Systematic errors and Artifacts in spectrometers

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3 position switching

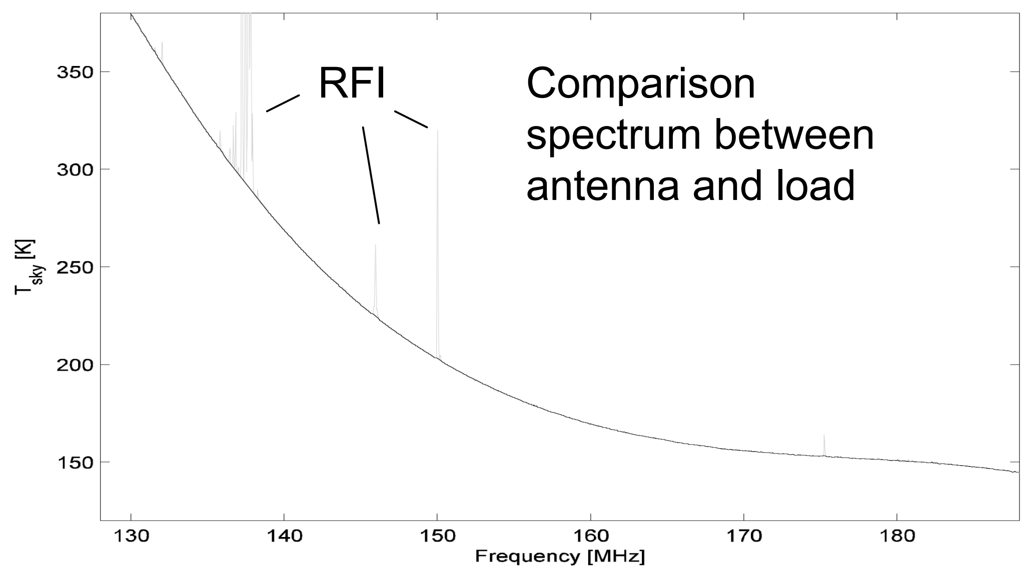
An ideal spectrometer has a perfectly flat frequency response. In the EDGES Acqiris spectrometer 3 position switching was used to remove the “bandpass”. In this case:

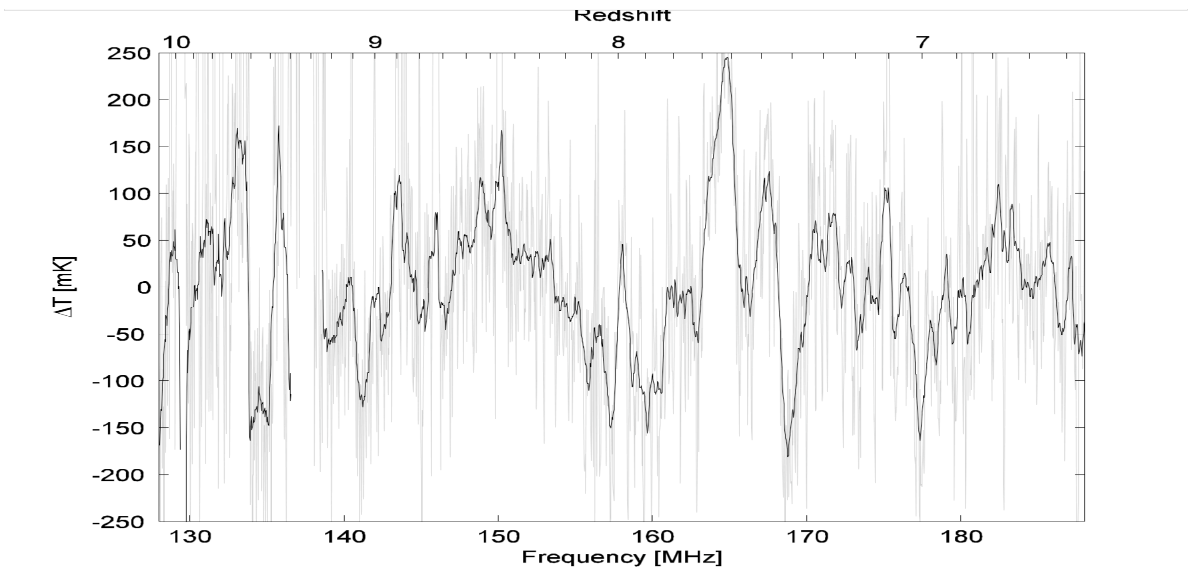
$$p0 = g(Ta + Tr) + c$$
$$p1 = g(Tload + Tr) + c$$
$$p2 = g(Tcal + Tload + Tr) + c$$

where:

Ta= antenna temperature
Tload = load temperature
Tr = receiver temperature
Tcal = calibration temperature
g = gain or bandpass function
c = constant receiver contribution

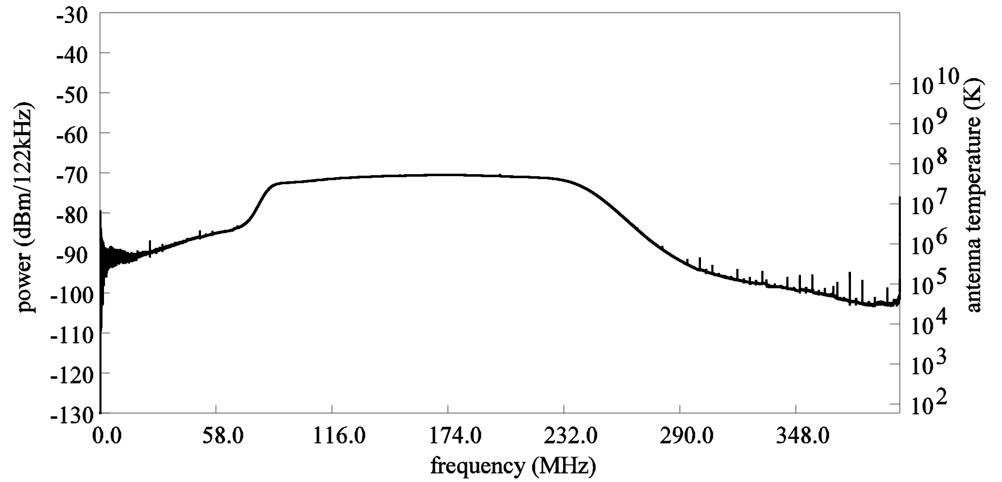
$$Ta = (p0 - p1) / (p2 - p1) + Tload$$





Residual systematics after removal of 7^{th}-order polynomial fit to spectrum

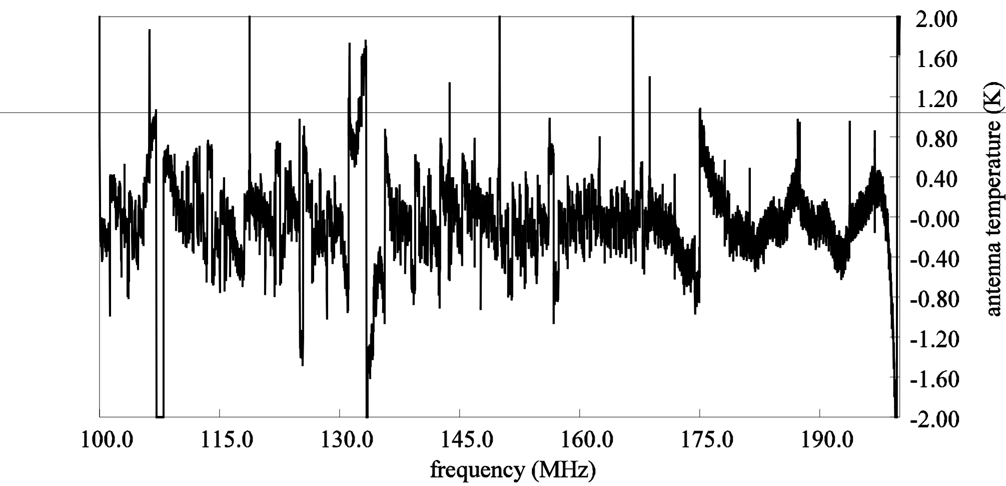
Bowman, J.D., Rogers, A.E.E. Hewitt, J.N. 2008, "Toward empirical constraints on the global redshifted 21 cm brightness temperature during the Epoch of Reionization" *Ap.J.*, **676**, Issue 1, pp. 1-9.



cor 1 npoly 0 dtyp 0 smooth 0 mdl 0.00 t150MHz nan tr nan tc nan file: 2007_029_17.acq
Acqiris fpgatm 42.8 degC adc 9 accum 0 fsv 0.50 pwr 3.0e+11 0.0e+00 0.0e+00 nav 17 srate 800
start 2007:029:17:02:15 stop 2007:029:18:30:59 res. 122.0 kHz cable 0.0 rfi 0 ref 0 avm 0 adcf 0 crr 0

Fri Feb 2 13:46:03 2007

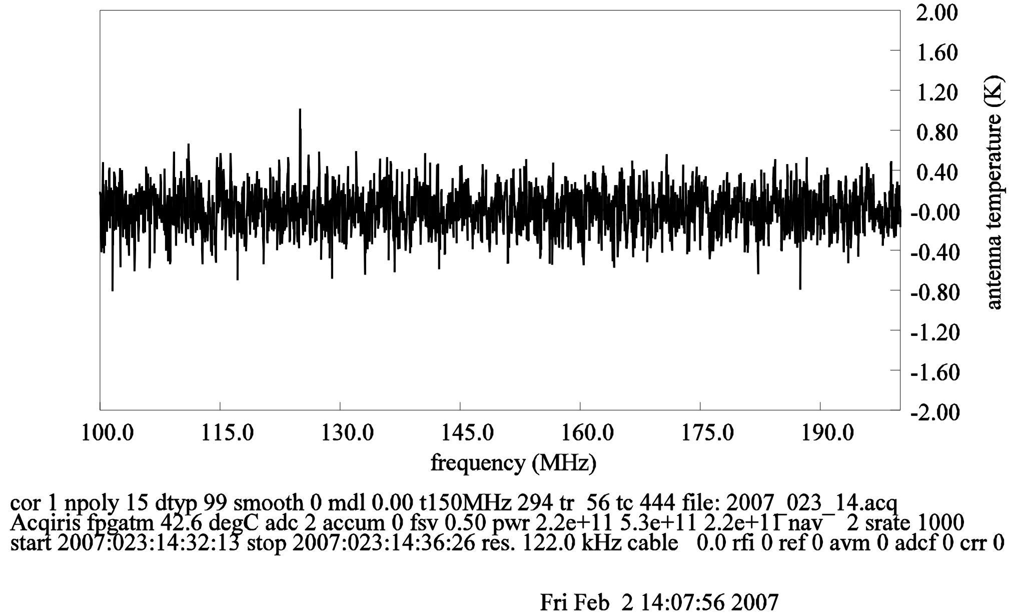
Spectrum of noise source from AC240 with 800 Ms/s. Note the spurs and steps in the spectrum beyond the edge of the analog filter at about 280 MHz



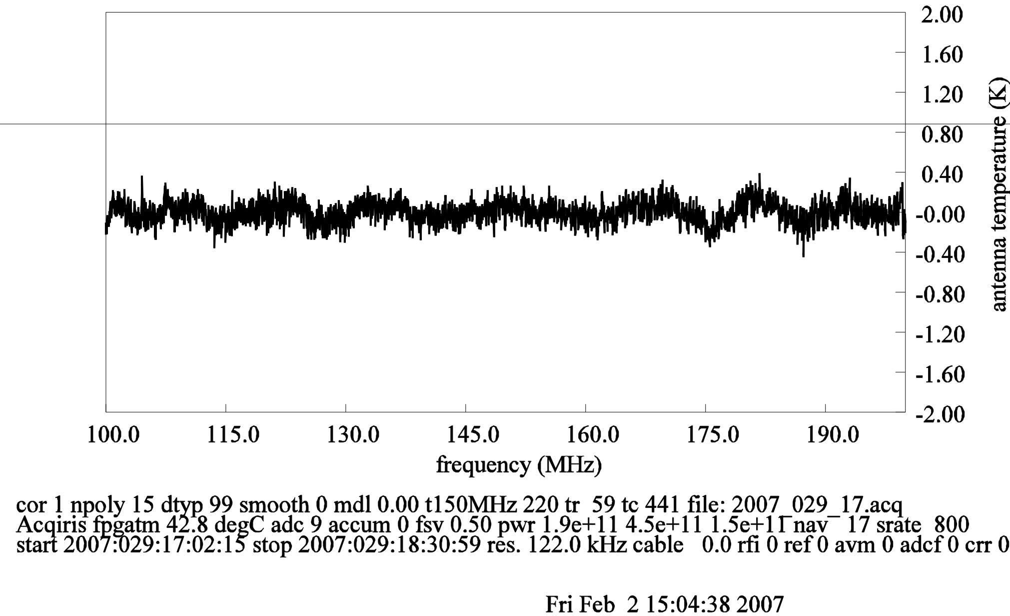
cor 1 npoly 15 dtyp 0 smooth 0 mdl 0.00 t150MHz nan tr nan tc nan file: 2007_029_17.acq
Acqiris fpgatm 42.8 degC adc 9 accum 0 fsv 0.50 pwr 1.9e+11 0.0e+00 0.0e+00 nav 17 srate 800
start 2007:029:17:02:15 stop 2007:029:18:30:59 res. 122.0 kHz cable 0.0 rfi 0 ref 0 avm 0 adcf 0 crr 0

Fri Feb 2 13:55:41 2007

The spectrum from 100 to 200 MHz of the data in figure above after the removal of a polynomial. The vertical scale is now expanded to a linear temperature



The difference spectrum between antenna and load at the same temperature



The difference spectrum between antenna and load at different temperatures

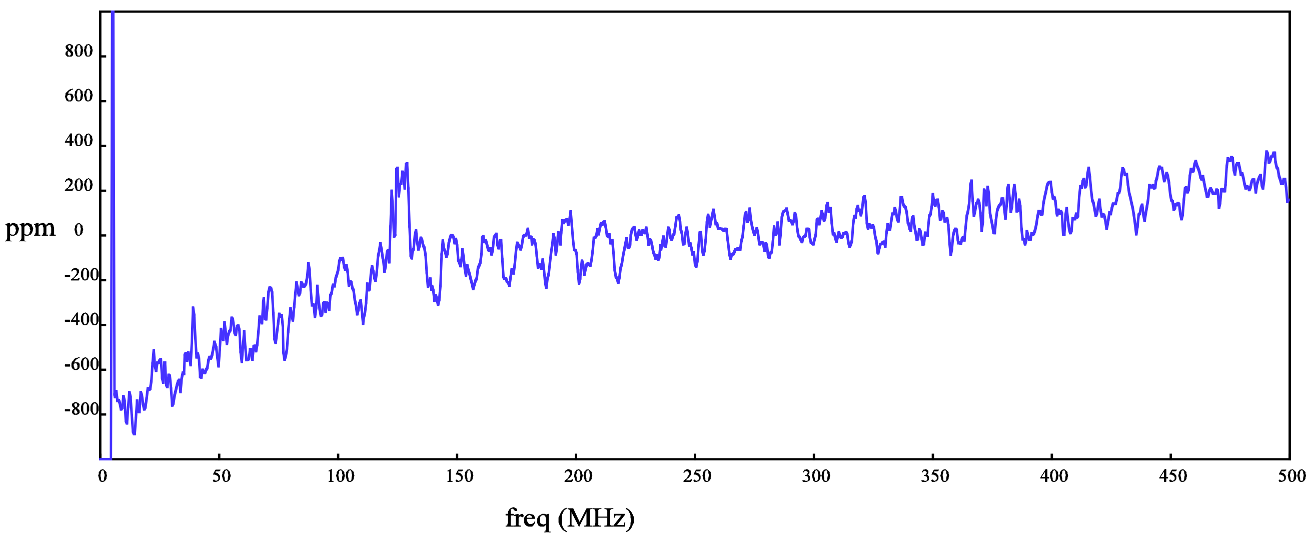
Defects by Dicke switching between a flat a linearly sloping spectrum which goes from 0.25 to 0.75 and a flat reference spectrum. In this case the total power for signal is half that of the comparison. The ADC defects result in deviations from the linear slope.

a. Non-linearity in the ADC amounting a peak deviation of 1 bit
b. Feedback from MSB of the ADC delayed by samples at a level of -70 dB below the ADC full scale
c. Sampling subharmonic at a level of -50 dBc
d. Spurs at a level of -90 dB below ADC full scale for resolution of 0.1% of the bandwidth.

ADC defect	#bits in ADC	Peak error (ppm)	Effect
Non-linearity 1 bit	7 8 9	500 100 30	Smooth distortion
Feedback -70 dB	Independent of # bits	50	Ripple
Sampling sub-harmonics -50 dBi	“	50	Distortion, and aliasing of bandedges into band
Spurs -90 dB	“	50	Spurs which don’t cancel

This table illustrates how critical the ADC performance is to a spectrometer performance for long integrations at wide bandwidth. For example a level of 50 ppm should be reached in only 30 minutes of integration with 1 MHz resolution.

Figure shows an example of the effect of ADC defects on the Dicke switched difference spectrum. The ripples in the spectrum are the result of feedback from the sign bit of the output back to the input at a level of -80 dB relative to full scale. The 2.5 MHz spectral feature at 125 MHz and another at 375 MHz are the result of aliasing of the 2.5 MHz high pass filtering by the sample clock jitter at ¼ its rate at a level of -30 dBc.



Software Simulation of ADC defect

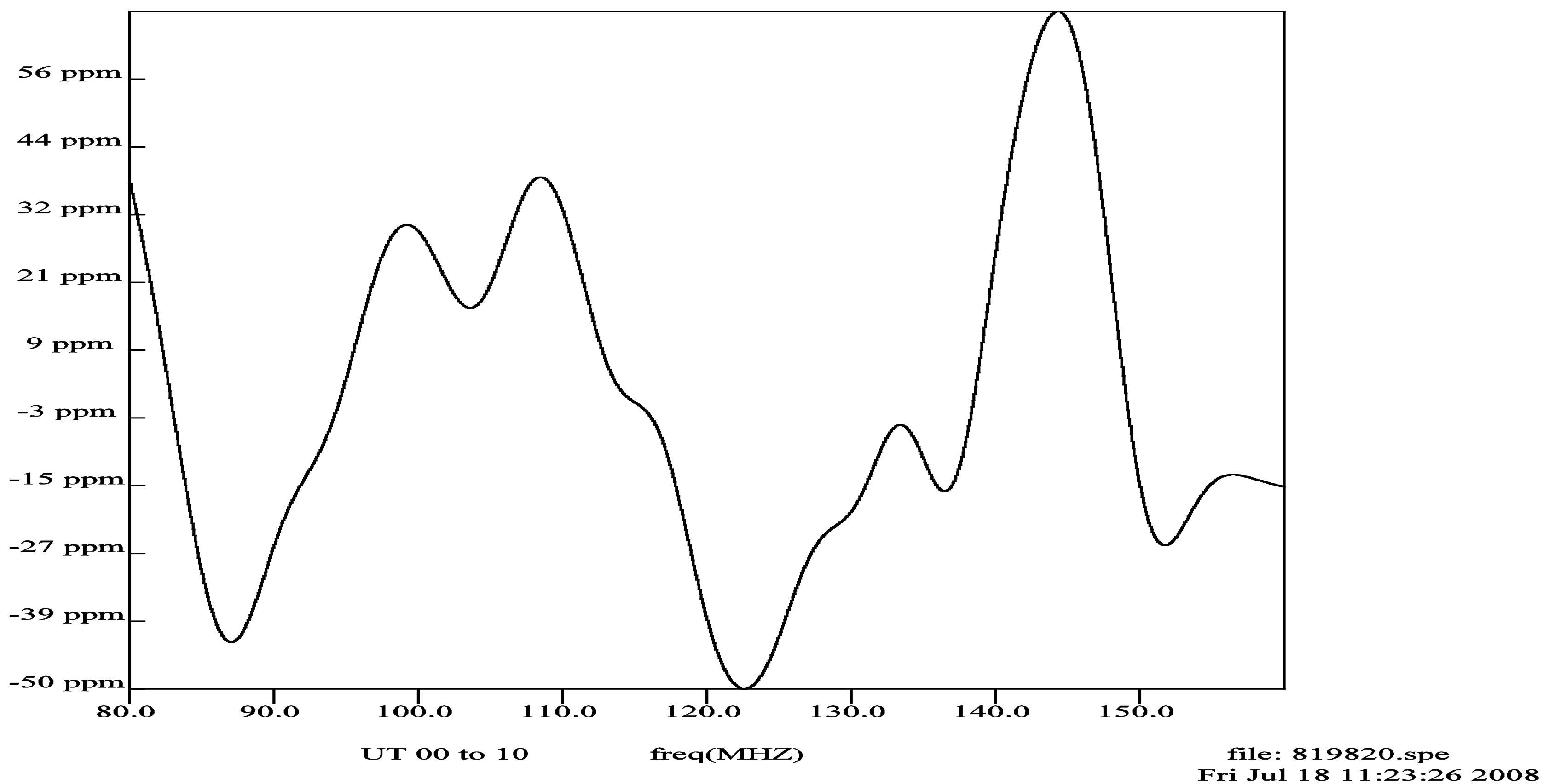
Mon Aug 6 22:31:27 2007

Frequency cycling

An alternate to 3 position switching in a spectrometer that employs a frequency shift mixing prior to the spectrum analysis to cycle the frequency shift. So that:

$$Ta(f) = \sum_{l=0}^{l=N-1} Ta(f)g(f+l) \Big/ \sum_{l=0}^{l=N-1} g(l)$$

where *g* (*l*) is bandpass function which repeats modulo N. In this case the bandpass function is equally sampled through its entire domain for every frequency, if the local oscillator is cycled with a step size equal to the frequency spacing. In practice even a step size larger than the frequency spacing will decrease the bandpass variation by a large amount.



Current limits over 2:1 frequency range:

~ 25 ppm rms which is reached in 4 hours at 10 MHz resolution

By stepping 5 MHz spectrum from 12-bit ADC @ 40 Ms/s from 60-200 MHz. Both 3-position switching and frequency cycling used with an updown converter.

Conclusions

- Direct sampling 8-bit ADC/FPGA worked well for 2006 EDGES expt
- But 8-bits is marginal owing to the presence of strong signals like those of Orbcomm 137-138 MHz and Artifacts are a problem
- Possible solutions are UpDown converter + narrowband spectrometer + frequency cycling OR new improved direct sampling