PD-500C

pin diode designers' HANDBOOK and CATALOG

UNITRODE

UNITRODE PIN DIODE DESIGNERS' HANDBOOK AND CATALOG

The selection of the best PIN diode for a given application is resolved, in many instances, through some combination of technical knowledge, prior experience, and "cut-and-try" evaluation. The main purpose of the **PIN DIODE** DESIGNERS' HANDBOOK and CATALOG is to help make this process more efficient, through a better understanding of how the performance of a given diode relates to the requirements of a specific application. To facilitate this selection process, this handbook contains in addition to data sheets, a condensed *Selection Guide (Section II) plus information on PIN diode device fundamentals and applications (Sections V and VI)* that relate diode electrical, physical and semiconductor characteristics to required circuit functions.

UNITRODE
PIN DIODE DESIGNERS' HANDBOOK
AND
CATALOG

Printed in U.S.A.

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I. INTRODUCTION

UNITRODE PIN DIODES

Unitrode PIN Diodes....With Special Features for Demanding Applications

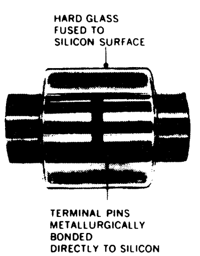
Unitrode PIN diodes have been providing solutions for difficult RF switching Applications for over 10 years. Our special diode designs and "fused-in-glass" packaging provided the answers on Viking, Safeguard, Trident, F-16, DSCS and countless other military programs requiring the high level of reliability and performance that is inherent in Unitrode PIN diodes.

High RF power handling and low distortion have become synonymous with Unitrode. Unitrode, in fact, offers PIN diodes that control power levels from milliwatts to tens of kilowatts, utilizing wide ranges of forward bias current, and reverse bias voltage that can frequently be as low as zero volts. Useful operating frequencies range from 500 kHz to well above 1 GHz. Such performance is the result of chip designs, semiconductor material and processes all carefully controlled for resistivity, minority carrier lifetime, and "I" region thickness.

Unitrode has developed specific diodes for commercial and industrial as well as for military applications. Manufacturing costs have been reduced as a result of increased usage in certain applications. The UM9401 and UM9415 switch diodes, and UM9301 attenuator diode are examples that offer clear economic as well as performance advantages.

THE UNITRODE "FUSED-IN-GLASS" CONSTRUCTION

The proven "fused-in-glass" construction of Unitrode diodes is responsible in large part for their outstanding performance as PIN diodes. The figure below shows the basic Unitrode PIN diode construction. Not only does this construction result in *low electrical losses and low thermal impedance,* with consequently higher power capability, but it also yields *high reliability under adverse temperature, acceleration, shock, and vibration conditions.*



Fused-in-Glass Diode

The diodes are fabricated with full-faced metallurgical bonds between the silicon PIN chip and two metal pins. This bonding takes place at a temperature of approximately 1000 °C in a controlled atmosphere. Because the pin metal is chosen to match the low thermal coefficient of expansion of silicon, the resultant bond is completely unstressed. The metal-silicon assembly is then fused to a sleeve of hard glass at approximately 800 °C. Since no varnish, epoxy, or other passivation is used, the silicon junction sees only this hyper-pure compatible glass. By also matching the thermal coefficient of expansion of the glass to the silicon and pins, the complete diode package *can successfully withstand repeated temperature shocks and cycling, from liquid nitrogen (−196 °C) up to +300 °C.* Subsequent bondings of the basic Unitrode diode to mounting hardware such as leads and studs, are all made at temperatures in excess of 400 °C. *Thus the diode package resulting from this process, is a stress relieved, highly stable unit capable of sustained operation under extreme power and temperature conditions.*

ORDERING INFORMATION

Order Unitrode PIN diodes by specifying your choice as follows:

Unitrode PIN diodes consist of the letters UM followed by four digits and one or two letters. The first two digits indicate the diode series, while the next two digits specify the voltage rating (V_R) in hundreds of volts. The remaining letters denote the specific package style. On non-symmetrical stud mounted packages, reverse polarity (anode on stud end) is available in C and D styles and denoted by adding a second letter R.

For Example:

UM 70 01 C R

Series UM7000 — 70

V_R (100 volts) — 01

Package Style C — C

Reverse Polarity — R

There are six other standard diodes that offer a single package outline and single voltage rating. These are ordered by their part numbers, without suffixes, as follows: UM9301, UM9401, UM9402, UM9415, 1N5767, 1N5957.

High Reliability Screening

Unitrode offers a standard high reliability screening program called "HR201M Screening" for PIN DIODES. Parts with this screening can be ordered from the factory by so indicating as part of your order. See page on "Reliability Screening", for futher information and the Unitrode O.E.M. Price List for costs.

Terms and Conditions

All factory orders are subject to a $250 minimum charge. Diodes with round axial leads (suffix-B) are also available from your local Unitrode distributor.

Orders are F.O.B. factory.

Terms: Net 30 days.

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II. PIN DIODE SELECTION GUIDE

PACKAGE AND CHIP CONSIDERATIONS WHEN SELECTING A PIN DIODE

As described on page 7 of the guide, Unitrode PIN diodes offer a unique highly reliable package due mainly to a voidless construction and whiskerless metallurgically bonded design. Aside from its mechanical integrity and high reliability, Unitrode PIN diodes offer significant electrical and thermal advantages in comparison to PIN diodes manufactured by other suppliers. For the same basic electrical characteristics of forward resistance (R_S), and total capacitance (C_T), the Unitrode PIN diode is generally constructed using a PIN chip that has a thicker I-region, larger cross sectional area and longer carrier lifetime. *This results in PIN diodes that produce lower signal distortion at all frequencies and power levels as well as devices that are capable of handling greater average and peak power than those manufactured by conventional techniques.*

In addition, since there are no ribbons or whiskers within the Unitrode diode package, parasitic resistance and inductance are minimized. Although the forward resistance (R_S) of Unitrode PIN diodes is specified at 100 mA, many diodes are employed at forward currents of 1 ampere and beyond in order to achieve significantly lower resistance.

APPLICATION CHART

The Application Chart highlights the PIN diodes generally recommended for RF and microwave signal control applications. This chart should be considered only as a general guide for indicating the most likely standard Unitrode diode to be considered for a particular application.

See Short Form Data Summary for quick comparison of diode types. Consult the individual data sheets for additional data. For unusual or special purpose applications not listed, the designer should consult his local Unitrode representative or the factory.

APPLICATION	RECOMMENDED PIN DIODE TYPES
Switches	
High Average Power (> 100W)	UM4000, UM4900
High Peak Power (> 10 KW)	UM4000, UM6000, UM7000
High Power CW Duplexers (> 10 KW)	UM4000, UM4900
Antenna Switching (> 100W)	UM9401, UM9415, UM9601-UM9604
High Frequency (> 1 GHz)	UM6000, UM7000, UM9601-UM9608
Low Frequency (< 10 MHz)	UM4300, UM7300
Low Reverse Voltage (< 28V)	UM4300, UM7300
Low Forward Current (< 20 mA)	UM6200, UM7200, UM7100, UM9701
Fast Speed (< 100 ns)	UM6200, UM7200
Low Distortion	UM4000, UM4300, UM7300
Attenuators	
High Power (> 1W)	UM4000, UM4300
CATV	1N5767, 1N5957, UM9301
AGC	UM6601, UM9301, 1N5767
Low Frequency	UM4300, UM7300, UM9301

SHORT FORM DATA SUMMARY

The Short Form Data Summary contains a listing of all standard Unitrode PIN diodes along with a summary of the principal characteristic of each diode series. These listings should enable the designer to quickly select from among the several diode series, those having the desired combination of resistance and capacitance for his specific application. The primary distinction between each series results from the different cross-sectional areas and I-region geometries employed in the manufacturing of the diode. It may be significant, therefore to note that the lowest cost diodes within any series are those with the lowest specified voltage rating (generally 100 volts) mounted in an unleaded or round axial leaded package (Style B).

(Refer to Individual Data Sheets in Section III for more detailed specifications)

HIGH POWER PIN DIODES

TYPE	Voltage Rating Range (V)	Capacitance (0V, 1 GHz) C_T max (pF)	Forward Resistance (100 mA, 1 GHz) R_S max (Ω)	Parallel Resistance (100V, 1 GHz) R_P min (KΩ)	Average Power Dissipation P_A (W)	Carrier Lifetime I_F = 10 mA min (μS)	I-Region Width min (μm)
UM4000	100 - 1000	3.0	0.5	2	25	5.0	150
UM4900	100 - 600	3.0	0.5	2	37	5.0	150
UM6000	100 - 1000	0.5	1.7	15	6	1.0	150
UM6200	100 - 400	1.1	0.4	10	6	0.6	40
UM6600	100 - 1000	0.4	2.5	10	4	1.0	150
UM7000	100 - 1000	0.9	1.0	10	10	2.5	150
UM7100	100 - 800	1.2	0.6	8	10	2.0	80
UM7200	100 - 400	2.2	0.25	7	10	1.5	40

HIGH POWER ATTENUATOR AND MODULATOR PIN DIODES

TYPE	Voltage Rating Range (V)	Total Capacitance (0V, 1 GHz) C_T (pF)	RF Resistance (100 mA, 1 GHz) R_S (Ω)	RF Resistance (10 uA, 1 GHz) R_S (Ω)	Average Power Dissipation P_A max (W)	Carrier Lifetime I_F = 10 mA min (μs)	I-Region Width min (μm)
UM4300	100 - 1000	2.2	1.5 max	1000 min	18	6.0	250
UM7300	100 - 1000	0.7	3.0 max	3000 min	7.5	4.0	250

LOW CAPACITANCE SWITCH AND ATTENUATOR PIN DIODE

TYPE	Voltage Rating (I_R = 10 μA) (V)	Total Capacitance **(50V, 1 MHz)** C_T max (pF)	RF Resistance (10 μA, 100 MHz) (Ω)	RF Resistance (20 mA, 100 MHz) (Ω)	RF Resistance (100 mA, 100 MHz) (Ω)	Carrier Lifetime **(I_F = 10 mA) Min** (μs)
1N5767 (5082 - 3080)	100	0.4	1000 min	8 max	2.5 max	1

LOW DISTORTION ATTENUATOR PIN DIODES

TYPE	Voltage Rating (I_R = 10 μA) (V)	Total Capacitance C_T max (0V, (100 MHz) (pF)	RF Resistance (100 mA, 100 MHz) Max (Ω)	RF Resistance (10 μ A, 100 MHz) Min (Ω)	Forward Current (R_S = 75Ω F = 100 MHz) Typ (mA)	Carrier Lifetime (I_F = 10 mA) Typ (min)
1N5957	100	0.4	3.5	1500	1.0	1.5
UM9301	75	0.8	3.0	3000	1.1	4

II. PIN DIODE SELECTION GUIDE

(Refer to Individual Data Sheets in Section III for more detailed specifications)

TWO WAY RADIO ANTENNA SWITCH PIN DIODES

TYPE	Voltage Rating (I_R = 10 μA) (V)	Total Capacitance (0V, 100 MHz) C_T Max (pF)	RF Resistance (50 mA, 100 MHz) R_S Max (Ω)	Transmit Harmonic Distortion F = 50 MHz I = 50 mA (dB)	Receive Third Order Distortion (PIN-10 mW, 0 Bias) F_A = 50 MHz F_B = 51 MHz Max (dB)	Average Power Dissipation P_A Max (W)
UM9401 UM9402	50	1.5	1	−80	−60	5.5
UM9415	50	4.0	1	−80	−60	10

LOW RESISTANCE ANTENNA SWITCHES

TYPE	Voltage Rating (I_R = 10 μA) (V)	Total Capacitance (50V, 1 MHz) C_T max (pF)	RF Resistance (10 mA, 100 MHz) R_S max (Ω)	Forward Bias Third Order I_M Distortion I = 10 mA F_a = 43 MHz F_b = 44 MHz max (dB)	Reverse Bias Third Order I_M Distortion V = 50V F_a = 43 MHz F_b = 44 MHz max (dB)	Average Power Dissipation P_A max (W)
UM9701	100	1.8	.8	−90	−90	2.5

MICROWAVE PIN DIODES (Mounted in Microstrip Packages)

TYPE	Voltage Rating (I_R = 10 μA) (V)	Series Resistance (100 mA, 1 GHz) R_S Max (Ω)	Parallel Resistance (0V, 1 GHz) R_P Min (KΩ)	Total Capacitance (0V, 1 GHz) C_T Max (pF)	Carrier Lifetime (I_F = 10 mA) Min (μs)
UM9601/04	100/400	.6	5	1.2	2
UM9605/08	100/400	1.7	7	.5	1

VOLTAGE RATINGS

Series	100V	200V	400V	600V	800V	1000V
UM4000	✓	✓		✓		✓
UM4300	✓	✓		✓		✓
UM4900	✓	✓		✓		
UM6000	✓	✓		✓		✓
UM6200	✓	✓	✓			
UM6600	✓	✓		✓		✓
UM7000	✓	✓		✓		✓
UM7100	✓	✓	✓		✓	
UM7200	✓	✓	✓			
UM7300	✓	✓		✓		✓

STANDARD PACKAGING

Five package options, as shown on the next page are offered for most of the PIN diodes series. Generally, styles A and E and the cartridge style C are recommended where minimal lead inductance is a major concern. The stud package style C and D (insulated) are offered for high average power handling. Either cathode or anode can be oriented to ground, with equal power handling. Axial leaded, style B, offers the lowest cost alternative.

	BASIC DIODE STYLE A	AXIAL LEADS STYLE B
UM4000 SERIES **UM4300 SERIES** **UM9415 (Axial leads only)**		
UM4900 SERIES		
UM6000 SERIES **UM6200 SERIES** **UM6600 SERIES** **1N5767 (Axial leads only)** **1N5957 (Axial leads only)**		
UM7000 SERIES **UM7100 SERIES** **UM7200 SERIES** **UM7300 SERIES** **UM9301 (Axial leads only)** **UM9401 (See data sheet)** **UM9600 SERIES (See data sheet)** **UM9701 (Axial leads only)**		

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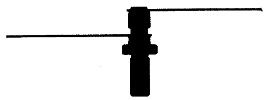
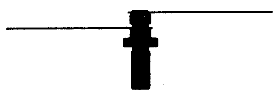
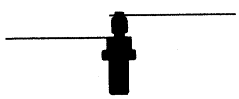
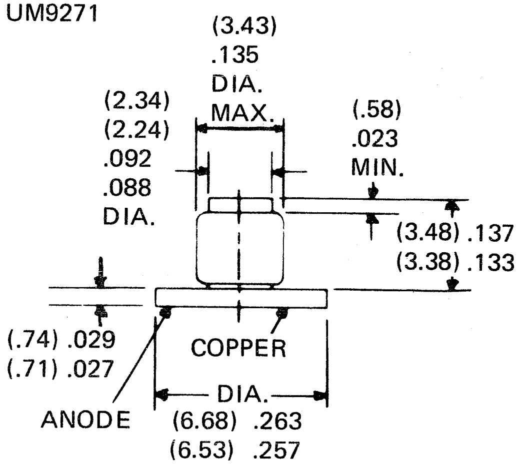
STUD/CARTRIDGE STYLE C	INSULATED STUD STYLE D	RIBBON LEADS STYLE E
		
		
	N/A	
		

CUSTOM PACKAGING

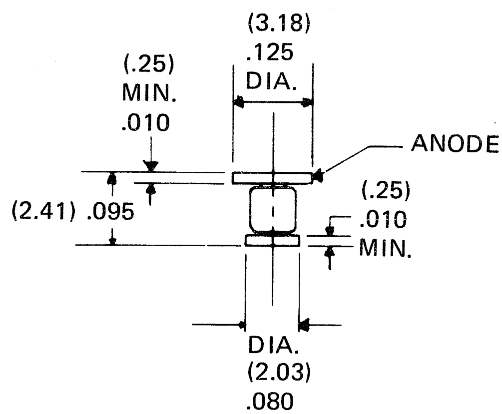
While most microwave application requirements can be satisfied with one of the Unitrode standard package styles, the individual nature of microwave circuits often demands special package configurations. Unitrode has developed a number of customized package styles, as shown below, and stands ready to assist you in the design and development of diode packages to maximize your circuit efficiency. Consult your Unitrode Sales Representative or the factory regarding YOUR custom requirements.

UM9271



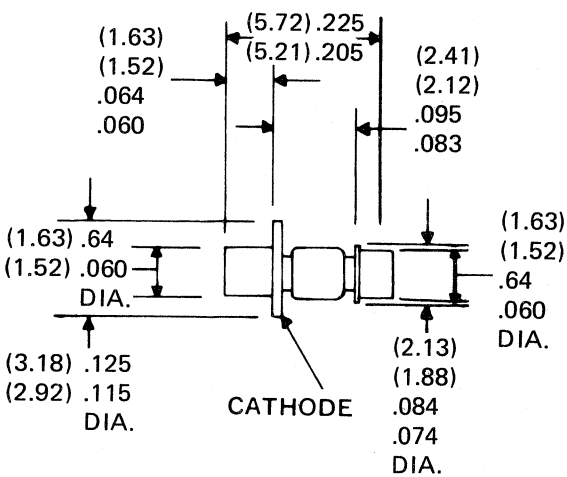
FOR UM4000 SERIES

UM9273



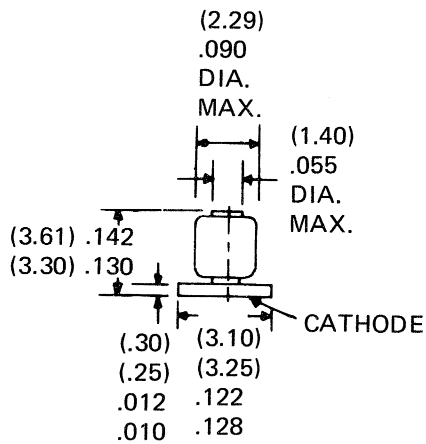
FOR UM6000 SERIES

UM9397



FOR UM7000 SERIES

UM9398



FOR UM7000 SERIES

Dimensions — English/Metric

III. DATA SHEETS

PIN DIODE

UM4000 SERIES
UM4900 SERIES

Features

- Power dissipation to 37.5W
- Voltage ratings to 1000V
- Series resistance rated at 0.5Ω
- Carrier lifetime greater than 5μs

Description

The UM4000 and UM4900 series feature high power PIN diodes with long carrier lifetimes and thick I-regions. They are especially suitable for use in low distortion switches and attenuators, in the HF through S band frequencies. While both series are electrically equivalent, the UM4900 series have higher power ratings due to a shorter thermal path between chip and package. High charge storage and long carrier lifetime enable high RF levels to be controlled with relatively low bias current. Similarly, peak RF voltages can be handled well in excess of applied reverse bias voltage.

Both series have been fully qualified in high power UHF phase shifters and megawatt peak-power duplexers, accumulating thousands of hours of proven performance. Both types have been used in the design of antenna selectors and couplers, where inductive and capacitive elements are switched in and out of filter or cavity networks.

MAXIMUM RATINGS

Average Power Dissipation and Thermal Resistance Ratings

Package	Condition	UM4000		UM4900	
		P_D	θ	P_D	θ
A	25°C Pin Temperature	25W	6°C/W	37.5W	4°C/W
B&E (Axial Leads)	½ in. (12.7mm) Overall Length to 25°C Contact	12W	12.5°C/W	12W	12.5°C/W
B&E (Axial Leads)	Free Air	2.5W	—	2.5W	—
C (Studded)	25°C Stud Temperature	25W	6°C/W	37.5W	4°C/W
D (Insulated Stud)	25°C Stud Temperature	18.75W	8°C/W	25W	6°C/W

Peak Power Dissipation Rating

All Packages	1 μs Pulse (Single) at 25 °C Ambient	100 KW

Operating and Storage Temperature Range: −65°C to +175°C

UNITRODE

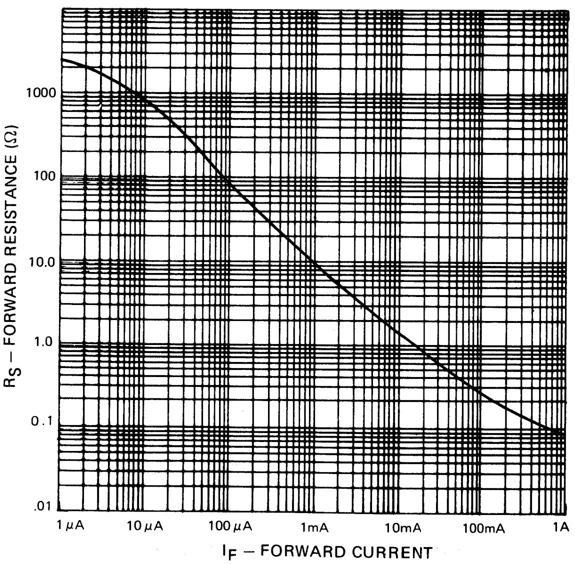
Voltage Ratings (25 °C)

Reverse Voltage (V_R) — Volts (I_R = 10 μ Amps)	Types	
100	UM4001	UM4901
200	UM4002	UM4902
400	—	—
600	UM4006	UM4906
1000	UM4010	—

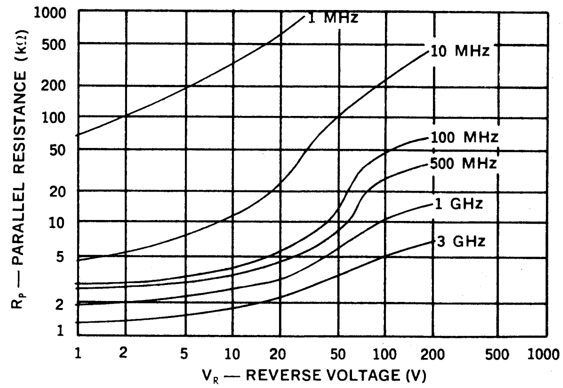
Electrical Specifications (25 °C)

Test	Symbol	UM4000 UM4900	Conditions
Total Capacitance (Max)	C_T	3 pF	0V, 1 GHz
Series Resistance (Max)	R_S	0.5Ω	100 mA, 1 GHz
Parallel Resistance (Min)	R_P	2 KΩ	100V, 1 GHz
Carrier Lifetime (Min)	τ	5μs	I_F = 10 mA
Reverse Current (Max)	I_R	10μA	V_R = Rating
I-Region Width (Min)	W	150μm	—

TYPICAL FORWARD RESISTANCE
VS
FORWARD CURRENT
(F = 100 MHz)



TYPICAL PARALLEL RESISTANCE CHARACTERISTIC



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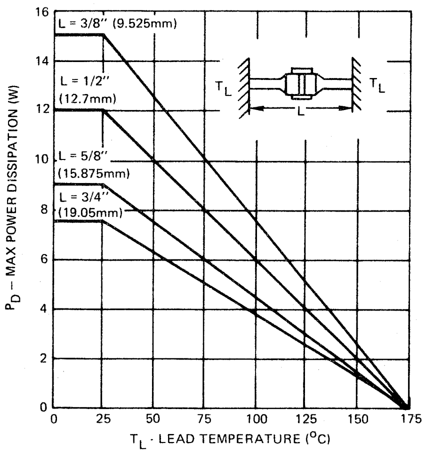
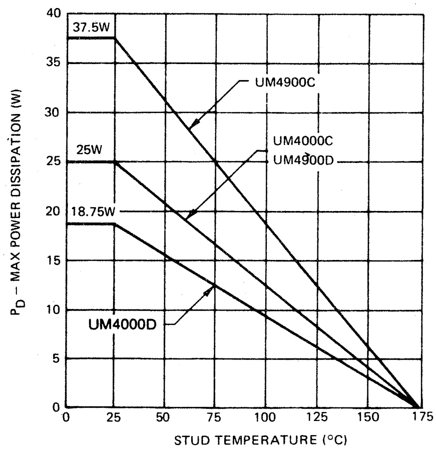
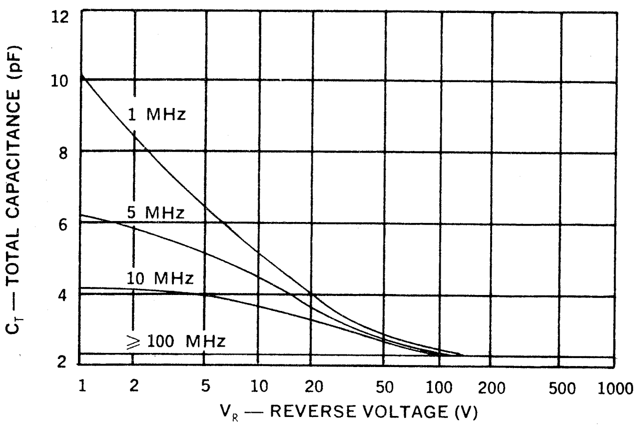
POWER RATING AXIAL LEADED DIODE



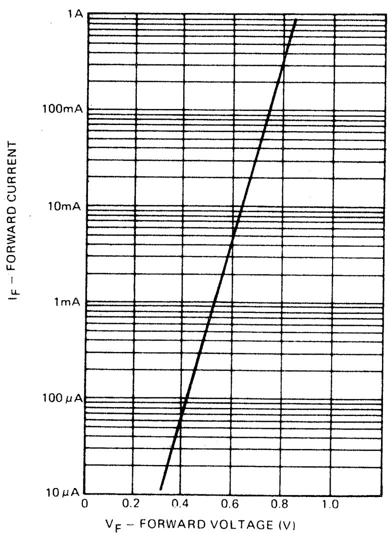
POWER RATING STUD MOUNTED DIODES



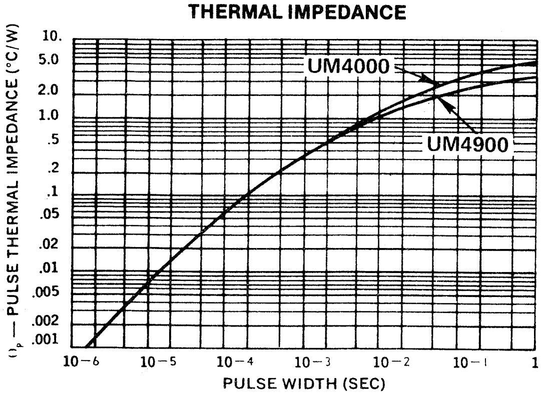
TYPICAL CAPACITANCE CHARACTERISTIC



DC CHARACTERISTICS FORWARD VOLTAGE VS FORWARD CURRENT (TYPICAL)



THERMAL IMPEDANCE



ORDERING INSTRUCTIONS

Part numbers of Unitrode PIN Diodes consist of the letters UM followed by four digits and one or two letters. The first two digits indicate the diode series, the next two digits specify the minimum breakdown voltage in hundreds of volts. The remaining letters denote the package style. Reverse polarity (anode large end cap) is available for the C style and denoted by adding second letter R.

For Example: UM|40|06|CR

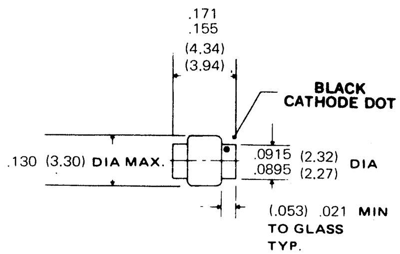
Series 4000 | 100 Volts | Style C | Reverse Polarity

MECHANICAL SPECIFICATIONS

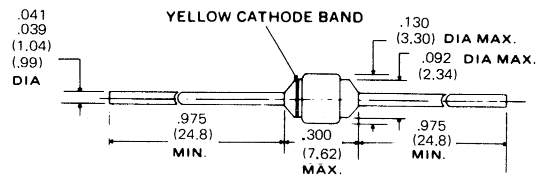
UM4000 Series

Dimensions — English/Metric

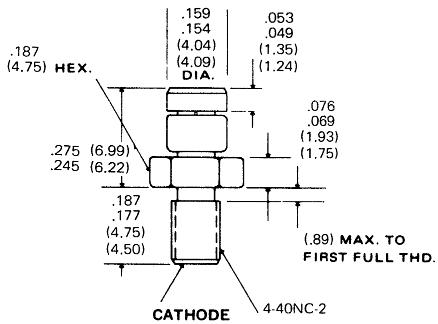
STYLE A



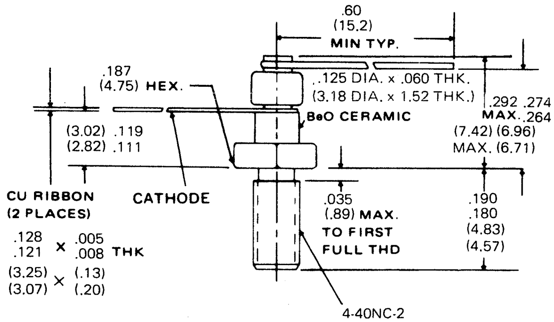
STYLE B



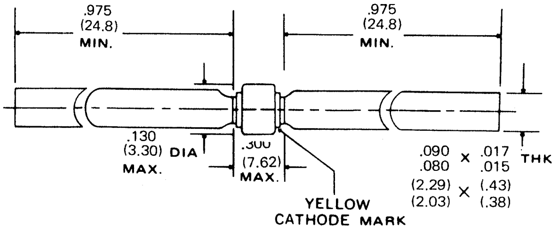
STYLE C
STUD



STYLE D
INSULATED STUD



STYLE E
RIBBON LEADS



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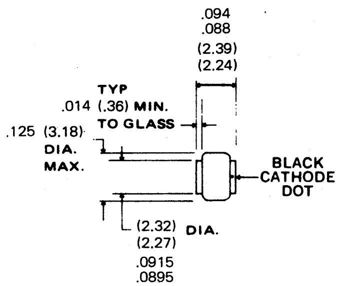
MECHANICAL SPECIFICATIONS (continued)

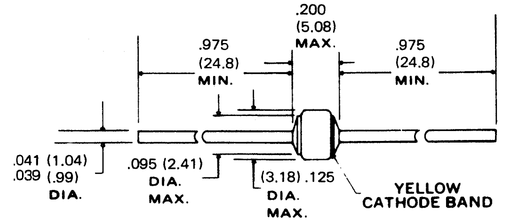
UM 4900 Series

Dimensions — English/Metric

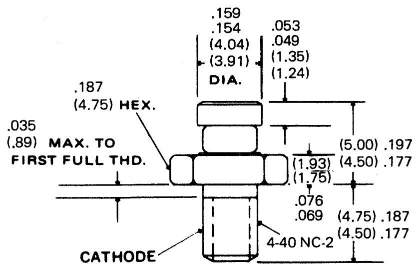
STYLE A



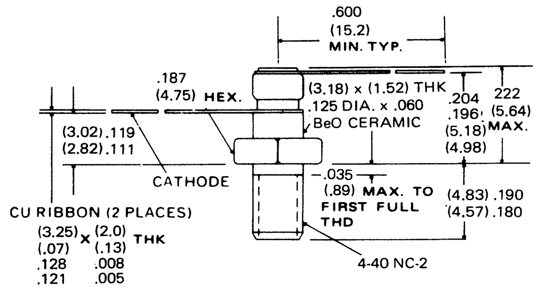
STYLE B



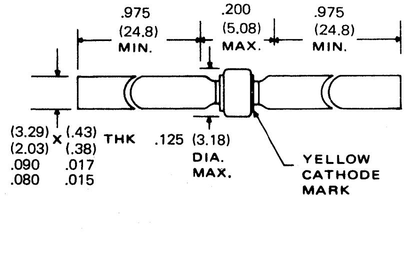
STYLE C
STUD



STYLE D
INSULATED STUD



STYLE E
RIBBON LEADS



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PIN DIODE

UM4300 SERIES
UM7300 SERIES

For Attenuator Applications

Features

- Extremely low distortion performance
- Useful frequency range extends below 500 KHz
- Power dissipation to 20W (UM4300)
- Capacitance as low as 0.7 pF (UM7300)
- Voltage ratings to 1000V

Description

The UM4300 and UM7300 series combine a diode chip of extremely thick intrinsic region with a low thermal resistance construction. This results in diodes uniquely applicable to very low distortion linear attenuators and specialized switching functions. The UM4300 series, with large cross-sectional chip area offers the highest power capability, of the two series. The UM7300 series offers lower capacitance.

Both diode series are intended for use in linear attenuators operating from HF to beyond 1 GHz. Low distortion at low frequencies is a result of transit time frequencies below 5 MHz.

Operated as RF switches, either diode series can be operated at low dc reverse bias voltages, to hold off much higher RF voltage levels.

MAXIMUM RATINGS

Average Power Dissipation and Thermal Resistance Ratings

Package	Condition	UM4300		UM7300	
		P_D	θ	P_D	θ
A	25°C Pin Temperature	20W	7.5°C/W	7.5W	20°C/W
B&E (Axial Leads)	½ in. Total Length to 25°C Contact	10W	15°C/W	4W	37.5°C/W
B&E (Axial Leads)	Free Air	2.5W	—	1.5W	—
C (Studded)	25°C Stud	20W	7.5°C/W	7.5W	20°C/W
D (Insulated Stud)	25°C Stud	15W	10°C/W	6W	25°C/W

Peak Power Dissipation Rating

All packages	1μs Pulse (Single) at 25°C Ambient	500 KW	100 KW

Operating and Storage Temperature Range: −65°C to +175°C

UNITRODE

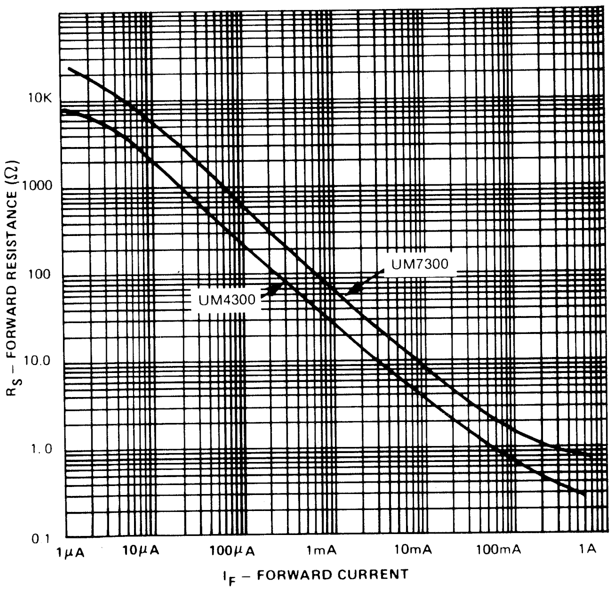
Voltage Ratings (25 °C)

Reverse Voltage (V_R) — Volts (I_R = 10 μA)	Types	
100V	UM4301	UM7301
200V	UM4302	UM7302
600V	UM4306	UM7306
1000V	UM4310	UM7310

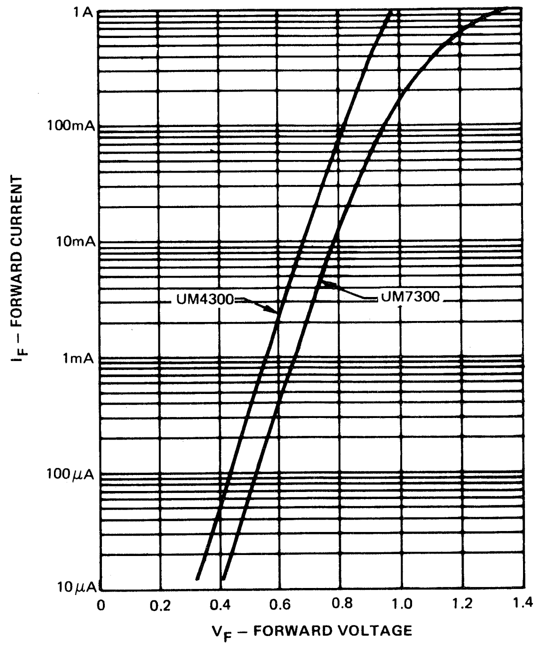
Electrical Specifications (25 °C)

Test	Symbol	UM4300	UM7300	Conditions
Total Capacitance (Max)	C_T	2.2 pF	0.7 pF	0V, 1 GHz
Series Resistance (Max)	R_S	1.5Ω	3.0Ω	100 mA, 1 GHz
Series Resistance (Min)	R_S	1000Ω	3000Ω	10 μA, 100 MHz
Carrier Lifetime (Min)	τ	6μs	4.0μS	I_F = 10 mA
Leakage Current (Max)	I_R	10μA	10μA	V_R = Rating
I-Region Width (Min)	W	250μm	250μm	—

TYPICAL FORWARD RESISTANCE VS FORWARD CURRENT (F = 100 MHz)

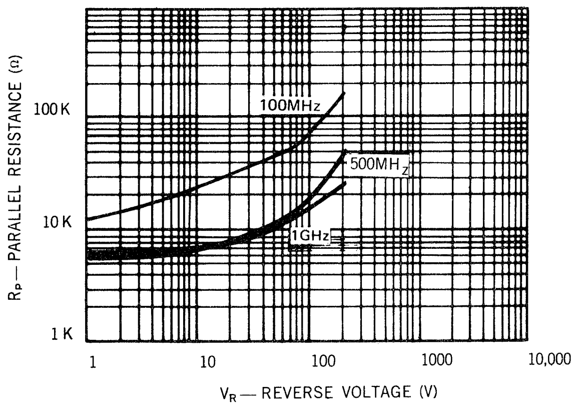


TYPICAL DC CHARACTERISTIC FORWARD VOLTAGE VS FORWARD CURRENT

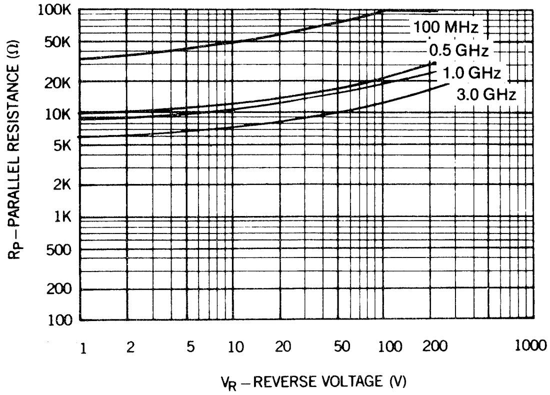


PARALLEL RESISTANCE VS REVERSE VOLTAGE

UM4300

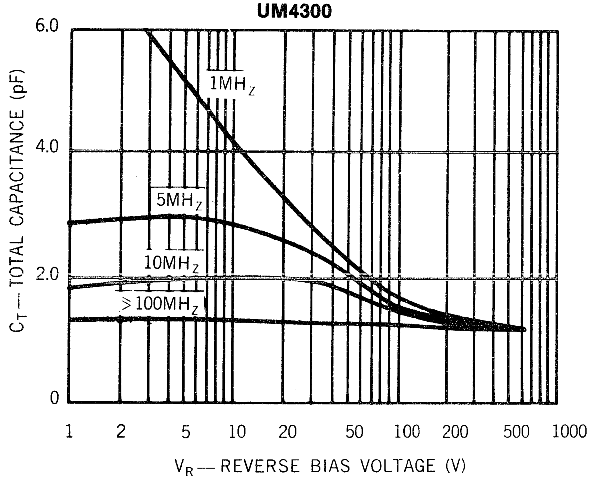


UM7300

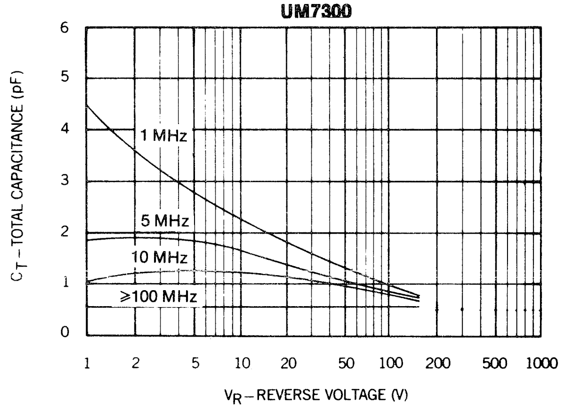


TOTAL CAPACITANCE VS REVERSE VOLTAGE

UM4300

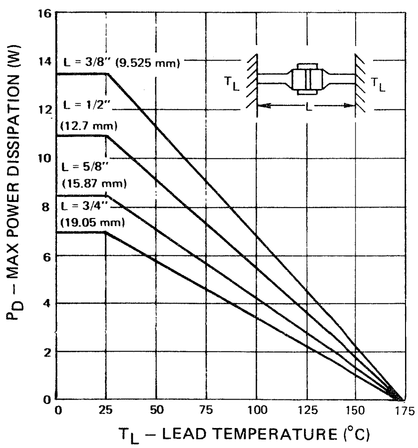


UM7300

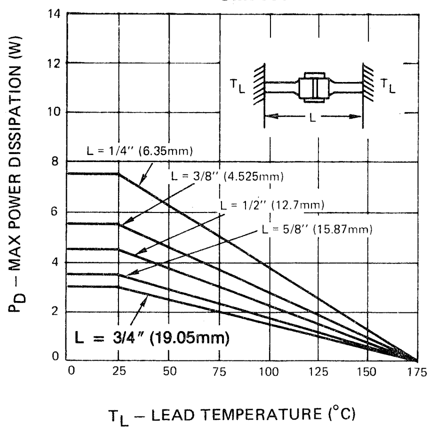


POWER RATING AXIAL LEADED DIODE

UM4300



UM7300



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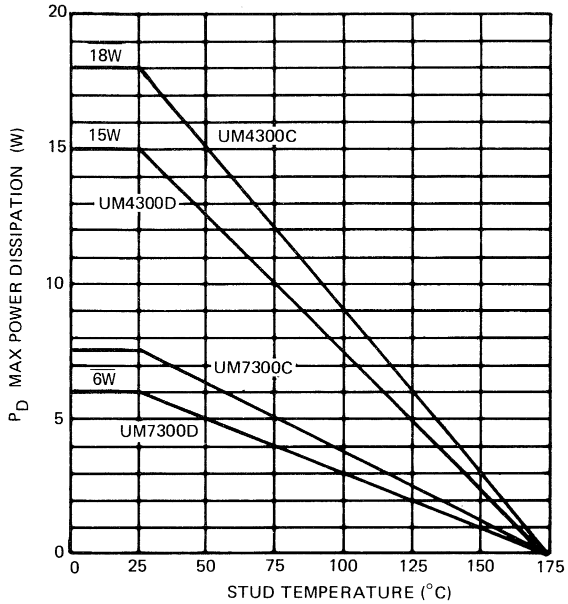
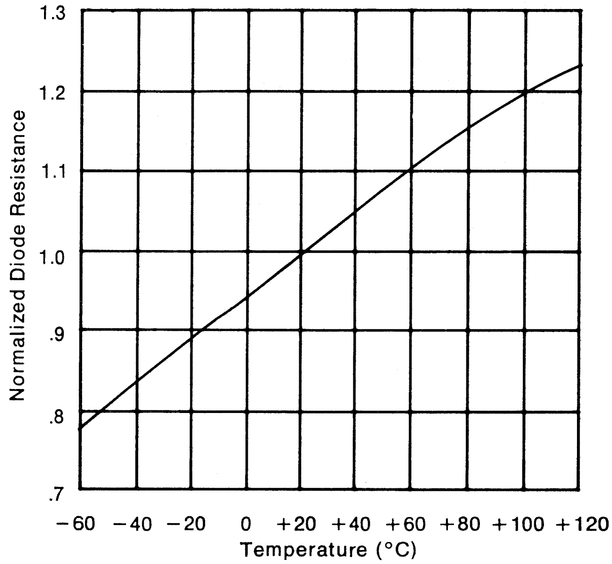
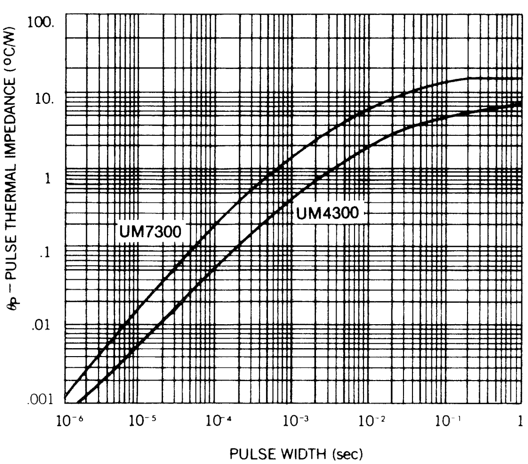
UM4300/UM7300 POWER RATING STUD MOUNTED DIODES



NORMALIZED R_S VS TEMPERATURE



PULSE THERMAL IMPEDANCE VS PULSE WIDTH



ORDERING INSTRUCTIONS

Part numbers of Unitrode PIN Diodes consist of the letters UM followed by four digits and one or two letters. The first two digits indicate the diode series, the next two digits specify the minimum breakdown voltage in hundreds of volts. The remaining letters denote the package style. Reverse polarity (anode on stud end) is available in C or D Styles and denoted by adding second letter R.

For Example: UM|73|01|C|

Series 7300 | 100 volts | Style C

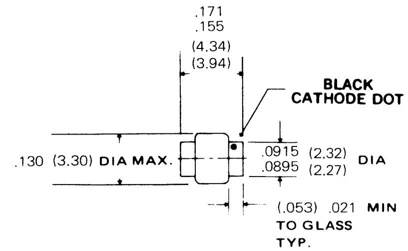
Reverse polarity available in C style. Part number designated by adding R.

MECHANICAL SPECIFICATIONS

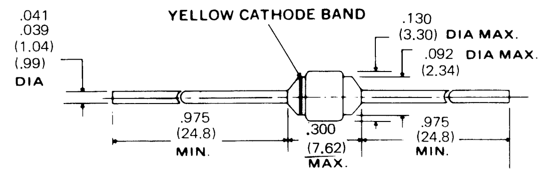
UM4300 SERIES

Dimensions — English/Metric

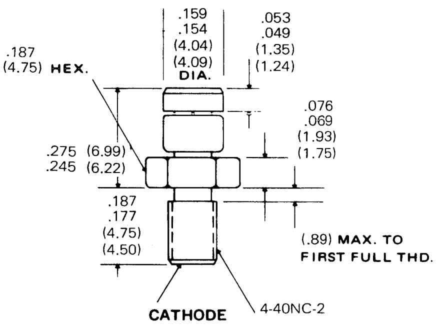
STYLE A



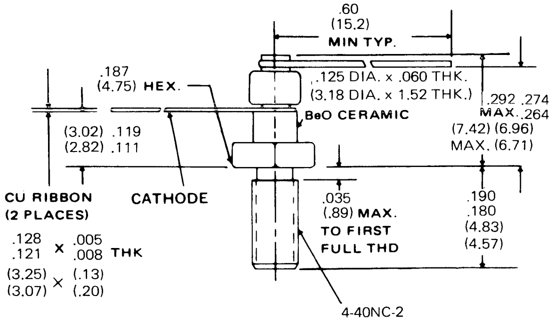
STYLE B



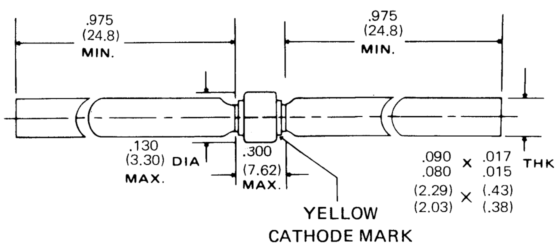
STYLE C
STUD



STYLE D
INSULATED STUD



STYLE E
RIBBON LEADS



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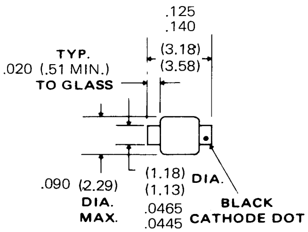
MECHANICAL SPECIFICATIONS (continued)

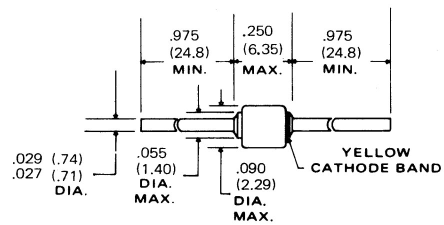
UM7300 Series

Dimensions — English/Metric

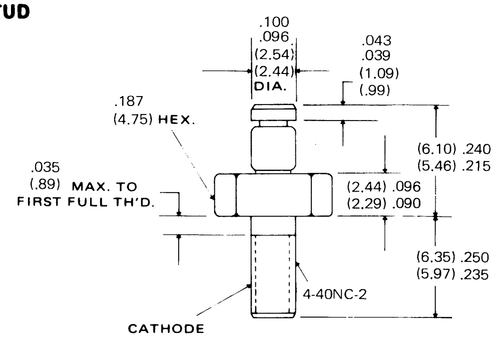
STYLE A



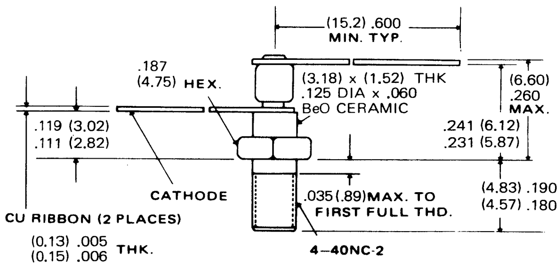
STYLE B



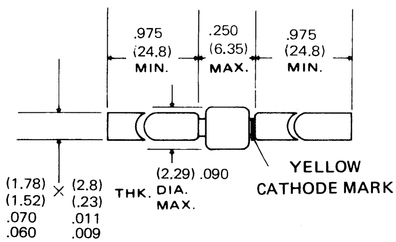
STYLE C
STUD



STYLE D
INSULATED STUD



STYLE E
RIBBON LEADS



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PIN DIODE

UM6000 SERIES
UM6200 SERIES
UM6600 SERIES

Features

- Capacitance specified as low as 0.4 pF (UM6600)
- Resistance specified as low as 0.4Ω (UM6200)
- Voltage ratings to 1000V
- Power dissipation to 6W

Description

These series of PIN diodes are designed for applications requiring small package size and moderate average power handling capability. The low capacitance of the UM6000 and UM6600 allows them to be used as series switching elements to 1 GHz. The low resistance of the UM6200 is useful in applications where forward bias current must be minimized.

Because of its thick I-region width and long lifetime the UM6000 and UM6600 have been used in distortion sensitive and high peak power applications, including receiver protectors, TACAN, and IFF equipment. Their low capacitance allows them to be useful as attenuator diodes at frequencies greater than 1 GHz. The UM6200 has been used successfully in switches in which low insertion loss at low bias current is required.

The "A" style package for this series is the smallest Unitrode PIN diode package. It has been used successfully in many microwave applications using coaxial, microstrip, and stripline techniques at frequencies beyond X-Band. The "B" and "E" style, leaded packages offer the highest available power dissipation for a package this small. They have been used extensively as series switch elements in microstrip circuits. The "C" style package duplicates the physical outline available in conventional ceramic-metal packages but incorporates the many reliability advantages of the Unitrode construction.

MAXIMUM RATINGS

Average Power Dissipation and Thermal Resistance Ratings

Package	Condition	UM6000 UM6200		UM6600	
		P_D	θ	P_D	θ
A&C	25°C Pin Temperature	6W	25°C/W	4W	37.5°C/W
B&E (Axial Leads)	½ in. Total Lead Length to (12.7 mm) to 25°C Contact	2.5W	60°C/W	2.0W	75°C/W
B&E (Axial Leads)	Free Air	0.5W	—	0.5W	—

Peak Power Dissipation Rating

All Packages	1 μs Pulse (Single) at 25°C Ambient	UM6000 - 25 KW UM6200 - 10 KW	UM6600 - 13 KW

Operating and Storage Temperature Range:	−65°C to +175°C

UNITRODE

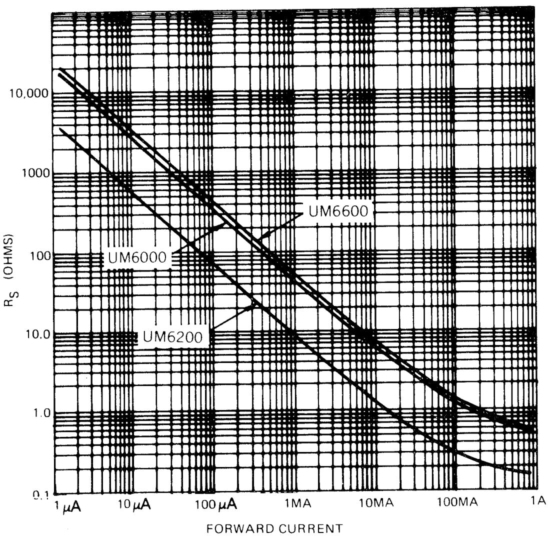
Voltage Ratings (25 °C)

Reverse Voltage (V_R) — Volts (I_R = 10 μA)	Types		
100V	UM6001	UM6201	UM6601
200V	UM6002	UM6202	UM6602
400V	—	UM6204	—
600V	UM6006	—	UM6606
1000V	UM6010	—	UM6610

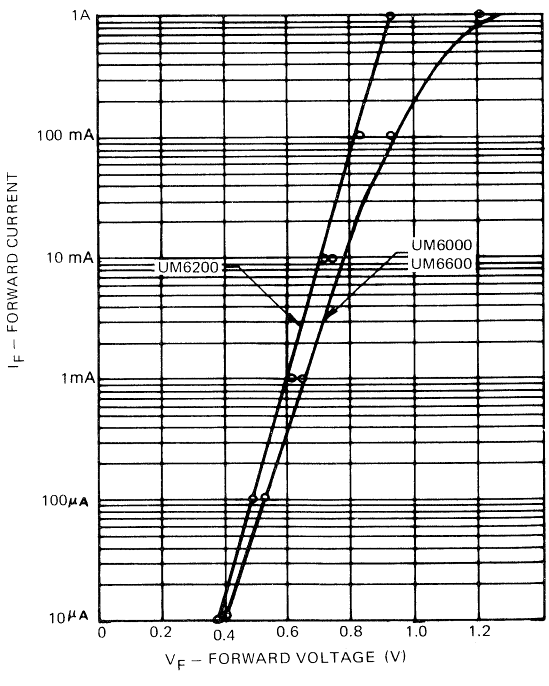
Electrical Specifications (25 °C)

Test	Symbol	UM6600	UM6000	UM6200	Conditions
Total Capacitance (Max)	C_T	0.4 pF	0.5 pF	1.1 pF	0V, 1 GHz
Series Resistance (Max)	R_S	2.5Ω	1.7Ω	0.4Ω	100 mA, 1 GHz
Parallel Resistance (Min)	R_P	10 KΩ	15 KΩ	10 KΩ	100V, 1 GHz
Carrier Lifetime (Min)	τ	1.0 μs	1.0 μs	0.6 μs	I_F = 10 mA
Reverse Current (Max)	I_R	10 μA	10 μA	10 μA	V_R = Rating
I-Region Width (Min)	W	150 μm	150 μm	40 μm	—

TYPICAL SERIES RESISTANCE VS FORWARD CURRENT (F = 100MHz)



DC CHARACTERISTICS FORWARD VOLTAGE VS CURRENT



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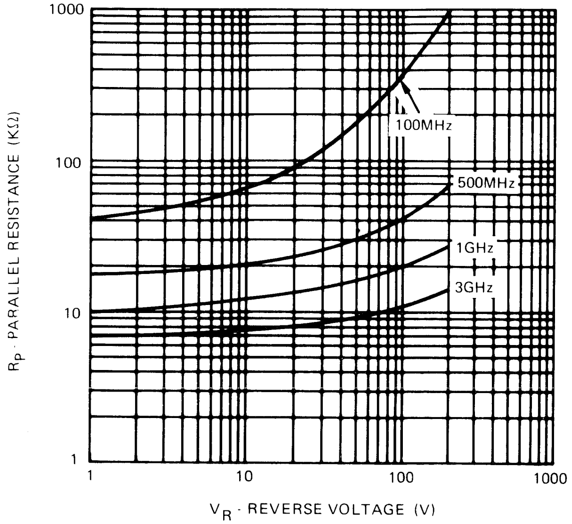
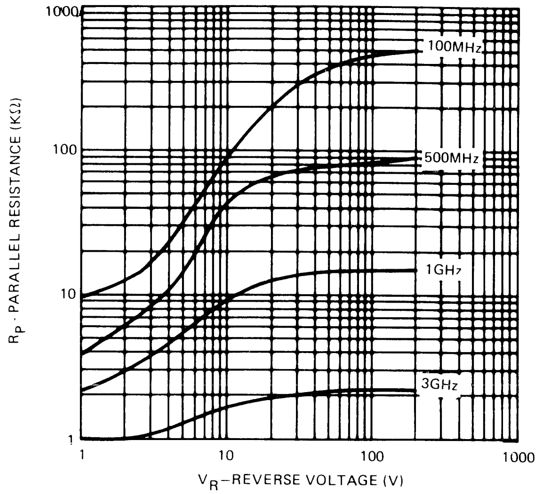
TYPICAL R_p VS VOLTAGE & FREQUENCY

UM6000/UM6600

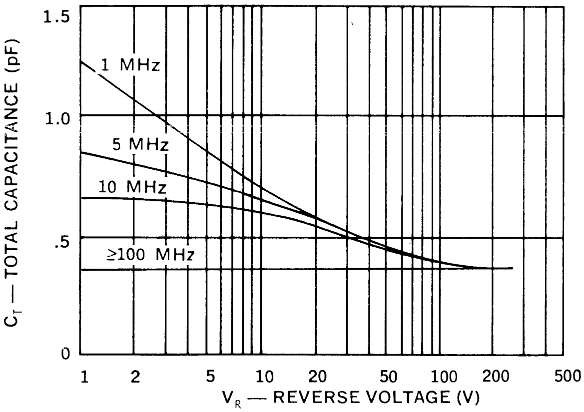


UM6200

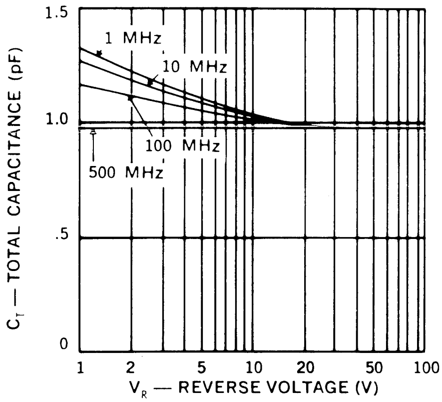


TYPICAL CAPACITANCE VS VOLTAGE AND FREQUENCY

UM6000 SERIES



UM6200 SERIES



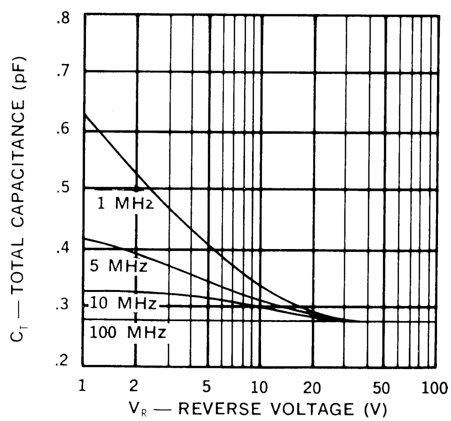
ORDERING INSTRUCTIONS

Part numbers of Unitrode PIN diodes consist of the letters UM followed by four digits and one or two letters. The first two digits indicate the diode series, the next two digits specify the minimum breakdown voltage in hundreds of volts. The remaining letters denote the package style. Reverse polarity (anode large end cap) is available for the C style and denoted by adding second letter R.

For Example: UM 60 06 CR

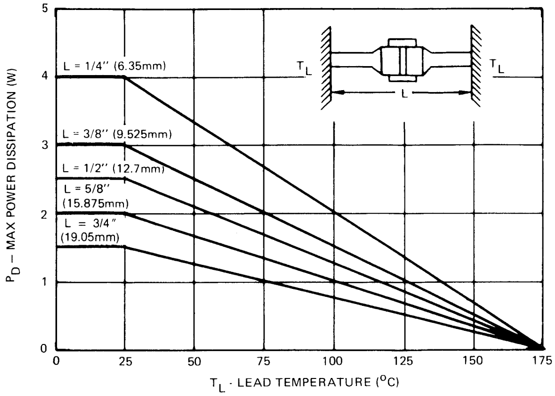
- Series 6000
- 600 Volts
- Style C Reverse Polarity

UM6600 SERIES

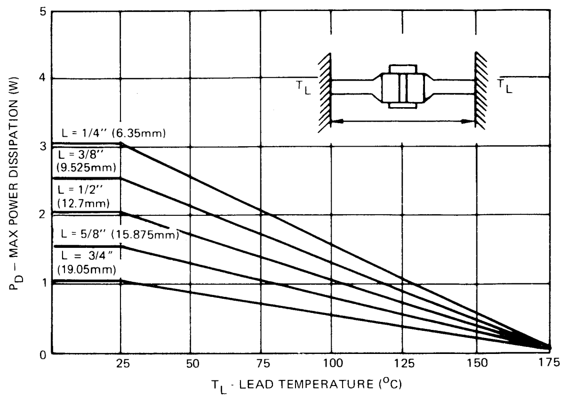


POWER RATING — AXIAL LEADED DIODE

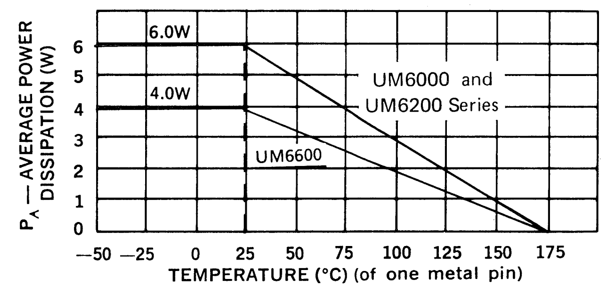
UM6000/UM6200



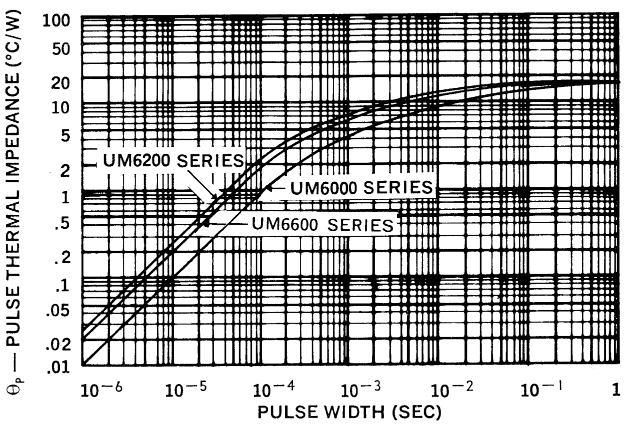
UM6600



POWER RATING

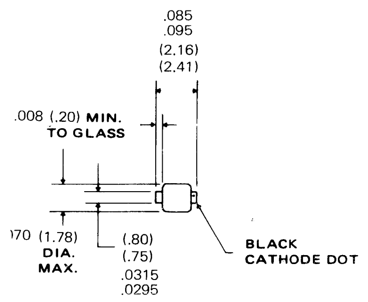


PULSE THERMAL IMPEDANCE VS PULSE WIDTH

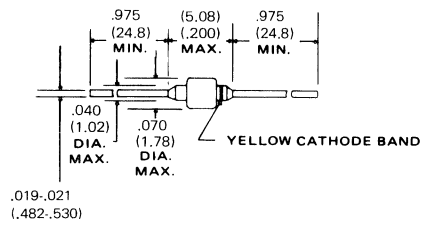


MECHANICAL SPECIFICATIONS

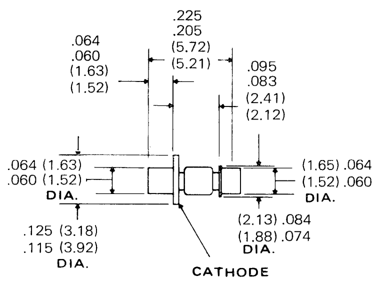
STYLE A



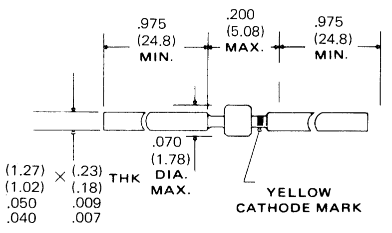
STYLE B



STYLE C
CARTRIDGE



STYLE E
RIBBON LEADS



PIN DIODE

UM7000 SERIES
UM7100 SERIES
UM7200 SERIES

Features

- Voltage ratings to 1000V (UM7000)
- Wide variety of package styles
- Rated average power dissipation to 10W
- Cost effective in volume applications

Description

The UM7000 and UM7100 series offer moderately high power handling in combination with reasonably low levels of both series resistance and capacitance. The UM7200 series offers the lowest series resistance, but the highest capacitance of the group. The differences in specified performance, for each of the series, results from different I-region thicknesses. The three series have broad applicability in many RF and microwave switch and attenuator circuits. Additionally, the UM7100 in leaded versions, is usually the most cost-effective diode choice in high volume usage.

MAXIMUM RATINGS

Average Power Dissipation and Thermal Resistance Ratings

Package	Condition	P_D	θ
A	25 °C Pin Temperature	10W	15 °C/W
B&E (Axial Leads)	½ in.(12.7 mm) Lead Length to 25 °C Contact	5.5W	27.5 °C/W
B&E (Axial Leads)	Free Air	1.5W	—
C (Studded)	25 °C Stud Temperature	10W	15 °C/W
D (Insulated Stud)	25 °C Stud Temperature	7.5W	20 °C/W

Peak Power Dissipation Rating

All Packages	1 µs Pulse (Single) at 25 °C Ambient	UM7000 - 60 KW UM7100 - 35 KW UM7200 - 20 KW

Operating and Storage Temperature Range: −65 °C to +175 °C

UNITRODE

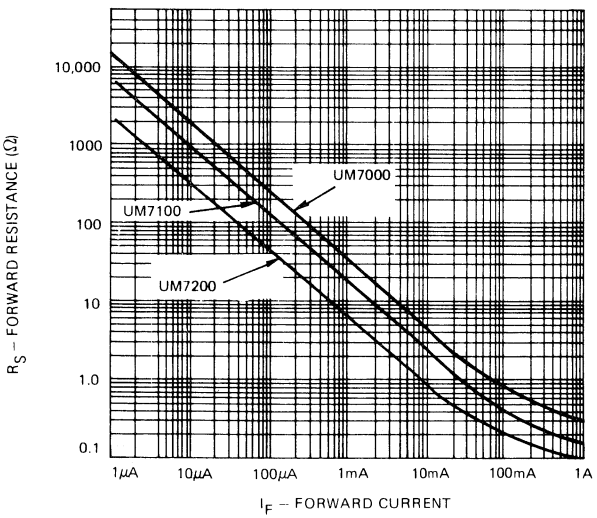
Voltage Ratings (25 °C)

Reverse Voltage (V_R) — Volts (I_R = 10 μA)	Types		
100V	UM7001	UM7101	UM7201
200V	UM7002	UM7102	UM7202
400V	—	UM7104	UM7204
600V	UM7006	—	—
800V	—	UM7108	—
1000V	UM7010	—	—

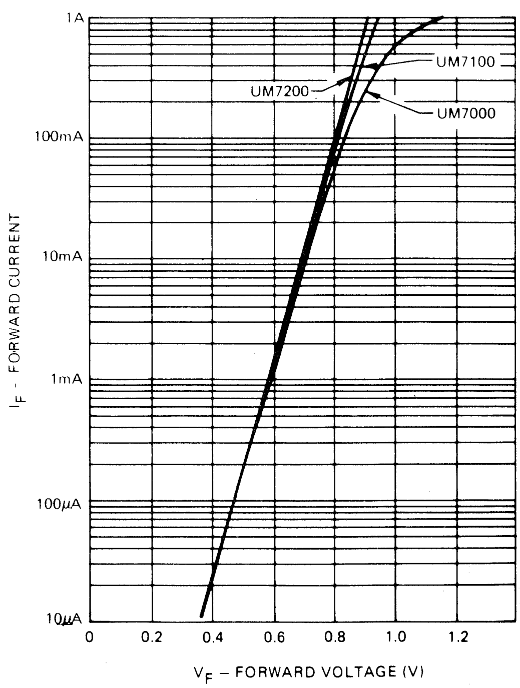
Electrical Specifications (25 °C)

Test	Symbol	UM7000	UM7100	UM7200	Conditions
Total Capacitance (Max)	C_T	0.9 pF	1.2 pF	2.2 pF	0V, 1 GHz
Series Resistance (Max)	R_S	1.0Ω	0.6Ω	0.25Ω	100 mA, 1 GHz
Parallel Resistance (Min)	R_P	10 KΩ	8 KΩ	7 KΩ	100V, 1 GHz
Carrier Lifetime (Min)	τ	2.5 μs	2.0 μs	1.5 μs	I_F = 10 mA
Reverse Current (Max)	I_R	10 μA	10 μA	10 μA	V_R = Rating
I-Region Width (Min)	W	150 μm	80 μm	40 μm	—

TYPICAL FORWARD RESISTANCE VS FORWARD CURRENT (F = 100 MHz)

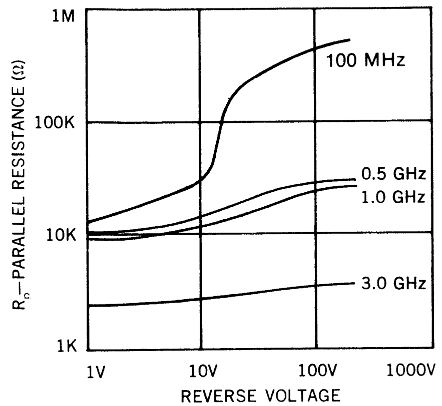


TYPICAL DC CHARACTERISTIC FORWARD VOLTAGE VS FORWARD CURRENT UM7000/UM7100/UM7200

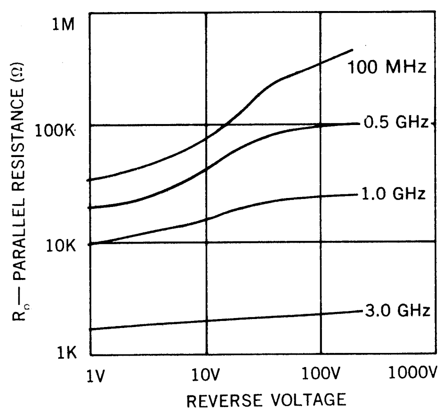


TYPICAL Rp CHARACTERISTIC

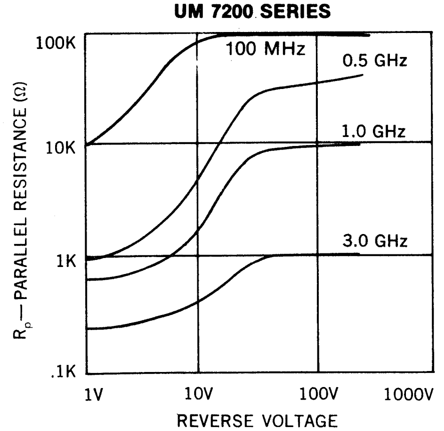
UM 7000 SERIES



UM7100 SERIES

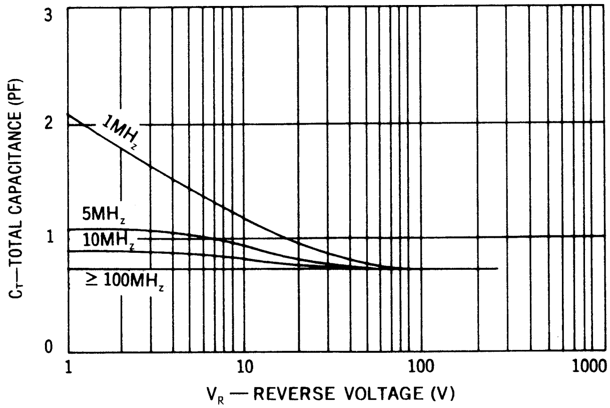


UM 7200 SERIES

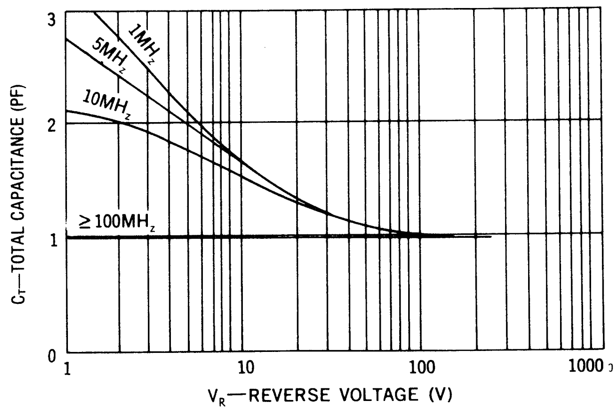


TYPICAL C_T CHARACTERISTIC

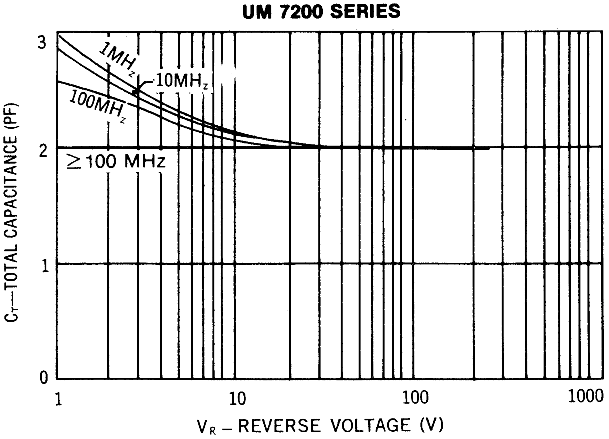
UM 7000 SERIES



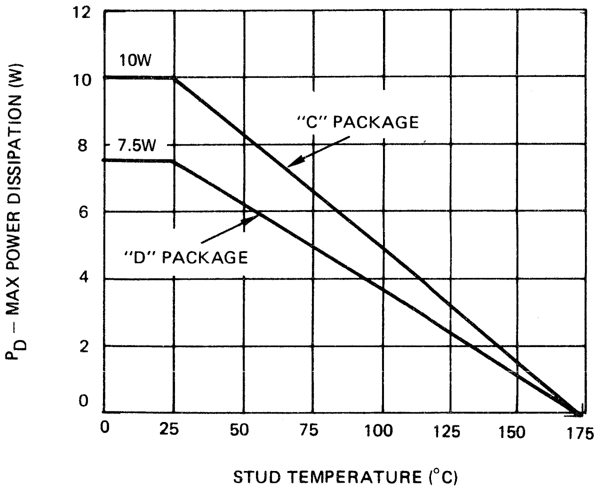
UM 7100 SERIES



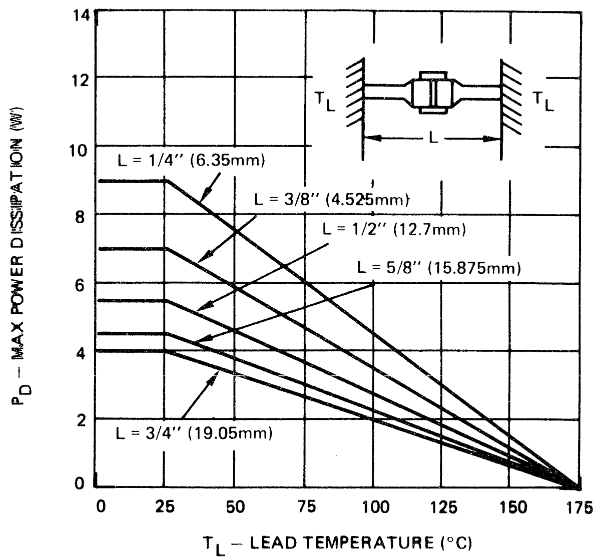
UM 7200 SERIES



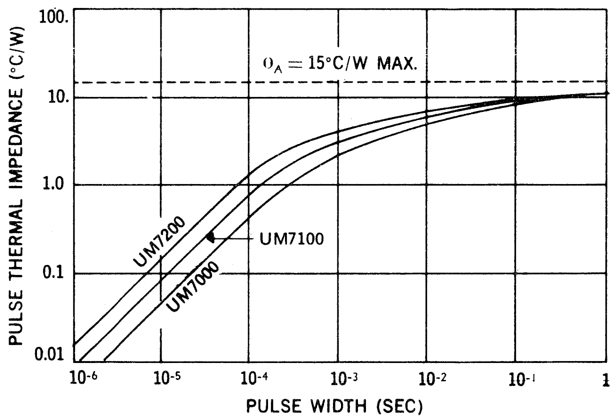
POWER RATING STUD MOUNTED DIODES



POWER RATING — AXIAL LEADED DIODES



PULSE THERMAL IMPEDANCE VS PULSE WIDTH



ORDERING INSTRUCTIONS

Part numbers of Unitrode PIN Diodes consist of the letters UM followed by four digits and one or two letters. The first two digits indicate the diode series, the next two digits specify the minimum breakdown voltage in hundreds of volts. The remaining letters denote the package style. Reverse polarity (anode on stud end) is available in C or D Styles and denoted by adding second letter R.

For Example: UM |70|01|C|

|Series 7000| |100 volts| |Style C|

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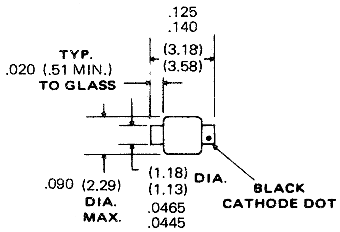
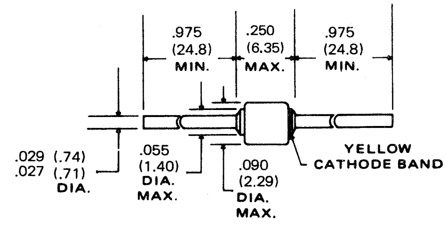
MECHANICAL SPECIFICATIONS

Dimensions — English/Metric

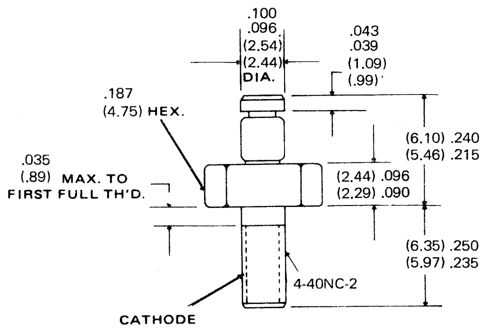
STYLE A



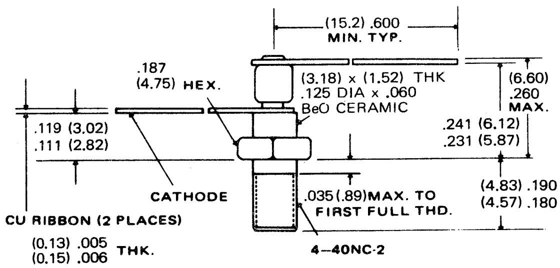
STYLE B



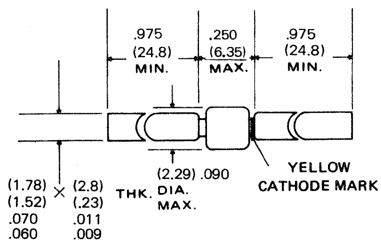
STYLE C
STUD



STYLE D
INSULATED STUD



STYLE E
RIBBON LEADS



PIN DIODE

COMMERCIAL ATTENUATOR DIODE

Features

- Specified low distortion
- Low rectification properties at low reverse bias
- Resistance specified at 3 current points
- High reliability fused-in-glass construction

Description

The UM9301 PIN Diode utilizes a special overall chip geometry with an extremely thick intrinsic "I" region, to offer unique capabilities in both RF switch and attenuator applications. Volume production also makes the diode an economical choice suitable for many commercial low power equipments.

The UM9301 has been designed for use in bridged TEE attenuator circuits commonly utilized for gain and slope control in CATV amplifiers. Low distortion and high dynamic range are characteristic of the diodes' outstanding performance.

The UM9301 is also appropriate for switch applications, when little or no bias voltage is available. Frequent applications occur in portable 12 volt-powered communications equipments, operating at frequencies as low as 2 MHz.

MAXIMUM RATINGS

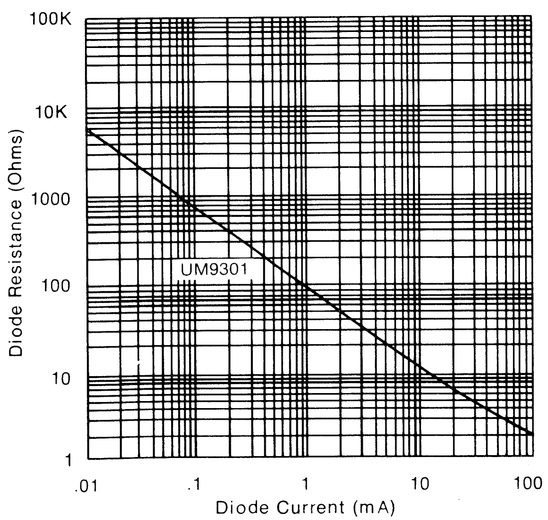
Reverse Voltage (V_R) — Volts (I_R = 10 μA)	75V
Average Power Dissipation @ (P_A) Leads ½ in. overall to 25°C Contact	1.0W (Derate linearly to 175°C)
Operating and Storage Temperature Range	−65°C to +175°C

UNITRODE

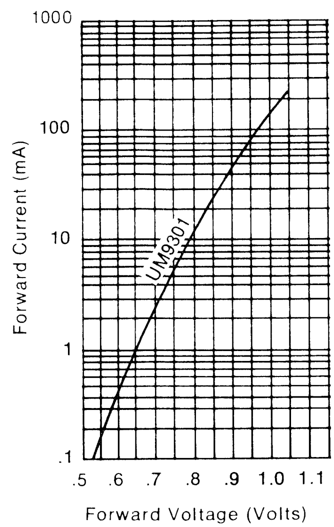
Electrical Specifications (25°C)

Test	Min	Typ	Max	Units	Conditions
Diode Resistance R_S		1.7 80 5000	3.0 150	Ω Ω Ω	I = 100 mA, f = 100 MHz I = 1 mA, f = 100 MHz I = 0.01 mA, f = 100 MHz
	3000				
Current for $R_S = 75\Omega$	0.5	1.1	2.0	mA	f = 100 MHz
Capacitance			0.8	pF	V = 0V, f = 100 MHz
Return Loss	25			dB	Frequency Range: 10 - 300MHz $R_S = 75\Omega$ @ 100 MHz Diode Terminates 75Ω line
Second Order Distortion		55	50	−dB	f_1 = 10 MHz, f_2 = 13 MHz P = 50 dBmV, See Test Circuit
		70		−dB	F_1 = 67 MHz, F_2 = 77 MHz P = 50 dBmV, See Test Circuit
Third Order Distortion		75	65	−dB	F_1 = 10 MHz, F_2 = 13 MHz P = 50 dBmV, See Test Circuit
		95		−dB	Triple Beat; 205 + 67 − 77 MHz P = 50 dBmV, See Test Circuit
Cross Modulation Distortion		75		−dB	12 Channel Test P = 50 dBmV, See Test Circuit Dix Hills Test Set
Reverse Current			10	μA	V = 75V
Carrier Lifetime	4.0			μs	I = 10 mA

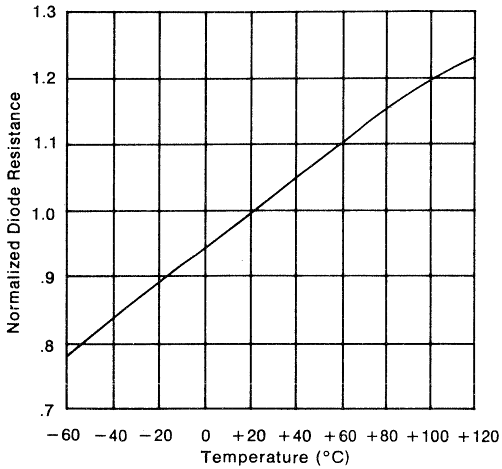
DIODE RESISTANCE VS DIODE CURRENT (TYPICAL)



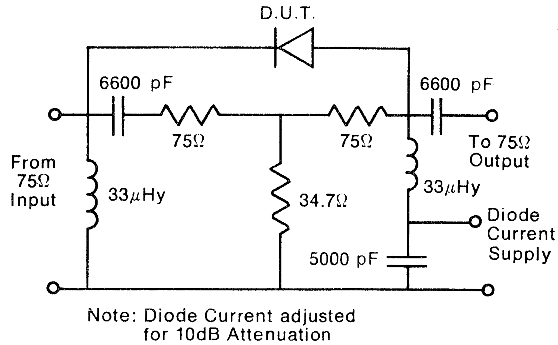
FORWARD CURRENT VS FORWARD VOLTAGE (TYPICAL)



NORMALIZED R_S VS TEMPERATURE

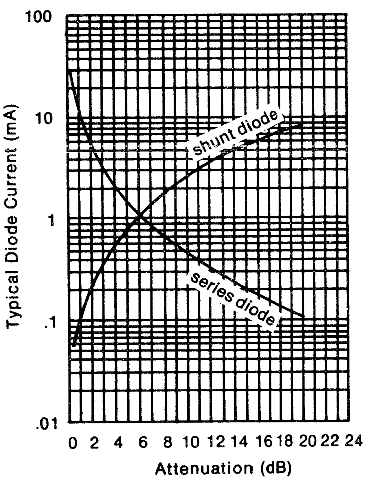


TEST CIRCUIT FOR DISTORTION MEASUREMENTS

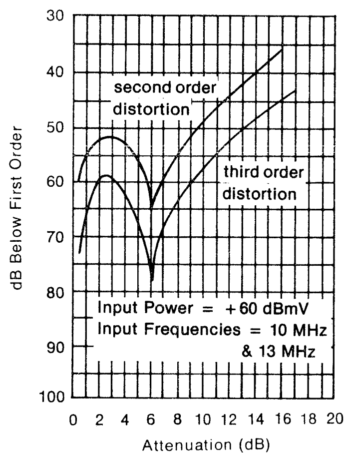


TYPICAL BRIDGED TEE ATTENUATOR PERFORMANCE

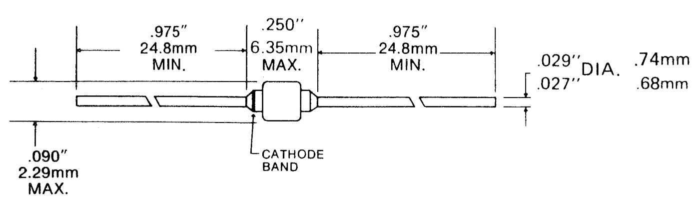
DIODE CURRENT VS ATTENUATION UM9301



DISTORTION ATTENUATION



MECHANICAL SPECIFICATIONS



PIN DIODE

UM9401 SERIES
UM9402 SERIES
UM9415 SERIES

COMMERCIAL TWO-WAY RADIO ANTENNA SWITCH DIODES

Features

- Specified low distortion
- Unitrode ruggedness and reliability
- Low bias current requirements
- Priced for high quantity applications

Description:

Unitrode offers a series of PIN diodes specifically designed and characterized for solid state antenna switches in commercial two-way radios. Antenna switches using the UM9401 and UM9415 series PIN diodes provide high isolation, low loss and low distortion characteristics formerly possible only with electromechanical relay type switches.

The UM9401 and UM9402 diodes can handle above 100W of transmitter power, while the UM9415 will handle over 1000W. The extensive characterization of these PIN diodes in antenna switch applications has resulted in guaranteed low distortion specifications under transmit and receive conditions. These diodes also feature low forward bias resistance and high zero bias impedance which are required for low loss, high isolation and wide bandwidth antenna switch performance.

MAXIMUM RATINGS

	UM9401	UM9402	UM9415
Reverse Voltage (V_R) — Volts (I_R = 10 μA)	50V	50V	50V

Average Power Dissipation (P_A)			
Leads - ½ in. Overall to 25 °C	5.5W	—	10W
Heat Sink 25 °C (Package Flange) Temperature	—	10W	—
Free Air	1.5W		2.5W

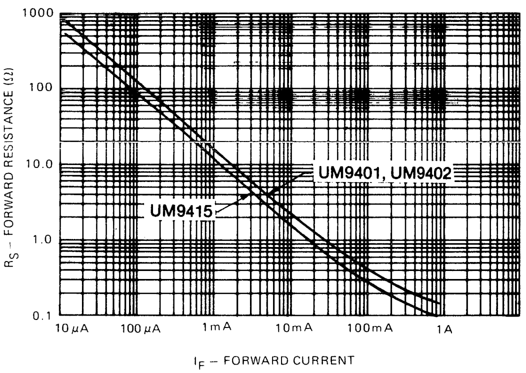
Operating and Storage Temperature Range	− 65 °C to + 175 °C

UNITRODE

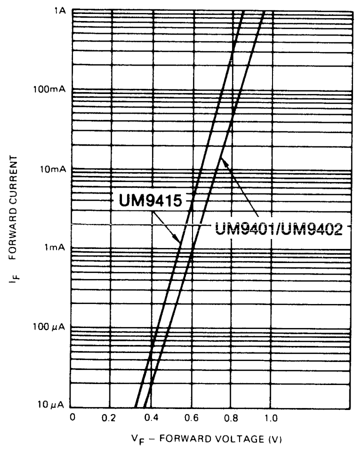
Electrical Specifications (at 25 °C)

Test	Symbol	UM9401/UM9402			UM9415			Units	Conditions
		Min	Typ	Max	Min	Typ	Max		
Series Resistance	R_S		0.75	1.0		0.75	1.0	Ω	f = 100MHz typical I = 50 mA
Diode Capacitance	C_T		1.1	1.5			4	pF	f = 100 MHz V = 0V
Parallel Resistance	R_P	5K	10K		1K	2K		Ω	f = 100 MHz V = 0V
Carrier Lifetime	τ	1.0	2.0		5			μS	I = 10 mA
Transmit Harmonic Distortion	$\frac{R_{2A}}{A}$, $\frac{R_{3A}}{A}$			80			80	−dB	P_{IN} = 50W f = 50 MHz, I = 50 mA
Receive Third Order Distortion	$\frac{R_{2AB}}{A}$			60			60	−dB	P_{IN} = 10 mW, 0V Bias f_A = 50 MHz, f_B = 51 MHz
Reverse Leakage Current	I_R			10			10	μA	V = 50V
Forward Voltage	V_F			1.0			1.0	V	I_F = 50 mA

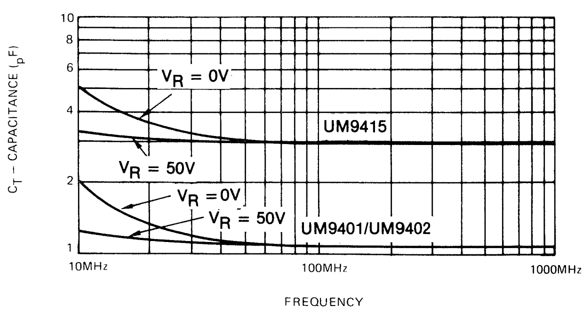
TYPICAL FORWARD RESISTANCE VS FORWARD CURRENT (F = 100 MHz)



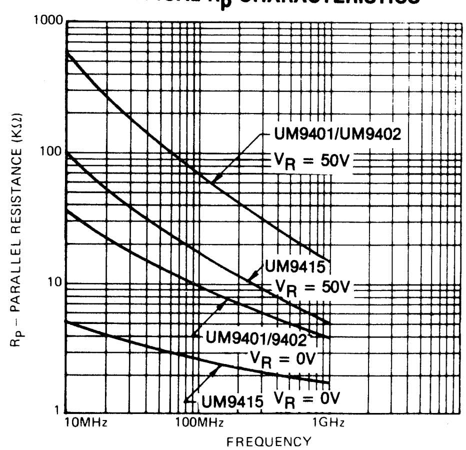
TYPICAL DC CHARACTERISTIC



TYPICAL CAPACITANCE CHARACTERISTIC



TYPICAL R_p CHARACTERISTICS



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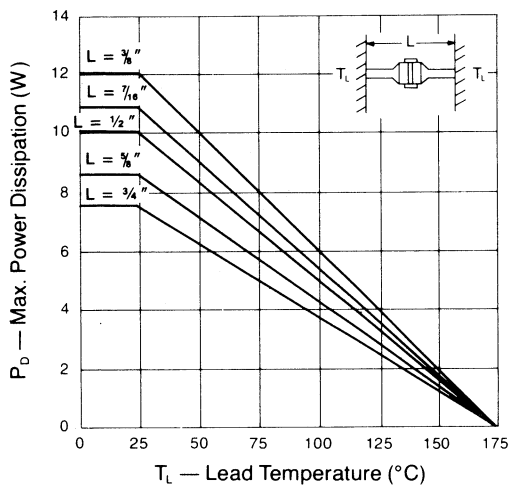
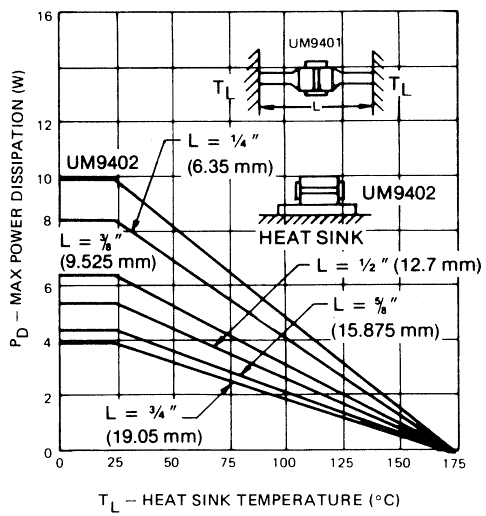
POWER RATING
UM9415

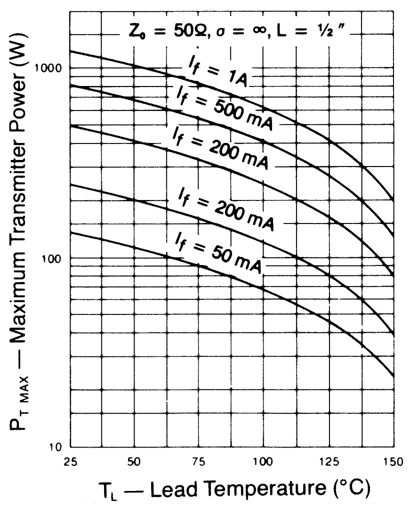


POWER RATING
UM9401/9402

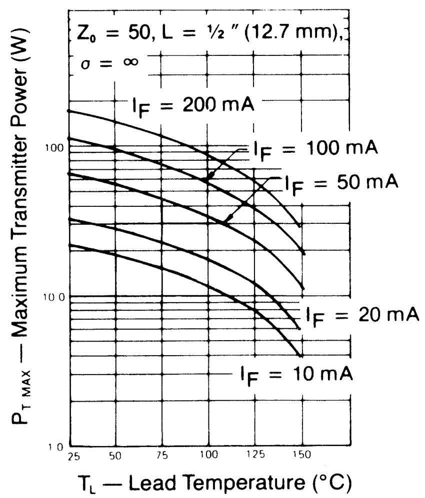


MAXIMUM TRANSMITTER POWER

UM9415



UM9401/UM9402



Maximum Transmitter Power

The maximum CW transmitter power, $P_{T(max)}$, a PIN diode antenna switch can handle depends on the diode resistance, R_S, power dissipation, P_D, antenna SWR, σ, and nominal impedance, Z_0. The expression relating these parameters is as follows:

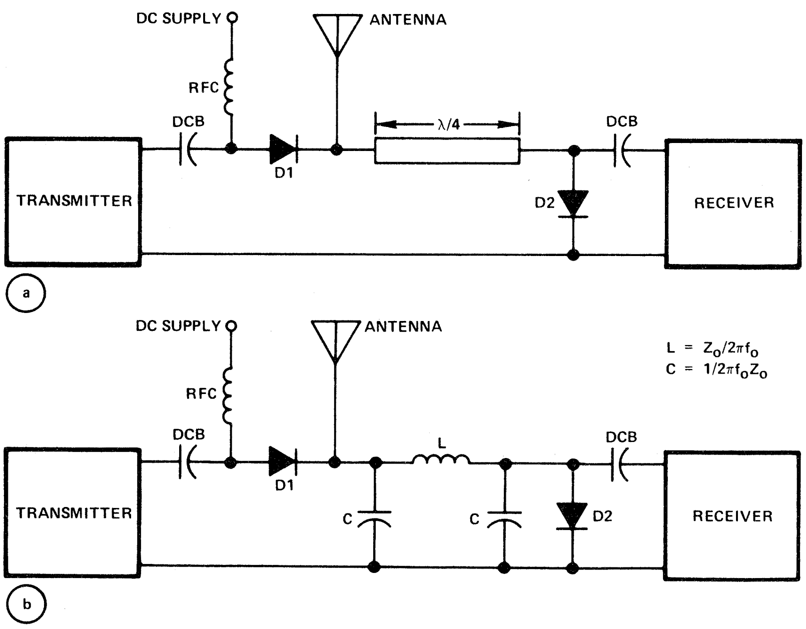
$$P_{T(max)} = \frac{P_D \times Z_0}{R_D} \left(\frac{\sigma + 1}{2\sigma}\right)^2 \text{ [Watts]}$$

Characteristic curves are shown in the data section which give both the maximum and typical diode resistance, R_S as a function of forward current. The maximum power dissipation rating of the PIN diode depends both on the length of the diode leads and the temperature of the contacts to which the leads are connected. A graph defining the maximum power dissipation at various combinations of overall lead length (L) and lead temperature (T_L) is given in the data section. From these curves and the above equation, the power handling capability of the PIN diode may be computed for a specific application.

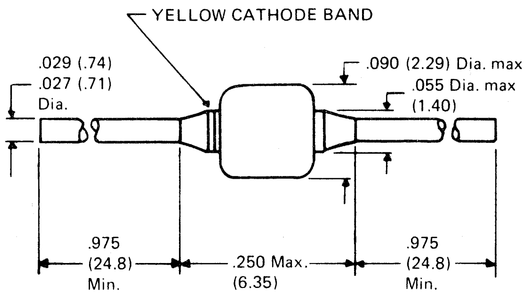
Curves are also presented which show the maximum transmitter power that an antenna switch using UM9401s and UM9415s can safely handle for various forward currents and lead temperatures. These curves are based on a typical design condition of a ½ in. total overall lead length, 50Ω line impedance and a totally mismatched antenna ($\sigma = \infty$). For the case of a perfectly matched antenna, the maximum transmitter power can be increased by a factor of 4.

Design Information

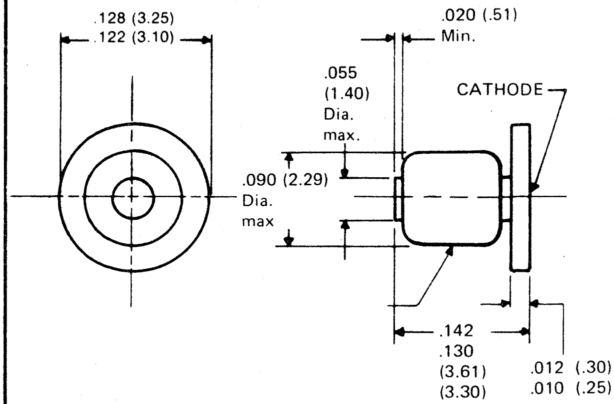
A circuit configuration for a two-way radio antenna switch using PIN diodes consists of a diode placed in series with the transmitter and a shunt diode placed a quarter wavelength from the antenna in the direction of the receiver as shown. For low frequency operation, the quarter wave line may be simulated by lumped elements. Typical performance of antenna switches using PIN diodes forward biased at 100 mA is less than 0.2 dB insertion loss and 30 dB isolation during transmit; at zero bias the receive insertion loss is less than 0.3 dB. This performance is achievable across a ±20% bandwidth at center frequencies ranging from 10 to 500 MHz.



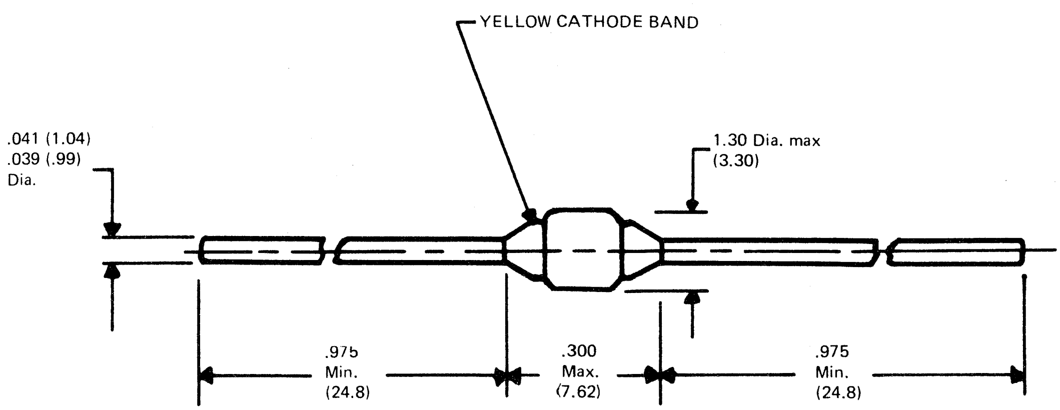
UM9401



UM9402



UM9415



Dimensions: inches (millimeters)

PIN DIODE

UM9601-UM9608

For Microstrip 900MHz Antenna Switches and Microwave Applications

Features
- Low Inductance Shunt Mount Package
- Characterized for Microstrip
- Unitrode Ruggedness and Reliability
- High Power Handling Capability
- Low Bias Current Requirement
- Excellent Distortion Properties
- Cost Effective in High Quantity Applications

Description
The UM9601-UM9608 series of PIN diodes was developed for shunt mount applications in microstrip circuits. Good switch performance is demonstrated at frequencies from UHF to 4GHz and higher. This performance is achieved using discrete low inductance Unitrode PIN diodes assembled with special hardware to permit good electrical and mechanical compatibility with microstrip transmission lines.

Design information is presented for preparation of microstrip circuit boards to accommodate these PIN diodes. A detailed design for a 900MHz quarter-wave antenna switch is given. This switch which employs a low cost UM9401 axial leaded PIN diode in conjunction with a UM9601, performs with 30dB receiver isolation over a 100MHz bandwidth and with transmitter insertion loss of less than 0.4dB. This switch can safely handle transmitter power levels up to 100 watts at infinite antenna SWR.

The Unitrode UM9601 series PIN diodes are constructed using a fused-in-glass process which results in a highly reliable, hermetic package. The process utilizes symmetrical, full faced metallurgical bonds to both surfaces of the silicon chip. This construction greatly minimizes the normal parasitic inductance and capacitance found in conventional glass or ceramic packaged diodes which employ straps, springs or whiskers.

The use of discrete UM9601-UM9608 diodes greatly minimizes handling problems commonly associated with passivated PIN diode chips while maintaining good microwave performance. In addition the power handling capibility of the UM9601-UM9608 series is considerably higher than PIN diode chips can provide.

Environmentally, the UM9601-UM9608 series PIN diodes can withstand thermal cycling from −195°C to +300°C and exceed all military environmental specification for shock, vibration, acceleration, and moisture resistance.

Typical Microwave Performance

	UM9601-UM9604			UM9605-UM9608		
Frequency	SPST Insertion Loss 0 Bias	SPST Isolation 100mA	SPNT* Isolation 100mA	SPST Insertion Loss 0 Bias	SPST Isolation 100mA	SPNT* Isolation 100mA
GHz	dB	dB	dB	dB	dB	dB
0.5	0.20	30	36	0.20	25	31
1.0	0.25	26	32	0.20	22	28
1.5	0.35	22	28	0.20	20	26
2.0	0.50	18	24	0.25	17	22
3.0	1.00	15	21	0.25	15	21
4.0	1.50	13	19	0.40	14	20

* Performance based on SPST Measurements In 0.025" (.635mm) Microstrip Test Circuit.

Note: All dimensions in inches and (millimeters).

Maximum Ratings

	UM9601 - UM9604		UM9605 - UM9608	
	P_D	θ	P_D	θ
Flange at 25° C	7.5W	20° C/W	4W	37.5° C/W
Free Air	1.5W	—	0.5W	—

Peak Power 1μS Single Pulse at 25° C Ambient	25KW	10KW

Operating and Storage Temperature	−65° C to +175° C

Reverse Voltage Ratings @ 10μA

100V	400V
UM9601 UM9603 UM9605 UM9607	UM9602 UM9604 UM9606 UM9608

Electrical Specifications (at 25° C)

Test	Symbol	UM9601-UM9604 Min	Typ	Max	UM9605-UM9608 Min	Typ	Max	Units	Condition
Series Resistance	R_S	—	0.4	0.6	—	1.5	1.7	Ω	I = 100mA F = 1GHz
Parallel Resistance	R_P	5K	—	—	7K	—	—	Ω	Zero Bias F =1GHz
Total Capacitance	C_T	—	—	1.2	—	—	0.5	pF	Zero Bias F =1GHz
Carrier Lifetime	τ	2.0	—	—	1.0	—	—	μS	I_F = 10mA
Forward Voltage	V_F	—	0.85	—	—	0.95	—	V	I_F = 100mA
I-Region Width	W	80	—	—	150	—	—	μm	

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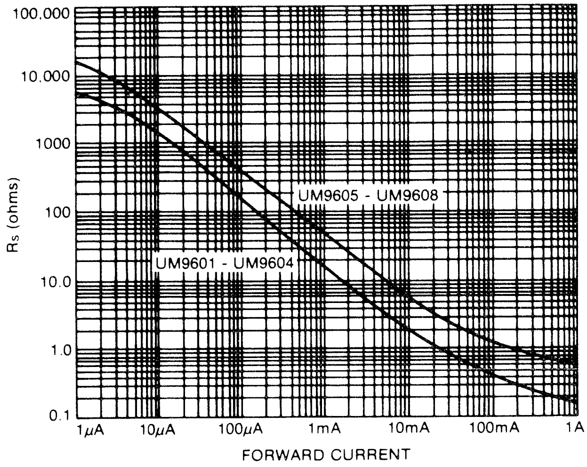
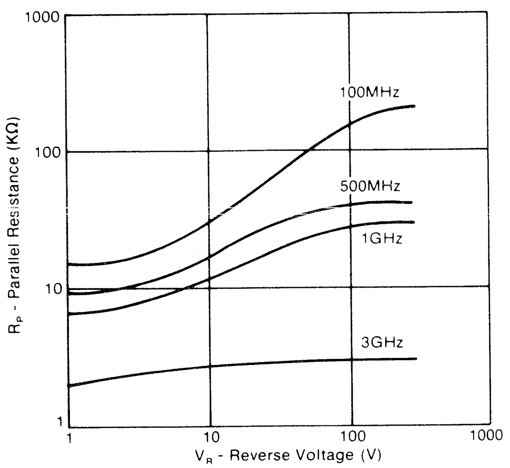
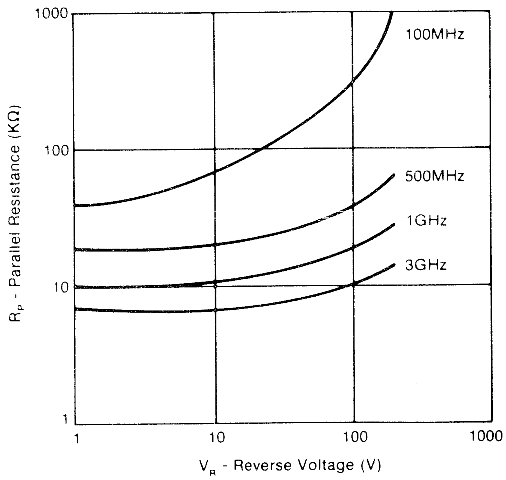
Typical Series Resistance vs Forward Current (F = 100MHz)



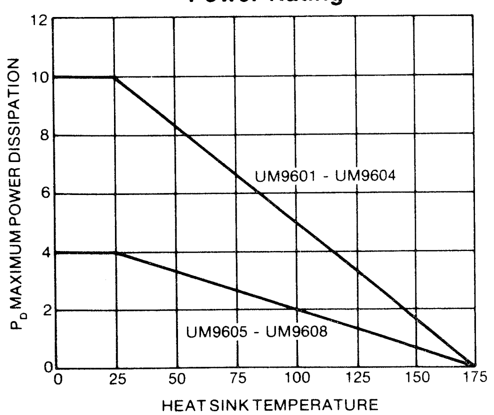
Typical R_P vs Voltage and Frequency UM9601 - UM9604



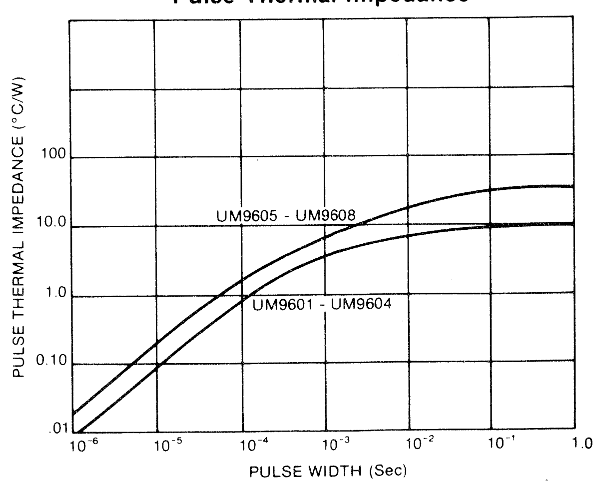
Typical R_P vs Voltage and Frequency UM9605 - UM9608



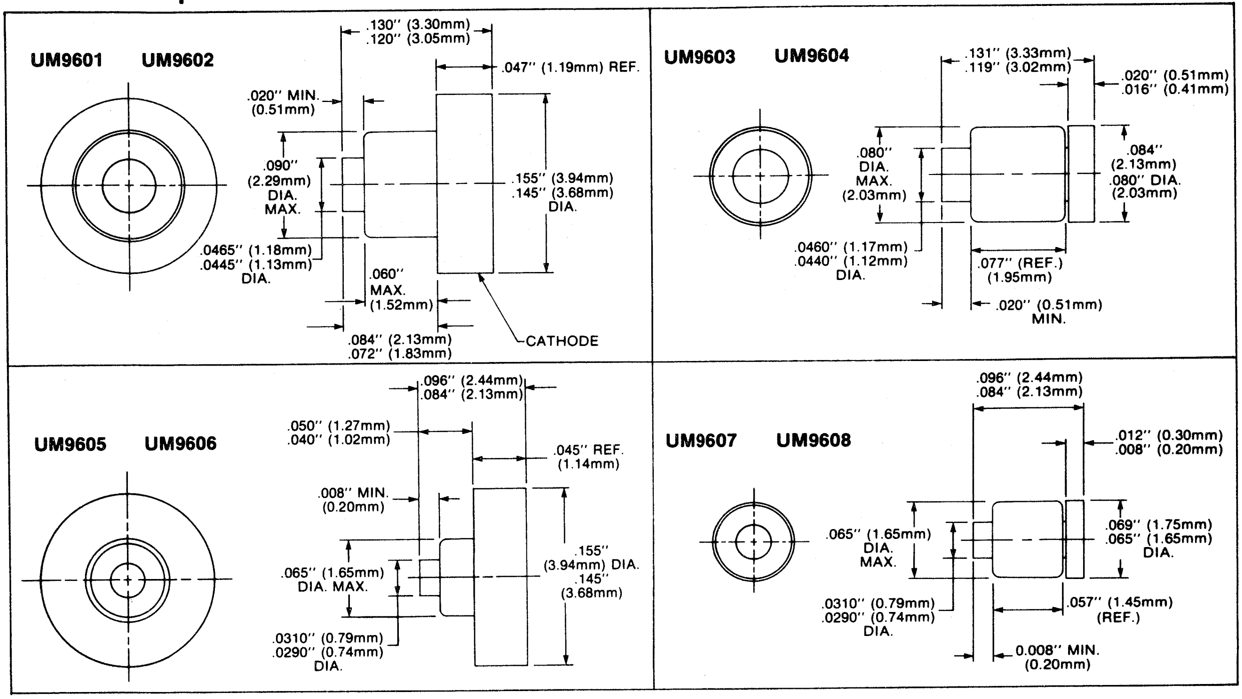
Power Rating



Pulse Thermal Impedance



Mechanical Specifications



Selection Guide

The following chart serves as a general guide for indicating the most likely diode from the series for a given application.

Applications	Recommended Types
1. High isolation switches to 2GHz at low dc drive 2. Quarter-wave antenna switches to 100 watts. 3. Priced for high volume commercial applications.	UM9601 (Affixes to microstrip ground plane.) UM9603 (Affixes to microstrip backing plate.)
High voltage rating version of UM9601 and UM9603 respectively for peak power handling to 3KW.	UM9602, UM9604
1. Low insertion loss switches to 4GHz. 2. Low distortion antenuator applications.	UM9605 (Affixes to microstrip ground plane.) UM9607 (Affixes to microstrip backing plate.)
High voltage version of UM9605 and UM9607 for peak power handling to 10KW.	UM9606, UM9608

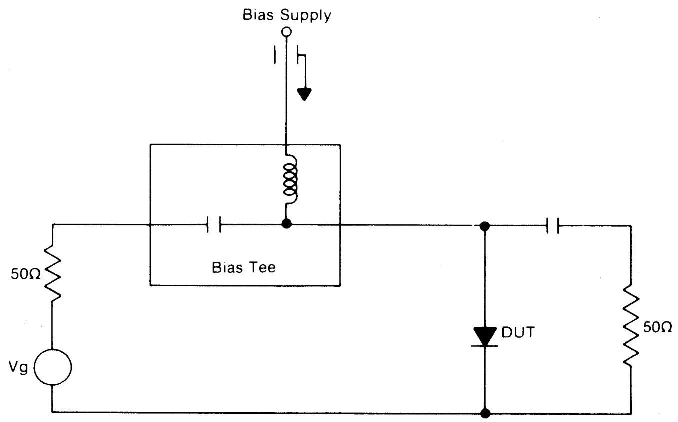
Microwave Characterization

The UM9601-UM9608 series has been designed and characterized as shunt switch elements at frequencies to 4GHz in microstrip circuits. Performance curves are given which demonstrate switch performance in 0.025" (.635mm) alumina microstrip.

The performance data were derived by evaluating externally biased microstrip circuits in which a UM9601 diode was installed. Each circuit consisted of a 1 inch length of 50 ohm nominal impedance 0.025" (.635mm) thick alumina microstrip and two SMA connectors. The data shown include the board and connector loss. Measurements performed using 0.050" (1.27mm) alumina substrates show similar performance at frequencies to 1.5GHz.

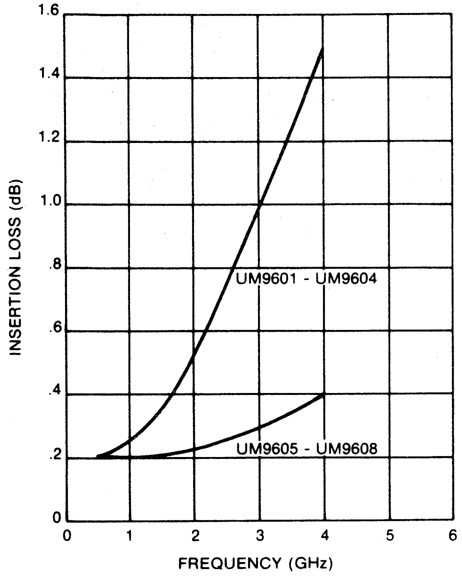
These circuits simulate simple SPST switches. Many designs require multithrow switches. It is important to recognize that a multithrow switch will have 6dB higher isolation than indicated for SPST switches. Also, a multithrow switch using shunt mounted PIN diodes require the diodes be placed a quarter-wavelength from the common port.

A further improvement in switch performance may be achieved by using 2 shunt PIN diodes in each arm spaced a quarter-wavelength from each other. In this case the isolation of each section will be twice the dB value of a SPST switch. The insertion loss due to the diodes should be less than twice the insertion loss of an SPST section due to the transforming effect of the quarter-wave line on the capacitance of a single diode.

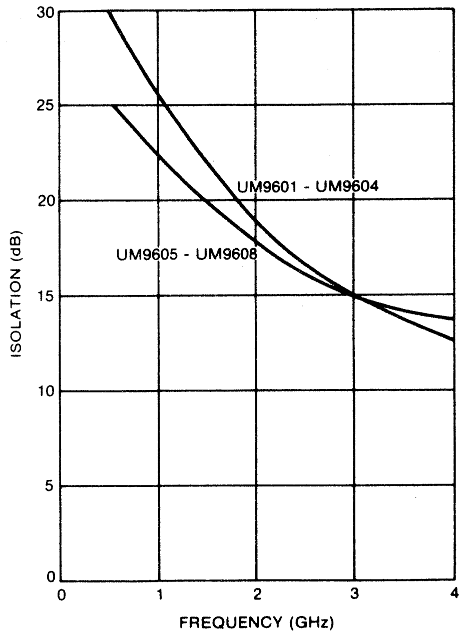


Microwave Test Circuit

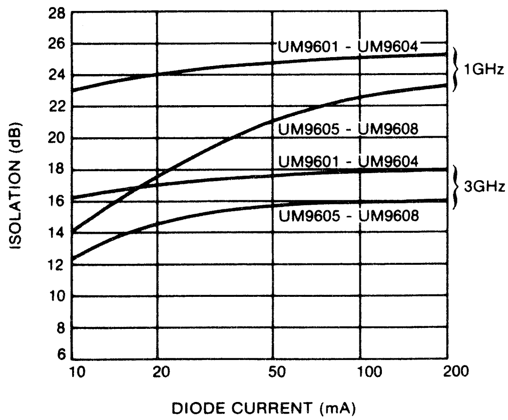
Typical Insertion Loss vs Frequency
0.025" (0.635mm) Alumina Microstrip SPST Switch
Diode at Zero Bias



Typical Isolation vs Frequency
0.025" (0.635mm) Alumina Microstrip SPST Switch
Diode Current = 100mA



Isolation vs Frequency and Diode Current
0.025" (0.635mm) Alumina Microstrip SPST Switch

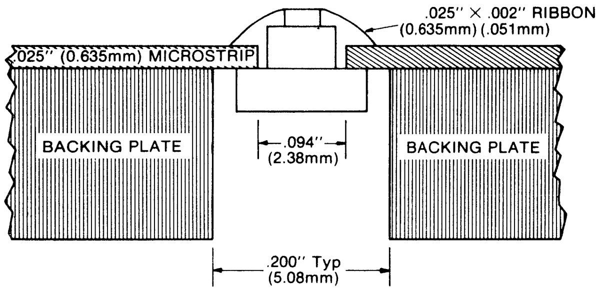


Installation in Microstrip

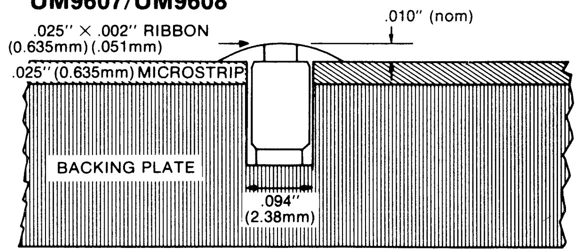
The cup type flange on the UM9601, UM9602, UM9605 and UM9606 is designed to be affixed to the ground plane surface of a microstrip board as shown. The UM9603, UM9604, UM9607 and UM9608 were designed to be affixed to a backing plate as shown. It was experimentally determined that at frequencies greater than 2GHz the anode of the diode should be approximately 0.010″ (.254mm) above the top surface of the microstrip for lowest insertion loss.

For solder adhesion the microstrip may be heated to solder melting temperature (up to 300° C) with no damage to the diode. Conductive epoxy may also be employed. The thermal resistance of solder mounted UM9601-UM9604 in their test boards was less than 20° C/W; for the UM9605-UM9608 thermal resistance was less than 30° C/W.

UM9601/UM9602 UM9605/UM9606 Microstrip Mount



UM9603/UM9604 UM9607/UM9608 Microstrip Mount



Design Example - 900MHz Antenna Switch

An example of a practical circuit design using a UM9601 diode is a quarter-wave antenna switch covering the frequency of 800-900MHz. The circuit design for this switch is shown and was constructed using 0.025″ (0.645mm) alumina microstrip.

This antenna switch uses a series mounted diode and a shunt mounted diode. The UM9601 was selected for the shunt mounted device (SPST performance at 1GHz: 0.2dB insertion loss and 25dB isolation) and because it is the lowest cost diode in the UM9601-UM9608 series. A UM9401 axial lead diode was chosen for the series mounted device.

The performance of this switch is displayed in the graphs and in the following table. It should be noted that the loss values are actual measured numbers including losses due to the capacitors, bias networks, connectors as well as the board. In a typical radio application where the antenna switch circuit board is integrated in the same microstrip board that contains transmitter and receiver elements the connector loss is eliminated. This will result in lower overall insertion loss values than indicated here.

The CW power handling capacity is determined by the allowable power dissipation of the series mounted UM9401. Using a gap in the line of 0.190″ (4.82mm) and lead soldered attached spacing of 0.250″ (0.635mm) the power rating of the UM9401 is 6 watts at a 25° C ambient. This was determined by performing a thermal resistance measurement on the circuit mounted UM9401. The relationship that derives the maximum transmitter power, P_T, is:

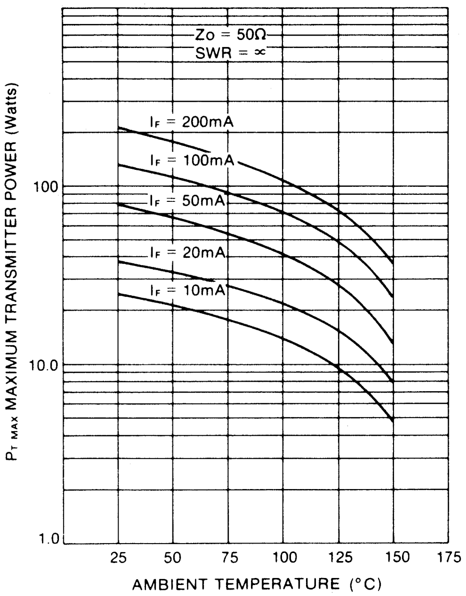
$$P_T = \frac{P_{DISS}}{R^S} \cdot Z_o \left(\frac{\sigma + 1}{2\sigma}\right)^2$$

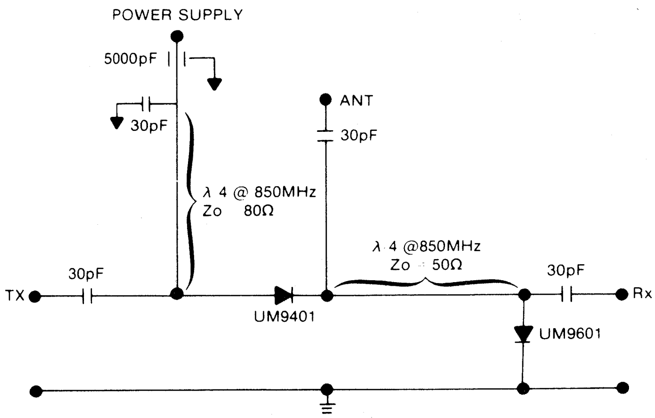
where σ = maximum antenna SWR

Using resistance values for the UM9401 and UM9601 the maximum transmitter power curve is given and shows that this circuit is able to handle 100 watts of transmitter power at 100mA forward biased and totally mismatched antenna at an ambient temperature of 60° C. For a perfectly matched antenna the power handling increases to 400 watts under the same bias and ambient temperature conditions.

Distortion is an important consideration in the selection of a PIN diode antenna switch design. The UM9401 and UM9601 PIN diodes are designed for low distortion applications. The level of distortion produced by this 900MHz antenna switch when operated in the transmit state (forward bias of 100mA) is expected to be at least 90dB below the carrier for a 50 watt transmitter level. In the receiver state (zero bias) the intermodulation distortion caused by two in-band signals at 0dBm are estimated to be at least 100dB below this level.

Maximum Transmitter Power vs Forward Current for UM9601/UM9401 900MHz Microstrip Antenna Switch





Circuit Diagram

Antenna Switch Performance

Frequency Range 800-900MHz

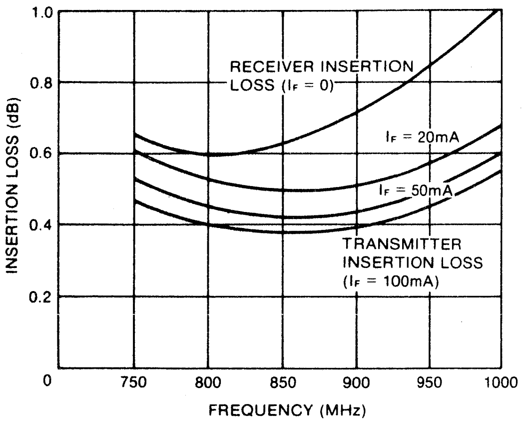
I. Transmit State
(I = 100mA, T_A = 60°C)

A. Maximum Transmitter Power - 100 watts (antenna SWR = ∞)
B. Maximum Transmitter Power - 400 watts (antenna SWR = 1)
C. Transmitter Insertion Loss - 0.4dB
D. Receiver Isolation - 31dB
E. Harmonic Distortion - −90dB (P_T = 100 watts)

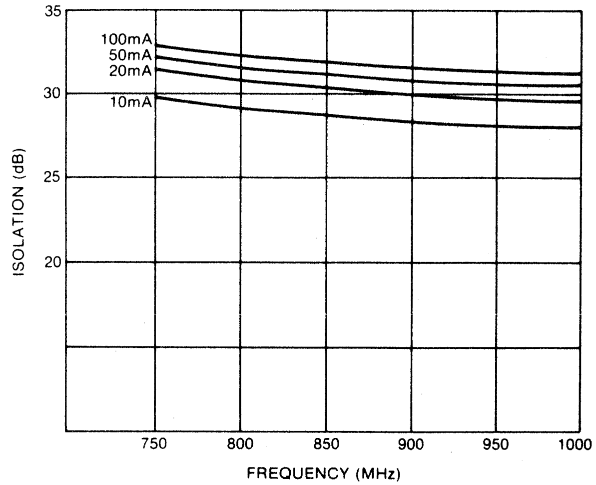
II. Receive State
(Zero Bias)

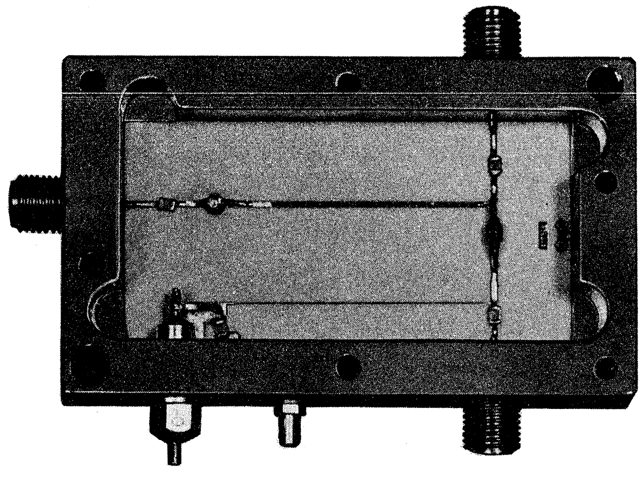
A. Receiver Insertion Loss - 0.6-0.7dB
B. Intermodulation Distortion - −100dB P_{in} = 0dBm

Antenna Switch Insertion Loss



Receiver Isolation vs Frequency and Diode Current





Photograph of 800-900MHz antenna switch test module using UM9401 and UM9601 PIN Diodes. In typical transceiver applications, the antenna switch circuit board is integrated.

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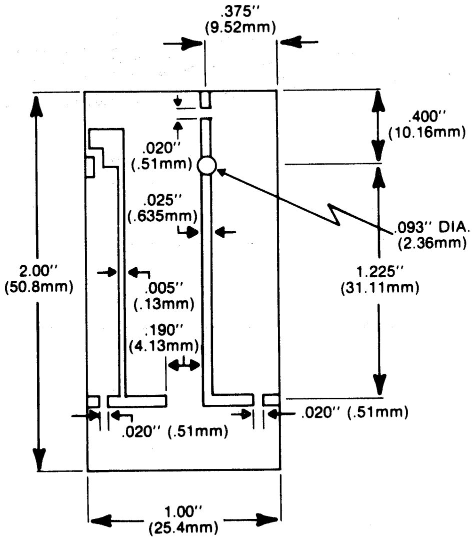
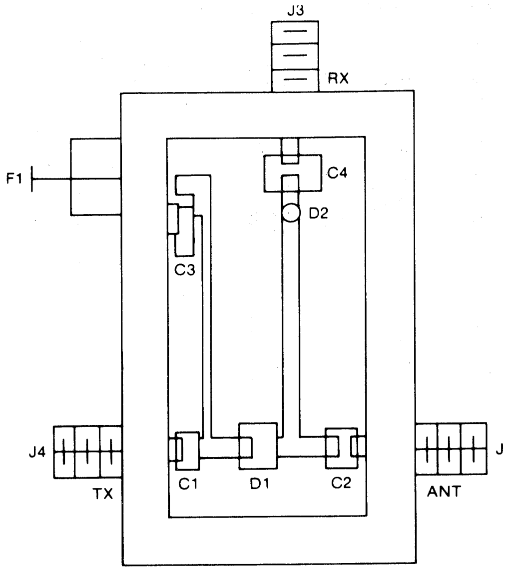


Substrate Drawing



Assembly Drawing

Parts List

F1	5000pF Feed through Filter	Erie 1270-016
C1-C4	30pF Chip Capacitor	Vitramon VJ0805A300KF
D1	PIN Diode	Unitrode UM9401
D2	PIN Diode	Unitrode UM9601
J1-J3	SMA Connector	Cablewave 971-028
	Substrate	Vectronics Microwave 79-9081-0401

PIN DIODE

UM9701

Low Resistance, Low Distortion, RF Switching Diode

Features

- Low Forward Resistance
- High Reverse Resistance
- Specified Low Distortion
- High Voltage Capability
- Good Power Handling
- Unitrode Ruggedness and Reliability

Description

The UM9701 PIN diode was designed for low resistance at low forward bias current and low reverse bias capacitance. This unique Unitrode design results in both forward and reverse bias.

These PIN diodes are characterized for low current drain RF and microwave switch applications particularly for digital filter switch designs. The construction and geometry of these devices provide good voltage and power handling capability.

These devices are constructed using a metallurgical full face bond to both surfaces of the silicon chip. A glass enclosure houses this bond in a reliable and hermetic package. The axial leads are attached to the refractory pins and do not touch the glass enclosure.

Environmentally these, and all Unitrode PIN diodes, can withstand thermal cycling from −195°C to +300°C and exceed all military environmental specifications for shock, vibration, acceleration, and moisture resistance.

Maximum Ratings

Reverse Voltage	100V
Average Power Dissipation Free Air at 25°C	500mW (Derate linearly to 175°C)
Average Power Dissipation ½″ Total Lead Length to 25° C Contacts	2.5W (Derate linearly to 175°C)
Operating and Storage Temperature	−65°C to +175°C

Electrical Specifications

Test	Symbol	UM9701	Condition
Series Resistance (MAX)	R_S	0.8Ω	F = 100MHz, I = 10mA
Total Capacitance (MAX)	C_T	1.8pF	F = 1MHz, I = 50V
Parallel Resistance (MIN)	R_P	100kΩ	F = 100MHz, V = 50V
Carrier Lifetime (MIN)	τ	1.5μs	I = 10mA
Reverse Current (MAX)	I_R	10μA	V = 100V
Forward Voltage (MAX)	V_F	0.8V	I = 10mA
Forward Bias Third Order IM Distortion (MAX)	$R \frac{2ab}{a}$	−90dB	I = 10mA Pa = Pb = +20dBm Fa = 43MHz, Fb = 44MHz
Reverse Bias Third Order IM Distortion (MAX)	$R \frac{2ab}{a}$	−90dB	I = 50V Pa = Pb = +20dBm Fa = 43MHz, Fb = 44MHz

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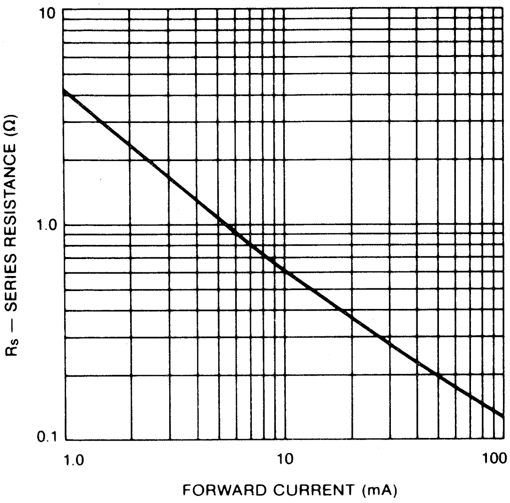
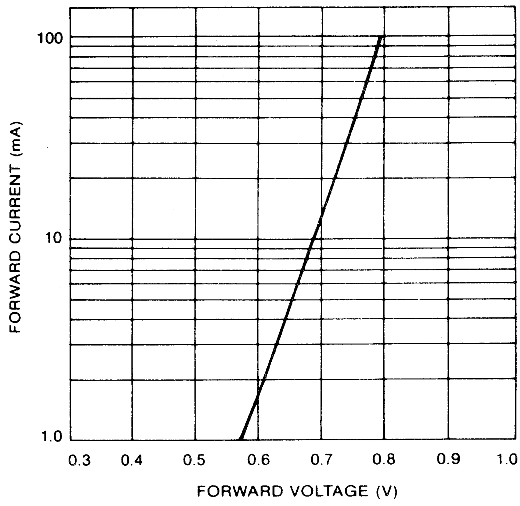
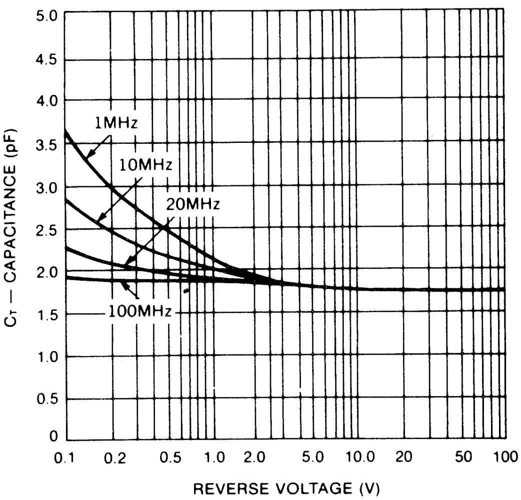
Typical Series Resistance vs Forward Current (F = 100MHz)



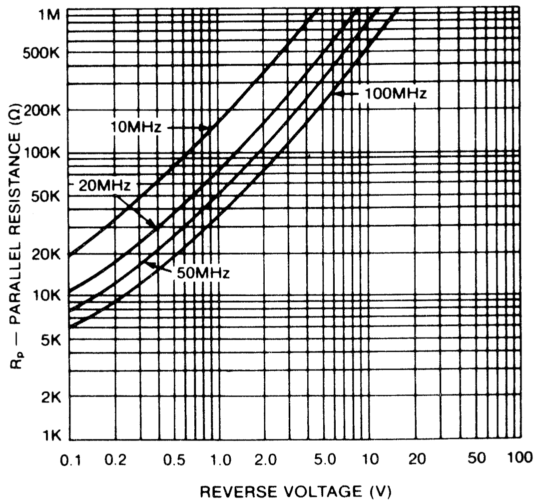
Typical DC Characteristic



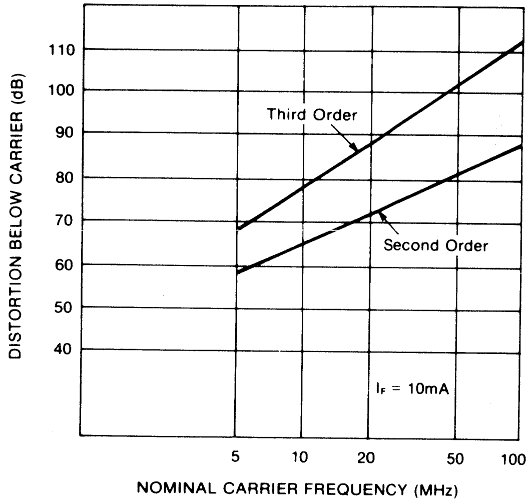
Typical Capacitance Characteristic



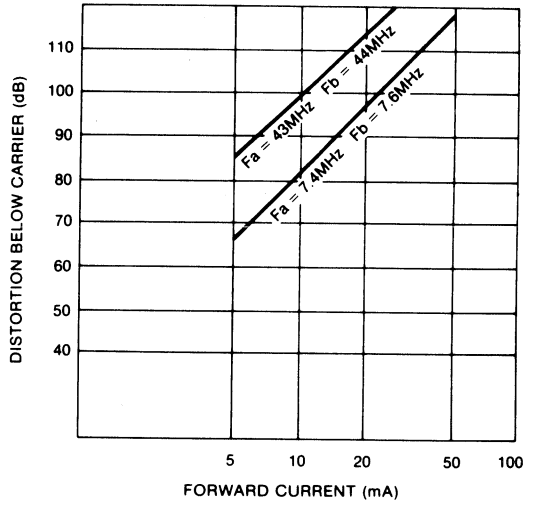
Typical Parallel Resistance Characteristic



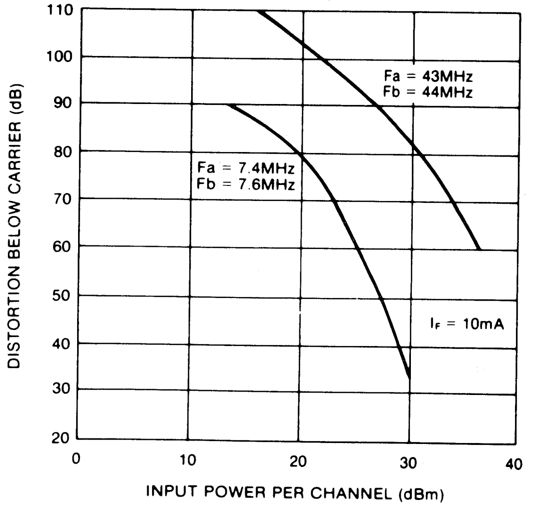
Typical Forward Bias Intermodulation Distortion vs Nominal Carrier Frequency at 20dBm per Channel



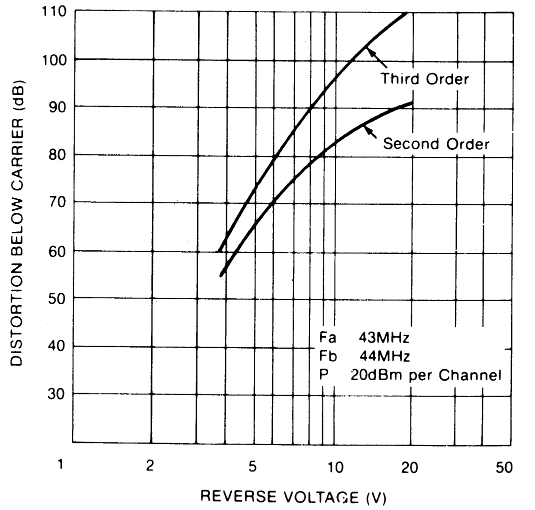
Typical Third Order Intermodulation Distortion $\left(R\ \frac{2ab}{a}\right)$ vs Forward Bias Current at 20dBm per Channel



Typical Forward Bias Third Order Intermodulation Distortion $\left(R\ \frac{2ab}{a}\right)$ vs Input Power per Channel



Typical Reverse Bias Intermodulation Distortion



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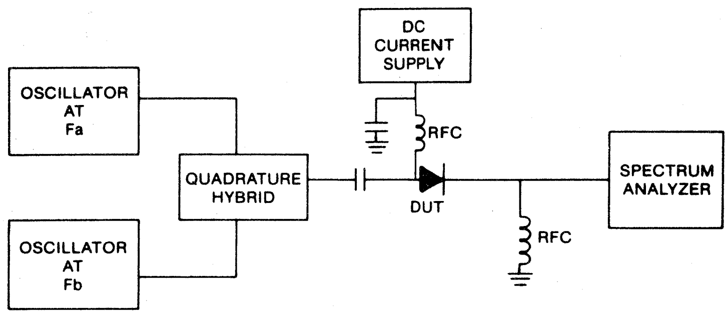
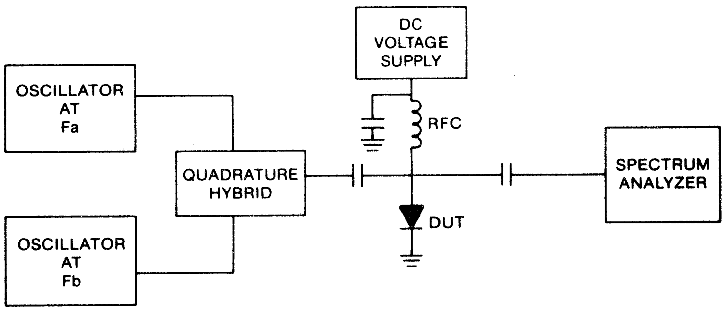
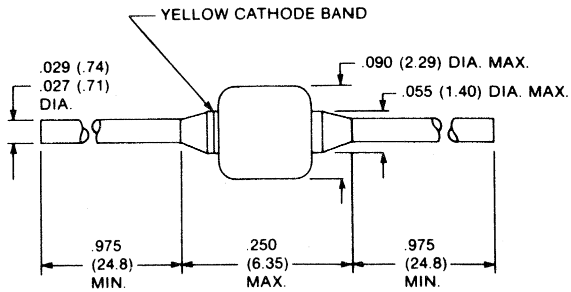
Forward Bias Distortion Test Set



Reverse Bias Distortion Test Set



Mechanical Specifications



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PIN DIODE

1N5767 (5082 - 3080)SERIES
1N5957 SERIES

Features

- Useful attenuation from 1 μA to 100 mA bias.
- Capacitance below 0.4 pF.
- Low distortion in switches and attenuators.
- Rugged Unitrode construction.

Description

The 1N5767 and 1N5957 PIN diodes are based upon low capacitance PIN chips designed with long minority carrier lifetime, and thick intrinsic width. Thus operation as low as 1 MHz is possible with low distortion. Additionally, the low diode capacitance allows useful operation well into the microwave frequency range.

The 1N5767 (5082-3080) is a general purpose low power PIN diode designed for both switch and attenuator applications.

The 1N5957 is primarily used as an attenuator PIN diode and is particularly suitable wherever current controlled, wide dynamic range resistance elements are required. The 1N5957 has also been characterized for the 75Ω attenuator, commonly employed in CATV systems.

MAXIMUM RATINGS

Reverse Voltage **(V_R) — Volts** **(I_R = 10 μA)**	100V
Average Power Dissipation: (25°C) Free Air (P_A)	400 mW (Derate linearly to 175°C)
Operating and Storage Temperature Range	−65°C to +175°C

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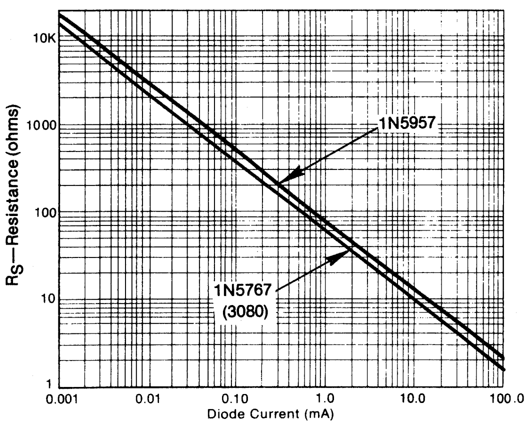
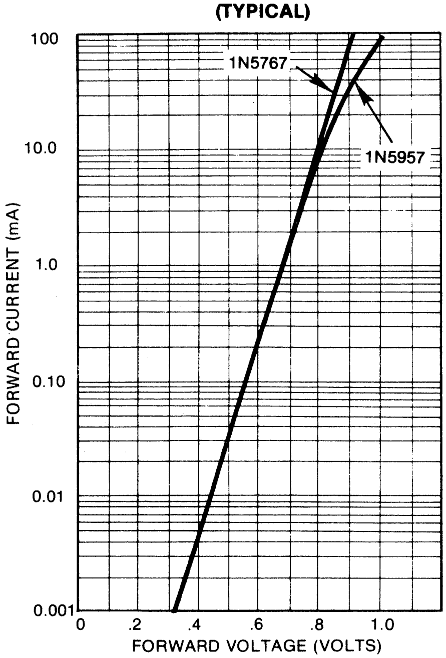
Electrical Specifications (25 °C)

Test	Symbol	1N5767 (5082-3080)	1N5957	Conditions
Total Capacitance (Max)	C_T	0.4 pF	0.4 pF	50V, 1 MHz
Series Resistance	R_S	1000Ω(min) 2000Ω(typ)	1500Ω(min) 3000Ω(typ)	10 μA, 100 MHz
Series Resistance	R_S	8Ω(max) 4Ω(typ)	8Ω(max) 6Ω(typ)	20 mA, 100 MHz
Series Resistance	R_S	2.5Ω(max) 1.5Ω(typ)	3.5Ω(max) 2.0Ω(typ)	100 mA, 100 MHz
Carrier Lifetime (Min)	τ	1.0 μS	1.5(min) 2(typ)	I_F = 10 mA
Reverse Current (Max)	I_R	10 μA	10 μA	V_R = Rating
Current for R_S = 75Ω (typ)	I_{75}	0.7 mA	0.8 mA– 1.2 mA	R_S = 75Ω
Return Loss (typ)	—	30 dB	30 dB	Diode terminates 75Ω line
Second Order Distortion (typ)	—	−40 dB	−50 dB	Bridged tee attenuator atten. = 10 dB
Third Order Distortion (typ)	—	−60 dB	−65 dB	P_{in} = 50 dBmV F_1 = 10 MHz, F_2 = 13 MHz

RESISTANCE VS FORWARD CURRENT (TYPICAL)



FORWARD VOLTAGE VS FORWARD CURRENT (TYPICAL)



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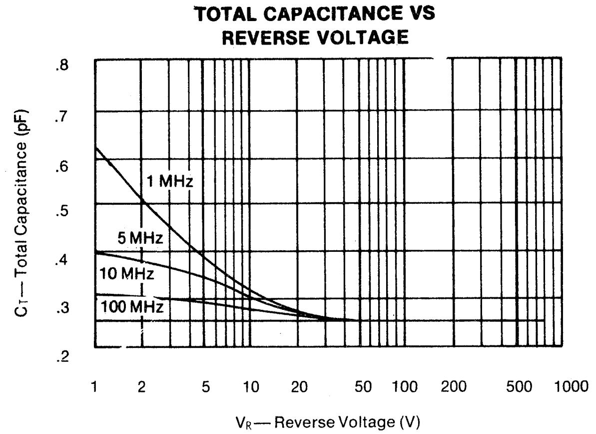
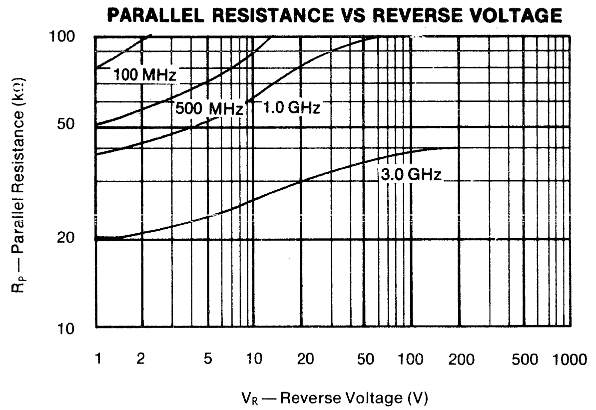
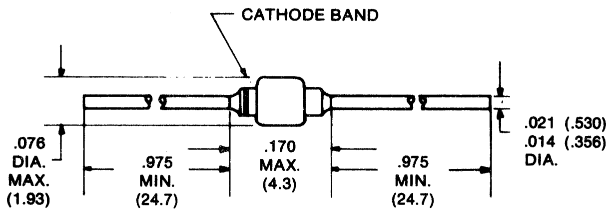




MECHANICAL SPECIFICATIONS



Dimensions: Inches (Millimeters)

IV. CIRCUIT MOUNTING CONSIDERATIONS

CIRCUIT MOUNTING CONSIDERATIONS

Unitrode offers a wide variety of package styles for each diode series, permitting virtually any circuit mounting requirement to be accommodated. Some precautions should be taken when mounting the various types. Guidelines are outlined as follows:

Stud Packages

Withstanding compression forces of up to 40 pounds, Unitrode pressure contact diodes (styles C and D) can be mechanically mounted without the need for unusual precautions. Each package is designed to provide excellent mechanical, thermal and electrical continuity for a variety of microwave circuit configurations.

A maximum torque of 28 inch-ounces is specified when installing either C or D style stud mounted packages. This torque is to be applied between the hex flats on the metallic flange of the diode package and any associated mounting hardware.

Solder Contacts

Bonding of the basic Unitrode fused-in-glass diode to leads or studs is made at temperatures in excess of 400°C during manufacturing. This high temperature fabrication permits great latitude in the soldering of Unitrode diodes to various circuit media. All exposed metallic surfaces are solderable. Temperatures up to 400°C may be applied to the diode mounting terminal within the following guidelines:

1. For solder contacts, soldering iron tips up to 200°C may be used without special precautions.
2. At temperatures between 200°C and 400°C, the heating and cooling rates should not exceed 20°C per minute.
3. At temperatures between 200°C and 400°C, it is important to keep both ends of the diode at equal temperatures. A hot plate can be used to maintain uniform diode temperature.

V. PIN DIODE FUNDAMENTALS

PIN DIODE FUNDAMENTALS

GENERAL DESCRIPTION

A PIN diode is a semiconductor device that operates as a variable resistor at RF and microwave frequencies. The resistance value of the PIN diode is determined only by its dc excitation. In switch and attenuator applications, the PIN diode should ideally control the RF signal level without introducing distortion which might change the shape of the RF signal. An important additional feature of the PIN diode is its ability to control large RF signals while using much smaller levels of dc excitation.

A model of a Unitrode PIN diode chip is shown in Figure 5-1. The chip is prepared by starting with a wafer of almost intrinsically pure silicon, having high resistivity and long lifetime. A P-region is then diffused into one diode surface and an N-region is diffused into the other surface. The resulting intrinsic or I-region thickness (W) is a function of the thickness of the original silicon wafer, while the area of the chip (A) depends upon how many small sections are cut from the original wafer.

The performance of the PIN diode primarily depends on chip geometry and the nature of the semiconductor material in the finished diode, particularly in the I-region. Characteristic of Unitrode PIN diodes are controlled thickness I-regions having long carrier lifetimes and high resistivity. These characteristics enhance this ability to control RF signals with a minimum of distortion while requiring low dc supply.

FORWARD BIASED PIN DIODES

When a PIN diode is forward biased, holes and electrons are injected from the P and N regions into the I-region. These charges do not immediately completely recombine. Instead, a finite quantity of charge always remains stored and effectively results in a lowering of the resistivity of the I-region. The quantity of stored charge, Q, depends on the recombination time, τ (commonly called the carrier lifetime), and the level of forward bias current, I_F, as follows:

$$Q = I_F \tau \quad \text{[coulombs]} \qquad (1)$$

The resistance of the I-region under forward bias, R_S is inversely proportional to Q and may be expressed as:

$$R_S = \frac{W^2}{(\mu_N + \mu_P)Q} \quad \text{[ohms]} \qquad (2)$$

where: W = I-region width
μ_N = electron mobility
μ_P = hole mobility

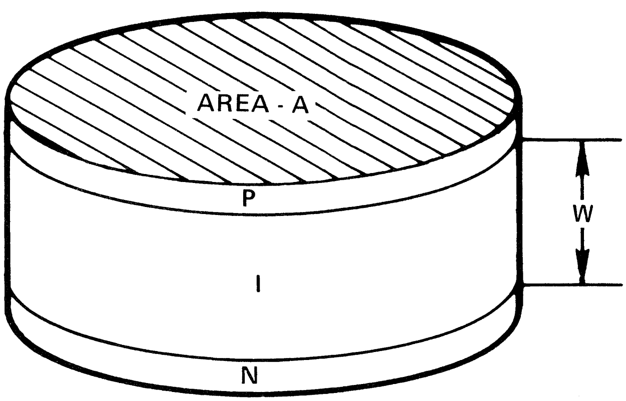


Figure 5-1 PIN Diode Chip Outline

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Combining Equations 1 and 2, the expression for R_S as an inverse function of current is shown as:

$$R_S = \frac{W^2}{(\mu_N + \mu_P)\tau I_F} \quad \text{[ohms]} \qquad (3)$$

Typically, PIN diodes display a resistance characteristic consistant with this model as shown in Figure 5-2. Resistances of the order of 0.1Ω at 1A forward bias increasing to about 10,000Ω at 1 μA forward bias represent a realistic range for a Unitrode PIN diode.

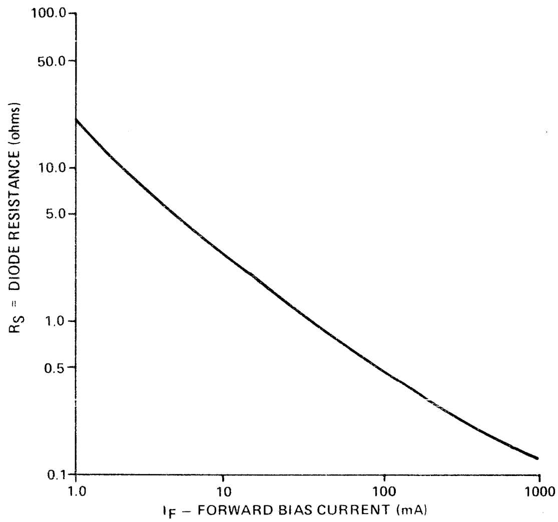


Figure 5-2 R_S vs Forward Current for UM4000 PIN Diode

The maximum forward resistance, $R_{S(max)}$, of a PIN diode is generally specified at 100 mA forward bias current. For some PIN diodes, Unitrode specifies not only the $R_{S(max)}$ but also the $R_{S(min)}$ at a lower forward bias current (10 μA). These specifications ensure a wide range of diode resistance which is particularly important in attenuator applications.

The results obtained from Equation 3 are valid over an extremely broad frequency range when Unitrode PIN diodes are used in a circuit. The practical low resistance limitations result from package parasitic inductances and junction contact resistances, both of which are minimized in the construction of Unitrode diodes. The high resistance range of PIN diodes is usually limited by the effect of the diode capacitance, C_T. In order to realize the maximum dynamic range of the PIN diode at high frequencies, this diode reactance may have to be tuned out.

It should be noted that "skin effect" is much less pronounced in relatively poor conductors such as silicon, than with good metallic conductors. This is due to the fact that the "skin depth" is proportional to the square root of the resistivity of the conducting material. Thus, RF signals penetrate deeply into the semiconductor and "skin effect" is not a significant factor in PIN diodes below X-Band frequencies.

At dc and very low frequencies, the PIN diode is similar to a PN diode; the diode resistance is described by the dynamic resistance of the I - V characteristics at any quiescent bias point. The dc dynamic resistance point is not, however, valid in PIN diodes at frequencies above which the period is shorter than the transit time of the I-region. The frequency at which this occurs, f_T, is called the transit time frequency and may be considered the lower frequency limit for which Equation 3 applies. This lower frequency limit is primarily a function of W, the I-region thickness and can be expressed as:

$$f_T = \frac{1300}{W^2} \quad \text{[MHz]} \qquad (4)$$

where W is the I-region thickness in microns. For Unitrode PIN diodes, this low frequency limit ranges from approximately 20 KHz for the thickest diodes (UM4300 and UM7300 series) to approximately 1 MHz for the thinnest diodes (UM6200, UM7200).

REVERSE BIASED PIN DIODES

At high RF frequencies when a PIN diode is at zero or reverse bias, it appears as a parallel plate capacitor, essentially independent of reverse voltage, having a value of:

$$C = \frac{\varepsilon A}{W} \quad \text{[farads]} \qquad (5)$$

where: ε = silicon dielectric constant
A = junction area
W = I-region thickness

The lowest frequency at which this effect begins to predominate is related to the dielectric relaxation frequency of the I-region, f_r, which may be computed as:

$$f_r = \frac{1}{2\pi\rho\varepsilon} \quad [\text{Hz}] \qquad (6)$$

where: ρ = I-region resistivity

For Unitrode PIN diodes, this dielectric relaxation frequency occurs below 100 MHz and the total packaged capacitance, C_T, is specified for most Unitrode diodes when zero biased at 1 GHz. Additional data is supplied in the form of typical curves showing the capacitance variation as a function of reverse bias at lower frequencies.

At frequencies much lower than f_r the capacitance characteristic of the PIN diode resembles a varactor diode. Because of the frequency limitations of common test equipment, capacitance measurements are generally made at 1 MHz. At this frequency the total capacitance, C_T, is determined by applying a sufficiently large reverse voltage which fully depletes the I-region of carriers.

Associated with the diode capacitance is a parallel resistance, R_P, which represents the net dissipative resistance in the reverse biased diode. At low reverse voltages, the finite resistivity of the I-region results in a lossy I-region capacitance. As the reverse voltage is increased, carriers are depleted from the I-region resulting in an essentially lossless silicon capacitor. The reverse parallel resistance of the PIN diode, R_P, is also affected by any series resistance in the semiconductor or diode contacts.

The minimum reverse parallel resistance is specified for all Unitrode PIN diodes at 1 GHz and 100 volts reverse bias. Curves are also given which show the variation of R_P as a function of frequency and voltage. This data shows R_P to be proportional to reverse voltage and inversely proportional to frequency.

EQUIVALENT CIRCUITS

Because of the unique construction of Unitrode diodes, the RF equivalent circuits are generally different and actually more simplified than those associated with PIN diodes constructed using conventional techniques. These equivalent circuits for Unitrode diodes are illustrated in Figure 5-3. Because of the absence of small wires or ribbons, the package capacitance is directly in parallel with the PIN chip, there is virtually no internal package inductance to consider as is the case with conventional PIN diodes. The full-faced bond achieved between the silicon chip and the metallic pins, combined with the relatively large chip area, result in negligible contact resistance. Hence, the "residual series resistance" in conventional diodes, is for all practical purposes, nonexistent in Unitrode PIN diodes.

Any self-inductance presented by the Unitrode diode is external to the diode's capacitance and is similar to that of a conducting cylinder having the same mechanical outline as the diode chip and pins. Calculations using self-inductance equations show the Style A package inductance to be on the order of 0.10 nHy for all Unitrode PIN diode types. Additional self-inductance is introduced by any lead attached to the Style A package.

Thus, at frequencies below 1 GHz, Unitrode package parasitic effects are usually negligible. At higher frequencies, the overall dimensions and materials of the diode package should be considered in both the diode selection and RF circuit design. For this purpose, it should be noted that Unitrode glass has a relative dielectric constant of 7.5 (nominal) and a loss tangent of less than 0.008 from dc through X-Band.

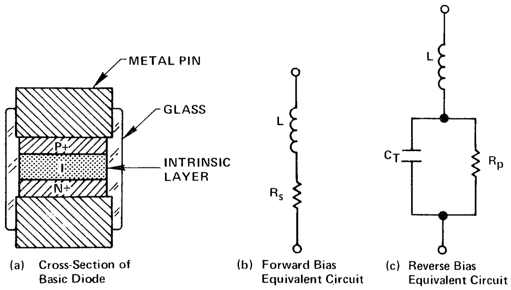


Figure 5-3 PIN Diode Equivalent Circuits

THERMAL CONSIDERATIONS

As a PIN diode dissipates power, its junction temperature begins to rise. The final temperature of the diode junction will depend on the amount of power dissipated, P_D, the ambient temperature, T_{Amb}, and the thermal resistance, θ_{JA}, between the diode junction and the ambient temperature. The specified power rating of a PIN diode is the power dissipation that will raise the junction temperature from a specified ambient (typically 25 °C) to its maximum allowable value, T_{Jmax}. Unitrode conservatively rates its diodes for a T_{Jmax} of 175°C. The maximum allowable power dissipation, P_{Dmax}, may then be computed from the following expression:

$$P_{Dmax} = \frac{T_{Jmax} - T_{Amb}}{\theta_{JA}} \quad \text{[watts]} \qquad (7)$$

The thermal properties of Unitrode PIN diodes are specified for both pulse and CW applications. For CW designs using stud mounted diodes (C and D type packages), thermal resistance between the diode junction and one surface of the diode package is specified for each type package. For leaded diodes (B and E type packages), power ratings are also specified in the data section for various lead lengths. In every case, the circuit designer must determine what maximum temperature will occur at the circuit contact to which the diode package is connected, before he can establish the absolute RF power capability for his application.

A practical approach to this problem is to assume a maximum diode package contact operating temperature of 100 °C. Using the information supplied in the data section for the particular diode type, one can then determine the amount of RF power which can be handled by the diode before its junction reaches the maximum reliable operating temperature. Use of either tell-tale crayon temperature indicators, or the observation of a small drop of water on the contact junction during RF operation, should give the designer strong confirmation regarding the accuracy of his original estimates.

For pulsed RF applications, the total power dissipation is determined by means of a thermal impedance graph which displays pulsed thermal resistance as a function of pulse width. These graphs, which are given for each diode type in the data section, which appear exponential in shape are actually a composite of the thermal impedances of the materials which comprise the thermal path between the diode junction and the package contact.

This thermal impedance graph may be used to compute both the heat capacity and the thermal time constant of the diode. Because of their large physical mass, Unitrode PIN diodes have the ability to store large amounts of heat. For example, the UM4300 diode is rated capable of dissipating a 500 KW peak power pulse of 1 microsecond duration when connected to a heat sink of 25 °C.

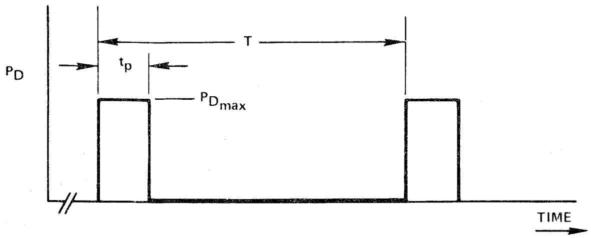
The peak junction temperature, T_{JP}, resulting from application of an RF pulse, occurs at the end of the pulse as shown in Figure 5-4. The diode junction temperature rise, ΔT, caused by an RF pulse, may be computed from the following equation:

$$\Delta T = T_{JP} - T_{JA}$$

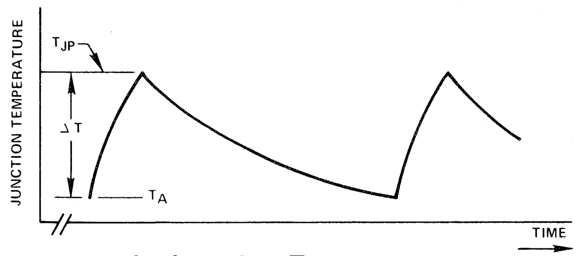
$$\Delta T = \theta_{eff} P_{Dmax} \quad [°C] \qquad (8)$$

where:

θ_{eff} = effective thermal resistance
T_{JP} = peak junction temperature
T_{JA} = ambient junction temperature



a. Power Dissipation



b. Junction Temperature

Figure 5-4 PIN Junction Temperature During RF Pulse Application

The effective thermal resistance, θ_{eff}, can be computed from the pulse and average thermal resistances of the PIN diode as follows:

$$\theta_{eff} = \frac{t_p}{T}\theta_{JA} + \left(1 - \frac{t_p}{T}\right)\theta_{(t + t_p)} - \theta_T + \theta_{t_p} \quad [°C/W] \qquad (9)$$

where T is the inter-pulse period; t_p is the pulse width; θ_T, θ_{t_p}, and $\theta_{(T+t_p)}$ are the diode thermal resistances at their respective pulse widths; and θ_{JA} is the average thermal resistance. For most pulse applications, where the duty factor (DF) is much less than unity

$$\left(\text{i.e., } \frac{t_p}{T} << 1 \text{ and } \theta_{(T + t_p)} \approx \theta_T\right),$$

the effective thermal resistance equation reduces to:

$$\theta_{eff} = (DF)\theta_{JA} + \theta_{t_p} \quad [°C/W] \qquad (10)$$

The unique construction of Unitrode PIN diodes is primarily responsible for their outstanding power handling characteristics. The full-face metallurgical bonds achieved between the chip and pin result in extremely low thermal resistance paths between the diode junction and case, thereby permitting higher diode power dissipation specifications. The UM4901C, for example, is rated to dissipate 37.5 watts with a heat sink temperature of 25°C. Under pulsed applications, this same diode is rated to handle 100 KW for pulse widths up to 1 microsecond duration. The excellent peak pulse power capability results from the large heat capacity of the chip and the low thermal resistance of its mounting structure.

Thermal ratings are conventionally specified for a device heat sinked at only one electrode. Since Unitrode's PIN diodes are thermally symmetrical, the designer may choose to heat sink either electrode. As a consequence, the power handling capability may be theoretically doubled by heat sinking both electrodes in a high power application.

Another potential thermal limitation imposed on most conventional PIN diodes is one related to a maximum allowable current. This rating is given if there is a possibility of fuse action occurring within the diode package at a current level below the power rating of the PIN chip. When a maximum current rating is specified for the PIN diode, the designer must ensure that the maximum RF current, under the worst SWR stress, does not exceed this value. Unitrode PIN diodes do not have separate maximum current specifications because there are no thin, fuseable wires contained within the diode packages.

SWITCHING SPEED

Since the PIN diode operates with different quantities of charge stored in its I-region, switching speed may be loosely defined as the time required to change this level of stored charge. In RF switching applications, this would be the time required to either fill up or remove the charge from the I-region. It is difficult to define the absolute switching speed of a PIN diode because there are no standard criteria defining RF switching; in addition, the actual switching speed achieved depends as much on the drive circuit as it does on the PIN diode.

When a PIN diode is forward biased to a current, I_F, it results in a stored charge, $Q = I_F \tau$, which puts the diode in a low resistance state. If the diode forward bias is suddenly removed, the negative and positive charges in the diode will eventually recombine. The time required for this recombination to occur is called τ, the carrier lifetime. If, however, a sufficiently large reverse voltage is applied to the forward conducting diode which produces an initial reverse current, I_R, the "forward to reverse" switching time, T_{FR}, may then be expressed as follows:

$$T_{FR} = \ln\left(1 + \frac{I_F}{I_R}\right)\tau \text{ [sec]} \quad (11)$$

Figure 5-5 shows such a typical PIN diode switching speed response. The shaded area of the curve below the zero current line is equal to the stored charge of the diode under forward bias. The accompanying chart shows how the speed of switching the diode from forward to reverse bias is affected by both the initial reverse current as well as the forward current level.

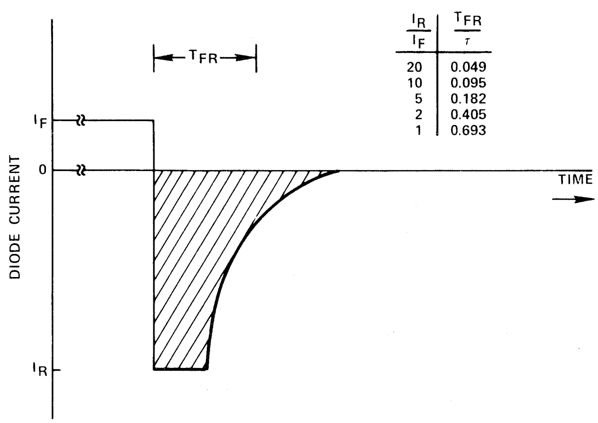


Figure 5-5 PIN Diode Switching Speed

The driver which supplies the reverse bias, I_R, need only deliver this level of current for a short period of time. In many practical applications, this current takes the form of an initial spike supplied by discharging a stored capacitor. Thus, an important parameter in high speed driver design is its maximum transient current capability rather than the level of voltage available from the driver power supply.

The fastest switching speed that will permit filling the I-region with stored charge depends primarily on the transit time of the I-region (i.e. the thickness of the diode) and the levels of reverse voltage and forward current which the driver circuit can supply. For Unitrode PIN diodes, this "reverse to forward" switching time, T_{RF}, is usually slower than the "turn-off" or T_{FR} time. Typical values for T_{RF} are shown in Table 1.

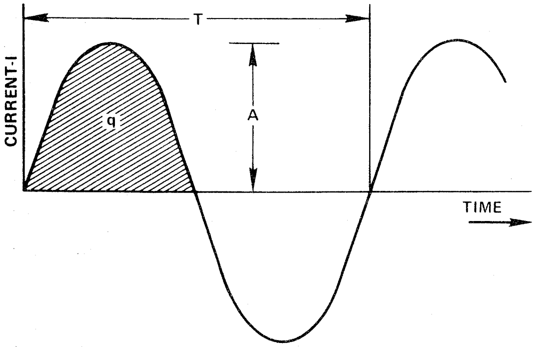
TABLE 1
Typical PIN Diode Switching Speeds (T_{RF})

Diode Type	To 10 mA from 100V	To 50 mA from 100V	To 100 mA from 100V
UM4000, 6000, 7000	5.0 μS	2.5 μS	1.5 μS
UM7100	2.0 μS	0.8 μS	0.5 μS
UM6200, UM7200	0.4 μS	0.2 μS	0.1 μS

LARGE SIGNAL OPERATION
Forward Bias

When a PIN diode is forward biased, the maximum RF current the diode can control depends on the amount of stored charge supplied by the dc forward bias relative to the charge variations produced by the RF signal.

Consider the example of a Unitrode UM4001B operating at a forward bias of 100 mA. Since the specified minimum carrier lifetime for this diode is 5.0 μS, the stored charge, calculated from Equation 1 is 500×10^{-9} coulombs. Let us now apply a 50 MHz signal of sufficient size to produce a 1 ampere (peak) RF current in the diode. Figure 5-6 shows that the incremental stored



$I = A \sin \omega t$

For a half cycle:

$$q = \int_0^{T/2} I\,dt = \int_0^{T/2} A \sin \omega t \; dt$$

and

$$q = \frac{AT}{\pi}$$

For a frequency of 50 MHz and a current A of 1 ampere,

$q = 6.37 \times 10^{-9}$ coulombs

Figure 5-6 RF Stored Charge

charge, "q", introduced or removed by this RF current, is only 6.37×10^{-9} coulombs or almost two orders of magnitude lower than the stored charge, Q.

From this it can be seen that the 100 mA forward diode bias represents a larger signal than the 1 ampere of RF current, from a stored charge point of view.

In order to prevent the RF current from drawing out the entire stored charge, the following inequality must hold:

$$Q > q$$

or

$$I_{DC}\tau > \frac{I_{RF}}{2\pi f} \quad \text{[coulombs]} \qquad (12)$$

where: I_{RF} = RF peak current
I_{DC} = diode forward bias current
f = operating frequency
τ = diode carrier lifetime

This indicates that the dc stored charge in the PIN diode will be able to withstand larger RF currents as the frequency of the RF signal increases. It also shows that an instantaneous diode current excursion may occur in the negative (reverse bias) direction without adversely affecting the diode low resistance state. In practical circuits, it is recommended that the value of dc stored charge be designed to be at least 10 times the RF stored charge. This condition should be met independent of the diode resistance required to satisfy power dissipation constraints.

Reverse Bias

When a PIN diode is at zero or reverse bias, there is essentially no charge stored and the intrinsic region can be thought of as a low loss dielectric. In order for this intrinsic region to remain in a low loss state, the maximum instantaneous reverse or negative voltage must not exceed the diode breakdown voltage and the positive voltage excursion must not cause thermal losses to exceed the diodes dissipation rating.

All Unitrode PIN diodes have a specified minimum reverse voltage rating. This is the voltage, V_R, measured at room temperature (25°C) where it is guaranteed that no more than 10 μA reverse current will flow. This current is mainly due to surface conditions of the semiconductor and is often referred to as surface leakage current. The breakdown voltage of the diode, V_B, which also determines the maximum allowable RF voltage swing, depends primarily on the dielectric strength of the I-region and is directly proportional to the I-region thickness. At the actual breakdown point, diode current increases rapidly as the applied voltage is increased and a zener or avalanche effect occurs.

Figure 5-7 displays a typical dc voltage — current relation for a PIN diode along with one voltage cycle of a superimposed large RF signal, V_1. The approximate breakdown voltage, V_B, and voltage ratings for various Unitrode PIN diodes are shown below:

Pin Diode Type	V_B	Voltage Ratings (V_R)
UM4300,UM7300	3000V	100,200,600,1000 V
UM4000,UM6000, UM7000	2000V	100,200,600,1000 V
UM7100	1200V	100,200,400,800 V
UM6200,UM7200	600V	100,200,400 V

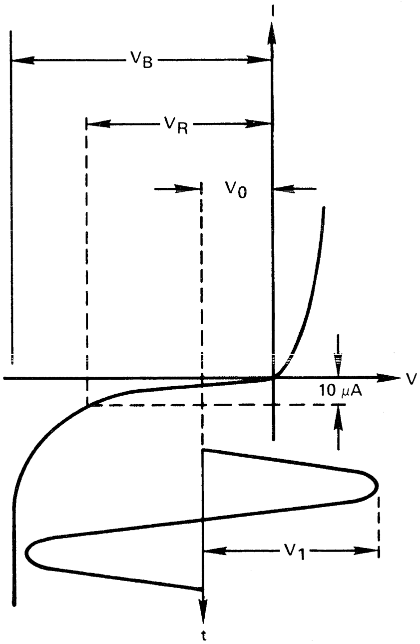


Figure 5-7 PIN Diode Voltage Relationships Under Reverse Bias

It is virtually impossible to measure the exact breakdown voltage of thick PIN diodes because of the surface leakage current. However, in specifying a PIN diode for large signal applications, the voltage rating must always exceed the applied dc reverse voltage but it need not be as high as the maximum RF voltage swing.

In addition to breakdown voltage, bias voltage, peak RF voltage and circuit losses, other parameters which must be considered in the selection and operation of PIN diodes under large signal conditions include the following: carrier lifetime, frequency, RF pulse length, duty cycle, and ambient temperature. Because of so many interacting parameters in high-power applications, frequently the only practical way to determine a proper bias voltage is through actual test and experimentation.

As a side effect of voltage excursions into either positive conduction or beyond breakdown, it should be noted that the dc reverse-bias power supply must deliver more than the normal diode reverse leakage current. Thus the normal reverse leakage will be less than 10 μA only when a diode is biased below its rated breakdown voltage. Under high RF signal power, this reverse leakage can increase to as much as 1 mA depending upon power level, bias voltage, frequency, and ambient temperature. In RF pulse applications, this leakage is observed to vary during the duration of the pulse and the maximum value obtained is generally called the "pulse leakage current." The level of this current and its stability are good measures of the adequacy of a given bias voltage for a particular application.

In a previous section it was pointed out that a diode with a long transit time will have a slow reverse to forward switching speed, T_{RF}. Similarly these devices will react slower to a rapidly changing RF signal. This infers that there is more of a tendency in a thick PIN diode to retain its quiescent level of stored charge.

The lower transit time frequency of a thick PIN diode also implies its ability to follow the stored charge model for diode resistance, per Equation 2, rather than the non-linear V-I characteristic at lower frequencies. Thus the higher the frequency and the smaller the signal the lower the effect of this non-linearity.

Non-linear behavior is often desired in PIN and other semiconductor diodes. Limiter diodes are designed as thin I-region PIN diodes operating near the transit time frequency of the devices. In a detector or mixer diode it is the ability of the diode to produce distortion that is being exploited. In this regard the term "square law detector" applied to detector diodes implies a good second order distortion generator.

Unitrode PIN diodes, on the other hand, are characterized by wide intrinsic regions containing stored charges whose levels are primarily controlled by applied dc bias signals. It is primarily this feature which enables these diodes to control strong RF signals without adding significant amounts of distortion to the desired signals. It may also be concluded that Unitrode PIN diodes do not perform well as self-biased limiter or detector diodes.

The effect of carrier lifetime on switch distortion relates to the level of stored charge at the operating forward bias current and the ratio of this stored charge to the incremental stored charge added or removed by the RF signal. Equation 12 is repeated here to show the conditions for low distortion switch performance:

$$Q > q$$

or

$$I_{DC}\tau > \frac{I_{RF}}{2\pi f} \qquad (12)$$

DISTORTION

The prior sections devoted to large signal operation and thermal considerations were concerned with determining operating conditions that would result in either significant changes in diode performance or excessive power dissipation in PIN diodes. A more subtle but often significant operating characteristic which we shall now consider, is the distortion or change in signal shape which is produced by a PIN diode in the signal it controls.

When an RF signal is applied to a PIN diode, some degree of distortion is always introduced in the signal. Such changes in shape are usually indicated by changes in the frequency content (or Fourier series) of the applied RF signal. The primary cause of this distortion is the variation of the PIN diode impedance during the period of the RF signal. This level of distortion can range from a low of better than 100 dB below the desired signal up to levels that approach that of the desired signal. Several specific methods for selecting and operating PIN diodes to obtain low distortion are discussed in the following sections.

A common misconception is that minority carrier lifetime is the only significant PIN diode parameter that affects distortion. This is indeed a factor, but another important parameter is the width of the I-region, which determines the transit time of the PIN diode.

Switch Distortion Reduction Techniques

In a distortion sensitive RF switch circuit, the PIN diode selected should have a wide I-region (W) and a long carrier lifetime, τ. The diode should be both forward biased to as high a current as feasible and reverse biased at the highest voltage possible. Distortion produced in the PIN diode circuit can be reduced further by adding another PIN diode in series with the first which increases the effective I-region width of the diode. In addition, the diodes are connected in a back to back orientation (cathode to cathode or anode to anode), an additional decrease in distortion will occur due to cancellation effects of these distortion currents.

Figure 5-8 shows an antenna switch which controls signal levels up to 100 watts CW at frequencies of 10–100 MHz and all harmonic distortion signals generated are better than

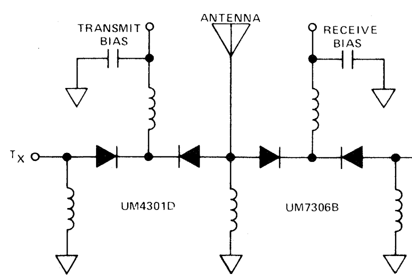


Figure 5-8 Low Distortion PIN Diode Antenna Switch

90 dB below the carrier level. The UM4301D diodes in the transmitter arm are each forward biased to 500 mA while the UM7306B receiver diodes are reverse biased at 500V to achieve this performance.

Attenuator Distortion Reduction Techniques

In attenuator applications, distortion is directly relatable to the ratio of RF to dc stored charge. In such applications, PIN diodes operate only in the forward bias state and often at high resistance values where the stored charge may be very low. Under these operating conditions, distortion will vary with changes in the attenuation level. Thus, PIN diodes selected for use in attenuator circuits need only be chosen for their thick I-region width, since the stored charge at any fixed diode resistance, R_S, is only dependent on this dimension. This relationship can be demonstrated by rewriting Equation 2 as follows:

$$Q = \frac{W^2}{(\mu_N + \mu_p) R_S} \quad \text{[coulombs]} \qquad (13)$$

The thickest I-region width PIN diodes manufactured by Unitrode are the UM4300 series, the UM7300 series and the UM9301. Using series connected PIN diodes, the effective I-region is increased which results in reduced distortion. A further improvement in distortion may be achieved by orienting the series connected diodes back-to-back which results in distortion signal cancellation.

Figure 5-9 shows a bridged TEE attenuator circuit which uses PIN diodes as variable resistors. Typical distortion performance of such a bridged TEE attenuator using UM9301 diodes is shown in Figure 5-10. The relative polarity orientation of the series and shunt diodes in Figure 5-9 results in partial cancellation of second and third order distortion terms except at 6 dB attenuation, where total cancellation is achieved. A reversal of the indicated relative diode polarities will result in some degradation of the second order distortion shown.

Additional improvements in signal distortion can be achieved by using two diodes in series in both the shunt and series arms of a bridged TEE attenuator. Typical results should yield a 7 dB improvement in second order and a 15 dB improvement in both third order and cross modulation relative to that achieved using a single diode in each position. Orienting each diode pair back to back will further improve second order distortion by approximately 20 dB relative to the performance obtained using a single diode in each position.

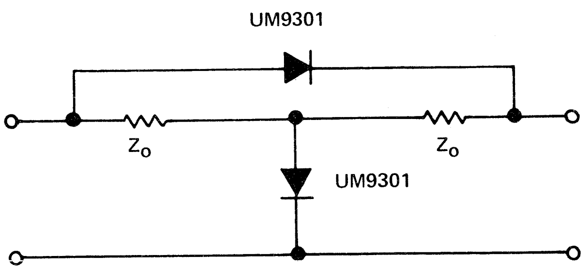


Figure 5-9 Bridged TEE Attenuator Circuit

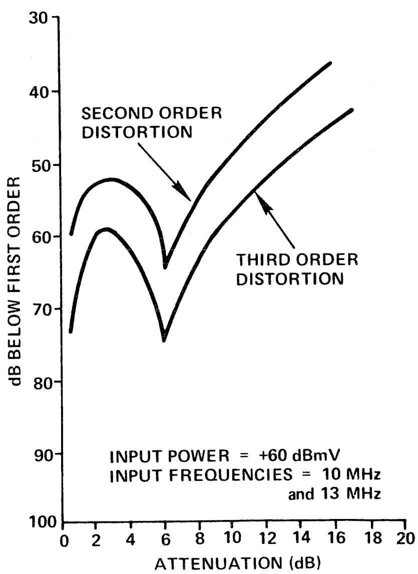


Figure 5-10 Distortion in Bridged TEE Attenuator

Distortion Measurement Techniques

The Unitrode PIN diode design, which enables low distortion performance, also permits PIN operation at frequencies below 100 KHz provided the circuit employs devices with long carrier lifetimes and thick effective I-region widths. Since distortion is inversely related to frequency, this parameter need only be measured at the lowest frequency of interest.

Because distortion levels are often 60 dB or more below the desired signal, special precautions are required in order to make accurate second and third order distortion measurements. One must first ensure that the signal sources used are free of distortion and that the dynamic range of the spectrum analyzer employed is adequate to measure the specified level of distortion. These requirements often lead to the use of fundamental frequency band stop filters at the device output as well as pre-selectors to clean up the signal sources employed. In order to establish the adequacy of the test equipment and signal sources for making the desired distortion measurements, the test circuit should be initially evaluated by removing the diodes and replacing them with passive elements. This approach permits one to optimize the test set-up and establish basic measurement limitations.

Since harmonic distortion appears only at multiples of the signal frequency, these signals may be filtered-out in narrow band systems. Second order distortion, caused by the mixing of two input signals, will appear at the sum and difference of these frequencies and may also be filtered. As an aid to identifying the various distortion signals seen on a spectrum analyzer, it should be noted that the level of a second order distortion signal will vary directly at the same rate as any change of input signal level. Thus, a 10 dB signal increase will cause a corresponding 10 dB increase in second order distortion.

Third order intermodulation distortion of two input signals at frequencies F_A and F_B often produce in-band, nonfilterable distortion components at frequencies of $2F_A - F_B$ and $2F_B - F_A$. This type of distortion is particularly troublesome in receivers located nearby transmitters operating on equally spaced channels. In identifying and measuring such signals, it should be noted that third order distortion signal levels vary at twice the rate of change of the fundamental signal frequency. Thus, a 10 dB change in input signal power will result in a 20 dB change of the third order signal distortion power observed on a spectrum analyzer.

VI. APPLICATIONS

APPLICATIONS

SWITCHES

The most common usage of a PIN diode is as a switching element to control RF signals. In these applications, the diode can be considered as either a high or low impedance device, depending on its dc bias condition.

A simple untuned single-pole, single-throw (SPST) switch may be designed using either a single series or shunt connected PIN diode as shown in Figure 6-1. The series connected diode is commonly used when a minimum insertion loss is required over a broad frequency range. This design is also easier to physically realize using printed circuit techniques, since no through holes are required in the circuit board. A single shunt mounted diode will, on the other hand, produce higher isolation values across a wider frequency range and will result in a design capable of handling more power since it is easier to heat sink the diode.

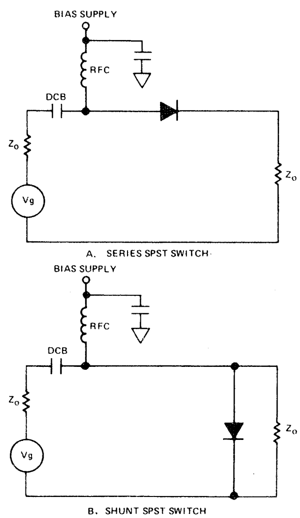


Figure 6-1 SPST PIN Diode Switches

Multi-throw switches rather than single-throw switches are more frequently required. Simple multi-throw switch designs employ a series PIN diode in each arm adjacent to the common port. Improved performance may be obtained using "compound switches," which are combinations of series and shunt connected PIN diodes, into each arm.

For narrow-band applications, quarter-wave spaced multiple diodes may also be used in various switch designs to obtain improved operation. In the following section, we shall discuss each of these general types of switches in some detail and present useful design information for selecting PIN diodes and predicting circuit performance.

Series Connected Switches

Figure 6-2 shows two basic types of PIN diode series switches (SPST and SPDT) commonly used in broad-band designs. In both cases, the diode is in an "ON" or "pass power" condition when it is forward biased and presents a low forward resistance, R_S, to the RF signal. For an "OFF" or "stop power" condition, the diode is at zero or reverse bias such that it presents a high impedance to the RF signal source. In series type switches, the maximum isolation obtainable depends primarily on the capacitance of the PIN diode, while the insertion loss and power dissipation are functions of the diode resistance. The principal operating parameters of a series switch may be obtained using the equations in the following sections.

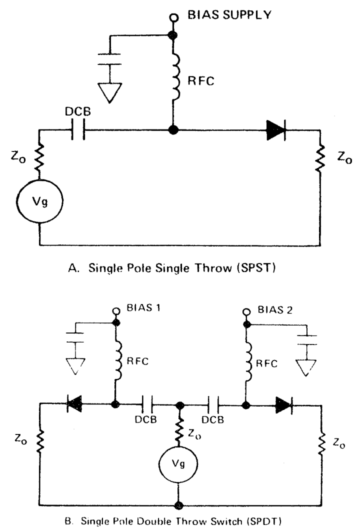


Figure 6-2 Series Connected PIN Switches

Insertion Loss (Series Switch)

$$IL = 20 \log\left(1 + \frac{R_S}{2Z_0}\right) \quad [\text{dB}] \qquad (13)$$

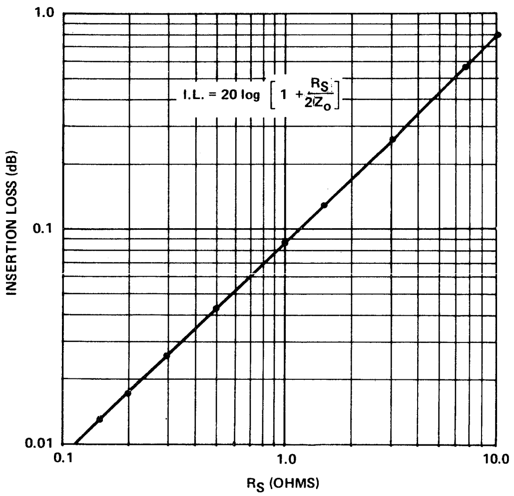


Figure 6-3 Insertion Loss for Series Connected Switch

This equation applies for a SPST switch and is graphically presented in Figure 6-3 for a 50 ohm impedance design as a function of R_S. For multi-throw switches, the insertion loss is slightly higher due any mismatch caused by the capacitance of PIN diodes in the "off" arms. This additional insertion loss can be determined from Figure 6-6 after first computing the total shunt capacitance of all "off" arms of the multi-throw switch.

Isolation (Series Switch)

$$I = 10 \log\left[1 + \frac{1}{(4\pi f C_T Z_0)^2}\right] \quad [\text{dB}] \qquad (14)$$

This equation applies for a SPST diode switch. Add 6 dB for a SPNT switch to account for the 50% voltage reduction across the "off" diode, due to the termination of the generator in its characteristic impedance. Figure 6-4 graphically presents isolation as a function of capacitance for simple series switches.These curves are plotted for circuits terminated in 50Ω loads. They may, however, also be applied to circuits having other characteristic impedances by following the instructions accompanying the graphs.

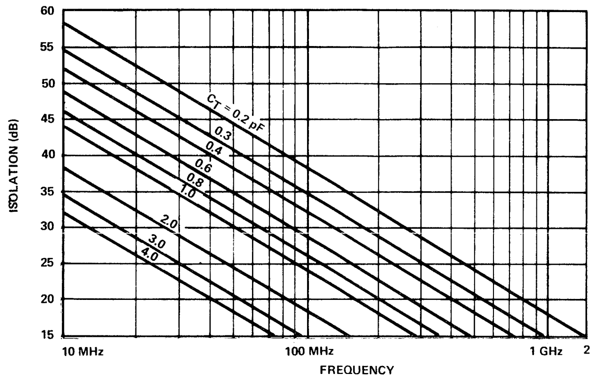


Figure 6-4 Isolation for Series Connected SPST Switch (Add 6 dB for Multithrow Switch)

Power Dissipation (Series Switch in Forward Bias)

$$P_D = \frac{4R_S Z_0}{(2Z_0 + R_S)^2} P_{AV} \quad [\text{watts}] \qquad (15)$$

For $Z_0 >> R_S$, this becomes:

$$P_D \approx \frac{R_S}{Z_0} P_{AV} \quad [\text{watts}] \qquad (16)$$

where the maximum available power is given by:

$$P_{AV} = \frac{V_g^2}{Z_0} \quad [\text{watts}] \qquad (17)$$

It should be noted that Equations 15 and 16 apply only for perfectly matched switches. For SWR (σ) values other than unity, multiply these equations by $[(2\sigma/(\sigma + 1)]^2$ to obtain the maximum required diode power dissipation.

Peak RF Current (Series Switch)

$$I_P = \sqrt{\frac{2P_{AV}}{Z_0}}\left(\frac{2\sigma}{\sigma + 1}\right) \quad [\text{amps}] \qquad (18)$$

In the case of a 50Ω system, this reduces to:

$$I_P = \frac{\sqrt{P_{AV}}}{5}\left(\frac{2\sigma}{\sigma + 1}\right) \qquad \text{[amps]} \qquad (19)$$

Peak RF Voltage (Series Switch)

SPST

$$V_P = \sqrt{8Z_0P_{AV}} \qquad \text{[volts]} \qquad (20)$$

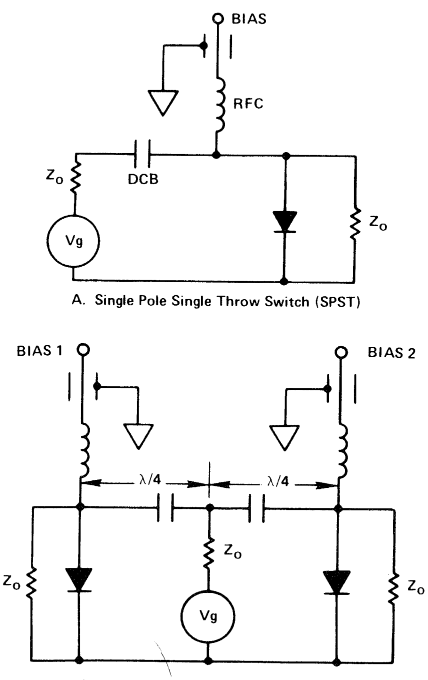
SPNT

$$V_P = \sqrt{2Z_0P_{AV}} \left(\frac{2\sigma}{\sigma + 1}\right)$$

For a 50Ω system, this becomes:

$$V_P = 20\sqrt{P_{AV}} \qquad \text{[volts]} \qquad (21)$$

$$V_P = 10\sqrt{P_{AV}} \left(\frac{2\sigma}{\sigma + 1}\right) \qquad \text{[volts]}$$



A. Single Pole Single Throw Switch (SPST)

B. Single Pole Double Throw Switch (SPDT)

Figure 6-5 Shunt Connected PIN Switch

Shunt Connected Switches

Figure 6-5 shows two typical shunt connected PIN diode switches. These shunt diode switches offer high isolation for many applications and since the diode is electrically grounded at one electrode, it is capable of handling more RF power than a diode in a series type switch.

In shunt switch designs, the isolation and power dissipation are functions of the diodes forward resistance, whereas the insertion loss is primarily dependent on the capacitance of the PIN diode. The principal equations describing the operating parameters of shunt switches are given in the following sections:

Insertion Loss (Shunt Switch)

$$IL = 10\log\left[1 + (\pi f C_T Z_0)^2\right] \qquad \text{[dB]} \qquad (22)$$

This equation applies for both SPST and SPNT shunt switches and is graphically presented in Figure 6-6 for a 50 Ω load impedance design.

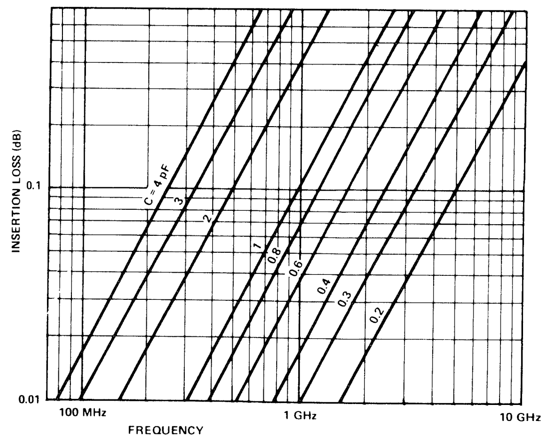


Figure 6-6 Insertion Loss for Shunt Connected SPST Switch

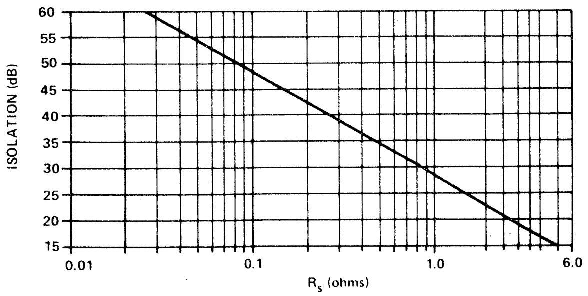


Figure 6-7 Isolation for Shunt Connected SPST Switch (Add 6dB for Multithrow Switch)

Isolation (Shunt Switch)

$$I = 20 \log\left(1 + \frac{Z_0}{2R_S}\right) \quad [\text{dB}] \qquad (23)$$

Equation 23, which is illustrated in Figure 6-7, applies to a SPST shunt switch. Add 6 dB to these values to obtain the correct isolation for a multi-throw switch.

Power Dissipation (Shunt Switch in Forward Bias)

$$P_D = \frac{4R_SZ_0}{(Z_0 + 2R_S)^2} \cdot P_{AV} \quad [\text{watts}] \qquad (24)$$

For $Z_0 >> R_S$, this becomes:

$$P_D \approx \frac{4R_S}{Z_0} P_{AV} \quad [\text{watts}] \qquad (25)$$

where the maximum available power is given by:

$$P_{AV} = \frac{V_g^2}{4Z_0} \quad [\text{watts}]$$

Power Dissipation (Shunt Switch in Reverse Bias)

$$P_D = \frac{Z_0}{R_P} P_{AV} \quad [\text{watts}] \qquad (26)$$

where R_P is the reverse biased diodes' parallel resistance.

Peak RF Current (Shunt Switch)

SPST

$$I_P = \sqrt{\frac{8P_{AV}}{Z_0}} \quad [\text{amps}]$$

SPNT

$$I_P = \sqrt{\frac{2P_{AV}}{Z_0}} \left(\frac{2\sigma}{\sigma + 1}\right) \qquad (27)$$

For a 50Ω system, this becomes:

$$I_P = 0.4\sqrt{P_{AV}} \quad [\text{amps}]$$

$$I_P = 0.2\sqrt{P_{AV}} \left(\frac{2\sigma}{\sigma + 1}\right) \quad [\text{amps}] \qquad (28)$$

Peak RF Voltage (Shunt Switch)

$$V_P = \sqrt{2Z_0P_{AV}} \left(\frac{2\sigma}{\sigma + 1}\right) \quad [\text{volts}] \qquad (29)$$

In the case of a 50Ω system, this reduces to:

$$V_P = 10\sqrt{P_{AV}} \left(\frac{2\sigma}{\sigma + 1}\right) \quad [\text{volts}] \qquad (30)$$

Design Hints

In evaluating the performance of a diode in a particular design, it is often desirable to replace the forward biased diode by an equivalent diameter solid metallic cylinder. The isolation or loss obtained using this equivalent diode should be representative of the best achievable results from this circuit. In actual switch designs, careful attention must be paid to minimizing the inductance of the shunt diode by keeping the physical length of the diode and its contacting lead as short as possible.

In practice, it usually is difficult to achieve more than 40 dB isolation with a single diode switch at UHF and higher frequencies, primarily because of radiation effects in the transmission medium. Better performance, even in excess of 100 dB isolation, however, is achievable using compound and tuned diode switches which are discussed in the following sections.

Compound Switches

The two most common forms of compound switches are PIN diodes mounted in either ELL (series-shunt) or TEE type configurations as shown in Figure 6-8. These switch designs offer improved performance over either of the single diode switches. Because all diodes are not biased in one or the other states (i.e. low loss or isolated), some increase in bias circuit complexity results. A summary of the formulas for calculating both maximum isolation and minimum insertion loss for SPST switches is given in Table 6-1. These formulas should permit one to compare the performance of simple single diode switches with ELL and TEE compound switch designs.

Figures 6-9 and 6-10 show the performance of these compound switch circuits as a function of frequency when using UM4000 PIN

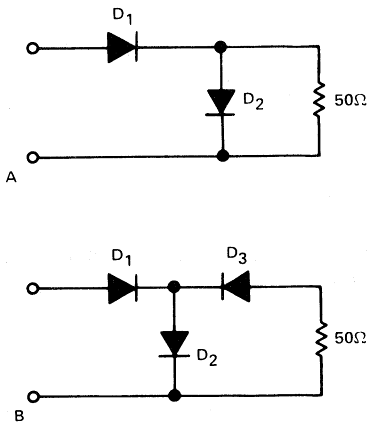


Figure 6-8 Compound Switches

TABLE 6-1
SUMMARY OF FORMULAS FOR SPST SWITCHES

TYPE	ISOLATION (dB)*	INSERTION LOSS (dB)
SERIES	$10 \log \left[1 + \frac{1}{(4\pi f C_T Z_0)^2}\right]$	$20 \log \left(1 + \frac{R_S}{2Z_0}\right)$
SHUNT	$20 \log \left(1 + \frac{Z_0}{2R_S}\right)$	$10 \log \left[1 + (\pi f C_T Z_0)^2\right]$
SERIES-SHUNT	$10 \log \left[\left(1 + \frac{Z_0}{2R_S}\right)^2 + \frac{1}{4\pi f C_T Z_0}\left(1 + \frac{Z_0}{R_S}\right)^2\right]$	$10 \log \left[\left(1 + \frac{R_S}{2Z_0}\right)^2 + (\pi f C_T)^2 (Z_0 + R_S)^2\right]$
TEE	$10 \log \left[1 + \left(\frac{1}{2\pi f C_T Z_0}\right)^2\right] + 10 \log \left[\left(1 + \frac{Z_0}{2R_S}\right)^2 + \left(\frac{1}{4\pi f C_T R_S}\right)^2\right]$	$20 \log \left(1 + \frac{R_S}{2Z_0}\right) + 10 \log \left[1 + (\pi f C_T)^2 (Z_0 + R_S)^2\right]$

***For SPNT Switch, Add 6 dB**

series diodes. These diodes are rated at 3.0 pF total capacitance and have a series resistance, R_S, of 0.5Ω at 100 mA. Because of their low thermal resistance rating of 6°C/W, these diodes are used in many high power switching applications.

Tuned Switches

Since many RF switch applications operate over a limited frequency range, the advantages of distributed circuit techniques can often be employed to obtain improved performance. For example, if two series connected diodes are spaced a quarter wavelength apart as shown in Figure 6-11, the resulting value of isolation (in dB) is twice that obtainable using a single series diode.

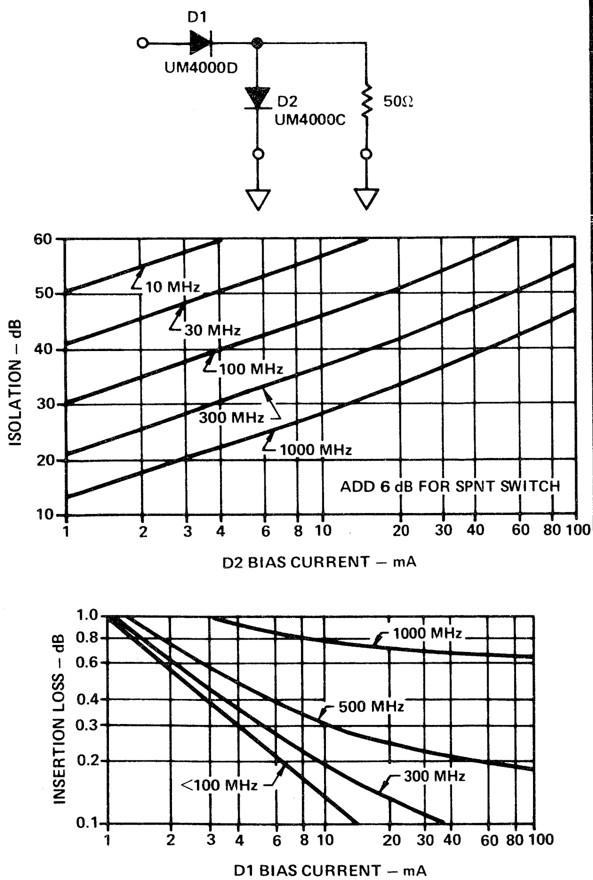


Figure 6-9 Series-Shunt Design Compound Switch

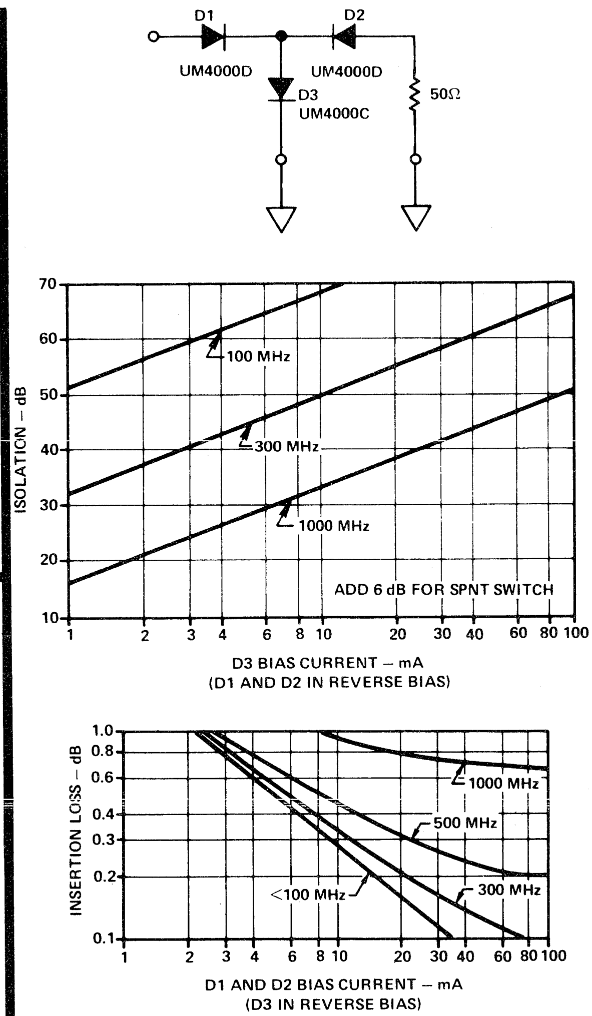


Figure 6-10 TEE Compound Switch Design

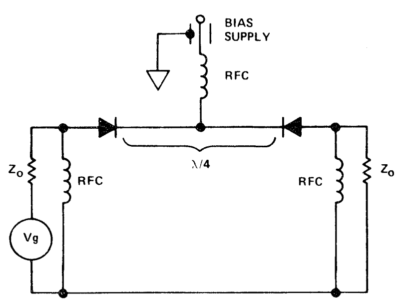


Figure 6-11 Tuned Series Switch (SPST)

The insertion loss for this switch can be either calculated from the formulas in Table 6-1 or obtained from Figure 6-3. In either case, one should use a total diode resistance, R_S, which is equal to the sum of the individual diode resistances. A further increase in isolation can be obtained by adding two or more quarter-wave sections to these switch designs. Such tuned switch techniques are effective in applications having bandwidths on the order of 10% of the center band frequency.

Quarter-wave spacing of series diodes also reduces the maximum RF voltage stress across each diode to half that imposed on a single diode switch. Since the diode capacitance now appears in series, this arrangement also allows the use of high power (higher capacitance) diodes for high frequency applications.

If the diodes were connected directly in series with no significant spacing between units, some increase in isolation would result since the effective diode capacitance is reduced by a factor of two. This arrangement, however, would only increase the isolation up to 6 dB above that obtained using a single diode.

The performance of shunt diode switches may also be improved by spacing multiple diodes at quarter wavelength intervals. In this case, the maximum isolation is also improved to twice the dB value obtained using a single diode switch. Figure 6-12 shows an example of a SPST shunt tuned switch while Figure 6-5b shows a typical multi-throw tuned shunt switch. The capacitive reactance of one diode is transformed by the quarter-wave spacing to resonate the capacitance of the second diode, thus, lower insertion loss can often be obtained using these shunt tuned switch circuits. While this technique also permits the use of high power (large capacitance) diodes at high frequencies, the effective band width of the switch is narrowed as the diode capacitance is increased.

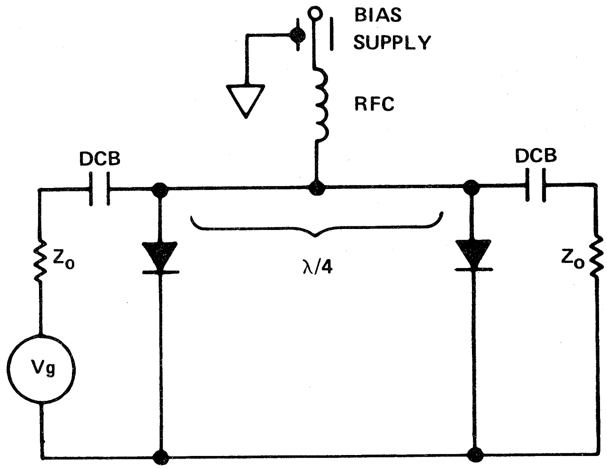
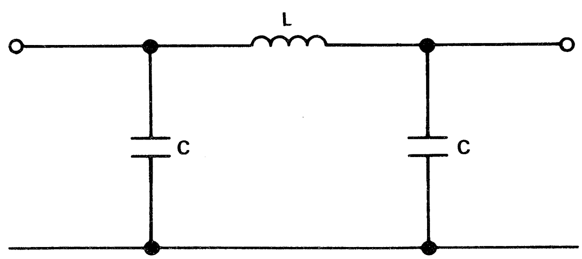


Figure 6-12 Tuned Shunt Switch (SPST)

Quarter-wave techniques may also be used effectively at low RF frequencies where use of a length of transmission line may be considered to be impractical because of its bulk. In such cases, a lumped circuit equivalent to the quarter-wave lines shown in Figure 6-13, can be used. In practice this network has been effective in simulating quarter-wave lines at frequencies below 10 MHz.



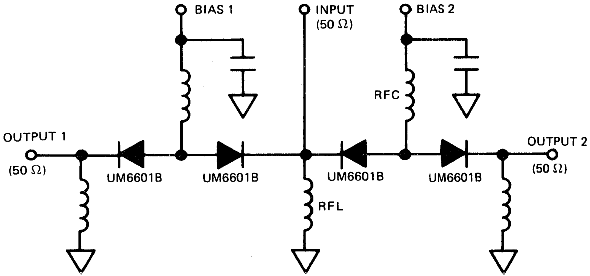
$$L = \frac{Z_o}{2\pi f_o} \quad \text{(henries)}$$

$$C = \frac{1}{2\pi f_o Z_o} \quad \text{(farads)}$$

Figure 6-13 Lumped Circuit Equivalent of Quarter Wave Line

Design Example

A simple, practical, high performance SPDT switch design using series connected PIN diodes using UM6601B diodes is shown as follows:



To operate the switch apply forward bias at the bias port associated with the desired low insertion loss path and zero bias at the other bias port.

The insertion loss values shown in the chart below are dependent only on forward bias current and independent of frequency.

I/Diode	Insertion Loss
(mA)	(dB)
20	1.0
50	0.66
100	0.42
200	0.21

If broad-band switch performance is required the diodes should be physically placed close to each other.

If quarter wave spacing were used between the diodes, higher isolation, covering about ±10% band width, will be achieved as shown in the following chart:

	ISOLATION	
Frequency	No Spacing	λ/4 Spacing
(MHz)	(dB)	(dB)
20	58	110
50	50	94
100	44	82
200	38	70
500	30	54
1000	24	42
2000	18	30

Transmit—Receive Switches

There is a general class of switches used in transceiver applications whose function is to connect the antenna to either the transmitter or the receiver during the appropriate transmit and receive states. When PIN diodes are used as switching elements in these applications, higher reliability, better mechanical ruggedness and faster switching speeds are achieved relative to comparable electro-mechanical designs. Unitrode PIN diodes are uniquely suited for such applications because of their high power ratings and properties which result in low distortion performance.

The basic circuit for this switch (see Figure 6-14a) consists of a PIN diode (D1), series

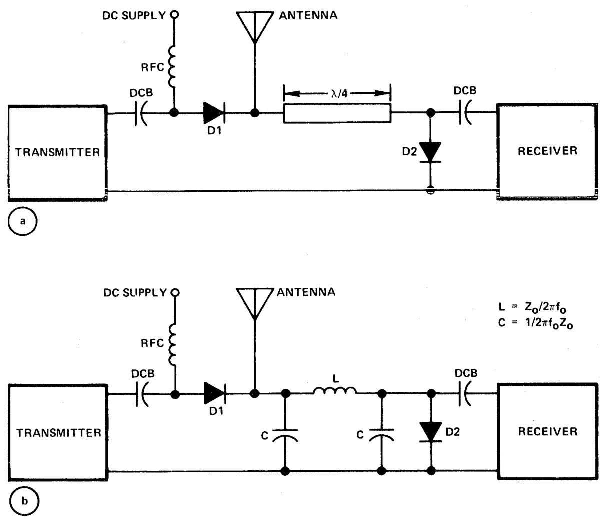


Figure 6-14 Quarter Wave Antenna Switches

connected in the transmitter line and a shunt diode (D2) in the receive arm. This shunt diode is connected a quarter-wavelength (λ/4) away from the antenna terminal but ahead of any input amplifier in the receiver. Figure 6-14b shows this same basic switch employing lumped elements to simulate the λ/4 section. It is preferable for transceivers operating at long wavelengths.

Blocking capacitors are included in the transmitter and receiver lines, to isolate these circuits from the main diode bias circuit. During transmission, a positive voltage is applied to the dc supply terminal, and both diodes are forward biased into a conducting state. The series diode now appears as a low impedance to the signal heading towards the antenna, while the shunt diode effectively shorts the receiver terminals and presents an open circuit at the antenna terminal, a $\lambda/4$ away. In this circuit, both transmitter insertion loss and receiver isolation depend on the forward resistance, R_S, of the diodes employed. Greater than 30 dB isolation and less than 0.25 dB insertion loss can be expected for a diode R_S of 1.0Ω or less. This performance is achievable over a 10% bandwidth.

In the receive condition, both diodes are either zero or reverse biased and each appears to be essentially a small capacitance, C_T, which permits a direct, low-insertion-loss path between the antenna and receiver. The "off" transmitter is isolated from the antenna by the high capacitive reactance of the series diode.

The maximum amount of power, P_{AV}, which this switch can handle, depends on the power rating of the PIN diode, P_D, and the forward biased diode resistance, R_S. This relationship is given below for an antenna having a maximum standing wave ratio (SWR) of σ.

$$P_{AV} = \frac{P_D Z_0}{R_S}\left(\frac{\sigma + 1}{2\sigma}\right)^2 \quad \text{[watts]} \qquad (31)$$

In a 50Ω system, where the condition of a totally mismatched antenna must be considered, this equation reduces to:

$$P_{AV} = \frac{12.5 P_D}{R_S} \quad \text{[watts]} \qquad (32)$$

Using Unitrode UM4901D and UM4901C diodes forward biased at 1 ampere in this circuit, these equations show that a power level of 2.5 KW may be safely controlled even when the heat sink temperature is 50 °C. The insertion loss in both the receive and transmit states is approximately 0.2 dB, due primarily to the diode forward resistance, R_S. This performance, along with typically 30 dB receiver isolation, is achieved over a 10% frequency band.

While it may not be readily apparent from Figure 6-14, it may be shown that the RF current in both the series and shunt diodes is almost identical. Thus, the shunt diode of this quarter-wave antenna switch dissipates about as much power as the series diode.

Another example of a tuned antenna switch is the balanced duplexer shown in Figure 6-15 which employs quadrature type hybrids. In this circuit, the transmitter signal is connected to the antenna by forward biasing the two shunt diodes located between the two hybrids. Because of the coupling and phase relationships of the quadrature hybrid, half of the transmitter power appears across each shunt diode.

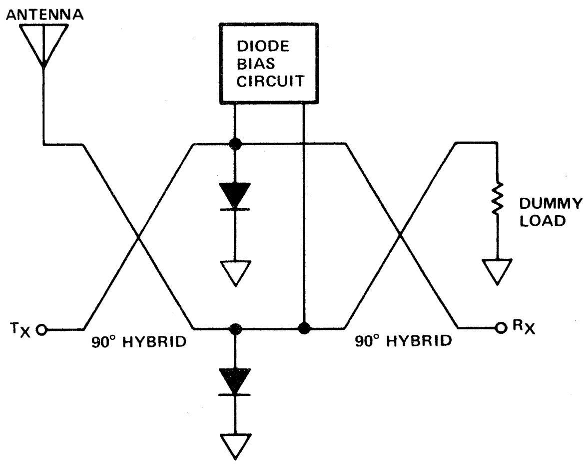


Figure 6-15 Balanced Duplexer T-R Switch

These signals are then reflected back to the input hybrid where their phase relations are such that they recombine at the antenna terminal. The final level of the transmitted signal is reduced slightly both by the small losses in the forward biased diodes and the round trip losses through the input hybrid. When the diodes are zero biased during the "receive" period, the resulting high diode impedances exert little effect on the receive signals. These low level signals are then coupled in the output hybrid and the combined signals appear at the receiver input terminal.

The power handling capacity of the balanced duplexer switch is considerably higher than the quarter-wave antenna design for three significant reasons:

1. The transmitter power is split into two equal paths.
2. The inherent isolation of the hybrid reduces the effect of antenna mismatch on the diodes.
3. Shunt diodes are employed exclusively which results in better thermal properties than achievable using series connected diodes.

The maximum power, P_{Tmax}, that a balanced duplexer can ideally handle, when working in a 50Ω system with a matched antenna, is expressed as follows:

$$P_{Tmax} = 100 \frac{P_D}{R_S} \quad \text{[watts]} \qquad (33)$$

Using UM4901C diodes operating at 1 ampere forward bias and a heat sink temperature of 50°C, results in a power switch capability exceeding 30 kW average. By using parallel, instead of single diodes in each arm, this rating can be multiplied to a point where the power is limited only by the hybrid's capability rather than by the PIN diodes. In pulsed RF applications, practical duplexer designs are capable of handling megawatts of power using Unitrode PIN diodes.

An important characteristic of the tuned antenna switches discussed above is that all the PIN diodes are forward biased under high power conditions. Thus high RF voltages need not be controlled by the PIN diodes, and only low voltage rated PIN diodes need be used. It should also be noted that during the receive period, no dc bias need be applied to either diode.

Broad-band antenna switches using PIN diodes may also be designed using the series connected diode circuit shown in Figure 6-16. The upper frequency limitation of this switch results primarily from the capacitance of D2, which limits the maximum isolation obtainable (see Figure 6-4). In this circuit, forward bias is applied either to D1 during transmit or D2 during receive. In high power applications (greater than 50W) it is often necessary to apply a reverse voltage on D2 during transmit. This bias may be accomplished either by connecting a negative polarity power supply at bias terminal 2 or by having the forward bias current of D1 flow through resistor R to develop the required negative voltage.

The operating band width of a broad-band PIN diode switch is often primarily dependent on the bias components, particularly the bias chokes, rather than the PIN diodes employed. It is suggested that the frequency response be first checked with all the bias components attached before installing the PIN diodes.

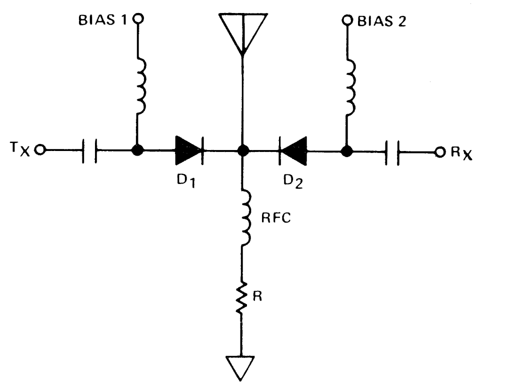


Figure 6-16 Broadband Antenna Switch

The selection of diode D1 is based primarily on its power handling capability. Thus, the UM4001 or UM4901, either in axial leaded or insulated studs (B or D packages) are recommended here because of their good thermal impedance properties. Diode D2 does not pass high RF current and should therefore be selected on the basis of its low capacitance and ability to handle high RF voltages with low distortion. The 1N5767, UM6600B, and UM7300B series are recommended for diode D2, with the voltage rating dependent on the reverse dc applied during the transmit cycle.

If a UM9401 is used as diode D1 and an 1N5767 as diode D2 the receiver isolation at 50 MHz will be greater than 40 dB and greater than 20 dB at 500 MHz. The transmitter and receiver insertion loss at 50 mA forward current will be 0.1 dB and 0.2 dB respectively. This circuit had been evaluated at power levels up to 50 watts.

An example of a high power broad-band antenna switch covering the frequency range of 10-100 MHz is shown in Figure 6-17. This switch has controlled 1 KW signals with the resulting harmonic distortion being greater than 80 dB below the carrier. This operation was achieved using a level of 1 ampere at bias terminal 1 and 500 volts at bias terminal 2.

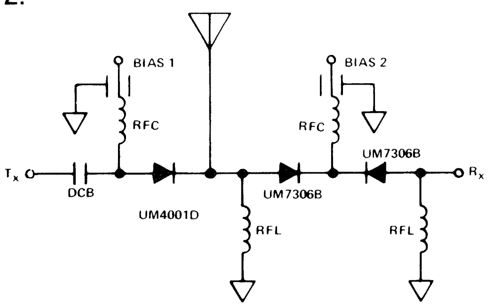


Figure 6-17 High Power Broadband Antenna Switch

PHASE SHIFTERS

PIN diodes are utilized as series or shunt connected switches in phase shifter circuit designs. In such cases, the elements switched are either lengths of transmission line or reactive elements. The criteria for choosing PIN diodes for use in phase shifters is similar to those used in selecting diodes for other switching applications. One additional factor, however, that must often be considered, is the possibility of introducing phase distortion particularly at high RF power levels or low reverse bias voltages. Of significant note is the fact that the properties inherent in Unitrode PIN diodes which yield low amplitude distortion, i.e., a long carrier lifetime and thick I-regions, also result in low phase distortion of the RF signal. Three of the most common types of semiconductor phase shifter circuits, namely: the switched line, loaded line and hybrid coupled designs, are described in the following sections.

Switched Line Phase Shifters

A basic example of a switched line phase shifter circuit is shown in Figure 6-18. In this design, two SPDT switches employing PIN diodes are used to change the electrical length of a transmission line by some length. $\Delta\ell$. The phase shift obtained from this circuit varies with frequency and is a direct function of this differential line length as shown below:

$$\Delta\phi = 2\pi\Delta\ell/\lambda \quad \text{[radians]} \qquad (34)$$

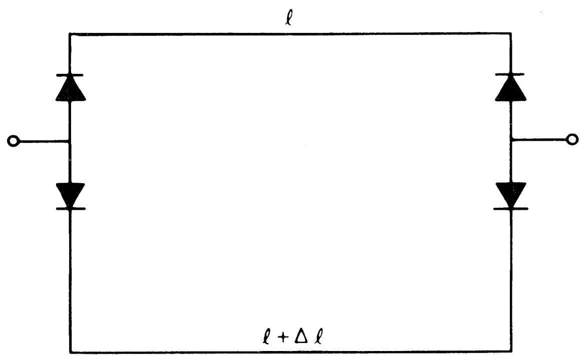


Figure 6-18 Switched Line Phase Shifter

The switched line phase shifter is inherently a broad-band circuit producing true time delay, with the actual phase shift dependent only on $\Delta\ell$. Because of PIN diode capacitance limitations this design is most frequently used at frequencies below 1 GHz.

The power capabilities and loss characteristics of the switched line phase shifter are the same as those of a series connected SPDT switch. A unique characteristic of this circuit is that the power and voltage stress on each diode is independent of the amount of differential phase shift produced by each phase shifter. Thus, four diodes are required for each bit with all diodes having the same power and voltage ratings.

Unitrode PIN diodes are especially well suited for this application because of their ability to dissipate considerable amounts of power in a series mounted device. For such applications, both the axial leaded (B and E packages) and insulated stud (D-package) designs should be considered.

Loaded Line Phase Shifters

The loaded line phase shifter design shown in Figure 6-19 operates on a different principle than the switched line phase shifter. In this design the desired maximum phase shift is divided into several smaller phase shift sections, each containing a pair of PIN diodes which do not completely pertubate the main transmission line. A major advantage of this phase shifter is its extremely high power capability due partly to the use of shunt mounted diodes plus the fact that the PIN diodes are never in the direct path of the full RF power.

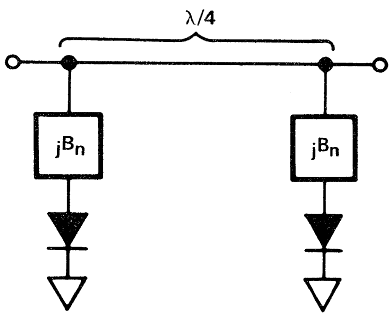


Figure 6-19 Loaded Line Phase Shifter

In loaded line phase shifters, a normalized susceptance, B_n, is switched in and out of the transmission path by the PIN diodes. Typical circuits use values of B_n much less than unity, thus resulting in considerable decoupling of the transmitted RF power from the PIN diode. The phase shift for a single section is given as follows:

$$\phi = 2\tan^{-1}\left(\frac{B_n}{1 - B_n^2/8}\right) \text{ [radians]} \quad (35)$$

The maximum phase shift obtainable from a loaded line section is limited by both bandwidth and diode power handling considerations. The power constraint on obtainable phase shift is shown as follows:

$$\phi_{max} = 2\tan^{-1}\left(\frac{V_R I_F}{4P_L}\right) \text{ [radians]} \quad (36)$$

where: ϕ_{max} = maximum phase angle
P_L = power transmitted
V_{BR} = diode breakdown voltage
I_F = diode current rating

The above factors limit the maximum phase shift angle in practical circuits to about 45°. Thus, a 180° phase shift would require the use of four 45° phase shift sections in its design.

The ability of the loaded line section to control multikilowatt pulsed RF signals, was one of the major reasons for its use in the PAR and MSR phased array antennas of the US Safeguard System. Unitrode PIN diodes are especially well suited for use in high power loaded line phase shifter circuits with the result that Unitrode was the only manufacturer qualified for both phased array radars of the Safeguard System.

Reflective Phase Shifters

A circuit design which handles both high, RF power and large incremental phase shifts with the fewest number of diodes is the hybrid coupled phase shifter shown in Figure 6-20. The phase shift for this circuit is given below:

$$\Delta\phi = 4\pi \Delta\ell / \lambda \text{ [radians]} \quad (37)$$

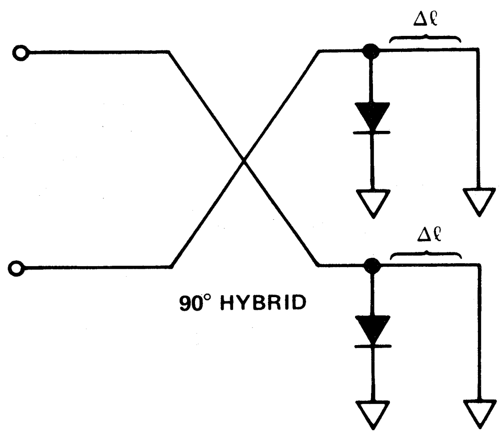


Figure 6-20 Hybrid Coupled Phase Shifter

The voltage stress on the shunt PIN diode in this circuit also depends on the amount of desired phase shift or "bit" size. The greatest voltage stress is associated with the 180° bit and is reduced by the factor $(\sin\phi/2)^{1/2}$ for other bit sizes. The relationship between maximum phase shift, transmitted power, and PIN diode ratings is as follows:

$$\phi_{max} = 2\sin^{-1}\left(\frac{V_R I_F}{8P_L}\right) \text{ [radians]} \qquad (38)$$

In comparison to the loaded line phase shifter, the hybrid design can handle up to twice the average or peak power when using the same diodes. In both hybrid and loaded line designs, the power dependency of the maximum bit size relates to the product of the maximum RF current and peak RF voltage the PIN diodes can handle. By judicious choice of the nominal impedance in the plane of the PIN diode, the current and voltage stress can usually be adjusted to be within the device ratings. In general, this implies lowering the nominal impedance to reduce the voltage stress in favor of higher RF currents. For Unitrode PIN diodes, the maximum current rating, in turn, depends on the diode power dissipation rating while the maximum voltage stress at RF frequencies is dependent on I-region thickness.

ATTENUATORS

PIN diode attenuator circuits are used extensively in automatic gain control (AGC) and RF leveling applications as well as in electronically controlled attenuators and modulators. A typical configuration of an AGC application is shown in Figure 6-21. The PIN diode attenuator may take many forms ranging from a simple series or shunt mounted diode acting as a lossy reflective switch or a more complex structure that maintains a constant matched input impedance across the full dynamic range of the attenuator.

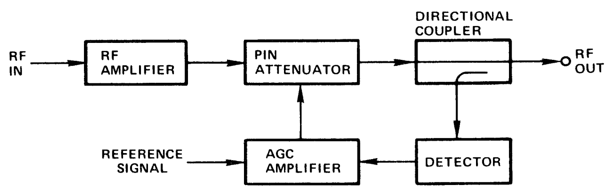


Figure 6-21 RF AGC/Leveler Circuit

Although there are other methods for providing AGC functions, such as varying the gain of the RF transistor amplifier, the PIN diode approach generally results in lower power drain, less frequency pulling, and lower RF signal distortion. The latter results are especially true, when Unitrode PIN diodes such as the UM7301B and UM4301B, with their thick I-regions and long carrier lifetimes are used in the attenuator circuits. Using this design approach, one can achieve wide dynamic range attenuation with low signal distortion at frequencies ranging from below 1 MHz up to well over 1 GHz.

Reflective Attenuators

An attenuator may be designed using single series or shunt connected PIN diode switch configurations (Figure 6-1). These attenuator circuits utilize the current controlled resistance characteristic of the PIN diode not only in its low loss states (very high or low resistance) but also at in-between, finite resistance values. The attenuation value obtained using these circuits may be computed from the following equations:

Attenuation of Series Connected PIN Diode Attenuator

$$A = 20 \log \left(1 + \frac{R_S}{2Z_0}\right) \quad [dB] \qquad (39)$$

Attenuation of Shunt Connected PIN Diode Attenuator

$$A = 20 \log \left(1 + \frac{Z_0}{2R_S}\right) \quad [dB] \qquad (40)$$

Figure 6-22 graphically displays these equations for series and shunt attenuators in 50Ω systems and clearly shows the effect of diode resistance (R_S) on attenuation. These curves and equations assume the PIN diode to be purely resistive. The reactance of the PIN diode capacitance, however, must also be taken into account at frequencies where its value begins to approach the PIN diode resistance value.

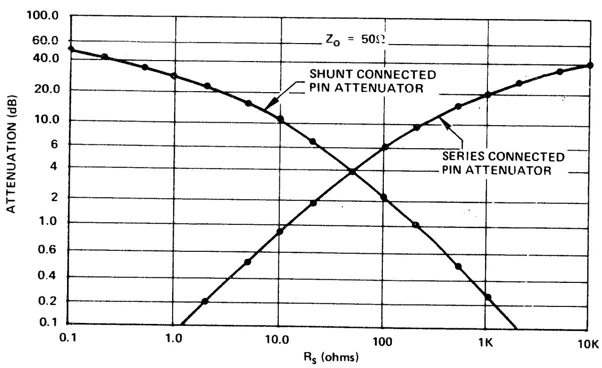


Figure 6-22 Attenuation of Reflective Attenuators

Matched Attenuators

Attenuators built from switch design are basically reflective devices which attenuate the signal by producing a mismatch between the source and the load. Matched PIN diode attenuator designs are also available which use either multiple PIN diodes biased at different resistance points or bandwidth-limited circuits utilizing tuned elements.

Quadrature Hybrid Attenuators

Although a matched PIN attenuator may be achieved by combining a ferrite circulator with one of the previous simple reflective devices, the more common approach makes use of quadrature hybrid circuits. Quadrature hybrids are commonly available at frequencies from below 10 MHz to above 1 GHz, with bandwidth coverage often exceeding a decade. Figures 6-23 and 6-24 show typical quadrature hybrid circuits employing series and shunt connected PIN diodes. The attenuation as a function of diode resistance, using these circuits in a 50Ω system, is given in Figure 6-25. The following equations summarize this performance:

Quadrature Hybrid (Series Connected PIN diodes)

$$A = 20 \log \left(1 + \frac{2Z_0}{R_S}\right)^{-1} \quad [dB] \qquad (41)$$

Quadrature Hybrid (Shunt Connected PIN diodes)

$$A = 20 \log \left(1 + \frac{2R_S}{Z_0}\right)^{-1} \quad [dB] \qquad (42)$$

The quadrature hybrid design approach is superior to the circulator coupled attenuator from the standpoint of lower cost and the achievement of lower frequency operation. Because the incident power is divided into two paths, the quadrature hybrid configuration is also capable of handling twice the power of the simple series and shunt diode attenuators. It can be shown that the maximum power dissipated in each diode will be

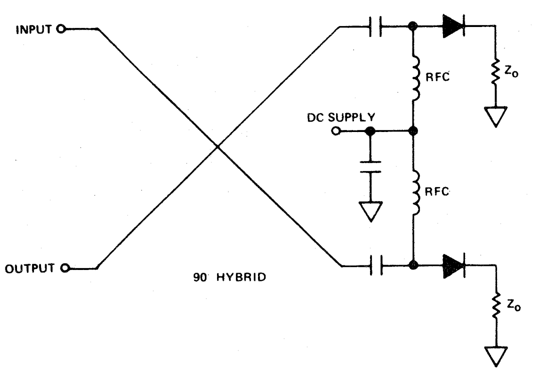


Figure 6-23 Quadrature Hybrid Matched Attenuator (Series Connected Diodes)

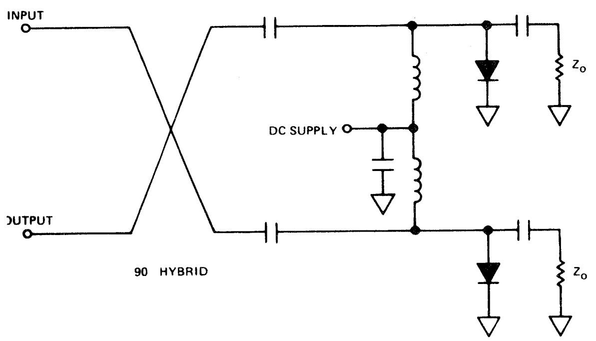


Figure 6-24 Quadrature Hybrid Matched Attenuator (Shunt Connected PIN Diodes)

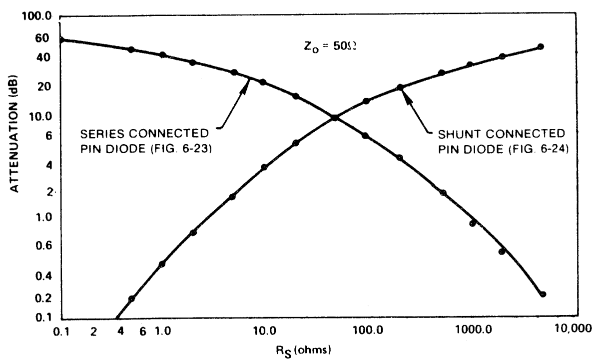


Figure 6-25 Attenuation of Quadrative Hybrid Attenuators

only one quarter of the incident power and this occurs at the 6 dB attenuation point. Each load resistor, however, must be capable of dissipating one half the total input power at the time of maximum attenuation.

Both of the above types of hybrid attenuators offer good dynamic range. The series connected diode configuration is, however, recommended for attenuators used primarily at high attenuation levels (greater than 6 dB) while the shunt mounted diode configuration is better suited for low attenuation ranges.

Quadrature hybrid attenuators may also be constructed without the load resistor attached in series or parallel to the PIN diode as shown. In these circuits the forward current is increased from the 50Ω, maximum attenuation, R_S value to lower resistance values. This results in increased stored charge as the attenuation is lowered which is desirable for lower distortion. The purpose of the load resistor is both to make the attenuator less sensitive to individual diode differences and increase the power handling capacity by a factor of two.

Quarter-Wave Attenuators

A matched attenuator may also be built using quarter-wave techniques employing either lumped or distributed elements. Figures 6-26 and 6-27 show examples of these circuits which have performance features equivalent to the previously discussed series or shunt connected attenuators.

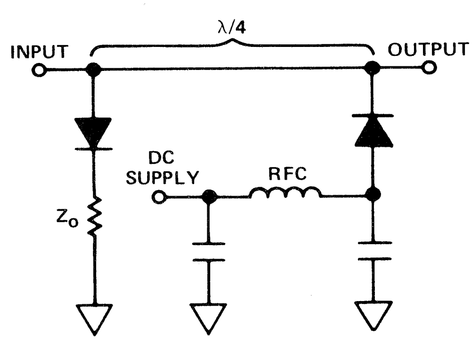


Figure 6-26 Quarter Wave Matched Attenuator (Series Connected Diode)

The performance equations for these circuits are given below and are also plotted in Figure 6-28 for a 50Ω system:

Quarter-Wave Attenuator (Series Connected Diode)

$$A = 20 \log \left(1 + \frac{Z_0}{R_S}\right) \text{[dB]} \quad (43)$$

Quarter-Wave Attenuator (Shunt Connected Diode)

$$A = 20 \log \left(1 + \frac{R_S}{Z_0}\right) \text{[dB]} \quad (44)$$

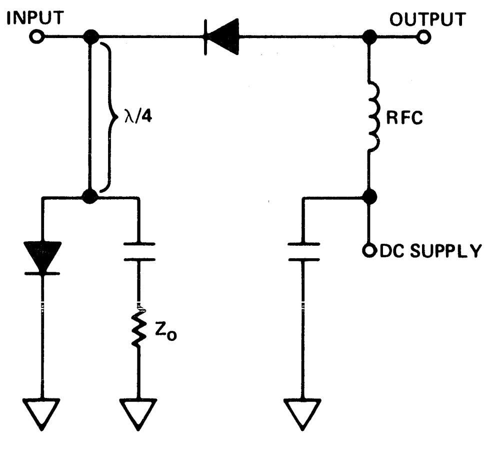


Figure 6-27 Quarter Wave Matched Attenuator (Shunt Connected Diode)

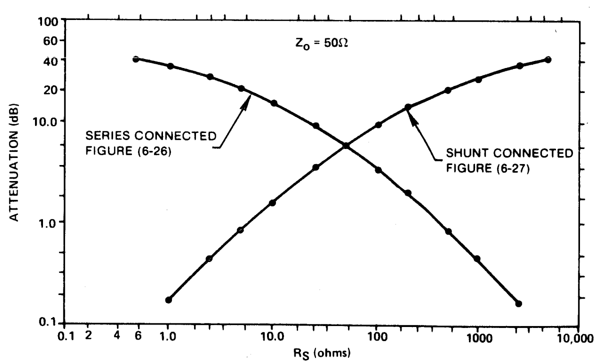


Figure 6-28 Attenuation of Quarter Wave Attenuators

A matched condition is achieved in these circuits when both diodes are at the same resistance. This condition should normally occur when using similar diodes since they are dc series connected, with the same forward bias current flowing through each diode. The series circuit of Figure 6-26 is recommended for use at high attenuation levels while the shunt diode circuit of Figure 6-27 is better suited for low attenuation circuits.

Bridged TEE and PI Attenuators

For matched broadband applications, especially those covering the low RF (1 MHz) through UHF, attenuator designs using multiple PIN diodes are employed. The most commonly used of all the possible attenuator configurations are the bridged TEE and PI circuits shown in Figures 6-29 and 6-30. The upper useful frequency of these circuits is often dependent on bias circuit isolation limitations rather than the PIN diode characteristics.

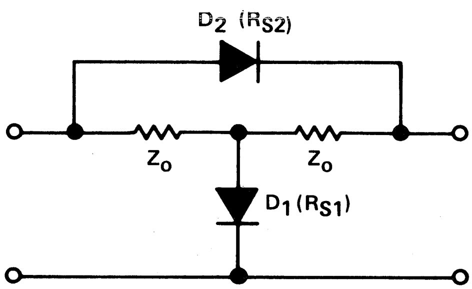


Figure 6-29 Bridged TEE Attenuator

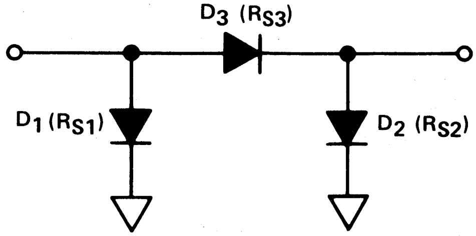


Figure 6-30 PI Attenuator

The attenuation obtained using a bridged TEE circuit may be calculated from the following:

$$A = 20 \log \left(1 + \frac{Z_0}{R_{S1}}\right) \text{ [dB]} \qquad (45)$$

where:

$$Z_0^2 = R_{S1} \times R_{S2} \text{ [ohms}^2\text{]} \qquad (46)$$

The relationship between the forward resistances of the two diodes insures maintenance of a matched circuit at all attenuation values. Figure 6-31 shows the resistances of diodes D1 and D2 (R_{S1} and R_{S2}) for a matched 50Ω bridged TEE attenuator.

The expressions for attenuation and matching conditions for the PI attenuator are given as follows:

$$A = 20 \log \frac{R_{S1} + Z_0}{R_{S1} - Z_0} \text{ [dB]} \qquad (47)$$

where:

$$R_{S3} = \frac{2R_{S1}Z_0^2}{R_{S1}^2 - Z_0^2} \text{ [ohms]} \qquad (48)$$

$$R_{S1} = R_{S2} \text{ [ohms]} \qquad (49)$$

Using these expressions, Figure 6-32 gives a graphical display of diode resistance values for a 50Ω PI attenuator. Note that the minimum value for R_{S1} and R_{S2} is 50Ω.

In both the bridged TEE and PI attenuators, the PIN diodes are biased at two different resistance points simultaneously which must track in order to achieve proper attenuator performance. A suggested voltage controlled bias circuit for the bridged TEE circuit is shown in Figure 6-33, while another bias circuit for the PI attenuator is shown in Figure 6-34.

Distortion in PIN Diode Attenuators

Distortion may often become particularly critical in PIN attenuator circuits. This results from the use of the PIN diodes operating at high resistance values where low or even zero stored charge exists in the I-region.

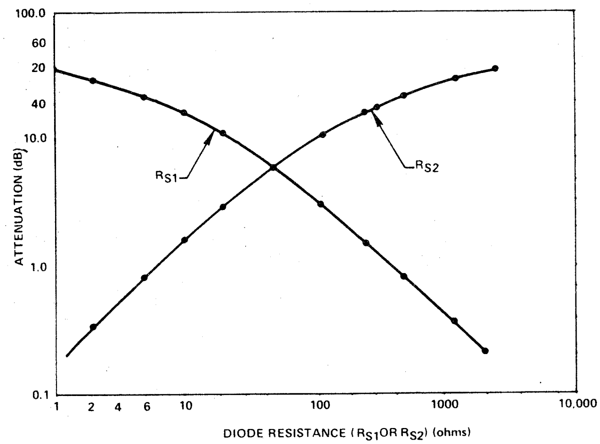


Figure 6-31 Attenuation of Bridged TEE Attenuators

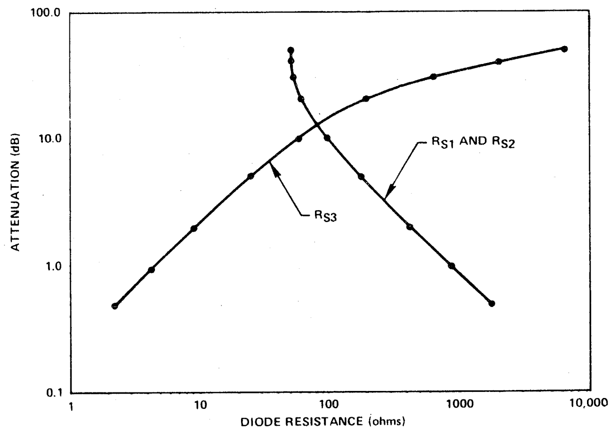


Figure 6-32 Attenuation of PI Attenuators

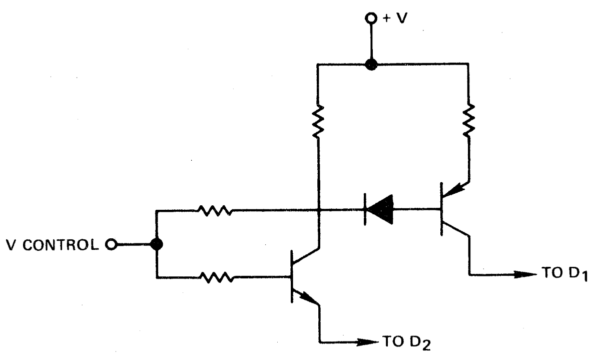


Figure 6-33 Bias Circuit for Bridged TEE Attenuator

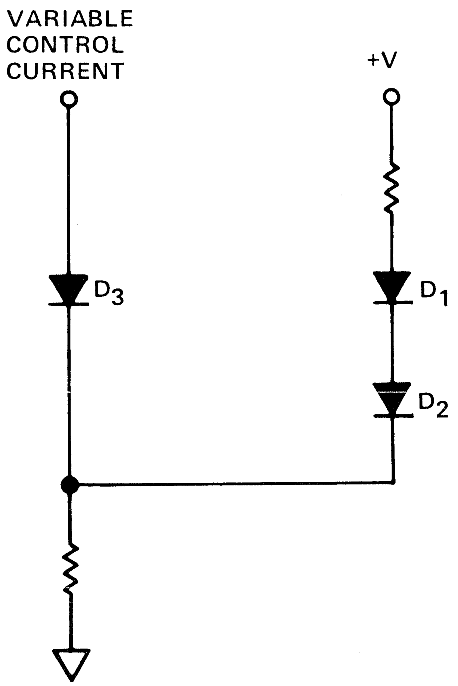


Figure 6-34 Bias Circuit for PI Attenuator

It was pointed out that, in an attenuator application, the distortion levels can always be reduced by increasing the effective I-region width of the PIN diode. This may be accomplished by using series connected PIN diodes, having thick I-region widths. Equation 13 indicated that stored charge at a fixed resistance point was theoretically only a function of W, the I-region width and not carrier lifetime. The basic distinction between a long and short lifetime PIN diode having the same I-region width is that the shorter lifetime device will require higher forward current to achieve the same resistance value. However, the resulting stored charge and the distortion generated for both diodes will be essentially the same.

The effect on stored charge by using series connected PIN diodes is demonstrated in the following example:

Consider a Unitrode UM4301B PIN diode used in an application where a resistance of 50Ω is desired. The UM4300 datasheet indicates that 1 mA is the typical diode current at which this occurs. Since the carrier lifetime specification for this diode is 5μS (minimum), the minimum stored charge for the UM4300 diode at 50Ω is 5 nC. If two UM4300 PIN diodes, however, are inserted in series, to achieve the same 50Ω resistance level, each diode must be biased at 20 mA. This results in a stored charge of 10 nC per diode or a net stored charge of 20 nC. Thus, adding a second diode in series multiplies the effective stored charge by a factor of 4. This would have a significant positive impact on reducing the distortion produced by attenuator circuits.

In some distortion sensitive attenuator applications, circuits have been developed which employ more than 10 PIN diodes in series in order to adequately reduce distortion. Obviously, this improved performance is accompanied by increased bias requirements for the multiple PIN diodes over those of a single diode. Additional improvements in distortion may also be obtained by orienting pairs of PIN diodes in a back-to-back (cathode to cathode or anode to anode) configuration. This further improvement is attributed to the cancellation effects of the generated distortion currents.

Aside from the high stored charge of series connected, thick I-region PIN diodes, these devices also have long transit time values. This is particularly important to prevent distortion induced rectification at low RF frequencies.

In the selection of PIN diodes for attenuator applications, one must be concerned with other factors beside optimizing the I-width for distortion sensitive applications.

Another major performance parameter, the dynamic range of the attenuator, depends essentially on the total resistance range of the PIN diode used. This diode resistance varies from a minimum value limited only by the maximum level of forward bias, on the one hand, to a maximum value, generally R_p, obtained at low or zero current bias. This latter value is further reduced at higher frequencies by the diode capacitance, which adds a parallel reactance.

Although all Unitrode PIN diodes are suitable for attenuator applications, the thicker I-region PIN diodes are recommended for distortion sensitive circuits. These diodes include the **UM4300, UM7300, UM4000, UM6000, UM7000, 1N5767, 1N5957 and UM9301** series.

Modulator applications use basically the same circuit configurations as attenuators. For pulsed, square-wave and linear modulators, the quadrature hybrid circuit shown in Figure 6-24 has been found most appropriate. High power modulators frequently employ studded packaged Unitrode diodes (Styles C and D) for better power handling capability.

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VII. RELIABILITY

RELIABILITY

GENERAL

All Unitrode PIN diodes are fabricated using a process which inherently results in a high-rel device. This unique manufacturing process and diode design eliminates most of the common causes of diode failures which are listed in Table 3.

Unitrode has performed reliability testing on its devices for such diverse programs as Safeguard/Sentinel, Patriot, Viking, Trident, Minuteman, Mariner, Tow, Cruise, and Poseidon. This imposing list of high reliability programs includes virtually every major military and space electronics program developed in the United States over the past two decades. A summary of the results of some typical MIL-STD-750 environmental tests on Unitrode PIN diodes are given in Table 4.

PREDICTED RELIABILITY

The predicted failure rate is often a significant design factor in the selection of a semiconductor component. Although PIN diodes are used in many RF and microwave applications, they should not be considered in the same reliability category as other high frequency semiconductors such as varactors, detectors, tunnel diodes, etc. This distinction results from the fact that most PIN diodes are constructed with comparatively much larger junction cross-sectional areas, thereby permitting an inherently more reliable device. In addition, the unique construction of the Unitrode PIN diode results in a device whose reliability is significantly better than conventionally built PIN diodes.

Operating life tests are continually performed at Unitrode, and the accumulated test data may be used to establish diode failure rates. All Unitrode diodes, including PIN diodes, are manufactured by the same fused-in-glass techniques, and on the same production lines. It follows therefore, that a single overall reliability estimate can be obtained, based upon a total accumulated 99.7 million device hours with only 3 catastrophic failures. This data results in a 0.0044% per thousand hours failure rate at a 60% confidence level, at maximum continuous rated power. The best estimate of failure rate in actual usage is 0.00037% per thousand hours.

Separate life tests on PIN diodes have accumulated approximately 500,000 device hours and resulted in no failures or degradations. In fact, no failures have ever been experienced as a result of barometric pressure (Method 1001), Hermetic Seal (Method 1071), constant acceleration (Method 2006) tests, or storage life (Methods 1031/1032).

MAJOR PROGRAM RESULTS

Extensive testing was performed by an outside agency to qualify the Unitrode PIN diode for the Missile Site Radar (MSR) phased array portion of the Safeguard Program. The diode specification called for a maximum failure rate of 0.02% per thousand hours when operated under the following stress and environmental conditions in a phase shifter design:

Junction Temperature	90 °C
Peak Power	15 kW
Frequency	S-Band
Pulse Width	120 μS
Duty Factor	0.03
Applied Reverse Voltage	250V

Using the most pessimistic data recorded during this test program, which also included diode failures induced by test equipment malfunctions, the Unitrode PIN diode performed within this reliability specification. By eliminating equipment induced failures, a more realistic calculation of the Unitrode PIN diode failure rates under these operating conditions was found to be better than 2×10^{-6} % per thousand hours.

Table 3
COMMON DIODE FAILURES ELIMINATED BY UNITRODE DESIGN

Cause of Diode Failure	Unitrode Design Feature
Whisker or ribbon-to-post connection failure. Whiskers or ribbon-to-die bond failure. Broken whiskers or ribbon. Insufficient whisker pressure.	No whisker, ribbons, or posts necessary. *Terminal pins are bonded to the die at approximately 1000°C.*
Mechanical failure of the die bond.	A uniform, true metallurgical bond takes place along both sides of the die. A fused glass seal extending beyond both sides of the die-to-pin bond gives added strength.
Lead fatigue.	Lead brazed directly to pin. Lead does not extend into the glass-to-metal seal; hence, no glass edge to cut into the lead. Lead bonding does not stress glass seal. Statistical quality-control sampling is performed to assure uniformity of braze.
Impurities in protective coating, movement and change in characteristics of coating (such as hardening or cracking), pin holes in coating.	*Glass is one of the most stable materials known.* A thick glass seal fused directly to the silicon surface eliminates the need for other protective coating.
Incomplete weld resulting in imperfect seal.	No weld is used for hermetic seal. Glass sleeve is remelted and fused around the silicon die to permanently seal and passivate the surface.
Lack of hermeticity in plastic devices.	Fused-in-glass construction.
Corrosion of diode components.	All components are inherently corrosion resistant. Material content is verified by certifications and by regular independent laboratory analyses.
Instability of paint used for light shields.	All paint cured during bakeout at 200°C.
Mismatch of thermal coefficient of expansion resulting in thermal fatigue failures.	Terminal pins, silicon and glass seal are matched for temperature coefficient of expansion. Material content verified by certifications and regular independent laboratory analyses.
Melting of eutectic compounds at temperatures that exceed diode ratings.	*Lowest melting combinations of elements is 200°C above maximum rated temperatures.*
Entrapped flakes of copper oxide, silver paste and gold, plus glass chips or other conductive or non-conductive particles.	No copper, silver paste, or gold used in device. In addition, there is absolutely no void in which particles may become entrapped. The metallurgical bond between die faces and both the terminal pins and overall fused glass seal make *Unitrode diodes void free.*
Weld splash residue contaminates junction.	No welding performed inside hermetic glass seal.
Voltage-activated ionic and molecular migrations, including electromigration of contact metals.	Migrations are restricted by virtue of the glass adhering directly to the silicon. Power-stress screening eliminates the remaining extremely small percentages of devices in which such changes occur.

Table 4
EFFECT OF ENVIRONMENTAL TESTS ON UNITRODE PIN DIODES

Test	Mil-Std-750 Method	Effect on Unitrode PIN Diodes
Barometric Pressure	1001	Void free package has never failed Mil-spec tests.
Moisture Resistance	1021	Glass seal is impervious to moisture.
Salt Atmosphere	1041 1046	No failures found to date
Temperature Cycling and Temperature Shock	1051 1056	Samples have passed +300°C to −196°C. No failures in routine testing.
Hermetic Seal	1071	No failures to date at any condition. Condition E (dye penetrant) used as a process control before painting.
Constant Acceleration	2006	No known failure modes at any G level.
Mechanical Shock	2016 2021	Will pass to limits of most test equipment.
Terminal Strength	2036	No failures to Mil-spec testing.
Vibration	2046 2056	Will pass to limits of most test equipment.
Radiographic Exam	2076	No known failure modes. One customer tested over 100,000 devices without detecting any failure.

SCREENING

Unitrode is equipped to perform a wide variety of high-rel screening procedures on its PIN diode product line. The screening requirement may be called out on the individual PIN specification or purchase order.

Unitrode recommends a screening procedure for applications where certified high-rel parts are required but specific screening conditions are not defined. This *PIN Diode Screening Specification* can be applied to any Unitrode PIN diode by adding HR201-M to the part number on the purchase order. This specification is defined in Table 5.

Table 5
PIN DIODE SCREENING SPECIFICATION (HR201-M)

This specification, when required by purchase order agreement, outlines the screening operations to which all devices shall be subjected prior to shipment.

1. *Case Integrity* — Submerge the diodes in a fluorescent dye, such as Zyglo ZL-1C, at 100 psi for one half (1/2) hour. Rinse in clear water, allow to dry and examine each device under ultra-violet light for evidence of defective seals.

2. *Thermal Fatigue* — Ten (10) cycles. Each cycle consists of a fifteen (15) minute exposure at +200°C ambient temperature followed by an immediate transfer to −65°C ambient for a fifteen (15) minute exposure. Start of the next cycle is immediate.

3. *Pre Burn-In Tests* — Reverse current shall be read and recorded for all devices in the lot. Devices will be handled and identified such that Delta End Points can be determerd in step 5.

4. *Reverse Bias Operation* — 80% of voltage rating (max. 200V) for 168 hours at 125°C. Temperature is then reduced to 25°C over a period of time not less than one (1) hour with full voltage maintained.

5. Read and record each unit for Reverse Current as in Step 3.

   Rejection Criteria: (1) Any unit that exceeds specified catalog limits.
   (2) ΔI_R ± 100% of initial value or 1 μA whichever is greater.

6. *Room Temperature Measurements* — All parameters shall be measured to ensure conformance with the appropriate specification. Any unit exceeding the specified limits or exhibiting unusual characteristics shall be removed from the lot.

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