Chapter 6

Testing of Piezo Coated Composite Reflectors for Antenna Efficiency

Detailed contents

Testing of
Piezo Coated Composite Reflectors for Antenna Efficiency

6.1 Introduction

This part of the exercise has been carried out as a corollary to the passive vibration damping investigation carried out in Chapter 5 to explore the practical suitability of the piezo coated composite reflectors. As mentioned in section 1.2 , weight and power consumption are at premium in satellites, hence there is always a requirement of state-of-the-art light weight, high specific stiffness and low thermal expansion materials for spacecraft reflectors. Size of the component is also a major consideration in spacecrafts, hence there is a requirement of small size composite reflectors operating at high frequencies. Although, Reflectors have existed since the days of Hertz, but they still unequivocally represent one of the best solutions for high Gain and light weight antenna systems.

For developing state-of-the-art doubly curved parabolic reflectors for satellites, need was felt to explore the possibilities of improving the antenna gain / efficiency of the Prime Fed (PF)[#] type of spacecraft antenna reflectors in the light of usage of smart materials.

Wide gamut of technical papers related to spacecraft reflector domain in the literature have been scanned and in then light of the need discussed above, it has been proposed to develop dielectric material spars[#] for PF type antenna reflectors using piezo coated materials as an hypothesis. Moreover, as discussed in section 5.4, the piezo layer acts like a viscoelastic layer and no polarization ,per se, takes place within the thickness domain of the piezo coating in the absence of any electrical field during vibration testing. This viscoelastic behaviour of piezo layer on composite reflector elements under RF signals perhaps become a selection criteria of piezoceramics usage in antennas for avoiding EMI / EMC issues.

6.2 RF blockage issue

An attempt has been made to identify by experimental investigations, the novel

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For antenna related vocabulary used in this chapter, please refer Appendix C dedicated to the Terminology.

materials for feed support spars for different transmit / receive frequencies for PF type reflectors. These feed support structural members called spars practically should be dielectric, RF (Radio Frequency) transparent and should exhibit the requisite stiffness, with a preference of reducing the RF blockage and improving the antenna efficiency.

In general, metallic spars are utilized to provide essential rigidity as a feed support. But the biggest disadvantage is that these spars are not transparent to electromagnetic waves, therefore the spars block the electromagnetic waves. This blockage reduces the overall radiating area of the reflector. This reduction results in overall reduction of Gain and overall efficiency of the antenna.

In the experimental investigation, an attempt has been made to identify such novel materials which may be transparent / translucent to electromagnetic radiation. Therefore, overall blockage may be reduced and Gain /Efficiency can be increased. Such materials are dielectric materials and various such materials have been chosen and spars were fabricated out of it. These spars were integrated with the parabolic reflector as shown in Fig 6.0 and put to electromechanical tests. The radiative properties were characterized at CATF /SAC as shown in Tables 6.1 & 6.2.

6.2.1 Feed Support Spars

In the present investigation, reflector feed is supported by four spars of diameter 19 mm, 3 mm thick as shown in Fig 6.0. Three different materials are tried as spars to investigate the RF blockage at two different Transmit / Receive frequencies for 0.7m dia. GFRP reflector.

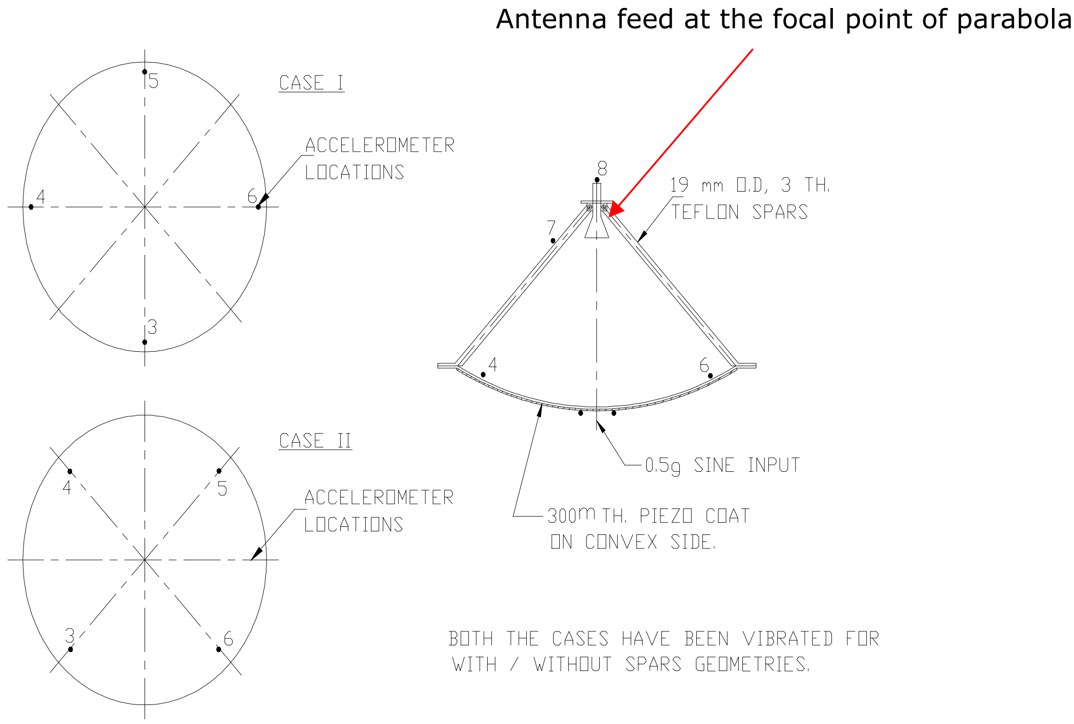


Fig 6.0 The Prime Fed type parabolic reflector with four spars

Therefore, Electro-mechanical testing of prime fed type of parabolic reflectors made up of feed support spars coated with thin hybrid piezoelectric material layers have been tried to investigate the reduction of the RF blockage and improvement in antenna gain and efficiency at CATF /SAC Ahmedabad. The main reason of this RF blockage is the shadow effect caused due to conventional Carbon fiber spars or metal spars as discussed in section 6.2, which are structurally stiff but reduce the efficiency of the antenna due to the RF blockage (their shadow) caused by them.

Four typical 19mm diameter spars finalized in Chapter 5 for 0.7 m diameter reflector from the structural analysis point of view to meet the natural frequency constraints, have a blockage area of (projected length of four spars equal to) 266 cm^2. This is approx. 6.9% of the aperture area (3848 cm^2 for the 0.7 m φ reflector with non-RF transparent metal spars). Therefore, because of the shadow area (266 cm^2) due to four metal / CFRP spars, the effective radiating aperture reduces from 3848 cm^2 3582 cm^2 .

As antenna is a passive device and not an active device, the gain of the omni directional antenna is a perfect sphere (360^o equal power), but radiation is required at a particular angle, therefore it gives rise to a concentrated main beam with side lobes as shown in Fig 6.12.

6.3 Piezo Coated Teflon Spars

The study is carried out using piezo coated spars developed using dielectric, surface activated plasma etched stiffened Teflon tubes for PF type parabolic reflectors for two different transmit radio frequencies for checking the improvement of efficiency and gain of antennas .

Teflon material has been chosen from the list of other potential aerospace materials like Torlon, Noryl, Zylon etc., because of its availability in the local market. In order to improve the properties of commercially available Teflon and to making it suitable for space use , various surface activation methods were tried. Proper RF Plasma etching treatment has been used for obtaining hybrid piezo coating on the Teflon spars on the outer surface . Etching treatment has been given to have coating on it and not for improving the outgasing[#] properties. It has been covered in detail in Chapter 7, that without any surface activation done on Teflon, how the thin piezo powder coat peels off form the Teflon tube surface while carrying out the investigations.

A thin hybrid layer of piezoceramic material when coated on the tubular Teflon spars after surface activation by specific plasma etching process may make the Teflon spars a right candidate to swap conventional CFRP / metal spars for the spacecraft reflectors in the space domain.

In support of this hypothesis, these spars were tested electrically in the CATF at SAC / ISRO Ahmedabad, India using the 0.7 m diameter GFRP reflector with feeds for two different frequencies bands (C-band and Ku-band).

6.4 RF Reflectivity Tests

For realistic test results Reflectivity tests have also been carried out at Planar Near Field (PNF) Test Facility, CATF /SAC / ISRO for the GFRP material specimen at three different microwave transmit radio frequencies viz., 6.5 GHz, (Extended C-band), 11 GHz & 14 GHz (Ku band) respectively. Table 6.1 shows the reflectivity test results for bare 3mm thick GFRP specimen along with three identical GFRP test specimen with 300 microns of piezo material hybrid coating (SP5A+ SP4 powder) on one side only of GFRP for comparison purpose.

For antenna related vocabulary used in this chapter, please refer Appendix C dedicated to the Terminology.

Table 6.1: RF Reflectivity test measurement

Specimen No. (Thickness in mm) GFRP	Reflectivity in % at Frequency 6.5 GHz		Reflectivity in % at Frequency 11 GHz		Reflectivity in % at Frequency 14 GHz	
	Front side of sample (coated)	Rear side of sample	Front side of sample (coated)	Rear side of sample	Front side of sample (coated)	Rear side of sample
Bare (3)	25.12	22.37	53.7	69.9	61.9	90
Coated (3.3)	33.9	26.92	61	71.0	71.6	70
Coated (3.3)	37.2	39.26	75	66	75	93
Coated (3.3)	39.8	39.4	55.6	75.8	62.4	93

It has been observed that, vis-à-vis, bare sample behavior, at 6.5 GHz, the results are encouraging for piezo material as against, 11 GHZ & 14 GHz. As per the Table 6.1, the bare GFRP sample reflectivity at 6.5 GHz is 22.37 % i.e. RF Transparency for piezo material is 77.63% (100-22.37). The piezo coated specimen no.3 gives, maximum reflectivity from rear side of 39.4% i.e. RF Transparency of 60.6 % as against 77.63 of bare sample. This means at 6.5 GHz the piezo material is almost RF transparent. In addition to that, it has been observed that at two other test frequencies, this not so the case with 11 GHz and 14 GHz, where the RF transparency remains significantly less.

Similar exercise has been repeated for 4.5 GHz (C-band). Reflection coefficient (Reflectivity) measurement for bare GFRP test specimen plus three similar specimen of different thickness of piezo material hybrid coating (SP5A + SP4 powder) have been tried at 6.5 GHz & 4.5 GHz on one side only. The results of the reflectivity tests are compiled in table 6.2.

Table 6.2: RF Reflectivity test measurement at lower frequency

Sr. No.	Sample Thickness	Reflectivity at Frequency 4.5 GHz		Reflectivity at Frequency 6.5 GHz	
	mm	Front side of sample (coated)	Rear side of sample	Front side of sample (coated)	Rear side of sample
1.	3.4	97.95%	86.1%	98.97%	83.75%
2.	3.2	97.91%	61.66%	96.94%	61.65%
3.	3.1	51.64%	52.18%	30.98%	29.82%
4.	Bare (1.5)	25.3%	26.8%	23.44%	20.42%

The results shown in Table 6.2 regarding RF transparency are encouraging for 4.5 GHz also as RF transparency remains almost 50% or so, vis-à-vis the bare sample. It was observed that as the thickness of piezo coat increases then RF Transparency drops down. The thickest 3.4 mm thick sample has just 13.9% transparency at 4.5 GHz.

Therefore, all RF tests were carried out at 6.5 GHz for gain measurement for the reflectors with spars made up piezo coated material. Moreover, one additional transmit / receive frequency of 11 GHz has also been tried for comparison purpose.

6.5 Electrical testing of the reflector

For the electrical testing part, the experimental investigation has been carried out on a 0.7 m dia. (F/D=0.4, where, F=Focal length of parabolic reflector & D = dia. of the reflector) Ku-band GFRP reflector, impregnated with copper coated Kapton on concave side for 6.5GHz & 11 GHz feeds.

A thin hybrid piezo material coating on the convex side was carried out on the reflector for attenuating micro vibrations as described in the chapter 5. Fig 6.1 shows the CFRP / metal spars in the form of quadripod (four legged structure for feed support) which cause blockage to the RF signals thereby reducing the efficiency of the reflectors as described earlier in section 6.2.

Fig 6.2 shows the C-band feed under test at CATF with piezo coated Teflon spars in the form of quadripod. Spars are structurally designed for 19 mm OD, 2mm thick tubular sections.

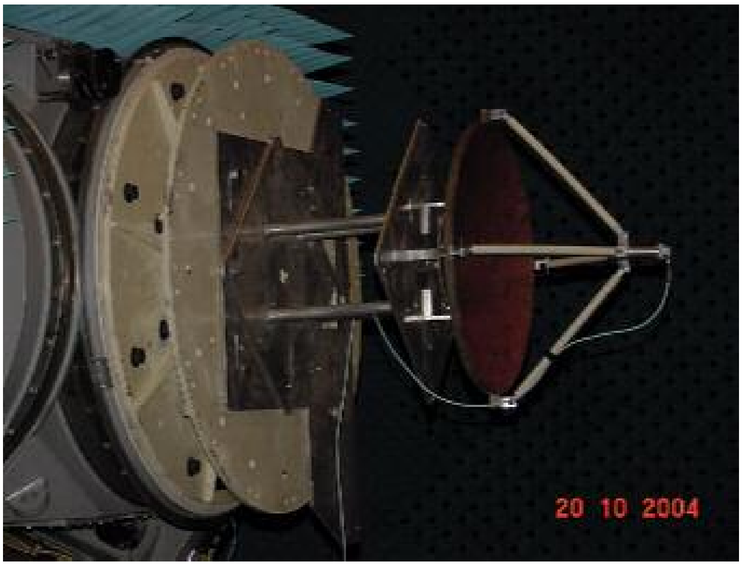


Fig 6.1 : Ku band Feed with Piezo Coated Teflon spars

Fig 6.2 : The C-band feed with Metal spars

Approximately 6.9 percentage of the projected area of the aperture goes in the blockage as a shadow due to four spars.

6.6 Types of spars tested and Observations

The investigation has been undertaken using three different types of spars from RF transparency point of view to meet the objective of improved efficiency & gain for the prime fed type of GFRP reflectors:

- RF Plasma etched piezo coated Teflon spars
- GFRP spars (with / without Alumnized tape wrap around)
- Metal spars

Fig 6.3 shows the experimental set up for the GFRP reflector with C-band feed under testing.

6.6.1 RF Plasma etched piezo coated Teflon spars

0.7 m dia. (F/D=0.4) GFRP antenna, parabolic in shape has been used one by one with 3 different sets of spars and the antenna system has been tested for 2 different Transmit / Receive frequencies i.e Ku band & C band .

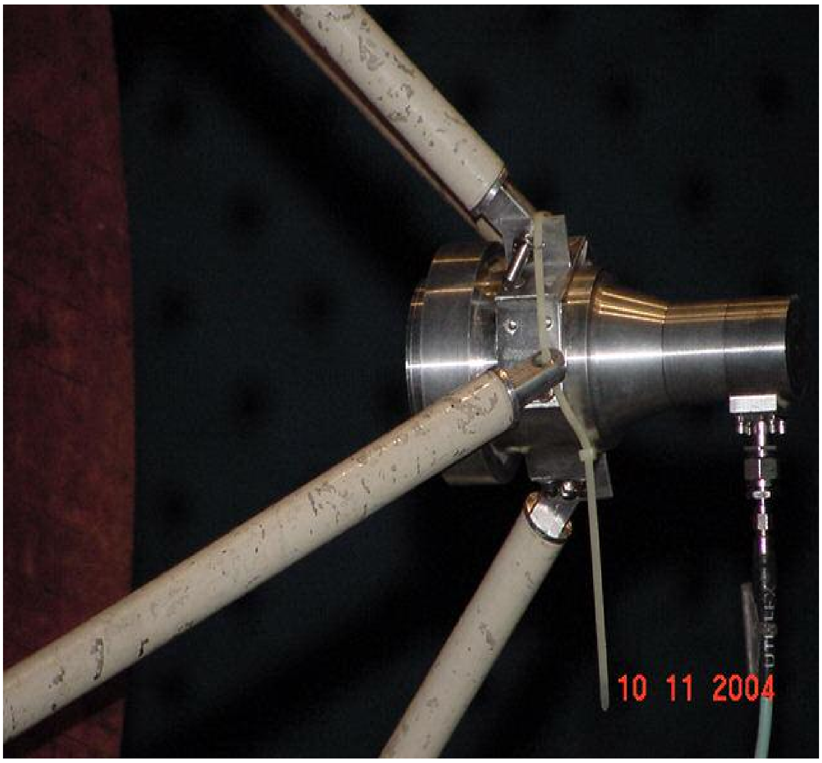


Fig 6.3 : Piezo coated Teflon spars showing C-band Feed

For handling Ku-band frequency signals the copper coated Kapton sheet was impregnated on the concave side of the reflector at M/S Moon Light Bhavnagar. This copper coated polymide film had 50 microns thickness of the substrate and had

30 microns thickness of the copper sufficient for 99.9 % reflectivity for the Ku-band microwave signals. Electrical testing was carried out at CATF at SAC/ISRO.

The gain of an antenna is related to its directivity, and directivity is related to the shape of the directive pattern (Refer Appendix – C). A commonly used index of directivity, and therefore the gain of an antenna, is a measure of the width of the major lobe (or lobes) of the plotted pattern. The width is expressed in degrees at the half power or –3 dB points, and is often called the beam width.

The gain of reflector $G = 10 \log_{10} [(4 \pi A \eta) / \lambda^2]$ Eq. 7.1

Where, A = Aperture area of the reflector $= \pi / 4d^2$

λ = wave length of the signal

η = Efficiency of the reflector

d = diameter of the reflector

In electrical testing at CATF, using Eq. 7.1, this antenna with piezo coated GFRP reflector with piezo coated Teflon spars reported increase in overall efficiency to the tune of 2% during measurements at CATF (0.2 dBi Gain) due to reduction in RF blockage (approx. 6.9% of the aperture area of the 0.7 m φ GFRP reflector) for both the type of frequency bands (C & Ku band) as these spars remained translucent to the RF signals up to Ku band.

This increase in overall efficiency of the reflector affects the Gain of the antenna system .

Fig 6.4 shows a typical Ku band feed on 0.7m metalized GFRP reflector under testing and Fig 6.5 depicts a typical C band feed on 0.7m metalized GFRP reflector.

Fig 6.6 shows the 3D Antenna performance pattern of 0.7 m dia. GFRP Ref. with Teflon spars . In this 3D plot, on X & Y axes , Device under Test (DUT) in elevation and Azimuth is plotted and on Z axis , the amplitude in dB is shown. A perfect main lobe and side lobes are visible in this 3D antenna performance pattern . Quantitative assessment is seen for a typical case in 2D representation of the antenna beam.

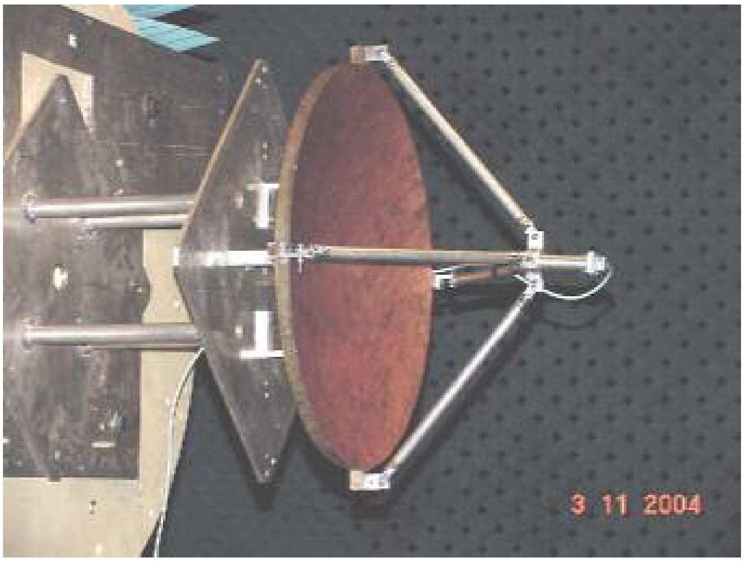


Fig 6.4 : Ku band feed on 0.7m metalized GFRP reflector with metal spars

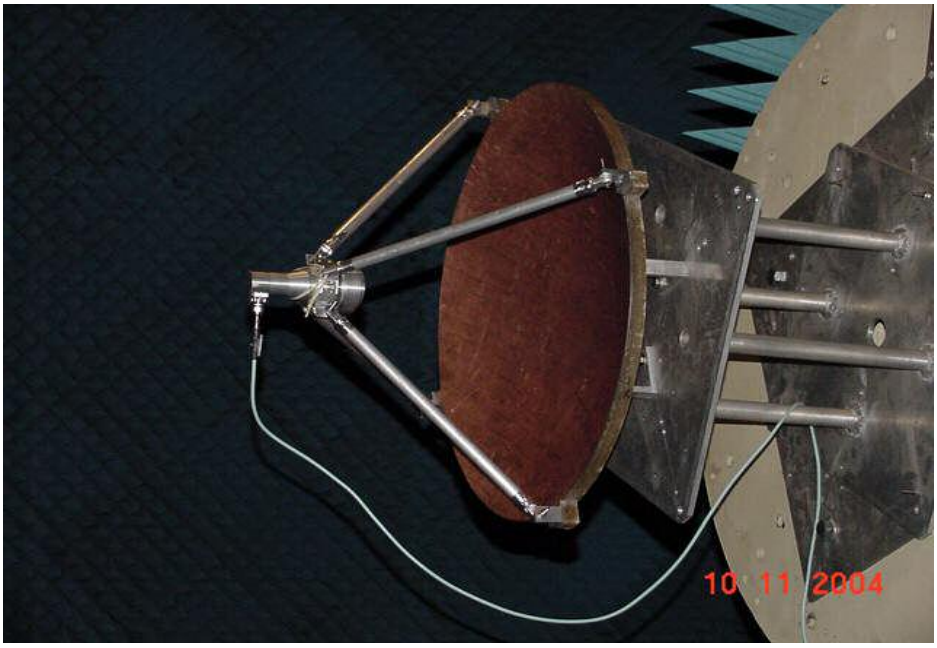


Fig 6.5 : C band feed on 0.7m metalized GFRP reflector with metal spars

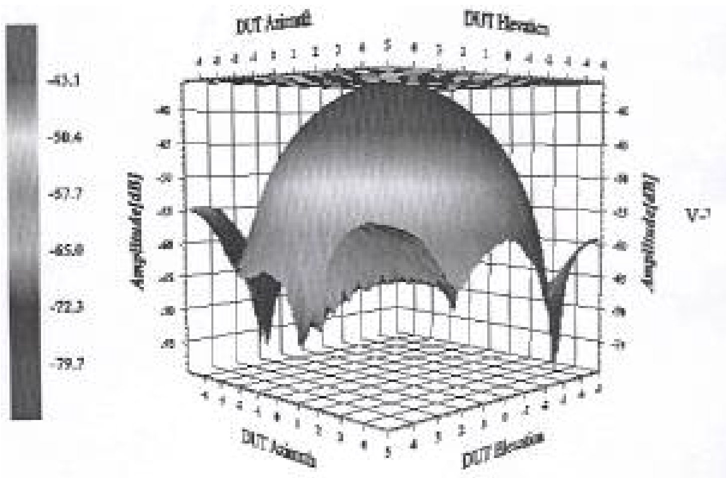


Fig 6.6 :Antenna performance pattern of 0.7 m dia. GFRP Ref. with Teflon spars

Therefore, considering this investigation, this approach in its totality for case-1 of the investigation, has given encouraging results with respect to improved antenna efficiency due to reduction in blockage area by using near RF transparent piezo coated Teflon spars for both the type of frequency bands (C & Ku Band).

Electrically no EMI / EMC interference issues have been encountered, when electrical tests were carried out for antenna efficiency due to piezo coated Teflon spars as there was overall improvement in the efficiency of the reflector.

The encouraging results w.r.t. the increase in overall antenna efficiency and thereby improved gain in electrical testing of the stiffened plasma treated Teflon spars with piezoelectric material coating confirms the hypothesis regarding the suitability of dielectric material spars for PF type high frequency space borne EV (Earth view) top deck mounted small size antenna reflectors on the spacecrafts.

The Plasma treated, piezo coated Teflon samples have also been outsourced for outgasing properties evaluation work to explore its space qualification possibilities, in the absence of such infrastructure at SAC.

6.6.2 GFRP spars (with / without Alumnized tape wrap around)

Comparison has also been made for two cases of GFRP material *per se,* for better insight into the hypothesis made in the beginning for the usage of dielectric material spars . The results in the form of antenna performance pattern are shown in Fig 6.7 for Teflon spars with Aluminum tape & without Aluminum tape at 11.6 GHz frequency on the same 0.7 m dia. GFRP reflector.

In this 3D plot, on X & Y axes , Device under Test (DUT) in elevation and Azimuth is plotted and on Z axis , the amplitude in dB is shown. A perfect main lobe and side lobes are visible in this 3D antenna performance pattern for without Aluminum wrap around case also as seen earlier.

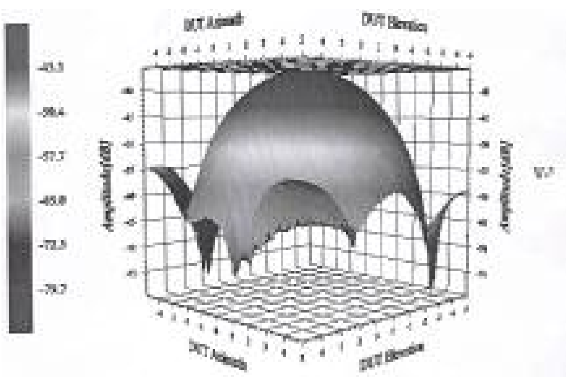
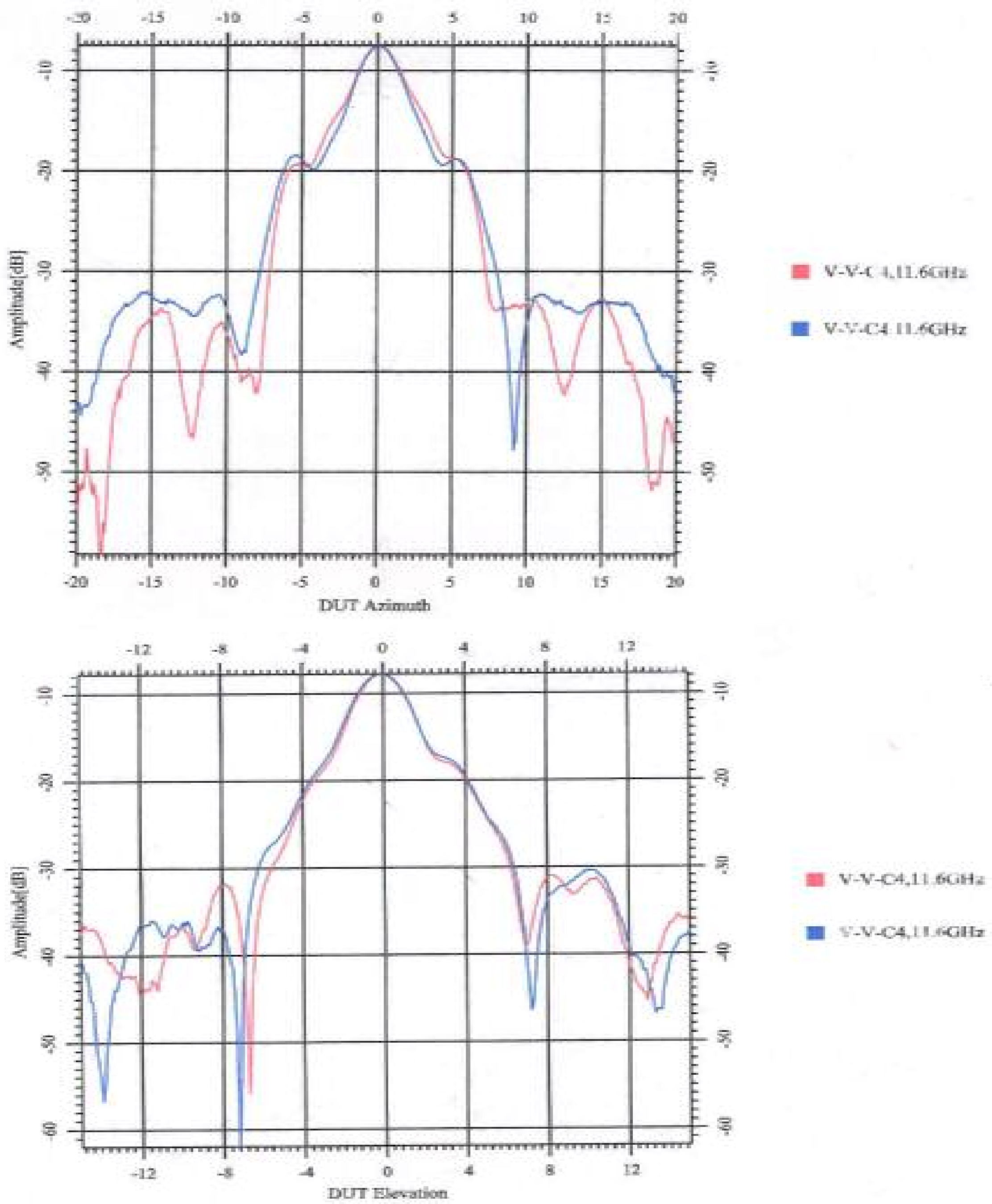


Fig 6.7 :Antenna performance pattern of 0.7 m dia. GFRP Ref. with Teflon spars

This phenomena is further seen in 2D representation of the antenna performance pattern for GFRP spars (which is also a near RF transparent material with dielectric constant near 2.5) also in addition to Teflon spars as follows:



Red : Without Aluminum Tape on GFRP spars
Blue : With Aluminum Tape on GFRP spars

Fig 6.8 : Antenna performance pattern at 11.6 GHz frequency in Azimuth & Elevation

Fig 6.8 shows the 2D antenna performance pattern of 0.7 m diameter GFRP reflector for with Aluminum tape and without Aluminum tape case options for GFRP spars. GFRP spars have indicated improvement in both main lobes and side lobes, vis-à-vis, metalized spars (metalized tape wrap around case on Teflon spars) for both the Elevation and Azimuth cases. The increase in area under the curve (Blue for GFRP spar case), vis-à-vis, the area under the curve (Red for metalized spars) for both elevation and Azimuth cuts, also directly indicate the increase in Gain of the antenna and overall improvement in the efficiency.

6.6.3 Metal spars

Fig 6.9 shows the antenna performance pattern of 0.7 m diameter GFRP reflector (3D Plot of performance) with Metallic spars. In this 3D plot, on X & Y axes , Device under Test (DUT) in elevation and Azimuth is plotted and on Z axis , the amplitude in dB is shown. A perfect main lobe and side lobes are visible in this 3D antenna performance pattern for metallic spars case but with reduced amplitude of power due to blockage of RF signals due to metal spars. This power has been compared with the case of Teflon tube Spars quantitatively in the following pages:

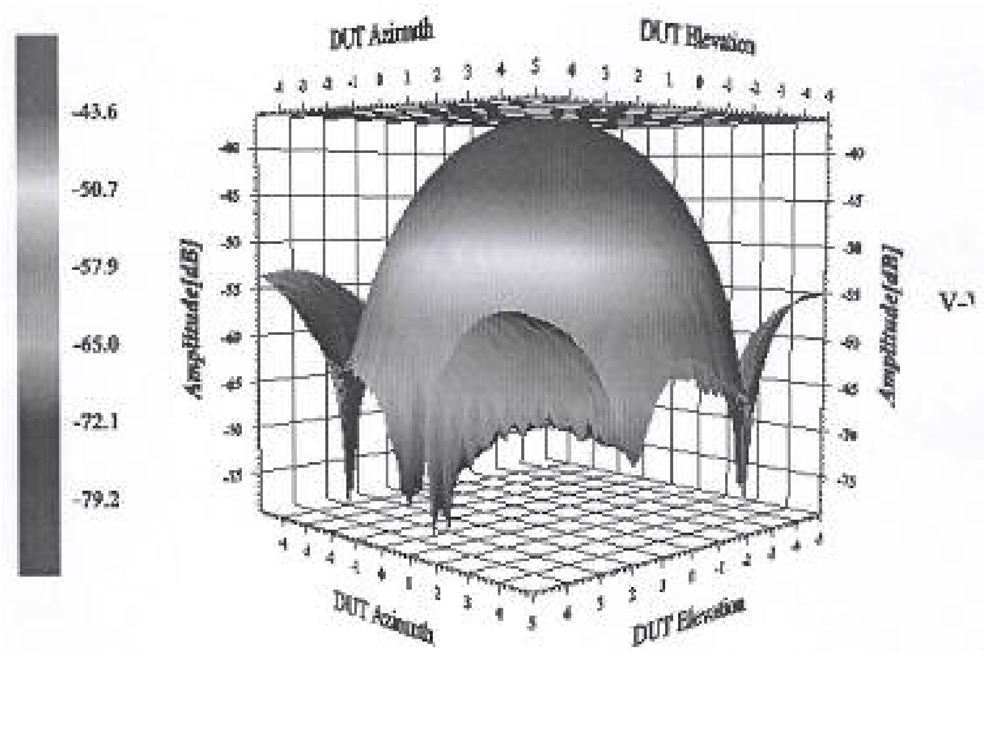


Fig 6.9 : Antenna performance pattern of 0.7 m dia. GFRP Ref. with Metallic spars

Fig 6.10 shows the Electrical testing of 0.7 m dia. GFRP reflector at CATF Ahmedabad for Metalized Teflon spars an equivalent to metal spars case at C band.

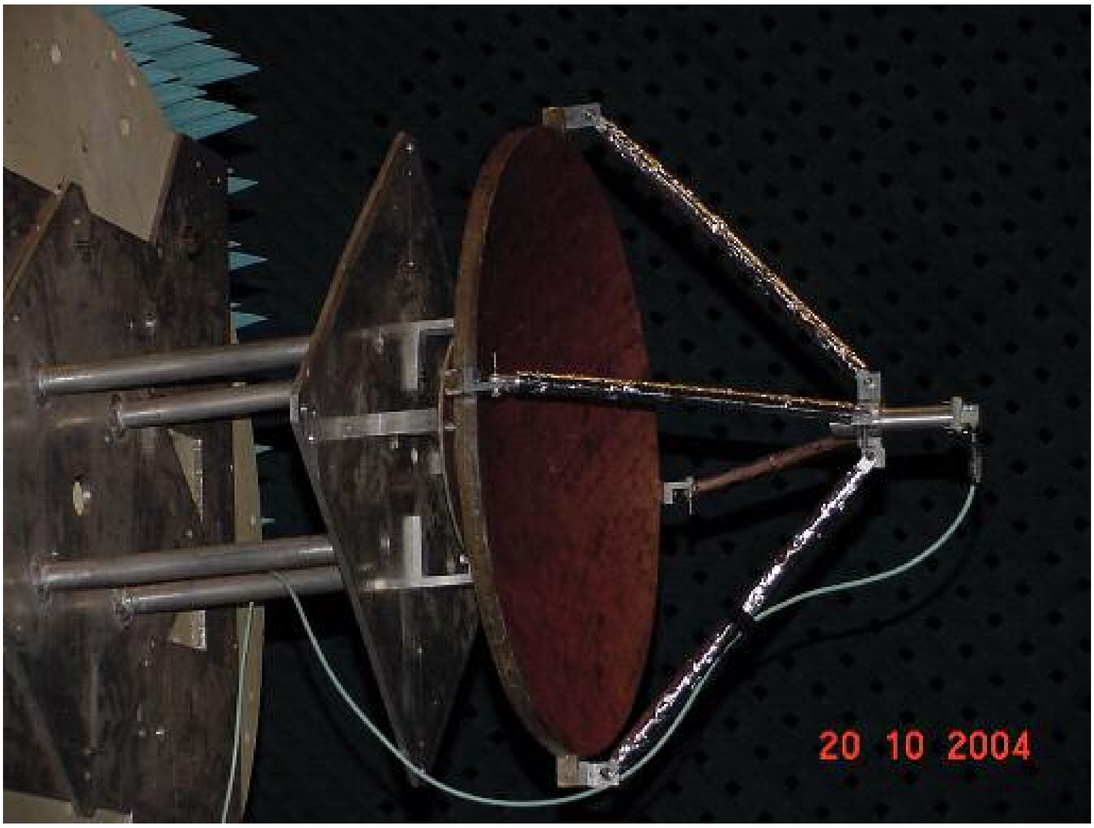
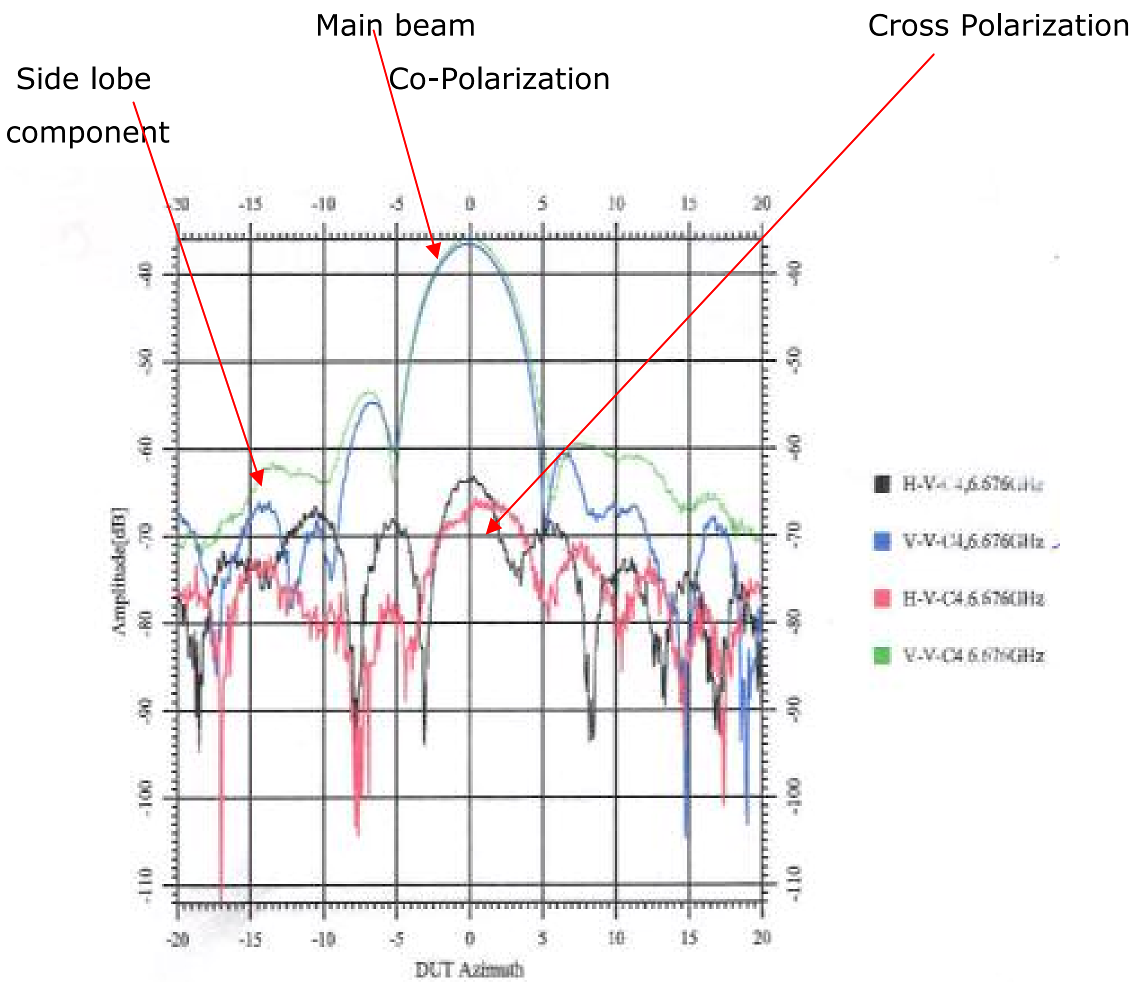


Fig 6.10 & 6.11 : 0.7 m dia. reflector with Teflon spars wrapped with Metal tape

Fig 6.11 shows the Electrical testing at Ku band for 0.7 m dia. with Metalized spars. Fig 6.12 shows the Electrical testing at 6.67 GHz of 0.7 m dia. GFRP reflector with Metalized & Teflon spars . With respect to the metalized spars, the improvement is seen clearly in both main as well as side lobes for the Teflon spars in Fig 6.12 .



Main lobe Green : With Teflon spars
Blue : With Metal spars

Cross Polarization Red : Without Aluminum Tape on Teflon spars
Black : With Aluminum Tape on Teflon spars

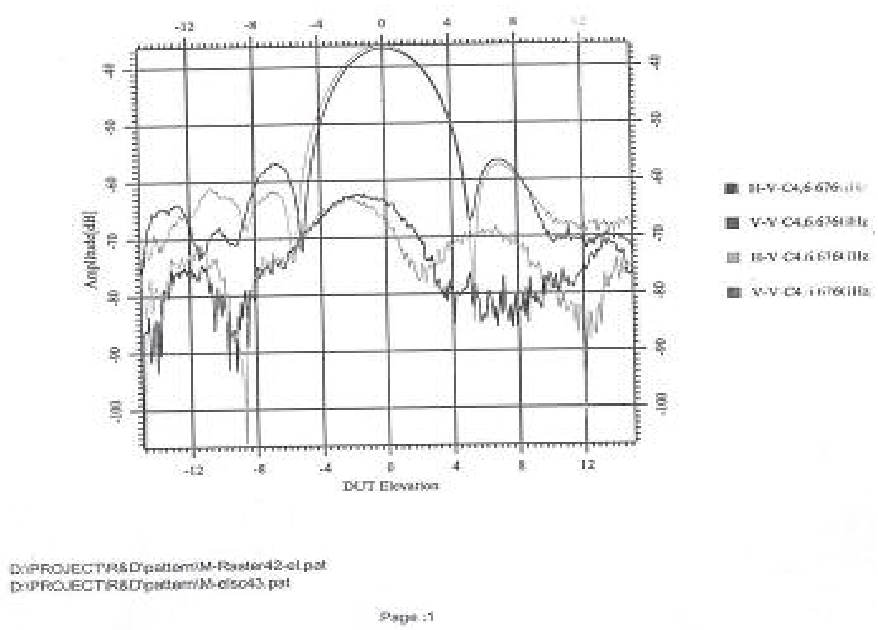


Fig 6.12 : Electrical testing at 6.67 GHz with Metallic & Teflon spars in Azimuth and Elevation

As shown in Fig 6.12 the Cross Polarization for both the Elevation and Azimuth cases, the improvement of -3 dB is seen (- 63 dB to -66 dB). Cross Polarization component has become half in the Teflon spar case, vis-à-vis, Metalized spars case for the 0.7 m φ GFRP reflector at 6.67 GHz frequency. This is significant change.

This will help increasing the Signal to Noise ratio for the Communication antennas. The measured value of Gain in this case is 0.2 dBi. As Gain is directly proportional to Efficiency as seen in equation 7.1, the measured value of the overall Efficiency of the antenna is 2% because of the increase in effective radiating aperture. This increase in antenna efficiency may lead to the reduction in the diameter of the reflector.

This is a desirable feature as it may result in the reduction in the overall weight of the antenna system on the spacecraft. As space is always a crunch on the spacecraft, the reduction in size of the reflector may help in accommodating smaller payloads.

6.7 Conclusions

The conclusions of the electrical investigation of the GFRP reflector are as follows:

- The PF type antenna Gain improves by about 0.2 dBi (measured value) for both the test frequencies when attempted at CATF / SAC as there is increase in the effective radiating aperture.

- The PF type antenna overall Efficiency improves by nearly 2% with Plasma etched piezo coated RF transparent Teflon spars for both the test frequencies of C- band & Ku-band. Overall increase of efficiency by 2% is quite desirable for Prime Fed type spacecraft reflectors where blockage due to CFRP/metal spars is potential issue for signals up to Ku band frequencies.

- As there is overall improvement in Efficiency and Gain of the antenna, it may be concluded that piezo ceramic material coated reflectors, when electrically tested at CATF Ahmedabad, did not give any EMI / EMC issues. The main lobe and side lobes of the electrical beam did not get affected and a normal antenna performance pattern was obtained. Hence, it is concluded that piezo coatings on the Teflon spars & reflectors may be used for achieving passive vibration damping without any electromagnetic issues in reflectors .

- Even 1cm reduction in diameter of the reflector is a desirable feature, because even a few millimeter reduction is important for satellites as weight reduction is linked with that of the exorbitant launch cost.

- Cross Polarization component has become half in the Teflon spar case, vis-à-vis, Metalized spars case for the 0.7 m φ GFRP reflector at 6.67 GHz frequency. This is a significant change. This increase in antenna efficiency may lead to the reduction in the diameter of the reflector. This is a desirable feature as it may result in the reduction in the overall weight of the antenna system on the spacecraft. As space is always a crunch and weight and power are at premium on the spacecraft, the reduction in size of the reflector may help in accommodating smaller payloads and reduction in the exorbitant launch cost.

- This concept of RF transparent piezo coated spars may also help in generating futuristic DTH (Direct to Home) systems with improved gain and performance with smaller diameter.

Chapter 7 describes the MLF estimation of piezo coated composite beam specimen at varying temperatures .

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