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CAD of Resonant Circular Iris Waveguide Filter with Dielectric Filled Cavities

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Abstract— Resonant Iris bandpass filters form compact structures. Filters composed of circular irises formed as a junction between two circular waveguide cavities has been designed. Mode matching method has been used to analyze discontinuity present in this filter. By using generalized scattering matrix method all the discontinuities that compose the filter are cascaded to obtain its performance. The filter dimensions have been further optimized to meet specifications more precisely. Filters with both empty and dielectric filled circular waveguide cavities between irises have been designed and optimized.

1. INTRODUCTION

Closed form solutions for the susceptance of rectangular and circular apertures in transverse plane of waveguides are available in literature [1]. Based on these solutions, filter in rectangular and circular waveguides are designed using the equivalent network theory approach [2]. This method may however yield filters whose performance does not meet specifications very well. Computer aided design based on mode matching method (MMM) is presented here to design filters in circular waveguide. Circular irises are used as coupling elements between cavities. Two filter structures have been designed for the same bandwidth. One filter uses empty sections of circular waveguide for the cavities, while the other filter uses dielectric filled circular waveguide cavities.

2. THEORY

The analysis of any discontinuity using MMM involves the following steps [3]. The fields on both sides of the discontinuity are expanded in terms of a series of modes of incident and reflected waves. The magnitude of power carried by each of the modes is set to unity. The continuity conditions for the tangential components of electric and magnetic fields are imposed. Using the principle of orthogonality of modes, the equations of continuity conditions are transformed into matrices relating the expansion coefficients of incident and reflected waves at the discontinuity. The matrices are rearranged and inverted suitably to obtain the generalized scattering matrix which describes the discontinuity in terms of the dominant and higher order modes. Theoretically the generalized scattering matrix is of infinite dimension corresponding to the infinite number of modes. The matrix is truncated to a finite size for numerical computations after testing the convergence of the S-parameters.

The filters discussed here are composed of discontinuity from a larger circular waveguide to a smaller circular waveguide as shown in Figure 1. While analyzing a discontinuity from larger to smaller circular waveguide (placed along z-axis) for dominant TE_{11} mode excitation it is sufficient to consider only TE_{1m} and TM_{1m} modes, where m is an integer alone for the analysis of the discontinuity. This is due to the fact that the circular waveguides have rotational symmetry and this is maintained when the two sides of the discontinuity are placed with their longitudinal axis coinciding. The electric and magnetic fields in the two regions of the discontinuity can be obtained from the electric and magnetic potential functions ψ^h and ψ^e in them. For example, for the region I (empty circular waveguide of radius a_1) of the discontinuity as shown in Figure 1 the potential functions are written as,

$$\psi(\rho,\phi)^{Ih} = \sum_{m=1}^{M^h} P_{1,m}^{Ih} J_1(k_{c1,m}^{Ih}\rho)\cos\phi$$

$$\psi(\rho,\phi)^{Ie} = \sum_{m=1}^{M^e} P_{1,m}^{Ie} J_1(k_{c1,m}^{Ie}\rho)\sin\phi$$

The coefficients P in the above equations are the power normalization constants that set the power carried in each of the modes to a watt. The cutoff wavenumbers of the TE_{1m} and TM_{1m}

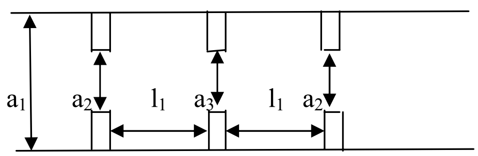

Figure 1: Longitudinal cross-section of the filter with empty circular waveguide for cavities and thickness of iris = 0.1 mm.

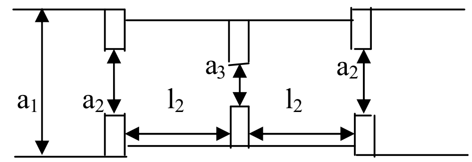

Figure 2: Longitudinal cross-section of the filter with dielectric filled and cavities, iris thickness = 0.1 mm.

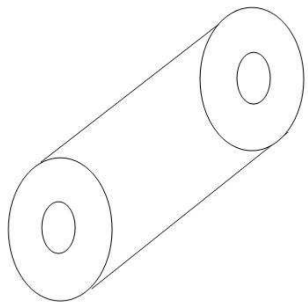

Figure 3: Circular waveguide cavities in the filter between circular irises (0.1 mm thick)

modes are $k_{c1,m}^{Ih}$ and $k_{c1,m}^{Ie}$. The number of TE and TM modes used in the analysis of the discontinuity is decided by M^h and M^e. Similarly the potential functions for region 2 (circular iris of radius a_2) are also written.

The electric and magnetic fields obtained from the potential functions are expressed as a sum of incident and reflected waves of unknown co-efficient on both the sides of the discontinuity. The continuity condition is applied as follows with $a_2$being the radius of the smaller waveguide or the iris.

$$\begin{aligned} E^I(\rho,\phi) =& E^{II}(\rho,\phi); \quad \text{where } \rho \in [0,a_2];\ \phi \in [0,2\pi] \\ E^I(\rho,\phi) =& 0; \quad \text{otherwise} \\ H^I(\rho,\phi) =& H^{II}(\rho,\phi); \quad \text{where } \rho \in [0,a_2];\ \phi \in [0,2\pi] \end{aligned}$$

Applying these continuity conditions results in scattering matrix of fundamental and higher order modes is given by the following matrix equation where U is a identity matrix, 0 is a zero matrix and V is the sub matrix of the coupling between TE and TM modes on both sides of the discontinuity. The dimension of sub matrices depends on the number of modes used for matching fields on both the sides of the discontinuity.

$$S = \begin{bmatrix} U & 0 & V'_{hh} & V'_{eh} \\ 0 & U & 0 & V'_{ee} \\ -V_{hh} & 0 & U & 0 \\ -V_{eh} & -V_{ee} & 0 & U \end{bmatrix}^{-1} \begin{bmatrix} U & 0 & V'_{hh} & V'_{eh} \\ 0 & U & 0 & V'_{ee} \\ V_{hh} & 0 & -U & 0 \\ V_{eh} & V_{ee} & 0 & -U \end{bmatrix}$$

$$V_{hh}(m,q) = \frac{1}{2} P_{1,m}^{II} P_{1,q}^{I} \left(\int_0^{a_2} \frac{1}{\rho} J_1(k_{c1,m}^{II}\rho) J_1(k_{c1,q}^{I}\rho) d\rho + \int_0^{a_2} J'_1(k_{c1,m}^{II}\rho) J'_1(k_{c1,q}^{I}\rho) \rho d\rho \right)$$

The coupling matrix V_{hh} given includes integrals of Bessel function but can be solved analytically in terms of Bessel functions. The other coupling sub matrices are similar equations with the integrals that can also be solved analytically in terms of Bessel functions. It has to be noted that if the waveguide is filled with dielectric the propagation constants will depend on the dielectric constant of the material used to fill the waveguide.

The scattering matrix of each discontinuity is cascaded using the generalized scattering matrix technique to analyze the filter [3]. The filter is further optimized to achieve the specifications desired using a practical quasi Newton algorithm [4].

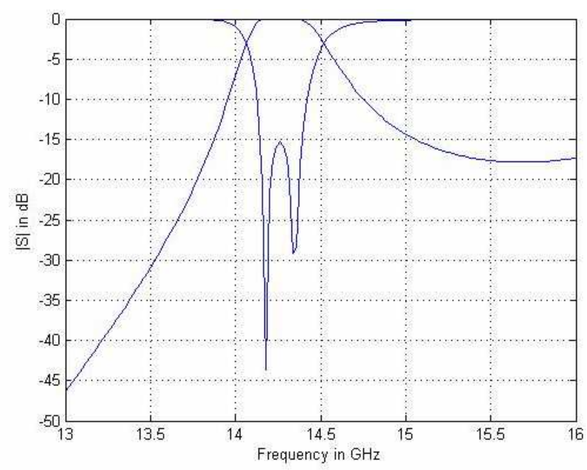

Figure 4: Performance of filter in Figure 1 $a_1 = 13.97\,\mathrm{mm}$, $a_2 = 8.68\,\mathrm{mm}$, $a_3 = 7.02\,\mathrm{mm}$, dia. of cavities $= a_1$, $l_1 = 18.7\,\mathrm{mm}$.

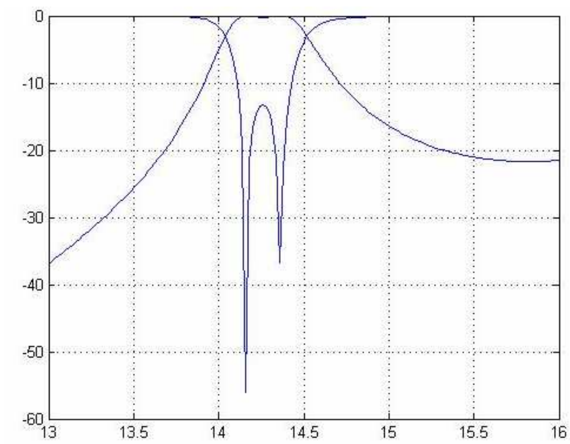

Figure 5: Performance of filter in Figure 2 $a_1 = 13.97\,\mathrm{mm}$, $a_2 = 7.5\,\mathrm{mm}$, $a_3 = 5\,\mathrm{mm}$, dia. of cavities $= 11.6\,\mathrm{mm}$, $l_2 = 17.6\,\mathrm{mm}$.

3. RESULTS

The discontinuity from a larger empty circular waveguide to smaller circular waveguide was analyzed with 40 TE and TM and convergence of the S-parameters has been observed. The filter using empty circular waveguide with two cavities has been analyzed and optimized further for the desired specifications. A return loss of better that 15 dB is observed in the passband as shown in Figure 4. A filter with cavities filled with dielectric was also analyzed and optimized for the same specifications. The cavities of this filter that were filled with dielectric were chosen to be of smaller radius in comparison to that of the filter with empty circular waveguide cavities. The length of the cavities is also reduced. The performance of the filter is shown in Figure 5. It has yielded a better performance in stopband, but the return loss in the mid passband is reduced slightly in comparison to that of the other filer. Further optimization may improve the passband performance of this filter. The performance and the dimension of both the filters are shown in Figures 4 and 5.

4. CONCLUSION

The Mode Matching Method used for the analysis and design of circular waveguide filters with cavities that are empty are dielectric filled is found to yield optimum solutions for the desired specifications. The filters with dielectric filled cavities have reduced dimensions. Cavities filled partially with dielectric can further be designed using this method.

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