Antenna Design for Switched-Beam Systems on Mobile Terminal

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Abstract: - In this paper, we propose a small switched-beam antenna for mobile terminal. This kind of antenna is a single compact slot antenna fed by microstrip line. This proposed antenna provides three different radiation patterns. The antenna is designed to cover 3G Universal Mobile Telecommunication Systems (UMTS; 1.92-2.17 GHz). Its advantage is small of size and easy to manufacture. The performance of proposed antenna is confirmed by both simulation and experimental results. In addition, the antenna is also tested under real environment to see its real performance in terms of signal strength and throughput. The obtained results show that it provides higher signal strength and throughput over the use of omni-directional antenna as currently employed in mobile terminal.

Key-Words: - 3G phone, Antenna design, Array antennas, Microstrip antenna, Mobile phone antennas, Switched-beam antennas

1 Introduction

Third generation (3G) is the terms to be used to describe the generation of mobile services which provide advanced voice communications and high-speed data connectivity, including access to the Internet, mobile data applications and multimedia content for users. This new generation mobile phone provides oral and written communication as well as video call, video messages, music player, data transfer and even other computer functions as office applications for their users. However, the mobile phone has a problem involved by interference signal coming from some other directions. So far, one efficient technique to ease this problem is smart antennas systems.

The smart antenna systems can be categorized into two types which are adaptive and switched-beam antennas [1]. The adaptive antenna can steer its main beam to desired direction. Additionally, side lobe or null are generated in the direction of interference by adjusting or weighting the received/transmitted signal. On the other hand, the switched-beam antennas select the beam direction relative to the maximum signal output from a number of fixed beam directions. However, switched-beam antennas avoid impairment of complexity and expense. So far, the smart antenna systems have been mainly installed at base station. This introduces some difficulties such as cost and complexity. Therefore, we focus on an idea utilizing switched-beam antennas in mobile terminal instead. However, the issue of size still remains. As a result, the main objective of this paper is to design a simple single element antenna capable of beam switching for mobile terminal.

From literatures, there are many studies designing antennas in terms of microstrip patch antenna for mobile phone [2-4]. For the work presented in [2], the authors have presented the multiband antennas using single microstrip patch antenna. In addition, a novel feeding technique has been proposed in [3]. The mentioned work has proposed to enhance the required bandwidth and reduce the size of microstrip patch antenna. However, the size of antenna is still a problem in which it cannot be installed in mobile terminal. For the work presented in [4], the authors have proposed a novel printed compact multiband planar antenna but the substrate is relatively thick. However, most of the antenna proposed for mobile terminal have omni-direction radiation. According to this, the interference signal coming from other directions cannot be tackled.

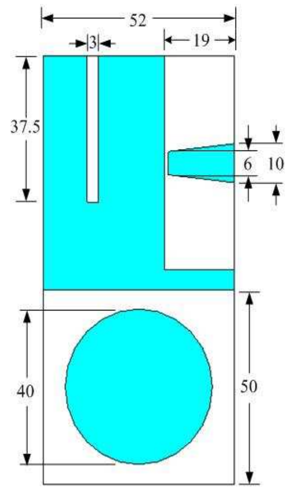
In [5], the authors have discussed about smart antenna systems for UMTS systems. However, the systems have been designed for base station, not mobile terminal. From literatures, there are a number of papers discussing about smart antennas on mobile terminal [6-8] to improve spectral efficiency and link quality. For the work presented in [6], the performance study of adaptive array antennas on mobile handset in the vicinity of a human operator has been presented. In addition, a number of monopole antennas have been employed. Also, the antennas are placed outside the mobile terminal. This is considerably not practical. In [7-8], they have studied the performance of W-CDMA adaptive array antennas. The authors have employed four monopole antennas. Then again, the overall size of antenna is too large to be implemented on mobile terminal. In addition, the systems are relatively complicated to be implemented on mobile terminal. The work presented in [9] have shown the use of switched-beam antennas on mobile terminal. For the mentioned work, a diversity combining technique have been proposed. However, overall size of antennas is still too large to be installed on mobile terminal.

The idea of this paper is to design a simple symmetrical structure offering the possibility of pattern diversity or beam switching by using various feeding points. Therefore, this paper presents a switched-beam antenna offering the possibility to adjust the main beam of the antenna in three directions using three different feeding points based on a combination of a slot antenna for UMTS (1.92-2.17 GHz) frequency bands. The proposed antenna can be easily fabricated on single layer PCB board. The antenna provides three different main beam directions which brings to interference reduction. The final design is confirmed by experiment to provide good return loss for all ports. The type of proposes switched-beam antenna is circle slot antenna and linear Tapered Slot Antennas (TSAs). The TSAs have lots of advantages such as low profile, low weight, low cost, easy fabrication, suitability for conformal installation and having directional radiation pattern [10].

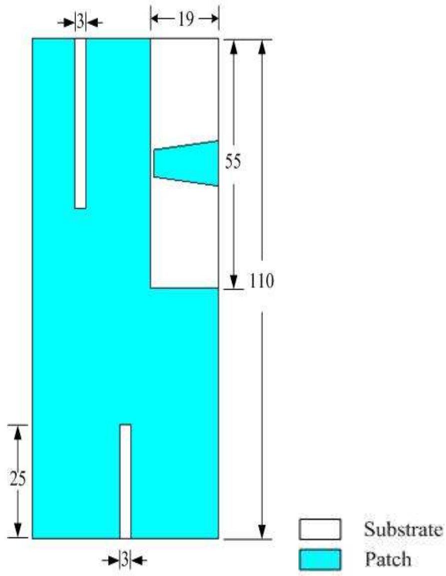
The remainder of paper is organized as follows. Section 2 describes the details of antenna design. Then simulation and experimental results including discussion are also given in Section 3. Then, Section 4 confirms the real performance of fabricated prototype in real environment. Finally, Section 5 concludes the paper.

2 Antenna Design

The configuration of proposes antenna is shown in Fig. 1. We have adopted the advantages of the antenna presented in [10] as its simplicity. Note that the antenna was designed on a single-layer printed circuit board using FR4-substrate with dielectric constant of 4.8 and the substrate thickness of 1.6



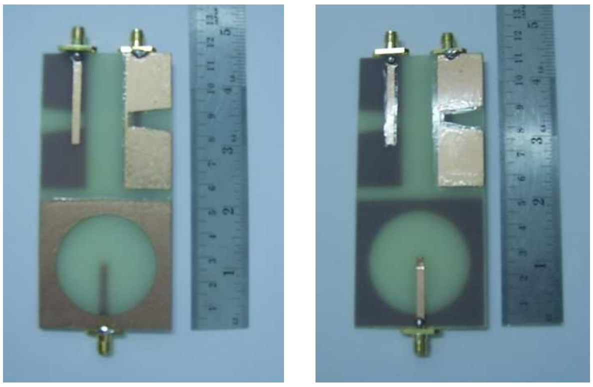
(a)



(b)

Fig. 1 Configuration of propose antenna in mm
(a) front view (b) back view

mm. The size of the main substrate is 52×110×1.67 mm^3. The overall size and dimension of the antenna is shown in Fig. 1. The proposes antenna is supposed to be fed by a 50Ω microstrip-line and its dimensions are 3×37.5 mm^2 and 3×25 mm^2 [11-12]. Two types of antennas are incorporated into the patch e.g. two parts of linear TSAs and a single circle slot antenna. The height of antenna is 55 mm, 50 mm, respectively and width of 19 mm, 52 mm, respectively. Note that this antenna element is designed for frequencies from 1.92 to 2.17 GHz.



(a) (b)

Fig. 2 Photograph of proposed antenna: (a) front view (b) back view.

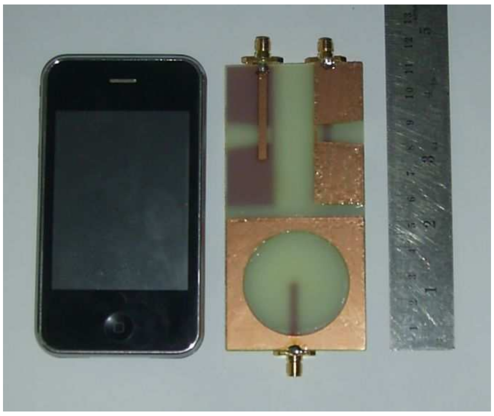
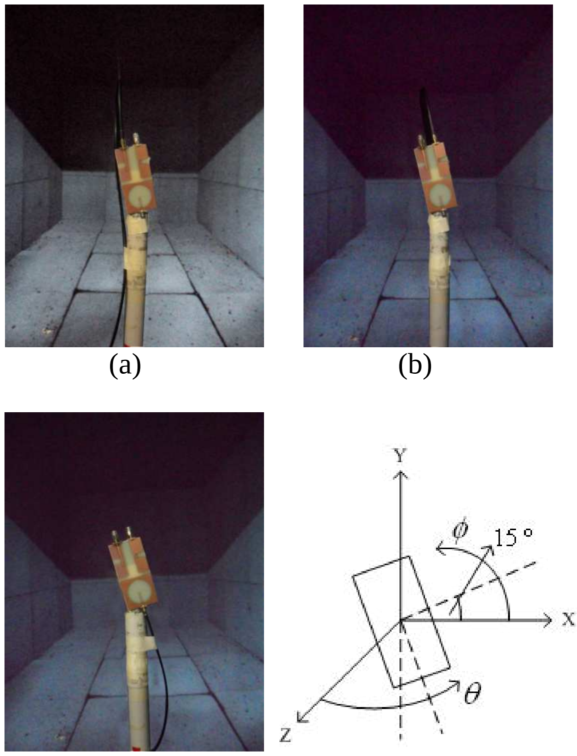


Fig. 3 Photograph of proposed antenna compared with iPhone.

The parametric analysis for antenna configuration is performed by numerical ways using CST simulator [13]. For the slot antennas, we firstly design for two pieces for linear tapered slot antennas. Secondly, we design a single circle slot antenna with its diameter of 20 mm. Performance of the proposed switched-beam antenna in this paper relies on its radiation pattern which is obtained from simulation and experiment. The CST Microwave Studio is utilized as a tool for simulation at the center frequency, f_c = 2.045 GHz. To confirm its performance, the photograph of proposed switched-beam antenna has been fabricated as shown in Fig. 2. The dimension of entire structure is small enough to allow the integration into a small handset as shown in Fig. 3.

We use a network analyzer to evaluate the prototype performance in terms of return loss and radiation pattern. Fig. 4 shows the measurement of its return loss using network analyzer. The cable is

Fig. 4 Photograph of return loss measurement.



(c) (d)

Fig. 5 Antenna measurement in anechoic chamber while feeding at (a) port1, (b) port2 and (c) port3 and (d) measurement position.

connected to each port at a time to measure its own return loss. Then, the radiation patterns of the antenna prototype are measured in an anechoic chamber as shown in Fig. 5. In this case, we slant the antenna with 15 degree apart from *x*-axis for all port as shown in Figs. 5(a)-(d). This is because the simulation results which will mentioned in next section reveal that the antenna gives maximum gain at this slanted plane. Next section shows the measured results in terms of return loss, radiation pattern, gain and polarization comparing with the ones obtained from computer simulation.

3 Simulation and Measurement Results

This section evaluates the performance of antenna prototype in terms of radiation pattern, return loss, gain and polarization. Also, some computer simulations have been produced to design the antenna using CST Microwave Studio. The comparison of those results are as follows.

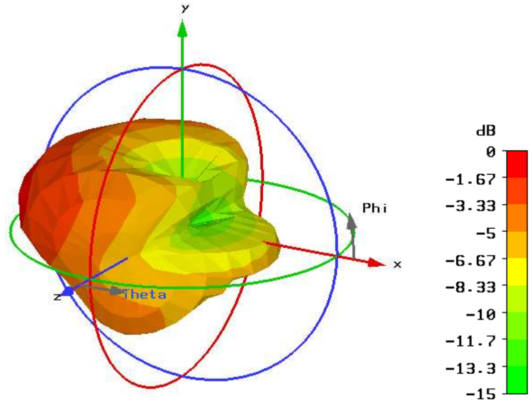
3.1 Radiation pattern

In the following simulations and measurements, each port is excited separately, while the two other ports are terminated with 50 Ω resistances. The proposed antenna configuration was designed using CST Microwave Studio and simulation results obtained from this programing are also compared with experiments results.

Fig. 6 shows the simulated radiation patterns of the proposed antennas in 3D. As we can see, the antenna can be directed to three different directions. Also, Fig. 7 shows the comparison of simulated and measured radiation patterns at the center frequency, f_c = 2.045 GHz, on ϕ-plane when ports 1, 2 and 3 are separately fed. As we can see, there are good agreements between simulated and measured ones in which its main beam can be directed to three different directions. In addition, the radiation patterns on θ-plane are revealed in Fig. 8. In this figure, the comparison of simulated and measured radiation pattern at the center frequency of proposed antennas when feeding to ports 1, 2 and 3. As expected, the simulated radiation patterns have the same trend comparing to measured ones. Also, the proposed antenna shows different three direction patterns e.g., front-back right and left directions. Also, beam directions are moderately comparable. Up to this point, the obtained results confirm that our low cost prototype is capable of three-direction beam steering.

3.2 Return loss

One important parameter to determine if the antenna w very well is return loss. For our proposed antenna, its measured and simulated return losses are shown in Fig. 9. In this figure, return losses (S1,1) in cases of simulation and measurement are compared. As we can see, the antenna provides a proper



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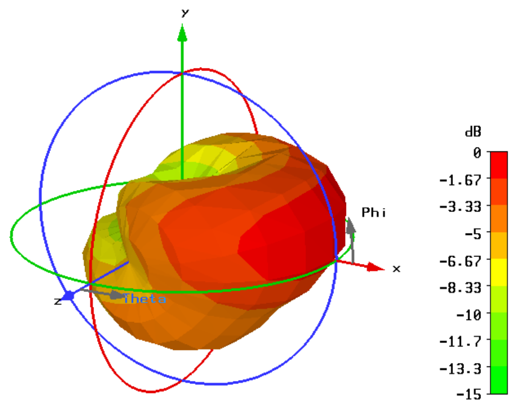

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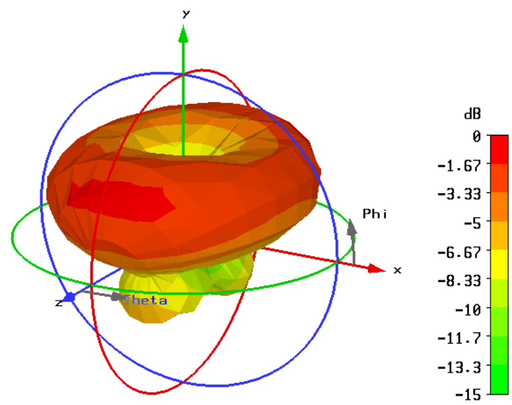


(c)

Fig. 6 Simulated 3D radiation pattern of the propose antennas when feeding at (a) Port1, (b) Port2 and (c) Port 3.

performance in terms of simulation having return loss lower than -10dB from frequencies 1.283 - 2.267 GHz, 1.278 - 2.2198 GHz and 1.888 - 2.671 GHz when feeding at port 1, 2 and 3 respectively. Also, we achieve similar results when performing measurement as follows. The antenna works very well from frequencies 1.42 - 2.35 GHz, 1.45 - 2.51 GHz and 1.9 - 2.9 GHz when feeding at ports 1, 2 and 3 respectively.

3.3 Gain

From simulation, the gains of the proposed antenna are 4.86 dB, 4.98 dB and 1 dB when feeding at ports 1, 2 and 3 respectively. Also, the measured gain is 4.17 dB, 4.72 dB, and 1 dB when feeding at ports 1, 2 and 3 respectively. The obtain results have a good agreement to each other.

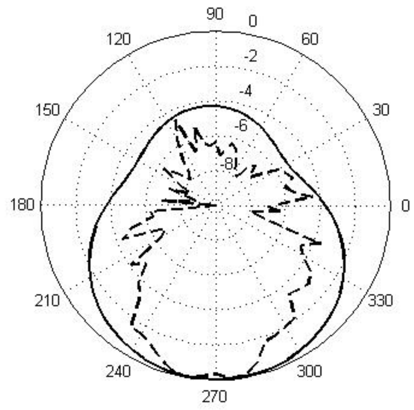
3.4 Polarization

To study the polarization of proposed antenna, we apply the radiation pattern measurement to indicate the type of polarization. Fig. 10 shows the measured polarization of the proposed antenna when we input the signal at ports 1, port 2, and port 3 respectively. The measurement was performed at far-field region which is 2 meters between transmitting and receiving antennas. The similar antennas are employed at both sides.

The general polarization of an antenna is characterized by Axial Ratio (AR) which can be approximated by the following formula (1)

$$AR = \frac{OA}{OB} \tag{1}$$

where OA is one half of major and OB is one half of minor types of polarization which are shown in Table 1. If the proposed antenna is circularly polarized, the axial ratio is $0 \leq AR < 3$ dB. In addition, if the proposed antenna is elliptically polarized, the axial ratio $3 \leq AR < 14$ dB. Otherwise, if the proposed antenna is linearly polarized, the axial ratio is $18.2 \leq AR < \infty$ dB [14]. From the results shown in Fig. 10, when we input signal at ports 1, 2 and 3, AR are 21.35, 20.25 and 22.4 dB respectively. This confirms that the proposed antenna is linearly polarized for all port excitation which is compatible with wave polarization from mobile base station.



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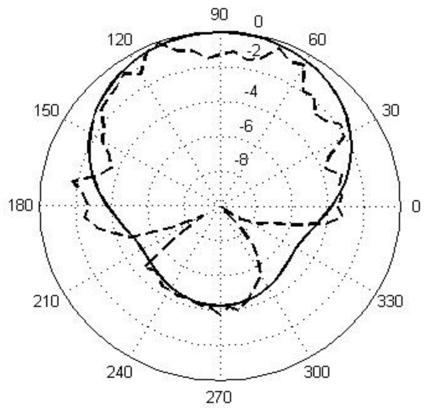

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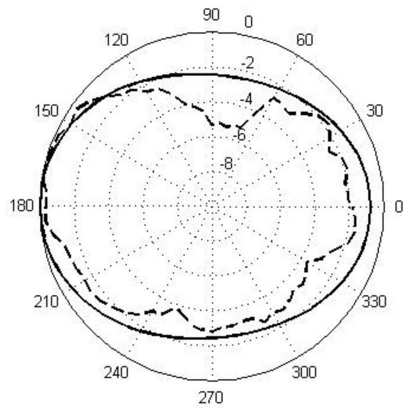

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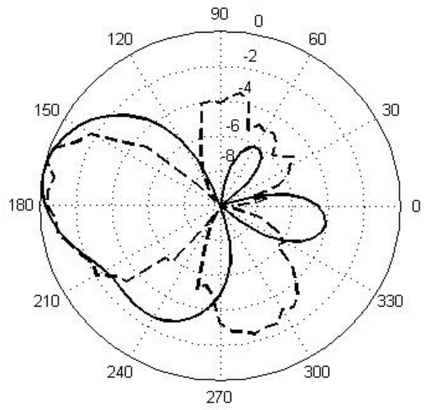
Fig. 7 Simulation and measured radiation patterns of propose antennas in ϕ-plane when feeding at (a) Port 1, (b) Port 2 and (c) Port 3.



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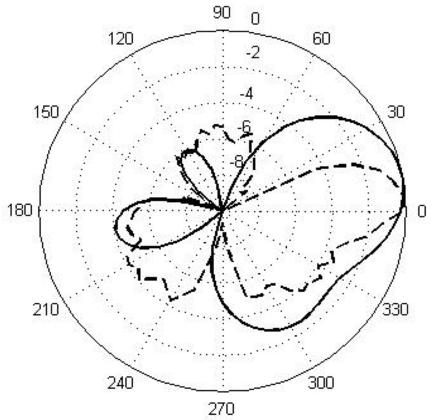

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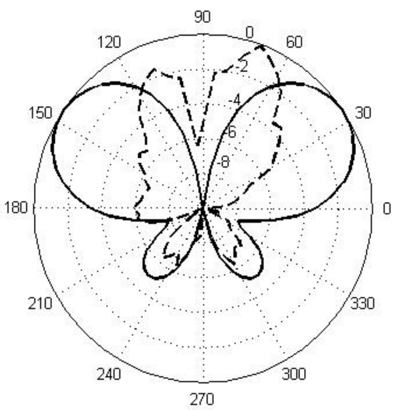
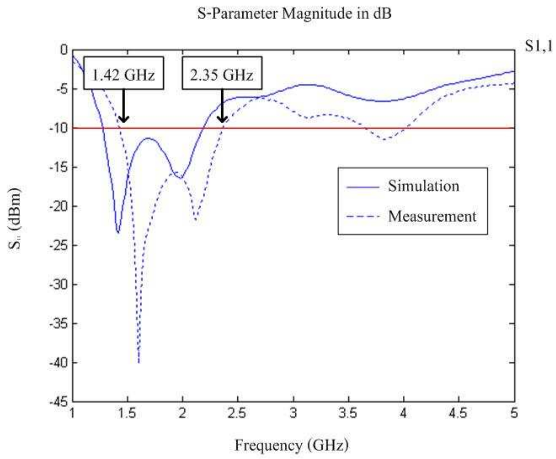


(c)

Fig. 8 Simulated and measured radiation pattern of proposed antennas in θ-plane when feeding at (a) Port 1, (b) Port 2 and (c) Port 3.



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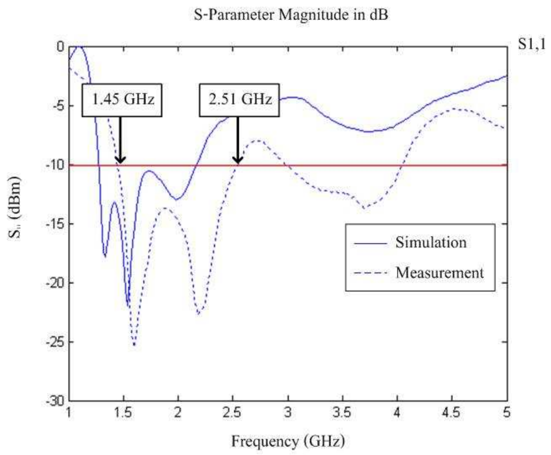

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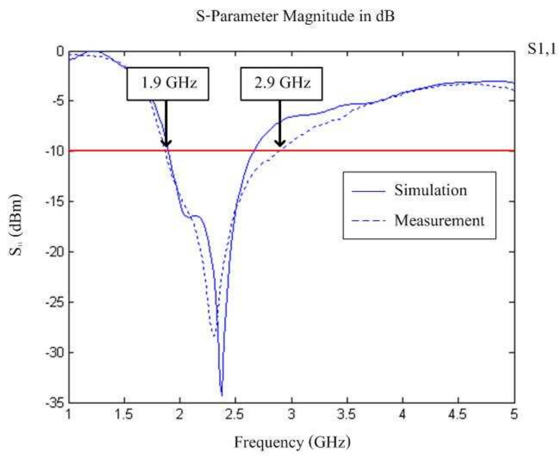
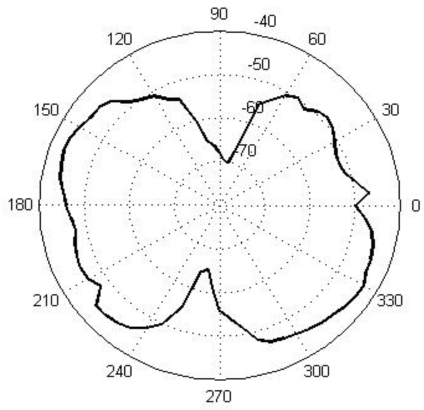


(c)

Fig. 9 Simulated and measured return loss (S1,1) of proposed antenna when feeding at (a) Port 1, (b) Port 2 and (c) Port 3.



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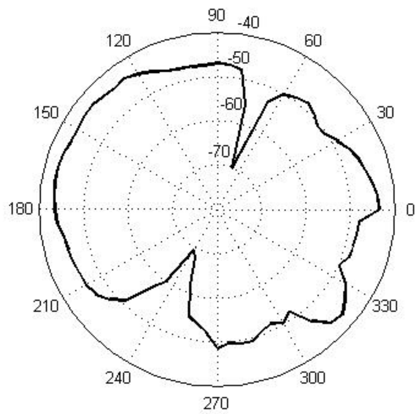

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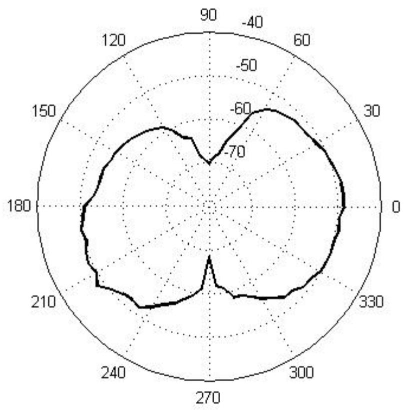


(c)

Fig. 10 Measured polarization of proposed antenna when feeding at (a) Port 1, (b) Port 2 and (c) Port 3.

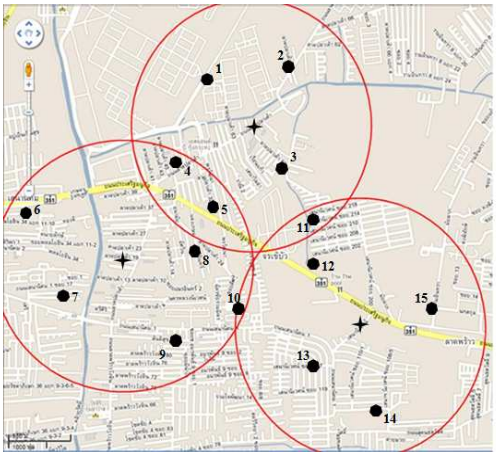
4 Real Environment Test

To confirm the performance of proposed antenna, the fabricated prototype is tested under existing 3G operations (2.1 GHz) at Ladprao zone, Chokchai 4 zone and Ladplakao zone in Bangkok, Thailand. The location of base stations and measurement are shown in Fig. 11. We chose 5 base stations located in different areas as seen in star symbols. Also, 24 location were chosen for measurement as shown in the figures as seen in black dot symbols. To confirm the stability of measured signal, 3 times of measurement are undertaken at each location. The prototype is connected to Air Card 3G Sierra Wireless 850 as shown in Fig. 12. In real environment test, we measure two parameters including signal strength and throughput. The comparison between using the proposed and omni-directional antenna is in focus. Note that monopole antenna is used in case of omni-directional antenna.

The measured signal strength and throughput for all cases mentioned above are shown in Figs. 13 and 14 respectively. The circle symbol represents the value of signal strength and throughput for the case of omni-directional antenna and also triangle symbol represents the value of signal strength and throughput for the case of proposed antenna. As we can see, signal strength in case of proposed antenna is always higher than the ones obtained from using monopole antenna. The average value indicates that we can improve signal strength up to 2.74 dB over the use of monopole antenna. Furthermore the throughput in case of proposed antenna is always higher than the ones obtained from using monopole antenna. The average value indicates that we can improve throughput up to 72.18 kbps over the use of monopole antenna. This is because the proposed prototype allows beam switching in different direction, hence increasing gain and interference avoidance.

5 Conclusion

The paper has proposed a design for switched-beam antenna on mobile terminal using slot antenna fed by microstrip line. The proposed antenna has three radiation patterns from three different feed positions. The simulation and measured results confirms the performance of proposed antenna in terms of radiation pattern, return loss, gain and polarization. In addition, the real performance of proposed antenna is tested under real environment in terms of signal strength and throughput. The overall outcome shows that the proposed antenna outperform omi-directional antenna for mobile terminal. This is because the antenna is capable of



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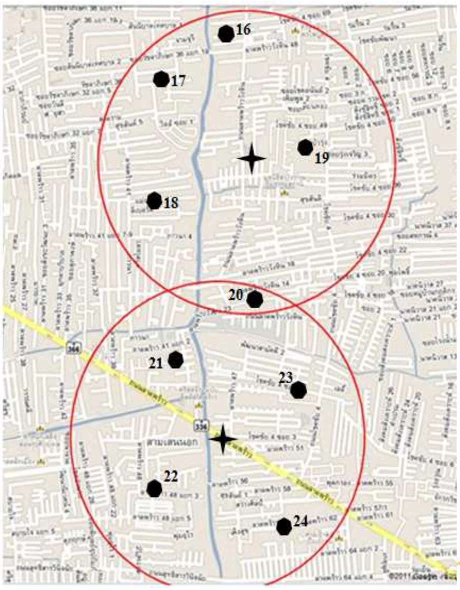

(b)

Fig. 11 Measurement location.

Fig. 12 Measurement setup under existing 3G scenarios.

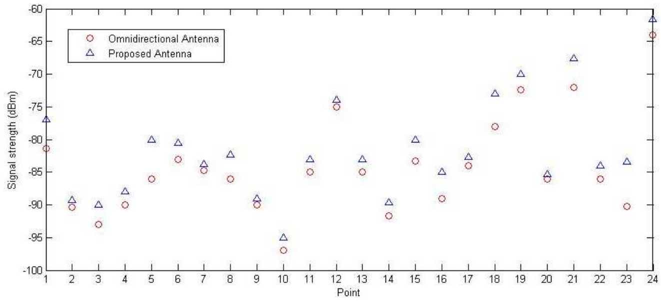

Fig. 13 Measured signal strength (dB) in real environment.

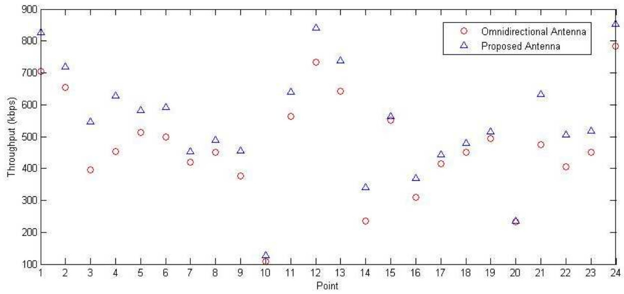

Fig. 14 Measured throughput (kbps) in real environment.

interference avoidance. The advantages of this antenna is that it is small of size for mobile terminal. Also it has a simple structure as can be easily fabricated on single layer PCB.

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