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Research Paper

A Stacked Planar Antenna with Switchable Small Grid Pixel Structure for Directive High Beam Steering Broadside Radiation

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Abstract

A radiation pattern of a reconfigurable pixel structure antenna that operates in three steerable beam directions of {-40º, 0º, 40º} is presented. The proposed antenna consists of a circular driven structure on the bottom layer with a pixel structure placed in the top layer. The pixel structures of small square-shaped metallic patches are used to provide beam steering reconfiguration capabilities to the antenna. The adjacent pixels are connected by PIN diode switches with ON/OFF status to change the electrical geometry of the pixel surface, which changes the current distribution on the antenna, thus provides reconfigurability in beam steering direction. The proposed antenna operates at 9.5GHz frequency for X-Band radar application. This antenna is capable to achieve a tolerable return loss of less than -10dB with an average gain of 8 dBi at all desired angles.

Keywords: *Electromagnetics, Beam steering, pixel structure, high gain beam, reconfigurable antenna*

1. Introduction

Reconfigurable radio networks are the most promising ideas for the next generation wireless network. This is due to the development of efficient antenna elements which capable to operate in multiband mode for specific applications and environment without altering its physical structure, length or size entirely[1]–[5]. Reconfigurable antenna offers flexibility on the frequency, radiation pattern and polarization which can be independently adjusted[1]. This re-configurability can be done by using either PIN diode switches, RF-MEMS switches or varactor diode switches to change the state of the switches that directly change the current distribution over the structure of the antenna[2]. Most of the reconfigurable antennas apply more than one RF switches to operate based on the application[3]–[7].
The approach used in this project is a multilayer planar antenna consists of driven element and small grid pixel structure. The driven element is a standard circular patch antenna that operates at 9.5GHz which placed on the bottom of the pixel layer. The pixel structure divides the radiating surface in small sections which interconnected with RF–switches. By activating the switching condition on the pixel structure, the antenna surface will be reshaped and configures the radiation pattern characteristics. The pixel structure has been proposed as parasitic structures in[2], [3], and provides good re-configurability to the antenna, leading to significant advantages in switch biasing and integration possibilities. As compared with[3], [5], [7], [8], the approach of separating the switches from the driven element has the advantages of minimizing the complexity of structure. Hence, it contributes to the improvement of the overall system performance requirement. Work presented in[3] shows the pixel structure concept that capable to steer at three different angles of -30º, 0º and 30º with an average gain of 5-6 dBi. However, the amount of the switches used in the pixel structure is approximately 60 pin diode, which could lead to high complexity of DC biasing and eventually increases the cost of the antenna.
This paper presents a reconfigurable pixel antenna that has the capability to steer the beam at three different beam angles of {-40º, 0º, 40º} with high gain of approximately 8 dBi at each beam direction compared to other works in[3], [6] with average gain of 5-6 dBi. Moreover, the DC biasing complexity is reduced while the amount of switches used for the pixel structure is minimized to 50 % compared to the previously designed antennas in[3], [4].

2. Antenna Design

Target performance for the antenna is set by the requirements in X-Band radar applications. The geometry of the proposed antenna is shown in Figure 1 and Figure 2.The antenna consists of driven layer and the pixel layer. A circular patch has been selected as driven antenna because of its simplicity, good radiation control and widespread use. The pixel layer is located on the top of the driven layer. This location maximizes the coupling between the driven layer and pixel surface that helps to generate significant current over the pixel layer, consequently affecting the characteristics of the radiation pattern. The driven and pixel layers (W= 80 mm and L= 30 mm) are made from Taconic dielectric substrate with the thickness of 1.6 mm and a dielectric constant ($\mathcal{E}r$) of 2.2. The air gap thickness between driven and pixel layers is 7mm provided a strong mutual coupling and that gives positive impact to the antenna reconfigurable capabilities. The gap between the driven and pixel layer is determine based on 0.04λg[4].

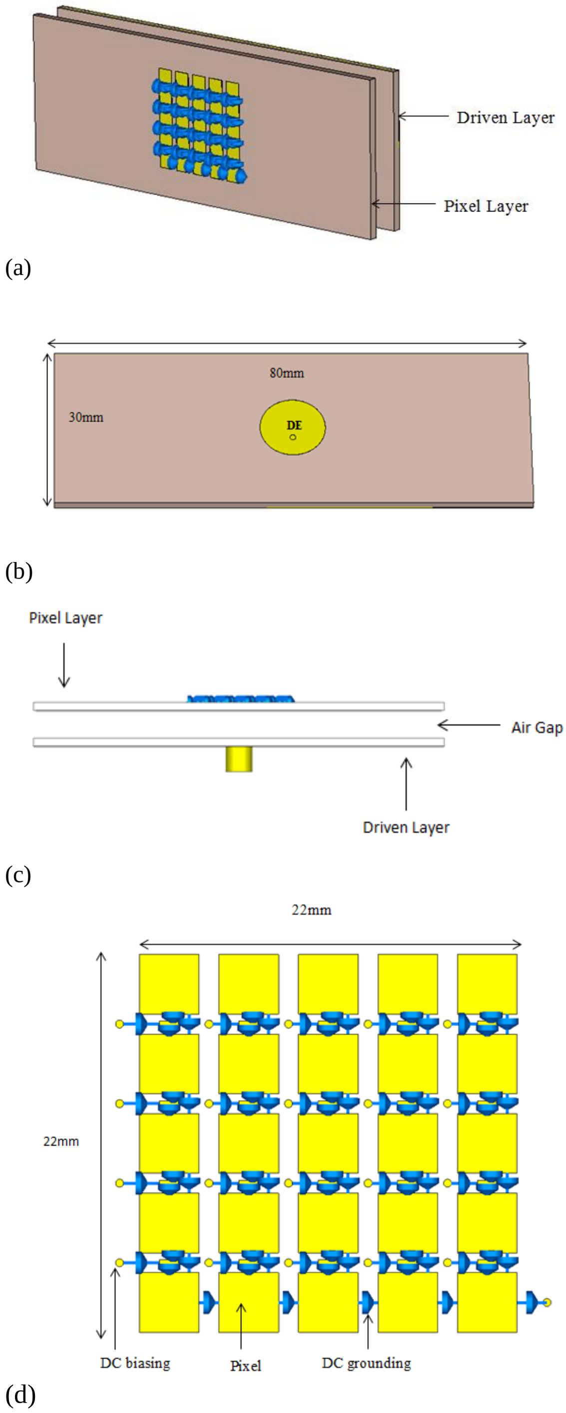
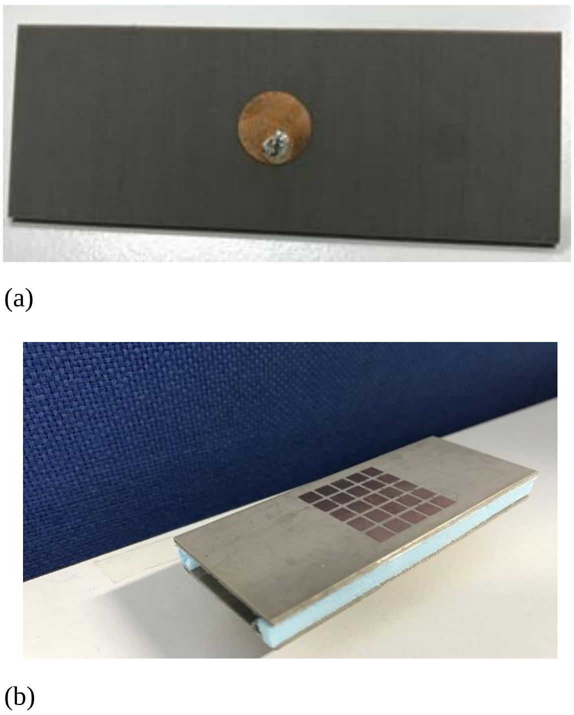


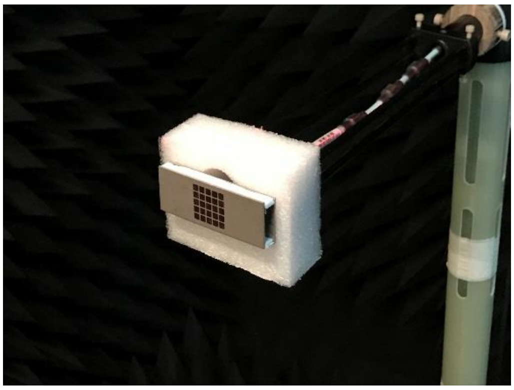
Fig.1: Geometry of the antenna, (a) 3D View, (b) Driven Layer, (c) Side view, & (d) Pixel Structure

The driven patch (radius = 5.6 mm) is designed to operate at 9.5 GHz frequency and is fed by 50-Ohm (SMA) coaxial feed from the back of the antenna. The pixel structure consists of a 5 x 5 square-shaped pixels, with an individual pixel size of 3x 3 mm² (λ/10) and an overall size of 22x 22 mm² (0.72λ). Twenty RF PIN diodes (HPND 4005) are integrated in vertical position between each pixel structure as RF switch. This design has taken off the RF-switches in horizontal position on the pixel structure compare to[3], [4], which the RF- switches integrated in vertical and horizontal position.

By minimizing the amount RF-switches in pixel structure, it can reduce the complexity of the antenna and improve the reconfiguration capabilities. The simulation test has been carried out using the CST software simulation tools. The RF PIN diode have been modelled as series resistor for ON state (4.7Ω) and parallel capacitor for OFF state (0.017pF) as suggested in the manufacturer's datasheet. There are four different components are used on the pixel layer as shown in Figure 3. The first component is PIN diode switches are used in between the pixels.

The pixel structure are connected or disconnected depends on the condition of the PIN diode. The conditions of the PIN diode switches change the geometry of the pixel surface, resulting in the changes of the current distribution and radiation pattern of the antenna. The second component is the RF chokes which are interconnected with each pixel structure to minimize the mutual coupling effects on the bias lines. The next component is inductors for DC grounding, where the inductors are placed between all pixels and grounded together to provide ground for DC biasing purpose. The inductor value of DC grounding is same RF chokes to keep the high RF impedance between pixels. DC block capacitor is used to bias the PIN diode switches and provide low RF impedance. The equivalent circuit models and components details of DC biasing scheme is shown in Figure 3 and Table 1.





(c)

Fig.2: The fabricated antenna, (a) Driven Antenna, (b) Structure of the driven pixel antenna & (c) Measurement process of driven pixel antenna in Atenlab (OTA-500) chamber

Table.1: Lumped components used on pixel structure

Type	Value
RF choke	27nH
DC grounding inductor	27nH
DC block capacitor	8pF

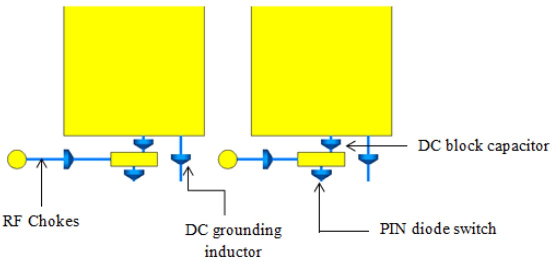


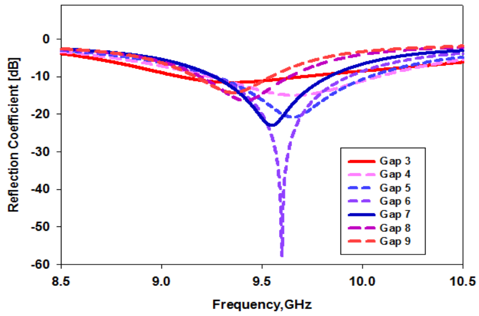
Fig.3: DC biasing scheme of the PIN diode switch

2.1 Working Mechanism

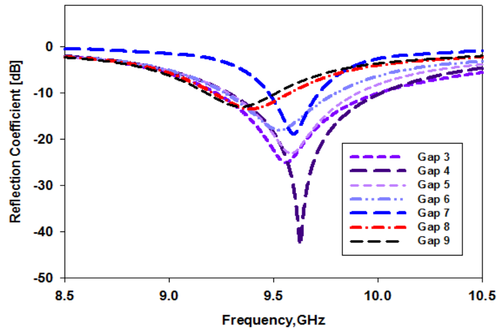
The working mechanism of this reconfigurable antenna is composed a single driven element and pixel structure with a full ground plane at the back side of the substrate. The driven element can direct into desired direction by the proper reactive loading of the pixel element. The concept of array and Yagi-Uda antenna has been applied in this antenna. In the proposed antenna, the beam direction is achieved based on the changes of specific geometry of the pixel surface, which controlled by the switching conditions of the PIN diode switch between the pixel structures. The pixel structure act as reflector when the PIN diode in ON conditions, while in OFF conditions act as director that will push and pull the radiation pattern, respectively. On the other hand, the strong coupling between the driven layer and the pixel surface generate significant currents over the pixel layer, therefore the location and distance of the driven element consider the current distribution of each is pixel structures. This approach has clear advantages from fabrication, integration and biasing perspectives. Moreover, the structure of the pixel layer can be easily matched with different driven antenna architectures with same specifications.

3. Optimizing the Distance between the Driven Layer and the Pixel Layer

The radiation pattern performance is influence from the mutual coupling effect between the driven and pixel layer. Therefore, the distance between the driven and pixel layer are strongly affects their mutual coupling and gives a significantly affect to the antenna reconfiguration capabilities. The parametric studies of the gap between the driven and pixel layers are determine at range of 3mm to 9mm. Based on the simulation optimization, the good agreement between reflection coefficient, gain and radiation pattern are highlighted in order to achieve ideal gap between the driven and pixel layer. The optimization of the gap between the driven and pixel layers has been further presented in Figure 4 and Figure 5 where the frequencies range and beam steering is analyzed for various gaps. The reconfigurations show, the frequency range and beam steering changes their antenna capability towards higher and lower performance based on the distance.



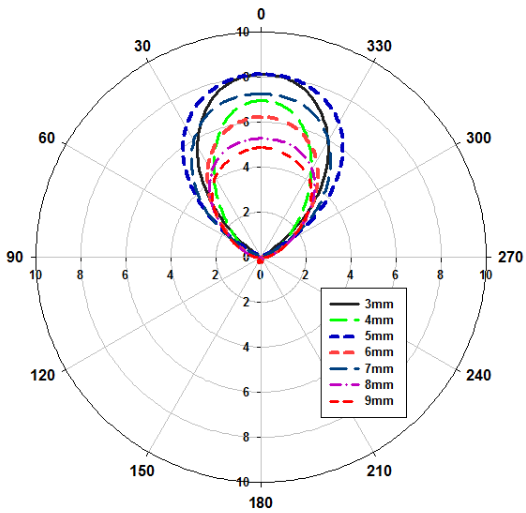
(a)



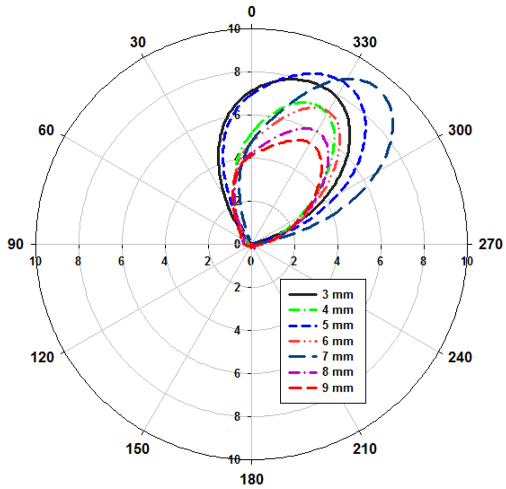
(b)

Fig.4: Reflection coefficient results on various driven-pixels: (a) P1and (b) P2

Based on the optimizations, the radiation pattern of gap 7mm shows the acceptable results with the requirement compared with the results of other reconfigurations as highlighted in Table 2. Although the beam steering is qualitatively the same, the level of the gain and frequency range achieved strongly depends on the gap of the driven and the pixel layers. It can be clearly observed that the central frequencies of P1 (0 degree) and P2 (-40 degree) are close to the range of 9.5GHz.



(a)



(b)

Fig.5: Beam steering optimization range of the driven and pixel layer for different gap: (a) P1and (b) P2

3.1 Result and Discussion

This section presents the simulated and measured result of the proposed antenna for the 9.5 GHz X- Band application. The performance level of the driven structure is observed as single layer to match with the pixel layer result. The simulated and measured reflection coefficient of the proposed antenna has achieved minimum tolerable S11 of less than -10 dB with a value of -29.79 dB and -18.18 dB at 9.5GHz operating frequencies. The value of the reflection coefficient changes slightly but still covers the operating frequency as shown in Figure 6.

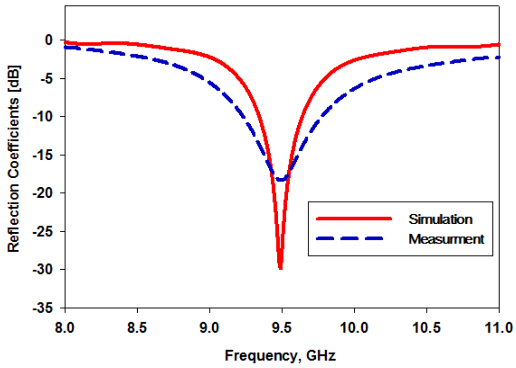


Fig.6: Measured and simulated reflection coefficient of driven layer

These changes are due to the effect of soldering or mismatch of coaxial feeding on the fabricated antenna. In the simulation, the driven structure capable to achieve the total efficiency more than 90 % and gain of 7.76dBi. This shows the antenna have a perfect front-to-back ratio where all radiation occurs towards the front and no radiation towards the back.

The next step is to simulate the pixel layer combined with the driven layer as shown Figure 2(b).The radiation pattern is achieved based on switching configurations on the pixel structure as shown in Figure 7. The yellow legends represent the ON condition and OFF condition represent for the grey legends as shown in Figure 6. The proposed antenna capable to steer at -40º, 0º and 40º with realized gain between 7.5 and 9.7 dBi. Table 3 shows the simulated results for the reflection coefficient, gain, antenna efficiency and the beam steering. From the simulated results, it can be seen that the antenna perform three pattern reconfigurations that operates at 9.5 GHz, namely P1, P2 and P3.

Table.3: Simulated switches configuration of the driven pixel antenna

Pattern	P1	P2	P3
Tilt angleº	-40º	0º	40º
Centre frequency [GHz]	9.59	9.54	9.59
Reflection coefficient [dB]	-18.83	-23.06	-18.83
Gain [dBi]	9.31	7.67	9.31
Antenna Efficiency (%)	84	90	84

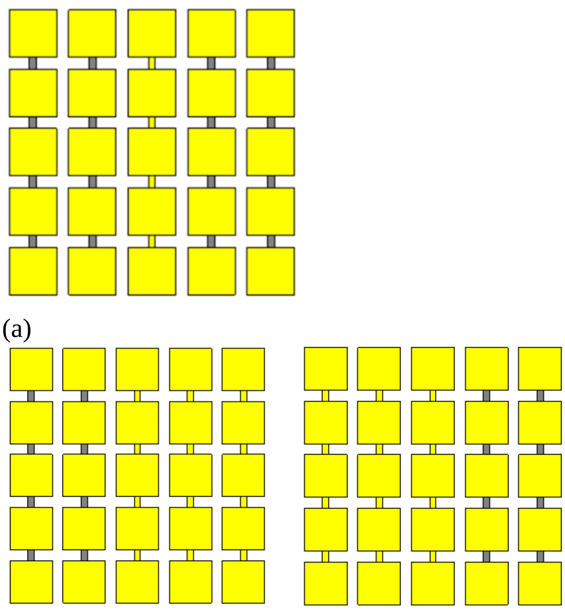
The realized gain at the beam direction P1 and P3 is 9.31dBi with a reflection coefficient of -18.83 dB. The P2 configuration gives 7.67 dBi of gain with S11 of -23.06 dB. It can observed that the antenna efficiency of the driven pixel antenna with all three configurations able to achieve 84% - 90%.The simulated result demonstrates a good beam pattern while gives a good matching at the centre frequency.

Figure 8 shows the simulated and measured result of the reflection coefficient for the driven pixel antenna. It gives a good agreement between the simulated and measured result. However, the measured result gives differences below 2% between the simulated results. The measured reflection coefficient for P2 is slightly higher compare to the simulated result whereby the simulated result is -23.06dB and the measured result is -30.77dB. Similarly, for P1 and P3 the measured results have slight changes compared to the simulated result. This may be due to the stronger coupling of the pixel layer with the driven patch antenna. The measured results are presented in Table 4.

Table.4: Measured switches configuration of the driven pixel antenna

Pattern	P1	P2	P3
Centre frequency [GHz]	9.43	9.52	9.48
Reflection coefficient [dB]	-20.79	-30.77	-21.57
Gain [dBi]	9.89	9.78	9.85

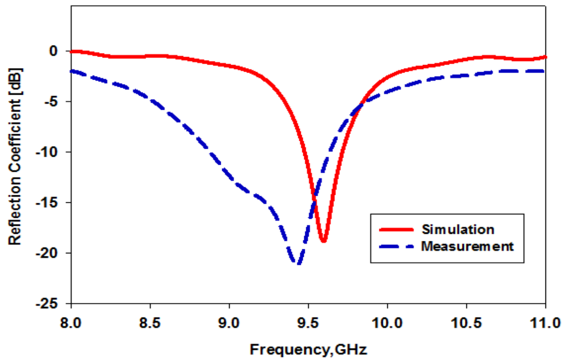
The measured beam patterns are effectively steered towards the pixel configurations in the simulation with a maximum gain of 9 to 9.8 dBi for each beam steering optimization. Figure 9 shows that the measured radiation patterns agree well with the simulated result. The proper optimization of the switching conditions between the pixels modifies the currents over the antenna surface and provides the beam-steering capability.



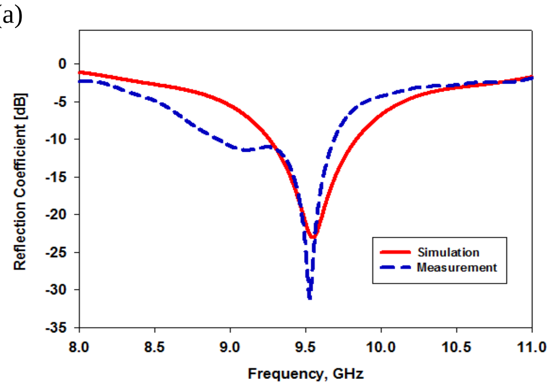
(a) (b) (c)

Fig.7: Switch configuration of the pixel layer: (a) P2, (b) P1 and

(c) P3



(a)



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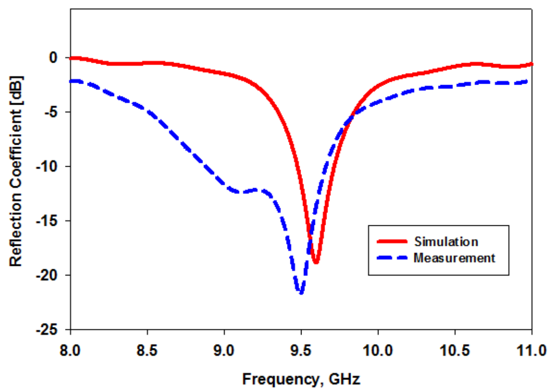
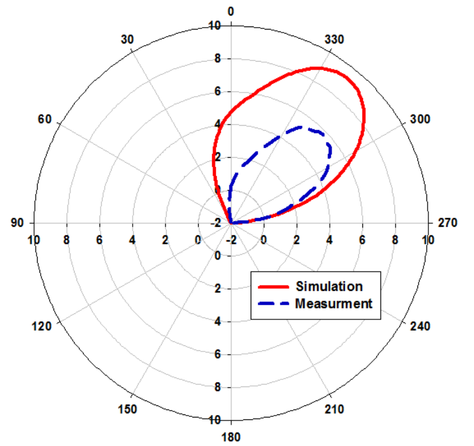
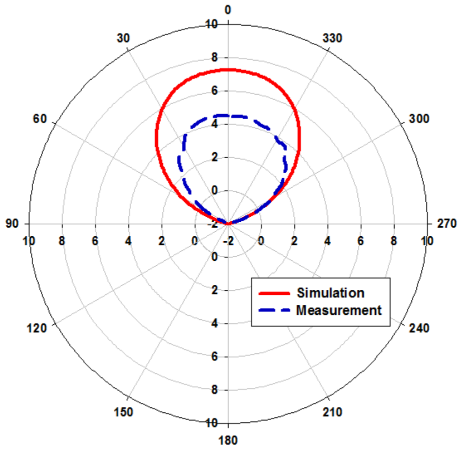


(c)

Fig.8: Simulated and measured reflection coefficient of the driven pixel antenna: (a) P1, (b) P2 and (c) P3



(a)



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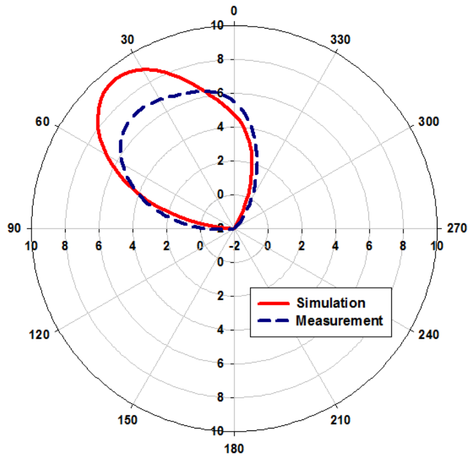

(c)

Fig.9: Simulated and measured radiation pattern: (a) P1, (b) P2 and (c) P3

4. Conclusion

In summary, the basic idea of this design is a combination of driven element and pixel layer has been presented. The antenna has possibilities to steer the direction at -40º, 0º, and 40 º with an average gain of 9.5 dBi, depending on the switching configuration. The simulated and measured results, it has confirmed that the antenna can operate at 9.5GHz with a good beam steering capability. The compactness and multi-functionality of the pixel structure leads to most promising concept for the reconfigurable antenna. The flexibility of switching conditions of the pixel structure has a great potential to be implemented for future wireless and radar system.

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