The Polarimetric Observation Facility at the Medicina 32 m Parabolic Antenna

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Abstract. We describe the wideband analog polarimeter made at the Medicina radio observatory usable with the receivers of our 32m parabolic antenna. The principle under which the electronics was designed as well as the circuit realization will be showed, togheter with the description of the software made to manage the observations and the off-line processing of the data acquired.

INTRODUCTION

The design and realization of a polarimetric facility for the Medicina radiotelescope was proposed years ago in collaboration with the Istituto TeSRE-CNR in order to make available a capability to measure, at as many frequencies as possible, the linear polarization of the galactic background in terms of Stokes parameters. The facility was inteded to also provide the amount of instrumental polarisation due to receiving system.

At the start of the project two possibilities were considered. One was to use commercially available products that process the signal at RF level and make available a correlation of the two channels coming from our receivers. This would need one device per receiver and, above all, the rearrangement of each receiver.

The other possibility was to build an IF polarimeter, i.e. a device that works in the down converted band 100-500MHz, so that it can process the signals coming from all our receivers.

The latter was chosen and in the last few years we have been working out the analog electronics that processes the left and right polarisation coming from the receivers placed on the parabolic antenna and gives four outputs, the LHCP (Left Hand Circular Polarisation) and RHCP (Right Hand Circular Polarisation) total powers (I Stokes parameter) and the Q,U Stokes parameters. The V parameter can also be derived by off line data processing .

THE HARDWARE OF THE POLARIMETER

The following relationship among Stokes parameters and electric fields of the RHCP and LHCP receiver outputs hold

$$I = < \mathbf{E}^2{}_r(t) > + < \mathbf{E}^2{}_l(t) > = I_p + I_n \quad (1)$$

$$Q = <\mathbf{E}_r(t)*\mathbf{E}_l(t)> = I_l\cos 2a \quad (2)$$

$$U = <\mathbf{E}_r(t)*\mathbf{E'}_l(t)> = I_l\mathrm{sen}2a \quad (3)$$

$$V = < \mathbf{E}^2{}_r(t) > - < \mathbf{E}^2{}_l(t) > = I_p\mathrm{sen}2\beta \quad (4)$$

The symbol < > indicates a time integration and:

- $\mathbf{E}_r$, $\mathbf{E}_l$ are the electric fields of RHCP and LHCP, $\mathbf{E'}_l$ is the electric field of the LHCP 90^o out of phase.
- I_p, I_n are the polarized and non polarized power.
- I_l is the linearly polarized power and Q,U the relative Stokes parameters, a is the polarisation angle.
- $I_p\mathrm{sen}2\beta$ (or V) is the circularly polarized power.

The relationships (1) to (4) say the electronics tasks are:
a) realizing two total powers, one for the LHCP input the other one for the RHCP
b) realizing two multipliers, one having RHCP and LHCP inputs, the other one having RHCP and LHCP 90^{o} out of phase. After each multiplier a low pass filter is needed to realize the operation of symbol < >. In fig. 1 the block diagram of the polarimeter is showed. For more details see [1].

All cables have the same length to minimize the degradation of the polarimeter axial ratio. For the same reason a second Hybrid 90 has been inserted, in principle not strictly necessary. A multiplexer is necessary because the A/D converter board have one input only. So doing the four outputs are not contemporary acquired: this is done at time spacing of the order of a second. A modem for RS232 link is necessary because of the long distance between the polarimeter (located in the vertex room of the antenna) and the computer placed in the control room: locating the polarimeter as near the receiver as possible avoids detection of phase fluctuation due to long coaxial cables.

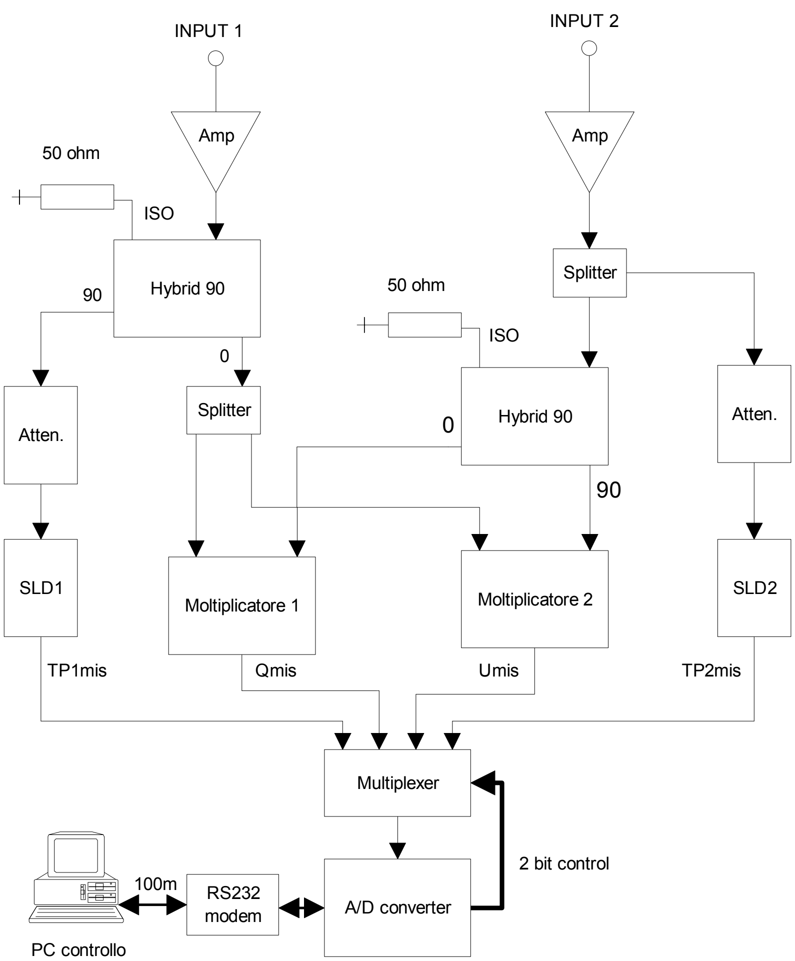

FIGURE 1. Block diagram of the polarimeter

FUNDAMENTALS FOR THE POLARIMETRIC OBSERVATION

The outputs of the hardware are not directly the Stokes parameters, because the data are not calibrated and because of the instrumental polarisation due to the whole receiving system. The effects are that the polarized part of the incident wave is partially depolarized and, inversely, the unpolarized part is partially polarized: the observation strategy, together with the mathematical model, gives the possibility to calibrate I,Q,U,V and to cancel out the contamination.

There are various references to polarimetric systems, for example [2,3,4] using interferometers, or [5] for single dish measurements but using two horns technique.

The mathematical model of our system is treated in [1]. The raw data acquired by the polarimeter, TP1mis, TP2mis, Qmis, Umis (fig. 1), are time labelled and acquired in an observation sequence that provides onsource data, offsource data, and data after injecting a noise calibration signal. The off line software makes true the model showed in equations (5) to (8)

$$I' = I + P\Sigma\cos(2\chi + 2a + \sigma) \tag{5}$$

$$V' = V - P\Delta\cos(2\chi + 2a + \delta) \tag{6}$$

$$Q' = P\cos(2\chi + 2a + \gamma_q + \psi_R - \psi_L) + I\Sigma\cos(\sigma + \gamma_q + \psi_R - \psi_L) + V\Delta\cos(\delta + \gamma_q + \psi_R - \psi_L) \tag{7}$$

$$U' = P\sin(2\chi + 2a + \gamma_u - \psi_R + \psi_L) - I\Sigma\sin(\sigma - \gamma_u + \psi_R - \psi_L) - V\Delta\sin(\delta - \gamma_u + \psi_R - \psi_L) \tag{8}$$

$\mathbf{P} \equiv Q + jU \equiv Pe^{j\theta}$ is the source polarisation vector (P magnitude, θ polarisation angle). The Medicina parabolic antenna is an alt-az mount antenna so when the source is tracked the receiving system sees it at variable angles, thus θ is a sum of a constant term (twice the source polarisation angle) and twice the parallactic angle χ. $\psi_R - \psi_L$ is the phase difference between left and right channels in the receiver, γ_q and γ_u are the phases due to the electric path inside the polarimeter, the $\mathbf{\Sigma},\mathbf{\Delta}$ vectors are a combination of the previous quantities, σ and δ their angles, and they represent the contamination. Some considerations on equations (5) to (8):

- The ideal case should be that the polarimeter gives us $Q'=P\cos(2\chi + 2a)$, $U'=P\sin(2\chi + 2a)$, $I'=I$, $V'=V$
- Receiving a polarized signal gives I',V' different from the true I,V Stokes parameters due to instrumental polarisation ($\Sigma,\Delta \neq 0$), depolarising part of the incoming power. Further, I,V pollutes also the true Q,U parameters giving Q',U'; again this happens for the presence of the instrumental polarisation.
- Observing non polarized signal should give true I,V and polluted Q,U.

The observing polarimeter software [6,7] consists of two parts. First of all the user is enabled to setup the observation by time scheduling the source(s) and interfacing with the control system of the antenna. Once the observation is started the second part of the software monitors the acquisition. The user interfaces are showed in fig. 2 and 3

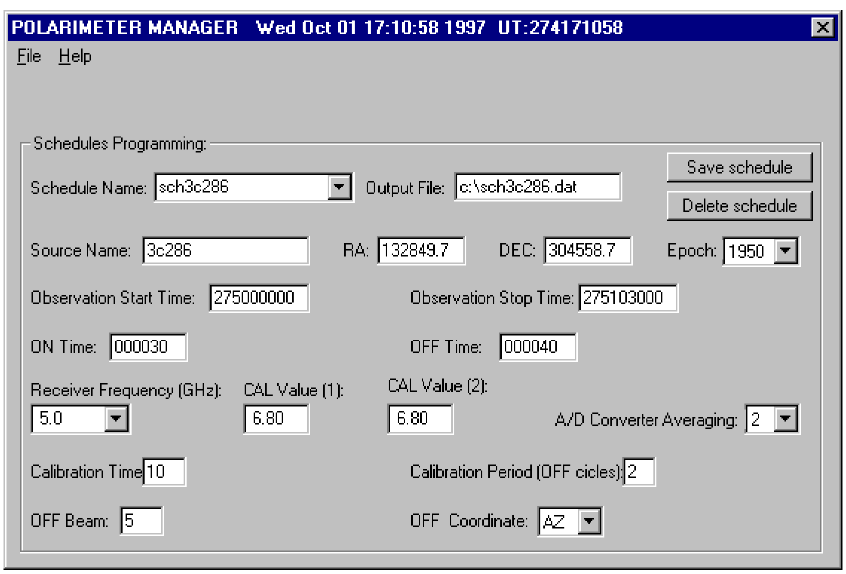

FIGURE 2. User interface to setup the observation

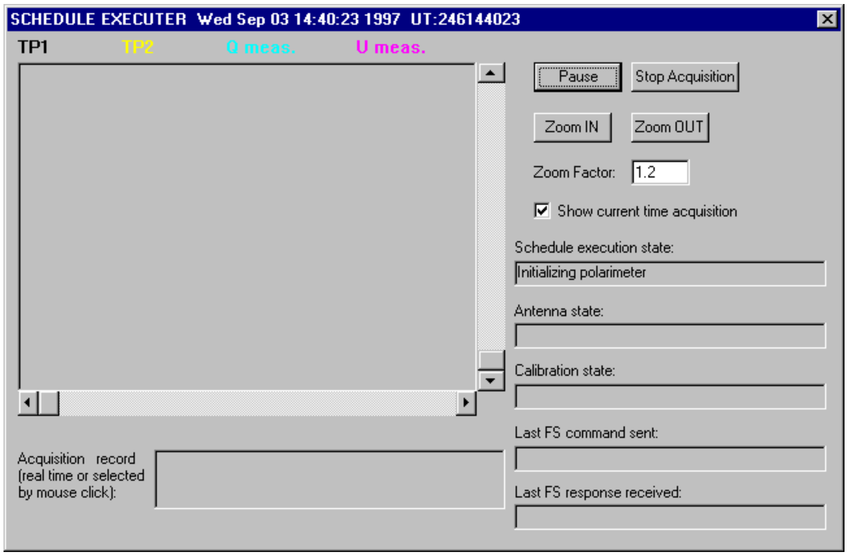

FIGURE 3. User interface during observation

In the setup menu, receiving frequency, sources, duration of on-off and calibration cycles, number of beams to go off together with which coordinate, are selectable. In the observing menu, flowing of data acquired, both numerically and graphically, as well as the antenna status are shown, together with the possibility to stop or to pause the acquisition .

Raw data Tp1mis, Tp2mis, Qmis, Umis are transformed in I', Q', U', V' by the post processing software and then a sinusoidal fitting versus parallactic angle is performed. Results of this fitting are the offsets, the amplitude and the phase of the sinusoids. Moreover, the software can show the polarization circle showing Q' versus U'. In any case Q, U, P, a, I, V and instrumental quantities can be derived.

TEST MEASUREMENTS WITH THE MEDICINA POLARIMETRIC FACILITY

First tests were performed at 5GHz on known polarized (3C286, 3C138) and non polarized sources (3C84). Complete results are in [1] and [6] and we could say here that the measurements fit the model. In the following figures 4 to 6 reduced data for 3C286 and 3C84 are reported. As foreseen, the polarized source observation gives a sinusoidal trend and a polarisation circle with a center offset (effect of the instrumental polarisation). The non polarized source observation, instead, gives only a cloud of points around a centre different from (0,0). Recall that the amount of offset is dependent on the total power of the observed source. You can disregard the outlier points present in each of the four picture of fig. 4.

Fig. 5 also allows to calibrate unknown sources because at 5GHz 3C286 has a flux of 7.48Jy and a polarisation percentage of 11.5%. This means that 1100 counts (the radius of the circle) correspond to 0.823 Jy.

During these years, tests have been repeated many times on different atmospheric conditions showing, as predictable, a very low dependance of the polarised outputs, on the weather conditions, compared to the total power outputs. At 8 GHz a factor 16 in the rms noise of the total power outputs was detected when passing from a rainy day to a clear sky day, while only a factor of 3 was observed in the Q, U outputs. The polarimetric facility was used for source as well as planet observation. A development of the software is in progress to make available sky measurement facilities by making a raster scan of the antenna. A rough estimation of the polarized output sensitivity at 8 GHz is $10mK/s^{1/2}$ by using a bandwidth of 80 MHz. This narrower band was used to avoid a known interference presents in the lower part of the IF band.

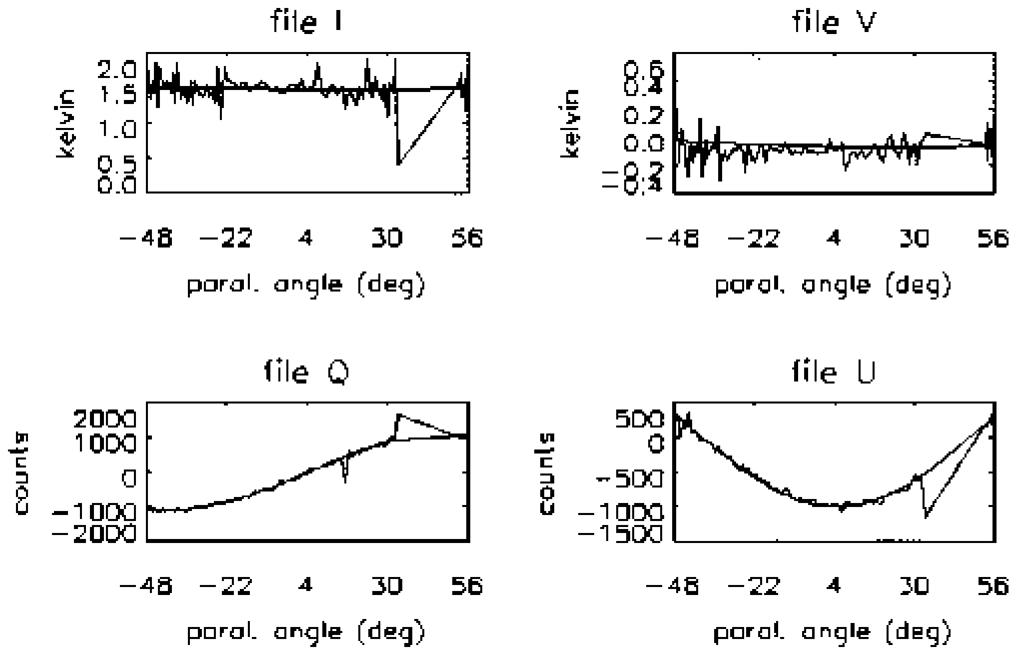

FIGURE 4. Stokes parameters for 3C286

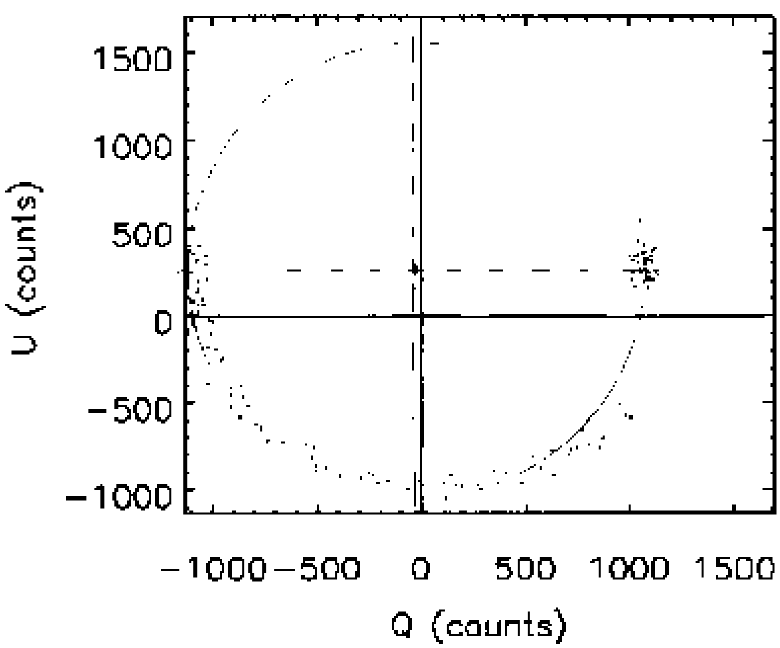

FIGURE 5. Polarisation circle for 3C286

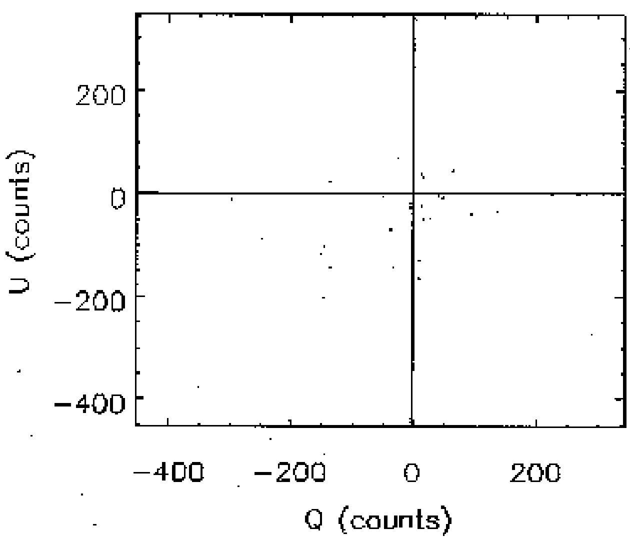

FIGURE 6. Polarisation circle for 3c84

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