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Operating the CA as a Tied Array . The phasing problem.

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<u>Conclusion</u> : There is likely to be no problem with the frequencies available to the AT during the first several years of operation. No real-time (on-line) self-calibration seems needed. The situation may be different in "Day two" operations, with higher, and lower frequencies. By that time further experience with the phase irregularities will have been gained, and a fresh appraisal of the need for heroic phase-control measures can be made. Two possible schemes are outlined.

The problem

In the "tied array" mode of operation we attempt to form a fan beam. We do this by adding the IFs from all the antennas with zero additional phase - we assume that the IFs have been correctly phased and delayed.

The quality of the fan beam, and hence the magnitude of the signal available to the LBA, will be degraded if, in fact, the IFs are not all in phase. This will occur if the atmosphere adds random phase to the various antennas. (I assume, for the moment, that instrumental phase errors have been detected, and corrected - there appears no fundamental obstacle to doing so).

This problem also afflicts the CA in its normal synthesis mode, resulting in maps with enhanced sidelobes. Since self-calibration has been very successful in countering the adverse effects of the phase errors, the suggestion has been made that we should consider some form of self-cal, operating in real-time, to monitor continuously the phase errors, and to provide continuous correction.

This note suggests that this will not be necessary on "Day one".

Magnitude of the effect

a. How much error can we tolerate?

If ϕ is the rms phase added to each antenna, then the amplitude of the signal is reduced by the factor :

$$\exp[-(2\phi/\pi)^2]$$

The S/N of the "tied" signal is reduced below the noise-free case by about 1% for ϕ = 10 degrees, and 10% for ϕ = 30 degrees.

The first question to settle, then, is the amount of tolerable degradation. (It should be emphasized that the phase tolerance for the CA is quite different: to obtain high dynamic range maps the phase errors must be reduced to below the 1 degree level; self-calibration operating on the entire data set can achieve this in favourable circumstances.)

b. What is the likely phase rms?

There are two obvious (well discussed) sources of phase errors: the troposphere and the ionosphere.

Troposphere.

The principal cause of trouble is due to regions of enhanced water vapour. These regions occur on all scales, and are in motion along with the winds. Large scale sizes will be seen as gradients, and will lead to an adequate fan beam pointing in the wrong direction. Small scale sizes produce random phases. The operative term is the scale size - if all the antennas are grouped together (ie. stations 1 to 5), then there will be little deterioration.

Sramek (1983) has examined the phase irregularities in New Mexico over baselines from 100 to 3000 m. On average the rms phase difference between two antennas separated by B (km) is :

$$\phi = 16\ B^{0.36} \text{ degrees, at 22GHz.}$$

The troposphere is non-dispersive at radio wavelengths, so this phase rms will scale with frequency:

$\phi \sim 11$ degrees for the 6 km CA at 10 GHz.

Ionosphere.

The scale size of the ionospheric disturbances are likely to be large (>100 km), so there is a fair probability that the phase fluctuations will be correlated from one antenna to the next.

Hinder and Ryle (1971) estimated that the irregularities, at $\lambda = 1$ m, and at an antenna spacing of 10 km, will be of order 10 cm. At 21 cm this translates to 7 degrees. The rms will be less - the mean antenna separation will be < 3 km.

It would seem that at the frequencies that will be available on "Day one" the decrease in signal/noise due atmospheric phase errors is too small be warrant real-time correction. A fall-back position would be to cluster the antennas near station one.

<u>"Day Two"</u>

Some limitations to Self-cal and Redundancy.

It is unfortunate that neither self-cal nor redundancy will work for those sources that most need assistance: weak sources that cannot easily be detected on a single baseline. Tweaking up the phases on the tied-array does little for the dynamic range of the LBA map of a strong source: extracting the largest possible signal from the tied-array for weak sources could, on occasion, make the difference between detection and garbage.

Neither technique is sensitive to a phase gradient. Thus, while we can form, (given sufficient signal/noise), an excellent fan beam, it may be pointing in the wrong direction. One solution would be to adopt the Noordam-de Bruyn technique and maintain fixed the centroid. In particular, it means that some form of "offset guiding" may be needed in complex fields.

Flux limits

We have to be able to detect the source on each baseline if self-cal is to work. With T(sys) =100K, 32 MHz bandwidth, and 10 seconds integration the limit is of order 50mJy.

Some possible schemes.

1. Very weak source option.

Cluster all the movable antennas to stations 1 to 5. These antennas will suffer little uncorrelated phase noise, and could be tied with no further correction. The 6 km antenna will appear in 5 similar baselines, so its phase error could be estimated, and corrected. (In effect, we could add all five baselines, improving the source detectability).

2. Detectable source option.

If the field has already been observed with the CA, we could use the Clean components from the CA self-cal to predict the phases on each of the tied array baselines. Thus we would use self-cal, but with a reasonably well established model.

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