Enhanced Patch Antenna Performance Using Two Layers Dielectric Superstrate in Probe-Edge-Inset and Aperture Feeding Methods

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***Abstract*—Dielectric superstrate enhanced patch antennas could advantageously replace conventional array antenna in several application. This new technology simplifies the antenna configuration and can potentially lead to lighter and cost effective solutions. In this paper, the design of a microstrip patch antenna utilizing superstrate layers for performance enhancement is presented. The proposed antenna is excited by using the edge, inset, probe and aperture feeding methods. The double layer dielectric superstrate disposed above the patch antennas are used for enhancing the directivity and also for getting better return loss since microstrip antennas have limitations in directivity, gain and efficiency. The proposed antennas are simulated by using the Ansoft HFSS software. The characteristics of the edge, inset, probe and aperture feeding patch antennas covered by superstrate are obtained in terms of return loss, directivity, VSWR and radiation pattern and are compared with those of the same patch antennas without superstrate. We also carry out a parametric study of the distance between the lower and the higher superstrate, and examine how this separation distance affects the directivity and beam shaping of the composite structure. The return loss up to -47.06dB and directivity equal to 13.5dB are obtained at the center frequency of 8 GHz for the aperture coupled patch antenna through the use of the superstrate layers. This antenna is found to be suitable for X band applications.**

***Index Terms*—patch antenna, HFSS, dielectric superstrate, return loss, directivity, radiation pattern**

I. Introduction

Microstrip Antenna (MPA) is one of the most useful antennas for wireless communication networks which are operating at microwave frequencies (f>1GHz) because of its inherent advantages like low profile, light weight and easy fabrication. Microstrip antenna consists of a metal "patch" on one side of a dielectric substrate and ground plane on the other side. The patch may be in a variety of shapes such as square, rectangular, circular and elliptical, but rectangular and circular are the most commonly used shapes [1]. Feeding techniques such as microstrip line feed, probe feed and Aperture coupled feed are commonly used to feed the microstrip antennas.

Most compact microstrip antenna designs show decreased antenna gain owing to the antenna size reduction. Traditionally microstrip arrays are used [2], in many telecommunication applications such as satellites and radars, but they need complex feeding networks to generate higher gain and good directivity and also the coupling between each element of the array. To meet this goal, smaller microstrip antennas have become an unavoidable choice. Several size reduction techniques have been developed to miniaturize antennas. Amongst these techniques is the implementation of optimization algorithms such as Genetic Algorithms (GA) [3] and Particle Swarm (PS). In addition, techniques based on algorithms are preferable when there are many variables involved such as antenna design. Although good size reduction rates comes at the expense of the antenna gain. Of interest is a technique to address this problem by enhancing the gain of the antenna.

To overcome this disadvantage and obtain an enhanced antenna gain, several designs for gain-enhanced compact microstrip antennas with the loading of a high-permittivity dielectric superstrate [4]-[6] have been demonstrated. Use of a high-permittivity superstrate loading technique [7]-[9] gives an increase in antenna gain and directivity as well as overcoming problems encountered using an array of several antennas.

However, to the best of our knowledge, all proposed superstrates in the literature are metallic structures, such as Split Ring Resonator (SRR) [10]. These types of superstrates need good arrangement to maintain the unit cell boundaries and lattice periodicity. In addition, the situation becomes harder when building structures of three dimensions. Furthermore, another disadvantage of these metallic structures is their tendency to become a high loss medium at high frequencies. However, dielectric layers superstrate will overcome some of these limitations easily.

In this paper a double layer superstrate rectangular patch antenna is designed for performance enhancement for X band applications. The proposed antenna is excited by using the edge, inset, probe and aperture feeding methods. The designed antennas are numerically simulated, and the effect of superstrate on directivity, return loss, VSWR and radiation pattern are investigated. The details of the proposed antennas design and results are presented in the following sections.

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II. Design of Microstrip Rectangular Patch Antennas with Dielectric Superstrate

The microstrip patch antenna consists of a metallic conductor called radiating element and deposited on a dielectric substrate. The lower face is completely metalized to provide a ground plane. Microstrip patch antennas can be fed in a variety of ways. 1. Contacting, 2. Non-Contacting.

In contacting method the RF power is fed directly to the radiating patch using a connected element, they are microstrip feed and coaxial feed [11]. In Non Contacting method, electromagnetic coupling is done to transfer the power between the feed line and the radiating patch, they are Aperture coupled feed and Proximity coupled feed [3].

A. Feeding Techniques

1) Edge feeding

The feed line is connected to the patch by a quarter wave transformer to achieve the impedance matching. This scheme has the advantage that the feed line and the radiating patch can be etched on the same substrate, however, conflicting substrate requirement for feed line and radiating element results in reduced system efficiency [11]. The design can be well explained with Fig. 1.

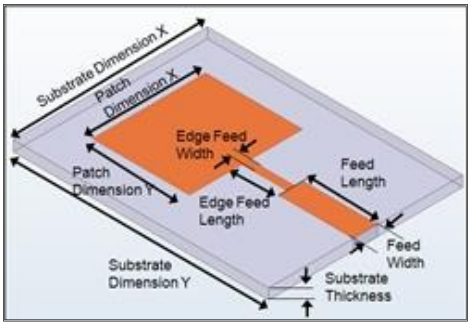

Figure 1. Edge feeding microstrip patch antenna

2) Probe feeding

This scheme involves drilling a hole through the ground plane and the substrate and extending the inner conductor of a coax through the hole. This conductor is then soldered to the radiating patch while the outer conductor of the coax is connected to the ground plane. Control of the input impedance is achieved by positioning of the probe. This method result in minimal spurious radiation but is very complicated since it involves precise drilling both on the ground plane and the substrate in terms of position and size [11]. The design can be well explained with Fig. 2.

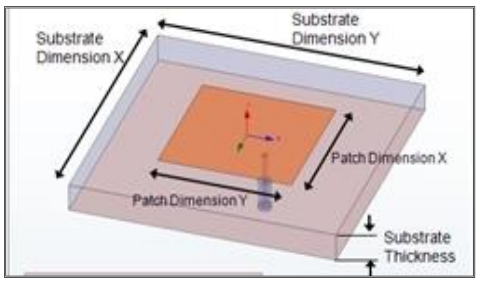

Figure 2. Probe feeding microstrip patch antenna

3) Inset feeding

This is a variation of the edge feeding where the fed line is in direct contact with one of the radiating edges of the patch. Impedance control is achieved by cutting out a notch from the radiating edge and extending the feed line into the notch. This scheme has the advantage that the feed line and the radiating patch can be etched on the same substrate making design and realization easier and highly suited for array design [11]. The design can be well explained with the Fig. 3.

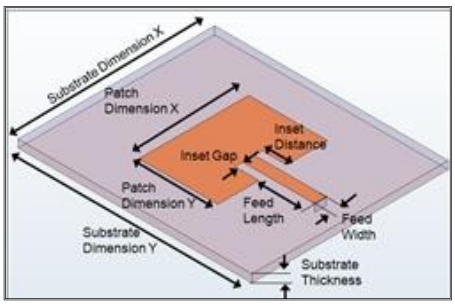

Figure 3. Inset feeding microstrip patch antenna

4) Aperture feeding

An aperture coupled patch antenna eliminates the direct electrical connection between the feed and radiating conductors by employing two dielectric substrates separated by a ground plane. This allows independent optimization of both the microstrip transmission line feed and radiating patch; patch and feed line are electromagnetically coupled through an aperture made on the ground [3]. Such a design can be well explained with the help of Fig. 4.

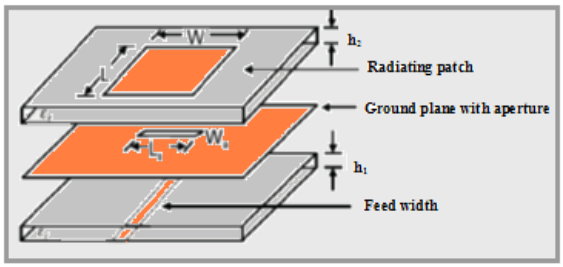

Figure 4. Aperture coupled microstrip antenna

B. Patch Antenna Design Parameters

For a rectangular patch, length L is usually $0.3333\lambda_0<L<\lambda_0$, where λ_0 is the free-space wavelength. Patch is usually very thin such that patch thickness t is very less than λ_0. The dielectric constant of the substrate ε_r ranges from 2.2 to 12. The thickness h of the dielectric substrate is usually in the range $0.003\lambda_0 \leq h \leq 0.05\lambda_0$.

The Performance of the microstrip antenna depends on its dimension, the operating frequency, radiation efficiency, directivity, return loss and other related parameters are also influenced [1]. For an efficient radiation, the width of the patch can be written as:

$$W = \frac{c}{2fr\sqrt{\frac{2}{\varepsilon r+1}}} \quad (1)$$

The length of the antenna becomes:

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

where:

$$\frac{\Delta L}{h} = 0.412\,\frac{(\varepsilon eff+0.3)\left(\frac{W}{h}+0.264\right)^{1}}{(\varepsilon eff-0.258)\left(\frac{W}{h}+0.8\right)^{1}} \quad (3)$$

and

$$\varepsilon eff = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\left(1+\frac{12h}{W}\right)^{-1/2} \quad (4)$$

where f_r is the resonant frequency; h is the height of the substrate; L and W are the length and width of the patch element respectively. The rectangular patch antenna has been designed to cover the frequency range of [8-10] GHz with input impedance of 50Ω, using RT-DURROID substrate (ε_r=2.2) with height (h=0.79mm), the ground plane and radiating patch are made of copper. The patch antennas have been designed with the parameters according to the Table I below:

TABLE I. RECTANGULAR PATCH ANTENNA DIMENSIONS IN EDGE-PROBE-INSET AND APERTURE FEEDING

Symbol	Parameter (mm)	Inset feed	Probe feed	Edge feed	Aperture feed
Ls	Substrat dimension Y	45	45	45	45
Ws	Substrat dimension X	60	60	60	60
h	Substrat thickness	0.79	0.79	0.79	0.79
W	Patch dimension X	11.86	11.86	11.86	11.86
L	Patch dimension Y	9.31	9.31	9.31	9.31
W_f	Feed width	2.408	-	2.408	2.408
L_f	Feed lenght	9.31		3.61	18
L_{qw}	Edge feed lenght	-	-	5.7	-
W_{qw}	Edge feed width	-	-	0.5	-
g	Inset gap	1.204	-	-	-
Y_0	Inset distance	2.155	-	-	-
L_a	Aperture lenght	-	-	-	0.63
W_a	Aperture width	-	-	-	2.6

C. *Patch Antennas with Dielectric Superstrate (DS)*

The configuration of the proposed rectangular patch antennas is shown in Fig. 5. It consists of a one-dimensional Electromagnetic Band Gap (1-D EBG) structure, made from two identical dielectric slabs, suspended over an edge-inset-probe and aperture feed antenna located above a PEC ground plane.

The dielectric material is taken to have a dielectric constant ε_r=9.2 which corresponds to the dielectric constant of the "Rogers TMM 10 (tm)" in the microwave frequency range. Adjustment of first superstrate layer is the most important stage in antenna design and it is about one third of operation wavelength (λ/3) above ground plane which cause to gain increase. The second layer, improve beam shaping and directivity. The distance of second layer from first layer is about λ/4. The thickness of the layers is adjusted to 4mm, to tune the antenna frequency range [8-10] GHz for the four types of feeding.

Below, we will present the simulation results in terms of the computed radiation patterns, return loss and directivity of the proposed antennas. We use HFSS, which is 3D High Frequency Structure Simulator software [12].

To obtain an optimum response, the air gap between the layers was varied to produce the final characteristic. The corresponding value is 7mm. Therefore it is important to control the air gap thickness in order to obtain a better performance from the antenna.

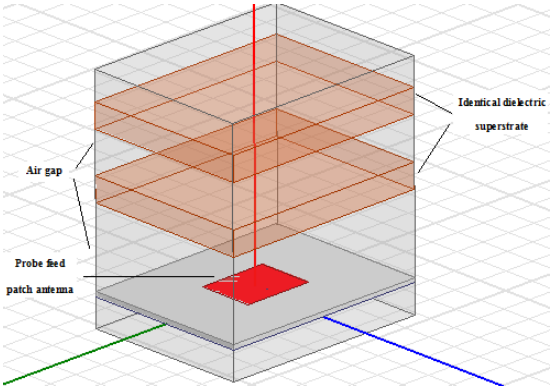

Figure 5(a). Probe feed rectangular patch antenna with dielectric superstrate

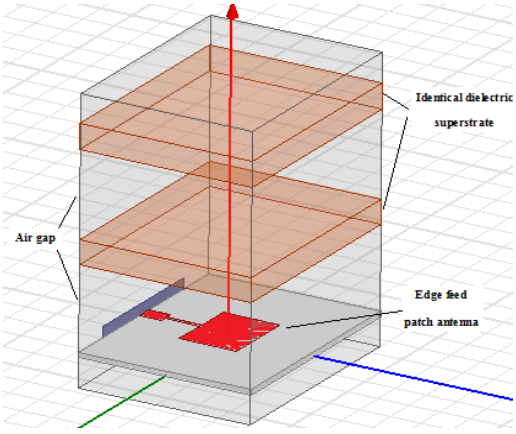

Figure 5(b). Edge feed rectangular patch antenna with dielectric superstrate

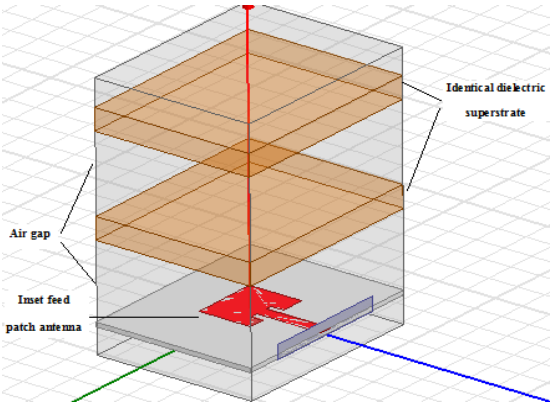

Figure 5(c). Inset feed rectangular patch antenna with dielectric superstrate

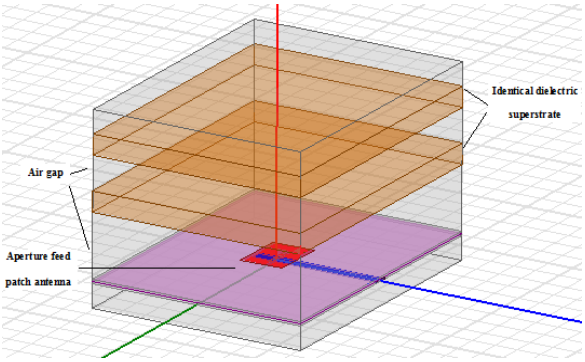

Figure 5(d). Aperture feed rectangular patch antenna with dielectric superstrate

III. Simulation Results and Discussion

Now-a-days, it is a common practice to evaluate the system performances through computer simulation before the real time implementation. A simulator *"Ansoft HFSS"* based on Finite Element Method (FEM) has been used to calculate return loss, radiation pattern and directivity. This simulator also helps to reduce the fabrication cost because only the antenna with the best performance would be fabricated.

A. Probe Feed Patch Antenna

The probe feed patch antenna covered by two layers dielectric superstrate is shown in Fig. 5(a). The parameters of this antenna are presented in Table I. The variation of the directivity as well as of S_{11} with frequency is shown in Fig. 6 and Fig. 7, respectively. We compare the performance of the MPA with and without the DS.

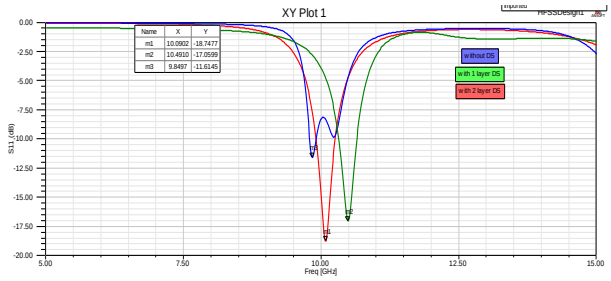

Figure 6. Reflection coefficients of the probe feed patch antenna with and without dielectric layers

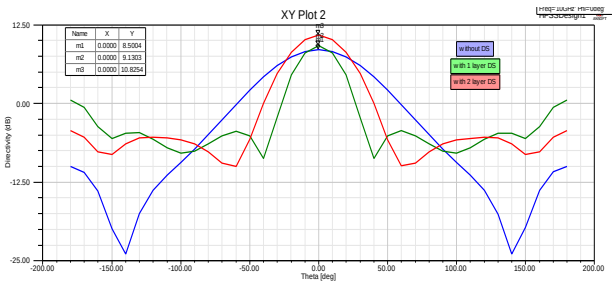

Figure 7. Results of directivity of a probe feed patch antenna with a double-layer DS and a single layer DS as well as that of the source antenna

From the Fig. 6 and Fig. 7, the performance of MPA with DS is better than MPA without DS. It is clear that return loss has been decreased in MPA from -11.61dB to -18.74dB when two layers DS applied. Directivity has been also improved after applying DS, it reaches 10.82dB at 10GHz instead of 8.5dB at 9.84GHz.

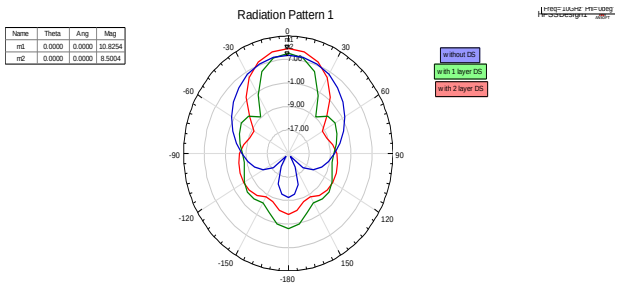

Figure 8. Radiation pattern of the double layer DS based antenna, a single layer DS based antenna and the probe feed antenna.

Fig. 8 displays Radiation pattern for the double layer DS based antenna, a single layer DS based antenna and the feed antenna.

The results for the beamwidth are 66°, 31° and 41° at the frequency of 9.84GHz, 10.49GHz and 10GHz for the simple antenna, antenna with one layer DS and antenna with two layer DS respectively.

It is obvious the use of two layer dielectric superstrate, cause the increase of directivity of the antenna but the antenna loaded with one layer DS provides a narrower beamwidth (31° at E-plane) along the forward direction.

We conclude that the designed antenna with two layers DS had the best results in terms of frequency, return loss, and directivity and the designed antenna with one layer DS had better beamwidth.

B. Edge Feed Patch Antenna

The edge feed patch antenna covered by two layer dielectric superstrate is shown in Fig. 5(b). The parameters of this antenna are presented in Table I. The variation of the directivity as well as of S_{11} with frequency is shown in Fig. 9 and Fig. 10, respectively. We compare the performance of the MPA with and without the DS.

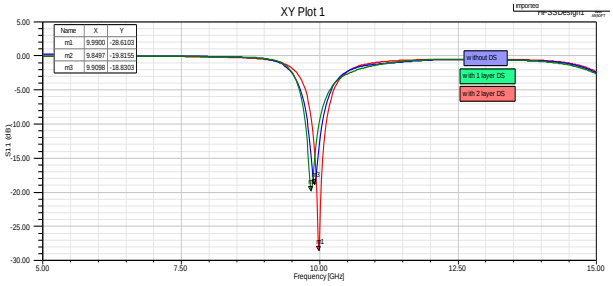

Figure 9. Reflection coefficients of the edge feed patch antenna with and without dielectric layers

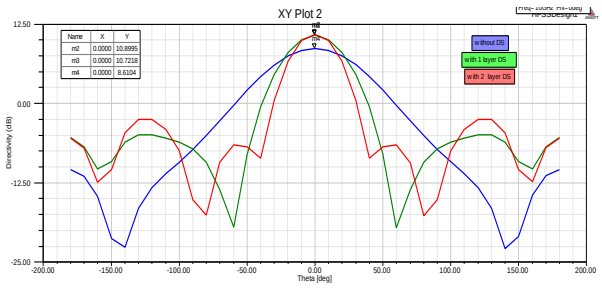

Figure 10. Results of directivity of an edge feed patch antenna with a double-layer DS and a single layer DS as well as that of the source antenna

The return loss should be minimal at resonance frequency for better performance; it can be seen that the reflection behavior of the unloaded antenna (without DS) shows low resonance over the X band. After the feed antenna is loaded with one and two layer superstrate, it can be seen that the reflection losses were minimized (-28.61dB) at 10GHz instead of -18.83dB at 9.9GHz which show that the double-layer structure provides a good impedance matching with the source antenna that was initially designed.

The results show that directivity of patch antenna with two layer DS can reach 10.89dB at 10GHz, which is

2.28dB above that of the MPA without a superstrate. The first layer has important role in this enhancement.

Fig. 11 displays Radiation pattern for the double layer DS based antenna, a single layer DS based antenna and the feed antenna.

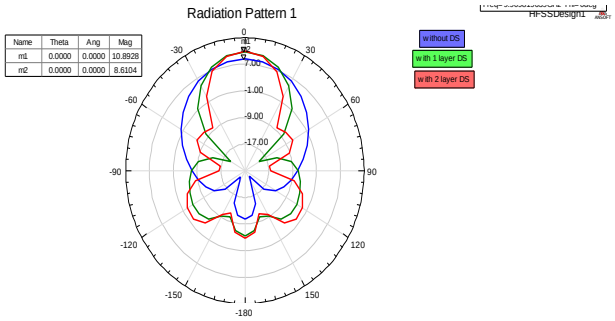

Figure 11. Radiation pattern of the double layer DS based antenna, a single layer DS based antenna and the edge feed antenna.

The results for the beamwidth are 64°, 41° and 32° at the frequency of 9.9GHz, 9.84GHz and 10GHz for the simple antenna, antenna with One layer DS and antenna with two layer DS respectively.

It is obvious the use of two layer DS cause the increase of directivity of the antenna, the new antenna provides a narrower beamwidth (32° at E-plane) along the forward direction.

We conclude that the designed antenna with two layer superstrate had the best results in terms of frequency, return loss, directivity and beamwidth as those of antenna with one layer superstrate and antenna without the superstrate.

C. Inset Feed Patch Antenna

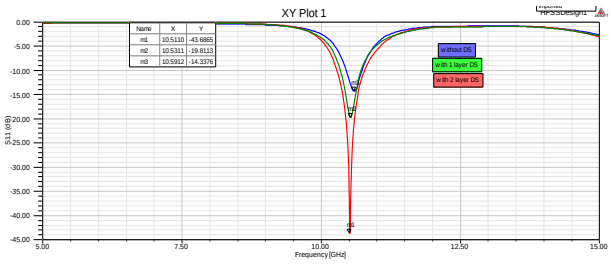

Figure 12. Reflection coefficients of the inset feed patch antenna with and without dielectric layers

Figure 13. Results of directivity of an inset feed patch antenna with a double-layer DS and a single layer DS as well as that of the source antenna

The inset feed patch antenna covered by two layer dielectric superstrate is shown in Fig. 5(c). The parameters of this antenna are presented in Table I. The variation of the directivity as well as of S_{11} with frequency is shown in Fig. 12 and Fig. 13, respectively. For comparison the results are also presented for the inset feed patch antenna without DS.

It can be seen that the reflection behavior of the unloaded antenna (without DS) shows resonance (-14.33 dB) over the X band including the center frequency at 10.6GHz. After the feed antenna is loaded with one layer superstrate, it can be seen that the reflection losses were minimized (-19.81dB at 10.53GHz), however the operation frequency is still far from 10GHz. Adding a second dielectric layer helps to further minimize the reflection losses, the results of the frequency response of the S_{11} parameter show that the double-layer structure provides a good impedance matching (S_{11} = -43.68dB) with the source antenna that was initially designed at a frequency of 10.5GHz.

The results show that directivity of patch antenna with two layer DS can reach 11.13dB at 10GHz, which is 2.24dB above that of the MPA without a superstrate. The first layer has important role in this enhancement.

Fig. 14 displays Radiation pattern for the double layer DS based antenna, a single layer DS based antenna and the feed antenna.

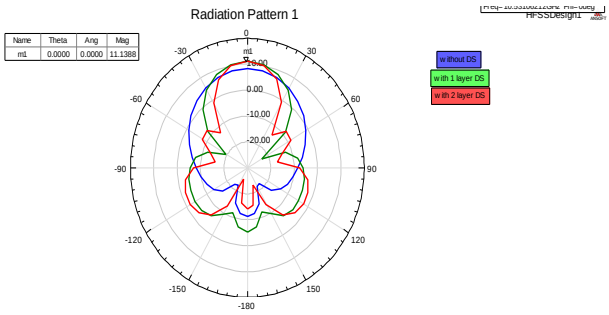

Figure 14. Radiation pattern of the double layer DS based antenna, a single layer DS based antenna and the inset feed antenna.

The results for the beamwidth are 62°, 40° and 29° at the frequency of 10.6GHz, 10.53GHz and 10.5GHz for the simple antenna, antenna with one layer DS and antenna with two layer DS respectively.

It is obvious the use of two layer DS causes the increase of directivity of the antenna. Furthermore, the new antenna provides a narrower beamwidth (29° at E-plane) along the forward direction.

We conclude that the designed antenna with two layer superstrate had the best results in terms of frequency, return loss, directivity and beamwidth as those of antenna with one layer superstrate and antenna without the superstrate.

D. Aperture Coupled Feed Patch Antenna

The aperture coupled feed patch antenna covered by two layer dielectric superstrate is shown in Fig. 5(d). The parameters of this antenna are presented in Table I. The variation of the directivity as well as of S_{11} with frequency is shown in Fig. 15 and Fig. 16, respectively. For comparison the results are also presented for the aperture coupled feed patch antenna without DS.

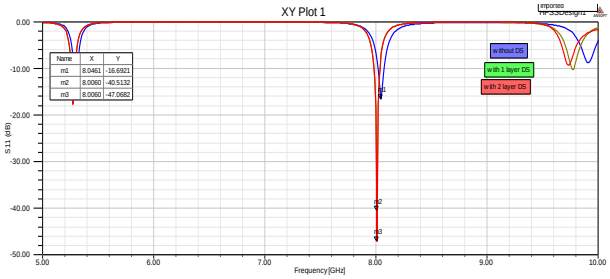

Figure 15. Reflection coefficients of the aperture coupled feed patch antenna with and without dielectric layers

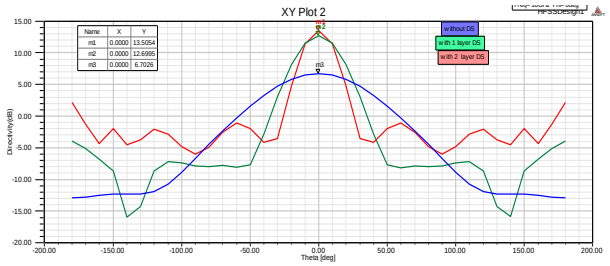

Figure 16. Results of directivity of an aperture coupled feed patch antenna with a double-layer DS and a single layer DS as well as that of the source antenna

The simulated return loss of the designed antenna with two layers DS is -47.06dB at 8GHz and for the antenna loaded with one layer DS is -40.51dB at 8GHz whereas it is -16.69dB at 8.04GHz without DS. This results show that the double-layer structure provides a good impedance matching.

From figures above, it is found that the antenna with two layer DS produced higher directivity which is 13.5dB compared to the antenna without DS which is just 6.7dB. The first layer has important role in this enhancement.

The maximum directivity of an aperture antenna is [13]:

$$D_{max}=(4\pi A)/\lambda^2$$

where A is the area of the aperture. Since $A \approx 60 \times 45mm^2$ and λ=37.5mm in the present configuration, one has D_{max}=13.8dB. The directivity of our designed antenna (13.5dB) is very close to the maximum directivity (13.8dB). That is physically possible for this size of antenna.

Fig. 17 displays Radiation pattern for the double layer DS based antenna, a single layer DS based antenna and the feed antenna.

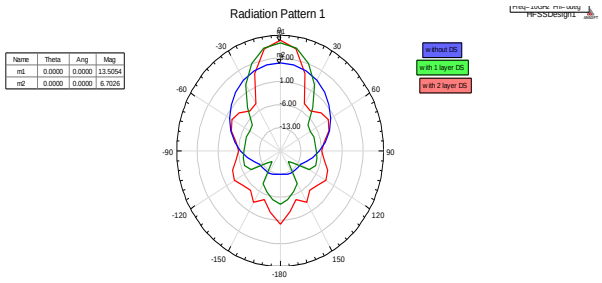

Figure 17. Radiation pattern of the double layer DS based antenna, a single layer DS based antenna and the inset feed antenna.

The results for the beamwidth are 73°, 31° and 22° at the frequency of 8.04GHz, 8GHz and 8GHz for the simple antenna, antenna with One layer DS and antenna with two layer DS respectively.

It is obvious the use of two layer DS causes the increase of directivity of the antenna, the new antenna provides a narrower beamwidth (22° at E-plane) along the forward direction.

E. Comparative Analysis of MPA for All Feeding Methods

The performance comparison between MPA without DS and MPA with DS for probe, edge, inset and aperture coupled feeding methods has been shown in Table II. It reveals that:

- The designed antennas with two layer DS had the best results in terms of return loss, directivity and beamwidth as those of antennas with one layer DS and antennas without the superstrate regardless of the feeding method.
- The first layer DS has important role in the enhancement of directivity and impedance matching.
- The aperture coupled feeding method gave better results compared to other feeding methods.

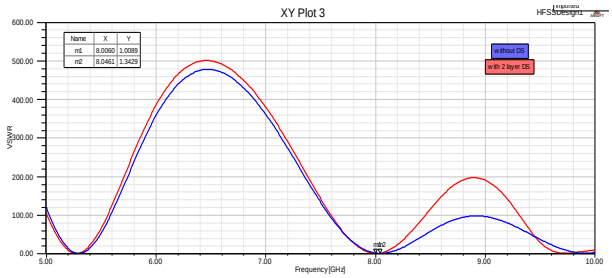

Figure 18. Results of VSWR of an aperture coupled feed patch antenna with and without DS

TABLE II. PERFORMANCE COMPARISON FOR PROBE, EDGE, INSET AND APERTURE FEED PATCH ANTENNAS

Patch Antenna	Probe feed			Edge feed			Inset feed			Aperture feed		
	Return loss	Directivity	Beam-width	Return loss	Directivity	Beam-width	Return loss	Directivity	Beam-width	Return loss	Directivity	Beam-width
Without DS	-11.61dB	8.5dB	66^0	-18.83dB	8.61dB	64^0	-14.33dB	8.89dB	62^0	-16.69dB	6.7dB	73^0
with one layer DS	-17.05dB	9.13dB	31^0	-19.81dB	10.72dB	41^0	-19.81dB	11.11dB	40^0	-40.51dB	12.69dB	31^0
with two layers DS	-18.74dB	10.82dB	41^0	-28.61dB	10.89dB	32^0	-43.68dB	11.13dB	29^0	-47.06dB	13.5dB	22^0

VSWR gives indication about mismatch between the antenna and feeding line impedances. VSWR=1 indicates perfect matching.

Fig. 18 shows that aperture coupled patch antenna loaded with DS had also the best VSWR (1.00) among all proposed antennas compared with MPA without DS

(VSWR=1.34). This type of antenna provides perfect impedance matching.

IV. Conclusion

This paper has addressed the problem of microstrip patch antennas limitations. We have proposed and investigated four different structures with the same physical dimensions that can operate at the X frequency band. We have studied the performance parameters of patch antennas fed by probe, edge, inset and aperture coupled feeding methods when dielectric superstrate is added on it and we have compared the simulation results with that of patch antennas without dielectric superstrate. The main impetus for studying this antenna structure with DS was the desire to realize increased directivity and reduced return loss without using complex structures such as FSS and DNG superstrate. It was found that the directivity level, beamwith as well as reflection coefficient and VSWR could be further enhanced by using superstrate with two layers rather than one, regardless of the feeding method (probe, edge, inset or aperture feeding). However observing the performance analysis of the four patch antennas covered by DS, it is convenient to say that aperture coupled patch antenna with DS provides better performance than the other antennas, -47.06dB in return loss, 13.50dB in directivity and VSWR=1 as well as narrow beamwidth (22 ° at E plane) are achieved at 8GHz. All simulations and designs are performed by HFSS simulation tool with different full wave methods. In the future, the work will be carried out for patch antennas with EBG structure used as substrate and superstrate.

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