A Novel Metamaterial Structure to Reduce Far-End Crosstalk in Printed Circuit Boards

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Abstract—Far-End crosstalk is a common problem in a printed circuit boards when two transmission lines are in close proximity. This paper proposes a newly designed method to reduce the far-end crosstalk using metamaterials as a complementary split ring resonator (CSRRs). The CSRRs are etched in the ground plane and are used to control the radiated electromagnetic fileds. Comparative analyses are taken for three cases with solid ground plane etching one CSRR and 2 CSRRs in the ground plane. Analysis shows that a significant reduction in the crosstalk is achieved when 2 CSRRs are etched in the ground plane. This design is made to reduce the crosstalk without additional components.

Keyword- Metamaterials, Crosstalk, Electromagnetic Coupling, Printed Circuit Boards (PCBs).

I. INTRODUCTION

In high-speed digital circuits, due to the high density of traces in the printed circuit boards, there exists the phenomenon called crosstalk due to the electromagnetic coupling between the adjacent transmission lines. The two types of crosstalk are near-end crosstalk (NEXT) and far end crosstalk (FEXT). The near end crosstalk is due to the mutual capacitance which exists between the two adjacent transmission lines and the far-end crosstalk is due to the mutual inductance. The FEXT is mainly because of the coupling of electromagnetic energy from source to victim line. To mitigate this crosstalk problem, it is essential to design suitable circuit models and structures using metamaterials.

Introducing a guard trace, serpentine guard and via-stitch guard in between the source and victim line significantly reduces the FEXT is discussed [1]. But this serpentine guard trace and via-stitch guard implementation causes additional impedance variations and cost adding process. To mitigate the crosstalk, a magnetic material composed of Fe-Si-B-Cr amorphous particles with a mean diameter of 6 micrometer is filled between the transmission lines instead of a ground line. This implementation gives a reduction of FEXT to a value of 20dB for a bandwith of 1GHz [2]. To supress the FEXT noise additional crosstalk, noise developed by the grounded guard trace line on the victim line with equal amplitude is proposed [3]. The metamaterial based CSRRs are introduced to reduce the electromagnetic coupling between two co-planar microstrip antennas and a reduction of 10dB is achieved [4].

By extending the crosstalk issue, a new method using metamaterial as a CSRR is etched in the ground plane to reduce the crosstalk. The simulations are carried out for the frequency range 5 GHz to 10 GHz.

II. THEORY OF CROSSTALK

Crosstalk is a noise due to unintended electromagnetic coupling between the two traces of a printed circuit boards which are in close proximity. Crosstalk occurs due to the effects caused by mutual capacitance C_m and mutual inductance L_m as shown in Fig. 1.

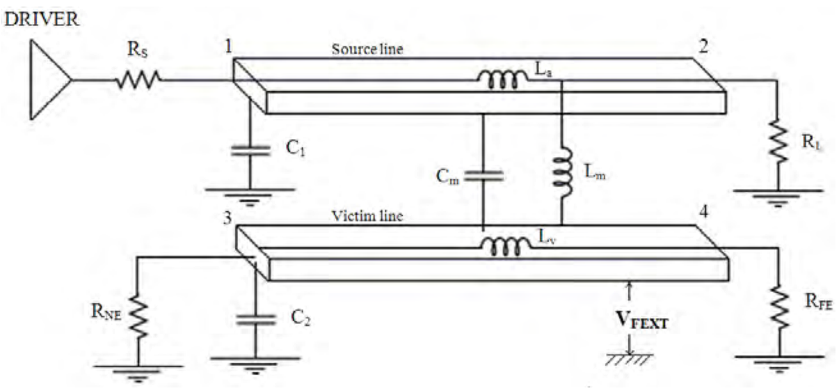

Fig. 1. Crosstalk phenomenon

With reference to the Fig. 1, the circuit parameters for a frequency of 'ω' the FEXT voltage at the far-end is given by the expression (1)

$$V_{FEXT} = -\frac{R_{FE}}{R_{NE}+R_{FE}} j\omega L_m \frac{1}{R_S+R_L} V_S + \frac{R_{NE}R_{FE}}{R_{NE}+R_{FE}} j\omega C_m \frac{R_L}{R_S+R_L} V_S \quad (1)$$

III. THEORY OF METAMATERIALS

Metamaterials are periodic or quasi periodic microstuctures designed artificially, to have electromagnetic properties not available in nature. These materials can be designed to operate in the region of simultaneously negative values of electric permittivity ε and magnetic permeability μ, termed as left handed medium. These microstructured materials are used on a scale much lower than the wave length as subwave length resonators. It is to be noted that not all the metamaterials are resonant in nature and the design is in such a way to control the effect of electromagnetic fields.

Babinet's principle relates the diffraction fields of one diffracting screen to those of the complementary screen. When a time varying magnetic field is applied parallel to the axis of the rings depending on the resonant property of SRRs and CSRRs, it produces an electromagnetic field that may either oppose or add the incident electromagnetic filed [5].

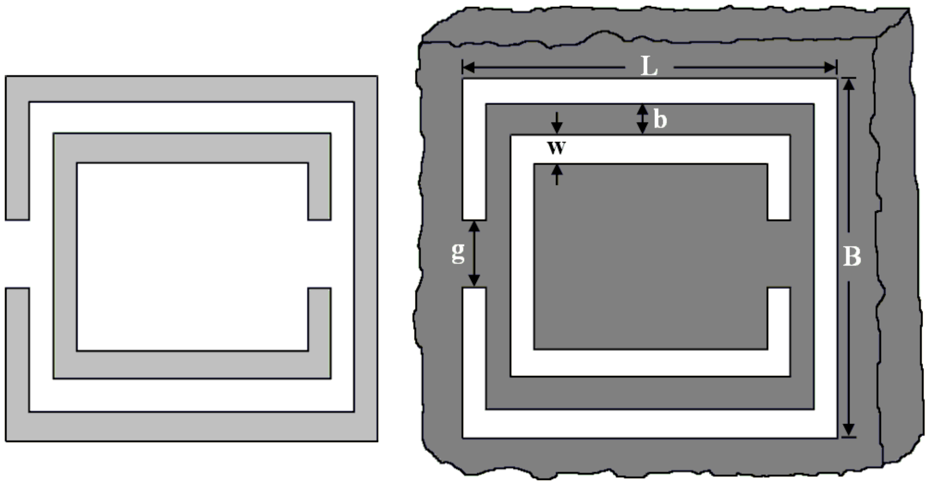

Fig. 2. Topologies of (a) SRR (b) CSRR. Grey colour represents metallization

IV. PROPOSED DESIGN

A. Description of CSRR

CSRRs are microstructures built from non magnetic materials which exhibit a magnetic property, when excited by electromagnetic waves. The value of μ and ε can be tuned to a value not accessible in naturally occurring materials [6]. Due to the presence of internal capacitance (C) and inductance (L) of split-rings, the structures are resonant in nature for a homogeneous medium. The resonant frequency (ω_r) of the complementary structure is given by (2)

$$\omega_r = \frac{1}{\sqrt{LC}} \quad . \tag{2}$$

Fig. 2. (b) shows dimensions of the unit cell of CSRR with L=7.6mm, B=7.66mm, b=0.6mm, g=0.4mm, w=0.4mm.

B. Description of PCB

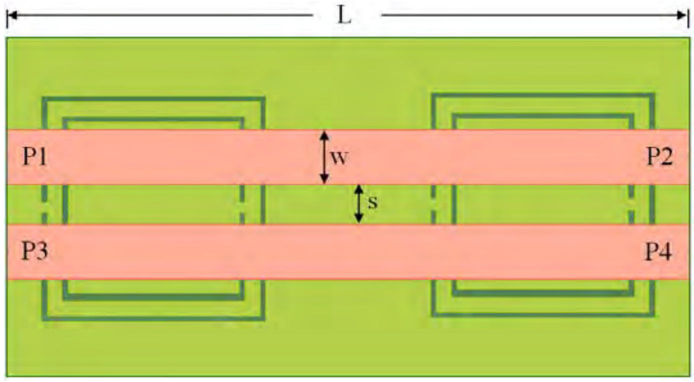

Fig. 3. PCB layout with two CSRRs etched in the ground plane

Fig. 3. shows the coupled microstrip lines that are designed for 50Ω termination with the following design parameters: width w = 2.35mm, length L= 40mm, spacing s = 1.93mm, $\varepsilon_r = 4.7$, tanδ = 0.02, height of the substrate h = 1.6mm, $Z_{odd} = 45.2\Omega$ and $Z_{even} = 55\Omega$, thickness of the conductor t = 1.35mil

V. EXPERIMENTAL VALIDATION

As a qualitative description of how the CSRRs give rise to a negative permittivity is impinging the incident voltage wave E between the parallel plates produces D=εE which also excites surface current density J_{ind} in the rings. This produces an electric polarization P that is anti-parallel to D. When polarization P overcomes D, the effective permittivity of the medium becomes negative. Similarly the current density J produces a time varying flux density in the transmission lines producing potential drops across the transmission lines. This potential drops develops magnetic polarization which is anti-parallel to flux density. When the magnetic polarization overcomes the flux density, the effective permeability of the medium becomes negative.

In our proposed design, the CSRRs are etched in the ground plane with two configurations namely one CSRR at the centre and two CSRRs along the sides. From the properties of CSRRs the inductance gives rise to negative electric polarization, while the capacitance gives rise to magnetic polarization. These two polarizations are responsible for the flux cancellation as depicted in the Fig. 4.

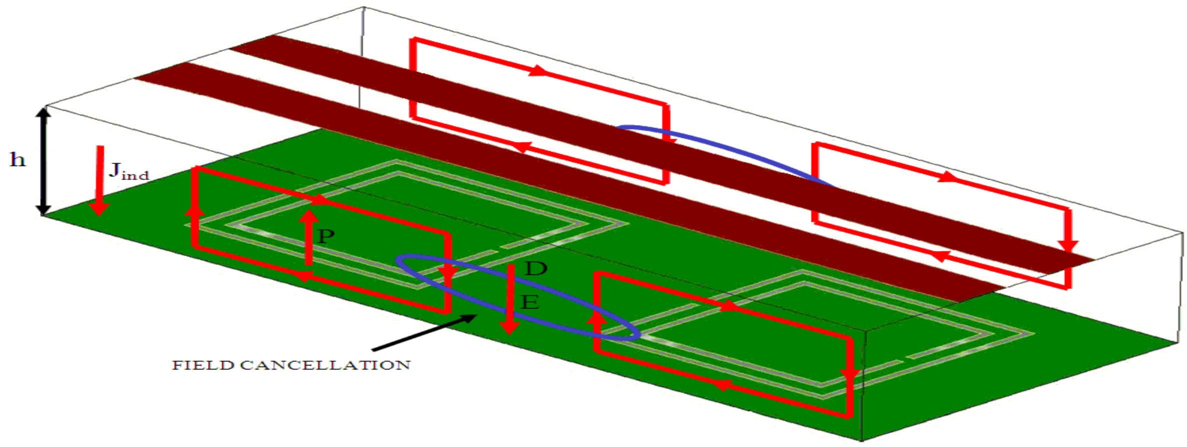

Fig. 4. PCB layout for the cancellation of the fields

VI. RESULTS AND DISCUSSION

The FEXT noise is represented by scattering parameters S_{41} as the energy coupled from source to victim line. The Fig. 5, shows S_{41} for three configurations with solid ground plane, with one CSRR at centre and two CSRRs along the sides etched on the ground plane of the PCB.

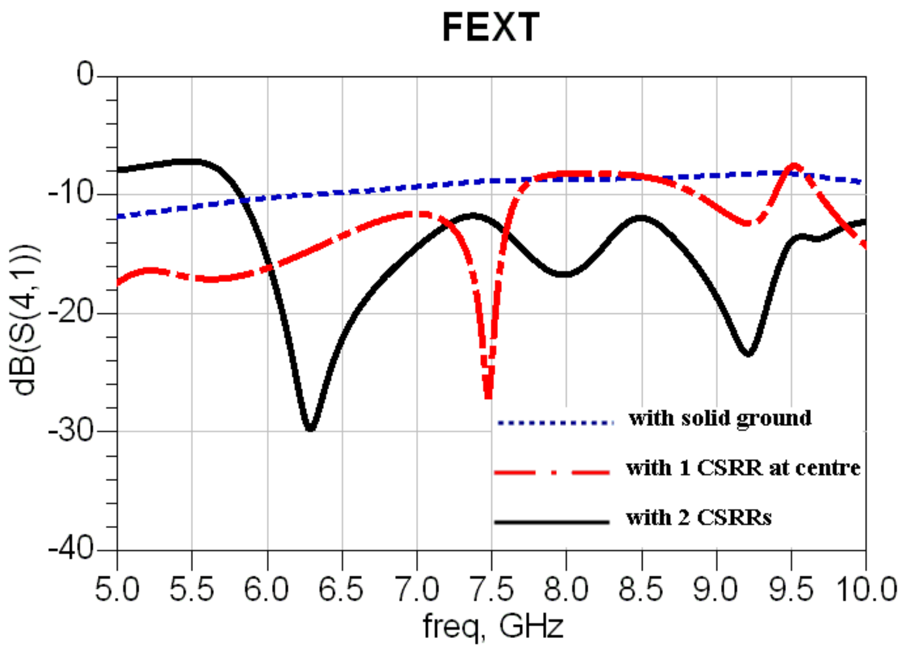

Fig. 5. FEXT, S_{41} with solid ground plane, one CSRR and with two CSRRs

The analysis shows that the FEXT noise S_{41}, by using the solid ground plane has an average value of −9dB between the frequency range 5 GHz to 10 GHz. When the ground plane has one CSRR, there is a significant reduction of FEXT noise level (S_{41}) to a value −28dB at a frquency of 7.5 GHz. If the two CSRRs etched on the ground plane, the S_{41} is −30dB at 6.3 GHz and −24dB at 9.3 GHz.

VII. Conclusion

Crosstalk analysis using CSRRs in the ground plane of a PCB was investigated and the results are compared with the solid ground. The comparative analysis shows that because of the presence of CSRRs in the ground plane a significant suppression is achieved in the far-end crosstalk.

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