Coupling coefficients of combline resonators.

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***Abstract* — Bandpass filters require elements that behave as series or parallel resonant circuits. In this paper, we discuss a variety of couplings between combline resonators in bandpass filter applications. Coupling coefficient used in filter realizations has been precisely calculated. Filter responses are presented by simulation, experiment and calculation. They were in very good agreement.**

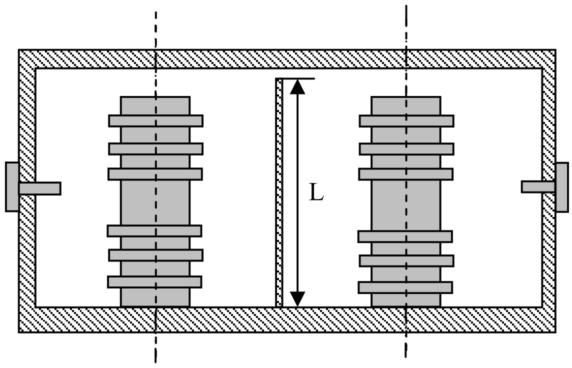
***Index Terms* — Combline resonators, coupling coefficients, filters.**

I. INTRODUCTION

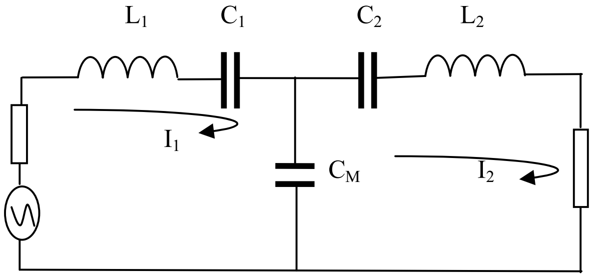
Bandpass and stoppass filters require elements that behave as series or parallel resonant circuits, such as, the coupled transmission line bandpass filters, direct-coupled waveguide cavity filters in microwave frequencies [1][2]. In this paper, we discuss coupling coefficient of combline resonators for filter applications. In the design procedures for the microwave filters, the lumped element prototype filter is used to achieve bandpass filter designs having approximately the same Tchebyscheff or maximally flat response. The multiple resonances inherent in transmission line or cavity resonators generally give bandpass microwave filters additional pass band at higher frequencies, which is far away from the dominant passband of the filter. Therefore, low frequency circuit theory is useful in microwave analysis.

II. ANALYSIS OF COUPLING COEFFICIENTS

A symmetric schematic of a second order filter under consideration is shown in Figure 1 (a). It consists of coupled combline resonators. Each of the resonators is a 6 disks periodically loaded combline resonator [3]. Two resonators connect by a coupling slot. Due to there be strong electric field exiting in the top part of the combline resonators, the coupling is called electric coupling. The coupling coefficient could be tuned by the length of L. The filter may be represented by an equivalent circuit of Figure 1 (b).



(a) Schematic diagram of a second order filter



(b) Equivalent circuit of the second order filter

Fig. 1 A second order filter

The corresponding radian resonant frequencies ω_{01}, ω_{02}, ω_0 and coupling coefficient k are

$$\omega_{01} = \omega_{02} = \omega_0 = \frac{1}{\sqrt{(C_1 + C_M)L_1}} = \frac{1}{\sqrt{(C_2 + C_M)L_2}} \quad (1)$$

$$k = \frac{C_M}{\sqrt{(C_1 + C_M)(C_2 + C_M)}} \quad (2)$$

Using the mesh equations in accordance with Figure 1(b), we have

$$\left|\frac{\mathbf{I_2}}{\mathbf{I_{2max}}}\right| = \frac{2A}{\sqrt{\left(1-\xi_1\,\xi_2 + A^2\right)^2 + \left(\xi_1 + \xi_2\right)^2}} \qquad (3)$$

where $\xi_1 = \xi_2 = Q\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right)$, $A = \frac{k}{k_c}$ donates coupling factor, $k_c = \frac{1}{\sqrt{Q_1 Q_2}}$ is the critical coupling coefficient, and Q_1, Q_2 are the quality factor of resonators.

For $Q_1 \neq Q_2$, rewriting Equation (3), we have

$$\left|\frac{\mathbf{I_2}}{\mathbf{I_{2max}}}\right| = \frac{2k_c k}{\sqrt{\varepsilon^4 + \left(d_1^2 + d_2^2 - 2k^2\right)\varepsilon^2 + \left(k_c^2 + k^2\right)^2}} \qquad (4)$$

where $d_1 = \frac{1}{Q_1}$, $d_2 = \frac{1}{Q_2}$, $\varepsilon = \frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}$.

III. SIMULATION AND EXPERIMENTAL RESULTS

Figure 2 shows the simulated filters responses using different slot couplings between coupled resonators. It is to be seen that the larger the slot width, the wider the filter bandwidth is. Using Equation (4), we plot the calculated filter responses in Figure 2 as well. For the narrow bandwidth filter response in Figure 2, there is a good agreement between simulated response and calculated response when choosing Q_1=80, Q_2=70, k_c=0.0134, k=0.019 and f_0=2.138 GHz in the Equation (4). For the wide bandwidth filter response in Figure 2, there is a good agreement between simulated response and calculated response when choosing Q_1=45, Q_2=40, k_c=0.0236, k=0.028 and f_0=2.155 GHz in the Equation (4).

When we remove the plate between the coupled resonators in Figure 1, the coupling between resonators becomes space coupling. Space coupling is a mixed coupling, which exists electric coupling and magnetic coupling. It realizes a very low Q and wide bandwidth filter application. For the space coupling, the two poles combline cavity filter responses is shown in Figure 3, there is a good agreement between measured responses, simulated responses and calculated responses when choosing Q_1=35, Q_2=28, k_c=0.032, k=0.048 and f_0=2.165 GHz in the Equation (4).

The comparison illustrates that Q factor of the resonators used in filter application is lower. This is because the optimum resonator structures no longer exist when existing coupling structures in the filter applications, especially, using space coupling. Strong feeding and loading are also one of main factors to lower the Q factor of resonators in
the filter application.

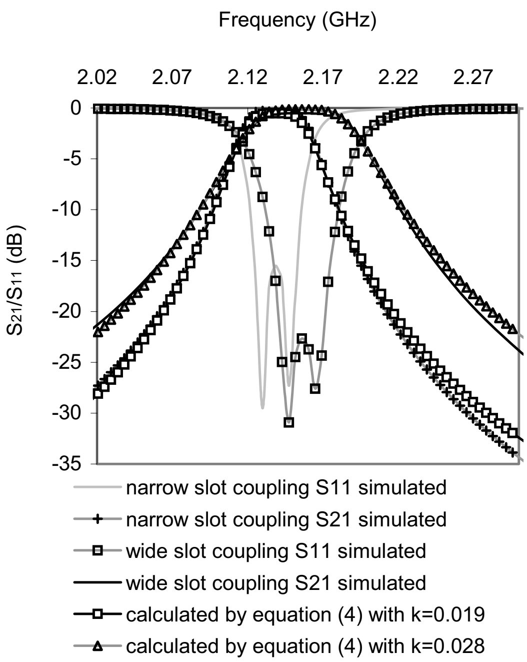


Fig. 2 Comparison of simulated filter responses with calculated responses using different slot couplings between coupled resonators

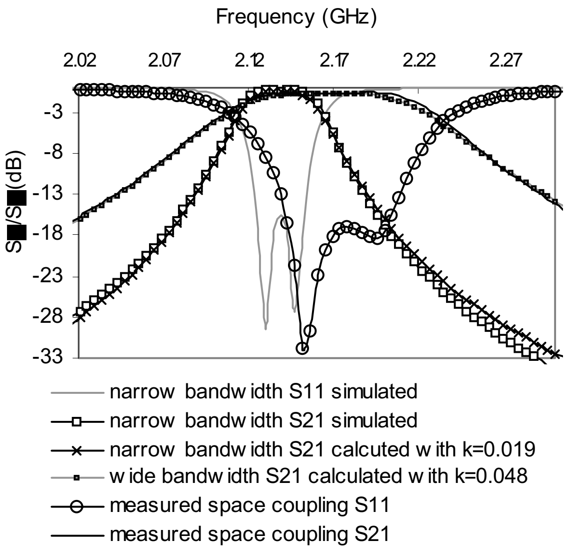


Fig. 3 Comparison of measured filter responses with calculated and simulated responses using slot coupling or space coupling between coupled resonators

VII. Conclusion

Using equivalent circuit, we obtain an expression for second order filter response. Therefore, we can precisely calculate the coupling coefficient k between the resonators used in filter applications. It is realized that the filters using high Q factor resonators with very small coupling coefficient k are essential to design narrow-band filters in the application for more and more crowded radio spectrum. A set of second order filter responses are presented by simulation, experiment and calculation. They were in very good agreement.

References

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