Reconfigurable microstrip patch antenna for WLAN Software Defined Radio applications

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Abstract - A reconfigurable microstrip patch antenna with RF pin diode switches is implemented for dual band of 2.4 GHz and 5.6 GHz WLAN Software Defined Radio (SDR) applications. For the dual band SDR system, the use of a single antenna with a wide bandwidth to cover both of the bands can be limiting for low power level signal applications due to wideband noise as well as changing radiation pattern at different frequencies. A reconfigurable nested microstrip patch antenna is designed on a Rogers 5880 RT/DUROID substrate which is fed by a coaxial probe from the back side of the grounded substrate. RF switching circuitry involves four RF pin diodes at each side of the inner patch. The dual bands of 2.4 GHz and 5.6 GHz frequency operation can be simply obtained by switching the PIN diodes on and off. The antenna is well matched and achieves approximately 7 dBi gain at both frequency bands. Simulation and measurement results show that the nested patch antenna is suitable for dual band WLAN SDR applications.

Key words: SDR reconfigurable antenna, WLAN antenna, tunable microstrip patch antenna

1. Introduction

In this paper, the design of a reconfigurable microstrip patch antenna with RF pin diode switches is presented for WLAN SDR applications. There have been many examples of antennas for SDR and multi frequency and frequency reconfigurable antennas for different applications [1-2]. However, these antennas are optimized for one of the frequency bands and may require additional reconfigurable tuning circuits for good impedance matching [3]. Dual frequency microstrip patch antennas have been the subject of many research papers for different applications. A pin diode switchable triangular microstrip patch antennas is described in [4] for SAR/GPS/WLAN applications. The dual frequency operation of the microstrip antenna with a stub embedded in the patch was also reported in [5]. The dual band microstrip structure in [6] consists of two stacked quarter wave elements. However, the radiation patterns are quite different at the two frequencies. At the lower frequency, beam is located at 45 degrees at the lower frequency and at 0 degrees for the upper frequency. Multimoding approach can be employed for multi frequency operation, the stacked patch and coplanar parasitic configurations have been extensively used for this purpose with different radiation characteristics, [7]. The PIN diode based, MEMS based switches are used for frequency tuning for microstrip patch antennas in [8,9] as well as varactor loading is employed for tuning/radiation pattern control of patch/wire antenna elements in [10,11]. We propose a reconfigurable microstrip patch antenna with no additional matching circuits for WLAN systems at 2.4 GHz and 5.6 GHz with alike radiation patterns at both frequencies. Most of the dual band antennas will have the impedance matching for the desired bands, but will not pay that much attention to radiation pattern. For the proposed structure, the radiation pattern will remain the same at the two frequencies of operation.

The 2.4 GHz band is commonly used by many WLAN systems. However, with many deployed systems at 2.4 GHz band, RF interference and noise level can be much higher at this band. There is also 5.6 GHz band available for WLAN and in general, use of the systems at this band is not that widespread as the use of 2.4 GHz systems. The proposed reconfigurable antenna will pave the way for an SDR or cognitive radio application where both frequency bands can be chosen to operate depending on the interference level for WLAN with the same coverage area due to the same radiation patterns at dual bands.

In this paper, design methodology of reconfigurable microstrip patch antenna is presented with simulation and measurement results of fabricated SDR antenna. The rest of the paper will be organized as follows: in Section 2, reconfigurable microstrip nested patch antenna design will be explained, in Section 3, simulation and measurement results will be presented, and finally the paper will be concluded.

2. Reconfigurable microstrip patch antenna

A schematic view of the proposed antenna is plotted in Figure 1. The antenna has two microstrip nested patches with sizes L1, W1 designed to operate at 2.4 GHz, and L2, W2 designed to operate at 5.6 GHz. The nested patches are connected or disconnected electrically using RF pin diodes located on each side of the inner patch. RF pin diode connections will ensure the formation of x and y current densities on the inner and outer patches. To complete the return of the RF PIN diodes current, a ground return is supplied on the outer patch corners using four quarter wavelength shorted stubs which are short circuits for DC bias and open circuits at 2.4 GHz at the edges of the outer patch.

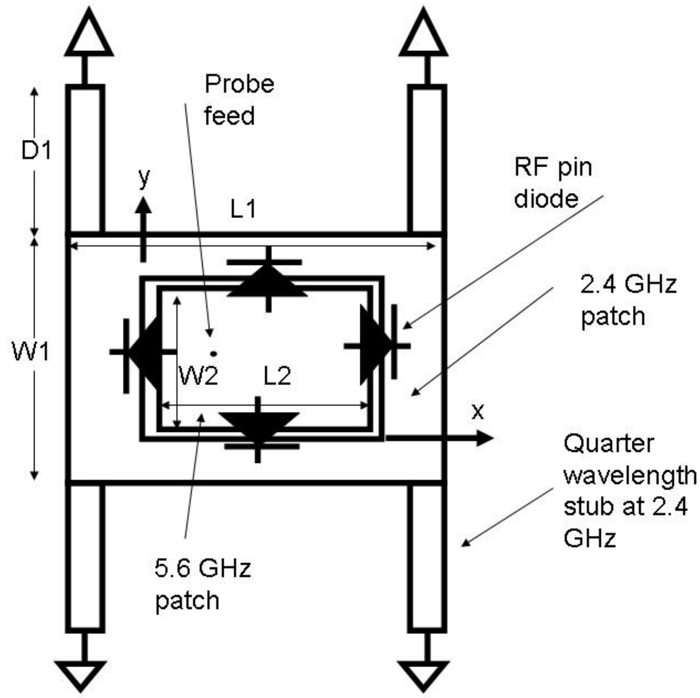

Fig. 1 Dual band 2.4/5.6 GHz reconfigurable patch antenna

The patch antennas are fed with a coaxial probe which is also optimized such that a good impedance matching is obtained for both of the patches. By the nested patch design as shown in Figure 1, one can obtain a good impedance match for any two different frequencies by adjusting the relative position of one microstrip patch with respect to the other patch as well as optimizing the single feed location. DC bias for all RF pin diodes are supplied from one source with a bias tee connected at the input port of the antenna. If the antenna is to operate at 5.6 GHz, the RF pin diodes will be reverse-biased so that the inner and outer patches are disconnected. Note that reverse bias capacitance of the pin diodes may change the resonance frequency of the inner patch. For an operation at 2.4 GHz, the pin diodes will be turned on and the inner and outer patches will be connected electrically and again note that the series resistance of the pin diodes may degrade the antenna gain at this frequency.

One of the features of this antenna is that by changing the relative position of the patches, a good impedance matching and the same radiation pattern can be obtained for both of the frequencies 2.4/5.6 GHz. The same radiation pattern is obtained due to the excitation of the same patch TM01 mode at two different frequencies. For dual frequency operation, one can design a single fixed antenna with two bands such as a dipole antenna with parasitic elements having two resonances at f1 and f2 frequencies as shown in Figure 2.

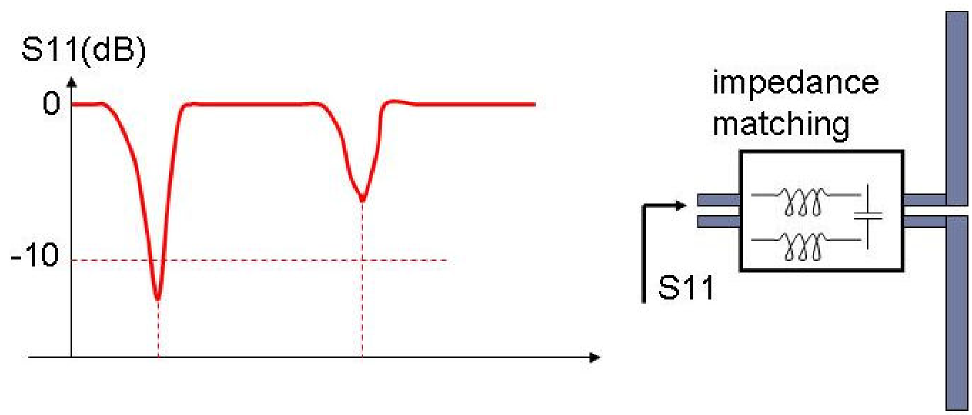

Fig. 2 A single fixed antenna with two resonances at f1 and f2

For the type of antennas with multiple resonances, additional impedance matching circuitry as shown in Figure 2 is needed since the matching and gain of the antenna at both frequencies can't be optimized simultaneously. Further, gain and radiation pattern control is limited as the matching circuit is not optimized for both of the frequencies, the currents on the antenna and hence the radition patterns will be determined by the currents. Note that the impedance matching circuitry with discrete components will also deteriorate the antenna gain performance due to loss of the elements. Alternative to dual frequency operating antenna, a broadband/wideband antenna or an UWB antenna such as TEM antenna as shown in Figure 3 working from f1 to f2 frequencies can also be used to cover dual frequencies of interest.

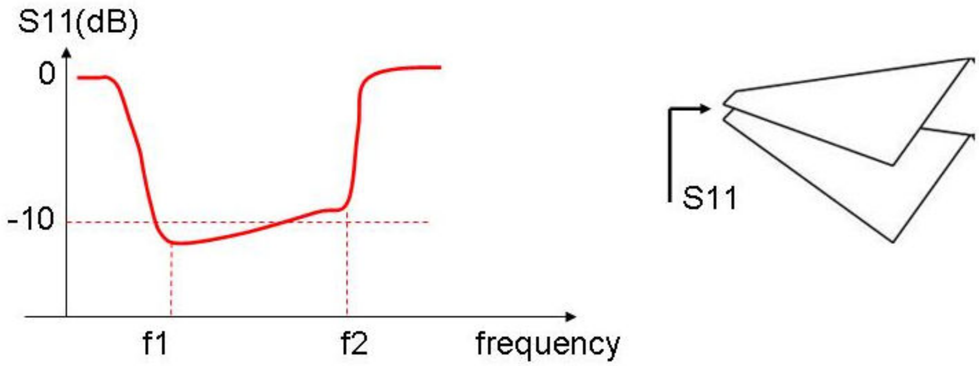

Fig. 3 An UWB parallel plate TEM antenna operating from f1 to f2 frequency

Use of such wideband antennas will require additional filtering for band selectivity. Also, wider noise bandwidth will result in smaller RF signal sensitivity for the overall system in addition to unavailability of control of radiation patterns at the two frequencies f1and f2. An antenna configuration wihich may solve above mentioned shortcomings is a reconfigurable antenna with switched resonance as shown in Figure 4.

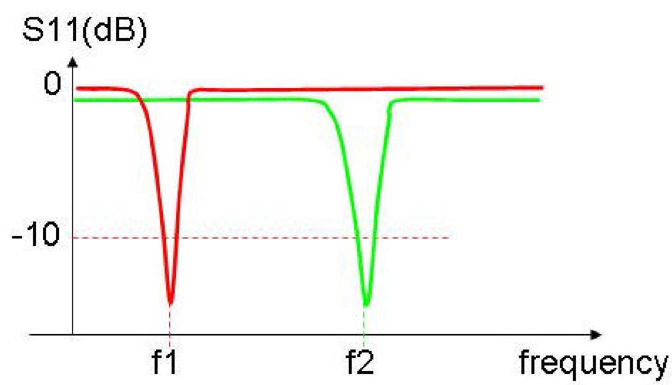

Fig. 4 Return loss of a reconfigurable antenna with switchable resonances f1 and f2

In this configuration, the antenna operates at one of the frequencies f1 or f2. No impedance matching circuitry is required since the antenna is optimized for both of the frequencies, antenna gain and impedance matching of the antenna can be optimized individually at both frequencies. Radiation pattern can be controlled independently at two different frequencies, which can be designed to be the same with some additional simple RF switching circuitry, RF pin diodes or RF MEMS capacitive/resistive swithces.

In the design procedure of the reconfigurable patch antenna, first, the inner patch antenna at 5.6 GHz is designed by optimizing its probe feed location for a good impedance matching well below 10 dB return loss. This can be done easily by commercially available EM software such as ADS Momentum. Once, a good matching is obtained for the inner patch, 5.6 GHz patch is designed independently by optimizing its probe feed location for a good impedance matching that is below 10 dB return loss, too. To combine these two antennas at 2.4/5.6 GHz into one antenna, the two separately designed antennas can be overlapped from their feed points and by opening a thin slot around the edges of the smaller of the microstrip patch antennas as shown in Figure 5. Finally, PIN diodes are placed across the slot for electrical connection between the inner and the outer patch for band selection. With nested patch antenna, a good impedance matching can be obtained for both of the frequencies independently. More importantly, the same radiation pattern can be obtained for both of the two frequencies which may not be available for other dual band fixed antenna designs.

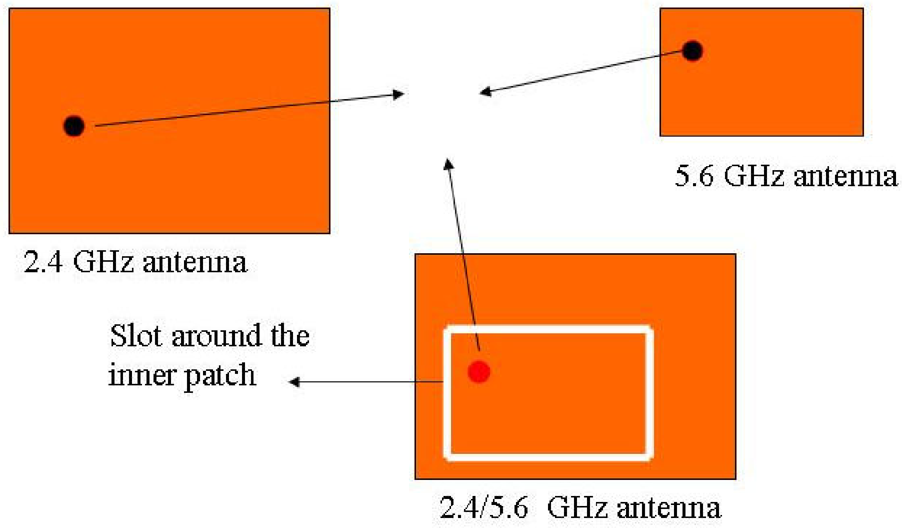

Fig. 5 Dual frequency antenna evolved from 2.4 and 5.6 GHz patch antennas

The reconfigurable dual band nested microstrip patch antenna is designed on an Rogers 5880 RT/DUROID substrate with a relative dielectric constant of $\varepsilon_r = 2.2$ and that has a thickness of 0.78 mm as shown in Figure 6. The antenna is fed by a coaxial probe from the back side of the grounded substrate. RF switching circuitry involves four RF pin diodes at each side of the inner patch that require three volts for biasing. The dual bands of 2.4 GHz and 5.6 GHz frequency operation can be simply obtained by switching the PIN diodes on and off. The RF pin diodes are MMP7000 series from Aeroflex corporation, which requires around 3 mA of forward current for bias per diode. The antenna dimensions for 2.4/5.6 GHz operations are optimized using ADS momentum with following dimensions: the inner patch dimensions are W1 = 15.9 mm and L1 = 17.3 mm. Outer patch dimensions are W2 = 39.8 mm and L2 = 41.3 mm. The short circuited stub width is 2 mm and the length is D1= 21.1 mm. The gap between inner and outer patch is 1.1 mm. The coaxial probe is connected to a point which is 6.7 mm from the left side of the inner patch and 7.1 mm from the bottom edge of the inner patch. DC bias for the RF PIN diodes and the RF signals are fed from the same port by using a Bias Tee. Note that the DC return path is provided by a quarter wavelength shorted transmission lines at the corners of the outer patch.

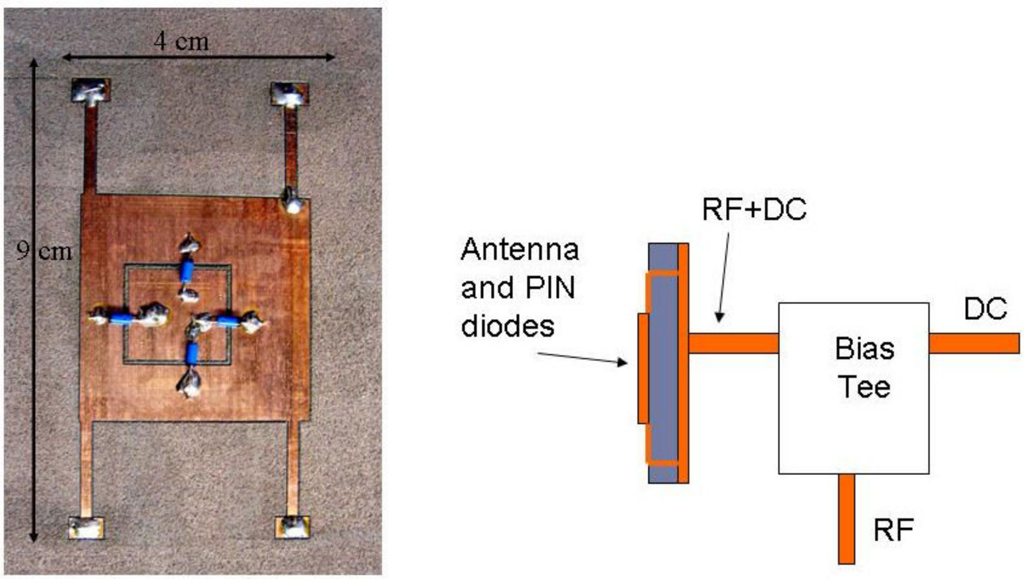

Fig. 6 Reconfigurable patch antenna with PIN diodes and its DC + RF feed circuit

3. Simulation and Measurement Results

The antenna is simulated using ADS Momentum tool for its return loss and radiation patterns. In Figure 7, the simulated and measured return losses of the antenna are shown for 2-7 GHz band for antenna operating at 2.4 GHz. For this case, PIN diodes are biased and total current through the circuit is 12 mA at 3 V. The main radiation mechanism is the outer microstrip patch antenna and the spurious radaiton from the quarter wavelength stubs. The simulation and measurement results are in good agreement, and for the 2.4 GHz band, the antenna achieves a -10 dB measured bandwidth of 15 MHz. Also, notice that higher order modes of the patch antenna are also excited at higher frequency band (4-7 GHz) for the 2.4 GHz band mode, however, these higher order modes can be easily filtered out.

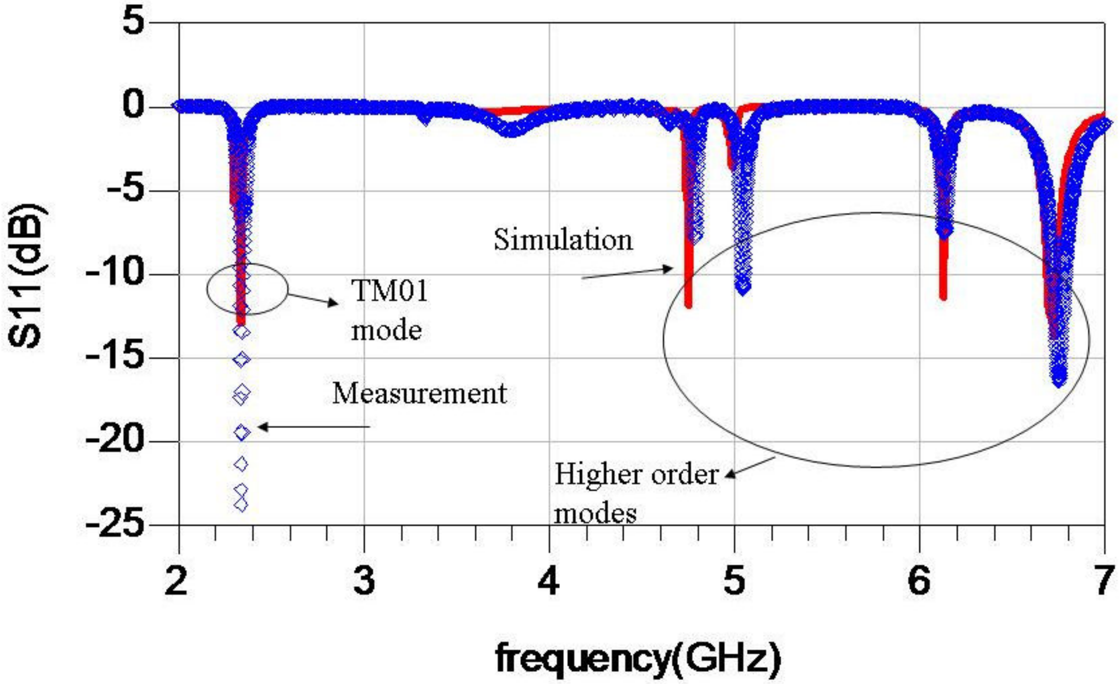

Fig. 7 S11 - Input return loss versus frequency (dB) - Simulated and measured (PIN diodes are ON)

Note that wider bandwidths can easily be obtained by using a thicker substrate. In Figure 8, the simulated and measured return losses of the antenna are shown for the band of 5.6 GHz. For this case, the RF PIN diodes are reverse biased and main radiation mechanism is the inner patch antenna. The antenna achieves a -10 dB measured bandwidth of 90 MHz. The minimum of S11 is measured to be -22 dB at 5.54 GHz, achieving a value of -16 dB at 5.6 GHz.

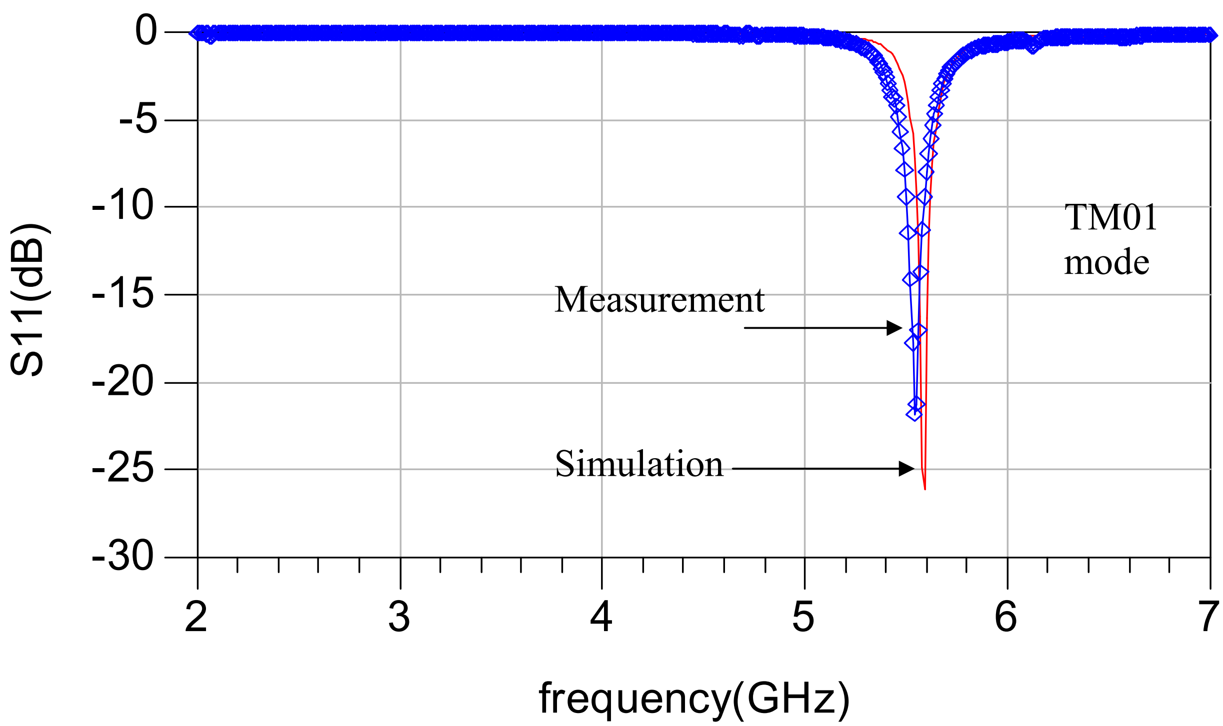

Fig. 8 S11 - Input return loss versus frequency (dB) - Simulated and measured – (PIN diodes are OFF)

Radiation patterns for the 2.4 GHz band are simulated and measured at 2.337 GHz where the simulated and the measured return losses has the minimum value. For the 5.6 GHz, simulation of the radiation pattern is performed at 5.6 GHz and measurement of the radiation pattern is obtained at 5.54 GHz where the return loss achieves its minimum. Simulated radiation patterns at 2.337 GHz (frequency of smallest return loss of -25 dB - co and cross polarizations) of the nested patch antenna for E plane and H plane are given in Figures 9 and 10, respectively. For the E-plane, antenna is linearly polarized with co/cross pol. ratio of 20.5 dB, and half power beamwidth is obtained as 98 degrees.

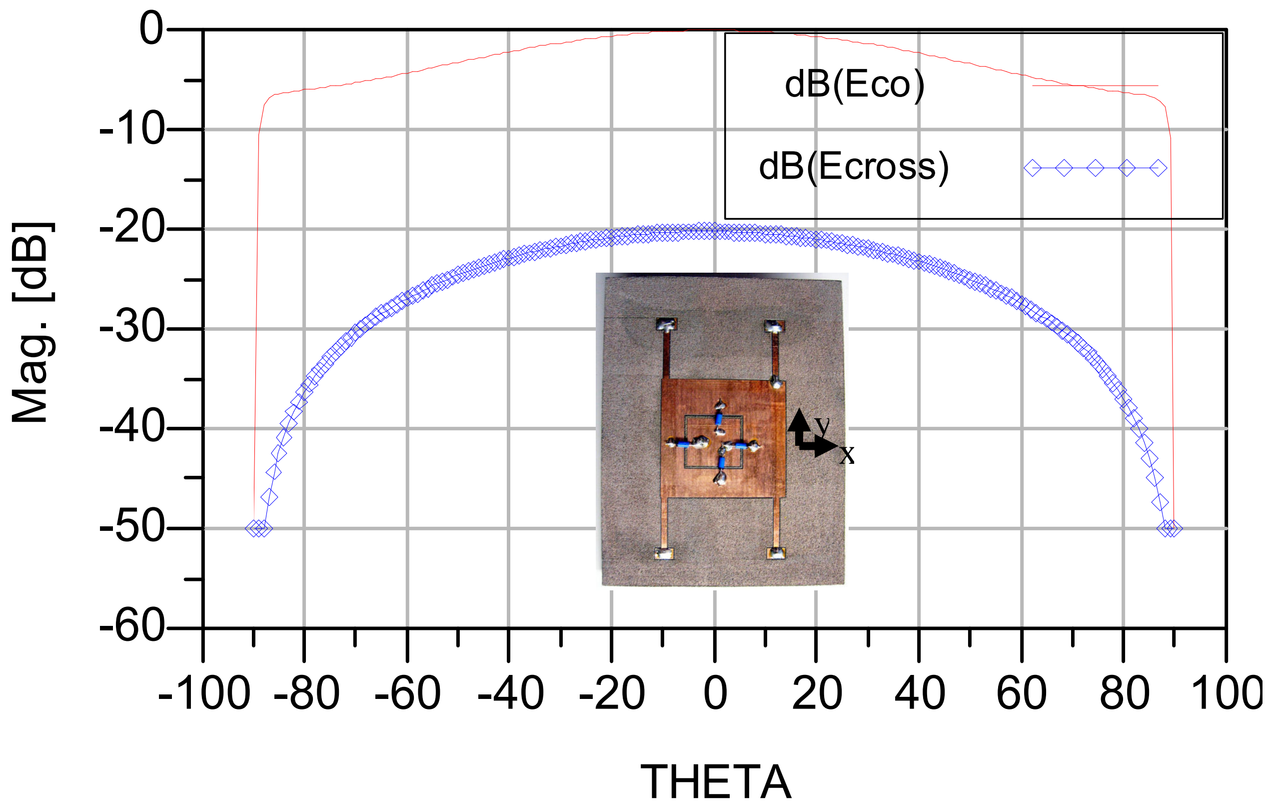

Fig. 9 E-plane radiation pattern at 2.337 GHz for co. pol. and cross polarizations

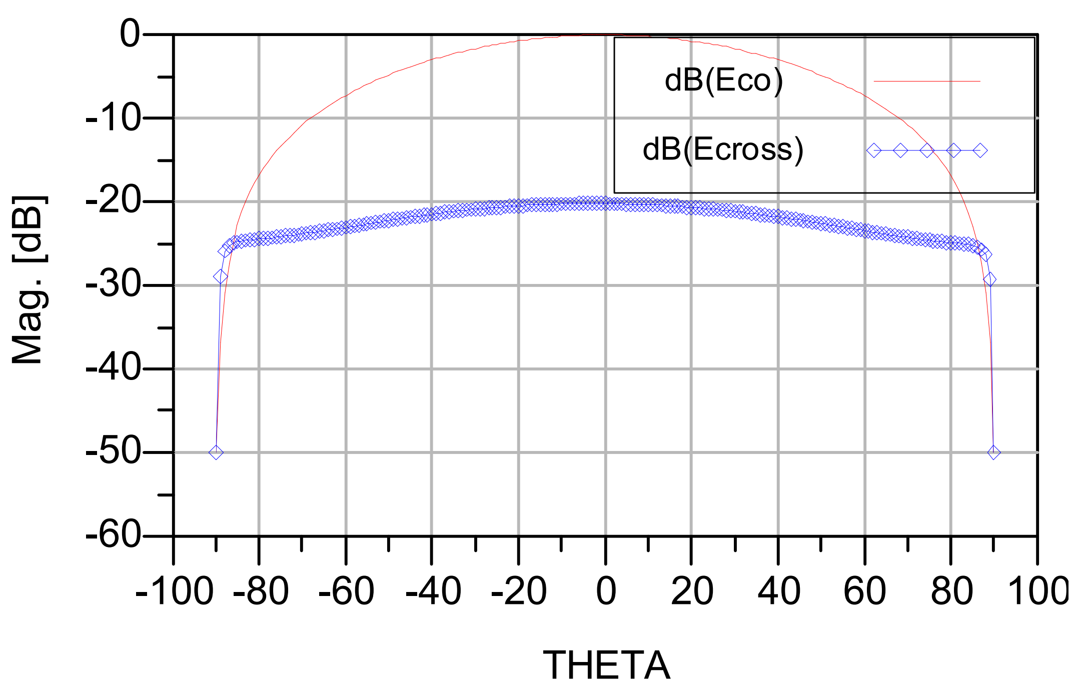

Fig. 10 H-plane radiation pattern at 2.337 GHz for co. pol. and cross polarizations

For the H-plane, antenna is linearly polarized with co/cross pol. ratio of 20 dB, and half power beamwidth is 80 degrees. For the 2.337 GHz, the antenna gain is calculated as 7.26 dBi. Simulated radiation patterns at 5.6 GHz of the nested patch antenna for E plane and H plane are given in Figures 11 and 12, respectively. For the E-plane, antenna is linearly polarized with co/cross pol. ratio of 44 dB, half power beamwidth is 96 degrees. Note that the half power beamwidth for the 2.337 Ghz band is simulated as 98 degrees.

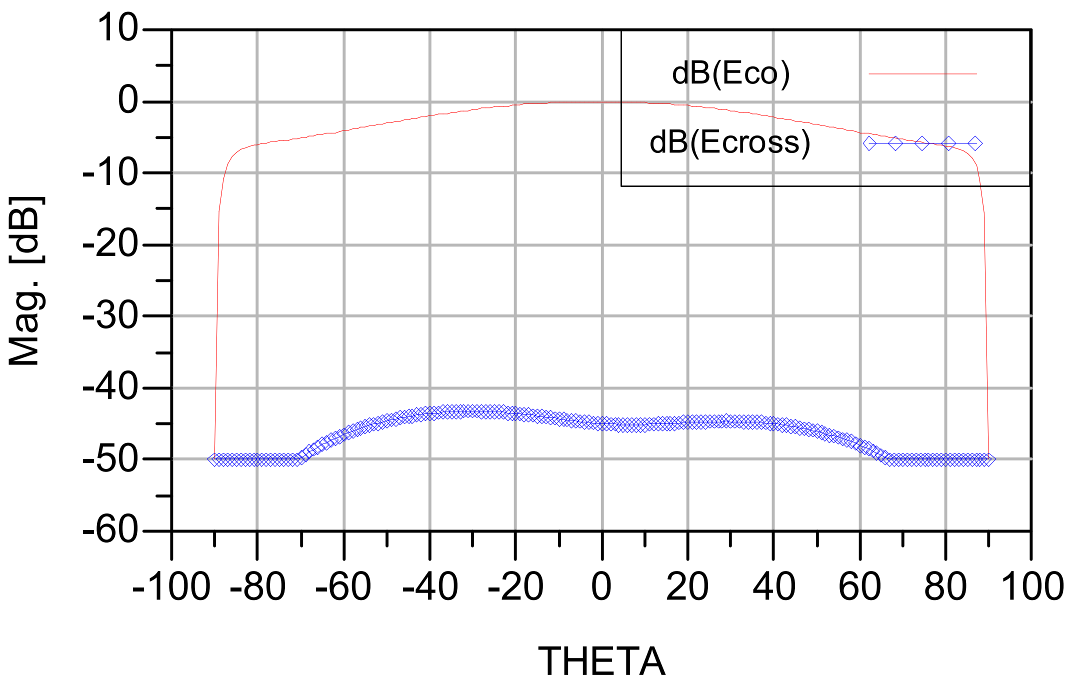

Fig. 11 E-plane radiation pattern at 5.6 GHz for co. pol. and cross polarizations

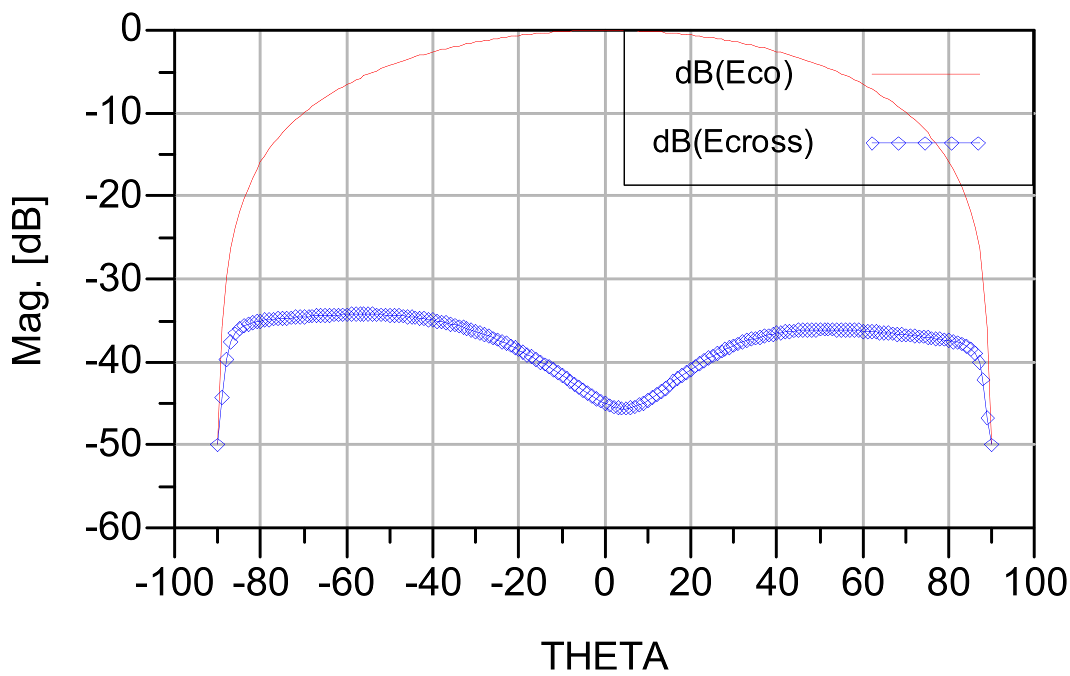

Fig. 12 H-plane radiation pattern at 5.6 GHz for co. pol. and cross polarizations

In H-plane, the antenna has a co/cross pol. ratio of almost 45 dB at 5.6 GHz with 86 degree half power beamwidth. The calculated gain is 6.93 dBi, which is very close to calculated gain at 2.337 GHz which is 7.26 dBi. The co/cross pol. ratio is higher at 5.6 GHz compared to 2.337 GHz band. This may be caused by the radiation from the quarter wave short circuited stubs which are used for RF pin diodes biasing. Radiation patterns are measured at NJIT anechoic chamber for the frequencies of 2.337 Ghz, 2.4 GHz, 5.54 GHz and 5.6 GHz. As a transmitter, for the 2.337 GHz, 2.4 GHz, Standard horn antenna is used, and the nested patch antenna is used as the receiver. For the 5.6 GHz, a conmercially available 2.4/5.6 GHz dual band WLAN antenna is used. The transmitter is an Agilent RF signal generator and the receieved power by the nested patch antenna is measured with an Boonton Microwave RF power meter. For the 2.337 GHz, the measured E and H-plane patterns are shown in Figures 13 and 14, respectively. Half power beamwidths are measured as 104 degrees (98 degrees simulated) in E-plane, 84 degrees (80 degrees simulated) in H-plane. Polarization ratios are measured as 10 and 11 dB for the E and H-planes. Simulated results for the co/cross polarization ratios were around 20 dB.

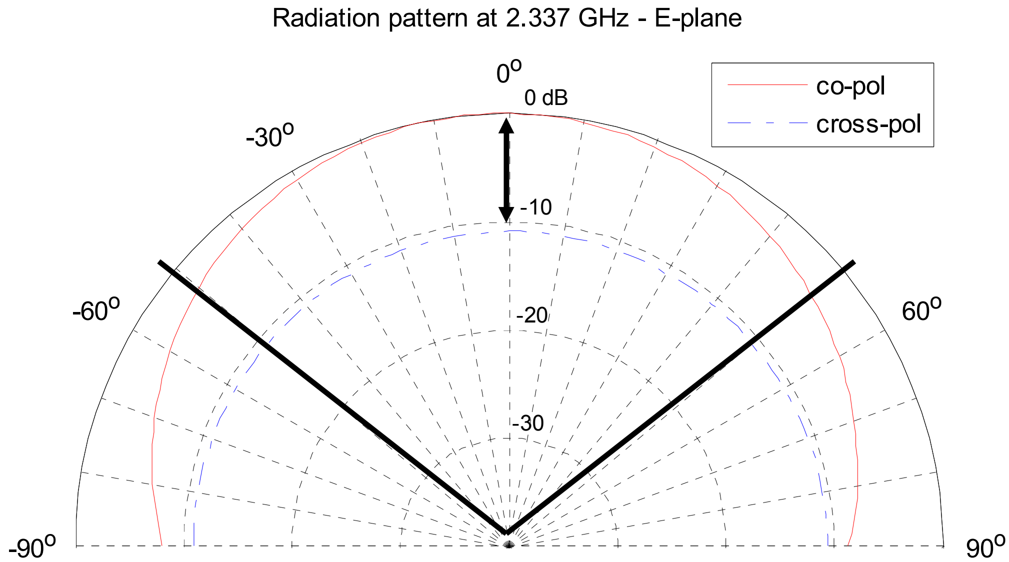

Fig. 13 E-plane measured radiation pattern at 2.337 GHz for co. pol. and cross polarizations

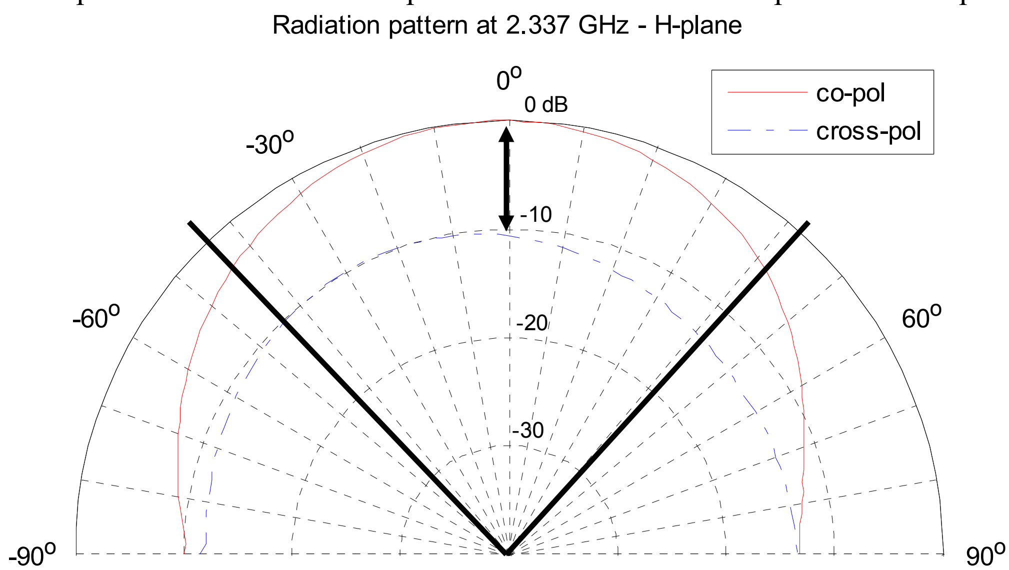

Fig. 14 H-plane measured radiation pattern at 2.337 GHz for co. pol. and cross polarizations

For the 2.4 GHz, the measured E and H-plane patterns are shown in Figures 15 and 16, respectively. Half power beamwidths are measured as 98 degrees in E-plane, 64 degrees in H-plane. Polarization ratios are measured as 16 and 14 dB for the E and H-planes. Simulated results for the co/cross polarization ratios were around 20 dB. For this frequency, the antenna gain is measured as 6.5 dBi with repspect to a standard gain antenna.

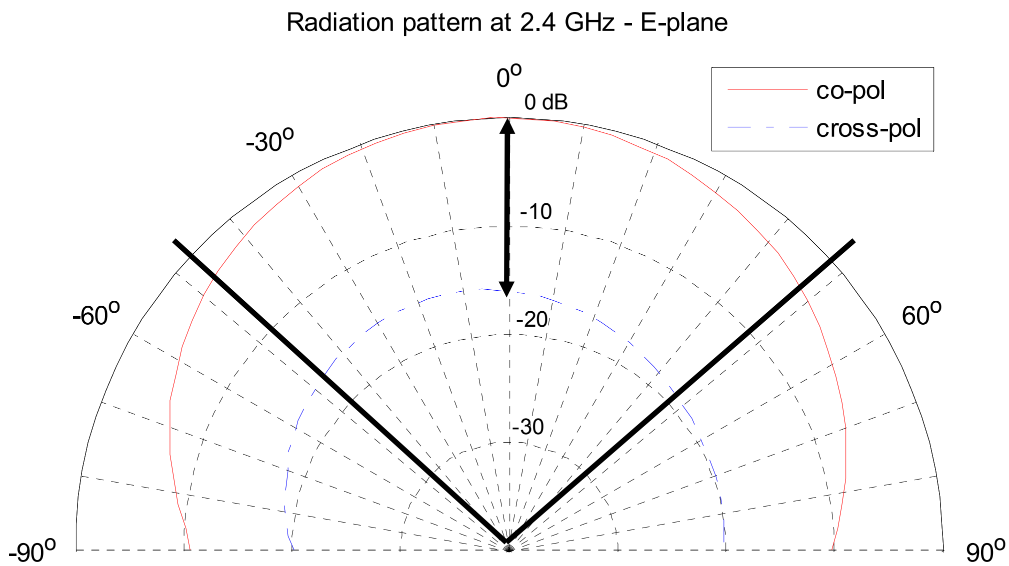

Fig. 15 E-plane measured radiation pattern at 2.4 GHz for co. pol. and cross polarizations

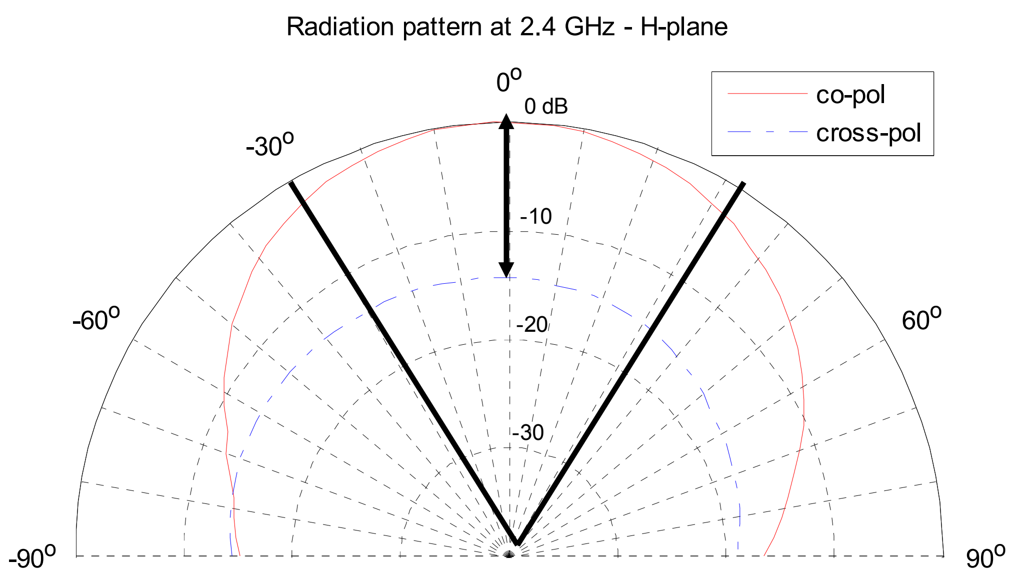

Fig. 16 H-plane measured radiation pattern at 2.4 GHz for co. pol. and cross polarizations

For the 5.54 GHz, the measured E and H-plane patterns are shown in Figures 17 and 18, respectively. Half power beamwidths are measured as 116 degrees in E-plane, 100 degrees in H-plane. Polarization ratios are measured as 8 and 8.5 dB for the E and H-planes. Note that for the 5.54 GHz, radiation patterns have very similar shape as in 2.7 GHz with very similar measured beamwidths.

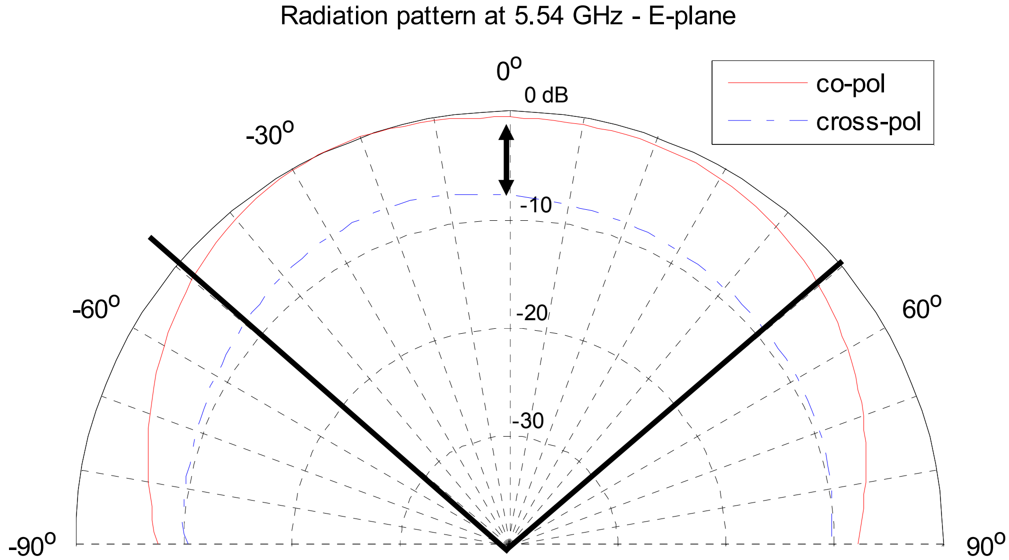

Fig. 17 E-plane measured radiation pattern at 5.54 GHz for co. pol. and cross polarizations

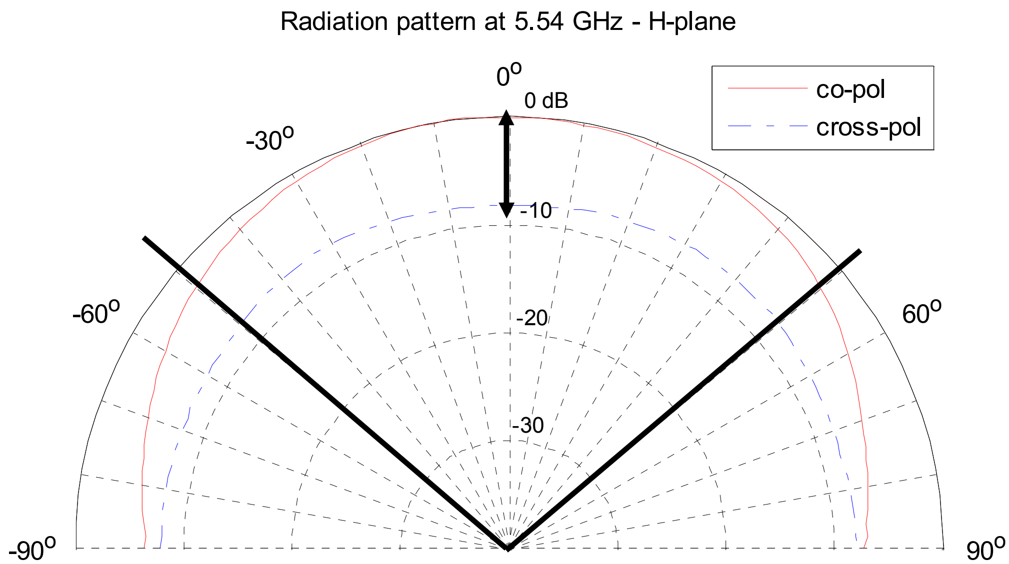

Fig. 18 H-plane measured radiation pattern at 5.54 GHz for co. pol. and cross polarizations

For the 5.6 GHz, the measured E and H-plane patterns are shown in Figures 19 and 20, respectively. Half power beamwidths are measured as 112 degrees (96 degrees simulated) in E-plane, 104 degrees (84 degrees simulated) in H-plane. Polarization ratios are measured as 10 and

9.5 dB for the E and H-planes. Note that for the 5.6 GHz, radiation patterns have very similar shape as in 5.54 GHz with very similar measured beamwidths. . For this frequency, the antenna gain is measured as 7 dBi with repspect to a standard gain antenna.

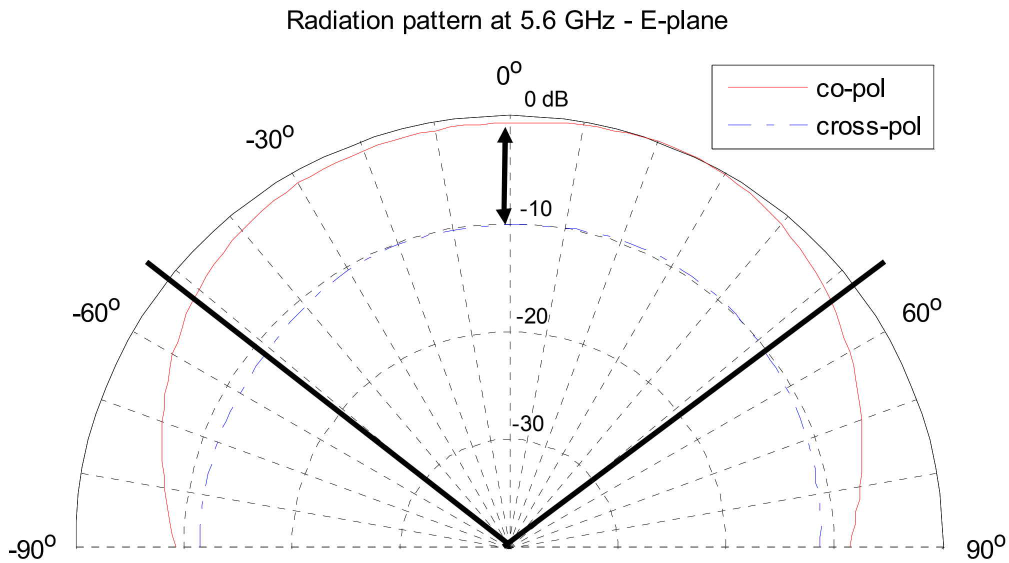

Fig. 19 E-plane measured radiation pattern at 5.6 GHz for co. pol. and cross polarizations

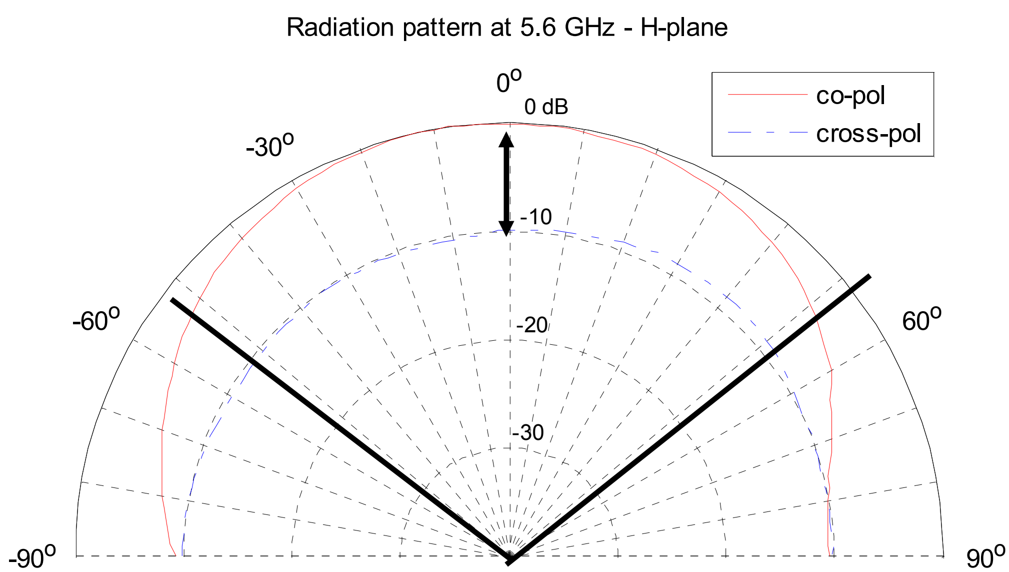

Fig. 20 H-plane measured radiation pattern at 5.6 GHz for co. pol. and cross polarizations

4. Conclusion and Future Work

A reconfigurable microstrip patch antenna with RF pin diode switches are presented for dual band of 2.4 GHz and 5.6 GHz SDR applications. Band switching is simply obtained by biasing the four RF pin diodes. The antenna is well matched and achieves a gain of approximately 7 dBi at both WLAN bands with very similar radiation patterns. Antenna have very similar characteristics at both frequencies in terms of impedance, radiation patterns, polarization and gain. As a future work, tunable bandwidth for each frequency and obtaining wider bandwidth using a thick substrate can be investigated.

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