UPDATE on EDGES-3

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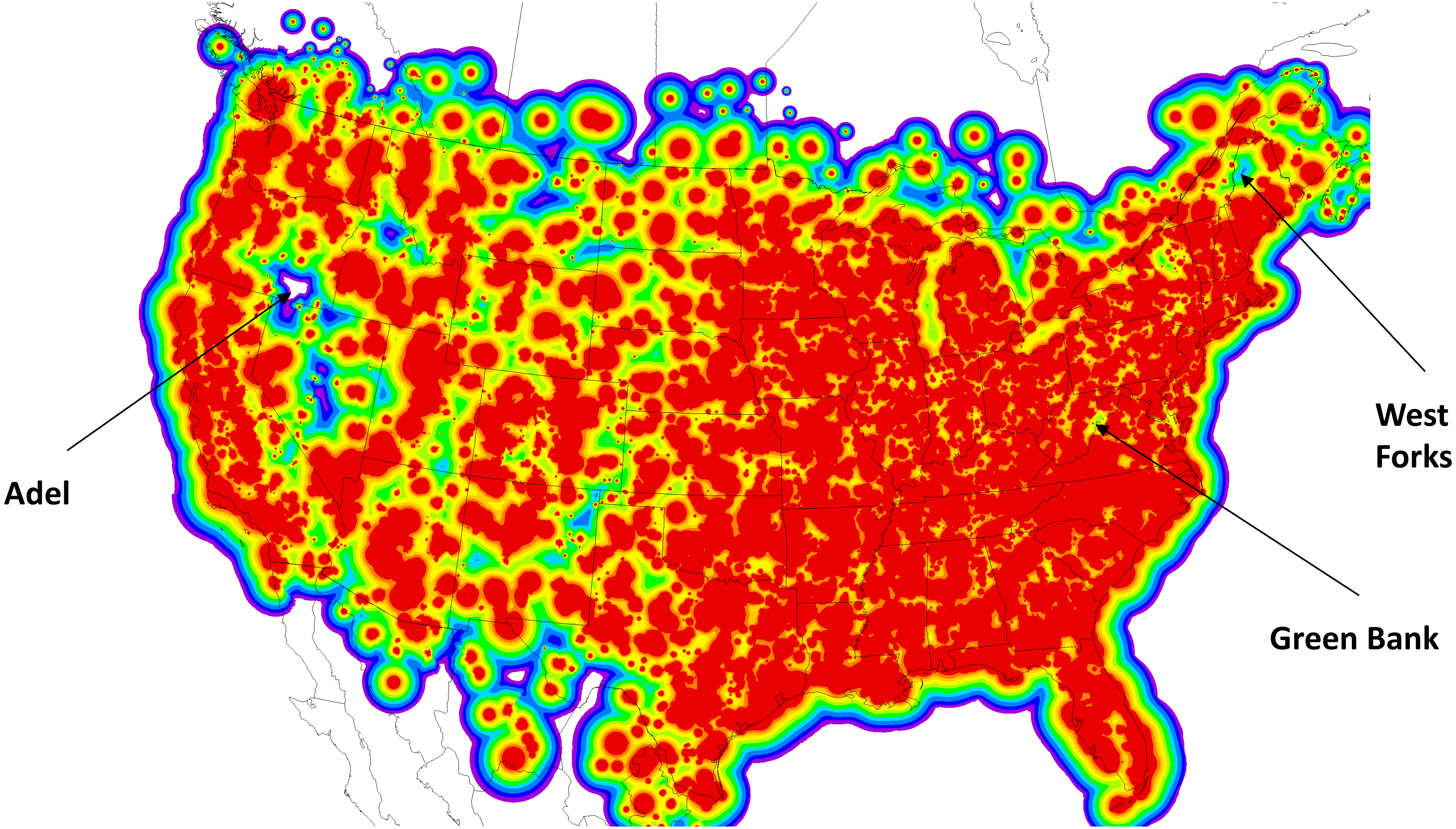
aeer   McGILL 7 October   2019

What I plan to cover

- Location of site in Oregon
- Details of EDGES-3 electronics
- EDGES-3 test in Oregon
- Results from Oregon
- RFI from micrometeors in Oregon, Nevada and the MRO
- Details of Calibration
- Refinements in RFI excision
- Test on soil without ground plane wires
- Tests with smoothing in frequency and Further Refinements in RFI excision



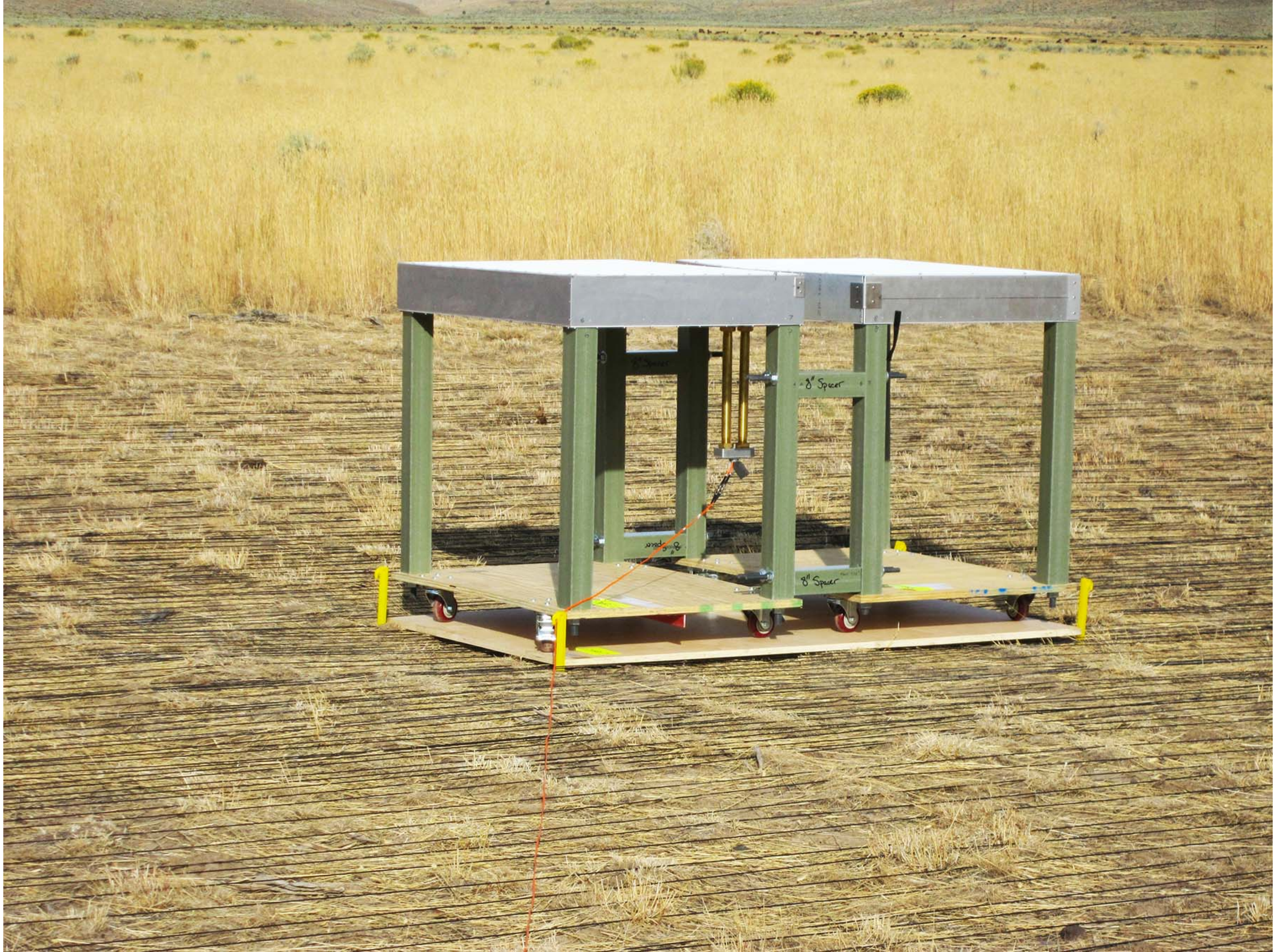
Integrated strength of FM radio for continental USA from radio-locator.com

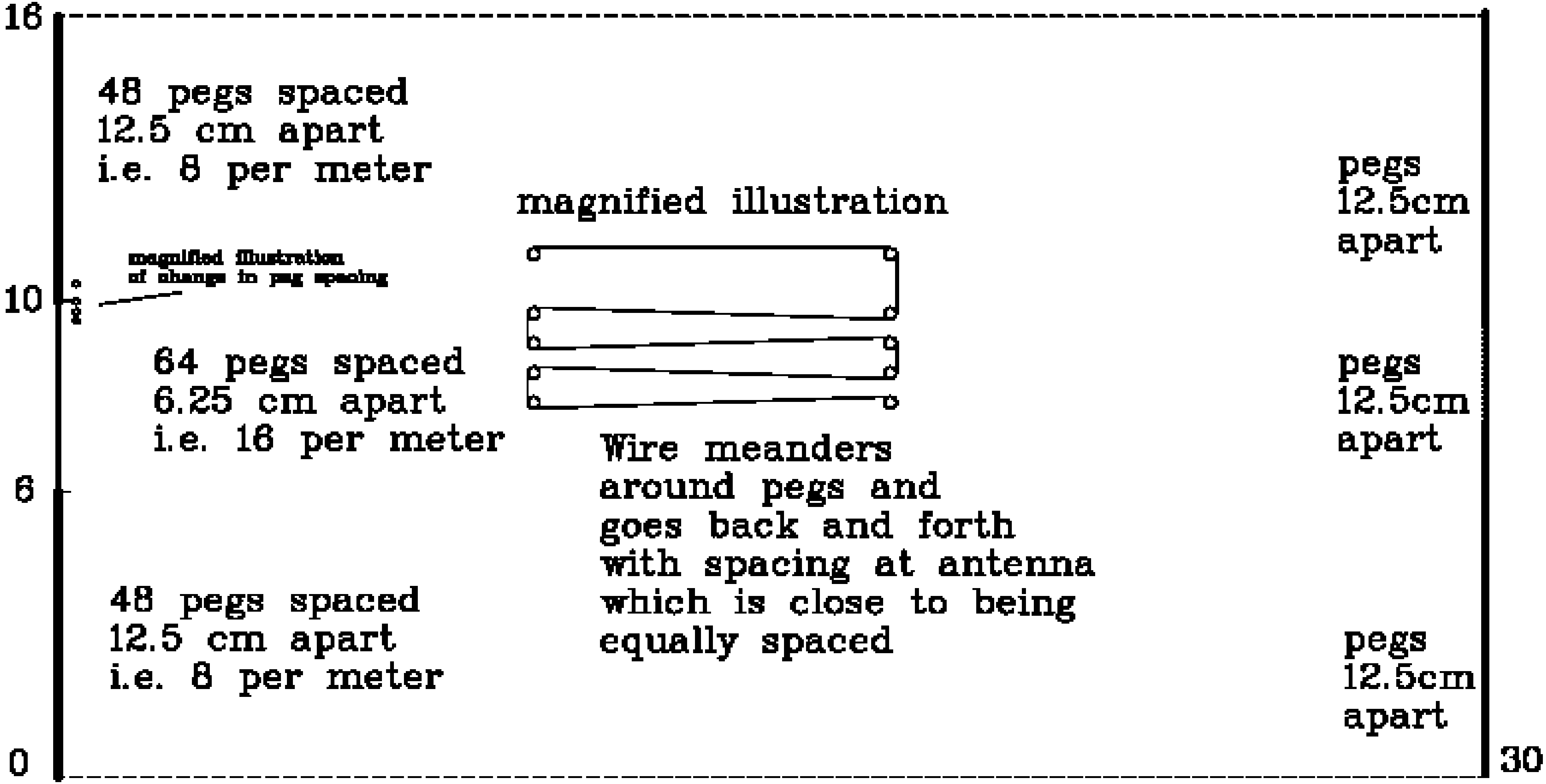
Quietest regions: West Forks, ME Adel, Oregon -better than Green Bank

"Catlow Valley" region of Oregon first explored in 2009 as a potential EDGES site
Roaring Spring Ranch was contacted in December 2018 and Skull Creek was visited by Mark Derome in January

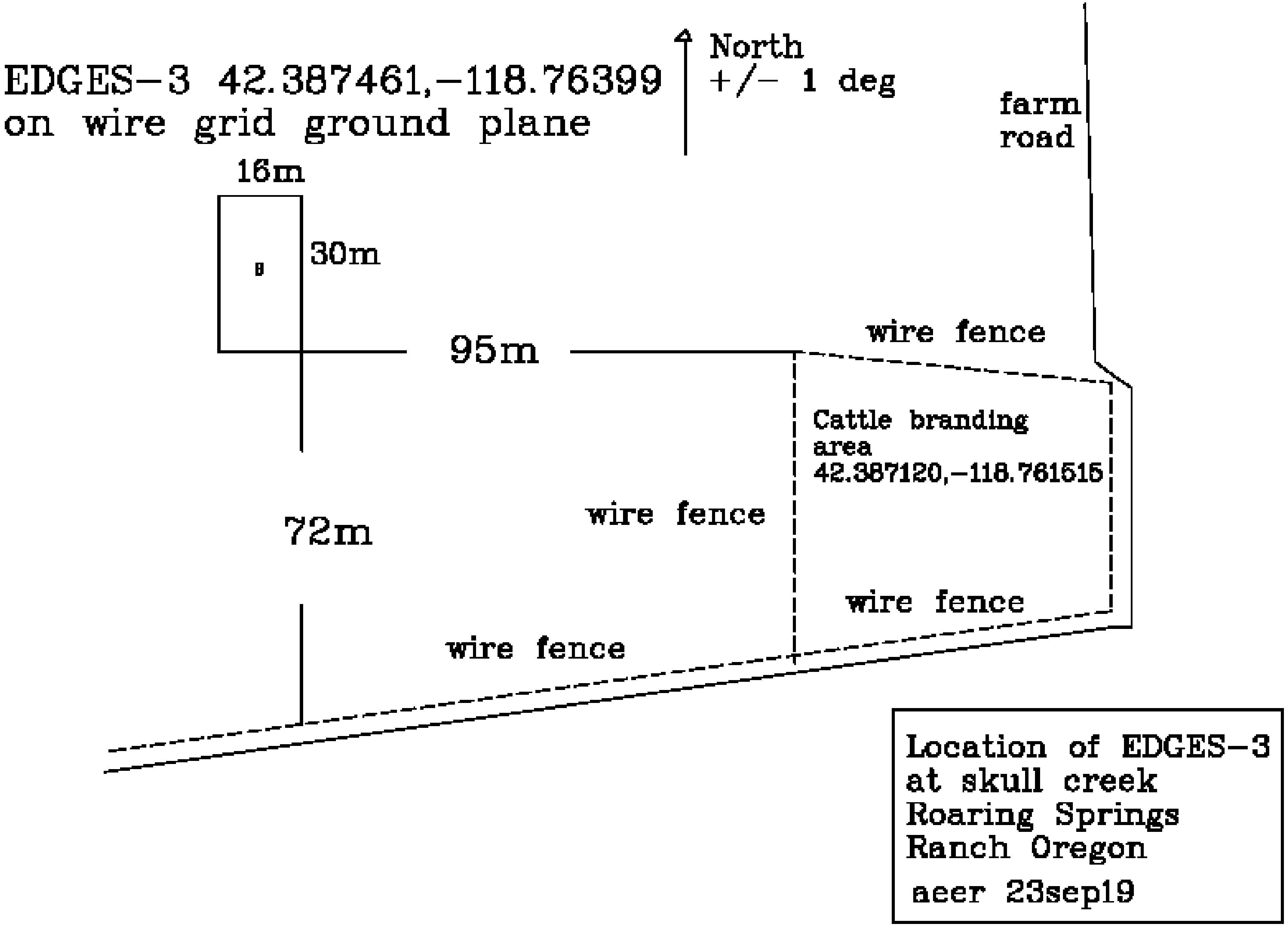
Terrain surrounding EDGES-3 location near Skull Creek Reservoir

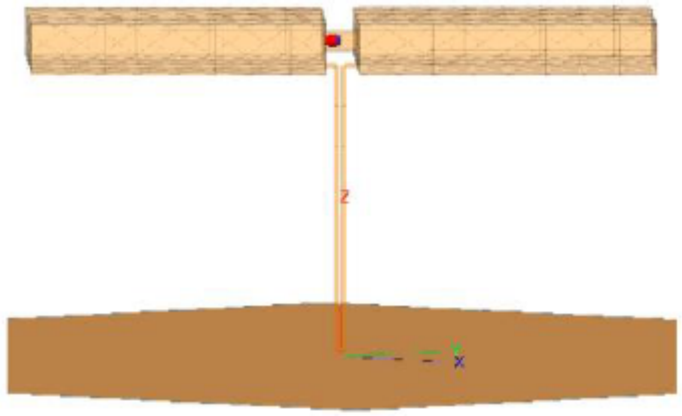

Echart Creek
Skull Creek
Skull Creek Rd
Skull Creek Rd
Skull Creek Reservoir
Cattle Branding Area
EDGES-3
Google


8" Spacer
8" Spacer

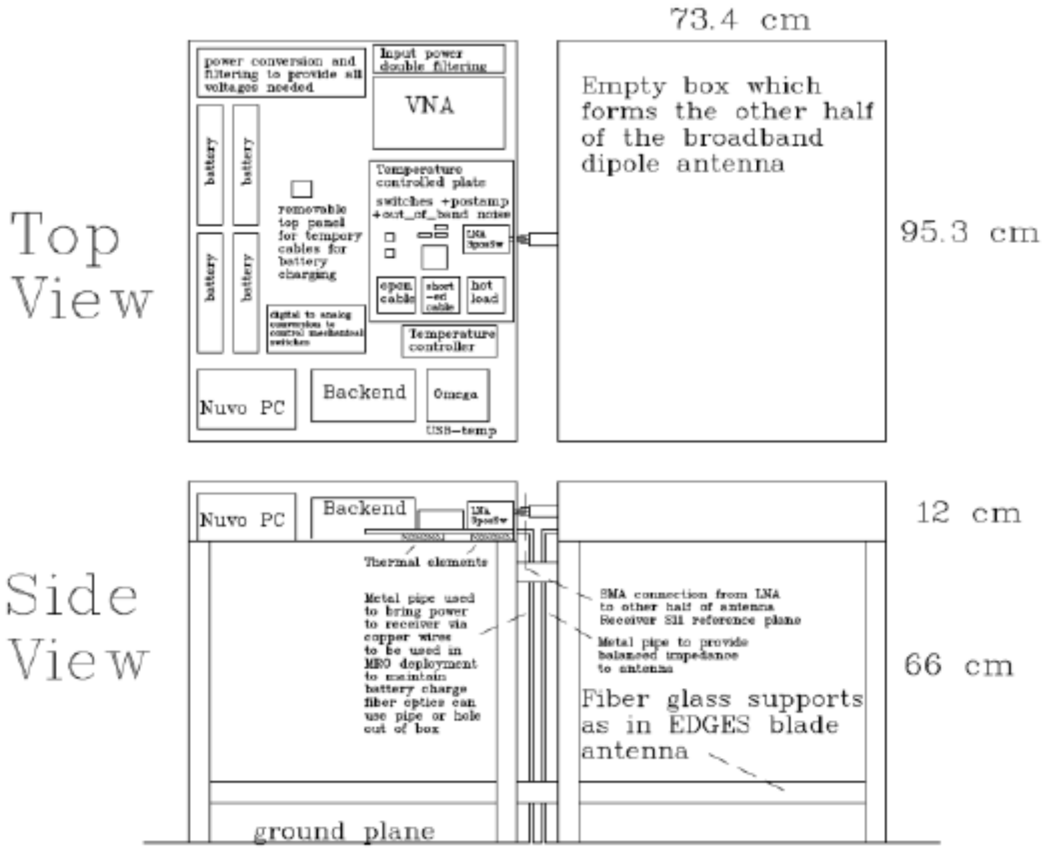


Wire grid ground plane


EDGES-3 42.387461,-118.76399
on wire grid ground plane
North
+/- 1 deg
farm
road
16m
30m
95m
72m
wire fence
Cattle branding
area
42.387120,-118.761515
wire fence
wire fence
wire fence
Location of EDGES-3
at skull creek
Roaring Springs
Ranch Oregon
aeer 23sep19



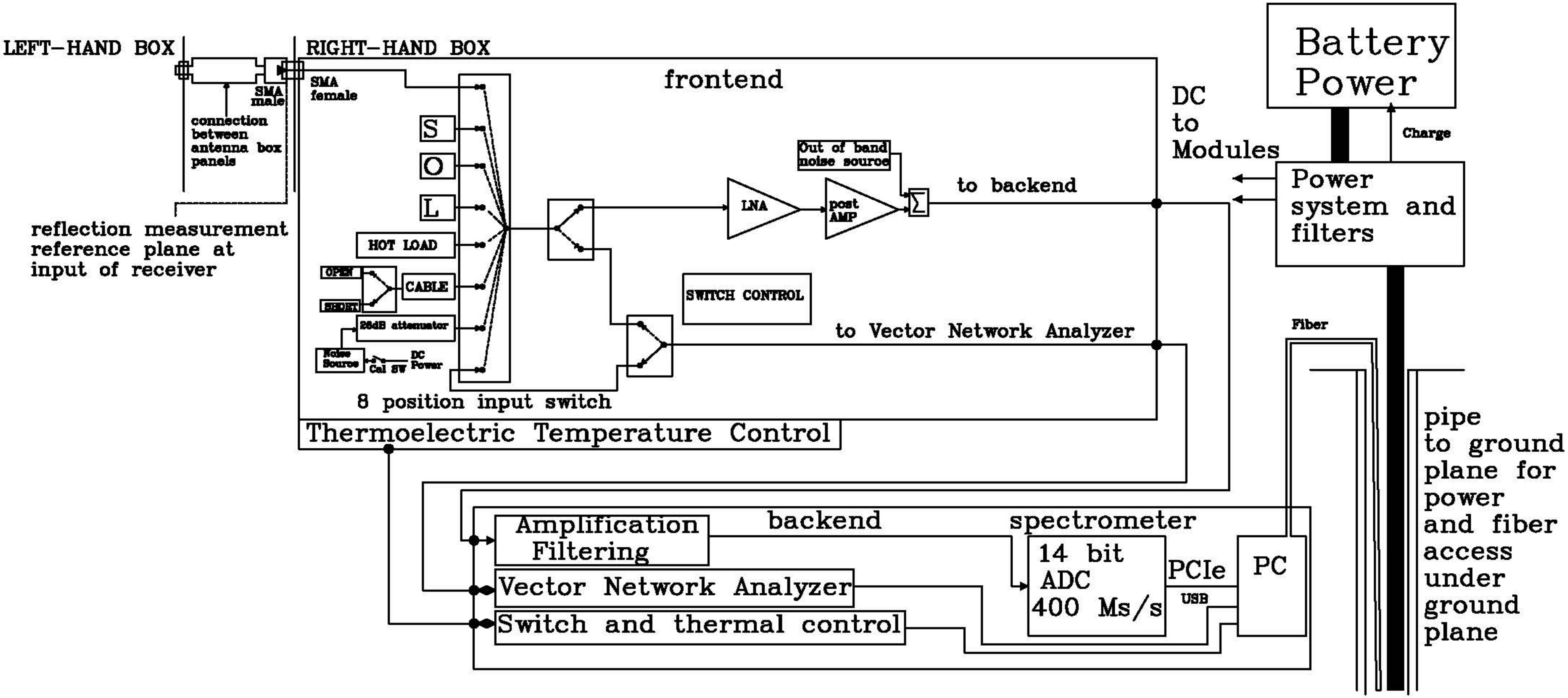
Horizontal profile view of the box-blade antenna design with same dimensions as the planar mid-band blade antenna, except 12cm panel height so that receiver can be located inside an antenna panel.



Layout of components inside antenna panel. Shown with optional batteries for field campaigns.

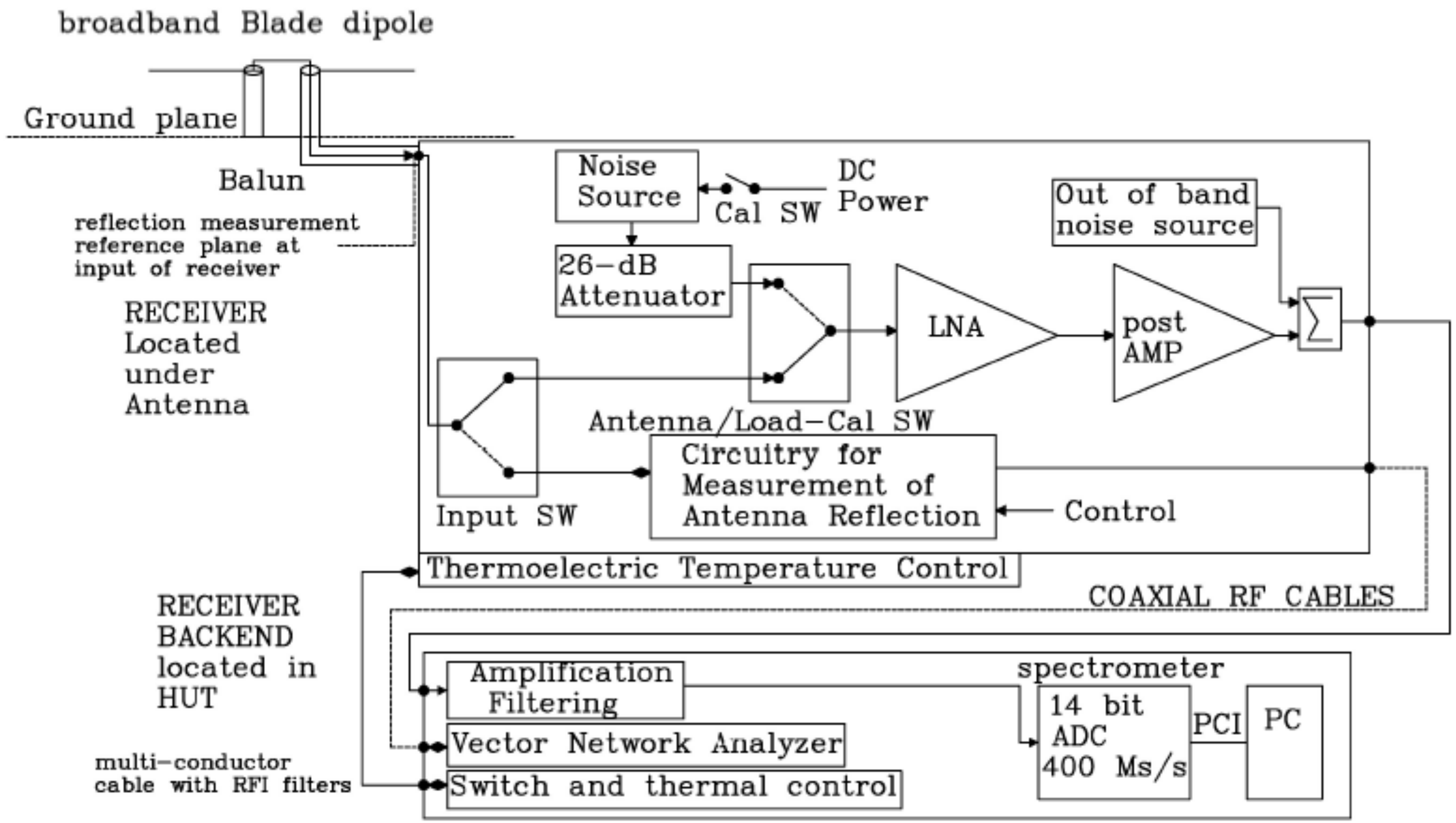
EDGES 3 system with built-in Calibration and all electronics in antenna proposed in November 2018. The advantages are:

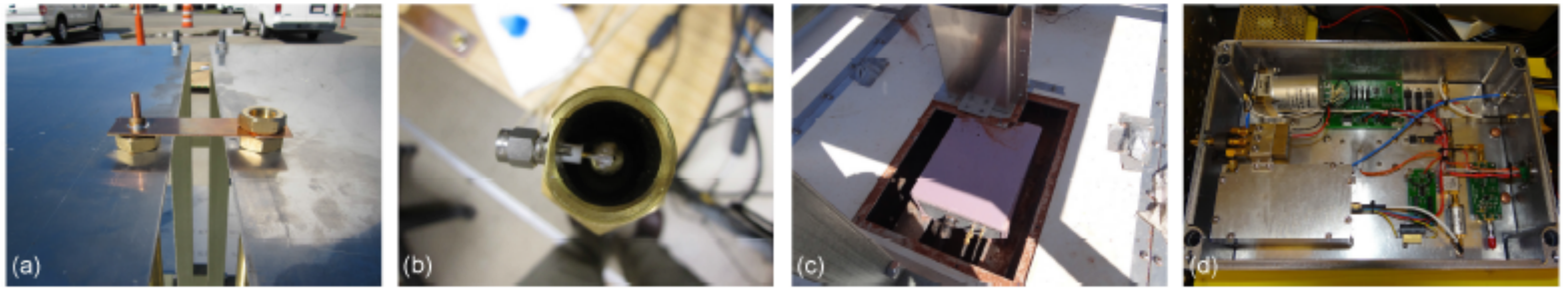
- **Reduced loss and less delay in antenna S11 from 22ns for EDGES-2 midband to 14ns for EDGES-3 – since balun is not needed**
- **Automated Calibration**
- **Easier deployment**

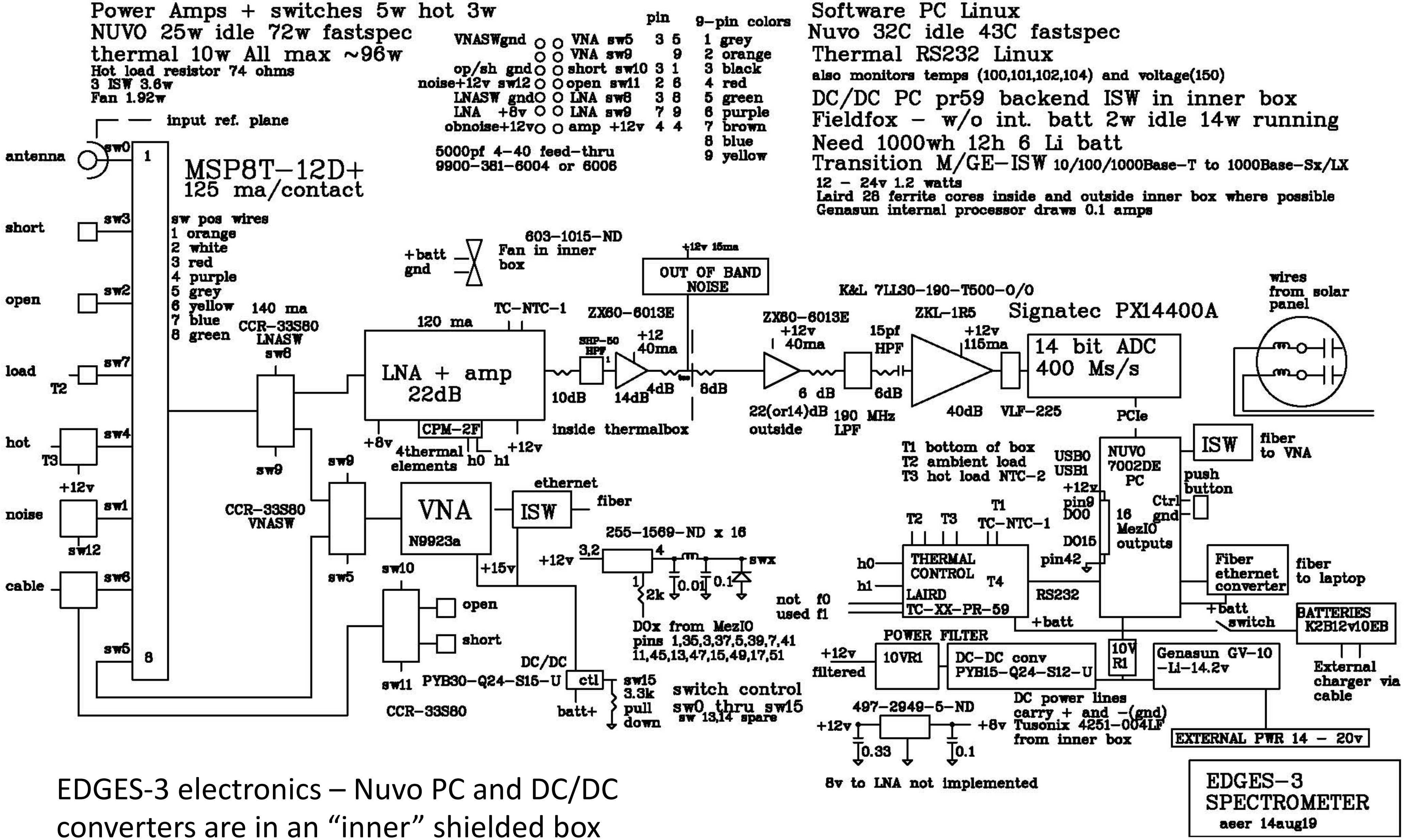


Block diagram of EDGES 3 system with built-in Calibration and all electronics in antenna

EDGES-2 for comparison requires backend to be located ~ 100m from antenna and manual calibration of receiver in Lab



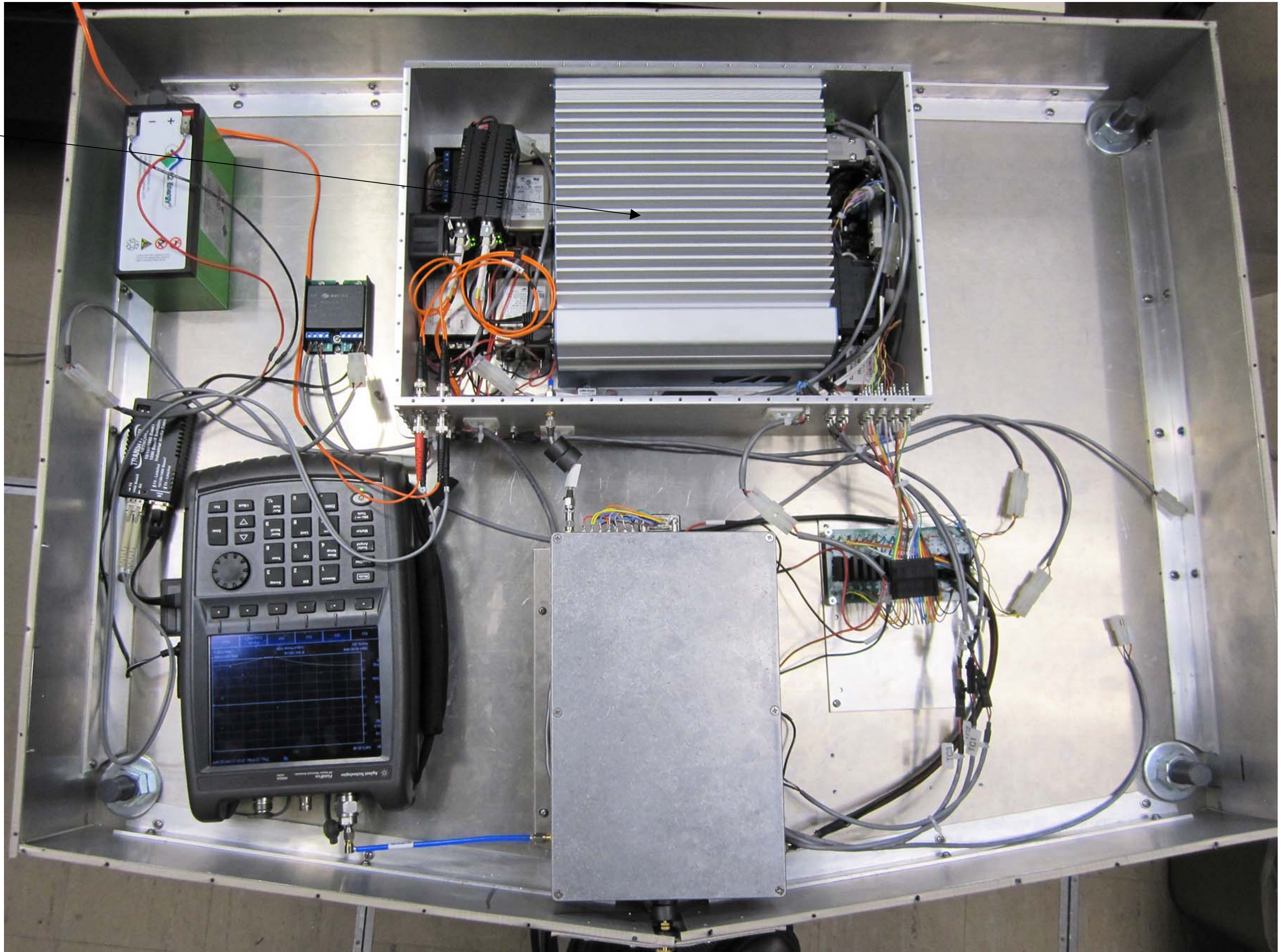




EDGES-3 electronics – Nuvo PC and DC/DC converters are in an “inner” shielded box “inner” shielded box with cover removed

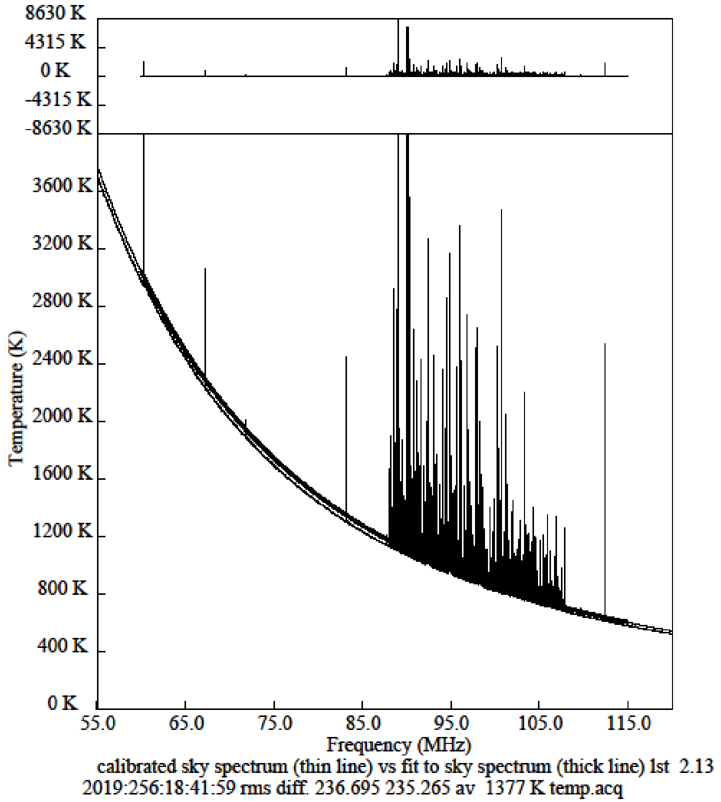
Notes:
VNA is only turned on for S11 measurements

Analog electronics is temperature controlled

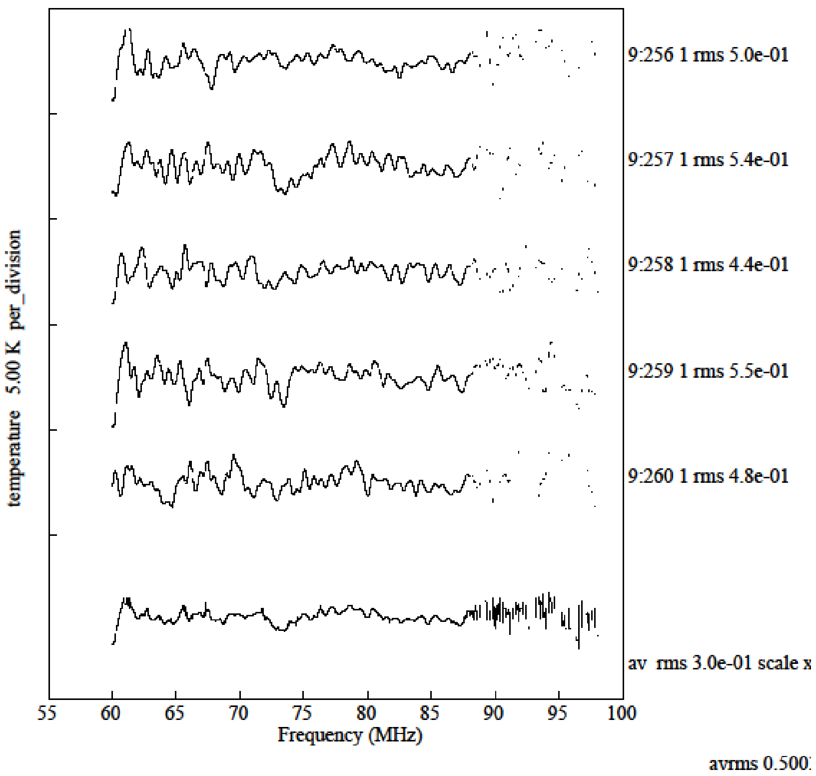


EDGES-3 test set-up in screen room at Haystack Observatory

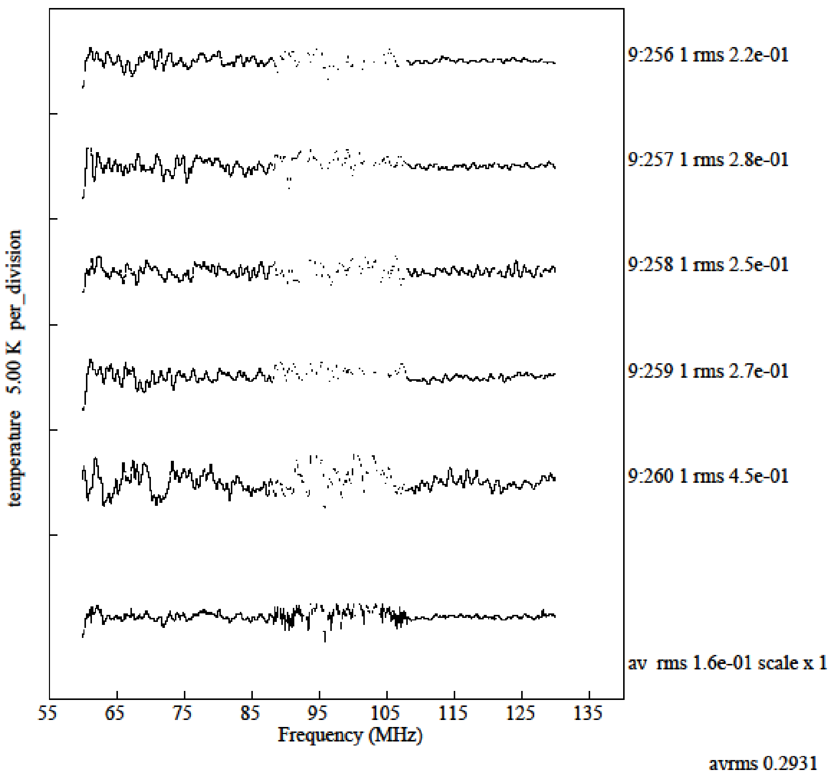
Test results from 3.5 hours each day on September 13,14,15 and 16



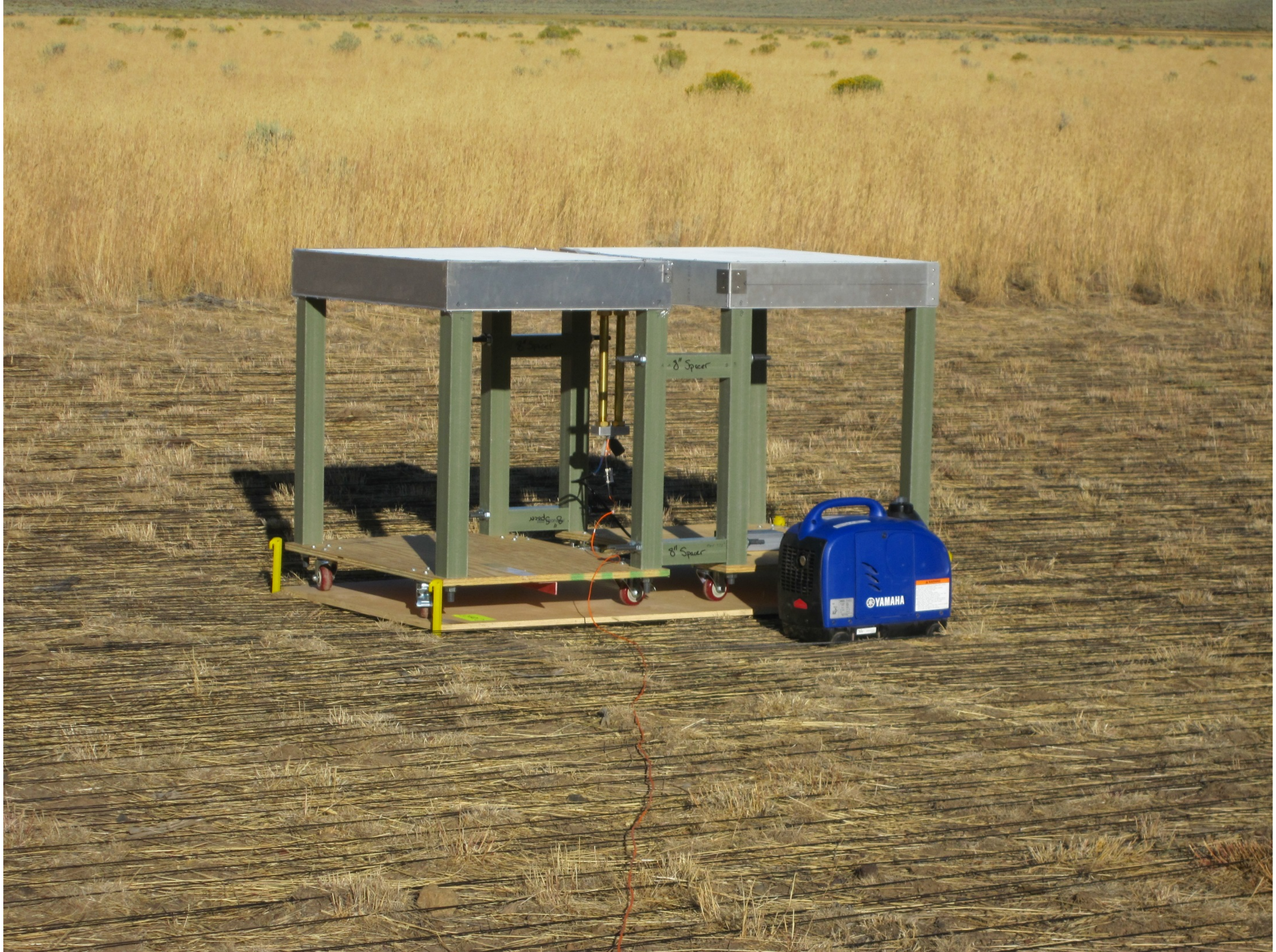
Spectrum without RFI excision

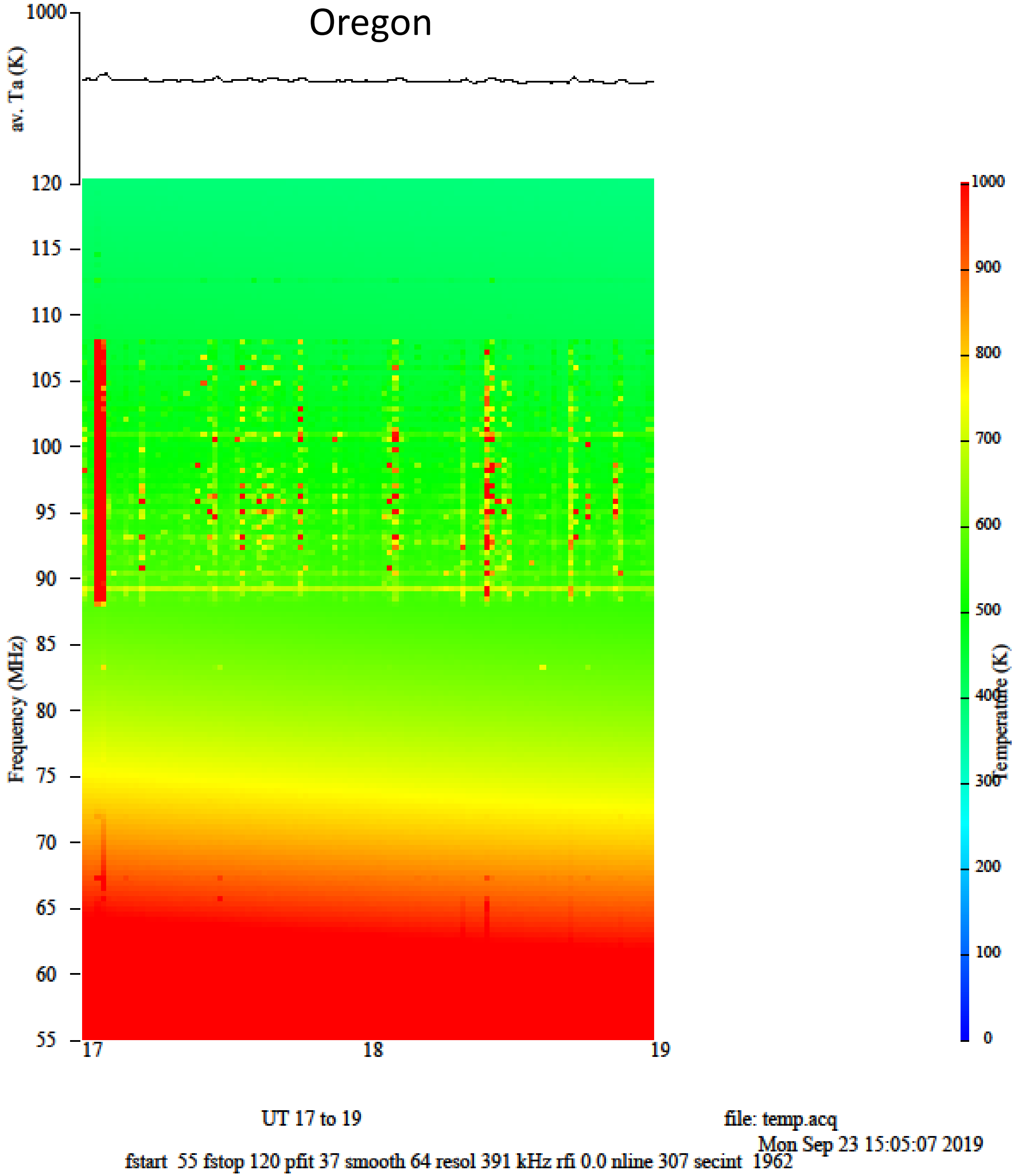


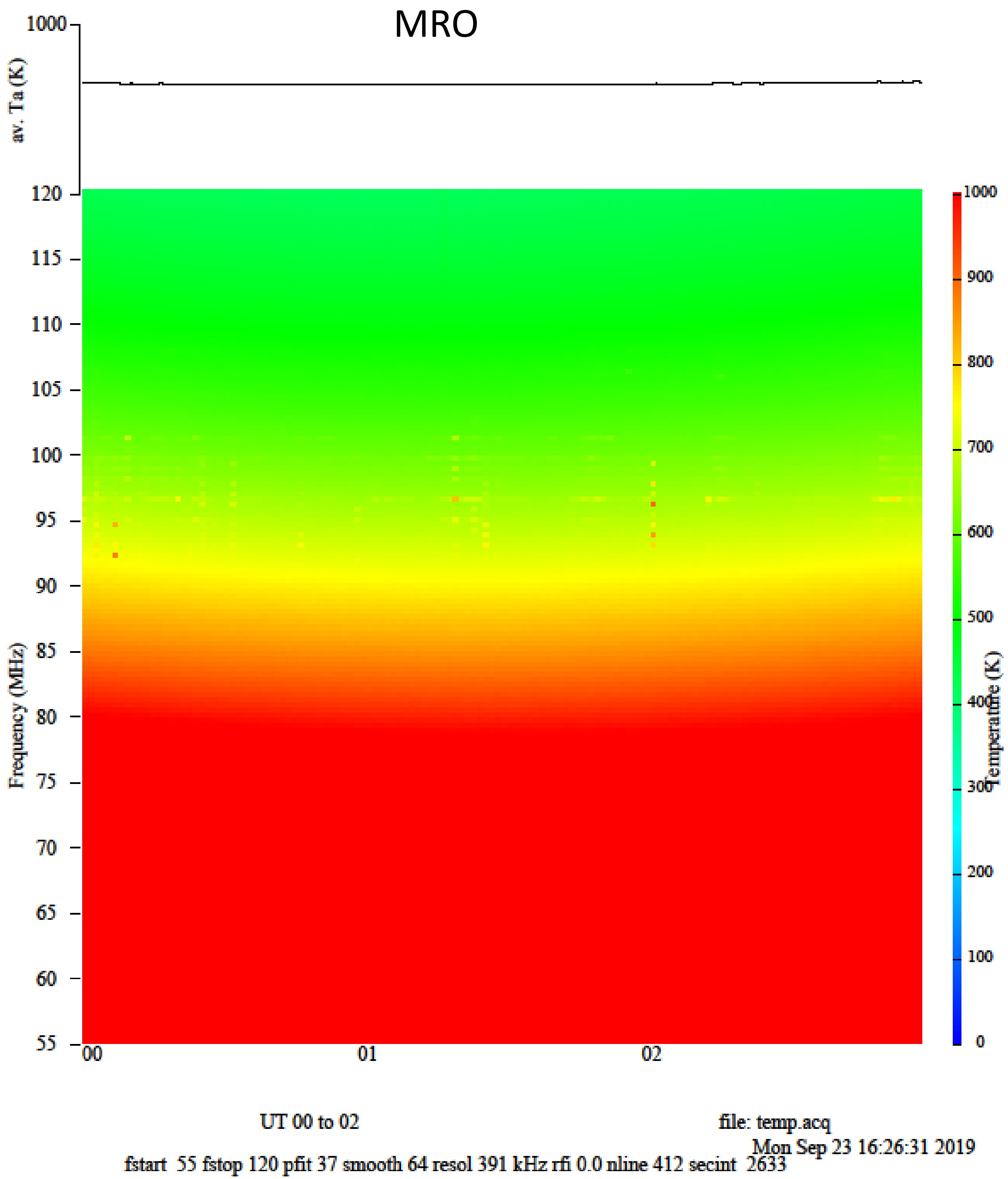
Spectra with RFI excision and 4 poly terms removed



Spectra with RFI excision and 5 poly terms removed


8" Spacer
8" Spacer
YAMAHA


Oregon
av. Ta (K)
1000
120
115
110
105
100
95
90
85
80
75
70
65
60
55
Frequency (MHz)
17
18
19
Temperature (K)
1000
900
800
700
600
500
400
300
200
100
0
UT 17 to 19
file: temp.acq
Mon Sep 23 15:05:07 2019
fstart 55 fstop 120 pfit 37 smooth 64 resol 391 kHz rfi 0.0 nline 307 secint 1962


MRO
av. Ta (K)
1000
120
115
110
105
100
95
90
85
80
75
70
65
60
55
Frequency (MHz)
00
01
02
Temperature (K)
1000
900
800
700
600
500
400
300
200
100
0
UT 00 to 02
file: temp.acq
Mon Sep 23 16:26:31 2019
fstart 55 fstop 120 pfit 37 smooth 64 resol 391 kHz rfi 0.0 nline 412 secint 2633

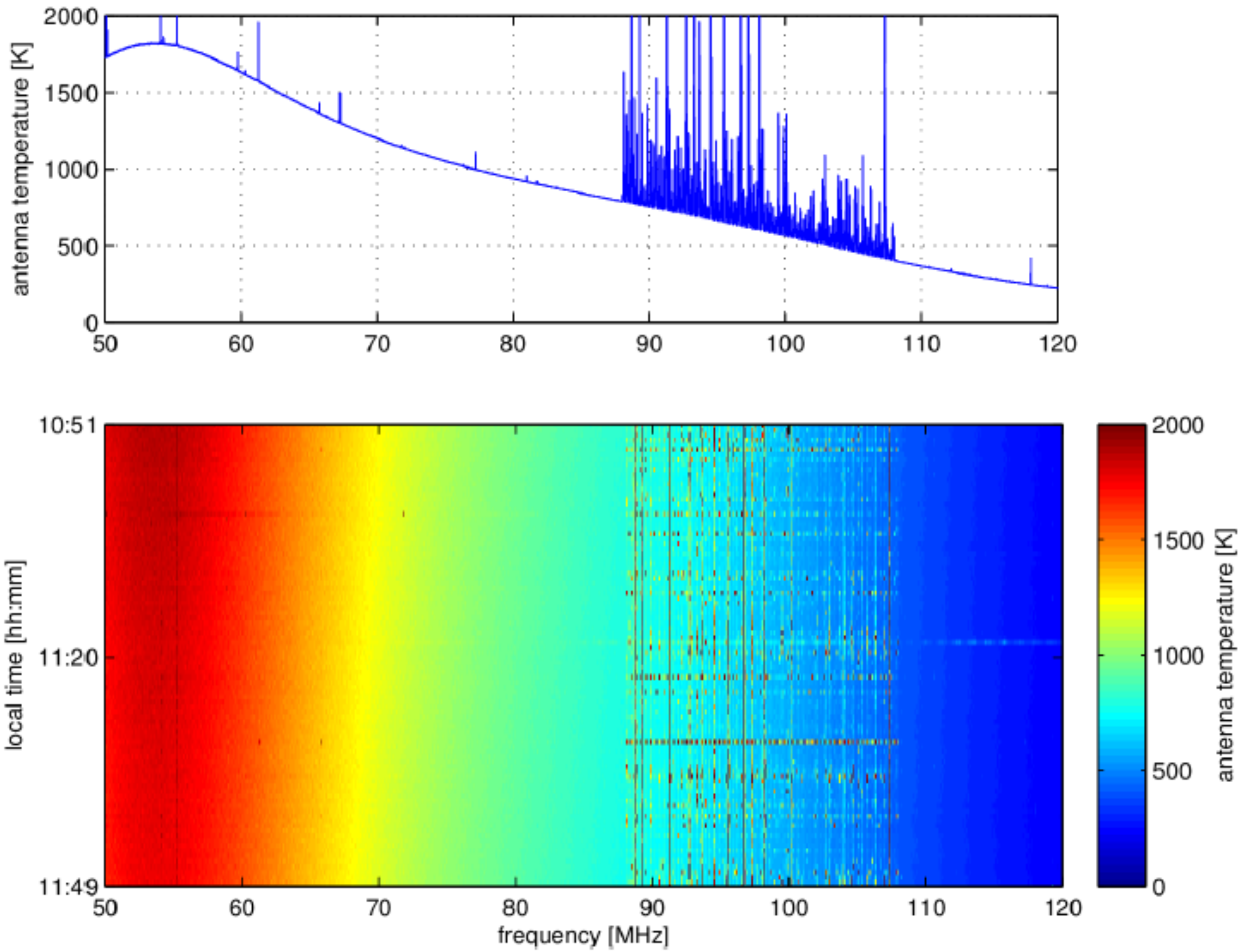
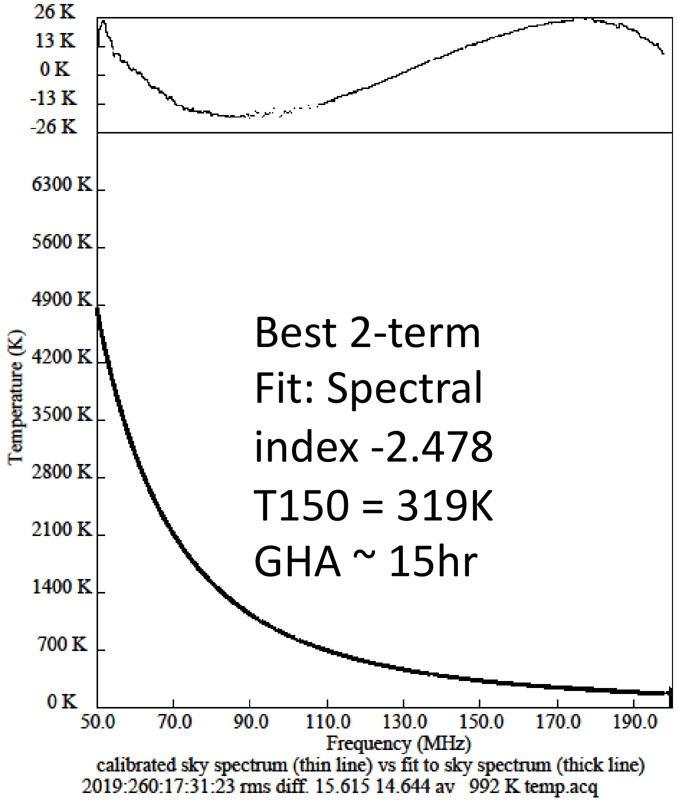


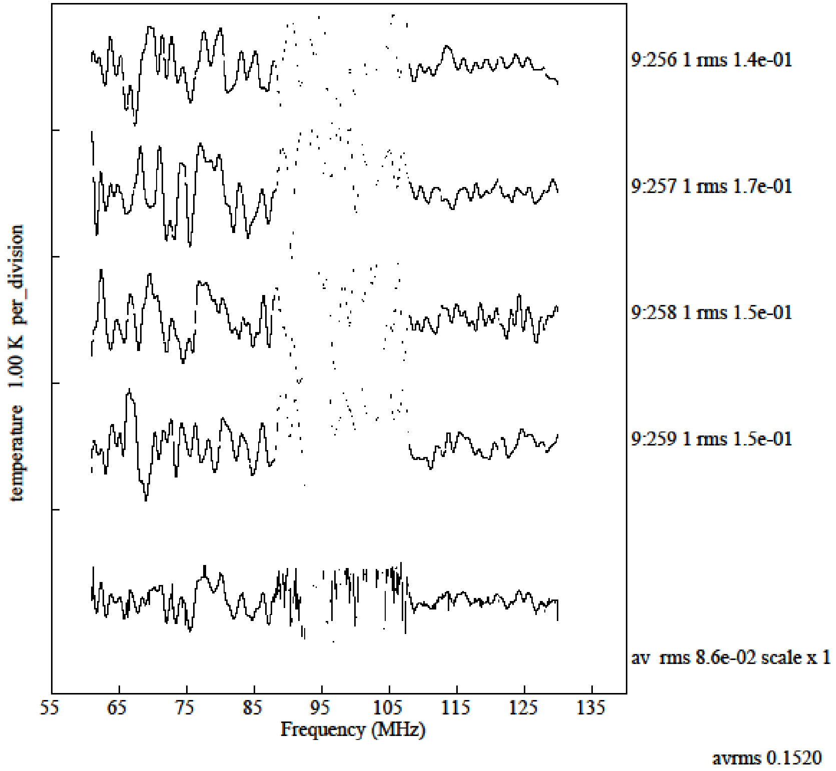
Figure 12: Site 1, low-band, NS orientation.

Comparison with a low-band test at Gund ranch Nevada
Raul Monsalve and Thomas Mozdzen July 2014

rms of 86 mK reached
with more smoothing and
RFI excision



Full calibrated spectrum
with 2-term fit to scale
and spectral index



Calibrated spectrum 60 – 130
MHz 5-poly terms removed with
RFI excision and smoothing to
781 kHz. About 80% excised

Calibration and processing procedure

In the Lab:

- Measure S11 of the resistance the internal calibration load and it’s temperature coefficient
- Measure S-parms of the cable from the internal 8-position switch to the antenna input by manually placing known SOL calibration loads on antenna input
- Run automated 3-position switched spectra on internal ambient, hot, open and shorted cable and S11 data on internal SOL ambient, hot, open and shorted cable loads as well as LNA
- Calculate calibration of receiver LNA noise waves and receiver gain and offset
- Connect artificial antenna to receiver input and measure S11 and take 3-position switched spectra

In the field:

- Repeat automated calibration when needed
- Take 3-position switched spectra of the sky and antenna S11 data

Using EM simulations

- Estimate the antenna and ground plane loss

Obtain absolute calibration of sky spectrum processing

- Using calibration data, antenna S11 and losses obtain sky spectrum
- Use weighted least squares with up to 6 physics based “basis” functions to remove foreground, ionosphere and solve for hydrogen line signature
- Error estimates from covariance matrix MCMC etc.

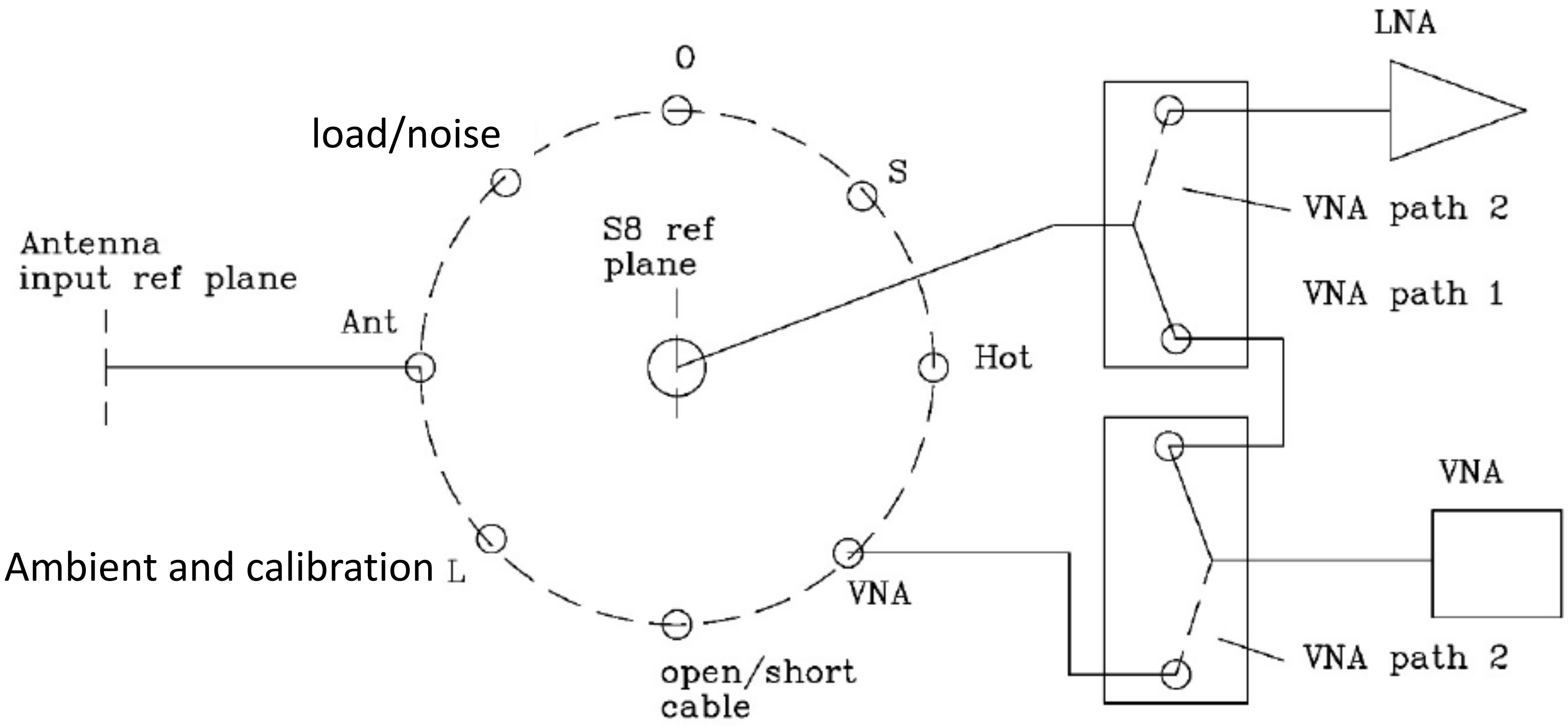
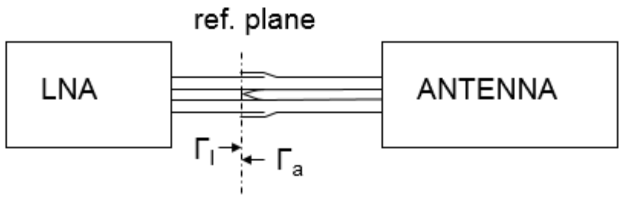


Figure 1. Schematic of change in reference plane.

S-parameters of input cable measured using calibration SOL placed on antenna input in Lab
Loss ~ 0.07 dB or about 1.5 % at 75 MHz

Antenna to Low Noise Amplifier mismatch



Compensating for the antenna mismatch

$$T_{sky}(1-|\Gamma|^2) = T_{sky}(1-|\Gamma_a|^2)|F|^2$$

where Γ is the reflection from the LNA and

$$\Gamma = \frac{Z_a - Z_l^*}{Z_a + Z_l}$$

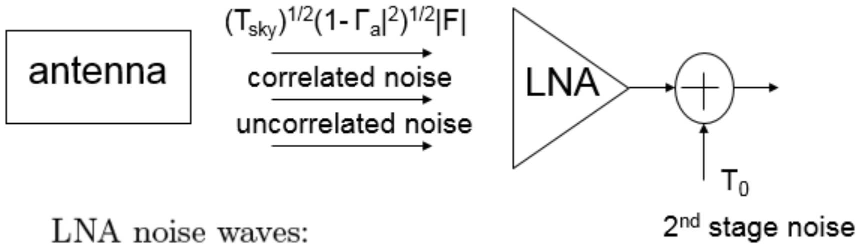
$$F = \frac{(1-|\Gamma_l|^2)^{1/2}}{1-\Gamma_a\Gamma_l}$$

where Γ_a and Γ_l are the reflections at 50 ohms ref. point

$$\Gamma_a = \frac{Z_a-50}{Z_a+50}$$

$$\Gamma_l = \frac{Z_l-50}{Z_l+50}$$

LNA noise waves reflected back from antenna



LNA noise waves:

$$T_{rec} = T_{sky}(1-|\Gamma_a|^2)|F|^2 + T_u|\Gamma_a|^2|F|^2 + (T_c cos(\phi) + T_s sin(\phi))|\Gamma_a||F| + T_0$$

T_u is the uncorrelated wave

$T_c cos(\phi)$ and $T_s sin(\phi)$ are the correlated portions which depend on the phase, ϕ, of the reflected wave.

ϕ is the phase of $\Gamma_a F$

T_0 is the "second stage noise".

3 – position input switching – antenna, load, cal to take out "bandpass" and set temperature scale

$$P_{ant} = gT_{rec}$$
$$P_{load} = g(GT_{amb} + T_0)$$
$$P_{cal} = g(G(T_{amb} + T_{cal}) + T_0)$$

where g is the receiver gain and G is $G = 1 - |\Gamma_l|^2$

$Tamb$ is the ambient temperature and T_{cal} calibration noise

The calibrated receiver output, T_{3p}, is

$$\begin{aligned} T_{3p} &= \frac{T_{cal}(P_{ant} - P_{load})}{(P_{cal} - P_{load})} + T_{amb} \\ &= T_{sky}(1-|\Gamma_a|^2)|F|^2G^{-1} \\ &+ T_u|\Gamma_a|^2|F|^2G^{-1} \\ &+ (T_c cos(\phi) + T_s sin(\phi))|\Gamma_a||F|G^{-1} \end{aligned}$$

Calibration requires measurements of antenna and LNA reflection coefficients as well correlated and uncorrelated LNA noise. Scale and offset are set from ambient and hot loads

Correction for losses

$$T = T_{sky}L + T_{amb}(1-L)$$

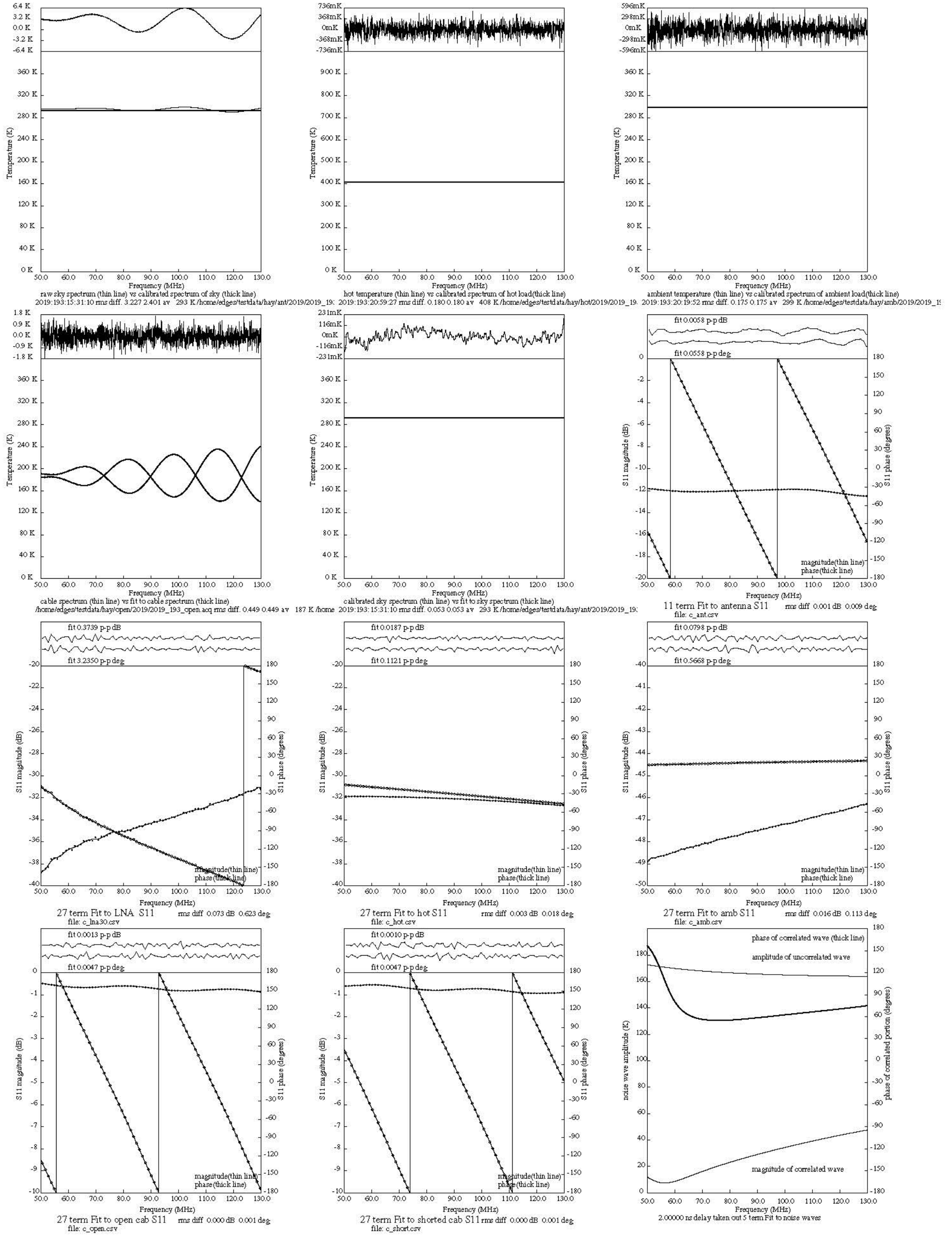
$$L = (1 - |\Gamma a|^2)^{-1}|S21|^2(1-|\Gamma|^2)/|1-S22\Gamma|^2$$

where:

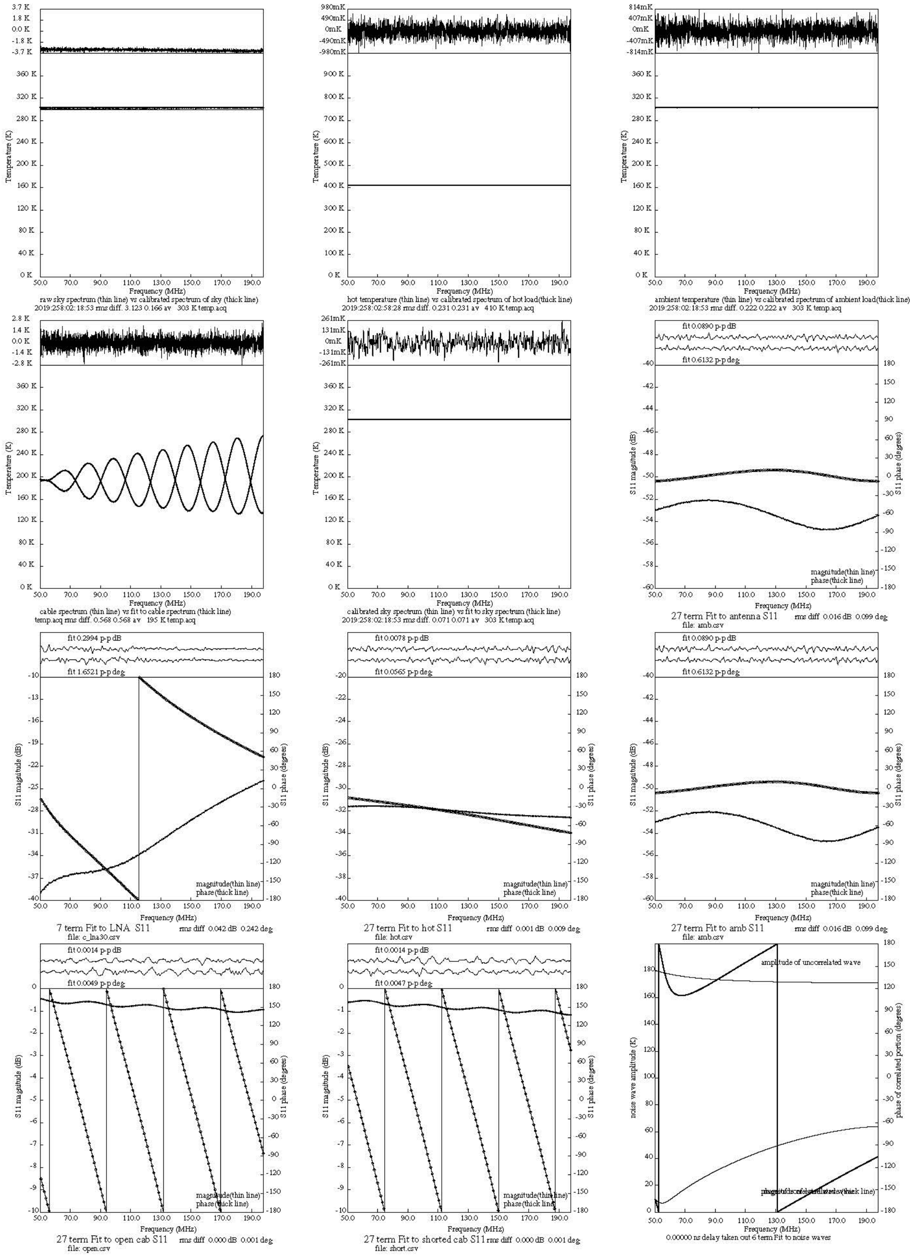
Γa = reflection coefficient on antenna measured from reference plane at 8-position switch

Γ = antenna reflection = $(\Gamma a - S11)/(S12S21 - S11S22 + S22\Gamma a)$

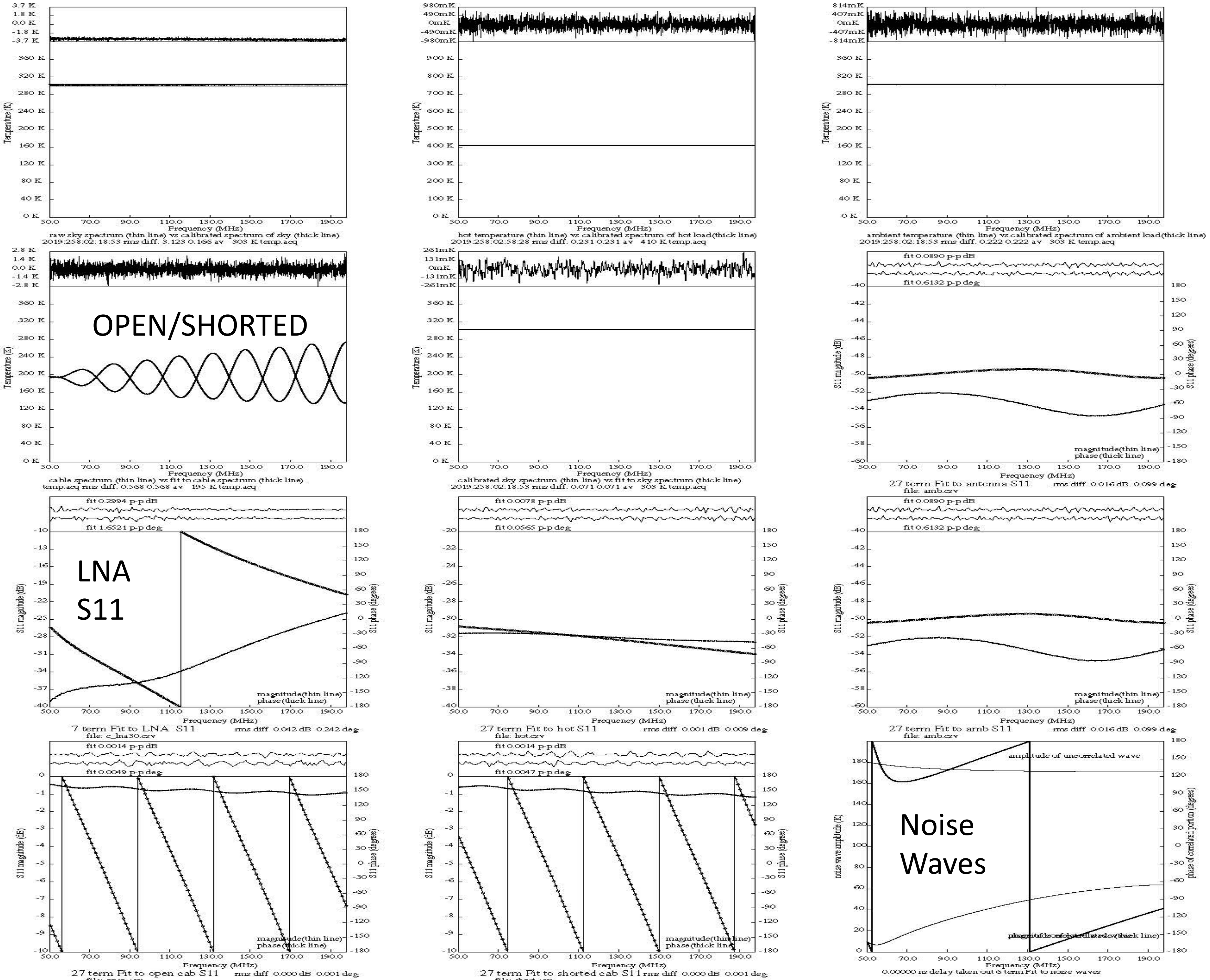
S11,S22,S12,S21 = scattering coefficients from reference plane to antenna connector on receiver input



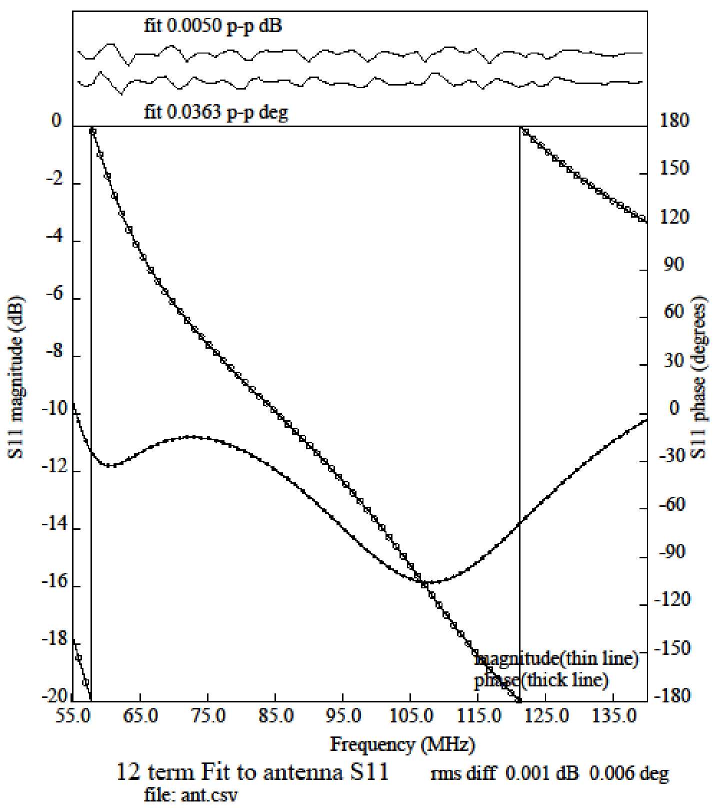
Calibration in Lab at Haystack

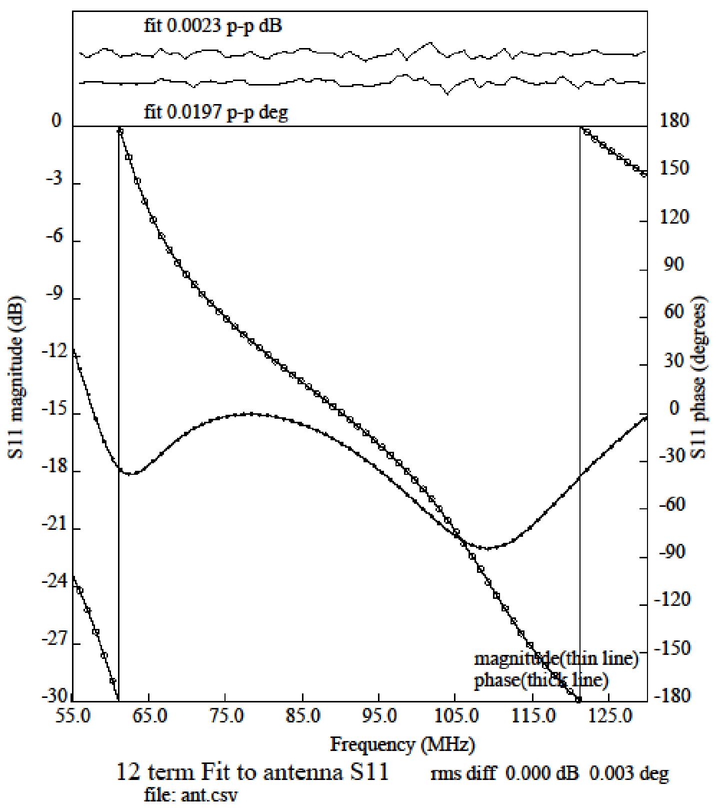


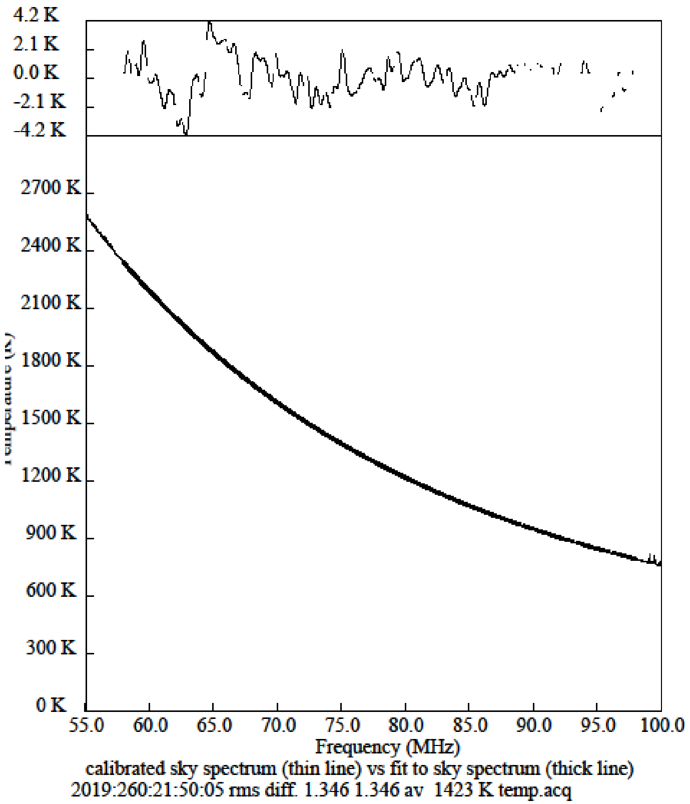
Calibration in Field in Oregon



raw sky spectrum (thin line) vs calibrated spectrum of sky (thick line)
2019:258:02:18:53 rms diff. 3.123 0.166 av 303 K temp.acq
hot temperature (thin line) vs calibrated spectrum of hot load(thick line)
2019:258:02:58:28 rms diff. 0.231 0.231 av 410 K temp.acq
ambient temperature (thin line) vs calibrated spectrum of ambient load(thick line)
2019:258:02:18:53 rms diff. 0.222 0.222 av 303 K temp.acq
OPEN/SHORTED
cable spectrum (thin line) vs fit to cable spectrum (thick line)
temp.acq rms diff. 0.568 0.568 av 195 K temp.acq
calibrated sky spectrum (thin line) vs fit to sky spectrum (thick line)
2019:258:02:18:53 rms diff. 0.071 0.071 av 303 K temp.acq
27 term Fit to antenna S11 rms diff 0.016 dB 0.099 deg
file: amb.csv
LNA
S11
7 term Fit to LNA S11 rms diff 0.042 dB 0.242 deg
file: c_lna30.csv
27 term Fit to hot S11 rms diff 0.001 dB 0.009 deg
file: hot.csv
27 term Fit to amb S11 rms diff 0.016 dB 0.099 deg
file: amb.csv
27 term Fit to open cab S11 rms diff 0.000 dB 0.001 deg
file: open.csv
27 term Fit to shorted cab S11 rms diff 0.000 dB 0.001 deg
file: short.csv
Noise
Waves
amplitude of uncorrelated wave
0.00000 ns delay taken out 6 term Fit to noise waves





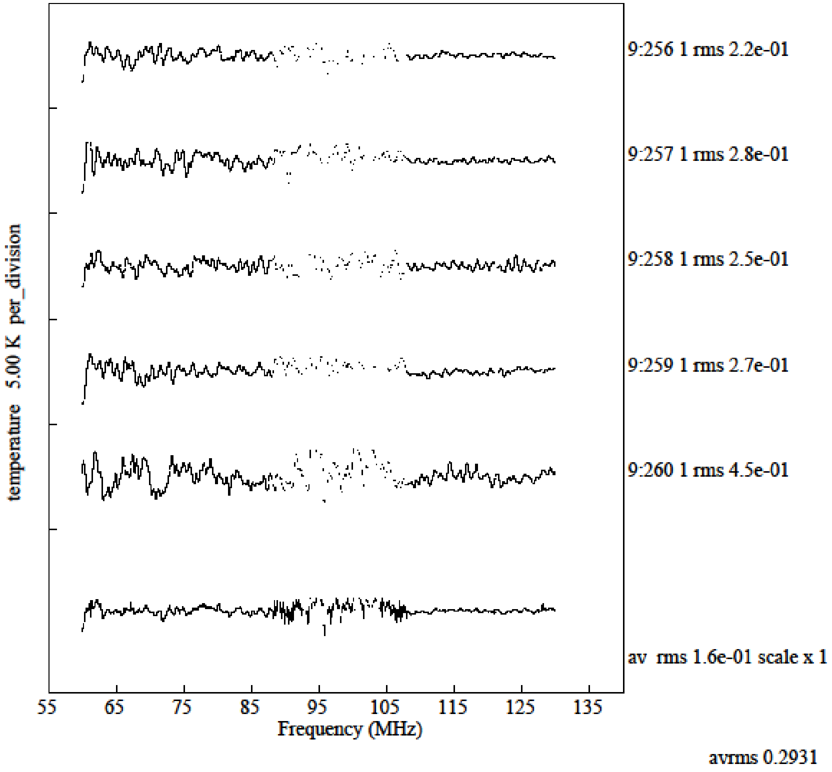


Antenna S11 on wire grid

on ground with
wire grid removed

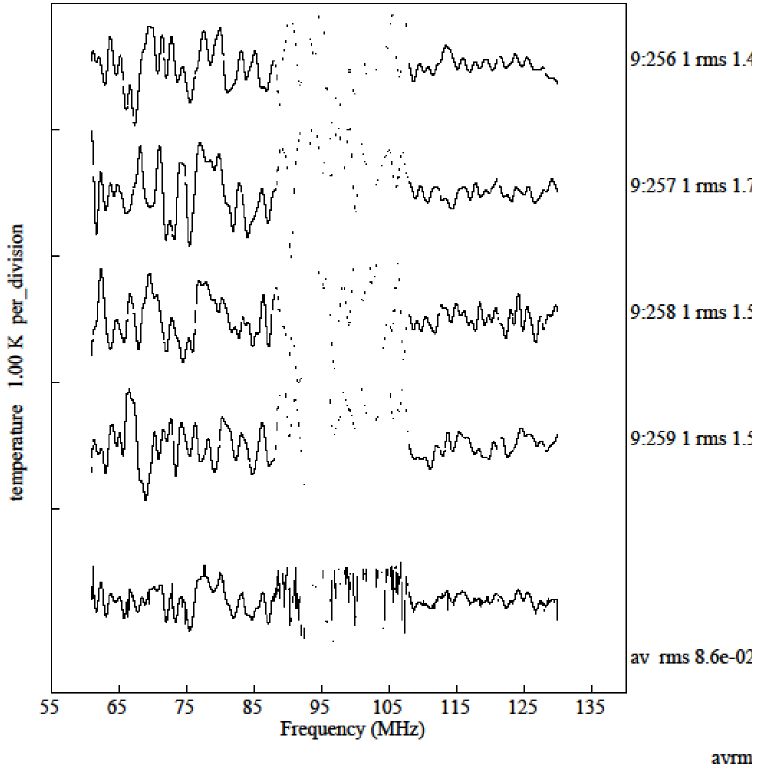
Tests of resolution and RFI excision

rms 160 mK



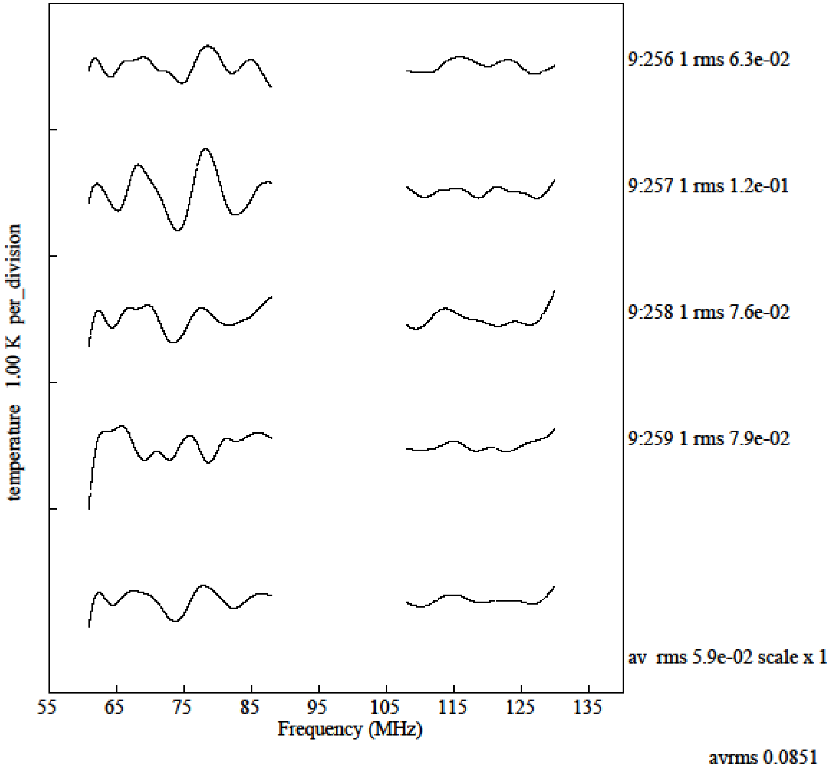
60-130 MHz 390 kHz

rms 86 mK



60-130 MHz 781 kHz

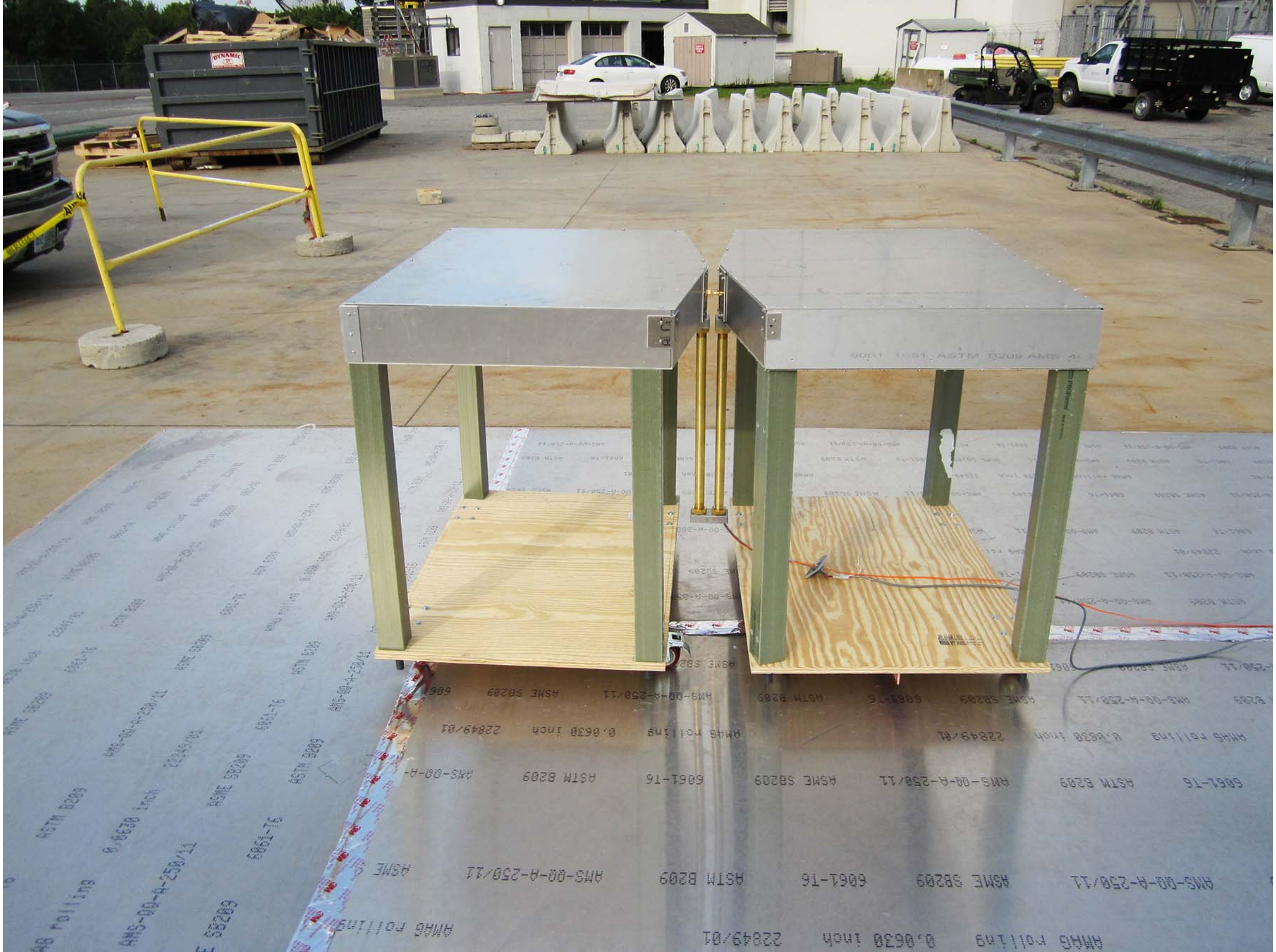
rms 59 mK



60-130 MHz 3MHz

5 poly terms removed

Thank you - Questions/Discussion



DYNAMIC
ASTM B209
6061-T6
ASME SB209
AMS-QQ-A-250/11
AMAG rolling
0.0630 inch
22849/01