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DESIGN OF RECONFIGURABLE MULTIPLE ELEMENTS MICROSTRIP RECTANGULAR LINEAR ARRAY ANTENNA

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Abstract—This paper presents a reconfigurable multiple element microstrip rectangular linear array antenna integrated with radio frequency (RF) switches. The corporate feed design concept is used to excite the linear array antenna that consists of 8 elements of rectangular patches at 5.8 GHz. Two PIN diode switches were deployed at the feeding line to activate the two arrays of patches that are located on the left and right sides of the antenna structure. The behavior of the reconfigurable multiple element linear antenna array system has been investigated with respect to the beam shaping characteristic. The comparisons of the performance between two structures, with and without Wilkinson Power Divider (WPD) are discussed in this paper. Two different beam patterns were achieved through the reconfigurable antenna at different number of elements design that incorporates with PIN diode switches and modified WPD concept. The simulation and the measurement results for 4 and 8 elements array antenna structure are presented.

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1. INTRODUCTION

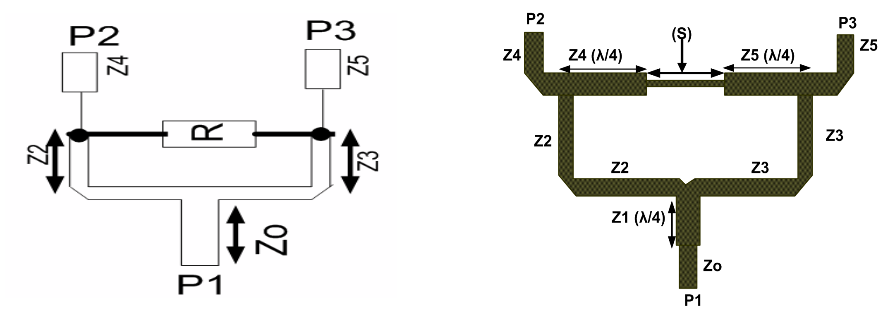
The reconfigurable antennas have drawn lots of attention in the wireless communication systems recently. The demand for reconfigurable antenna has increased drastically since a decade. Reconfigurable beam shaping is an ideal for the detection of small and large targets at both short and long ranges, including that the antenna is mounted on a high tower or hillside [1, 2]. Reconfigurable antennas are ideal for many military and mobile communication applications where it is required to have a single antenna that can be dynamically reconfigured to transmit or receive on the same or multiple frequency bands [3–5]. It is advantageous to integrate beam shaping functionality into the systems so one can vigorously vary the beam shapes in many applications such as airplane radar, protection from smart weapons and point to point communication.

In [6, 7], the authors presented reconfigurable antennas, which radiated at different beam pattern by adjusting the apertures and maintaining their operating frequencies. The antenna presented in [3], described a dual band dipole antenna integrated with MEMS switches. However, this method typically used a dual operating frequency to reconfigure the beam pattern. The antennas proposed in [8, 9] worked at dual operating frequencies with a reconfigurable radiation pattern. In the reconfigurable antenna, the structure of the antenna can be changed by integrating with the switches such as PIN diode switches [10], the field-effect transistor (FET) [11], the photo conductor switches [12] or by electromechanical system (MEMS) switch [13–15], which were proposed a few years ago. By controlling the states of the switches, to ON or OFF mode, several approaches were proposed for implementing the reconfigurable antenna. Most of these approaches were able to alter the fundamental characteristics of the antenna such as operating frequency, bandwidth, polarization characteristics and radiation pattern [13].

Works presented in this paper describe and analyze the reconfigurable corporate feed microstrip patch antenna incorporated with PIN diode as an RF switch. The switching mechanism is controlled by the external DC voltage. Two switches are utilized to realize the antenna with switchable beam shaping at frequency 5.8 GHz. The antenna performances such as input return loss, bandwidth, half power beamwidth (HPBW), and radiation patterns were obtained.

2. ANTENNA DESIGN

The configuration of the proposed reconfigurable antenna structures is shown in Figure 4. There are two structures of reconfigurable microstrip patch antenna proposed in this design, without WPD as in structure 1 and added with modified WPD as in structure 2. The antenna structure was constructed on FR-4 glass epoxy substrate which has a relative permittivity (ε_r) of 4.6 and loss tangent (δ) of 0.03; the thickness of the substrate is 1.6 mm.



(a) (b)

Figure 1. (a) Conventional Wilkinson power divider (b) the modified Wilkinson power divider geometry.

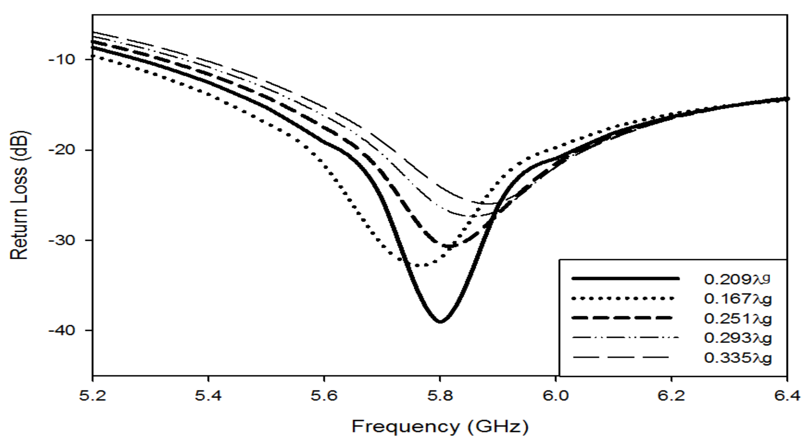


Figure 2. Return loss due to length of 100 Ω transmission line.

2.1. Power Divider Concept

The power divider is one of the most commonly used components in RF and microwave systems for power division and/or combination ratio as n-port network. The ideal design parameters are given in [8]. There are two common types of power divider used in an array antenna design, which are Wilkinson power divider and T-junction power divider. Figure 1 shows the structure of Wilkinson power divider. A lumped resistor, $100\,\Omega$ (R), is connected between the outputs of two branches and provides the required isolation. The dimensions of chip resistor must be very small, of the order of 1×0.5 mm. This implies that the two branches of the power divider must be placed very close to each other to be connected to the resistor. This could produce strong mutual coupling between the output lines.

To overcome this problem, the $100\,\Omega$ chip resistor will be replaced by the $\lambda/4$ lengths of $100\,\Omega$ transmission line (S). A $\lambda/4$ length of $100\,\Omega$ transmission line is placed in between $\lambda/4$ length of $50\,\Omega$ transmission line (Z4 and Z5) as in Figure 1(b). The electrical performance of the WPD depends on the length of transmission line. These properties of modified WPD are illustrated in Table 1. In Figure 2, it can be seen that when the length of $100\,\Omega$ transmission line increases, the resonant frequency of the divider is shifted to the higher frequency, and the matching performance becomes worse. For these reasons, the proposed modified WPD is designed using $100\,\Omega$ transmission line with a length of $0.209\lambda_g$. Figure 3 shows the performance of modified WPD which has good electrical characteristic with -39 dB of return loss at 5.8 GHz.

Table 1. The properties of modified Wilkinson power divider.

Characteristics	Z_0	Z_1	Z_2	Z_3	Z_4	Z_5
Impedance (Ω)	50	42.04	59.46	59.46	50	50
Width (W), mm	2.92	3.65	2.239	2.239	2.92	2.92

A Wilkinson power divider with an arbitrary power ratio is expressed as follows in Equation (1) to (7) [17].

$$\frac{P_2}{P_3} = \frac{1}{K^2} \tag{1}$$

$$Z_2 = Z_0\sqrt{K\left(1+K^2\right)} \tag{2}$$

$$Z_3 = Z_0\sqrt{\frac{\left(1+K^2\right)}{K^3}} \tag{3}$$

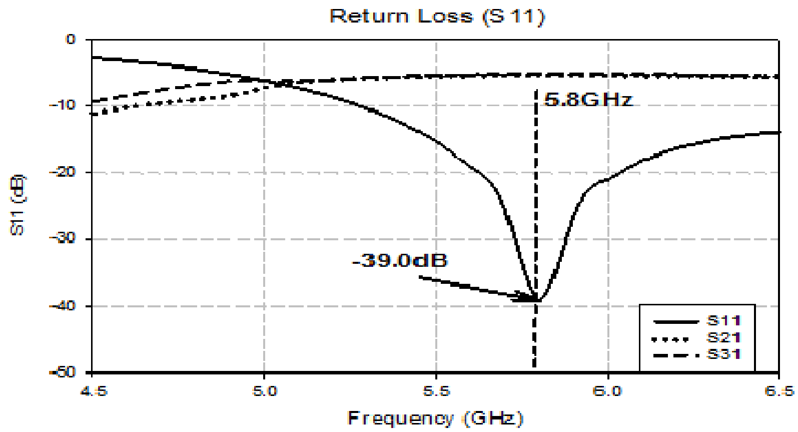


Figure 3. Return loss plot for modified WPD.

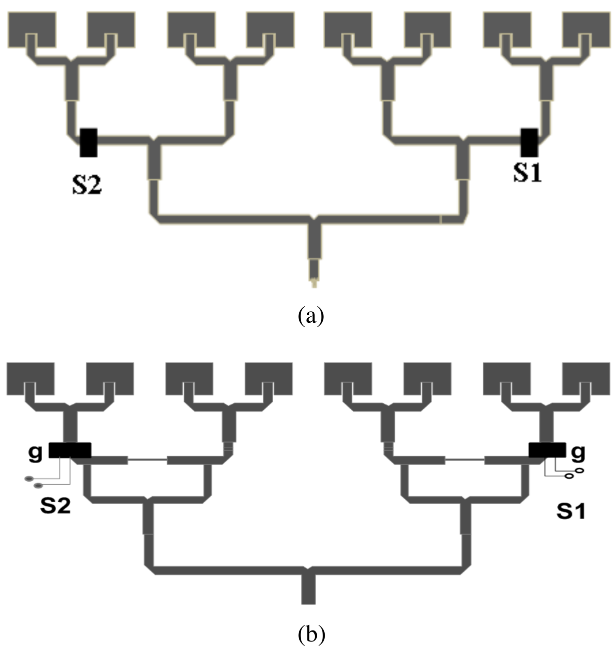


Figure 4. Configuration of two structures of corporate fed reconfigurable antenna array (a) Structure 1 (without WPD) (b) Structure 2 (with modified WPD).

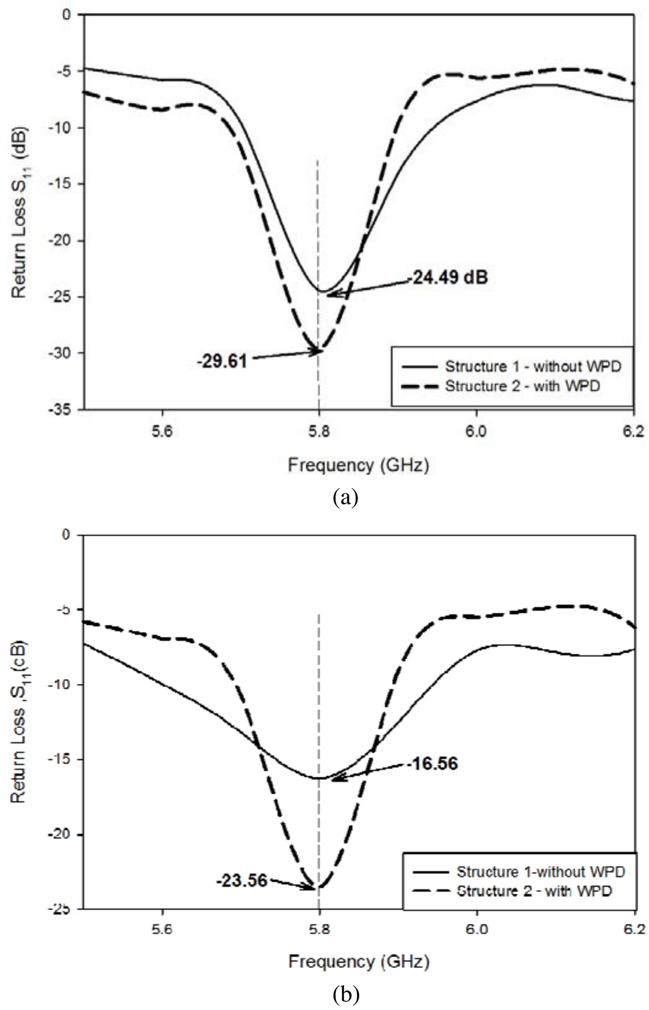


Figure 5. Comparison of return loss S_{11} (dB) between antenna structures 1 and 2 (a) 4 radiated elements (b) 8 radiated elements.

$$Z_4 = Z_0\sqrt{K} \tag{4}$$

$$Z_5 = \frac{Z_0}{\sqrt{K}} \tag{5}$$

$$R = Z_0 = \frac{\left(1+K^2\right)}{K} \tag{6}$$

$$w = \exp\left[\frac{z_c\left(\sqrt{\varepsilon_r}+1.41\right)}{87}\right]\frac{0.8}{5.98h} \tag{7}$$

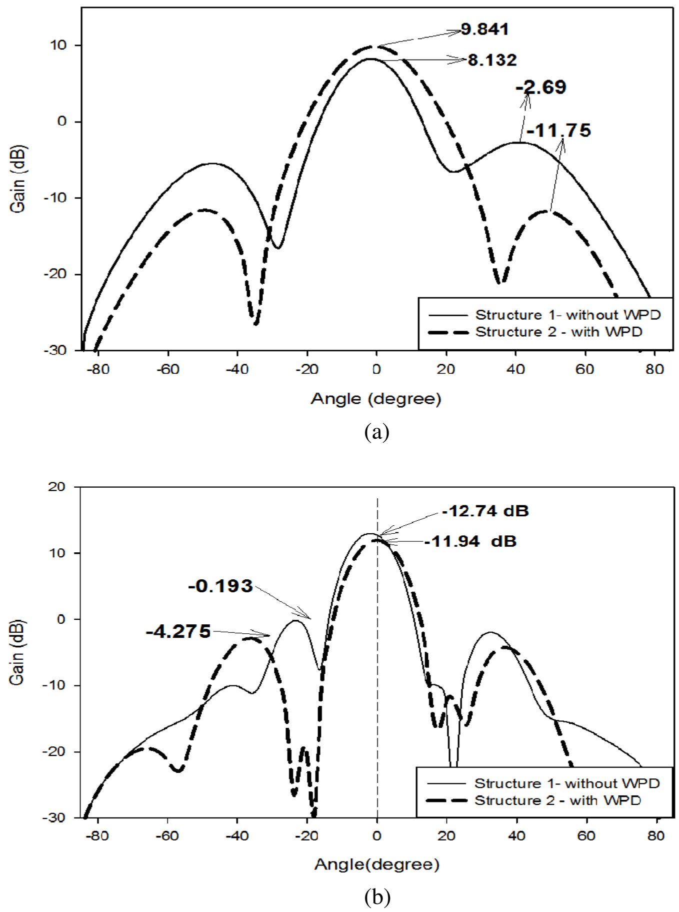


Figure 6. Comparison of radiation pattern between antenna structure 1 and 2 (a) 4 radiated elements (b) 8 radiated elements.

where: $w =$ width of transmission line
$H =$ thickness of substrate
$\varepsilon_r =$ dielectric constant

2.2. Corporate Feed Patch Array Structure

Figure 4 shows two structures, a reconfigurable multiple element microstrip rectangular linear array antennas without WPD (structure 1) and with modified WPD (structure 2). The PIN diode switches are represented as a rectangle at S1 and S2 in two locations. As the size

Table 2. The summary of simulation results obtained for the reconfigurable linear array antenna for both structures.

Antenna	Return loss S_{11}(dB)		Gain (dB)		Sidelobe Ratio (dB)	
	ON	**OFF**	***ON***	***OFF***	***ON***	***OFF***
Structure 1	−16.56	−24.49	12.74	8.13	12.93	10.82
Structure 2	−23.56	−29.61	11.94	9.84	16.22	21.6

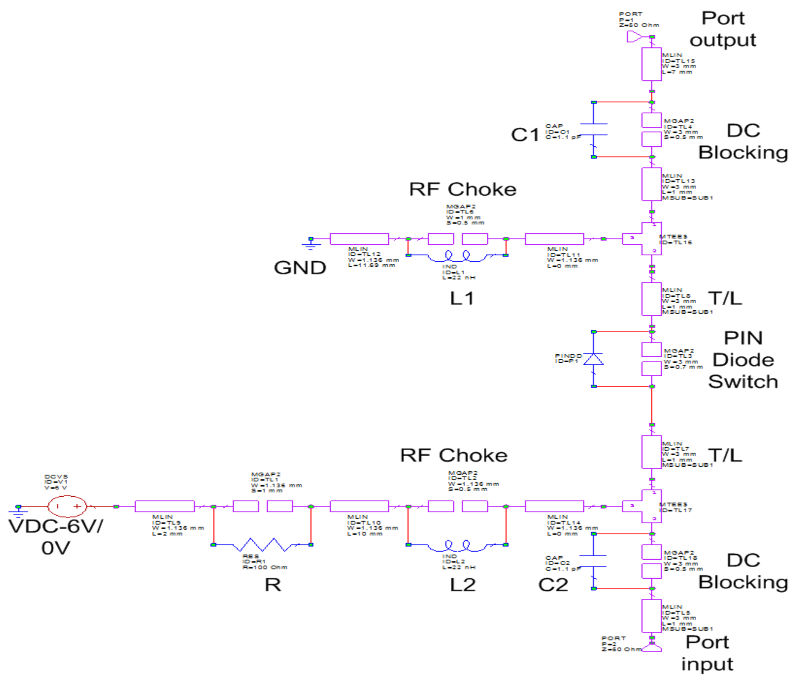


Figure 7. Schematic representation of the switching circuit components inserted in active feeding network.

of the switch is 2.5×1.4 mm, the gap (g) between the transmission lines is designated as 0.5 mm. In this method, a DC bias circuit is used to control the ON/OFF mode of PIN diode switches. The beam width can be varied by altering the number of array elements. When all the diodes are switched ON, this antenna basically operates at a concave pattern of 5.8 GHz. In contrast, when they are turned OFF, the antenna element is reduced to four elements with a convex pattern

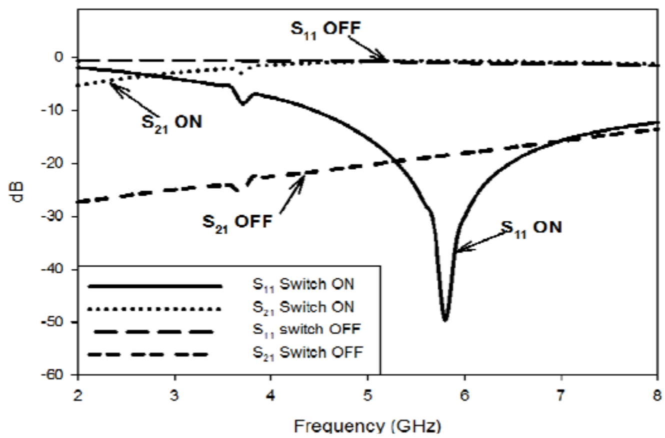


Figure 8. Calculated return loss (S_{11}) for ON and OFF states (a) switch ON mode and (b) switch OFF mode.

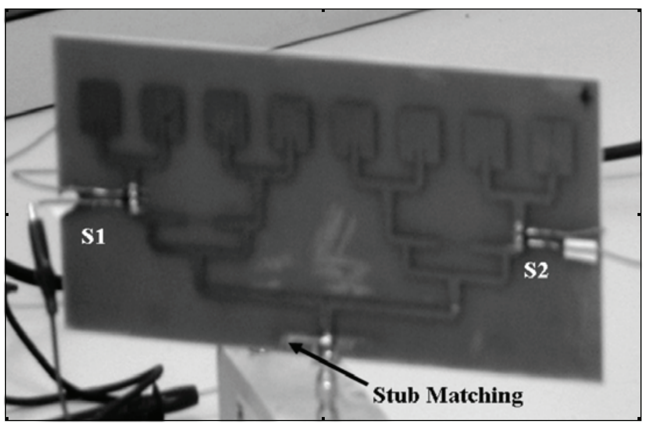


Figure 9. Photo of the fabricated reconfigurable linear array antenna with single stub matching and PIN diodes.

at the same frequency.

The comparison between the simulation results of the reflection coefficient of both structures is demonstrated in Figure 5. After some iteration, the second structure has produced "lower side-lobe to main-lobe power ratio" value compared to the first structure. Since the return loss and radiation pattern for the 'structure 2' shown in Figure 5 and Figure 6 are much better compared to 'structure 1', so the 'structure 2' is selected for the simulation and fabrication purpose.

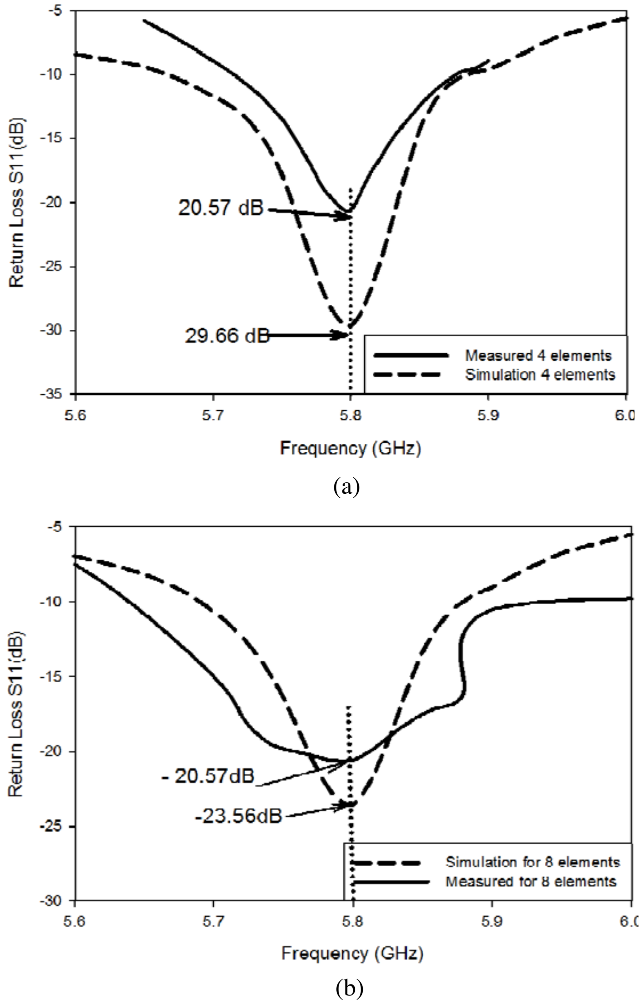


Figure 10. Measured and simulation results of return loss S_{11} (dB) for structure 2 (a) 4 elements radiated (b) 8 elements radiated structure.

In structure 2, any mismatch or reflected power due to the switching connection will be mostly absorbed by the $100\,\Omega$ transmission line [18]. Table 2 is the summary of the simulation results obtained for the reconfigurable linear array antenna for both structures.

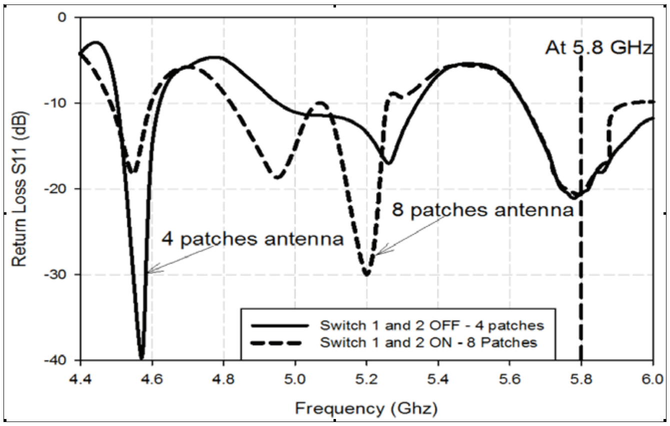


Figure 11. Measured results of S_{11} when switch on/off state.

2.3. PIN Diode RF Switching Circuit

Philips PIN diodes, BAP51-02 [16] have been selected in this design. Figure 7 shows the schematic diagram of the switching circuit. It can be seen that the switch is inserted in between two transmission lines. Each switching circuit consists of a PIN diode, two DC block capacitors, two inductors and one resistor. The capacitors, (C1-C2), are used as DC blocking and the inductors, (L1-L2), are used as RF chokes which provide low impedance for DC. The biasing voltage (6 V) has been connected to $100\,\Omega$ resistor to limit the current flow to the switch. The simulation results using the PIN diode's equivalent circuits for the OFF and ON-stages are presented in Figure 8. The return loss is less than -40 dB for the ON stage and an approximate of 0 dB for the OFF stage at 5.8 GHz. The selected capacitance and inductance values were chosen to be 6.8 pF and 22 nH, respectively.

3. EXPERIMENTAL RESULT

The antenna with modified WPD (structure 2) described in Section 2 has been fabricated and tested. The prototype of the antenna is shown in Figure 9. To tune the frequency of the antenna to have better impedance matching, a single open stub is necessary. Therefore, a single quarter-wavelength open stub, which operates at 5.8 GHz, is added to microstrip feeding line as shown in Figure 9. According to the simulation results, the radiation pattern characteristic of the antenna forming has been tuned efficiently, since its structure is symmetrical by the center. The pattern obtained is directed to zero degree.

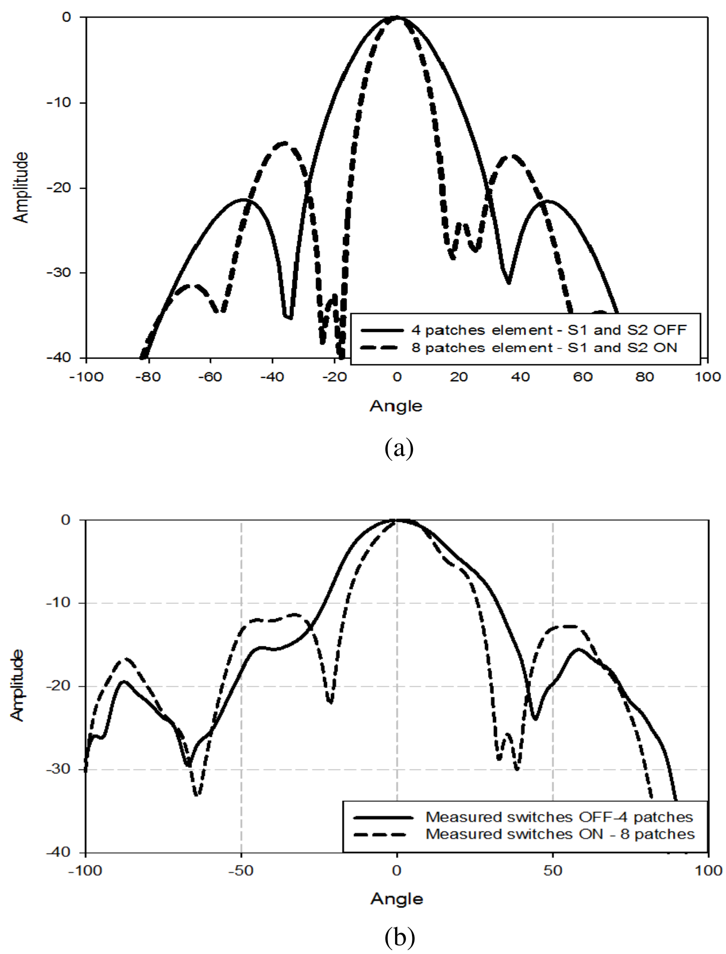


Figure 12. Simulation and measured results of normalized radiation pattern for 4 and 8 element structures.

The radiation pattern of the 4 and 8 elements structure are shown in Figure 12(a) with 3 dB half power beamwidth (HPBW) of 22° and 12.6°, respectively. Meanwhile the simulated return loss for the two structure are −29.43 dB and −23.56 dB, respectively as shown in Figure 10. Referring to Figure 12, it is clearly shown that when the numbers of the elements are increased, the beamwidth becomes narrow with lower sidelobe and higher magnitude.

Measurements of reconfigurable beam shaping antenna was also conducted. The measured return loss compared with the simulated

Table 3. Selectable performance for the reconfigurable microstrip antenna for structure 2.

Antenna	***Return Loss*** S_{11} ***(dB)***		***HPBW***$(\theta°)$	
	Sim.	**Meas.**	**Sim.**	**Meas**
4-patches	−29.66	−20.57	22	29
8-patches	−23.56	−20.25	12.6	21

results for both types of configurations (4 and 8-elements) are shown in Figure 10. The antenna shows good impedance matching for both cases with better than 20 dB return loss observed. Figure 11 shows the measurement of return loss when the switches are turned to ON and OFF-stages. The measured radiation patterns, in Figure 12(b), show very good agreement with the simulation. The results show two different beam patterns at −3 dB, about 29° and 21° at the same frequency. Table 3 is the summary of simulation and measurement results obtained for the reconfigurable linear array antenna.

4. CONCLUSION

In this paper, experimental data have demonstrated the concepts of reconfigurable number of elements that produced broad and narrow beam radiating pattern characteristics. By using a modified WPD in the antenna structure, it produced a better performance in terms of return loss. This research has taken advantage of the flexibility of the number of elements technique by applying it to the problem of reconfigurable multiple beam array combination. The reconfigurable dual-beam antenna pattern at fixed frequencies across the entire 5.7–5.9 GHz band is presented in this paper with excellent radiation patterns.

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