Design of a 2.3 GHz Band Mobile-WiMAX MIMO Antenna using Split Ring Resonator

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1. Introduction

In recent mobile communication systems, high data rates and large channel capacities are required to satisfy the various user's demands. The multiple input multiple output (MIMO) system is a space-time signal processing approach in which the time dimension is complemented by the spatial dimension through the use of spatially distributed multiple antennas. The MIMO system can increase the capacity or reliability of a communication channel without requiring additional power or spectrum, unlike other systems [1]. In the MIMO system, two or more antennas are used on both the transmitter and receiver sides. However, the antenna elements are strongly coupled with each other and even with the ground plane because they share a surface current [2]. Many studies have been performed to improve the isolation characteristic of a MIMO antenna using a shorting strip [3], a new ground structure with slits to act as a band-stop filter [4] and a corrugated ground plane [5]. However, these techniques limit the space available for other system components as well as do not guarantee an uniform radiation pattern.

Metamaterials can be defined as man-made homogeneous electromagnetic structures with unusual properties not readily available in nature. Microwaves cannot propagate in a medium with a negative electrical property ($\varepsilon < 0$ or $\mu < 0$). Negative permeability materials can usually be obtained using the SRR structure at a specific frequency band. The resonance frequency is determined by the capacitance and inductance of its structure [6].

In this study, the Split Ring Resonator (SRR) structure is inserted between the two radiating elements to improve the isolation characteristic between two radiating elements for Mobile-WiMAX band (2.3 ~ 2.4 GHz). Details of the antenna design and experimental results are presented and discussed.

2. Antenna Design and Analysis

2.1 Antenna Configuration

Fig. 1 shows the configuration of the proposed MIMO antenna. The proposed MIMO antenna consists of a system ground, two radiating elements and a SRR isolator. The volume of the system ground is 45 mm × 80 mm × 1.2 mm, which is constructed on the three layered FR4 substrate ($\varepsilon_r = 4.4$) each of which has the thickness of 0.4 mm. A Ground planes are placed at front and back sides of three layered FR4 substrate. Each radiating element consists of a meander line on the front surface of Layer1 and a coupling stub on the back surface of Layer3 as shown in Fig. 1 (a). By the coupling between the meander line and stub, the radiating elements have good impedance matching characteristic. Two radiating elements of the MIMO antenna are printed symmetrically with respect to the center and were placed near the two corners of the top edge of the ground plane. The size of each radiating element is 12 mm × 12mm. The SRR isolator is placed at Layer2 as shown in Fig. 1 (b). The SRR is printed on the top and bottom surfaces of the Layer2 which has the dimension of 3 mm × 19 mm × 0.4 mm. The top and bottom surfaces of SRR are connected by via holes. The resonance frequency of SRR is controlled by the length of the interdigital capacitor, Ls.

The antenna structure was designed and analyzed using a high frequency structure simulator (HFSS Ver.12) [7].

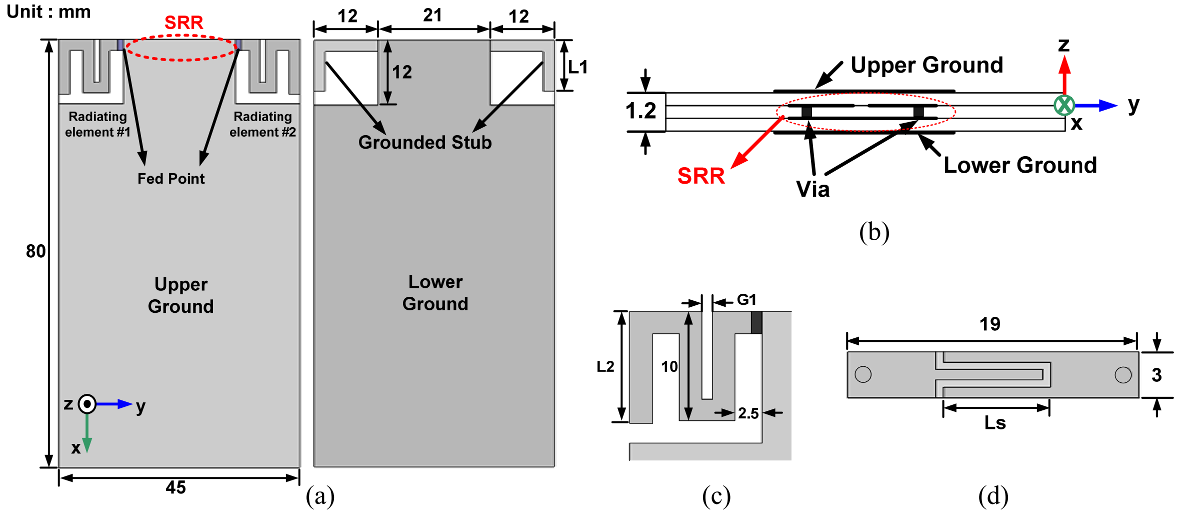


Figure 1: Geometry of the proposed antenna:
(a) Front and back view, (b) side view, (c) radiating element and (d) SRR structure.

2.2 Analysis of the Impedance and Isolation Characteristics

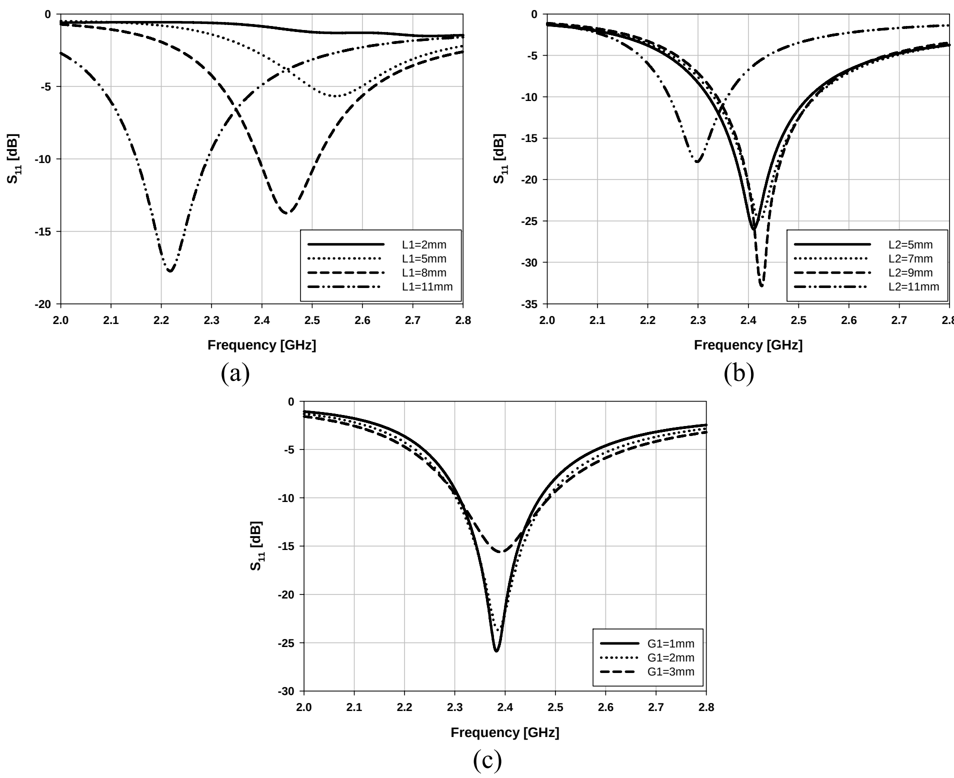
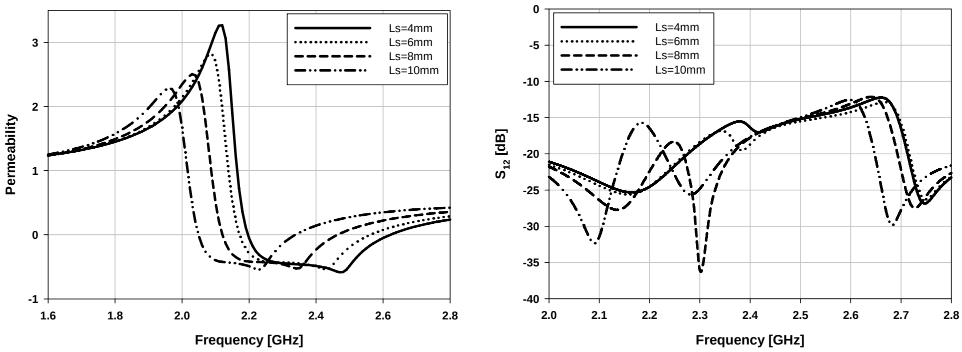


Figure 2: Simulated S_{11} characteristics for different design parameter values:
(a) Variation in L1, (b) Variation in L2, (c) Variation in G1.

Fig. 2 shows the simulated S_{11} characteristics of the proposed antenna. As the length (L1) of the grounded inverted-L stub increases, the resonance frequency shifts toward a lower frequency band and the impedance bandwidth becomes wider, as shown in Fig. 2 (a). However, the equivalent reactance of the meander line becomes either the series capacitance or the series inductance depending on the value of L2. In Fig. 2 (b), the resonance frequency shifts toward higher frequency side due to the series capacitance effect for values of L2 varying from 5 mm to 9 mm. On the other hand, the resonance frequency becomes lower when the value of L2 is 11 mm. The gap (G1) of meander line does not affect the resonance frequency significantly as shown in Fig. 2 (c).

The effective permeability characteristics of the SRR unit cell can be determined using the method described in [8-9]. The SRR structure stores magnetic energy so that the magnetic field is perpendicular to the surface of the SRR, which acts as an inductor. The gap of the SRR introduces a capacitor for storage of electrical energy. Therefore, the SRR can be equivalently modelled as an LC resonant circuit. Once the resonance frequency is determined by the capacitance and inductance of its structure, the SRR structure can display negative permeability characteristics at the specific frequency band. The resonant frequency is dependent upon the length of the SRR structure, the length and gap distance of the capacitance area. Figs. 3 (a) and (b) show the effective permeability of the SRR unit cell and the isolation characteristics of the MIMO antenna for various lengths of the interdigital capacitor, Ls. As the length of the interdigital capacitor is increased, the cut-off frequency is shifted to a lower frequency band. Also, the improved isolation characteristic is observed at a lower frequency band.



(a) (b)

Figure 3: Simulated effective permeability and S_{12} characteristics :
(a) Effective permeability for variation in Ls, (b) isolation for variation in Ls.

3. Results

The simulated S-parameters with and without SRR structure are illustrated in Fig. 4. In this analysis, the design parameters of radiating elements are fixed at L1=9.6 mm, L2=10.2 mm, G1=1 mm and Ls=7 mm. It is obvious that the addition of the SRR structure improves the isolation characteristic. The designed antenna has a 10 dB return loss bandwidth from 2.3 GHz to 2.45 GHz, and an isolation of less than -20 dB over the operating frequency band.

To investigate the effect of the SRR structure on the isolation characteristic, the current distributions at 2.35 GHz with and without SRR structure were calculated and are shown in Fig. 5. When one of the two radiating elements was excited, a strong current was induced at the other element in the absence of the SRR structure. After the SRR structure was inserted, the induced current on the non-excited element became very weak.

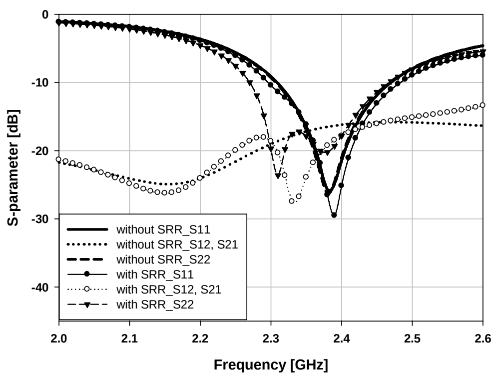
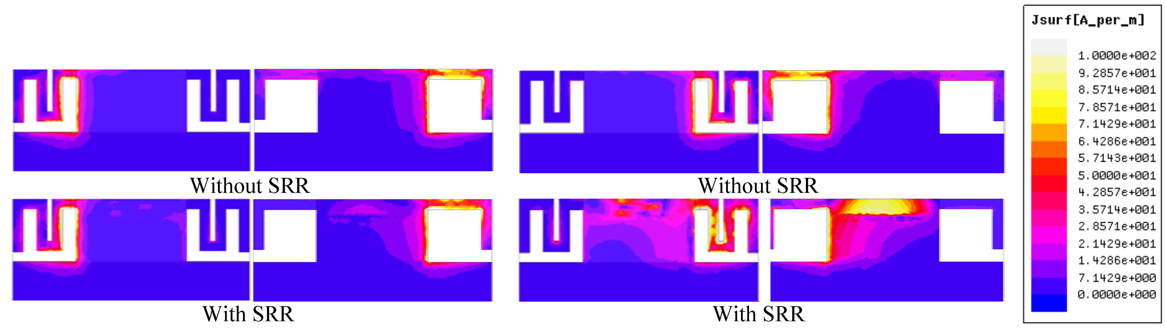


Figure 4: S-parameters for with /without SRR.



(a) (b)

Figure 5: Simulated current distributions is excited
(a) only element 1, (b) only radiating element 2 is excited.

4. Conclusion

In this study, we propose a method to improve the isolation characteristic of the MIMO antenna using an SRR. The proposed MIMO antenna consists of two meandered monopoles with a grounded inverted-L stub for Mobile-WiMAX (2.3 ~ 2.4 GHz) service. The SRR structure was inserted between the two elements and placed between the ground planes (Layer2) to improve the isolation characteristic. By inserting the SRR, the induced current on non-excited element became very weak. The return loss was higher than 10 dB, and the isolation characteristic was less than -20 dB over the whole Mobile-WiMAX band. Therefore, the SRR structure can be used in MIMO antenna systems to obtain the high isolation characteristic necessary for mobile applications.

Acknowledgments

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