

Microstrip-Fed Circular Disc Monopole Antenna with Defected Waveguide Structures

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ABSTRACT

This paper presented the microstrip-fed circular disc monopole antenna with defected waveguide structure. First, the microstrip-fed circular disc monopole antenna was designed. Next, the monopole antenna was designed with waveguide and lastly followed by the defected waveguide structure where the uniplanar compact (UC) structure was used. CST Microwave studio software was used for simulation and parametric studies process. Initially, the microstrip-fed circular disc monopole antenna was designed to achieve return loss less than -10dB for wideband frequencies. Then, the gain and directivity was improved with the integration of waveguide. The highest directivity of 11.38dBi found at 13.5GHz. However, low efficiency and narrower bandwidth were obtained. Next, uniplanar compact defected waveguide structure (UC DWS) was designed at inner surface of waveguide. The bandwidth achieved 3.09GHz where it covered from 10.91GHz to 14GHz. Meanwhile, the directivity maintained higher than the monopole antenna with highest directivity of 8.84dBi at 10GHz. The gain was also improved from 11GHz to 14GHz with highest gain of 6.38dB occurred at 13.5GHz.

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1. INTRODUCTION

The technology of wireless communication system are enhancing to support the demand of higher resolution and higher data rate requirement. For example, by having higher resolutions and data rates, people can send the videos and pictures instead of text in clear view. Therefore, UWB technology is used to fulfill the demand. There are many antennas for UWB technology. However, monopole antenna receives great attention due to its low profile, low cost, easy to fabricate and perform omnidirectional pattern. By designing antenna with low profile into communication device, thus it can support the mobility access by providing anywhere and anytime service to people. Nowadays, there is a challenge to design monopole antenna with wide bandwidth, high gain and radiation efficiency with compact dimension. Besides that, monopole antenna has poor directivity. Meanwhile, it is found that it does not design with waveguide by having the defected structure on it. The DWS is expected to improve the directivity and miniaturize dimension of antenna.

There are few wideband antennas such as horn antenna [1], log periodic antenna [2], dipole antenna [3] and monopole antenna [4-13]. Horn antenna and log-periodic antenna are normally designed in large dimension. In this project, monopole antenna with low profile and low cost is focused. Different types of feeding line can be designed for monopole antenna such as microstrip feeding [4] and coplanar waveguide

(CPW) feeding [5-7]. Monopole antenna itself can be designed in different structure such as in slot [6-8], fractal [9-11] and circular disc [4], [5], [12], [13]. Circular disc monopole antenna is the most simple to design and thus it is selected. Meanwhile, artificial magnetic conductor (AMC) is a metamaterial which does not exist in nature [14]. Example types of AMC are electromagnetic bandgap (EBG) [15], [16], frequency selective surface (FSS) [17], defected such as defected ground structure (DGS) [18] and defected microstrip structure (DMS) [19]. Defected structure can be designed at ground and microstrip feed line, thus the defected structure at waveguide is called DWS.

In this paper, a microstrip-fed circular disc monopole antenna with DWS is presented. UC DWS is used as the defected structure at the inner surface of waveguide. This study will investigate the effects of DWS towards antenna parameters such as return loss, gain, directivity and efficiency at microwave frequency region.

2. ANTENNA DESIGN

The microstrip-fed circular disc monopole antenna (Design A) is designed first. It is designed based on the previous experimental study [4] where it can operate in wideband frequencies. It achieves return loss of less than -10dB from frequency of 2.69GHz to 10.16 GHz in simulation. Based on the study, the parameter studies are done for the length of feed gap and width of ground plane. Finally, the feed gap with length of 0.3mm and the ground plane with width of 42mm are chosen. The designed and fabricated Design A are showed in Figure 1 and 2.

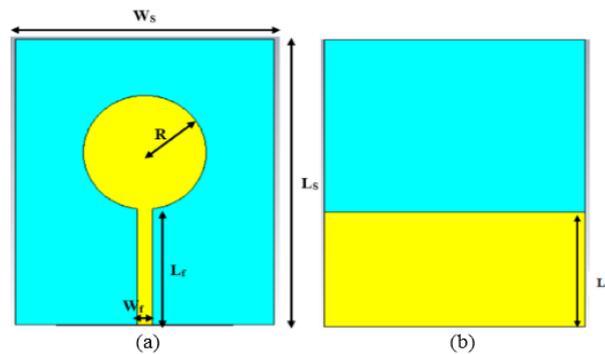


Figure 1. The (a) front and (b) back view of Design A

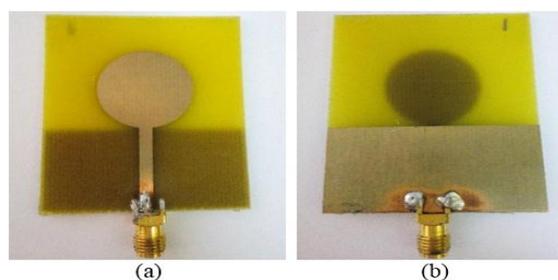


Figure 2. The (a) front and (b) back view of prototype Design A

Table 1. The antenna parameters of microstrip-fed circular disc monopole antenna

Parameters	Value	Parameters	Value
W_s	42mm	L_f	20.3mm
L_s	50mm	R	10mm
W_f	2.6mm	L_g	20mm

The material used to design the antenna is the FR4 board with 1.6mm thickness, 4.4 dielectric constant and 0.019 tangent loss of substrate. The thickness of copper is 0.035mm. Table 1 shows the

optimized parameters used in the antenna design. For antenna parameters, W_s and L_s are the width and height of substrate respectively. Meanwhile, W_f and L_f are the dimensions of feed line. Radius of circular disc monopole antenna is R while height of ground plane is L_g .

R can be determined by using microstrip circular patch's Equations as below [20]:

$$a = \frac{F}{\sqrt{1 + \frac{2h}{\pi \epsilon_r F} \left[\ln\left(\frac{\pi F}{2h}\right) + 1.7726 \right]}} \quad (1)$$

where

a = actual radius

$$F = \frac{8.791 \times 10^9}{f_r \sqrt{\epsilon_r}}$$

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 below [21]:

Characteristic impedance, Z_o

$$Z_o = \frac{60}{\sqrt{\epsilon_{reff}}} \ln\left(\frac{8h}{W} + \frac{W}{4h}\right) \text{ for } \frac{W}{h} < 1 \quad (2)$$

$$Z_o = \frac{120\pi}{\sqrt{\epsilon_{reff}} \left[\frac{W}{h} + 1.393 + 0.667 \ln\left(\frac{W}{h} + 1.444\right) \right]} \text{ for } \frac{W}{h} > 1 \quad (3)$$

where

W = line width

Effective dielectric constant, ϵ_{reff}

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \frac{1}{\sqrt{\left(1 + 12 \frac{h}{W}\right)}} \quad (4)$$

Then, the monopole antenna (Design A) is designed with waveguide as Design B as shown in Figure 3 and Figure 4. The waveguide is designed based on the dimension of the Design A in rectangular shape. The waveguide material used is FR4 board with the copper at the inner surface of waveguide. The length of waveguide is varied by 10mm to obtain the optimized antenna design. The finalize design dimension with optimized performance for return loss, directivity, gain and efficiency are $W_1=40\text{mm}$ and $W_2=30\text{mm}$.

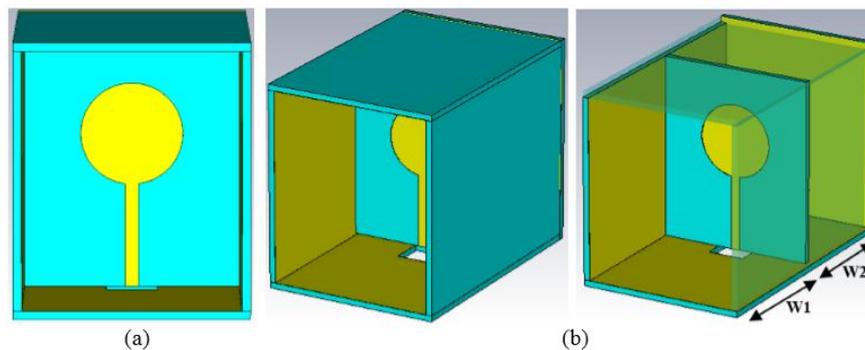


Figure 3. The (a) front (b) side view of Design B

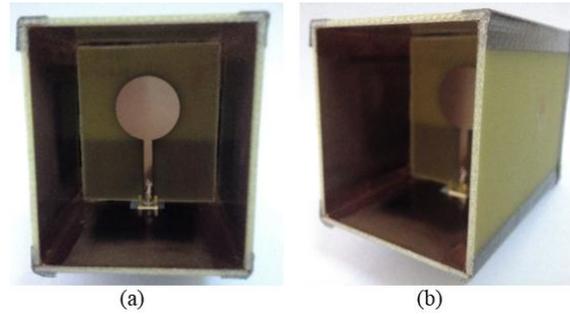


Figure 4. The (a) front and (b) side view of prototype Design B

After that, the UC structure is designed. Due to its planar and compact structure, it can be printed on the FR4 board easily. From previous studies [22-25], it is used to design to achieve wide bandgap characteristic in compact size, have high gain and low backward radiation. It can be applied for microstrip antennas and filters at microwave frequencies. It is designed to have periodic pattern to act as high impedance surface. It can be represented as the equivalent distributed LC circuit at resonant frequency to act as bandpass filter. The central frequency of the bandgap can be calculated by using the Equation (5) below.

$$f_c = \frac{1}{2\pi\sqrt{LC}} \quad (5)$$

The UC DWS is designed with square shape at the beginning. Then, it is modified to remove rectangular shapes of 12.5mm x 0.25mm from each edge of the square. Then, rectangular shapes with another dimension of 1.5mm x 2.5mm are removed twice with a distance of 1mm in between from each edge of the square. The inset strip is designed at centre which is slightly longer to act as bridge to connect with other UC structures beside. Thus, a small rectangular shape of 1.5mm x 2.5mm is added at each inset strip. The UC DWS with complete designed structure is showed at Figure 5.

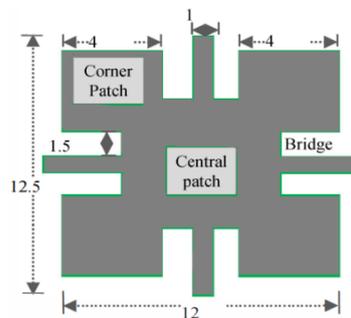


Figure 5. The unit of UC structure

UC structures are normally designed to be interconnected with the equivalent circuit formed as shown in Figure 6. The gap between the corner patch of two UC structures forms the equivalent capacitance while the connection of inset strip between two UC structures forms the equivalent inductance. D represents the dimension of UC structure. t is the width of gap between the corner patch and bridge. d is the length of bridge which is connected to side of another UC structure. δ is the width of the bridge. ϵ_e is the effective permittivity where it is defined when the UC structure is located on a FR4 board with ϵ_r . L and C then can be represented by using the Equations (6) and (7) below [22].

$$L = \frac{\mu_0 D}{2\pi} \ln\left(\frac{2D}{\pi t}\right) \quad (6)$$

$$C = \frac{2d\epsilon_e\epsilon_0}{\pi} \ln\left(\frac{2D}{\pi\delta}\right) \quad (7)$$

where

$$\epsilon_e = \frac{(\epsilon_r + 1)}{2}$$

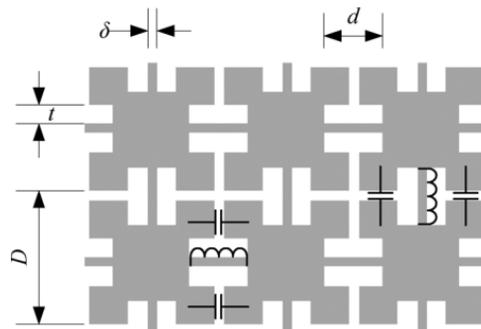


Figure 6. The connection of UC structures with the equivalent circuit

Then, UC is designed at the inner surface of waveguide as Design C. At first, the UC DWS is varied by the dimension where the UC DWS is reduced to half of the original dimension of UC structure. It is found that the smaller dimension of UC DWS as shown in Figure 7 of Design C (i) provide wider bandwidth, higher directivity and higher gain. Then, the UC DWS is designed to have gap between structures as shown in Figure 7 of Design C (ii) and Design C (iii). It is observed that the Design C (ii) gives the wider bandwidth, higher gain and higher efficiency. The UC DWS is varied again to have different length of gap. Finally, the Design C (ii) with gap length of 1.5mm is chosen to fabricate as shown in Figure 8 and 9.

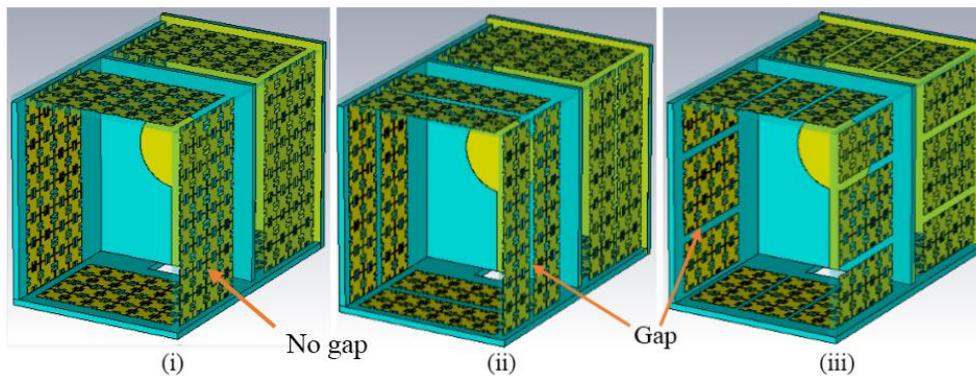


Figure 7. The view of Design C (i) without gap, Design C (ii) and Design C (iii) with gap

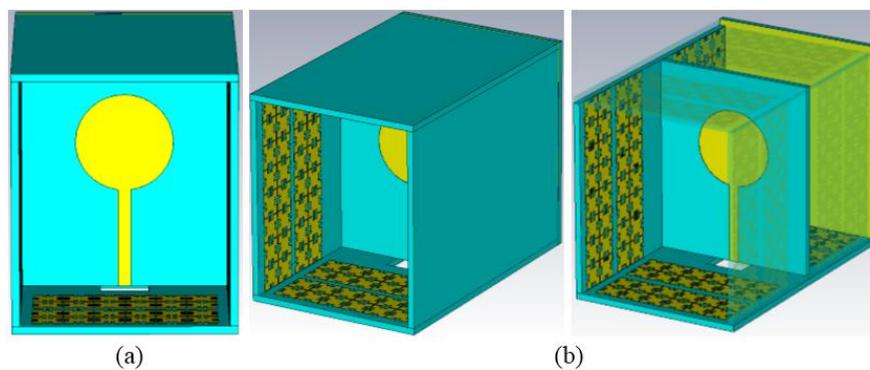


Figure 8. The (a) front (b) side view of Design C (ii)

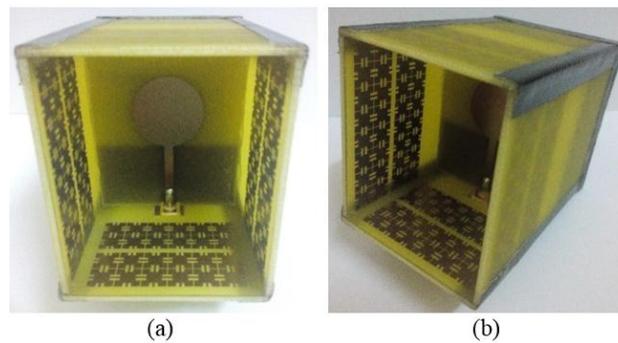


Figure 9. The (a) front and (b) side view of prototype Design C (ii)

3. RESULTS AND ANALYSIS

The comparison results are done for Design A, Design B and Design C (ii) as shown in Figures 10-13. The measurement of return loss are done for each design.

In Figure 10, it shows that the lowest return loss of Design A simulated is -34.28dB at 13.43GHz . Design B simulated achieves the lowest return loss of -32.56dB at 12.27GHz while Design C (ii) simulated achieve the lowest return loss of -46.83dB at 11.88GHz . Besides that, it is observed that Design A covers bandwidth of 2.53GHz from 11.74GHz to 14GHz . For Design B, it covers the bandwidth of 1.29GHz from 11.34GHz to 12.63GHz . Bandwidth of Design C (ii) is 3.09GHz which is covered from 10.91GHz to 14GHz .

The lowest return loss measured is shifted to the left compare to the return loss simulated for each design. All the return loss measured are also higher than the simulated results except for Design B. Design B achieves lowest return loss of -35.8dB at 10.91GHz . Both Design A and Design C (ii) achieve lowest return loss of -19.2dB at 10.58GHz and -19dB at 11.62GHz respectively with frequency shifted to left. It is found that the bandwidth of Design B become narrower when waveguide is integrated. When waveguide with UC DWS is applied, the lowest return loss is shifted to left with wider bandwidth due to equivalent distributed LC circuit uses at resonant frequency of 11.88GHz .

It is found that Design B achieves the highest gain while Design A achieves the lowest gain from frequency 11.5GHz to 12.5GHz in Figure 11. Design B has obvious increase and decrease for the gain value. It starts to increase from 0dB at 10GHz to highest gain of 6.56dB at 12.5GHz and drop to -1.5dB at 14GHz . Meanwhile, both Design A and Design C (ii) have small different between the lowest and highest value of gain. Design A achieves highest gain of 5.25dB at 10GHz and drops to lowest gain of 2.76dB at 12GHz and increases again to 4.22dB at 14GHz . Design c (ii) starts with gain of 6.26dB and drops to lowest gain of 2.8dB 10.5GHz and then increases again with highest gain of 6.38dB occurs at 13.5GHz .

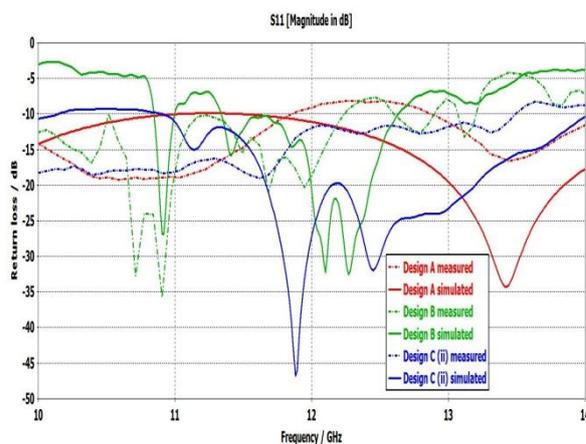


Figure 10. Return loss of all the simulated and measured results

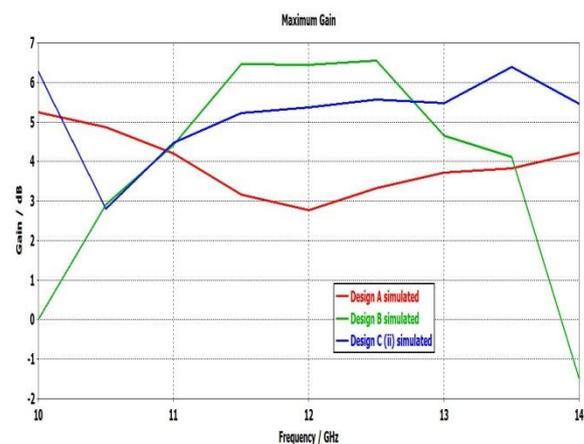


Figure 11. Gain of all the simulated results

The directivity for each design is also showed in Figure 12. Design B shows the highest directivity while Design A shows the lowest directivity. Design A performs highest directivity of 6.72dBi at 10GHz. The highest directivity of Design B and Design C (ii) are 11.38dBi at 13.5GHz and 8.84dBi at 10GHz respectively. Both Design B and Design C (ii) show fluctuated directivity while Design A shows lowest directivity at center frequency range that is showed in Figure 12. Besides that, Design A and Design C (ii) perform almost same curve for result of maximum gain and directivity where they are related to each other.

The efficiency is also related to directivity and gain of antenna which is showed in Figure 13. Although Design A shows low gain and directivity, it shows highest efficiency in overall. Design A shows highest efficiency of -1.47dB at 10GHz. Design B shows highest efficiency of -2.76dB at 12GHz while Design C (ii) shows the highest efficiency of -1.84dB at 12GHz. Both Design B and Design C (ii) show the highest efficiency at the same frequency. It is observed that both Design A and Design C (ii) have less change of efficiency. Design B shows a big different which is 6.25dB between the highest and lowest efficiency. It is also found that it has the almost similar curve for graph maximum gain and efficiency where the maximum peak is occurred at almost center of frequency range.

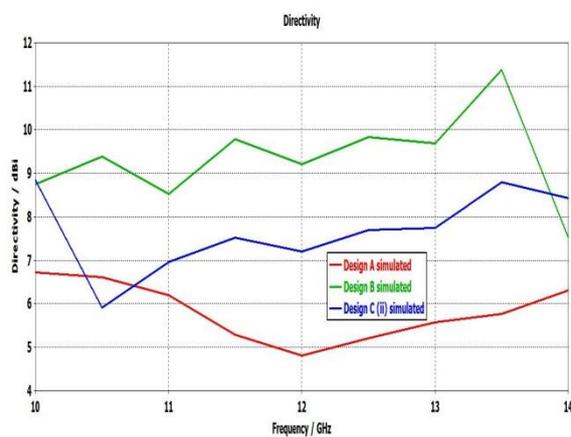


Figure 12. Directivity of all the simulated results

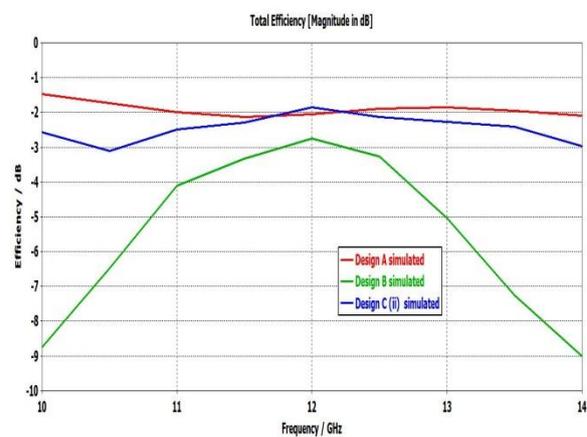


Figure 13. Efficiency of all the simulated results

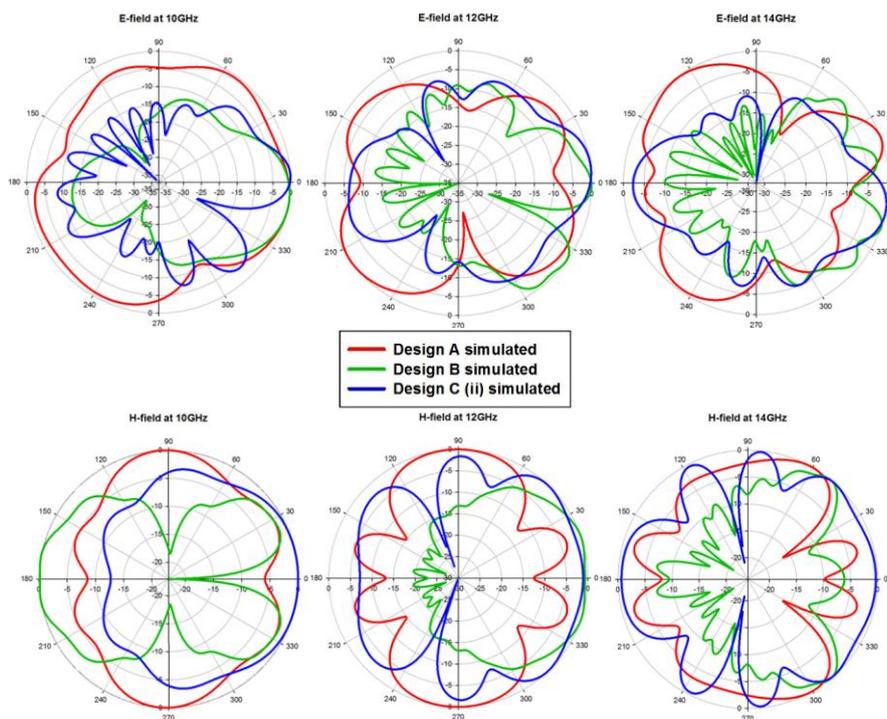


Figure 14. Radiation pattern of all the simulated results at 10GHz, 12GHz and 14GHz for E-field and H-field.

The radiation pattern of each design is simulated in Figure 14. Design A performs equivalent radiation pattern for H-field but not for E-field. At frequency 12GHz and 14GHz, the radiation pattern for H-field performed are slightly similar as omnidirectional radiation pattern but with minor lobes at front and back lobe. Meanwhile, Design B performs directional radiation pattern especially for E-field at 10GHz and H-field at 12GHz. It mostly performs less directivity at the back lobe of radiation pattern. However, it shows highest directivity at the back lobe of 180 degree for H-field at 10GHz. For Design C (ii), it almost performs the directional radiation pattern. It also shows less directivity at the back lobe. It is noticed that it shows less directivity at the side for E-field compares to H-field.

4. CONCLUSION

The microstrip-fed circular disc monopole antenna with DWS is presented. The design of DWS to the microstrip-fed circular disc monopole antenna shows that the directivity and gain can be improved. The directivity and gain are enhanced significantly from 11GHz to 14GHz. The highest directivity is 8.84dBi at 10GHz while the highest gain is 6.38dB at 13.5GHz. The bandwidth is 3.09GHz where it covers from 10.91GHz to 14GHz. The lowest return loss is -46.83dB at 11.88GHz. The radiation pattern is also changed mostly near to directional radiation pattern at 12GHz and 14GHz for both E-field and H-field. The research can be continued by changing the shape of UC DWS into rectangular shape instead of square to study the effects.

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