RSRO Report

Stuartt A. Corder

National Radio Astronomy Observatory, 520 Edgemont Road, Charlottesville, VA, scorder@nrao.edu

Abstract

This document summarizes the work, plans and future direction of the EVLA switch power application, specific to CASA. Various aspects of this work, including technical and software, are described in varying levels of detail. Technical problems addressed include the influence on pointing and the scatter among visibilities on different baselines before and after switched power application. Software issues addressed include an end-to-end verification of the calibration process, including scaling both visibilities and weights. Flagging and smoothing are deferred until later. The mechanics of concept of new CASA tasks are addressed with outlines of the relevant parameters. I also outline the work done and the plan for continued work on simultaneous joint deconvolution of single dish and interferometer data.

Summary:

- End-to-end application of switched power data to visibilities and weights has been verified (8-bit). The precise factors needed to scale the visibilities and weights to their proper values are known and discussed below.
- Proper scaling, to physical units, of weights are necessary, especially to further the effort for joint deconvolution with other systems.
- The T_{cal} values are not particularly well determined in some cases as the scatter in baseline ensemble visibility amplitudes is sometimes increased with the application of switched power.
- Flagging and smoothing of the solutions remains to be tested but will be necessary as some specific switched power values are bad/noisy. The bad points represent a small fraction of the total dataset. (On average a couple of points on a few antennas per 8 hour observations.) One example of particularly bad performance is noted.
- I will continue to work on joint deconvolution in the coming months.

1 Switched Power

The application of switched power has three basic goals. First among these is to remove time variations in the gain. These variations can occur on time scales smaller than measurements of the amplitude gain calibrator. The other principle reason for applying the switched power results themselves is to bring the scale of the observations to a true Kelvin scale. Finally, the application of switched power, when combined with the total power, provides weights for the data allowing them to be set on a physical scale.

The details of the switched power measurement and general application are described in EVLA Memo 145 (Perley). The equations presented here are cast in terms of the definitions therein. In the following sections I discuss the two potential technical issues, the application to pointing observations and the spread of visibility amplitudes before and after application of the switched power corrections. I also discuss my work on the CASA implementation side, including various checks on the application.

1.1 Potential Technical Issues with Switched Power

1.1.1 Application of Switched Power to Pointing Scans

The switched power gains are not applied to the visibilities prior to the calculation of pointing solutions on the EVLA. If there are strong gain changes over the limited pointing scan, this can result in invalid pointing solutions. As part of investigating the end-to-end application of the switched power values to CASA, it was noticed that antenna EA19 had rapidly variable, 20% peak to peak, over the course of less than 10 s. If the changes in visibility amplitudes were occurring at a similar rate, this could potentially bias the results of the pointing. Further inspection indicated that the changes in other antennas were much smaller over these time periods, typically less than 1%.

The problem seems to then be specific to EA19. Upon deeper inspection of the visibility amplitudes it appears as though this variation is not seen. Therefore application of the switched power in this case is the cause of the visibility amplitude variation. An unanswered question therefore remains. **Why does the switched power oscillate so much on EA19 at 8.5 GHz.**

1.1.2 Visibility Spread

It was surprising to me that the spread in visibilities among different baselines, at a given instant, was not reduced. This was expected by the expert CASA users that applied the switched power results. It appears as though the scatter in the visibilities is sometimes, for some subsets of antennas, reduced. However, there appear to be significant outliers that sometimes broaden the amplitude spread post application. It appears as though the tracking of the T_{cal} values and their changes could be done more accurately.

However, it is unclear that there is an immediate benefit to such a path forward. After all, errors in T_{cal} represent a simple scaling of the antenna based amplitudes after time variations in switched power, elevation gain and opacity are removed. Such differences are removed by amplitude gain calibration. It is my opinion that such applications are hiding the source of the problem, which fundamentally is the T_{cal} values themselves. Eventually, a better tracking of the behavior of the T_{cal}s seems advised but it is not currently harming the output data quality provided that on average the T_{cal} values are accurate.

2 CASA Implementation

2.1 Generation and Application of the CalTable

The basic mechanics of the CASA application of the switch power gains and scaling of the weights were verified by independent calculation. The propagation of values from switched power to gain table was verified exactly. The application of the switched power cal table to the parent visibilities was verified in an average sense and there is no clear indexing problem in the switched power application, either in time, spectral window, or antenna. The calibration of the weights has been similarly verified. The generation of the T_{sys} values in the CalTable is accurate and the application of those T_{sys} values to the visibility weights is similarly accurate.

2.2 Flagging

Flagging of the switched power data is often vital as extreme outlier points, but rarely entire antennas, often appear.

The flagging behavior in the new CalTables cannot yet be verified since they have yet to make an appearance in the new test build. This is expected on 28-March-2012. GM is currently verifying that completely flagged solutions are not written to the new CalTable. In the end, the option will be to flag data around the calibration solution or potentially ignore the flagged solutions and not flag any actual data. Given the change in implementation in the CalTables, it seemed futile to test the implementation in old CASA. Further testing of this performance is needed after full deployment of the new CalTables, including flagging.

2.3 Smoothing

Smoothing of the switched power data is needed for proper application. This is because the process is inherently noisy and we do not expect massive changes in switched power on the order of a few seconds. Oscillations on this order have been seen in some antennas, but the oscillation was restricted to the switched power data itself and not the visibilities implying issues specific to the switched power measurement and not the system.

Smoothing in the old CalTables was done simply in time. The field and scan divisions were not present. The new implementation, when finished, will allow standard options like smoothing on a time scale but not crossing field and time boundaries. Optimal smoothing periods have not yet been explored but timescales for any change in power that does not come at a scan and/or field boundary will set twice the maximum

2.4 Expected Functionality

Conversations with the CASA group have led us to decide on a set of three functions for applying pre-calibration. It breaks down as follows:

- **Opacity Correction**: The current implementation of the opacity correction will remain. This corrects for elevation atmospheric opacity effects.
- **Gain Curve:** The application of the gain curve will be expanded. The antenna efficiency factors, which may also account for the conversion from Kelvin to Janskys, will be applied. Given the user may eventually want to have the gain curve applied but keep the units of the visibilities in Kelvin, the option to apply the efficiency factor only or convert from Kelvin to Janskys should be preserved.
- **Switched Power:** The application of the switched power is intended to take the visibilities to Kelvin inside the atmosphere.

It is envisioned that these will result in 3 CalTables. A desire has been expressed to execute all of these in a single task.

The **Opacity Correction** remains unaltered and is complete as is. It would merely need to be incorporated into the new task. For completeness the factor applied, per antenna, is $e^{-\tau a/2}$, where τ is the per antenna opacity and a is the per antenna airmass. Typically the opacity will be constant for all antennas but for very extended configurations of some arrays, this value can be different. Weights are to be adjusted as a normal, time-dependent gain calibration.

The **Gain Curve** functionality merely needs to have the current gain curve functionality contain a per antenna factor of
$\sqrt{\frac{A\eta}{2k}}$ or $\sqrt{\eta}$,
where η is the per antenna aperture efficiency (currently the same for all antennas) and A is the antenna area. The selection of factor accounts for the case of values in Jy or K. An additional option to apply the gain curve may be useful. The efficiency factors for the EVLA are constant across antennas to first order and are provided here for reference:
frequencies (GHz): 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2.0, 2.0, 2.3, 2.7, 3.0, 3.5, 3.7, 4.0, 4.0, 5.0, 6.0, 7.0, 8.0, 8.0, 12.0, 12.0, 13.0, 14.0, 15.0, 16.0, 17.0, 18.0, 19.0, 24.0, 26.0, 26.5, 28.0, 33.0, 38.0, 40.0, 43.0, 48.0
efficiencies: 0.45, 0.48, 0.48, 0.45, 0.46, 0.45, 0.43, 0.44, 0.44 0.49, 0.48, 0.52, 0.52, 0.51, 0.53, 0.55, 0.53, 0.54, 0.55, 0.54, 0.56, 0.62, 0.64, 0.60, 0.60, 0.65, 0.65, 0.62, 0.58, 0.59, 0.60, 0.60, 0.57, 0.52, 0.48, 0.50, 0.49, 0.42, 0.35, 0.29, 0.28, 0.26

The application of the **Switched Power** has been discussed in EVLA Memo 145. Here we assume the nomenclature in that document. The gain factors should be calculated as follows, per antenna:
$\sqrt{P_{diff}\eta_c\eta_l}$
where P_{diff} is the switched power, η_c is the correlator efficiency, which is 0.32 for the currently used 4-bit correlation and 0.96 for 7-bit correlation. η_l is the lobe rotator factor, 1.17. The weights are adjusted according to the system temperature:
$\frac{2P_{diff}\eta_c}{P_{sum}T_{cal}}$
where P_{sum} is the total power and T_{cal} is the effective temperature of the noise diode.

Further adjustment of the weights is currently planned. This includes use of the spectral (channel) weights and the inclusion of the integration time and channel width in the spectral weights.

2.5 Future Directions

It appears that a sky based calibration of the T_{cal} values could help track changes in time and temperature. Also, a back check of T_{cal}, i.e., check the value after the receiver is removed before further work is done, could given an idea of long time stability in a controlled laboratory environment.

The end to end checks of the CASA functionality need not be repeated with the new CalTables, but flagging behavior and smoothing needs to be checked.

Finally, in relation to the needs for Joint Deconvolution (see below), we need to complete the work on the weight scale, rationalizing the calibration of the weights and the initialization of the weights both in the currently used spectral window average sense, and the forthcoming channelized weight scheme.

3 Joint Deconvolution

3.1 Work Summary

Some initial work and planning took place on the usage of simultaneous joint deconvolution in CASA. This is opposed to feathering and the use of the single dish image as a model. It has been decided that Kumar will provide utilities for us to work with in June. A CASA task force has been set up to work on this task, which is not necessarily dependent strictly on the EVLA. Two ALMA representatives, Eric Villard and Ed Fomalont, join me (ALMA+EVLA interest), and an EVLA-centric person would also be appreciated.

Juergen Ott's name has been suggested. The goal here is to push through ALMA Baseline correlator, ACA and Total Power antenna combinations. It is expected that this is the best dataset to press the capability given the data processing and collection will be unified and treated equivalently in reduction. Combinations with the GBT and EVLA will depend on the ability to get GBT data, specifically from the K-band Focal Plane Array, and will require input from GBT specialists.

3.2 Continuing effort

Two critical items remain to be done. Initial work is scheduled by the above group in June and July. First, the weights of the data must be treated in a uniform way for all ALMA data. A uniform treatment of the EVLA data in CASA is also strongly desired by this point. Initial work on this is underway. It is expected that if the input datasets are not on the same fundamental weight scale, then the resulting image combination will be subject to arbitrary scaling factors which is not an attractive option. The other thing that remains is the exercise of the CASA functionality. I plan to continue working on this both from the ALMA and EVLA prospective. I have EVLA mosaic data and K-band FPA data from the GBT that needs to be combined.