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Design of a wideband common-mode filter using approximate closed-loop pattern of compact C-shaped defected ground structure

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Abstract

A compact common-mode filter is proposed to suppress common-mode noise for application of high-speed differential signal traces. The filter adopts one big C-shaped defected ground structure (DGS) cell in the left of ground plane and two small C-shaped DGS cells with opposite direction in the right of ground plane. Because these DGS cells have different dimensions, the filter has three adjacent equivalent resonant points, which can suppress wideband common-mode noise effectively. The left C-shaped DGS and its adjacent C-shaped DGS cell form an approximate closed structure, which can efficiently reduce the influence of the mutual capacitance. The filter provides a common-mode suppression from 3.6 GHz to 14.4 GHz over 15 dB while it has a small size of 10 mm× 10 mm. The fractional bandwidth of the filter is 120%, and the differential signals still keep good signal integrity. The experimental results are in good agreement with the simulated results.

Keywords common-mode filter, approximate closed-loop structure, defected ground structure, insertion loss

1 Introduction

Relying on the advantages of higher immunity against crosstalk, simultaneous switching noise (SSN) and non-ideal return paths over single-ended signaling, differential signal transmission has been applied more and more in high-speed digital circuits. However, in practical circuits, common-mode noise is inevitably caused by unbalanced routing, patterned ground plane and clock skew [1]. They have a significant impact on the electromagnetic compatibility (EMC) performance of the system as well as worsen the differential signal by crosstalk onto nearby traces or through mode conversion.

To suppress wideband common-mode noises, conventional methods include high permeability ferrite cores or multilayer low-temperature co-fired ceramic (LTCC) techniques [2], which take up space on the printed circuit board (PCB) board, pay an additional expenses, and cause undesirable attenuation of the intentional differential signal. Electromagnetic bandgap (EBG) [3–4] and DGS [5–8] are new approaches. However, common-mode filters adopting EBG need to take up a large space, which is not suitable for the application of embedded system. Common-mode filters adopting DGS can suppress the wideband common-mode noises while it has small dimensions. In Ref. [5], Wu et al. adopted two identical U-shaped and one H-shaped coupled patterned DGS to broaden the bandwidth, of which the bandwidth range is from 3.6 GHz to 9.1 GHz and the area is 10 mm× 10 mm. In Ref. [6], Liu et al. adopted three periodic DGS to broaden the bandwidth, of which the bandwidth range is from 3.3 GHz to 5.6 GHz and the area is 15 mm× 24 mm. In Ref. [7], Zhu et al. adopted improved complementary split ring resonator to broaden the bandwidth, of which the common-mode noise can be suppressed from 1.52 GHz to 4.07 GHz and the area is about 44.4 mm× 17.6 mm. In Ref. [8], Kufa et al. adopted reduced fractal DGS to broaden the bandwidth, of which the bandwidth range is from 3.6 GHz to 10.1 GHz and the area is about 42.2 mm×

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11.0 mm. Recently, a common-mode suppression filter utilizing the existing mutual inductance and mutual capacitance in the DGS patterns to improve the in-band gain-flatness of the filter was demonstrated by our group in a PCB [9]. It adopts two Π-shaped and one button-headed H-shaped DGS, of which the DGS patterns are complementary and compact. The existing mutual inductance and mutual capacitance is used to broaden the bandwidth, but they are seldom analyzed respectively. The bandwidth range of it is from 3.2 GHz to 12.4 GHz and the area is about 10 mm× 10 mm.

In this paper, we propose a low-cost filter with compact common-mode DGS. It uses three C-shaped DGS cells to broaden the bandwidth. Because the sizes of the three DGS cells are different, the filter has three different resonant frequencies, which is effective to broaden bandwidth of the filter compared to filter adopting single DGS with the same area of the proposed filter. And more, it adopts an approximate closed loop DGS pattern structure to reduce the influence of the mutual capacitance. The approximate closed loop DGS pattern is made up of two adjacent DGS cells. The direction of left C-shaped DGS cell are opposite that of the right C-shaped DGS cells. An equivalent circuit model is given to analyze the impact of equivalent mutual inductance and mutual capacitance on the performance of common-mode noise suppression. The filter can suppress wideband common-mode noise over 15 dB between 3.6 GHz and 14.4 GHz.

2 Design and analysis for new common-mode filter

As is shown in Fig. 1, two small C-shaped DGS cells are in the right side, and one big C-shape DGS cell is in the left side. 'Smooth transition' [10] is used to achieve a better flatter of filter, which adopts a quarter circle with radius of R to deal with the right-angle corners. The DGS cells are symmetric to the central line between the differential signal lines. Since differential signal is propagated in the odd mode, relatively low current density returns through the ground plane. The degradation of the differential signals caused by the defected ground planes is relatively small. The proposed common-mode equivalent circuit model is shown in Fig. 2, each of the DGS cells of the proposed filter for the common-mode can be modeled as an ideal transmission line with even-mode characteristic impedance Z_e and a parallel LC resonator cascaded on the ground plane. The parallel LC resonator can block the common-mode noise at resonance frequency. C_i and L_i (i = 1, 2, 3) denote the gap capacitance between two sides of the slit and the equivalent inductance of the signal passing through the DGS respectively. Because the three DGS cells are located closely, mutual capacitance and mutual inductance between any two resonators need to be considered. Therefore, a more detailed equivalent circuit of the proposed filter needs to be modeled, where L_{Mi} and C_{Mi} (i=1,2,3) are the mutual-inductance and mutual-capacitance respectively.

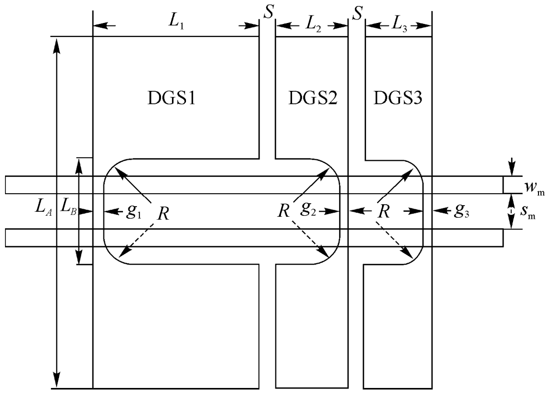

Fig. 1 Schematic diagram of the proposed common-mode DGS filter

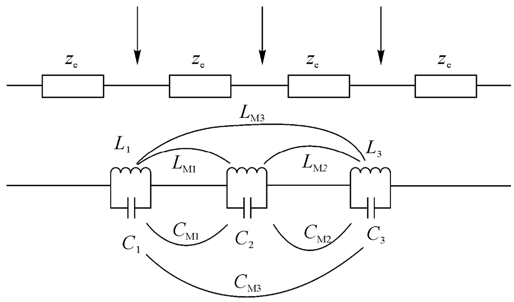

Fig. 2 Equivalent LC resonant circuit model of the DGS structure

Simulate result of the proposed common-mode filter is shown in Fig. 3. And the parameters of DGS with L=4 mm are shown in Table 1.

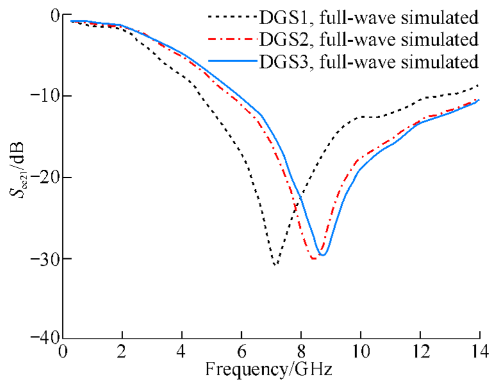

Fig. 3 Simulated result of filter adopting DGS1, DGS2, DGS3 respectively