EVLA Memo 108

LO/IF Phase Dependence on Antenna Elevation

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Abstract

EVLA test observations revealed interferometric phase changes that track EVLA antenna elevation motion. These phase changes are not corrected by the Round Trip Phase Measurement system. In January and February of 2007, three EVLA antennas were placed into a subarray to locate and isolate the source(s) of this effect.

Laboratory tests have duplicated the effects seen on the antennas, and are allowing closer inspection of the mechanisms responsible for the phase dependence on elevation angle.

Test methods, results and conclusions are discussed, and specific EVLA electronic modules are considered for modification to eliminate this effect.

Keywords: phase stability, EVLA modules, elevation, phase, temperature

Introduction

VLA/EVLA baseline observations have revealed interferometer phase changes that correlate to the elevation angle of EVLA antennas. Antenna position offsets were found to be responsible for a portion of this effect, but up to 60^{o} of phase change with elevation remains that is otherwise uncompensated.

These changes are independent of the fiber delay as measured by the Round Trip Phase Monitor. The fiber delay changes rather predictably as diurnal changes in air temperature and annual changes in ground temperature affect the effective optical length of the LO transmission fibers. The Round Trip Phase Monitor is capable of correcting these delay changes to the outbound LO signal. Phase changes that are not attributable to LO transmission path effects are not corrected by the Round Trip Phase Monitor.

Covering January 22 – 30 and February 13 - 16, 2007, a subarray of three EVLA antennas was employed for the purpose of isolating the phase-versus-elevation effect. One antenna (18) was fixed in elevation while two others (24 and 26) were slewed in elevation as a linear ramp with a period of approximately 18 minutes.

Once the modules of interest had been identified in the antenna, a laboratory setup was constructed that allowed tipping of one to six individual modules. This device, the "Tilt-a-Rack", incorporates two standard EVLA module bins, cooling fans, a network switch and power supply. By locking in either a vertical or horizontal position, it allows measurement of the phase and thermal step responses to elevation changes.

On-Antenna Tests

The first round of testing, from January 22 – 30, 2007 was aimed at duplicating the phase dependence on elevation and eliminating the front ends as the source of the effect. This consisted of two tests:

Test 1a. Data from nearest baseline on-sky observations for the three antennas under test, showing the phase variation, and

Test 1b, 1c, and 1d. A series of Local Oscillator/Intermediate Frequency-only tests, which would eliminate the Front Ends as the cause of the effect. This test involved three simultaneous measurements aimed at isolating the module or modules responsible.

The second round of testing, from February 13 - 16, 2007 included only two antennas, 18 and 26, and was aimed at isolating those electronic modules responsible for the phase/elevation dependence. This consisted of two tests:

Test 2a. Injecting a stable signal directly into the digitizers, thereby bypassing all EVLA electronics except the DTS, and

Test 2b. Injecting a frequency-translated version of the L302 synthesizer output directly into the digitizer, in order to eliminate the T304.

Test 1a: On-sky baseline test

Antennas 18, 24, and 26 were set to observe on the sky at X-Band. Antenna 18 was held fixed in elevation while 24 and 26 were tipped between 10^o and 80^o elevation with a slew period of 18 minutes. Figure 1a shows the elevation angles of the three antennas versus time and the resulting phase versus time of the three baselines.

Result: +/- 20^o to +/- 60^o of phase change are observed that track elevation, seen after best fit antenna offsets with fiber drifts removed. The effect is antenna-dependent, but appears the same across all Ifs within an antenna.

The procedure was to tip antennas 24 and 26 while correlating the injected tones with antenna 18 (not tipped) and measuring other signals with additional modules and external test equipment. Three simultaneous measurements were made:

Test 1b: Correlation between antennas

Injected signals on each antenna were downconverted, digitized, transmitted, and correlated as though they were astronomical signals. This test includes all operations hardware after the injection point except the Front End, first mixer, and first LO.

Result: About 20^o phase variation is still present on antenna 26, and negligible variation is seen on antenna 24, which is a known good antenna, in correlated data.

Conclusion: Front end, first frequency conversion components are exonerated, although partial cancellation of effects from several modules is still possible.

Test 1c: Measurement of LO signals

During this test two L352 round-trip phase meters were used on antenna 26. The first was used in its intended configuration to monitor the round trip phase on the LO fiber. The L305 512MHz Phase Locked Oscillator was monitored with a second L352 round-trip meter. Figure 4 shows measured round trip and one-way phase of these two signals overlaid against the measured elevation angle of antenna 26.

Result: Neither outbound nor return LO showed significant phase change with elevation.

Conclusion: The L304 and L305 are eliminated as the source of the elevation dependence.

Test 1d: Measurement of IF fiber/deformatter phase

During this test, the phase of the recovered clock from the 10Gbps IF data stream was measured using a DDS configured in the D351 FPGA and a Fluke synthesizer locked to the maser.

Result: The synthesized 50MHz signal showed +/-0.1^{o} phase change with elevation, or 20^{o} if scaled to 10GHz.

Conclusion: The effect of this on sky data occurs not at 10GHz, but at some lower frequency (e.g. sampler clock?) and should be independent of sky frequency.

Test 1b was rerun, but the IF A D351 deformatter was clocked with a coherent (non-IF fiber-dependent) 128MHz clock. It did not eliminate the phase change with elevation. A phase change of 20^{o} was still observed on the antenna 18 - antenna 26 baseline IFA, which used the coherent clock, as well as on IFs C and D, which used the recovered clock.

Conclusion: The recovered clock in the DTS, and by extension the IF fiber, is not the main culprit.

Having eliminated the front ends, LO fiber, L304, L305, and IF fiber, the second round of on-antenna testing focused on those modules that remained—namely, the L300, L302, T304, and DTS. The next two tests use only antenna 18 as the fixed antenna and 26 as the tipped antenna.

Test 2a: Elimination of the DTS

An 857 MHz CW signal was sent out on a spare LO fiber, and injected directly into the digitizers. This bypasses the L302 and T304 and tests only the DTS. 857 MHz was chosen since it aliases to 1191MHz, the same frequency presented to the digitizers by the T304s in the previous test. 1191MHz is beyond the rated frequency response of the fiber transmitter/receiver pairs used in our LO modules.

The same observe script as Tests 1a – d was run and the signals correlated as before.

Result: No phase change was seen with elevation.

Conclusion: L300, L302 or T304 cause phase change with elevation. DTS is exonerated.

Test 2b: Separation of synthesizer from downcoverter

A 12967MHz L302 signal was mixed down by an L300 512MHz comb to 1191 MHZ and injected directly into the digitizers. This bypasses only the T304 and is intended to test the L302. The procedure was the same as the previous test but with the L302 set to a different frequency.

Result: No phase change was observed with elevation. The test setup was not necessarily valid. Multiple comb lines were likely present and their relative phases were changing. In addition, any phase change in the L300 will propagate to the L302, and mixing their outputs may mask the phase change.

Conclusion: Since the L300 has not been eliminated as the source of the phase variation, the mixing process between the L302 and L300 is suspected to have caused uncontrolled and unrepeatable results. This test was inconclusive.

Laboratory Testing

With a manageable subset of the EVLA antenna electronics isolated from the entire system, closer inspection in the laboratory was practical. A baseline test was conducted in the lab, in which an L300, L302, and T304 were placed in the Tilt-a-Rack and tipped. The T304 output phase was measured against a stationary HP 8660 synthesized signal generator. All phases were measured with an HP8660 Vector Voltmeter. This instrument was characterized and found not to show phase drift over periods of days.

In addition, care was taken to minimize other parasitic sources of phase change in the modules-under-test. Reference oscillators were thermally stabilized and isolated. All RF cabling was vetted for phase stability and subjected to least-bend routing configurations.

As Figure 3a indicates, the phase change with elevation was duplicated in the laboratory. However, the separate contributions of the three modules must be analyzed.

The “face down” position represents a standard EVLA electronics rack when the antenna is pointed at the horizon (elevation = 0^{o}). Likewise, “vertical” represents the position of an antenna pointed at zenith (elevation = 90^{o}). “Face up”, which would correspond to an antenna elevation of 180^o, was tested in order to determine symmetry in the phase response of the modules, although this condition could not obtain in the field.

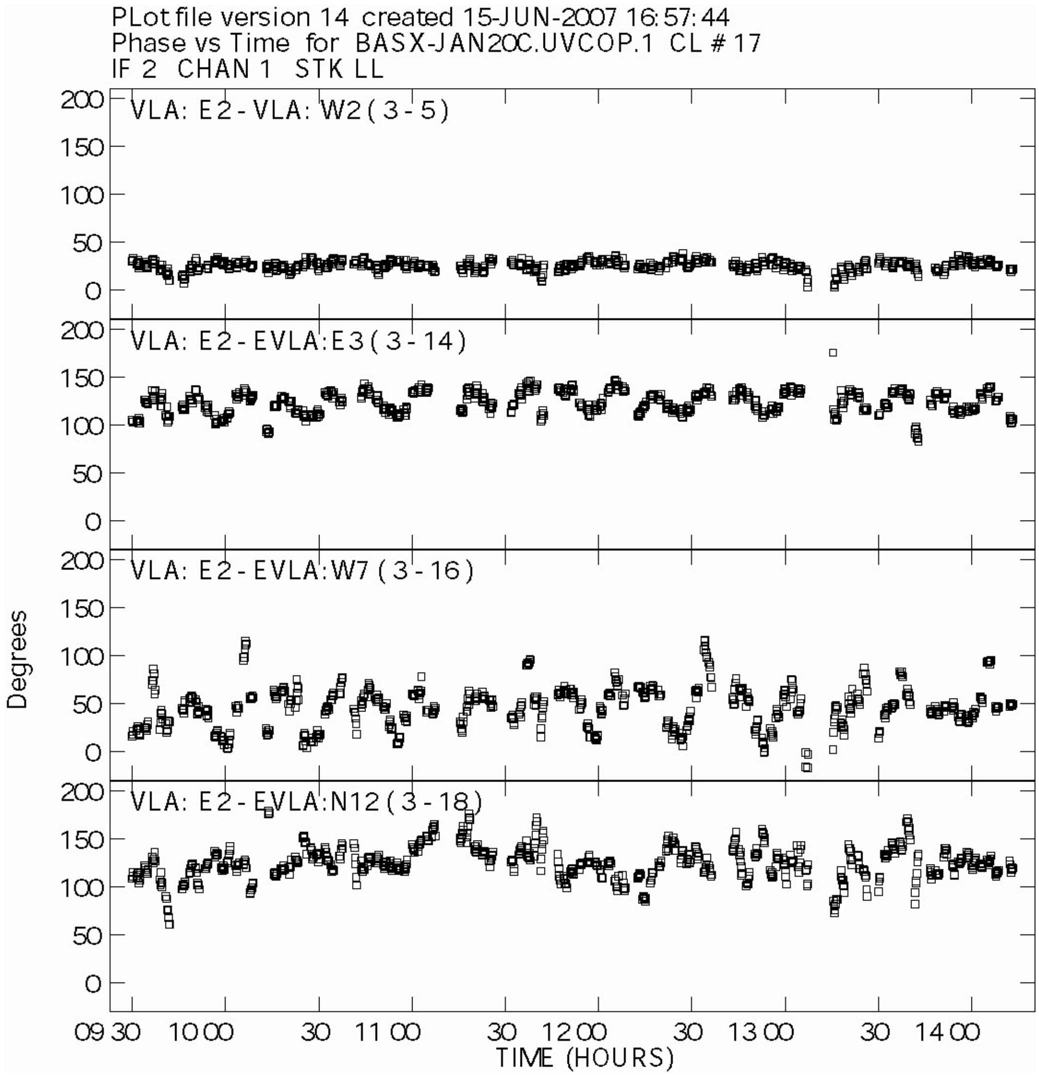
The L300 has been tested in isolation, and found to have a unique “tipping” phase signature, as shown in Figure 3b. The plot shows two complete tips of the module, with a significant pause between tips to allow all transients to stabilize. Two distinct features are visible—one that lasts approximately 5 – 10 minutes, and one that is about 4 to 5 times slower, and in the opposite direction!

Unlike the on-antenna test, all tips are 90^o step changes in orientation. The step response of the phase change eliminates possible smoothing effects induced by a ramp change in orientation. The time scales over which these step responses unfold are consistent with the thermal time constants of the components and cabling within the modules. Phase changes due to bending cables occur instantaneously, as do phase changes due to accelerometer effects such as those exhibited by crystal oscillators.

Conclusions

The phase dependence on elevation is consistent with changing thermal gradients within the modules—both in the still air and along metal center plates. In the case of the L300 in particular, the air and metal each contribute components to the changing phase, and these components are resolvable by the timescales over which they occur. Aggressive thermal management of modules and their internal components will likely stabilize the module output phase.

Since the phase of the L300 directly affects the phases of the L302 and T304, the harmonic generator must be stabilized before any progress can be made on correcting the synthesizer or downcoverter.



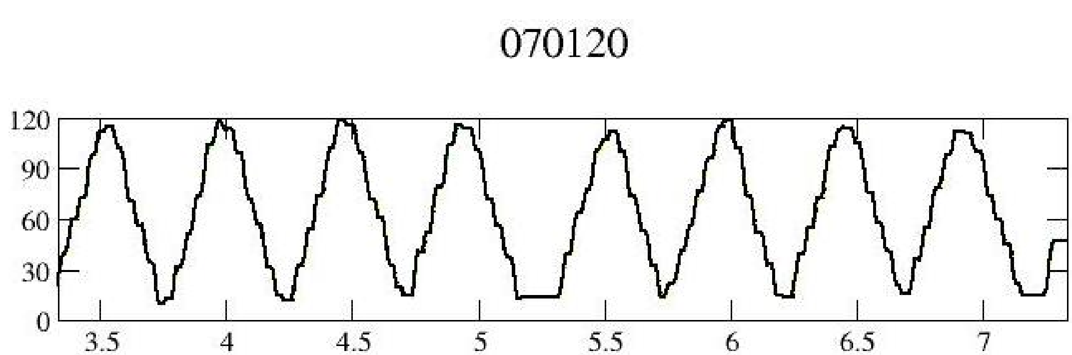


Figure 1a: Baseline data from January 20, 2007 showing phase variation after best-fit antenna positions have been removed (top) and corresponding antenna elevation (bottom).

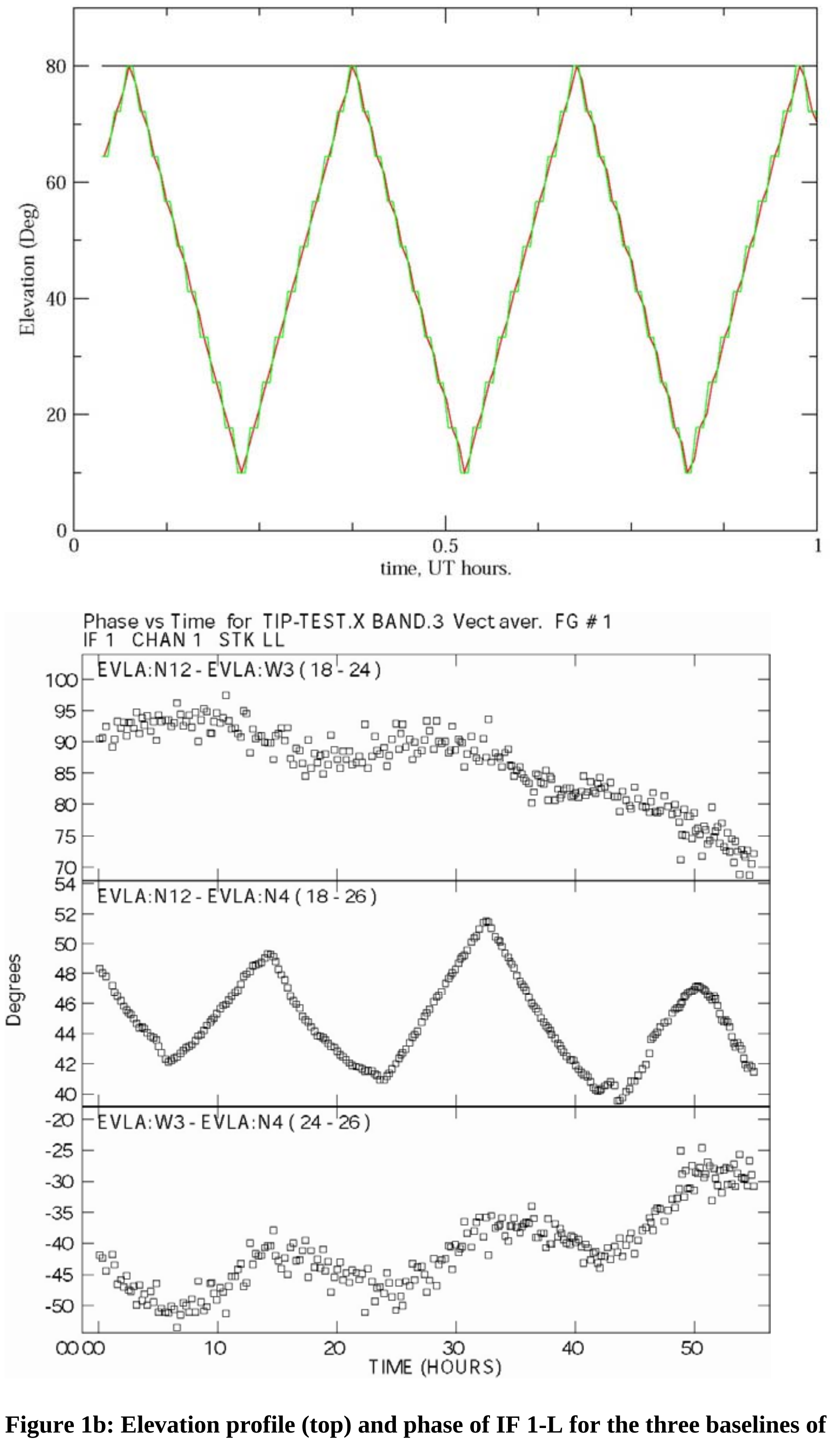


Figure 1b: Elevation profile (top) and phase of IF 1-L for the three baselines of injected CW signal on correlated signal (bottom). Elevation signature is clearly discernible in the 18 – 26 baseline.

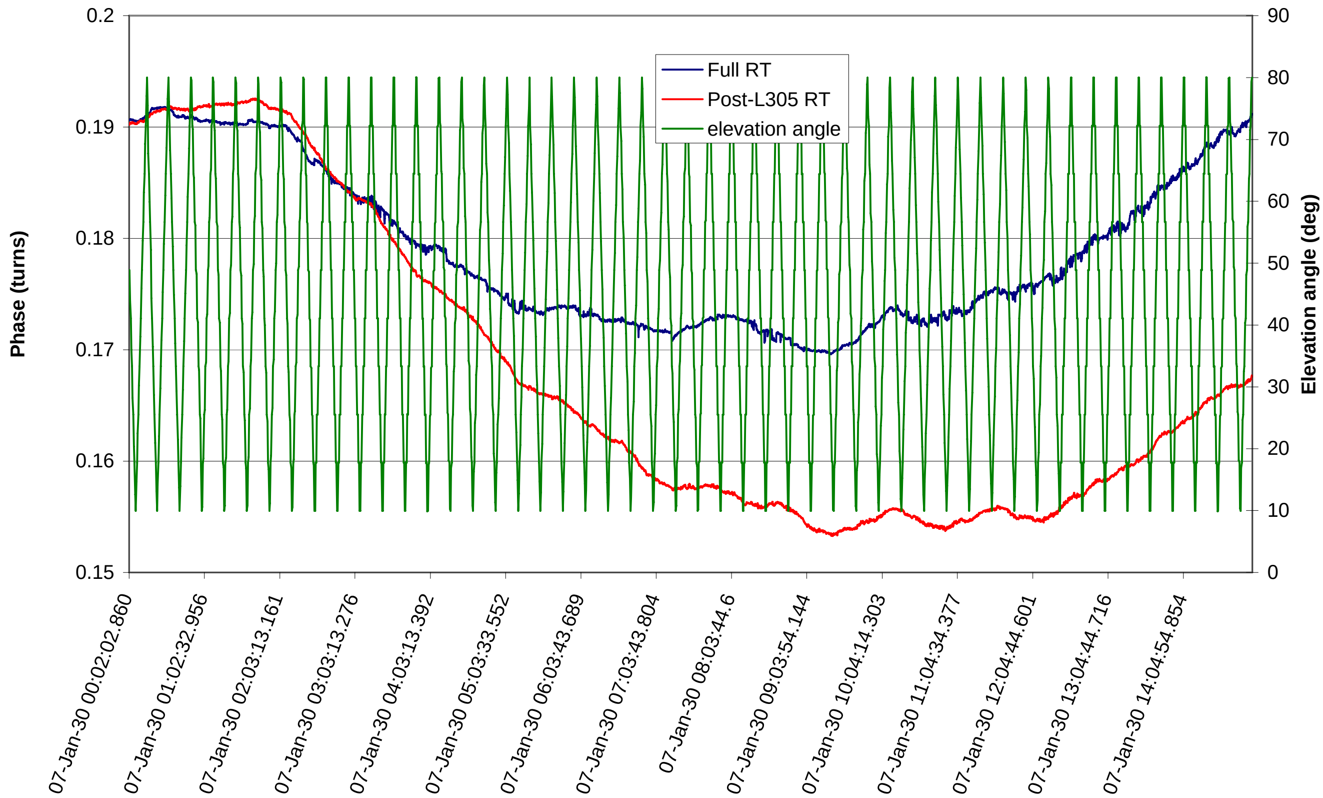


Figure 1c: Antenna 26 Round trip phase and antenna elevation angle. No elevation signature is present in round trip phase measurement.

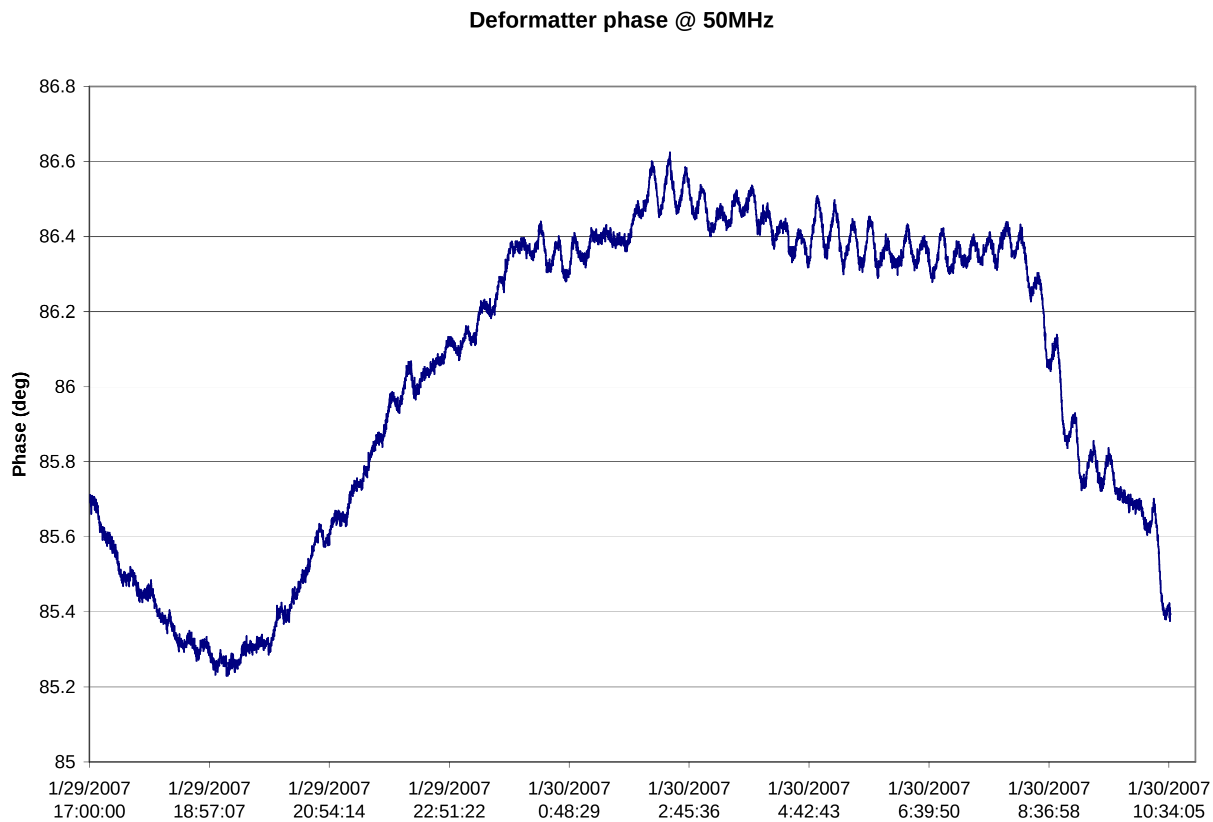


Figure 1d: Deformatter phase @ 50MHz, clocking DDS with recovered data clock. The sawtooth phase variation has a non-stationary frequency, and does not correlate to antenna tipping.

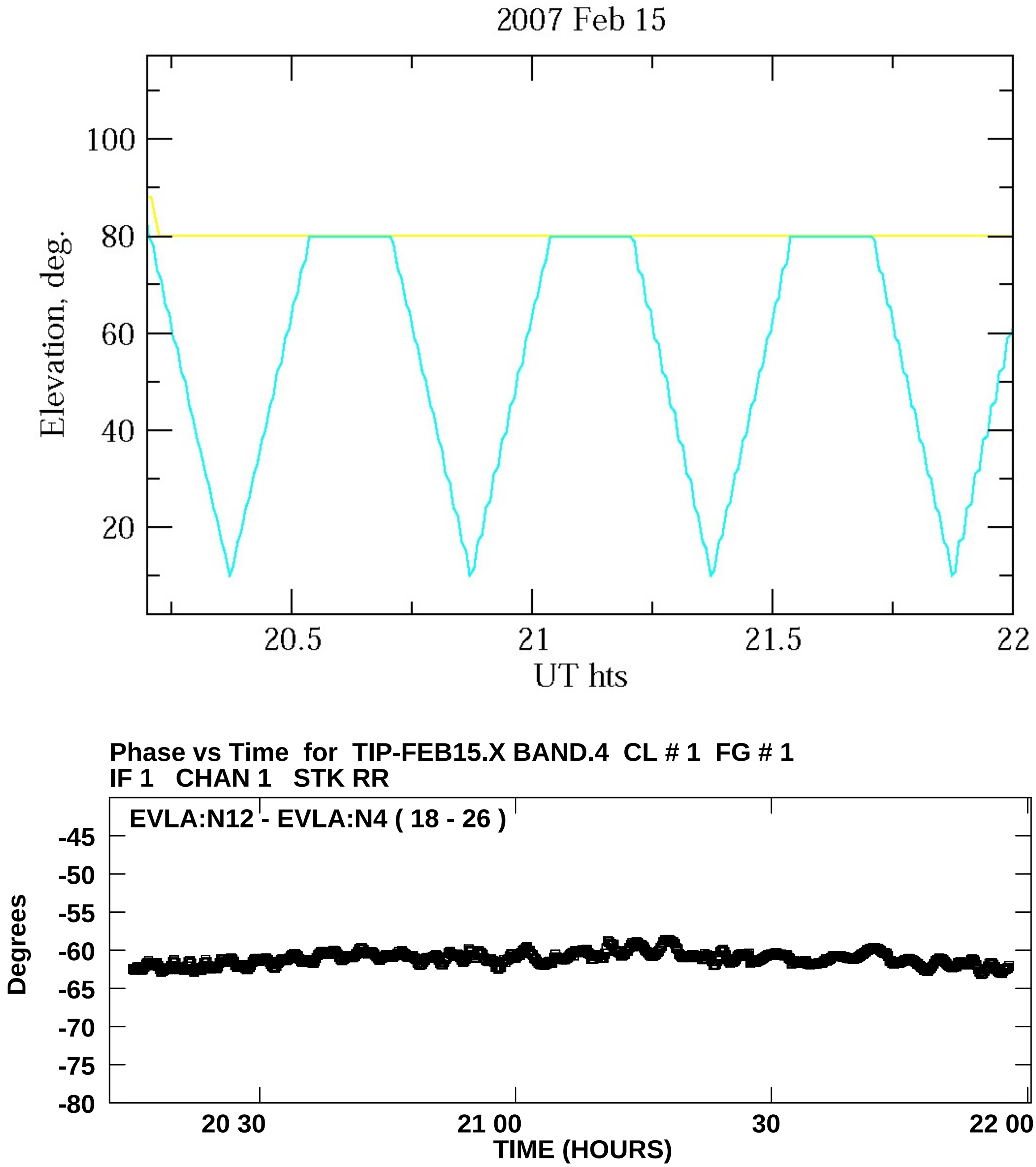


Figure 2a: Elevation profile for second round of on-antenna tests (top) and interferometer phase (bottom). The elevation signature is not present in the correlation of the injected signal.

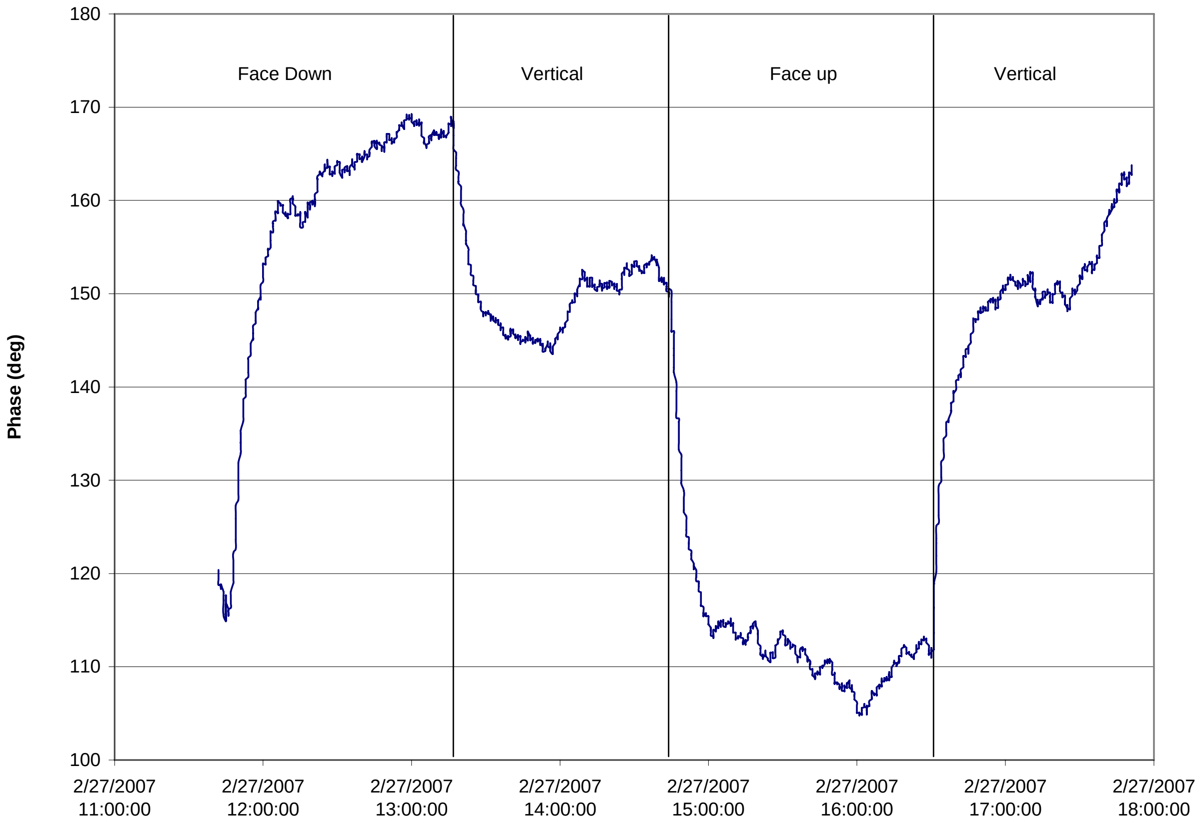


Figure 3a: Laboratory tip test. Phase of L300/L302/T304 system versus stationary reference signal. Tip points are clearly articulated.

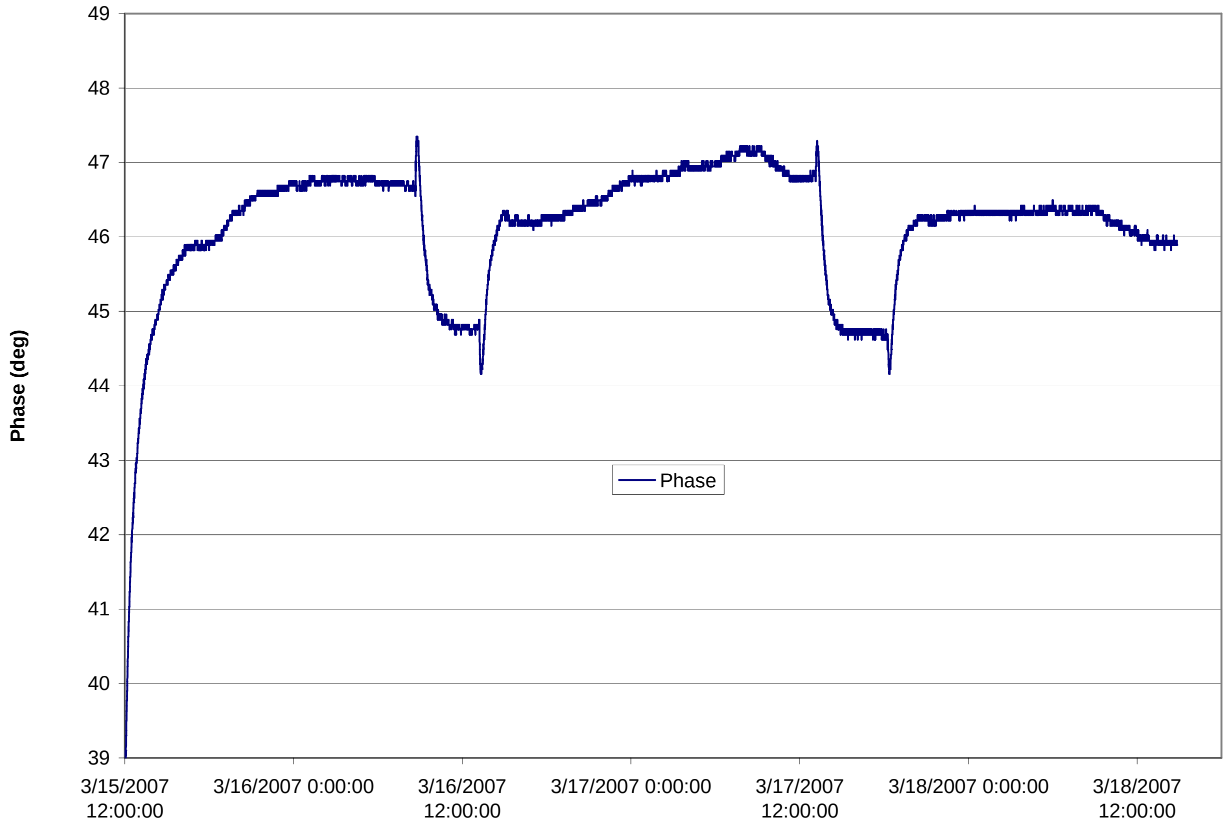


Figure3b: Phase of tipped L300 versus stationary L300. Again, the tip point is clearly articulated, and shows processes of at least two different time constants.