EVLA Memo 142: Surveying Calibrators for the EVLA

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1 Current status of the calibrator survey (CALSUR)

To supplement open array time the calibrator survey project (CALSUR) was operated from April 2009 until the shutdown in January 2010. This survey was performed at C-, X-, and K-band to provide an update to the VLA calibrator manual. The sources observed were from the VLA, VLBA, GBT, ATCA, PdBI, and SMA calibrator catalogs which had 1860, 3934, 7106, 2038, 685, and 438 sources respectively. After cross-referencing between the catalogs, to eliminate any overlapping sources, the CALSUR project had a total of 7719 sources. This project was performed only when there was unscheduled time on the array. The number of sources observed at each band in each RA range are shown in Figures 1, 2, and 3.

K-band was the first band to be part of this project since the VLA calibrator manual lacks information about these sources at this band. Observations at K-band required referenced pointing so the sources were grouped into 1-hour slots. C-band observations were added to the CALSUR project since the K-band observations required 1-hour slots and good weather. The C-band observations were setup in 30 minute intervals to allow the greatest flexibility of working into the VLA schedule during open time. X-band was eventually added to cover open 30 minute blocks left by the C-band files that were quickly observed at low-observing-pressure LST ranges. The figures below show that LST ranges that are over-subscribed received the least amount of CALSUR time. To ensure that calibrators are surveyed uniformly for all RA ranges dedicated array time has to be allocated to this project.

After general discussion about this project the consensus was that adding calibrators to the VLA calibrator manual is important for high-frequency observing to ensure that phase calibrators are available within 2° of target sources. Therefore, approximately 10,000 calibrators should be available to the user community to ensure that high-frequency observations can be properly calibrated. The VLA calibrator manual currently has 1860 sources of which there are 1590 sources listed at Q-band with fluxes greater than 100 mJy.

The following conclusions were drawn about this current survey:

1. Array time has to be dedicated to this project in order to survey calibration sources across the whole sky;

2. More phase calibrators are required at high-frequencies and in the galactic plane (10,000 calibrators would be ideal) but the current list of ∼7700 will suffice for now;

3. The position information about the calibrators in the current combined list needs to be determined;

4. The output of the analysis of the current survey should be positions, fluxes, images, and visibility functions;

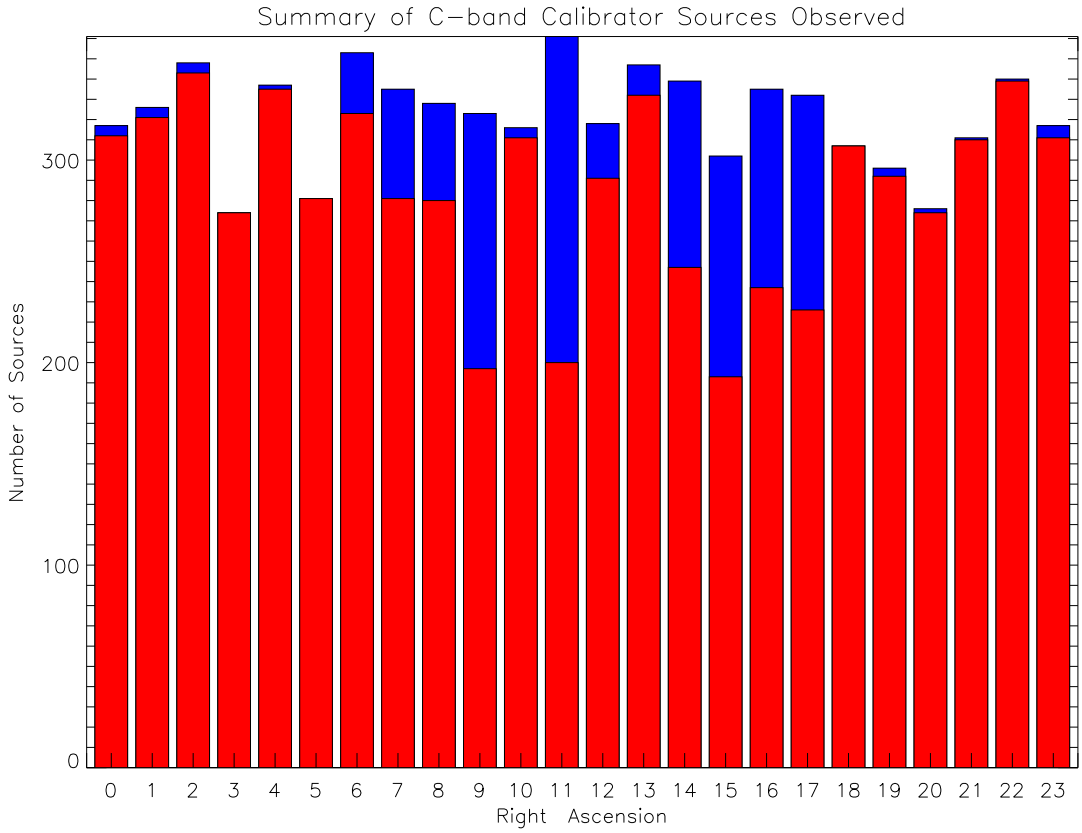

Figure 1: The total number of sources in each RA range (blue) based on the combination of the VLA, VLBA, GBT, ATCA, PdBI, and SMA calibrator catalogs. The total number of sources observed by the CALSUR project at C-band (red).

5. The VLA calibrator manual should be updated with the results of this project; and,

6. The Observing Planning Tool (OPT) should have an updated combined calibrator list (rather than the separate lists currently available) which will become the EVLA calibrator list once positions, fluxes, images, and visibility functions are determined. This list will include more visible information in the OPT about the quality of the calibrator.

2 Plans for the future calibrator survey

It was determined that the calibrator survey project should continue on the EVLA with dedicated time. It will be performed at Ka-band in C- and A-array. Each program observed should contain a VLA flux density calibrator so that fluxes of new calibrators can be well-determined. This program can also be continued to utilize unscheduled time in any array configuration in the future.

2.1 Previous observing procedure

The procedure for observing in 1-hour blocks for K-band for the project CALSUR has been tested and works well (the observing procedure did not fail and analysis of the data show it to be of good quality). Since referenced pointing is required for Ka-band, this project could also follow the procedure developed for observing calibrators with K-band. The K-band calibrator survey was

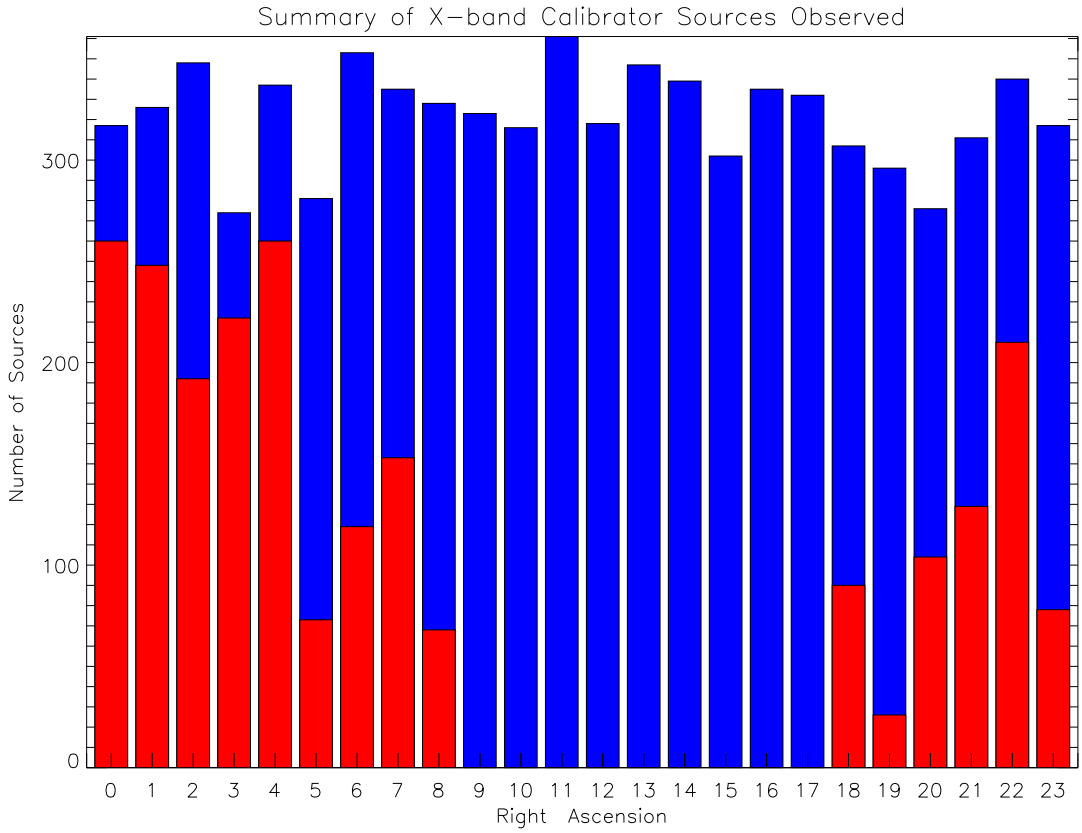

Figure 2: The total number of sources in each RA range (blue) based on the combination of the VLA, VLBA, GBT, ATCA, PdBI, and SMA calibrator catalogs. The total number of sources observed by the CALSUR project at X-band (red).

performed by dividing the sources into RA blocks and sorting them in declination. The sources were then split into 40-source groups. One 40-source group made up an hour of observing. This hour was created by 10 minutes of unwrap time (padding time to allow the antenna to unwrap if necessary), 3-minutes of referenced pointing, 40 1-minute observations (including move time) on each calibrator, 6-minutes of move time plus referenced pointing on the nearby flux density calibrator, followed by 1-minute of observing time on the flux density calibrator. The total time required to complete this project for Ka-band in one array configuration is:

$$\text{time} = \frac{7719 \text{ sources}}{40 \text{ sources per 1hr of observation}} = 193 \text{ hours} \quad (1)$$

Therefore, to perform this survey in this fashion approximately 200 hours of time will have to be set aside for the CALSUR project in each array configuration. The additional 7 hours is necessary for sources that may need to be re-observed because of weather, slew times, or instrumental faults. This calculation does not include the time required to do accurate astrometric measurements of sources in the list. These observations can be performed in OSRO1 mode at standard Ka-band frequencies, but may also benefit from extended bandwidth modes.

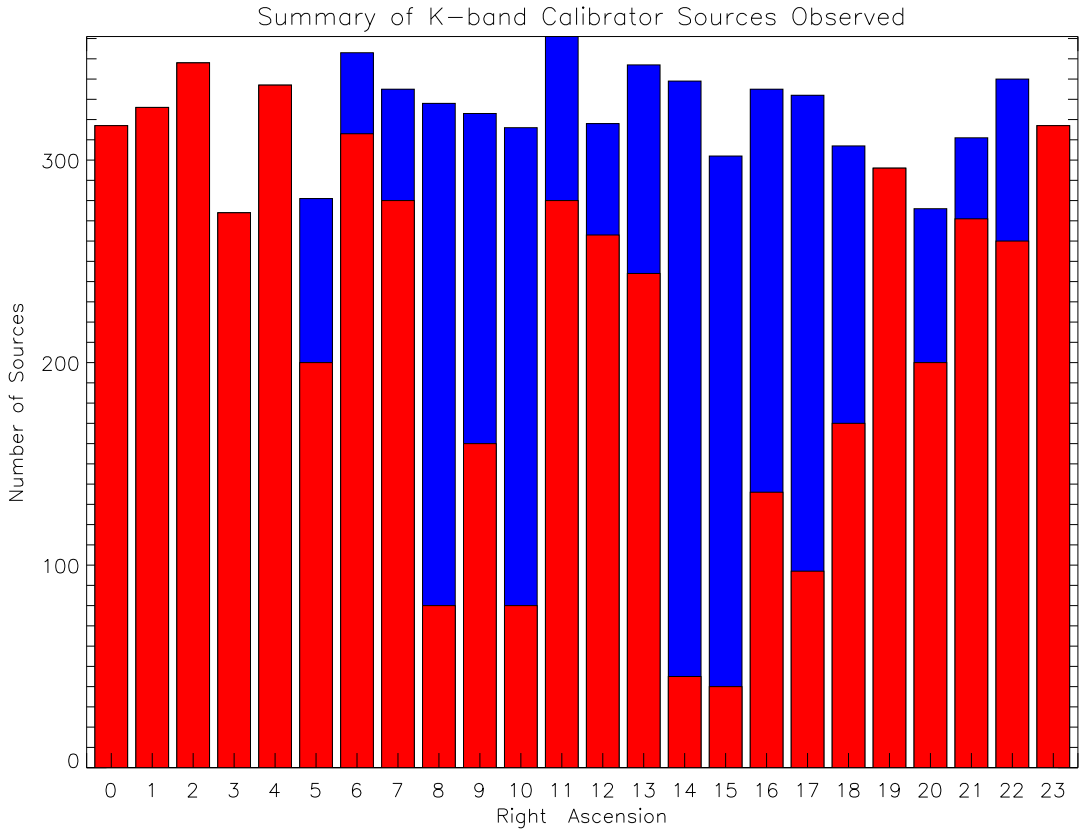

Figure 3: The total number of sources in each RA range (blue) based on the combination of the VLA, VLBA, GBT, ATCA, PdBI, and SMA calibrator catalogs. The total number of sources observed by the CALSUR project at K-band (red).

2.2 Additional options

In the above estimation 20 minutes of every hour is overhead to account for antenna unwrap, flux density calibration, and referenced pointing. The above estimation can be reduced to approximately 150 hours (a 25% reduction) if this project is performed in large time segments and there is attention paid to source sequencing (this will reduce the amount of antenna unwraps needed). As this is a Ka-band project and weather is important it is not possible to schedule this type of observation for 8 continuous days so it is unlikely the survey can be performed in less than 150 hours.

In order to have accurate astrometric measurements of sources previously unknown to the VLA calibrator manual a significant change in the Ka-band observing procedure would be required for the A-array observations. Observations of VLA calibrator sources, with "A" positional codes, would need to be interleaved into the observations. Following the guidelines of the survey by Wrobel *et al.* (2001) a source with an "A" positional code should be cycled back to every 6 minutes. Accounting for overheads this will add approximately 29 hours to the project in A-array.

2.3 Alternate C-array option

It was also identified that we should consider coming up with a procedure to do pre-observing of phase calibrators for programs allocated time on the EVLA. This will enable the VLA staff to determine if the calibrator chosen is sufficient at the current band and array configuration for the

astronomers project. It is thought that this will reduce the number of calibrators that need to be surveyed but continue to update the calibrator manual. To estimate the feasibility of such a project estimates have been made based on the number of high-frequency (K, Ka, and Q) sources being observed for D-array from accepted OSRO proposals. 18, of the accepted 264 sources, spaced evenly across the sky were chosen to do this estimate. There are on average 10 calibration sources within a 4° search radius of each source. Therefore, a total of 2640 calibrators would need to be surveyed at the beginning of the array configuration to provide accurate information about the calibrators to our users. This survey will take 57.2 hours (2.4 days) if the calibrators are observed at a rate of 1 source per minute and a 30% calibration overhead is applied (the overhead includes: referenced pointing, unwrap time, and flux density calibration). This type of survey will be very time intensive to create in the current OPT.

2.4 OPT upgrade requirements

In order to perform calibrator surveys a number of upgrades are required to the OPT. The following options do not currently exist in the OPT but are needed to reduce the amount of time required to create calibrator surveys:

1. The ability to automatically generate a schedule from an imported source list, and a pre-selected resource;
2. The ability to import a list of sources and automatically generate a list of calibrators within a cone radius of the sources;
3. The ability to create a scheduling block for thousands of sources when we wish to observe in long blocks of time;
4. The ability to export sources from the Source Catalog Tool (SCT) with more information than in the traditional PST format but with less complexity than XML format for ease of use in other software programs;
5. The ability to assign one resource to many scans automatically;
6. The ability to cut and paste multiple items at once; and,
7. The ability to create large projects which do not affect the speed at which the application runs.

2.5 Increasing the number of sources

Another goal of this project would be to add new calibrators to the current list of approximately 7700. ATCA is currently doing a survey at 20 GHz for sources with declinations below 0°. In addition, the VLBA has a program to look for new calibrators. The Combined Radio All-Sky Targeted Eight GHz Survey (CRATES) is an 8.4 GHz survey of bright, flat-spectrum radio sources assembled from existing observations, especially CLASS and the PMN-CA survey, augmented by reprocessing of archival VLA and ATCA data (Healey *et al.* 2007, 2009). The CRATES catalog provides precise positions, sub-arcsecond structures, and spectral indices for over 11,000 sources. Sources identified through all of these programs could be surveyed to help increase the VLA calibrator list to the 10,000 source goal.

The VLA has also done observing programs to search for calibrators such as the survey by Wrobel *et al.* (2001) at 8.5 GHz. To fill in the gaps of surveys of flat-spectrum sources a group of variable sources were selected from the GB6 catalog. These sources were eventually added to the

VLA calibrator manual. This represents yet another method that can be used to identify additional sources to bring the VLA calibrator manual towards its 10,000 source goal.

2.6 Manpower

To ensure that these data are looked at in a timely manner the EVLA will need to dedicate manpower resources to this project. As mentioned above, many improvements to the OPT software are needed to ensure that developing this observing program does not create a substantial amount of work. In addition to monitoring the program while it is being observed, a procedure in CASA for auto-flagging and pipelining this data will need to be developed to characterize the structure, positions, and fluxes of these sources. It may, however, turn out that at this time it is more efficient to continue processing this data in AIPS.

3 The need for more flux-density calibrators

Developing the observing program for the CALSUR project identified another area of weakness when observing calibrators with the VLA. Currently there are only two flux density calibrators that astronomers are advised to use for the VLA: 3C48 and 3C286. These sources are located at respectively 1 hour and 13 hours RA. Sources at RA's of approximately 5-9 and 17-20 hours often have difficulty accessing these two flux density sources. Observing with the EVLA would greatly benefit by adding more flux density calibrators to the list. Approximately 2 sources for every 3 hours of RA, with the two sources spaced in declination, would make observing flux density calibrators for any project significantly easier. At minimum, the EVLA staff should advise all users that accurate models exist across all bands for 3C48, 3C286, 3C138, and 3C147.

4 References

S. E. Healey, R. W. Romani, G. B. Taylor, E. M. Sadler, R. Ricci, T. Murphy, J. S. Ulvestad, and J. N. Winn (2007). CRATES: An All-Sky Survey of Flat-Spectrum Radio Sources, *ApJ* **171**, 61.

S. E. Healey, L. Fuhrmann, G. B. Taylor, R. W. Romani, and A. C. S. Readhead (2009). Filling the Gaps in the 4.85 GHz Sky, *AJ* **138**, 1032.

J. M. Wrobel, G. B. Taylor, P. C. Gregory (2001). Phase Calibration Sources in the Northern Sky at Galactic Latitudes |b|$< 2^{\circ}.5$, *AJ* **122**, 1669.