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A Study on Improved Isolation of Indoor Repeating Antenna using Metamaterial Absorber for WCDMA System

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Abstract – This paper proposes a novel design for a compact, high-isolation WCDMA indoor repeater antenna. The proposed antenna consists of a patch antenna and metamaterial absorber. The required WCDMA bandwidth is obtained by utilizing the coupling between the main and the parasitic patches. In addition, high isolation is achieved using the metamaterial absorber, which has an absorption of about 98% at 2.1 GHz. Overall, the proposed antenna has a gain of over 7 dBi, a Voltage Standing Wave Ratio (VSWR) of less than 2, more than 85 dB of isolation between the service and donor antennas over the WCDMA band and a total volume of the proposed antenna only 70 mm × 70 mm × 43.8 mm.

Keywords: Absorber, Antenna, Isolation enhancement, Metamaterial, WCDMA indoor repeater

1. Introduction

WCDMA indoor repeater is a widely used and cost effective solution for extending service coverage to shadow areas, which have low signal levels in wireless communication. In general, a WCDMA indoor repeater consists of a service antenna and donor antenna that operate at the same frequency. Thus, the characteristic of isolation between these two antennas is important for avoiding self-oscillation of the repeater system. Indeed, improvement of this isolation constitutes one of the major considerations in the design of repeater antennas [1]. The simplest method to improve the isolation between the service and donor antennas is to increase the physical distance between them [2, 3]. However, this is not a recommended alternative as the physical size of the device is limited by practical considerations. Another option to reduce the mutual coupling between antennas is to use additional slit patterns or coupling elements; however, this requires almost complete redesign of a conventional repeater antenna system [4]. For high isolation, the two linearly polarized antennas are aligned along orthogonal (vertical and horizontal) directions to each co-polarized component and are positioned at the center of each reflector. However, although the two antennas are aligned along orthogonal polarizations, the surface waves on the walls of the reflectors can cause cross-polarization, which will lead to unwanted mutual coupling between the antennas. To solve this problem, several types of high impedance surfaces (HISs) have been presented [5]. A frequency selective surface (FSS) has also been proposed for high isolation. However, it has a complicated structure that must be mounted on the indoor repeater antennas. Indeed, several such methods supported by experimental and simulation results have been suggested [6, 7]; however, all have drawbacks such as increased wall size. Metamaterials are artificial effectively homogeneous electromagnetic structures composed of metals and dielectrics. The initial impetus driving meta-material research was the realization of effective negative permittivity, permeability and refractive index [8-10]. The radar absorbing material structure with a mushroom-like HIS and a chip resistor is proposed [11, 12]. This structure with a chip resistor is able to provide an absorbing performance and a suppressing surface waves among all transverse fields on the ground surface. However, when this structure is applied to the indoor repeater antenna, it is difficult to maintain the peak gain owing to the degradation of a radiation pattern. The defected ground structure is presented to improve the isolation between a pair of closely packed Planar Inverted-F Antennas (PIFAs), patches, and monopole antennas on the common ground plane [4, 13, 14]. This structure can obtain a band-stop effect due to the combination of an inductance and a capacitance, so that it applies to antenna designs to suppress the harmonics and the cross-polarizations. However, it is required to redesign the ground plane for conventional indoor repeaters because this structure is etched onto the single ground plane. Alternately, resonant absorbers based on the meta-material structure have attracted much attention for high isolation with a small device volume [15, 16].

This paper proposes a WCDMA indoor repeater antenna employing an absorber based on the metamaterial structure to improve the isolation between the service and donor antennas. The metamaterial absorber is composed of square rings with eight arrow shaped arms on the top surface and an etched circle on the bottom surface. High isolation is

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achieved using the metamaterial absorber, which has absorption of about 98% at 2.1 GHz.

2. Metamaterial Absorber

The proposed absorber based on the metamaterial structure, as shown in Fig. 1, consists of square rings with eight arrow shaped arms on the top surface and a circle etched on the bottom surface. It was printed on a FR-4 (ε_r = 4.4) substrate with a thickness of 1.2 mm. The unit cell of the proposed absorber has a volume of 12 mm × 12 mm × 1.2 mm. Perfect magnetic conductor (PMC) boundary conditions were set on the left and right faces of the box, and perfect electric conductor (PEC) boundary conditions were set on the top and bottom faces of the box, respectively. In addition, a wave ports were set on the front and back faces of the box.

From the simulation, absorption *A*, reflection *R*, and transmission *T* characteristics of the proposed absorber were obtained, which were calculated from the S-parameters as follows:

$$R = S_{11}^2, \quad T = S_{21}^2, \quad A = 1 - R - T. \tag{1}$$

On the top plane, the squares and arrow-shaped arms have line widths of 0.325 mm (thin-line) and 0.65 mm (thick-line). Moreover, on the bottom plane, the radius of the etched circle is 2.45 mm.

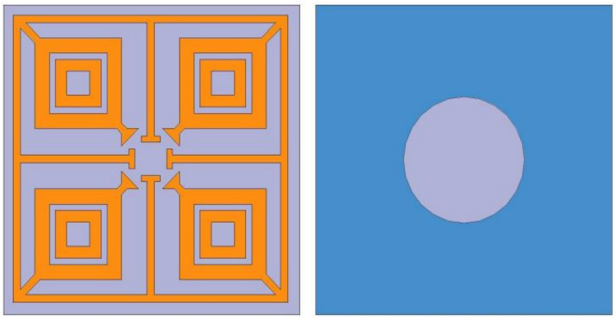

Fig. 1. Configuration of metamaterial absorber

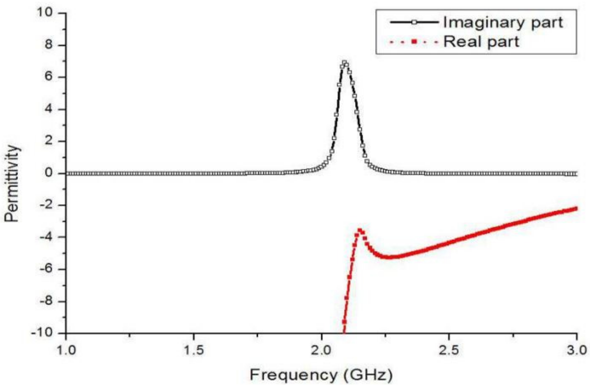

Fig. 2. Retrieved effective permittivity of absorber

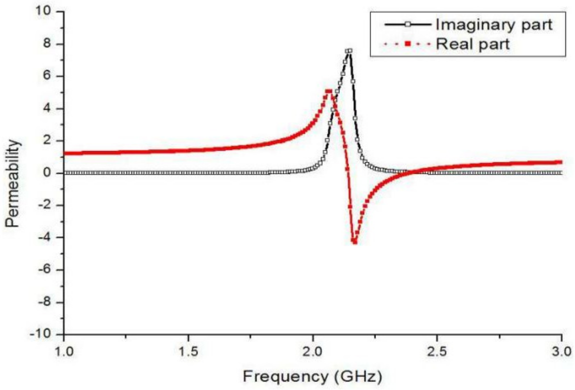

Fig. 3. Retrieved effective permeability of absorber

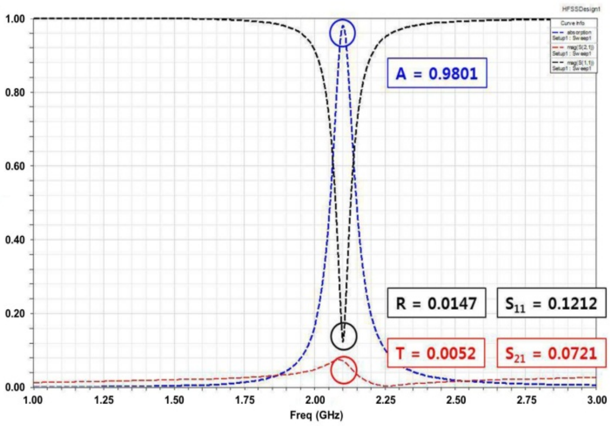

Fig. 4. Simulated result for the proposed absorber

We can calculate the effective permittivity and permeability from the S-parameters as follows [17]:

$$n = \frac{1}{kd} cos^{-1} \left| \frac{1}{2S_{21}} \left(1 - S_{11}^2 + S_{21}^2\right) \right| \tag{2}$$

$$z = \sqrt{\frac{(1+S_{11})^2 - S_{21}^2}{(1-S_{11})^2 - S_{21}^2}}, \quad \varepsilon = \frac{n}{z}, \quad \mu = n \cdot z \tag{3}$$

Figs. 2 and 3 show the retrieved parameters. As shown in these figures, the real parts of the effective permittivity and permeability of the metamaterial absorber possesses negative. And their imaginary parts have a maximum value. The value of effective permittivity is about -4.2+j7.1, and the value of effective permeability is -2.1+j7.8. Therefore, in this frequency region, the proposed absorber acts as a metamaterial.

Overall, the metamaterial absorber has absorption of about 98%, reflection of 1.4%, and transmission of 0.5% at 2.1 GHz, as shown Fig. 4.

3. Proposed WCDMA Indoor Repeater Antenna

A seen from the top view in Fig. 5, the proposed antenna

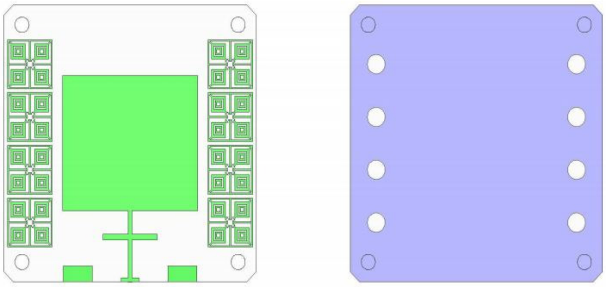

Fig. 5. Configuration of antenna: top view, bottom view

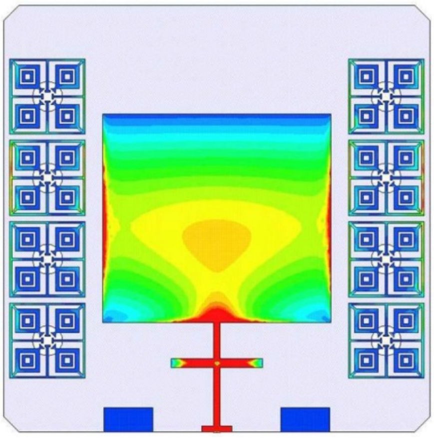

Fig. 6. Current distribution of main patch

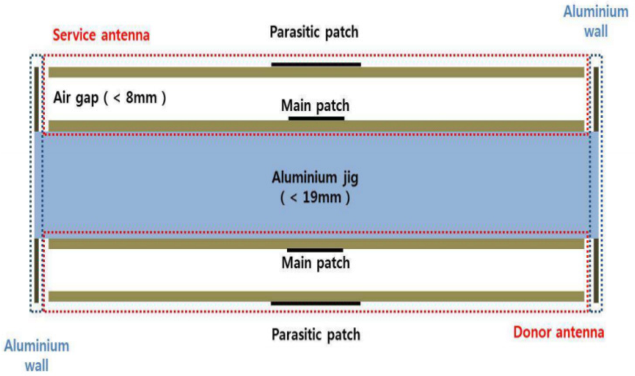

Fig. 7. Configuration of proposed WCDMA indoor repeater

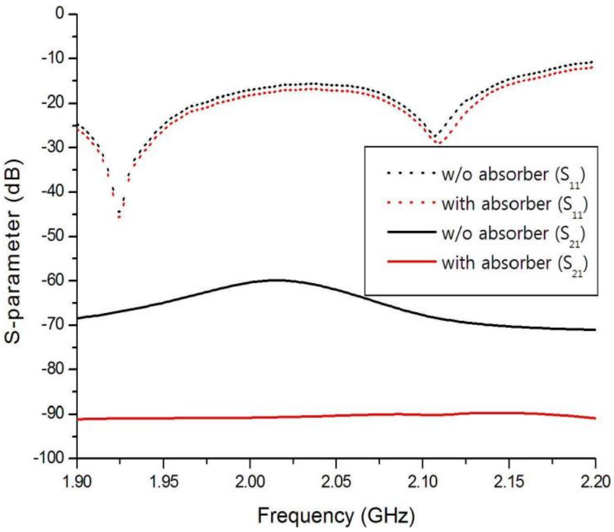

Fig. 8. Simulated results for proposed antenna

consists of the main patch and the metamaterial based absorber on the top plane. And, bottom plane consists of a ground and the metamaterial absorber (etched circle).

The current distribution of proposed antenna is shown in Fig. 6. The leakage currents of main patch affect the isolation between the service and the donor antennas. The absorber based on the metamaterial structure is located in side of main patch. As shown Fig. 6, leakage current is absorbed to the metamaterial absorber. Therefore, the isolation between the service and donor antennas is improved by metamaterial absorber. For high isolation, the service and donor antennas are mounted perpendicular to each other on the opposite sides of the aluminum jig, which has a thickness of 19 mm. The overall WCDMA indoor repeater configuration in Fig. 7, shows that each antenna consists of a ground plane, main patch, parasitic patch, metamaterial absorber, and aluminum jig. The two FR-4 substrates have a different thickness (main: 1.2 mm, parasitic: 3.2 mm). The ground plane is printed on the bottom of the FR-4 substrate of the main patch. The main patch and metamaterial absorber are placed on the top of the same substrate. The dimensions of the main patch are 37.5 mm × 34.2 mm and those of the proposed absorber are 12 mm × 12 mm, respectively. The proposed absorber is located in-side the main patch on the FR-4 substrate. The parasitic patch, which is printed on the top of the FR-4 substrate, has dimensions 41.2 mm × 38.2 mm and is supported by plastic stub that keeps it 8 mm above the main patch. The required bandwidth can be obtained by controlling the distance between the service and donor antennas. The overall size of the proposed antenna is 70 mm × 70 mm × 43.8 mm.

As shown in the comparison in Fig. 8, the proposed antenna (red line) has almost the same characteristic of reflection response and VSWR as a conventional antenna (black line). However, the characteristic of isolation between the service and donor antennas is approximately 20 dB greater by using the metamaterial absorber. The simulated VSWR bandwidth (< 2) of the designed antenna ranges from 1.92 GHz to 2.17 GHz.

4. Fabrication and Experiment of Antenna

The proposed antenna is shown in Fig. 9. It consists of main patch and metamaterial absorber. Fig. 10 show the measurement setup for proposed antenna by using network analyzer. The characteristic of isolation can be achieved

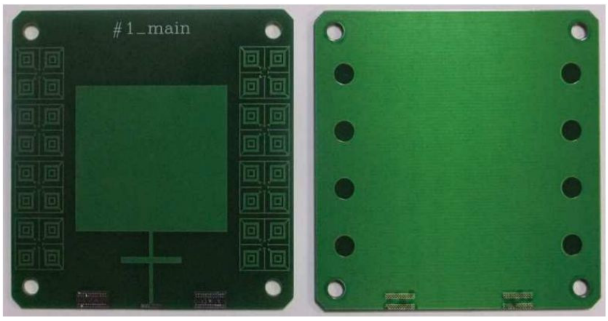

Fig. 9. Photograph of antenna: top view, bottom view

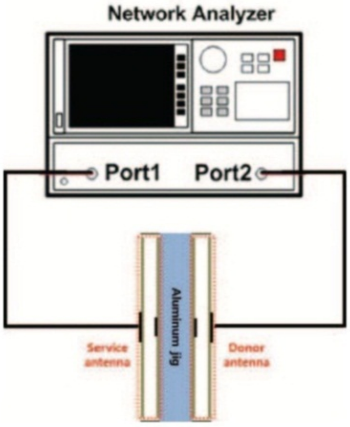

Fig. 10. Measurement setup using network analyzer

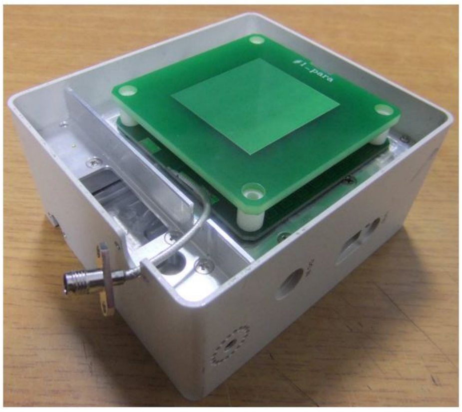

Fig. 11. Photograph of proposed repeater antenna

from the measured S_{21} value between service and donor antennas. The fabricated of proposed antenna is shown in Fig. 11. This antenna is designed to operate in the range of 1.92 GHz to 2.17 GHz. The main patch is fed by a 50Ω coaxial cable.

An experiment was also performed to verify our design. The return loss (S_{11}) and isolation (S_{21}) of the proposed repeater antenna were measured with the 8719D network analyzer, with results as shown in Fig. 12. The radiation patterns at each frequency are shown in Fig. 13. The gain of the proposed antenna was greater than 7 dBi, with only a single main patch. The half-power beam widths (HPBWs) of the service and donor antennas are about 70° at each frequency, respectively.

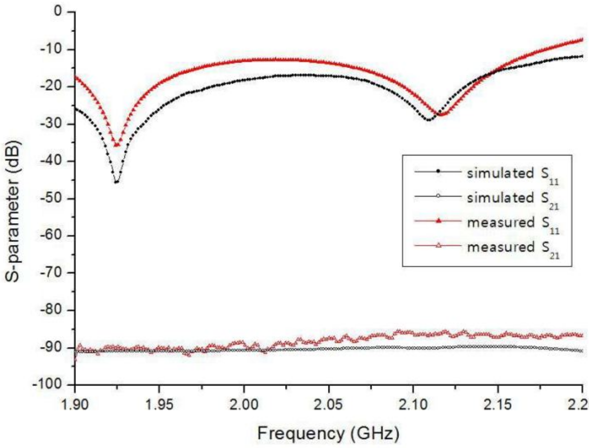

Fig. 12. Comparison result of proposed repeater antenna

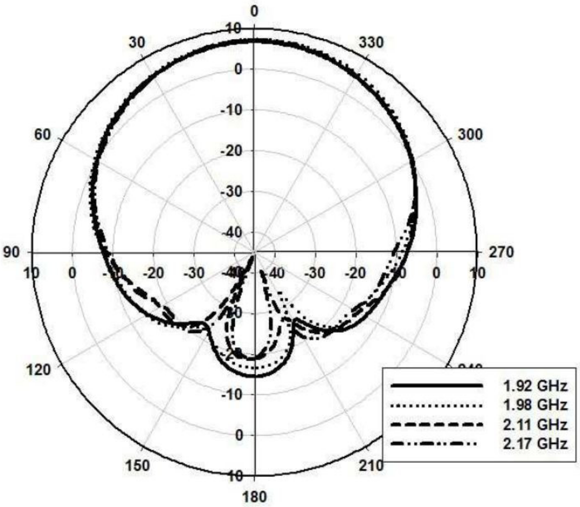

Fig. 13. Radiation pattern for proposed repeater antenna

5. Conclusion

This paper proposed a WCDMA indoor repeater antenna design with high isolation. The required WCDMA bandwidth was achieved by utilizing the electromagnetic coupling between the main and parasitic patches. Isolation between the service and donor antennas over the WCDMA band was improved by placing the two antennas perpendicular to each other and by using metamaterial absorbers based in-side the main patch. The proposed metamaterial absorber has absorption of about 98 % at 2.1 GHz. The gain of the proposed WCDMA indoor repeater antenna is greater than 7 dBi, with only a single main patch, and a volume of only 70 mm × 70 mm × 43.8 mm. The

HPBWs of the service and donor antennas are about 70° in the E-plane and H-plane, respectively. Although the distance between the service and donor antennas is close (19 mm), over 85 dB of isolation is attained over the WCDMA band.

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