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Design of Carbon Fiber Reinforced Polymer Based Parabolic Reflector

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***Abstract*—In this paper, a parabolic reflector antenna has been designed using carbon fiber composite. Carbon fiber Numerical approach and Electromagnetic simulator based computer simulation approach was adopted. Theoretical and simulation results of carbon fiber based composites was compared with aluminum based reflector. It was observed that CFC material is a feasible alternative for antenna applications in comparison to metallic based reflector.**

***Index Terms*—Carbon fiber composite, carbon fiber reinforced polymer composite, computer simulation technologies**

NOMENCLATURE

Symbol	Definition
F	Focal length
D	Depth
D	Diameter of parabola
Ө	Beam width
S	Surface area of parabola
F	Frequency
G	Gain
η	Efficiency of parabolic reflector for antenna

1. INTRODUCTION

Antenna had been used from many decades for signal transfer. To communicate over long distances therefore, sophisticated form of antenna designed, that is used for the transmission and reception of signals over miles. An antenna is defined as “a device that can be used for radiating or receiving radio waves.” The parameters for the designing of antenna are gain, directivity, antenna apertures, radiation intensity, polarization, radiation intensity, effective height. A very common antenna that can designed for such an application is the parabolic reflector. In parabolic antenna, basically horn (feed horn) is used to convey radio waves between transmitter or receiver and the parabolic reflector. The role of parabolic antenna that it is used is its high directivity. The large dimensional antennas are needed to achieve the highest possible gain that can be required to transmit or receive signals after millions of miles of travel [1].

Material play an important role in efficient designing and reliable antenna. Conventionally, metallic based reflectors are being used. But now a days, composite material is a choice for structures such as antennas A composite is a material that can be formed from two or more constituent materials - (CFRP) are basically carbon fiber composites. (CFC) consists of carbon fibers that are embedded in a polymer matrix. Carbon fibers are electrically conductive whereas the matrix is non-conductive, and it is typically a resin. The basic aim to use CFRP is found in their mechanical as well as electrical properties. The lightweight construction of reflectors, in large parabolic dishes or space applications is done by CFRP, since it is having excellent specific tensile strength, stiffness, modulus, fatigue strength, light weight. The antennas designed using CFRP are resistant to corrosion and sustain under lightening conditions. From material point of view, the electrical conductivity, permittivity, and magnetic permeability of the material is of interest. The general view states that the conductivity, permittivity, permeability of CFRP are identical in all directions [2].

In this paper, an attempt has been made to design CFRP material based parabolic reflector, which has the potential to improve the parameters desired for efficient communication.

2. MATERIAL

CFRP composite has been selected as a material for designing reflector antenna. The CFRP material is formed by the assembling of carbon fibers that are submerged in an epoxy resin forms the CFC material. Approximately, carbon fiber 60% and epoxy resin 40% by volume is assumed in this research work. The shapes of fibers are continuous and have cylindrical format with diameter of 7.1 micrometers [5].

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Each set having 12000 fiber with a cross sectional area of0.48〖 mm〗^2.The material consists of ten layers having thickness of 0.21mm, the first and the last two layers are arranged in a manner that they have an orientation of [0,90] and the remaining are arranged with the orientation of [45,-45].

Elastic modulus(E_c) of the composite is given by the equation:

$$E_c = vE_f + (1-v)E_m \quad (1)$$

where

'v' is the volume fraction of fiber

E_f & E_m are Elastic modulus of fiber and matrix. The electrical conductivity and effective permittivity of the CFRP composite is evaluated by the rule by the rule of mixture in terms of their volume fractions and properties are given below[2],[3]:

$$\sigma_{eff}=v\sigma_{carb} + (1-v)\sigma_{res} \quad (2)$$

$$\varepsilon_{eff}=v\varepsilon_{carb} + (1-v)\varepsilon_{res} \quad (3)$$

The indexes *carb* and *res* denotes the parameters like carbon and resin, and the index *eff* denotes the effective parameter of CFC.

Considering the relative permittivity:

ε_{res}=4.0, ε_{carb}=12.0

The electrical conductivities:

σ_{res}=0, σ_{carb}=1.0 ×10^5 S/m

The percentage of carbon **v** = 0.6,

It is obtained,

ε_{eff}= 8.8

$\sigma_{eff} = 5.9 \times 10^4$ S/m

Thus, it has been concluded that CFC is considered as a homogenous material [5].

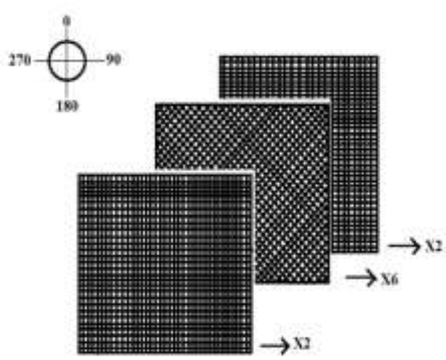

Fig 1. CFC sample with fibers orientation and layers

3. DESIGN

The antenna used here is the parabolic reflector. It is used to convert the spherical wave into plane waves. The feed antenna known as primary antenna whereas the reflector is known as secondary antenna. All the incoming rays, which are parallel to the axis of parabola, are reflected through focus. To obtain the results on the basis of mathematical calculations the following diagram and equations should be taken into consideration.

Here the parabolic reflector is taken with 80 cm diameter, 25 cm depth and operating at 5GHz.

Considering the equation of parabola: $y = ax^2$ (4)

where $a = \frac{1}{4f}$

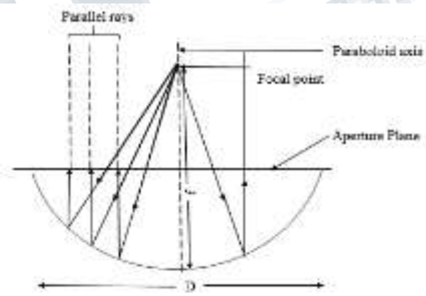

Fig.2: Diagram showing the parabolic reflector

Focal length (*f*)

$$f = \frac{D^2}{16d} \quad (5)$$

Beam width

$$\frac{f}{D} = \frac{1}{4}\tan(\theta/4) \quad (6)$$

Surface area of reflector

$$s = \frac{\pi(a^2D^2+1)^{3/2-1}}{6a^2} \quad (7)$$

$$\lambda = {c}/{F}$$

Gain of parabolic reflector

$$G = 10log_{10}\left(\frac{4\eta\pi A}{\lambda^2}\right) \quad (8)$$

where A=$\frac{\pi D^2}{4}$

4. WIND LOAD ANALYSIS

Determining the wind pressure on the reflector surface is essential in the analysis of antenna. The calculation of force and pressure on antenna is dependent on the static effect of wind. Consider the wind having the different operational speeds at different angle of attack [6].

Wind dynamic pressure (p) = $\frac{1}{2}\rho v^2$ (9)

ρ=Density of Air (1.20 kg/m^3)

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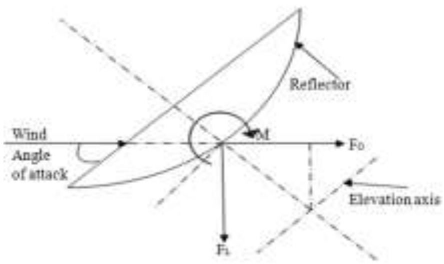

Fig.3: Wind torque with respect to rotational axis

p= (0.5×1.25× (1000/3600) $\times \boldsymbol{v^2}) \boldsymbol{N/m^2}$
p=0.0482×v^2 N/m^2.

5. RESULTS

Mathematical modelling result:
For the paraboloid reflector antenna with the 80 cm diameter, 25 cm depth, operating at 5.0 GHz frequency

Parameters	Calculated Values
Focal length	0.16 m
Wavelength	0.06 m
Gain	72.437 dB

Wind Load Analysis Result:
Taking equation (7), the pressure at different operational speed is calculated. Thus, the pressure on the antenna increases with an increase in the operational speed of the wind.

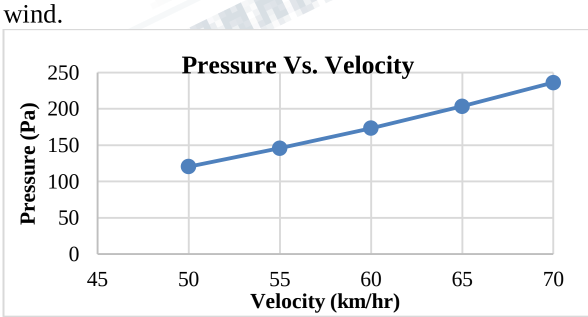

Figure 4. Graph showing variation of pressure with the change in velocity

Software based results:
The software used for designing is computer simulation technologies (CST). The process consists of the designing of the horn antenna then parabolic dish.Here the radio waves are directed by the horn antenna.The material used for the designing process is aluminium.The signals tranmitted by horn are reflected by parabolic dish which is showing below.

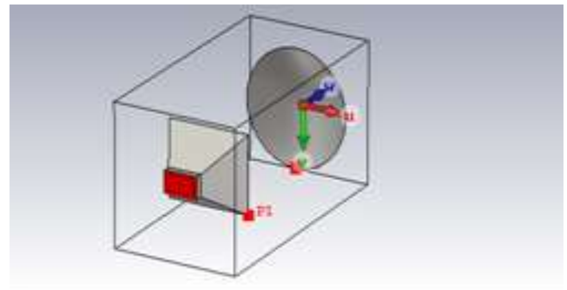

Fig. 5: Design of Aluminum based parabolic Reflector using CST software.

The figure depicts the farfield plot for an isotropic antenna i.e radiating with same intensity in horizontal and vertical direction .

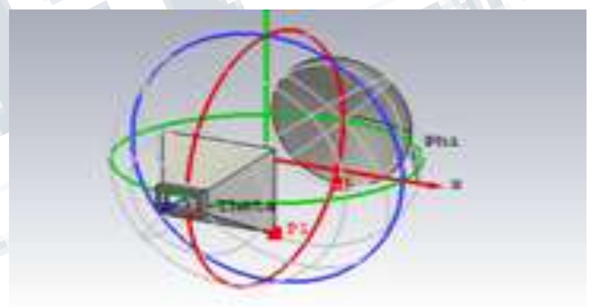

Fig. 6: Far field plot for an isotropic antenna with Aluminum reflector.

Proposed antenna shows the S-parameter response with respect to frequency of 8GHz to 12GHz where S_{11} shows the response at 8GHz to 8.376GHz (-17.101855 to -10.00547), rest of the frequency showing the maximum return loss with respect to signal.

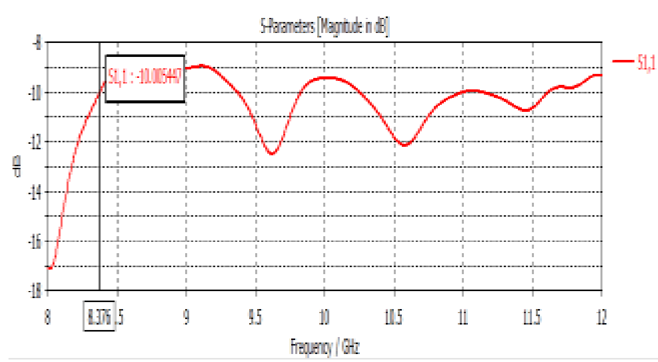

Fig.7: S Parameter plot for Aluminum reflector

VSWR plot for the frequency of 8.376 GHz is 1.924(VSWR<2), it shows the better characteristics in the given frequency range.

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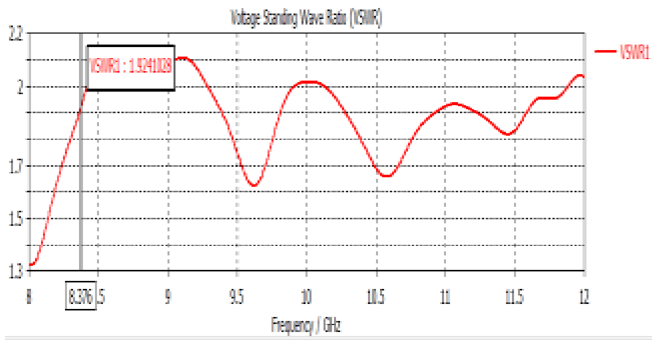

Fig.8: VSWR Plot for Aluminum reflector

Here the design process is continued and a composite layer is presided over the parabolic dish. Then the farfielad plots are obtained for an isotropic antenna. The corresponding signal plot is obtained for the parabolic reflector designed using composite.

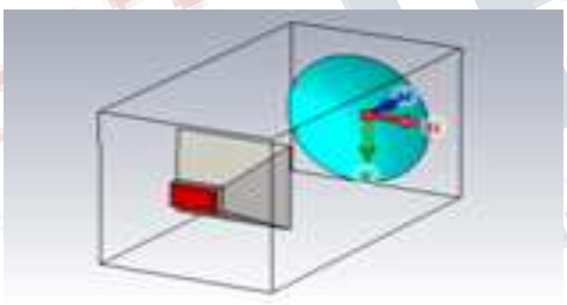

Fig 9: Design of Carbon fiber composite based parabolic reflector using CST software.

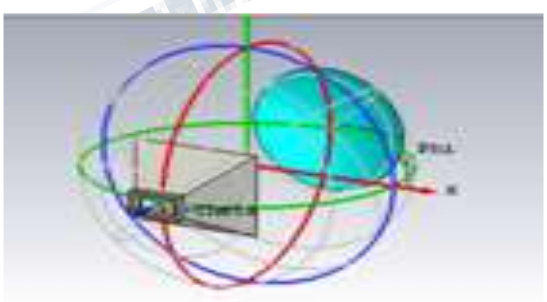

Fig 10: Far field plot CFRP based Isotropic Antenna.

Proposed antenna shows the S-parameter response with respect to frequency of 8 GHz to 12 GHz where S_{11} shows the response at 8.0033GHz to 8.9468GHz (-18.936553 to -10.0025176), rest of the frequency showing the maximum return loss with respect to signal.

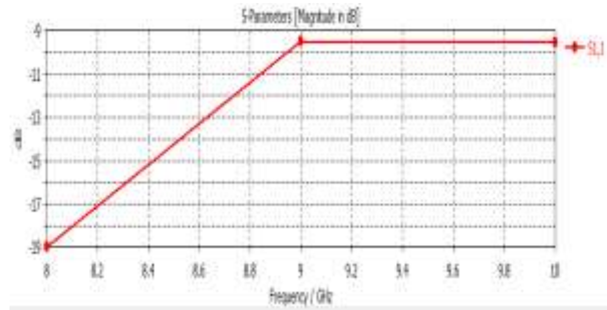

Fig. 11: S Parameter Plot for carbon fiber composite based reflector.

VSWR plot for the frequency of 8.003 GHz is 1.25630 (VSWR<2), it shows much better characteristics in the given frequency range.

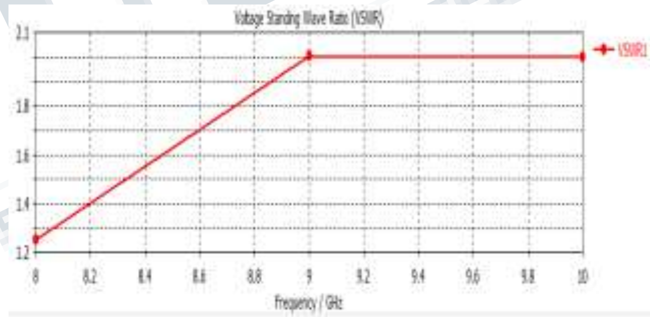

Fig.12: VSWR Plot for carbon fiber composite based reflector.

Material / Attributes	Aluminium	Carbon-fiber
Young modulus	69 GPa	228 GPa
Tensile strength	276 MPa	110 GPa
Stiffness against weight (Specific modulus Unit:$10^6 m/s^2$	26	120
VSWR	1.924	1.256

It has been stated that CFRP material provides strength and stiffness at low density. It is 40% lighter in weight than aluminum. CFRP is approximately 10 times stronger than aluminium.

CONCLUSIONS

The model designed using CFC shows that CFC is a good approximation for the designing the parabolic reflector. All the design parameters are within the desired range. Thus, CFC material is a probable alternative of aluminium for antenna.

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