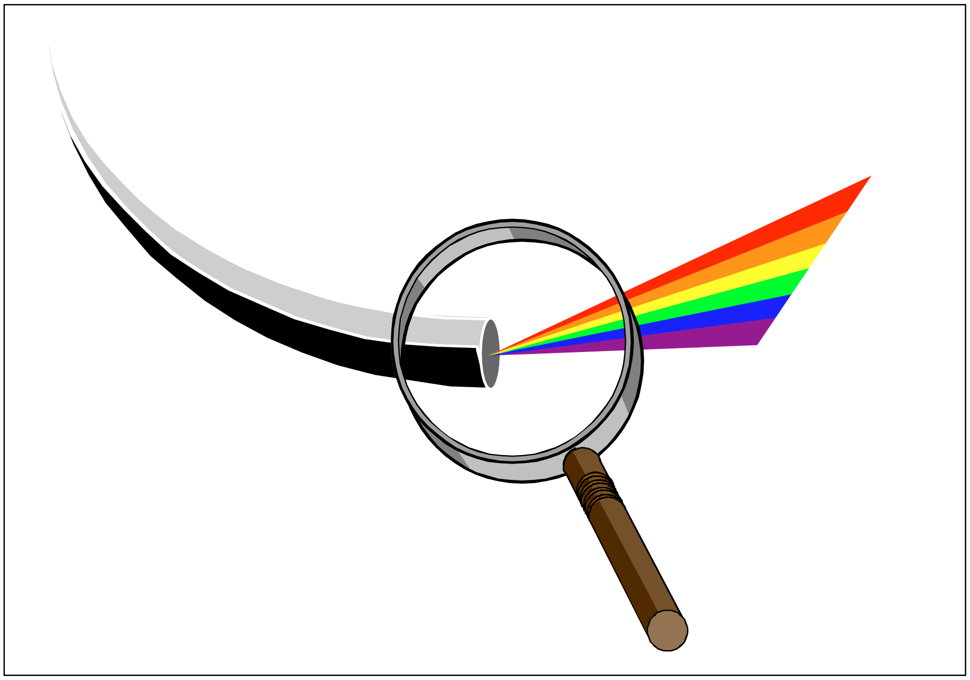
Tektronix

Technical Brief

Performance Assessment of Photonic Networks



TOPICS COVERED:

- **Photonic network overview, market maturity, standardization, and system architectures**
- **Photonic network performance parameter categories and correlation**
- **Optical physical layer performance parameters**
- **Signal transmission layer performance parameters**
- **Data transport layer performance parameters**

Ensuring High Transmission Quality in the Optical Transport Network

Introduction

This technical brief reviews the performance parameters that are used to specify the quality of photonic networks, and examines how they can be effectively tested and assessed.

We focus on the use of SDH/SONET signals as the client-layer service, since this is the mainstream application of Wavelength Division Multiplexing (WDM) technology in core networks today. Other applications of WDM to support PDH services, IP data, and even analog signals are or may be possible in the future.

For the purposes of this technical brief, the transmission network is divided into three layers so that different impairments and different test methods can be clearly categorized:

- Optical physical layer
- Signal transmission layer
- Data transport or client layer

It's difficult to correlate measurements made at the optical layer, with the performance of a higher layer; e.g., the client layer. This is primarily because optical impairments combine in a complex analog fashion – the consequence of which is not easily predicted. This critical issue is discussed and some implications reviewed.

Testing philosophies are discussed, particularly as they apply to the cost-effective manufacture and qualification of WDM systems.

Note: Throughout this technical brief, SDH terminology is used; SONET systems and applications can be considered equivalent within the context of this paper.

Photonic Network Overview

WDM technology doesn't just promise increased capacity and lower costs; the reality is being established in networks around the world. It provides operators with an immediately-increased bandwidth without deploying new fiber. The business benefits for operators are real.

There's a tremendous demand for new services from the Internet and advanced video services. And of course, many operators are enthusiastic to gain revenue from these new services. WDM is being established as a key tool that will help them accomplish that.

WDM as a technology has been in laboratories for many years – almost since optical fibers were first invented. However, it is only recently that it's been used in real volume applications out in the network, so there are still issues to be solved.

For example, there may be issues regarding integration and compatibility with existing networks and some of these may not be apparent until the network is actually installed.

Finally, operators and manufacturers are demonstrating in the current trial networks that the available systems are robust enough to carry traffic for customer applications.

Photonic Market Maturity

It's reasonable to say that WDM and the much-heralded photonic network is, in terms of evolution today, where the SDH network was in 1989/90:

- International standards that exist are certainly incomplete
- Further standardization is needed to guarantee inter-vendor (transverse) compatibility
- Trial networks are being installed to gain experience
- Practical network architectures are limited to point-to-point schemes

Due to the early phase of market development, there's a clear impact on system design and installation:

- Lack of absolute industry standards to test to creates uncertainty in performance requirements and assessment methods
- There are compatibility issues during system deployment and interworking
- There is an increased chance that deployed systems may need to be upgraded in the future

Nevertheless, the problems are being overcome and the market moves inexorably towards an early maturity.

Photonic Standardization

Progress in standardization organizations such as ITU-T and ETSI has been established, which is a significant driver towards market maturity.

Development of some early standards in the WDM arena has unfortunately been delayed due to Intellectual Property Rights issues and patents held by various companies. Nevertheless, the key Recommendations G.691 and G.692 (previously known as G.scs and G.mcs) have been published by ITU-T as stable drafts and are in widespread use by the industry.

The ITU-T has created a phased development plan (actually defining quite aggressive time scales) for new optical standards:

- Phase I: Standardize point-to-point systems; target completion – end of 1998
- Phase II: Extend standards to include add-drop muxes and optical cross-connects; target completion – mid 2000
- Phase III: Extend standards to cover optical layer survivability; target completion – beyond year 2000

A comprehensive list of relevant ITU-T Recommendations is provided at the end of this paper.

WDM System Architecture Categories

By definition, WDM systems operate in the optical frequency and wavelength domain and one objective often stated is that they should be transparent to the type of client signal being transported. In reality, some constraint is always placed on the client-layer characteristics.

Two general categories of system can be established, which are illustrated in a generic fashion in Figure 1 and Figure 2.

These figures illustrate the main functional blocks. The OSC (Optical Supervisory Channel) is shown in a generic form – this has not yet been standardized at ITU-T, but it's likely that some OSC functions, such as trail trace, will be defined.

Open (stand-alone) systems. These WDM systems are characterized by their ability to accept and transport a (potential) variety of incoming signals with a range of formats and characteristics (see Figure 1).

They do this by providing signal conversion and wavelength adaptation using, for example, a transponder or a remodulator function. In this way, non-compliant signals can be adapted and transported by the WDM layer.

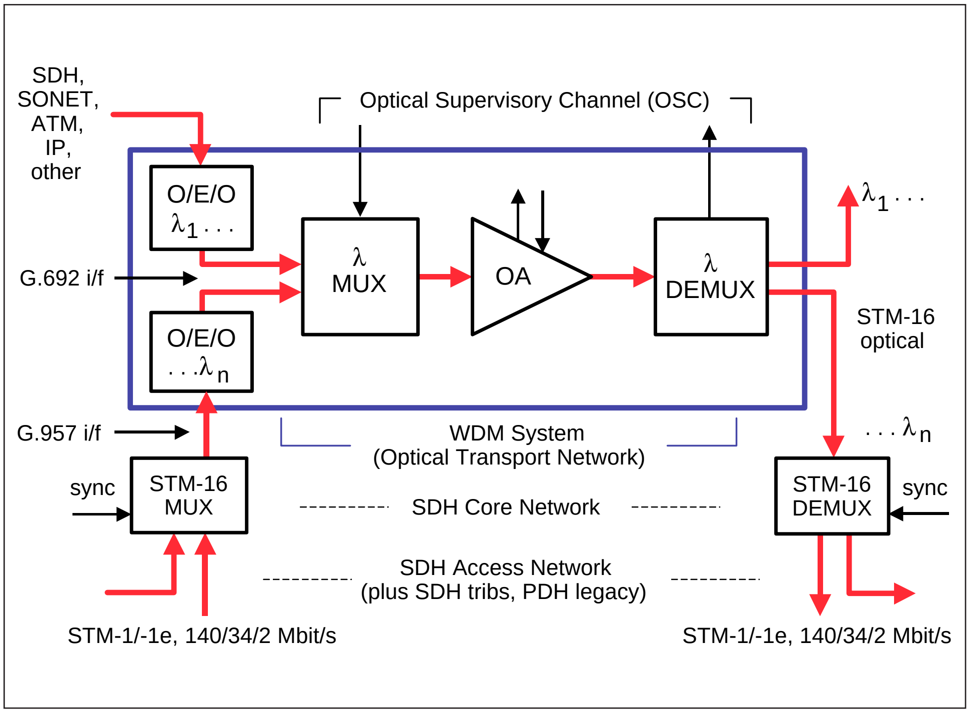


Figure 1. Generic open WDM system architecture.

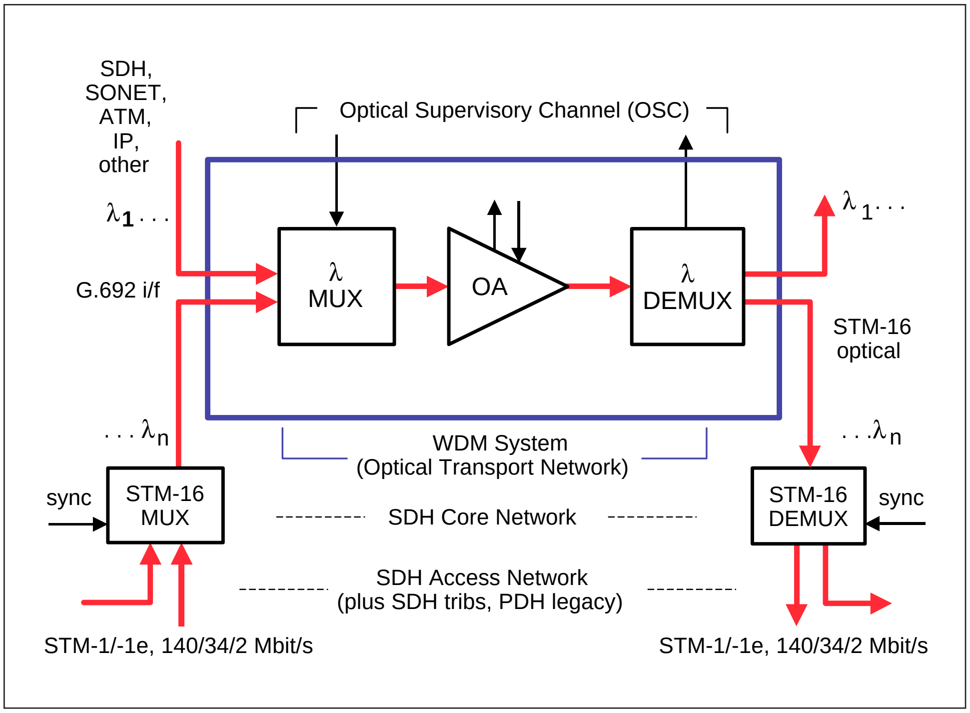


Figure 2. Generic integrated WDM system architecture.

Integrated (terminal) systems. These WDM systems are more closely integrated within a parent SDH system (see Figure 2).

The SDH system transmitters themselves provide the required signal format; e.g., "colored" light ready for wavelength multiplexing.

Choice of architecture. Operators will carefully select the more suitable architecture, considering their particular economics, installed equipment base, desired network evolution, services to be offered, etc.

Open WDM systems are, in general, seen as more flexible today – able to transport legacy PDH as well as SDH and other signals, at a variety of bit-rates and optical power levels. On the other hand there is the risk of increased cost due to the additional equipment and management functionality.

Integrated WDM systems are proposed as a more suitable solution in the longer term. In this way, client signals can be directly adapted to the WDM/photonic layer, whether the client terminal equipment is an SDH admux or, indeed, an IP router.

Photonic Network Performance Parameter Categories and Correlation

In order to categorize the various performance parameters and better understand their inter-relationship, we can organize the network layers as follows (note that this is not a formal decomposition of the network layers):

- Data transport layer
- Signal transmission layer
- Optical physical layer

We make a clear distinction between the optical layer and the signal layer on the basis of time-variance; i.e., the optical parameters are considered to be time-averaged (e.g., mean optical power), while the signal parameters are time-sampled (e.g., eye pattern mask).

This is a key distinction, and another reason why it's difficult to correlate optical layer measurements with client-layer performance.

Examples of specific tests within these categories are highlighted below.

Data transport (client) layer tests:

- Error performance, BER
- Jitter/wander performance

Signal transmission layer tests:

- Eye pattern mask
- Extinction ratio
- Q-factor (e.g., in an electrically-amplified system)
- Jitter (e.g., in a fully-regenerated system)
- Laser chirp performance

Optical physical layer tests:

- Total and per-channel power levels
- Wavelength and channel spacing
- Optical SNR, crosstalk
- SMSR, spectral power density, reflectance

Bit error rate performance. The most effective and accurate method of performance assessment in network applications is to directly examine the data transport layer; e.g., using the BER (Bit Error Rate) parameter.

BER provides an unambiguous characterization of the actual digital service quality; it's considered as the fundamental measure of signal quality. In the majority of applications today, the services transported by WDM are SDH- or SONET-based and so it's this performance that is the most critical.

Troubleshooting methods. If there's a problem at the data transport layer, the signal transmission layer tests will normally provide a fast and efficient indication of where and why the system is failing.

The basic optical parameters such as power, wavelength, etc., are useful during system line-up and other functional checks.

Only for extreme cases of troubleshooting would the precise optical characteristics of crosstalk, laser chirp, etc., be examined in order to diagnose a problem.

Correlation of Network Performance Parameters

The correlation between optical layer behavior and client layer performance can be established in a theoretical fashion and through simulation. However, correlation in a practical network using a minimum of parameters and modest optical measuring/-monitoring technology is much more difficult to establish.

In other words, a parameter such as OSNR is a necessary but not a sufficient measure of network health. It's possible to have a high OSNR in a working system, yet the client BER can be unacceptable.

The underlying reason behind this is the time-variance of the parameters themselves. A time-averaged parameter such as OSNR is a good measure in itself, but by definition, it's unable to measure time-varying characteristics such as signal modulation or impairments such as signal distortion.

The consequence is that optical impairments such as self-phase modulation, cross-phase modulation, and polarization-mode dispersion cannot be detected from the optical signal spectrum. In addition, the effects of these impairments combine in a complex analog fashion and theoretical analysis remains difficult.

Therefore, it's essential to measure/monitor the client layer performance directly in order to ensure an adequate service quality.

ITU-T performance objectives. At present, the accepted standards for path-level error performance are based on ITU-T Recommendation G.826. If possible, a link should be established between this type of objective and the optical layer performance. For the reasons outlined above, this is likely to be difficult.

Future developments. On the other hand, future photonic networks may be more transparent, thereby allowing client signals with a wide variety of different formats to be transported. Therefore, the correlation between optical-layer and client-layer performance becomes still more important but becomes more difficult to achieve.

Summary

The correlation of WDM network performance parameters is a critical issue and standardization organizations and commercial companies are today examining the options, in order to make forward progress.

This is one of two critical issues that need to be resolved before photonic networks can become a reality (the other being WDM/photonic network management).

Performance Parameters for Photonic Systems

In mainstream WDM networks, the consequence of transmission impairment is digital bit errors at the client layer. This is the “bottom-line” impairment and of most importance for the service user and service provider.

The source of the impairment is ultimately analog noise or analog signal defects at the receiver where the optical layer is terminated. One objective at the network design stage is to allocate sufficient margin so that these effects are not a problem during system operation.

Table 1. Transmitter output parameters and application

Transmitter Output Parameter	Units	G.957	G.691	G.692
Operating wavelength (min-max)	nm	X	X	
Central frequency	THz			X
Central frequency deviation	GHz			X
Mean launched power (min-max)	dBm	X	X	X
Spectral width, –20 dB (max)	nm	X	X	X
Side mode suppression ratio, SMSR (min)	dB	X	X	X
Spectral power density (max)	mW/MHz		X	
Optical signal-to-noise ratio, OSNR (min)	dB		X	

Table 2. Multichannel interface parameters and application

Multi-channel Interface Parameter	Units	G.957	G.691	G.692
Per channel mean power (min-max)	dBm			X
Total mean power (min-max)	dBm			X
Per channel OSNR	dB			X
Maximum channel power difference	dBm			X
Optical crosstalk	dB			X

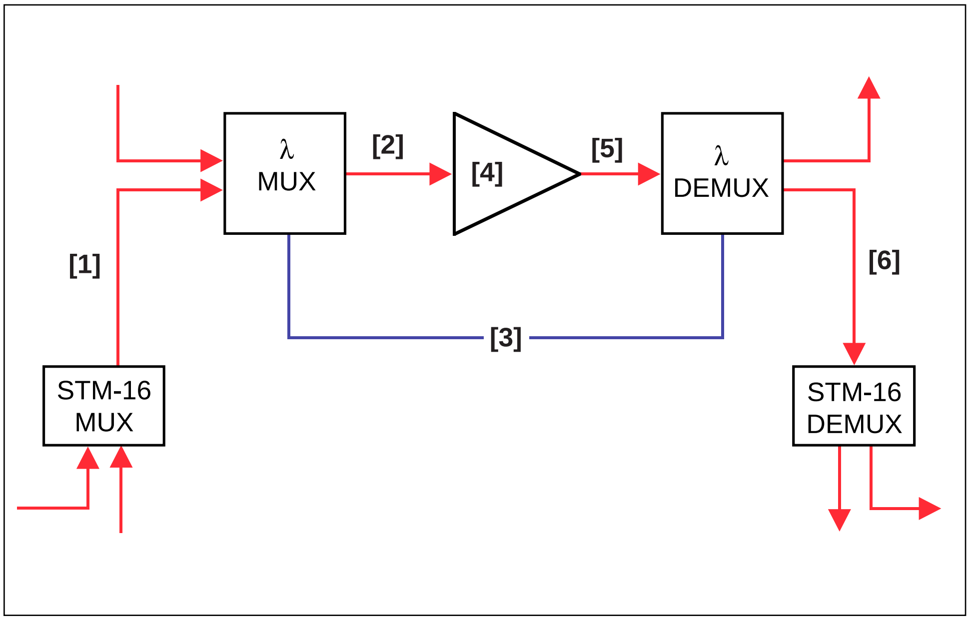


Figure 3. Location of interfaces within the WDM network.

System margin is normally controlled by specification limits placed on the many optical parameters that have been established by ITU-T. The parameters can be conveniently grouped as shown in Figure 3:

[1] Transmitter Output
[2] Multi-Channel Output Interface
[3] Optical Path
[4] Optical Amplifier
[5] Multi-Channel Input Interface
[6] Receiver Input

We will examine each of these interfaces in turn, according to the network layer model described earlier.

Reference 1 may be consulted for further details and information on the performance parameters.

Optical Physical Layer Performance Parameters

Transmitter output [1]. Table 1 provides a complete list of optical parameters that are used to specify the transmit interface. The key ITU-T Recommendations are shown here, which should be referred to for specification limits:

- G.957 is the basic SDH single channel interface specification
- G.691 (ex-G.scs) is the long distance (optically-amplified) type of system, also including STM-64
- G.692 (ex-G.mcs) is the multi-channel system

A core of optical parameters are evident, which are common to all of these different systems; i.e., mean launched power, spectral width, etc.

For the G.692 multichannel systems, a new category of central frequency and central frequency deviation parameters are provided, because tighter control is needed compared with the older systems.

Particular to the G.691 long-haul optical systems, new parameters are specified – source chirp (alpha factor), spectral power density and, of course, the optical signal-to-noise ratio is an important parameter.

Multi-channel Interface Parameters [2], [5]. When considering a multi-channel interface, a set of additional parameters apply (see Table 2).

For example, per channel mean power and the total mean power are needed because they must be compatible with optical amplifiers further downstream in the network.

One key parameter is the per channel optical signal-to-noise ratio that has to be controlled.

In summary, this set of optical specifications is applied both at the transmit-side [2] and the receive-side [5] of the system. In this way, the optical performance of the entire link can be bounded by using this set of parameters.

Optical path parameters [3]. The optical path parameters (see Table 3) specifically relate to the optical fiber in the system.

A common core of parameters exists across the three different system types; i.e., attenuation, dispersion, return loss, and reflectance.

Table 3. Optical path parameters and application

Optical Path Parameter	Units	G.957	G.691	G.692
Attenuation range (min-max)	dB	X	X	X
Chromatic dispersion (min-max)	ps/nm	X	X	X
Optical return loss, ORL (min)	dB	X	X	X
Discrete reflectance (max)	dB	X	X	X
Passive dispersion compensation (min-max)	ps/nm		X	
Polarization mode dispersion, PMD	ps/nm		X	

Table 4. Optical in-line amplifier parameters and application

Optical In-Line Amplifier Parameter	Units	G.957	G.691	G.692
Gain variation	dB			X
Gain tilt	dB/dB			X
Gain difference	dB			X
Total received power	dBm			X
Total launched power	dBm			X
Signal spontaneous noise figure	dB			X

Table 5. Receiver input parameters and application

Receiver Input Parameter	Units	G.957	G.691	G.692
Sensitivity for 10^{-10} BER (min)	dBm	X		
Sensitivity for 10^{-12} BER (min)	dBm		X	X
Overload for 10^{-10} BER (min)	dBm	X		
Overload for 10^{-12} BER (min)	dBm		X	X
Optical path penalty	dB	X	X	X
Reflectance (max)	dB	X	X	X
Optical crosstalk (max)	dB			X
Optical signal-to-noise ratio, OSNR (min)	dB			X

For the new long-range system specification, limits are placed on the passive dispersion compensation and the allowable polarization mode dispersion.

Optical in-line amplifier parameters [4]. For reference, the parameters relating to optical amplifier system performance are summarized in Table 4.

In addition, there is a set of documents relating to submarine optical amplifier systems. Amongst these are ITU-T Recommendations G.661, G.662, and G.663.

Receiver input parameters [6]. Considering the far end of the system, there's a set of parameters which apply at the receiver input. These parameters are listed in Table 5.

Of particular importance to performance, note that the BER objectives at the sensitivity level have been decreased by 2 decades to 10^{-12}, compared with the older G.957 specification. This is a formal statement that new WDM systems are expected to perform at a higher level than the established SDH systems based on G.957.

Summary. A panoply of optical parameters exist, as reviewed previously – and these are distinctly analog in nature. In terms of qualifying a system, much time could be spent measuring all these parameters and trying to understand what the performance of the complete system is! Fortunately, this will normally be done by the manufacturer during their system design and characterization phases.

However, it should be noted that when the published ITU-T documents are examined, not all of these parameters actually have specification limit values set. Many of the precise values are still being discussed at the standardization organizations.

It must also be noted that, even if all these optical parameters are measured and fall within their limits (where defined), it's possible that the system may still provide a low transport quality to client services! That is to say, the optical signal quality can be measured as perfect, yet the client signal quality can still be unsatisfactory.

The reasons for this situation are reviewed in the previous section ***Photonic Network Performance Parameter Categories and Correlation***.

Signal Transmission Layer Performance Parameters

Table 6 lists the relevant parameters from the key ITU-T specifications. These are discussed in more detail below.

Eye Pattern Mask

Figure 4 is an example of an eye mask test – it's a live representation of the optical channel which exists on the system. A pass/fail determination can easily be made against the ITU-T G.957, G.691, or G.692 limit masks.

Table 6. Transmitter output parameters and application

Transmitter Output Parameter	Units	G.957	G.691	G.692
Eye pattern mask	n/a	X	X	X
Extinction ratio, EX (min)	dB	X	X	X
Source chirp, α factor	n/a		X	

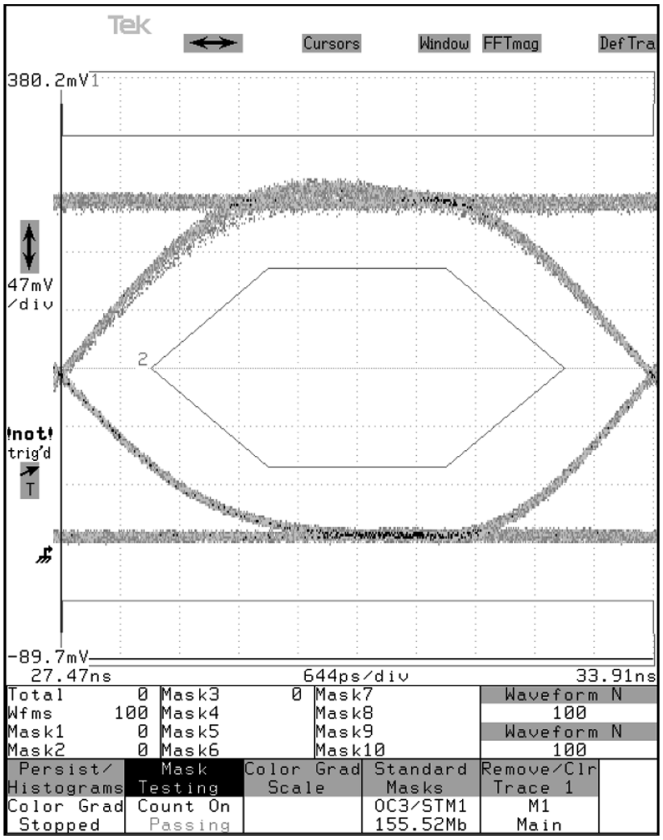


Figure 4. Eye pattern mask (G.957) with example signal under test.

A reference optical receiver (with precisely-defined frequency response characteristic according to ITU specification) is applied to the signal under test and then the signal shape is examined using an oscilloscope (refer to Figure 5).

This test determines, at a transmit interface, whether the optical signal we are sending into the system is within specification.

In addition, other key parameters such as the extinction ratio of the laser transmitter, and other waveform characteristics can be evaluated using the same test configuration.

An important benefit is that a large number of individual laser performance characteristics are consolidated into a single test which makes for a very powerful pass/fail determination.

Application at receive interface. At present, eye pattern mask test is defined as a transmit-side measurement, but the key value of this method is recognized and its use at the receive-side of the system is currently under study at standardization organizations.

The objective is that a standard interface should be defined at the receive-end of the system. This will provide an overall system indication of whether or not the link is operating correctly.

For example, if there are reflection- or dispersion-induced impairments in the optical layer (or time-variant ASE), that will appear directly in the eye pattern signal. In this way, all the signal impairments of the optical link will be accounted for in this single pass/fail test.

Eye pattern mask is a single test of signal goodness that directly evaluates the time-variant characteristics of the optical layer. In this way, it's possible to establish a correlation with the client-layer quality.

Extinction Ratio

Extinction ratio is derived from a measurement of the eye pattern signal. Extinction ratio is defined as the ratio of a "1" signal level to a "0" signal level:

$$EX = 10 \log (\mu_1 / \mu_0) \text{ dB}$$

where:

μ_1 and μ_0 are the respective mean signal levels

Some further information is provided in ITU-T G.957 and G.691.

Extinction ratio is used to ensure that the system is not penalized due to incorrect transmitter modulation levels. A poor extinction ratio at the source transmitter or any intermediate repeater directly impacts the system sensitivity.

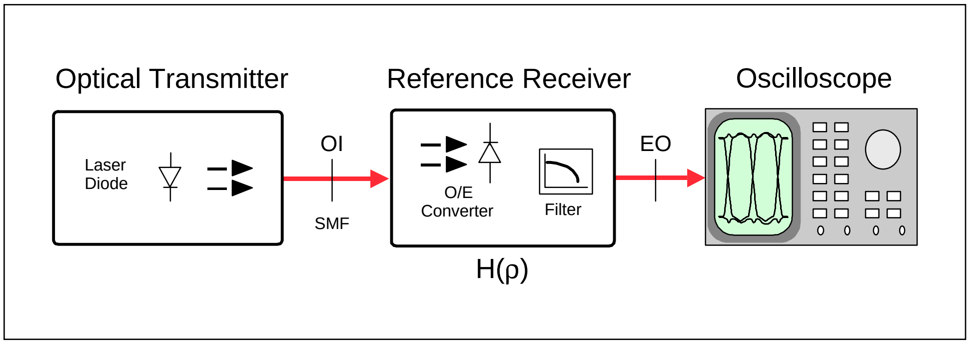


Figure 5. Test configuration for signal layer tests.

Q-Factor

Q-factor is also derived from a measurement of the eye pattern signal. Q-factor is defined as the ratio of peak-to-peak signal to total noise (conventionally electrical):

$$Q = (\mu_1 - \mu_0) / (\sigma_0 + \sigma_1)$$

where:

μ_1 and μ_0 are the respective mean signal levels

σ_1 and σ_0 are the respective standard deviations

Also by definition:

$$\text{Electrical SNR} = 20 \log(Q) \text{ dB}$$

Some further information is provided in ITU-T G.976.

When assessed at the terminating receiver at the electrical level prior to the final decision point, the Q-factor can be used to predict the BER of the client layer. The theoretical relationship can be expressed as:

$$BER = 0.5 \operatorname{erfc}(Q / \operatorname{sqrt}(2))$$

where:

erfc is the complementary error function

(Assuming an optimum decision threshold using the conventional NRZ signal format.)

Evaluation of the Q-factor at the optical level can be considered, but a clear correlation with client-layer performance has not been established (due to noise bandwidth and other issues). This critical area remains under study at the ITU-T.

Jitter

Jitter is a key assessment parameter at the client layer. However, at the photonic layer, fully-regenerated (i.e., type “3R”), systems are not presently in use. Therefore, jitter accumulation is not yet a primary assessment parameter.

Laser Chirp Performance

It’s important to limit and control the degree of laser chirp (dynamic frequency change during modulation). This is a dominant limiting factor in the distance/bit-rate trade-off.

Any frequency changes of the laser source, in combination with the fiber dispersion, cause an increasing degree of signal impairment as the system reach is extended – particularly at the higher bit-rates of 10 Gbit/s.

The solution is to ensure the use, at the design phase, of transmitter components with adequate quality and stability for the system under consideration.

Some further information on the alpha factor and measurement configuration is provided in ITU-T G.691.

Summary

Signal transmission layer parameters provide a key assessment of the performance of the optical layer under modulated conditions.

Correlation of these parameters with the performance of the client layer can be established, although some issues remain to be resolved.

Data Transport Layer Performance Parameters

As reviewed earlier, Bit Error Rate (BER) is the primary performance parameter to be considered when the optical layer is terminated and the service is delivered.

The timing/synchronization parameters of jitter and wander are also relevant at this point, but we will not cover these aspects in this technical brief; Reference 2 may be consulted for full details.

Categories of Test

Various categories and reasons for client-layer performance and test can be identified:

- Design characterization and system commissioning
- Demonstrate reliability, inter-operability
- Third-party verification of system performance, especially where inter-operation is required
- Characterization of BER against variables such as attenuation, dispersion

Example Test Configuration

Figure 6 provides an example multi-channel WDM system test configuration. The system has wavelength multiplex and demultiplex functions – with a number of test sets transmitting at different frequencies on the ITU-T G.692 grid.

For a cost-effective test, manufacturers can typically use four different frequencies – one at the low-frequency end, one at the high-frequency end and two in-band – in order to measure performance across the optical amplifier bandwidth. So, this configuration provides a good cost-effective test of the overall optical channel.

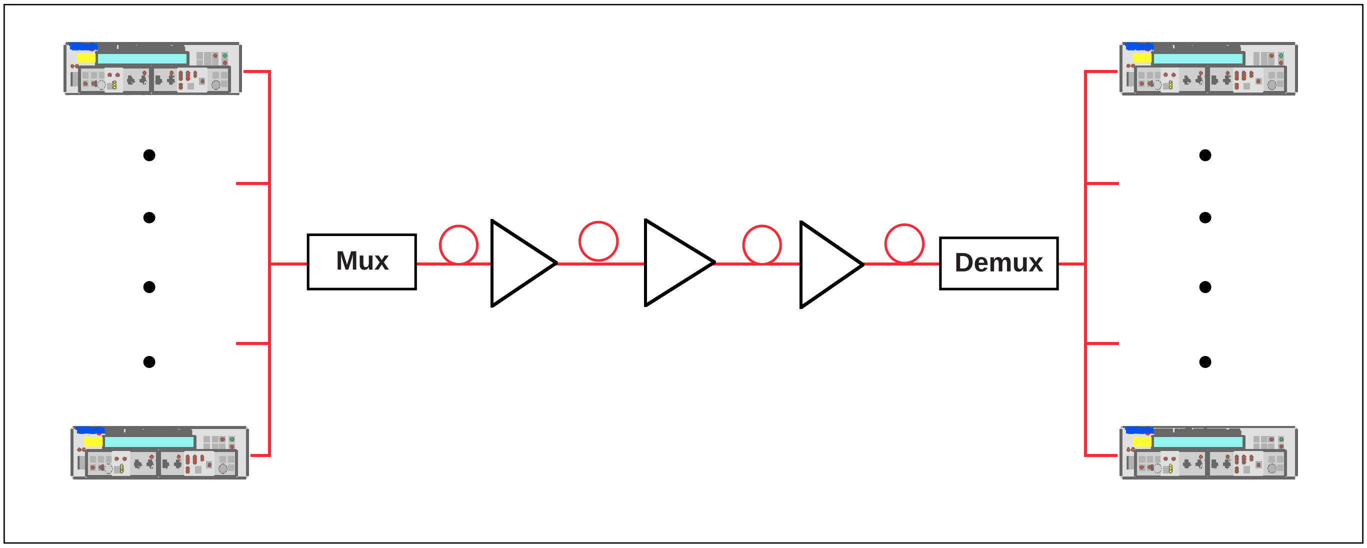


Figure 6. Example multi-channel transport layer test.

BER Test Objectives

The objective is to test for data transparency during installation, commissioning, and maintenance, making sure that the error performance is demonstrably better than 1 error in 10^{12} received bits. In practice, some margin is also desired by both operators and manufacturers, meaning that this is a minimum requirement.

In order to test to these very low levels, the duration of the test can become excessive – 24 hours or an even longer duration. Alternatively, various methods exist to accelerate the BER measurement which are under study by the standards organizations.

An effective philosophy is to use the STM-16 bulk payload PRBS test. Using the entire STM-16 payload, rather than just an individual channel or tributary, gives a 16-fold increase in test speed (or a 16-fold increase in error confidence). This aspect is very important for manufacturing cost margins!

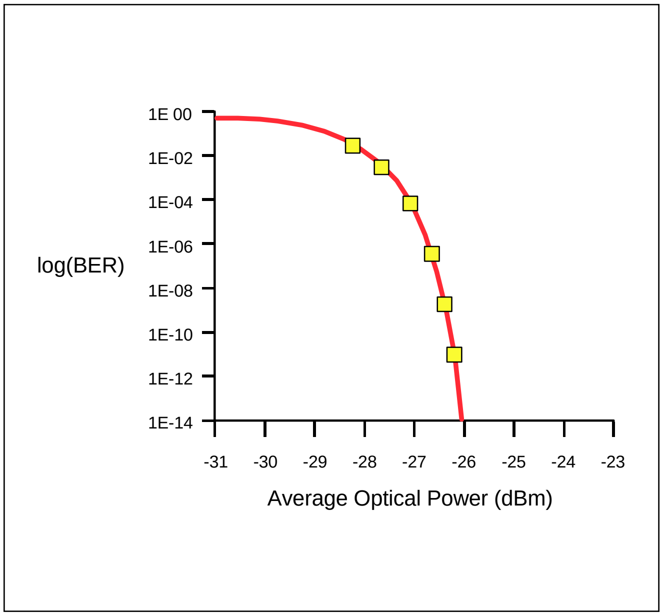


Figure 7. Example BER client-layer performance characteristic.

BER Performance Results

Bit error rate can be thought of as the “multimeter of transmission systems.” The result obtained from a typical test is the very well-known bit error rate characteristic.

In the example shown in Figure 7, BER performance versus received optical power is examined.

Summary

Client-layer performance assessment is the final assurance of quality. This section has briefly reviewed test methods and results obtained that can be used in an out-of-service condition.

For the in-service condition, the SDH network has been designed to unambiguously identify and locate the source of errors by continuously monitoring the data quality through a layered CRC mechanism; e.g., B1 byte at the regenerator section.

There is no equivalent mechanism at the optical layer – nor has any been identified to date. However, standardization organizations continue to study the options available. The clear goal is to provide the equivalence in functionality that is demanded for modern network operations. The key question is “how good is the correlation with the client layer?”

Conclusions

WDM is still a new technology, but it is capable of satisfactory application in networks today and forms the foundation for future photonic networks. We highlight the following items:

- Longitudinal and Transverse compatibility remain a challenge which continues to be addressed by standardization organizations.
- Careful characterization is still necessary – at design and manufacturing phases – but also during installation and maintenance of the network.
- STM-16/OC-48 are the most popular clients of WDM network links and test equipment such as BER test sets are available today with WDM-focused functions.
- Looking to the future, what is deployed in today’s networks is 8 or 16 channels perhaps at 200 or 100 GHz channel spacing. The trend is to quickly evolve to 80 or more channels at 50 GHz spacing.
- Economic test of all individual channels will be difficult, so it’s important to establish a cost-effective test strategy.
- Two different test domains exist, one being the optical physical layer and the other being the client-service layer – these are, in fact, complementary. Particularly in network applications, it’s not necessary to be concerned with every precise optical parameter detail.
- As the final arbiter of performance – and often the contracted service – the transmission error performance of the client layer has to be carefully established and monitored using BER. In this way, the services provided over new WDM networks will be of the high quality that operators and customers demand.

References

1) Tektronix, ***Test Issues for Dense WDM in SDH Communication Systems.*** Tektronix, Inc. March 1998.

2) Lum, Wolaver, ***Performance Assessment of Timing and Synchronisation in Broadband Networks.*** Tektronix, Inc. March, 1997.

Acronyms

ASE – Amplified Spontaneous Emission

ATM – Asynchronous Transfer Mode

BER – Bit Error Rate

CRC – Cyclic Redundancy Check

DEMUX – Demultiplexer

DWDM – See WDM

ETSI – European Telecommunications Standards Institute

EX – Extinction Ratio

IP – Internet Protocol

ITU-T – International Telecommunication Union, Telecommunication Standardization Sector

MUX – Multiplexer

OA – Optical Amplifier

OC-N – Optical Channel, level N

ORL – Optical Return Loss

OSC – Optical Supervisory Channel

OSNR – Optical Signal-to-Noise Ratio

PDH – Plesiochronous Digital Hierarchy

PMD – Polarization Mode Dispersion

PRBS – Pseudo-Random Binary Sequence

SDH – Synchronous Digital Hierarchy

SMSR – Side Mode Suppression Ratio

SNR – Signal-to-Noise Ratio

STM-N – Synchronous Transport Module, level N

WDM – Wavelength Division Multiplexing

WDM/SDH Network and Equipment References

ITU-T Recommendations:

http://www.itu.int

G.661 – Definition and test methods for the relevant generic parameters of optical fiber amplifiers

G.662 – Generic characteristics of optical fiber amplifier devices and sub-systems

G.663 – Application related aspects of optical fiber amplifier devices and subsystems

G.665 (draft) – Optical networking components (ex-G.onc)

G.681 – Functional characteristics of inter-office and long-haul line systems using optical amplifiers, including optical multiplexing (ex-G.lon)

G.691 – Optical interfaces for single-channel SDH systems with optical amplifiers (ex-G.scs)

G.692 – Optical interfaces for multi-channel systems with optical amplifiers (ex-G.mcs)

G.707 – Network node interface for the SDH

G.709 (draft) – Structures and mapping for the optical transport network (ex-G.ons)

G.783 – Characteristics of SDH equipment functional blocks

G.798 (draft) – Functional characteristics of optical networking equipment (ex-G.oef)

G.805 – Generic functional architecture of transport networks

G.826 – Error performance parameters for international CBR paths at or above the primary rate

G.871 (draft) – Framework for optical networking recommendations (ex-G.onf)

G.872 (draft) – Architecture of optical transport networks (ex-G.otn)

G.873 (draft) – Optical transport network requirements (ex-G.onr)

G.874 (draft) – Management of optical network elements (ex-G.onm)

G.875 (draft) – Information models for optical network equipment (ex-G.oni)

G.957 – Optical interfaces for equipment and systems relating to the SDH

G.958 – Digital line systems based on the SDH for use on optical fiber cables

G.959.1 (draft) – Physical layer aspects of optical networks (ex-G.onp)

G.971-G.975 – Optical fiber submarine cable systems

G.976 – Test methods applicable to optical fiber submarine cable systems

Further Information From Tektronix

- ***Test Issues for Dense WDM in SDH Communication Systems* –** Comprehensive introduction to testing WDM systems.
- ***SDH at a Peak of Performance* –** Achieving superior Quality of Service through broadband network test.
- ***Performance Assessment of Timing and Synchronisation in Broadband Networks* –** Reference booklet on ITU-T and ETSI requirements and test methods.

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Written by Mark J. Lum, Telecoms Market Development Manager, Tektronix, Europe.

Mark Lum, MA MSc, studied Natural and Electrical Sciences at Cambridge University, and started work with ITT-STL (now Nortel Technology) on high-speed fibre-optic network systems in 1981. As part of his work, STL sponsored further study for an MSc in Telecommunication Systems.

He joined Tektronix in 1985 and, following a variety of technical and marketing assignments, he now manages Tektronix' standardization programmes at ITU and ETSI. He is ITU-T Rapporteur for SDH/PDH Jitter/Wander test and an active contributor on issues of broadband network performance and SDH/ATM test.

For further information, contact Tektronix:

World Wide Web: http://www.tek.com; **ASEAN Countries** (65) 356-3900; **Australia & New Zealand** 61 (2) 9888-0100; **Austria, Central Eastern Europe, Greece, Turkey, Malta,& Cyprus** +43 2236 8092 0; **Belgium** +32 (2) 715 89 70; **Brazil and South America** 55 (11) 3741-8360; **Canada** 1 (800) 661-5625; **Denmark** +45 (44) 850 700; **Finland** +358 (9) 4783 400; **France & North Africa** +33 1 69 86 81 81; **Germany** + 49 (221) 94 77 400; **Hong Kong** (852) 2585-6688; **India** (91) 80-2275577; **Italy** +39 (2) 25086 501; **Japan (Sony/Tektronix Corporation)** 81 (3) 3448-3111;
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