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MINIATURIZED DUAL-MODE COMPOSITE-RIGHT/LEFT-HANDED LINE RESONATOR FILTER WITH WIDE HARMONIC SUPPRESSION

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Abstract—This letter presents a miniaturized dual-mode composite-right/left-handed line resonator with wide harmonic suppression. The pure right-handed microstrip transmission line adopt 36° electrical length instead of 90°, thus the size of the dual-mode filter can be reduced significantly meanwhile the spurious response suppression are improved effectively. A prototype filter is designed and implemented at 730 MHz, which not only has a size reduction of 92% against a conventional dual-mode filter, but also exhibits harmonic suppression characteristics over a decade bandwidth.

1. INTRODUCTION

Miniaturized planar microstrip filters are always a highly active area of research. Among various circuit configurations, the dual-mode square ring bandpass filters have been extensively used due to their attractive features such as compact size, high selectivity, and simple design [1–14]. However, the conventional dual-mode square ring resonator suffers from their large size. To reduce the circuit size, various methods of designing a compact dual-mode filter have been proposed [5–14]. For instance, by using meander loop resonator, Hong and Lancaster designed a dual-mode filter with a 53% size reduction of the conventional design [5]; by capacitive loading in the free area inside a dual-mode ring resonator, Fok et al. designed a dual-mode filter with a 54% size reduction of the conventional design [7]; by adding

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crossed slot on the circular patch resonator, Singh and Chakrabarty proposed a dual-mode bandpass filter with an 87% size reduction of the conventional design [8].

Besides the miniaturization of dual-mode filters, the spurious suppression of dual-mode filters deserves more considerations. Several techniques have been proposed for harmonic suppression of the dual mode filters [6–14]. The techniques may be classified into two types. One is using modified ring resonators with characteristic of mode suppression [6–12]. The other is adding series bandstop filters or frequency-notched structures in the input/output (I/O) microstrip lines of a filter [13, 14]. However, the first solution impacts on the fundamental passband responses and increases the circuit design complexity and the second adds additional circuit elements against compact filter design.

Recently, there has been considerable interest in using composite right/left-handed transmission line (CRLH) in dual-mode resonators [15–17]. For further improving the size reduction and spurious suppression of the resonator, this letter proposed a novel dual-mode resonator which consists of 36° PLH transmission line and CRLH transmission line. The total phase response can be $-360°$ at nonzero resonant frequency f_R. At f_R, the CRLH ring behaves in the same way as the conventional dual-mode ring. However, the performances of size reduction and harmonic suppression are improved significantly.

2. STRUCTURE AND THEORY ANALYSIS

2.1. Conventional CRLH Dual-mode Ring Resonator

The circuit topology of the composite-right/left-handed (CRLH) ring resonator proposed in [15, 16] is shown in Fig. 1. The upper arm of the ring is right-handed (RH) microstrip line with $50\,\Omega$ characteristic impedance. The lower arm of the ring is a CRLH transmission line.

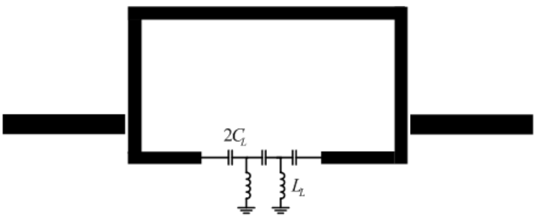


Figure 1. The configuration of the conventional composite-right/left-handed (CRLH) ring resonator.

It consists of two 50 Ω microstrip (RH) lines connecting a left-handed (LH) line formed by two lumped element T-sections.

The formula for the phase shift in the lower arm (CRLH) is given as [16]:

$$\phi_{\text{CRLH}} = \phi_{RH,\,MS} + \phi_{LH,\,LC} \tag{1}$$

In this equation, RH refers to the right-handed line; MS indicates that it is a microstrip line. LH refers to a left-handed line and LC indicates that the left-handed line is made of inductors and capacitors. Further, it is given

$$\phi_{\text{CRLH}} = -2\pi f\sqrt{\varepsilon_{eff}}\,l_{MS}/c + N/(2\pi f\sqrt{L_L C_L}) \tag{2}$$

where l_{MS} is the physical length of the RH microstrip line and N indicates the number of unit cells in the LH transmission line. L_L and C_L represent shunt inductor and series capacitor of the left-handed transmission line.

The ring is constructed on a Rogers 4003 substrate having a thickness of 0.508 mm and a relative dielectric constant of 3.38. Fig. 2 shows the simulated S_{21} parameter of the conventional CRLH dual-mode ring resonator. The resonator features a size of $12 \times 24\,\text{mm}^2$, equivalently $0.2\lambda_g \times 0.4\lambda_g$. Here λ_g is the guided wavelength of a 50 Ω microstrip line on the same substrate at 730 MHz. The simulated results indicate the first dual-mode resonance at 0.73 GHz. The second dual-mode resonance approximately occurs at the fourth harmonic, 2.8 GHz.

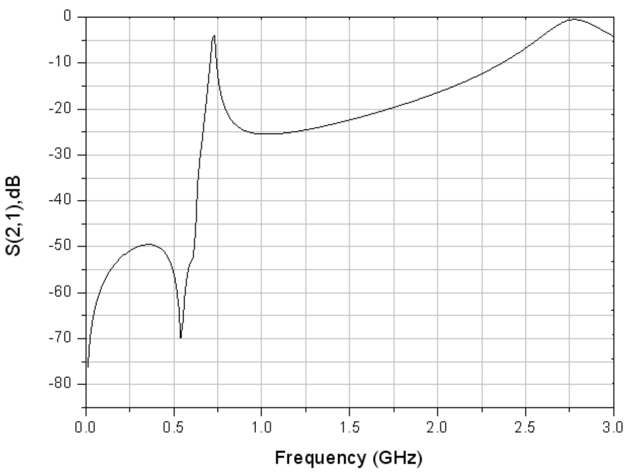


Figure 2. The simulated magnitude of S_{21} parameter of the conventional CRLH dual-mode ring resonator.

2.2. Proposed CRLH Dual-mode Ring Resonator

For further improving the size reduction and spurious suppression of the resonator, a novel dual-mode CRLH ring is constructed with 36° PRH microstrip transmission line and CRLH transmission line. The proposed filter is shown in Fig. 3.

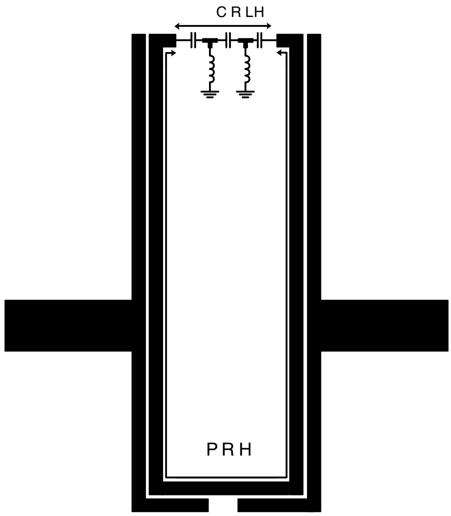


Figure 3. The configuration of the proposed CRLH dual-mode filter.

The ring is designed to exhibit a first dual resonance at f_R 0.73 GHz. The second resonance is designed to resonant at 7.4 GHz, which are 10.13 times of f_R. Fig. 4 shows the extracted dispersion diagrams of the CRLH transmission line, PRH TL and the total ring obtained from the de-embedded S-parameters. At resonator frequency f_R, the phase of the CRLH transmission line is $-324°$ with two T-section connecting lumped elements and the phase of the total ring resonator is equal to $-360°$. Thus, the CRLH ring behaves in the same way as the conventional CRLH dual-mode ring in [15, 16]. At $10.13f_R$, the phase of the CRLH transmission line is $-355°$ and the phase of the PRH TL is equal to $-365°$, so the total phase of the CRLH dual-mode ring resonator is equal to $-720°$ and resonates as dual-mode ring. Thus, by manipulating the phase response of the CRLH TL, the phase of the total ring was not equal to $2n$*pi, and hence no dual mode resonance occurred from f_R to $10.13f_R$.

The PRH transmission line is constructed on a Rogers 4003 substrate having a thickness of 0.508 mm and a relative dielectric constant of 3.38. The total length of the PRH transmission line of

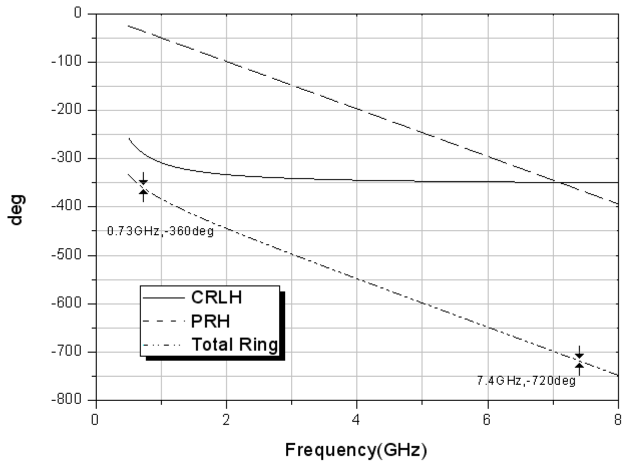


Figure 4. Extracted dispersion diagram of the designed CRLH transmission line, PRH transmission line and the total ring.

the dual-mode ring is 24 mm, which is one-tenth-wavelength of the resonance frequency with 100 Ω characteristic impedance.

The CRLH parameters L_L, C_L and l_{MS} are determined according to the following [18].

$$\frac{N}{(2\pi\sqrt{L_L C_L})f_R} - \frac{2\pi f_R\sqrt{\varepsilon_{eff}}\, l_{MS}}{c} = -\frac{9\pi}{5} \tag{3}$$

$$\frac{N}{(2\pi\sqrt{L_L C_L})10.13 f_R} - \frac{2\pi * 10.13 f_R\sqrt{\varepsilon_{eff}}\, l_{MS}}{c} = -\frac{71\pi}{36} \tag{4}$$

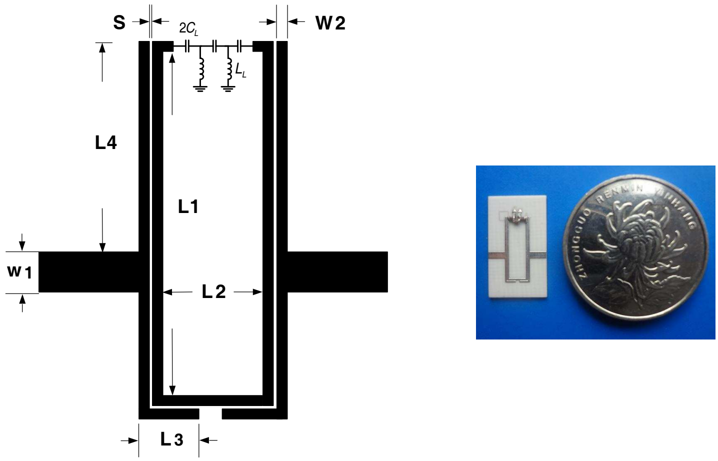
$$\sqrt{\frac{L_L}{C_L}} = Z_0 \tag{5}$$

where N indicates the number of unit cells in the LH transmission line, f_R is the resonance frequency, Z_0 is the characteristic impedance, l_{MS} is the physical length of the microstrip line of two T-section connecting lumped elements.

From the equations above, the design parameters were determined to be $N = 2$, $Z_0 = 50\,\Omega$, $L_L = 28\,\text{nH}$, and $C_L = 11\,\text{pF}$, $l_{MS} = 0.2\,\text{mm}$, respectively. To increase the dual-mode coupling, the RH and LH transmission line are designed to exhibit different characteristic impedance.

The input/output feed lines are connected to two pairs of open-circuited stubs which exhibit both coupling and tuning effects. The tapping position for input and output $L4$ can be used to adjust the position of the transmission zeros of the resonator. After simulating with IE3D and elaborating tuning [19], the circuitry dimensions of the proposed resonator are determined as follows: $W1 = 1.2\,\mathrm{mm}$, $W2 = 0.3\,\mathrm{mm}$, $L1 = 10.6\,\mathrm{mm}$, $L2 = 3\,\mathrm{mm}$, $L3 = 1.9\,\mathrm{mm}$, $L4 = 6.2\,\mathrm{mm}$, $S = 0.1\,\mathrm{mm}$. The circuit dimension of the proposed CRLH dual-mode filter is shown in Fig. 5(a). The total area of the proposed resonator is $3.7 \times 11.3\,\mathrm{mm}^2$, which corresponds to a size of $0.0125\lambda_g \times 0.038\lambda_g$. Compared with the conventional dual-mode resonator with a size of $0.25\lambda_g \times 0.25\lambda_g$, the proposed structure shows a 92% size reduction. Meanwhile, by substituting the electrical lengths of the PRH TL with 36 deg, the proposed CRLH dual-mode filter leads to a size reduction of 75% with respect to the conventional 90 deg CRLH dual-mode filter in [15, 16].

Figure 5(b) shows the photograph of the fabricated filter. The measurement was performed with an Agilent's E8363B network analyzer. Fig. 6 shows the simulated and measured frequency responses of the proposed dual-mode filter. The measured insertion loss is 3 dB which includes the loss of the SMA connectors. The simulated and measured results are in good agreement. Unlike the conventional dual-mode bandpass filters, the second passband of the proposed filter are located around 7.3 GHz, which is about 10 times away from the first resonation frequency 0.74 GHz.



(a) (b)

Figure 5. (a) The circuit dimension of the proposed CRLH dual-mode filter. (b) Photograph of the fabricated filter.

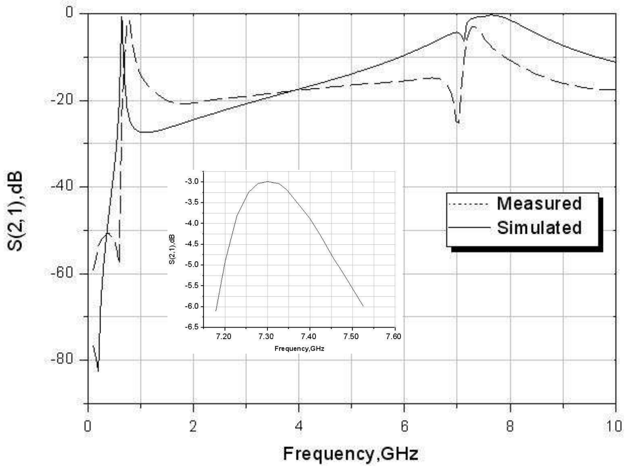


Figure 6. The simulated and measured S-parameters of the proposed dual-mode filter, Inset: Passband response of the filter (Measured).

Table 1. Comparison of Various Dual-mode BPFS.

Refers	Frequency (GHz)	Insertionloss (dB)	Configuration	Second harmonic (f_0-center frequency)	Size reduction
[6]	1.59	1	tree-shape patches	$2.4f_0$	56%
[7]	0.9	3	stepped-impedance resonator	$>3f_0$	54%
[8]	0.81	0.78	crossed and parallel slots	$4.66f_0$	87.4%
[9]	1.55	2	stepped-impedance open stubs	$3.6f_0$	68%
[10]	1.59	2.5	right crossed slots	$2.88f_0$	58%
[11]	2	3.6	periodical loadings	$2.4f_0$	48%
[12]	1.93	1.7	PSIRR	$3.76f_0$	60%
This work	0.73	3	CRLH	$10.1f_0$	92%

Table 1 compares the sizes and harmonics characteristics of the proposed resonator of other published works with simultaneous size reduction and spurious response suppression in reference. Results show that the proposed filter cannot only reduce the circuit size significantly, but also achieve wide upper stopband as well.

3. CONCLUSION

A novel 45° CRLH dual-mode filter is proposed for reducing the size and improving the out-of-band rejection of the dual-mode filter. A bandpass filter at the center frequency of 730 MHz is designed, fabricated and tested to demonstrate the performance of the proposed CRLH dual-mode resonator. The filter can not only reduces the occupied area up to 92% of the conventional one, but also effectively remove the second harmonic response 10.13 times away from the fundamental frequency.

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REFERENCES

1. Chiou, Y.-C., P.-S. Yang, J.-T. Kuo, and C.-Y. Wu, "Transmission zero design graph for dual-mode dual-band filter with periodic stepped-impedance ring resonator," *Progress In Electromagnetics Research Letters*, Vol. 108, 23–36, 2010.
2. Chen, Z.-X., X.-W. Dai, and C.-H. Liang, "Novel dual-mode dual-band bandpass filter using double square-loop structure," *Progress In Electromagnetics Research Letters*, Vol. 77, 409–416, 2007.
3. Chen, C.-H., C.-S. Shih, T.-S. Horng, and S.-M. Wu, "Very miniature dual-band and dual-mode bandpass filter designs on an integrated passive device chip," *Progress In Electromagnetics Research Letters*, Vol. 119, 461–476, 2011.
4. Wei, C.-L., B.-F. Jia, Z.-J. Zhu, and M. Tang, "Design of different selectivity dual-mode filters with E-shaped resonator," *Progress In Electromagnetics Research Letters*, Vol. 116, 517–532, 2011.
5. Hong, J.-S. and M. J. Lancaster, "Microstrip bandpass filter using degenerate modes of a novel meander loop resonator," *IEEE Microw. Guided Wave Lett.*, Vol. 5, No. 11, 371–372, Nov. 1995.
6. 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 Letters*, Vol. 77, 67–73, 2007.
7. Fok, S.-W., P. Cheong, K.-W. Tam, and R.-P. Martins, "A novel microstrip square-loop dual-mode bandpass filter with simultaneous size reduction and spurious response suppression,"

IEEE Trans. Microw. Theory Tech., Vol. 54, No. 5, 2033–2041, May 2006.

8. Singh, Y.-K. and A. Chakrabarty, "Miniaturized dual-mode circular patch bandpass filters with wide harmonic separation," *IEEE Microw. Wirel. Compon. Lett.*, Vol. 18, No. 9, 584–586, Sep. 2008.
9. Wang, Y.-Z. and M.-L. Her, "Miniaturised dual-mode microstrip bandpass filters with wide upper stopband," *IET Microwaves, Antennas & Propagation*, Vol. 1, No. 4, 904–910, Apr. 2007.
10. Tu, W.-H. and K. Chang, "Miniaturized dual-mode bandpass filter with harmonic control," *IEEE Microw. Wirel. Compon. Lett.*, Vol. 15, No. 12, 838–840, Dec. 2005.
11. Wang, Y.-Z., C.-A. Wang, and K.-Y. Lin, "Miniaturized dual-mode quasi-elliptic function bandpass filter with wide rejection bandwidth," *Asia-Pacific Microwave Conference*, 1569–1574, 2006.
12. Kuo, J.-T. and C.-Y. Tsai, "Periodic stepped-impedance ring resonator (PSIRR) bandpass filter with a miniaturized area and desirable upper stopband characteristics," *IEEE Trans. Microw. Theory Tech.*, Vol. 54, No. 3, 904–910, Mar. 2006.
13. Weng, M.-H. and H.-W. Wu, "Stopband improvement of a dual-mode ring bandpass ?lter using DGS," *Microw. Opt. Technol. Lett.*, Vol. 44, No. 3, 247–249, Mar. 2005.
14. Griol, A., J. Marti, and L. Sempere, "Microstrip multistage coupled ring bandpass filters using spur-line filters for harmonic suppression," *Electron. Lett.*, Vol. 37, No. 9, 572–573, Sep. 2001.
15. Allen, C.-A., K.-M. K.-H. Leong, and T. Itoh, "Dual-mode composite-right/left-handed transmission line ring resonator," *Electron.Lett.*, Vol. 42, No. 2, 19–20, Feb. 2006.
16. Su, H.-T. and K.-H. Manas, "Redesign of a dual-mode ring resonator using composite-right/left-handed line," *Asia-Pacific Microwave Conference Proceedings*, Vol. 4, 2269–2272, 2007.
17. Su, H.-T., K.-K. Fong, M.-K. Haldar, and M.-L.-D. Wong, "New 4-pole dual-mode resonator filter using composite-right/left-handed line," *Asia-Pacific Microwave Conference*, 1–4, 2008.
18. Caloz, C. and T. Itoh, *Electromagnetic Metamaterials: Transmission Line Theory and Microwave Applications*, Wiley, New York, 2005.
19. 13 IE3D Version 10.1, Zeland Software Inc.