Electronics Division Technical Note No. 222
4-millimeter Receiver Calibration

S. D. White
November 20, 2015

Introduction

This note documents the improvement in calibration of the 4mm receiver by reducing coupling to the Dewar cavity. It is worth noting that resonant waveguide modes in the Dewar cavity are known to enter into the signal path, which produces varying noise temperature fluctuations, as noted in EDIR 318.[1] Reflections resulting from impedance mismatches are the dominant effect for calibration inaccuracies. Techniques described in this technical note also reduce cavity mode coupling, and applying absorbing material inside the additional structure is possible.

4mm Receiver Description

The dual-beam receiver is linearly polarized, covers the nominal 68 to 92GHz frequency band, and is located at the Gregorian focus. The block diagram is shown in Figure 1. Two corrugated feed horns, separated by 10.4", illuminate the sub reflector with -13db taper producing an approximate Gaussian main-beam shape. Beam separation is 4.7 arc minutes, with one beam typically being the reference beam and the other containing the source. The OMT is constructed in WR-10 waveguide, so the performance degrades gradually below 75GHz to a minimum observable frequency of 67GHz. The waveguide on the output of the OMT is constructed in WR-12 waveguide, which limits the upper frequency to 93GHz.

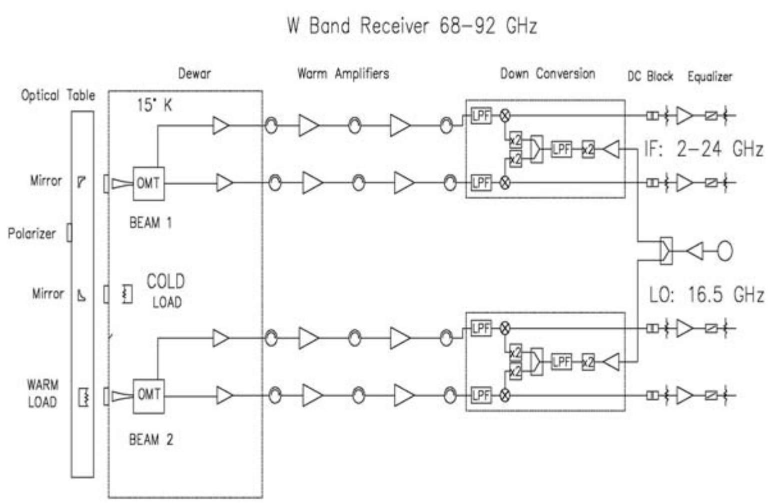

Figure 1. Receiver Block Diagram

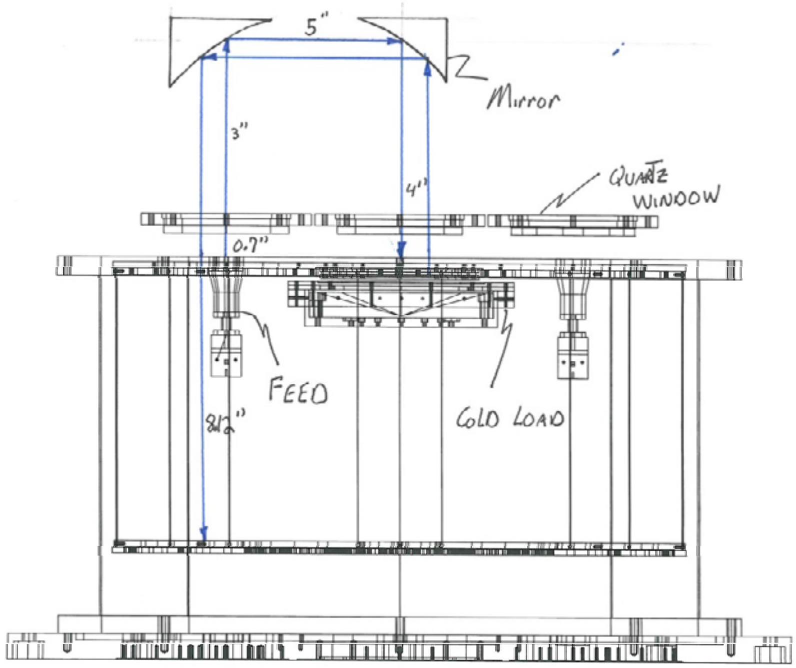

Figure 2. Path length of reflections from internal cold load to feed. Including the path to the bottom radiation shield, the total is 24.1".

Calibration

The cryostat is a cylindrical cavity with an internal radius of 8.95", a Dewar length of 11.370", and a length of 8.12" to the bottom radiation shield, as shown in Figure 2. The feeds are internal and cooled to 15K. Waveguide windows are constructed, as described in EDIR 315, for each feed, and the internal cold load.[2] In situ calibration, using the Y-factor method, is accomplished by the aid of an external turntable with six selectable positions, as shown in Figure 3. For calibrations on the GBT, the hot load is a disc of absorber, Cuming LF-72, located in one of the six optical table positions. Opposite the hot load is an offset parabolic mirror that directs the beam to the center of the table, where an identical mirror illuminates the cold load located inside the Dewar through a waveguide window. A conformal coating of Stycast epoxy impregnated with carbon filings is applied to an aluminum block, with one side milled into a concave surface. Cured epoxy provides the best combination of thermal conductivity and absorption characteristics, while the conical shape improves return loss. Effective noise temperature of the cold load, based on receiver measurements, is 54° K, which is greater than the physical temperature of 21° K. A filter constructed from HDPE material reduces the infrared loading. Low thermal conductivity of the epoxy causes a thermal gradient across the device (the sensor is on the metal backing), thus the discrepancy in black body temperature versus noise temperature. The final location positions a quarter waveplate over one of the beams for VLBI circular polarization observing.

Measurements

For lab tests, a flat disk of LF-72 absorber is used both as an absorber and as the cold load by submerging a similar disk of absorber in liquid nitrogen. Conical loads constructed of LF-72 were also tried, but very slight differences noted in noise temperature. So, most measurements employ the flat loads, as the conical loads where cumbersome with the wheel in place. A representative measure of noise temperature, as shown in Figure 4, displays the characteristic large ripple across the band. The measurement is shown for beam 2, polarization Y, with beam 1 and X polarization giving similar results. A higher resolution measurement of YR1 is shown in Figure 4. Average noise temperature is in good agreement with predictions, given the losses preceding the amplifiers. However, the large excursions from the average value produce the problematic calibration errors. Since the Y-factor measurement is a ratio of hot-load power to cold-load power, reflections from the hot load, cold load, or combination of both are possible. Since the path length for the cold load is approximately the distance required to produce the ripple, reflections from the cold load is presumed to be the dominant effect.

The path length of the feed horn reflecting from the mirrors back into the Dewar, as shown in Figure 2, is 24.1". The corresponding frequency ripple, generated from multiple reflections, equates to 245MHz, in close agreement with the length. Using an external cold load located on the window, the ripple frequency increases to 715MHz, which is the length of reflection to the bottom of the radiation shield.

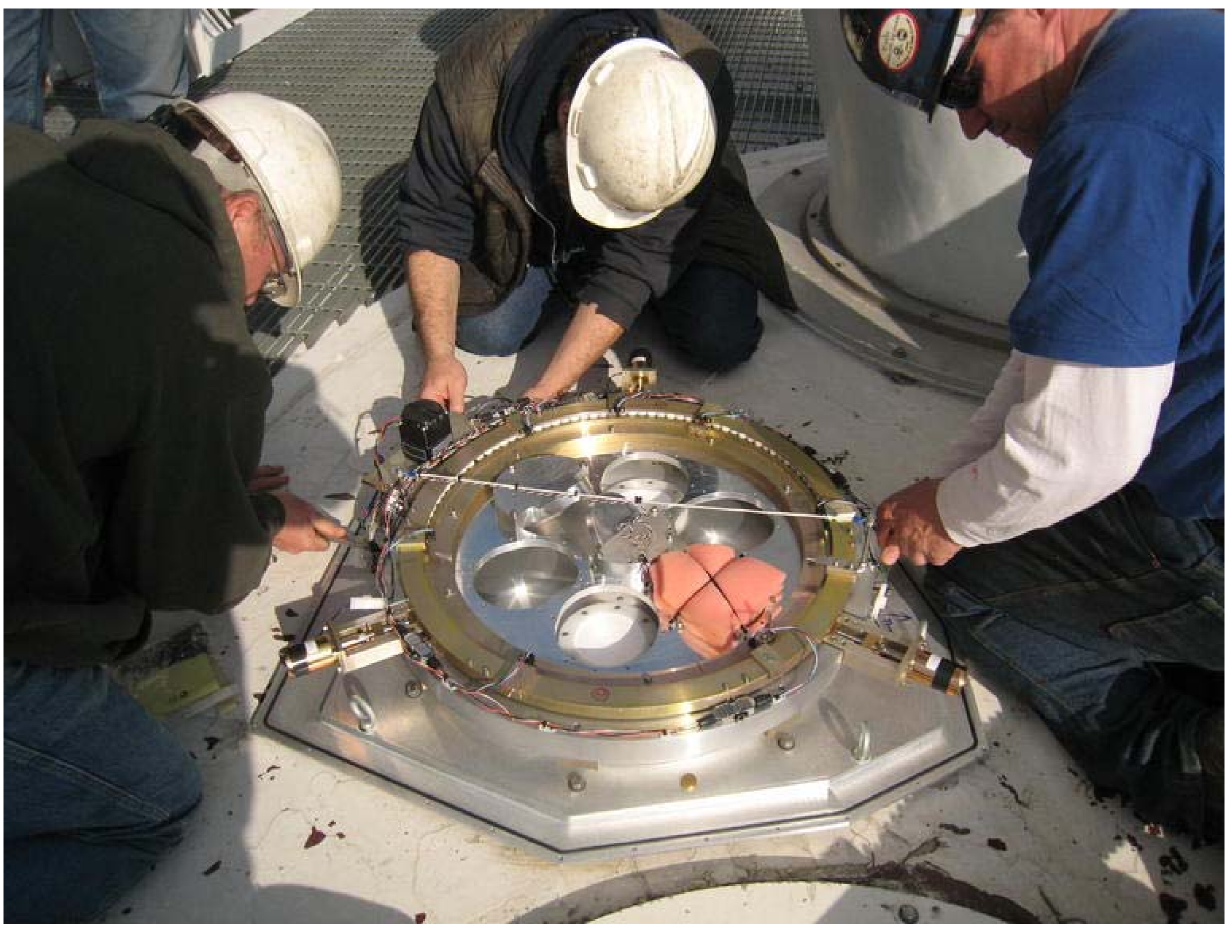

Figure 3. Photograph of the 4mm calibration wheel when mounted on the GBT turret. The position of the wheel, as shown, is two-pixel observing.

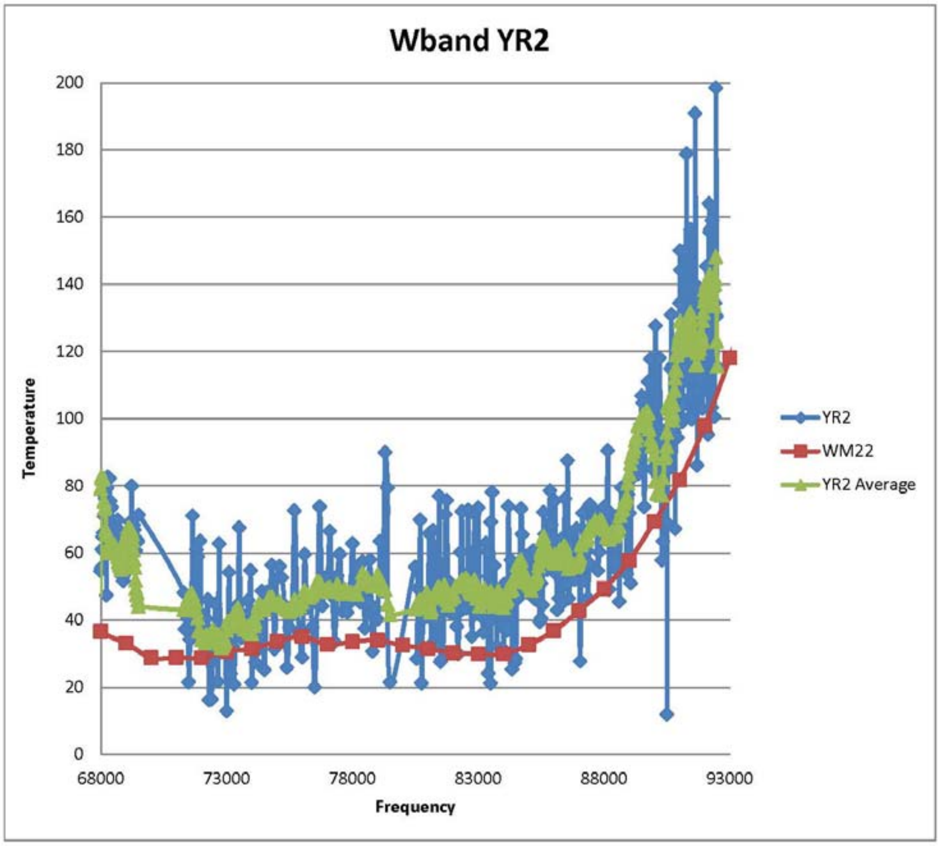

Figure 4. W-band channel YR2 noise temperature measurement.

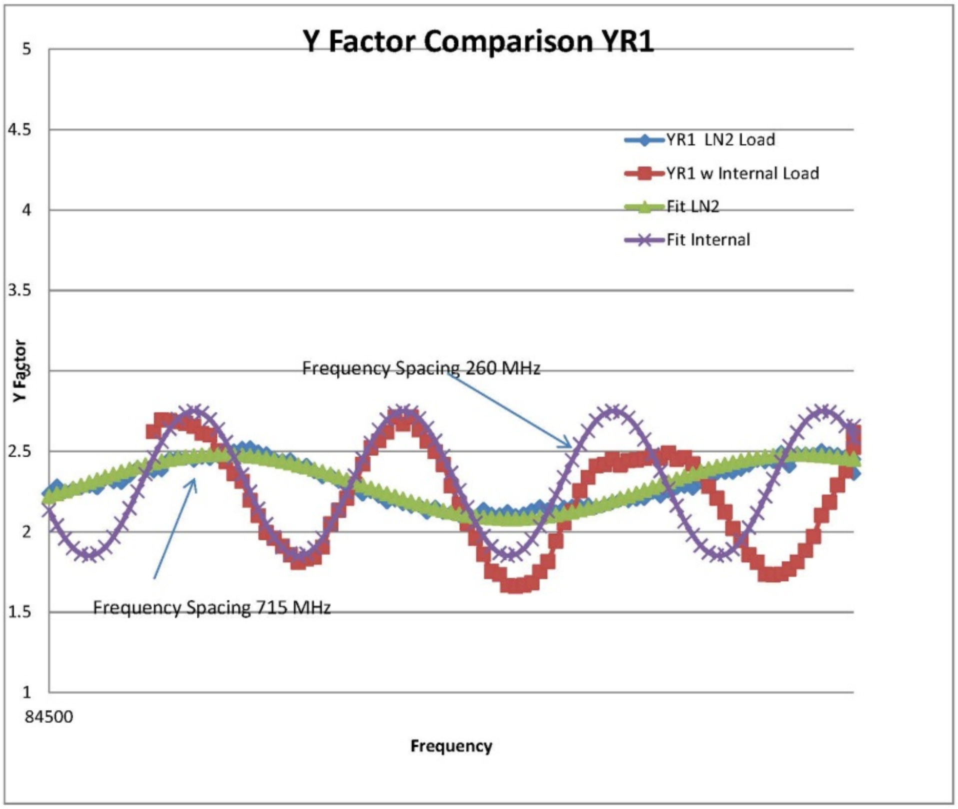

Figure 5. Comparison of Y-factors: internal cold load and external LN_2 load. The curve fit to the LN2 load was in very good agreement with the reflected lengths of the cavity. The internal load indicates more than a simple reflection model is needed.

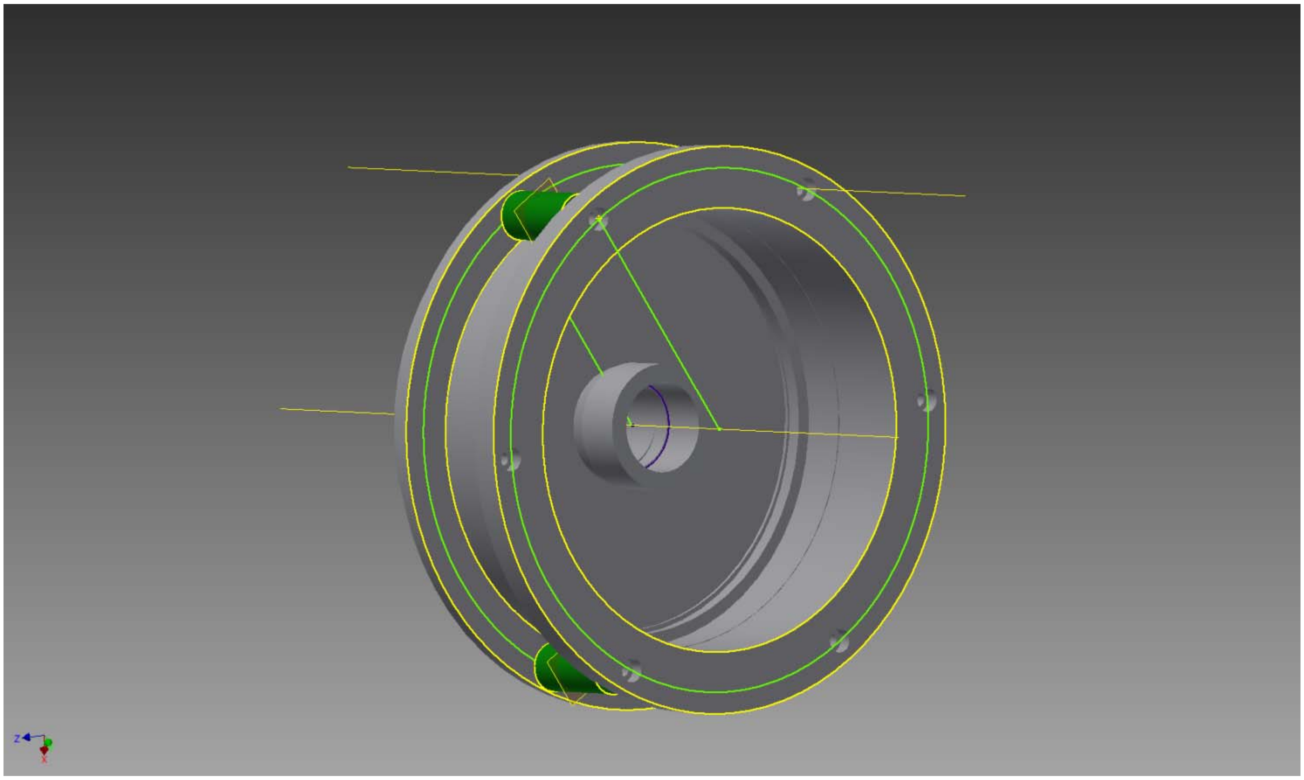

Figure 6. Shroud with thermal gap constructed around each feed that isolates the feed from the cavity. The cavity length is 1.1", and the diameter is 3.6".

Shroud Construction

To isolate the feed from the cavity, a shroud was constructed, as shown in Figure 6. The shroud consists of three components: a bottom plate that clamps to the feed with a circular grove milled for a metal braid, a middle section that rests on the bottom plate that encloses the feed and forms the lower thermal gap, and the top section with the upper section of thermal gap that attaches to the Dewar top plate. Three G10 rods set the thermal gap of 0.01". The G10 rods add 1.0 Watt of loading to the second stage of the CTI model 350 refrigerator.

Improvement in noise temperature measurements is shown in Figure 7. Notice the absence of ripple in the measurement. Path length of the reflections is reduced so a reflection would produce ripple the measurement at 465MHz, but none is observable.

Acknowledgements

Roger Dickinson provided much needed assistance in the design, construction and fitting of the shroud. Marian Pospiesalski provided four ALMA Band-2 amplifiers that were well matched in noise and gain that aided in characterizing the receiver.

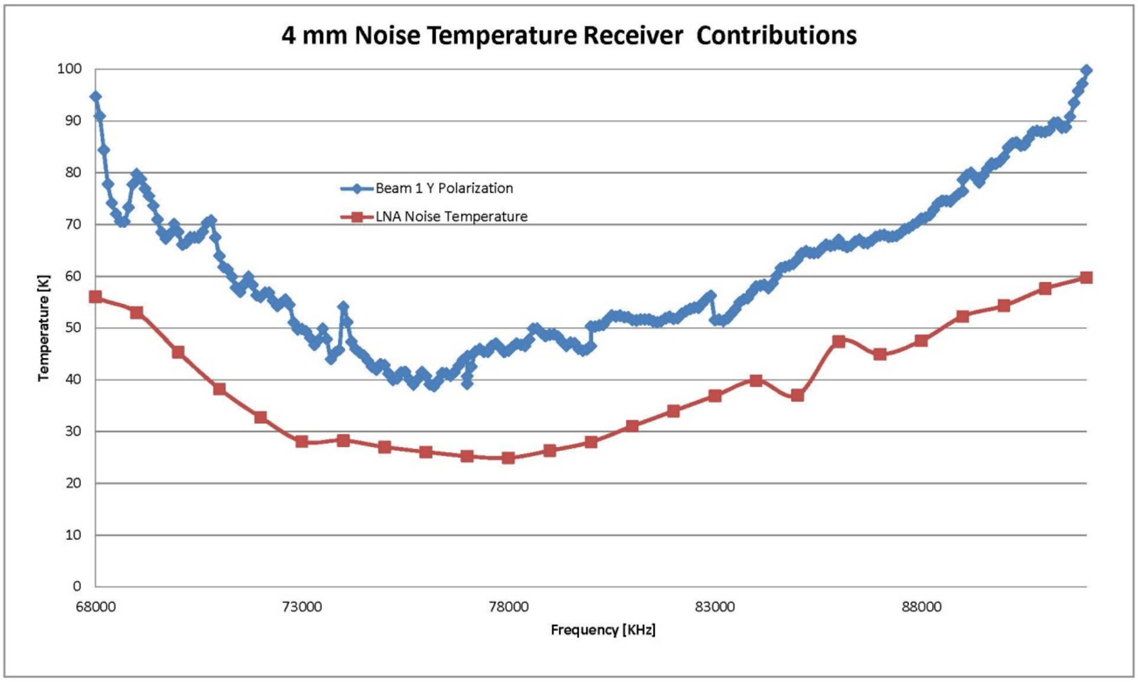

Figure 7. YR1 Noise temperature measurement illustrates improvement.

References

1 **"Cryostat Cavity Noise and the Impact on Spectral Baselines"**, R. Norrod, Electronics Division Internal Report 318, April 2007.

2 "**GBT 3mm Receiver Quartz Vacuum Window Fabrication"**, R. Simon, Electronics Division Internal Report 315, October 2005.