

The Characteristics of Electromagnetically Coupled Two Layered Dielectric Loaded Patch Antenna

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Abstract In this paper, characteristics of electromagnetically coupled (EM) dielectric loaded rectangular patch have been analyzed using HFSS. The proposed antenna structure has been studied with single and double dielectric loadings, basically to provide necessary protection to patch antenna from environmental hazards. The projection area of two layered patch antenna is kept same as single layered patch antenna. The effect on performance characteristics such as resonant frequency, gain, directivity, efficiency of rectangular patch antenna with varying permittivity of dielectric material has been studied. The proposed structure is fed with coaxial probe feed which leads to good impedance matching and its operating frequency is 6 GHz.

Keywords EM Coupled Patch Antenna, Dielectric Loading, Resonant Frequency, Directivity

1. Introduction

Microstrip antenna is gaining more importance these days because it possesses attractive features and unique properties such as: low profile, light weight, low cost and flexibility. Due to the above features microstrip patch antenna is widely being used for communications applications. However, narrow bandwidth and low gain are the major disadvantages of the patch antenna. The issues of increasing gain and bandwidth of microstrip antenna elements has been considered by several researchers.

In general a dielectric layer is almost equivalent to any physical condition changes in microstrip patch antenna due to snow, ice or by introduction of a radome in the manufacturing stage for the purpose of protection from the environmental hazards. The performance characteristics of the antenna structure may be adversely affected if relative permittivity and thickness of the dielectric substrate used for design, are not chosen properly. It has been observed that the resonant frequency of the microstrip antennas is shifted which cause unexpected changes in the behavior of the antenna. When the patch antenna is covered with dielectric sheet (called superstrate), its properties like effective dielectric constant, losses, Q factor change. The change in effective dielectric constant is of much more importance than any other characteristics. The amount of change depends on the thickness and relative permittivity of dielectric loading. For this reason, it is important to analyze dielectric loading

effects so that the performance of the antenna may be understood better or a proper choice of cover parameters may be used.

Available literature reveals that significant efforts have been made by antenna engineers to study the characteristics of EM coupled patch antennas. In 1983, A. Sabban designed and tested a two-layer stacked antenna working over S to Ku band[1]. Later H. Y. Yang and N.G. Alexopoulos, proved that it is possible to enhance gain of printed circuit antennas by applying multiple superstrates[2]. Further, a two layered electromagnetically coupled antenna (EMCP) operating in the broadband region was studied for describing the effects of varying the thickness of the superstrate and resonant frequency, impedance bandwidth, 3dB beam width were calculated[3].

In 1990, a rectangular patch antenna with two coupled layers was investigated, and the effects of varying distance between the two layers were examined for the bandwidth and gain. Along with this, the changing the relative sizes of the parasitic and fed patches was also considered in the study[4]. Later J.S. Row and K.L. Wong studied a rectangular microstrip antenna and presented the complex resonant frequency analysis with superstrate loading. The obtained results show a significant variation when the superstrate permittivity is greater than that of substrate[5]. A circularly polarized rectangular patch antenna was analyzed using spectral domain analysis, and the effects of dielectric superstrate were studied by Lei Zhu, Eikichi Yamashita and Ikuhiro Jouishi[6]. An enhanced gain circular region was obtained by cutting slits in square patch with circular radiation and covering the antenna by a high permittivity superstrate[7].

In 2001, A.K. Verma and Nasimmuddi observed an

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improved version of the wolff model (cavity model) with isotropic/anisotropic substrate and superstrate to calculate the resonant frequency and input impedance of the patch antenna[8]. Next year, a multilayer miniature patch antenna was proposed. The comparative results of the single and two layered patch antenna showed an increase in the bandwidth by 5% of the multi layer antenna. In another design, the upper patch was cut in to the bow-tie shape, which produced a good radiation pattern[9]. In 2003, a simple formulation for accurate computation of the resonant frequency applicable for both high and low dielectric constant superstrates was presented. The results were in close agreement with the present theories and can be applied to conventional antennas also[10]. A neural network model was developed for the variation in the resonant frequency of a rectangular microstrip antenna with dielectric loading. The proposed model was found to be in good agreement when simulated using method of moments[11].

Self biased films are successfully introduced into patch antenna as a result novel patch antenna design with spin spray deposited ferrite film have led to miniaturised patch antennas on magneto dielectric substrate/superstrate with enhanced bandwidth ,improved directivity and efficiency [12].

Recently, a method for accurate calculation of the resonant frequency considering the effect of superstrate layer has been presented using variation in the patch dimensions. The antenna performances were also investigated for various cases of permittivity and thickness of the superstrate layer[13].

In this paper, a patch antenna is designed to operate at 6 GHz frequency. This design is based on the various selection criteria such as thickness of dielectric material and dielectric constant (permittivity) for loading. Effect on the parameters with respect to change in dielectric constant of dielectric loading layer has been simulated and analyzed. The primary effect of such loading is the change in the resonant frequency of the antenna which has been presented in this paper.

2. Antenna Design

The proposed antenna consist of a printed rectangular patch antenna with dimension 1.7cm x 1.3cm on Roger RO4232 substrate of thickness $h=0.0762\text{cm}$ and dielectric constant ($\epsilon_r=3.2$). The structure incorporates an antenna element, dielectric material and a vertical coax probe connected to the patch. The substrate has following dimensions: $L= 4\text{cm}$ and $W= 5.2\text{cm}$.

The transmission line model will be used to design the antenna.

Step 1: Calculation of the patch Width (W): The width of the Microstrip patch antenna is given by:

$$W = \frac{c}{2fo\sqrt{\frac{\epsilon_r+1}{2}}} \quad (1)$$

Where W is the width of the patch in (cm),
 c is the speed of the light ,

fo is resonant frequency

ϵ_r is the dielectric constant of the substrate .

Substituting $c = 3e8 \text{ m/s}$, $\epsilon_r = 3.2$ and $fo = 6 \text{ GHz}$, we get:
 $W = 1.7\text{cm}$

Step 2: Calculation of Effective dielectric constant (ϵ_{eff}): The effective dielectric constant is calculated as:

$$\epsilon_{eff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2} \left[1 + 12 \frac{h}{w}\right]^{-1/2} \quad (2)$$

Where h is the height of substrate.

Substituting $\epsilon_r = 3.2$, $W = 1.7 \text{ cm}$ and $h = 0.0762 \text{ cm}$ we get: $\epsilon_{eff} = 2.8$

Step 3: Calculation of the Effective length (L_{eff}): The effective length is given as:

$$L_{eff} = \frac{c}{2fo\sqrt{\epsilon_{eff}}} \quad (3)$$

Substituting $\epsilon_{eff} = 2.8$, $c = 3e8 \text{ m/s}$ and $fo = 6 \text{ GHz}$ we get:

$$L_{eff} = 1.4 \text{ cm}$$

Step 4: Calculation of the length extension (ΔL): The length extension is given as:

$$\Delta L = 0.412 \frac{(\epsilon_{eff} + 0.3) \left(\frac{w}{h} + 0.264\right)}{(\epsilon_{eff} - 0.258) \left(\frac{w}{h} + 0.8\right)} \quad (4)$$

Putting the values, we get $\Delta L = 0.033 \text{ cm}$

Step 5: Calculation of actual length of patch (L): The actual length is obtained by :

$$L = L_{eff} - 2\Delta L \quad (5)$$

Substituting the values, we get:

$$L = 1.3 \text{ cm}$$

A. Single Patch Antenna with Single Loading

The geometry of rectangular patch antenna covered with single layer of dielectric material is depicted in Figure 1. The loading parameters chosen are as follows:

Case 1: Dielectric material FR4 with dielectric constant 4.4 ($\epsilon_r = 4.4$).

Case 2: Dielectric material for dielectric loading is RT/Duroid-5880 with dielectric constant 2.2 ($\epsilon_r = 2.2$).

Case 3: Magneto dielectric is used for loading. Magnetic thin films provide a unique opportunity for achieving self-biased magnetic antenna substrates with $\mu_r > 1$ at frequencies greater than 1 GHz ($\epsilon_r = 1.6$, $\mu_r = 1.6$).

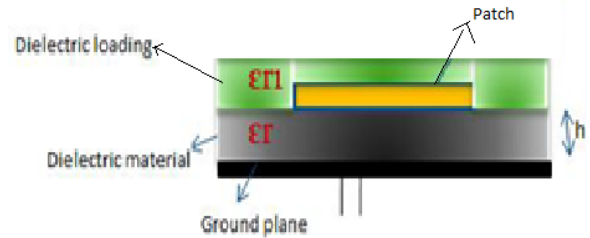


Figure 1. Geometry of single patch antenna with single loading

B. Single Patch Antenna with Double Loading

The proposed geometry for the above antenna is shown in Figure 2. In this, the patch is covered with two layers of different dielectric materials. Three cases of study are:

Case 1: Dielectric material RT/Duroid-5880 with dielectric constant 2.2 is used for first loading and FR4 dielectric material with dielectric constant 4.4 for second

loading ($\epsilon_{r1} < \epsilon_{r2}$).

Case 2: Dielectric material RT/Duroid-5880 is used for both loading ($\epsilon_{r1} = \epsilon_{r2}$).

Case 3: Dielectric material FR4 is used for first loading and RT/Duroid -5880 for second loading ($\epsilon_{r1} > \epsilon_{r2}$).

Case 4: Magneto dielectric is used for both loading. ($\epsilon_{r1}=1.6$, $\mu_{r1}=1.6$).

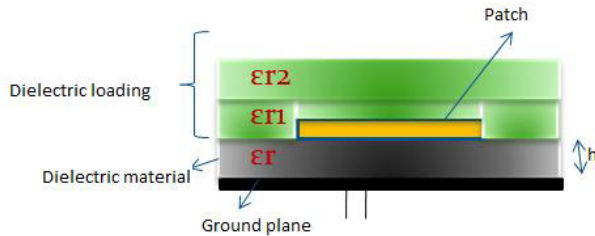


Figure 2. Geometry of single patch antenna with double loading

C. Stacked Patch Antenna with Single Loading

Proposed geometry of stacked patch antenna is shown in Figure 3. in which two stacked patches are designed with single loading. Three cases studied are:

Case 1: $\epsilon_{r1}=4.4$,

Case 2: $\epsilon_{r1}=2.2$.

Case 3: $\epsilon_{r1}=1.6$, $\mu_{r1}=1.6$.

D. Stacked Patch Antenna with Double Loading

The proposed geometry of stacked patch antenna is shown in figure 4 where two stacked patches are covered with two layers of different dielectric materials which have different dielectric constants. Three cases studied are:

Case 1: $\epsilon_{r1} < \epsilon_{r2}$,

Case 2: $\epsilon_{r1} = \epsilon_{r2}$,

Case 3: $\epsilon_{r1} > \epsilon_{r2}$,

Case 4: $\epsilon_{r1}=1.6$, $\mu_{r1}=1.6$, $\epsilon_{r2}=1.6$, $\mu_{r2}=1.6$,

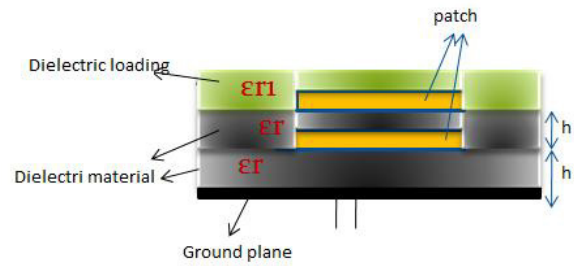


Figure 3. Geometry of stacked patch antenna with single loading

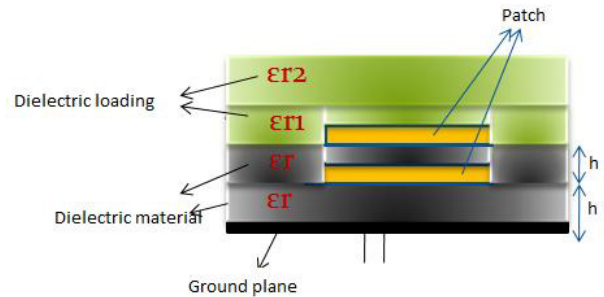


Figure 4. Geometry of stacked patch antenna with double loading

3. Results

a. Result of Single Patch Antenna with Single Loading Case 1

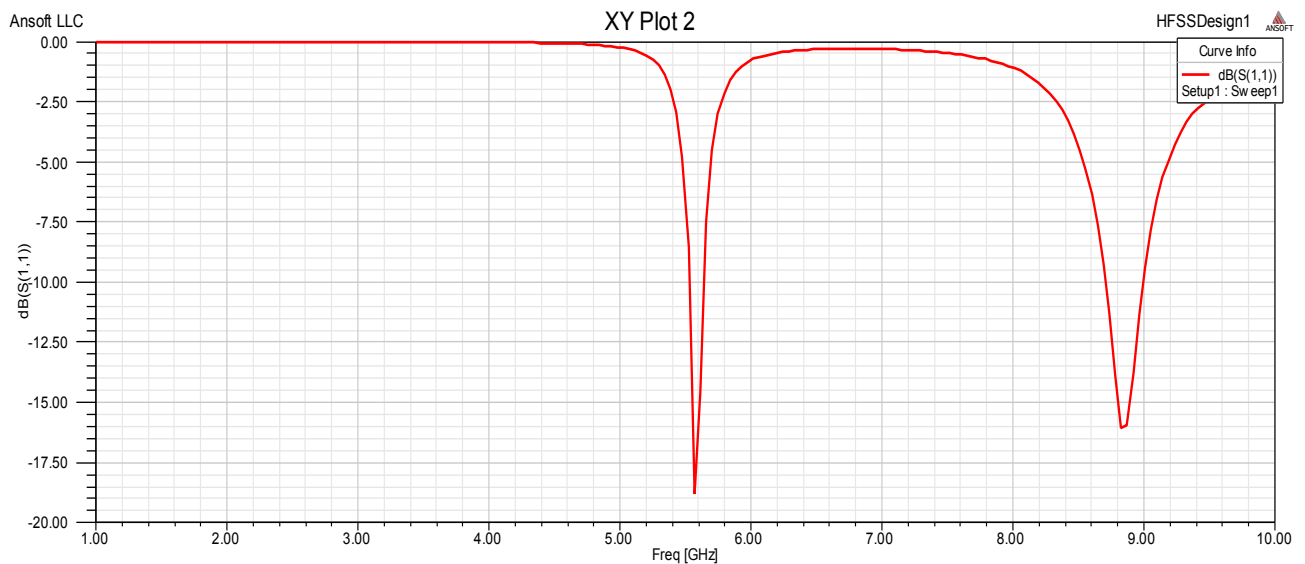


Figure 5(a). Return Loss vs Frequency

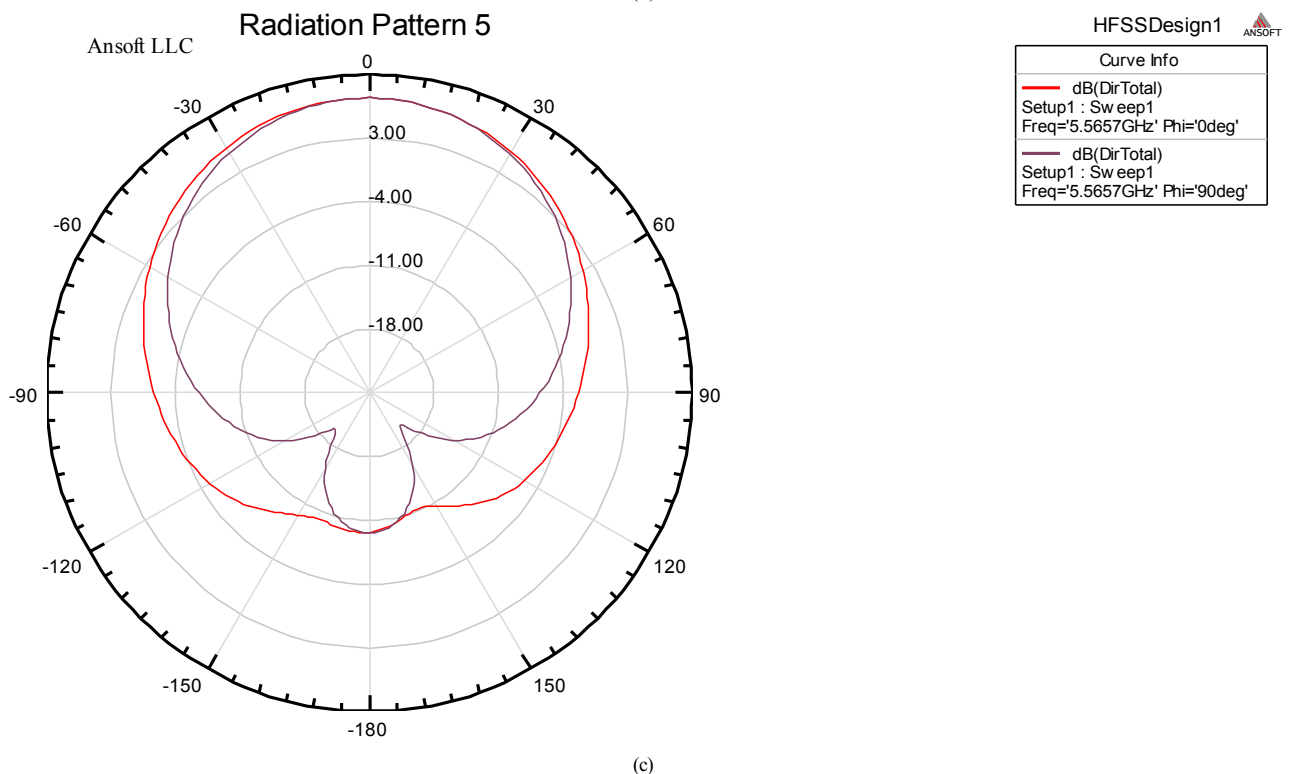
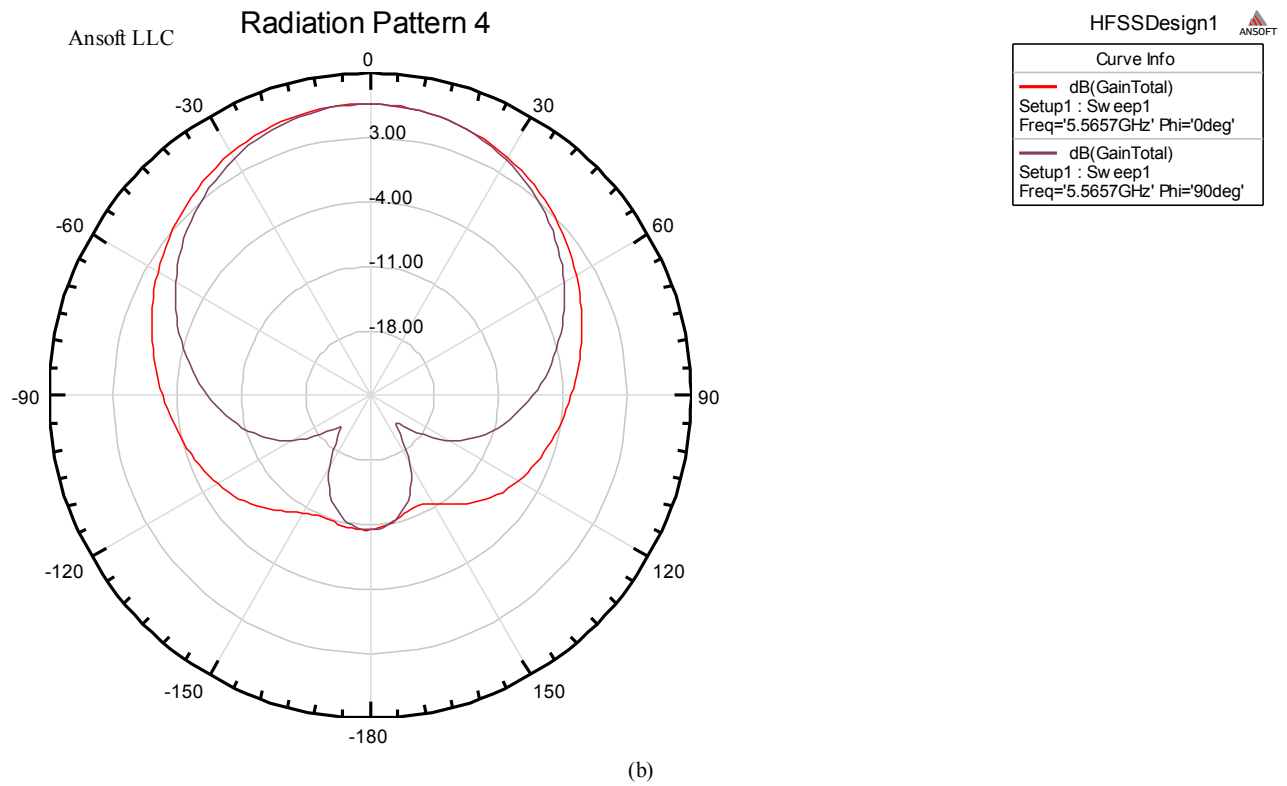


Figure 5(b),(c). Radiation Pattern for Gain and Directivity

Case 2

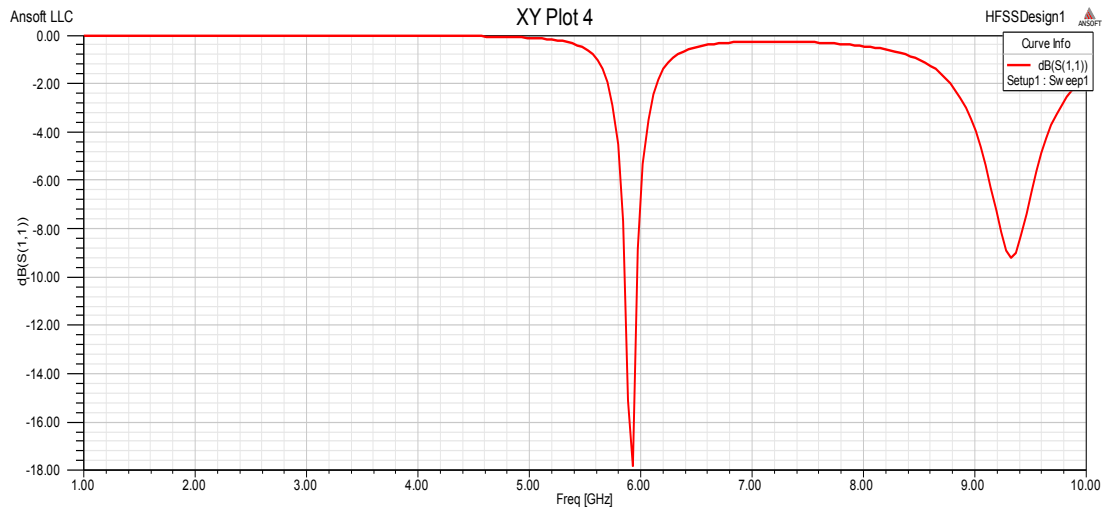


Figure 5(d). Return Loss vs Frequency

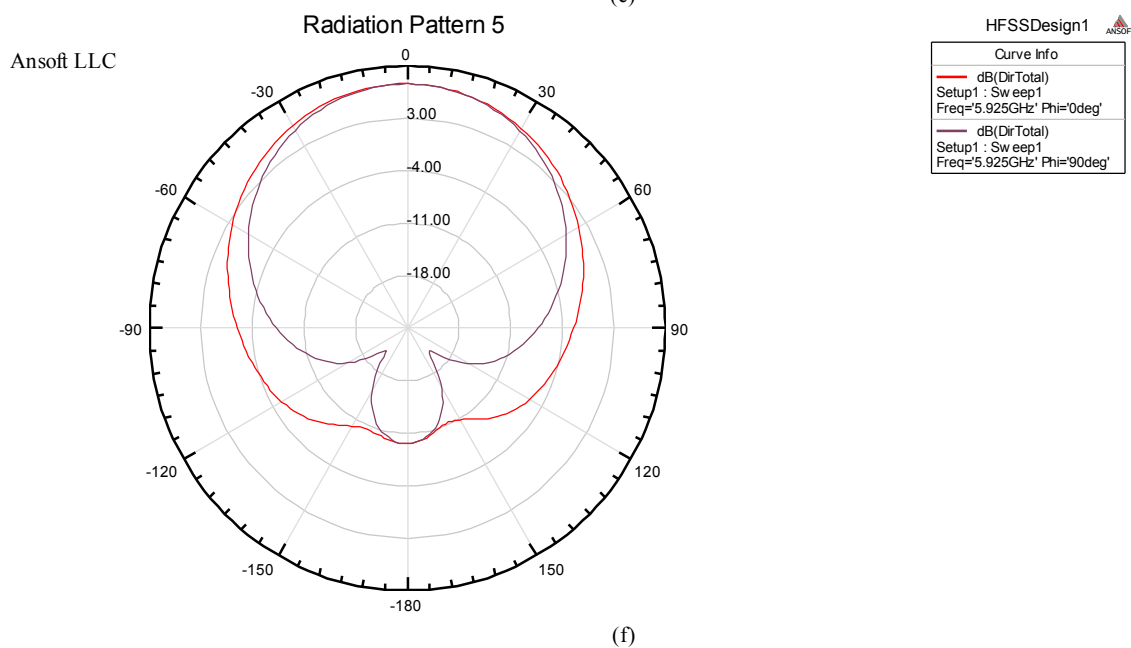
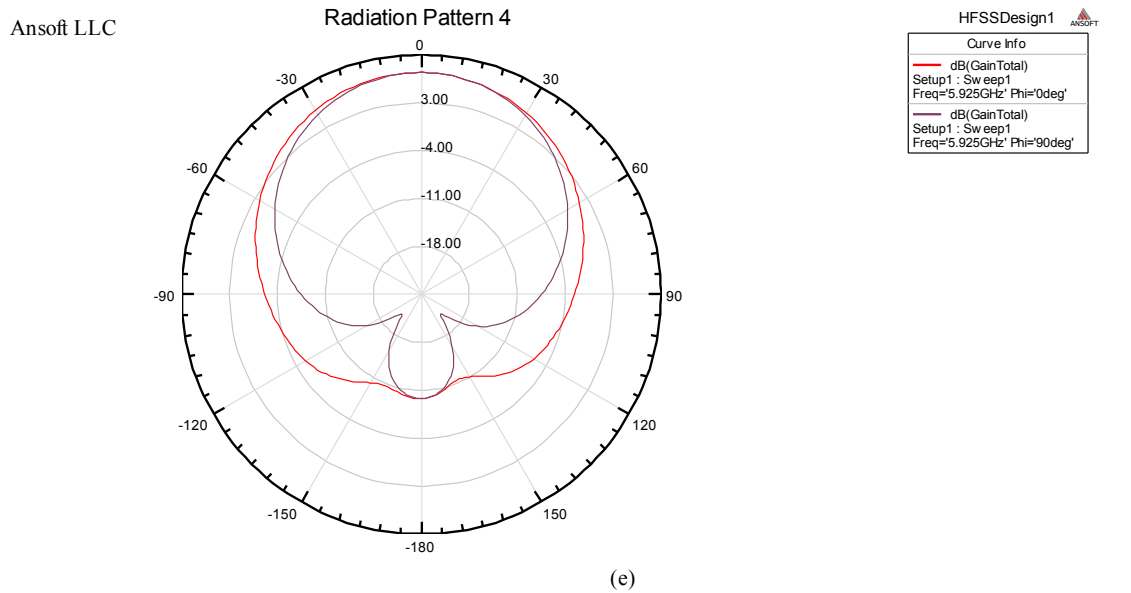


Figure 5(e),(f). Radiation Pattern for Gain and Directivity

Case 3

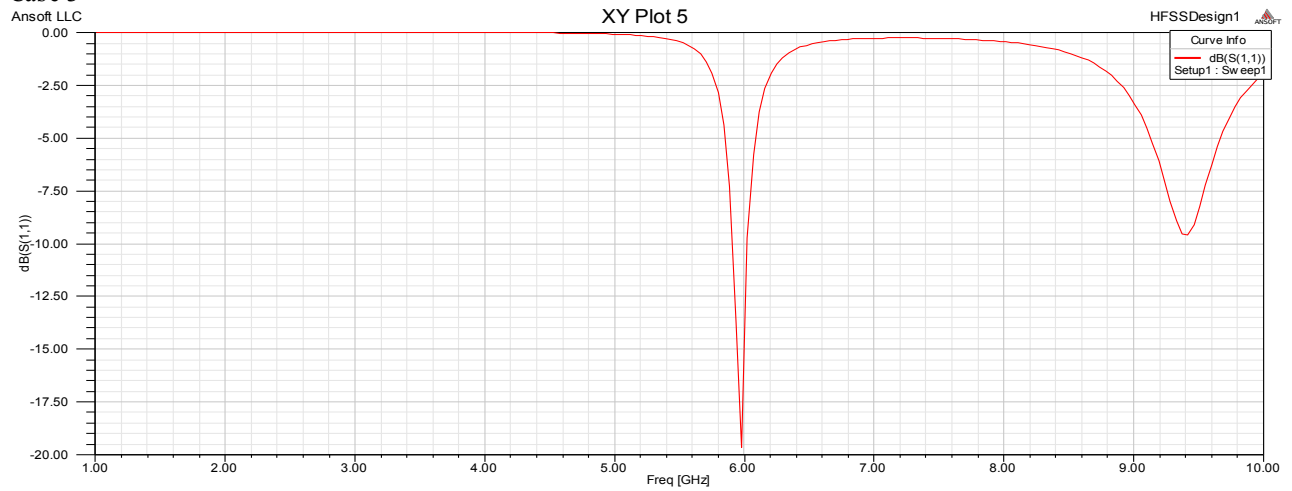
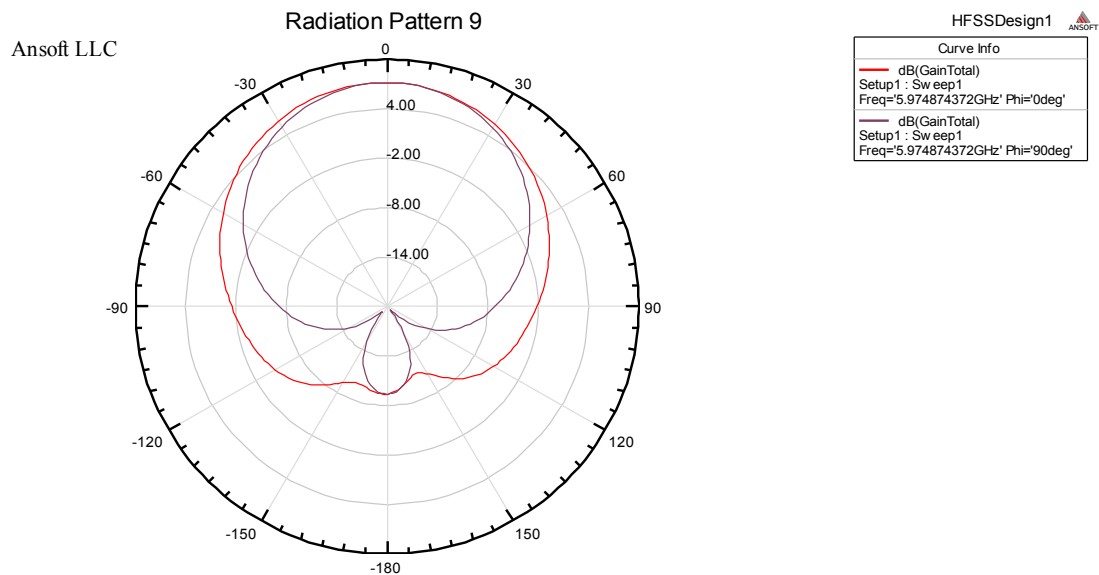
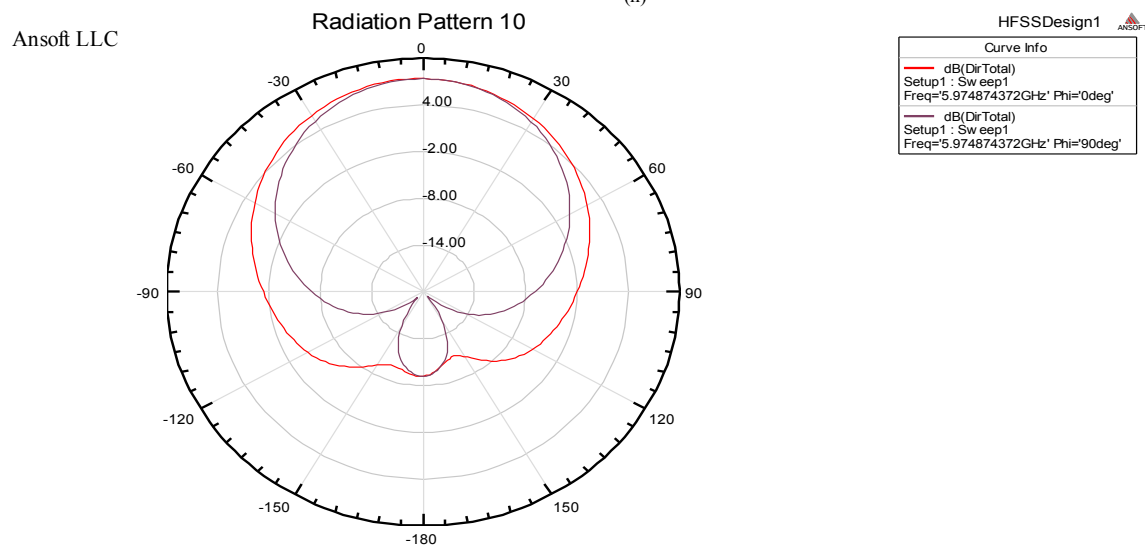


Figure 5(g). Return Loss vs Frequency



(h)



(i)

Figure 5(h),(i). Radiation Pattern for Gain and Directivity

b. Result of Single Patch Antenna with Double Loading

Case 1

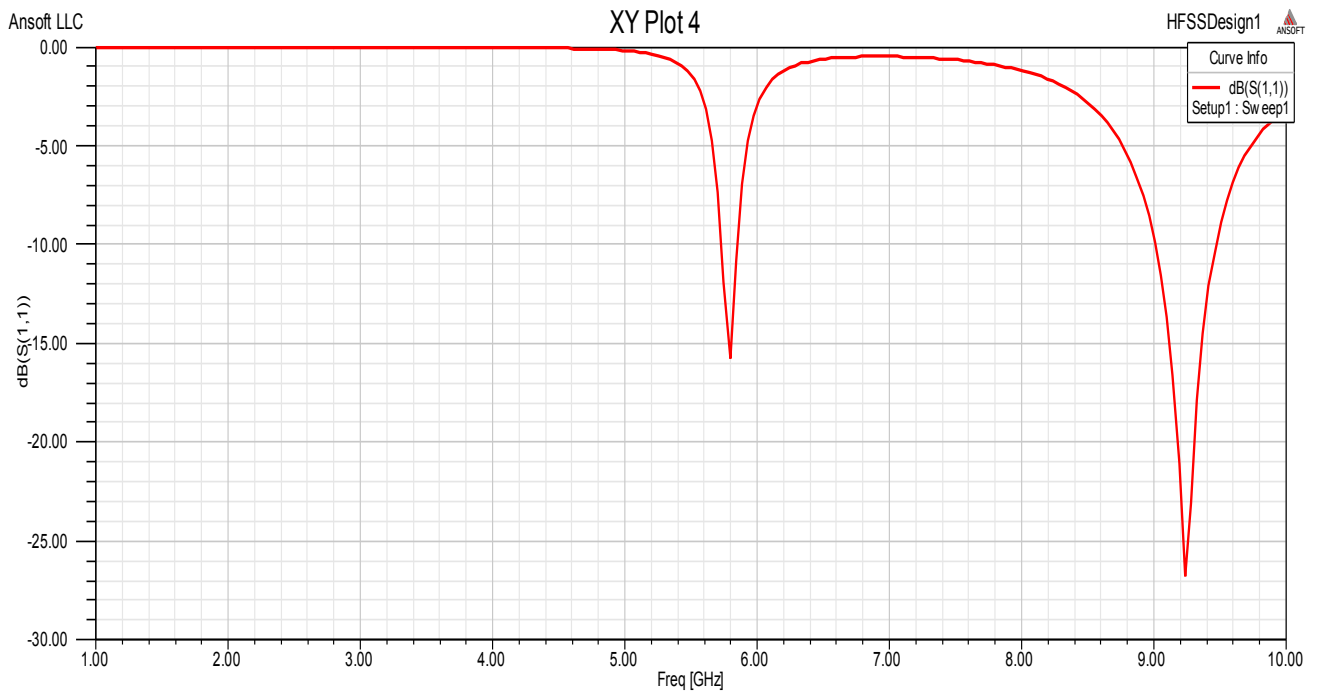
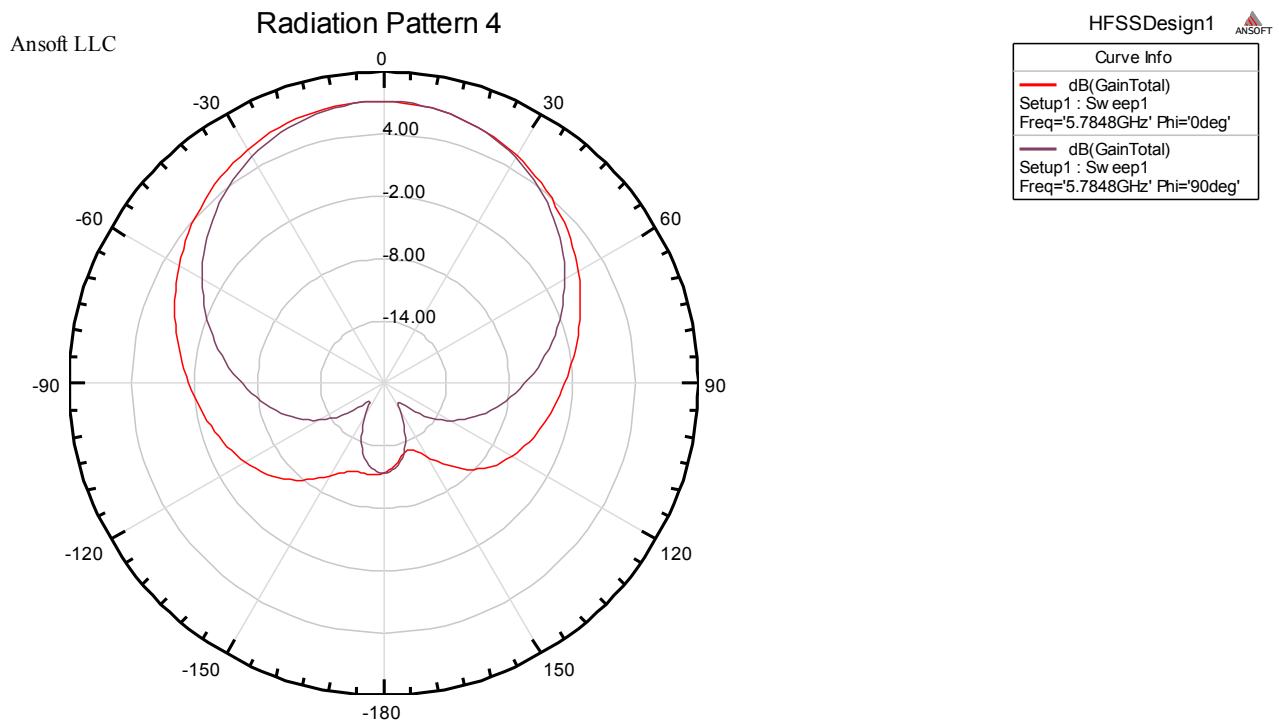


Figure 6(a). Return Loss vs Frequency



(b)

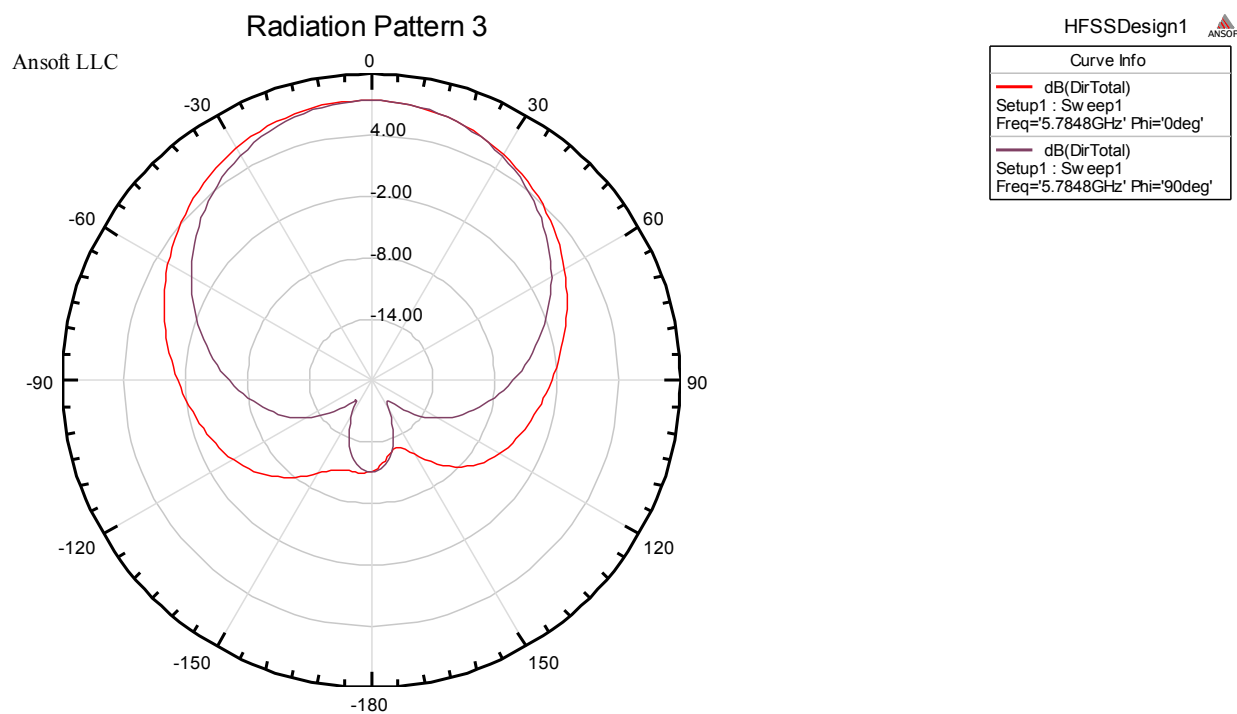


Figure 6(b),(c). Radiation Pattern for Gain and Directivity

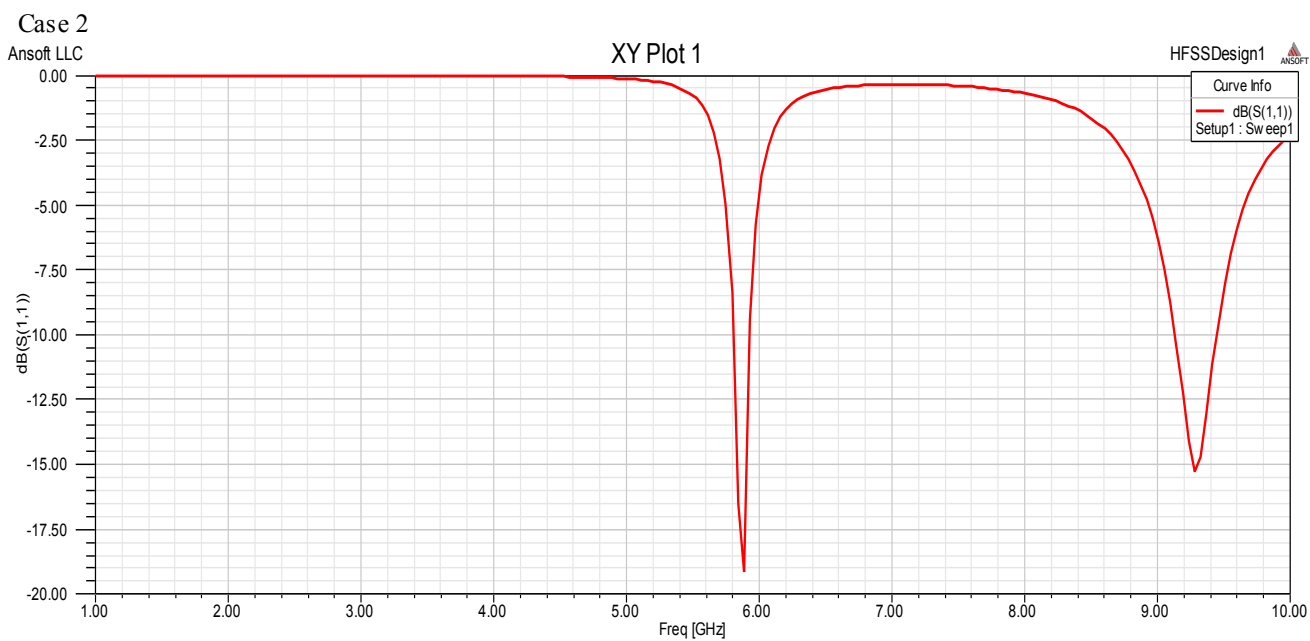


Figure 6(d). Return loss vs Frequency

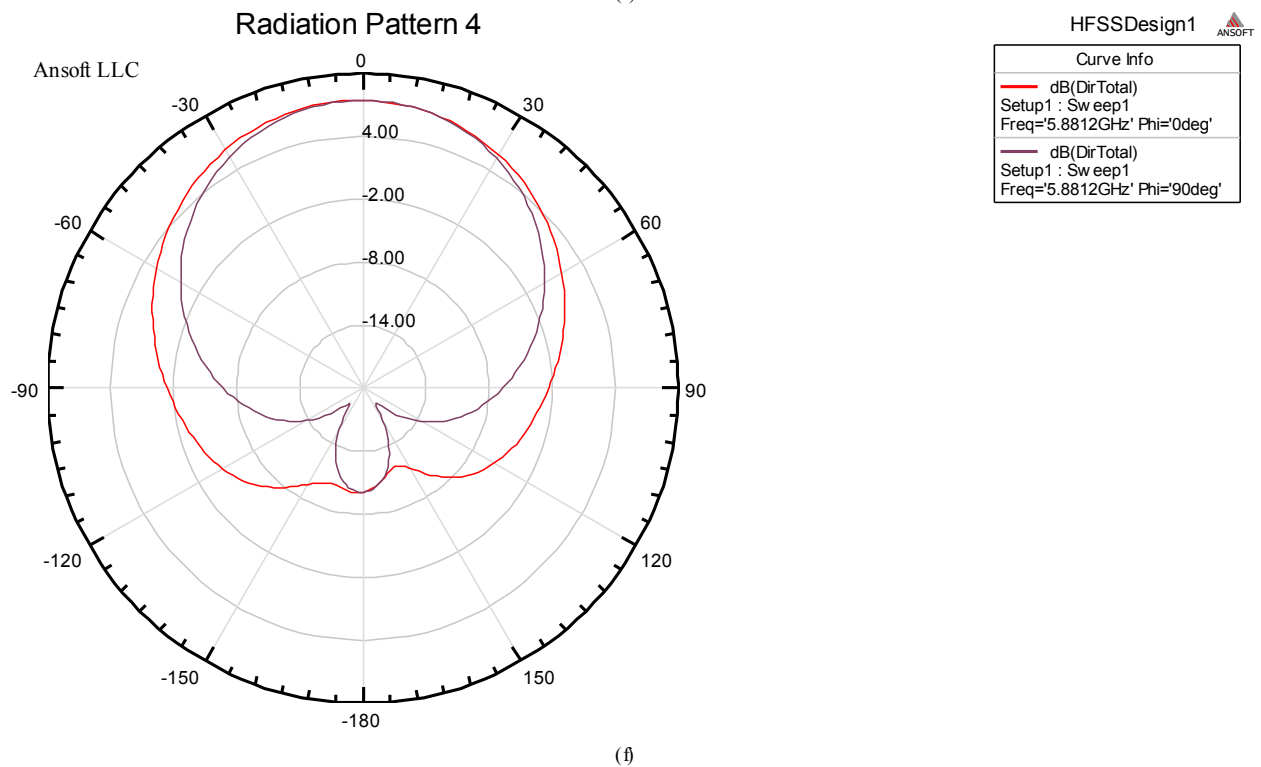
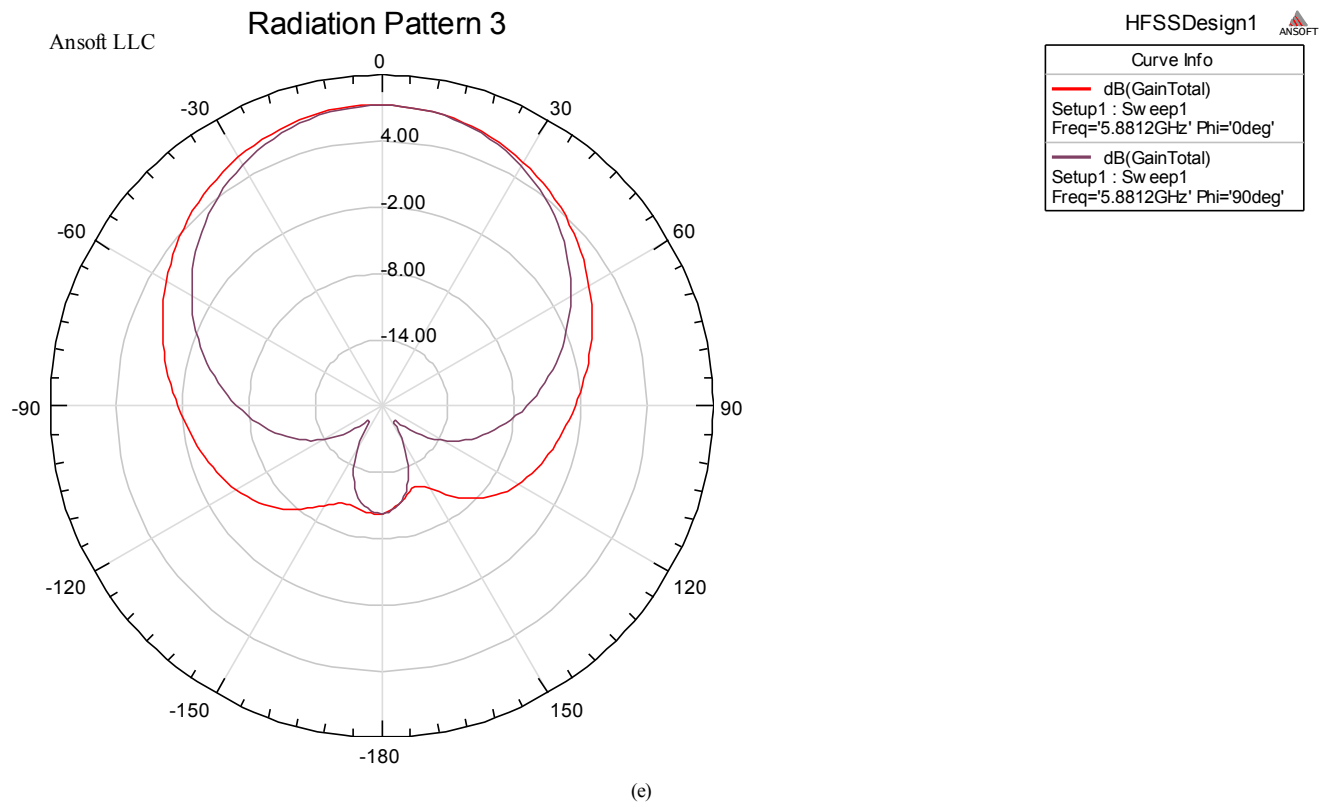


Figure 6(e),(f). Radiation Pattern for Gain and Directivity

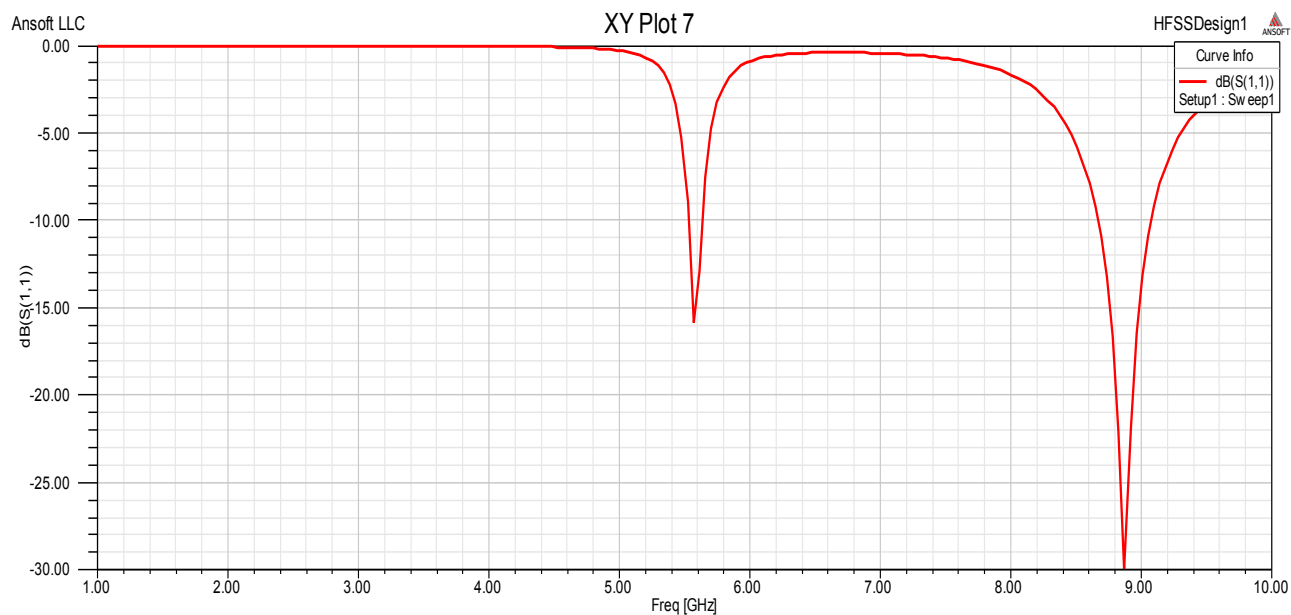
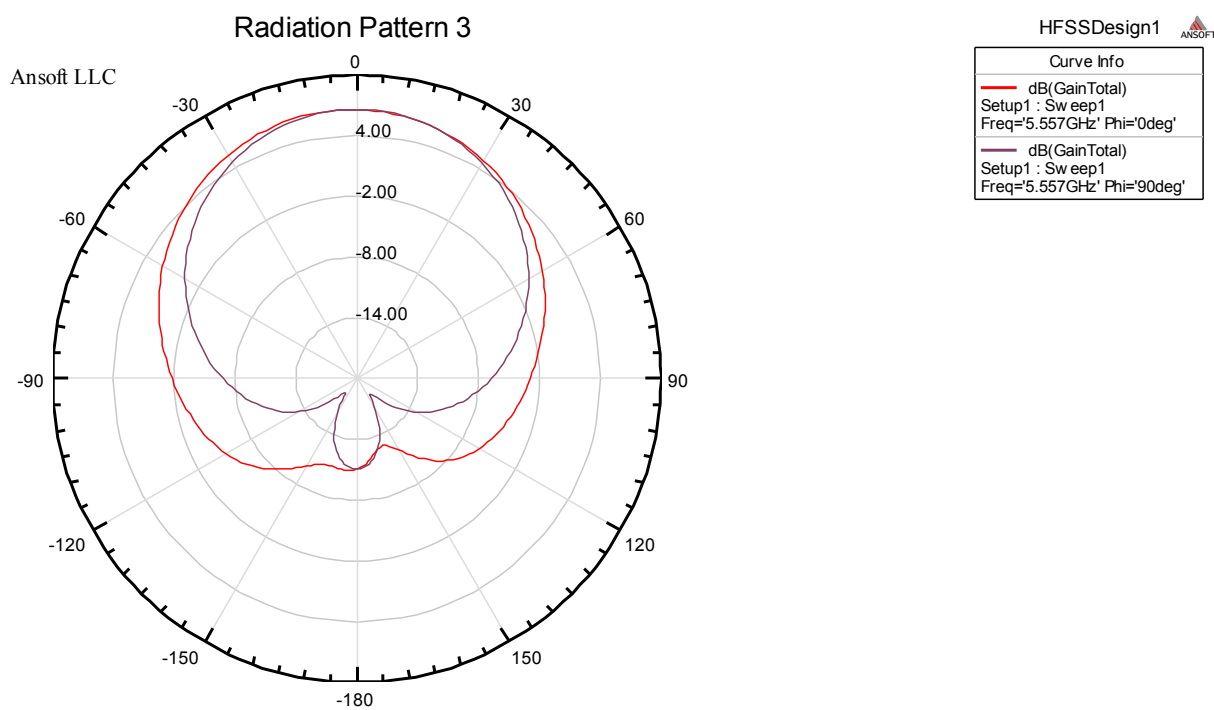


Figure 6(g). Return Loss vs Frequency



(h)

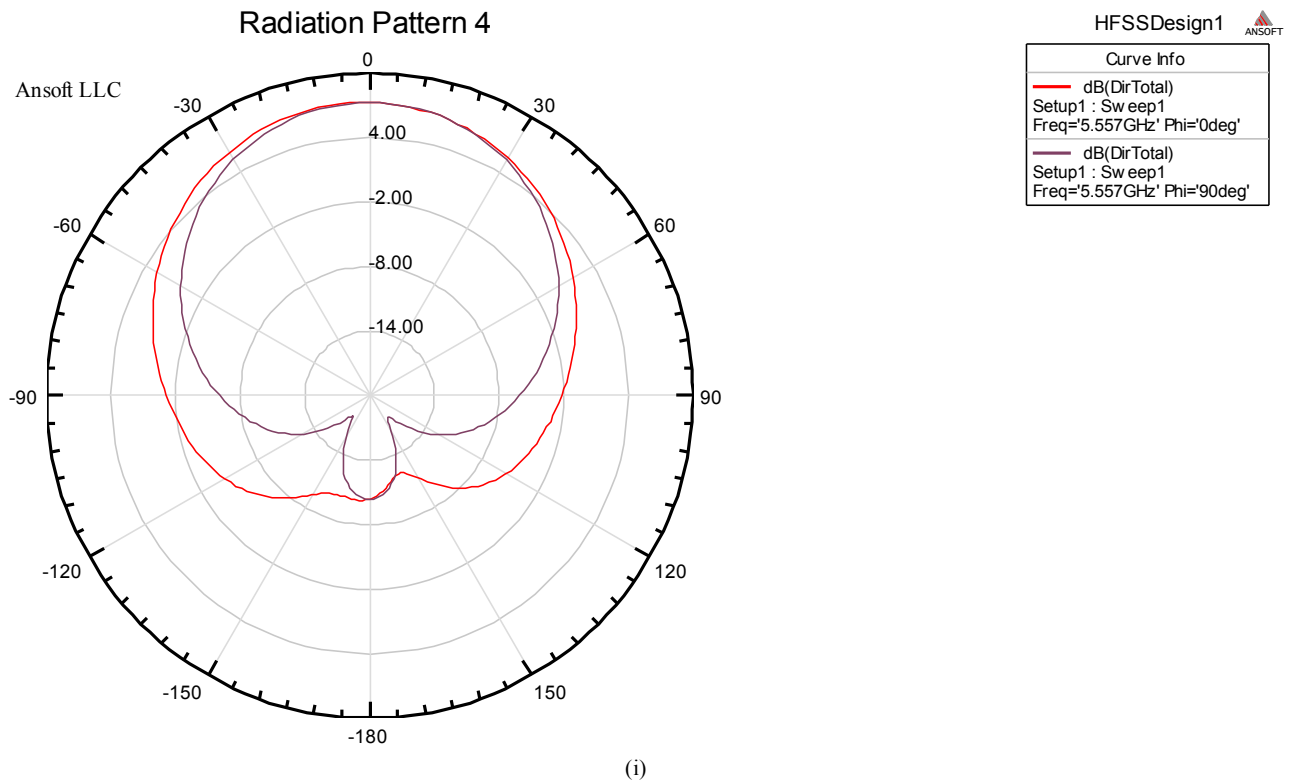


Figure 6(h),(i). Radiation Pattern for Gain and Directivity

Case 4

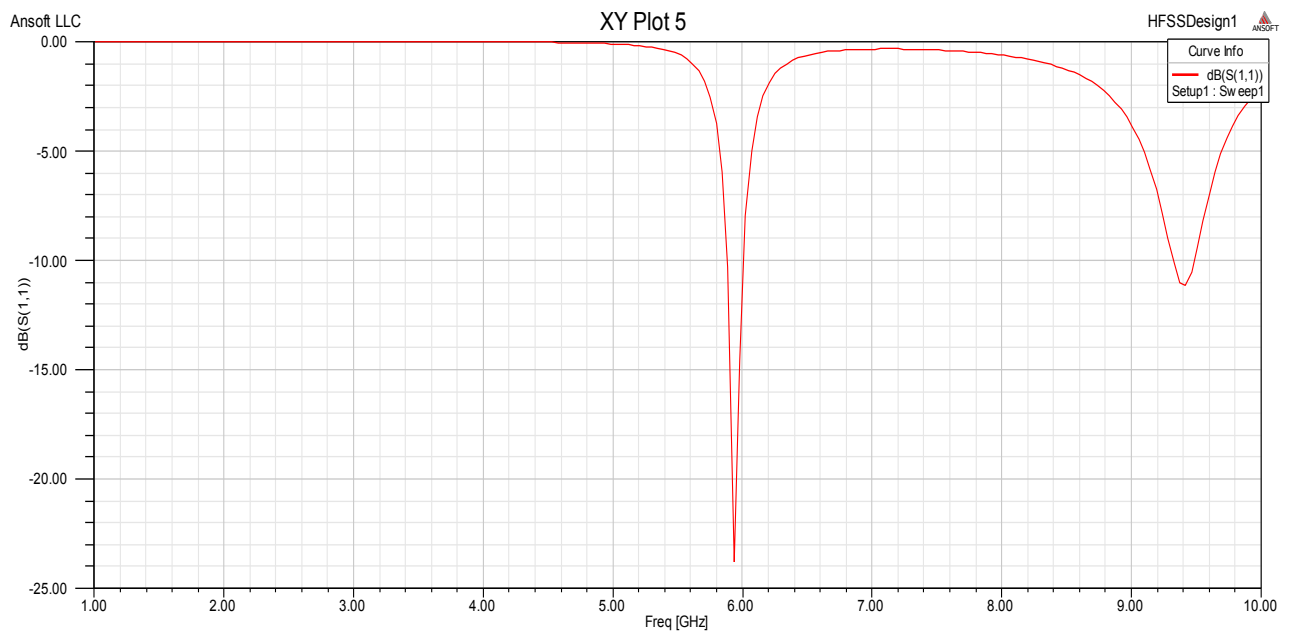
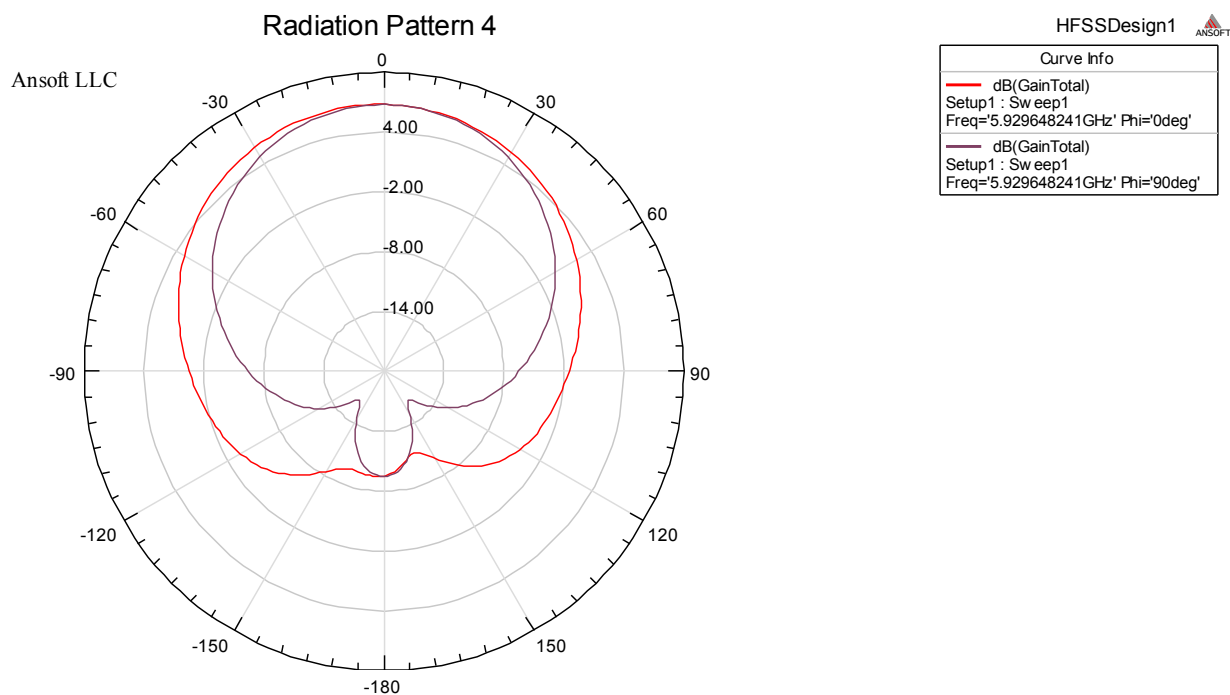
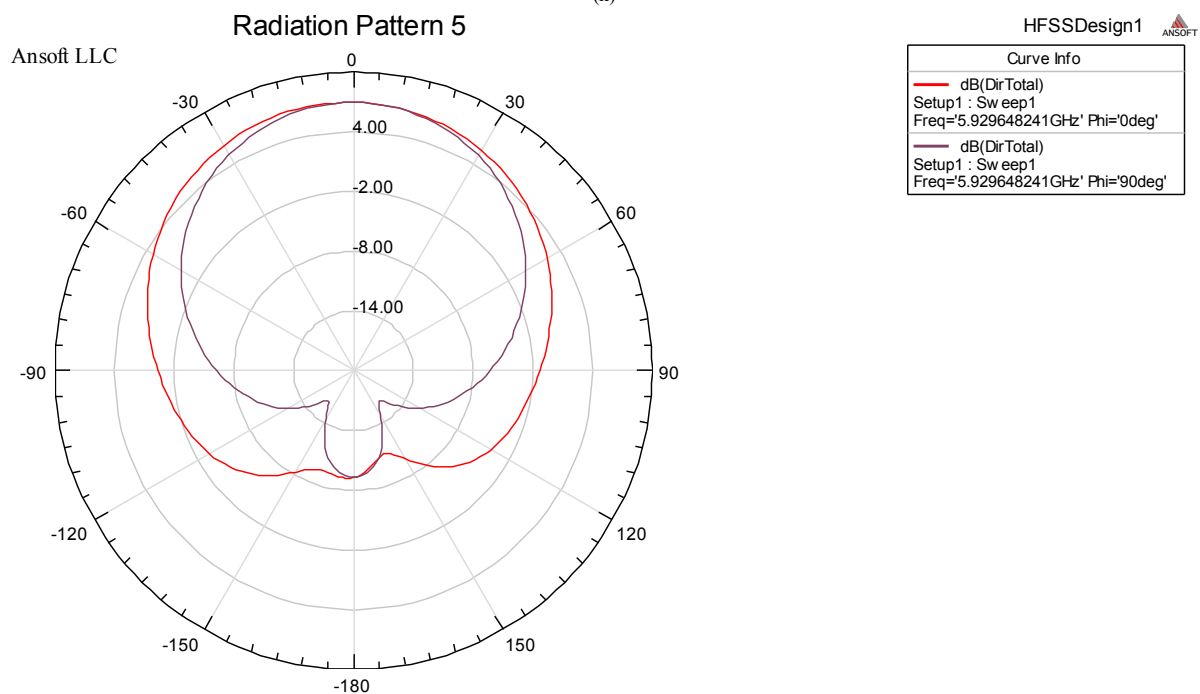


Figure 6(j). Return Loss vs Frequency



(k)



(l)

Figure 6(k),(l). Radiation Pattern for Gain and Directivity

c. Result of Stacked Patch Antenna with Single Loading
Case 1

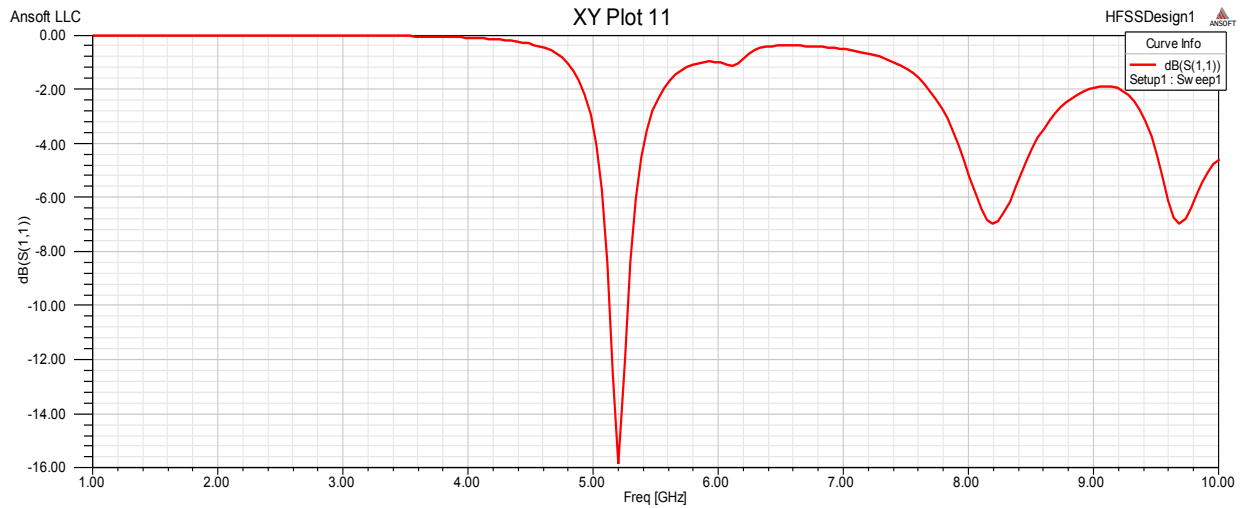
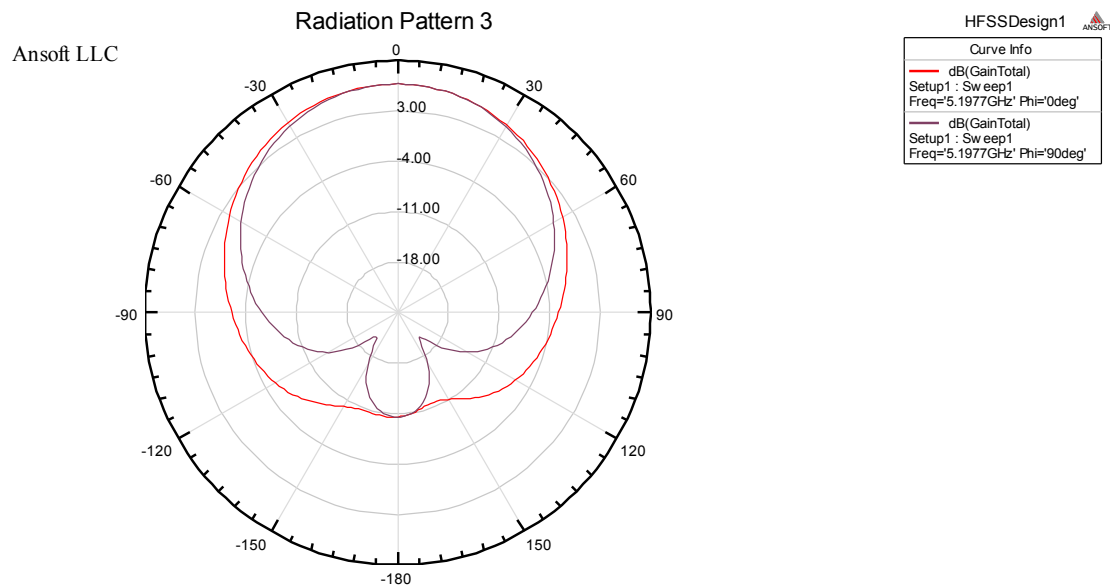
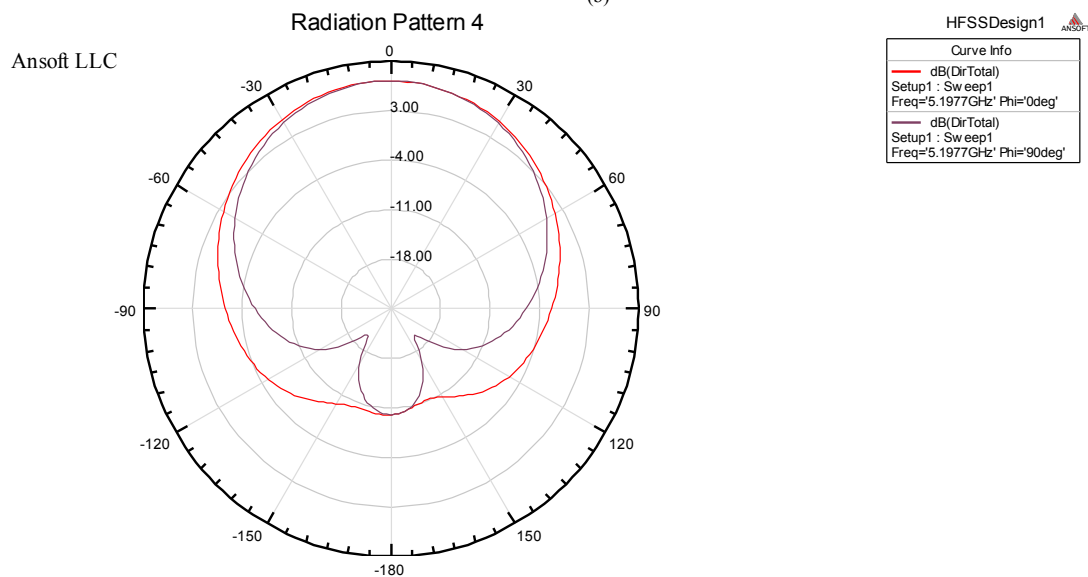


Figure 7(a). Return Loss vs Frequency



(b)



(c)

Figure 7(b),(c). Radiation Pattern for Gain and Directivity

Case 2

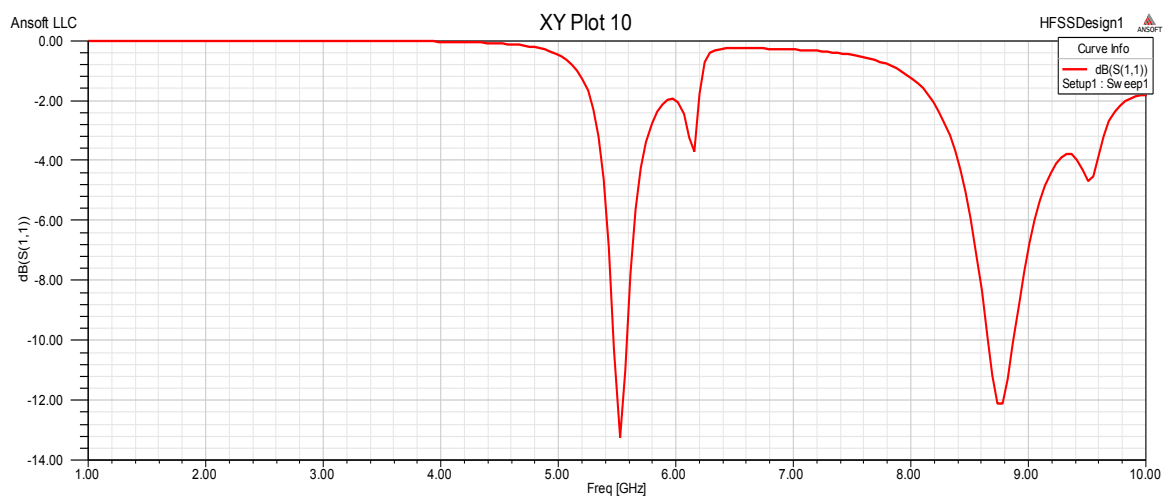
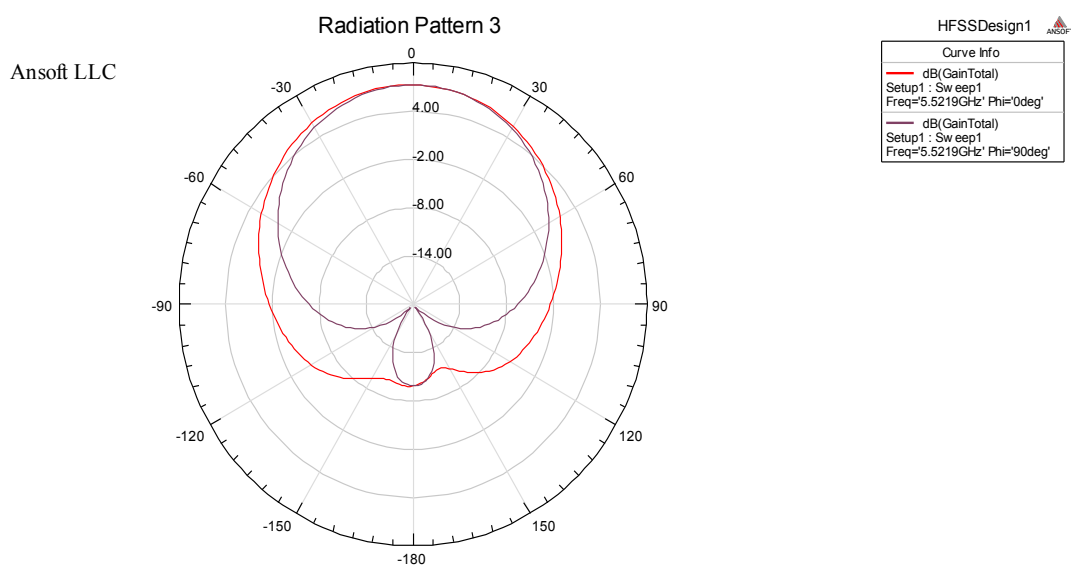
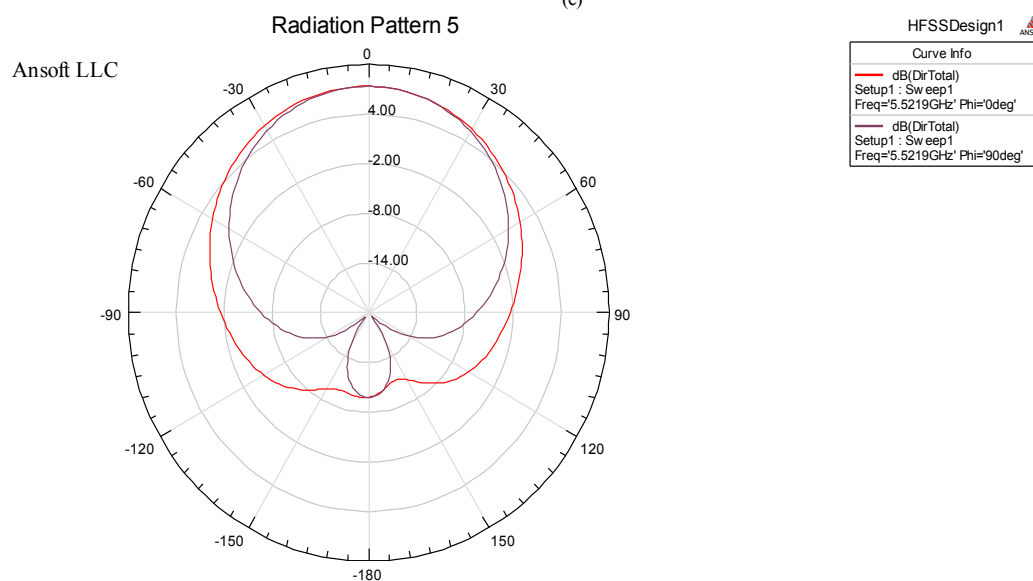


Figure 7(d). Return Loss vs Frequency



(e)



(f)

Figure 7(e),(f). Radiation Pattern for Gain and Directivity

Case 3

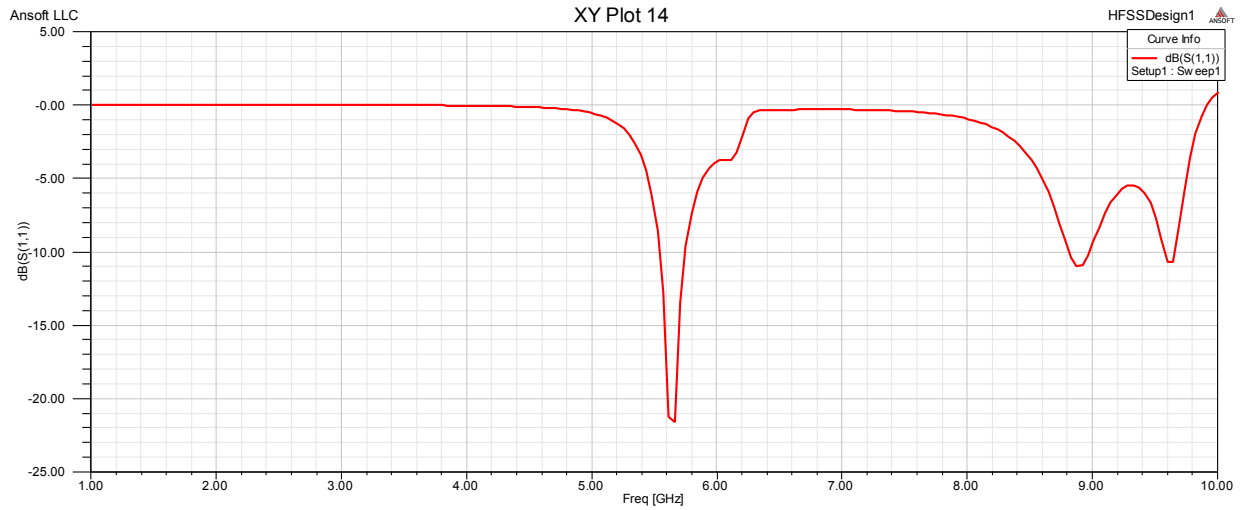
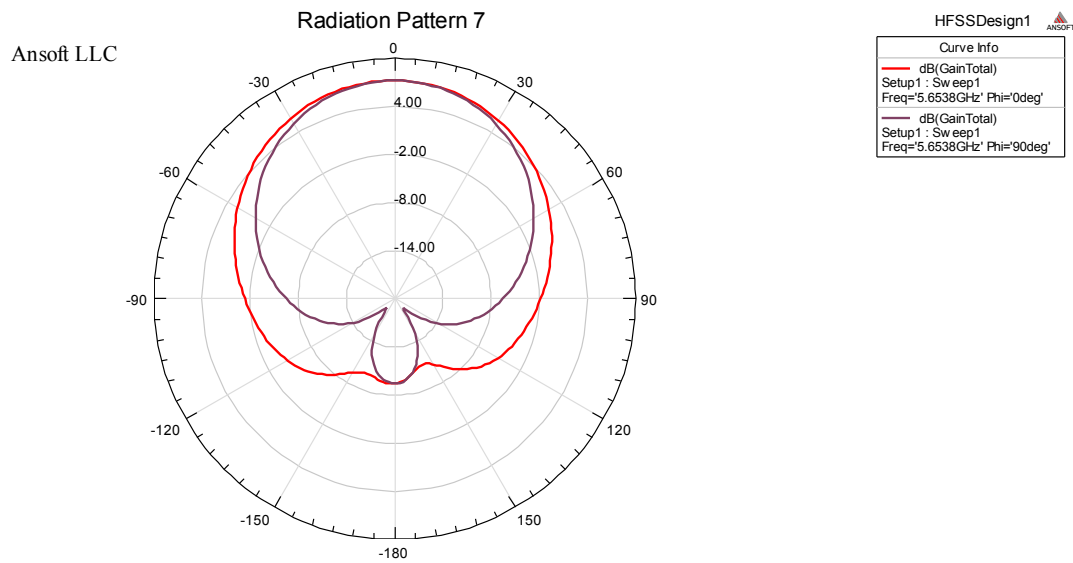
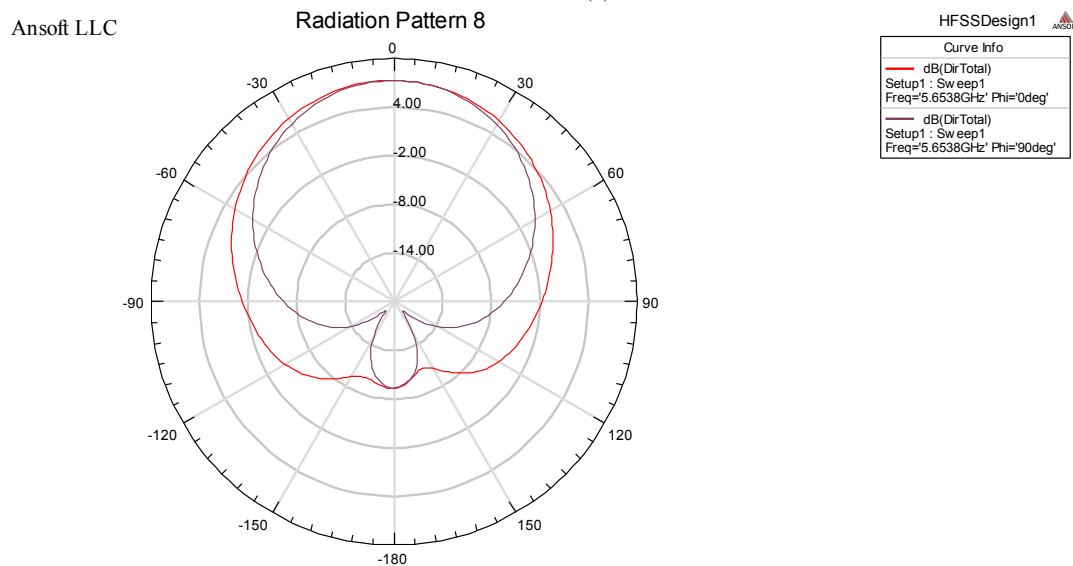


Figure 7(g). Return Loss vs Frequency



(h)



(i)

Figure 7(h),(i). Radiation Pattern for Gain and Directivity

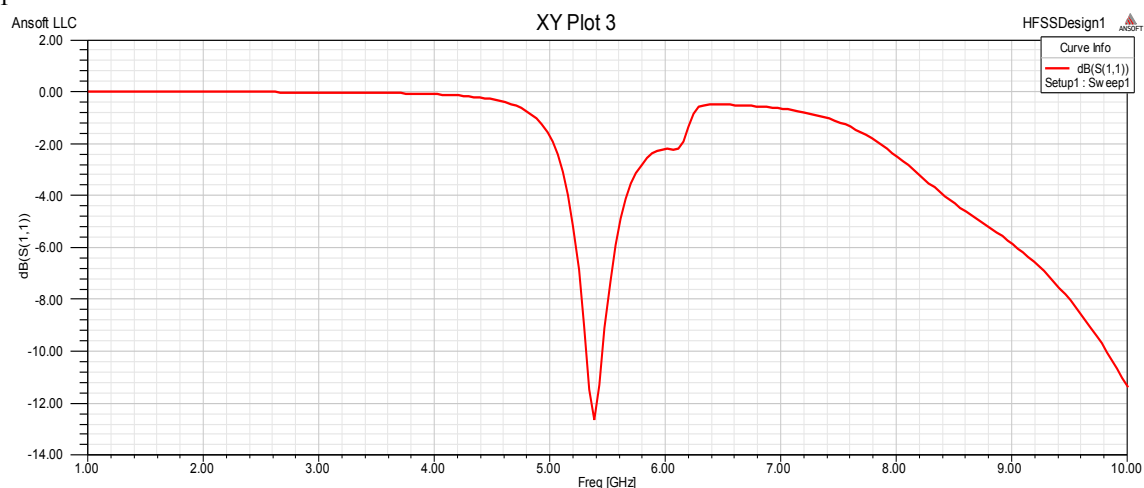
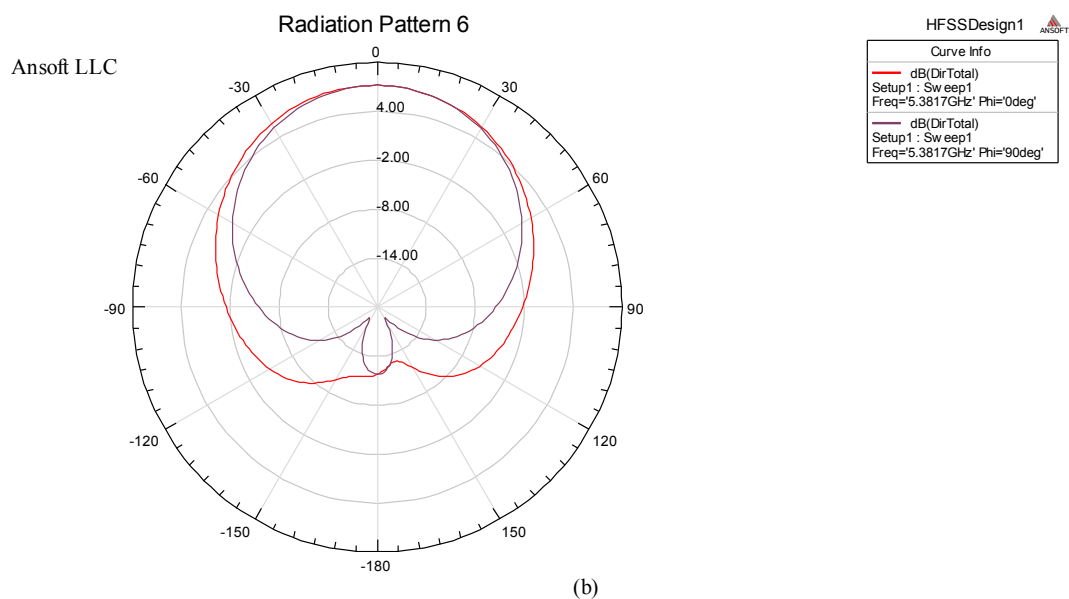
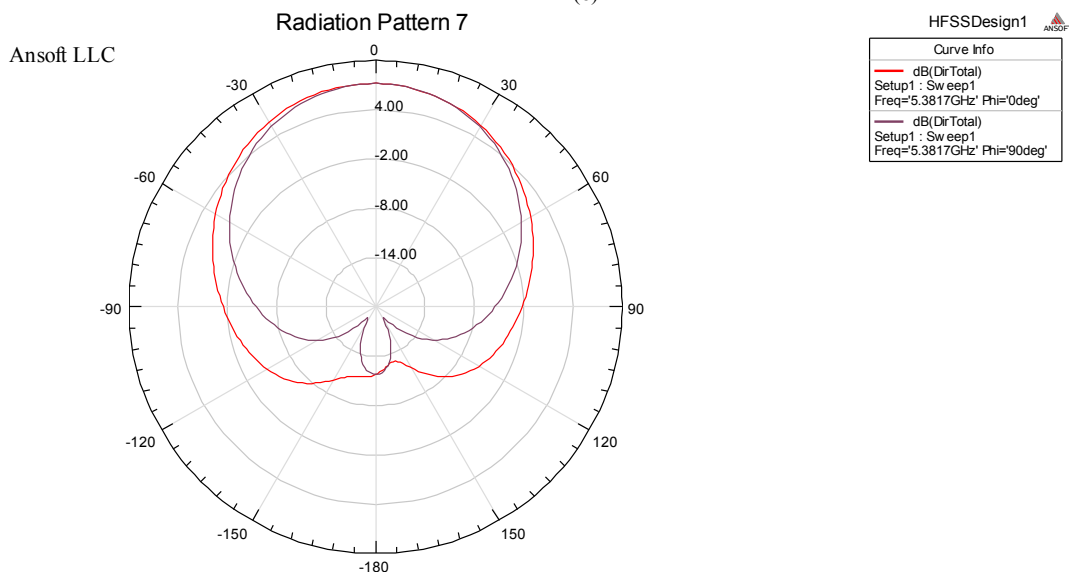
Result of Stacked Patch Antenna with Double Loading
Case 1

Figure 8(a). Return Loss vs Frequency



(b)



(c)

Figure 8(b),(c). Radiation Pattern for Gain and Directivity

Case 2

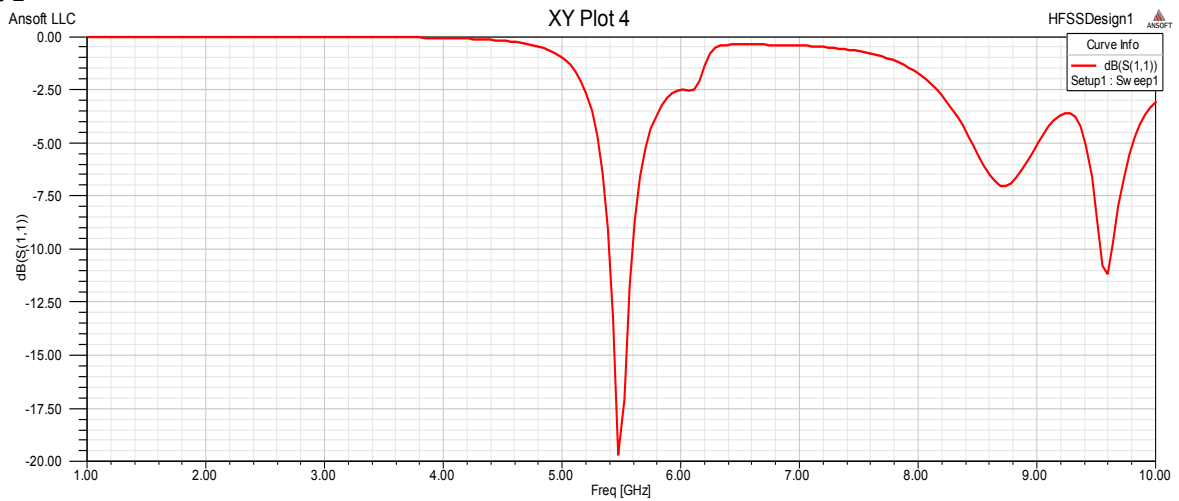
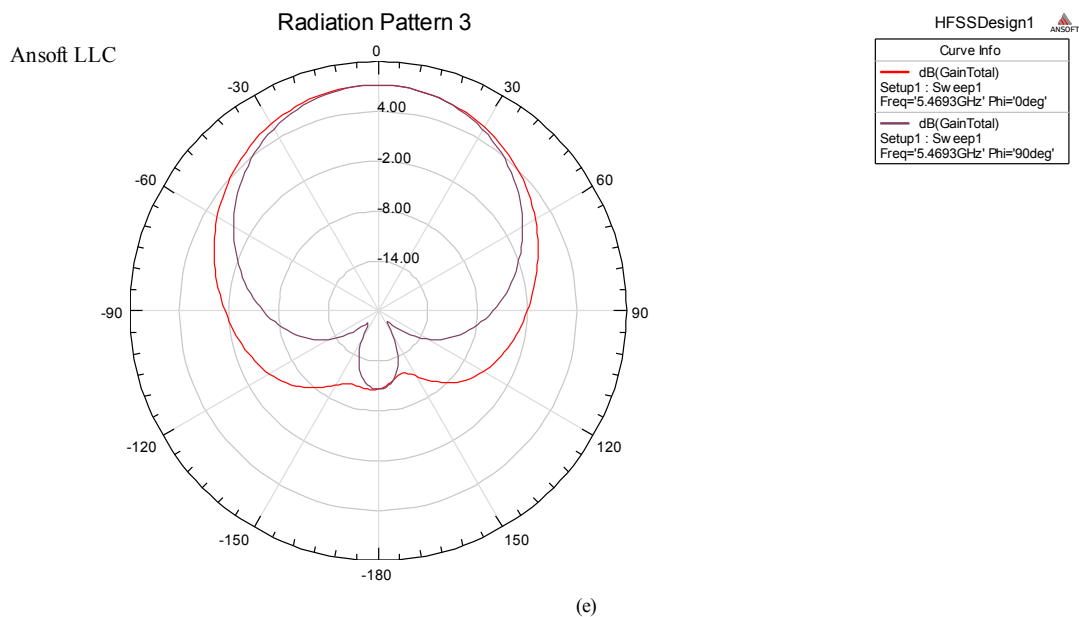
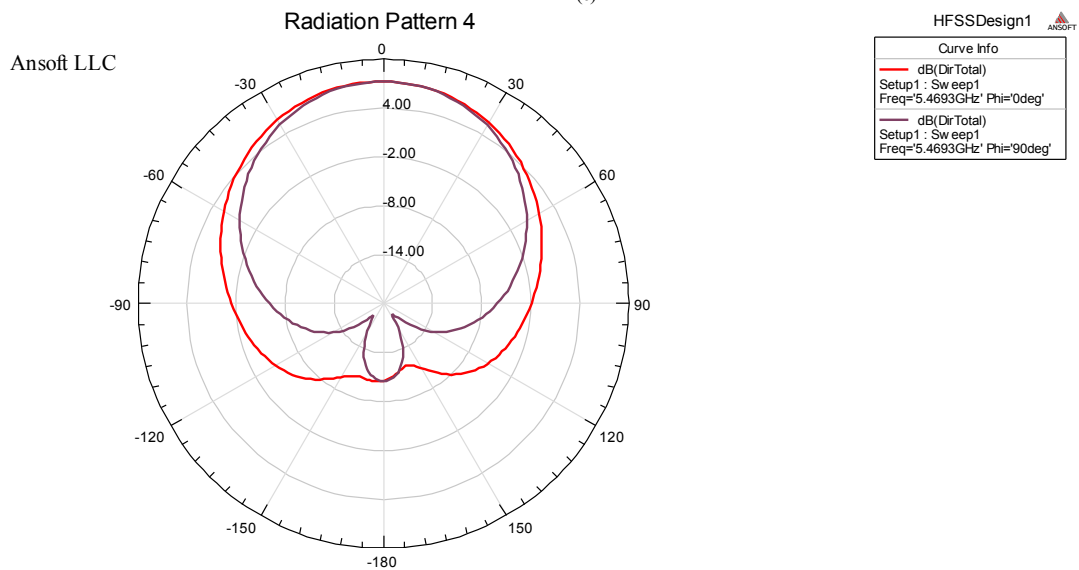


Figure 8(d). Return Loss vs frequency



(e)



(f)

Figure 8(e),(f). Radiation Pattern for Gain and Directivity

Case 3

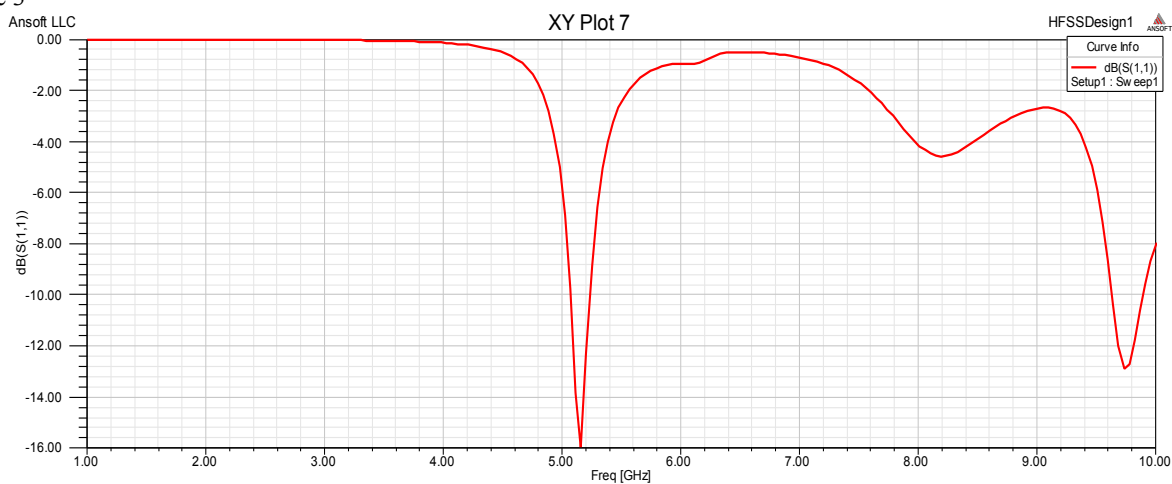
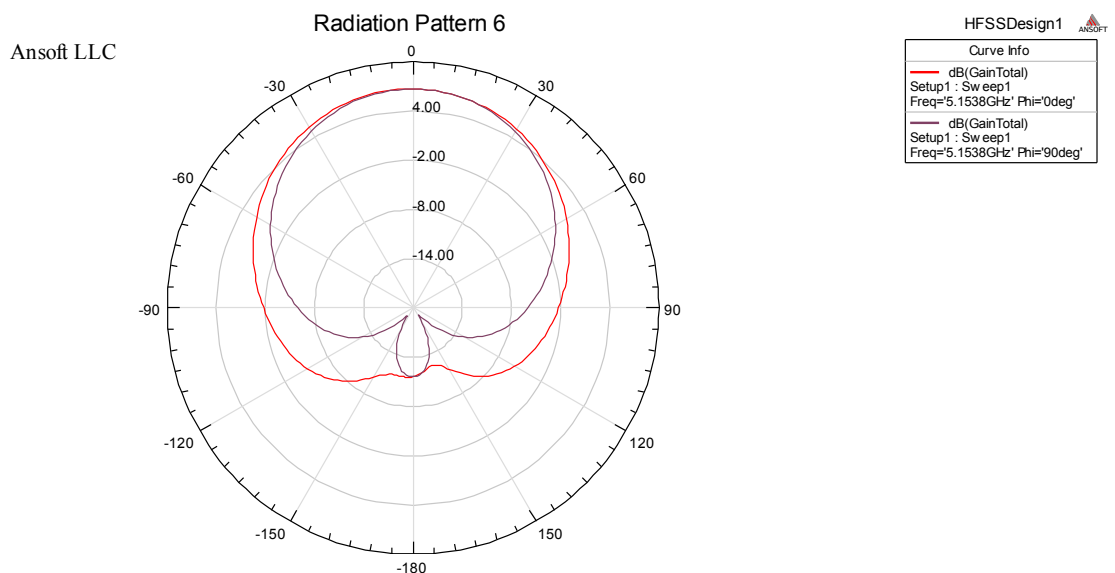
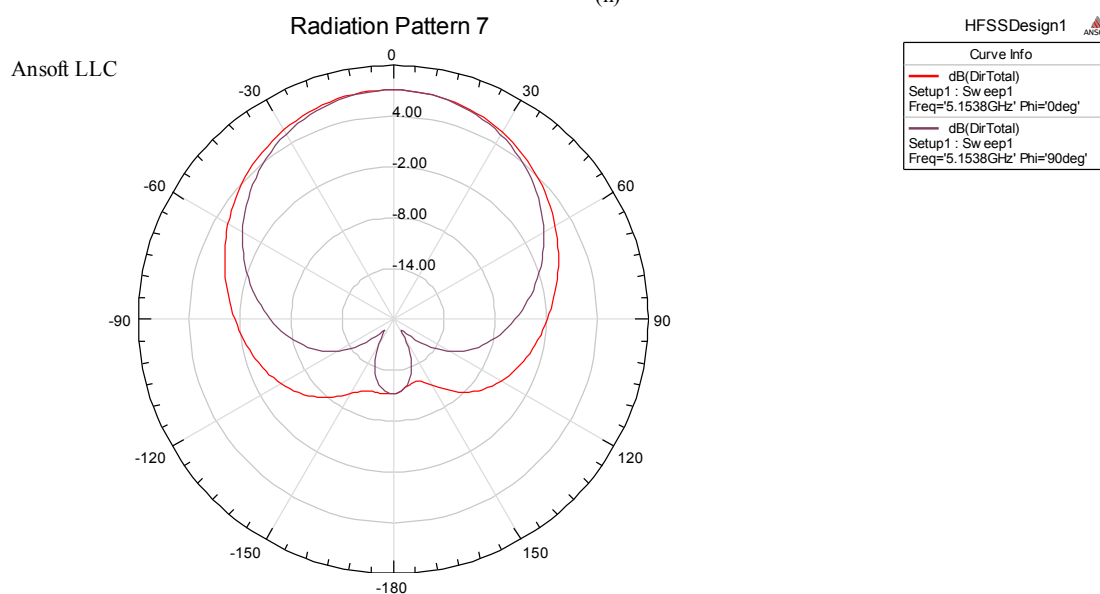


Figure 8(g). Return Loss vs Frequency



(h)



(i)

Figure 8(h),(i). Radiation Pattern for Gain and Directivity

Case 4

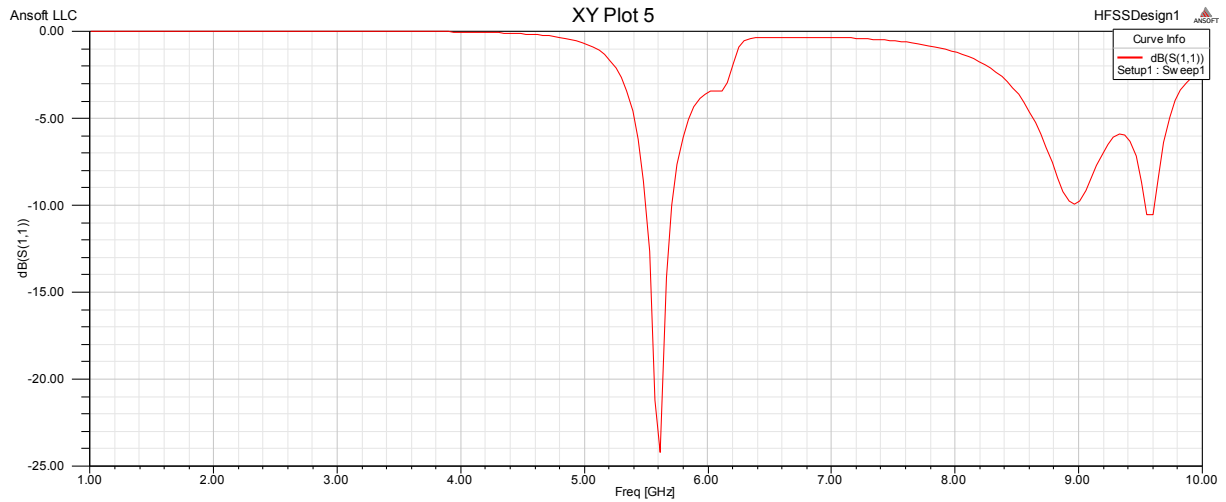
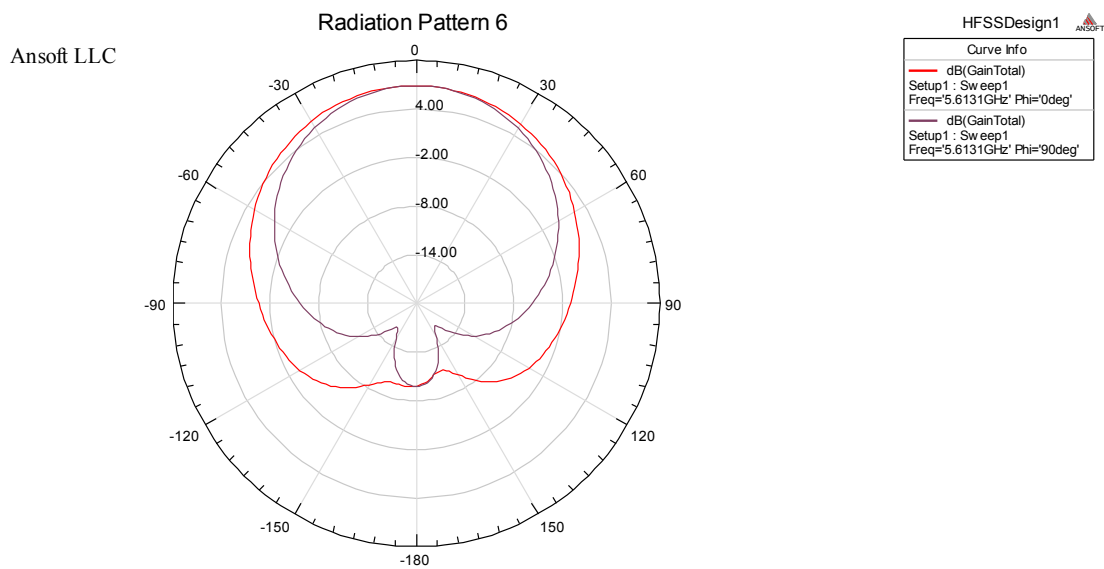
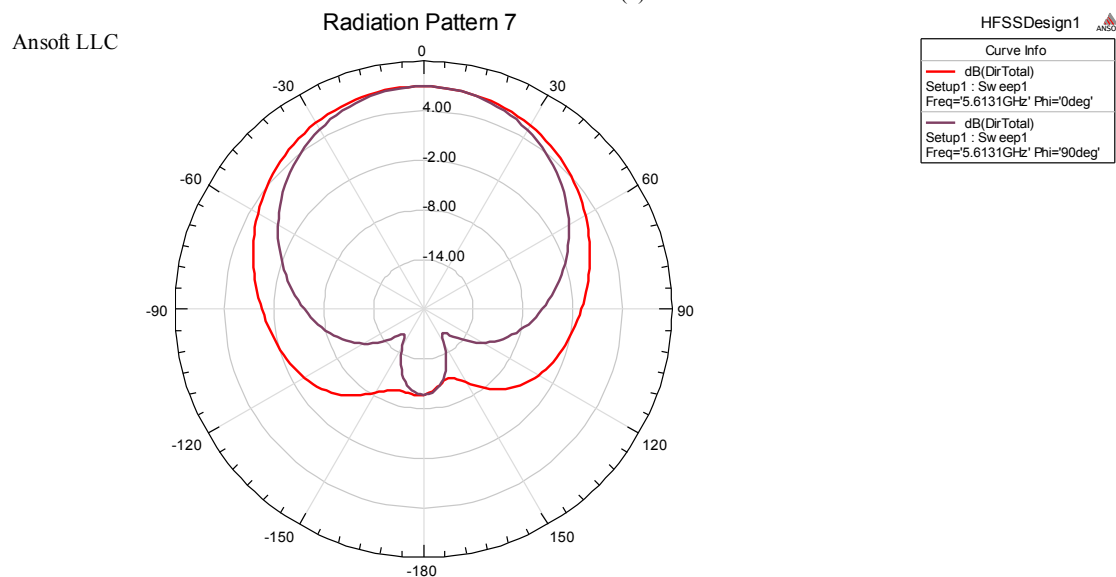


Figure 8(j). Return Loss vs frequency



(k)



(l)

Figure 8(k),(l). Radiation Pattern for Gain and Directivity

The following Table presents all the obtained results in terms of resonant frequency, Directivity, Gain and Efficiency.

VI. Fabrication and testing results

d. Fabrication of Single Patch Antenna with RT/Duroid 5880 Single Loading

After the modeling of probe feed patch antenna and achieving results we came to fabrication part. RT/Duroid 5880 substrate are used for dielectric loading. The dielectric constant of the dielectric loading is 2.2 and the thickness is

0.16cm. The substrate size for every fabricated antenna is 4 x 5.2 cm.



Figure 9(a). Front View of Fabricated Patch Antenna

Table I. Combined Results

S. No.	Design		Resonant Frequency (GHz)	Directivity (dB)	Gain (dB)	Efficiency
1.	A	Case1 ($\epsilon_{r1}=4.4$)	5.5657	5.544	4.66	0.84073
		Case2 ($\epsilon_{r1}=2.2$)	5.9250	5.7825	5.53	0.95717
		Case3 ($\epsilon_{r1}=\text{mag.dielec.}$)	5.9749	5.4742	5.25	0.96066
2.	B	Case1 ($\epsilon_{r1}<\epsilon_{r2}$)	5.7848	5.5133	5.22	0.94725
		Case2 ($\epsilon_{r1}=\epsilon_{r2}$)	5.8812	5.5648	5.34	0.96073
		Case3 ($\epsilon_{r1}>\epsilon_{r2}$)	5.5570	5.3488	4.57	0.85443
		Case4 ($\epsilon_{r1}=\epsilon_{r2}=\text{mag.dielec.}$)	5.9296	4.9818	4.77	0.95838
3.	C	Case1 ($\epsilon_{r1}=4.4$)	5.1977	5.1342	4.61	0.89915
		Case2 ($\epsilon_{r1}=2.2$)	5.5219	5.4687	5.38	0.98423
		Case3 ($\epsilon_{r1}=\text{mag.dielec.}$)	5.6538	5.3822	5.30	0.98516
4.	D	Case1 ($\epsilon_{r1}<\epsilon_{r2}$)	5.3817	5.2695	5.08	0.96541
		Case2 ($\epsilon_{r1}=\epsilon_{r2}$)	5.4693	5.3373	5.24	0.98228
		Case3 ($\epsilon_{r1}>\epsilon_{r2}$)	5.1538	5.1264	4.68	0.91367
		Case4 ($\epsilon_{r1}=\epsilon_{r2}=\text{mag.dielec.}$)	5.6131	4.9647	4.88	0.9848

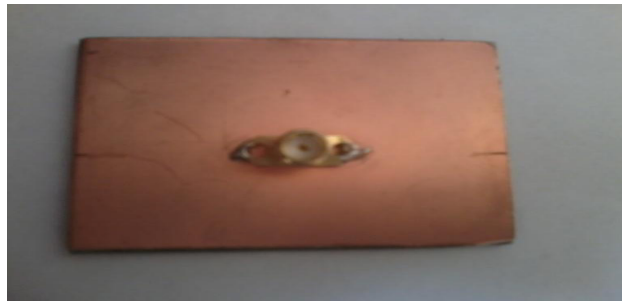


Figure 9(b). Back View of Fabricated Patch Antenna

e. Testing Result

Testing of patch antenna is done by network analyzer. Network analyzers are used mostly for high frequencies. Network analyzer is an instrument used to analyze the properties of electrical network, especially those properties associated with the reflection and transmission of electrical signals known as scattering parameters.

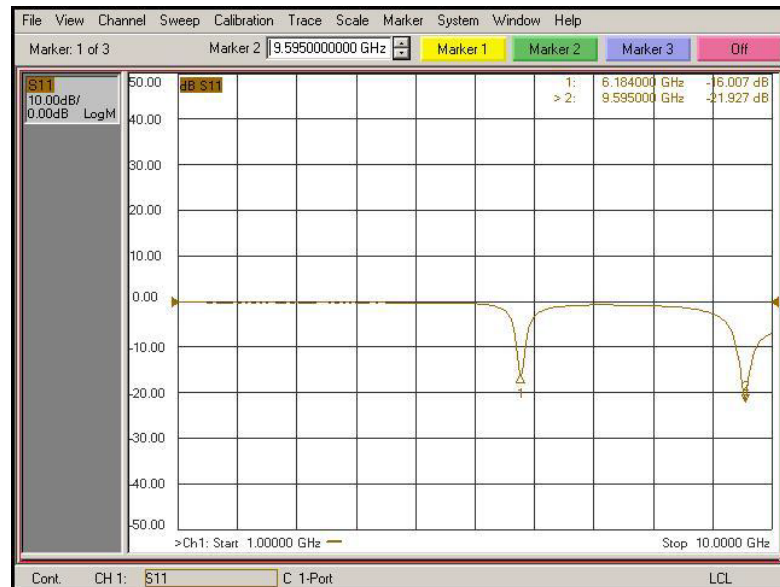


Figure 10. Tested Result of Fabricated Patch Antenna

The testing results of single patch antenna with single loading. The dielectric material RT/Duroid 5880 is used for loading. The antenna is designed at 6 GHz frequency. Even though antenna is desired to operate at this frequency, when tested practically it is found that its resonant frequency is 6.1 GHz.

4. Conclusions

Behavior of the patch antenna due to the effect of dielectric loading having different dielectric constants is investigated. Dielectric constant play major role in overall performance of patch antenna. The study reveals that dielectric loading not only changes the resonant frequency but also affects its other parameters such as gain, directivity and efficiency. It has been observed that resonant frequency of patch antenna is shifted to a lower value after compared all cases as a result of dielectric loading with dielectric constant 2.2 is used on antenna. Dielectric loading with magneto dielectric provides less frequency shift which is closer to the operating frequency i.e. 6 GHz and other parameters are improved after comparison when dielectric loading with lowest dielectric constant (2.2) is used.

REFERENCES

- [1] A.Sabban, "A new broadband stacked two-layer microstrip antenna", IEEE Trans. Antenna Propagat. Soc. Int. Symp. Dig., pp. 63–66, 1983.
- [2] H.Y.Yang and H.G. Alexopoulos, "Gain enhancement methods for printed circuit antennas through multiple superstrates", IEEE Trans. Antennas Propagat., vol. AP-35, pp.860–863, 1987.
- [3] R.Q. Lee and A.J Zaman, "Effects of dielectric superstrates on a two layer electromagnetically coupled patch antenna", IEEE Trans. Antennas Propagat., 1989.
- [4] R.Q.Lee and K.F.Lee, "Experimental study of the two-layer electromagnetically coupled rectangular patch antenna", IEEE Trans. Antennas and Propagat., vol 38, no 8, 1990.
- [5] Jeen-Sheen Row and Kin-Lu Wong, "Resonance in a superstrate-loaded rectangular microstrip structure", IEEE Trans. On Microwave Theory And Tech., vol 41, No.8, 1993.
- [6] Lei Zhu, Eikichi Yamashita and Ikuhiro Jouishi, "Spectral domain analysis of circularly polarized rectangular patch antennas with a dielectric superstrate", IEEE Trans., 1996.
- [7] Chih-Yu Huang and Jian-Yi Wu, "Compact microstrip antenna loaded with very high permittivity superstrate", IEEE Trans., 1998.
- [8] A.K Verma and Nasimuddin, "Input impedance of rectangular microstrip patch antenna with iso/anisotropic substrate-superstrate", IEEE Microwave and Wireless Components Letters, vol 11, No.11, 2001.
- [9] R. Chair and K.M. Luk "Measurement and analysis of miniature multilayer patch antenna", IEEE Trans. Antenna Propag , vol.50, pp.244-250, 2002.
- [10] Debatosh Guha and Jawad.Y.Siddiqui, "Resonant frequency of circular microstrip antenna covered with dielectric superstrate", IEEE Trans. On Antennas and Propagat., vol 51, No 7, 2003.
- [11] Samik Chakraborty, Sabyasachi Mandal and Bhaskar Gupta, "Neural network modeling for the fast estimation of superstrate loading effect on rectangular microstrip patch antennas", IEEE Trans., 2007.
- [12] G.M.Yang and K.Naishadham, "Loading effects of self biased magnetic films on patch antennas with substrate/superstrate sandwich structure", IET Microw. Antennas Propag, vol 4, pp.1172-1181, 2010.
- [13] R. K. Yadav and R. L. Yadava,"Performance analysis of superstrate loaded patch antenna and abstain from environmental effects," *International Journal of Engineering*

- Science and Technology (IJEST)*, Vol. 3, No. 8, pp. 6582-6591, August 2011.
- [14] R. K. Yadav and R. L. Yadava, "Effect on performance characteristics of rectangular patch antenna with varying height of dielectric cover," *International Journal of Power Control Signal and Control (IJPCSC)*, Volume 2, No. 1, pp. 55-59, March 2011.
- [15] Samir Dev Gupta and Amit Singh, "Design and analysis of multielectric layer microstrip antenna with varying superstrate layer characteristics", *International Journal of Advances in Engineering & Tech.*, vol 3, pp.55-68, 2012.