A 100-kW SOLID-STATE COAXIAL LIMITER FOR L-BAND

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ABSTRACT

This paper concerns the development of a 100-kW peak power, self-biased, pulsed limiter covering the 1250 to 1350 MHz band. The limiter requires no external power sources and uses four 70 μm PIN diodes as the active elements in a power-sharing, axially symmetric, shunt-loaded arrangement in a 50-ohm, 7/8-inch OD, coaxial transmission line. Two shorting stubs used for zero-bias tuning and dc returns are in the same electrical plane as the PIN diodes. Four symmetric Schottky-barrier, high-voltage detector diodes decoupled from the main transmission line provide fast leading edge, high-amplitude current biasing pulses to each PIN diode. The one-stage limiter demonstrated a spike leakage of 2.8 kW/65 ns, a flat leakage of 32 watts peak, and a 1-dB recovery period of 17 μs for an incident power level of 100 kW/2.8 μs. Passive zero-bias loss was under 0.5 dB.

Introduction

For many years investigators have been seeking and experimenting with solid-state RF passive power limiters that will supplant gas TR tubes used for radar duplexing and receiver protecting. Substantial progress has been made over the microwave frequency range for low to moderate peak powers (milliwatt to a few kilowatts) using ferrite and diode technologies. Ferrite limiters have seen wide use in low RF power, inexpensive commercial radars. However, because of their slow turn-on response time leading to high spike leakage, and because of their increasing insertion loss with temperature rise caused by the absorbed incident RF power, ferrites have seen limited use in modern radars of high average power.

PIN diode limiters, on the other hand, can be designed to handle substantial RF power levels,[1] and such limiters have been designed to handle a few hundred kilowatts of peak power at frequencies below 0.5 GHz. Maddix[2] has recently shown that the RF voltage-handling capability of a shunt-mounted PIN limiter is related, not only to V_{BB}, the bulk breakdown voltage, but also to an additional factor, which is the rate of rise of the RF line voltage pulse. Using this technique, the RF peak power-handling capability can be greatly increased over that determined by the diode's V_{BB} design limits. Thermal or average power ratings are not affected by this rate of rise parameter except that the use of thin I-regions to obtain rapid charge injection require additional paralleling of diodes for RF current-sharing.

This paper concerns experiments that have investigated the enhanced peak-power capability using the above risetime effects to obtain a 100-kW peak power, self-biasing, coaxial limiter, the output leakage power levels of which can be handled easily by a conventional cascaded varactor limiter to provide adequate receiver protection.

Diode Biasing Configuration

The concept of self-switching in which a PIN diode is biased by a fast-acting detector diode has also been known for many years. In these designs the reverse breakdown voltage of the PIN diode is chosen so as to handle the peak RF voltage swing of the microwave incident pulse. In the device described in this paper, a decoupled detector diode biases the PIN into conduction on a time scale considerably shorter than the risetime of the incident power pulse so as to minimize the RF voltage developed across the PIN diode. Both thin (5 μm) PIN diodes and Schottky barrier detectors were experimentally tried as biasing rectifiers. It was found that the Schottky barrier diode provided a relatively large output current response with a leading edge of 5 to 10 ns. We chose a recently developed (by Microwave Associates) Schottky diode with a $V_B = 450$ V, 1.3 pf, 0.5 A capability. This diode was found to be reliable and efficient in the 26 dB decoupled self-bias auxiliary line. At the full 100-kW line power, the RF voltage across the decoupled Schottky detector diode in the nonconducting direction was 160 volts peak.

Four detector diodes were circumferentially mounted in 50 ohm decoupled lines to drive four PIN diodes as shown schematically in figure 1. In this configuration each Schottky diode supplied 10-ns-risetime current pulses of up to 350 mA at 100 kW. The detailed mount, shown in figure 2, was designed so the coupling factor could be widely varied by rotating or recessing the loop. The purpose of the fast-acting, high-current detector diode biasing network is to drive the shunt-mounted PIN diodes into conduction before significant RF voltage can be developed across the PIN diodes. The ability of the biasing current to reduce the PIN diode impedance more rapidly than the risetime of the leading edge of the incident pulse is critical to the lowering of the limiter design voltage rating. In this mode low voltage PIN diodes can be made to handle peak RF line voltages V_p much greater than the diodes' V_{BB}.

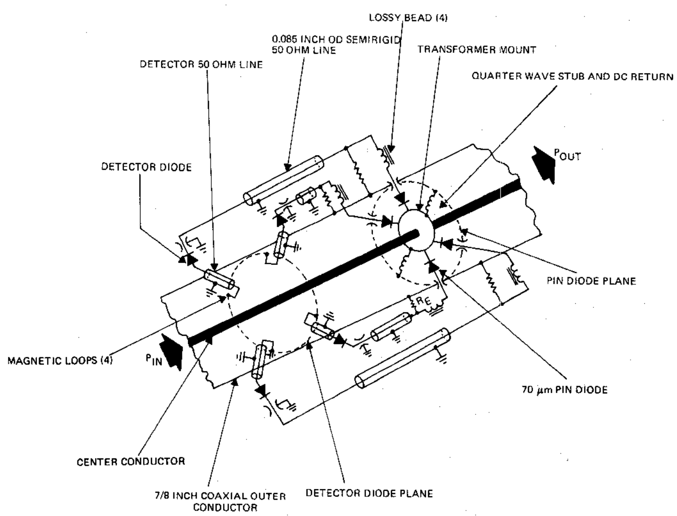

Figure 1. Schematic of Quadrodiode Limiter Showing Four-Diode Symmetry. R_E Controls Discharge Time of PIN Diodes and Affects Recovery Period

High Power Considerations

A model has been suggested by Maddix[2] in which the PIN diode is charged in a time period shorter than the risetime of the leading edge of the RF incident line pulse. In this model the injected current I_{RF} into the I-region gives rapid rise to conductivity modulation resulting in the reverse RF cycle seeing the same diode impedance Z_d as the forward RF cycle. This mode of operation leads to a limiter where $V_{BB} < V_p$, whereas heretofore it was necessary in zero-bias limiter

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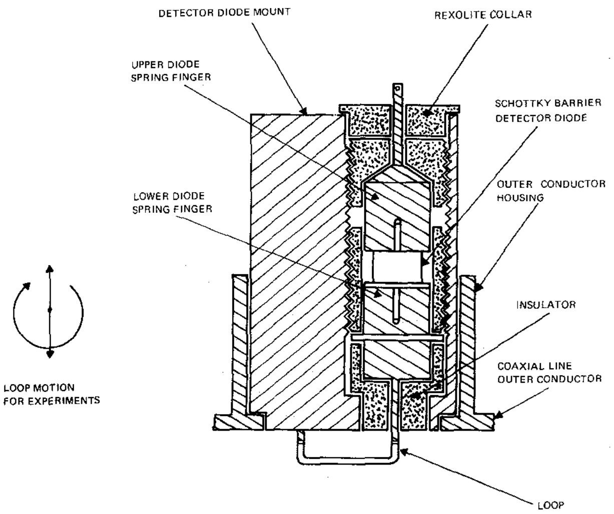

Figure 2. Detailed Sketch of Loop-Coupled Schottky-Barrier Detector Biasing Circuit

design to provide $V_p \leqslant V_{BB}$. The maximum peak power handling capability of the shunt diodes, assuming a linear risetime of the leading edge of the microwave pulse, is given by

$$P_{max} = \frac{V_{BB}^2}{Z_T} \times \frac{t_r}{t_d}$$

where

V_{BB} = reverse breakdown voltage of PIN diode
Z_T = mount impedance
t_r = incident pulse risetime
t_d = diode turn-on time.

A 70 μm diode with V_{BB} = 800 V mounted on a 35 ohm transformer section must turn on 5.5 times faster than the risetime of an incident pulse to handle a 100-kW power level. This suggests that the PIN diode must be externally charged in a time that is brief compared to the risetime of the input microwave pulse so that the line voltage does not exceed the rated reverse bulk breakdown voltage. This is a severe condition for a very wide I-region diode because of the large volume necessary to be filled with charge. Therefore, for a given PIN diode where V_{BB} and t_d are fixed, the transmitter pulse risetime t_r must be adjusted to obtain the required power handling capability.

The quadrodiode assembly was fabricated using a 2.5 inch diameter mount and locating the PIN diodes approximately in the center of a 6 inch length of a 7/8 inch OD coaxial line. The PIN diodes and stubs are arranged diametrically opposite to minimize mount parasitics. Initial tests at high peak power levels were made to determine the temperature rise of the PIN diodes and to determine the accuracy of RF current sharing. The junction temperatures were measured by first calibrating the diode voltage drop at known currents in a heating chamber at controlled temperatures. The mount then was subjected to an 80 kW/3 μs incident pulse where the voltage drop and rectified current were measured. Comparison with calibration charts indicated the highest junction temperature was approximately 135°C.

Small-Signal Design

By disconnecting the Schottky barrier detector diodes and driving the four 70 μm PIN diodes in the quadrodiode mount as a switch, a set of small-signal data was experimentally observed. This data over the 1250 to 1350 MHz band measured 0.37 dB zero-biased loss, 1.2 VSWR, and 36 dB gated isolation. Gated isolation was performed with 100 mA dc through each PIN diode. The gated recovery period was 17 μs for a 330 ohm shunting resistor. The experiment was run so that the charged PIN's had to discharge through this shunting resistor.

Peak Power Experiments

The peak power capability of the shunt-mounted PIN diode limiter can be greatly enhanced by using large values of t_r/t_d. An experiment was designed to evaluate this effect. A series of high power filters were designed to increase the leading edge rise of a 100-kW pulse in approximately 100 ns steps. The experimental results are shown in table I. The predicted peak power handling capability is also shown. The test magnetron generated a 150 kW/2.8 μs/300 pps pulse with a risetime of 30 ns at 1.3 GHz.

TABLE I
FILTER PARAMETERS, MEASURED RISETIMES, AND COMPUTED POWER CAPABILITY

Parameter	Filter 1	Filter 2	Filter 3	Filter 4
f_o (MHz)	1283	1294	1299	1302
Δf (MHz)	5	4	3	1.6
$Q = f_o/\Delta f$	256	323	433	810
Insertion Loss (dB)	1.5	1.6	2.4	2.4
Transmitter Pulse Risetime t_r at Filter Output, 10% - 90% (ns)	110	220	330	430
Computed RF Power Handling Capability (kW)	25	50	75	100

The 800 volt, 70 μm PIN diode was selected for the high power experiment because a t_d = 80 ns and t_r = 430 ns gave a predicted result of the required peak power handling capability (100 kW). Four 70-μm PIN diodes were embedded in a coaxial limiter as shown in figure 3, and high power tests were conducted. The experimental results, depicted in figure 4, show that the spike leakage decreases with increasing risetime. The peak power capability, which was expected to increase with longer risetimes, did not occur up to the power limitations of the variable risetime testset. Operation using 30 ns risetime, 3 μs/100 kW transmitter pulses was satisfactory. We did not observe any signs of PIN diode degradation or RF burnout, as evidenced by small-signal zero-bias insertion loss tests made after each high power measurement.

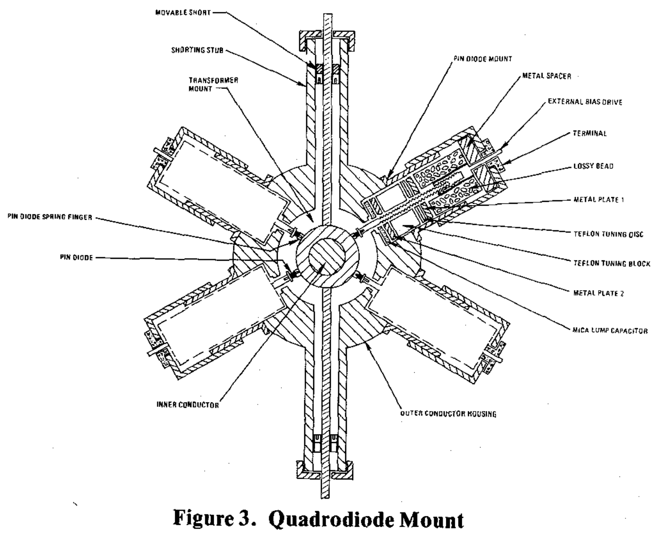

Figure 3. Quadrodiode Mount

A high power test with a 30 ns risetime pulse was performed with four 70 μm PIN diodes using a 2.6 μs pulse at 300 pps repetition rate into a matched (VSWR < 1.1) load. Figure 5 depicts the high power test data for the quadrodiode limiter at power levels varying from 10 kW to 100 kW. The maximum spike leakage is 2.8 kW/65 ns; the maximum flat leakage is 32 watts. The maximum video output from the Schottky barrier detector diode was approximately 360 mA at

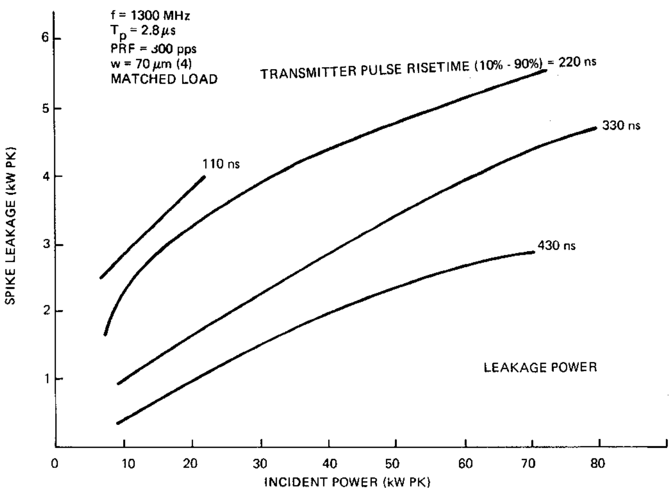

Figure 4. Test Data for Quadrodiode Limiter With Incident Pulse Risetime as a Parameter

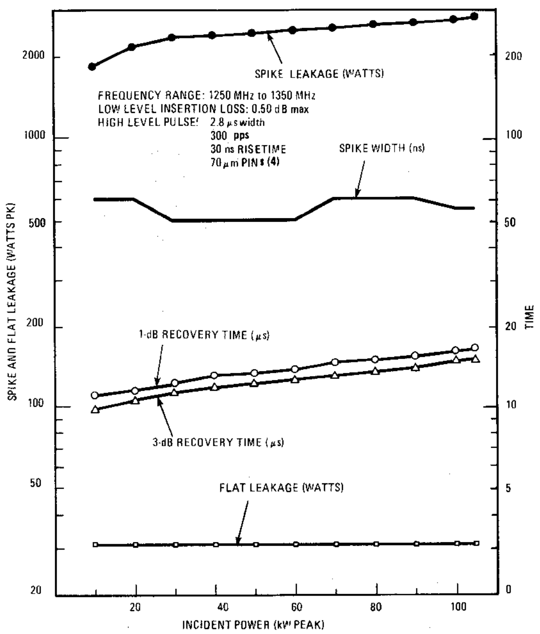

Figure 5. Quadrodiode Test Results

100 kW. The decoupled RF voltage at the Schottky detector diodes input side was 158 volts peak (250 watts). The low level insertion loss of the quadrodiode limiter was measured to be 0.5 dB maximum after a 100 kW test run of 4 hours.

Applications

The L-band power limiter shown in figure 6 and discussed above was designed to operate in front of a low-power multiple-stage varactor limiter that would reduce spike and flat leakages of 2.8 kW and 32 watts pk respectively to levels low enough that FET or bipolar low noise amplifiers are adequately protected from burnout or gain-recovery phenomena. The device was designed for use in L-band high power surface radars.

Conclusions

A single-stage, multiple-diode, 100-kW solid-state coaxial quasiactive limiter for the 1250 to 1350 MHz band has been demonstrated using four 70-μm PIN diodes. The spike leakage and recovery time characteristics showed distinct dependence on the ratio of the input pulse risetime to the diode turn-on time. Although the number of diodes was determined from the thermal dissipation model, the PIN diode parameters were determined on the basis of the reverse breakdown voltage, pulse risetime model. The use of 450 volt, 0.5 amp, 1.3 pF Schottky barrier diodes as rectifying devices to provide an efficient and fast-acting bias to the PIN diodes was considered to be very important in high peak power operation. We also observed that the reverse breakdown voltage model discussed here, which accounts for variations in input pulse risetime and diode turn-on time, did not significantly affect the power handling capability of the limiter up to the 100 kW level. A comparison of the results reported here with similar work reported by other investigators is shown in table II.

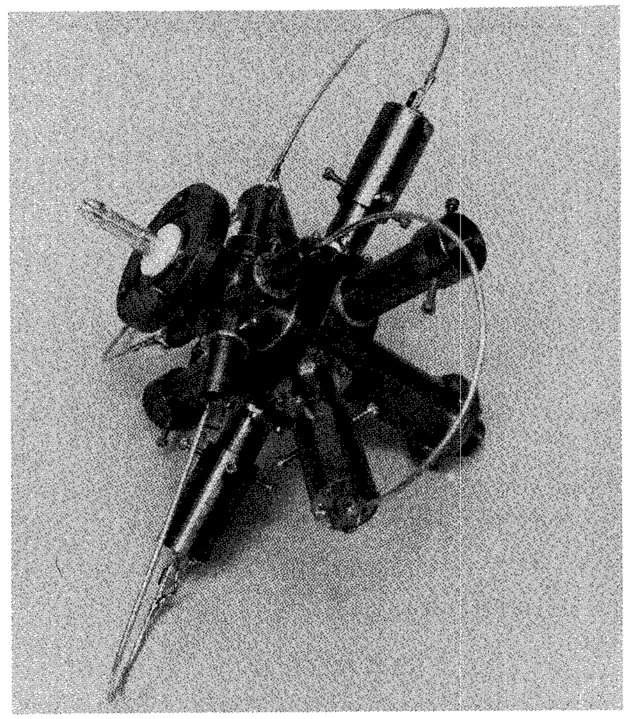

Figure 6. Photo of Westinghouse WD-367 Coaxial Limiter

TABLE II
SUMMARY OF HIGH POWER LIMITER RESULTS

Parameter	Brown[1]		Maddix[2]	Data
Frequency (MHz)	225	450	450	1300
Peak Power (kW)	150	1000	300	100
Average Power (kW)	10	2	5	0.1
Pulsewidth (μs)	200	4	60	3
Number of Diodes in Plane	16	31	4	4
Insertion Loss (dB)	2	3.5	0.75	0.5
I-Region Width (μm)	25	12	50	70

References

1. N.J. Brown, "Design Concepts for High-Power PIN Diode Limiting," *IEEE Transactions on Microwave Theory and Techniques,* Vol. MTT-15 (December 1967).

2. H.S. Maddix and D.C. Broderick, "Rectified RF for High Power PIN Duplexing," *IEEE MTT 1979 International Microwave Symposium Digest.*