Field Theory Based CAD of Resonant Iris Filter in Circular Waveguide

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Abstract - Computer aided design of resonant iris filter in circular waveguide technology is described here using Mode Matching Method(MMM). This numerical technique is first used to analyze the key element of the filter namely circular to rectangular waveguide discontinuity or circular to circular waveguide discontinuity. The generalized S-matrix of these discontinuities that form the filter structure are then cascaded to obtain the performance of the filter. Using optimization techniques the analyzed filter dimension are altered to improve its performance. Two filters using rectangular and circular irises have been designed and presented here. The MMM analysis of key elements in the filter have been verified with measurements available in literature.

I Introduction

Resonant Iris bandpass filters form compact structures. These filters are composed of circular or rectangular irises formed as a junction between two rectangular or circular waveguides. Closed form solutions for the susceptance of rectangular and circular apertures in transverse plane of circular waveguide is available in [1,2]. Based on these solutions and relevant theory[3,4] such filters are designed. Mode matching method is an elegant tool to analyze discontinuity present in these filter[5,6,9]. By using generalised scattering matrix method[7] all the discontinuity that compose the filter can be cascaded and hence its performance is obtained. Computer aided design based on MMM of resonant iris filters in circular waveguide using both circular and rectangular apertures is discussed here. Further, optimization[8] of the filter dimensions have been done to improve the performance of the design based on equivalent network theory approach.

II Theory

The analysis of any discontinuity using MMM involves the following steps. 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

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of the S-parameters.

The resonant iris coupled cavity filter constitutes resonant iris followed by empty sections of waveguide as shown in Figure 1 and Figure 2. This paper discusses filters with circular and rectangular iris placed in between sections of empty circular waveguide. The fields in both the sides of discontinuity namely region R are obtained from the electric and magnetic vector potential (superscript e and h) which satisfy the wave equations.

While analyzing a discontinuity from larger to smaller circular waveguide (placed with axes along z-axis) for dominant mode (TE_{11}) excitation it is sufficient to consider only TE_{1m} and TM_{1m} modes alone to be excited at such a discontinuity due to rotational symmetry. The potential functions in one region represented as I of discontinuity can be written as follows.

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

$$\psi(\rho,\phi)^{Ie} = \sum_{m=1}^{M^e} P_{1,m}^{Ie} J_1(k_{c_{1,m}}^{Ie}\rho)\sin\phi \quad (2)$$

The potential function in the other region II is also written similarly with P as the power normalisation constants and k_c being the cutoff wavenumbers and M^h and M^e being the number of modes included in the MMM. The electric and magnetic fields as a sum incident and reflected fields with unknown amplitude coefficients are obtained from these potentials and matched at the discontinuity based on the continuity conditions. By using the principle of orthogonality a set of algebraic equations is obtained. The integrals though involving bessel functions can be solved using closed form solutions. By rearranging them and with some matrix inversions the generalized scattering matrix (GSM) of this discontinuity is obtained. By cascading the GSM of a series of several such discontinuity the filter characteristics is obtained.

For a discontinuity from a larger circular to rectangular waveguide in the case of rectangular aperture housed in circular waveguide (placed with their axes aligned along the z-axis) the potential functions in the rectangular waveguide (region I) and circular waveguide (region II) is written as

$$\psi_{m,n}^{Ih}(x,y) = \sum_{mn} T_{m,n}^{Ih} \frac{\cos(k_{x_m}^{I}x)\cos(k_{y_n}^{I}y)}{\sqrt{1+\delta_{0,m}}\sqrt{1+\delta_{0,n}}} \quad (3)$$

$$\psi_{p,q}^{Ie}(x,y) = \sum_{pq} T_{p,q}^{Ie} \sin(k_{x_p}^{I}x)\sin(k_{y_q}^{I}y) \quad (4)$$

$$\psi(\rho,\phi)^{IIh} = \sum_{qr} P_{q,r}^{IIh} J_q(k_{c_{q,r}}^{IIh}\rho)\cos q\phi \quad (5)$$

$$\psi(\rho,\phi)^{IIe} = \sum_{qr} P_{q,r}^{IIe} J_q(k_{c_{q,r}}^{IIe}\rho)\sin q\phi \quad (6)$$

While matching the electric and magnetic fields at the interface of circular to rectangular waveguide due to different co-ordinate systems in the two regions, the following equation is used [5]

$$J_q(h\rho) \cong \frac{j^q}{N}\sum_{l=0}^{N-1} e^{\frac{j2lq\pi}{N}} e^{-jh(C_l x + S_l y)} \quad (7)$$

where $x=\rho\cos\phi, y=\rho\sin\phi, C_l=\cos(l2\pi/N), S_l=\sin(l2\pi/N)$. This equation which converges after a certain value of N and transforms the cylindrical waveguide modal functions into cartesian co-ordinates. Thus matching of fields at the interface of discontinuity is done in cartesian co-ordinates. A set of algebraic equations is obtained using principle of orthogonality. The integrals involved in these equations have to be summed upto N. This results in increased computation time as compared to the analysis of a larger circular to circular waveguide discontinuity. However the rest of the analysis is same.

III Results

A program to analyze the discontinuity from larger circular waveguide to smaller one was developed. It was observed that inclusion of a maximum of 40 TE and TM modes in the analysis was sufficient for the convergence of S-parameters. The ratio of number of modes in region I and II was chosen approximately equal to the ratio of the radius of regions I and II in order to avoid relative convergence error. The S-parameters of such a discontinuity was compared with measurements available in literature [6] and found to be in agreement as shown in Table 1 . A filter was designed and analyzed using MMM and then optimized. Its performance and dimensions are as shown in Figure 3. A program to analyze the discontinuity from circular to rectangular waveguide was developed. It was observed that inclusion of about 40 TE and TM modes in the circular waveguide and modes with upto the same cutoff frequency on rectangular waveguide is sufficient for the convergence of S-parameters. The number of modes used in this work is less compared to [5]. This is due to the fact that symmetry has been taken advantage of unlike in [5]. This analysis is however different from that presented in [9].The S-parameter of discontinuity from WR-75 to a circular waveguide with radius of its equal to its larger dimension was verified with results from [5] as shown in Figure 4. A filter was designed and analyzed using MMM and further optimized. The performance and dimensions of the filter are as shown in Figure 5.

IV Conclusions

This paper has shown that efficient computer aided design of resonant iris filter can be achieved using MMM and optimization. Such filter are compact and can be easily fabricated.

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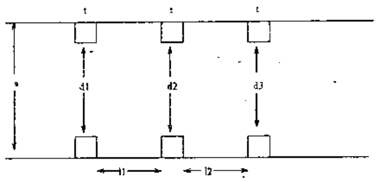

Figure 1: Resonant Iris Filter's cross section along the direction of propagation - iris shape could be rectangular or circular)

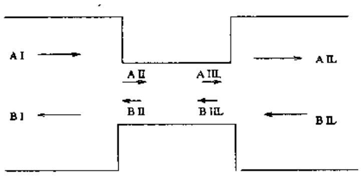

Figure 2: Discontinuity regions in a resonant iris filter showing incident and reflected wave amplitudes and finite thickness of iris

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Thickness	Reflection Coefficient s_{11}			
(inch)	Calculated		Measured[6]	
	Magnitude	Phase (o)	Magnitude	Phase (o)
0.005	0.837	150.5	0.855	150.5
0.008	0.881	151.1	0.866	151.7
0.050	0.938	156.5	0.927	155.3
0.100	0.963	159.3	0.956	158.1
0.200	0.990	161.6	0.981	160.6
0.500	0.999	162.6	0.993	161.1
1.000	1.000	162.6	0.995	161.5

Table 1. Calculated and measured [6] S_{11} of discontinuity from circular waveguide of radius 0.5015in to 0.25in of thickness as above and at frequency of 9.0GHz

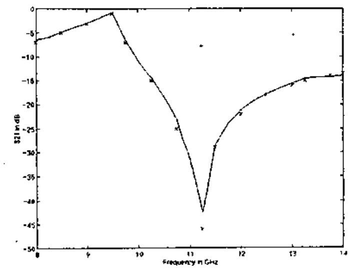

Figure 3: S-parameter of discontinuity from larger circular to rectangular waveguide (WR-75 to circular waveguide with radius of larger dimension)

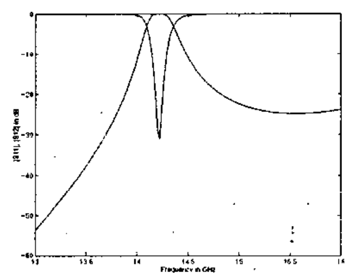

Figure 4: Performance of optimized resonant iris filter with circular iris in a circular waveguide of dimensions, a/2=6.985mm, thickness of the iris=t=0.2mm, l1=l2=20.522mm, d1/2=d3/2=3.0mm, d2/2=5.5mm

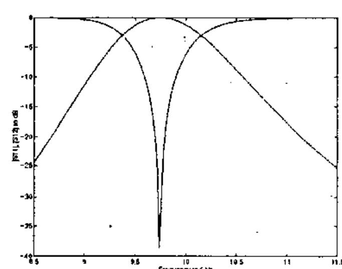

Figure 5: Performance of optimized resonant iris filter with rectangular iris in a waveguide of dimensions, a=23.83mm, thickness of the iris=t=0.125mm, l1=l2=20.4mm, d1=d3=13.5mm and d2=12.1mm (d's-broad wall dimension of the rectangular iris, narrow wall dimension of the irises=2mm)