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Investigations on Wideband U-Slot Microstrip Patch Antenna with Dielectric Superstrate

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Abstract: *This paper presents the effect of the dielectric superstrates on bandwidth and gain of U-slot microstrip patch antenna without superstrate and loaded with superstrates. It is found that there is a degradation in the performance of the antenna when the superstrate is touching the patch antenna i.e the height of the superstrate above the patch H =0 mm. Further, it is also observed that the degraded performance characteristics of the U-slot microstrip patch antenna can be improved by placing the superstrate at optimum height (H) =H_{opt}. The patch antenna without superstrate has a bandwidth of 0.20 GHz (SWR≤ 2) at 2.07GHz, and patch antenna loaded with superstrate for H = 0, shows that the resonate frequency is decreased and achieved impedance bandwidth is 0.19 GHz (SWR≤ 2) at 2.07GHz. As the dielectric constant of the superstrate increases, it has been observed that the center frequency varies from 2.07GHz to 1.58 GHz, bandwidth is decreased to 0.19 GHz from 0.20 GHz. Gain is decreased to 6.51dB from 9.50 dB. As the height of the superstrate is increased, the performance of the patch antenna improves and at particular optimum height (H_{opt}) the gain and bandwidth (9.5%) for all the superstrates will be closer to the free space radiation conditions of the patch antenna without superstrate. However, for H = H_{opt} the variation in the return-loss is within ± 2.5 dB of the free space radiation conditions for all dielectric constants of the superstrate and it is within acceptable limits. There is a good agreement between simulated and measured results.*
Keywords: *U-slot patch antenna, Dielectric superstrate, bandwidth, axial ratio etc.*

I. Introduction

Microstrip antennas have been employed in the airborne and spacecraft system because of their low profile and conformal nature. Many of these applications require a dielectric superstrate over the radiating element to provide protection against heat, physical damage and other environmental hazard etc., results in change of important parameters like impedance, bandwidth (frequency range for SWR ≤ 2), gain, resonant frequency. This geometry of microstrip patch loaded with dielectric superstrate can form part of a specific high performance airborne system. In view of this, it becomes imperative to investigate the effect of superstrates on the performance of the microstrip patch antennas.

The characteristics of U- slot microstrip patch antenna have been studied by simulations and experiments by various authors [1-4] .The attention of the most of the researchers [5-7] have been on the evaluation of radiation characteristics of simple U-slot patch antennas without any superstrate loading. Such an attempt is made in the present work in which all the performance characteristics of superstrate loaded U –slot patch antenna has been evaluated. It would be of particular interest to realize the advantages associated with superstrate loaded U- slot patch antenna.

This paper presents effect of the superstrate on the characteristics of U-slot microstrip patch antenna. The schematic diagram of the patch antenna loaded with superstrate is shown in Fig. 1. The superstrates of different dielectric constants are used to study the effect on the performance of the patch antenna. The height of the superstrate is varied and the effect of the height is investigated. The simulation method using High Frequency Structure Simulator (HFSS), version 13.0, is employed to obtain the simulated results of performance characteristics without and loaded with superstrates as a function of dielectric constant and height of the superstrate. The experimental results are obtained with the help of Precision Network Analyzer (Agilent E8363B) and anechoic chamber.

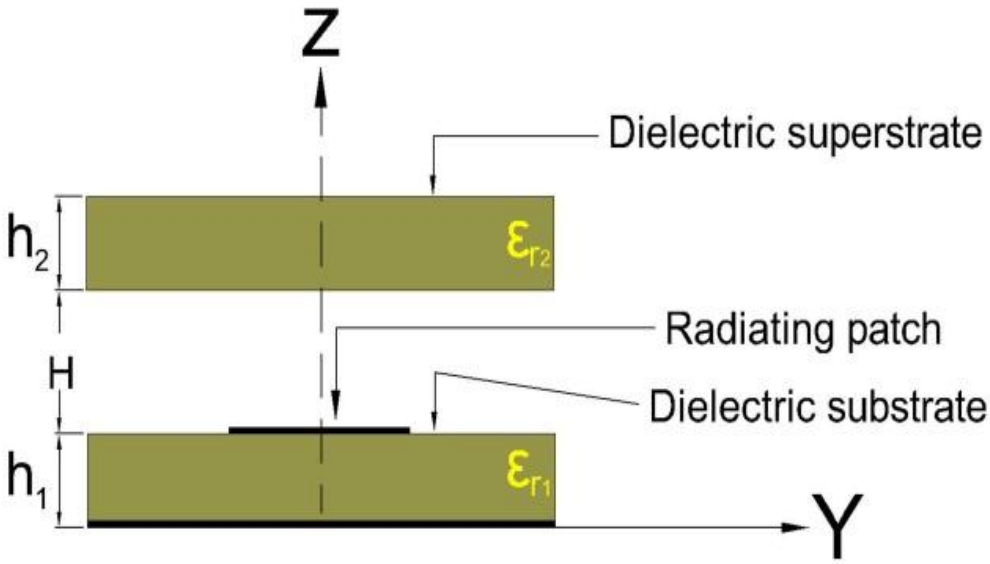


Fig.1 The schematic of a U-slot patch antenna loaded with a superstrate at height H above the patch (side view).

II. Specifications

The specifications of suitable dielectric substrate and superstrate [8-10] are shown in Table 1 and Table 2 respectively. A thicker substrate is mechanically strong with improved impedance bandwidth [10, 11]. However it will increase weight and surface wave losses. The substrates dielectric constant ε_r plays an important role similar to that of the substrate thickness. A low value of ε_r for the substrate will increase the dielectric loss and therefore reduces the antenna efficiency [8-14].

Table 1: Specification of dielectric substrate (ε_{r1}) material used in the design of U- slot patch antenna.

Substrate material	Dielectric constant (ε_{r1})	Loss tangent (Tanδ)	Substrate thickness(h_1),mm
Arlon Diclad 880	2.2	0.0009	1.6

Table 2: Specifications of dielectric superstrate (ε_{r2}) materials used to study the effect of the superstrate on the performance of the U-slot patch antenna.

Superstrate materials	Dielectric constant (ε_{r2})	Loss tangent ($Tan\delta$)	Thickness of the superstrates (h_2)
Air	1.0	0.00009	-
Arlon Diclad 880	2.2	0.0009	1.6
Arlon AD320	3.2	0.003	3.2
FR4	4.8	0.02	1.6
Arlon AD 1000	10.2	0.0035	0.8

III. Design of U-Slot Patch Antenna and its Geometry

The U-slot patch antenna produces a wideband beam. The U-slot microstrip patch antenna is designed at 2.0 GHz on Arlon diclad 880 substrate (ε_{r1}=2.2, h_1=1.6 mm), using expressions available in the standard literature [1-6, 13, 14]. The designed dimensions of U-slot patch antenna are given in Table 3. The patch antenna is fed with coaxial probe at point where the input impedance of the patch is 50 Ω. The geometry of the U-slot microstrip patch antenna is shown in Fig.2, where W_S = Substrate width, L_S= Substrate length, W_P= Patch width, L_P = Patch length, S_1= Length of the left slot, S_2=Length of the top slot, S_3=Length of the right slot, S_W=Width of the slot and (f_x , f_y) are co-ordinates of the feed point.

An U-slot patch antenna is easily formed by cutting two slots from a rectangular shape and fed with coaxial probe as shown in Fig.2.

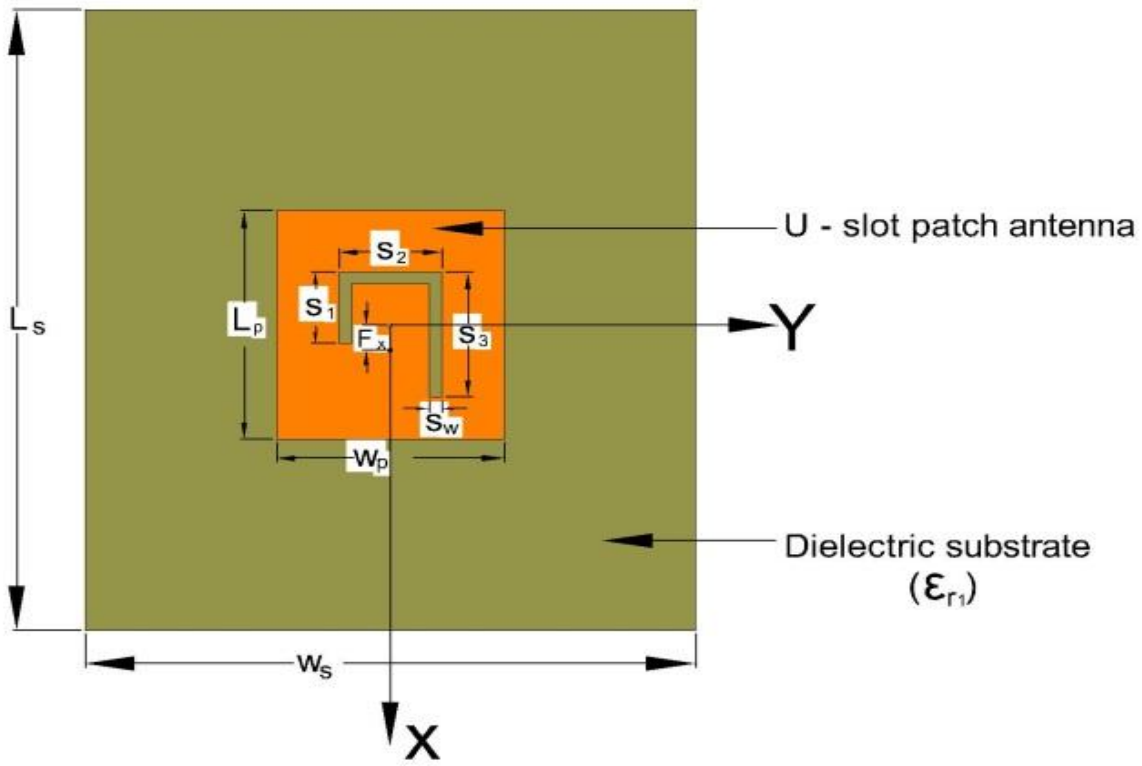


Fig.2 The geometry of U-slot microstrip patch antenna (top view).

Table 3: The designed dimensions of U-slot microstrip patch antenna in mm.

f_r	ε_{r1}	h_1	W_S	L_S	W_P	L_P	S_1	S_2	S_3	S_W	F_X
2.0 GHz	2.2	1.6	150	150	55	55	17	25	30	3	19,0

IV. Effect of Superstrate on U-Slot Patch Antenna

The U-slot patch antenna is covered with the dielectric superstrate as shown in Fig.3. When superstrate is placed above the patch (H = 0 mm), the resonant frequency is shifted to lower side and other parameters such as bandwidth, gain etc. are adversely affected. As the height of the superstrate is increased, the performance of the patch antenna improves at particular optimum height (H_{opt}).

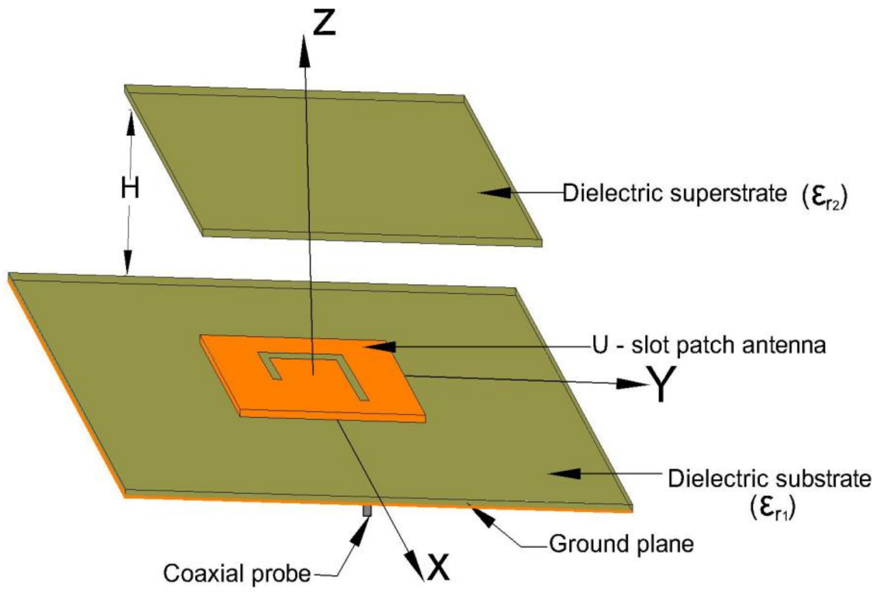


Fig.3 The geometry of U-slot microstrip patch antenna with dielectric superstrate

V. Simulated and Experimental Results

The performance characteristics of the U-slot patch antenna are evaluated without dielectric superstrate using commercial electromagnetic software such as High Frequency Structure Simulator (HFSS) version 13.0. Then the change in performance of the antenna is studied with loaded dielectric superstrates of different dielectric materials as mentioned in Table 2. The effect of the height of the superstrate above the patch (H) is also studied by simulation. The height at which the performance of the patch is optimum is also found by simulation. The measurements were carried out by using

(I). Precision Network Analyzer (Agilent E8364B) to measure the return-loss (VSWR), center frequency and bandwidth and

(II). Anechoic chamber to measure the radiation characteristics. The antenna under test (patch antenna with and without dielectric superstrate) is used as receiving antenna and the transmitting antenna is a pyramidal horn antenna (0.5-6GHz). The antenna measurements were carried out in Anechoic chamber having dimensions (30×20×15) feets. The distance between transmitting and receiving antennas is kept as 5.3mts. The radiation pattern measurements were carried out at 2.0GHz.

VI. Results And Discussion

As in the case of other patch antennas [13, 14], it is observed that there is degradation in the performance of the antenna when the superstrate is touching the U-slot patch antenna (H =0 mm). The simulated results show that the center frequency is decreased to 1.58 GHz from 2.07 GHz; bandwidth is decreased to 0.19 GHz from 0.20 GHz, gain is decreased to 6.41 dB from 9.40 dB. The geometry of the patch antenna loaded with dielectric superstrate at a height (H) is shown in Fig.3. A dielectric constant ε_{r2}=1 (air), implies that the patch antenna is without superstrate. Typical dielectric superstrates with ε_{r2}=2.2, 3.2, 4.8, 10.2 and thicknesses (h_2)=1.6 mm, 3.2 mm, 1.6 mm, 0.8 mm respectively are employed.

The return-loss as a function of frequency for U-slot patch antenna without superstrate (free-space condition) is shown in Fig.4. The return-loss as a function of frequency, for particular case, when the superstrate is placed at optimum height ($H_{opt)}$ for superstrate dielectric constant, ε_{r2}=4.8 is shown in Fig.5. The overall typical results for the U-slot patch antenna are given in Table 4, for ε_{r2}=1.0, 2.2, 3.2, 4.8, 10.2 for, H =0 mm and H =H_{opt}. The E-plane and H-plane radiation patterns with loaded superstrate at H =0 and H = $H_{opt,}$ for superstrate dielectric constant, ε_{r2}=4.8 are shown in Figs.6 and 7. The gain of the patch antenna is observed to be decreasing with increase in the dielectric constant of the superstrate for H=0. The optimum height is dependent only on the dielectric constant of the superstrate and is not dependent on the shape of the patch antenna. As the dielectric constant of the superstrate varies from 2.2 to 10.2, the optimum height varies from 21.07 mm to 9.78 mm i.e. the optimum height decreases with increase in dielectric constant of the superstrate.

As the height of the superstrate is increased, the performance of the patch antenna improves and at a particular optimum height the gain and bandwidth (9.5%) for all the superstrates will be closer to the free space radiation conditions of the patch antenna without superstrate. However, the variation in the return-loss for H =H_{opt}.is within ± 2.5 dB of the free space radiation condition for all dielectric constants of the superstrate and it is within acceptable limits. The U-slot patch antenna produces nearly circular polarization (AR≤ 3 dB) over the operating frequencies. When the superstrate is placed at height, variation in the axial ratio is ± 1.25. The comparison of simulated and measured axial ratio versus frequency plot of loaded dielectric superstrate for (ε_{r2}) = 4.8 is shown in Fig. 8. There is good agreement between simulated and measured results.

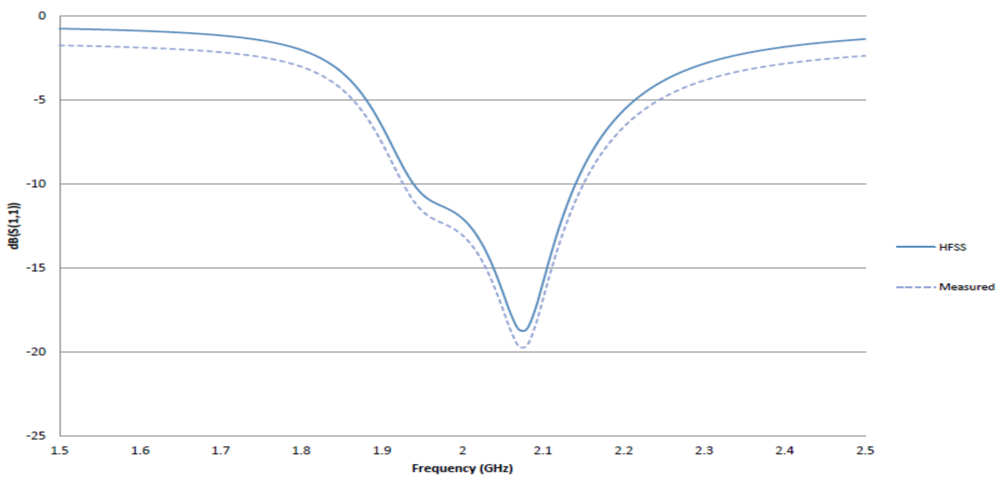


Fig.4 Comparison of measured and simulated results of return-loss for U-slot patch antenna without a dielectric superstrate (free space radiation conditions), (ε_{r1} = 2.2, h_1=1.6 mm) at 2.07GHz.

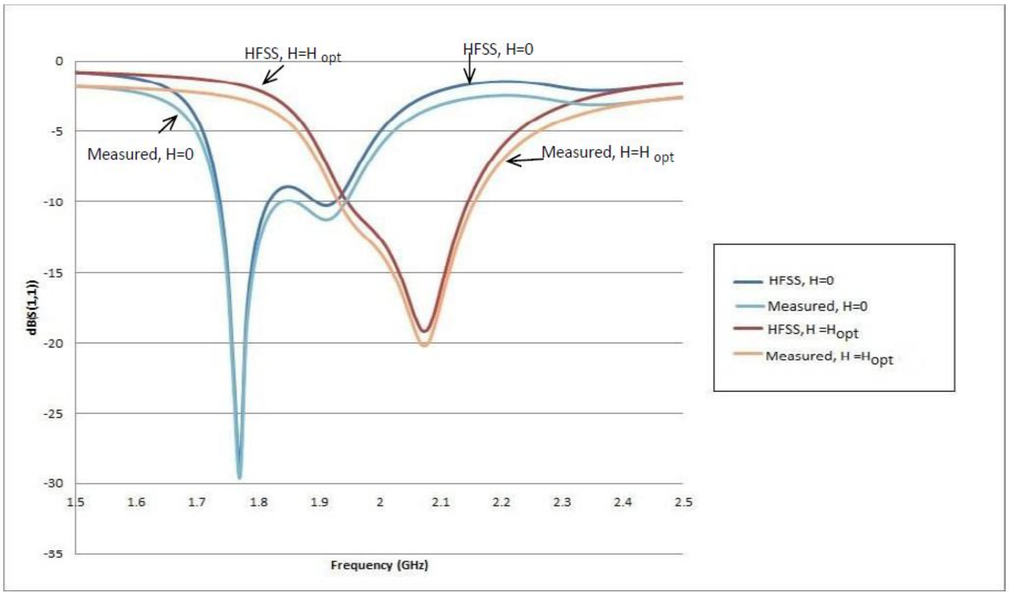
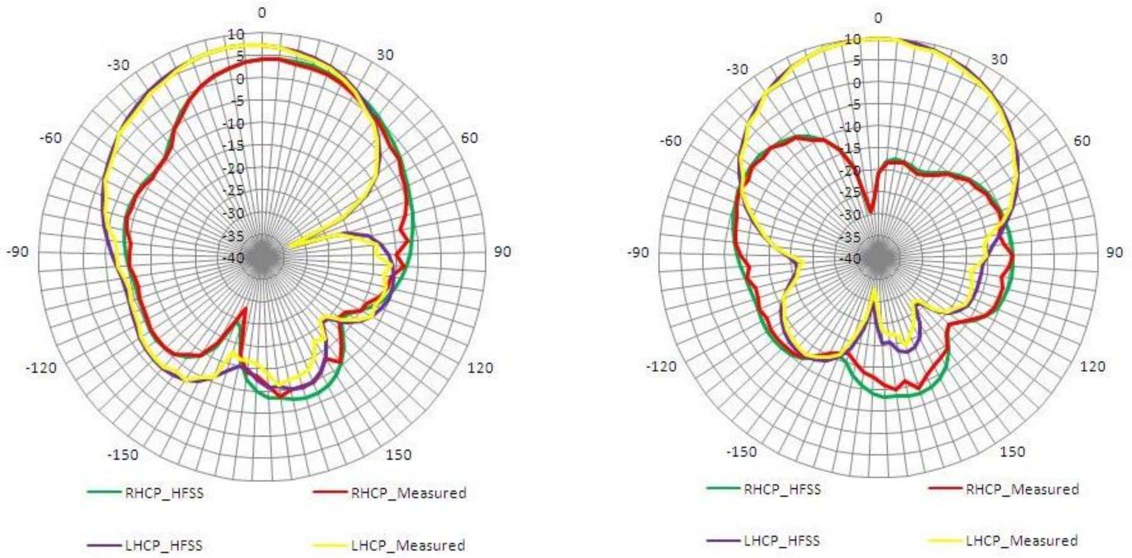
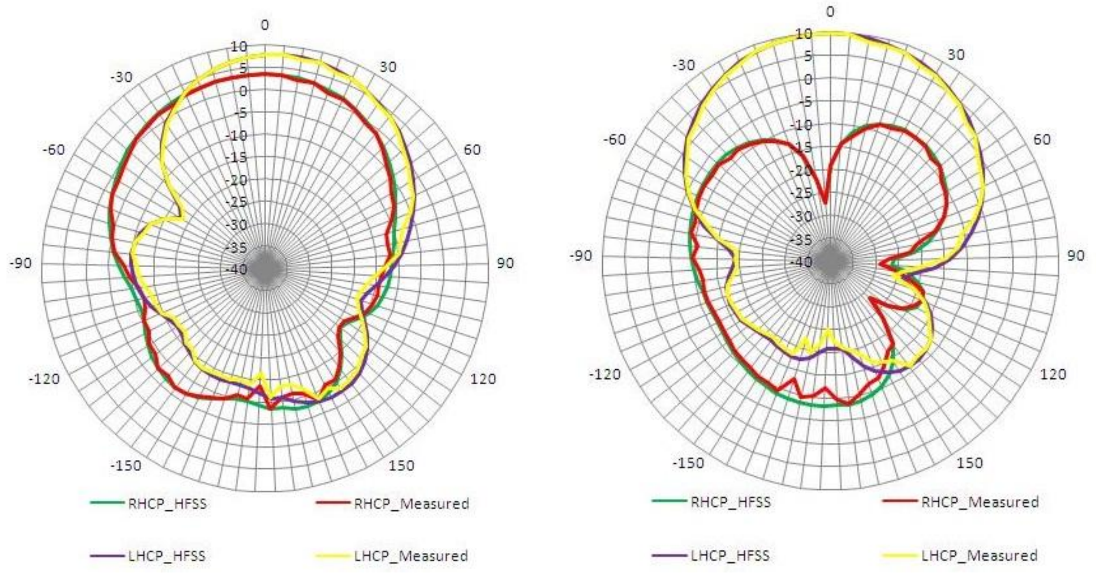


Fig.5 Comparison of measured and simulated results of return-loss for U-slot patch antenna loaded with a dielectric superstrate, ($\mathcal{E}_{r2}$ = 4.8, h_2=1.6 mm) for H=0 and H=H_{opt}.



(a) H = 0 mm **(b) H = 14.26 mm**

Fig.6 Comparison of measured and simulated radiation patterns for (a) H = 0 mm, phi =0^0 (b) H = 14.26 mm, phi =0^0 for U- slot patch microstrip antenna in E-plane ($\mathcal{E}_{r2)}$ =4.8 at 1.97GHz.



(a) H = 0 **(b) H = 14.26 mm**

Fig.7 Comparison of measured and simulated radiation patterns for (a) H = 0 mm, phi = 90^0 (b) H = 14.26 mm, phi =90^0 for U- slot patch microstrip antenna in H-plane ($\mathcal{E}_{r2}$) = 4.8 at 1.97GHz.

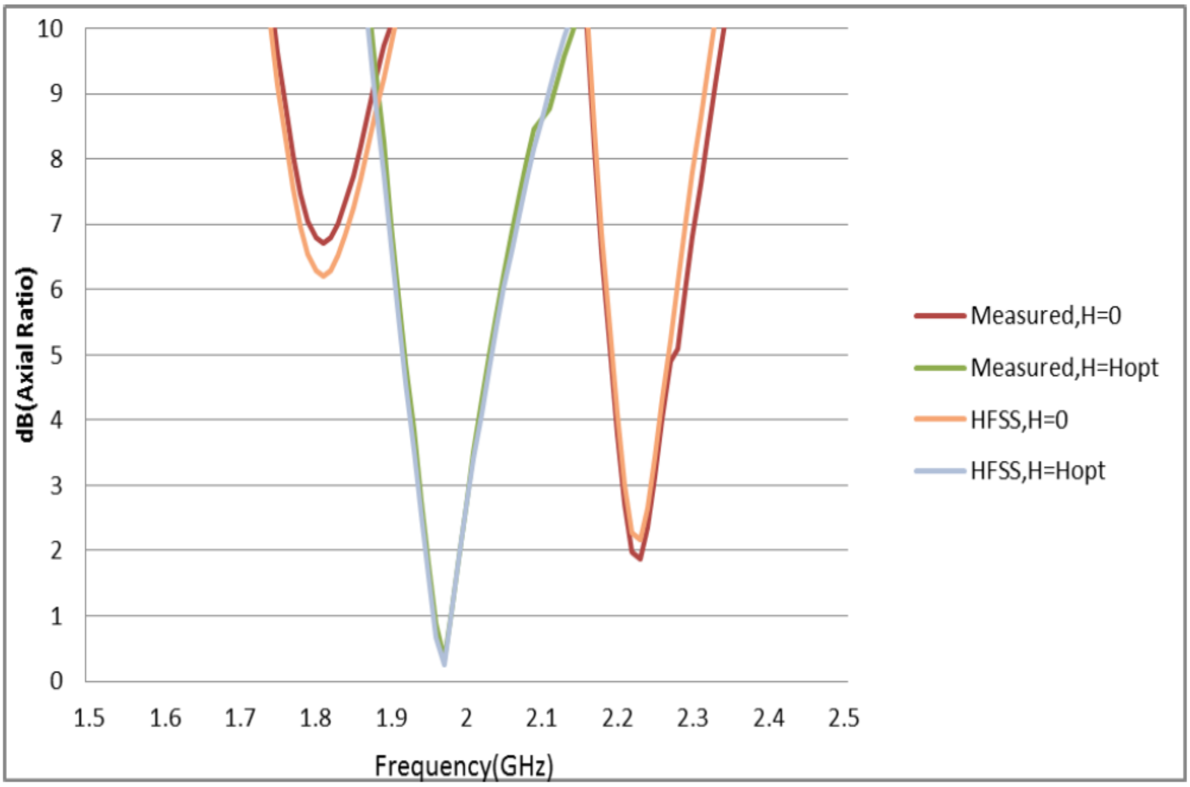


Fig.8 Comparison of measured and simulated results of axial ratio versus frequency plot of U-slot patch antenna loaded with a dielectric superstrate for ($\mathcal{E}_{r2}$) = 4.8 at H=0 and H= H_{opt}

Table 4: Comparison of simulated and measured results of resonant frequency, return-loss, bandwidth and gain of U-slot patch antenna without superstrate and loaded with superstrate for H =0 and H =H_{opt}.

ϵ_{r2}	Height (H) mm	Frequency (GHz)		Return Loss (dB)		Bandwidth (GHz)		GAIN (dB)	
		Simulated	Measured	Simulated	Measured	Simulated	Measured	Simulated	Measured
1.0*	-	2.07	2.07	-18.65	-17.27	0.20	0.20	9.50	9.40
2.2	0	2.01	2.01	-15.50	-14.90	0.19	0.19	9.25	9.10
	21.07 (H_{opt})	2.08	2.08	-20.47	-21.15	0.19	0.19	9.80	9.70
3.2	0	1.84	1.84	-19.87	-18.50	0.20	0.20	8.62	8.60
	17.46 (H_{opt})	2.07	2.07	-20.49	-21.91	0.20	0.20	9.82	9.80
4.8	0	1.77	1.77	-28.58	-29.58	0.19	0.19	7.32	7.40
	14.26 (H_{opt})	2.07	2.07	-19.14	-21.55	0.19	0.19	9.85	9.80
10.2	0	1.58	1.58	-7.57	-8.57	0.19	0.19	6.51	6.41
	9.78 (H_{opt})	2.07	2.07	-16.38	-17.38	0.19	0.19	9.76	9.70

*without dielectric superstrate

VII. Conclusions

U-slot microstrip patch antenna has been designed and fabricated at 2.0GHz on Arlon diclad 880 substrate having dielectric constant (ϵ_{r1})=2.2. The effect of the superstrate with different dielectric materials having ϵ_{r2}=2.2, 3.2, 4.8 and 10.2 has been investigated. The simulation and measurements have been carried out for studying the effect of superstrates on various parameters like resonant frequency, bandwidth, gain and return-loss. It has been observed that there is a degradation in the performance of the antenna when the superstrate is touching the patch antenna (H=0 mm). As the dielectric constant of the superstrate increases, it has been observed that the center frequency decreased to 1.58GHz from 2.07GHz, bandwidth is decreased to 0.19 GHz from 0.20 GHz and gain is decreased to 6.51dB from 9.50 dB.

As the height of the superstrate is increased, the performance of the patch antenna improves and at a particular optimum height the gain and bandwidth (9.5%) for all the superstrates will be closer to the free space radiation conditions of the patch antenna without superstrate. However, the variation in the return-loss is within ± 2.5 dB of the free space radiation condition for all dielectric constants of the superstrate and it is within acceptable limits. The U-slot patch antenna produces nearly circular polarization over the operating frequencies. It has been observed from the results, that the degradation in the antenna parameters is minimum for the superstrate having lowest dielectric constant ϵ_r =2.2, when the superstrate is touching the patch antenna. In the case of conventional patch antennas such as rectangular, square and circular patch [13, 14], higher dielectric constant superstrates should not be used unless deterioration in the return-loss is acceptable. In the case of U-slot antenna this limitation is not applicable.

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