Theory on Rotated Excitation of a Circular Dual-Mode Resonator and Filter

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Abstract

Analysis of a circular dual mode filter without any perturbation in the resonator itself is given, using a branch line model which is generally applicable to all types of circular resonators. The extended theory for the structure with shunt susceptances to the external circuit is also verified by an experiment on a coplanar ring resonator.

1.Introduction

Circular resonators are useful to reduce the dimension of BPF's due to a repetitive use of the space[1][2]. We have experimentally shown that their rotated excitation induces the mutual coupling of the degenerate modes without any internal perturbation in the resonator[3]. Thus one can fabricate a two-stage BPF of very simple structure with attenuation poles. This article introduces the branch line model of the resonator and derives analytical expressions for the coupling constant k, external Q, and the frequency of attenuation poles. A shunt susceptance is also successfully added to the external circuits which controls k and Qe independent of the attenuation poles.

2. Coupling constant and external Q

Circular resonators can be analyzed by the branch line model shown in Fig.1, including even a cylindrical resonator such as hollow waveguide configuration by characterizing the propagation constant β and characteristic impedance Z_a of the equivalent azimuthally - propagating transmission line. The coupling constant is easily obtained by insertion of the electric or magnetic wall at the symmetry plane and by the difference of each resonant frequency. The resonance condition for the even mode, for example, is given by

$$\tan \beta(L-\ell)+\tan \beta\ell + b' = 0, \qquad (1)$$

where

$$b' = \frac{Z_a}{Z_0}\frac{b_c}{1+b_c^{\,2}} \quad , \; b_c = Z_0 B_c,$$

and Zo is the characteristic impedance of the external circuit. The shift of resonant frequency from the non-perturbed state becomes

$$\Delta f^e = f_0\left(-\frac{b'}{\pi}\cos^2\beta_0 l + \frac{L-2l}{\pi L} b' \sin\beta_0 l \cos^3\beta_0 l\right) \qquad (2)$$

The coupling constant is obtained as

$$k = 2\frac{\left|f^0 - f^e\right|}{f^0+f^e} = \frac{\left|\Delta f^0 - \Delta f^e\right|}{f_0 + \frac{\Delta f^e + \Delta f^0}{2}} = \frac{2b'}{2\pi - b'}\left|\cos\left(\frac{2\pi}{L}\ell\right) - \frac{L-2\ell}{2L} b' \sin\left(\frac{2\pi}{L}\ell\right)\right| \qquad (3)$$

and shown in Fig.2. The shift of center frequency of the filter is

$$\Delta f_0 = \frac{f^0+f^e}{2} - f_0 = -\frac{b'}{2\pi} f_0 \qquad (4)$$

It should be noted that the coupling constant becomes maximum at θ=0° or 180°, where θ gives the angle between two external circuits, and it is not zero at θ=90° as is usually supposed. It is because the second order effect of b' is not negligible.

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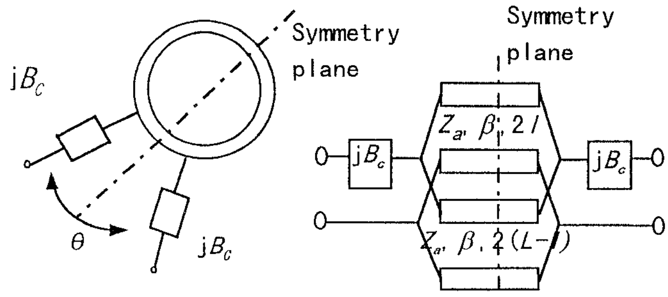
The external Q of each orthogonal mode is obtained considering the equivalent circuit with the external circuit as shown in Fig.3.

$$Q_e = \frac{G_0 b + \omega_0 C}{G_0 g} = \frac{1}{b_c} + \frac{Z_0}{Z_a}\pi\left(1+\frac{1}{b_c^2}\right) \qquad (5)$$

The matching condition for a Wagner filter is given by the intersection of k and Q_e^{-1} in Fig.4 and the filter bandwidth is readily calculated as shown in Fig.5. It indicates that the bandwidth is uniquely determined by the excitation angle θ as long as the matching condition is to be satisfied . The experimental result is also plotted in the same figure, showing a good agreement with the theory.



(a) Circular ring resonator (b) Branch line model

Fig.1. A model for rotated excitation of a circular resonator

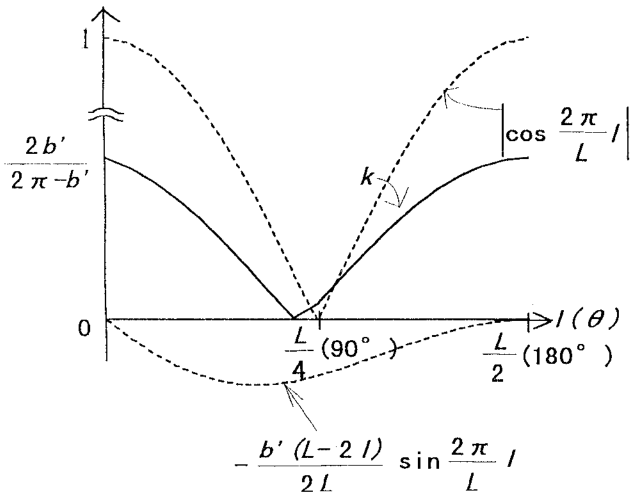
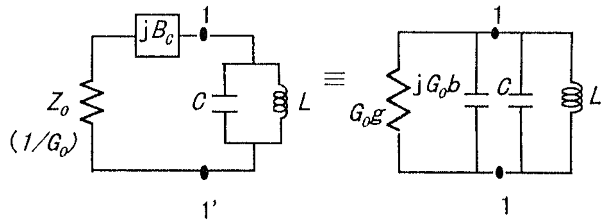


Fig.2. Coupling constant k versus the angle θ between two external circuits



$$\left.\begin{aligned} g &= \frac{b_c^2}{1+b_c^2} \\ b &= \frac{b_c}{1+b_c^2} \end{aligned}\right\}$$

Fig.3. Circuit model for calculation of external Q

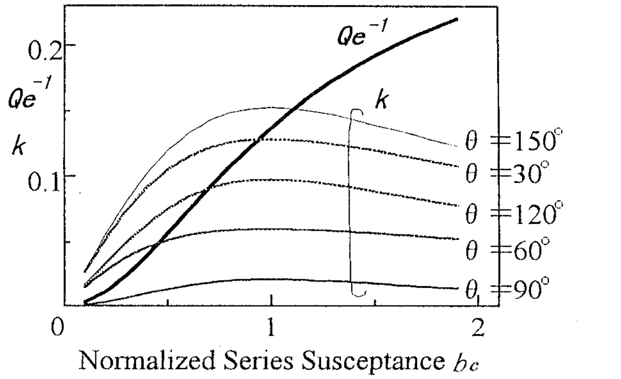


Fig.4. Matching condition of a 2-stage Wagner filter

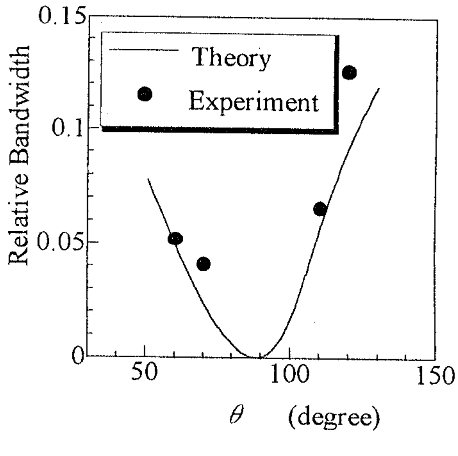


Fig.5. Relative bandwidth versus θ

3.Attenuation poles

Transmission from port 1 to 2 in a 2-port circuit dose not occur when the admittance matrix component Y_{21} is equal to zero. Therefore the condition for attenuation poles is given by putting the sum of Y_{21}'s for each path to zero as

$$\sin 2\beta\ell + \sin 2\beta(L-\ell) = 0, \qquad (6)$$

which gives the following two frequencies

$$f_1 = f_0 \quad , \quad f_2 = \frac{90}{180-\theta} f_0 \qquad (\theta\text{: in degree}) \qquad (7)$$

They are drawn in Fig.6 as a function of the angle between two external circuits.

Since the center frequency of the BPF shifts downward from f_o according to eq.(4) for capacitive excitation, the attenuation poles are located at each side of the passband for $\theta \leqq 90^\circ$, and the upper side for $\theta \geqq 90^\circ$. Circles in Fig.6 are experimental results for some θ's, showing quite good agreement with the theory. But Fig.5 and 6 tell us that the angle θ determines the bandwidth and the location of the attenuation poles at the same time.

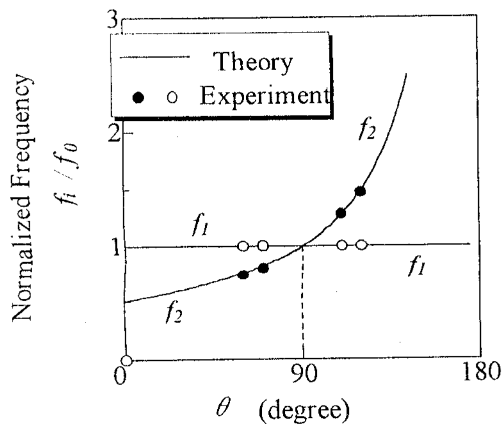


Fig.6. Frequency of attenuation poles for rotated excitation

4. Addition of shunt susceptance

In order to secure a comparative independence of the bandwidth from the attenuation pole frequency, one can add a shunt suscepance to the external circuit as shown in Fig.7. It enables us to control the external Q and the coupling constant k by the combination of B_1 and B_2. We will take an example of θ=90° which was considered most difficult configuration to realize a BPF.

The conductance and susceptance of the external circuit shown in Fig.7 is easily calculated as

$$\frac{Y_{in}}{G_0} = \frac{b_1^2}{(b_1+b_2)^2+1} + jb_1 \frac{b_2(b_1+b_2)+1}{(b_1+b_2)^2+1} = g + jb, \qquad (8)$$

$$b_1 = B_1 Z_0 \quad , \quad b_2 = B_2 Z_0$$

and used to modify the Q_e and k in eqs. (5) and (3), respectively. Thus the matching condition and the relative bandwidth are obtained as shown in Fig.8. We have simulated the response of the new structure along the solid line in Fig.8(a), but could not find a good matching somehow. Thus Fig.9 shows the simulated results for combinations indicated by crosses in Fig.8(a) based on the branch line model. The experimental confirmation is shown in Fig.10 for the coplanar structure corresponding to P1. One can see a close agreement with the simulation including the attenuation pole which is expected to be only one by eq.(7). The simulated and experimental relative bandwidth is plotted in Fig.8(b).

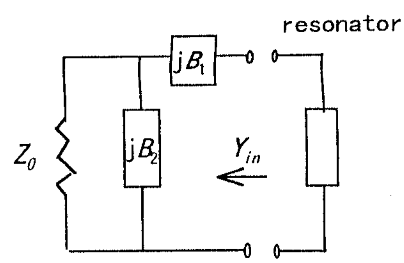
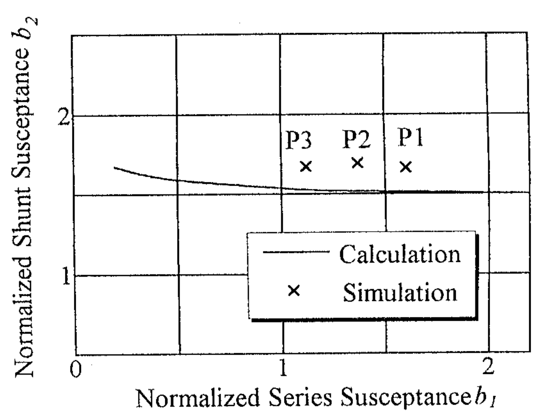
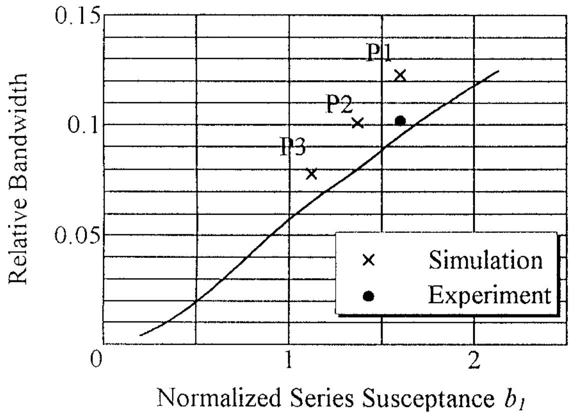


Fig.7. A shunt susceptance excitation



(a) Matching condition



(b) Relative bandwidth versus b_1

Fig.8. Condition for dual-mode BPF with shunt suscepance (θ=90°)

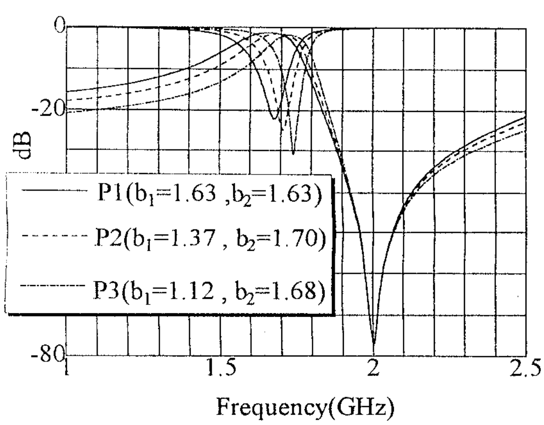


Fig.9. Simulation of BPF with shunt susceptance (θ=90°)

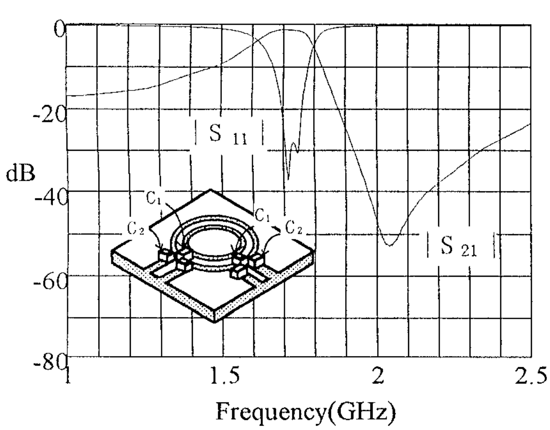


Fig.10. Characteristics of BPF with shunt susceptance (θ=90° , b_1=1.63, b_2=1.63)

5.Conclusion

We have generally analyzed a rotated excitation of circular resonator filters with the branch line model and found simple equations to describe the response. The newly proposed shunt susceptance has successfully extended the room for design.

References

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