Design and Simulation of a Slotted Diamond-shaped Microstrip Patch Antenna with Modified Ground Plane

[1]A.Ismahayati, [#1,2]P.J Soh, [1]N.B.M Hashim, [1]F.Malek, [2]G.A.E Vandenbosch
1School of Computer and Communication Engineering, Universiti Malaysia Perlis
02000 Kuala Perlis, MALAYSIA
{ismahayati, pjsoh, baya, mfareq}@unimap.edu.my

[2]ESAT-TELEMIC, Katholieke Univesiteit Leuven,
Kasteelpark Arenberg 10, 3001 Leuven, BELGIUM
{pingjack.soh, guy.vandenbosch}@esat.kuleuven.be

1. Introduction

Mobile communication is one of the fastest growing, and considered one of the most important telecommunication applications. Thus, the demand for multi-function portable device is rapidly increased with the miniaturization of portable devices. In line with this trend, mobile devices' antennas are required to operate in at least two frequency bands, aside from being compact, efficient and low-profile [1].

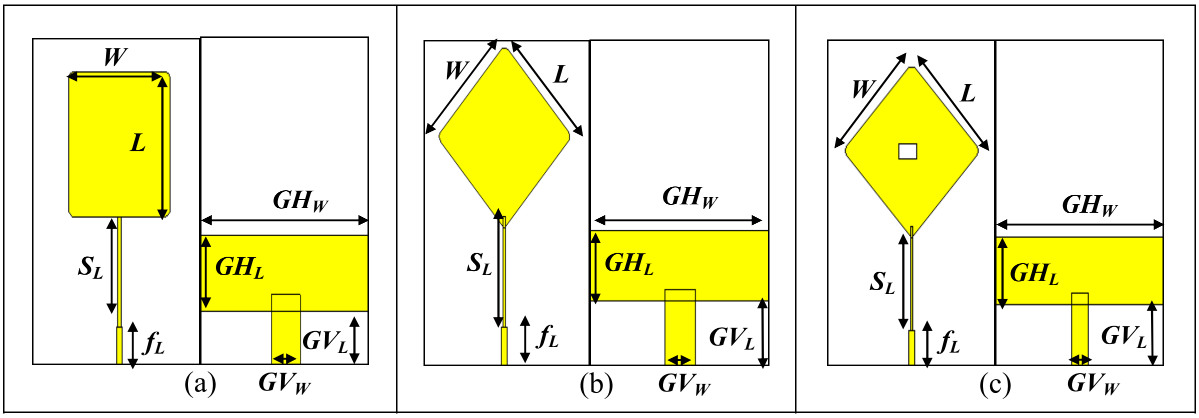
Microstrip patch antenna (MPA) is among the best choice to be implemented for operation in electronic devices, as it offers many attractive features such as simple structure, low production cost, light weight, robustness and ease of fabrication [2, 3]. However, the drawback of the patch antenna is the limitation by its narrow impedance bandwidth. To overcome this, many techniques have been suggested – probe fed stacked antenna [4, 5], microstrip patch antennas on electrically thick substrate [6], slotted patch antenna [7-9], and addition of parasitic elements [10].

In the present work, design and analysis of a line-fed, slotted diamond-shaped microstrip patch antenna is carried out. In order to proof its improvements, it is also benchmarked along a non-slotted diamond-shaped antenna and a conventional rectangular microstrip patch antenna, which are both designed for operation in the 2.45 GHz Industrial, Scientific and Medical (ISM) band. The proposed design is able to operate in at least two other frequency ranges (5.2 GHz and 5.8 GHz) satisfactorily, with broad impedance bandwidth and gain. Details of the investigation based on experiments and simulations of the proposed antenna are described.

2. Antenna Design

In this investigation, three antenna prototypes are designed; first, a conventional square microstrip antenna (Antenna A), a diamond-shaped antenna without slots (Antenna B) and finally, a diamond shaped antenna with a small slot (Antenna C). All prototypes are fed by a 50 Ω connector using a microstrip transmission line and implemented on a partial, dipole-shaped ground plane. The ground plane, which consists of two parts – vertical ground and horizontal ground – are dimensioned using its length and width (GV_L and GV_W for vertical; GH_L and GH_W, for horizontal, respectively). These antennas are designed on a 100 x 80 mm Roger RO4003C substrate with 0.813 mm thickness (h), copper thickness, t, of 0.035 mm, and substrate permittivity, ε_r, of 3.38. The dimension of the proposed antenna's patch width (W) and length (L) are calculated from equation [11]:

$$W = L = \frac{c}{2 f_0 \sqrt{\varepsilon_{eff}}} \qquad (1)$$



(a) (b) (c)

Figure 1: Dimension of the diamond shaped microstrip patch antenna (a) Antenna A; (b) Antenna B and (c) Antenna C

Table 1: Summary of dimensions and antenna performance for all three prototypes (all in mm unless specified)

Parameters/Prototype	Antenna A	Antenna B	Antenna C
Patch width (W)	33	30	30
Patch length (L)	33	30	30
Feed length (F_L)	10	10	10
Feed width (F_W)	1.9	1.9	1.9
Stub length (S_L)	25	28	28
Stub width (S_W)	1.0	0.9	0.9
Horizontal ground width (GH_W)	59	62	64
Horizontal ground length (GH_L)	18	18	15
Vertical ground width (GV_W)	10	10	6
Vertical ground length (GV_L)	13	17	17
10dB limit (lower) (GHz) (f_L)	2.0377	1.5680 4.7963	1.5397 4.7011
10dB limit (high) (GHz) (f_H)	3.5763	2.6078 6.5621	2.5765 6.5563
Bandwidth (MHz)	1538.6	1039.8 1765.8	1036.8 1885.5
Min S_{11}(dB) (freq(GHz))	-26.02 (3.03)	-41.72 (2.03) -22.05 (6.01)	-33.45 (2.21) -20.57 (6.01)
Efficiency (%) (freq(GHz))	84.96 (2.4)	88.89 (2.4) 93.26 (5.2) 94.21 (5.8)	89.45 (2.4) 95.13 (5.2) 95.68 (5.8)
Gain (dB) (freq(GHz))	2.452 (2.4)	2.262 (2.4) 3.631 (5.2) 3.632 (5.8)	1.338 (2.4) 3.853 (5.2) 3.796 (5.8)

where W is the width of the rectangular patch, L is its length, c is the free space velocity of light ($3\text{x}10^8$ m/s), f_0 is the operating frequency and ε_{eff} is the effective permittivity of the substrate calculated from:

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \qquad (2)$$

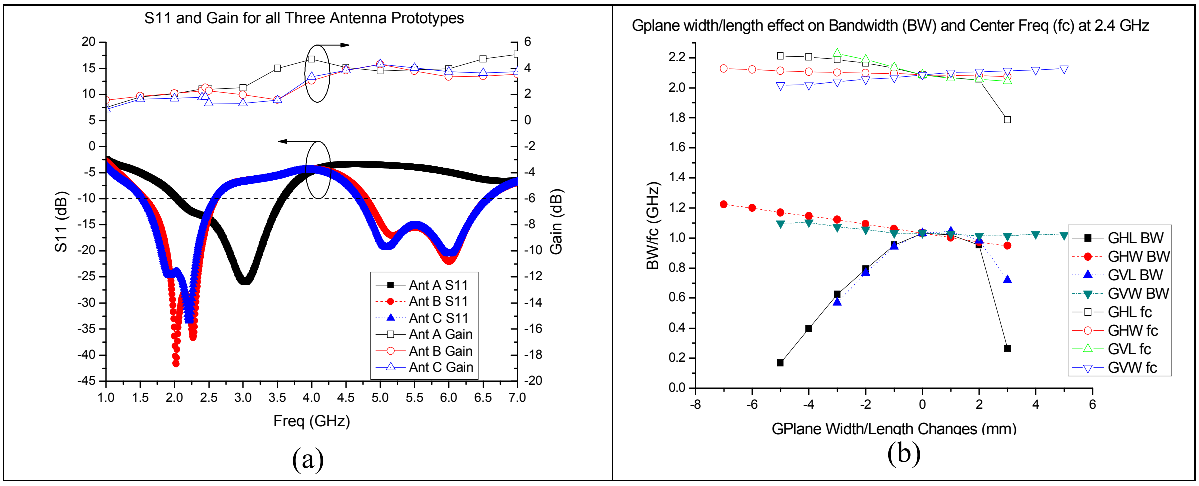
At 2.4 GHz, the calculation yields a $\varepsilon_{\mathrm{eff}}$ of 3.26, and subsequently, W and L_{eff} of 33.91 mm for the conventional microstrip patch antenna. Using optimization of commercial electromagnetic solver CST Microwave Studio (MWS), W and L are dimensioned as 33 mm for antenna A, while for B and C, patches are sized at 30 x 30 mm. For antenna C, a small slot (6 x 4 mm) is positioned at the center of the patch. All three antennas are fed using a transmission feed line with length (F_L) of 10 mm and width (F_W) of 1.9mm. It is also matched using a stub dimensioned with a length of S_L and width, S_W. Details of the dimension can be obtained in Figure 1 and Table I.

3. Results and Discussion

In general, it can be observed that generally, bandwidth is able to be improved significantly with the addition of the dipole-shaped ground plane, even when implemented on a conventional square patch antenna. For antenna A, a broad operation bandwidth of 1.5 GHz is obtained, with an efficiency of 85% and gain of 2.5 dB. Antennas B and C both achieved similar performance in term of bandwidth, which indicates that the addition of the slot on the patch is insignificant. Two large resonance areas are also detected for both structures, one centered at about 2.06 GHz and another at 5.65 GHz. The operating frequencies for both antennas are between 1.6 GHz and 2.6 GHz (for lower frequency) and between 4.7 GHz and 6.6 GHz (at the higher frequency), achieving bandwidths of more than 1 GHz and 1.7 GHz, respectively. Table 1 and Figure 2(a) summarize the reflection coefficient (S_{11}), bandwidth (BW), gain and efficiency for all three antenna prototypes.

Due to the broadband antenna feature which is achieved using the ground plane, it is important to examine the contribution made by the two ground plane elements (one horizontal, the other vertical) due to their dimensional changes. This investigation is summarized in Figure 2(b) for 2.4 GHz. Dimensions for horizontal and vertical ground plane width and length (GH_W, GH_L, GV_W, GV_L, respectively) are changed in 1 mm steps, investigated using antenna B. It can be noticed that the lengths of both ground plane are very significant in changing the bandwidth and center frequency (f_c) of the antenna, indicating that impedance matching can be carried out alternatively using these two elements. On the other hand, changing the widths has decreased the bandwidth steadily. Increasing the width of the vertical ground plane has shifted f_c upwards, while for the horizontal ground, similar changes are not distinguishable.

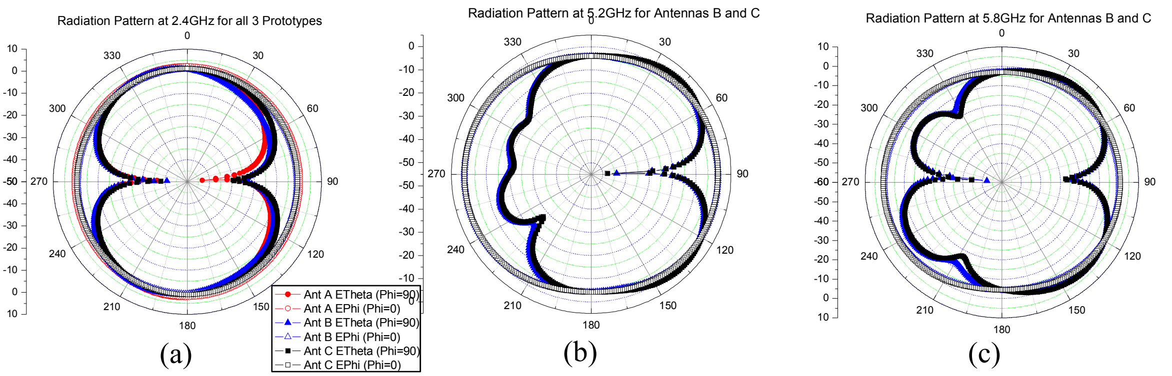
Gain and efficiency produced by all three antennas are also satisfactory. At the lower band, all three antennas produced efficiencies of between 85 % and 90 %. Antenna A produced the best gain with 2.45 dB, while the worst is shown by antenna C. However, at higher frequencies of 5.2 GHz and 5.8 GHz, antenna C is seen to produce about 2 dB higher in gain and 1 to 2 % higher in terms of efficiency, when compared to antenna B. The radiation patterns for three antenna prototypes shown in Figure 3 indicated an omni-directional coverage in the azimuth plane.



(a)

(b)

Figure 2: (a) S_{11} and gain for all three antennas; (b) ground plane dimensional sensitivity on BW and f_c



(a) (b) (c)

Figure 3: Radiation pattern at (a) 2.4 GHz, (b) 5.2 GHz and (c) 5.8 GHz

4. Conclusions

A broadband, diamond-shaped microstrip patch antenna for wireless applications is presented. The proposed design, which incorporates a modified ground plane, has been successfully designed for multiband operations at GSM 1800, 3G-UMTS, Bluetooth, and WLAN applications. A simulated 95% efficiency with maximum gain of 3.5 dB is readily achieved using the proposed structure.

References

[1] Garima, D. Bhatnagar, V. K. Saxena, and J. S. Saini, "Broadband circular patch microstrip antenna with diamond shape slot for space communication," in *Emerging Trends in Electronic and Photonic Devices & Systems, 2009. ELECTRO '09. International Conference on*, 2009, pp. 332-335.

[2] T. Jing-Yao, O. Ban Leong, and L. Mook Seng, "Diamond-shaped broadband slot antenna," in *Antenna Technology: Small Antennas and Novel Metamaterials, 2005. IWAT 2005. IEEE International Workshop on*, 2005, pp. 431-434.

[3] S. Satthamsakul, N. Anantrasirichai, C. Benjangkaprasert, and T. Wakabayashi, "Rectangular patch antenna with inset feed and modified ground-plane for wideband antenna," in *SICE Annual Conference, 2008*, 2008, pp. 3400-3403.

[4] M. T. Islam, N. Misran, M. N. Shakib, and B. Yatim, "Wideband Stacked Microstrip Patch Antenna for Wireless Communication," in *Parallel and Distributed Processing with Applications, 2008. ISPA '08. International Symposium on*, 2008, pp. 547-550.

[5] A. S. Elkorany, A. A. Sharshar, and S. M. Elhalafawy, "Ultra wideband stacked microstrip patch antenna," in *Antennas and Propagation, 2009. EuCAP 2009. 3rd European Conference on*, 2009, pp. 1464-1466.

[6] M. Rahman and M. A. Stuchly, "Wideband microstrip patch antenna with planar PBG structure," in *Antennas and Propagation Society International Symposium, 2001. IEEE*, 2001, pp. 486-489 vol.2.

[7] Y. K. Cho, J. H. Yoo, E. J. Kim, Y. Kim, and Y. S. Lee, "Wideband microstrip-fed slot loop antenna with the conducting via," in *Electromagnetic Compatibility (APEMC), 2010 Asia-Pacific Symposium on*, pp. 834-838.

[8] H. S. Shin and N. Kim, "Wideband annular ring slot microstrip antenna with low impedance feed line," in *Antennas and Propagation Society International Symposium, 2002. IEEE*, 2002, pp. 288-291 vol.2.

[9] V. Natarajan, E. Chettiar, and D. Chatterjee, "An ultra-wideband dual, stacked, U-slot microstrip antenna," in *Antennas and Propagation Society International Symposium, 2004. IEEE*, 2004, pp. 2939-2942 Vol.3.

[10] P. Jearapraditkul, W. Kueathaweekun, N. Anantrasirichai, O. Sangaroon, and T. Wakabayashi, "Bandwidth Enhancement of CPW-Fed Slot Antenna with Inset Tuning Stub," in *Communications and Information Technologies, 2008. ISCIT 2008. International Symposium on*, 2008, pp. 14-17.

[11] C. A. Balanis, "Antenna Theory: Analysis and Design, John W iley & Sons," 1997.