ANALYSIS OF QUARTER WAVELENGTH CERAMIC COMBLINE FILTERS

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ABSTRACT

This paper describes a rigorous method for analysis of coupled dielectric quarter wavelength combline resonators. The results of resonant frequencies and couplings by different coupling structures are presented. A filter design technique using the results of numerical analysis is presented. A three-pole slot coupled filter is designed and tested. Excellent experimental results verify the theory.

I. INTRODUCTION

The rapid expansion of mobile communication market demands a huge amount of compact and inexpensive hand-held communication sets. Reducing filter's size and cost are very important for a high quality and low cost hand-held set. One of the most suitable ways of miniaturizing the filters and reducing the cost is to use high dielectric constant and low loss ceramic material in quarter wavelength combline type filters [1]-[4].

An inhomogeneous dielectric block combline filter was first introduced in [1], where quarter wavelength dielectric combline resonant blocks are coupled by unplated full-through air grooves. A similar inhomogeneous dielectric monoblock filter, using full-through air holes to provide the required inter-resonator couplings, is presented in [3]. In both cases, the couplings between adjacent resonators are computed using the finite difference method by treating the coupled resonators as coupled parallel TEM transmission lines. This treatment is valid only when the air grooves extend through the dielectric and the operating frequency is well below the cut-off frequencies of all higher order modes of the coupled lines. Another drawback of the method is the difficulty of obtaining convergent results when the dimensions of air grooves are very small [1]. In addition to the full-through air grooves, irises between resonators are also employed in construction of quarter wavelength combline filters in [4], where the iris dimensions are determined experimentally.

To make accurate and efficient designs of high performance quarter wavelength dielectric combline filters, investigation of new coupling structures and precise computation of the coupling coefficients are desired. In this paper, a full wave method is applied to analyze the resonant performance of a dielectric combline cavity perturbed by a partial height air groove and to compute the couplings between two quarter wavelength resonators coupled by different coupling structures such as partial or full height air grooves, air holes, and coupling irises. Design of quarter wavelength combline filters is carried out and constructed. Expermental results verify the validation and accuracy of the method.

II. ANALYSIS

Fig. 1 shows the structure of two dielectric combline resonators coupled by a partial height air hole. The air hole could be replaced by an air gap, a slot, or other coupling structure. Since the dielectric constant of the material usually is high ($\epsilon_r > 20$), the electromagnetic fields are trapped inside the material and the unmetalized top surface of the structure can be viewed

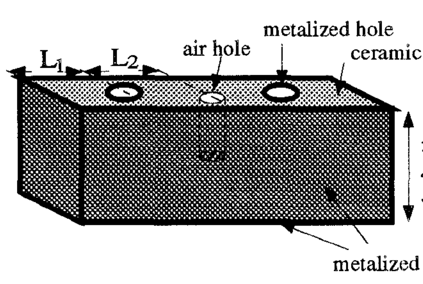

Fig. 1 Schematic structure of two dielectric quarter wavelength combline resonators coupled by a partial height air hole.

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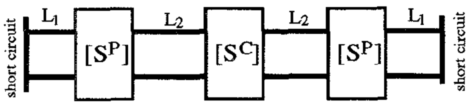


Fig. 2 S-matrix network representation of the coupled structure.

as a PMC surface when dealing with the numerical solution. Without the coupling structure, the resonators will resonate at quarter wavelength and there will be no coupling between resonators due to the electric-magnetic phase cancellation of quarter wavelength coupled lines [5].

Following the same procedure in [6], the coupled structure can be modeled as a cascade of two full-through metal posts and an air hole in a rectangular waveguide with PMC at its top surface and short circuit condition at the two ends as shown in Fig. 2. The generalized scattering matrix $[S^P]$ of the metal post and $[S^C]$ of the air hole can be obtained by the mode matching method presented in [6]. When the metal post or the air hole is off-centered from the rectangular waveguide, field transformation between two parallel shifted cylindrical coordinate systems need to be used [7] [8]. If the coupling structure is a partial height air gap or a slot instead of an air hole, $[S^C]$ can also be readily solved by conventional mode matching method.

With the knowledge of generalized scattering matrices of all the discontinuities involved in the coupled structure, the eigen equations for the natural resonant frequencies can be derived by applying the cascading procedure using S-matrices [9] in conjunction with the termination conditions. Two natural resonant frequencies f_e and f_m, corresponding to PEC and PMC at the symmetrical plane of the structure, can be acquired from the equations, and the coupling coefficient can be computed as [10]

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

$k > 0$ represents that the coupling is mainly contributed by the magnetic fields; $k < 0$ indicates that the electric field coupling is dominant.

The frequency shift due to the loading of coupling may be defined as

$$\Delta = \frac{f_r - f_0}{f_0} \tag{2}$$

where f_0 is the resonant frequency of the quarter wavelength resonator without the loading effect; $f_r = 0.5(f_e + f_m)$ is the midfrequency of the coupled resonators.

III. RESULTS

A. Resonant Frequency and Coupling

A dielectric combline cavity usually resonates at the frequency of a quarter wavelength. The resonant frequency could be tuned by making an air hole in the cavity. Fig. 3 shows the tunability of air holes with different heights and locations. In general, an air hole shifts the resonant frequency higher. The closer the air hole to the resonant rod, the bigger the frequency shift.

Fig. 4 presents the midfrequency shift and the couplings of two quarter wavelength rods coupled by partial height air holes varying the radii, where λ_m is the wavelength in the medium at frequency f_0. Also presented in the figure is the couplings of full through air hole ($d/\lambda_m = 0.25$) computed by the finite difference method in [3]. Fig. 5 gives the results of the frequency shift and the coupling coefficients of two coupled resonators by air gaps with fixed distance between the resonators. As indicated in [2], the figure shows that the couplings increase with increasing the degree of inhomogeneity, i.e. the height and the thickness of the gaps. However, the increase of coupling tends to "saturate" while the midfrequency shift continues to increase. Both air hole and air gap provide only the magnetic (positive) coupling. To realize the electric (negative) coupling as required in design of elliptic function filters, irises have to be used. The results using iris as coupling structure are presented in Fig. 6, where the irises are opened from the unmetalized side of the coupled cavities. As the figure shows, the material filled in the irises greatly affects the coupling properties.

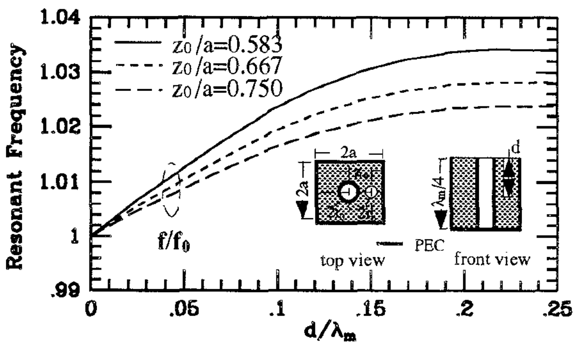
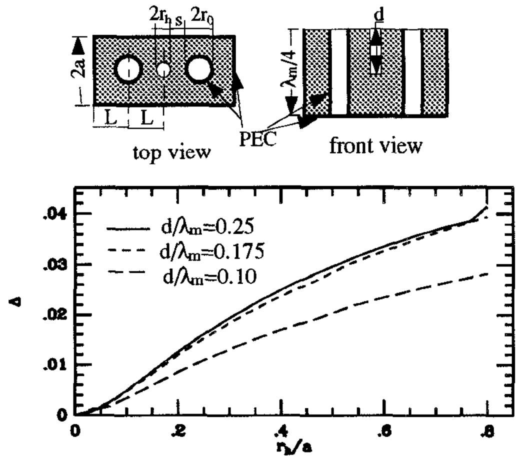
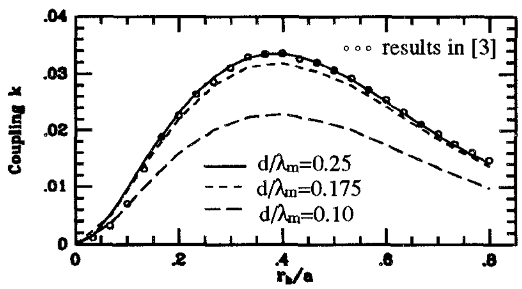


Fig. 3 Normalized resonant frequency of a quarter wavelength combline cavity tuned by a partial height air hole. $2a/\lambda_m = 0.0578$, $r_0/a = 0.275$, $r_h/a = 0.2$, $\epsilon_r = 38.6$, and $f_0 = 0.915$ GHz.

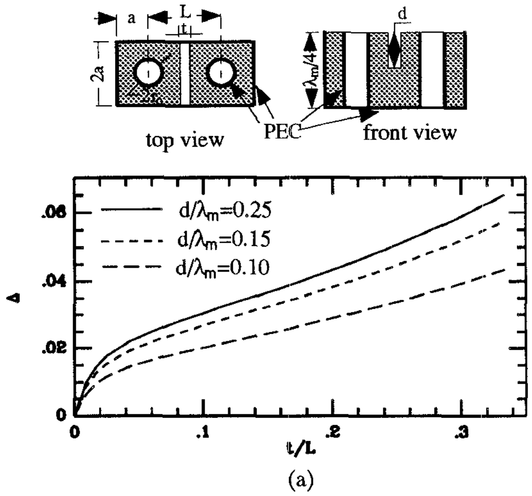


(a)

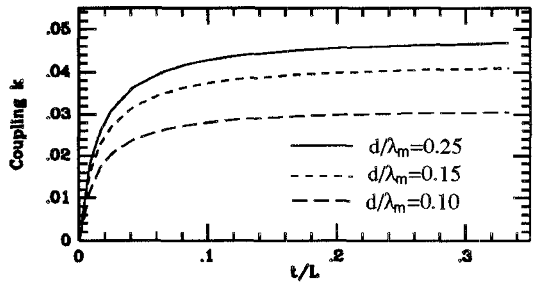


(b)

Fig. 4 (a) Frequency shift and (b) coupling coefficients of quarter wavelength rods coupled by partial length air holes. $2a/\lambda_m = 0.1432$, $r_0/a = 0.4$, $s/a = 0.2667$, $\epsilon_r = 80$, and $f_0 = 0.8$ GHz.



(a)



(b)

Fig. 5 (a) Frequency shift and (b) coupling coefficients of quarter wavelength rods coupled by partial length air gaps. $2a/\lambda_m = 0.0578$, $r_0/a = 0.275$, $L = 2a$, $\epsilon_r = 38.6$, and $f_0 = 0.915$ GHz.

B. Filter Design

An equivalent circuit of a general band pass filter is shown in Fig. 7, where M_{ij} is the mutual inductance between resonator i and j which is related to the coupling coefficient k_{ij} by $k_{ij} = M_{ij}/L$. For given specifications of a filter, the required couplings could be obtained by synthesis [11]. The dimensions of coupling structures can be determined by the method presented in the last section according to the desired coupling values. In addition to providing coupling, each coupling structure also contributes loading to each of its coupled cavities. As shown previously, the loading makes each cavity resonates at a higher frequency. In order to have all the cavities resonate at filter's center frequency f_0 when coupled together, each individual cavity has to be designed at a lower frequency to compensate for the loading effect of the couplings. For cavity i, it can be readily proved [4] that the resonant frequency should be designed at

$$f_{0i} \approx f_0(1.0 - \sum_j \Delta_{ij}) \quad i \neq 1 \; or \; n \qquad (3a)$$

$$f_{0i} \approx f_0(1.0 - \Delta_{0i} - \sum_j \Delta_{ij}) \quad i = 1 \; or \; n \qquad (3b)$$

where Δ_{ij} is the frequency shift due to the loading of inter-resonator coupling and can be calculated by the mode matching method; Δ_{0i} is the contribution of the input/output loading and may be determined experimentally.

Using the accurate analysis, a slot coupled quarter wavelength combline three-pole Tchebyscheff filter with the center frequency of 0.915 GHz and the bandwidth of 27 MHz is designed and constructed. The measured results without tuning the dimensions of the slots and the length of the middle resonator are presented in Fig. 8.

IV. CONCLUSIONS

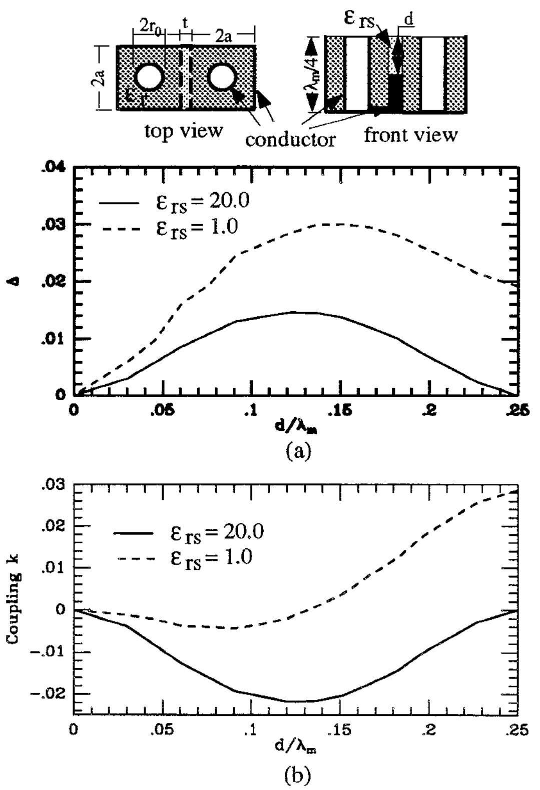


Fig. 6 (a) Frequency shift and (b) coupling coefficients of quarter wavelength rods coupled by air filled and dielectric filled slots. $2a/\lambda_m = 0.1432$, $r_0/a = 0.3333$, $t/a = 0.127$, $\epsilon_r = 20$, and $f_0 = 0.8$ GHz.

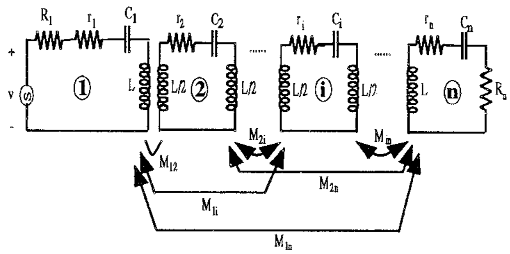


Fig. 7 An equivalent circuit of a general band pass filter.

A full wave method is developed to analyze the resonant and coupling properties of quarter wavelength dielectric combline resonators coupled by different coupling structures. The technique provides an accurate and efficient way for designing low loss and small size combline filters for mobile communication applications. The accuracy and validation of the method is verified by experiments.

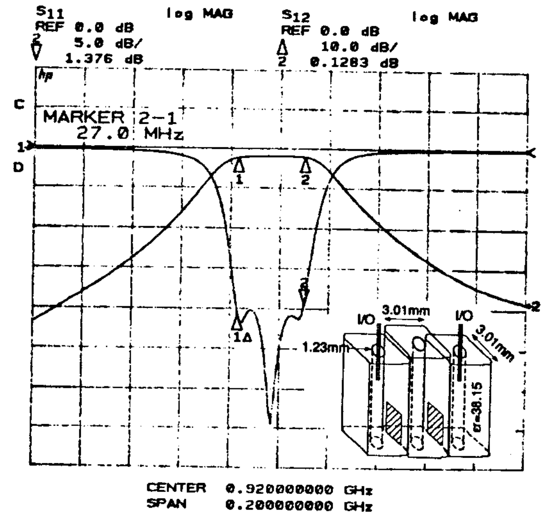


Fig. 8 Measured responses of three-pole slot coupled quarter wavelength dielectric combline filter.

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