Ghost Images Of Strong Signals Arising At ±100 MHz And From Aliased Power In GBT Spectrometer Spectra

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1 Introduction

The GBT Intermediate Frequency (IF) system uses a Voltage Controlled Crystal Oscillator (VXCO), running at 100 MHz, to generate a Local Oscillator (LO) signal. The 100 MHz signal from the ocillator is followed by a X5 frquency multiplier to produce a 500 MHz signal output signal within the VXCO. The VXCO is phase locked to a 500 MHz reference signal from a hydrogen maser. The VXCO 500 MHz signal is, among other things, sent through a X21 multiplier to produce the 10.5 GHz reference signal used in the third LO (LO3).

The VXCO output has sidebands that are at 400 and 600 MHz. When a strong signal is present, such as the LO1B test tone or a very strong spectral line (e.g. maser), then the VXCO sidebands can appear as ±100 MHz sidebands. This can lead to ghosts of the test tone or spectral line showing up at ±100 MHz offsets from the real line in the observed spectra. Although first discovered at Q-band for an SiO maser, the ±100 MHz sidebands are common to all receivers and backends for signals that use LO3. This allows for the use of a test tone injected at any frequency to be used to study the sidebands.

The GBT spectrometer is an auto-correlation spectrometer. It samples/digitizes the input IF signal at a sampling rate of 100 MHz or 1.6 GHz using a few micro-seconds chunks of the input signal (the exact time depends on the mode of the spectrometer). These are then auto-correlated and accumulated. Post processing then applies Van Vleck corrections and Fourier Transforms the auto-correlation lags into a frequency spectrum. If there is a narrow and strong spectral signal present, then this signal's power can be aliased to other parts of the spectra. This can also create ghosts of the spectral lines. This aliasing of power is a feature of all auto-correlation spectrometers.

1.1 Test Measurements Made With The LO1B Test Tone

The Ku-band receiver was used as the front end for the test observations along with the GBT spectrometer as the backend. Two spectral windows with 200 MHz bandwidth were observed. The central sky frequencies of the spectral window were 13420 MHz and 13580 MHz. The LO1B test tone was used to simulate a narrow but strong spectral line. The test tone was injected at 13500 MHz with varying signal strengths.

An integration time of 30 seconds was used during two minute data taking scans. The Ku-band noise diode was fired during all of the scans to provide a means of calibration. One scan was obtained with the test tone at its minimum power level and with its frequency set to 17 GHz. This scan was used as a reference scan. Scans with the test tone set to 13500 MHz are used as signal scans. The "calibrated" data were then found by using the $\frac{sig-ref}{ref}$ scheme commonly used for position switched astronomical observations.

The test tone generator does not produce a stable enough power output level to use the resulting spectra to determine the absolute power levels between the main signal and the ghosts. This would also not be possible due to the aliasing of power within the sampling of the signal in the spectrometer. However, the test tone is stable in frequency and can be used to find where ghosts appear in the spectrum.

In Figures 1–4 the full spectra at each of the power settings for the test tone are shown. In Figures 5–7, we zoom in on the baseline so that we are able to see the ghosts in the spectra. We see that the ghost ±100 MHz emission begins to show up between the −30 dB and −20 dB settings of the test. The ratio of the test tone strength to the ghost strength in the −20 dB spectra are about −33 dB.

In Figure 8 all of the ghosts have been identified. The ghosts at the frequencies shown by the blue arrows are the ±100 MHz ghosts from the VXCO. All of the other ghosts arise from aliased power in the sampling of the IF signal. Let the mininum frequency of the spectrum be f_{min} and the maximum be f_{max} while the strong signal is at f_o. Now we define the aliasing frequency as

$$f_{alias} = \min\left([f_o - f_{min}], [f_{max} - f_o]\right). \qquad (1)$$

where min() is the minimum value operator. The ghosts from aliased power can then show up at

$$f_{min} + i \times f_{alias} \qquad (2)$$

$$f_{max} - j \times f_{alias} \qquad (3)$$

$$f_o + 100.\ \text{MHz} + k \times f_{alias} \qquad (4)$$

where i, j, and k are all positive integers, including zero. In Figure 8 the ghosts given by Equation 2 are shown via black arrows, those from Equation 3 are shown with the magenta arrows, and the orange arrows shown the ghosts from Equation 4.

2 Possible Data Reduction Methods

It was not possible to determine the strengths of the ghosts relative to the test tone power due to the aliasing of the power and the slight power level instability of the the test tone generator. However, we can say that the strongest ghosts, the ±100 MHz ghosts, are usually at least at a level of −30 dB compared with the test tone. This means that there is a great

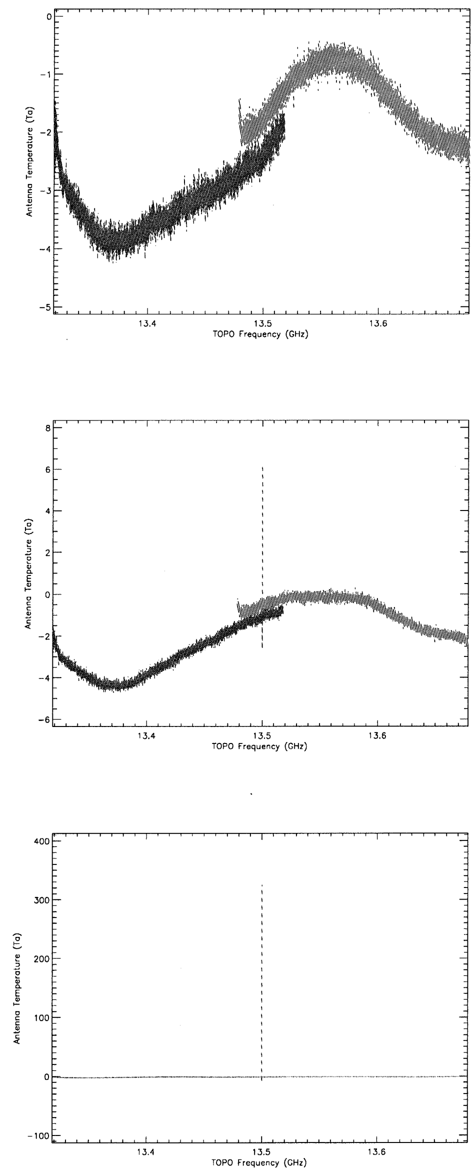

Figure 1: Test Tone signal at: −110 dB (top), −50 dB (middle), −30 dB (bottom).

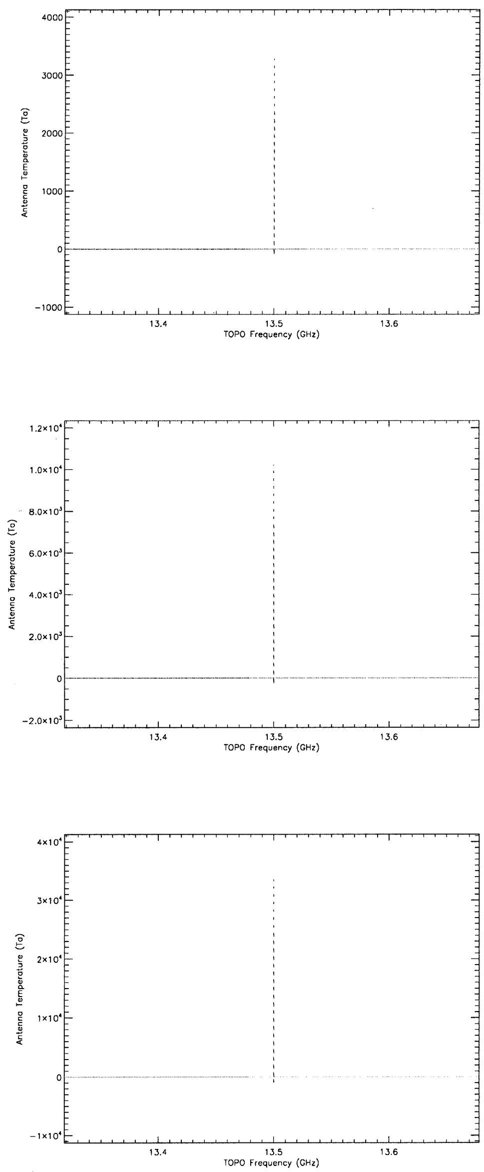

Figure 2: Test Tone signal at: $-20\,\mathrm{dB}$ (top), $-15\,\mathrm{dB}$ (middle), $-10\,\mathrm{dB}$ (bottom).

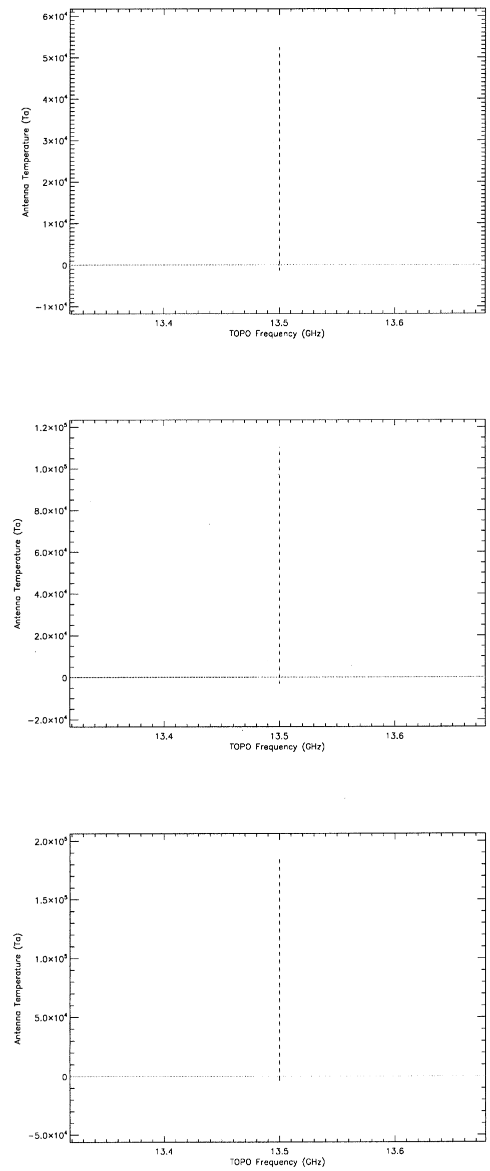

Figure 3: Test Tone signal at: $-8\,\mathrm{dB}$ (top), $-5\,\mathrm{dB}$ (middle), $-3\,\mathrm{dB}$ (bottom).

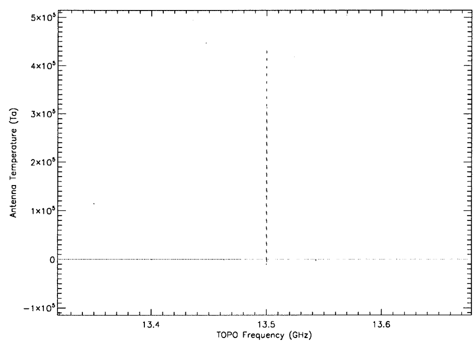

Figure 4: Test Tone signal at 0 dB.

amount of signal to noise in the test tone or the spectral line relative to the signal to noise of the ghosts. This should make it possible to fit any observed spectral line shape derived from the spectrum to the signal at the expected ghosts frequencies to determine the amplitude of the ghosts. These fits could then be removed from the spectra (ala the interferometeric clean method) to produce a spectrum without the ghosts. This may have to be an iterative process depending on the width of the spectral lines.

3 Future Improvements To The IF System

Currently there is ongoing work investigating the use of a new VXCO design. The new VXCO should reduce the strength of the ±100 MHz sideband ghosts once they are installed. Initial tests indicate that the ±100 MHz ghost images can be expected to be −65 dB relative to the spectraline line strength once the new VXCO is put into use. The new VXCO should be available by the end of the summer in 2007.

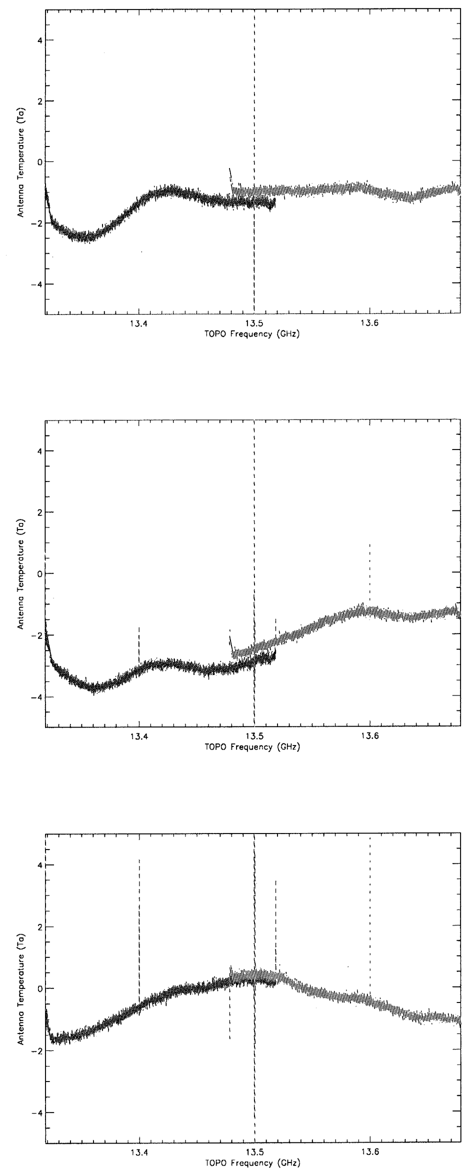

Figure 5: Basesline and ghost images at: −30 dB (top), −20 dB (middle), −15 dB (bottom).

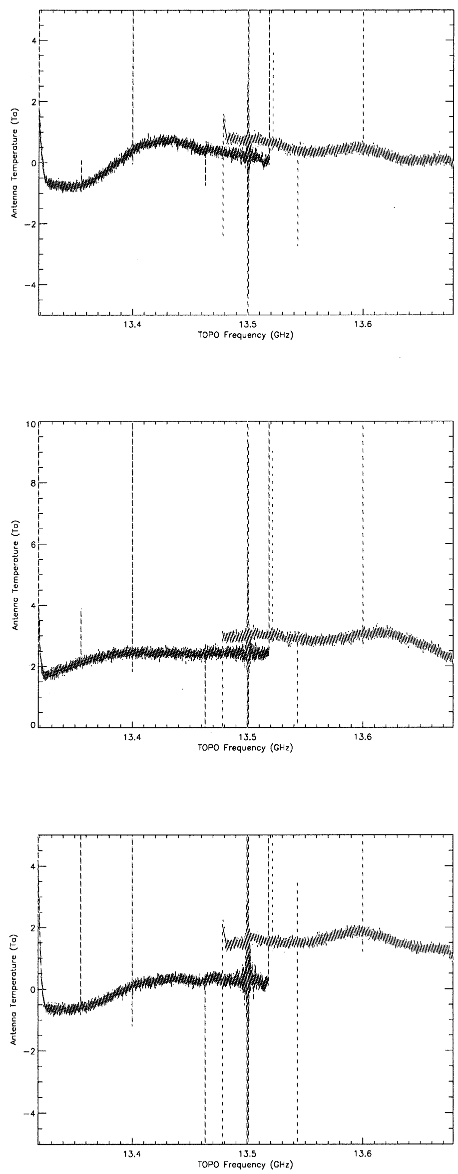

Figure 6: Basesline and ghost images at: $-10\,\mathrm{dB}$ (top), $-8\,\mathrm{dB}$ (middle), $-5\,\mathrm{dB}$ (bottom).

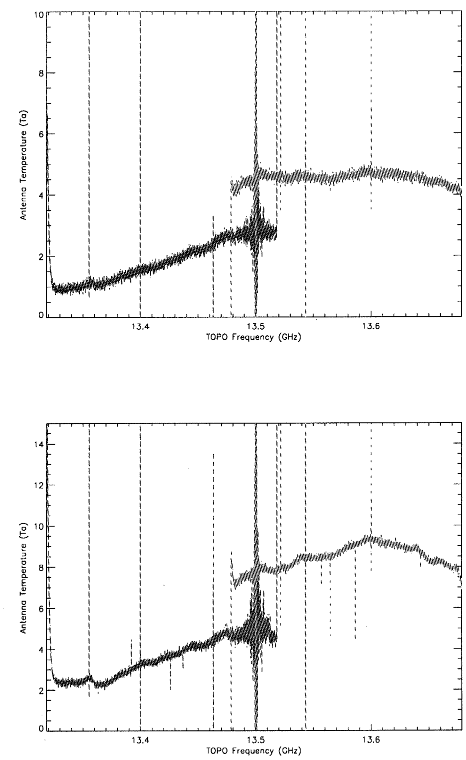

Figure 7: Basesline and ghost images at: $-3\,\mathrm{dB}$ (top), $0\,\mathrm{dB}$ (bottom).

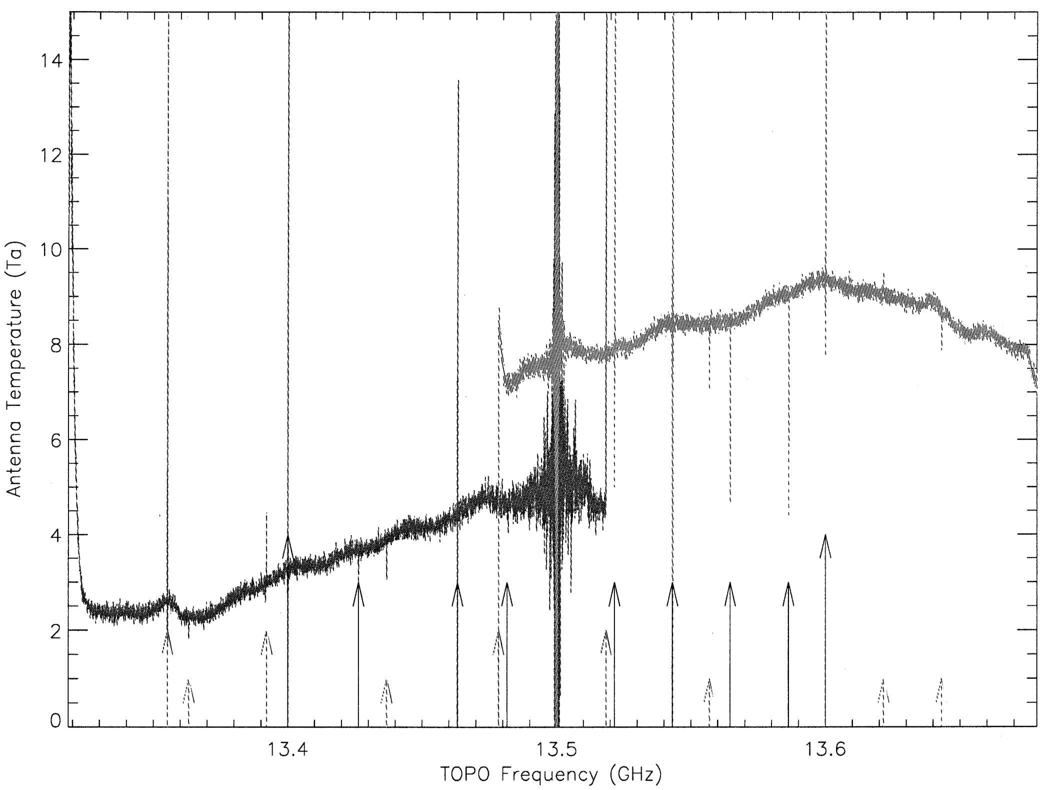

Figure 8: All identified ghosts of the test tone in the 0 dB spectra.