MICROSTRIP PLASMA LIMITER

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ABSTRACT

An operational microstrip plasma limiter was developed for DC to 18-GHz operation. The limiter threshold is 65 W for a 1-μs microwave pulse. Spike leakages of less than 20 μJ and flat leakage of less than 1 W were achieved from S- to X-band. Device power handling capacity is 50 kW peak.

INTRODUCTION

Gas plasma limiters or TR tubes used in high-power radar receiver systems are typically developed in hollow-pipe waveguide. These limiters are narrowband (up to 10%), bulky, and heavy. A lightweight, miniature wideband plasma limiter is needed to protect sensitive receiver front ends in EW applications. This paper describes a passive limiter which meets these requirements.

Three limiter units were designed, fabricated, and tested at Westinghouse for the 0.01- to 18-GHz frequency range, with design goals of 0.6-dB insertion loss, 20-μJ spike leakage energy, and 10-W flat leakage for incident peak power levels up to 50 kW. A 50-ohm unit was developed as a drop-in for coaxial systems. For systems requiring lower leakage, the plasma limiter would be followed by a PIN diode limiter.

PRINCIPLE OF OPERATION

Figure 1 shows the cross-section of a microstrip plasma limiter (1). W/h determines the characteristic impedance of the microstrip line in the xenon gas suspended between two hermetic beads soldered in the ends of the gas chamber (see Fig. 2). The microstrip center strip is not rectangular in cross section but trapezoidal to form sharp edges, and the ground plane is projected upward under the strip to concentrate the fields to enhance gas breakdown at the conductor edges. At high microwave power levels, a discharge is initiated at the edges and spreads toward the center region. A 150 millicurie tritium titride radioactive primer, near the edge of the microstrip line, provides free electrons to initiate the gas discharge. The conductive plasma discharge then short-circuits the microstrip line reflecting and absorbing the incident power. This discharge yields relatively low spike and flat leakages at the output port of the limiter.

MODEL DEVELOPMENT AND FABRICATION

The insertion loss consists primarily of two factors: the microstrip (conductor and radiation) losses, and the alumina microstrip to glass bead to free space microstrip transition losses (see Fig. 2). These losses were estimated to be 0.6 dB at 18 GHz for the limiter assembly, which consisted of a 1.7-inch, 50-ohm suspended microstrip, two 0.15-inch alumina microstrip lines for coaxial connector attachment, and two wideband coaxial beads.

Low spike and flat leakages have been achieved by using gases with low firing thresholds. These thresholds are estimated from the Paschen curves (2)(3). Noble gases, e.g., argon, krypton and xenon, have minimum breakdown thresholds at 10 to 20 Torr pressure at X-band. We obtained consistent firing and stable low spike leakage with xenon at 28 Torr. Figure 3 shows the final limiter design with SMA connectors for coaxial insertion.

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LOW AND HIGH POWER TESTS

A comparison of the measured insertion loss for the brassboad and the two operational models is shown in figure 4. An insertion loss less than 1 dB was achieved up to 17 GHz for the brassboard model. By reducing the VSWR at the bead-microstrip interfaces, we achieved 0.7 dB loss to 10 GHz, with higher losses above 10 GHz for the two operational models.

The firing thresholds, spike energy, and flat leakages at L-, S-, C- and X-band frequencies were measured with the use of a 1-us RF pulse with 50-ns risetime at 100 pulses per second. A summary of high-power data for the operational model X02 is presented in Table 1. Typical firing thresholds are in the 50-W range from S- to X-band. Oscillograms (Fig. 5) show the spike leakage (output) and incident power (input) at X-band. A 3-dB spike width of 30 ns and a spike amplitude of 115 W were measured with a 50-ns risetime RF pulse of 500-W peak amplitude. The spike energies and flat leakages from S- to X-band are below 20 uJ and 1 W, respectively. At L-band the spike leakage rises to 44 uJ at the maximum incident power level of 5.8 kW. The maximum incident RF levels were limited by arcing at the input SMA connector.

DISCUSSION

It is believed that the higher leakage observed at L-band is due to large plasma oscillation amplitudes and a high collision frequency-to-RF ratio, which resulted in high electron losses in the discharge.

One of the most important parameters to consider when a gas discharge limiter is being built is whether or not the limiter functions properly after it has been inactive for some time. After a time interval of one week, the limiter performance was tested and found to operate properly on the first pulse.

At incident power levels near the turn-on threshold of the limiter, variation in spike energy and flat leakage result. Figure 6 shows the plasma limiter output for a 10-GHz, 250-ns incident pulse with a 3-ns risetime and 378-W amplitude. Five pulses were incident on the limiter, and the resulting leakage characteristics were seen to vary (total leakage energy varies from 8 to 21 μJ in Fig. 6).

In this photograph another interesting result is noteworthy. About 100 ns into the pulse, three of the five traces appear to start following a path leading to a finite flat leakage, but suddenly drop to zero. We believe that this transition is attributed to the classical glow discharge to arc discharge transition in typical spark gap devices (4). Typical glow discharges exhibit gap voltages in the tens to hundreds of volts range, while arc gap voltages are typically less than 10 V. For the 50-ohm characteristic impedance, the peak RF voltage corresponding to the finite flat leakage in Figure 6 is around 33 V, which indicates a glow discharge is taking place. However, before this statement can be verified, more detailed RF and DC measurements must be made.

The average spike leakage energy versus incident power is plotted in Figure 7. The pulse-to-pulse variation (see Fig. 8) in leakage energy was large near the turn-on threshold, as expected. The standard deviation of the total leakage energy versus incident power is shown in Figure 8.

Gas discharge devices exhibit variable turn-on characteristics near their turn-on threshold (in this case, from about 80 to 250 W), so our data are consistent with expected results. It is important to note that, unlike PIN limiting diodes, the turn-on threshold of gas devices is not abrupt, and the pulse to pulse performance, even above the threshold, is not very consistent.

CONCLUSION

A passive wideband plasma limiter operating from L- to X-band has been demonstrated. Spike energy and flat leakage goals were achieved from S- to X-band. Insertion loss is higher than expected but can be reduced with better control of mismatches between transmission media. As expected, the spike leakage is highest when the incident pulse is just above the firing threshold. The statistics of the spike energy leakage at X-band for intermediate power levels were measured. Further investigation of the statistics are being performed.

REFERENCES

1) S. Patel and L. Dubrowsky,"A Gas Substrate Broadband Microstrip Plasma Protection Stage," Westinghouse patent disclosure No. AA 85-317, Dec 1986.

2) A.D. MacDonald, Microwave Breakdown In Gases, J Wiley & Sons, 1966.

3) S.C. Brown, Introduction To Electrical Discharges In Gases, J Wiley & Sons, 1966.

4) M.F. Hoyaux, Arc Physics, Springer-Verlag, Inc, NY, NY, 1968.

Table 1: Model X02 High Power Test Data

Test Frequency	Max Peak Input Power	Firing Threshold	Spike Ampl.	Leakage 3dB Width	Flat Leak.
(GHz)	(W)	(W)	(W)	(ns)	(W)
1.3	5800	62	440	100	10
3.3	820	58	365	50	0.9
5.4	860	50	94	30	<.01
9.6	1100	50	175	20	<.01

NOTES: 1 μs pulsewidth, ~ 50 ns risetime, 100 Hz PRF
Peak power limited by arcing at connectors.

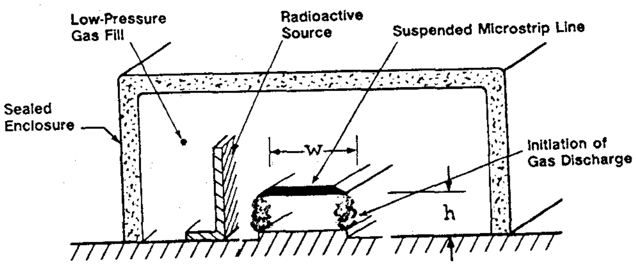

Fig 1 Cross-section showing the principle of operation of a microstrip plasma limiter.

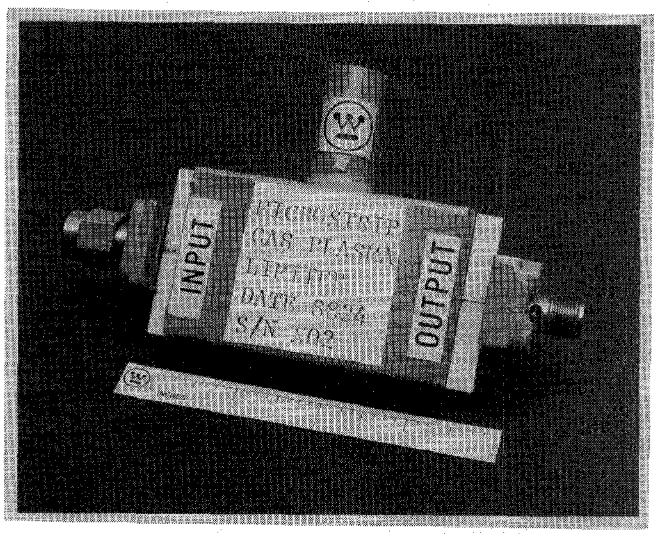

Fig 3 Photograph of the microstrip plasma limiter, Model X02, which was delivered to HDL.

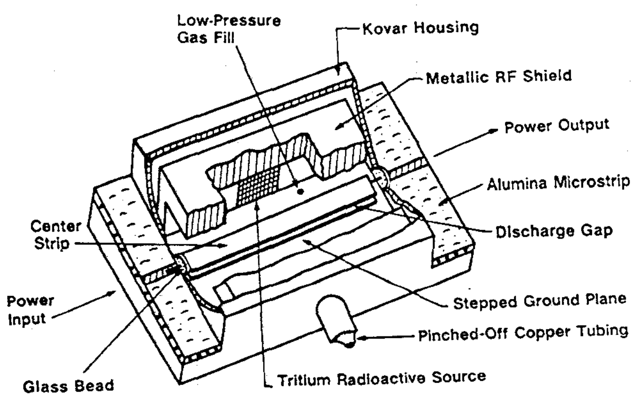

Fig 2 Cutaway view of the microstrip plasma limiter.

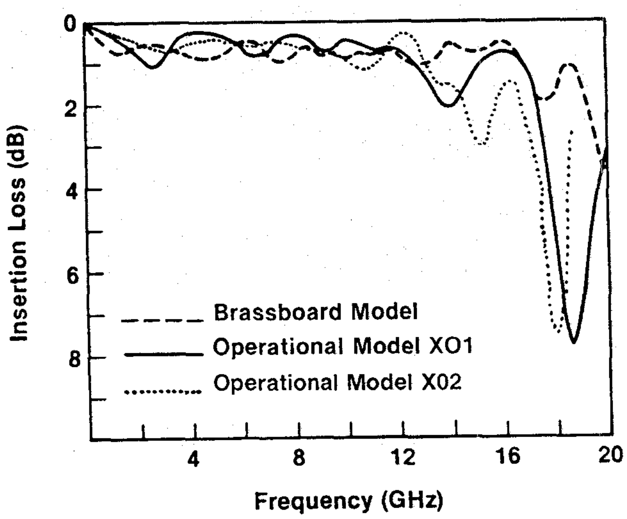

Fig 4 A summary of measured insertion loss data for the brassboard and the two operational models.

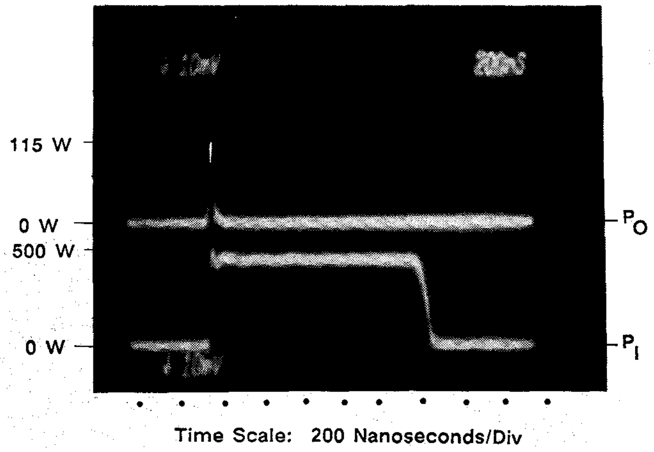

Fig 5 Oscillogram showing spike and flat leakage waveforms for Model X02 for a 500 W, 1 μs incident pulse at 100 Hz PRF.

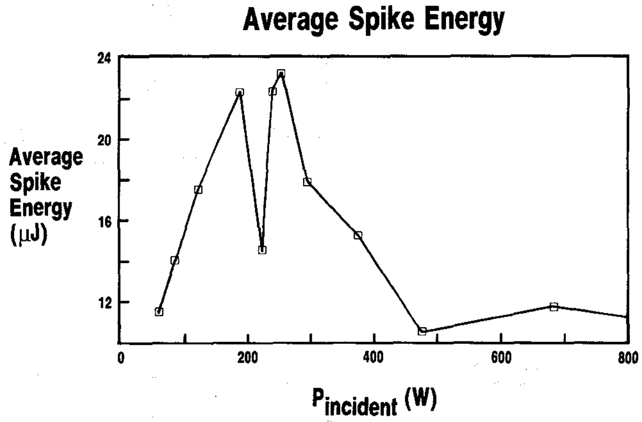

Fig 7 Data showing the variation in spike energy vs. incident power for 250-ns-wide, 3-ns risetime, 10-GHz pulses.

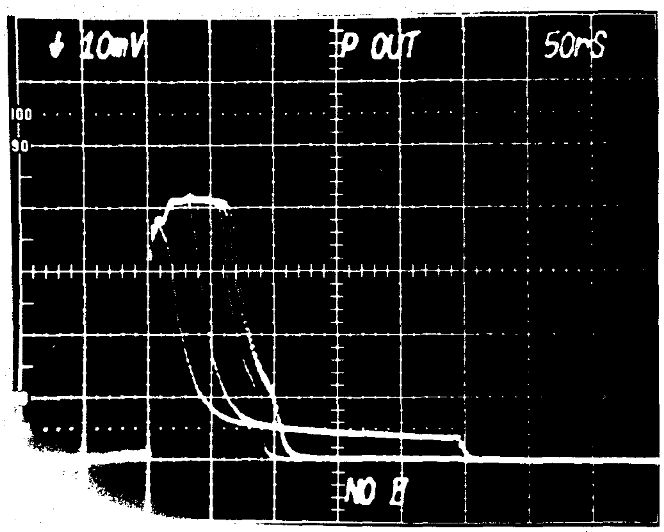

Fig 6 Oscillogram showing the limiter output for 5- 378 W amplitude, 250-ns, 3-ns risetime 10-GHz pulses. Note variation in both spike leakage width and flat leakage levels.

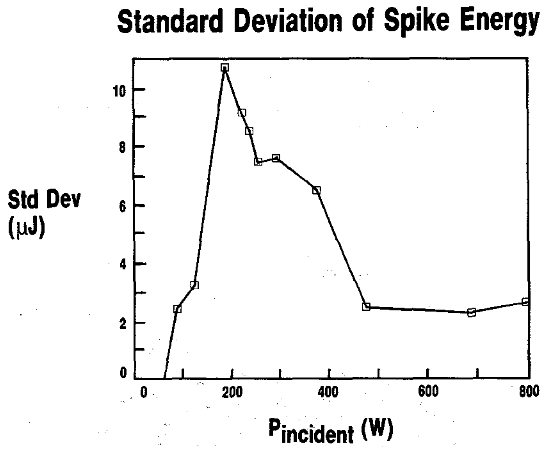

Fig 8 Standard deviation of data contained in Fig. 7. Note the large deviation for limiter operation near the turn-on threshold (~ 80 to 250 W).