Design and Simulation of E-Shape Microstrip Patch Antenna for Wideband Applications

Indu Bala Pauria, Sachin Kumar, Sandhya Sharma

Abstract— ***This paper presents the design and simulation of E-shape microstrip patch antenna with wideband operating frequency for wireless application. The shape will provide the broad bandwidth which is required in various application like remote sensing, biomedical application, mobile radio, satellite communication etc. The antenna design is an improvement from Previous research and it is simulated using HFSS (High Frequency Structure Simulator) version 11 software. Coaxial feed or probe feed technique is used in the experiment. Parametric study was included to determine affect of design towards the antenna performance. The performance of the designed antenna was analyzed in term of bandwidth, gain, return loss, VSWR, and radiation pattern. The design was optimized to meet the best possible result. Substrate used was air which has a dielectric constant of 1.0006. The results show the wideband antenna is able to operate from 8.80 GHz to 13.49 GHz frequency band with optimum frequency at 8.73 GHz.***

Index Terms— ***E-shape microstrip patch antenna, HFSS (High Frequency Structure Simulator) version 11 software, wideband.***

I. INTRODUCTION

Microstrip patch antenna is a key building in wireless communication and Global Positioning system since it was first demonstrate in 1886 by Heinrich Hertz and its practical application by GuglielmoMarconi in 1901. Future trend in communication design is towards compact devices. Microstrip patch antenna have been well known for its advantages such as light weight, low fabrication cost, mechanically robust when mounted on rigid surfaces and capability of dual and triple frequency operations all these features, attract many researchers to investigate the performance of parch antenna in various ways. However, narrow bandwidth came as the major disadvantage for this type of antenna.

Several techniques have been applied to overcome this problem such as increasing the substrate thickness, introducing parasitic elements i.e. co-planar or stack configuration, or modifying the patch's shape itself. Modifying patch's shape includes designing an E-shaped patch antennas or a U-slot patch antenna.

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U-slot microstrip antenna provides bandwidth up to 30% while E-shaped patch antenna can increases bandwidth above 30% compared to a regular rectangular patch antenna. Comparing both designs, the E-shaped is much simpler to construct by only adjusting length, width and position of slots. In this paper, a wideband single patch antenna is proposed as in Figure 1. The main objective of this paper is to optimize the base design in to obtain higher bandwidth. This single patch antenna operates at voltage standing wave ratio of less than 2 (VSWR < 2). Theoretical simulation and optimization are performed using HFSS (High Frequency Structure Simulator) version 11 software.

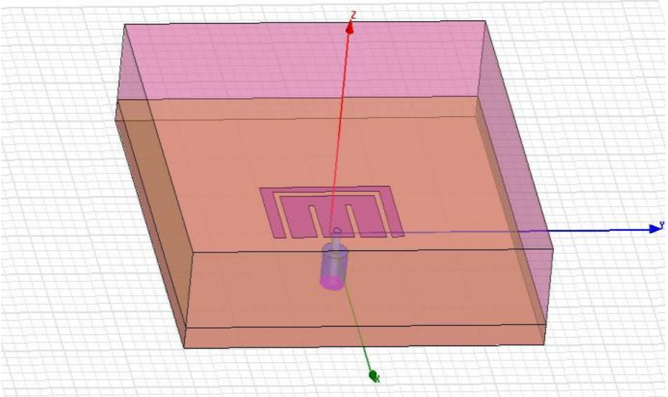


Figure 1: Design of E+U shaped patch antenna

II. DESIGN METHODOLOGY OF RADIATING ELEMENT

Recently there have been numerous methods of enhancing the bandwidth of an antenna for example modifying the probe feed, using multiple resonances, using folded patch feed, or using the slotted radiating element.

The U shape slot in the radiating element tends to have wideband characteristics. It also suggests that a U shape slot introduces the capacitive component in the input impedance to counteract the inductive component of the probe. Also to compensate the increasing inductive effect due to the slots, thickness of the substrate is increased.

As we know that as thickness increases the bandwidth increases accordingly. The input impedance of about 42% is achieved. The slots making it to look alike inverted E shape; it demonstrated a bandwidth enhancement by 30 %.In this design an air-filled or foam has been essential to realize broadband characteristics. This design uses substrate material with relative permittivity (ε) of 1.0006 i.e. Air and the patch shape is the combination of inverted E and inverted U.

A. Simulation Setup

The antenna's resonant properties were predicted and optimized using High Structure simulation software Ansoft version 11. The design procedure begins with determining the length, width and the type of dielectric substance for the given operating frequency as shown in flow diagram Fig.2. Then using the measurements obtained above simulation has been setup for the basic rectangular microstrip antenna and the parameters are optimized for the best impedance matching. Furthermore two parallel slots are incorporated and optimized such that it closely resembles E shape; this increases the gain of the antenna. After that two more parallel slots and one perpendicular slots are incorporated and optimized such that it closely resembles U shape.Then dielectric substrate od dielectric constant of 1.0006 introduces to decrease the size of the antenna and to further enhance the bandwidth. At last the probe feeding is introduced for attaining a required bandwidth, resonating frequency and gain value. The proposed design methodology of the antenna is given in Fig.(2).

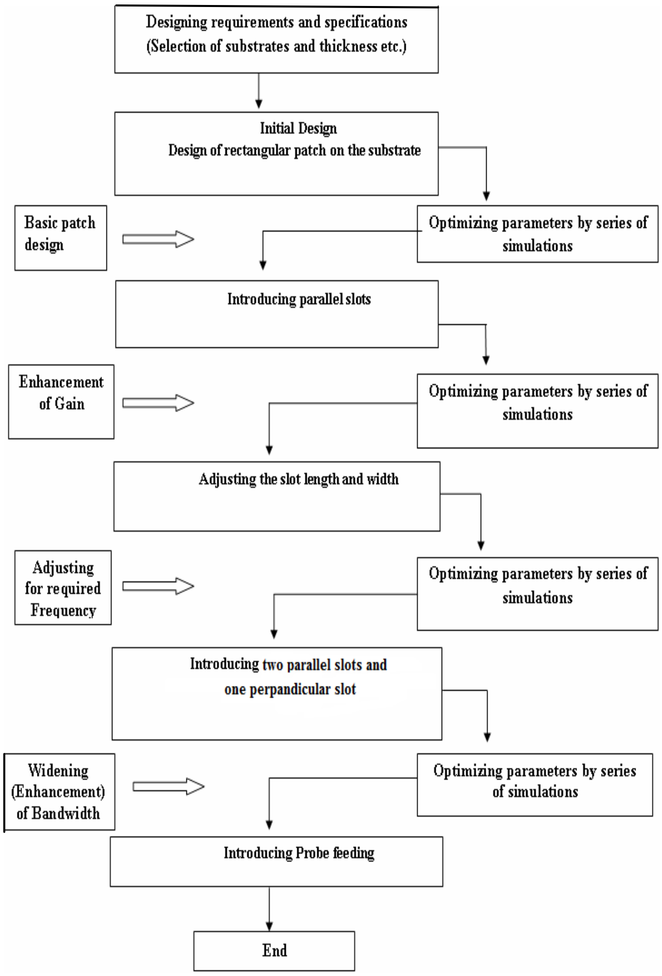


Fig.2 Flow diagram of designing procedure

B. Geometry of the antenna

The geometry of the designed antenna is shown in the Fig.3.The antenna is made of a single patch on top, one layers of dielectric (air) and a vertical probe connected from ground to the upper patch.

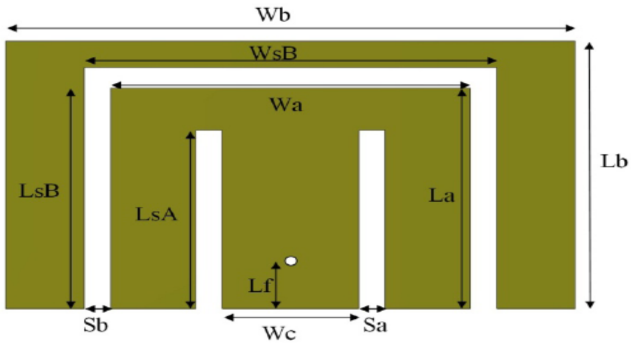


Fig.3 Design geometry of E shaped patch antenna

The main E shaped patch has Wa x La dimension while the outer patch has Wb x Lb dimension. The antenna is fed by a SMA connector positioned at the center arm. The center of probe is positioned at (Wc/2,Lf). The width and length of the microstrip antenna are determine as follows

$$W = \frac{1}{2 f_r \sqrt{\mu_0 \varepsilon_0}} \sqrt{\frac{2}{\varepsilon_r + 1}} = \frac{v_0}{2 f_r} \sqrt{\frac{2}{\varepsilon_r + 1}} \qquad (1)$$

Where vo is the free-space velocity of light.

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2} \qquad (2)$$

Where the dimensions of the patch along its length have been extended on each end by a distance *ΔL*, which is a function of the effective dielectric constant εreff and the widthto- height ratio (*W/h*), and the normalized extension of the length, is

$$\Delta L = 0.412\, h \frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \qquad (3)$$

The actual length of the patch (L) can be determine as

$$L = \frac{1}{2 f_r \sqrt{\varepsilon_{reff}} \sqrt{\mu_0 \varepsilon_0}} - 2 \Delta L \qquad (4)$$

Parallel slots in this design are responsible for the excitation of next resonant mode i.e. main parallel slot excite 2^{nd} resonant frequency while outer slot excite 3^{rd} resonant frequency. Slotslength (LsA and LsB), slot width (S), main slot width (WsB) and center arm (Wc) controls the frequency of the next resonant mode. Figure 4 shows the cut plane view of the antenna. The patch and ground are separated by closed-cell low loss air of thickness 3.2 mm. Dielectric constant for this foam is 1.0006, and it benefits to obtain wider bandwidth and higher gain.

Air gap was used as substrate and infinite ground was assumed. This paper design a finite set of ground dimension which is defined by Wg x Lg. SMA connector design is according to specification in using Teflon of dielectric constant = 2.08. The default value of this antenna design is shown in Table 1.

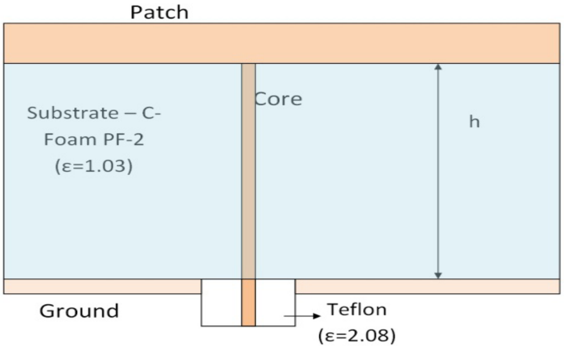


Fig.4 Cut plane view of antenna

Table 1: Default microstrip patch antenna specifications

Parameter		Label	Dimension (mm)
Main Patch	Length	La	10.9
	Width	Wa	15.7
Outer Patch	Length	Lb	13.2
	Width	Wb	21.7
Slot	Main slot width	WsB	17.7
	Slot Width	Sa,Sb	1.0
	Slot A length	LsA	8.4
	Slot B length	LsB	10.9
Centre Arm	Width	Wc	5.2
Feed point	Width	Wc/2	2.6
	Length	Lf	1.8
Substrate Air	Thickness	h	3.2
	Dielectric constant	ε_{rs}	1.0006
Substrate and Ground	Width and Length	Wsub, Lsub Wg, Lg	60
SMA	Core Diameter	Dc	1.275
	Teflon Diameter	Dt	4.17
	Teflon Dielectric constant	ε_{rt}	2.08

III. PARAMETRIC STUDY

The default value of dimension for this antenna is presented in Table 1. Dimension that are kept constant in this paper are Main Patch, Outer Patch, Substrate's thickness, LsB and SMA feed. Other parameters are set as variables. Only one parameter is allowed to change at a time while other variables remain constant as default except ground and substrate that will varied together. All dimension mentioned in graphs are in millimetre (mm).

A. Changing Air Gap with C-Foam PF-2

The microstrip antenna is simulated with C-Foam PF-2 substrate that has a dielectric constant of 1.03 and compared the output with the microstrip antenna which is simulated with Air that has a dielectric constant of 1.0006. The result is shown in Figure 5. Replacing air gap (blue) with C-Foam PF-2 (red) we found that the bandwidth is slightly decreased as compared to air gap(blue) so air gap gives wider bandwidth than foam. The reason to use C-Foam PF-2 is because outer patch in is connected to main patch by switches, but in this paper, no switches will be used, so a substrate is needed to connect outer patch to main patch. As mentioned, dielectric constant for this foam is 1.03 which is very close to air gap, so that the reference result would not be much difference when using air gap. Using C-Foam PF-2, the frequency band is from 8.74 GHz to 13.36 GHz while when using Air gap, the band is from 8.80 GHz to 13.49 GHz, which create a slightly wider bandwidth.

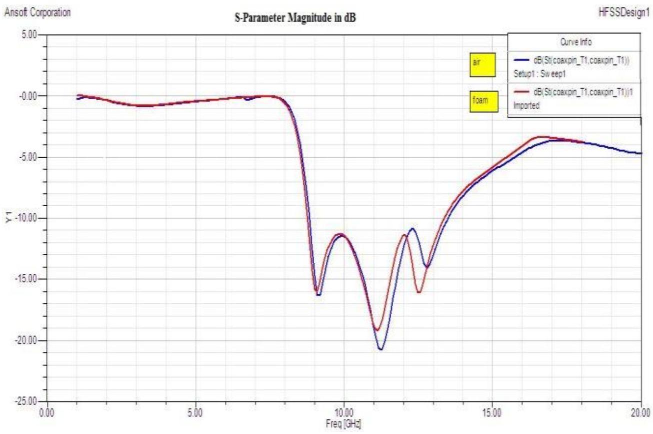


Fig.5 S_{11} for air and foam substrate

B. Changes in substrate size

Figure 6 shows the S11 parameter when dimension of substrate is changing where Wsub = Lsub = Wg = Lg. These parameters are decreased by 10 mm for each run, starting from 60 mm to 30 mm. The result doesn't show much difference in terms of bandwidth but slightly affect the magnitude of S11. The magnitude decreased when dimension decreased from 40 mm to 30 mm only at 1st and 2nd resonant frequency. but when increased from 40 mm to 50 mm, only magnitude at 2nd and 3rd resonant frequency increased. The magnitude at 60 mm is almost same when at 40 mm.

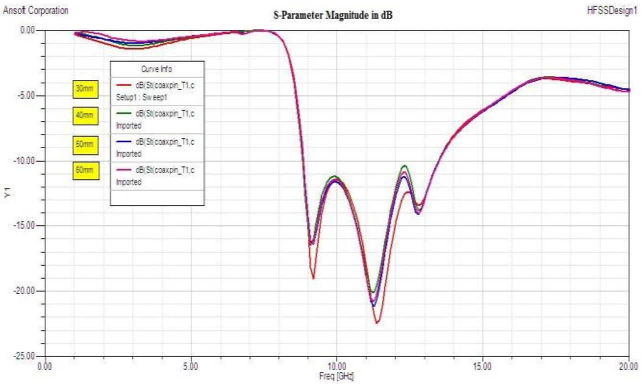


Fig.6 S_{11} of various size of substrate

C. Changes in Centre Arm Width (Wc)

Figure 7 shows the S11 parameter when Wc varied from 4.2 mm to 6.2 mm by 0.5 mm increment. As the width increases, the 1st and 2nd resonant frequency shifted to lower frequency and the magnitude of S11 decreases. The opposite occur at the 3rd resonant frequency where the frequency does not seem to change very much, but magnitude of S11 increases as the width of centre arm increases.

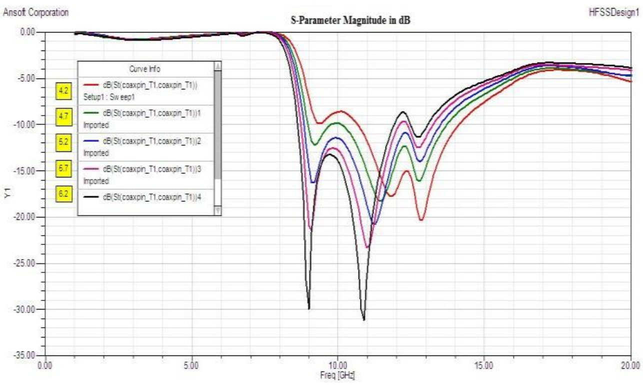


Fig.7 S_{11} of various size of Wc

D. Changes in Slot Length (LsA)

Figure 8 shows S11 magnitude when LsA varied from 7.6 mm to 9.6 mm with 0.4 mm increment. As the length increases, the 1st and 2nd resonant frequency shifted to lower frequency and the magnitude of S11 decreases but not the case when LsA = 9.2 mm & 9.6mm where the magnitude at 1st resonant frequency increase. The opposite also occurred at the 3rd resonant frequency where the frequency does not seem to change very much, but magnitude of S11 increases as the length of LsA increases.

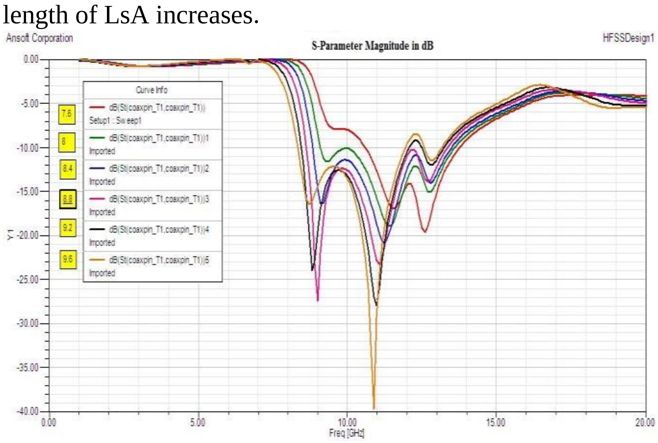


Fig.8 S_{11} of various size of LsA

E. Changes in Main Slot Width(WsB)

WsB is varied from 15.7 mm to 19.7 mm with increment of 1 mm. The result shown in Figure 9 shows a pattern when WsB is varied Low cut-off frequency is virtually the same for all values. The upper cut-off decreases as WsB increases. It can be said WsB influence the bandwidth of other parameters are kept constant.

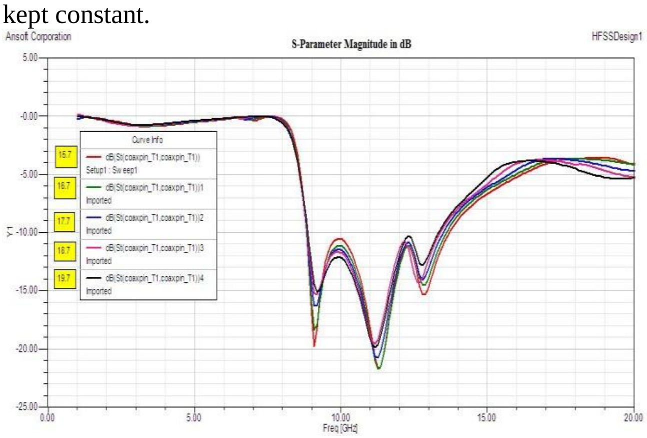


Fig.9 S_{11} of various size of WsB

F. Changes in Slot Width (Sa,Sb)

Slot widths, Sa and Sb is varied from 0.5 mm to 2mm, with increment of 0.5 mm. For Sa, almost similar pattern can be seen in Figure 10. Magnitude for S11 at 1st resonant frequency decreases as Sa Increase while the opposite happen at 3rd resonant frequency, when magnitude of S11 increases as Sa decreases. S11 magnitude is very low when Sa= 2 mm.
In Figure 11, when Sb varied all value show a similar pattern. Magnitude for S11 at 1st and 3rd resonant frequency decreases as Sb Increase. Very low S11 magnitude occurred when Sb = 2 mm.

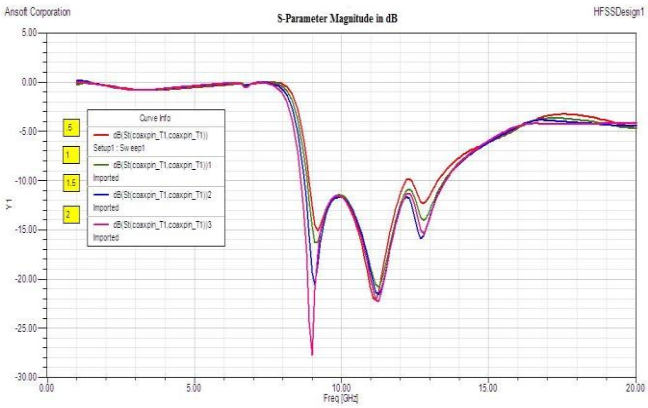


Fig.10 S_{11} of various size of Sa

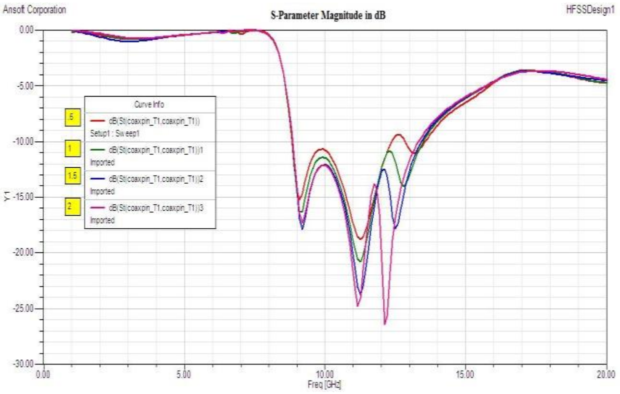


Fig.11 S_{11} of various size of Sb

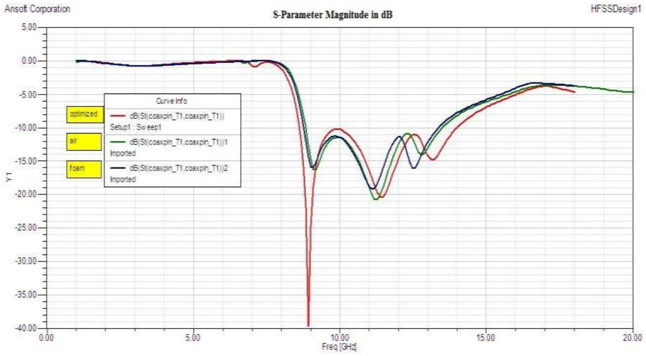


Fig.12 Comparison of three antenna design

IV. RESULTS AND DISCUSSION

Antenna is optimized based on the results obtained in section III. The aim of optimization is to obtain better gain and bandwidth than in Figure 5. The varied parameters specification after optimization is shown in Table 2.

Table 2: Optimized parameters

Parameter		Label	Dimension (mm)
Slot	Main slot width	WsB	15.7
	Slot A Width	Sa	2
	Slot B Width	Sb	0.6
	Slot A length	LsA	8.8
Centre Arm	Width	Wc	4.7
Ground	Width	Wg	60
	Length	Lg	60

A. Improvement in Bandwidth, Gain,S11 and VSWR

Figure 12 shows S11 parameter for the original air gap substrate, the original foam substrate, and the optimized wideband antenna. The frequency band for the optimized wideband antenna range from 8.59 GHz up to 13.99 GHz. Compared to original default bandwidth (using Air), the bandwidth is expanded from 4.68 GHz to 5.4 GHz which is a 15.38% bandwidth improvement. The obvious improvement is the position of low cut-off frequency. The antenna operates optimally at 1st resonant frequency which is 8.73 GHz, followed by 2nd resonant at 11.45 GHz and finally 3rd resonant at 13.15 GHz.

The gain measured for default design at its most optimum frequency (11.24 GHz) is 8.31 dB and the gain using air substrate at 8.73 GHz, the gain is 7.33 dB.

S11 represents how much incident signal at port 1, being reflected at port 1. The S11 is the ratio of reflected wave, b1 to incident wave, a1 (b1/a1). If S11 = 1, it indicates that all signal is reflected and nothing is radiated. In foam substrate, at its most optimum frequency 11.11 GHz radiated power is measured to be 0.00826W while in air gap substrate, radiated power is 0.0085726W at 8.73 GHz, which indicates smaller amount of signal is reflected back at port 1.

Figure 13 shows the VSWR comparison of default specification antenna and the optimized antenna. VSWR is a measure of how well matched an antenna is to the cable impedance. A perfectly matched antenna would have a VSWR of 1:1. This ratio indicates how much power is reflected back or transferred into a cable. VSWR is closely related to S11 The line impedance set in this paper is 50 Ω. For default specification, the lowest VSWR value is 1.67 for 11.24GHz while for optimized antenna which uses Air substrate substrate acquires the lowest VSWR of 0.217 at the optimum frequency (8.73 GHz) and 1.61 at the optimum frequency of 11.45GHz.

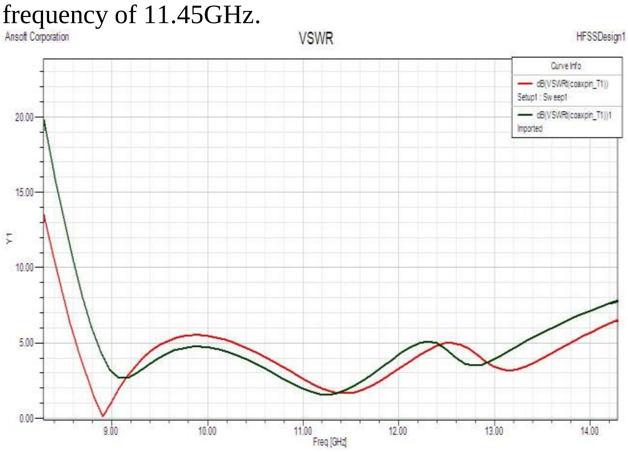
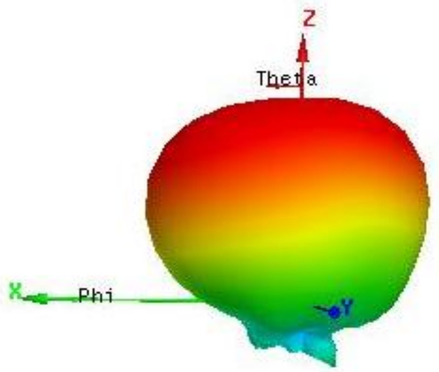


Fig. 13 VSWR of optimized wideband antenna

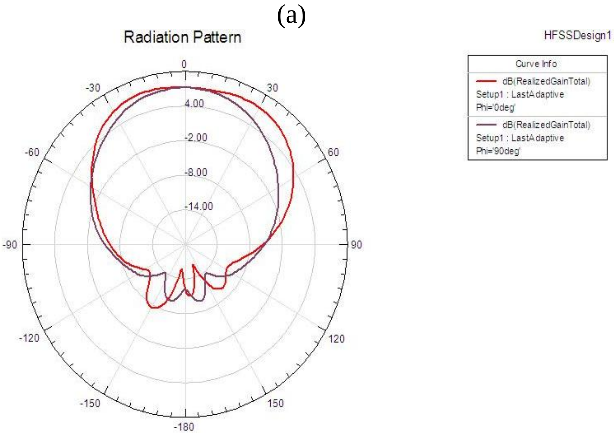
B. Radiation Pattern of Optimized Antenna

Figure 14(a) and (b) show the radiation pattern for the antenna at 8.73 GHz. HPBW is the angular separation which the magnitude of the radiation pattern from the peak of the main beam decreases by 50% or -3 dB. HPBW (angle) is 70˚

for Optimum Frequency of 8.73 GHz.



(a)



(b)

Fig. 14(a) & (b) 8.73 GHz radiation pattern

Table 3: Values for radiation parameter for each frequency

Frequency (GHz)	8.73	11.45	13.15
Gain (dB)	7.33	8.43	7.79
Radiation efficiency (dB)	.02641	0.1254	0.3035
Front to back ratio (dB)	15.2	17.299	19.53
Max U (W/Sr)	0.0039681	0.0045996	0.0068782
Peak Directivity	5.8169	6.767	5.6102
Radiated power(W)	0.0085726	0.0085418	0.015407
Accepted Power(W)	0.008521	0.0082989	0.014366
Incident Power(W)	0.0087812	0.0083887	0.014814

V.CONCLUSION

In this paper, an E-shaped wideband microstrip patch antenna using Air substrate has been designed, simulated, optimized and analyzed using HFSS (High Frequency Structure Simulator) software version 11. A parametric study is presented with the results showing that the antenna can be operated at 8.80 GHz up to 13.49 GHz frequency band. This result is an improvement when compared to the original specification which saw the bandwidth is expanded from 4.68 GHz to 5.4 GHz. Other parameters such as S11 and VSWR also have been improved.

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