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To: EDGES Group  
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Subject: EDGES LNA Optimization

Memo #50 discussed the desired properties of the EDGES LNA is

1. 50 ohm input impedance
2. Low noise
3. Low noise correlation

The 50 ohm requirement allows standard components like the low loss microwave switch to be used for the 3 position switch cycle. The low noise and low noise correlation are required to minimize the corruption of the spectrum by the LNA noise reflected from the imperfect match of the EDGES antenna. A good test of the LNA performance is to connect a long low loss cable, open at the end, to EDGES. In this case the observed calibrated spectrum is approximately given by

$$T_{LNA} \left( L^2 + 2\rho L \operatorname{Re} \left( e^{-i\omega\tau} e^{i\phi} \right) \right) + T_{amb} (1 - L^2)$$

Where  $T_{LNA}$  is the noise launched out of the LNA towards the antenna

$L$  is the one-way cable loss

$T_{amb}$  is the ambient temperature

$\tau$  is the 2-way cable,  $\rho$  is the correlation magnitude and  $\phi$  is the correlation phase.

While  $T_{LNA}$  is expected to vary slowly with frequency the phase of the antenna reflection can vary rapidly so that it is desirable to minimize  $\rho T_{LNA}$ .

In order to minimize  $\rho T_{LNA}$  a complete noise model of the LNA has been constructed based on equivalent circuit. It is written in C using complex arithmetic. The circuit is similar to those given by M. Pospieszalski (1989). The feedback required to obtain a good input match (see memo #16) is included in the model.

In order to illustrate how it is possible to obtain a correlation near zero consider the over simplified circuit model shown in Figure 1.

In this circuit the dominant noise source is the noise,  $z_r$ , associated with feedback resistor. This noise produces noise at the output,  $v_{out}$ , which is 180 degrees out of phase with the noise emitted from the input into  $z_{in}$ . We now introduce another noise source by adding a resistor,  $r_s$ , in series with the input, the noise from this resistor at the output,  $v_{out}$ , is in phase with the noise emitted from the input. In general it appears to be

possible to introduce added noise with the opposite correlation to lower the overall correlation at the added cost of increasing the LNA noise. Figure 2 shows a simulation of the circuit in Figure 1 with  $g = 0.4S$ ,  $r = 1200\text{ ohms}$ ,  $r_{out} = 80\text{ ohms}$  and  $r_s$  initially equal to zero which produces the sinusoidal structure with frequency when  $z_{in}$  is a lossless open line 50 ns long. When  $r_s$  is changed to 1.3 ohms the sinusoidal variation is cancelled (darker lines in plot).

Figure 3 shows a circuit model for the ATF-58143 used in the current version of EDGES. The model included the feedback resistor and its stray capacitance. Figure 4 shows the measured and simulated noise power (after calibration with 3-position switching) when an open LMR-240 cable with 16 ns 2-way delay is connected to EDGES in place of the antenna. In this case the open cable is not lossless and this case there is added contribution to the variation with frequency due to imperfect input match of

$$T_{amb} (1-L) 2 \text{Re}(\Gamma e^{-i\omega\tau})$$

Where  $\Gamma$  is the input reflection coefficient. It is possible to minimize the noise correlation and improve the input match by adding some inductance to the feedback resistor, adjusting the value of the feedback resistor, and minor adjustment of the load on the output of the HEMT.

Table 1 also shows a proposed circuit change to the feedback to be made in a revision of the circuit board.

	Original	New
Feedback capacitance*	0.7 pf	
Inductance of Rs	0.4 nH	
Resistance of Rs	0.5 $\Omega$	
Capacitance Cg	1.12 pf	
Resistance of zout	80 $\Omega$	
Resistance Rg	2.5 $\Omega$	
Transconductance	0.42S	
Delay in transconductance	12 ps	
Resistance of Rf	1200 $\Omega$	900 $\Omega$
Inductance of Rf	0	350 nH
*Cgd = 0.265pf plus stray from board and components.		

Table 1

The deviation of the spectrum from the sky temperature spectrum due to imperfect input match is not as much of a concern for EDGES because it can be calibrated using from the variation of sky temperature with hour angle. On the other hand the derivation due to the amplifier correlation cannot be separated from the spectrum of the EoR.

Since it is not possible to obtain perfect input match and zero noise correlation data taken with an open line might be used along with the measured antenna reflection coefficient to model the spectrum and apply a first order correction.

Pospieszalski, M.W., "Modeling of noise parameters of MESFETs and MODFETs and their frequency and temperature dependence," IEEE MTT-S digest 1989, pp 385-388

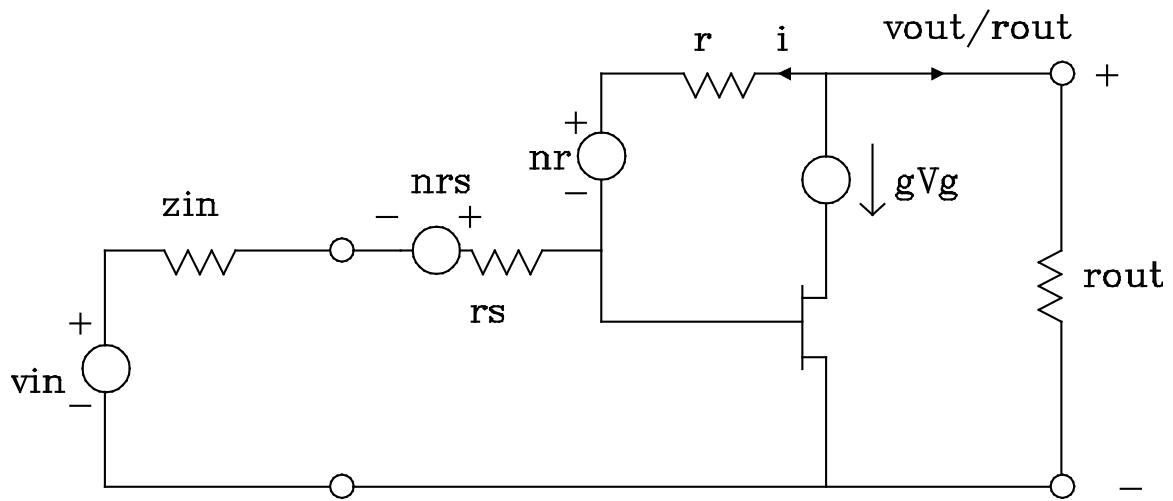
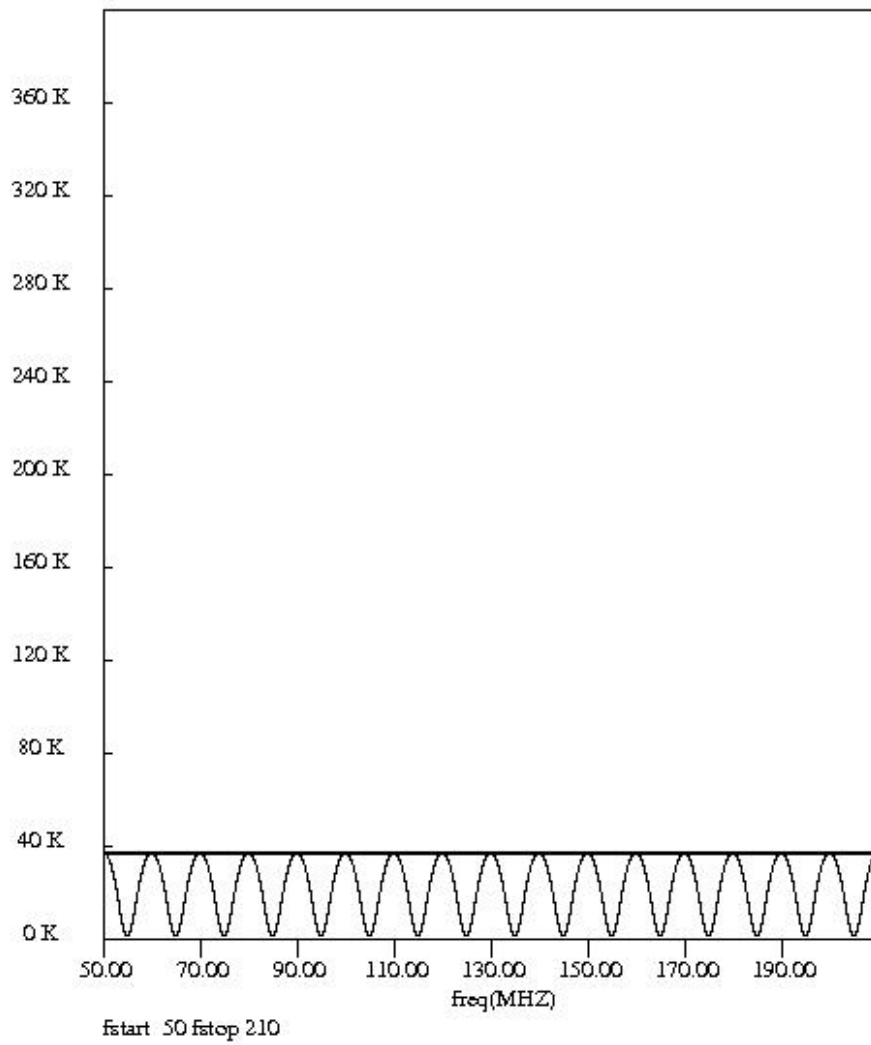


Figure 1. Simplified model for illustration only



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Figure 2

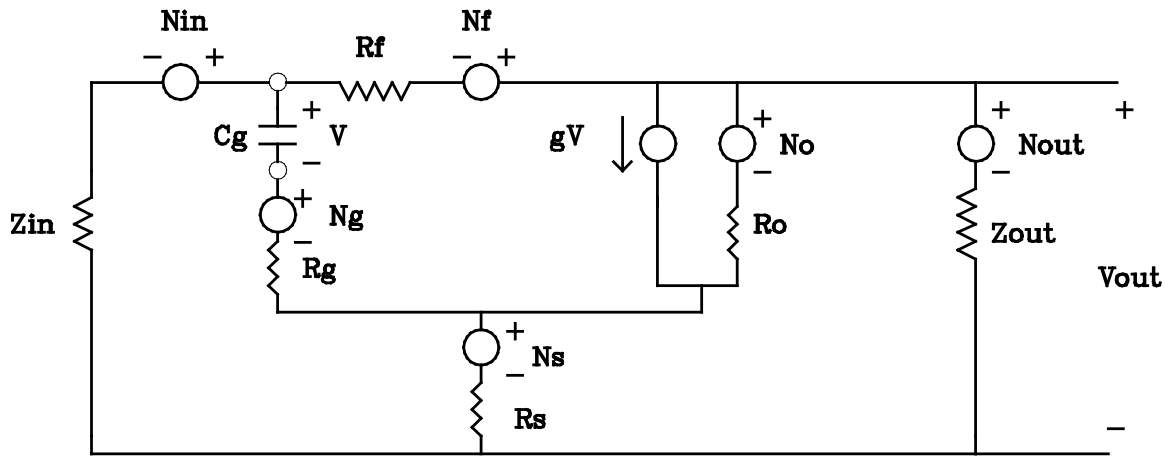
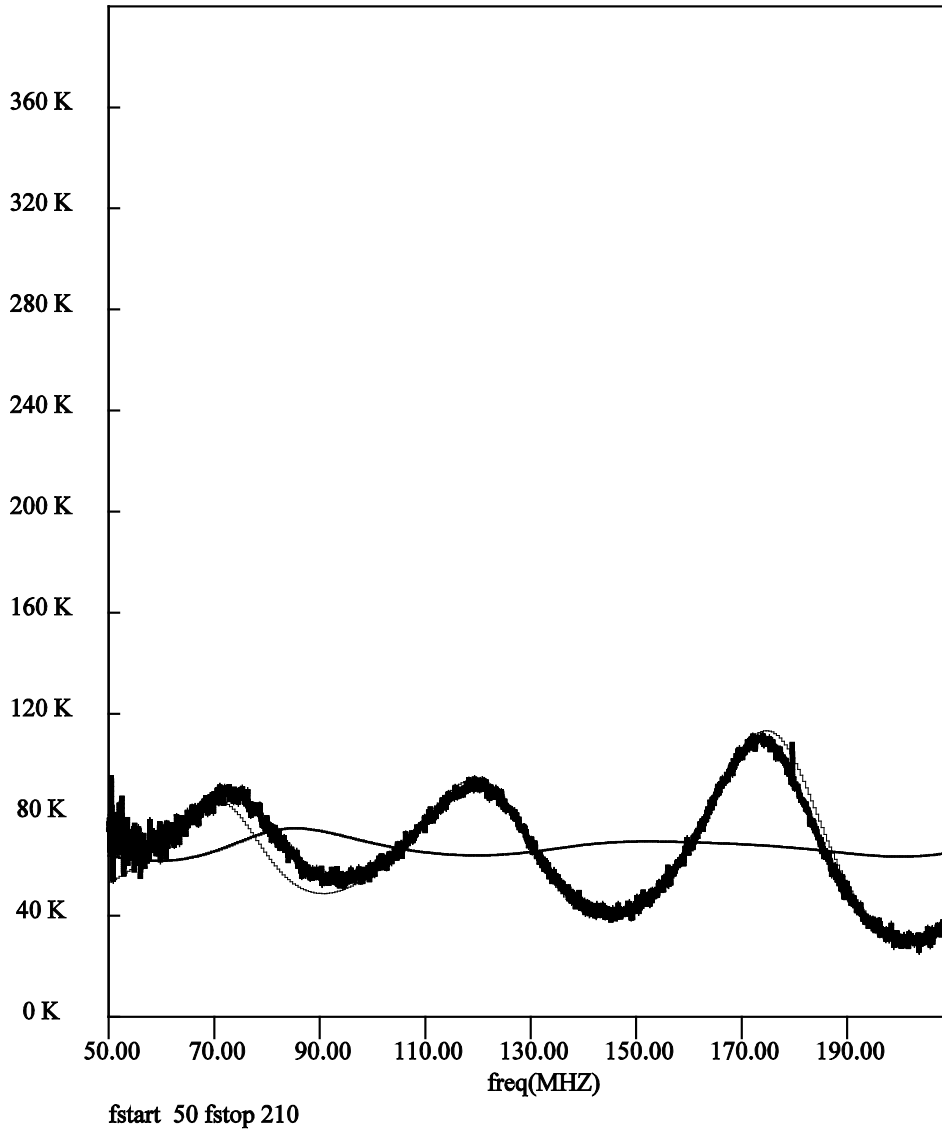


Figure 3 Noise model of EDGES LNA. While some elements are shown as being only resistive they are assumed to be complex. [Not shown, but included in the model, is high pass filter and short cable between the LNA and the 3-position switch.]



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Figure 4. Spectrum of EDGES connected to 6 foot LMR-240 cable. Thin curve is spectrum computed from LNA model and the second thin curve is predicted performance following the circuit changes proposed in table 1.