EDGES MEMO #055

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To: EDGES Group
From: Alan E.E. Rogers
Subject: More on using Galactic noise for calibration

The 3-position switch takes out the electronics gain function:

$$p_0 = gT_a + b \quad (1)$$

$$p_1 = gT_L + b \quad (2)$$

$$p_2 = g\left(T_L + T_{cal}\right) + b \quad (3)$$

where p_0, p_1, p_2 are the spectra on antenna, load and load plus noise cal, g is the electronic gain (or bandpass function). T_a and T_L are the antenna and load temperatures and b is a constant noise contribution from LNA and following stages.

From the relations above

$$T_a = T_{cal}\left(p_0 - p_1\right) / \left(p_2 - p_1\right) + T_L \quad (4)$$

In order to calibrate the antenna response we need another calibration which can be accomplished using the Galaxy as a noise source:

$$T_{a1} = G\left(T_{sky} + T_{eor} + c\right) \quad (5)$$

$$T_{a2} = G\left(T_{sky} + T_G + T_{eor} + c\right) \quad (6)$$

where

T_{a1} is the antenna response with the Galactic plane below the horizon, T_{a2} is the antenna response with the Galactic plane above the horizon. T_{sky}, T_G, T_{eor} are the sky, Galaxy and EoR temperatures convolved with the antenna beam pattern. c is the contribution from the ground pick-up and resistive loss in the antenna, and G is the antenna response due to mismatch. c also includes noise radiated by the LNA and reflected back from the antenna mismatch. G can be eliminated by taking the ratio, R.

$$R = T_{a1} / \left(T_{a2} - T_{a1}\right) = G\left(T_{sky} + T_{eor} + c\right) / \left(GT_G\right) = \left(T_{sky} + T_{eor} + c\right) / T_G \quad (7)$$

T_{sky} *and* T_G have close to the same spectral index so that $\left(T_{sky} / T_G\right)$ is close to being a constant. T_{eor} is the small signal we are trying to detect so that dividing by T_G just normalizes the EoR signature as a fraction of the background.

If we can minimize c the ratio given in equation 7 the ratio should be close enough to a constant to be fit with a polynomial with far fewer terms than needed to fit T_a of equation 4.

Figure 1 shows the spectrum of R for data taken at Boolardy on day 265 of 2009. R has been scaled by $(T_{a2} - T_{a1})$ at 150 MHz so that it has the value of T_{a1} at 150 MHz. This scaling puts R in units of Kelvin and allows easy comparison with spectra without "Galactic calibration." The increase at low frequencies is probably due to a combination of increased ground pick-up at low frequencies owing to the finite ground plane and increased LNA noise due to the increase in VSWR. The increase at high frequencies is probably the result of reflected LNA noise. This suggests 2 improvements to the EDGES antenna:

1. Increase the size of the ground plane
2. Add a small capacitance to the antenna terminals to improve the VSWR at the high end of the band.

In Figure 1 which shows the "Galactic noise calibrated" (GNC) spectrum for the data from 2009_265_00.acq the data with the Galaxy "up" was taken to be when the local hour angle of the Galactic center is between -6 to +6 hours and the Galaxy "down" data for the remainder of the time. Figure 2 shows the GNC data for an anomalous day 2009_258 (15 September). To amplify the anomaly the Galaxy "down" time was taken to be from 16 to 17 hours UT. The only explanation I can come up with is that the antenna was wet at this time and the water effected the antenna VSWR.

Figure 3 shows the average GNC data for the days 236 through 266 omitting days 248, 258 and 266 which had large residuals. A 7 term polynomial was fit to the data from 105 to 205 MHz and the spectrum was smoothed to a resolution of 3 MHz. The rms of the spectrum is 17 mK.

The peak at 150 MHz may be statistically significant. This could be the result of imperfect removal of RFI or even the presence of low level sidebands on the 150 MHz satellite signals. It's cause is still under investigation.

Figure 4 shows the spectrum from day 266 in which digital TV channels 7 and 9 are clearly present at the level of a few Kelvin. The propagation this day, 23 Sept 09, may have been tropospheric bending.

Figure 5 shows the spectrum from the data for the Galaxy "down" portions only of the data in Figure 4. In order to get below 200 mK rms a polynomial with 11 terms was removed from the data and the data was smoothed to a resolution of 3 MHz. The rms of the spectrum in Figure 5 is 25 mK.

Comments:
The Galactic noise calibration provides a useful diagnostic of the antenna performance and in addition has the potential for reducing the number of terms needed in the polynomial fit. Reducing the number of terms in the polynomial is probably essential for the detection of all but the most rapid EoR scenarios. The table below gives the rms vs the number of terms in the polynomial.

Rms	+terms
235	7
117	8
56	9
33	10
12	11

Examples of different types of propagation of RFI observed at Boolardy.

1] Direct Line of sight (LOS) path
LOS Transmissions are from satellites, aircraft and lightning. The strongest signals are the Orbcomm satellites at 138 MHz.
2] Reflections from aircraft
Distance FM stations are scattered from aircraft. These signals typically last for tens of minutes compared with meteor scatter which is "bursty" (see memo #54)
3] Meteor scatter
Always present at some level (see memo #54).
4] Troposcatter and tropospheric bending
Troposcatter is always to be present at some very low level. However in some cases the radio curves can be bent or ducted to follow the Earth's curvature by an inversion layer. The best example is between 16 and 24 hrs on day 2009_266 when the FM signals increase by about 20-30 dB. Unlike meteor scatter this propagation varies slowly in time and has little frequency dependence so that the TV channels, which normally virtually undetectable become quite strong.
5] "Sporadic E"
Not sure we have seen this yet due to the current low level of solar activity.
6] "Multipathed" lightning
Distant lightning is broadband radiation that arrives from several different paths so that the spectrum contains ripples. Since type of "RFI" has the potential for serious corruption of the EDGES spectrum so that it is important to filter out any broadband transients from the data. The data from 2009_265 has several examples of lightning pulses.

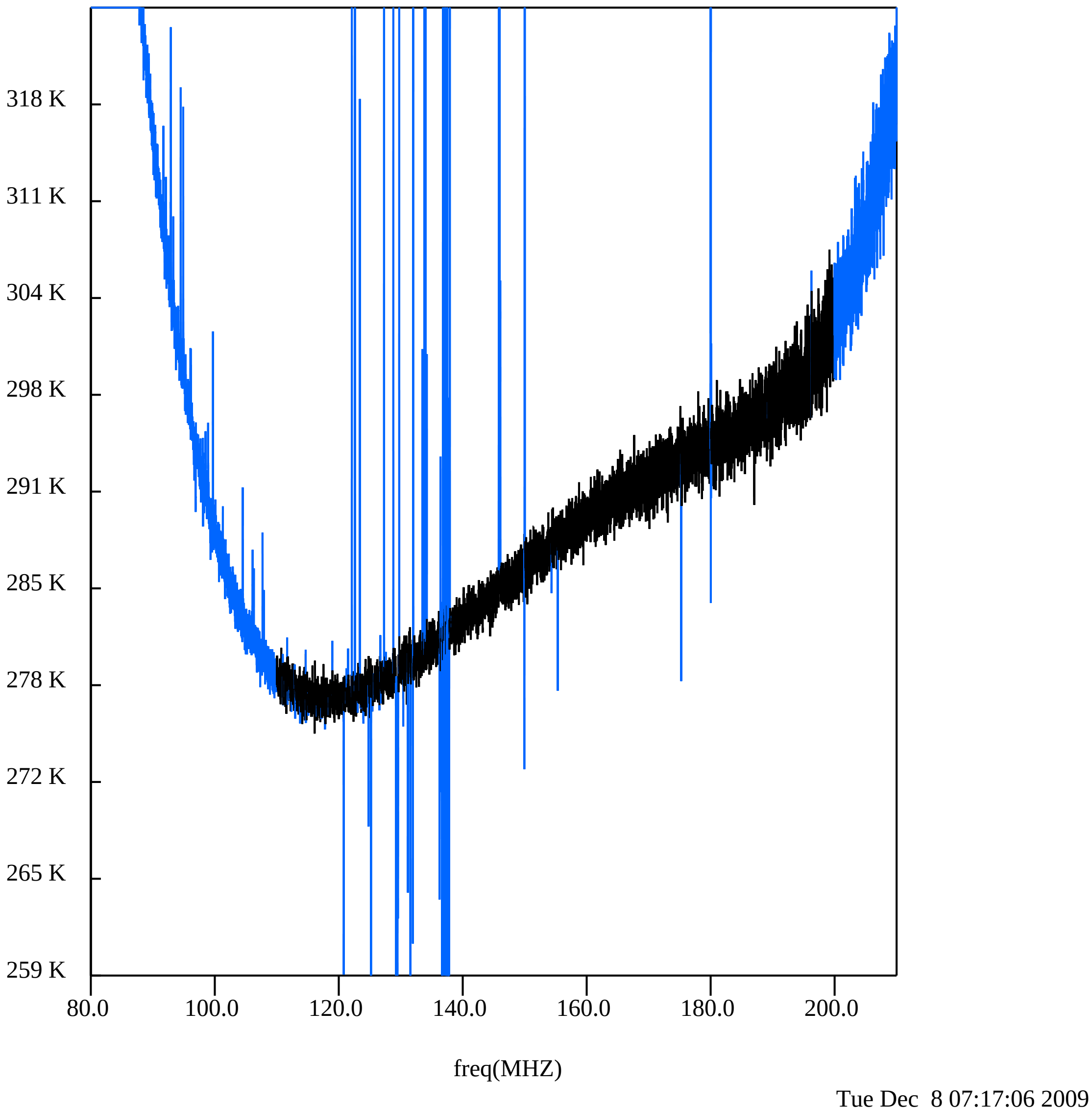

Figure 1. GNC spectrum for 2009_265

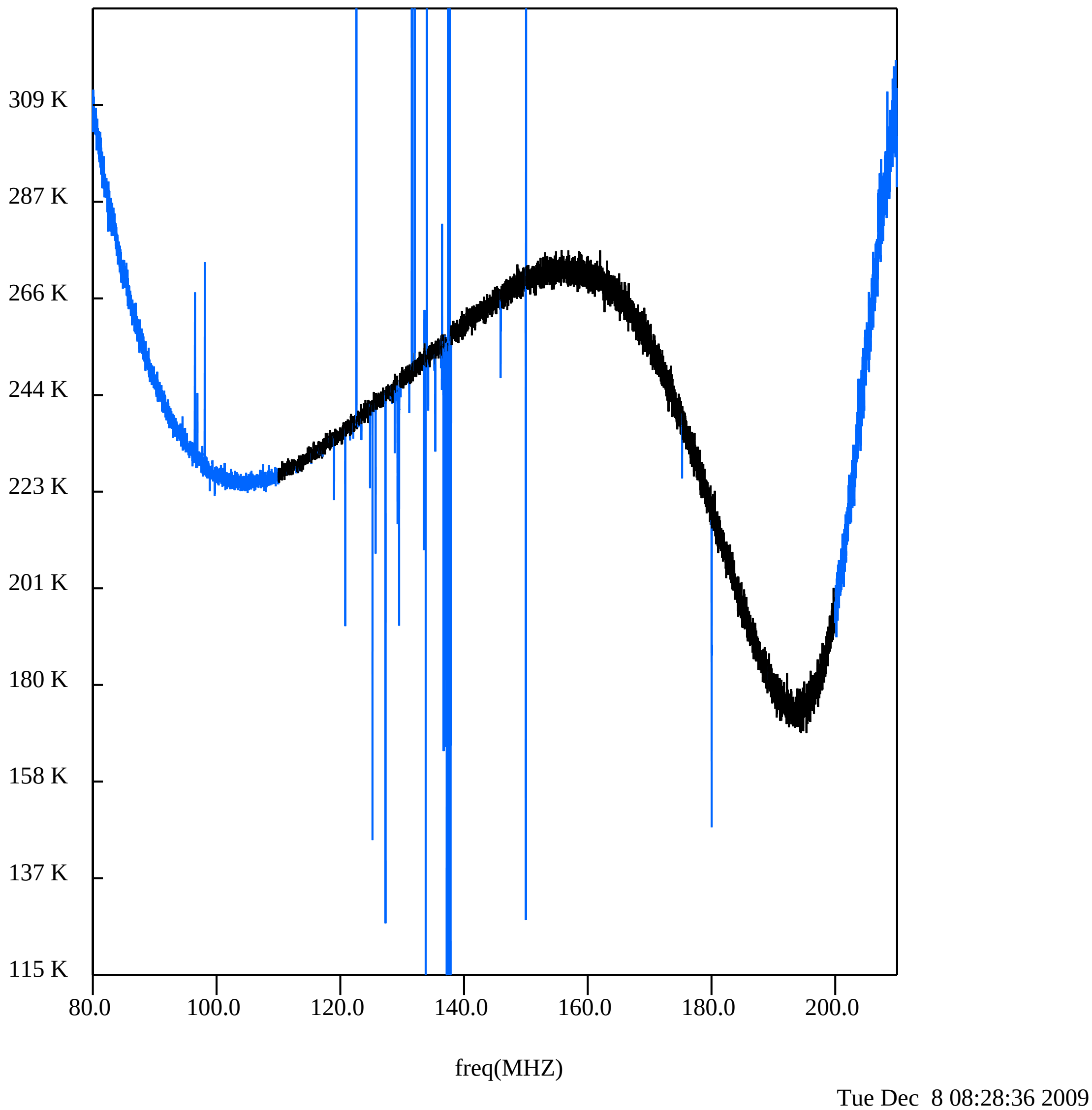

Figure 2. Anomalous GNC spectrum for 2009_258

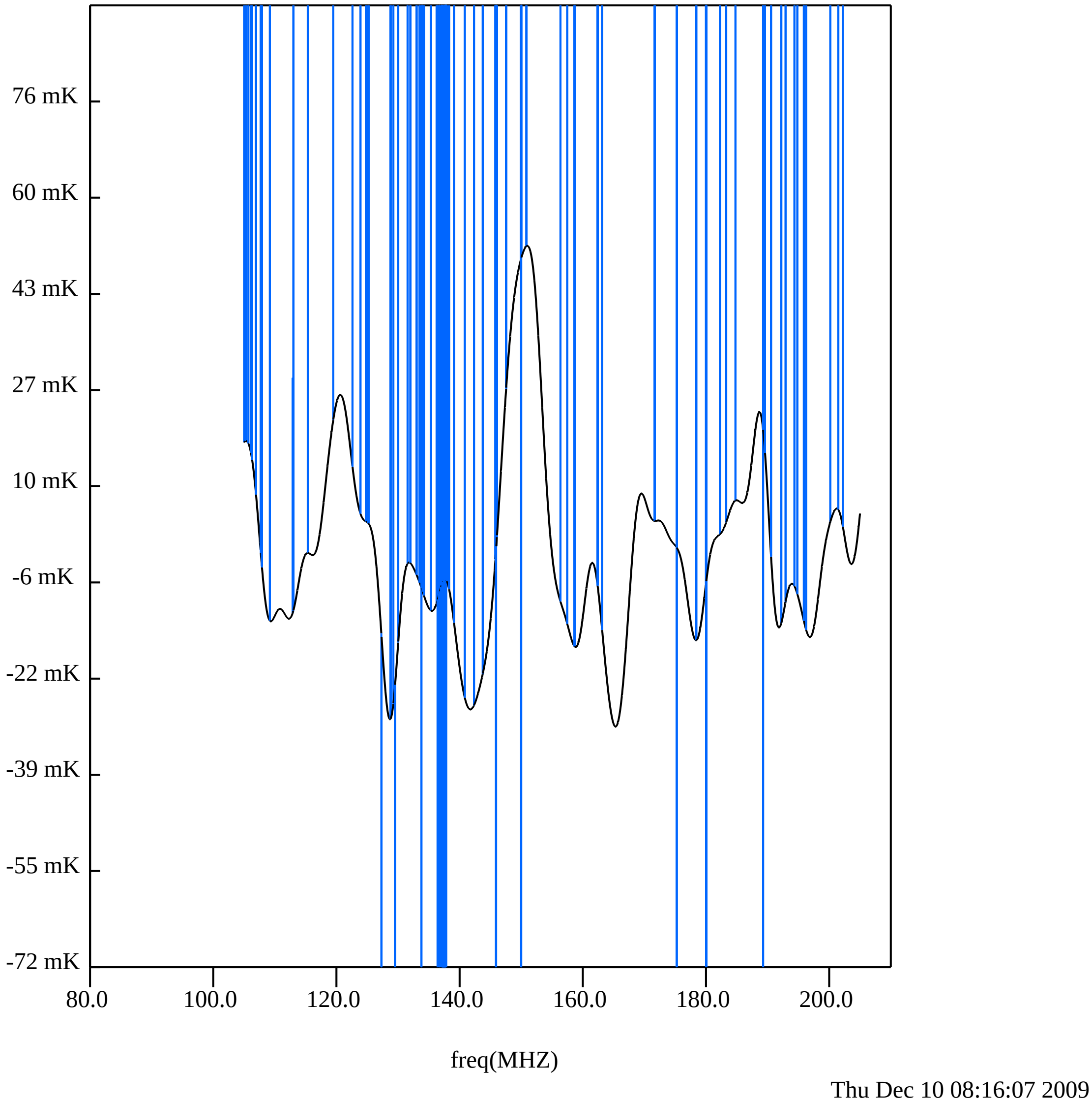

Fig 3. GNC spectrum average for 28 days.

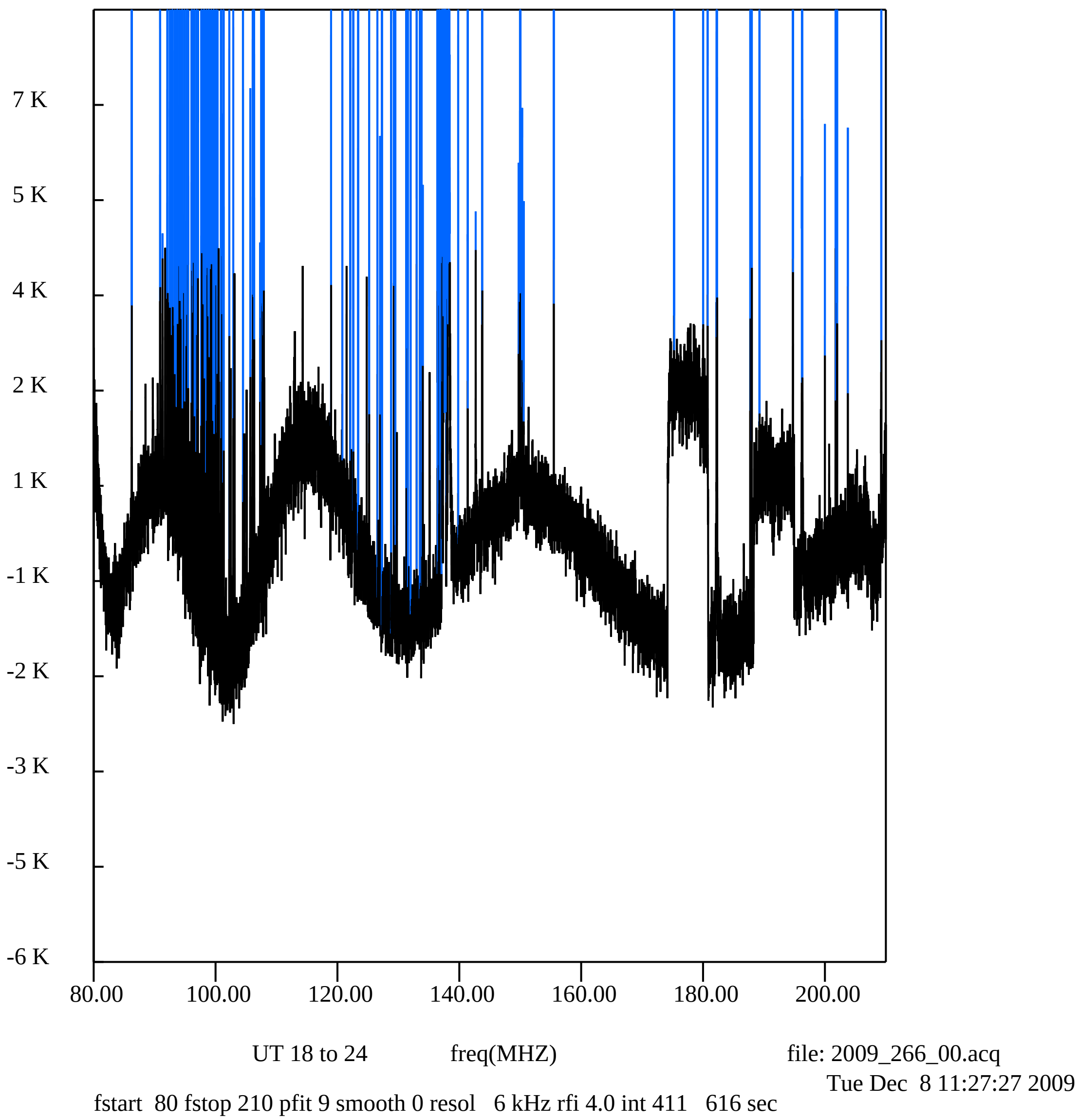

Fig 4. Spectrum for 2009_266 showing channel 7 and 9 TV RFI.

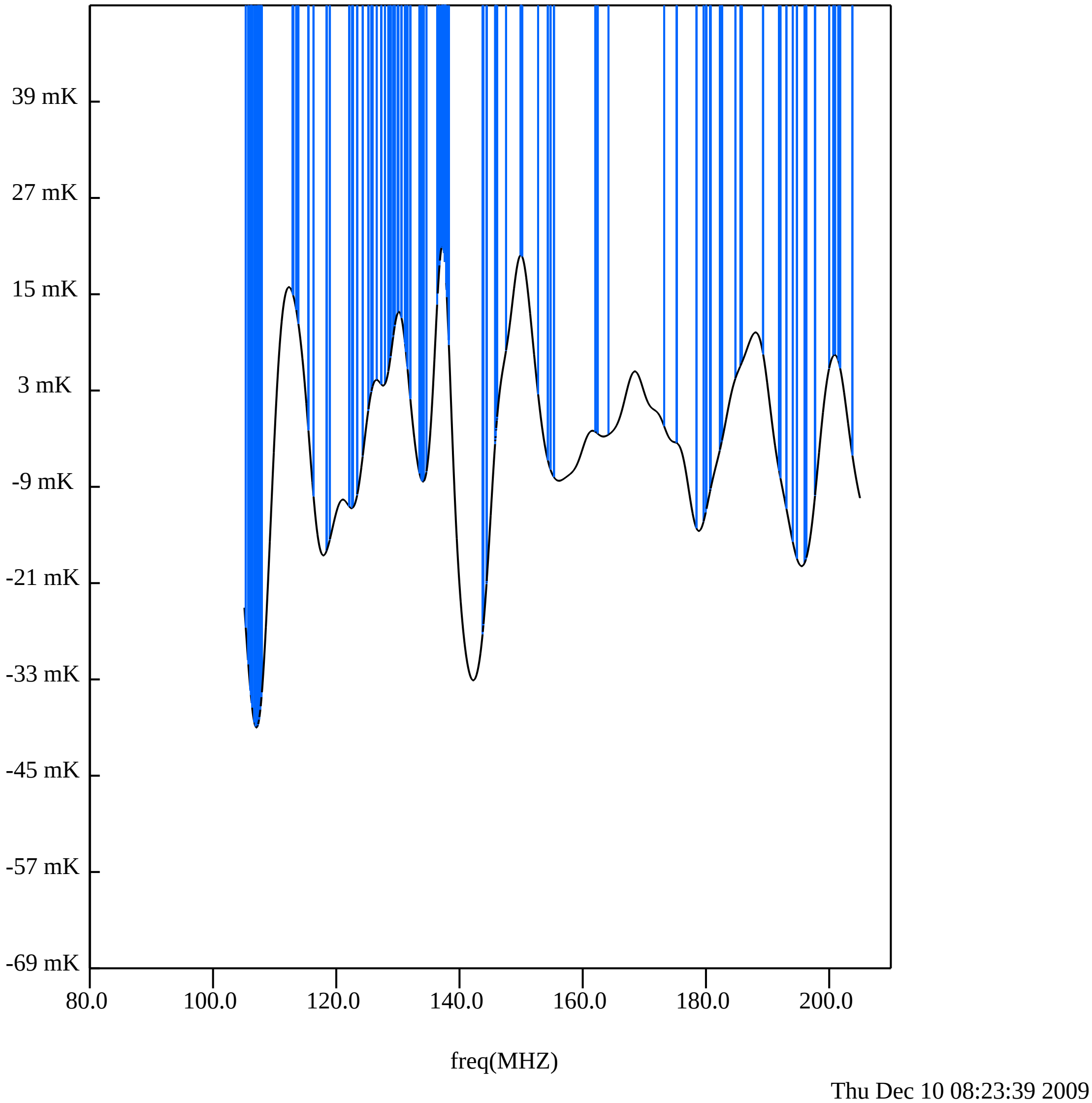

Fig 5. Average spectrum for 28 days