工學碩士 學位論文

# *A Study on Mutual Coupling Suppression for MIMO Antenna Array*

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# *Contents*

Abstract

Wireless communication is rapidly becoming the most popular solution to deliver voice and data services due to flexibility and mobility that can be offered at moderate infrastructure costs. Unfortunately, current wireless systems are unable to support some services offered by wire line systems due to the limited data rates achievable over wireless links. At the same time, there is a growing demand from the operators for better coverage to reduce infrastructure costs and enhance the wireless experience of the customers. One of the most promising solutions to overcome these issues is multiple-input multiple-output (MIMO) technology.

A Multiple-input multiple-output (MIMO) Antenna system is a well-known technique to enhance the performance of wireless communication systems. The channel capacity that a MIMO antenna system provides is much larger than that provided by the conventional wireless system.

The MIMO wireless technology uses multiple antennas at the transmitter and receiver to produce significant capacity gains over single-input single-output (SISO) systems using the same bandwidth and transmit power. It has been shown that the capacity of a MIMO system increases linearly with the number of antennas in the presence of a scattering-rich environment.

In spite of this advantage, the MIMO antenna system has many practical problems because the signal processing techniques do not consider the degradation of the correlation coefficients due

to the coupling between antenna elements. Many researchers try to resolve the problem system-wise, or by using baseband algorithms and signal processing techniques. Therefore, to solve this problem and to operate the MIMO antenna system with properly, the characteristics of the MIMO antenna in real environment must be considered when developing processing algorithms. To implement a MIMO antenna system in real MIMO environment, we must consider the mutual coupling between MIMO antenna elements. Suppressing the coupling between antenna elements is an important problem in MIMO or multiple antenna systems because the coupling between the antenna elements influences the correlation coefficient in free space significantly.

This thesis describes several design techniques for MIMO antenna system having low mutual coupling between each antenna element. Two examples of the proposed models employed parasitic elements for mutual coupling suppression; they show strong possibility of mutual coupling suppression between patch antenna elements to realize an independent channel for MIMO antenna system. It is proposed a compact 2-channel WiBro-MIMO antenna for the practical handy terminal. It is employed the projected (凸) ground structure for isolation between two antenna elements and it suppressed both of the mutual coupling and the radiation coupling. In addition, for the MIMO application, a ultra small and ultra wideband antenna having a novel antenna input impedance matching structure is proposed in this thesis.

The MIMO antenna design techniques proposed in this thesis are shown very low mutual coupling and very good antenna characteristics such as radiation pattern, antenna gain, resonable antenna size, etc.. Due to the these merits of the proposed design techniques, it is expected the proposed design techniques could be applied in the wireless communication system which is employed in MIMO system.

# *Chapter 1. Introduction*

In recent years, there have been many studies on the multi-input multi-output (MIMO) antenna system for the application of mobile communication and W-LAN system, etc., Because the MIMO antenna system is a suitable candidate for the 4th generation mobile communication requiring high speed, high quality transmission involving large amount of data transfer. To achieve this end, the use of multiple antennas at the transmitter-ends and receiver-ends has drawn attention of many researchers since the mid-1990's. The channel capacity that a MIMO antenna system provides is much larger than that provided by the conventional wireless system. Thus, the MIMO antenna system can significantly enhance the performance of the wireless communication system [1].

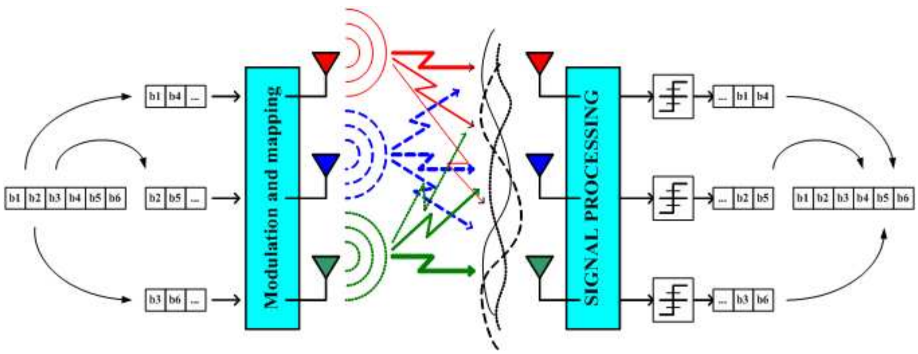



Fig. 1.1 A block diagram of the ideal MIMO system.

In spite of this advantage, the MIMO antenna system has many practical problems because the signal processing techniques do not consider the degradation of the correlation coefficients due to the coupling between antenna elements. Many researchers try to resolve the problem system-wise, or by using baseband algorithms and signal processing techniques [2]. Therefore, to solve this problem and to operate the MIMO antenna system with properly, the characteristics of the MIMO antenna in real environment must be considered when developing processing algorithms [3].

To implement a MIMO antenna system in real MIMO environment, the antenna system with multiple channels is required. Suppressing the coupling between antenna elements is an important problem in MIMO or multiple antenna systems because the coupling between the antenna elements influences the correlation coefficient in free space significantly[4],[5].

Pioneer researches on suppressing the mutual coupling between antenna elements include placing electric walls and electromagnetic absorber between antenna elements so that the phase difference between the elements is 180 degree [6] using isolation cards with a certain height between antenna elements [7] and encircling each element with metallic walls [8], which all use 3-dimensional structures to suppress the mutual coupling by separating the antenna elements to a half wavelength in electrical distance. However, because the above mentioned pioneer researches all include 3-dimensional structures, the sizes of the array antennas and the cost of manufacturing the antennas are significantly increased.

Thus, the research presented in this thesis is focused on suppressing the mutual coupling between antenna elements by using a 2-dimensional structure, and is focused on developing the small antennas that minimizes the coupling between antenna elements for use in MIMO antenna systems.

# *Chapter 2. Planar array of mutual coupling suppression*

## *2.1 4-CH antenna for narrow band*

### *2.1.1 Single element structure*

A miniature patch antenna which is proposed in this chapter is employed air substrate and gap feed with via hole for miniature size of the antenna and broad bandwidth. Commercial tools such as Ensemble V6 and HFSS V9 are used for antenna design. Fig. 2.1 shows the design structure and specification of a miniature patch antenna which is considered its current distribution[4]. The dielectric substrate used for antenna design is FR4($\varepsilon r$ = 4.4). The thickness of the FR4 is 1.6 mm. The size of the patch antenna at 5.25 GHz is 17.1 mm width and 14.5 mm length. The proposed patch antenna employs a coupled feeding method with 1 mm gap between feed and patch. The proposed patch antenna employs a 5 mm air substrate for broad bandwidth.

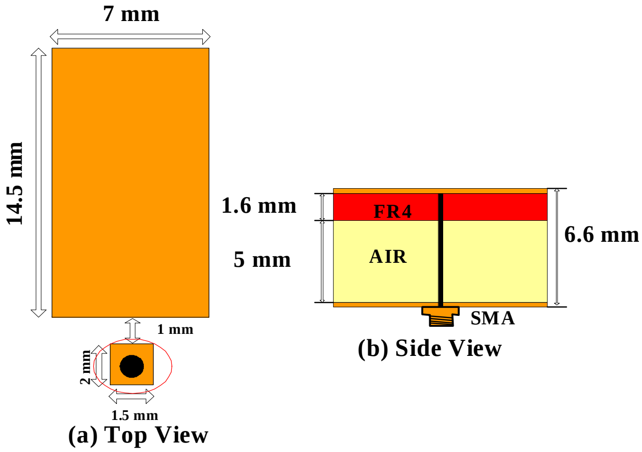



Fig. 2.1 Design structure and specification of a miniature patch antenna.

Fig. 2.2 shows a photograph of the fabricated miniature patch antenna. Fig. 2.3 and 2.4 show a measured reflection coefficients of the fabricated antenna and radiation patterns at 5.25 GHz, respectively. The measured bandwidth of the fabricated antenna is about 62 % at VSWR 2 and it observes reasonable agreement with prediction. The measured radiation patterns of the fabricated antenna are almost same comparing with simulation results at 5.25 GHz. Back lobes in measured result depend on the ground plane size.

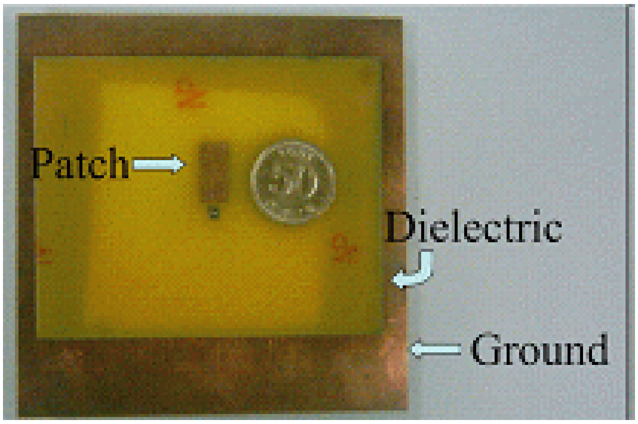



Fig. 2.2 Photograph of the fabricated antenna.

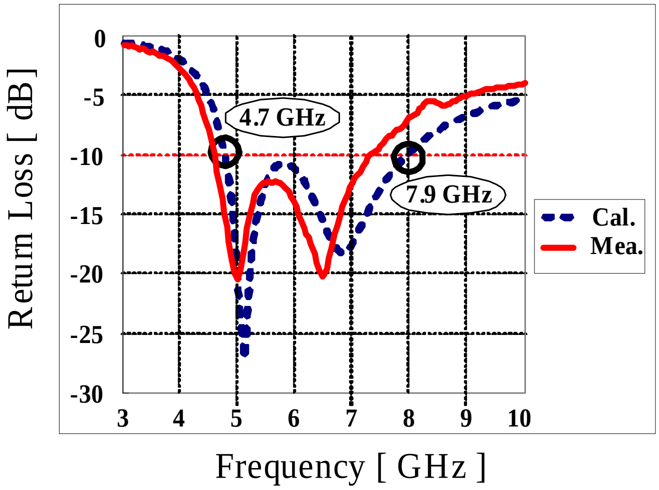



Fig. 2.3 Measured reflection coefficient of the antenna.

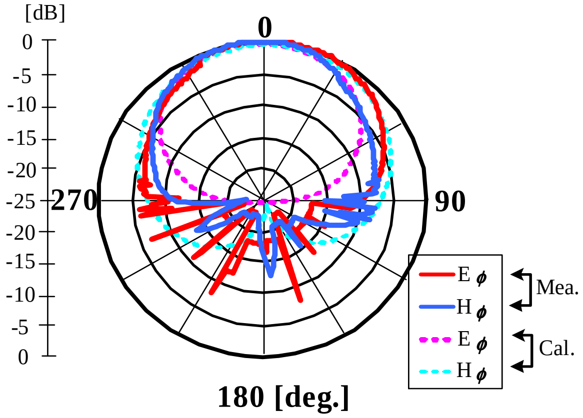



Fig. 2.4 Measured radiation patterns of the fabricated at 5.25 GHz.

### *2.1.2 4-channel antenna array*

Single antenna element proposed in chapter 2.1.1 is employed for array design. These antenna elements are arrayed with a half wavelength interval in both horizontal and vertical directions, respectively(Fig. 2.5). Fig. 2.6 and Fig. 2.7 show measured S-parameters and radiation patterns of the conventional 4-channel MIMO antenna, respectively. As shown in Fig. 2, each antenna element satisfies VSWR<2 for the W-LAN band, while the mutual couplings (S21, S31, S41) between the elements vary from -15 dB to -23 dB at 5.25 GHz.

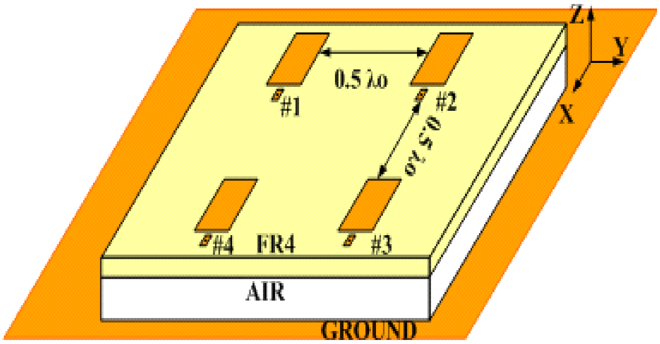



Fig. 2.5 Geometry of conventional 4-channel MIMO antenna.

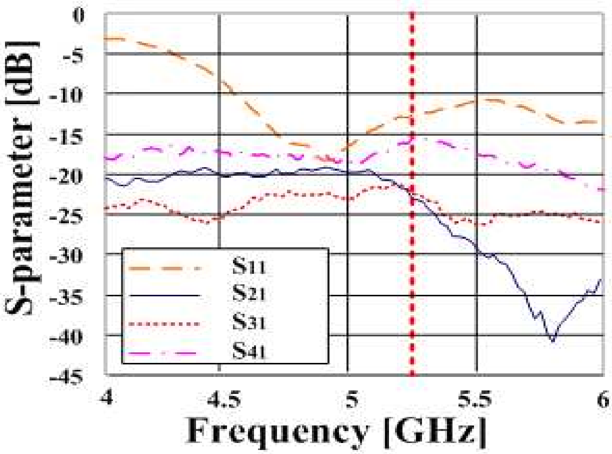
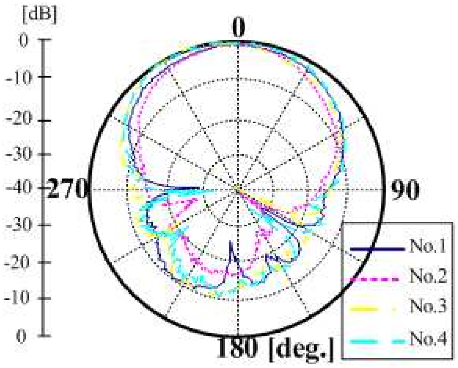
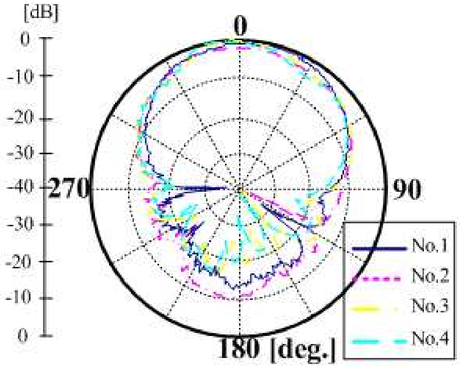



Fig. 2.6 Characteristics of conventional 4-channel array antenna: measured S-parameters




(a) E-pie




(b) E-theta

Fig. 2.7 Characteristics of conventional 4-channel array antenna: calculated radiation pattern.
(Epie indicates XZ-plane and Etheta indicates YZ-plane)

### *2.1.3 Mutual coupling suppression using parasitic elements*

To suppress mutual coupling between elements, parasitic elements of microstrip lines are considered[10]. These parasitic elements are used as resonant elements. Two parasitic microstrip lines having the length (L1) are employed between two horizontal antenna elements, and one parasitic microstrip line having the length (L2) as depicted in Fig.4.

As shown in Fig. 2.9(a) and 2.9(b), the mutual coupling changes with different number of parasitic elements and different lengths of parasitic elements. In Fig. 2.9(a), the mutual coupling values with two and three parasitic elements are lower than that with one parasitic element. Therefore, two parasitic elements are chosen to suppress the mutual coupling in this design. When two parasitic elements with length of 16.55 mm are positioned between the two antenna elements, the mutual coupling between two antenna elements is reduced below -40 dB at 5.25 GHz. Fig. 2.9(b) shows the amount of coupling with variation of a parasitic element length (L1). By changing its length, the resonance frequency is shifted and the amount of coupling is also changed. Therefore, the length of 16.55mm is adopted in design. For the case of antenna elements aligned in the vertical direction, a parasitic element in the same direction is employed to suppress mutual coupling.

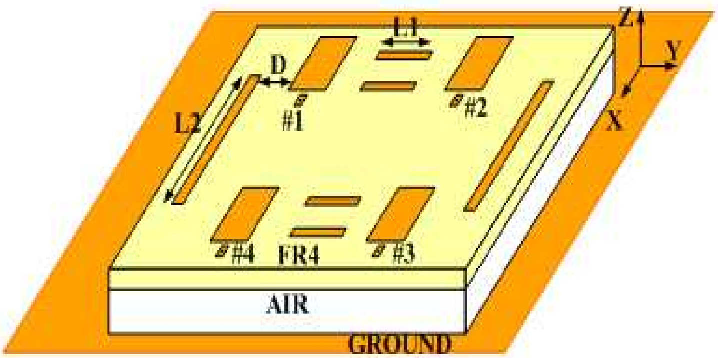
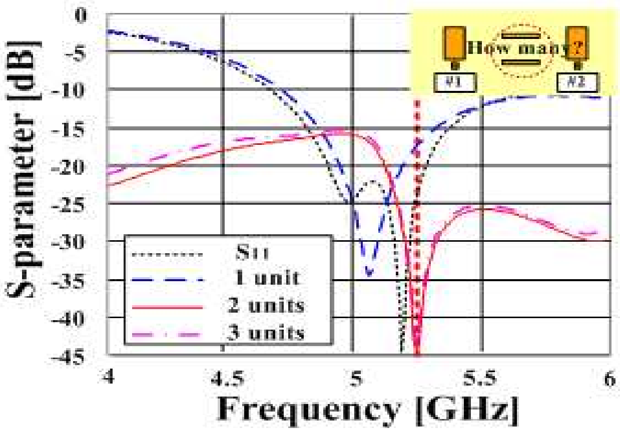
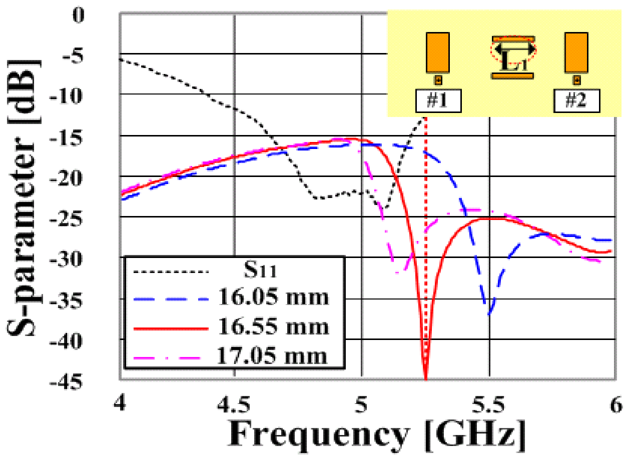



Fig. 2.8 Geometry of the proposed 4-channel planar patch array antenna (half lambda interval).




(a)

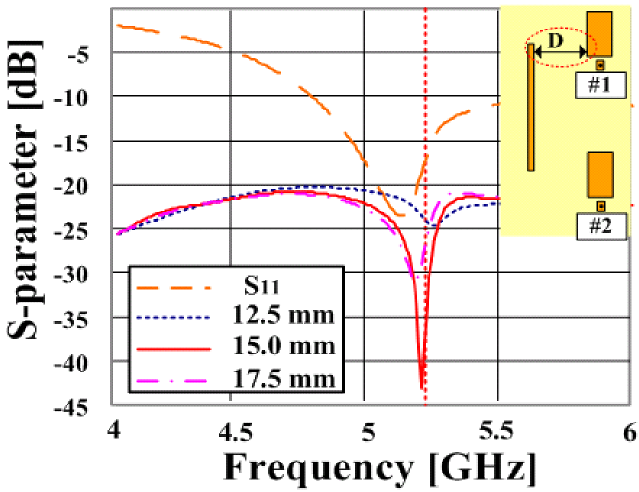



(b)

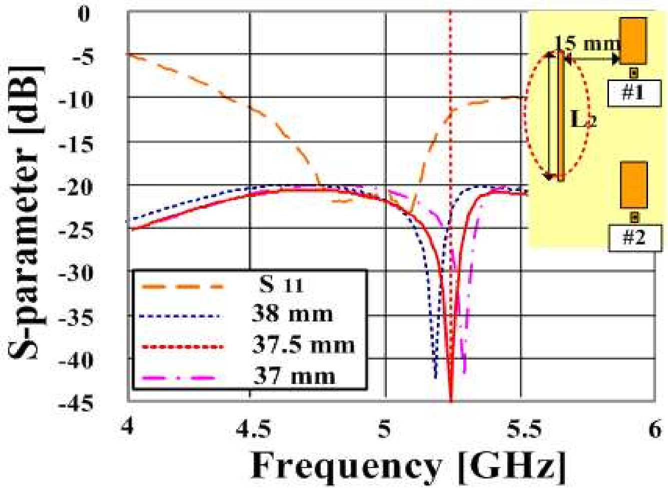
Fig. 2.9 Variation of S parameters with respect to:

(a) number of horizontal parasitic element,

(b) length (L1) of horizontal parasitic element.




(a)




(b)

Fig. 2.10 Variation of S parameters with respect to:
(a) distance (D) between antenna and vertical parasitic element,
(b) length (L2) of vertical parasitic element.

Fig. 2.10 shows similar behavior of the mutual coupling compared with the horizontal case. Thus, it is possible to control the mutual coupling using one parasitic element. Fig. 2.10(a) and 2.10(b) show variations of S-parameters according to the offset and the length of parasitic elements. The mutual coupling between antenna elements is changed according to the offset and the length of parasitic element, respectively. When a parasitic element with the length of 37.5 mm and the offset of 15 mm is placed between the two antenna elements, the mutual coupling is suppressed to about -40 dB at 5.25 GHz.

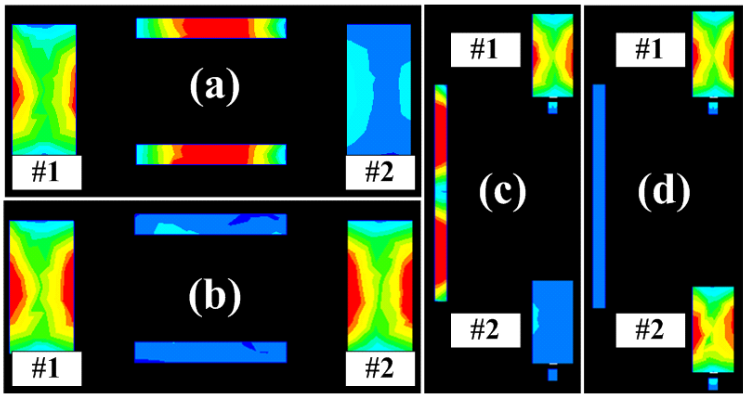



Fig. 2.11 Current distributions of antenna elements and parasitic elements.

Fig. 2.11 shows the current distributions of the proposed antenna with parasitic elements. As shown in Fig. 2.11(a), current flows on the antenna and the parasitic elements when only the element #1 is fed. In Fig. 2.11(b), it is shown that the interference currents are cancelled by the parasitic elements located on the horizontal direction when the elements #1 and #2 are fed simultaneously. The current distributions of the elements #1 and #2 are ideally mirror images of each other. Since the surface wave between the antenna elements #1 and #2 is cancelled by the horizontally located parasitic elements, the mutual coupling between two elements is strongly suppressed. In Fig. 2.11(c) and 2.11(d), the characteristics of the currents flowing on the antenna and the parasitic elements of the vertical array show similar phenomenon as the results in Fig. 2.11(a) and 2.11(b) for the vertically positioned parasitic elements.

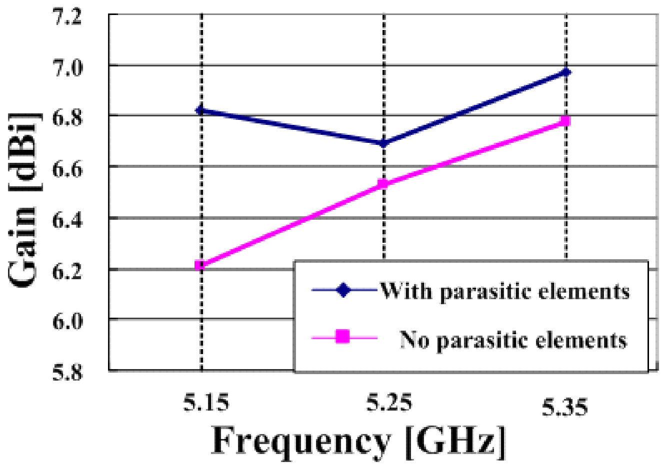



Fig. 2.12 Comparison of the calculated gain of the proposed antenna with the gain of the conventional antenna

In addition, these parasitic elements contribute not only to the improvement of the mutual coupling, but to the antenna gain as well. In Fig. 2.12, the simulated antenna gain of the proposed antenna with parasitic elements shows improvement by 0.6 dBi at 5.15GHz and by 0.2 dBi from 5.25GHz to 5.35GHz, compared with the antenna without parasitic elements.

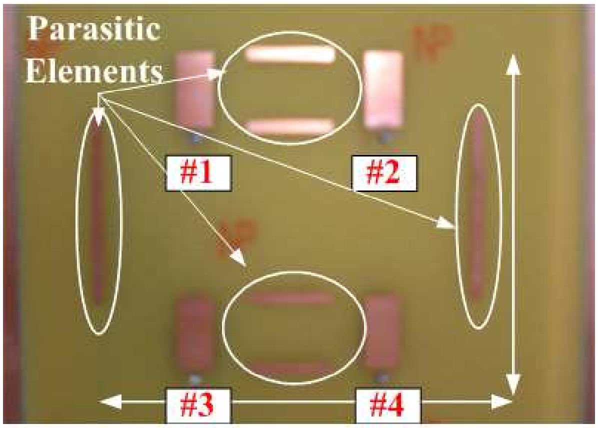
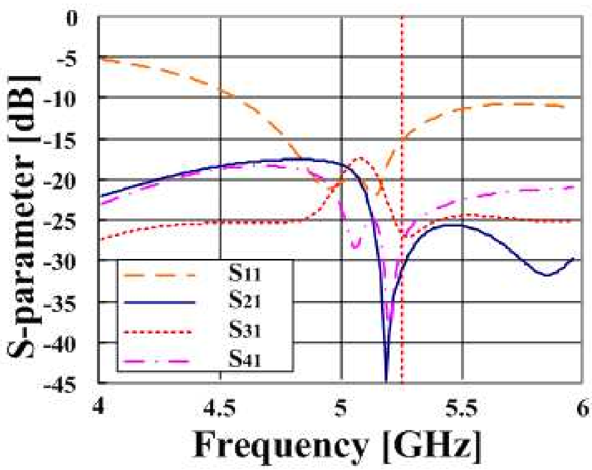
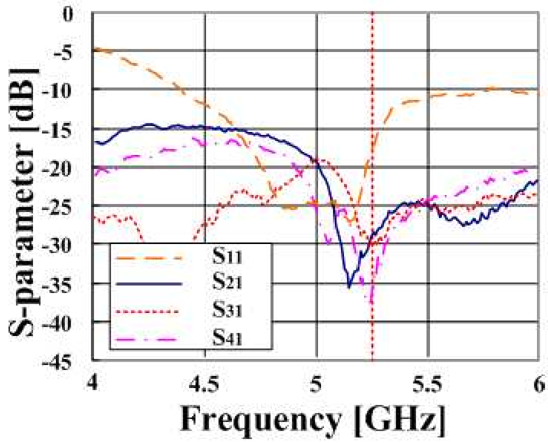



Fig. 2.13 Fabricated proposed 4-channel MIMO antenna.




(a)




(b)

Fig. 2.14 Variation of S parameters with respect to frequency (a) calculated S-parameters, (b) measured S-parameters.

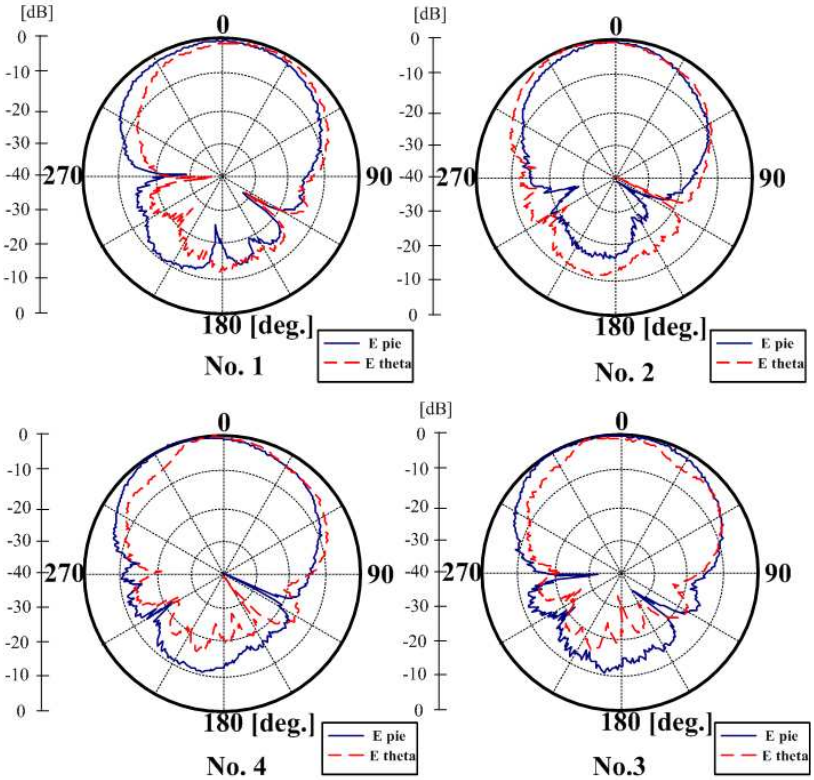



Fig. 2.15 Measured radiation pattern of the proposed 4-channel MIMO antenna: (Epie indicates XZ-plane and Etheta indicates YZ-plane)

Fig. 2.13 shows the photograph of the fabricated 4-channel MIMO antenna with suppression of mutual coupling using four parasitic elements. In Fig. 2.14(b), the measured S-parameters show reasonable agreement with the predicted values in Fig. 2.14(a). In addition, while the main beam patterns of E theta are tilted a bit to each other due to their mutual coupling in Fig. 2.7, the radiation patterns of E theta in Fig. 2.15 show pattern improvement that the main beams are located at 0 degree.

## *2.2 2-CH antenna for broad band*

### *2.2.1 Mutual coupling suppression using reversed 'U' structure*

In this section, a reversed 'U' structure with a via hole is considered for mutual coupling suppression between two antenna elements. Fig. 2.16 shows the 2-channel MIMO antenna with half wave length interval. In this case, the coupling between the elements is -18 ~ -20 dB over the frequency range between 5.25GHz and 5.8GHz.

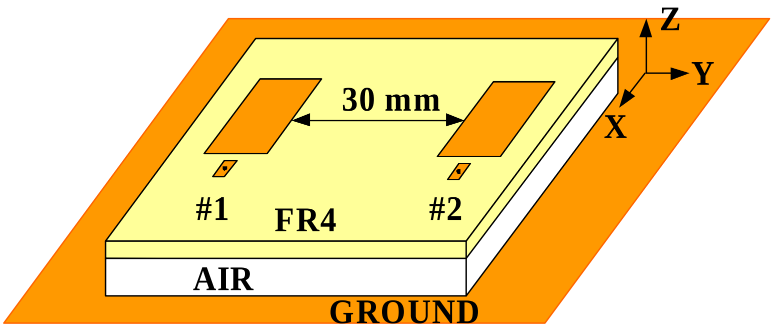
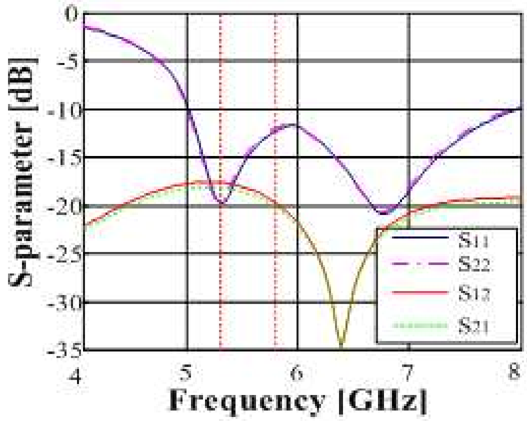
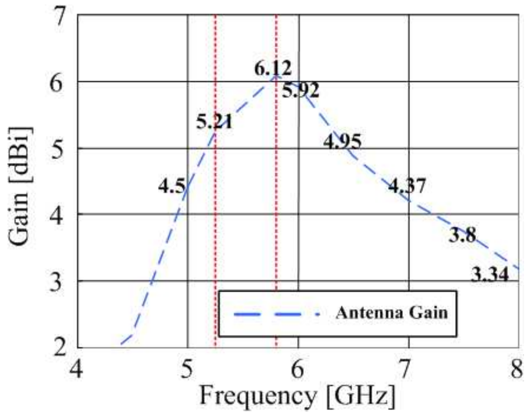



Fig. 2.16 Geometry of a conventional 2-channel conventional planar patch array antenna (half lambda interval).




(a)




(b)

Fig. 2.17 Characteristics of 2-channel planar array antenna: (a) calculated S parameters, (b) calculated gain of the each antenna element.

Figures 2.17(a) and 2.17(b) show the calculated S11and S21 of the planar array antennas and the gain of the single element as functions of frequency, respectively.

The diagram of the 2-channel planar array antenna structure proposed in this chapter to suppress the mutual coupling is presented in Fig. 2.18 The reversed 'U'-shape structure grounded by a via hole is placed to suppress the mutual coupling between the elements. The use of the reversed 'U'-shape microstrip line cancels the interference signals significantly, which otherwise cause the mutual coupling between elements.

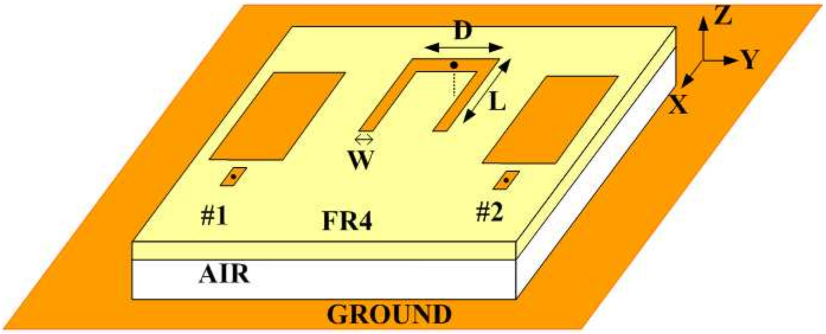
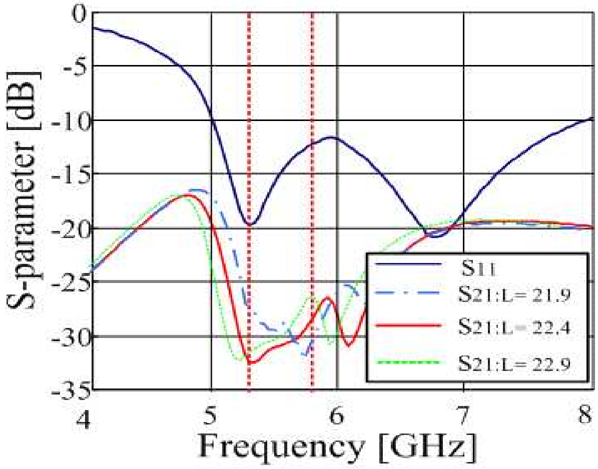
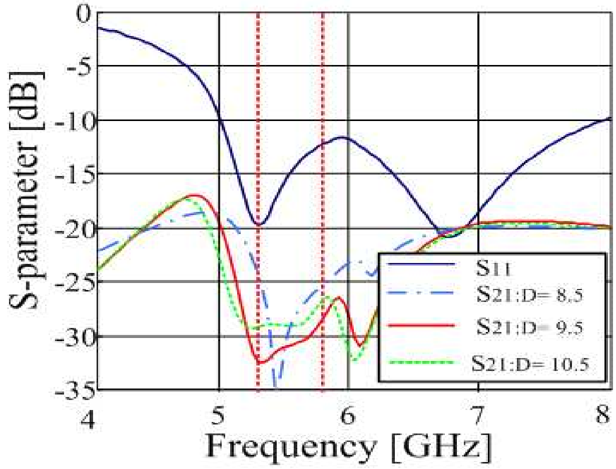



Fig. 2.18. Geometry of a conventional 2-channel planar patch array antenna (half lambda interval).

The reversed 'U'-shape structure proposed in this chapter has a total length of one wavelength. It effectively isolates the interference signals through a resonant phenomenon and guides them toward the ground plane through the via hole.


S-parameter [dB]
Frequency [GHz]
0
-5
-10
-15
-20
-25
-30
-35
4
5
6
7
8
S11
S21:L= 21.9
S21:L= 22.4
S21:L= 22.9

(a)


S-parameter [dB]
Frequency [GHz]
0
-5
-10
-15
-20
-25
-30
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4
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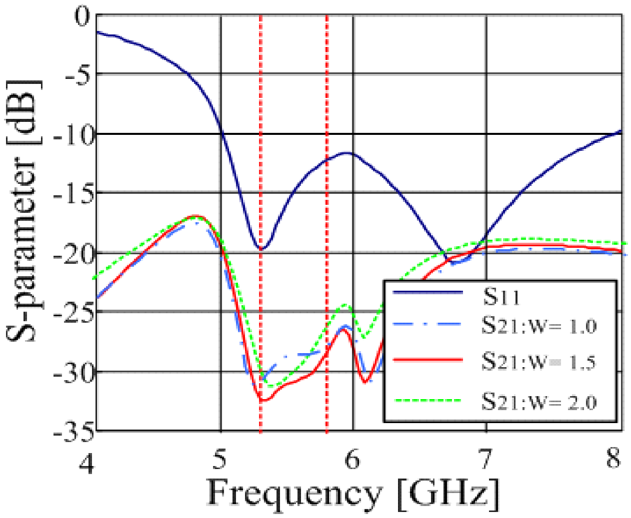
S11
S21:D= 8.5
S21:D= 9.5
S21:D= 10.5

(b)




(c)

Fig. 2.19 Variation of S parameters with respect to:

(a) a length (L) of the reversed 'U' structure,

(b) a width (D) of the reversed 'U' structure,

(c) a line width (W) of the reversed 'U' structure.

Figure 2.19(a)shows the variations of the mutual coupling according to the length (L) of the reversed 'U'-shape structure. Notice that, while the resonant frequency of the antenna is not varied, S21near the resonant frequency is lowered. This shows that, by properly adjusting the length L, not only the bandwidth requirement specified by the IEEE 802.11a standard is satisfied, but also the bandwidth where the mutual coupling is suppressed can be adjusted according to user demands. Figures 2.19(b) and 2.19(c) show the variations of S21 according to the width (D) and the width of the microstrip line (W) of the reversed 'U'-shape structure, respectively. As can be seen in Fig. 2.19(b), the width (D)has influences on the resonant frequency and the degree of the resonancy in S21, and results in the optimum value near 5GHz when D is 9.5mm. In addition, since the width of the microstrip line W determines the characteristic impedance, W has influence on the degree of the resonancy in S21. Figure 2.19(c) shows the calculated results when W is varied from 1mm to 2mm. The figure shows that the impedance of the reversed 'U'-shape structure varies and thus S21 varies as does the width W.

From the results shown above, the parameters that can effectively suppress mutual coupling over the entire bandwidth specified in IEEE 802.11a standard are given as L=22.4mm, D=9.5mm, and W=1.5mm. These values are determined through the process of optimizing the antenna characteristics with the parameters varied.

Figure 2.20 shows the current distributions of the conventional 2-channel planar array antenna and the 2-channel planar array antenna with the proposed reversed 'U'-shape structure. Fig. 2.20(a) shows a picture of current distributions when two antenna elements without a reversed 'U'-shape structure are fed simultaneously. In this case, the current distributions on the two antenna elements are identical, and the mutual coupling between the elements is approximately -18dB and -21dB near 5.25GHz and 5.8GHz, respectively.

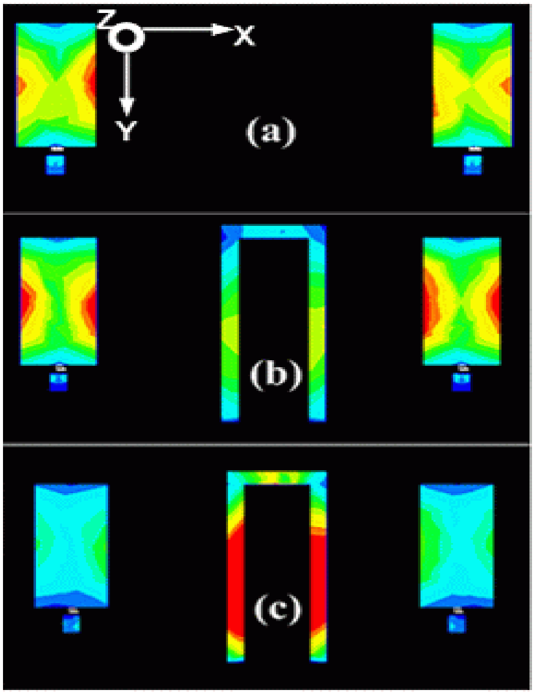



Fig. 2.20 Current distributions of antenna elements and parasitic elements

When two antenna elements are arrayed as in the case of Fig. 2.20(a), the main polarization is the vertical polarization, but the unwanted horizontal polarization causes rather high mutual coupling between the two antenna elements. However, as one can observe in Fig. 2.20(b), when a reversed 'U'-shape structure is placed between two antenna elements, the unwanted radiation components are canceled by the reversed 'U'-shape structure. The reason for this is that the reversed 'U'-shape structure is placed approximately 1/4 wavelength away from each element so that the wave incident to and the wave reflected from the structure have phase difference of 90 degree and thus cancel each other. In addition, interference signals excited in the reversed 'U'-shape structure is absorbed in the ground plane through the via hole. Figure 2.20(c) shows the case when the current distributions are opposite of the case shown in Fig. 2.20(b). Notice that the current density is high on the reversed 'U'-shape structure. This means that the reversed 'U'-shape structure operates as an antenna. The reversed 'U'-shape structure not only suppresses the mutual coupling but also enhances the antenna gain by operating as a parasitic antenna.

The gain of the 2-channel planar array antenna with the proposed reversed 'U'-shape structure as a function of frequency is presented in Fig. 2.21 Notice that the gain is improved approximately 2dBi when compared with the gain of the antenna shown in Fig. 2.17(b). The operation of the proposed reversed 'U'-shape structure as a parasitic antenna effectively improves the antenna gain.

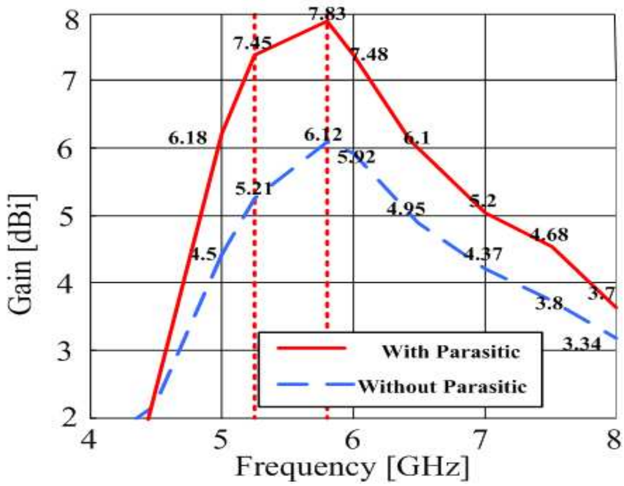



Fig. 2.21 Comparison of the calculated gain of the proposed 2-channel antenna with the gain of the conventional antenna.

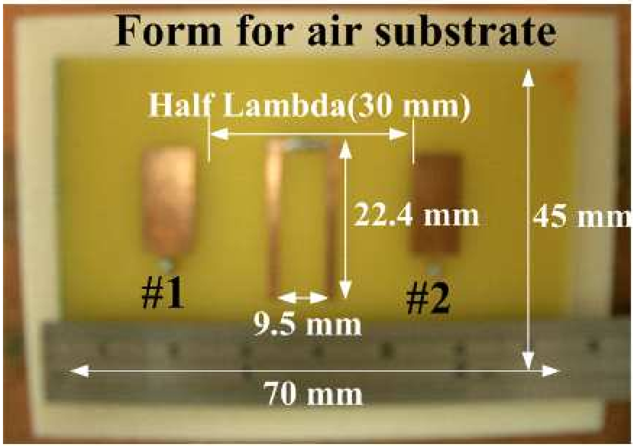
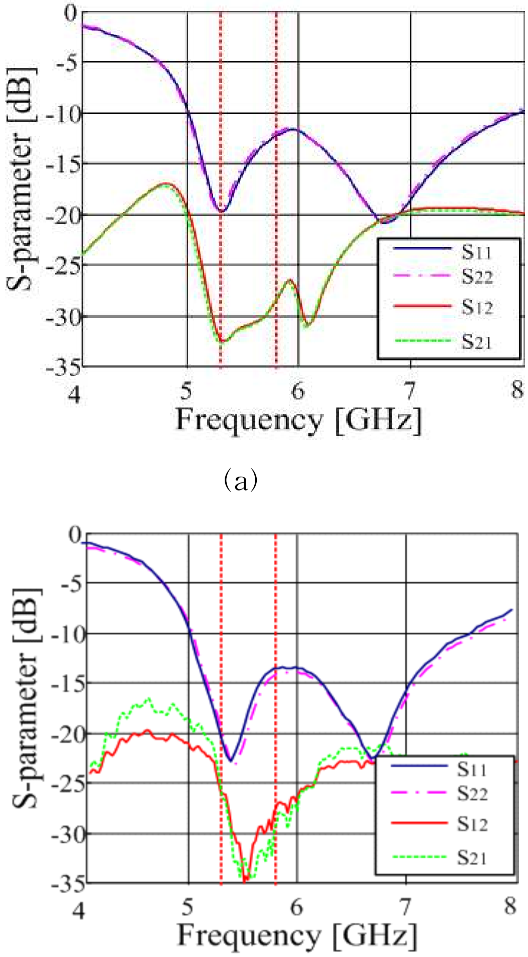



Fig. 2.22 Fabricated proposed 2-channel MIMO antenna with reversed U structure.

Fig. 2.22 shows the photograph of the fabricated 2-channel planar array antenna with the proposed reversed 'U'-shape structure with the optimized parameters mentioned above. The S-parameters and the radiation patterns of the fabricated antenna have been measured and shown in Figs. 2.23(b) and 2.24, respectively. The measured return loss (S11, S22) and mutual coupling (S12, S22) of the fabricated antenna agree reasonably with the calculated results in Fig. 2.23(a). Each antenna element satisfies the bandwidth requirement by the IEEE 802.11a standard, and the mutual coupling is well suppressed to -28~-29dB near 5.25GHz and 5.8GHz. The radiation patterns have been measured at 5.25GHz and 5.8GHz. The radiation patterns are slightly distorted due to the presence of the reversed 'U'-shape structure but are still adequate to be applied in the real wireless communication environment.




(a)



(b)

Fig. 2.23 Variation of S parameters with respect to frequency (a) calculated S-parameters, (b) measured S-parameters.

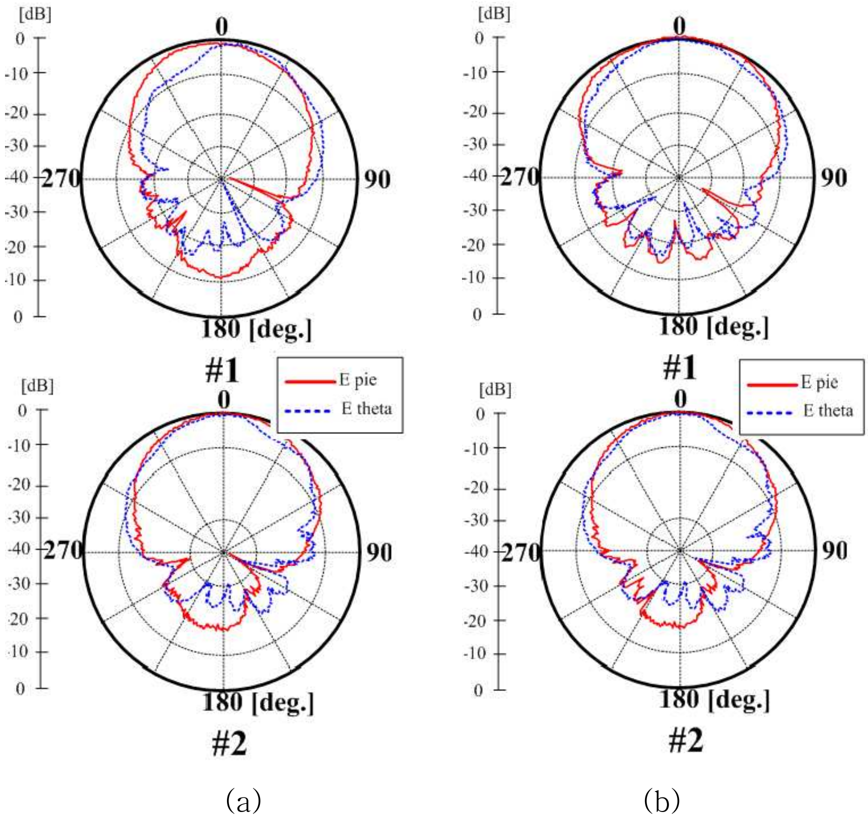



Fig. 2.24 Measured radiation pattern of proposed 2-channel MIMO antenna (a) at 5.25 GHz, (b) 5.8 GHz.: (Epie indicates XZ-plane and Etheta indicates YZ-plane)

## *2.3 Summary*

This chapter presents a high possibility of mutual coupling suppression between antenna elements using parasitic elements to realize independent channel operation for MIMO antenna systems. Conventional multi-channel MIMO antennas show about -20 dB mutual coupling in arrays with half-wavelength separation.

However, the mutual coupling of the novel multi-channel MIMO antennas is remarkably improved by more than 10 dB compared with conventional types.

Two novel designs are presented for the suppression of the mutual coupling between antenna elements. One design is for the 4-channel MIMO antenna array, and the other for the 2-channel MIMO antenna array. In the 4-channel MIMO antenna array design, two 2-unit parasitic elements are placed horizontally and two 1-unit parasitic elements are placed vertically. The use of the parasitic elements lowers the coupling between the antenna elements by more than 20dB when compared with the coupling observed between antenna elements without parasitic elements. The gain of the new array antenna is also slightly improved. In addition, the suppression of the mutual coupling improves the beam pattern of the antenna elements.

In the 2-channel MIMO antenna array design, a reversed 'U'-shape, microstrip line structure is used as a parasitic element. The structure is about a wavelength in total length and is grounded through a via hole that is placed at the center of the microstrip. With the new design, the mutual coupling between antenna elements is lowered by more than 10dB when compared with the coupling observed between antenna elements without a parasitic element. The use of the parasitic element also improves the gain of the array antenna by approximately 2dBi, which is due to the phenomenon that the parasitic element operates as a radiating element. It is also notable that mutual coupling is suppressed over a wide bandwidth in the new design.

Most of the previous research has dealt with three-dimensional structures for the mutual coupling suppression resulting in complex structures. However, the novel designs proposed in this thesis shows only two-dimension structures. Therefore, these design structures have two distinctive advantages. The first advantage is that it can be reduced the size of the entire array antenna since it is employed only 2-dimensional structure to suppress the mutual coupling in this research. The second advantage is the effective suppression of the mutual coupling between MIMO antenna elements with the improvement of antenna gain. The proposed novel methods for mutual coupling suppression can be applied to many fields of the MIMO antenna system and the array antenna system.

# *Chapter 3. 2-channel MIMO antenna for WiBro handy terminal*

## *3.1 WiBro System*

WiBro(Wireless Broadband) is a wireless broadband internet technology being developed by the Korean telecoms industry. In February 2002, the Korean government allocated 100 MHz of electromagnetic spectrum in the 2.3 GHz band, and in late 2004 WiBro Phase 1 was standardized by the TTA (Telecommunications Technology Association) of Korea[11].

WiBro base stations will offer an aggregate data throughput of 30 to 50 Mbit/s and cover a radius of 1-5 km allowing for the use of portable internet usage within the range of a base station. From testing during the APEC Summit in Pusan in late 2005, the actual range and bandwidth were quite a bit lower than these numbers. The technology will also offer Quality of Service(QoS). The inclusion of QoS allows for WiBro to stream video content and other loss-sensitive data in a reliable manner. These all appear to be the stronger advantages over the WiMAX standard, but the proprietary nature of WiBro and its use of licensed spectrum that may not be available across the globe may keep it from becoming an international standard. While WiBro is quite exacting in its requirements from spectrum use to equipment design, WiMAX leaves much of this up to the equipment provider while providing enough detail to ensure interoperability between designs.

In this work, it is tried a combination of the WiBro and the MIMO antenna system for higher channel capacity in WiBro communication system.

## *3.2 Design configuration of the 2-channel MIMO antenna for WiBro handy terminal*

### *3.2.1 Antenna configuration and evaluation of the $\rho_c^{mc}$ and the $\rho_{cij}^{rp}$ factors*

To improve the performance of MIMO antenna system, it is must be considered the complex correlation coefficient ρcij(i,j = element number) and the envelope correlation coefficient ρeij which related (3.1).

$$\rho_{eij} \cong \left|\rho_{cij}\right|^2 \qquad (3.1)$$

ρcij can be evaluated either from the mutual coupling between antenna ports or from the radiation patterns of the antenna elements. The former is estimated by using the normalized mutual resistance according to [12]. rij=Re(Zij)/Re(Zii) according to [12].

$$\rho_c^{mc} \cong r_{ij} \qquad (3.2)$$

On the other hand, the effect of radiation patterns can be calculated from (3.3) and (3.4)

$$\rho_{cij}^{rp} = \frac{\int_0^{2\pi} Aij(\varphi)d\varphi}{[\int_0^{2\pi} Aii(\varphi)d\varphi \int_0^{2\pi} Ajj(\varphi)d\varphi]^{1/2}} \quad (3.3)$$

$$Aij(\varphi) = \Gamma E_{\theta i}(\frac{\pi}{2},\varphi)E_{\theta j}^{*}(\frac{\pi}{2},\varphi)$$

$$+E_{\varphi i}(\frac{\pi}{2},\varphi)E_{\varphi j}^{*}(\frac{\pi}{2},\varphi) \quad (3.4)$$

where EΘ and EΦ are the Θ and Φ polarized electric field patterns of the antennas at the azimuth plane and Γ the cross polarization discrimination (XPD) of the incident field. The asterisk denotes the complex conjugate[13][14]. In MIMO system, it is must be employed the same polarization for each antenna element, it is not considered the XPD in this research [15].

By the formula(3.1), (3.2), (3.3) and (3.4), we can easily find out the fact that to improve the performance of a MIMO antenna system, it must be decreased the values of formula (3.2) and (3.4). If it can be reduced values $\rho_c^{mc}$ and $\rho_{cij}^{rp}$, the performance of the MIMO antenna will be improved. Thus in this research it is employed a projected(凸) ground structure which can decrease both of the values $\rho_c^{mc}$ and $\rho_{cij}^{rp}$.

Fig. 3.1 shows the proposed antenna configuration in this paper. The total size of a proposed 2-channel antenna which is included handy terminal ground size is 40 mm x 80 mm x

1.6mm. Each antenna is the printed meander line antenna having grounded arm and resonates at 2.35 GHz.

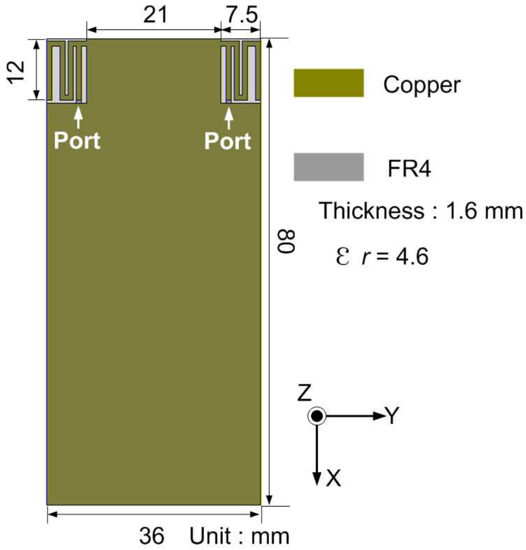



Fig. 3.1. A proposed antenna configuration.

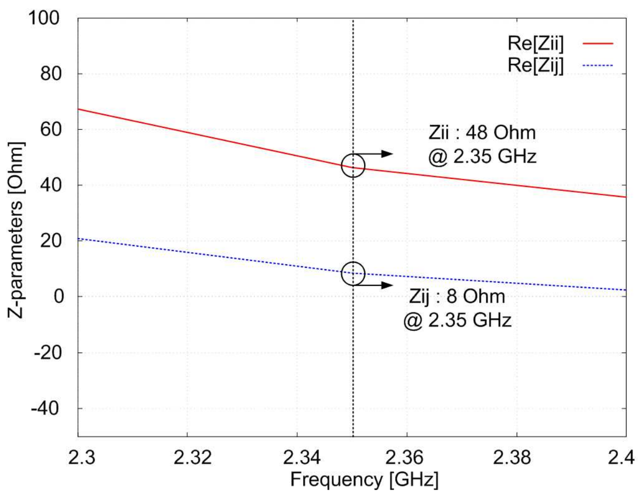



Fig. 3.2 Simulated antenna input and mutual impedances of a proposed antenna.

Fig. 3.2 shows the simulated antenna input and mutual impedance of the proposed antenna. The real part of Zii and Zij shows 48 Ohm and 8 Ohm at center frequency, respectively. Using these factors, it can be calculated the value of $\rho_c^{mc}$, it is 0.16. Since the antenna input impedances are well matched, also the mutual impedance($\rho_c^{mc}$) between two antenna elements are convergence to nearly 0. On the other hand, a projected(凸) ground structure is employed in this antenna so that two antenna elements are separated electrically. Since the projected part of ground plane operates as a reflector of each antenna, two antenna elements radiate opposite direction, respectively(Fig. 3.3).

Thus it could be reduced the radiation pattern coupling($\rho_{cij}^{rp}$) explained in chapter 3.2.1. Additionally, the radiation null angles are located in the circuit board direction, so it is not much affected on the circuits.

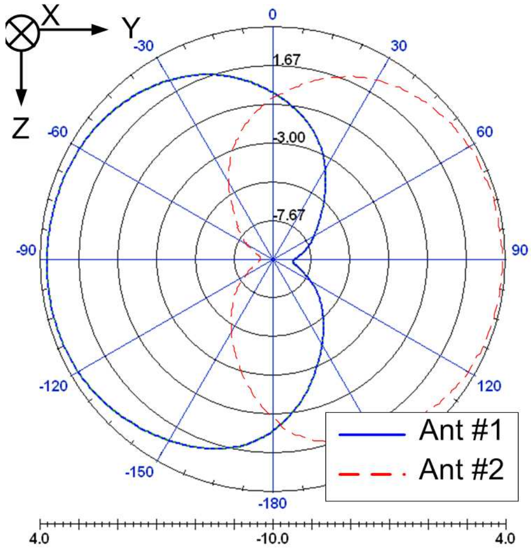



Fig. 3.3 Simulated radiation patterns of each antenna element on yz-plane.

### *3.2.2 Experimental results of the fabricated antenna*

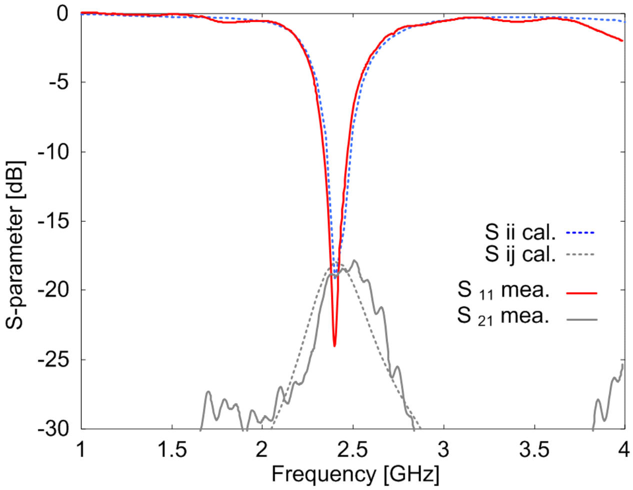
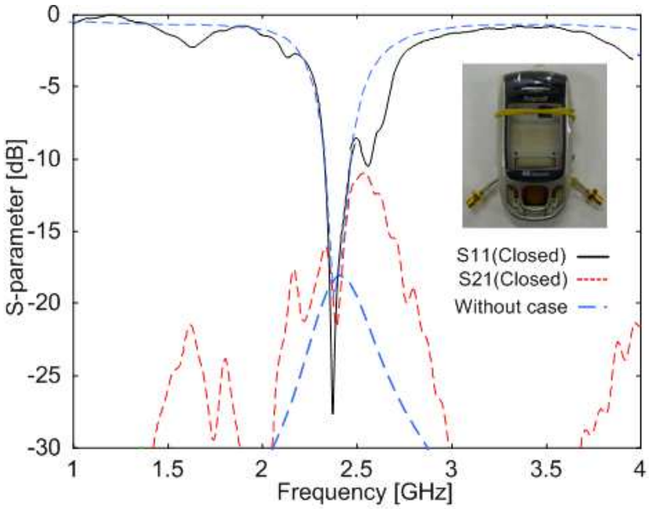
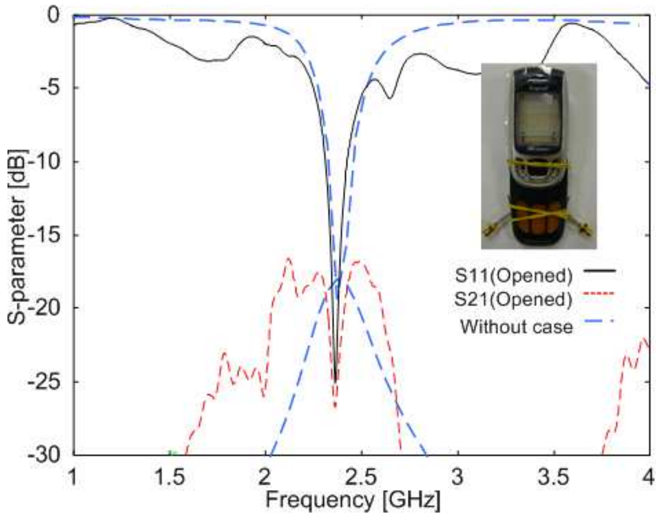



Fig. 3.4 Simulated and Measured S-parameters of the proposed antenna without a practical case.

As shown in Fig. 3.4, the measured and simulated S-parameters are exactly the same as depicted in Fig. 3.4. The proposed antenna is well tuned in the 2.3 - 2.45 GHz WiBro band and have over 150 MHz (6%) bandwidth. The mutual coupling(Sij) is under -17 dB at all frequency bands. For practical usage, it is examined the S-parameters and radiation patterns with a case of practical mobile device. The SCH-S130 slide phone model(Samsung) is used for the practical examination. it is examined each value to inspect the variation in practical usage for both of the open-slide and the closed-slide, respectively. The measured return-loss with the case are satisfied 2.3-2.45 GHz WiBro band below -10 dB, also the measured S21 are shown below -15 dB at WiBro band for both of the open-slide and the closed-slide, respectively. It shows reasonable agreements with the measured S-parameters without the case.




(a) Closed-Slide




(b) Opened-Slide

Fig. 3.5 Measured S-parameters of the proposed antenna with a practical case.

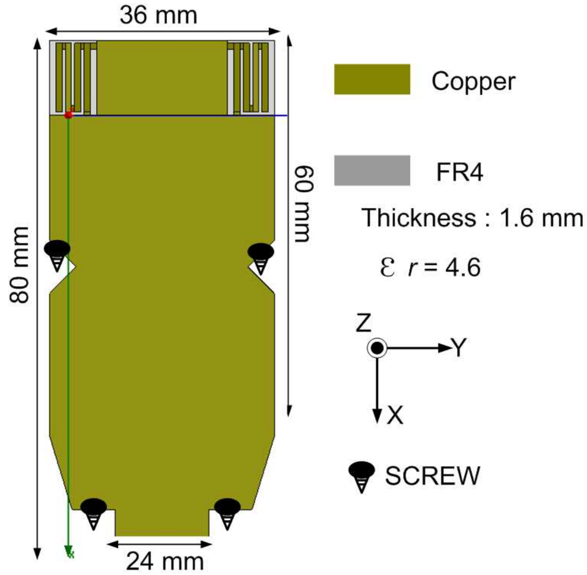



Fig. 3.6 A modified antenna configuration for the built in the case.

As shown in Fig. 3.5, the measured S-parameters with the case show good agreements with the measured S-parameters without the case. In case of the closed-slide, the measured return-loss is satisfied the WiBro band width below -10 dB and the measured S21 is shown below -15 dB at 2.3~2.4 GHz. On the other hand, In case of the opened-slide, the measured return-loss is also satisfied the WiBro band width below -10 dB and the measured S21 is shown below -17 dB at 2.3~2.4 GHz. Both of the cases of the closed-slide or the opened-slide, some frequency tunings are performed due to the frequency downward caused by the effect of the case[16]. Not only the frequency tuning, but we modify the structure of the PCB circuit board for builtin the case. Fig. 3.6 shows the modified antenna structure for the built in the case.

Fig. 3.7 and Fig. 3.8 show the measured radiation parameters with the case. The radiation patterns are measured on yz-plane and xz-plane, respectively. The yz-patterns and xz-patterns are H-plane and E-plane of the antennas and they are examined with closed-slide and opened-slide, respectively. As shown in Fig. 3.7(a), the measured yz-radiation patterns of each antenna with the closed-slide are toward to completely opposite directions and they show wide beamwidth for each direction. In case of measurement with the opened-slide(Fig. 3.7(b)), the measured radiation patterns are distorted by the effect of EMI paint on the upper slide. Because the EMI paint is same as the conductor, the measured yz-radiation patterns of each antenna are distorted a little. Fig. 3.8(a) and (b) show the measured xz-plane radiation patterns with the case. Since the proposed antenna has the similar E-filed comparing with a typical dipole antenna, the measured xz-plane radiation patterns are shown similar as the E-plane of the typical dipole antenna. However the effect of the upper slide of the case, the main beam direction of the measured radiation is toward to the back side of the handy terminal.

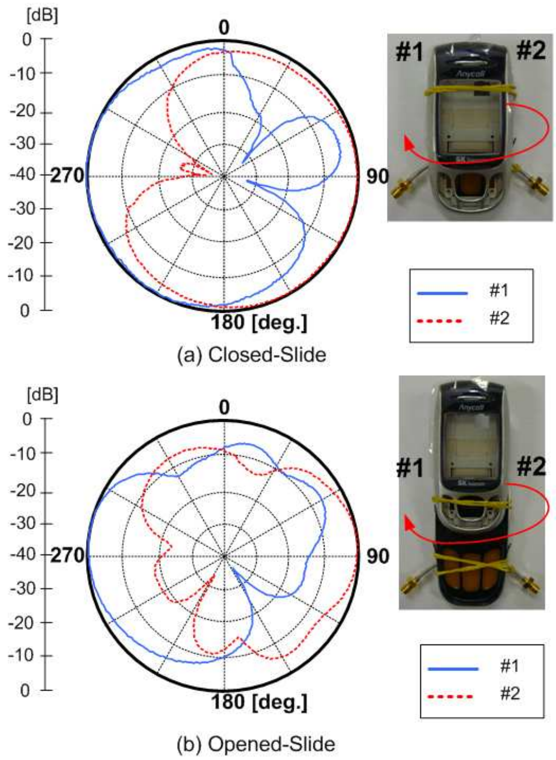



Fig. 3.7 Measured radiation patterns of each antenna element on yz-plane with a practical case.

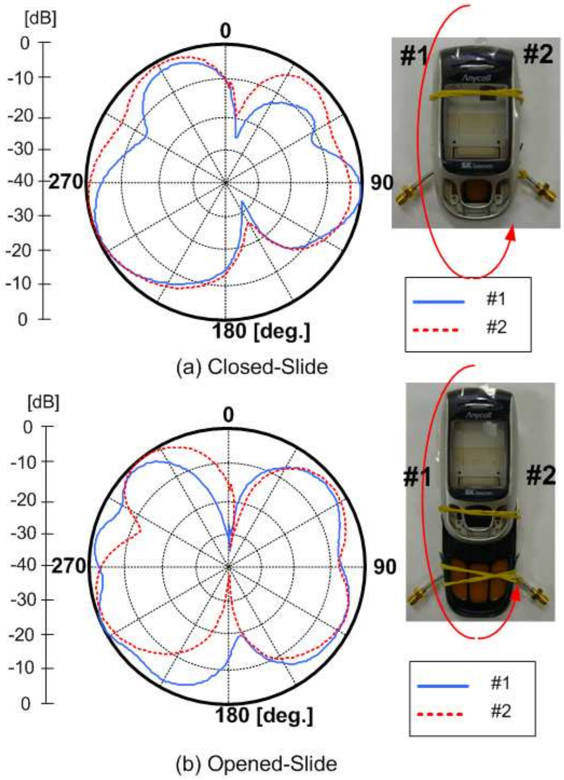



Fig. 3.8 Measured radiation patterns of each antenna element on xz-plane with a practical case.

The S-parameters and the radiation patterns are examined with the LCD panel and battery, respectively. As shown in Fig. 3.9, the measured S-parameters are shown good agreement with the measured results without the LCD panel and battery. However, the measured bandwidth with the LCD panel and battery is reduced about 10 MHz comparing with the case without the LCD panel and battery.

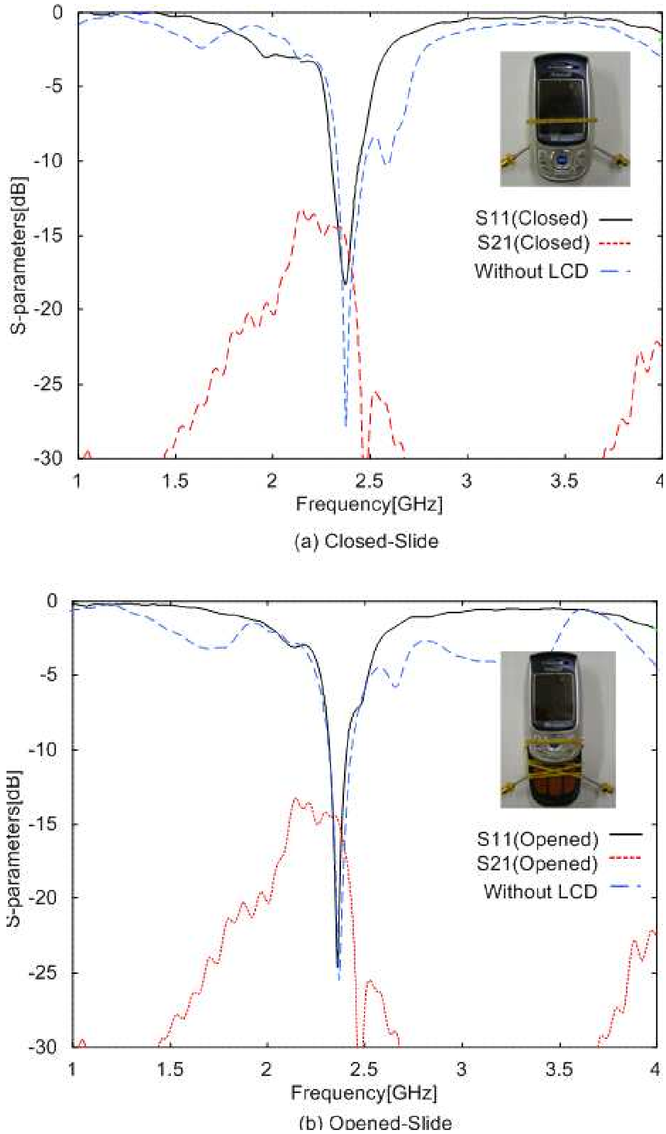
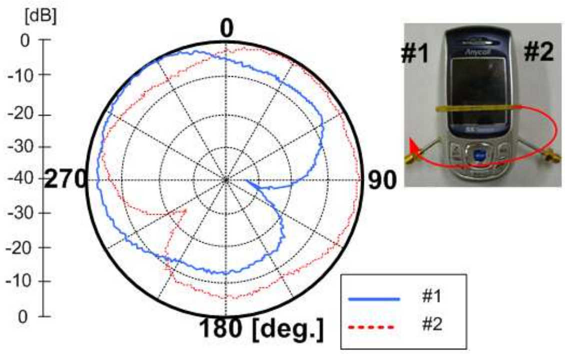


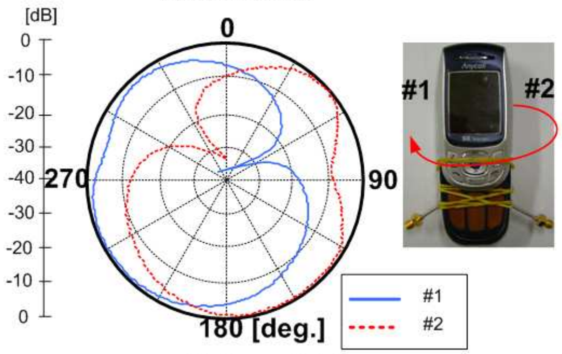

Fig. 3.9 Measured S-parameters of the proposed antenna with the LCD panel and the battery.

Fig. 3.10 and Fig. 3.11 show the measured radiation parameters with the LCD panel and the battery. The radiation patterns are measured on yz-plane and xz-plane, respectively.

Even it is occurred the scattering and the diffraction phenomenon on radiation patterns by the effect of the LCD panel, the measured radiation patterns with the LCD panel and the battery are shown reasonable agreement compared with the case without the LCD panel and the battery.




(a) Closed-Slide




(b) Opened-Slide

Fig. 3.10 Measured radiation patterns of each antenna element on yz-plane with the LCD panel and the battery

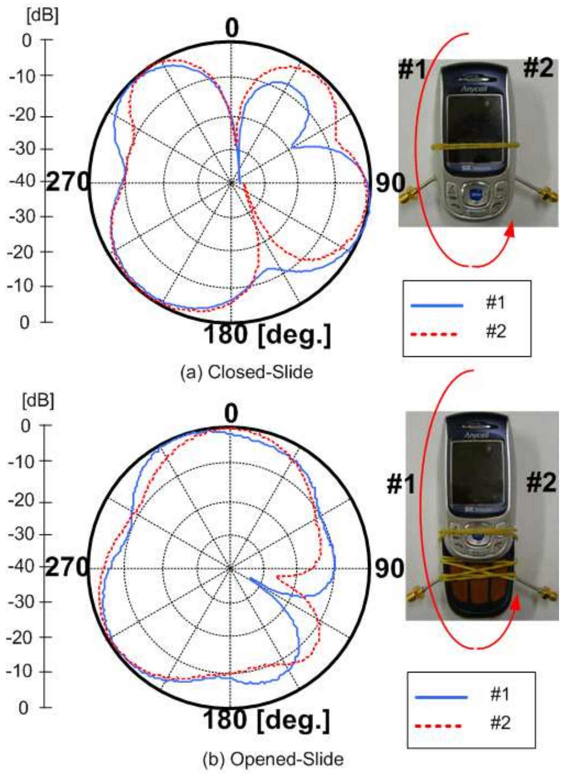



Fig. 3.11 Measured radiation patterns of each antenna element on xz-plane with a practical case.

## *3.3 Summary*

A compact 2-channel MIMO antenna operating in the 2.35 GHz WiBro band is proposed. The proposed antenna consists of two printed meander antennas which have compact size, easy tunability. The mutual coupling between two antenna elements is very low because of the projected ground structure. Additionally, the radiation pattern coupling is low due to the projected ground structure operates as an antenna reflector which can separate the radiation patterns of two antenna elements.

The S-parameters and radiation patterns are examined and they show reasonable agreements with the simulated results. They examined also with a practical handset case, a LCD panel and the battery. By the effect of the case, the measurement results are changed a little, however they are tuned easily to satisfy the design conditions.

The proposed antenna has a suitable structure for handy terminal, nice radiation pattern, and enough bandwidth for WiBro application. Thus it is expected the proposed antenna model can apply many fields for the WiBro-MIMO antenna system.

# *Chapter 4. A monopole antenna with a novel impedance matching structure*

## *4.1 Characteristics of small antennas*

The demand for smaller communication devices for personal communication systems has led to a research for the methods to reduce the personal devices for radio communications. Because of the recent trend of the miniaturization for mobile devices, it is necessary to develop the circuits, the chips and the antennas for small mobile devices. Especially, a miniaturization is much required in antenna devices since the antenna devices are occupied large space in the mobile handy terminals. However, the wavelength does not decrease with the same speed as the size of the mobile phones due to the higher frequency bands used[17]. Even a quarter wavelength antenna, such as the planar monopole antenna tends to become too large, thus creating a demand to decrease the size of the antenna.

Size reduction can be accomplished simply by shortening the antenna or using high permittivity dielectric substrates, etc[18][19]. However, at lengths shorter than the resonant length, the radiation resistance changes, and the impedance at the terminals of the antenna become reactive. The latter can be compensated for by the self-impedance matching structure which proposed in this research. The self-impedance matching structure is employed for the cancellation of the capacitance, thus it improve the impedance matching and the antenna efficiency[17].

In this research, it is designed an antenna for W-LAN band. So we assumed that the proposed antenna operates at IEEE 802.11b(2.4~2.484 GHz) and it satisfies IEEE 802.11b frequency band below VSWR 2. We expect that the antenna shows the omni-directional radiation patterns at the all frequency band.

In recent years, almost of the mobile devices for W-LAN employ $\lambda/4$ antennas[20]. However it is necessary to reduce much the antenna size with considering recent trends which requiring smaller size. Thus we proposed a planar monopole antenna with $\lambda/8$ length in this research. Not only the reduction of the antenna size, but we investigated the possibility of the reduction of a ground plane for practical usage. We assumed that the proposed monopole antenna has the ground plane smaller than $\lambda/4$ width for the adoption in mobile devices. In this research, a FR4($\varepsilon r$=4.4, thickness=1 mm) dielectric substrate is used for the antenna design due to its low price and reasonable permittivity constant.

## 4.2 Antenna design procedure

### 4.2.1 1/8 λ Folded monopole antenna characteristic

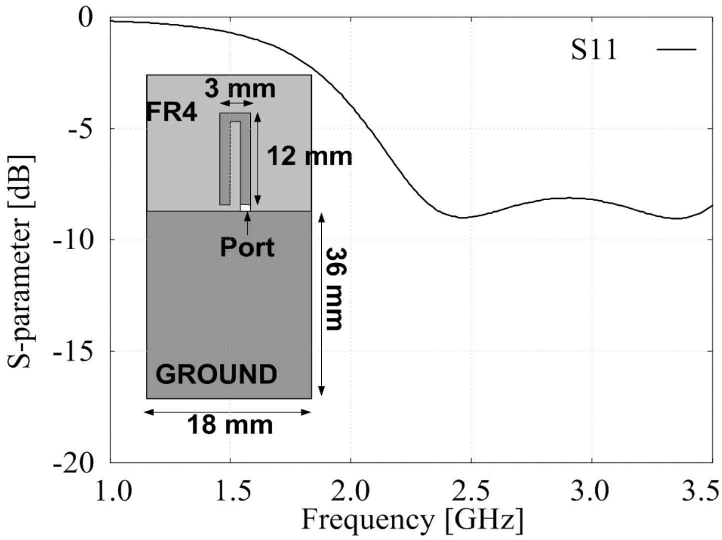



Fig. 4.1 A typical λ/8 wavelength folded monopole antenna and its return loss.

Fig. 4.1 shows the folded monopole antenna with λ/8 length. The total length of the folded monopole antenna is about λ/4 wavelength, it shows the resonant phenomenon at around 2~3 GHz. However as shown in Fig. 4.2, the impedance of antenna shows much capacitive characteristic at the design frequency. Thus we need to compensate the capacitive characteristic by using some impedance matching methods. Thus, We introduce a novel method for effective impedance matching at the terminal of the antenna. As well known in general, the input impedance of small antennas smaller than λ/4 wavelength is very capacitive, so we must find an effective matching method for compensation of the capacitive reactance on antenna structure.

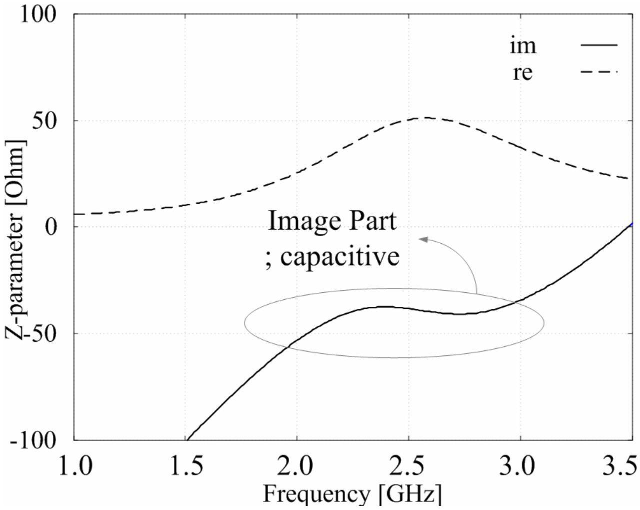



Fig. 4.2. A impedance characteristic of the typical λ/8 wavelength folded monopole antenna.

### *4.2.2 A novel design for impedance matching*

The antenna used in this research shows much capacitive characteristic(Fig. 4.1 and Fig. 4.2), thus an inductive matching method is employed as shown the equivalent circuit in Fig. 4.3(b). Fig 4.4 shows the antenna structure with the inductive line for impedance matching and its impedance characteristic.

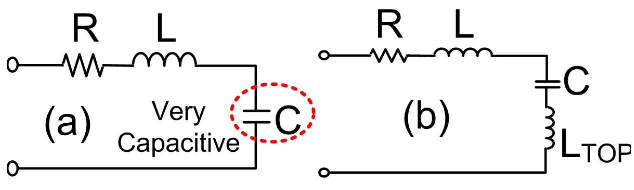



Fig. 4.3. Equivalent circuits of the small antennas. (a) A general equivalent circuit of the small antennas (b)The equivalent circuit of the proposed small antenna.

By the effect of the inductive line on the top of the antenna, the capacitive imaginary part of the antenna impedance is reduced much. However it shows still capacitive characteristics, so it is needed to reduce the capacitive imaginary part of antenna impedance. For better impedance matching, as an application of the structure in Fig. 4.4, it is considered a symmetry structure of the structure in Fig. 4.4. Fig. 4.5 shows the proposed symmetry antenna structure for the nice impedance matching. Fig. 4.6 and 4.7 show the return loss and impedance characteristic of the proposed antenna structure, respectively. Table 1 shows the optimized parameters of the proposed antenna.

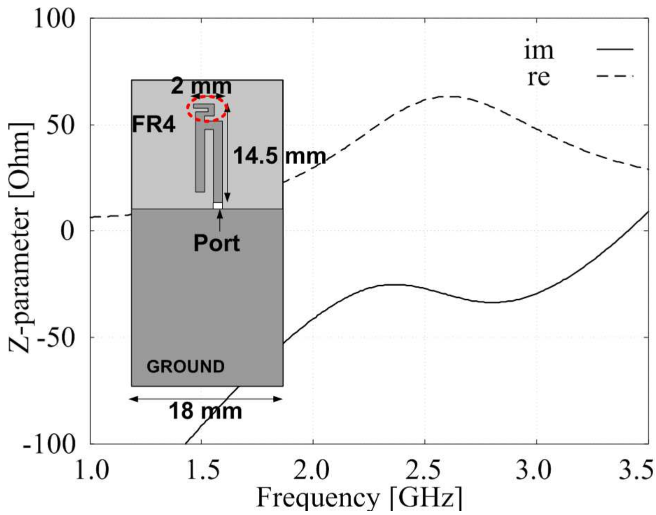



Fig. 4.4. A λ/8 wavelength folded monopole antenna with inductive matching line and its return loss.

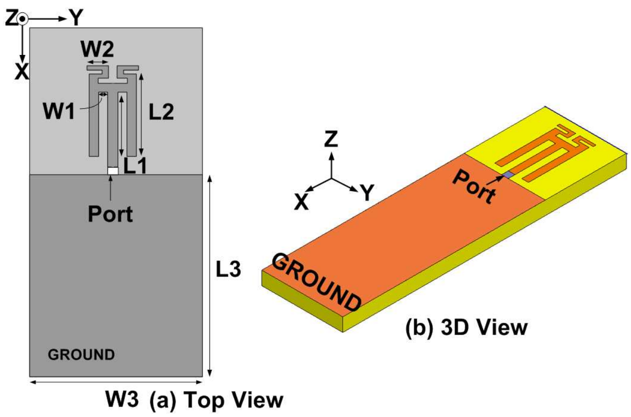



Fig. 4.5. A configurations of the proposed λ/8 symmetrical folded monopole antenna with inductive matching lines.

Table I

Parameters for the proposed antenna structure(Fig. 4.5) (unit : mm).

| L1 | L2 | L3 | W1 | W2 | W3 |
|---|---|---|---|---|---|
| 11.5 | 12 | 36 | 1 | 2 | 18 |

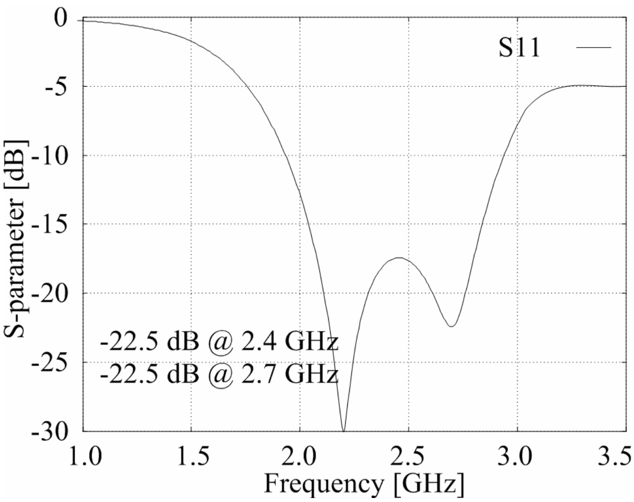



Fig. 4.6. A return loss of the proposed λ/8 symmetrical folded monopole antenna with inductive matching lines.

As shown in Fig. 4.6 the antenna return loss shows dual resonance at 2.4 GHz and 3 GHz, respectively. Two resonance frequencies are close, so the antenna return loss shows broad bandwidth characteristic from 2 GHz to 3.25 GHz at VSWR 2 below. The antenna bandwidth is over 47 % about the center frequency of design conditions(2.4~2.484 GHz). Additionally, image part of the antenna input impedance is approached to nearly 0 by the novel impedance matching structure on the top of the antenna. Fig. 4.7 shows the antenna input impedance characteristic of the proposed antenna.

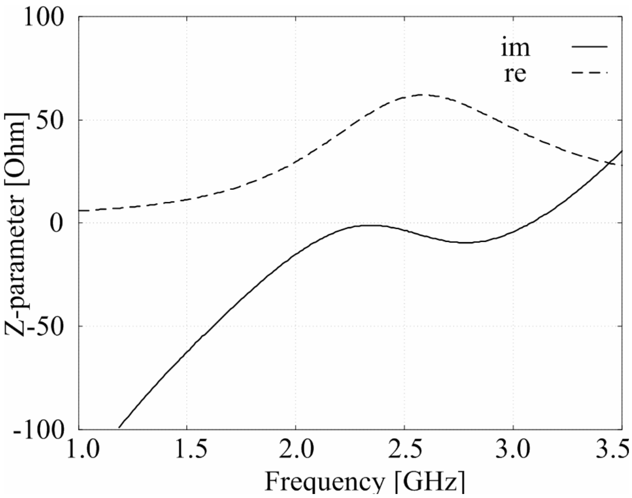



Fig. 4.7. A impedance characteristic of the proposed λ/8 symmetrical folded monopole antenna with inductive matching lines

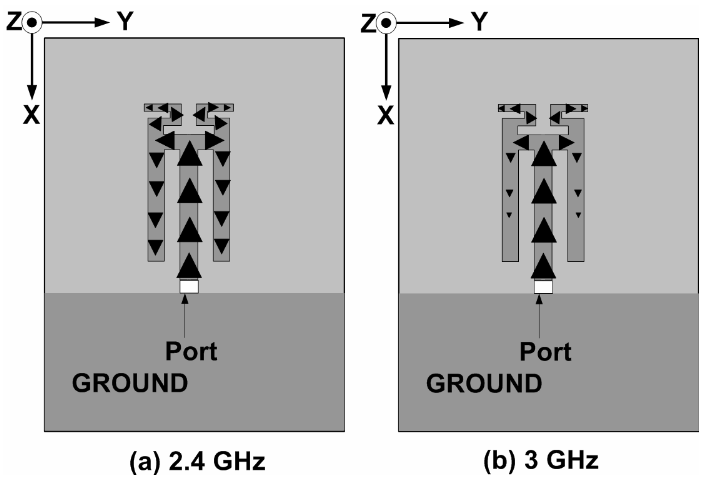
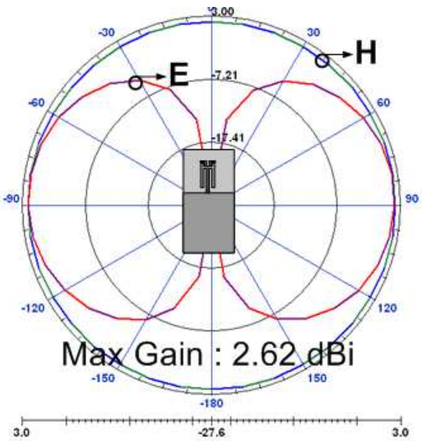
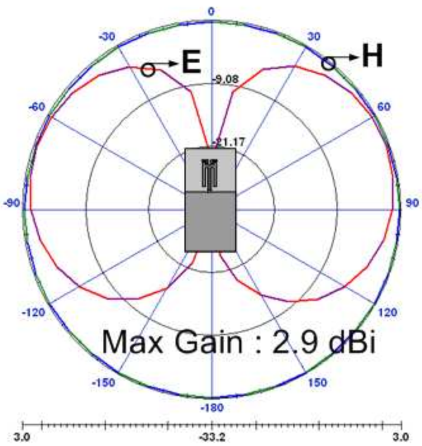



Fig. 4.8. Current paths for the each resonance frequency of the proposed λ/8 symmetrical folded monopole antenna with inductive matching lines.

The broad bandwidth characteristic of the proposed antenna is based on the antenna structure. It can be explained in Fig. 4.8. In Fig. 4.8, we can easily find out the reason of the dual resonance. According to the current paths at each frequency, the inductive lines on the top of the antenna operate as the impedance matching structure for both of low and high resonance frequencies and as shown in Fig. 4.8, the antenna structure is constructed for dual resonance. Thus the impedance matching structure successfully matches the antenna impedance for both of low and high resonance frequencies; therefore the performance of the proposed antenna is very good for broad bandwidth.




(a) 2.4 GHz




(b) 2.7 GHz

Fig. 4.9. Radiation patterns of the proposed λ/8 symmetrical folded monopole antenna with inductive matching lines at the W-LAN frequency bands and resonance frequency.

Fig. 4.9 shows the radiation patterns of the proposed antenna at each resonance frequency. E-plane and H-plane of the antenna radiation patterns show similar as a typical monopole antenna radiation patterns even though the antenna structure is remarkably smaller than a typical monopole antenna. The calculated antenna gains at 2.4 GHz and 2.7 GHz show 2.62 dBi and 2.9 dBi, respectively and they are reasonable results comparing with the typical λ/4 monopole antenna gain. Nice radiation patterns and antenna gains are leaded by good impedance matching with inductive lines on the top of the antenna.

### *4.2.3 Experimental results and discussion*

In this paper, the λ/8 wavelength folded monopole antenna with self-impedance matching structure is presented. We suggested a novel method for antenna impedance matching structure using inductive lines on the top of the antenna; it shows an effective compensation about the capacitive characteristic of the antenna.

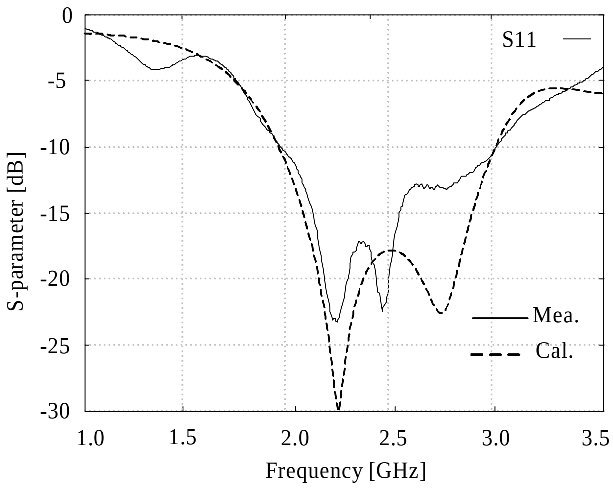



Fig. 4.10. Measured S-parameter of the fabricated antenna proposed in this research.

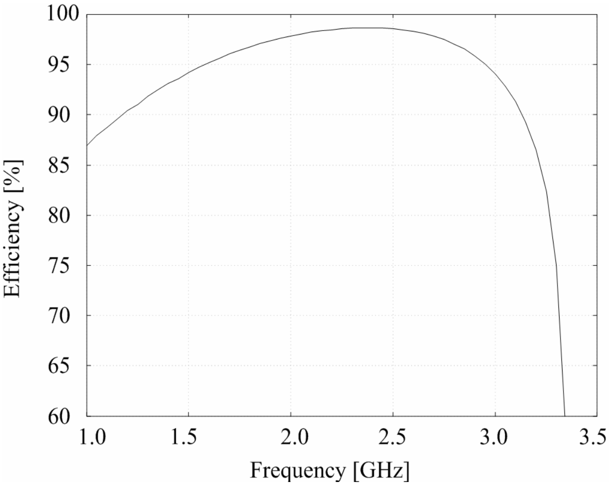



Fig. 4.11. Measured antenna radiation efficiency of the fabricated antenna proposed in this research by using the Wheeler-Cap method.

Fig. 4.10 and Fig. 4.11 show the measured S-parameter and antenna radiation efficiency of the fabricated antenna. Although the measured S-parameter shows a little difference comparing with the simulated one according to the measurement and fabrication errors, they show a reasonable agreement. The antenna radiation efficiency is examined by using the Wheeler-Cap method, it shows about 95 ~ 99 % at the 2~3 GHz bands.

## *4.3 Summary*

The proposed antenna shows good performances for the W-LAN band and it operates well above W-LAN band due to its dual resonance characteristic by the antenna structure. The antenna radiation patterns and the antenna gain show reasonable results in spite of its remarkably small structure. Although the proposed antenna has $\lambda/8$ wavelength size, it shows omni-direction radiation patterns and about 2~3 dBi antenna gain at 2~3 GHz frequency band, respectively.

Due to the small size and nice performance of the proposed antenna in this paper, we expect that the proposed antenna could apply to mobile handy terminals such as PDA and laptop computers.

# *Chapter 5. Conclusion*

A MIMO Antenna system is a well-known technique to enhance the performance of wireless communication systems. The channel capacity that a MIMO antenna system provides is much larger than that provided by the conventional wireless system.

To implement a MIMO antenna system in real MIMO environment, the antenna system with multiple channels is required. Suppressing the coupling between antenna elements is an important problem in MIMO or multiple antenna systems because the coupling between the antenna elements influences the correlation coefficient in free space significantly.

This paper presents several design techniques for MIMO antenna system having low mutual coupling between each antenna element. Two examples of the proposed models employed parasitic elements for mutual coupling suppression; they show strong possibility of mutual coupling suppression between patch antenna elements to realize an independent channel for MIMO antenna system. We proposed a compact 2-channel WiBro-MIMO antenna for the practical handy terminal. It is employed the projected (凸) ground structure for isolation between two antenna elements and it suppressed both of the mutual coupling and the radiation coupling.

Most of the previous research has dealt with three-dimensional structures for the mutual coupling suppression resulting in complex structures. However, the novel designs proposed in this paper shows only two-dimension structures.

Therefore, this design structure has both advantages that it can reduce the entitle size and suppress the mutual coupling between MIMO antenna elements, effectively.

Additionally, it is proposed a ultra small antenna with the novel impedance matching structure could be applied in MIMO application in this thesis. Due to the small size and nice performance of the proposed antenna in this thesis, it is expected that the proposed antenna could be applied to mobile handy terminals such as PDA and laptop computers for MIMO application.

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# 감사의 글

오늘의 제가 있기까지 큰 관심과 세심한 배려로, 각별한 사제지간의 정을 일깨워주신 민 경식 교수님께 감사드립니다. 또한 학부와 대학원 6년 동안 많은 가르침을 주신 김 동일 교수님, 조 형래 교수님, 정 지원 교수님, 김 기만 교수님, 강 인호 교수님, 윤 영 교수님께 감사드립니다.

무엇보다도 오늘 날 제가 있을 수 있게 해주시고, 마음 편히 공부만 할 수 있도록 늘 배려해 주신 나의 부모님과 형, 형수님에게 깊은 감사를 드립니다. 공부에 앞서, 진정으로 따뜻한 가정에서 제 인생을 설계할 수 있었음은 모두가 나의 가족들의 덕이기에 말로 전할 수 없는 고마운 마음을, 평생을 사는 동안 조금이나마 갚아갈 것을 못난 논문에 대고 약속드립니다.

좋은 연구 결과를 얻을 수 있도록 늘 도와주신 삼성종합기술원의 여러 전문연구원님들께도 깊은 감사를 드립니다. 신선한 연구 테마와 여러 전문연구원님들의 각별한 관심으로 논문이 잘 마무리되었습니다. 특히 언제나 형님처럼 돌봐주시고 마지막 논문 심사의 심사위원장까지 흔쾌히 맡아주신 종합기술원의 박 세현 형님과 가정에 고마운 마음을 전합니다.

대학에 입학할 때부터 대학원을 마치는 지금 이 순간까지 나와 동고동락을 함께한 진우, DSP 연구실의 형준이와 찬섭이, 연구실 생활하는 동안 늘 많이 도와준 철근이형, Vu Manh Dat, Tran Viet Hong, Tran Thanh Ngon에게도 감사드립니다. 또한 이제 연구실의 기둥이 될 민성이, 승목이, 건도에게 늘 말만 많고 제대로 챙겨주지 못한 못난 선배로서 미안하고 고마운 마음을 전합니다. 열심히 해서 졸업할 때 후회하지 않고 당당히 사회로 진출할 수 있도록 더욱 노력해달라는 작은 부탁을 드립니다. 나의 소중한 친구들- 덕우, 동명이인인 두 상봉이, 민

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지난 5년간, 늘 저에게 더욱 열심히 살아갈 이유가 되어준 사랑하는 예리에게, 아들처럼 생각해 주시고 늘 도와주신 예리의 부모님과 선혁이에게 감사드리며 앞으로 더욱 열심히 살아 자랑스러운 사람이 될 것을 약속드립니다.

6년간 머물렀던 학교라는 둥지를 떠나 넓은 세상으로 떠납니다. 학교라는 작은 사회에서 저에게 많은 가르침을 주신 모든 분들께 다시 한 번 깊은 감사를 드립니다.

김동진 올림