# MODELING OF COUPLING BY PROBES IN DUAL MODE CAVITIES*

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## ABSTRACT

An accurate model of coaxial probes used as input and output ports in dual mode cavities (either air filled or dielectric loaded) is presented. The model precisely predicts such empirically observed phenomena as limited out-of-band isolation, generation of extra transmission zeros and assymmetric responses. The model parameters can be determined from simple measured data. Experimental verification of the model for several configurations showed excellent agreement with theory.

## 1. INTRODUCTION

Canonical dual mode filters realized in empty waveguide resonators[1] or in dielectric loaded resonators[2],[3] require that the input and output ports of the filters be located in the same physical cavity. The simplest port configuration employs two coaxial connectors, with their center conductors extending into the resonators at 90° to each other, as shown in Fig. 1. The coaxial probes in Fig. 1 couple to the radial electric fields of each of the two orthogonal dual modes of the resonator. Although this coupling configuration is simple, it has been observed experimentally that the maximum isolation achievable between the input and output ports is limited (to about 30 dB)[1]. In reference [3], it was also observed experimentally in a four pole filter that if the coupling screw in the input/output cavity is in orientation "A", of Fig. 1, a pair of extra transmission zeros are created in the filter's response. Orientation "B", on the other hand, does not introduce these real transmission zeros. This behavior is attributed to spurious coupling between the input and output probes.

The objective of this present paper is to develop a circuit model that predicts the precise behavior of two probes in a dual mode cavity. The circuit model could be used in the analysis and calculation of any given filter structure and can also be employed in any synthesis procedure of this type of filters. Experimental verification of the model is carried out and the measurements also provide useful data for the design and prediction of canonical dual mode fitlers responses.

## 2. CIRCUIT MODEL

The usually employed equivalent circuit model of the two probes coupled to a dual mode cavity in a multiple coupled cavity filter is shown in Fig. 2. The two probes external Q's are represented by the resistances $R_1$ and $R_2$; the series LC circuits represent the two dual modes of resonance in the cavity, and the two port network represents the rest of the filter. The coupling $M_{12}$ is produced by means of the 45° screw that couples the

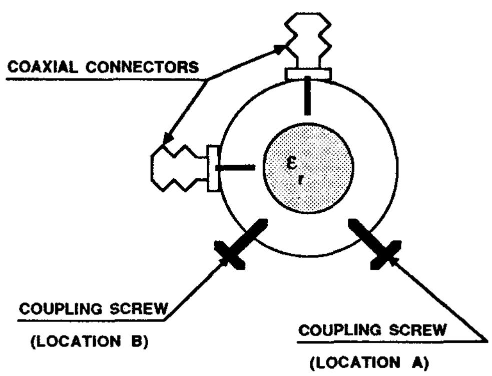


FIG. 1 Cross section of dual mode cavity with input and output coaxial probes.

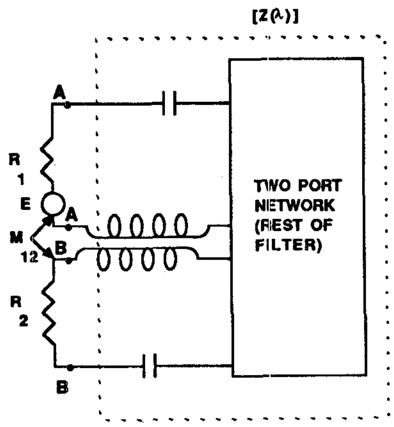


FIG.2 Circuit model of the probes neglecting coupling by higher order modes

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two resonant modes. This model does not properly predict the observed measured frequency responses of canonical dual mode filters, since the model does not include any provision for direct coupling between the probes through evanescent fields in the resonator. The model shown in Fig. 3 accounts for such coupling. This model represents each probe by a coupling loop. In addition, the resistances $R_1$ and $R_2$ representing the external Q's of the probes, the coupling loops (shown by the circled numbers 1 and 2 in Fig. 3) contain the couplings $M_1$, $M_2$, $M_0$, $M_{13}$ and $M_{24}$. The inclusion of these couplings properly models the observed frequency response of the filters, as will be shown subsequently. Each of the shown couplings has a physical interpretation through the fields existing within the resonators. A similar equivalent circuit model to that shown in Fig. 3 was presented by Bell[4], to represent canonical assymmetric filters.

Analysis of the model in Fig. 3 can be carried out using the loop equations. Since the objective is the modeling of coupling by the probes, the two port network representing the rest of the filter in Fig. 3 is replaced by short circuits and the resulting model consists of a two pole filter. The transfer function $t(\lambda)$ of such a filter is readily calculated in terms of the element values of the model to be:

$$t(\lambda) = -2j\sqrt{R_1R_2}\,\frac{b_0 + b_1\lambda + b_2\lambda^2}{a_0 + a_1\lambda + a_2\lambda^2} \qquad (1)$$

where:

$\lambda = \left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right)$ is the normalized low pass frequency variable;

$$\begin{aligned}
a_0 &= R_1R_2\,M_{12}^2 - M_0b_0 - M_{13}M_{24}C_0 - M_1M_2\,C_1 + j2M_{12}C_2\\
a_1 &= -2M_0b_1 + j\{R_1(M_2^2 + M_{24}^2) + R_2(M_1^2 + M_{13}^2)\}\\
a_2 &= -(R_1R_2 + M_0^2)\\
b_0 &= M_{12}(M_1M_2 - M_0M_{12} + M_{13}M_{24})\\
b_1 &= M_1M_{24} + M_2M_{13}\\
b_2 &= M_0\\
C_0 &= M_0M_{12} - M_{13}M_{24} + M_1M_2\\
C_1 &= M_0M_{12} - M_{13}M_{24} - M_1M_2\\
C_2 &= R_1M_2M_{24} + R_2M_1M_{13}
\end{aligned}$$

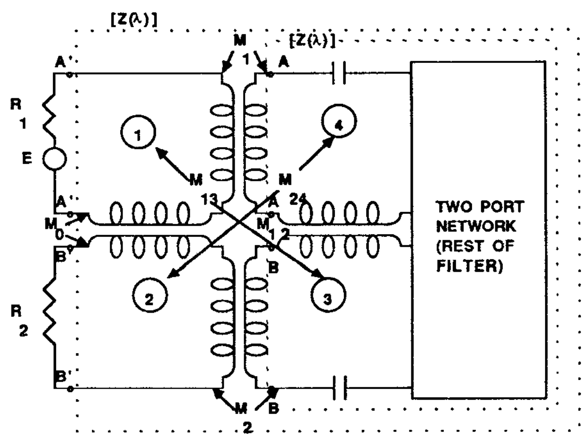


**FIG.3 Circuit model of the probes including the effect of coupling by higher order modes**

Several properties of this transfer function are observed. As $\lambda \to \infty$, $t(\lambda) \to \frac{2jM_0\sqrt{R_1R_2}}{M_0^2 + R_1R_2}$. Assuming that the spurious coupling $|M_0| \ll \sqrt{R_1R_2}$, the input/output isolation of this filter is limited to approximately $-20\log\left|\frac{2M_0}{\sqrt{R_1R_2}}\right|$ dB. Further, the transfer function has zeros of transmission $\lambda_{Z_1}$, $\lambda_{Z_2}$ at:

$$\lambda_{Z_{1,2}} = \frac{-b_1 \pm \sqrt{b_1^2 - 4M_0b_0}}{2M_0} \qquad (2)$$

The transmission zeros are real if $b_1^2 - 4M_0b_0 \geq 0$, and are complex if $b_1^2 - 4M_0b_0 < 0$. For the most commonly used parameters, it can be shown that $\lambda_Z^2 \simeq \frac{-M_1M_2M_{12}}{M_0}$. Since $\left(\frac{M_1M_2}{M_0}\right)$ is always positive in this configuration, it is seen that $\lambda_Z^2$ will be positive if $M_{12}$ is negative and vice versa. The coupling $M_{12}$ is negative for the coupling screw location $A$ and positive for location $B$ shown in Fig. 1. This can be seen from the relative direction of the electric field components of the fields $E_1$ and $E_2$, parallel and perpendicular to the coupling screws, as shown in Fig. 4. When the components of $E_1$ and $E_2$ are both in the same direction as the coupling screw, $M_{12}$ is negative, and when these components are in opposite direction, the coupling $M_{12}$ is positive, since these components must satisfy the boundary condition of vanishing total tangential electric field on the perfectly conducting screw. This therefore explains the experimentally observed phenomena of extra pair of transmission zeros present in the response of four pole canonical dual mode filters having input and output coaxial probes in the same cavity. Figure 5 shows the computed response of three 2-pole filters having identical external Q's ($R_1, R_2$), and $M_{12}$. The solid curve in this figure corresponds to the case where $M_0 = 0$, i.e. the input/output probes are in two different cavities. The two dotted curves $A$ and $B$ in Fig. 5 correspond to locations $A$ and $B$ of the coupling screw of Fig. 1, respectively. The effect of the sign of $M_{12}$ on the response is clearly evident in the presence of the two transmission zeros in curve $A$.

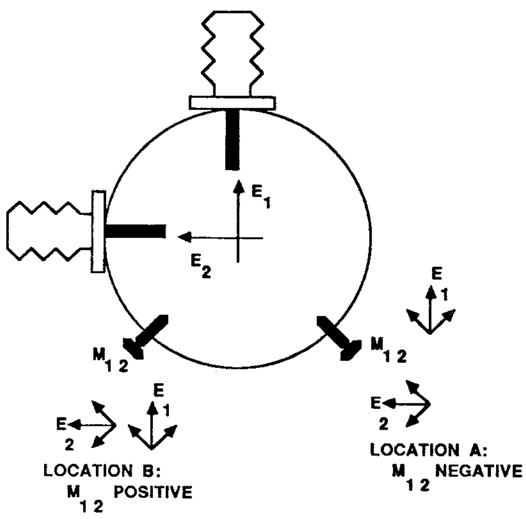


**FIG.4 Electric field components parallel & perpindicular to the coupling screws for locations A & B**

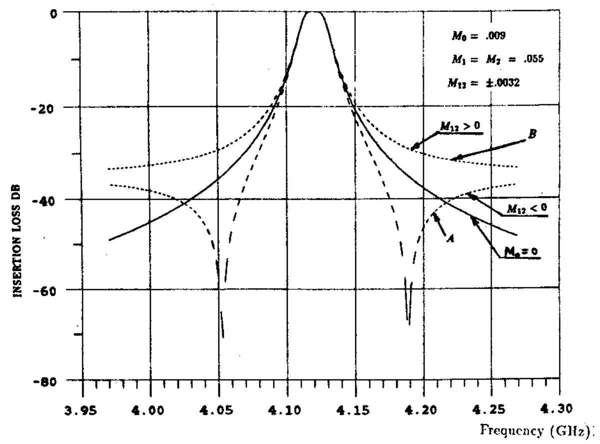


Fig. 5. Computed Insertion Loss Response of 2-Pole Filters.

## 3. EXPERIMENTAL AND COMPUTED RESULTS

Parameters of the equivalent circuit can be determined from the above equations using measured values of $|t(\infty)|$, $\lambda_{Z_1}$ and $\lambda_{Z_2}$. The values of $R_1, R_2$ and $M_{12}$ are determined from one port phase measurements described in Ref. [5].

Experimental measurements were performed to determine the variation of the various couplings with the angle $\phi$ between the two probes. From a large number of measurements it was found that the coupling $M_0$ is almost independent of all the parameters of the coupling structure, except the probes depth and diameter. Thicker and deeper probes tended to produce larger $M_0$. Typical measured data showing the variation of the couplings $M_{12}$ and $M_{24}$ with the angle $\phi$ between the probes are shown in Fig. 6.

When used as a two pole filter, the filter response is highly dependent on the angle $\phi$. The model of Fig. 3 accurately predicts these responses, including the locations of the transmission zeros, the asymmetry of the response and the maximum achievable out of band isolation. Typical measured and computed data depicting the accuracy of the model are given in Fig. 7. Finally, Fig. 8 shows the response of two 4-pole filters with positions of coupling screws $A$ and $B$ as shown in Fig. 1, indicating the presence of the two extra transmission zeros due to the presence of the coupling $M_0$.

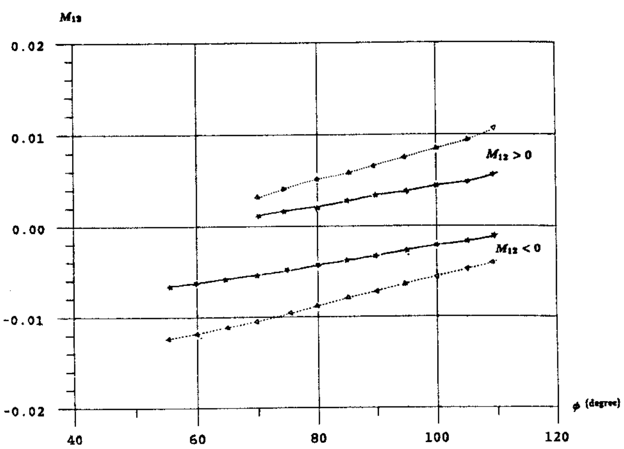


Fig. 6-a Variation of $M_{12}$ with $\phi$

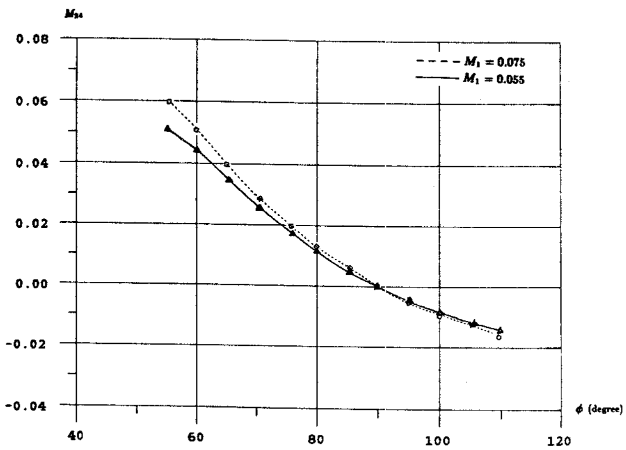


Fig. 6-b Variation of $M_{24}$ with $\phi$

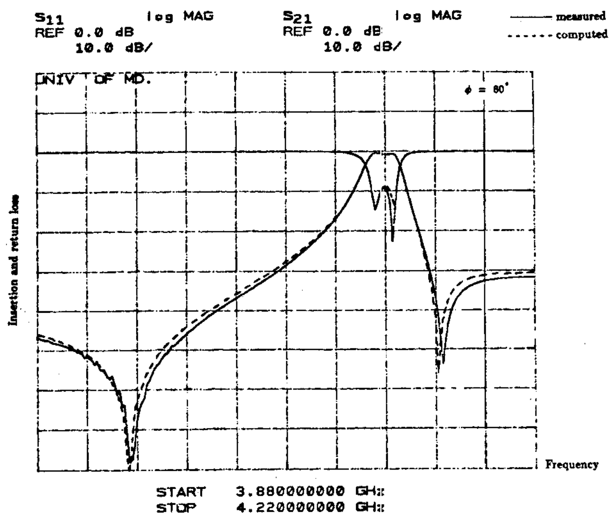


Fig. 7-a Insertion and return loss vs. frequency

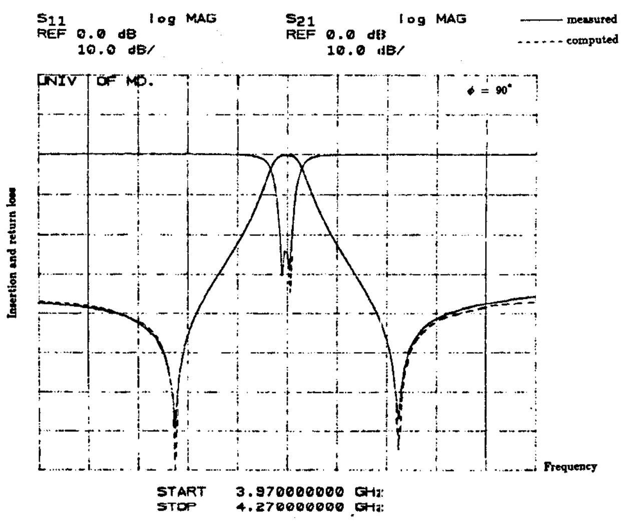


Fig. 7-b Insertion and return loss vs. frequency

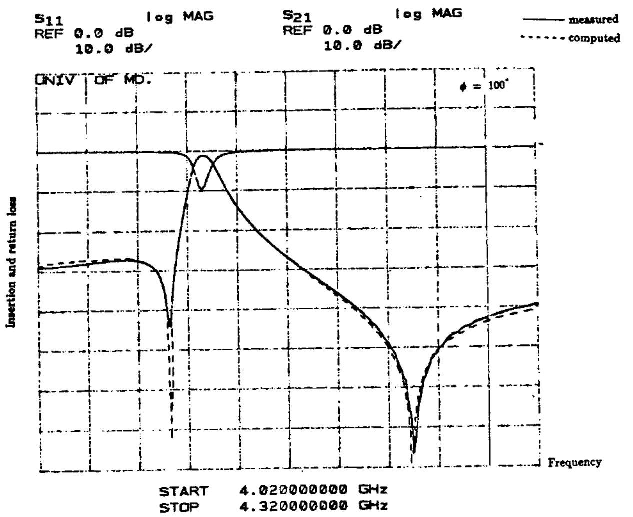


**Fig. 7-c Insertion and return loss vs. frequency**

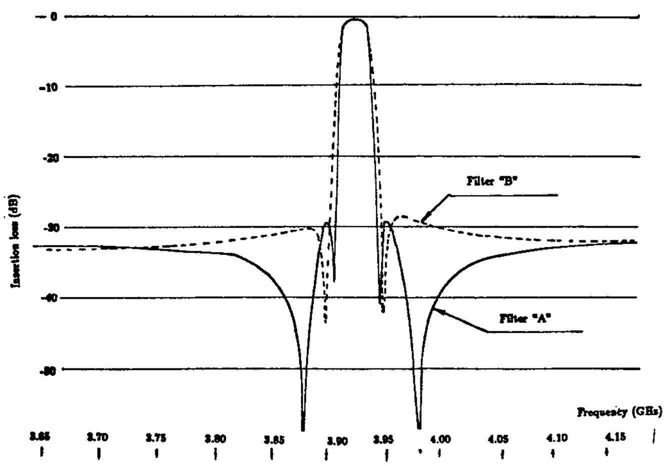


**Fig. 8 Measured wide band insertion loss responses of two 4-pole canonical dual mode filters.**

## 4. CONCLUSION

The circuit model presented of two coaxial probes in a dual mode cavity accurately predicts all the behavior of the circuits using this type of configuration. Extensive measurements were carried out and the corresponding models responses computed and compared. There is very limited control on how small the spurious coupling $M_0$ can be made. Although in higher order filters the minimum value of the out of band isolation can be slightly improved, there is always a limit on the maximum achievable isolation which is set by the presence of the spurious coupling $M_0$.

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