EDGES MEMO #244

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To: EDGES Group

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Subject: Sensitivity of the lowband signature to RFI excision parameters

While RFI is in low band generally less significant in the low band than in the high band there is a concern that the absorption signature reported in memos 222, 225, 226, 233, 237, 239, and 240 could be produced or affected by RFI.

In this memo we continue the study done in memo 227 using recent data from the second low band system (lowband2) covering 2017_082 to 2017_102.

Figure 1 shows the residuals with 4 polynomial terms removed from 1 hour blocks on day 90. In this case the RFI excision has only removed narrow band RFI which exceeds 6.5 sigma relative to the noise in a 6 kHz channel in a 1 hour integration. This shows that the FM RFI is very variable in strength and is only relatively strong at GHA=19 hours.

Figure 2 shows 2 hour integrations on days 90 and 91 limited to a GHA range from 6 to 18 hours. The RFI excision is now limited to 6.5 sigma in 6 kHz in 2 hours and the scale is now 20 K per division. The spectra on day 90 at GHA=9 hours and on day 91 at GHA=11 hours are effected by broadband RFI which is most likely to be from the Sun as no broadband RFI is seen in Figure 3 which shows only nighttime data. In each 2 hour block we see some FM RFI which most likely originates from meteor scatter of distant FM Stations while the FM signals at GHA=19 hours in Figure 1 is probably the result of troposcatter via a temperature inversion.

Figure 4 shows the residual spectra for 4 polyterms removed for 2 hour blocks in the range of GHA=6 to 18 hours for each data from 2017_82 to 2017_102. In this case the data has been smoothed to reduce from 6 kHz to 98 kHz. The scale for the average has been expanded so now the signature can be seen along with the corruption RFI. Figure 5 shows the result of reducing the RFI excision threshold for 6.5 to 2.5 sigma. In this figure the channels with zero weight due to RFI can be seen as blank space.

The average is a weighted average and is only set to zero if less than 30% of the blocks have zero weight. As a result the average has relatively few channels with zero weight. The 30% criteria is one of the many adjustable parameters in the RFI excision process listed at the end of the memo. Figure 6 shows the same process as in Figure 5 with resolution of 390 kHz. Figure 7 shows the results of a signature grid search for center frequency and width with fixed flattening at tau = 7 on the average spectral residual shown in Figure 6.

To access the effect of the RFI on the signature the parameters which effect the excision are expolored. The key parameters are the RFI excision threshold and the number of adjacent channels that are assigned zero weight. The results listed in Table 1 show that a threshold of about 2.5 sigma gives the best rejection of FM RFI as long as it is accompanied by assigning zero weight to some adjacent channels.

Block len (hr)	rfi (σ)	nrfi	Stage 1 (kHz)	Stage 2 (kHz)	lim (K)	Freq (MHz)	SNR	Amp (K)	Width (MHz)	Comments
2	2.5	4	49	391	0.6	78.9	27.3	0.51	18.2	Reference fig 7
2	2.5	4	49	391	0.3	78.5	25.2	0.46	18.1	
2	2.5	4	24	98	0.6	78.8	32.5	0.54	18.3	Figure 5
2	2.5	0	24	98	0.6	79.2	21.6	0.61	19.2	rfi evident
2	6.5	4	24	98	0.6	79.6	14.0	0.78	19.9	rfi eviden figure 6
2	3.5	4	24	98	0.6	79.0	26.7	0.58	18.8	rfi barely evident
2	2.0	4	24	98	0.6	78.7	25.6	0.50	18.7	No rfi evident
2	2.5	8	24	98	0.6	78.7	27.1	0.47	18.2	No rfi evident
2	2.5	16	24	98	0.6	79.0	18.7	0.38	18.0	A large fraction zero wt
12	2.5	4	24	98	0.2	78.5	17.7	0.44	18.7	
12	2.5	4	24	98	0.3	78.9	27.4	0.48	18.8	
2	2.5	4	24	49	1.0	78.9	31.1	0.51	18.8	
2	2.5	4	24	49	1.0	78.8	19.9	0.40	18.3	Moon below horizon
2	2.5	4	24	49	1.0	78.8	28.0	0.58	19.1	Moon above horizon
2	2.5	4	6	12	1.5	78.8	39.4	0.52	18.5	
12	2.5	4	6	12	0.5	78.9	32.1	0.49	18.6	

Table 1. Best fit signature parameters for a range of RFI excision parameters.

If too many adjacent channels of given zero weight the final weighted average has a large fraction of channels with zero weight.

General comments on FM RFI

A separate test on the lowband 1 and 2 data shows no significant change in signature amplitude between a search using only data when the moon is below the horizon and a search with only data when the moon is above the horizon. This implies that most of the FM signals are from various modes of propagation or from scattering and little from reflections from the moon. FM RFI could be eliminated at a location, which is more than 3000 km from FM transmitters such as some island locations. One such island is Tristan da Cunha which has one FM transmitter which is turned off late at night and Nightingale Island and 20 miles away with only "emergency" housing and no inhabitants. Even better is the far side of the moon as planned by the DARE project. Another possibility is install a broadband blade monopole antenna at one of the broadband sites. Such an antenna will be much more sensitive to FM RFI which mostly arrives at low elevation. This would significantly increase the effect of FM RFI to better quantify its effect.

Moon refection levels revisited

The strength of FM reflections was estimated in memo 2 to be about 10 mK in 1 MHz from a 100 kw Earth based FM transmitter.

The reflected power is given by

$$T = P_T G_T G_r \pi r_m^2 \lambda^2 \sigma \Big/ \left(16\pi^2 d^4 4\pi k B\right)$$

P_T = transmitter power – 10^5 W

G_T = transmitter gain – $0\ dB_i$

r_m = radius of the moon $-1.7\times10^6 m$

λ = wavelength – 3m

σ = moon radar cross-section – 0.1 (Evans et al. 1959)

d = distance to the moon – $3.8\times10^8 m$

K = Boltzmann's constant – 1.38×10^{-23}

B = effective bandwidth of FM transmitter 10^5 Hz

T~15 mK

While 15mK is barely significant the effective transmit gain is higher especially for FM transmitters on the limbs of the Earth as seen from the moon.

A better estimate of the level of FM reflected from the moon can be obtained from the MWA observations of the moon[1] from a flux density of about 80 J was obtained. This corresponds to 100 mK when the moon is at the zenith. Figures 9 and 10 show the RFI levels with and without the moon for lowband 2 data from 2017_82 to 2017_102 from GHA 6 to 18 hours.

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[1] McKinley, B., F. Briggs, D. L. Kaplan, L. J. Greenhill, G. Bernardi, J. D. Bowman, A. de Oliveira-Costa et al. (2013), Low-frequency observations of the moon with the Murchison Widefield Array. AJ, 145, 23, doi:10.1088/0004-6256/145/1/23.

RFI excision related parameters:

1) First stage processing of field data (x.acq files)
   a) Actions on single 3-position cycle

      peakpwr. Minpwr, pdpwrm, adcov, maxsmsf, dloadmax

   b) Action on entire data block

      Block length set by time span or GHA span

      rfi threshold in Sigma per 6 kHz for block

      pfit number poly terms in rfi fit

      nrfi number of adjacent 6 kHz channels set to zero whose weight is also set to zero

      Smooth number of 6 kHz channels in each output channel to second stage of processing

2) Second stage processing which takes first stage output and performs calibration
   Smooth number of input channels "smoothed" into output to third stage processing
   Output to third stage processing
3) Third stage processing which filters and averages data blocks and does model fitting etc.

   nfit number of poly or physical parameters fit

   lim max rms of the residuals to each block accepted

   Fstart, fstop

   sig- type of parameters

Zooming in on the edges of the FM band using a narrow frequency from both lowband 1 and highband with 3 terms removed sharp steps of about 50 mK are present at 88 and 108 MHz in the residuals from data with moon above 30° elevation.

The residuals with moon above 30° elevation and moon below the horizon are shown in Figure 11.

Probably best estimate of the average effect of the moon reflections on the signature amplitude is 20 mK from lowband1 for which there is much more data. The results in table 2 indicate that without moon filter 2o mK should be subtracted from the amplitude.

Filter	Amplitude (K)
Moon > 30°	0.50
Moon < 0°	0.46
Without moon filter	0.48

Table 2. Effect of moon the signature amplitude.

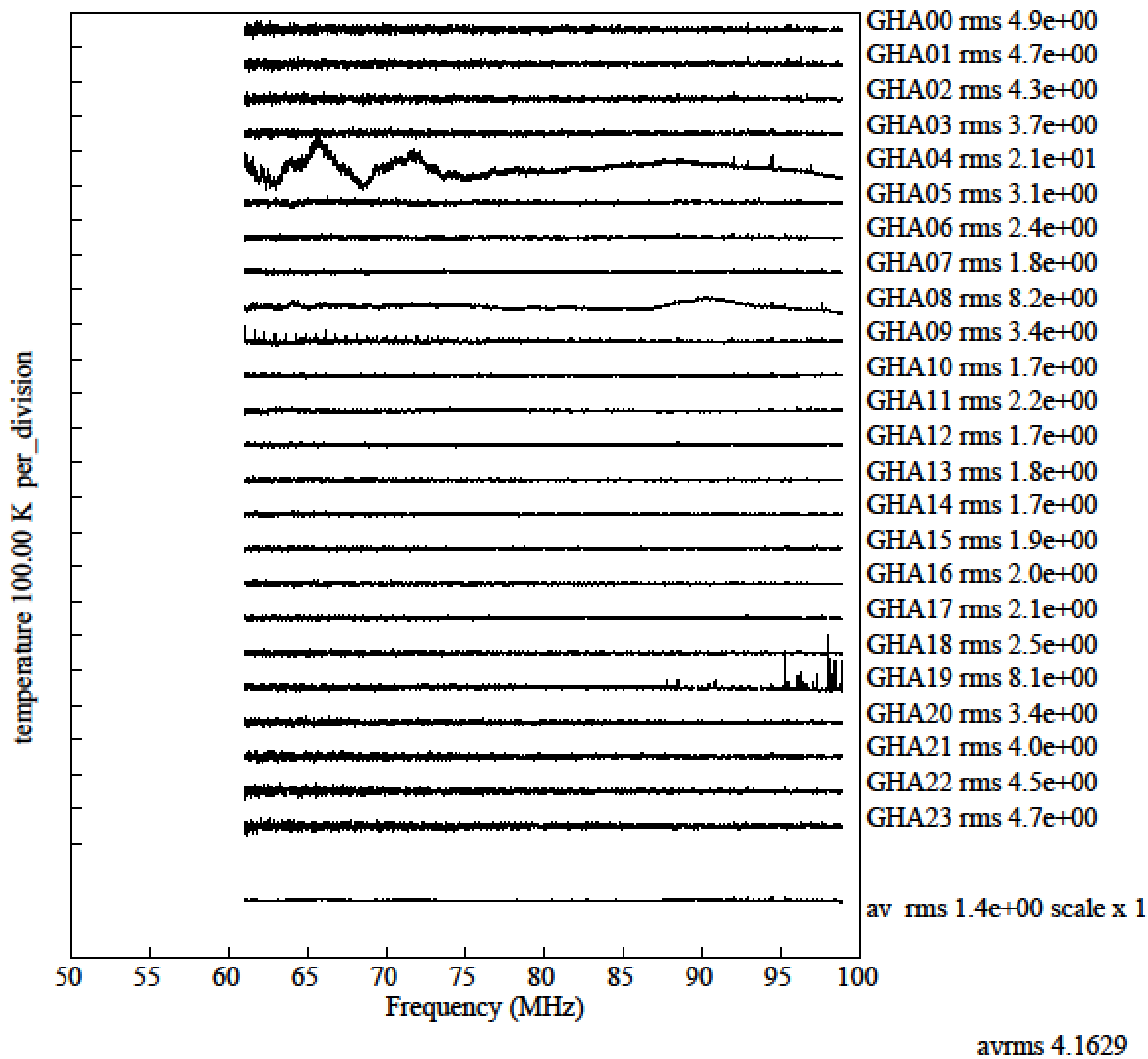


Figure 1. Spectral residuals with 4 polynomial term removed from 1 hour blocks on day 2017_090. Resolution is 6 kHz and RFI excision is limited to 6.5 sigma.

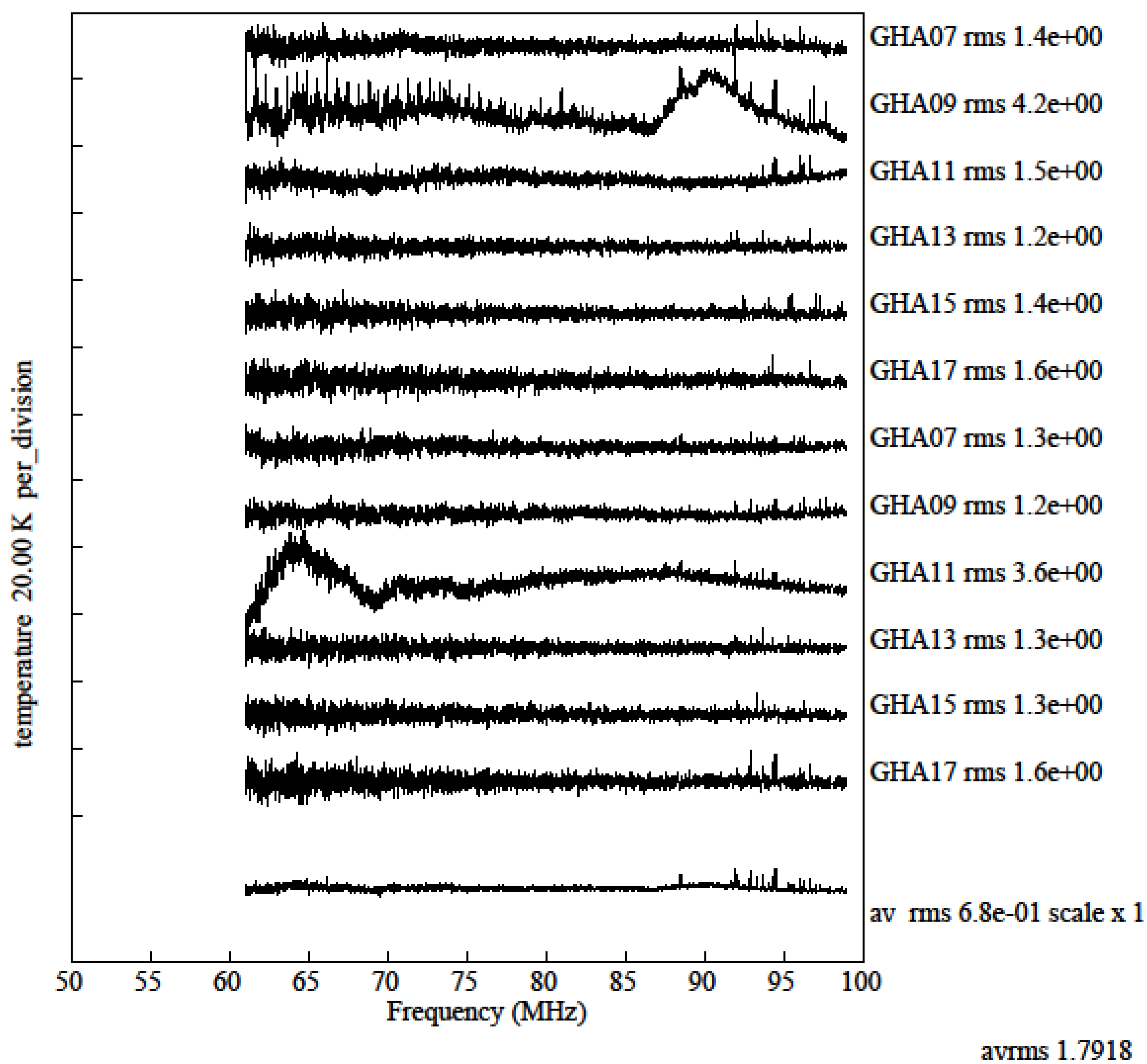


Figure 2. Residuals from 2 hour blocks on days 2017_090 and 2017_091. RFI excision limited to 6.5 sigma.

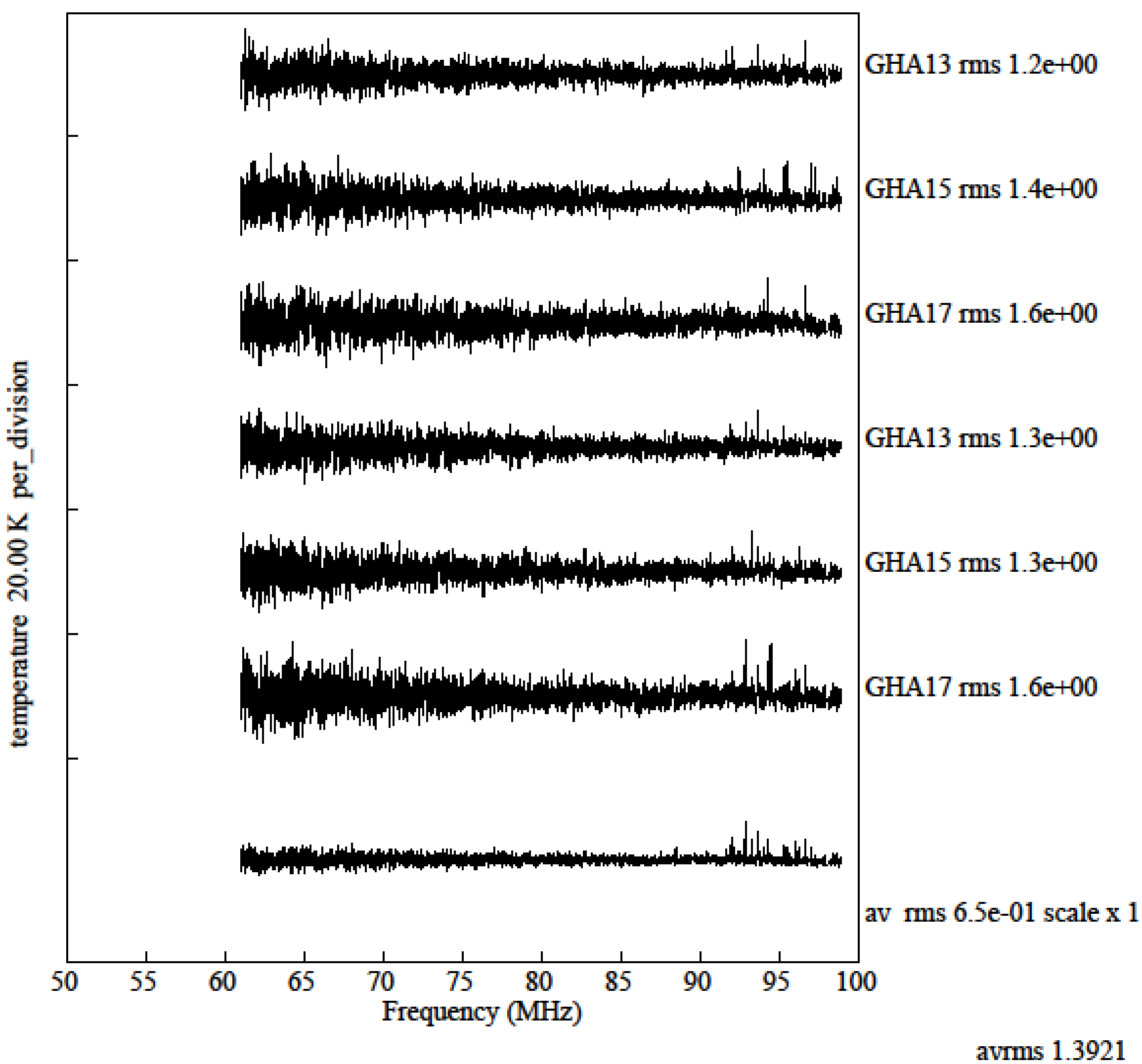


Figure 3. Same as Figure 2 with data from nighttime only.

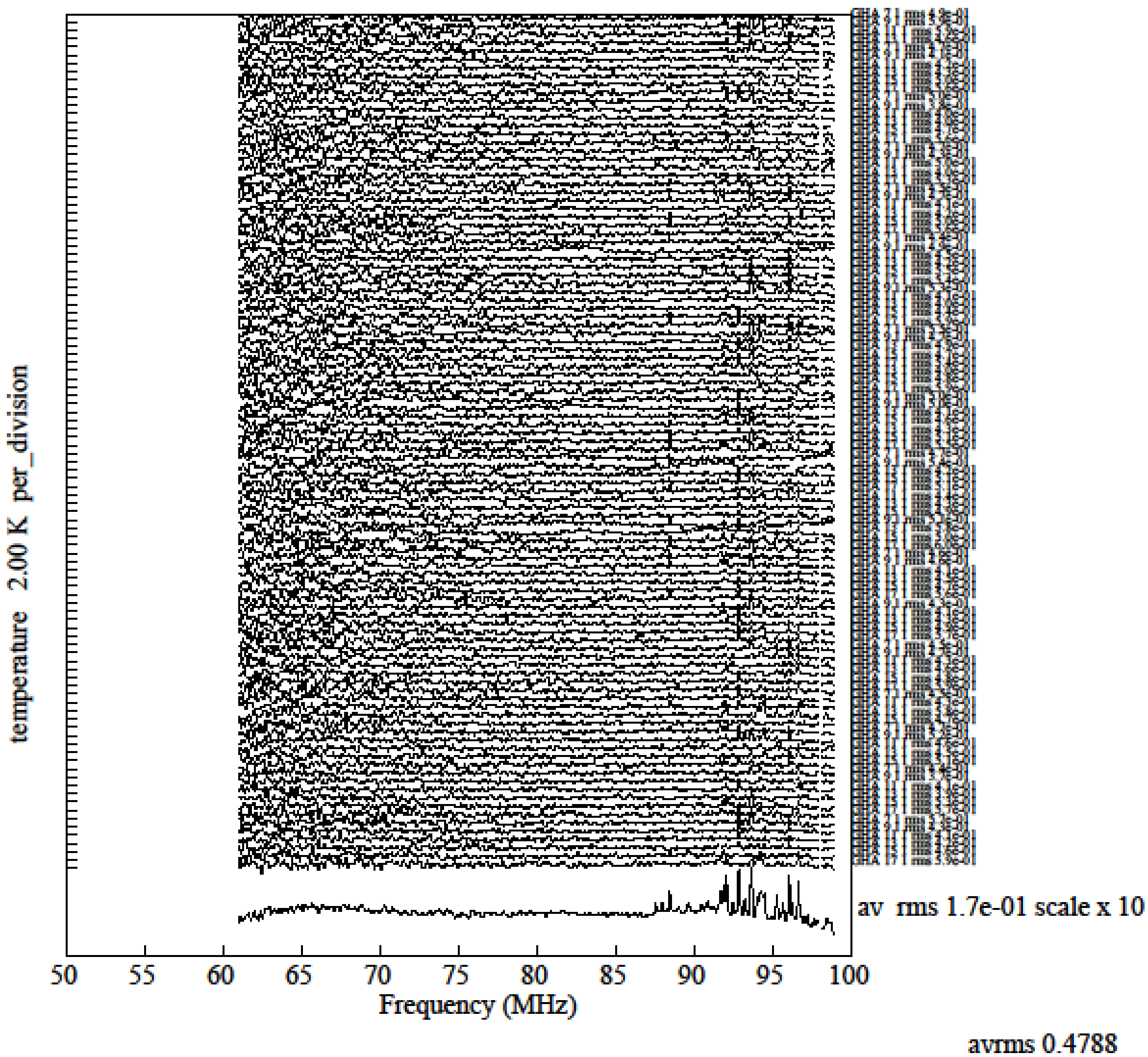


Figure 4. Residuals from 2 hour blocks for data from 2017_082 to 2017_102. Spectra are smoothed to resolution of 98 kHz.

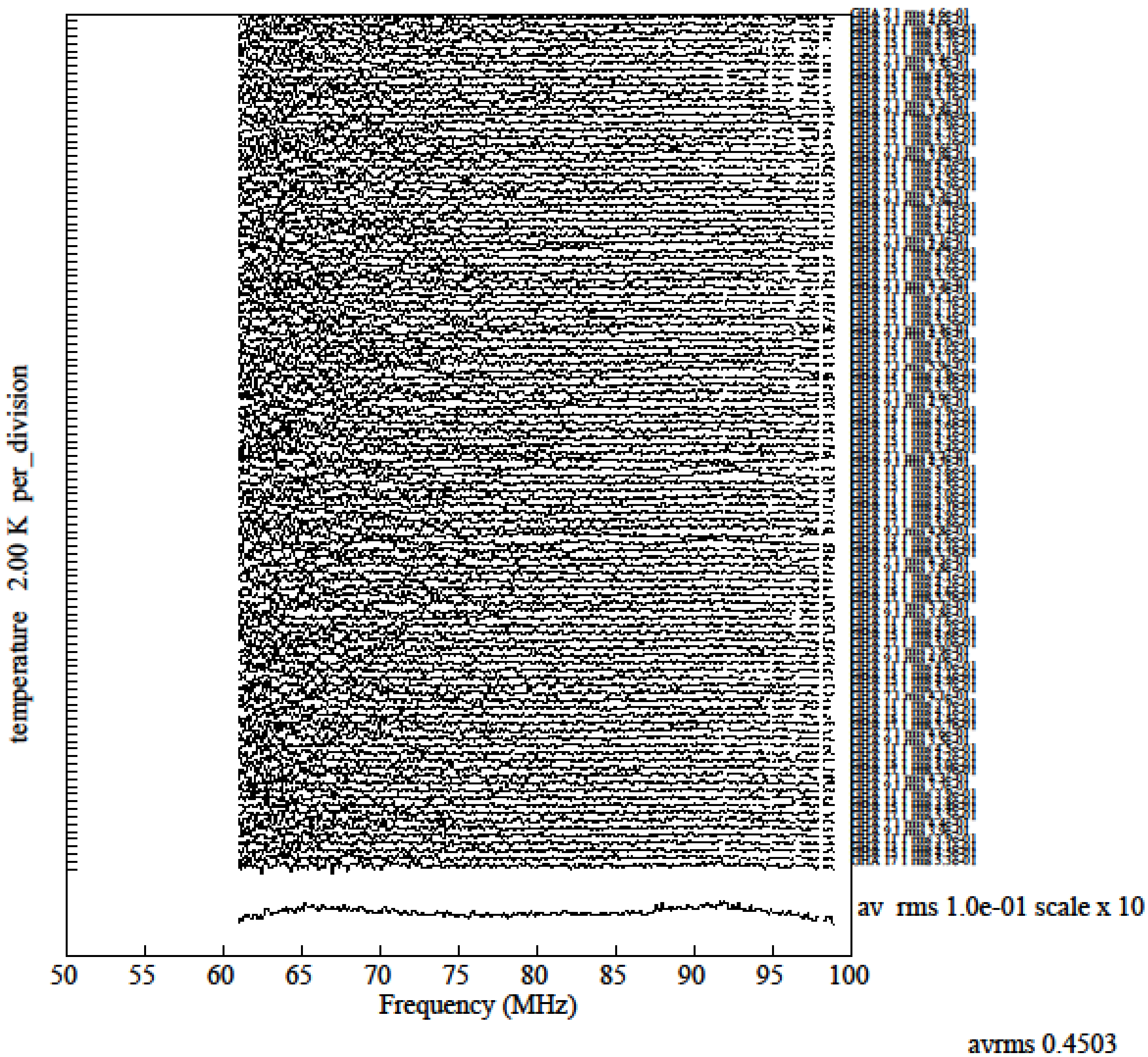


Figure 5. Same as Figure 4 with RFI excision threshold reduced from 6.5 to 2.5 sigma.

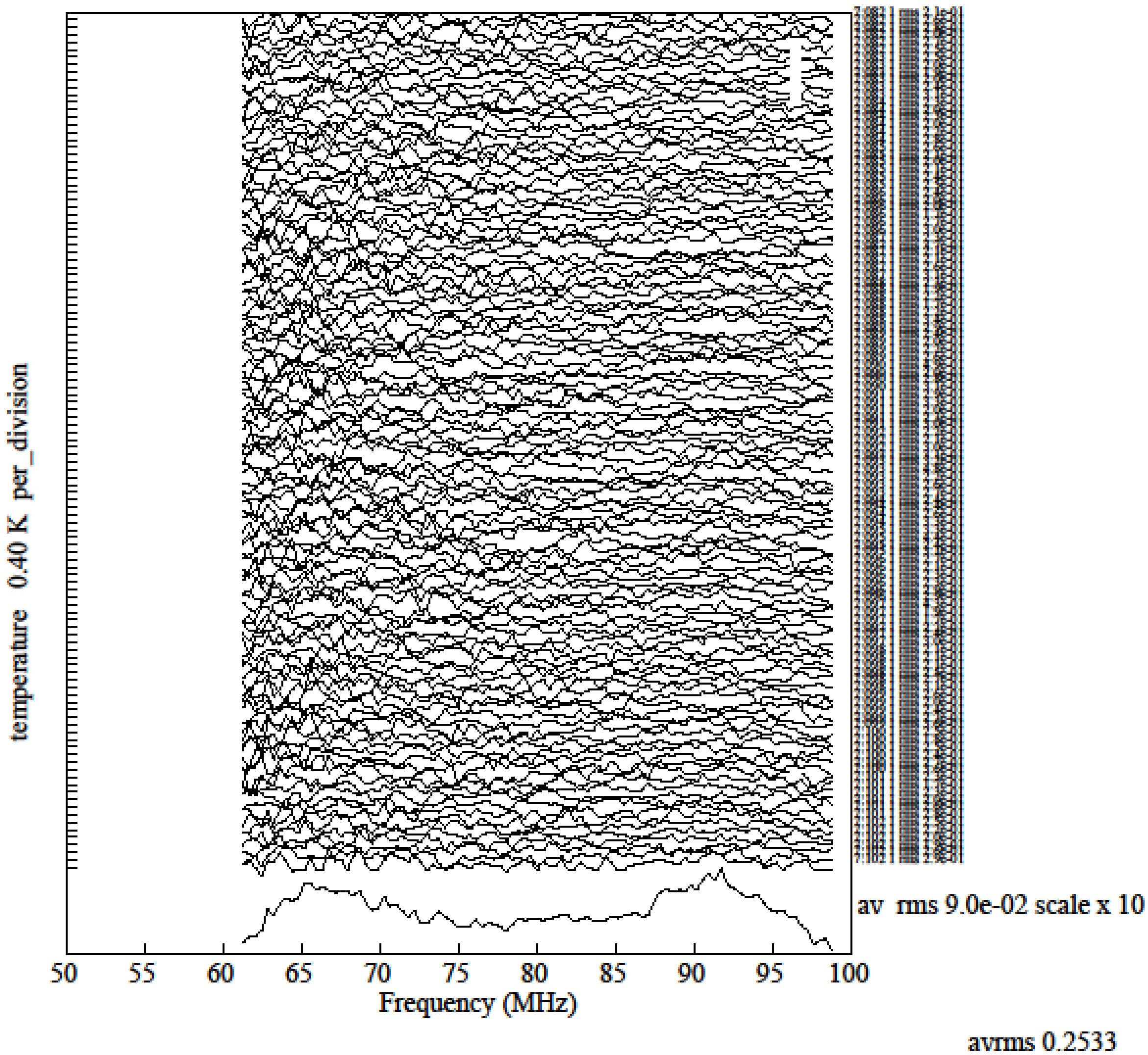


Figure 6. Same as Figure 5 with resolution of 390 kHz.

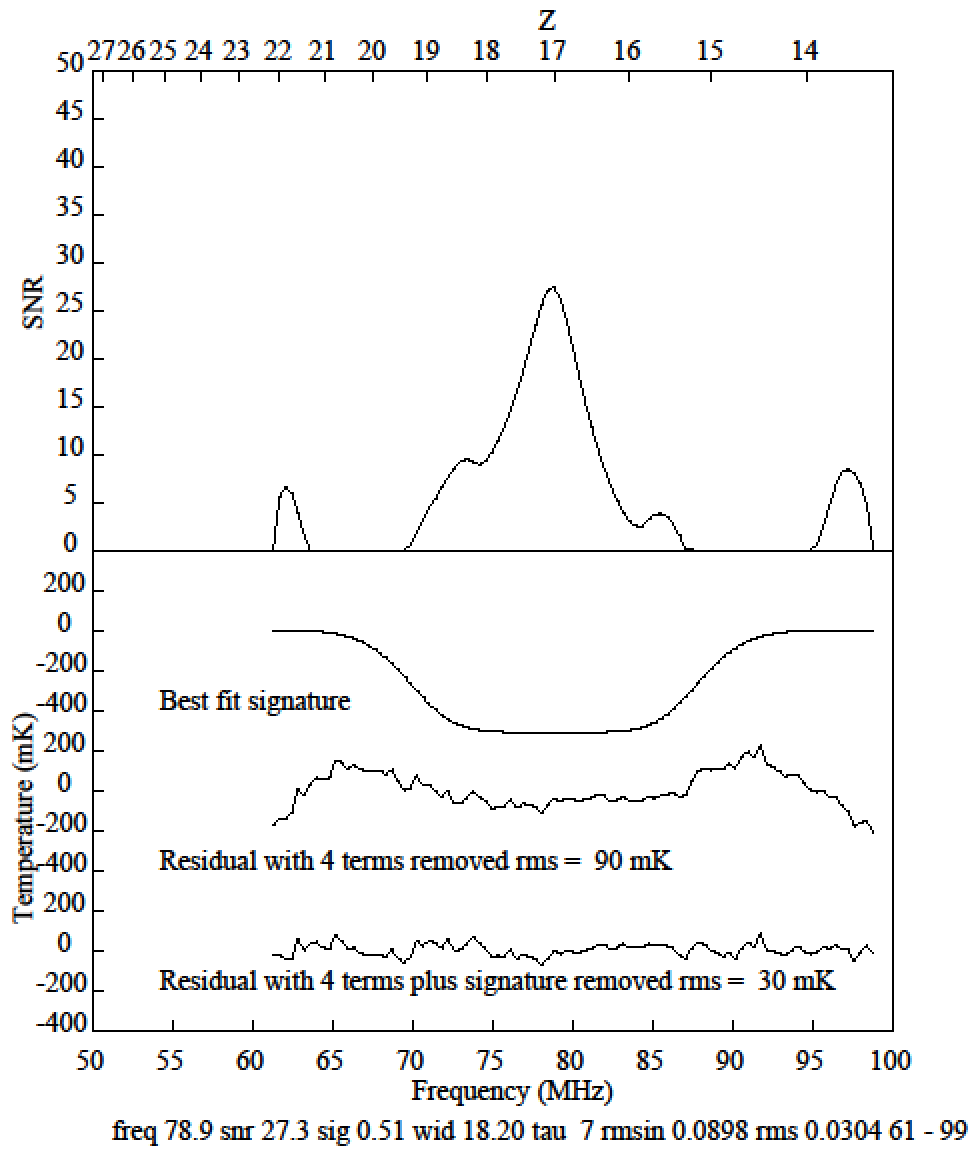


Figure 7. Grid search for signature center frequency and width with fixed flatness of tau = 7.

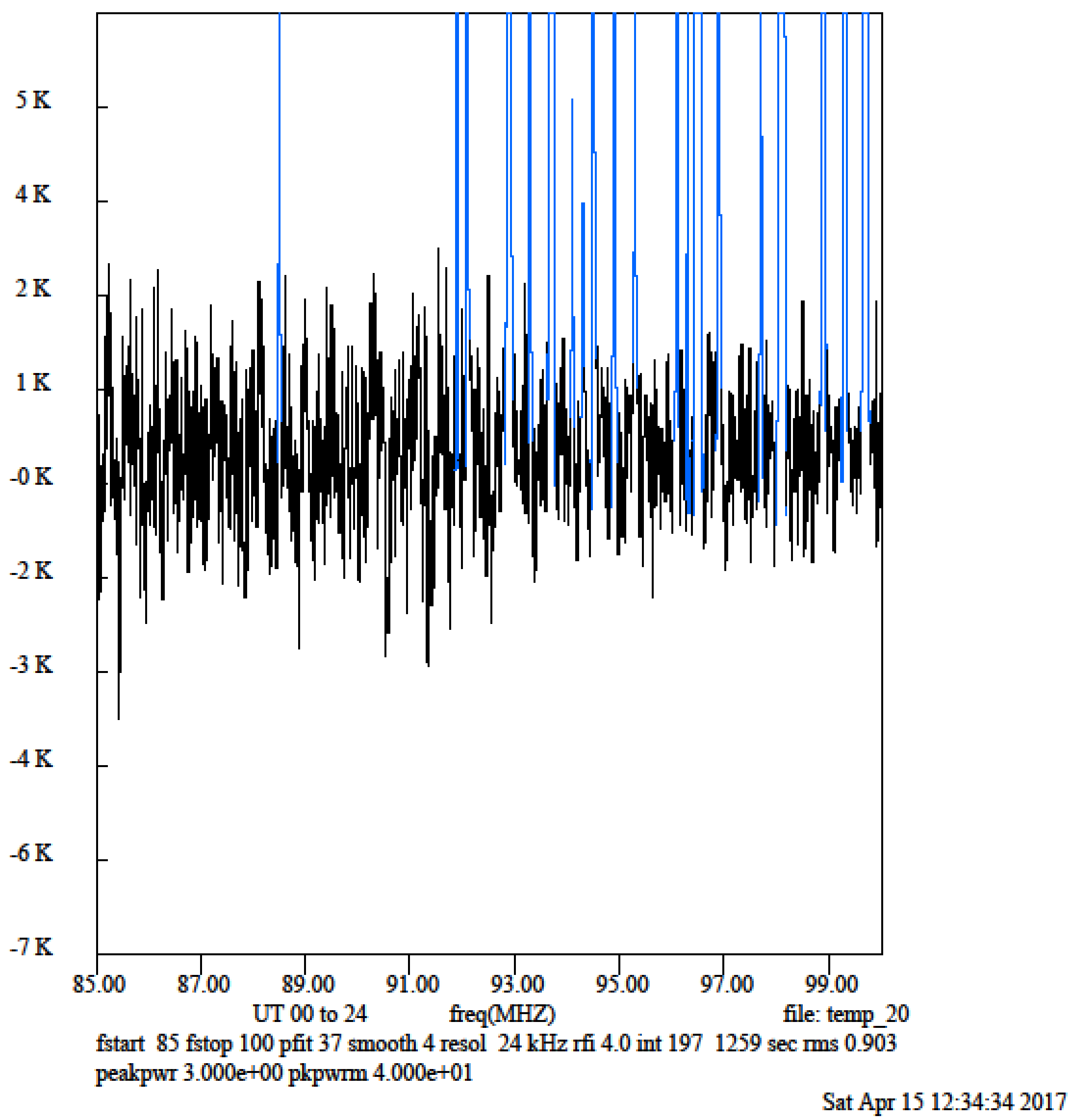


Figure 8. Portion of 6 kHz spectrum in stage one processing. Blue indicates channels excised. Data is 1 hour block at GHA=11.

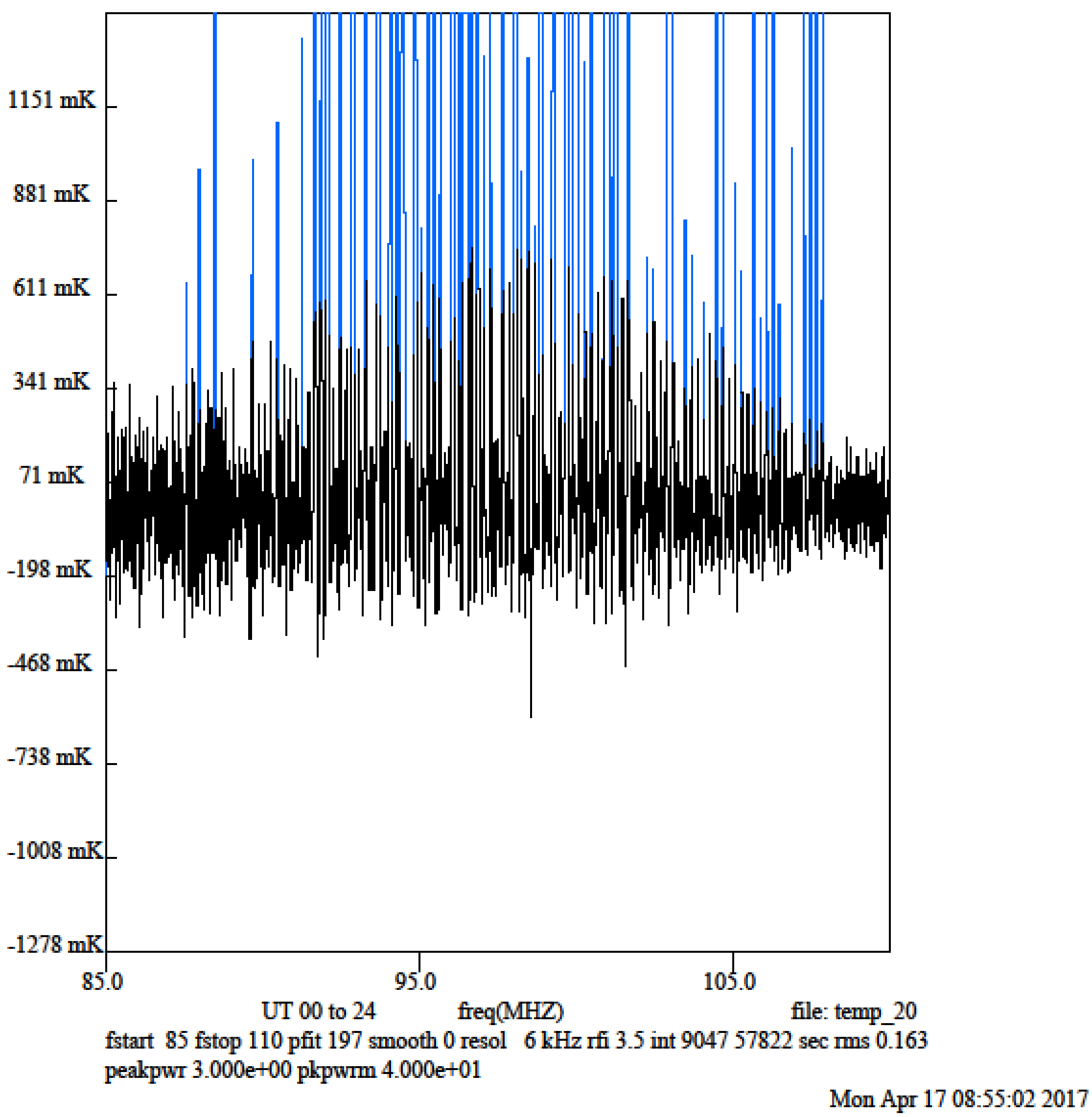


Figure 9. RFI using data with moon above 30 degrees elevation.

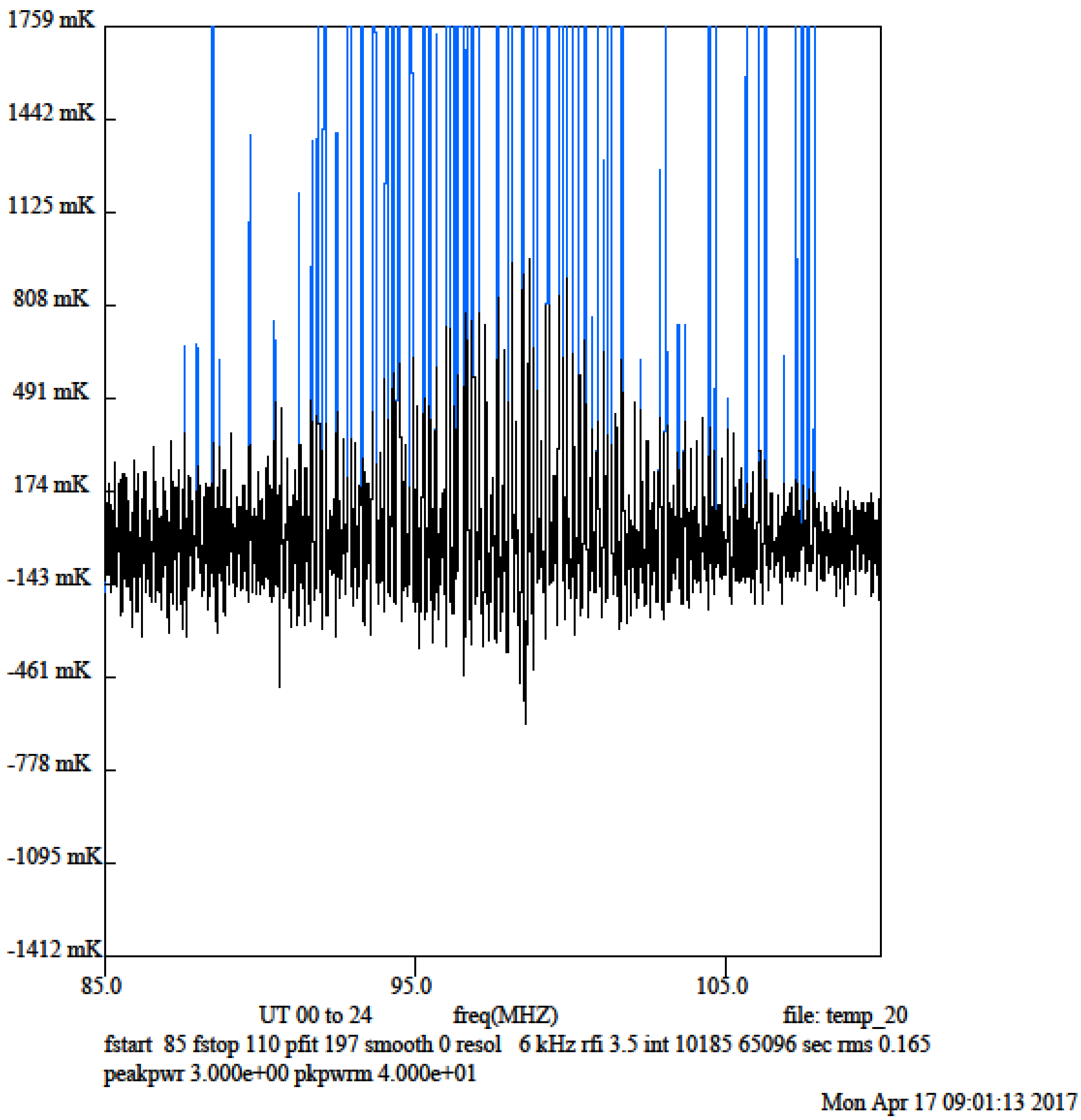
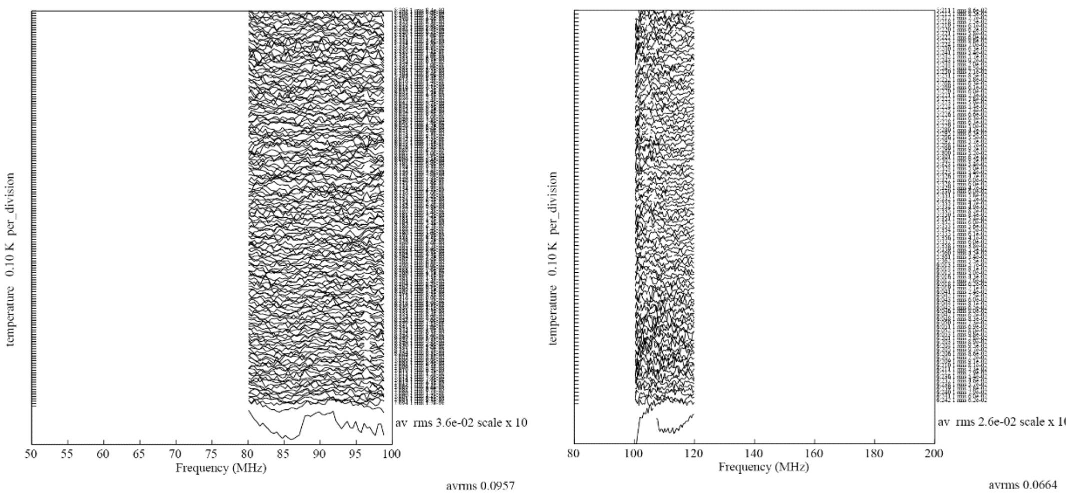
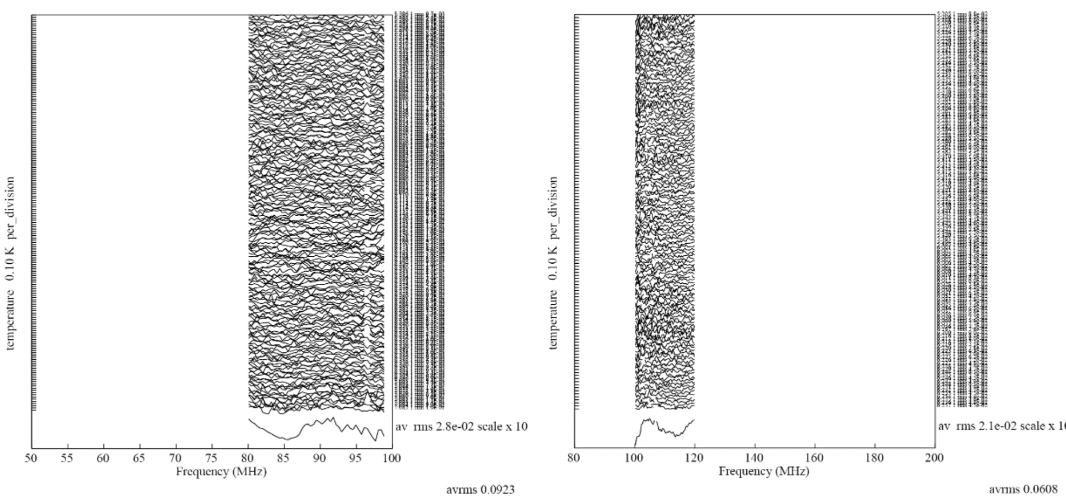


Figure 10. RFI using data with moon below the horizon.



Moon above 30°



Moon below 30°

Figure 11.Comparison of residuals with moon above 30° and below the horizon.