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Design of Two-port MIMO Antennas without Space for Isolation

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Abstract

We propose a structure for a multiple input multiple output antenna which has no space for isolation. The antenna operates in a frequency range of 2.4-2.48 GHz and can achieve a high channel capability as a Bluetooth antenna. The MIMO antenna consists of two planar inverted F antennas with symmetric structure. We designed the proposed antenna using HFSS simulator, and we designed the fabricated antenna using PCB fabricator. The MIMO antenna's isolation S_{21} ≤ -10 dB and reflection coefficient S_{11} ≤ -20 dB. The proposed antenna's specification satisfies Bluetooth antenna's criteria and has more space than the existing MIMO antennas, which have space for isolation.

Key words : MIMO, PIFA, Bluetooth antenna, HFSS, meander line

1. INTRODUCTION

Multiple input multiple output (MIMO) antennas are widely used to achieve diversity and to mitigate the effects of multipath fading [1]. MIMO systems have much higher channel capacity than conventional single input single output (SISO) and single input multiple output (SIMO) systems. MIMO systems employ multiple antennas for the transmission and reception of the signals [2]. The channel capacity in the communication system is bounded by the Shannon's theoretical channel capacity [3]. According to the theorem, the upper bound on the channel capacity *C*, with no bit error rate is given by

$$C = B\log\left(1+\frac{S}{N}\right), \qquad (1)$$

where *B* is the bandwidth, *S* is the signal power over an analog communication channel, *N* is the power of additive white Gaussian noise (AWGN), and *S/N* is the signal to noise ratio (*SNR*). Theoretically channel capacity can be increased by increasing *SNR* or *B*. Increasing *SNR* is difficult because of the inherently noisy nature of the communication channel; but transmission power increases with *B*. MIMO systems are used to overcome this problem of increasing the channel capacity.

The channel capacity of MIMO systems depends on cross-correlation coefficients among signals received by different antenna elements. Thus, to increase the system capacity in MIMO antenna design, an important objective is to minimize the correlation coefficient among antenna elements. Conventionally, the correlation coefficient can be reduced by increasing the distances between antenna elements. However, installing several antenna elements is difficult in the limited space available in mobile handsets. Therefore, having a design strategy is indispensible to find appropriate positions on a handset for installing antenna elements in such a way that the system capacity is maximized.

Many design strategies have been proposed for diminishing the mutual couplings of antennas, such as decoupling networks [3], specific ground structures [4]-[5], the neutralization technique [6], electromagnetic band gap (EBG) filters [7] and coupling elements [8]. Most of this research on planar MIMO antenna structures focused on the isolation improvement for two-element systems.

The objective of this paper is to present a MIMO antenna design that does not use space for isolation. The MIMO antenna consists of two planar inverted F antennas (PIFA) for

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Bluetooth(2.40-2.48 GHz). The antenna's goal specifications are: return loss RL > -10 dB, isolation S_{12} < -10 dB, maximum gain G > 0 dBi, omnidirectional radiation pattern, linear polarization and radiation efficiency e_r > 50%.

2. MATERIALS AND METHODS

Our design starts with a Printed inverted F antenna (PIFA) which resonates on a single frequency. We employ a J-shaped slot[9] which divides the original PIFA into two parallel PIFAs. Using these methods, we designed a new two-port MIMO antenna with 2.45 GHz center frequency.

A. Proposed Antenna

We designed the MIMO antenna (Fig. 3) using simulator (Ansoft corp. HFSS Ver 11.0). To strengthen isolation, we considered four factors. The first factor was distance between two PIFA antennas. By sweeping the distance parameter, we found that optimal distance d is 34 mm (about 1/4 wavelength). The second factor was feeding location. Because feeding location affects the antenna's length, radiation properties, center frequency, isolation and bandwidth, we simulated repeatedly up to the goal specification. The third factor is ground shape such as the slot in [9]. Many isolation methods using ground slots have been suggested [3]-[8] but we didn't use this method, because the isolation effect is very small in our PIFA antenna. The fourth factor was E-field distribution of PIFA antennas. The PIFA antennas have reverse shafe to avoid electric field coupling. So this fourth factor is the most important design object.

Simulated materials were as follows. Conducting materials (ground plane and antenna conducting parts) were copper, the ground substrate was FR4 with 1.6-mm height and the space material was air. We analyzed simulation results using S-parameters (Fig. 4, 7).

B. Fabricated Antenna

After simulation design, we fabricated this MIMO Antenna. First we laid out the simulated design using AutoCAD 2008 software and PCAM software. Second we fabricated antenna parts using a PCB fabrication machine. Third we assembled the parts into a MIMO antenna. Then we measured S-parameters of the fabricated antenna using Network Analyzer (NA). We calibrated NA using the Calibration Set 85052D kit. Because the result was slightly different than simulated, we tuned the antenna using copper tape. To measure radiation properties (such as gain, directivity, radiation efficiency), we used a total reflection chamber room.

3. RESULTS

A. Proposed Antenna

The proposed antenna was designed using the PIFA antenna frequency equation (2), the deleted ground structure (Fig. 1) and the slit-meander method ((3), Fig. 2).

$$f_r = \begin{cases} rf_1 + (1-r)f_2 & \text{for } k \le 1 \\ r^k f_1 + (1-r^k)f_2 & \text{for } k > 1 \end{cases}, \quad (2)$$

Where f_r = the resonance frequency, $f_1 = c/\{4(L_p+h)\}$, $f_2 = c/\{4(W_p+L_p+h-w)\}$, $r = w/W_p$, $k = W_p/L_p$, w = the width of ground, h = the height between ground and patch, L_p = the length of patch, W_p = the width of patch, and c = the speed of light (in a vacuum).

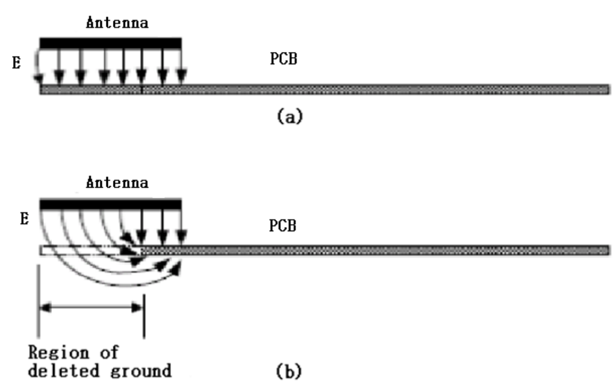

Fig. 1. PIFA antenna using deleted ground. PCB: printed circuit board; E: electric field; arrows: direction of electric field flux.

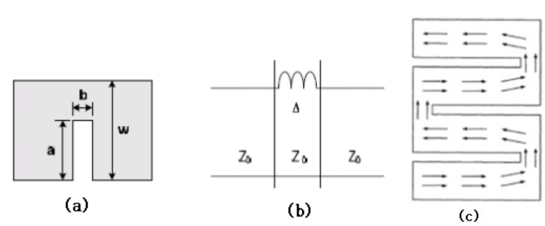

Fig. 2. Transmission Line (a), equivalent model (b), meander structure (c) using slit. a is the branch length, b is the distance between two branches, w is the width of plane.

If we cut a slit into the transmission line (Fig. 2), inductive loading will occur. Then electrical length becomes long. Therefore we can miniaturize the antenna and calculate this inductive load Δl (3).

$$\Delta l = \frac{\mu_0 \cdot \pi \cdot h}{2} \times \left(1 - \frac{Z_0}{Z_0'} \sqrt{\frac{\varepsilon_{reff}}{\varepsilon_{eff}}} \right), \qquad (3)$$

Where μ_0 = permeability of free space, h = the thickness of the substrate, Z_0 = the characteristic impedance of line when line width is w, $Z_0{}'$ = the characteristic impedance of line when line width is $(w - a)$, ε_{reff} = effective relative permittivity, and ε_{eff} = effective permittivity of free space.

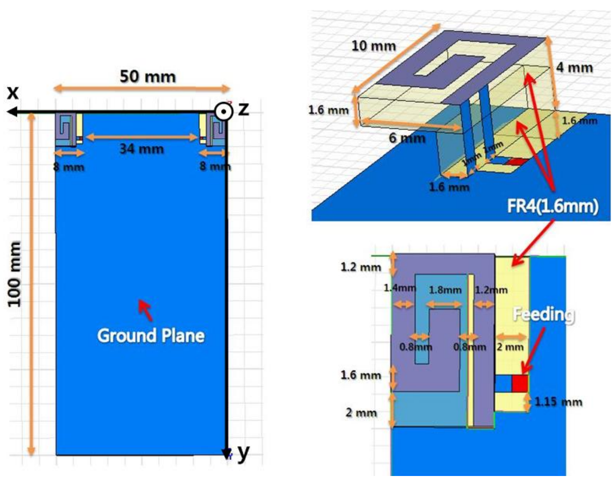

Fig. 3. Geometry of the proposed antenna with 1.6 mm FR4.

The ground size of the antenna (50 mm x 100 mm) is similar to that of a mobile phone (Fig. 3). The distance between two PIFA antennas affects the isolation property (S_{12} or S_{21}). To obtain good isolation and small size, the optimized distance was 34 mm.

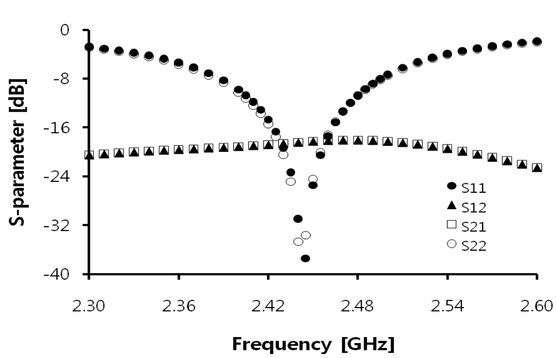

Fig. 4. S-parameter vs. Frequency of the proposed antenna.

Both S_{11} and S_{22} are radiation (or reflection) properties, but both S_{12} and S_{21} are isolation (or transmission) properties. Both S_{11} and S_{22} were minimal at 2.44 GHz; both S_{12} and S_{21} < -15 dB (Fig. 4), so this proposed antenna´s S-parameter properties satisfied the goal specification.

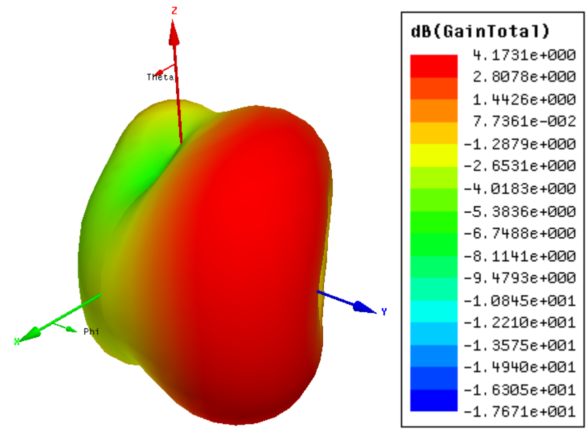

Fig. 5. 3D radiation pattern of the proposed antenna. XY-plane is the ground plane, Z-axis is the normal vector direction of the patch antenna plane and the ground plane.

The proposed antenna´s gain was between -18.7 dB and 4 dB, and its radiation pattern was omnidirectional (Fig. 5), so the proposed antenna radiation pattern and gain satisfied the goal specification (maximum gain $G > 0$ dBi, omnidirectional radiation pattern).

B. Fabricated antenna

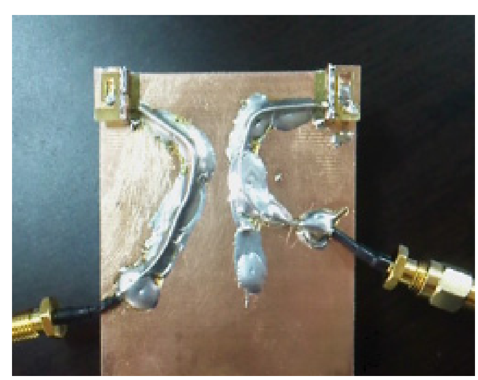

Fig. 6. The fabricated antenna

The proposed antenna and the fabricated antenna (Fig. 6) had a similar resonant frequency (Fig. 7). S_{12} is different from S_{21} in the fabricated antenna, because feeding lines are less symmetric than the proposed antenna.

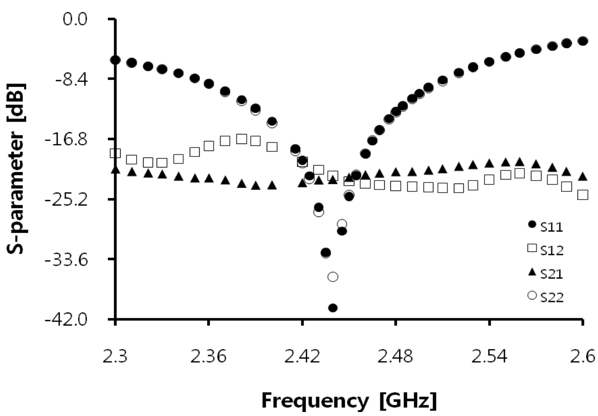

Fig. 7. S-parameter vs. Frequency of the fabricated antenna.

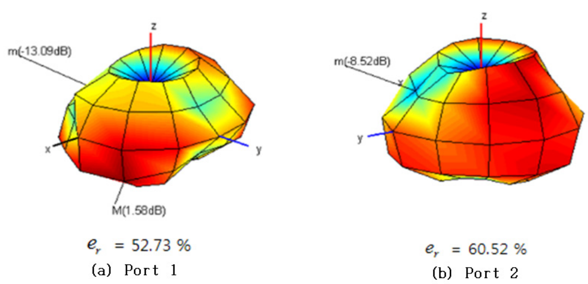

Fig. 8. 3D radiation pattern of the fabricated antenna. XY-plane is ground plane, Z-axis is normal vector direction of patch plane and ground plane. Radiation efficiency : port 1: e_r = 52.73 %; port 2: e_r = 60.52 %. M: maximum beam; m: minimum beam.

4. DISCUSSION

Orientation a MIMO antenna can be isolated from other antennas by using isolation methods such as a slotted ground, or a band-stop filter, but S_{12} and S_{21} can be reduced by altering the PIFA antenna shape without using such methods. So we designed the MIMO antenna without using any special isolation method. In our new designed MIMO antenna, having no space for isolation is the most important property, so the antenna has more space than the existing MIMO antennas (which have space for isolation).

The distance between shorting pin and feeding pin affected the antenna length, resonance frequency and circle radius in a Smith chart. Increasing the distance between shorting pin and feeding pin increased the circle radius of Smith chart. Because this means that the distance was one of the most important factors in the antenna design, we could not ignore the distance.

Using a meander type patch, we designed a small antenna. The meander type's principal is as follows. Inserting a slit in the transmission line causes inductive loading, so electrical length is fixed and physical length is short. Therefore we can miniaturize the antenna and calculate this inductive load Δl (3).

The ground size (50 mm x 100 mm) is similar to that of a mobile phone. The distance between two PIFA antennas affects isolation property (S_{12} or S_{21}). To obtain good isolation and small size, the optimized distance was 34 mm.

Both S_{11} and S_{22} are radiation (or reflection) properties, but both S_{12} and S_{21} are isolation (or transmission) properties. Both S_{11} and S_{22} were smallest at 2.44-GHz, and both S_{12} and S_{21} < -15 dB, so this proposed antenna's S-parameter properties satisfied the goal specification.

The proposed antenna gain was -18.7 dB ≤ G ≤ 4 dB, and its radiation pattern was omnidirectional, so both of these characteristics satisfied the goal specification.

The processes of tuning, soldering or attaching copper tape caused center frequency to change. While we fabricated the antenna, we considered these factors to fit the resonance frequency to goal frequency in a step-by-step process.

The proposed antenna and the fabricated antenna had a similar resonant frequency but the fabricated antenna's S_{11} and S_{22} were lower than the proposed antenna's S_{11} and S_{22}, so the fabricated antenna radiates better than the proposed antenna.

The gain and radiation pattern of the fabricated antenna were similar to those of proposed antenna. The radiation efficiency e_r was higher at port 2 than at port 1. This means that we fabricated port 2 better than port 1, so we can modify the radiation efficiency difference between port 1 and port 2 using accurate fabrication.

5. CONCLUSION

We designed a new Multiple-Input and Multiple-Output (MIMO) antenna for Bluetooth antenna. We designed this antenna using two Planar Inverted F Antennas (PIFAs) and a symmetric ground plane. Therefore we started by designing one PIFA antenna at 2.44-GHz center frequency. Then we made a two-port MIMO antenna symmetric structure in a mirror image form using two PIFA antennas. To isolate each of the PIFA antennas, we considered the ground width, feeding position and reverse shape to avoid coupling of electric field distribution. To design, we used HFSS simulator software, then simulated our antenna design repeatedly up to the goal specification. After the design was completed, we fabricated the antenna and measured it using the Network Analyzer. Because the result was slightly different than expected, we tuned it using copper tape. The completed MIMO antenna's gain, isolation, radiation pattern, polarization, return loss, radiation efficiency, center frequency and bandwidth were satisfactory. This paper is valuable as more practical space use than any existing MIMO antenna designs.

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