Intensity measurements with feeds in p.a. 0 and 45 degrees

Johan Hamaker
ASTRON, Dwingeloo, Netherlands; hamaker@astron.nl

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1 Summary

The ASAC meeting of september 2000 has rejected the option of having some of the feeds rotated over 45 deg in position angle on the ground that it would squander correlator capatity in intensity-only observations. I indicate how this loss can be recovered by a simple hardware addition. The idea is to electronically undo, prior to correlation, the effect of the rotation. This is simple to do in principle, but good gain and phase control is needed to avoid signal-to-noise degradation.

2 The rationale for rotated feeds

For polarimetry, a heterogeneous array has the important advantage of fixing the relative phases of *all* antenna channels in the primary calibration on an unpolarized source. The full proof is in my Paper IV based upon matrix analysis; a 'conventional' quasi-linear analysis showing the same for a simple case was given by Weiler in 1973. (See references in my SPIE paper distributed earlier.)

Various schemes proposed for *measuring* the phase difference all have nontrivial problems. *The heterogeneous configuration is a valuable alternative option that should be left open if possible.*

3 Recovering the $\times 2$ inefficiency factor

Let the feed of an antenna be rotated over 45 deg, so its receptors are sensitive to the fields $e_\mathrm{x} + e_\mathrm{y}$ and $e_\mathrm{x} - e_\mathrm{y}$. The corresponding signals at the input to the correlator are then

$$v_\mathrm{x} = g_\mathrm{x}(e_\mathrm{x} + e_\mathrm{y}), \quad v_\mathrm{y} = g_\mathrm{y}(e_\mathrm{x} - e_\mathrm{y})$$

Rather than presenting these signals directly to the correlator, insert a circuit to form

$$\begin{aligned} v'_\mathrm{x} &= v_\mathrm{x} + v_\mathrm{y} = (g_\mathrm{x} + g_\mathrm{y})e_\mathrm{x} + (g_\mathrm{x} - g_\mathrm{y})e_\mathrm{y} \\ v'_\mathrm{y} &= v_\mathrm{x} - v_\mathrm{y} = (g_\mathrm{x} - g_\mathrm{y})e_\mathrm{x} + (g_\mathrm{x} + g_\mathrm{y})e_\mathrm{y} \end{aligned}$$

(Give or take a minus sign somewhere and a factor 2.)

Using these as inputs to resp. the XX and YY correlations for an unpolarized source, we may ignore the 'cross' terms involving $g_\mathrm{x} - g_\mathrm{y}$, to retain

$$\begin{aligned} v'_\mathrm{x} &= (g_\mathrm{x} + g_\mathrm{y})\ e_\mathrm{x} \\ v'_\mathrm{y} &= (g_\mathrm{x} + g_\mathrm{y})\ e_\mathrm{y} \end{aligned}$$

Thus in an intensity-only observation, our modified antenna is equivalent to one with non-rotated feeds and X and Y gains $(g_\mathrm{x} + g_\mathrm{y})$.

4 Effect of gain/phase deviations on S/N ratio

The signal and noise powers are proportional to, respectively

$$S = |(g_\mathrm{x} + g_\mathrm{y})|^2; \quad N = (|g_\mathrm{x}|^2 + |g_\mathrm{y}|^2).$$

S/N has a maximum of 2 for $g_\mathrm{x} = g_\mathrm{y}$. The S/N degradation relative to this condition is

$$F = \frac{|(g_\mathrm{x} + g_\mathrm{y})|^2}{2(|g_\mathrm{x}|^2 + |g_\mathrm{y}|^2)}$$

For gains in the X and Y channels deviating by $\pm\Delta g/2$, this can be approximated by

$$F \approx 1 - \left(\frac{\Delta g}{2g}\right)^2$$

If, for example, the relative gain deviation is .2, then $\Delta g = .1$ and $F = .99$.

For a phase difference $\Delta\phi$

$$F = (1 + \cos\phi)/2$$

A 20 deg phase error, for example, results in $F = .97$.

5 Conclusion

The proposed method works in principle, but the signal-to-noise ratio may degrade under typical operating conditions, primarily due to phase variations. How serious this is will depend on the phase stability to be attained in practice. If we should rotate one half of the feeds relative to the other half, one half of all interferometers will suffer from this effect.

The main source of phase drift is generally the first local oscillator. Since it is common to the X and Y channels, it does not affect differential phase. Controlling differential drift within a few tens of degrees may be a reasonable spec. This control must be on-line, since S/N loss cannbot be recovered afterwards.

While possible in principle, the proposed solution is not an obviously ideal one. It is to be looked at as another option in addition to other ones that are already being considered. In weighing its advantages for polarimetruy against the disadvantages for intensity observations, the question that ASAC might give an answer to is

Is a potentially important improvement of polarimetric accuracy worth a sensitivity loss in intensity observations? What is the maximum loss that is acceptable?