Investigate Optical Fiber Modulator Stability Project TBASEDSB030110, 10 January 2003

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Introduction

The external optical fiber modulators produce a 2.4 MHz ripple in total power spectra with amplitudes of $\sim$ 25 dB relative to the total noise spectral density. The spread in ripple amplitude is about 5 dB between different modulators and about 8 dB from IF frequencies 1.5–6 GHz (see TBASEDSB021211). The new external modulator is down in amplitude by about 20 dB but still exists. The questions that remain are how stable is the ripple with time, with environmental conditions, with different input power levels, etc?

Here we investigate the stablity of the ripple using the IF noise source as input to the optical driver modules (ODMs). Only the even ODMs were tested for a continuous period of $\sim$ 200 minutes. The telescope was stationary except for two time periods where the antenna was moved from survival to snow dump and then back. The IF input level was not changed during the test. The connection matrix between the IF rack and the spectrometer is shown in Table 1. The spectrometer was configured in four bank mode to produce redundancy in the data. Although only ODM 6 had two good channels because of problems in the spectrometer. The spectrometer integration time was 30 seconds. ODM 2 was an original external modulator; ODM 4 was out of service; ODM 6 was a new external modulator; and ODM 8 was a direct modulator.

Table 1: IF Rack to Spectrometer Connection Matrix

AC Bank	Rcvr	ODM	CM	SF	AC Sampler	Comment
1	1	2	1	1	0	
1	2	4	5	5	1	ODM out of service
2	1	6	10	2	2	
2	2	8	14	6	3	100 MHz comb
3	1	2	3	3	4	ACF step at channel 1024 (weak)
3	2	4	7	7	5	ODM out of service
4	1	6	12	4	6	
4	2	8	16	8	7	

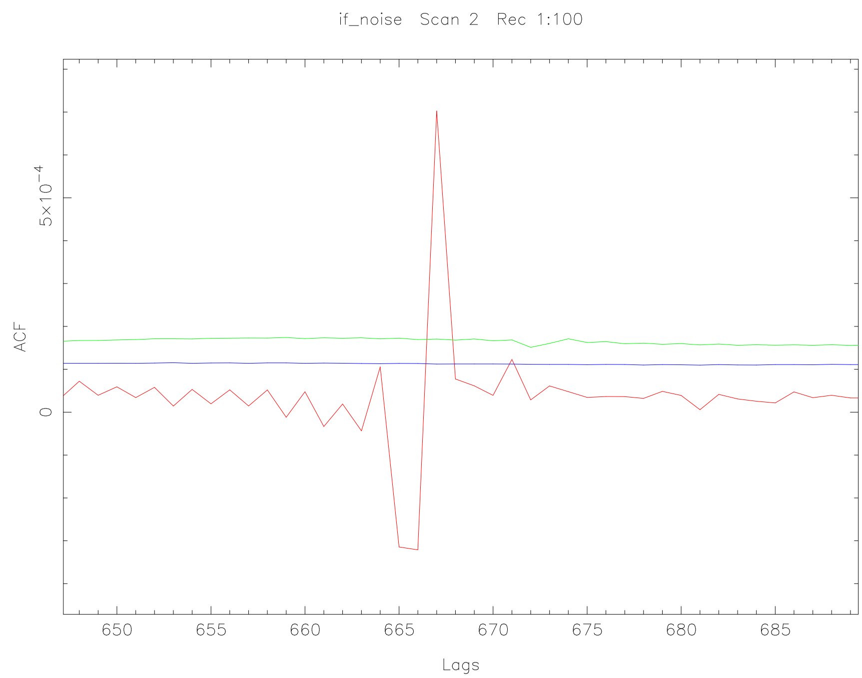


Figure 1: Auto-correlation function for ODM 2 (red), ODM 6 (green), and ODM 8 (blue). Records 1–100 have been averaged for scan 2.

Stability of 2.4 MHz Ripple

Figure 1 shows the average ACF for the first 100 records (50 minutes) for ODM 2, 6, and 8. The ripple amplitude is reduced in ODM 6 relative to ODM 2 by about 17 dB. The stability of the ripple with time is assessed by calculating (Record N–Record 1)/Record 1. The resulting spectrum is Fourier transformed for inspection of the 2.4 MHz ripple. The sensitivity is based on only 30 seconds of integration time.

The results are shown in Figures 2–5. For each ODM two sequences of N were used. The first was N = 2, 10, 20, 30, 40, and 50 comparing data as much as 25 minutes apart. The second was N=2, 50, 100, 200, 300, and 400 comparing data as much as 200 minutes apart. The 2.4 MHz ripple is only detected in the processed data for ODM 2 after about 15 minutes (N=30). The power in the Fourier component for the 2.4 MHz ripple does not get any larger than ~ 0.18 which corresponds to an rms of $\sim 0.02\%$ of the system temperature. (A synthetic sine wave with a peak-to-peak amplitude of 0.01—1% of the system temperature—produces an Fourier component with power 3.7. This corresponds to an rms of $0.01/2.8 = 0.0036$ or 0.36% of the system temperature.) Notice that the power in the 2.4 MHz ripple increases with time from N = 2 to 50, but then decreases from N = 50 to 100.

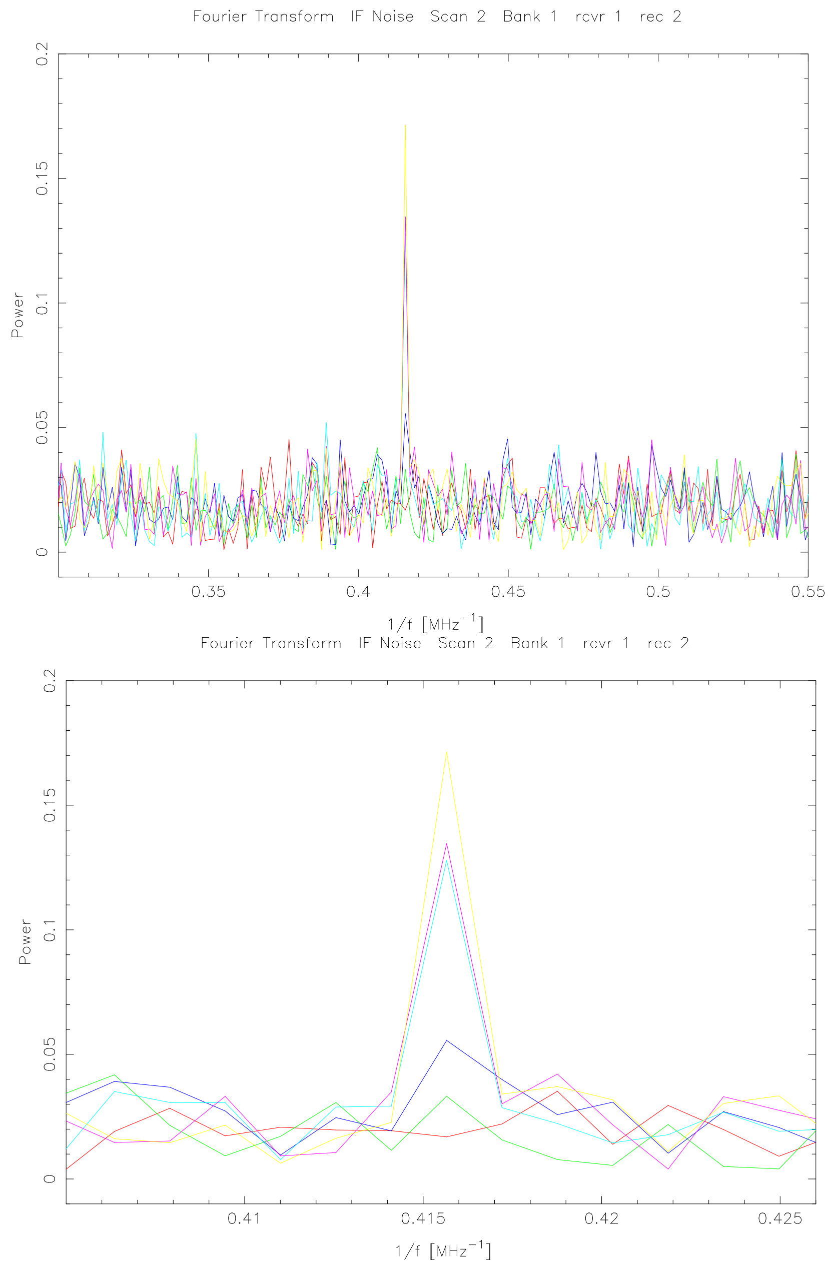


Figure 2: Fourier transform plots for the original external modulator in link number 2 spanning records 1–50. The transformed spectra were produced by calculating (Record N–Record 1)/ Record 1 where N = 2 (red), 10 (green), 20 (blue), 30 (green/blue), 40 (red/blue), and 50 (yellow). The bottom panel shows an expanded view.

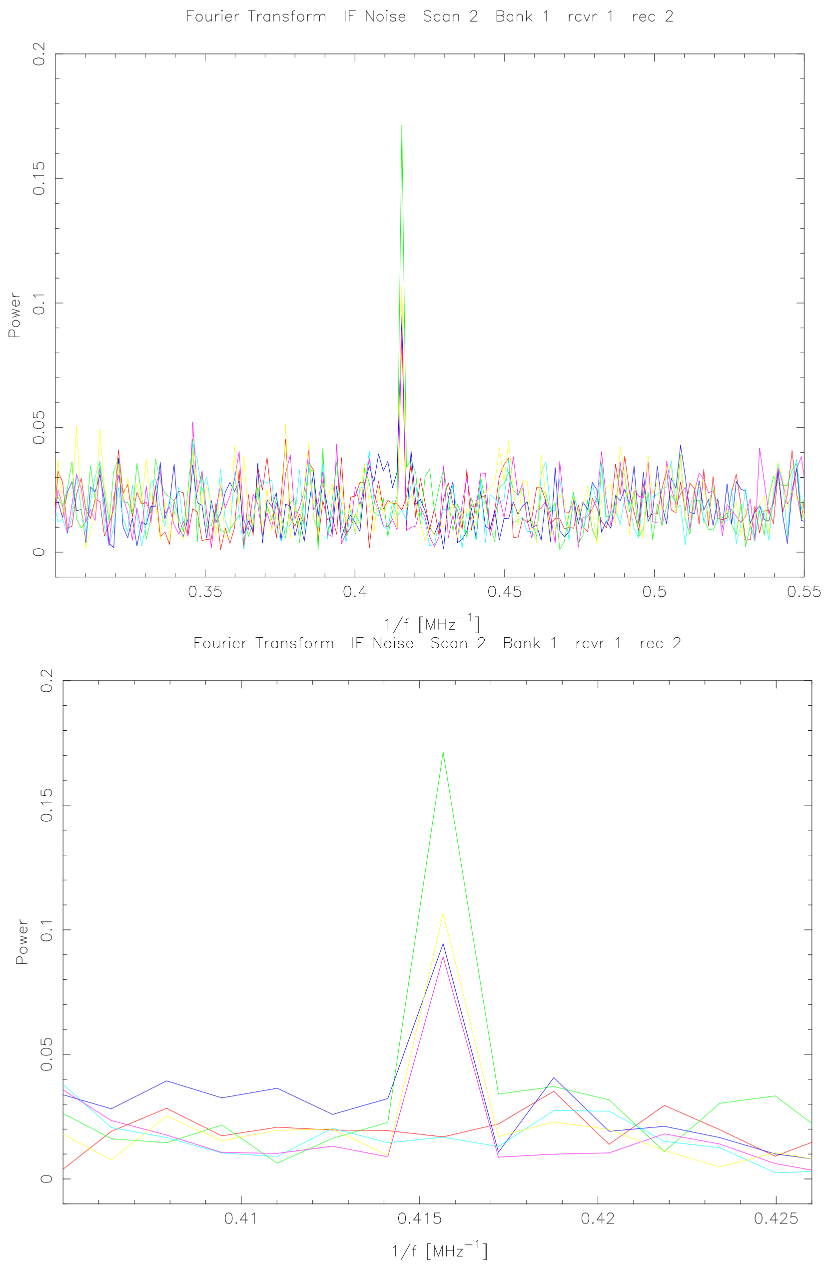


Figure 3: Fourier transform plots for the original external modulator in link number 2 spanning records 2–400. The transformed spectra were produced by calculating (Record N–Record 1)/ Record 1 where N = 2 (red), 50 (green), 100 (blue), 200 (green/blue), 300 (red/blue), and 400 (yellow). The bottom panel shows an expanded view.

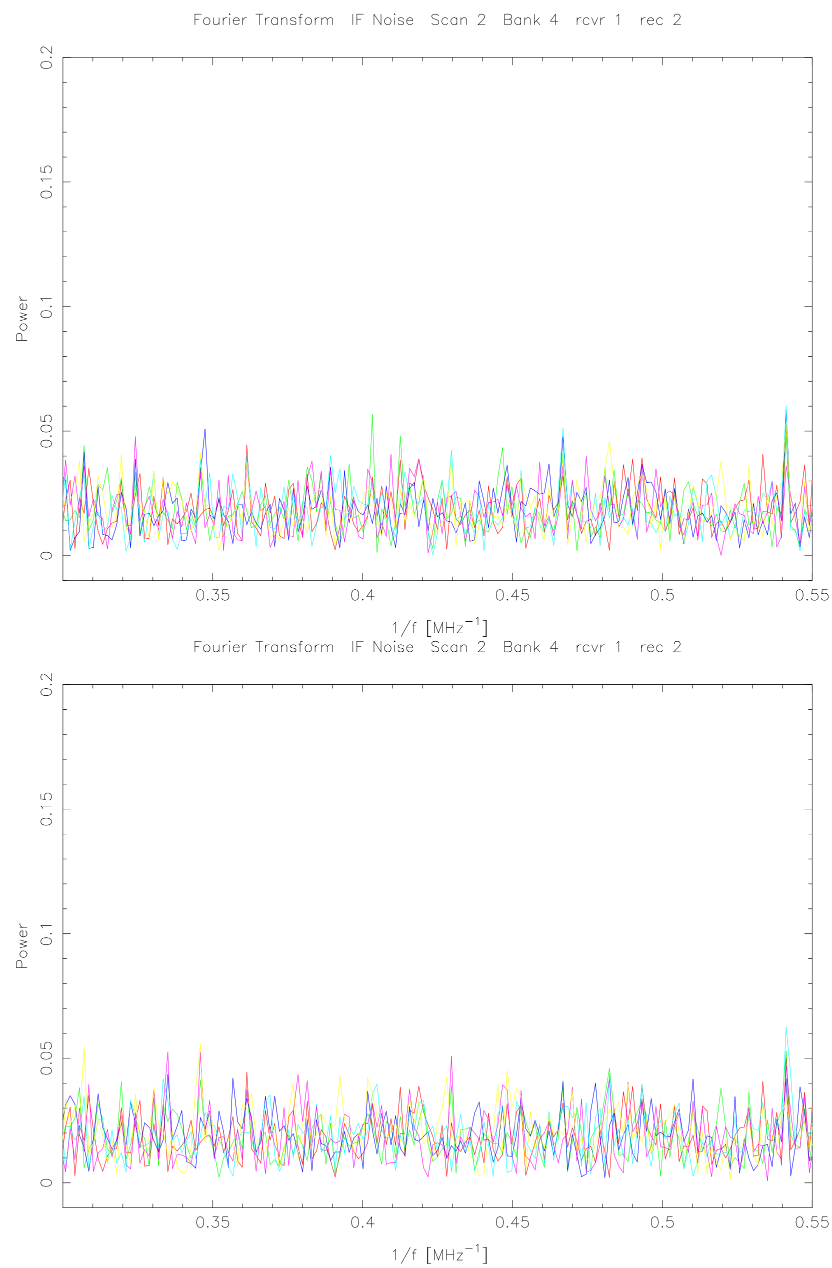
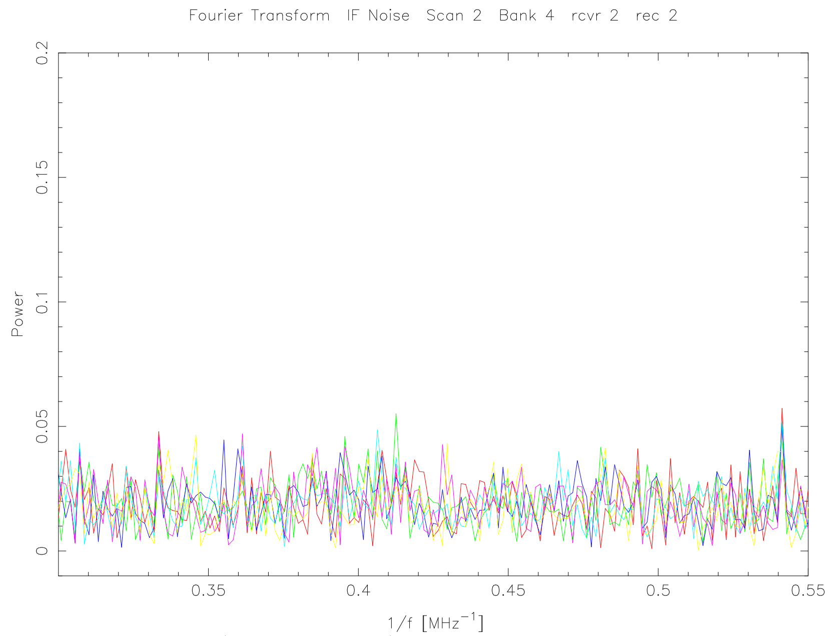


Figure 4: Fourier transform plots for the new external modulator in link number 6. The transformed spectra were produced by calculating (Record N–Record 1)/Record 1. Top panel: shown are N = 2 (red), 10 (green), 20 (blue) , 30 (green/blue), 40 (red/blue), and 50 (yellow) Bottom panel: shown are N = 2 (red), 50 (green), 100 (blue), 200 (green/blue), 300 (red/blue), and 400 (yellow).



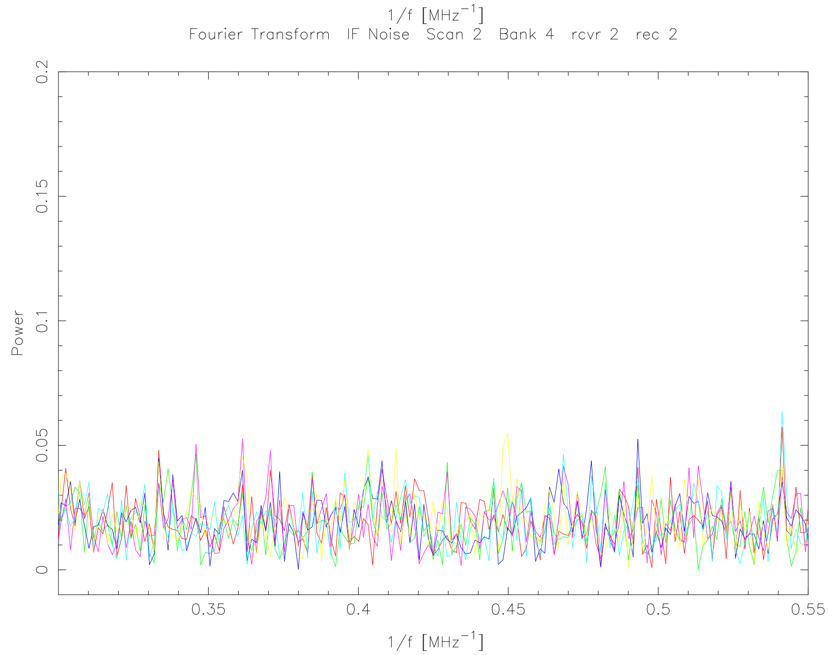


Figure 5: Fourier transform plots for the direct modulator in link number 8. The transformed spectra were produced by calculating (Record N–Record 1)/Record 1. Top panel: shown are N = 2 (red), 10 (green), 20 (blue) , 30 (green/blue), 40 (red/blue), and 50 (yellow) Bottom panel: shown are N = 2 (red), 50 (green), 100 (blue), 200 (green/blue), 300 (red/blue), and 400 (yellow).

Synthetic on-off Measurements

The 2.4 MHz ripple may appear in processed spectra with a magnitude that will depend on the amplitude of the signal in raw spectra and the stability of the ripple in time. If the ripple is very stable over periods of 10 minutes then on-off data taken over this time period may effectively remove the ripple when the data are processed.

On-off data are simulated by calculating (Sig-Ref)/Ref for consecutive groups of records to model total power observations. Let M equal the number of records to be averaged. For example, to simulate a 5 min "on" and 5 min "off" pair the Ref spectrum consists of records 1–10 and the Sig spectrum consists of records 11–20. The Fourier transform is then taken to detect the 2.4 MHz ripple in the processed data with better sensitivity.

The results are shown in Figures 6–9. For ODM 2 two sequences of M were analyzed. The first was M = 1, 4, 8, and 10. So for M = 10 the "on" and "off" scans have a 5 minute integration time. The second sequenced was M = 10, 20, 30, 40, and 50. Here the M = 50 data have an "on" integration time of 25 minutes. Only the second sequence was used for ODM's 6 and 8. The 2.4 MHz ripple is only detected in ODM 2. The amplitude is less than 0.011% of the system temperature. The maximum amplitude is for M = 30–40. The amplitude appears to decrease when enough data are averaged together.

To increase the sensitivity several 5 minute on-off pairs have been averaged together. First the data were divided into four groups of 100 records (50 minutes) each consisting of five on-off pairs. Then these four spectra were averaged together for a total of twenty on-off pairs (200 minutes). The results are shown in Figures 10 and 11 for ODM 2, Figures 12 and 13 for ODM 6, and Figures 14 and 15 for ODM 8, respectively. Notice that in most spectra the $\sim$ 60 MHz ripple is present. The amplitude is larger in the signal path for ODM 6 and 8 than for ODM 2. In fact, the phase of the 60 MHz ripple appears to change for ODM 2 such that the ripple averages out in the final 200 minute spectrum. This is not true for ODM 6 and 8 where the phase does not appear to change significantly.

The 2.4 MHz ripple is only detected in ODM 2. It appears less stable in the first 100 minutes and averages out in the second 100 minutes. The amplitdue has decreased by more than a factor of 10 from the worst case shown in Figure 2. The rms noise integrates down as expected to within $\sim$ 10% if a relatively flat region of the spectrum is used to calculate the rms. After 200 minutes (an "on" integration time of 100 minutes or 6000 seconds) the expected rms noise is $\frac{rms}{T_{\rm sys}} = 3.6 \times 10^{-5}$. For the spectrum in Figure 11 the rms noise using channels 600–700 is 3.8×10^{-5}.

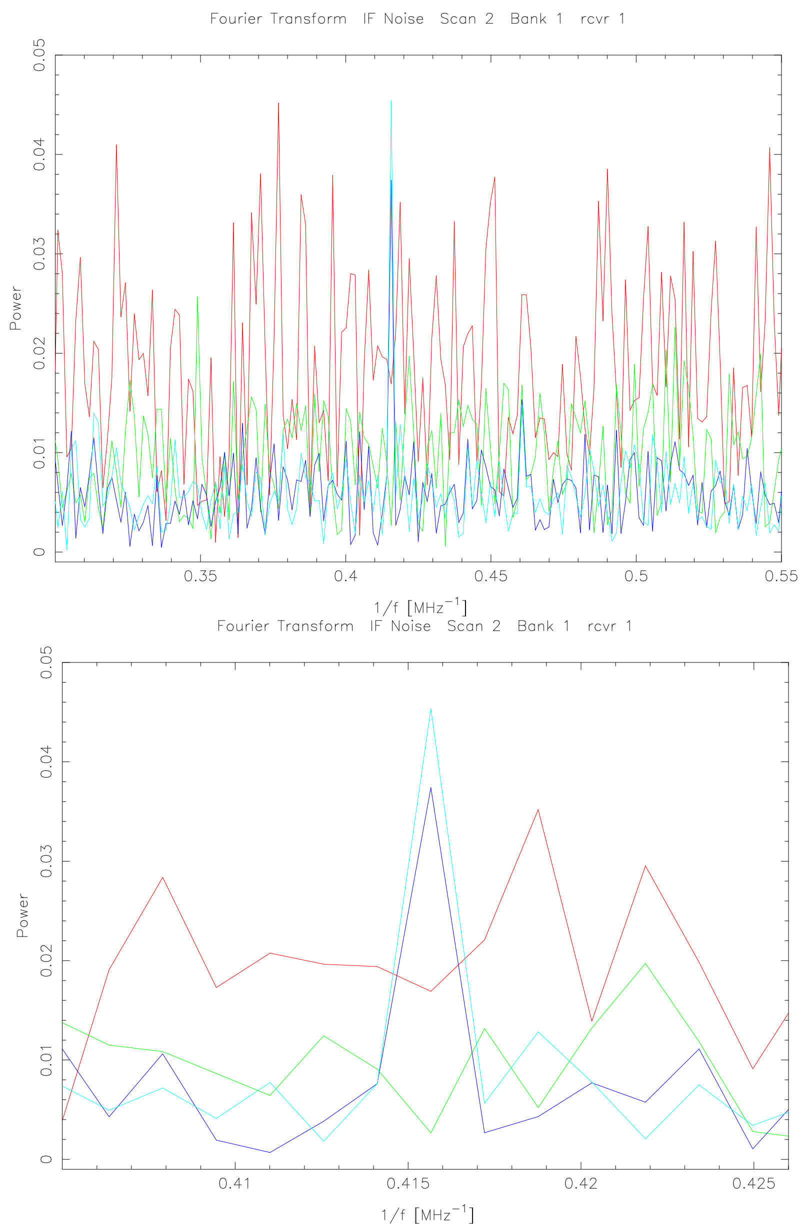


Figure 6: Fourier transform plots for the original external modulator in link number 2 spanning records 1–20. The transformed spectra were produced by calculating (Sig–Ref)/Ref where Sig is the averaged spectrum over the first M records and Ref is the averaged spectrum over the following M records. Therefore, this procedure is simulating an on-off spectrum. Since the integration time is 30 seconds the time spent in the Sig or Ref phases is M/2 minutes. Shown are M = 1 (red), 4 (green), 8 (blue), and 10 (green/blue). The bottom panel shows an expanded view.

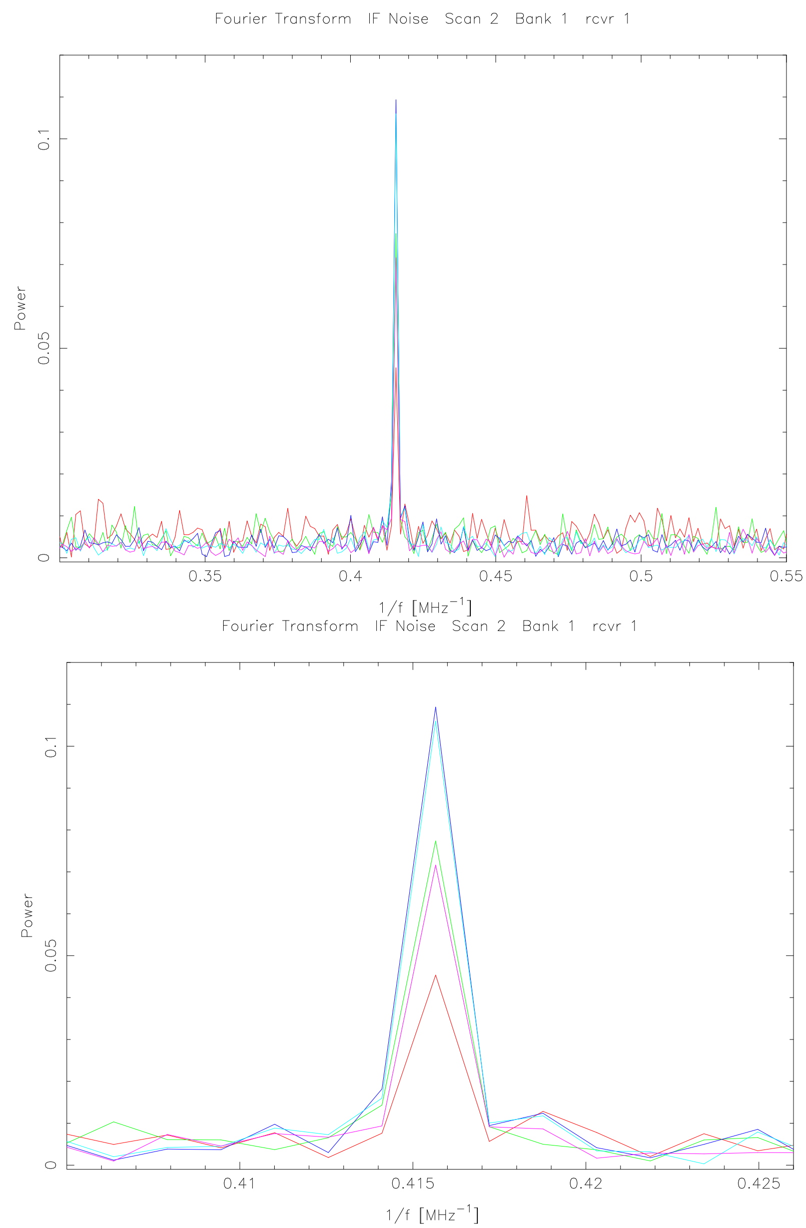


Figure 7: Fourier transform plots for the original external modulator in link number 2 spanning records 1–100. The transformed spectra were produced by calculating (Sig–Ref)/Ref where Sig is the averaged spectrum over the first M records and Ref is the averaged spectrum over the following M records. Therefore, this procedure is simulating an on-off spectrum. Since the integration time is 30 seconds the time spent in the Sig or Ref phases is M/2 minutes. Shown are M = 10 (red), 20 (green), 30 (blue), 40 (green/blue), and 50 (red/blue). The bottom panel shows an expanded view.

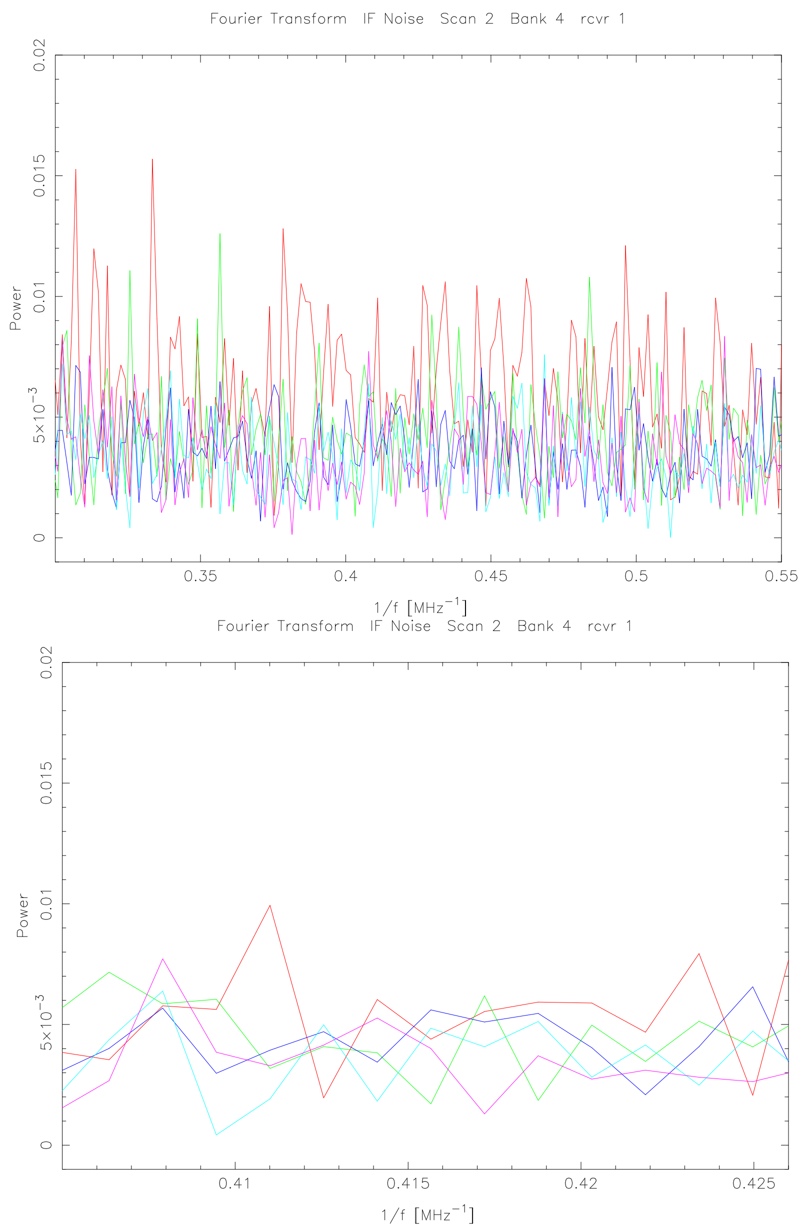
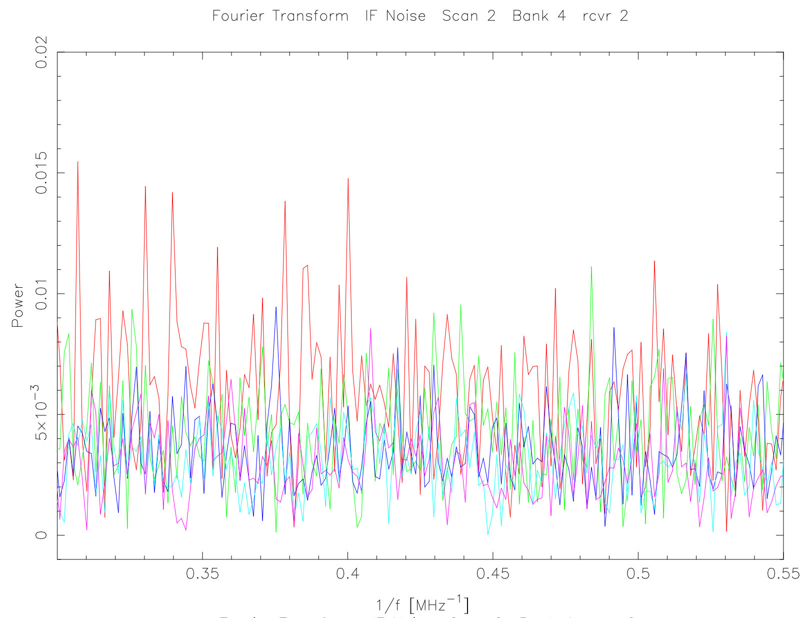


Figure 8: Fourier transform plots for the new external modulator in link number 6 spanning records 1–100. The transformed spectra were produced by calculating (Sig–Ref)/Ref where Sig is the averaged spectrum over the first M records and Ref is the averaged spectrum over the following M records. Therefore, this procedure is simulating an on-off spectrum. Since the integration time is 30 seconds the time spent in the Sig or Ref phases is M/2 minutes. Shown are M = 10 (red), 20 (green), 30 (blue), 40 (green/blue), and 50 (red/blue). The bottom panel shows an expanded view.



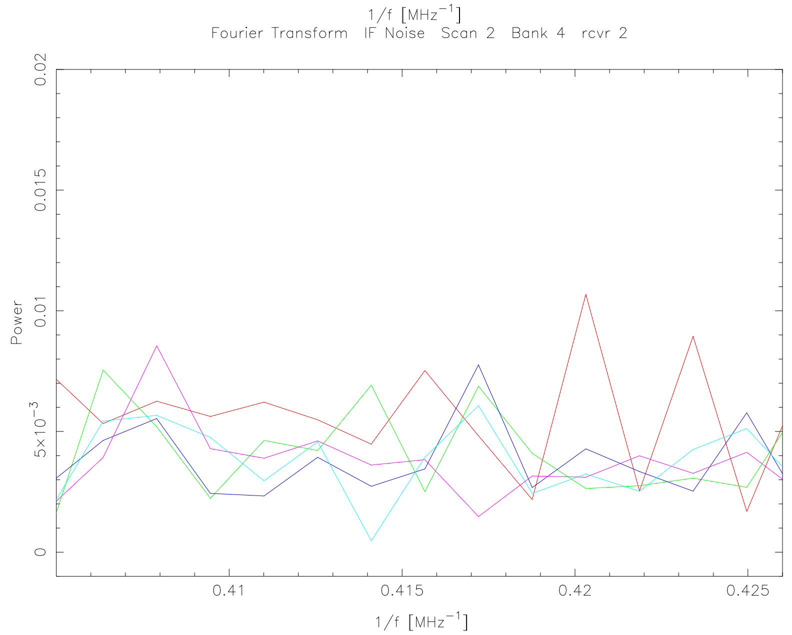


Figure 9: Fourier transform plots for the direct modulator in link number 8 spanning records 1–100. The transformed spectra were produced by calculating (Sig–Ref)/Ref where Sig is the averaged spectrum over the first M records and Ref is the averaged spectrum over the following M records. Therefore, this procedure is simulating an on-off spectrum. Since the integration time is 30 seconds the time spent in the Sig or Ref phases is M/2 minutes. Shown are M = 10 (red), 20 (green), 30 (blue), 40 (green/blue), and 50 (red/blue). The bottom panel shows an expanded view.

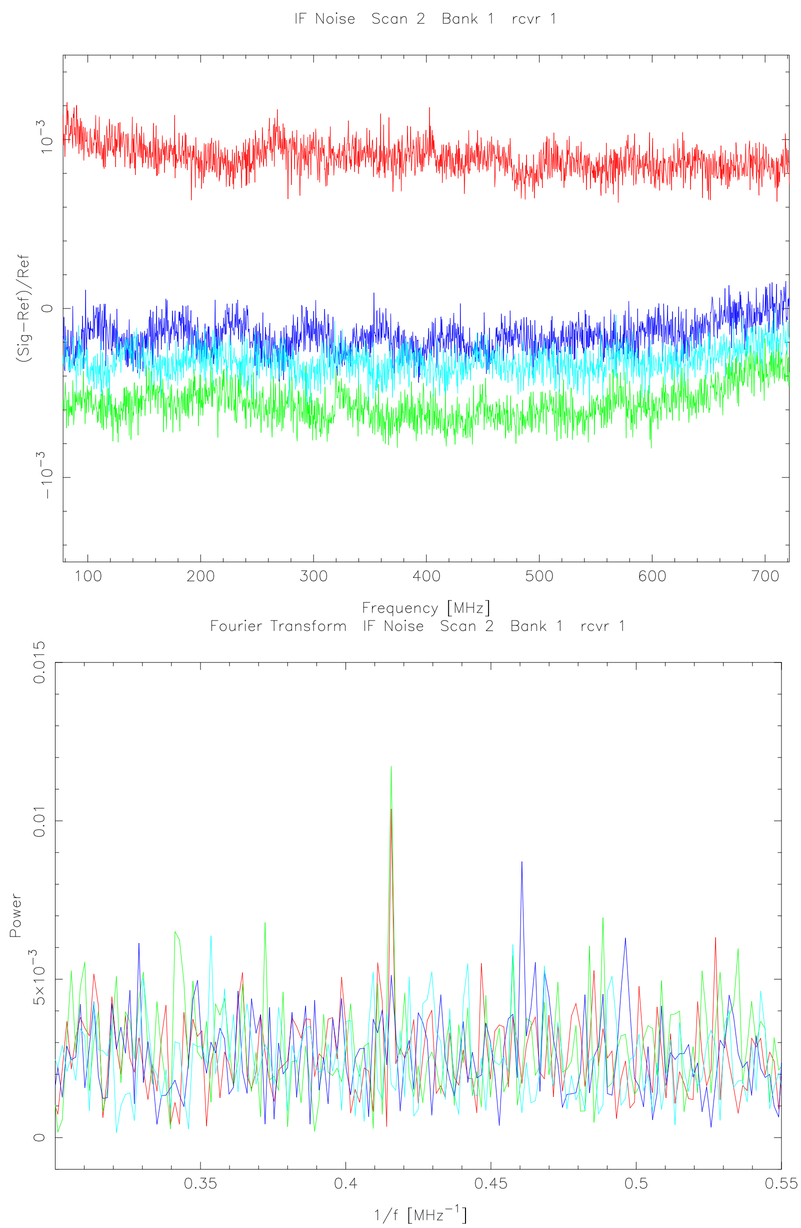


Figure 10: Top panel: IF noise source spectra for ODM 2 simulating on-off data with an integration time of 5 minutes. Each spectrum shown consists of an average of five on-off pairs for a total time of 50 minutes (100 records). Specifically each spectrum is calculated using (Sig–Ref)/Ref where Sig consists of records (1–10 + 21–30 + ...) and Ref consists of records (11–20 + 31–40 + ...). The four plots correspond to records 1–100 (red), 101–200 (green), 201–300 (blue), and 301–400 (green/blue). Botton panel: Fourier transform of the spectra in the top panel.

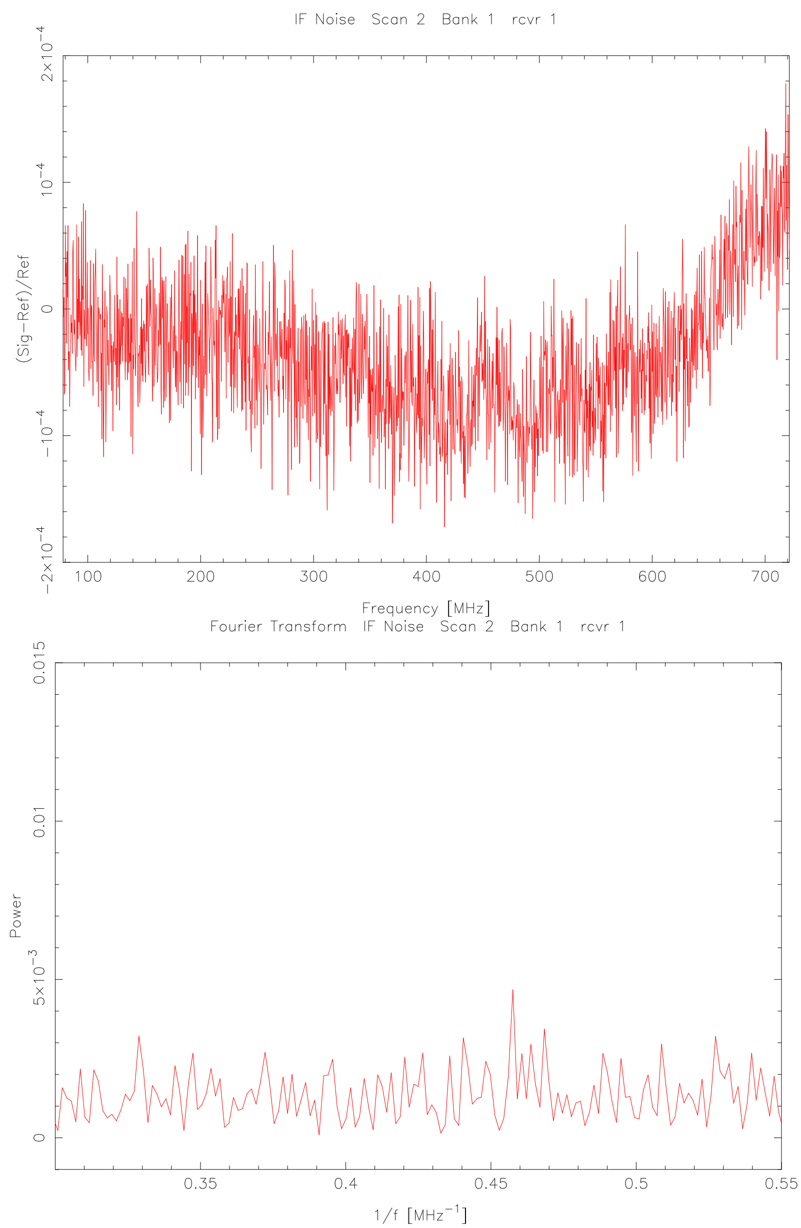
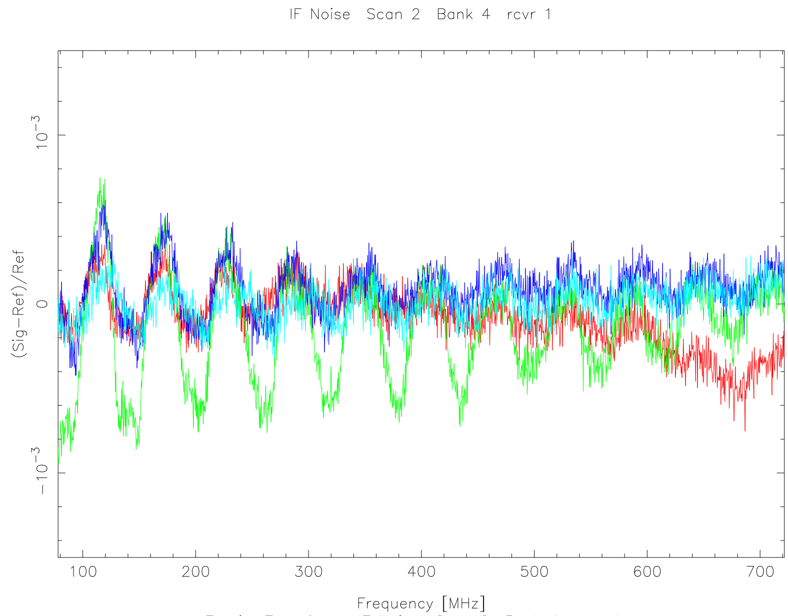


Figure 11: Top panel: IF noise source spectra for ODM 2 simulating on-off data with an integration time of 5 minutes. The spectrum consists of twenty on-off pairs for a total time of 200 minutes (400 records). Specifically the spectrum is calculated using (Sig–Ref)/Ref where Sig consists of records (1–10 + 21–30 + ...) and Ref consists of records (11–20 + 31–40 + ...). Botton panel: Fourier transform of the spectrum in the top panel.



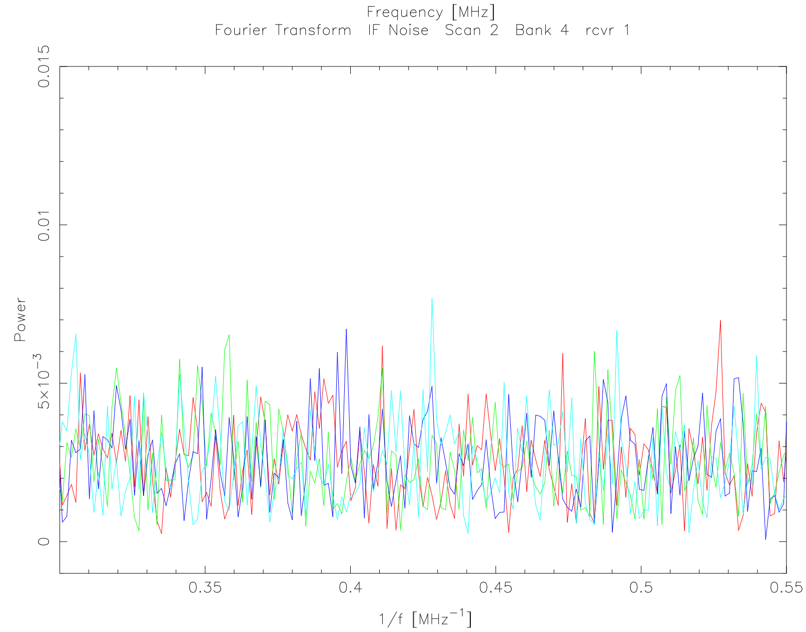


Figure 12: Top panel: IF noise source spectra for ODM 6 simulating on-off data with an integration time of 5 minutes. Each spectrum shown consists of an average of five on-off pairs for a total time of 50 minutes (100 records). Specifically each spectrum is calculated using (Sig–Ref)/Ref where Sig consists of records (1–10 + 21–30 + ...) and Ref consists of records (11–20 + 31–40 + ...). The four plots correspond to records 1–100 (red), 101–200 (green), 201–300 (blue), and 301–400 (green/blue). Botton panel: Fourier transform of the spectra in the top panel.

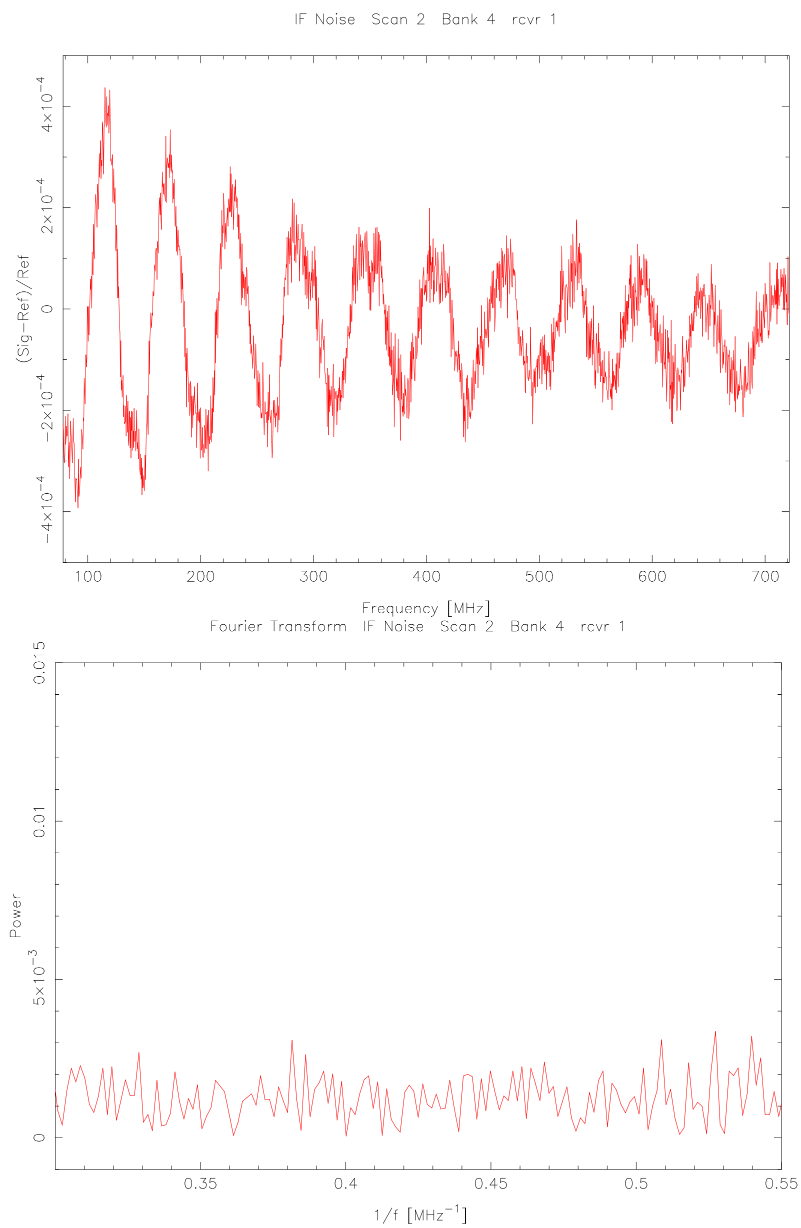


Figure 13: Top panel: IF noise source spectra for ODM 6 simulating on-off data with an integration time of 5 minutes. The spectrum consists of twenty on-off pairs for a total time of 200 minutes (400 records). Specifically the spectrum is calculated using (Sig–Ref)/Ref where Sig consists of records (1–10 + 21–30 + ...) and Ref consists of records (11–20 + 31–40 + ...). Botton panel: Fourier transform of the spectrum in the top panel.

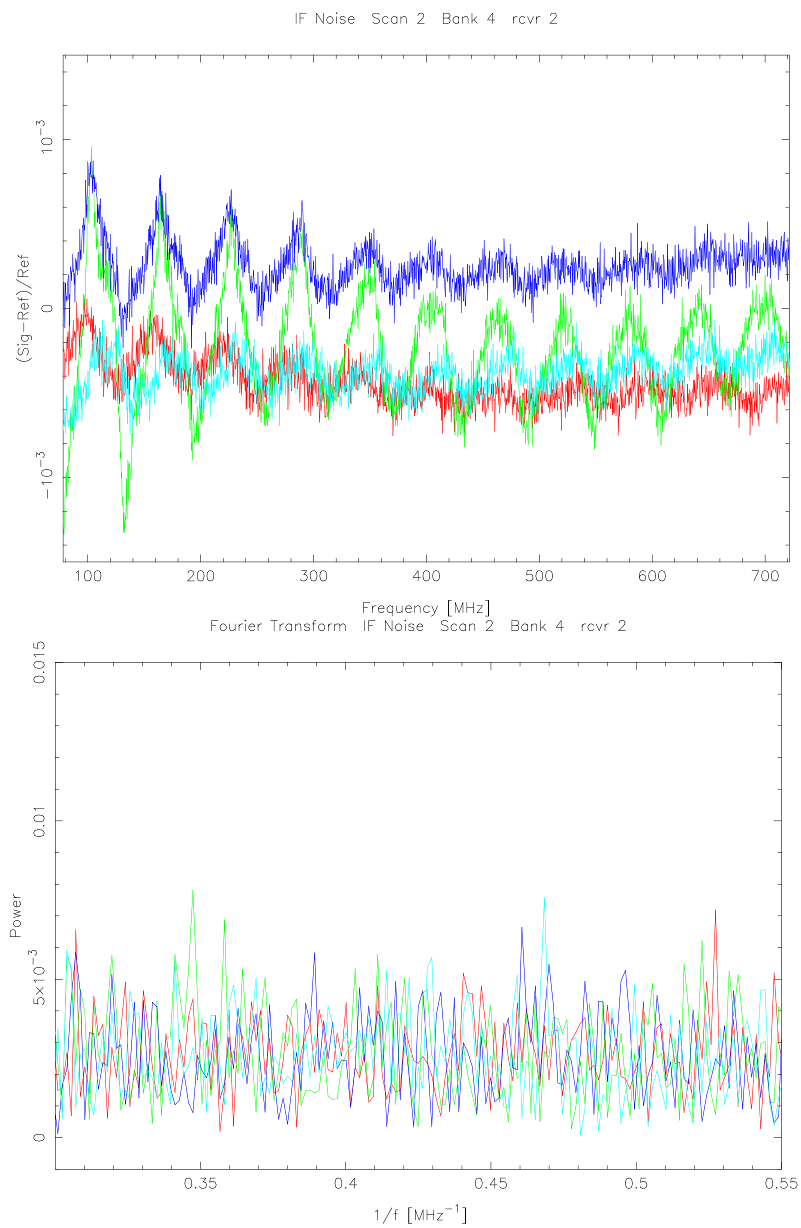


Figure 14: Top panel: IF noise source spectra for ODM 8 simulating on-off data with an integration time of 5 minutes. Each spectrum shown consists of an average of five on-off pairs for a total time of 50 minutes (100 records). Specifically each spectrum is calculated using (Sig–Ref)/Ref where Sig consists of records (1–10 + 21–30 + ...) and Ref consists of records (11–20 + 31–40 + ...). The four plots correspond to records 1–100 (red), 101–200 (green), 201–300 (blue), and 301–400 (green/blue). Botton panel: Fourier transform of the spectra in the top panel.

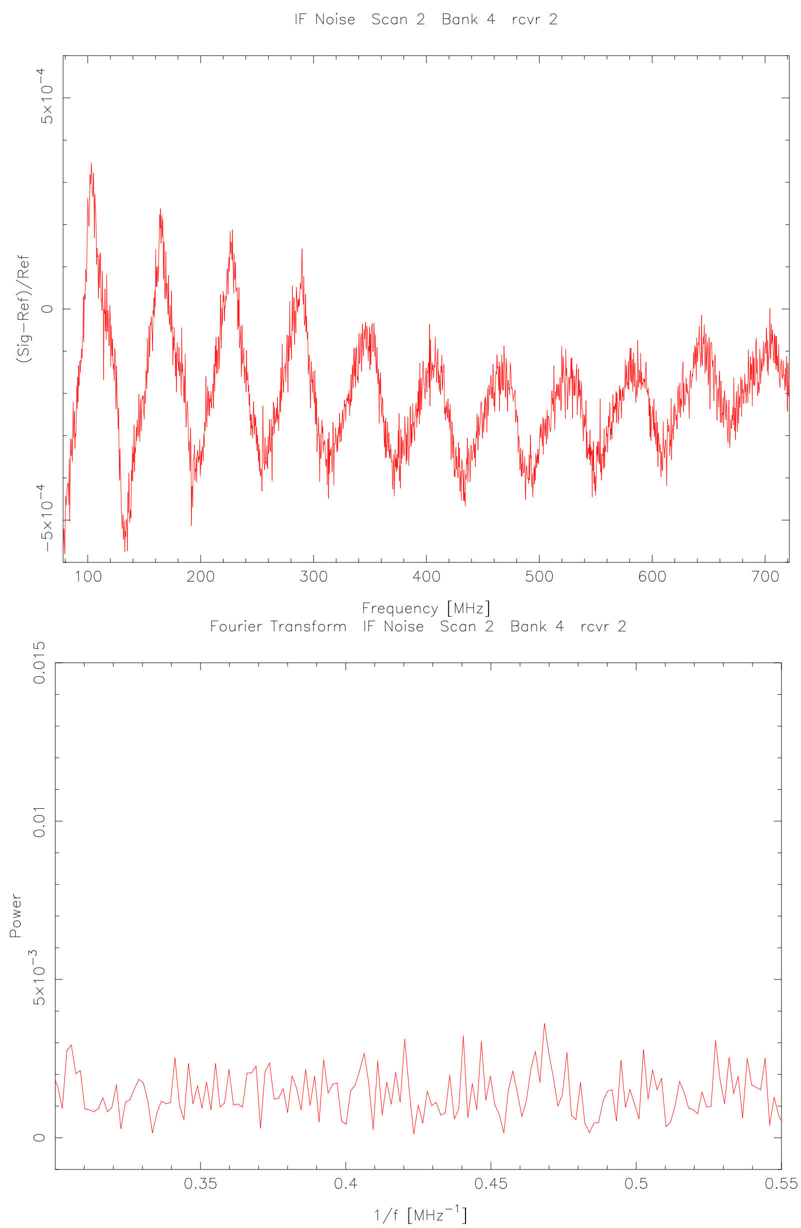


Figure 15: Top panel: IF noise source spectra for ODM 8 simulating on-off data with an integration time of 5 minutes. The spectrum consists of twenty on-off pairs for a total time of 200 minutes (400 records). Specifically the spectrum is calculated using (Sig–Ref)/Ref where Sig consists of records (1–10 + 21–30 + ...) and Ref consists of records (11–20 + 31–40 + ...). Botton panel: Fourier transform of the spectrum in the top panel.