VLBA Test Memo 73

VME Transition VLBA Pointing Issues

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July. 2021

Abstract This memo serves describes the transition away from the Motorola Versa Module Europa (MVME) 147 single board station computers, to a VLBA Executor control system, and the resulting issues affecting pointing throughout 2019.

1 Background

The MVME 147 single board computer, acting as VLBA station computers, was developed by Motorola and first available in 1996 and has since been discontinued. Given the difficulty finding parts a decision was made in 2008 to replace the telescope control computers at all sites with standard linux machines running a version of the VLA Executor adapted for the VLBA (Internal Memo, 2008). In part the decision to use a version of the VLA executor was made to simplify the maintenance of software, rather than maintaining two separate systems. The transitions at sites were staggered, with deployments between August 2018 and October 2019 (see Table 1).

Station	Date of Transition
KP	2018-08-08
HN	by 2018-12-31
BR	by 2019-02-04
NL	by 2019-02-11
LA	by 2019-03-25
FD	2019-06-05
OV	2019-06-10
SC	2019-08-29
MK	2019-10-16
PT	2019-10-30

Table 1: Date of transition from VME to Executor control for each station.

There are differences between how the VLA Executor handles telescope pointing and how the VLBA antenna control units (ACUs) expect data, requiring a separate VLBA version of the Executor software. Some of those differences, along with implementation difficulties resulted in issues affecting the pointing of the antennas, and thus data quality. Major issues and resulting effects on the data are presented here in Section 2

2 Issues

2.1 Database transition from VME system to Executor control

The pointing parameter database had to be transitioned to a new database (vlbaparm) as the Executor expects these data in a different format than the VME systems. During this transition several sign errors in pointing colimation offsets were introduced summarised in Table 2.

In addition the East-West sag term in the pointing equation for each telescope is swapped in sign between the VME and Executor system. The error cause by this is thought to be quite small and was fixed by October 2019.

Station	Band	Start Date	End Date	Error	Amplitude Error
OV	2cm	2019-09-09	2019-09-10	AZ 7.0'	100 %
SC	2cm	2019-09-09	2019-09-13	AZ 0.34'	4 %
LA	4cm	2019-09-09	2019-10-16	EL 5.4'	97%
PT	2cm	2019-10-10	2019-11-01	AZ 1.3'	47 %
PT	20cm	2019-10-30	2019-11-07	AZ 0.83'	0.03 %

Table 2: Sign errors introduced during transition from VME system and resulting approximate amplitude error (percentage) introduced.

2.2 Focus Position

The VLBA corrects the focus position for each observation band, as well as a smaller correction for elevation throughout each observation. There are two major differences in how the VME system stored and interpreted these corrections compared to the Executor:

1. The VME system stores each band correction with a 'zero point' at Elevation 0°and adds a correction with increasing elevation. In contrast the VLA (and hence VLBA) Executor stores each band correction with its 'zero point' at Elevation 90°and subtracts a correction with decreasing elevation. See Figure 1 for a visual representation. When the VME focus corrections database was imported to the Executor database this 'zero point' position was not corrected for the difference in interpretation. This causes a focus error equal to the difference in focus position at elevation 0°and 90°. These focus errors (and resulting amplitude errors introduced) only apply at wavelengths of 2 cm and shorter (lower frequencies do not require an elevation correction) and the correction is of form $F(el) = F(0) + 0.65Sin(el)$, so the 'zero point' ($F(0)$) for each band was out by 0.65 cm. Resulting errors for each band are shown in Table 3. Note these are estimates based on measurements taking from VLBA Test Memo 67 and may be slightly overestimated. Zero positions were corrected on the 25th of September 2019, so telescopes will have been affected from their transition date to September 25 2019.

2. The correction for elevation (not for band) int the VME system was stored in units of mm and the Executor expects units of cm. This resulted in elevation dependent focus corrections being too small by a factor of 10. This error however is negligible compared to the error described in 1.

Band	Amplitude Error
2cm	12 %
1cm	60 %
7mm	100 %
3mm	100 %

Table 3: Amplitude loss due to a 0.65 cm error in focus position due to incorrect 'zero position'. These were calculated based on measurements in VLBA Test Memo 67 and may be slightly overestimated.

2.3 Reference Pointing Offset

Both 3 mm and 7 mm observation frequently make use of reference pointing, where pointing is peaked on a strong source near the target. 3 mm observations are usually referenced at 7mm given the difficulty finding strong 3 mm sources. To find the offsets in pointing the VLBA observes a 'Craig's cross' (Figure 2).

A new upgrade allowed by the swap to the Executor makes observing this pointing pattern take a dynamic amount of time: waiting until three points of unflagged total power data are observed at each pointing position. This however makes the total time per pointing pattern unknown. Therefore we schedule

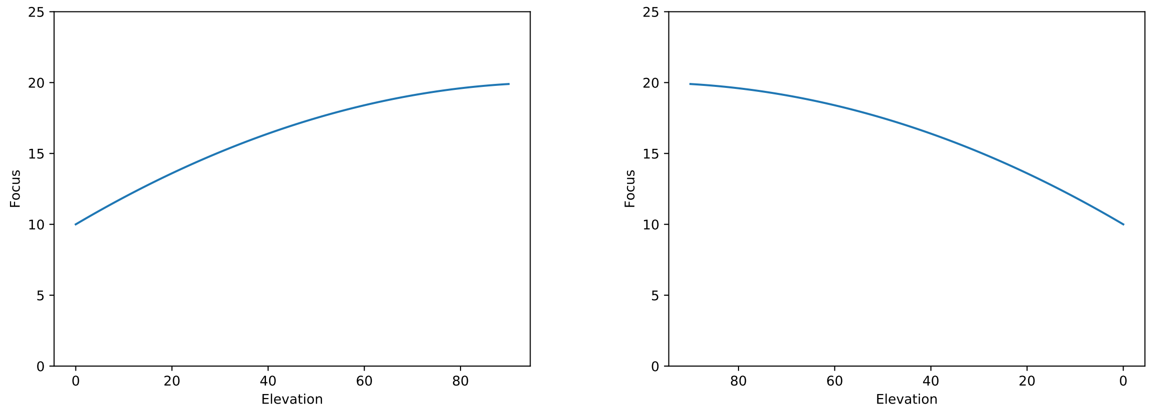

Figure 1: Focus corrections for the same band as the VME system interprets them (left) and as the Executor interprets them (right). Note the X-axis is inverted. The correction (Y-axis) and shape here are illustrative only. In this example the difference in interpretation would produce a focus error of 10 units.

sufficient for x pointing patterns plus a little extra. The last pattern is thus likely to be interrupted before completion. Unfortunately a bug in the Executor caused the offset required to reach the final interrupted pointing position in the pattern to be applied to the next scan. For example if the pattern is interrupted at position 22, the next scan will observe position 22 with respect to the new source. Given eight out of the ten positions are at half power or worse that gives a roughly 80 % chance of not being on source for the following scan. This bug was corrected in the Executor March 11 2020.

2.4 Degradation of pointing performance

The overall pointing accuracy also diminished during this time, especially at high frequencies due to several reasons:

- Lack of staff meant the pointing model had not been closely watched for some time.
- Focus measurements could not initially be made with the new system. This is now possible
- Rotation measurements could not be made with the new system. This in ongoing development.
- It was not possible to search for a source that was not in the beam with the Executor system. A 'raster pattern' mode was implemented allowing 3 mm colimation offsets to be updated (at least enough to bring sources within the beam). This was mitigated somewhat as attempts were made to peak up the 3 mm colimation prior to each switch over - although these were not succesful in each case.
- Initial pointing patterns did not allow enough time per pointing position to get sufficient unflagged data for nice fits.
- Issues with synthesizers made getting unflagged data challenging even after dynamic pointing positions were implemented.
- Line pointing sources were not correctly subtracting the background noise. This reduced signal to noise for these sources dramatically, reducing the number of sources available for pointing updates.

It is difficult to quantify the total effect the above issues had on data quality, however qualitatively issues are expected to have caused errors at the 10 % or less level at 2 cm and longer. The VLBA fiber project is prompting some very exciting upgrades to VLBA pointing, allowing for interferometric pointing. This

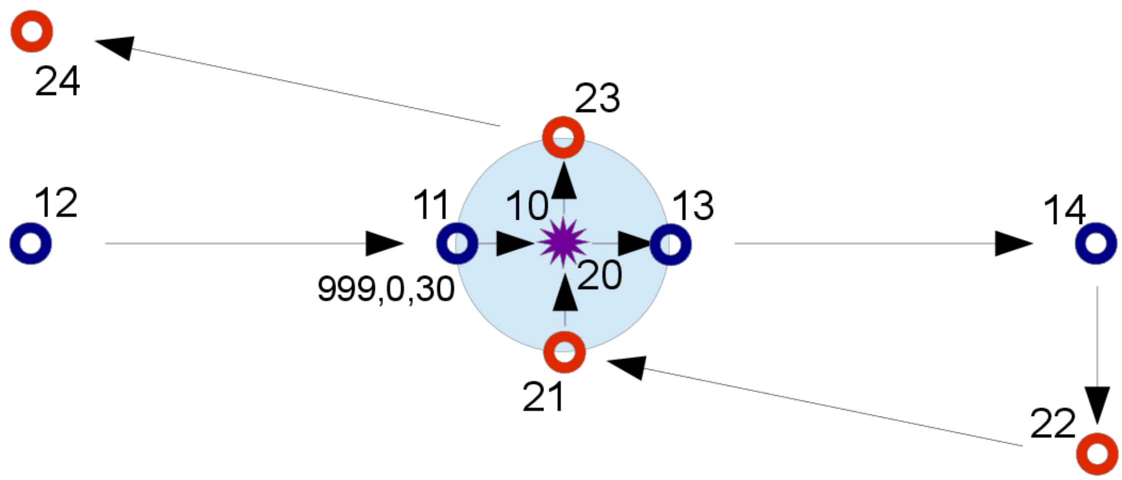

Figure 2: The pointing sequence (Craig Cross). The large shaded region is the half power primary beam. The symbols are pointing positions. The numbers are the qualifier code attached to the scan on each position. The pattern is observed in the sequence 12, 11, 10, 13, 14, 22, 21, 20, 23, 24. Often that sequence is then repeated. The elevation off-source positions are offset in azimuth to allow the steps between the 5 elevation scan pointings to be evenly spaced in elevation. This improves the interpolation of the off-source power when at low elevations when there is a gradient with elevation. Image and caption taken from VLBA Test Memo 72.

currently is used for pointing parameter maintenance only but work is underway to allow real time reference pointing to use interferometric pointing also leading to a much more accurate determination of parameters and offsets and a larger source pool.

3 Correcting for these errors

If your observations were affected by the above issues and your require an accurate flux scale here are some suggestions on how to correct the flux scale for your observations. If you do not require accurate fluxes to better than 10 % or so it is not recommended to make these corrections. Please note that the sensitivity loss caused by the above issues can not be corrected for in post processing. If you are sensitivity limited and feel your observation has been affected to such an extent that the data are no longer useful (or you are struggling with corrections) please contact the helpdesk.

3.1 Correcting for focus position errors

All users with 7mm or 3mm observations affected by the focus position error have been contacted. If you have 3mm or 7mm data affected by this problem and have not been contacted please reach out to the helpdesk. Observations at wavelength longer than 2cm will be entirely unaffected by the focus issue and thus no correction is needed. At 2 cm you may attempt a flux scale correction by using AIPS task CLCOR:

```
default clcor
getn x
```

```
opcode 'GAIN'
CLCORPRM(1) = 1.12
go clcor
```

You may try a similar approach at 1 cm except use CLCORPRM(1) = 1.60. Note however this is a very large correction. Again don't hesitate to contact the helpdesk with any issues.

3.2 Correcting for pointing errors

Correcting for the losses due to pointing issues is a little more complicated - testing had shown that the errors can be both elevation and azimuth dependent. If possible, if you have a bright enough source in your observations, it is recommended to make an initial model of the source with the affected antenna(s) removed. Then use that model in a selfcal step with the full array. This provides a much nicer solution than attempting a gain correction as described for focus errors above. Corrections from that selfcal can then be applied to all sources. Please do contact the helpdesk if you are struggling with these corrections. Note again that sensitivity loss can not be corrected for, but that hopefully no significant source structure changes are expected from these issues (if data end up with nulls in the measured visibilities, this will affect structure).

4 Acknowledgements

Thanks to Walter Brisken, Bryan Butler, Vivek Dhawan, Wayne Koski, Jim Ogle, Bruce Rowen, and Anthony Sowinski, for their help on this memo.