DESIGN OF A CHANNEL DIPLEXER FOR MILLIMETER WAVE APPLICATIONS

Chung-Li Ren
Bell Telephone Laboratories, Incorporated
1600 Osgood Street
North Andover, Massachusetts 01845

The design of millimeter wave filters is in principle no different from the design of conventional microwave filters. In practice, however, several factors impose limitations to the choice of the filter structure. As a result, new filter structures must be used requiring new techniques for their design. In this paper, a new channel diplexer structure is described and a technique for its design is given. The expected electrical performance and the design procedure were verified by measuring the performance of a scaled filter model centered at 3.95 GHz. The results of these measurements are given. Practical application of the filter at millimeter wave frequencies will require further effort in the areas of physical design and manufacturing techniques.

A Millimeter Wave Channel Diplexer

One of the controlling design objectives for a millimeter wave channel diplexer is that the intrinsic losses must be kept reasonably low for both the through channels and the dropped channel. To fulfill this requirement, oversized waveguide and oversized cavities must be used. However, this will impose stringent limitations to the choice of the waveguide and cavities because, within the specified frequency band, no spurious modes should pass through cutoff in the main waveguide and spurious resonant modes in the cavities must be avoided.

Furthermore, there are physical limitations. First of all, at millimeter wave frequencies, the coupling waveguides of the bandstop sections must be 5/4 λg as compared to 3/4 λg used in conventional microwave designs. Also, the coupling apertures must be thick compared to the wavelength so that the fabrication of the filter is feasible. Finally, the cross-section of the waveguides at the diplexer ports (and the modes involved) are in general prescribed.

Obviously, these constraints make it necessary to search for new structures. Figure 1 shows such a new channel diplexer structure. It represents a compromise among the various design objectives enumerated above. The main waveguide is an oversized semicircular waveguide propagating the H_{01}^{o} mode. It can provide 18 percent frequency band with no mode passing through cutoff in the main waveguide. The resonant mode in the circular cavities is in the H_{112}^{o} mode. The dimensions of the circular cavities are determined such that no spurious modes exist within the band specified in the design. As in the conventional microwave filter design, the aperture coupled H_{112}^{o} cavities have asymmetrical frequency response. They are compensated to be symmetrical by the semicircular ridges in the main waveguide (Figure 1), which do not disturb the circular symmetry of the H_{01}^{o} mode and, therefore, excite no spurious modes. In order that the compensating ridges compensate for the asymmetry of the cavity frequency response without significantly affecting the aperture coupling, they have to be placed λg/2 away from the coupling aperture locations.

Diplexer Synthesis

Unlike conventional filters where only one mode function is involved, the millimeter wave channel diplexer shown in Figure 1 involves three different mode functions. Therefore, the frequency transformation commonly used in waveguide filter synthesis is no longer applicable. In addition, the 5/4 λg coupling waveguides introduce another problem in the synthesis which must be solved.

A new synthesis technique has been developed for the design of the channel diplexer of Figure 1. The proposed technique is briefly summarized as follows:

(a) The reflection and transmission properties of the coupling apertures are basically calculated from small aperture theory. The polarizibilities of the apertures, however, are derived from measured data.

(b) The resonant cavities have an asymmetrical frequency response. A symmetrical response can be obtained by extracting a negative inductance and subsequently compensating for it by a positive inductance. It is shown that the proposed compensation ridges provide such an inductance.

(c) In conventional microwave filter synthesis, coupling waveguides are treated as ideal impedance inverters with a correction applied to the Q's of the adjacent cavities. This step in the synthesis represents an approximation which deteriorates as the number of multiples of the quarter wavelengths increases and is not applicable at all for filter structures involving several modes. In the proposed synthesis technique, each 5/4 λg coupling waveguide is replaced with an exact equivalent circuit composed of frequency sensitive reactance elements and an impedance inverter. The characteristic impedance of the impedance inverter is shown to deviate significantly from a constant at the 3 dB points of the filter even for very narrowband designs.

(d) A suitable equivalent circuit of the diplexer of Figure 1 is shown in Figure 2. As a final step of the synthesis the circuit parameters of Figure 2 are matched at the specified half power frequencies to satisfy the condition of constant input impedance.

When a diplexer designed by this synthesis technique is analyzed, it exhibits precise 3 dB bandwidth, over 40 dB inband return loss and over 30 dB out-of-band return loss. It might be added that this technique is applicable to other filter structures involving a number of modes.

Experimental Design

An experimental model of the channel diplexer of Figure 1 with center frequency at 3.95 GHz, 3 dB bandwidth of 20 MHz and 0.175 inch thick irises, was designed and fabricated (Figure 3). At this frequency the dimensional tolerances of a fabricated filter can be effectively controlled and the design theory can be verified with high degree of accuracy. This filter is a scaled version of a diplexer intended for 102.75 GHz.

Figure 4 shows the measured return loss at the input port of the semicircular waveguide and Figure 5 shows the measured insertion loss both for the through channels and the dropped channel. The 3 dB bandwidth is seen to be 20.2 MHz which is only 1 percent larger than the design specification of 20 MHz. When the data of Figure 5 are compared with the characteristics of an ideal second order Butterworth filter the agreement is very good.

The experimental model was made mostly of machined brass. The measured loss at the center of the dropped channel (3.95 GHz) is 0.29 dB. If copper were used, the measured loss is estimated to be about 0.15 dB. This estimate is based on the ratio of the dc conductivities of brass and copper.

Summary

It has been shown that a channel diplexer, envisioned for use in a millimeter wave waveguide transmission system, can be designed. Very good agreement has been established between synthesis objectives, the theoretical performance and the measured performance of a scaled model. When the experimental model is scaled to 102.75 GHz, it should have a 3 dB bandwidth of 520 MHz and an operating band of over 12 GHz. If the waveguide surface roughness could be scaled, the minimum transmission loss of the dropped channel would be 0.8 dB. However, in practice, a surface roughness of 8 microinches is expected, and according to experience, the loss is likely to become higher; but it should be less than 1.5 dB. It must be pointed out that practical application of the filter at millimeter wave frequencies will require further development effort in the areas of physical design and manufacturing techniques.

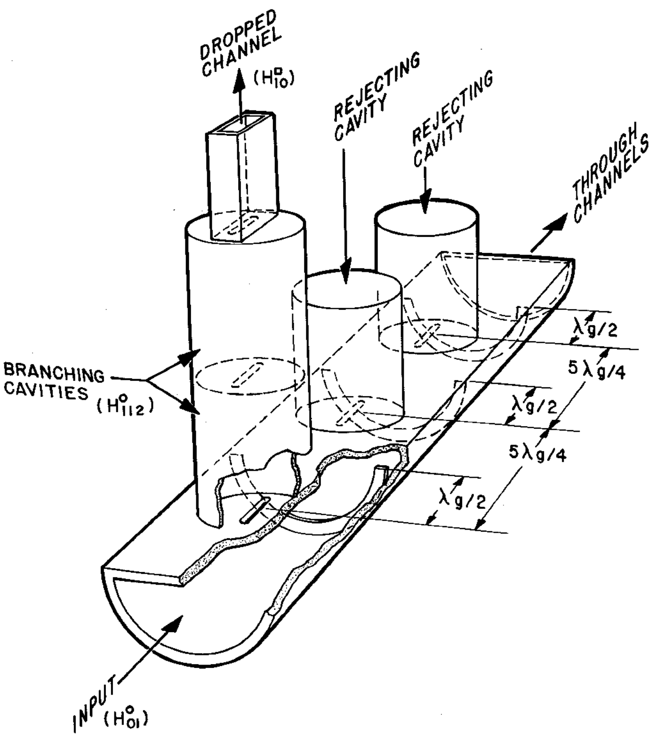

FIG. 1 SCHEMATIC DRAWING OF THE CHANNEL DIPLEXER

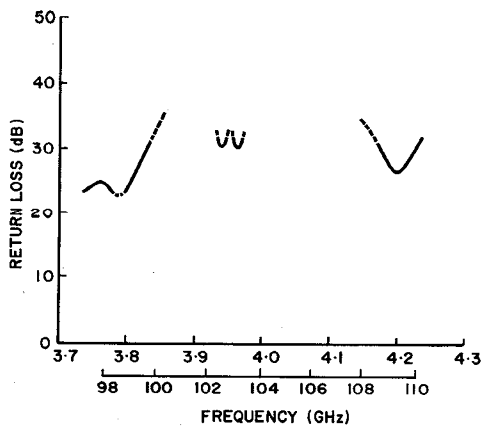

FIG. 4 MEASURED RETURN LOSS AT THE COMMON PORT

Acknowledgements

The author wishes to thank Dr. H. C. Wang of Bell Laboratories for helpful suggestions and discussions in arriving at the basic filter configuration, Mr. J. D. Connor for fabrication of the filter, Mr. F. G. Joyal for his assistance with measurements.

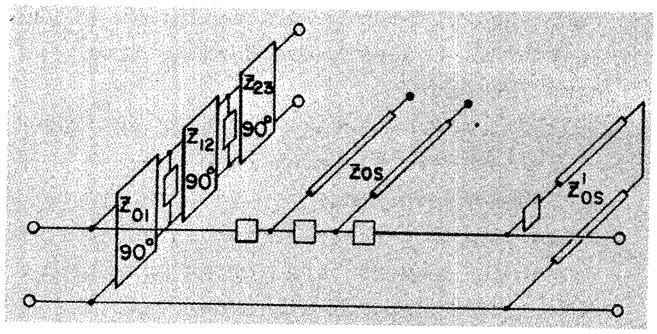

FIG. 2 EQUIVALENT CIRCUIT OF THE COMPLEMENTARY FILTER

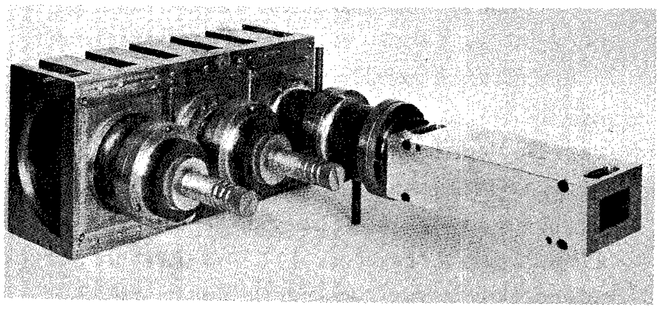

FIG. 3 PHOTOGRAPH OF H^o_{112} CHANNEL DIPLEXER

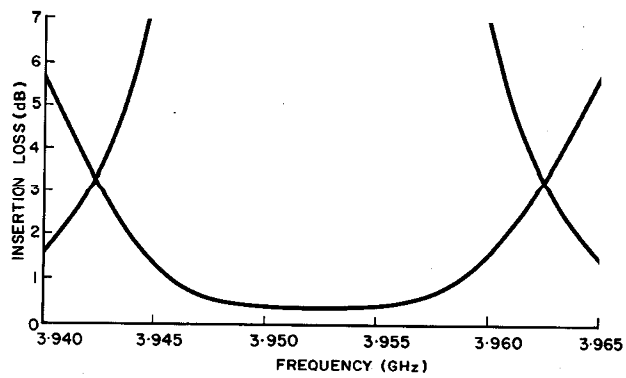

FIG. 5 MEASURED INSERTION LOSS