VLBA TEST MEMO 75

Determining Rail Behavior From Pointing Measurements

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It is clear from examining the plots in VLBA Test Memo 74 that there are short timescale variations in pointing that reproduce well from day to day. These are surely the reflections of short spatial scale variations in the track height. The rail height correction software is not doing its job at some stations. There are also logistical problems with rail height measurements. These are traditionally taken by looking at a scale sitting on the rail with a theodolite. This is supposed to be done as part of the tiger team visits. So at each station, the rail is measured about every two years. These measurements are then processed by fitting a mean tilt, and by converting the measurements to millimeters. These measurements are inserted into a database. Values are retrieved at observe time, and the rail heights at the locations of the mount wheels are used to calculate azimuth and elevation offsets which are applied to the antenna pointing. Somewhere, this chain is currently disrupted, and new rail height measurements have not been installed in the database for two or three years. There have also been cases of repairs to the grout supporting the rail, which may change the rail height, either per se or effectively by changing the stiffness.

For these reasons, it is worth considering determining the rail height more directly, via on-sky pointing measurements. Again, Memo 74 gives some confidence that this can work. From agreement between adjacent measurements we can see that the attainable precision is of order three arcseconds, and the day to day repeatability is not much worse.

I also recommend a change in the pointing model, so that corrections flow more directly from the measurements to the parameters to the corrections. To start from scratch for a model, we separate the effect of the mount from the effects of the track. The parameters associated with the mount are:

Tilt North
Tilt West

Axis Perpendicularity	
Azimuth Encoder Zero	
Elevation Encoder Zero	
Subreflector Sag	
Encoder Centering errors	For elevation and azimuth encoders
Elevation Collimation Offsets	(for each feed)
Azimuth Collimation Offsets	(for each feed)

Some of these are redundant. Adding a number to the Elevation Encoder Zero and subtracting the same number from the Elevation Collimation Offsets leaves no change. Similarly, the cosine component of the Elevation Encoder Centering Error has the same functional form as the Subreflector Sag term, and only one need be solved for.

The remaining pointing effects are presumed due to the track. The Tilt North and Tilt East might also be allocated to the track, but as a matter of convenience it is nice to have them available when solving for mount parameters. As noted below, determining the offsets due to rail height variation by on-the sky pointing measurements is an expensive operation. It is convenient to have these tilts available to bridge small changes between infrequent complete determinations.

Instead of solving for wheel positions from the observations, I propose to resolve them onto an intuitive basis, which helps in thinking about them. There are four wheels. Raising (or lowering) all four wheels produces no change in pointing. We therefore need three rail effects to describe the net pointing. These effects are illustrated in the figure on the next page, a sketch representing the antenna base, with the antenna (not shown) at the top of the figure. The effect illustrated in panel B is a tilt of the antenna, by, for instance, raising the two back wheels. Let us call that the fore-aft tilt, and represent it below by the symbol H. This affects only elevation, not azimuth. The sideway tilt depicted in panel C, called T below, affects only azimuth, not elevation. The situation depicted in panel D I have called ‘rack’ and denote it by R. It represents a bending of the antenna structure; if the elevation bearings may be thought of as supported by A frames running to the wheels, one A frame is bent forward, the other is bent backward. This distortion does not affect elevation offset, only azimuth. H, T, and R are, obviously, functions of azimuth. With the usual symbol for azimuth and zenith distance, A and z, one sees by inspection, that the pointing offsets are given by the following equations.

$\Delta El = H(A)$

$\Delta Az = T(A)\cos(z) + R(A)\sin(z)$

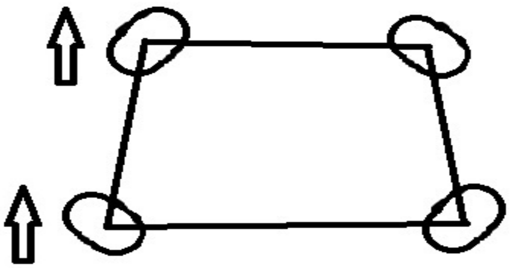
There are symmetry relations, assuming only that rail flexure is independent of azimuth. This in fact does not appear to hold, but it is a good starting point. The first two arise from reversing the telescope.

$H(A) = -H(A+180\text{degrees})$

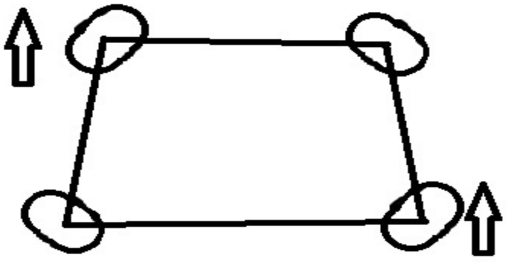
$R(A) = R(A+180\text{degrees})$

And one nearly as good, neglecting the difference in rail flexure between the front and back wheels.

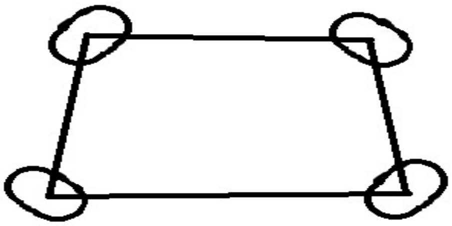
$T(A) = H(A+90\text{degrees})$



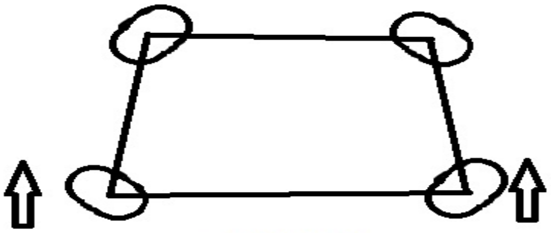
C - Sideways Tilt



D - Rack



A

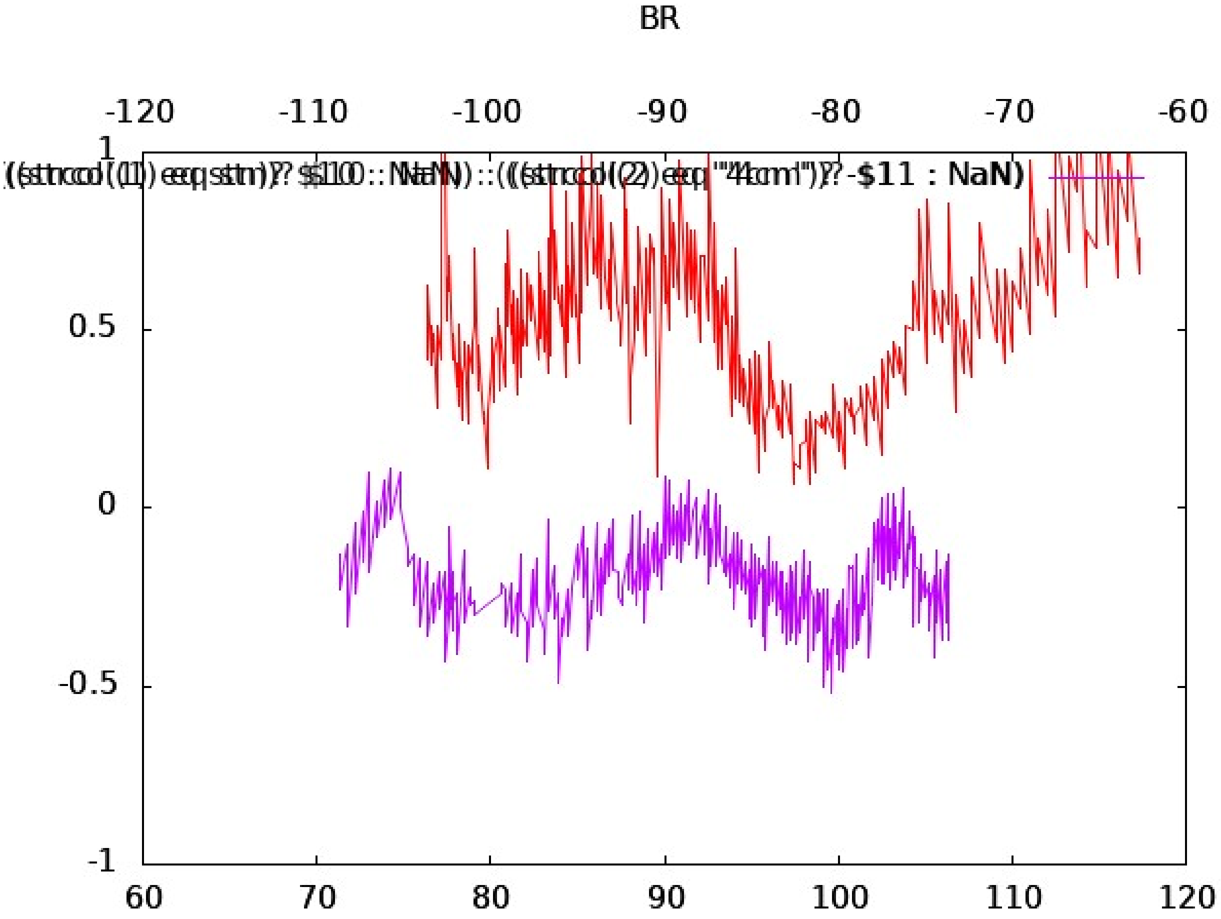


B - Fore-aft Tilt

With the symmetries above, one need only measure the pointing over a half circle, not the full azimuth range. This is still a substantial investment of time. In the most favorable case (BR because of its high latitude) it requires an observation of 5 hours and 20 minutes to cover 180 degrees if azimuth. And this may need to be done separately for each station, because doing it on a single source simplifies the concept, and is in fact the only way I have tested this stability.

There are also parameters in the current model that are irrelevant with this approach, and I propose to eliminate them. The current model absorbs as part of the mount model terms of sine and cosine of twice the azimuth, (some call this term the potato chip distortion) due to the track. This can be absorbed directly into the track measurement. It could also be argued that the tilt parameters could be absorbed into these rail behavior measurements. I have refrained from doing so. The rail measurements are so expensive in observing time that they should be done only every year or two. It is convenient to have those parameters available for more frequent adjustments to roughly accommodate any changes which occur on months to year timescales.

A test was done of how well this approach might work by observing two segments of pointing separated by 180 degrees at BR. In particular, the elevation error, if due to track unevenness, in the west should be the negative of the elevation in the east. The figure below makes this comparison. The red trace (data taken in the east) plots elevation error as a function of azimuth, using the azimuth scale at the bottom of the figure. The blue trace (data taken in the west) plots elevation error as a function of azimuth, using the azimuth scale at the top of the figure, and with the vertical scale inverted. The general similarity of the two traces is obvious. The vertical separation between the two traces corresponds to an elevation collimation error of 0.2 arcminutes. The fact that the two traces are not exactly the same I can only attribute to slightly different flexures at the two azimuths. The two traces are sufficiently similar that appreciably better pointing would be achieved by implementing a correction given by the formulas above.



As mentioned above, a substantial amount of observing time is required to determine the rail parameters. To get a full 180 degree swing of azimuth, one must choose a source which passes south of the zenith at the station in question. The closer to the zenith it passes, the less time is needed to get 180 degrees of azimuth. But too close to the zenith makes the points near the meridian too widely spaced in azimuth. Keeping to the three degree spacing of points used by the rail height measurements, the standard 72 second pointing cycle requires an azimuth rate no faster than 2.5 degrees per minute, or ten times sidereal; the source may pass no closer than 5.6 degrees to the zenith. This condition is nicely met by the source used to make the above plot, 1030+405, passing 7.6 degrees south of the zenith at BR. I propose to initiate use of these observation derived corrections by scheduling a long observation of this source, and using it to produce the corrections for BR.