EVLA Memo 213
EVLA Radome Material Selection

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Abstract

Due to unavability of the radome material currently used for EVLA X-Q band feeds, the VLA Front End group has undertaken investigation and testing of alternative radome materials. RF performance and hail impact resilience were selected as of primary importance for characterization of materials already marketed as 'outdoor stable', implying UV resistance. The fluoropolymers FEP and PFA were found to perform well in these tests, and have been selected for radome material testing in the EVLA array as radomes and feed covers.

1 Introduction

The VLA feed horns require a RF-transparent cover to keep rain, dust, hail, and other debris out of the receiver optics. This cover ("radome") must withstand UV and weather exposure. For L through K bands, this is accomplished by a radome covering the end of the feed horn. The Q and Ka band receivers have the feed horn attached to the receiver with its own feed cover, but mounted inside a feed protection tower a with its own radome, so the inner feed cover is not exposed to weather. Historically, the Ka and Q band feed covers have been of mylar which deteriorates over time due to UV exposure through the gore-tex material.

The Gore RA 7906 ("gore-tex") used for the EVLA radomes for X band through Q band receivers[1] has become unavailable due to the producer no longer manufacturing it. Both the deterioration of the mylar feed covers and the increasing unavailability of the gore-tex fabric drives a need to identify alternative materials for both radomes and feed covers. L, S, and C band receivers use Esscolam 10 for radomes[1], which remains available as of this writing.

Experiments in 2019-2021 using PTFE (polytetrafluoroethylene) as radome material in the array have ended up with mixed success. PTFE film worked adequately from a Tsys perspective[2], but was found inadequate to survive a hailstorm (September 2021, Antenna 24) resulting in flooding of the K, Ku, and X band feeds.

Were the gore-tex material still available for purchase, it is still not ideal as a radome because it is a fabric. When there is a failure of the pressurized dry air system for any particular feed, moisture can (and does) penetrate the weave and flood the feeds. Thus, continuing investigations into alternative feed radome materials continue.

Several 'outdoor stable' polymers are available on the market at sizes sufficient to cover the various VLA feeds up through X band. Availability, long-term (exposure) durability, hail performance, and RF performance all play a role in consideration. The fluorinated polymers FEP (fluorinated ethylene propylene), PFA (perfluoroalkoxy alkane), and ETFE (ethylene tetrafluoroethylene) exhibit attractively higher yield strengths than PTFE, higher impact toughness than PTFE, and similar environmental resistance to degradation due to exposure (Table 1). In addition, all three

Table 1: Material properties of test materials cited by suppliers and manufacturers.[3–9]

Material	transparency	Izod impact (ft-lb/in)	UTS (ksi)	elongation to failure (%)	
kapton	clear orange	0.6	33.5	72	
PEEK	translucent yellow	1.6	7.4	15-50	
polycarbonate	clear	3.5	2.0	7	
polypropylene	translucent or opaque	variable	4.0	2.2	
HDPE	translucent or opaque	1.1	4.0	500	
acrylic	clear	0.4	7.8	4-70	
PTFE	opaque	3.5	3.35	300	
PFA	clear	nb†	3.9	300	
ETFE	clear	nb	6.0	275	
FEP	clear	nb	3.0	300	

are available in fully transparent forms enabling workers to visually assess the presence or absence of water in a feed. In addition to the fluorinated polymers, materials like polypropylene, polycarbonate, acrylic, PEEK (polyether ether ketone), Kapton (polyimide), and HDPE (high density polyethyline) are all mentioned as potential radome materials due to attractive combinations of availability in large films, strength, and nominal exposure resistance.

Commonly available performance data for the various polymers is highly variable, and often not definitively useful for prediction of performance as a radome material. The measurement of impact energy requires testing of thick sections. Tensile strength measurements may, or may not, have been performed on samples of the thickness of interest. RF dissipation measurements are generally not available for the frequencies of interest in radio astronomy. Finally, due to the lack of any standardized test for resistance to failure (puncture) in multiple-impact hail situations (such as the most common cause of radome failure at the VLA, the hailstorm), it was felt that the most useful approach was to purchase and test commercially available samples. Testing of samples with specific supplier part numbers would therefore be expected to produce known and repeatable behaviour as a radome material.

In order to assess these various materials for use as potential radome materials, sheets of various thicknesses and compositions were acquired for RF and mechanical testing by the VLA Front End group.

2 Experimental Procedure

2.1 RF Testing

Q and Ku band receivers were used for RF testing of the compositions and thicknesses of material as laid out in table 2. This included a measurement of the current standard gore-tex for comparison purposes. RF testing largely mimicked the standard receiver characterization procedure used for EVLA receivers, measuring receiver output power looking at 'hot' (room temperature, 295K) and 'cold' (ℓN_2, 77K) test loads through a standard feed, and calculating the receiver temperature contribution at each test frequency according to:

$$T_{\text{rcv}} = \frac{(T_{\text{hot}} - T_{\text{cold}} \cdot \frac{P_{\text{hot}}}{P_{\text{cold}}})}{\frac{P_{\text{hot}}}{P_{\text{cold}}} - 1} \tag{1}$$

Table 2: Potential radome films tested

Material	thickness (10^{-3} inch)	Material	thickness (10^{-3} inch)
Gore RA 7906		HDPE	16
Kapton	3	HDPE	23
PEEK	3	acrylic	10
polycarbonate	5	PFA	5
polycarbonate	10	ETFE	5
polycarbonate	15	FEP	5
polypropylene	16	FEP	10
polypropylene	20	FEP	20

where P_{hot} and P_{cold} are the power out of the receiver for the hot and cold loads, respectively. T_{rcv} was measured for the receiver itself, and an average calculated over the entire bandpass (40-50 GHz for Q band and 12-18 GHz for Ku band) for both polarizations. The same process was repeated for each sample tested, as well as for a section of the currently-used gore-tex favbric. RF performance was characterized as the increase in measured T_{rcv} for each sample over that of the receiver itself, and compared to the gore-tex performance by

$$\frac{100 \cdot \Delta T_{\mathrm{rcvGore}} - \Delta T_{\mathrm{rcvsample}}}{T_{\mathrm{rcv}}} \% \tag{2}$$

where the subscript is the average T_{rcv} for the receiver without the sample across the feed, and $\Delta T_{rcv} = T_{\text{rcvwith sample}}$ - $T_{\text{rcvbare receiver}}$. Thus a negative percentage indicated less degradation of the signal that the gore-tex, and a positive percentage worse performance than the gore-tex.

Due to the nature of the Q band test loads, Q band measurements were conducted using a stand-off frame to separate the cold and hot loads from the test sample, as water condensate on the test samples tended to be a problem. Condensate on the cold load was a significant problem, but was accounted for by periodic measurements of the sample-less receiver. Typically those baseline tests showed $\sim$1% variability from one test to the next, and this can be considered a measure of the resolution of the tests.

Ku band measurements were conducted by laying test samples across the Ku band feed, with the hot and cold loads above the sample. Air gap due to drooping of the test samples away from the cold load prevented condensation of water on the test samples, and insensitivity of the Ku band to minor water condensation allowed significantly easier testing.

In all cases, acceptable performance of a given film at a higher frequency was taken as proof of acceptable performance at lower frequencies and thinner sample thicknesses. This is because of the increasing sensitivity of electromagnetic radiation to its environment with frequency.

2.2 Impact Mechanical testing

There exists no standard test to simulate the effects of hail on thin to meso-scale polymer films. Of interest is the resistance of the film to failure under hail conditions such as seen at the plains of Saint Augustine, and defining failure as being any puncture, rip, or tear that would allow water to pass into the feed. Because of this lack, we devised a mechanical test to simulate hail conditions.

Hail impact speeds as a function of hailstone size were obtained[10] for 1", 1.75", and 2" diameter hailstones (table 3). Hailstone mass was calculated for these diameters assuming a density of 1.0

$g/_{cm^3}$; this will likely be more massive than actual hailstones of these sizes, but represents the upper mass limit of a purely liquid water droplet. This was felt to be the most conservative mass estimate. Impact energy of these differing spheres at their impact speed was calculated as shown in the table, and corresponding drop heights calculated for 52100 alloy steel ball bearings[11] as durable test masses. Since impacts in a hailstorm will consist of differing-sized hailstones, and the relative durability of a film to multiple impacts is the parameter of interest, it was decided to characterize the films under test by successively dropping 1” diameter, 1.75” diameter, and 2” diameter test spheres onto the same film until failure was detected. Drop heights for the steel spheres were calculated so as to duplicate the impact energy of the same-sized hailstones, as shown in table 4; thus a film would experience a 1” ball dropped from 81.5cm, a 1.75” ball from 208 cm, a 2” ball from 253 cm, followed by the 1” ball, etc. until failure or ten cycles were completed. The sample fixtuire used consisted of two aluminum plates with 7.5” diameter thru holes. The top plate was 1/2” thick, and the bottom 3/4” thick. 1500 grit silicon carbide samdpaper was glued to the bottom plate to provide grip. Drops were conducted freehand so as to avoid concentrating the damage to one spot, and better simulate the random impact pattern expected of a hailstorm. The upper cutoff of 2” simulated hail was chosen arbitrarily as a point at which other antenna systems would also be damaged, and thus radome failure would become of secondary importance. Samples were tested with sequential drops of 1”, 1.75”, and 2” balls, testing terminating once the sample was pierced or developed a tear, or after ten sets of 1”, 1.75”, and 2” drops. Sample impact resistance was characterized as the total energy survived by the sample *prior* to failure.

Table 3: Hail characteristics[10], and calculated properties as discribed in the text.

Hail diameter (in)	impact speed (mph)	mass at 1 g/cc (g)	speed (m/sec)	impact energy (J)
1”	25	8.58	11.176	0.536
1.75”	40	45.98	17.88	7.35
2”	44	68.64	19.670	13.28

Table 4: Simulated hail impact test conditions using 52100 steel balls.

ball diameter (in)	mass (kg)	drop distance (m)	impact speed (m/s)	impact energy (J)
1”	0.067	0.815	4.00	0.536
1.75”	0.359	2.087	6.40	7.35
2”	0.536	2.526	7.04	13.28

3 Results

The RF performance and impact resistance testing results are summarized for the Q, Ku, and K band band receivers in tables 5, 6, and 7, respectively.

The lower strength and impact toughness materials tend to fail in one of the initial series of impacts, while tougher, more ductile, and stronger materials tend to survive one or more series of impacts. The thickest films with one or more of these properties performed the best.

In general, the fluoropolymers performed well for both the Q and Ku band tests, while the thicker FEP, thick polycarbonate, and Kapton did well for hail impact resistance. Note the nature

Table 5: RF and impact testing performance of tested films at Q band.

Material	thickness (10^{-3} inch)	increase in T_{rcv} over gore-tex (%)	impact energy before failure (J)
Kapton	3	+0.2%	106
PEEK	3	+0.9%	0.5
polycarbonate	5	+1.5%	29
polycarbonate	10	+3.0%	29
polycarbonate	15	+6.3%	211 (no failure)
polypropylene	16	+0.5%	0.5
polypropylene	20	+10.7%	8
HDPE	16	+1.1%	8
HDPE	23	+1.2%	0.5
acrylic	10	+2.9%	8
PFA	5	-1.5%	0.5
ETFE	5	-0.3%	29
FEP	5	-0.1%	85
FEP	10	-0.1%	71
FEP	20	+0.6%	211 (no failure)

Table 6: RF and impact testing performance of tested films at Ku band.

Material	thickness (10^{-3} inch)	increase in T_{rcv} over gore-tex (%)	impact energy before failure (J)
polycarbonate	10	-3.5%	29
polycarbonate	15	+2.3%	211 (no failure)
polypropylene	20	-4.1%	8
HDPE	23	-0.1%	0.5
acrylic	10	+3.4%	8
FEP	10	-5.4%	71
FEP	20	-5.9%	211 (no failure)

Table 7: RF and impact testing performance of tested films at K band.

Material	thickness (10^{-3} inch)	increase in T_{rcv} over gore-tex (%)	impact energy before failure (J)
FEP	10	-0.4%	71
FEP	20	-0.1%	211 (no failure)

of the impact testing produces a quantized increase in impact energy befiore failure, with each ball adding ~0.5J, ~7J, and ~13J to the total without failure. Survival of all 10 sets of impacts totals to ~211 J of impact energy.

4 Discussion

While testing of multiple samples for the impact testing would be useful to account for the variation in impact location on the impact energy to failure, the single tests shown in tables 5 and 6 may be expected to show the general trends in the impact behaviour of these films.

Considering RF performance at Q band, the materials fall roughly into three categories. For RF performance at high frequency the thinner fluoropolymers PFA, ETFE, and FEP all show improvement over the current standard gore-tex, and FEP at 10 mil thickness shows superior performance over gore-tex. The thickest 20 mil FEP, 16 mil polypropylene, 3 mil Kapton, and 3 mil PEEK all perform somewhat worse than gore-tex at Q band, while the polycarbonates and acrylic perform siginficantly worse than goretex. The marginally worse performance of 20 mil FEP at Q band is sufficiently diminished at K band to render the 20 mil FEP a more-resiliant alternative to gore-tex. Cross referencing the RF performance with the hail resistance, FEP comes across as a good candidate for a long-lasting, resiliant radome material for high-frequency receivers, while in the protected conditions experienced by the Q band and Ka band feed covers, PFA would offer the best RF-performing long-term UV resistant feed cover.

For performance at K band and lower frequencies the 20 mil FEP is quite attractive, offering excellent impact resistance and superior RF performance.

5 Conclusions

Due to the expected chemical durability and early RF testing results, 2 mil (0.002") PFA film was chosen as a replacement for the currently-used 2 mil Mylar film for the Q band and Ka band feed covers. The 10 mil FEP film was chosen for field testing for the Q band and Ka band feed tower radomes, while the 20 mil FEP film has been chosen for field testing for the K band, Ku band, and X band radomes.

6 References

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