Cross Polarized Delay Calibration of Linear Feeds with XYDly and General Polarization Calibration

W. D. Cotton, April 18, 2025

***Abstract*—The usual technique for independent calibration of parallel–hand visibilities, RR & LL or XX & YY allows for an arbitrary offset in delay and phase between the two parallel systems. In order to use the cross–polarized visibilities, this offset must be determined and removed. For arrays with linearly polarized feeds, determining the X–Y phase and delay is relatively straightforward with some complications. The phase of the XY and YX correlations are a simple, if ambiguous, measure of the cross-hand phases and delays. The known EVPA and RM of calibrators can be used to resolve this ambiguity. The technique presented, XYDly, is successfully applied to some MeerKAT data. It is shown that there are parallactic angles for a given calibrator for which the XY and YX correlations are relatively insensitive to the linear polarization; such times should be avoided if the data are to be used for polarization calibration. XYDly is incorporated into a script, MKPolCalXY, for polarization calibration of low frequency arrays with linearly polarized feeds. A test using this procedure on a MeerKAT L band dataset shows good results; imaging of 3C286 gives linearly polarized values very close to those of [1].**

***Index Terms*—interferometry, polarization, calibration**

I. Introduction

Radio interferometry provides a powerful tool for probing the structure of the polarized emission from celestial sources. To utilize such observations, corrections must be applied for the effects of the independent, and imperfect, electronics as well as paths through the atmosphere that corrupt the data.

The traditional calibration technique for radio interferometric data has been to determine the calibration for the two parallel–hands of polarization separately. This requires some care with arrays with linearly polarized feeds; the parallel hand correlations "XX" and "YY" measure Stokes I plus $\pm$ a function of the calibrator linear polarization. As many calibrator sources are at least a few percent, and up to $\sim$10%, linearly polarized, the parallel–hand calibration may corrupt the polarization calibration.

Independent calibration of the parallel–hands has the disadvantage that it allows an arbitrary delay and phase offset between the two parallel systems. The phase, delay and gain offsets between the parallel–hands need to be determined and removed before the cross–polarized visibilities can be used for astronomical imaging.

"Polarization calibration" consists of two distinct components:

- **Instrumental calibration.** Antennas are generally outfitted with a pair of orthogonality polarized receptors, AKA "feeds" [1], with a nominal polarization, either circularly or linearly polarized. In practice, these are never perfect and these imperfections cause unpolarized emissions to appear to have a polarized component. The imperfections can be parameterized as "d" terms or the feeds can be characterized by the actual ellipticity and orientation of the signals to which they are sensitive. Obit uses the latter. Once the feeds are characterized, the data can be transformed to what would have been measured with perfect feeds.
- **Phase, delay and gain relations between the parallel hands.** Independent parallel–hand calibration allows for an arbitrary offset between the two parallel hand systems in gain, phase and delay (derivative of phase with frequency). If an unpolarized calibrator is available, it can be used to align the amplitudes of the gains of the parallel hand systems. This memo discusses measuring and correcting the phase and delay offsets for systems using linearly polarized feeds in the Obit package [2] [2]. A similar discussion for calibrating circularly polarized feeds is given in [3] and [4] and much of the discussion here follows that in these references.

II. Interferometric Polarimetry

Telescopes using heterodyne electronics as are commonly used in interferometers at radio wavelengths are sensitive to a single polarization state of the incoming wave. In order to fully sample the celestial signals, sets of electronics nominally sensitive to orthogonal polarizations are used. To sample the full state of the visibility measured with an interferometer, cross–correlations of all (4) combinations of the polarizations states are made on each baseline, or pair of antennas. Denote the various visibilities measured between antennas j and k and using detectors for polarization states p and q as v_{jk}^{pq}. Typically, either right and left–hand circular polarizations ("R", "L") or orthogonal linear polarizations ("X", "Y") are used in radio interoferometers.

In practice, the two polarizations measured are not precisely those desired but can be modeled by the desired state plus a complex value, called the "leakage" term, d_{jp} times the orthogonal state. Thus, the signal received by a detector on antenna j nominally in polarization state p is actually:

$$s'_{jp} = s_{jp} + d_{jp} s_{jq} \tag{1}$$

National Radio Astronomy Observatory, 520 Edgemont Rd., Charlottesville, VA, 22903 USA email: bcotton@nrao.edu

[1]These are called feeds rather than receptors as engineers always think of antennas as transmitters even when they're not.

[2]http://www.cv.nrao.edu/~bcotton/Obit.html

To first order, the interferometric response for an interferometer between antennas j and k using linear detectors of an unresolved source is [5]:

$$
\begin{aligned}
v_{XX} =& \frac{1}{2} g_{jX} g^*_{kX} (I + Q\cos 2\chi + U\sin 2\chi, \\
v_{XY} =& \frac{1}{2} g_{jX} g^*_{kY} [(d_{jX} + d^*_{kY}) I - Q\sin 2\chi + U\cos 2\chi + iV)], \\
v_{YX} =& \frac{1}{2} g_{jY} g^*_{kX} [(d_{YX} + d^*_{kX}) I - Q\sin 2\chi + U\cos 2\chi - iV)], \\
v_{YY} =& \frac{1}{2} g_{jY} g^*_{kY} (I - Q\cos 2\chi - U\sin 2\chi),
\end{aligned}
\quad (2)
$$

where g_{jp} is the complex gain of the electronics for polarization p on antenna j, "*" denotes the complex conjugate, I, Q, U, and V are the Stokes parameters of the source emission, i is $\sqrt{-1}$ and, χ is the parallactic angle given by:

$$
\chi \;=\; \tan^{-1}\Big(\frac{\cos\lambda\,\sin h}{\sin\lambda\,\cos\delta \;-\; \cos\lambda\,\sin\delta\,\cos h}\Big) \quad (3)
$$

where δ is the source declination, λ is the latitude of the antenna and h is the hour angle of the source. For linearly polarized detectors with detectors rotated from the local horizontal and vertical, this rotation needs to be added to the value of χ given above. Characterizing the feeds interms of their ellipticities and orientations is equivalent to using the "d" terms and has the advantage that the orientations can, in principle, be measured with a plumb bob and protractor.

To simplify the notation in the following, we assume nearly identical parallactic angles at all antennas at a given time. In the Obit usage for antennas with H (horizontal) and V (Vertical) feeds, "X" corresponds to H and "Y" to V. This differs from the usage in AIPS and CASA. For more details on the response of an interferometer to a partially polarized signal see [5].

III. Hardware Calibration

Some interferometer arrays such as ATCA and MeerKAT use a noise diode signal to calibrate the cross–hand differences downstream of the point at which this signal is injected. For MeerKAT, this is after the Orthomode Transducers (OMTs) which have their own, but stable, contributions to the X-Y delay offsets. If the X-Y phase spectrum derived from this calibration signal is applied to the data before any other phase–like calibration, the bulk of the instrumental X-Y phase spectrum is removed from the data. The remainder is generally stable and may not need to be determined for each dataset.

IV. Independent Parallel Hand Calibration

For a given baseline, $j - k$, the measured correlations ($v^{pp\_obs}_{jk}$) are related to the calibrated visibilities ($v^{pp\_cal}_{jk}$) by:

$$
v^{pp\_cal}_{jk} \;=\; v^{pp\_obs}_{jk}\; g^p_j\; g^{p*}_k \quad (4)
$$

where g^p_j is given by:

$$
g^p_j \;=\; a^p_j\; e^{-2\pi i(\Delta\tau^p_j \nu) - \phi^p_j},
$$

and a^p_j is the amplitude correction, $\Delta\tau^p_j$ the delay residual from the correlator model, ϕ^p_j the model phase residual, and ν the observing frequency. Calibration parameters a^p_j, $\Delta\tau^p_j$ and $\phi^p_j p$ can be determined from observations of (calibrator) sources of known brightness, structure and position. Calibration quantities are generally a function of time.

This system of equations is degenerate in that only differences in $\Delta\tau^p_j$ and ϕ^p_j are actually measured. The system is generally made determinate by assigning the values of a "reference antenna" to zero. Thus, all phase–like quantities are determined relative to the reference antenna leaving only the relationship between the two hands of polarization at the reference antenna undetermined.

A. *Constraints on Parallel–Hand Calibration for Polarization*

If polarization calibration is to be used, this puts some constraints on the parallel–hand calibration. As can be seen from Equation 2, the parallel hands respond to Stokes I $\pm$ a (time variable) function of Q, U and χ. If a strong, unpolarized source is available, it can be used to align the X and Y gains by means of an amplitude and phase bandpss calibration for each XX and YY. Any subsequent gain calibration using a potentially linearly polarized source must average the XX and YY correlations before determining the solutions; this will cancel the contribution from linear polarization.

V. Residual Cross–hand Delay/Phase Offset

Independent calibration of the parallel–hand systems allows for a difference between $\Delta\tau^p_r$ and $\Delta\tau^q_r$ as well as between ϕ^p_r and ϕ^q_r where r denotes the reference antenna. Denote these differences as $\Delta\tau^{pq}_r$ and ϕ^{pq}_r. Note: if the observing bandwidth is divided into multiple "spectral windows" with at least partially independent electronics and signal paths, the calibration parameters may vary between sub-windows. The relation per spectral window between parallel–hand calibrated data ($v^{pq\_cal}_{jk}$) and cross–hand calibrated data ($v^{pq\_xcal}_{jk}$) is:

$$
v^{pq\_xcal}_{jk} \;=\; v^{pq\_cal}_{jk} e^{-2\pi i \Delta\tau^{pq}_r \nu - \phi^{pq}_r}. \quad (5)
$$

Note: there is a single pair of values per spectral window, $\Delta\tau^{pq}_r$ and ϕ^{pq}_r needed to calibrate the cross–polarized visibilities. Averaged cross-polarized spectra of MeerKAT calibrator data with parallel–hand but not cross–hand calibration applied, as well as instrumental polarization calibration, is shown in Figure 1.

VI. A Method of Determining the Cross–hand Offset

While there are but two parameters to be determined per spectral window, there are a number of complications. The most serious of these is spurious instrumental polarization (d_{jp}) in Eq. 2. which can contribute a significant fraction of the strength of the source polarization to the cross–polarized visibilities. This spurious instrumental polarization is independent of source polarization and can vary strongly with frequency and baseline. In Obit instrumental polarization is done using task PCal which is not described in detail here.

A second complication is for arrays with alt-az mounts for which the antenna rotates with parallactic angle (χ) as

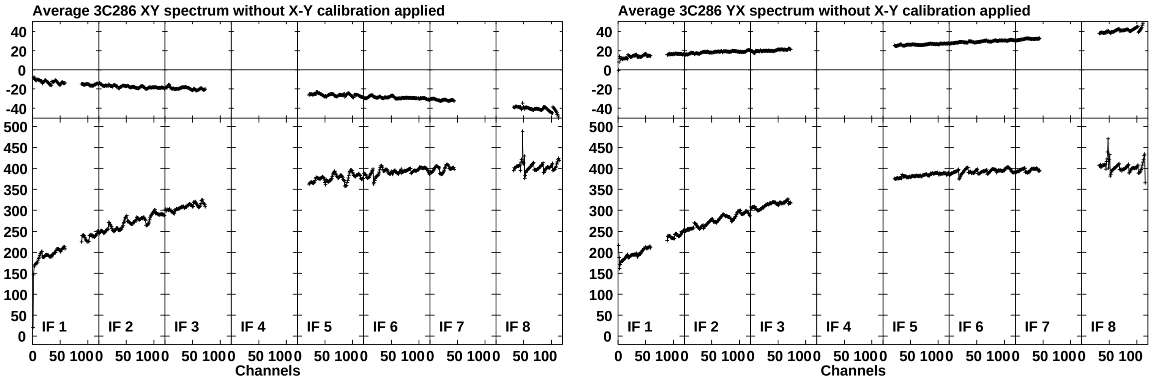

Fig. 1. Sample MeerKAT cross–hand visibility spectra for 3C286 averaged over all baselines and time in a 10 minute scan. Parallel–hand, "noise diode" and instrumental polarization ("d term") calibration has been applied but not the residual delay and phase differences between the X and Y systems. The upper plot in each panel gives the phase and the lower, the amplitude. Note the drift of cross–polarized phase with frequency indicating a residual delay offset. The decreasing amplitude with decreasing frequency is the result of depolarization in the source.

seen by the source (Eq. 3). As can be seen from Eq. 2, after calibration, the cross–polarized correlations have a real part that is a function of Q, U and χ and an imaginary part that is $\pm$ Stokes V. For alt-az mounts, χ is a function of time. If Stokes V is assumed to be 0, the X-Y phase spectrum is $\pm$ the phase of the XY and YX correlation spectra. However, the phase correction is ambigious as the real part of the correlations can change sign and go through zero. An example of this is shown later in Figure 3. If data is only available near the zero crossing, it may not be useful for calibration. The ambiguity in the solution must be resolved.

A further complication is the case in which the source has significantly resolved polarized structure. In this case, the source component of the cross–polarized response will vary with time, frequency and baseline.

A. Linearly Polarized Detectors

The case of interferometers, such as ALMA or MeerKAT, whose elements are sensitive to linear polarization is relatively simple. As can be see from Eq. 2, the source polarization component of the cross–hand visibility spectrum is:

$$\begin{aligned} v_{jk}^{XY\_cal} &\approx (-Q\sin 2\chi + U\cos 2\chi + iV)e^{+2\pi i(\Delta\tau_r^{pq}\nu)+\phi_r^{pq}} \\ v_{jk}^{YX\_cal} &\approx (-Q\sin 2\chi + U\cos 2\chi - iV)e^{-2\pi i(\Delta\tau_r^{pq}\nu)-\phi_r^{pq}}. \end{aligned} \tag{6}$$

Stokes V for most sources is very small and can be ignored. However, the linearly polarized component is a more complex function of parallactic angle.

The averaged XY and YX spectra can be used to determine the residual X-Y phase and delay difference and the SNR. The phase and delay correction solutions are ambigious depending on the sign of the real part of the XY and YX correlations. As the SNR in each visibility measurement is generally too small to determine the sign without much averaging, another method is needed to resolve the ambiguity.

The Electric Vector Polarization Angle (EVPA or "polarization angle") and the rotation measure (RM) are generally known more precisely for polarized calibrators than the linearly polarized intensity and can be used to determine which ambiguity to select. From the calibrator EVPA and RM, the polarization angle in each channel can be derived and a "pseudo Q" and "pseudo U" can be derived which would give the same polarization angle (PA) as the actual data as is shown in the following pseudo code snippets:

$$PA \;=\; 0.5 * \mathrm{atan2}(\mathrm{PseudoU}, \mathrm{PseudoQ})$$

. For channel i, pseudo Q and U values can be obtained by

```
PA[i] = mod(PA[i], 2*pi)
if      (PA[i]<=0.5*pi)  PseudoU[i] = +1.0
else if (PA[i]<=pi)      PseudoU[i] = -1.0
else if (PA[i]<=0.75*pi) PseudoU[i] = +1.0
else                     PseudoU[i] = -1.0
PseudoQ[i] = PseudoU[i] / (tan(2.0*PA[i]))
```

The choice of which solution to take (sign flips of the real and imaginary parts of the measured correlations) depends on the time dependent parallactic angle, chi;

```
linP = -PseudoQ[i]*sin(2*chi)+
        PseudoU[i]*cos(2*chi)
// For XY
if (linP>0) {
    vis.re = -vis.re;  vis.im = +vis.im
} else {
    vis.re = +vis.re;  vis.im = -vis.im
}
// For YX
if (linP>0) {
    vis.re = -vis.re;  vis.im = -vis.im
} else {
    vis.re = +vis.re;  vis.im = +vis.im
}
```

VII. XYDly: An Obit Implementation

In order to derive the cross–hand delay and phase for each Spectral Window and solution interval, a weighted sum of the data in each (possibly averaged) spectral channel is made for the XY and YX correlations. The sums use the data weights derived in the parallel–hand calibration and the signs of the visibillity components are adjusted as described above. If after summing over time and baseline, the real part is still negative, the weighted sum of the visibilities is adjusted.

The actual fitting is done by a direct parameter search in delay using all the channels in each spectral window and both XY and YX sums. A series of searches is performed with decreasing step sizes. The unwrapped amplitude of the summed visibilities is used to pick the optimum delay. The test amplitude for a given test delay (τ) is

$$t \ = \Big| \sum_{i=0}^{n} (vis_i \times e^{(2\pi j \ \tau \times i)} * wt_i) \Big| / \sum_{i=0}^{n} (wt_i)$$

where the summation is over channel and correlation product, vis_i is the summed visibility for a given channel/correlation product, wt_i the corresponding weight, τ is the test delay in turns per channel and j is $\sqrt{-1}$. The $\Delta\tau_r^{pq}$ value is the test delay (expressed in seconds) which gives the maximum test amplitude.

The phase (ϕ_r^{pq}) is the unwrapped phase evaluated at the Spectral Window reference frequency. The SNR of the solution is derived from the RMS residual of the channel/correlation product post fit residual phases:

$$SNR \ = \ (RMS_{residphase})^{-1}.$$

This technique has been implemented in the Obit[2] package with the fitting done in the routine ObitUVXYDelay implemented in task XYDly.

Data may be selected by source, antenna, time range, and UV range. Values of the Electric Vector Polarization angle (EVPA) and rotation measure (RM) of each calibrator may (i.e. should) be specified. After fitting $\Delta\tau_r^{pq}$ and ϕ_r^{pq} in each Spectral Window, an AIPS SN table is written which can be applied to an AIPS CL table using Obit task CLCal. The fitted quantities are written as the second polarization in each AIPS SN table record where i is the Spectral Window ("IF") index:

```
row->Real2[i]   =  cos(phase[i]);
row->Imag2[i]   = -sin(phase[i]);
row->Delay2[i]  = -delay[i];
```

A single, identical record is written for each antenna per solution interval.

VIII. Testing

The calibration data from a MeerKAT observation was used to test this technique; these data are shown in Figure 1 prior to cross–hand phase and delay calibration. The data were at L band ($\sim$850 – $\sim$1650 MHz) with 8 second integrations; recorded all four combinations of the 2 linearly polarized feeds. After parallel–hand calibration, the data were divided into 8 Spectral Windows of 119 channels each. Unpolarized calibrators 0408-65 and 1934-638 were used in PCal to determne the instrumental polarization parameters and 3C138 and 3C286 were known polarized calibrators used jointly in XYDly to derive the cross-hand phase and delay corrections. The data after applying parallel hand and instrumental polarization corrections were averaged in blocks of 8 channels and 2 minutes in time and combined in a single solution interval. Applying the derived calibration and averaging over baseline and the 10 minutes of the scan on 3C286 gives the results in Figure 2. The residual phases show a small scatter around zero indicating a very weak (if any) Stokes V contribution.

Another observation which involved repeated observations of 3C138 was used to explore the effects of parallactic angle on the XY and YX correlations. The instrumental calibration for this data was based on 0408-65 and the cross-hand calibration used a single solution in XYDly over all times in the dataset. The success of this calibration shows the need for and validity of the adjustment of visibility phases described in Section VI-A as the real part of the XY (or YX) correlation have both positive and negative signs. The real part of the XY correlation for a single channel averaged over baseline and 30 seconds is shown in Figure 3. Had 3C138 only been observed near the zero crossing, the delay and phase calibration would not be robust.

IX. Polarization Calibration Of Linearly Polarized Feeds

XYDly is but one component of the overall polarization calibration of interferometer data with linearly polarized feeds. The overall process of polarization is discussed in the following.

A. *MK_PolCal_XY.py*

Since XYDly is part of a sequence of calibration steps, it is useful to incorporate it into a polarization calibration script. Such a script is $OBIT/share/scripts/MK_PolCal_XY.py which, while explicitedly targeted toward MeerKAT L Band observations, can be adapted to other circumstances involving arrays using linearly polarized feeds. This script has the following functions

- **Clip** calibrator data with excessive amplitudes using AutoFlag.
- **Phase calibrate** calibrators with point model using Calib/CLCal.
- **PCal** for instrumental calibration.
- **XYDly** for X-Y phase and delay calibration.
- **CLCal** to apply the XYDly solution to CL table.

This script recognizes a number of calibrators, thru several aliases, for which it knows the relevant calibration parameters. Unrecognized calibrators will be included in the estimation of the instrumental polarization parameters in PCal while fitting for any potential polarized component. This feature is useful for calibrators (i.e. gain calibrators) that are observed over a range of parallactic angle which allows separating instrumental and source polarization. Documentation for this script is given in Figure 4.

B. *Test Calibration*

MKPolCal was tested in a particularly well calibrated MeerKAT L Band observation of the Galaxy IC 4296 [6]. This dataset had 0408-65 and 1934-638 as unpolarized and 3C138 and 3C286 as polarized calibrators. The gain calibrator, unknown polarization, was J1323-4452. The procedure described in Section IX-A was applied and the calibrators imaged in Stokes I, Q, U and V.

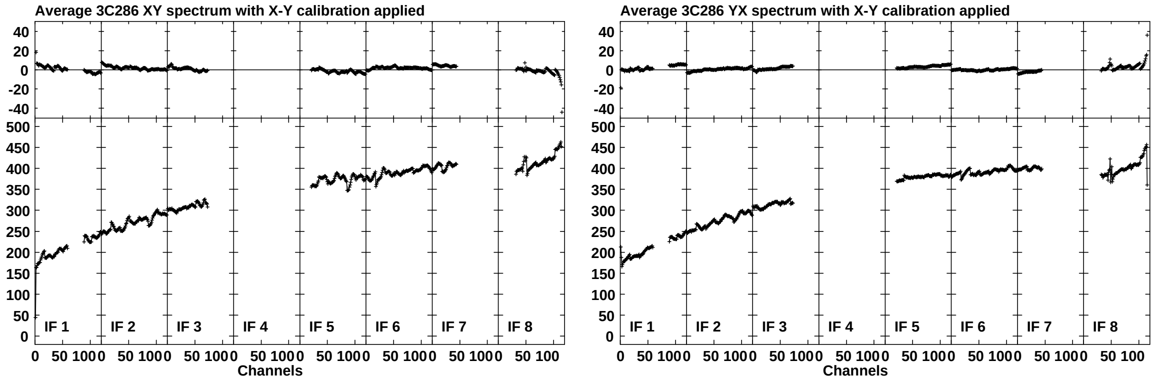

Fig. 2. Data shown in Figure 1 but with the X–Y delay and phase offsets applied. A combination of the strongly polarized sources 3C286 (data shown) and 3C138 were used used for the calibration.

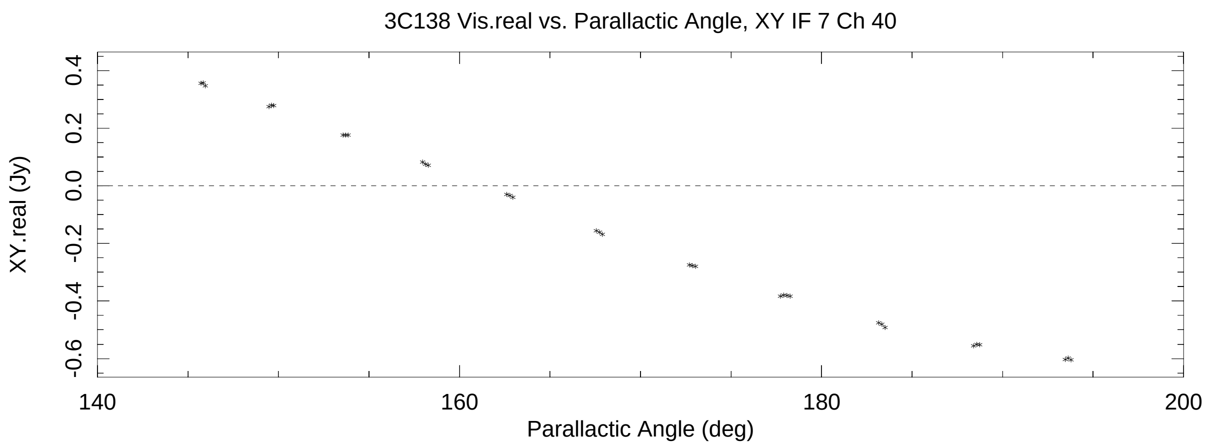

Fig. 3. Baseline and 30 second average values of the real part of the XY correlation of 3C138 for one spectral channel as a function of parallactic angle. The dashed line is at 0.

1) Linear Polarization: The success of the calibration was evaluated using rotation measure fitting and plots of the peak in each calibrator shown in Figure 5. As expected, the "unpolarized" calibrators show very low fractional polarization but enough coherence in the EVPA plots that they should be considered very low polarization rather than completely depolarized. The two "known polarized sources" show EVPAs closely scattered around the fitted RM line; 3C286 values are very close to the well measured, recent values of [1]. 3C138 has undergone a major outburst and its polarization appears to have changed since the measurements cited by [7]. Note the EVPAs of these standard polarization calibrators were not used to fit the solutions beyond resolving ambiguities in the solution (Sect VI-A); the absolute values depend on the nominal orientations of the feeds. The gain calibrator is only about 0.1% polarized but still shows relatively consistent EVPA.

2) Circular Polarization: The circular polarization for synchrotron emitting sources such as these is generally very low, 0.5% is strongly polarized and this emission is generally thought to be the conversion of linear to circular by transmission throught the material near the source. The peak circular polarization resulting from the imaging decribed in the previous section, essentially upper limit, is given in Table I.

TABLE I
Calibrator Fractional Stokes V

Source	I Jy/bm	Peak frac. cir. pol %
0408-65	16.07	0.028
1934-638	14.68	0.062
3C286	15.87	0.11
3C138	8.06	0.18
J1323-4452	3.29	0.055

For the weakly linearly polarized sources this limit is quite small, less that 0.1%. It is of the order of 0.1% for the strongly polarized sources. Equation 2 shows that any errors in the determination of the X-Y phase will rotate some linear polarization into apparent circular. This has likely happened to 3C286 and 3C138. Tighter limits on circular polarization likely need more careful, and frequent calibration of the X–Y phase.

3) Additional Polarization Calibrators: Good standard polarization calibrators are rare in the Southern sky. An addi-

```
MKPolCalXY(uv, cals, err, refAnt=59, nthreads=1, doCalib=True,
        doClip=False, doPCal=True, doXYDly=True, ChWid=17,
        timeAvg=2.0, chAvg=8, solInt=1440, fitType=0, debug=False,
        noScrat=[0, 0, 0])
    Polarization calibrate a MeerKAT dataset using PCal and XYDly

    A list of "standard" calibrators has known MeerKAT L band values.
    Log file given in file 'PolnCal_'+uv.[AF]name.strip()+'.log'
    * uv       = Python Obit UV object, AIPS or FITS
    * cals     = list of calibrator source names, recognizes known calibrators:
                 unpolarized: 1934-638, J1939-6342, 0408-65,
                 Polarized: 3C138, J0521+1638, 3C286, J1130-4049, J2329-4730
                 Others will be included in PCal as sources with joint
                 source & instrumental polarization.
    * err      = Python Obit Error/message stack
    * refAnt   = the reference antenna used for parallel hand calibration
                 NB: this is NOT used as the reference antenna in PCal.
    * nthreads = the number of threads to be used in calculations
    * doClip   = If True, clip excessively high values in data.
    * doCalib  = If True, do point source calibration for sources in
                 cals writing a new CL table
    * doPCal   = If True, run PCal
    * doXYDly  = If True, run XYDly
    * ChWid    = width of block of channels for PCal
    * timeAvg  = Data Averaging time (min) for PCal, XYDly
    * chAvg    = Number of channels to average in XYDly
    * solInt   = Solution interval for XYDly
    * fitType  = fitting type in XYDly, 0=>both, 1=>XY, 2=>YX
    * debug    = if True, save input files
    * noScrat  = List of AIPS disks to avoid for scratch files
```

Fig. 4. Interface documentation for function MKPolCalXY.

tional 2-4% fractional calibrator in L Band, J1130-1449, has been added to MKPolCalXY based on the combination of multiple observations and is shown in Figure 6.

X. Calibration Without a Known Polarized Calibrator

Good standard polarized calibrators are rare enough that it is not always possible to include one in an observation, especially one of short duration. Archival data of interest may also have been observed without a suitable polarized calibrator. If the observation in question has a strong, unpolarized calibrator - ususlly possible at low frequencies - the instrumental polarization calibration can still be carried out using script MKPolCalXY with option doXYDly=False. This will derive an AIPS PD table for that observation.

The remaining calibration needed is the X-Y phase function. The most variable parts of this can be removed by applying a calibration derived from the Noise Diode calibration (see [8]) BEFORE ANY OTHER CALIBRATION. The residual from this calibration depends on the Ortho Mode Transducer (OMT) on the reference antenna used and is relatively stable in time; residual calibration derived from other data can be used to complete the calibration.

The X-Y phase and delay calibration in script MKPolCalXY produces an AIPS SN table which can be copied to another dataset and applied to an AIPS CL table to complete the calibration. The older scheme described in [8] uses an AIPS BP (bandpass) table to the same end. The relevant calibration tables are in files in $OBIT/share/data. Calibration tables derived from the average of multiple datasets prior to 2023 are MKMedAvg59.PolCalTab.uvtab.gz and MKMedAvg61.PolCalTab.uvtab.gz. The “59” and “61” indicate AIPS reference antenna numbers 59 and 61 corresponding to antennas m058 and m060. As of 2023, the relevant tables are in MKMedAvg59_2023.PolCalTab.uvtab.gz and MKMedAvg60_2023.PolCalTab.uvtab.gz with AIPS reference antennas 59 and 60 (m058, m059). BP (and PD if needed) tables version 1 should be copied to the data to be calibrated and applied.

File MKMedAvg_m058_2025.PolCalTab.uvtab.gz in the $OBIT/share/data/ directory contains the PD and SN tables derived from the average of a number of datasets calibrated with reference antenna 59 (AIPS 59 = m058). The SN table should be applied to a CL table with *****clcal.refAnt=-1***** to keep the solutions from being rereferenced - thus all set to zero.

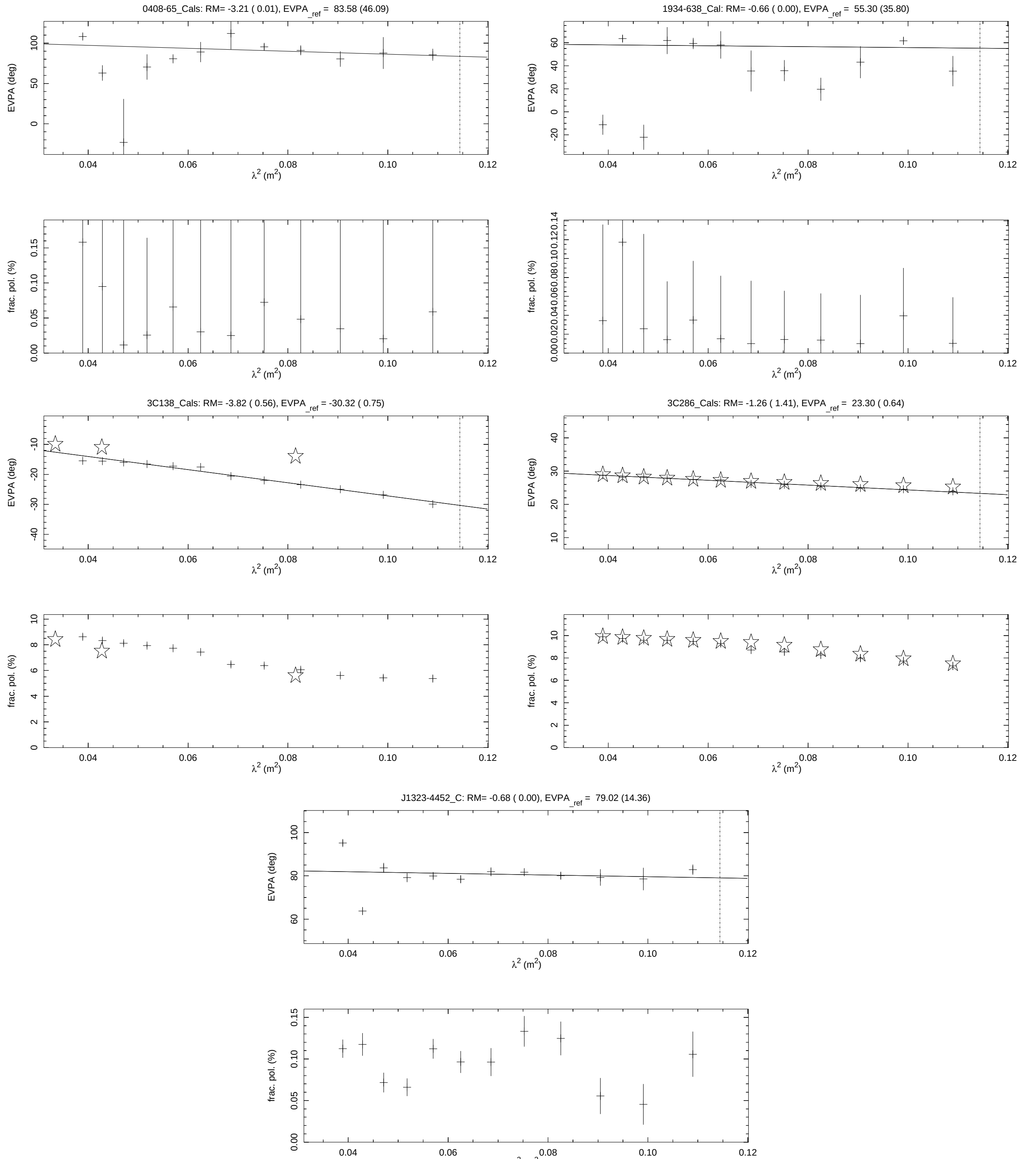

Fig. 5. EVPA (upper panel) and fractional polarization (lower panel) as a function of λ^2 with a fit to the rotation measure for various calibrators. The solid line is the fitted rotation measure with parameters given in the title bar. The vertical dashed line shows the λ^2 of the reference frequency. Top row has unpolarized calibrators, the middle row shows the known polarized calibrators and the bottom is the gain calibrator. Open stars represent values from [1] (3C286) or [7] (3C138). Note 3C138 has undergone a major outburst since [7].

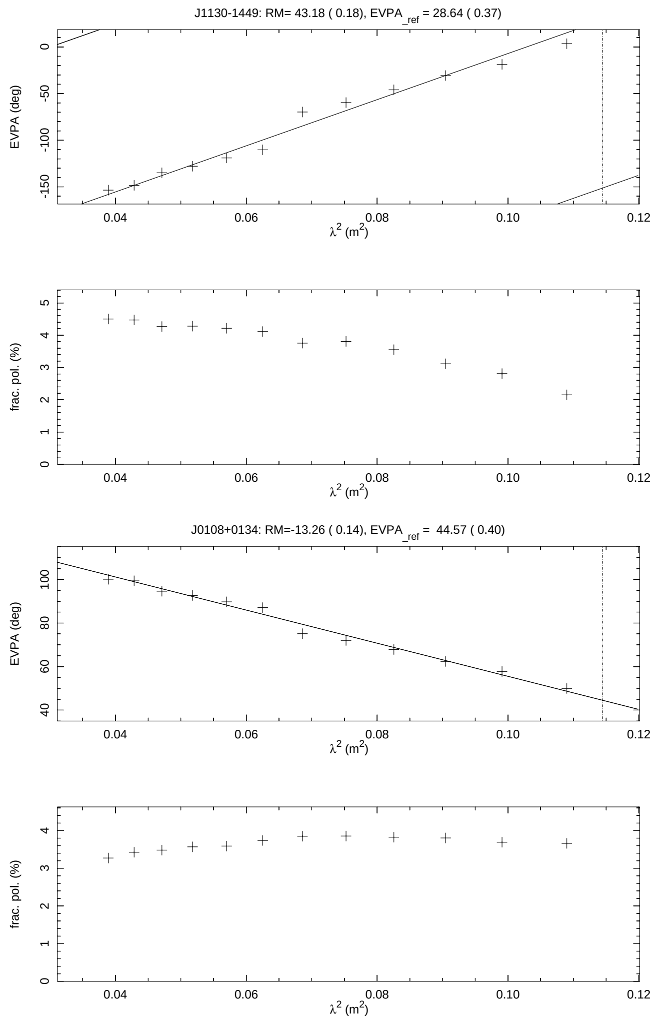

Fig. 6. Like plots in Figure 5 but for J1130-1449 (upper) and J0108+0134 (lower).

XI. Discussion

A relatively general and robust method for fitting cross–polarized delays and phases for arrays with linearly polarized feeds is presented and tested using MeerKAT data. The method is based on the fact that the real part of XY and YX correlations is the same functon of Stokes Q, U and parallactic angle whereas the imaginary is ±Stokes V. The phase of the XY and YX correlations are a simple, if ambigious, measure of the cross-hand phases and delays. A method for resolving this ambiguity based on the known EVPA and RM values of calibrators is presented. The technique is applied to MeerKAT data and the results shown. The phase slope in the cross–polarized spectra due to the difference in the parallel–hand delays is essentially removed. The technique presented here is available for use in the Obit package as task XYDly. It is worth noting that for a given polarized calibrator, there are parallactic angles for which the XY and YX correlations are relatively insensitive to the linear polarization compromising their use in polarization calibration.

A general polarization calibration scheme for calibrating low frequency arrays with linearly polarized feeds incorporating XYDly is given in a python script, MKPolCalXY. This script is used to polarization calibrate a MeerKAT L Band data set; the resulting images of the polarized sources are consistent with the fitted rotation measure and for 3C286, very close to the values of [1]. Residual circular polarization of the calibrators is quite low.

References

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