RECTIFIED RF FOR HIGH POWER PIN DUPLEXING

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Abstract

Thin PIN diodes, loosely coupled to the main line, generate bias currents capable of driving high power PIN diodes in a low insertion loss duplexer with a capability greater than 300 kw peak - 5 kw average.

Introduction

Brown[1] presented experimental data that described the frequency at which a PIN diode could be used as a high power limiter diode. Garver[2] observed that this data fits a straight line when plotted on a log-log axis. The data shows that i-layer widths of 25 um can be used at frequencies up to about 200 MHz and 2.5 um at frequencies up to 10,000 MHz.

Brown[1] described a limiter with 31-12 um PIN diodes and a passive balanced duplexer with 16-25 um PIN diodes in each channel. Both devices exhibited an insertion loss of 2.0 dB at 225 MHz. When the circuit was retuned to 450 MHz, insertion loss increased to 3.5 dB. Brown's results are summarized in the first four columns of Table 1.

A passive technique which allows duplexing and limiting at moderate power levels and with reasonable values of insertion loss at frequencies well above 450 MHz has been described which employs point contact or Schottky-Barrier detector diodes[2-5]. A rectified current obtained by loosely coupling the detector diode to the main line is used to bias the high power PIN diode. In this paper we present a self-bias technique that extends the frequency limits at which low insertion loss, high power limiters can be built.

TABLE 1

HIGH POWER LIMITER RESULTS

Frequency-MHz	225	300	450	225	450
i-Layer Width-um	12	12	12	25	50
No Diodes/Channel	31	31	31	16	4
Total Cjo/Channel-pf				32	8
Insertion Loss-dB	2.0	2.5	3.5	2.0	.75
Duplexer Power					
Peak-kw		1000		150	300
Average-kw		2		10	5
Pulse Width-us		4		200	60
Spike Leakage-mW					60

Self-Bias Diode Considerations

Use of Schottky-Barrier or point contact detector diodes is restricted because of a maximum rectified current capability of about 25 mA. This value of current is too low to drive the thick PIN diodes needed for high power duplexing.

A type of diode which should be capable of producing bias currents greater than 100 mA is a thin i-layer PIN diode. Since the criterion for efficient rectification is essentially the same as for microwave limiting, a 5 um PIN diode, for example, could be used as a bias diode at frequencies up to about 4,000 MHz.

Power Handling Capability During Turn-on

During the turn-on interval the high power PIN diode must change from a high resistance state to a low resistance state in a time interval less than the rise time of the RF pulse.

Turn-on time, again, is controlled primarily by the i-layer width. The exact value depends on drive circuit conditions. For external switching from -10 V to + 100 mA (for example) turn-on times vary from 1500 ns for a 150 um width to 100 ns for a 50 um width and 2 ns for a 5 um width. For passive duplexing no data is available; however, faster turn-on times can be expected because of higher voltage drive conditions.

As a worst case model we can assume that during the turn-on interval the series resistance (R_s) of the PIN diode is equal to the characteristic impedance of the transmission line (Z_o). At the end of the turn-on interval R_s drops abruptly to zero as shown in Figure 1A.

The consequences of such a model are that half of the main line power is dissipated in the PIN diode and that full main line voltage is developed across the diode during the turn-on interval. Maximum power handling for the first condition can be developed by determining the maximum pulse power that occurs when half of the main line energy in the turn-on interval is equal to the energy dissipation rating (W_D) of the diode. As seen in the pulse diagram in Figure 1B, this leads to:

$$P_{MAX} = 4 W_d t_r / t_d^2 \quad (1)$$

The second power handling condition can be obtained by determining P_{MAX} that results when the main line voltage at t_d is equal to the diode reverse voltage breakdown rating (V_B). As seen from an inspection of the pulse diagram in Figure 1C, this condition leads to a power handling capability of:

$$P_{MAX} = V_b^2/Z_o \cdot t_r/t_d \qquad (2)$$

Substituting values into equation (1) leads to power handling capabilities greater than 2,000 kW for the power dissipation condition. Equation (2) is graphed in Figure 2 for a single 50 um and 150 um diode and for the special case of a rise time of 0.4 us. For multiple diodes the power handling values for the dissipation conditions would increase further because of current sharing while the values for the breakdown voltage conditions would not change. It is seen that the voltage breakdown condition imposes a more severe restriction on power handling.

Design and Operating Results of a 450 MHz Passive Duplexer

The concepts described above have been evaluated in a 400-450 MHz balanced duplexer originally designed to operate with externally switched diodes at peak power up to 1,000 kW and average powers up to 5 kW. Four high power PIN diodes driven separately by 5 um PIN bias diodes were used in each channel. A typical diode mount arrangement is shown in Figure 3.

The peak rectified current generated during a 5 us pulse by the 5 um PIN bias diode is shown in Figure 4 for a duplexer power range of .05 to 1,000 kW. These results indicate that the concept of using single PIN diodes as bias diodes can be utilized over a dynamic power range greater than 43 dB, and that bias currents as high as 850 mA can be obtained.

Dynamic current pulse shapes observed at duplexer power levels of 200 kW for 50 um and 150 um diodes are presented in Figure 5A. The duplexer power rise characteristic is given in Figure 5B for comparison. The 150 um diode shows an irregular response. An initial current pulse was followed by a dip to near zero levels before the current built up to a near steady level. The time interval to reach 100mA during the second rise was about 0.3 us. The 50 um diode exhibited a rapid current rise to 100 ma in about .02 us and to 500 mA in about 0.1 us.

These results represent a speed up in turn-on time by a factor of 5 relative to typical external switching conditions. Using the observed turn-on times with the graphs in Figure 2, we see that the voltage breakdown restriction leads to a minimum power handling capabilities of about 175 kW for a 150 um diode and to 400 kW for the 50 um diode.

A complete duplexer was fabricated with 4-50 um diodes in each arm and with a conventional clean-up limiter at the receive port to restrict spike leakage powers. Final duplexer performance is tabulated in the last column in Table 1. It is seen that the duplexer loss of 0.75 dB is significantly less than obtained with prior techniques at comparable power levels.

The duplexer was operated for 50 hours in an operational radar installation at 200 kW peak and 4 kW average power with a 60 us pulse. No evidence of diode degradation was observed.

References

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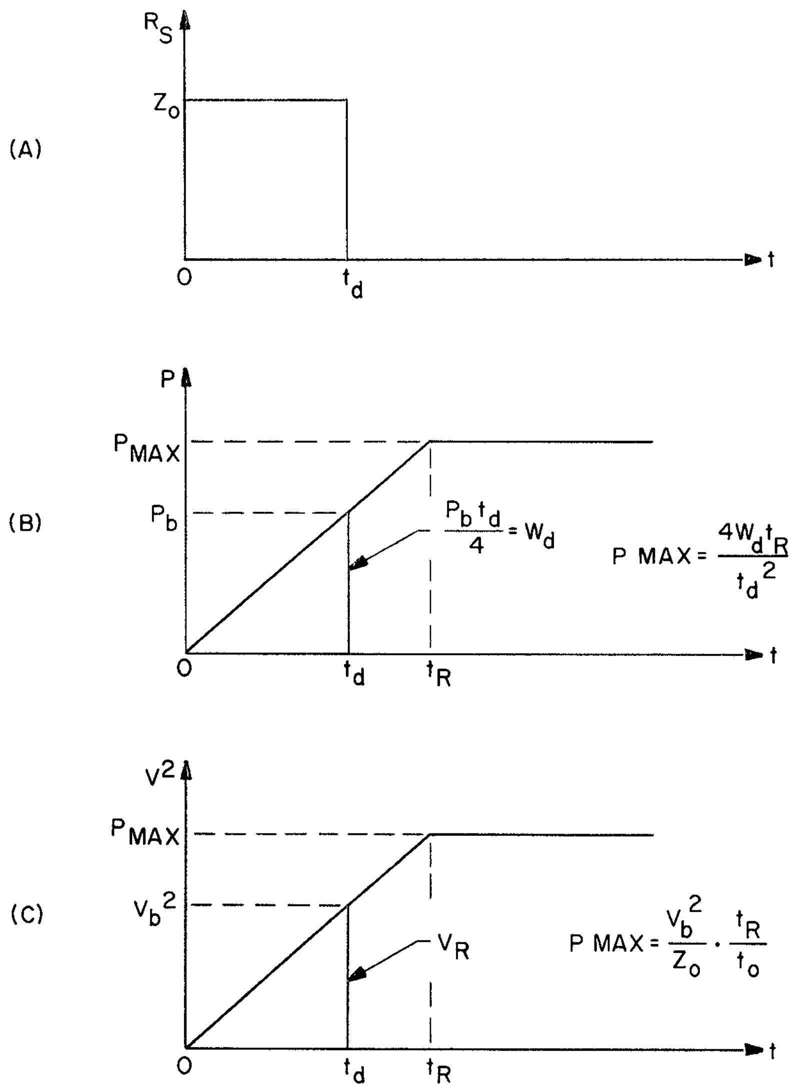

FIGURE 1. PULSE DIAGRAMS FOR DETERMINING TURN-ON POWER HANDLING

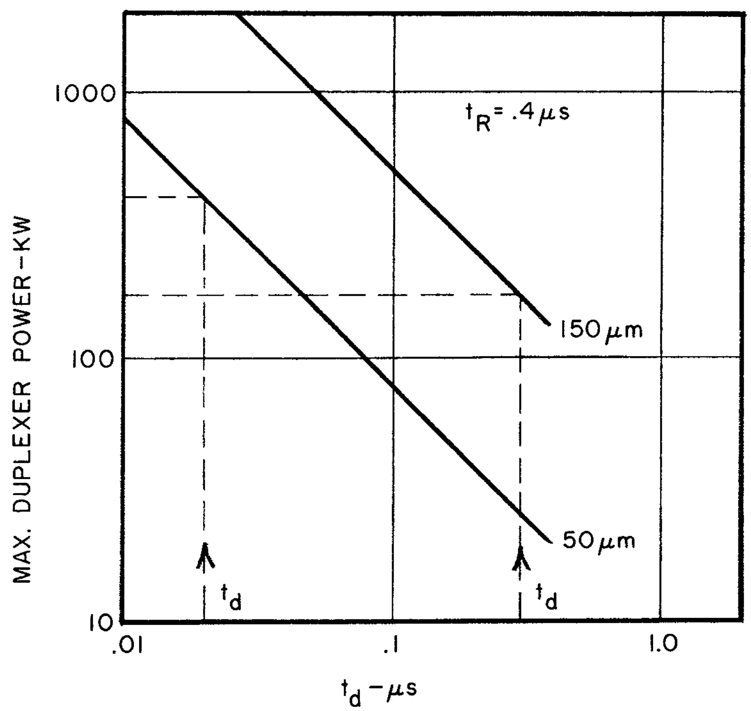

FIGURE 2. POWER HANDLING RESTRICTED BY VOLTAGE BREAKDOWN

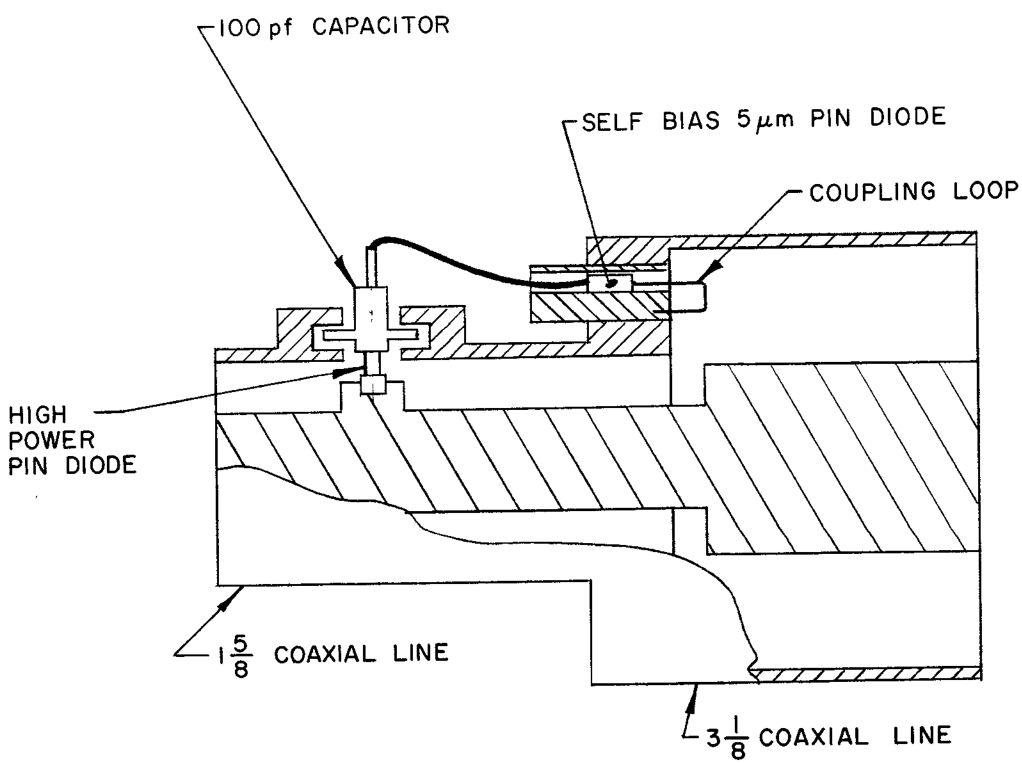

FIGURE 3. TYPICAL DIODE MOUNT

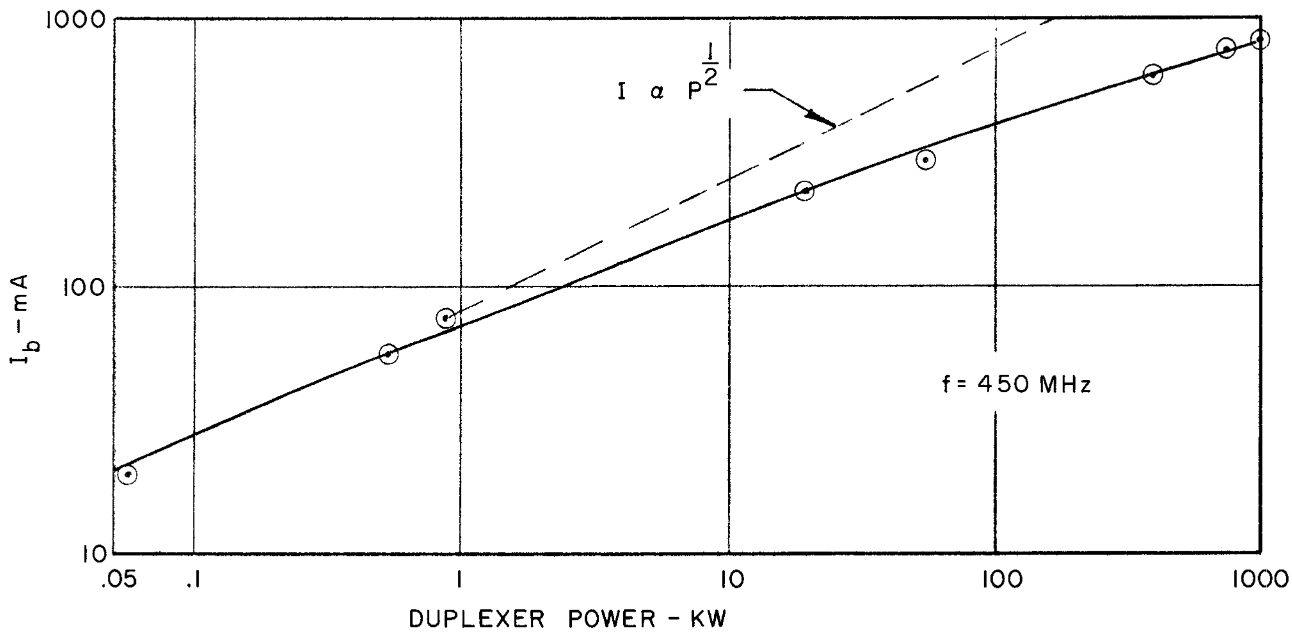

FIGURE 4. PEAK BIAS CURRENT FROM 5 μm PIN DIODE

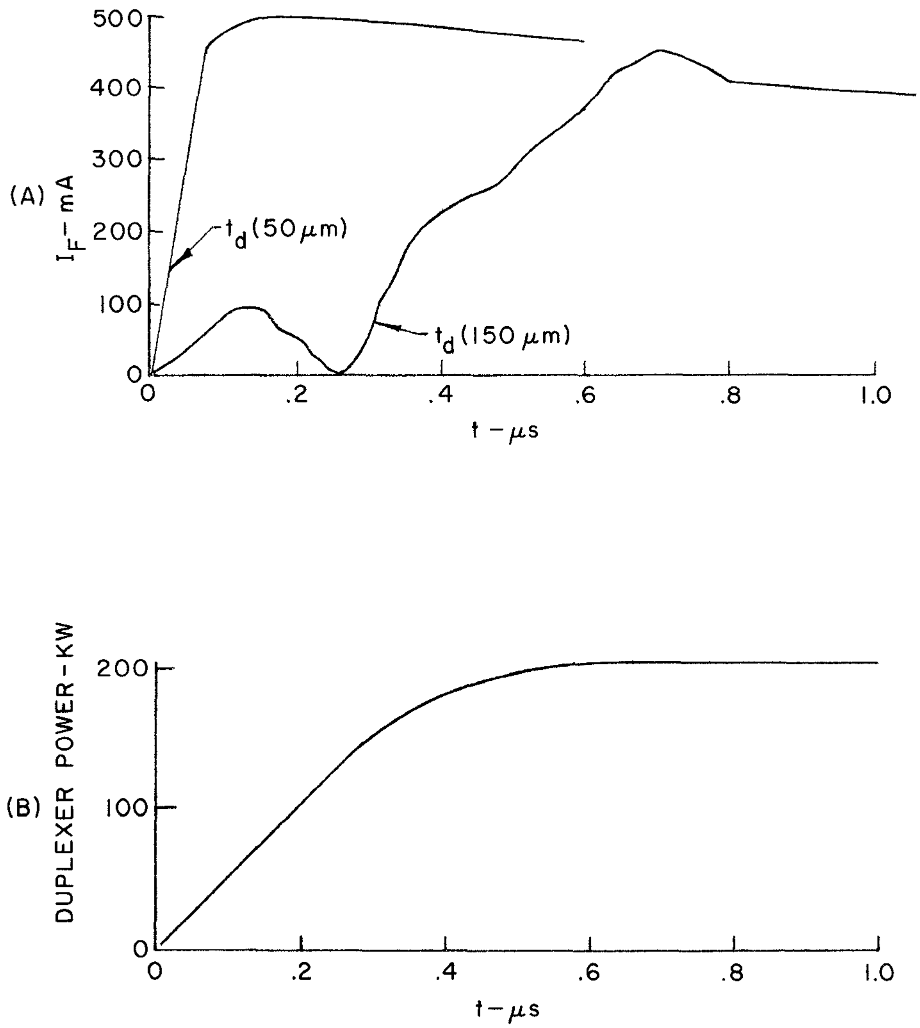

FIGURE 5. DIODE TURN-ON CURRENTS AT 200 KW FOR 50 AND 150 μm PIN DIODE