EDGES MEMO #106

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To: EDGES Group

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Subject: Options and error estimates for EDGES-2 deployment

In memos 99 it was shown that introducing a cable between the antenna and the LNA reduces the sensitivity to errors in VNA phase and in memo 105 it is shown that placing this cable between the 3-position switch and the LNA instead of before the switch has added advantages. Bench tests of an added cable and an attenuator show that provided the EDGES LNA and the added cable are stable the dominant instrumental error is the error in the magnitude of the antenna S11 which is

$$2\left|\Gamma_a\right|\left(1-\left|\Gamma_a\right|^2\right)^{-1}\Delta\left|\Gamma_a\right|$$

In fractional units, where $\Delta\left|\Gamma_a\right|$ is the error in antenna S11 magnitude. For $\left|\Gamma_a\right| = 0.2$ or -14 dB an error of 0.01 dB corresponds to 10^{-4} or 100 milliK out of 1000 K. If the antenna reflection coefficient could be reduced to -20 dB an error of 0.01 dB would correspond to only about 2×10^{-5}.

An ideal configuration for EDGES-2 would be to locate the LNA in an underground room below the antenna. This room would provide a stable environment for the LNA, cable and VNA. Alternately the switch could be placed at the base the antenna and the cable run in a pipe a few feet underground to the LNA as illustrated in Figure 1.

1] Ground plane

For the 100-200 MHz range a 16m×16m with 0.02 m wire spacing is needed to reduce the ground loss to a level at which the loss can be estimated to within an error of 0.005 dB.

2] Thermal considerations

a) Antenna

The antenna and balun materials have been chosen to minimize the change in S11 with temperature. In memo 89 it is estimated that the S11 should remain within 0.01 dB its value at 25°C over a range over 30°C. However this needs to be tested.

b) 3-position switch

The 3-position switch contains the comparison load and diode noise source. Both of these are sensitive to temperature and need to be held within a few degrees or corrections need to be made.

c) LNA

Since the temperature of the 3-position switch is measured and the accuracy of the calibrated spectra is relatively insensitive to temperature so geothermal heat exchange could be used to limit the diurnal and seasonal temperature variation. At a depth of 6 feet diurnal variation is well under ±1K and seasonal variation is about ± 5K. To obtain geothermal control of the 3-position switch consider the thermal transfer via a square aluminum tube 6”×6” with ¼” walls. For a 1K gradient over 1 meter the heat transfer

$$k\ A\ \Delta T/L \approx 0.8W$$

Where k is the thermal conductivity (200 w/(m-K) for aluminum)

A is the cross-section area

$\Delta T/L$ is the temperature gradient. If we assume radial heat transfer to the soil is

$$k\ 2\pi\ell\ \Delta T\left[\ln\left(r2/r1\right)\right]^{-1}$$

where k is the thermal conductivity (~0.2 w/(m-K) for sandy soil)

ℓ is the length of the rod

ΔT is the temperature difference and (r2/r1) is the ratio of radial distance in the soil at which the reference temperature is measured to the radius of the pipe whose temperature is measured. For ℓ of 1 meter the heat transfer is about 0.5W per K.

The 3-position switch is attached to the heat conduction pipe which is insulated from the ground plane and top few inches of soil whose temperature makes large diurnal temperature swings. The thermal path via the pipe is designed to dominate over the path to the outside via the sma connection and the air. Internal heat from the switch is about 1W on average. Heat conduction pipes to the LNA may not be needed if the trench is deep enough.

3] S11 measurements

S11measurements of the antenna and LNA can be measured by disconnecting the antenna from the 3-position switch and substituting the cable from the VNA. Since the VNA cable will be exposed the measurements need to be made under stable conditions.

EDGES-2 Error estimate for 100-200 MHz

		Residual mK			Notes
Error Source	Assumed error	A	B	C	
Antenna S11	0.01 dB	16	10	7	
Antenna loss	0.01 dB	110	6	0	
Ground plane loss	0.005 dB	55	3	0	1
Antenna beam	Fourpoint	400	12	0	2
Ionosphere	0.015 dB @150 MHz	171	44	0	3
Foreground	$\sigma\left(\delta\alpha\right)=0.1$	600	50	1	4

Atmosphere	0.01 dB	100	60	0	5
Lunar scatter		~200	?	?	6
Meteor scatter		~100	?	?	7
Noise Source	5K	100	12	1	8
Comparison load	5K	1140	20	7	9

Error estimate for 100-200 MHz. Residuals for all sources, expect the ionosphere increase by a factor of 5 for 50-100 MHz. The ionosphere residuals increase by 20.

A residual after removal of scale f^{-s} where s is best fit spectral index

B residual after removal of f^{0}, f^{-s}

C residual after removal of $f^{0}, f^{-s}, f^{-2.0} f^{-s-2.0}$

Notes: 1] assume large ground plane see memo #88

2] From simulations using beam patter from FEKO see memos 94 and 99

3] See memo #79

4] Assumes Liu model see memo #101

5] The Zenith atmospheric attenuation is dominated by oxygen from 100-200 MHz and is estimated to range from 3.5×10^{-4} to 10^{-3} dB/km from 100 to 200 MHz from NRL report 7461 Radar/Radio Tropospheric Absorption by L.V. Blake 1972.

6] Lunar reflection of FM – see memo #2

7] Need to be 2000 km from transmitters to avoid – see memo #54.

While the 4 parameters of case C are needed to solve for the ionosphere and reduce the effects of error sources listed above they also "soak-up" some of the EoR signature. For example a 25 MHz wide EoR signature is reduced by a factor of 10 making detection difficult. However if the width is reduced to 10 MHz there is little reduction of the EoR signature.

8] The noise (Noisecom NC302L) diode changes output and spectrum with temperature. At constant current the measured coefficients are $4.6\times10^{-3}/K$ and $2.4\times10^{-3}/K$ at 50 and 200 MHz respectively. This can be corrected using a thermistor to increase the current by $3\times10^{-3}/K$. However the accuracy of the correction and the coefficient needed for the correction depends on the individual diode. The residuals given are for an uncorrected drift of 5K.

9] The residuals are for antenna measurements following a 5K uncorrected change in comparison load temperature of 5K from the temperature at which the calibration data was taken. While it is possible to make a correction based on the interpolation of calibration data taken at 2 different temperatures it is highly desirable to maintain the 3-position switch at a constant temperature. If it is not possible to use geothermal stabilization the switch, cable and LNA need to be enclosed in a temperature controlled box.

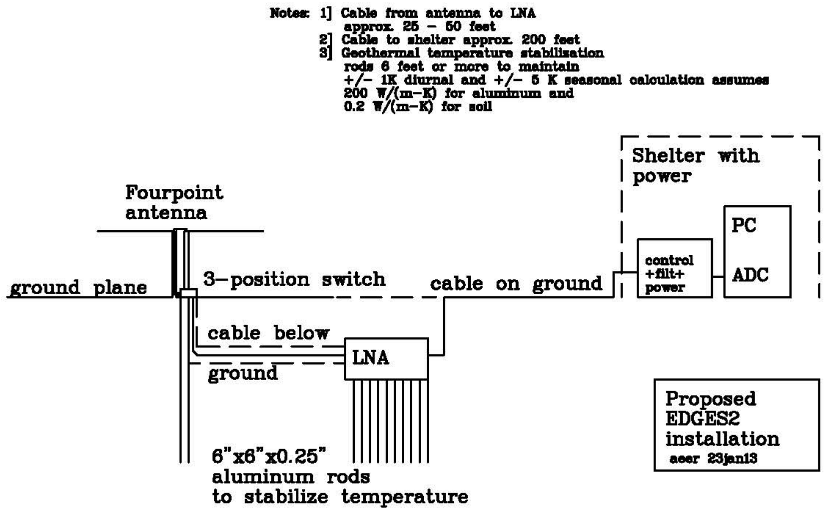
Notes: 1] Cable from antenna to LNA
approx. 25 - 50 feet
2] Cable to shelter approx. 200 feet
3] Geothermal temperature stabilization
rods 6 feet or more to maintain
+/- 1K diurnal and +/- 5 K seasonal calculation assumes
200 W/(m-K) for aluminum and
0.2 W/(m-K) for soil
Shelter with
power
Fourpoint
antenna
PC
ADC
control
+filt+
power
ground plane
3-position switch
cable on ground
cable below
ground
LNA
6"x6"x0.25"
aluminum rods
to stabilize temperature
Proposed
EDGES2
installation
aeer 23jan13

Figure 1.