EDGES MEMO #025

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December 13, 2006

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To: EDGES Group
From: Alan E.E. Rogers and Judd D. Bowman
Subject: Deployment of EDGES at Mileura Station, Western Australia

Introduction

The EDGES system was taken to Mileura Station in Western Australia and deployed near the homestead from 29 November through 8 December 2006. All equipment was transported to the site as luggage that accompanied us on commercial airline flights. The EDGES "fourpoint" antenna was transported in a bicycle case, while the receiver box and Acquiris AC240 FPGA board traveled separately in suitcases.

Mileura Station is an active sheep and cattle station (ranch) in a remote area approximately 620 km north of Perth, Western Australia (see Figure 1). The nearest towns are Meekathara (~100 km east) and Cue (~150 km southeast), and the nearest small city is Geraldton (~350 km southwest). Mileura can be reached from Perth by car or truck in approximately 10 hours over paved and dirt roads.

In order to draw power from the homestead generator, EDGES was deployed within a few hundred meters of the nearest buildings. Several long extensions cords were used to connect to the homestead power supply in a small cottage. Figure 2 shows the approximate arrangement of the system with respect to the nearest structures. The locations in Figure 2 labeled A, B, C, D, and E were measured by GPS and have the following coordinates:

Table 1

Location	**Latitude**	**Longitude**
A (EDGES)	S26.37212	E117.33151
B (Windmill)	S26.37266	E117.33195
C (NW Gate)	S26.37290	E117.33263
D (SW Gate)	S26.37218	E117.33257
E (Cottage)	S26.37191	E117.33277

The windmill was about 80 m from the antenna and the cottage was about 100 m. In general, the average horizon blockage was estimated to be under 5º. We estimated the scatter from the windmill to be of order 0.3 mK.

The EDGES antenna was aligned by eye in a roughly north-south/east-west configuration before acquiring data. Precise alignment was determined using GPS at the end of the field deployment.

The final alignment was found to be 18 degrees clockwise of a north-south/east-west configuration, with an estimated 2 degree uncertainty from the GPS measurements. The antenna was moved and replaced several times during the measurements, although care was taken in each instance to align the antenna as accurately as possible with markers indicating the original configuration. An uncertainty due to incorrect replacement of the antenna for any particular observation of about 5 degrees is estimated, giving a combined uncertainty of about 7 degrees. Thus the alignment is taken to be:

18° ± 7 east of north

EDGES Hardware Configurations

During the field deployment, the EDGES system hardware was operated in 5 manually interchangeable configurations (see Figures 3-6 for some examples). Each configuration was designed to facilitate the measurement of a property of the system or of the sky. The configurations and corresponding measurements included:

a) Antenna VSWR measurement

The EDGES antenna VSWR was measured in place using a noise source, long cable and resistive power splitter as described in Memo #23.

b) Cable calibration measurement radiometric

The EDGES 3-position switching spectrometer has an internal noise source in the "LNA-Module" calibration that can be checked using a HP precision calibrated noise source (and liquid nitrogen load while at Haystack). The precision HP noise can be injected directly into the LNA switched input or into the end of a cable connected to the LNA box input.

c) Absolute sky noise measurement

In this mode, the LNA module is located close to the spectrometer and the antenna is connected via a long LMR-400 super flex cable to the input of the LNA input switch. The frequency dependence of the phase of the LNA noise reflected from the antenna mismatch plus the antenna noise reflected by the LNA mismatch allows the effects of mismatch to be removed—as described in memo #15—provided the magnitude of the antenna mismatch is known. This mode had a secondary sub-configuration in which the ground plane was extended using aluminum foil to test the effects of non-infinite ground plane on the ground loss. This sub-configuration is shown in Figure 5.

d) "EoR step" measurement

In this mode, the LNA module is connected directly to the antenna, as shown in Figures 3 and 4. While absolute calibration is limited in this configuration by the effect of the unknown phases of the reflections on the spectrum, the compact size of the antenna and the small signal path delays result in a very smooth response which can be fit by a low order polynomial. Any sharp spectral feature in the sky noise spectrum, such as an "EOR step" should stand out in the residuals to the polynomial fit. In this mode the LNA module is connected to the spectrometer by three 50' LMR-240 super-flex cables, each with ferrite common mode suppression filters every three feet (see Figure 6).

e) Sky noise simulator

Owing to an unfortunate defect in the AC240 FPGA spectrometer the spurious signals due to the cross-coupling between the digital signals and the ADC the spectrometer is severely limited by instrumental errors when the antenna and internal load spectrum are different. Connecting a filtered noise source with a spectrum close to that observed from the antenna can ameliorate this instrumental defect. "Double Dicke" switching is then carried out on a slow cycle of 1 hour on the antenna followed by 1 hour on the simulator by manually changing the input. [Future plans for EDGES include conversion to another FPGA spectrometer which has better isolation of the ADC from the digital signals]

For this deployment, a noise simulator consisting of a chain starting with a noise source, followed by 31 dB attenuation, followed by a low-pass filter, followed by another 3 dB of attenuation was found to closely match the observed Galactic background noise.

EDGES Acquisition Configurations

In addition to the 5 hardware configurations of the system, the acquisition software was run in 3 modes during the deployment:

a) Slow cycle (about 3.5 minutes):

Ambient Load	100	1 sec blocks
Load + calibration	10	1 sec blocks
Antenna	100	1 sec blocks

b) Medium cycle (about 20 seconds):

Ambient Load	10	1 sec blocks
Load + calibration	1	1 sec blocks
Antenna	10	1 sec blocks

c) Modified medium cycle (about 25 seconds):

Ambient Load	10	1 sec blocks
Load + calibration	5	1 sec blocks
Antenna	10	1 sec blocks

The medium cycle was introduced when it was noticed that many signals—like the satellite transmission in the 136-137 MHz range—were not resolved in time. The medium cycle was modified to include a longer internal calibration to reduce the noise in the calibrated spectrum for regions of the spectrum with large unbalance between the antenna and load. The individual 1 second blocks for each switch position are averaged before recording to a disk file. The disk files are named with the UT year and day of year, and the UT time at the end of each 3 position cycle accompanies the data. A comparison of the computer clock with the GPS receiver time indicated that the computer clock is slow by approximately 4 seconds.

Data and Uncertainties

On all measurements, a window function was used to analyze a 0 to 500 MHz band with 16384 spectral points at 122 kHz resolution. In addition to numerous acquisitions to test the setup of EDGES system, the following data relevant to scientific observations were taken:

Table 2

File	**Hardware Mode**	**Acquisition Mode**	**Notes**
2006_334_02	VSWR	Slow	Antenna on lawn
2006_334_10	Absolute	Slow	Antenna dipole EW 50’
2006_335_10	Absolute	Slow	Added 3x3 m foil ground
2006_336_10	EoR	Slow	Removed foil ground
2006_337_10	EoR	Medium	
2006_338_10	EoR + Sim	Medium	
2006_339_10	EoR + Sim	Modified medium	
2006_340_10	EoR	Modified medium	
2006_341_09	Absol. + VSWR	Modified medium	100’ LMR-400
2006_341_11	Absol. + VSWR	Modified Medium	NS

Additionally, for calculating the sky properties of interest (either Galactic spectral index or EoR step), the following estimated errors and connections were used:

Table 3

	Correction	**Estimated error in correction**	**Comments**
Antenna VSWR	Varies (see Fig. 7)	< 1%	Measured in field (VSWR mode)
Ground loss	0.05 dB	< 0.5%	Model
Horizon pick-up	0.05 dB	< 0.5 %	Model
Antenna balun	0.1 dB	< 1 %	Measured in lab
Antenna loss	0.1 dB	< 1 %	Model
Spectrometer calibration error	In tcal ( )	< 1 %	Checked with HP precision source

Initial Results

Figure 7 plots the VSWR of fourpoint antenna from the measurements made at the site. This data was fit with a polynomial whose coefficients were coded into the analysis software.

Figure 8 plots the calibrated sky noise spectrum for 14-16 hours UT December 2006.

Figure 9 shows the variation of spectral index along with the sky temperature, at 150 MHz weighted by the antenna beam, vs LST. All data was taken at night to avoid contributions from Sun.

Table 4 gives the results of the sky spectrum spectral index, sky temperature at the 150 MHz, and residuals to the spectral index fit and formal errors.

Table 4

File	**UT time span (hrs)**	**Spectral index Av.**	**T 150 K Av.**	**Comments**
2006_334_11	11-20	-2.45	280	50 ft cable
2006_335_10	11-20	-2.55	280	50 ft + extended ground
2006_341_11	11-12	-2.47	280	100' – no foil

Comments on RFI

Figure 10 shows the residuals to a polynomial fit to the spectrum for the data of from 14 to 15 hours on day 340. There were 2 levels of RFI reduction applied to this data.

a) For each cycle the spectrum was searched for spikes > 6 sigma. These channels were marked and not used in the polynomial fit for this cycle. In addition, the entire cycle was discarded if the residuals to the polynomial fit exceeded 6 sigma.

b) The residuals to the polynomial fits for all the accepted cycles were averaged and searched for RFI spikes > 6 sigma. Finally a polynomial was performed on the average residuals for all accepted cycles. Any channel which was marked in an individual cycle or marked in the average was not in the final polynomial fit.

The spectral points of unmarked channels in Figure 10 have been averaged using a Gaussian convolution with half power width of 8 MHz.

Figure 11 shows the spectrum of an EoR step of 400 mK over 10 MHz processed in the way as the data in Figure 10. This signal is about twenty times the expected EoR step and indicates that the Mileura EDGES data can only set an upper limit of this value.

Figure 1. Map of Australia showing EDGES deployment location (arrow) at Mileura Station in Western Australia. Image from *Google Maps.*

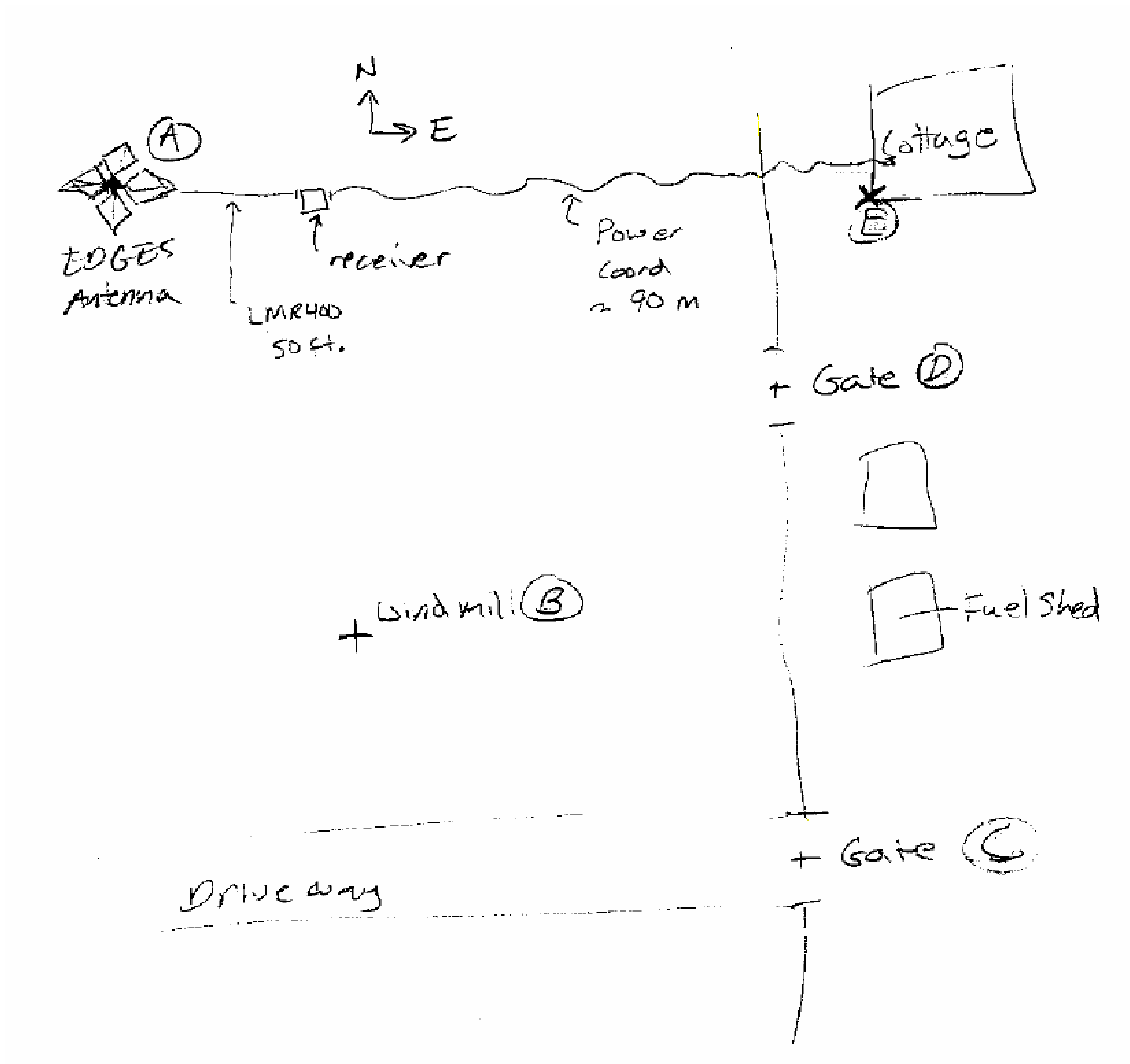


Figure 2. Sketch of EDGES location outside the homestead area at Mileura Station.

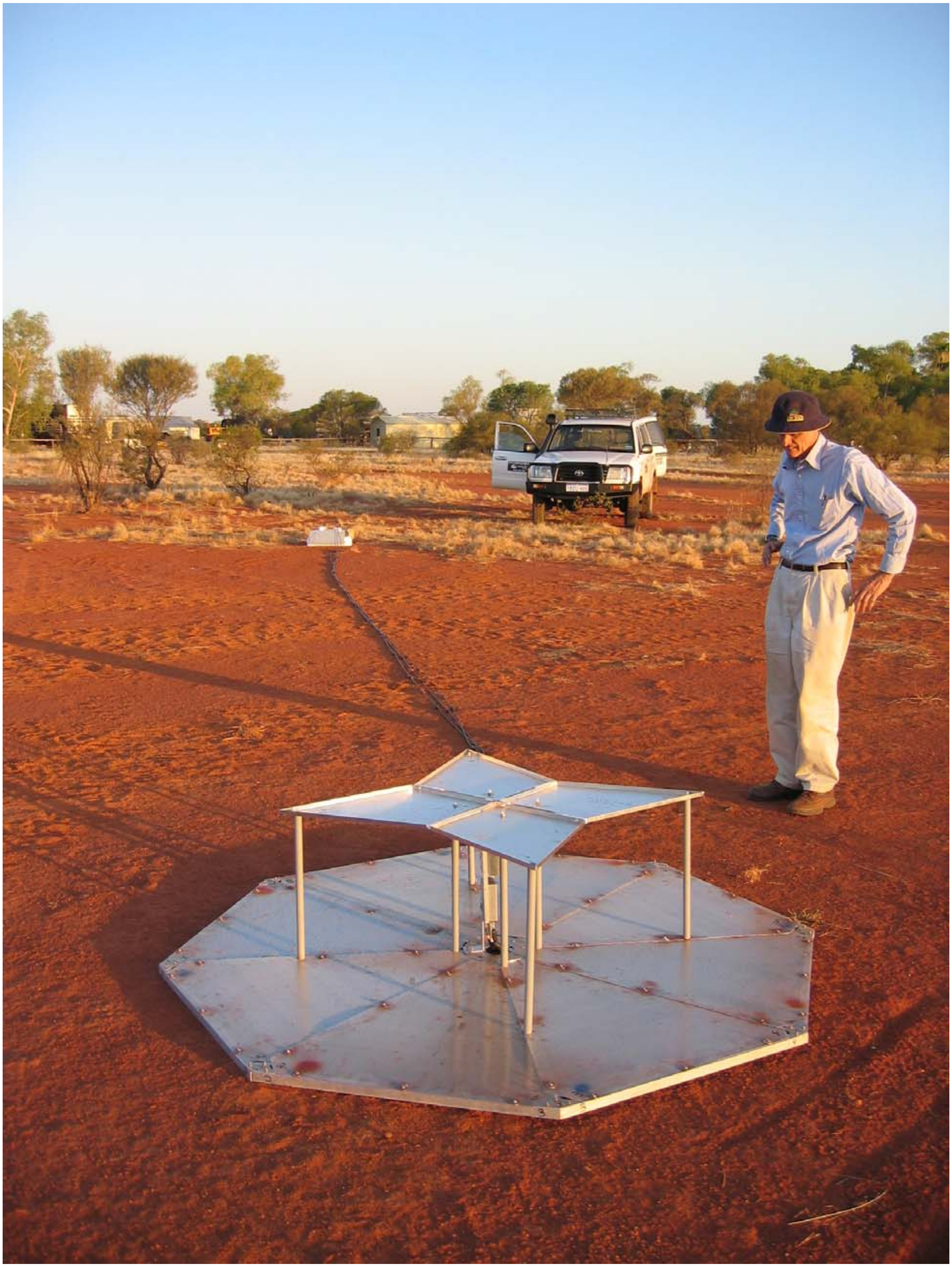


Fig. 3. EDGES in "EoR step" mode at Mileura Station, Western Australia

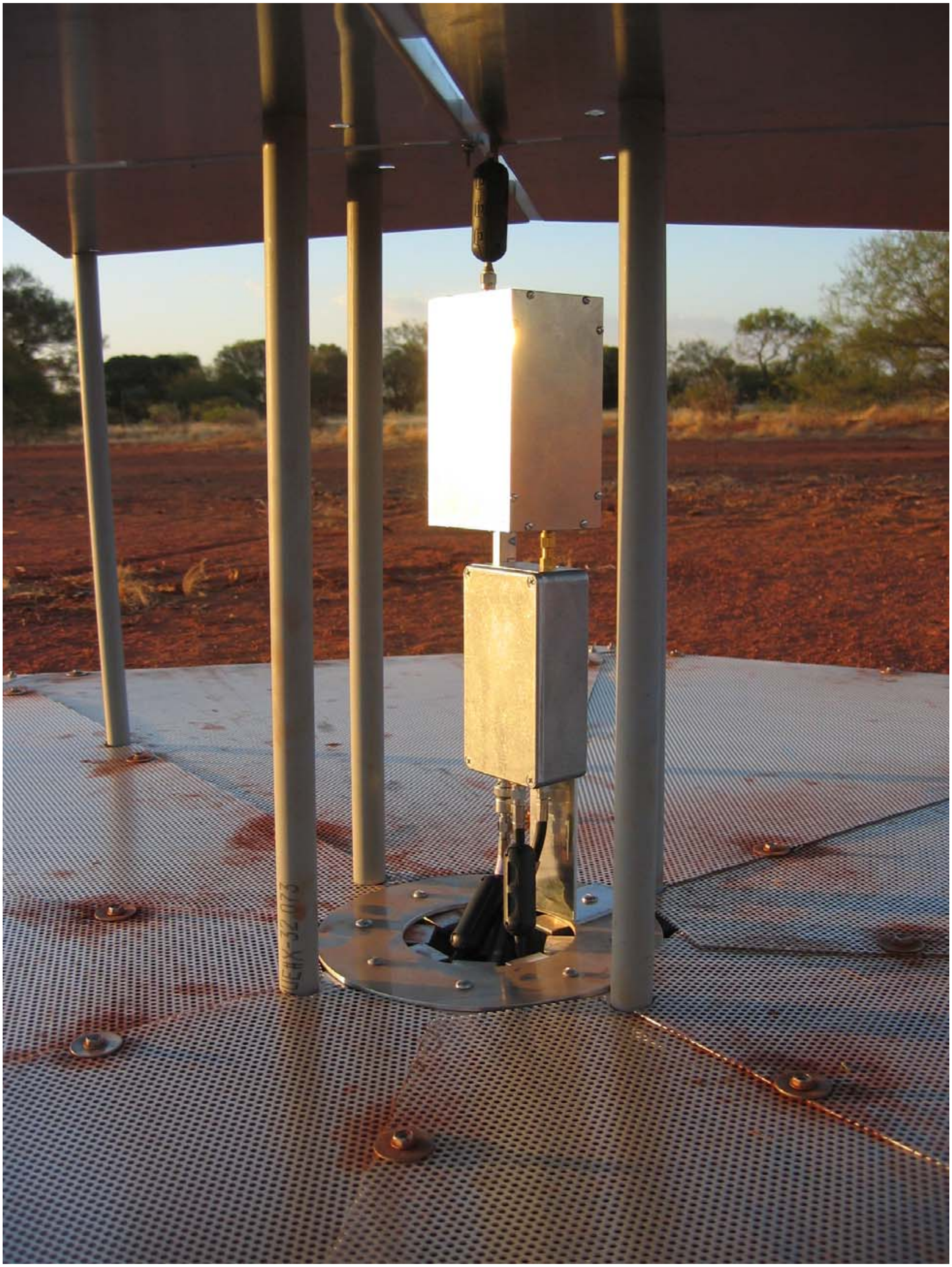


Figure 4. Configuration of the LNA module for EDGES in “EoR step” mode.

Figure 5. EDGES in “absolute sky noise” mode with temporary extended ground plane.

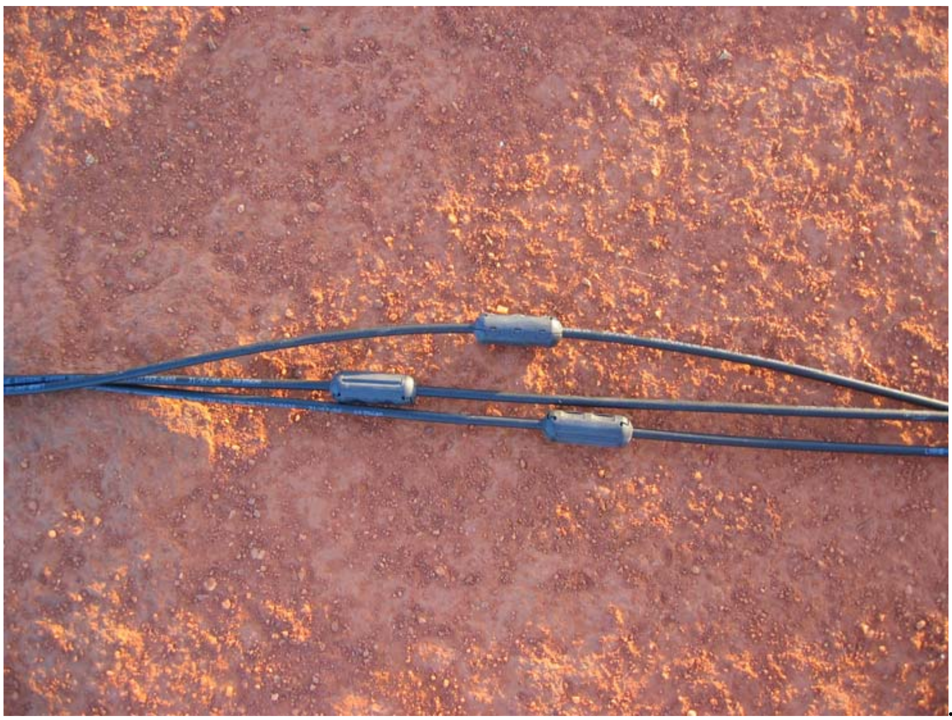
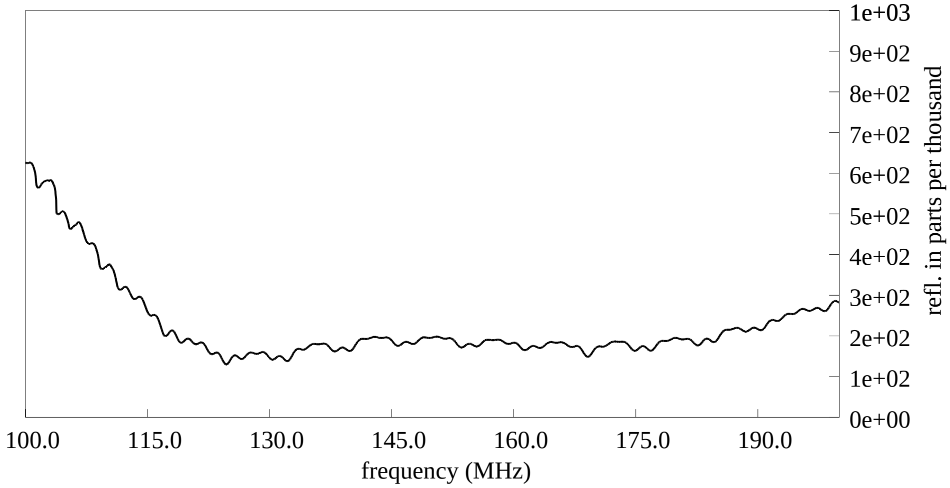


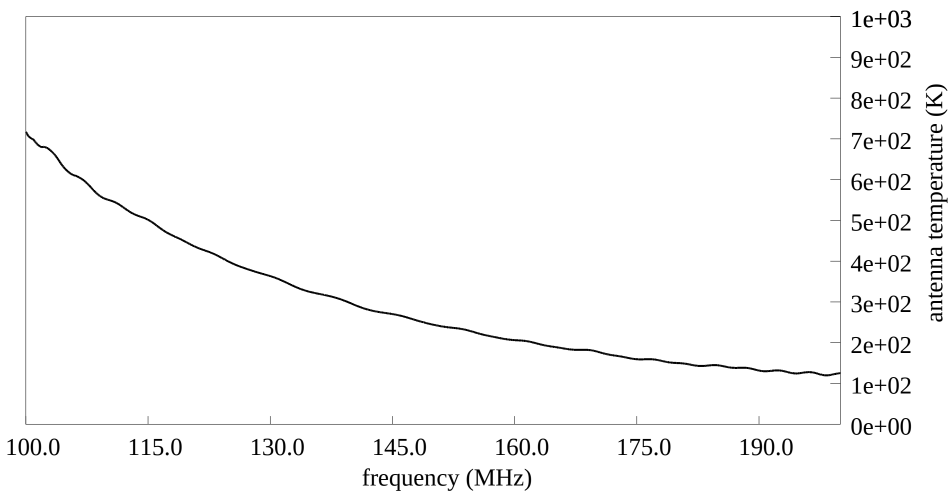
Figure 6. Ferrite common mode suppression filters used on cables in “EoR step” mode.



cor 5 npoly 0 dtyp 99 smooth 0 mdl 0.00 t150MHz 1605 tr 57 tc 444 file: 2006_341_09.acq
Acqiris attn 0 fpgatm 56.2 degC adc 6 accum 0 fsv 0.50 pwr 2.1e+11 5.0e+11 1.0e+12
start 2006:341:09:46:54 stop 2006:341:09:53:54 resolution 122.0 kHz cable 101.0

Wed Dec 13 14:43:00 2006

Fig 7. Edges antenna reflection coefficient



cor 3 npoly 0 dtyp 99 smooth 30 mdl 0.00 t150MHz 247 tr 62 tc 437 file: 2006_341_11.acq
Acqiris attn 0 fpgatm 51.2 degC adc 276 accum 0 fsv 0.50 pwr 2.2e+11 5.3e+11 2.3e+11
start 2006:341:14:00:17 stop 2006:341:15:59:41 resolution 122.0 kHz cable 95.0

Wed Dec 13 15:15:05 2006

Fig 8. EDGES calibrated sky spectrum

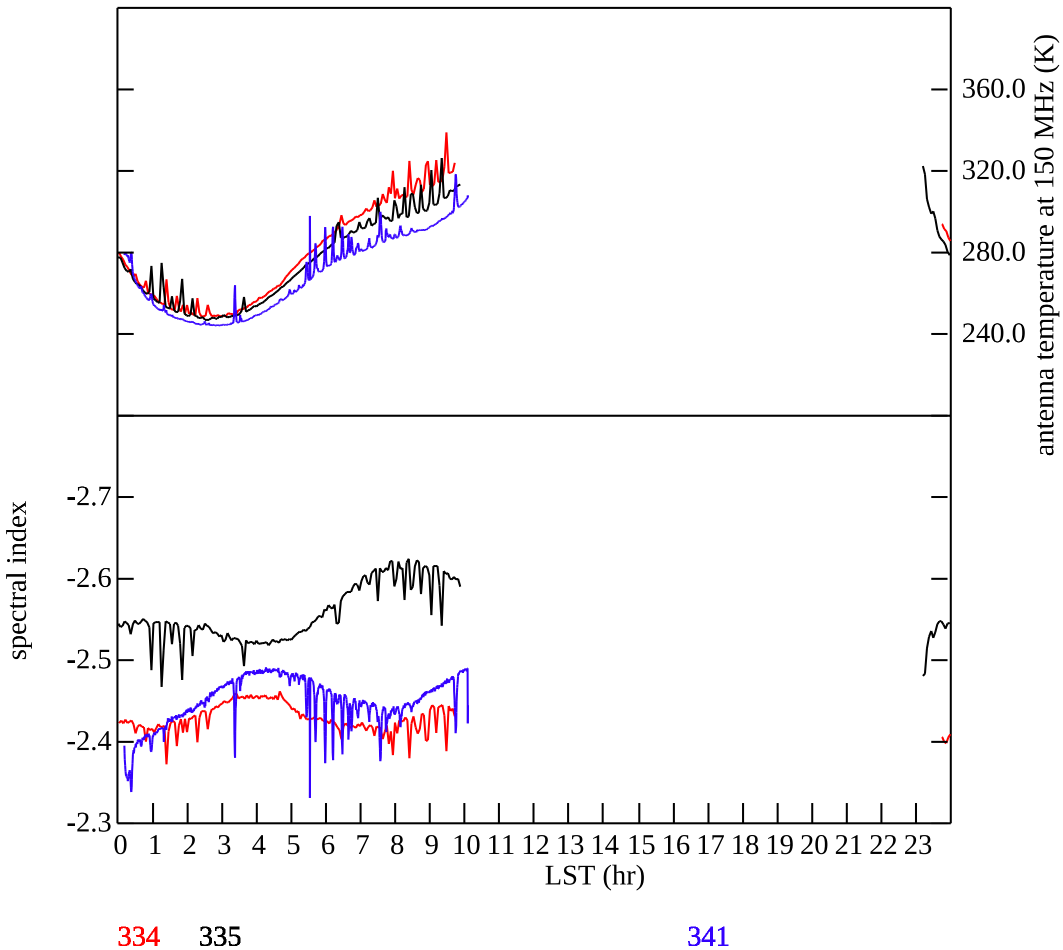


Fig. 9. Spectral index and 150 MHz brightness vs LST

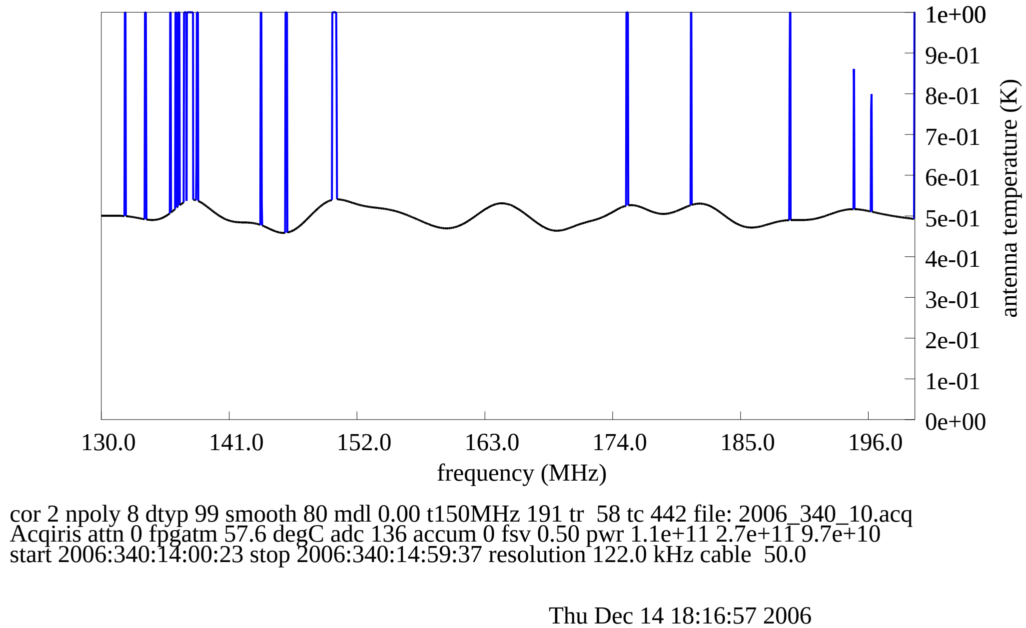


Fig. 10. Residuals to polynomial fit to spectrum in EoR mode. Blue spikes are the channels with RFI.

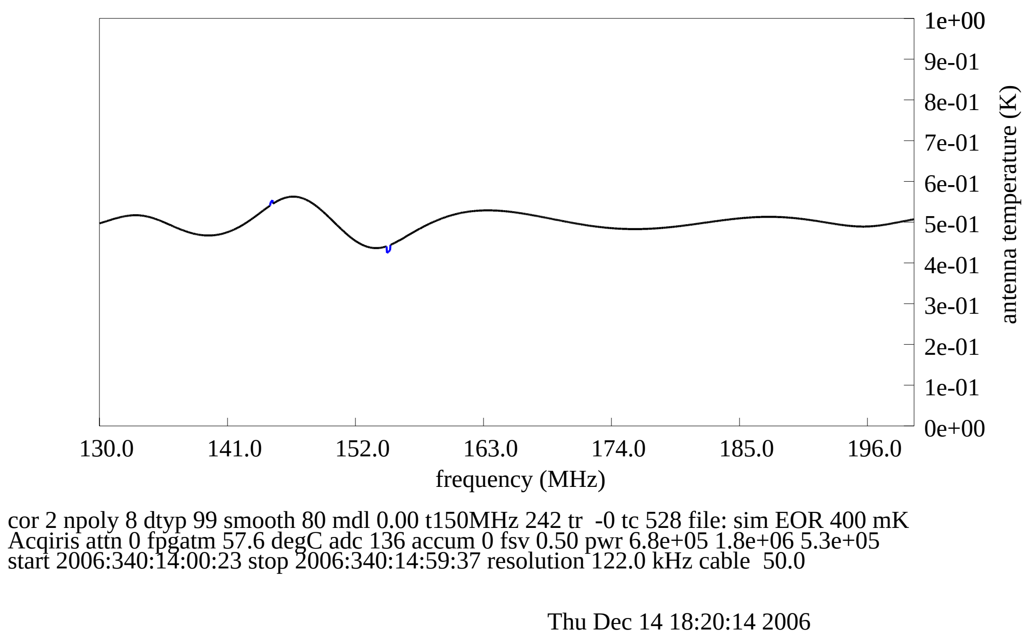


Fig. 11. Simulated EoR step of 400 mK over 10 MHz.