Effect of External Circuit Susceptance Upon Dual-Mode Coupling of a Bandpass Filter

Arun Chandra Kundu, *Member, IEEE*, and Ikuo Awai, *Senior Member, IEEE*

***Abstract*—The effect of external circuit susceptances in the coupling between the dual-modes of a microstrip ring resonator bandpass filter in addition to the main stub perturbation susceptances is described. New theoretical expressions are devised to calculate this coupling and they are experimentally verified.**

***Index Terms*—Coupling, dual-mode, external circuit.**

I. Introduction

DUAL-MODE microstrip resonator filters are widely used in communication systems due to their compactness. In general, the coupling between the dual dominant modes is provided by addition of perturbations, which may be of several types. But the second order effect of external circuit susceptances also provides a considerable effect upon dual-mode coupling [1]. For a perturbed dual-mode resonator we have found experimentally that with the increase of the external circuit susceptance the coupling constant increases or decreases depending upon the position of the perturbation stubs with respect to the I/O terminals. The nature of dual-mode coupling (capacitive or inductive) for a particular type of perturbation depends upon its placement with respect to the I/O terminals [2]. Theoretical expressions for the coupling constant, including the effect of external circuit susceptances are developed for different placements of stub perturbations, and experimentally verified.

II. Conventional Calculation of Coupling Constant

The physical structure of a dual-mode microstrip ring resonator BPF for capacitive excitation is shown in Fig. 1. The model microstrip ring resonator of Fig. 1 has the following dimensions: external diameter $=$ 10 mm, internal diameter $=$ 6 mm, height $=$ 1.6 mm and dielectric constant $\varepsilon_r = 10.5$. Symbolic representation of the microstrip ring resonator BPF is shown in Fig. 2.

For even mode excitation, the symmetry plane of Fig. 2 will act as an open circuit, and the equivalent circuit is the transmission line model as shown in Fig. 3 (excluding external circuit susceptance). From this the normalized input admittances y_1 and y_2 can be expressed as follows

$$y_1 = j\frac{b_p + 2\tan 3\theta}{2 - b_p \tan 3\theta} \tag{1}$$

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A. C. Kundu is with the RF Filter Group, TDK Corporation, Ichikawa 272-8558, Japan.

I. Awai is with the Faculty of Engineering, Yamaguchi University, Ube 755-8611, Japan.

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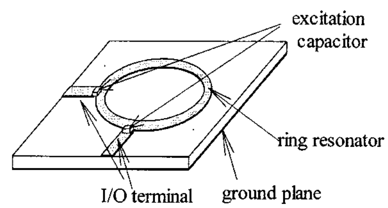

Fig. 1. Structure of the microstrip ring resonator BPF.

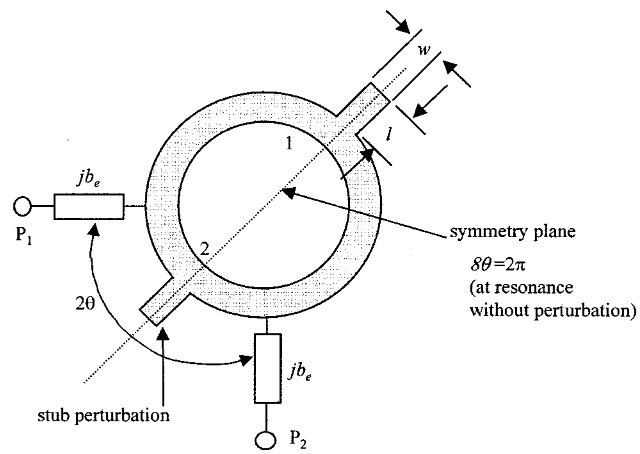

Fig. 2. Symbolic representation of the BPF.

and

$$y_2 = j\frac{b_p + 2\tan\theta}{2 - b_p\tan\theta} \tag{2}$$

where $8\theta = 2\pi =$ total electrical length of the microstrip ring resonator in the unperturbed condition; $b_p = (Y_b/Y_a)\tan\beta l =$ normalized susceptance of the perturbation stub [3]; $Y_b =$ characteristic admittance of the perturbation stub; $Y_a =$ characteristic admittance of the ring transmission line; $l =$ length of stub perturbation; and $\beta =$ propagation constant.

At resonance

$$y_1 + y_2 = 0 \tag{3}$$

$$\therefore \tan 4\theta + \frac{4b_p}{4 - b_p^2} = 0. \tag{4}$$

Since $\theta = \pi/4$ at resonance without perturbations, the even mode angular resonant frequency θ_e is obtained as

$$\theta_e = \frac{\pi}{4} - \frac{1}{2}\tan^{-1}\frac{b_p}{2}. \tag{5}$$

For odd mode angular resonant frequency (θ_o), the symmetry plane will act as a short circuit and the stub perturbations have

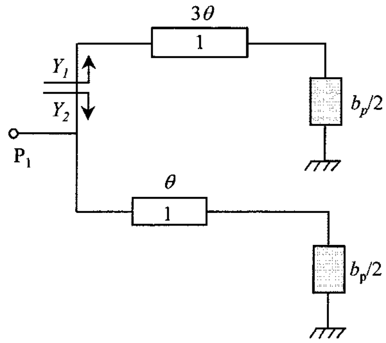

Fig. 3. Even mode transmission line equivalent circuit excluding the effect of external circuit.

no effect upon resonant frequency. Hence, the coupling constant becomes

$$k = \frac{2|f_e - f_o|}{f_e + f_o} = \frac{2|\theta_e - \theta_o|}{\theta_e + \theta_o} = \frac{\frac{2}{\pi}\left|\tan^{-1}\frac{b_p}{2}\right|}{1 - \frac{1}{\pi}\tan^{-1}\frac{b_p}{2}}. \quad (6)$$

It is well known that the 3-dB bandwidth of a BPF and coupling constant are related by

$$k = \frac{1}{\sqrt{g_1 g_2}}\frac{B}{f} \quad (7)$$

where $g_1 = g_2 = 1.414$ (for maximally flat BPF); $B =$ 3-dB bandwidth; and $f =$ resonant frequency. The 3-dB bandwidth versus internal coupling constant, excluding the effect of the external circuit susceptances is shown by a solid line in Fig. 4.

Coupling coefficient of a resonator to the external circuits is usually expressed by an external Q value. It is approximately obtained by [4]

$$Q_e = \frac{\omega_0}{2G}\frac{dB_{\text{in}}}{d\omega}\bigg|_{\omega_0} \quad (8)$$

taking off all the perturbations from the resonator, where B_{in} is the input susceptance of the resonator, G is the characteristic admittance of the external circuit, and ω_0 is the angular resonant frequency [Fig. 5(a)].

When the resonator is connected to the external circuit via series susceptance as shown in Fig. 5(b), Q_e is modified as

$$\begin{aligned} Q_e &= \frac{1}{g_c}\left(b_c + \frac{\omega_0}{2G}\frac{dB_{\text{in}}}{d\omega}\bigg|_{\omega_0}\right) \\ &\cong \frac{1}{g_c}\left(b_c + \frac{\pi Y_a}{G}\right) = \frac{1}{k} \end{aligned} \quad (9)$$

where $g_c = B_c^2/(G^2 + B_c^2), b_c = GB_c/(G^2 + B_c^2)$ and $B_c = \omega_0 C_e, C_e =$ excitation capacitance.

When the coupling constant (k) is known, from (9) the following relation can be easily obtained to calculate the excitation capacitance (C_e):

$$C_e = \frac{kG^2 + G\sqrt{k^2G^2 + 4(G - k\pi Y_a)k\pi Y_a}}{4\pi f(G - k\pi Y_a)}. \quad (10)$$

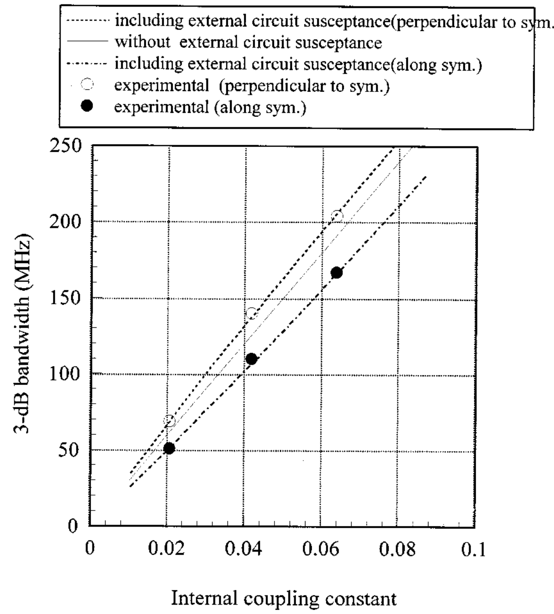

Fig. 4. The 3-dB band width versus internal coupling constant.

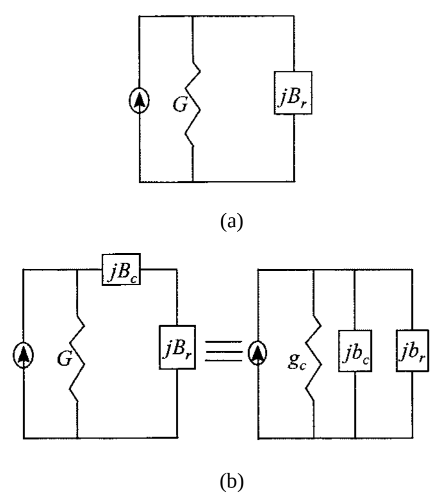

Fig. 5. Connection of a resonator with external circuit. (a) Direct connection. (b) Connection via.

III. Coupling Constant Including the Effect of External Circuit Susceptance

A. Coupling Constant for Stub Perturbation Perpendicular to the Symmetry Plane

For even mode excitation, the equivalent transmission line model becomes as of Fig. 6. From this model the admittance y_1, y_2 can be expressed as follows:

$$y_1 = j\frac{b_p + \tan 2\theta + \tan\theta}{1 - (b_p + \tan 2\theta)\tan\theta} \quad (11)$$

$$y_2 = j(b_e + \tan\theta) \quad (12)$$

where normalized external circuit susceptance

$$b_e = \frac{2\pi G^2 f C_e}{(G^2 + \omega^2 C_e^2)} \times \frac{1}{Y_a}.$$

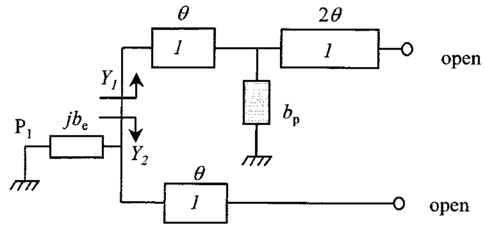

Fig. 6. Even mode transmission line equivalent circuit perturbation for 90° to the symmetry plane.

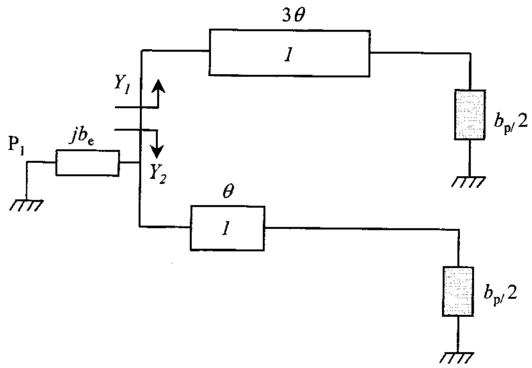

Fig. 7. Even mode transmission line equivalent circuit for perturbation into the symmetry plane.

Applying the resonance condition we obtain

$$\tan 2\theta + 2\tan\theta + (b_p + b_e) - b_e \tan\theta \tan 2\theta - b_p b_e \tan\theta - b_p \tan^2\theta - \tan 2\theta \tan^2\theta = 0. \quad (13a)$$

For a small change of resonant frequency due to the stub perturbations and external couplings, let us suppose that

$$\theta = \pi/4 + \Delta\theta \quad (13b)$$

Substituting (13b) in (13a) and neglecting the 3rd order terms, we have the following relation to calculate the change of even mode resonant frequency $(\Delta\theta_e^e)$

$$-(8b_p + 5b_e)\tan^2 \Delta\theta_e^e + (8 + 3b_e - 2b_p b_e) \times \tan \Delta\theta_e^e + b_e = 0. \quad (14)$$

For the odd mode equivalent circuit, the open ends in Fig. 6 will be simply shorted and we obtain the following relation for the change of odd mode resonant frequency $(\Delta\theta_o^e)$

$$(-8 - 3b_e - 2b_p + b_p b_e)\tan^2 \Delta\theta_o^e + (8 - 3b_e - 2b_p - b_p b_e)\tan \Delta\theta_o^e + (2b_p + b_e + b_p b_e) = 0. \quad (15)$$

Thus, the coupling constant (k_e), including the effect of external circuit susceptance becomes

$$k_e = \frac{2\,|f_e^e - f_o^e|}{f_e^e + f_o^e} = \frac{|\Delta\theta_e^e - \Delta\theta_o^e|}{\pi/4 + \Delta\theta_e^e + \Delta\theta_o^e}. \quad (16)$$

To design a BPF, if b_p is known we can calculate coupling constant from (6) and when coupling constant k is known we can calculate C_e with the help of (10).

Now if we substitute the values of b_p and corresponding C_e values in (16) we can calculate the coupling constant k_e, which includes the effect of excitation susceptance. With the help of this coupling constant we can calculate the 3-dB bandwidth of the BPF.

The calculated 3-dB bandwidth versus internal coupling constant for stub perturbations perpendicular to the symmetry plane is shown in Fig. 4. We observe that the bandwidths calculated by considering the effect of excitation susceptances have higher values than that calculated neglecting the effect of the excitation susceptances i.e., the additional coupling effect is contributed by external circuit susceptances. Here the capacitive stub perturbations placed by 90° from the symmetry plane gives capacitive internal coupling [2] similar to the external couplings, and the resultant coupling of the bandpass filter is increased.

The experimentally obtained filter bandwidth for this configuration is plotted in Fig. 4, and shows good agreement with theoretical results.

B. Coupling Constant for Perturbation Stubs in the Symmetry Plane

When the perturbation stubs are placed into the symmetry plane, the equivalent transmission line circuit for the even mode resonant frequency is shown in Fig. 7. By applying the resonant condition (as described earlier), we obtain the following relation for the change of even mode resonant frequency $(\Delta\theta_e^i)$

$$6\left(-8b_p - 4b_e + b_e b_p^2\right)\tan^2 \Delta\theta_e^i + \left(-8b_p^2 + 2b_e b_p^2 - 16b_e b_p + 8b_e + 32\right)\tan \Delta\theta_e^i + 8b_p + 4b_e - b_e b_p^2 = 0. \quad (17)$$

Similarly, for the change of odd mode resonant frequency we have $(\Delta\theta_o^i)$

$$6b_e \tan^2 \Delta\theta_o^i + (b_e - 4)\tan \Delta\theta_o^i - b_e = 0. \quad (18)$$

The filter bandwidths calculated with the help of (17) and (18) are shown also in Fig. 4. Here the coupling given by the perturbation stubs are inductive in nature [2] and that of the external circuit susceptances are capacitive in nature i.e., they are opposite in sign. Hence, the bandwidth of the BPF decreases in comparison with that excluding the effect of external circuit susceptance. Here the experimental results are also in good agreement with theory.

IV. Conclusion

A quantitative theory giving the contribution of external circuit susceptances of a dual-mode microstrip bandpass filter on the coupling between the dual-modes is proposed and experimentally verified.

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