A Broadband Common Mode Filter With Embedded Ring Structure

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***Abstract*—A broadband common mode filter embedded in the multi-layer printed circuit board is proposed in this paper. The filter is composed of four metal layers, and the ring structure with the serpentine transmission line connected on the third metal layer from the top to bottom layer is designed for creating transmission zeros at separate frequencies. This property is utilized to accomplish broadband suppression of common mode noise with a compact filter design. HFSS is used to verify the filter design and the simulation result shows the common mode noise can be suppressed over 10 dB from 1.57 to 7.87 GHz with 133 percent fractional bandwidth. With this excellent performance of noise suppression, the differential mode insertion loss of the proposed common mode filter can still be smaller than 2 dB below 10 GHz.**

Keywords—Common mode filter; embedded; signal integrity; electromagnetic interference

I. Introduction

With increasing frequency of high-speed digital system design, the asymmetry between two complementary signals in a differential pair can induce common-mode noise and then result in severe problems of signal integrity, power integrity, and electromagnetic interference. The common mode noise propagating on transmission lines may further become the problem of radiation emission, so that to keep the symmetrical routing of a differential pair is always expected. However, the skew between two legs in a differential pair is unavoidable in reality. Even though the intra-pair length is matched, the routing angle can still create common mode noise due to the running skew. Also, the non-uniform dielectric can give rise to substantial skew between conductors in a differential pair due to fiber weave effects of printed circuit board (PCB) [1].

Several solutions using PCB based filters for suppression of the common mode noise have been proposed in [2]-[6]. These filters can be directly embedded in the PCB without additional cost. However, the physical dimensions of filters are still not small enough if the stopband needs to be extended to lower frequencies. This design constraint limits the practical application so that to design a compact filter with broadband suppression of common mode noise is needed.

In this paper, the proposed common mode filter is comprised of four metal layers, and can still be embedded in the PCB without additional cost. A differential pair is allocated on the top layer, and a patch directly underneath the differential pair is placed on the second layer as reference plane. The ring structure on the third layer is connected to the patch and a solid ground plane at the second and the bottom layer respectively. Multiple vias with a serpentine transmission line segment are used to connect the patch, ring structure, and ground plane. By optimizing the length of the serpentine transmission line segment between vias and the size of the ring structure, the proposed filter presents wider stopband for suppressing the common mode noise over 10 dB from 1.57 to 7.87 GHz with 133% fractional bandwidth, and the insertion loss of the differential mode can still be smaller than 2 dB below 10 GHz.

II. Design Concept of Filter

Fig. 1 shows the configuration of the proposed filter on a four layers PCB. The filter is designed with 4.6 mm × 5 mm area and embedded in a 14 mm × 14 mm PCB. A serpentine differential pair is allocated on the top layer of PCB, and the patch on the second layer plays a role of reference plane of the differential pair. The ring structure on the third layer connects the patch on the second layer and the ground plane on the bottom layer. The trace width, the routing length, and the

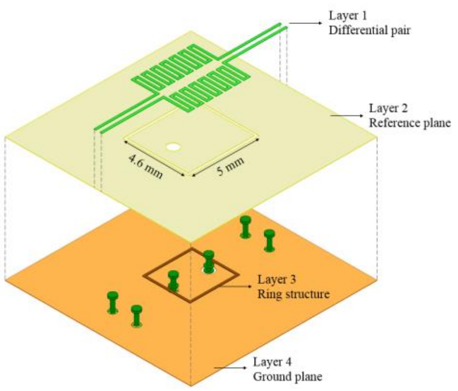

Fig. 1. Initial configuration of the proposed common mode filter

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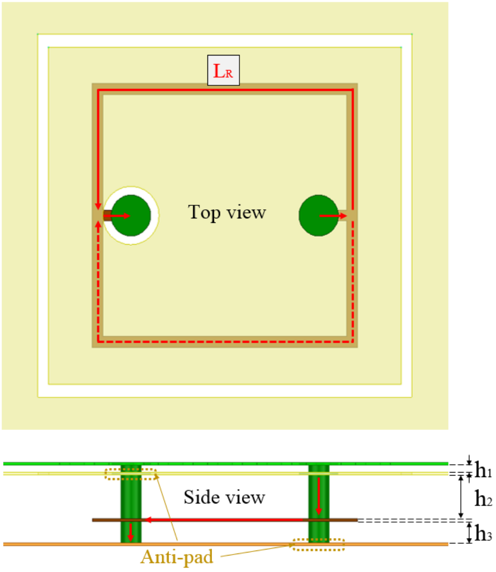

Fig. 2. Top and side view of the initial configuration of the proposed filter

separation between two coupled legs in a differential pair are 0.15 mm, 29.7 mm, and 0.3 mm respectively. The thicknesses of h_1-h_3 are 0.1 mm, 0.6 mm, and 0.3 mm. Fig. 2 shows the path of return current of the differential pair. The current passes through the patch on the second layer, layer transition via, ring structure with 7.2 mm line segment on the third layer, and the ground plane on the bottom layer. The inductance of vias with connected ring structure and the capacitance between the patch and the reference plane can be a parallel resonator. The simulation result shows the differential pair and the ring structure can create a total of four transmission zeros in the analyzed frequency range, and the bandwidth of suppression of common mode noise shown in Fig. 3 is 4.12 GHz to 7.84 GHz based on the 10 dB criterion. As moving the transmission zero to lower frequency for broadband suppression of common mode noise is the design target, the length of the ring structure, denoted as L_R, is increased from 6.5 mm to 7.2 mm and 7.9 mm for further analysis. In Fig. 4, the first and the fourth transmission zeros are both shifted to lower frequencies due to increased inductance. However, the bandwidth of suppression of common mode noise is not extended significantly. It is because the simultaneous moving of transmission zeros limits the feasibility of overlapping effective bandwidth of four

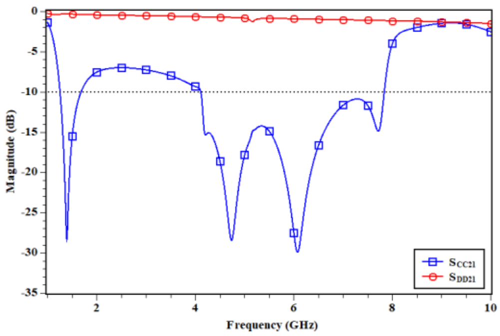

Fig. 3. S_{CC21} and S_{DD21} of the proposed filter with initial configuration

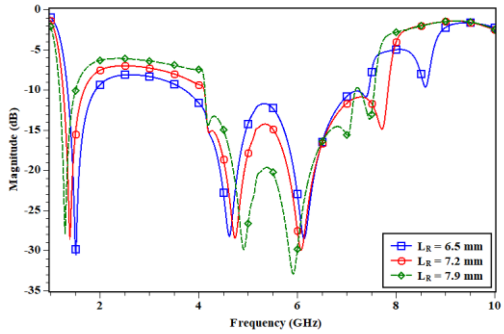

Fig. 4. S_{CC21} of the proposed filter with varied L_R for initial configuration

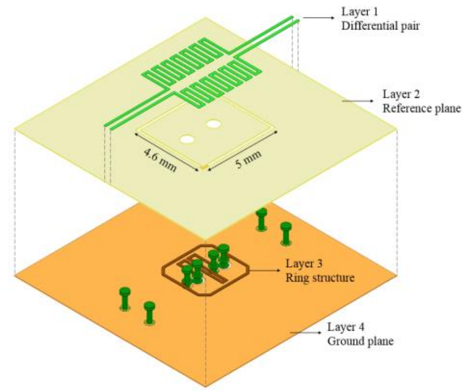

Fig. 5. Configuration of the proposed common mode filter

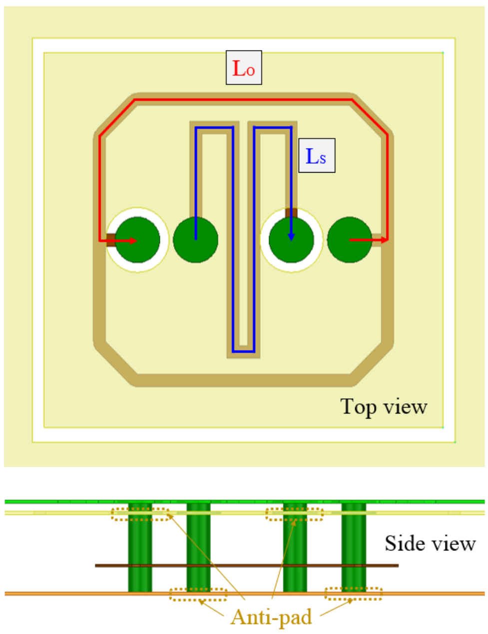

Fig. 6. Top and side view of the configuration of the filter

transmission zeros. In order to further extend the bandwidth of suppression of common mode noise, additional two layer transition vias with serpentine transmission line connected are deployed. Fig. 5 shows the improved configuration of the

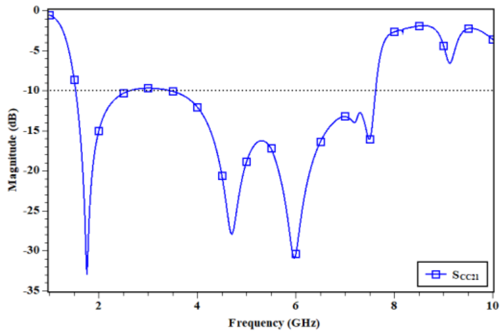

Fig. 7. S_{CC21} of the proposed filter

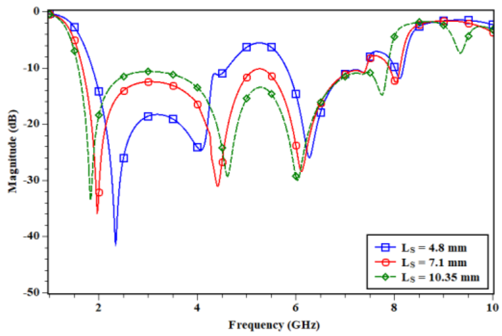

Fig. 8. S_{CC21} of the proposed filter with varied L_S

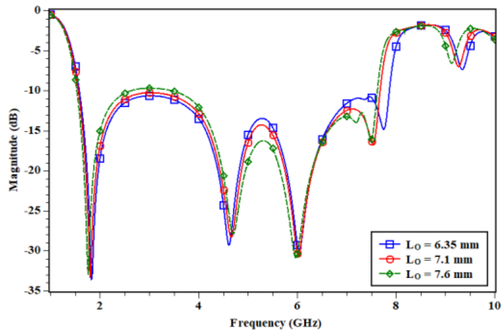

Fig. 9. S_{CC21} of the proposed filter with varied L_O

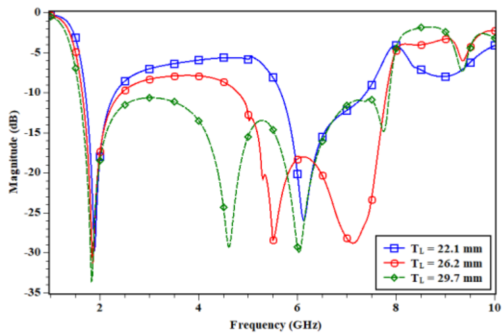

Fig. 10. S_{CC21} of the proposed filter with varied length of differential pair

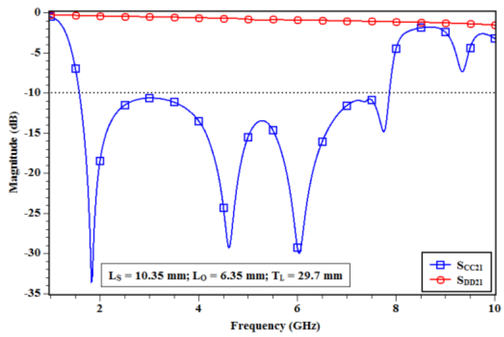

Fig. 11. S_{CC21} and S_{DD21} of the proposed filter with optimized bandwidth of common mode noise suppression

proposed filter. The side view of PCB and the layout pattern on the third layer are shown in Fig. 6. The width and the length of the serpentine transmission line, L_S, are 0.15 mm and 10.35 mm. The width and the length of the ring structure, L_O, are 0.15 mm and 7.6 mm. As changing either the length of the ring structure or that of the serpentine transmission line can vary the inductance of the parallel resonator, the first and the fourth transmission zeros can be shifted accordingly. This flexibility can be utilized to move transmission zeros individually, so that the improvement of broadband noise suppression is expected. The S_{CC21} of the configuration of the proposed filter is shown in Fig. 7. It can be seen that the forth transmission zero is significantly shifted to lower frequency compared to that of the filter in Fig. 1, and the first transmission zero is contrarily shifted to higher frequency. The effective bandwidth of transmission zeros can be linked for increasing bandwidth of noise suppression, and the optimized filter design based on the parametric analysis will be shown in section III.

III. Parametric Analysis

With sensitivity analysis, the length of the ring structure, the length of the serpentine transmission line on the third layer, and the length of the differential pair on the top layer are parameterized. The simulation results are shown in Fig. 8, Fig.9, and Fig. 10. It indicates the first transmission zero is more sensitive to the length of serpentine transmission line compared to that of the ring structure. Contrarily, the fourth transmission zero is more sensitive to the length of the ring structure compared to that of the serpentine transmission line. That means the first and the fourth transmission zeros can be designed individually, and the effective bandwidths of all the transmission zeros can be overlapped for the broadband suppression of the common mode noise. Furthermore, the second transmission zero can be determined by the length of the pair of the serpentine transmission lines on the top layer. The additional transmission zero can be created when the electrical length of the differential pair matches to a half of wavelength. By optimizing these design parameters of the proposed filter, the simulation result shown in Fig. 11 proves the common mode noise can be suppressed over 10 dB from 1.57 to 7.87 GHz with 133% fractional bandwidth, and the insertion loss of the differential mode can still be smaller than 2 dB below 10 GHz.

IV. Conclusion

A broadband filter for suppression of the common mode noise from 1.57 to 7.87 GHz has been proposed. The excellent performance of noise suppression has been validated by the simulation in this paper. Meanwhile, the differential mode insertion loss is smaller than 2 dB up to 10 GHz. Although the sensitivity analysis can be the reference for optimization of the filter design, the full wave simulation can still be time consuming for the filter design. Hence, the equivalent circuit model of this proposed filter will be studied for efficient filter design, and the measurement result is expected for the correlation.

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