EVLA Memo 189
Performance of the VLA's New ACU System

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Abstract

The VLA's new ACU design, as implemented on ea14 and ea21, easily meets its minimum requirement of matching the old ACU design specification. The tracking capability of these two antennas, when utilizing the new 'OTF' sky survey modes, is equal to the other antennas, and is limited by residual pointing errors. The new design also meets the requirement of maximizing time on target by enhancing servo settling time performance. Specifically, the new design virtually eliminates both the 2.2 Hz antenna resonance, and the large pointing overshoot of the old systems for antenna motions of a few arcminutes.

1 Introduction

The VLA's original ACUs (Antenna Control Units) have been in use since the 1970s. Although the performance of these systems remain minimally adequate, there are two important reasons why they need to be replaced: First, the current system is at end-of-life. Discrete components utilized in these units are steadily degrading, and it is becoming more difficult to find replacement parts, resulting in increasing reliability issues. Secondly, the current system has the very undesirable characteristic of abruptly starting and stopping motion, which excites a strong 2.2 Hz resonance oscillation in the antenna position, and creates a large overshoot, particularly in azimuth, upon the antenna's arrival at the target position. The resonance effects can last up to 20 seconds following arrival. These characteristics were not considered detrimental for the original purpose of the VLA – the array was designed to observe a single source for up to eight consecutive hours, with calibration typically once every 10 minutes, or longer.

A clear trend in VLA useage is towards high frequency observing, and in short-duration survey modes – including 'snapshots' and 'on the fly' observing. All of these require a much more frequent calibration regimen, which in turn requires a greatly increased useage of short antenna motions. For these, the resonance ringing and overshoot characteristic of the old ACU design is a negative feature which both stresses the antennas, and wastes time while the system damps. Modern ACU design permits the implementation of shaped acceleration and deacceleration profiles, which in turn can significantly reduce the resonant ringing and overshoot.

2 Overview of the New ACU Design

The new ACU design is described by Maglathlin and Jackson 2011 (EVLA Memo # 153) as part of an overall upgrade of the EVLA Servo Control System. The new design incorporates the following key design criteria:

- Meet or preferably exceed current performance specifications.
- Modernize interfaces and actuators to enhance supportability and maintainability, therefore effectively extending the life of the VLA control system
- Maximize time on target by enhancing servo settling time performance.
- Open architecture (hardware and sofware) to allow for EVLA internal support and enhancement.
- Implement the upgrade path so that it is directly applicable to the VLBA.

The new system described in this memo permits a smooth acceleration and deceleration in both azimuth and elevation, which should permit minimizing the 2.2 Hz antenna resonance and the large azimuth overshoot characteristics of the old ACU design.

Two prototype systems have been deployed on the array, in antennas ea14 and 21. The tests described in this memo address the first and third key design goals described above.

3 Testing Methodology

One of the requirements of the new system is that it maximize time on source by reducing the servo settling time. The new ACU design, by incorporating smooth acceleration and deacceleration profiles, is expected to nearly eliminate both the resonant ringing and the large overshoot which are very evident with the old design. To test how well these has been accomplished, the 'referenced pointing' procedure was utilized. In this mode, the antennas are driven to the half power points of the antenna beam in the following sequence:

- On Source
- + Elevation
- - Elevation
- + Azimuth
- -Azimuth

the duration for each of the positions is 20 seconds, so the entire cycle takes 100 seconds, excluding overhead. Normally, the resulting correlations from each of these five positions are used to solve for the primary beams' locations. For these tests, the quantities of interest are the variations in antenna power as a function of time as the antennas move from position to position. These are derived from the data with a 0.1 second time resolution. The data for these tests were taken in June, 2014, and in March, 2015.

Another key requirement of the new ACU design is that it meet the tracking performance of the old systems. To test this, I utilized the new 'OTF' tracking modes, which enable the antennas to survey the sky at rates up to 5 arcminutes/second, keeping all antenna beams within a few arcseconds in position, for distances of $\sim$ 10 degrees or more. I utilized this mode to survey along right ascension and declination as follows:

- Scans of 2, 4, and 10 degrees length were arranged to terminate just beyond the strong source J2136+0041.
- Two scans, in opposite directions, were done consecutively for each of the three lengths, in both right ascension and declination.
- Each scan pair was done with three different speeds: 1, 2, and 3 arcminutes/second. Thus, a total of 36 scans were made.
- The scans were done near meridian transit, so the antenna motions are almost purely in azimuth and elevation.
- The observations were done at X-band. Note that at the highest speed, the antenna beam was traversed (from first null to first null) in $\sim$ 4.0 seconds of time.
- Referenced pointing was done prior to the scans, to remove the largest antenna pointing errors.

As with the antenna settling tests, the antenna powers, as a function of time, were derived from the visibilities as the antennas beams traversed the target source.

For both test regimens, the data were dumped at 10 Hz rate (100 msec integration), providing adequate time resolution. To keep data volumes manageable, only two SPWs were recorded. The frequencies were chosen to fairly well span the observing band. Basic calibration (delay, bandpass, phase, amplitude) using 'on-source' observations was done using the usual methodology. For the 'OTF' mode tests, and extra step of calibration was required to remove the phase gradient arising from the large delay error of the target source moving through the primary beam. (For the 'referenced pointing' tests, this is not an issue as the delays are kept fixed on the source). For both test regimens, the antenna powers, as a function of time, were derived from the calibrated data visibilities, for each antenna, polarization, and spectral window.

4 Results

4.1 Short-Throw Tests

The major results presented below are derived from data taken on 17 March 2014, utilizing L, C, X and Ku-bands, utilizing the referenced pointing modes. The offset angles were 17, 5.6, 3.0, and 1.9 arcminutes, for L, C, X, and Ku-bands, respectively. These angles are 'on-sky' – for the azimuth direction, the antenna motion is increased by $\sec(El)$ – a factor of 1.4. the source used was 3C345, observed at an elevation of $\sim$45 degrees, and an azimuth of about 290 degrees.

4.1.1 Azimuth Motion

The typical responses of the new and old ACUs for 'short-throw' steps, as determined from the referenced pointing tests, are shown in Figure 1. Shown are the antenna powers, in dB, as a function of time, normalized so that 'on-source' is 0 dB, for L (upper left), C (upper right), X (lower left) and Ku (lower right) bands. The motions are 48, 16, 8.6, and 5.4 arcminutes, respectively, as the antenna moves from positive to negative azimuth. Each of the four panels contains two plots, on the same scale: the top half shows the response of ea20 – an old ACU, the lower half shows ea21, which has the prototype new ACU. The plots show that the antenna moves through the source (traces rise from -3 to 0 dB), then down to the ~ -3dB power level on the other side of the beam. The old ACUs show a large overshoot, reaching nearly to the first null at the three higher frequency bands, before returning to the desired position, with slow (10 second period) resonant behavior seen more clearly in the C-band plot. The overshoot is large – approximately 26, 9.2, 5.2, and 3.3 arcminutes are the four bands. This overshoot is nearly eliminated in the new ACU design. At the highest frequency band (Ku – lower right), a small resonant oscillation at 2.2 Hz is visible in the new design. This resonance is also present in the old design, but is less visible due to the large overshoot. The effect of the shaped acceleraton is easily visible – the new ACU design takes longer to reach the main beam center (1.0 seconds, compared to 0.4 seconds for the old ACU at L-band), but reaches a stable position in much less time – 3 seconds for the new ACU, compared to 6 seconds for the old. This difference is more pronounced at the higher frequency bands, where $\sim$ 10 seconds is needed to damp out the large overshoot oscillation.

4.1.2 Elevation Motion

The results from the elevation motion are shown in Figure 2, arranged in the same way as Figure 1. The overshoot in the old ACU design is also clearly evident for elevation motions, although of slight smaller magnitude. The notable new feature in the elevation motion, for the old ACUs, is the excitation of the 2.2 Hz antenna resonance for the short steps used at X and Ku bands (lower two panels). These oscillations have a large initial amplitude (2.5 arcminutes) and persist for nearly 10 seconds. Curiously, they are barely visible at C-band, and completely absent at L-band, presumably due to the larger step angle. The new ACU design nearly eliminates both the overshoot and the resonant ringing. The only negative feature is a small overshoot for the shortest step (lower right panel).

To illustrate the severity of the 2.2 Hz resonance, I show in Figure 3 antenna 9's behavior when stepped 3.8 arcminutes in elevation, at Ku-band.

4.1.3 Resonant Behavior when $d(El)dt = 0$

An earlier set of tests was done to specifically search for instabilities which might occur when either the rate-of-change of azimuth or of elevation is near zero. These tests were taken in June 2014 at L, C, and Ku bands, using the same referenced pointing regimen discussed above. Two sources were observed, the first with $dAz/dt = 0$, the second with $dEl/dt = 0$. The test results were the same as reported above, with a single exception: At Ku-band, the azimuth motion in ea14 showed a strong resonance when $dEl/dt = 0$, as shown in the left panel of Figure 4. (ea21 failed to point in this test). The responses should look like the lower panel of Figure 4. What is seen superposed ia a large, erratic oscillation of $\sim$3 second period. On the right panel is the response following further adjustment of the new ACU parameters. The oscillation is eliminated.

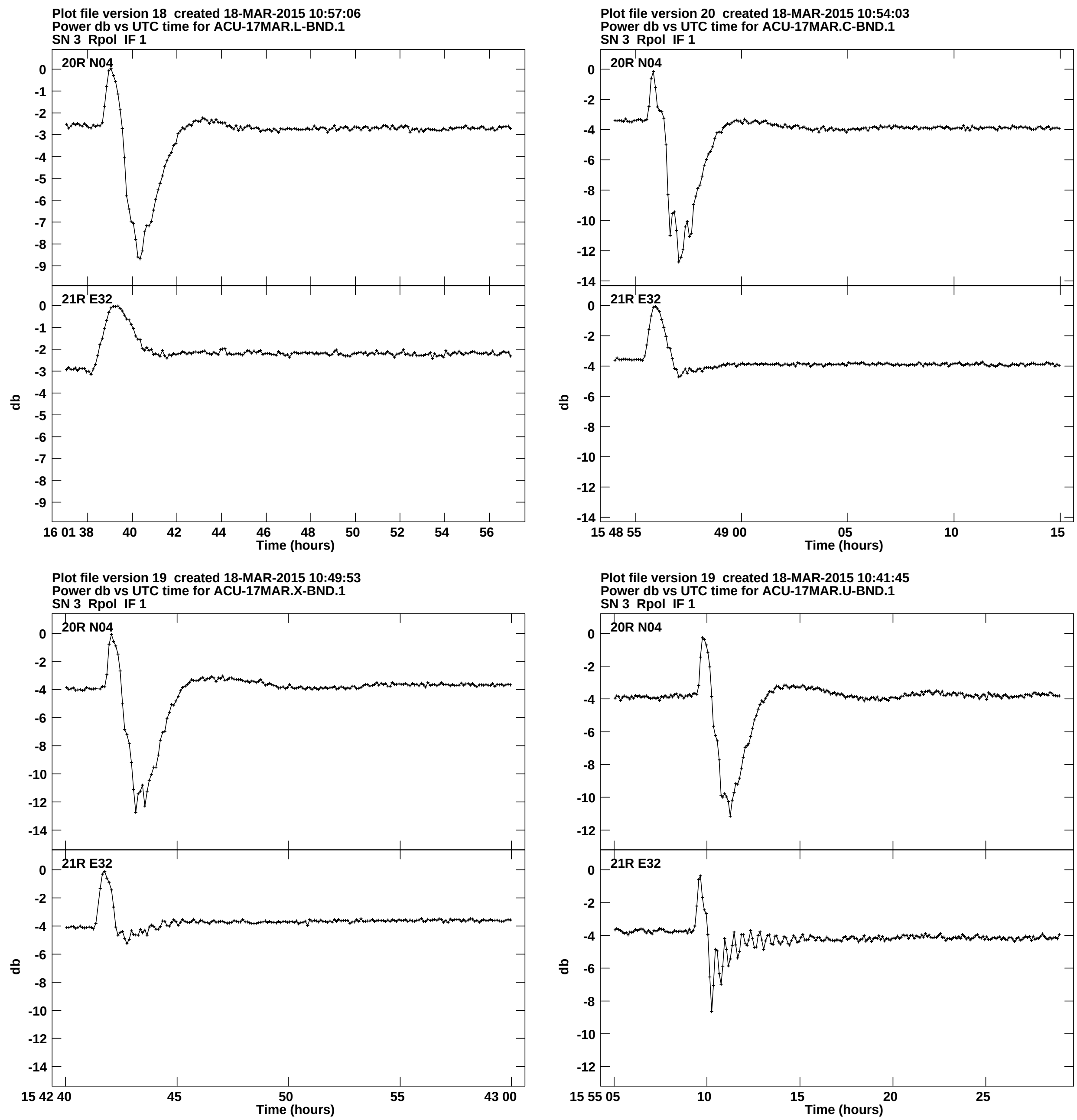

Figure 1: The typical responses of the old and new ACUs to short azimuth motions, determined from referenced pointing observations. For all four panels, the old ACU response (ea20) is above, the new ACU response (ea21) is below. All plots are on the same scale – antenna power vs. time. Upper left: 48 arcminute motion (L-band); Upper right: 16 arcminute motion (C-band); Lower left: 8.6 arcminute motion (X-band); Lower right: 5.4 arcminute motion (U-band). The time resolution is 0.1 seconds, and the axis labelling is in seconds.

4.2 OTF Tests

The second major requirement these tests were to check is the antenna tracking – will the new-ACU antennas track together with the old design, while in the new 'OTF' sky survey modes? Observations made in March 2015 were designed to test this by scanning the antennas through a known strong source.

The time of beam crossing can be determined with considerable precision. Shown in Figure 5 are the four profiles for ea14 and ea20, from each polarization and SPW. Internal checks indicate the accuracy of the

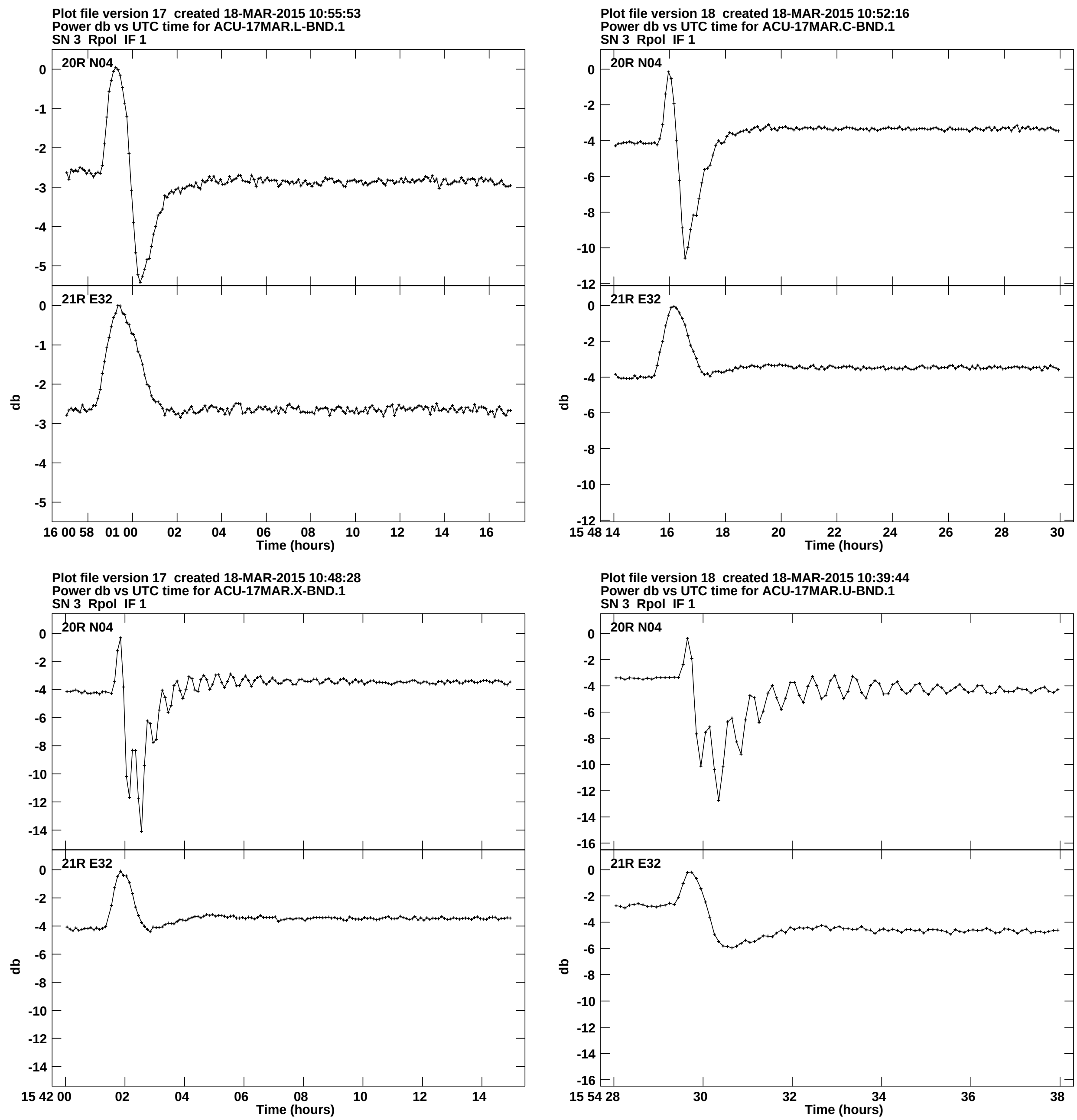

Figure 2: The typical responses of the old and new ACUs to short elevation motions, determined from referenced pointing observations. For all four panels, the old ACU response (ea20) is above, the new ACU response (ea21) is below. Upper left: 34 arcminute motion (L-band); Upper right: 9 arcminute motion (C-band); Lower left: 6.0 arcminute motion (X-band); Lower right: 3.8 arcminute motion (U-band). The plots are all on the same scale, showing power in dB versus time in seconds.

determination of the maximum is certainly better than 40 milliseconds of time, and perhaps half that. This corresponds to typically 1 arcsecond in angle, at the sky survey rates employed. The primary purpose the this test was in fact a check of the performance of the 'OTF' scanning mode. A detailed summary was given in a circular to the 'EVLA Tests' email exploder. The global mean crossing time for all antennas established the 'normal', and the deviations from this, as a function of antenna and type of test (length of scan, speed of scan). For this report, all that is germaine is whether the 'new ACU' antennas (ea14 and ea21) are consistent in performance with the old. The answer is 'yes' – these antennas work as well in this mode as any other. The major conclusion of this test was that the current primary limitation of the OTF sky survey modes is the effect

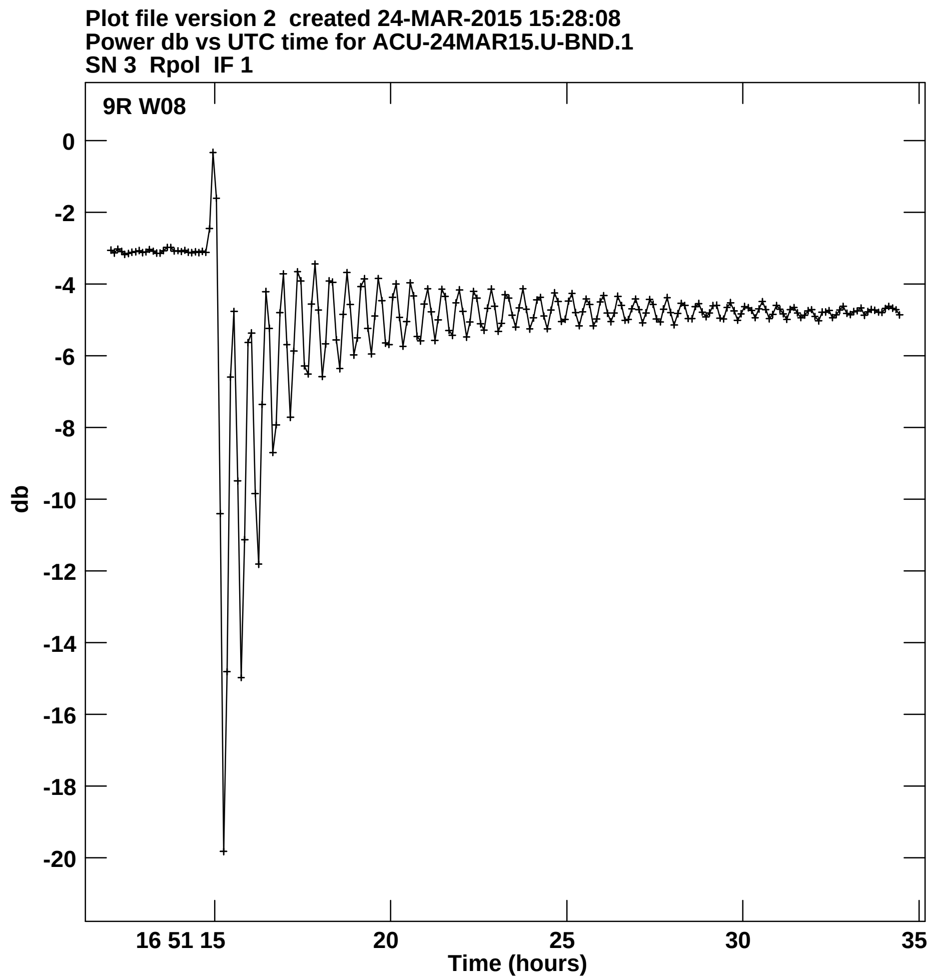

Figure 3: The 2.2 Hz resonance in elevation can persist for more than 20 seconds for some antennas. This is the response for ea09 to a 3.8 arcminute move with the old ACUs. The time axis is in seconds, the vertical is power in dB.

of residual pointing errors, (after referenced pointing is applied), which can exceed 10 arcseconds.

5 Conclusions

The new ACU design, outfitted in ea14 and 21, match old ACU performance is terms of large-scale motion (antenna slews, and observing in the new sky survey modes), and easily exceed the old ACU performance is small-scale motion (settling time is significantly reduced in pointing modes and holography modes.

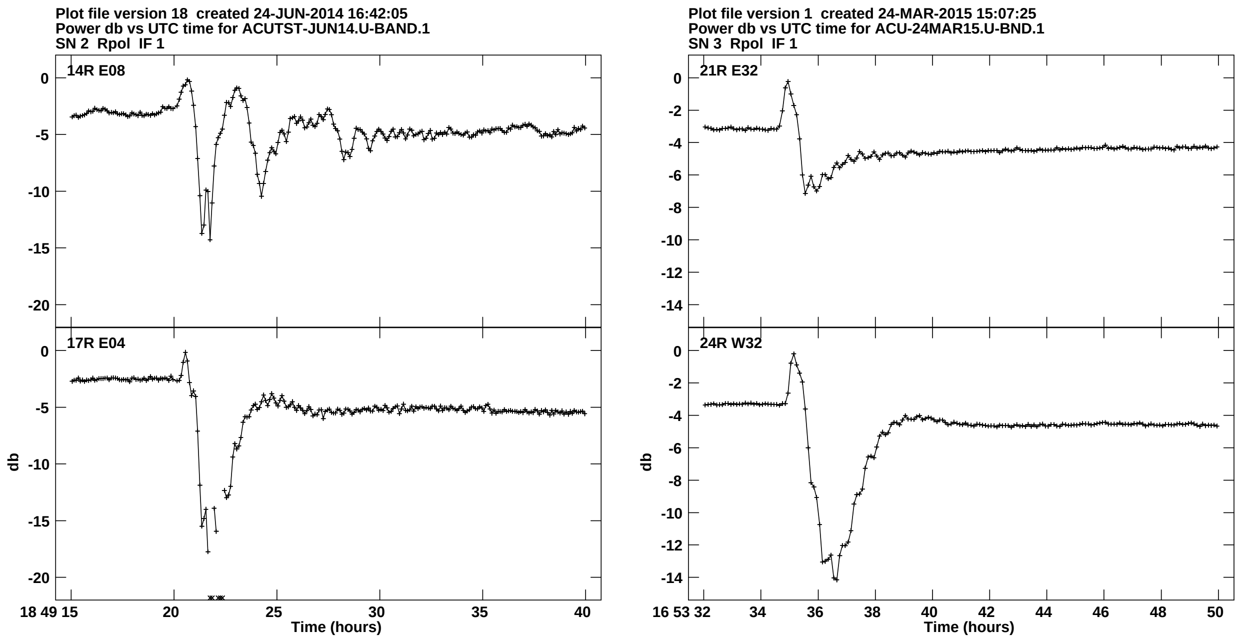

Figure 4: (left) The azimuth resonance discovered in testing on ea14 in June 2014. The left side shows ea14 (above, new ACU) with ea17 (below, old ACU). The oscillatory response for ea14 occurred only on the Ku-band motion (3.8 arcminute motion) when the rate-of-change of elevation was zero. (right) The same test taken in March 2015, on ea21, with the same conditions as in June 2014. There is no sign of the resonance.

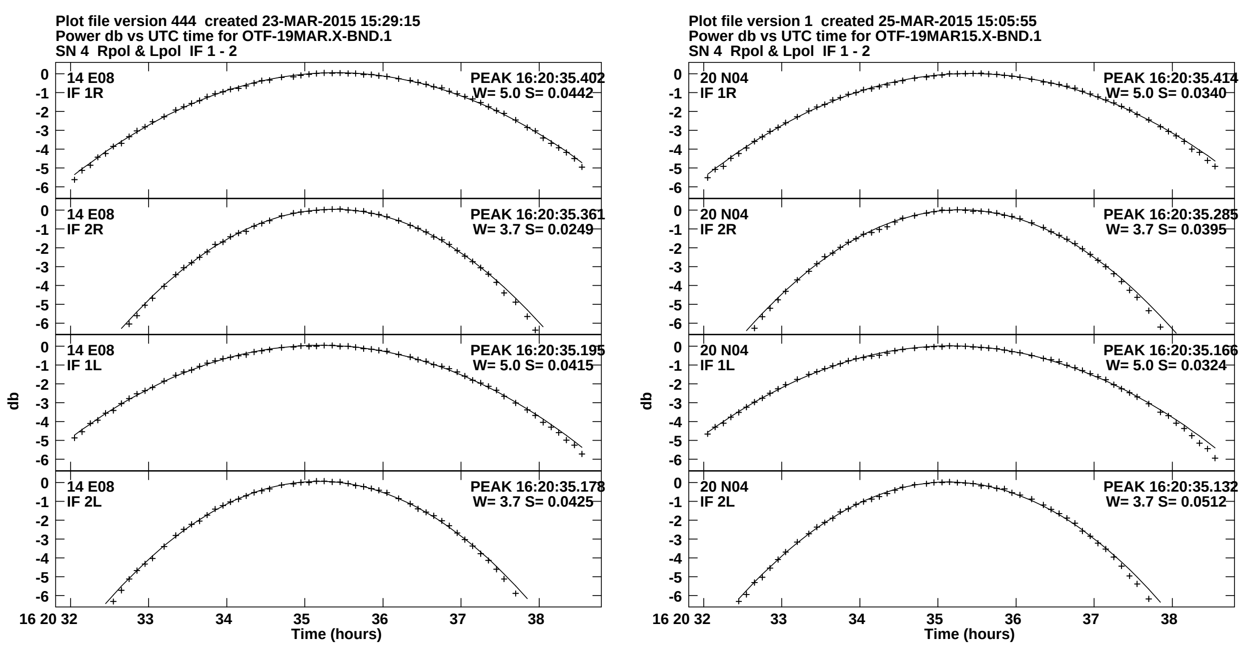

Figure 5: (left) The elevation beam cuts for ea14 (left, new ACU) and ea20 (right, old ACU), for an OTF scan at a rate of 1 arcmin/second. The four vertical plots show the fits in RCP (upper pair) and LCP (lower pair) at 8.3 GHz (wider plots) and 11.3 GHz (narrower plots)