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Miniaturization of Substrate Integrated Waveguide based Antennas for Microwave Communications

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Abstract

Substrate Integrated Waveguide (SIW) technology is the most emerging technology for the implementation of effective radiating systems for the future wireless systems. It is a synthetic rectangular electromagnetic waveguide which is formed in a dielectric substrate by densely arraying metalized posts or via-holes which connect the upper and lower metal plates to form a radiating system. SIW antennas are used in many applications in the field of communication systems due to several advantages such as light weight, low production cost, low profile, reproducibility, reliability, and integration with solid state devices. This paper presents the methods of miniaturization of equilateral triangular micro strip antenna based on SIW technology. The performance of the proposed antennas is observed by doing some significant changes to the construction of the patch, substrate and ground with specified dimensions. The coaxial feeding at a specified location is used to achieve better impedance matching and Arlon AD270 substrate having dielectric constant 2.7 with optimum values of substrate heights are used. The miniaturization and performance of the antennas are compared in terms of Return losses, VSWR, radiation pattern and gain. The proposed antennas are designed and simulated using Finite element method based HFSS (High Frequency Structure Simulator) version software.

Keywords: *Substrate integrated waveguide, Miniaturization, Equilateral triangular antenna, Metallic vias,Coaxial-Fed, HFSS software*

INTRODUCTION

Antenna miniaturization is one of the most emerging and interesting subjects in antenna and related fields due to the need of compact systems in the present wireless communications era. The desire for small and multipurpose and multiband antennas has been ever increasing to reach the requirements of small mobile devices, including cell phones, handheld portable wireless equipment for internet connection, long- and short-range communication equipments, Radio Frequency Identification (RFIDs), small equipment and devices used for navigation and data transmission [7]. These microwave communication applications and continuing growth of wireless devices will continue to challenge the research community to design and create smaller and more multifunctional antennas [1, 2].

Based on dielectric substrates with top and bottom metal layers perforated with metalized holes, Substrate Integrated Waveguide (SIW) structures offer a compact, low loss, flexible, and cost-effective solution for integrating active circuits, passive components, and radiating elements on the same substrate [1]. In the present paper, a SIW based equilateral triangular patch antenna is constructed on an Arlon AD270 substrate with dielectric constant 2.7 and fed with coaxial feed. The two sides of the equilateral triangle are made PEC (Perfect Electric Conductor) wall with array of metallic vias. The remaining side is equivalent to PMC (Perfect Magnetic Conductor) as it kept open circuited [3]. The miniaturization can be achieved by introducing single, double slits and branchlike slits on the patch of the antenna [4]. The simulation has been done using Finite Element Method based tool, HFSS (High Frequency Structure Simulator) software version 14.0.

This paper is structured as follows. Section II describes methodology followed for design of six models of micro strip patch antennas with and without SIW metallic vias. Section III describes the impact of branchlike slits, slots and SIW construction on proposed antenna performance. Section IV shows the results explaining antenna parameters like Resonance frequencies, Radiation pattern, Return loss, VSWR, Gain with specifications tabulated and finally Section V is conclusion.

METHODOLOGY

Antenna Design

This paper presents six models of equilateral triangular micro strip antennas. As the initial step, the dielectric constant $\boldsymbol{\varepsilon_r}$ and substrate height **h** need to be chosen. They were chosen according to the design frequency of operation [5]. The chosen substrate material is Arlon AD270 with dielectric constant 2.7. Figures 1 to 6 shows the construction of all the six models of equilateral triangular shaped patch with and without SIW based constructions. The proposed antenna configurations are

1. *ANTENNA-1: Equilateral Triangular Micro strip Antenna.*
2. *ANTENNA-2: Equilateral Triangular Micro strip Antenna with branchlike slots.*
3. *ANTENNA-3: SIW based Equilateral Triangular Micro strip Antenna.*
4. *ANTENNA-4: SIW based Equilateral Triangular Micro strip Antenna with single slit.*
5. *ANTENNA-5: SIW based Equilateral Triangular Micro strip Antenna with double slit.*
6. *ANTENNA-6: SIW based Equilateral Triangular Micro strip Antenna with branchlike slots.*

The design parameters of the proposed antennas are

1. Substrate thickness(h)= 0.89mm
2. Dielectric constant of the substrate(ε_r)= 2.7
3. Loss tangent tan= 0.0028
4. Side of the patch (s)= 34.18mm
5. Substrate length and width=L=W=58mm
6. Thickness of the slot(d)= 1.15mm

The location of the feed has been chosen to achieve the perfect impedance matching between feed and patch.

Geometry of Equilateral Triangular Micro strip Antenna (ANTENNA-1)

The geometry of ANTENNA-1 is shown in the Figure 1. It is made of a single equilateral triangular patch on top, one layers of dielectric and a ground with coaxial feed connected to the upper patch.

Geometry of Equilateral Triangular Micro strip Antenna with branchlike slots (ANTENNA-2)

By embedding a pair of branchlike slots of proper dimensions, the first two broadside-radiation modes TM10 and TM20 of the triangular SIW patch antenna can be obtained such that their resonant frequencies are decreased and make them close to each other to obtain a wide impedance bandwidth. The geometry of ANTENNA-2 is shown in Figure 2. The specified dimensions of the each branch are l_1=15.5 and l_2=7mm.

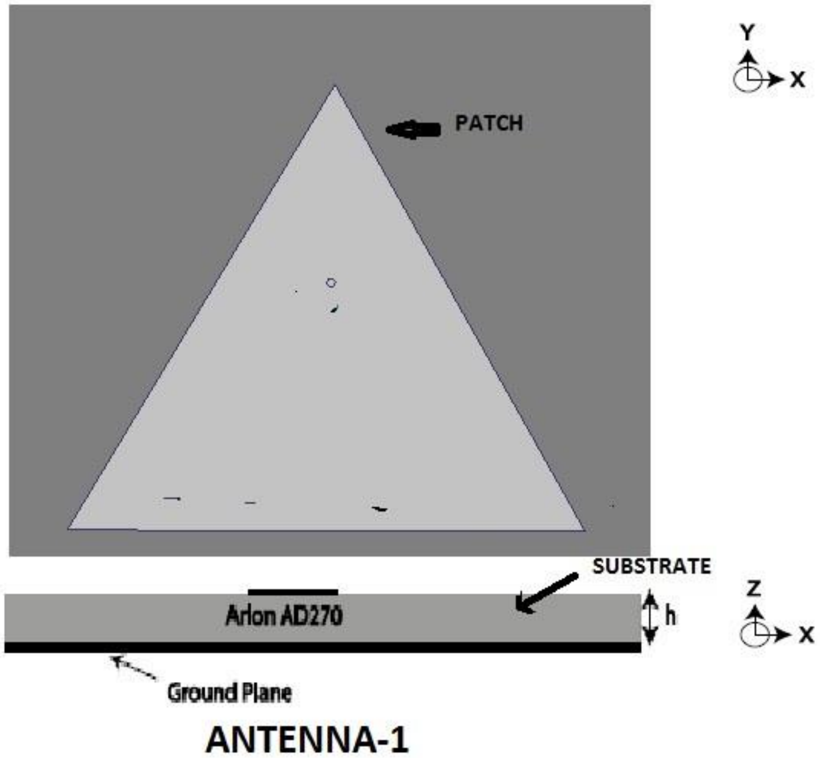


***Figure 1**: Equilateral Triangular Micro strip Antenna.*

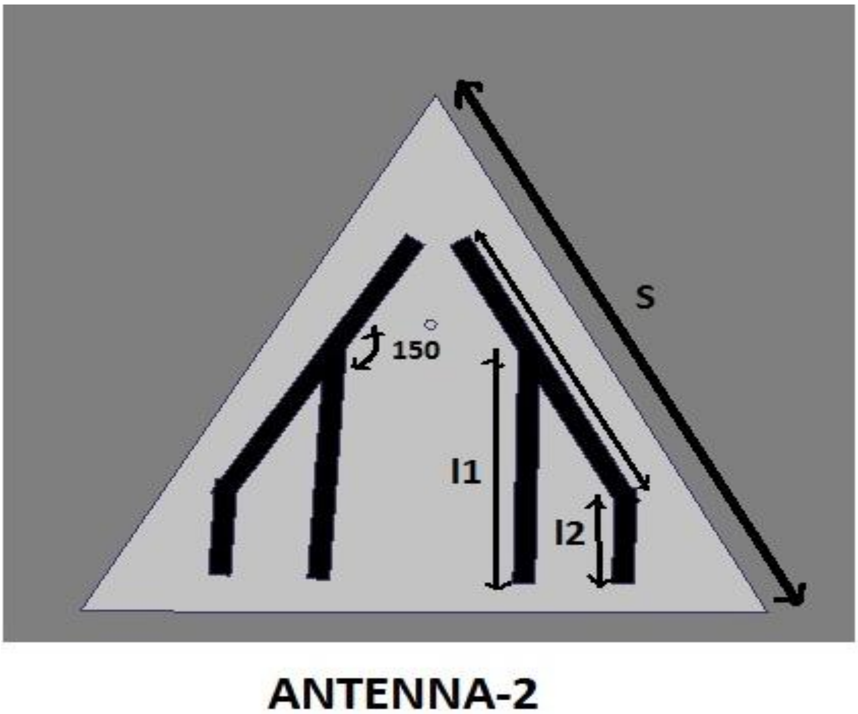


***Figure2**: Equilateral Triangular Micro strip Antenna with Branch Like slots.*

Geometry of SIW based Equilateral Triangular Micro strip Antenna (ANTENNA-3)

Figure 3 shows the Substrate integrated waveguide based micro strip antenna without slits. This configuration can radiate with optimum radiation pattern with enhanced bandwidth with resonant frequency of 5.28GHz with sufficient return losses.

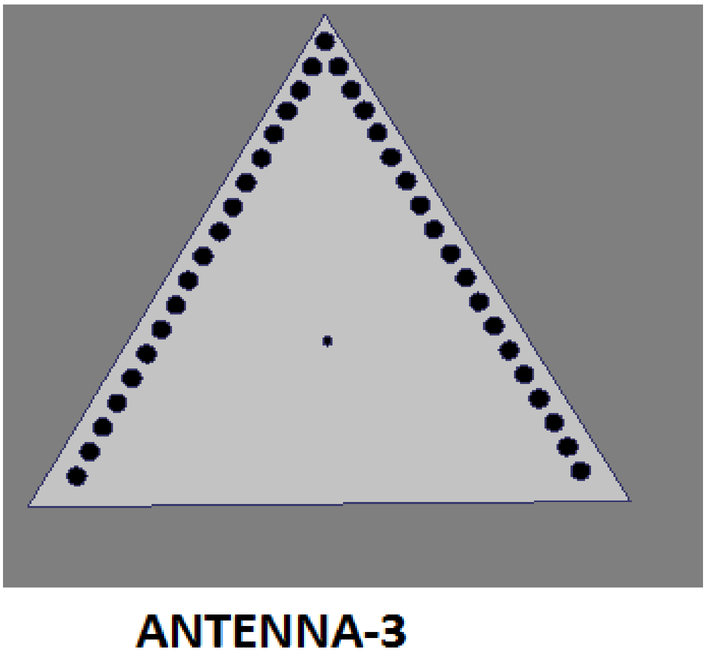


***Figure 3**: SIW based Equilateral Triangular Micro strip Antenna.*

Geometry of SIW based Equilateral Triangular Micro strip Antenna with single slit (ANTENNA-4)

Figure 4 shows the antenna introduced by a small single vertical slot at the right side of the antenna to decrease the resonant frequency further to 4.29GHz. A small amount of inductive reactance is introduced by locating slot with specified dimensions of the length l_3 equal to 7mm with thickness 1mm. This leads to miniaturization of the antenna shown in Figure 3.

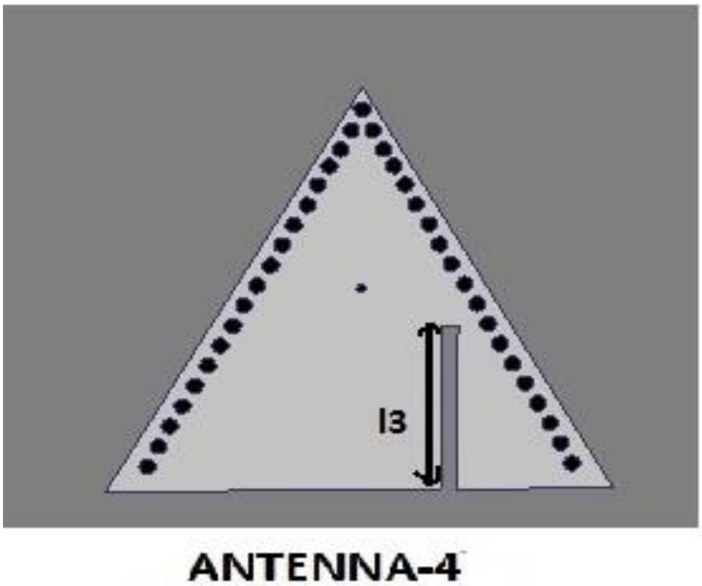
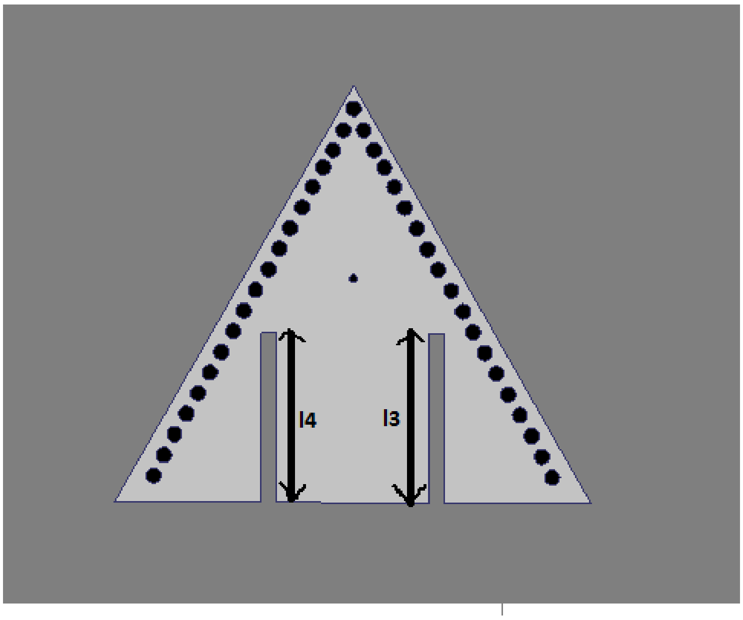


***Figure 4**: SIW based Equilateral Triangular Micro strip Antenna with Single Slit.*

SIW based Equilateral Triangular Micro strip Antenna with double slit (ANTENNA-5)

One more slot l_4 has been introduced parallel to the l_3 slot with the same length. This configuration is shown in Figure 5.

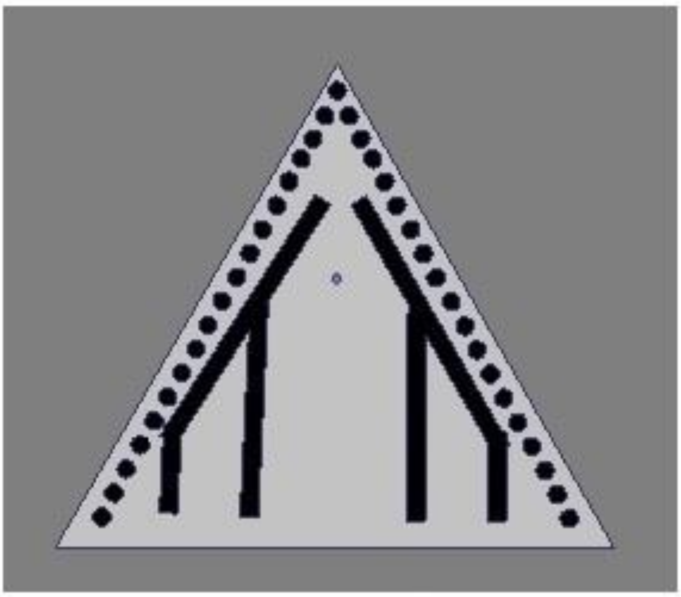


ANTENNA-5

***Figure 5**: SIW based Equilateral Triangular Micro strip Antenna with Double Slit.*

SIW based Equilateral Triangular Micro strip Antenna with branchlike slots (ANTENNA-6)

A pair of branchlike slots of proper dimensions is introduced on the patch of the normal SIW configuration to form antenna 6. This configuration is shown in Figure 6.



ANTENNA-6

***Figure 6**: SIW based Equilateral Triangular Micro strip Antenna with Branch Like Slots.*

The designs of the proposed antennas are done with the tools available in the HFSS 14.0 software platform and represented in Figure 7 to 12. The coaxial feeding technique is used to assign the excitation to the patch directly to the patch through ground and substrate layers.

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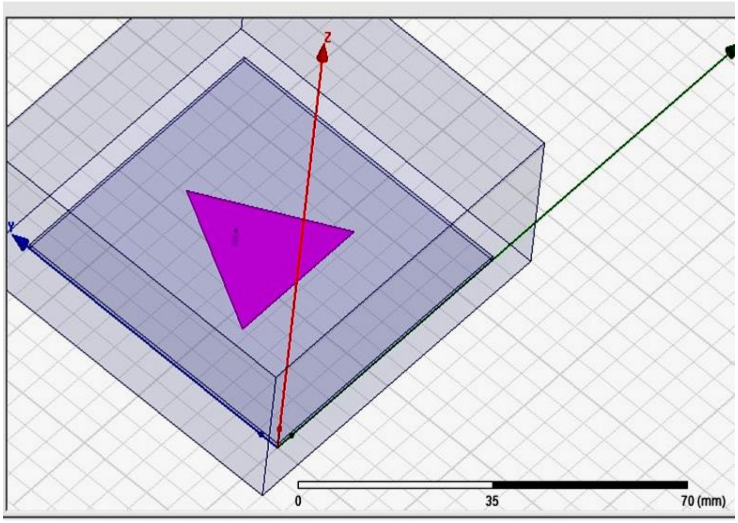

***Figure 7**: Design of Equilateral Triangular Micro strip Antennain HFSS Software.*

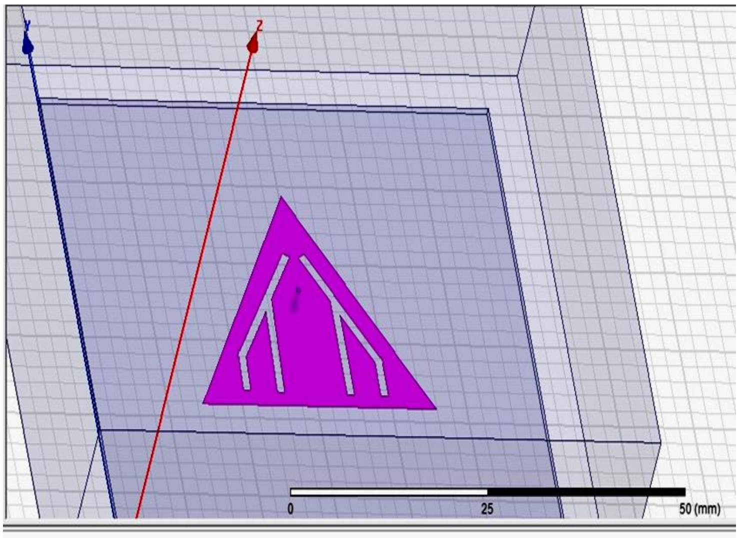

***Figure 8**: Design of Equilateral Triangular Micro strip Antenna with Branch Like Slotson HFSS Workspace.*

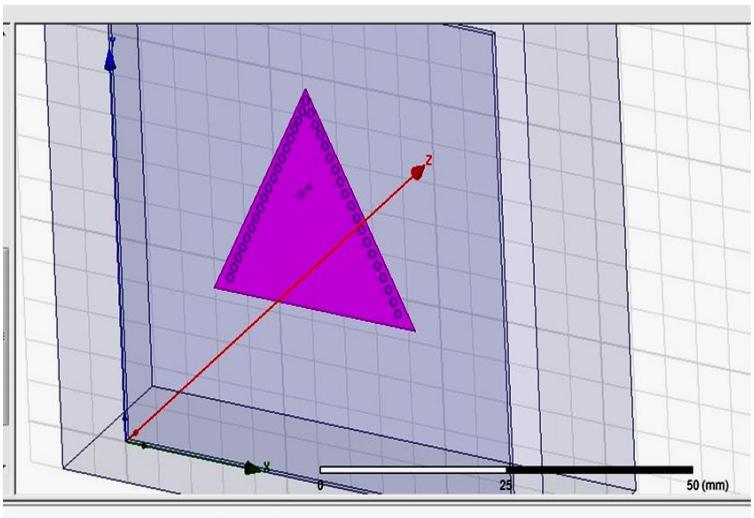

***Figure 9**: Design of SIW based Equilateral Triangular Micro strip Antennaon HFSS Workspace.*

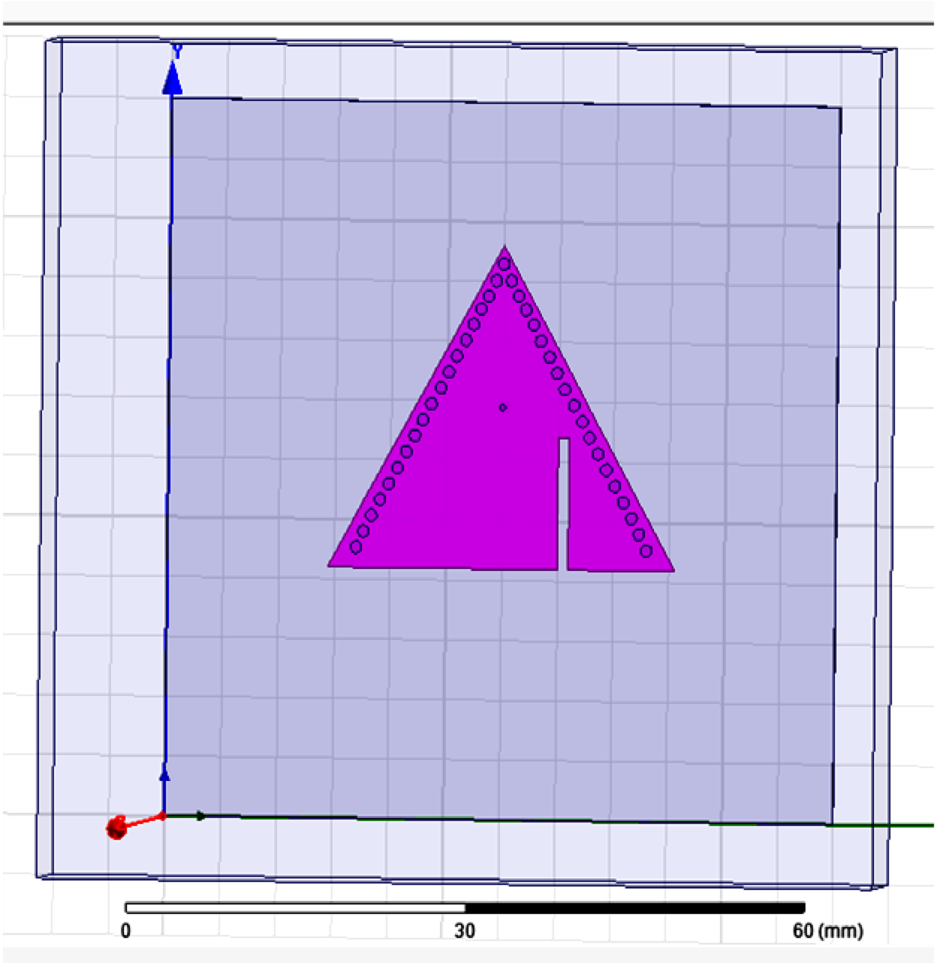

Figure 10*: Design of SIW based Equilateral Triangular Micro strip Antenna with Single Sliton HFSS Workspace.*

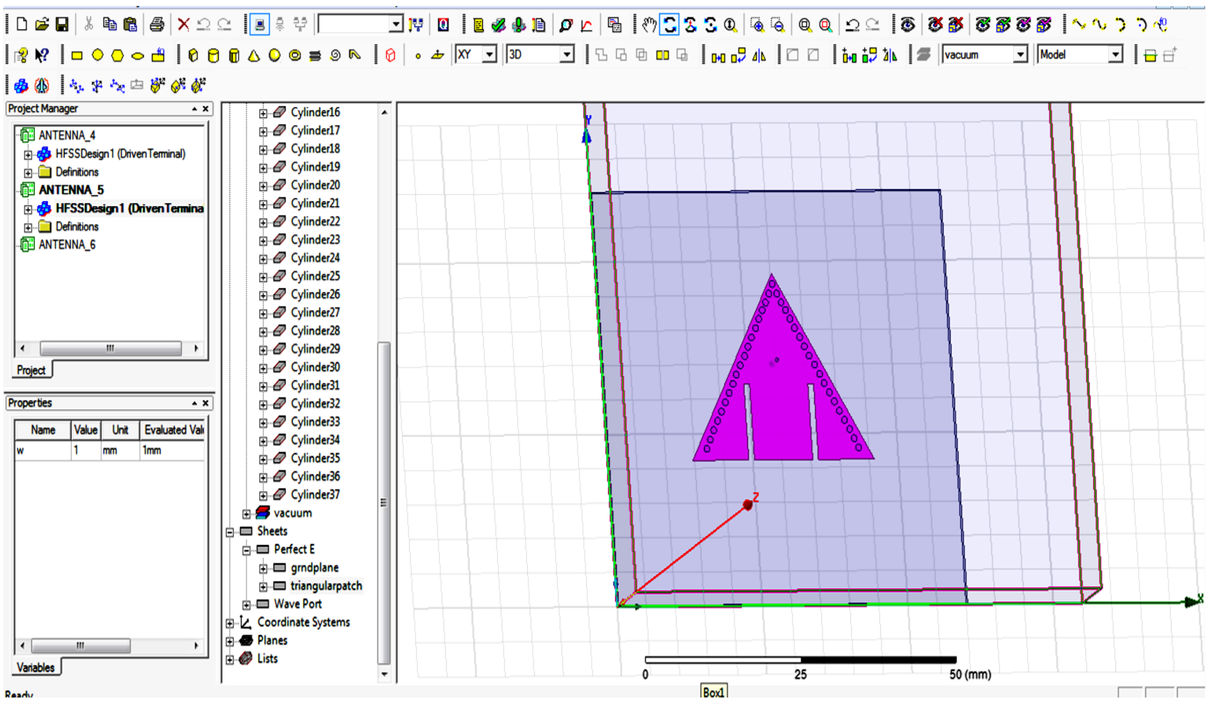

Figure 11*: Design of SIW based Equilateral Triangular Micro strip Antenna with Double Sliton HFSS Workspace.*

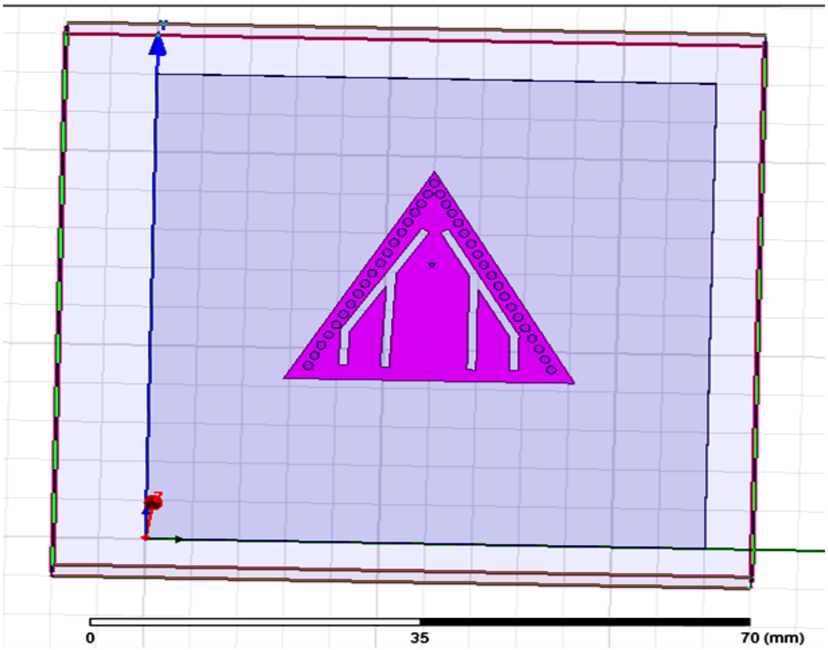

***Figure 12**: Design of SIW based Equilateral Triangular Micro strip Antenna with Branch Like Slotson HFSS Workspace.*

RESULTS

Return Losses

Return loss is defined as

***R*=20log10|K| (1)**

Where, K is the reflection coefficient. The Return loss is related with the VSWR and operating frequencies.

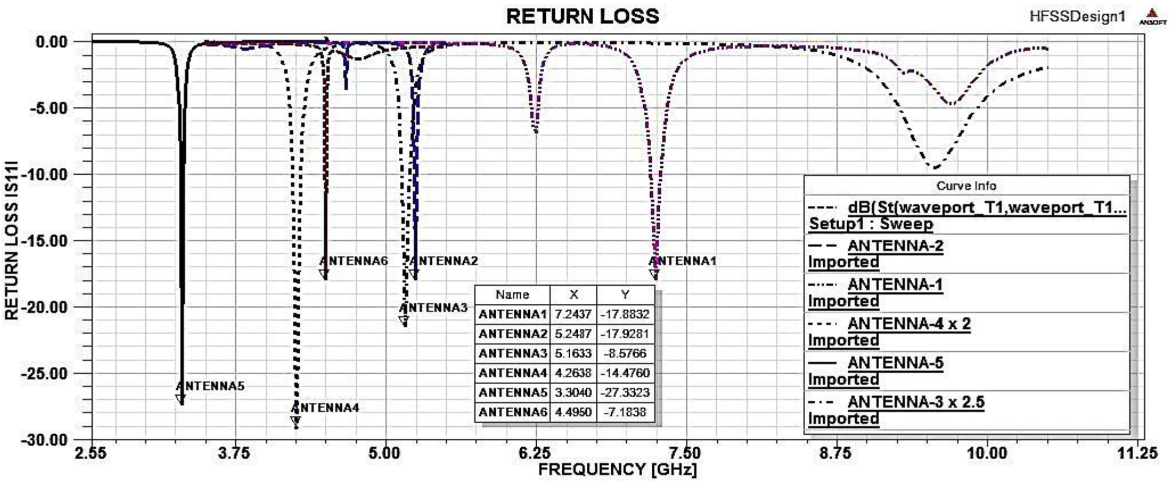

***Figure 13:** Return Losses of all the Proposed Antennas.*

Radiation Pattern

The two dimensional radiation patterns can be plotted by taking the variation of the absolute value of field strength or power as a function of θ. The directional characteristics of the proposed antenna can be determined by observing parameters including HPBW, FNBW, Direction of Propagation, FBR etc., By changing the values of the substrate thickness, dielectric medium constants of the substrate material, shape of the patch, diameter of the vias and Feed position effect the Directional characteristics of the Proposed SIW antenna. The radiation pattern shows the propagation characteristics of the antenna for optimization.

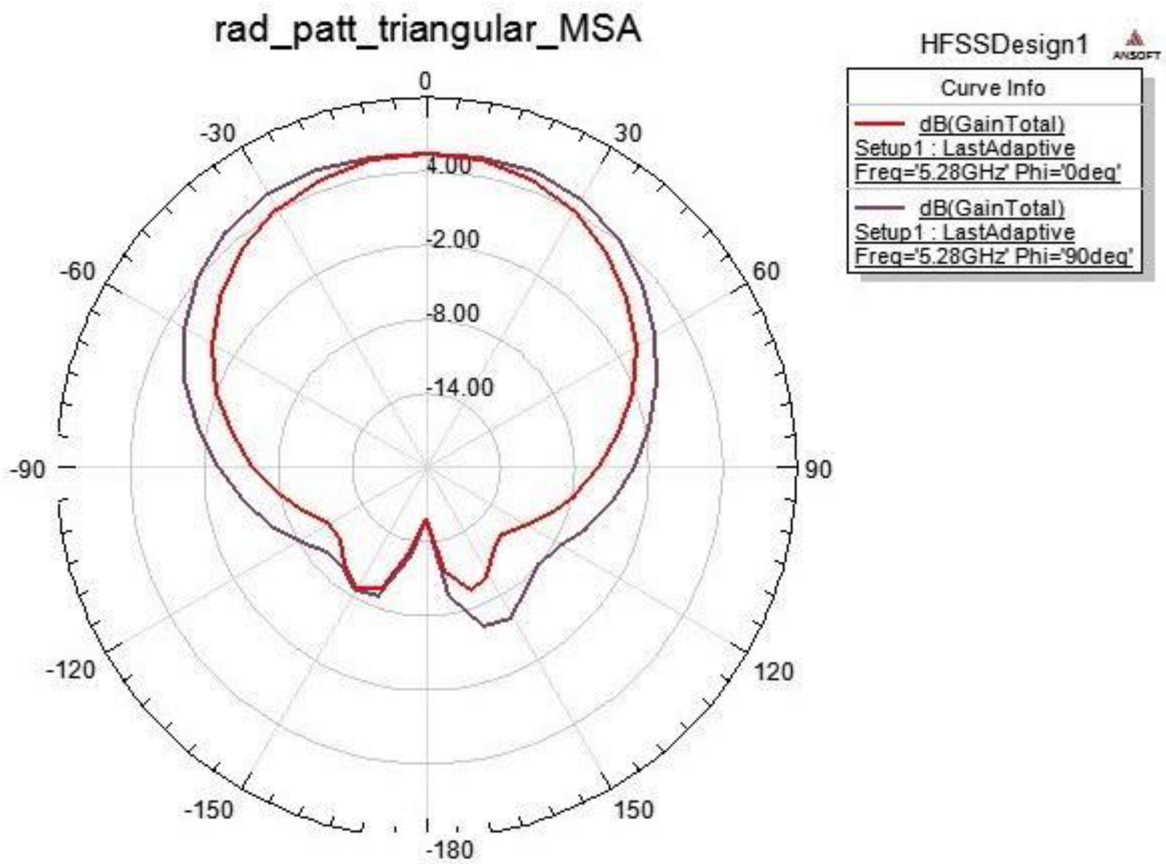

Figure 14: *Radiation Pattern of Antenna-1.*

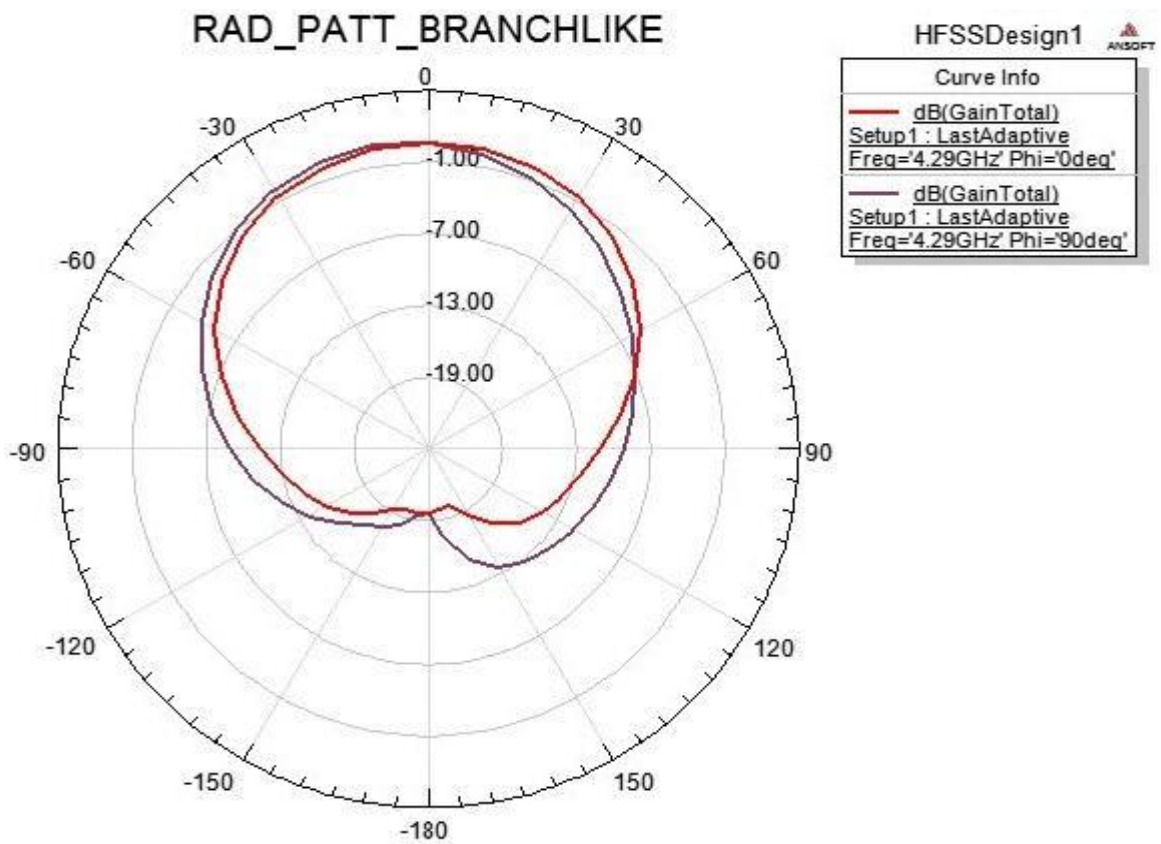

Figure 15: *Radiation Pattern ANTENNA-2.*

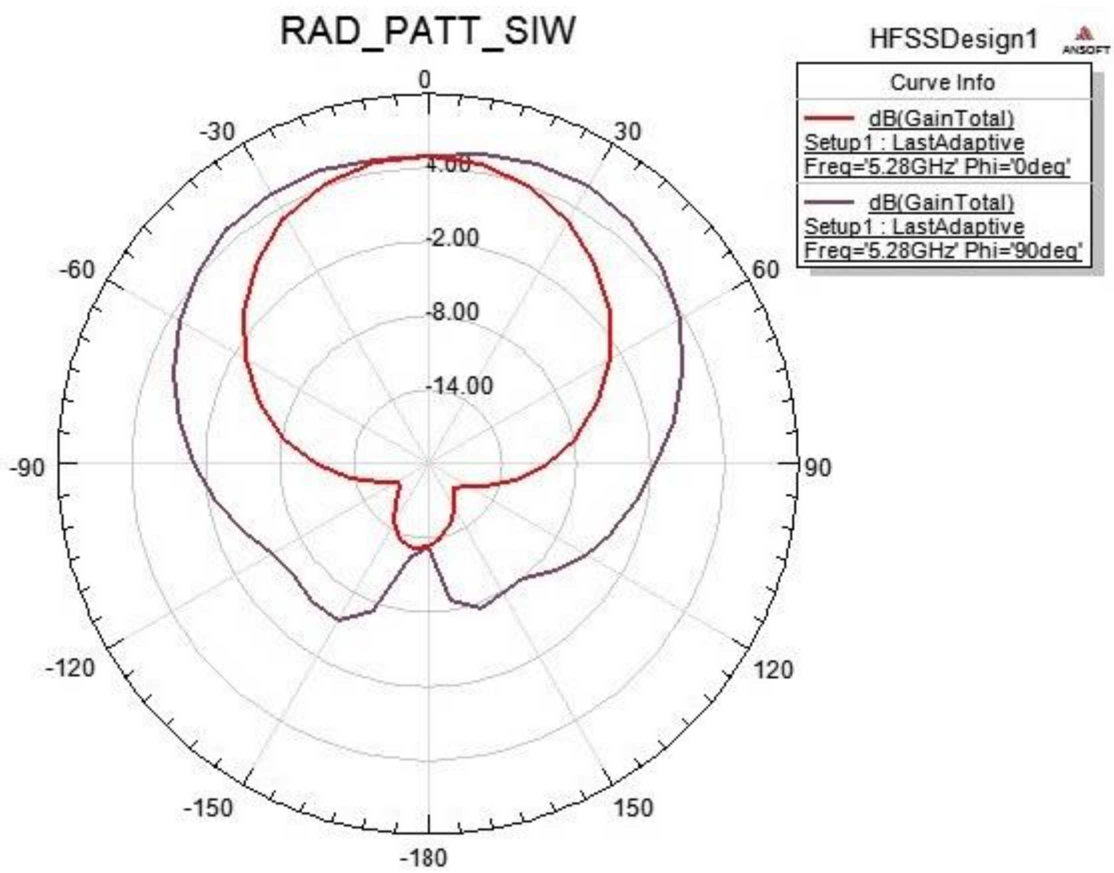

***Figure 16**: Radiation Pattern ANTENNA-3.*

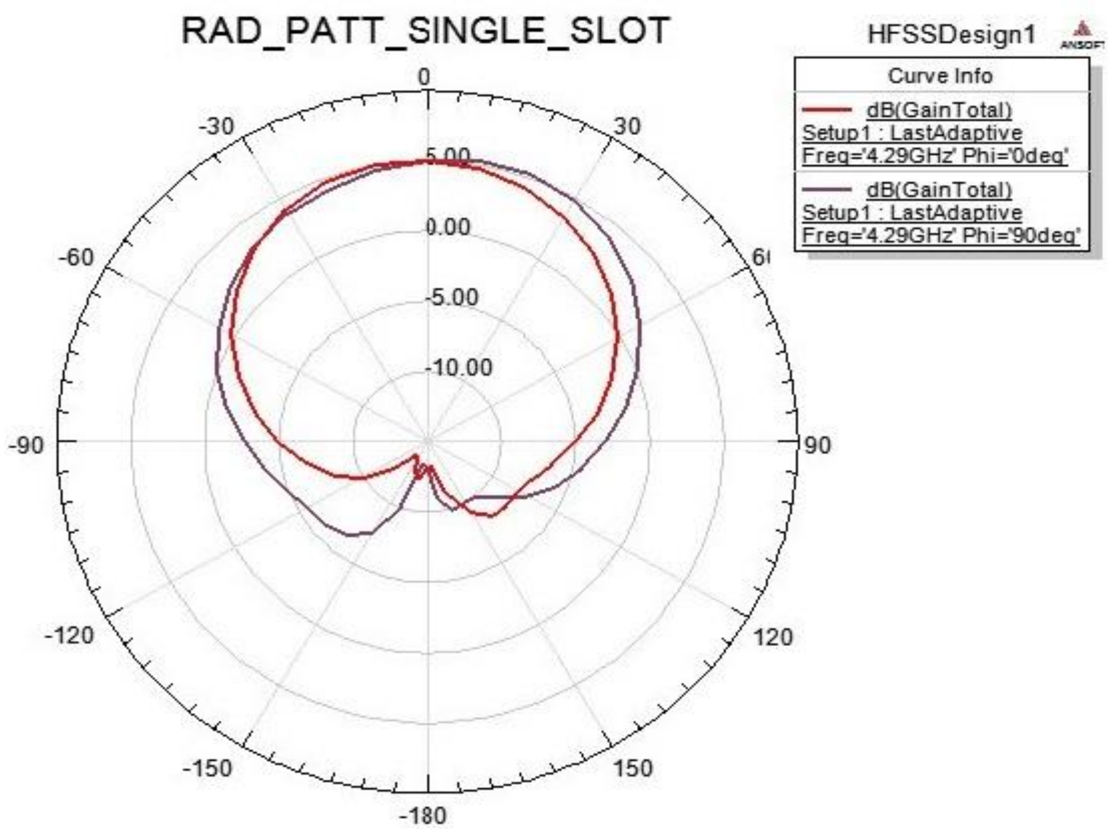

***Figure 17**: Radiation Pattern ANTENNA-4.*

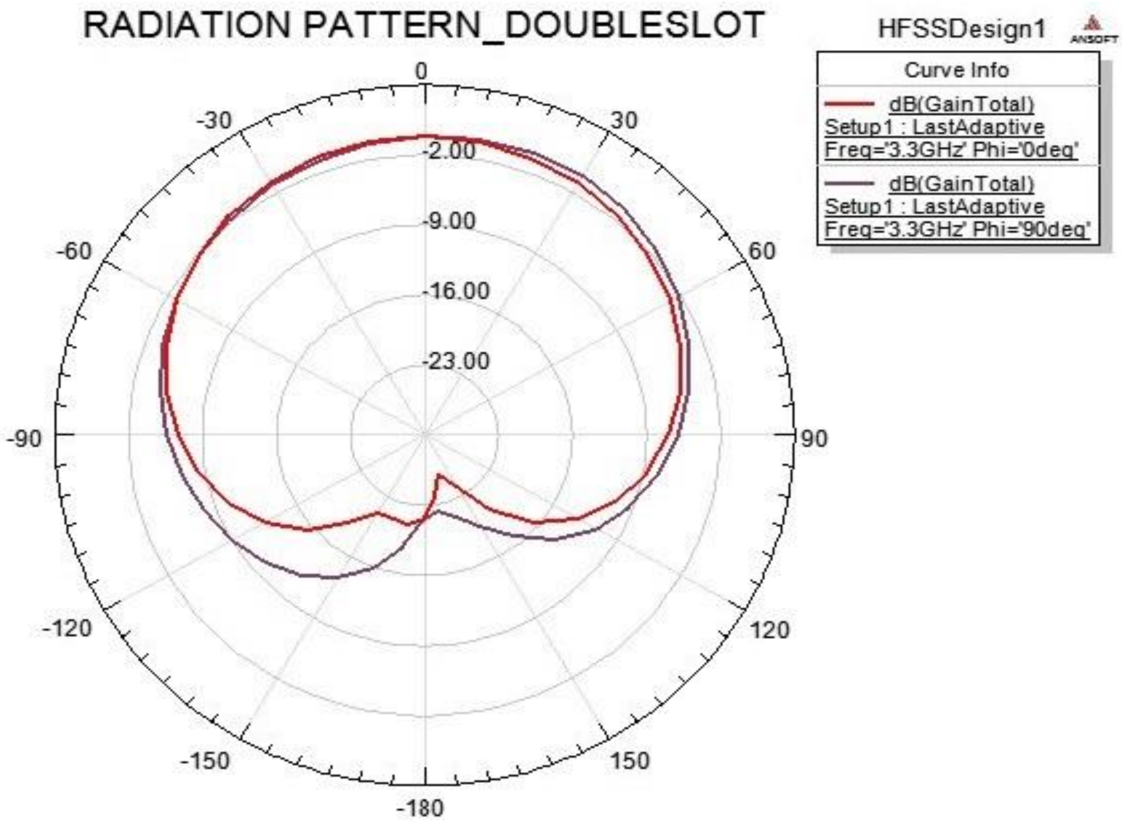

Figure 18: *Radiation Pattern ANTENNA-5.*

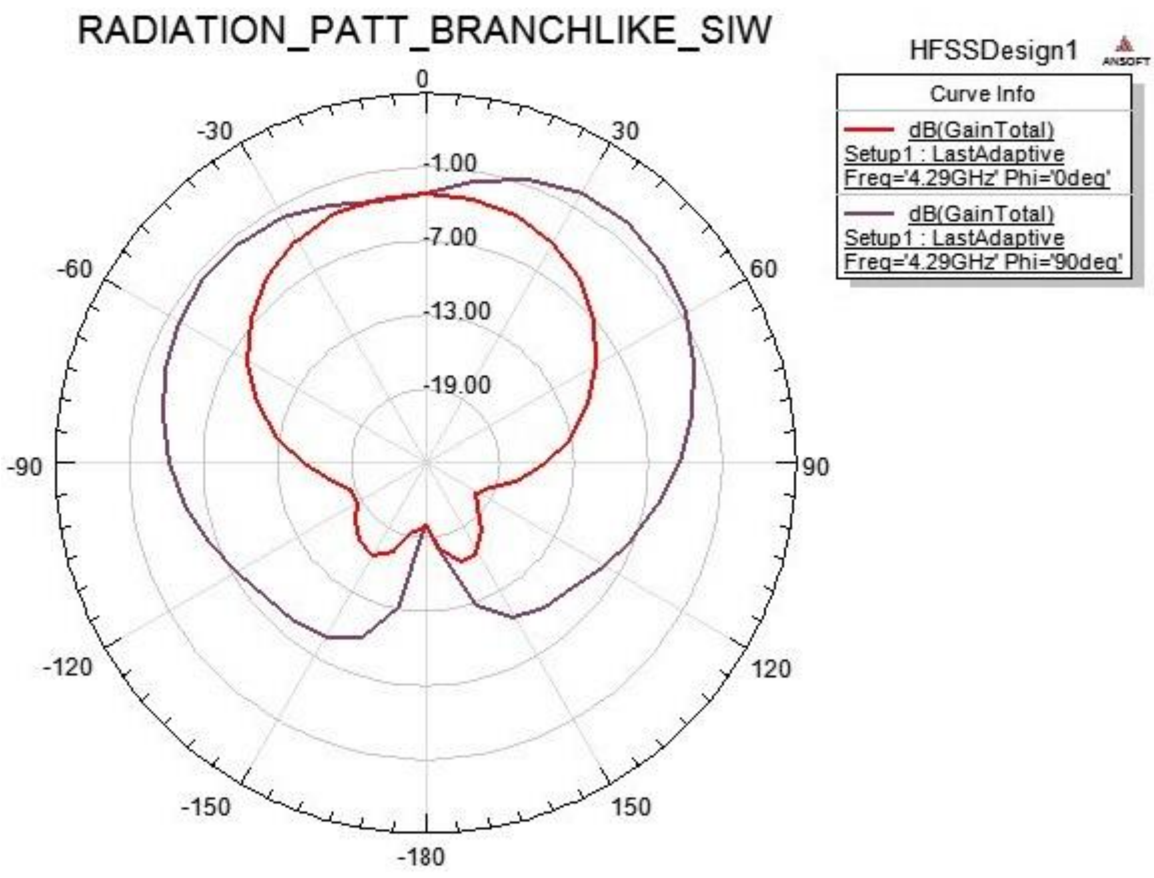

Figure 19*: Radiation Pattern ANTENNA-6.*

3-D Radiation Pattern

The radiation pattern is the plot of variation of Field or radiated power as a function of space coordinates around the antenna in free space. We can observe the 3 dimensional view of the pattern of proposed SIW based antennas in Figures 20 to Figure 25.

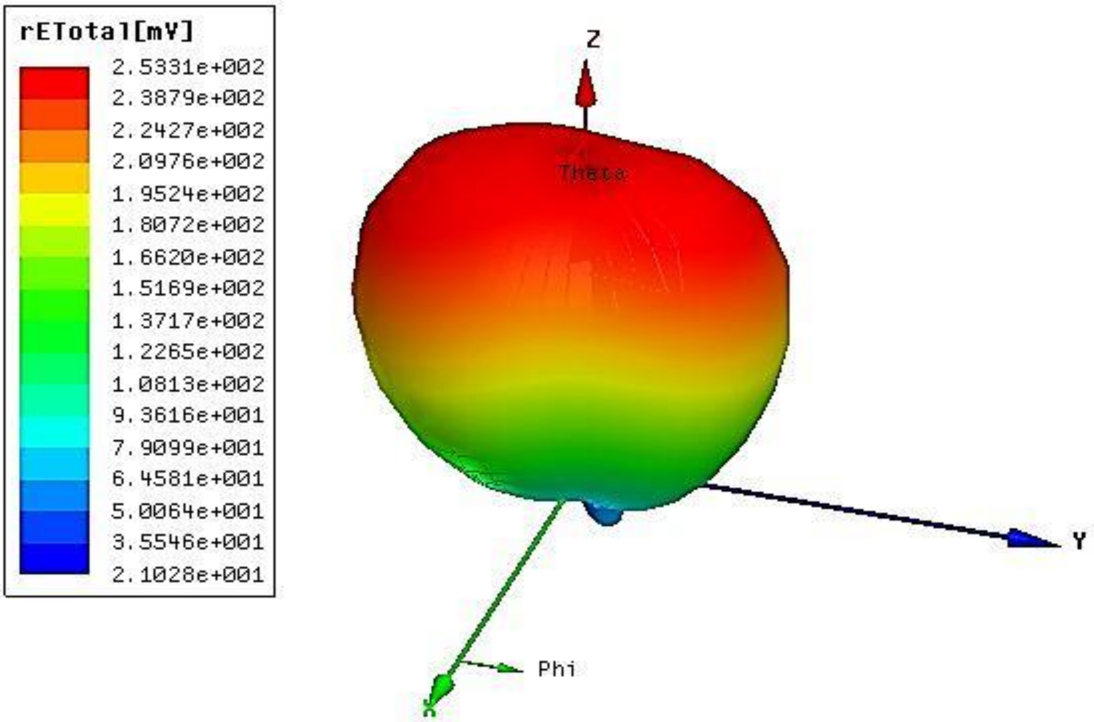

Figure 20*: 3D-view of Radiation Pattern for ANTENNA-1.*

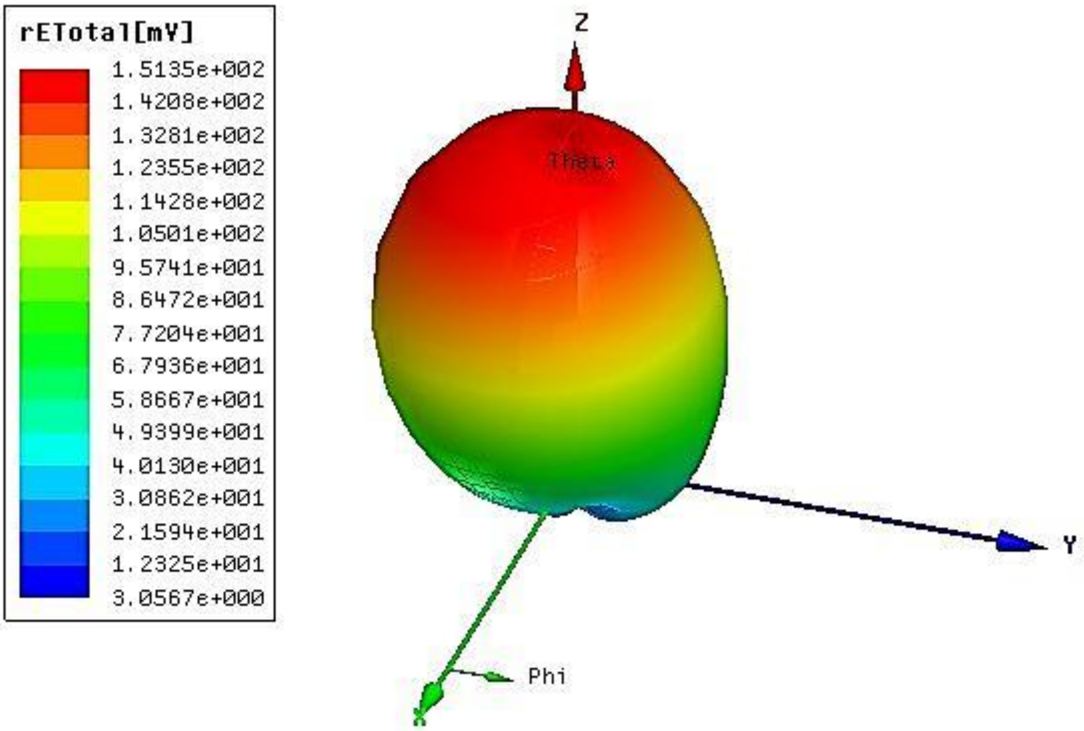

Figure 21*: 3D-view of Radiation Pattern for ANTENNA-2.*

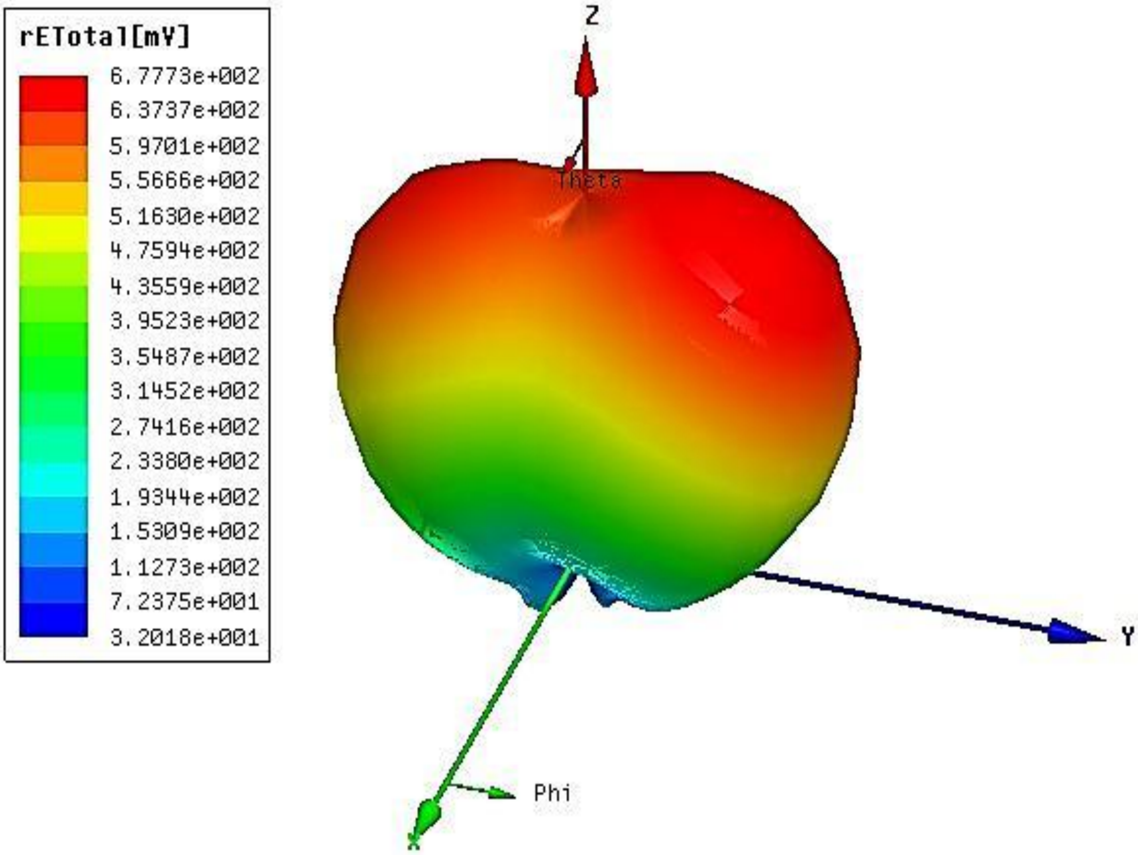

***Figure 22**: 3D-view of Radiation Pattern for ANTENNA-3.*

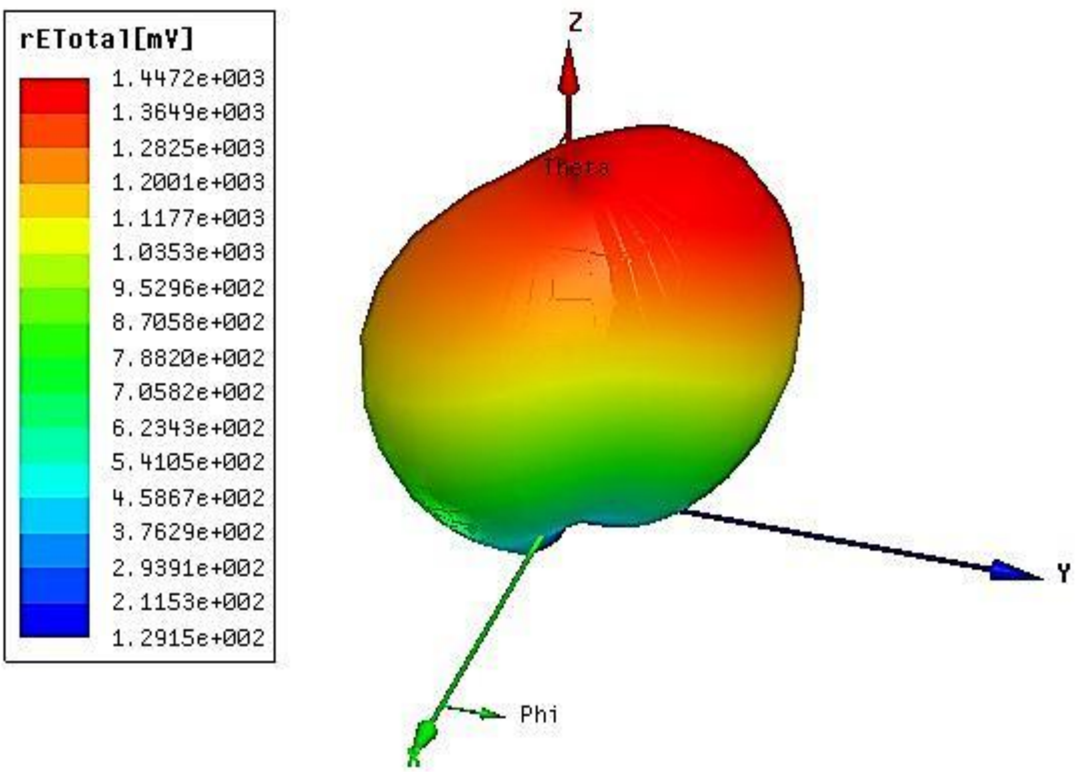

***Figure 23**: 3D-view of Radiation Pattern for ANTENNA-4.*

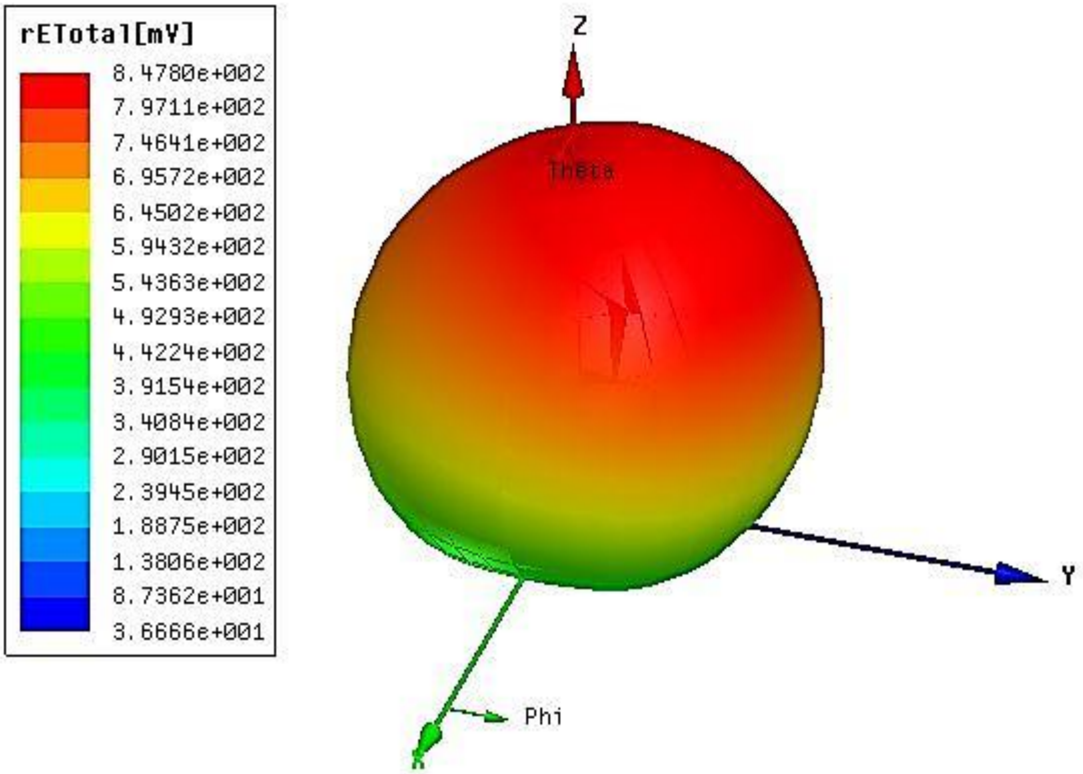

***Figure 24**: 3D-view of Radiation Pattern for ANTENNA-5.*

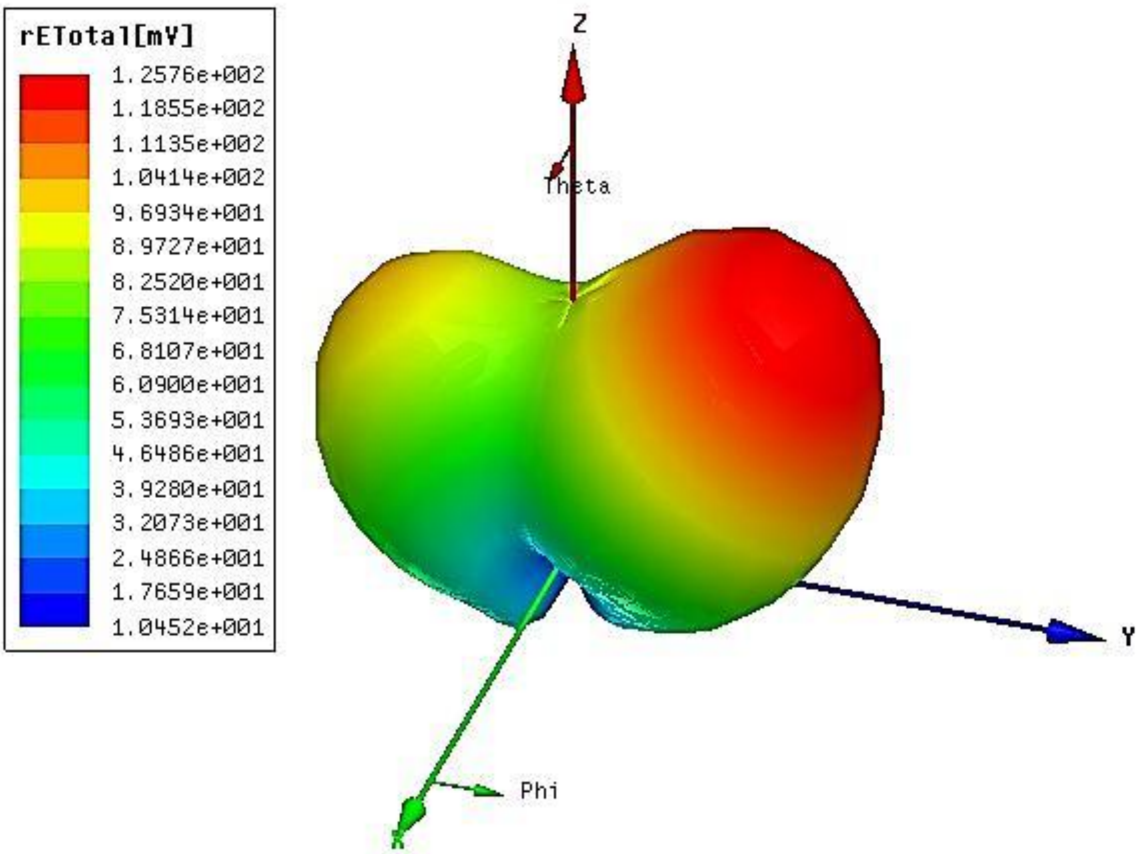

***Figure 25**: 3D-view of Radiation Pattern for ANTENNA-6.*

Radiation Characteristics

***Table 1**: Radiation Characteristics of Proposed Antennas.*

ANTENNA TYPE/PARAMETER	ANTENNA -1	ANTENNA -2	ANTENNA -3	ANTENNA -4	ANTENNA -5	ANTENNA -6
Frequency(GHz)	7.24	5.24	5.16	4.26	3.30	4.49
Gain (dB)	5.79	7.05	6.03	5.6	5.04	6.46
Radiation Efficiency (%)	89.49	24.01	85.54	81.97	78.66	25.66
Peak Directivity	4.25	5.07	4.7	4.43	1.2	1.13763
Radiated Power(W)	0.000251285	7.51766e-005	0.00162995	0.00787733	0.0090349	5.9458e-005
Accepted Power(W)	0.000280773	0.000313078	0.00190531	0.00960991	0.0114853	0.000231707
FBR	16.8835	70.0646	14.3481	34.1	40.7	7.9
Return loss (s_{11})	-17.88	-17.92	-8.17	-14.47	-27.33	-7.18

EXPLANATIONS

In this section, we will discuss and compare the performance of all the proposed antennas designs. The design results in the form of return losses and radiation patterns are calculated with the High Frequency Structure Simulator. The miniaturization performance and radiation characteristics are tabulated in Table1. The reflection coefficient (S_{11}) of all antennas is presented in Figure 13. It is observed that the basic equilateral triangular antenna (ANTENNA-1) can radiate with resonant frequency 7.24GHz with gain of 5.79dB with 89% of efficiency. By introducing branchlike slots into ANTENNA-1, the resonance frequency is decreased to 5.24GHz. Due to the transition from ANTENNA-1 to ANTENNA-2, a satisfactory level of miniaturization with gain of 7.05dB is observed but the efficiency is decreased drastically to 24.01%.

By embedding the metallic vias to the basic structure using SIW principle, it is observed that at resonance frequencies of 5.16GHz, the ANTENNA-3 radiates with the optimum gain of 6.03dB with 83% efficiency. But the return loss S_{11} is not at satisfied level. In ANTENNA-4, by introducing single slot vertically on patch, we can observe the resonance frequency of 4.26GHz with optimum gain and efficiency of 5.6 and 82% respectively with good return losses.

Further miniaturization is observed in ANTENNA-5 with resonance frequency 3.30GHz at gain and efficiency of 5.04 and 78% respectively with optimum return losses. From the performance characteristics of the ANTENNA-6, it is observed that, the antenna can radiate at 4.46GHz with 6.46dB of gain. But the return losses and efficiency are not at required levels.

CONCLUSION

In this paper, six models of equilateral triangular micro strip patch antennas using Arlon AD270 substrate excited with coaxial feed, and analyzed the performance using Finite Element Method based tool, HFSS (High Frequency Structure Simulator) software. The performance of the designed antennas was analyzed in term of bandwidth, gain, return loss, VSWR, and radiation pattern. From the simulation results of return losses, gain, radiation pattern and efficiency, it is observed that the effective level of miniaturization can be achieved from ANTENNA-1to ANTENNA-6. ANTENNA-5, ANTENNA-4 can provide 54.4%, 41.1% of miniaturization respectively with optimum radiation characteristics. It is also observed that ANTENNA-3 provides 27.6% of miniaturization with high gain at the cost of low efficiency. Due to the frequency of operation, and compact size, optimum radiation characteristics, ANTENNA-5 exhibits efficient radiation in the required applications as compared to its patch counterpart.

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