SWITCHING PERFORMANCE OF MM-WAVE PIN DIODES FOR ULTRA HIGH DATA RATES

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ABSTRACT

The 300 Mb/s switching performance of 40 to 110 GHz PIN diodes is presented as a function of their storage and fall time, which varied from 2 to 18 and 0.2 to 1.2 ns, respectively.

PIN millimeter-wave switching diodes were developed for operation in a two phase path-length modulator,[1] over the frequency range 40-110 GHz. We investigated the effect of diode stored charge and switching speed on modulator output. At high data rates, these factors cause timing effects significant in comparison to the baud period. A baud rate of 300 Mb/s was used.

Thin, high resistivity silicon epitaxy was grown on heavily doped substrates. Diodes were fabricated from both n- and p-type epitaxy. The diode junction capacitance at -10V typically ranged from 0.015 to 0.04 pF by varying the junction diameter.

The n-type epitaxial diodes were beam-leaded (substrate only) and bonded on a gold-plated copper base - Figure 1. A gold ribbon connects the oxide-nitride passivated mesa junction to the metallized top of an adjacent quartz standoff (~0.014 pF - parasitic capacitance). The p-type epitaxial diodes were unpassivated chips bonded inside a centered hermetically sealed quartz package (~0.08 pF-parasitic capacitance). The same base was used for both types of diodes.

The forward to reverse switching transient of the diodes was characterized in terms of a storage time, T_S, and a fall time, T_F. The drive condition was $I_F = I_R = 10$ mA, where I_F and I_R are the forward and reverse current, respectively. For this measurement the diode is placed in series to the center conductor of a coaxial line.

In the path-length modulator, the diode terminates a coaxial line which couples into the waveguide - Figure 2. Bias is applied to the diode with the coaxial center conductor which passes through the waveguide to contact the standoff or the hermetic package. To achieve phase modulation a driver circuit switches the diode between forward and reverse bias. In one bias state the mm-wave signal is reflected by the switch; in the other bias state the signal passes through the switch and is reflected by an adjustable short behind the switch position. Each diode was tuned individually to provide equal amplitude, but a 180° phase difference between bias states. For a given frequency, the lateral coaxial position, L_1, and the diode position, L_2, were kept constant and all the tuning was done with the bias filter position, L_3, and the short position, L_4.

The schematic eye diagrams of Figure 3 illustrate the switching behavior resulting from the application of a pseudorandom data stream to the input of the driver circuit. The reverse to forward switching (R to F) follows a single path, while the multipath forward to reverse switching (F to R) introduces a timing jitter, T_J. T_J is due to the difference in the amount of stored charge which is built up in the I layer depending on the number of baud periods the diode spent in the forward bias state prior to the reverse switching.

Upon application of a reverse drive the diode switching behavior in the circuit exhibits two distinct time intervals: a) a delay time during which the majority of the previously injected charge is removed from the I region and b) a switching time T_{FR} during which the residual charge is removed and, most importantly, the diode switches from a low forward to a high reverse bias impedance state.[2] Any variation in delay time leads to a spread in the pattern of the reverse transient and manifests itself as the timing jitter, T_J. During the delay time the drive signal stays close to zero, although it would be already strongly negative if no diode were connected.

As a consequence of the delay time, a timing error ε_T is introduced in both the mm-wave amplitude and phase-Figure 3. The extreme values of this error are ε_{T1} and ε_{T2}. The timing error can be minimized by a correction of the driver. The driver is adjusted such that the reverse drive does not start an integer number of baud periods after the forward drive, but rather starts $(\varepsilon_{T1} \pm \varepsilon_{T2})/2$ earlier. Then the error becomes a minimum

$$\varepsilon_T = \pm T_J/2.$$

This is shown by the dotted curves in Figures 3a and 3c.

The losses during the switching transients, visible in the deep amplitude dips, indicate that the transients are close to resistive. This was confirmed in a more elaborate transient study.[3] A resistive switching path is very desirable in many systems because it permits relaxation of transient and error timing requirements.

A sample of diodes with a range of about 2 to 18 ns in T_S and 0.2 to 1.2 ns in T_F was selected to determine the timing quantities T_J, T_{FR}, and T_{RF} (FR-forward to reverse transient, RF-vice versa) at 300 Mb/s.

Figure 4 shows the dependence of T_J upon T_S for three current values of the forward bias state. The charge storage effect becomes clearly more pronounced with increasing forward bias. An independent estimation of T_S can be made by measuring the average diode current upon application of a pseudorandom bias output from the driver. We found the average diode current to decrease in a well behaved manner as a function of increasing T_S. The dependence exists because less charge is lost through internal recombination in the diode as T_S increases.

Figure 5 shows T_{RF} and T_{FR} as a function of the diode switching time T_F. As expected, the dependence of T_{RF} on T_F is not as well defined since the diode turn-on mechanism is somewhat different from turn-off. All measurements were made at 81% of the mm-wave power.

In Figure 4 and Figure 5 the times T_S, T_F, T_J, T_{RF} and T_{FR} are also normalized to the baud period T in order to permit the measurements performed at 300 Mb/s to be related to other data rates.

All the measured results depend on the particular driver which is used. More specifically, for T_{RF} a forward drive overshoot is quite important and was introduced to shorten T_{RF}. For the delay time and T_{FR} the maximum available reverse drive discharge current is critical. It was 90 mA in our driver.

The power handling capability of the modulator was also tested at 10 mA forward and 10V reverse diode bias. No significant change in performance was found up to 250 mW, the maximum available power.

Figure 6 shows the measured modulator output with $T_{RF} \simeq .45$ ns, $T_{FR} \simeq .4$ ns and $|\varepsilon_T| < .15$ ns. In Figure 6a we see the earlier start of the reverse drive. As a consequence the timing is optimized and the eye width is maximized as can be seen in Figures 6b and 6c.

Additional measurements at 55, 80 and 108 GHz of diodes with the same T_S and T_F resulted in practically identical switching transients.

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[1] W. J. Clemetson, et al., "An Experimental MM-Wave Path Length Modulator, "BSTJ, Vol. 50, No. 9, Nov. 1971, pp. 2917-2945.

[2] O. G. Petersen, et al., "Numerical Method for the Solution of the Transient Behavior of Bipolar Semiconductor Devices," Solid State Electronics, Vol. 16, 1973, pp. 239-251.

[3] F. Bosch and S. S. Cheng, "Direct Polar Display of Subnanosecond MM-Wave Switching Transients at 300 Mb/s," to be published in IEEE Transactions on MTT.

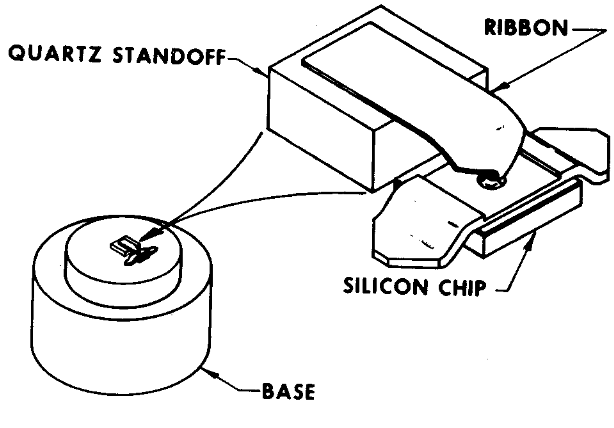

Figure 1 - MM-Wave PIN switching diode.

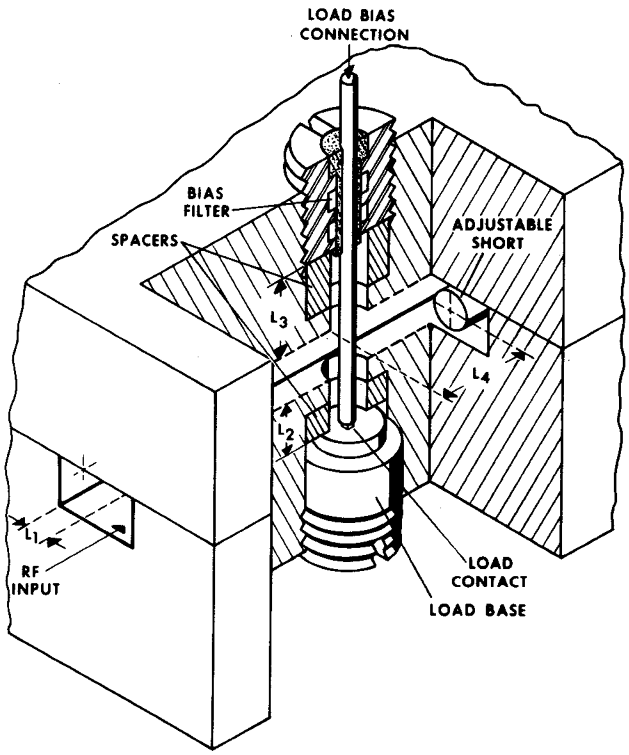

Figure 2 - Waveguide switch with coaxial diode mount.

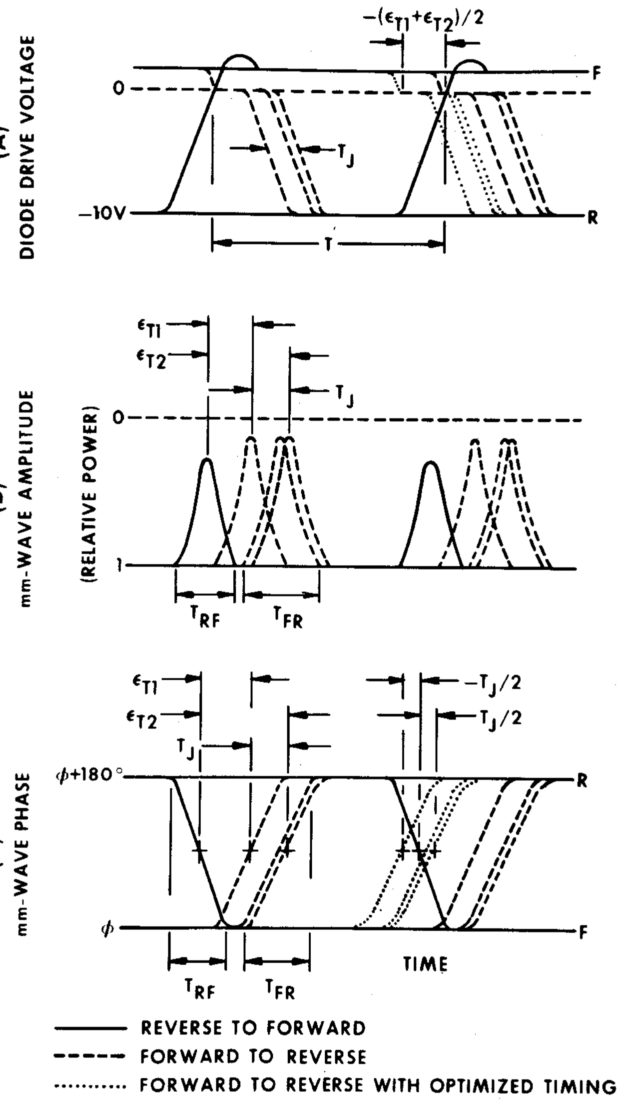

Figure 3 - Schematic switching behavior as a function of time: a) drive voltage, b) amplitude, c) phase.

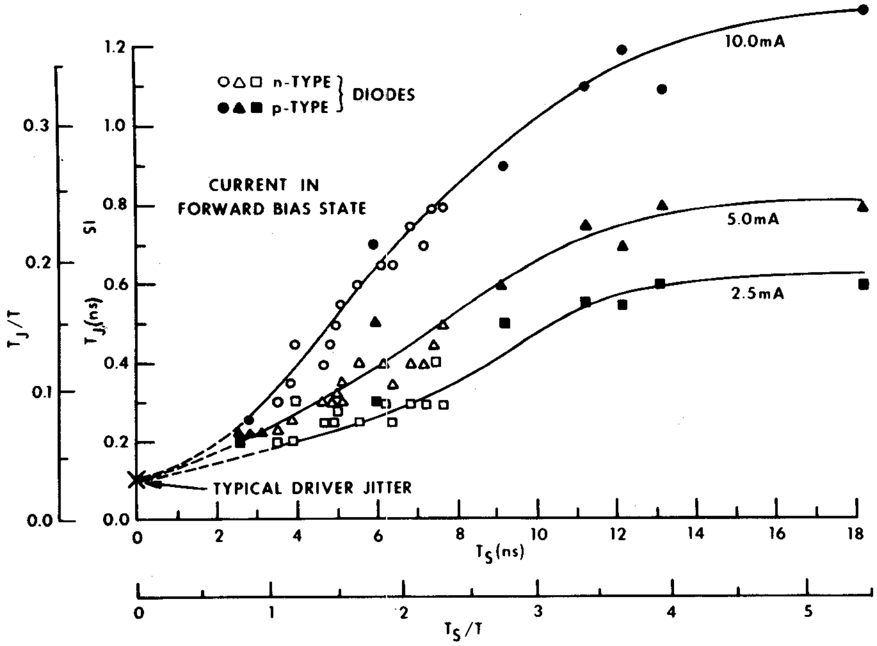

Figure 4 - Timing jitter as a function of diode storage time for various currents of the forward bias state.

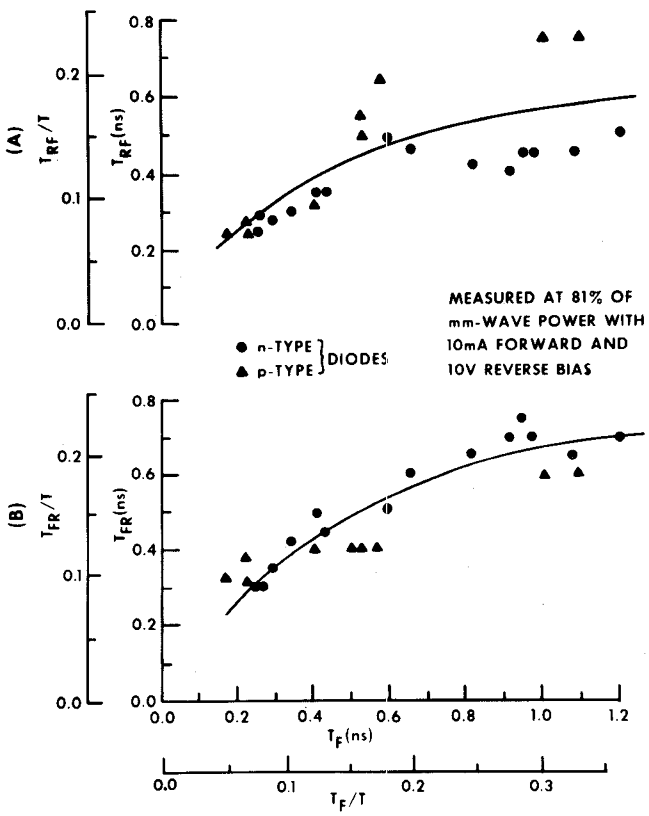

Figure 5 - Transient times as a function of diode fall time a) T_{RF}-Reverse to forward transient b) T_{FR}-Forward to reverse transient.

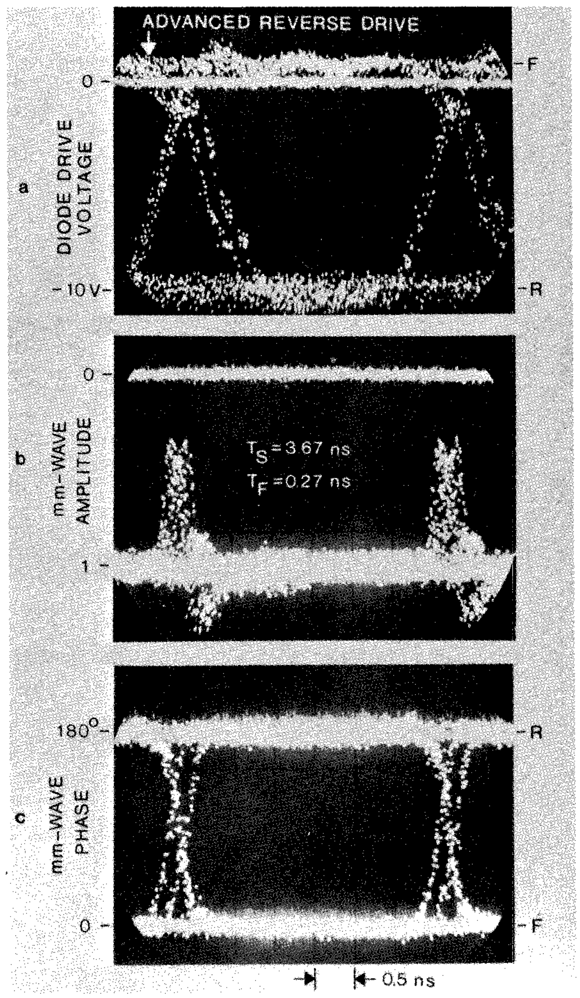

Figure 6 - Modulator performance with optimized timing.