EDGES MEMO #074

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To: EDGES Group

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Subject: Sensitivity of antenna impedance to environment change

1] Introduction

If the antenna impedance changes with the environment it will be necessary to make frequent measurements and these will need to be automated unless the changes are slow enough to allow infrequent manual measurements. Automated measurements would need an additional low loss switch to connect the network analyzer. If the changes are only temperature dependent it might be sufficient to make corrections based only on temperature measurements.

2] Stability of antenna impedance

Simulations using FEKO show that the sensitivity to any dimensional changes in the antenna including its height above the ground plane result in a change of about 1 ohm per percent of dimensional change. If the entire structure changed uniformly the change is equivalent a change in wavelength since the impedance is a function of its size in wavelengths. However if the antenna is made of materials that have different coefficients of thermal expansion the change is more complex. For example, an antenna supported on PVC pipe will change its height by a larger fraction than the metal parts since the thermal expansion coefficient of PVC is $50 \text{ ppm} / {}^\circ C$ compared with $20 \text{ ppm} / {}^\circ C$ for aluminum.

Item changed	Ω/%
Antenna height	3
Gap between panels	1
Ground plane size about 8m	0.01
Dielectric constant of Teflon	1

Table 1 shows the values of change in the real part of the antenna impedance with antenna structure change and an example of the change in the amplitude and phase antenna reflection change for a 1.223 inch change in height is plotted in Figure 1.

3] Stability of the balun

The variation of the balun with environment is dominated by a temperature sensitivity of the ferrite which results in a change of attenuation of $8 \times 10^{-4}\, dB / {}^\circ C$ around the nominal value of 0.26 dB. Since the antenna is measured through the balun a change in loss changes the measured real part of antenna impedances by about 10 Ω per dB so the temperature coefficient of antenna impedance due to a change in the balun is about $2\times10^{-2}\,\Omega/{}^{\circ}C$ compared with $1.5\times10^{-2}\,\Omega/{}^{\circ}C$ for the height change using PVC supports.

4] Effect on antenna temperature

If we assume a sky temperature of 2000 K at 75 MHz and a nominal real part of the impedance of 40Ω then a change of $2\times10^{-2}\,\Omega/{}^{\circ}C$ becomes about $100\,mK/{}^{\circ}C$. A change in balun loss also changes the ambient thermal noise from balun by about $7.4\,mK/10^{-3}\,dB$ so that the contribution from the ferrite temperature coefficient becomes $6\,mK/{}^{\circ}C$.

5] Skin effect loss

The loss from an aluminum antenna is expected to result in an impedance change of no more than 0.01 Ω and it will result in systematic error of a few tens of millikelvin.

6] Simulations of the effect of temperature

Since the antenna impedance is a function of the antenna size in wavelengths the impedance of a uniformly expanded antenna can be accurately predicted from

$$z(t,f)=z(t_0,f)-f\delta\frac{\partial z(t,f)}{\partial f}(t-t_0)$$

$z(t,f)$ is the antenna impedance

t is the temperature

f is the frequency

δ is the temperature coefficient of expansion $\left(20\,\text{ppm}/{}^{\circ}C\right)$

Using the impedance from FEKO, a sky temperature of 2000 K and spectral index of -2.5 at 75 MHz, a frequency range of 60 to 120 MHz the rms difference between antenna temperatures for a change of $1^{\circ}C$ is about 30 mK. A similar analysis for $1^{\circ}C$ change in balun temperature results in an rms difference of 30 mK after removal of a slope. These two different curves are shown in Figure 2.

The impedance will also change with the change in atmospheric refractivity given by

$77.6\,P/T+3.73\times10^{5}\,e/T^{2}$ N-unites (or ppm)

Where $P=$ pressure in millibar

T = temperature in Kelvin

e = water vapor partial pressure in millibar at $P=1000\,\text{mb}$ and T=300K results in a change of wavelength of 0.86 ppm. The effect of an increase in temperature is opposite and much smaller than the thermal expansion. A change in pressure also has a small effect as typical weather pattern only change the pressure by about 20 mb resulting in only 5 ppm change in refraction. A change in humidity has a much larger effect since 100% humidity at $38^{\circ}C$ is equivalent to 66 mb of water vapor with a refraction of 254 ppm. This suggests we need to measure the humidity as well as the temperature. An alternate possibility is to set-up an identical antenna some distance from EDGES equipped with a network analyzer to continuously monitor the impedance but in order to see the effect of a 10% change in humidity on the antenna impedance the network analyzer need to be able to measure the reflection coefficient amplitude to within $10^{-3}\,dB$ and phase to better than 0.01 degrees which will be stretching the capability of a network analyzer so a simple temperature and humidity measurement is probably the best practical solution. Table 2 summarizes the level of systematic errors. If the frequency range is limited to 60 to 105 MHz, over which the antenna reflection coefficient is less than -10 dBm, and curvature is removed in addition to the removal of a slope and constant the rms differences in table 2 are reduced by a factor of about 3. Given the limitations of the network analyzer[1] it may be necessary to solve for parameters with functional form of the errors. On the one hand this will "soak-up" some of the EoR signature while on the other hand the expected changes with temperature and humidity could help act as a discriminant against a false detection of the EoR signature.

Error source	rms (mK)
$1^{\circ}C$ in physical temperature of antenna balun	30
10% in relative humidity at $38^{\circ}C$	35
0.01 Ω resistive loss in antenna	50

Table 2 rms errors from changes in environments

7] Comments

The temperature sensitivity of the antenna might be reduced by using a low temperature coefficient support like porcelain or pyrex glass. However since significant observations will only be made at night, measurements of the ambient temperature with probe on the balun might be the best solution. However accurate modeling will be needed to be able to correctly compensate for the temperature change. Some tests of the variation of impedance on the antenna with balun attached would be useful.

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[1] It is noted that a Agilent 4294A precision impedance analyzer has specified accuracy of 0.08% which is a higher accuracy than can be achieved by a network analyzer.

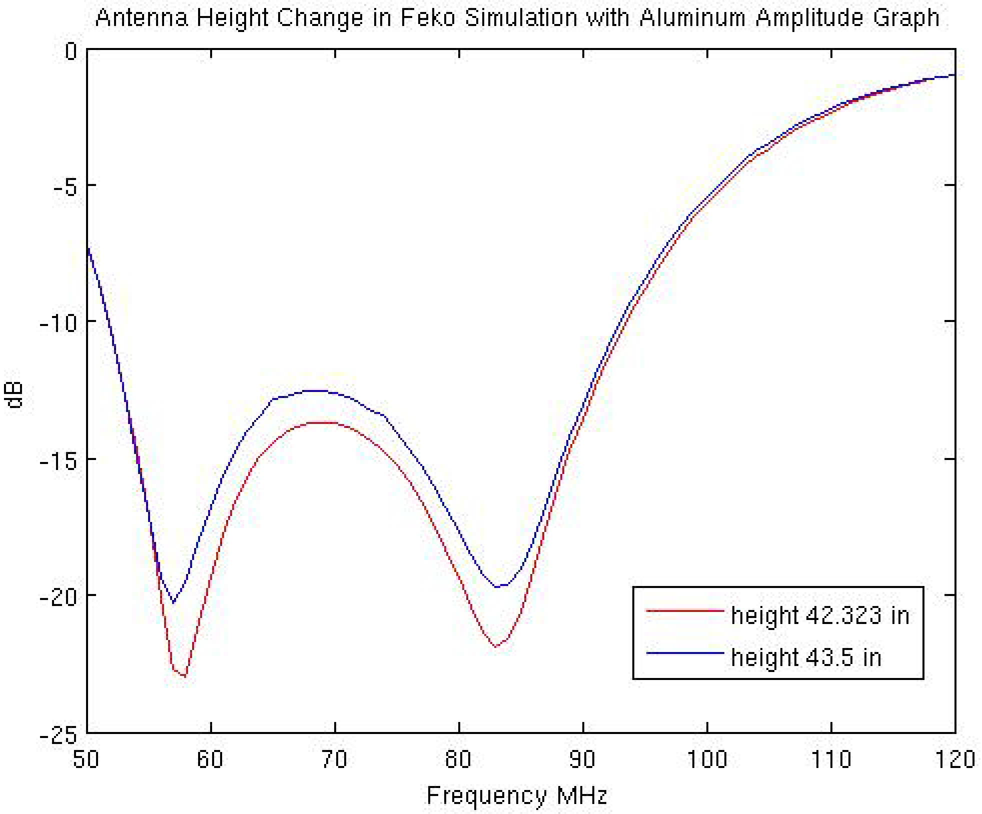

Figure 1A. Change of S_{11} amplitude with height

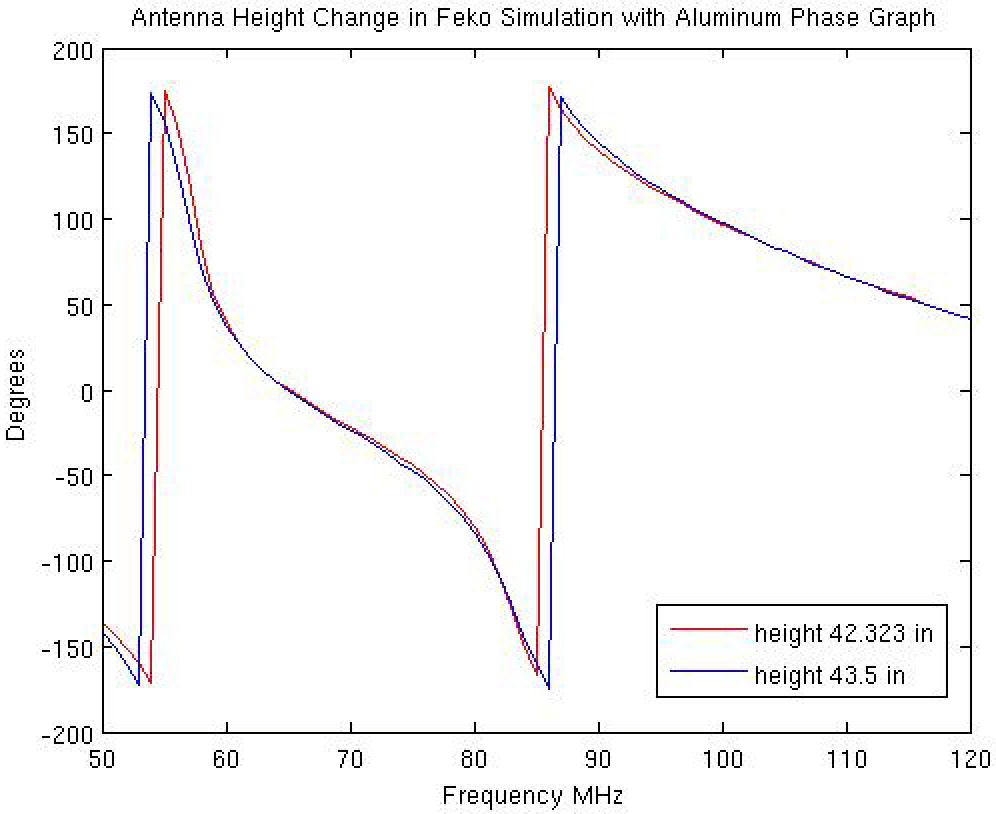

Figure 1B. Change of S_{11} phase with height

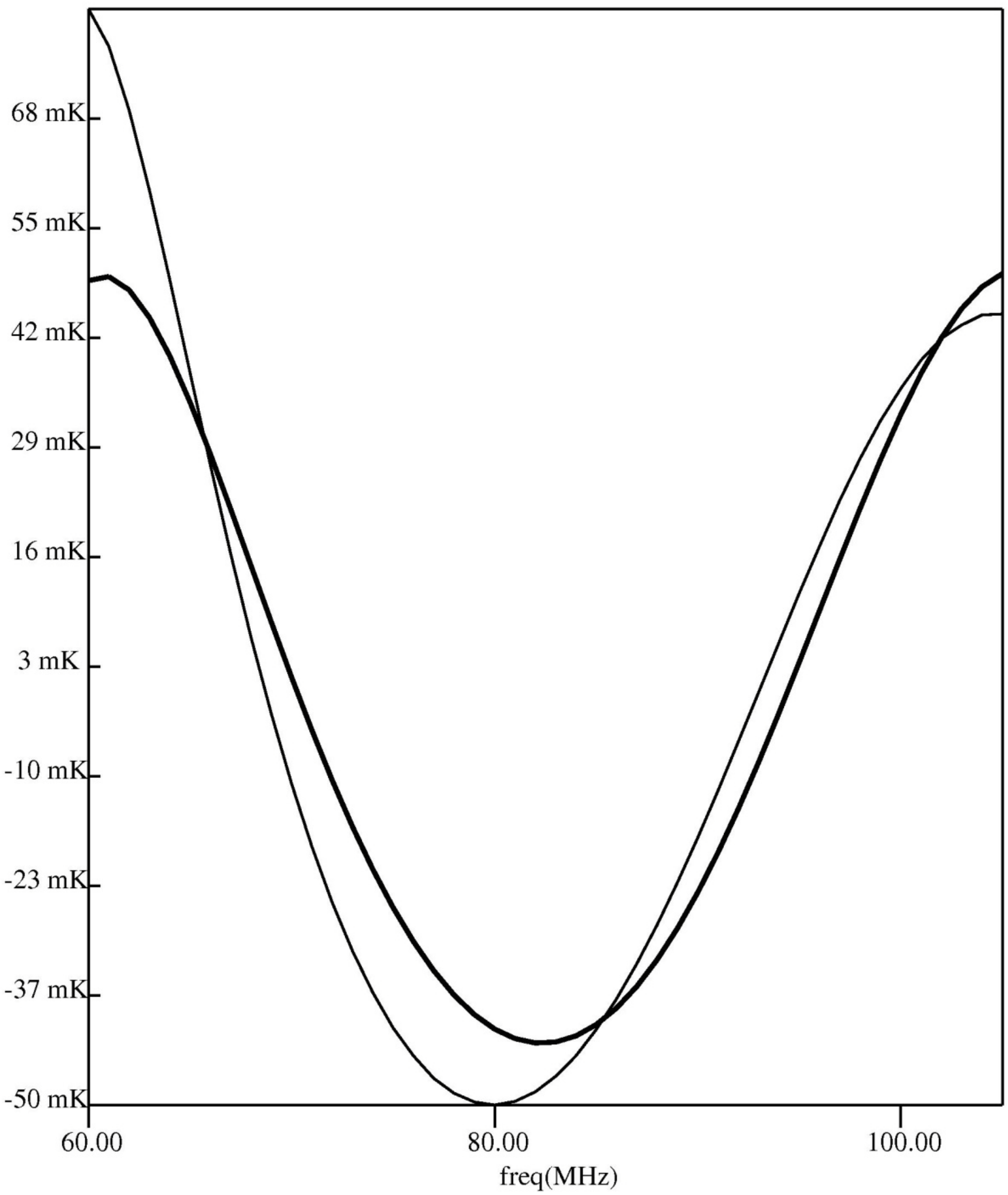

Figure 2. Effect of a change $1^{\circ}C$ in antenna (thick line) and balun (thin line)