GMRT:PSR:pol_cal.03

A Technique For Instrumental Polarisation Calibration

an internal note prepared 13/8/91 by Y. Gupta.

1. Aim of the note :

To outline a technique for polarisation calibration of the electronics system, using noise generators as calibration sources.

2. Introduction :

Proper calibration of an antenna system involves calibration of i) the gains (amplitude and phase) of each polarisation channel, ii) the phase difference between the two polarisation channels and iii) the cross coupling parameters for the two channels - these characterise the leakage of one polarisation channel into another. For a multi-element system like GMRT, this calibration is normally carried out by observing a set of suitable calibration sources in the sky (see report GMRT:PSR:Pol_cal:02 titled "GMRT polarisation calibration and Pulsars" for details). The resulting calibration takes into account all the variable effects including instrumental (antenna + electronics) as well as those due to the atmosphere (mainly the ionosphere). It is useful to have a scheme for estimating the effect of just the electronics on the calibration parameters so that one can separate out the effect of the ionosphere. Besides, this can also be useful as a diagnostics tool for debugging the electronics. Here, we describe such a scheme and discuss some of its implications on the hardware set-up. This scheme can be easily be implemented with minor modifications to the proposed noise injection system being designed for the RF front end.

3. Instrumental calibration using noise injection :

Figure 1 shows a schematic of the original proposal for the front end electronics system for a single GMRT antenna. The two orthogonal linear polarisations received by the feed system are converted to (nominally) orthogonal circular components in the polariser. Calibration noise signals are coupled into the signal path at the output of the polariser, using directional couplers. At present the idea is to have a single noise generator and use a power divider to provide equal noise signal power to the two channels. The signals then go to the LNAs and thence to the rest of the receiver system.

The nominally right and left circularly polarised signals that emerge from the polariser get corrupted due to cross coupling as they progress through the electronics system. Some of this cross coupling takes place at the reflector surface and the feeds, some in the polariser itself and the rest in the electronics system. Furthermore, the electronics can produce variable gains for the channels, which will, in general, be independent. The final measured signals from the two polarisation channels, E_L' and E_R', are given in terms of the true responses, E_L and E_R, by

$$E_L' = G_L \left[E_L + \varepsilon_1 E_R\right] \tag{1a}$$

$$E_R' = G_R \left[E_R + \varepsilon_2 E_L\right] \tag{1b}$$

where ε_1, ε_2 are complex constants specifying the cross coupling and G_L, G_R are the complex gains for the left and right channels. These are the quantities we would like to estimate.

The correlator provides measurements of the self and cross correlations of the signals from the two polarisation channels of a dish. These can be expressed as

$$|E_L'|^2 = |G_L|^2 [\ |E_L|^2 + \varepsilon_1 E_L^* E_R + \varepsilon_1^* E_L E_R^*\ ] \tag{2a}$$

$$|E_R'|^2 = |G_R|^2 [\ |E_R|^2 + \varepsilon_2 E_L E_R^* + \varepsilon_2^* E_L^* E_R\ ] \tag{2b}$$

$$E_L'^* E_R' = G_L^* G_R [\ E_L^* E_R + \varepsilon_2 |E_L|^2 + \varepsilon_1^* |E_R|^2\ ] \tag{2c}$$

If we measure the above three quantities under the following three conditions, we can solve for the unknown quantities :

Case I : $E_R = 0$ i.e. $E_x = E_y e^{j\pi/2}$
This gives the following useful equations :

$$SIa = |E_L'|^2 = |G_L|^2 |E_L|^2 \tag{3a}$$

$$SIb = E_L'^* E_R' = |G_L||G_R| e^{j\phi_{RL}} \varepsilon_2 |E_L|^2 \tag{3b}$$

Case II : $E_L = 0$ i.e. $E_x = E_y e^{-j\pi/2}$
This gives the following useful equations :

$$SIIa = |E_R'|^2 = |G_R|^2 |E_R|^2 \tag{4a}$$

$$SIIb = E_L'^* E_R' = |G_L||G_R| e^{j\phi_{RL}} \varepsilon_1^* |E_R|^2 \tag{4b}$$

Case III : $|E_L| = |E_R|$, $\chi_{RL} = \pi/2$ i.e. $E_x = E_y$
This gives the following useful equations :

$$SIIIa = |E_L'|^2 = |G_L|^2 |E_L|^2 [\ 1 + \varepsilon_1 e^{j\pi/2} + \varepsilon_1^* e^{-j\pi/2}\ ] \tag{5a}$$

$$SIIIb = |E_R'|^2 = |G_R|^2 |E_R|^2 [\ 1 + \varepsilon_2 e^{-j\pi/2} + \varepsilon_2^* e^{j\pi/2}\ ] \tag{5b}$$

$$SIIIc = E_L'^* E_R' = |G_L||G_R| e^{j\phi_{RL}} |E_L|^2 [\ e^{-j\pi/2} + \varepsilon_1^* + \varepsilon_2\ ] \tag{5c}$$

Assume all non-zero amplitudes of E_L and E_R in the three cases to be equal. Then $|G_L|$ and $|G_R|$ are obtained from eqns.(3a) and (4a). Adding (3b) and (4b) and subtracting (5c) from the result then gives a value for ϕ_{RL}, the phase difference between the right and left channels. Estimates for ε_1 and ε_2 can then be obtained from eqns.(3b) and (4b) or from eqns.(5a) and (5b).

In the present design of the front end, the noise sources are coupled into the RF path AFTER the polariser. Implementing the noise signals for the three cases will require switches (or large attenuators - > 50 dB) in both noise channels, as well as a phase shifter in any one of the noise channels, before they are coupled. In this context, it would be useful to alter the design and have the noise sources coupled into the signal path, BEFORE the polariser. In this case, all that will be needed is a phase shifter (in any one of the noise channels) which can give three values : 0 and $\pm \pi/2$.

For various other reasons, an alternative design for the front end that is being considered is to have the LNAs before the polariser (figure 2). In this case, if we inject the noise signals just before the polariser, the calibration procedure described above will not include the LNAs. In this case, the noise injection should be shifted to before the LNAs. The other major difference in this set up will be that the gain and phase changes introduced by the LNAs will now act on the linearly polarised signals, instead of the circularly polarised signals. As a result, any phase mismatch between the LNAs (due to bad tracking, for example) will no longer show up simply as a change in the value of ϕ_{RL}; it will instead change the effective values of ε_1 and ε_2. This will make it harder to diagnose problems in the LNAs.

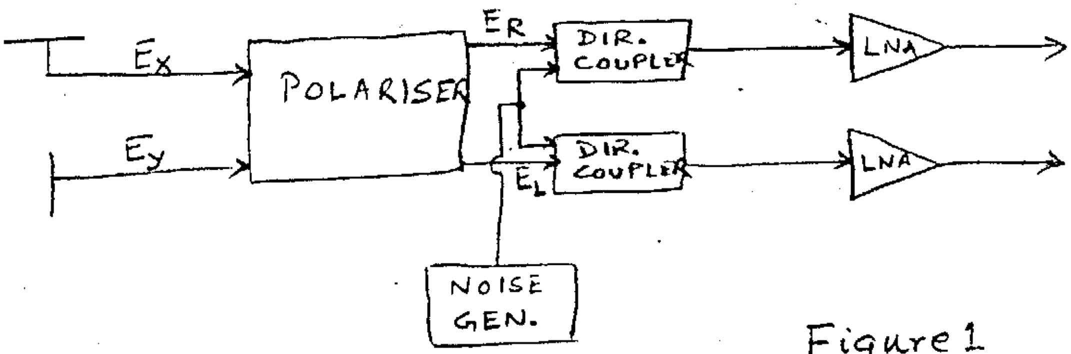

Figure 1

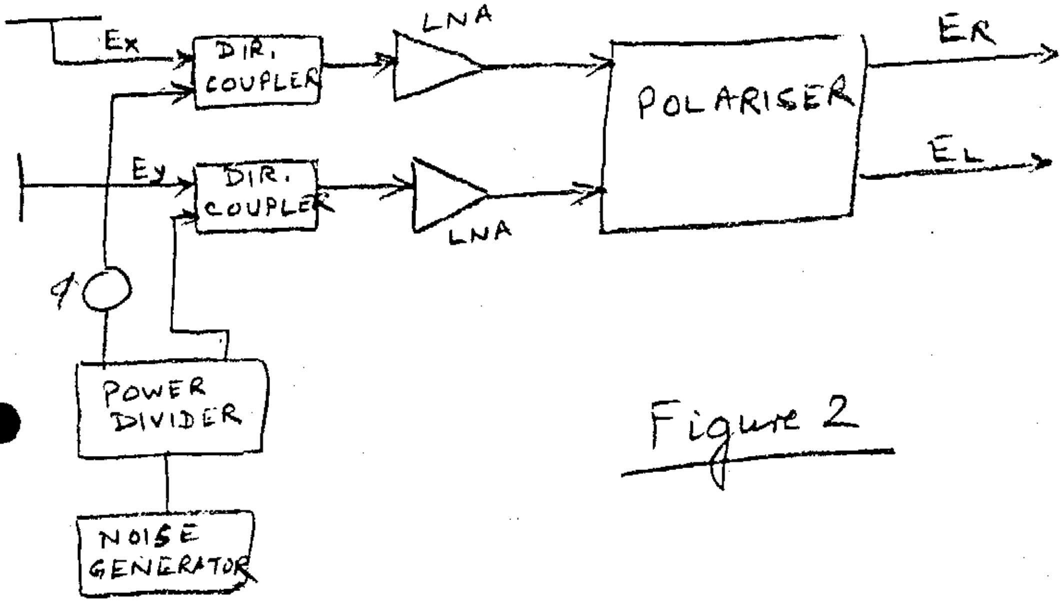

Figure 2