Design of 2-Pole Band Pass Filters Using Closed Loop Resonator and Coupled Lines

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Abstract

In this paper, a new design method of band pass filters which have improved stop band characteristics, using closed loop resonator and coupled lines, is presented. The stepped impedance line has been used in resonator structure for improving the performance and reducing physical size of band pass filters. The connections between in/output ports and resonator has been realized with microstrip coupled lines. In order to show the excellence of design method presented here, we have designed and fabricated a 2-pole band pass filter with a 25-mil-thick microstrip substrate(ε_r = 10.2) at 1.885 ~ 1.905 frequency bands. The measured results are in good agreement with the simulated performances.

1. Introduction

In design of Band Pass Filters(BPF) using J-inverters, it is very difficult to achieve all required goals of the lowest insertion losses in pass band, of the highest attenuation at out of band and of the smallest size at the same time. Furthermore the realization of BPF is getting more difficult as frequency goes up[1]. For resolving these problems, BPF is usually realized with microstrip and strip type at high frequency region. However The Q-values of microstrip and strip line are so small that the insertion losses is large.

It is well known that ring resonator has high Q-value and small radiation losses. This characteristics of ring resonator has been used in measurement of the dielectric constant of substrates. The design methods of dual mode BPF using existed ring resonator had been presented in many papers.[2],[3] However there are many problems and difficulties in realization because the analysis and design of resonator and filter are performed by field theory on the basis of non-TEM mode.

On the contrary, we applied the network analytical method on the basis of TEM mode in analysis of close loop resonator which is more general form of ring resonator.[4] A small 2-pole BPF can be designed very easily with this method, and notch points also can be predicted at desired frequency.

In order to prove that our design method is very useful, we designed, realized and measured a BPF through our design method. We will show good agreement between the predicted performances of designed BPF and the measured performances of fabricated BPF.

2. Design Method and Theory

Fig. 1 shows the structure of 2-pole BPF using closed loop resonator and coupled lines.

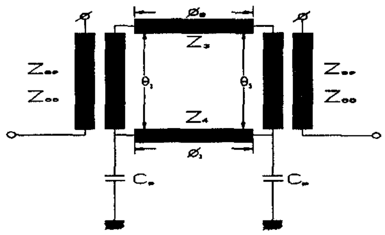


Fig. 1 The structure of 2-pole BPF

Fig. 2 shows the general type of coupled lines with one of ports is open. The equivalent circuit for Fig. 2 is shown in Fig. 3 [5].

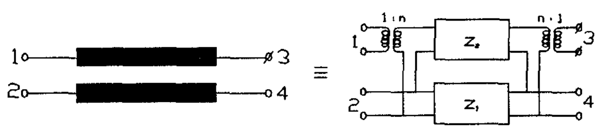
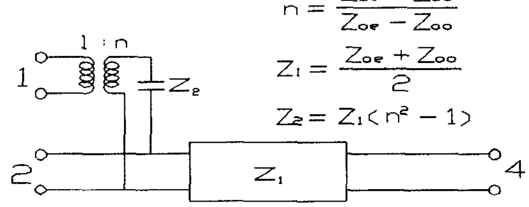


Fig. 2 Coupled lines with one of ports is open



$$n = \frac{Z_{oe} + Z_{oo}}{Z_{oe} - Z_{oo}}$$

$$Z_1 = \frac{Z_{oe} + Z_{oo}}{2}$$

$$Z_2 = Z_1(n^2 - 1)$$

Fig. 3 The equivalent circuit for Fig. 2

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Thus, the equivalent circuit of 2-pole BPF can be expressed as shown in Fig. 4.

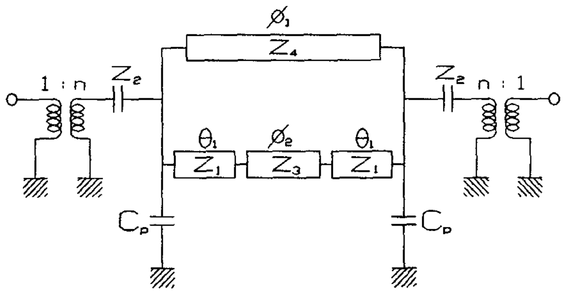

Fig. 4 The equivalent circuit of 2-pole BPF shown in Fig. 1

The transformers in Fig. 4 can be eliminated, and this results in another equivalent circuit as shown in Fig. 5.

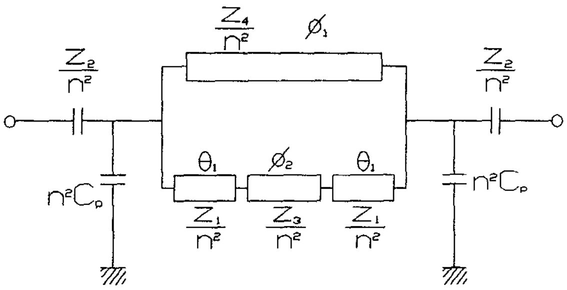

Fig. 5 2-pole BPF of which transformers have been eliminated from Fig. 4

Fig. 5 can be converted to Fig. 6 using π-type equivalent circuit of transmission line.

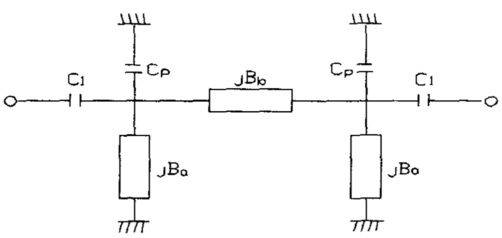

Fig. 6 Simplified π-type equivalent circuit of 2-pole BPF

C_1, jB_a and jB_b in Fig. 6 are expressed as eq. (1) ~ (3).

$$j\omega C_1 = j\frac{n^2}{Z_2}\tan\theta_1 \qquad (3)$$

The equivalent circuit of 2-pole BPF with J-inverters is shown in Fig. 7.

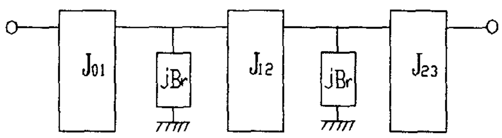

Fig. 7 The equivalent circuit of 2-pole BPF with J-inverters

Fig. 6 should be equivalent with Fig. 7 in order to have the characteristics of BPF. So eq. (4) ~ (7) are derived from the equivalence between Fig 6. and Fig. 7.

$$jB_r = j(B_a + B_b) + j\omega C_t \qquad (4)$$

$$J_{01} = \sqrt{\frac{Y_0 B_{r1}(\omega_2)}{\omega_1' g_0 g_1}} \qquad (5)$$

$$J_{12} = \sqrt{\frac{B_{r1}(\omega_2) B_{r2}(\omega_2)}{(\omega_1' g_1)(\omega_1' g_2)}} \qquad (6)$$

$$J_{23} = \sqrt{\frac{Y_0 B_{r2}(\omega_2)}{\omega_1' g_2 g_3}} \qquad (7)$$

, where

$$C_t = \left(C_p n^2 + C_1^e\right) \qquad (8)$$

$$C_1 = \frac{\frac{J_{01}}{\omega_0}}{\sqrt{1 - \left(\frac{J_{01}}{Y_0}\right)^2}} \qquad (9)$$

$$C_1^e = \frac{C_1}{1 + \left(\frac{\omega_0 C_1}{Y_0}\right)^2} \qquad (10)$$

J_{01} and J_{23} are determined by coupling amount of coupled lines. Eq. (4) should satisfy the resonant condition, expressed in eq. (11), for Fig. 7 to have the characteristics of BPF. From this fact, we can obtain eq. (12).

$$B_r(\omega_0) = 0 \qquad (11)$$

$$j\omega_0 C_t = -j(B_a + B_b) \qquad (12)$$

Now the equivalent circuit in Fig. 6 can be converted to Fig. 7 through eq. (4) ~ (7) and (12). In other words, one can obtain the characteristics of 2-pole BPF with J-inverters by using the above equations and closed loop resonator as shown in Fig. 1. In addition, it is possible to design and realize an elliptic BPF which has two notch points by the characteristics of closed loop resonator.

3. Simulation and Measurements

A 2-pole BPF designed by presented method in this paper has closed loop resonator with 46Ω of characteristic impedance. The total electrical length of resonator of this BPF is 360° at 2.1GHz. The electrical lengths of $(2\theta + \phi_2)$ and ϕ_1 are 290° and 70° each, and the passband is 1.885 to 1.905GHz. Fig. 8 shows the simulated performances of BPF. We have realized this BPF using a 25-mil-thick teflon substrate($\varepsilon_r = 10.2$) and measured the practical performances using Vector Network Analyzer(VNA). The measured results are shown in Fig. 8 (b), and these are in quite agreement with predicted results, Fig. 8 (a).

4. Conclusion

We have presented equations for design 2-pole BPF using closed loop resonator. To verify the usefulness of our equations and design method, we designed a 2-pole BPF and obtained coincidence between simulated performances and measured results. Much more applications are possible with presented design method, and one of examples is a duplexer which has high Q-value, small radiation losses and compact size.

5. References

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$$jB_a = jn^2\left[Y_4 \tan\frac{\phi_1}{2} + Y_1 \frac{Y_3 \tan\frac{\phi_2}{2} + Y_1 \tan\theta_1}{Y_1 - Y_3 \tan\frac{\phi_2}{2} \tan\theta_1}\right] \qquad (1)$$

$$jB_b = -jn^2\left[Y_4 \csc\phi_1 + \frac{Y_1^2 Y_3}{\sin\phi_2\left(Y_1^2\cos^2\theta_1 - Y_3^2\sin^2\theta_1\right) + Y_1 Y_3 \sin 2\theta_1 \cos\phi_2}\right] \qquad (2)$$

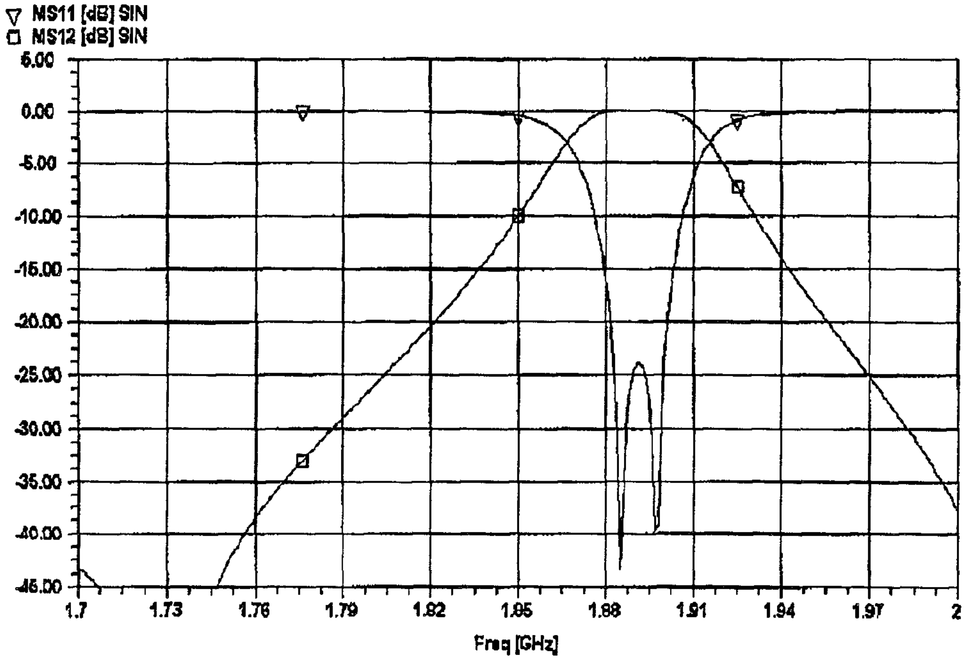

Fig. 8 (a) The simulated results of 2-pole BPF at 1.885 ~ 1.905GHz

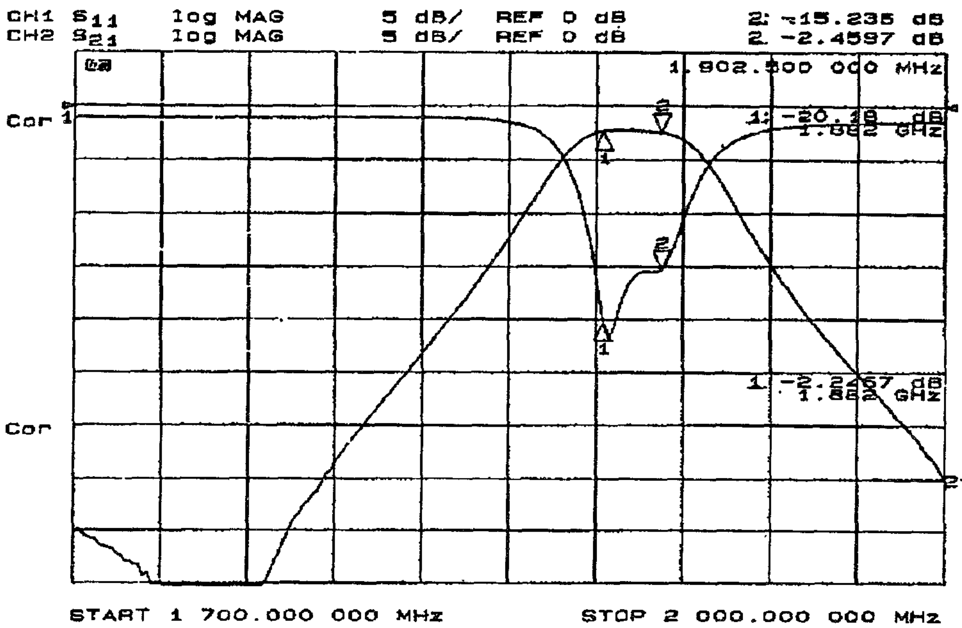

Fig. 8 (b) The measured performances of 2-pole BPF