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To: EDGES Group
 From: Alan E.E. Rogers
 Subject: Preliminary results of modeling EDGES

In order to “calibrate” single antenna measurements over a range of frequencies the “traditional” method involved the following:

1. Match the antenna to a standard impedance which is usually 50 ohms.
2. Either make a LNA with 50 ohm input impedance or use an isolator in front of the LNA or use dual LNAs with quadrature hybrids. (see EDGES memo #10)
3. Switch the input between the antenna and a “hot” and “cold” load.

In this case the antenna temperature is given by

$$T_A = (T_H - T_a)(P_A - P_C)/(P_H - P_C) + T_c$$

Where P_A, P_H, P_C are the measured power on antenna, hot load, cold load respectively. In EDGES the hot load is a previously calibrated noise source and the cold load is an ambient temperature load. To cover a range of frequencies the antenna has to be returned at each frequency with a matching device.

In the case of EDGES the antenna is not matched to 50 ohms and there is no isolator between the LNA and the input. As a result the “antenna temperature” from the 3-position switch doesn’t equal the “true antenna temperature” which equals the sky brightness convolved with the antenna pattern. The true antenna temperature can be obtained from the measured temperature from the 3-position switch by modeling. The modeling requires the following:

1. Measurements of the antenna impedance balun included
2. Measurement of balun open and shorted impedance.
3. Measurement of spectrum with low loss open end cable connected to the 3-position switch in place of the unbalanced end of the balun.

The modeling then proceeds as follows:

1. The real and imaginary components of the antenna impedance and fit with a polynomial to reduce any noise in the measurements.
2. The balun is modeled as a 4 terminal “PI” network where the parallel impedance on the antenna side is twice the impedance of each ferrite choke assumed to be resistance in parallel with half the capacitance of the short connecting coax. The series impedance is taken as the inductance of the short coax and the parallel

impedance of the balun on the receiver side is taken as half the short coax capacitance. The equivalent temperature out of the balun is the combination of the sky noise attenuated by the balun and the resistive noise at ambient temperature from the ferrite chokes.

3. Antenna impedance is transformed and attenuated by the short coax path from the antenna connection to the input of the LNA.
4. The LNA output spectrum is modeled using the noise model of figure 3 in memo #62 with the addition of a low pass filter at the input of the LNA consisting of a PI network of 2 270 nH inductors and a series 100 pf capacitor. In the case of modeling the hot and cold loads of the 3-position switch an impedance of 50 ohm is assumed along with the appropriate temperature.

Tests of the model

In order to test the modeling I measured the impedance of the EDGES antenna set-up at Haystack using a network analyzer. Unfortunately was not able to use exactly the same antenna and balun as used in the measurements made in Boolardy in 2009 as this antenna and balun were destroyed in a windstorm. I also used the network analyzer to measure the balun open and shorted impedance. The first test was to compare the model with data taken with the EDGES connected to a 186 cm length of LMR-240 open at the end.

Adjusting the model parameters to fith the open cable data the following were obtained:

Feedback	0.65 <i>pf</i> (-13%)	Parallel with	1200 Ω
Rs	0.4 nH	In series with	0.5 Ω
Cg	1.12 <i>pf</i>		
Rout	80 Ω		
Rg	2.5 Ω		
gm	0.41 s (-10%)		
Delay in gm	12 ps		
Coax delay	0.63 ns		

Where the numbers in () are the percent adjustment made from nominal to best fit shown in figure 1. The balun parameters derived from the network analyzer were as follows:

Antenna site 900 Ω in parallel with 3.33 *pf*

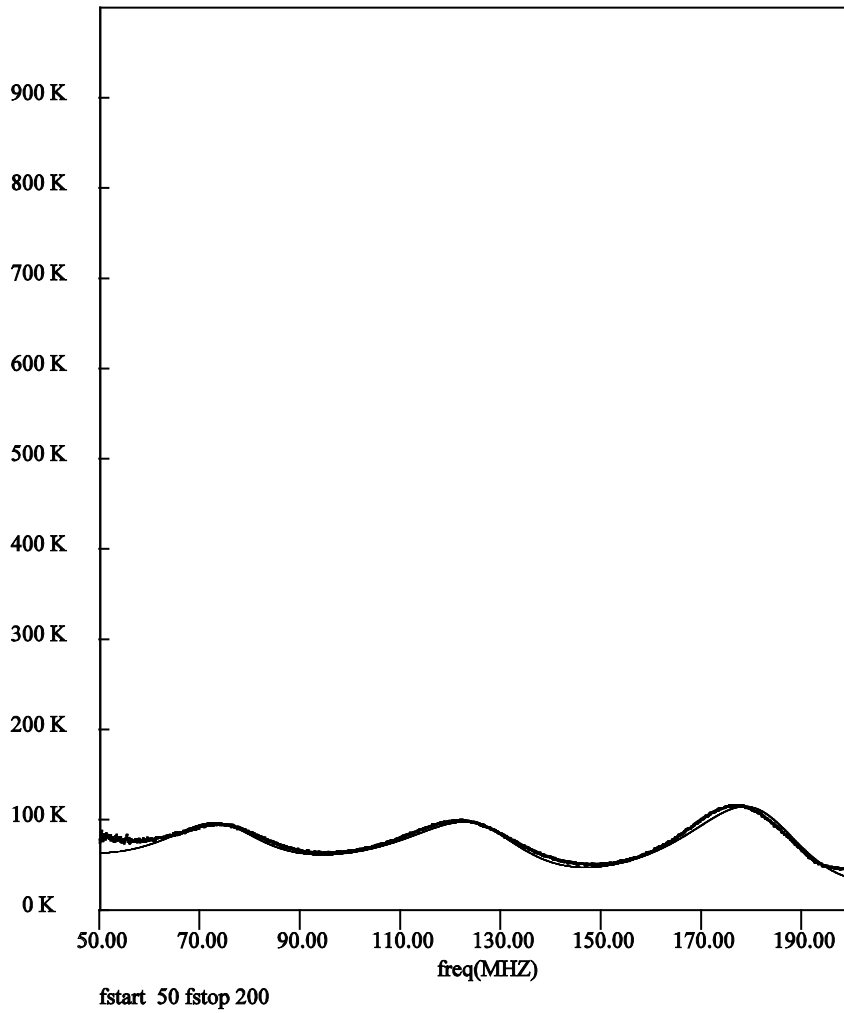
Series inductance 16.667 nH

Receiver side 3.33 *pf*

Figure 2 and 3 show the model fit to the data for 0 to 1 hr UT and 12 to 13 hr UT on day 2009_240. The bestfit spectral index was close to -2.4 in each case but changes to about

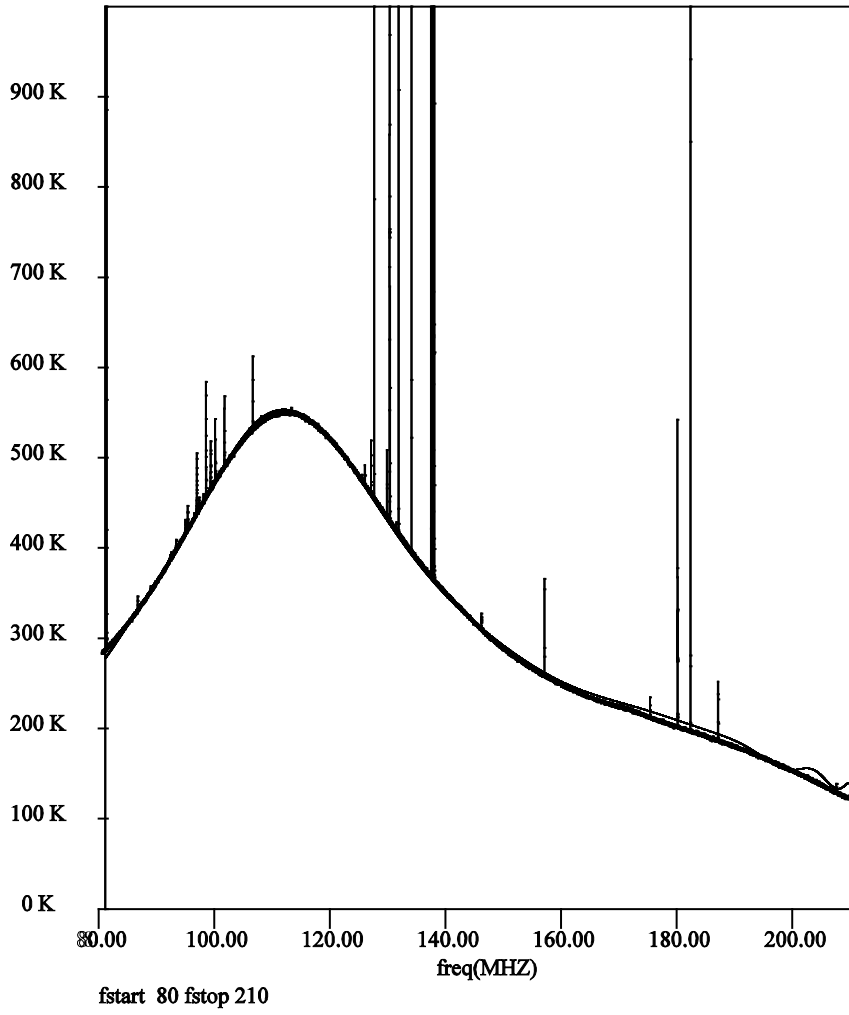
-2.5 if the values of the best fit g_m and feedback capacitance¹ are also determined from the sky data. These differences are being examined but could be the result of errors in the antenna impedance measurements, differences between the antenna and balun used to be the sky measurements and that for which the impedance measurements were made or errors in the model.

¹ These were -13% and -18% for capacitance and g_m respectively.



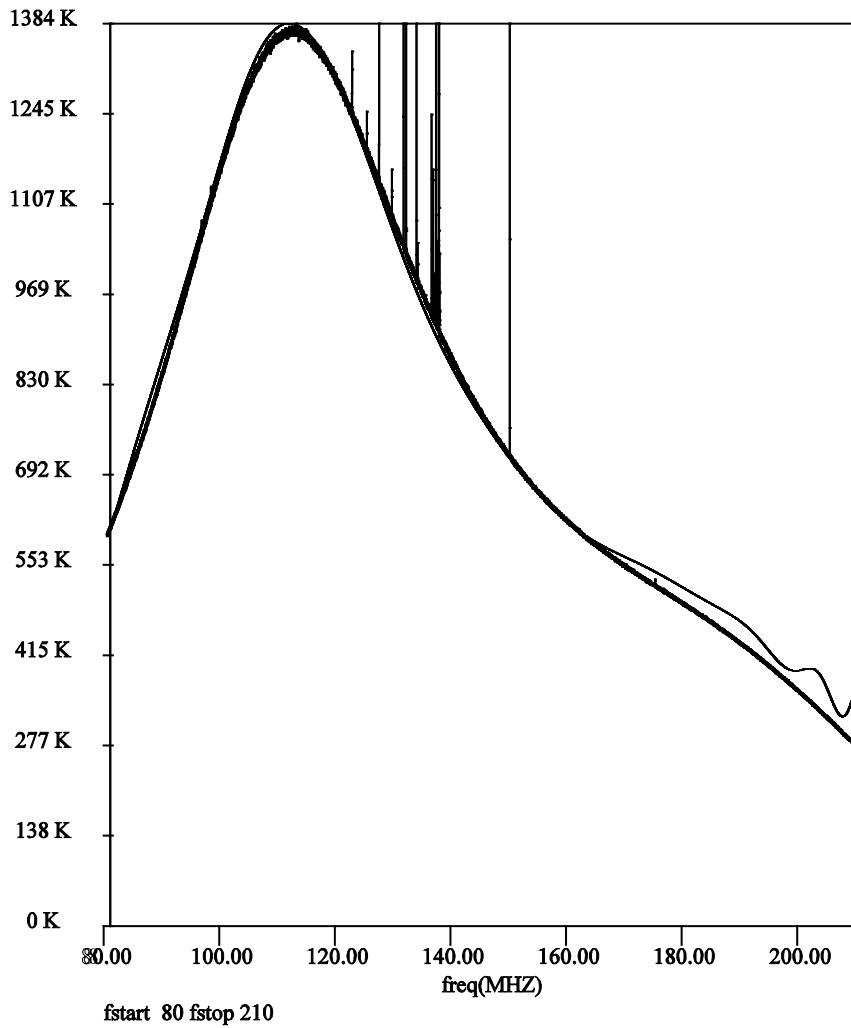
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Figure 1. Open line. The thick curve is the data and the thin curve is the best fit model after LNA parameter adjustment.



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Figure 2. Model fit to observations for 0 to 1 hr UT on 2009_240.



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Figure 3. Model fit for data from 12 to 13 UT (Galactic center overhead) on 2009_240. Thin curve is model. Ripples in model at 200 MHz are due to sparseness of antenna measurements which were taken every 10 MHz from 50 to 210 MHz.