A Measurement of the frequency response of the SKALA4.1 antenna.

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Background

Fine-scale frequency structure in the system bandpass has been a limiting factor in EoR observations with MWA. In that case the origin of the bandpass structure was multi-path propagation of RF signals within the electronics due to impedance mismatches at ends of transmission lines. The bandpass structure failed to be calibrated out because the bandpass calibration was limited to solving for coefficients of polynomial approximations. That experience led to emphasis on design for smoothness in instrument response in SKA-low antenna elements.

Motivated by the requirement for spectral smoothness in response and limiting the departure from a smooth gain specification, SKALA antenna design has evolved to have an increasing number of elements in a log-periodic dipole array configuration and a small opening angle between the boom arms.

Nevertheless, EM simulations of the SKALA4.1 antenna shows small glitches in the directivity of the antenna, versus frequency. These are present at all elevations where the gain is significant. The glitches appear as spectral structure with fine frequency scale of order 1 MHz. Reproduced here is the directivity versus frequency plot from Bolli et al. (2020); their Fig. 5.

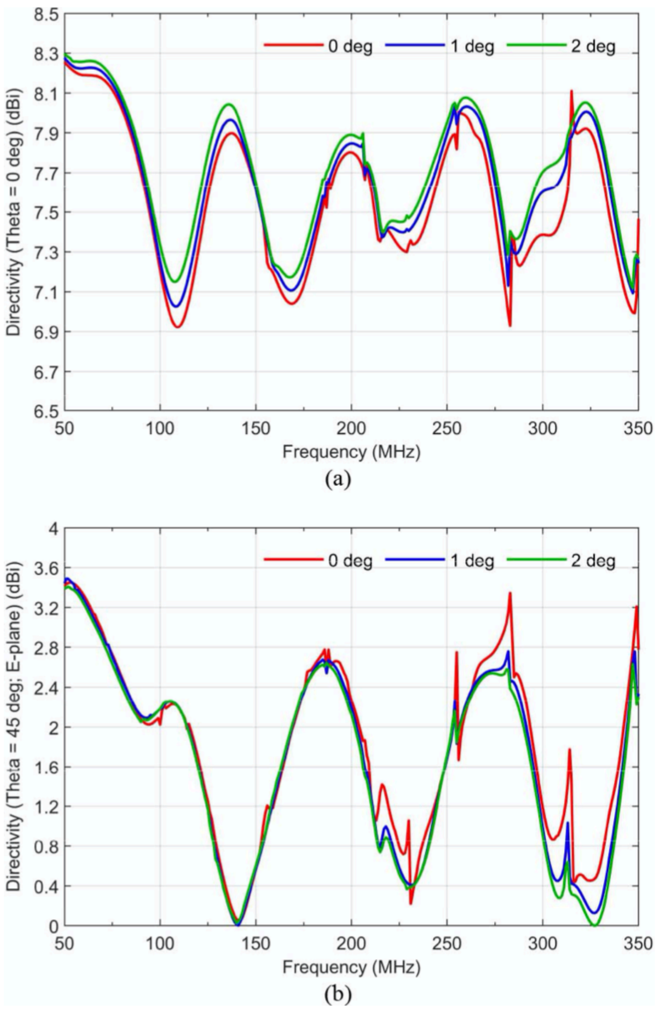


FIGURE 5. Directivity of the 50-ohm single-ended antenna for different values of the boom opening angle at two zenith angles: (a) 0 deg and (b) 45 deg on the *E*-plane.

The Measurement

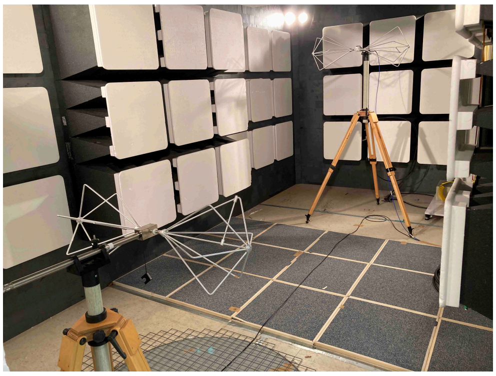
A measurement of the antenna frequency response was attempted to examine for the fine spectral structure expected from the EM simulations. Measurements were done in the CIRA anechoic chamber at Curtin University, which has ferrite tile absorber walls and roof and ferrite tile panels on the ground, thus making this a suitable chamber for the long wavelength measurement.

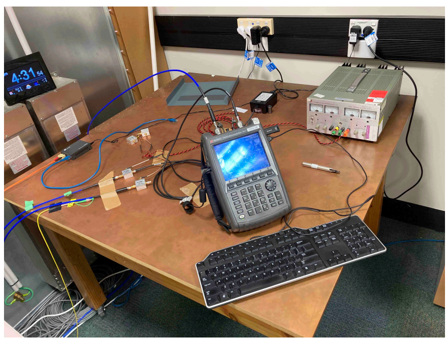
A SKALA4.1 antenna was assembled on one side of the rectangular chamber and fitted with receivers in both polarisations. A section of wire mesh covered the floor beneath the antenna, and the antenna booms were electrically shorted and connected to this ground plane. A commercial biconical antenna - BBAK 9137 along with VHBB 9124 balun, both from Schwarzbeck - that operates over the band 45-450 MHz was mounted on a stand on the far side of the chamber. The separation was about 3.5 metres. The antennas were aligned with horizontal polarisations parallel and facing each other.

A Fieldfox network analyser configured to make an S21 measurement was used. This was operated outside the shielded room and the two ports were cabled in via bulkhead connectors. The transmit port went to the biconical antenna. Coaxial cables from both polarisations of the SKALA antenna were brought out of the shielded room via the bulkhead connectors and provided with appropriate d.c. power using RF bias-tees. The parallel polarisation was cabled to the receive port of the network analyser and the perpendicular polarisation was provided with a 50-ohm termination.

The Fieldfox was set up for amplitude/phase S21 measurement over 40 to 400 MHz, with 3601 points covering the band and using 100 kHz IF bandwidth. 100 traces were averaged in the Fieldfox and the average S21 was recorded. Measurement was made with the bicone and SKALA4.1 in the nominal setting, then a second measurement was done with the bicone moved 0.5 m closer to the SKALA antenna, then a third measurement was made with the bicone moved 0.5 m off to one side of the nominal position. Then the SKALA antenna was removed from the chamber, replaced with a second 9137 bicone, and a reference S21 measurement made.

Pictures of the setups with the antennas in nominal position, with SKALA replaced with bicone, and of the Fieldfox outside the chamber, are shown here.





In each of the four measurement setups multiple recordings were made of the averaged S21 to examine for consistency and stability. The averaging of 100 traces yields S21 with peak-to-peak noise less than 0.01 dB, well enough to detect glitches in spectral gain of 0.1 dB and greater. Thus the limitations in the measurement might be dominated by systematic errors due to reflections off the walls of the closed confined space of the anechoic chamber, and perturbations to the EM performance as a result of the absorbing walls close to the antenna, rather than measurement noise.

The output power level was adjusted to be -20 dBm to keep the SKALA4.1 amplifiers operating in the linear regime. When the SKALA4.1 antenna was replaced with a second bicone, measurements were made without changing the power level and also with the power increased to 0 dBm, to check for consistency and also to reduce measurement noise. This was necessary since the amplifiers on the SKALA antenna have about 40 dB gain, where as the bicones have no active amplifiers.

The recorded spectra are shown in Fig. 1 below. In blue is the S21 amplitude for the bicone in nominal position, in magenta is the S21 with the bicone moved closer to the SKALA antenna, in green is the S21 with the bicone moved to one side and in black is the reference spectrum with the SKALA antenna replaced with the second bicone. The reference trace has been shifted up by 40 dB to compensate for the absence of the SKALA amplifier in the signal path. As expected, the S21 amplitude is somewhat higher for the case where the antennas are closer.

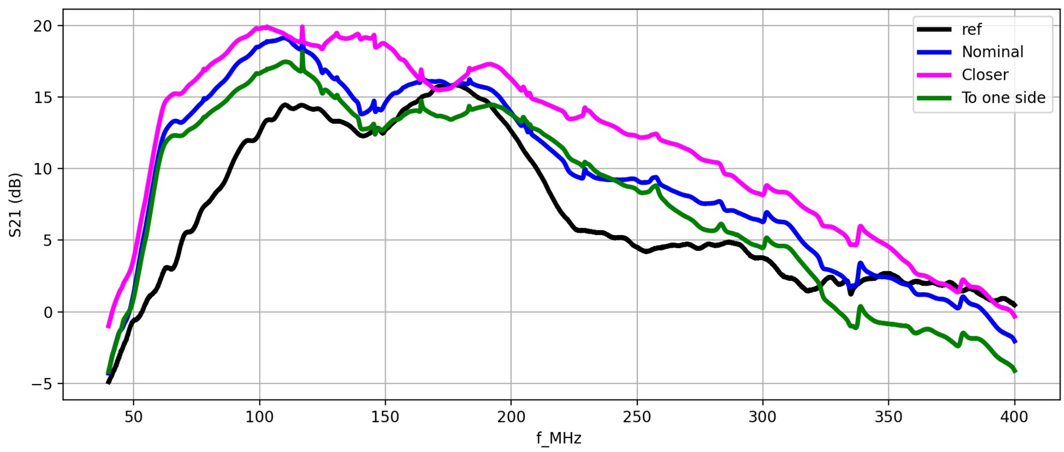


Fig 1: S21 amplitudes with the bicone in nominal position (blue), closer to SKALA (magenta) and offset to one side (green). In black is the reference S21 with a bicone replacing SKALA.

There is considerable spectral structure in all traces, which may simply be due to the measurements being made in a relatively small anechoic chamber. However, there is considerably more fine-scale frequency structure that consistently appears in all the three traces between the bicone and SKALA, which are absent in the reference spectrum. A collage of such narrow band features in shown in Fig. 2 below.

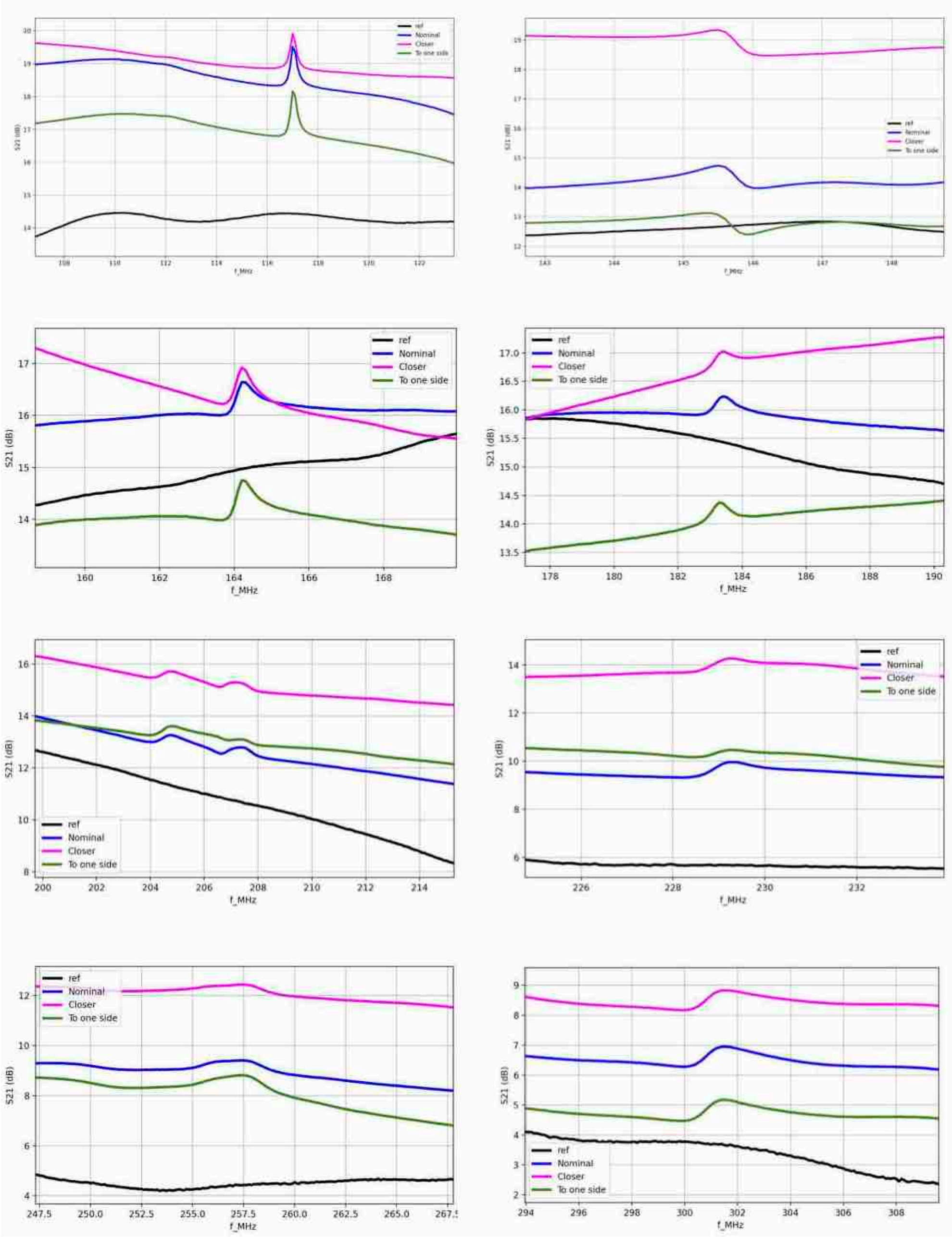


Fig 2: Sample spectral segments where there is fine-scale frequency structure in the S21 for the bicone-SKALA pair, which is absent in the reference spectrum.

Summary:

The measurements suggest that there is indeed narrow band (0.5-1.0 MHz) structures in the SKALA4.1 antenna frequency response, with amplitudes 0.25-1.0 dB. It might be best to confirm and quantify this with a field measurement, and using sky data. If genuine, it implies that CD/EoR power spectrum observations would require bandpass calibration on a per-channel basis, as is usually done in conventional spectral line observations with Fourier synthesis telescopes.