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WHAT'S SO GREAT ABOUT PHASE STABILITY?

by the Devil's Advocate
(communicated by RPN)

ASTROMETRY ON A PHASE STABLE INTERFEROMETER

On a phase-stable interferometer, an absolute position is measured using the following recipe:

1. Assume a position for the source

2. Using the assumed position, calculate the required phase and delay compensation.

3. Using the calculated phase and delay compensation, observe the source.

4. From those observations, measure the phase of the fringes. If the atmosphere was perfectly stable, and the assumed position was exactly correct, the fringes would have zero phase (i.e. just a dc output from the correlator)

5. In practice, the phase will not be zero. It will contain random terms due to atmospheric variations and a sinusoidal term with a 24^h period due to the error in the assumed source position. So, the next step is to correct the phases as far as possible for atmospheric variations. In general this needs (for C-band and above) a water-vapour radiometer and (for S-band and below) a model of the ionosphere plus f0f2 ionosonde measurements. I gather that the remaining atmospheric phase variations will be of the order of tens of degrees (at S-band) or hundreds of degrees (at X-band) with a timescale of hours.

6. Fit a sinusoid of the form

   $$A\sin(dHA) + B\cos(dHA) + C$$
   $$(\text{where } dHA = HA_{baseline} - HA_{source})$$

   to the phase. A and C will then yield [illegible] in declination of the assumed position ([illegible]) and B will yield the error in RA. [illegible] C will be useless because of slow [illegible] lobe ambiguities, so only A and B are [illegible]

The uncertainty in the final [illegible] dominated by the inability to separate [illegible] random atmospheric changes. The positional [illegible]

[illegible] the residual atmospheric errors to about 1/[illegible] (S-band) or 1/2 (X-band) of a beam, or about 0.01 arcsec in either case. (It should be noted that these uncertainties may be a little on the pessimistic side.) The uncertainties can be reduced still further by calibrating the atmospheric fluctuations by observing a nearby unresolved calibrator source of known position.

Now, in principle the positions derived from a phase-stable interferometer are absolute in the sense that declination can be measured purely from fringe rate, and does not require a calibrator. (For RA, of course, the situation is different since a calibrator is needed to define the zero-point of RA). However, in a complex long baseline array there will always be residual phase drifts, and sources of arbitrary delay offsets (e.g. the radio link), which are difficult to measure other than by astronomical means. Thus in practice the interferometer must be calibrated to determine its fixed delay offset and phase offset. However, this calibration need be made only rarely and can be on any unresolved source, which need not be close in the sky to the target source. Therefore, no measurement made with such an interferometer is truly absolute - the positions ultimately depend on the position of a known calibrator, such as 3C273. It should also be noted that use of satellite LO's will introduce still more uncertainties into the sytem, which will presumably require even more calibration.

ASTROMETRY ON A NON-PHASE-STABLE INTERFEROMETER

Let us first agree that bandwidth synthesis cannot compete with phase-stable interferometry. However, consider a system which is used in all respects like a phase-stable system, except that its phase drifts randomly. Let us suppose that Lucifer (my employer) supplies us with a clock with a stability (on the scale of hours) of 10^{-15}. This stability implies that at X band the local oscillators will drift by about 10°/hour.

This drift is therefore small compared to the atmospheric uncertainties discussed above. This drift can be calibrated out by observations of a unresolved calibrator source of known position. Since this calibrator [illegible] be observed only at hourly intervals, there is no [illegible] to be close in the sky to the target source. Suppose, therefore, that we choose an arbitrary northern hemisphere source (e.g. 3C273) as our calibrator, and observe it once per hour throughout our observations. Then the recipe for deriving astrometric positions follows that of the phase-stable system exactly, with the addition for a correction for the clock drift. Since the residual uncertainty is small compared to that of the atmosphere, the resulting astrometric positions have similar uncertainties to those derived in the phase stable system. Furthermore, all the positions are ultimately relative to some arbitrary calibrator (e.g. 3C273) in both cases.

I rest my case, M'lud.

Note

Note that my argument rests on the provision of an oscillator with remarkable stability (Allan variance on hours $\sim 10^{-15}$). This is the sort of performance claimed by exponents of the U.WA oscillators. If however, these claims proved to be optimistic, and we had to use the cheaper masers (or - God forbid - Rubidiums), then this argument would collapse. The argument might just about survive if we could afford the better masers, which have stabilities better than 10^{-14}.