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RADIATION PATTERN RECONFIGURABLE MICROSTRIP PATCH ANTENNA USING DUAL DELAY LINE

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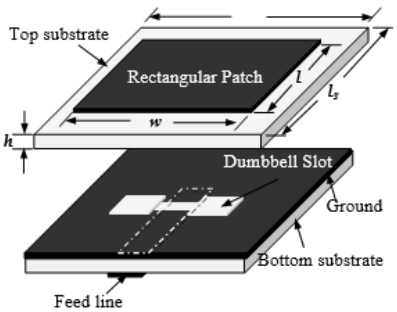
Graphical abstract



Abstract

This paper proposes radiation reconfigurable patch antenna using feeding delay line technique. The 2 x 2 antenna array is designed and investigated. The direction of radiation pattern is newly controlled by interchanging two different lengths of corporate feeding network based on dedicated switches' states of feeding line network. The size of radiating patches are remained minimum by introducing dumbbell slot structure that etched on the ground layer with dual functions, to couple the feeding network on the bottom substrate with radiating patches on the top substrate, and to get desired working frequency at 7.5 GHz. Three directions of radiation pattern are obtained from the proposed reconfigurable antenna according to states of OPEN and SHORT of feeding line network. From the antenna structure, the antenna beam is steerable towards three angles -30 degree, 0 degree and +30 degree. With return loss (S11) in range of -20 dB to -33 dB, the antenna successfully resonant at 7.5 GHz during OFF while 7.46 GHZ during ON condition. In addition, the directivity gain of the antenna almost consistent at three different directions in range of 9.67 dBi to 9.8 dBi. The results from fabricated antenna are agreed with simulated, and the antenna has potential to serve for outdoor wireless communication systems.

Keywords: Radiation pattern, reconfigurable, delay line, array, wireless, CST

Abstrak

Kertas kerja ini mencadangkan antena boleh ubah. Arah isyarat electromagnetik boleh diubah ke arah tertentu dengan menggunakan kaedah lambatan, yang mana dua talian transmisi yang berbeza panjang dibuat pada transmisi utama pada antena tersebut. Nilai frekuensi diperolehi berpandukan bentuk ruang yang dibuat pada lapisan kedua antena yang dicadangkan. Selain daripada menentukan frekuensi untuk antena ini, bentuk ruang juga amat berguna sebagai penghubung di antara transmisi pada lapisan bawah dan elemen pemancar pada lapisan atas. Dengan mengubah keadaan transmisi lambatan bersambung atau terbuka, arah radiasi dapat dihalakan ke arah +30 darjah, 0 darjah dan -30 darjah. Dengan nilai S11 di antara -20 dB hingga 33 dB, antena boleh ubah ini bekerja pada frekuensi 7.5 GHz pada 0 darjah dan 7.46 gHz pada -30 dan +30 darjah. Sementara itu kekuatan antena untuk tiga arah di antara 9.67 dBi hingga 9.8 dBi dengan kecekapan hampir sekata pada 80%. Berdasarkan perbandingan keputusan di antara simulasi dan protaip antena yang dicadangkan ada potensi digunakan untuk antena komunikasi luaran tanpa wayar.

Kata kunci: Corak sinaran, boleh ubah, transmisi lambatan, jajaran, tanpa wayar CST

1.0 INTRODUCTION

Reconfigurable antenna with multifunction capability promises more efficient antenna compared with conventional antenna in order to support wide area and very complex wireless communication systems [1]. Typically the conventional technique to cover more frequencies for wireless communication is focusing on designing wideband microstrip antenna. However, due to its wideband characteristic, interference from unwanted signal and noise will be received by the wideband antenna [2] while radiation beam conventionally controlled by using phased array antenna. However, the approach requires split circuit to activate the phased array switch [3]. Basically, reconfigurable antenna is represented individually according to three main antenna characteristics, frequency reconfigurable antenna, radiation reconfigurable antenna and polarization reconfigurable antenna [4]. However, for more versatile function of the antenna, compound reconfigurable antenna has been introduced to reconfigure two or more main parameters antenna simultaneously based on specific requirements. Theoretically, the reconfigurability of an antenna is achievable by changing or modifying the antenna current distribution as required for specific function [5], and this current alteration usually controllable via electronic switching technique, material properties alterations [6] and mechanical movement [7]. Meanwhile, with very rapid demand in satellite communication systems to support huge numbers of applications [8] such as forecast monitoring, scanning activities, and broadcasting, steerable radiation pattern antenna without separate phase shifter circuit is very significant to provide excellent respond to replace the conventional phased-shifter array antenna. In addition, radiation pattern reconfigurable antenna also offers efficient function to feed smart antenna technology for cellular radio system to minimize interference by isolating unwanted signals for better communication link [9]. However, in order to support outdoor or long distance wireless communication systems, high and consistent gain for any direction of reconfigurable antenna is needed, and this capability is achievable by utilizing all radiation elements of radiation pattern reconfigurable antenna.

Over the years, there are many techniques have been proposed in designing radiation pattern reconfigurable antenna to provide flexible function to elevate or steer antenna beam [10]. Previously, The 2 x 2 planar array antenna with single PIN diode has been designed to control the direction of radiation pattern [11]. In OFF condition only three elements are working. Inversely, if the PIN is turning ON all four elements are activated. Consequently, two different gains are obtained. Dual cylindrical structure with pair of PIN diode switches capable to provide multiple angles of radiation pattern [12], with only one element activated once a time, the gain of antenna is limited to cover point-to-point outdoor wireless system. Radiation reconfigurable antenna using parasitic element has been designed by [13], [14]. Since the radiation pattern is steered according to selected parasitic elements, gain degradation will limit the function of proposed antenna to support outdoor wireless systems. More complex radiation reconfigurable antenna array with wide coverage angle direction has been proposed by [15] and [16], designed for WLAN and LTE applications the such structure provides wide covered angle. However, the technique will create multilayer structure that will contribute to a big volume structure of reconfigurable antenna. According to the reported results and performance most of the proposed designs are limited for outdoor wireless applications. This obstruction is due to the small number of array element and very complex antenna structure. Integrated with switching network to control the reconfigurability of the antenna, solid state devices such as PIN diode promises efficient current modification due to very low driving voltage, high tuning speed (1–100 ns), high power handling capability, very reliable since there are nonmoving part, and extremely low cost [17].

In this paper, radiation pattern reconfigurable patch antenna using dual delay line is proposed. The 2 x 2 planar antenna array has designed at 7.5 GHz. However, to prove the concept the preliminary research was designing and fabricating the antenna in deal condition (without PIN diode) where ON and OFF of switch mode to control the beam directions based on OPEN and SHORT of copper feeding line pad.

Based on classical concept, the direction of radiation pattern is controllable via line shifting by creating delay effect on the feeding line. Thus different phase technique to steer The direction of radiation pattern is controllable by changing the length of feeding line at specific length as reported in [18], [19]. The effect of feeding line length towards radiation beam angle can be described as shown in Figure 1 with the related equations (1) to (4).

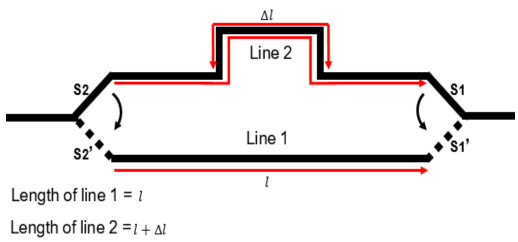


Figure 1 Delay line concept

Consider bottom line (Line 1) with length *l as* reference line, while top line (Line 2) has additional length *l+Δl* . If two switches are shifted from lower to upper line, *Δl* will create phase delay effect, to steer the antenna beam to specific direction according to the following equation:

$$\beta = \sqrt{\varepsilon_r} K \, \Delta l \qquad (1)$$

Where

$$K = \frac{2\pi f}{c} \qquad (2)$$

$$\beta = \frac{\sqrt{\varepsilon_r} \times 2\pi f \times \Delta l}{c} \quad (3)$$

Since this structure is applied for microstrip antenna design, the length of *Δl* is determined by:

$$\Delta l = \frac{\beta \times c}{\sqrt{\varepsilon_r} \times 2\pi f} \quad (4)$$

Where c is speed of light, and ε_r is dielectric constant of substrate.

In order to minimize the number of switching element, the novel technique by placing the delay line on the selected feeding line is introduced. By consider the sub array element as a load, equation (1) to (4) is applied to determine the suitable physical length to elevate antenna beam towards specific directions and Figure 2 shows the equivalent circuit the delay line with antenna to illustrate the concept.

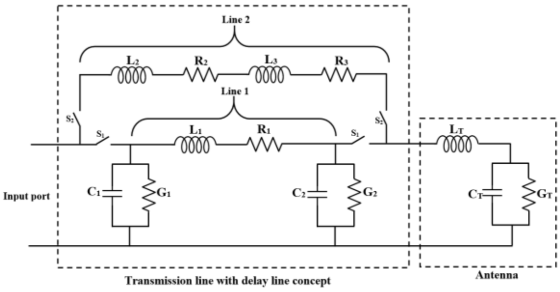
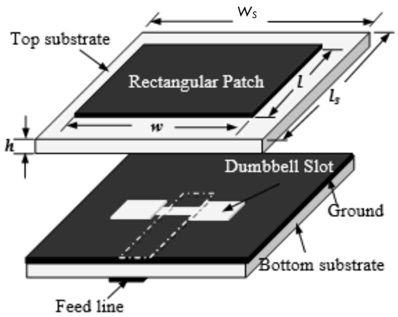


Figure 2 Equivalent circuit for the delay line concept

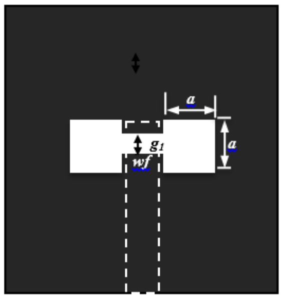
2.0 METHODOLOGY

2.1 Antenna Design

The antenna is designed on Rogers substrate with permittivity 5.16 and 0.64 mm thickness. The thin substrate is chosen due minimum dielectric loss and lightweight, and subsequently provides better gain and efficiency. For more efficient antenna, two layers of substrates are separated by airgap in order to provide good bandwidth on selected application. Initially, single element of the proposed antenna is designed with rectangular radiating patches are fabricated on the top substrate, while ground and corporate feeding line are etched on the bottom substrate as illustrated in Figure 3(a). Meanwhile, dumbbell slot structure is proposed and etched on the ground layer with dual functions, to couple the feeding network on the bottom substrate with radiating patches on the top substrate, and to get desired working frequency at 7.5 GHz as shown in Figure 3(b). The physical dimension of the single element of the antenna with etched dumbbell structure is listed in Table 1.



(a)



(b)

Figure 3 (a) Single element of proposed antenna, (b) Ground layer with dumbbell-shaped slot

Table 1 Dimension for rectangular patch and dumbbell-shaped slot

Parameters	Value (mm)
h	0.64
Air gap	1
l	8.71
w	11
lf	9.34
ls	15
	15
a	2.36
g1	0.4

The whole final structure of the reconfigurable antenna designed with newly two delay lines is illustrated in Figure 4. Meanwhile, the feeding network with delay line labeled with L1 and L2 and switches location is depicted in Figure 5, where the two identical delay lines are designed at 50 ohm feeding line. The position of delay lines have creates six points to represent switching network labeled as S1, S2, S3, S4, S5 and S6. Where, S1, S2 and S3 placed in top group, S4, S5 and S6 placed in bottom group. Through simulation and optimization process the final dimensions for all elements are listed in Table 2. In this paper, the length of delay lines are optimized at 9.28 mm to steer the beam to -30 and +30 degrees.

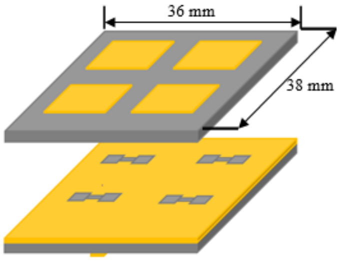


Figure 4 Two by two (2 x 2) Antenna array

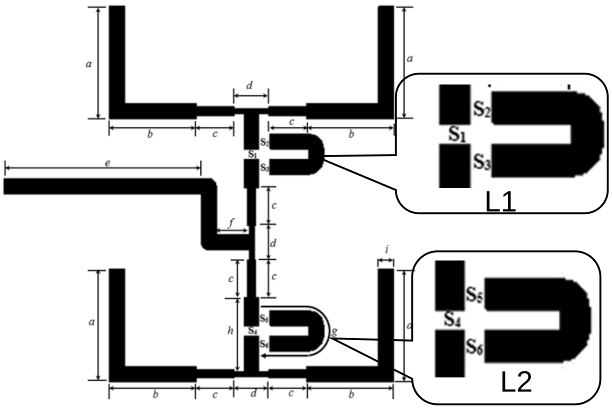


Figure 5 position of six switches and two delay lines designed on the feeding network

Table 2 Lengths and widths of corporate feeding network

Length and Width	Values (mm)
a	7.50
b	5.77
c	2.51
d	2.27
e	15.67
f	2.77
g	9.28
h	4.93
i	0.99

3.0 RESULT AND DISCUSSION

3.1 Simulations and Measurement Results

The proposed reconfigurable antenna is simulated using CST based on specific combination of switches attached on the feeding network, since, the delay lines are located at the first junction of the feeding network, three directions of antenna beam have expected from the antenna. Where the **ON** and **OFF** conditions of delay lines relies on specific configuration **S1** to **S6**. Therefore, the mode of switches for three directions is notated as condition one (1), condition two (2), and condition three (3) as listed in Table 3. To interchange the length of L1 and L2 all switches are alternately activated and deactivated to give the effect on the antenna current distribution according to the stated conditions.

Table 3 Combination of switches to steer radiation beam

Switches	S1	S2	S3	S4	S5	S6
Condition 1(OFF)	short	open	open	short	open	open
Condition 2 (ON)	open	short	short	short	open	open
Condition 3 (ON)	short	open	open	open	short	short

Analysis and simulation process are conducted refers to the activation or deactivation of switches. Assuming condition 1 as the reference length, two delay lines are disconnected by shorting S1 and S4, while S2, S3 and S5 are in open states. As a result, current is not flowing through delay lines L1 and L2 on feeding line network to allow it equally flow to the top and the bottom line as shown in Figure 6(a). Consequently, this configuration generates the 3D radiation pattern radiate at zero degree as shown in Figure 5(b).

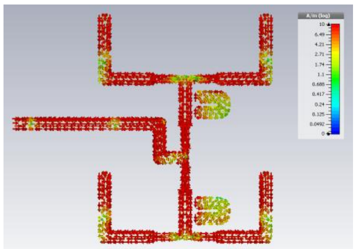


Figure 6(a) Current flow on the feeding line in condition 1

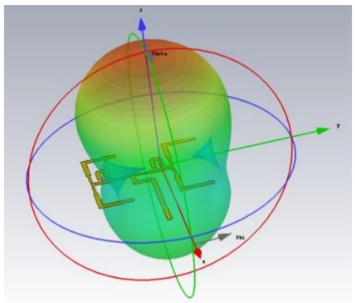


Figure 6(b) Simulation of radiation pattern in condition 1

Next simulation is conducted by setting all switches to connect the top delay line with the feeding network so that the antenna works in condition 2. In order to get this configuration, S2, S3 and S4 are placed in short condition. Meanwhile, S1, S5 and S6 are in open condition. This condition causes L1 is connected and two different length of feeding network between top and bottom is obtained as shown in Figure 7(a). Consequently, creates delay effect to steer the radiation pattern to the right direction as depicted in Figure 7(b).

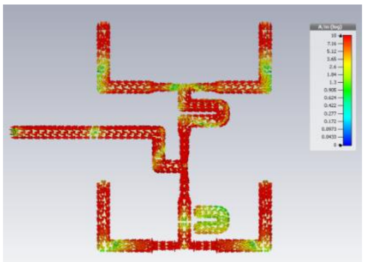


Figure 7(a) Current flow on the feeding line in condition 2

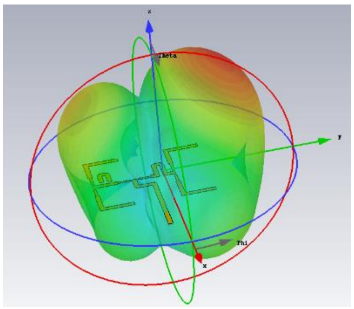


Figure 7(b) Simulation of radiation pattern in condition 2

Inversely, the feeding line network is changed so that delay line L2 is connected, while L1 is disconnected to create delay effect at the bottom feed, as shown in Figure 8(a). Where, S1, S5 and S6 are placed in short condition, and S2, S3 and S4 in open condition. In this condition, the proposedantenna is working in condition 3 and generates 3D radiation pattern elevates to the left side as depicted in Figure 8(b).

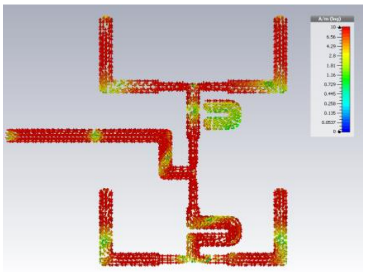


Figure 8(a) Current flow on the feeding line in condition 3

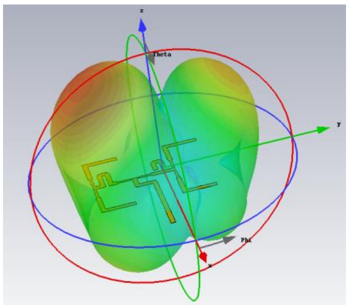


Figure 8(b) Simulation of radiation pattern in condition 3

Based on switches modes are listed in Table 3, results of simulated S_{11} for all three conditions are summarized and illustrated in Figure, 9. It can observe that in condition one (1) the antenna resonances at 7.5 GHz with S_{11} is -33.56 dB. When the delay line L1 and L2 are activated to generate condition two (2) and condition three (3) alternately, resonant frequency slightly shifted to 7.503 GHz and 7.504 GHz, respectively with S_{11} is -23.45 dB for condition two (2) and S_{11} for condition three (3) is -23.44 dB. The shifted frequency values for both conditions are possibly contributed by the delay line effect that designed at the first junction of the corporate feeding network.

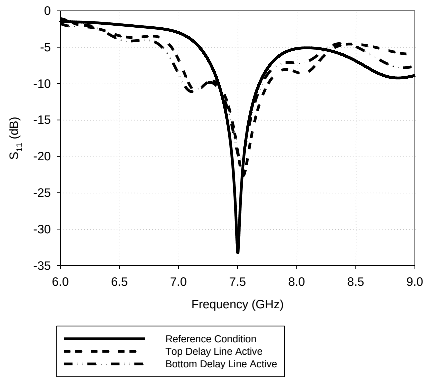


Figure 9 Values of S_{11} for three conditions of switches modes

For more clear view, all the direction of antenna beams are summarized and illustrated in Figure 10, and it shows that the directions of radiation pattern is controllable to the three angle directions. In condition one (1) the angles of radiation pattern remain at zero degree. Meanwhile, the radiation pattern is steered to -30 degree when the feeding network in condition two (2). In contrast, the angle of radiation pattern is steered to +30 when the feeding line in condition three (3). The elevating angles ± 30 degrees in condition two (2) and condition three (3) are significantly is related with length of delay line (*g*) from the Table 2. The final dimension obtained from simulation and optimization process, the directivity of proposed antenna almost consistence at 9.8 dBi in condition one (1), 9.67 dBi in condition two (2) and 9.76 dBi in condition three (3). With efficiencies more than 80% for all directions, the antenna offers good signal radiation, and Table 4 and Table 5 are summarized the simulation results.

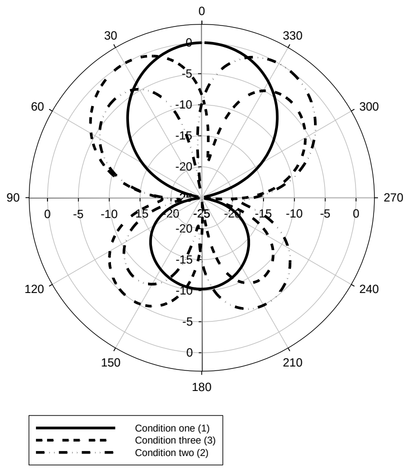


Figure 10 Radiation patterns for three different angles

Table 4 Combination of switches and direction of radiation pattern

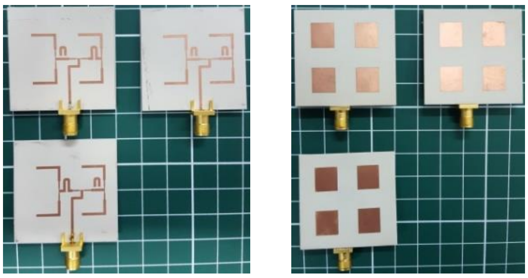
Switches	Angle
Condition one (1)	0 degree
Condition two (2)	+30 degree
Condition three (3)	-30 degree

Table 5 Output from the proposed antenna

	Conditions		
	Condition one (1)	**Condition two (2)**	**Condition three (3)**
Frequency	7.5 GHz	7.503 GHz	7.504 GHz
Efficiency	90.21%	89.28%	89.16%
Directivity	9.8dBi	9.70dBi	9.76dBi

3.2 Fabrication and Radiation Measurement

The final design of the proposed antenna is fabricated using conventional etching process and measured in anechoic chamber to determine the practical response mainly the directivity and efficiency. Figure 11 shows the fabricated antenna with three conditions of feeding line network to represent the stated conditions. S_{11} values of the antenna are measured using PNA-L Network Analyzer Model N5234A, while radiation patterns are measured in anechoic chamber model ATENLAB OTA-500.



(a) (b)

Figure 11 Fabricated antenna with different condition of feeding line, (a) Rear view, and (b) front view

Figure 12 show the comparison result of S_{11} in condition one (1), and from the graph value of S_{11} for fabricated antenna slightly shifted to 7.48 GHz. But the fabricated antennas provide the better performance compared to simulated structure. Interestingly two identical results between condition two (2) and three (3) indicate that the consistency of the designed antenna, both results are depicted in Figure 13 and Figure 14, respectively.

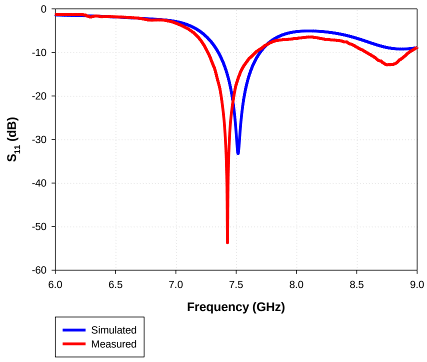


Figure 12 Comparison between Fabricated and simulated antenna at condition one (1)

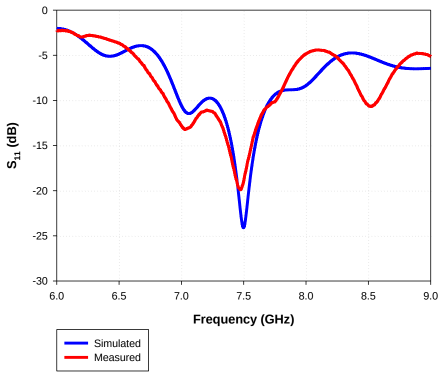


Figure 13 Comparison between Fabricated and simulated antenna at condition two (2)

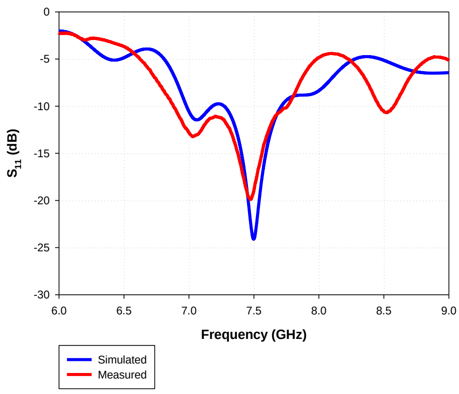


Figure 14 Comparison between Fabricated and simulated antenna at condition three (3)

Meanwhile, three radiation patterns to represent the three conditions of the antenna are illustrated in Figure 15, Figure 16, and Figure 17, respectively. However, the large side lobes obtained during steers the radiation beam as shown in Figure 16 and 17. These effects due to asymmetrical structure of feeding network. Nevertheless, result from simulated and fabricated are closely agreed, while directivity and efficiency for all directions are consistent, means that designed antenna is a good candidate for outdoor antenna systems; all results are summarized in Table 6, Table 7 and Table 8.

Table 6 Result for condition one (1)

	Simulated	Measured
Frequency (GHz)	7.5	7.48
Efficiency (%)	90.21	90.02
Directivity (dBi)	9.8	10.01
Angle (Degree)	0	0

Table 7 Result for condition two (2)

	Simulated	Measured
Frequency (GHz)	7.5	7.488
Efficiency (%)	90.21	89.97
Directivity (dBi)	9.78	9.9
Angle (Degree)	29.98	24.05

Table 8 Result for condition three (3)

	Simulated	Measured
Frequency (GHz)	7.5	7.489
Efficiency (%)	90.21	89.02
Directivity (dBi)	9.77	9.53
Angle (Degree)	-29.997	-34.01

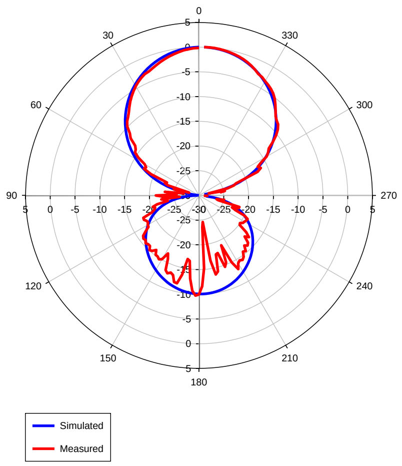


Figure 15 Comparison of radiation pattern between Fabricated and simulated antenna at condition one (1)

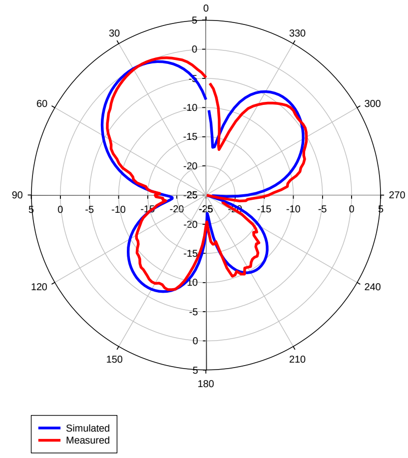


Figure 16 Comparison of radiation pattern between Fabricated and simulated antenna at condition two (2)

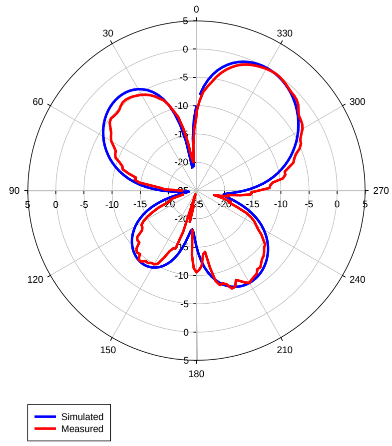


Figure 17 Comparison of radiation pattern between Fabricated and simulated antenna at condition two (3)

4.0 CONCLUSION

From the research, radiation pattern reconfigurable patch antenna is feasible by using delay line technique. The directivity of the reconfigurable antenna is almost consistent for all directions because all four elements are used for all angle elevations. In addition, fabricated results for S_{11} and radiation patterns are closely similar with simulated structure. Interestingly, the reconfigurable antenna is not required separate phase-shifter circuit to steer the direction of radiation pattern.

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