NATIONAL RADIO ASTRONOMY OBSERVATORY
MEMORANDUM

DATE: January 26, 2001
TO: Pointing/Focus Handling Committee
FROM: Ron Maddalena
SUBJECT: Scenario for the early commissioning pointing/focus observations

An action item from the January 23 meeting of the Pointing/Focus Handling Committee was for me to write a scenario that describes the pointing and focusing observations and data reduction we will use during only Phase I and II of commissioning. As such, I am not covering our needs for Phase III commissioning.

Much of this material is already well covered in a memo I wrote years ago that is available at: http://www.gb.nrao.edu/~rmaddale/GBT/Allsky2.html. I suggest you review the ideas covered there before reading this memo.

I've broken down the scenario into three major areas of (I) individual pointing observations, (II) all-sky pointing observations, and (III) focus observations. Each area is further broken down into specifying (a) observations, (b) observing techniques and real-time data analysis, and (c) off-line data analysis.

I. Pointing -- Individual/Interactive Observation

I.a. Specifying Observations

Individual pointing observations are the atoms from which all-sky pointing and focus measurements will be made. Both all-sky and focus observations will bundle together individual observations and will be mostly an automated process that would require observing files and scripts. However, individual pointing observations will be useful for one-time only diagnostics or for determining local pointing offsets. As such, an observer should be able to also specify a pointing observation without having to bother with creating an observing file. Thus, observers must be able to specify individual pointing observations either through observing files or interactively through GO.

The parameters that must be specified for a single pointing observation include:

- Source name (for data base queries and for any efficiency measurements made with the data)
- Source position and coordinate system (if not available from a catalog)
- Parameters for the observing technique that will be frequency/beam-size dependent. If I assume we'll be using the OTF cross-scan method described below, these parameters are:
    - Slew rates in the two cardinal directions of the cross-scan.
    - Extent of the slew in the two cardinal directions of the cross-scan. One should be able to specify whether the extent of the slew in the Az/RA/Long direction is corrected by secant(EL/Dec/Lat)
    - Sampling rates
    - (Optional) Whether the slewing will be in the same coordinate system as the source positions or in AZ or EL.

I.b. Observing Technique and Near Real-Time Data Reduction

The steps in a pointing observation are:

- GO commands the M&C system to perform an E-W OTF slew observation through a commanded source position using the appropriate parameters specified by the user. GO waits for M&C to finish the observation.
- GO commands the M&C system to perform a W-E OTF slew observation through a commanded source position. GO waits for M&C to finish the observation. [The order of these observations is not important.]
- Aips++ catches the end of these observations and performs near real-time data analysis. More details of the data analysis can be found at http://www.gb.nrao.edu/~rmaddale/GBT/Allsky2.html but, in summary, for each of the two observations, Aips++ will:

    - Automatically determine to which channels to fit a baseline;
    - Fit and remove a low-order baseline;
    - Determine the position of the peak emission and the half-power points of the peak;
    - Fit a Gaussian between the half power points
    - Determine the offset of the Gaussian center from the catalog source position in both sky coordinate directions.
    - Aips++ displays the base-lined data with an overlay of the Gaussian fit plus the resulting height, width, center, offsets, Chi Square, and standard deviations.

- The results from the two observations are averaged and delivered to GO as a delta Az and delta El; GO then applies the offsets. (GO possibly could have an option that specifies whether the user/operator will be asked whether they should apply an offset or whether the offset is automatic applied without user intervention.) Or, until we can get the interaction between Aips++/GO working, the results could be displayed for the operator and the operator will type them into GO. Probably the results of the fit, and all necessary, ancillary data (see my memo) should be logged to a file for further analysis.
- GO commands the M&C system to perform an N-S OTF slew observation through a commanded source position. GO waits for M&C to finish the observation.
- GO commands the M&C system to perform an S-N OTF slew observation through a commanded source position. GO waits for M&C to finish the observation. [The order of these observations is not important.]
- Aips++ performs the same data reduction as for the E-W and W-E observations. The results are similarly applied using GO.

It would be nice but not imperative that the GO script, if interrupted, can repeat the second half (N-S, S-N) part of the observing script.

II. Pointing -- All-sky Observation

The all-sky pointing part of the scenario is, I think, almost completely explained in http://www.gb.nrao.edu/~rmaddale/GBT/Allsky2.html. I will only summarize the important points from this memo.

II.a Specifying Observations

- Observers will need to specify the same set of parameters as described in I.a.
- Observing will be done though observing files only and will be toward multiple sources distributed across the sky.
- The best sampling is not necessarily uniform but depends upon the expected pointing model.
- A tool to help create the observing file would be useful.

II.b. Observing Technique and Near Real-Time Data Reduction

- The observing file, for each source in the file, will call the observing script described in I.b. above.
- Aips++ will perform the real-time data analysis described in I.b above.
- GO or the operator will apply pointing offsets in the same manor as described above.

II.c. Off-line Data Reduction

Off-line data reduction fits an all-sky function to the offsets determined from an all-sky observing run. For the most part, the above-mentioned memo fully describes the analysis. The offsets used in the all-sky fit could be those determined as part of the real-time data analysis. But, we will also frequently want to re-analyze the all-sky data using methods that are identical or more sophisticated than the real time analysis (e.g., using template fitting instead of Gaussian fitting). For now, we can ignore sophisticated routines but require a way to off-line analyze pointing data using the same algorithms as in the real-time analysis.

My impression is that TPOINT will make a most satisfactory tool for performing the all-sky fit once offsets are determined..

Note that embedded in the fitted Gaussian heights and widths (or the results of the template fitting) is information on the telescope beam and aperture efficiency. Other offline tools, which are beyond the scope of this memo, will be used to derive these important telescope characteristics.

III. Focus Fitting

We will probably use at least two techniques for focus fitting, one for low and the other for high frequencies. The only difference between techniques will be in off-line data reduction.

III.a Specifying Observations

Observations will be done either interactively or through observing scripts. In addition to the parameters described in I.a, observers will specify:

- The focus coordinate system they will want to explore (i.e., F1/F2, XYZ, or Actuator encoder).
- The axis they want to explore in that system (i.e., F1-X if using F1/F2 system).
- The range of focus values they want to explore along that axis (e.g., from -200 to +200 mm).
- The resolution along that axis at which measurements will be made (e.g., every 10 mm)
- A value for the focus offsets to use and keep constant for the other axes in that system (e.g., F1-Y, F1-Z, F2-X, F2-Y, and F2-Z)

III.b. Observing Technique and Near Real-Time Data Reduction

The observing technique entails:

- Moving the focus along the specified axis to the first value in the desired range of focus values.
- Performing the pointing measurements and Aips++ analysis described in I.b.

- The focus is moved along the specified axis by the specified resolution.
- Repeating the last two steps until the focus position reaches the last value in the specified range of values.

We can further package this set of observations in a few ways:

- One could repeat the above observations on the same source to examine how the focus changes along a single axis as a source rises or sets.
- One could repeat the above observations on the same source but vary the axes of interest (e.g., first explore F1-X, then F1-Z, then F2-X, then F2-Z, etc.). The axes of interest usually will not be all of the available axes (e.g., do not explore F1-Y and F2-Y)
- One could repeat the above cycle of axes to examine how the focus changes along a set of axes as a source rises and sets.

III.c. Off-line Data Reduction

For Phase I and probably Phase II commissioning, we will analyze each focus axis separately. The analysis will be simple at low frequencies since we do not expect the position of best focus to measurably change with elevation. At high frequencies, the analysis is a bit more complicated.

III.c.i Single elevation data reduction (low frequency)

For a single elevation, the item of interest will be a 1-dimensional plot of the fitted Gaussian heights (y-axis) versus focus offset (x-axis). Typically, the shape of the focus gain curve is known theoretically and is expected to be asymmetric. As such, Aips++ should use the theoretical curve and template fitting to determine (i) the focus offset that produces the maximum fitted height and (ii) an interpolated value of the expected height at that offset.

III.c.i Multiple elevation data reduction (high frequency)

If measurements for a single axis were made for a range of elevations, the item of interest will be a contour or similar plot of fitted heights (z-axis) versus focus offset (x-axis) and elevation (y-axis). To understand the analysis, one must have a picture of what this plot will look like:

- At any elevation, the 1-dimensional cross section of the plot should be the theoretical asymmetric focus gain curve shifted in focus offset and scaled in height.
- The focus offset position of maximum height should vary smoothly from the lowest to highest elevation.
- The maximum height should vary smoothly from the lowest to highest elevation.

Thus, the plot would be similar to a topographic contour map of an asymmetric, almost north-south hill whose height varies slowly with latitude and whose crest changes smoothly with longitude.

In summary, the crest of the curve maps out the focus offset that produces the highest telescope gain. The change in crest at different focus offsets is the change of position of best focus offset (best gain) with elevation. The change in crest at different telescope elevations is the change of telescope gain with elevation.

The determination of best focus offset as a function of elevation can be derived by fitting a surface to the above plot. Probably as high as 40 GHz we can model the gain of the telescope as a function of elevation with A + B*Cos(El) + C*Sin(El). Likewise, the focus offset that produces maximum gain can probably be modeled by O + M*Cos(El) + N*Sin(El). Let the theoretical focus gain curve along an axis be TEMPLATE[OFFSET] where OFFSET is the focus offset position. The surface that Aips++ will need to fit is:

$$\{ A + B*Cos(El) + C*Sin(El) \}*\{ TEMPLATE[OFFSET + O + M*Cos(El) + N*Sin(El)] \}$$

where A, B, C, M, N, and O are the parameters to fit. Note that each coordinate system and each axis in those systems will have different templates. Aips++ must either maintain a complete set of templates and be able to switch to the appropriate template automatically or the user will supply the template.