ALMA RF membrane simulations

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Introduction

There has been extensive discussion about the RF membrane to be used to cover the aperture in the main reflector. No conclusive solution has been proposed and several materials are still under discussion regarding their suitability for this task.

The main requirement for the RF membrane has been summarized in the ALMA RF membrane Science Requirements[1] document establishing:

1. The overall loss of sensitivity must be no greater than 3% in any ALMA receiver band.
2. Cross - polarization introduced by membrane must be less than 0.1% in band 7, and no more than 0.3% in any other band.
3. The RMS perturbation of the wavefront passing through the membrane from any receiver feed should not exceed a differential path of 5 microns.

The second and third requirements set up the need for a very homogeneous and isotropic material, but due the outstanding sensitivity of ALMA the first one is probably the most difficult to reach.

The present document report simulations (Microwave Office) for the candidate materials to be used as RF membrane, with an appropriate thickness to ensure good mechanical properties and using compared information from many sources about their electrical properties at millimeter/submillimeter wavelengths.

Scope

The analysis is centered in the millimeter/submillimeter wavelength membranes' performance and other issues like thermal isolation and vibrations are not taken in to account considering the following criteria:

a) In view of NRAO wiki page[2] Richard Hills contribution is assumes that the space between the membrane and the FESS will be (or could be easily) isolated from the cabin, so as not to require consideration of the thermal properties of the candidate membranes.

b) It is assumed that the loss of tension reported for Gore-Tex (or other expanded plastics) could be solved with a self-tensioning (spring-mounting) mechanism or re-tensioning the membrane periodically as a part of the scheduled maintenance procedures.

c) The membrane must have low reflection coefficient to meet specs and as it must be mounted at a 5 degree angle with respect to the focal plane (specs requirement)[1]: the standing waves between the membrane and the receivers are can be neglected, taking out the discussion about the vibration of the membrane except with respect to their mechanical integrity.

d) The ALMA spec data (showed in violet) represents the trasmissivity for an overall loss of sensitivity of 3% for a total system temperature of:

Frequency (GHz)	τ_0	$T'_{rx}\, e^{\tau_0 A}$ (K)	$\epsilon_l\, T_{atm}\, (e^{\tau_0 A} - 1)$ (K)	$(1 - \epsilon_l)\, T_{sbr}\, e^{\tau_0 A}$ (K)	T_{sys} (K)
35^+	0.016	8.4	5.1	13.7	29
110^+	0.049	18.5	16.5	14.2	50
230^+	0.078	35.3	26.1	14.6	76
345^+	0.276	65.6	105	18.7	190
409^+	0.544	110	250	26.3	380
675^+	1.789	1200	2200	129.5	3500
850^+	1.601	2500	1600	99.9	4200

as estimated by Bryan Butler and Al Wootten in ALMA memo No. 276.

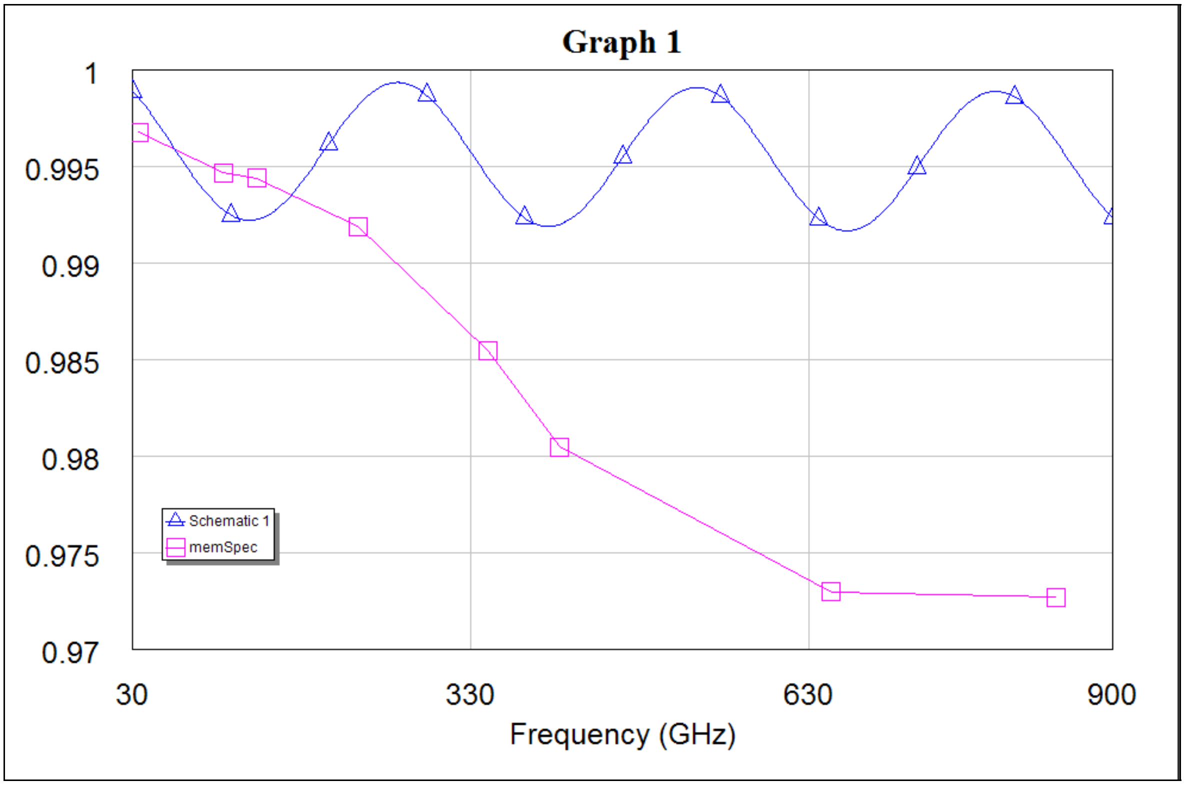
The minimum transmissivity of the membrane to have an overall loss no greater that 3% was calculated as suggested in the RF membrane specs document using the following expression:

$$Tx = \frac{T_{sys} + T_{membrane}}{1.03\, T_{sys} + T_{membrane}}$$

With $T_{membrane}$=300K and Tx=fraction of transmission through the membrane[1] what seems to be a good approximation for membrane temperature close to atmosphere temperature, and trasmissivities close to 1.

Gore-Tex RA 7956/7957

500um Gore-Tex sheets have been proposed from the beginning for the RF membrane. Several measurements of the dielectric constant have been reported with values from 1.2 to 1.3 over ALMA frequencies[3]. The loss of the material was measured to be no greater than 18 dB/m at the same frequencies[4]. A values of Er=1.275 and Att=18dB/m were chosen for this simulation showing out of spec performance for band 2, 3 and 4.

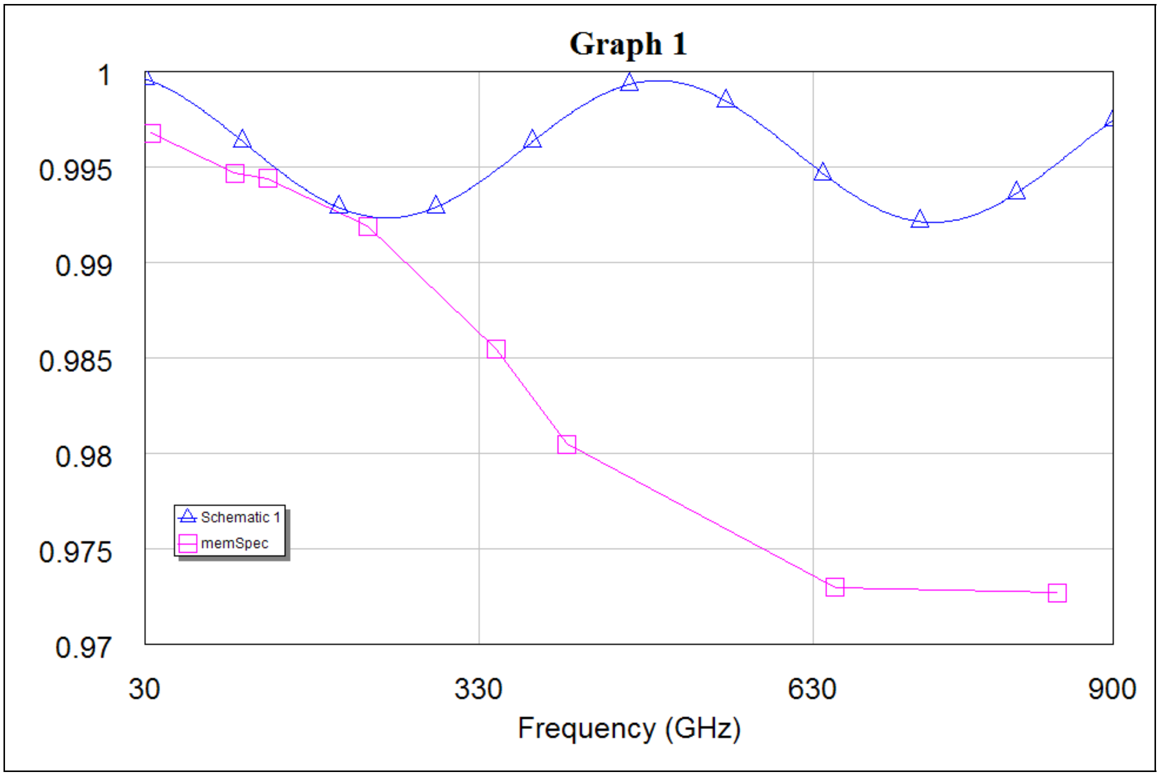


500um Goretex RA membrane

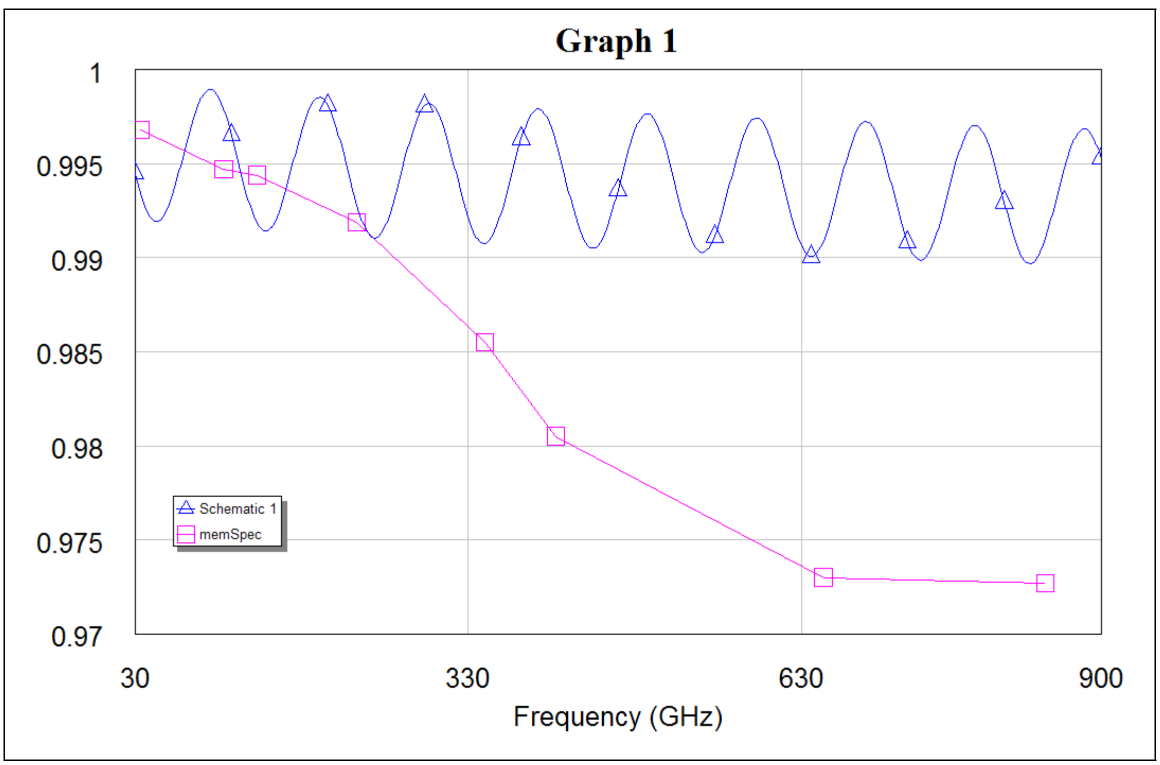
Discussion

The needed thickness to produce a full-in-spec outcome with Gore-Tex is about 270 um. No material like that is commercially available. Even if we could ask for a custom order we have no data about the mechanical performance.

On the other hand the thickness of the Gore-Tex can be tuned to meet specs for band 3 and bands 5 to 10, but giving an unacceptable performance for bands 1, 2 and 4. This could allow us to be in spec with all the initial ALMA bands, but would be necessary to be reconsidered in the future. A membrane like that should have a thickness of 1350um and could be obtained as a special order. Its mechanical properties should exceed those of the 500um material.



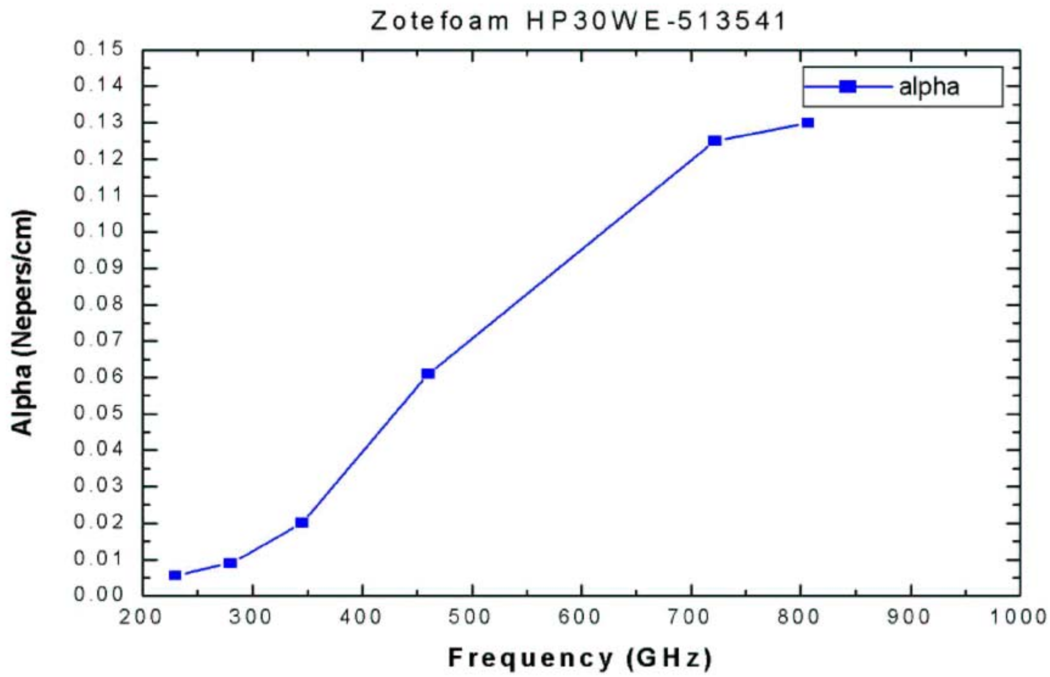
“Hypothetical” 270um Gore-Tex membrane



1350 um Gore-Tex membrane meeting specs for bands 3 and bands 5 to 10

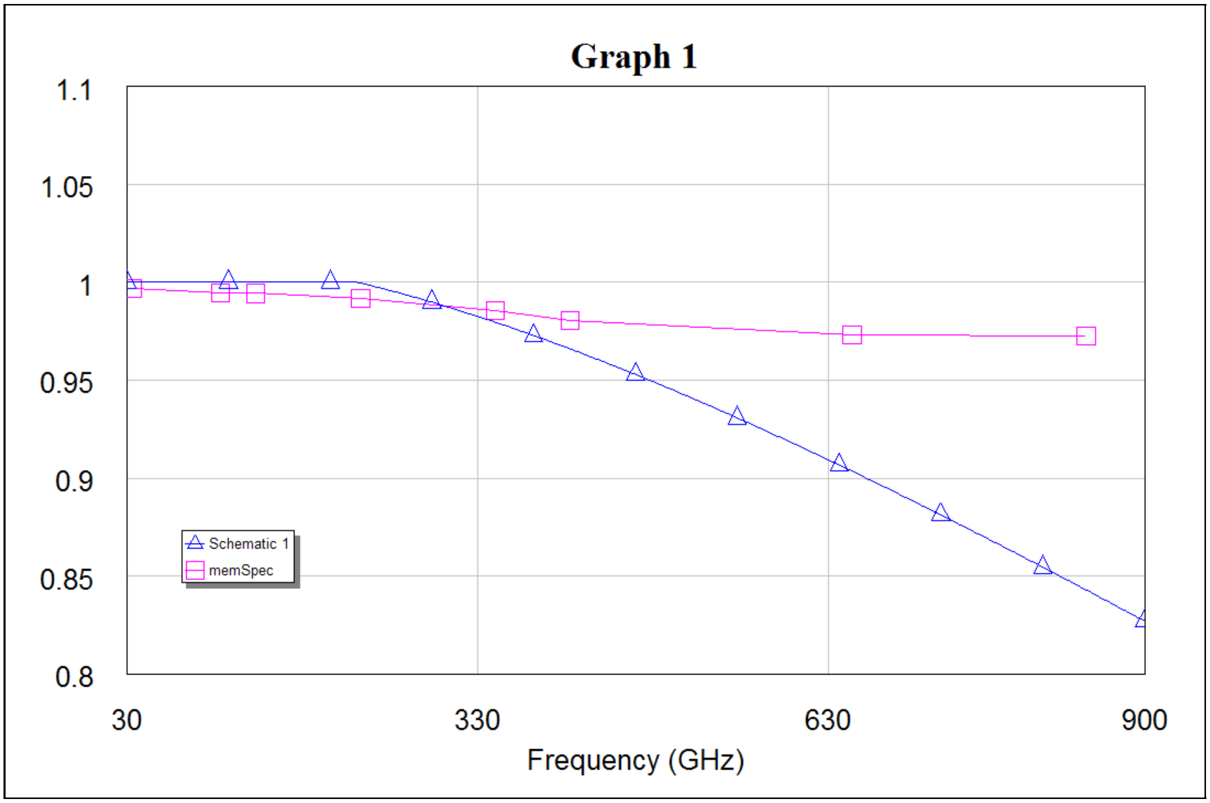
Zotefoam PPA-30

Zotefoam PPA-30 has been used in vacuum windows and as a radome material in millimeter wave applications. There were a generalized suspicious about the behavior of this kind of foam at submillimiter wavelengths. Jacob Kooi (CSO: Caltech Submillimiter Observatory)[5] has measured Zotefoam PPA-30 up to 800GHz showing that “the loss rises rapidly above 400 GHz, possibly due to scattering off the foam cells”.



Discussion

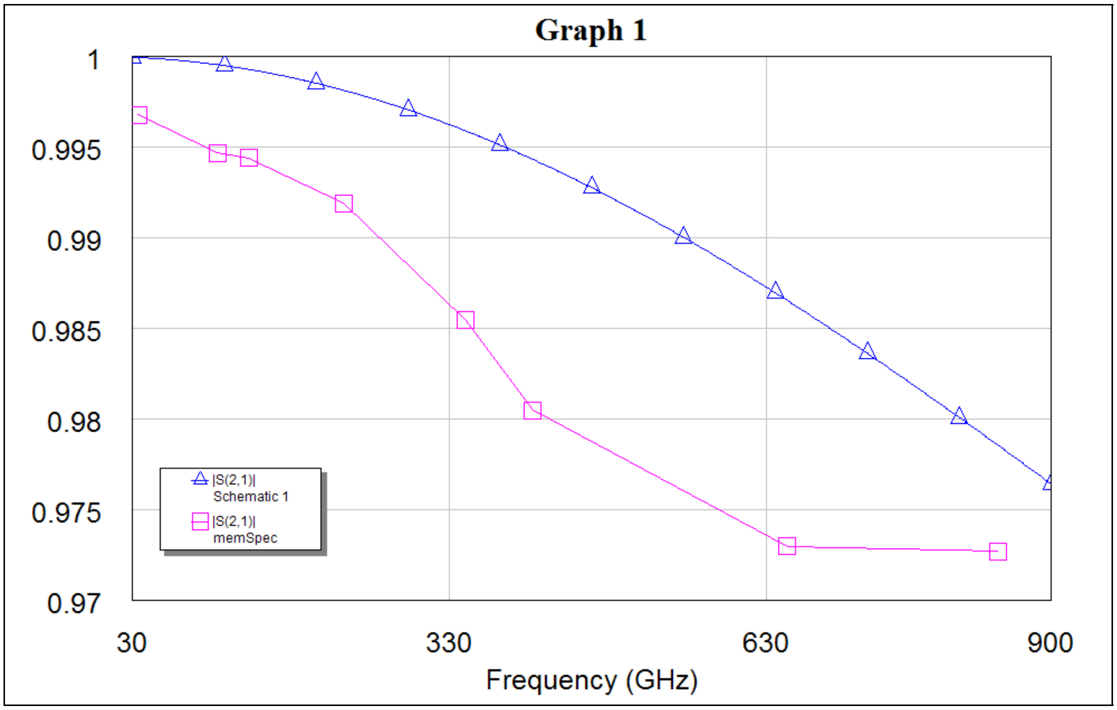
Simulations were performed for thin 1cm slab (the stock thickness is above 1in).
Even neglecting the reflections (Er=1) the simulation shows that the very high looses at submillimeter wavelengths preclude the use of this material, and probably many of the available closed-cell foams as a radome for ALMA.



1cm Zotefoam Slab with Er=1 with the attenuation reported by CSO

FEP (Fluorinated Ethylene Propylene) films

FEP Films was the chosen radome material for CARMA Interferometer. They use a film provided by McMaster-Carr P/N 85905K64 of 25um thick.
The following simulation was performed for a 25um film with a relative dielectric constant of Er=2; this value has been confirmed by several manufacturers at 1GHz[6,7] but there is no data available for higher frequencies. Considering these are continuous films I would expect no big changes in the dielectric constant over several hundreds GHz, but this assumption must be verified.



25um FEP Film

Discussion

The FEP film meets ALMA Specs and even being a very thin film good mechanical performance has been verified at CARMA.
Dick Plambeck described: "Mechanically it has been very good. We stretch the membrane across an opening about 16 inches wide. After 2 years none of the membranes have cracked or allowed water to leak into a receiver cabin".

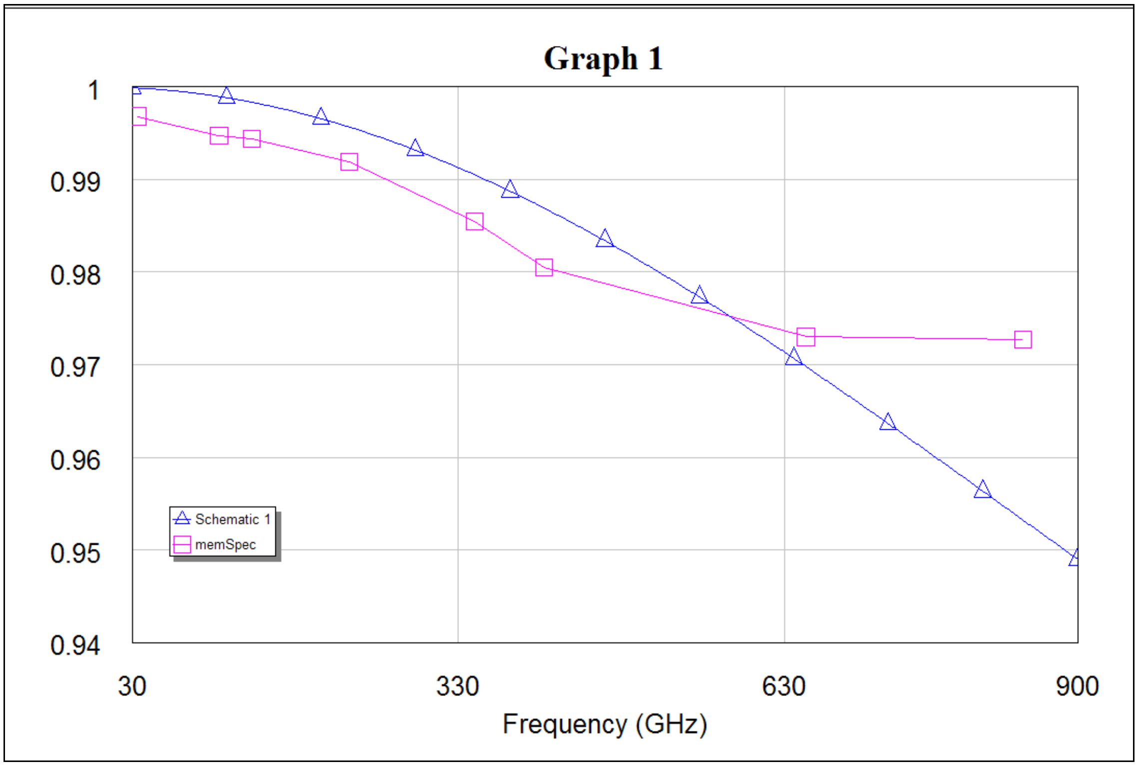
As a continuous very thin film, good behavior is expected with respect to the polarization and wavefront phase perturbation.

Resistance to snow, rain or hailstones should not be a membrane requirement since it will be protected by a metallic shutter under these conditions.

FEP film seems to be a suitable solution for ALMA, but studies of their loss and dielectric constant must be performed at submillimeter wavelengths.

Mylar

Mylar films has been proposed as candidates too, but their dielectric constant is fairly high compared with FEP In all their forms (Er > 2.6[7] or even more[8]) resulting in a bad behavior above 600Ghz for a 25um thick film.



25um mylar film

References

1- ALMA RF membrane science requirements Version: A2 Status: Draft 2006- July- 25
2- https://wikio.nrao.edu/pub/ALMA/RfMembrane/RF_Membrane.pdf
3- D. Koller, G. A. Ediss, A. R. Kerr, Alma memo 309
4- Scott Paine, Smithsonian Astrophysical Observatory
5- measurements were made by Jacob Kooi at the CSO using the CSO facility receivers with the Hot/Cold/Cold+Zotefoam method.
6- ADC Telecommunications (www.adc.com), Zeus inc. (www.zeusinc.com)
7- http://www.texloc.com/closet/cl_refractiveindex.html
8- http://www.grafixplastics.com/mylar_prop.asp