A Novel Coupling Method for Dual Mode Waveguide or Dielectric Resonator Filters

by

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Abstract— A new method for coupling dual mode waveguide or dielectric resonator cavities is described and analyzed. The method provides a practical, flexible, economic means of replacing irises, and offers easy tunability of the coupling over a wide range of coupling values. Calculation of the resonator's coupling parameters using the mode matching methods yields accurate results and is verified by measurements. An experimental X-band 4-pole dual mode elliptic function waveguide cavity filter using the new coupling method was constructed and tested. The test results showed excellent agreement with theory.

I. Introduction

Dual mode filters realized in empty waveguides or using dielectric resonators offer significant performance, size, and mass advantages over conventional direct coupled cavity filters [1]-[3]. These filters require irises to provide couplings among resonators. The iris has to be produced (machined and silver plated) to a high degree of precision, which contributes significantly to the high costs of producing the filter. Recently, realizations were introduced [4] of canonical and longitudinal dual mode dielectric resonator filters without iris. These realizations have the significant advantage of eliminating the most expensive part of the filters, i.e., the coupling irises, and replacing each iris by a simple length of the dielectric resonator enclosure and a pair of tuning screws. Although extremely attractive from the production point of view, this realization has the disadvantage that the filter length becomes excessively long, especially if small couplings are needed in the narrow bandwidth filter. A compromise to achieve a minimum number of iris and also maintain the filter length at a reasonable value was recently introduced [5], which used a single iris to provide the smallest required coupling in an 8-pole filter, while the rest of the couplings were realized without irises.

The present paper introduces a new method for coupling any two dual mode cavities (either empty waveguide or dielectric loaded resonators) without iris. The method has the ability to reduce considerably the coupling section length and to easily adjust the coupling value. An accurate method for the analysis of the coupling configuration is presented. The method uses mode matching and yields accurate results which were verified by measurements. To illustrate the application of the new coupling mechanism, an experimental dual mode 4-pole elliptic function filter was designed, constructed, tuned, and tested. Measured results from the filter showed excellent agreement with theory.

II Analysis

Fig.1 shows the common methods of coupling two dual mode circular waveguide cavities (air-filled or dielectric resonators loaded). In Fig.1(a) and 1(b), a cross iris is used to provide, through the magnetic fields of the modes, the required couplings M_{14} and M_{23}. The lengths of the horizontal and vertical slots can be independently chosen to achieve any values of the two couplings. In Fig.1(c) and 1(d), the circular iris provides equal couplings for both modes; hence, $M_{14} = M_{23}$. These types of equal couplings are required in the realizations of symmetrical canonical form filters[4]. In Fig.1(e), the couplings between the two dual mode dielectric resonators are achieved through the evanescent mode in the enclosure by adjusting the resonator's spacing $2\ell_t$ [6]. If the required couplings M_{14} and M_{23} are equal, the tuning screws shown in the figure will not be required. To achieve unequal couplings among the modes, the two pairs of tuning screws placed symmetrically midway between the two resonators are used.

The coupling method of Fig.1(e) is not suitable for the empty cavity case, since the connecting guide between the two cavities is not beyond cut-off. The new coupling method shown in Fig.2 introduces a short section of a waveguide beyond cut-off to couple the two dual mode cavities. Two equivalent circuits of this coupling structure are shown in

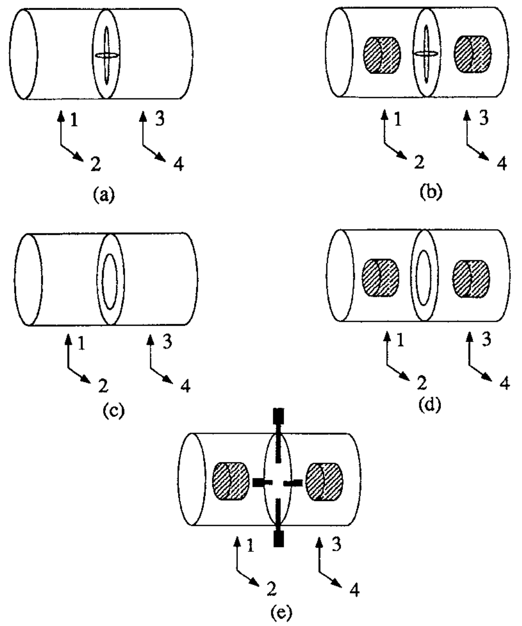
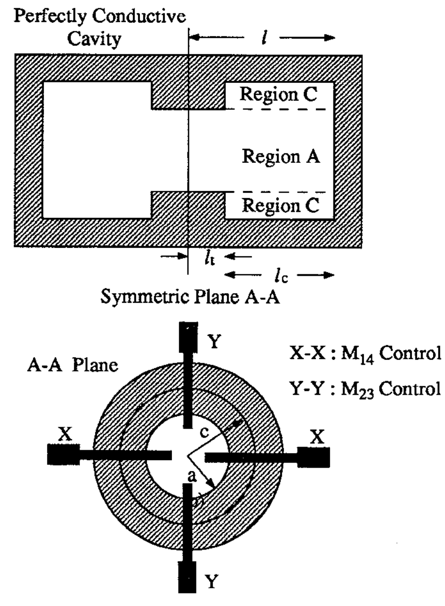
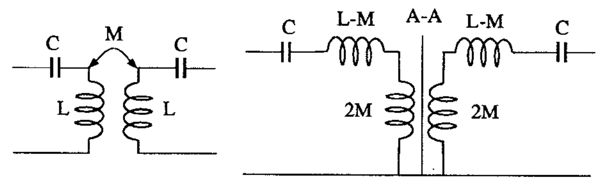


Fig.1 Methods of coupling two dual mode cavities. (a) Cross coupling iris of two empty cavities ($M_{14} = M_{23}$). (b) Cross coupling of two D. R. ($M_{14} = M_{23}$) (c) Circular coupling of two empty cavities (used for canonical form realization $M_{14} = M_{23}$). (d) Circular coupling of two D.R. (used for canonical form realization $M_{14} = M_{23}$). (e) Coupling through the enclosure of two D.R.



(a)



(b)

Fig.2(a) New Coupling method between two dual mode (empty) cavities. (b) Equivalent circuits of the resonators in (a).

Fig.2(b). If the coupling coefficients between the cavities is M, then from the symmetry of the structure, it is possible to calculate M from a knowledge of the resonant frequencies f_e and f_m of either one of the two cavities, where f_e and f_m represent the resonant frequencies assuming the plane $A - A$ as a perfect electric conductor (PEC) and a perfect magnetic conductor (PMC), respectively. The coupling is simply:

$$k = \frac{M}{L} = \frac{f_e^2 - f_m^2}{f_e^2 + f_m^2} \tag{1}$$

The two pairs of screws $X - X$ and $Y - Y$ shown in Fig.2(a) affect the electric fields of the two orthogonal dual modes in cases when a magnetic wall exists in the symmetry plane $A - A$, but have no, or negligible, effects on any fields in the cases when an electric wall exists in the symmetry plane $A - A$. Furthermore, the effect of inserting these screws deeper into the cavities is to lower the value of f_m, leaving f_e unchanged. Therefore, insertion of these screws inside the cavities has the effect of increasing the coupling coefficient between the corresponding modes. Thus, the new coupling mechanism controls the values of the coupling between the dual modes in each of the cavities independently by proper adjustment of the screws' penetration into the cavities.

Theoretical computations of f_e and f_m (and, hence, the coupling) are possible by using the mode matching technique [6] to compute the resonant frequencies of one-half of the structure shown in Fig.2(a), when the plane $A - A$ is replaced by the electric wall or magnetic wall, respectively. The half section is divided into two regions as shown in Fig.2(a). Consider TE modes only, the transverse fields in each region are expressed as expansions of eigenfields:

$$\begin{aligned} \overline{E}_{AT} &= \sum_i A_i J_n'(\xi_{A_i} r)\hat{e}_{A_i T} \\ \overline{H}_{AT} &= \sum_i A_i J_n(\xi_{A_i} r)\hat{h}_{A_i T} \end{aligned} \tag{2}$$

and

$$\begin{aligned} \overline{E}_{CT} &= \sum_i C_i F_n'(\xi_{C_i} r)\hat{e}_{C_i T} \\ \overline{H}_{CT} &= \sum_i C_i F_n(\xi_{C_i} r)\hat{h}_{C_i T} \end{aligned} \tag{3}$$

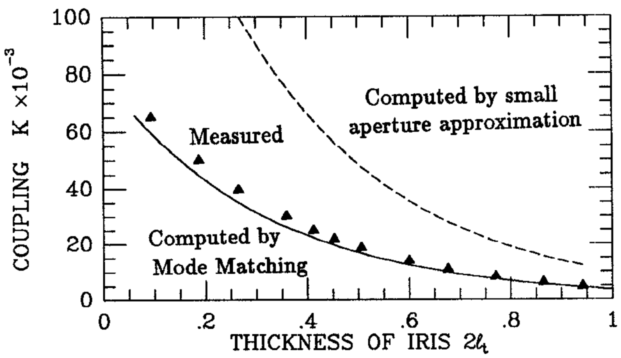


Fig.3 Comparison of Measured coupling coefficients with different theoretical approaches (a = 0.365″, c = 0.565″, ℓ_c = 1.24″).

where $\hat{e}_{A_iT}(\hat{e}_{C_iT})$ and $\hat{h}_{A_iT}(\hat{h}_{C_iT})$ are transverse electric and magnetic fields respectively of the i^{th} eigenmode existing in region A(C). $A_i's(C_i's)$ are unknown mode coefficients to be determined and $F_n(\cdot)$ and $F_n'(\cdot)$ are combinations of Bessel functions. Since the transverse fields are continuous at the boundary between region A and C, we have

$$\overline{E}_{AT}(r=a) = \overline{E}_{CT}(r=a)$$

$$\overline{H}_{AT}(r=a) = \overline{H}_{CT}(r=a) \tag{4}$$

Applying orthogonality property of eigenmodes Equations (4) can be transformed to a homogeneous linear system of equations, i.e.

$$[D]\ [A] = 0 \tag{5}$$

where $[A]$ is a column vector with elements $A_i's$. and D is a matrix having coefficient D_{ji} which depends upon the inner product of j^{th} eigenmode in region C with i^{th} eigenmode in region A. For existence of nontrivial roots of the homogeneous linear system (5), the determinant of the matrix D has to be zero, i.e.,

$$det[D] = 0 \tag{6}$$

The resonant frequencies f_e (for PEC) and f_m (for PMC) are solved by finding the roots of equation (6) are equation (1) is used to find the coupling. Results of these computations and their experimental verifications are given in the next section.

III Numerical Results

A computer program that implements the mode matching technique described above was written to compute f_e, f_m, and k. Numerical results obtained from the program and by

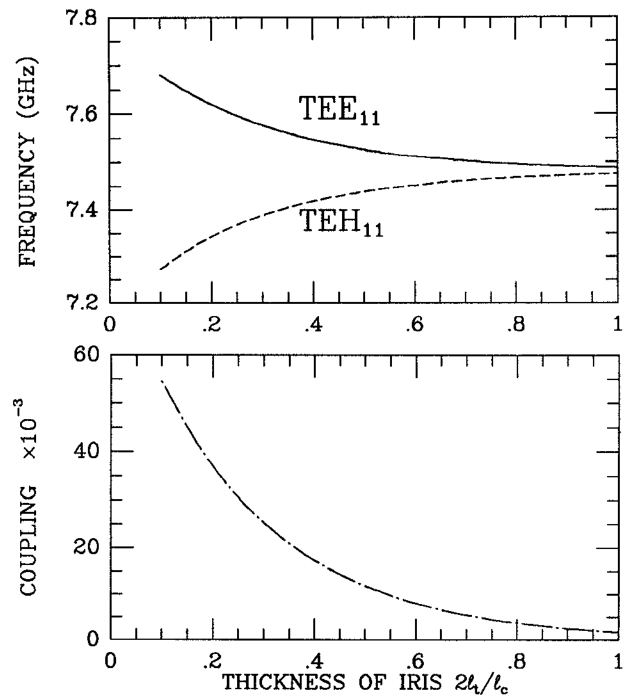


Fig.4(a) Variaion of resonant frequencies of TE_{11} modes with thickness of iris, (b) Variaion of coupling coefficient with thickness of iris.

using the small aperture approximation[7] – [8], as well as experimental measurements for coupling between two cavities with a circular iris of considerable radius and thickness are shown in Fig.3. In the small aperture approximation, the coupling coefficient between two air-filled cavities are computed by replacing the aperture with electric dipole proportional to the electric polarizability $P_i = -(2/3)a^3$ and a magnetic dipole proportional to the magnetic polarizability $M_i = (4/3)a^3$ at the plane of the aperture and evaluating the radiation from them. The coupling is given by [1],[8]

$$k = \frac{4}{9}\left(\frac{a}{\ell_c}\right)^3\left(\frac{\lambda}{c}\right)^2\frac{1}{1-\left(\frac{\lambda_c}{\lambda}\right)^2}\times 10^{-\frac{2.73(2\ell_t)}{\lambda_c}\sqrt{1-\left(\frac{\lambda_c}{\lambda}\right)^2}} \tag{7}$$

where c is radius of the cavity, λ is the wavelength in free space and $\lambda_c = 3.41a$ is cut-off wavelength of the iris with radius a. It is shown in Fig.3 that coupling coefficients obtained by (7) deviate from the measured results because the thickness and radius of the iris are comparable with the wavelength λ. Typical computed results of f_e, f_m, and k as a function of the ratio of the cut-off section length to the cavity length are shown in Fig.4. Variations of f_e, f_m and k with the radius of cut-off section are shown in Fig.5. It is

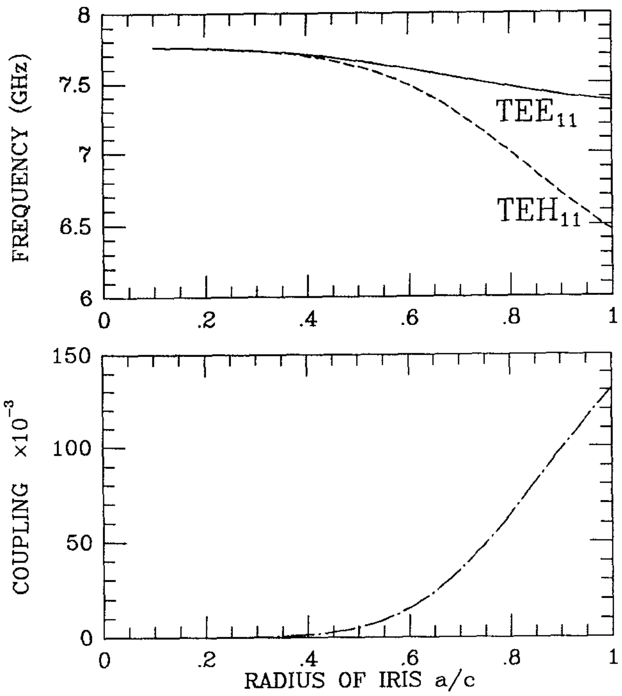


Fig.5(a) Variaion of resonant frequencies of TE_{11} modes with radius of iris, (b) Variaion of coupling coefficient with radius of iris.

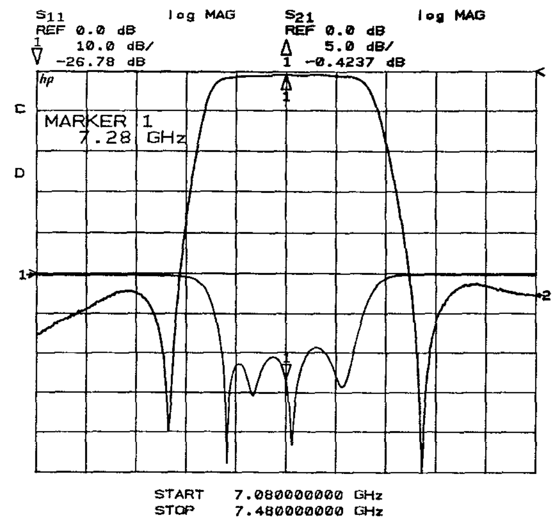


Fig.6 Measured response of the dual mode filter

worth noting that f_e is affected considerably by the radius of the cut-off section for thick circular iris in contrast to the case of thin iris, where the radius has negligible effects on the resonant frequencies assuming PEC in the symmetry plane.

To verify the usefulness and validity of the new coupling mechanism in filter applications, a 4-pole X-band filter using this new technique was designed and tested. The coupling coefficient between dual mode cavities is $M_{14} = -0.238$. TE_{11} modes are used in the design. Thickness ℓ_t and radius a of the cut-off section are chosen such that f_e and f_m satisfy $M_{14} = k$ in the equation (1). The measured results obtained from the experimental filter are shown in Fig.6. These results agree very closely with the theoretical filter response.

IV Conclusions

The new coupling mechanism introduced in this paper is simple, flexible, and allows a good range of tunability of the coupling with reasonable length. The method of mode matching was applied successfully to accurately compute the coupling. Experimental verification of the mode matching calculations were made. Finally, an X-band 4-pole filter was designed using the new coupling mechanism and showed excellent potential and viability of this method.

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