Miniaturized LTCC Bandpass Filter with Harmonic Suppression

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Abstract ─ This paper presents a harmonic-suppressed bandpass filter using a 3-dimensional (3-D) half-wavelength transmission line resonator, which is fabricated using low temperature co-fired ceramic (LTCC) technology. Owing to the distributed-element method in this 3-D design, the spurlines can be easily etched on the coupled feed lines to generate an extra transmission zero in the stopband without enlarging the circuit size. As a result, the second harmonic can be rejected to a great extent. For demonstration, a pair of two-order LTCC bandpass filters centered at 2.45 GHz with/without spurlines are designed using the compact 3-D resonator, and the size of the circuits is only 4.4×4.2×1.6 mm^3.

Index Terms ─ Harmonic suppression, LTCC, spurline, transmission zero.

I. INTRODUCTION

In modern communication systems, high-performance, compact and low-cost microwave components are urgently needed. Bandpass filter, as an indispensable passive component in microwave systems, usually suffers from the spurious responses at about twice/three times of the centre frequency of the desirable passband when using half-/quarter-wavelength resonators, which not merely reduces rejection levels in the stopband but also affects passband symmetry. Diverse techniques have been developed to suppress the harmonics and spurious response [1-6], such as discriminating coupling [1], spurline [2-4], and defected ground structure [5] and so on. The harmonic-suppressed filters proposed in [1-6] are planar topologies which may endure the bulky sizes. To achieve miniaturization, low-temperature co-fired ceramic (LTCC) bandpass filters based on lumped/semi-lumped elements have been developed in [7-9]. However, the harmonic suppression of the LTCC filters is seldom discussed. In [9], an extra stepped impedance quarter-wavelength ($\lambda_g/4$) open stub has to be added to reject the second harmonic.

In this paper, a 3-dimensional (3-D) $\lambda_g/2$ resonator is employed for designing LTCC bandpass filters centered at 2.45 GHz. Owing to this multilayer resonator, the size of the LTCC filters can be reduced significantly. Harmonic suppression can be easily achieved by etching the spurlines on the coupled feeding lines without increasing the entire size of the filter.

II. LTCC BANDPASS FILTERS DESIGN

The vertically and horizontally folded transmission line resonator is shown in Fig. 1. As there is a voltage null node at the middle point of the $\lambda_g/2$ resonator, a virtual ground can be set in the symmetrical plane of the 3-D multilayer resonator at the fundamental resonant frequency [10]. In this way, each part of the 3-D resonator has its corresponding ground (actual/virtual ground) to form the return path of the signal, although some striplines are overlapped in the vertical direction (z direction).

Based on the proposed 3-D multilayer resonator shown in Fig. 1, LTCC filters using the 3-D multilayer resonator are designed accordingly. The 3-D view, each layer configuration and the cross-section view of the proposed LTCC bandpass

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filter with etched spurlines are shown in Fig. 2 and each layer configuration is illustrated in Fig. 3.

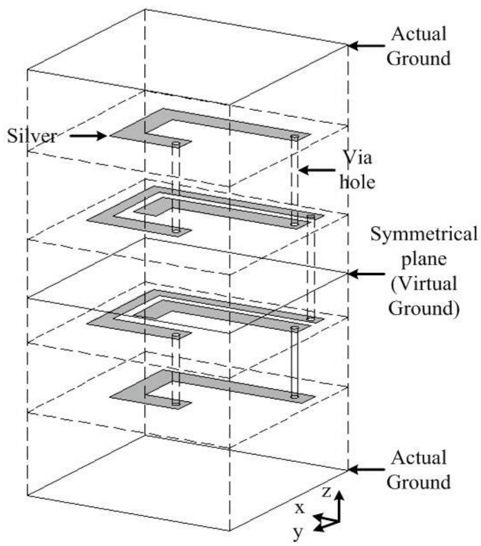

Fig. 1. 3-D structure of the vertically and horizontally folded $\lambda_g/2$ resonator.

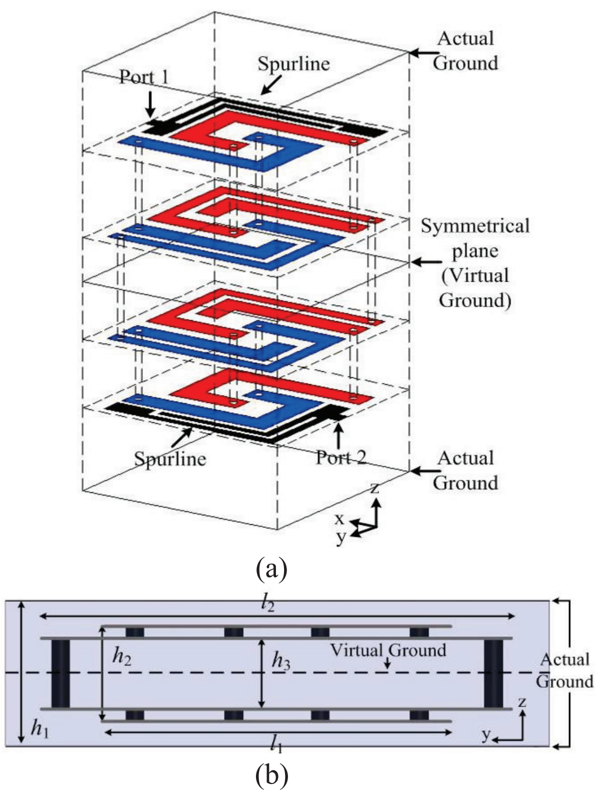

Fig. 2. Proposed LTCC bandpass filter with spurline: (a) 3-D view of the proposed LTCC bandpass filter, and (b) cross-section view of the proposed LTCC bandpass filter.

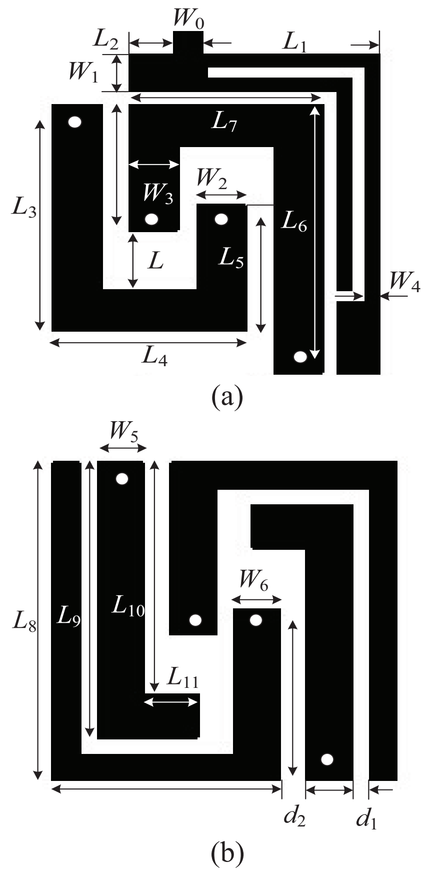

Fig. 3. Layer configuration: (a) layer details of layer 1 and layer 4, and (b) layer details of layer 2 and layer 3.

Then, according to the specification of the quasi-elliptic response with 2.45 GHz and FBW=10%, the coupling coefficients and I/O external quality factors calculated from [11] may be expressed as:

$$Q_e = \frac{g_0 g_1}{FBW} = 17.7, \qquad K = \frac{FBW}{\sqrt{g_0 g_1}} = 0.079,$$

where, g_0, g_1 and FBW are the element values of the lowpass prototype filter and fractional bandwidth.

Once the physical dimensions of 3D $\lambda_g/2$ resonator are determined, the parameters with respect to the tap position L_2 and the distance L between the resonators can be obtained by using the design curves as shown in Fig. 4 and Fig. 5.

The proposed filter can obtain two transmission zeros owing to the 0° feed structure [12], realizing good selectivity. The spurlines are introduced by etching them on the coupled feeding lines for second harmonic rejection, as shown in Fig. 2 (a). Meanwhile, unlike the planar configuration in [2-4], the etched spurlines will not enlarge the size of the LTCC filter.

For demonstration and comparison, a pair of LTCC bandpass filters centered at f_0=2.45 GHz with/without spurlines are designed and fabricated on sixteen layers of LTCC Ferro A6-M substrate with dielectric constant of 5.9 with a loss tangent of 0.002. Accordingly, the occupied sizes of the two LTCC bandpass filters are identical; i.e., 4.4×4.2×1.6 mm^3 ($0.088\lambda_g \times 0.084\lambda_g \times 0.032\lambda_g$ at f_0). The simulated results (using Ansoft HFSS) of the LTCC filters with/without spurlines are shown in Fig. 6. It can be seen from Fig. 6 that the etched spurlines on the coupled feeding lines have few effects on the fundamental passband. To suppress the second harmonic and obtain a suppression level of higher than 30 dB from 3 to 6 GHz, the total length of the spurline is optimized to be 4.9 mm, which approximately corresponds to quarter guided wavelength at the frequency of the newly-generated extra transmission zero shown in Fig. 6.

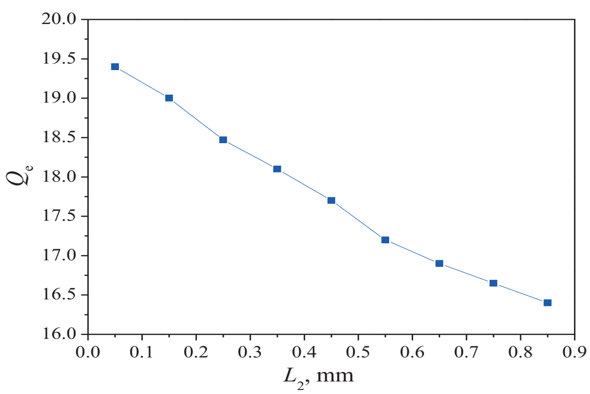

Fig. 4. Simulated external quality factors against the tap position of feeding lines.

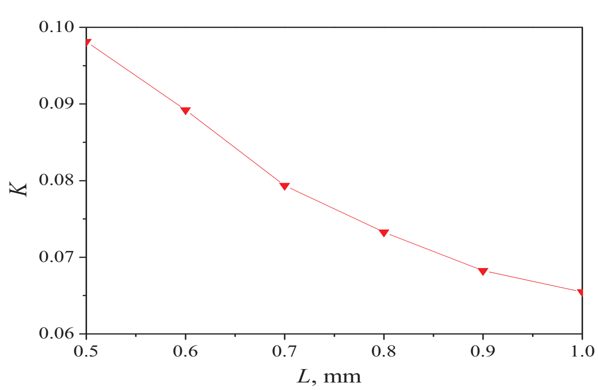

Fig. 5. Simulated coupling coefficients versus the gaps between resonators.

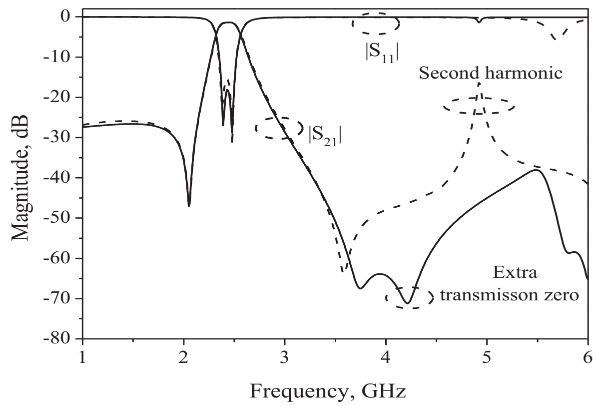

Fig. 6. Simulated results of the LTCC bandpass filters with/without spurlines (dot line: without spurlines, solid line: with spurlines).

III. MEASURED RESULTS

After optimization, the parameters of the LTCC filter with harmonic suppression are determined as follow: W_0=0.3 mm, W_1=0.45 mm, W_2=0.5 mm, W_3=0.5 mm, W_4=0.15 mm, W_5=0.5 mm, W_6=0.5 mm, L=0.7 mm, L_1=1.85 mm, L_2=0.45 mm, L_3=2.7 mm, L_4=2 mm, L_5=1.5 mm, L_6=3.2 mm, L_7=2 mm, L_8=3.7 mm, L_9=3.2 mm, L_{10}=3.7 mm, L_{11}=0.8 mm, d_1=0.2 mm, d_2=0.3 mm, diameter=0.15 mm, l_1=2.8 mm, l_2=3.8 mm, h_1=1.2 mm, h_2=0.8 mm, h_3=0.6 mm. The proposed LTCC bandpass filters with/without spurlines have been mounted on the printed circuit boards (PCBs) for measurement, as shown in Fig. 7. The measurement is carried out by network analyzer Agilent E8363C. According to the measurement, the LTCC filters center at 2.45 GHz. The insertion losses of these two filters are 2.3 dB, and the return losses are both better than 20 dB within the passbands, as can be seen from Fig. 8. As expected, more than 30 dB suppression level from 3 to 6 GHz is realized when the spurlines are employed as shown in Fig. 8. From Fig. 6 and Fig. 8, little disparity can be observed between simulation and measurement of the LTCC filters, which is believed to be caused by the fabrication tolerance in the multilayer and co-fired implementation.

Comparison between the proposed harmonic-suppressed LTCC filter and previously reported LTCC bandpass filters [13-17] is tabulated in Table 1. According to Table 1, it can be seen that the proposed LTCC filter with harmonic suppression shows compact size and comparable harmonic suppression performance.

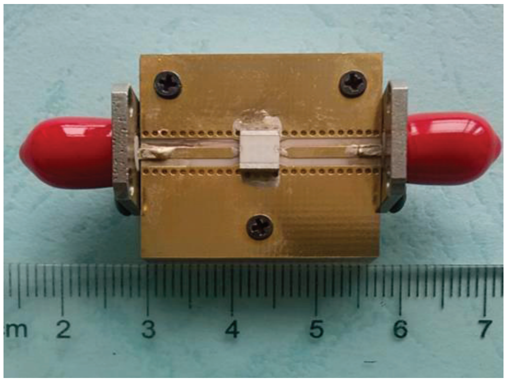

Fig. 7. Photograph of the proposed LTCC bandpass filter mounted on the PCB.

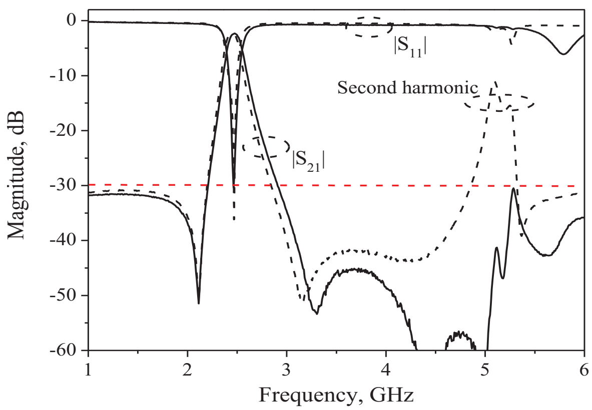

Fig. 8. Measured results of the LTCC bandpass filters with/without spurlines (dot line: without spurlines, solid line: with spurlines).

Table 1: Comparison between previously reported LTCC filters

Ref.	f_0 GHz	Filter Order	Stopband Performance	Electric Size (λ_g^3)
13	4.3	3	2.6 f_0 >20 dB	0.418×0.209×0.035
14	2.45	3	2 f_0 >40 dB	0.094×0.047×0.031
15	2.45	2	2.3 f_0 >30 dB	0.123×0.089×0.017
16	2.55	2	2.2 f_0 >25 dB	0.091×0.069×0.022
17	1.95	2	1.2 f_0 >10 dB	0.106×0.106×0.013
This work	2.45	2	>2.45 f_0 >30 dB	0.088×0.084×0.032

IV. CONCLUSION

In this paper, miniaturized LTCC bandpass filters with/without harmonic suppression are designed and fabricated based on the 3-D distributed-element resonator. Two transmission zeros on both sides of the passband improve the selectivity of the proposed filter. An extra transmission zero is generated by etching spurlines on the coupled feeding lines for harmonic suppression while the circuit size keeps the same. The measured harmonic rejection level of the bandpass filter is higher than 30 dB. The simulated and measured results are presented and show good agreement.

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REFERENCES

[1] X. Y. Zhang and Q. Xue, "Harmonic-suppressed bandpass filter based on discriminating coupling," *IEEE Microw. Wireless Compon. Lett.*, vol. 19, no. 11, pp. 695-697, Nov. 2009.

[2] A. Torabi and K. Forooraghi, "Miniature harmonic-suppressed microstrip bandpass filter using a triple-mode stub-loaded resonator and spur lines," *IEEE Microw. Wireless Compon. Lett.*, vol. 21, no. 5, pp. 255-257, May 2005.

[3] W. H. Tu and K. Chang, "Compact microstrip bandstop filter using open stub and spurline," *IEEE Microw. Wireless Compon. Lett.*, vol. 15, no. 4, pp. 268-270, Apr. 2005.

[4] M. Hayati and S. Roshani, "A novel wilkinson power divider using open stubs for the suppression of harmonics," *Appl. Comp. Electro. Society (ACES) Journal*, vol. 28, no. 6, pp. 530-538, Jun. 2013.

[5] J.-S. Park, J.-S. Yun, and D. Ahn, "A design of the novel coupled-line bandpass filter using defected ground structure with wide stopband

performance," *IEEE Trans. Microw. Theory Tech.*, 50, no. 7, pp. 2037-2043, Sep. 2002.
[6] L. Gao, X. Y. Zhang, and Q. Xue, "Miniaturised bandpass filter using novel feeding structure for harmonic suppression," *Electron. Lett.*, vol. 48, no. 22, pp. 1414-1415, Oct. 2012.
[7] W.-S. Tung, Y.-C. Chiang, and J.-C. Cheng, "A new compact LTCC bandpass filter using negative coupling," *IEEE Microw. Wireless Compon. Lett.*, vol. 15, no. 10, pp. 641-643, Oct. 2005.
[8] G. Brzezina, L. Roy, and L. MacEachern, "Design enhancement of miniature lumped-element LTCC bandpass filters," *IEEE Trans. Microw. Theory Tech.*, vol. 57, no. 4, pp. 815-823, Apr. 2009.
[9] C.-W. Tang, "Harmonic-suppression LTCC filter with the step-impedance quarter-wavelength open stub," *IEEE Trans. Microw. Theory Tech.*, vol. 52, no. 2, pp. 617-624, Feb. 2004.
[10] J.-X. Chen, C. Shao, Q. Y. Lu, H. Tang, and Z. H. Bao, "Compact LTCC balanced bandpass filter using distributed-element resonator," *Electron. Lett*., vol. 49, no. 5, pp. 354-356, Feb. 2013.
[11] J. S. Hong and M. J. Lancaster, *Microstrip Filters for RF/Microwave Applications*, New York: Wiley, 2001.
[12] C.-M. Tsai, S.-Y. Lee, and C.-C. Tsai, "Performance of a planar filter using a 0° feed structure," *IEEE Trans. Microw. Theory Tech.*, vol. 50, no. 10, pp. 2362-2367, Oct. 2002.
[13] X. J. Zhang, H. H. Zhang, and X. P. Ma, "Design of compact wideband LTCC filter using pentagonal-shaped SIR," *Electron. Lett.*, vol. 47, no. 5, pp. 327-328, Mar. 2011.
[14] M. Höft and T. Shimamura, "Design of symmetric trisection filters for compact low-temperature co-fired ceramic realization," *IEEE Trans. Microw. Theory Tech.*, vol. 58, no. 1, pp. 165-175, Jan. 2010.
[15] Y.-H. Jeng, S.-F. R. Chang, and H.-K. Lin, "A high stopband-rejection LTCC filter with multiple transmission zeros," *IEEE Trans. Microw. Theory Tech.*, vol. 54, no. 2, pp. 633-637, Feb. 2006.
[16] C. W. Tang and H. C. Hsu, "Development of multilayered bandpass filters with multiple transmission zeros using open-stub/short-stub/serial semilumped resonators," *IEEE Trans. Microw. Theory Tech.*, vol. 58, no. 3, pp. 624-634, Mar. 2010.
[17] V. Piatnitsa, E. Jakku, and S. Leppaevuori, "Design of a 2-pole LTCC filters for wireless communications," *IEEE Trans. Wireless Commun.*, vol. 3, no. 2, pp. 379-381, Mar. 2004.

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