ALMA RF Membrane Science Requirements

SCID-xx.xx.xx.xx-001-A2-SPE

Version: A2
Status: Draft

2006-July-25

§

Prepared By:	Organization	Date
Anthony J. Remijan, Geoff Ediss, Darrel Emerson, Al Wootten	NRAO	2006-07-25
Approved by:	**Organization**	**Date**
Released by IPT Lead(s):	**Organization**	**Date**

Change Record

Version	*Date*	*Affected Section(s)*	*Change Request #*	*Reason/Initiation/Remarks*
A	2006-07-12	ALL	Draft A	Initial version by A. Remijan from previous documents [RD1], [RD2], [RD3] and wiki page comments
A2	2006-07-25	ALL	Draft B	Revisions and corrections supplied by D. Emerson, G. Ediss and A. Wootten

Table of Contents

List of Acronyms

ALMA	Atacama Large Millimeter Array
APEX	Atacama Pathfinder Experiment
ATF	ALMA Test Facility
CARMA	Combined Array for Research in Millimeter Astronomy
CSO	Caltech Submillimeter Observatory
JCMT	James Clerk Maxwell Telescope
HVAC	Heating, Ventilating and Air Conditioning
IPT	Integrated Product Team
RF	Radio Frequency
SMA	Submillimeter Array
SMT	Submillimeter Telescope

1. Documentation

1.1. Applicable Documents

The following documents are included as part of this document to the extent specified herein. If not explicitly stated differently, the latest issue of the document is valid.

Reference	*Document Title*	*Date*	*Document ID (if available)*
[AD1]	ALMA Scientific Specifications and Requirements	2003-03-23	ALMA-90.00.00.00-001-A-SPE
[AD2]	Technical Specification for the Design, Manufacturing, Transport and Integration on Site of the 64 ALMA Antennas	2003-12-15	ALMA-34.00.00.00-006-A-SPE

1.2. Reference Documents

The following documents contain additional information and are referenced in this document.

Reference	*Document Title*	*Date*	*Document ID (if available)*
[RD1]	Dielectric Constant of Goretex Radome Material between 1 MHz – 2 THz	2000-05-18	ALMA Memo 309
[RD2]	Cross Polarization characteristics of Goretex slabs at band 9 frequencies	2006-06-15	ALMA Memo 551
[RD3]	RF Membrane: Requirements and options: note by Richard Hills	2005-07-17	Available at: https://wikio.nrao.edu/pub/ALMA/RfMembrane/RF_Membrane.pdf
[RD4]	RF Membrane price quote	2001-01-30	Available at: http://www.cv.nrao.edu/

Reference	*Document Title*	*Date*	*Document ID (if available)*
			~awootten/mmaimcal/Calibration/RFMembrane/goretex_quote.pdf
[RD5]	RF Membrane Specifications Datasheet	2001-04-01	Available at: http://www.cv.nrao.edu/~awootten/mmaimcal/Calibration/RFMembrane/RA7956andRA7957TypicalDataSheet.pdf
[RD6]	Overview - Polytetrafluoroethylene (PTFE), Molded		Available at: http://www.matweb.com/SpecificMaterial.asp?bassnum=O1900&group=General
[RD7]	Manufacturing process of Goretex RA 7956		Available at: W. L. Gore and Associates, Inc., 1901 Barksdale Rd., P.O. Box 9236, Newark, DE 19714-9236 http://www.gore.com/en_xx/

2. Science Requirements for the RF Membrane

This document discusses the scientific specifications required for the RF membrane that will cover the aperture through which the RF beam enters the cabin at the primary vertex hole. Also included in Appendix A of this document is a discussion of what has been used at other observatories. This represents the complete discussion on this topic taken from the RF Membrane ALMA wiki page: (https://wikio.nrao.edu/bin/view/ALMA/RfMembrane).

In order to achieve the ALMA Level One Science requirements set out in the ALMA Scientific Specifications and Requirements Document [AD1], and to satisfy the high level requirements outlined in section 1.7 of [AD1], specifically:

1. ALMA shall cover all available millimeter and submillimeter windows.
2. ALMA shall maximize sensitivity over its frequency bands.
3. ALMA shall maximize imaging capability, both as an interferometer and as a collection of single antennas, at both large and small angular resolutions.
4. ALMA shall be able to measure all polarization cross-products simultaneously.

we specify the following requirements of the RF membrane:

Table 1. Science Requirements for the ALMA RF Membrane

Requirement category	***Specification***
Overall Loss of Sensitivity	Must be no greater than 3% in any ALMA receiver band
Cross-Polarization introduced by membrane	Must be less than 0.1% in band 7, and no more than 0.3% in any other band.
Phase Loss	The rms perturbation to the wavefront passing through the membrane from any receiver feed should not exceed a differential path of 5 microns. As an example, if the refractive index of the material is 1.25, this implies a physical uniformity of thickness of the membrane of no worse than 40 microns.

The dominant causes of loss of sensitivity are assumed to be (1) loss in the membrane causing thermal emission into the receiver, and (2) the loss of signal itself through the membrane. Table 2 shows the acceptable loss in a membrane that would reduce the overall ALMA sensitivity by 2 and 3% as a function of ALMA receiver band. . The factor for loss of sensitivity is calculated from $([(T_{sys}+(1-t)*T_{membrane})/(T_{sys}*t)]-1)*100\%$, where t is the fraction of transmission ***through*** the membrane and $T_{membrane}$ is assumed to be 300K. Finally, the membrane will be mounted at an angle of 5^{o} to minimize the production of standing waves and shall be settable in steps of 45 degrees in relation to the elevation axis.

Table 2: Sensitivity impact for different membrane loss factors

Freq (GHz)	T_{rx}	T_{atm}	$T_{spillover}$	$T_{system} = T_{rx} + T_{atm} + T_{spillover}$	**%transmission loss in membrane (1-t)**	**Factor of loss of sensitivity to ALMA**
100	37	5	5	47	0.27%	2%
100	37	5	5	47	0.40%	3%
700	175	120	5	300	1.0%	2%
700	175	120	5	300	1.5%	3%

There exists, at present, enough evidence to support the use of a 20 mil (0.5 mm) sheet of Goretex RA7956 for use as the ALMA receiver cabin cover RF membrane. From the scientific point of view the material appears to satisfy the science requirements listed in Table 1 over the frequency range of 580-710 GHz. However, it must be noted that currently, no data exists testing the transmission of the material at frequencies lower than 580 GHz or over 710 GHz. We suggest testing the transparency of the membrane at the ATF near 100 GHz and at APEX near 1.5 THz to accurately measure the loss.

It should be noted that if the transmission loss through the membrane is ~3% instead of the predicted 0.3-0.4% in band 3 (Table 2), this will result in a loss of sensitivity on the order of ~20% in that band, which is not acceptable. Thus, it may be a removable membrane may be the best option. Nevertheless, a study needs to be undertaken to test the attenuation through the membrane over the entire ALMA band range before a definitive decision can be made.

3. Discussion

After an extensive investigation of several candidate materials for the RF membrane, it has been determined that Goretex RA 7956 is the best material to use because of its excellent transmission and polarization properties [RD2], despite earlier concerns about its availability [RD1]. On 2006 March 23, Jeff Zivick reported that he had "contacted the manufacturer (W. L. Gore & Associates) and they have confirmed that the GORE radome material, RA7956, is available today and they have no plans to discontinue its production."

On 2006 July 20, Andrey Baryshev added "In general, Goretex is really transparent between 500-1000 GHz and if no polarization sensitive transmission measurements are done, it is even more transparent. I believe for most of the measurements that ALMA is going to do, polarization does not really matter....I do not expect Goretex being worse at 100 GHz than at 600 GHz. Typically, the band 3 people should be able to measure the performance loss with this Goretex really easily "

In 2001 and 2003, ALMA bought the Goretex in 2 different POs. A quote [RD4] identifies price ($3100/sheet) and quantity (5 sheets) for 2001. This material was shipped to VA for fabrication of the prototype RF Membranes. A datasheet [RD5] is available.

As recently as April 2006, testing was still taking place regarding the RF membrane and candidate material. A Goretex sales person in Japan contacted Masao Saito and described a prototype material slightly different from what ALMA planned to adopt.

The differences were:

- Surface is smooth rather than poromeric so resistant to dust accumulation.
- A higher tensile strength by a factor of 3. This should lead to less fluttering when attached.
- A little more loss than RA7956
- A minimum thickness of 1 mm

Subsequent experiments on this new material demonstrated that the transmission loss of 1 mm thick sheet in power ranges from 3 to 18% (~0.1 - 0.9 dB) between 200 and 1000 GHz. The maximum loss of RA7956 is 4.5 %(0.2 dB) in the same freq range.

4. Product Description

The Technical Specification for the Design, Manufacturing, Transport and Integration on Site of the 64 ALMA Antennas Document [AD1], section 6.3.5 states:

"A thin RF-transparent membrane (Goretex) will cover the aperture through which the RF beam enters the cabin at the vertex hole. The RF transparent membrane will be tilted at an angle of 5 degrees from a plane perpendicular to the boresight axis. The orientation of the 5 degrees inclination shall be settable in steps of 45 degrees in relation to the elevation axis. The change in orientation may be achieved by unbolting and refastening the mechanism from inside the receiver cabin. The mounting of the membrane shall not vignette the free optical space.

The characteristics of this membrane are defined by ALMA. The baseline specification [AD1] is:

Table 3. Physical Characteristics of the RF Membrane

Type	Radome Material (Goretex)
Fabric Type	RA 7956 / RA7957
Material	100% fluoropolymer
Thickness	up to 1.5 mm

The characteristics will be confirmed by ALMA and the Radome material will be provided by ALMA as specified by the Statement of Work.

The membrane shall be protected by a remotely operated metallic shutter, when the receiver is not in use and in case of precipitation (snow, rain, hailstones). Precipitation water entering through the vertex hole in the back-up structure (BUS) and reaching the membrane and the space above the cabin shall be evacuated by opening and/or drainage pipes. The drainage system shall be effective also with the Antenna pointing at Zenith."

Taken from [RD1], "Goretex RA7956/7957 is expanded polytetrafloroethylene (PTFE, aka Teflon) sheet, produced by W. L. Gore in a proprietary manufacturing process [RD7]. It has approximately ¼ the density of solid Teflon. There is some confusion regarding the part number. According to the company, samples thinner than 40 mils are referred to as RA7957, while thicker sheets are RA7956. Gore, however, has not been consistent in using this definition. The material is referred to as Radome Material or alternatively as Hyper-sheet gasket material...From the testing performed described in detail in [RD1], the dielectric constant of a 20-mil sheet of RA7956 had an average value of 1.26 from 1 MHz to 2.025 THz."

5. Engineering Difficulties of the RF Membrane

5.1. Resistance to Wind

It is noted in [RD3] that the membrane needs to withstand the operational wind speeds of v~10m/s. In that document, Richard Hills suggested that a flat membrane is a hopeless design even if it is tensioned up or back pressured. The membrane will eventually start to flap around which is bad for stability and will soon cause it to get slack and eventually break from fatigue.

It was therefore recommended by Richard Hills in [RD3] to the Science IPT that the membrane should be mounted on a frame that provides a doubly curved (saddle) shape, that is already implemented at the JCMT, with the ability to apply tension to appropriate areas.

On 2006 July 20, Andrey Baryshev added "For using Goretex as a membrane I would have few other concerns rather than just pure loss.

1) The Goretex foil has poor mechanical stability that will lead to:
   a) poor phase stability due to displacement of membrane (vibration, antenna movement for fast phase calibration, changing wind pressure).
   b) decreased amplitude stability due to same reasons as a)
2) There is a cross polarization effect, which can be dealt with by using two cross-oriented layers.
3) The Goretex material tends to "float" so the effects in 1) are going to worsen over time. "

We suggest testing at the ATF to test the effects of how the membrane reacts under high wind conditions when mounted with a given curvature.

5.2. Thermal Conductivity

Finally, Masao Saito pointed out that "Given the ambient and cabin temperature of -20 and 20 deg, the heat transfer from the membrane window with a thickness of 1.0 mm (< 1.5 mm according to Antenna spec) is about 0.24 * (20 - (-20)) * $(0.75/2)^2 * \pi$ / (0.001) ~ 4.2 kW. This is not negligible because HVAC capacity of the prototype antenna is close to 10 kW, I believe."

Thus, on the engineering side, it is up to the members of the Antenna IPT to maintain a constant temperature in the receiver cabin and to conduct a study to further test the physical properties of the material mounted on an ALMA antenna to test its stability against temperature variations (ie. The expansion and contraction of the membrane and the amount of heat transfer).

6. Conclusions

We conclude that there exists, at present, enough evidence to support the use of a 20 mil (0.5 mm) sheet of Goretex RA7956 for use as the ALMA receiver cabin cover RF membrane. From the scientific side, the material appears to satisfy the science requirements listed in Table 2 [RD2] in the frequency range of 580-710 GHz. However, it must be noted that currently, no data exists testing the transmission of the material at frequencies outside this range. We suggest testing the transparency of the membrane at the ATF near 100 GHz and at APEX near 1.5 THz to measure the loss. Nevertheless, a study needs to be undertaken to test the attenuation through the membrane over the whole ALMA frequency range before a definitive decision can be made. On the engineering side, a study needs to be undertaken at the ATF to further test the physical properties of the material mounted on an ALMA antenna to test its stability against temperature variations (ie. the expansion and contraction of the membrane and the amount of heat transfer) and how the membrane reacts under high wind conditions when properly mounted. We recommend that the membership of the study group be defined and the studies begin as soon as is practical.

Appendix A.
Experiences from Other Observatories

JCMT

Hills mentioned in a Calibration Group telecon that the woven fabric with mm spacing used at the JCMT now has some loss and polarization characteristics which might be improved but that with a 60' aperture there were requirements for strength and durability which might differ from ALMA requirements. It is also noted that he mentioned that the JCMT membrane had good UV properties.

SMT

Chris Walker at the U of A "Arizona Radio Observatory" has been using a material called "Zote Foam" as a dewar window. It's evidently very strong, and although it's relatively thick they claim the loss even at 1 THz is unmeasurable. They used the material on the 7-pixel 345 GHz DesertSTAR? receiver windows for the HHT. The material is ZoteFoam ? PPA-30 (1 inch thick). Chris must have data on this material, maybe he could loan us a little sample for study. The company Zotefoams http://www.zotefoams.com/uk/company.asp) makes all kinds of foams that are being used in radio applications. EVLA uses their products to build highly shielded boxes. They have low loss materials that we could use on the ALMA antennas.

SMA

Further information on this from the SMA, from Jim Moran: there is a door in front of mirror 3 just behind the hole in the center of the main reflector that we open when the weather is good for observations, so the radiation gets a clear shot.

APEX

Peter Schilke, at APEX: Concerning the Goretex cover, this is a sad story. The material we have (same as you) has, contrary to your statement, quite good submm transmission - I have measurements somewhere, which I could dig out. It also doesn't seem to affect the 800 GHz transmission significantly. We wanted to replace it, because it's lost tension and we get bad standing waves when we look to the west (where the wind comes from), since it flutters in the wind. Apparently, this specific material isn't manufactured any more by Goretex. The replacement materials they sent DOES have bad submm performance. One of our engineers dug out some old material, which was good as well, but is also not manufactured any more. They could do it again, but since it would be a special production run, it would be a ridiculous price - one square meter sheet 3000 Pounds (we're dealing with Gore UK), and minimum order 10 sheets or so. There is one other material that's OK, but that's very thin - somebody suggested to use two sheets of it in layers, and pump them full of air to keep the tension, but I don't know if that would be feasible. So we're kind of stuck, but would be very much interested in any solution you come up with. Foam, in the past, wasn't very good, because of the inhomogeneity, but maybe modern one would be fine.

Comment from R. Laing: Just a note about Goretex membranes before I forget. Apparently the membrane on APEX is insufficiently stiff, and can vibrate in windy conditions. This causes some nasty standing-wave problems at low frequencies (specifically 86 GHz).

CSO

The Cassegrain hole in the dome-enclosed CSO telescope is open, although some instruments mount there.

CARMA

Contacting Alberto Bolatto at CARMA, he noted that the membrane on the CARMA antennas was a sheet of 2 mil FEP film (not PFE or PTFE). McMaster-Carr item 85905K64.