PIN DIODE LIMITER SPIKE LEAKAGE, RECOVERY TIME, AND DAMAGE

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ABSTRACT

A predominantly experimental study was performed on PIN diode limiter spike leakage, and some preliminary recovery time and damage level results are discussed. Dependencies on the thickness of the intrinsic region (0.5 to 10 um) and input power at X-band are given.

INTRODUCTION

Pin diode limiters are used to protect sensitive receiver components from internal transients (such as transmit/receive switch spike leakage) and nearby sources (such as radars that may sweep through the main beam of the receiving antenna). As shown in figure 1, spike leakage is the turn-on transient of rf energy that passes through the limiter before limiting begins. PIN diode limiters are widely used because they can be directly integrated into microstrip circuits and because they can respond "instantly" to transients, thus eliminating very short transients that may damage a mixer or a sensitive low noise amplifier. But the PIN diode as a limiter has limitations of its own, which have not been thoroughly explored.

When a PIN diode limiter is made with a short enough intrinsic region (I-region), the plateau is limited to 10 mW and there is no detectable spike leakage. But in order to handle more power and to reduce the capacitance of the PIN junction, diodes with thicker I-regions are preferred. As pulse power increases to a limiter with a thick I-region, the plateau raises above 10 mW and the limiter begins to exhibit spike leakage. Since a PIN diode limiter also takes time to recover from its isolation state, the sensitivity of the receiver is reduced until this recovery takes place.

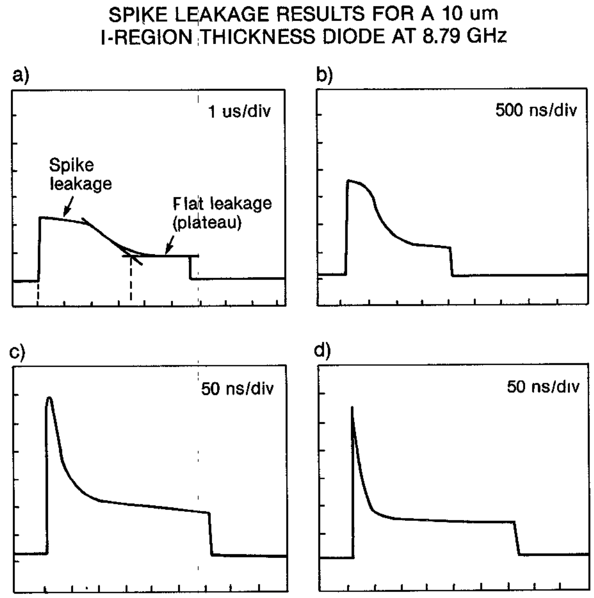

Figure 1. Spike leakage results of a 10 um diode at 4 different input power levels.

a) Input 23.1 W Spike 8.7 W Duration 3.5 us Plateau 2.3 W	b) Input 49.3 W Spike 16.1 W Duration 750 ns Plateau 3.6 W
c) Input 257.3 W Spike 59.1 W Duration 60 ns Plateau 13.2 W	d) Input 497.9 W Spike 105.5 W Duration 40 ns Plateau 15.7 W

The damage level of the PIN diode is a function of the I-region thickness, but the exact mechanism has not been published. The diode also has a finite single-pulse damage threshold, which has not been addressed in the specifications of commercial products. It is desirable to optimize the spike leakage and damage level properties.

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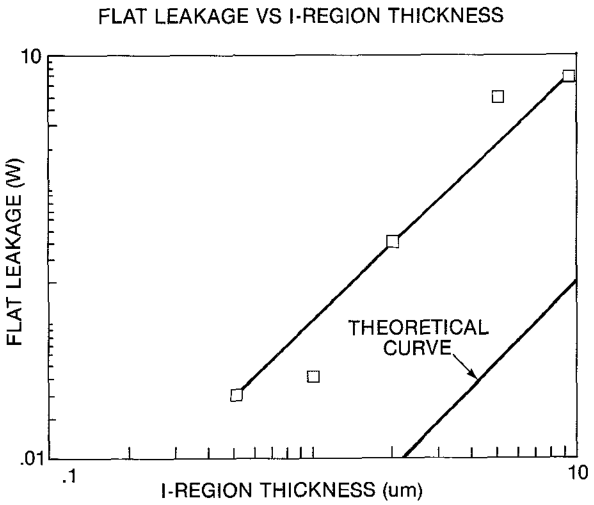

Figure 2. Comparison of measured I-region thickness vs. flat leakage with Leenov's theory shows qualitative agreement.

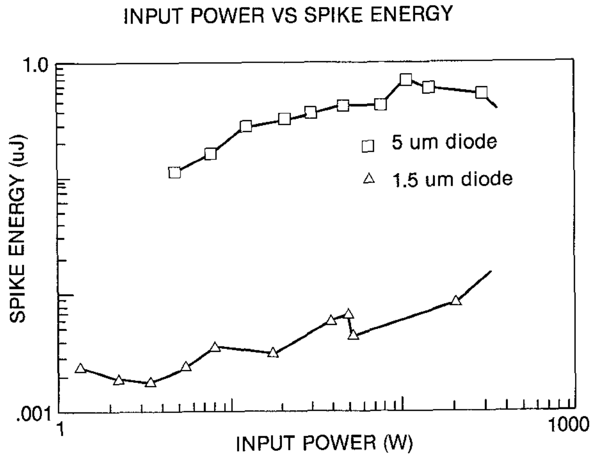

Figure 3. The spike energy as a function of input power for 1.5 um and 5 um I-region thickness diodes shows that the energy in the spike increases 1 decade for a 3 decade increase in power.

This paper gives spike leakage measurements at X-band of PIN diodes with I-region thicknesses from 0.5 to 10 um. Preliminary recovery time and damage measurements are also discussed. The effect of varying input power (up to 800 W) and I-region thickness on the turn-on (spike leakage) transient is studied. The rf turn-on is also compared to dc turn-on time. Two-diode limiters containing diodes with different I-region thicknesses are suggested to reduce spike leakage and limiter burnout.

FLAT LEAKAGE

PIN diode flat leakage is compared to theory developed by D. Leenov (1) which gives the RF resistance of a PIN diode as

$$R = \frac{h}{B}\left(\frac{wZ}{DP}\right)^{1/2}$$

where h is the I-region thickness in cm; B = q/KT; D is the diffusion coefficient (15.6 cm/s); and P is the incident power. R. Garver (2) plotted this for a 50-ohm shunt limiter in terms of flat leakage vs. I-region thickness. After some manipulations,

$$\text{flat leakage power} = \frac{4h^2 w}{B^2 DZ}$$

Leenov's theory neglects all package parasitics. The package inductance will tend to limit the amount of isolation given by the limiter. The theoretical curve is compared to data taken and there is qualitative agreement as seen in figure 2.

SPIKE LEAKAGE

As the input pulse power to a limiter with a thick PIN diode is increased, the peak amplitude of the spike leakage past the limiter increases while the duration of the spike decreases. Figure 1 is a typical example of this change in spike leakage as the input power is increased (the risetime of the rf input is 1.5ns). The width of the spike is determined graphically by the point where the straight-line projection of the falling edge of the spike intersects the straight-line projection of the flat leakage as shown in figure 1(a).

The energy in the spike leakage increases only one decade for a three-decade increase of input power (see figure 3). This indicates that the energy in the spike leakage can be estimated based on the I-region thickness. The larger the I-region thickness, the more energy will bypass the limiter in the form of spike leakage. Figure 4 is a plot of the spike leakage energy versus the I-region thickness taken at 10 W.

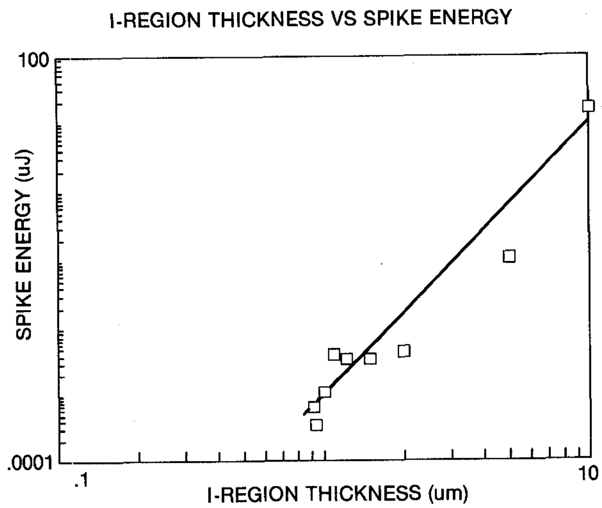

Figure 4. Spike energy increases as the I-region thickness is increased. This data was taken at X-band with a 10 W input power.

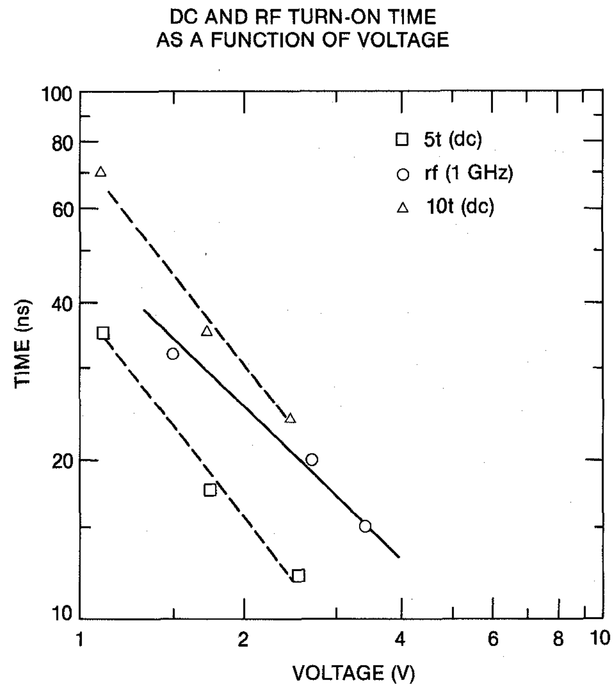

Figure 5. Comparison of dc and rf turn-on times as a function of voltage. The applied rf voltage plotted is the root mean square of the maximum voltage.

RECOVERY TIME

Following the application of an 800 W limiting power pulse, recovery time was measured on PIN diode limiters covering a range of I-region thicknesses and input power levels. The recovery time was undetectible for an HP-37711A limiter (<20 ns). The 1-through 10-um diodes recovered within 3 dB of the low loss in less than 20 ns.

A more sophisticated method is needed for measuring fast recoveries, perhaps using fast diode switches ahead of the detector to prevent the limiting power pulse from obscuring the recovery measurements.

DAMAGE THRESHOLD

Preliminary measurements of PIN diode limiter single-pulse damage showed three different stages of degradation.

(1) At the lowest power level, the effect is to lower the reverse breakdown voltage of the PIN diode, while there is no obvious degradation of the insertion loss and/or the isolation of the limiter.

(2) As the pulse power is increased, the insertion loss of the junction at low power levels begins to increase, but the diode continues to operate as a limiter.

(3) At the highest power levels, the junction finally vaporizes, and the diode becomes an open circuit, giving low insertion loss, but no limiting (isolation).

A general trend in the data shows that PIN diodes with thicker I-regions have higher damage levels.

DC PULSE MEASUREMENTS

Concurrent studies have complemented and augmented the microwave experimental results. A particularly interesting result shows that the turn-on times for a PIN diode excited with rf power are approximately a constant multiple of the step voltage (dc) turn-on time. Experimental results that verify this prediction are shown in figure 5 for a 5-um diode excited with 1-GHz rf power. Since both calculations and experiments with dc are simpler, this result allows PIN limiter performance at rf to be estimated from dc measurements.

CONCLUSION

These measurements and analyses provide new data for subsystem and component designers faced with preventing rf burnout. The spike leakage in PIN diode limiters has several important characteristics. First, because the PIN diode limiter has low insertion loss during the turn-on time, the spike leakage can have voltage peaks as great as the incoming rf pulse. This is important if the limiter is to be used to protect devices that are damaged by high peak voltages. Second, the energy in spike leakage is a function of I-region thickness as shown in figure 4. For low spike leakage energy, a thin PIN diode is needed. For high damage levels, a thick PIN diode is needed. A diode with a thicker I-region can be used to handle the high power level, and a diode with a thinner I-region can be used to remove the spike that bypassed the thicker I-region diode. Recovery time and damage threshold experiments are ongoing. Correlation of the spike leakage and recovery time measurements with the HDL "DIODE" analysis program is continuing.

REFERENCES

(1) D. Leenov, "The Silicon PIN Diode as a Microwave Radar Protector at Megawatt Levels," IEEE Transactions on Electronic Devices, vol. ED-11, pp. 53-61, Feb. 1964.

(2) R. Garver, "Microwave Diode Control Devices," Artech House,Inc.,1976.