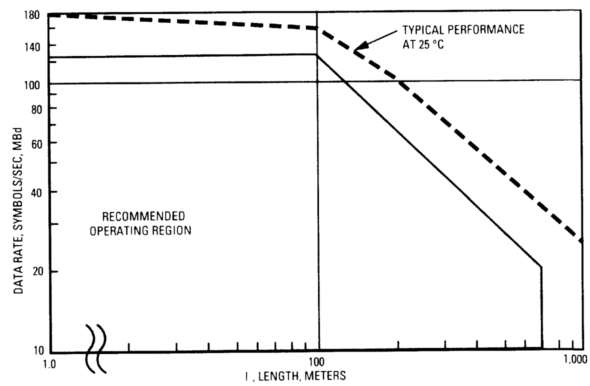

Figure 2. Distances and Data Rates Possible with 200 HCS Fiber.

circuits recommended in this application note, digital fiber-optic links can normally be implemented at distances and data rates within the shaded portions of Figure 1 and Figure 2 . The fiber-optic transceiver shown in this publication was optimized for operation at 125 MBd. Greater distances can be achieved at data rates less than 125 MBd by optimizing the transmitter and receiver circuits for operation at lower speeds.

Figure 1 shows the performance possible with 1 mm diameter plastic fiber. The HFBR-15X7/25X6 components can be used with standard 1 mm plastic cables to build 20 meter links which are capable of transmitting data at a rate of 125 MBd. When low loss plastic fiber is used, distances of 25 meters are possible at 125 MBd. As data rate decreases, the distance achievable with 1 mm fiber increases. Figure 1 shows that a distance of 100 meters is typically possible at rates as low as 33 MBd when using low loss 1 mm plastic fiber.

Composite fiber with a silica glass core and plastic cladding can achieve greater distances than possible with an all plastic fiber. Figure 2 shows what can be accomplished when HFBR-15X7 and HFBR-25X6 components are used with 200 μm diameter hard clad silica (HCS) fiber. Substantial increases in cable length are possible when using 200 μm HCS™ fiber since it has a much lower optical attenuation than 1 mm plastic fiber. Figure 2 indicates that 125 MBd data rates are typically possible with 125 meter lengths of 200 μm HCS™ fiber when using the transceiver recommended in this publication. Distances of 1 km can typically be achieved at data rates as low as 20 MBd due to the much lower optical losses of 200 μm HCS™ cable.

Advantages of Encoded Run Limited Data

Fiber-optic transceivers are commonly used in systems that use some form of encoding. When data is encoded the original data bits are replaced with a different group of bits known as a symbol. Data is encoded to prevent the digital information from remaining in one of the two possible logic states for an indefinite period of time. When data is encoded, a characteristic known as the "run limit" is established. If data is not changing, the run limit defines how much time may pass before the encoder inserts a transition from one logic state to another. The run length, or run limit of the encoder, is the number of symbol periods that are allowed to pass before the encoder changes logic state. Encoders also force the encoded data to have a 50 % duty factor, or they restrict the duty factor to a limited range, such as 40 to 60%. When data is encoded, the fiber-optic receiver can be ac coupled as shown in Figure 3.

Without encoding, the fiber-optic receiver would need to detect dc levels to determine the proper logic state during long periods of inactivity, as when there is no change in the transmitted data. AC-coupled fiber-optic receivers tend to be lower in cost, are much easier to design, and contain fewer components than their dc-coupled counterparts.

The output of the HFBR-25X6 should not be direct coupled to the amplifier and comparator shown in Figure 3. Direct coupling decreases the sensitivity of a digital fiber-optic receiver, since it allows low-frequency flicker noise from transistor amplifiers to be presented to the receiver's comparator input. Any undesired signals coupled to the comparator will reduce the signal-to-noise ratio at this critical point in the circuit, and reduce the sensitivity of the fiber-optic receiver.

Another problem associated with direct-coupled receivers is the accumulation of dc offset. With direct coupling, the receiver's gain stages amplify the effects of undesirable offsets and voltage drifts due to temperature changes. These amplified dc offsets will eventually be applied to the comparator and result in reduced sensitivity of the fiber-optic receiver. The dc offset at the comparator can be referred to the optical input of the receiver by dividing by the receiver gain. This division refers the dc offset at the comparator to the receiver input where it appears as a change in optical power that must be exceeded before the receiver will switch logic states. Problems with dc drift can be avoided by constructing the receiver as shown in Figure 3.

Encoding has other advantages. Encoding merges the data and clock signals in a manner that allows a timing-recovery circuit to reconstruct the clock at the receiver end of the digital data link. This is essential because fiber-optic links can send data at such high rates that asynchronous timing-recovery techniques, such as over-sampling, are not very practical. Without encoding, the clock signal required to synchronously

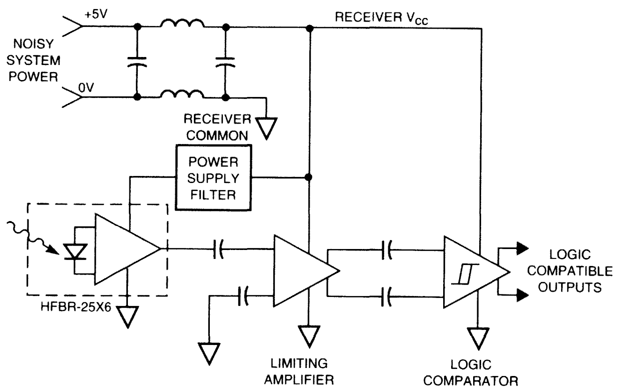

Figure 3. Fiber-Optic Receiver Block Diagram.

HCS is a registered trademark of SpecTran Corporation.

detect the data would need to be sent via a second fiber-optic link. Separate transmission channels for data and clock signals are usually avoided due to cost, but problems with time skew between the data and clock can also arise if separate fibers are used to transmit these signals.

Characteristics of Encoders

A Manchester encoder replaces each bit with two symbols, for instance, a logic "1" is replaced by a ("1","0") symbol, and a logic "0" is replaced by a ("0", "1") symbol. Manchester code is not very efficient since it doubles the fundamental frequency of the data by substituting 2 symbols for each bit transmitted. Block substitution codes such as 4B5B replace 4 bit groups of data with a 5 bit symbol. Another popular block substitution code is 5B6B, which replaces each group of 5 bits with a 6 bit symbol. Substitution codes encode the data more efficiently. If a Manchester code is used to transmit data at 100 Mbits/second the fiber-optic channel must be capable of passing 200 M symbols/second. Baud (Bd) is expressed in units of symbols/second, thus the Manchester encoder in this example requires a serial data link that can work at 200 MBd. If the Manchester encoder is replaced by a 4B5B encoder, the 100 M bit/second data can be sent at a signaling rate of 125 MBd. In binary transmission systems the maximum fundamental frequency of the data is half the symbol rate expressed in Bd. When a Manchester encoder is used to send 100 M bit/second data, at a symbol rate of 200 MBd, the maximum fundamental frequency of the data is 100 MHz. By using a 4B5B encoder, the same 100 M bit/second data can be transmitted at 125 MBd, at a maximum fundamental frequency of 62.5 MHz.

The minimum fundamental frequency that the fiber-optic link must pass is determined by the encoding rule chosen. The run limit of the encoder determines the maximum number of symbol periods that the encoder will allow before it forces a transition, thus the encoder's run limit determines the minimum fundamental frequency of the encoded data. Manchester code will allow only two symbol periods to pass without a transition. As many as 3 symbol times without a transition will be allowed by the 4B5B encoder used in the AMD TAXIchip™.

Figure 4 illustrates the attributes of various encoding techniques. Figure 4 shows that as encoder efficiency improves the bandwidth needed in the fiber-optic communication channel is reduced, or conversely, for a fixed communication channel bandwidth the number of bits/second that can be transmitted will go up as encoder efficiency improves.

Total Solution Cost

125 Mbd Link Costs

The cost of a 125 MBd link consists of the cost of the data transceiver, and the cost of the media (cable and connectors). For the recommended +ECL transceiver discussed in this application note, the material costs in low volume are approximately $28.

The total material cost for a logic-to-light transceiver is under $30 in moderate volume, which compares favorably with the cost of a wire transceiver solution capable of 125 MBd performance over 100 meter spans, but the big advantage of this low cost fiber-optic technology is its ability to provide better data integrity than comparably priced wire alternatives.

Cable costs

The price per meter of HCS cable from HP and SpecTran is comparable to the cost of shielded twisted pair wire in similar volumes. Connectors cost approximately a dollar, similar to typical twisted pair RJ jack connectors for data communications. Connec-

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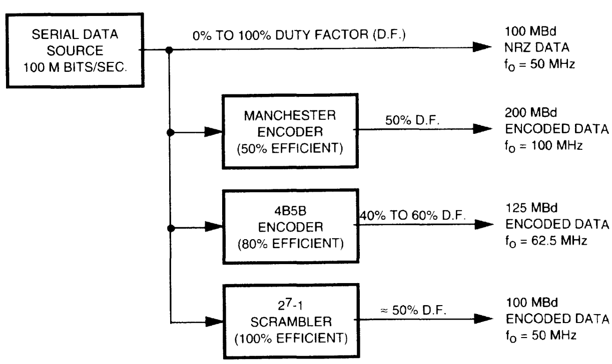
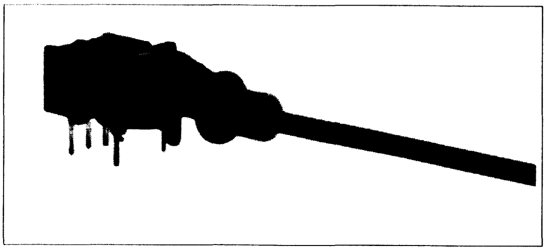
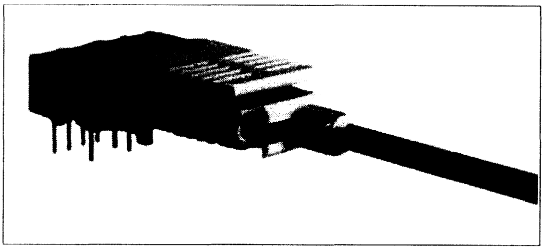


Figure 4. Attributes of Encoding.



Versatile Link Receiver with Simplex Connector for HCS® fiber attached.



Stacked Versatile Link Transmitter/Receiver pair with Latching Duplex Connector for plastic fiber attached.

tor installation requires no epoxy or polishing, and can be completed in less than a minute per connector. Therefore the installed cost of HCS cable is similar to the installed cost of wire links of comparable performance.

For shorter distance links, preconnectored plastic fiber cable assemblies are available from Hewlett-Packard Distributors at attractive prices. For example, a 1 meter, duplex, pre-connectored plastic fiber cable has a suggested list price of approximately $13 for a quantity of more than 50 units. Again, these costs compare favorably with the cost of data grade wire cable assemblies at similar volumes.

The costs of the 125 MBd Versatile Link electronics, cable, and connectors are all competitive with wire solutions. However, wire solutions frequently incur additional costs in use due to unanticipated trouble-shooting of electrical interference due to poor terminations or adjacent sources of electrical noise. The inherent electrical isolation of optical fiber results in a more robust solution and lower cost to the end user.

Circuits Recommended for use with HFBR-15X7 and HFBR-25X6

The HFBR-15X7/25X6 components can be used in a diverse range of applications. Not all applications can be addressed with the circuits shown in this publication, however, the transceiver recommendation which follows is useful in a wide range of systems which transmit encoded data at rates up to 125 MBd. If the design suggestions given in this publication do not meet your needs, please feel free to contact your Hewlett-Packard Components representative for more information.

Recommended Transmitter

The transmitter shown in Figure 5 is recommended for use with 1 mm plastic fiber. The transmitter in Figure 5 applies a forward current of 20 mA to the HFBR-15X7 LED. If 200 μm HCS™ fiber is to be used the LED forward current must be increased to 60 mA and the drive circuit shown in Figure 6 is recommended. The forward current applied to the HFBR-15X7 was chosen so that the LED will couple the maximum amount of light into the core of the fiber without overdriving the HFBR-25X6 receiver when short optical cables are used.

The transmitters shown in Figures 5 and 6 use the following techniques to improve LED performance. When the output of U1 is a logic "1", resistor R11 applies a small residual prebias current to the LED. This small prebias current minimizes the propagation delay distortion of the LED. Prebias also improves LED linearity sufficiently to permit the use of a frequency compensation circuit, which reduces the optical rise/fall time of the fiber-optic transmitter.

This frequency compensation technique is often called drive current peaking, because it adds brief current spikes to the LED drive current pulses. When prebiased, the HFBR-15X7 LED has an amplitude versus frequency response which is

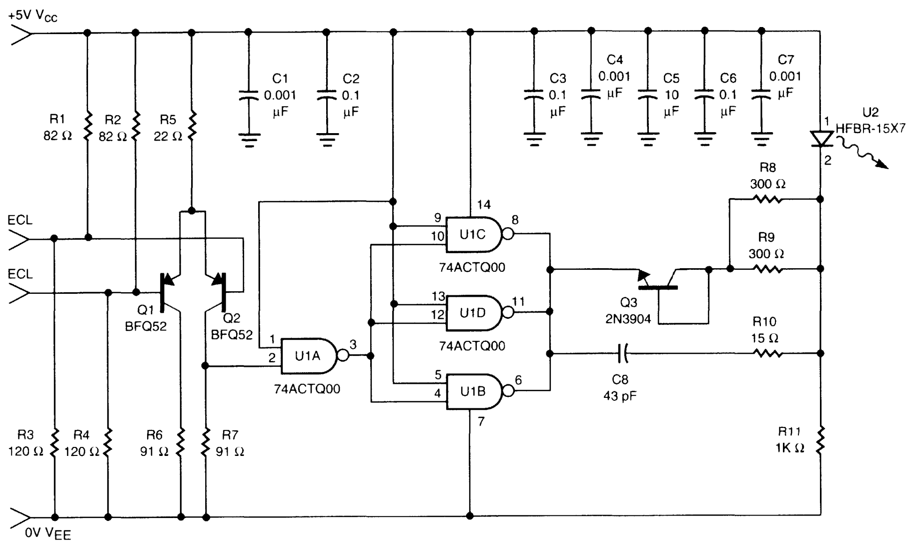


Figure 5. +5 V ECL Through Hole Transmitter for 1 mm Plastic Optical Fiber (POF).

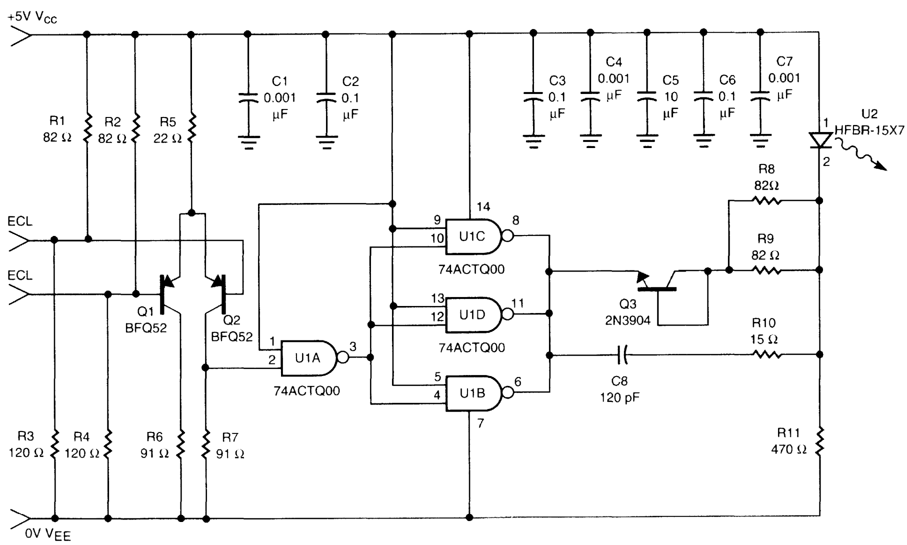


Figure 6. +5 V ECL Through Hole Transmitter for 200 µm HCS™ Fiber.

roughly equivalent to a first order low pass filter. Without prebias and peaking, the HFBR-15X7 LED has a typical 10% to 90% optical rise time of 12 ns. When prebias is provided by R11, and frequency compensation (peaking) is provided by R10, and C8, the 10% to 90% optical rise time of the HFBR-15X7 LED decreases to a typical value of 3 ns, when using 1 mm plastic fiber. Optical rise times of 3.5 ns are typical when the peaked LED driver is used with 200HCS fiber. The LED's on-state current is primarily determined by the values of resistors R8 and R9, but Equation 1 shows that some on-state current is also provided by R11. Transistor Q3 is connected to form a low cost high speed diode. This diode allows LED prebias current to be set independent of the resistance chosen for R8 and R9. The LED's prebias current can be calculated as shown in Equation 2. Capacitance between the emitter and collector of Q3 changes as a function of the diode connected transistor's forward current. Current dependent changes in the capacitance of Q3 ensure that the current peak which turns the LED off will have a larger amplitude than the current peak applied when the LED is switched on. LEDs are characteristically harder to turn off than on. The difference between the amplitude of the peak current applied at turn on, and turn off, helps to reduce the optical pulse width distortion of the fiber-optic transmitter. One of the best features of this recommended LED driver circuit is that all of the active and passive components needed to build 10,000 of the transmitters shown in Figures 5 or 6 can be purchased for about $10.00 per circuit.

Equation 1:

$$I_{FON} = \frac{(V_{cc} - V_{FON})}{R11} + \frac{[V_{cc} - (V_{FON} + V_{CE_{Q3}} + V_{OL_{U1}})]}{[(R8)(R9)/(R8 + R9)]}$$

Equation 2:

$$I_{FOFF} = \frac{(V_{cc} - V_{FOFF})}{R11}$$

Recommended Receiver

The recommended receiver is shown in Figure 7. The HFBR-25X6 component used in this receiver linearly converts changes in received optical power to a corresponding change in voltage. The output of the HFBR-25X6 is an analog signal which can easily be converted to logic by a post amplifier and comparator. This post amplifier comparator function is often called a quantizer. A very inexpensive quantizer can be implemented using an MC10H116 ECL line receiver. The MC10H116 provides three low cost differential amplifiers in a single package. The MC10H116 can accommodate a large range of input voltages. *The large dynamic range of the MC10H116 is very important!* The quantizer must have a large dynamic range because the output of the HFBR-25X6 can change from a few millivolts to hundreds of millivolts when fiber length and attenuation are varied.

Several subtle techniques are used to maximize the receiver's sensitivity to optical pulses, while minimizing the receiver susceptibility to electromagnetic interference (EMI). In most systems, the same +5 V dc supply which powers the fiber-optic receiver is also used to power micro processors and digital logic. *The receiver must be isolated from noisy dc power supplies!* This isolation is provided by low pass filters that prevent noise injection into the HFBR-25X6, and quantizer, through the +5 V power connections. The HFBR-25X6 is a miniature hybrid circuit that, due to its small physical size, is relatively immune to environmental noise. In most applications, the HFBR-25X6 has sufficient noise immunity to operate without any additional electrostatic shielding, but the connection between the HFBR-25X6 and the non-inverting input of the MC10H116 forms a loop antenna with sufficient area to receive significant amounts of EMI. The receiver's susceptibility to EMI is minimized by connecting a second loop antenna with equal area to the inverting input of the MC10H116 quantizer. When connections to the quantizer's input are symmetric, and have equal loop areas, the common mode rejection of the MC10H116's difference amplifiers will assure that the fiber-optic receiver provides good EMI immunity.

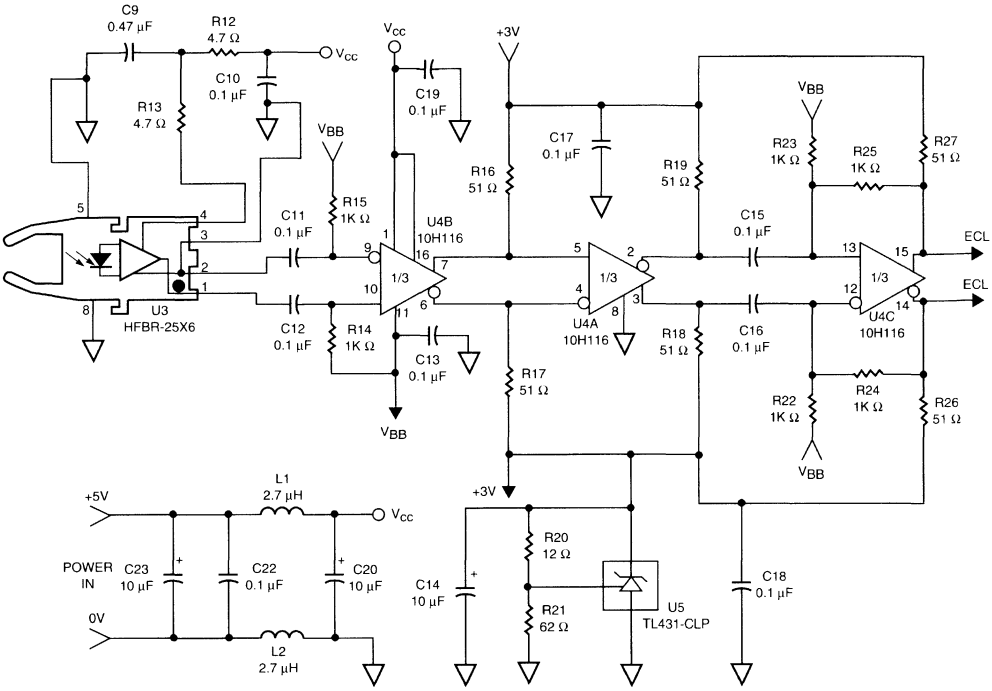


Figure 7. +5 V ECL Receiver with Through Hole Pin Out.

Design techniques which improve the EMI immunity of the receiver help to minimize crosstalk between the transmitter and the receiver. Crosstalk will also be reduced when the printed circuit for the fiber optic transceiver is designed so that pin 4 of the HFBR-15X7 LED transmitter is next to pin 1 of the HFBR-25X6 receiver. This arrangement maximizes the distance between pin 2 of the HFBR-15X7 LED and the power supply lead (pin 4) of the HFBR-25X6. When the distance between pin 4 of the HFBR-25X6 and pin 2 of the LED is maximized, the crosstalk between the LED transmitter and the HFBR-25X6 receiver's power pin is reduced. The typical transmitter to receiver crosstalk which occurs when using the printed circuit shown in this application note is equivalent to a 0.5 dB reduction in receiver sensitivity. The effect of transceiver crosstalk has already been factored into the recommended distances and data rates shown in Figures 1 and 2.

The 125 MBd receiver shown in Figure 7 typically provides a sensitivity of -28 dBm average modulated when used with 1 mm plastic fibers. The same receiver can be used with 200 µm HCS™ fibers and will provide a typical sensitivity of -29 dBm average modulated at a data rate of 125 MBd. Overload characteristics of the receiver are not influenced by characteristics of the MC10H116 quantizer. The maximum power which can be applied to the receiver shown in Figure 7 is determined by the saturation characteristics of the transimpedance amplifier used in the HFBR-25X6. The HFBR-25X6 is guaranteed to provide pulse width distortion which is less than 2 ns when received optical power is less than -9.4 dBm peak. Many features have been incorporated into the receiver recommended in this publication, but one of the most prominent characteristics of the circuit shown in Figure 7 is that all of the active and passive components needed to build 10,000 fiber-optic receivers can be purchased for about $15.00 per circuit.

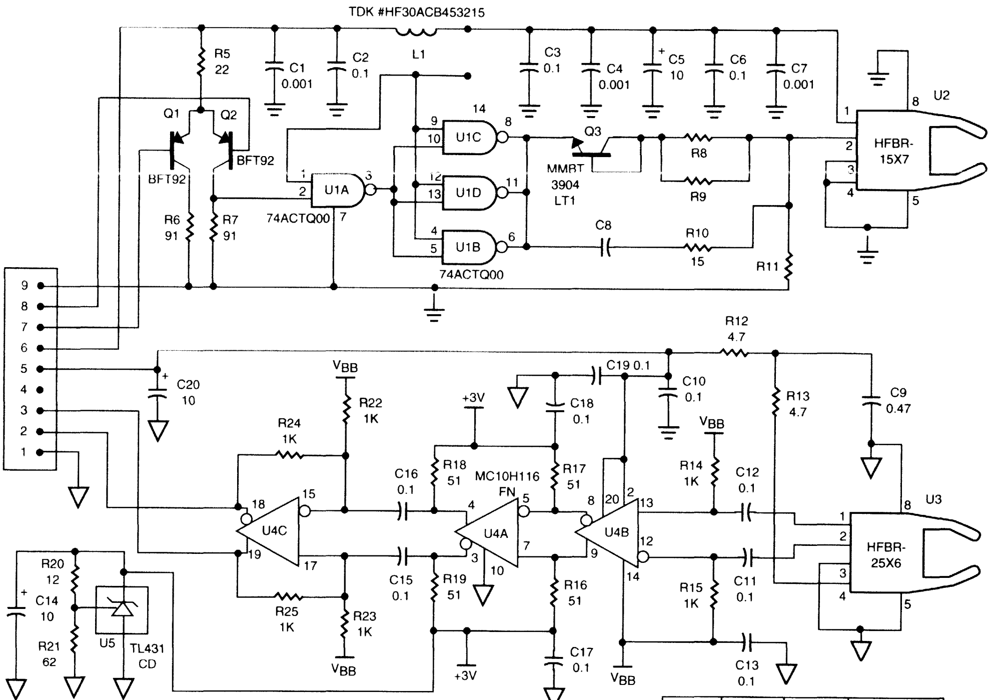
A Complete Fiber-Optic Transceiver Solution

Figure 8 shows the schematic for a complete fiber-optic transceiver. This transceiver is constructed on a printed circuit, which is 1" wide by 1.6" long, using surface mount components. When the transceiver shown in Figure 8 is tested at a data rate of 125 MBd, using 100 m of 200 µm HCS™ fiber, it provides a typical eye opening of 5.4 ns at a BER of 1×10^{-9}. The power supply filter and ECL terminations shown in Figure 9 are recommended for use with the transceiver shown in Figure 8.

The artwork for the surface mount transceiver is shown in Figure 10, and a complete parts list is shown in Table 1. Designers interested in inexpensive solutions are encouraged to embed the complete fiber-optic transceiver described in this Application Note into the next generation of new data communication products.

Local Area Network Links

High speed LANs such as FDDI and ATM have adopted a common footprint +5 V ECL transceiver, often referred to as a "1X9 transceiver". The circuit in Figure 8 matches the electrical functions of these industry standard transceivers, with the exception that there is no signal detect function in the Figure 8 circuit (pin 4 is nonfunctional). Therefore, the recommended circuit can be directly inserted into boards designed for 1X9 transceivers and used as a lower-cost alternative to the industry standard 1300 nm transceivers. If the MC10H116 comparator is replaced with a Signetics NE5224 IC, the signal detect function can



NOTES:

(1) ALL CAPACITORS ARE IN µF WITH ±10% TOLERANCE UNLESS OTHER WISE NOTED.

(2) ALL RESISTORS ARE IN OHMS WITH ±5% TOLERANCE UNLESS OTHER WISE NOTED.

	POF	HCS™	TOLERANCE
R8	301 Ω	82.5 Ω	1%
R9	301 Ω	82.5 Ω	1%
R11	1K Ω	475 Ω	1%
C8	43 pF	120 pF	5%

Figure 8. Fiber-Optic Transceiver Using Surface Mount Components.

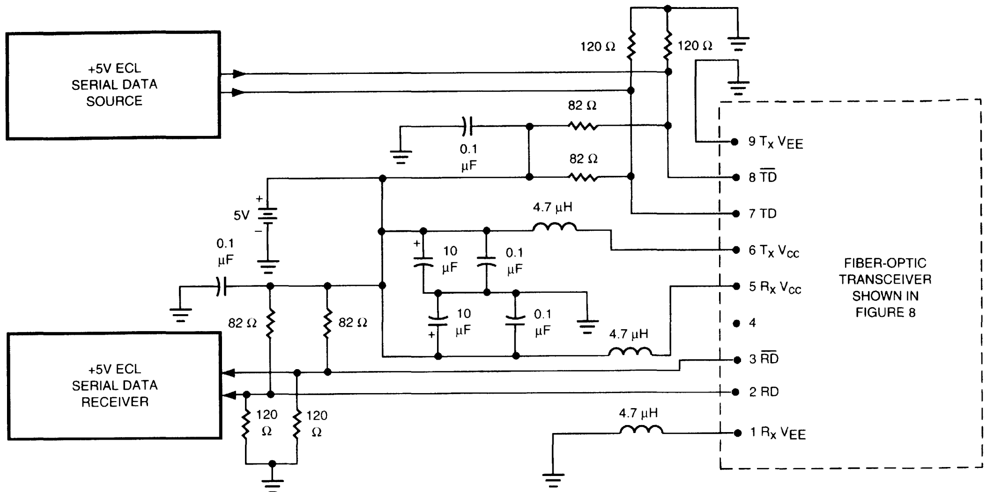


Figure 9. Recommended Power Supply Filter and +5 V ECL Signal Terminations.

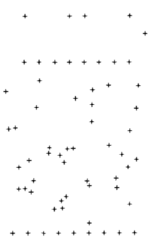


Figure 10a. Drill Drawing

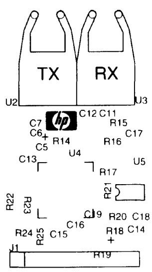


Figure 10b. Top Silkscreen

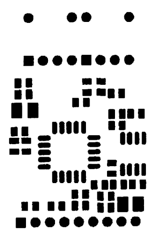


Figure 10c. Top Side Solder Mask

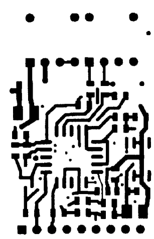


Figure 10d. Top Layer

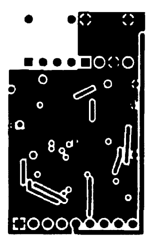


Figure 10e. Second Layer

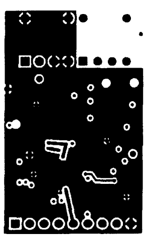


Figure 10f. Third Layer

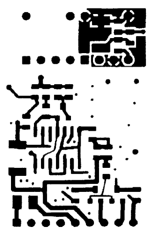


Figure 10g. Bottom Layer

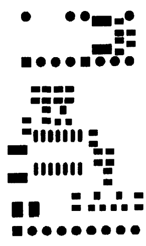


Figure 10h. Bottom Side Solder Mask

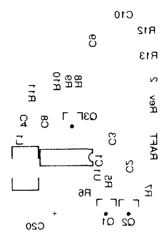


Figure 10i. Bottom Silkscreen

WARNING: DO NOT USE PHOTOCOPIES OR FAX COPIES OF THIS ARTWORK TO FABRICATE PRINTED CIRCUITS.

also be implemented, at a total transceiver cost that is slightly higher than the MC10H116 circuit, but still significantly less than half the cost of an integrated 1300 nm 1X9 transceiver. Lower speed LANs such as Ethernet and Token Ring typically use TTL ICs. The circuit of Figure 8 can easily be modified for TTL I/O for such networks. Also note that the HFBR-25X6 receiver will work well with the Micro Linear ML4622/4624 quantizer ICs designed specifically for Ethernet and Token Ring.

The fiber-optic data links described in this note will not be interoperable with the available industry standard transceivers, and do not conform to the specifications of IEEE or ANSI LAN standards as currently defined. However, these fiber-optic links can be used in proprietary systems where a lower-cost, fiber-optic solution is desired.

Byte-to-Light Data Communication

The fiber-optic transceiver shown in Figure 8 has a +5 V ECL interface that is compatible with the AMD TAXIchip. This transceiver can be combined with the TAXIchip to build complete data communication systems that bridge the gap between the serial architecture of optical fibers and the parallel architecture used in computing, peripheral, and telecom systems. TAXIchip provides all of the MUX, DEMUX, encode, decode, and timing recovery functions needed to interface a serial fiber-optic communication channel to a parallel processor. The transceiver shown in Figure 8 provides all of the circuitry needed to interface the HFBR-15X7 and HFBR-25X6 components to the Am7968/Am7969 TAXIchips. Figure 11 shows how the fiber-optic transceiver should be connected to the Am7968 and Am7969.

TAXIchip is a registered trademark of Advanced Micro Devices, Inc.

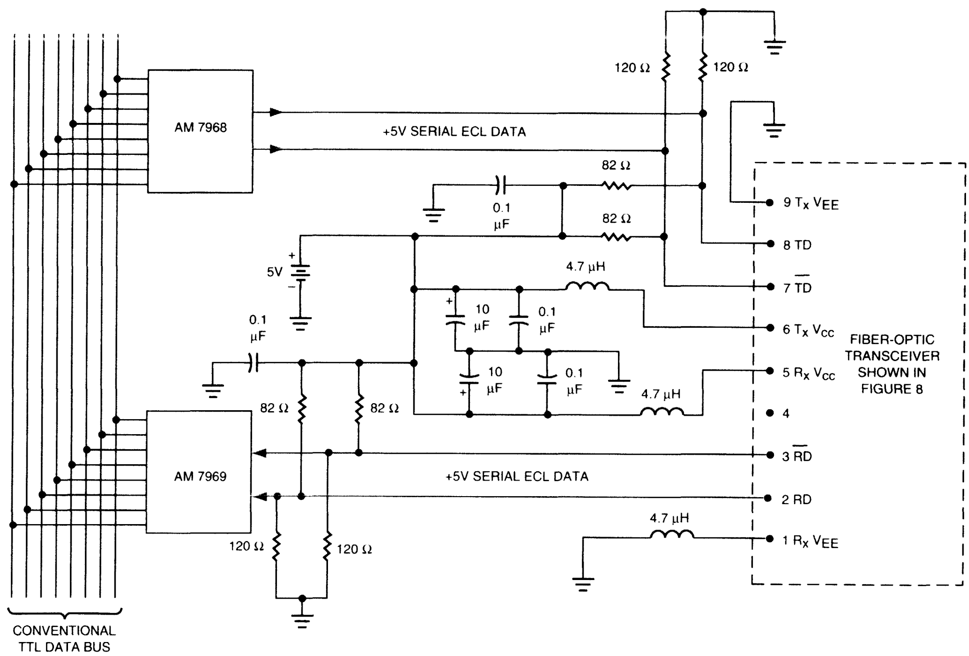


Figure 11. Byte-to-Light Transceiver.

Testing Digital Fiber-Optic Links

The overall performance of a complete digital fiber-optic link can be determined by stimulating the transmitter with a pseudo random bit sequence (PRBS) data source while observing the response at the receiver's output. A PRBS data source is a shift register where data bits from two or more shift register stages are combined using an exclusive-or gate. When a clock signal is applied to the CLK input of the shift register, and the output of the exclusive-or gate is applied to the D_S input of the shift register, the PRBS generator produces a serial bit stream which appears to be random, but is actually periodic and reproducible. If the PRBS generator is constructed using a 23 bit long shift register, the exclusive-or feedback can be configured so that the shift register will be in one of 2^{23}-1 possible states at any given clock time. The 2^{23}-1 PRBS data generator appears to be a source of random serial data, but it is actually the output of a shift register which is in one of 8,388,610 precisely repeatable states. PRBS generators send an exactly repeating serial data pattern that can be checked bit-by-bit to determine if the fiber-optic link made errors while transporting the data. A bit-error-ratio test set is an instrument which contains a PRBS generator, a bit-by-bit error detector, and an error counter. Bit-error-ratio test sets measure the probability that the fiber-optic link will make an error. Probability of error is commonly expressed as a bit-error-ratio or BER. The BER is simply the number of errors which occurred divided by the number of bits transmitted through the fiber-optic link in some arbitrary time interval.

The +5 V ECL interface of the transceiver shown in Figure 8 is convenient for use with off-the-shelf VLSI chips like the TAXIchip, but it is not compatible with the majority of the test equipment used to measure the performance of fiber-optic links. Most bit error rate (BER) test sets have conventional -5 V ECL inputs and outputs. The test fixture shown in Figure 12 provides a convenient way to convert +5 V ECL to -5 V ECL. This test fixture allows the transceiver in Figure 8 to be used with any BER test set (BER machine) with a conventional -5V ECL interface. The test fixture in Figure 12 was used to collect the performance data shown in this application note.

The waveforms shown in Figures 13 and 14 are known as eye diagrams. These eye diagrams were measured by connecting a Digitizing Oscilloscope, with a 1 GHz bandwidth, to the receiver's +5 V ECL output. The HP 54100A oscilloscope used for these measurements was triggered from the PRBS generator's clock. The lack of correlation between the oscilloscope's time base, and the PRBS generator's clock, assures that the oscilloscope will randomly sample the PRBS data. The infinite persistence mode of the HP 54100A Digitizing Oscilloscope was used, and the electrical output of the receiver was measured for roughly 1 hour, to determine the eye opening. As eye opening, or eye width, increases, the probability that the fiber-optic link will make an error decreases. A wide eye opening makes it easier to extract the clock signal which is normally encoded with the data passing through the serial communication channel. Fiber-optic links are less likely to make errors when the eye is wide open, because there is more time for the clock to synchronously detect the data while it is stable and unchanging.

The results measured in Figure 13 were obtained at room temperature when 125 MBd PRBS data was transmitted through a plastic fiber-optic link. Figure 13 shows that the eye opening is typically 5.52 ns when the recommended transceiver in Figure 8 is used with 20 meters of 1 mm plastic fiber. Excellent performance can also be achieved by using the transceiver in Figure 8 with HP's 200 µm HCS™ fiber. Figure 14 indicates that the eye opening is typically 5.56 ns wide when 125 MBd data is transmitted through 100 meters of 200 µm HCS™ fiber.

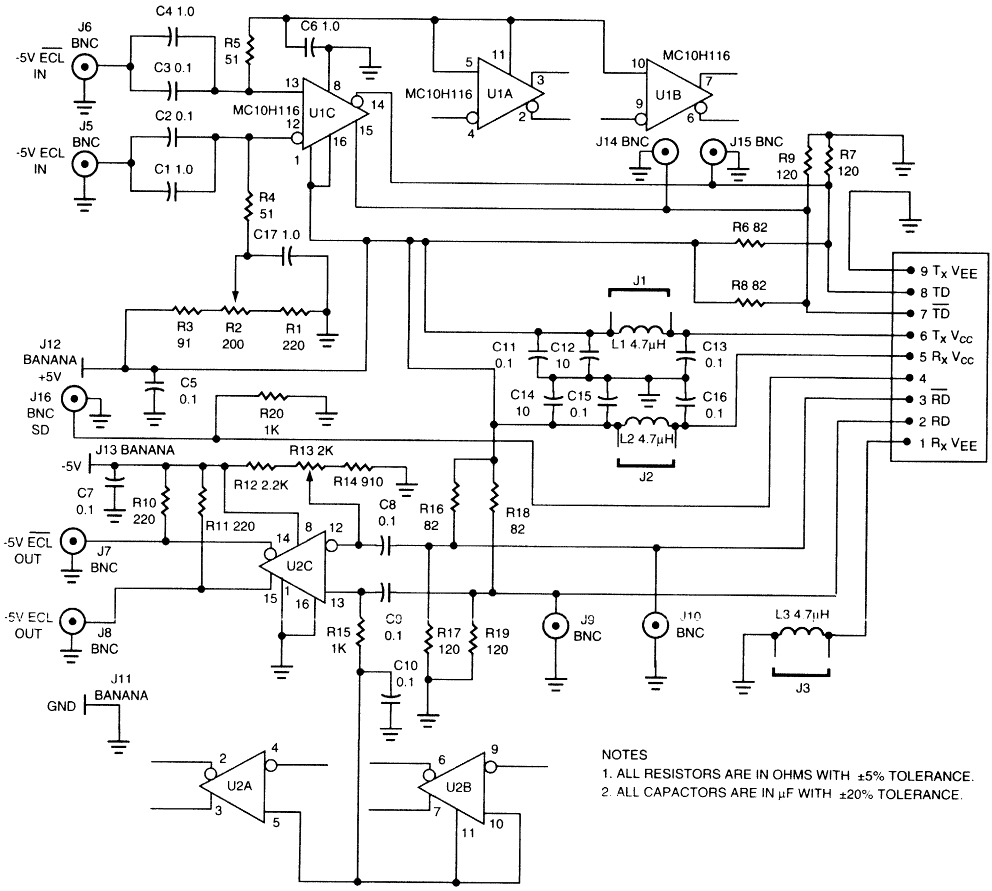


Figure 12. Fiber-Optic Transceiver Test Fixture.

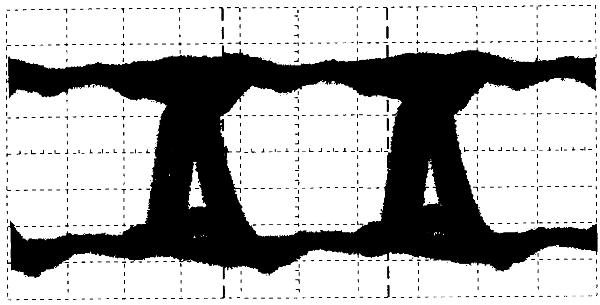


Figure 13. Typical Eye Opening with 25 m of Low Loss 1 mm Plastic Optical Fiber (POF).

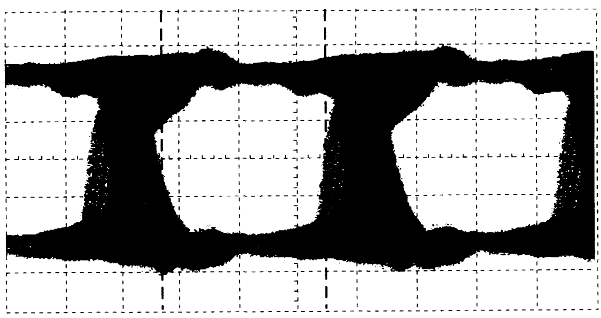


Figure 14. Typical Eye Opening with 100 m of 200 µm HCS™ Fiber.

A better method for measuring the performance of a complete optical data link is to use a computer controlled delay line and a BER test set. This technique uses a computer to adjust the delay of the BER test set's clock relative to the PRBS data. At a data rate of 125 MBd the clock delay was changed in 100 ps increments. The test system then measures and stores the probability of error at each 100 ps delay step until the clock has been swept through the entire 8.0 ns period of every 125 MBd symbol transmitted through the fiber-optic link. The results in Figure 15 were obtained when the BER test set applied 2^{23}-1 PRBS data to the transmitter portion of the transceiver under evaluation. Figure 15 shows that when using the transceiver recommended in Figure 8 BER is typically $\leq 1 \times 10^{-10}$ for 5.8 ns of each pseudo random symbol transmitted through a 20 m length of 1 mm plastic fiber. The optical power applied to the receiver was Pr = -16.4 dBm average for the measured results shown in Figure 15. Figure 16 shows the performance that can be achieved at 125 MBd with 200 µm HCS™ fiber. Figure 16 shows that when using the transceiver recommended in Figure 8, BER will be typically $\leq 1 \times 10^{-10}$ for 5.3 ns of each pseudo random symbol transmitted through a 100 m length of 200 µm HCS™ fiber. The optical power applied to the receiver was Pr = -18.0 dBm average for the measured results shown in Figure 16.

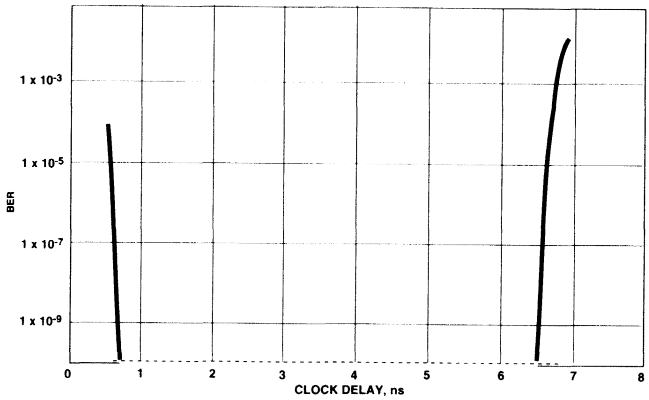


Figure 15. Typical BER vs. Clock Delay at 125 MBd with 20 m of 1 mm Plastic Fiber.

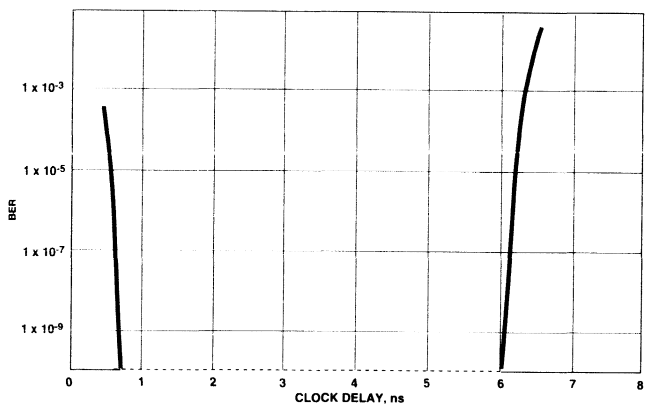


Figure 16. Typical BER vs. Clock Delay at 125 MBd with 100 m of 200 μm HCS™ Fiber.

Applications Support

Variations in performance due to circuit layout can be avoided by using the artwork shown in Figure 10. Designers that would like to use the printed circuit layout developed by HP are encouraged to embed the PC artwork shown in this Application Note into their systems. The PC art shown here is available from an electronic bulletin board that can be down loaded using a 2.4 kBd telephone modem. If you desire an electronic copy of this PC art call your Hewlett-Packard Components representative.

System designers can quickly determine if the HFBR-15X7 and HFBR-25X6 will meet their needs by ordering the HFBR-0527. The HFBR-0527 is a completely assembled demo board for the transceiver shown in Figure 8. When using plastic fiber order the HFBR-0527P, and when using 200 μm HCS™ fibers specify the HFBR-0527H. The test fixture in Figure 12 is also available as the HFBR-0319. The HFBR-0319 is a fully assembled test fixture. This test fixture adapts any fiber-optic transceiver with a 1x9 footprint to test equipment with -5 V ECL inputs and outputs. The HFBR-0527 and the HFBR-0319 minimize the effort needed to design new products which use fiber-optic data links. The HFBR-0527 and the HFBR-0319 provide a high level of technical support. This high level of technical assistance drastically reduces the time needed to develop and market new products which utilize the fundamental advantages of optically isolated data communication.

Conclusion

The HFBR-15X7 and HFBR-25X6 components can be used with large core fibers and inexpensive optical connectors to build exceptionally low cost digital fiber-optic links. When these Versatile Link components are used with 1 mm plastic, or 200 μm HCS™ fibers, digital data links that are comparable with the cost of shielded twisted pair wire can easily be implemented. The HFBR-15X7 and HFBR-25X6 provide designers with a short haul data communication solution that costs the same as shielded twisted pair wire, but this low cost fiber-optic solution has none of the grounding and electromagnetic compatibility problems inherent in metallic cables.

Table 1. Parts List for Circuit Shown in Figure 8.

Designator	Part Type	Description	Footprint	Material	Part Number	Quantity	Vendor 1
C1	0.001	Capacitor	805	NPO/COG	C0805NPO500102JNE	3	Venkel
C4	0.001	Capacitor					
C7	0.001	Capacitor					
C10	0.1	Capacitor	805	X7R or better	C0805X7R500104KNE	12	Venkel
C11	0.1	Capacitor					
C12	0.1	Capacitor					
C13	0.1	Capacitor					
C15	0.1	Capacitor					
C16	0.1	Capacitor					
C17	0.1	Capacitor					
C18	0.1	Capacitor					
C19	0.1	Capacitor					
C2	0.1	Capacitor					
C3	0.1	Capacitor					
C6	0.1	Capacitor					
C9	0.47	Capacitor	1812	X7R or better	C1812X7R500474KNE	1	Venkel
C14	10	Capacitor	B	Tantalum, 10v	TA016TCM106KBN	3	Venkel
C20	10	Capacitor					
C5	10	Capacitor					
C8 1mm Plastic	43 pF	Capacitor	805	NPO/COG	C0805COG500470JNE	1	Venkel
C8 200HCS	120 pF	Capacitor	805	NPO/COG	C0805COG500121JNE	1	Venkel
U4	MC10H116FN	IC, ECL line receiver	PLCC20		MC10H116FN	1	Motorola
U5	TL431CD	IC, Voltage Regulator	SO-8		TL431CD	1	T.I.
L1	CB70-1812	Inductor	1812		HF30ACB453215	1	TDK
R12	4.7	Resistor	805	5%	CR080510W4R7JT	2	Venkel
R13	4.7	Resistor					
R20	12	Resistor	805	5%	CR080510W120JT	1	Venkel
R10	15	Resistor	805	5%	CR080510W150JT	1	Venkel
R5	22	Resistor	805	5%	CR080510W220JT	1	Venkel
R16	51	Resistor	805	5%	CR080510W510JT	4	Venkel
R17	51	Resistor					
R18	51	Resistor					
R19	51	Resistor					
R21	62	Resistor	805	5%	CR080510W620JT	1	Venkel
R8 1mm Plastic	301	Resistor	805	1%	CR080510W3010FT	2	Venkel
R9 1mm Plastic	301	Resistor					
R8 200HCS	82.5	Resistor	805	1%	CR080510W82R5FT	2	Venkel
R9 200HCS	82.5	Resistor					
R6	91	Resistor	805	5%	CR080510W910JT	2	Venkel
R7	91	Resistor					
R11 1mm Plastic	1K	Resistor	805	1%	CR080510W1001FT	1	Venkel
R11 200HCS	475	Resistor	805	1%	CR080510W4750FT	1	Venkel
R14	1K	Resistor	805	5%	CR080510W102JT	6	Venkel
R15	1K	Resistor					
R22	1K	Resistor					
R23	1K	Resistor					
R24	1K	Resistor					
R25	1K	Resistor					
Q1	BFT92	Transistor	SOT-23		BFT92	2	Philips
Q2	BFT92	Transistor					
Q3	MMBT3904LT1	Transistor	SOT-23		MMBT3904LT1	1	Motorola
U1	74ACTQ00	IC			74ACTQ00	1	National
U2	HFBR-1527	Transmitter			HFBR-1527	1	HP
U3	HFBR-2526	Receiver			HFBR-2526	1	HP

HEWLETT PACKARD

DC to 10 MBd Versatile Link with Plastic Optical Fiber or Hard Clad Silica Fiber (HCS®) for Factory Automation and Industrial Control Applications

Application Note 1080

Contents

HCS® is a registered trademark of SpecTran Corporation

I. Introduction

This application note discusses the functions and features of the **New 10 MBd HFBR-0508 Fiber Optic Versatile Link**, which is designed for a variety of industrial applications. These include serial data interfaces in robots, machine tools, assembly and printing machines, and gate-drive circuits in frequency inverters. Circuit design hints and other subjects not found in the product data sheet will also be presented. The reader can use this information to design reliable fiber-optic links based on plastic optical fibers (POF) for distances below 50 m and hard clad silica (HCS®) fibers for distances up to 500 m.

Further information about fiber-optic link design can be found in Application Briefs AB 73 and AB 78, and Application Notes AN 1035 and AN 1066, which are listed in appendix VII. Hewlett-Packard applications engineers or your local certified distribution application engineers are available for further design assistance.

1. Interconnects without Crosstalk

Fiber-optic technology is completely changing data communications, particularly in industrial environments, where data must be transferred between machines more quickly than ever before. HP believes that fiber optics is replacing copper cabling in many of these applications because of the wide range of advantages inherent to fiber cable. Glass and plastic fibers, being dielectric materials, are completely immune to stray electromagnetic fields, which are common in industrial applications that use motors and power switches. These fibers can be placed in a duct alongside high-voltage metal cables without being susceptible to crosstalk. This feature simplifies system installation. Twisted-pair copper cables require a minimum distance from power lines to guarantee error-free data transfer.

2. International EMC Regulations

Due to increasingly stricter international control over electromagnetic compatibility of electronic equipment, manufacturers often cannot legally sell their products in many countries unless specific immunity and emission limits are met. These limits are based on standards such as FCC, VCCI, EN, CISPR, IEC, VDE, and so forth. For example, beginning January 1, 1996, all equipment and systems that will be sold into the European Union have to meet European EMC standards, otherwise they can be excluded from the market. The generic standards for the industrial field are EN 50081-2 (emission) and EN 50082-2 (immunity). In many applications design engineers do not have a cost-effective alternative to fiber optics if their systems must meet the national or international regulations for electromagnetic compatibility.

3. Fiber Optic Connectors vs. Electrical Connectors

In the past, many design engineers were reluctant to design with fiber optics. Terminating fiber cable was more time consuming than connecting twisted-pair wire because fibers required epoxy and their ends needed to be polished. Large-core polymer optical fiber [POF] and the new crimp and cleave technology for the Versatile Link Snap-in connector (V-System) allow fiber optic cables to be terminated more easily than shielded twisted-pair cables, while offering an electromagnetic-compatible communication link. This is a very strong reason for using fiber optic cables, a reason that the installation and service divisions of a company should also accept.

4. Galvanic Insulation

Ground-loop currents due to different ground potentials are a common problem in industrial communication networks. Ground loops and their associated noise problems are totally eliminated by the insulation characteristics of fiber, allowing a straightforward and fast system integration. In addition, the insulating property of glass and plastic fibers is ideal for many monitor and control functions needed in high-voltage applications. For intrinsically safe applications, which are

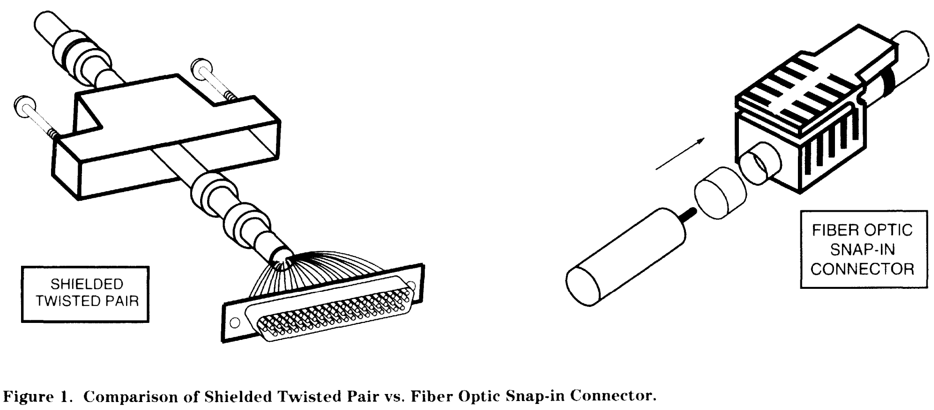


Figure 1. Comparison of Shielded Twisted Pair vs. Fiber Optic Snap-in Connector.

common in the chemical industry, fiber optics is easy to qualify and is also the best medium for connecting one electrical device to another through an isolation barrier.

II. Product Description

1. Housing and optical port
The Versatile Link family has been used successfully in many different industrial applications based on plastic fibers. Users have the benefit of a reliable system that is easy to install in the field. The compact package is made of a flame retardant (UL V-0) material in a standard, six-pin DIP. Transmitters or receivers can be stacked together, creating duplex optical ports that save printed circuit board space and avoid fault connections. The conductive housing of the HFBR-2528 receiver provides an excellent EMI shield. The color-coded packages eliminate confusion between transmitters and receivers. A plug protects the optical port during auto-insertion and soldering.

The Versatile Link package uses an active alignment system to ensure proper coupling between the fiber and the optoelectronic converter. Figure 3 illustrates how the alignment system operates. The precision-molded lens on the insert is located at the bottom of a depression in the shape of a truncated cone. The connector is inserted into the package; the jaws of the housing force the bevelled end of the connector into the cone-shaped depression. This accurately centers the fiber directly above the molded lens on the insert and ensures efficient, reliable and repeatable connections.

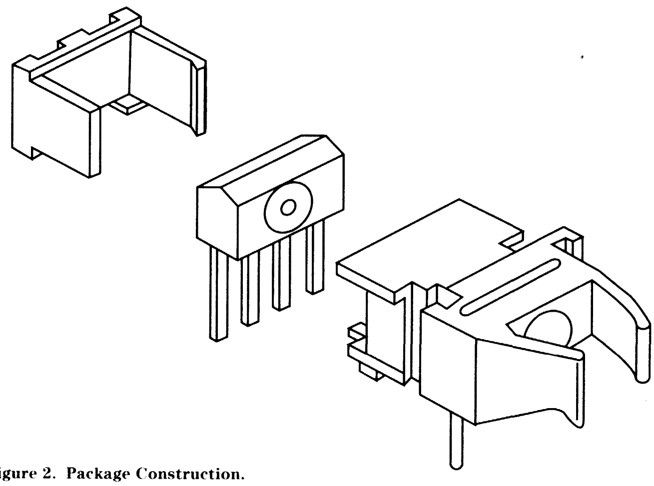


Figure 2. Package Construction.

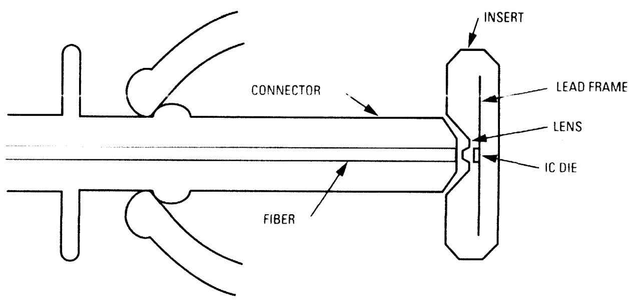


Figure 3. Connector Alignment to Transmitter LED or Receiver IC.

2. Transmitter Technology
The new HFBR-1528 transmitter uses a high quantum efficiency LED based on a new HP AlInGaP technology. At a 60 mA drive current, the coupled power into a 1 mm POF is typically -3 dBm, a 6 dB improvement over previously used transmitters. With a center wavelength of 650 nm at room temperature, the transmitter is in the minimum attenuation window of the POF. Typical link distances of 100 m with low-cost plastic fibers are now a reality. When using the

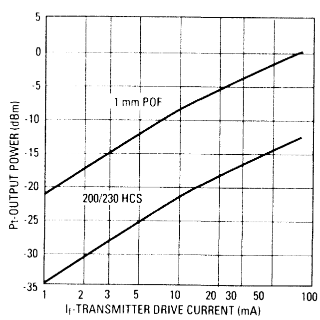


Figure 4. Typical Transmitter Output Power vs. Drive Current.

200 µm HCS fiber link, 500 m distances are possible. In addition to the higher coupled power, the optical rise and fall times have become much faster, allowing much simpler LED drive circuits without the need for peaking and pre-biasing for data rates of 10 MBd.

3. Receiver Technology

The new HFBR-2528 receiver with its TTL/CMOS-compatible output is specified for data rates from dc to 10 MBd NRZ (non-return to zero). It has a sensitivity of -21 dBm peak with 1 mm POF, or a sensitivity of -23 dBm peak with 200 HCS® fiber. Propagation delay times t_{PLH} (output low to high) and t_{PHL} (output high to low) are equally distributed to achieve pulse-width distortion (PWD) of less than ±30 ns over a large input power range. As a result, LED drive current adjustments for different link lengths and fiber types are unnecessary.

A patented first-bit PWD correction circuit makes the HFBR-2528 the ideal product for arbitrary duty-cycle links or for the use in frequency inverters such as gate-drive applications. Other products on the market with similar optical and electrical specifications require the transmission of overhead bits prior to the data because of heavily distorted first bits. Therefore, the user has to add additional circuitry to transmit a preamble prior to the data bits, making the transmit and receive circuit more complex and costly. For better electromagnetic compatability, a conductive housing material has been chosen for shielding the receiver in electromagnetically polluted industrial environments.

4. Types of Fiber Optic Cables

Historically, glass fibers have been used in long-haul telecommunication links and local-area networks because of low attenuation and large bandwidth. Ethernet and FDDI (Fiber Distributed Data Inter-face) standards, for example, have specified multimode 62.5/125 µm glass fibers. These small-core fibers need high-precision connectors to minimize the coupling loss. For industrial application, fibers with lower-cost connectors, which are easier to install and less sensitive to dirty environments, are required. For these applications, 1 mm POF (Polymer Optical Fibers) and 200 µm HCS (Hard Clad Silica) fibers are the best media.

While there are many types of fiber-optic cables (a cable is composed of a fiber and a jacket), only two types, 1 mm POF and 200 HCS, are specified for use with Versatile Link POF and HCS Snap-In Connectors. These step-index fibers are made from silica (HCS) or a polymer (POF) in which the core has a higher refractive index than the cladding. A 2.2 mm jacket around the fiber protects against mechanical or thermal damage and increases the strength of the cable.

4.1. Polymer Optical Fiber (POF)

The large-core diameter (980/1000 µm) and numerical aperture of the POF (Polymer Optical Fiber) are well matched to the large effective diameter and numerical aperture of the optical ports, allowing the power launched into the core to be as high as 0 dBm with the HFBR-1528 transmitter. The POF also offers comparably low-cost termination, which can be done

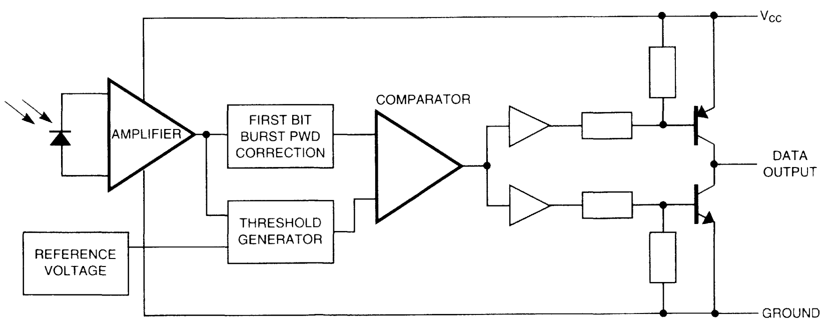
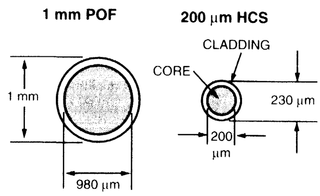


Figure 5. Receiver Block Diagram.



PARAMETER	POF 1 mm	HCS 200/230 μm
TENSION (60 min) TENSION (10 YEAR)	50N 1N	100N 25N
BEND RADIUS (1H)	25 mm	10 mm
FLEX	1,000 X	50,000 X
ATTENUATION (660 nm)	200 dB/km	6 dB/km
NA	0.47	0.37
INSTALLATION TEMPERATURE	-20°C TO +70°C	-20°C TO +85°C
FLAMMABILITY	VW1	RISER PLENUM LSZH

Figure 6. Polymer vs. Hard Clad Silica Cables.

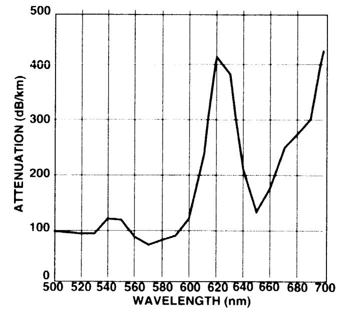


Figure 7. Attenuation vs. Wavelength for POF.

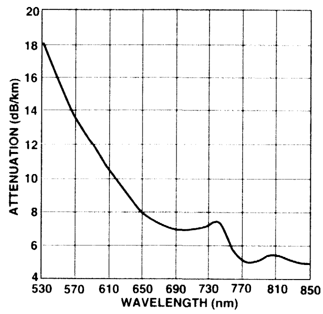


Figure 8. Typical Attenuation vs. Wavelength of HCS Fibers.

"in the field" in less than a minute using a simple and inexpensive crimping and cutting procedure. The attenuation minimum is at 650 nm and is typically about 0.2 dB/m. It should be noted that the spectrum of the new transmitter has a center wavelength at 650 nm at the minimum attenuation of the POF.

4.2. Hard Clad Silica Fiber (HCS)
Step-index silica fibers, such as PCS (Plastic Clad Silica) or HCS® (Hard Clad Silica) fibers with a large-core (200 μm diameter compared to glass fibers with 62.5 μm core diameter) permit the use of low-cost transmitter/receiver lensing systems. Because of the high attenuation in the visible red wavelength range, PCS fibers are commonly used in a lower attenuation window with higher-cost infrared LEDs. The fiber with the lowest attenuation in the visible red wavelength range is the HCS fiber. At 650 nm the attenuation is typically 8 dB/km.

The core of the HCS fiber is silica and the cladding is a proprietary hard polymer that also acts as a strength enhancer and makes it impervious to moisture and impurities. High temperature specifications for extended industrial temperature ranges, and UL ratings for plenum and riser applications are also available.

The snap-in V-System connectors can be crimped directly onto the HCS fiber because the proprietary hard cladding bonds to the silica core material, thus eliminating the need for messy epoxies. A patented cleaving tool cuts the excess fiber protruding from the connector end. Due to the simplicity of the termination process, the Versatile Link Snap-In connector can be mounted in less than 45 seconds.

III. Fiber Optic Link Design
The HFBR-0508 family is designed and characterized for data rates from dc to 10 MBd; Hewlett-Packard specifies link length for 1 mm POF fibers (0 to 60 m) and 200 μm HCS fibers (0 to 500 m). Power supply variations, connector coupling loss and temperature drift effects are part of the guaranteed data sheet specifications. In addition, a 3 dB margin takes aging into account. HP specifies the link performance using the transmitter and receiver interface circuits described in the product data sheet, which gives HP customers the maximum available design security. The following considerations will help the design engineer to become more familiar with low-cost, fiber-optic link design and gives guidelines to optimize the link performance for particular applications.

1. Link Length Considerations
A fiber-optic system basically consists of an LED, a length of fiber, and an optical detector. The LED transmitter, modulated by the electrical input signal, couples light into the fiber. The light travels along the fiber to an optical detector, which converts the light into an electrical signal again. The important specifications for fiber-optic links are how much light is coupled into the fiber, how much light the

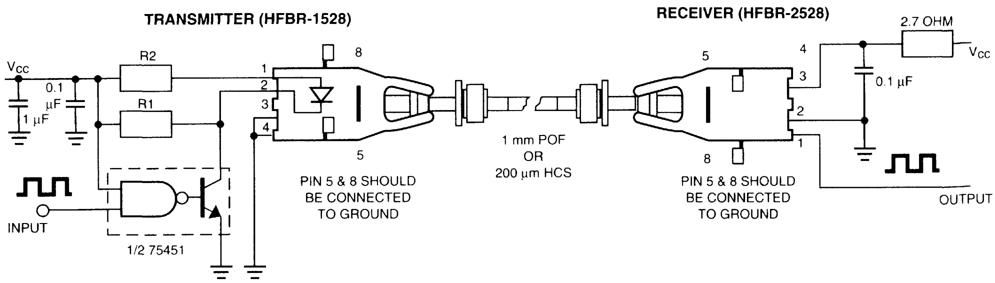


Figure 9. Versatile Link Set-Up.

receiver needs to function properly, and how much light is lost in the fiber between the transmitter and the receiver.

Depending upon the fiber length and wavelength of the signal source, if data rates are very high (125 MBd or greater), the optical signal is distorted. This effect, called dispersion[3], limits the bandwidth of the fiber-optic system. Fortunately, in most industrial communication systems the data rate is less than 10 MBd and the dispersion effect contributes only if the link length exceeds 100 m with POF or 1000 m with HCS Fibers. Below these values the links are limited by attenuation, so a straightforward optical power budget calculation is the only consideration.

1.1 Optical Power Budgeting Computation

The optical power budget is the difference between the output power of the transmitter and the sensitivity of the receiver. The maximum length of the optical fiber is determined by the attenuation of the fiber, additional losses due to feed-through connections and a "safety factor" called optical power margin (see

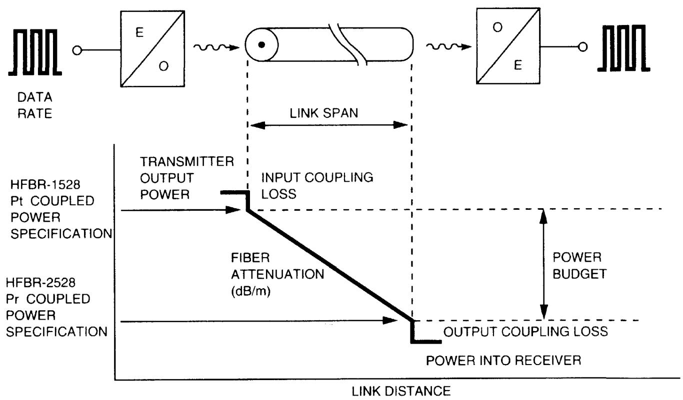


Figure 10. Fiber Optic Link Main Parameters.

chapter III/1.4). Formula III/1 gives the maximum link length for worst-case conditions:

Equation III/1:

$$l(\max) = \frac{P_T(min) - P_{RL,\,min} - IL - OPM}{\alpha(\max)} \quad (\mathrm{m})$$

$P_T(\min)$:	Minimum coupled power of transmitter (dBm)
$P_{RL,\,\min}$:	Sensitivity of the receiver (dBm)
IL:	Sum of insertion loss of feed-throughs (dB)
OPM :	Optical power margin, which accounts for LED degradation, supply voltage variation, etc. (dB)
$\alpha(\max)$:	Maximum attenuation of fiber (dB/m)

Versatile Link transmitter and receiver specifications account for coupling losses to and from 1 mm POF or 200 μm HCS fiber.

1.2. Dynamic Range

An important link design consideration is the receiver's optical dynamic range, the difference between sensitivity ($P_{RL,\,min}$) and overdrive conditions ($P_{RL,\,max}$) : in other words, the dynamic range specifies the minimum-to-maximum link length. Exceeding the dynamic range of the receiver may lead to an increase in PWD. The maximum allowed power level of the receiver specifies the minimum link length needed to avoid overdrive condition. The maximum optical power that the HFBR-1528 can launch, however, is well matched to the HFBR-2528 receiver's overdrive characteristics. If the LED drive circuit recommended in the HFBR-1528 data sheet is used, the transmitter cannot over-drive the HFBR-2528 receiver even when the length of the fiber-optic cable is virtually zero meters.

Equation III/2:

$$l(\min) = \frac{P_T(\max) - P_{RL,\,max}}{\alpha(\min)} \quad (\text{in m})$$

$P_T(\max)$: Maximum coupled power of transmitter (dBm)

$P_{RL,\,(max)}$: Maximum optical power level of receiver (dBm)

$\alpha(\min)$: Minimum attenuation of fiber (dB/m)

The extremely large dynamic range of the HFBR-2528 receiver typically allows room-temperature distances from 0 to 100 meters when using 1 mm plastic fibers. Typically, LED current adjustments are not needed as the length of the plastic fiber can vary from 0 to 100 meters at room temperature, and the maximum adjustment-free distances possible over the temperature range are specified in the HFBR-0508 series data sheet.

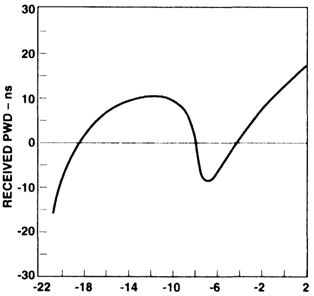


Figure 11. Typical Receiver Pulse-Width Distortion vs. Optical Input Power at 10 MBd.

1.3 Temperature Drift Considerations

The data sheet includes the transmitter output power range for ambient temperatures at $T_A = 25°C$, $T_A = 0$ to $+70°C$, and $T_A = -20°C$ to $+85°C$, in addition to the guaranteed link length specifications. But by knowing and understanding all different temperature drift effects that the link depends on, the design engineer will be able to optimize the link performance, particularly, the maximum fiber length.

The output power of the transmitter is inversely proportional to the junction temperature, resulting in a lower output power at high temperatures ($\Delta P_T/\Delta T$).

Equation III/3:

$$P_T\ (T) = P_T\ (25) - \frac{\Delta P_T}{\Delta T} \bullet (T - 25)$$

$P_T(T)$: Output power at desired temperature (dBm)

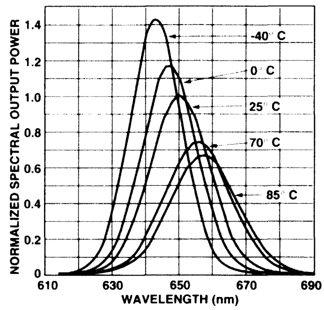


Figure 12. Typical Normalized Optical Spectra to Peak at 25°C.

$P_T(25)$: Output power at room temperature specified in the data sheet (dBm)

$\Delta P_T/\Delta T$: Output power temperature coefficient (dB/°C)

The forward voltage ($\Delta V_F/\Delta T$) of the LED will drop with an increase in temperature, causing an increase of drive current, which partially compensates for the decreasing output power.

Equation III/4:

$V_F(T)$: Forward Voltage at desired temperature (V)

$V_F(25)$: Forward Voltage at room temperature, specified in the data sheet (V)

$\Delta P_T/\Delta T$: Forward Voltage temperature coefficient ($\Delta V/\Delta°C$)

The center wavelength of the LED transmitter, typically 650 nm at room temperature, changes wavelength as the temperature changes. In the POF data sheet, attenuation is specified at 660 nm because of compatibility with the older type, lower output power 660 nm GaAsP transmitters. At room temperature the center wavelength of the new AlInGaP transmitter is exactly in the minimum attenuation window of the POF. Therefore, the optical power budget allows a longer link distance at 25°C than specified in the data sheet. Attenuation at 650 nm is about 0.05 dB/m less than at 660 nm, which permits a 65 m link . (Please see note 3 in the HFBR-0508 Series data sheet. [5])

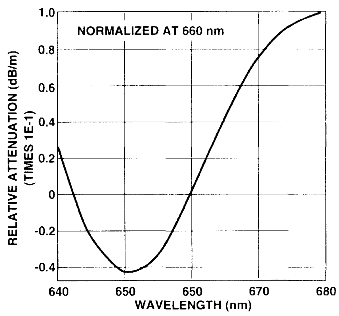


Figure 13. Typical Normalized Spectral Attenuation of 1 mm POF.

Because of the complexity of the receiver circuit IC, a detailed discussion about sensitivity temperature drift is beyond the scope of this application note. Drift effects are specified in the product data sheet and one should not be concerned about them.

1.4. Reliability Considerations

The service lifetime of the fiber-optic link is, however, quite often a concern. One can separate link reliability into transmitter, receiver, connector and fiber reliability. HCS fibers are known to be very stable under harsh ambient conditions and have been qualified for 30-year lifetimes. POFs are estimated for up to 20-year lifetimes. Short-term and long-term bend radius, tensile load, flexing, as well as the mechanical properties of the connectors are specified in the cable data sheet [8]. A detailed discussion about fiber [11,12] and connector [8] reliability is beyond the scope of this application note.

More of a concern is the useful lifetime of short-wavelength LED transmitters, which must be taken into account in power budget calculations. It can be assumed that the receiver sensitivity will not change over time. The transmitter light output reduction is a function of junction temperature, drive current, and endurance time. The useful lifetime of the LED transmitter is typically defined when the initial light output is reduced by 3 dB. Reliability tests of the HFBR-1528 transmitter project a median useful life of 9 years at -3dB, 85°C, 50 % duty cycle, and forward current equal to 60 mA. Therefore, the optical power budget must be decreased by the expected reduction in light output at the end-of-life specification. More detailed information can be found in the reliability data sheet [6].

Table III/1: Projected useful life for various temperatures, where end of life is defined as a 50% drop (-3dB) in light output.

I_F [mA] 50% DC	T_A [°C]	Median Useful Life [y]	90% Survival Life [y]
60	85	9	4
60	70	17	8
60	55	33	15
60	40	68	32

1.5. Connector Loss

Connector coupling losses at the transmitter and receiver are already included in the data sheet specifications. Connector coupling losses due to connections through bulkhead adapters need to be determined. The following table shows the minimum and maximum insertion loss specifications for HP's 1 mm POF bulkhead connections. As the number of bulkhead connections increases, the range of losses increases, as does the magnitude of the losses. Coupling loss characterization of special bulkhead connectors for the 200 µm HCS fiber was not completed when this application note was printed.

Table III/2. Feed Through Loss Specifications.

Part No.	Fiber Size	Min. Loss	Typ. Loss	Max. Loss
HFBR-45X5	1 mm POF	0.7 dB	1.5 dB	2.8 dB

1.6. Coupling Loss

If light from a larger-core fiber is coupled into a smaller-core fiber, a significant loss of optical power can be measured. The loss is a function of the difference in area (d) and the numerical aperture (NA), and is expressed by the following formula:

Equation III/5:

$$IL(dB) = 20 \bullet \log\frac{d1}{d2} + 20\bullet\log\frac{NA1}{NA2}$$

d1: Emitting fiber diameter
d2: Receiving fiber diameter
NA1: Numerical Aperture emitting fiber
NA2: Numerical Aperture receiving fiber

Light from a smaller core fiber will be coupled into a larger core fiber without area and NA losses.

2. Transmitter Drive Circuits

LED-based transmitters are easy and simple to drive because the current through the LED is proportional to the optical output power. The current can be amplitude modulated using only a switching transistor and a single resistor in series with the LED. Because of the simplicity of the drive circuit, the design engineer has many options to realize this function. As mentioned previously, the HFBR-0508 link performance is guaranteed when using the drive circuit in the data sheet (see also 2.2), as it meets most application requirements. The pros and cons of a few other approaches that will help design engineers to optimize their link performance for specific applications are discussed in the following section.

2.1. Pros and Cons of Parallel and Series Transmitter Drive Circuits

Basically, two methods exist for driving LEDs. One uses a series driver (Figure 9), the other is based on a parallel driving scheme (Figure 14). Series driving circuits consume only half the power but generate higher transient noise in the power supply line when the LED current is switching. The parallel driver uses a constant current from the power supply rail, thus minimizing power supply noise, which could couple into the receiver and degrade sensitivity. The parallel drive circuit also presents a very low impedance to the LED junction during turn off. This low impedance rapidly discharges the junction and quickly extinguishes the optical output of the LED.

One should keep in mind that the transmitter drive circuit

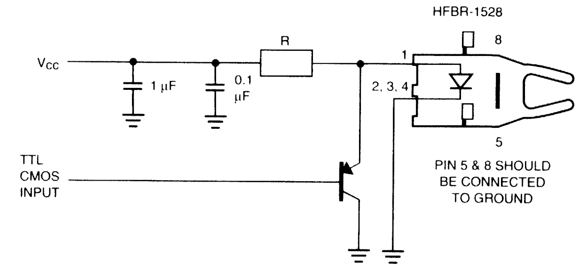


Figure 14. PNP Shunt Drive Circuit.

topology contributes to the overall pulse-width distortion (PWD) of the fiber optic link. Therefore, it is important that the optical rise and fall times are fast compared to the symbol time. The transmitter propagation delay times, t_{PLH} and t_{PHL}, should also be equally balanced for the PWD of the entire link to be low. Fortunately, the HFBR-1528 transmitter has rise and fall times that are fast enough to be switched without peaking and prebias[3] for data rates as high as 10 MBd. This keeps the drive circuit as simple as possible. Drive circuits for rise and fall times on the order of 3 ns are discussed in AN1066[3].

2.2. Series Driver Circuit using Standard TTL Buffer ICs

Data sheet Drive Circuit

The driver circuit, Figure 9, is designed in such a way that the LED is in series with the open-collector output of the driving gate. Resistor R2 sets the drive current through the LED, and resistor R1 provides a discharge path when the LED forward current is turned off.

Equation III/2:

$$R1 = \frac{V_{CC} - V_{CE} - V_F}{I_F}$$

The low-impedance path R1 quickly discharges the LED, decreasing the optical fall time. A 2 kOhm resistor was empirically found to be an optimum value for best PWD. It is important to note that capacitors C1 and C2 near the LED anode filter the noise in the power supply line during switching periods.

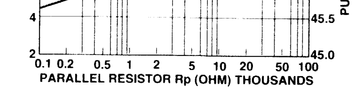


Figure 15: Typical Optical Switching Speed vs. Parallel Resistor R1.

Figure 16 shows how LED forward current deviates from the intended or nominal room temperature design value when using a series drive circuit, due to the following factors:

a. part-to-part variations in LED forward voltage,

b. current-limiting resistor tolerance,
c. power supply tolerance, and
d. variations in the Vce saturation potential of the 75451 peripheral driver.

Figure 16 also shows that as Vcc increases, the total variation in LED forward current, due to other circuit tolerances, is minimized.

The recommended LED driver shown in Figure 9 takes advantage of the negative temperature coefficient of the HFBR-1528 LED forward voltage. When temperature rises, the forward voltage of the LED decreases and a greater percentage of the supply potential must be dropped across resistor R2. As temperature increases and LED forward voltage declines, the potential difference across R2 increases and Ohm's law dictates that the current through R2 and the HFBR-1528 will increase. This increase in the drive current partially equalizes the reduced light output due to the negative output-power temperature coefficient.

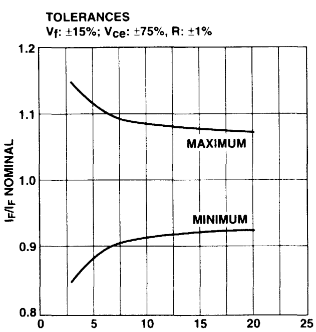


Figure 16. Output Power Variation vs. Supply Voltage and Components Tolerances.

The coupled power into 1 mm POF and 200 μm HCS is specified for minimum and maximum values versus the temperature range for 20 mA and 60 mA. Intermediate power levels can be calculated based on Figure 2 in the HFBR-1528 data sheet. At drive currents less than specified in the data sheet, the part-to-part variation of the output power increases.

2.3. The Simplest LED Transmitter Shunt Drive Circuit

The circuit shown in Figure 14 is a simple-shunt drive transmitter circuit that uses a pnp transistor. The primary feature is its simplicity: only two components are required and the circuit can be interfaced to TTL or CMOS gates without additional components. The circuit is also fast for several reasons:

- the transistor never saturates,
- it presents a very low impedance during turn off of the LED, and
- the emitter base junction voltage "prebiases" the LED junction resulting in a faster optical rise time

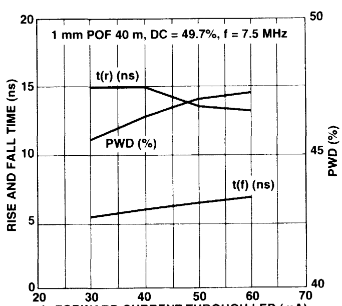


Figure 17. Switching Speed vs. Drive Current.

In addition, the pnp drive circuit generates low power-supply ripple because of the constant load during LED switching. The drawback is increased power consumption due to the constant current flow through the bias resistor.

3. Receiver Interface Circuit Design

The HFBR-2528 receiver has a push/pull digital output. It is capable of sourcing and sinking current as high as ±6 mA (receivers HFBR-25X1,2,3,4 need pull-up resistors) and can drive CMOS and TTL logic families without external resistors. HP recommends that an RC first-order, low-pass filter (see Figure 9) be used to minimize the power-supply noise between the ground and power supply terminals of the receiver. This arrangement will meet the power-supply rejection specification. The bypass capacitor should be connected as close as possible to the power supply terminals of the HFBR-2528 receiver. A ground plane underneath the conductive receiver housing and connected to pins 5 and 8 provides an excellent shield against electric fields as high as 8 kV/m, which could otherwise interfere with the receiver IC.

3.1. Sensitivity

DC-coupled receivers, such as the HFBR-2528, are specified for sensitivity at different conditions than ac-coupled receivers[3] in which the bit-error ratio (BER) is an important criterion. For the HFBR-2528, sensitivity is the minimum optical power level for a PWD of less than |30| ns, measured with a 50 percent duty cycle, square-wave signal.

3.2. Off-State-Limit
HP recommends that no light be coupled to the receiver when it should remain in the logic-high state. In some instances, it might not be possible to turn the transmitter totally off. But the power delivered to the receiver should be always less than -42 dBm for 1 mm POF or -44 dBm for 200 µm HCS fibers to ensure that the output does not randomly change state.

3.3. Overdrive Limit
The overdrive limit is specified where the PWD exceeds |30| ns. For example, at low temperatures, power levels can be above $P_{RL,max}$ > +1 dBm and PWD may exceed 30 ns, when using a driver circuit topology other than specified in the data sheet. The transmitter application circuit, recommended in the product data sheet, decreases the LED drive current at low temperatures because of the higher voltage drop across the LED transmitter.

IV. Manufacturing Consideration

1. Handling and Assembly Guidelines

Non-stacked Versatile Link parts do not require special handling during assembly onto printed circuit boards. HP advises, however, that normal static precautions be taken in handling and assembly of these components to prevent damage and/or degradation, which may be induced by electrostatic discharge (ESD).

HFBR-1528	Class 3
HFBR-2528	Class 1

ESD Human Body Model
Mil. Std. 883 Method 3015

All transmitters and receivers are delivered to customers in standard tubes for dual in-line packaged components and can be easily picked and placed with auto-insertion machines. During soldering, an optical port plug is recommended to prevent contamination of the port. Solderability is specified under Mil. Std. 883 Method 2003. Please follow the maximum time and temperature guidelines given in the product and reliability data sheet. Water-soluble fluxes, not rosin-based fluxes, are recommended.

2. Connectoring Guidelines

2.1. Plastic Fiber
Plastic optical cables can be terminated in less than 30 seconds by using Versatile Link Snap-in connectors and standard tools[27]. After cutting the cable to the desired length, 7 mm of the fiber jacket should be removed with a 16-gauge wire stripper. The crimp ring and connector are positioned then crimped over the end of the cable. Any excess fiber protruding from the connector end may be cut off. For better light coupling the fiber end must be polished by using 600-grit abrasive paper. See the detailed connecting instruction in the appendix of the fiber-optic cable data sheet [8].

2.2. 200 µm HCS Crimp and Cleave Termination
The 200 µm HCS fiber can be easily terminated by using the Snap-in V-System connector and the HFBR-4584 termination kit [28], which contains one fiber buffer strip tool, one cable strip tool, one pair of scissors and a diamond cleaving tool. The entire process does not need either epoxy or polishing and so can be completed in less than a minute. The following is an abstract from the detailed Crimp and Cleave Connectoring manual:

1. Remove cable jacket
2. Remove fiber buffer
3. Apply first crimp ring to fiber buffer
4. Crimp connector to jacket
5. Cleave the fiber end

2.3. Optical Port Protection
During equipment manufacture HP recommends using the optical port plug inserted into the transmitter and receiver when delivered to prevent contamination of the port. During the operational life of the communication equipment the port plug may be misplaced or lost. Therefore, a very simple "optical short circuit" between the transmitter and receiver can be constructed of a short length of 1 mm POF and a duplex connector (Figure 18). A small ring and chain can be fed through the cable opening and screwed to the front or back panel of the system so that the port plug can always be located.

Whenever the connector is inserted the station will receive its own signal and the function of the optical serial interface can be tested. In addition, a warning message telling the user that the serial port is not connected might be displayed on a system monitor.

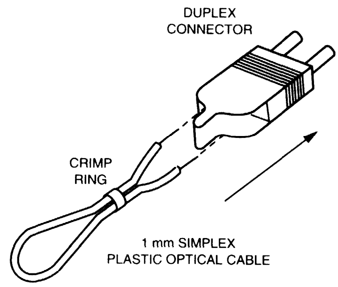


Figure 18. In use Optical Port Protection Connector.

V. Application Examples

1. Introduction to Industrial Communication Networks

Compared to 10 years ago, today's industrial control equipment has changed dramatically. No longer are many single twisted-paired lines from sensors and actuators bundled into one huge and heavy cable and connected to a programmable logic controller. Today, the intelligence is distributed in the network; the actuators and sensors are connected via a bus, star or ring topology to a master unit. Standards committees and user groups have defined serial data rates from several kBd to more than 2 MBd for twisted pair and fiber-optic media interfaces. But these open-system standards do not always meet the application requirements because of speed, noise immunity, and distance specifications. Proprietary networks for critical, real-time applications, for example, must have faster response times than today's standards are specified for. These applications need serial noiseless communication channels with data rates as high as 10 MBd to achieve the desired performance of the control system. At these conditions, it is worth considering the de-facto industry standard HFBR-0508, fiber-optic link for isolated and reliable optical interconnects.

1.1. Interface to RS 422 and RS 485

Many networks are based on an RS-485/422 physical media interface, which are based on a bus topology. Different ground potentials and noise sources may not allow a non-isolated bus structure. Therefore, active star couplers with fiber-optic ports are preferred. Quite often, a mixed topology consisting of fiber cable and twisted-pair wire is desired. In this case, the Versatile Link family is the most cost-effective line of products for fiber-optic inter-repeater links. The Versatile Link's small package allows HP's parts to be assembled into an adapter housing for an electrical-optical converter. One side of the housing holds the electrical subminiture connector to interface with the twisted-pair bus, the opposite side has the duplex, snap-in, fiber-optic connection. Standard "off-the-shelf" line drivers and receivers for RS- 422 and RS-485 [15,16,20] interface between the twisted-pair bus and the TTL receiver output and transmitter input.

While the majority of industrial communication applications are specified for data rates of 2 MBd and below (much lower than the speed of the HFBR-0508 link), the large dynamic range of the HFBR-2528 receiver allows a fiber-optic link to be designed without transmitter optical output power adjustment. This factor makes the installation instruction much simpler and avoids trouble-shooting exercises due to receiver overdrive conditions. Whether the link is anywhere from zero meters up to the maximum length specified in the data sheet or whether the fiber is HCS or POF, the link will work reliably the moment that the power is turned on.

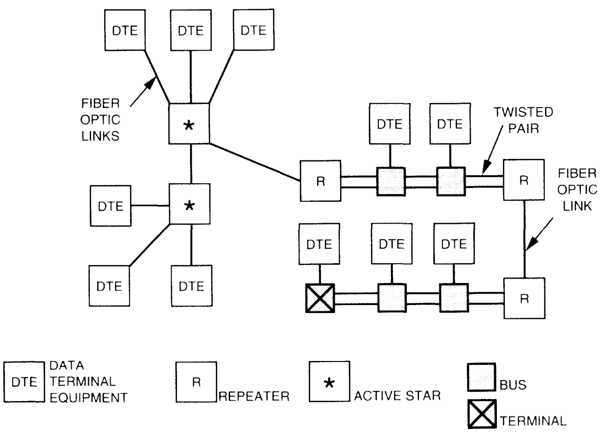


Figure 19. Network Overview with RS 485 TP Bus and Fiber Optic Active Star

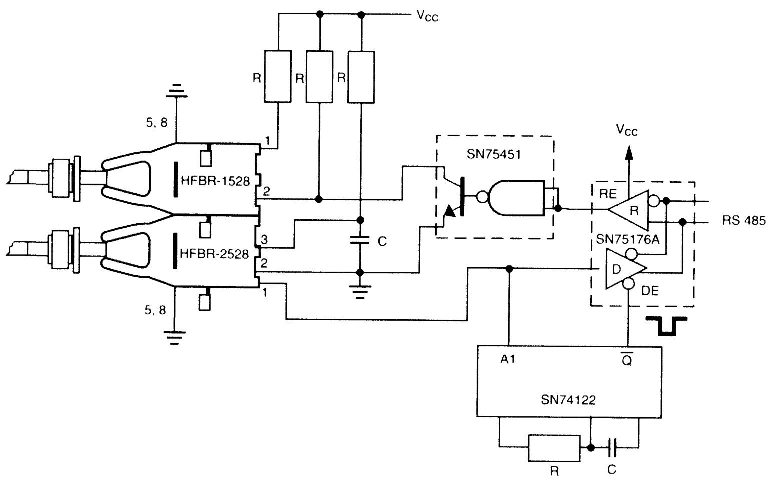


Figure 20. Basic RS 485 Fiber Optic Interface Adapter to Data Terminal.

Table V/1. Link Length Overview of HFBR-0508 for POF and HCS Fibers.

Fiber Type	Guaranteed Link Distance	Temperature Range	Conditions
1 mm POF	0.1 to 50 m 0.1 to 40 m 0.1 to 30 m	T_A = 25°C 0°C< T_A<+70°C -20°C< T_A<+85°C	I_F = 60 mA, 10 MBd
200 HCS	0.1 to 500 m 0.1 to 300 m 0.1 to 100 m	T_A = 25°C 0°C< T_A<+70°C -20°C< T_A<+85°C	I_F = 60 mA, 10 MBd

For more details please see product data sheet!

1.2. Controller Area Network (CAN)

A special controller-area network (CAN), which meets the stringent reliability requirements of automobile manufacturers, has been developed for low-cost, real-time applications in cars. CAN can be found in field buses because of its open-system interface and high noise immunity. Semiconductor manufacturers [18,19,21] offer integrated circuits for ISO layer 1 (Physical) and 2 (Data Link). When using fiber optics the best network configuration is a passive star coupler. The passive star coupler [23, 24, 25 ,29] divides the optical signal from one source into multiple optical signals of nearly equal amplitude. Therefore, all devices connected to the coupler receive the transmitted data at the same time.

In the past, the high insertion loss of the passive star couplers for 1 mm POF (see Table V/2) reduced the optical power budget to nearly 0 dB, making the use of fiber optics impossible. The new transmitter technology, with 6 dB-higher output power, allows expanded networks based on passive star couplers. Because the coding is NRZ, a dc-coupled receiver with TTL output should be used. Design engineers have two choices for the receiver interface. For data rates of 125 kBit/s

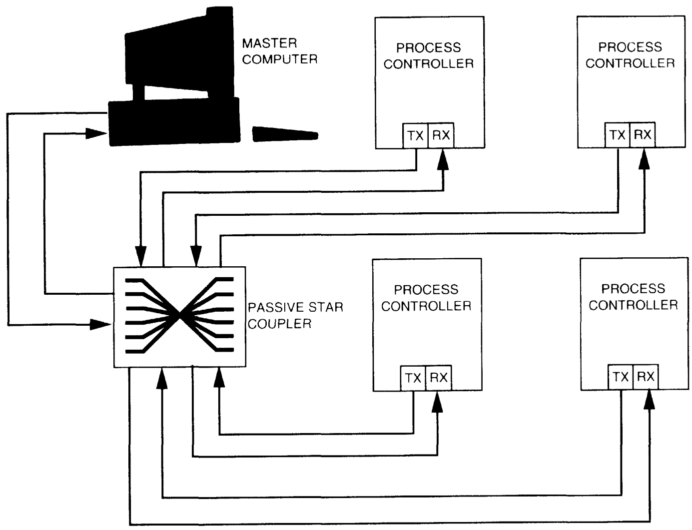


Figure 21. CAN with Passive Star Coupler.

(ISO/DIS 11519-1), they can use the HFBR-25X2 receiver. If the serial bit rate is 1 MBit/s (ISO/ DIS 11898), they should consider the HFBR-2528 receiver because of its lower pulse-width distortion (PWD) specification and large dynamic range. The large dynamic range will compensate for the spread of insertion loss by the coupler.

Table V/2: Typical Insertion Loss at 660 nm for 1 mm POF Star coupler.

Ports	Insertion Loss
2•2	4 dB
3•3	7 dB
4•4	7 dB
5•5	10 dB
7•7	11 dB

For detailed specifications, please contact suppliers [23 ,24, 25].

The following equation (V/2) should be used to calculate the maximum possible link length.

The maximum link length is the sum of the distance from the transmitter to the bulkhead connector and from the bulkhead connector to the receiver.

Equation V/2:

$$l = \frac{P_T(\min) - P_{RL,\,min} - IL(\max) - OPM}{\alpha(max)}$$

- $P_T(\min)$: Minimum coupled power of transmitter in (dBm)
- $P_{RL,\,(\min)}$: Sensitivity of the receiver [coupled power] (dBm)
- IL: Insertion loss measured from input port to output port (dB) of the passive star coupler
- OPM: Optical power margin in (dB)
- $\alpha(\max)$: Maximum attenuation of fiber in (dB/m)

The maximum data rate is also a function of the maximum distance between two nodes, because the propagation delay time must be less than half the bit time. The propagation delay constant for optical signals is 4.8 ns/m in fiber-optic links because the signal speed is equal to the speed of light divided by the refractive index. The propagation delay of the transmitter and receiver are listed in Table V/3. Transmitter and receiver delays must be added to the propagation delay of the fiber to determine the total delay of the fiber-optic link.

2. Gate Driving Using Fiber-Optic Interfaces

With the improvements in the development of power switches such as GTOs and IGBTs, frequency inverters can be operated at higher speed and higher power levels. On one hand, the circuit needed to drive the gates of IGBTs and GTOs has to be fast.

On the other hand, the gate-drives must reliably reject the higher and faster switching transient voltages caused by the large variations in current in the power rails.

Traditional techniques based on transformers for galvanic isolation and shielded cables require very experienced engineers to design a "trouble free" interface. Even so, minimum distance requirements between the signal lines and power units and good ground contacts can make the system larger and more costly than it would be if the features inherent to fiber optics are taken advantage of. In these applications, transformers will become redundant because of the dielectric property of the fiber and the fact that it will easily meet any regulatory requirements of IEC, UL, CSA, CENELEC, VDE, etc. In addition, the fiber is immune to any kind of electromagnetic fields and can be placed alongside power lines without affecting the transmission quality. The result is a simplified design with higher reliability and less sensitivity to system failures during installation and maintenance.

The following aspects should be considered when taking advantage of the many features the new Versatile Link offers for gate-drive applications. These include shielded housing, high-temperature HCS fiber, low PWD, and the fact that the receiver can accept arbitrary duty-cycle. HP recommends one of the transmitter drive circuits from chapter III because the switching speed is a major design issue. Because the link distance is very short in such applications, the drive current can be set to a value as low as 20 mA. The output power at 20 mA is specified in the data sheet and the power budget calculation from chapter III should be followed. The receiver and its conductive housing should be grounded and a good power-supply filter should be used because the isolated power supply is known to be very noisy.

The dead-time specification is one of the most important design parameters. A worst-case propagation delay from the controller to the gate of the power switch has to be computed. For the fiber-optic link, the overall propagation delay time is the sum of transmitter, receiver and fiber delay times. Typical fiber optic link delay times are listed in Table V/3. The PWD is specified in the HFBR-2528 data sheet. Since the speed of light is limited to about 2.99E-8 m/s in a vacuum, photons will travel at a lower speed in dense media such as glass or plastic fibers.

Equation V/2.

$$vp = \frac{c}{n} \quad \text{in m/s}$$

c: Speed of light in vacuum c = 2.99E-8 m/s
n: Refractive index of the media n =1.5 for PMMA

Table V/3: Typical Propagation Delay Times at 25°C for HFBR-0508 Link with 1m POF

Parameters	Tx(in) to Rx(out) with 1 mm POF	Units
tp LH	140	ns
tp HL	158	ns

To avoid fault connections, which can cause shoot-through conditions in a half bridge, HP recommends that the transmitters for a single half bridge be latched in pairs. Duplex connectors have a key function and will fit into the latched pair in only one position. Therefore, human error, such as mixing the cables, can cause only a fail function and will not destroy the power switches.

VI. Introduction to Optical Power and Loss Measurements

The theoretical methods used to specify optical parameters were discussed in chapter III. Theoretical values must be verified, however, not only by empirical functional tests but also by optical power and loss measurements. The relevant standard for loss measurements on cables and connectors is IEC 874-1. A detailed discussion of all the different methods described in the standard is beyond the scope of this application note. Only the most important methods will be briefly described. The recommendations in this application note for measurement equipment and accessories will help the newcomer to fiber optics, even one with financial constraints, to quickly implement a system.

1. Recommended Equipment and Accessories

The following items are needed: connectors, several meters of cable, transmitters and receivers, and tools to terminate the plastic or HCS cable. The lowest-cost approach is the POF termination kit [27]. For details, please see fiber-optic cable data sheet [8]. One of the Versatile Link transmitters can be used as an optical reference source. Power meters with a large-area Si detector, LED sources for 1 mm POF and 200 µm HCS, and adapter accessories are available from several manufacturers listed in the appendix [26].

1.1. Transmitter Output Measurement

A reference cable of 50 cm should be terminated with a carefully polished connector on each end. The cable is connected to the transmitter and the optical power meter. The coupled power into a 1 mm POF can be read in the display in power (mW) or reference power (dBm).

Equation VI/1:

$$P\ (dBm) = 10 \bullet \log \frac{P(mW)}{1mW}$$

P(mW): Power in mW
P(dBm): Power in decibels referenced to 1 mW

If the detector area is larger than the fiber's cross-sectional area, the coupling loss between connector and detector can be neglected. HP also recommends repeating the measurement with the connections reversed. A different power-level reading will indicate coupling loss variation.

It is also possible to measure the output power of a pulsed transmitter. A 50% duty-cycle pulse gives an average power-level (Pavg) reading. The actual peak amplitude (Ppk) is twice as high (3 dB in referenced power) as the average.

Example: Pavg = -21 dBm
Ppk = -18 dBm

1.2. Receiver Sensitivity Measurement

The transmitter and receiver are linked by a fiber-optic cable and pulsed with the desired data rate at a 50% duty cycle. An optical attenuator or different fiber length is used to lower the power at the receiver while monitoring the pulse-width distortion (PWD). Using a simple vise, one can also construct a gap attenuator by increasing the Z-axis spacing of the two fibers. When the PWD is 30 ns, the fiber is disconnected from the receiver and inserted into the optical power meter. The optical power meter shows the average received power. To calculate the receiver peak-power sensitivity, $P_{RL,min}$, add 3 dB to the reading.

1.3. Cable Attenuation Measurement

First the reference cable is connected to the transmitter and the power meter is set to zero (0 dB). Then the attenuation of the fiber being tested is measured. The power meter displays the incremental change in attenuation. This value is divided by the length of the fiber to calculate the optical loss per meter in dB/m. Typically, longer cables are measured; and so, the attenuation of the reference cable (about 0.1 dB to 0.2 dB) can be neglected. HP recommends repeating the measurement with the connections reversed. A different power reading will indicate coupling loss variation due to connector-port dimension tolerances and/or uneven polished fiber surfaces.

VII. Appendix

1. Literature Reference

[1] Application Bulletin 73; Low Cost Fiber Optic Transmitter and Receiver Interface Circuits
[2] Application Bulletin 78; Low Cost Fiber Optic Links for Digital Applications up to 155 MBd
[3] Application Note 1066; Fiber Optic Solutions for 125 MBd Communication Applications at Copper Wire Prices
[4] Application Note 1035; Versatile Link
[5] Data sheet HFBR-0508 Series; 10 MBd Versatile Link Fiber Optic Transmitter and Receiver for 1 mm POF and 200 µm HCS
[6] Reliability Data sheet HFBR-1527/8
[7] Reliability Data sheet HFBR-2528
[8] Data sheet; Plastic Optical Fiber and HCS Fiber Cable and Connectors for Versatile Link
[9] Fiber Optic Handbook, Hewlett-Packard, Christian Hentschel
[10] IEC 874-1
[11] POF Data book, MRC Techno Research
[12] High Strength, Reliable, Hard Clad Silica HCS® Fibers, Ensign-Bickford Industries
[13] Elektronik Plus, Automatisierungstechnik 1,
[14] EMV Störfestigkeitsprüfung, Fischer,Balzer,Lutz, Franzis Verlag

2. Supplier Reference

[15] Texas Instruments
[16] Motorola
[17] SGS Thomson
[18] Siemens
[19] Philips
[20] Maxim
[21] Intel
[22] Spectran
[23] Kabelwerke Rheinshagen GmbH
[24] MicroParts
[25] Nichimen
[26] a. RIFOCS "V-Kit Measurement Instruments" 557B Power Meter, 253B LED Source; b. Photodyne, Model 18XTA; c. Mitsubishi, Rayon, EMT 100-205
[27] Plastic Fiber Termination Accessories, HFBR -4593 Polishing Kit, HFBR-4597 Plastic Fiber Crimping Tool
[28] HCS Termination Kit, HFBR-4584

HEWLETT® PACKARD

Single-Mode Fiber-Optic Solutions for Ethernet LAN Applications

Application Note 1082

Introduction

Ethernet LAN traffic is easy to transmit through single-mode fiber-optic cables when using Hewlett-Packard's HFBR-1315 and HFBR-2315 1300 nm components. The HFBR-1315 and HFBR-2315 can be substituted into the circuits recommended in Application Note 1038 for Hewlett-Packard's 820 nm components. The long wavelength HFBR-2315 can be directly substituted for the short wavelength HFBR-24X6 in the receiver circuits shown in AN-1038. The long wavelength HFBR-1315 edge emitting LED (ELED) can directly replace the short wavelength HFBR-14X4 planar LED in the transmitter circuits shown in AN-1038.

Conversion from 820 nm Multimode to 1300 nm Single-Mode

The receiver circuits shown in AN-1038 require no modifications; simply replace the 820 nm HFBR-24X6 with the 1300 nm HFBR-2315. The transmitter circuits in AN-1038 could be used as shown, but a significant increase in transmitter performance can be achieved if some simple changes are made to a few passive components when the HFBR-1315 LED replaces the HFBR-14X4 LED.

Recommended Transmitter for Single-mode Fiber-Optic Ethernet Hub, Bridge, Router, and Repeater Applications

The HFBR-1315 LED should be operated at a higher maximum forward current than the HFBR-14X4. The optical power which the HFBR-1315 couples into 9/125 µm single-mode fiber is specified at $I_F = 100$ mA. By comparison, the HFBR-14X4 is usually operated at a forward current of 60 mA in Ethernet LAN applications. The transmitter circuit recommended for the HFBR-1315 is shown in Figure 1. Optical transmitter duty cycle distortion is minimized by a small prebias current which keeps the LED junction charged when the light is off. The prebias current provided by R9 is so small that extinction is typically ≤ -70 dBm. The rise and fall time of the LED is minimized by a frequency compensation network comprised of R7, R8, and C17. The transmitter shown in Figure 1 of this application note is very similar to an 820 nm transmitter circuit recommended in AN-1038.

Recommended Receiver for Single-mode Fiber-Optic Ethernet Hub, Bridge, Router, and Repeater Applications

The HFBR-2315 and HFBR-24X6 use the same trans-impedance amplifier with different PIN diodes suited for different optical wavelengths. The short wavelength HFBR-24X6 uses a silicon PIN diode detector, and the long wavelength HFBR-2315 uses an InGaAs photodetector. Figure 2 of this application note shows a long wavelength single-mode receiver which is virtually identical to the short wavelength multimode receiver shown in AN-1038. The high quantum efficiency of the 1300 nm PIN detector used in the HFBR-2315 improves receiver sensitivity. Receiver sensitivity typically improves by 3.9 dB, when the HFBR-2315 single-mode 1300 nm component is used in place of the HFBR-24X6 multimode 820 nm component.

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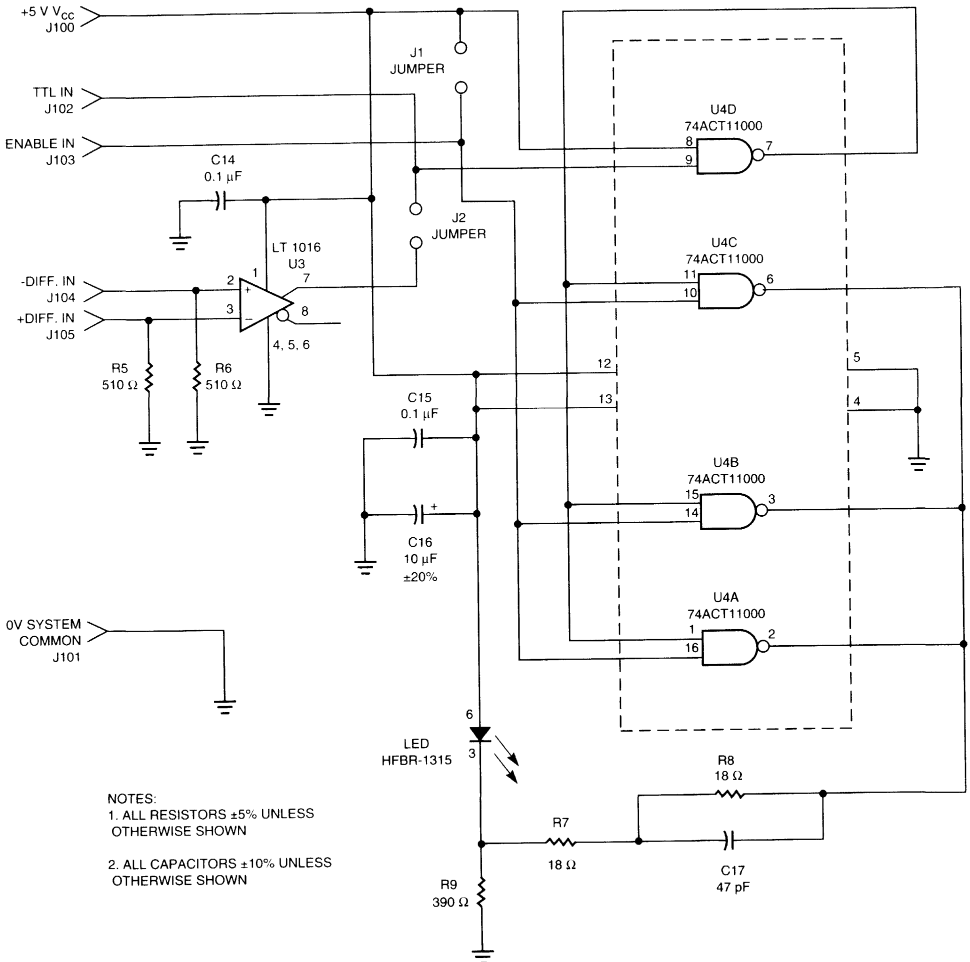


Figure 1. Voltage Source Transmitter for Hub, Bridge, Router, and Repeater Applications.

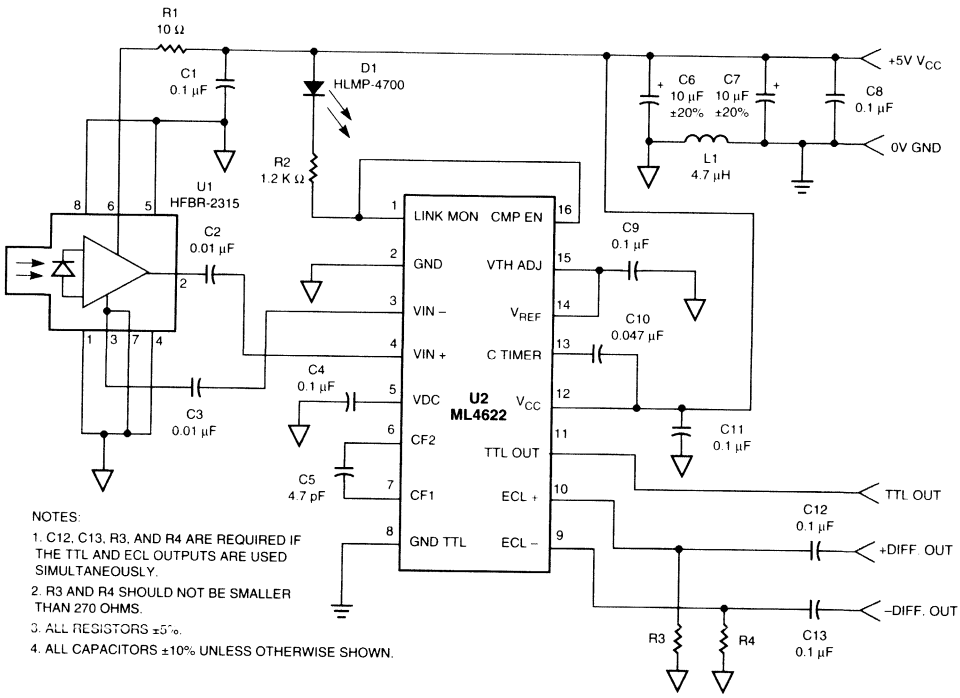


Figure 2. Receiver for Hub, Bridge, Router, and Repeater Applications.

The HFBR-2315 cannot be overdriven when a short fiber is connected between the transmitter and receiver, if the HFBR-1315 ELED is operated at an on state forward current ≤ 100 mA. If the HFBR-2315 is used with other ELED or LASER optical sources, excessive pulse width distortion can occur if the receiver is overdriven. To avoid pulse distortion, the maximum power applied to the HFBR-2315 should be ≤ -17 dBm average (-14 dBm peak).

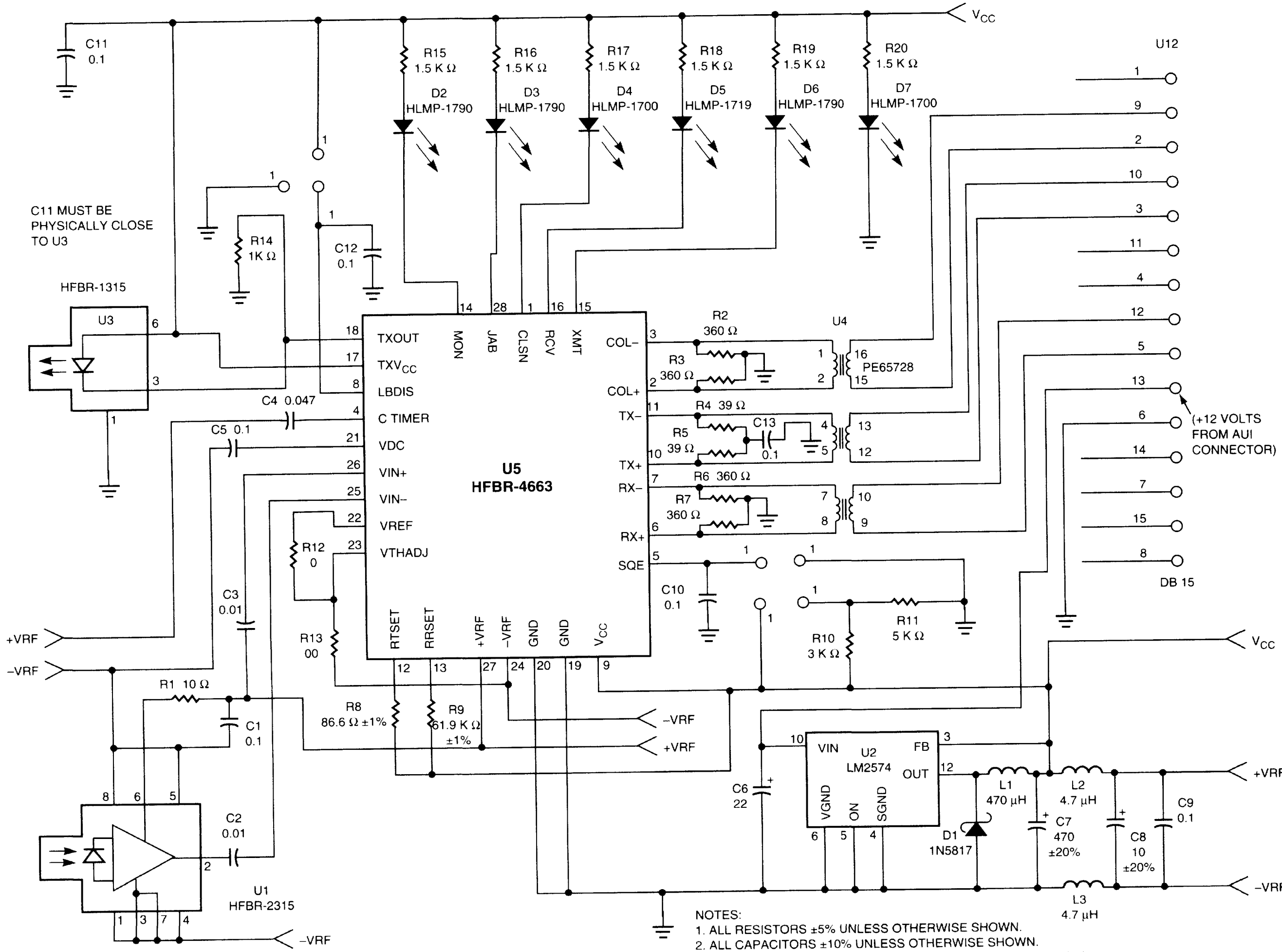
Recommended Circuit for Single-mode Fiber-Optic Ethernet MAU Applications

The recommended schematic for an Ethernet MAU that is compatible with single-mode optical fibers is shown in Figure 3. The only change recommended relative to the MAU shown in AN-1038 involves changing R8 from 100 Ω ±1% to 86.6 Ω ±1%. Reducing the value of R8 increases LED drive current from 60 mA to 69 mA. The equation which describes the LED current provided at TxOUT, pin 18, of the HFBR-4663 is:

$$I_{OUT} = \left[\frac{52\text{ mA}}{\text{RTSET}}\right](115\ \Omega)^{*}$$

When using the HFBR-4663 to drive the HFBR-1315, forward current should be set to 69 mA so that the absolute maximum rating of the LED driver integrated into the HFBR-4663 is not exceeded.

* The equation for LED current found on page 5-52 of the 1993 edition of the Hewlett-Packard Optoelectronics Designer's Catalog is in error and has been corrected in subsequent editions of the HFBR-4663 data sheet.



NOTES:
1. ALL RESISTORS ±5% UNLESS OTHERWISE SHOWN.
2. ALL CAPACITORS ±10% UNLESS OTHERWISE SHOWN.
3. THE HFBR-4663 DATA SHEET (PUBLICATION #5091-7391E 4/93) CONTAINS ERRORS THAT HAVE SUBSEQUENTLY BEEN CORRECTED IN THIS SCHEMATIC.
4. ALL CAPACITORS ARE IN µF.

Figure 3. Ethernet Fiber-Optic MAU Transceiver.

Recommended Printed Circuit Layout

The printed circuits recommended in AN-1038 require no changes when the long wavelength HFBR-1315 and HFBR-2315 components are substituted for the short wavelength HFBR-14X4 and HFBR-24X6 components.

The transmitter circuit for the HFBR-1315, and the receiver circuit for the HFBR-2315, are very similar to the circuits recommended in AN-1038, only the value of a few passive components in the transmitter need to be changed when 1300 nm single-mode components are used in place of the 820 nm multimode components. The HFBR-1315 and HFBR-2315 single-mode components have a footprint and pin assignment that are compatible with printed circuits that were originally designed for the HFBR-14X4 and HFBR-24X6 multimode components. This footprint and pin compatibility permit the printed circuit artwork shown in AN-1038 to be used with no changes, when HP's long wavelength single-mode components are used in place of HP's short wavelength multimode components.

Fiber-Optic Link Analysis

The fiber-optic transmitter shown in Figure 1 typically launches an average optical power of -24 dBm average into a 9/125 μm single-mode fiber-optic cable. The optical power variation over process and temperature specified on the HFBR-1315 data sheet is -30 dBm average minimum to -18 dBm average maximum. Receiver overdrive will not be a concern since the P_R maximum specification at which the HFBR-2315 begins to saturate is -14 dBm peak or -17 dBm average. The receiver sensitivity of the HFBR-2315 is typically better than -42 dBm average when used in the receiver shown in Figure 2. Worst case receiver sensitivity will be -39 dBm average as calculated from the R_P variation specified in the HFBR-2315 data sheet using equation (a) shown in the table below.

At a data rate of 20 MBd, the effects of the optical fiber's modal and chromatic dispersion are negligible, therefore the available optical power budget (OPB) is the difference between minimum launched power and minimum receiver sensitivity as calculated using equation (b) shown in the table below.

Accounting for Fiber Repairs and LED Aging

If another 1 dB is subtracted from the optical power budget to allow for 2 splices of the single-mode fiber and an additional 1 dB is allowed for LED aging or connector contamination, the OPB becomes 7 dB. See equation (c) below.

When using fiber with a maximum loss of 0.5 dB/km the worst case distance can be calculated as shown in equation (d) below.

The typical distance attainable with the solution recommended in this application note is in excess of 20 km.

Conclusion

The circuits shown in Hewlett-Packard Application Note 1038 can easily be converted for use with single-mode fibers. When the HFBR-1315 and HFBR-2315 long wavelength components are used as recommended in this application note, distances greater than 20 km are typically possible with commonly available 9/125 μm single-mode fibers.

Equations

$$P_R(\text{min}) = P_R(\text{typ}) + \Delta P_R = (-42\ \text{dBm avg}) + [10 \log (17/8.5)] \quad \textbf{(a)}$$
$$P_R(\text{min}) = (-42\ \text{dBm avg}) + 3\ \text{dB} = -39\ \text{dBm average}$$

$$\text{OPB} = P_T(\text{min}) - P_R(\text{min}) = (-30\ \text{dBm avg}) - (-39\ \text{dBm avg}) \quad \textbf{(b)}$$
$$\text{OPB} = 9\ \text{dB}$$

$$\text{Worst case OPB} = 9\ \text{dB} - 1\ \text{dB (2 splices)} - 1\text{dB LED aging} = 7\text{dB} \quad \textbf{(c)}$$

$$\text{Worst case distance} = \{\ [\text{Worst Case OPB}]\ (\text{dB})\}\ /\ [0.5\ (\text{dB/km})] \quad \textbf{(d)}$$
$$\text{Worst case distance} = (7\ \text{dB})\ /\ [0.5\ (\text{dB/km})\ ] = 14\ \text{km}^{**}$$

** The transmitter and receiver circuits shown in Figures 1 and 2 of this Application Note are capable of worst case distances up to 14 km. When the HFBR-4663 transceiver integrated circuit is used, the worst case distance is 11 km because the maximum ELED forward current that the HFBR-4663 can supply is 70 mA.

HEWLETT PACKARD

Inexpensive dc to 32 MBd Fiber-Optic Solutions for Industrial, Medical, Telecom, and Proprietary Data Communication Applications

Application Note 1121

Introduction

Low-cost fiber-optic data-communication links have been used to replace copper wire in numerous industrial, medical, and proprietary applications. The fiber-optic transmitter and receiver circuits in this publication address a wide range of applications. These recommended circuits are compatible with unencoded or burst-mode communication protocols originally developed for use with copper wire. Complete TTL-compatible digital transceiver solutions, including the schematic, printed circuit artwork, and material lists, are presented in this application note, so that users of this low-cost fiber-optic technology do not need to do any analog design. Designers are encouraged to imbed these complete fiber-optic solutions into their products, and various methods for electronically downloading the reference designs are described.

Why Use Optical Fibers?

Copper wire is an established technology that has been successfully used to transmit data in a wide range of industrial, medical and proprietary applications, but copper can be difficult or impossible to be used in numerous situations. By using differential line receivers, optocouplers, or transformers conventional copper wire cables can be used to transmit data in applications where the reference or ground potentials of two systems are different, but during and after the initial installation great care must still be taken not to corrupt the data with noise induced into the cable's metallic shields by adjacent power lines or differences in ground potential. Unlike copper wires, optical fibers do not require rigorous grounding rules to avoid ground loop interference, and fiber-optic cables do not need termination resistors to avoid reflections. Optical transceivers and cables can be designed into systems so that they survive lightning strikes that would normally damage metallic conductors or wire input/output (I/O) cards; in essence, fiber-optic data links are used in electrically noisy environments where copper wire fails.

In addition to all of these inherent advantages there are two other reasons why optical fibers are beginning to replace copper wires. The first reason is that optical connectors suited for field installation with minimal training and simple tools are now available. The second reason is that when using plastic optical fiber (POF), or hard clad silica (HCS) fiber, the total cost of the data communication link is roughly the same as when using copper wires.

Wire Communication Protocols and Optical Data Links

Many existing serial wire communication protocols were developed for differential line receivers or optocouplers that can sense the dc component of the data communication signal. This type of serial data is often called arbitrary duty factor data because it can remain in the logic "1" or logic "0" state for indefinite periods of time. Arbitrary duty factor data has an average value, which can instantaneously be anywhere between 0 percent and 100 percent of the binary signal's amplitude, or in other words, arbitrary duty factor data contains dc components.

Communication protocols that were developed specifically for use with copper wire often require an optical receiver that is dc coupled or capable of detecting if the data is changing from a high-to-low or low-to-high logic state. That is, the receiver needs to be an edge detector. At relatively modest data rates between zero and 10 Mbits/sec it is possible to construct dc coupled TTL-compatible fiber-optic receivers. The HP HFBR-2521 is a TTL-compatible, dc-to-5 Mbit/sec receiver, and the HFBR-2528 is a dc-to-10 Mbit/sec CMOS or TTL-compatible receiver. Additional information about dc-to-5 Mbit/sec applications can be found in Hewlett-Packard AN-1035, and applications support for dc-to-10 Mbit/sec applications can be obtained by reading AN-1080. This application note will focus on higher speed or higher performance arbitrary duty factor optical data communication links that work at higher data rates or greater distances than achievable with the HFBR-2521 or HFBR-2528 components. The optical transceivers shown in this application note can also be used in burst-mode applications where the data is transmitted in packets and there are no transitions between bursts of data.

The Pros and Cons of Arbitrary Duty Factor or Burst Mode Data

The most important advantage of any existing data communication protocol is that it already exists, and typically works reasonably well with copper wires in many applications. On the other hand, existing protocols for copper wire are usually not the best choice for optimizing the performance of a fiber-optic link. For example, a receiver designed for use with arbitrary duty factor data, or burst mode data, will typically be 4 dB to 7 dB less sensitive than when the same components are used in receiver circuits optimized for use with encoded data. Encoded data normally has a 50 percent duty factor, or restricted duty factor variation, which allows the construction of higher-sensitivity fiber-optic receivers. The best arbitrary duty factor or burst-mode receivers described in this application note are considerably less sensitive than the encoded data receivers described in AN-1122.

When sending arbitrary duty factor data, a separate optical link must be used to send the clock if synchronous serial communication is desired, or an asynchronous data communication system can be implemented if the data is oversampled by a local clock oscillator located at the receiving end of the fiber-optic data link. To avoid excessive pulse-width distortion (PWD), the local oscillator used to oversample the received data must operate at frequency that is greater than the serial data rate. For instance, if the data rate is 32 M bits/sec, a clock frequency of 100 MHz will assure three times oversampling of the received serial data. As the sampling rate decreases, the PWD of the reclocked data increases. Conversely, when the sampling rate is increased, the PWD of the asynchronous data link decreases. At modest data rates such as 32 Mbits/sec the frequency of the local clock oscillator will rise sharply if higher oversampling rates are attempted, for instance; to guarantee five times oversampling, the clock oscillator at the receiver would need to operate at a frequency slightly greater than 160 MHz. Refer to Figure 1 for a graphical representation of the relationship between the sampling rate and PWD of an asynchronous serial data communication link.

Burst-mode serial communication systems also have some interesting characteristics. They usually require more communication channel bandwidth, since the most common burst-mode protocols normally use a Manchester encoder, which transmits more than one symbol for each bit. Figure 2 shows how the communication channel's bandwidth must increase when the Manchester code normally used in Ethernet data communication systems is applied to unencoded serial data. The big advantage of encoding is that it merges the clock and data so that only one communication channel is needed for both signals. In most high-performance fiber-optic communication systems, the data and clock are merged onto a

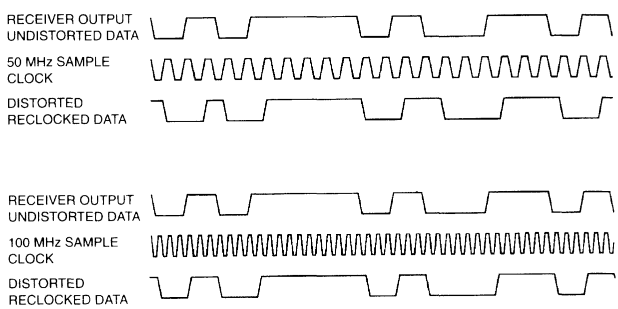
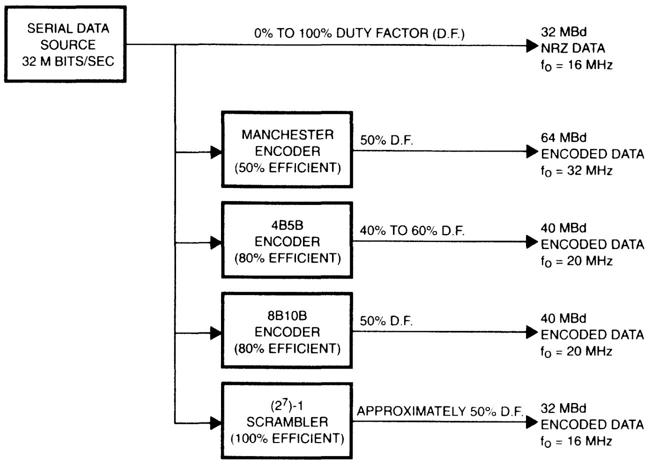


Figure 1. Relationship Between PWD and Sampling Rate



NOTE THAT f_O IS THE MAXIMUM FUNDAMENTAL FREQUENCY OF THE ENCODED DATA. THE MINIMUM FUNDAMENTAL FREQUENCY OF THE ENCODED DATA IS DETERMINED BY THE ENCODER'S RUN LIMIT.

Figure 2. Attributes of Encoding

single serial channel using a method that has better efficiency than Manchester encoding. Figure 2 shows several common encoding methods with better efficiency than Manchester code. Other important relationships between bits/second, and symbols/second, expressed in Baud (Bd) are explained by Figure 2. Note that arbitrary duty factor unencoded data is one of the few instances when data rate in bits/second, and the symbol rate in Bd are equal. Relationships between the signaling rate expressed in Baud and the fundamental frequency of digital data communication signals are also shown in Figure 2.

Burst-mode communication protocols are used in popular serial communication systems such as Ethernet, or Arcnet. Burst-mode protocols allow many network users to share a common pair of copper conductors with a tapped connection for each user network interface. The key disadvantages of this simple tapped line architecture is that only one user can send data at any time, and a preamble must be sent to wake up or initialize the receiving node's timing recovery circuit at the beginning of each packet of burst-mode data. Burst-mode, shared-wire communication links are not particularly fast, because no data can be transmitted during the preamble and each node must wait until the tapped line is quiet before data can be transmitted. Burst-mode protocols are not necessarily the best choice for optical communication links, because optical fibers are not easily and inexpensively tapped. When Ethernet traffic is sent via optical fibers, the wiring architecture is changed from a tapped serial transmission line to hubs that contain active fiber-optic transmitters and receivers. The active hubs are then connected to one another in a "star" configuration, because this star architecture is compatible with existing low-cost fiber-optic transceiver and cabling technologies. Fiber-optic receivers can be designed to accommodate burst-mode data, but it is much easier to build high-sensitivity fiber-optic receivers when data is sent continuously.

Continuous transmission also has other advantages. Continuous transmission increases the throughput of the LAN since there is no dead-time between packets of data. Throughput is substantially improved when data is continuously transmitted, because no time is wasted sending preambles of sufficient length to allow the receiver's timing-recovery circuit to acquire the phase lock required to synchronously detect each serial data packet.

It is interesting to note that the IEEE 802.3 10Base-FL standard for fiber-optic media uses a different transmission protocol than the 10Base-T standard for copper wire. The 10Base-T copper standard sends no transitions between packets of Ethernet data, but the 10Base-FL standard for optical fiber media inserts a 1 MHz square wave between each packet of Ethernet traffic. The 1 MHz idle signal described in the IEEE 802.3 10Base-FL standard assures that the burst-mode protocol used for copper wire Ethernet is converted to a protocol that will optimize the performance of a fiber-optic receiver.

More details about inexpensive fiber-optic solutions suitable for use with higher-efficiency block substitution codes, such as 4B5B, and 8B10B, can be found in HP Application Notes 1122 and 1123. This publication will stay focused on solutions compatible with unencoded data, because many system designers need a fiber-optic solution that can use protocols originally developed for use with copper wires.

Distances and Data Rates Achievable

The simple transceivers recommended in this application note can be used to address a very wide range of distances, data rates, and system cost targets. The maximum distances allowed with various types of optical fiber when using HP's wide range of fiber-optic transceiver components are shown Table 1. One simple calculation is needed to optimize the receiver for use at the desired maximum symbol rate of your system application. No transmitter or receiver adjustments are needed when using fiber cable length that vary from virtually zero length up to the maximum distances specified in Table 1.

Simple TTL Compatible LED Transmitter

A high-performance, low-cost TTL-compatible transmitter is shown in Figure 3. This transmitter recommendation is deceptively simple, but has been highly developed to deliver the best performance achievable with HP's LED transmitters. The recommended transmitter is also very inexpensive, because the 74ACTQ00 gate used to current modulate the LED can typically be obtained for under $0.40. No calculations are required to

Table 1

Transmitter Component Part # and Wavelength	Receiver Component Part # and Wavelength	Fiber Diameter Type	Maximum Distance at 32 MBd with the transceiver circuits recommended in this publication
HFBR-15X7 650 nm LED	HFBR-25X6 650 nm	1 mm plastic step index	27 meters with transmitter in Fig. 3 and receiver in Fig. 4
HFBR-15X7 650 nm LED	HFBR-25X6 650 nm	1 mm plastic step index	42 meters with transmitter in Fig. 3 and receiver in Fig. 5
HFBR-15X7 650 nm LED	HFBR-25X6 650 nm	200 µm HCS step index	690 meters with transmitter in Fig. 3 and receiver in Fig. 4
HFBR-15X7 650 nm LED	HFBR-25X6 650 nm	200 µm HCS step index	1.0 kilometer with transmitter in Fig. 3 and receiver in Fig. 5
HFBR-14X2 820 nm LED	HFBR-24X6 820 nm	200 µm HCS step index	690 meters with transmitter in Fig. 3 and receiver in Fig. 4
HFBR-14X2 820 nm LED	HFBR-24X6 820 nm	200 µm HCS step index	1.0 kilometer with transmitter in Fig. 3 and receiver in Fig. 5
HFBR-14X4 820 nm LED	HFBR-24X6 820 nm	62.5/125 µm multimode glass	800 meters with transmitter in Fig. 3 and receiver in Fig. 4
HFBR-14X4 820 nm LED	HFBR-24X6 820 nm	62.5/125 µm multimode glass	1.6 kilometers with transmitter in Fig. 3 and receiver in Fig. 5
HFBR-13X2 1300 nm LED	HFBR-23X6 1300 nm	62.5/125 µm multimode glass	1.3 kilometers with transmitter in Fig 3. and receiver in Fig. 4
HFBR-13X2 1300 nm LED	HFBR-23X6 1300 nm	62.5/125 µm multimode glass	3.3 kilometers with transmitter in Fig. 3 and receiver in Fig. 5
HFBR-1315 1300 nm ELED	HFBR-2315 1300 nm	9/126 µm single-mode glass	4.0 kilometers with transmitter in Fig. 3 and receiver in Fig. 5

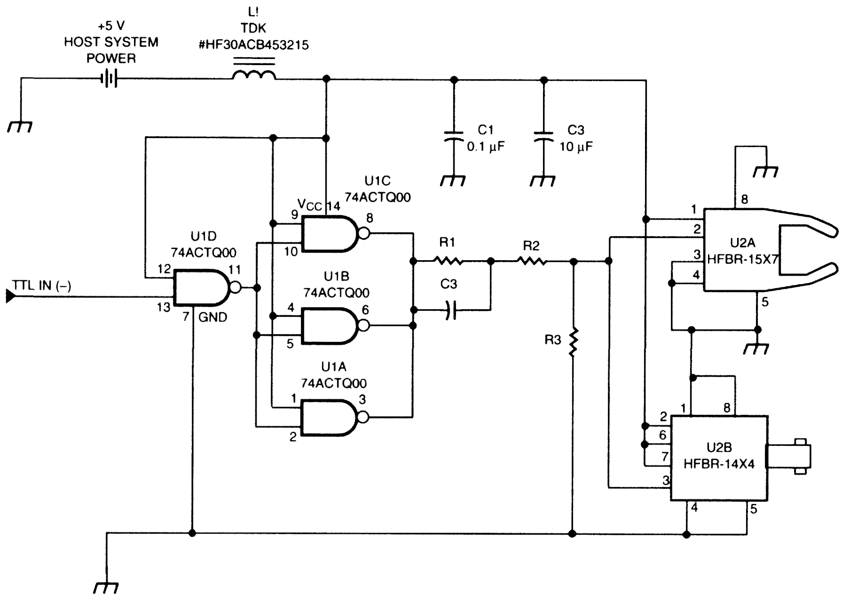


Figure 3. TTL-Compatible LED Transmitter

Table 2

Transmitter	HFBR-15X7 650 nm LED		HFBR-14X4 820 nm LED	HFBR-13X2T 1300 nm LED	HFBR-1315 1300 nm ELED
Fiber Type	1 mm Plastic	200 µm HCS	62.5/125 µm	62.5/125 µm	9/125 µm
R1	120 Ω	33 Ω	33 Ω	22 Ω	18 Ω
R2	120 Ω	33 Ω	33 Ω	27 Ω	18 Ω
R3	390 Ω	270 Ω	270 Ω	∞	390 Ω
C3	82 pF	470 pF	75 pF	150 pF	47 pF

determine the passive component needed when using various HP LEDs with a wide range of optical fibers. Simply use the recommended component values shown in Table 2, and the transmitter shown in Figure 3 can be used to address a broad range of applications.

Simple TTL Compatible Receiver

A very simple TTL-compatible receiver that has adequate sensitivity for a wide range of applications is shown in Figure 4. Equation 1 allows the designer to quickly determine the values of C6 and C7 so that the receiver is optimized for operation at any data rate up to a maximum of 32 MBd.

Enhanced TTL Compatible Receiver

The receiver circuit shown in Figure 5 is suitable for use in applications that require greater optical cable lengths. The receiver in Figure 5 provides 6 dB more receiver sensitivity than the simplified receiver shown in Figure 4. Equation 2 allows the designer to quickly determine the values of C9 and C10 so that the receiver is optimized for operation at any data rate up to a maximum of 32 MBd.

Printed Circuit Artwork

The performance of transceivers that use HP fiber-optic components are partially dependent on

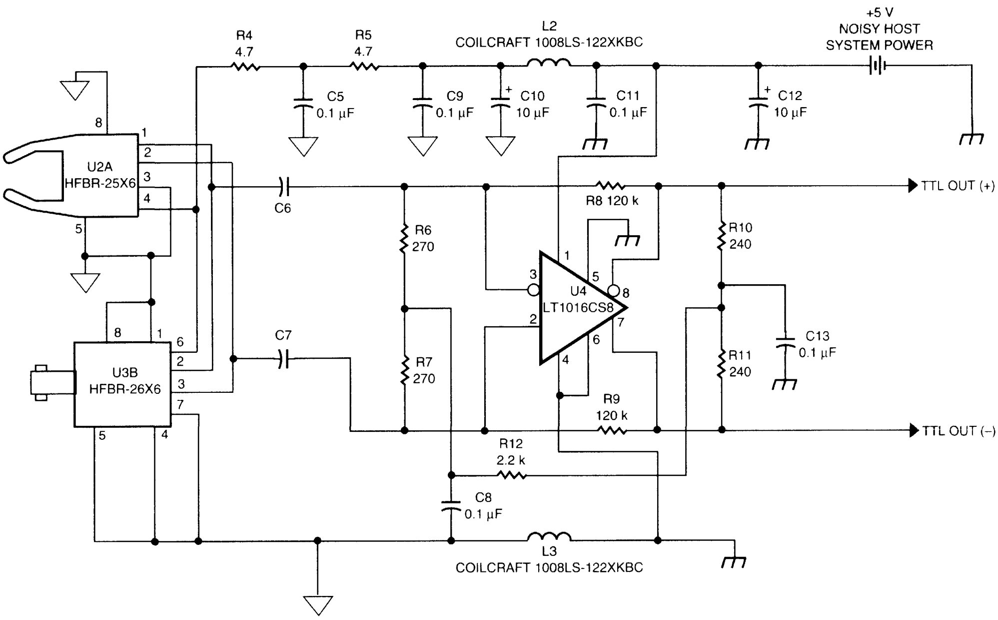


Figure 4. Simple Fiber-optic Receiver for use with dc to 32 MBd Arbitrary Duty Factor Data

the layout of the printed circuit board on which the transceiver circuits are constructed. System designers are encouraged to imbed the printed circuit designs provided in this application note to achieve the fiber-optic link performance described in Table 1. The printed circuit artwork in Figure 6 is for the transmitter in Figure 3 and the receiver in Figure 4. The printed circuit artwork in Figure 7 is for the transmitter in Figure 3 and the receiver in Figure 5. Electronic copies of the Gerber files for the artwork shown in this application note can be obtained by using the Internet to download the printed circuit designs located at the following URL:

http://www.hp.com/HP-COMP/fiber/fiber_index.html

Equation 1

$$C6 = C7 = \frac{2}{(3)\ (R6 + R7)\ [\ \text{Data Rate (Bd)}\ ]}$$

Table 3

Receiver	HFBR-25X6 650 nm		HFBR-24X6 820 nm	HFBR-23X6 1300 nm
Fiber Type	1 mm Plastic	200 µm HCS	62.5/125 µm	62.5/125 µm

Download the file named **trans1.exe** to obtain the artwork for the transmitter shown in Figure 3 and the receiver shown in Figure 4. Download the file named **trans2.exe** to obtain the artwork for the transmitter shown in Figure 3 and the receiver shown in Figure 5.

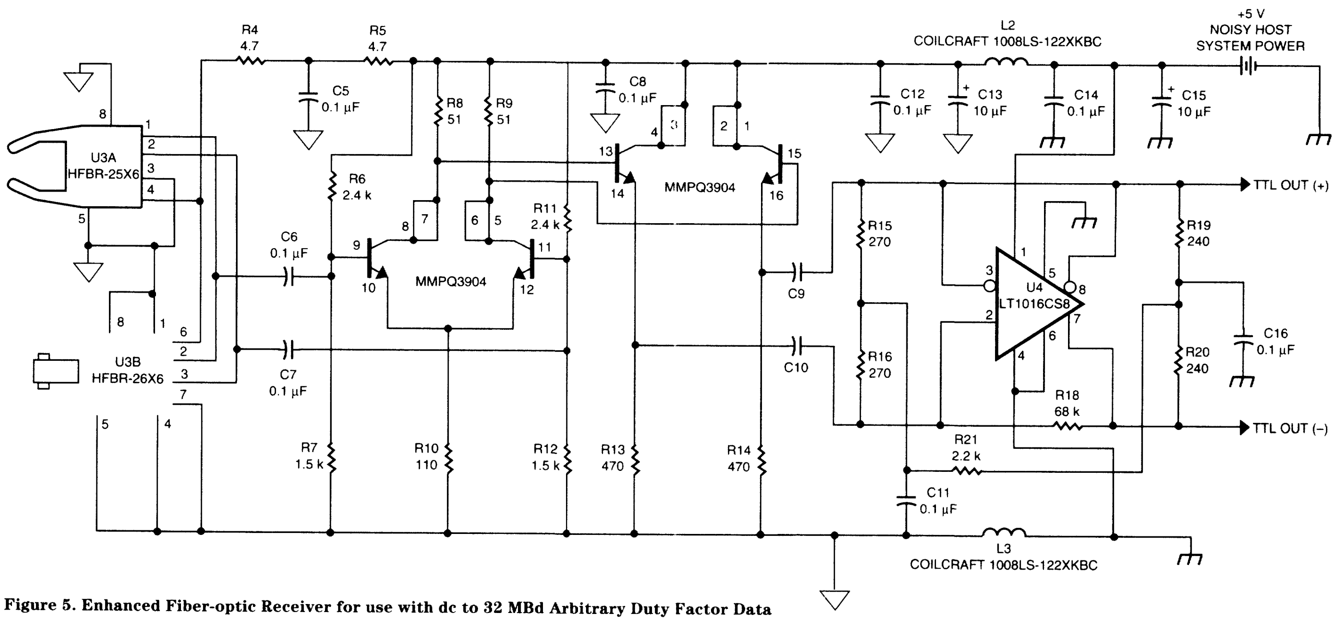


Figure 5. Enhanced Fiber-optic Receiver for use with dc to 32 MBd Arbitrary Duty Factor Data

Equation 2

$$C9 = C10 = \frac{2}{(3)\,(R15 + R16)\,[\text{ Data Rate (Bd) }]}$$

Table 4

Receiver	HFBR-25X6 650 nm		HFBR-24X6 820 nm	HFBR-23X6 1300 nm	HFBR-2315 1300 nm
Fiber Type	1 mm Plastic	200 µm HCS	62.5/125 µm	62.5/125 µm	9/125 µm

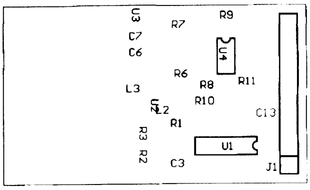


Figure 6a. Top Overlay

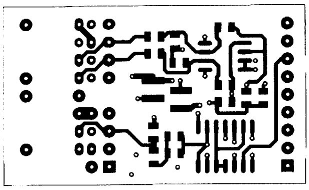


Figure 6b. Top Layer

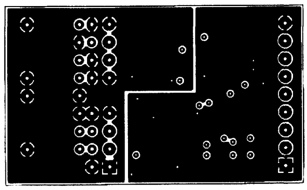


Figure 6c. Mid Layer 2

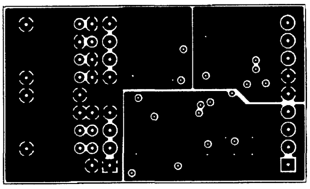


Figure 6d. Mid Layer 3

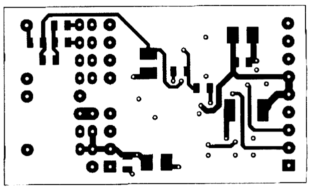


Figure 6e. Bottom Layer

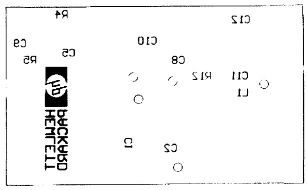


Figure 6f. Bottom Overlay

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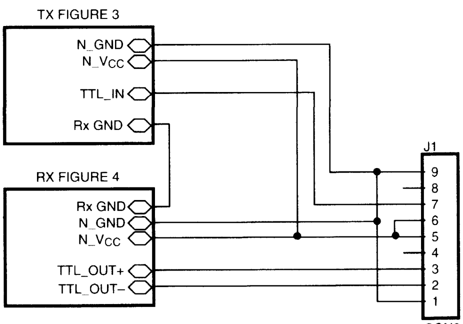

Figure 6g. Trans 1 Schematic

Figure 6. Printed Circuit Artwork for Transmitter shown in Figure 3 and Receiver in Figure 4

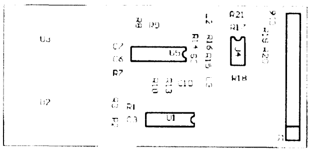

Figure 7a. Top Overlay

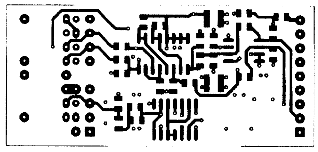

Figure 7b. Top Layer

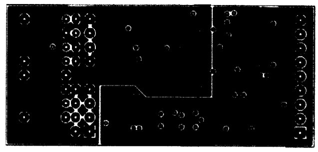

Figure 7c. Mid Layer 2

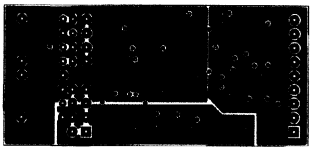

Figure 7d. Mid Layer 3

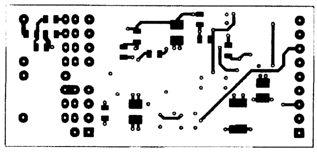

Figure 7e. Bottom Layer

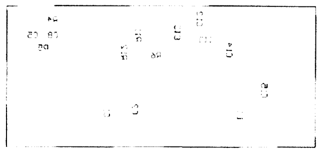

Figure 7f. Bottom Overlay

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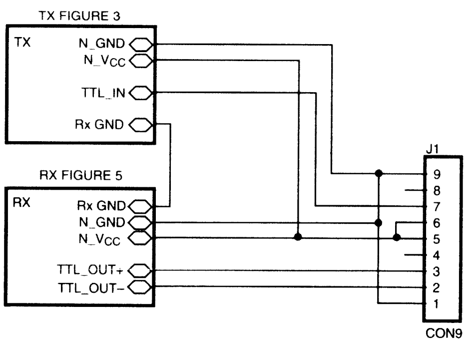

Figure 7g. Trans 2 Schematic

Figure 7. Printed Circuit Artwork for Transmitter in Figure 3 and Receiver in Figure 5

Error Rates and Noise Immunity

The probability that a fiber-optic link will make an error is related to the receiver's own internal random noise and its ability to reject noise originating from the system in which it is installed. The total noise present in any fiber-optic receiver is normally the sum of the PIN diode pre-amplifier's noise and the host system's electrical noise. The amount of hysteresis applied to the comparator determines the minimum signal amplitude (also known as minimum signal threshold level) at which the receiver can reliably detect data. The ratio between the comparator's switching threshold (also known as hysteresis) and the receiver's noise also has a dramatic impact on probability of error. Small increases in the comparator's threshold-to-noise ratio result in a very sharp reduction in the probability of error. Figure 8 shows that the receiver's probability of error is reduced by six orders of magnitude from ($1x10^{-9}$ to $1x10^{-15}$) when the receiver's threshold-to-noise ratio improves from 12:1 to 15.8:1.

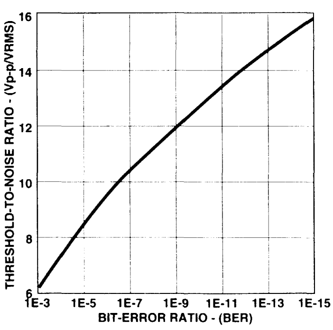

Figure 8. Receiver Threshold-to-Noise Ratio vs. Probability of Error (aka BER)

At any fixed temperature the total value of the receiver's random noise plus the host system's noise can be assumed to be a constant. So the most obvious way to reduce the probability of error is to increase the comparator's hysteresis and increase the amplitude of the optical signal applied to the receiver. A less obvious but better technique for lowering the error rate is to improve the receiver's ability to reject electrical noise from the system in which it resides. The fiber-optic receivers recommended in this application note have sufficient noise immunity to be used in most systems without electrostatic shielding. The HP PIN diode pre-amps, which are used in the receiver's first stage, are small hybrid circuits, and these small hybrid components do not function as particularly effective antennas. For extremely noisy applications, HP offers PIN diode pre-amps in electrically conductive plastic or all metal packages. HP manufactures a wide range of conductive and non-conductive fiber-optic components that mate with various industry-standard fiber-optic connectors. However, the overwhelming majority of the fiber-optic applications successfully implemented with HP's fiber-optic components have not required conductive plastic or metal receiver housings.

The most insidious and the most overlooked source of noise is usually the host system's +5 V power supply. The host system's +5 volt supply normally powers the fiber-optic receiver, the fiber-optic transmitter and an entire system comprised of relatively noisy digital circuits. The simple and inexpensive power supply filters recommended in this publication have been proven to work in a wide range of system applications. The power-supply filters recommended in this application note are normally sufficient to protect the fiber-optic receiver from very noisy host systems, but in extremely noisy applications additional power supply filtering could be needed.

Parts List

The TTL-compatible fiber-optic transceivers recommended in this publication are very simple and inexpensive, so only a few external components are needed. Complete parts lists for the circuits recommended in this application note are provided in Table 5 and Table 6. The parts listed in Table 5 are for the transmitter in Figure 3 and the receiver in Figure 4. The parts listed in Table 6 are for the transmitter in Figure 3 and the receiver in Figure 5. All of the components described in the part lists are compatible with the printed circuit artworks shown in Figure 6 and Figure 7, thus minimizing the design time and resources needed to use the low cost fiber-optic transceivers shown in the application note.

Conclusion

The complete TTL-compatible fiber-optic transceiver solutions provided in this publication can be used to improve the noise immunity of existing data communication systems that use protocols originally developed for use with copper wire. When fiber-optic media is used in place of conventional copper wire, it is possible to build new communication systems that are immune to large noise transients caused by utility power switch gear, motor drives or high voltage power supplies. Furthermore the non-conductive cables used in optical communication links have an intrinsically higher probability of surviving lightning strikes than copper wire alternatives. The optical data communication solutions shown in this application note are also capable of sending high-speed 32-MBd data over long distances that would be impractical with copper wire cables. System designers can quickly develop noise-immune communication links with minimal engineering costs by imbedding the complete fiber-optic solution shown in this application note.

Table 5. Parts List for the Transmitter in Figure 3 and Receiver in Figure 4

Designator	Part Type	Description	Footprint	Material	Part Number	Quantity	Vendor 1
C1 C5 C8 C9 C11 C13	0.1 µF 0.1 µF 0.1 µF 0.1 µF 0.1 µF 0.1 µF	Capacitor Capacitor Capacitor Capacitor Capacitor Capacitor	805	X7R or better	C0805X7R500104KNE	8	Venkel
C6 C7	Determined by Equation 1	Capacitor Capacitor	805 805	NPO/COG NPO/COG		1 1	Venkel Venkel
C2 C10 C12	10 µF 10 µF 10 µF	Capacitor Capacitor Capacitor	B	Tantalum, 10 V	TA010TCM106MBN	3	Venkel
C3	See Table 2	Capacitor	805	NPO/COG		1	Venkel
U1	I.C.	Nand Gate	S014		74ACTQ00	1	National
U2	Fiber-Optic	Transmitter		See Table 2	HFBR-1XXX	1	HP
U3	Fiber-Optic	Receiver		See Table 4	HFBR-2XXX	1	HP
U4	LT1016	IC, comparator	S08		LT1016CS8	1	Linear Tech
L1	CB70-1812	Inductor	1812		HF30ACB453215	1	TDK
L2 L3	1.2 µH	Inductor		10%	1008LS-122XKBC	2	Coilcraft
R4 R5	4.7 4.7	Resistor Resistor	805	5%	CR080510W4R7JT	2	Venkel
R1	See Table 2	Resistor	805	1%		1	Venkel
R2	See Table 2	Resistor	805	1%		1	Venkel
R3	See Table 2	Resistor	805	1%		1	Venkel
R6 R7	270 270	Resistor	805	5%	CR080510W271JT	2	Venkel
R8 R9	120 K 120 K	Resistor	805	5%	CR080510W124JT	2	Venkel
R10 R11	240 240	Resistor	805	5%	CR080510W241JT	2	Venkel
R12	2.2 K	Resistor	805	5%	CR080510W222JT	1	Venkel
J1		Pins			343B	9	McKenzie

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Table 6. Parts List for the Transmitter in Figure 3 and Receiver in Figure 5

Designator	Part Type	Description	Footprint	Material	Part Number	Quantity	Vendor 1
C1	0.1 µF	Capacitor	805	X7R or better	C0805X7R500104KNE	8	Venkel
C6	0.1 µF	Capacitor					
C7	0.1 µF	Capacitor					
C8	0.1 µF	Capacitor					
C11	0.1 µF	Capacitor					
C12	0.1 µF	Capacitor					
C14	0.1 µF	Capacitor					
C16	0.1 µF	Capacitor					
C9	Determined by	Capacitor	805	NPO/COG		1	Venkel
C10	Equation 2	Capacitor	805	NPO/COG		1	Venkel
C2	10 µF	Capacitor	B	Tantalum, 10 V	TA010TCM106MBN	3	Venkel
C13	10 µF	Capacitor					
C15	10 µF	Capacitor					
C3	See Table 2	Capacitor	805	NPO/COG		1	Venkel
U1	I.C.	Nand Gate	S014		74ACTQ00	1	National
U2	Fiber-Optic	Transmitter		See Table 2	HFBR-1XXX	1	HP
U3	Fiber-Optic	Receiver		See Table 4	HFBR-2XXX	1	HP
U4	LT1016	IC, comparator	S08		LT1016CS8	1	Linear Tech
U5	Quad NPN	Transistor	S016		MMPQ3904	1	Motorola
L1	CB70-1812	Inductor	1812		HF30ACB453215	1	TDK
L2	1.2 µH	Inductor		10%	1008LS-122XKBC	2	Coilcraft
L3							
R4	4.7	Resistor	805	5%	CR080510W4R7JT	2	Venkel
R5	4.7	Resistor					
R1	See Table 2	Resistor	805	1%		1	Venkel
R2	See Table 2	Resistor	805	1%		1	Venkel
R3	See Table 2	Resistor	805	1%		1	Venkel
R6	2.4 K	Resistor	805	5%	CR080510W242JT	2	Venkel
R11	2.4 K						
R7	1.5 K	Resistor	805	5%	CR080510W152JT	2	Venkel
R12	1.5 K						
R8	51	Resistor	805	5%	CR080510W510JT	2	Venkel
R9	51						
R10	110	Resistor	805	5%	CR080510W111JT	1	Venkel
R13	470	Resistor	805	5%	CR080510W471JT	2	Venkel
R14	470						
R15	270	Resistor	805	5%	CR080510W271JT	2	Venkel
R16	270						
R17	68K	Resistor	805	5%	CR080510W163JT	2	Venkel
R18	68K						
R19	240	Resistor	805	5%	CR080510W241JT	2	Venkel
R20	240						
R21	2.2 K	Resistor	805	5%	CR080510W222JT	1	Venkel
J1		Pins			343B	9	McKenzie

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Inexpensive 2 to 70 MBd Fiber-Optic Solutions for Industrial, Medical, Telecom, and Proprietary Data Communication Applications

Application Note 1122

Introduction

Low-cost fiber-optic data-communication links have been used in place of copper wire in numerous industrial, medical and proprietary data communication systems. The fiber-optic transmitter and receiver circuits recommended in this publication address a wide range of applications. These circuits are compatible with existing copper wire protocols, which encode the data before it is sent through the serial communication media. A complete TTL-compatible digital transceiver solution, including the schematic, printed-circuit artwork and material list, is presented in this application note. This complete solution makes it easy for potential users to imbed this low-cost fiber-optic technology into new products because no analog design is required. System engineers interested in using the recommendations contained in this publication are encouraged to imbed these reference designs in their products, and various methods for electronically downloading these reference designs are described.

Why Use Optical Fibers?

Although copper wire is an established technology that has been successfully used to transmit data in a wide range of industrial, medical and proprietary applications, it can be difficult or impossible to be used in numerous situations. By using differential line receivers, optocouplers or transformers, conventional copper wire cables can be used to transmit data in applications where the reference or ground potentials of two systems are different. However, when using copper wires great care must be taken during and after the initial installation to assure that the data is not corrupted by noise induced into the cable's metallic shields from adjacent power lines or differences in ground potential. Unlike copper wires, optical fibers do not require rigorous grounding rules to avoid ground loop interference, and fiber-optic cables do not need termination resistors to avoid reflections. Optical transceivers and cables can be designed into systems so that they survive lightning strikes that would normally damage metallic conductors or wire input/output (I/O) cards. In essence, fiber-optic data links are used in electrically noisy environments where copper wire fails.

In addition to all of these inherent advantages, there are two other reasons why optical fibers are beginning to replace copper wires. The first reason is that optical connectors suited for field installation with minimal training and simple tools are now available. The second reason is that when using plastic optical fiber (POF) or hard clad silica (HCS) fiber, the total cost of the data communication link is roughly the same as when using copper wires.

Wire Communication Protocols and Optical Data Links

Many existing serial wire communication protocols were developed for use with differential line receivers or optocouplers that can sense the dc component of the data communication signal. This type of serial data is often called arbitrary duty factor data because it can remain in the logic "1" or logic "0" state for indefinite periods of time, and therefore has a duty factor or average value which arbitrarily varies between 0% and 100%. Some existing wire communication protocols require an optical receiver that is dc coupled or capable of detecting if the data is changing from high-to-low or low-to-high logic state, i.e. the receiver needs to be an edge detector. At relatively modest data rates between zero and 10 M bits/second, it is possible to construct dc coupled TTL compatible fiber-optic receivers. The HP HFBR-2521 is a TTL compatible dc to 5 M bit/sec receiver, and the HFBR-2528 is a dc to 10 M bit/sec CMOS or TTL compatible receiver. Additional information about dc to 5 M bit/sec applications can be found in Hewlett-Packard AN-1035, and applications support for dc to 10 M bits/sec applications can be obtained by reading AN-1080. This application note will focus on optical data communication links that work at much higher data rates and much greater distances than achievable with the dc coupled HFBR-2521 or HFBR-2528 components. The optical transceivers shown in this application note are intended for use with data that has been encoded so that the average value of the data is equal to approximately 50 % of the data's amplitude. If your communication system sends unencoded arbitrary duty factor data, or burst mode data where the average value of the signal can instantaneously be anywhere between 0% and 100% please refer to the solutions provided in HP Application Note 1121.

The Pros and Cons of Encoding Data

One of the most important reasons for encoding the data is that the sensitivity of the fiber-optic receiver improves dramatically. A receiver circuit designed for use with encoded data is typically 4 dB to 10 dB better than receiver circuits optimized for use with arbitrary duty factor data, or burst-mode data. Encoded data normally has a 50 % duty factor, or restricted duty factor variation, which allows the construction of optimal noise-limited fiber-optic receivers which provide very high performance. The arbitrary duty factor or burst mode receivers described in HP Application Notes 1035, 1080, and 1121 are considerably less sensitive than the fiber-optic receiver solution described in this publication. The optimized receiver in this application note is capable of providing excellent sensitivity because it was designed specifically for use with encoded data.

As the data rate increases, other reasons for encoding quickly become apparent. When unencoded arbitrary duty factor data is transmitted through an optical communication system, a separate fiber-optic link must be used to send the clock if synchronous serial communication is desired. In most high-speed serial communication systems, the data and clock are merged onto a single fiber-optic link to avoid problems with time skew, which can occur when data and clock signals are sent through two different optical fibers. Asynchronous data communication systems, which oversample the serial data using a local clock oscillator located at the receiving end of the fiber-optic data link, are limited to lower-speed applications, because the sampling frequency required to assure low pulse-width distortion rises dramatically as data rates increase.

The most apparent drawback of encoding data is the additional complexity of the encoder function, which must be added to the integrated circuits that convert parallel data to serial data at the transmitting end of the communication link. At the receiving end of the data communication link, a corresponding decoder function must also be added to the circuits that convert serial-data back to parallel-data. At first glance, encoding and decoding seem to add too much complexity, but encoder and decoder circuits actually do not have a significant impact on the cost of the complex serializer and deserializer integrated circuits already needed to connect two parallel architecture systems via a serial communication channel. In fact, many off-the-shelf protocol chips for serial communications applications imbed encoding and decoding features for all of the reasons that have just been described.

High Performance ac Coupled Receiver Topology

When data is encoded, the fiber-optic receiver can be ac coupled as shown in Figure 1. Without encoding, the fiber-optic receiver would need to detect dc levels or edges to determine the proper logic state during long periods of inactivity, as when there is no change in the transmitted data. AC-coupled fiber-optic receivers tend to be lower in cost, are much easier to design, provide better sensitivity and contain fewer components than their dc-coupled counterparts.

No matter which type of fiber-optic medium is used, the receiver's PIN diode pre-amplifier should be ac coupled to a limiting amplifier and comparator as shown in Figure 1. Direct coupling the PIN pre-amp to the post amplifier and comparator (also known as quantizer) will reduce the sensitivity of the fiber-optic receiver, since this

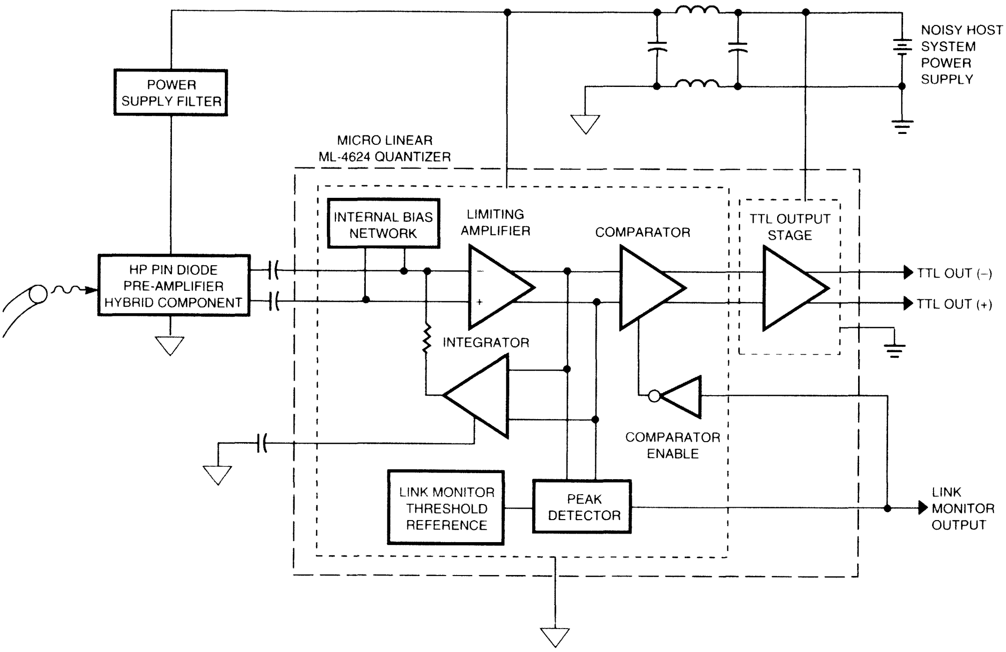


Figure 1. Simplified TTL-Compatible Fiber-Optic Receiver Block Diagram for Applications with Encoded Data

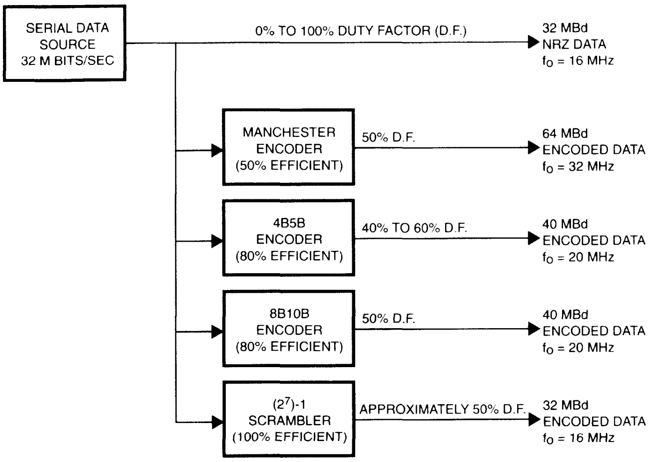
allows low-frequency flicker-noise from the first transistor in the PIN pre-amp to be applied to the receiver's comparator. Any undesired noise coupled to the comparator will reduce the signal-to-noise ratio at this critical point in the circuit, and reduce the sensitivity of the fiber-optic receiver. Another problem associated with direct-coupled receivers is the accumulation of dc offset. With direct coupling, the receiver's gain stages rapidly multiply the PIN pre-amplifier's small offsets and voltage drifts due to temperature change. Sensitive receivers require high-gain amplifiers, which will quickly magnify relatively small PIN pre-amp offsets. The amplification of dc offset will saturate the quantizer's amplifiers, resulting in undesired pulse-width distortion, which limits the maximum data rate and sensitivity of inexpensive dc-coupled receivers. Problems with dc drift and low-frequency flicker-noise can be avoided by constructing ac-coupled fiber-optic receivers as recommended in Figure 1.

Relationships Between bits/sec, Baud, and Hertz

Figure 2 shows more details about encoding techniques that are commonly used with inexpensive fiber-optic solutions. Simple Manchester encoders which send two symbols for each bit can be used in low-speed data communication applications, but high efficiency block substitution codes, such as 4B5B and 8B10B, are preferred for serial communication systems that operate at symbol rates greater than 32 MBd. When using a high efficiency encoding scheme, the channel bandwidth needed to carry the serial data is minimized, and the distances achievable with low-cost fiber-optic technologies increase. Figure 2 illustrates several important relationships between bits/second, symbols/second, expressed in Baud (Bd), and the fundamental frequency of various digital data communication signals. Note that arbitrary duty factor unencoded data is one of the few instances when data rate in bits/second, and the symbol rate in Bd are equal.

Only One Transceiver Design Needed

This application note will show that various HP LED transmitters and PIN-diode pre-amplifiers can



NOTE THAT f_O IS THE MAXIMUM FUNDAMENTAL FREQUENCY OF THE ENCODED DATA.
THE MINIMUM FUNDAMENTAL FREQUENCY OF THE ENCODED DATA IS DETERMINED BY THE ENCODER'S RUN LIMIT.

Figure 2. Attributes of Encoding

be used in a single transceiver design that can be electronically down-loaded and imbedded into a wide range of products to provide very low-cost data communication solutions. Without changing the form-factor or printed circuit design, the transceiver shown in this publication can be populated with components that are capable of sending digital data via various types of fiber-optic cables. When the recommended circuits are electronically imported and imbedded into your system, the same inexpensive transceiver can be used with a variety of fiber-optic cables so that one design can be used to address an extremely wide range of data communication applications.

Distances and Data Rates Achievable

The simple transceivers recommended in this application can be used to address a very wide range of distances, data rates, and system cost targets. The maximum distances allowed with various types of optical fiber and HP's

Table 1

LED Transmitter Component Part # and Wavelength	Receiver Component Part # and Wavelength	Fiber Diameter Type	Maximum Distance at 50 MBd with the transceiver circuits recommended in this publication
HFBR-15X7 650 nm	HFBR-25X6 650 nm	1 mm plastic step index	80 meters with transmitter in Fig. 3 and receiver in Fig. 4
HFBR-15X7 650 nm	HFBR-25X6 650 nm	200 µm HCS step index	300 meters with transmitter in Fig. 3 and receiver in Fig. 4
HFBR-14X2 820 nm	HFBR-24X6 820 nm	200 µm HCS step index	300 meters with transmitter in Fig. 3 and receiver in Fig. 4
HFBR-14X4 820 nm	HFBR-24X6 820 nm	62.5/125 µm multimode glass	1.5 kilometers with transmitter in Fig. 3 and receiver in Fig. 4
HFBR-13X2 1300 nm	HFBR-23X6 1300 nm	62.5/125 µm multimode glass	3.8 kilometers with transmitter in Fig 3. and receiver in Fig. 4
HFBR-1315 1300 nm	HFBR-2315 1300 nm	9/125 µm single-mode glass	14 kilometers with transmitter in Fig. 3 and receiver in Fig. 4

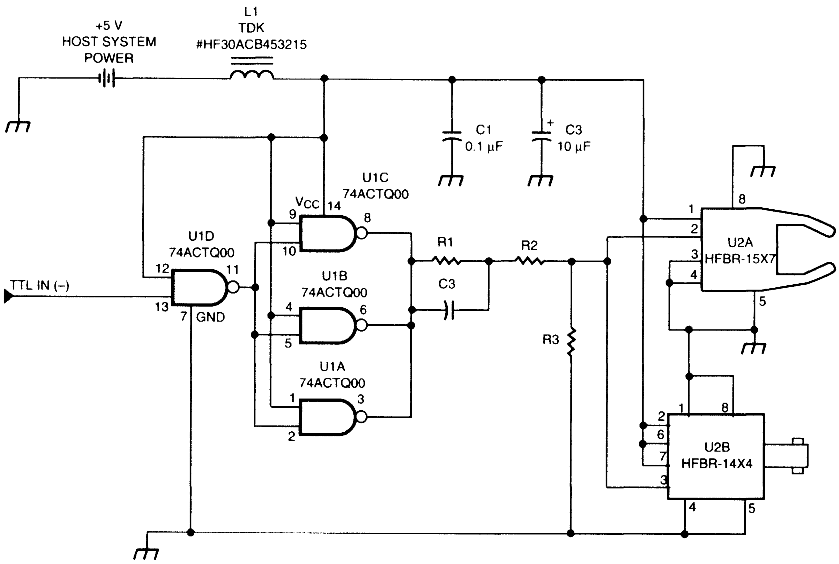


Figure 3. TTL-Compatible Fiber-Optic Transmitter

Table 2

Transmitter	HFBR-15X7 650 nm LED		HFBR-14X4 820 nm LED	HFBR-13X2T 1300 nm LED	HFBR-1315 1300 nm ELED
Fiber Type	1 mm Plastic	200 µm HCS	62.5/125 µm	62.5/125 µm	9/125 µm
R1	120 Ω	33 Ω	33 Ω	22 Ω	18 Ω
R2	120 Ω	33 Ω	33 Ω	27 Ω	18 Ω
R3	390 Ω	270 Ω	270 Ω	∞	390 Ω
C3	82 pF	470 pF	75 pF	150 pF	47 pF

broad range of fiber-optic components are shown in Table 1. Only one simple calculation is needed to optimize the receiver for use at the desired maximum symbol rate of your system application. No transmitter or receiver adjustments are needed when using fiber cables that vary from virtually zero length up to the maximum distances specified in Table 1.

Simple TTL-Compatible LED Transmitter

A high performance, low cost TTL compatible transmitter is shown in Figure 3. This transmitter recommendation looks deceptively simple but has been highly developed to deliver the best performance achievable with a wide range of HP LED transmitters. The recommended transmitter is also very inexpensive since the 74ACTQ00 gate used to current modulate the various LED transmitters can typically be obtained for under $0.40. No calculations are required to determine the passive component needed when using the broad selection of HP LEDs with various optical fibers. Simply use the recommended component values shown in Table 2, and the transmitter shown in Figure 3 can be used to address a wide range of applications.

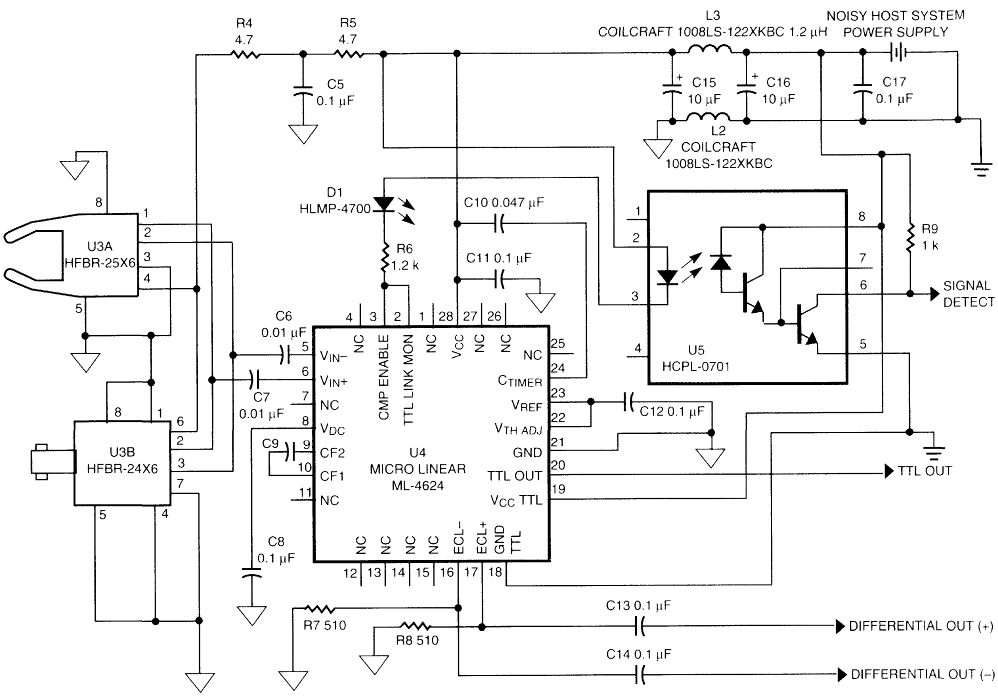


Figure 4. Simple High-Sensitivity TTL-Compatible Receiver

Simple High-Sensitivity, TTL-Compatible Receiver

A very simple TTL-compatible receiver that has excellent sensitivity and is suited for many different applications is shown in Figure 4. Equation 1 allows the designer to determine the value of C9 which optimizes the quantizer's bandwidth for best receiver sensitivity at data rates ≤20 MBd. At data rates >20 MBd the bandwidth limitations of the quantizer's amplifier provide the low pass filtering required, so no capacitor should be connected between the CF1 and CF2 terminals of the ML-4624. The receiver shown in Figure 4 can be configured to address the unique

Equation 1

When data rate is ≤20 MBd then

$$C9 = \left[\frac{1}{2\,\pi\,800\,(\text{Bd})}\right] - [\,4\,(\text{pF})\,]$$

Table 3

Receiver	HFBR-25X6 650 nm		HFBR-24X6 820 nm	HFBR-23X6T 1300 nm	HFBR-2315 1300 nm
Fiber Type	1 mm Plastic	200 µm HCS	62.5/125 µm	62.5/125 µm	9/125 µm

requirements of various applications; simply refer to Table 3 to find the component values best suited for your specific application.

The receiver in Figure 4 uses the Micro Linear ML-4624 quantizer that has been used successfully with HP's HFBR-2416 820 nm PIN pre-amp in numerous 20-MBd Ethernet and 32-MBd Token Ring LAN applications since 1992. The ML-4624 quantizer maximizes the sensitivity of the fiber-optic receiver when used with a broad range of HP PIN pre-amps. The ML-4624 can be used with the HFBR-2526 PIN pre-amp to build a 650-nm receiver that is compatible with 1 mm plastic optical fibers (POF) or 200 μm hard clad silica (HCS) fibers. The ML-4624 quantizer can also be used with HP's HFBR-2316 PIN pre-amp for 1300 nm miltimode glass fiber applications, or the ML-4624 can be used with HP's HFBR-2315 to construct 1300 nm receivers that are compatible with 9/125 μm single-mode fibers.

The ML-4624 quantizer provides the best digital receiver sensitivity possible no matter which HP PIN pre-amp is used, provided the modulation code that encodes the data does not allow excessive time intervals between transitions from one logic state to another. The maximum time interval allowed between the edges of encoded data symbols is known as the encoder's run limit. For a better understanding of how the encoder's run limit affects receiver performance, refer to Figure 1. To obtain optimum performance from the ML-4624 quantizer, the encoder's run-limit time interval must be orders of magnitude shorter than the time constant of the integrator imbedded in the ML-4624 quantizer's feedback loop. As the encoder's run-limit approaches the time constant of the ML-4624's integrator, the dc bias voltage applied to the inverting input of the quantizer begins to slew up or down and the receiver's sensitivity decreases. The maximum run-limit time recommended for use with the ML-4624 quantizer should be ≤ 500 ns.

Printed Circuit Artwork

The performance of transceivers that use HP fiber-optic components are partially dependent on the layout of the printed circuit board on which the transceiver circuits are constructed. To achieve the fiber-optic link performance described in Table 1, system designers are encouraged to imbed the printed circuit design provided in the application note. The printed circuit artwork in Figure 5 is for the transmitter in Figure 3 and the receiver in Figure 4. Electronic copies of the Gerber files for the artwork shown in this application note can be obtained by using the Internet to download the printed circuit designs located at the following URL:

http://www.hp.com/HP-COMP/fiber/fiber_index.html

Download the file named **rll70.exe** to obtain the artwork for the transmitter shown in Figure 3 and the receiver shown in Figure 4.

Parts List

The TTL-compatible fiber-optic transceiver recommended in this publication is very simple and inexpensive, so only a few external components are needed. To simplify the process of obtaining the passive and active components required to assemble the transceiver, a complete parts list is provided in Table 4. All of the components described in the parts list were selected to assure that they are compatible with the printed circuit artwork shown in Figure 5, thus minimizing the design time and resources needed to use the low-cost, fiber-optic transceiver shown in this application note.

Error Rates and Noise Immunity

The probability that a fiber-optic link will make an error is related to the receiver's own internal random noise and the receiver's ability to reject noise originating from the system in which it is installed. The total noise present in any fiber-optic receiver is normally the sum of the PIN diode pre-amplifier's noise and the host system's electrical noise. As the

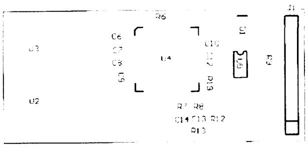


Figure 5a. Top Overlay

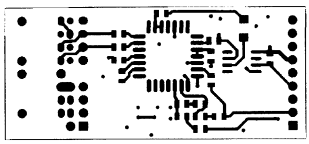


Figure 5b. Top Layer

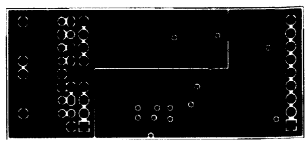


Figure 5c. Mid Layer 2

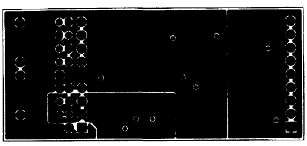


Figure 5d. Mid Layer 3

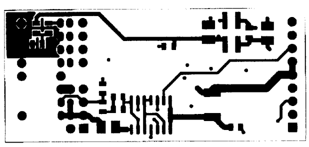


Figure 5e. Bottom Layer

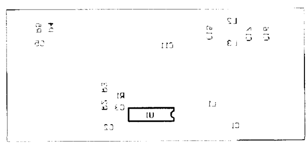


Figure 5f. Bottom Overlay

WARNING: DO NOT USE PHOTO-COPIES OR FAX COPIES OF THIS ARTWORK TO FABRICATE PRINTED CIRCUITS.

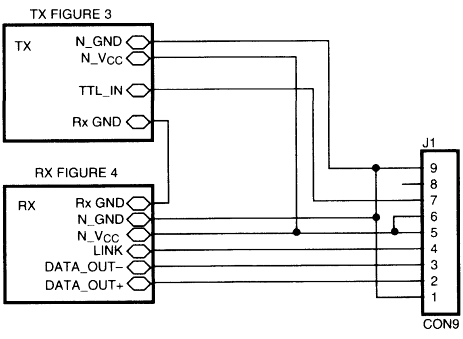


Figure 5g. Trans 3 Schematic

Figure 5. Printed Circuit Artwork for Transmitter shown in Figure 3 and Receiver in Figure 4

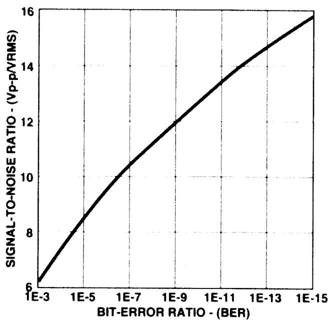


Figure 6. Receiver Signal-to-Noise Ratio vs. Probability of Error (aka BER)

optical signal applied to the receiver increases, the probability that the receiver's total noise will alter the data decreases. Small increases in the receiver's signal-to-noise ratio will result in a very sharp reduction in the probability of error. Figure 6 shows that the receiver's probability of error is reduced by six orders of magnitude (from $1x10^{-9}$ to $1x10^{-15}$) when the receiver's signal-to-noise ratio improves from 12:1 to 15.8:1.

At any fixed temperature the total value of the receiver's random noise plus the host system's noise can be assumed to be a constant, so the most obvious way to reduce the probability of error is to increase the amplitude of the optical signal applied to the receiver. A less obvious but better technique for lowering the error rate is to improve the receiver's ability to reject electrical noise from the system in which it resides. The fiber-optic receiver recommended in this application note has sufficient noise immunity to be used in most systems without electrostatic shielding. The HP PIN diode pre-amps that are used in the receiver's first stage are small hybrid circuits, and these small hybrid components do not function as particularly effective antennas. For extremely noisy applications, HP offers PIN diode pre-amps in electrically conductive plastic or all-metal packages. HP manufactures a wide range of conductive and non-conductive fiber-optic components that mate with various industry-standard fiber-optic connectors, but the overwhelming majority of the fiber-optic applications successfully implemented with HP's fiber-optic components have not required conductive plastic or metal receiver housings.

The most insidious and the most overlooked source of noise is usually the host system's +5 V power supply. Many applications utilize a solitary +5 volt supply that powers the fiber-optic receiver, the fiber-optic transmitter and an entire system comprised of relatively noisy digital circuits. The receiver circuit in Figure 4 uses very inexpensive power supply filter inductors that are located in the receiver's +5 volt and 0 volt connections to the host system's power supply. The simple and inexpensive power supply filters recommended in this publication have been proven to work in a wide range of noisy system applications, but in extremely noisy applications additional power supply filtering could be needed.

The HCPL-0701 optocoupler shown in Figure 4 allows the TTL LINK MONITOR output of the ML-4624 quantizer to be connected to electrically noisy TTL circuits. If the communication protocol chosen for the data communication system requires that the quantizer's link monitor must be connected to higher level protocol circuits, then some type of noise isolation circuit, or an optocoupler, must be used to assure that digital circuits in the communication system's physical layer do not inject noise into the low-level analog circuits of the Micro Linear ML-4624 quantizer. Note that the TTL LINK MONITOR output (pin 2) of the ML-4624 quantizer is low when a sufficient amount of optical power is applied to the PIN pre-amp, but the HCPL-0701 optocoupler inverts the TTL LINK MONITOR output so that the signal detect (SD) output of the circuit in Figure 4 is high when a sufficient amount of light is applied to the fiber-optic receiver's input.

Conclusion

The complete TTL compatible fiber-optic transceiver solutions provided in this publication can be used to improve the noise immunity of existing data communication systems currently using encoded data protocols originally developed for use with copper wire. When copper wire transceivers are replaced with comparably priced optical transceivers, industrial and proprietary communication systems have a much better probability of surviving large noise transients caused by utility power switch gear, motor drives or lightning strikes. The optical data communication solutions shown in this application note can also send high-speed, 70 MBd data over long distances that would be impractical with copper wire cables. By imbedding the complete solution shown in this application note, system designers can quickly develop noise-immune optical communication links in a very short time with minimal R&D costs.

Table 4. Parts List for the Transmitter in Figure 3 and Receiver in Figure 4

Designator	Part Type	Description	Footprint	Material	Part Number	Quantity	Vendor 1
C1	0.1 μF	Capacitor	805	X7R or better	C0805X7R500104KNE	8	Venkel
C5	0.1 μF	Capacitor					
C8	0.1 μF	Capacitor					
C11	0.1 μF	Capacitor					
C12	0.1 μF	Capacitor					
C13	0.1 μF	Capacitor					
C14	0.1 μF	Capacitor					
C17	0.1 μF	Capacitor					
C19	0.1 μF	Capacitor					
C6	0.01 μF	Capacitor	805	X7R or better	C0805X7R103KNE	2	Venkel
C7	0.01 μF	Capacitor					
C9	See Equation 1	Capacitor	805	NPO/COG		1	Venkel
C10	0.047 μF	Capacitor	805	NPO/COG		1	Venkel
C2	10 μF	Capacitor	B	Tantalum, 10 V	TA010TCM106MBN	3	Venkel
C15	10 μF	Capacitor					
C16	10 μF	Capacitor					
C3	See Table 2	Capacitor	805	NPO/COG		1	Venkel
D1	HLMP-4700	LED lamp			HLMP-4700	1	HP
U1	I.C.	Nand Gate	S014		74ACTQ00	1	National
U2	Fiber-Optic	Transmitter		See Table 2	HFBR-1XXX	1	HP
U3	Fiber-Optic	Receiver		See Table 3	HFBR-2XXX	1	HP
U4	ML4624	IC, quantizer	PLCC28		ML4624CQ	1	MicroLinear
U5	HCPL-0701	Optocoupler	S08		HCPL-0701	1	HP
L1	CB70-1812	Inductor	1812		HF30ACB453215	1	TDK
L2	1.2 μH	Inductor		10%	1008LS-122XKBC	2	Coilcraft
L3							
R4	4.7	Resistor	805	5%	CR080510W4R7JT	2	Venkel
R5	4.7	Resistor					
R1	See Table 2	Resistor	805	1%		2	Venkel
R2	See Table 2	Resistor					
R7	510	Resistor	805	5%	CR080510W511JT	2	Venkel
R8	510	Resistor					
R3	See Table 2	Resistor	805	1%		1	Venkel
R6	1.2 K	Resistor	805	5%	CR080510W122JT	1	Venkel
R9	1K	Resistor	805	5%	CR0805510W102JT	1	Venkel
J1	Pins				343B	9	McKenzie

HEWLETT PACKARD

Inexpensive 20 to 160 MBd Fiber-Optic Solutions for Industrial, Medical, Telecom, and Proprietary Data Communication Applications

Application Note 1123

Introduction

Low-cost fiber-optic data-communication links have been used in place of copper wire in numerous industrial, medical and proprietary applications. The fiber-optic transmitters and receivers shown in this publication can be used in a wide range of applications that convey encoded serial data provided by off-the-shelf, large-scale, mixed-signal integrated circuits such as the AMD TAXIchip ™, the Cypress HOTLink ™ or the PMC Sierra S/UNI-LITE ™. Byte-to-light solutions can be quickly implemented when these off-the-shelf serializer/deserializer circuits are combined with the fiber-optic transceivers described in this publication. Complete +5 V ECL (PECL)-compatible digital fiber-optic transceivers are presented in this application note. These complete solutions include the schematic, printed circuit artwork and material lists, so that users of this low-cost optical technology will not need to do any analog design. Designers interested in the recommendations contained in this publication are encouraged to imbed these reference designs in their products, and various methods for electronically down-loading these reference designs are described.

Why Use Optical Fibers?

Although copper wire is an established technology that has been successfully used to transmit data in a wide range of industrial, medical and proprietary applications, it can be difficult or impossible to use in numerous situations. By using differential line receivers or optocouplers, copper wires can be used to transmit data in applications where the reference or ground potentials of two systems are different, but care must be taken not to corrupt the data with noise induced into the metallic conductors or shields by adjacent power lines or differences in ground potential. Unlike copper wires, optical fibers do not require rigorous grounding rules to avoid ground loop interference, and optical transmission lines do not need termination resistors to avoid reflections. Optical transceivers and cables can be designed into systems so that they will survive lightning strikes that would normally damage metallic conductors or wire input/output (I/O) cards. In essence, fiber-optic data links are used in electrically noisy environments where copper wire fails.

In addition to all of these inherent advantages, there are two other reasons why optical fibers are beginning to replace copper wires. The first reason is that optical connectors suited for field installation with minimal training and simple tools are now available. The second reason is that when using plastic optical fiber (POF) or hard clad silica (HCS) fiber, the total cost of the data communication link is roughly the same as when using copper wires.

Communication Protocols and Optical Data Links

Many existing serial communication protocols were developed for use with copper wire. At data rates below 30 Mbits/second, copper wire has routinely been used with differential line receivers or optocouplers that can sense the dc component of binary data communication signals. This type of serial data is often called "arbitrary duty factor" data because it can remain in the logic "1" or logic "0" state for indefinite periods of time. Arbitrary duty factor data has an average value, which can instantaneously be anywhere between 0 percent and 100 percent of the binary signal's amplitude, or in other words, arbitrary duty factor data contains dc components. Communication protocols that were developed specifically for use with copper wire often require an optical receiver that is dc coupled or capable of detecting if the data is changing from a high-to-low or low-to-high logic state, that is, the receiver needs to be an edge detector. At relatively modest data rates between zero and 10 Mbits/sec it is possible to construct dc coupled TTL-compatible fiber-optic receivers. The HP HFBR-2521 is a TTL-compatible, dc-to-5 Mbit/sec receiver, and the HFBR-2528 is a dc-to-10 Mbit/sec CMOS or TTL-compatible receiver. Additional information about dc-to-5 Mbit/sec applications can be found in Hewlett-Packard AN-1035, and applications support for dc-to-10 Mbit/sec applications can be obtained by reading AN-1080. This application note focuses on optical data communication links that operate at much higher data rates and much greater distances than achievable with the dc-coupled or edge-detecting fiber-optic receivers. The optical transceivers shown in this application note are intended for use with parallel data that has been replaced by serialized encoded symbols. When encoding is used, the average value of the serial data is equal to approximately 50 percent of the serialized data's amplitude. If your communication system sends unencoded or burst-mode data where the average value of the serial data can arbitrarily be anywhere between 0 percent to 100 percent of the binary signal's amplitude, please refer to the solutions provided in HP Application Note 1121.

Advantages of Encoded Run-Limited Data

As the data rate of a digital communication link increases, the reasons for encoding the raw data become more compelling. When data is encoded, the original data bits are replaced with a different group of bits known as symbols. The symbols that replace the original data are selected so that the encoded data is compatible with simple, highly sensitive, ac-coupled fiber-optic receivers. Encoding enables the construction of optimal fiber-optic receivers which are limited by the random noise inherent in the receiver's first amplifier stage. Noise-limited ac-coupled receivers can provide very low error rates when used with long optical fibers, or can be useful in applications that utilize optical splitters having large amounts of fixed optical losses.

Data is encoded to prevent the digital information from remaining in one of the two possible logic states for an indefinite period of time. When data is encoded, a characteristic known as the "run limit" is established. If data is not changing, the run limit defines how much time may pass before the encoder inserts a transition from one logic state to another. The run length, or run limit of the encoder, is the number of symbol periods that are allowed to pass before the encoder changes logic state. Encoders usually force the encoded data to have a 50 percent duty factor, or they restrict the duty factor to a limited range, such as 40 percent to 60 percent. When data is encoded, the fiber-optic receiver can be ac-coupled as shown in Figure 1. Without encoding, the fiber-optic receiver would need to detect dc levels, or edges, to determine the proper logic state during long periods of inactivity when there are no changes in the transmitted data. AC-coupled fiber-optic receivers tend to be lower in cost, are much easier to design, provide better sensitivity and contain fewer components than their dc-coupled counterparts.

No matter which type of fiber-optic media is used, the receiver's PIN pre-amplifier should be ac-coupled to a limiting amplifier and comparator as shown in Figure 1. Direct coupling decreases the sensitivity of a digital fiber-optic receiver, since it allows low-frequency flicker noise from transistor amplifiers to be presented to the receiver's comparator input. Any undesired signals coupled to the comparator will reduce the signal-to-noise ratio at this critical point in the circuit, and reduce the sensitivity of the fiber-optic receiver.

Another problem associated with direct-coupled receivers is the accumulation of dc offsets. With direct coupling, the receiver's gain stages amplify the effects of undesirable offsets and voltage drifts due to temperature changes. These amplified dc offsets will eventually be applied to the comparator and result in reduced sensitivity of the fiber-optic receiver. The dc offset at the comparator can be referred to the optical input of the receiver by dividing by the receiver's gain. This division refers the dc offset at the comparator to the receiver input where it appears as a change in optical power that must be exceeded before the receiver will switch logic states. Problems with

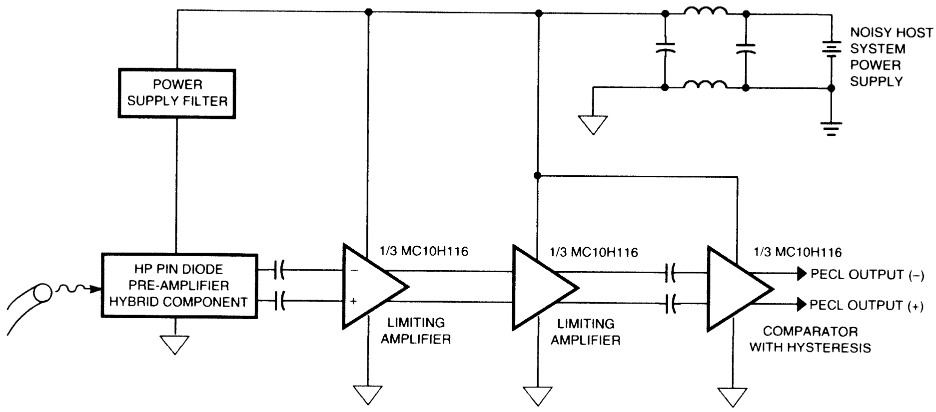


Figure 1. Simplified +5 Volt ECL (PECL-compatible) Fiber-optic Receiver Block Diagram for High Data Rate Applications with Encoded Data

dc drift can be avoided by constructing the receiver as shown in Figure 1.

Encoding has other advantages. Encoding merges the data and clock signals in a manner that allows a timing-recovery circuit to reconstruct the clock at the receiver end of the digital data link. This is essential because fiber-optic links can send data at such high rates that asynchronous timing-recovery techniques, such as over-sampling, are not very practical. Synchronous detection can be accomplished without encoding, but the clock signal required to synchronously detect the data would need to be sent via a second fiber-optic link. Separate transmission channels for data and clock signals are usually avoided due to cost, but problems with time skew between the data and clock can also arise if separate fibers are used to transmit these signals.

Characteristics of Encoders

A Manchester encoder replaces each bit with two symbols. For instance, when using Manchester code a logic "1" is replaced by a ("1", "0") symbol, and a logic "0" is replaced by a ("0", "1") symbol. Manchester code is not very efficient since it doubles the fundamental frequency of the data by substituting two symbols for each bit transmitted. Block substitution codes such as 4B5B replace four bit nibbles of data with a five bit symbol. Other popular block substitution codes are also used. A 5B6B encoder replaces each group of five bits with a six bit symbol and an 8B10B encoder replaces an entire eight bit byte with 10 symbols. Block substitution codes encode the data more efficiently. If Manchester code is used to transmit data at 100 Mbits/second, the fiber-optic channel must be capable of passing 200 million symbols/second. Baud (Bd) is expressed in units of symbols/second, thus the Manchester encoder in this example requires a serial data link that can work at 200 MBd. If the less efficient Manchester encoder is replaced by a more efficient 4B5B encoder, the same 100 Mbit/second data can be sent at a signaling rate of 125 MBd. In binary transmission systems, the maximum fundamental frequency of the data is half the symbol rate expressed in Bd. When a Manchester encoder is used to send 100 M bit/second data, at a symbol rate of 200 MBd, the maximum fundamental frequency of the data is 100 MHz. By using a 4B5B encoder, the same 100 Mbit/second data can be transmitted at 125 MBd, at a maximum fundamental frequency of 62.5 MHz.

The minimum fundamental frequency that the fiber-optic link must pass is also determined by the encoding rule chosen. The run limit of the encoder determines the maximum number of symbol periods that the encoder will allow before it forces a transition,

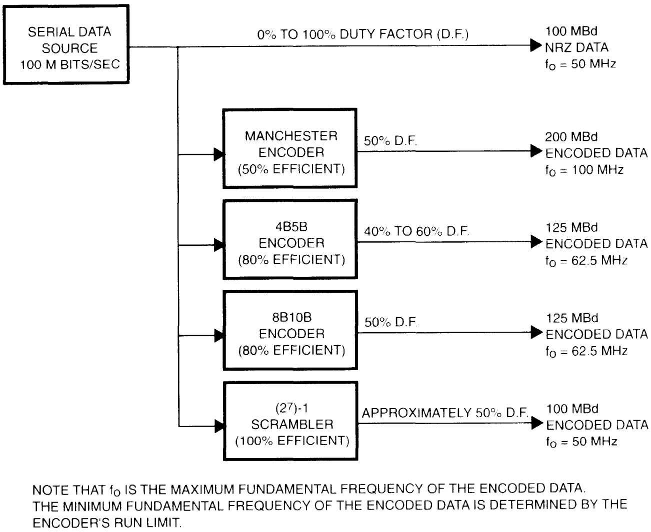


Figure 2. Attributes of Encoding

thus the encoder's run limit determines the minimum fundamental frequency of the encoded data. Manchester code will allow only two symbol periods to pass without a transition. As many as three symbol times without a transition will be allowed by the 4B5B encoder used in the AMD TAXIchip™.

Figure 2 illustrates the attributes of various encoding techniques. Figure 2 shows that as encoder efficiency improves, the bandwidth needed in the fiber-optic communication channel is reduced. Conversely, for a fixed communication channel bandwidth the number of bits/second that can be transmitted will increase as encoder efficiency improves.

Off-the-Shelf Parallel-to-Serial and Serial-to-Parallel Converter Chips

Large scale integrated physical layer circuits (PHY chips) such as the AMD TAXIchip, CYPRESS HOTLink and PMC Sierra S/UNI LITE do more than encode the data. Modern PHY chips provide the digital and analog functions needed to transform the parallel data found in virtually all parallel architecture computer-based systems to the serial data needed for transmission via an optical fiber communication link. The mixed-signal LSI chip at the transmitting end of the fiber-optic link synthesizes a high-frequency clock from the host system's byte-rate clock, multiplexes parallel TTL data to serial data and provides the control words and synchronizing signals needed to manage a serial data communication link. The mixed-signal LSI chip at the receiving end contains a phase-locked loop to recover the clock signal imbedded in the received serial data, a decoder to strip off the encoding, plus a demultiplexer that converts the serial data and control signals back to a parallel TTL output. The high-speed serial inputs and outputs of most PHY chips are compatible with +5V ECL (PECL) logic. Since the fiber-optic transceiver described in this application note has PECL-compatible inputs and outputs, it can be easily combined with the TAXIchip, HOTLink or S/UNI-LITE chips to build byte-to-light communication systems.

Only One Transceiver Design Needed

This application note will show that various HP LED transmitters and PIN-diode pre-amplifiers can be used in a single transceiver design that can be electronically down-loaded and imbedded into a wide range of products to provide very low-cost data communication solutions. Without changing the form-factor or printed circuit design, the transceiver shown in this publication can be populated with components that can send digital data via plastic optical fiber, hard clad silica fiber, multimode glass fiber or single-mode glass fiber. When these schematics and printed circuit artworks are electronically imported and imbedded into your system, the same inexpensive transceiver circuit can be used with a wide variety of fiber-optic cables so that one design can be used to address an extremely wide range of data communication applications.

Distances Achievable at Data Rates up to 160 MBd

The simple transceivers recommended in this application can be used to address a very wide range of distances, data rates and system cost targets. The maximum distances allowed with various types of optical fiber and HP's wide range of fiber-optic transceiver components are shown Table 1. No transmitter or receiver adjustments are needed when using fiber cable lengths that vary from virtually zero length up to the maximum distances specified in Table 1.

Simple PECL-Compatible LED Transmitter

A high-performance, low-cost PECL-compatible transmitter is shown in Figure 3. This transmitter recommendation looks deceptively simple but has been highly developed to deliver the best performance achievable with a wide range of HP LED transmitters. The recommended transmitter is also very inexpensive since the 74ACTQ00 gate that modulates the current of the various LED transmitters can typically be obtained for under $0.40. No calculations are needed to determine the passive component needed when using various HP LEDs and various optical fibers. Simply use the recommended component values shown in Table 2, and the transmitter shown in Figure 3 can be used to address a wide range of applications.

Simple High-Sensitivity PECL-Compatible Receiver

A very simple PECL-compatible receiver with excellent sensitivity and suited for a wide range of applications is shown in Figure 4. The receiver in Figure 4 is optimal for operation at any data rate between 20 and 160 MBd. A single low-cost 10H116 ECL line receiver is used to amplify and digitize the output of the HP PIN diode pre-amp component, which functions as the receiver's first stage. The third section of the 10H116 integrated circuit is configured to provide hysteresis, so that when no light is applied to the receiver's optical input the digital output of the receiver will not chatter. The simple low-cost circuit shown in Figure 4 provides excellent sensitivity, adequate for many applications. Some data communication protocols however require that the optical receiver provide an optical link status flag (also known as signal detect) that switches state when received power is low, or the optical fiber is disconnected. An alternative receiver that provides this signal detect function is shown in Figure 5. Both receiver circuits have similar relationships between sensitivity, and error rate, since the random noise from the HP PIN diode pre-amp used in the first stage has a dominant effect upon the receiver's performance.

Table 1

LED Transmitter Component Part # and Wavelength	Receiver Component Part # and Wavelength	Fiber Diameter Type	Maximum Distance at 160 MBd with the transceiver circuits recommended in this publication
HFBR-15X7 650 nm	HFBR-25X6 650 nm	1 mm plastic step index NA = 0.35	50 meters with the transceiver in Fig. 7 or Fig. 8
HFBR-15X7 650 nm	HFBR-25X6 650 nm	200 µm HCS step index NA = 0.37	50 meters with the transceiver in Fig. 7 or Fig. 8
HFBR-14X2 820 nm	HFBR-24X6 820 nm	200 µm HCS step index = 0.37	50 meters with the transceiver in Fig. 7 or Fig. 8
HFBR-14X4 820 nm	HFBR-24X6 820 nm	62.5/125 µm multimode glass	500 meters with the transceiver in Fig. 7 or Fig. 8
HFBR-13X2 1300 nm	HFBR-23X6 1300 nm	62.5/125 µm multimode glass	2 kilometers with the transceiver in Fig. 7 or Fig. 8
HFBR-1315 1300 nm	HFBR-2315 1300 nm	9/125 µm single-mode glass	6 kilometers with the transceiver in Fig. 7 or Fig. 8

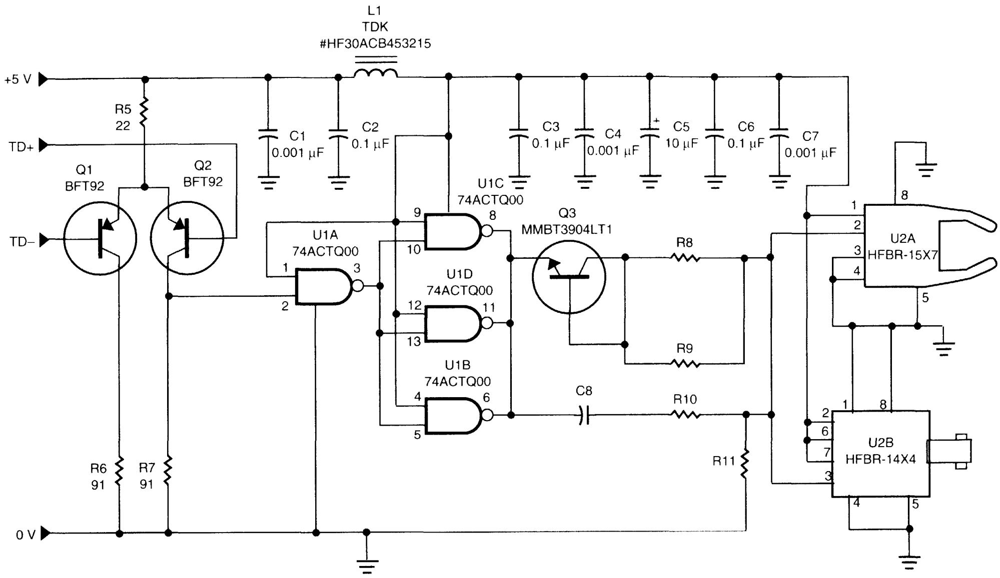


Figure 3. +5 V ECL (PECL-compatible) 160 MBd Fiber-optic Transmitter

Table 2

Transmitter	HFBR-15X7 650 nm LED		HFBR-14X2 820 nm LED	HFBR-14X4 820 nm LED	HFBR-13X2 1300 nm LED	HFBR-13X5 1300 nm ELED
Fiber Type	1 mm Plastic	200 μm HCS	200 μm HCS	62.5/125 μm	62.5/125 μm	9/125 μm
R8	301 Ω	82.5 Ω	300 Ω	84.5 Ω	78.7 Ω	53.6 Ω
R9	301 Ω	82.5 Ω	300 Ω	84.5 Ω	78.7 Ω	53.6 Ω
R10	15 Ω	15 Ω	82 Ω	56 Ω	47 Ω	33 Ω
R11	1 kΩ	475 Ω	2.2 kΩ	2.2 kΩ	∞	1.2 kΩ
C3	43 pF	120 pF	18 pF	33 pF	56 pF	56 pF

A Complete Fiber-Optic Transceiver Solution

Figure 6 shows the schematic for a complete fiber-optic transceiver. This transceiver is constructed on a printed circuit, which is 1" wide by 1.97" long, using surface-mount components. When the transceiver shown in Figure 6 is tested at a data rate of 155.5 MBd, using a 50 m length of 1 mm diameter plastic optical fiber with a numerical aperture (N.A.) of 0.33, it provides a typical eye opening of 3.6 ns at a BER of $\leq 1.1 \times 10^{-10}$. Designers interested in inexpensive solutions are encouraged to embed the complete fiber-optic transceiver described in this application note into the next generation of new data communication products. The circuit in Figure 6 matches the electrical functions of industry-standard 1300 nm transceiver modules, with the exception that there is no signal-detect function in the Figure 6 circuit (pin 4 is nonfunctional). If your system's protocol requires a signal-detect feature, the transceiver shown in Figure 7 will provide it. The transceiver circuits shown in Figure 6 or Figure 7 can be directly inserted into boards designed for industry-standard fiber-optic transceivers modules with a 1X9 footprint and used as a cost-effective alternative in industrial, medical, telecom and proprietary data communication applications.

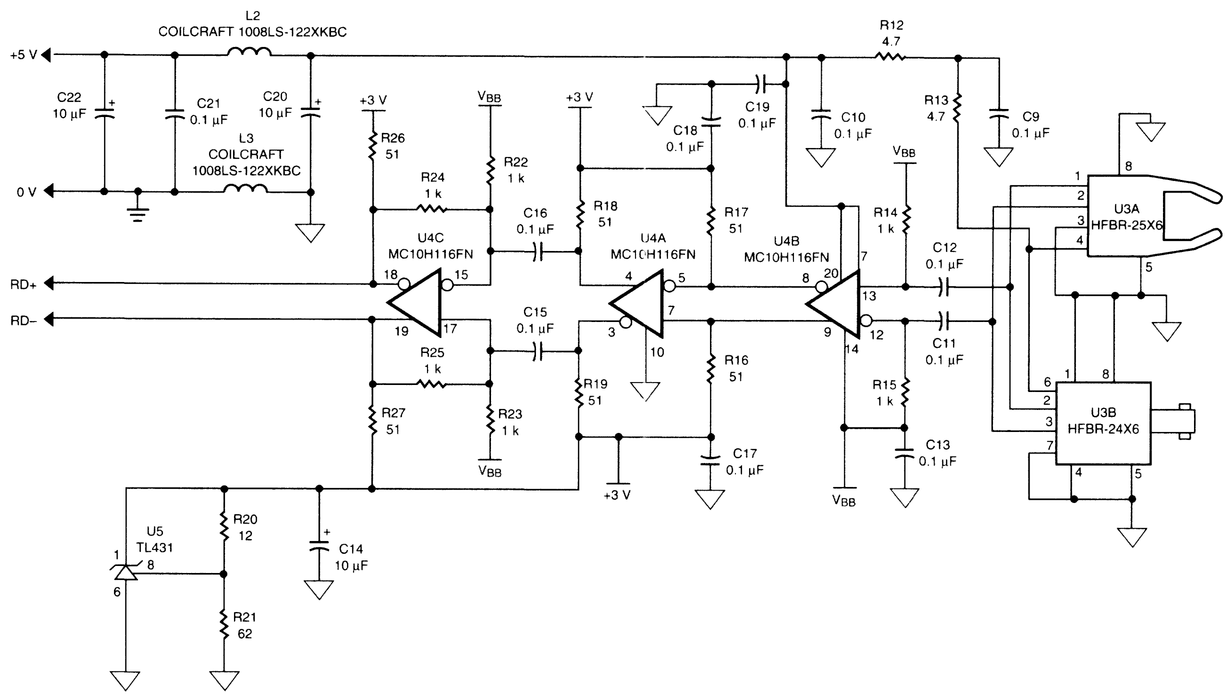


Figure 4. +5 V ECL (PECL-compatible) 160 MBd Fiber-optic Receiver

Table 3

Receiver	HFBR-25X6 650 nm		HFBR-24X6 820 nm	HFBR-23X6 1300 nm	HFBR-2315 1300 nm
Fiber Type	1 mm Plastic	200 µm HCS	62.5/125 µm	62.5/125 µm	9/125 µm

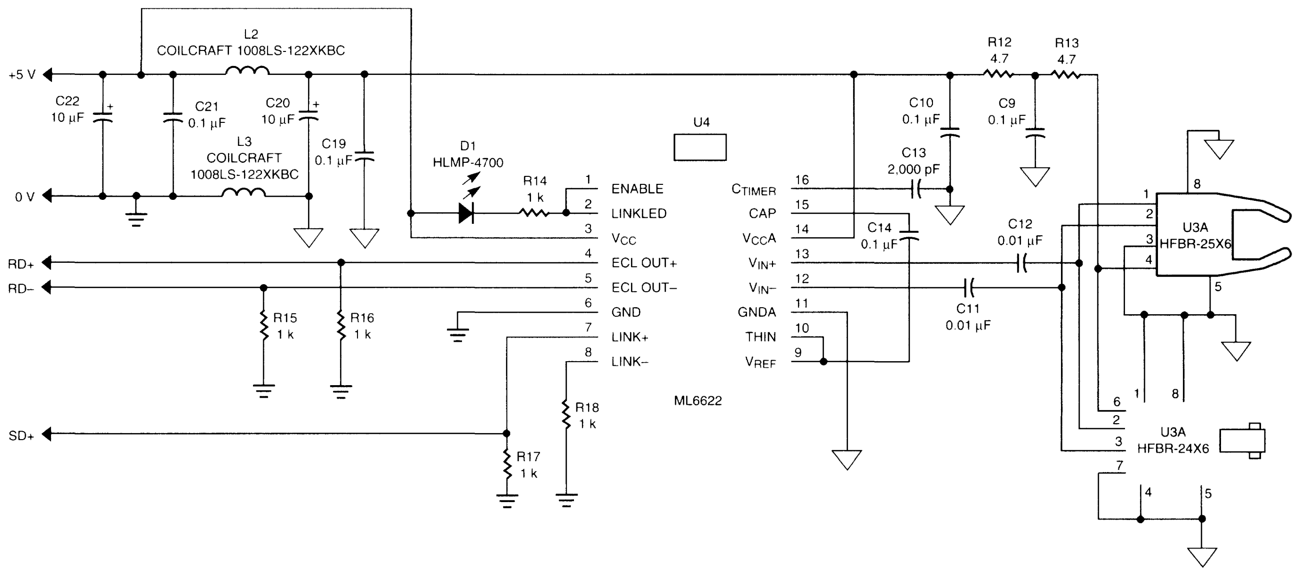


Figure 5. PECL-compatible 160 MBd Fiber-optic Receiver with Signal-Detect Function

Table 4

Receiver	HFBR-25X6 650 nm		HFBR-24X6 820 nm	HFBR-23X6 1300 nm	HFBR-2315 1300 nm
Fiber Type	1 mm Plastic	200 µm HCS	62.5/125 µm	62.5/125 µm	9/125 µm

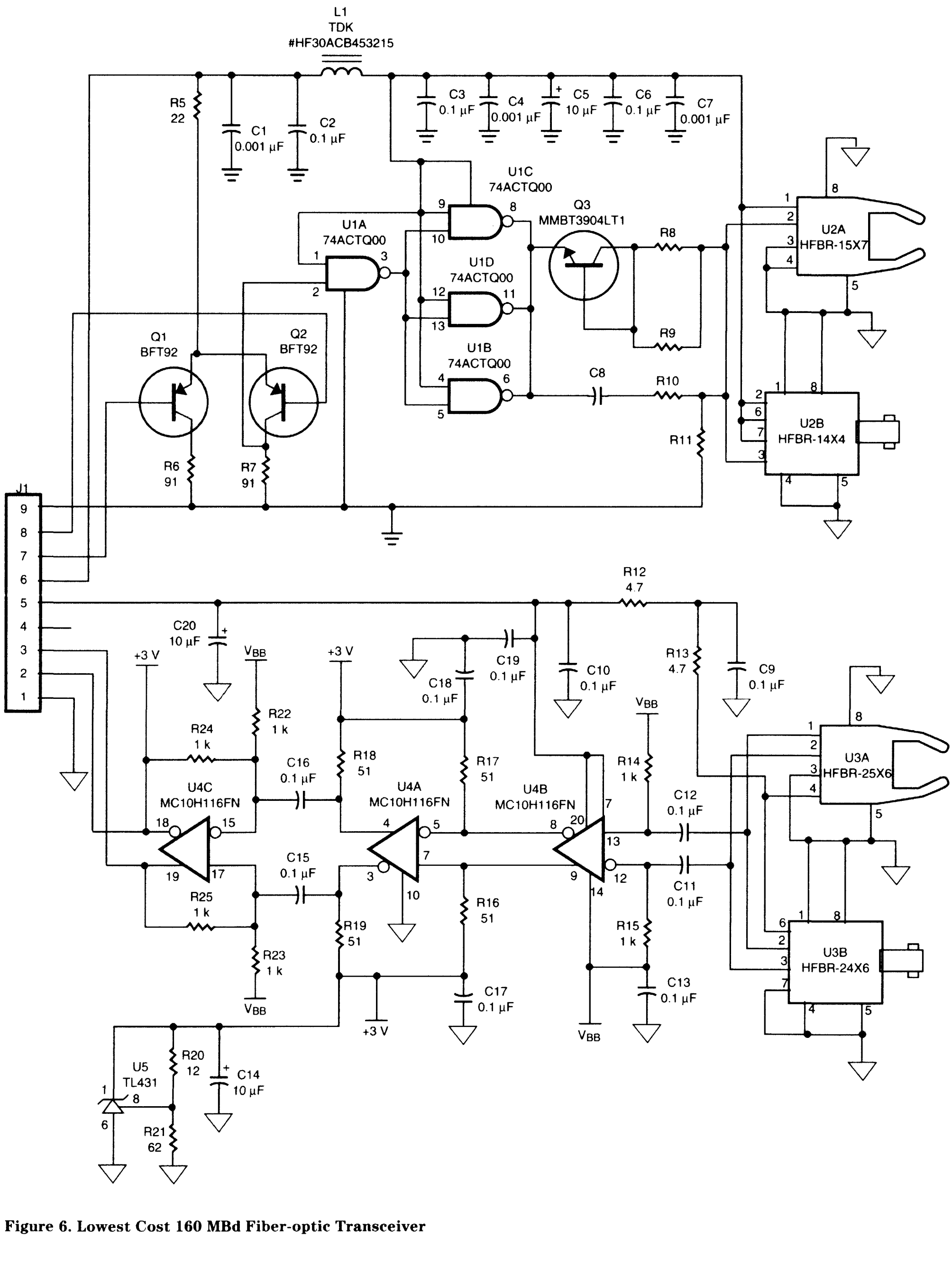


Figure 6. Lowest Cost 160 MBd Fiber-optic Transceiver

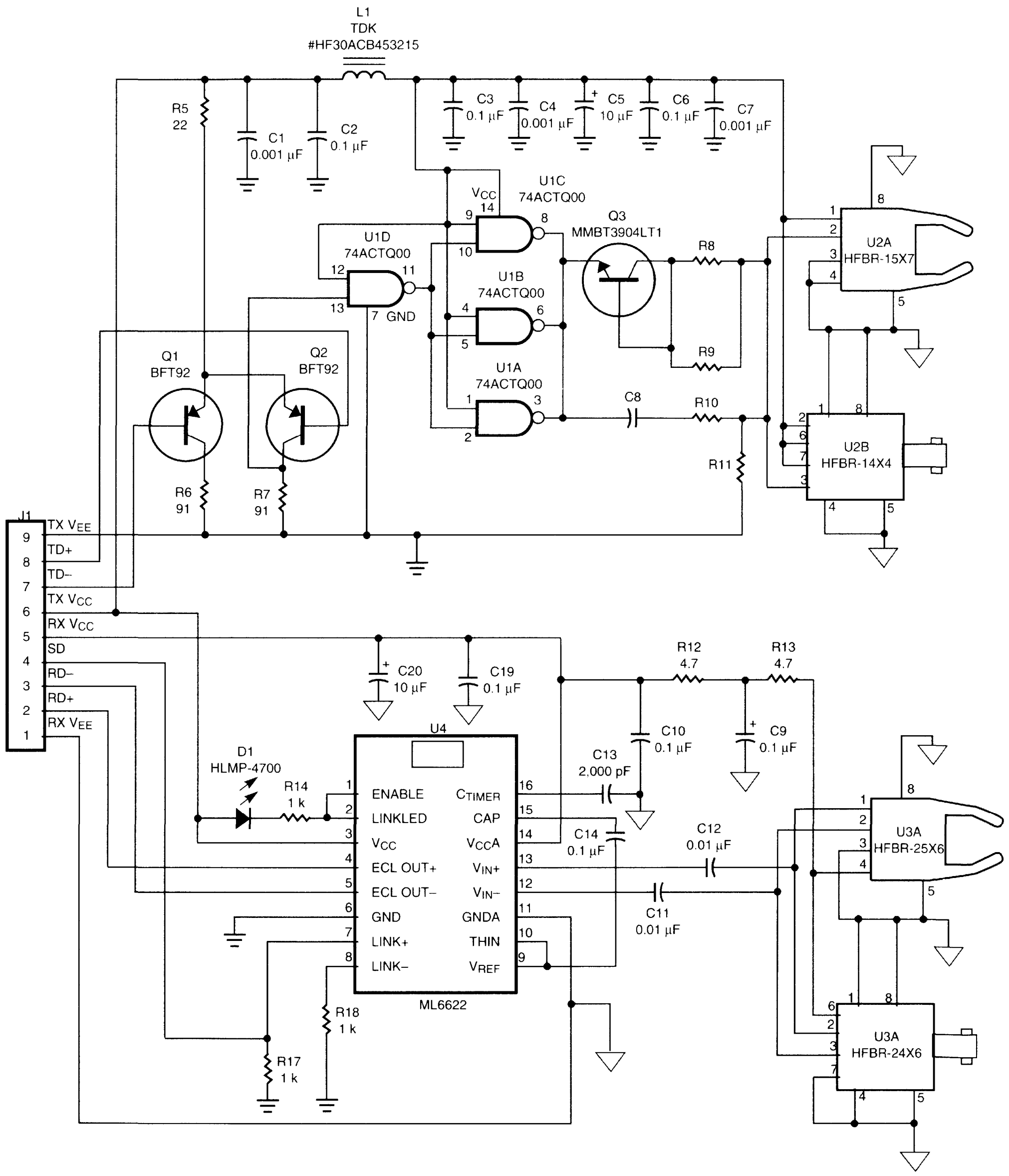


Figure 7. Full-featured 160 MBd Fiber-optic Transceiver with Signal-Detect Function

Signal Terminations and Power Supply Filtering Requirements

If the proper signal terminations and power supply filter circuits are used, the transceiver circuits in Figure 6 and Figure 7 have been proven to provide excellent performance. When using serializer and deserializer chips that provide PECL-compatible high-speed serial inputs and outputs, the power supply filter and terminations shown in Figure 8 are required. The signal terminations and power supply filtering shown in Figure 9 are required if the fiber-optic transceivers recommended in this application note are used with the PMC-Sierra PM5946 S/UNI-LITE chip for SONET OC-3 applications.

Error Rates and Noise Immunity

The probability that a fiber-optic link will make an error is related to the receiver's own internal random noise and the receiver's ability to reject noise originating from the system in which it is installed. The total noise present in any fiber-optic receiver is normally the sum of the PIN diode pre-amplifier's noise and the host

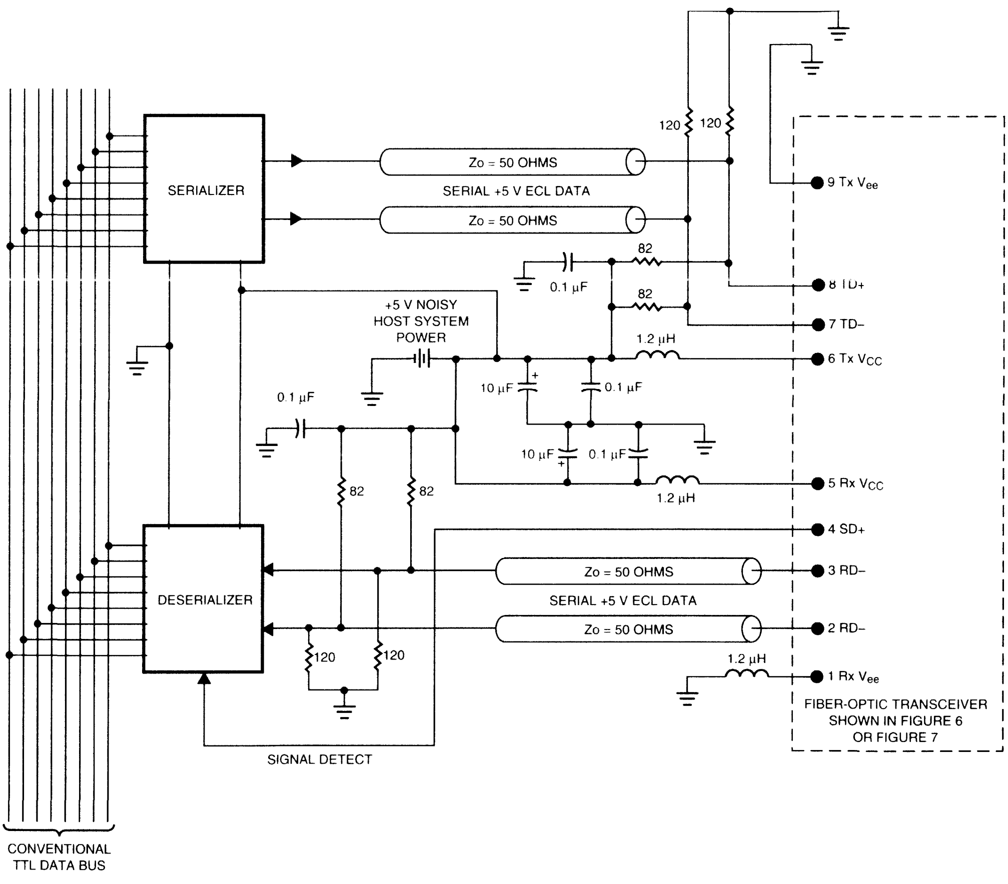


Figure 8. Recommended Power Supply Filter and +5 V ECL (PECL) Signal Terminations for the AMD TAXIchip™ and Cypress HOTLink™

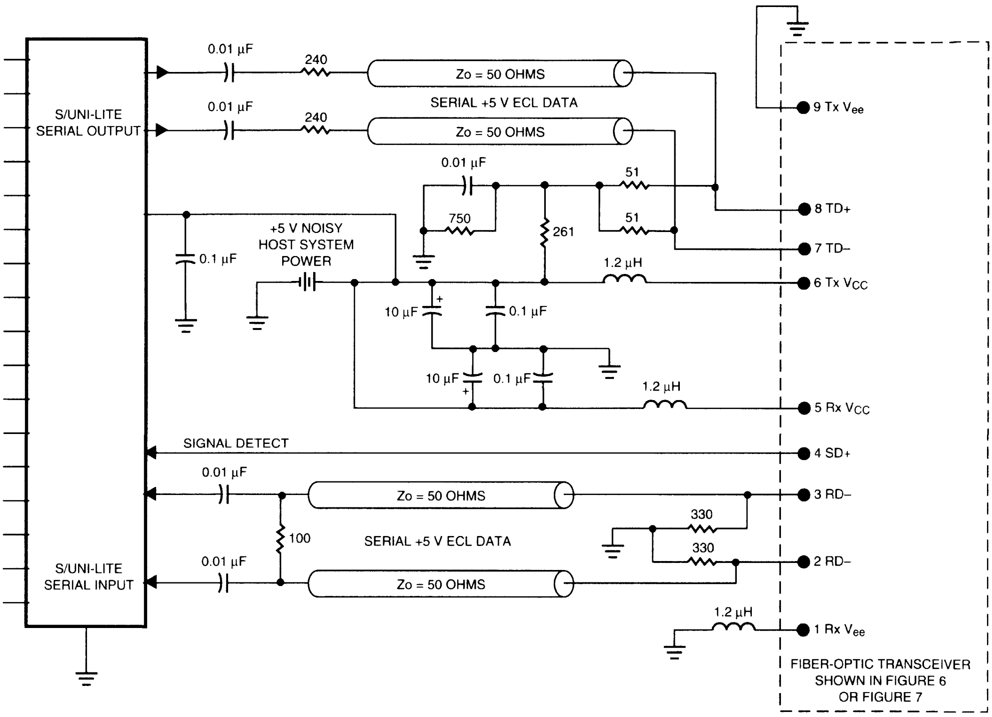


Figure 9. Recommended Power Supply Filter and +5 V ECL (PECL) Signal Terminations for the PMC-Sierra PM5946 S/UNI-LITE™

system's electrical noise. As the optical signal applied to the receiver increases, the probability that the receiver's total noise will alter the data decreases. Small increases in the receiver's signal-to-noise ratio will result in a very sharp reduction in the probability of error. Figure 10 shows that the receiver's probability of error is reduced by 6 orders of magnitude (from $1x10^{-9}$ to $1x10^{-15}$) when the receiver's signal-to-noise ratio improves from 12:1 to 15.8:1.

At any fixed temperature, the total value of the receiver's random noise plus the host system's noise can be assumed to be a constant, so the most obvious way to reduce the probability of error is to increase the amplitude of the optical signal applied to the receiver. A less obvious technique for lowering the error rate is to improve the receiver's ability to reject electrical noise from the system in which it resides. The fiber-optic receivers recommended in this application note have sufficient noise immunity to be used in most systems without electrostatic shielding. The HP PIN diode pre-amps, which are used in the receiver's first stage, are physically small hybrid circuits, and they do not function as particularly effective antennas. For

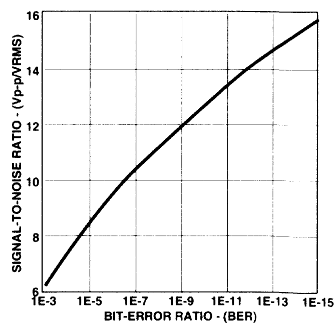


Figure 10. Receiver Signal-to-Noise Ratio vs. Probability of Error (aka BER)

extremely noisy applications, HP offers PIN diode pre-amps in electrically conductive plastic or metal packages. HP manufactures a wide range conductive and non-conductive fiber-optic components that mate with various industry standard fiber-optic connectors, but the overwhelming majority of the fiber-optic applications successfully implemented with HP's fiber-optic components have not required conductive plastic or metal receiver housings.

The most insidious and the most overlooked source of noise is usually the host system's +5V power supply. The host system's +5 volt supply normally powers the fiber-optic receiver, the fiber-optic transmitter and an entire system comprised of relatively noisy digital circuits. The simple and inexpensive power supply filters shown in Figure 8 and Figure 9 of this publication have been proven to work in a wide range of system applications and these recommended power supply filters are normally sufficient to protect the fiber-optic receiver from very noisy host systems.

Printed Circuit Artwork

The performance of transceivers that use HP fiber-optic components are partially dependent on the layout of the printed circuit board on which the transceiver circuits are constructed. To achieve the fiber-optic link performance described in Table 1 system designers are encouraged to imbed the printed circuit design provided in this application note. The printed circuit artwork in Figure 11 is for the transceiver shown in Figure 6. If your system requires a fiber-optic receiver with a signal-detect feature, the artwork shown in Figure 12 can be used to construct the transceiver shown in Figure 7. Electronic copies of the "Gerber" files for the artwork shown in this application note can be obtained by using the Internet to download the printed circuit designs located at the following URL:

http://www.hp.com/HP-COMP/fiber/fiber_index.html

Download the file named **raftv3.exe** to obtain the artwork for the transceiver shown in Figure 6. Download the file named **sor_v3.exe** to obtain the artwork for the transceiver shown in Figure 7.

Parts List

The PECL-compatible fiber-optic transceivers recommended in this publication are very simple and inexpensive, so only a few external components are needed. Complete parts lists are provided in Table 5 and Table 6. All of the components are compatible with the printed circuit artworks shown in Figures 11 and 12, thus minimizing the design time and resources needed to use the low cost fiber-optic transceivers shown in this application note.

Conclusion

The complete PECL-compatible fiber-optic transceiver solutions provided in this publication can be used to build new data communication systems that work at higher data rates and provide better noise immunity than possible with copper wire. When fiber-optic media is used in place of conventional copper wire, it is possible to build new communication systems that are immune to large noise transients caused by utility power switch gear, motor drives or high-voltage power supplies. Furthermore, the non-conductive cables used in optical communication links have an intrinsically higher probability of surviving lightning strikes than copper wire alternatives. The optical data communication solutions shown in this application note can also send high-speed, 160 MBd data over long distances impossible with copper wire cables. By imbedding the complete solutions shown in this application note, system designers can quickly develop a new generation of high-speed, noise-immune, optical communication links in a very short time with minimal research and development costs.

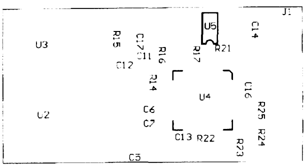


Figure 11a. Top Overlay

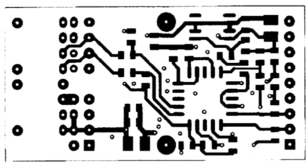


Figure 11b. Top Layer

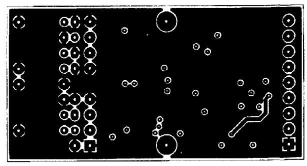


Figure 11c. Mid Layer 2

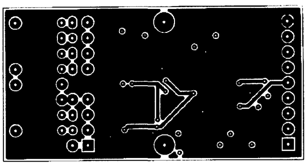


Figure 11d. Mid Layer 3

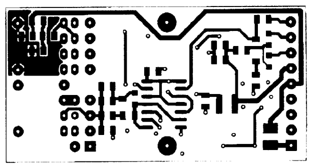


Figure 11e. Bottom Layer

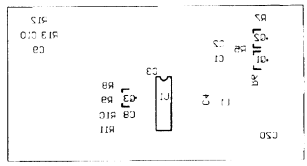


Figure 11f. Bottom Overlay

WARNING: DO NOT USE PHOTOCOPIES OR FAX COPIES OF THIS ARTWORK TO FABRICATE PRINTED CIRCUITS.

Figure 11. Printed Circuit Artwork for Transceiver shown in Figure 6

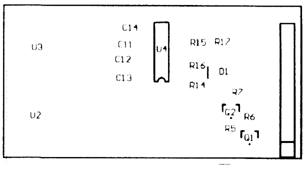


Figure 12a. Top Overlay

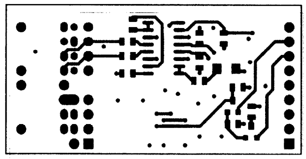


Figure 12b. Top Layer

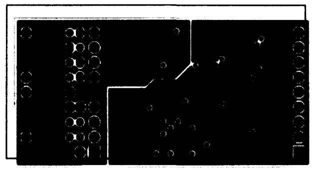


Figure 12c. Mid Layer 2

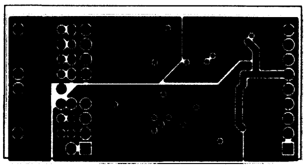


Figure 12d. Mid Layer 3

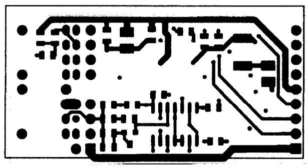


Figure 12e. Bottom Layer

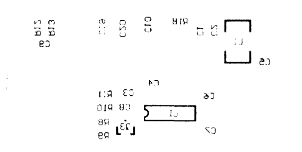


Figure 12f. Bottom Overlay

WARNING: DO NOT USE PHOTOCOPIES OR FAX COPIES OF THIS ARTWORK TO FABRICATE PRINTED CIRCUITS.

Figure 12. Printed Circuit Artwork for Transceiver shown in Figure 7

Table 5. Parts List for the Transceiver in Figure 6

Designator	Part Type	Description	Footprint	Material	Part Number	Quantity	Vendor 1
C1	0.001 µF	Capacitor	805	NPO/COG	C0805NPO500102JNE	3	Venkel
C4	0.001 µF	Capacitor					
C7	0.001 µF	Capacitor					
C10	0.1 µF	Capacitor	805	X7R or better	C0805X7R500104KNE	13	Venkel
C11	0.1 µF	Capacitor					
C12	0.1 µF	Capacitor					
C13	0.1 µF	Capacitor					
C15	0.1 µF	Capacitor					
C16	0.1 µF	Capacitor					
C17	0.1 µF	Capacitor					
C18	0.1 µF	Capacitor					
C19	0.1 µF	Capacitor					
C2	0.1 µF	Capacitor					
C3	0.1 µF	Capacitor					
C6	0.1 µF	Capacitor					
C9	0.1 µF	Capacitor					
C14	10 µF	Capacitor	B	Tantalum, 10 V	TA010TCM106MBN	3	Venkel
C20	10 µF	Capacitor					
C5	10 uF	Capacitor					
C8	See Table 2	Capacitor	805	NPO/COG		1	Venkel
U1	I.C.	Nand Gate	SO14		74ACTQ00	1	National
U2	Fiber-Optic	Transmitter		See Table 2	HFBR-1XXX	1	HP
U3	Fiber-Optic	Receiver		See Table 2	HFBR-2XXX	1	HP
U4	MC10H116FN	IC,ECL line rec.	PLCC20		MC10H116FN	1	Motorola
U5	TL431CD	IC, Voltage Reg.	SO-8		TL431CD	1	T.I.
L1	CB70-1812	Inductor	1812		HF30ACB453215	1	TDK
R12	4.7	Resistor	805	5%	CR080510W4R7JT	2	Venkel
R13	4.7	Resistor					
R20	12	Resistor	805	5%	CR080510W120JT	1	Venkel
R10	See Table 2	Resistor	805	5%		1	Venkel
R5	22	Resistor	805	5%	CR080510W220JT	1	Venkel
R16	51	Resistor	805	5%	CR080510W510JT	4	Venkel
R17	51	Resistor					
R18	51	Resistor					
R19	51	Resistor					
R21	62	Resistor	805	5%	CR080510W620JT	1	Venkel
R8	See Table 2	Resistor	805	1%		2	Venkel
R9	See Table 2	Resistor					
R6	91	Resistor	805	5%	CR080510W910JT	2	Venkel
R7	91	Resistor					
R11	See Table 2	Resistor	805	1%		1	Venkel
R14	1 k	Resistor	805	5%	CR080510W102JT	6	Venkel
R15	1 k	Resistor					
R22	1 k	Resistor					
R23	1 k	Resistor					
R24	1 k	Resistor					
R25	1 k	Resistor					
Q1	BFT92	Transistor	SOT-23		BFT92	2	Philips
Q2	BFT92	Transistor					
Q3	MMBT3904LT1	Transistor	SOT-23		MMBT3904LT1	1	Motorola
J1		Pins			343B	9	McKenzie

Table 6. Parts List for the Transceiver in Figure 7

Designator	Part Type	Description	Footprint	Material	Part Number	Quantity	Vendor 1
C1 C4 C7	0.001 μF 0.001 μF 0.001 μF	Capacitor	805	NPO/COG	C0805NPO500102JNE	3	Venkel
C2 C3 C6 C9 C10 C14 C19	0.1 μF 0.1 μF 0.1 μF 0.1 μF 0.1 μF 0.1 μF 0.1 μF	Capacitor Capacitor Capacitor Capacitor Capacitor Capacitor Capacitor	805	X7R or better	C0805X7R500104KNE	7	Venkel
C5 C20	10 μF 10 μF	Capacitor Capacitor	B	Tantalum, 10 V	TA010TCM106MBN	2	Venkel
C8	See Table 2	Capacitor	805	NPO/COG		1	Venkel
C11 C12	0.01 μF 0.01 μF	Capacitor Capacitor	805	X7R or better	C0805X7R500103JNE	2	Venkel
C13	2,000 pF	Capacitor	805	NPO/COG	C0805NP0500202JNE	1	Venkel
D1	HLMP-4700	LED lamp			HLMP-4700	1	HP
U1	I.C.	Nand Gate	SO14		74ACTQ00	1	National
U2	Fiber-Optic	Transmitter		See Table 2	HFBR-1XXX	1	HP
U3	Fiber-Optic	Receiver		See Table 2	HFBR-2XXX	1	HP
U4	ML6622	IC, quantizer	SO16		ML6622CS	1	MicroLinear
L1	CB70-1812	Inductor	1812		HF30ACB453215	1	TDK
R12 R13	4.7 4.7	Resistor Resistor	805	5%	CR080510W4R7JT	2	Venkel
R10	See Table 2	Resistor	805	5%		1	Venkel
R5	22	Resistor	805	5%	CR080510W220JT	1	Venkel
R8 R9	See Table 2 See Table 2	Resistor Resistor	805	1%		2	Venkel
R6 R7	91 91	Resistor Resistor	805	5%	CR080510W910JT	2	Venkel
R11	See Table 2	Resistor	805	1%		1	Venkel
R14 R17 R18	1 k 1 k 1 k	Resistor Resistor Resistor	805	5%	CR080510W102JT	3	Venkel
Q1 Q2	BFT92 BFT92	Transistor Transistor	SOT-23		BFT92	2	Philips
Q3	MMBT3904LT1	Transistor	SOT-23		MMBT3904LT1	1	Motorola
J1		Pins			343B	9	McKenzie

HEWLETT® PACKARD

Generic Printed Circuit Layout Rules for HP's Low-Cost Fiber-Optic Components

Application Note 1137

Introduction

Hewlett-Packard's discrete fiber-optic components have been used to construct high-performance optical transmitters and receivers for numerous cost-sensitive LAN, telecom, industrial, and proprietary point-to-point data communication applications. When using discrete fiber-optic components the layout of the printed circuit board will have a significant impact upon the performance of the optical transmitter and receiver. A printed circuit board layout for inexpensive, high-performance fiber-optic transceivers can usually be developed in one design cycle, using the generic rules described in this publication.

What are discrete fiber-optic components?

HP manufactures a broad range of discrete transmitter, receiver, and transceiver components suited for use with a wide variety of fiber-optic cables and connectors. Discrete transmitter components have integral LED or LASER optical emitters, lens assemblies, and housings that mate with industry-standard fiber-optic connectors. This publication will focus upon discrete transmitters implemented with planar- and edge-emitting LEDs. Discrete LED transmitters have been successfully designed into a wide range of data communication applications. This technology is popular because discrete LEDs can meet tough performance, reliability, and cost targets when used in conjunction with very simple, inexpensive circuitry. Discussions regarding the use of discrete LASER transmitters are beyond the scope of this application note.

Receiver components also have integral lens assemblies and housings that are compatible with various industry-standard fiber-optic connectors. At data rates less than 10 MBd, receiver components can be manufactured using monolithic optical detectors that integrate all of the functions needed to provide TTL-compatible outputs. Digital fiber-optic receivers are usually highly integrated at data rates less than 10 MBd, but these integrated receiver components are often classified as discretes because they are commonly used with discrete LED transmitters that require the use of simple external circuitry.

At data rates greater than 10 MBd the receiver is typically a simple hybrid component that contains an optical detector and a transimpedance amplifier. These hybrid receiver components are commonly known as PIN pre-amplifiers, since they include both the PIN diode detector and the transimpedance amplifier needed to convert detector current to voltage. Hybrid PIN pre-amps are classified as discrete components because they require external passive and active circuitry to digitize the PIN pre-amp's analog output signal. Techniques for using discrete fiber-optic components in low-speed digital applications at data rates less than 10 MBd are described in HP Application Notes 1035 and 1080. This publication focuses upon the printed circuit design methodologies needed for using LED transmitter components and PIN pre-amp components in higher-speed applications at data rates between 10 and 160 MBd.

Differences between discrete fiber-optic components and fiber-optic modules

HP manufactures both discrete fiber-optic components and integrated fiber-optic modules. A fiber-optic module normally includes the LED emitter, PIN pre-amp, lenses and the external housing needed to mate with various types of fiber-optic cables and connectors. In addition, fiber-optic modules typically include the LED driver and receiver digitizing circuits needed to provide logic-compatible inputs and outputs. Fiber-optic modules are usually designed to address specific standards-based applications, whereas fiber-optic components are very flexible since they can be combined with simple external circuits to address a much wider range of proprietary applications. Because they require less external circuitry, fiber-optic modules have commonly been used to reduce design-in costs and shorten product development cycle time.

Implementing digital transceivers with fiber-optic components

Hewlett-Packard's fiber-optic components are easy to use in digital data communication applications. Inexpensive, off-the-shelf, advanced CMOS logic gates are commonly used to current modulate (drive) the LED transmitter components. Low-cost ECL line receiver integrated circuits or off-the-shelf high-speed comparators can be used to digitize (quantize) the analog output voltage of the PIN pre-amp front-end. Integrated quantizers can also be used with PIN pre-amp components to lower the receiver's parts count and provide more functions. One of the objectives of this publication is to simplify the design process for discrete fiber-optic components so that they can be used to address cost-sensitive applications that would normally be implemented with copper wires. For more details about proven circuits recommended for use with inexpensive fiber-optic components in digital data communication applications, please refer to the Hewlett-Packard application notes listed in Table 1.

Table 1. HP Application Notes for Discrete Fiber-Optic Components

Application Note Number	Application	HP Publication Number
AN-1123	20 to 160 MBd with +5V ECL I/O	5966-1269E
AN-1122	2 to 70 MBd with TTL I/O	5966-1270E
AN-1121	dc to 32 MBd with TTL I/O	5966-1353E
AN-1082	Ethernet with single mode fiber	5964-2295E
AN-1073	Testing +5V ECL F.O. transceivers	5963-2202E
AN-1066	1 to 155 MBd with plastic fibers	5966-8542E
AN-1065	Token Ring LANs at 8 or 32 MBd	5963-9626E
AN-1038	Ethernet LANs at 20 MBd	5091-9356E
AB-78	1-155 MBd with glass fibers	5965-6005E

Where do the generic design rules for fiber-optic components apply?

The generic design rules in this publication have been proven to work with HP's 650 nm, 820 nm and 1300 nm discrete fiber-optic components. These generic printed circuit design rules can be applied to all of the HP components and Application Notes listed in Table 2.

Design rules for surface-mount technology

The following rules should be followed if you desire to use surface-mount technology and a four-layer printed circuit board to construct inexpensive fiber-optic transceivers.

1) Design the PC board with different ground and power planes for the transmitter and receiver. Providing two individual ground planes is the critical technique for minimizing crosstalk between the transmitter and receiver circuits. Use wide power distribution traces when power planes are not possible. These techniques reduce the inductance of the ground and power leads, minimize crosstalk between the transmitter and receiver circuits, and maximize the receiver circuit's damping and sensitivity.

2) Minimize the size of cuts or openings in the ground and power planes. This minimizes the parasitic inductance and improves the dampening of both the transmitter and receiver circuits. Route connections between components on the top and bottom planes; locate the ground and power planes on inner layers of the printed circuit. ***Do not*** make long rectangular openings in the power planes if you have several vias in a row. Allow planes to connect between adjacent vias, this assures that there are no long rectangular cuts in the ground or power planes.

Table 2. Components and Application Notes where Generic Layout Rules Apply

HP Publications	Applications	Data Rate (symbols/sec)	Transmitter Part Number	Receiver Part Number	Wavelengths
AB-78	Telecom & Proprietary	10 to 155 MBd	HFBR-14X4 HFBR-1312	HFBR-24X6 HFBR-2316	820 nm 1300 nm
AN-1038	Ethernet	20 MBd	HFBR-14X4	HFBR-24X6	820 nm
AN-1065	Token Ring	8 & 32 MBd	HFBR-14X4	HFBR-24X6	820 nm
AN-1066	Telecom & Proprietary	10 to 155 MBd	HFBR-15X7	HFBR-25X6	650 nm
AN-1082	Ethernet	20 MBd	HFBR-1315	HFBR-2315	1300 nm
AN-1121	Industrial, Medical, Telecom & Proprietary	dc to 32 MBd	HFBR-1312 HFBR-1315 HFBR-14X2 HFBR-14X4 HFBR-15X7	HFBR-2316 HFBR-2315 HFBR-24X6 HFBR-24X6 HFBR-25X6	1300 nm 1300 nm 820 nm 820 nm 650 nm
AN-1122	Industrial, Medical, Telecom & Proprietary	2 to 70 MBd	HFBR-1312 HFBR-1315 HFBR-14X2 HFBR-14X4 HFBR-15X7	HFBR-2316 HFBR-2315 HFBR-24X6 HFBR-24X6 HFBR-25X6	1300 nm 1300 nm 820 nm 820 nm 650 nm
AN-1123	Industrial, Medical, Telecom & Proprietary	20 to 160 MBd	HFBR-1312 HFBR-1315 HFBR-14X2 HFBR-14X4 HFBR-15X7	HFBR-2316 HFBR-2315 HFBR-24X6 HFBR-24X6 HFBR-25X6	1300 nm 1300 nm 820 nm 820 nm 650 nm

3) The two circuit traces that connect the PIN pre-amp to the differential input of the receiver's quantizer should be of equal length and the components in both traces should be placed to achieve symmetry. This minimizes the cross talk between the fiber-optic transmitter and receiver and improves the receiver's immunity to environmental noise. When viewed from the optical inputs and outputs (looking toward the lenses) the LED transmitter should be on the right and the PIN pre-amp should be on the left to minimize crosstalk between the transmitter and receiver.

4) Connections between the drive circuit and the LED should be of minimum length. This minimizes the noise emitted by the transmitter circuit and improves the optical rise/fall time of the LED.

5) A large, 10 µF, electrolytic capacitor and a 0.1 µF monolithic ceramic capacitor should be located as close as possible to the circuit that drives (current modulates) the LED. This minimizes the noise emitted by the transmitter and improves the optical response time of the LED.

6) A ferrite EMI suppressor should be used to isolate the transmitter circuit's 5 V supply from the host system's 5 V supply.

7) Low-pass filters must be used to protect the fiber-optic receiver from noise present in the host system's 5 V power supply. The required power supply filtering can be quickly and easily incorporated by adhering to the recommended schematics published in Hewlett-Packard application notes.

8) Inductors or a common-mode choke should be used in series with the receiver's V_{CC} and V_{EE} connections. (V_{CC} = +5 V and V_{EE} = 0 V.) The receiver should be referenced to V_{CC} and V_{EE} islands that are isolated from the remainder of the host system's power planes. A differential electrical interface at the receiver's output is required if inductors are used in series with V_{CC} and V_{EE}. Figure 1 in Hewlett-Packard Application Note 1122 shows that this differential interface has been imbedded in the quantizer's integrated circuit when using Micro Linear's ML-4624.

9) Use monolithic ceramic chip capacitors. This type of capacitor minimizes parasitic coupling between the receiver's output and input stages. Minimizing the parasitic coupling between the receiver's outputs and inputs assures that the receiver will not oscillate. Monolithic chip capacitors have small geometries that minimize their ability to function as undesirable radiating or receiving antennas. In addition to the features already discussed, monolithic ceramic capacitors have low parasitic inductance and a high self-resonant frequency that make them an excellent choice for radio frequency applications such as fiber-optic transceivers.

10) For capacitances greater than 1.0 µF, tantalum chip capacitors are recommended. Tantalum capacitors are well suited for high-speed fiber-optic transceivers because they have small geometries and are capable of providing a low impedance at high frequencies.

11) The filter network for the +5 V power supply connection to the receiver's PIN pre-amp should be as far as possible from the +5 V bypass capacitors for the driver circuit that current modulates the LED transmitter. The filter network connected to the power pin of the receiver's PIN pre-amp should be physically separated from the LED driver's bypass caps to minimize crosstalk between the fiber-optic transmitter and receiver.

12) Do not fold the receiver layout in an attempt to save board space. The receiver should be constructed in the straightest possible line beginning at the PIN pre-amp and ending at the receiver's logic output. Fiber-optic receivers normally have sufficient gain and phase shift to meet the criteria for oscillation. To achieve stability the receiver's input and output stages must be sufficiently isolated from one another to assure that loop gain is less than one. Receiver stability is easily attained when the printed circuit design rules in this publication are used with the fiber-optic transceiver circuits recommended in Hewlett-Packard application notes.

13) The receiver's power supply filtering is just as important as good printed circuit layout. Undesirable feedback between the receiver's output and the PIN pre-amp input can occur if the receiver's power bus is improperly bypassed. To assure receiver stability the power supply filter circuits recommended in Hewlett-Packard application notes should be used to prevent undesirable conductive feedback through the receiver's +5 volt power connections.

Design rules for through-hole technology

The following rules should be followed if you desire to use through-hole technology and four-layer printed circuit boards to construct inexpensive fiber-optic transceivers. The design rules for surface-mount and through-hole technology are nearly identical so only the rules that have significant differences are described in detail.

1) Use the techniques described for surface-mount technology.

2) Minimize the size of cuts or openings in the ground and power planes. This minimizes the parasitic inductance and improves the dampening of both the transmitter and receiver circuits. Route connections between components on the top and bottom planes; locate the ground and power planes on inner layers of the printed circuit. ***Do not*** make long rectangular openings in the ground and power planes where IC leads or rows of passive component leads penetrate the printed circuit board. Allow the planes to connect between each component lead and allow the plane to connect between every lead of an integrated circuit.

3) Use the techniques described for surface-mount technology.

4) Use the techniques described for surface-mount technology.

5) Use the techniques described for surface-mount technology.

6) Use the techniques described for surface-mount technology.

7) Use the techniques described for surface-mount technology.

8) Use the techniques described for surface-mount technology.

9) Use monolithic ceramic radial lead capacitors. This type of capacitor minimizes parasitic coupling between the receiver's output and input stages. Minimizing the parasitic coupling between the receiver's outputs and inputs assures that the receiver will not oscillate. Monolithic ceramic radial lead capacitors have small geometries which minimize

their ability to function as undesirable radiating or receiving antennas. In addition to the features already discussed, monolithic ceramic capacitors have low parasitic inductance and a high self resonant frequency that make them an excellent choice for radio frequency applications such as fiber-optic transceivers.

10) For capacitances greater than 0.47 µF, tantalum capacitors are recommended. Tantalum capacitors are well suited for high speed fiber-optic transceivers because they are physically small, have low ESR, and are capable of providing a low impedance at high frequencies.

11) Use the techniques described for surface-mount technology.

12) Use the techniques described for surface-mount technology.

13) Use the techniques described for surface-mount technology.

Conclusions

The generic design rules in this publication have been applied to every currently available Hewlett-Packard application note regarding the use of fiber-optic components. These rules were used to design the printed circuits shown in nine HP fiber-optic application notes published over a six year period. Designers interested in using inexpensive fiber-optic components are encouraged to imbed the circuits and printed circuit layouts shown in HP's application notes. Printed circuit artwork for HP's fiber-optic components can be electronically downloaded from the Hewlett-Packard Components Group web page at **http://www.hp.com/HP-COMP/fiber/fiber_index.html.** If the existing artworks shown in HP's application notes are not compatible with your manufacturing process or form factor requirements, then the generic rules in this publication are useful for quickly designing your own unique printed circuit with a minimal amount of engineering effort.

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