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Beam chromaticity analysis: Effects of concrete bricks on EDGES beams

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This memo analyzes and summarizes the beam chromaticity effects of placing concrete bricks on the large 48mx48m ground plane. This is to reduce the large undulations (>7cm) seen on the ground plane (memo#202), which are caused by welding the individual mesh panels.

For this analysis, we simulate the antenna beams with and without the concrete bricks and compare the resulting beams. We compare the beams directly by differencing the power beam patterns. We also generate simulated spectra by convolving the beams with the Haslam (408MHz) sky model using edges-analysis. To the generated simulated spectra, we fit a Linlog model and assess the effect of the concrete bricks on the beam chromaticty by comparing the residuals.

Simulations:

1.) EDGES2 over 48m X 48m ground plane with no concrete bricks.
2.) EDGES2 over 48m x 48m ground plane with 16 concrete bricks.
3.) EDGES2 over 48m x 48m ground plane with a concrete brick on each mesh. So, in total, 76 bricks on the central square and 42 bricks, in total, on the triangles.

Concrete brick specification: with relative permittivity of 2.12 and loss tangent of 0.9 at 2 GHz (conductivity of 0.1 S/m). The size of each of the pavers is 0.6m x 0.6m x 0.05 m

The three simulated models are shown below:

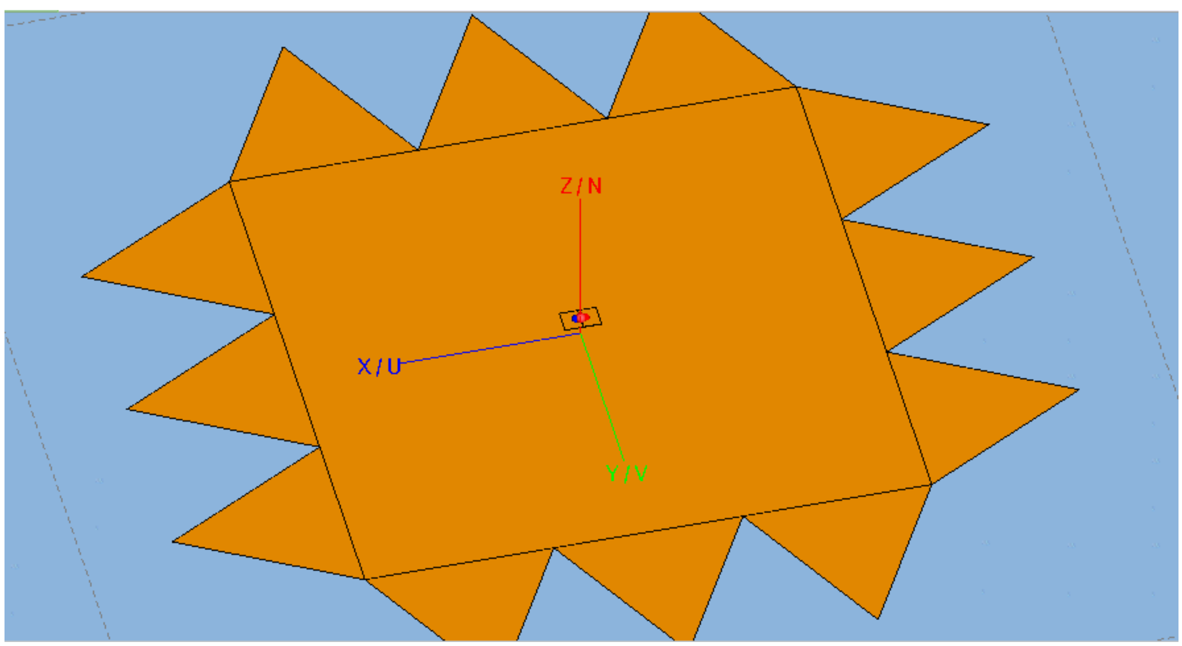

Figure 1: EDGES2 lowband blade antenna over the 48m x 48m perforated ground plane simulated in CADFEKO

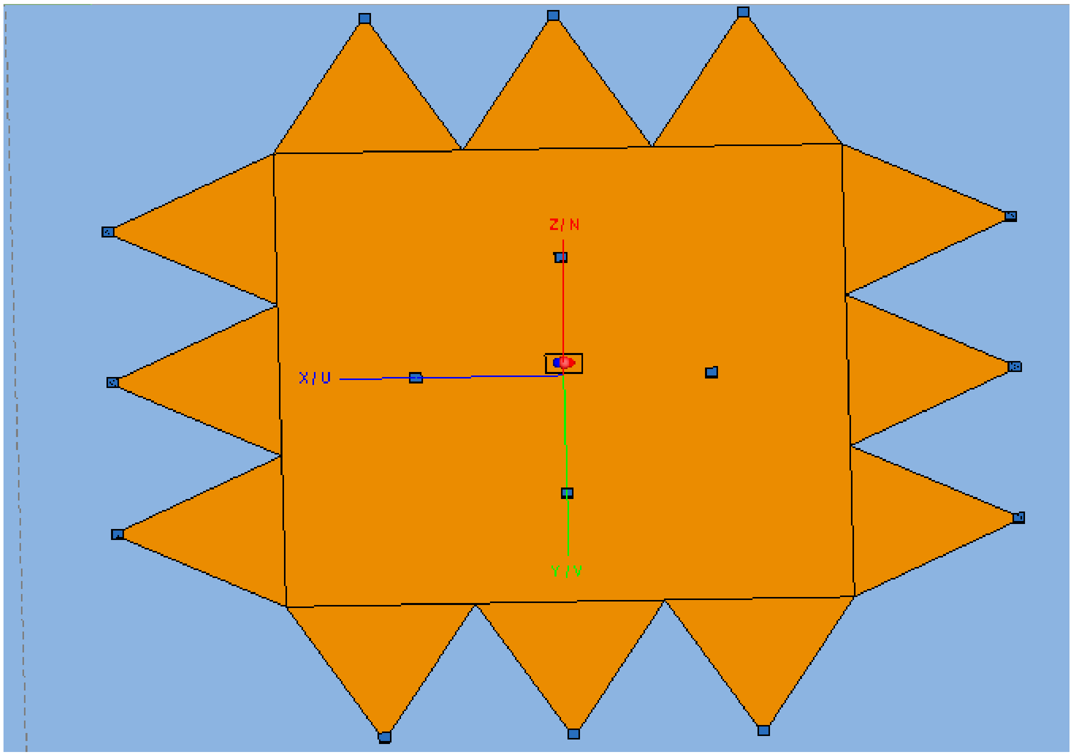

Figure 2: EDGES2 low-band blade antenna over the 48m x 48m perforated ground plane. Also simulated are the 16 concrete bricks in dark blue.

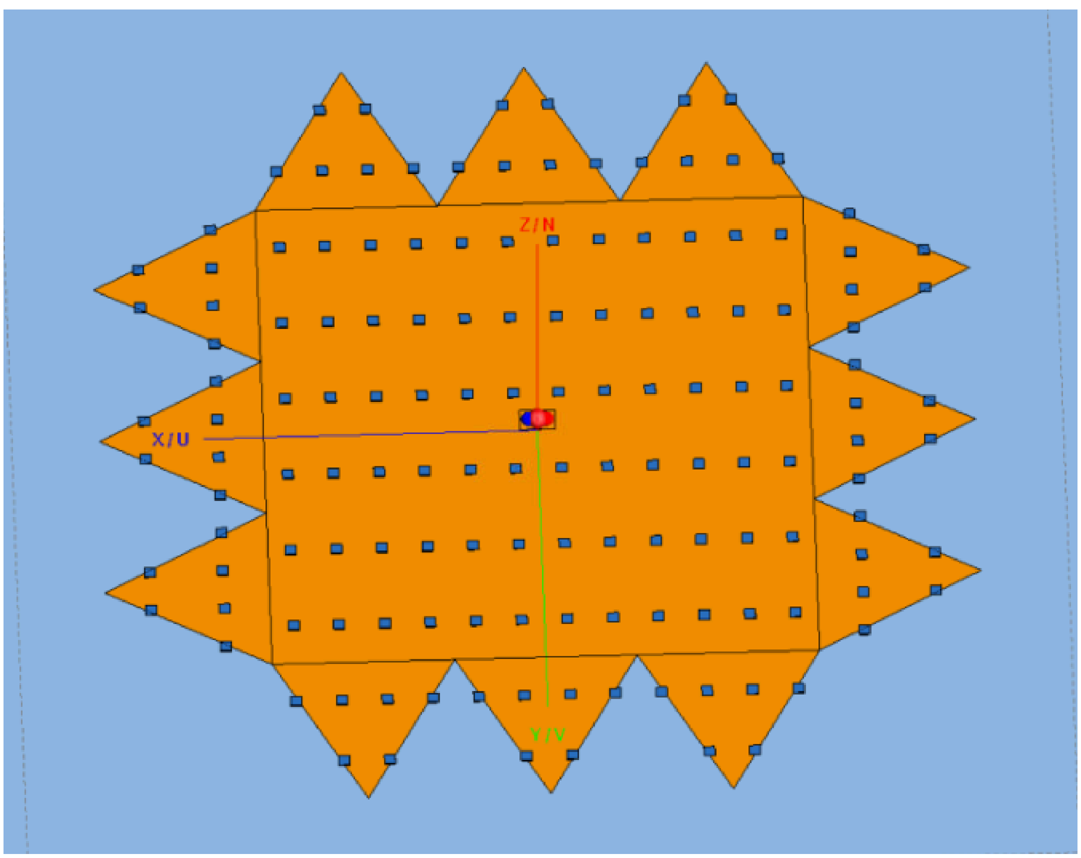

Figure 3: EDGES2 low-band blade antenna over the 48m x 48m perforated ground plane. Also included in the simulation is a concrete brick on each mesh panel of the ground plane

Assessing the beam patterns:

The 3D beam patterns (at 1 deg resolution in theta and phi) for each simulated model are obtained at every 1MHz between 40 and 60 MHz. We calculate the derivative plots for each of the beam cases as shown below:

1.) No concrete bricks

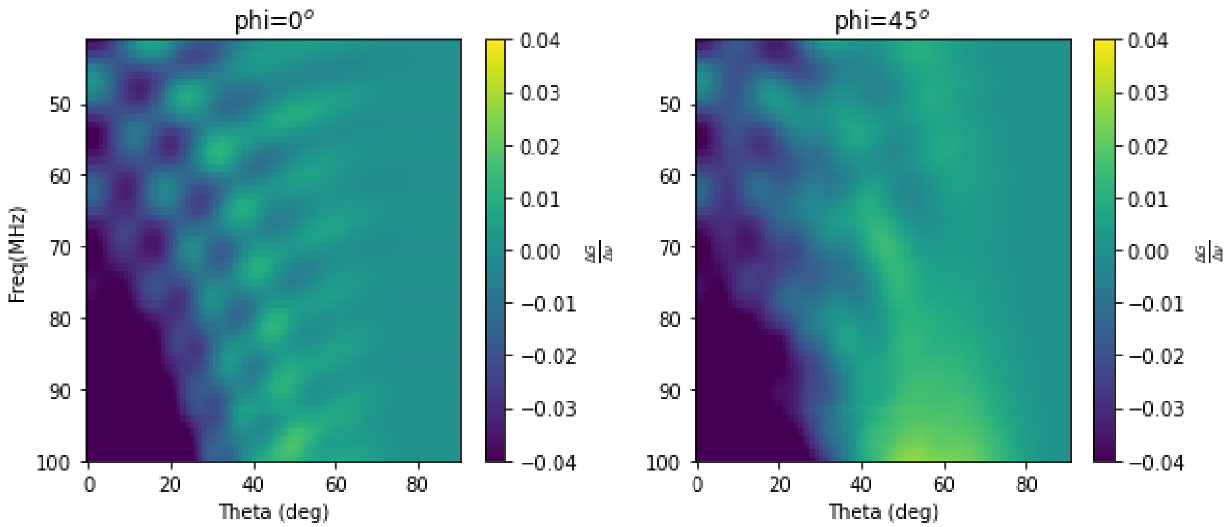

Figure 4: Change in gain per MHz as a function of elevation angle along the E-plane (left) and phi = 45deg the simulation with no concrete.

2.) 16 concrete bricks on the ground plane

Visually, the derivate plots of the simulation with the 16 concrete bricks look similar to the no concrete brick case.

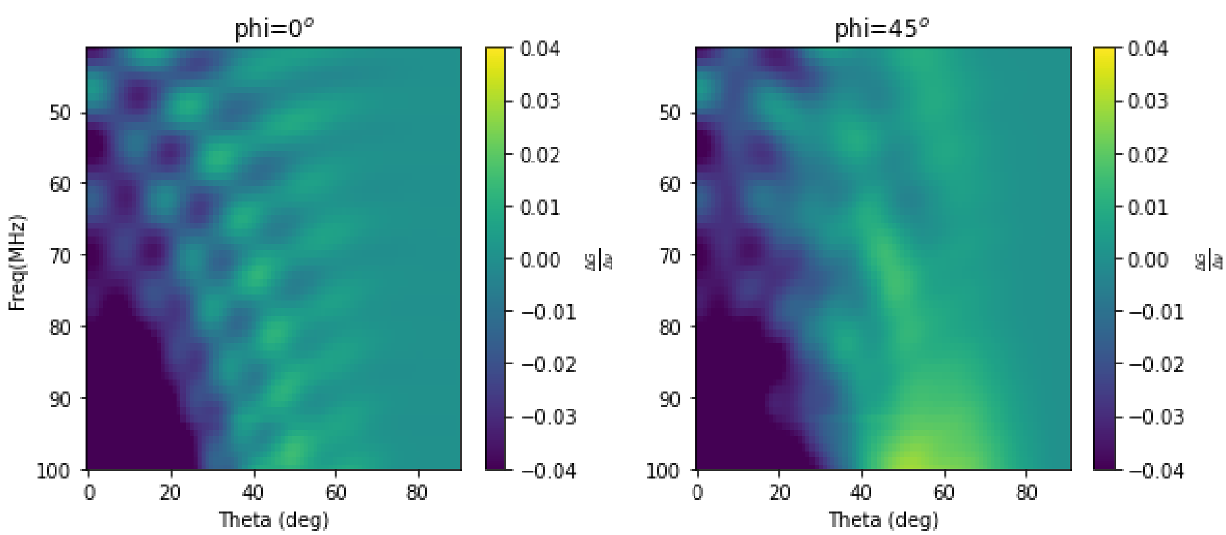

Figure 5: Change in gain per MHz as a function of elevation angle along the E-plane (left) and phi = 45deg of the simulation with 16 concrete bricks.

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3.) Concrete brick on each mesh panel ⇒ 118 concrete bricks

Adding a brick on each mesh panel certainly increases the beam chromaticity. The chromaticity is worse at lower frequencies. At frequencies >75 MHz it looks similar to the the derivative plots as above.

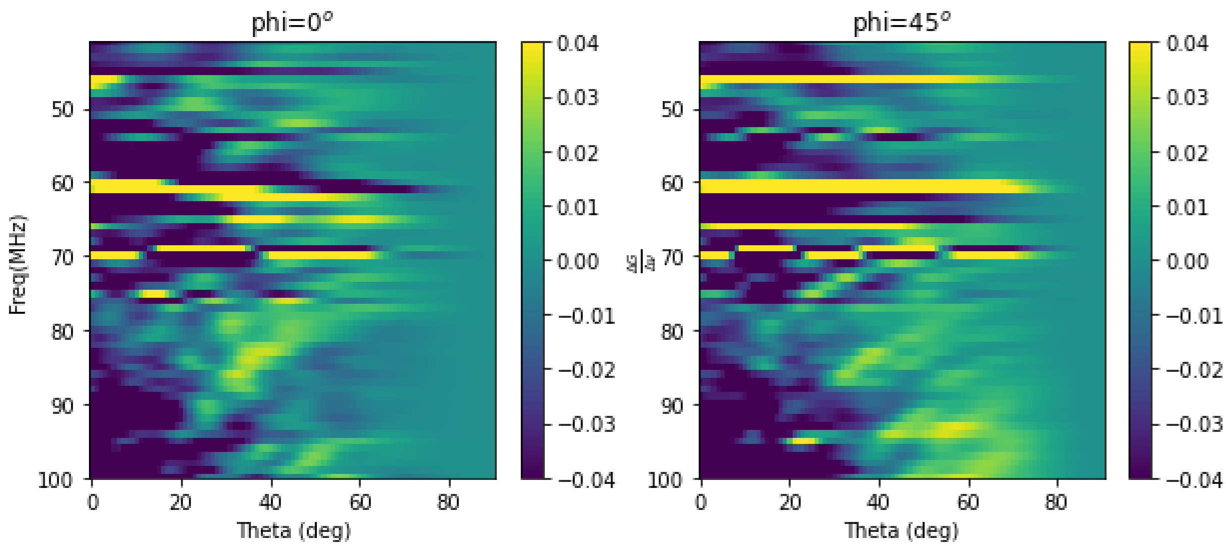

Figure 6: Change in gain per MHz as a function of elevation angle along the E-plane (left) and phi = 45deg for the simulation with a concrete brick on each mesh panel of the ground plane.

For comparison, we calculate the fractional differences by differencing the 3D beam patterns of the simulations with and without the concrete bricks to access the effects of the bricks

1.) 16 concrete bricks

In the figures below, we plot the fractional differences of the beam for two cuts (phi =0 and phi=45) Adding the 16 bricks causes upto 0.6% variation in the chromaticity within 30 deg from the zenith. And the maximum variation is about 8% seen at higher thetas (>70 deg).

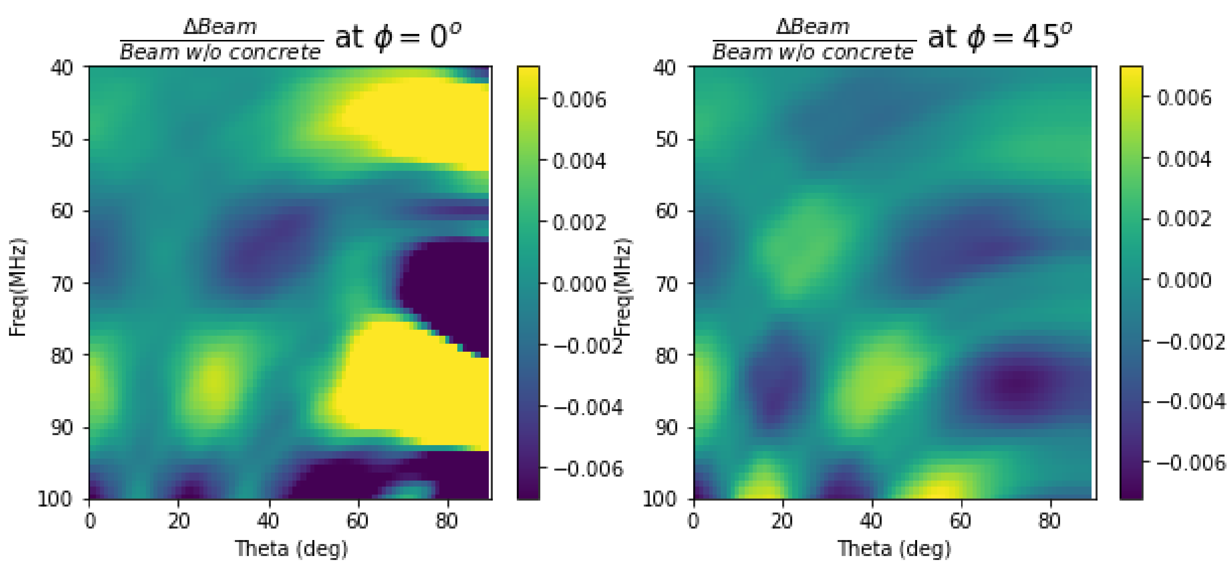

Figure6: Fractional differences of the 16 brick concrete simulation with respect to the no concrete brick simulation. The fractional differences are plotted for two different phi cuts.

2.) For the case of a brick on each mesh panel.
Here the fractional differences have increased to 20%.

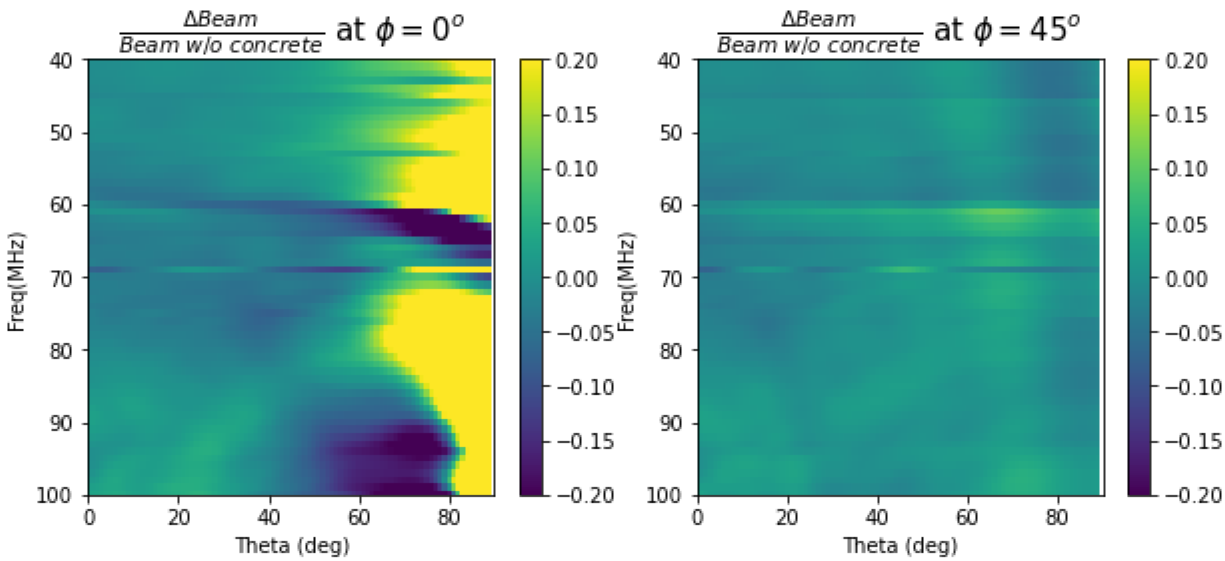

Figure6: Fractional differences of the 16 brick concrete simulation with respect to the no concrete brick simulation. The fractional differences are plotted for two different phi cuts.

Simulated Spectra Analysis:

In this section, we convolve each of the 3D beam patterns with the Haslam sky map. The Haslam sky map is extrapolated to lower frequencies using a constant spectral index of -2.55. We obtain the simulated spectra between 50 and 100 MHz for 361 LST points. The simulated spectra are then binned into 2-hour LST bins. Each binned spectrum is fitted with a 5-term linlog model, and the residuals are compared. The residuals for each two-hour bin are shown in the plot below.

The residuals of the no-concrete and with 16 concrete bricks bins are at similar levels. The differences between them can be noted by reading the rms at the side of the plots. But the residuals of the simulation with a concrete brick on each mesh panel is consistently larger in each bin. Becoming prominent at the LST 8 to 10hr bin.

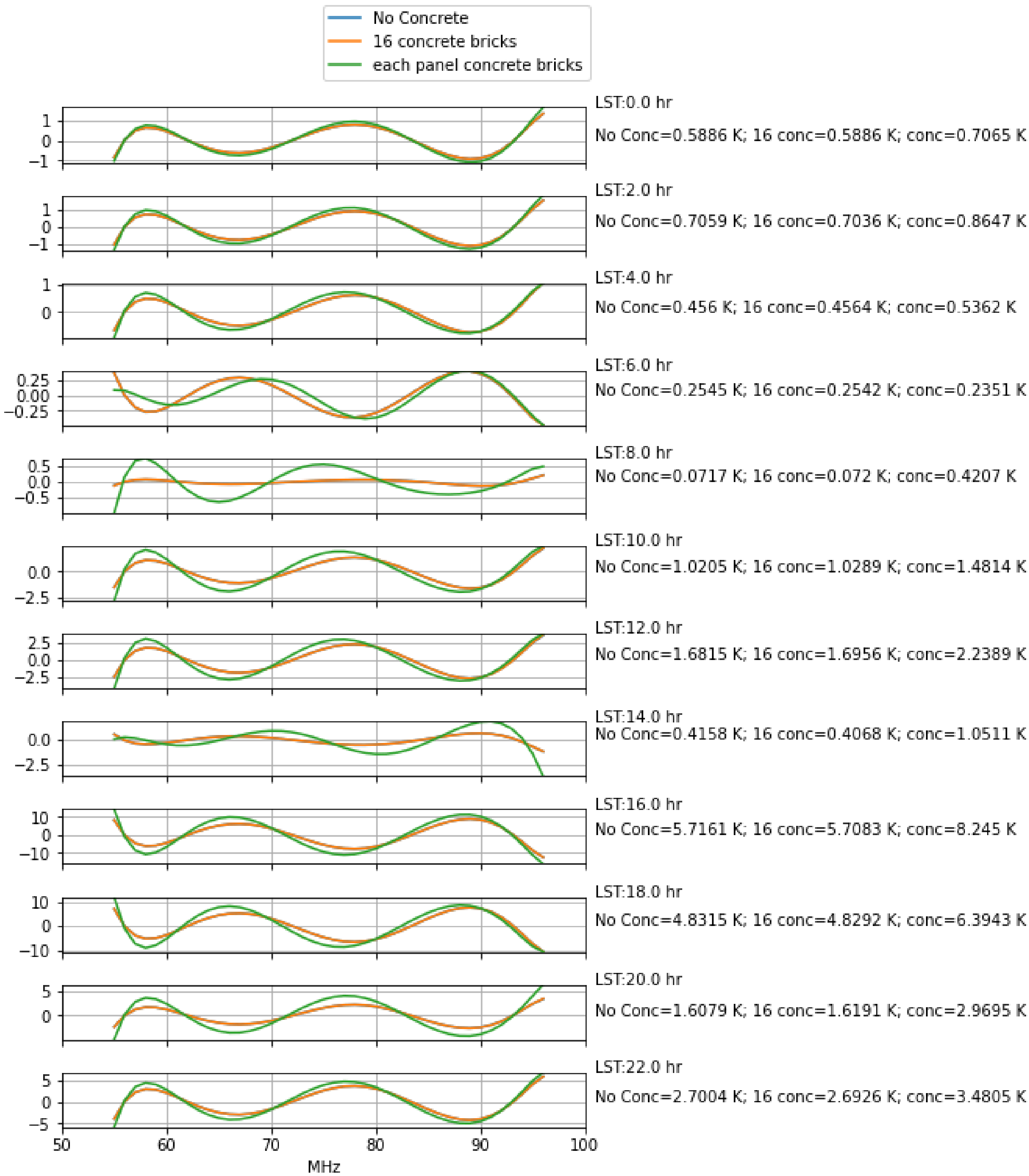

Figure7: Residuals of the simulated spectra fit to a 5-term linlog model Vs Frequency. The blue curve corresponds to no concrete simulation, green to the simulated spectra with 16 brick, and red to the spectra using simulation with 118 bricks. These curves are for the EDGES 2 over 48m x 48m ground plane configuration. The individual subplots are averaged 2-hour bins for different Local Sidereal Times. The numbers for each row indicate the rms of the residuals over 55-97MHz.

Observations

To level the ground plane, we will need to place at least one concrete brick on each mesh panel. The analysis here shows that doing that will considerably affect the beam chromaticity, increasing the frequency structure of the beam-convolved sky spectra and making the residuals a 5-term foreground model larger than what is desired for cosmology signal detection. However, it might be useful to note that the high conductivity assumed for the concrete brick (0.1S/m) was given by FEKO. The conductivity of the concrete bricks may be lower, which might change the inferences here. In addition, based on the simulations here, the 16-brick case has a negligible effect and can be managed for our science case, as seen in the analysis done with the simulation spectra. So, a more careful simulation and analysis can be done where the number of bricks is increased in steps. The effects can be quantified based on which location of the bricks affects the beam more.