E-shape Resonator Dualband Common Mode Filter

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Abstract—**An E-shape resonator dualband common mode filter is introduced in this paper. The proposed design features the advantages of two-layer printed circuit board design with solid ground plane. Furthermore, the equivalent common mode circuit of coupled step impedance quarter-wavelength resonator improves the common mode suppression performance.**

***Index terms*—Common-mode filter, coupled step impedance quarter-wavelength resonator, radio frequency interference mitigation**

I. Introduction

Differential signaling plays an important role in high-speed data transmission scheme such as SATA, PCIe, USB, HDMI, etc. With tolerance to ground offset and noise as well as resistance to electromagnetic interference and crosstalk, differential signaling is superior to single-end signaling. Nevertheless, timing skew and unbalanced amplitude from the chip as well as asymmetric geometry and ground discontinuity from the routing on the printed circuit boards (PCBs) may induce common mode noise in practical environment. The problems caused by these unwanted effects lead to electromagnetic interference (EMI) and radio frequency interference (RFI).

The conventional method to reduce EMI and RFI is applying noise suppression components such as ferrite core common mode chokes [1] or low-temperature cofired ceramic (LTCC) common mode filters [2]. However, ferrite core common mode chokes encounter operating frequency range limitation due to degradation of permeability and LTCC common mode filters are rather expensive. Recently, research on PCB common mode filter design is widely developed. The PCB common mode filters are categorized into defected ground structure (DGS) type [3] [4] and mushroom-like structure (MLS) type [5]. Despite the fact that both PCB common mode filters achieve broadband common mode suppression, the performance of DGS type may be deteriorated with adjacent structure surrounded and have potential radiation problems, and MLS type requiring more than two layers may be incompatible on PCBs.

In [6] and [7], two-layer common mode filters with solid ground plane are proposed. The short-ended self-coupled ring resonator (SCRR) providing common mode suppression is applied. However, the limited tuning range for stopbands of the first and the third resonance of quarter-wavelength resonator is not desirable. In this paper, an E-shape resonator dualband common mode filter is introduced.

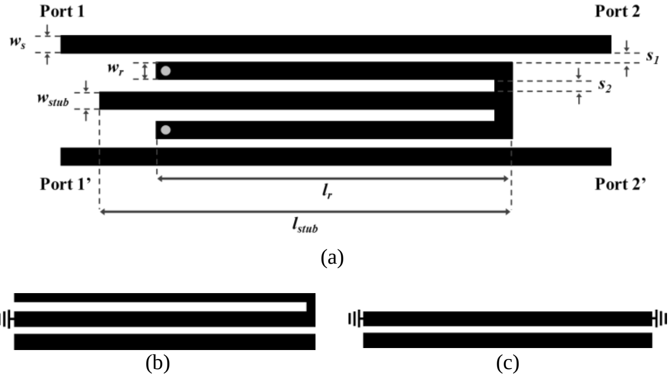


Fig. 1 (a) Proposed layout, equivalent circuits for (b) common mode, and (c) differential mode

II. Analysis of Common Mode Filter

The proposed design is an E-shape resonator placed between the differential pair with two arms connected to ground by vias, as depicted in Fig 1(a). Applying the boundary condition derived in [8] on the plane of symmetry between the differential pair, the equivalent circuits of common mode and differential mode are shown in Fig. 1(b) and (c).

The equivalent circuit of differential mode is a signal trace coupled to a half-wavelength resonator with both ends grounded, presenting all-pass response as derived in [9]. In contrast, the equivalent circuit of common mode performs band-stop response due to the resonances of coupled step impedance quarter-wavelength resonator.

The coupled quarter-wavelength resonator introduced in this paper creates several improvements compared to [6] and [7]. In contrast with [6], the additional open stub of coupled quarter-wavelength resonator theoretically lowers the resonance frequency with slight increase on the total width of the structure. Fig. 2 shows the comparison between quarter-wavelength resonator and coupled quarter-wavelength resonator that are the common mode equivalent circuit of the short-ended SCRR common mode filter and E-shape resonator dualband common mode filter. The length is 23.4mm for l_s of short-ended SCRR structure as well as l_s and l_o of E-shape structure. The dot line representing the resonance of coupled quarter-wavelength resonator shows the first resonance frequency of 1.55 GHz, which is lower than 2 GHz of quarter-wavelength resonator.

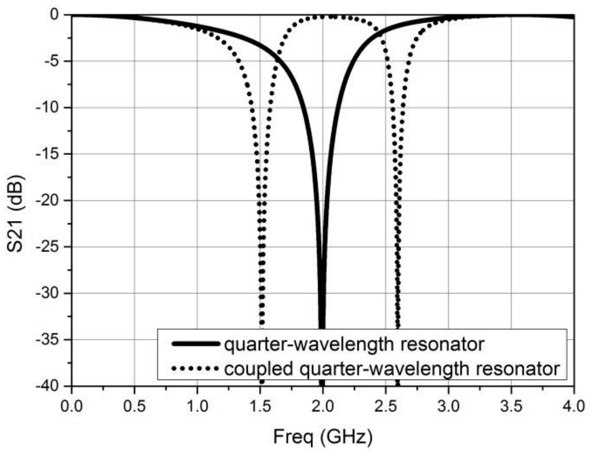


Fig. 2 Comparison between resonance of quarter-wavelength resonator and coupled quarter-wavelength resonator

By folding the quarter-wavelength resonator, coupling between two sections of the structure becomes another degree of freedom in the design. The coupling between the open stub and the short stub refers to the spacing s_2. The larger s_2, namely the stronger coupling leads to increase in first resonance frequency. With the following design parameters: l_s = 20 mm, l_o = 22 mm, w = 0.3 mm, w_s = 0.3 mm, w_o = 0.3 mm, s_1 = 0.1 mm, Fig. 3 shows the variation of common mode suppression with different s_2.

The further demonstration of the tuning range relates to the width of open stub and short stub. The resonance condition of the coupled step impedance quarter-wavelength resonator can be expressed as:

$$Z_0 tan\theta_0 = Z_s cot\theta_s$$

Z_o and Z_s represent the characteristic impedance respectively. The condition indicates that the first resonance frequency is higher and the third resonance frequency is lower provided that the characteristic impedance of open stub is increased or the characteristic impedance of short stub is decreased. In Fig. 4 (a) and (b), the variation of Z_o and Z_s is realized by different w_o and w_s. The first and third resonance frequencies are centralized with narrower w_o and wider w_s, and vice versa.

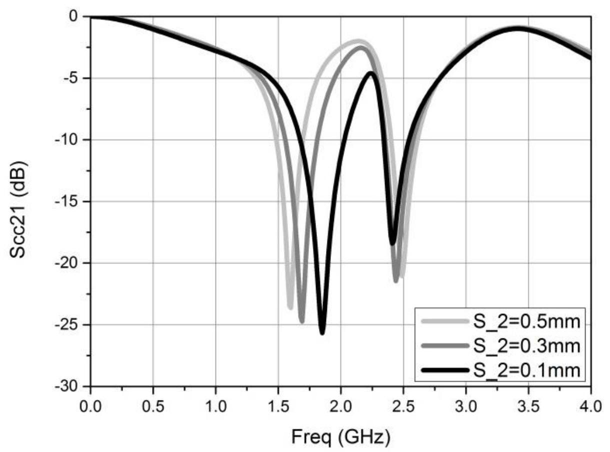
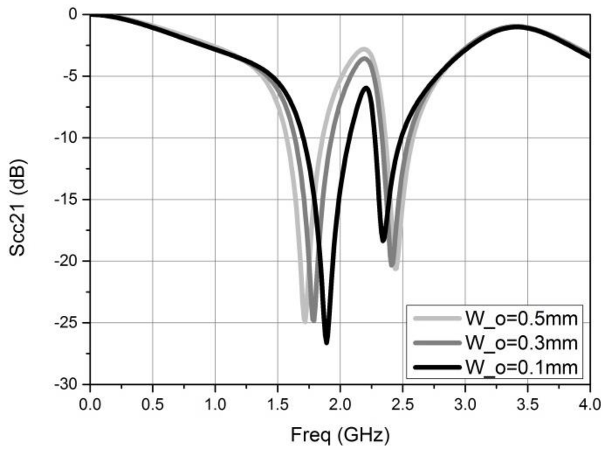
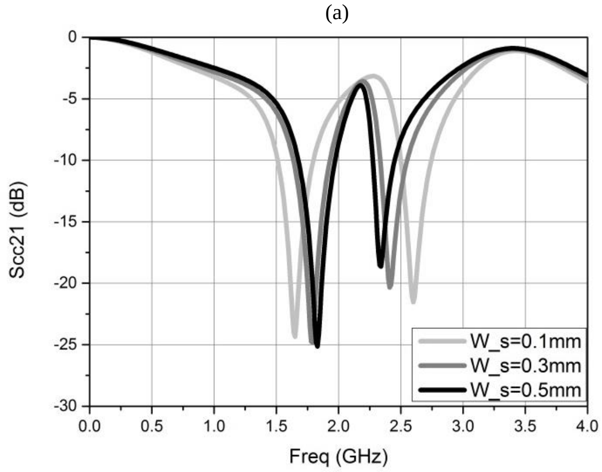


Fig. 3 Variation of S_{cc21} with different spacing s_2.



(a)



(b)

Fig. 4 Variation of S_{cc21} with (a) different width w_o and (b) different width w_s

With numerous factor designed properly, the proposed design is able to suppress arbitrary bands with EMI of RFI issues rather than the harmonics of the quarter-wavelength resonator adapted in [6] and [7].

III. Experimental Results and Discussion

The design parameters are FR4 substrate with dielectric constant 4.3, loss tangent 0.02 and thickness of 1.6mm; l_s = 19.5 mm, l_o = 20 mm, w = 0.3 mm, w_s = 0.3 mm, w_o = 0.1 mm, s_1 = 0.1 mm, s_2 = 0.38 mm. The Full-EM simulation result is presented in Fig. 5.

The first and third resonant frequencies are designed at 1.82 GHz and 2.5 GHz, covering 1.67 to 1.98 GHz and 2.4 to 2.64 GHz. The proposed design targets on RFI mitigation of LTE bands and Wi-Fi 2.4 GHz. The ratio of third and first resonance frequencies is 1.37, which is more centralizing than previous work [7]. In comparison to [6], the first resonance frequency is 24% lower with similar area occupation. The insertion loss of differential mode is less than 1.9 dB, maintaining acceptable signal quality.

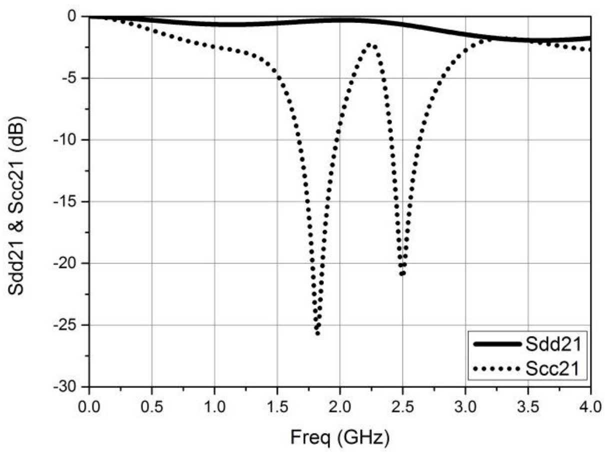


Fig. 5 S_{cc21} & S_{dd21} of the E-shape resonator dualband common mode filter

IV. CONCLUSIONS

In this work, the proposed E-shape resonator dualband common mode filter features the advantages of good compatibility in multi-layer printed circuit board with two-layer and solid ground plane design as well as the great control ability of common mode suppression that covers multiple bands. The mechanism is discussed and the result is presented, with notable common mode suppression of LTE bands and Wi-Fi 2.4 GHz. Characteristic of coupled quarter-wavelength resonator on the suppression bands centralization and effective area reduction are performed. Consequently, the design flexibility is improved compared to previous work.

ACKNOWLEDGEMENT

I would like to acknowledge the program of communication engineering leadership sponsored by the Ministry of Education Taiwan, ASUSTeK Computer Inc. and Graduate Institute of Communication Engineering of National Taiwan University. The great support establishes positive research environment.

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