EDGES MEMO #096

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
HAYSTACK OBSERVATORY
WESTFORD, MASSACHUSETTS 01886

October 10, 2012

Telephone: 781-981-5400
Fax: 781-981-0590

To: EDGES Group

From: Alan E.E. Rogers

Subject: Summary of EDGES-2 calibration and processing

1] Laboratory Measurements

Perform S11 measurements of ambient, hot and noise wave measurement cable at nominal lab temperature of 25 °C. Measure S11 of LNA at 5, 25 and 45 °C. Measure spectra of ambient, hot and cable at 5, 25 and 45 °C.

2] Processing of Laboratory measurements.

Since the ambient and hot loads are not perfect LNA noise waves will be reflected from these loads so that an internal noise diode calibration is made assuming zero for the 3 noise waves:

$$thot = w3pinv\left(S11_{hot}, S11_{\text{lna}}, sp_{hot}, o\right)$$

$$tamb = w3pinv\left(S11_{amb}, S11_{\text{lna}}, sp_{amb}, o\right)$$

Where w3pinv is the inverse of the function w3p (equ.(13) of ref 1) which gives the output of the 3-position switch as a function of the S11 of the load, S11 of the LNA, temperature of the load and the LNA noise parameters.

$$sp = w3p\left(S11, S11_{\text{lna}}, t, nw\right)$$

Where sp is the output spectrum and temperature S11 and t are the reflection coefficient and temperature of the device attached to the 3-position switch input. $S11_{\text{lna}}$ is the S11 of the LNA and nw is the array of 3 LNA noise waves.

The first order scale factor, sca, and offset, ofs, errors in the EDGES spectrometer are given by

$$sca = \left(hot - amb\right)/\left(thot - tamb\right)$$

$$ofs = tamb - amb$$

These values are used to correct the spectra and solve for the noise waves and update the values of $thot$ and $tamb$. Convergence is reached in about 3 iterations when $thot$ = hot and $tamb$ = ambient temperatures. The iterative scaling can then be combined into a single scale and offset for correcting the sky spectra.

$$scale = \prod_{0}^{N-1} sca_i$$

$$offset = \sum_{0}^{N-1} \left[ofs_i \left(\prod_{j=i+1}^{N-1} sca_j \right) \right]$$

$$sp_c = \text{scale} \times (\text{sp-offset})$$

The scale and offset as well are noise wave parameters are estimated for widely separated temperatures (nominally 5,25,45 °C) so that interpolated values along with interpolated values of the LNA noise wave parameters and S11 for the LNA can be used to correct antenna spectra for intermediate temperatures.

3] Field Measurements

Lacking the provision to make repeated measurements of the antenna S11 it is assumed that the antenna S11 will be stable over a large temperature range and every effort is being made to ensure that the EDGES-2 antenna S11 will remain within 0.01 dB and 0.5° over at least 10 °C with small corrections for the full range of 5 to 45 °C. The antenna, LNA S11, noise wave parameters as well as scale and offset corrections need to be smoothed by fitting appropriate fourier or low order polynomial series. While tests of the antenna show that the presence of the EDGES-2 front-end has a barely measureable effect on S11 the measurements should be made with the VNA coax routed through a dummy front-end box.

4] EDGES-2 spectral processing

The raw EDGES spectra are written to disk for the 3 positions of the input switch designated antenna, load, calibrate. Information on the LNA temperature is embedded in the spectra (see memo 92). The first stage of processing is to remove the RFI and average the spectra over a period of about one hour. These nominally hour averages can then be corrected for scale and offset using values for the average temperature for that hour. And then inverted using w3pinv with values of antenna, LNA S11 and LNA noise wave parameters for that temperature.

5] Parameter fit to search for 21-cm line

The calibrated spectra are then corrected for the effects of antenna beamshape based on the 408 MHz sky map and information on the sky spectral index (work in progress) before removing the effects of the ionosphere and remaining residual effects of the frequency dependence of the beamshape (see memo 94).