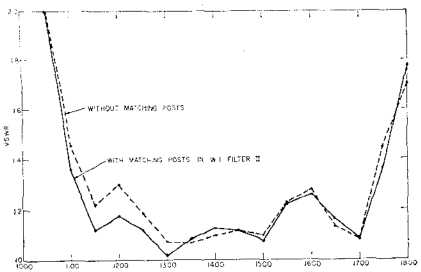

Fig. 4—VSWR of Waffle-Iron Filters I and II in cascade between two 6.500-inch by 0.400-inch waveguides.

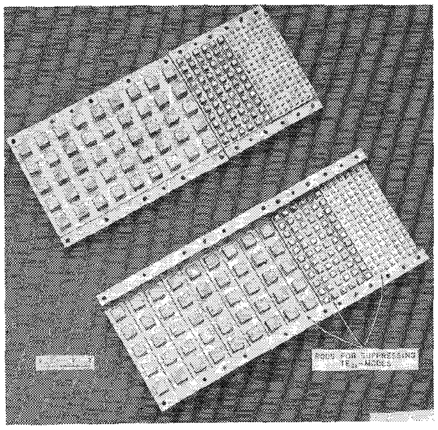

Fig. 5—Exploded view of three waffle-iron filters in cascade.

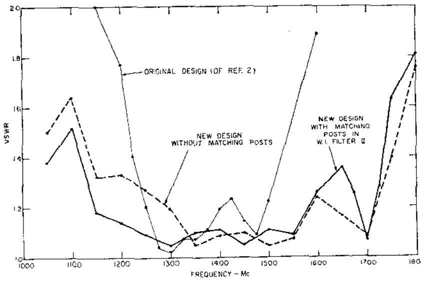

Fig. 6—VSWR of Waffle-Iron Filters, I, II, and III in cascade between two 6,500-inch by 0.400-inch waveguides, with capacitive bars near Waffle-Iron Filter III. (The VSWR of the original design [2] is also shown.)

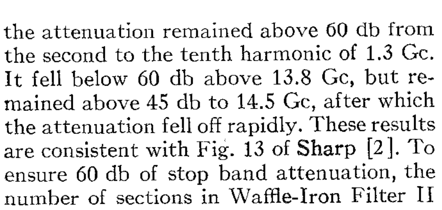

Fig. 7—Dimensions and positions of capacitive bars near Waffle-Iron Filter III.

the attenuation remained above 60 db from the second to the tenth harmonic of 1.3 Gc. It fell below 60 db above 13.8 Gc, but remained above 45 db to 14.5 Gc, after which the attenuation fell off rapidly. These results are consistent with Fig. 13 of Sharp [2]. To ensure 60 db of stop band attenuation, the number of sections in Waffle-Iron Filter II should probably be increased from 6 to 7 or 8. The wide stop band of the waffle-iron filter makes it useful in suppressing harmonic and other spurious frequencies, whether from laboratory signal generators or high-power transmitters [4].

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The Effect of Increased Design Bandwidth Upon Direct-Coupled-Resonator Filters*

INTRODUCTION

The Cohn synthesis[1] is generally preferred as a convenient design technique for direct-coupled waveguide filters covering a moderate bandwidth. Approximations inherent in the theory result in considerable deviations from the theoretical pass band response as the design bandwidth increases. The magnitude of the deviations is difficult to predict and proves troublesome in designs requiring a low pass band VSWR.

Some idea of the deviations likely to occur in practice has been obtained with the aid of a computer for the particular case of a 7-cavity filter. The method employed was to use the Cohn synthesis to calculate the filter parameters necessary to satisfy a particular specification. The resultant filter structure of shunt inductance elements, separated by lengths of transmission line, can be represented conveniently by matrices of rank two. In this representation the frequency response of such a structure can be swiftly evaluated with the aid of a conventional digital computer.

Thus the exact response of the synthesized filter structure can be found and the deviation from the theoretical curve determined.

EVALUATION PROCEDURE

In practice the susceptance of a post or iris in waveguide is given by a complicated function of guide wavelength, which is difficult to fit into a computer program. To avoid narrowing the scope of the analysis a simple proportionality relationship was assumed between the susceptance and guide wavelength. The other approximation in the analysis was the neglect of absorption in the waveguide. This assumption was justified for the bandwidths of interest in this investigation. Pass band responses were restricted to the equal-ripple Chebyshev type, and were computed for a range of bandwidths from 1 per cent to 20 per cent, centered at 9.5 kMc, in wg 16.

Results for specified pass band VSWR ripples of 1.05, 1.1 and 1.25 are shown in Figs. 1–3, respectively. For convenience all design bandwidths have been normalized in width on a frequency scale, so that the design equal-ripple points on the slopes of the characteristic coincide. The change in pass band response with increase in bandwidth, or reduction of the specified pass band VSWR, is thus made readily apparent. Two main effects can be observed from the curves,

1) For the responses in Figs. 1 and 2 large peaks occur near each end of the pass band. These peaks grow in amplitude with increase in design bandwidth, the upper peak shifting towards the center of the pass band. There is no sign of such peaks in Fig. 3.
2) A shift down in frequency of the upper skirt of the filter response occurs in all cases. This shift increases with increase in design bandwidth. There is a much smaller shift upwards in frequency of the lower skirt.

The difference in effect upon the upper and lower slopes of the response and the shift in the upper frequency VSWR peak is consistent with the symmetry of the design pass band response on a guide wavelength scale. This results in the design center frequency shifting towards the low-frequency end of the pass band. Thus any approximations in the synthesis which are dependent upon frequency will be more evident at the high-frequency end of the pass band.

Computations were made with higher values for the specified pass band VSWR. The results obtained were similar to those shown in Fig. 3. In general there is a slight decrease in the amplitude of the VSWR ripples, as the design bandwidth increases, accompanied by comparable shift in the attenuation slopes of the response.

ERROR IN COMPUTED CURVES

An attempt was made to estimate the error in the computed curves resulting from the approximate relation assumed for the guide wavelength. Because of a practical requirement measurements were made upon a 9-cavity wg 16 filter. The filter was manufactured using single posts of circular cross section for the inductive susceptances. Dimensions and positions for the posts were obtained from computations based upon formulas determined by Lewin.[2] These

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* Received August 12, 1963.

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[2] L. Lewin, "Advanced Theory of Waveguides," Iliffe and Sons, Ltd., London, England, p. 35; 1951.

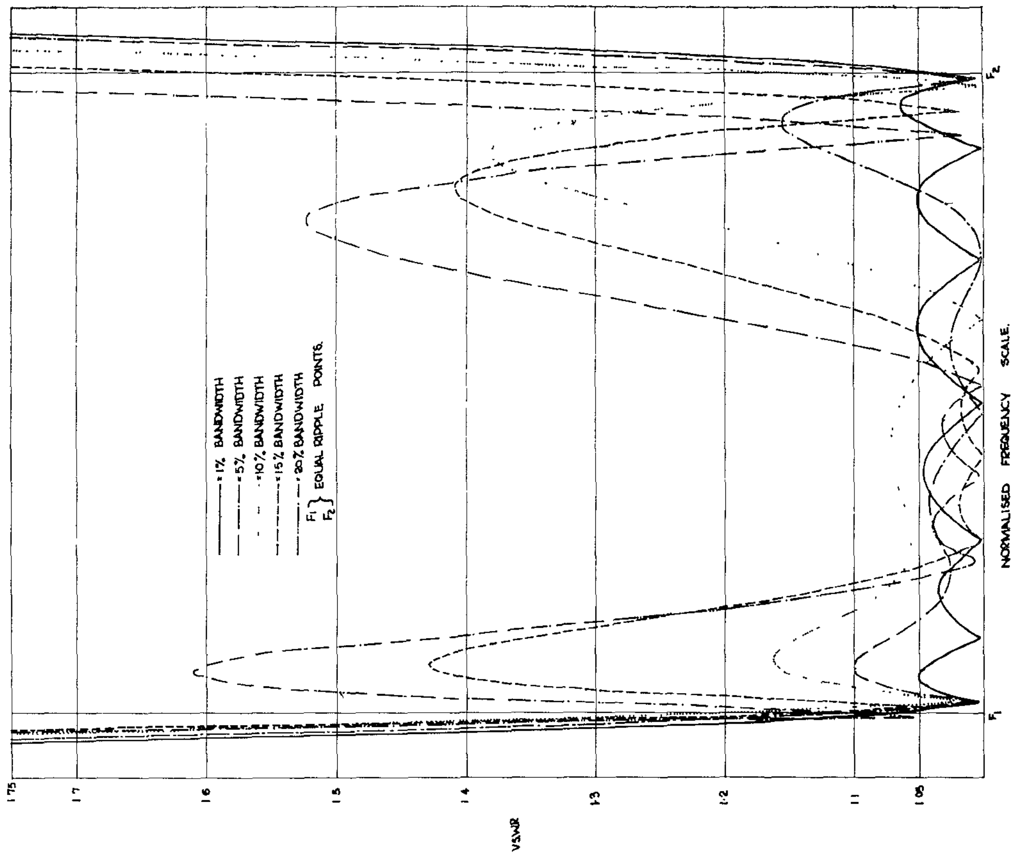

Fig. 1—Deterioration in pass band response with variation in bandwidth for specified VSWR ripple of 1.05.

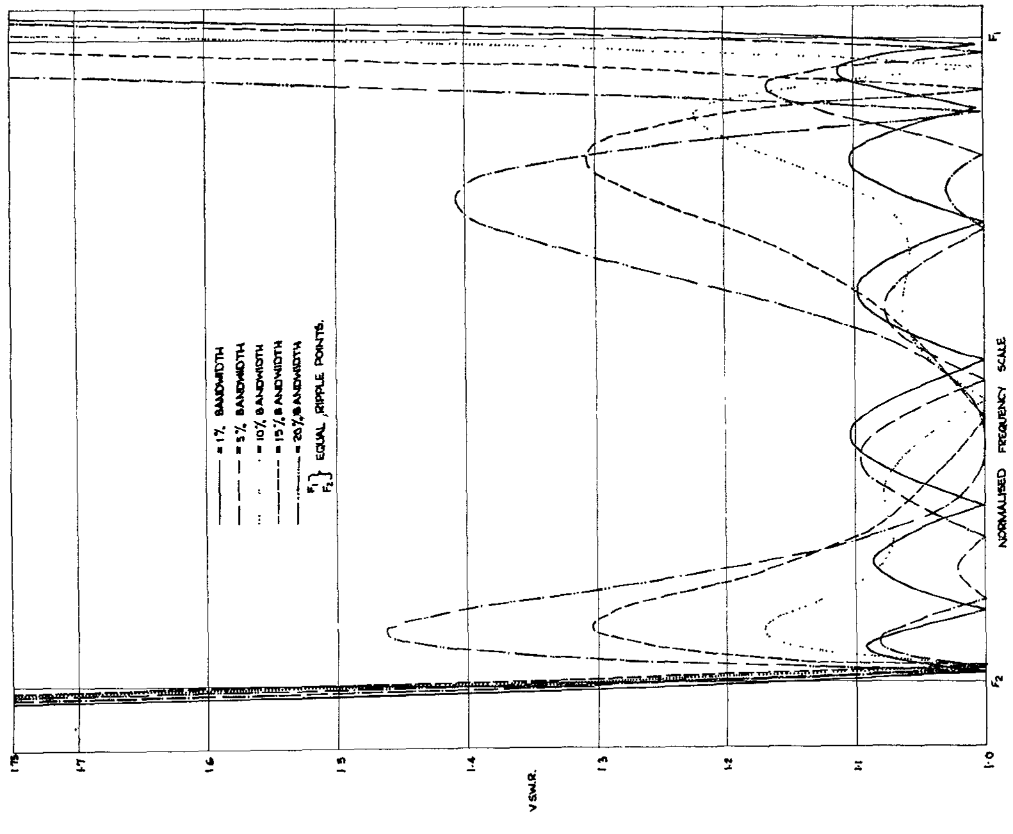

Fig. 2—Deterioration in pass band response with variation in bandwidth for specified VSWR ripple of 1.1.

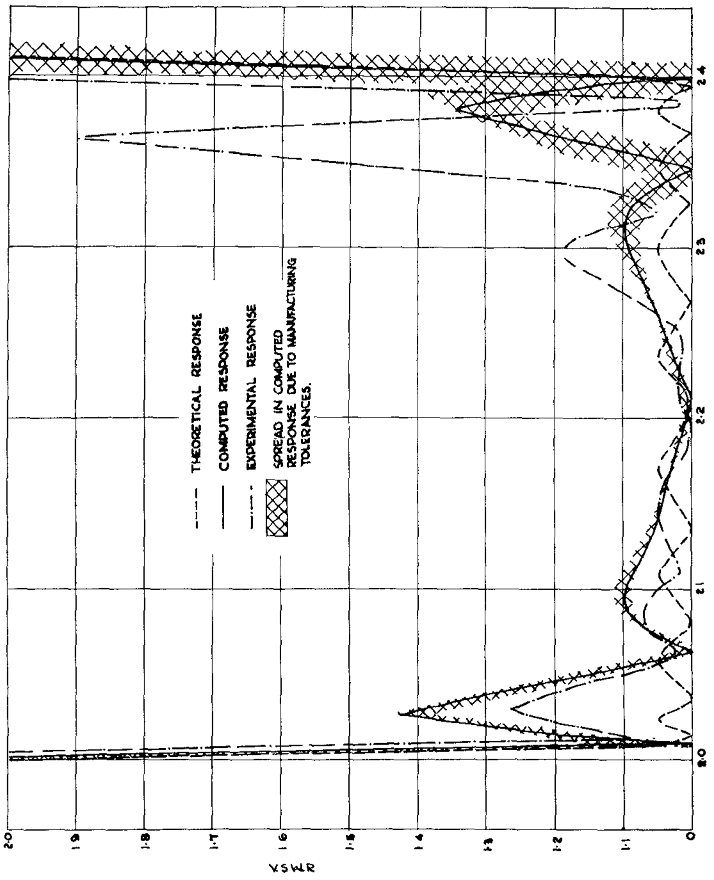

Fig. 4—Comparison of computed, theoretical and experimental responses for 9-cavity filter.

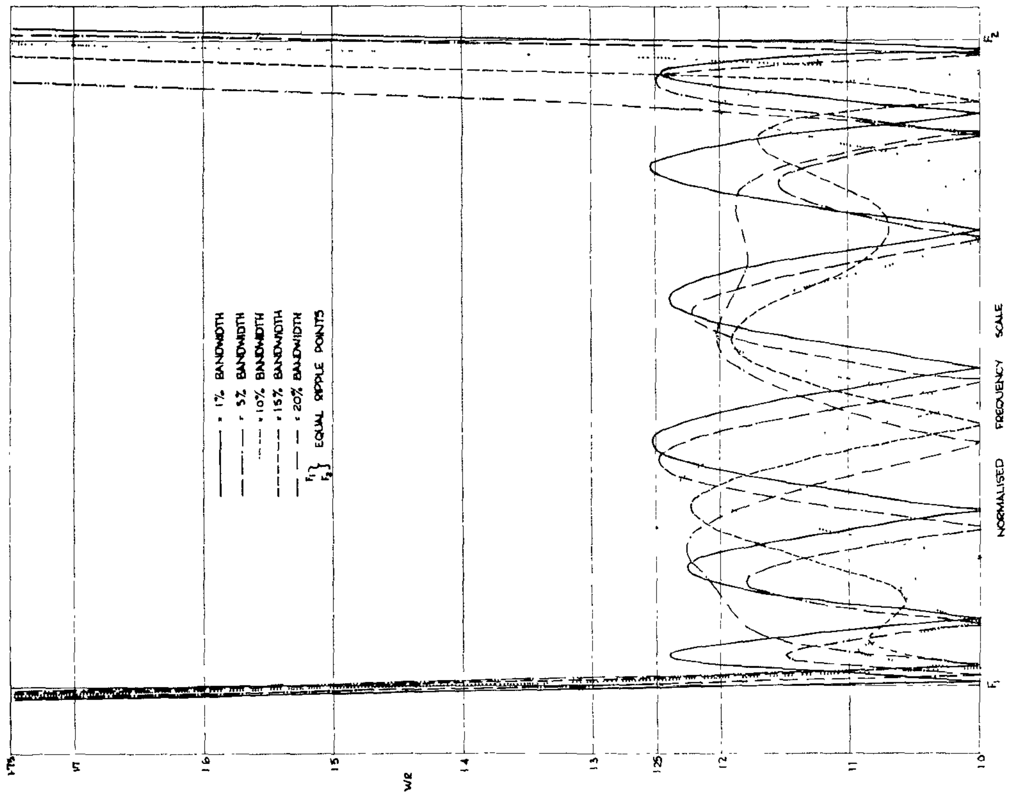

Fig. 3—Deterioration in pass band response with variation in bandwidth for specified VSWR ripple of 1·25.

formulas also permitted corrections to be made for the finite thickness of each post. Tuning screws were omitted from the design. In this manner the conditions necessary in the computation were simulated as far as possible in the actual design. Thus any differences between computed and experimental results would be due to manufacturing tolerances or errors involved in the susceptance structures. These latter errors are caused by the approximate relationship assumed for the frequency variation of the susceptance and errors inherent in Lewin's formulas, which were expected to have an accuracy of a few per cent.

The filter was designed for a nominal pass band VSWR ripple of 1.05 over a bandwidth of approximately 7 per cent, centered at 8.5 kMc. In Fig. 4 the experimental results are compared with the theoretical and computed responses. Manufacturing tolerances of ±0.001 inch were placed upon the position and diameter of each post. The overall effect of extreme tolerance error upon the susceptance values and cavity lengths was estimated and the resulting response computed in each case. The shaded area indicates the variation in response expected as a result of manufacturing tolerances. The experimental curve follows the computed curves fairly closely, except near the limits of the pass band. Thus the deviations at the pass band extremes, between the computed and experimental curves, result mainly from the approximate relationship assumed for the frequency variation of the coupling susceptances in the computation.

CONCLUSIONS

Although computations have been made for the special case of a 7-cavity filter the results are a good indication of the effects arising from increase in design bandwidth for all filters. In general it is to be expected that the deterioration in performance will be more severe with increase in number of cavities for a given filter. The results show that it is not advisable to design for a very low pass band VSWR when the bandwidth exceeds about 5 per cent as excessive peaks will be obtained in the pass band. For the particular case of the 7-cavity filter a design VSWR ripple of about 1.25 was found to be free from undesired peaks for bandwidths up to 20 per cent. Another factor which must be taken into account is the reduction in pass band width resulting mainly from a shift in the upper attenuation slope.

The computations have been carried out using a simple proportionality relationship for the variation of susceptance with guide wavelength. An experiment has indicated that a more accurate expression for susceptance may lead to the spurious pass band peaks becoming accentuated. A further reduction in pass band width will also occur, mainly as a result of a shift in the lower frequency skirt.

The process of repeated analysis can be applied to the problem of synthesizing filters with improved performances.[3] At the present time a technique is being developed which involves the progressive perturbation of the filter parameters starting with the approximate Cohn values. The technique has produced responses approaching the design specification for a 9-cavity filter, and it is hoped that results will be published in the near future.

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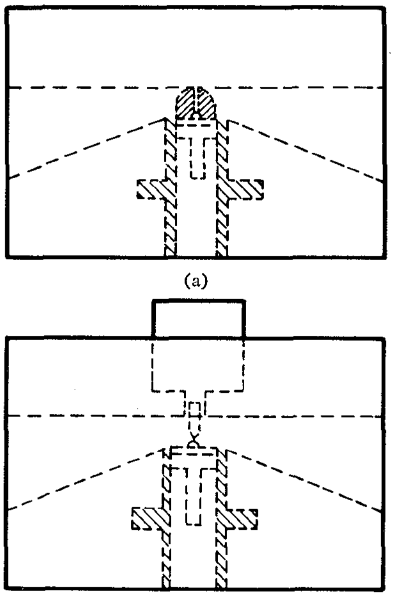
Tunnel Diodes as Millimeter Wave Detectors and Mixers*

Backward diodes and tunnel diodes have been successfully operated as detectors and mixers at microwave frequencies [1]–[5]. The extension of their usage from microwave frequencies to millimeter wave frequencies is a natural outgrowth of earlier work.

Tunnel diodes usually have less series resistance than ordinary crystal diodes or backward diodes and thus can be expected to give higher sensitivity and a lower noise factor. The frequency response of the negative resistance of tunnel diodes is good at microwave frequencies. However, at millimeter wave frequencies the usefulness of the negative resistance is curtailed by the junction capacitance. Reduction of this capacitance is difficult, but can be accomplished within the limits of practical design.

This correspondence reports the results obtained with a tunnel diode as a 55-Gc detector and as a mixer. Alloying techniques were used to fabricate the tunnel diodes which were then integrated into a tapered section of RG-98/U waveguide. Fig. 1 shows the arrangement of the diode in the waveguide. The first mount is made with an epoxied contact while in the second the contact is made by means of a wire passing through an opening in the top of the waveguide. No difference in sensitivity of diodes made by the two methods has been noticed; however, the epoxy method gives more mechanical stability.

The diodes used were of n-type gallium antimonide and tellurium. The impurity concentration of the gallium antimonide was 1 to 2×10^{18} per cc and the resistivity was 0.001 to 0.0025 Ω-cm. Fig. 2 is the I-V characteristic of a typical diode. Units


(a)

(b)

Fig. 1—Tunnel-diode mounts for millimeter wave mixer.

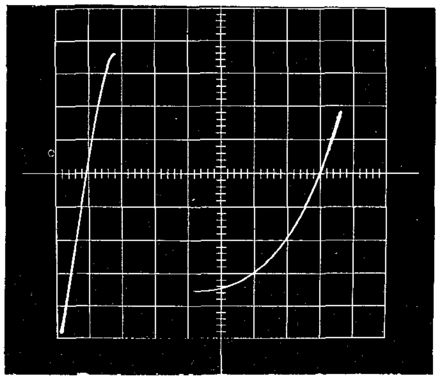


Fig. 2—I-V characteristic of a GaSb tunnel diode (0.1 ma/vertical division and 0.05 v/horizontal division).

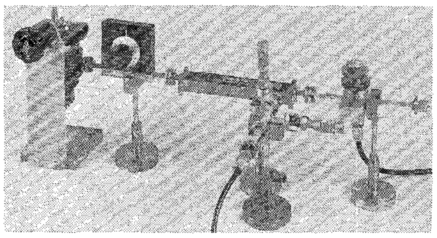


Fig. 3—A millimeter wave tunnel-diode detector.

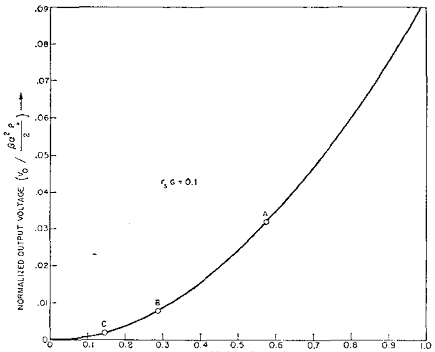


Fig. 4—Normalized output voltage as a function of diode quality factor.

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