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Feeds for the AT
The use of Linear Polarization as it affects VLBI and LBA measurements.

Max Komesaroff,
29 November 1984.

Introduction

The fact that the feeds proposed for the AT are to be linearly polarized appears to pose problems when the AT is used as an element in a VLBI network. This is because, traditionally, the feeds employed for VLBI work have been circularly polarized.

This note is intended to show that if one element in, say a VLBI network is equipped with a circularly polarized feed, and another element, such as the AT, is equipped with a pair of orthogonal linearly polarized feeds, some extra facilities will be required, but these need not be very demanding, and, in any case, they are likely to be required by future developments in VLBI techniques.

Some comments are included regarding the choice of feeds for the LBA elements.

A Two Element Interferometer: Circularly Polarized Feeds.

First let us consider the case of an interferometer for which each element is alt-az mounted and equipped with a pair of feeds, one right hand and the other left hand circularly polarized. Such a system will, of course, be capable of measuring the Fourier components of all four Stokes parameters. The four correlator outputs (apart from a constant of proportionality) are

$$S_{RR} = [\underline{I}+\underline{V}] \exp i(\chi_a - \chi_b + \phi) \qquad (1a)$$

$$S_{RL} = [\underline{Q}-i\underline{U}] \exp i(\chi_a - \chi_b + \phi) \qquad (1b)$$

$$S_{LR} = [\underline{Q}+i\underline{U}] \exp -i(\chi_a - \chi_b + \phi) \qquad (1c)$$

$$S_{LL} = [\underline{I}-\underline{V}] \exp -i(\chi_a - \chi_b + \phi) \qquad (1d)$$

Here $\underline{I}$, $\underline{Q}$, $\underline{U}$, and $\underline{V}$ are the spatial Fourier components of I, Q, U and V respectively, χ_a and χ_b are the parallactic angles at the two telescope sites, and ϕ is the phase difference between the downcoming rays at the two sites.

Clearly, since χ_a and χ_b can be calculated at any time, a measurement of S_{RR} alone yields [$\underline{I}$ + $\underline{V}$]. If it is known that $|\underline{V}| \ll \underline{I}$, this one measurement then allows us to estimate $\underline{I}$.

A Two-Element Interferometer: One Element with a Circularly Polarized Feed, the other with Orthogonal Linear Feeds.

If one interferometer element has, say, a right hand circularly polarized feed, and the other element has a horizontal (x) and a vertical (y) linearly polarized feed, each connected to its own receiver, then, clearly, it must be possible to utilize the system in such a way as to estimate S_{RR} and S_{RL}. This follows because, with a pair of orthogonal linearly polarized feeds, we can, in principle, always 'synthesize' a right hand or a left hand circularly polarized feed by adding the outputs with a $\pi/2$ phase shift in the appropriate sense.

However it is possible, without any additional hardware, to evaluate S_{RR} and S_{RL} separately by correlating each of the two linearly polarized outputs with the circularly polarized output. This yields

$$S_{Rx} = [\underline{I} + \underline{V}]\exp i(\chi_a - \chi_b + \phi - \pi/2) + [\underline{Q} - i\underline{U}]\exp i(\chi_a + \chi_b + \phi + \pi/2)$$

$$S_{Ry} = [\underline{I} + \underline{V}]\exp i(\chi_a - \chi_b + \phi) + [\underline{Q} - i\underline{U}]\exp i(\chi_a + \chi_b + \phi)$$

If we now advance the phase of S_{Rx} by $\pi/2$, and add the result to S_{Ry} we obtain

$$2[\underline{I}+\underline{V}]\exp i(\chi_a - \chi_b + \phi) = 2S_{RR}$$

and, on taking the difference,

$$2[\underline{Q}-i\underline{U}]\exp i(\chi_a - \chi_b + \phi) = 2S_{RL}$$

(see Equations 1).

(It should be noted that in the case of an unpolarized source, the signal/noise for either S_{Rx} or S_{Ry} alone is less by a factor $\sqrt{2}$ than that for S_{RR}. This is because the feeds used in measuring S_{Rx} or S_{Ry} are not identical. However, after phase shifting S_{Rx} and adding, the full signal/noise is recovered.)

Possible Options for VLBI

At the moment most VLBI experiments involve recording one sense of circular polarization (say right hand) from each telescope.

From the foregoing discussion it follows that one possible way of combining the compact array output with output from other telescopes with circularly polarized feeds in a VLBI network is:

1. Record the two orthogonal linearly polarized IF outputs of the compact array. Each of these can be subsequently correlated with the circularly polarized outputs from the other elements of the network, phase shifted and added.

Other possibilities are:

2. Add the two linearly polarized RF outputs from each receiver, after shifting the phase of one by $\pi/2$ radian. Thereafter convert to IF.

3. Add the two IF outputs (x and y) from the 'tied array' after phase shifting one by $\pi/2$. The phase shift could be effected by either

(a) A $\pi/2$ hybrid in one IF line.
(b) A $\pi/2$ phase shift applied digitally.
(c) A $\pi/2$ phase shift in one local oscillator of each telescope.

Of these various possibilities, 2 seems appealing, as it requires only one IF channel per frequency, but the engineering difficulties are very great and would almost certainly make the method extremely expensive. The same considerations probably apply to 3(c).

Methods 3(a) and 3(b) seem to merit serious consideration.

Method 1 has the disadvantage that it requires two IFs and two tapes per channel. However it has the advantage of not requiring additional hardware. More important: it seems probable that future developments of VLBI techniques will involve polarization measurements. For these it will be necessary to record two tapes per frequency. The AT will then be equipped for such developments and be at no disadvantage. Provided two opposite polarizations are recorded at each element of an array all four Stokes parameters may be recovered.

Feeds for the LBA Elements

It has been decided that only two IF channels will be provided for each LBA telescope. At the time this decision was made, radio link systems were being considered. If, as now seems likely, tape recorders are to be used, the possibility of four IF channels per telescope might perhaps be reconsidered.

If, nevertheless, only two IFs per telescope are to be provided, there appear to be two possibilities.

1. Use circularly polarized feeds for the LBA elements. This would allow the LBA system to operate at two frequencies simultaneously, since, as shown earlier, a single circularly polarized IF from an LBA telescope, when correlated with each of the linearly polarized IF outputs from a compact array telescope, can provide a measurement of [I+V] unmixed with Q or U. With linearly polarized feeds for the LBA, two IF channels would be required for each frequency.

2. Use linearly polarized feeds for the LBA, but employ a system of frequency switching. This configuration should yield the same signal/noise as 1. above.

Antennas and Feeds
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