

# Antenna Design with Combination of Electric-Magnetic Radiators for RFID System

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## Abstract

In this paper, a directive antenna design with a combination of electric-magnetic radiators for an radio frequency identification(RFID) system is presented. To generate a directive antenna radiation pattern, a structure combining a dipole and loop antenna is presented. A reader antenna and tag antenna are proposed for the RFID system. For the reader antenna, the frequency bandwidth defined by  $S_{11} < -10$  dB is approximately from 820 ~ 990 MHz. The forward and backward gain differences are 1.5 ~ 2 dBi. For the tag antenna, the frequency bandwidth is approximately from 860 ~ 920 MHz with a maximum gain of 3.58 dBi at 910 MHz. In both cases, directive radiation characteristics are observed.

**Key words:** RFID, Reader Antenna, Tag Antenna, Electric-Magnetic Combined Antenna, Directive Antenna.

## I. Introduction

Radio frequency identification(RFID) systems to track and control goods and products, as well as obtain information through transponders(tags) from people and objects, are developing very rapidly in the area of modern communications<sup>[1]</sup>. In antenna technology, RFID antennas are mainly studied and developed with a view to reducing the size of the antenna and matching the input impedance between the chip and tag antenna<sup>[2]-[6]</sup>. In addition, researchers and engineers have a growing interest in using an RFID system in a mobile cellular phone. This allows people to obtain useful information from the RFID tag easily in ubiquitous society. In this case, the RFID reader antenna, which may be inserted in or printed on the circuit board of the mobile hand-set, should be very small and radiate enough energy to activate the RFID tag chip. However, it is very difficult to maintain a small-size antenna that can provide enough antenna gain to support a reasonable read range. It is known that a high-gain antenna is needed to produce a reasonable range<sup>[7]-[9]</sup>.

In this paper, we introduce a reader antenna of combined electric-magnetic radiators that can be installed in the mobile hand-set<sup>[10]</sup>. In addition, we propose an RFID tag antenna with wide-band impedance characteristics and a directive radiation gain pattern. When the strengths of the excitations of the electric radiator and the magnetic radiator are properly provided, the phase difference between

the two sources has little impact on the bandwidth enhancement of the combined antenna. However, the maximum gain of the antenna is a strong function of the phase difference, and a gain enhancement of up to 3 dB is possible compared with the gain of either individual radiator<sup>[11]</sup>. Moreover, combining electric-type and magnetic-type antennas can extend the operation bandwidth in the lower frequency direction<sup>[12]</sup>. Below the first resonance frequency of the dipole-type antenna, its input impedance is capacitive. In contrast, a magnetic-type radiator such as the loop antenna in this paper has an inductive input impedance before it becomes an efficient radiator with respect to frequency. Therefore, when the resonance frequencies of the antennas are matched, the combined antenna structure can radiate before each of the individual radiators becomes an efficient radiator.

The purpose of combining a dipole and a loop antenna to form one antenna is to reduce the size of the overall antenna and produce a directive antenna radiation pattern. In this paper, we propose an RFID reader antenna and a tag antenna as combining the dipole and loop antenna in order to generate directive radiation gain patterns with a wide band and increase the total read range for the RFID system.

## II. Reader Antenna Design and Measurement

The geometry of combined dipole antenna and loop antenna is shown in Fig. 1. The dipole antenna is a simple Inverted-F Antenna(IFA) type antenna. The antenna ra-

Manuscript received May 31, 2010 ; revised August 18, 2010. (ID No. 20100531-012J)

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diator size is 40×25×1 mm, and the ground plate size of 40×74×1 mm is selected as representative of a typical cellular phone circuit board. The radiating element of the IFA type antenna is on the top layer of the substrate (FR4-Epoxy board,  $\epsilon_r=4.4$ ). In addition, the total physical length of the loop antenna is 20.8 cm ( $0.6 \lambda$  at  $f=860$  MHz). The loop antenna is designed to be embedded or printed on the outer case of the mobile handset. The dipole antenna and loop antenna are excited by a single feeding point. Specific antenna dimensions are shown in Fig. 1. A full-wave simulation was performed using the commercial software Ansoft HFSS.

The radiation pattern of the antenna is shown in Fig. 2. The forward radiation gain in the  $-x$  direction (RFID application direction) is 4.4 dBi. It is approximately 1.5~2 dBi higher than the typical antenna gain of each individual antenna. The simulation result of return loss shown in Fig. 3 indicates that the centre frequency is 910 MHz and the antenna satisfies  $S_{11} < -10$  dB over 870~950 MHz, making it suitable for all of the 900 MHz band

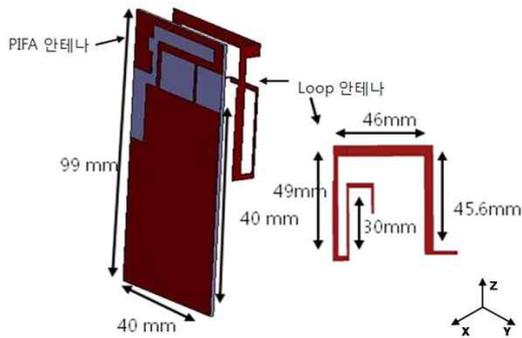


Fig. 1. Combined antenna configuration for the RFID system.

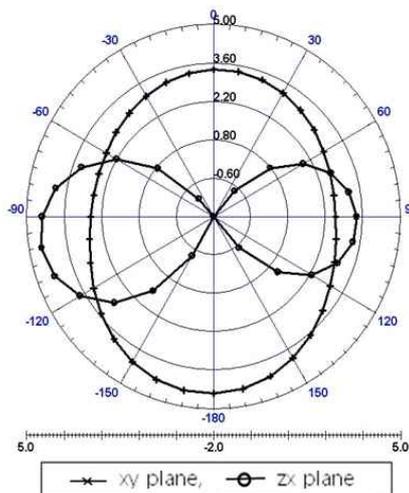


Fig. 2. Simulated radiation pattern of the combined antenna.

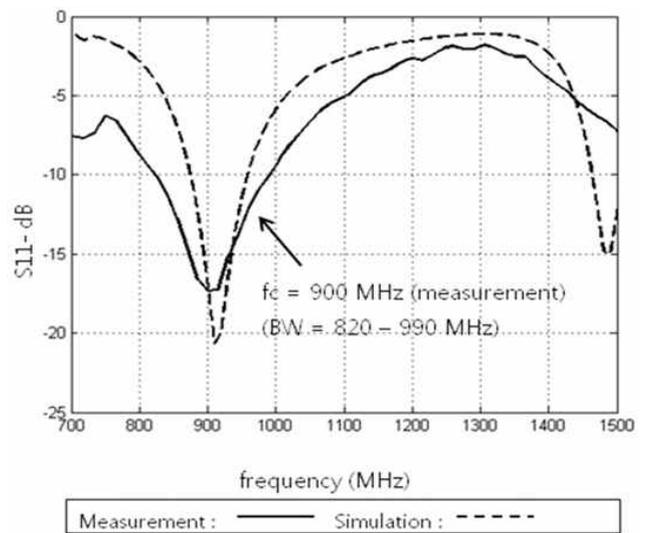


Fig. 3. Simulated and measured results of return loss of the combined antenna.

RFID operations.

Fig. 4 shows radiation E field distribution of the antenna in the  $x$ - $y$  plane. It is noted that the strong E field is radiated in the  $-x$ -axis direction.

The prototype of the proposed antenna is fabricated and a photo of the antenna is shown in Fig. 5.

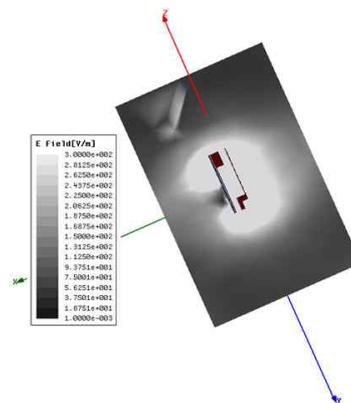


Fig. 4. E field radiation on the  $x$ - $y$  plane of the antenna.

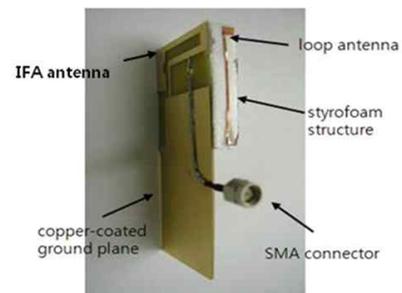


Fig. 5. Photograph of the prototype of the proposed RFID reader antenna.

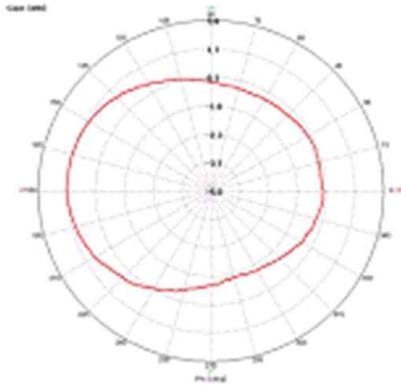


Fig. 6. Measured radiation pattern of the proposed combined antenna (co-polarization, x-y plane).

The input impedance and the radiation characteristics have been measured. The reflection coefficient parameter ( $S_{11}$ ) was measured with an Agilent 8722 ES vector network analyzer. Fig. 3 shows the measured  $S_{11}$  plot between 700 MHz and 1.5 GHz. The frequency bandwidth defined by  $S_{11} < -10$  dB is approximately from 820~990 MHz. The azimuthal gain pattern (x-z plane) of the antenna was measured in an anechoic chamber and the results are shown in Fig. 6. The proposed antenna has a directive radiation characteristic in the  $-x$  direction with maximum gain of 1.83 dBi. It is noticed that the measured gain value is approximately 2.7 dBi less than the gain value of the simulated result. We measured the single IFA, which is shown in Fig. 1 for reference antenna. It is also observed that the measured gain is less than  $-3$  dBi compared to the simulation result. The differences between them are mainly attributed to measurement errors and the lab-manufacturing product model. The gain difference between the forward direction ( $-x$  direction) and backward direction ( $+x$  direction) is still maintained at about 1.5 dBi  $-2$  dBi.

### III. Tag Antenna Design and Measurement

The geometry of the dipole antenna for the electric radiator is shown in Fig. 7(a), and the geometry of the loop antenna for the magnetic radiator is shown in Fig. 7(b). The dipole antenna is a simple dipole antenna with a total physical length of 19.2 cm ( $0.57 \lambda$  at  $f=900$  MHz). The antenna radiator size is  $2.17 \times 8.5$  cm. The substrate (FR4-Epoxy board,  $\epsilon_r=4.4$ ) size is  $4 \times 9.9 \times 0.1$  cm. The total length of the loop antenna is approximately 31.8 cm ( $0.956 \lambda$  at  $f=900$  MHz). The position of the feeding for the loop antenna is the same as that of the dipole antenna shown in Fig. 7. The simulated results of input impedance are shown in Fig. 8. The center frequency of the dipole antenna is 920 MHz, with a 40 MHz bandwidth ( $S_{11} < -9$  dB); the center frequency of the loop

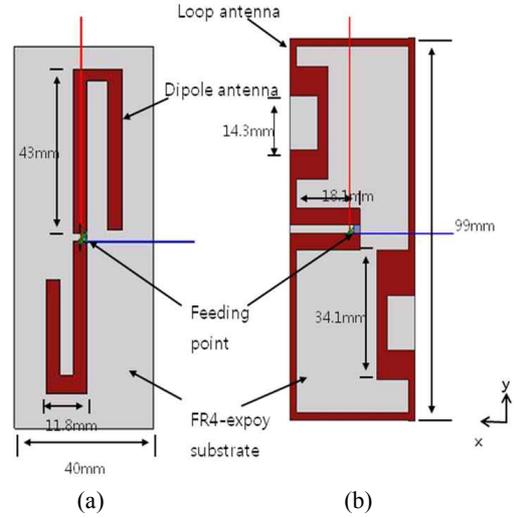


Fig. 7. (a) Dipole antenna configuration, (b) Loop antenna configuration.

antenna is 1,100 MHz with a 100 MHz bandwidth ( $S_{11} < -5$  dB).

In this study, the dipole and loop combined tag antenna was fed by a 50-Ohm coaxial probe to illustrate the directive radiation characteristics. A full-wave simulation was performed using the commercial software Ansoft HFSS.

The combined antenna structure is shown in Fig. 9. The fundamental antenna geometries of the dipole and loop antenna in the combined model are same as those for the antennas shown in Fig. 7. The impedance matching slots, which improve wideband characteristics, are inserted in Fig. 9.

The simulated result for return loss is shown in Fig. 10.

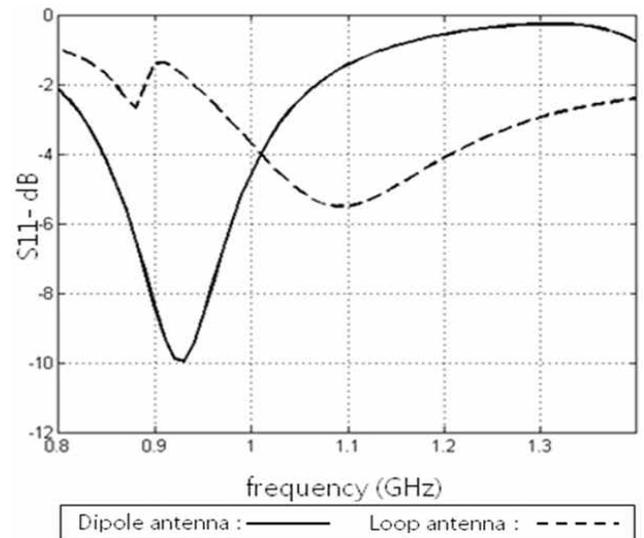


Fig. 8. Simulated  $S_{11}$  results of the dipole antenna and loop antenna when they are separated.

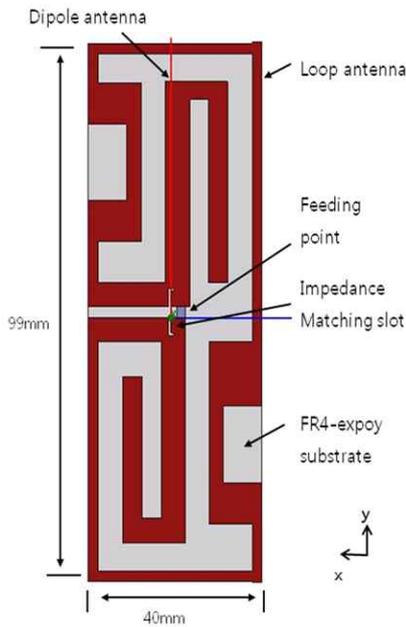


Fig. 9. Combined dipole and loop antenna configuration for RFID tag application.

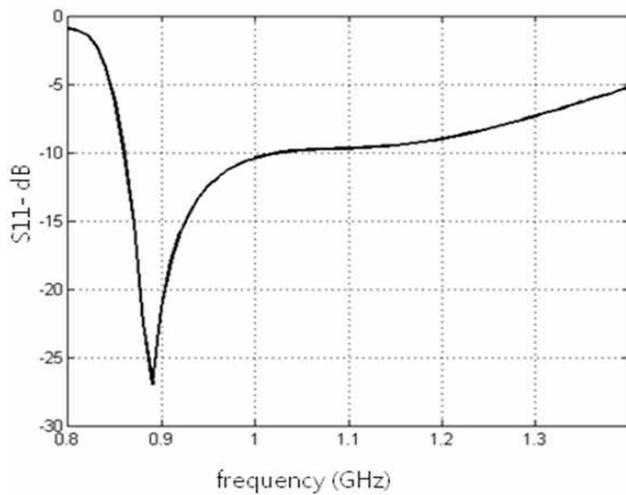


Fig. 10. Simulated  $S_{11}$  results of the combined antenna for RFID tag application.

The center frequency of the combined antenna is 890 MHz, with a 170 MHz bandwidth ( $S_{11} < -10$  dB).

The simulated antenna radiation plots of the combined antenna at 920 MHz are shown in Fig. 11. The radiation gain plots show a directive radiation gain pattern in the  $-z$ -axis direction. The maximum gain values are 3.93 dBi at 920 MHz. The current distribution at 920 MHz on the antenna is shown in Fig. 12. It is shown that the current is evenly distributed in the dipole and loop antenna surface.

The prototype of the proposed antenna has been fabricated, and a photo of the antenna is shown in Fig. 13.

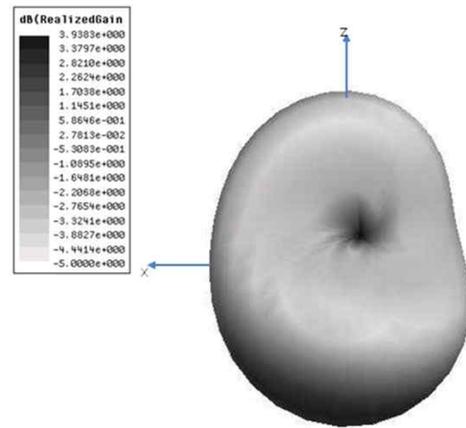


Fig. 11. Simulated radiation pattern of the combined antenna at 920 MHz.

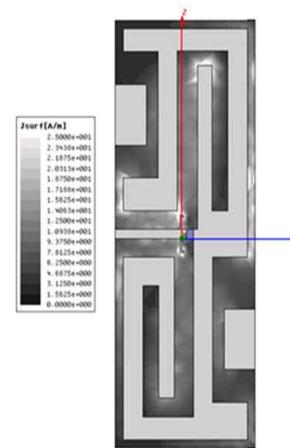
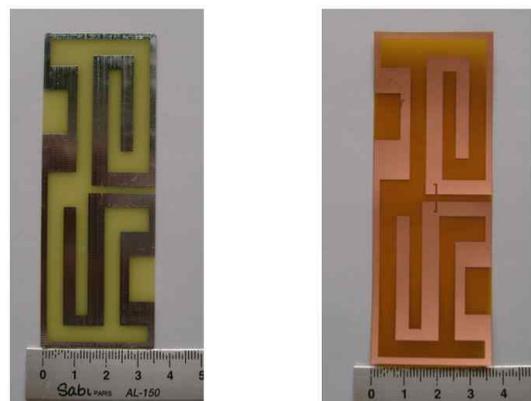


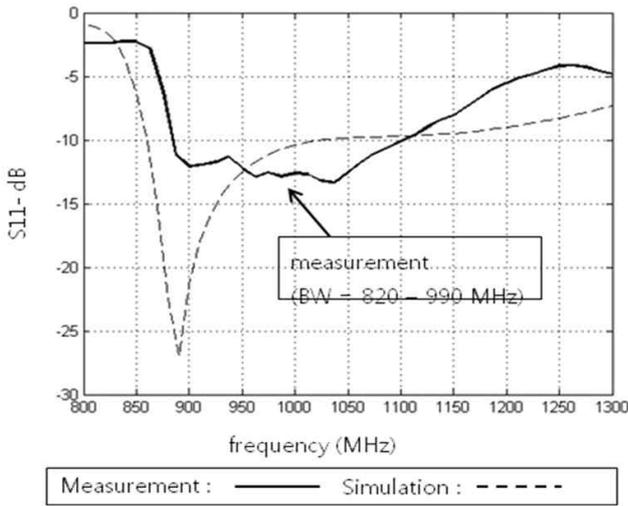
Fig. 12. Current distribution on the antenna surface.



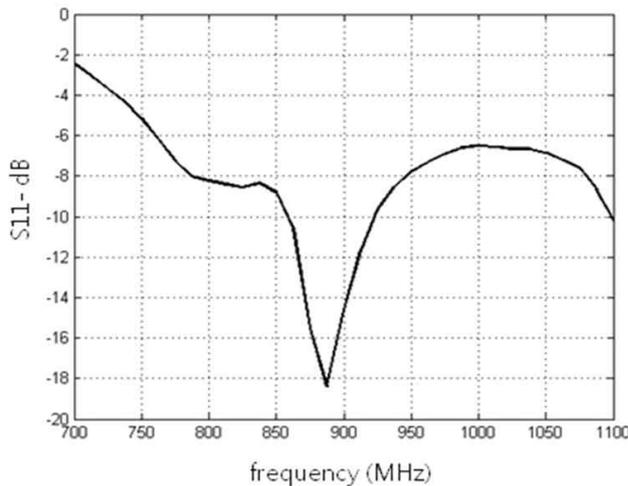
(a) Fabricated on an FR4-epoxy board (b) Fabricated on flexible PCB

Fig. 13. Photograph of the proto-type antenna model.

The return loss and radiation characteristics were measured; the reflection coefficients ( $S_{11}$ ) parameters were measured with an Agilent 8722 ES vector network ana-



(a) FR4-epoxy board



(b) Flexible PCB

Fig. 14. Measured  $S_{11}$  plots of the combined tag antenna fabricated.

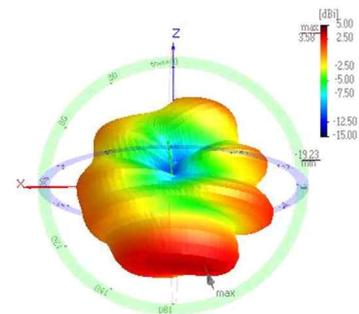
lyzer. Fig. 14(a) shows measured and simulated  $S_{11}$  plot of the combined antenna fabricated on an FR4-epoxy board and Fig. 14(b) shows the measured  $S_{11}$  plot of the combined antenna fabricated on the flexible PCB board. For the antenna on the FR4-epoxy board, the frequency bandwidth defined by  $S_{11} < -10$  dB is approximately from 885~1,100 MHz(225 MHz). For the antenna on flexible PCB board, the frequency bandwidth defined by  $S_{11} < -10$  dB is approximately from 860~920 MHz(80 MHz) and from 1,100~1,160 MHz (60 MHz). It is shown that the combined antenna models have wideband characteristics in the 900 MHz band.

The 3-D gain patterns of the combined antenna fabricated on the FR4-epoxy board were measured in an anechoic chamber and the results are shown in Fig. 15. The proposed antenna has a directive radiation charac-

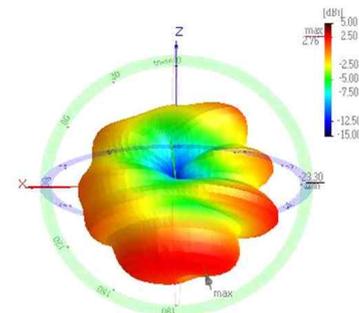
teristic with a maximum gain of 3.58 dBi at 910 MHz and 2.76 dBi at  $f=950$  MHz.

It is noted that the simulation gain patterns shown in Fig. 11 are fairly close to the measured gain patterns. It is shown that the proposed combined antenna for RFID tag application has a directive radiation characteristic.

The measured radiation patterns in the x-z plane and



(a) 0.910 GHz



(a) 0.951 GHz

Fig. 15. Measured 3-D radiation gain pattern plots of the combined tag antenna fabricated on the FR4-epoxy board.

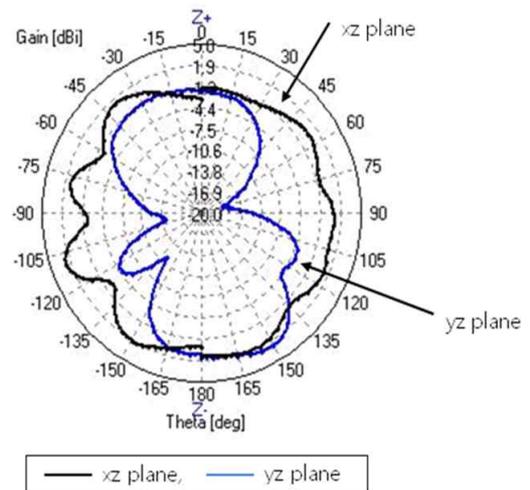


Fig. 16. Measured 2-D radiation gain pattern plots of the combined tag antenna fabricated on the FR4-epoxy board(x-z plane and y-z plane).

y-z plane at 910 MHz are shown in Fig. 16. A maximum gain of 3.58 dBi is observed at  $\theta=150$  degrees and  $\varphi=125$  degrees.

#### IV. Conclusions

In this paper, we introduce a combined dipole and loop antenna with a directive radiation characteristic for a radio frequency identification(RFID) system. For the reader antenna case, the antenna can be inserted or mounted on the mobile hand-set. The antenna gain difference between the forward direction(-x direction) and backward direction(+x direction) is about 1.5~2 dBi. The frequency bandwidth defined by  $S_{11}<-10$  dB is approximately from 820~990 MHz. For the RFID tag antenna case, it has an approximately 225 MHz bandwidth defined by  $S_{11}<-10$  dB between 885 and 1,100 MHz. In addition, it can produce a directive radiation gain pattern with a maximum gain of 3.58 dBi at 910 MHz. The needs for directive antennas will be increased rapidly as new mobile communication services and devices are applied. The introduced combined antennas can be also used for multiple-input multiple-output(MIMO) antenna system and Specific Absorption Rate(SAR) reduction mobile antenna.

This work was supported by 2009 Inha Technical College Research Grant.

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