Electronically Steered MIMO Patch Antenna with Conformal Feeding for 5 G Applications

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Research Article

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Abstract

Multiple input multiple output antenna is the key technology which enables the design of 5 G networks. In order to achieve desired beam forming and side lobe reduction capabilities, antennas used in MIMO technology are required to feed with signals having different phase and amplitude. It is possible to achieve variable phase shift and variable attenuation using phase shifter and amplitude limiters. However when these devices are used between source and antenna, they makes the system non planner and non-conformal. This research presents a 16 element, multiple user MIMO Patch antenna with conformal and planner power divider network to achieve electronically steered beam along with desired side lobe level reduction. Wilkinson power divider is used to achieve conformal and planner power divider for MIMO antenna. Desired beam forming capabilities are achieved by controlling the phase of input signal to antennas by controlling the length of microstripline and desired side lobe reduction capabilities are achieved by controlling the amplitude of input signal to antenna by controlling the width of microstrip line used in Wilkinson power divider. This provides an overall planner and conformal structure. In this research same antenna is used is generate two major beams by controlling the phase and amplitude of input signal. The achieved radiation pattern of designed antenna consists of one major beams having gain of 18 dB and located at theta equal to 10^0 and Phi equal to 180^0. When phase of input signal to antennas are changed a major beam having gain of 18 dB and located at theta equal to 10^0 and Phi equal to 270^0 is obtained. The side lobe level less than 13 dB of main beam is achieved using designed antenna. The designed structure is simulated and analyzed using HFSS. Simulated results for the designed MIMO antenna are verified by analyzing the fabricating structure using vector network analyzer and horn antenna.

Index Terms— Multiple Input and Multiple Output Antenna (MIMO), Wilkinson Power Divider (WPD), Patch Antenna, Microstrip Line.

I. INTRODUCTION

Introduction: The evolution of wireless technology is continuously influencing the every sphere of life. Initially wireless technology was emerged to communicate between two devices separated by large distance. But with the improvement in data rate and Channel capacity the scope of wireless technology is improving continuously. In this concern world had witnessed four generations of wireless technology with improvement in data rate and channel capacity with each generation. Now world had entered into fifth generation of wireless technology where date rate up to 20 GBPS, Channel bandwidth of 500 MHz and latency time less than one millisecond is achievable. This could make possible due to use of millimeter waves in 5G technology [1-7]. Using 5G technology it is possible to connect and control various real time devices [8-11]. This is attracting the interest of many academicians and industrialist in research and development of 5G technology. The key requirement to implement 5G technology are antennas having, very high gain, electronically beam steering capabilities, able to operate in millimeter wave dimensions and having conformal structure. These requirements can be achieved through a great extent by using multiple input and multiple output technology (MIMO). In MIMO system multiple antennas are used in transmitter and receiver. As many antennas are used in MIMO technology so gain is significantly improved. Further by changing the phase of input signals direction of major lobe can be steered electronically. The additional advantage of MIMO system is to have high energy efficiency and low latency time [12-14]. In MIMO system we use orthogonal frequency division multiplexing in which multiple symbols are transmitted at the same time for relatively longer period of time. The transmitted symbol occupies very narrow bandwidth as compared to available spectrum which results in a very high channel capacity. Digital signal processing techniques can be used to reconstruct the original signal from received symbols. Receiving the received symbol for a longer time makes possible for the receiver to recover the transmitted symbol even with the noise interference. MIMO systems can be classified as single user MIMO or multiple user MIMO. In SU MIMO all the transmitted symbols by the transmitter are received by only single user while in MU MIMO transmitted symbols by the transmitter are received by many users. SU MIMO has the advantages to improve the data rate within available spectrum while MU MIMO has the advantage of improving the channel capacity[15-17]. Various radiating elements like monopole, dipole, yagiuda, Horn or Dish can be used as radiating elements in MIMO system However due to plannar and conformal design and ease of performance enhancement techniques, antennas designed using microstrip technology are most favored for MIMO system [18-29]. Several antenna designs are proposed in literature for MIMO system[30-33]. All these designs are suffering from one serious problem of using non planer and non-conformal feeding structure [34-36].

In this research we proposed to generate two main beams by adjusting the phase of antenna elements. Antenna structure is

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designed by 16 element probe fed patch antenna fed by Wilkinson power divider. Two main beams are obtained by adjusting the phase difference between patch elements by +45° and -45° respectively. Required phase difference between elements is achieved by adjusting the length of microstrip line in WPD. The proposed MIMO antenna can be potentially used in Radar base stations.

II. MIMO CONFORMAL ANTENNA DESIGN

Various prototypes are required to be designed for MIMO conformal antenna. The first part includes the design of radiating element. Second part includes the designing of array of radiating elements. Designing of array is dependent on the requirement of gain and beamforming technique. Array elements are required to be fed in particular fashion in terms of amplitude and phase. So third part includes the design of power dividing circuit for the antenna array. This section elaborates the complete design process adopted in this work.

II.a. Design of radiating element:

In this research probe fed patch antenna is selected as radiating element for MIMO antenna design. Probe fed patch antenna is selected owing to its enormous advantages like planer and conformal structure, ease of fabrication, low cost and various technologies available to enhance the performance parameters of antenna. Probe fed patch antenna is preferred as compared to microstrip patch antenna due to its easiness of feeding when array of antenna are required to be fed. A coaxial connecter is soldered between ground and patch to feed the patch antenna.The first step in designing patch antenna is to choose the dielectric constant and dimensions of substrate. The dielectric constant of patch antenna varies from 2.2 to 12. For large bandwidth and higher efficiency requirements patch antenna with thich substrate and low dielectric constant are preferred. However they suffer from high dieletric loss. Miniaturization of patch antenna can be obtained using thin substrate having high dielectric constant. However they possess low efficiency and smaller bandwidth. The patch on substrate is the radiating element which is concerned with radiations. Operative frequency of patch is decided by the length of patch antenna, Dielectric constant of substrate, and height of substrate. The width of patch antenna dictates the efficiency of antenna. The optimized length and width of patch antenna as proposed in [19-30] is given by

$$w = \frac{C}{2f\sqrt{\frac{\epsilon_{eff}+1}{2}}} ------ (1)$$

Here C is the velocity of light and ϵ_{eff} is the effective permittivity of the substrate which is given by expression

$$\varepsilon_{eff} = \frac{\varepsilon+1}{2} + \frac{\varepsilon-1}{2}\sqrt{1+12\frac{h}{w}} ------ (2)$$

Here ε is the dielectric constant of substrate and h is the thickness of the substrate.
The patch length is given by the expression

$$L = \frac{C}{2f\sqrt{\epsilon_{eff}}} ------ (3)$$

In this design parameters of Patch antenna are.

Table 1: Patch antenna parameters

Patch Material	Perfect Electric Conductor
Patch Length	12.45 mm
Patch Width	16 mm
patch Thickness	.05 mm
Material of Substrate	Rogers RT/duroid 5880 (tm)
Dielectric constant of Substrate	2.2
Substrate height	.794 mm
Operative frequency	7.55 GHz

II.b. Design of Patch array:

Superior characteristics in terms of directive gain, side lobe reduction and beam steering capabilities can be achieved using array of antennas. Antenna elements can be feed in series manner or in corporate manner. In series feed manner each antenna element is feed by its preceding element however in corporate feed antenna elements are feed by many transmission lines. It is possible to control the phase and amplitude of exciting signal in corporate feed antenna precisely as compared to series feed antennas. So improved beam forming and side lobe reduction can be achieved by using corporate feed antenna. Various synthesis methods are proposed in literature to design antenna array [19-30].

The radiation pattern of antenna array can be calculated by multiplying the radiation pattern of single element and antenna array factor.

For N element antenna array in one dimension array factor is given by

$$AF(\theta) = \sum_{n=1}^{N} I_N e^{i\alpha} e^{(ikdcos\theta)} ------4$$

Here antenna elements are separated by distance d. I_N is the magnitude of feeding current to various elements. α Is the progressive phase shift between antenna elements. The point of observation makes angel θ with array axis and k is phase shift constant.

Enhanced beam steering and side lobe reduction can be achieved by arranging antenna elements in two dimensional arrays.
When antenna elements are arranged in two dimensional structure then array factor is given by

$$AF(\theta,\varphi) = \sum_{m=0}^{M-1}\sum_{n=0}^{N-1} I_{mn} e^{i\alpha_{mn}} e^{(ik\hat{r}.\vec{r}_{mn})} ----- 5$$

I_{mn} is the magnitude of feeding current of mn^{th} element.
$\vec{r}_{mn}$ Is the location of mn^{th} element.

$$\vec{r}_{mn} = x_{mn}\hat{x} + y_{mn}\hat{y} + z_{mn}\hat{z}$$

And

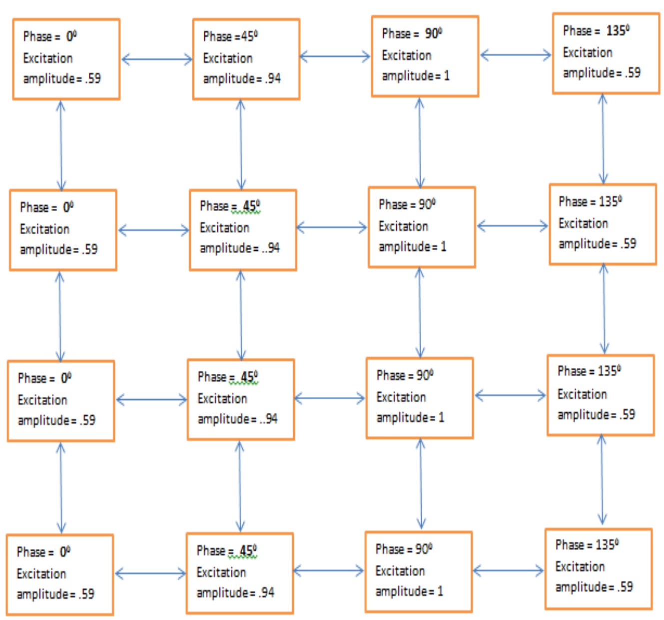
$\hat{r}$ is the location of observation point

$$\hat{r} = \ Sin\theta cos\emptyset\hat{x} + Sin\theta Sin\varphi\hat{y} + Cos\theta\hat{z}$$

α_{mn} is the excitation phase difference between elements.

Tapering of antenna arrays is used to achieve the desired side lobe rejection level. Tapering of antenna arrays is achieved by controlling the excitation currents of antenna elements.

In this research we are using array of 4*4 patch antenna arranged as shown in Fig(1). Separation between elements is kept as λ/2. Excitation phase difference between elements is kept at45°and - 45° to obtain two positions of major lobe. Elements are feed as per Tchebychef polynomial to obtain side lobe reduction.



Fig(1) Patch antenna array

II.c. Power dividing circuit:

Power dividing circuit is needed to feed antenna elements with required phase and excitation current. It is the phase and excitation amplitude to the antenna elements which are responsible for desired beam forming and side lobe reduction. Wilkinson power divider is extensively used a power divider in monolithic microwave devices[37-40].
In this research we are using Wilkinson power divider for feeding antenna elements so as to obtain desired phase shift and excitation coefficients for output ports.
Structure of Wilkinson power divider is as shown in Fig (2).

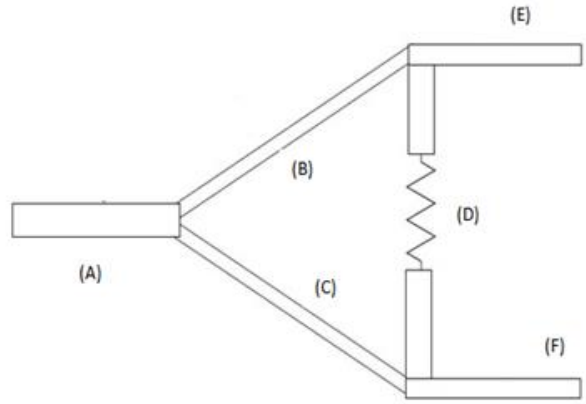


Fig (2) Wilkinson power divider

Each section of Wilkinson power divider is designed using microstrip line. Section A of WPD is connected with source of microwave signal. Section A is a microstrip line having characteristics impedance of 50Ω. Section B and Section C is a microstrip line having characteristics impedance of 70Ω. Section D is a lumped resistance of 100Ω.
Section E and section F of Wilkinson power divider are microstrip lines to feed antenna elements.
In this research length of microstrip line E and F is adjusted to obtain the required excitation phase difference to feed patch elements.
The phase shift introduced by microstrip line depends on the length and effective permeability of substrate.
The optimized expression for phase shift introduced by microstrip line is given as

$$\Delta\varphi = \sqrt{\varepsilon_{re}}\frac{2\pi f L_M}{C_o} - - - - - (6)$$

Here f is the operative frequency, L_M is length of microstrip line and C_o is velocity of light.
Required coefficient of excitation current to patch antenna is obtained by adjusting the VSWR between WPD and Patch element.
The expression of VSWR between WPD and Patch element is given by

$$VSWR = \frac{I_{reflected}}{I_{input}} = \frac{Z_{Patch} - Z_C}{Z_{Patch} + Z_C} - - - - - - (7)$$

Here Z_{Patch} is the input impedance of patch antenna and Z_C is the characteristics impedance of line feeding the antenna. From the expression it is evident that If characteristics impedance of Patch antenna is same as that of microstrip line then maximum power will be delivered from microstrip line to patch antenna. Mismatching of impedance of microstrip line with patch antenna is used to obtain the required coefficient of excitation current to patch antenna.
In this research work feeding current I_{input} to the patch antenna can be controlled by controlling the characteristics impedance of microstrip line. Characteristics impedance of microstrip line depends on the width (W) of microstrip line, height (h) and relative permeability $\varepsilon_r$of substrate [41- 45].

The optimized expressions of Characteristics impedance of transmission line is given as

For $\frac{W}{h} \leq 1$

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[\{1 + 12\,(\frac{H}{W})\}^{-\frac{1}{2}} + .004\,\{1 - (\frac{W}{H})\}^{2}\right] ------(8)$$

$$Z_C = \frac{60}{\sqrt{\varepsilon_{re}}}\ln\left(8\frac{H}{W} + .25\frac{W}{H}\right) ------(9)$$

For $\frac{W}{h} \geq 1$

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[\{1 + 12\,(\frac{H}{W})\}^{-\frac{1}{2}}\right] ------(10)$$

$$Z_C = \frac{120\pi}{\sqrt{\varepsilon_{re}} \times [\frac{W}{H} + 1.39 + \frac{2}{3}\ln(\frac{W}{H} + 1.44)]} ------(11)$$

In this research two WPD are designed to obtain a phase shift of 0^0, 90^0 and 45^0,90^0 between output ports. By adjusting the characteristics impedance of microstrip line an excitation coefficients of 1, .94 and .59 are obtained to feed the patch antenna.

III. Results and Discussion

Several prototypes of MIMO antenna are designed and analyzed using HFSS. Fabricated prototypes of MIMO antenna using FR4 substrate and analyzed using VNA. Fabricated prototypes of MIMOalong with VNA is as shown in Fig (3).

Fig (3) Fabricated prototypes of MIMO along with VNA

The designed patch antenna resonates at 7.5 GHz. The simulated and measured results of return loss S_{11} are plotted in Fig (4). Simulated and measured return loss at 7.5 GHz is read to be -16 dB and -21 dB respectively.

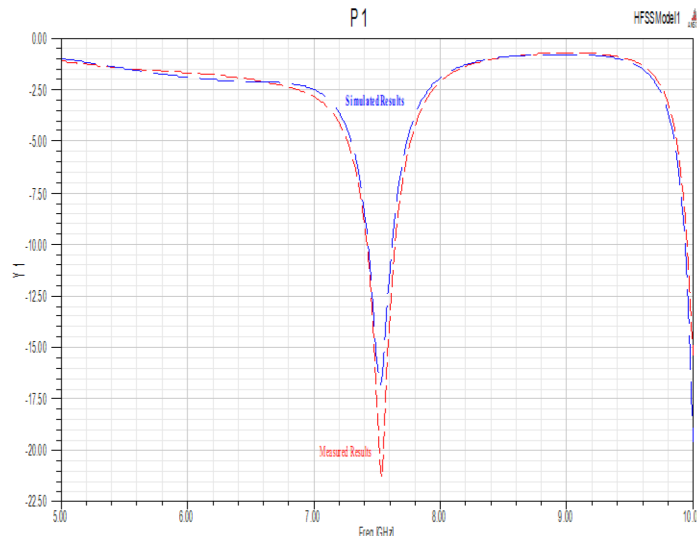


Fig (4) Return loss of Patch antenna

The maximum obtained simulated directive gain of patch antenna is 7.1 dB in boresight direction as shown in Fig (5,6). Measured gain using Horn antenna and VNA is 6.8 dB.

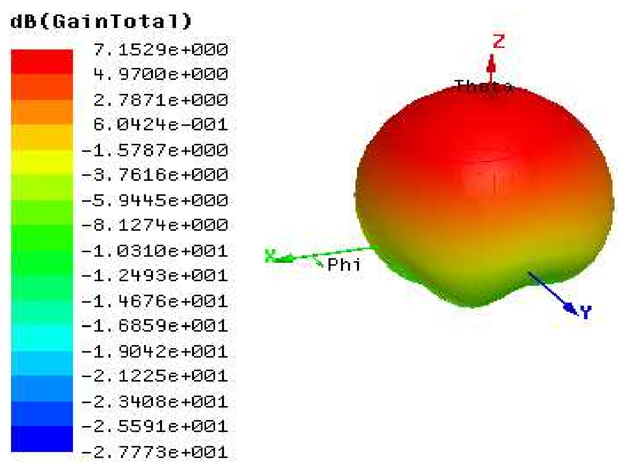


Fig (5) Directive Gain of Patch antenna

The Magnitude of transmission parameters of designed Wilkinson power divider between input port (1) and output ports, Port (2) and Port(3) are plotted in Fig(7). At frequency of operation Transmission parameter is achieved to be -3.0 dB.From the Transmission parameter S_{12} it is evident that power is equally divided among the output ports.

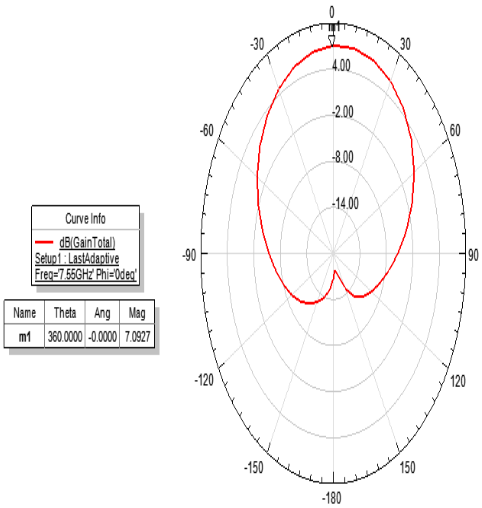


Fig (6) Maximum Directive Gain of Patch antenna

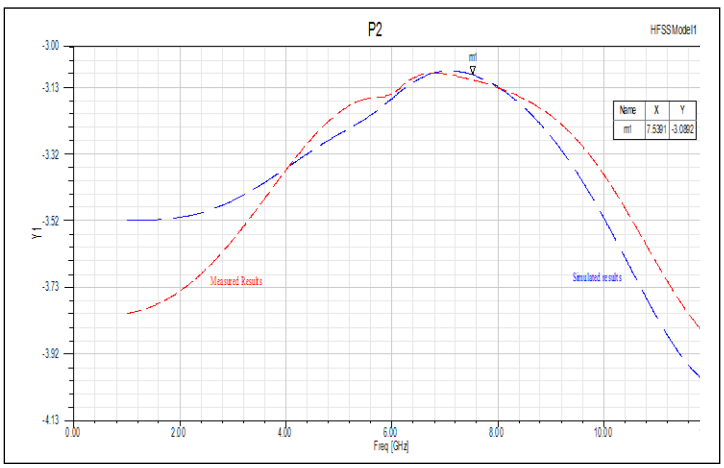


Fig (7) S_{12} Parameters between port (1) and Port(2)

The Magnitude of transmission parameters of Wilkinson power divider obtained by varying the width of microstrip line of output ports are plotted in Fig (8).

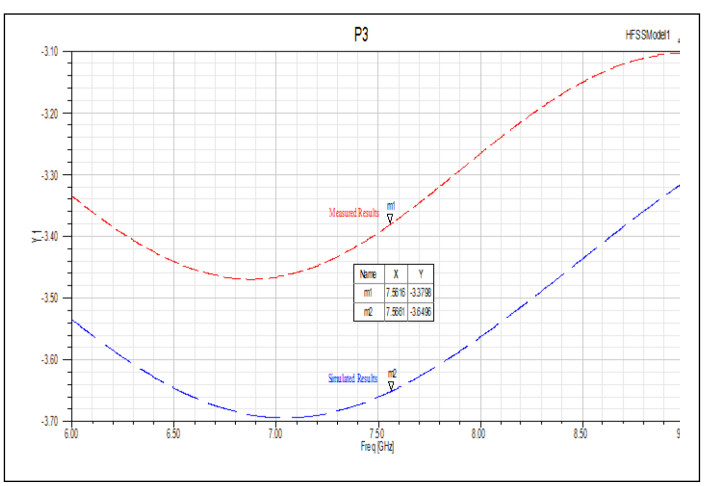


Fig (8) S_{12} Parameters between port (1) and Port(2)

From the Fig (8) it is evident that an attenuation of -3.37 dB is achieved at port (2) while an attenuation of – 3.64 dB is achieved at port (3) as was required by Tchebychef polynomial.

Two Wilkinson power dividers are designed to achieve a phase shift of 0^0, 90^0 and 45^0,90^0 between output ports as required by MIMO antenna. Fig (9,10) indicates the phase of S_{12} and S_{13} for two Wilkinson dividers.

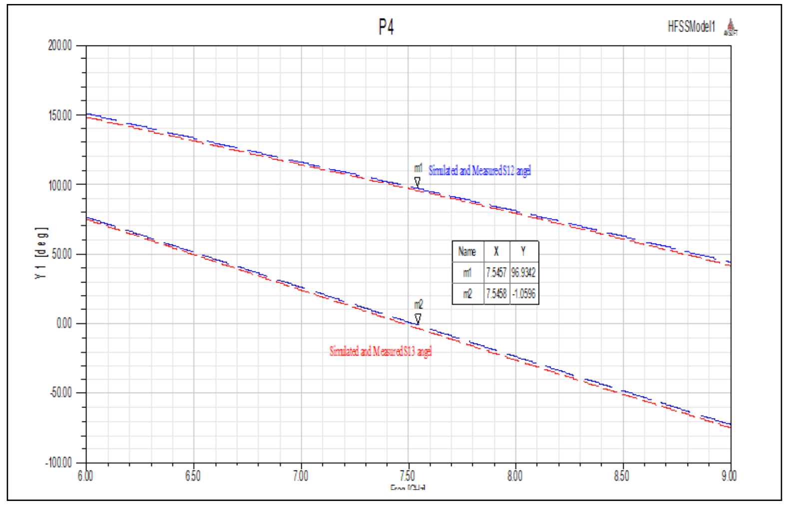


Fig (9) Phase of S_{12} and S_{13} Parameters

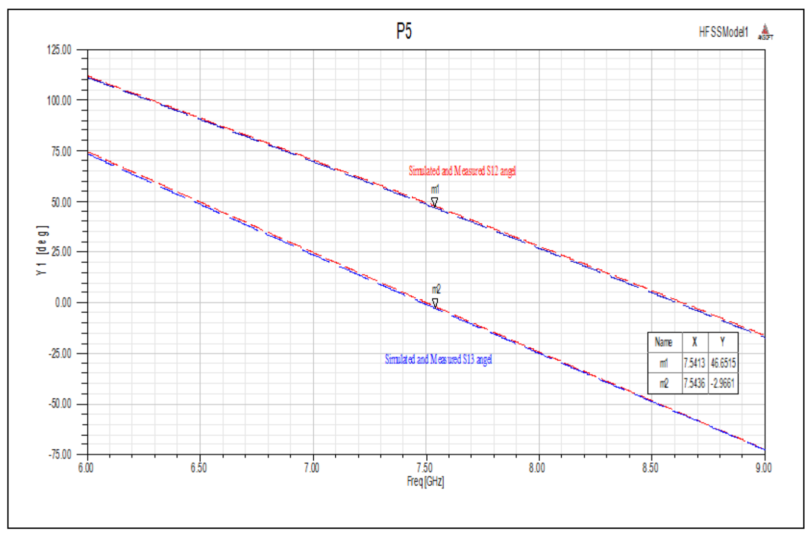


Fig (10) Phase of S_{12} and S_{13} Parameters

From the graph it is evident that a phase shift of 90^0 between output ports is achieved in first WPD and a phase shift of 45^0 between output ports is achieved in second WPD. The designed Wilkinson power dividers are used to feed patch antenna arrays as per the specifications given in Fig(1). When the phase difference between adjacent elements is 45° one major beam having gain of 18 dB, at theta equal to 10^0 and Phi equal to 180^0 is obtained. The side lobe level less than 13 dB of main beam is achieved using designed antenna. The simulated results are plotted in Fig (11,12).

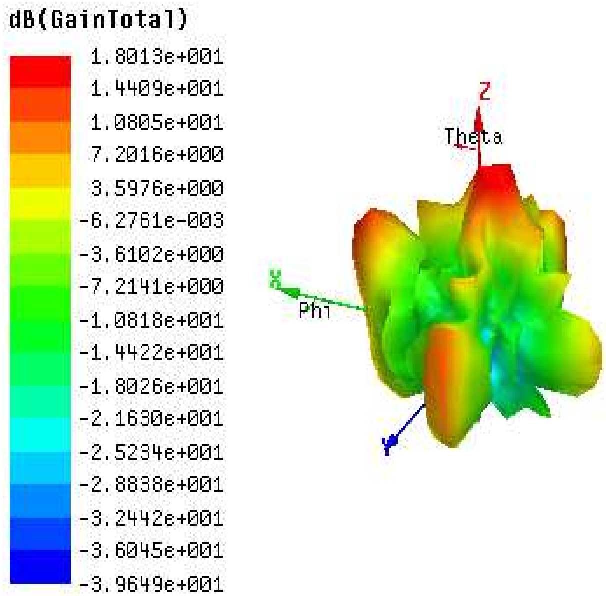


Fig (11) Radiation Pattern of MIMO Antenna.

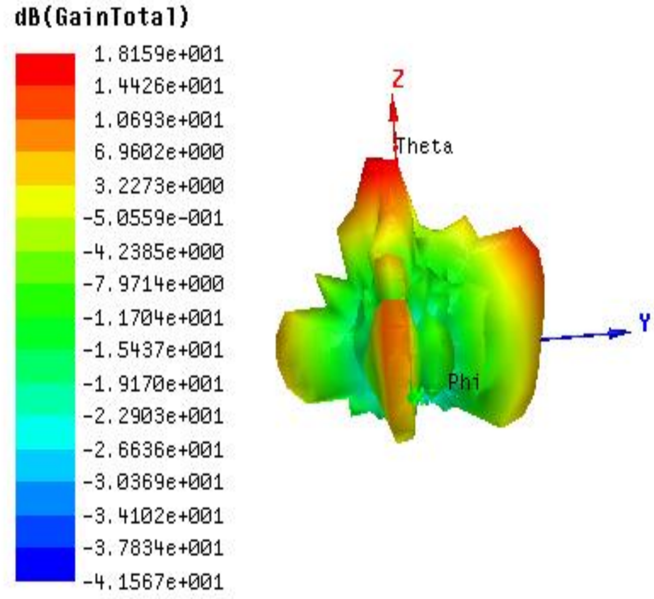
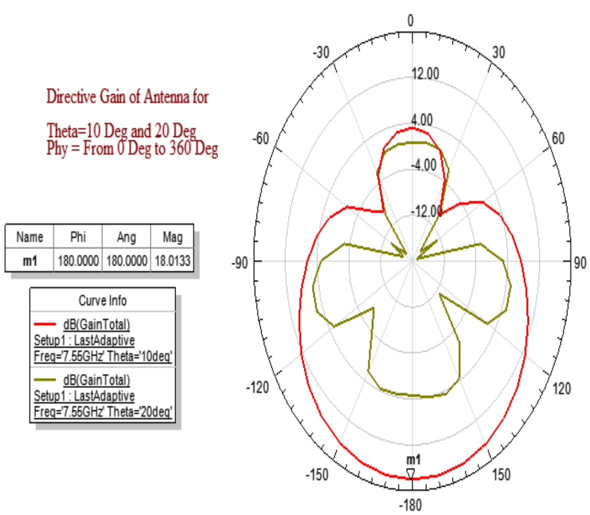


Fig (13) Radiation Pattern of MIMO Antenna.



Fig(12) Maximum directive gain and Side lobe level of MIMO Antenna.

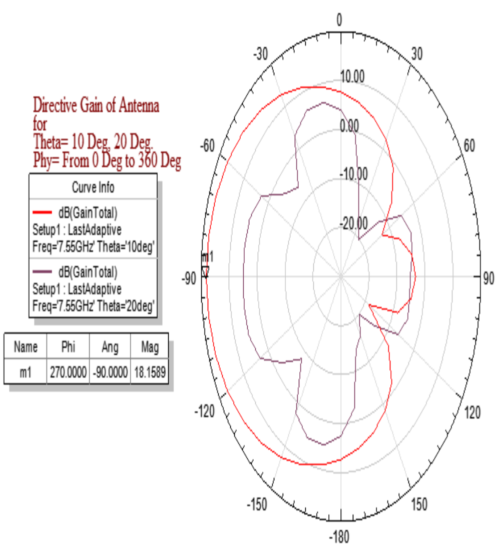


Fig (14) Maximum directive gain and Side lobe level of MIMO Antenna.

When the phase difference between adjacent elements is -45^{o} one major beam having gain of 18 dB, at theta equal to 10^{0} and Phi equal to 270^{0} is obtained.. The side lobe level less than 13 dB of main beam is achieved using designed antenna. The simulated results are plotted in Fig (13,14).
The gain of fabricated structure is also measured using VNA and Horn antenna. The achieved gain of major lobe for fabricated structure is 16.8 dB.

Conclusion:

An multiuser MIMO antenna using planar and conformal power partition circuit is designed and simulated. The novelty of this research work lies in designing the conformal power divider circuit using Wilkinson Power Divider. A complete conformal and planer MIMO antenna system is presented in this work.

Declarations:

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Conflicts of interest/ Competing interests: Not applicable
Availability of data and material: Not applicable
Code availability: Not applicable

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Figures

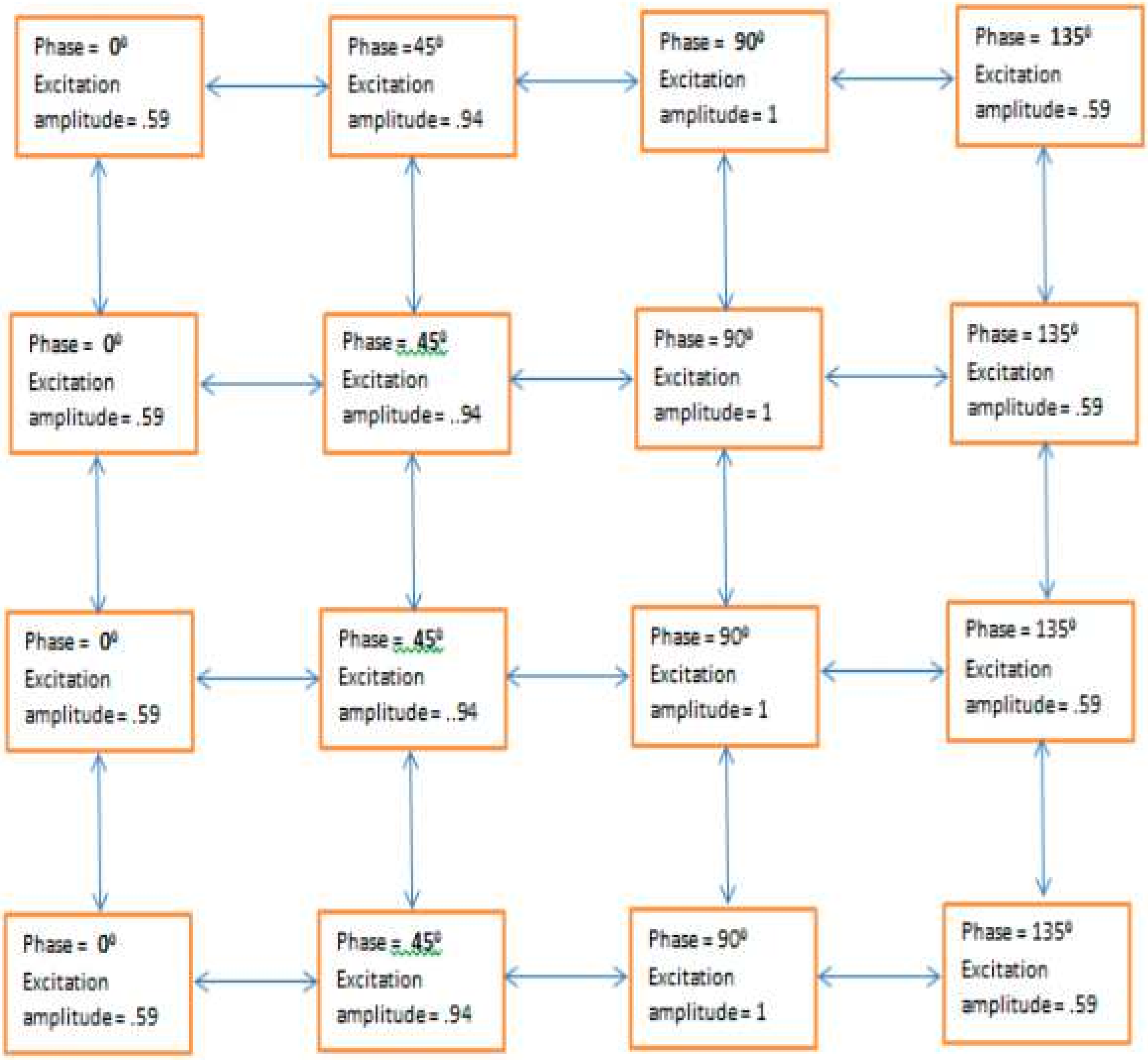

Figure 1

Patch antenna array

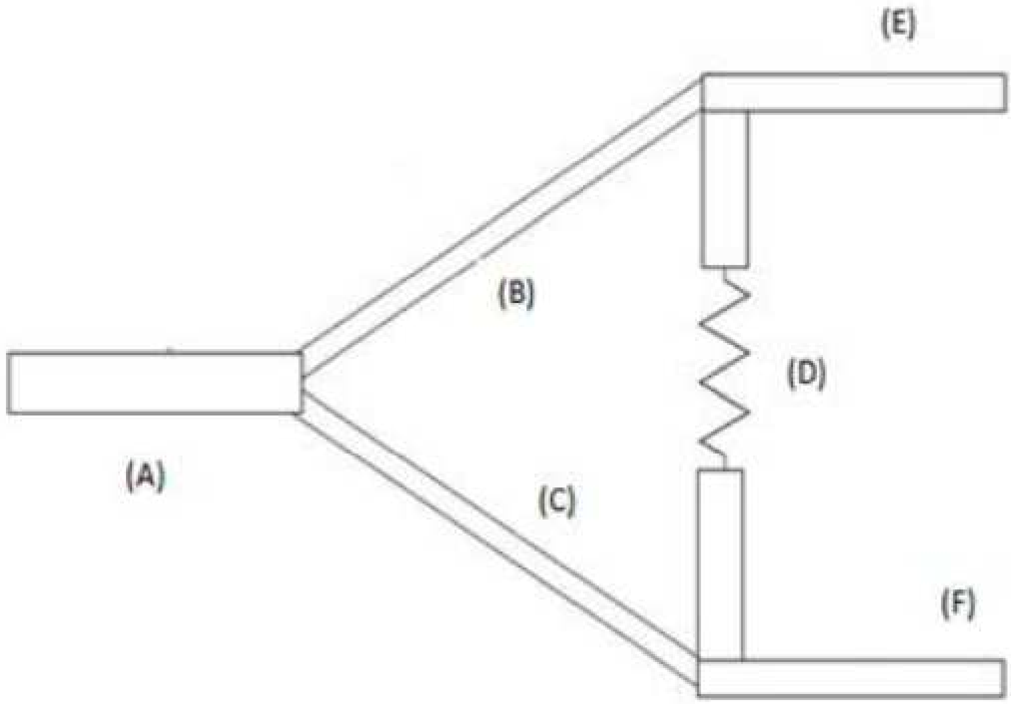

Figure 2

Wilkinson power divider

Figure 3

Fabricated prototypes of MIMO along with VNA

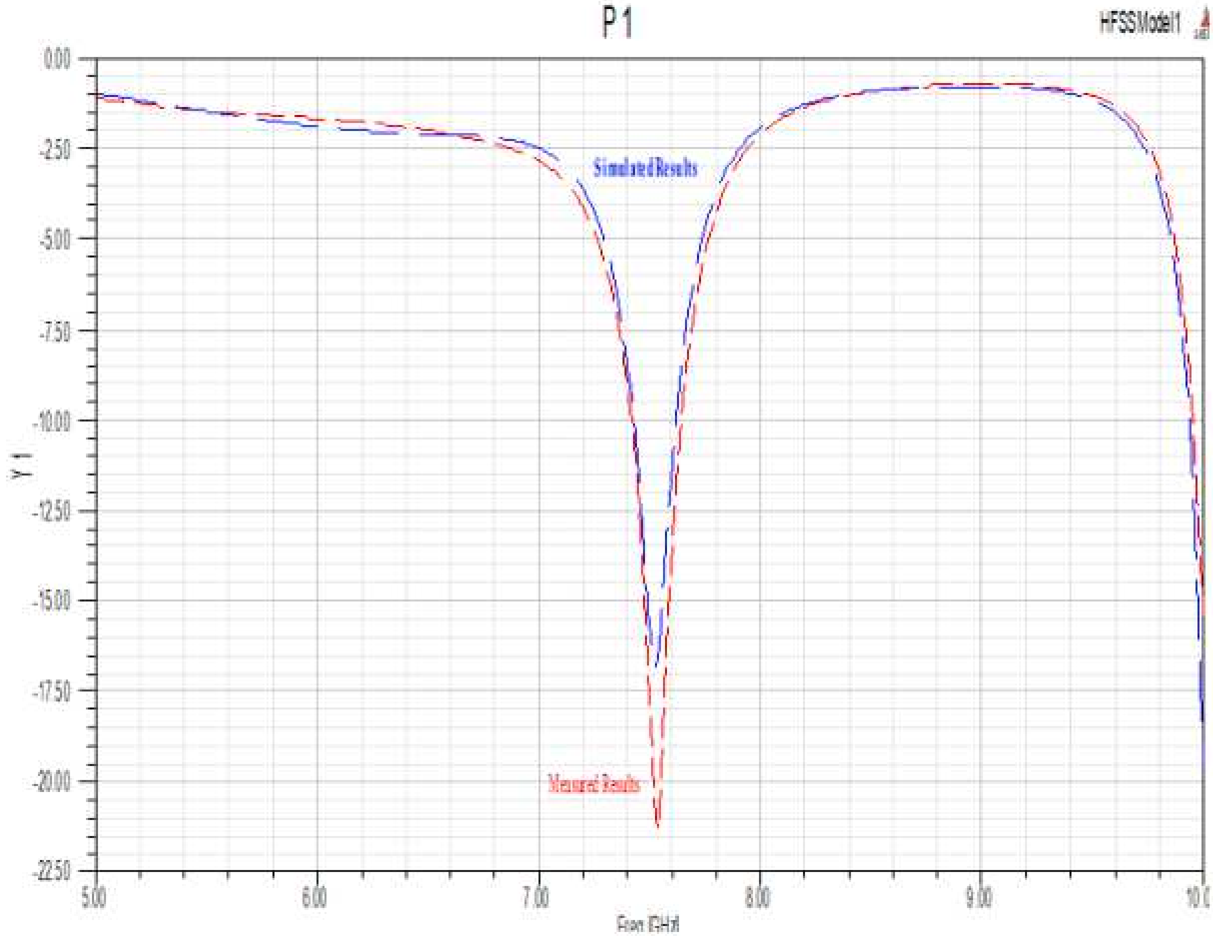

Figure 4

Return loss of Patch antenna

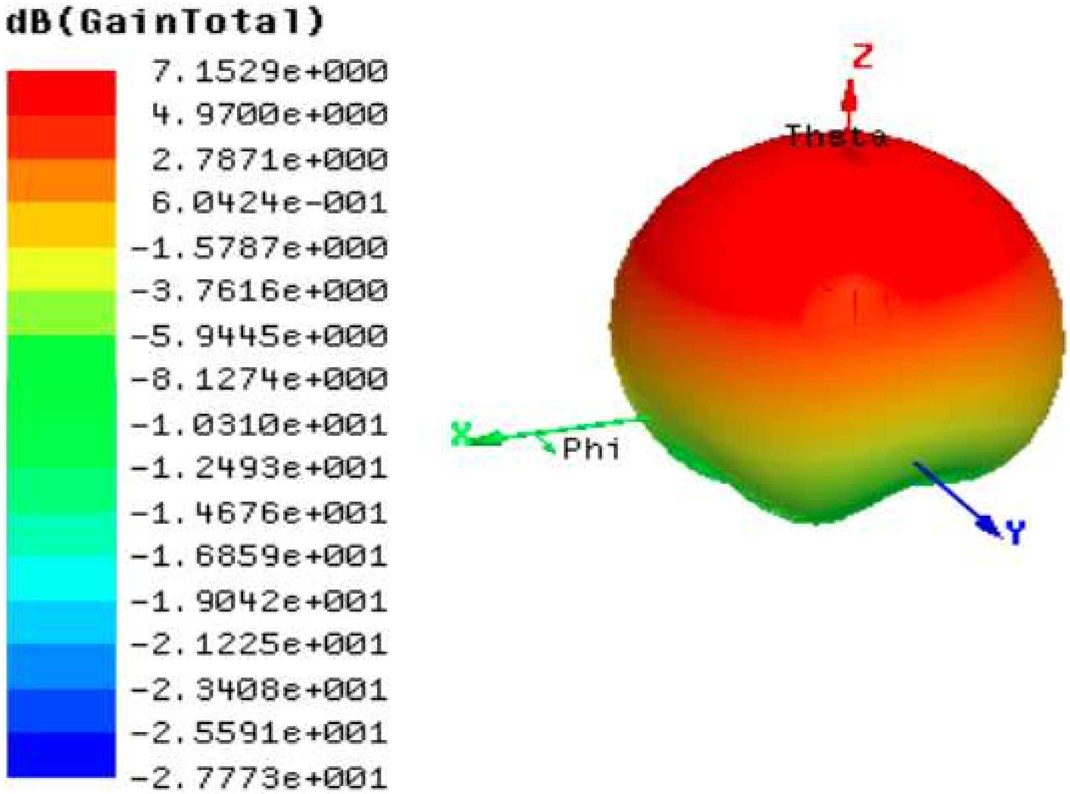

Figure 5

Directive Gain of Patch antenna

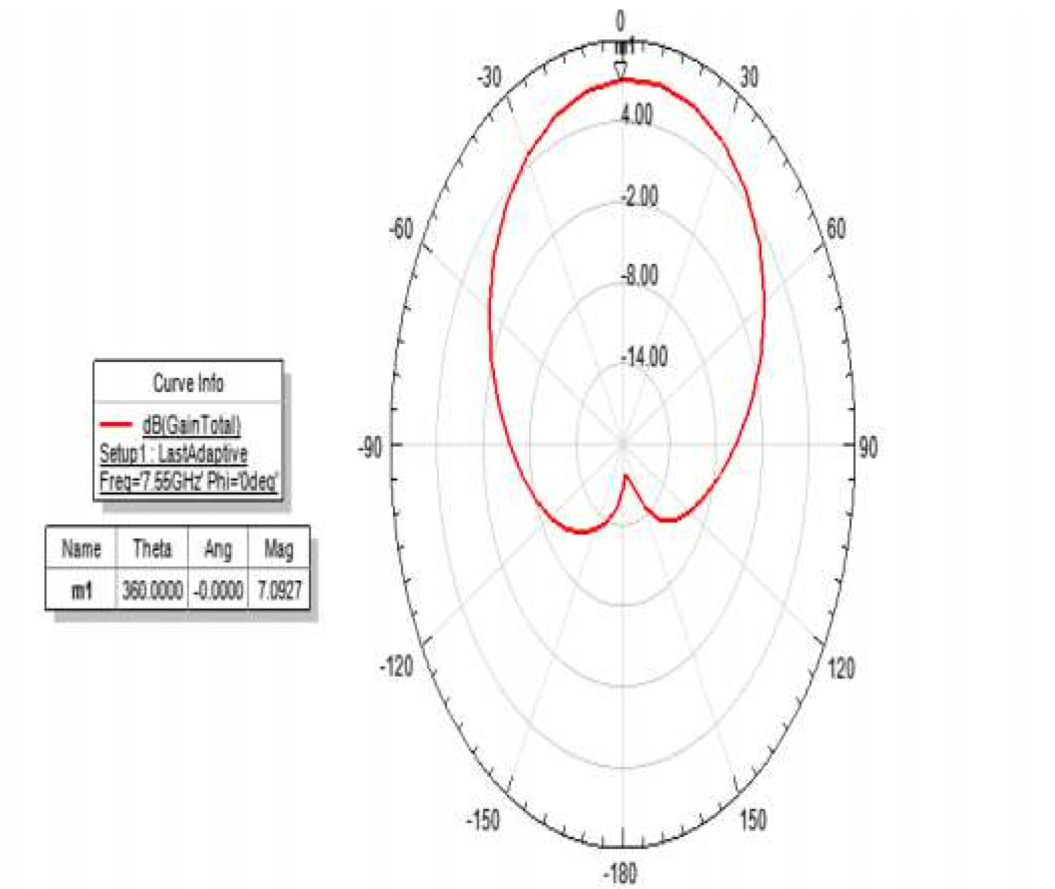

Figure 6

Maximum Directive Gain of Patch antenna

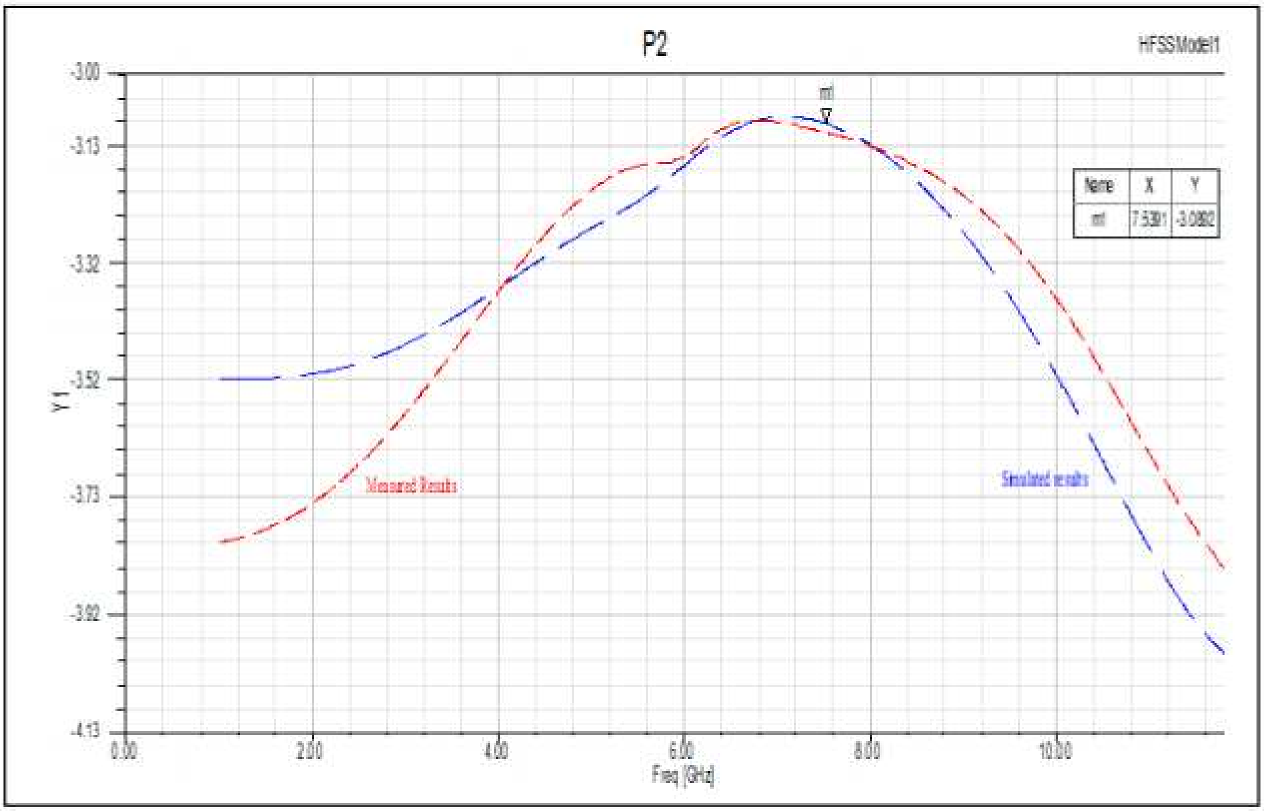

Figure 7

S12 Parameters between port (1) and Port(2)

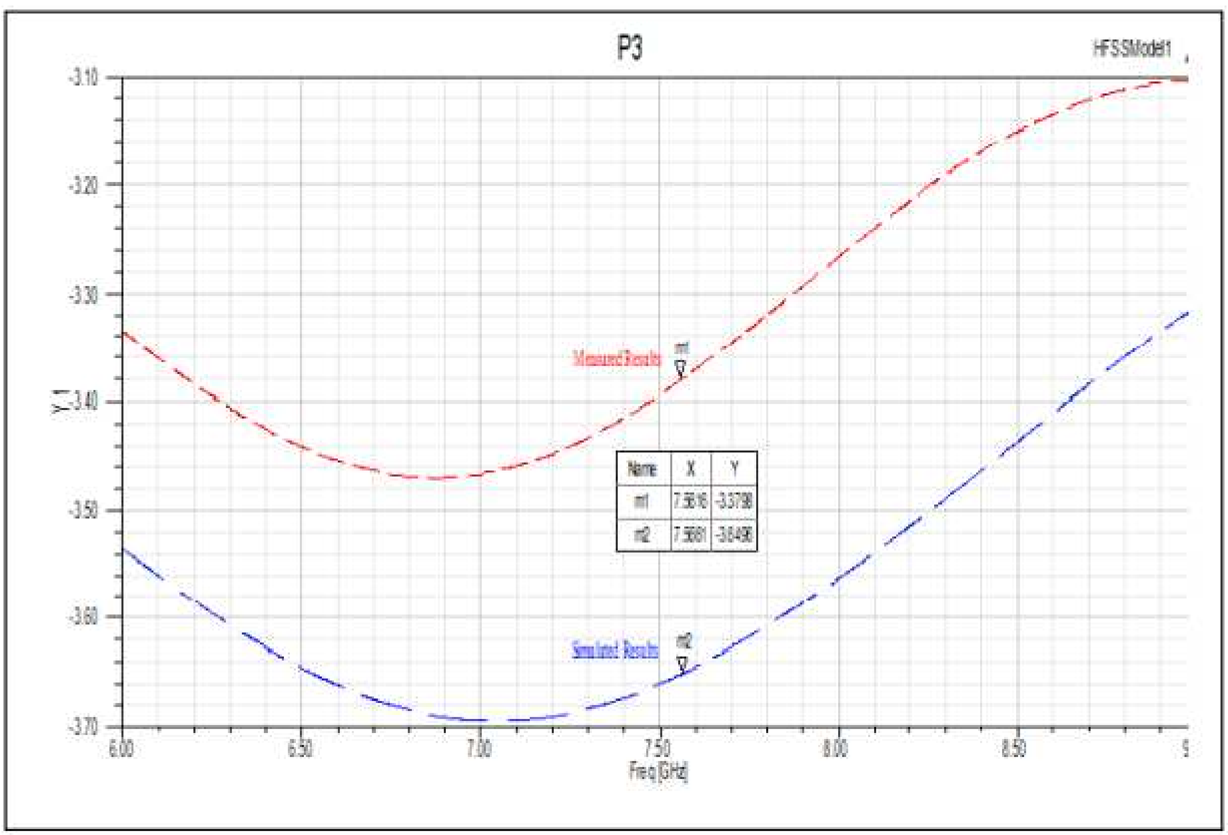

Figure 8

S12 Parameters between port (1) and Port(2)

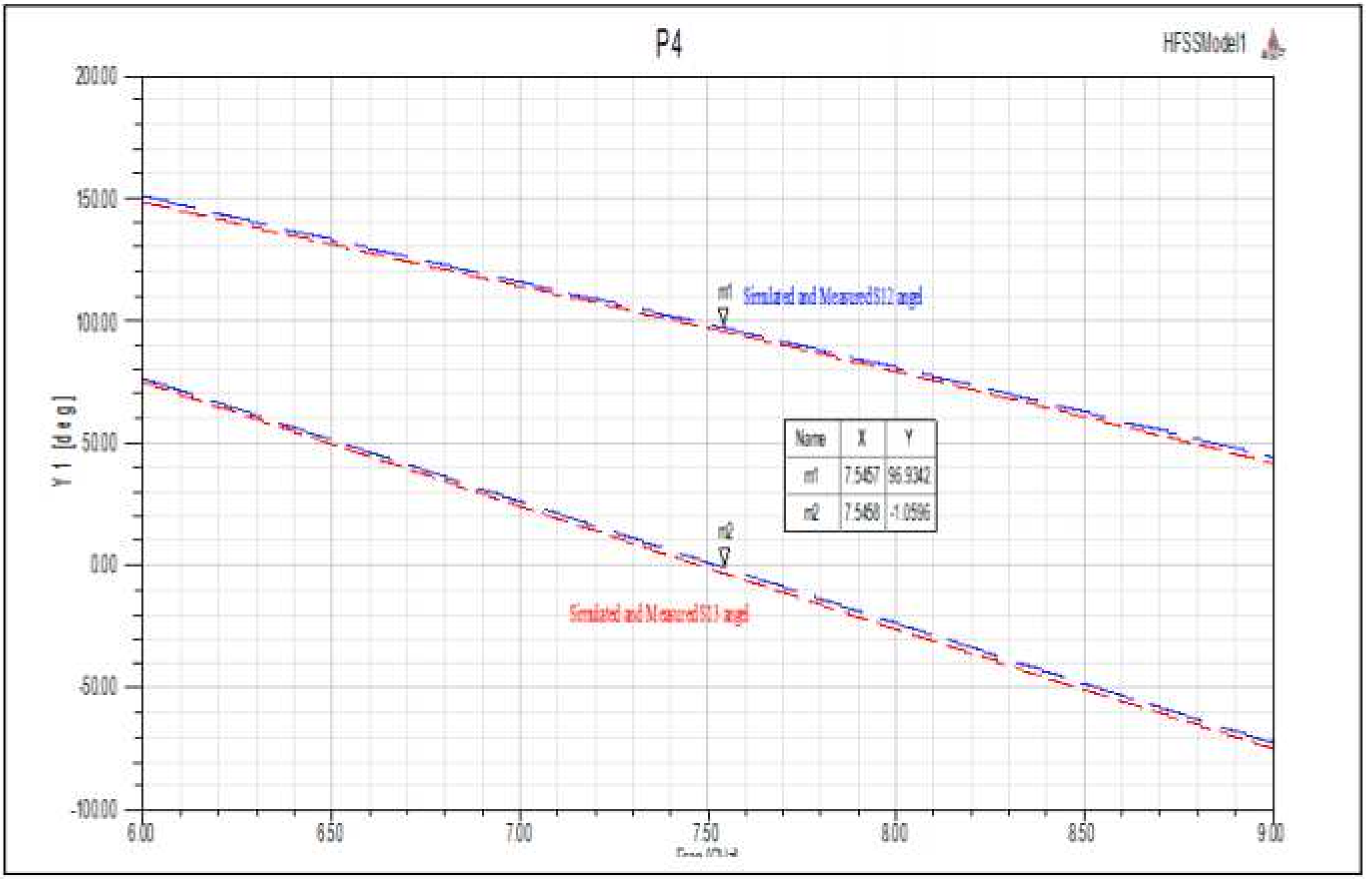

Figure 9

Phase of S12 and S13 Parameters

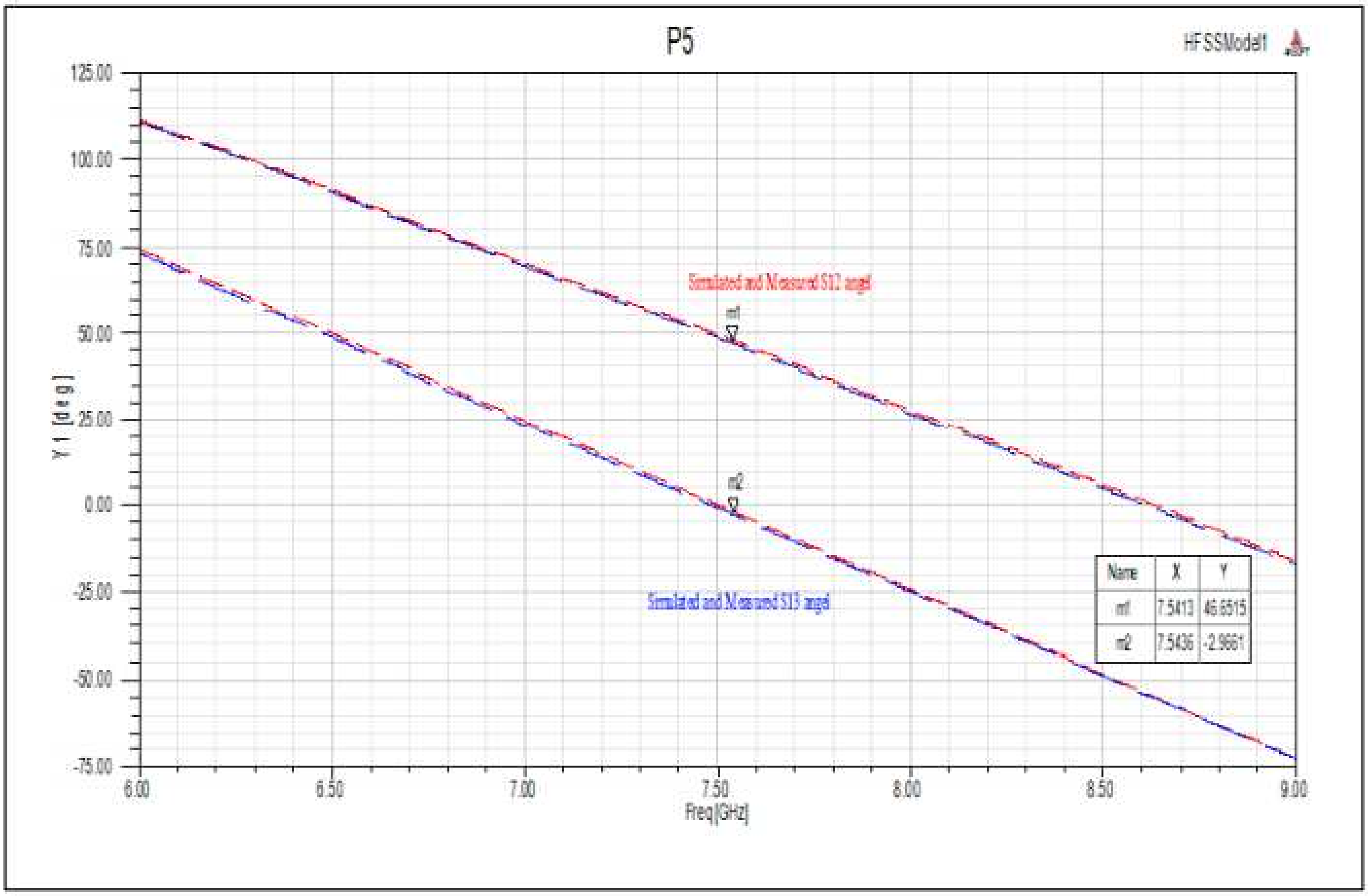

Figure 10

Phase of S12 and S13 Parameters

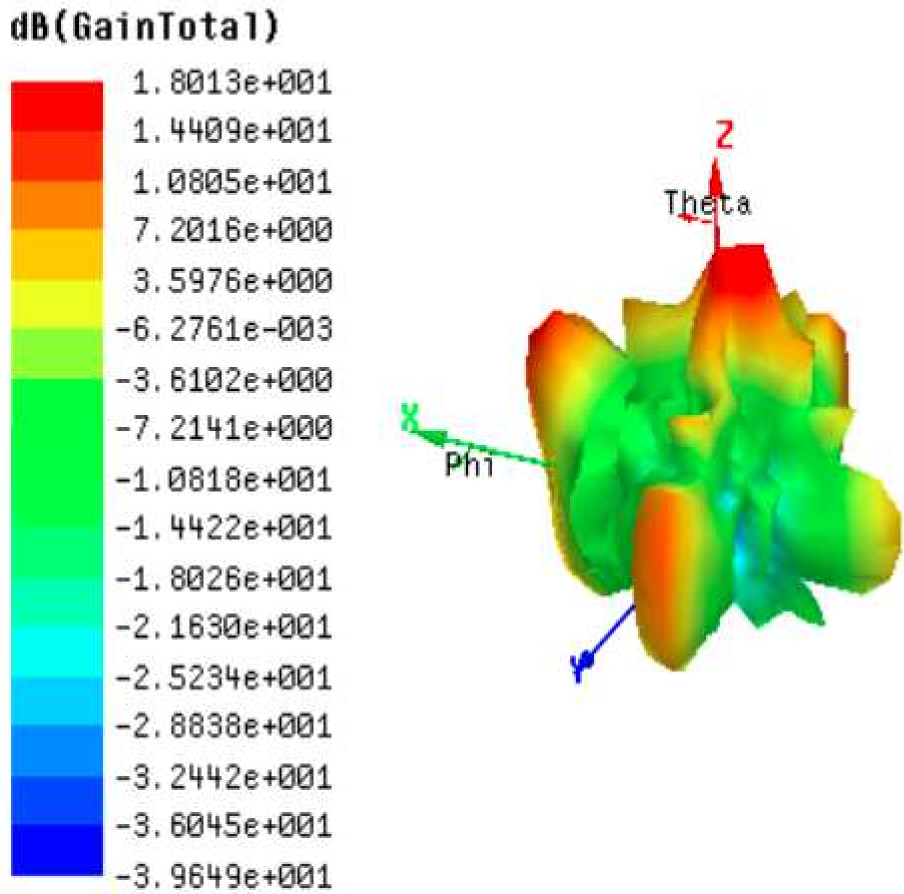

Figure 11

Radiation Pattern of MIMO Antenna.

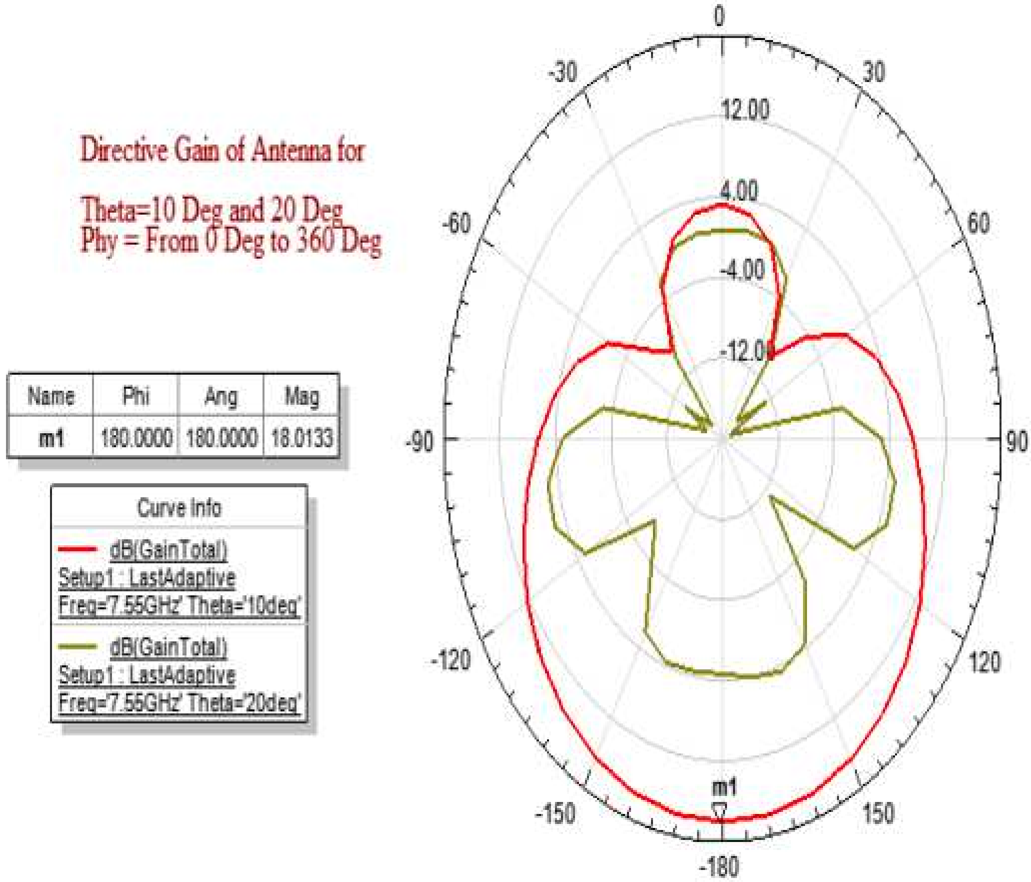

Figure 12

Maximum directive gain and Side lobe level of MIMO Antenna.

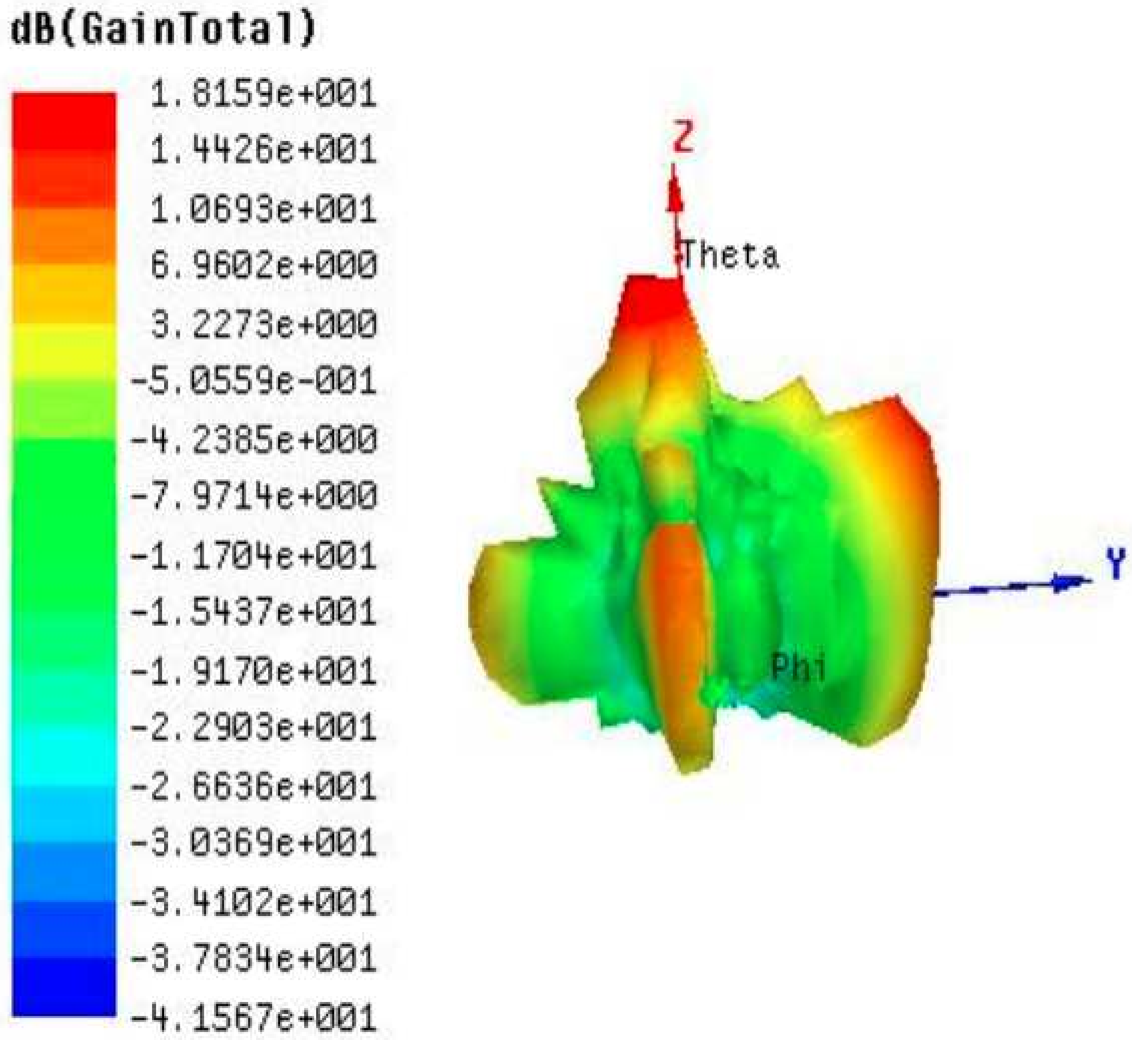

Figure 13

Radiation Pattern of MIMO Antenna.

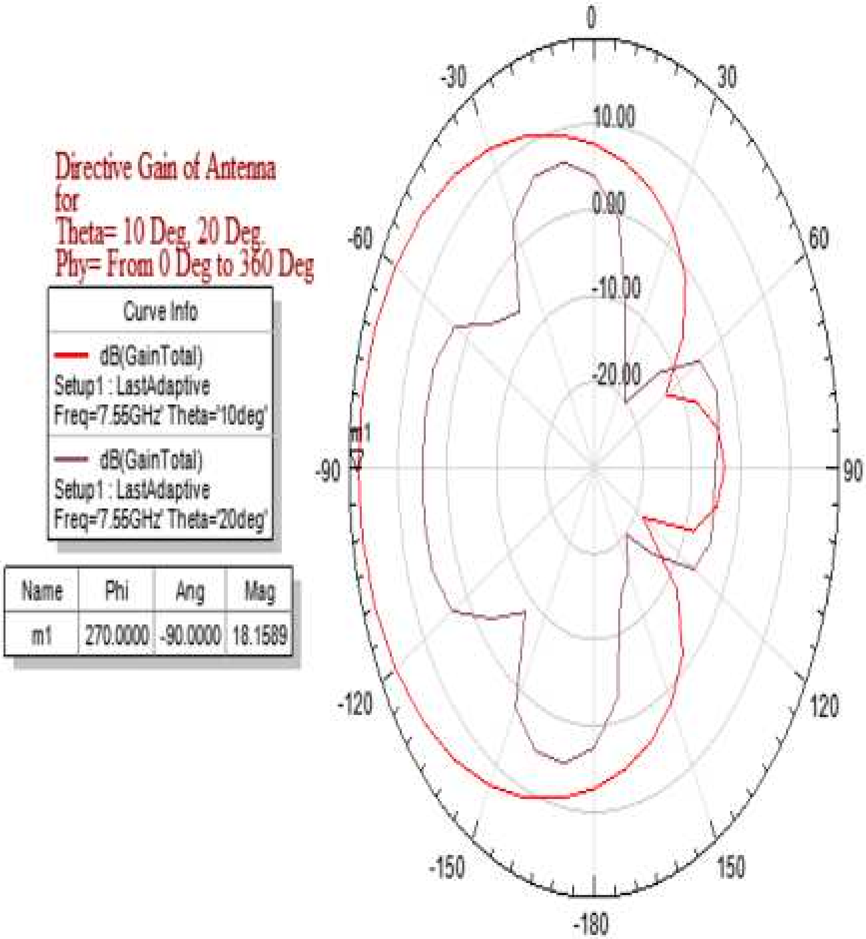

Figure 14

Maximum directive gain and Side lobe level of MIMO Antenna.