H_{01} CIRCULAR WAVEGUIDE LOW-PASS FILTER FOR MILLIMETER WAVE TRANSMISSION SYSTEM

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Abstract

A broadband low-pass filter in a multimode circular waveguide has been designed for the millimeter-wave waveguide transmission system.[1] It provides high stopband insertion loss and good passband return loss with very low intrinsic as well as mode conversion loss. The physical realization of the filter is simple and economical.

Low-pass Filter in Multimode Circular Waveguide Loaded With Dielectric Discs

In a two-way transmission system, the leakage of the high level transmitter signals into the receiving paths in the channel multiplexing networks can cause serious system degradations. Low-pass filters are therefore needed in the multiplexing networks to protect the receiving channels.

Numerous known microwave low-pass filter structures are available in the literature.[2] However, these known structures are applicable for dominant mode waveguides only. In a waveguide transmission system, every receiving channel would have required one such filter, and a very large number of filters would have been needed in the entire multiplexing system. Besides, in the millimeter wave frequency range, the intrinsic loss of these known structures will be prohibitively high, and their diminishing dimensions will be too small to be fabricated economically. An alternative scheme is to place the low-pass filters in the signal paths before the channelizing networks, hence, only a few broadband low-pass filters are required. The Marcatili interferometer low-pass filter is a broadband device useful for such applications.[3] While this device does possess broadband characteristics and steep cut-off response, however, the scope of its application is limited by its low stopband insertion loss and its relatively high insertion loss in the passband due to mode conversion. It is also mode selective. The proposed filters in this paper will be designed to provide very high stopband insertion loss in a highly over-moded circular waveguide with the low loss circular electric mode (H_{01} mode) propagating. The design has very low intrinsic loss, and its physical dimensions are large for easy physical realization except that, since the circular waveguide is highly over-moded, the mode conversion problem in the design requires special attention.

The proposed low-pass filter structure is shown in Figure 1 and consists of a parallel array of transverse dielectric discs. The dielectric material of each dielectric disc is homogeneous and isotropic so that there can be no mode conversion in the filter structure. In addition, because the waveguide is highly over-sized for most of the modes concerned in our design, the waveguide could be regarded as nondispersive. The stopband of the filter provides isolation for the H_{01} mode as well as most of the undesired modes which might exist in the system.

Design Techniques

The Image Method

The design of the low-pass filter on the image parameter basis consists of two steps. First, a filter section is designed and the needed number of the identical filter sections is determined in accordance with the stopband specifications. To insure good return loss in the passband, impedance matching sections are then designed to match the image impedance of the filter section into the waveguide characteristic impedance. The design techniques of the quarter wave impedance transformer may be used in the design of the matching section, provided that the passband is not too close to the cut-off frequency of the filter. The advantage of the image method is that the resultant filter consists of mostly uniform sections and, therefore, is relatively economical to fabricate.

Design From Low-pass Filter Prototype Circuit (Figure 2)

In the case where the guard band requirement is more stringent, i.e., the passband is located very close to the cut-off frequency, a direct filter synthesis approach should be used. To obtain a steeper response in the vicinity of the cut-off frequency, a Chebyshev low-pass filter is synthesized directly from the low-pass prototype circuit shown in Figure 2.[4] For the design with 22 dielectric discs, ripple VSWR=1.05 and BW=1.2,[5] the computed filter performance is shown in Figure 3. In this design, more dielectric discs and their spacings will vary in thickness as compared to the low-pass filter from the image design. The fabrication cost will therefore be higher.

It might be pointed out that the insertion loss in the stopband may be increased arbitrarily by adding sections identical to the center section of the 22-section design without appreciably affecting the passband return loss. A typical example is a filter of 36 sections derived from the 22-section design by adding 14 uniform sections. Its computed performance is compared to that of the 22-section design in Figure 3.

Design Examples

Figure 4 shows the photograph of the filter designed using the image technique. Fused quartz with a dielectric constant of 3.78 and loss tangent of 5×10^{-4} is used for the dielectric discs in the filter to provide sufficient bandwidth, realizable disc thickness, and low intrinsic loss. One filter is designed to have a passband from 40 GHz to 54 GHz and a cut-off frequency of 73.5 GHz. The stopband is from 76 GHz to 110 GHz. As shown in Figure 5, both the measured passband return loss and the stopband insertion loss agree very well with the theory. The insertion loss in the passband is measured to be less than 0.1 dB which indicates that the intrinsic loss as well as the mode conversion level in the filter structure are extremely low. The computed theoretical intrinsic loss is 0.05 dB. The high insertion loss in the stopband is measured on a single frequency basis.

The second filter is designed to have a passband from 55 GHz to 74 GHz and a cut-off frequency of 79 GHz. The insertion loss requirement in the stopband is much lower, and hence, there are fewer dielectric discs in the filter. The measured performance of this filter is shown in Figure 6.

The measured performance of the low-pass filter has been shown to vary less than 0.1 GHz over the temperature variations of 53 to 96°F.

Acknowledgments

We wish to thank many of our colleagues at the Bell Laboratories for their cooperation which has made the progress of this project possible. Especially, we would like to thank Messrs. R. P. Hecken, H. A. Kvinlaug, and J. C. Williams for their efforts in the computer aided design and physical realization studies during the early phase of this program.

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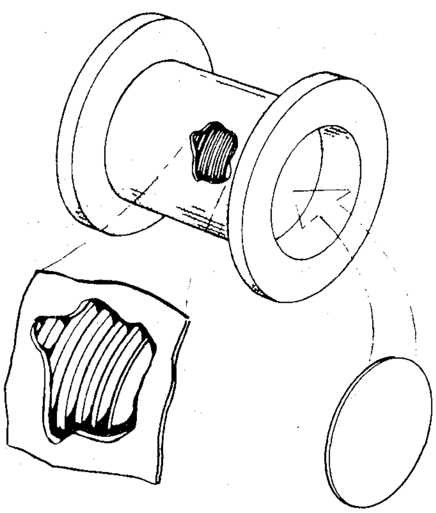

Fig. 1 Dielectric disc low-pass filter

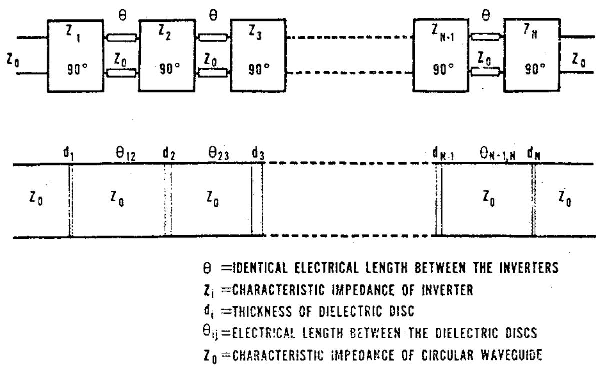

Fig. 2 Equivalent circuit of the low-pass filter

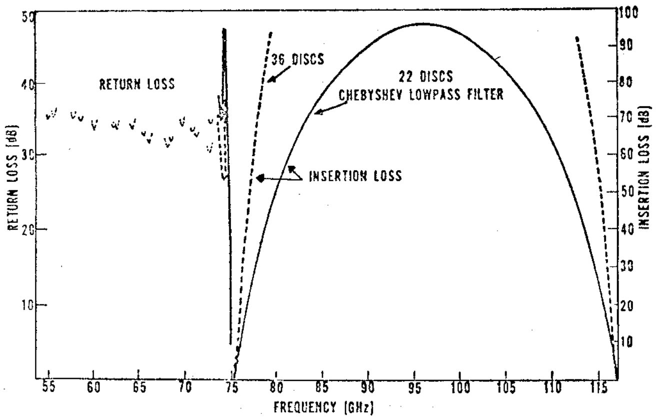

Fig. 3 Computed response of Chebyshev low-pass filter

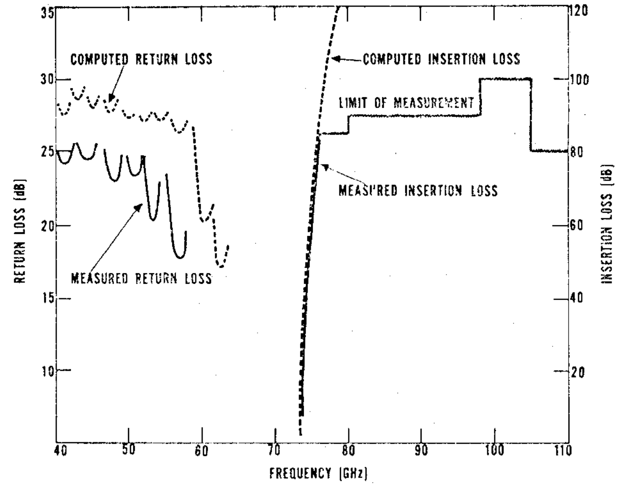

Fig. 5 Measured and computed performance of a low-pass filter

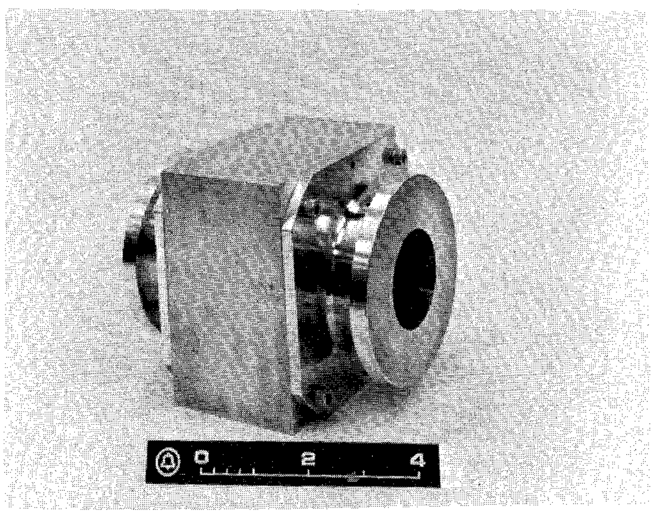

Fig. 4 Photograph of the dielectric disc low-pass filter

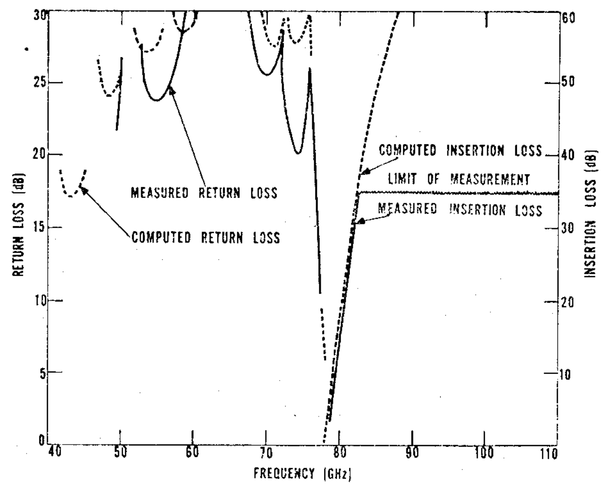

Fig. 6 Measured and computed performance of a low-pass filter