Computer-Aided Design of Circular Ridged Waveguide Evanescent-Mode Bandpass Filters Using the FDTLM Method

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Abstract

This paper describes the analysis and design of a circular ridged waveguide evanescent mode bandpass filter. Two and three resonators filters are presented for the 30GHz range. Insertion loss is typically below 1dB and return loss is better than 20dB on the average. The full-wave FDTLM method is used to compute the generalized s-parameters of the overall filter structures including the effect of finite metallization thickness and mode interaction between filter discontinuities. A comparison to other filter structures in circular waveguides shows excellent agreement between measured and computed results.

Introduction

Ridged waveguide filters in a rectangular enclosure are well known as compact devices with high power handling capability and large passband separation. Because of that they are frequently used in satellite and terrestrial communications sytems.

As attractive as they are, they are not easy to design because of their sensitivity to manufacturing tolerances with respect to ridge height (resonator section), metallization thickness and resonator separation. Therefore most designs use a number of tuning screws to compensate for design shortcomings and mechanical tolerances. An exception is the work reported in [2] where a mode matching procedure is used to analyze and design ridged waveguide filters. However, this approach is computationally extremely time consuming and not very flexible.

Although mostly used in rectangular waveguide housings, ridged waveguide filters can also have an advantage when used in circular waveguides. For this application, however, no rigorous design methodology has been published so far. Therefore, in this paper a rigorous analysis procedure is introduced. Since the mode matching procedure shows slow convergence with sinusoidal functions and the convergence rate is even slower with Bessel functions (circular waveguide), we have adopted the frequency-domain TLM (FDTLM) method which was published recently [3,4]. In this approach the circular coordinate system is discretized by a transmission line matrix network. But instead of going through the time-domain excitation, as in the time-domain TLM method, the FDTLM approach operates entirely in the frequency-domain. Therefore, the filter design is extremely fast and takes into account mode interaction between cascaded discontinuities as well as the finite metallization thickness of the ridges. Metallic losses of the ridge sections and the waveguide walls can be accounted for. Furthermore, in comparison to the mode matching technique, the FDTLM is extremely flexible because the filter structure can be changed without changing the algorithm.

Theory

Since the FDTLM method is not restricted to a Cartesian mesh, it can also be used with general orthogonal meshes. Here the cylindrical mesh is used to discretize the cylindrical structure. The structures investigated in this paper are symmetrical and the modes can be separated into TE and TM modes. Therefore, the center of the waveguide is implemented by a circle of infinitesimal circumference at which all radial lines are terminated. This circle is taken as a short-circuit or open-circuit boundary, depending on the choice of mode.

As shown in Fig.1, the discontinuities for a complete filter structure can be divided into three sections: the step junction between two circular waveguides with different diameters; the double-ridged circular waveguide; and the below cutoff circular waveguide. Two semi-infinity waveguides

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are attached as input and output ports. A brief description outlining the method is given here. For more details of the FDTLM, the reader is referred to [3,4]. First, each section of the filter is characterized by its corresponding s-matrix. Then the overall intrinsic s-matrix, which characterizes the discontinuity region of the filter, can be determined from these s-matrices by cascading the individual s-matrices. The s-matrix for the discontinuity region reads:

$$\begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = \begin{pmatrix} s_{11} & s_{12} \\ s_{21} & s_{22} \end{pmatrix} \begin{pmatrix} a_1 \\ a_2 \end{pmatrix} \quad (1)$$

For two semi-infinity waveguides attached to the discontinuity region, we can then construct their reflection coefficient matrices R_1 and R_2

$$R_1 = (b_{i1}) \cdot (a_{i1})^{-1} \quad (2)$$

$$R_2 = (b_{i2}) \cdot (a_{i2})^{-1} \quad (3)$$

where a_{i1}, b_{i1} are the incident and reflected mode vectors corresponding to the modal field distributions at the input port, while a_{i2}, b_{i2} denote the output port. In the discontinuity region, both R_1 and R_2 are related by

$$a_1 = R_1 \cdot b_1 \quad (4)$$

$$a_2 = R_2 \cdot b_2 \quad (5)$$

Combining with matrices (1) and (5), we can establish the following relationship in discontinuity region.

$$\begin{aligned} b_1 &= [S_{11} + S_{12}R_2(1 - S_{22}R_2)^{-1}S_{21}] \cdot a_1 \\ b_2 &= [(1 - S_{22}R_2)^{-1}S_{21}] \cdot a_1 \end{aligned} \quad (6)$$

Thus, we have established the relationship between the reflected waves of the two ports and the incident wave at the input port. The corresponding scattering parameters can be obtained from the coefficient matrix relating the reflected and input waves. This procedure is explained in [3].

Results

In order to verify our theoretical approach, we first calculate a bow-tie shaped [1] metal septum loaded 3-resonator circular waveguide bandpass filter and compare with the field theoretical design presented here. As shown in Fig.2, excellent agreement is found between the mode matching computation [1], measurements and the FDTLM. The design of a Ka-band circular ridged waveguide bandpass filter follows next. The input and output ports of the circular waveguides are 8 mm in diameter. A 4 mm diameter circular waveguide is chosen as below cutoff evanescent-mode waveguide connecting the resonator ridged waveguide sections. Fig. 3 illustrates the effect of changes in the ridge diameter on the center frequency. As known from the rectangular ridge waveguide filter, reducing the ridge diameter increases the center frequency. The inverse effect can be observed in Fig.4 when the length of the ridge section increases. Fig.5 demonstrates the influence of the distance T between a single ridged waveguide section and the attached above cutoff waveguide. The closer the ridge section is located to the input waveguide, which means the stronger the coupling into the resonator section, the higher the loading and the flatter the resonant curves. It can also be seen from Fig.5 that the resonant frequency changes depending on the loading, which makes perfectly sense. Fig.6 shows the calculated response of a two- and three-resonator circular ridge waveguide filter which is currently manufactured. The computed insertion loss is better than 1 dB.

Conclusion

This paper has presented a theoretical design procedure for evanescent-mode double ridge circular waveguide filters The method is based on the powerful FDTLM algorithm extended to a circular coordinate system. Measured results for a metal septum loaded circular filter, the mode matching method and the FDTLM show excellent agreement confirming the accuracy of the method presented.

References

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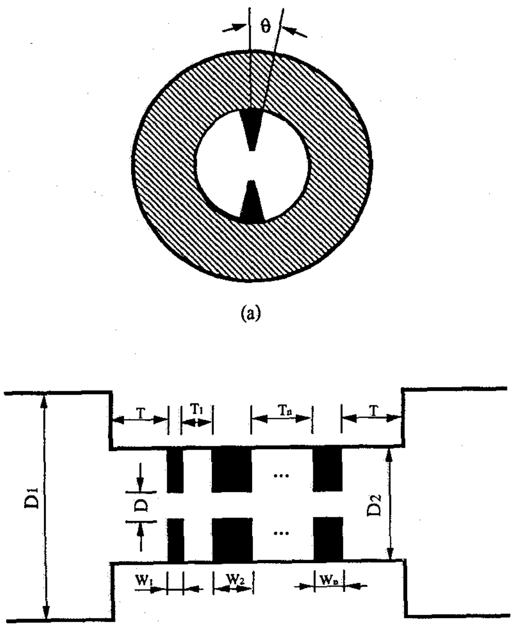

Fig.1 Evanescent -mode double-ridged circular waveguide bandpass filter. (a) Cross sectional view;(b) Longitudinal section dimensions.

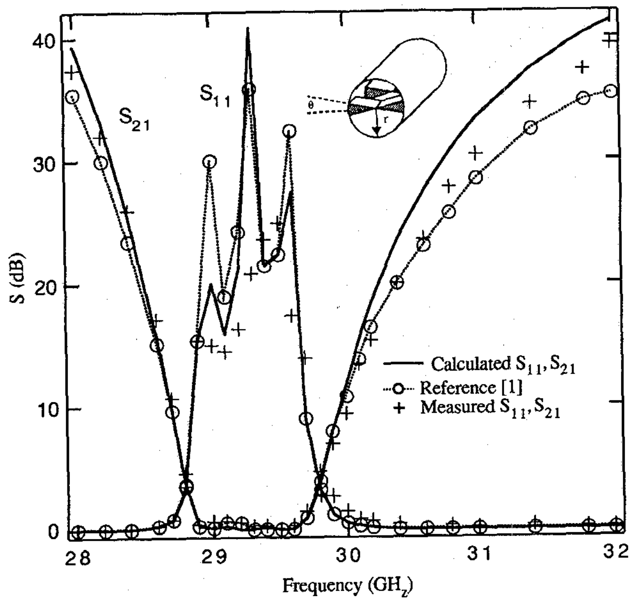

Fig.2 Performance versus frequency of a 3-resonator circular waveguide filter Mechanical dimensions: r=4.0 mm, θ=2.0 deg.; Septum length (mm): $T_1=T_4=0.844$, $T_2=T_3=2.985$; Resonator length (mm): $L_1=L_3=5.683$, $L_2=5.768$.

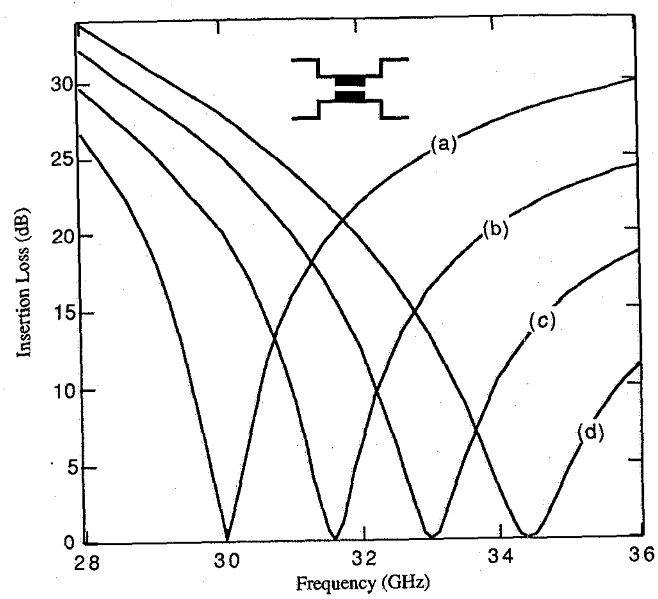

Fig.3 Insertion loss of the filter versus frequency for different diameters D of the ridge. $D_1=8.0$ mm, $D_2=4.0$ mm, T=2.0 mm, $W_1=0.3$ mm, θ=2.0 deg.: (a): D=0.4 mm, (b): D=0.6 mm, (c): D=0.8 mm, (d): D=1.0 mm.

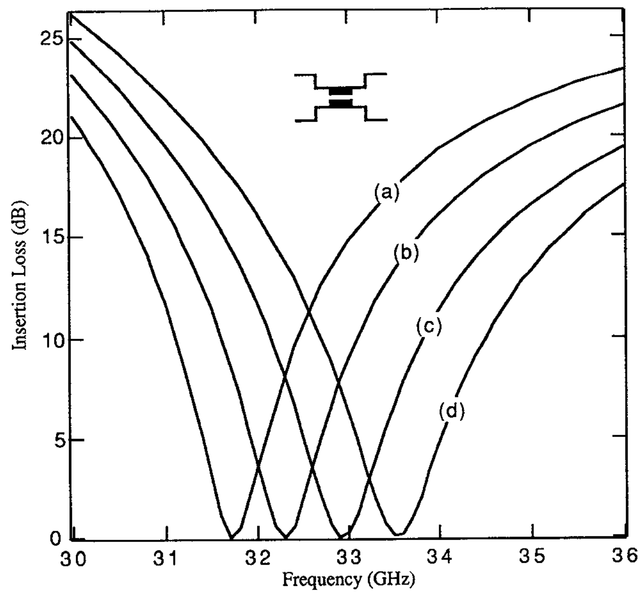

Fig.4 Insertion loss of the filter versus frequency for different widths W of the ridge. D_1=8.0 mm, D_2=4.0 mm, T=2.0 mm, D=0.7 mm, θ=2.0 deg.; (a): w=0.4 mm, (b): w=0.3 mm, (c): w=0.2 mm, (d): w=0.1 mm.

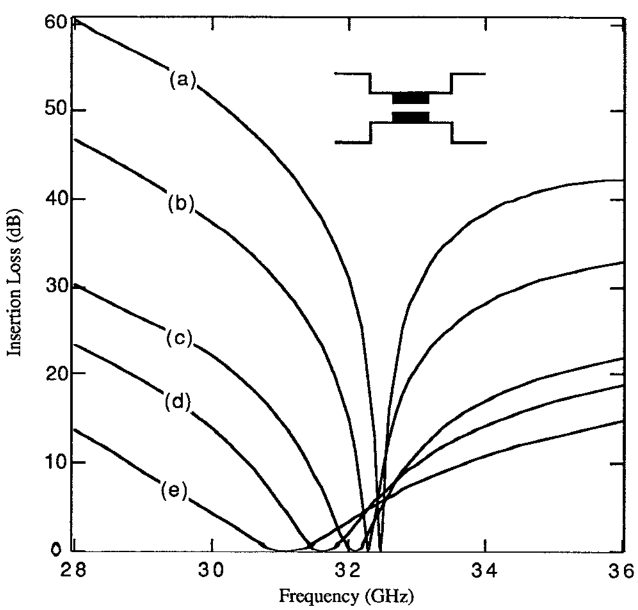

Fig.5 Insertion loss of the filter versus frequency for different distances T. D_1=8.0 mm, D_2=4.0 mm, W=0.3 mm, D=0.7 mm, θ=2.0 deg.; (a): T=4.0 mm, (b): T=3.0 mm, (c): T=2.0 mm, (d): T=1.5 mm, (e): T=1.0 mm.

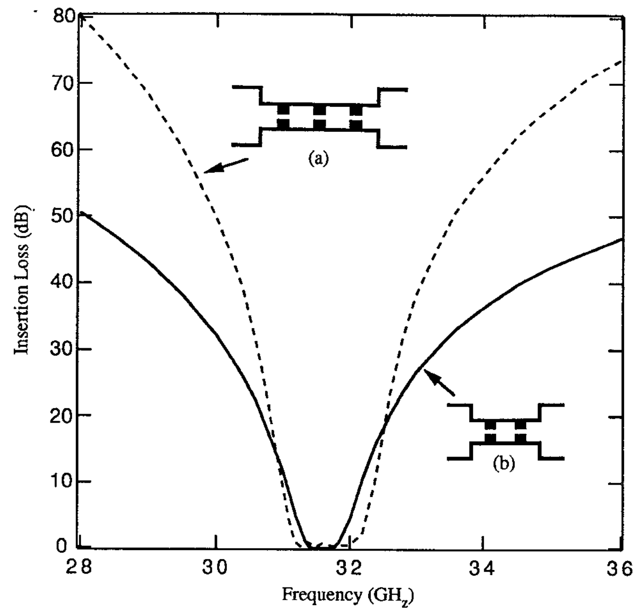

Fig.6 Insertion loss for the evanescent-mode circular waveguide filter loaded with two or three double-ridges. (D_1=8.0 mm, D_2=4.0 mm, D=0.7 mm, θ=2.0 deg.) (a) Three double-ridges: T=1.55 mm, T_1=T_2=4.6 mm, W_1=W_2=W_3=0.41 mm; (b) Two double-ridges: T=2.0 mm, T_1=4.5 mm, W_1=W_2=0.3 mm.