V-15. Improved Duplexing Techniques Employing Gas TR and Semiconductor Limiter Devices

R. Tennenholtz and P. Basken

Microwave Associates, Inc., Burlington, Mass.

The TR Tube Dilemma. The present-day TR tube, through constant improvements, has approached a point where basically all parameters, with the exception of one or two, can be optimized. The designer, at best, can satisfy a specific rigid requirement only at the expense of another. This typically involves a "trade off" in performance with respect to such characteristics as crystal protection, life, recovery time or power handling capability.

Figure 1 shows performance characteristics of a typical X-band TR tube. In many applications, extremely fast recovery time is required. As a result, spike energy, and with it crystal noise figure degradation, increase. This is a result of the incompatibility between fast recovery time and reliable crystal protection. This dilemma does not occur infrequently; it can be safely stated that a primary effort in TR design within the last ten years is to improve crystal protection capability. This has been especially true in the frequency region of X-band and above. No major breakthrough, other than improved keep-alive designs, has been achieved in that time, although relatively minor improvements have occurred, primarily through refinements of known techniques. This general situation exists due to the basic unstable nature of gas plasmas as found in TR tubes. Periodically, bursts of large energy values can pass through the TR tube and cause unexplained crystal failures.

The Semiconductor Limiter Concept. In the field of microwave power limiting, large advances have been made as a result of the availability of high-quality semiconductor diodes, namely, the varactor and PIN diodes.

Figure 2 illustrates the equivalent circuit and rf impedance characteristics of such diodes. The varactor can be considered as a voltage variable capacitance, while the PIN diode behaves as a voltage variable resistance. By incorporating either of these diodes into a suitable microwave circuit environment, efficient limiting action can be obtained. This results from the interaction of the PN junction and the applied rf voltage across it. As can be

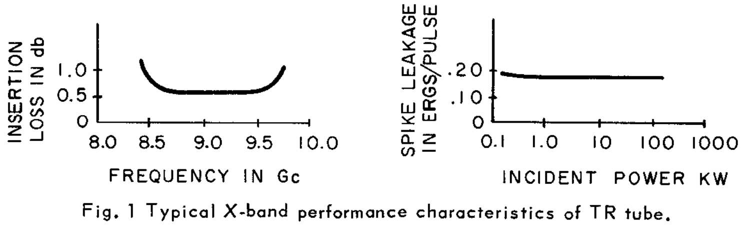

Fig. 1 Typical X-band performance characteristics of TR tube.

seen by the impedance plots in Fig. 2, a drastic change in diode impedance is obtained as bias voltage is varied. This bias voltage can be secured either through rectifying the applied rf signal or application from an external dc source; the latter is characteristic of a diode switch.

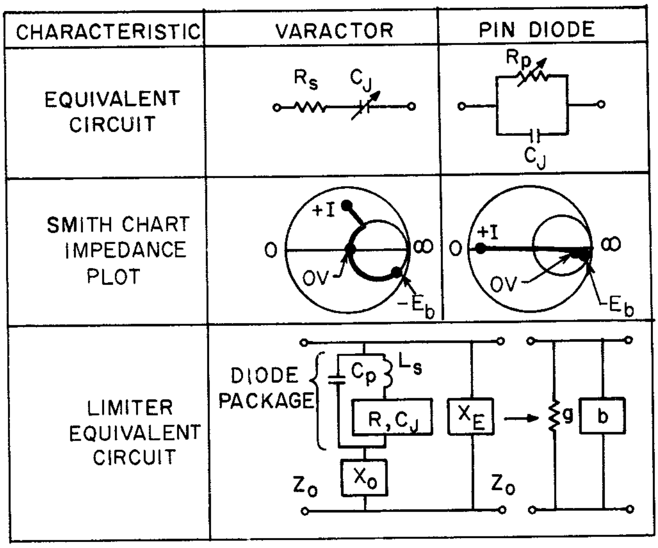

Fig. 2 General characteristics of limiter diodes and typical limiter equivalent circuit.

In the case of a varactor, self-rectification easily occurs and limiting action is automatic. However, the PIN diode is an inefficient rectifier at high microwave frequencies. To overcome this, a crystal diode can be placed preceding the PIN diode to sample some small portion of the applied rf power. Its rectified output can then be fed to the PIN diode and enable it to switch. Through use of this scheme, the PIN can be made to operate as a true passive limiter.

Because of its constructional details, the PIN diode has a very small capacitance per unit junction area when compared with a varactor. As a result, it is larger and more rugged in nature and can dissipate more power than the varactor. However, as a by-product, the PIN exhibits relatively slow switching time characteristics (20–50 nanosecs). As a result, a spike leakage power characteristic will be evident. Therefore, the PIN is used to limit an initial high power level, and its leakage is reduced by a following varactor limiter stage. To date, at X-band, PIN limiters have operated at levels of 2,000 watts and varactor limiters at levels of 100 watts. This illustrates the desirability of a combination PIN varactor limiter.

Also shown in Figure 2 is the equivalent circuit of a typical limiter stage. The values C_p and L_s represent diode package parasitic reactances. The values X_o and X_E are external reactances intentionally introduced to secure high isolation and low loss under high and low applied power conditions, respectively. This enables the limiter to approach ideal open and short circuited conditions across the transmission line, Z_o.

Semiconductor Limiter Performance. Figure 3 illustrates typical *X*-band performance characteristics of a high-power PIN/varactor limiter configuration. A basic module circuit consisting of a coax stub in shunt with the waveguide is utilized. The diode, either PIN or varactor, is placed at the end of this coax line. This permits an extremely close approximation of the circuit shown in Fig. 2 to be achieved.

As for reliability, several high-power *X*-band limiters have been life tested at 500 W for longer than 4,000 hours. At the conclusion of these tests, no change in over-all performance was detected.

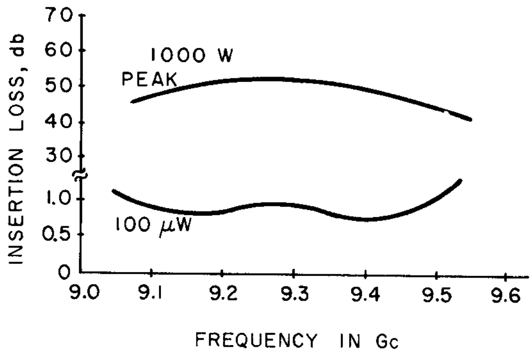

Fig. 3 X-band performance characteristics of a high-power PIN/varactor limiter ($t_p = 1\ \mu s$; $D_u = 0.001$).

TR/Semiconductor Limiter Performance. Utilizing the TR shown in Fig. 1 and a low-power varactor limiter, a series of tests was conducted. Figure 4 shows results of these tests on flat and spike leakage power as a function of ambient temperature over the range of 25 °C to 130 °C. The TR tube had a flat leakage power of 12 mw at room temperature. At 130 °C, this increased to 75 mw—a potentially dangerous level for low noise figure crystals. By introducing the varactor limiter after the TR tube, flat leakage was reduced to 4 mw. In addition, spike leakage energy was reduced to a very low level. These represent a significant reduction in TR leakage at the cost of a few tenths of a db insertion loss.

In terms of crystal protection, it is usually not the 0.10 to 0.15 ergs of leakage energy from a TR tube that causes burnout; crystals at *X*-band can withstand this. However, they cannot withstand the occasional burst of 0.5 to 1.0 ergs due to little understood plasma oscillation in the keep-alive discharge. It is here where the limiter proves its greatest worth.

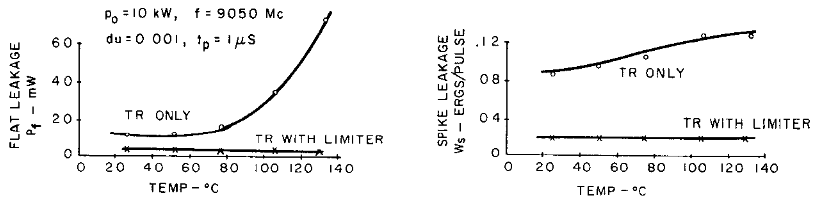

Fig. 4 TR-limiter combination performance characteristics.

A Proposed Long-Life Duplexer. Utilizing present-day technology, a combination gas-semiconductor duplexing device as shown in Fig. 5 is proposed. No keep-alive is employed. In addition to the performance characteristics listed in Table I, it also offers complete crystal protection over the entire temperature and power range.

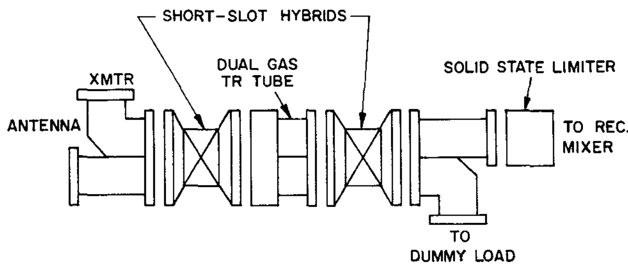

Fig. 5 Proposed X-band duplexer.

TABLE I
Characteristics of Proposed X-band Duplexer

	Minimum	Maximum
Bandpass	–	800 Mc
Receive Loss	–	1 db
Transmit Loss	–	0.5 db
Operational Life	5000 hrs.	–
Operational Temperature	$-55\,^{\circ}C$	$125\,^{\circ}C$
Peak Power Handling	0	1 mw
Average Power Handling	0	2 kw
Pulse Width	20 nsec	10 μsec
Crystal Degradation (Δ_{NF})	–	0.5 db
Recovery Time (3 db)	–	2 μsec
Spike Energy (2 : 1 Ant. Mismatch)	–	0.02 erg

In conclusion, it can be said that through use of a relatively new device —the semiconductor limiter—the design of gas TR devices can be optimized to take advantage of their excellent power handling capability. In addition, an order of magnitude in crystal protection capability is achieved.