A LIMITING FILTER

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ABSTRACT

A limiting filter is a new type of microwave circuit device, combining the nonlinear properties of a limiter with those of conventional filter designs. A limiting filter whose design is based on standard filter design theory is modified by the addition of PIN diodes or other nonlinear devices, which give the filter limiting properties at high power levels.

INTRODUCTION

A limiting filter is a new type of microwave circuit device (patent pending), that is essentially a filter modified by the addition of PIN diodes or other protection devices, which give the filter nonlinear limiting properties in its pass band. The function performed by the limiting filter is currently accomplished by a combination of a filter and one of the many existing protection devices (for example, the PIN diode limiter [1,2]). A potential application for a limiting filter would be the front end of microwave receivers. It would prevent receiver interference from out-of-band signals, and would prevent receiver upset or damage by limiting inband rf transients.

A limiting filter's design is based on standard filter design theory [3]. This paper specifically investigates stripline and microstrip filter designs modified by the incorporation of PIN limiter diodes.

ADVANTAGES AND DISADVANTAGES OF A LIMITING FILTER

A limiter incorporated within the design of a filter has many advantages. First, it is more compact than a separate filter and limiter. Second, because of the design of many microwave filters, the proper placement of limiter diodes can provide greater pass-band isolation in the on state than could be achieved with the same number of diodes in a standard limiter design. Third, a limiting filter can be fabricated easily in existing microwave circuit structures (i.e., microstrip, monolithic, etc) using existing filter design methods. Fourth, the PIN diodes could prevent arcing in filters at very high powers.

A limiting filter has several disadvantages. First, the limiting filter tends to have more insertion loss because the Q of the PIN diode is less than the standard resonator. Second, because of the nonlinear properties of diodes at intermediate power levels, the diodes could generate harmonics that could be a problem with some applications. To date this phenomenon has not been seen. The future work planned will address this potential problem. Third, if the junction capacitance of the diode varies, the frequency response of the limiting filter will also vary. This effect has not been seen because as the junction capacitance changes, the junction resistance changes, which seems to dominate the frequency response of the limiting filter.

EXAMPLES OF LIMITING FILTER DESIGNS

Presently, the limiting filter concept has been tried on three types of filters: (1) a band-pass filter using quarter-wavelength shorted stubs and quarter-wavelength connecting lines, (2) a bandpass interdigital filter, and (3) a bandpass coupled line-filter. All three filters were de-signed in either stripline or microstrip and simulated on a computer-aided design (CAD) program, Touchstone*.

Experimental data are available only for the quarter-wave shorted-stub filter. The quarter-wavelength shorted-stub filter used is a four-pole, 0.5-dB Tchebyscheff ripple design, with a 1.0-to 2.0-GHz passband. This filter design is based on standard filter design theory [3]. The filter was then modified by the addition of two PIN diodes, as shown in figure 1. The circuit in figure 1 was modeled on Touchstone, and the calculated S_{21} parameters are shown in figure 2 for both normal low-power operation and limiting

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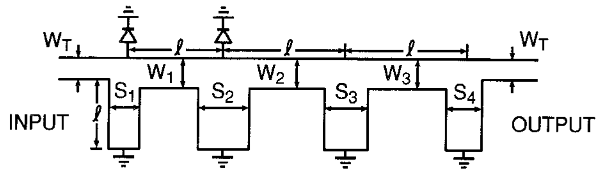

Figure 1. Four-pole Tchebyscheff 0.5-dB ripple 1- to 2-GHz passband limiting filter in stripline transmission line. PIN diodes are placed a quarter wavelength apart at voltage maxima of first two input stubs. Limiting filter was fabricated using 1/16-in. ϵ_r = 2.55 substrate, where W_T = 90.6, l = 1232.3, W_1 = 185, W_2 = 232.3, W_3 = 185, S_1 = 185, S_2 = 409.5, S_3 = 338.6, and S_4 = 126 mils.

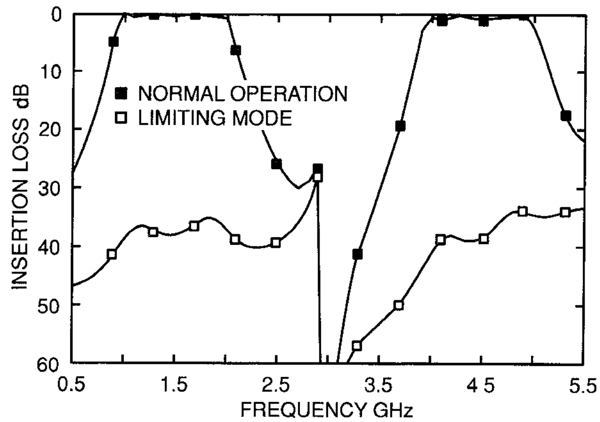

Figure 2. Computer response of filter in figure 1. Two curves represent response of limiting filter at low input power and high input power.

mode. The PIN diodes are modeled using the circuit in figure 3, where R_j = 2 Ω or 2 MΩ for on or off states, respectively, C_p = 0, $C_j(0)$ = 0.15 pF, R_s = 1 Ω, and L_s = 0.1 nH. Two diodes in this limiting filter provide over 35 dB of isolation without affecting the stop band of the filter. The filter was fabricated in stripline, and two packaged PIN diodes were used (Alpha Inc. package 375-001). A diode with a 5-μm-thick intrinsic region (I-region) was used for the input diode, and a 1-μm-thick I-region diode was used for the output diode (see fig. 1). The purpose of different I-region-thickness diodes is to give the limiting filter higher power handling capability and lower spike leakage energies [4]. Network analyzer measurements of S_{21}, which are shown in figure 4 for 0-dBm input, compare well with the simulated response in figure 2. The high-power characteristics, which were measured in the passband (1.5 GHz), shown in figure 5 as a plot of output power versus input power. At 1.5 GHz, the limiting filter provides over 30 dB of

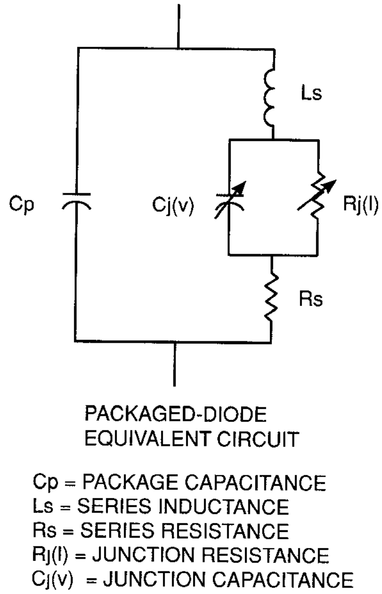

Figure 3. PIN diode model used in Touchstone for modeling diodes in limiting filters.

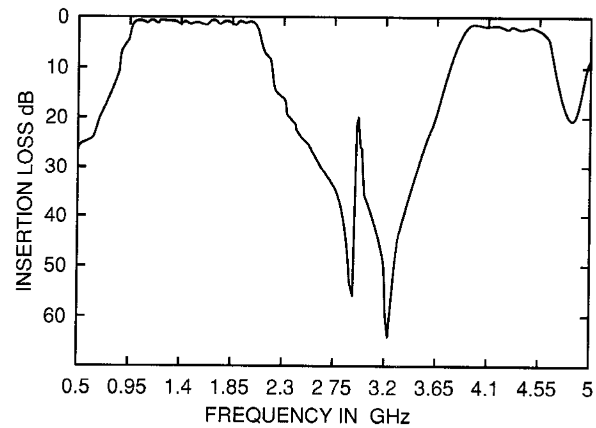

Figure 4. Transmission-loss measurements of quarter-wave shorted-stub limiting filter.

protection for inputs over 35 W. It is predicted that measured high-power results would compare well to the CAD results since the point at 1.5 GHz compared well. The spike leakage was also measured and is also shown in figure 5. With a 500-W, 1-ns-risetime input pulse, the spike leakage was 4 nJ.

The interdigital limiting filter uses the design of an existing five-pole, 0.1-dB Tchebyscheff ripple, 2.8- to 3.4-GHz passband interdigital filter [5]. Figure 6 shows the limiting filter design. In the original filter there were capacitors where the diodes are. The computer model for the diodes is shown in figure 3, where R_j = 2 or 2 MΩ for on or off states, respectively, R_s = 1 Ω, L_s = 0.5 nH, C_p =

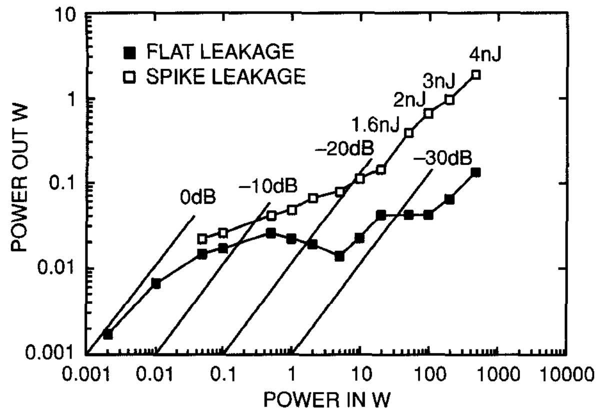

Figure 5. Limiting characteristics of quarter-wave shorted-stub limiting filter measured at 1.5 GHz. One curve represents flat leakage, while other represents peak spike leakage power from a 1-ns-risetime rf pulse. Energy of spike leakage is also labeled at various power levels.

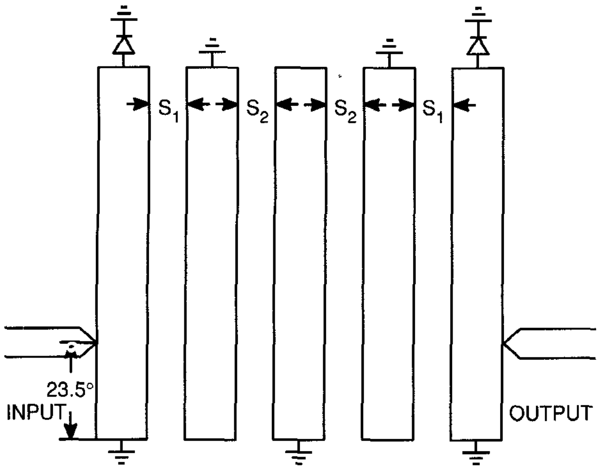

Figure 6. Five-pole Tchebyscheff 0.1-dB ripple, 2.8- to 3.4-GHz pass band interdigital limiting filter. PIN diodes are placed at voltage maxima of input and output elements. Circuit was simulated on 25 mil, ϵ_r = 9.9 alumina, where all filter elements are 23.6 mils wide, quarter wavelength long, S_1 = 28.3, and S_2 = 35.8 mils [5].

0.01 pF, and $C_j(0)$ = 0.15 pF. The calculated S_{21} parameter response of the interdigital limiting filter is shown in figure 7. In the on state, the limiting filter provides greater than 20 dB of isolation in the passband and retains its isolation in the stop band. This limiting filter's passband insertion loss was very sensitive to the diode parasitics. One may be able to improve the limiting filter by modifying its design to compensate for these parasitics.

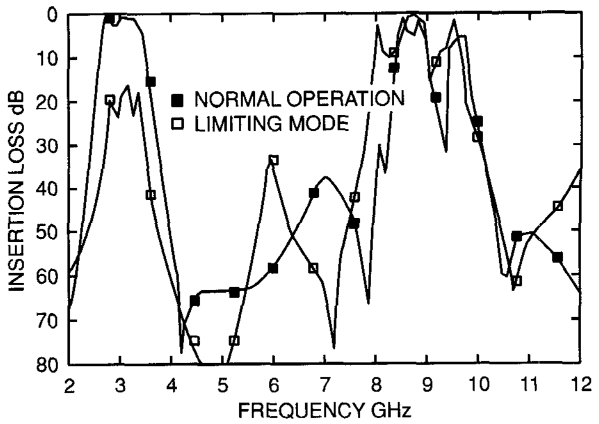

Figure 7. Computer response of interdigital limiting filter. Two curves represent scattering parameter S_{21} characteristics at both low and high input powers.

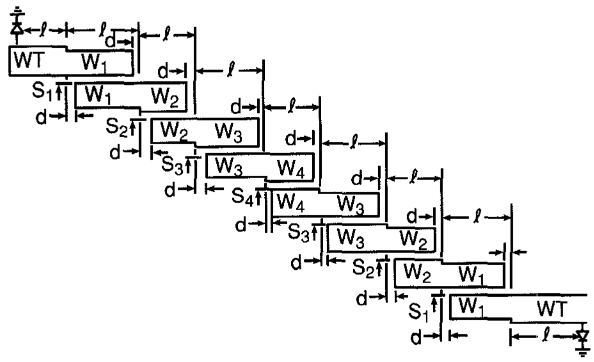

Figure 8. Coupled-line microstrip limiting filter. Limiting filter simulated on microstrip with a substrate thickness of 1/16 in. and ϵ_r = 2.55, where 1 = 1533.3, d = 10.3, W_T = 173.3, W_1 = 123, W_2 = 181.5, W_3 = 182.05, W_4 = 170.83, S_1 = 7.63, S_2 = 38.74, S_3 = 71.89, and S_4 = 76.74 mils.

The bandpass coupled-line limiting filter uses a filter design from Matthaei et al [3] of a seven-pole 0.01-dB ripple, Tchebyscheff filter with the band pass centered at 1.207 GHz. Again, the filter was modified by the use of two PIN diodes located at voltage maxima at the input and output of the diode, as shown in figure 8. The CAD S_{21} results for both on and off states are plotted from 0.5 to 5.0 GHz in figure 9. Over 37 dB of isolation is obtained in the limiting mode in the full sweep from 0.5 to 5 GHz. Note that in the limiting mode, spurious pass bands are also being limited. Because the coupled-line filter has no inherent ground return, one would have to be supplied at the input and output for this particular design to operate most effectively [4].

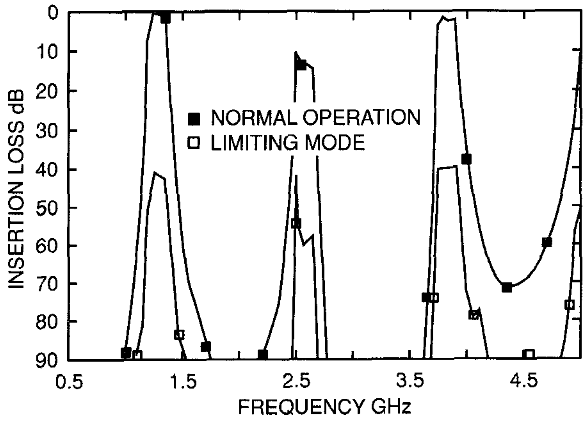

Figure 9. CAD results for coupled-line limiting filter in both normal operating and limiting modes.

LIMITING FILTER DESIGN CONSIDERATIONS

The following issues should be considered when a limiting filter with PIN diodes is being designed:

(1) The diodes need a dc return in order for them to work well; therefore, a filter design with an existing dc return is favorable.

(2) To minimize the limiting threshold power, the diode should be placed at a voltage maximum. This also tends to give high isolation in the limiting mode.

(3) Multiple diodes can be used to increase isolation. The three limiting filter designs were also run on the CAD program with only one diode. The results showed an increase in isolation in the on mode with the addition of the second diode.

(4) Spike leakage and power handling can be controlled by the intrinsic region thickness of the PIN diodes used [4].

(5) The diodes should be placed in the filter so that when the diode has a low impedance, the filter is detuned, eliminating the pass band but not raising the stop band.

DISCUSSION AND CONCLUSIONS

No rigid design techniques have been developed to optimize diode placement. In the three limiting filters designed, the placement of the diodes was based on engineering judgement and the use of a CAD program. Microwave filters incorporating diodes or FET's could most advantageously be used in monolithic circuits where damage can occur at low levels, and there may be little room for external limiters. For example, diodes could be used in place of shunt capacitors in a low-pass filter structure, where the diode's junction capacitance could be adjusted to the appropriate value. Future work is planned to explore limiting filters in monolithic microwave integrated circuits (MMIC) and waveguide. A study of the possible harmonics generated by limiting filters is also planned in future work.

References

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*Touchstone is a trademark of EEsof Inc.