High Performance LTCC Wideband Bandpass Filter Based on Coupled Lines

Wenjie Feng[1], Xin Gao[1], Wenquan Che[1], Wanchen Yang[1]

[1]Department of Communication Engineering, Nanjing University of Science and Technology, Nanjing, China

E-mail: fengwenjie1985@163.com

(Invited talk)

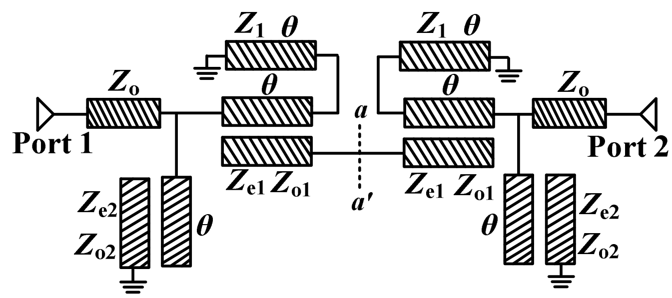
***Abstract*- Compact LTCC bandpass filter with high performance using coupled lines with open/shorted stubs are proposed in this paper. Two conventional coupled lines with open/shorted stubs are used to increase the passband order for the proposed filters. By using LTCC fabrication technology, the coupled lines and stubs can be located at different layers to achieve very compact size. A fifth-order wideband bandpass filter centered at 3 GHz is designed and fabricated for verification.**

***Index Terms*—Wideband, LTCC, bandpass filter, coupled lines, open/shorted stubs**

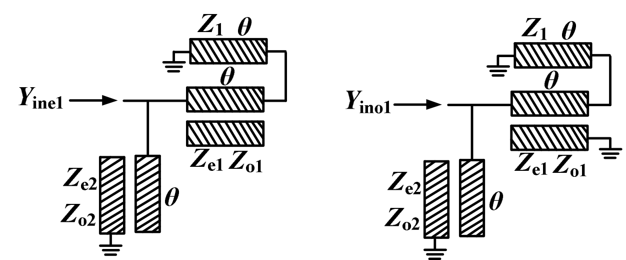
I. Introduction

Wideband bandpass filters with high performance such as enhanced out-of-band rejection, good harmonic suppression and compact circuit size are extremely desirable in modern RF/Microwave systems [1]-[2]. Conventional quarter-wavelength coupled lines are always used to design wideband bandpass filters, however, the multi-order passbands are realized by the cascaded elements, which usually increase the circuit size and insertion loss [3]. By introducing intentionally a passband constructive interference and out-of-band signal energy cancellations to produce power transmission zeros, high-selectivity filtering responses and harmonic suppression were achieved from transversal signal-interference concepts [4]-[6]. In the past several years, low-temperature cofired ceramic (LTCC) technology has been one promising method to realize circuit size reduction for 3-D microwave passive circuits [7]-[10].

In this paper, a LTCC wideband bandpass filter using coupled lines with open/shorted stubs is proposed, two and four independent transmission zeros near the passband are realized to improve the passband selectivity and harmonic suppression. Compact circuit size can be easily realized by using LTCC fabrication technology. The desired filter configurations can be obtained using the specific center frequency and even/odd-mode characteristic impedance of the coupled lines and characteristic impedance of the stubs. For demonstration of the design strategies, a LTCC wideband bandpass filter is implemented with high selectivity and wide stopband, which is suitable for system-in-package (SiP) applications. All the circuits and structures are simulated with Ansoft Designer v3.0 and Ansoft HFSS v11.0, and constructed on the LTCC substrate with the dielectric constant $\varepsilon_r = 5.9$, and $tan\delta = 0.002$.



(a)

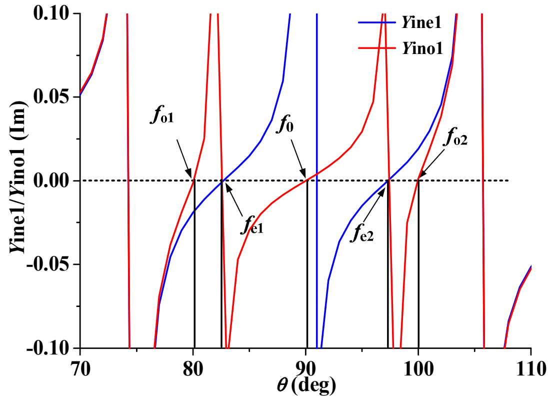


(b) (c)

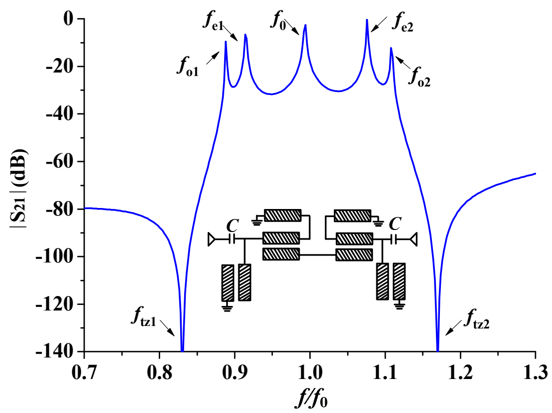
Fig. 1 Transmission line circuit of the wideband filter with two transmission zeros. (a) Schematic diagram, (b) even-mode circuit, (c) odd-mode circuit.

II. Analysis of Proposed LTCC Wideband Filters

Fig. 1(a) shows the ideal transmission line circuit of the wideband bandpass filter with two transmission zeros, two quarter-wavelength shorted stubs (Z_1, θ) are connected in the end of the open coupled lines (Z_{e1}, Z_{o1}, θ), two open/shorted coupled lines (Z_{e2}, Z_{o2}, θ) are connected in for each side, and the two transmission lines with characteristic impedance Z_0 = 50 Ω are connected to ports 1, 2. Due to the symmetry of the filter circuit, even-odd-mode analysis is employed to simplify the analysis [3]. When the even/odd-mode is excited in the two ports, a virtual open/shorted will appear in the symmetric lines *a-a*′, and the even/odd-mode input admittances Y_{ine1}, Y_{ino1} can be illustrated as:



(a)



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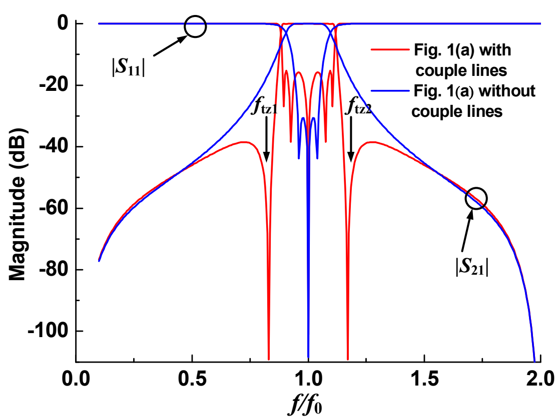

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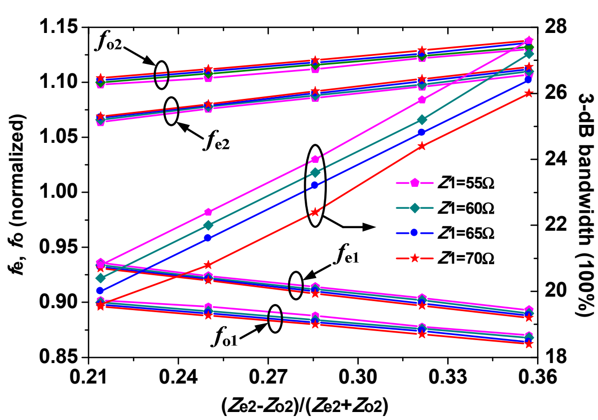

(d)

Fig. 2 Simulated frequency responses of Fig. 1. (a) even/odd-mode resonant frequencies versus θ (b) analysis of resonator frequencies under weak coupling, C=0.08pF, (c) $|S_{21}|$&$|S_{11}|$, (d) $f_{e1/2}/f_o$, $f_{o1/2}/f_o$ and bandwidth versus Z_1, $(Z_{e2}-Z_{o2})/(Z_{e2}+Z_{o2})$. ($Z_1$= 60 Ω, Z_{e1} = 170 Ω, Z_{o1} = 105 Ω, Z_{e2} = 180 Ω, Z_{o2} = 105 Ω)

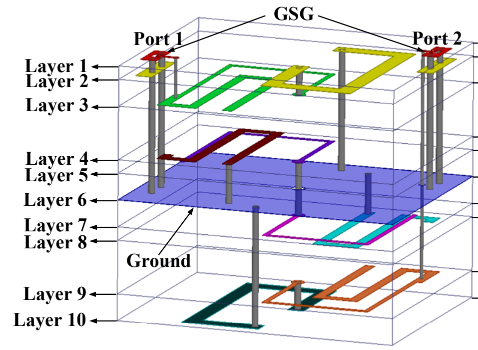

Fig. 3 Layout of the proposed LTCC wideband bandpass filter.

$$Y_{ine1}=\frac{j(Z_{e2}+Z_{o2})\sin 2\theta}{(Z_{e2}+Z_{o2})^2\cos^2\theta-(Z_{e2}-Z_{o2})^2}-\frac{j[(Z_{e1}+Z_{o1})-4Z_1\tan^2\theta]}{(Z_{e1}+Z_{o1})(2Z_1+Z_{e1}+Z_{o1})\tan\theta}$$

$$Y_{ino1}=\frac{j(Z_{e2}+Z_{o2})\sin 2\theta}{(Z_{e2}+Z_{o2})^2\cos^2\theta-(Z_{e2}-Z_{o2})^2}-\frac{j2\cos\theta\left[2Z_{e1}Z_{o1}\cos^2\theta-Z_1(Z_{e1}+Z_{o1})\sin^2\theta\right]}{2Z_{e1}Z_{o1}\sin\theta\cos^2\theta(Z_{e1}+Z_{o1})+Z_1\sin\theta\left[(Z_{e1}+Z_{o1})^2\cos^2\theta-(Z_{e1}-Z_{o1})^2\right]} \quad (1)$$

When Y_{ine1}/Y_{ino1}=0, the passband even/odd-mode can be solved directly. In addition, After *ABCD*- and *Y*- parameter conversions for the bandpass filter circuit of Fig. 1(a), when S_{21} = 0, the two transmission zeros (f_{tz1}, f_{tz2}) near the passband can be solved as:

$$\theta_{tz1}=\arccos\frac{Z_{e2}-Z_{o2}}{Z_{e2}+Z_{o2}},\quad \theta_{tz2}=\pi-\theta_{tz1} \quad (2)$$

Figs. 2(a)-(c) show the even/odd-mode resonant frequencies versus θ and analysis of resonator frequencies for the bandpass filter, the bandwidth of the bandpass filter is mainly determined by the two odd-modes (f_{o1}, f_{o2}), and the mid-passband can be adjusted by the two even-modes (f_{e1}, f_{e2}). Moreover, the passband-order can be increased from third to fifth due to the two open/shorted coupled lines, and the bandwidth decreases as Z_1 increases, and increases as the coupling coefficient of the coupled lines increases. It should be pointed that the two transmission zeros (f_{tz1}, f_{tz2}) have no relationships with the characteristic impedance Z_{e1}, Z_{o1}, and Z_1 (from equation 1), and the characteristic impedance Z_{e1}, Z_{o1}, and Z_1 can be seen as independent parameters for adjusting the passband-order and out-of-band harmonic suppression of the bandpass filter, this transmission characteristic can be seen an advantage for this kind of balanced filter with two transmission zeros, which doesn't like former bandpass filters in [4]-[10].

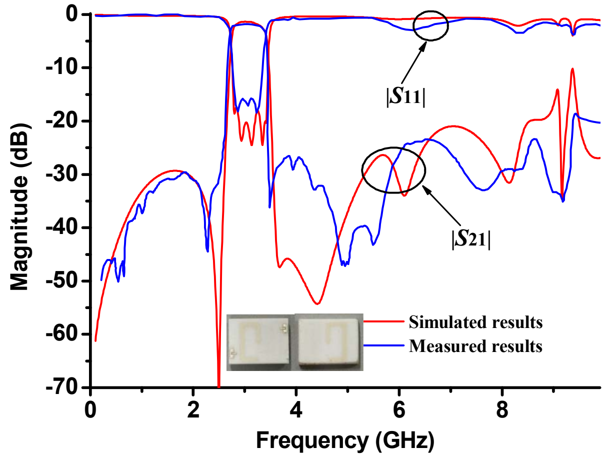

Fig. 4 Measured and simulated results for the LTCC bandpass filter.

III. Experiment and Results Disscusions

Based on the above discussions, the 3-dB bandwidths of the two LTCC bandpass filter is chosen as 23.5% with the center frequency at 3.1 GHz, and the circuit parameters for Fig. 1 and Fig. 3 are chosen as: Z_1= 85 Ω, Z_{e1} = 180 Ω, Z_{o1} = 110 Ω, Z_{e2} = 175 Ω, Z_{o2} = 100 Ω; g = 0.37 mm, w_1 = 0.13 mm, w_2 = 0.5 mm, w_3 = 0.5 mm, w_4 = 0.15 mm, w_5 = 0.3 mm, l_1 = 1.2 mm, l_2 = 2 mm, l_3 = 2.8 mm, l_4 = 1.8 mm, l_5 = 5.5 mm, l_6 = 1.9 mm, l_7 = 2.85 mm, l_8 = 3 mm, l_9 = 4.15 mm, l_{10} = 1.5 mm, l_{11}= 0.6 mm, l_{12} = 4.5 mm, l_{13} = 0.8 mm, l_{14} = 0.6 mm, l_{15} = 6.7 mm, l_{16} = 8.55 mm, d_1 = 0.2 mm, d_2 = 0.1 mm, d_3 = 0.2 mm, d_4 = 0.4 mm, d_5 = 0.2 mm

The measured results and photograph of the LTCC wideband bandpass filter are also shown Fig. 4. For the bandpass filters with two transmission zeros, the 3-dB bandwidth for the passband is about 23% (2.7-3.4 GHz) with insertion loss less than 2.0 dB, three measured results are located at 2.28, 3.48 and 4.88 GHz, the upper stopband insertion loss is greater than 20 dB from 3.4 to 9.38 GHz (3.1 f_0).

IV. Conclusion

In this paper, a LTCC wideband bandpass filter with multiple transmission zeros using coupled lines and open/shorted stubs is proposed. Two transmission zeros near the passband can be easily realized due to the added open/shorted coupled lines, and the in-band and out-of-band performance can be adjusted independently by changing the parameters of the coupled lines and stubs. The proposed LTCC wideband filter has advantages of high selectivity, wide harmonic suppression and compact circuit size, which is a good choice for microwave communication systems.

Acknowledgment

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