Gain and Pattern Improvements of Array Antenna using MSA with Asymmetric T-shaped Slit Loads

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Abstract: - This paper presents a 1×4 array antenna using asymmetric T-shaped slit loaded microstrip antenna (MSA). The antenna consists of four MSAs align vertically on a dielectric substrate and ground plane. This antenna will be utilized in WLAN applications as the commercial panel antenna. A modified array configuration is proposed to further enhance the antenna radiation characteristics and usable bandwidth. The desired patterns of array are improved by adjusting the array element spacing from λ/2 down to λ/3. Moreover, alternating of the slit loads positions on each side of some patches in array can control the directive patterns to be symmetric shapes. The measured results of the radiation pattern, input impedance, return loss, VSWR, directive gain, and are also conducted for verification of the IE3D-based simulated results. With good agreement between the simulated and measured results and accordance of the requirements, therefore, this proposed panel antenna is appropriate for the wireless applications.

Key-Words: - Array Antenna, Directive Gain, Microstrip Antenna, Radiation Patterns, Slit Load

1 Introduction

At present, the advance of wireless systems require an increasment in bandwidth and sharing in limited frequency bands, particularly in PDC (Personal Digital Cellular Telecommunication System), PHS (Personal Handy-Phone System), IMT-2000 (International Mobile Telecommunication-2000), and WLAN (Wireless Local Area Network) [1]. The popular antennas for WLAN access point are linear dipole, slot array, and microstrip antenna [2]-[4]. These antennas will be usually placed at the well of rooms or buildings. Several designs of the single feed dual-band Microstrip Antennas (MSAs) have recently been reported, for example, a dual-band circularly polarized aperture-coupled stacked microstrip patches [5], a spur-line filter-embedded nearly square microstrip patch [6], a circular microstrip patch with two pairs of arc-shaped slots [7], a broad-band U-Shaped PLFA with dual band capability for Bluetooth and WLAN [8], and a square MSA inserted with four T-shaped slits at the patch edges or four Y-shaped slits at the patch corners [9]-[10]. The lattermost one proposed a reactively-load technique which is using four T-shaped slit loads on each patch edge symmetrically. It is small of size, low of cost, low of profile, and light of weight compared to the work which are presented in [5]-[7]. Nevertheless, its dual bandwidths of 1.17% and 1.05% are not sufficient to be implemented as well as it is not suggested to be used in any application. Therefore, Wongsan *et al.* [12] reported an alternative technique providing dual-frequency wider bandwidth MSA using a rectangular patch and modifying the dimensions of four T-shaped slit loads asymmetrically. Moreover, the thickness of FR4 substrate was increased from 1.6 mm to 3.2 mm in order to enlarge the lower and higher bands of this antenna. However, the antenna has low directive gain and asymmetric radiation pattern.

In this paper, we present an array antenna using the rectangular patch array with asymmetric T-shaped slit loaded MSA. The high directive gain is presented along with a parametric study based on numerical and experimental results. In addition, the radiation patterns are presented for a modification by alternating the slit loads positions on each side of rectangular patches array configuration. The simulation for the proposed antennas are performed by using the IE3D-based simulations. The measured results of the radiation pattern, input impedance, return loss, VSWR, directive gain are also conducted for verification of the simulated results.

Section 2 describes the array antenna configuration using a rectangular patch with asymmetric T-shaped slit loaded MSA and numerical results. In addition, we present details of pattern improvement which are adjusted by element patch spacing and modified by alternating the slit loads positions on each side of patches. The measured results for the 1×4 arrays are reported and compared with the simulated results in section 3. Finally, this paper is concluded in section 4

2 Array Antenna Configuration and Numerical Results

Fig. 1 illustrates the dual-frequency of single-feed slit-loaded rectangular microstrip antenna. The antenna consists of four T-shaped slits inserted at the patch edges. The rectangular patch has a side length L and width W, printed on a substrate of thickness h and relative permittivity ε_r. A narrow center slot of dimensions $l_s \times w_s$ $(l_s > w_s)$ is embedded in the x-axis near the patch center of the rectangular patch. A single probe feeds at point (x_p, y_p) along the diagonal of the patch. For the designed dimensions of four T-shaped slit, the left and right arms have the same dimensions of a narrow width s_1 and a length l_1. The dimension of each center arm is indicated by $d_1 \times w_1$ with the different arm width $d_1 > d_2$. The dimensions of upper and center arms are of $s_2 \times l_2$ and $w_2 \times d_2$, respectively. The dimensions of lower and center arms are of $s_3 \times l_2$ and $w_3 \times d_2$, respectively. Using those dimensions, the operating frequency is higher.

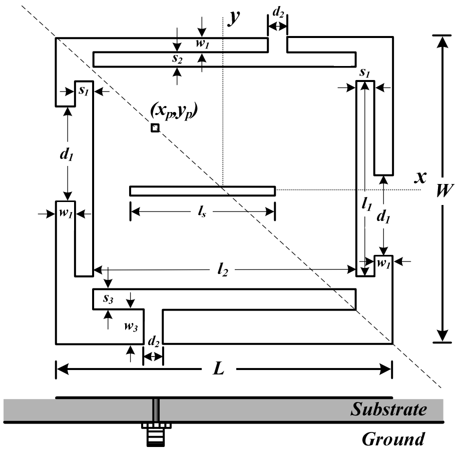


Fig.1 Dual-frequency rectangular microstrip antenna with asymmetric T-shaped slit loads.

Moreover, it is found that both shifting a narrow slot out of the patch center along the negative x-axis and increasing the height of substrate can increase bandwidths to cover the required ISM (Industrial Sciences Medicine) bands.

An asymmetric T-shaped slit loaded antenna has the following parameters: ε_r = 4.4, ground-plane size = 7.5×7.5 mm^2, h = 1.6, (x_p,y_p) = (-8.25,6.275), L = 36.87, W = 31.232, d_1 = 2.14, d_2 = 0.067, w_1 = 1.511, w_2 = 2.015, w_3 = 3.525, w_s = 1.007, l_s = 15.830, l_1 = 19.948, l_2 = 28.603, s_1 = 2.015, s_2 = 1.41 and s_3 = 2.017. All dimension units are millimeter. By using parameter above, Wongsan *et al.* [7] shown that the resonant frequencies of the asymmetric T-shaped slit loads are 2.45 GHz, 5.25 GHz, and 5.8 GHz, respectively. However, this antenna has low directive gain and asymmetric radiation pattern.

2.1 1×4 Array Elements

To improve radiation characteristics, a rectangular patch with asymmetric T-shaped slit loaded MSA is arrayed with element spacing of λ/2 to increase the directive gain as shown in Fig.2. This work proposes the design of asymmetric T-shaped slit loaded MSA which is modeling 1×4 array [13].

As reported in Table 1, the simulated results show that directive gain of array antenna are increased up to 7 dBi, 9 dBi, and 12 dBi for the lower, middle and higher frequency bands, respectively. The simulated radiation patterns of the array antenna at the center of three ISM bands are shown in Fig.3.

It is noted that the azimuth patterns in H-plane were wide. On the other hand, the elevation patterns E-plane were narrow, while the propagation losses in undesired areas can be operated reduced in WLAN band. Therefore, this array antenna is therefore suitable for installation on the wall.

Table 1 Directive gain for one and four elements.

Frequency Directive gain	2.45 GHz	5.25 GHz	5.8 GHz
One-element [12] (dBi)	3.98	3.7	6.14
Four-elements (dBi)	7	9	12

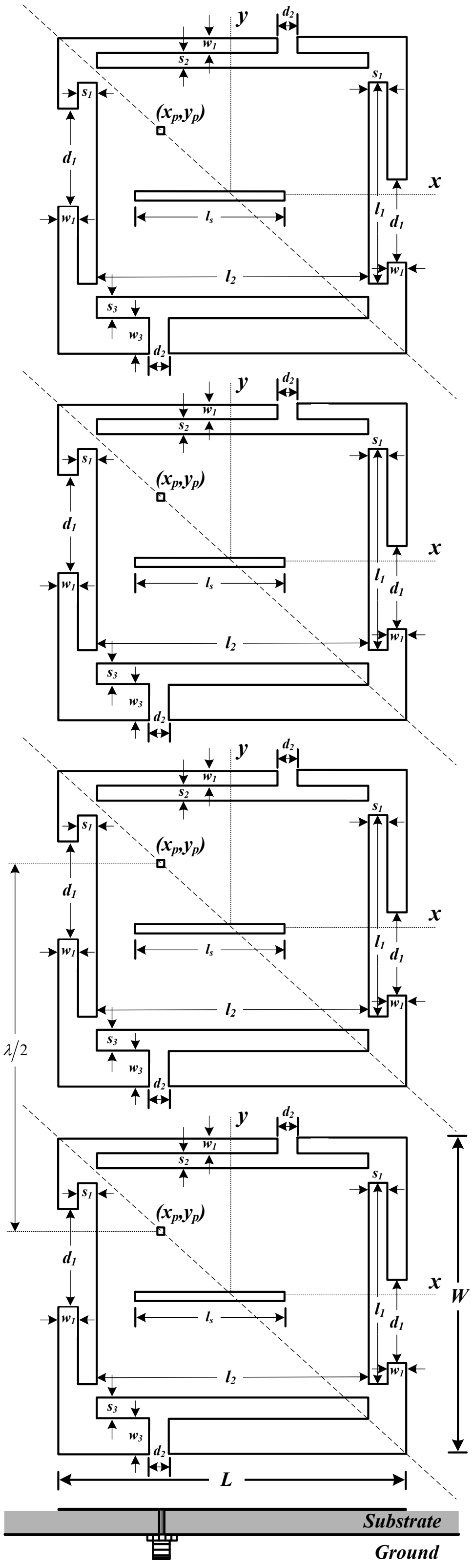
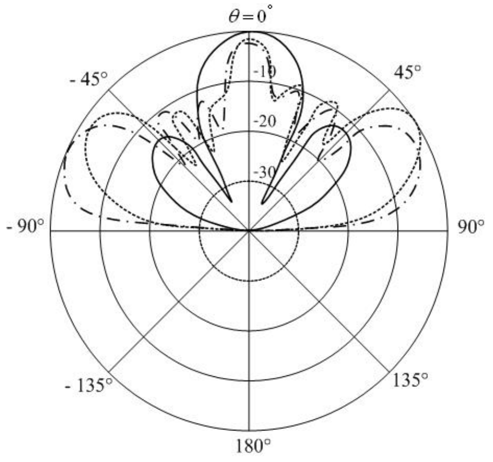
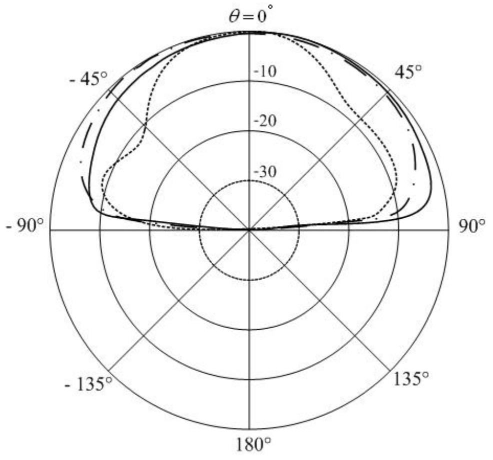


Fig.2 A 1×4 array antenna using rectangular patch with asymmetric T-shaped slit loaded MSA for element spacing of λ/2.



(a) E-plane



(b) H-plane

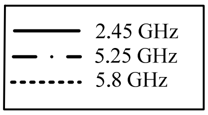
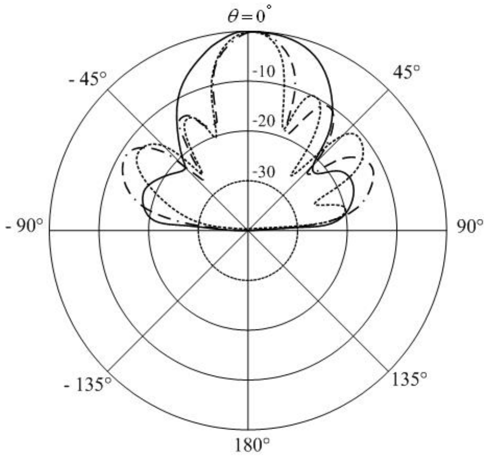


Fig.3 Simulated radiation patterns at 2.45 GHz, 5.25 GHz, and 5.8 GHz for element spacing of λ/2.

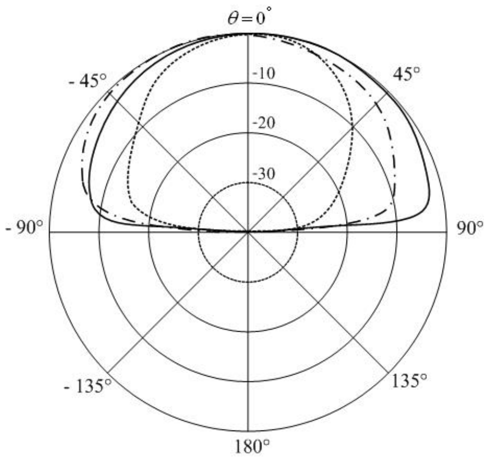
2.2 Radiation Patterns Improvement by adjustment of Patches Spacing

Although array element spacing of λ/2 can increase the directive gain, its beamwidth in E-plane still be narrow and occurring the side lobed pointed to undesired directions. Therefore, this array antenna will be improved in this section. In addition, if its spacing is shorter than λ/3, patch antennas are overlapped and if its spacing is wider than λ/2, the radiation patterns yields higher sidelobe level. Thus, the appropriate spacing between the patchs is considered here by adjusting the spacing distance from λ/2 down to λ/3 (40.816 mm).

Fig.4 illustrates the radiation patterns of the array antenna at distance λ/3. We found that the adjustment of element spacing at least λ/3 can reduce sidelobe level when compared to the element spacing of λ/2.



(a) E-plane



(b) H-plane

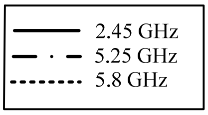
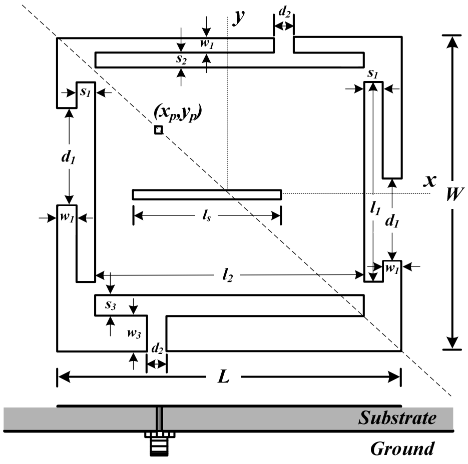


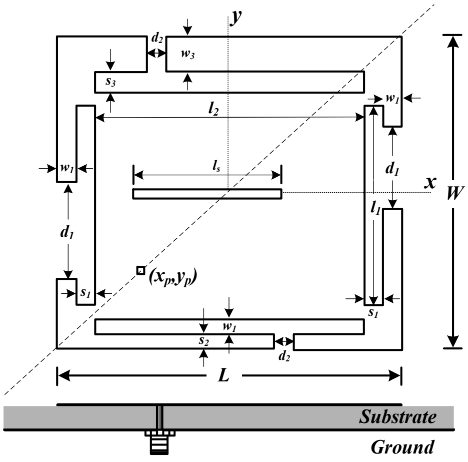
Fig. 4 Simulated radiation pattern at 2.45 GHz, 5.25 GHz, and 5.8 GHz for element spacing of λ/3.

2.3 Radiation Patterns Modification by Alternating the Slit Loads Positions on each Side of Patches

To depict in Fig.5 (a), prototype antenna A is the original dual-frequency rectangular microstrip antenna with asymmetric T-shaped slit loads [12]. Since a 1×4 array prototype antenna A at element spacing of λ/3, the radiation patterns are asymmetrical as shown in Fig.4. For solving a problem aforementioned, in Fig.5 (b), the prototype antenna B that has been modified by alternating the slit loads positions on each side of patches is designed to improve the radiation patterns to be symmetric shape and cover the required area.

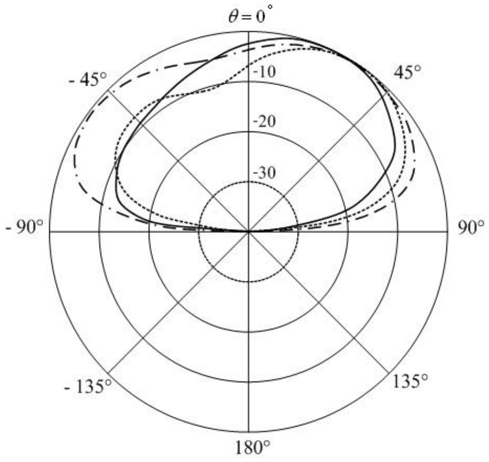


(a) Prototype antenna A

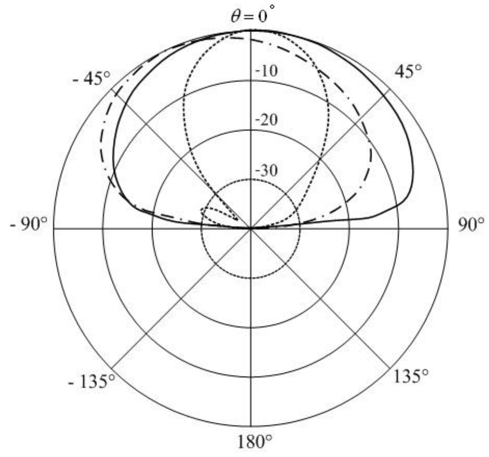


(b) Prototype antenna B

Fig. 5 Two prototypes of dual-frequency rectangular microstrip antenna for total pattern improvement of array.



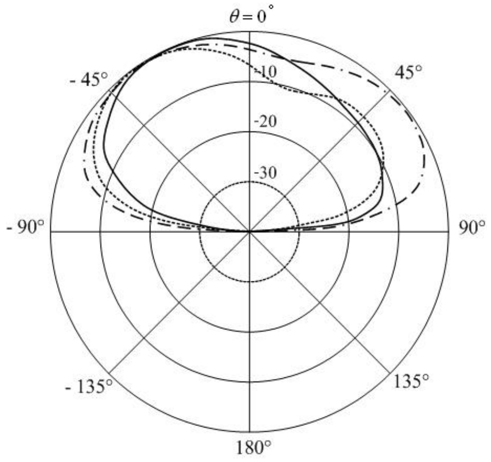
(a) E-plane



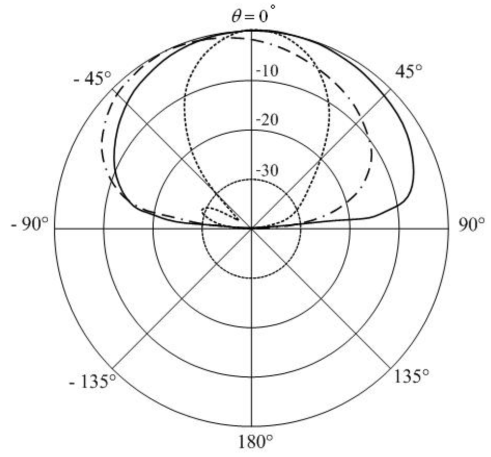
(b) H-plane

Fig. 6 Radiation patterns of a prototype antenna A.

Figs. 6 and 7 show the radiation pattern of prototype antenna A and B, respectively. When they are rearranged for 1×4 array antenna as shown in Fig.8, its total patterns both in E- and H-planes will be improved as shown in Fig.9.



(a) E-plane



(b) H-plane

Fig. 7 Radiation patterns of a prototype antenna B.

3 Experimental Results

This paper proposes two techniques for radiation patterns improvement. First, we propose the adjustment of patch spacing to λ/3, which can reduce the sidelobe levels. We then propose the modification of array antennas by alternating the slit loads positions on each side of patches to achieve the symmetric radiation patterns.

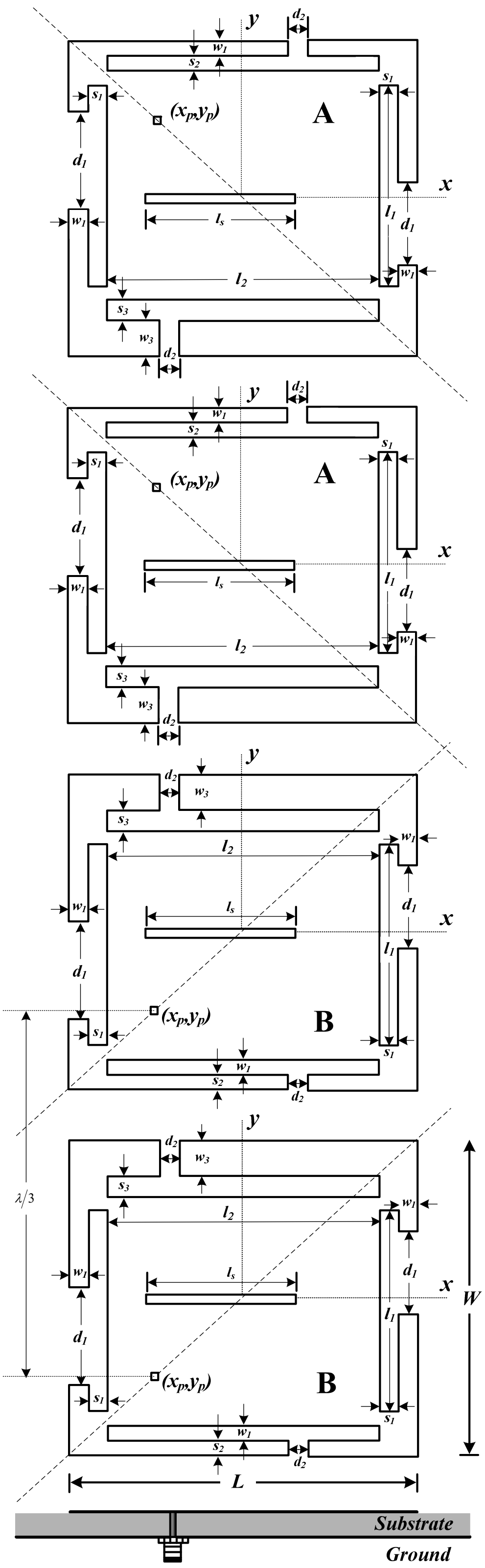
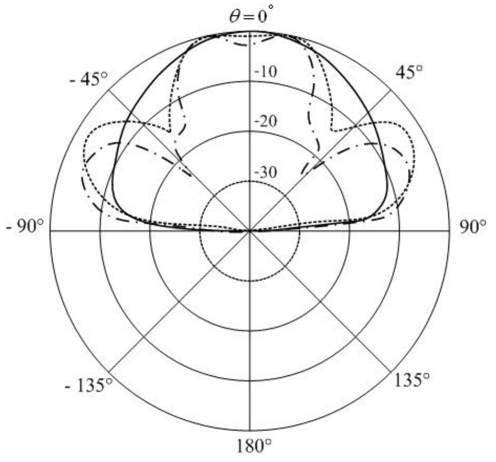
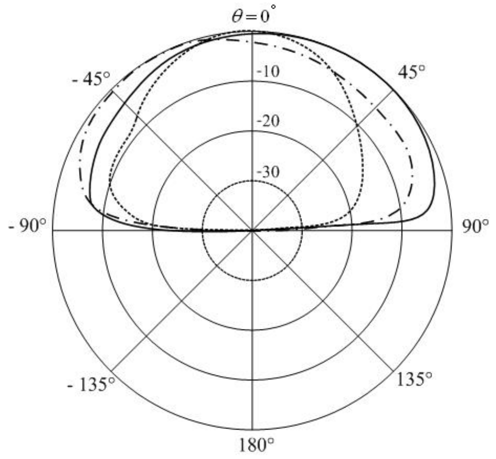


Fig.8 A 1×4 array antenna using rectangular patch with alternating the slit loads positions on each side of the MSAs (group B) for element spacing of λ/3.



(a) E-plane



(b) H-plane

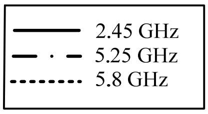
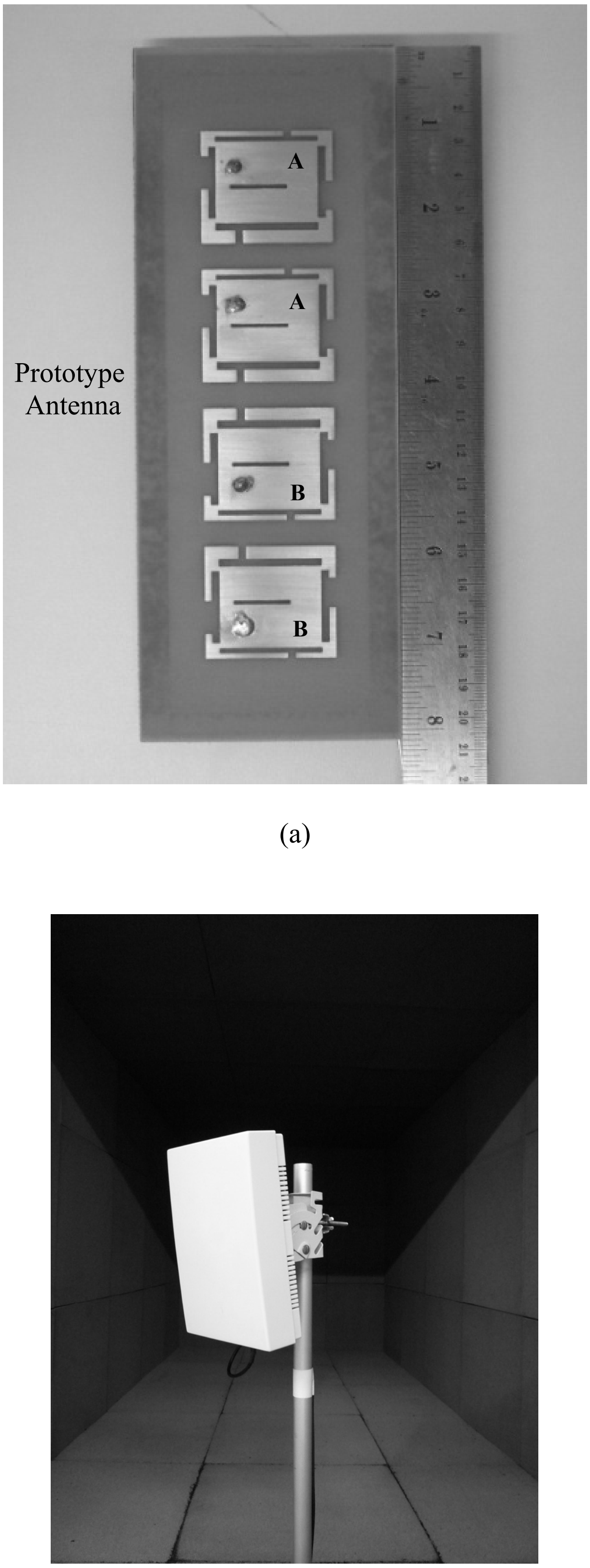


Fig. 9 Radiation patterns of 1×4 array antenna with prototype antenna A and B.

In order to implement this concept, the 1×4 rectangular microstrip array antenna with asymmetric T-shaped slit loads is designed and fabricated as shown in Fig.10. The thickness of FR4 substrate is 3.2 mm, which is fabricated using two layer of 1.6 mm FR4 PCB, which can result in a gap. The proposed antenna is fed with a 50 Ω SMA connector and connected to an HP8722D network analyzer in order to test the reflection coefficients.



(a)

(b)

Fig.10 Proposed rectangular microstrip array antenna by changing slit loads position on each side of patches.

From Fig.11, it can be clearly seen that the measured reflection coefficients are superimposed with the simulated ones and the good agreement. The simulated results show that at the lower frequency band (2.403-2.57 GHz), its bandwidth is 167 MHz, at the middle and higher frequency bands (5.221-5.456 GHz), its bandwidth is 235 MHz, (5.658-5.96 GHz), its bandwidth is 302 MHz, respectively. Also, the measured results show that at the lower frequency band (2.38-2.536 GHz), its bandwidth is 156 MHz, the middle and higher frequency bands (4.979-6.308 GHz), their bandwidth are 1.33 GHz. Both of them can cover the required three ISM bands. Fig.12 shows the simulated and measured VSWR. The simulated results show that at the lower, middle, and higher frequency bands, their VSWR are 1.22, 1.40, and 1.55, respectively. The measured results show that at the lower and middle frequency bands, their VSWR are 1.55, and higher frequency band, its VSWR is 1.23. In Figs.13 and 14, the simulated and measured results show that the input resistance and input reactance at the lower, middle, and higher frequency bands, are approximately 50 Ω and 0 Ω, respectively. The simulated and measured far-field radiation patterns of the proposed antenna at the center of three ISM bands are 2.45 GHz, 5.25 GHz, and 5.8 GHz as shown in Fig.15. It can be seen that similar radiation patterns for three operating frequency bands are in good agreement.

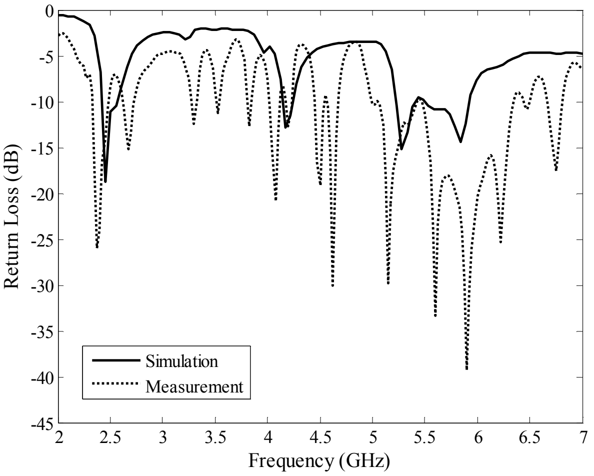


Fig.11 Simulated and measured return loss.

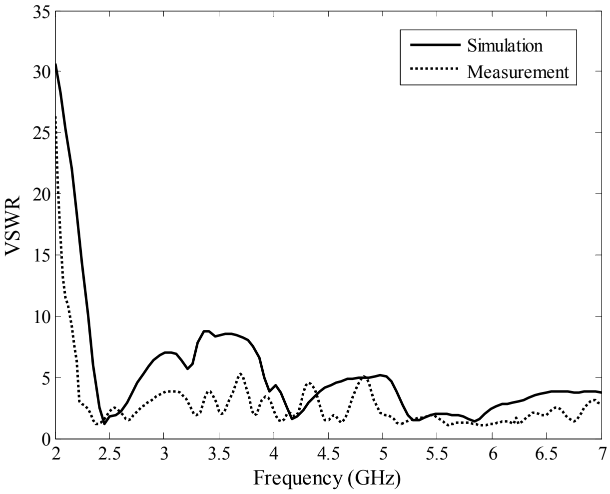


Fig.12 Simulated and measured VSWR.

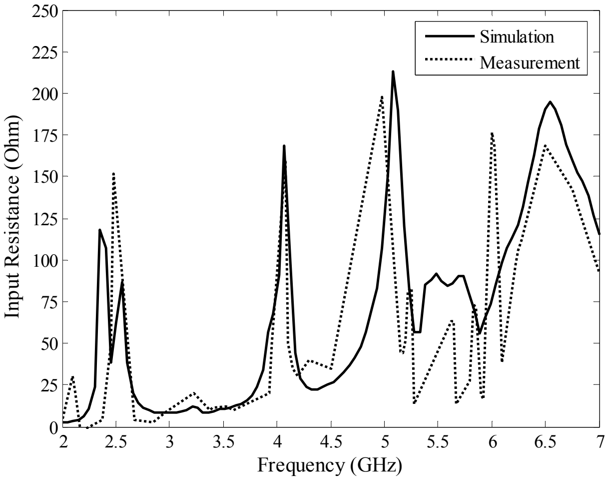


Fig.13 Simulated and measured input resistance (Ohm).

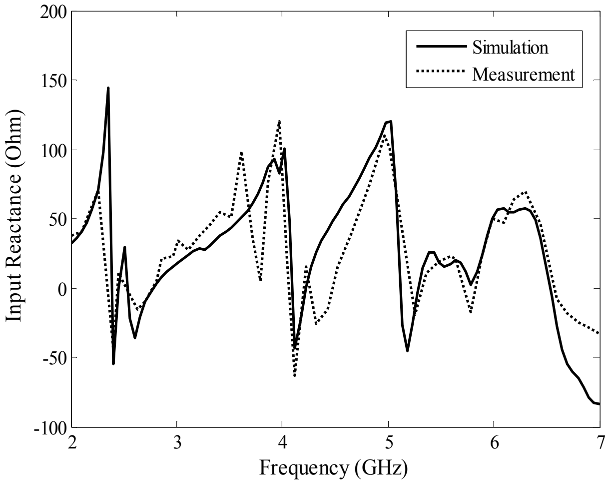
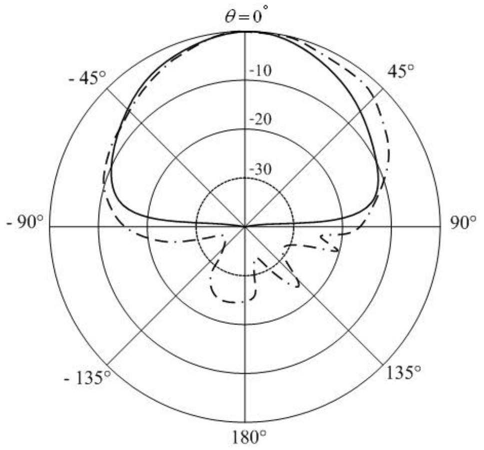
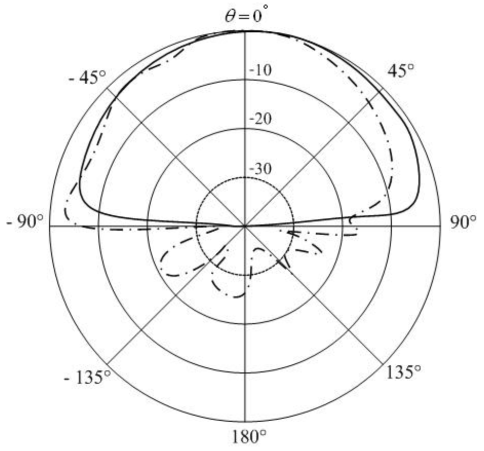


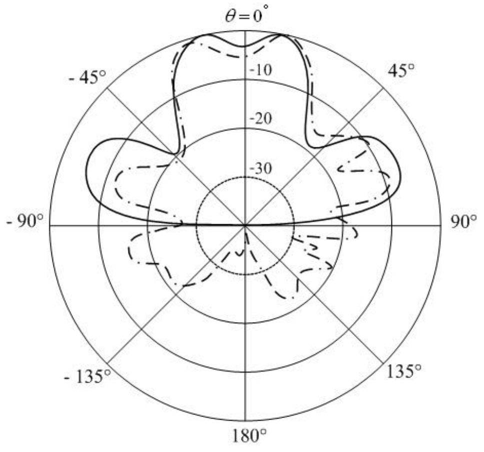
Fig.14 Simulated and measured input reactance (Ohm).



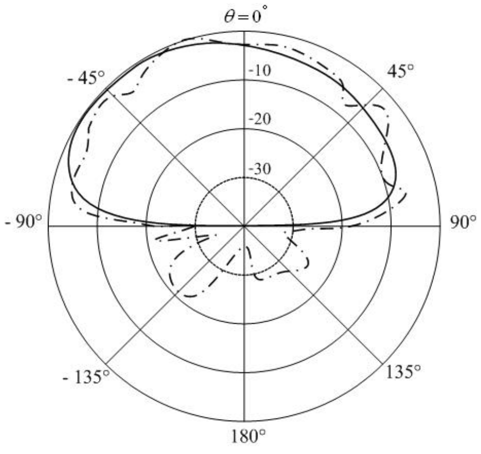
(a) E-plane at 2.45 GHz



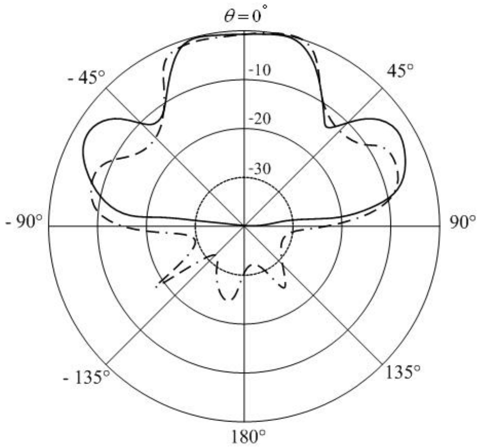
(b) H-plane at 2.45 GHz



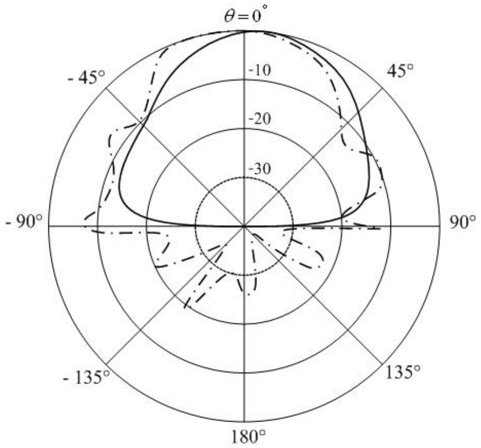
(c) E-plane at 5.25 GHz



(d) H-plane at 5.25 GHz



(e) E-plane at 5.8 GHz



(f) H-plane at 5.8 GHz

Fig.15 Simulated and measured far-field radiation patterns at 2.45 GHz, 5.25 GHz, and 5.8 GHz. (—— Simulation and –·–· Measurement)

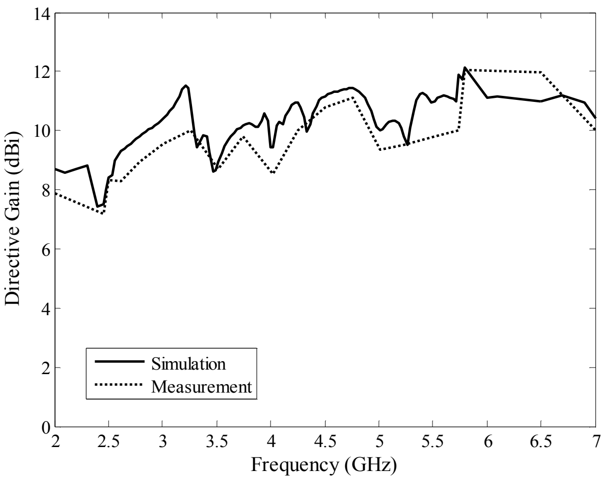


Fig.16 Simulated and measured directive gain.

As shown in Fig.16, the simulated results show that the directive gain at the lower, middle, and higher frequency bands, are 7.5 dBi, 9.6 dBi, 12.2 dBi, respectively. Also, the measured results are 7.2 dBi, 9.3 dBi, 12 dBi, respectively. It is shown that, the measurement and simulation for three operating frequency bands are in good agreement.

From the results of patterns modification by alternating the slit loads positions on each side of patches, we found that at the lower frequency band, its directive gain and radiation patterns are better. Furthermore, the sidelobe level is reduced at middle and higher frequency bands consequently, their directive gain in such bands will be increased.

4 Conclusion

From this paper, the performance improvement an array antenna using 1×4 rectangular MSA with asymmetric T-shaped slit loads is proposed for directive gain increament and pattern shaping. The simulated and measured results have been shown that when the array element spacing is adjusted from λ/2 down to λ/3, the covering required area will be increased. The modification by alternating the slit loads positions on each side of patches can improve the radiation patterns to be symmetric shape. In addition, the important parameters consist of the directive gain, return loss, VSWR, input impedance, and radiation patterns have been simulation and measurement for validation. The measured results are in good agreement with the simulated results. The obtained directive gains at the lower, middle, and higher frequency bands are 7dBi, 9dBi, and 12 dBi, respectively. Also, the bandwidth measured results show that at the lower frequency band, its bandwidth is about 156 MHz. For the middle and higher frequency band, its combination of two bandwidths are about 1.33 GHz. Therefore, both of them can cover the required three ISM bands. Furthermore, the VSWRs over the required bands are lower than 1.55. Finally, this proposed antenna as panel antenna can be realized and applied for wireless applications.

5 Acknowledgement

This work was supported by the Research Department Institute of Engineering, Suranaree University of Technology, Thailand. Also, the authors would like to express their acknowledgements to Prof. Prayoot Akkaraekthalin, King Mongkut's University of Technology North Bangkok, Thailand, supporting the IE3D Zeland Software for simulation.

References:

[1] H. Toshikazu, “Broadband/Multiband Printed Antenna,” *IEICE Trans. Commun.*, Vol.E88-B, No.5, May 2005, pp. 1809-1817.

[2] G. Tsachtsiris, M. Karaboikis, C. Soras, V. Papamichael and V. Makios, Multi Element Fractal Rectangular Curve Patch Antenna for Indoor Access Points, *WSEAS Transactions on Communications,* Vol.3, No.2, 2004, pp. 478-481.

[3] P. Krachodnok and R. Wongsan, Design of Broad-Beam Microstrip Reflectarray, *WSEAS Transactions on Communications*, Vol.7, No.3, 2008, pp. 180-187

[4] V. Thaivirot, P. Krachodnok and R. Wongsan, Radiation Pattern Synthesis from Various Shaped Reflectors Base on PO and PTD Methods for Point-to-Multipoint Application, *WSEAS Transactions on Communications*, Vol.7, 2008, pp. 531-540

[5] D.M. Pozar and S.M. Duffy, “A dual-band circularly polarized aperture-coupled stacked microstrip antenna for global positioning satellite”, *IEEE Trans. Antennas Propagat.*, Vol.45, 1997, pp. 1618-1625.

[6] D. Sanchez-Hemamdez, G. Passiopoulos, M. Ferrando, E. Reyes, and I. D. Robertson, “Dual-band circularly polarized microstrip antenna with a single feed,” *Electron. Lett.*, Vol.32, 1996, pp. 2296-2298.

[7] G. B. Hsieh, M. H. Chen, and K. L. Wong, “Single feed dual-band circularly polarized microstrip antenna,” *Electron. Lett.*, Vol.32, 1998, pp. 1170-1171.

[8] H. Elsadek, D. Nashaat and H. Ghali, Broad-band U-Shaped PLFA with Dual band Capability for Bluetooth and WLAN Application, *WSEAS Transactions on Computers*, Vol.3, No.6, 2004, pp. 1788-1793.

[9] K.P. Yang, K.L Wong., “Dual-band Circularly-Polarized Square Microstrip Antenna,” *IEEE Transaction on Antenna and Propagation*, AP-49, 3, March 2001, pp. 377-382.

[10] U. Kongmuang, “Bandwidth Analysis of Dual-band Asymmetric Y-shaped Slit-loaded MSA,” *ECTI-CON 2008.*, Vol.1, 2008, pp. 281-284.

[11] James, J.R., and P.S. Hall, *Handbook of Microstrip Antenna*, London: Peter Peregrinus Ltd., 1989 ch. 1

[12] R. Wongsan and U. Kongmuang, “Bandwidth Analysis of Dual-band Asymmetric T-shaped Slit-Loaded MSA Using FDTD,” *ISAP2007*, 2007, pp. 310-313.

[13] S. Kampeephat, P. Krachodnok, M. Uthansakul, and R. Wongsan, “Directive Gain Array Antenna using MSA with Asymmetric T-shaped Slit Loads,” 12th *WSEAS International Conference on Communications, Greece*, 2008, pp. 334-339