HEWLETT PACKARD

APPLICATION NOTE 985

Achieve High Isolation in Series Applications with the Low Capacitance HPND-4005 Beam Lead PIN

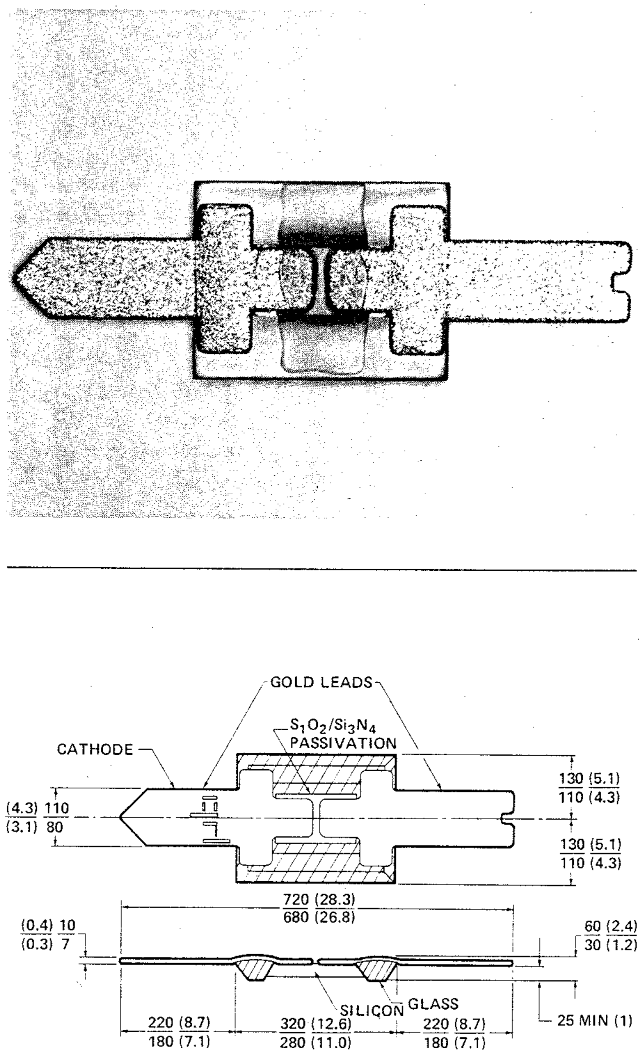
INTRODUCTION

Conventional beam lead diodes depend on a large silicon body to provide support to the fragile beam leads. The result is additional parasitics attributed to the silicon with a compromise in performance or a low capacitance diode with weak beams. The HPND-4005 beam lead PIN diode is designed to offer exceptional lead strength while achieving excellent electrical performance at microwave frequencies. This diode (shown in Figure 1) is produced by a new HP planar process which captures a minimum amount of active silicon material in a dielectric frame. This process minimizes the amount of parasitic silicon and produces a diode with a very low resistance — capacitance product, while providing on the dielectric frame large beam anchor points which increase beam strength. Typical capacitance of the HPND-4005 is 0.017 pF at a reverse bias of 10 volts and typical RF resistance is 4.7 Ohms at a forward bias of 20 mA. The diode's rugged construction features a typical pull strength of 6 grams on either lead. In addition, a polyimide surface layer is applied for scratch protection.

The HPND-4005 beam lead PIN is designed primarily for use in stripline or microstrip circuits. Applications include switching, attenuating, modulating, phase shifting, and other signal control functions at microwave frequencies in test instrumentation, communication, electronic warfare, navigational, and phased array radar systems. The extremely low capacitance and low resistance of this diode make it particularly suited for circuits requiring high isolation and low insertion loss in the series diode configuration. In this application note the capabilities of this diode as a series switching element will be demonstrated in a SPST (single pole single throw) and a SPDT (single pole double throw) circuit.

SERIES SWITCHING ANALYSIS

The simplified schematic of a series PIN SPST reflective switch is shown in Figure 2. For a first order analysis, if packaging parasitics are neglected, the forward biased PIN diode can be approximated by a resistor and the reverse biased PIN diode by a capacitor. Hence, when the switch is ON (PIN forward biased), the insertion loss is primarily determined by the resistance of the PIN diode. When the



DIMENSIONS IN μm (1/1000 INCH)

Outline

Figure 1. The HPND-4005 Beam Lead PIN Diode

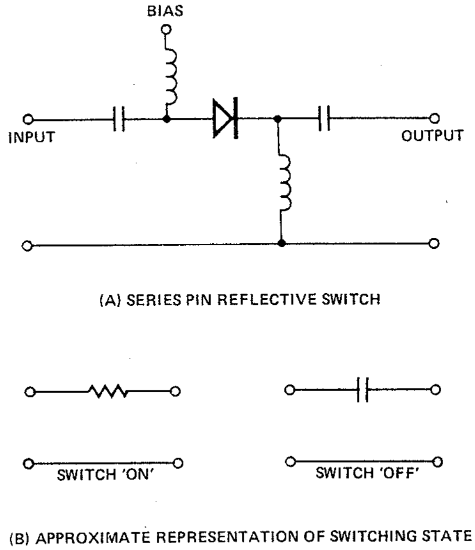


Figure 2. Simplified Schematic of Series PIN Reflective Switch and Model for "ON" and "OFF" States

switch is OFF (PIN reverse biased), the isolation is principally dependent on the capacitance of the PIN diode and the frequency of the RF signal. The approximate insertion loss and isolation that can be achieved by a PIN series switch in a 50 Ohm system can thus be easily determined from the curves or equations in Figures 3 and 4. For the series diode switch the lower the capacitance the higher is the isolation at a given frequency. On the other hand, low resistance is needed for low insertion loss. Therefore, it is apparent that the HPND-4005 beam lead PIN diode has the required low capacitance to achieve high isolation at microwave frequencies, while its resistance is also low to provide low insertion loss.

The simplified analysis above provides a quick first order approximation of series PIN switching performance, but neglects the effects of package and circuit parasitics. In practice, the effects of these parasitics may not be negligible, particularly at higher frequencies. In this case, the attenuation is given by

$$\alpha = 10 \log \left[\frac{\left(\frac{R_s}{Z_o} + 2\right)^2 + \left(\frac{X_s}{Z_o}\right)^2}{4} \right]$$

where R_s and X_s are, respectively, the series equivalent resistance and reactance of the combined impedance of the packaged diode and circuit parasitics.

SERIES SWITCHING PERFORMANCE

The actual performance of the HPND-4005 as a series switch was measured in the circuit shown in Figure 5. The circuit consisted of a 50 Ohm coplanar transmission line built on a 25 mil alumina substrate ($\epsilon_r = 10$). The conductor line and spacing dimensions were optimized with due consideration for minimum circuit parasitics. The HPND-4005 was mounted in series with the center conductor of the coplanar line.[1] The circuit was tested in a fixture (Figure 6) which provided the transition to APC-7 connectors. The measurement setup appears in Figure 7. Transmission and reflection characteristics of this series switch were observed from 2 to 18 GHz. A storage normalizer provided the means for excluding the loss contribution from circuit parasitics.

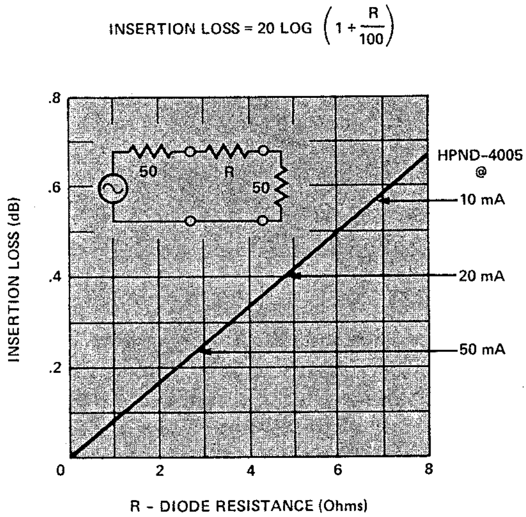


Figure 3. Approximate Insertion Loss of Series PIN Switch in 50 Ohm System

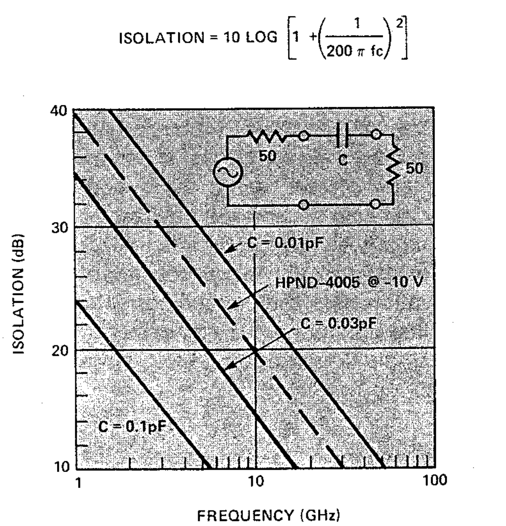


Figure 4. Approximate Isolation of Series PIN Switch in 50 Ohm System

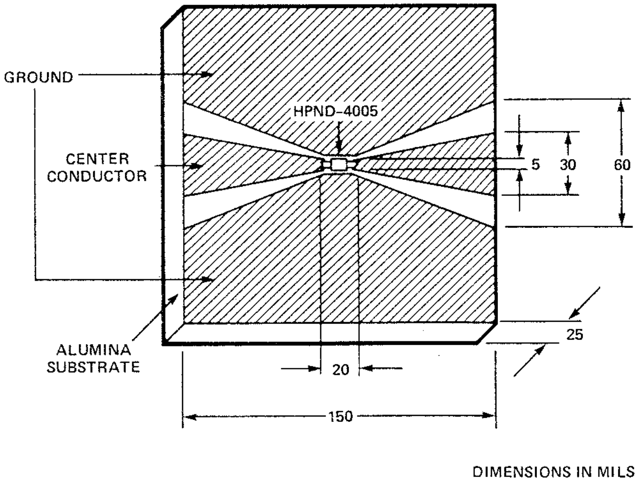


Figure 5. The HPND-4005 Series Switch on a 50 Ohm Coplanar Transmission Line Built on an Alumina Substrate

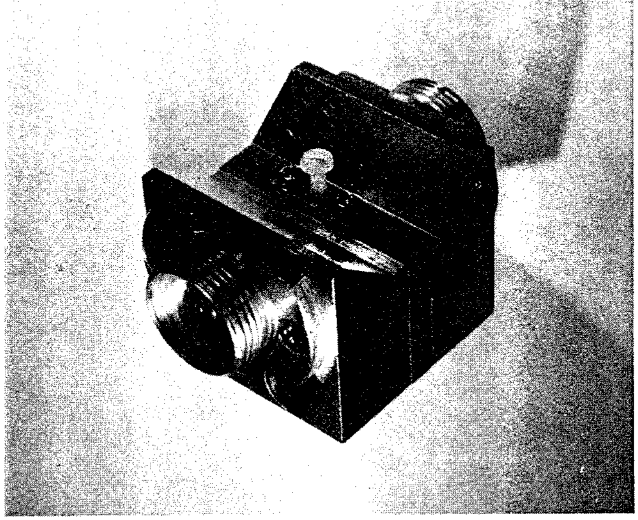


Figure 6. The Test Fixture Used to Test the HPND-4005 Series Switch Circuit

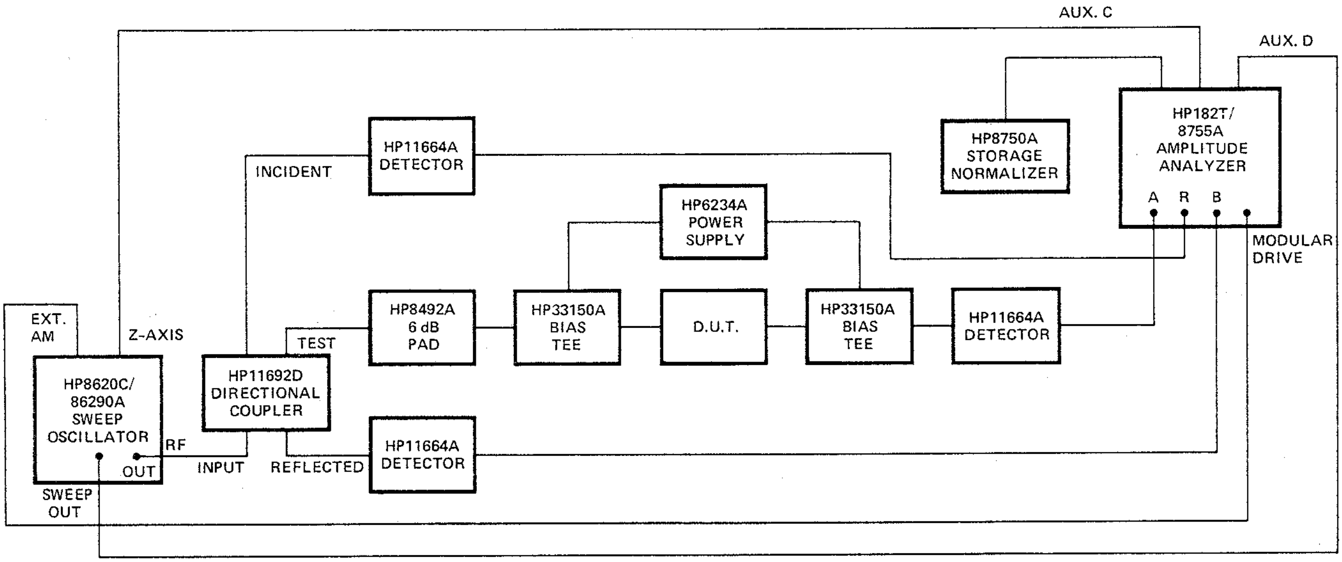
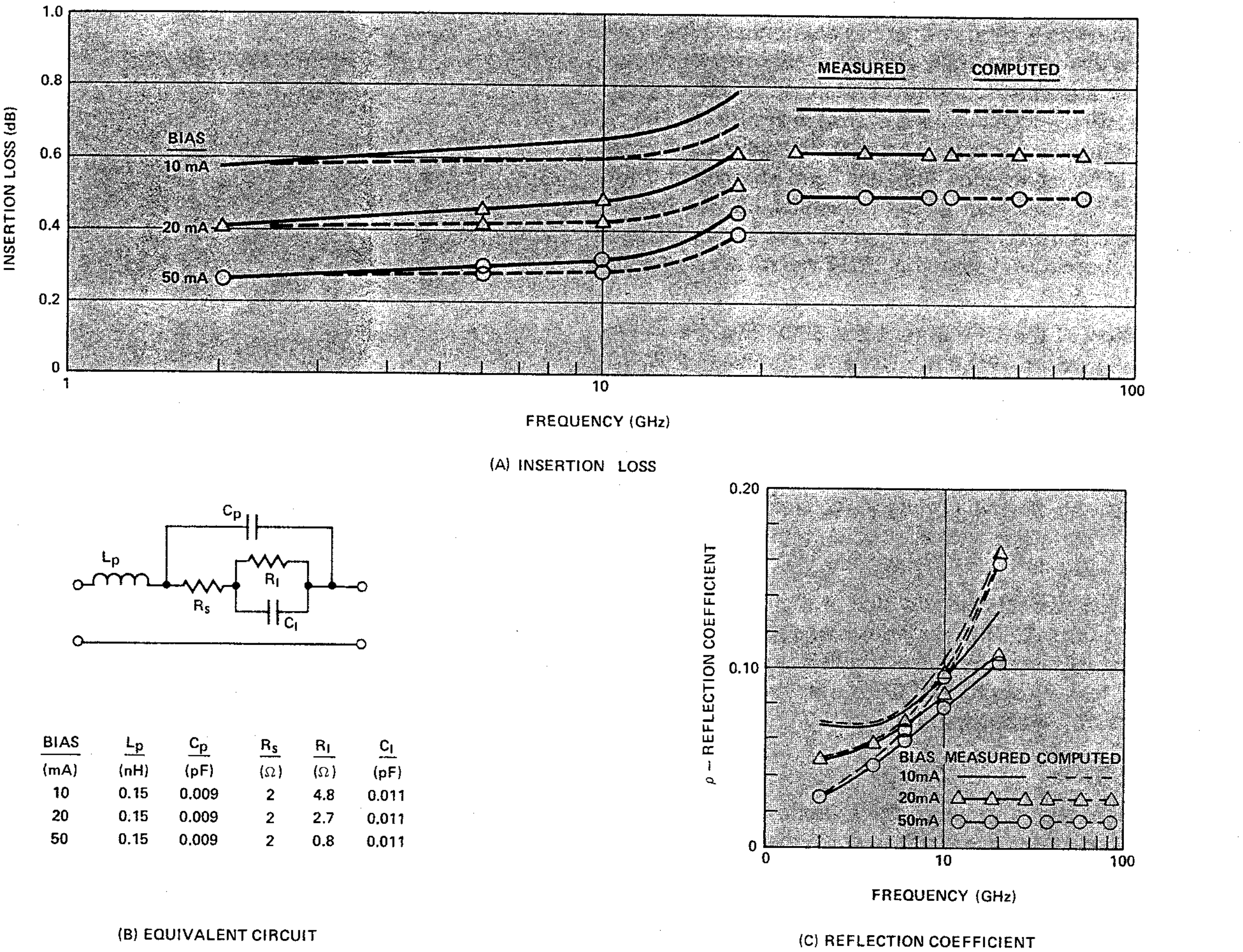


Figure 7. The Measurement Setup for the Series PIN Switch

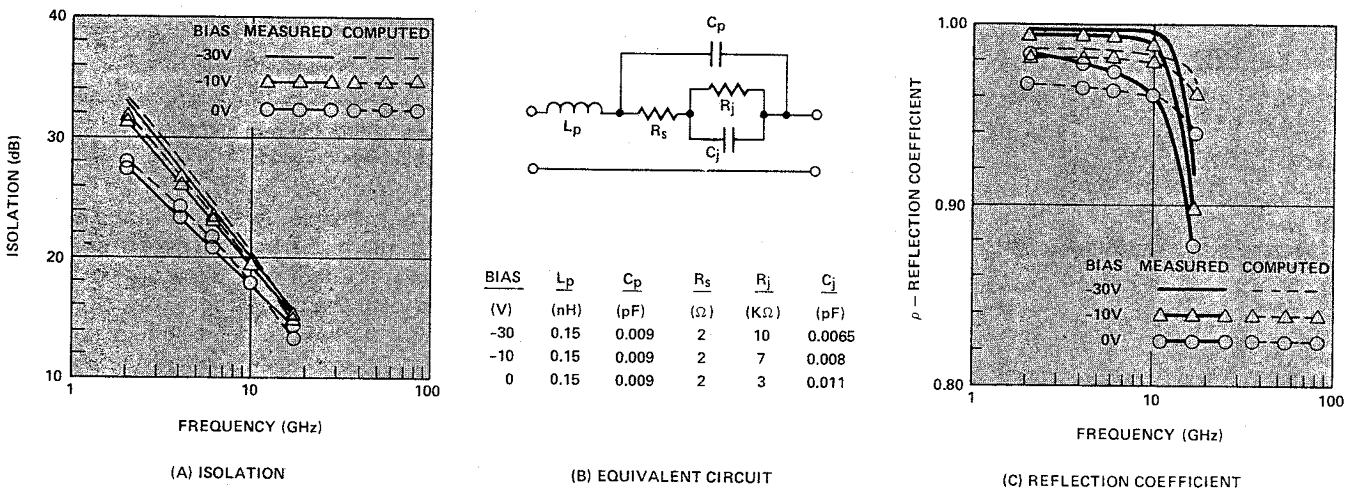
The forward biased characteristics of the switch are shown in Figure 8. Figure 8(A) shows the insertion loss based on both the measured performance of the actual circuit and the computed performance of the equivalent circuit derived with the COMPACT Network Analysis Program. The equivalent circuit is illustrated in Figure 8(B). At low frequencies the low insertion loss is attributed to the low I-layer resistance, R_I, and the low series resistance, R_S, of the substrate. The slight increase of insertion loss with frequency is due to the small contribution from package inductance, L_P. The effects of package capacitance, C_P, and I-layer capacitance, C_I, (both of which are low) on forward biased performance through Ku-Band are insignificant. The insertion loss characteristics in Figure 8(A) show very good agreement (within 0.1 dB) between the actual and equivalent circuits. The reflection characteristics shown in Figure 8(C) confirm the close agreement.



BIAS (mA)	L_p (nH)	C_p (pF)	R_s (Ω)	R_I (Ω)	C_I (pF)
10	0.15	0.009	2	4.8	0.011
20	0.15	0.009	2	2.7	0.011
50	0.15	0.009	2	0.8	0.011

(B) EQUIVALENT CIRCUIT

Figure 8. Forward Biased Characteristics of the HPND-4005 as a Series Switch



BIAS (V)	L_p (nH)	C_p (pF)	R_s (Ω)	R_j (KΩ)	C_j (pF)
-30	0.15	0.009	2	10	0.0065
-10	0.15	0.009	2	7	0.008
0	0.15	0.009	2	3	0.011

(B) EQUIVALENT CIRCUIT

Figure 9. Reverse Biased Characteristics of the HPND-4005 as a Series Switch

The reverse biased characteristics of the switch are shown in Figure 9. In Figure 9(A) are the isolation characteristics of both the actual (measured) circuit and the equivalent (computed) circuit shown in Figure 9(B). The package capacitance (C_p), junction capacitance (C_j), and junction resistance (R_j) are the dominant parameters in determining isolation performance. In particular, the low capacitance of the HPND-4005 is responsible for the high isolation. The effects of the package inductance (L_p) and series resistance (R_s) of the substrate are virtually negligible. The close agreement ($\leq$ 1 dB) between the actual and equivalent circuits is apparent in the isolation characteristics of Figure 9(A) and confirmed in the reflection characteristics of Figure 9(C).

SPDT SWITCHING

Its capabilities as a series switching element and its small size make the HPND-4005 attractive for hybrid circuit applications such as multi-throw switching. A SPDT switch using two HPND-4005 diodes is shown in Figure 10. The 50 Ohm microstrip circuit is built on a 10 mil alumina substrate ($\epsilon_r = 10$). The conductor line and gap dimensions are determined for minimum circuit parasitics, i.e., the largest gap possible is used to minimize gap capacitance.[1,2] Performance characteristics of the SPDT switch are shown in Figures 11 and 12.

The isolation of the OFF arm of the SPDT switch is illustrated in Figure 11. When the ON arm is unbiased (0 mA) the isolation of the OFF arm (with reverse bias of 0 or -10 volts) is essentially identical to that of the single diode series switch. With the application of 10 mA of forward bias to the ON arm, the isolation of the OFF arm increases by 6 dB as expected. Under this condition the isolation of the OFF arm (with reverse bias of 0 or -10 volts) is greater than 20 dB through Ku-Band.

The insertion loss of the ON arm of the SPDT switch is shown in Figure 12. There is little deviation from the insertion loss characteristics of the single diode series switch. The shunt loss through the OFF diode is obviously trivial because of its low capacitance.

CONCLUSION

Low capacitance is required for a diode to achieve high isolation in the series configuration. On the other hand, low resistance is needed for low insertion loss. This combination of characteristics in the HPND-4005 beam lead PIN diode makes it well suited for series switching applications. Particular advantage can be gained in the case of a SPDT switch, where added isolation can be achieved without sacrificing insertion loss. The diode's small size but rugged construction, offering exceptional lead strength for high assembly yields and protection against external abuse, allows this beam lead diode to be used in a wide variety of signal control applications, including switching, attenuating, modulating, and phase shifting. The equivalent circuits derived in this note would be useful in the design of circuits for these applications.

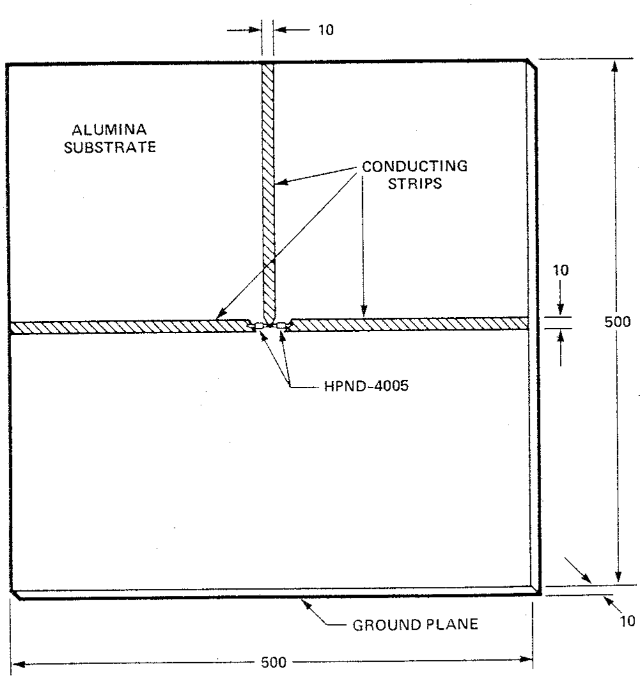


Figure 10. The SPDT Switch Using Two HPND-4005 Beam Lead PIN Diodes on a 50 Ohm Microstrip Circuit Built on an Alumina Substrate.

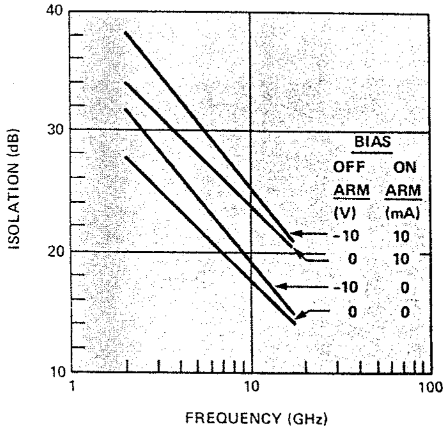


Figure 11. Isolation of the OFF Arm of the SPDT Switch Using HPND-4005 Beam Lead PIN Diodes

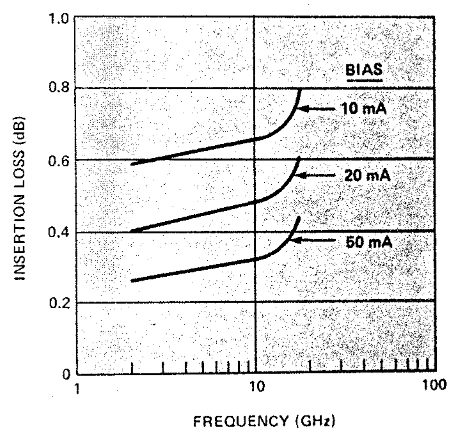


Figure 12. Insertion Loss of the ON Arm of the SPDT Switch Using HPND-4005 Beam Lead PIN Diodes

Notes:

1. Application Note 979 describes the equipment and techniques that can be used to facilitate the handling and bonding of beam lead devices. Proper mounting will result in minimum overall parasitics.
2. Microwave Engineers' Handbook, Volume 1, published by Artech House, Inc., shows Gap Capacitance vs. Gap Spacing for Strip Transmission Lines on page 144.

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