EDGES MEMO #115

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To: EDGES Group

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Subject: Effect of a cable impedance deviation in loss estimate

The calculation of the effect of cable or attenuator loss is straight forward when its impedance is equal to the VNA's 50 ohms. In this case the loss can be measured from the S11 of an open or shorted cable so that $L = |S11|$ and the observed temperature is

$$T_{ant} L\phi + T_{amb}\left(1 - L\phi\right)$$

Where $L\phi = L\left(1 - |\Gamma|^2 \big/ L_\phi^2\right) \Big/ \left(1 - |\Gamma|^2\right)$.

$\Gamma = S11$ of the antenna measured through the cable and T_{ant} and T_{amb} are the antenna and cable temperatures respectively.

When the cable is not exactly 50 ohm the loss calculation is more complex. In this case the Loss, $|S11|$, will be different for an open and shorted cable. At low frequencies, even a cable which has the perfect dimensions, dielectric constant, etc. will not be exactly 50 ohms because of the skin effect the magnetic field penetrates into the conductors. The detailed analysis of Ramo and Whinnery is given in memo #84.

The analysis in memo #84 has been extended. For cable whose impedance, $zcab$, different from 50 ohms by $\Gamma_c = (zcab - 50)/(zcab + 50)$

The loss is

$$\left(1 - |\Gamma|^2\right)\left(1 - |\Gamma_a|^2\right)^{-1}\left(1 - |\Gamma_c|^2\right)^2 \Big/ B$$

Where Γ and Γ_a antenna reflection coefficients measured directly and through the cable respectively.

$$B = L^{-1} - 2\Gamma_c \operatorname{Re}(\Gamma) L^{-1} + 2\Gamma_c \operatorname{Re}\left(\Gamma e^{i\phi}\right) + \Gamma_c^4 L + 2\Gamma_c^2 \operatorname{Re}\left(e^{i\phi}\right)$$

$$\phi = -2\pi f d$$

L is the cable loss in its impedance frame and d is the 2-way delay. For zcab of 49.8 ohms, antenna reflection of -10 dB and loss of 0.3 dB the impedance deviation from 50 ohms results in a peak to peak ripple of 250 mK in 1000 K. This residual ripple has a period of the inverse of the cable delay and to some extent can be corrected by determining the cable delay and to some extent can be corrected by determining the cable impedance by modeling the open and shorted cable S11. The loss L can be estimated from

$$\left(\left|\Gamma_{open}\right|+\left|\Gamma_{short}\right|\right)/2$$

For a search of an EoR signature whose width is broader than the ripple period the advantages of the cable might outweigh this disadvantage. In principle the effects of an imperfect cable could be measured with 2-port VNA analysis but an accuracy of 0.001 dB is required to reach 250 mK out of 1000 K.