FAST-ACTING VARACTORS FOR SUB-NANOSECOND POWER LIMITING IN RECEIVER PROTECTORS*

T. M. Nelson and H. Goldie
Westinghouse Defense and Electronic Systems Center
Systems Development Division
Baltimore, Maryland

Abstract

Fast-acting pn junctions were developed to self-limit in less than 1 nsec at relatively high peak levels at X-band frequencies. The cascading of junctions in order of decreasing base region thickness behind high average power plasma limiters resulted in a passive receiver protector capable of limiting 1 nsec risetime multi-kilowatt RF pulses to 1 watt spike levels. It is also shown that 1 watt spikes of less than 10 nsec duration do not degrade the noise figure of balanced mixers employing small-junction (5 to 10 μ diameters) Schottky barrier diodes.

Introduction

Due to the recent advent of sub-nanosecond risetime multi-kilowatt sources at microwave frequencies, a new requirement has been imposed on devices functioning as radar receiver protectors. This requirement concerns protection from receiver sensitivity degradation due to incidence (either from one's own transmitter or external jamming or interfering signals) of sub-nanosecond risetime RF pulses. Present-day receiver protectors of the ferri-diode or plasma-diode type cannot respond fast enough to suppress the leading edge of the RF incident pulse to yield the required low spike amplitudes (under 1 watt). The work reported in this paper covers the development of a fast-acting pn junction to act as a self-limiter. The junctions, when phase-integrated and cascaded behind plasma limiters, form passive receiver protectors capable of providing adequate protection to low-noise receivers using Schottky barrier-type mixers with 5 to 10 μ diameter junctions. This protection extends to RF pulses having risetimes $\geq$ 0.8 nsec and power levels up to tens of kilowatts.

Varactor Development

To achieve sub-nanosecond turn-on in RF self-activated (no dc bias) limiters, the depletion layer must be relatively small so that charge injection will occur in times of the order of a few RF cycles. Since breakdown voltage is not an important consideration in self-limiting, the base region can be made quite small. The turn-on time for a mesa-type pn junction is primarily a function of stored charge and series resistance, and it can be shown to be proportional to w_b^2. Limitations due to charge mobility (silicon μ = 500 $cm^2/V\text{-}S$) for a 1.2 μ thickness at unity impressed voltage yielded injection time of 0.06 nsec.

A series of 0-bias punchthrough wafers was fabricated with depletion layers ranging from 0.4 to 1.8 μ (figure 1a). Certain wafers were not passivated so that C_J (nominally 0.15 pF) could be controlled by etching down mesa diameter and continuously monitoring capacitance. The junctions had nominally R_sC_J product of 0.5 psec, lifetimes of 6 ±1 nsec, and $C_{J(0)}/C_{J(-6)} \leq 1.15$. All were packaged in the 023 case with C_C = 0.2 pF and L_C = 0.42 nH, and all were evaluated for transient isolation response to a nanosecond risetime incident pulse.

Varactor Transient Attenuation Response

The mount (figure 1b) used to evaluate the diodes had no provision for external bias; thus each diode was tuned for steady-state isolation by sweeping RF pulsed power at 0.5 mW (low-loss) and 10-W (isolation) amplitudes. This method ensured optimized high/low loss performance at resonance prior to the constant-frequency transient isolation experiments. The mount was checked for any transmission delays by using a cased dummy capacitance in a circuit capable of measuring 0.1 nsec time lags; no measurable delay was found. The mount equivalent circuit is shown in figure 2.

To determine the transient isolation of the pn junctions, an incident step pulse with near-zero risetime is required. Such an RF source would simplify the measurement, since the transient isolation would be observable as the risetime of the pulse at the output port of the mount. A special plasma switch was fabricated (figure 3) and used to clip the front and back of a magnetron-generated RF pulse to yield a 1 nsec risetime, 2 nsec pulsewidth, 90 kW peak power pulse; suitably attenuated with adjustable width control this pulse was used as the evaluation source. However, the risetime of this source was approximately equal to the transient isolation periods

*The work reported in this paper was performed under contract No. F33615-72-C-2054, Avionics Laboratory, USAF, WPAFB, Ohio.

expected; consequently, a measurement technique was devised that allowed the finite risetime of the RF source pulse to be separated from the isolation response.

In figure 4, data on transient isolation α_T is plotted with reference to the rising edge of the 6 nsec, 10-W source pulse. Also plotted is the steady state isolation (α_s) as a function of time; however, α_s was measured as a function of incident power using a 1 μsec pulse. Parameter α_s is a plot of the isolation response of the limiter as though the diode were acting with zero time lag. Thus, the α_S-α_T plot is a measure of the attenuation response, which essentially eliminates the contribution due to the finite risetime of the RF source. This method was used for comparing diodes of different base-region thicknesses.

Figure 4 shows that 0.5 nsec into the RF pulse the limiter lags the ideal response by 5 dB; at 3.5 nsec the transient isolation period ends and 13.5 dB steady-state isolation occurs. This method requires a point-by-point plot of each sampling CRO waveform photographed. The 5 dB lag caused by the slow diode response is shown by the spike on the output waveform in figure 5. Attempts to reduce this spike by using externally-coupled Schottky barrier or point-contact diodes failed due to nanosecond delays of the external circuitry. Figure 6 depicts the data of attenuation response with depletion layer widths from 0.4 to 1.8 μ at constant frequency. The 0.4 μ diode reaches 10 dB isolation (corresponding to a spike output under 1 W) in 0.5 nsec with a relatively high steady-state isolation of 18 dB in 1.5 nsec.

Separate tests to burn out two 1.8 μ junctions using 6-nsec RF pulses showed that 500 W caused one to open, and 1 kW caused the other to short.

Integrated Receiver Protector

A four-diode quarter-wavelength spaced self-biased limiter was fabricated using two 1.8 μ junctions as the coarse limiters and two 0.9 μ junctions as the fine limiters. A signal below the threshold (less than 0.5 mW) was attenuated 0.35 dB over a 700 MHz band for the four-stage limiter. Three plasma limiters were phase-integrated in front of the diode limiter to form a high average power passive receiver protector with under 0.8 dB loss over a 7 percent band. Using a 6 nsec pulse with a 1 nsec risetime, the high power data depicted in figure 7 shows that from 0 to 35 kW the spikes do not exceed either 0.9 W or 0.03 ergs. A set of leakage data using from two to four diodes of various junction thicknesses is shown in figure 8. It is seen that reduced spike amplitudes are a function of both the number of junctions and the base region thicknesses. The 0.4 μ diodes are still being evaluated and data is not yet available. Figure 9 shows a 1.4 W, 1.8 nsec output spike at an incident power of 26 kW, using a 2 nsec, 9.3 GHz source.

Balanced Mixer Burnout Data

Pairs of GaAs Schottky barrier packaged diodes were sequentially installed in a waveguide balanced-mixer located immediately behind the receiver protector, and a series of RF burnout (defined as a 1 dB increase in NF) measurements was made. Each test consisted of subjecting the diode pair in the mixer to 10^6 spikes at each output amplitude by controlling the amplitude of the 6 nsec incident pulse. Both during the burnout test and in the periodic NF checks, the LO power was optimized for minimum NF and the input VSWR was measured. The results of the mixer burnout tests are shown in table 1.

TABLE 1

MIXER BURNOUT DATA

Mixer		Measured NF with 1.5 dB IF					
		Initial (dB)			Final (dB)		
Schottky Diode Type (Case)	Pairs Tested	No. 1	No. 2	No. 3	No. 1	No. 2	No. 3
Alpha D5880A (DO-23)	3	7.2	7.2	7.2	7.2	7.2	7.3
MA 40071G (DO-23)	2	6.4	6.6		6.4	6.6	
MA 40071H (DO-23)	2	6.1	5.9		6.0	5.9	
GE VX4534 (DO-23)	3	6.6	7.8	7.4	6.7	7.9	7.4
HP 5082-2711 (49)	2	10.1	10.3		10.1	10.3	
HP 5082-2713 (49)	2	8.3	8.3		8.4	8.8	

The data indicates that negligible (under 1 dB) change in NF occurred for all diode pairs. From this, one may conclude (1) that for a series of 5 to 10 μ junction diameter GaAs Schottky barrier diodes in a balanced mixer configuration, a safe value for the highest spikes is $\leq$ 1 W for spike durations 10 nsec or less; and (2) that, for the power limiter being investigated in this paper, adequate protection of Schottky barrier mixers is obtained for a wide range of input pulse risetimes ($\geq$ 1 nsec), durations ($\geq$ 2 nsec), and amplitudes (0-35 kW).

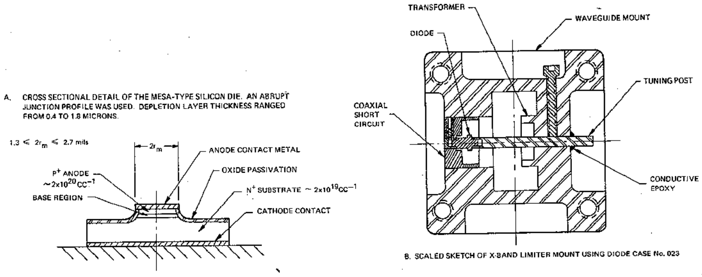

Fig. 1 Die and Packaged Chip in Mount

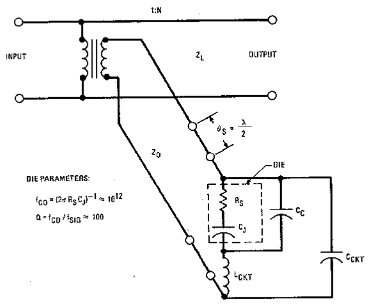

Fig. 2 Equivalent Circuit of Limiter Mount Under Reverse Bias, Low-Loss Mode

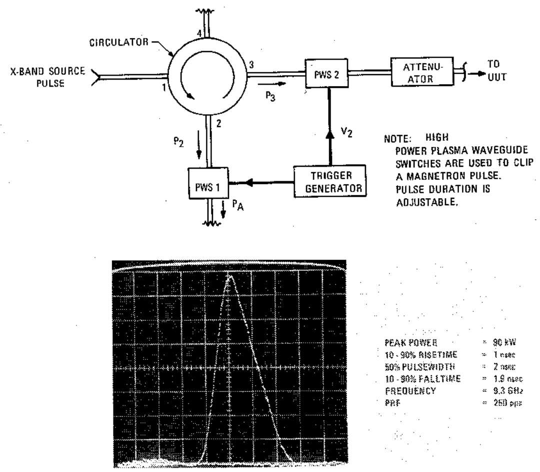

Fig. 3 a) Generalized Schematic of Circuit Used to Generate Fast Rise Output Pulse
b) Double Exposure Oscillogram of Detected RF Envelope of Incident Power Pulse and Zero Power Baseline

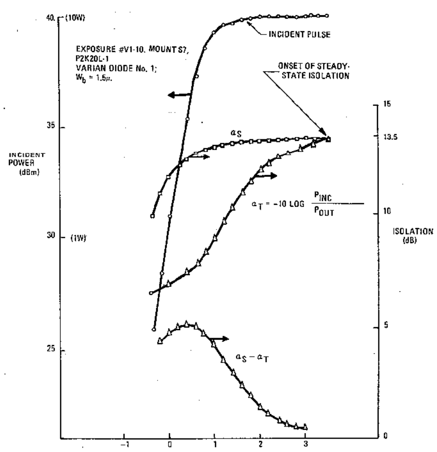

Fig. 4 Attenuation as a Function of Time Referenced to Risetime of Incident RF Pulse

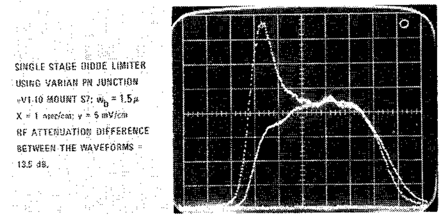

Fig. 5 Double Exposure of the Detected Waveform of the Output (Spike) Pulse and 10 W, 6 nsec Input Pulse at 9.3 GHz

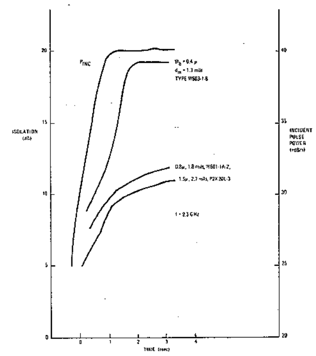

Fig. 6 10 W Isolation Data for Various Base Region Thickness at Constant Frequency

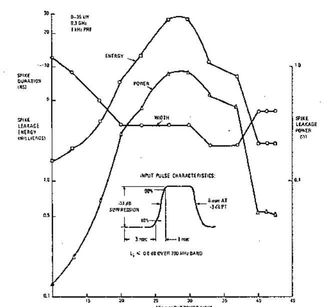

Fig. 7 High Power Data Using Two Coarse Limiters (1.6 μ) and Two Fine Limiters (0.9 μ) (S/N 02 DL-4)

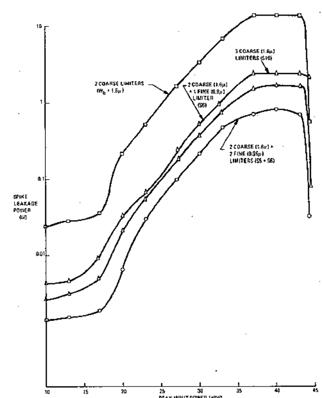

Fig. 8 Spike Leakage Power vs Input Power at 9.3 GHz for Three Plasma Stages Cascaded with Diode Limiters

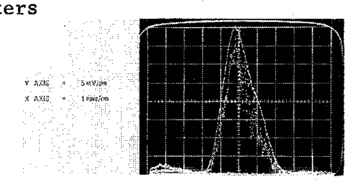

Fig. 9 Double Exposure Oscillogram of 26 kW, 2 nsec Input Pulse and 1.4 W, 1.8 nsec Output Pulse