

Chapter 18

The 4mm (68-92 GHz) Receiver

18.1 Overview

The 4 mm receiver (“W-band”) is a dual-beam, dual-polarization receiver which covers the frequency range of approximately 67-93 GHz. The performance degrades significantly outside of this range. After the amplifier upgrade in the fall of 2012, typical system temperatures are under 100 K over much of the band (Figure 18.1). A key difference between the 4 mm receiver and other GBT receivers is that there are no noise-diodes for the 4 mm receiver. This impacts the observing and calibration techniques for the receiver. Users need to take a calibration sequence whenever the configuration changes or whenever the IF system is balanced for any data that needs to be calibrated. The receiver has an optical table with an ambient and cold load that is used for calibration (Figure 18.2). The optical table can also convert linear polarization into circular polarization using a 1/4-wave plate in front of one of the beams for VLBI observations. The two beams are separated by 286'' in the cross-elevation direction on the sky (i.e., along azimuth).

In this chapter, we present information for carrying out W-band observations. We concentrate on items specific to W-band, and assume the user is familiar with chapters 1–13 of the observing guide. Contact your support astronomer if you have questions.

18.2 Configuration

The 4mm Receiver uses the standard config-tool software that automatically configures the GBT IF system based on user input (e.g., frequency and bandwidth). Example w-band configuration files are given in `/home/astro-util/projects/4mm/`. The 4mm system is broken into into four separate filter bands:

- FL1: 67-74 GHz
- FL2: 73-80 GHz
- FL3: 79-86 GHz
- FL4: 85-93 GHz,

You can only use one of these bands at a time (i.e., you cannot simultaneously observe lines in more than one band). The millimeter down-converter filters of the system limits the instantaneous bandwidth

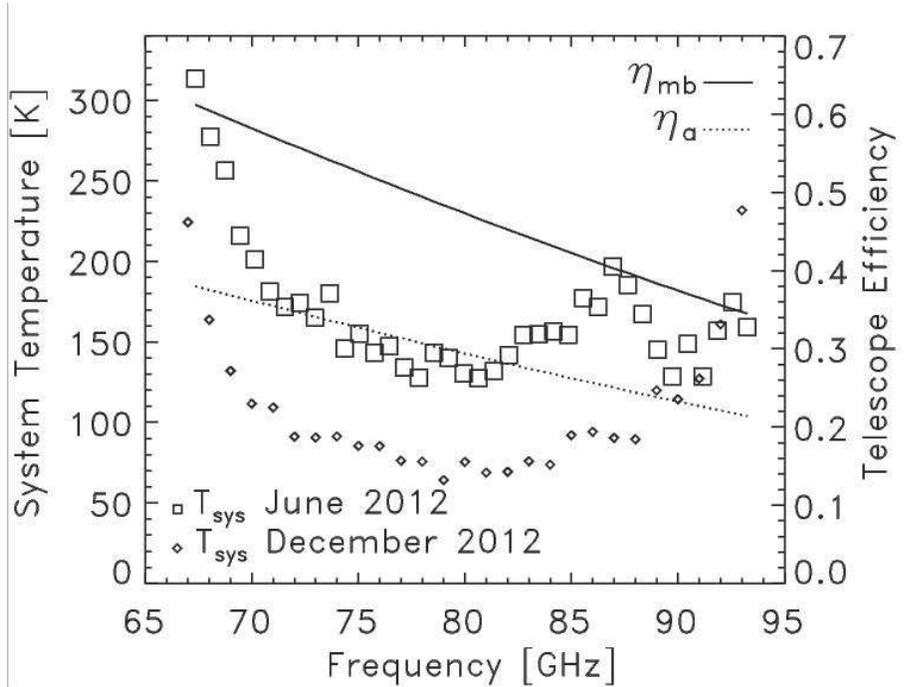


Figure 18.1: The derived main-beam (η_{mb}) and aperture (η_a) efficiencies from 2012 are given by the solid and dotted line respectively. These estimated efficiencies are based on measurements made after an AutoOOF, and the η_a values are slightly less than expected (measurements correspond to surface errors of $280\mu\text{m}$ instead of the advertised $240\mu\text{m}$ errors for the dish). The squares and diamonds show the measured system temperatures for the original amplifiers (2012 June) and the upgraded amplifiers (2012 December) respectively. Both sets of data were collected under similar conditions with $\tau_o \simeq 0.2$ at 86 GHz.

to 4 GHz for 73-93 GHz (filters FL2, FL3,FL4), while up to 6 GHz of total bandwidth is available for 67-74 GHz (filter FL1).

The configuration items specific to the 4mm receiver are the following:

- receiver = 'Rcvr68_92' (name of the receiver)
- beam = 'B12', 'B1', or 'B2' (dual beam receiver)
- swmode = "tp_nocal" or "sp_nocal". There are no noise diodes with this receiver.
- polarization = "linear" or "circular" (Default is linear). If user selects circular, then the 1/4-wave plate is placed in front of the chosen beam. There is only one 1/4-wave plate, so users can have circular polarization for only one of the beams.

18.3 Observing

In general, observations should be carried out during the night under stable thermal conditions to maximize the observing efficiency for targets smaller or similar in size to the beam ($\sim 10''$). During the daytime, the effective point-source aperture efficiency decreases significantly since the beam shape increases in size. Depending on the science goals, successful daytime observations are possible for extended sources.

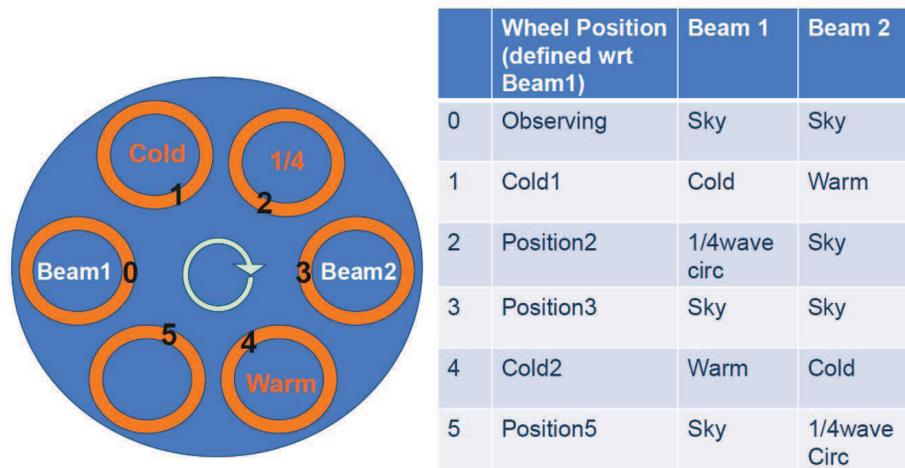


Figure 18.2: Diagram showing the positions of the 4mm Calibration wheel. The wheel is rotated above the cryostat, the location of the beams are separated by 180 degrees on the wheel. In the Observing position, both beams see the sky. In the Cold1 position, beam-1 sees the cold load and beam-2 sees the ambient load, while for the Cold2 position, beam-2 sees the cold load and beam-1 sees the ambient load. The 1/4-wave plate can be placed over only one of the beams at a time.

- Start the project with an AutoOOF (unless observing extended sources during the day). This sets the active surface, including the thermal corrections, as well as getting initial pointing and focus corrections.
- After configuration and balancing, check the RF power levels in the IF rack to confirm that power is going through the channels and that the power levels are not saturated (< 10). Beam-1 uses channels 1 and 3, and beam-2 uses channels 5 and 7. To avoid possible saturation on the warm load, the power levels on the sky need to be at < 6 . Although reasonable looking data may be detected downstream, observers should avoid non-linear calibration effects when the IF power saturates (RF Power = 10), and special care should be taken in calibration of such data. The target power level for w-band is 1.5, and the software adjusts the attenuation to reach this level. If the channel(s) are saturated with maximum attenuation (31dB), users can decrease the bandwidth of the observations (e.g., avoid using “All Pass” or choose a smaller filter to decrease the power levels). If the channel(s) do not have enough power with the no attenuation (0dB), users can increase the filter bandwidth or choose “All Pass” to increase the power levels. In general, manual changes of the default configuration values for the IF rack should not be needed for most configurations.
- Users must run the CalSeq procedure to calibrate the data (see § 18.3.1). During the calibration sequence, users can watch the movement of the calibration wheel from the Rcvr68_92 cleo page (Figure 18.3).

18.3.1 CalSeq

The CalSeq procedure is used to calibrate w-band data. This procedure should be run after every configuration and balance. This is needed to convert instrumental voltages into antenna temperatures. The syntax for the Calseq command is the following:

CalSeq(type, scanDuration, [location, beamName, fixedOffset, tablePositionList, dwellFractionList]), where the arguments in [] are optional.

- type: string keyword to indicate type of calibration scan: manual, auto, autocirc
 - "manual" – A separate scan will be done for each table position. The user can input a list of calibration table wheel positions with the tablePositionList argument.
 - "auto" – default dwell fraction = (0.33, 0.33, 0.34) and default three positions = (Observing, Cold1, Cold2). The user can specify a list of positions and dwell times with the tablePositionList and dwellFractionList arguments.
 - "autocirc" – dwell fraction = (0.25, 0.25, 0.25, 0.25) and four positions = (Observing, [Position2 for beamName='1' or Position5 for beamName='2' for use with circular VLBI observations], Cold1, Cold2).
- scanDuration: scan exposure time, in seconds. For manual mode, each specified position will be observed for the scan exposure time (i.e., separate scans for each position). For auto modes, the total scan exposure time will be divided between positions based on the dwell fractions (i.e., one scan for all positions).
- location: a Catalog source name or Location object; default is None (use current location).
- beamName: Beam name associated with pointing location. This argument is a string. Default beam is '1'.
- fixedOffset: offset sky position (used in cases when observing a bright source and want to measure the system temperature of the sky off-source). This argument should be an Offset object. Default sky offset is 0.
- tablePositionList: user-specified, variable-length ordered list of cal table positions for the manual or auto modes. The default sequence is ['Observing', 'Cold1', 'Cold2'].
- dwellFractionList: user-specified, ordered list of dwell fractions associated with the tablePositionList for use only with the auto mode. By using auto mode with tablePositionList and dwellFractionList, expert users can control the wheel in any order of positions and dwell fractions. This input not needed for autocirc or manual modes is ignored in these modes if given.

Example usage of the CalSeq command:

- CalSeq("auto",30.0). This command can be used for most observations, which uses the default tablePositionList=['Observing', 'Cold1', 'Cold2'].
- CalSeq("auto",30.0,fixedOffset=Offset("J2000", "00:00:00", "00:02:00")). This command can be used for bright objects where one wants a system temperature measurement on blank sky. In this example, the offset is 2' to the north. If observing a large object, one can increase the offset size to move off-source for the blank-sky measurement.
- CalSeq("manual",10.0,tablePositionList=['Position2', 'Observing', 'Cold1', 'Cold2']). This is an example command for calibration of VLBI observations with beam-1 circular polarization. We can only observe the cold and ambient loads with linear polarization. The calibration from linear to circular requires observations of the same sky with both linear and circular polarization (Observing and Position2, respectively, in this example).

18.3.2 Pointing and Focus

Blind pointing at the start of the observing run may not be successful since the blind pointing errors can be similar to the beam size, and the source may be missed in the simple Az-El scans used by the Peak procedure. Initial pointing offsets can be found with the AutoOOF procedure, or users may want to point on Jupiter or another large source as needed. Pointing and focus for w-band requires special attention, and users should not blindly accept the default solutions provided by the software system. Users can enter solutions manually as needed as discussed in Section 5.1.3.4.

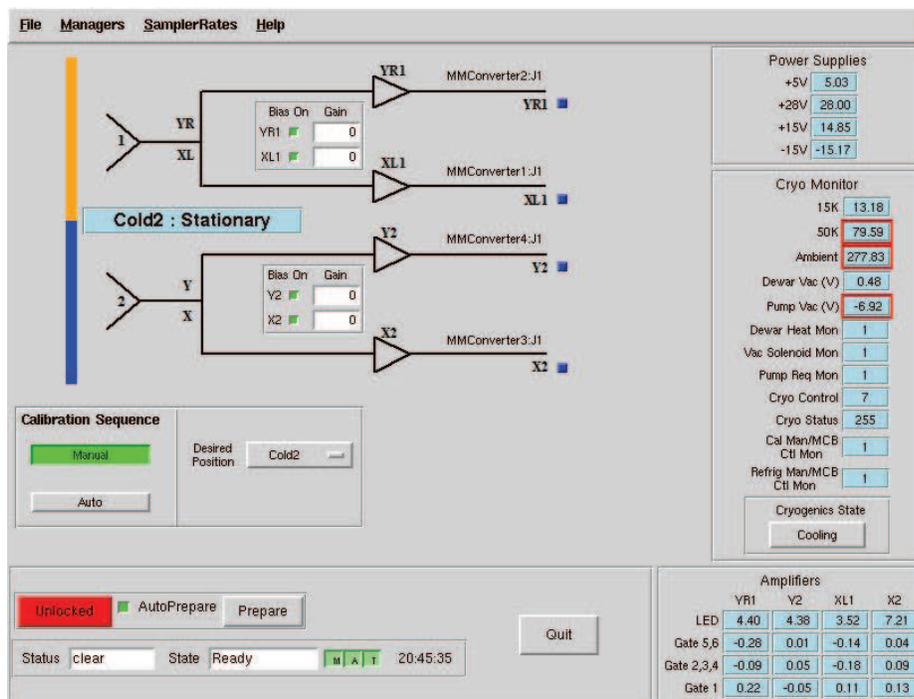


Figure 18.3: The 4mm Receiver CLEO window. Users can manual move the wheel by using the “Desired Position” button. The temperature of the ambient load used for calibration is given by the “Ambient” temperature sensor value shown at the right (277.83 K in this example).

18.3.3 AutoOOF Thermal Corrections

Optimal point-source observations should be carried out with regular AutoOOF measurements (every 2-4 hours) during the nighttime when the thermal stability of the dish is best. Based on commissioning tests with the 4mm receiver, the AutoOOF corrections improves the point-source aperture efficiency by 30–50%. Application of these corrections during the day are typically not practical for the 4mm receiver given the thermal environment of the dish is generally not sufficiently stable. During the day, the measured beam sizes can vary significantly (e.g., 10–14”), but the beam shape typically remains well-behaved (fairly symmetric and Gaussian). Although the variation of beam size has a direct impact on the point-source aperture efficiency (η_a), it has less of an impact on the effective main-beam efficiency (η_{mb}) used for the calibration of extended sources. For example during the commissioning of the instrument, we measured a beam size of 10.8” at 77 GHz and derived $\eta_a = 31\%$ and $\eta_{mb} = 50\%$ in good nighttime conditions with the application of the thermal AutoOOF corrections. Without the AutoOOF corrections, the beam-size increased to 12.5” and the aperture efficiency decreased to 23%, but the main-beam efficiency remained nearly constant at about 50% ($\eta_{mb} \propto \theta_{mb}^2 \eta_a$). Therefore, extended sources may be observed during the day without the AutoOOF corrections if the science is not impacted by the primary beam variations.

18.4 Calibration and Data Reduction

For accurate calibration, users are recommended to run a CalSeq before and after each set of source data. Users are also recommended to take a short nod observation on their pointing & focus source every hour to track the relative efficiency of the system. If users only want absolute calibration done to within

Table 18.1: 4mm Channel Definitions

Channel	Polarization	Beam
ch1	beam1 (fdnum=0)	X or L (plnum=0)
ch3	beam1 (fdnum=0)	Y or R (plnum=1)
ch5	beam2 (fdnum=1)	X or L (plnum=0)
ch7	beam2 (fdnum=1)	Y or R (plnum=1)

Table Notes: The GBT IF channel numbers 1,3,5,7 and their corresponding beam and polarization definitions. The parameters fdnum and plnum are GBTIDL keywords.

20–30%, then the default calibration from the cold&ambient loads may be used. For more accurate absolute flux calibration, a source of known flux density should be used. Both ALMA and CARMA have extensive flux density histories for many of the bright 3mm point sources. By using ALMA and/or CARMA flux density values as a function of time, 10-15% calibration uncertainties can be obtained for w-band data.

The standard GBTIDL scripts (getps, getnod, getfs) do not work since these assume a noise diode for calibration. W-band scripts for the reduction of spectral line data can be found at /home/astro-util/projects/4mm/PRO. For continuum (DCR) reduction, contact your support scientist. Users can use the calseq.pro within GBTIDL to derive the gains for each of the channels. After deriving the gains, users can and reduce the spectra-line data, for example, using wonoff.gain.pro.

The formulae for calibrating data are given below. The observed antenna temperature is

$$T_A = T_{\text{sys}}(V_{ON} - V_{OFF})/V_{OFF}, \quad (18.1)$$

where V_{ON} and V_{OFF} are the observed voltages of the ON and OFF scans. The system temperature (T_{sys}) is given by

$$T_{\text{sys}} = gV_{OFF}, \quad (18.2)$$

and the gain (g) is

$$g = [(T_{\text{amb}} - T_{\text{cold}})/(V_{\text{amb}} - V_{\text{cold}})], \quad (18.3)$$

where T_{amb} and T_{cold} are the temperatures of the ambient and cold loads and V_{amb} and V_{cold} are the observed voltages of the ambient and cold load scans. The ambient load is given on the receiver CLEO page and within the receiver FITS files. The cold load is measured in the lab (Table 18.2). The main-beam temperature T_{mb} is related to the observed antenna temperature T_a by

$$T_{mb} = T_A \exp(\tau_o A)/\eta_{mb}, \quad (18.4)$$

where τ_o is the zenith opacity and A is the airmass. The main-beam efficiency is given by

$$\eta_{mb} = 0.8899\eta_a(\theta_{FWHM}D/\lambda)^2, \quad (18.5)$$

where θ_{FWHM} is the full-width half-maximum beam size in radians, D is the diameter of the GBT (100m), and λ is the observed wavelength. For the GBT, the effective aperture efficiency is

$$\eta_a = 0.3516T_A \exp(\tau_o A)/S_\nu, \quad (18.6)$$

where S_ν is the flux density of a known calibration source.

The opacity as a function of time can be obtained by the weather database derived for Green Bank using the getatmos.pro script. Except for periods of rapidly changing weather conditions, the predicted opacities are accurate to within $\Delta\tau_o \simeq 0.006$ based on historical measurements.

Table 18.2: Effective Cold Load Temperature for W-band

Date Range	Average Temperature
2010 May – 2012 April	53 K
2012 May – 2012 June	56 K
2012 October –	50 K

Table Notes: The estimated effective cold load temperature. The temperature is estimated to better than ± 5 K, and there is marginal evidence for a small increase in the temperature across the full band of about couple of degrees. Note, that a 10% error in the cold load measurement corresponds to only about a 2.5% error in the measured T_a or η_a .

18.5 Web Documentation

- 4mm Web Page: <http://www.gb.nrao.edu/4mm/>
- 4mm Project Book: <http://www.gb.nrao.edu/4mm/ProjectBook/>
- 4mm Wiki: <https://safe.nrao.edu/wiki/bin/view/GB/Gbt4mmRx>
- 4mm Status and Commissioning Wiki which provides latest info on performance and notes for users: <https://safe.nrao.edu/wiki/bin/view/GB/Gbt4mmRxCommissioning>