CPW-Fed Circular Disc Monopole Antenna with Defected Waveguide Structure

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***Abstract*—This paper presented a parametric study on coplanar waveguide-fed (CPW-fed) circular disc monopole antenna with defected waveguide structure (DWS). The CPW-fed circular disc monopole antenna was designed to cover wideband frequencies. Afterward, the monopole antenna was attached to a waveguide with a uniplanar compact defected waveguide structure (UC DWS). The simulation design and parametric studies were done by using the CST Microwave studio software. Initially, the CPW-fed circular disc monopole antenna was designed to achieve return loss of -10dB from 2.36GHz to 10GHz. The directivity has improved significantly when the monopole antenna was attached to a waveguide where the highest directivity was 9.83dBi at 8.5GHz. However, narrower bandwidth and lower efficiency were achieved. It achieved a bandwidth of 0.49GHz and highest efficiency of -1.76dB at 8.5GHz. The UC DWS was then designed on the inner surface of the waveguide with smaller dimension with 6.25 x 6.25mm^2 and a small gap of 0.3mm. The directivity and gain have been improved. The highest directivity and gain were 7.10dBi at 8.5GHz and 5.42dB at 6.5GHz respectively. The bandwidth was 3.66GHz where it covered from 6.34GHz to 10GHz.**

***Index Terms*—Circular Disc Monopole Antenna; CPW-Fed; UC DWS; Wideband.**

I. Introduction

Recently, the Ultrawideband (UWB) technology is introduced to satisfy the demand of high resolution and high data rate. Thus, the wideband antenna receives great attention. Among many types of wideband antenna, the monopole antenna is a potential candidate due to its low profile, low cost, easy to fabricate and perform the omnidirectional pattern. However, it is found that it has poor directivity and gain. Meanwhile, it is found that it is not designed with waveguide by having the defected structure on it. It is expected that the defected waveguide structure (DWS) can improve the directivity and miniaturize dimension of the antenna.

Monopole antenna is one of the families of wideband antenna. It can be designed by using different types of feeding line which include microstrip feeding [1, 2] and coplanar waveguide (CPW) feeding [3, 4]. There are also several design techniques for monopole antenna that can be found for example slot antenna [5, 6], fractal antenna [7, 8] and circular disc monopole antenna [9, 10]. For defected, it belongs to metamaterial family. Metamaterial is a material that does not exist in nature. There are various types of metamaterial which include artificial magnetic conductor (AMC) [11], electromagnetic band gap (EBG), frequency selective surfaces (FSS), defected such as defected ground structure (DGS) and defected microstrip structure (DMS). Several techniques are used to enhance directivity and gain such as monopole textile antenna integrate with a flexible (EBG) surface [12], UWB antenna design with compact multilayer FSS [13], triple-band microstrip fed monopole antenna design with DGS [14] and microstrip patch antenna design with DMS [15].

In this paper, a CPW-fed circular disc monopole antenna with DWS is presented. This study investigates the effects of uniplanar compact defected waveguide structure (UC DWS) towards antenna parameters such return loss, gain, directivity, efficiency and radiation pattern.

II. Antenna Design

First, the CPW-fed circular disc monopole antenna (Design A) is designed. It is simple to design and fabricate. It is designed based on the previous experimental study [16]. It has a single copper layer. It is also analyzed through parameters studies of the length of feed gaps, the width of ground plane and radius of the disc. Finally, the length of feed gap h=0.3mm, width of ground plane W_s=47mm and radius of disc R=12.5mm are selected. Figures 1 and 2 show the simulated and fabricated Design A.

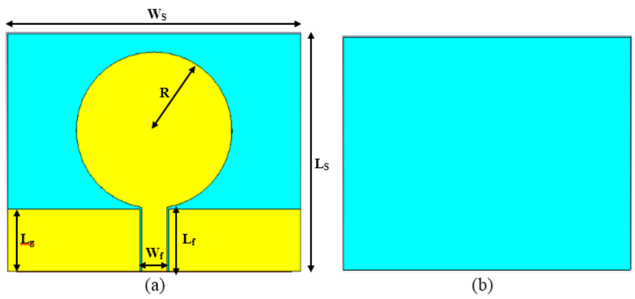

Figure 1: The (a) front and (b) back view of simulated Design A

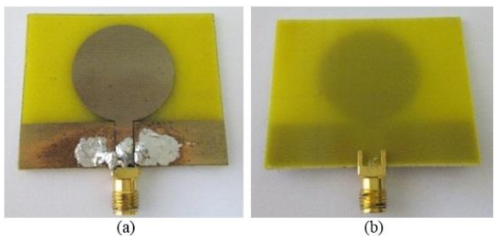

Figure 2: The (a) front and (b) back view of fabricated Design A

The antenna is designed on the FR4 board with 1.6mm thickness, 4.4 dielectric constant and 0.019 tangent loss of substrate. The thickness of copper used is 0.035mm. For antenna parameters, Ws and Ls are the width and height of substrate respectively. Meanwhile, Wf and Lf are the dimensions of the feed line. The radius of circular disc monopole antenna is R while the height of ground plane is Lg. The optimized antenna parameters are showed in Table 1.

Table 1
Optimized Antenna Parameters of Design A

Parameters	Value
W_s	47mm
L_s	38mm
W_f	4mm
L_f	10.3mm
R	12.5mm
L_g	10mm

R can be determined by using microstrip circular patch's equations as the following [17]:

$$a = F / \left[1 + (2h/\pi\varepsilon_r F)(\ln(\pi F/2h) + 1.7726)\right]^{1/2} \quad (1)$$

where a = actual radius

$F = 8.791 \times 10^9 / f_r(\varepsilon_r)^{1/2}$

f_r = resonant frequency

h = substrate height

ε_r = substrate dielectric constant

W_f and L_f can be calculated by using the microstrip feed line equations as the following [18]:

Characteristic impedance, Z_o

$$Z_o = \left[30\pi / \left(\varepsilon_{reff}\right)^{1/2}\right] \times \left[K'(k)/K(k)\right] \quad (2)$$

where $k = S/(S+2W)$

S = width of CPW-fed line

W = gap between CPW-fed line and ground

Ratio of K/K' ,

$$K(k)/K'(k) = (1/\pi)\ln\left[2 \times (1+\sqrt{k})/(1-\sqrt{k})\right] \quad (3)$$

for $0.707 \le k \le 1$

$$K(k)/K'(k) = \pi / \ln\left[2 \times (1+\sqrt{k'})/(1-\sqrt{k'})\right] \quad (4)$$

for $0. \le k \le 0.707$

Effective dielectric constant, ε_{reff}

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2}\left[\begin{array}{l}\tanh\{1.785\log(h/W) + 1.75\} + \\ \frac{kW}{h}\left\{\begin{array}{l}0.04 - 0.7k + 0.01 \\ (1 - 0.1\varepsilon_r)(0.25 + k)\end{array}\right\}\end{array}\right] \quad (5)$$

Then, Design A is integrated inside waveguide as Design B. The rectangular waveguide is designed based on the dimension of antenna Design A. The waveguide is designed without having a connection with Design A. The waveguide consists of a FR4 board with copper at the inner surface of the waveguide. The length of the waveguide is studied through parametric studies by varying 10mm for each design. Then, the design of W1 = 60mm and W2 = 50mm is selected with optimized performances in return loss, gain, directivity and efficiency. Figure 3 and 4 show the simulated and fabricated Design B.

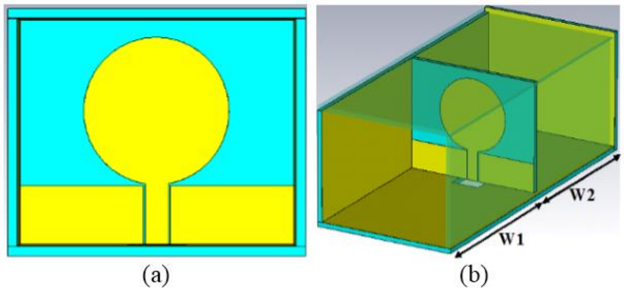

Figure 3: The (a) front and (b) side view of simulated Design B

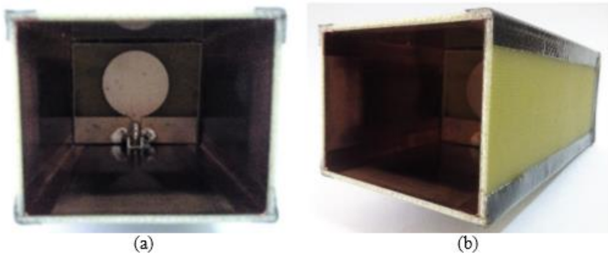

Figure 4: The (a) front and (b) side view of fabricated Design B

Next, the UC DWS is designed based on the previous studies [19-21]. It is a planar type and easier to fabricate. Besides that, it also has a regular shape so that it is easy to arrange on the inner surface of the waveguide. It consists of the square shape of 12.5 x 12.5mm^2 at the beginning. Then, it is modified to have the shape in Figure 5. It consists of four corner patches connect to central patch with the inset strip between patch to form a connection with the next UC structures in Figure 6. Rectangular slots of 12.5 x 0.25mm^2 are removed from the sides of the square shape. Then, slots of 1.5 x 2.5mm^2 are removed twice with a separated distance of 1mm in between at each side of the square shape. The inset strip at center has an extra length of the rectangular shape of 0.25 x 1mm^2 so that they are interconnected.

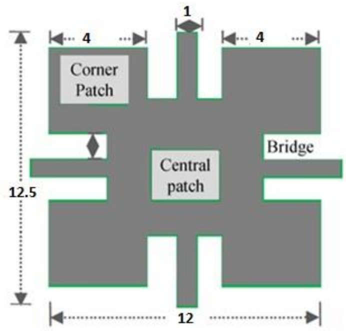

Figure 5: The unit of UC structure

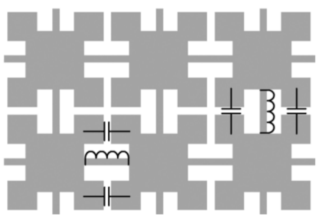

Figure 6: The UC structures are designed to have connectivity with the equivalent circuit introduced

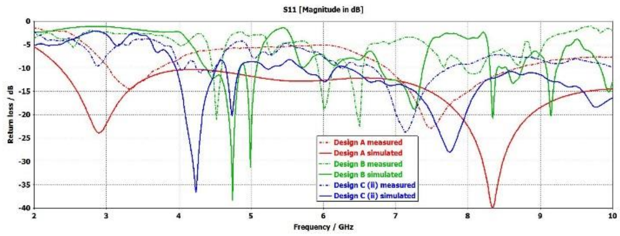

Figure 9: Return loss of all the simulated and measured results

For Design C, the UC structure is designed at the inner surface of the waveguide. It is designed to have a different dimension of UC structure. The smaller dimension of UC structure which is 6.25mm^2, half of the original dimension gives an optimized performance in return loss, gain, directivity and efficiency. Then, a small gap is designed in Figure 7 to study their effects. Finally, the Design C (ii) with a gap of length 0.3mm is chosen. Figure 8 shows the fabricated Design C (ii).

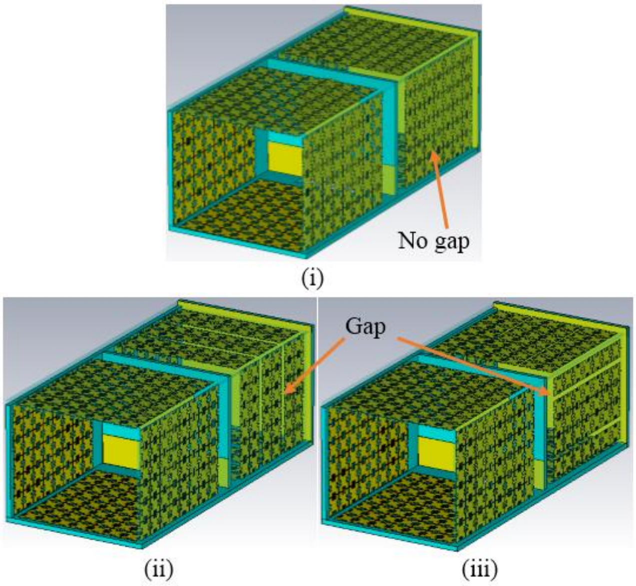

Figure 7: The view of Design C (i) without gap, Design C (ii) and Design C (iii) with gap

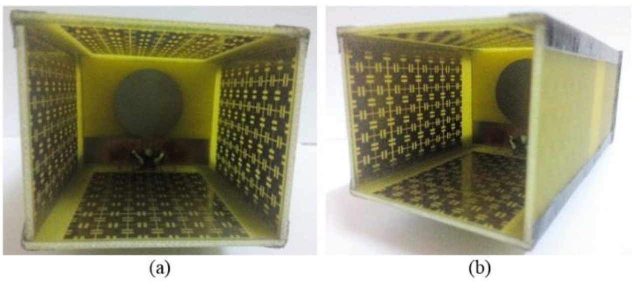

Figure 8: The (a) front and (b) side view of fabricated Design C (ii)

III. RESULTS

Figures 9 to Figure 13 show the comparison between the Design A, Design B and Design C (ii). The antenna parameters such as return loss, gain and radiation pattern are measured for each design to compare with the simulation result.

For return loss, all the measured results are higher than the simulated results but with almost similar curve in Figure 9. Design A achieves the lowest return loss of -39.87dB at 8.34GHz in the simulation. Design B achieves lower return loss of -38.29dB at 4.75GHz while Design C (ii) achieves lowest return loss of -36.53dB at 4.23GHz. It is also observed that Design A achieves the bandwidth of 7.64GHz from 2.36GHz to 10GHz in simulation in Figure 9. The bandwidth becomes narrower for Design B. It achieves a bandwidth of 0.49GHz where it covers from 6.89GHz to 7.38GHz. The bandwidth of Design C (ii) is 3.66GHz where it covers from 6.34GHz to 10GHz.

Meanwhile, all the measured gains are much lower than the simulated gains in Figure 10. Design A performs the highest gain of 5.84dB at 9.5GHz in the simulation. Design B performs the highest gain of 8.07dB at 8.5GHz. For Design C (ii), it performs the highest gain of 5.42dB at 6.5GHz. Besides that, it is found that the gain of Design B fluctuates in the overall frequency range. Design A and Design C (ii) perform steady curve compare to Design B. Their gain is increased with the increase of frequency although there is some drop of gain at a certain frequency. Design C (ii) performs higher gain than the gain of Design A at 4-5GHz and 7-8GHz.

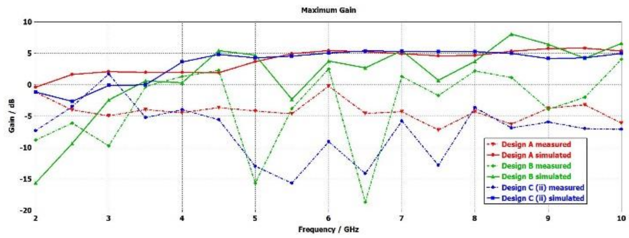

Figure 10: Gain of all the simulated and measured results

For antenna parameters of directivity and efficiency, the results are obtained from the simulation as shown in Figures 11 and 12. It is observed that Design B achieves the highest directivity in overall. It achieves the highest directivity of 9.83dBi at 8.5GHz. However, it shows fluctuated directivity. It also shows lower directivity of 5.75dBi than Design A and Design C (ii) at 6.5GHz. Design A achieves the highest directivity of 6.77dBi at 9.5GHz while Design C (ii) achieves the highest directivity of 7.10dBi at 8.5GHz. Both Design B and Design C (ii) show the highest directivity at the same frequency.

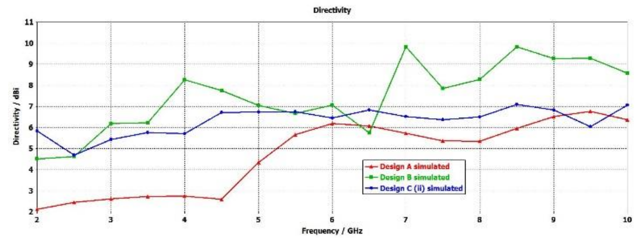

Figure 11: Directivity of all the simulated results

Although Design B performs the highest directivity, it shows lowest efficiency. Design A shows the highest efficiency in overall where the highest efficiency of -0.54dB at 3GHz. The highest efficiency of Design B and Design C (ii) are -1.76dB at 8.5GHz and -1.06dB at 7.5GHz respectively. Design A shows the steady curve where its values appear mostly flat along the frequency. Again, Design B shows fluctuated efficiency. This is because efficiency is related to gain and directivity.

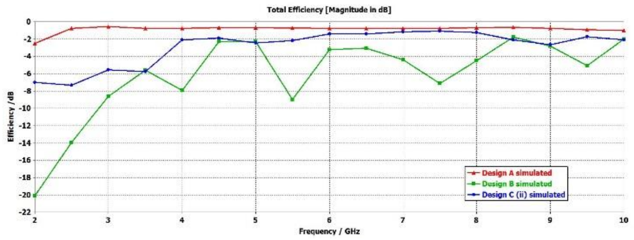
Figure 12: Efficiency of all the simulated results

The radiation pattern of the antenna at the frequency of 3GHz and 5GHz are shown in Figure 13 as they perform radiation pattern clearly in a lower frequency. Design A performs omnidirectional radiation pattern for E-field. However, it shows really isotropic radiation pattern for H-field. Design B performs directional radiation pattern at 3GHz for both E-field and H-field. It also shows the highest directivity at front lobe for E-field with less directivity at sides and back lobes. However, Design B shows the highest directivity at 30 degree and 330 degree with sides lobes. Design C (ii) shows directional radiation pattern for E-field. It shows less directivity for both E-field and H-field. It has the highest directivity at the front lobe of 0 degree and 325 degree at 3GHz and 5GHz respectively.

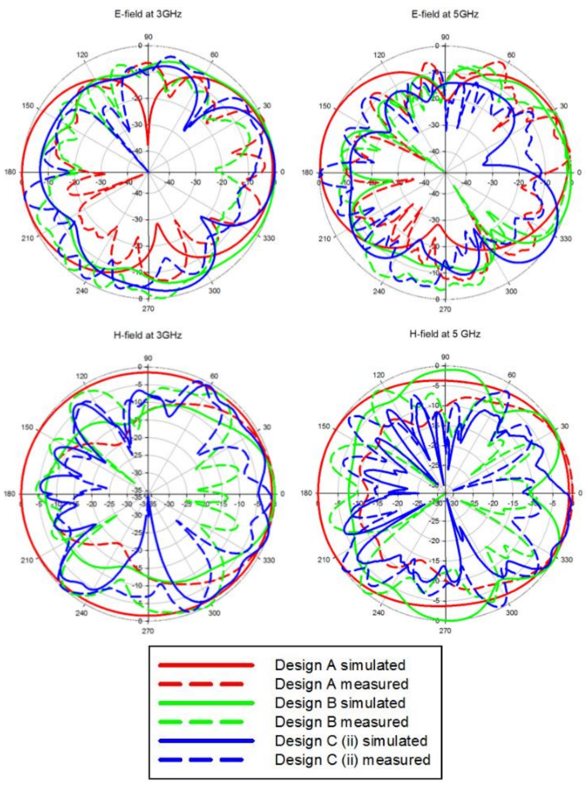

Figure 13: Radiation pattern of all the simulated and measured results at 3GHz and 5GHz for both E-field and H-field

IV. CONCLUSION

A CPW-fed circular disc monopole antenna with DWS is presented. The directivity is improved significantly when monopole antenna is designed with DWS. The highest directivity and gain are 7.10dBi at 8.5GHz and 5.42dB at 6.5GHz respectively. The bandwidth is 3.66GHz where it covers from 6.34GHz to 10GHz. The lowest return loss is -36.53dB at 4.23GHz. This research can be continued by changing the shape of UC DWS into pentagon or hexagon shapes to study the effects.

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REFERENCES

[1] G. A. H. Majeed, K. H. Sayidmarie, F. M. A. Abdussalam, R. A. Abd-Alhameed and A. Alhaddad, "A microstrip-fed pentagon patch monopole antenna for ultrawideband applications," *Internet Technologies and Applications (ITA)*, pp. 452-456, September 2015.

[2] A. H. Majeed, K. H. Sayidmarie, F. M. A. Abdussalam, R. A. Abd-Alhameed and A. Alhaddad, "A microstrip-fed pentagon patch monopole antenna for ultra wideband applications," *Internet Technologies and Applications (ITA), Wrexham*, pp. 452-456, 2015.

[3] M. w. Wang and B. p. Guo, "Multi-band CPW-fed planar monopole antenna with M-shaped strip for WLAN/WiMAX," *IEEE International Conference on Signal Processing, Communication and Computing (ICSPCC 2013), KunMing*, pp. 1-4, 2013.

[4] H. Zhang, G. Li, J. Wang and X. Yin, "A novel coplanar CPW-fed square printed monopole antenna for UWB applications," *Microwave and Millimeter Wave Technology (ICMMT), 2010 International Conference*, pp. 352-354, May 2010.

[5] M. K. Shrivastava, A. K. Gautam and A. K. Singh, "A CPW-fed UWB monopole-like slot antenna," *International Conference on Communications, Devices and Intelligent Systems (CODIS), Kolkata*, pp. 235-237, 2012.

[6] M. T. Wu and M. L. Chuang, "Multibroadband slotted bow-tie monopole antenna," *IEEE Antennas and Wireless Propagation Letters*, vol. 14, pp. 887-890, 2015.

[7] L. Wang, S. Lin, R. N. Cai, G. L. Huang and W. B. Zhang, "Multiband printed monopole antenna with square-nested fractal," *Communications and Networking in China (CHINACOM), 6th International ICST Conference*, pp. 929-932, August 2011.

[8] H. Fallahi and Z. Atlasbaf, "Study of a class of UWB CPW-fed monopole antenna with fractal elements," *Antennas and Wireless Propagation Letters, IEEE*, vol. 12, pp. 1484-1487, 2013.

[9] A. E. Teirab, J. A. Jervase and S. S. Mneina, "Bandwidth enhancement of coplanar waveguide fed disc monopole antenna for ultra-wideband communication applications," *Eighth International Conference on Wireless and Optical Communications Networks, Paris*, pp. 1-5, 2011.

[10] B. Saidaiah, A. Sudhakar, K. Padma Raju, "Circular disk monopole antenna for broadband applications," *International Journal of Scientific and Research Publications,* vol. 2, issue 6, pp. 1-4, June 2012.

[11] E. Y. Kim, J. H. Yoon, Y. J. Yoon and C. G. Kim, "Low profile dual-band reflector antenna with dual resonant AMC," *IEEE International Symposium on Antennas and Propagation (APSURSI), Spokane, WA*, pp. 1800-1803, 2011.

[12] A. Alemaryeen, S. Noghanian and R. Fazel-Rezai, "EBG integrated textile monopole antenna for space health monitoring application," *IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting, Vancouver, BC*, pp. 1209-1210, 2015.

[13] N. Kushwaha and R. Kumar, "High gain UWB antenna using compact multilayer FSS," *IEEE International Microwave and RF Conference (IMaRC), Bangalore*, pp. 100-103, 2014.

[14] S. Oudayacoumar, T. Karthikeyan and V. Hariprasad, "A triple-band microstrip fed monopole antenna using defected ground structure for WLAN and Wi-MAX applications," *Advances in Electrical Engineering (ICAEE), International Conference*, pp. 1-4, January 2014.

[15] V. S. Kushwah and G. S. Tomar, "Size reduction of microstrip patch antenna using defected microstrip structures," *International Conference on Communication Systems and Network Technologies*, pp. 203-207, 2011.

[16] J. Liang, L. Guo, C. C. Chiau, X. Chen and C. G. Parini, "Study of CPW-fed circular disc monopole antenna for ultrawideband applications," *IEE Proceedings - Microwaves, Antennas and Propagation*, vol. 152, no. 6, pp. 520-526, December 2005.

[17] B. J. Kwaha, O. N. Inyang and P. Amalu, "The circular microstrip patch antenna-design and implementation," *International Journal of Recent Research and Applied Studies (IJRRAS)*, 8 (1), pp. 86-95, July 2011.

[18] G. W. M. Whyte, *Antennas for Wireless Sensor Network Applications*. Scotland: University of Glasgow, 2008.

[19] H. Qin, D. Su and X. Zeng, "Novel design of 4 elements GPS antenna array with UC-EBG structure," *Microwave Technology & Computational Electromagnetics (ICMTCE), IEEE International Conference Qingdao*, pp. 280-283, 2013.

[20] M. S. Alam, M. T. Islam and N. Misran, "Performance investigation of a uni-planar compact electromagnetic bandgap (UC-EBG) structure for wide bandgap characteristics," *Asia-Pacific Symposium on Electromagnetic Compatibility, Singapore*, pp. 637-640, 2012.

[21] A. Bondarik and D. Sjöberg, "Implementation of UC-EBG structure for 60 GHz gridded parasitic patch stacked microstrip antenna," *9th European Conference on Antennas and Propagation (EuCAP), Lisbon*, pp. 1-5, 2015.