A New Type of Low-Pass Filter That Attenuates by Dissipation

General

Leaky-wall filters [1]–[3] usually consist of a straight section of main waveguide to which are attached many narrower terminated auxiliary waveguides. These may be connected only to the broad walls or to both the broad and narrow walls. Attenuation in the stop band, above the main waveguide band, is due to absorption of power in the auxiliary waveguides. Unfortunately, the attenuation in the stop band eventually decreases as frequency increases because of the "optical beam" effect in oversize waveguide. A second fault of these structures is that there often are narrow regions of relatively low attenuation in the stop band, which are caused by multiple scattering from the periodic internal facets of the main waveguide.

A new type of filter that is essentially free of these undesired traits is shown schematically in Fig. 1. The input and output waveguides are connected by a waveguide structure of standard width, that zigzags in the E plane. Attenuation in the stop band is mainly resistive. The resistive (dissipative) structures are reduced-width waveguides connecting the main guiding structure to lossy material at the outer edges of the enclosure. These connecting waveguides are below cutoff in the pass band of the low-pass filter structure and, therefore, absorb power only in the stop band. No line-of-sight path exists between input and output, which in turn is due to the repeated change of direction of the guiding structure.

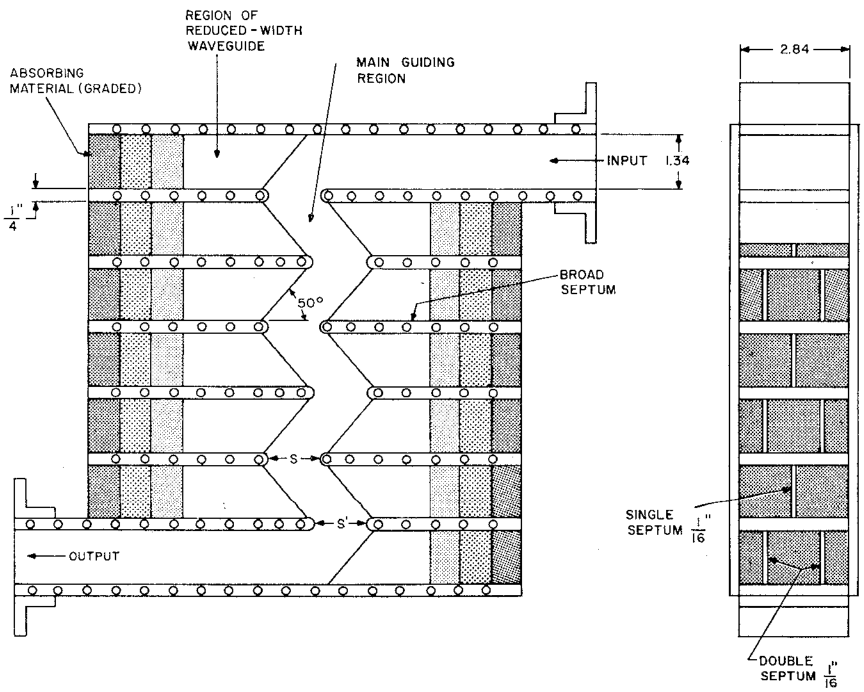
Manuscript received February 15, 1965; revised June 7, 1965. This work was supported by the U. S. Air Force, through the Rome Air Development Center, Griffis AFB, N. Y., under Contract AF 30(602)-3174.

The reduced-width waveguides are formed from normal-width waveguides containing septums. In the originally proposed structure the septum ends were at right angles to the walls. Here the septum ends are cut at an (arbitrarily chosen) angle of 50° to the walls of the cutoff waveguides, and tend to form a smoothwave-guiding structure rather than a reactive-filter structure. The input and output waveguides are in line with cutoff waveguides that are terminated with loads, and, therefore, absorb power in the stop band. This arrangement of input and output waveguides tends to lower the VSWR in the stop band. It is believed that the single and double septums of Fig. 1 efficiently absorb modes having either even or odd symmetry in the waveguide. The maximum width of the cutoff waveguides is one-half standard width in each case. Additional principles used in designing this filter are that the guiding structure should be as uniform as possible and of such proportions that it closely matches the rectangular waveguide impedance, i.e., it should be the same height, approximately as standard waveguide. A further precaution is that the cutoff frequency of the low-pass filter formed by residual discontinuity lumped -L and -C should be above the main waveguide band.

An Experimental S-Band Filter

An S-band filter was developed along the lines of Fig. 1. A photograph of this filter with cover-plate removed is shown in Fig. 2. Initial measurements on the structure of Fig. 2 indicated that a very good match could be obtained over the band 2.7 to 2.9 Gc/s; therefore, spacings s for the center portion of the filter and s' for the end sections of the filter, in Fig. 1, were methodically adjusted to optimize the match in that band. The final values of spacing are $s=29/32$ inch and $s'=1$ inch. The VSWR is less than

Fig. 1. Cross section of filter.



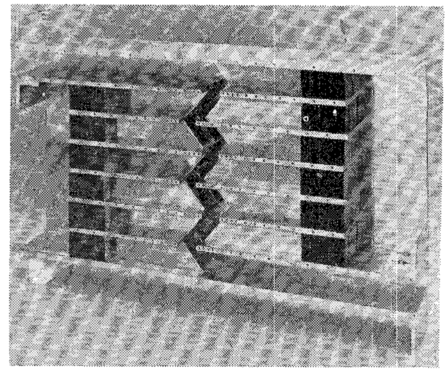


Fig. 2. Experimental filter with a cover plate removed.

1.27:1 and the insertion loss is less than 0.5 dB in the 2.7-to-2.9-Gc/s band. Figure 3(a) shows the VSWR in this range (upper graph), and Fig. 3(b) shows the total insertion loss as well as its two component parts, dissipation loss and mismatch loss (lower set of graphs). The sum of dissipation loss (which was measured independently as will be explained) and mismatch loss (which was calculated from the measured VSWR) is seen to equal the measured insertion loss to within experimental accuracy. The dissipation loss was measured by the short-circuit VSWR method. A short circuit was placed at the output of the filter and the VSWR of the filter was measured. The dissipation loss was then calculated from the following formula, accurate for large values of VSWR:

$$\text{Dissipation Loss} \approx (8.686/\text{VSWR}) \text{ dB}.$$

Adjustment of the filter was facilitated by grooves in the broad-wall (H-plane) septums in which the single and double E-plane septums could slide. Thin braided wire at the bottom of each groove aided in maintaining good electrical contact between the broad wall and the septums. The longer broad-walls (Fig. 1) are individually adjustable, and the shorter broad-walls and their connected single and double septums on each side are adjustable as units.

The performance of the filter over the band 2.4 to 19 Gc/s is shown in Fig. 4 which shows attenuation vs. frequency for the TE_{10} mode. The attenuation vs. frequency for the TE_{01} mode and reflection coefficient vs. frequency for both modes were also measured. Figure 4 was reduced from continuous frequency-swept recorded data. Long, smooth waveguide tapers appropriate for each waveguide band formed part of the input and output test equipment. The filter was, therefore, properly terminated and there were no intervening waveguide discontinuities. As a further precaution, in the event that the changing cross section of the tapers might excite higher modes, bulk pad material was inserted in the wide (S band) end of the terminating waveguide tapers (nearest the filter) to dampen potential resonances that might be caused by these higher modes. To measure reflection coefficient the pads were removed from the input and output tapers and a matched load was placed at the output.

Although the attenuation is generally above 35 dB in the stop band, there is a nar-

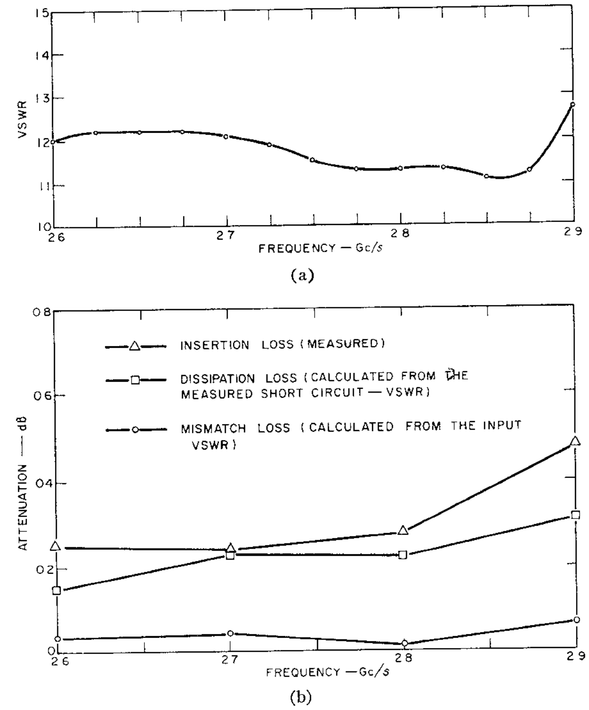


Fig. 3. VSWR and insertion loss in the pass-band of the filter of Fig. 2.

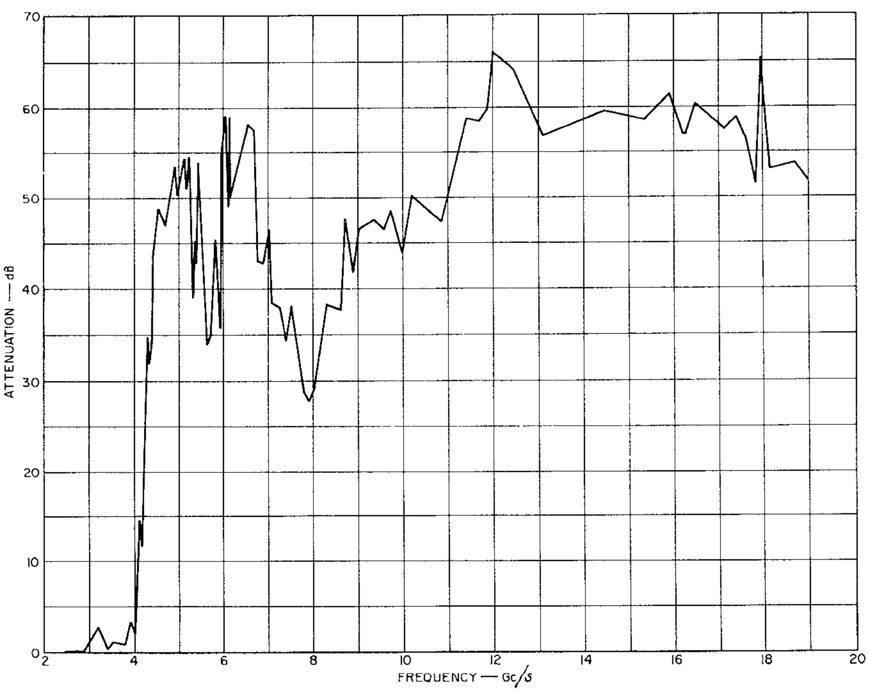


Fig. 4. Attenuation of the filter of Fig. 2 for the TE_{10} mode.

row band close to 8 Gc/s where the attenuation falls to about 27.5 dB. A tendency to a narrow spurious pass band (23-dB minimum attenuation) at about the same frequency was also found in the attenuation curve of the TE_{01} mode (not shown). The spurious response at 8 Gc/s, and other spurious responses could be reduced substantially by adding more side waveguides, with the septums placed in other positions than those shown in Fig. 1. The stop band is generally strong above this frequency for both the TE_{10} and TE_{01} modes and so confirms the basic philosophy of this new filter configuration. The measured reflection coefficient for both the TE_{10} and TE_{01} modes tended to decrease with increasing frequency toward a value less than 0.01 at 19 Gc/s. The filter structure including the effects of input and output tapers was found to be fairly well matched throughout the stop band. Only in the transition region at about 4 Gc/s where the side waveguides do not yet propagate the TE_{10} mode, and the filter impedance is mismatched (because of the reactive filter effect in the periodic structure) to the waveguide impedance, is there a reflection greater than half the input power. Below 2.9 Gc/s the measured reflection coefficient is below about −15 dB, in accordance with low measured VSWR (see Fig. 4).

A high-power test was made on the experimental filter. The available peak power was not enough to cause breakdown in the filter and the full peak power capability of this device is not known. However, it withstood 108 kW of peak pulse power with 2.6 μs pulse length and 0.002 duty cycle at 2856 Mc/s, without any sign of arcing. It should be emphasized that these tests were made in air at atmospheric pressure.

Conclusion

Both the passband performance and stopband performance of the filter conform generally to what was predicted, but further work would be required to achieve the optimum results. Although the filter is low-pass from 2 to 4 Gc/s and has a sharp cutoff due to increasingly strong reactive effects at 4 Gc/s, the filter as constructed (Fig. 2) was matched only from 2.7 to 2.9 Gc/s, and no attempt was made to obtain a good match out to 4 Gc/s. Of particular interest is the fact that the attenuation in the stop band tends to increase with frequency, unlike conventional leaky-waveguide filters, which tend to lose their attenuation at the higher frequencies.

Acknowledgment

E. Fernandes very helpfully performed the many tedious measurements and adjustments on the trial filter.

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References

[1] S. B. Cohn, "Design considerations for high-power microwave filters," *IRE Trans. on Microwave Theory*, vol. MTT-7, pp. 149–153, January 1959.
[2] V. Met, "Absorptive filters for microwave harmonic power," *Proc. IRE*, vol. 47, pp. 1762–1769, October 1959.
[3] V. G. Price, *et al.*, "Harmonic suppression by leaky-wall waveguide filter," *1959 IRE WESCON Conv. Rec.*, pt. 1, vol. 3, pp. 112–118.

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Re-entrant Directional Coupler Using Strip Transmission Line

This correspondence describes a printed-circuit directional coupler design that is applicable to tight coupling (1 to 10 dB) values; it is a strip transmission line equivalent of the re-entrant coaxial coupler de-

Manuscript received April 19, 1965.