

Suppression of the Mutual Coupling between Microstrip Antenna Arrays Using Negative Permeability Metamaterial on LTCC Substrate

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Abstract—A simple tridimensional negative permeability metamaterial structure Split Ring Resonator (SRR) based on Low Temperature Co-fired Ceramic (LTCC) substrate is proposed to eliminate mutual coupling between array elements. Embedded SRRs can help in the reduction of mutual coupling by using their capability of suppressing surface waves propagation in a given frequency range. By placing the SRR array between two adjacent microstrip antennas, greater than 15 dB peak isolation is achieved for array elements spacing of $0.2\lambda_0$.

I. INTRODUCTION

The isolation between antennas is a critical parameter in many practical applications such as antenna arrays, multiple input and multiple output (MIMO) communication systems, and diversity antenna communication systems. However, the close spacing between each of antenna elements generates the cross talk factor, and it restricts the integration of antenna system [1]. In addition, closely packed antennas as a consequence of size reduction in portable communications devices suffer from mutual coupling effects. Hence, there is a need to provide a high degree of isolation between closely spaced antenna elements in order to substantially reduce mutual coupling.

The mutual coupling between closely spaced antenna elements is attributed to two aspects [2]. In a planar dielectric substrate, the coupling is mainly caused by excitation of substrate modes. This type of coupling is more significant when high dielectric constant materials are used. The second reason is due to the free space radiation when low dielectric substrates are used.

In literature, various methods have been studied to improve the mutual isolation. The use of two ground-plane side walls erected vertically next to adjacent antennas and the side walls defected with a lattice pattern of slots to form a defected wall structure (DWS) to significantly reduce the mutual coupling between closely spaced antennas operating at the same frequency band is presented in reference [1]. Planar EBGs based on a truncated frequency selective surface (FSS) grounded slab using a multilayer dielectric substrate are investigated in reference [2]. Two-dimensional EBGs such as Mushroom-like structures and uniplanar compact electromagnetic band-gap (UC-EBG) structures are described to reduce mutual coupling between the radiating elements in references [3, 4]. However, all the periodic structures increase the antenna dimensions and weight prominently. Moreover, this type of approach needs a large dimension of structure and a

large number of periodicity. Therefore, it is difficult to suppress the coupling of electrically small structures.

To address this problem, a new type of approach is presented in this paper. By using the simple tridimensional split ring resonator (SRR) in LTCC manufacturing, the complexity of fabrication process can be decreased. The SRR as a canonical metamaterial structure gives rise to an effective negative permeability with a stopband in its resonant frequency band [5]. This proposed approach can achieve the improvement of isolation between two antenna elements with a small dimension of structure and small number of periodicity.

II. LTCC NEGATIVE PERMEABILITY METAMATERIAL ANALYSIS AND DESIGN

LTCC (Low Temperature Co-fired Ceramic) manufacturing has become popular because of its advantages for high density and high frequency applications. The LTCC technique offers integrated and complex multilayer fabrication for low-cost manufacturing. LTCC manufacturing techniques are well suited for the small pattern sizes required by metamaterial for microwave applications. Meanwhile, it is easy to make multilayer designs of complex microstructures.

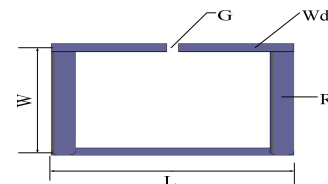


Figure 1. The tridimensional geometry of SRR.

The designed tridimensional SRR for LTCC fabrication is plotted in Figure 1. The substrate is composed of Ferro ULF140 ceramic films, where the permittivity is 14, the dielectric loss tangent is 0.002, and the permeability is 1. The microstructure is composed of one modified SRR. The SRR has a loop, which is composed of two metal lines and two microvias. Metal lines are connected by microvias filled with metal. Considering the LTCC processing, the SRR structure should be prolate for easy fabrication. The width of the metal lines (Wd) is 0.2 mm, and the size of the gap (G) is 0.1 mm. The radius of the microvia (R) is 0.1 mm. The length of the outside ring (L) is 2 mm, and the width of it (W) is 0.5 mm. The axis of the ring should be parallel with the magnetic field to excite the magnetic response. The electromagnetic

parameters of the negative permeability metamaterial can be retrieved using the S parameters retrieval method.

III. MUTUAL COUPLING SUPPRESSION

In this type of antennas, surface waves are strongly excited in E-plane when the antenna is operated in the fundamental mode (TM_{10} for rectangular patches). In this mode, the field distribution inevitably excites the first propagating mode of surface waves (TM_0) in E-plane, given that this mode has no cutoff frequency [2]. Hence, the array of resonant elements is placed between two closely spaced antennas in E-plane direction. The overall geometry and the side view are shown in Figure 2. The array incorporates eleven elements of the unit cell. The distance between the centers of the unit cells is 1 mm. The size of the patch antenna is 5.7 mm x 11 mm. The distance between the feed is $0.2\lambda_0$ mm. The thickness of the patch antenna is 0.006 mm, which is the same as that of the metal line in the SRR structure, and the thickness of the substrate is 2 mm.

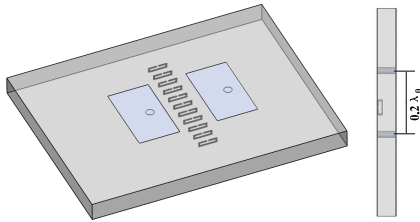


Figure 2. Schematic illustration of the antenna geometry and the side view.

Since the surface waves are mainly existed in the surface of the substrate. The prolate SRRs structure should be embedded near the patch plane. However, if the top plane of the SRRs and the patch plane are at the same plane, it will affect the resonance structure of the antenna evidently. To split the difference, the distance between the patch antenna plane and the top plane of the SRR structure is 0.15 mm.

The initial design of metamaterial substrate for two adjacent microstrip antennas is presented in Section II. Because the practical boundary condition is different from ideal parameters retrieval, the resonance frequency of designed SRR will be apparently changed. Therefore, the structure dimensions must be optimized to achieve the desired attenuation level and frequency separation. The simulated and measured performances of two antennas with and without SRRs are compared on the same dielectric substrate.

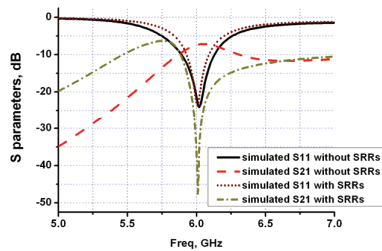


Figure 3. Simulated S parameters of the antenna with and without SRRs.

The simulation results have been plotted in Figure 3. The antenna on the dielectric substrate has the resonance frequency at 6 GHz with 3.67% percentage bandwidth (-10dB bandwidth), while the resonance frequency of the antenna on the metamaterial substrate is at 6 GHz with 3% percentage bandwidth. Simulation results confirm that the use of the proposed structures is very close to the patch antenna, though in a different layer does affect the antenna matching. A clear and significant mutual coupling reduction is achieved for this case from 5.9 GHz to 6.5 GHz.

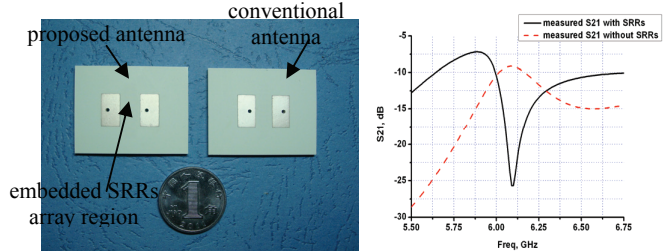


Figure 4. Photograph of the processed antennas and the measurement results of S21.

The antennas are fabricated and measured using Agilent E8363B vector network analyzer (VNA). The photograph of the processed antennas and the measured S21 of the antenna with and without SRRs are plotted in Figure 4. According to the measurement results, the initial coupling is about -10 dB and the embedded SRRs create a narrow dip in the mutual coupling goes below -25 dB. The difference between the simulated and measured mutual coupling is caused by the material tolerances, the manufacture accuracy of LTCC, the indoor measurement environment and the effect of the SMA connector.

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