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A BANDPASS FILTER USING CIRCULAR DISCONTINUITIES IN NONRADIATIVE DIELECTRIC WAVEGUIDE.

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Abstract. The design of a new bandpass filter in Nonradiative Dielectric (NRD) Waveguide is described. The filter makes use of an inverter-prototype and series fullwave resonators. The T-sections necessary to realize the inverters are realized by means of round holes drilled through the dielectric centre conductor. The properties of the round discontinuities are fitted to those of rectangular holes, and the design is executed by means of closed form equations. The measured practical response is in very good agreement with the predicted theoretical properties.

I INTRODUCTION.

A variety of filter structures have by now been described for the realization of filters in NRD. Yoneyama et al [1] have designed and tested bandpass filters, while the present authors [2] have described a bandstop filter. In this paper a new bandpass filter is described that makes use of round holes drilled through the dielectric.

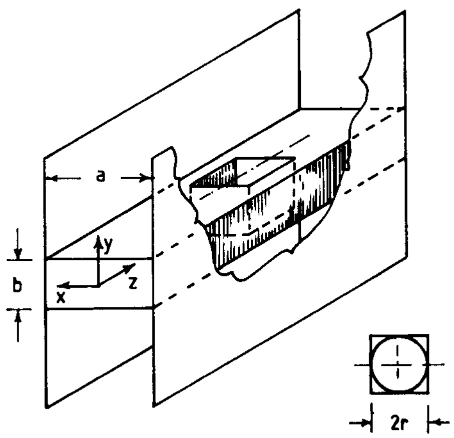

Fig. 1. Rectangular hole through the dielectric strip of an NRD-guide.

The reactances of the round holes are obtained as a fit to closed form equations for rectangular holes derived elsewhere by the authors [3]. The filters are clearly extremely simple to manufacture, and have the advantage that the guide itself is left intact. The design procedure is developed and the theoretically predicted filter frequency response compared to measurements.

II RECTANGULAR AND ROUND DISCONTINUITIES

Fig. 1 shows an isometric view of the rectangular hole through the centre dielectric. Analytical expressions are derived in [3] by means of a variational bound method for the network parameters of this rectangular discontinuity, which has its axis normal to the propagation direction, and parallel to the side plates. Referring to Fig. 2, the network parameters, X_1 and X_2 of the structure are given in terms of the odd and even

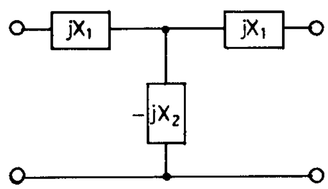

Fig. 2. Equivalent circuit for a discontinuity in the centre dielectric strip

phase shifts of the total fields due to reflection and far from the discontinuity. These are in turn related to the length and width of the rectangular hole (for expressions, see [3] in these proceedings).

Due to the practical difficulty of machining rectangular holes in the dielectric strip, measurements were made on round holes, and the resultant measured reactances compared to the values calculated for a rectangular hole. (It should be noted that the variational bound method is not suited to the analysis of a round obstruction). It was found that the theory for rectangular discontinuities yields excellent results when the hole is made square, and the diameter of the round hole made equal to the width of the square hole. This compares with a value of 1.15 calculated by Marcuvitz [4, Fig. 5. 11-7, p. 265] for the case where the theory for a round metallic post in a rectangular waveguide is used for a square post.

The variational bound method described in [3] was also used to obtain expressions for the reactance of a rectangular dielectric post in a metal waveguide and then compared to the values given by Marcuvitz for a round dielectric post in a rectangular metal waveguide [4, para 5.12, p.266]. Fig. 3 shows the agreement between the reactances for three round posts calculated by the latter method and rectangular reactances calculated by the variational bound method, for the case of the diameter equal to the post length; it is obvious that the results are very similar.

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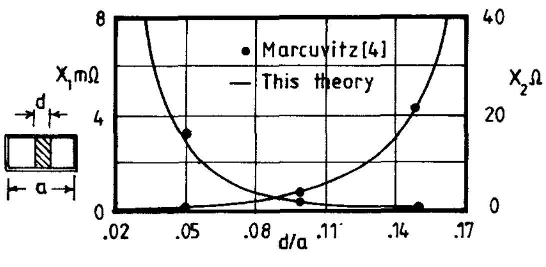

Fig. 3 Comparison of the calculation of reactances according to Marcuvitz [4], for a round post and the variational bound method, for a rectangular post.

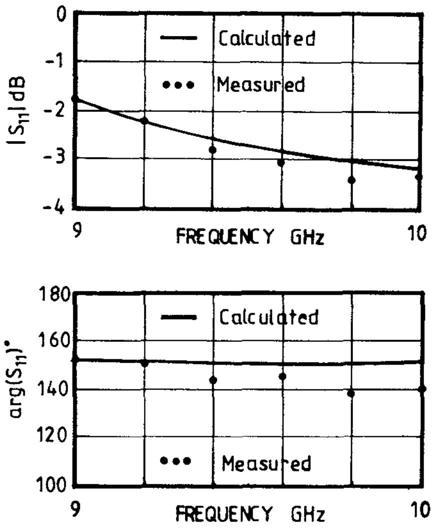

Fig. 4 Calculated magnitude (a) and phase (b) of the reflection coefficient of a rectangular discontinuity, solid line. Dots show measured values for a round hole.

Fig. 4 shows the calculated magnitude and angle of the reflection coefficient versus frequency caused by a rectangular hole, and is compared to the measured values for the corresponding round hole of 6 mm radius. Similar results were obtained for holes of 4 and 5 mm radius.

As the equations that describe the hole properties are in closed form, they can be used for filter design directly.

III FILTER DESIGN

The filter design follows the procedure outlined by [5]for halfwave resonator filters coupled by impedance inverters. Each impedance inverter is realized as a negative length of line cascaded with a T-section consisting of capacitive series arms and an inductive shunt arm, the T-section being realized by means of the hole, as shown in Fig. 5. The inverter parameter and line length are given by [5],

$$K = \tan(\phi/2 + \tan^{-1} x_1) \qquad (1)$$

$$\phi = -\tan^{-1}(2X_2 + X_1) - \tan^{-1} X_1 \qquad (2)$$

For an n^{th} order prototype, with filter element values g_k, the necessary inverter parameters are calculated from,

$$K_{k,k+1} = \sqrt{\frac{wx}{g_k g_{k,k+1}}}, \quad k = 0,n-1 \qquad (3)$$

$$K_{k,k+1} = \frac{wx}{\sqrt{g_k g_{k,k+1}}}, \quad \text{otherwise} \qquad (4)$$

The reactance slope parameter, x is given by, from [1]

$$x = \frac{\pi}{2}\left(\frac{\varepsilon_r k_o}{k_z}\right)^2 \frac{2}{2}\,\frac{(\beta^2+\alpha^2\varepsilon_r)+\alpha_b(\beta^2+\alpha^2\varepsilon_r)}{\varepsilon_r(\beta^2+\alpha^2)+\alpha_b(\beta^2+\alpha^2\varepsilon_r)} \qquad (5)$$

The transverse wave numbers, α and β are solutions of the trancendental equation,

$$\beta\tan(\beta b/2) = \varepsilon_r\alpha \qquad (6)$$

subject to the constraint

$$\alpha^2+\beta^2 = k_o^2(\varepsilon_r-1) \qquad (7)$$

The guide wave number is calculated from,

$$k_z = \sqrt{k^2-(\pi/a)^2-\beta^2} \qquad (8)$$

The line lengths are calculated from,

$$\Phi_k = \pi + \phi_{k-1,k}/2 + \phi_{k,k+1}/2 \qquad (9)$$

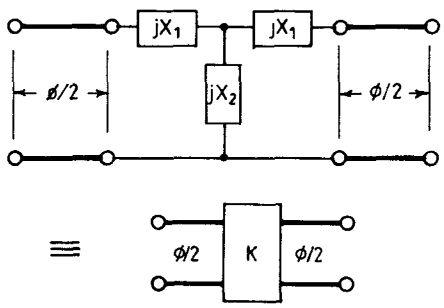

Fig. 5. Definition of the inverter parameter and its ideal equivalent in transmission line realization

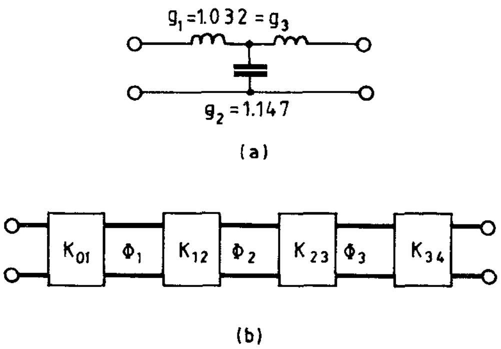

Fig. 6. Lumped element prototype filter, (a), and waveguide realization, (b).

IV DESIGN EXAMPLE

The example outlines the design of a third order Chebyshev bandpass filter with 0.1 dB ripple and 5% bandwidth at 9.5 GHz. The NRD guide has a dielectric constant of 2.55, with a dielectric height b = 10.16 mm and plate separation a = 15 mm. The element values are shown in Fig. 6, and the calculated filter parameters were,

$$\alpha = 139.6 \quad \beta = 205.6 \quad k_z = 123.3 \quad \lambda = 50.94\text{mm}$$

$$k_{01} = k_{34} = 0.63; \; k_{12} = k_{23} = 0.37.$$

$$d_1 = d_3 = 19.22\text{mm}; \; d_2 = 21.02\text{mm}$$

$$r_{01} = r_{34} = 4.2 \text{ mm}; \; r_{12} = r_{23} = 6.7 \text{ mm}.$$

where α and β are the transverse wave numbers of the NRD, k_z is the wave number in the direction of propagation, k_{ij} are the impedance inverter values, and d_i the physical line lengths connecting the cylindrical holes of radii $r_{i-1,i}$ and $r_{i,i+1}$.

A filter was constructed to these specifications. The filter performance was not satisfactory, due to direct coupling of higher order modes between the holes; this coupling had not been taken into consideration in the design. At the same time the variational bound method for obtaining the discontinuity reactances does not make provision for the calculation of such coupling. Consequently the holes were shifted a further half wavelength away from each other, and the additional line lengths incorporated into the design. This modification gives new separations between the holes,

$$d_1 = d_3 = 44.7 \text{ mm}; \; d_2 = 46.5 \text{ mm}.$$

Figure 7 shows the dimensions of the completed filter.
The measured transmission versus frequency response is shown in Fig. 8. Note that for purposes of comparison, the theoretical response using the theory for the holes from [3] is also shown, as well as the predicted response of the filter using ideal impedance inverters and lines of one wavelength.

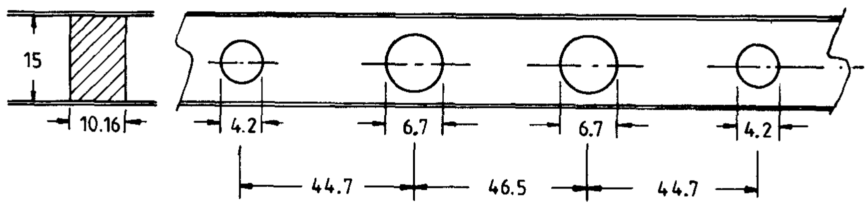

Fig. 6. Dimensions of the third order Chebyshev filter for realization in NRD

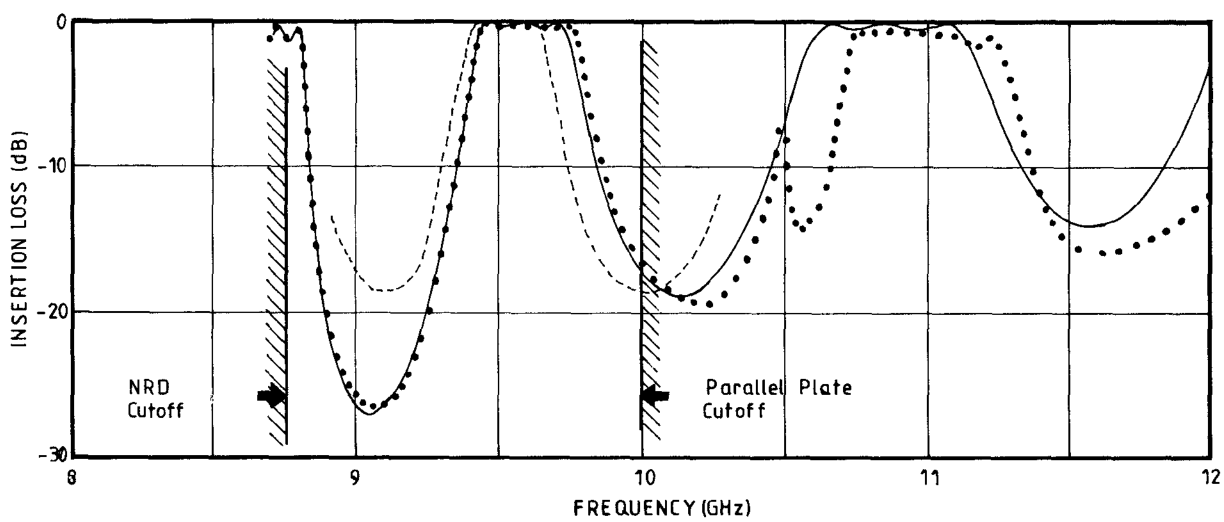

Fig. 7. Transmission response of third order NRD bandpass filter; measured values are shown by a dotted line. The calculation using ideal inductors and fullwave line sections is shown by the dashed line, while the response calculated using the theory for discontinuities from [3] is shown by a solid line.

The reason for the bandwidth expansion has no yet been fully been investigated. The curve shows the full response from the point at which the NRD-waveguide cuts off (8.57 GHz) to where the guide loses its usefullness due to the fact that the plate separation is more than one half free space wavelength, which occurs at 10 GHz. It is also extremely interesting to note that even beyond 10 GHz, except for the spike at 10.5 GHz, the filter still functions in reasonable accordance with the predicted theory, even though the theory does not take higher order modes into consideration. It can only be concluded from this that the higher order modes generated to satisfy the boundary conditions do not radiate too strongly.

V CONCLUSION.

A design procedure for bandpass filters in NRD waveguide using round holes that can be easily drilled has been presented. The possible disadvantage of the design is that tuning of the filter is difficult. Fortunately, the analysis procedure can readily predict the performance, and once a design has been perfected, the advantages in ease of manufacture are substantial. Bandwidth expansion is still evident, and this is being investigated.

References.

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