

NEW DUAL-BAND BANDPASS FILTER WITH COMPACT SIR STRUCTURE

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Abstract—New dual-band bandpass filters with compact coupling and sizes reduction are proposed by using split ring stepped-impedance resonators and two paths coupling. In the new design, split ring SIR and defected ground structure are applied not only to reduce filter size but also to improve the filter performances. The presented filters have advantages of compact and novel structures, miniaturization and dual-band with nicer performances such as high selectivity, low passband insertion losses and so on, and these performances are demonstrated by measurement. The new design may be quite useful in wireless communication systems.

1. INTRODUCTION

In many communication related applications, it is important to keep RF (radio frequency) filter structures to a minimum size and weight, and filter performances to a low passband insertion losses, high frequency selectivity, flat group delay within the passband, etc. Microstrip bandpass filters [1–5] are essential circuits for wireless communication systems because they satisfy the above characteristics more easily. Currently, RF filters with dual-band

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operation [1, 2, 5, 6] are paid much attention because the increasing demand of wireless communication applications necessitates RF transceivers operating at dual or multi-frequency bands in order that users can access various services with a single handset. Stepped-impedance resonator (SIR) [7, 8] was presented in the past years to take the place of traditional half-wavelength microstrip parallel-coupled resonator (MPCR) because bandpass filters implemented by MPCR have narrow stopband between the fundamental response and the first spurious response, and compared to the traditional MPCR, SIR not only restrains the spurious responses, but also shortens the resonator size. SIR can also be used to design dual-band and tri-band filters by tuning the higher order resonant modes. [9] reported a bandpass filter by using SIR with two-path coupling, however, only a single band was realized. In this report, dual-band bandpass filter is obtained with split ring SIR and DGS by using two-path coupling.

Defected ground structure (DGS) [10] is formed by etching a defected pattern on the metallic ground plane, and this structure increases the effective capacitance and inductance of microstrip line, and as a result, DGS restrains the spurious responses by rejecting harmonic in microwave circuits, and the performances of filters or other microwave components are effectively improved. This report presents dual-band SIR bandpass filters by using DGS and two-path coupling, and better performances of transmission zeros, low passband insertion losses, desired dual-band as well as compact structures and size reduction are implemented compared with [8, 9]. In the research, it is shown that DGS not only restrains the spurious responses by rejecting harmonics in microwave circuits, but also introduces a wider bandwidth of passband.

2. RESONANT CHARACTERISTICS OF MICROSTRIP STEPPED-IMPEDANCE RESONATOR

A microstrip stepped-impedance resonator (SIR) unit as shown in Fig. 1(a) is formed by joining together two microstrip transmission lines with different characteristic impedance Z_1 and Z_2 (the corresponding characteristic admittances are Y_1 and Y_2), and the corresponding electric lengths are θ_1 and θ_2 , respectively. l_1 and l_2 are physical lengths corresponding to electric length θ_1 and θ_2 , respectively. Z_i is input impedance, and Y_i is input admittance. If the discontinuous of microstrip step and margin capacitance of open-circuit port are omitted, Z_i can be expressed as [11]

$$Z_i = jZ_2 \frac{Z_1 \tan \theta_1 + Z_2 \tan \theta_2}{Z_2 - Z_1 \tan \theta_1 \tan \theta_2}. \quad (1)$$

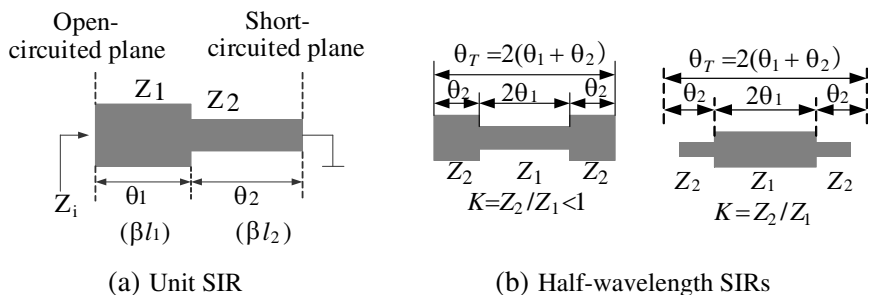


Figure 1. Unit SIR and traditional half-wavelength SIR structures.

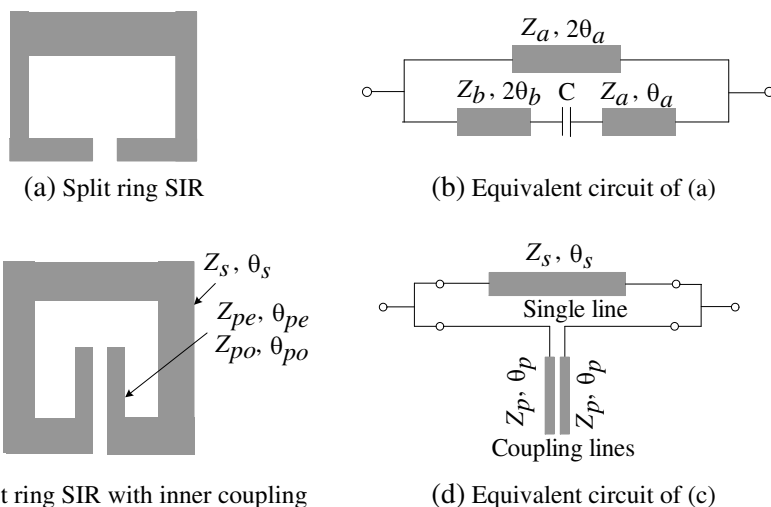


Figure 2. Split ring SIR applied in the design.

The parallel resonant condition can be obtained on the base of $Y_i = 0$ as $Z_2 - Z_1 \tan \theta_1 \tan \theta_2 = 0$, and it can be written as

$$K = \tan \theta_1 \tan \theta_2 = Z_2/Z_1. \tag{2}$$

where, K is impedance ratio. Fig. 1(b) shows half-wavelength SIRs, and their input impedance can be expressed as

$$Z_{in} = jZ_2 \cdot \frac{2(1 + K^2) \tan \theta_1 \tan \theta_2 - K(1 - \tan^2 \theta_2)(1 - \tan^2 \theta_1)}{2(K - \tan \theta_1 \tan \theta_2)(\tan \theta_2 + K \tan \theta_1)}. \tag{3}$$

where, θ_2 is electric length of outer step, and $2\theta_1$ is the electric length of inner step. The resonant condition can be obtained by $Y_i = 0$ as

$$K = \tan \theta_1 \tan \theta_2. \tag{4}$$

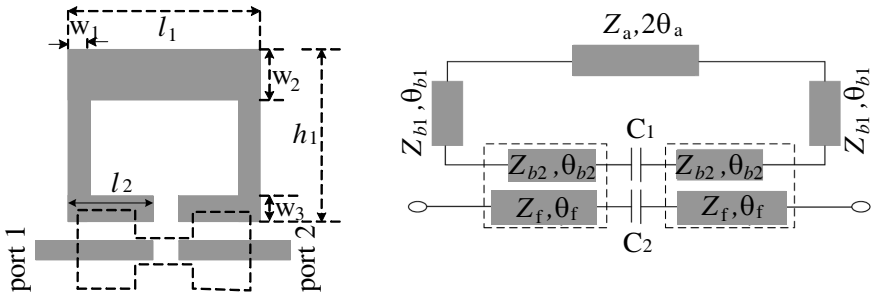
Figures 2(a) and 2(c) shows split ring SIRs, and their equivalent transmission line models are shown in Figs. 2(b) and 2(d), respectively. Split ring SIR with inner coupling is formed by a ring transmission line and end open-circuited parallel coupled lines, and when $\theta_{pe} = \theta_{po} = \theta_p$, resonant condition can be expressed as [12]

$$(Z_{pe}Z_{po}ctg\theta_p - Z_s^2tg\theta_p) \sin \theta_s + Z_s(Z_{pe} + Z_{po}) \cos \theta_s - Z_s(Z_{pe} - Z_{po}) = 0. \quad (5)$$

where, Z_s and θ_s are characteristic impedance and electric length of the single line, and Z_{pe} and Z_{po} are even and odd-mode impedance of the parallel coupled lines, respectively.

3. NEW DUAL-BAND BANDPASS FILTERS WITH COMPACT COUPLING BY USING SPLIT RING SIRs

Currently, dual-band bandpass filters are paid much attention in communication systems for the requirement of portable equipment, and users can access more services with a single handset. If the first coupling path implements the first passband, and the second path implements the second passband, a required dual-band filter can be introduced by the two-path coupling. In this report, split ring stepped-impedance resonators as shown in Fig. 2 are selected for coupling in different path. In order to show the work principle of two-path coupling, hairpin SIR bandpass filters with 1-path coupling as shown in Figs. 3 and 6 are designed, and Fig. 3(b) is the equivalent transmission line model of filter model 1, where, $Z_a = 22.15 \Omega$, $2\theta_a = 102.4^\circ$, $Z_{b1} = 42.4 \Omega$, $\theta_{b1} = 68.5^\circ$, $Z_{b2} = 42.4 \Omega$, $\theta_{b2} = 46.1^\circ$. In order to improve filter performances, a dumbbell-shaped DGS on the ground plane is applied,



(a) Topology of filter model 1

(b) Equivalent transmission line model

Figure 3. A dual-band bandpass filter with SIR by using 1-path coupling $w_1 = 1.7 \text{ mm}$, $w_2 = 4.7 \text{ mm}$, $l_1 = 22 \text{ mm}$, $l_2 = 10.5 \text{ mm}$, $h_1 = 22 \text{ mm}$. DGS: $a = b = 8 \text{ mm}$, $l = 4 \text{ mm}$, $f = 2 \text{ mm}$.

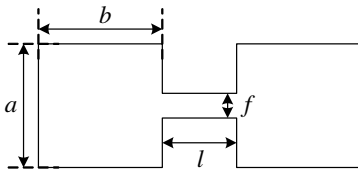


Figure 4. Dumbbell shaped DGS on the ground plane.

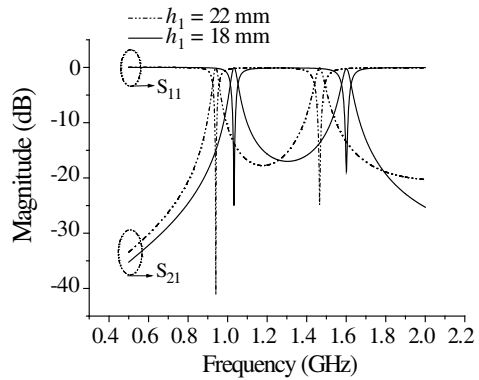
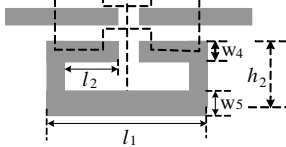
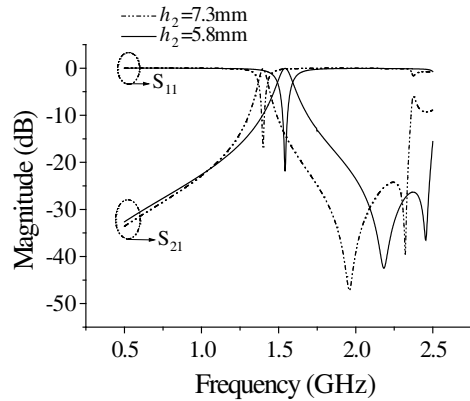


Figure 5. Frequency responses of bandpass filter model 1.



(a) Topology of filter model 2



(b) Frequency responses

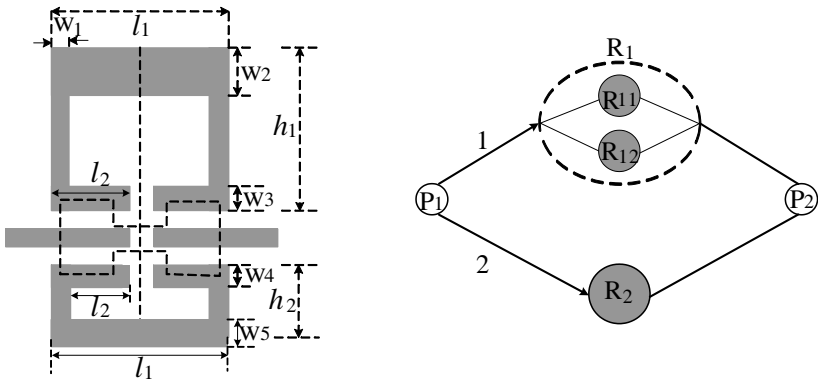
Figure 6. A single band SIR bandpass filter with 1-path coupling and its frequency responses, $w_4 = 1.7$ mm, $w_5 = 2.5$ mm, $l_1 = 22$ mm, $h_2 = 7.3$ mm.

and the topology is shown in Fig. 4, where, $a = b = 8$ mm, $l = 4$ mm, $f = 2$ mm. The filter is designed on substrate with a dielectric constant of 10.2 and a thickness of 1.27 mm. Frequency responses of filter model 1 are shown in Fig. 5, it can be seen that when $h_1 = 18$ mm, the filter operates at 1.03 GHz and 1.61 GHz, respectively, and has relative bandwidth of 4.0% and 3.1%, respectively, and passband insertion losses are no more than 0.3dB, and both operation frequencies increase with h_1 decreasing. Frequency responses of filter model 2 are shown in Fig. 6(b), it shows a single operation band with transmission zeros is obtained by using this structure, and when $h_2 = 5.8$ mm, the filter

operates at 1.54 GHz with a relative bandwidth of 6.4%, and operation frequency increases with h_2 decreasing.

We also notice that DGS plays important role in the design, and it not only restrains the spurious responses by rejecting harmonic in microwave circuits for DGS has a characteristic of band rejection, but also widens the passband bandwidth for DGS increases the effective capacitance and inductance of microstrip line.

If filter model 1 and model 2 are fitted together, a dual-band bandpass filter with transmission zeros, and low passband insertion losses is obtained, as Fig. 7 shows, and Fig. 7(b) is the coupling structure. It is known that with the assistance of DGS, R_1 introduces dual-passband, and R_2 introduces a single passband with transmission



(a) Topology of bandpass filter model 3 (b) Coupling structure

Figure 7. Dual-band bandpass filter with compact SIR by using 2-path coupling.

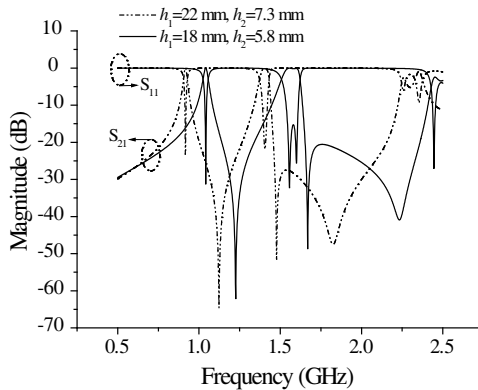


Figure 8. Frequency responses of bandpass filter model 3.

zeros. The second band produced by R_1 and the band produced by R_2 nearly overlap. The new design makes the filter's second passband obtain wider bandwidth and transmission zero because of the coupling of the resonance in path 1 and path 2, as Fig. 8 shows. It also shows the operation frequency increases with parameters h_1 and h_2 decreasing, so, a smaller filter dimension is introduced when higher operation frequency is required. It can be seen that for $h_1 = 18$ mm, $h_2 = 5.8$ mm, the dual-band filter operates at 1.04 GHz and 1.56 GHz, respectively, and with a relative bandwidth of 3.9% and 7.0%, respectively, and has transmission zeros and low passband insertion losses. It also shows the new design not only implements the required band but also improves the filter performances greatly.

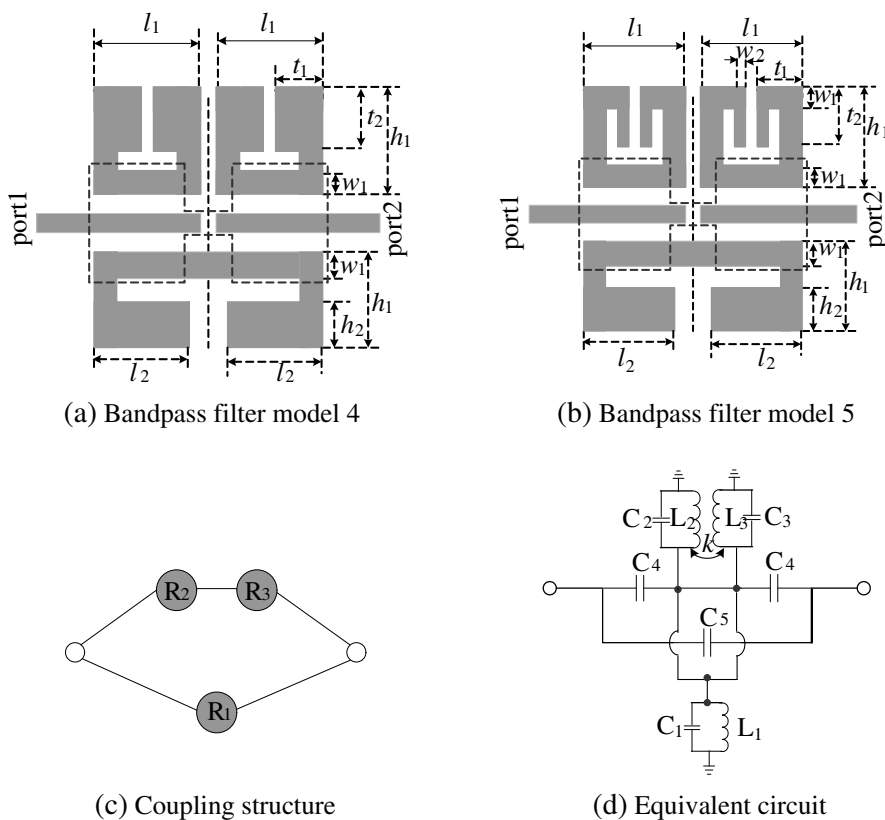


Figure 9. Dual-band bandpass filter with compact SIR using 2-path coupling, $\epsilon_r = 2.2$, $w_1 = 1.7$ mm, $w_2 = 1.0$ mm, $l_1 = 10.9$ mm, $l_2 = 10$ mm, $t_1 = 4.4$ mm, $t_2 = 6.7$ mm, $h_1 = 10.9$ mm, $h_2 = 5.3$ mm, DGS: $a = 8$ mm, $b = 10$ mm, $l = 4$ mm, $f = 1$ mm.

Dual-band bandpass filters with two-path coupling by using slow-wave SIR and inner coupling SIR are also proposed, as Fig. 9 shows, and the filters are designed on duroid substrate with a dielectric constant of 2.2 and a thickness of 0.8 mm. Coupling structure and equivalent circuit are shown in Figs. 9(c) and 9(d), respectively, where, SIRs are denoted by R_i ($i = 1, 2, 3$), and the corresponding sketch resonant circuits are denoted by the parallel of L_i and C_i , and I/O feed line is denoted as a capacitor C_4 , and their coupling is denoted as C_5 . Here, the first coupling path which transverses the slow-wave structure R_1 implements the first passband, and the second coupling path which transverses R_2 and R_3 constructs the second passband. Filters S parameters are shown in Fig. 10, and it shows that filter model 4 operates at 1.93 GHz and 2.85 GHz, while, filter model 5 operates at

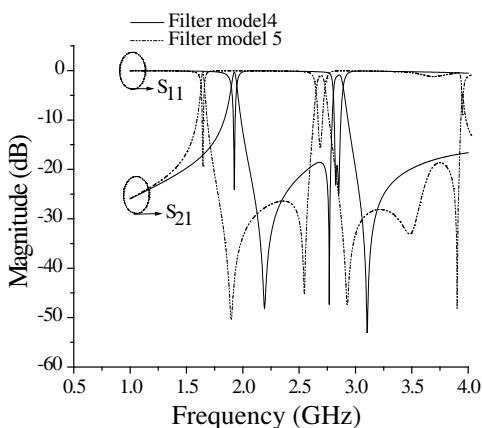
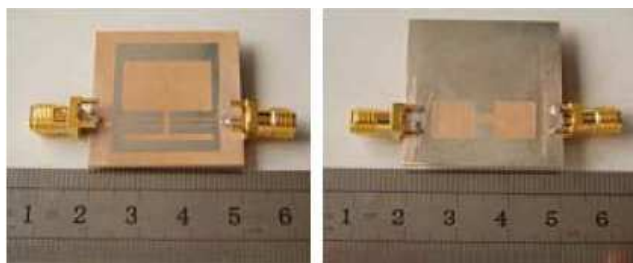


Figure 10. Simulated frequency responses of bandpass filter model 4 and model 5.



(a) Top view (b) DGS on the ground plane

Figure 11. Photograph of the fabricated filter, $h_1 = 18$ mm, $h_2 = 5.8$ mm.

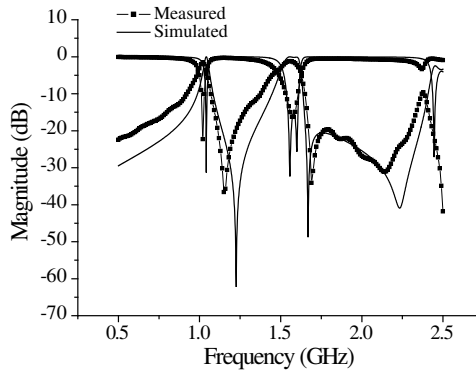


Figure 12. Measured results.

1.64 GHz and 2.68 GHz, respectively, and both have transmission zeros, and passband insertion losses are no more than 1.0 dB.

In order to verify the design, filter model 3 is fabricated, as Fig. 11 shows, and the measured results as shown in Fig. 12 are got by Agilent E5071C vector network analyzer, and it can be seen the measurement is in good agreement with the simulation.

4. CONCLUSION

In this article, new dual-band bandpass filters with compact structures by using two-path coupling are proposed, and split ring SIR and DGS are applied not only to reduce the circuit sizes but also to improve the filter performances of frequency selectivity, harmonics suppression and wide stopband neighboring the operation passband. The design is demonstrated by experiment. The presented filters have advantages of miniature, compact and novel structures, and nicer performances of transmission zeros and low passband insertion losses.

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REFERENCES

1. Yang, R.-Y., H. Kuan, C.-Y. Hung, and C.-S. Ye, "Design of dual-band bandpass filters using a dual feeding structure and embedded

- uniform impedance resonators,” *Progress In Electromagnetics Research*, Vol. 105, 93–102, 2010.
2. Zhao, L.-P., X.-W. Dai, Z.-X. Chen, and C.-H. Liang, “Novel design of dual-mode dual-band bandpass filter with triangular resonators,” *Progress In Electromagnetics Research*, Vol. 77, 417–424, 2007.
 3. Wang, Y.-X., B.-Z. Wang, and J. P. Wang, “A compact square loop dual-mode bandpass filter with wide stop-band,” *Progress In Electromagnetics Research*, Vol. 77, 67–73, 2007.
 4. Wu, H.-W., S.-K. Liu, M.-H. Weng, and C.-H. Hung, “Compact microstrip bandpass filter with multispurious suppression,” *Progress In Electromagnetics Research*, Vol. 107, 21–30, 2010.
 5. Vegesna, S. and M. A. Saed, “Novel compact dual-band bandpass microstrip filter,” *Progress In Electromagnetics Research B*, Vol. 20, 245–262, 2010.
 6. Kuo, J. T., T. H. Yeh, and C. C. Yeh, “Design of microstrip bandpass filter with a dual-passband response,” *IEEE Trans. Microwave Theory Tech.*, Vol. 53, 1331–1337, 2005.
 7. Sagawa, M., M. Makimoto, and S. Yamashita, “Geometrical structures and fundamental characteristics of microstrip stepped-impedance resonators,” *IEEE Trans. Microwave Theory and Techniques*, Vol. 45, 1078–1085, 1997.
 8. Kuo, J. T. and E. Shih, “Microstrip stepped impedance resonator bandpass filter with an extended optimal rejection bandwidth,” *IEEE Trans. Microwave Theory and Techniques*, Vol. 51, 1554–1559, 2003.
 9. Choil, W.-W., K.-W. Tam, and R. P. Martins, “A novel microstrip transversal bandpass filter with simultaneous size reduction and spurious responses suppression,” *2005 Asia-Pacific Microwave Conference Proceedings*, Vol. 1, 508–511, 2005.
 10. Dal, A., J. S. Park, C. S. Kim, et al., “A design of the lowpass filter using the novel microstrip defected ground structure,” *IEEE Trans. Microwave Theory and Techniques*, Vol. 49, No. 1, 86–93, 2001.
 11. Makimoto, M. and S. Yamashita, *Microwave Resonators and Filters for Wireless Communication*, Springer-Verlag, Berlin, Heidelberg, 2001.
 12. Sagawa, M., K. Takahashi, and M. Makimoto, “Miniaturized hairpin resonator filters and their application to receiver front-end MIC’s,” *IEEE Trans. Microwave Theory and Techniques*, Vol. 37, 1991–1996, 1989.