EDGES MEMO #081

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To: EDGES Group

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Subject: Initial Lab tests of absolute calibration

A. Required measurements

1] Measurement of the input impedance of the antenna port SMA female connector

2] Measurement of the antenna (or antenna simulator) impedance at the SMA male connector at the EDGES input.

3] Measurement of the impedance of the noise wave calibration cable at the SMA male connector

4] Impedance of ambient load SMA male connector

5] Impedance of hot load SMA male connector

6] Balun measurement

7] Spectrum from antenna

8] Spectrum of noise wave calibration cable

9] Spectrum of ambient 50Ω load

10] Spectrum of heated load

11] Spectrum of HP346 noise source via 6 dB attenuator.

12] Ambient temperature

The expectation is that all these measurements with the exception of #1, #7 and #12 can be made in the laboratory and saved in files to be used in the calibration of all data taken in the field.

B. VNA Calibration

Since VNA measurements are needed for both male and female SMA ports it is advantageous to have a SOL (short, open, load) calibrator of both sexes. If this is not available a software correction can be made when an adaptor is used.

C. Hot and ambient Loads

Measurement of hot and ambient loads are needed to calibrate the EDGES internal noise source for flatness and, owing to uncertainty in the temperature of the hot load, a measurement of the HP346 is needed to set an accurate temperature scale.

Unfortunately the ambient hot loads have an impedance which differs by a few tenths of a ohm from the normal 50 so that software corrections are needed.

For example, the load is not exactly 50 ohms the spectrum will differ by the factor

$$\left(1-|\Gamma|^2\right)\Big/\left(1-|\Gamma_{50}|^2\right)$$

Where $\Gamma_{50} = \left(50 - Z_\ell^*\right)\Big/\left(50 + Z_\ell\right)$

$\Gamma = \left(Z - Z_\ell\right)/\left(Z_2 - Z_\ell\right)$

Z = load impedance

Z_ℓ = LNA impedance

Which typically amounts to about 10^{-3} for 0.5 ohm deviation. The hot load (see memo #63) is 50.15 ohms at ambient and 50.500 ohms at $100^\circ C$. [Better high temperature resistors have been found and the hot load will be upgraded with a resistor which has less than 0.01 ohm error and less than $0.2\,\text{ppm}/{}^\circ C$. Temperature coefficient. Vishay Y17455OR000T9R z-foil SMD.]

D. Test using open 6 dB attenuator
An open 6 dB attenuator at ambient temperature simulates an isotropic antenna with reflection coefficient of 0.251 looking at uniform sky at the ambient temperature. Figure 1 shows the spectrum before and after calibration using the algorithms of the calibration paper ("Absolute Calibration of a Wideband Antenna and Spectrometer for Sky Noise Spectral Measurements," Rogers & Bowman in preparation) The rms error in the calibrated spectrum is 1.5 degrees and is largely the result of mismatch in the hot load.

E. Test using thermal noise from filament of a 28V lamp.
A "lamp" source was made by coupling the thermal noise from a lamp filament into EDGES. The impedance of the "lamp" source was measured with a VNA with the lamp turned on. This is critical as the filament resistance is a strong function of its temperature. Figure 2 shows the measured impedance and Figure 3 shows the calibrated spectrum. The measured temperature was only 1800 K because the 28v lamp was run at only 14v. The rms residuals are 10K and while some of the error is due to the mismatch of the hot load calibration most of the error is thought to result from unaccounted effects in the filament. For example the filament is not at a uniform temperature as the ends are not far above ambient. The non-uniform temperature would not be a problem if the resistance was constant but the skin effect makes the resistance a function of frequency. More study is needed to determine if this method of simulating an antenna is valid. A simulator based on the hot load design with low loss inductive and capacitive structure to force an impedance deviation from 50 ohms may be a better approach. Unfortunately the hot load is limited to relatively low temperatures compared with the lamp filament.

F. Another check on calibration

Another check on calibration is using the open cable data used to measure the noise waves as "antenna" data. Figure 4 shows the uncalibrated and calibrated result which should be the ambient temperature. In this case any errors are amplified by the division by $1-|\Gamma|^2$ which is a small number because of the small loss in the cable.

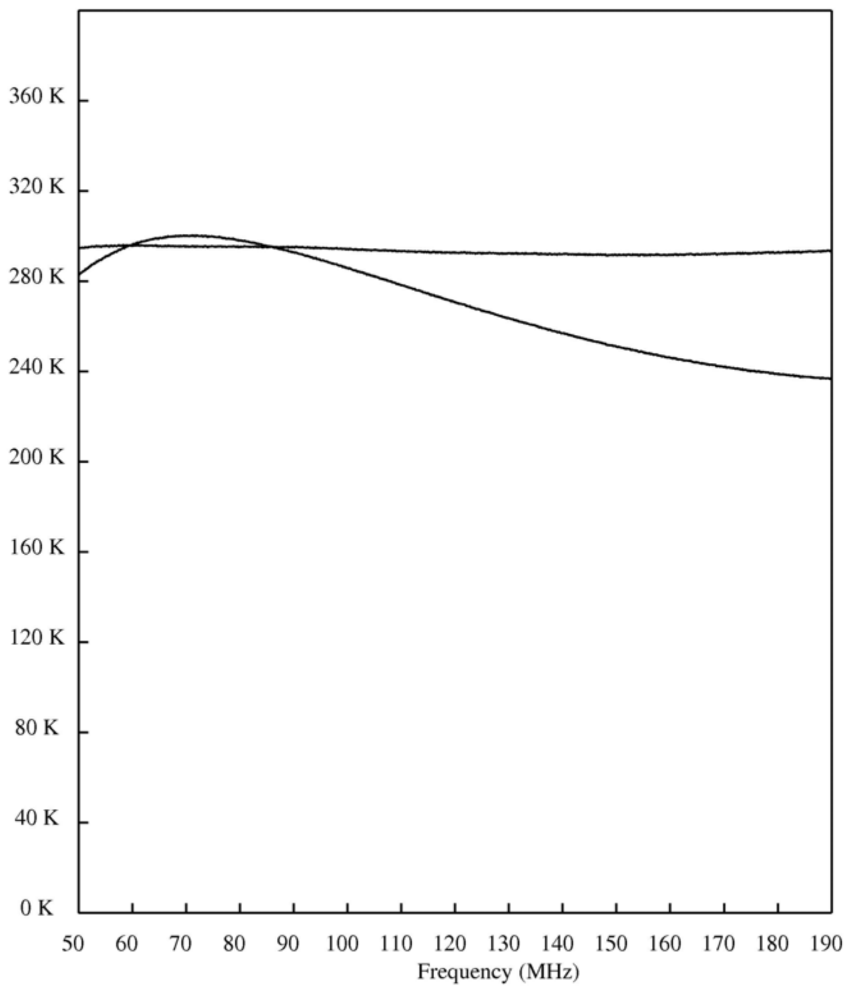

Figure 1. Upper and lower curves are the calibrated and uncalibrated spectra of the 6 dB "open ended" attenuator.

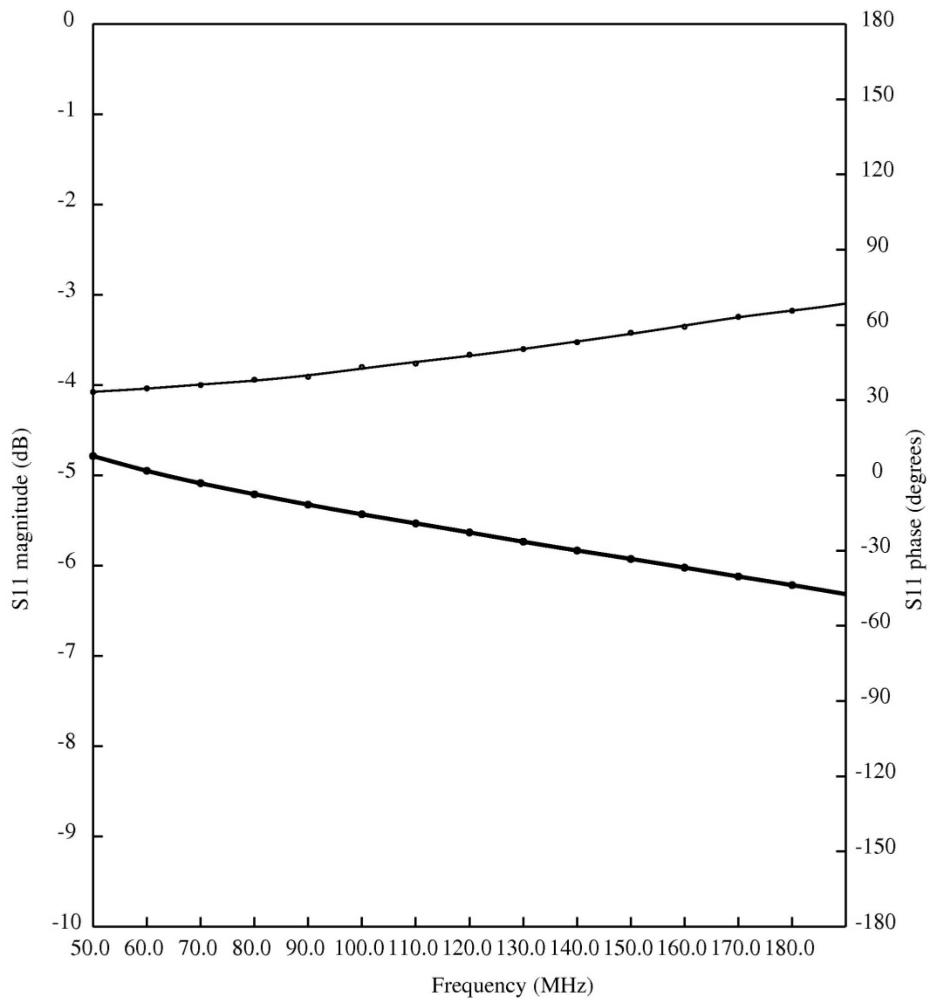

Figure 2. Reflection coefficient of “hot filament” source. Lower curve is the phase.

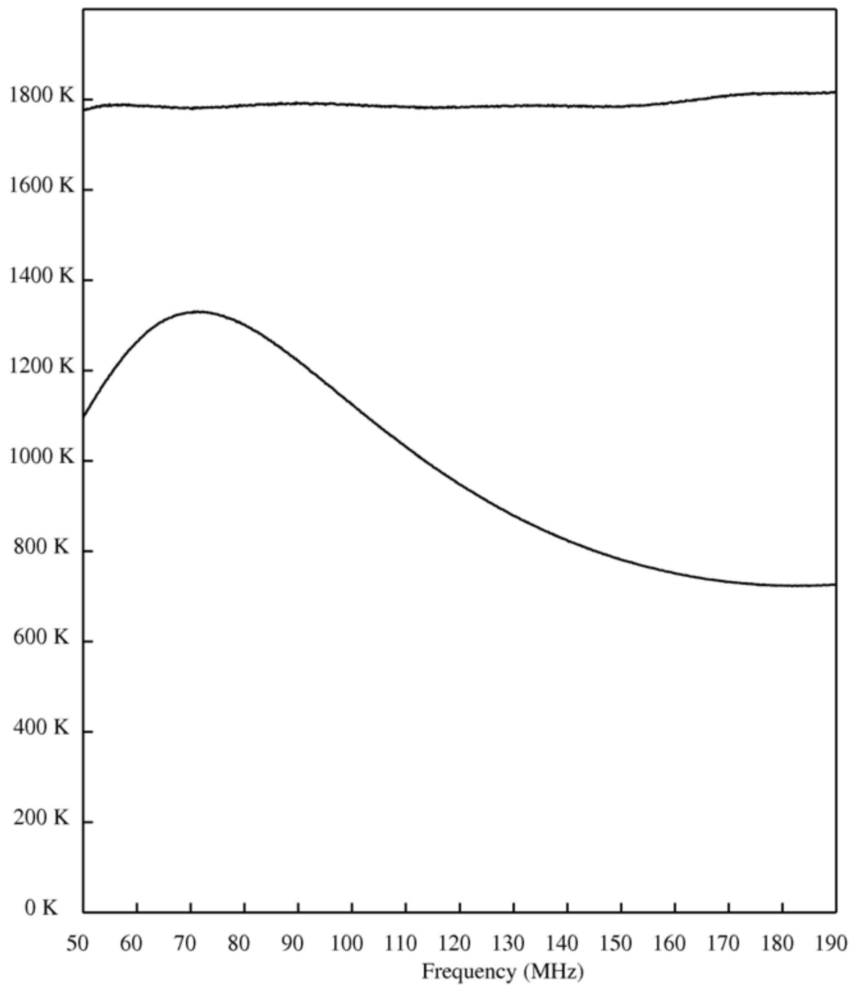

Figure 3. Upper and lower curves are the calibrated and uncalibrated spectra of the "hot filament" source respectively.

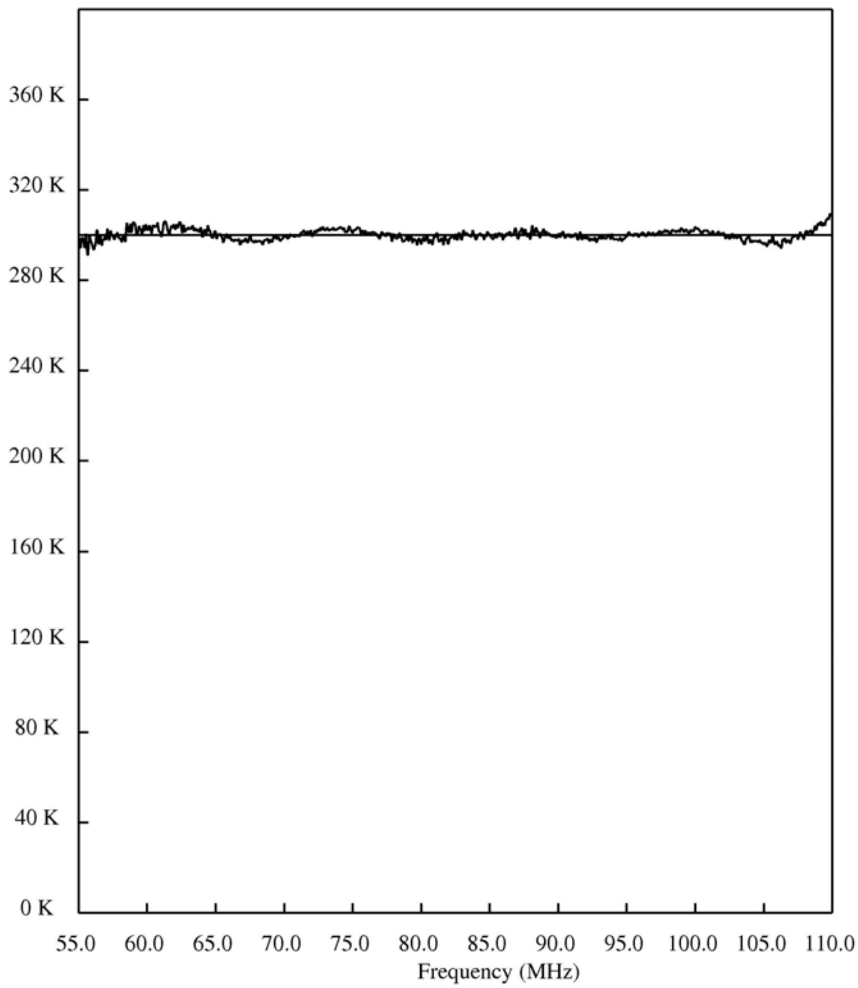

Figure 4. Upper and lower curves are the calibrated and uncalibrated spectra from the open cable.