GBT Memo 260
Standing Waves Excited By Extended Sources In The X-band Feed Horn

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1 Introduction

The use of vector calibration, where the noise diode fluxes are determined as a function of frequency from a calibration source and then are applied to the target source, eliminates or greatly reduces baseline structures for a large number of observations. This technique is able to remove structures whose origin is within the IF chain and after the injection of the noise diode signals. This technique will not eliminate standing waves that arise in the GBT optics and feeds before the injection of the noise diode signals.

As part of project AGBT08B_026 the vector calibration observing technique was used. It was found that for extended objects that are about the beam size or larger, standing waves would be present in the data while they would be absent for unresolved sources. The likely source of these standing waves is within the X-band feed horn.

2 Unresolved Sources

BL Lac and 3C 286 are both unresolved at 10 GHz with the GBT. Position switched observations of these sources determine the standing wave behavior for point sources.

BL Lac was used as the target source and 3C 286 was used as the calibration source for determining the noise diode levels versus frequency. The resulting data, after fitting and removing the spectral flux of the form $S(\nu) = S_o \nu^{\alpha}$, is shown in Figure 1. The data for both polarizations is shown in Figure 1. The "raw" data are shown as the red line. A Savitzky-Golay smoothing filter (function savgol in idl) was used to smooth/remove the noise in this data. The resulting smoothed signal is shown as the green line in Figure 1. The data above

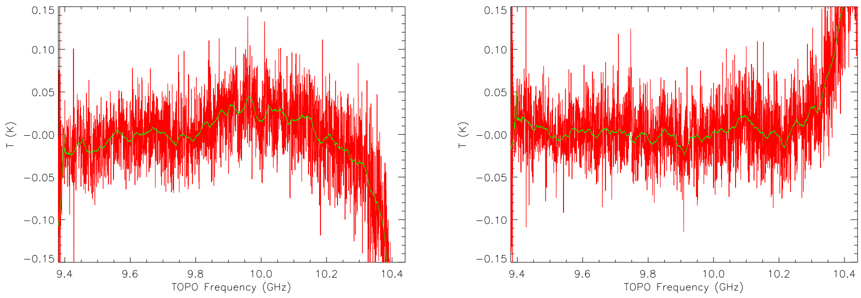

Figure 1: Observations of BL Lac using 3C 286 as the calibration source. A flux vs. frequency of the form $S = S_o\nu^\alpha$ was fit and removed from the data. The raw data showing the standing wave are in red. The green line is the result of using a Savitzky-Golay filter on the data. The left panel shows the results for the left circular polarization and the right panel shows the right circular polarization results. A receiver resonance exists above about 10.35 GHz.

$\sim$ 10.3 GHz should be ignored due to a receiver resonance and were not used in any of the following analysis.

The BL Lac data do not show any strong evidence for standing waves.

3 Resolved Sources

3C 348 is a double-lobed source with a separation of about 115 arcseconds between the two components. 3C 353 is an extended source with a size of about 150 arcseconds. 3C 286 was once again used to determine the noise diode levels.

The 3C 348 results are plotted in Figure 2. Once again the spectral flux of 3C 348 has been removed from the data. A standing wave with a size scale of $\sim$ 1.12 m (44.1 in) is clearly evident in this data (blue line in Figure 2. This standing wave would originate between two reflective surfaces that are 56.0 cm (22.0 in) apart. Fitting for a second standing wave improves the fit (black line in Figure 2). The second standing wave has a scale size of 81.9 cm and would arise from two reflective surfaces separated by $\sim$ 41.0 cm (16.1 in). It is difficult to definitely claim the existence of this standing wave.

In determining the size scale of the standing wave, I have fitted a function of the form

$$T(\nu) = T_o \cos\left(\frac{2\pi\nu d}{c}\right) \tag{1}$$

where T_o is the amplitude of the wave and d is the size scale of the standing wave. The frequency, ν, is in Hz, and the size scale is in meters. As can be seen in Figure 2, a cosine is not the exact shape of the actual standing waves.

The actual standing wave structure has a bit more of a saw-tooth shape. The actual standing wave also exhibits some repeatable sub-structure. We should thus consider the size scale of the standing wave determined by using equation 1 as being good to within about 10 percent.

The 3C 353 results are plotted in Figure 3. The spectral flux of 3C 348 has been removed from the data. A standing wave with a size scale of $\sim 1.15\,\mathrm{m}$ (45.3 in) is clearly evident in this data. This standing wave would originate between two reflective surfaces that are 57.5 cm (22.6 in) apart.

It is obvious from this data that extended sources are exciting standing wave modes that unresolved sources do not excite. A standing wave with a size scale of order 113 cm (44.5 in) seems to be excited by any source with structure on the size of the X-band beam. If the source flux is not spatially smooth but has a few bright components, such as the two lobes of 3C 348, the another standing wave might be excited with a size scale of about 82 cm. It is clear that the different source structure of 3C 353 and 3C 348 are creating different baseline structures.

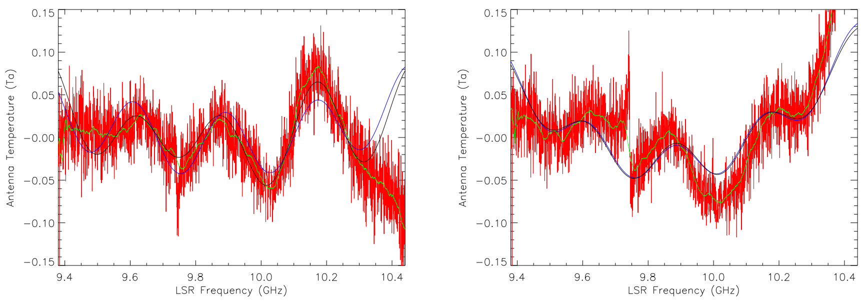

Figure 2: Observations of 3C 348 using 3C 286 as the calibration source. A flux vs. frequency of the form $S = S_o \nu^\alpha$ was fit and removed from the data. The raw data showing the standing wave are in red. The green line is the result of using a Savitzky-Golay filter on the data. The blue line is a fit of a third order polynomial plus a single standing wave of length 1.12 meters (44.1 in). The black line is a fit of a third order polynomial and two standing waves of lengths 1.12 m (44.1 in) and 0.81 m (31.9 in). The left panel shows the results for the left circular polarization and the right panel shows the right circular polarization results. A receiver resonance exists above about 10.35 GHz.

4 Standing Waves in the Feed

A schematic of the X-band feed is shown in Figure 4. We can see that the size scale of the feed from the throat (left side of the diagram) to the feed opening

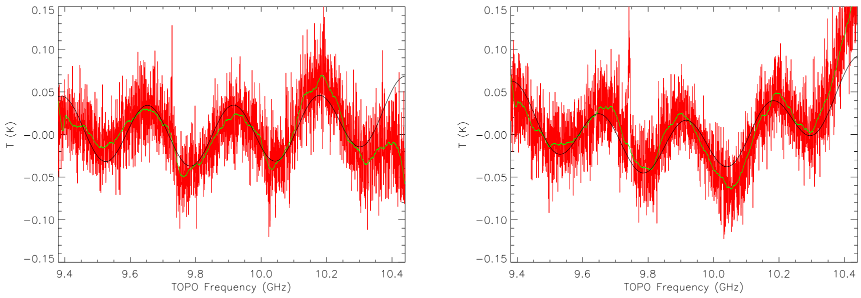

Figure 3: Observations of 3C 348 using 3C 286 as the calibration source. A flux vs. frequency of the form $S = S_o \nu^\alpha$ was fit and removed from the data. The raw data showing the standing wave are in red. The green line is the result of using a Savitzky-Golay filter on the data. The black line is a fit of a third order polynomial plus a single standing wave of length 1.12 meters (44.1 in). The left panel shows the results for the left circular polarization and the right panel shows the right circular polarization results. A receiver resonance exists above about 10.35 GHz.

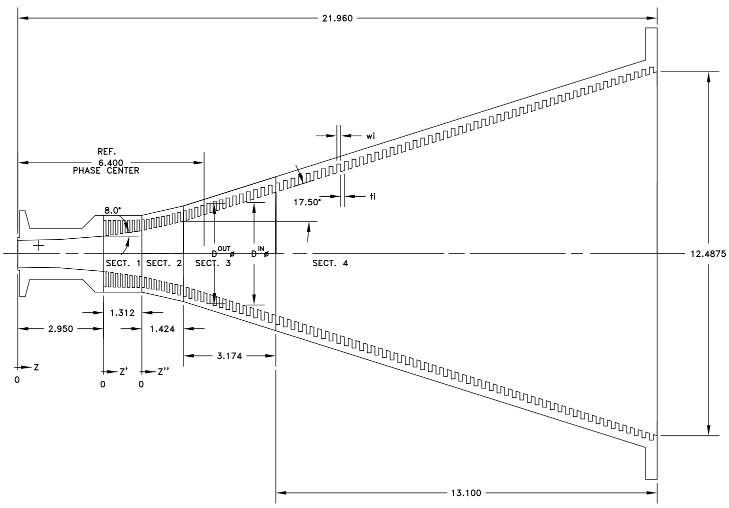

Figure 4: An engineering schematic of the X-band feed. All units are in inches.

is about the right distance for the 113.0 cm (44.5 in) standing wave. No other structures on the GBT have been identified which could create this standing wave.

The distance between the outer edges of the feed opening flange is approximately 39.0 cm (15.4 in). It is possible that the second standing wave excited by 3C 348 (if real) is present across the opening of the feed.

5 Removing the Standing Waves From Observations

It is possible to remove these standing waves from observations data. The smoothed standing wave structures from the 3C 353 and 3C 348 (the green lines in Figures 2 and 3) were used to fit and remove the baseline structure in observations of K3-50, which is a bright, compact, H II region within a larger extended complex of H II regions. The K3-50 data and the fit of the standing wave structures to that data are shown in Figure 5. It can be seen from Figure 5 and 6 that the baseline structure can be reduced by up to an order of magnitude by using the 3C 353 and 3C 348 data as templates for removing the baselines. There is another, smaller, receiver resonance at about 9.7 GHz that results in some residual structure in fitting for the standing waves. It should be noted that the Hydrogen and Helium recombination lines seen in Figure 5 (the narrow "spikes") were removed from the data and then the data were smoothed to obtain the results shown in Figure 6.

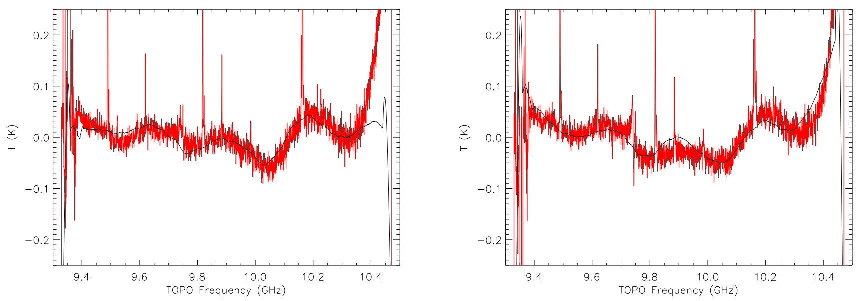

Figure 5: Observations of K3-50 using BL Lac as the calibration source. A flux vs. frequency of the form $S = S_o \nu^\alpha$ was fit and removed from the data. The raw data are shown in red. The black line is a fit of the standing wave structures to the data. The left panel shows the results for the left circular polarization and the right panel shows the right circular polarization results. A receiver resonance exists above about 10.35 GHz.

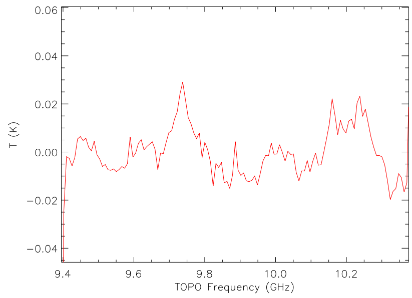

Figure 6: The K3-50 spectrum after removing the standing wave fits and averaging the two polarizations together.

6 Discussion

An origin for these standing waves can not be clearly pinpointed at this time. We know that the standing waves do not depend on a source having continuum emission. It does not seem to be weather dependent either. These standing waves only seem to be excited when the source has extended structure that is as large or larger than the beam size. It may be that the extended emission coming from off-axis encounters a diffraction pattern at the opening end of the feed horn which then sets up the standing wave.

Further tests are needed to obtain a reasonable understanding of these standing waves.