2017 4th International Conference on Electronics and Communication Systems (ICECS)

# COMPACT PATCH ANTENNA FOR 2.4 GHz

Varindra Kumar
Department of Engineering,
University of Cambridge,
Cambridge

***Abstract*— Here various patch antennas such as square, pentagon, hexagon, heptagon and octagon of the same arm size has been modelled using copper as its conducting media and its various parameters such as reflection coefficient, directivity, gain and radiation efficiency has been calculated and compared for its effectiveness of the dimensional space. These antennas have been modelled over a polyimide (Kapton) based substrate with copper as its conducting media for its operation at 2.4 GHz. Assuming a human body parts with some curvature, theses patches has been bent with the size of its arm length to show the antenna behaviour and its various parameters has been compared. These comparisons show that the least dimensional space of a square shape provides a comparable gain, directivity and efficiency of the other patch antenna thus it can be selected for WLAN applications at 2.4 GHz frequency while saving the real estate of the PCB. The proposed antenna is perfectly suited for its integration into flexible and wearable electronics design.**

***Keywords*— *Antenna, Flexible, Square, Octagonal, Pentagonal***

## I. INTRODUCTION

Wearable electronics due to its wide range of applications has provided an opportunity to design small, compact and flexible components. A key feature of the wearable electronics is its communication over wireless media at 2.4 GHz frequency due to the industry standard wireless communication protocol. At the same time due to miniaturization of electronics devices and rapid prototyping in a PCB environment, the antenna needs to be compact and small. Hence various patch antenna for its compact size, simplicity in construction, PCB fabrication and other features such as good directivity, gain and radiation efficiency has been designed [1 – 4] and compared for its antenna parameters such as directivity, gain, reflection coefficient and radiation efficiency. The paper talks about these patch antennas working at 2.4 GHz for its application using copper as conducting media with Kapton as substrate and PEC as ground. The paper also presents the effect of bending of these structures for their electrical parameters and its comparison with these planar structures. Various past papers have presented the bending effect due to its various upcoming applications such as antenna printed on a textile and wearable electronics [4]. The paper has been divided into various sections such as design methodology, modelling and simulation results, comparison of parameters, conclusion and acknowledgement.

## II. DESIGN METHODOLOGY

A patch antenna as shown in Fig. 1 can be defined by its configuration of a patch with substrate over a ground plane. The patch can be made of various shapes such as a regular and irregular polygon or any enclosed area. The material selection of the patch, substrate and ground plane here has been made based on the flexibility of antenna for its wearable electronics application. The material for the patch is annealed copper of very thin size while the polyimide (Kapton) as a substrate has been selected due to its bending nature [5] and a thin PEC material has been selected for its ground plane.

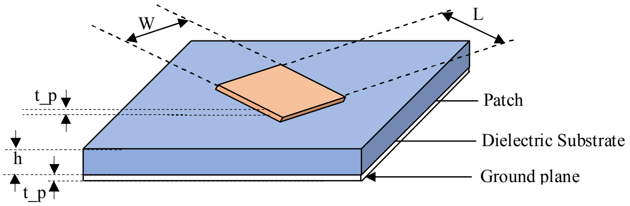

Fig. 1 Patch planar antenna

So far little research has been done on flexible antenna using polyimide and its comparison with planar antenna. The present work provides a comparison of various regular shape patch antenna such as square [6], pentagonal, hexagonal [7], heptagonal and octagonal [8] patch at 2.4 GHz for its dimensional space over a planar and bend structure. Performance of a patch antenna can be defined by its reflection co-efficient, directivity, gain and efficiency and these parameters can be calculated using various factors such as conductivity and dimension of the patch, substrate media and feeding mechanism. The patch can be defined using its length ‘L’, width ‘W’ and thickness ‘h’. The thickness ‘t_p’ is considerably small in comparison of the wavelength of the propagation, $\lambda_0$ and has been defined using the weight of copper, 1 ounce copper corresponding to 35 µm. In the present case, these patches have been made of a regular polygon with its arm length ‘A’. Equations (1) - (7) [9] can be used to calculate various design parameters. The effective dielectric constant of effective permittivity is dependent on surrounding media (it can be homogenous or inhomogeneous) and its effective dielectric constant. Assuming W being the width of the metal plate and h being the height of dielectric slab, a wide microstrip trace’s (electric field can be considered to be located at the center of the strip) $\varepsilon_{eff}$ can defined by (1) for the condition W >> h. Similarly W, $L_{eff}$, ΔL and L can be obtained using (2), (3), (4) and (5) [9].

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \frac{1}{\sqrt{1 + \frac{12h}{W}}} \quad \text{for } W \geq h \tag{1}$$

$$W = \frac{c}{2 f_r \sqrt{\frac{\varepsilon_r + 1}{2}}} \tag{2}$$

$$L_{eff} = \frac{c}{2 f_r \sqrt{\varepsilon_{reff}}} \tag{3}$$

$$\Delta L = 0.412h \frac{(\varepsilon_{reff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \tag{4}$$

$$L = L_{eff} - 2\Delta L \tag{5}$$

$$L_g = 6h + L \tag{6}$$

$$W_g = 6h + W \tag{7}$$

Using above equations, we can obtain geometric shape of the radiating plate L, W, $\varepsilon_{reff}$, $L_{eff}$, ΔL and size of its substrate and ground plane ($L_g$ and $W_g$). The dimensional space of a regular polygon with its arm length 'A' can be defined using (8) while its $x_i$ and $y_i$ co-ordinates can be obtained using (9) and (10). Using (8), it can be shown that a square patch has the least dimensional space among all these patch configurations.

$$Area = \frac{A^2 N}{4 \tan(\pi/N)} \tag{8}$$

$$x_i = A \cos(2\pi i/N) \tag{9}$$

$$y_i = A \sin(2\pi i/N) \tag{10}$$

For its application at 2.4 GHz, the dimension of its various patch configurations has been obtained as 17 mm arm length with a copper thickness of 35 µm (1 oz. copper) over a polyimide substrate of 24 mm x 24 mm with permittivity of 3.5 and thickness 1 mm. The ground layer is made of PEC and covers the feed length, leaving the patch antenna just over the substrate and has a width and length of 24 mm while the feed of the patch antenna has been designed for 50 ohm characteristic impedance with patch width of 2.2 mm, length of 10 mm and thickness of 0.035 µm. These patch configurations has been bent to its arm length size that is a radius of 17 mm to create corresponding bend structures.

### A. *Kapton Substrate*

Due to flexible behavior, Kapton has been widely used in various types of antenna designs [5]. In addition, the physical, mechanical, thermal endurance and chemical property of the material provides a basis for its application in wearable electronics [10]. The dielectric constant (with $\varepsilon_r$=3.5 and tan(δ) = 0.002) behavior of the material provides an excellent property to be used as a substrate.

## III. MODELLING AND SIMULATION RESULTS

The CST software has been used to model and simulate the patch antenna. Section A describes details about S11 parameter, gain, directivity and total efficiency for various patch antennas with copper conductive media over a planar surface while section B talks about these parameters for the same size patch antenna over a bend.

### A. *Patch Antenna over a plane*

Figs. 2.1, 3.1, 4.1, 5.1 and 6.1 show the structure of various patch configurations over a plane and its corresponding bend form has been shown in Figs 2.2, 3.2, 4.2, 5.2 and 6.2. As seen from Fig. 7, various patch configurations show its resonance behavior at 2.4 GHz with a minimum of -11.83 dB reflection. While Figs. 5 and 6 show the directivity and its gain has been shown in Figs. 7 and 8.

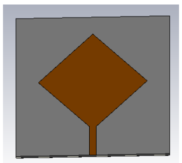
Fig. 2.1 Square planar antenna

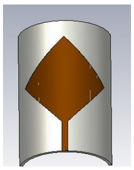
Fig. 2.2 Square bend antenna

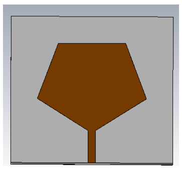
Fig. 3.1 Pentagon planar antenna

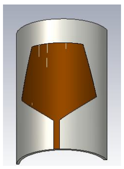
Fig. 3.2 Pentagon bend antenna

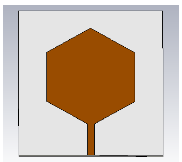
Fig. 4.1 Hexagon planar antenna

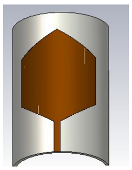
Fig. 4.2 Hexagon bend antenna

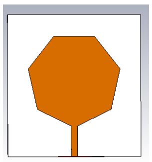
Fig. 5.1 Heptagon planar antenna

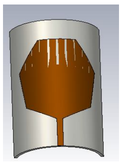
Fig. 5.2 Heptagon bend antenna

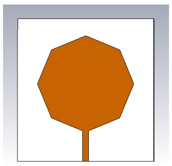
Fig. 6.1 Octagon planar antenna

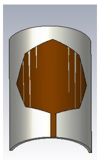
Fig. 6.2 Octagon bend antenna

978-1-4244-xxxx-x/17/$25.00 ©2017 IEEE

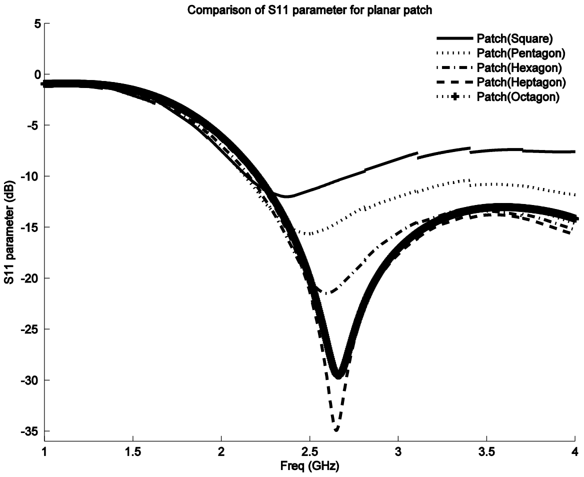

Fig. 7 – Comparison of S11 parameter for planar patch

As seen from Fig. 7, the reflection coefficient of these planar structures is well below −11.5 dB at 2.4 GHz with a slight shift in resonating frequency with an increase in size of the patch.

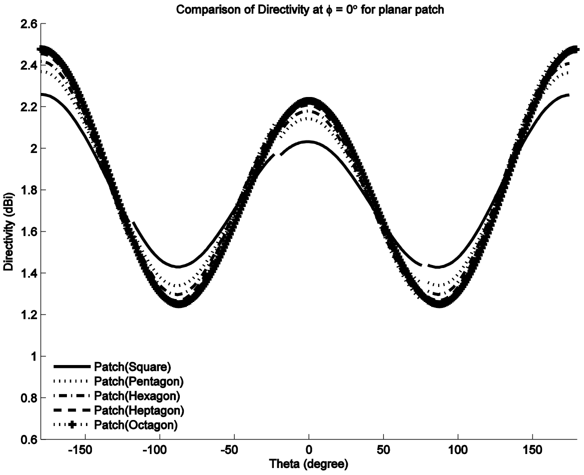

Fig. 8 Comparison of Directivity at Phi = 0° for planar patch

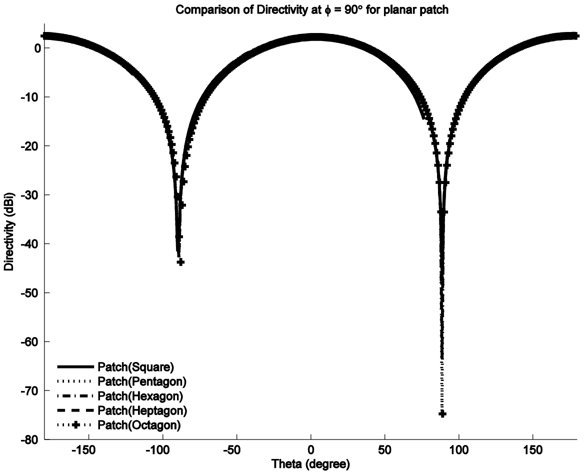

Fig. 9 Comparison of Directivity at Phi = 90° for planar patch

Figs. 8 and 9 show the comparison of its directivity at ϕ= 0° and 90° for various patch configurations such as square, pentagon, hexagon, heptagon and octagon where all structures show the same directivity at ϕ = 0° while there is about 0.2 dBi difference at ϕ = 90° for these structures. The maximum directivity for each of these patch configurations is nearly same at ϕ = 0° and 90°.

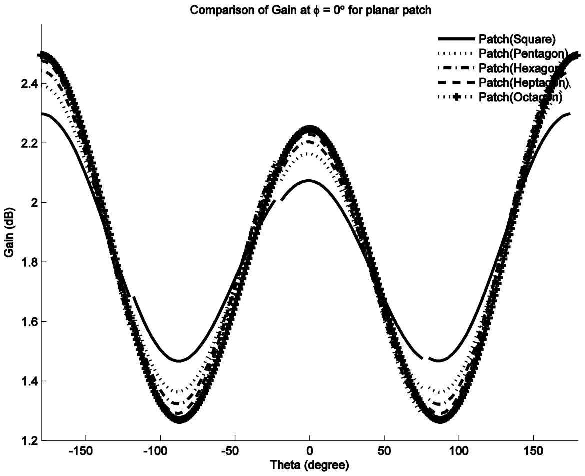

Fig. 10 Comparison of Gain at Phi = 0° for planar patch

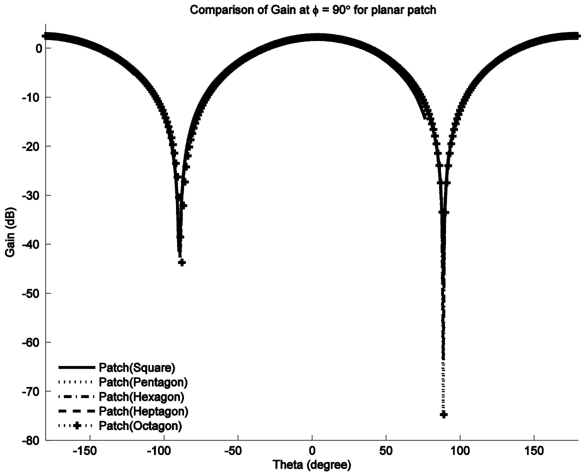

Fig. 11 Comparison of Gain at Phi = 90° for planar patch

Similarly Figs. 10 and 11 show the gain at ϕ= 0° and 90° where there is a small difference of about 0.2 dB in gain at 0° for various structures with the highest gain for octagonal patch and the least gain for the square patch however the difference in gain is very minimal. These obtained antenna parameters show a comparable result for the least patch sized square shape in comparison of other oversized patch structures.

### *B. Patch Antenna over a bend*

All of these planar configurations has been bent with the same size of its arm length, that is 17 mm radius. The comparison of the bend structure for various shapes such as square, pentagon, hexagon, heptagon and octagon has been described in this section.

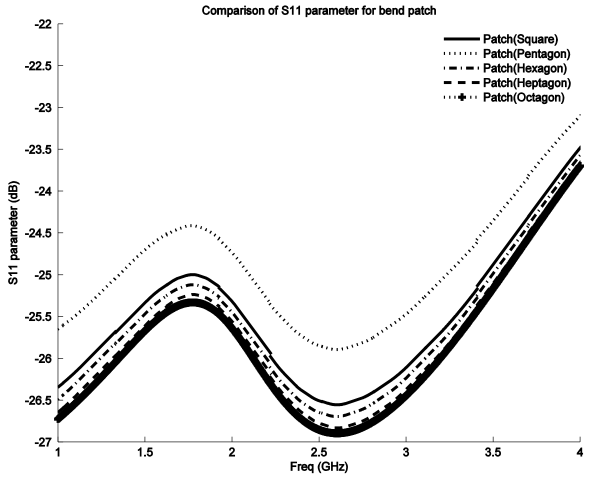

Fig. 12 – Comparison of S11 parameter for bend patch

As seen from Fig. 12, the S-parameter for these patch configurations is quite comparable with the reflection loss being less than -25.5 dB at 2.4 GHz, although there is some shift in its resonating frequency with an increase in patch area.

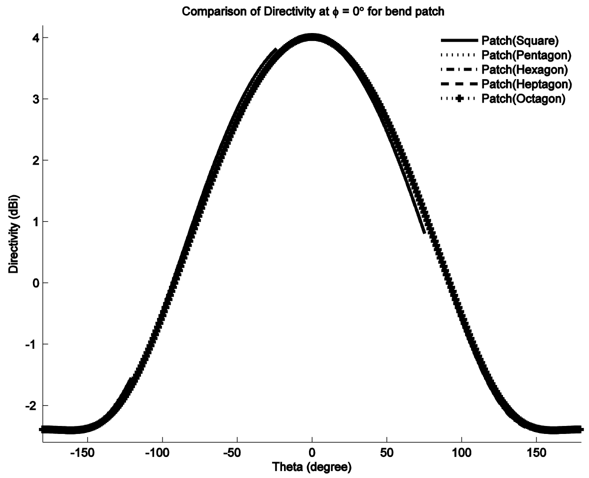

Fig. 13 Comparison of Directivity at Phi = 0° for bend patch

Figs. 13 and 14 show the comparison of its directivity for various bend structures at $\phi$= 0° and 90°. As seen here the bend structures for various patches such as square, pentagonal, hexagonal, heptagonal and octagonal show the similar directivity of 4 dBi and 5 dBi at $\phi$ = 0° and $\phi$ = 90° respectively.

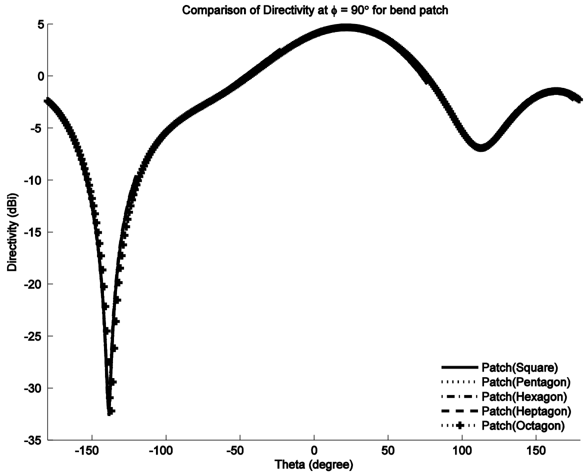

Fig. 14 Comparison of Directivity at Phi = 90° for bend patch

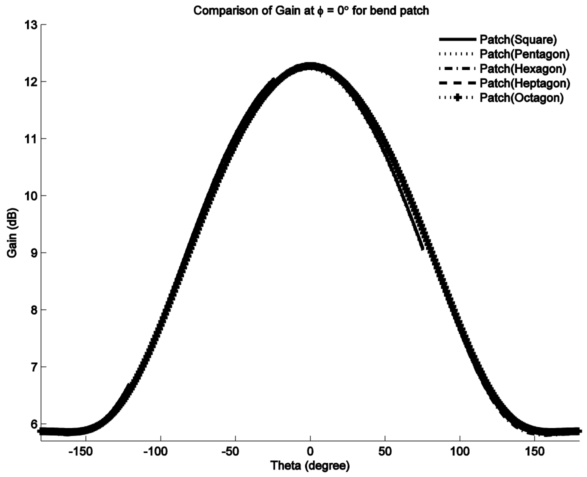

Fig. 15 Comparison of Gain at Phi = 0° for bend patch

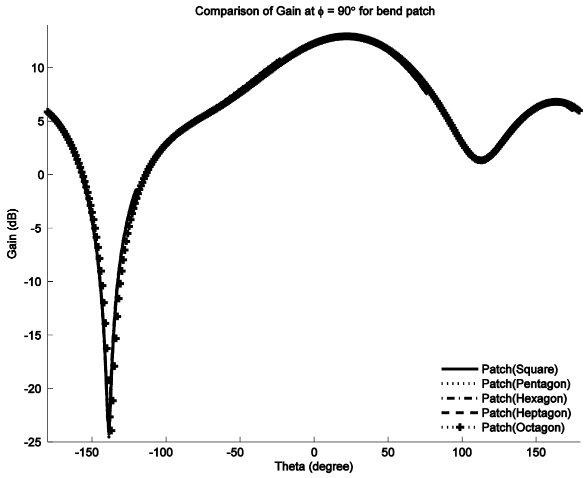

Fig. 16 Comparison of Gain at Phi = 90° for bend patch

Similarly Figs. 15 and 16 show the comparison of gain for these patch configurations at $\phi$ = 0° and 90° where the obtained gain is 12.9 dB. These results show that after bending these patch configurations these patch antennas provide similar behavior and there is a significant increase in the dB level in comparison of its planar configuration.

## IV. COMPARISON OF PARAMETRS

TABLE I
COMPARISON OF PLANAR ANTENNA

| Patch | S11 (dB) | VSWR | Gain (dB) | Directivity (dBi) |
|---|---|---|---|---|
| Square | -11.83 | 1.69 | 2.3 | 2.26 |
| Pentagonal | -15.21 | 1.42 | 2.4 | 2.38 |
| Hexagonal | -16.99 | 1.33 | 2.45 | 2.43 |
| Heptagonal | -16.51 | 1.35 | 2.48 | 2.46 |
| Octagonal | -15.61 | 1.40 | 2.51 | 2.49 |

TABLE II
COMPARISON OF DIRECTIVITY AT ø = 90° FOR PLANAR ANTENNA

| Patch | Main Lobe magnitude (dBi) | Main Lobe direction (deg) | 3 dB Angular width (deg) | Total efficiency (dB) |
|---|---|---|---|---|
| Square | 2.26 | 178 | 83.6 | -0.256 |
| Pentagonal | 2.38 | 178 | 83.1 | -0.110 |
| Hexagonal | 2.42 | 178 | 83 | -0.063 |
| Heptagonal | 2.46 | 177 | 82.9 | -0.076 |
| Octagonal | 2.49 | 177 | 82.8 | -0.102 |

TABLE III
COMPARISON OF BEND ANTENNA

| Patch | S11 (dB) | VSWR | Gain (dB) | Directivity (dBi) |
|---|---|---|---|---|
| Square | -26.38 | 1.10 | 12.9 | 4.67 |
| Pentagonal | -25.74 | 1.11 | 12.9 | 4.66 |
| Hexagonal | -26.50 | 1.10 | 12.9 | 4.68 |
| Heptagonal | -26.65 | 1.10 | 12.9 | 4.67 |
| Octagonal | -26.73 | 1.09 | 12.9 | 4.67 |

TABLE IV
COMPARISON OF DIRECTIVITY AT ø = 90° FOR BEND ANTENNA

| Patch | Main Lobe magnitude (dBi) | Main Lobe direction (deg) | 3 dB Angular width (deg) | Total efficiency (dB) |
|---|---|---|---|---|
| Square | 4.67 | 22 | 93.4 | -5.741 |
| Pentagonal | 4.66 | 22 | 93.5 | -5.769 |
| Hexagonal | 4.68 | 22 | 93.4 | -5.778 |
| Heptagonal | 4.67 | 22 | 93.4 | -5.728 |
| Octagonal | 4.67 | 22 | 93.4 | -5.732 |

Table I shows the comparison of reflection coefficient, VSWR, Gain and Directivity at ø = 90° for square, pentagonal, hexagonal, heptagonal and octagonal planar antenna. Table I shows that the gain and directivity of these shapes are similar which can be an important factor in the selection of the patch configuration for the real estate saving at PCB. Similarly Table II shows various parameters for the directivity at ø = 90°. As seen from these Tables I - IV, the bend structure provides significantly higher gain and directivity while measuring reflection coefficients within its limit. Similarly the bend structure in comparison of planar structure provides a similar bandwidth while providing higher total efficiency.

## V. CONCLUSION

The modelling and simulation results of various compact patch antenna over a Kapton substrate for wearable electronics using CST software have been investigated. As seen from their various simulation results, the designed square patch antenna although significantly smaller in size in comparison of other patch antennas such as pentagonal, hexagonal, heptagonal and octagonal shape provides a comparable gain and directivity with its efficiency at 2.4 GHz. Looking from Table I - IV, the bending of the structure provides an improvement in the parametric results such as reflection coefficient, gain, directivity and radiation efficiency of the planar antenna except for its main lobe direction. The gain and other parameters can be further increased with an array of antenna. The designed antenna being flexible makes it an excellent choice for wearable electronics applications apart from many other automotive and medical applications.

## ACKNOWLEDGMENT

The author would like to acknowledge the CSIC at Department of Engineering, University of Cambridge for providing the necessary support and funding for the project. This project was completed as part of the supervision to UROP projects.

## REFERENCES

[1] J. Q. Howel, “Microstrip Antennas,” *Proc. IEEE Int. Symp. Antennas Propag.*, 1972, 177-180.

[2] K. R. Carver and J. W. Mink, “Microstrip Antenna Technology,” *IEEE Trans. Antennas Propag.*, 29(1), 1981, 2-24.

[3] K.-L. Wong, “Compact and Broadband Microstrip Antennas,” *John Wiley & Sons*, New York, 2002.

[4] P. S. Hall and Y. Hao, “Antennas and Propagation for Body-Centric Wireless Communications (2nd Ed.),” *Artech House, Inc.*, Norwood, MA (USA), 2012.

[5] H. R. Khaleel, H. M. Al-Rizzo, and D. G. Rucker, “Compact polyimide based antennas for flexible displays,” *J. Display Technol.*, 8(2), 2012, 91-97.

[6] R. Wakodkar, B. Gupta and S. Chakraborty, “Analysis of square patch antennas for resonant frequency, return loss, gain and bandwidth using ANN,” *2009 International Conference on Emerging Trends in Electronic and Photonic Devices & Systems*, Varanasi, 2009, 387-390.

[7] V. Hamsakutty, A. V. P. Kumar, J. Yohannan, and K. T. Mathew, “Hexagonal dielectric resonator antenna for 2.4 GHz WLAN applications,” *Microw. Opt. Technol. Lett.*, 2007, 49, 162-164.

[8] T. Hariyadi, “A coplanar waveguide (CPW) wideband octagonal microstrip antenna,” *2013 International Conference of Information and Communication Technology (ICoICT)*, Bandung, 2013, 340-343.

[9] C. A. Balanis, “Antenna theory: analysis and design (3rd ed.),” *John Wiley & Sons*, New Jersey, USA, 2005.

[10] Dupont Kapton Polyimide Specification Sheet [Online]. Available: www2.dupont.com/kapton