# SELF ACTIVATED, 20 kW X-BAND BULK EFFECT SEMICONDUCTOR LIMITER

G. Morris, V. Higgins, G. Hall
U. S. Army Electronics Technology
and Devices Laboratory, ERADCOM,
Fort Monmouth, NJ 07703

Y. Anand, R. Bilotta, F. Jellison
Microwave Associates, Inc.
Burlington, MA 01803

## ABSTRACT

A self activated solid-state X-band multi-stage receiver protector using a high power bulk semiconductor limiter followed by a two-stage junction diode limiter has been developed for military radar applications. The receiver protector handles 20 kW of peak power at a 0.25 μsec pulse width and 4000 Hz pulse repetition frequency. Spike and flat leakage powers are less than 250 mW and 50 mW respectively. High volume semiconductor batch processes and fabrication techniques were implemented to obtain this low cost, yet reliable receiver protector. In addition the bulk limiter concept has been successfully applied to millimeter wave frequency.

## Discussion

An all semiconductor broadband receiver protector consisting of a bulk semiconductor high power stage and lower power, diode "clean-up" limiter has been developed for the frequency range 9.0 - 9.65 GHz. The bulk semiconductor limiter operates on the principle of field induced avalanche breakdown in near-intrinsic silicon to achieve isolation. The bulk semiconductor chip is mounted in a fixed tuned resonant waveguide cavity (iris), as shown in Fig. 1. The bulk semiconductor limiter responds quickly to incident microwave energy. It provides uniform, reliable attenuation of the leading edge of incident pulses on a pulse to pulse basis. Spike leakage is 13 dB or more below incident pulse power and flat leakage 6 to 10 dB below the spike. By combining the bulk limiter stage with conventional low level diode limiters, the incident pulse is further attenuated to a leakage power tolerable by the most sensitive X-band mixer.

The "clean-up" limiter is usually a dual diode limiter consisting of a high power PIN diode followed by a lower power diode, e.g., a varactor. The diodes are electrically spaced for the best combination of low insertion loss and high isolation. A detector diode with good rectification properties samples the incoming pulse and provides DC bias to the limiting diodes[1]. The stage by stage limiting process is shown in block form in Fig. 2 and a cross sectional view of the complete limiter is shown in Fig. 3. Interstage tuning elements are incorporated for broadband performance.

### Fabrication of X-Band Bulk Limiter Element

The bulk limiter elements were fabricated from high resistivity, uncompensated silicon wafers (resistivity, $\rho$ = 8000 Ωcm to $\rho$ = 26000 Ωcm, <1,1,1>, p type). These wafers were etched and polished to a thickness of 3-5 mils. Both sides of the wafer were then diffused with a checkerboard pattern of N and P type degenerate regions which act both as injection sources for carriers when subjected to high microwave fields and as recombination sites as fields diminish. The diffusion depths are shallow and not critical. However, it is critical that the bulk resistivity remain substantially unchanged during processing. Should it change, the insertion loss of a completed bulk limiter would increase.

A high temperature metallization process was used to insure good ohmic contact to both surfaces which were electroplated with 2.0 - 3.0 mil thickness of gold. The active area of the element was then defined by masking and etching a 10 mil diameter region forming a gold post on the top side of the wafer. Silicon mesa etching and silicon nitride passivation were performed while the elements were still in a wafer form. The wafer was next cut into 40 mil squares and separated into individual chips. The chips were then tested for their current versus voltage and zero bias capacitance characteristics. Low capacitance, less than 0.14 pF, and symmetrical I-V characteristics are essential for low insertion loss, broad bandwidth and fast recovery time, but at the expense of power handling capability. Therefore a compromise must be effected between the various low level and high level performance parameters.

Next in the fabrication process is the ball bonding of 5 mil gold wire to the bulk limiter chips. A bulk limiter chip with a gold wire bond is shown in Fig. 4. Finally the bulk limiter chips were mounted in gold plated copper, resonant irises. The bulk limiters are tested for both low level RF performance (insertion loss, bandwidth and frequency) and high power RF performance (recovery time, spike and flat leakage) prior to mating with a "clean-up" limiter.

The equivalent circuit of the bulk device and its theory of operation is well detailed in the references[2,3]

### RF Performance at X-Band Bulk Limiter

The complete bulk-diode limiter assembly is shown in Fig. 5. Twenty units of this type were constructed and subjected to a variety of RF and MIL Standard type environmental tests. A compilation of the RF results are listed in Table 1 and the leakage pulse of one of these units, at 5 kW peak input power, is shown in Fig. 6. Typical spike leakage of 150 mW and flat leakage of 40 mW is observed when the complete bulk diode limiter assembly is subjected to a 20 kW peak, 0.25 μsec wide pulse over a frequency range of 9.0 GHz - 9.65 GHz. The power transmitted versus the incident power for both the spike and flat is shown in Fig. 7.

### Narrowband Marine Radar Limiter

A low cost, narrowband units was also developed for marine radar applications. This receiver protector consists of a bulk stage limiter and a low cost single-stage diode "clean-up" limiter.

The entire circuit is optimized for the narrowband performance (200 MHz) of certain military as well as commercial marine radar systems. A prototype

protector, will have operating characteristics similar to those listed in Table 2.

Ka-Band Bulk Limiter

Bulk semiconductor techniques have successfully been applied for millimeter wave limiter applications (35 GHz). Slightly different design criteria than previously noted for X-band devices were used.

Preliminary experimental results indicate that for a chip capacitance between .06 and .08 pF exhibit an insertion loss of .6 to .8 dB and bandwidth 200 - 400 MHz.

Detailed electrical performance of a Ka-band bulk semiconductor limiter will also be presented.

## Conclusions

This work demonstrates the capability and potential of an X-band bulk diode limiter for military and commercial radar applications. The bulk diode limiter assembly, a passive semiconductor device, is more reliable than its TR tube counterpart.

From experimental results to date show that the bulk semiconductor process can be extended successfully to attest to the Ka-band frequencies.

## Acknowledgements

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## References

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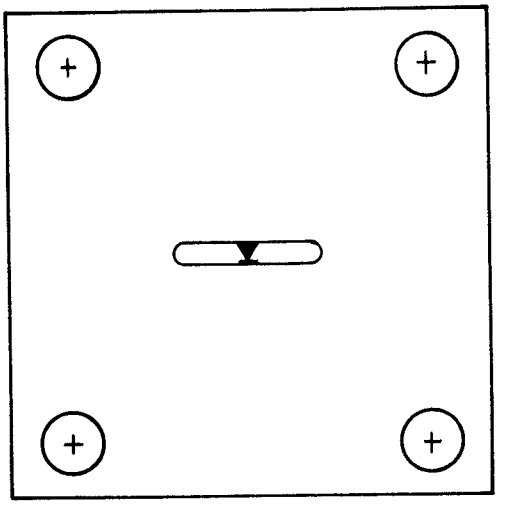

FIGURE 1 SINGLE SLOT BULK LIMITER

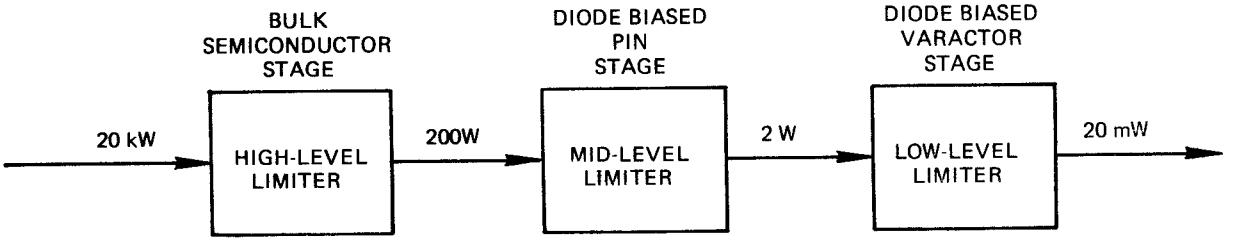


FIGURE 2. MULTI-STAGE MICROWAVE LIMITER

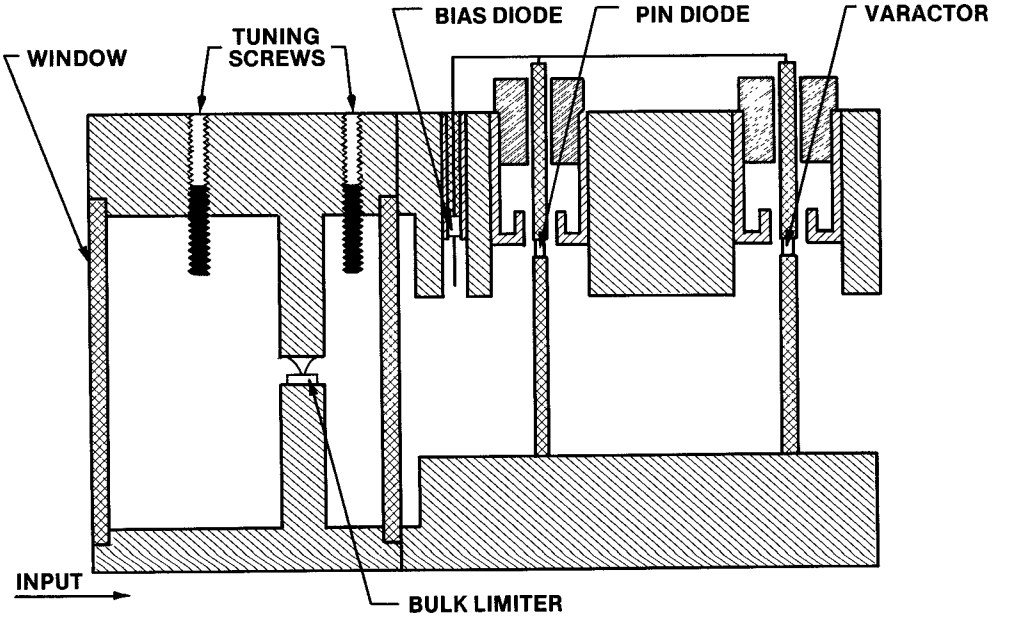


FIGURE 3. BULK DIODE LIMITER

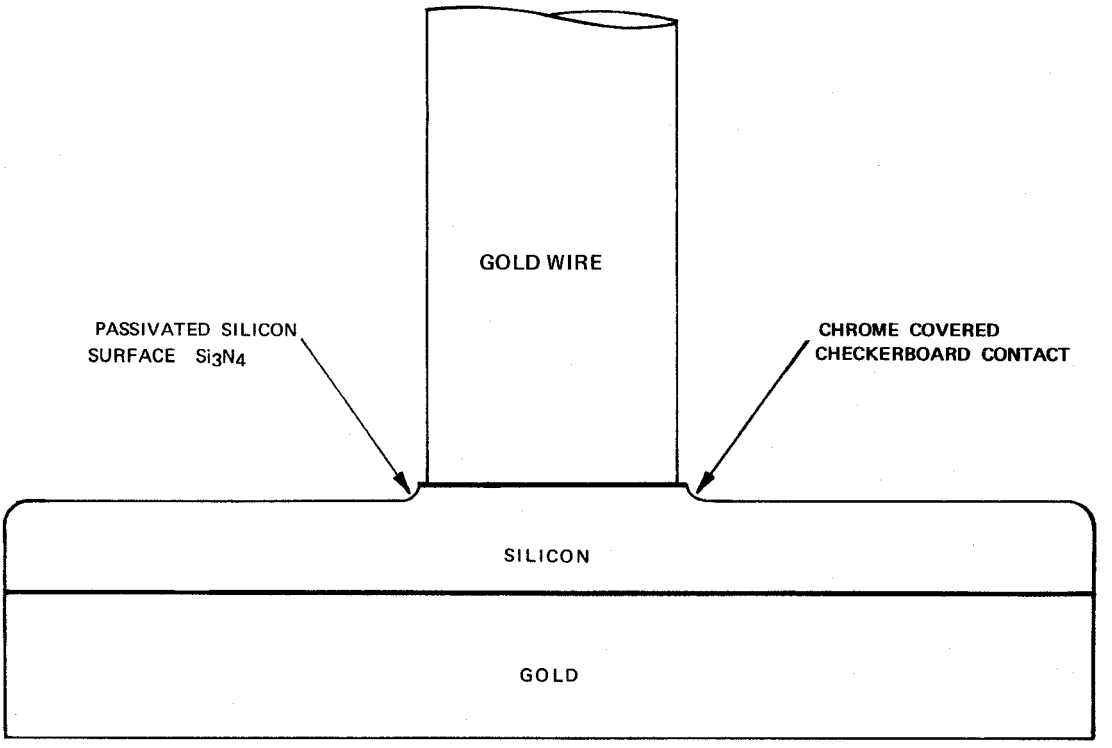


FIGURE 4. COMPLETED CHIP READY FOR IRIS MOUNTING

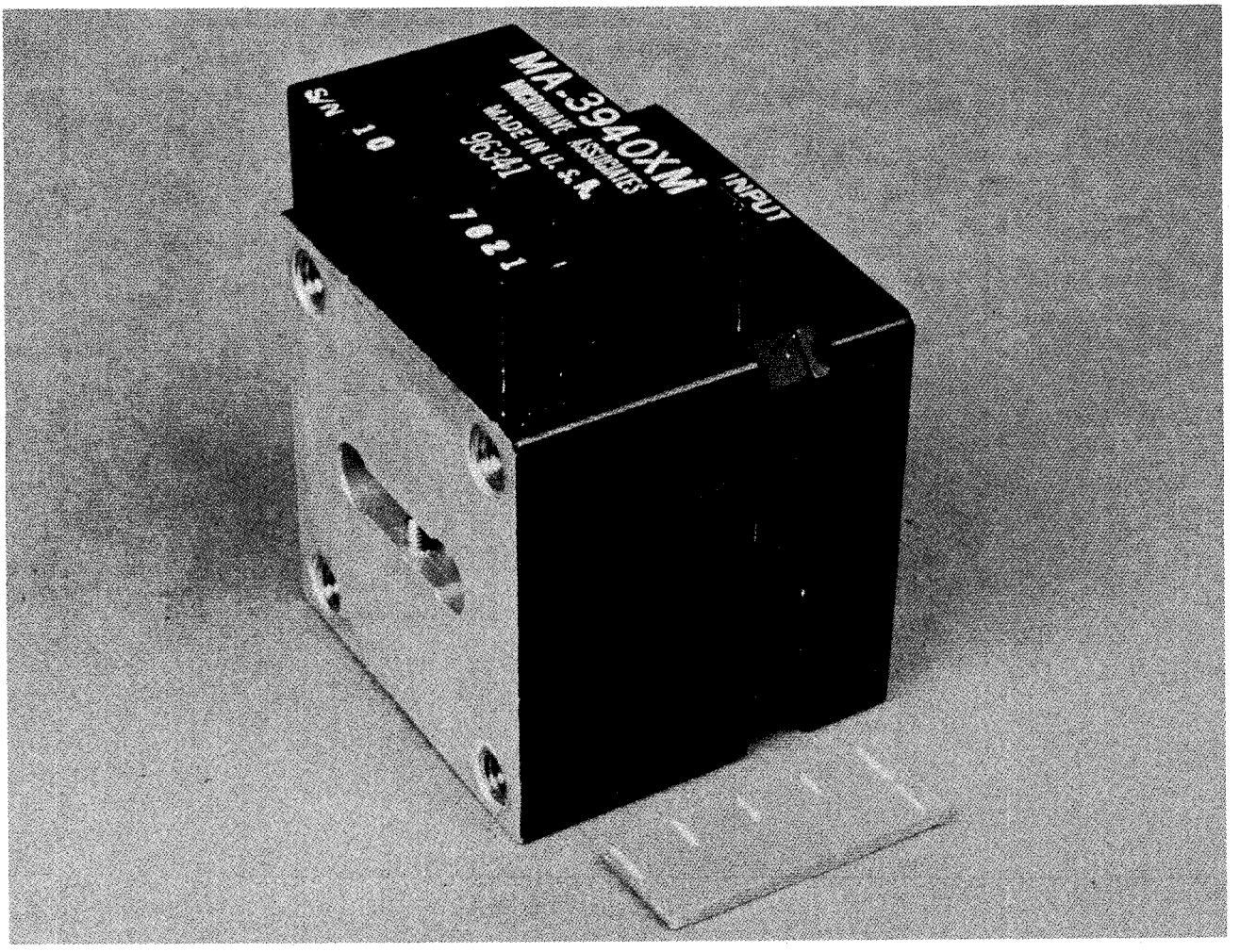


FIGURE 5. BROADBAND BULK-DIODE LIMITER

TABLE 1

RF Performance of Broadband Bulk-Diode Limiter

| Application | Peak Power kW | Insertion Loss dB | VSWR | Trans. Flat Power mW | Trans. Spike Power mW | Recovery Time (3 dB) μsec |
|---|---|---|---|---|---|---|
| Broadband Radar 9.0 - 9.65 GHz | 20 (pulse width = 0.25 μsec, 4000 pps) | 0.8 | 1.5 | 40 | 150 | 1.6 |

NOTE: Multi-stage Clean-up Limiter

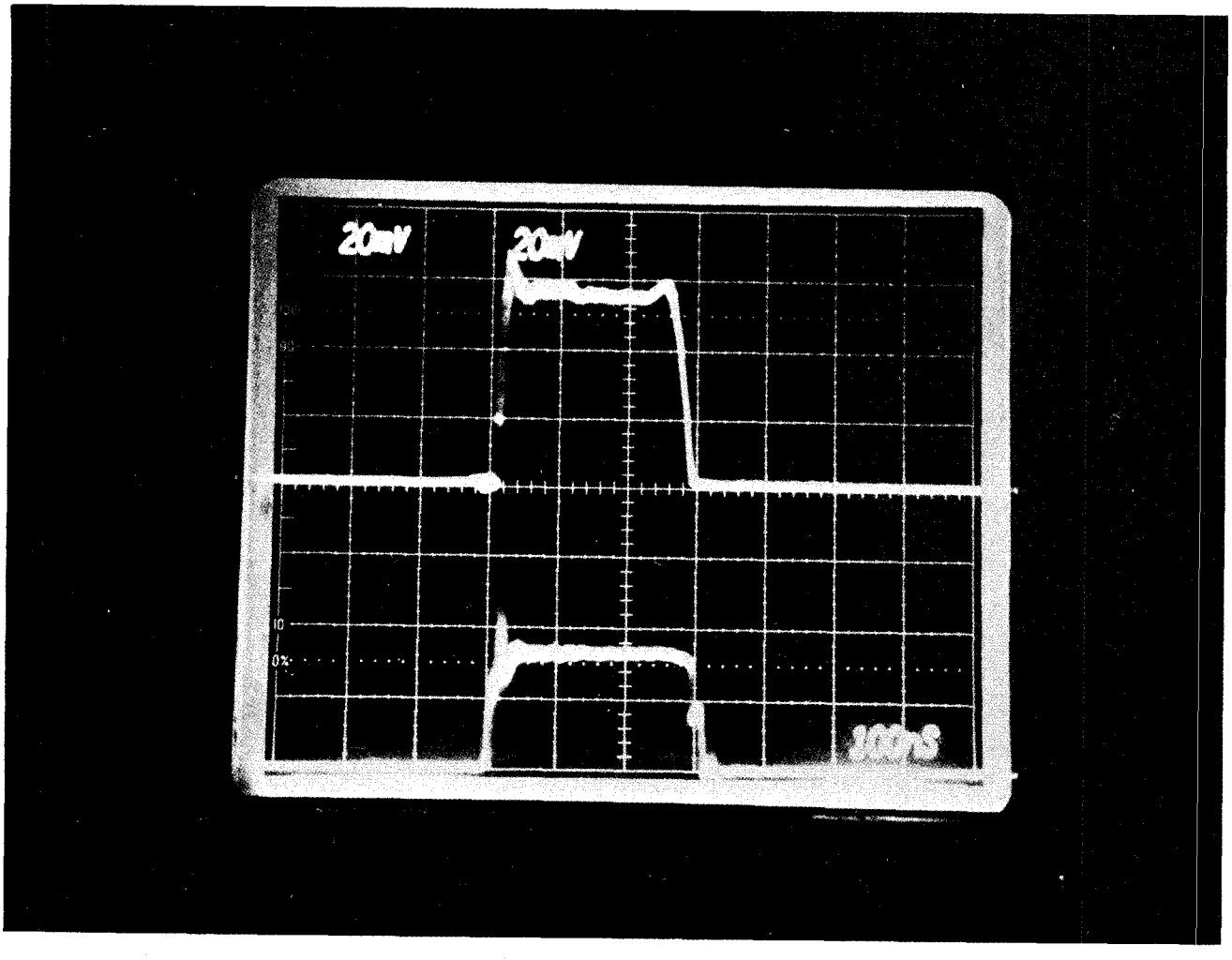


FIGURE 6. LEAKAGE PULSE CHARACTERISTICS OF BROADBAND BULK-DIODE LIMITER

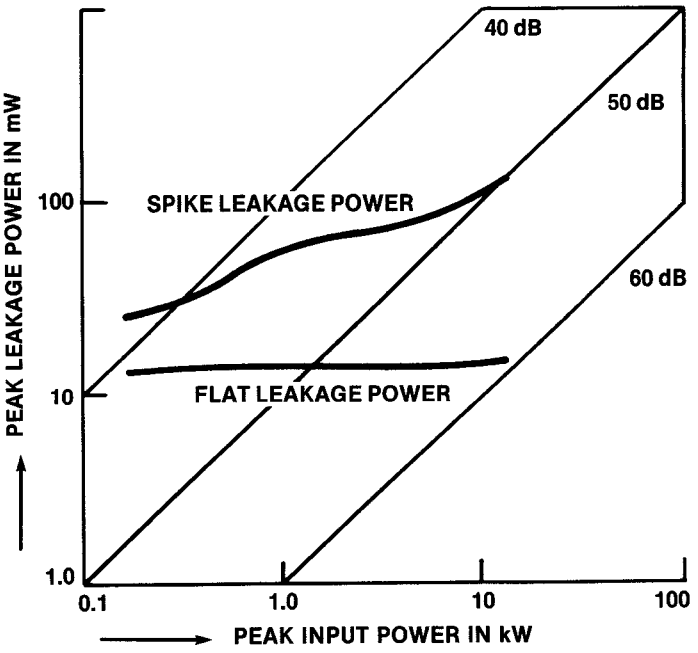


FIGURE 7. TYPICAL LIMITER CHARACTERISTICS OF BROADBAND BULK-DIODE LIMITER

TABLE 2

RF Performance of Narrowband Bulk-Diode Limiter

| Application | Peak Power kW | Insertion Loss dB | VSWR | Trans. Flat Power mW | Trans. Spike Power mW | Recovery Time (3 dB) μsec |
|---|---|---|---|---|---|---|
| Narrowband Marine Radar 9.3 -9.5 GHz | 10 (pulse width = 1 μsec, 1000 pps) | 0.8 | 1.35 | 50 | 250 | 1.5 |

NOTE: Single Stage Diode Clean-up Limiter