EDGES MEMO #291

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
HAYSTACK OBSERVATORY
WESTFORD, MASSACHUSETTS 01886

November 19, 2018

Telephone: 617-715-5533
Fax: 617-715-0590

To: EDGES Group

From: Alan E.E. Rogers

Subject: FEKO simulations for EDGES-3 box blade antenna.

The proposed EDGES-3 antenna described memo 289 is the midband blade antenna with the antenna panels replaced with boxes about 12 cm in height. One of these boxes will house the entire EDGES system consisting of LNA, post amplifiers, back-end and digitizer as well as the PC, VNA and all the switches, loads etc. to enable the automated calibration currently done manually in the lab. A significant study of antennas with low beam chromaticity was made in memos 152 and 162. Some of the general trends in an antenna designed for a constant beam are discussed in memo 163. Some of the general characteristics needed to get low bam chromaticity are also discussed in memo 289. A comparison antennas with vertical and horizontal polarization is discussed in memo #288.

As discussed in memo 152 the lowest beam chromaticity for a horizontally polarized antenna on the ground or on a ground plane is achieved with a planar structure of minimum size placed as close to the ground plane as possible. However it is more difficult to achieve a wideband match to 50 ohms as the size the height are reduced. It is also found that any part of the antenna or ground plane that supports vertical currents will degrade the beam chromaticity. The box blade, has vertical structure in the walls of the boxes and in the metal tubes which will be needed to bring in power to charge the batteries in permanent deployments but the increased chromaticity is small.

Since it has been found that the chromaticity introduced by the antenna and that introduced by the ground plane are largely independent we start with simulations of the antenna on a perfectly electrically conducting (PEC) infinite ground plane which require the minimum computing time in FEKO.

Starting with the following dimensions:

Box size: 73.4×95.3×12 cm L×W×H

Height of bottom of box above ground: 72 cm

Gap length between boxes: 10 cm

	rms mK		S11 MHz				
H cm	50-100	50-120	60	80	100	120	Note
82	75	291	-9	-14	-14	-11	
72	58	281	-7	-13	-13	-9	
62	40	240	-6	-10	-13	-10	
52	27	170	-4	-7	-12	-12	
72	27	127	-10	-25	-19	-12	A
78	39	203	-6	-10	-11	-12	B

Table 1. rms residuals from simulations of beam chromaticity with 5 LINLOG terms removed.

Table 1 shows the beam chromaticity average rms for 2 hr blocks over full range of GHA along with antenna S11 values from FEKO. The Cases A and B are for the boxblade on a uniform soil ground and for the midband blade on an infinite PEC ground respectively. FEKO simulations of the large ground plane with perforated edges are given in Table 2.

	rms mK		
Size	50-100 MHz	50-120 MHz	Details
30×30 m	178	338	Soil $\varepsilon = 3.5\ \sigma = 2e-2$
30×30 m	229	367	Soil with conductivity $1e-4$
40×40 m	105	311	20×20 m plus 16 5×10 m triangles
50×50 m	101	307	

Table 2. Average rms over GHA in 2 hr blocks for boxblade antenna on large ground plane with perforated edges.

The general trends in the beam chromaticity for the box blade or other horizontal dipoles are as follows:

1] The beam chromaticity can be considered to be approximately the sum in quadrature of 4 parts:

a. The chromaticity of the antenna on an absorber or in free space
b. The chromaticity of the antenna on an infinite PEC ground plane
c. The chromaticity due to the edges of a finite ground plane
d. The added chromaticity introduced by the presence of any vertical currents in the antenna or ground plane

If we then consider the chromaticity of these 4 parts we find for each part

a. The chromaticity depends on the antenna length and width and to first order these contributions can be considered separately and are small when less than ½ a wavelength.
b. The chromaticity contribution of this part is small when the height above the ground plane is less than ½ a wavelength
c. The power of the reflections from the edges of the ground plane according to the radar equation would be inversely proportional to the radius assuming cross-section is proportional to the circumference cubed so the voltage and consequently the chromaticity is expected to depend inversely on the radius to the power of 1.5 going from a 30×30 m to a 50×50 m ground plane is expected to reduce the chromaticity contribution by a factor of about 2 but there are other factors which come into play. For example, the perforated edges help to smear the phases of the reflections which reduces their effect on the chromaticity. On the other hand the larger the ground plane the larger the delay of the reflections which results in a finer frequency structure in the reflections so that they are not as easily removed by a low order polynomial.
d. For the box blade the vertical currents in the box walls are approximately cancel for a small box height because the currents in the upper half are in the opposite direction to those in the lower half.

In general, the considerations which result in the lowest chromaticity for the box blade are as follows:

1) Use a very large ground plane or put the antenna over a uniform soil with very small or no ground plane
2) Keep antenna size as small as possible
3) Keep antenna as close to the ground plane as possible

These last two considerations are a conflict with the desire to maintain a low reflection coefficient at the low end of the band and consequently a compromise is needed between low chromaticity and low antenna S11.

The choice of the size of the box blade antenna depends on the relative importance of the low frequency end. Table 3 shows 3 possible choices.

	L	W	H	50	60	70	80	90	100	110	120	130	140	150	160	
A	73.4	95.3	72	-2.6	-7.3	-11	-13	-14	-14	-12	-9	-8	-6	-6	-6	1006
B	70.0	90.0	70	-2.0	-6.3	-11	-13	-14	-14	-13	-11	-0	-7	-6	-6	881
C	60.0	87.0	67	-0.9	-3.5	-8	-12	-15	-18	-20	-16	-12	-10	-8	-7	802
A	on soil			-5.0	-11	-16	-22	-28	-23	-16	-12	-10	-8	-7	-6	600

Table 3. The dimensions for 3 choices of size in cm along with the expected values of S11 from 50 to 160 MHz.

The last column gives the beam chromaticity in average rms in mK for 2 hr blocks of GHA over the full range of GHA from residuals to a 5-term LINLOG fit from 50 to 155 MHz. The S11 values and chromaticity are for the antenna on an infinite PEC ground plane. The two significantly different choices of deployment are for placement on a very large ground plane and on a uniform ground without a ground plane at the same height or possibly at a lower height. Direct placement on the ground yield an unacceptable S11.

The last entry in Table 3 is for choice A over soil with dielectric 3.6 and conductivity 1e-2 S/m. The beam chromaticity is for the latitude of the MRO.

Some tests of the sensitivity of the absorption detection to errors in beam correction and S11 for choice A on an infinite ground plane over uniform soil are given in Table 4 for a frequency range of 50-100 MHz and a 6 hour block centered at GHA=12 hrs at the MRO.

Ground	Error source	# terms	rms0	rms1	rms 2
PEC	No beam corr	5	20	76	12
PEC	S11 + 0.002 dB	5	8	95	6
PEC	S11+0.01 dB	5	40	118	27
PEC	S11+100 ps	5	33	64	15
Soil	No beam corr.	5	7	84	5
Soil	S11 +0.01 dB	5	7	95	5
Soil	S11 +100 ps	5	9	82	5
Soil/PEC	Different S11	10	14	36	13

Table 4. Effects of beam correction and S11 errors in simulations of signature search.

The values of rms residual in Table 4 are as follows:

rms0 = residual in mK to linpoly fit without addition of signature

rms1 = residual to LINLOG fit with 0.5 K absorption at 78 MHz with 18 MHz width and $\tau = 7$ flattening added to simulated data

rms2 = residuals to fit which included an absorption term

These results show that the beam correction is small and even smaller for the antenna on soil. It also shows that the sensitivity to S11 errors are smaller for the antenna on soil. The last entry for which a 10-term LINLOG is needed to account for the systematic errors due to using the S11 from FEKO for the antenna on a PEC ground to simulate the data which is then processed with the S11 from FEDO for the antenna on soil. The differences in S11 are of the order of several dB as in Table 1. Figure 1 shows the result of the grid search for the signature. The reason that the signature extraction needs 10 terms is that the S11 values from FEKO has been fit with a 10 term polynomial so as long as the antenna S11 is smooth at this level it should till be possible to extract an absorption with only model based information on the antenna S11. In practice, the antenna S11 is probably smoother as judged by the VNA measurement of the midband antenna S11 so that fewer than 10 terms will be needed to remove a combination of S11 errors and ground loss estimate. Figure 1 also illustrates the large ambiguities in signature when so many terms are used. With the expected level systematics no more than 6 terms should be needed over a 2:1 frequency range. Over a larger frequency range more than 6 terms may be needed and over the wider frequency range may not lead to ambiguities.

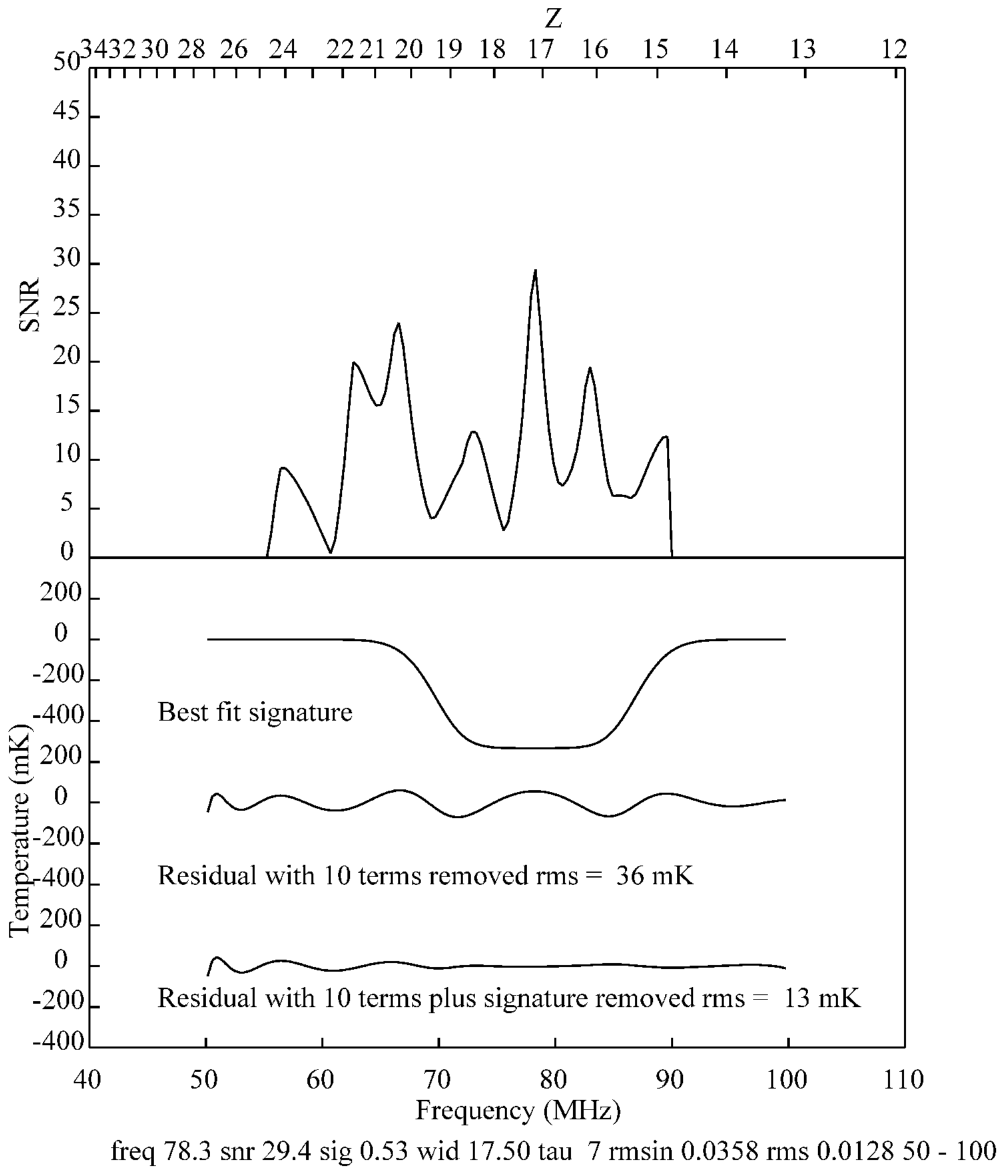

Figure 1. Simulated grid search for signature with 10-terms to remove large errors in antenna S11.