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To: EDGES Group

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Subject: Simulations of the effects of EDGES-3 S11 corrections

In EDGES-3 the hot, ambient, open and shorted cables are not placed at the antenna input reference plane as in EDGES-2. There are two approaches to correcting EDGES-3. In the first approach both the spectra and the s11 need to be corrected to result in fully calibrated spectra with reference plane at the antenna input. In the second approach the reference plane is taken as the center of the 8 position switch (s8). In this approach only the s11 need to be corrected as long as the path from the center of the 8 position switch is considered part of the antenna and a correction for its loss is made. In this second approach the s11 corrections to the hot, ambient, open and shorted cable and the antenna involve the same S-parms which are those of the path from the antenna input.

A schematic of the 8 position switch along with 2 paths for the VNA is shown in Figure 1. VNA path 1 is used to:

a) Obtain the s11 of the internal SOL by measuring the s11 values of an external SOL calibration kit manually placed on the antenna input in the lab as in EDGES-2.
b) Obtain the s11 values of the antenna, hot, ambient load and open and shorted cables. Once calibrated these s11 values refer to the antenna input reference plane.
c) An additional s11 measurement can be made in which the s8 switch is left open (i.e. not connected to any input).

VNA path 2 is used to:

a) Measure the LNA s11 when s8 is connected to the VNA position indicated in Figure 1.
b) An additional s11 measurement can be made in which the s8 switch is left open and not connected to any input.

The additional measurements in which the s8 switch is left open for path 1 and 2 can be used along with the measurements of the internal open and short to move the reference plane to the center of s8. Also needed is a model of the cable and the short internal path in S8 from which the S-parameters can be calculated. These models can be checked using lab measurements of a sample cable and S8 switch.

Case	Description	Delay ps	Inches 1-way
1	Open at antenna	4	0.016
2	Calibration open	65	0.268
3	Internal open	-474	-1.955
4	s8 open path 1	-760	-3.135
5	s8 open path 2	-1606	-6.624

Table 1. Path length fits

Table 1 gives the best fit paths from the calibrated s11 data. Case 4 provides an estimate of S-parameters from the cable model needed to move the calibrated s11 data from the input reference plane to the reference plane at the center of s8 using

$$\Gamma_c = s11 + (s12 \times s12 \times \Gamma)/(1 - s11 \times \Gamma)$$

Where Γ_c is the corrected s11, Γ is the measured s11 and s11 and s12 are the cable S-parameters for one-way length of 3.135". The path length from case 4 minus that for case 3 minus that from a calibration open provides an estimate for path in s8 of

$$3.135-1.955-0.268 = 0.912"$$

This path length is needed along with the path length of 6.624" from case 5 for a correction of 6.624 – 0.912 = 5.71" to correct the LNA s11 measurement.

It is emphasized that these corrections are model dependent and may be corrected following measurements made on spare cables and s8 switch. While it is possible to disconnect some parts in the front-end it is not easy as the "hand-flex" cables have been formed in place. A spare s8 switch was ordered in early June and is expected in late July. A comparison with manual calibration, as in EDGES-2, is planned along with a comparison of artificial antenna results using manual calibration and automated calibration.

The sensitivity of calibrated spectra to cable model parameters have been made using simulations.

For a frequency range of 60-130 MHz and a spectrum of 1700 K at 75 MHz with spectral index of -2.5 the effects of an error in cable model, using the parameters given in Table 2 and given in Table 3.

Dielectric diameter	0.1175"
Inner conductor	0.0362"
Outer conductivity	4.768e7 S/m
Inner conductivity	5.96e7 S/m
Dielectric constant	2.04
Loss tangent	2e-4

Table 2. Cable model parameters

Change	s11 terms	rms 1-term	rms 5-terms
0.1"	Antenna	150 mK	1 mK
0.1"	LNA	170 mK	1 mK
3% dielectric	Antenna	920 mK	2 mK
3% dielectric	LNA	810 mK	1 mK
Loss correction	Antenna	424 mK	1 mK

Table 3. Simulated effects on rms residuals to the calibrated spectrum for error in cable model parameters

The last entry in Table 3 is the simulated effect of not making a loss correction for the change in reference plane.

An alternate and simpler approach

Tests made on a spare s8 switch using bench top VNA show that all 8 positions have the same S-parameters when connected to the center port to within ± 1 ps and 0.001 dB. If we also assume that the SOL are calibration standards with known s11 we can use these to obtain the reference plane at the circle of the 8 input ports. In this case, we can use the SOL calibration placed manually on the antenna input to derive the S-parameters of the cable from the antenna input to the s8 switch. These S-parameters will then only be used to derive the loss which will then be considered as part of the antenna loss. In this approach only the LNA s11 needs correction to obtain difference between VNA path 1 plus delay through switch minus the delay via path 2 which is nominally

Case 2 + delay of internal open – case 5
= -1.955 + delay of internal open + 6.62 = 4.86" inches 1-way.

When tested using the antenna simulator data of memo 305 similar results and residuals were obtained. The SOL calibration loads installed in the EDGES-3 prototype are Maury microwave 8050 with offset delays of 16 ps.
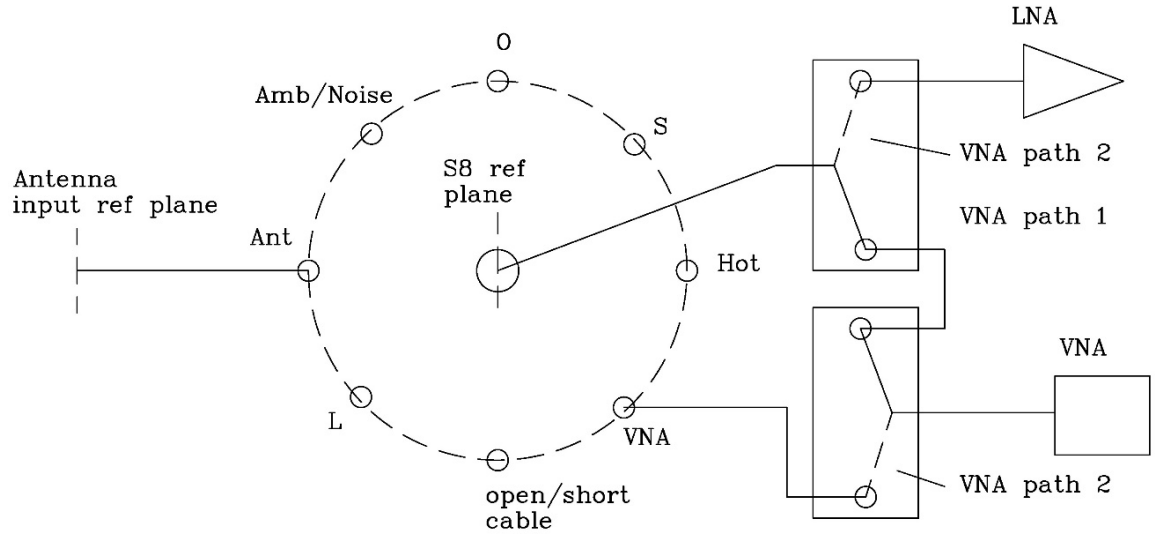

Figure 1. Schematic of change in reference plane.