GBT Spectral Baselines

Dana S. Balser, J. R. Fisher, & Roger Norrod

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Contents

1 Introduction

This document summarizes the efforts to characterize and improve the spectral baseline quality of the GBT. The unblocked aperture of the GBT should significantly improve the quality of the spectral baselines. Nevertheless, second order effects will exist and spectral baseline structure can arise in other parts of the system (e.g., reflections in the IF system). At the very best we hope to isolate the specific causes for the baseline structure and remove them. If we are unable to eliminate these features in the spectrum we may be able to calibrate them sufficiently to remove them in the data reduction process.

2 Spectral Baseline Phenomena

2.1 40 MHz Ripple in Spectral Processor

2.1.1 Summary

Initial commissioning observations for the C-band (4-6 GHz) receiver showed a variation in measured $T_{\rm sys}/T_{\rm cal}$ across the 40 and 20 MHz passbands which can appear to be a ripple in the $T_{\rm sys}/T_{\rm cal}$ spectrum of a receiver if spectra are concatenated. The amplitude can be as large as 10% of the system temperature. This has probably colored the baseline measurements made with other receivers. Using both the spectral processor and the spectrometer has revealed that this ripple probably resides in the spectral processor. Also, since the magnitude of the ripple is a function of input power level it appears that this effect may be related to the quantization. The wavelength of the ripple matches the spectral processor bandwidth and the amplitude appears to increase with bandwidth.

2.1.2 Observations

Routine commissioning observations on 24 April 2002 (pnt_lowgreg_34) were made to determine the intensity calibration scale for the C-band (4–6 GHz) receiver. Total power OFFON observations were made towards 3C286 using the spectral processor (SP) in the 2×1024 mode with a bandwidth of 40 MHz. Figure 1 shows $T_{\rm sys}/T_{\rm cal}$ across the C-band receiver towards blank sky (OFF position). Notice several OMT resonances at 4750 MHz, 5230 MHz, and 5680 MHz (see §2.7). There is also a large amplitude ripple with a wavelength of 40 MHz across the entire C-band receiver. Although only one polarization is shown this structure exists in both linear polarizations. The ripple is also observed in the source antenna temperature towards 3C286 (Figure 2).

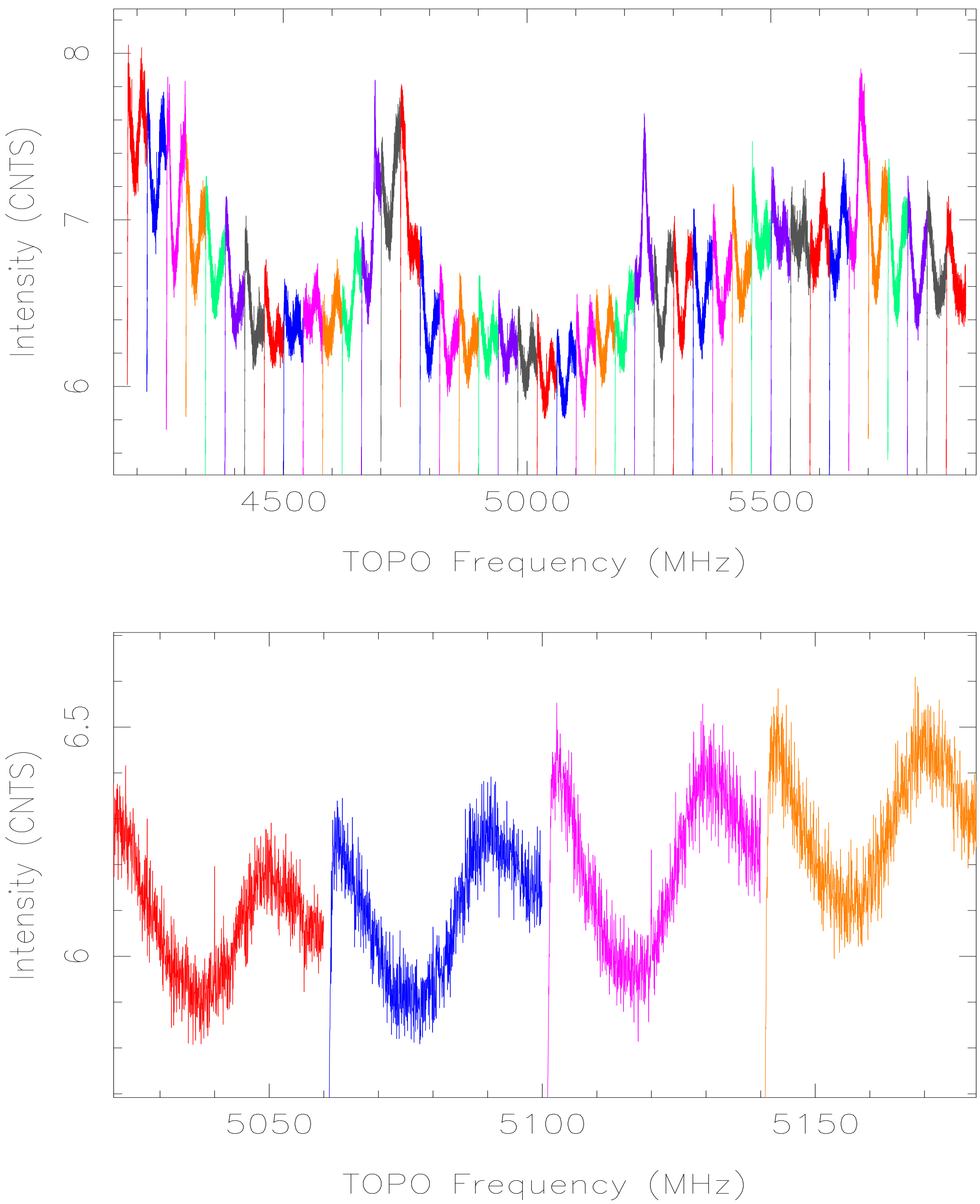

Figure 1: $T_{\rm sys}/T_{\rm cal}$ on blank sky across the C-band receiver, where $\frac{T_{\rm sys}}{T_{\rm cal}} = 0.5\frac{(P_{\rm on}+P_{\rm off})}{(P_{\rm on}-P_{\rm off})}$. Only the X linear polarization is shown. The spectral processor was used in 2×1024 mode with a bandwidth of 40 MHz. The long vertical lines are the edge of the 40 MHz pass-band. The bottom panel shows and expanded view. [project pnt_lowgreg_34; procedure OFFON; scans 11-96.]

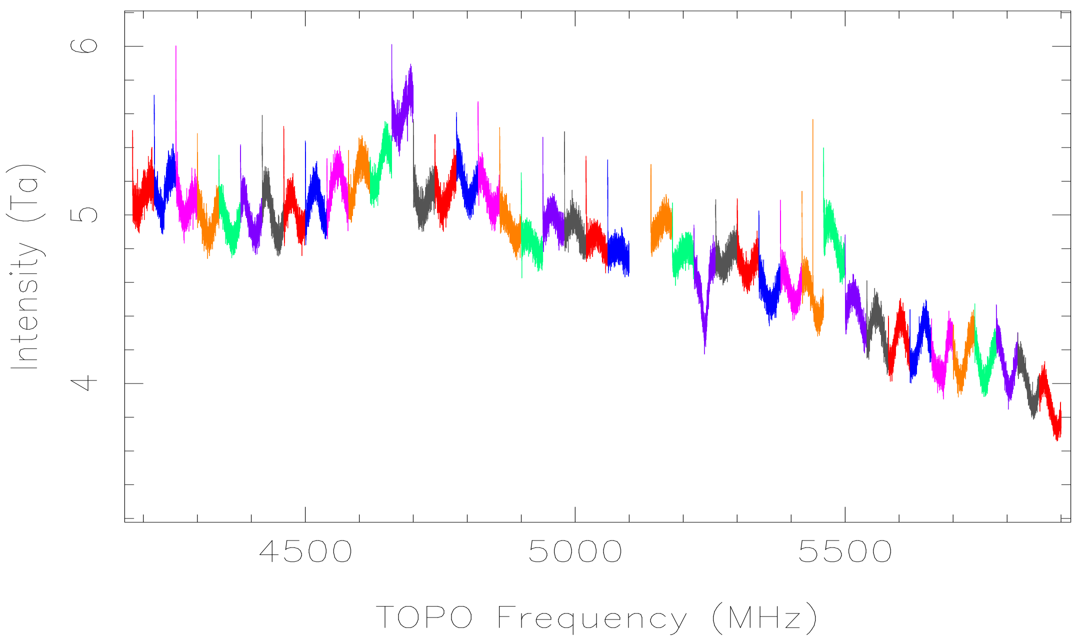

Figure 2: $T_{\rm a}/T_{\rm cal}$ towards 3C286 across the C-band receiver, where $\frac{T_{\rm a}}{T_{\rm cal}} = T_{\rm sys}\frac{P_{\rm sig}-P_{\rm ref}}{P_{\rm ref}}$. Only the X linear polarization is shown. The spectral processor was used in 2×1024 mode with a bandwidth of 40 MHz. The long vertical lines are the edge of the 40 MHz pass-band. [project pnt_lowgreg_34; procedure OFFON; scans 11-96.]

Additional observations were made on 19 May 2002 (baseline_07) where both the spectral processor and the spectrometer were used to explore these baseline effects. Blank sky was observed while running the TRACK procedure. The 800 MHz bandwidth mode of the spectrometer was used to cover the entire C-band receiver. Figure 3 summarizes the results where the system temperature is plotted as a function of frequency. The 40 MHz ripple is not observed but a 48 MHz ripple with smaller amplitude is present.

Observations with the spectral processor towards blank sky at two different bandwidths reveal that the baseline structure appears to reside within the spectral processor. Figure 4 shows the system temperature for the 40 MHz and 20 MHz bandwidth modes. Notice that the ripple wavelength corresponds to the spectrum spacing and that the amplitude of the 20 MHz ripple is smaller.

Observations at C-band with the spectral processor were made on 16 August 2002 (baseline_13) to better characterize this baseline structure. Blank sky was observed while running the TRACK procedure. The spectral processor was in 2×1024 mode with a bandwidth of 40 MHz. Several different power levels were input into the spectral processor. Figure 5 shows that when less power is fed into the spectral processor that the baseline ripple is exacerbated. A similar test was done with a 10 MHz bandwidth (Figure 6). For all cases the baseline ripple amplitudes are larger for the larger bandwidths.

2.2 48 MHz Ripple at 5 GHz

2.2.1 Summary

In the C-band (4-6 GHz) receiver a 48 MHz ripple is observed in $T_{\rm sys}/T_{\rm cal}$ as measured with the spectrometer and with the spectral processor after the effect discussed in §2.1 is removed. This ripple has an amplitude that varies from about 1 to 7 percent across the receiver passband. This 48 MHz ripple does not appear in the $T_{\rm sys}/T_{\rm src}$ spectrum, which leads us to believe that the ripple is in the calibration noise source amplitude.

2.2.2 Observations

While attempting to track down the 40 MHz ripple discussed in §2.1 observations were made on 19 May 2002 (baseline_07) where both the spectral processor and the spectrometer were used investigate baseline structure. Figure 3 shows that the large amplitude 40 MHz ripple observed with the spectral processor was not seen with the spectrometer. However, a smaller amplitude 48 MHz ripple with amplitudes from 1–7% was detected.

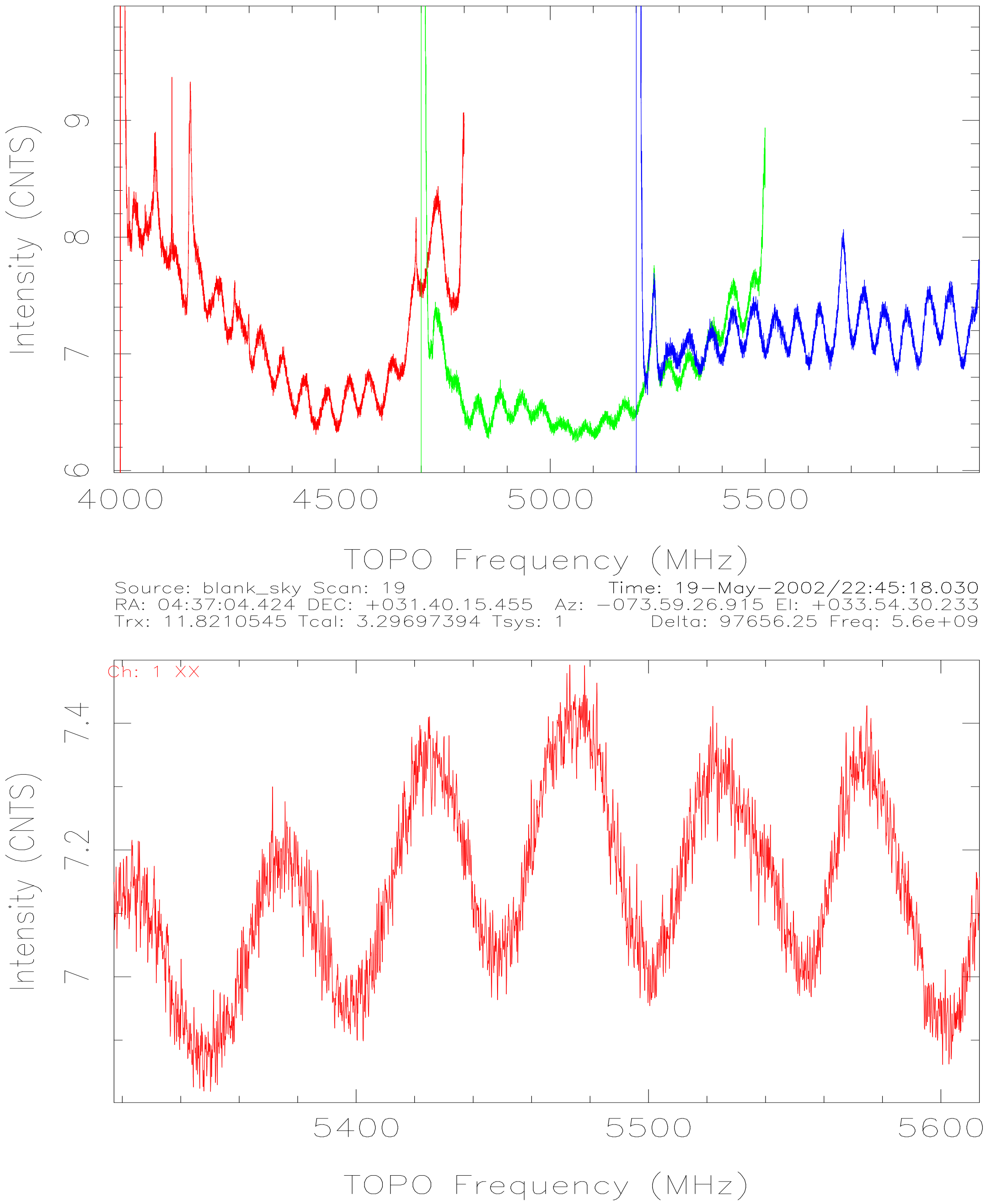

Figure 3: $T_{\rm sys}/T_{\rm cal}$ towards blank sky for the C-band receiver, where $\frac{T_{\rm sys}}{T_{\rm cal}} = 0.5\frac{(P_{\rm on}+P_{\rm off})}{(P_{\rm on}-P_{\rm off})}$. Only the X linear polarization is shown. The spectrometer was used with an 800 MHz bandwidth (2W1-5X-800). Notice the persistent ripple with a wavelength of just under 50 MHz. The top pannel shows the entire 4-6 GHz, while the bottom panel shows an expanded scale of the same figure. [project baseline_07; procedure TRACK; scans 17-19.]

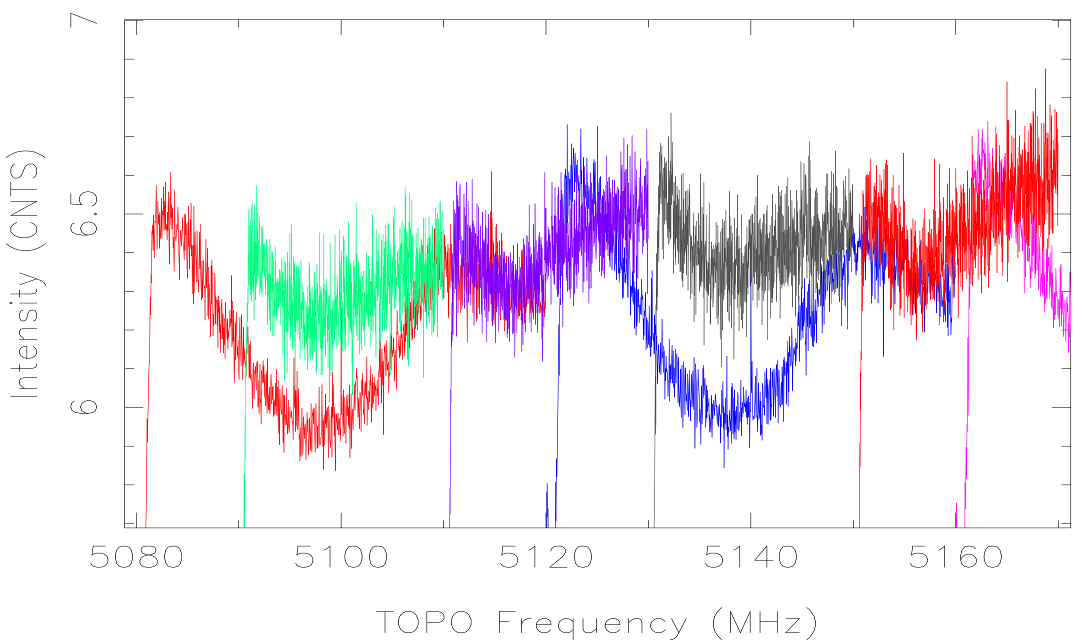

Figure 4: $T_{\rm sys}/T_{\rm cal}$ towards blank sky for the C-band receiver, where $\frac{T_{\rm sys}}{T_{\rm cal}} = 0.5\frac{(P_{\rm on}+P_{\rm off})}{(P_{\rm on}-P_{\rm off})}$. Only the X linear polarization is shown. The spectral processor was used in 2×1024 mode with a bandwidth of 40 MHz (larger amplitude ripple) and 20 MHz. [project baseline_07; procedure TRACK; scans 64-67 for BW=40 MHz and scans 68-71 for BW=20 MHz.]

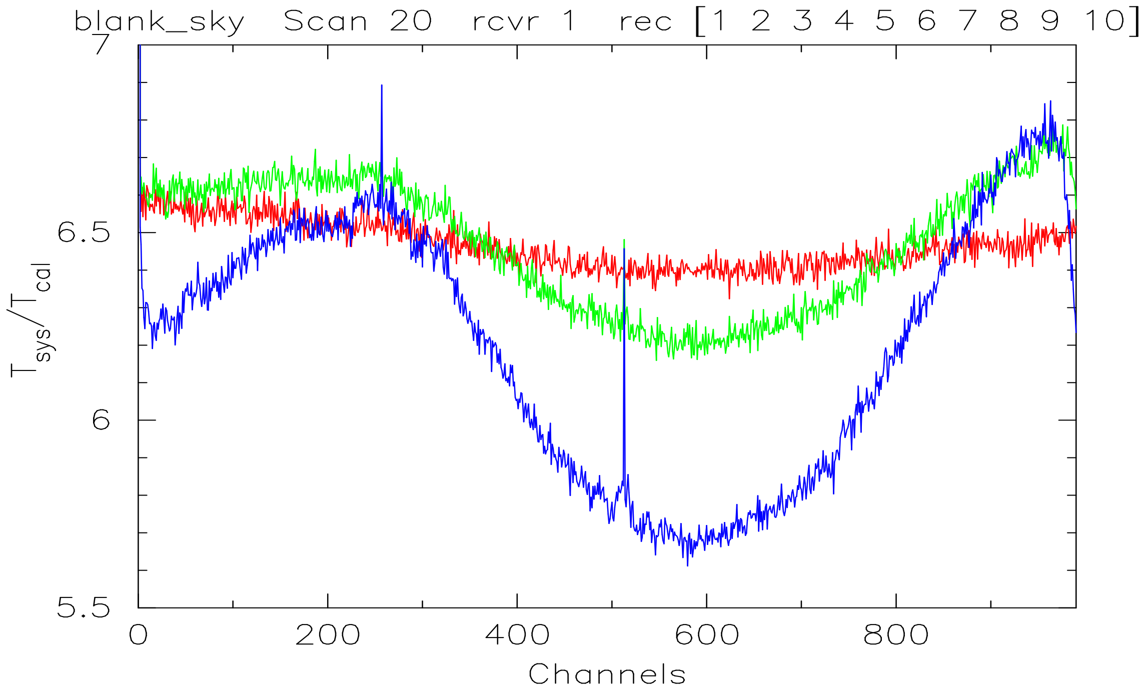

Figure 5: $T_{\rm sys}/T_{\rm cal}$ towards blank sky for the C-band receiver, where $\frac{T_{\rm sys}}{T_{\rm cal}} = 0.5\frac{(P_{\rm on}+P_{\rm off})}{(P_{\rm on}-P_{\rm off})}$. Only the X linear polarization is shown. The spectral processor was used in 2×1024 mode with a bandwidth of 40 MHz. The three curves compare different spectral processor attenuator setting corresponding to power levels of approximately -5, -12, and -15 dBm. The larger the amplitude of the ripple the lower the power. [project baseline_13; procedure TRACK; scans 20,21,23.]

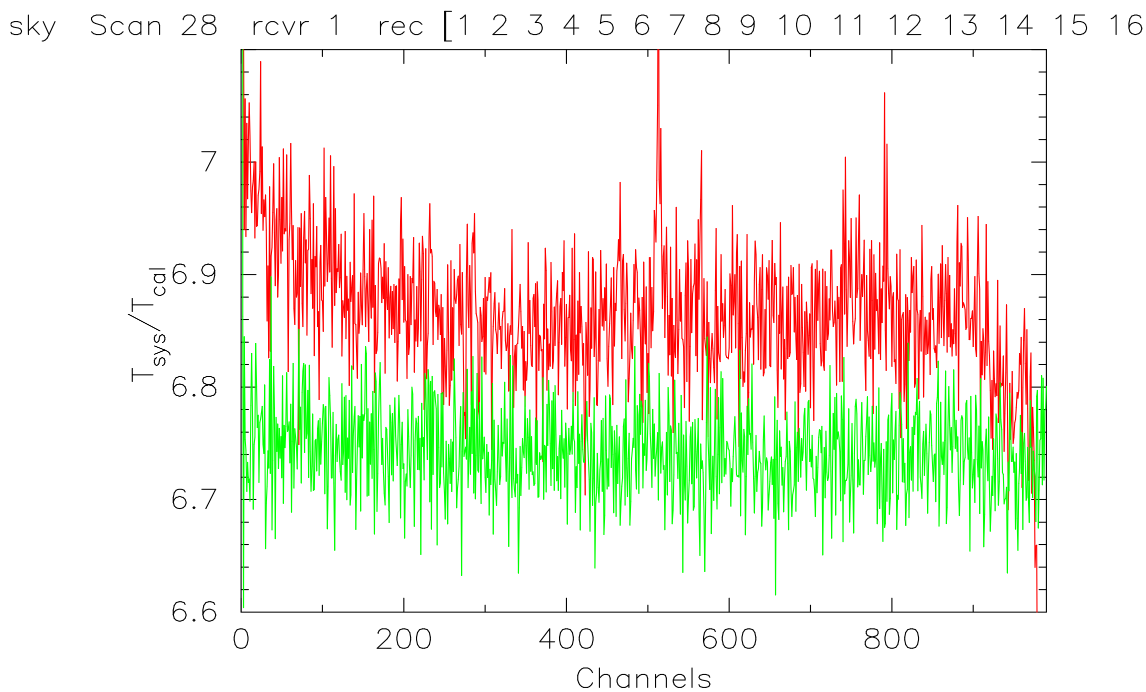

Figure 6: $T_{\rm sys}/T_{\rm cal}$ towards blank sky for the C-band receiver, where $\frac{T_{\rm sys}}{T_{\rm cal}} = 0.5\frac{(P_{\rm on}+P_{\rm off})}{(P_{\rm on}-P_{\rm off})}$. Only the X linear polarization is shown. The spectral processor was used in 2×1024 mode with a bandwidth of 10 MHz. The two curves compare different spectral processor attenuator setting corresponding to power levels of approximately -6 and -16 dBm. The lower power level corresponds to the top curve. [project baseline_13; procedure TRACK; scans 28,30.]

2.3 20 MHz Ripple at 8.6 GHz

2.3.1 Summary

During test observations using the X-band (8–10 GHz) receiver for project GBT02A-041 a spectral baseline ripple with a wavelength of 20 MHz was observed. This feature appears in system temperature measurements as well as the antenna temperture for total power position switching data. The problem appears to be upstream of the LO1 and not created by reflections from the telescope structure or related to the optics. It is also not dominated by any structure in the calibration noise tube.

2.3.2 Observations

During tests for an observing program at X-band on 26 July 2002 (project TGBT02A-041-3) and 31 July 2002 (project TGBT02A-041-4) a 20 MHz baseline ripple was observed in essentially all spectra. The ripple can be observed in the system temperature data as well as the antenna temperature when position switching for both polarizations. Figure 7 shows the OFF position system temperature towards 3C286. A similar feature is observed when the data are processed to produce the antenna temperature, although the phase appears to invert (Figure 8). The amplitude appears to roughly scale with system temperature. (Note that the spectrometer was not balanced between the OFF and ON scans.)

This structure appears to be upstream of the LO1 mixer since the phase of the ripple moves with LO1 frequency. Also, the baseline structure persists when plotting (Sig – Ref)/Ref for only the CAL OFF phase. Therefore, this structure does not appear to be significantly related to any structure in the calibration noise tubes. Furthermore, when the secondary optics is adjusted $\pm\lambda/8$ the phase of the ripple does not move. Thus the spectral baseline structure does not appear to be related to the telescope structure.

2.4 2.4 MHz Ripple in Fiber Modems

2.4.1 Summary

This ripple was first observed at X-band but was later observed in all 8 IF channels. It was later tracked down to be associated with the optical IF links. It appears to be internal to the optical modulator used in the links. It will be present in all receiver spectra with a peak-to-peak amplitude that depends on the IF frequency on the fiber. Some fiber modems may be worse than others, so an inventory should be conducted and possibly the modems with the smallest gain ripple placed in the most frequently used channels. At first the structure appeared to be very stable but in some cases it is clearly visible within a 12 minute total power position swithcing observation. The contractor is aware of the problem and is attempting to make improvements. An improved modulator has been ordered for evaluation. Some results should be available by the end of the year.

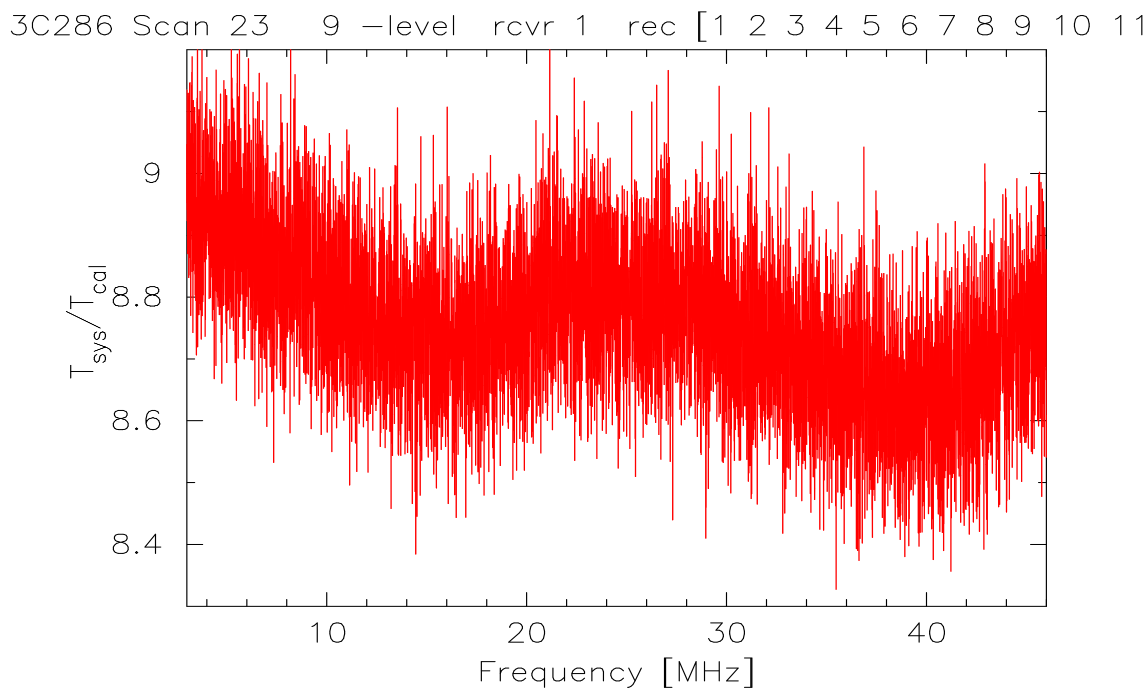

Figure 7: $T_{\rm sys}/T_{\rm cal}$ towards the OFF postion of 3C286 using the X-band receiver at a rest frequency of 8665.30 MHz, where $\frac{T_{\rm sys}}{T_{\rm cal}} = 0.5\frac{(P_{\rm on}+P_{\rm off})}{(P_{\rm on}-P_{\rm off})}$. Only the RCP channel is shown. The spectrometer was used with a bandwidth of 50 MHz (1N2-0B-50-9). [project TGBT02A-041-4; procedure OFFON; scan 23.]

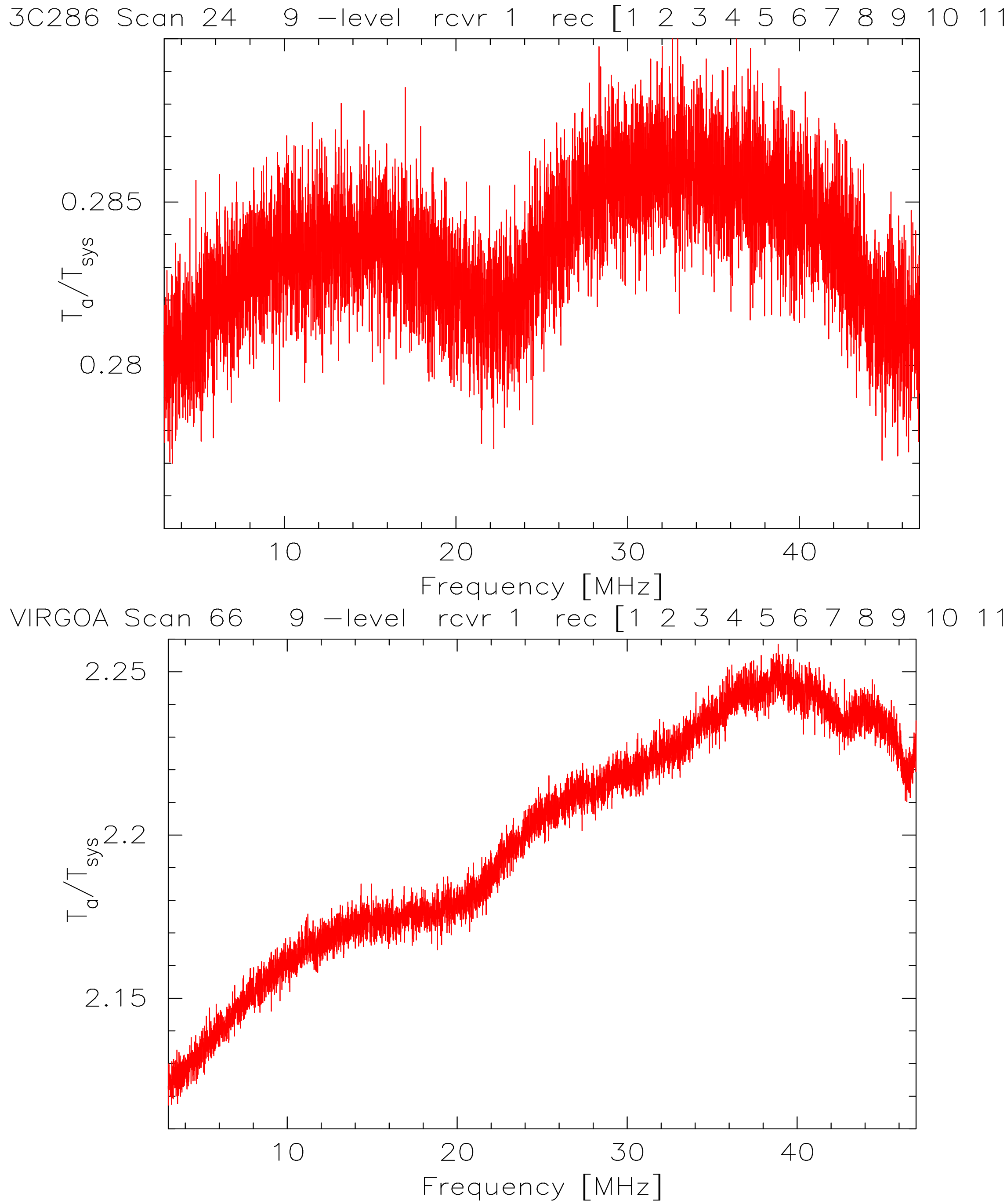

Figure 8: $T_{\rm a}/T_{\rm sys}$ towards 3C286 and VirgoA using the X-band receiver at a rest frequency of 8665.30 MHz, where $\frac{T_{\rm a}}{T_{\rm sys}} = \frac{P_{\rm sig}-P_{\rm ref}}{P_{\rm ref}}$. Only the RCP channel is shown. The spectrometer was used with a bandwidth of 50 MHz (1N2-0B-50-9). Balancing was not performed between the OFF and the ON scans. [top panel: project TGBT02A-041-4; procedure OFFON; scan (23,24) bottom panel: project TGBT02A-041-3; procedure OFFON; scan (65, 66)]

2.4.2 Observations

The 2.4 MHz ripple can easily be observed in a total power spectrum. For example, Figure 9 show a power spectrum taken at X-band during tests with the spectrometer in the 50 MHz bandwidth mode. The integration time is 30 seconds. The ripple can sometimes be observed in the auto-correlation function as well (see Figure 10). In some cases this baseline structure is not very stable and can be observed with only 12 minutes of integration time.

2.5 L-band Frequency Switching

2.5.1 Summary

During GBT spectral line, frequency switching observations at L-band it was noticed that one polarization (linear Y) had significant baseline structure. There appeared to be structure which was roughly periodic with a wavelength of $\sim$ 8 MHz. Initial tests were performed to investigate this problem. By swapping cables along the signal path it appeared that this structure was coming from the RF filter component. Baseline variations with smaller amplitudes were also observed as a function of subreflector position in both polarizations. The standard $\pm\lambda/8$ defocussing appeared to cancel most of this smaller amplitude structure. The receiver was taken down for inspection. No major problems were discovered although an isolator which had a dip in its passband was replaced.

When the receiver was re-installed on the telescope the baseline structure still existed. In fact with longer integration times there appeared to be $\sim$ 10 MHz structure in both polarizations and a $\sim$ 1.5 MHz ripple in the linear Y polarization. This structure was observed with both the spectrometer and the spectral processor.

2.5.2 Observations

Spectral baseline tests were first performed on 20 February 2002 (project baseline_01) and 28 February 2002 (project baseline_02). The L-band receiver was used at several different frequencies with the spectral processor in 2×1024 mode with a bandwidth of 10 MHz. Frequency switching was employed with an offset frequency of -5 MHz. This setup was used to reproduce the previously observed effects discovered during GBT astronomical spectral line observations.

Figure 11 shows the antenna temperature towards blank sky and illustrates that the linear Y polarization has significantly worse baseline structure. After swapping cables to various places in the signal path it appeared that the problem was isolated in the RF filter.

A part of the observed baseline structure of both polarizations appear to reside from the telescope structure. The subreflector was shifted axially by $\pm$ $\lambda/8$ and the phase of the structure moved. Figure 12 shows the spectra for each polarization. When the two subreflector positions are averaged the linear X polarization channel becomes very flat and

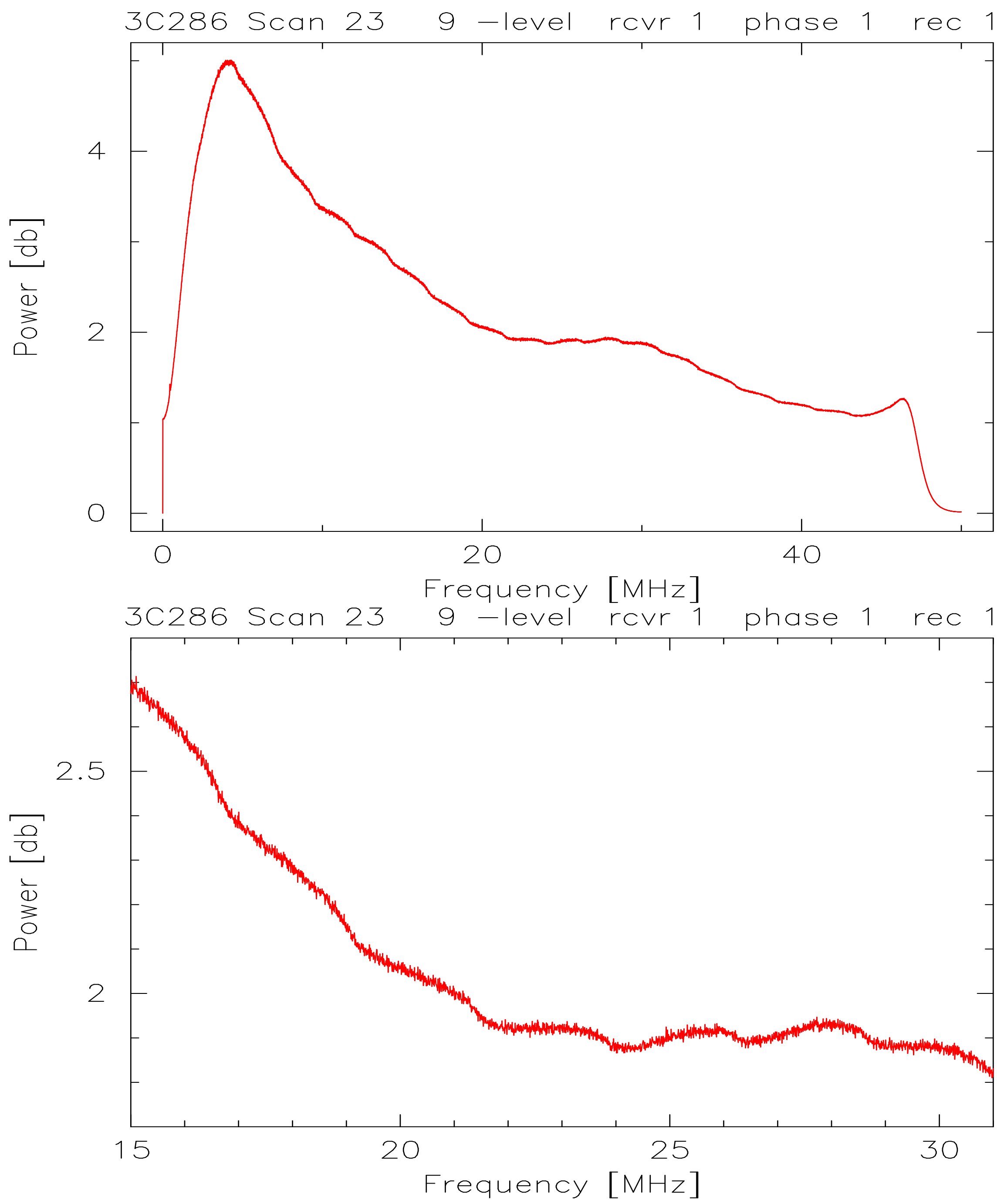

Figure 9: The raw total power spectrum towards the OFF position of 3C286 taken at X-band with a rest frequency of 8665.30 MHz. The spectrometer was used with tha bandwidth of 50 MHz (1N2-0B-50-9). The 2.4 MHz ripples are easily detected. The lower panel shows an expanded view. [project TGBT02A-041-4; OFFON procedure; scan 23]

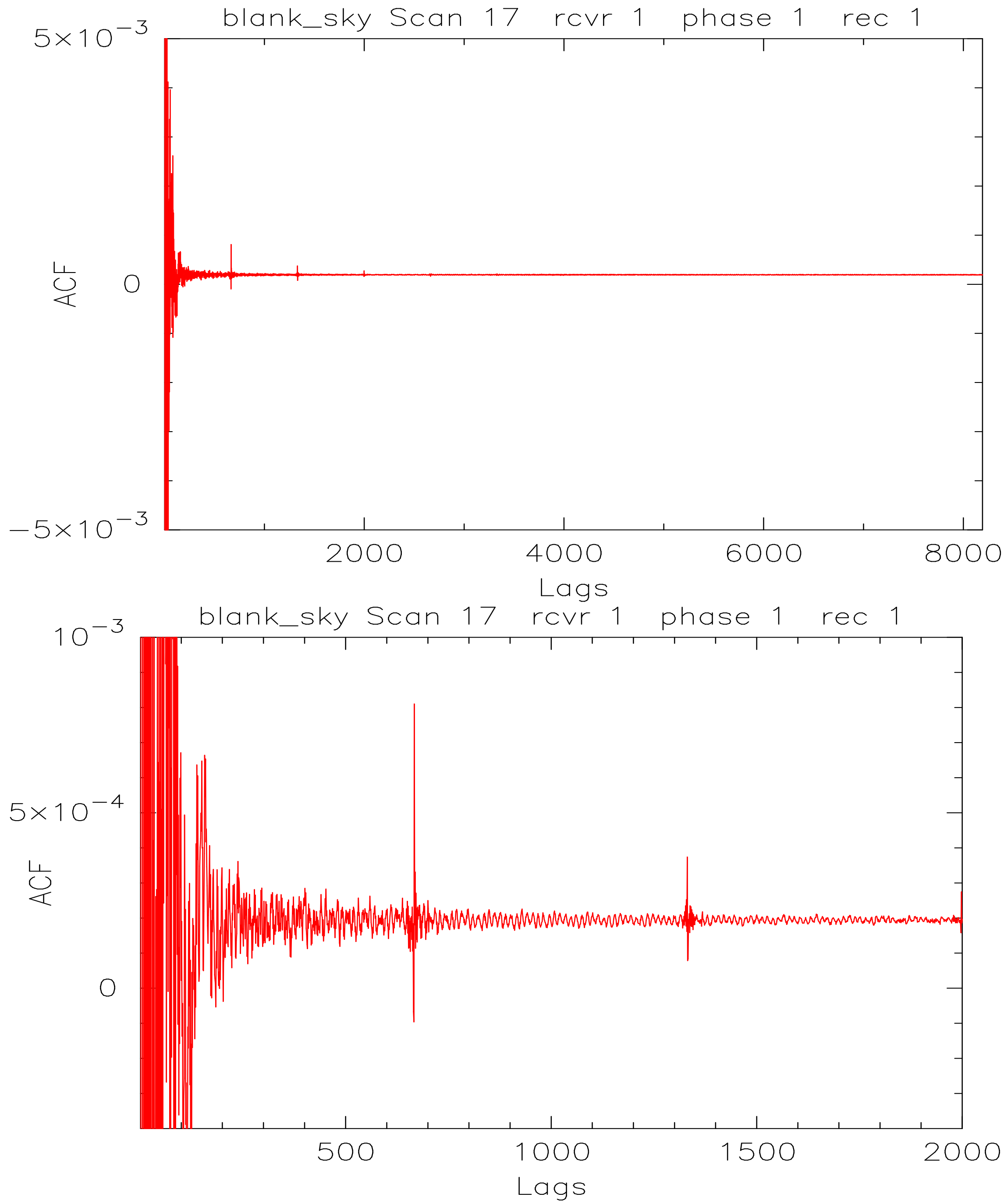

Figure 10: The auto-correlation function (ACF) for the first 800 MHz spectrum in Figure 3. Notice the features at lags 669 and 1337 which correspond to frequencies 2.4 MHz and 1.2 MHz. [project baseline_07; TRACK procedure; scan 17]

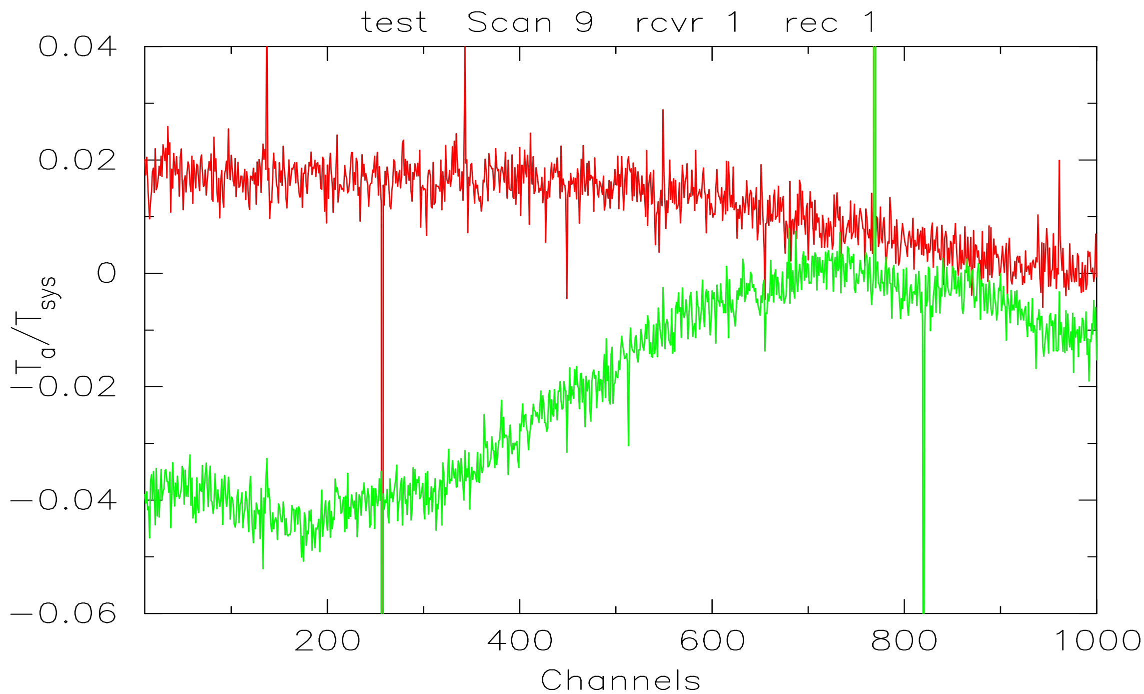

Figure 11: $T_{\rm a}/T_{\rm sys}$ towards blank sky using the L-band receiver at a rest frequency of 1412.5 MHz, where $\frac{T_{\rm a}}{T_{\rm sys}} = \frac{P_{\rm sig} - P_{\rm ref}}{P_{\rm ref}}$. The spectral processor was used in 2×1024 mode with a bandwidth of 40 MHz. Frequency swithcing was employed with an offset frequency of 5 MHz. The top curve is linear polarization X while the bottom curve is linear polarization Y. [project baseline_01; procedure TRACK; scan 9.]

while the linear Y polarization channel is sinusoidal (see Figure 13).

The L-band receiver was taken down and inspected. An isolator which had a dip in its passband was replaced. After re-installation tests were performed with the spectrometer on 17 July 2002 (project baseline_10) and with the spectral processor on 7 August 2002 (project baseline_11). Figure 14 shows irregular baseline structure in both polarizations with a period of ~ 10 MHz. Also revealed with longer integrations is a ~ 1.5 MHz ripple in only the linear Y polarization. The same results are indicated with the spectral processor although the larger wavelength ripple is probably being modified by the problems discussed in §2.1. The 1.5 MHz ripple appears to be in front of the RF transfer switch. Also, the 1.5 MHz appears to shift 180 degrees in phase when the subreflector is shifted by only $\lambda/8$. This would appear to be a double reflection with a round trip path difference of 200 meters.

It was thought that a polarized broadband source was causing this structure. On 13 August 2002 (project baseline_12) various sources of RFI on the telescope were tested. Power to the feed-arm servo, the quadrant detector, the weather station 3, the PF power, the holography reference antenna, the HVAC, the air craft warning light, and the active surface electronics were turned off. In all cases the 1.5 MHz ripple persisted. On 22 August 2002 (project baselines_14) the L-band receiver was rotated 90 degrees. The 1.5 MHz ripple clearly moved from linear Y to linear X polarization. When the receiver was rotated back to the nominal

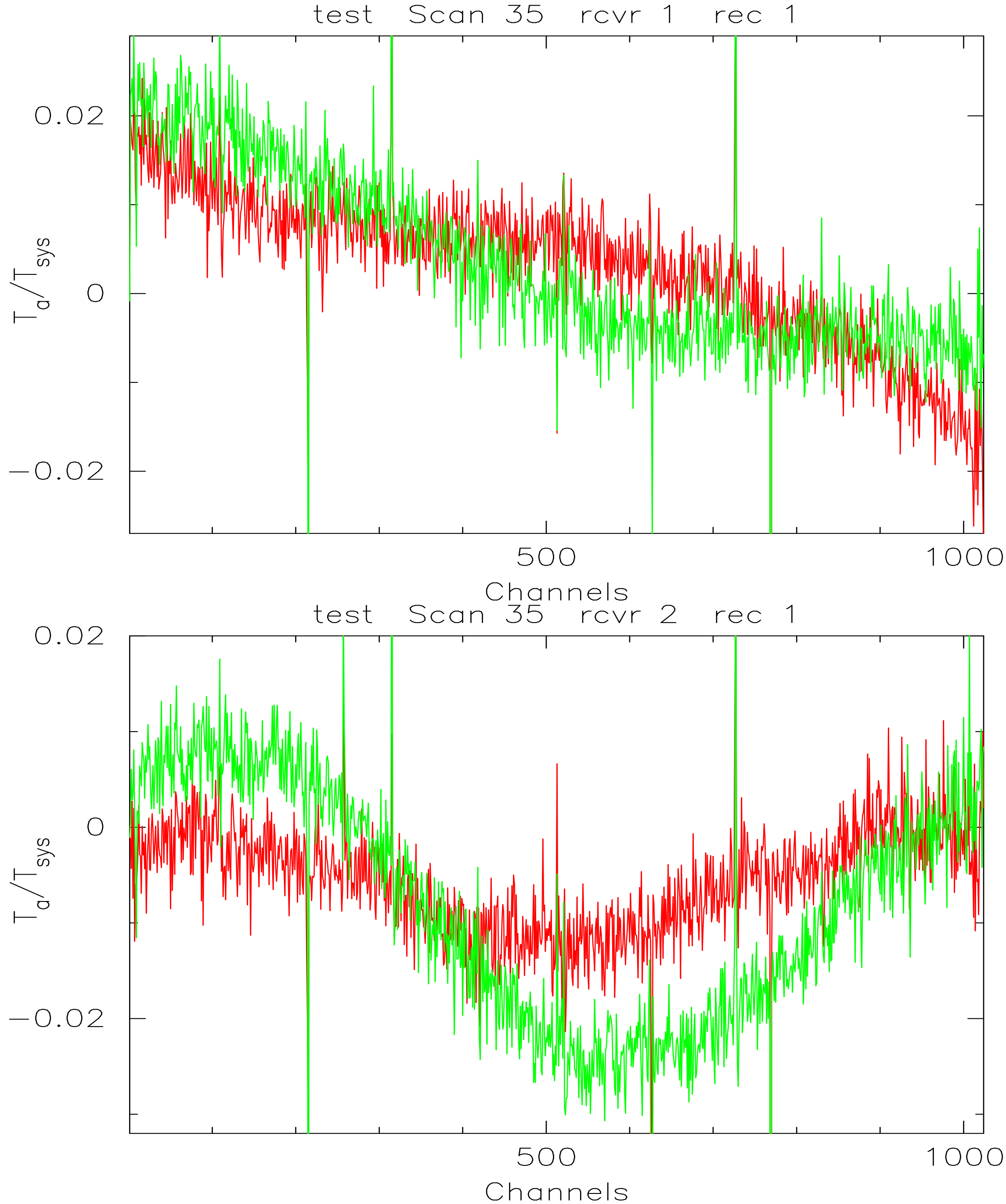

Figure 12: $T_{\rm a}/T_{\rm sys}$ towards blank sky using the L-band receiver at a rest frequency of 1412.5 MHz, where $\frac{T_{\rm a}}{T_{\rm sys}} = \frac{P_{\rm sig}-P_{\rm ref}}{P_{\rm ref}}$. The spectral processor was used in 2×1024 mode with a bandwidth of 40 MHz. Frequency swithcing was employed with an offset frequency of 5 MHz. The two curves are the $+\lambda/8$ and $-\lambda/8$ focus positions of the subreflector. Top panel: linear X polarization. Bottom panel: linear Y polarization [project baseline_02; procedure TRACK; scan (35, 36).]

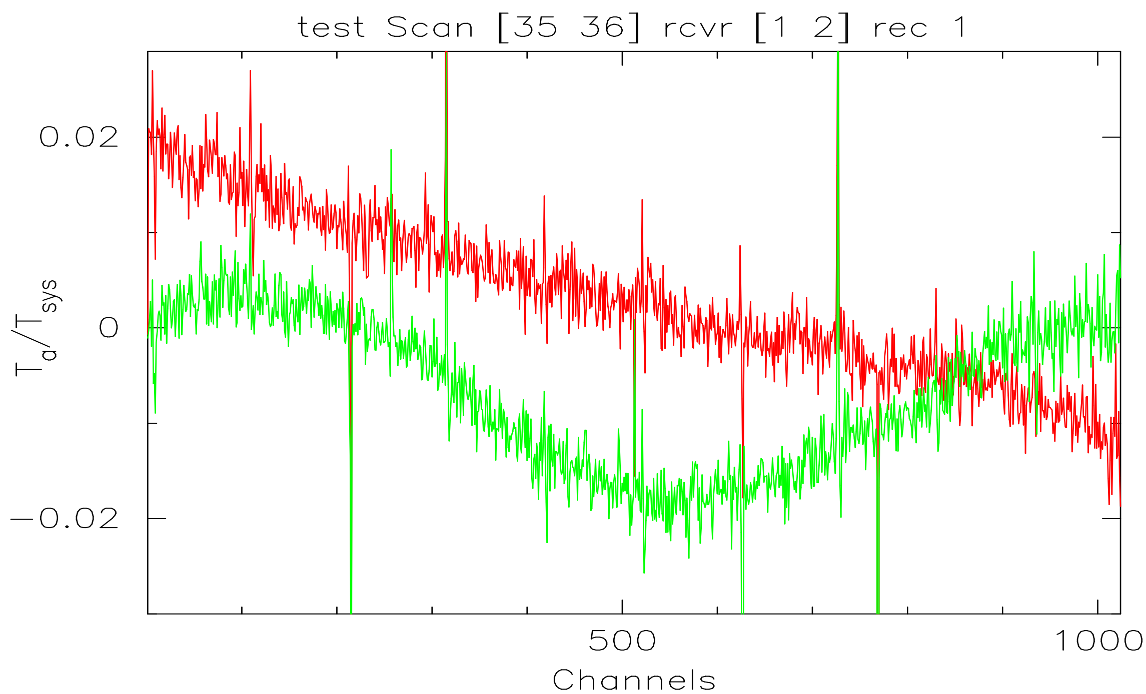

Figure 13: T_a/T_{sys} towards blank sky using the L-band receiver at a rest frequency of 1412.5 MHz, where $\frac{T_a}{T_{sys}} = \frac{P_{sig} - P_{ref}}{P_{ref}}$. The spectral processor was used in 2×1024 mode with a bandwidth of 40 MHz. Frequency swithcing was employed with an offset frequency of 5 MHz. The $+\lambda/8$ and $-\lambda/8$ scans have been averaged for each polarization. [project baseline_02; procedure TRACK; scan (35, 36).]

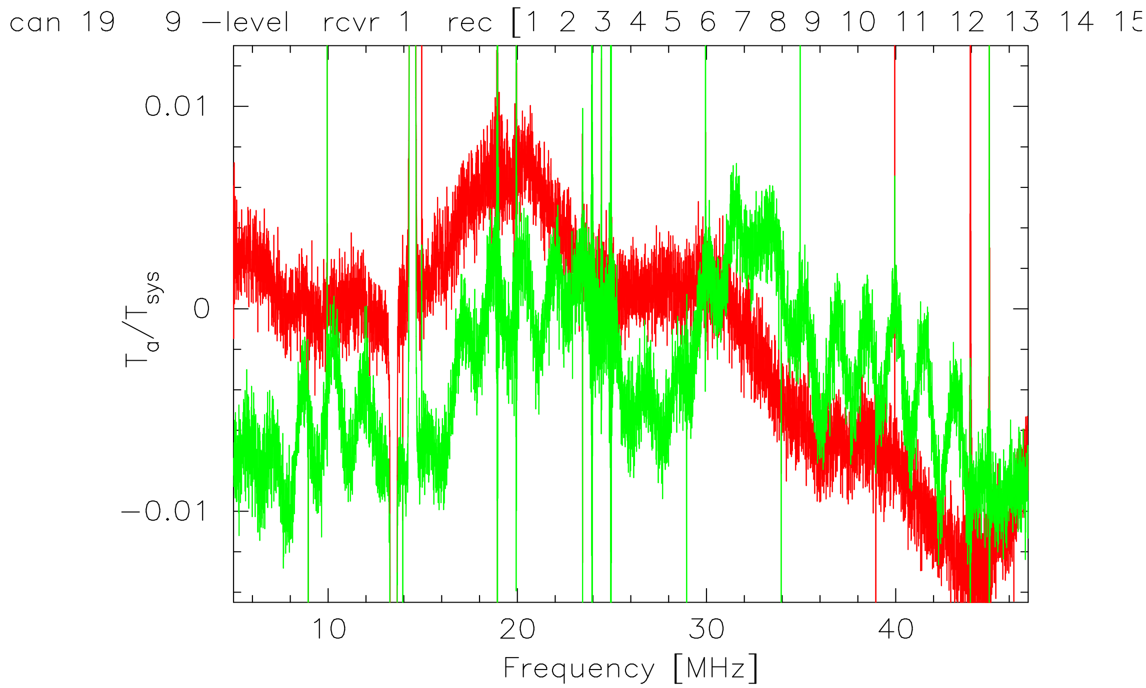

Figure 14: $T_\mathrm{a}/T_\mathrm{sys}$ towards blank sky using the L-band receiver at a rest frequency of 1410 MHz, where $\frac{T_\mathrm{a}}{T_\mathrm{sys}} = \frac{P_\mathrm{sig}-P_\mathrm{ref}}{P_\mathrm{ref}}$. The spectrometer was used with a bandwidth of 50 MHz (1N2-0A-50-9). Frequency swithcing was employed with an offset frequency of 1 MHz. [project baseline_10; procedure TRACK; scan 19]

position the ripple moved back the Y.

2.6 K-band Instability

2.6.1 Summary

While performing a beam-switched observation it was noted that although both channels always had some baseline structure that in most instances channel B was not usable. The problem appears to be in the receiver room, outside the dewar, but before the fiber interface. Note that even the “good” channel appears to be less stable than one expects. This could be more than one problem but we need to understand the stability problems. The K-band receiver has been removed from the telescope and is being tested in the lab.

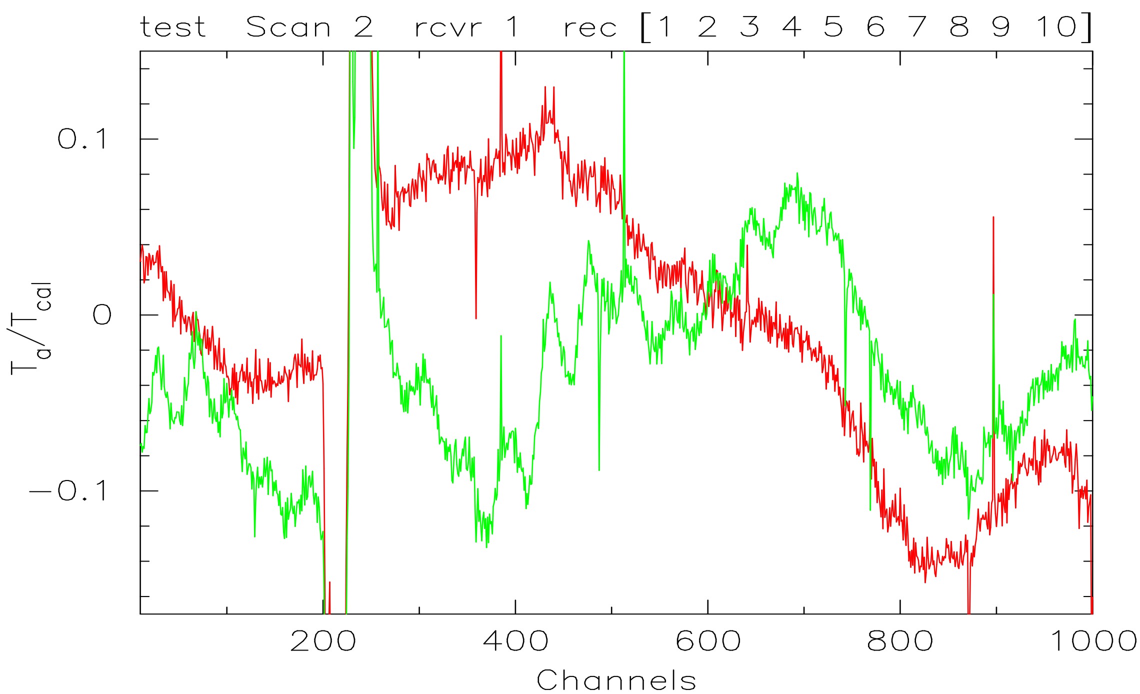

Figure 15: T_a/T_{sys} towards blank sky using the L-band receiver at a rest frequency of 1410 MHz, where $\frac{T_a}{T_{sys}} = \frac{P_{sig}-P_{ref}}{P_{ref}}$. The spectral processor was used in 2×1024 mode with a bandwidth of 40 MHz. Frequency swithcing was employed with an offset frequency of 1 MHz. [project baseline_12; procedure TRACK; scan 2]

2.6.2 Observations

2.7 OMT Resonances

2.7.1 Summary

Several OMT resonances have been identified in the 4-6 GHz receiver. Similar resonances exist in other receivers and need to be measured and documented. Currently, laboratory measured frequencies for the PF1, 1.2-1.7, and 2-4 GHz receivers have been made.

2.7.2 Observations