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Pattern Reconfigurable Patch Array for 2.4GHz WLAN systems

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Abstract - In this project, a pattern reconfigurable simple 2 patch array antenna has been designed and implemented to operate at a fixed frequency of 2.4 GHz for beam scanning purpose. Proposed antenna operates at three different modes in which the radiation pattern steers 0^0, $\pm 30^0$ with respect to the antenna broadside. In this paper, a different approach has been taken to implement the reconfigurable antenna which is very simple and cost-effective compared to previous works. For this, a SP3 RF switch is used to steer the radiation pattern by applying phase difference between the two antenna elements. A reconfigurable patch array is designed on a Rogers 5880 RT/DUROID substrate in which antenna element is fed in inset configuration. Measured and simulated results are well matched but with some minor deviations. Designed antenna array has a gain of 9 dBi in broadside and the gain drops to 7.5 dB when the beam is rotated by either $\pm 30^0$. Pattern reconfigurable antenna can be used in wireless communication systems where antenna pattern needs to be aligned with strongest signal sources or when the antenna needs to be kept away from noisy environments or interfering signals.

Key words: Pattern Reconfigurable Antenna, Patch antenna array, WLAN Antenna

1. Introduction

Having an antenna system with different functionality could be promising regarding overall cost, size and complexity. Reconfigurable antennas are among those antennas. Many studies have been conducted on reconfigurable antennas in the last decade and many still ongoing. Generally speaking, tunable antennas can be divided into three main categories: Pattern, frequency or polarization reconfigurable antennas [1]. It's also possible to have an antenna with multiple functionalities such as antenna with both pattern and frequency tune options. Switching between different operation modes can be carried out mechanically or electrically. Generally, electrical tuning is preferred since it is easier and more cost effective. Electrical phase shifter and switches can be used for this purpose [2]. Phased arrays are among the first designed reconfigurable antennas which use electrical phase shifter to steer the main beam direction. Phased array is a term referred to a very complex and bulky antenna array system with radar application [3]. However, for small modems and handheld devices, an array of antenna with two or three elements can be used to satisfy the gain and pattern scanning requirement. Planar antennas are attractive for this purpose since they are compact, low cost and easy integration with RF front ends [4]. Various methodologies are reported to realize the phase shifter such as reflection type phase shifter, line loaded phase shifter and switched line phase shifter [5].

In this paper, an array of two patch antennas together with a novel switch-based phase shifting mechanism is used to steer the radiation pattern. One RF SP3 switch is used to choose between different operating modes. Proposed phase shifting mechanism is a simple, compact and very low cost solution. RF SP3 switch can be implemented either with MEMS switches or other solid state switching devices such as PIN diode based switches[6]. Designed antenna has potential application of being used at 2.4GHz WLAN system specially when it is required to direct the antenna beam toward strong signal source or avoid interfering signals or to use in MIMO

Network implementation. The rest of the paper is organized as follow: section 2 describe the working principle of proposed antenna, in section 3, simulation and measurement result will be presented and finally the paper will be concluded.

2. Antenna design and working principle

Fig. 1 shows the architecture of proposed antenna array topology. As it can be seen from the figure, the topology comprises of two antenna elements (two patches) with distance d apart. The distance d can be determined based on the trade-off between grating lobe and mutual coupling effects. As the antenna elements are placed closer, mutual coupling effects deteriorate and as they go apart, the grating lobes will emerge. Grating lobes cause antenna to radiate in unwanted direction and waste a portion of input energy.

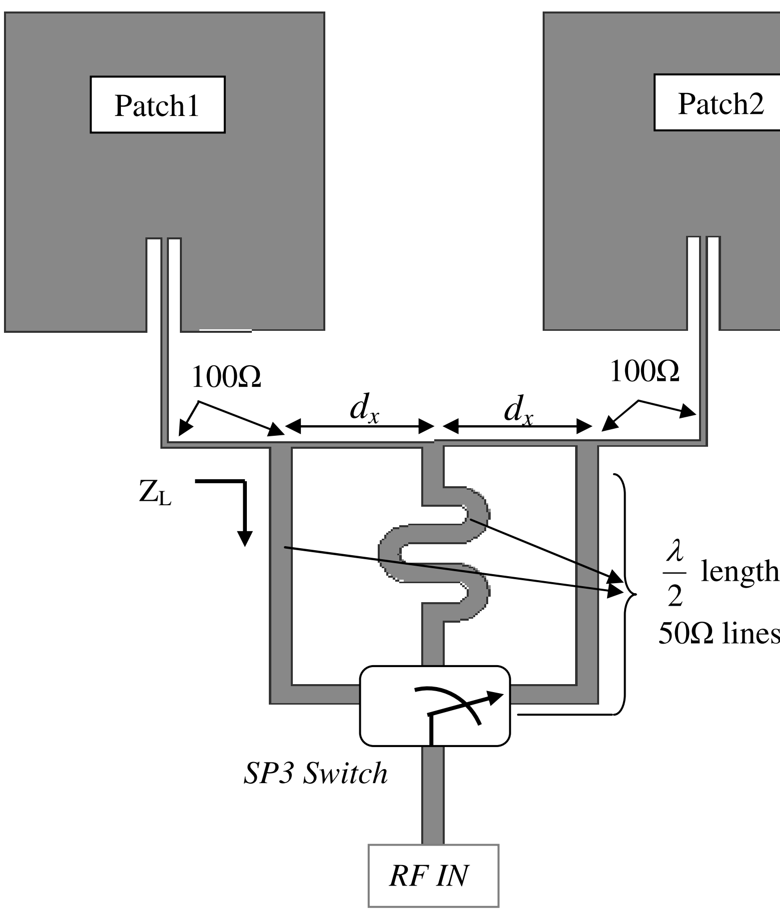

Fig. 1 Two antenna with feed lines and the RF switch

Based on the array theory, overall array pattern would be the times product of the element factor with the array factor. Element factor is always fixed while the array factor can be steered by inserting phase difference between antenna array elements [7]. Since the array elements are microstrip patch type so the element factor would be that of a single patch antenna. Array factor and element factor can be determined as follows:

Element factor = single patch antenna pattern

$$\text{Array factor} = \cos\left(\frac{\beta_0 * d}{2}\sin(\theta) - \theta_0\right) \text{ and } \theta_0 = \beta_g \times d_x \qquad (1)$$

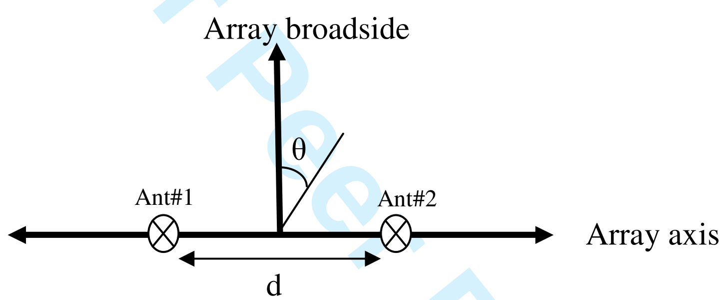

Fig. 2 Two antenna array configuration

θ is the angle from antenna broadside and θ_0 is the rotation angle which depends on the phase difference inserted between two patch elements as in Fig. 2. Two different propagation constants exist at the formula; β_0 is for free space and β_g is propagation constant at substrate.

$$\beta_0 = \frac{2 * \pi}{\lambda_0} \ , \ \beta_g = \frac{2 * \pi}{\lambda_g} \qquad (2)$$

In equation (2) λ_g is guided wavelength at substrate. To insert phase difference between array elements, it's common to use switched transmission line based phase shifter or surface mount phase shifter in each antenna's feed lines [8-9]. Fig.3 shows how these types of phase shifting mechanism works.

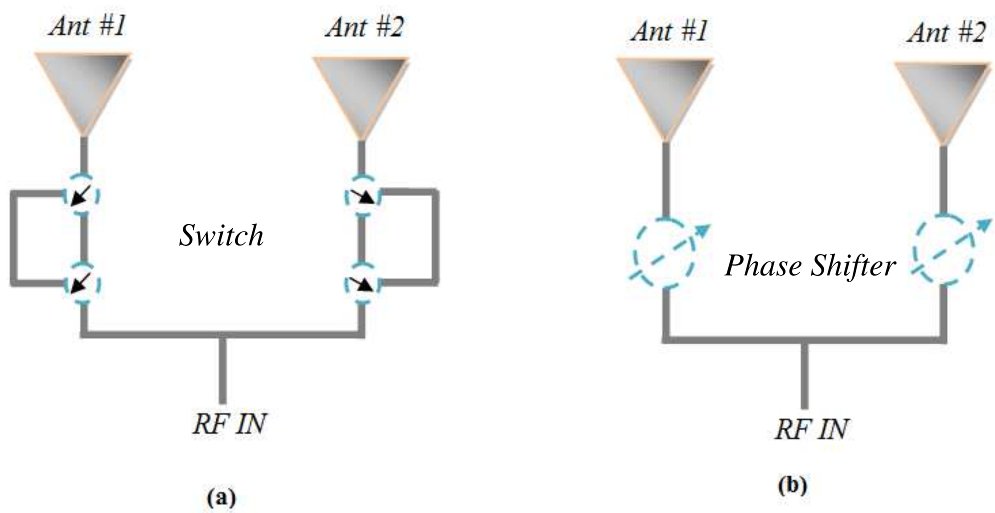

Fig. 3 Various methods of inserting phase difference between array elements

In the first type, Fig.3a, switches are used to select between two different delay-transmission-lines, and so, it is possible to feed antenna elements with two different phases. With this topology in hand, radiation pattern can be directed in three different directions. However, there are two switches for each antenna element and the total number of four switches. More importantly, these switches are at separate places and this make topology bulky and complex. In the second type, Fig. 3b, electrical phase shifter is placed in each feed line to insert phase difference. Using phase shifter, it would be possible to insert any phase difference between elements and steer the radiation pattern in many directions. However, phase shifters are expensive components. If the antenna topology is required to have three different directions for radiation pattern, it is possible to make the design much simpler and compact by using a one SP3 switch. The SP3 switch in our antenna prototype will provide three different phase differences.

The SP3 switch simply chooses between three 50Ω branch lines and connects just one of them to the main 50Ω line (RF IN) and leaves the rest of the ports open. All these 50Ω branch lines are terminated at 100Ω feed lines but at different points with respect to array center. 100Ω line interconnects two patch elements and feed them in inset configuration. The antenna elements

(Patch1 and 2) would be excited with different phase if we offset feed them with respect to array center. This can be done by connecting either left/right 50Ω branch line to main 50Ω line (RF IN). To emphasize, SP3 switch suppose to connect the main 50Ω feed line to one of the 50 Ω lines and must leave the rest two 50Ω branch lines open. Moreover, the 50Ω branch lines length must be λ/2 at operating frequency. With this type of connection, open lines don't load the 100Ω line when they are left open by switch since their impedance (Z_L) would be infinity looking from 100Ω line side.

There would be three different operation scenarios with three different switch positions. In the first scenario, as shown in Fig.4a, SP3 switch connects the main 50Ω (RF IN) feed line to the 50Ω branch in the middle part of the circuit. The electric current flows in 50Ω line until it reaches two parallel 100Ω lines and then split into two signals with the same amplitude. Split signal travel the same length of transmission line, and hence, feed the patches with the same phase. So, the current distribution on the patches would be the same and the main beam will be directed to the array broadside.

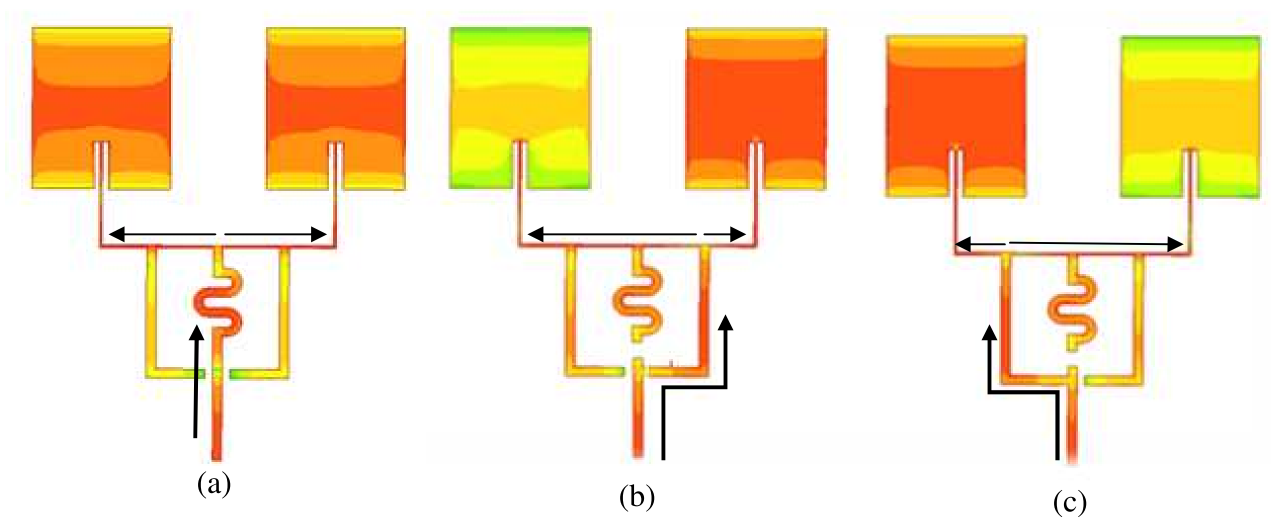

Fig.4 Current distribution when a) the middle line, b) the right line, c) the left line is selected

In the next two scenarios, as shown in Fig.4 b.c, switch connects main feed 50Ω line (RF IN) to either 50Ω branches line at the left or right. Like before, the electric current flows until it reaches two parallel 100Ω lines and then split into two signals with the same amplitude. However, in this case, split point has d_x distance from the array center. This way, one signal will travel longer distance, and hence, patch element will be fed by different phase and the current distribution would be different. This will result in radiation pattern rotation with respects to array broadside. The angle in which the pattern steers can be determined by d_x (split point with respect to array center) and β_g (substrate propagation constant) as equation (2):

3. Antenna implementation

First, proposed topology was simulated using full-wave HFSS software and then realized using available printed technology. Fig.5 shows the implemented antenna with the realized dimensions. As illustrated in the Fig.5, the array axis lies at the H-plane of the patches so that the pattern rotation will be at the H-plane. This is while the pattern remains constant at the E-plane for different operating modes.

Proposed topology is simulated and implemented on 0.787mm Rogers 5880 RT/DUROID substrate. The SP3 switch functionality is done manually by soldering the desired branch lines to main lines. The following results were obtained based on the simulation and measurement results.

Implemented patch array has a gain of 9dB, when the branch line in the middle is selected, and the main beam is directed at broadside. Reflection coefficient measurement shows perfect match between antenna and the feed line. Moreover, HPBW for array is about 50^0, and in this operating mode, antenna will cover about $\pm 25^0$ off the broadside. For the next two scenarios, the gain drops to 7.5 dB when beam is rotated by $\pm 30^0$ and antenna is still perfectly matched. HPBW for array is still about 50^0. All in all, the implemented antenna topology, considering three different operation modes, can cover $\pm 55^0$ of the broadside with proposed switching mechanism.

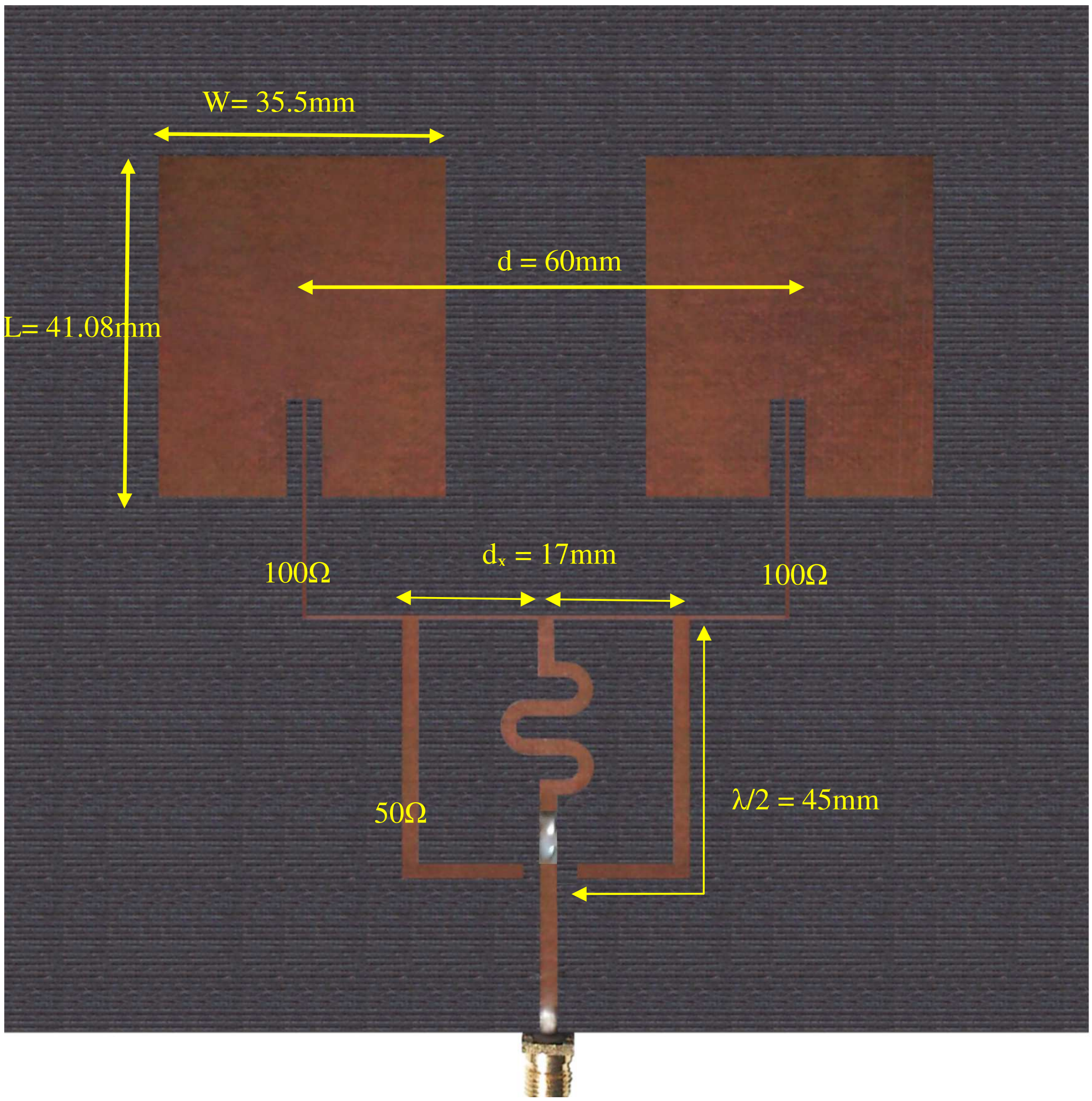

Fig. 5 Fabricated Antenna

The measurement is an outdoor antenna measurement setup. So, to some extent, the difference between measured and simulated can be attributed to measurement setup errors like unwanted reflections. Arrows in the radiation pattern indicate the antenna 3dB beam-width, in other word antenna coverage range.

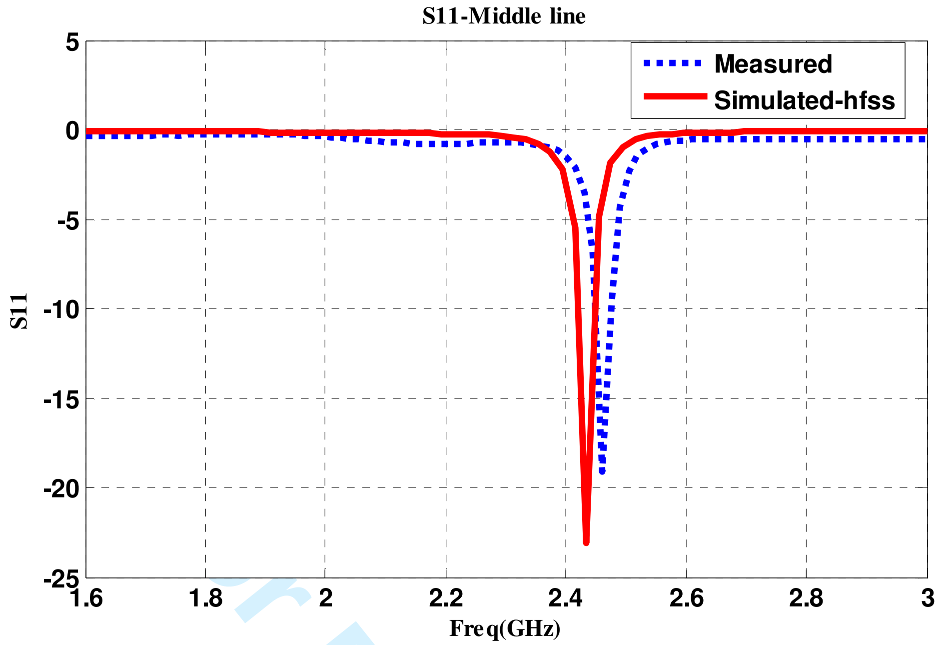

Fig.6 a) Reflection coefficient when SP3 connects the middle line

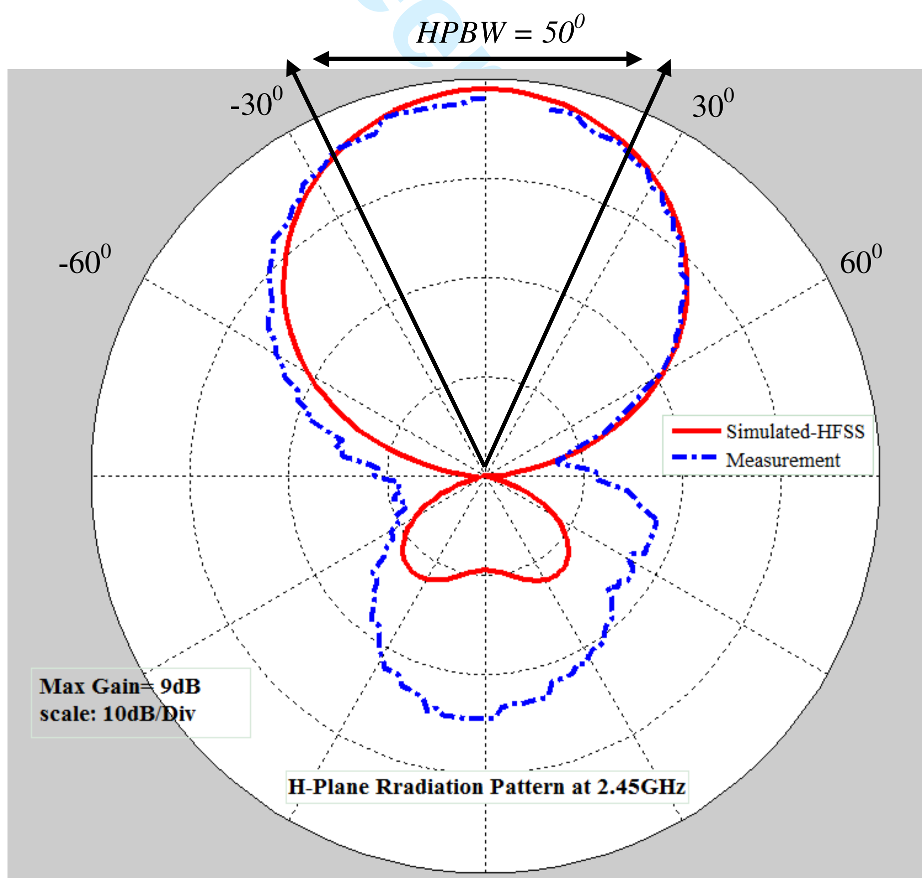

Fig.6 b) Radiation Pattern when SP3 connects the middle line

Fig.6a shows the measured and simulated reflection coefficient when the middle line is selected by SP3 switch. Simulated antenna resonates at 2.43GHz with 30MHz of bandwidth with respect to -10dB S11 level. The measured reflection coefficient is almost the same but with about 25MHz shift to higher frequencies. This frequency shift can be attributed to the construction process in which the acid eats out more of metal edges when the sample is kept for long time in acid solution. Fig.6b shows the radiation pattern of the antennas with the main branch line is connected. The measured and simulated results are in well agreement and the total realized gain of the antennas is 9dBi with peak directed at antenna broadside direction. 3dB beam-width of the pattern is about 50^0, and in this mode of operation, antenna will cover the $\pm 25^0$ angles off broadside.

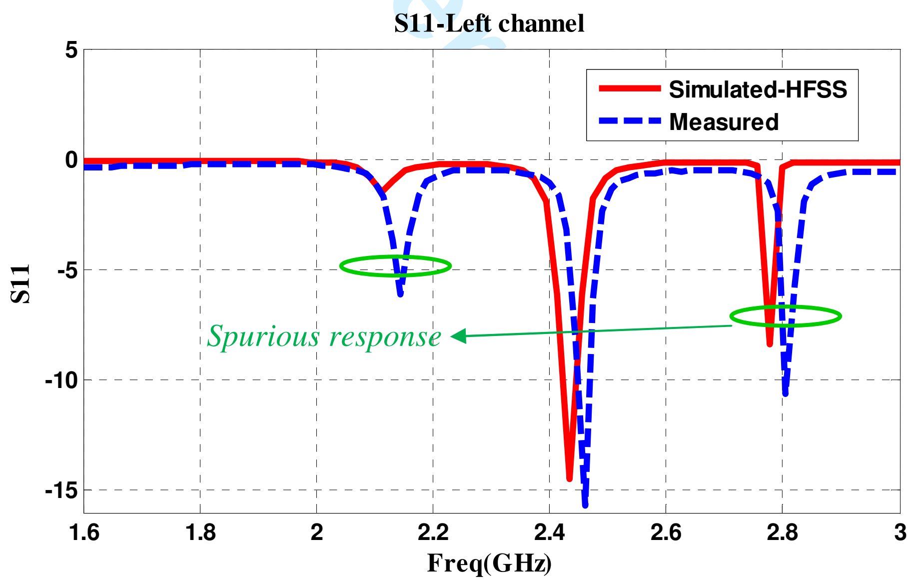

Fig.7 a) Reflection coefficient when SP3 switch selects the right branch line

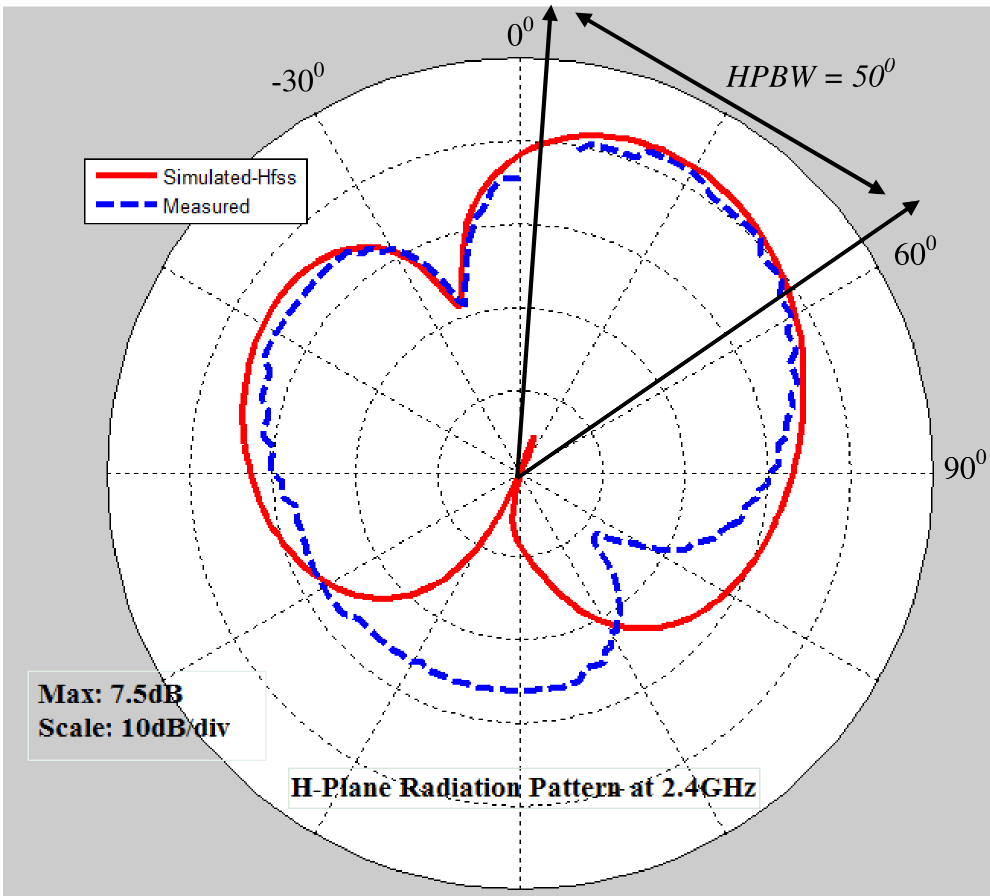

Fig.7 b) Radiation Pattern when SP3 switch select the right branch line

Fig.7a shows the reflection coefficient when the SP3 switch connects the right branch line to the RF input. Like previous scenario, the antenna resonates at 2.43GHz. However, there are two other spurious resonances at 2.15GHz and 2.8GHz as noticed in Figure 7a. This resonance like response comes from the loading effect of two other branch lines which are left open; they no longer exhibit infinite impedance at those frequency and absorb part of input signal and show such resonance like behavior. At the Fig.7b, the steered radiation pattern is depicted which is rotated by $+30^0$ with respect to antenna broadside. As it can be seen in Fig 7.b, while the radiation pattern rotates, the grating lobes start emerging. However, the grating lobe is 8dB below the main beam. The antenna 3dB beam-width is similar to previous case of main branch line feed (50^0) and since the antenna is rotated by $+30^0$, it will cover the range of $+5^0$ to 55^0.

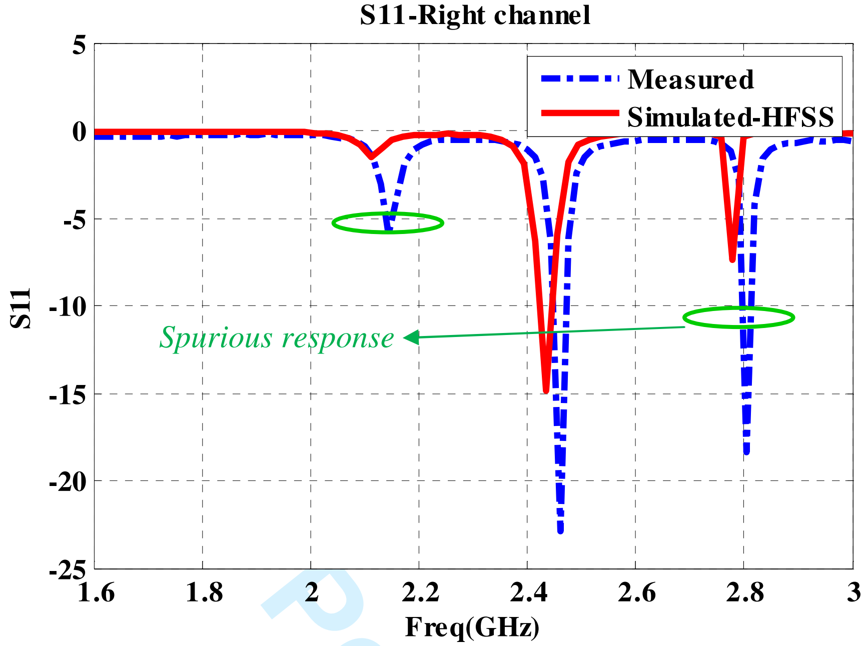

Fig.8 a) Reflection coefficient when SP3 switch select the left branch line

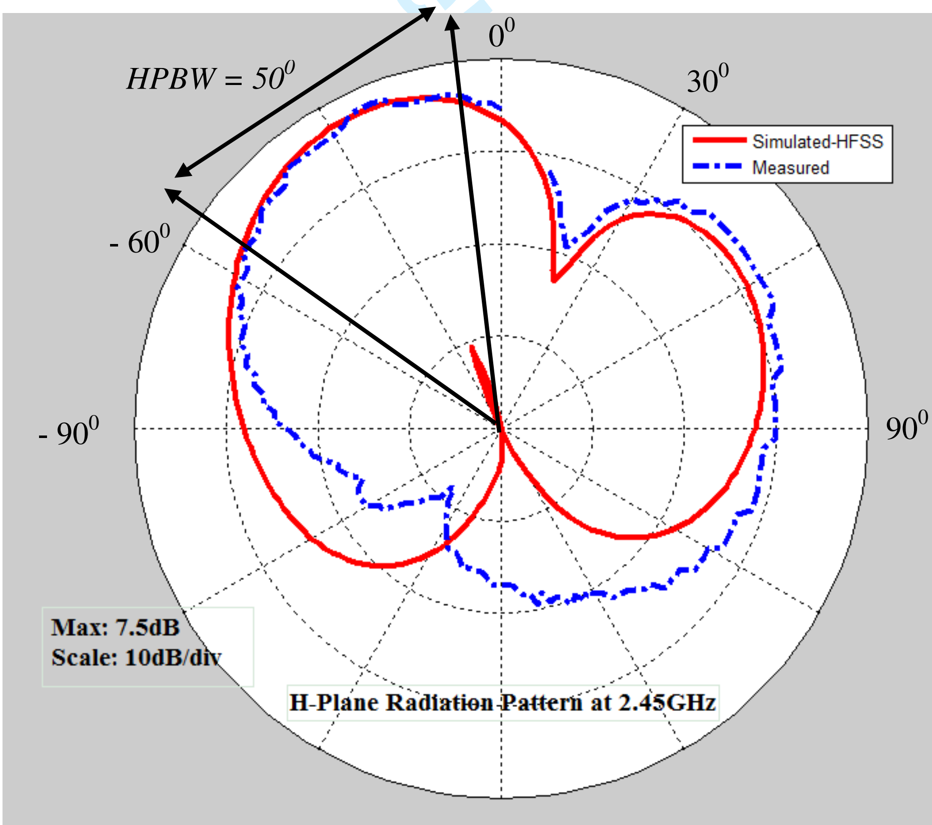

Fig.8 b) Radiation Pattern when SP3 switch select the left branch line

Fig.8 shows the measured and simulated reflection coefficient and radiation pattern when the RF SP3 switch selects the left transmission line. The results are almost the same as previous cases. The only difference is that the radiation pattern is rotated to -30^0 with respect to antenna broadside. This time antenna will covers -5^0 to (-55^0) range.

To summarize the results, reflection coefficient figures show that the antenna is very well matched for different operating modes. Measured and simulated radiation pattern are also close but with minor deviation and this can be attributed to the measurement setup which is outdoor antenna setup. Anechoic chamber can be used to improve the measurement setup and get rid of ambient reflections. Moreover, as it can be seen from the figures, the more the beam is rotated the grating lobes problem becomes more severe. So, the rotation angle can be determined based on this trade off. Implemented antenna topology can cover spatial angle from -55^0 to +55^0 and can be used at WLAN system.

4. Conclusions

A patch array with reconfigurable properties is realized and tested. A potential application area could be at WLAN system where it is required to keep antenna main beam away from interfering signals and use beam steering for higher Signal to noise ratio. The array antenna uses a new phase shifting mechanism based on λ/2 transmission lines and using a single RF SP3 switch. RF SP3 switch connects the transmission lines that are used to insert phase shift between array elements, and hence, to fulfill the pattern steering functionality. A prototype of the antenna array is implemented and measured. Results show that two patch array antenna works at 2.4 GHz band with good impedance matching. The antenna array achieves 7.5 dBi worst case gain and cover a total of 110 degrees azimuth angle with 50 degree beam-width with 30 degree beam rotations.

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