ANALYSIS AND DESIGN OF CYLINDRICAL SHAPED CONFORMAL UWB ANTENNA

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ABSTRACT

This paper presents the parametric analysis and design of aperture coupled conformal antenna operating in the Ultra-Wideband range. The design proposed utilizes the advantages of aperture coupled feeding with the cylindrical conforming surface, thus providing the bandwidth of 636MHz.The emphasis is given to the analysis of the relationship between the geometrical parameters of the antenna- length of the patch, width of the patch, slot dimensions and position on the substrate and thickness of the substrate layers employed, and the crucial antenna output parameters. A parametric study is made upon the deviations in the Operating frequency, Return Loss VSWR, Gain, Polarization ratio and Bandwidth due to the variations in the input parameters. The antenna could be employed for the aircraft communication links as the bandwidth is sufficient enough to cover the entire link.

KEYWORDS: *Conformal antenna, Ultra-wide band, VSWR, Return Loss.*

I. INTRODUCTION

One of the most promising advancements in the antenna design is the conformal antennas[1][2]. They are finding enormous applications in various domains of the technology including Automobiles-where the drag caused by the protrusion of the linear aerials (approximately 1.5) can be almost nullified, [9]Biomedical-increased accuracy in the results involving the radiation as the conformability of the antenna to the epidermis leads to the better functioning. In defense and other military applications, the conformability of the antenna plays a significant role in the mitigation of the communication link maintenance, since the common military applications include missiles-can be represented as the [1][2][7][11]cylindrical conformal antenna and satellites and RADAR-which can be represented as the [9] spherical and conical conformal antenna respectively, are exposed to the external environment for a prolonged duration. This conformability ensures that the aerial encounters minimal risk of being attacked by the environmental and climatic factors. [9][18] Microstrip patch is an attractive part of the conformal antenna as it is with various constructive parts like the low cost to fabricate, simplicity in design, conformability nature.

The frequency range chosen here is the [3][10] Ultra-wideband (UWB) ranging from 3.1GHz to 10.6GHz. The reason behind the opting of this particular band is the enormously larger bandwidth (>500MHz), in theory, which when properly utilized using proper antenna structures could be achieved to somewhat desired extent. And more over the recent research in this UWB area indicates that this will be the future thrust of communications. So, looking towards the near future the 802.11 will be using the UWB range. Normally the applications of UWB is divided into three parts

- Communications and sensors.
- Radar applications.
- Medical application.

The UWB facilitates data transmission at a high rate of about a 110 Mbps (Optimum data speeds of 480 Mbps will be possible at distances from six to ten feet 2-3 meters. As devices become further apart, so data rates drop), which facilitates high resolution video transmission, internet access and multimedia services. In the defense sector the UWB antennas are primarily employed for range determination, identification and tracking of targets. Another important application of UWB antenna is bio-medical imaging. Such an UWB antenna when combined with the data processing technique facilitates imaging in both down range and cross range with increased resolution. UWB technology in **W**ireless **B**ody **A**rea **N**etwork (WBAN) facilitates limited power budget which cannot be achieved using narrowband technology.

This Paper deal with the following chapters:

- Section II deals with the proposed system which depicts about the characteristics of the substrate and frequency of operation.
- Section III consists of design procedure of the patch (width and length), effective dielectric substrate and effective length.
- Section IV focuses on the simulation parameters such as the S-parameter, VSWR, Gain and Polarization effects.
- Section V depicts the results and discussions simulated in the HFSS software.
- Section VI deals with parametric analysis based on the simulated results taken.
- Section VII considers the conclusion and future work of the project by implementing various methodology, such as increasing the number of patches and changing the shape.

II. PROPOSED SYSTEM

The antenna model proposed here is [8][14] aperture coupled cylindrical patch element operating in 9GHz.There are specific application related areas where the antenna is needed to get conformed to the surface chosen, which can be the underbelly of the aircraft or a RADAR. Geometrical, Aerodynamics and Electromagnetic limitations are the main reasons for designing the antenna to be conformal. The efficiency of the antenna is improvised depending upon the feeding technique employed. The aperture coupled feeding technique ensures that the impedance bandwidth is ranging between 5% and 50% depending upon the line feed, where the bandwidth of the single layer microstrip line fed aperture coupled antenna is limited to 10-15% and it is of 30-40% for the stacked patch arrangement. Another unique advantage of this feeding is that it provides zero cross polarization, theoretically and it also supports dual- and circular polarization apart from the basic linear polarization. This increased bandwidth utilization and radiation parameters can be attributed to the two dielectric layers of independent dielectric constants chosen for the feeding and they can be optimized since there are numerous possible variations in the patch shape, aperture shape slot dimensions and feed line type. The feed circuitry is shielded from the antenna by a conducting plane with a hole (aperture) to transmit energy to the antenna .The upper[4] substrate can be made with lower permittivity to produce loosely bound fringing fields yielding better radiation .The lower substrate can be independently made with a high value of permittivity for tightly coupled feeds that don't produce spurious radiation. For the simplicity in geometry, rectangular patch is taken here.The three essential parameters for the design of a rectangular microstrip patch antenna are:

- Frequency of operation (f_0)
- Dielectric constant of the substrate (ε_r)
- Height of dielectric substrate (h)

Frequency of operation (f_0) is the resonant frequency selected and it is 9GHz for our design. [4] The dielectric materials selected for the design are RT Duroid 5880 and FR4 Epoxy, with the dielectric constant of 2.2 and 4.4 respectively. Here the FR4 Epoxy forms the lower layer of the aperture coupled and the RT Duroid forms the upper layer of the aperture coupled feeding. The substrates with considerably high gain has been selected since it gives maximum radiation.It is essential that the antenna should not be not bulky so that it gets conformed to the cylindrical surface and exhibits mitigated external protrusion. Hence, the height of the dielectric substrate is selected as 1.5 mm. Therefore, the essential parameters for the design are:

- f_0 = 9 GHz
- ε_r = 2.2 (RT Duroid 5880)
  4.4 (FR4 Epoxy)

- h = 1.5 m

III. DESIGN PROCEDURE

Step 1: Calculation of the Width (W):
The width of the Microstrip patch antenna is given as:
$W=1/2\ f_0(\sqrt{\varepsilon_0\ \mu_0})[\sqrt{2/(\varepsilon_r+1)}]$…………………………………………………………(1)
εr= Dielectric Constant
ε0=permittivity free space = 8.85 x 10-12 farad per meter (F/m)
μ0= permeability free space= 4π x 10-7 H.
Step 2: Calculation of Effective dielectric constant (ε_{reff}):
The effective dielectric constant can be given as:
$\varepsilon_{reff}=[(\varepsilon_r+1)/2] +[(\varepsilon_r-1)/2][1+12(h/w)]$ ……………………………………………….(2)
h/w = Height to width ratio.
Step 3: Calculation of the Effective length (L_{eff}):
The effective length can be given as:
$L_{eff}= c/ 2f_0(\varepsilon_{reff})$ ……..(3)
Step 4: Calculation of the length extension (ΔL):
The length extension can be given as:
$\Delta L=0.412h\ [(\varepsilon_{reff}+0.3)/ (\varepsilon_{reff}+0.258)][(w/h + 0.264)/(w/h + 0.8)]$…..............................(4)
Step 5: Calculation of actual length of patch (L):
The actual length is obtained by re-writing equation as:
$L= L_{eff}- 2\Delta L$……………………………………………………………….…(5)
Step 6: Calculation of the ground plane dimensions ($L_g$andW_g):
The transmission line model is applicable to infinite ground planes only. However, for practical considerations, it is essential to have a finite ground plane. It has been shown by that similar results for finite and infinite ground plane can be obtained if the size of the ground plane is greater than the patch dimensions by approximately six times the substrate thickness all around the periphery. Hence, for this design, the ground plane dimensions would be given as:
$L_g=6(h) +L$ …………………………………………………………………………(6a)
$W_g=6(h) +W$ …………………………………………………………………………(6b)

3.1aperture design:

The commonly employed feeding techniques of a patch antenna includes co-axial probe feed, Edge coupled (radiating and non-radiating), Proximity coupled, [8][14]Aperture coupled and CPW feed. Among the mentioned feed techniques radiating edge coupled, proximity coupled and aperture coupled show high utilization of bandwidth, with the aperture coupled taking the lead (21%).
Calculation of microstrip feed line:
$B= (60^* \varepsilon_r^2)/(Z_0\sqrt{\varepsilon_r})$……………………………………………………...….(7a)
Where,
Output impedance, Z_0=22.97Ω
Dielectric constant, ε_r=2.2
$W=2h/\pi\{B-1-\ln(2B-1)+((\varepsilon_r-1)/2\ \varepsilon_r)[\ln(B-1) + 0.39-(0.6/ \varepsilon_r)]\}$……………………..(7b)
T-junction power divider:
$L=\lambda_0 /(4\sqrt{\varepsilon_{eff}})$…………………………………………………………………….... (8)
Length, l=5.907 mm
Free space wavelength, λ_0 =0.033m
Effective dielectric, ε_{eff} =1.99
Aperture slot design:
$L_a= 0.2\ \lambda_0$.. (9a)
$W_a=0.1\ L_a$..(9b)
The design variables calculated using the Transmission Line model are summarized in the Table-I which is given below

Table 1. Patch dimensions at 9GHz

S.No	Symbols	Parameters	Dimensions
1.	L_p	Length of the Patch	10.27mm
2.	W_p	Width of the patch	13.17mm
3.	L_{ps}	Length of the patch substrate	19.27mm
4.	W_{ps}	Width of the patch substrate	22.17mm
5.	L_a	Length of the aperture	6.6mm
6.	W_a	Width of the aperture	0.66mm
7.	L_g	Length of the Ground plane	19.27mm
8.	W_g	Width of the Ground Plane	22.17mm
9.	L_m	Length of the microstrip line	5.90mm
10.	W_m	Width of the microstrip line	4.84mm

IV. SIMULATION PARAMETERS

The simulation parameters taken into consideration for the analysis are the S-parameter, VSWR, Gain and Polarization effects.

4.1 S-Parameter

This parameter is used to compute the amount of energy being reflected from the receiver. The ideal value of the S-parameter should be less than [6][9]-10dB, which accounts for only less than 10% of the incident power being reflected to the source. The lesser the S-parameter value than -10dB, the minimal will be the energy reflected. The hike in the S-parameter (S_{11} > -10dB) simultaneously increases the amount of energy reflected.

4.2 Voltage Standing Wave Ratio:

It is the ratio of the maximum and minimum voltage of antenna. [13][19]The ideal VSWR value is 1.0 (Reflected Power=0dB), which accounts for the perfect matching of the antenna to the transmission line. The lesser the VSWR, the better the antenna is matched to the transmission line and the more power is delivered to the antenna.

4.3 Gain:

The amount of power transmitted in the desired direction stands for the [15]Antenna gain. Typical gain value ranges between 1-1.5dB (minimum value) and 40-50dB (maximum value). The higher the gain, the higher will be the radiation in the desired direction.

4.4 Polarization Effects:

The polarization effects can be computed using the[7][9] Co- and Cross Polarisation, with the ideal condition as the co-polarization should be maximum and cross polarization should be nullified.

(i.e) Co-Pol= 100% and X-Pol = 0%.The values of the Co-pol and X-pol determines the amount of power transmitted in the desired direction.

V. RESULTS AND DISCUSSIONS

The proposed antenna is designed in the HFSS v13.0 and the following variables calculated.

5.1 Simulated S-Parameter:

The simulated S-parameter for the antenna is represented in the Figure 1 as a function of frequency.

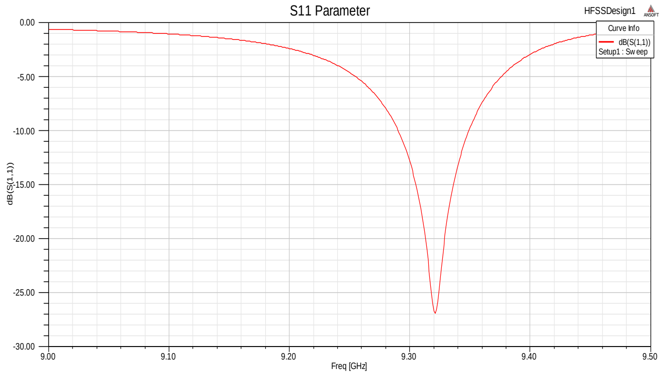

Figure 1. Simulated S-Parameter value.

The calculated and the simulated S-parameter values are represented in the Table-II and Table-III. The two layers of different dielectrics in the aperture coupled are matched well at around 9.3GHz and the Return loss remain below -27.5dB, which can be attributed to the dielectric loss value of the material considered for the simulation.

5.2 Simulated VSWR:

The simulated VSWR for the antenna is shown in the Fig.3.b. The calculated and the simulated VSWR for the antenna are represented in the Table-II and Table-III.

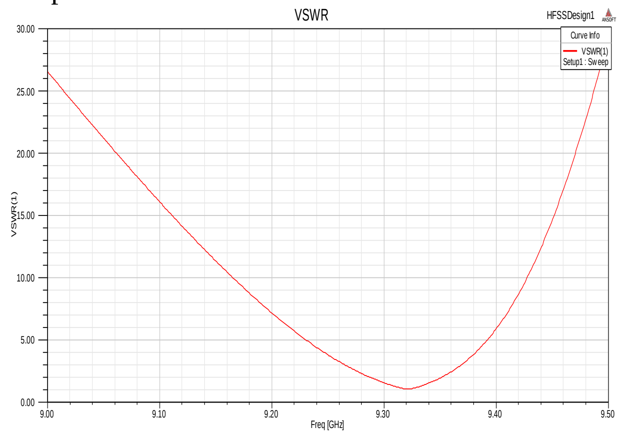

Figure 2. Simulated VSWR

The simulated VSWR value is 1.5 (< 2) at 9.3GHz. . The obtained VSWR (< 3) implies that the reflection co-efficient is 0.5. The value of VSWR=1.5 implies that the insertion loss is -0.01dB. The lesser the insertion loss, the minimal the amount of energy reflected to the source.

5.3 Simulated Gain:

The simulated gain for the antenna is represented in the Figure 3

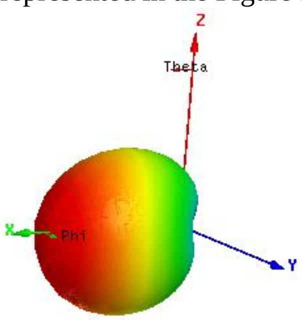

Figure 3. 3-Dimensional view of simulated gain

The ideal value of gain for the cylindrical conformal antenna operating in the UWB range is 2dB. The simulated gain for the antenna is 1.3dB.

5.4 Polarization components:

The cross- and co- polarization components have been measured at the f_0. The simulated polarizations are represented in the Figure 4 and Figure 5.

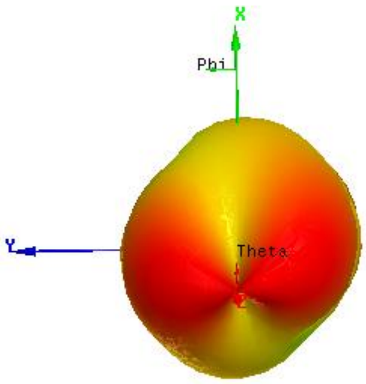

Figure 4. 3 Dimensional view Co-polarization

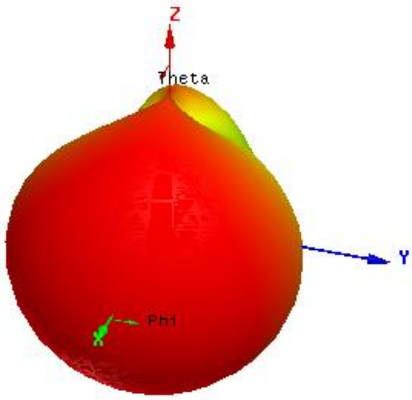

Figure 5. 3 Dimensional view of Cross-polarization

VI. PARAMETRIC ANALYSIS

- The discrepancies in the S_{11} parameter can be attributed to the dielectric constant of the material chosen and also the thickness of the substrate plays a significant role in achieving the ideal value.
- The deviation of the VSWR from the ideal value is attributed to the reflected and the transmitted power. The factor that affects the ideal VSWR value is the impedance mismatching, attributed by the feed line width.
- The gain of the antenna is determined by the operating wavelength and aperture efficiency. The deviations in the gain is attributed to the area covered by the slot in the feed (i.e Effective area), position of the slot in the ground plane. Apart from these input parameters, gain is also affected by the Return loss as it is directly proportional.
- The shift in the operating frequency is attributed to the curvature of the conforming surface. Once the patch is conformed to the surface, variations occur in the dielectric constant, which produces fringing fields. The fringing field generation is attributed to the thickness of the substrate. The less thick the substrate, the less will be the fringing field generated.

Table 2- Output Parameters

Output Parameters	Theoretical Values	Simulated values
S_{11}	< -20dB	-27.5dB
VSWR	2	1.5
Gain	2dBi	1.3dBi
Reflection coefficient	0.2	0.2
Bandwidth	0.636GHz	0.63GHz

VII. CONCLUSION AND FUTURE WORK

The conformal antenna with a patch is designed on the cylindrical surface meeting out the desired performance. The significant result is achieved with respect to S parameter, Polarization (both cross- and co-polarization). The return loss for the single patch is -27.5dB, which is a good value for the bandwidth of 636MHz. The VSWR also matches with the return loss, giving the value of 1.5, close to the theoretical value. The future work can be done by improving the number of patches with different polarizations for the conical and spherical conformal antenna.

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