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Experimental Study on Increasing the Received Power of Antenna using Circularly-Polarized Array Antenna

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ABSTRACT

A method to increase the received power of an antenna system by combining polarization, space and frequency diversities is investigated in this paper. The antenna system under investigation consisted of an array of 10 microstrip antenna elements. Each antenna element is a microstrip antena with circular polarization. Two array antennas with circularly polarized elements have been designed for receiving electromagnetic energy in 900 MHz and 1800 MHz band. Laboratory measurement has been conducted to study the increase of antenna received power caused by combining space, polarizarion and frequency diversities. Results show that the proposed method is able to increase the received power by 12.9 dB at 900 MHz and by 8.4 dB at 1800 MHz in an indoor environment; and by 15.8 dB at 900 MHz and by 9.5 dB at 1800MHz. This increase is mainly contributed by the use of space diversity, namely the use of array of 10 elements which contributed to increase the received power by 10.3 dB in an indoor environment. The useof circularly-polarized element increased the received power by 2.6 dB. Of the three diversities proposed, frequency diversity was found to have the least significant contribution becase the received power from 1800 MHz band is smaller than the 900 MHz band.

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1. INTRODUCTION

Capability to receive high electromagnetic energy is an important characteristic for an antenna system to be used for rectifying antennas (rectennas). The electromagnetic power received by an antenna system is determined by both the antenna efficiency and its receive diversity. To increase the received power of an antenna system, several diversity types can be utilized. High received power is crucial for rectennas, therefore an antenna specifically designed to increase its received power must be used for a rectenna system.

Researches on rectifying antennas have been in progress since the 1960s. At first rectifying antennas were developed for microwave power transmitter for satellite systems [1]. This initial concept has thus been developed for other systems namely Radio Frequency Identification [2], where a rectifying antenna is utilized as a power supply needed by a smart card to transmit identification data. The trend towards developing alternative and renewable energy sources has put rectifying antennas in a new light. Several researches on mechanisms to recycle electromagnetic energy into electrical sources have been conducted [3-5].

A method on microwave energy recycling using rectifying antenna system with a broadband antenna at 2-18 GHz frequency range has been proposed [3]. The received electromagnetic energy can be increased by expanding the effective aperture of the antenna, which is done by using array antenna.

Other attempts to increase the received electromagnetic energy include the use of polarization diversity, in the form of a circularly-polarized antenna [6]. The incident electromagnetic waves with varied polarizations can be exploited more efficiently by antennas with elliptical or circular polarization.

Investigations have been conducted on rectenna systems for particular frequency bands, namely FM Band [4], ISM Band [6], 900-950 MHz [2] and C band [7]. The recyclable energy available at an antenna system will increase provided that the said antenna system is capable to receive electromagnetic energy originating from different frequency bands.

This research investigated a method to increase the received power of an antenna system for rectenna by combining space diversity, polarization diversity and frequency diversity. The antenna system under investigation consisted of an array of 10 microstrip antenna elements. Each antenna element is a microstrip antenna with circular polarization. Two array antennas with circulary polarized elements are designed for receiving eloctromagnetic energy from GSM band, namely 900 MHz and 1800 MHz bands. Laboratory measurement is conducted to study the increase of antenna received power and the contribution of each diversity mechanism.

2. RESEARCH METHOD

For the experimental study we determined the antenna element and its construction method to attain polarization diversity. The next step was to determine the array antenna suitable for two GSM frequency bands namely 900 and 1800 MHz. The antenna dimension was determined using (1) to (9). The design was realized for laboratory measurements and experiments. The received power measurements were taken using a spectrum analyzer. Based on the experiment results, the effects of combining space, polarization and frequency diversities and the contribution of each type of diversity on the increase of received power were analysed.

2.1 Circularly-Polarized Microstrip Antenna Element

In this research microstrip antenna was used as a basic element of the antenna system. A square microstrip antenna on an *xy* plane has an omnidirectional transmit pattern at φ direction and a directional characteristic at angle θ direction due to the existence of a ground plane [6]. Circular polarization is attainable by cutting off the diagonal corners of a square microstrip or exciting the microstrip using two feeds as shown in Figure 1 [8]. In this research the microstrip antenna was designed so that the polarization is nearly circular.

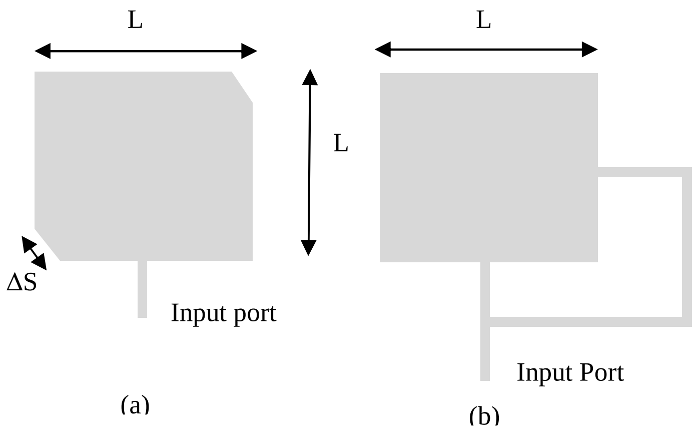

Figure 1. Methods to yield circularly/elliptically-polarized square microstrip antenna (a) Cutting off the Corners (b) Double Feeding

The resonance frequency f_r is a function of the effective length of the antenna, which can be determined using the following:

$$f_r = \frac{1}{2L_{eff}\sqrt{\mu_0\varepsilon_0}\sqrt{\varepsilon_{eff}}} = \frac{v_0}{2(L+\Delta L)\sqrt{\varepsilon_{eff}}} \qquad (1)$$

Therefore the length of the antenna can be derived as

$$L = \frac{v_0}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L \quad (2)$$

Right triangles at the diagonal corners of the antenna are cut off, where the length *c* of the two sides of the triangle is equal, and *c* is calculated using [9]

$$c = \sqrt{\Delta S} \quad (3)$$

ΔS is the area of the triangle, which can be stated as

$$\frac{\Delta S}{S} = \frac{1}{2Q} \quad (4)$$

where :
S is the area of the antenna patch
Q is the quality factor of the antenna patch

To determine the quality factor of the antenna *Q*, the effective loss tangent δ_{eff} as stated below is needed [4]

$$\delta_{eff} = \frac{1}{Q} \quad (5)$$

δ_{eff} can be determined using

$$\delta_{eff} = \delta + \frac{\Delta}{h} + \frac{P_r}{2\omega_0 w_e} \quad (6)$$

Where Δ denotes skin depth and defined by

$$\Delta = 503\sqrt{\frac{\rho}{\mu_r fr}} \quad (7)$$

ρ = conductor resistivity
f_r = resonance frequency
μ_r = medium permeability

The electrical energy w_e at resonance is

$$w_e = \frac{\varepsilon_0 \varepsilon_r ab V_0^2}{8h} \quad (8)$$

where V_0 = antenna output voltage

The radiated power P_r can be calculated using [10]

$$P_r = \frac{V_0^2 A\pi^5}{R_0 192}\left[(1-B)\left(1-\frac{A}{15}+\frac{A^2}{420}\right)+\frac{B^2}{5}\left(2-\frac{A}{7}+\frac{A^2}{189}\right)\right] \quad (9)$$

where R_0 = intrinsic impedance of free-space
with $A = [\pi(a+2\Delta a)/\lambda_0]^2$ and $B = [\pi(b+2\Delta b)/\lambda_0]^2$ and since a square antenna is used, a = b = L.

2.2. Antenna Array and Frequency Diversity

To increase the received electromagnetic power, circularly-polarized microstrip array antenna is used. Based on Pointing theorem, the receive power of the antenna can be increased by expanding the aperture of the antenna. The array configuration is given in Figure 2. The elements are distanced at λ/4 at *x* direction and λ/2 at *y* direction. The distance in each direction is determined on the basis of minimum coupled impedance between elements, so that each element can be considered independent. Based on this assumption, an array of *n* antenna will theoretically increase the antenna gain by a factor of 10 *log n* [8]. In our experiment the number of antenna elements are 10 so that antenna is expected to increase the receive power by 10 dB.

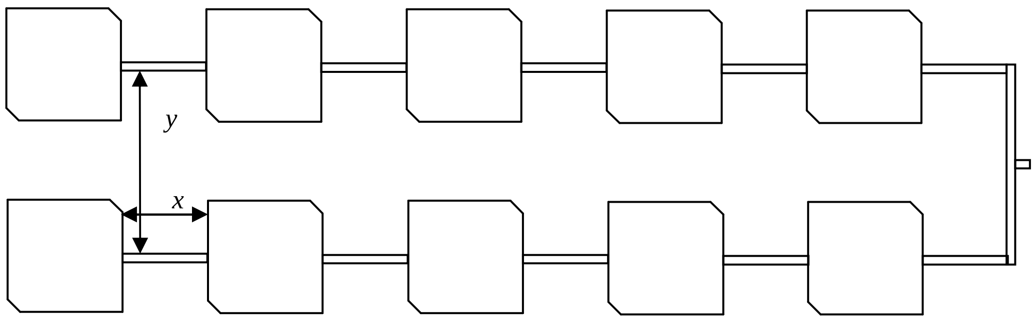

Figure 2. Array of 10 circularly-polarized square microstrip antenna elements

To attain frequency diversity, 2 microstrip antenna elements with circular polarization at frequencies 900 and 1800 MHz were used. If each antenna receive the same power level then the total receive power will increase by 3 dB. The proposed element is given in Figure 3 and the dimension of each element is given in Table 1. Using (1) to (9) the dimensions of the proposed antenna can be calculated. The antenna was designed using FR4 epoxy dielectric substrate with ε_r=4.4 and height (*h*) 0.8 mm. Table 1 shows the calculated dimensions of the antenna.

Table 1. Dimension of a circularly-polarized square microstrip antenna

	Frequency Band 900 MHz	Frequency Band 1800 MHz
ΔS	4.27 mm	3.17 mm
L	75.47 mm	38.78 mm

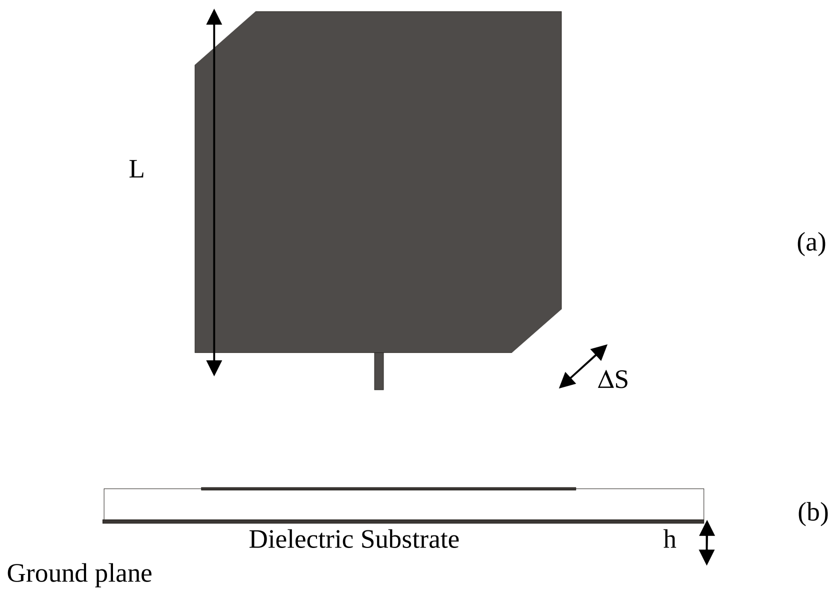

Figure 3. Structure of circularly-polarized square microstrip antenna (a) Top view (b)Side view

3. RESULTS AND ANALYSIS

Microstrip antenna element for frequency band 900 MHz has been designed for 947 MHz. The axial ratio measurement was done by comparing the received power from the dipole antenna in Figure 4 which is connected to a signal generator and oriented to *x* and *y* directions. The result of axial ratio measurement at the antenna main lobe direction shows that the antenna has an axial ratio of 0.9 dB, which is categorized as nearly circular polarization. The result of polarization measurement is given in Table 2.

Microstrip antenna element for 1800 MHz band was designed for 1844 MHz. Axial ratio measurement result at the direction of the antenna main lobe shows that the antenna possesses an axial ratio of 1 dB, which can be categorized as nearly circular polarization. The result of the polarization measurement is given in Table 2. To investigate the effect of polarization diversity of a circular antenna to increase the received power, the received power was compared to that of a printed dipole linear antenna. The measurement result is given in Table 3. The received powers of a linear and circular antenna differ by 2.6 dB in an indoor environment, whereas in an outdoor environment the difference is 3.9 dB. This shows that a circularly-polarized antenna will increase the received power by 2.6 dB in an indoor environment, and by 3.9 dB in an outdoor environment.

To investigate the effect of using antenna array to increase the received power, we used an array antenna comprising of 10 circularly-polarized microstrip elements as shown in Figure 4 and 5. The measurement result is given in Table 4. Theoretically circularly-polarized elements have the same received levels at two orthogonal directions (x and y) and the total received power increases by 3dB compared to that of linearly-polarized elements. Experiments with circularly-polarized microstrip antenna indicates a relatively same result with theoretical. Considering the theoretical and experimental results, polarization diversity attained by circularly-polarized antenna elements will increase the received power by about 3 dB.

Table 2. Polarization Measurement Results At Antenna Main Lobe for 900 and 1800 MHz

Frequency	Reception at *y* direction	Reception at *x* direction	Axial Ratio
	900 MHz Antenna		
925	-16.4 dBm	-17.6 dBm	1.2 dB
930	-16.6 dBm	-17.3 dBm	0.7 dB
947	-16.6 dBm	-17.3 dBm	0.7 dB
950	-16.5 dBm	-17.4 dBm	0.9 dB
955	-16.4 dBm	-17.5 dBm	1.1 dB
925	-16.4 dBm	-17.6 dBm	1.2 dB
	1800 MHz Antenna		
935	-14.6 dBm	-15.6 dBm	1 dB
1830	-14.6 dBm	-15.5 dBm	0.9 dB
1844	-14.5 dBm	-15.5 dBm	1 dB
1850	-14.5 dBm	-15.5 dBm	1 dB
1855	-14.7 dBm	-15.8 dBm	1.1 dB

Table 3. Received Power Measurement Result of Linearly- and Circularly-Polarized Antennas

	Linear Antenna (printed dipole)	Circular Antenna (circular microstrip antenna)
Received power, indoor environment	-98.6 dBm	-81.2 dBm
Received power, outdoor environment	-99.5 dBm	-83.4 dBm

Table 4. Received Power Measurement Results of a Circularly-Polarized Array Microstrip Antenna

900 MHz Band	Single Element	Array of 10 Elements
Received Power, Indoor environment	-81.2 dBm	-68.3 dBm
Received Power, Outdoor Environment	-83.4 dBm	-67.6 dBm
1800 MHz Band	Single Element	Array of 10 Elements
Received Power, Indoor environment	-91.4 dBm	-83 dBm
Received Power, Outdoor Environment	-91 dBm	-81.5 dBm

The measurement results show that an array of 10 circularly-polarized microstrip elements will increase the received power by 12.9 dB at 900 MHz and by 8.4 dB at 1800 MHz in an indoor environment. For an outdoor environment, the array of 10 circularly-polarized microstrip elements will increase the received power by 15.8 dB at 900 MHz and by 9.5 dB at 1800 MHz.

Circular polarization has been shown to increase the received power by 2.6 dB in an indoor environment. Since the use of 10 circularly-polarized microstrip elements show an increase of received power by 12.9 dB, it can be concluded that the array contributes to increase the received power by 10.3 dB. The contribution of an array antenna to increase the received power in an outdoor environment is 11.9 dB. Theoretically, the use of 10 antenna elements will increase the received power by 10 dB. The discrepancy between the theoretical and the experimental results are due to imperfections in the measurement environment. Received power can be increased by increasing the number of array element.

Frequency diversity was attained by combining the received power of the array at 900 and 1800 MHz. However as the received power of 1800 MHz array is relatively lower than 900 MHz array, the combination of the two will not significantly affect the increase of the received power in dB.

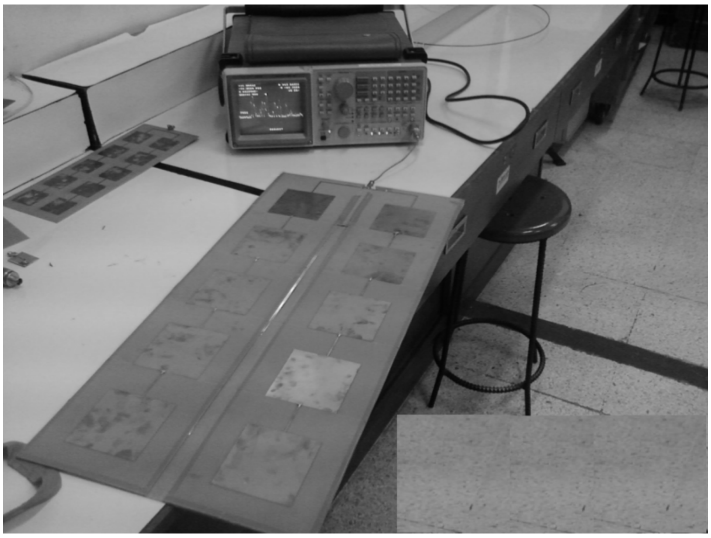

Figure 4. Measurement of Circularly-Polarized Microstrip Array Antenna at 900 MHz

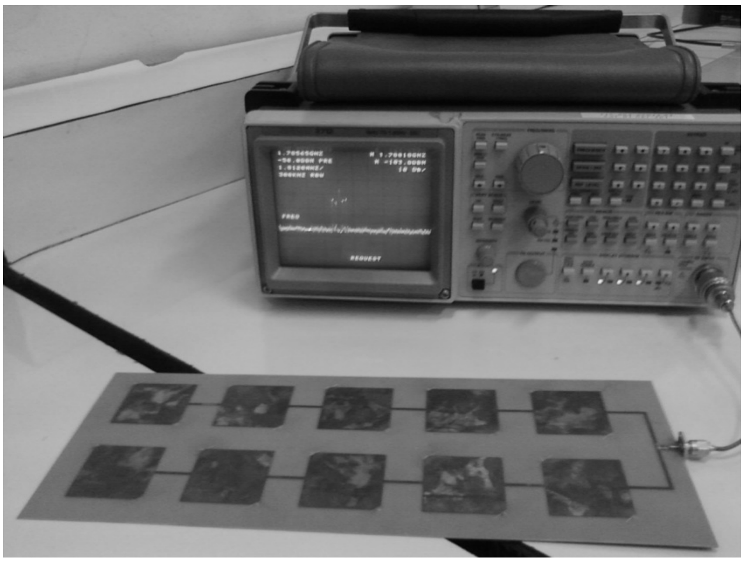

Figure 5. Measurement of Circularly-Polarized Microstrip Array Antenna at 1800 MHz

4. CONCLUSION

Laboratory experiments showed that the combination of polarization diversity and the use of both antenna array and frequency diversity into one system will increase the received electromagnetic power of an antenna. In an array of ten circularly-polarized microstrip antenna, the array is the main contributor of the increase of the received electromagnetic power. The least contribution to the received power is attained through frequency diversity. Experiments showed that the use of circularly-polarized square microstrip array antenna can increase the received power by 12.9 dB, from which 2.6 dB was contributed by polarization diversity and 10.3 dB was contributed by the array of 10 antenna elements.

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