GALFACTS MEMO: # 12
Engineering Test of pDev Spectrometer Polarisation Properties

J. S. Dever, C. J. Salter

February 5, 2007

1 Introduction

As part of the first phase of the pDev spectrometer commissioning, the respective ALFA science groups were invited to take data with the spectrometer and report on their findings. The Galfacts group were particularly interested in the polarimetry behaviour of the instrument and therefore concentrated efforts on the derivation of initially calibrated Stokes parameters (I, Q, U, V) and polarisation properties (PI, PP, PA) for a small number of compact sources. This memo reports our procedures and findings as a result of these brief tests.

2 Measurements

These observations were intended to confirm the observational polarisation parameters of the spectrometer from a Galfacts perspective. The normal Galfacts meridian nodding scan mode was not suitable for these tests, so other methods were used. Three types of measurements were made:

A) High time resolution ($\sim 1ms$) with spectrometer-controlled winking low-cal, while tracking sources.

B) Tracking of a single source while rotating the ALFA receiver from –90 to 90° in 30° increments.

C) Low time resolution ($\sim 0.2s$) while doing CIMA-controlled cross scans, with a manual high-cal at the end of the run. Four polarised sources were measured in this manner, with one of them being observed twice.

Measurements of type A were taken to confirm the cal control and reporting behaviour of the spectrometer. Measurements of type B were made in case there was ambiguity in confirming the position angles, but this turned out to be unnecessary. For the purposes of the following analysis, only the measurements of type C are considered.

3 Calibration

One difficultity in dealing with the polarisation data is that the calibration must be done to a sufficient level before any sensible interpretation of the data can be made. The data taken was actually in quite a different format than that for the planned Galfacts all-sky survey, but were chosen to test spectrometer behaviour for polarimetry. This required some effort to develop software to the point where the existing calibration routines from the pre-cursor observations would be valid.

To clarify the details of the actual calibration performed on the test measurements, the processing steps performed on the data are described below. These steps were written into a C test program which is in part compiled from the existing Galfacts calibration program, code supplied for the pDev spectrometer and custom routines written while at AO.

0) The raw pDev files were read directly without using an intermediate format. Source code provided for the spcvt utility was used with minimal modifications to accomplish this.

1) The s_{0123} values from the pDev spectrometer differ slightly from those that the Galfacts precursor observations compute from the WAPP data. To preserve the existing calibration methods and subroutines, the s_{0123} values were converted into comparable auto/cross correlations using the following relations:

$$\begin{aligned} XX &= \tfrac{1}{2}s_0 \\ YY &= \tfrac{1}{2}s_1 \\ XY &= \tfrac{1}{2}(s_2 + s_3) \\ YX &= \tfrac{1}{2}(s_2 - s_3) \end{aligned}$$

2) The integrations where the manual high-cal was ON were averaged together to produce a spectrum. The same was done for a range where cal was OFF and these spectra subtracted to produce an average rawcal spectra. This measured cal spectrum was computed independently for each source.

3) Tcal spectra (calibration diode temperatures) from Desh's characterisation were produced for each sub-band at the channel width and center frequency for the pDev setup used for these tests.

4) Calibration into Stokes parameters was done using the Tcal spectra and the measured rawcal spectra for every measurement made during the test observations. Each of the two 170-MHz subbands was calibrated completely independently from seperate pDev data files.

5) The ON and OFF spectra were averaged independently with time for all four Stokes parameters, and then subtracted to produce spectra for each measured source.

6) Polarised Intensity (PI), Percentage Polarisation (PP) and Position Angle (PA) were computed for the

source spectra as follows:

$$
\begin{aligned}
PI &= \sqrt{Q^2 + U^2} \\
PP &= \frac{PI}{I} \times 100 \\
PA &= \tfrac{1}{2} \arctan\left(\frac{U}{Q}\right) - \textit{parallactic angle}
\end{aligned}
$$

7) Plots of all four Stokes parameters and the three derived polarisation properties were made on a single plot, both bands, for each of the 5 sources measured. These plots were then analysed and compared with catalogued values.

4 Source Selection

A number of compact, polarised sources were selected from the NRAO NVSS catalogue such that they lay within the area of sky which was available at the time when the test observations were scheduled. The selected sources all had percentage polarisations at 1.4 GHz (as listed in the NVSS catalogue) of $> 5\%$. During the observations, four of these were observed in the "slow dump" mode, three for a single cross scan, and the other (B0423+047) on two occasions separated by about 30 min. The sources and their parameters were;

Table 1: NVSS values for the selected sources

Source	RA(1950)	Dec(1950)	S(1.4 GHz)	PP	PA
B0349+262	034902.6	261521	1409	6.4%	76.1°
B0405+294	040517.4	292927	648	7.2%	–27.3°
B0423+047	042340.3	044342	1325	11.6%	–35.0°
B0518+165	051816.5	163527	9100	7.1%	–11.0°

(Where, S(1.4 GHz) is the flux density at 1.4 GHz, PP is the percentage polarisation, and PA is the position angle in degrees, all taken from the NVSS catalogue.)

5 Results

The Stokes parameters I, Q, U and V were estimated at the peaks of the sources. No correction was made for Stokes-I leakage into Stokes Q, U and V. To get an estimate of the Stokes-I leakage into Stokes V, the deflection in Stokes I and V were estimated at the peak of a source, and the V deflection expressed as a percentage of I. The mean value of this deflection was $2.1 \pm 0.3\%$. It is likely that the Stokes Q and U for the sources in the above list will be similarly affected by leakage of I into Q and U.

5.1 Measured Telescope Gain

The mean apparent telescope gain was measured to be $19.5 \pm 0.4\,K/Jy$. (One of the observation of B0423+047 was made at $ZA > 18.5°$, so this mean value is likely to be a little smaller than the actual value at lower zenith angles.) The mean value is close to double the expected ALFA Beam-0 gain. Hence, the processing of the data clearly has introduced a factor of two into the Stokes-I temperature calibration. This will be rectified before processing future data.

A plot of the measured total-intensity spectrum for B0423+047 is shown in Figure 1. All data, including RFI infected channels and the band edges, remain in this plot as blue dashed lines. This is overlaid by the best-fit intensity spectrum for the source derived from values in the literature. The two spectra are normalised to coincide at 1400 MHz. The agreement between the slopes of the best-fit and the measured spectra is pleasing, as is the agreement between the two half bands of the of the complete spectrum which overlap between 1350 and 1400 MHz

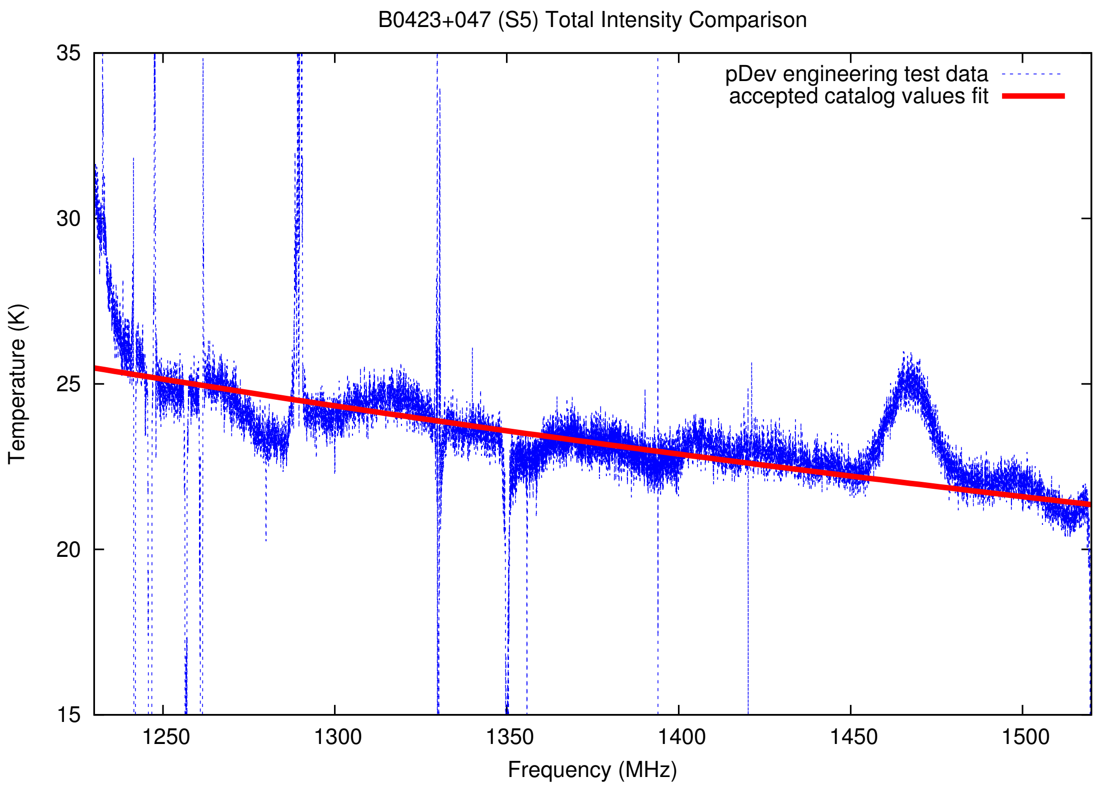

Figure 1: Total-intensity plot of the measured values overlaid with the best-fit spectrum to the catalogued flux densities between 74 and 5000 MHz for B0423+047. The best-fit spectrum is normalised to the data at 1400 MHz.

Table 2: Percent Polarisation Comparison

Source	PP(est.)	PP(NVSS)	PP(est.)/PP(NVSS)
B0349+262	7.0%	6.4%	1.09
B0405+294	7.9%	7.2%	1.10
B0423+047	14.65%	11.6%	1.265 (Two measurement average)
B0518+165	8.6%	7.1%	1.21

5.2 Measured Percentage Polarisations

The estimated percentage polarisations from our data were compared with those at 1.4 GHz from NVSS. These are given in Table 2.

The average percentage polarisation we measured divided by the percentage polarisation in the NVSS catalogue is 1.17 ± 0.05. This ratio is rather larger than the anticipated value of 1.0. A number of things could contribute to this. The NVSS survey acquired its data between 1340 and 1460 MHz (with a mean frequency of 1400 MHz), so sources with a large value of rotation measure (RM) would yield a lower-than-actual value of polarisation percentage. As an example, an RM of 66 $rad\, m^{-2}$ would result in a 30° position angle rotation between the two ends of the NVSS band. Only one of the 4 sources observed presently has a measured RM (B0518+165 with $RM = -2.1 \pm 0.7\, rad\, m^{-2}$).

A second uncertainty that affects the ALFA measurements is that no correction has been applied to our data for Stokes-I leakage into the Q and U channels. Further, no correction has been applied to the Arecibo data for Ricean bias, which will raise the apparent percentage polarisation, although for all our sources the system noise level is very much smaller than the polarised signal.

In short, it is not too surprising that the measured percentage polarisations come out to be some 17% higher than those expected.

5.3 Measured Position Angles

The estimation of polarisation position angles (PA's) for the sources observed was considered to be of especial importance in order to check that the signs of the Stokes Q and U components are correct (or not, as the case may be!) The source B0423+047 was measured on two occasions separated by 30 min to obtain a sizable swing in parallactic angle. This is imperative to check that all quantities are being combined correctly in determining the polarisation PA on the sky. The estimated PA's are listed in Table 3, along with the 1.4-GHz values from NVSS, and the difference between the two.

The calculated mean difference between our measured values of PA and those from the NVSS catalogue is $+42.8° \pm 0.7°$. This is pleasingly close to the expected value of +45° derived from consideration of the orientation of the feed probes in the OMT. At this stage, the apparent 3-σ offset from +45° is not considered to be significant.

Table 3: Position Angle Comparison

Source	PA(est.)	PA(NVSS)	PA(est.) - PP(NVSS)
B0349+262	–61.5°	+76.1°	+42.4°
B0405+294	–163.0°	–27.3°	+44.3°
B0423+047	+9.0°	–35.0°	+44.0° (Measurement 1)
B0423+047	+7.1°	–35.0°	+42.1° (Measurement 2)
B0518+165	–150.0°	–11.0°	+41.0°

5.4 Rotation Measures

Having a PA distribution with frequency across a 250-MHz bandwidth for the sources, we derived apparent RM values for the two objects with the largest polarised intensities. The value for B0518+165 came out to be $RM = -9.9\ rad\, m^{-2}$. The likely error in the derived RM is hard to quantify, but is likely to be at least $\pm 5\ rad\, m^{-2}$. This derived RM value compares satisfactorily with the value obtained by Tabara & Inoue (1980) of $-2.1 \pm 0.7\, rad\, m^{-2}$.

The source B0423+047 has no previously determined RM estimate. However, we estimate a value of $RM \sim +30\, rad\, m^{-2}$ for the object.

6 Conclusions

The purpose of these tests was to make a determination of the polarimetric behaviours of the pDev spectrometer. While keeping this focused goal in mind, the following statements can be made:

1) Calibration flags are being set correctly for when the cal is controlled by the spectrometer, as well as when the cal is controlled externally.

2) The Stokes precursor values produced by the spectrometer and the associated test mixers can indeed be calibrated and converted into sensible Stokes parameters.

3) The sign convention of all Stokes precursors (i.e. s_{0123}) appears to be correct. The finding that we can recover sensible position angles from the measurements and recover the projected dipole orientation on the sky of 45° supports this statement.

4) The calibration steps performed have a factor of 2 offset that will be rectified.