MASSACHUSETTS INSTITUTE OF TECHNOLOGY
HAYSTACK OBSERVATORY
WESTFORD, MASSACHUSETTS 01886

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Telephone: 781-981-5400
Fax: 781-981-0590

To: EDGES Group

From: Alan E.E. Rogers

Subject: Simulations of attenuation and delay between 3-position switch and LNA

In the first test of absolute calibration described in Memo #82 and in Rogers & Bowman 2012 an attenuator was placed between the antenna and the 3-position switch. The added attenuation reduces the sensitivity to the effects of the LNA S11. In this memo we look at the advantage of placing an attenuator after the switch. In this case the attenuator improves the match to the LNA thereby reducing the sensitivity to S11 phase errors. The table below summarizes the effect of error in S11 and temperature vs attenuation.

		rms residual in mK from 50-200 MHz				Note
Source error	magnitude	0 dB	6 dB	10 dB	20 dB	1
Antenna S11	0.01 dB	63	39	34	32	2
Antenna S11	1°	417	162	112	81	3
LNA S11	0.1 dB	345	75	29	6	
LNA S11	1°	398	87	33	6	
Cable phase	1°	20	68	71	72	3
Ambient drift	5°	148	70	55	47	4
Hot	5°	0	0	0	0	5

Notes:

1] Simulations done for antenna reflection ~ -20 to -14 dB and 1500 sky noise

2] Attenuation beyond 6 dB makes no improvement in errors of antenna S11 magnitude

3] Beyond 6 dB the sensitivity to the phase of the antenna S11 is limited by the correlated LNA noise. An error in the S11 phase of the cable used for noise wave calibration has the same effect.

4] An uncorrected drift in the temperature of the internal load results in error

5] An error in the hot load calibration only effects the scale.

A large reduction of all the errors, except that due to the antenna S11 magnitude and the ambient drift can be obtained by inserting a large lossless delay in the antenna and averaging over a frequency range equal to the half period of the delay.

Further it turns out that it is a significant advantage to insert the cable between the 3-position switch and the LNA. In this case averaging over a half period of the cable delay reduces the sensitivity to the S11 phase errors. In addition the effects of the cable loss are calibrated and the noise waves can be calibrated using just an open or a short. A simulation of this configuration gave the following results

		rms residual in mK from 50-200 MHz				Note
Source error	magnitude	0 dB	3 dB	6 dB	10 dB	
Antenna S11	0.01.dB	29	26	25	24	
Antenna S11	1°	31	20	14	11	
LNA S11	0.1 dB	17	8	4	1	
LNA S11	1°	27	12	6	2	
Open phase	1°	5	10	10	11	1
Ambient drift	5°	43	43	43	43	
Hot	5°	0	0	0	0	

Notes: 1] In this configuration an open is used to calibrate the noise waves.

One disadvantage of attenuation after the switch is that it increases the noise. The most significant increase results from the large decrease in the power ratio hot to ambient load used to determine the noise dipole calibration. The following table shows the rms residuals noise in the calibrated spectrum as a function of attenuation and temperature difference between hot and ambient loads. An integration of 1 hour for each spectrum and spectral resolution of 750 kHz are assumed. It is also assumed that the spectrometer only acquires 20 minutes of true integration per hour owing to the computing overhead.

	rms residual			Hot-ambient	Note
Attenuation	0 dB	3 dB	6 dB	K	
No smoothing	1229	2382	4694	80	
No smoothing	233	423	806	180	
Smoothing	259	433	789	80	1
Smoothing	95	152	270	180	2

Notes:

1] Calibration data of noise source and 3-position switch offsets are smoothed with 6th order polynomial.

2] Current hot load is limited to 373 K. Increasing the temperature of the hot load would provide a substantial reduction in the noise but 50 ohm loads for temperatures greater than about 400 K are not available and consequently more integration time may be required for calibration. A custom built load with a high temperature resistor might reach 500 K. The match would be poor but the calibration algorithms full account for mismatch.

Bench test of cable delay and attenuation:

The set-up of the tests described in memo #104 was changed to include a cable and attenuator between the 3-position switch and the LNA. In order to avoid interference from the strong signals in the Haystack control room the cable was coiled up into the aluminum box surrounding the EDGES-2 LNA. Owing to the limited shielding factor of about 100 dB it was determined that box covers were needed. 100 feet of LMR-240-UF with 129 ns delay was used along with 6 dB attenuation placed after the switch. The ambient, hot load and 1540 K filament and their S11 measurements from the tests of memo 104 were used. The S11 looking into the switch input port was measured and seen to have approximately the expected magnitude and phase based on the LNA S11 from earlier tests modified by the cable and attenuation. The LNA noise waves were measured using an open and assuming a value of +1 for the S11. In this respect the revised set-up is simpler in that it requires one less S11 measurement for calibration.

Preliminary results:

The measured rms from 60 to 190 MHz was 420 mK with smoothing of the calibration data with 6^{th} term polynomial and smoothing of the calibrated spectrum to a resolution of 10 MHz. The result is close to the expected 400 mK for the noise in the 1 hour integration used for each spectrum plus the quadrature addition of 200 mK for a 0.005 dB uncertainty in the S11 measurement of the filament source.