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A polarimetric facility for the SRT

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Abstract. Based on the experience matured in polarimetry with the Medicina radiotelescope, it is possible to develop a new optimized polarimetric facility as a back-end of the forthcoming SRT-antenna. The back-end can consist of a circular polarization digital correlation polarimeter, having 1-GHz bandwidth and giving the Stokes parameters I, Q and U. Here, development, results and performances obtained with the polarimetric facility of the Medicina radio telescope are briefly presented and used to identify requirements for an advanced device aimed at the SRT.

1. Introduction

A polarimeter is a back-end to reveal the four Stokes parameters of the sky radiation: the total intensity I; the two parameters Q and U measuring the linear polarized component; the parameter V measuring the circular polarized component. When the receiver uses the left-hand and right-hand circular polarizations E_L and E_R, the Stokes parameters can be obtained as

$$I = \left\langle |E_R|^2 \right\rangle + \left\langle |E_L|^2 \right\rangle \quad (1)$$

$$Q = 2\,\Re(E_R E_L^*) = I_p \cos 2\theta \quad (2)$$

$$U = 2\,\Im(E_R E_L^*) = I_p \sin 2\theta \quad (3)$$

$$V = \left\langle |E_R|^2 \right\rangle - \left\langle |E_L|^2 \right\rangle \quad (4)$$

$$I_p = \sqrt{Q^2 + U^2} \quad (5)$$

where θ is the polarization angle and I_p is the polarized intensity. In this case, the system is optimized to simultaneously measure the linear polarized terms Q and U, that are obtained by correlating the two input fields. Alternatively, the receiver can use the linear polarizations E_x and E_y. In this case, however, Q is obtained as the difference between the two total power outputs $|E_x|^2 - |E_y|^2$, so providing bad stability performances.

Also, polarimeters can be either digital or analog, depending on whether the correlation is made via software or hardware, respectively. While the former directly detects the electric fields and digitally performs the correlation between them, the latter correlates the two polarizations at the RF (or IF) stage by a passive device and does the digitation only after the diode detection (see e.g. Comoretto & Natale, and Montebugnoli in these Proceedings). A generic architecture scheme is given in Fig. 1.

2. Medicina polarimeter

The polarimeter available at the Medicina Radioastronomical Station can be considered as a prototype for the Sardinia Radio Telescope (SRT). It consists of an analog unit correlating the two circular polarizations at intermediate frequency (500 MHz). To minimize interferen-

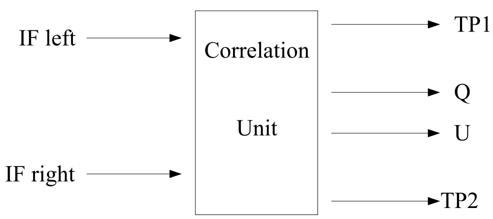

Fig. 1. Correlation polarimeter scheme.

ces, an 80-MHz filter centred at 350 MHz is used for both C- and X-band observations.

A new software has been developed to work as an interface between the polarimetric back-end and the field system, that controls the antenna. The software is aimed at allowing fast scans of the sky. It manages the commands to be sent to the field system to move the antenna according to the observing strategy. Also, it manages both the real-time acquisition of the polarimeter data up to a sampling rate of 40 Hz, and the association to pointing information. The latter allows us to assign the correct sky position to the observed data. The software is developed using Labwindows/CVI (by National Instruments), which can even use ANSI C routines. It is equipped with a graphical user interface that allows both real-time quick look monitoring and back-end setup. It is based on a client/server architecture, which allows the remote control.

Two observing modes are possible for both point-source observations and extended sky area mapping. The former consists of an ON-OFF strategy, where acquisitions on the source are followed by observations on a reference position away from the source itself (position switching). The mapping mode is realized by scans of the area to be imaged. It requires a full integration with the antenna control by synchronizing the data stream from the polarimeter with the antenna pointing information. The software has been designed in order to be operated by the field system using the standard scheduling procedure.

Calibration, data reduction and map-making software have been developed as well. Based on destriping techniques, it allows one to remove instabilities on time scales larger than the scan time, allowing effective realizations of sky maps (see Carretti et al. 2005 for an application).

3. Characterization

The polarimeter has been tested to determine the system performances by means of specific observations in both the X- (central frequency ν_0=8450 MHz) and C-band (ν_0=5070 MHz). This allowed us to measure:

- sensitivity of the Q and U channels;
- instrumental polarization (both on- and off-axis);
- pointing accuracy as a function of the scanning speed;

As a spin-off, information from our intensive use has allowed improvements to be made by the maintenance and development team of the antenna. Also, we achieved useful indications concerning the polarization performances for the development and design of the forthcoming SRT receivers.

The sensitivity has been measured using power spectra of observations of the North Celestial Pole. This has the advantage to allow long observations with no antenna motion, thus minimizing spillover, atmosphere and gain variations, while observing the same sky position. Table 1 summarizes the obtained values.

Table 1. Q and U sensitivities

Band	Q [mK $s^{1/2}$]	U [mK $s^{1/2}$]
C	5.4	5.4
X	5.0	5.0

The calibration of the system has been done observing the source 3C 286 (RA = $13^h31^m08\overset{s}{.}3$, Dec = $+30°30'32''$, J2000), which has well known polarization properties (e.g. Tabara & Inoue 1980). It has been observed during a wide range of parallactic angles using the position–switching observing

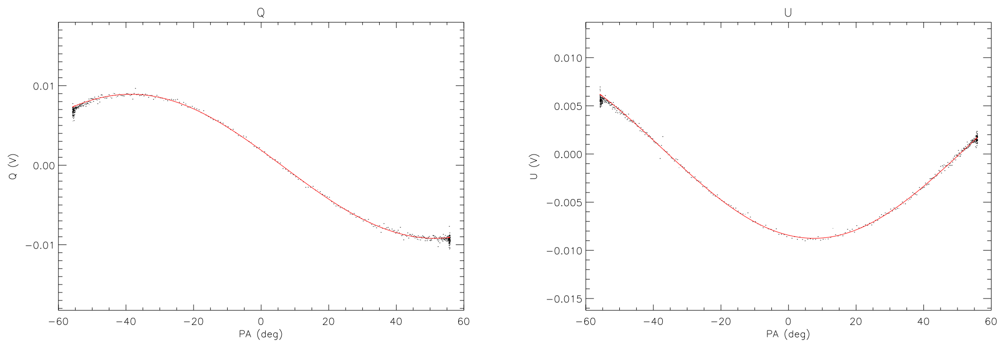

Fig. 2. C-band calibration observation of 3C 286. Left panel: Q(V); right panel: U(V).

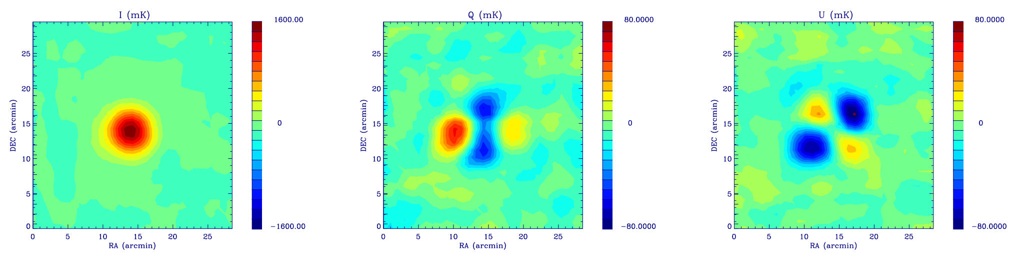

Fig. 3. 3C 84 as imaged by the X-band system. The source is unpolarized and the *Q* and *U* images provide a measure of the instrumental polarization. Pixel size and scan speed are Δ_{PIX}=1′ and 40″/s, respectively.

mode. Calibrations for the C-band are shown in Fig. 2. The polarization angle can be measured in the instrument reference frame with a precision down to σ=0°.6, which competes with the accuracy of the calibration reference values present in the literature (0.5–1°, e.g. Tabara & Inoue 1980).

The instrumental polarization has been measured through observations of unpolarized sources. Several maps of 3C 84 have been made at 5 and 8.4 GHz (e.g. Fig. 3) along both orthogonal directions RA and Dec.

For the C-band we derive an on-axis instrumental polarization of about 0.5%. Also, the off-axis instrumental polarization is limited to about 1%. The X-band features worse values. The on-axis instrumental polarization is about 2%, while off-axis one reaches the large value of ≈5%. This gives important indications for future receiver developments. The generation of such an effect is studied by Carretti et al. (2004), who found it to be given by a combination of co- and cross-polar patterns of the optics (mirrors and feed horn). Although the final level depends on both amplitude and phase of these patterns, it can be evaluated that optics with cross-polarization lower than −35 dB should ensure instrumental polarizations less than 1%. The on-axis instrumental polarization, instead, can be minimized using high-isolation orthomode transducers (> 40 dB) and well-balanced polarizers (differential attenuation between the two polarizations less than −20 dB).

4. Conclusions

Useful indications for a general purpose polarimetric facility at the SRT come from the experience matured in developing the Medicina device. In order to provide the SRT with a competitive polarimetric back-end, the receiver is required to ensure a low level of instrumental polarization: all astrophysical research would benefit from an instrumental polarization less than 1% both on- and off-axis. Although the final level depends on the design details, as a first indication we can say that this is achievable with: optics with cross-polarization less than −35 dB, polarizers with differential attenuation between the two polarizations within −20 dB, and Ortho-Mode Transducers (OMTs) with isolation better than 40 dB. To ensure high sensitivity, a band as wide as 1 GHz would be necessary, especially at the highest frequencies. A digital architecture would be preferable. This ensures a spectral investigation which allows us to carefully remove interferences, thus optimizing the useful bandwidth. In addition, a digital correlator can be shared with other back-ends (e.g. a spectrometer), reducing the hardware to be developed for the radio telescope (and the costs). Finally, a digital polarimeter, using programmable logics (Field Programmable Gate Arrays, FPGAs), allows future improvements by means of software upgrades.

As a final consideration, an important experience has been acquired by the technical/scientific team in developing the Medicina polarimeter. The knowledge matured in developing scanning strategies, in managing both antenna and data while performing fast sky scans, and in developing calibration and data reduction software, represents a solid basis for future SRT applications.

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