V-5. A LOW-LOSS 1-NANOSECOND 1-WATT X-BAND SWITCH

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This paper discusses the operation of fast, moderate power microwave switches obtained through the utilization of PIN diodes.

A typical PIN doping profile is displayed in Fig. 1, and its general equivalent circuit in Fig. 2a. Under a steady state forward bias (conducting state) both holes and electrons populate the I region giving rise to a low resistance, space-charge-neutral plasma with the effective microwave equivalent circuit of Fig. 2b where R_s is a small parasitic resistance essentially independent of bias current for high forward current. Under a high steady state reverse bias (non-conducting state) the I region is swept free of charge and the diode's microwave impedance becomes predominantly reactive with the equivalent circuit of Fig. 2c. R_s' is a small parasitic resistance of the order of R_s. C_j is essentially independent of bias voltage, for large reverse bias. This variability from essentially a short circuit to a large reactance under different biasing conditions, allows PIN diodes to function as microwave switching elements.

The packaged PIN diode is mounted between the broad faces of reduced height (0.050") X-band waveguide. A short length of 43 ohms impedance coaxial line is fabricated in series with the diode and incorporated within one of the waveguide walls. A trapping arrangement is employed at the other diode terminal which allows the introduction of short bias pulses from external sources but contains the microwave energy.

The complete (first order) microwave equivalent circuit for this configuration is displayed in Fig. 3a, where L_{stub} is the inductance of the short length of coaxial line, L_{pkg} the capacitance associated with the package and R_H a small resistance, ~0.1 ohm, associated with the holder. For the forward and reverse bias states this simplifies to the forms shown in 3b and 3c where R_T includes both diode and holder losses, and $C'_{pkg} = C_{pkg} + \frac{C_j}{1-C_j\omega^2 L_{pkg}}$: For appropriately small C_j, $C'_{pkg} \approx C_{pkg}$ and the equivalent circuit is independent of the diode's junction capacitance. For the band reject case, L_{stub} and C'_{pkg} are series resonant, yielding a transmission loss T of

$$T = \frac{1}{4}\left[2 + \frac{Z_o}{R_T + j\left(\omega L_{stub} - \frac{1}{\omega C_{pkg}}\right)}\right]$$

For the band pass case R_s introduces a small loss on the order of 0.1 db with another 0.2 db associated with transformers from full to reduced height waveguide. Typical steady state band pass and band reject transmission curves are displayed in Fig. (4).

Planar epitaxial diodes with a 3000 Gc cutoff frequency (provided by L. P. Marinaccio of Bell Telephone Laboratories) gave reproducible operation ranging from 0.4×10^{-9} sec pulse capability at the 1 milliwatt level to 1.0×10^{-9} sec at the 1 watt level. Band pass insertion losses were typically less than 0.3 db with a peak isolation of 22 db. Required bias levels and pulse drive vary of course with the desired switching performance. The low loss one watt one nanosecond operation required 30 volts reverse bias and a 35 volt 0.9 nanosecond pulse. Thinner diodes operating at reduced power levels have produced nanosecond switching with reverse bias levels as low as 5 volts and correspondingly reduced bias pulses. The incorporation of a second diode spaced 3/4 wavelength doubled the peak isolation (in db) at the small expense of an additional 0.1 db band pass loss. A typical sampling oscilloscope presentation of the detected RF power of a 1 nanosecond 1 watt RF pulse is displayed in Fig. 5 where the horizontal scale is 1×10^{-9} sec per major division.

This switching performance is unique in (a) its low loss, (b) its insensitivity to junction parameters, and (c) its incorporation of "thin" PIN diodes having switching speeds at least one order of magnitude faster than those previously reported for this type diode.

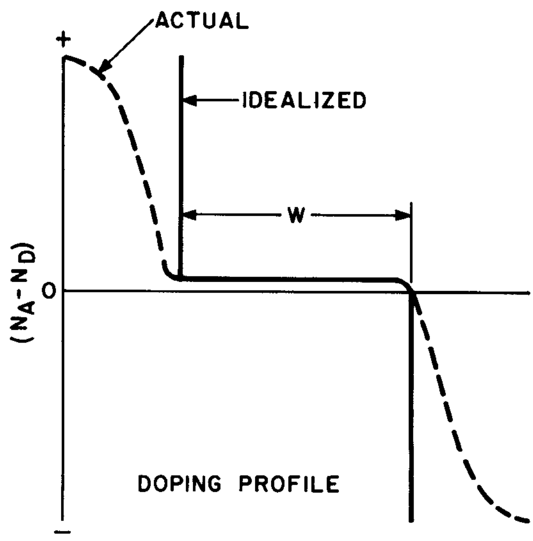

Figure 1. Doping Profile of Typical PIN Diode

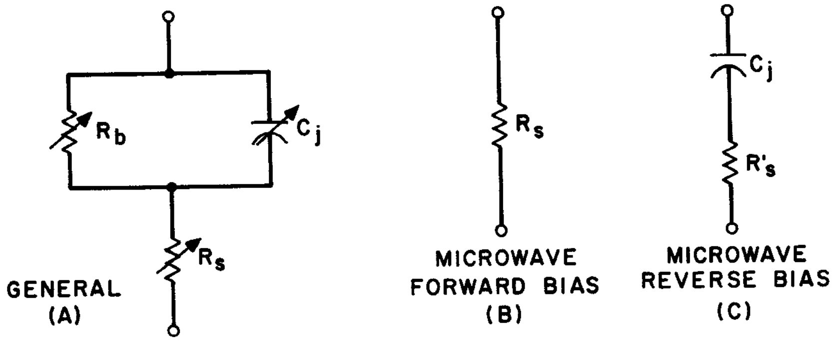

Figure 2. Equivalent Circuits of PIN Diodes

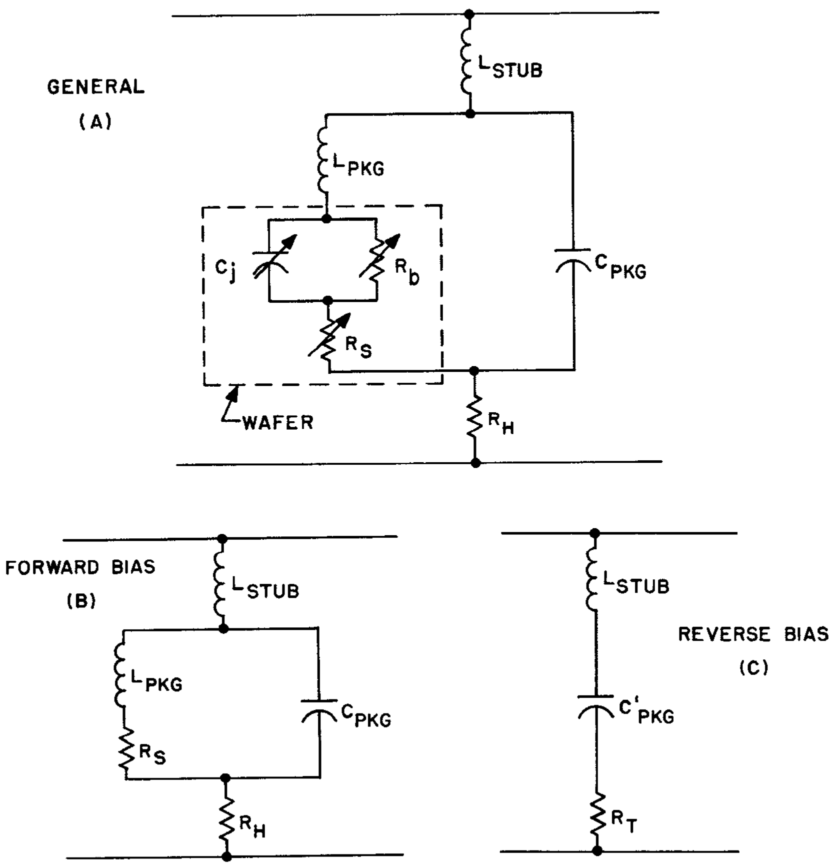

Figure 3. Equivalent Circuit of PIN Switch

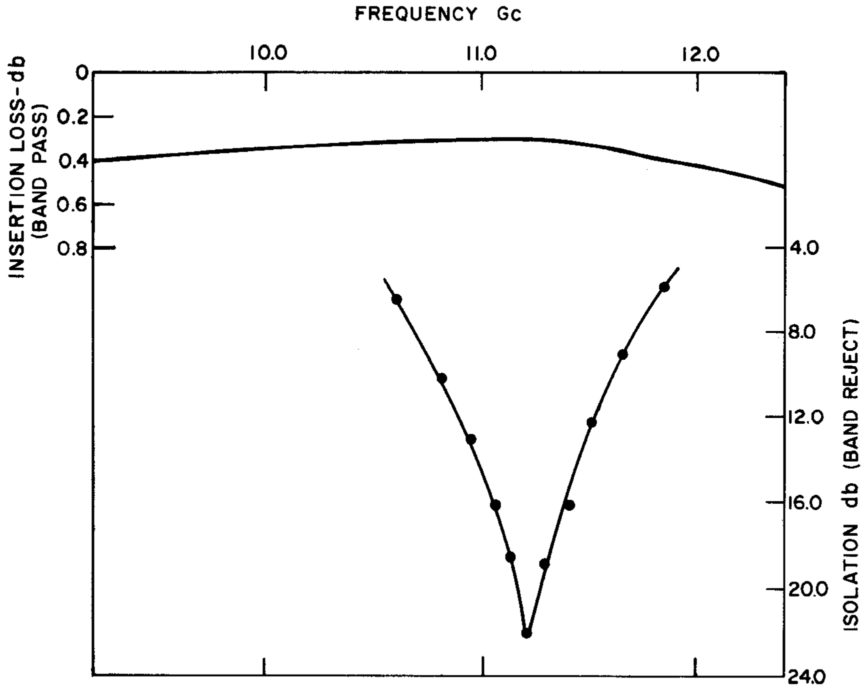

Figure 4. Steady State Performance of PIN Diode Switch

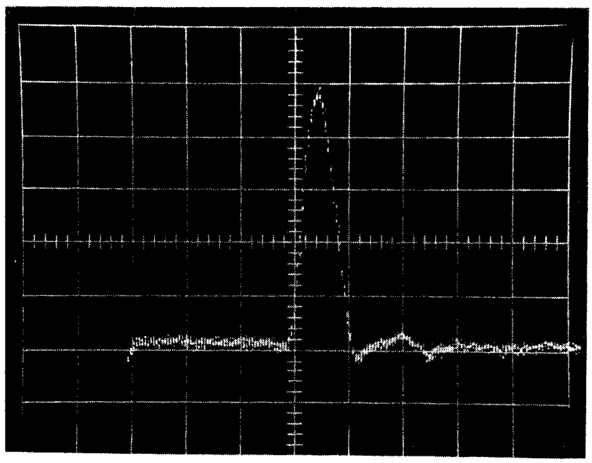

Figure 5. Pulsed Operation of PIN Diode Switch