

## Re-calibration of the EDGES High-Band Receiver at 25C (Jan 2017) Including details of the Noise Source Measurements

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The high-band receiver was brought back from the EDGES site after being in the field for many months. The 3D printed cowling airflow conduit connectors was removed by cutting away the silicon sealer that was used to keep the airflow moving across the thermal plate and its heatsink. The sealer appeared to be in very good shape and completely intact. We attached a fan (always on) to the heatsink, attached the thermal control wires to the Oven Industries thermal controller and set the temperature to 25°C. We allowed the receiver to stabilize at that temperature for one day before taking measurements..

We calibrated the VNA using the following settings:

- Frequency range = 50 - 200 MHz
- Frequency steps = 601 → frequency step size = 250 kHz
- Power = -35 dBm
- IF = 100 MHz
- Averaging = 100

The receiver S11 was measured directly at the VNA several times in the course of collecting the calibration data. These VNA settings were used when measuring the S11 of the receiver.

When measuring the Hot Load, Ambient Load, Shorted Cable, Open Cable, and Ant Sim 2, two VNA settings were modified:

- Power = 0 dBm
- Averaging = 10

When measuring the Noise Source, two VNA settings were modified:

- Power = -20 dBm
- Averaging = 50

All calibration data was stored on enterprise: [/data5/edges/data/calibration\\_jan\\_2017\\_highband/](#)

- 1.) **Receiver S11 -1 (Jan 24)** : The standards were measured (OSL) using the VNA and then the receiver was connected to VNA to measure its S11 .The process was repeated once.

*Folder: ./S11/Receiver\_1st\_measurement/*

**2.) Ambient Load (Jan 24-26):** The ambient load was connected to the receiver and a Fluke logging multimeter monitored the resistance of the load via the thermistor port. A series low pass filter was placed on the cable from the Fluke meter to the thermistor port on the load. The pxspect code was started, which began the cycling of the three position switch of the LNA and ran for 2 days. The voltage on the ambient load was set to 0 volts. After stopping the code, S11 data was taken of the Ambient Load attached to the receiver and of the 3 internal OSL standards using the internal 4 position switch using externally applied voltages<sup>1</sup>. The VNA settings of power and number of averaging samples were changed from the -35 dBm / 100 samples settings to 0 dBm / 10 samples setting. The cable from the receiver to the VNA was supported in mid section to avoid any sag in the cable. Cable sagging during previous S11 measurements was noticed and thus the protective steps taken to prevent the cable from sagging. The S11 readings were stored on the VNA internally. All control of the VNA was done via the mouse so that no buttons were pressed on the VNA so that the chance of disturbing the cable connection to the receiver was minimized.

*Folder: a.) Spectra - ./spectra/AmbientLoad\_2017\_024(25 & 26)\_23.acq\**  
*b.) Resistance - ./resistance/AmbientLoad\_25C.csv*  
*c.) S11 - ./S11/AmbientLoad/*

**3.) Hot Load (Jan 26-28):** The ambient load was converted to a hot load by the changing the input voltage on the load from 0 V to 12 V. The procedure of step 2 was followed, and the data collection also lasted for approximately two days.

*Folder: a.) Spectra - ./spectra/HotLoad\_2017\_027( & 28)\_00.acq\**  
*b.) Resistance - ./resistance/HotLoad\_25C.csv*  
*c.) S11 - ./S11/HotLoad/*

**4.) SimAnt2 (Jan 28-30):** The next load connected to the receiver was the Antenna Simulator 2. The receiver was left switching for 2 days again. After which the S11 was taken as before.

*Folder: a.) Spectra - ./spectra/SimAnt2\_2017\_028(29&30)\_23.acq\**  
*b.) Resistance - ./resistance/SimAnt2.csv*  
*c.) S11 - ./S11/SimAnt2/ (and SimAnt2\_redo - This was because the cable connecting the receiver and the VNA was discovered to be not as tight as it should have been.)*

**5.) Open Cable (Jan 30-31):** The cable box was placed in a faraday cage and it was connected to a standard open on one end and to the receiver on the other. The receiver was left switching for a day. After which the S11 was taken as before. The thermistor resistance was recorded.

*Folder: a.) Spectra - ./spectra/OpenCable\_2017\_031\_01.acq\**  
*b.) Resistance - ./resistance/OpenCable.csv*  
*c.) S11 - ./S11/OpenCable/*

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<sup>1</sup> Open, short, Match, External, Open, Short, Match, External - was the order followed while taking the S11 readings. The respective voltages used were 28.0 V, 31.3 V, 34.0 V, and 37.0 V.

**6.) Receiver S11 -2 (Jan 31):** After the Open Cable was disconnected, a second reading of the receiver S11 was taken with the VNA connected. The VNA settings of power and number of averaging samples were changed from the 0 dBm / 10 samples settings to -35 dBm / 100 samples setting.

*Folder: ./S11/Receiver\_2nd\_measurement/*

**7.) 50 ohm Terminated Cable (Jan 31 - Feb 1):** The cable box was placed in a faraday cage and it was connected to a 50 ohm termination (not a short - mistakenly used the 50 ohm termination) on one end and to the receiver on the other. The resistance of the thermistor was recorded. The receiver was left switching for a day. After which the S11 was taken as before with the receiver settings back to 0 dBm / 10 samples.

*Folder: a.) Spectra - ./spectra/ShortedCable\_2017\_032(& 031)\_00.acq\**

*b.) Resistance - ./resistance/ShortedCable.csv*

*c.) S11 - ./S11/ShortedCable/*

**8.) Noise Source 0 dB extra (Feb 1 - 2):** The noise source was connected to the power supply with the voltage set to 12 V. The noise source contained a 6 dB attenuator which was considered an integral part of the Noise Source. The other end was connected to the receiver without using any more attenuation. The noise source was enclosed in a faraday cage. The receiver was left switching for a day after which the S11 was taken as before.

*Folder: a.) Spectra - ./spectra/NoiseSource\_0dB\_extra\_2017\_033\_00.acq\**

*b.) S11 - ./S11/NoiseSource\_at\_Receiver\_0dB\_extra/*

**9.) Noise Source at VNA 0dB and 3dB extra (Feb 2):** The noise source was disconnected from the receiver, but left powered up, and connected directly to the VNA to obtain its S11 reading. The OSL calibration standards were measured as well.

*Folder: S11 - ./S11/Noise\_Source\_at\_VNA\_0dB\_extra\_1st\_measurement/*

We then added an additional 3 dB attenuator to the noise source and recorded the S11. Power was not disconnected during the addition of the 3 dB attenuator.

*Folder: S11/S11/Noise\_Source\_at\_VNA\_3dB\_extra/*

**10.) Noise Source 3 dB extra (Feb 2 - 3):** The Noise Source with the 3 dB additional attenuation was enclosed in the faraday cage and connected to the receiver. The receiver was left switching for a day. After which the S11 was taken as before with the same VNA settings

*Folder: a.) Spectra - ./spectra/NoiseSource\_3dB\_extra\_2017\_033(& 034)\_00.acq\**

*b.) S11/S11/NoiseSource\_at\_Receiver\_3dB\_extra/*

**11.) Noise Source at VNA (6dB) (Feb 3):** The noise source was disconnected from the receiver and the 3dB extra attenuator was replaced by a 6dB. The Noise Source (6 dB intrinsic attenuator) and the 6 dB extra attenuation was connected directly to the VNA to obtain its S11. The settings of the VNA were as before.

*Folder: S11 - ./S11/NoiseSource\_at\_VNA\_6dB\_extra/*

**12.) Noise Source 6dB extra (Feb 3 - 4):** The Noise Source with the extra 6dB was enclosed in the faraday cage and connected to the receiver. The receiver was left switching for a day. After which the S11 was taken as before. 12 V power was still applied

*Folder: a.) Spectra - ./spectra/NoiseSource\_6dB\_extra\_2017\_034(& 035)\_00.acq\**  
*c.) S11 - ./S11/NoiseSource\_at\_Receiver\_6dB\_extra/*

**13.) Receiver S11 - 3 (Feb 4):** After the Noise source was disconnected, a third reading of the receiver S11 was taken with the VNA connected. The VNA settings of power and number of averaging samples were changed from the -20 dBm / 50 samples settings to -35 dBm / 100 samples.

*Folder: S11 ./S11/Receiver\_3rd\_measurement/*

**14.) Adapters (Feb 7):**

The S11 of the two extra attenuators (3 dB and 6 dB) was measured at the VNA. The VNA settings were as before but had a power setting of 0 dBm and 10 sample average.

*Folder: S11 ./S11/Adapters*

**15.) Shorted Cable(Feb 6- 7):** The cable box with the standard short at one end was connected to the receiver. Basically step 7 was redone because we realized the wrong termination was used. The receiver was left switching for a day. The S11 was taken with the VNA settings at 0 dbm/10 samples.

*Folder: a.) Spectra - ./spectra/ShortedCable\_0ohms\_2017\_037(& 038)\_00.acq\**  
*b.) Resistance - ./resistance/ShortedCable\_0ohms.csv*  
*c.) S11 - ./S11/ShortedCable\_0ohms/*

**16.) Hot Load(Feb 7- 9) - 2nd: Repeat for more data**

*Folder: a.) Spectra - ./spectra/HotLoad\_2nd\_Measurement\_2017\_039( & 40)\_00.acq\**  
*b.) Resistance - ./resistance/HotLoad\_25C\_2nd\_measurement.csv*  
*c.) S11 - ./S11/HotLoad\_2nd\_Measurement/*

**17.) SimAnt2 - 2nd (Feb 9 -11) : Repeat for more data**

*Folder: a.) Spectra - ./spectra/SimAnt2\_2nd\_run\_2017\_040(41 & 42)\_18.acq\**  
*b.) Resistance - ./resistance/SimAnt2\_2nd\_run\_Feb11.csv*  
*c.) S11 - ./S11/SimAnt2\_2nd\_run\_Feb11/*

**18.) Receiver S11 - 4 (Feb 11):** After the Antenna simulator 2 was disconnected, a fourth reading of the receiver S11 was taken with the VNA connected. The VNA settings of power and number of averaging samples were changed from the 0 dBm / 10 samples settings to -35 dBm / 100 samples setting.

*Folder: ./S11/Receiver\_4th\_measurement/*

----- **Additional Steps after performing the correction on the S11 data**-----

**19.) Receiver 1 hour readings - 1st (Feb 13-14):** After looking at the corrected S11 measurements of the receiver (./corrected - Feb13), we noticed that there was a dependence on the time delay of when the S11 reading was taken after the receiver switching was stopped. So we left the receiver switch for a day with nothing connected to it. We then stopped it, connected the VNA (with the power set to -35 dBm and averaging set to 100 samples), and took several S11 measurements periodically for 1 hour.

*Folder: ./S11/Receiver\_1hr\_readings\_1/*

**20.) Receiver 1 hour readings - 2nd (Feb 14-15):** The above procedure was repeated. So we left the receiver switching for a day with nothing connected to it. And then stopped it, connected the VNA with the power setting of -35 dBm and averaging set to 100 samples and took S11 measurements again.

*Folder: ./S11/Receiver\_1hr\_readings\_2/*

**21.) Additional attenuators (Mar 2):** This was performed to better understand the accuracy limits. The S11 of the attenuators (3 dB, 6 dB, 10 dB, 15 dB) were measured at the VNA with power setting of 0 dBm and averaging set to 10 samples<sup>2</sup>. We also measured another set of attenuators of the same values.

*Folder: ./S11/Attenuators/0db/*

The S11 of the same attenuators, plus additional attenuators of the same values, were measured again<sup>2</sup> but with the power set to -30 dBm and 50 samples for averaging.

*Folder: ./S11/Attenuators/30dB/*

To test the stability of the VNA, the VNA power was turned off and was turned back on 2 hours later. One day later, the S11 of the above attenuators were remeasured<sup>2</sup> at the power setting of -30 dBm and 50 samples averaging.

*Folder: ./S11/Attenuators/30dB\_reset/*

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<sup>2</sup> 1st measurement, 1st measurement\_copy Open, Short, Load, 2nd measurement, 2nd measurement\_copy - was the order followed while taking the S11 readings of the attenuators.