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May 25, 2011

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To: EDGES Group

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Subject: Effect of attenuation the sensitivity of EDGES to antenna match

Ideally the EDGES spectrometer with 3-position switching should measure the integrated sky temperature from T_a according to

$$T_{sky} = \eta T_a \Big/ \left(1 - |\Gamma|^2\right) \tag{1}$$

where Γ is the reflection coefficient relative to 50Ω and η is a small correction for the balun and ground loss. However, without an isolator between the antenna and the LNA the measurement is effected by the reflection of outgoing noise from the LNA. In the low frequency band of 50 to 100 MHz the effects of stray circuit inductance and capacitance are small and the LNA performance is largely determined by the gate to drain feedback resistor (see memo 16) and the FET transconductance. In addition, the sky noise is high (~ 3000 k at 60 MHz) allowing the use of an attenuator between the antenna and the input to EDGES. Even a 10 dB attenuator will not result in significant loss of sensitivity and reduces the sensitivity of the sky noise measurement to the LNA parameters. In the limit of high attenuation and high sky noise the sky temperature given by

$$T_{sky} = \eta \left[a^{-1} \left(T'_a - tload \right) \Big/ \left(1 - |\Gamma|^2\right) + tload \right] \tag{2}$$

Where T'_a is the temperature measured by the 3-position switch and a is the attenuation. High sky noise is needed to dominate the LNA noise and high attenuation is needed to make the impedance seen by the antenna close to the 50Ω assumed in the calculation of the reflection coefficient. An attenuation of the sky temperature from 3000 K down to about 600 K also reduces the differences between the antenna and load positions of the 3-position switch easing the requirement for linearity in the digitization.

Simulations show that adding attenuation improves the detectability up to about 10 dB for 100 mK EoR absorption centered at 70 MHz. For a noise of $5 \times 10^{-6} \big/ MHz$ times the sky noise a maximum detectable absorption width of 20 MHz (full width at half-power points) was obtained by simulation at 6 dB attenuation compared with about 10 MHz without attenuation.

For these simulations the following parameters were estimated:

1. FET transconductance
2. Sky (or equivalently calibration) constant
3. Sky spectral index
4. Sky spectral index slope
5. Sky spectral index curvature
6. Real Impedance bias
7. Imaginary Impedance bias
8. Ground loss
9. EoR signature

It should be noted that it is advantageous to use only parameters which are related to known physical errors while avoiding a general polynomial which may "soak-up" the EoR signature. In summary adding attenuation between the antenna and the EDGES input is useful for reducing the sensitivity to the LNA parameters and for limiting the dynamic range that is required. In the 50-100 MHz range simulations shown that up to about 10 dB attenuation improves the detectability EoR with large delta-z for a given integration time.

Details of the simulations

Table 1 shows the initial model and the data used in the simulations. The difference being adequately represented (i.e. residuals close to the noise) by the parameters listed above.

Term	Model	Data
Spectral index	2.5	2.4
Ground noise	3 K	20 K
Transconductance	Nominal	+20%
Additional loss	0 dB	0.1 dB
Error in antenna reZ	0 ohm	0.5 ohm
Error in antenna ImZ	0 ohm	0.5 ohm

Table 1. Data and model used in simulation.

Table 2 shows the maximum width of the EoR signature, assumed to be a Gaussian absorption of 100 mK centered at 70 MHz, which can be reliably undetected. The criteria for reliable detection was taken at the 95% confidence level determined from 128 trials.

Attenuation (dB)	Detectable width (MHz)*
0	3
2	8
4	12
6	16
8	20
10	16

*Full-width half maximum

Table 2. Maximum detectable width of EoR signature vs Attenuation.

In addition a sensitivity study was made in which the data was corrupted by various sources of the given in table 3. Showing that the measurement of antenna impedance is extremely critical. The effect of the change of antenna beam with frequency is still under study but is expected to be very small when the galaxy is “down.”

Source of error	Maximum detectable width (MHz)
Impedance scale error of 2%	16
Reflection coefficient error of 0.05 dB	16
Reflection coefficient error of 0.1 dB	8
Reflection coefficient phase error	Very little effect as it doesn’t effect $1-\|\Gamma\|^2$
Change of antenna beam with frequency	Less than 10 mK at LST 6 hrs.
Additional ground loss of 20 K	Very little effect

Table 3. Sensitivity of maximum detectable EoR width to sources of error.