VLA Test Memorandum No. 202:
Referenced Pointing at the VLA

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This memo is the original version of a Web page devoted to referenced pointing. That Web page will change to track the best current information; the purpose of putting the original out as a memo is to keep some more permanent record not subject to the vaguaries of Web maintenance.

Using the standard pointing constants, the pointing error for the VLA antennas is generally 10 to 20 arcseconds, and can be as bad as an arcminute. These pointing errors significantly degrade the sensivity at the nominal field center at the higher frequencies, for which the *a priori* pointing can be off by a large fraction of the primary beam (FWHP about an arcminute at 7mm (Q band) and two arcminutes at 1.3cm (K band)). Single dish observers habitually "fine tune" the pointing near a source by pointing up on a nearby bright object, a procedure involving measuring the signal at the nominal position and four positions offset in each of the cardinal directions (N S E W), and using a simple model for the beam shape to find the peak in the received signal. A similar procedure is now available for the VLA; here it is referred to as referenced pointing.

The purpose of this memorandum is to collect the available information and lore about referenced pointing, and to communicate a simple understanding of why, when, and how to use it. The references at the end give more detailed information.

Contents:

Primary Referenced Pointing

The basic procedure for using referenced pointing is simple:

1. determine the pointing offsets by pointing up on a nearby, bright, point-like source;
2. tell the on-line system to apply those corrections to any number of subsequent scans;
3. go back to (1) when the pointing has changed significantly from when the pointing offsets were determined. The pointing may change for example because the source has moved to a different (Az, El), or because a change in temperature has slightly altered the shape of the dish.

The pointing offsets are usually determined using full-bandwidth continuum observations at 3.6cm (X band): full bandwidth to give maximum sensitivity; 3.6cm both because that is the most sensitive band at the VLA, and because the *a priori* pointing even in the worst cases will lie well within the half-width of the beam at that frequency (about 2.7 arcminutes). The pointing calibrator should be near where the source will be, during the time for which the derived pointing offsets will be used; it should be bright, so that the pointing observations can be short without thermal noise dominating the solutions; and it should be point-like, so that source structure does not get confused with the antenna response. The actual limits depend on the sensitivity and pointing behavior of the VLA. How often to check the pointing depends on the quality of the default pointing model, and on the local weather conditions (e.g., sunrise and sunset lead to significant temperature gradients which can produce rapidly varying pointing errors). The current wisdom on these issues is given in the section on Lore, below.

Notice that the pointing is determined at X band, and is then applied to scans at arbitrary observing frequencies. This is called "primary referenced pointing", to distinguish it from "secondary referenced pointing" (see the next section), in which an additional pointing calibration is done at the same frequency as the main observations.

Second Order Referenced Pointing

Second order referenced pointing, also referred to as "double referenced pointing" (e.g., in the 7mm Status Summary) or "secondary referenced pointing" (e.g., in OBSERVE), was developed to refine the pointing corrections even further. Primary referenced pointing determines primary pointing offsets based on observations at some relatively low frequency, usually X band; secondary referenced pointing determines additional, presumably smaller secondary pointing offsets, based on observations at the frequency of interest. There are two reasons this might be useful. First, there may be small differences in the pointing (because of collimation differences) between the bands. Second, the smaller primary beam at higher frequencies can give more accurate pointing determinations.

The procedure is an elaboration of that for primary referenced pointing:

1. determine the primary pointing offsets at X band;
2. determine the secondary pointing offsets at the desired frequency;
3. tell the on-line system to apply both primary and secondary corrections to any number of subsequent scans on calibrator(s) and source(s) of interest;
4. if you wish to touch up the pointing after a while but feel the primary pointing offsets are still good enough, return to (2);
5. if you wish to touch up the pointing after a while and feel the primary pointing offsets are *not* still good enough, return to (1).

Second order referenced pointing is nicely adapted to observations of a single source at multiple frequencies. You might for instance determine primary pointing offsets at X band, determine secondary offsets at Q band, observe the source at Q band, determine secondary (refresh) offsets at K band, observe at K band, determine secondary (refresh) offsets at U band, observe at U band, etc.

We don't know yet whether second order works better than primary referenced pointing alone, or (if it does) how often one needs to update the secondary and the primary pointing offsets.

Useful Lore, Wisdom, and Rules of Thumb

Pointing accuracy, before and after:

Without referenced pointing, the "blind" rms pointing errors (averaged over antennas and the sky) are about 15-18 arcseconds under good weather conditions on calm nights (Newell 1983, Morris 1991). The daytime rms pointing errors are probably at least 20 arcseconds (Morris 1991; but see also Newell 1982). Drifts of up to 35-40 arcseconds, on timescales of less than 30 minutes, have been reported around sunrise and sunset (e.g., Bagri 1996). Errors on individual antennas, in some parts of the sky, can be up to about an arc minute.

Primary referenced pointing (when successful) lowers the rms pointing error to about 2 arcseconds in azimuth and 5 arcseconds in elevation, for elevations below about 80 degrees (R. Perley, M.S. Yun, priv. comm.). Above 80 degrees the pointing changes rapidly with sky position, making referenced pointing less effective. Why this is, and whether it can be corrected, is currently under study.

No firm results are available for the efficacy of secondary referenced pointing. Bagri (1996) showed that there is no systematic offset between the pointing at Q, K, and X bands.

When to use referenced pointing:

Referenced pointing should be used if the improved sensitivity (due to accurate pointing) outweighs the time lost to pointing calibration. Primary referenced pointing is essential at Q band (7mm), and probably helps at K band (1.3cm) as well. At U band (2cm) the improved sensivity roughly cancels the time spent pointing, while pointing at the longer wavelengths is generally a waste of time. The NRAO staff are still debating whether secondary referenced pointing is ever worth doing, even at 7mm.

Another case where referenced pointing may be helpful is that of high dynamic range mosaicing. Consider a source like Centaurus A, dominated by a very bright central source but with interesting, low-level extended structure. In mosaicing one observes several pointings separated by something like the half-width of the beam; this means that the points adjacent to the center would have the bright central source roughly at the half-power point. Obviously it would be useful to have all the telescopes pointed well enough that their half-power points roughly coincided, so that the relative gains of the antennas were roughly the same both at this very bright source way out in the sidelobe, and near the center of the beam where you're actually pointing. Otherwise the equivalent of calibration artifacts from the bright source will spread junk over the rest of the field. Referenced pointing would alleviate the problem by ensuring that the gains of all the antennas varied in as similar a fashion as possible across the primary beam.

How often to point up:

As a rough guide, pointing up every hour or so seems adequate, except when the temperature is changing rapidly. The most predictable instances of the latter are sunrise and sunset, around which times it is advisable to point up every half hour. See e.g. Bagri (1996) for an example of the data leading to these conclusions.

We do not yet know how often secondary referenced pointing should be done -- if it should be done at all.

Flux density required for pointing calibrator:

For successful pointing calibration at X band using the standard 10 second integrations, the pointing calibrator should be at least 0.3 Jy. Stronger is better for flux densities up to about 1 Jy; for even stronger sources, thermal noise no longer dominates the errors in the solutions. Longer integration times do increase the sensitivity as sqrt(t), assuming the phases are coherent on those timescales; shorter integration times similarly decrease it.

The required flux density for the pointing calibrator should scale roughly linearly with the VLA's sensitivity and the size of the beam, but this has not yet been measured. For now one may probably safely assume minimum flux densities of about 1 Jy at 2, 1.3, and 0.7cm. Probably this is a bit conservative at the longer wavelengths.

Note that the source must be this strong on individual baselines! The VLA determines pointing corrections using amplitudes calculated from self-calibration of the interferometric visibilities, using a point-source model. A resolved source will work less well than one which is truly point-like.

Distance from pointing calibrator:

For pointing calibration to be useful, the pointing corrections must be nearly the same for the pointing calibrator and for the source(s) to which the corrections will be applied. M.S. Yun's analysis of the regular pointing runs suggests that the pointing calibrator should be no more than 10 degrees in Az or El from the source position(s); azimuth seems to be more critical (Yun 1997). There is anecdotal evidence for up to 30arcsec pointing errors near transit, even when the pointing calibrator is within 10 degrees of the source (M.S. Yun, priv. comm.).

Clearly putting the pointing calibrator and the observed source(s) on opposite sides of the zenith is a bad idea.

Size required for pointing calibrator:

The source used for pointing calibration should obviously be small compared to the primary beam, to avoid confusing pointing errors with source structure. A more stringent limit is that there be enough flux on *individual baselines* to allow ANTSOL to find a solution; and that any structure larger than the synthesized beam should not cause significant variations in the gains reported by ANTSOL on the timescale of the pointing scan (a few minutes). These considerations imply that VLA phase calibrators suitable for the array and wavelength in question will be the most reliable pointing calibrators as well.

Pointing at high elevations:

The pointing model for the VLA is particularly bad at elevations above 80 degrees (Yun 1997), and the residual pointing errors change rapidly with sky position there as well. Furthermore diurnal source motion near zenith can lead to rapid changes in azimuth as the source transits, again giving large differences in the residual pointing errors from one moment to the next. Both the *a priori* and referenced pointing therefore do a very poor job at high elevations, though the errors made have not yet been quantified.

Effect of wind on pointing:

8 m/s (18 mph) winds give an additional pointing error of 23 arc seconds for 90% of the sky (Morris 1991). In one test run (R. Perley, priv. comm.), pointing calibration failed (no solutions for more than half the antennas) for winds this strong or stronger. Clearly one should not bother with referenced pointing in these conditions, and should also not observe at all at 7mm (Q band). The problem with 7mm observations in particular is that, with the antennas flopping about in the wind, some will be seeing the source not at the beam center but off at the half-power point; as the

pointing moves around the observed amplitude of the source will change rapidly, by large factors. In 6-8 m/s winds, that same test run found that pointing calibration was iffy -- sometime it worked, sometimes not. Pointing in slightly less strong winds worked as well as in completely calm conditions (R. Perley, priv. comm.).
Note that the wind speed is reported occasionally in the operator's log (automatically sent to the observer), and stored for each pointing scan in a computer file (see Finding Out What's Going On, below, to find out how to get this).

When pointing calibration fails:

During a pointing scan the pointing offsets are calculated by the on-line system and stored for use in future scans. Sometimes no good solutions will be found for one or more antennas. In these cases the pointing offsets for those antennas are set to zero. Primary and secondary pointing offsets are stored separately. It is quite possible for a secondary pointing scan to fail after primary pointing calibration has yielded good solutions; on such occasions the primary pointing offsets will be left as they were (i.e., non-zero), while the failed secondary pointing offsets will be zeroed.

Telling the VLA What to Do

This section is based primarily on conversations with and memos from Ken Sowinski. The latter are listed in the section on references. The "What actually happens" sections are essentially a rehash of Sowinski's memos; they are included here for completeness, and as background for the remainder of this document.

What actually happens: pointing scans

Whenever a subarray is in pointing mode, a program (PTG) is run to estimate the current pointing offsets for each antenna. The pointing scan itself consists of a series of five-point pointing cycles. The phase center of the array is kept constant at the nominal position of the calibrator. For each of the five positions, ANTSOL derives the antenna gains via self-calibration of the interferometric visibilities using a point-source model. The amplitude gains from the five ANTSOLs are collected by PTG, which derives the beam width and pointing offset in Az and El for each antenna. The offsets are considered valid and recorded only if three conditions are met:

1. There must be enough flux at each pointing, as reported for each antenna by ANTSOL, to be able to determine a statistically significant solution.
2. The offset and beamwidth that are estimated must be reasonable.
3. There must be valid solutions for both polarizations, since the offsets stored are the average of the offsets determined for each polarization.

This last condition is important if the pointing scan is done in spectral line mode: a correlator mode must be chosen that will provide at least one IF of each polarization.

The resulting beamwidths and offsets are recorded (1) in a file which may be processed off-line to determine updates to the default pointing model; (2) on paper, for inspection in real time (note that less information is reported here); and (3) in memory, so the offsets may be used to correct the pointing model for subsequent scans. Currently, by default, *none* of these records are actually sent to the observer. Eventually the procedure will be streamlined. For now, the paper versions may be obtained by putting a request under the Special Instructions section of the OBSERVE file; these will then be mailed to the observer after the run. Similarly, the observer can obtain an ASCII summary of the pointing file (with rather more information) by requesting this *before* the observing run, through the analysts (*analysts@nrao.edu*) or one of the support staff. See Appendix 1 for a description of this file.

The dwell time for a pointing scan must be long enough to allow at least one five-point cycle (no less than two minutes when using a ten second integration time). The integration time should be a multiple of ten seconds: shorter integration times will only decrease the sensitivity of the observations, not save any time, as each point in the cycle will still take 10 seconds on-source. (There are still some special cases where shorter integration times might be desirable; for instance, if the weather is so bad that the phase wraps in 10 seconds prevent ANTSOL from finding a solution. Normally one would just give up at that point, but if one's source is sufficiently strong for self calibration on those timescales, one can still obtain useful data.)

If the source used for a pointing scan is not a calibrator (i.e., the "calcode" is blank), it is forced to be a calibrator (it is given calcode 'P') so that ANTSOL will run, and we hope for the best. See the section on Lore for a discussion of what sort of sources can be used as pointing calibrators.

What actually happens: second order referenced pointing

Second order referenced pointing is described fully in Sowinski's 1996 screed, *Second Order Referenced Pointing*. Smudging over a few details, it works basically as above, except that the results are stored in a separate table in memory. The complications of second order referenced pointing within OBSERVE files are discussed below.

What actually happens: applying the pointing offsets

The pointing offsets that have been determined will be applied (1) if you ask for it, (2) if they exist, and (3) if they are not more than 12 hours old. (There is also a position test, but that is currently disabled.) These tests are applied independently for each antenna in the subarray. When referenced pointing is requested a bit is recorded on the Archive tape which describes, for each antenna, whether or not the pointing correction was applied. This bit knows only about the last pointing scan, and so will refer to the last secondary/refresh pointing scan in the case of second order referenced pointing. FILLM (as of 15OCT96) does not yet do anything with this information.

Asking for pointing offsets to be applied during a primary pointing scan is generally a *bad* idea, as the new pointing offsets determined in that scan will not be rememebered. Occasionally this mode may be useful, for instance to gauge how well referenced pointing is working, or to estimate interband collimation errors. Secondary pointing scans by definition use the existing pointing offsets.

The OBSERVE cards

The source card contains all information on referenced pointing.

- Columns 59-60 give the Observing Mode:
    - "IR" --> a pointing scan; could be either primary or secondary. In OBSERVE, set by ObservingMode = "Det. primary ref pntg", "Det. secondary ref pntng", or "Det. refresh ref pntng".

    - "IA" --> identical to "IR", but sends more output to the line printer at the VLA. In OBSERVE, set by ObservingMode = "Interf. pointing, I.F. A".
    - " " --> regular scan. In OBSERVE, set by ObservingMode "Standard Interferometer".

  There are various other possibilities as well, but these are the ones most important for referenced pointing.
- Column 69 contains a flag determining whether previously determined offsets are applied. This flag has slightly different implications depending on whether this is a pointing scan, as determined by the Observing Mode entry described above.
  Standard observations (Obs. Mode " "):
    - blank --> do not apply any previously determined offsets. In OBSERVE, set by Referenced Pointing = blank or No.
    - T --> apply previously determined offsets; if both primary and secondary offsets are available, their sum will be used. In OBSERVE, set by Referenced Pointing = Yes.

  Pointing scans (Obs. Mode "IR" or "IA"):
    - blank --> do not apply any previously determined offsets; any previously determined primary and secondary offsets will be forgotten; the offsets determined during this scan will be remembered. Should be used for primary referenced pointing. In OBSERVE, set by Referenced Pointing = blank or No.
    - T --> apply previously determined offsets; the offsets determined during this scan will NOT be remembered. *This mode should NOT be used for ordinary pointing scans!* In OBSERVE, set by Referenced Pointing = Yes.
    - S --> previously determined offsets will be applied and saved as "primary" offsets; the offsets determined during the scan will be saved as "secondary" offsets. Should be used for the first secondary pointing determination following a primary pointing determination. In OBSERVE, referred to as ObservingMode "Det. secondary ref pntng".
    - R --> any previously saved primary offsets will be applied and not changed; previously determined secondary offsets are forgotten; the offsets determined during this scan will be saved as secondary offsets. Should be used for the second and subsequent secondary pointing determinations following a primary pointing determination. In OBSERVE, referred to as ObservingMode "Det. refresh ref pntng".

Note that there is a subtle distinction between the column 69 flags "S" and "R". The former saves the previous offsets as "primary" offsets; the latter does not. This means that there should always be a mode "S" scan before any mode "R" scans. This is illustrated in the sample OBSERVE files, below.

Using OBSERVE to do referenced pointing

OBSERVE version 3.2.0 is the earliest version which knows about primary referenced pointing; version 4.0 is the earliest version which knows about both primary and secondary referenced pointing. The latest version of OBSERVE is available via anonymous ftp (ftp ftp.aoc.nrao.edu, and look in pub/observe). If you have difficulty fetching or installing it, please send email to Wes Young (*wyoung@nrao.edu*). The following discussion is based on OBSERVE 4.0. Earlier versions are similar but did not know about secondary/refresh referenced pointing.

Within OBSERVE, referenced pointing is handled on the Source page. The two important entries are (1) ObservingMode, and (2) Referenced Pointing. ObservingMode determines whether this is a pointing scan or not; Referenced Pointing determines whether any pointing offsets previously found are applied.

ObservingMode "Det. primary ref pntng" should be used for primary pointing scans; ObservingMode "Det. secondary ref pntng" or "Det. refresh ref pntng" should be used for secondary pointing scans. "Det. secondary ref pntng" sets the referenced pointing flag in column 69 to "S"; "Det. refresh ref pntng" sets that flag to "R". The difference between those two flags is discussed in the previous section -- basically the first secondary pointing scan following a primary pointing determination should use "Det. secondary ref pntng", while all subsequent secondary pointing scans should use "Det. refresh ref pntng".

Referenced Pointing can be set either to Yes or No (blank means No). If you want referenced pointing corrections applied to any regular (non-pointing) scan, set this to Yes. Otherwise, set this to No. The most common mistake is to set Referenced Pointing Yes for pointing scans: this will not affect ObservingMode "Det. secondary... or "Det. refresh ref pntng" scans, but will make ObservingMode "Det. primary ref pntng" scans useless.

The section on sample OBSERVE files gives examples of runs involving referenced pointing.

The devil's in the details

This section collects various important but arcane restrictions. See also the section on Lore for more detailed comments. Please let me know if you run across restrictions or problems not duscussed here!

Pointing scans:

- Correlator mode: must use a mode which provides at least one IF of each polarization -- even if the rest of the experiment uses only a single polarization. For primary referenced pointing one usually uses the NRAO Default XX, i.e., standard continuum observations at X band.
- Integration time: should be a multiple of ten seconds for pointing scans. Can be shorter if necessary due to rapid phase wrapping.
- Dwell time: should be enough to allow at least one full five-point pointing cycle: two minutes minimum, when using 10 second (or shorter) integration times.
- Calibrator type: need not be a calibrator, but ANTSOL must give results indicating sufficient flux for statistically significant pointing solutions. VLA calibrators are probably the safest bets, with minimum flux densities of about 0.3 Jy at X band (3.6cm), and 1 Jy at shorter wavelengths.
- Applying pointing offsets to a pointing scan: DON'T! unless you really know what you're doing.
- A mode "S" pointing scan determines secondary pointing offsets, and should occur after a primary pointing scan. If several secondary pointing scans are to be done between primary pointing scans, the first must be mode "S", and all others must be mode "R".

Referenced pointing must be turned on in all "regular" scans, in order to use the offsets determined during pointing scans. Otherwise the *a priori* pointing will be used.

Spectral line pointing and referenced pointing in multiple subarrays have various other oddities as well -- these are covered in the section on Special Cases, below.

Sample OBSERVE files

A Simple File

We want to observe a single source at K band, using referenced pointing for maximum sensitivity. We don't think secondary referenced pointing is worth it. We want to use 5 second integrations for our observations. The run might be sketched as follows:

- Primary pointing scan on flux cal. at X band: 2min10sec dwell time
- Flux cal. at K band: 3min dwell
- Primary pointing scan on phase cal. at X band: 2min10sec dwell
- Phase cal at K band: 1min dwell
- Source at K band: 9min dwell
- Phase cal at K band: 1min dwell
- Source at K band: 9min dwell
- etc.

The corresponding OBSERVE file, using default frequencies and starting on 3C286 at 16:00, would be:

```
/.ADA000
//* ***
//* *** NRAO VLA Observe Program,  Version U4bbbbb, 1996.12.29
//* ***
//* *** Observation day 57,160 at 16 00 00 LST, 1997.01.02 09:21:06 MST.
//* ***
//* *** Observer
//* ***  I. Point-Well                                          Phone
//* ***                                                  Office: 505/835-6666
//* ***                                     During observation:
//* *** E-Mail address
//* ***
//* *** Observing mode(s): Continuum
//* ***
//* *** Special Instructions
//* ***   Please send hardcopy of pointing results to the observer.
//* ***
//* ***  Date Prepared: 1997.01.02 10:47:03 MST.
//* ***
//* Primary pointing scan: flux cal
1328+307      16 03 11 13 28 49.6579 +30 45 58.641     XX IRA   0000
//DS            10
//* Flux cal
1328+307      16 06 34 13 28 49.6579 +30 45 58.641     KK   A   0000T
//DS             5
//* Primary pointing scan: source/phase cal
1624+416      16 11 51 16 24 18.2505 +41 41 23.552     XX IRA   0000
//DS            10
//* Phase cal
1624+416      16 13 16 16 24 18.2505 +41 41 23.552     KK   A   0000T
//DS             5
//* Source
N6145         16 22 38 16 23 21.6000 +41 03 35.000     KK       0000T
//DS             5
//* Phase cal
1624+416      16 24 04 16 24 18.2505 +41 41 23.552     KK   A   0000T
//DS             5
//* Source
N6145         16 33 29 16 23 21.6000 +41 03 35.000     KK       0000T
//DS             5
//* Phase cal
1624+416      16 34 58 16 24 18.2505 +41 41 23.552     KK   A   0000T
//DS             5
//* Source
N6145         16 44 23 16 23 21.6000 +41 03 35.000     KK       0000T
//DS             5
```

```
etc.
```

Notes:

- The pointing scans use 10 second integrations, while the ordinary scans can use whatever is desired (in this case, 5 seconds).
- The pointing scans do NOT have a T after the bandwidth code: referenced pointing is turned OFF during primary pointing scans.
- The pointing scans have dwell times (taking data) of 2min10sec, a bit longer than the required 2min just to be certain.
- The "special instructions" section must specifically ask for pointing results to be sent to the observer; otherwise the printed results will vanish, at least from the observer's perspective.

Secondary Referenced Pointing

Let's say we want to map the continuum from 3C84 at 7mm, over the entire VLA primary beam. We want to do secondary referenced pointing, in hopes that will help the 7mm sensitivity, and because the field is large enough that it matters whether the half-power points of the different antennas' primary beams coincide. We also want to be sure that the phase does not wrap significantly during an integration, so we use 3 second integrations throughout, even for the pointing scans (otherwise ANTSOL might fail due to the phase wrap). The plan then is something like

- Primary pointing scan on flux cal. at X band: 2min10sec dwell time
- Secondary pointing scan on flux cal. at Q band: 2min10sec dwell time
- Flux cal. at Q band: 3min dwell
- Primary pointing scan on source at X band: 2min10sec dwell
- Secondary pointing scan on source at Q band: 2min10sec dwell
- Source at Q band: 10min dwell
- Refresh pointing scan on source at Q band: 2min10sec dwell
- Source at Q band: 10min dwell
- Refresh pointing scan on source at Q band: 2min10sec dwell
- Source at Q band: 10min dwell
- etc.

The corresponding OBSERVE file, using default frequencies and starting on 3C84 at 03:00, would be:

```
/.AP0001  115
//* ***
//* *** NRAO VLA Observe Program,  Version U4bbbbb, 1996.12.29
//* ***
//* *** Observation day 57,160 at 03 00 00 LST, 1997.01.01 20:23:14 MST.
//* ***
//* *** Observer
//* *** Rick Perley                                                Phone
//* ***                                                Office: 505-835-7312
//* ***                                  During observation: 505-835-3317
//* ***
//* *** E-Mail address
//* *** rperley@nrao.edu
//* ***
//* *** Observing mode(s): Continuum
//* ***
```

```
//* *** Special Instructions
//* *** This file is for Subarray #1.  Put the Q-band antennas in this
//* *** subarray.  Ensure the first pointing scan completes before progressin
//* *** Please send all printouts to Rick Perley.
//* ***
//* ***
//* ***  Date Prepared: 1997.01.02 14:30:05 MST.
//* ***
//* Primary pointing scan for 3C84
0319+415      03 05 00 03 19 48.1601 +41 30 42.106C    XX IRA   0000  24.00
//DS             3
//* Secondary pointing scan for 3C84
0319+415      03 07 30 03 19 48.1601 +41 30 42.106C    QQ IRA   0000S
//DS             3
//* source scan on 3C84
0319+415 10   03 17 50 03 19 48.1601 +41 30 42.106C    QQ   A   0000T
//DS             3
//* Refresh pointing scan on 3C84
0319+415      03 20 20 03 19 48.1601 +41 30 42.106C    QQ IRA   0000R
//DS             3
//* source scan on 3C84
0319+415 20   03 30 40 03 19 48.1601 +41 30 42.106C    QQ   A   0000T
//DS             3
//* Refresh pointing scan for 3C84
0319+415      03 33 10 03 19 48.1601 +41 30 42.106C    QQ IRA   0000R
//DS             3
//* source scan on 3C84
0319+415 30   03 43 30 03 19 48.1601 +41 30 42.106C    QQ   A   0000T
//DS             3
//* Primary pointing scan for 3C84
0319+415      03 46 00 03 19 48.1601 +41 30 42.106C    XX IRA   0000  24.00
//DS             3
//* Secondary pointing scan for 3C84
0319+415      03 48 30 03 19 48.1601 +41 30 42.106C    QQ IRA   0000S
//DS             3
//* source scan on 3C84
0319+415 10   03 58 50 03 19 48.1601 +41 30 42.106C    QQ   A   0000T
//DS             3
//* Refresh pointing scan on 3C84
0319+415      04 01 20 03 19 48.1601 +41 30 42.106C    QQ IRA   0000R
//DS             3
//* source scan on 3C84
0319+415 20   04 11 40 03 19 48.1601 +41 30 42.106C    QQ   A   0000T
//DS             3
//* Refresh pointing scan for 3C84
0319+415      04 14 10 03 19 48.1601 +41 30 42.106C    QQ IRA   0000R
//DS             3
//* source scan on 3C84
0319+415 30   04 25 00 03 19 48.1601 +41 30 42.106C    QQ   A   0000T
//DS             3

etc.
```

Notes:

- The pointing scans use 3 second integrations to allow for very rapid phase wraps at 7mm. The scan still has to last at least 2mins. Using 3 second averages gives lower sensitivity than the usual 10 seconds, but 3C84 is ridiculously strong (24 Jy at 3.6cm, 10.5 Jy at 7mm) so it doesn’t really matter.
- Note the use of secondary and refresh referenced pointing, as seen in the use of "S" and "R"

after the bandwidth code on the source cards. Secondary ("S") pointing scans occur just after primary pointing scans, with refresh ("R") pointing being used for subsequent pointing updates. There is probably no need to do another primary pointing at all, given how often secondary/refresh pointing is done; here the observer is being somewhat cautious.
- As above, the "Special Instructions" section asks explicitly that pointing results be sent to the observer. Here the observer has also requested that the first scan be extended as long as necessary to get a good pointing solution; otherwise, if the previous observer left the array 180 degrees from 3C84, the first pointing might never get done, which would probably lead to the secondary pointing failing as well.

Finding Out What's Going On

As mentioned above, various subsets of the pointing scan results are kept in three places: on paper at the VLA site; in a file on one of the online computers; and in computer memory for use when requested by subsequent scans.

Currently one must be in New Mexico to see the pointing solutions in real time. If you want to poke around from Socorro, consult one of the local pundits (see the section on Help!). At the VLA site, the number of antennas which fail to point up is printed out in real time for each pointing scan, so you have some idea how you're doing, but not what the actual pointing offsets are. Using observing mode IA, the pointing offsets and beam sizes are also printed. If you're pointing up in several subarrays at once this can get rather confusing...

After the observations, the printouts from the site will be mailed to the observer, if that has been requested in the Special Instructions section of the OBSERVE file. A text version of the computer file can also be sent; this should be requested well *before* the observing run, by emailing the analysts (*analysts@nrao.edu*) or one of the support staff. A sample of this computer listing is given in Appendix 1. Basically it gives the numbers of antennas which did and did not point successfully; the beamwidths and pointing offsets derived for those which did; and a few useful tidbits about the weather, including the wind speed.

Eventually FILLM should be modified to notice the referenced pointing flag bit set by the online system, but this is a ways off yet. At some point the online system will also be modified to make the pointing results easier to access; this again will be a while.

Special Cases

- Multiple subarrays: pointing simultaneously in multiple subarrays now works. However, there are still a few hazards.
  - The first subarray determines integration times; so if you're pointing in subarray 2, you should be sure the integration time in subarray 1 is a multiple of 10 seconds.
  - The correlator requires that all subarrays must be in continuum, or all subarrays must be in spectral line modes. This may force you to point up in spectral line mode. Note that there are some odd correlator restrictions on bandwidths in the various subarrays -- see Sowinski's

memo on *Some Issues for Q Band Observing*.

- Spectral line pointing: this works, but has seldom been used. Contact the analysts (*analysts@nrao.edu*) before doing anything rash! In general pointing is better done in continuum mode.
  - Pointing scans require good results from *both* polarizations. Any spectral line mode used for pointing must include at least one IF of each polarization.
  - A pointing scan may use different bandwidths for the different IFs.
  - In spectral line mode, the pointing solutions will be based on the "Channel 0" data, corresponding to the inner three-quarters of the requested total bandwidth. Obviously this means the pointing calibrator has to be even stronger than usual. One *cannot* request that pointing be done using a particular channel, e.g. for a maser source; at best one can only narrow the total bandwidth as much as possible.
  - There is a factor two difference in the required flux levels for spectral line and continuum pointing, in the sense that the source flux must be *a factor two stronger* to successfully point up in spectral line mode. Since the sensitivity will also be lower, due to the decreased bandwidth, pointing calibrators must be quite strong to be useful in spectral line mode.
- VLBI: referenced pointing can certainly be used in VLBI experiments, and at the highest frequencies undoubtedly should be.
  - Walker's sched program knows about primary referenced pointing and applying pointing offsets; the relevant commands are PEAK and NOPEAK. See the sched manual for details.
  - PTG also has a "2-antenna mode" that allows pointing corrections for VLBI observations using only a single VLA antenna. This is invoked just like primary referenced pointing, but for a single-antenna subarray. Since the VLA points up using interferometric data, a reference antenna is "stolen" from the main array, and the pointing is done based on the change in amplitudes on that one baseline as the VLBI antenna moves through the five points. Talk to a pundit for details.

Help!

For more detailed information or more lucid explanations, talk to Chris Carilli (*ccarilli@nrao.edu*), Michael Rupen (*mrupen@nrao.edu*), or Greg Taylor (*gtaylor@nrao.edu*).

References

This document is based on discussions with local pundits, particularly Bryan Butler, Chris Carilli, Frazer Owen, Rick Perley, Bill Sahr, Ken Sowinski, Wes Young, and Min Su Yun; as well as on the references given below.

Bagri, D.S. 1996. *VLA Test Memo No. 199: Antenna Pointing.*
...test observations of VLA and VLBA pointing variations in Nov-Dec 1995

Carilli, C. 1996. *VLA 7mm System Status*.
...includes hints and suggestions for 7mm pointing, and a sample OBSERVE file

Kestevan, M. 1994. *VLA Test Memo No. 183: Reference Pointing and the Pointing Mode.*
...mostly deals with the (old) pointing model; some discussion of referenced pointing tests, and

whether second order referenced pointing is necessary
Newell, R.T. 1982. *VLA Test Memo No. 138: Antenna Thermal Insulation.*
...gives day/night pointing results for two antennas
Newell, R.T. 1983. *VLA Test Memo No. 142: Discussion of VLA Pointing.*
...review of pointing procedures and results from the good ol' days
Morris, D. 1991. *VLA Test Memo No. 182: A Review of VLA Pointing.*
...summary of "blind" pointing characteristics; analysis of sources of errors, with particular attention to the effects of wind
Sowinski, K. 1995. *Some Issues for Q Band Observing*.
...includes the basic discussion of how to use referenced pointing
Sowinski, K. 1996a. *Second Order Referenced Pointing*.
...the basic discussion of second order referenced pointing; includes very clear explanations of what the OBSERVE cards actually mean
Sowinski, K. 1996b. *VLA Online Software Update of December 4, 1996*.
...corrected a few bugs in pointing calibration
Yun, M.S. 1997. *VLA Pointing Update*.
...a description of the improved VLA pointing model, implemented in November 1996, and the resulting pointing errors as functions of (Az, El). To be released Real Soon Now.

Appendix 1: Sample Pointing Output

The text printed out in real-time at the site simply reports the number of antennas which have successfully pointed up, and lists those antennas which have not. If multiple subarrays are pointing up at the same time, the output from the various subarrays will be interleaved in some random fashion.

The file emailed to the observer (if requested) is more substantial, and more helpful. The following gives part of the pointing output from a 7mm run. The content and format may change significantly with time. Lines beginning with *** are comments -- they do not appear in the actual listing.

Note that primary and secondary pointing results are *not distinguished* in this listing; you have either to compare the reported time with the OBSERVE file, or to check the observing band.

```
file: mrupen1.ptg.96.12.20

-----------------------------------------------------------------
sub 1


The file to be viewed is: *BOSS0!H0/PTG_1/96_355_06:44/OFFSETS
Continue ? (Y or N):
y
        Dts            Source    B  Crmode
//OFS1  96 355 06:46   0112-017  X  Continuum
*** OFS1: year, DOY, time, source, obs. band, and obs. mode (cont./line)
        Date               LST          LST
//OFS2  96DEC20 06:46      1.449635    5h32m13.09s
       Dts             Wndspd   Wnddir     Temp    Barom  Dew Pnt
//WX1  96 355 06:46      2.18   255.78    -5.66   790.64   -15.31
*** WX1: reliable weather information from the control building.
***   The most interesting number is the windspeed [m/s], here measured
```

```
***   during the central pointing.
       Dts            Blk Ball Wht Ball     Diff   Wspmax   Wsprms
//WX2  96 355 06:46     -9.81   -12.82     3.15     2.50   0.2750
*** WX2: more weather information from the control building.
***   The max. wind speed and wind speed rms [m/s] are determined over the
***   entire pointing scan.

//SUB  1 OBSERVE FILE: 147K432A
//SUB  2 DATA FILE: *BOSS0!H0/PTG_1/96_355_06:44
//SUB  3 SUBARRAY #:  1
//SUB  4 SUBN:  13
*** SUBN: number of antennas in subarray
//SUB  5 SUBIDS1:  3  4  6  8 11 12 13 14 16 20 22 25 27 -1
//SUB  6 SUBIDS2: -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
//SUB  7 REFN:   0
*** REFN: VLBI reference antenna(s).  Not important for pointing scans.
//SUB  8 REFIDS1: -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
//SUB  9 REFIDS2: -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
//SUB 10 GOODN:  13
*** GOODN: number of antennas giving good PTG solutions
//SUB 11 GDIDS1:  3  4  6  8 11 12 13 14 16 20 22 25 27 -1
//SUB 12 GDIDS2: -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
//SUB 13 BADN:   0
*** BADN: number of antennas giving bad PTG solutions
//SUB 14 BADIDS1: -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
//SUB 15 BADIDS2: -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
//SUB 16 ANTNR:  3  AZ: -106d 23m 12.7s  EL: 20d 13m 7.0s
*** ANTR: the Az and El of a representative antenna (here, #3).
//SUB 17 SINA: -0.9594 COSA: -0.2821 SINH:  0.3456 ABS(COSH):  0.9384
*** SINA etc: sines and cosines of that Az and El
```

Offset Records for dts = 96 355 06:46

#		Elpt	Elbm	Azpt	Azbm	Power	O	S	W	Wsp1	Wsp2
3	R	0.334	1.100	-0.030	1.058	0.096	F	F	R	0.00	0.58
3	L	0.006	1.122	0.002	1.075	0.096	F	F	R	0.00	0.58
4	R	0.129	1.089	-0.056	1.072	0.096	F	F	R	1.50	-0.04
4	L	-0.163	1.102	-0.134	1.096	0.097	F	F	R	1.50	-0.04
6	R	0.168	1.096	0.019	1.080	0.121	F	F	R	-0.38	-0.34
6	L	-0.158	1.061	0.037	1.081	0.119	F	F	R	-0.38	-0.34
8	R	0.351	1.099	0.100	1.089	0.095	F	F	R	0.98	0.74
8	L	0.087	1.082	0.051	1.065	0.096	F	F	R	0.98	0.74
11	R	0.197	1.070	0.072	1.072	0.095	F	F	R	0.00	0.00
11	L	-0.143	1.074	0.043	1.064	0.095	F	F	R	0.00	0.00
12	R	-0.193	1.096	-0.061	1.095	0.095	F	F	R	1.50	5.16
12	L	-0.493	1.081	-0.132	1.098	0.095	F	F	R	1.50	5.16
13	R	-0.376	1.097	-0.003	1.076	0.095	F	F	R	-0.02	2.79
13	L	-0.678	1.071	-0.002	1.071	0.092	F	F	R	-0.02	2.79
14	R	-0.056	1.066	0.031	1.114	0.097	F	F	R	0.00	0.00
14	L	-0.392	1.080	0.023	1.111	0.095	F	F	R	0.00	0.00
16	R	0.314	1.082	0.095	1.107	0.094	F	F	R	0.04	0.04
16	L	0.028	1.085	0.055	1.109	0.095	F	F	R	0.04	0.04
20	R	0.063	1.077	0.089	1.100	0.094	F	F	R	0.00	-0.04
20	L	-0.226	1.090	0.050	1.083	0.093	F	F	R	0.00	-0.04
22	R	0.379	1.086	-0.107	1.078	0.096	F	F	R	0.07	4.00
22	L	0.139	1.088	-0.157	1.092	0.096	F	F	R	0.07	4.00
25	R	0.327	1.068	0.005	1.081	0.095	F	F	R	2.59	2.41
25	L	0.013	1.060	-0.070	1.078	0.095	F	F	R	2.59	2.41
27	R	0.077	1.084	0.049	1.100	0.094	F	F	R	0.51	0.00
27	L	-0.215	1.088	-0.054	1.078	0.097	F	F	R	0.51	0.00

```
*** Fields are: antenna #; pol'n;
***   pointing offset in elevation [arcmin];
```