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Mutual Coupling Suppression in Microstrip Lines Using Metamaterial on Low Temperature Co-fire Ceramic (LTCC) Substrate

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1. Introduction

With the current demands on electronic systems being miniaturization and diverse functionality, electromagnetic interference (EMI) between the RF signals critically affects the system performance. A major limitation in realizing high-density microwave hybrid integrated circuits and SIP (system-in-package) is the parasitic coupling that arises between neighboring transmission lines. So far in literature there have been several studies aimed toward alleviating these problems. One approach involves thinning the substrate under signal lines to facilitate quasi-TEM mode propagation, but this requires an involved etching process [1]. Another method to effectively reduce this coupling is to use Electromagnetic Band-Gap structures (EBGs) [2]. Different types of EBGs have been reported in literature along with methods to evaluate their suitability to a particular application and performance [3]-[5]. But both plane EBGs and vertical EBGs are very difficult in manufacturing together with other circuit sections, which restricts the application of EBGs.

Metamaterials provide effective isolation between microwave circuit elements in specific frequency band. The basic function of metamaterial insulators is the blocking of EM energy from being transmitted across the insulation boundary [6]. Meanwhile, LTCC (Low Temperature Co-fired Ceramic) manufacturing technique has become popular because of its advantages for high density and high frequency applications, which is well suited for the small pattern sizes required by metamaterials for microwave applications. Additionally, it is easy to make multilayer designs of complex microstructures. In this paper metamaterials designed in LTCC substrate are shown to be effective tools for achieving mutual coupling suppression in physically small stated volume.

This paper introduces a mutual coupling-reduction scheme for high-density circuits within aptotic volumes that allows adjacent lines operating at the same frequency band to lie closer. We address a specific case of transmission line coupling that occurs when the lines carry the same signals, as in a densely antenna array feeding network. The transmission line couple mode is equivalent to a symmetrical four-port network. This network can be analyzed by the even and odd modes method described by Reed and Wheeler [7].Metametarial resonators consisted of metal microstructures are symmetrically embedded in substrate between two transmission lines. The results show that mutual coupling can be reduced prominently.

2. Design of Couple Model with Metamaterial

In a planar dielectric substrate, the mutual coupling between transmission lines is mainly caused by excitation of substrate modes [8]. This type of coupling is more significant when high dielectric constant materials are used.

The SRR (Split Ring Resonator) is a metamaterial sample which was proposed by Pendry [9] and has been studied and developed by many researchers because it is possible to get negative permeability in a narrow frequency region. The SRR is a ring with a gap, and the axis of the ring should be parallel with the magnetic field. The patterns of the metamaterial are composed in the multilayer structure and connected through microvias between layers.

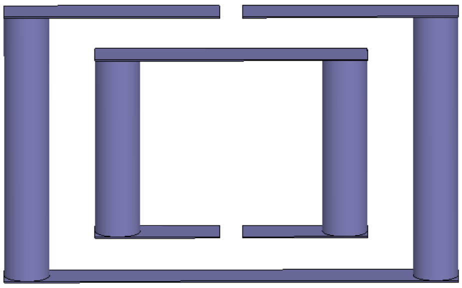
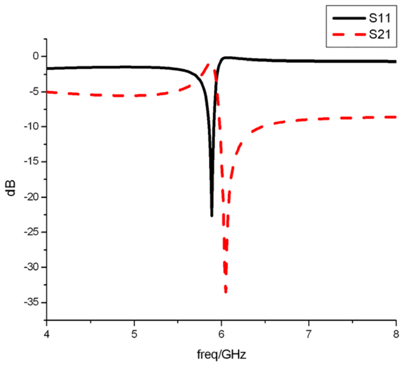
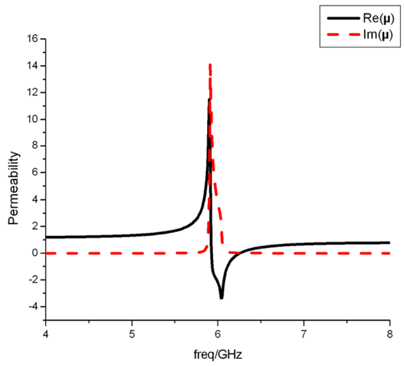


Fig. 1: The three-dimensional geometry of SRR

Fig. 1 is the designed SRR for LTCC fabrication. The microstructure is composed of two SRRs. The SRR has a loop, which is composed of two metal lines and two microvias. Metal lines are connected by microvias filled with metal. The geometric parameter of the SRR determines the resonance frequency. Therefore, it must be optimized to achieve the desired attenuation level and frequency separation.



(a) Simulated S parameters of SRR



(b) Retrieved effective permeability of SRR

Fig. 2: Reflection and transmission coefficients are used to retrieve effective permeability of SRR

To extract the effective permeability, the reflection and transmission coefficients are simulated for the incident plane wave using Ansoft HFSS full-wave simulator. As can be seen in Fig. 2(a), there is a stopband around 6 GHz, where substrate surface waves are eliminated. The effective parameters can be extracted from these parameters. The effective permeability of the substrate with the SRR is shown in Fig. 2(b). The real part of permeability is negative from 5.9 GHz to 6.2 GHz.

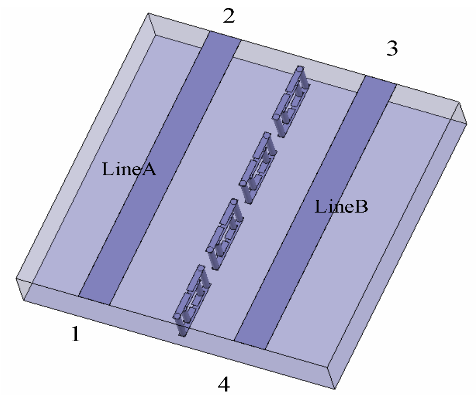


Fig. 3: Coupling reduction scheme for adjacent microstrip lines carrying the same frequencies. SRRs are embedded between two adjacent transition lines.

Fig. 3 shows two adjacent 50Ω microstrip lines separated by 4mm. Line A connecting Ports 1 and 2 is intended to guide a signal, while Line B connecting Ports 3 and 4 is intended to guide another signal with the same frequency. The lines are printed on a substrate with embedded SRRs (Split Ring Resonators) which is composed of Ferro ULF140 ceramic films, where the permittivity is 14, the dielectric loss tangent is 0.002 and the permeability is 1.

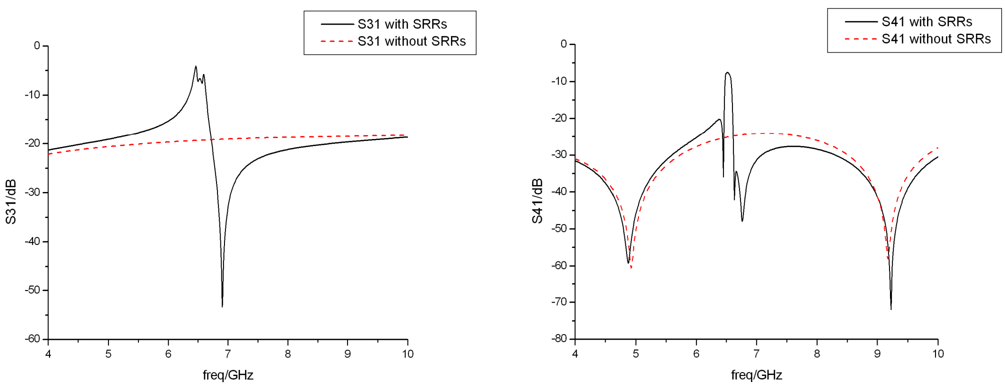


Fig. 4: Simulated S parameters of coupling model with SRRs and without SRRs

To investigate the effect of metamaterial resonators, the S parameters are simulated for the incident plane wave using Ansoft HFSS full-wave simulator. Fig. 4 compares the simulated S parameters, which is designed to reject mutual coupling at the same frequency band. The forward coupling (S31) and backward coupling (S41) are reduced more than 10 dB from 6.8 GHz to 7.4 GHz, even more than 20 dB from 6.8 GHz to 7.0 GHz.

3. Analysis of the even and odd modes method

The transmission lines are analyzed as a symmetrical four-port network by the even and odd modes method. The characteristic impedances and propagation constant of the transmission line are investigated. The coupling performance is determined by Z_{0i} and θ_i, here Z_{0i} and θ_i designate the characteristic impedances and electrical lengths of the transmission lines in the even or odd mode, respectively. The differential pair simulation is intend to show common signal (c11 and c21) is suppressed from 6.8 GHz ~ 7.0 GHz in Fig .5.

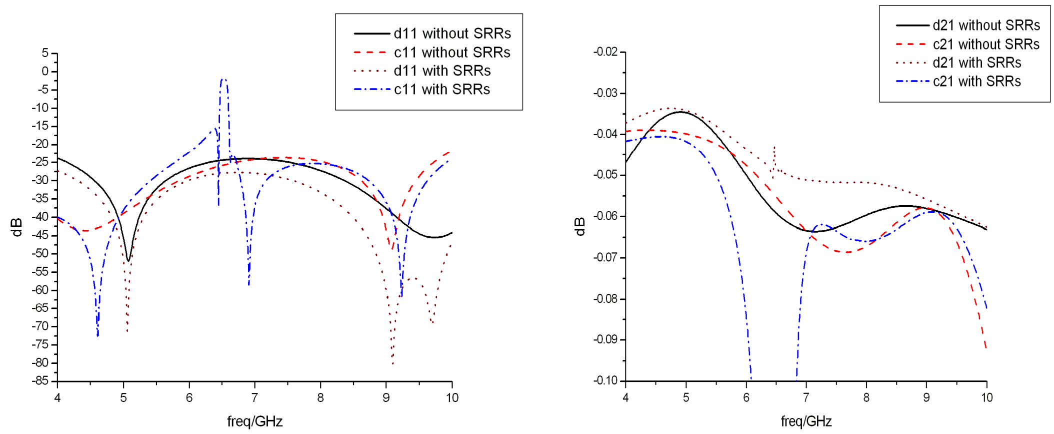
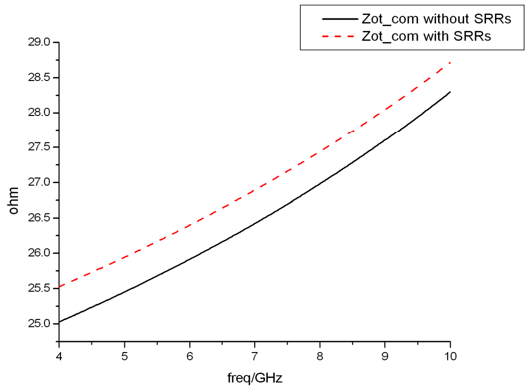


Fig. 5: Simulated reflection (S11) and transmission (S21) coefficients of differential pairs

The characteristic impedances and electrical lengths of the transmission lines in the even and odd mode are shown in Fig. 6 and Fig.7. There are few differences in Z_{0i} and θ_o, while θ_e with SRRs is reversed around 6.5 GHz comparing to θ_e without SRRs. For propagation constant (β) is determined by electrical length (θ) and L (the physical length of transmission lines). A conclusion is drawn that the reverse θ_e leads to the counteraction of even mode coupling, which caused the prominent mutual coupling suppression.



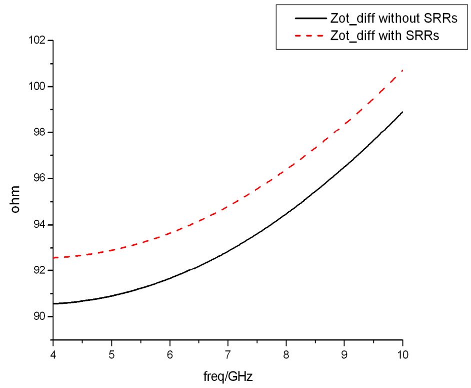


Fig. 6: The characteristic impedances of the even and odd mode

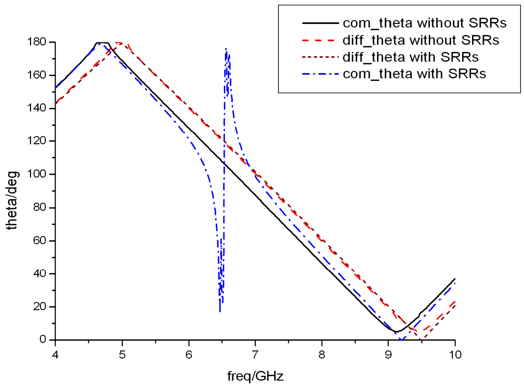


Fig. 7: The electrical lengths of the transmission lines in the even and odd mode

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