# ALFA Memo: On the Calibration of Spectral HI Line Drift Data with the WASP

R. Giovanelli, M. Haynes, B. Kent
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With the advent of ALFA, a number of wide angle surveys will be carried out in the HI line. Initially, HI surveys will use the Wide band Arecibo Spectral Processors (WASP; also known as WAPP). Several of those surveys will operate in drift mode, i.e. with data taken at fixed (AZ, ZA), as the sky drifts by at approximately 12 sec/beam. The calibration of data taken in that mode will rely on noise diodes fired at regular intervals. Several questions of concern arise:

- (1) Drifts in the "electronic " system gain, as well as in the counts produced by firing the calibration diode will occur: on what time scale and amplitude?
- (2) Ideally, calibration diodes are fired when the telescope tracks a fixed location in the sky, and Cal ON and Cal OFF counts are used to estimate the system temperature. However, acceleration of the telescope to match the sidereal rate, integration on the cal, deceleration to zero to ready it for resumption of drift operation will demand a substantial amount of time, well in excess of the integration time on the cal. If the frequency of cal firing is high, calibration in tracking mode can lead to low efficiency of telescope time usage. Alternative options can be investigated:
- (2a) If a cal diode of sufficiently high temperature is used, the integration time necessary to achieve satisfactory statistics can be very low, e.g. 1 sec. Can then the time required to (i) stop data taking on the drift scan, (ii) fire and integrate over the cal and (iii) resume integration on a new drift scan be made short enough that the loss of sky coverage during normal sky sampling over the given strip of sky amount to a small fraction of the beam width ($\sim$ 12 sec at L band)?
- (2b) If, at the time of firing the cal, a continuum source drift by the telescope beam, the calibration measurement will be affected, yielding a spurious calibration: how often will that occur and at what amplitude would that affect the calibration of the data?

- (2c) Is it possible to economically devise a calibration scheme that will obviate the problem described in part (2b)?

On 18 January 2004, we carried out a set of tests to investigate the performance of the WASPs for HI line drift surveys. Among the tests carried out, one was particularly relevant to the issues described above.

Jeff Hagen kindly produced, on very short notice, software that allowed us to take data in the following mode: with the telescope fixed in (AZ,ZA) a sequence of N pairs of scans were taken; each pair consisted of a 10 sec integration with the cal OFF, followed by a 1 sec integration with the cal ON, with the minimum possible dead time between scans and the following cycle. The telescope never moved. We carried out the sequence of N=200 such cycles. A bandpass of 50 MHz centered at 1390 MHz was used foro all WASPs. The drift strip at a constant declination of 12° 03' started at RA = $23^h.28$. A brief summary of the results of this test follow:

- The total duration of the sequence was 2707 seconds, for an average duration of 13.5 sec per ON–OFF pair. The "dead time" per cycle was thus 2.5 sec, and the full time needed to fit a 1 sec calibration step was on the average 3.5 sec. That means that with current observing modes, tied to "second ticks", the data "lost" during the drift strip for a 1 sec calibration is equivalent to less than 1/3 of a beamwidth per calibration episode. This is acceptable, albeit it would be even more desirable to have available a data taking mode with zero dead time, e.g. one where the 1 sec cal scan only takes 1 sec, rather than 3.5 sec.

- Several strong continuum sources were encountered during the 11° long drift, each affecting both the cal ON and the cal OFF counts, as shown in Figures 1 and 2, separately for pols A and B.

- The long–term stability of the $T_{sys}$ for the duration of the drift strip — over the 45 minutes duration of the test — was about 1%, as shown in Figure 3. That change could be produced by either variations in the sky background or by variations in the conversion from system counts to power. As seen in Figure 4, the ratio between cal and $T_{sys}$ is constant along the strip to within 0.1–0.2%. Assuming that the power injected by the cal is constant, we infer that the 1% drift in the counts seen in Figure 3 is due to variations in the conversion from counts to $T_{sys}$, rather than in the sky emission and the absolute value of $T_{sys}$. Re–calibrating the conversion from counts to $T_{sys}$ on timescales shorter than $\sim$ 1000 sec seems to be necessary, if 1% fidelity is desired in the data.

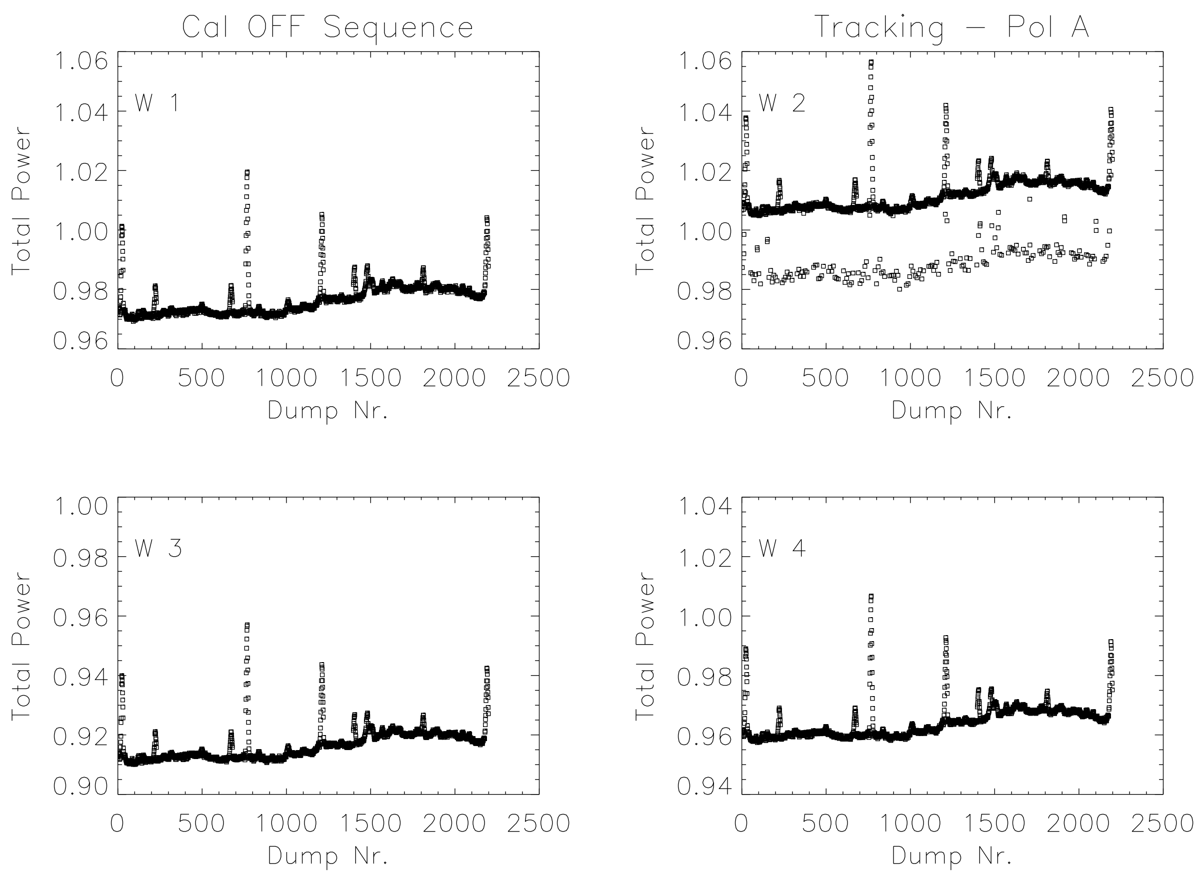


Fig. 1.— Total power for pol A along a drift of 2707 seconds at Dec= 12° 03' (J2000). The data correspond to the total power of 2000, 1 sec dumps for which the cal was off. Cals were interspersed through the drift, and they are not shown here. Occasional drops in the counts by about 2% occurred for WASP 2 (upper right panel). We discussed the cause of that in a different memo).

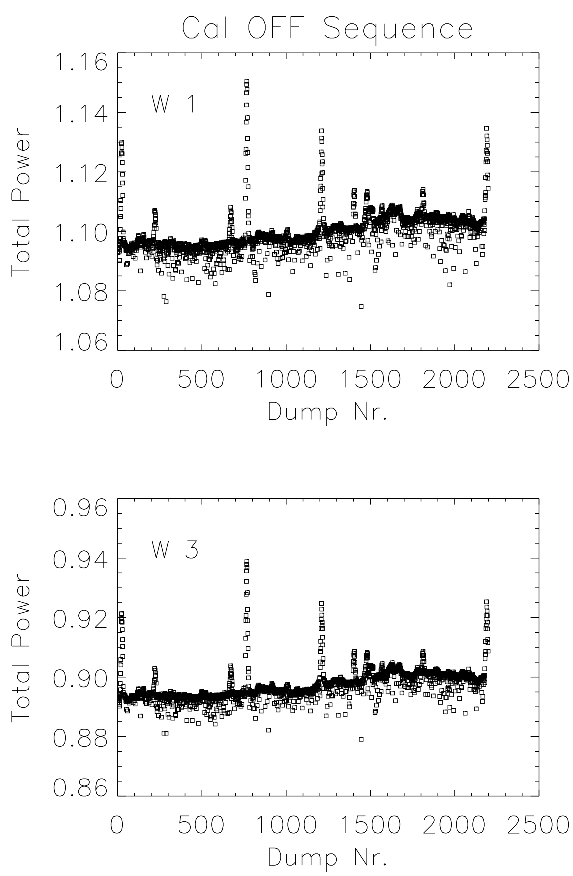


Fig. 2.— Total power for pol A along a drift of 2707 seconds at Dec= 12° 03'. The data correspond to the total power of 2000, 1 sec dumps for which the cal was off. Cals were interspersed through the drift, and they are not shown here. Drops in the total counts occurred frequently for all the WASPs in this polarization: they appear as "fuzz" below the median power line. We discuss their cause in a separate memo.

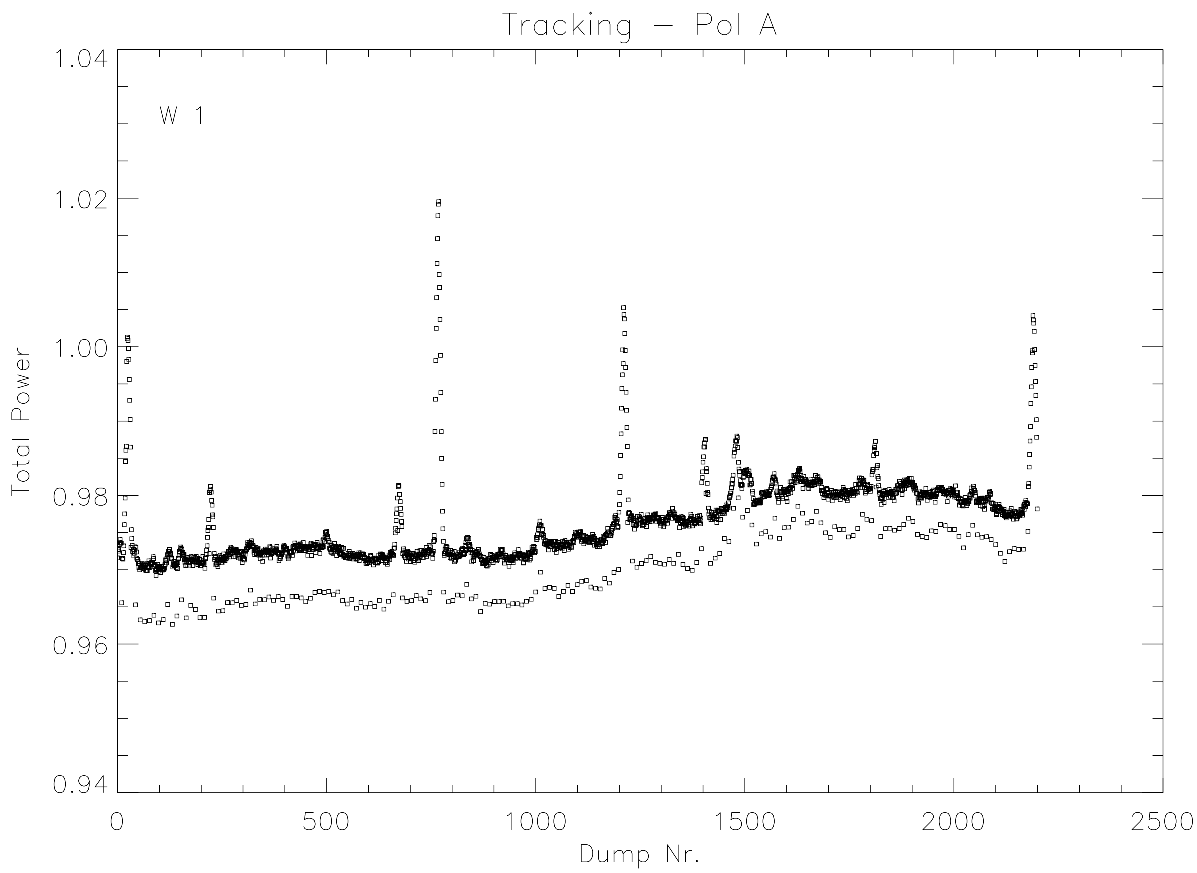


Fig. 3.— Total power counts along a drift of 2707 seconds. The upper tracing corresponds to the power counts for 2000, 1 sec dumps for which the cal was off, while the lower tracing correspond to the counts for 200 dumps in the course of which the cal was on, in system units. The cal tracing had 0.35 subtracted, to ease the comparison.

- The long–term stability of the noise cal counts was high, as shown in Figure 3. The strip of sky sampled is at high galactic latitude, away from regions of high galactic synchrotron emission.
- Apart from localized variations associated with the transit of strong continuum sources, the trend in the noise contributed by the cal diode to the total system temperature, as a fraction of the latter, remained stable to within 0.1 % throughout the strip, as shown in Figure 4, which plots (Cal ON - Cal OFF)/(Cal OFF). Cal ON and Cal OFF were measured by integrating over the full bandpass.
- Approximately 1 in 10 calibration scans were affected by continuum sources, producing calibrations scaling which was spurious at a level in excess of 0.5% of $T_{sys}$.

**Conclusions:**

- 1. It is possible to achieve fidelity at a level of 1% or better in the calibration of the system, by using the WASPs in drift mode, and firing the cal as the sky drifts..
- 2. Conversion of system counts to $T_{sys}$ power units needs to be calibrated at least once every 1000 sec. In order to circumvent the impact of spurious calibrations produced by the transit of continuum point sources, it is advisable to fire the cal often, perhaps every few hundred sec, maintain a running mean of contiguous cal measurements over a few thousand sec and interpolate across calibration episodes showing unusual deviations from the norm. E.g. in Fig. 4, an interpolating fit acrosss ON–OFF cycle nr. 110 would produce better calibration than using the counts conversion value derived from a single calibration.
- 3. Total time required for a 1 sec calibration scan can be 3 to 4 sec at most (and hopefully it can be further reduced to 1 sec), so that loss of sky sampling can be minimized to a small fraction of a beamwidth and motion of the telescope can be avoided.

**Recommendations:**

1. The implementation of a drift observing mode whereby the starting coordinates (rather than those of the center of the strip) are given, and data taking can initiate immediately after reaching that location should be implemented.

2. The dead time between the end of a scan and the beginning of the next — be it a calibration scan or the resumption of a a drift strip — should be reduced to as close as possible to zero.

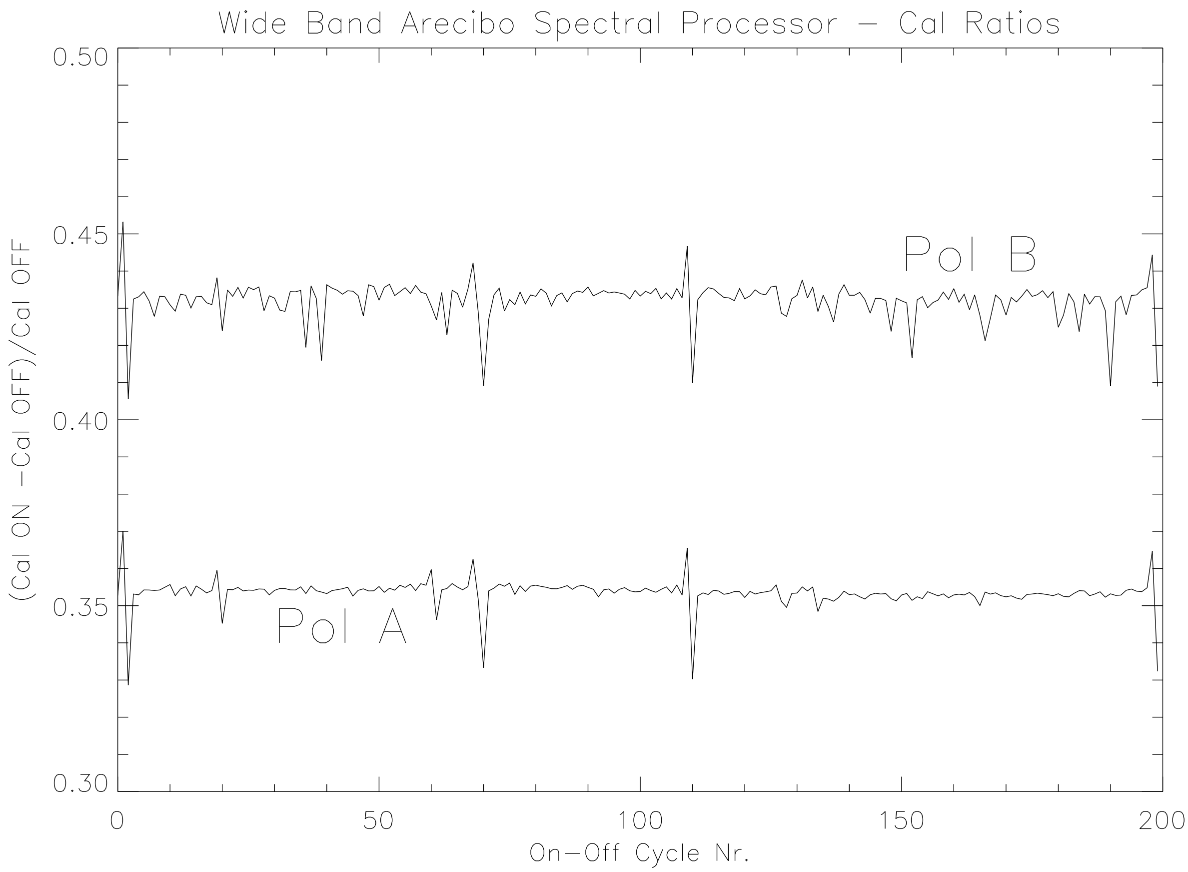


Fig. 4.— Cal power as a fraction of the total power for WASP 4, for 200 Cal OFF–Cal ON cycles. The Cal OFF step was 10 sec long, the Cal ON step was 1 sec long. Other WASPs exhibit similar behavior. Total power was measured by integrating over the full bandpass of 50 MHz.