GBT Spectrometer Tests at L-Band

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Summary

This document describes tests with the GBT Spectrometer at L-band on the weekend of 2001 January 13, 14 and 15. This test used the L-band feed over the frequency range 1.0 to 1.8 GHz, the IF rack, fiber optic modems, converter rack, analog filter rack and the GBT spectrometer.

The purpose of this test was to survey the sky for broadband Radio Frequency Interference (RFI) and confirm the proper functioning of the RF/IF chain from the receiver to the spectrometer.

The test provided useful estimates of the RFI environment at L-Band and shows astronomical signals are being collected and transmitted to the equipment room. Although many RFI sources are present in the band, important astronomical observations should be possible as soon as the telescope may pointed.

GBT Setup

For this test, the GBT was parked at Azimuth=1.900 degrees CCW and Elevation 77.840 degrees. The observations started on 2001 January 13 (Saturday) at noon and ended on 2001 January 15 at 2:00 EST (Monday). This test was done in parallel with other tests of the GBT and was occasionally interrupted for software resets and IF electronics work.

Both circular polarizations of the GBT 1-2 GHz receiver were used for this test. The GBT RF and IF chain was controlled using CLEO and the M&C software system, which performed well. All hardware setup was done via interactive use of the CLEO screens. This software functioned well. Neither the Guest Observer (GO) system nor the scan coordinator were used for this test. (Note one minor adverse feature of the software was that during reboot, the entire hardware configuration was reset, which required a manual re-configuration of all hardware. Leaving the hardware unchanged is preferable.)

The first LO was tuned to fixed (topocentric) frequency such that the 1.4 GHz sky frequency was placed at 3.0 GHz in the first IF chain. Optical modems one and three were used with their 3 GHz wide band band filters inserted. The optical levels were adjusted using the "Balance" feature of the CLEO IF rack screen. Only the lasers for modems 1 and 3 were powered.

The converter modules 1 and 5 were used to convert the 1.4 GHz sky frequency at 3.0

GHz IF frequency to 1.2 GHz in the converter rack. LO2 was set to 12300 GHz to achieve this. The IF chain equation was: The negative sign in the "Sky frequency" term

$$\begin{aligned}\text{Spectrometer IF frequency} &= 3.0 - 1.4 + 10.5 - 12.3 - \text{Sky frequency (GHz)}\\ &= 0.2 - \text{Sky frequency GHz}\end{aligned}$$

indicates there is a net side-band flip in the IF chain.

The converter rack attenuators were set to 25 db in order to achieve a ~1.0 Volt power level reading at the analog filter modules.

The focus and pointing checks of the GBT have not yet been performed at L-band, so there is some question concerning the location of any true astronomical sources found during these observations. Pointing and Focus should not strongly effect the systems sensitivity to RFI.

Spectrometer Setup

Only the first quadrant of the GBT spectrometer was used for these tests. The first two high speed (1.6G Hz) samplers were used. The analog filter number 1 input was in its nominal configuration and was connected to left circular polarization. and the output of analog filter 5 was connected to sampler input 2. The spectrometer was set up to produce 2 2048 channel spectra in the wide band mode (800 MHz spectral width). The software configuration of the spectrometer was done via Jeff Hagen's "spec" software. (This program can be used on any Sun Unix computer with the command `spectrometer`. By default the program will display data taken by user "visitor" and can also be used to take additional data. To get additional help, start `spectrometer` and use the HELP button.)

This software was extensively modified by G.L. to allow more control and data processing options. This software runs simultaneously on the MVME167 board internal to the spectrometer and on a Sun Unix (VEGA) workstation. The two processors communicate via a mailbox protocol. The MVME167 processor communicates with the microprocessors internal to the spectrometer, which allows selection of sampler inputs and configuration of the XILINX chips which route the samples to the correlation chips. The micro processors query the lag chips and buffer the data for communication to the MVME167 processor.

The MVME167 receives the lag data along with counts used to calibrate the lag intensities. The MVME167 re-orders the lag data and corrects for the differing integration times for the different correlator chips. The MVME167 processor may optionally van Vleck correct, FFT and hanning filter the lag data, but this feature was not used in these tests.

The MVME167 packs the data into a binary data structure containing a short description of the data and the floating point lags. The MVME167 initiates the communication to the Sun Unix computer upon completion of an integration.

The Sun Unix computer receives the lag data, attaches a time tag and writes the data on the site network disks. During this test, a new feature of the Sun Unix computer was used. The lag data were taken with one second integrations. These data were Van Vleck corrected, hanning filtered and Fourier transformed. After this processing the spectra were put on a data stack (the two polarizations were kept separate). When 25 spectra were obtained for each polarization, the spectra were median filtered on a channel by channel basis to produce a median spectra for each of the two polarizations. Only the median spectra for the two polarizations were archived. This process continued for two and a half days.

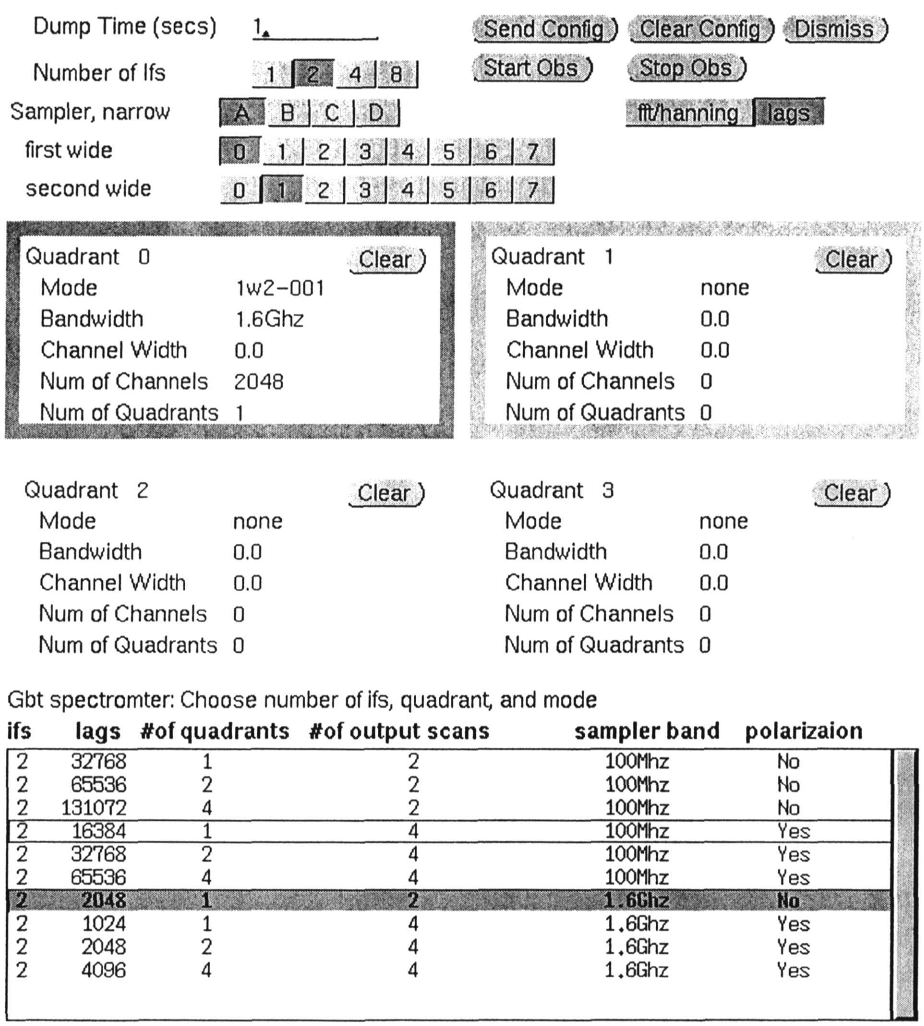

Figure 1. Sun Unix display of the software used to configure the GBT spectrometer for these observations. The 2 sampler, 2048 lag configuration is selected for quadrant one, with 1 second integrations and no Fourier Transforming.

Spectrometer Tests

R. L. constructed a test fixture for the spectrometer which includes a wide band noise source and a frequency generator capable of tuning over the entire input range of the spectrometer samplers. Figure 2 shows data from the noise test fixture (without a narrow-band noise source). Figure 3 shows a "calibrated" spectrum from the noise source. The data are calibrated by taking two spectra with 5 second integrations (separated by 30 seconds). One spectrum is identified as Signal and the other as Reference. The Reference is also used as the calibration signal and an assigned a noise temperature of 1000 K. Ie:

$$CalibratedSignal = T_{Sys} \times \frac{RawSignal - RawReference}{RawReference}$$

Figure 3 shows a noise level of a few Kevin, based on this calibration, which is consistent with the channel bandwidth (800 MHz over 2048 channels) and integration time (5 seconds). Ie. $\Delta T = 1000/sqrt(5 \times 8 \times 10^8/2048) \sim 1000K/1398 \sim 0.7K$. This shows the spectrometer does not generate any significant narrow-band short-term-variable features in the spectrum at the level of better than 1 part in 1000.

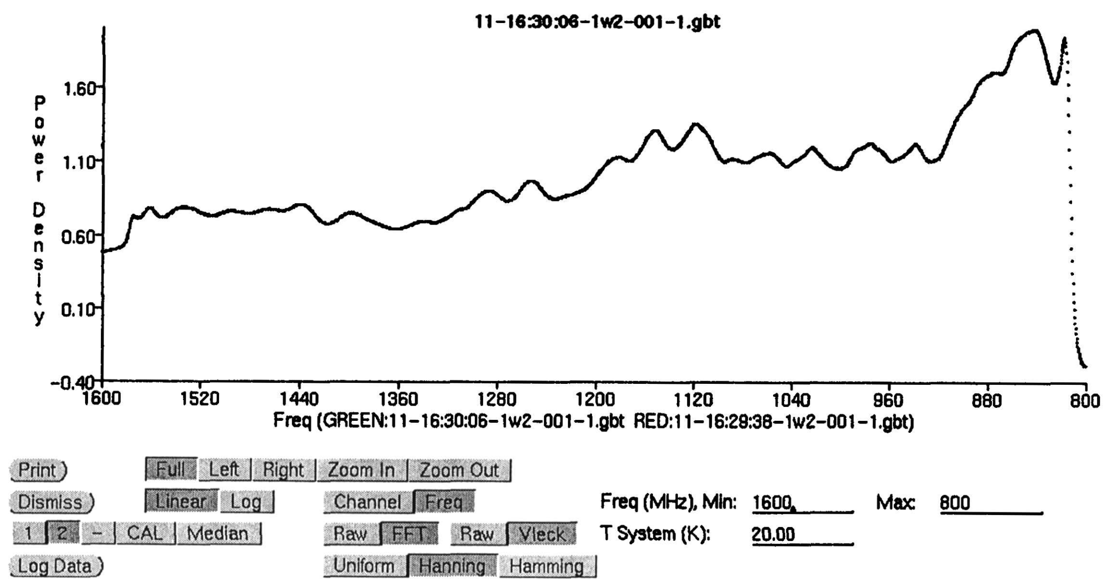

Figure 2. Sun Unix display program for spectra computation and plotting is show. These two spectra are from 5 second integrations with the spectrometer with input from the noise source test fixture. The integrations were separated by 30 seconds. Note the second (red) spectrum almost completely overlaps the first (green) spectrum taken 30 seconds earlier.

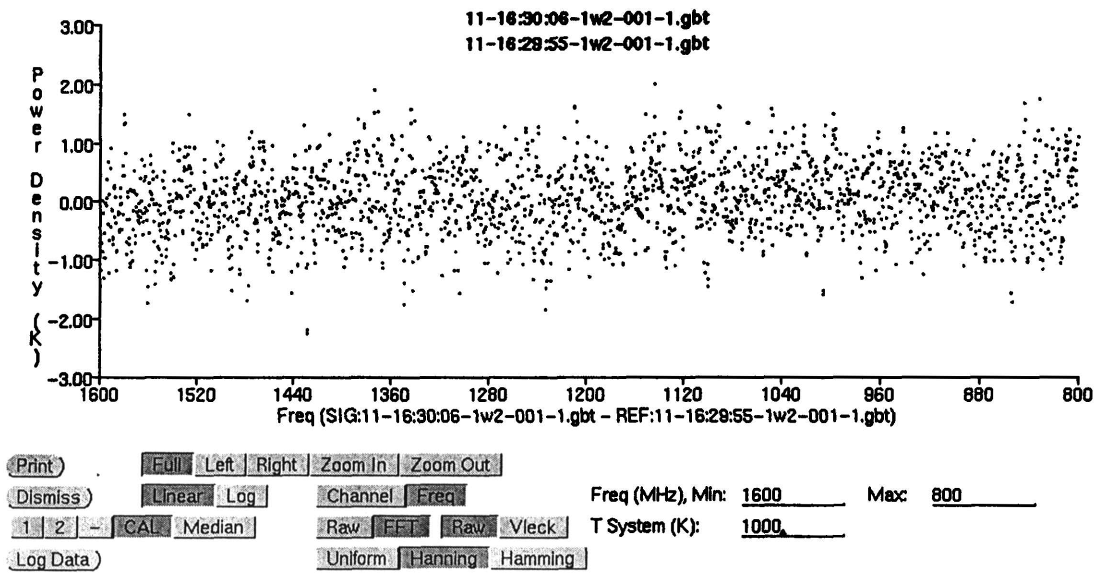

Figure 3. "Calibrated" spectrum of the Spectrometer noise fixture. Note that noise level is approximately 1000th of the signal, as expected.

Comparison of Two Spectra

Two spectra from 2001 January 13 are shown in Figure 4. The spectra were taken at 02h30m (red) and 14h30m EST (green), twelve hours apart. In the 14h30m (green) spectrum, the neutral hydrogen line is visible at 1420 MHz, but both spectra are dominated by RFI. The band pass response of the system is also visible.

Figure 5 shows the "calibrated" spectrum of the 14h30m data, using the 2h30m data as the reference and assuming a 17 K system temperature at 2h30m. Notice the RFI shows up as positive and negative features due to the time-variability of the RFI.

$$Calibrated\ 14h30m\ Spectrum = T_{Sys} \times \frac{Raw\ 14h30m\ Data - Raw\ 02h30m\ Data}{Raw\ 02h30m\ Data}$$

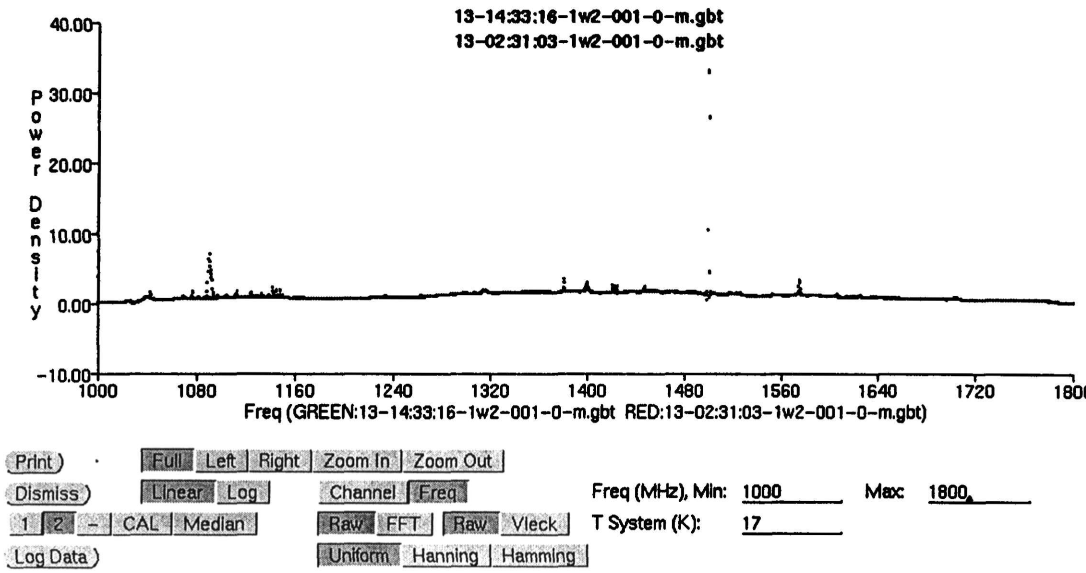

Figure 4. Two spectra from 2001 January 13. The X axis shows the sky frequency from 1.0 to 1.8 GHz. The spectral intensity is in arbitrary units.

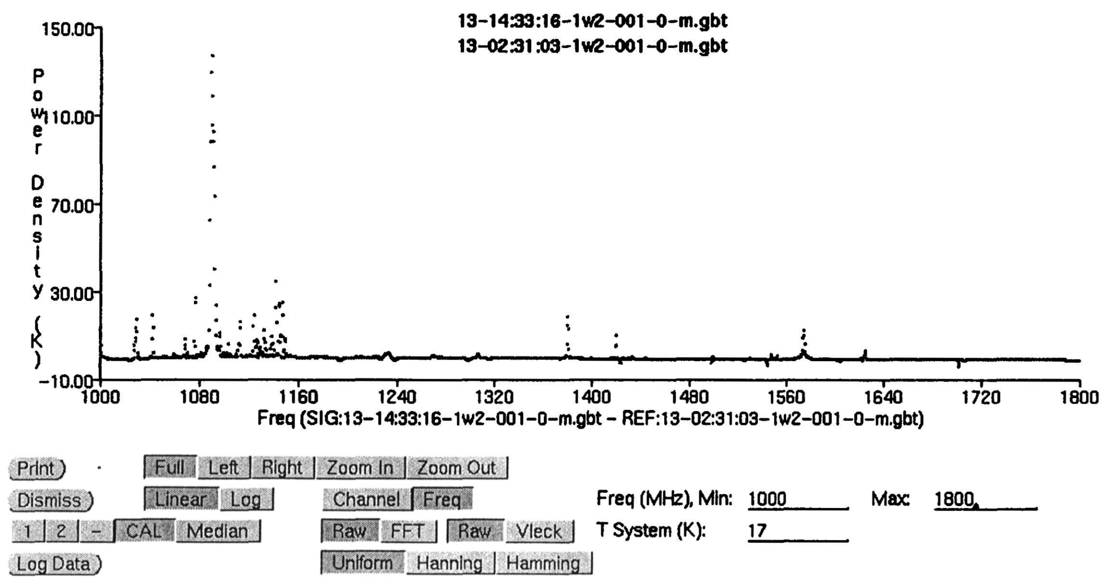

Figure 5. "Calibrated" spectrum from 14h30m on 2001 January 13. The X axis show the sky frequency from 1.0 to 1.8 GHz. The spectral intensity scale is Kelvins.

Data Overview

Lag data were taken continuously for three days. The median filtered spectra were archived in a raw binary format that contained a minimum description of the observational setup. After obtaining these data, experiments were performed and programs written to calibrate and display the data. Individual spectra were examined using the `spectrometer` program, but this proved to slow for analyzing all 8000 spectra obtained. A special purpose program `specImage` was written to read all data, filter, calibrate and grid the data into a FITS format image. The images were analyzed using AIPS.

The `specImage` program performed data calibration in three steps. The first step was to produce a median spectrum from an entire days data, where each frequency channel was separately examined. This single spectrum was the Reference for the entire day, and was assigned the measured system temperature 17 K. The reference spectrum was median filtered in frequency with an 80 MHz width to smooth out the effects of RFI on the calibration. Finally each individual spectrum was divided by the reference and scaled by the system temperature 17 K. This calibration should be good to approximately 20%.

After calibration the spectra were gridded into an 1024 channel by 640 RA rows. All spectra corresponding a single row, (time range ΔRA = 2 minute, 15 second), were averaged to produce the image. At 50.58 degrees declination, the 2m15s RA increment corresponds to an angular distance of 37 arc-minutes, which is coarser than the 7 arcminute beam of the GBT at 1.4 GHz. Finer RA increments were used for tests, but the resulting large images, were difficult to work with.

The images in figures 6, 7 and 8 show the spectral intensity (units are Kelvins/beam) for the three calendar days. The X axis of the plot is topocentric sky frequency (Hz) and the Y axis is the Right Ascension (RA) of the spectra. Since the telescope did not move during the observations, the spectra of astronomical sources should be identical on all days. This allows discrimination between sporadic RFI and true astronomical sources. The intensity is color coded with intensity range -1 K/beam (black) through 0 K/beam (blue) to 3 K/beam (red). The constant Az, El corresponds to a fixed declination, 50.58 degrees, for these observations. The galactic plane is crossed twice during these observations, at RA = 3h20m (65d) and RA = 21h20m (320d). Peaks in the 1420 MHz emission are clearly seen at these times. Only the Right circularly polarized data is presented. The Left circularly polarized data show similar features.

Note the bright wide RFI features due to GPS (1.227, 1.575 GHz), GLONASS (1245, 1602) and Iridium (1625) are always present, but the calibration process of median filtering in channel (frequency) makes these features appear to rise and fall. Since no astronomical features are continuously present, this processing increases the detectability of astronomical sources passing through the beam, while reducing the RFI impact.

Figure 6 shows the data for 2001 January 13. Local midnight for this day corresponds roughly to 7 hours 12 minutes (108 degrees) RA. The observation started at in the afternoon, at RA $\sim$ 288 degrees. The data in this image end at EST midnight. Note

Figure 7 shows the data for 2001 January 14. The for EST midnight are at 109 degrees RA. At approximately 5 PM, the M&C system was rebooted. At this time all the GBT settings were reset to their default configuration. After the reset the attenuation settings in the IF chain were slightly different. This has a larger effect than was expected on the total power calibration, as is shown by the changes in the spectral shape after reset. The observation continued until midnight.

Figure 8 shows the data for 2001 January 15. The observation ended at about 2 PM EST. During this time, some IF work was performed on the L-Band system, which makes the afternoon data unreliable.

Discussion

The monitor data shows a number of RFI features. Most RFI features are continuously present, but have varying intensity. Selected features are listed in Table 1. The Radar altimeter band, 1.05 to 1.150 GHz, has a minimum intensity in the early hours of the morning, so that high redshift HI work might be carried out at that time.

Also note that some RFI seems to be very intermittent and initially were confused with true sources, but the RFI does not exactly repeat each day.

The galactic HI is easily detected at 1.420 GHz at the times the drift scan crossed the galactic plane. However the emission is somewhat fainter than expected. It was hoped that these observations would yield detection of OH/IR stars which have maser emission at 1.612, 1665, 1667 and 1720 GHz (table 2), however none were detected. Near these frequencies RFI is present.

Several continuum sources are detected in the observations, which are distinguished by short term increases in the overall intensity of the spectra, particularly at the low frequency end of the spectra. The continuum sources repeat daily, as expected.

The effects of the IF chain attenuator settings on spectral intensity should be examined in more detail.

In conclusion, a large part of L-band range is free of RFI, particularly above 1.7 GHz, which may not have been appreciated before. There remain a large number of RFI sources at lower frequencies. A number of the RFI sources in the protected band may be local to GB, and their source should be found and suppressed.

Further astronomical work requires careful focus and pointing checks. The search for masers and other narrow band emission will be made easier by use of the higher resolution spectrometer modes.

Frequency Minimum (GHz)	Frequency Maximum (GHz)	Red Shift (z)	Source Type	Note
1.000	1.030	0.296-0.278		Very little gain
1.042	1.150	0.278-0.183	Radar Altimeters	Minimum 11 PM to 7 AM
1.220	1.234	0.141-0.131	GPS	L2 = 1227.60
1.242	1.247	0.126-0.122	GLONASS	$1246 + k \times 0.44$ MHz
1.256	1.256	0.116	Radar New Bedford, VA	Sweep every 12 sec.
1.292	1.292	0.090	Radar New Bedford, VA	Sweep every 12 sec.
1.311	1.375	0.077-0.032		Periodic Narrow lines
1.381	1.381	0.028	GPS house keeping	Intermittent
1.417	1.417	0.002		
1.424	1.424			
1.426	1.426			
1.435	1.435			
1.447	1.447			
1.499	1.501		Laser Range Finder	
1.515	1.530			
1.548	1.548		INMAR SAT ?	
1.552	1.555		INMAR SAT ?	
1.557	1.557			
1.570	1.580		GPS	L1 = 1575.42 MHz
1.602	1.609		GLONASS	$1602 + k \times 0.56$ MHz
1.621	1.627		IRIDIUM	
1.681	1.686		GEOS SAT ?	
1.691	1.691		GEOS SAT ?	
1.699	1.710		NOAA WX SAT?	
1.724	1.726			

Table 1: Selected RFI sources at L-Band. The redshift column refers to the redshift expected for a source radiating at the neutral hydrogen rest frequency.

Frequency (GHz)	Atom / Molecule Name	Transition
1.420406	H_I	Hyperfine
1.4732	N_{II}	$^3P_1 -^3 P_0$
1.612231	OH	$^2\Pi_{3/2}F = 1 - 2$
1.665400	OH	$^2\Pi_{3/2}F = 1 - 1$
1.667358	OH	$^2\Pi_{3/2}F = 2 - 2$
1.720529	OH	$^2\Pi_{3/2}F = 2 - 1$

Table 2: Selected Astronomical Line sources at L-Band.

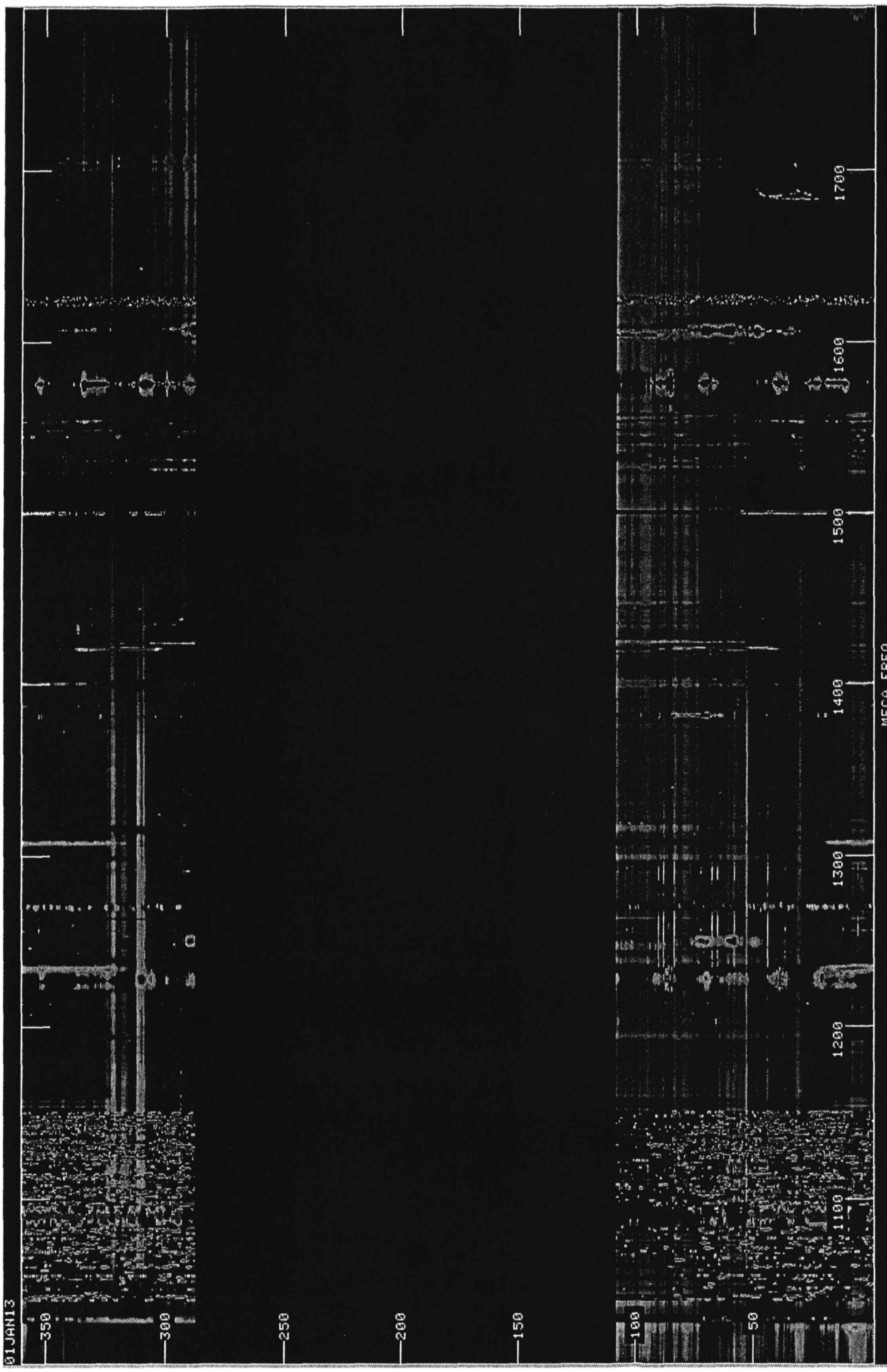

Figure 6. Spectral intensity for 2001 January 13, as frequency (X axis), range 1.0 to 1.8 GHz and Right Ascension (Y Axis) J2000 range 0 to 360 degrees.

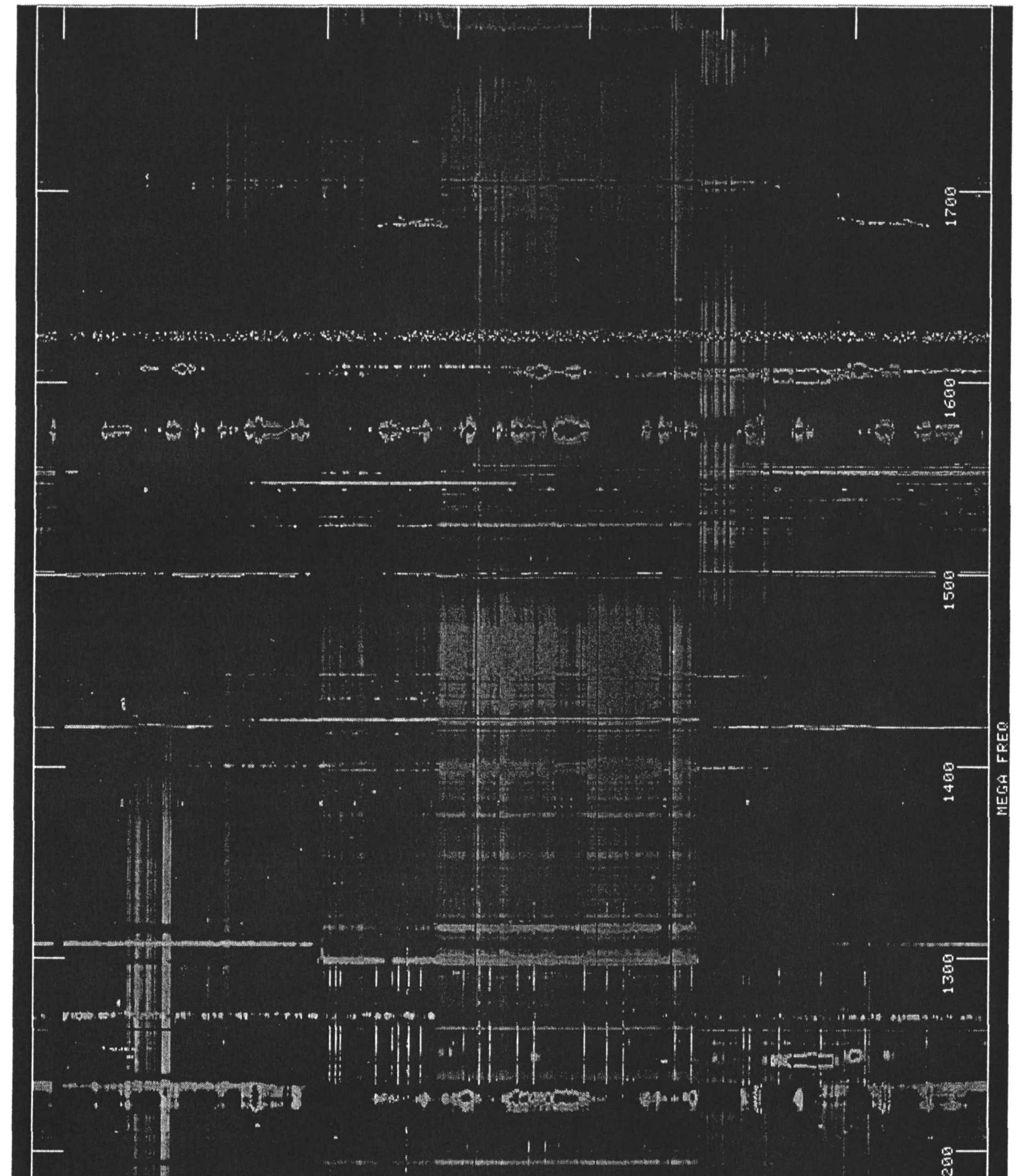

Figure 7. Spectral intensity for 2001 January 14, as frequency (X axis), range 1.0 to 1.8 GHz and Right Ascension (Y Axis) J2000 range 0 to 360 degrees.

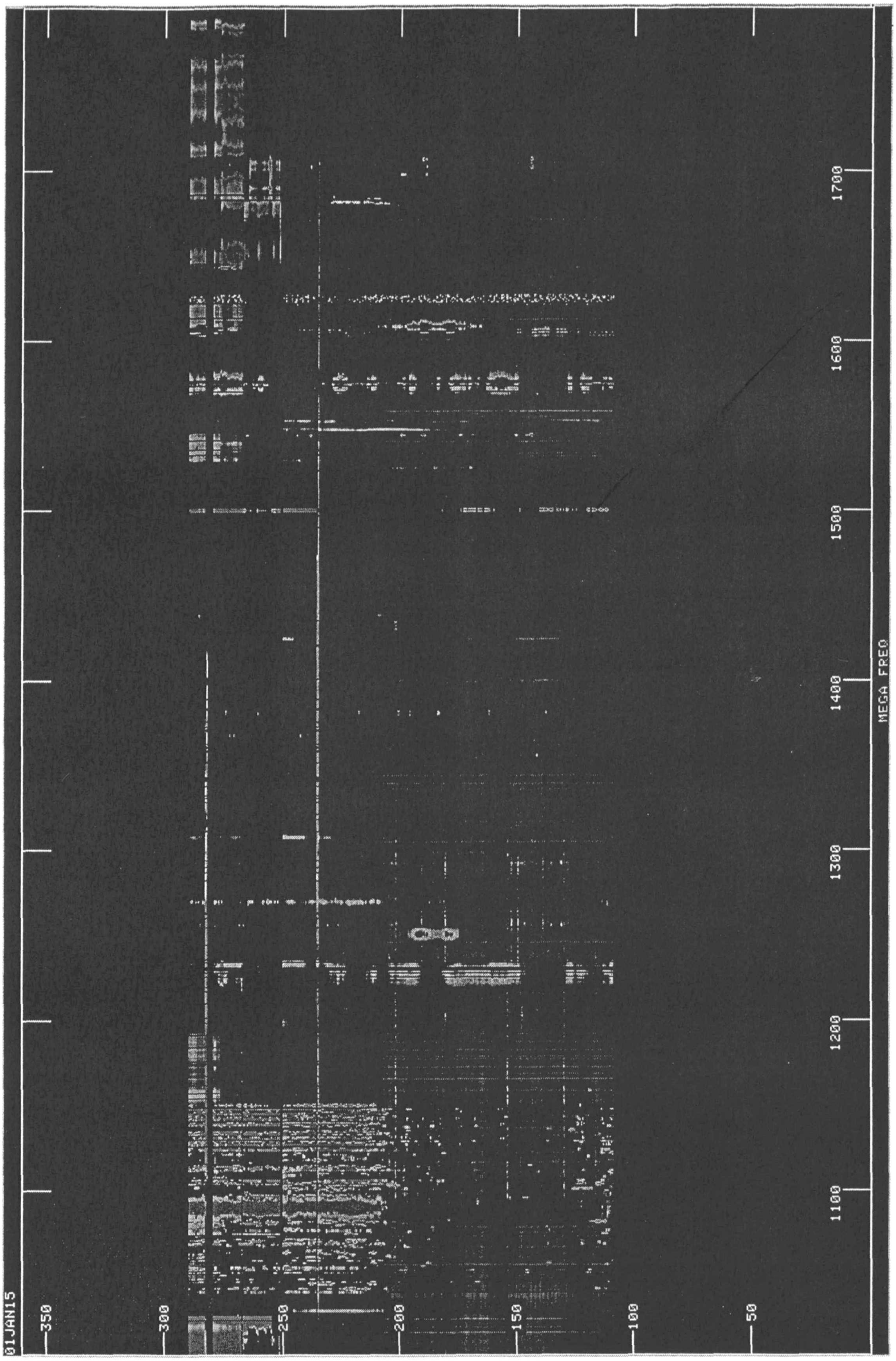

Figure 8. Spectral intensity for 2001 January 15, as frequency (X axis), range 1.0 to 1.8 GHz and Right Ascension (Y Axis) J2000 range 0 to 360 degrees.