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To: EDGES Group
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Subject: EDGES data analysis

1] Spectrum calibration and bandpass removal

The EDGES radiometric spectrometer takes spectra in 3 switch positions.

Sw posn.	
0	Ambient load
1	Ambient load + calibration noise
2	Ambient load + antenna input

If the effects on mismatch are ignored

$$p_0 = g\left(T_L + T_R\right)\left(1 + n_0\right) \quad (1)$$

$$p_1 = g\left(T_L + T_R + T_{cal}\right)\left(1 + n_1\right) \quad (2)$$

$$p_3 = g\left(T_A + T_R\right)\left(1 + n_2\right) \quad (3)$$

where

p_0, p_1, p_2	are the power spectra
g	frequency dependent gain or bandpass
T_L	Ambient load temperature
T_R	Total receiver noise
T_{cal}	Calibration noise
T_A	Antenna temperature
n_0, n_1, n_2	Gaussian noise = $\left(b\tau_i\right)^{-1/2}$
b	Resolution bandwidth (Hz)
τ_i	Integration time (sec)

From equations 1,2,3

$$
\begin{aligned}
T_A &= T_{cal}\left(p_2 - p_0\right)/\left(p_1 - p_0\right) + T_L \\
&= \frac{T_{\mathrm{cal}}\, \mathrm{g}\left(T_A - T_L + n_2\left(T_A + T_R\right) - n_0\left(T_L + T_R\right)\right)}{g\left(T_{cal} + n_1\left(T_L + T_R + T_{cal}\right) - n_0\left(T_L + T_R\right)\right)} + T_L \\
&= \left[\left(T_A - T_L\right) + n_2\left(T_A + T_R\right) - n_0\left(T_L + T_R\right)\right] \\
&\times\left[1 + n_1\left(T_L + T_R + T_{cal}\right)T_{cal}^{-1} - n_0\left(T_L + T_R\right)T_{cal}^{-1}\right]^{-1} + T_L \qquad (4) \\
&\simeq T_A + n_0\left(\left(T_L + T_R\right)\left(T_A - T_L\right)T_{cal}^{-1} - \left(T_L + T_R\right)\right) \\
&+ n_1\left(T_L + T_R + T_{cal}\right)\left(T_A - T_L\right)T_{cal}^{-1} + n_2\left(T_A + T_R\right) \\
&\simeq T_A - n_0\left(T_L + T_R\right) + n_1\left(T_A - T_L\right) + n_2\left(T_A + T_R\right) \\
&\text{when } T_{cal} >> T_L
\end{aligned}
$$

If the total time for a 3 position switch cycle is T and f_0,f_1 and f_2 are the fractions of time spent in each position the noise in a measurement of T_A is

$$
\left[\left(f_0 bT\right)^{-1}\left(T_L + T_R\right)^2\left(f_1 bT\right)^{-1}\left(T_A - T_L\right)^2 + \left(f_2 bT\right)^{-1}\left(T_A + T_R\right)^2\right]^{1/2}
$$

$$
\simeq \left(5/2\right)^{1/2} b^{-1/2} T^{-1/2}\left(T_A^2 + T_L^2 + 2\left(T_A - T_L\right)^2\right)^{1/2}
$$

when TR is small and f_0, f_1 and f_2 are 2/5, 1/5, 2/5 respectively. For example if $T_A = T_L$ = 300K and T = 30 sec (b = 122 kHz)

ΔT_A rms ~ $550mK$

If the results of 100 cycles (~ 1 hour) are averaged and the resolution is smoothed to 1 MHz the rms noise is reduced to approximately 20 mK.

2] RFI reduction

There are a number of options for RFI reduction. The most extreme is to excise any cycle which has any spectral point above 10 sigma. A less extreme approach is to exclude spectra channels which exceed 10 sigma or some other fixed threshold.

3] Processing method

a. Perform calibration on each cycle using equation (4)

b. Search for 10 sigma deviations in residuals to sliding polynomial fit of n terms over m spectral points. Mark rfi channels and save rfi spectrum separately.

c. Remove cable ripple by fitting ripple period plus polynomial if in absolute mode.
- cable x (x = cable length in ft)

d. Correct for cable attenuation

e. Correct for antenna VSWR and balun loss

f. Calculate VSWR if in VSWR mode

g. Remove polynomial with n terms
control – npoly n (default 0)

h. Plot waterfall with max scale of 10^nK control –water n

For averages

i. Average results of each cycle keeping rfi removed points separate for plotting in blue. Also estimate noise for each spectral point.

j. Remove bestfit polynomial from average

k. Smooth over n spectral points
Control: - smooth n (default 0)

l. Set linear plot scale max and min
Control: - lin max_min (default 0-0)

m. Convert to fractional units if desired
Control – ppm 1 (default 0)

The steps c thru c are controlled by the keyword “cor”

- cor 1	EOR mode – no cable correction
- cor 2	EOR mode – corrects for cable
- cor 3	absolute antenna temperature
- cor 4	- not used
- cor 5	VSWR mode – returns reflection coefficient