L-band Continuum Source Spectra at Beam Half-Power Points
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Introduction

We are studying the possibility of calibrating the frequency dependence of the GBT front-ends' gain and noise temperature using relatively strong continuum radio sources. As part of this study we'd like to know whether the transfer characteristics of the feed-OMT-LNA combination has any dependence on the continuum source's position in the antenna beam. Any beam-position dependency will affect the accuracy of calibration of extended continuum sources and the accuracy with which the beam must be pointed to transfer point source calibrations.

In this session we measured the spectra of the continuum radio source, 1042+1203 (S = 3.31 Jy) at beam center and at roughly the north, south, east, and west half-power points while following the source for about five and a half hours.

Setup

The L-band linearly polarized receiver channels X and Y were connected to fibers 1 and 3, respectively. The IF rack filters were set to 2960 to 3040 MHz passband, and the analog filter rack outputs were set to 50 to 100 MHz passband. The spectrometer was set up for 50 MHz bandwidth, 9-level, 2 samplers, 1 quadrant, 8192 channels per IF configuration (1N2-0A-50-9). The signal path connections are shown in Table 1. An integration time of 30 seconds was used for all measurements. The sky center frequency was 1405 MHz. All spectra were smoothed by truncating the ACF at 2048 lags and Hanning convolving the resulting spectra.

The Measurements

Table 2 lists the telescope beam positions for the series of observations. Each line in this table corresponds to an on-off scan pair, where the 'off' position was 5 min and 30 sec east of the 'on' position.

Table 1: IF Rack to Spectrometer Connection Matrix

Rcvr	OR	CM	SF	Sampler
X	1	1	1	0
Y	3	5	5	4

Table 2: Telescope positions at the beginning of the continuum source, 1042+1203, on-off scan pairs. The "Offset" designations North, South, East, and West refer to the beam center being 4 arcminutes offset in that direction.

Offset	Scans	UTC	Azimuth	Elevation
Center	1-2	07:17:38	120.2	48.95
North	3-4	07:28:22	123.1	50.78
Center	5-6	07:39:08	126.4	52.47
South	7-8	07:49:55	129.9	54.08
Center	9-10	08:00:43	133.5	55.72
East	11-12	08:11:32	137.3	57.17
Center	13-14	08:22:23	141.7	58.59
West	15-16	08:33:16	146.4	59.87
Center	17-18	08:44:08	151.2	60.94
North	19-20	08:55:02	156.4	61.95
Center	21-22	09:05:58	161.9	62.65
South	23-24	09:16:54	167.7	63.14
Center	25-26	09:27:52	173.6	63.55
East	27-28	09:38:49	179.5	63.68
Center	29-30	09:49:47	185.7	63.58
West	31-32	10:00:45	191.8	63.24
Center	33-34	10:11:41	197.4	62.71
North	35-36	10:22:37	203.0	62.05
Center	37-38	10:33:32	208.2	61.05
South	39-40	10:44:25	213.1	59.90
Center	41-42	10:55:17	217.7	58.72
East	43-44	11:06:08	221.9	57.39
Center	45-46	11:16:58	226.0	55.91
West	47-48	11:27:46	229.8	54.27
Center	49-50	11:38:33	233.2	52.66
North	51-52	11:49:19	236.5	50.98
Center	53-54	12:00:04	239.4	49.15
South	55-56	12:10:48	242.2	47.26
Center	57-58	12:21:32	244.9	45.42
East	59-60	12:32:14	247.3	43.55
Center	61-62	12:42:56	249.8	41.55

Continuum Source Spectrum

The basic data used in this analysis are shown in Figures 1 and 2. Figure 1 shows the spectral power density difference between the 'on' and 'off' beam positions on the sky for 1042+1203 in the center of the GBT beam. This spectrum is the product of the source power density and the total gain of the telescope system from the antenna aperture to the spectrometer sampler. All receiver and antenna noise, aside from the radio source and source confusion, should cancel out in this spectrum.

Figure 2 shows the ratio of spectral power density from the radio source, 1042+1203, to the power density from the telescope system when looking at the 'off' position on the sky, i.e., (on - off) / off. This is essentially T_{source}/T_{sys}, where T_{sys} is referred to the aperture plane of the telescope. It includes all of the telescope system noise contributions and the system gain, but not all system noise components have the same frequency dependence. For example, the LNA noise does not contain the frequency dependence of the antenna, feed, and OMT transfer functions. This makes the interpretation of T_{source}/T_{sys} very tricky because of the complex combination of system gain and noise terms, but, to first order, it does remove the the frequency dependent gain terms of the filters and amplifiers following the RF amplifiers.

Temporal Variations in Continuum Source Spectra

Figures 3 through 6 show the variations in the 1042+1203 continuum source spectrum with time over the five-hour observing run listed in Table 2. These figures display the ratio of (on - off) / off or (on - off) spectra between scan pair 1/2 and a later scan pair with the source in the center of the beam. The source 1042+1203 is about 5% linearly polarized so the spectra were corrected for linearly polarized feed parallactic angle for the center of the spectral band. The spectrum ratios are not perfect, but they drift remarkably little over this time interval. What drift there is is not terribly smooth. In channel Y there seems to have been a fairly abrupt change in the spectrum shape midway through the run. At least in channel Y, the ratios of (on - off) spectra are generally better than the (on - off) / off ratios.

Offset Beam Changes in Continuum Source Spectra

Figures 7 through 10 show the 1042+1203 continuum source spectrum ratios between the source at the center of the beam and at each of the four cardinal beam offset directions. The 4-arcminute offsets are slightly less than half of a half-power beamwidth. A slope in these spectral ratios is expected because of the changing beamwidth with frequency. The expected slopes are plotted in the figures, and they match the measurements quite well.

There is an interesting difference between the east-west offset spectra and the north-south offset spectra. The north-south offset spectral ratios show considerable ripple with a period of about 2.3 MHz. The Fourier transform of one

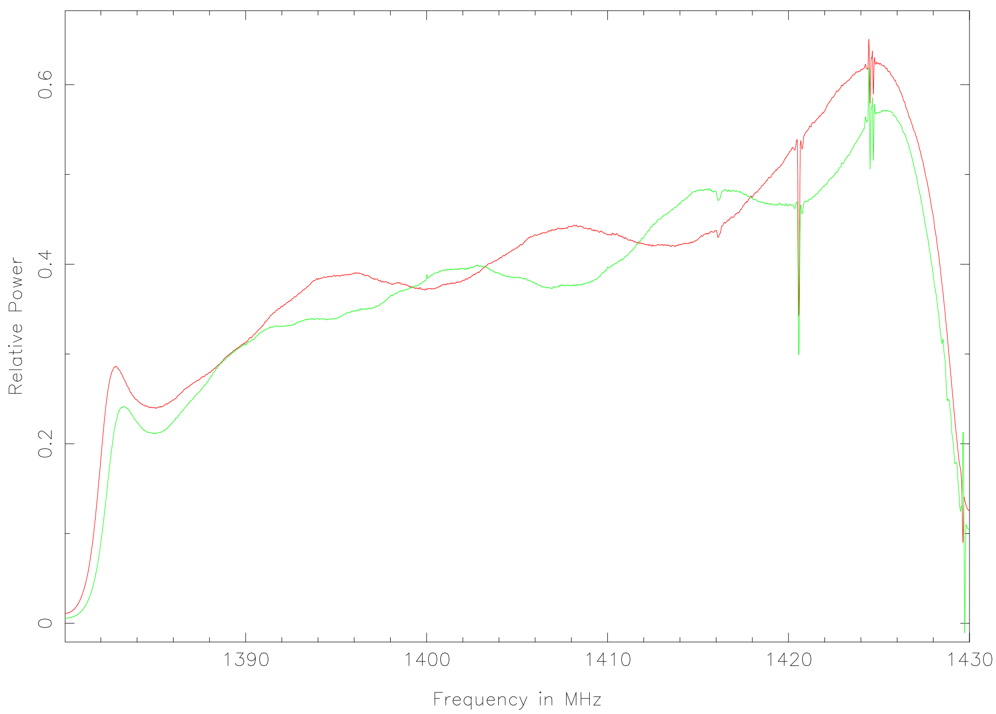

Figure 1: Scans 1 and 2, spectral power density difference between the 'on' and 'off' beam positions on the sky for 1042+1203 in the center of the GBT beam. The vertical scale is in arbitrary linear power units. The red curve is receiver channel X, and the green curve is channel Y.

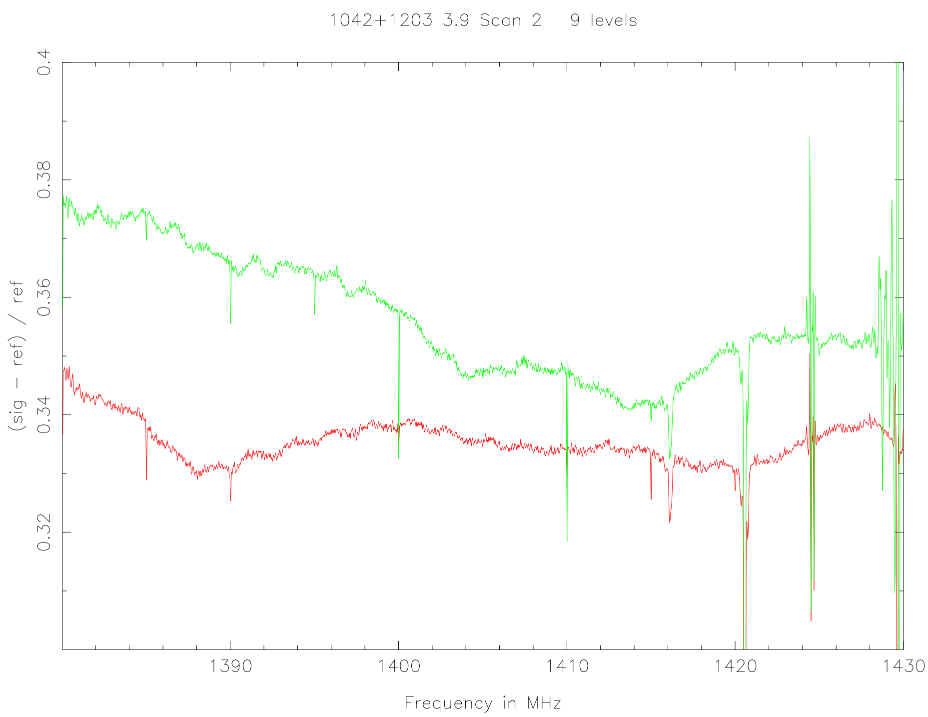

Figure 2: Scans 1 and 2, Tsrc/Tsys spectra for 1042+1203 in the center of the GBT beam. The red curve is receiver channel X, and the green curve is channel Y.

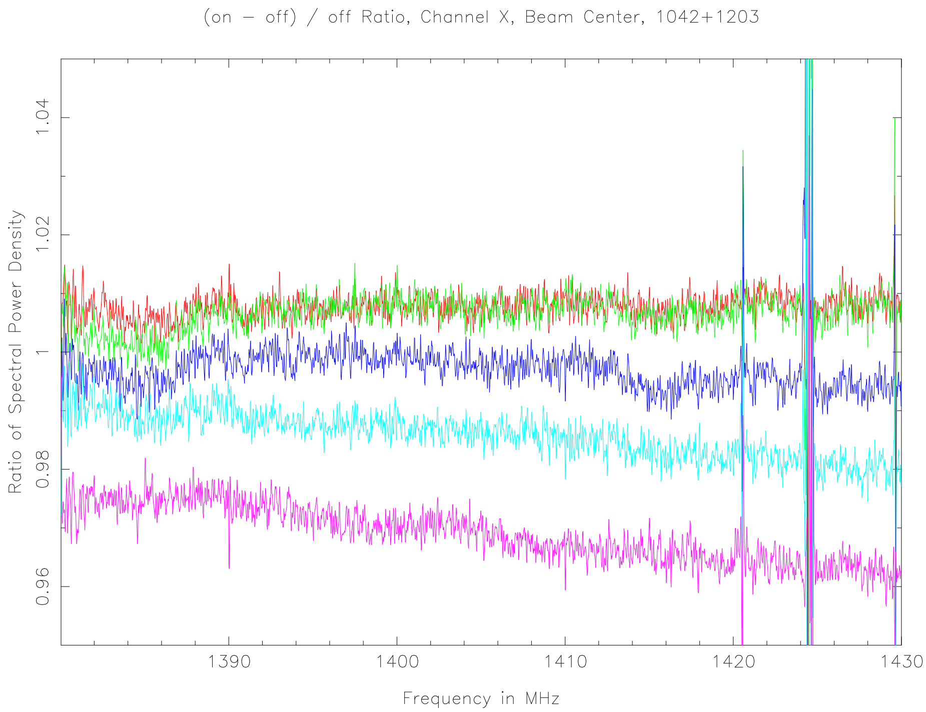

Figure 3: Scans 1, 2, 9, 10, 21, 22, 33, 34, 45, 46, 57, and 58; receiver channel X ratios of scanN / scan1 of (on - off) / off spectra with 1042+1203 in the center of the beam in the 'on' scans. The red, green, dark blue, blue-green, and violet lines are the spectral rations of scan pairs 9/10, 21/22, 33/34, 45/46, and 57/58 to scan pair 1/2 with time separations of 43, 108, 174, 239, and 304 minutes, respectively. The source flux density was corrected for changing linear polarization response as the parallactic angle of the feed changed with time.

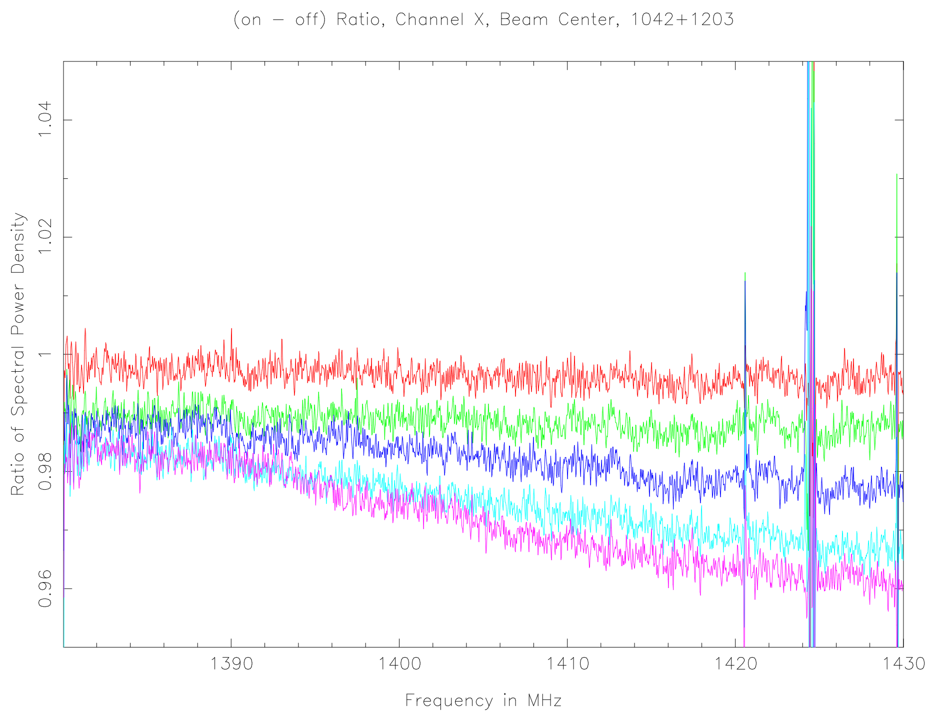

Figure 4: Scans 1, 2, 9, 10, 21, 22, 33, 34, 45, 46, 57, and 58; receiver channel X ratios of scanN / scan1 of (on - off) spectra with 1042+1203 in the center of the beam in the 'on' scans. The red, green, dark blue, blue-green, and violet lines are the spectral rations of scan pairs 9/10, 21/22, 33/34, 45/46, and 57/58 to scan pair 1/2 with time separations of 43, 108, 174, 239, and 304 minutes, respectively. The source flux density was corrected for changing linear polarization response as the parallactic angle of the feed changed with time.

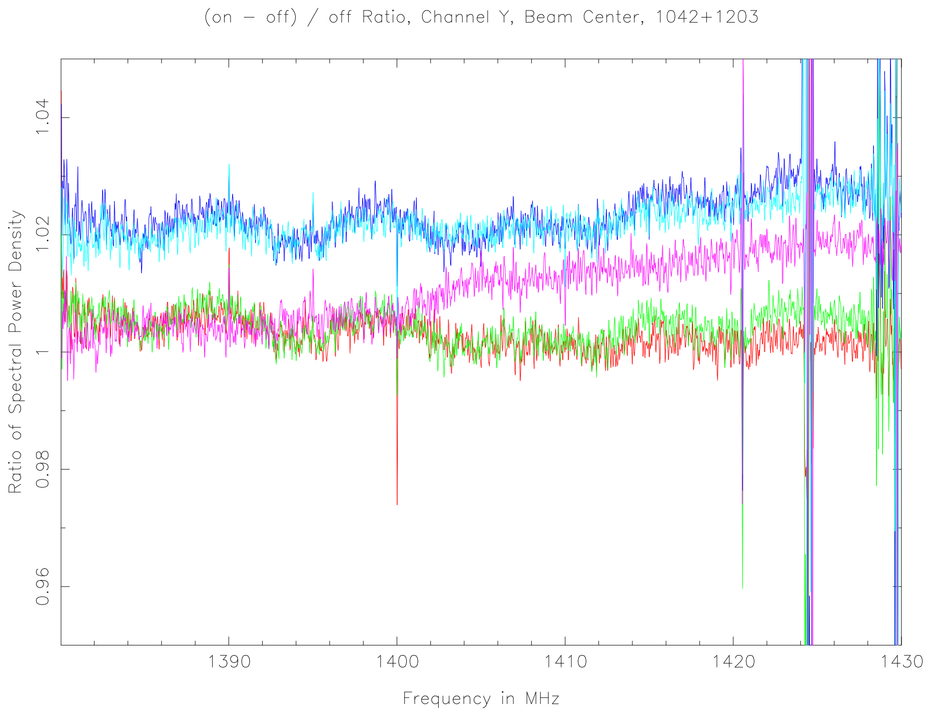

Figure 5: Scans 1, 2, 9, 10, 21, 22, 33, 34, 45, 46, 57, and 58; receiver channel Y ratios of scanN / scan1 of (on - off) / off spectra with 1042+1203 in the center of the beam in the 'on' scans. The red, green, dark blue, blue-green, and violet lines are the spectral rations of scan pairs 9/10, 21/22, 33/34, 45/46, and 57/58 to scan pair 1/2 with time separations of 43, 108, 174, 239, and 304 minutes, respectively. The source flux density was corrected for changing linear polarization response as the parallactic angle of the feed changed with time.

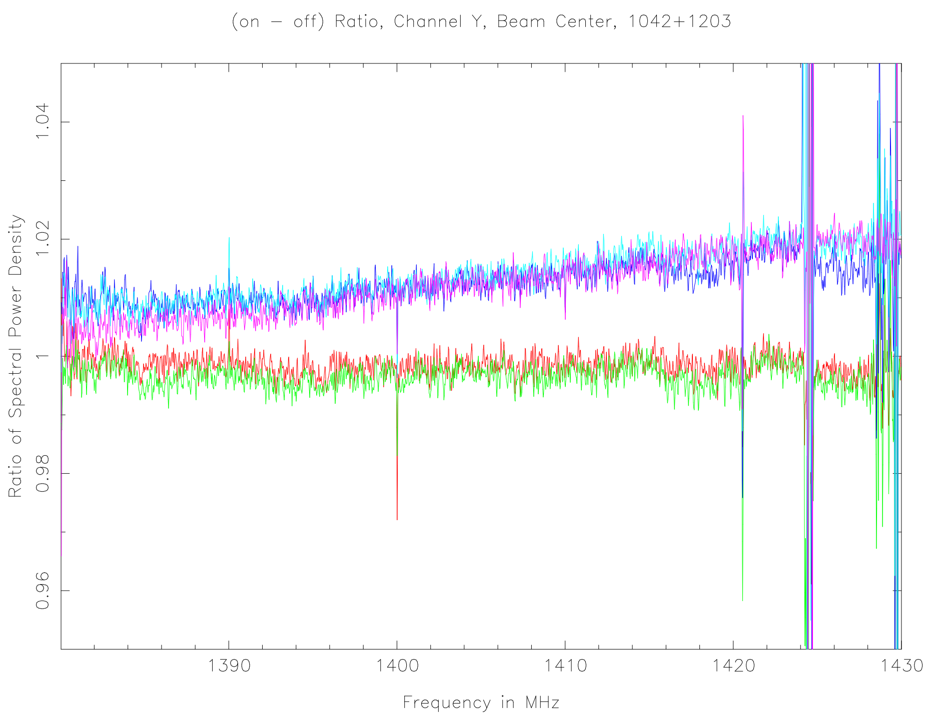

Figure 6: Scans 1, 2, 9, 10, 21, 22, 33, 34, 45, 46, 57, and 58; receiver channel Y ratios of scanN / scan1 of (on - off) spectra with 1042+1203 in the center of the beam in the 'on' scans. The red, green, dark blue, blue-green, and violet lines are the spectral rations of scan pairs 9/10, 21/22, 33/34, 45/46, and 57/58 to scan pair 1/2 with time separations of 43, 108, 174, 239, and 304 minutes, respectively. The source flux density was corrected for changing linear polarization response as the parallactic angle of the feed changed with time.

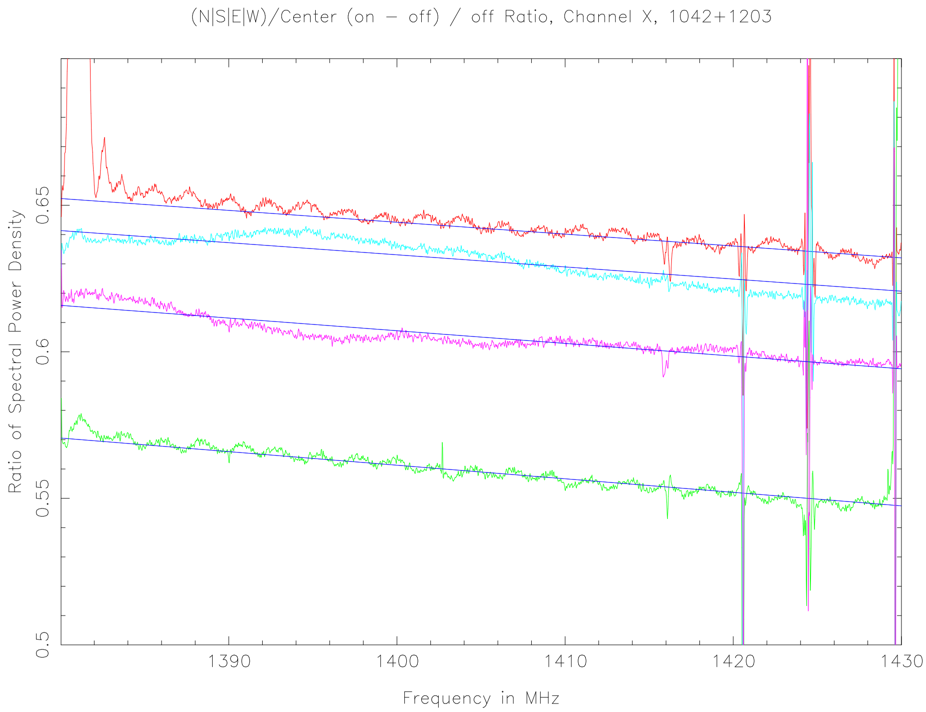

Figure 7: Scans 1-60; receiver channel X averages of offset to center-beam source spectrum ratios of (on - off) / off spectra of 1042+1203. The red, green, blue-green, and violet lines correspond to 4-arcminute north, south, east, and west beam offsets. The blue lines show the expected ratio slope due to changing beam size with frequency.

of these spectra displayed in Figure 11 shows that this ripple is very likely due to the extra reflection of the continuum source radiation between the subreflector and main reflector, which has a one-way distance of 65 meters. Since the radio source was observed more or less symmetrically around transit, the north-south offset was roughly in the elevation direction, and the east-west offset was, on average, in the azimuthal direction. A plausible explanation of the spectral differences between the east-west an north-south offsets is that the subreflector/main reflector specular points move onto and off the edge of these reflectors when the telescope is moved in the elevation direction.

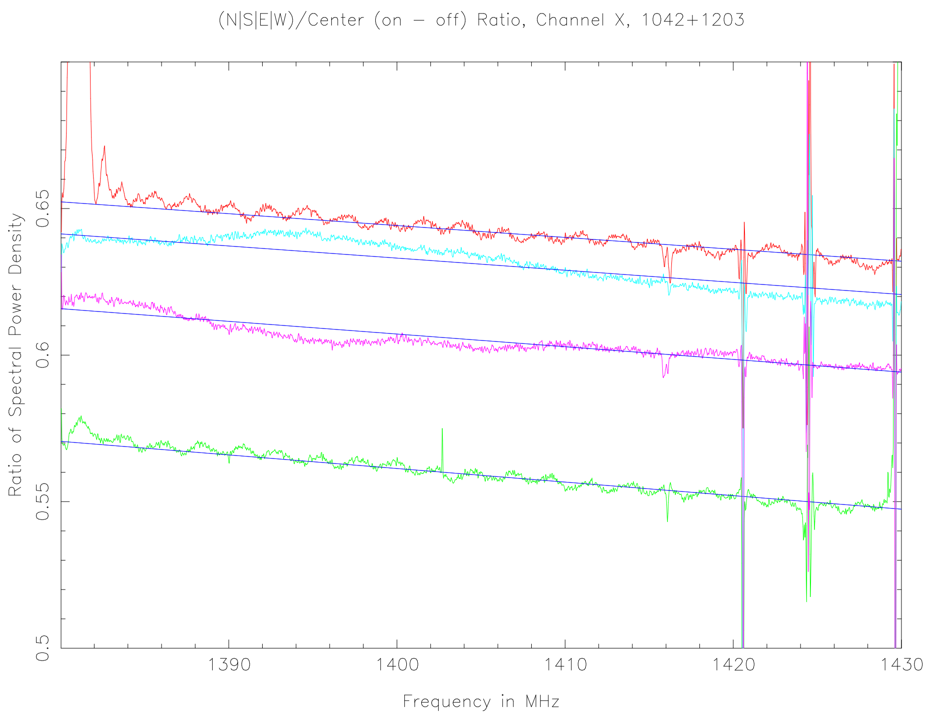

Figure 8: Scans 1-60; receiver channel X averages of offset to center-beam source spectrum ratios of (on - off) spectra of 1042+1203. The red, green, blue-green, and violet lines correspond to 4-arcminute north, south, east, and west beam offsets. The blue lines show the expected ratio slope due to changing beam size with frequency.

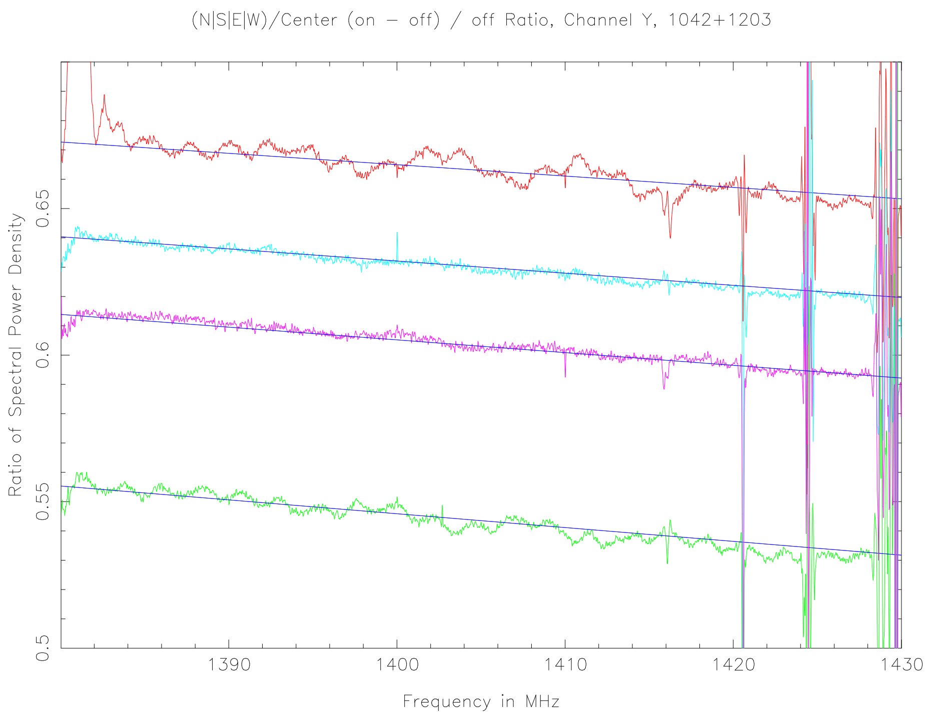

Figure 9: Scans 1-60; receiver channel Y averages of offset to center-beam source spectrum ratios of (on - off) / off spectra of 1042+1203. The red, green blue-green, and violet lines correspond to 4-arcminute north, south, east, and west beam offsets. The blue lines show the expected ratio slope due to changing beam size with frequency.

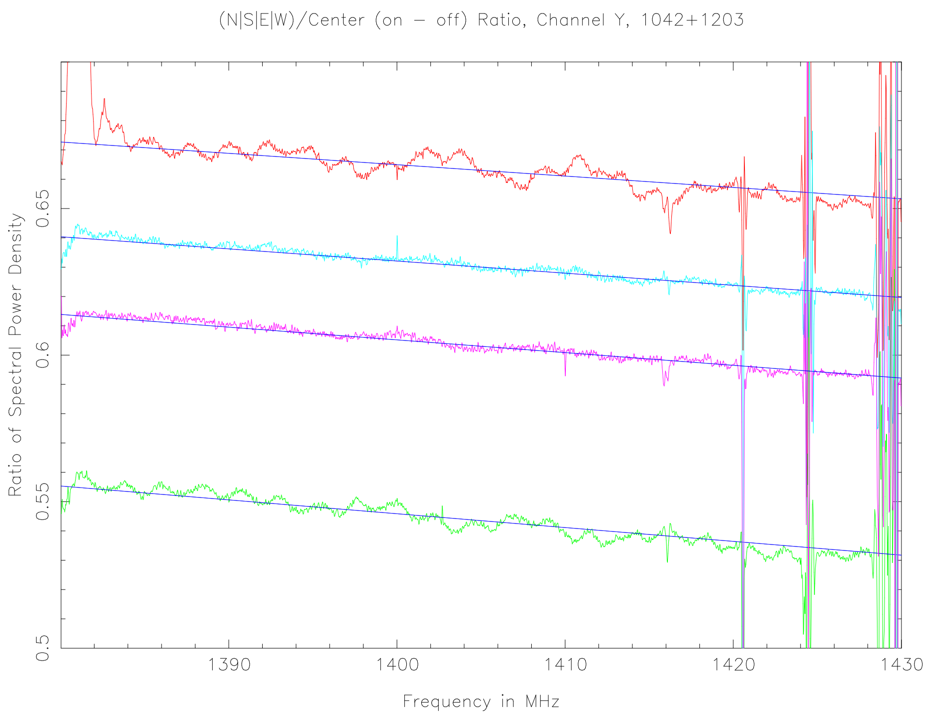

Figure 10: Scans 1-60; receiver channel Y averages of offset to center-beam source spectrum ratios of (on - off) spectra of 1042+1203. The red, green, blue-green, and violet lines correspond to 4-arcminute north, south, east, and west beam offsets. The blue lines show the expected ratio slope due to changing beam size with frequency.

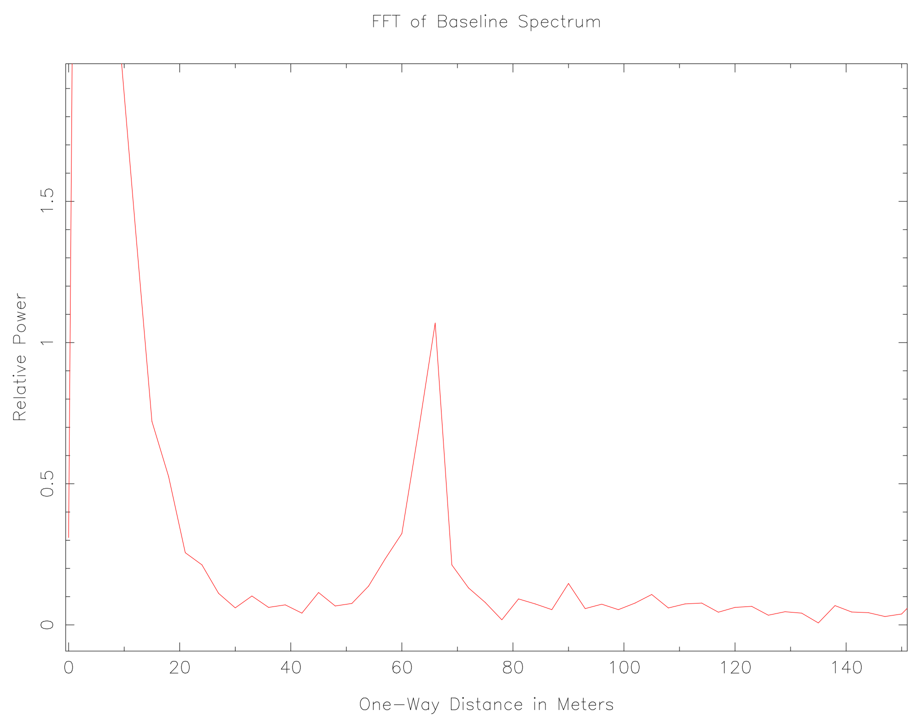

Figure 11: Scans 5-8, 21-24, 37-40, and 53-56; Fourier transform of the south/center beam positions for the receiver channel X (on - off) spectra, which is shown as the green line in Figure 8. The horizontal axis is the one-way distance of a reflection point that can cause the corresponding ripple period in the spectrum. The spike at 65 meters corresponds to the distance between the main reflector and subreflector surfaces nearest the paraboloid axis.