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Modelling AAVS2 station beam patterns

Executive Summary

In this note I show station beam patterns for AAVS2, computed at 110 MHz for X polarisation using embedded element patterns. The effect of antenna based amplitude/phase calibration errors on the quality of the station beam is examined, for appreciation of the accuracy desired in the derivation of gain calibration.

First, assuming negligible antenna gain calibration errors, the quality of the station beam is determined by the array factor rather than the position dependent gain errors arising from dissimilarity in embedded element patterns (EEP). Thus the station beam is largely unchanged if computed using the EEPs compared to using the average EEP for all elements.

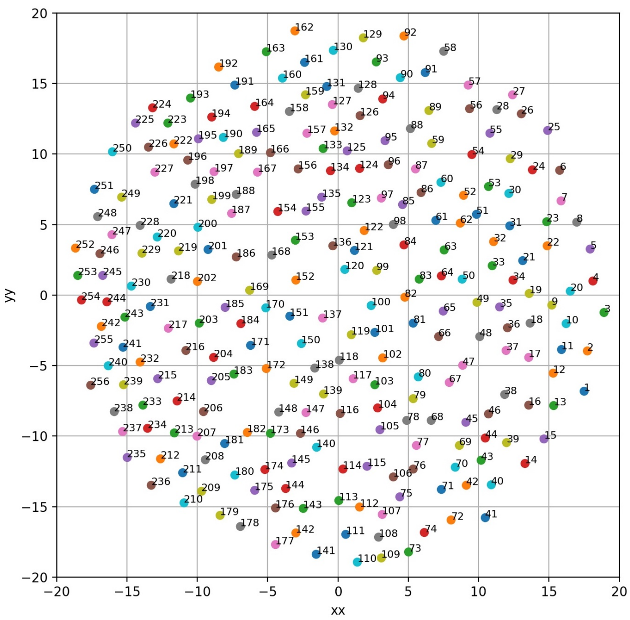
Second, the station beam is fairly robust to significant antenna calibration errors, particularly amplitude errors, presumably due to the large number of elements in the station. With phase errors of RMS value 10° and amplitude calibration errors of 20%, the peak gain of the station beam appears to drop by $4 \pm 3\%$. Additionally, for such errors, the RMS value of far sidelobes, which is nominally about -28 dB below peak, rises by just 10–20% above the nominal low value.

The analysis is for the configuration adopted for AAVS2, and revisions in layouts that maintain the random nature would be expected to retain this quality unless introduction of periodicities in antenna placements generate gratings.

Computation of the beam model

The AAVS2 station antenna locations were assumed to be at coordinates listed in the file AAVS2_loc_italia_190429.txt. The station layout is show below (with x and y axes in metres).

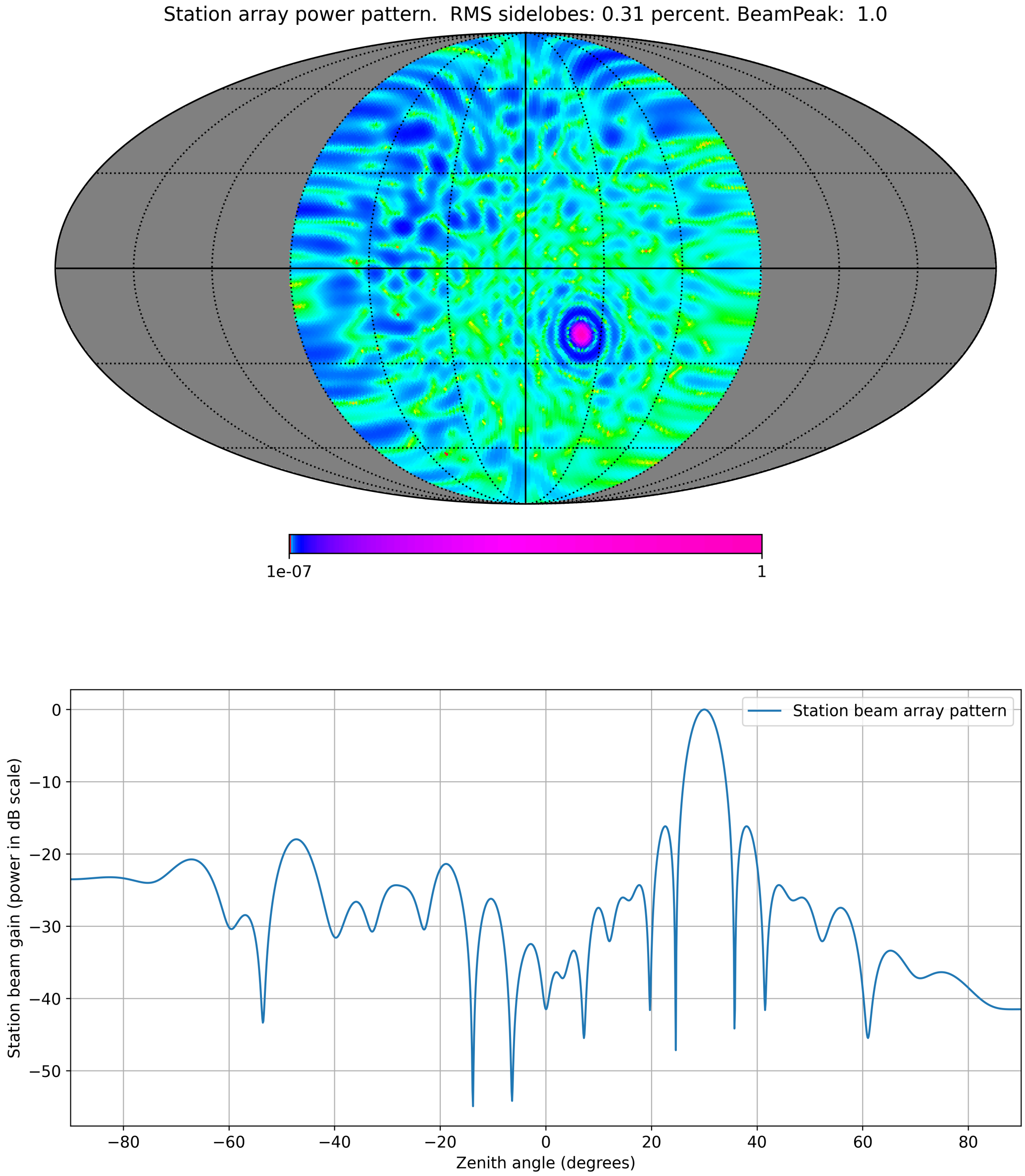
Figure 1



The antenna distribution is fairly uniform random over the station of 38 metres diameter. At 110 MHz frequency, the station diameter corresponds to about 14 wavelengths and the station beam would have a FWHM of about 4° for uniform weighting and towards zenith.

Shown below is the array pattern for the station, computed for phasing towards azimuth $-135°$ and zenith angle $30°$. The 2D beam power pattern is shown along with a slice profile made along the line through zenith and the peak of the beam.

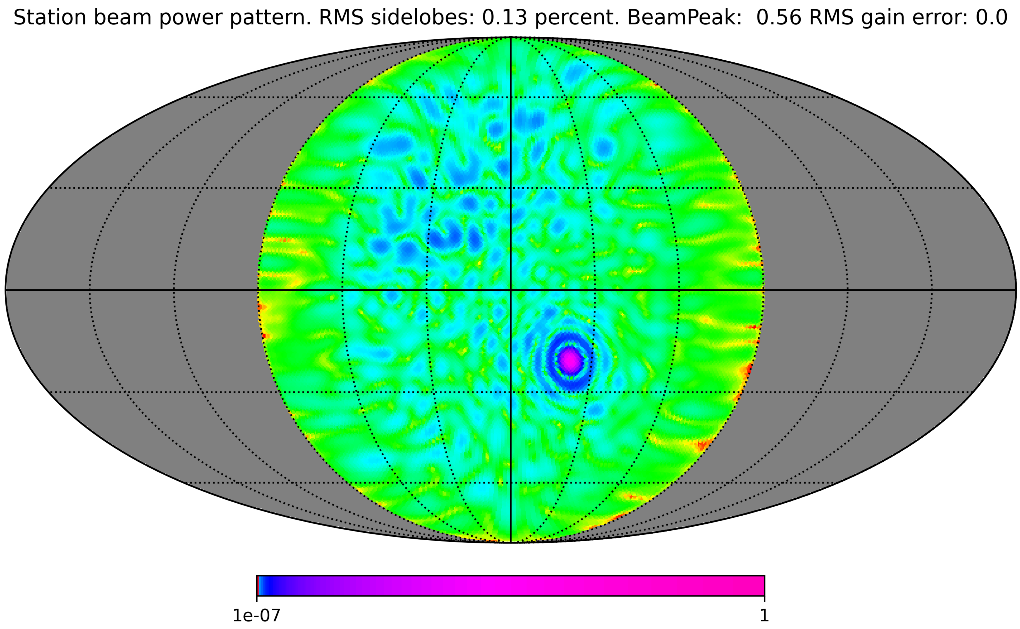
Figure 2

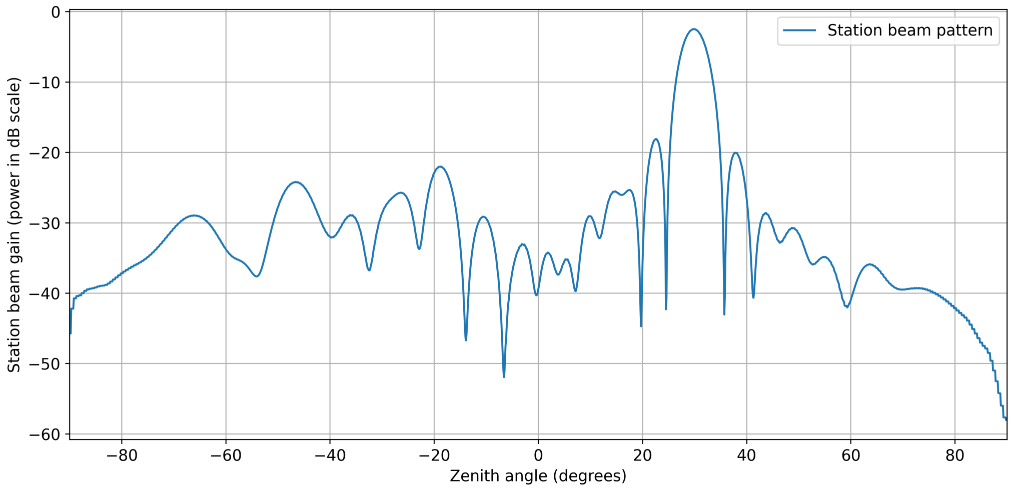


The RMS value of the sidelobe pattern, computed over the three quadrants of the sky excluding the one where the peak is located, is 0.31%. This is -25 dB below the peak. With *N* antennas in the station, the station beam would be limited, approximately, in dynamic range to about $1/\sqrt{N}$, and the RMS value for the far sidelobes computed here is consistent with the dynamic range expected for a 256-element station.

I next compute the station beam pattern using the embedded element patterns (EEPs) for the antennas. The embedded element patterns are from the FEKO EM simulations done by the groups at Curtin and INAF for the AAVS2 array configuration and SKALA4.1 antenna. The computation of the station beam pattern assumes the absence of antenna-based calibration errors. The embedded patterns are used together with their individual amplitude and phase responses that are sky-position dependent. This nominal station beam pattern is shown below.

Figure 3





As expected, the far sidelobes of the station beam - closer to the horizon - are attenuated by the element patterns. The near sidelobes appear to have retained their strength relative to the peak and also their distribution around the peak, unchanged by the position dependent errors introduced by the EEPs. The RMS value of far sidelobes of the beam power pattern is 0.13% and they are -28 dB below peak.

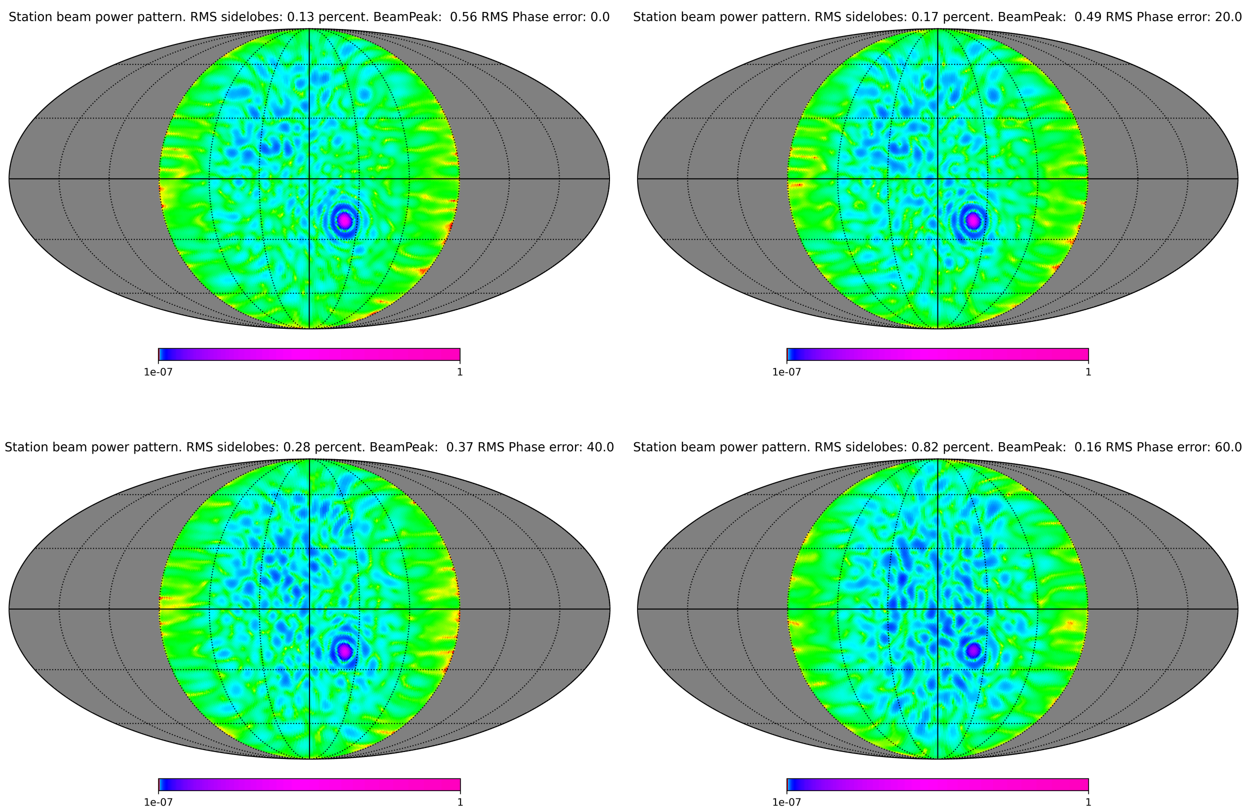
The calculated station beam patterns are by and large unchanged if the average of the EEPs are used and assumed same for all antennas.

Effect of antenna calibration errors: Phase errors

I have next computed station beam patterns using the EEPs for elements of AAVS2, now adding Gaussian random phase errors in all antennas in the station.

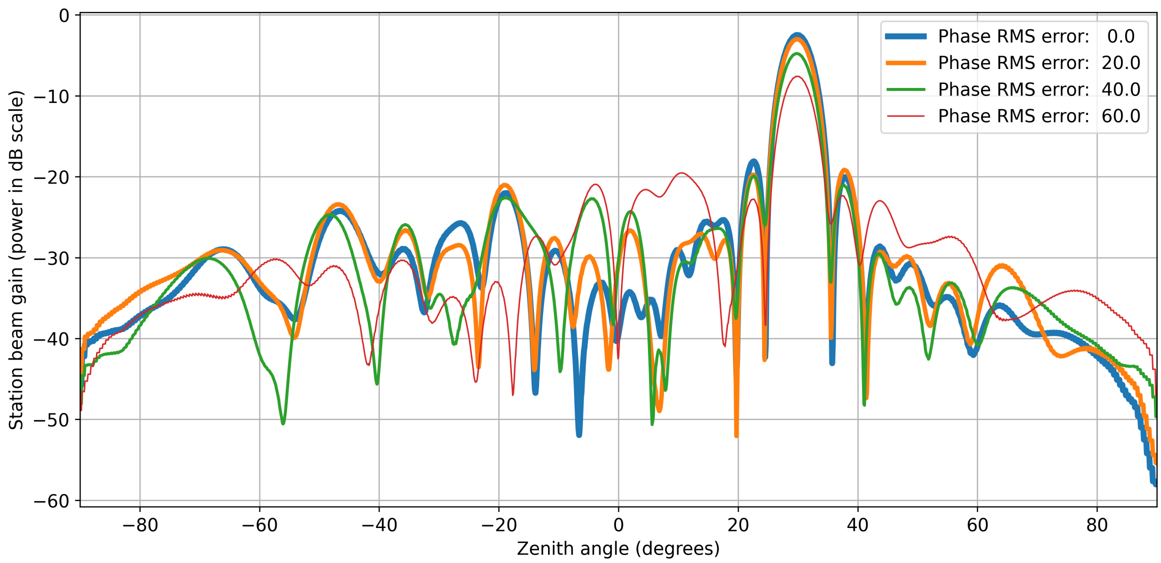
The station was phased towards azimuth -135° and zenith angle 30°. The decrease in beam peak and increase in RMS value of the sidelobes in quadrants not containing the peak were examined as different magnitudes of phase errors were added to the antenna complex gains. The station beam power patterns, computed for phase errors with RMS value 0, 20, 40, and 60 degrees, are given below: each panel has a title that gives the peak gain and RMS level of far sidelobes relative to the peak.

Figure 4



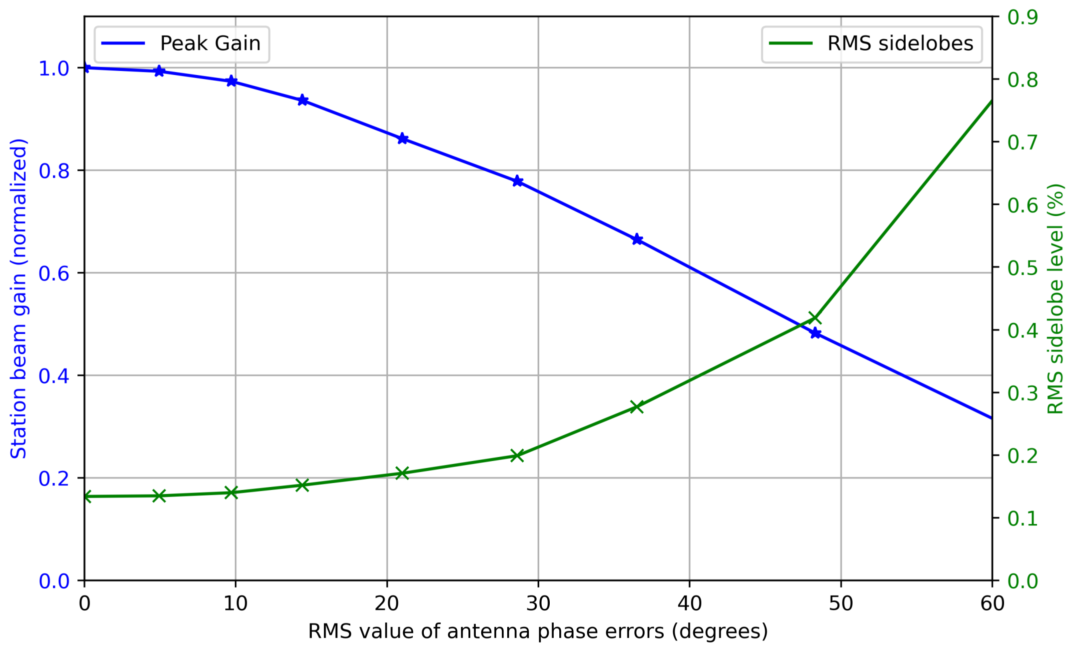
Given below is slices across these beams:

Figure 5



I show below a plot with the run of peak gain and RMS level of far sidelobes versus the RMS value of the phase error in calibration of the station phasing.

Figure 6

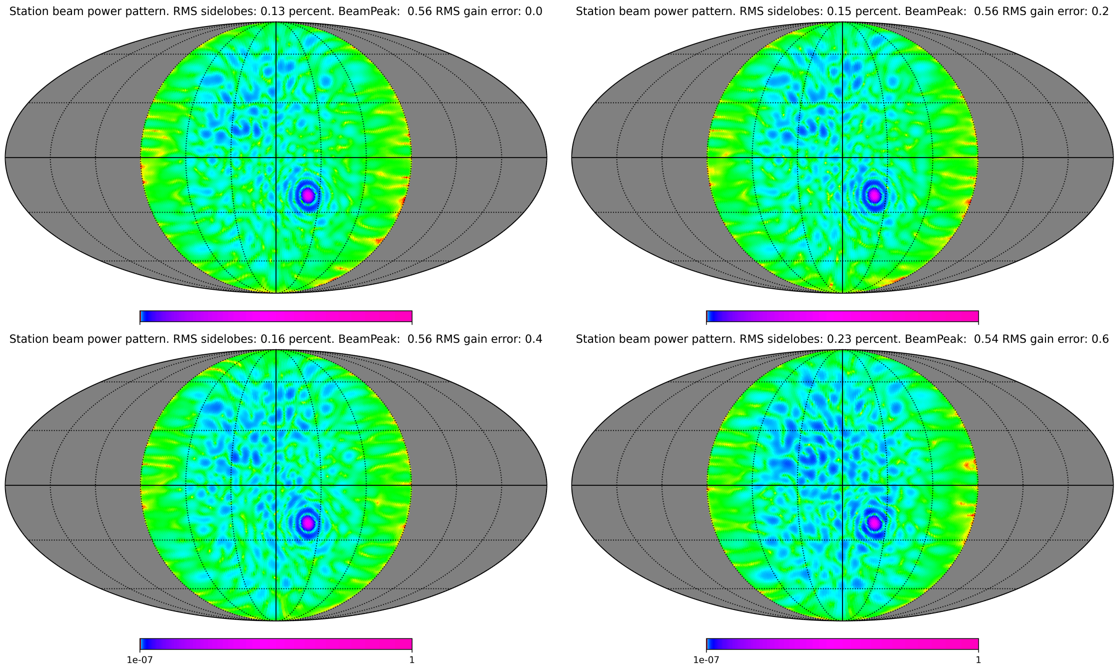


Phase calibration that keeps RMS errors within about 20˚ will keep the gain of the station beam within 10% of maximum. Reducing phase errors to 10˚ will have station gain within 4% of maximum.

Effect of antenna calibration errors: Amplitude errors

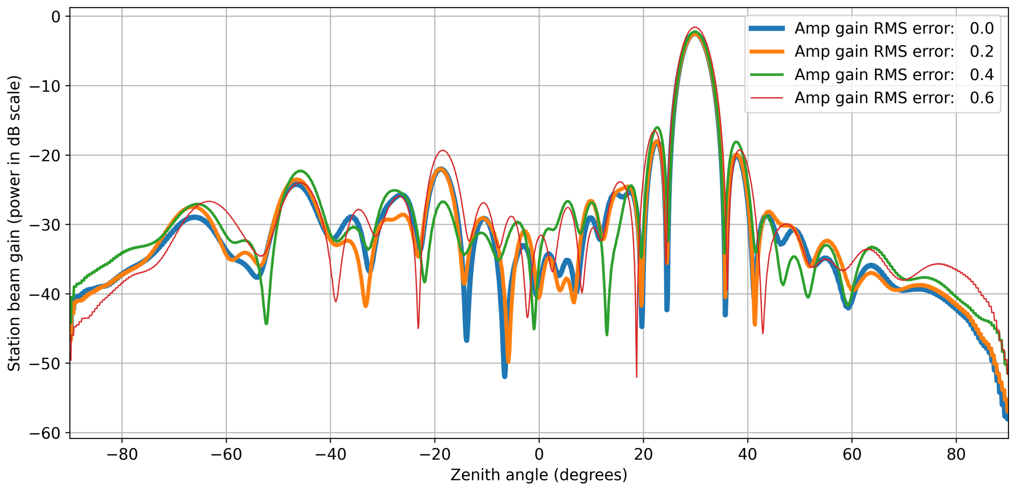
I have introduced amplitude calibration errors by multiplying the complex antenna signals by a Gaussian random scaling factor with mean unity. The computed station beam pattern is shown below for different standard deviations for the scaling factor: 0, 20, 40 and 60%.

Figure 7



Slice profiles made along the great circle through the beam peak and zenith are shown below.

Figure 8



The station beam is fairly robust and degrades little for significant errors in element amplitude calibration.   With increasing magnitude of amplitude errors, the primary effect is a small systematic rise in the level of far sidelobes, relative to the beam peak. As is the case for Fourier Synthesis imaging, a ~20% amplitude error appears to result in degradation in sidelobe quality comparable to that for 10 degrees phase error.

Station beam patterns assuming amplitude & phase errors together

I show below three examples of the slice profile assuming 10˚ phase errors together with 20% amplitude errors, compared to the profile expected for the case where there are no calibration errors. The different panels below are for different random realisations for the errors.

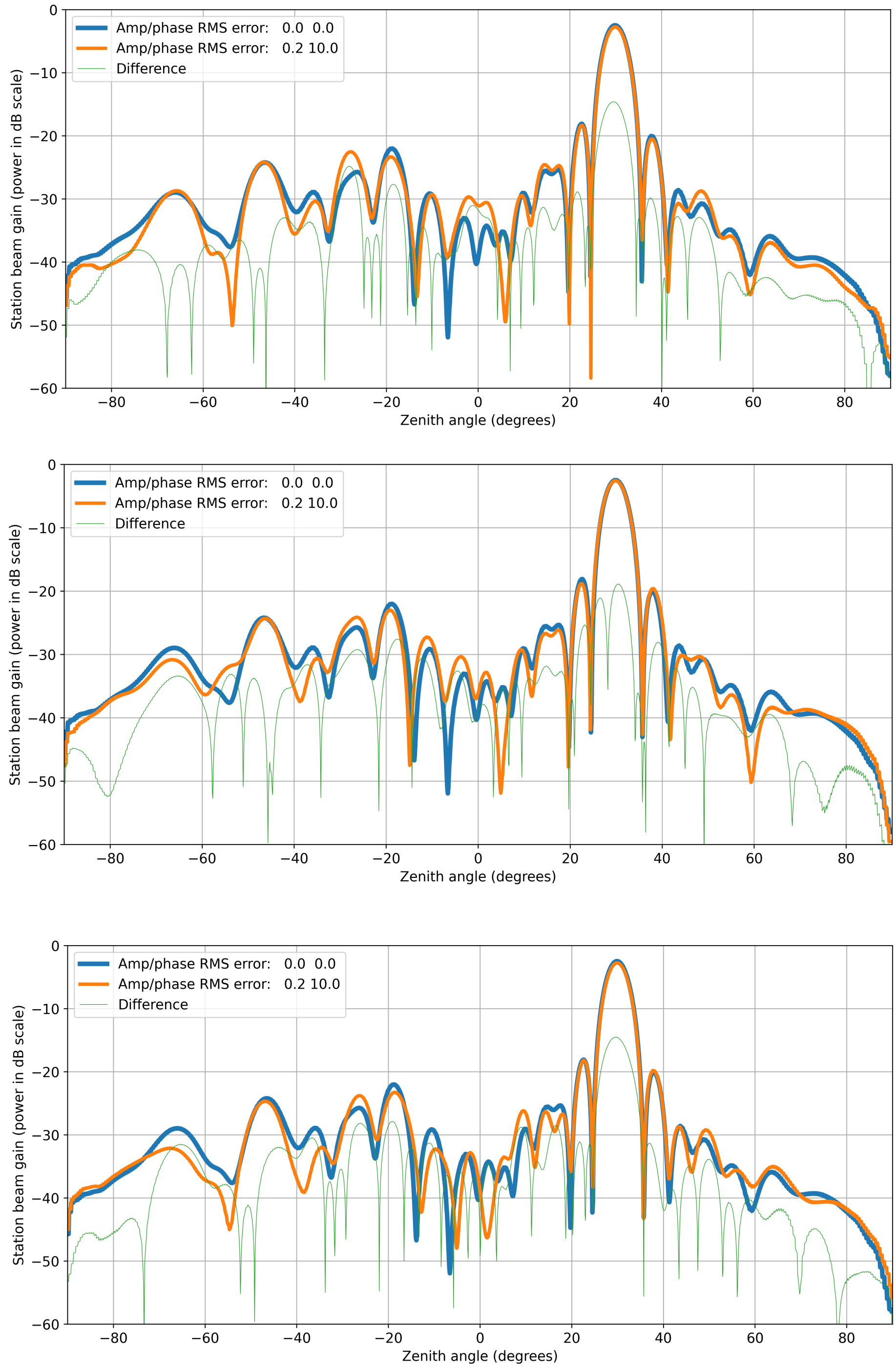


Figure 9

The differences are also shown in the above profile plots; these differences are by and large about 10 dB below the nominal response indicating that 10˚ & 20% calibration errors will perturb the beam main lobe and sidelobes at the 10% level.