ANALYSIS OF DIELECTRIC LOADED RESONATOR DUAL-MODE FILTER

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A dielectric loaded rectangular cavity for the design and realisation of different elliptic function filters topologies is presented. The 3-D Transmission Line modelling method (TLM) is applied to the analysis of the cavity to obtain the resonant frequencies and couplings between the rectangular cavities. As an application to the analysis, a 4-pole elliptic function filter is designed and measured results presented

Keywords: dielectric filter, dual-mode filter

1 INTRODUCTION

Combination of dual-mode and dielectric resonator technologies will result in a significant reduction of the filter size and weight. Non-axially symmetric modes in cylindrical dielectric resonator which are hybrid and twofold degenerate (i.e. two identical modes with the same resonant frequency and perpendicular polarisations) have been successfully implemented to construct an eight-order dual-mode dielectric loaded cylindrical cavity filter having elliptic function response [1]. A similar filter was also designed using degenerate hybrid modes in [1], [2]. In this filter, the coupling between resonant modes is adjusted by appropriate spacing between dielectrics in a cylindrical cavity. The coupling between the resonators are also realised by apertures calculated by small aperture approximation [3]-[7]. In such structures, it is difficult to physically support the resonators. The types of topologies that can be realised by such structures are limited. Achieving compact filters is hampered by the limited filter topologies.

A structure where the dielectric loaded resonators are symmetrically loaded in a rectangular enclosure and held perpendicular to either the top or the bottom plane of the rectangular enclosure is proposed in this paper. In such a structure, different topologies (e.g. the stack or planar) can be realised and coupling between cavities can be achieved by apertures at the common wall. These structures result in filters that are compact and have good mechanical stability.

The rigorous modelling of the proposed dielectric loaded resonator in a rectangular cavity is achieved by using the 3-D Transmission Line Modelling method (TLM) [8]. The resonant frequencies of the proposed structure and the coupling coefficients between two identical cavities are obtained. As an application, a 4-pole elliptic function bandpass filter is designed and tested. The experimental results of the filter are presented to verify and the accuracy of the numerical modelling.

2 DESIGN OF THE RESONATOR

The proposed dielectric loaded resonator structure is shown in figure 1. The cylindrical dielectric resonator is loaded symmetrically and held perpendicular to either the top or the bottom plane of a perfectly conducting metallic rectangular enclosure. PTFE supporters are used to hold the dielectric ceramic resonator in the required location within the cavity. This structure offers good mechanical stability than structures in which the dielectric resonators are loaded axially in cylindrical enclosures where it is difficult to support the physical resonators.

The dimensions of the rectangular cavity are: $a = b = 50\ mm$ and $h = 30\ mm$. The dielectric rod has radius $r = 18\ mm$, height $H = 16$ mm and dielectric constant $\varepsilon_r = 37$. The dimensions of the dielectric resonator and that of the rectangular cavity are chosen such that the resonant frequency of the resonator and thus the filter is about 2.000 GHz for the mode $HE_{11\delta}$, which is degenerate.

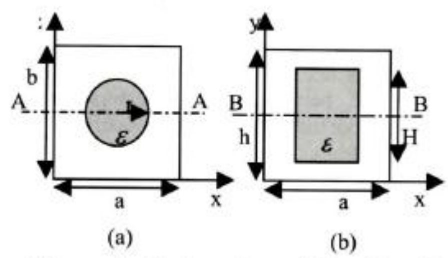

Figure. 1: Configuration of the dielectric loaded rectangular cavity (a) Equatorial plane (symmetry plane BB) (b) Meridian plane (symmetry plane AA)

3 DESIGN OF FOUR-POLE FILTER

3.1 COUPLING MATRIX

The attenuation specifications that give a fourth-order elliptic function filter are as follows:

(i) Maximum loss in the passband = 0.05 dB
(ii) Minimum loss in the stopband =34 dB
(iii) Selectivity = 0.55

The resulting normalised input/output resistances and coupling matrix calculated using the technique in [9] which is based on matrix are as follows:

$$R_{in} = R_{out} = 1.0159\,\Omega,$$

$$M = \begin{bmatrix} 0.0000 & 0.8459 & 0.0000 & -0.2075 \\ 0.8459 & 0.000 & 0.7790 & 0.0000 \\ 0.0000 & 0.7790 & 0.0000 & 0.8459 \\ -0.2075 & 0.0000 & 0.8459 & 0.0000 \end{bmatrix} \quad (1)$$

The theoretical frequency response that describes the coupling matrix in equation 1 is shown in figure 2.

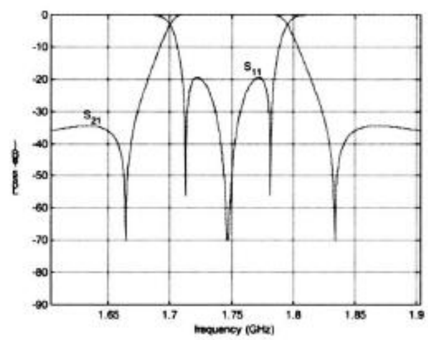

Figure 2: The theoretical response of the 4-pole elliptic function filter

3.2 COUPLING COEFFICIENTS GRAPH

The method for determining the coupling coefficients between two-coupled identical dielectric loaded rectangular cavities is outlined in [10]. The coupling coefficient k between the resonators can be determined from the following expression:

$$k = \frac{f_e^2 - f_m^2}{f_e^2 + f_m^2} \quad (2)$$

where f_e and f_m correspond, respectively, to the odd and even mode resonant frequencies of the coupled resonators. To compute f_e, an electric wall is considered at symmetry plane between the resonators and to obtain f_m, the electric wall is replaced by the magnetic wall. Depending on the values of f_e and f_m, the coupling coefficient k, in equation 2 can be positive or negative. If the coupling $k > 0$, the coupling is mainly contributed by the magnetic field and if $k < 0$, then it is dominated by the electric field.

The thickness of the common wall between the cavities is 0.2 mm. The width of the coupling aperture is 2 mm. By varying the aperture length, a range of coupling coefficients can be obtained. Figure 2 shows the computed graph of the coupling coefficients as a function of the length of the aperture opening obtained by the TLM method. Also shown in figure 2 are the coupling coefficients results obtained by measurement. Both calculated and measured couplings are in good agreement. The difference between the two sets of results is due the fact that the dielectric constant of the supporters was assumed to be unity during simulation. PTFE material of dielectric constant $\varepsilon_r \approx 2$ was used during the coupling measurements.

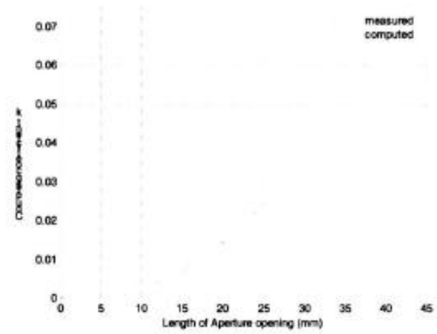

Figure 3: Coupling coefficients between two-coupled identical dielectric loaded rectangular cavities

3.3 FILTER LAYOUT

A schematic of the fourth-order elliptic function filter is shown in figure 4. The physical configuration of the realisation of the filter is shown in figure 4. Two identical dielectric loaded rectangular cavities are stacked on top of each other. The coupling screws and tuning screws are not shown in this figure. The tuning screws at the side of the cavity oriented at 0° and 90° to the normal field polarisation in each resonator are used for the resonant frequency tuning. The couplings M_{12} and M_{34} were achieved by the screws oriented at 45°. With this configuration, it is possible to realise all the intercavity couplings with apertures. Cross apertures are used to realise M_{23} and M_{14}. The dimensions of the apertures to realise these two intercavity couplings can be obtain from the coupling coefficients graphs shown in figure 3.

For a true elliptic function response, M_{14} has to be negative as shown in the coupling matrix in equation

1. But M_{14} is realised through the magnetic field, which gives a positive coupling. To achieve the negative coupling value of M_{14}, the coupling screws M_{12} and M_{34} are placed at spatial orientation of 90° apart to give a field reversal of 180° in the two resonators. This method has been used to design true elliptic function dual-mode filters [2], [3].

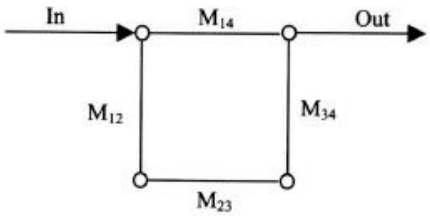

Figure 4: Schematic of a fourth-order dual-mode elliptic function filter

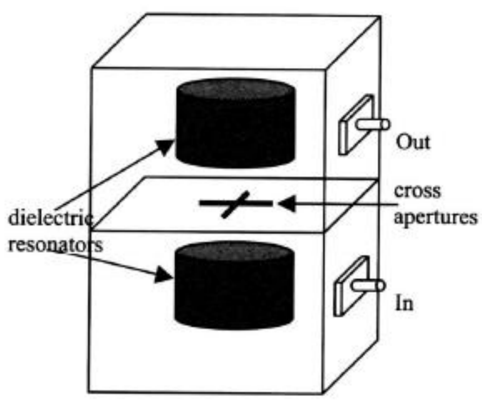

Figure 5: The physical configuration of the fourth-order dual-mode elliptic function filter

4 RESULTS

The measured frequency responses of the filter are shown in figure 6. It can be seen that the filter achieved the desired centre frequency and bandwidth. Figure 2 and figure 6 compares well. The filter has three poles and two transmission zeros. The two transmission zeros of this filter are symmetric. The out-of-band rejection of 34 dB has been correctly achieved. The insertion loss of the filter at centre frequency is 0.1385 dB. This filter achieved a very low insertion, which confirms the high Q-factor of the resonators employed to build the filter. The return loss of the filter is about 12 dB. The tuning mismatch may have contributed to the poor return of the filter.

The measured wide-band response of the filter is shown in figure 7. The filter exhibits inferior spurious response. This is due to tuning screws having shifted the resonant frequencies of the higher order modes down towards the passband. The higher order modes can be shifted away from the filter response by using resonators with cylindrical dielectrics [11]

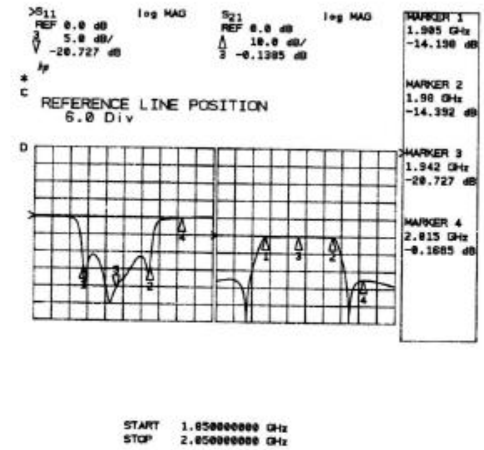

Figure 6: The measured frequency response of the dual-mode four-pole elliptic function filter.

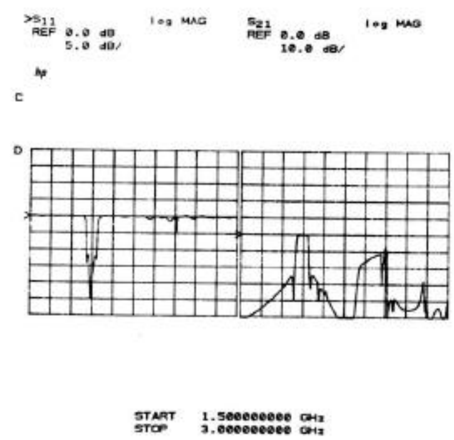

Figure 7: The wide band frequency of the dual-mode four-pole elliptic function filter.

5 CONCLUSION

A structure where the dielectric loaded resonators are symmetrically loaded in a rectangular enclosure and held perpendicular to either the top or the bottom plane of the rectangular enclosure was proposed. In such a structure, different topologies (e.g. the stack or planar) can be realised and coupling between cavities can be achieved by apertures at the common wall. This structure has good mechanical stability.

The dielectric resonator in a rectangular cavity was modelled using the TLM method. The coupling coefficients between the cavities through an aperture in the common wall of the cavities were produced. The practical design graph was presented. From this design graph, the dimensions of the apertures are chosen to provide the correct coupling of the desired mode and at the same time minimises the couplings of all the spurious modes at their resonant frequencies.

As an application, a four-pole elliptic function bandpass filter was designed constructed and tested. The measured frequency responses of the filter verify the theory and the numerical modelling of the dielectric loaded resonator in a rectangular cavity. The filter is very compact and offers great saving in both size and volume, but it suffers from inferior spurious free performance.

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