From: "A. Richard. Thompson" <athompso@nrao.edu>
To: Dave DeBoer <ddeboer@seti.org>, Peter Napier <pnapier@nrao.edu>, "Peter.Hall" <Peter.Hall@csiro.au>, kant <kant@nfra.nl>, nrd <nrd@bao.ac.cn>, res <res@jb.man.ac.uk>, schilizzi <schilizzi@jive.nl>, tbeasley <tbeasley@ovro.caltech.edu>, ananth <ananth@ncra.tifr.res.in>, "Bruce.Veidt" <Bruce.Veidt@hia.NRC.CA>, dreher <dreher@seti.org>, tcornwel <tcornwel@nrao.edu>
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Subject: Hybrid array

Dear Peter et al.,

I thought that it might be useful to mention that a further reason for the hybrid approach concerns the effects of the ionosphere at meter wavelengths. In particular, synthesis imaging becomes very much more difficult when the beamwidth of the antennas (or groups of phased elements that are cross correlated) is wider than the angular size of the isoplanatic patch of the ionosphere. The isoplanatic patch size can be defined as the area over which the variation of the excess phase due to the ionosphere is small compared with a 2pi radians. If the beam is wider than the isoplanatic patch, and if it is necessary to map the full beam area, then one has to allow for variation of the phase calibration over the field of view. Data on the angular size of the isoplanatic patch is not precise, but at 100 MHz a representative value is 5 deg. If we take the full width (between first zeros) of the beam of a circular aperture as 2.4 x (wavelength/diameter), the diameter for which this is equal to 5 deg at 100 MHz is 82 m.

If the individual receiving elements have beams wider than the isoplanatic patch, a possible approach is to form phased subarrays of elements and cross correlate the subarray signals rather than those from individual antennas. However, since one is using the beam response to limit the synthesized field, sources outside the field entering through sidelobes can degrade the dynamic range. To minimize sidelobes the individual elements should be closely spaced to provide a combined aperture that is as nearly continuous as possible. However, this requirement is likely to be at odds with the avoidance of shadowing or the optimization of (u,v) coverage at shorter wavelengths. Problems associated with the isoplanatic patch size at long wavlengths are a prime concern for LOFAR (see, e.g. J. E. Noordam, Report ASTRON-LOFAR-11227) and sophisticated methods of calibrating the angular variation of the phase are likely to be developed. Nevertheless, for the SKA, the use of small diameter paraboloids or Luneburg lenses at the at frequencis of a few hundred MHz, at best complicates long wavelength observations, and may jeopardize the possibility of success in the important studies of the epoch of ionization for which high dynamic range is required. The large continuous apertures of the Aperture Array, or concepts with large reflectors, are better adapted for achievement of high dynamic range at such frequencies. The station diameter of the AA in the 120-300 MHz band is 160 m, so the hybrid scheme suggested in the IEMT report provides a good solution to the problem.

The variation of the size of the isoplanatic patch with frequency is also of interest. The excess phase introduced by the ionosphere on any path is proportional to nu^-1, where nu is the frequency. This results from the variation of the refractive index [proportional to nu^(-2)], and the path length. Thus, as frequency is decreased, smaller structures in the ionosphere become important and one can take the patch size as approximately proportional to frequency. To be more precise, the structure of the ionospheric irregularities also affects the frequency dependence, and if this is taken into account the isoplanatic patch size is found to be proportional to nu^(6/5). This result was pointed out by Jim Moran, and is derived as follows. The atmospheric irregularities are characterized by the structure function which gives the variance of the phase difference for two paths separated by a distance d. This is discussed for the case of Kolmogorov turbulence in the neutral atmosphere in TMS2 (pp. 534-539) and results are shown in Table 13.2. For distances up to a few tens of km (i.e. small compared to the thickness of the ionosphere) it is appropriate to consider 3D turbulence, for which the structure function is proportional to d^(5/3), so the rms phase difference is proportional to d^(5/6). For the ionosphere, the frequency variation of the refractive index also introduces a further dependence on nu. As noted above, for a fixed path in the ionosphere the phase is proportional to nu^(-1). The dimensions of a blob of the turbulent structure are assumed to be similar in directions parallel and perpendicular to the line of sight. Thus the rms phase difference for paths with separation d is proportional to d^(5/6) x nu^(-1). The isoplanatic patch size (in length or angle) is represented by a constant phase difference, so d^(5/6) x nu^(-1) is a constant, in which case d is proportional to nu^(6/5). Applying this result, the 82 m aperture required at 100 MHz becomes 18 m at 200 MHz and 7 m at 300 MHz. Thus the problem disappears rapidly as the frequency increases, but remains serious over the frequency range that is essential for the important epoch-of-ionization studies.

Dick

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A. Richard Thompson
NRAO, 520 Edgemont Road, Charlottesville, VA, 22903
Phone: (434) 296-0285   Fax: (434) 296-0287
athompso@nrao.edu

CC: <kkellerm@polaris.cv.nrao.edu>, Dick Thompson <athompso@nrao.edu>