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WR-10 Waveguide Vacuum Feedthrough for the ALMA Band-6 Cartridge.

G. A. Ediss, N. Horner, F. Johnson, D. Koller, A. R. Kerr
National Radio Astonomy Observatory

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Abstract

This report describes the WR-10 waveguide vacuum feedthrough used in the local oscillator train of the ALMA Band 6 receivers. The vacuum window is a short section of epoxy-filled waveguide. A second identical window spaced ~$\lambda_g/4$ from the first matches the feedthrough over the desired band (73.7-88.3 GHz). The electrical characteristics and leak rates of the epoxy-filled windows are compared with those of the simpler but less satisfactory Mylar window.

Introduction

Commercially available vacuum windows for WR-10 waveguide are expensive, ~ $1000 each, and have limited bandwidth. Typically [1], a piece of glass is welded inside a length of Kovar waveguide, which gives a helium leak rate < 10^{-8} mbar.l/sec. In order to provide a cheaper alternative for the ~128 feedthroughs required for ALMA Band 6, we have developed an epoxy-filled waveguide vacuum window. To improve the return loss within the desired band, 73.7-88.3 GHz, the complete feedthrough uses two identical epoxy-filled windows separated by ~$\lambda_g/4$ as shown in Fig. 1. The assembly is essentially a Fabry-Perot etalon with two reflecting layers spaced to maximize transmission over the band of interest.

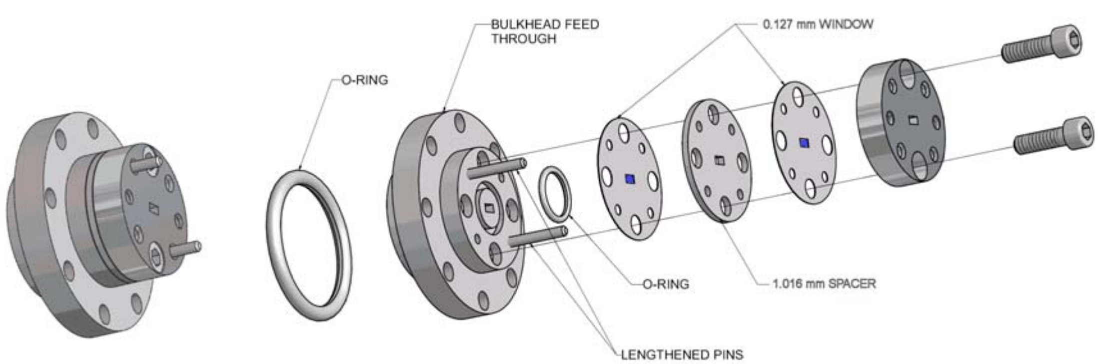

Fig. 1. Assembled and exploded views of the feedthrough. The two 0.127 mm waveguide windows are filled with epoxy. The left window, against the small O-ring, provides the vacuum seal and the second window, to the right of the 1.016 mm spacer, cancels reflections from the first.

Mylar Windows

A commonly used waveguide vacuum window consists of a sheet of Mylar clamped between waveguide flanges with an O-ring seal. This has several shortcomings: (i) Unless thick Mylar is used, the He leak rate is unacceptably high. (ii) Thick Myalr windows are lossy, with resonances at some frequencies, and are not well matched. (iii) RF leakage may be significant. Fig. 2 shows the measured He leak rates of Mylar windows of various thicknesses in WR-10 waveguide. Fig. 3 shows the transmission loss and return loss of Mylar sheets of several thicknesses clamped between the flanges of an Agilent 8510 VNA.

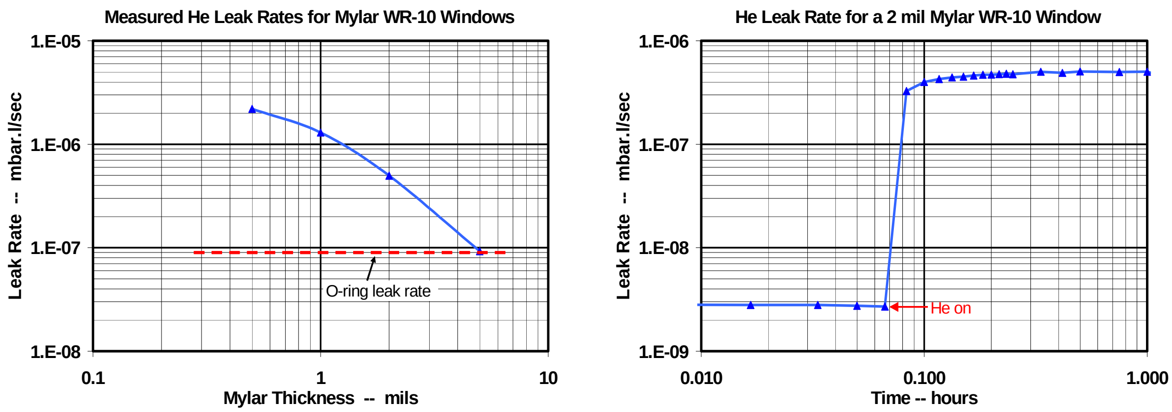

Fig. 2. He leak rates of Mylar WR-10 waveguide windows: (left) as a function of Mylar thicknesses, and (right) as a function of time for a 2 mil window.

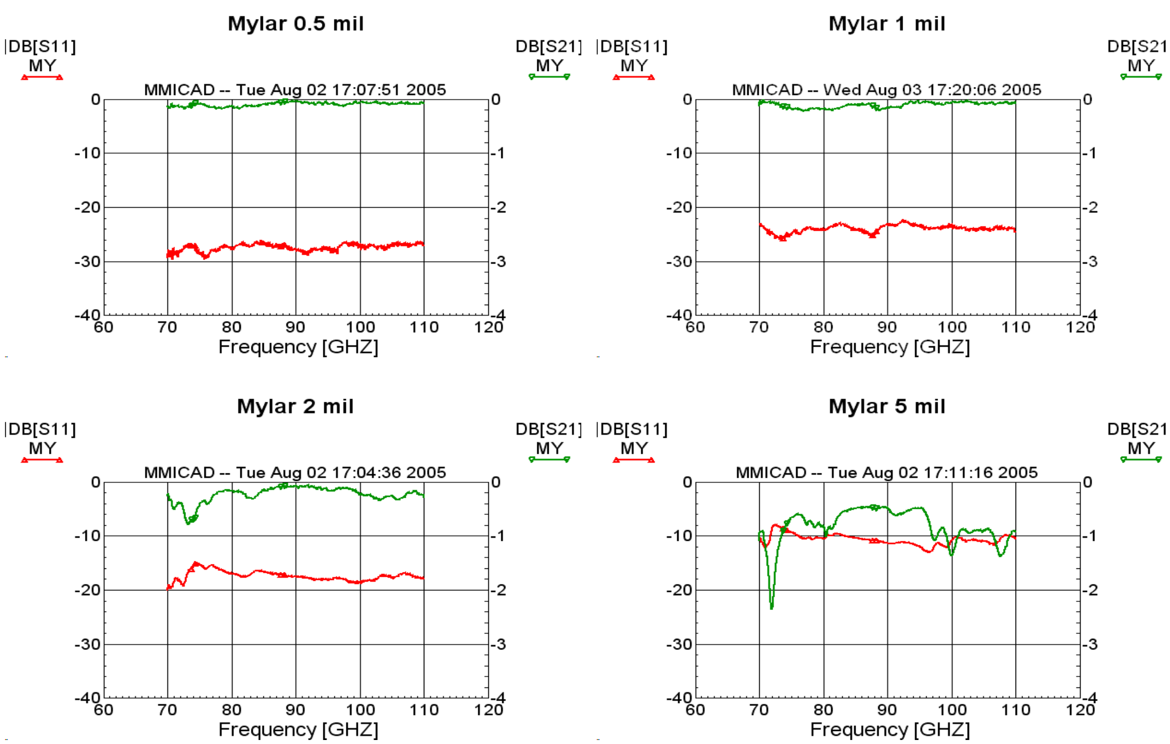

Fig. 3. $|S_{11}|$ (red, dB, left scale) and $|S_{21}|$ (green, dB, right scale) of Mylar sheets of several thicknesses clamped between the WR-10 waveguide flanges of an Agilent 8510 VNA.

Epoxy Windows

A good material for a waveguide vacuum window is Epo-Tek 301-2 [2] epoxy, which has a low dielectric constant and loss. Extrapolating from FTS measurements on Epo-Tek 301-2 in the range 300 GHz - 1.5 THz [3], $\epsilon_r = 2.8$ and $\alpha = 0.27$ dB/mm near 100 GHz. Fig. 4 shows the measured transmission loss and return loss of a 5 mil (127 μm) length of WR-10 waveguide filled with Epo-Tek 301-2 — cf. Fig. 3 for Mylar.

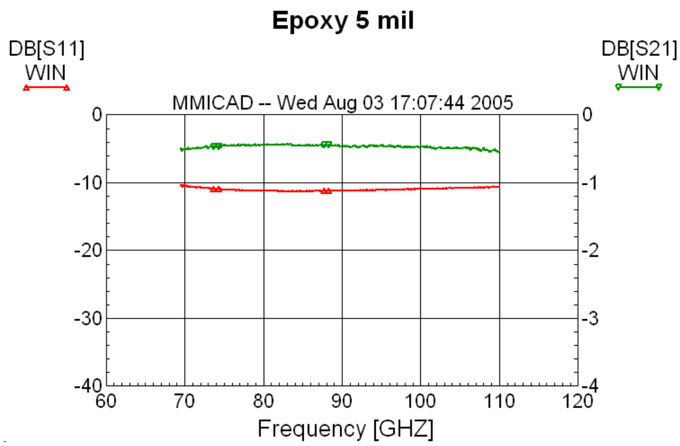

Fig. 4. $|S_{11}|$ (red, dB, left scale) and $|S_{21}|$ (green, dB, right scale) of a 5-mil section of WR-10 filled with Epo-Tek 301-2.

The measured He leak rates of eight WR-10 waveguide sections, 5 mils long, filled with Epo-Tek 301-2 are shown in Fig. 5 (left). The continued rise in the leak rate for ~2 hours after the initial application of helium gas is due, at least in part, to leakage through the O-ring. The leakage of the O-ring alone is shown in Fig. 5 (right) and reaches ~1×10^{-7} mbar.l/sec after ~1 hr, which is consistent with [4]. The O-ring is an Atlantic Rubber model 5-197 made of Viton [5].

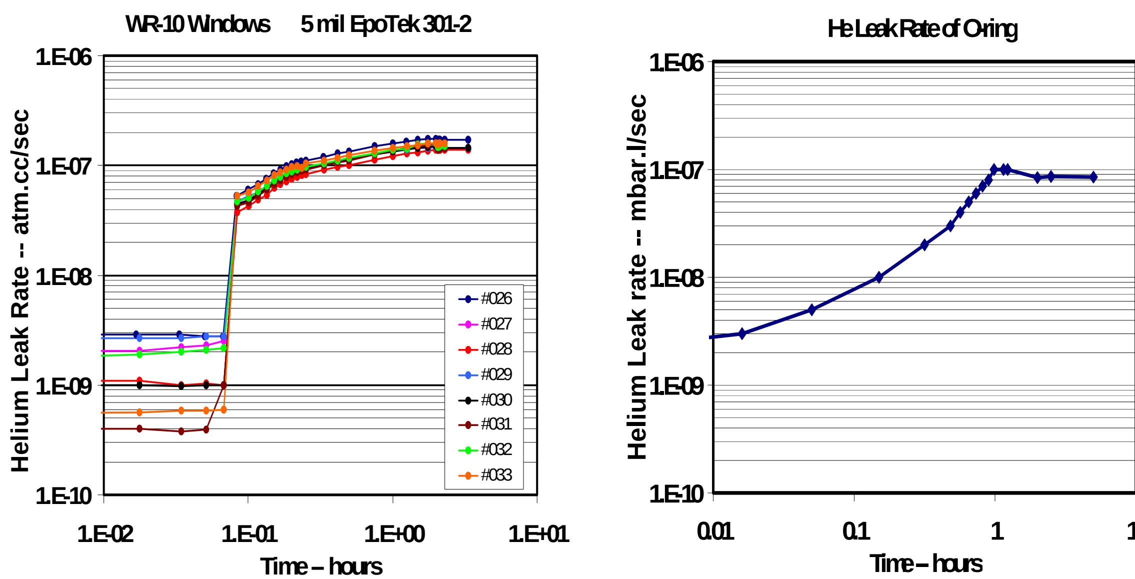

Fig. 5. Left: Helium leak rate as a function of time, for eight windows. Right: Leak rate of the O-ring. The window under test was covered with a balloon full of helium during the measurements.

Matching

The epoxy window is tuned by placing a second, identical, window approximately $\lambda_g/4$ from the first as shown in Fig. 1. The EM simulator QuickWave [6] was used to optimize the length of the waveguide spacer for the frequency band of interest — 73.7-88.3 GHz. The result is shown in Fig. 6. Measured results for four different feedthrough assemblies are shown in Fig. 7.

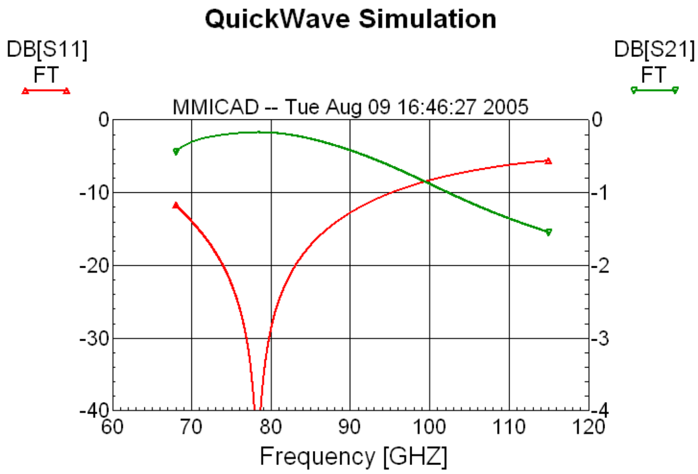

Fig. 6. QuickWave Simulation of the feedthrough assembly in Fig. 1. $|S_{11}|$ (red, dB, left scale) and $|S_{21}|$ (green, dB, right scale).

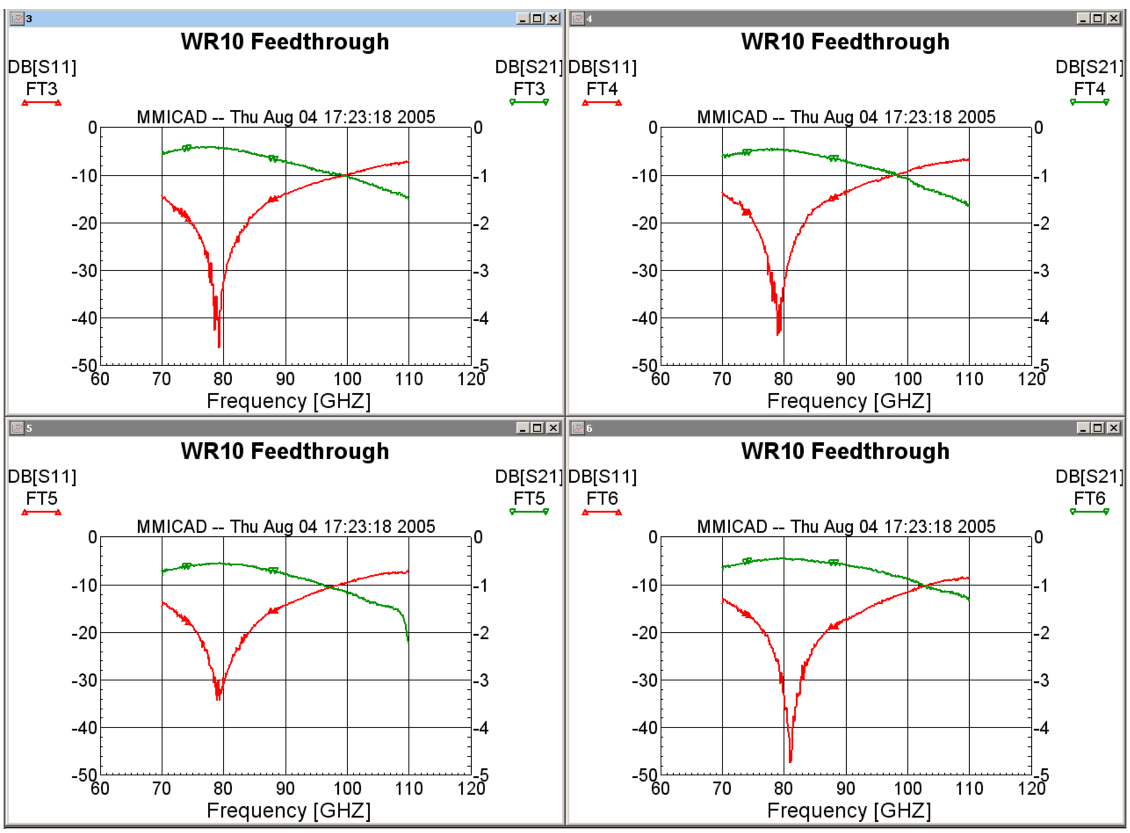

Fig. 7. Measurements on four feedthrough assemblies with epoxy windows. $|S_{11}|$ (red, dB, left scale), $|S_{21}|$ (green, dB, right scale).

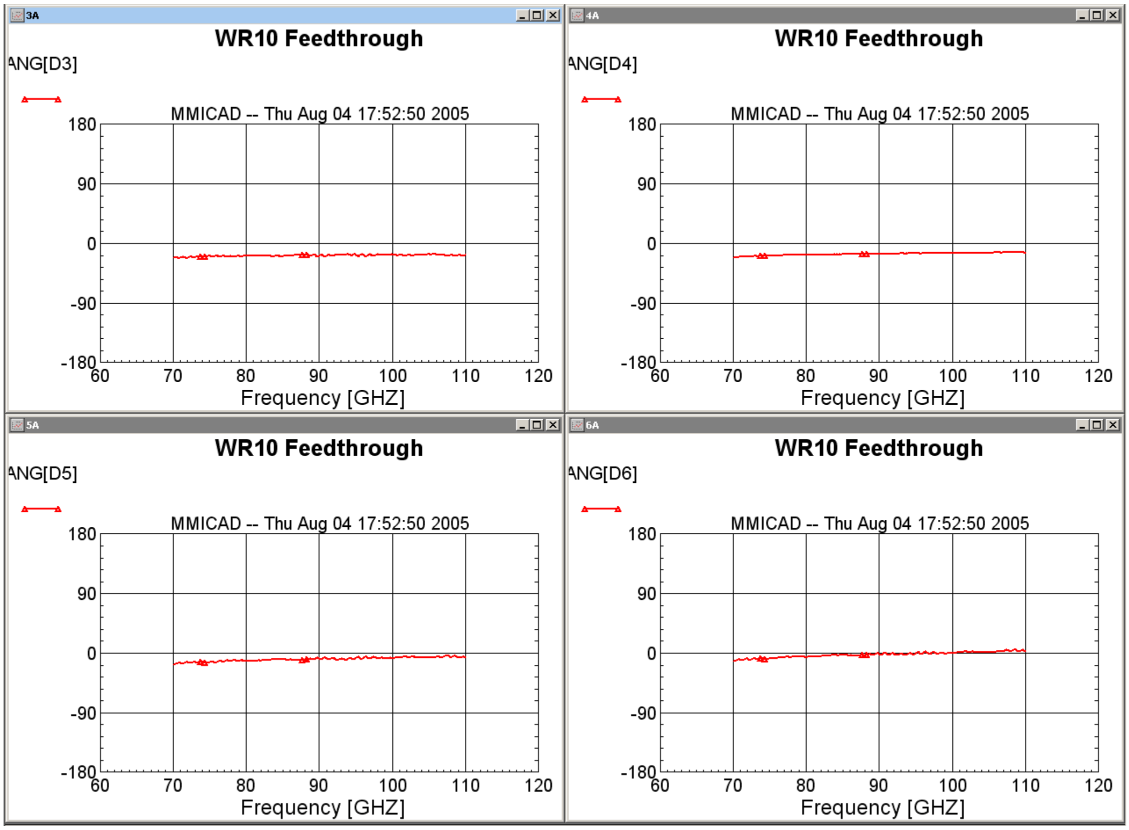

Fig. 8. Measured phase of S_{21} for the same four feedthroughs measured in Fig. 7. The phase is relative to that of a 0.740" length of waveguide.

In the ALMA LO chain, it is important that the phase vary smoothly with frequency. Fig. 8 shows the measured phase of S_{21}, relative to that of a 0.740" length of waveguide, for the feedthroughs measured in Fig. 7.

Construction

The bulkhead feedthrough shown in Fig. 1 is supplied by Aerowave [7] and is based on their model 10-1662 Bulkhead Flange Unit, a hermetic WR-10 feedthrough which does not contain a vacuum window. The following modifications are made to the standard Aerowave feedthrough[1]:

(i) The waveguide flange pins, on the right side of the bulkhead feedthrough in Fig. 1, are lengthened to accommodate the additional elements shown in Fig. 1.

(ii) The eight mounting holes are changed to M3 clearance size in compliance with the ALMA requirement that these screws be metric.

[1]The Aerowave designation for the modified flange is currently model 10-1662NRAO.

(iii) The larger O-ring is replaced with a slightly smaller one — Parker 2-115. This is necessary because the O-ring supplied with the standard Aerowave unit is too large for its groove, which makes it impossible to seat the feedthrough flush with the cartridge base plate.

The windows are made from 0.127 mm thick gold plated electroformed copper waveguide shims obtained from Custom Microwave [8]. The procedure for filling the windows with Epo-Tek 301-2 epoxy is described in Appendix I.

The 1.016 mm waveguide section, and the pressure plate at the right-hand end of the assembly in Fig. 1, are made from brass waveguide flange blanks [7] which are gold plated after machining. The left face of the pressure plate is machined with a waffle-iron pattern [9] to suppress suckouts seen in an early prototype of the feedthrough assembly in which the 0.127 mm windows were deformed; this appears not to be necessary in the production units in which the windows are flat.

Fig. 10 shows the components of the feedthrough before assembly.

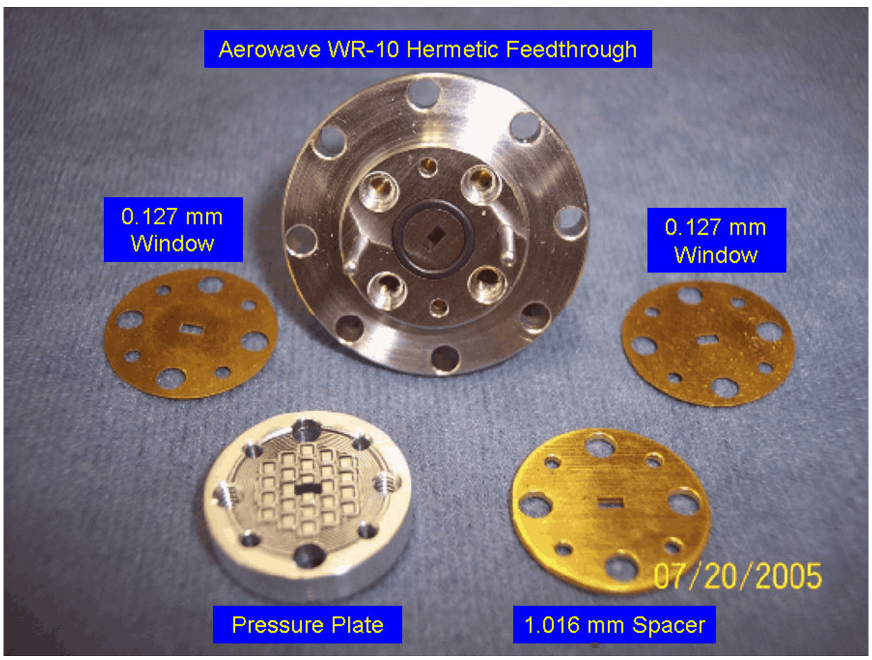

Fig. 10. Components of the feedthrough.

References

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[2] Epoxy technology, 14 Fortune drive, Billerica MA 01821, http://www.epotek.com/.

[3] D. Koller, G. A. Ediss, J. L. Hesler, C. Cunningham, "FTS measurements of some window materials." NRAO Electronics Division Technical Note No. 184, August 1999, http://www.gb.nrao.edu/electronics/edtn/edtn184.pdf.

[4] Section 3.12.1 on page 3-21 of Parker Hannifin Corporation, O-Ring Division Catalog at http://www.parker.com/o-ring/Literature/03-5700.pdf

[5] Atlantic Rubber Co., http://www.atlanticrubber.com.

[6] QuickWave FTDT EM simulator, QWED s.c. Zwyciezcow 34/2, 03-938 Warszawa, Poland. http://www.qwed.com.pl

[7] Aerowave Inc, 344 Salem Street, Medford, MA 02155.

[8] Custom Microwave, Inc., Longmont, CO. http://www.custommicrowave.com.

[9] J. L. Hesler, A. R. Kerr, N. Horner, "A broadband waveguide thermal isolator." ALMA memo 469, 30 May 2003. http://www.alma.nrao.edu/memos/index.html

[10] V. Summers, NRAO Plating Lab Report no. 13, 7 Jan 2000.

[11] American Society for Testing and Materials. West Conshohocken, PA. http://www.astm.org

APPENDIX I — Fabrication of the Epoxy-Filled Waveguide Windows

The windows are made from 0.127 mm thick gold plated electroformed copper waveguide shims obtained from Custom Microwave [8]. The waveguide opening is filled with Epo-Tek 301-2 epoxy. Before applying the epoxy, the waveguide walls are scored using a no.11 scalpel blade under a microscope to scratch a shallow cross pattern on each surface, then cleaned as described below. The scoring provides greater adhesion of the epoxy to the waveguide walls.

<u>Cleaning</u>:

1. Wash the window in hexane for 3 minutes in an ultrasonic bath. The inside of the waveguide is scrubbed using a horse hair acid brush. Remove and blow dry with nitrogen.
2. Wash the window in acetone for 3 minutes in an ultrasonic bath making sure the inside of the waveguide is scrubbed. Remove and blow dry with nitrogen.
3. Wash the window in isopropanol for 3 minutes in an ultrasonic bath making sure the inside of the waveguide is scrubbed. Remove and blow dry with nitrogen.
4. Bake the windows dry for 1 hour at 100 C.

<u>Epoxy Preparation</u>:

1. Use Epo-Tek 301-2 low viscosity optical epoxy.
2. Weigh out the epoxy in the correct ratio (35 g of Part B to 100 g Part A) into a weighing cup: Weigh out 5 grams of Part A. Add 1.750 grams of Part B to the weighing cup. This quantity should be measured to the nearest milligram. Be sure all of Part B is in the bottom of the weighing dish so that it can be mixed into Part A. If any of the drops are left on the side of the weighing dish it will affect the mix ratio.
3. Stir the mixture at least 5 minutes using a glass rod. As the mixture is stirred, be sure that all of the epoxy gets mixed together.
4. Place the epoxy mix in a vacuum vessel and draw a vacuum for at least 1 hour until the bubbles die down. At first it may boil furiously and splatter on the inside of the vessel, so cover the cup. If the epoxy mix starts to boil out of its container it may be necessary to draw the vacuum in steps. The bubbles should subside after approximately 30 minutes and be almost gone after an hour under vacuum.

<u>Applying the Epoxy</u>:

1. Place the window on the bottom half of a PTFE assembly jig (Appendix II). Put the top half of the jig in place to press the window against the bottom section. Carefully remove the top cover leaving the window on the bottom half.
2. Place a small drop of the Epo-Tek 301-2 mixture in the waveguide opening in the center of the window. Allow the epoxy to flow to the edge of the opening to ensure there is enough to fill it, with some excess to be squeezed out when the top cover is installed.
3. Install the fixture top cover and tighten the screws.
4. Place the clamped assembly on a shelf and let it cure at room temperature 2-3 days. This step is necessary to prevent the uncured epoxy running out of the window when heated.

5. Remove the window from the PTFE jig and place it on a microscope slide in the oven. Also place the weighing cup containing the remaining epoxy in the oven. Cure at 65°C for at least 16 hours.
6. Remove the window and inspect under a microscope to be sure there are no air bubbles or voids.
7. Using a surface plate and 3M brand Imperial Wetordry 2500A abrasive paper, polish both sides of the window to remove any excess epoxy on the surface of the window. This step removes the gold plating from the faces of the window.
8. Clean the window assembly with isopropanol to remove the metal dust.

Gold Plating:

1. Clean the window and gold plate with a Pur-A-Gold 125 flash followed by 50 μin BDT- 200 bright gold, as described in [10].
2. Rinse the plated window in hot water for 5 minutes.
3. Bake the window dry for 1 hour at 100°C.

Leak Testing [11] with the Varian 979 Helium Leak Detector (ASTM 1605):

1. Calibrate the leak detector system using the standard leak.
2. Place the window on the test fixture and connect it to the test port of the leak detector.
3. Evacuate the test fixture until the vacuum gauge reads $<10^{-5}$ Torr.
4. Measure the background leak rate in the absence of helium. It should be in the range of 1-2 x 10^{-9} mbar.l/sec.
5. Fill a balloon with helium gas and place it over the window and test fixture.
6. After 1 minute, note the helium leak rate of the window under test. The reading should go no higher than 5 x 10^{-8} mbar.l/sec. If the leak rate is higher than this value, the window should be discarded..
7. Continue monitoring the leak rate for two hours. The leak rate should be < 2 x 10^{-7} mbar.l/sec for the whole test period.

APPENDIX II — Window Assembly Jig

(For four windows)