May 2007 LWDA Site Visit: Development of Outrigger Interferometer, Ground Screen Measurements, & other activities

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During the week of May 14-18, an LWA project team from NRL, ARL-UT, and UNM visited the LWDA site in New Mexico for a series of field measurements and activities. The trip was inspired by the annual boreal summer visit of Bill Erickson to North America. Together with Bill, members of the visiting team included Brian Hicks, Namir Kassim, and Nagini Paravastu (from NRL), Jonathan York (from ARL-UT), and Eduardo Gonzales (from UNM). Pat Crane (NRL), John Dickel (UNM), Greg Taylor (UNM), and Lee J Rickard (UNM) all resident in New Mexico, made day trips to the site over the course of the campaign.

The exercise had four main goals: 1) to perform routine repair and maintenance work on the LWDA, 2) to measure the impact of ground screens on the performance of isolated LWA prototype antennas; 3) to review protocol for remote RFI measurements; and 4) to establish an outrigger antenna to work as an interferometer with the LWDA.

1) LWDA calibration and servicing work

This work was led by Johnathan York, and many of the aspects described here are extracted from a more focused report of his activities being prepared separately. A number of routine LWDA maintenance tasks were accomplished during this trip, which was conveniently scheduled approximately 7 months after the installation of LWDA. The first task accomplished was the retrieval of approximately 400 gigabytes of data from the LWDA raid, which were transported back to ARL:UT via external hard disk. Although LWDA has a high-speed Internet collection for normal data retrieval, a number of new high-rate collection modes have been implemented over the last 6 months and the development of analysis software for these modes is facilitated by local access to large amounts
of this data.

The second major task accomplished was to diagnose and repair the malfunctioning LWDA receive chain #10. Initial tests performed on-site confirmed the pathology observed remotely: the amplitude of channel 0 on receive chain #10 was tens of dB low, but with both local RF signals and the 60-88 MHz passband still visible. Swapping the cables for antennas 9 and 10 leading from the rack to the shelter patch panel did not alter the measurement thereby revealing that the problem resided within the racked equipment. Further diagnostic steps revealed that commanding 6dB SGS gain steps resulted in 3dB noise floor changes. The suspected culprit is one of the two SGS gain stages on the receive chain, although opening the SGS cases revealed no obvious problems. The failed chain was brought back for further examination at ARL:UT. After field diagnosis, the antenna 10 receive chain was replaced with a spare receive chain brought for the purpose. Replacement involved disconnecting each of the 16 cables going to the bottom level 1 enclosure, removing the bottom level 1 enclosure from the rack, removing the cover, replacing the failed receive chain, and then reassembling. After replacement and re-assembly, all channels, including the previously problematic channel 10:0 operated correctly.

Vijay Sitaram (ARL-UT) performed a postmortem examination of the failed #10 receive chain in Austin and while a full report is available upon request, the key findings are that 1) the receive chain operated correctly when tested at ARL, and that 2) each component individually passed additional testing. The ultimate cause of (the apparently temporary) failure remains unknown.

The third task accomplished was the phase re-calibration of the LWDA hardware. This non-astronomical calibration was performed using equal-length cables to inject coherent noise at the balun inputs under test and then measuring the relative arrival delay at the receivers. The freshly replaced antenna 10 receive chain was the primary focus of re-calibration, although spot-checks were made on unmodified antennas to quantify the stability of the phase-calibration relative to the calibration made at installation in October 2006. The results with delay values in nanoseconds relative to channel 1:0 are summarized below:

Channel	Oct 2006 Calibration	May 2007 Calibration	Change
1:1	-0.451	-0.449	+0.002
2:0	-6.675	-6.662	+0.013
2:1	-7.450	-7.438	+0.012
9:0	0.783	0.798	+0.015
9:1	0.510	0.529	+0.019
10:0	55.719	55.138	-0.581
10:1	53.812	53.439	-0.372

Of the 5 unmodified chains sampled, the maximum deviation was 19ps corresponding to approximately 5 millimeters of LMR-240 cable change or equivalently 0.16% of the highest observed wavelength. The hardware for antenna 10 that was replaced resulted in a 0.372 and 0.581 ns change for the two channels. Two conclusions can be drawn: 1) the LWDA phase calibration is stable for unchanged hardware to the six month level, a result consistent with Bill Erickson's experience at Clark Lake; and 2) hardware replacements (especially analog LC filter components) should be cause for immediate re-calibration. Means of conducting such tests using interferometer measurements of cosmic sources is also being considered as an alternative means of remote (and more frequent) calibration.

A fourth task consisted of installing a spare receive chain onto port 7 of the level-2 adder board. This installation was made in anticipation of connecting to a 17th "outrigger" antenna (see section 4), but it became apparent that the control software relies on an assumption that there will be an equal number of aggregator boards between each of the receivers and the PC. Installation of the extra receiver will require either software updates or the fabrication of an additional aggregator component. In the end, the extra receiver was left installed to support remote software development, but the outrigger antenna was connected in place of antenna 16, channel 0.

A fifth task was continuing debugging of the new revision of the LWDA command and control software, especially the power up sequencing code which is most easily performed on-site with access to the receiver status LEDs. During this process, it became apparent that while the receivers all powered on reliably, a few (normally 1-2 out of 16) receivers intermittently power on in an errant mode with several characteristics:

1. The DLL lock successfully
2. Valid 8b10b frames are transmitted
3. Frame checksums from the receiver are correct
4. Frame counters and other meta-data from the receiver are correct 5. The output I&Q samples are unusual:
5a. Every sample value (aside from the first and last) are repeated four times before it changes
5b. Both channels and both I&Q seem appear to have different values 5c. The values resemble a random walk within a frame, wrapping at +127 and -128
5d. The first 2 samples in the frame are the same, and then each following set of 4 are the same, and the last 2 samples in the frame are the same 5e. The samples respond to FIR value updates, that is, zeroing the FIR taps cause zeroed output samples.

Resetting the DLL does not cure the problem, while power cycling the individual receiver will. The problem is almost certainly in the receiver firmware, most likely in the DSPChannel code, with Johnathan's working hypothesis being that the bitslew_req flag causes the DSPChannel to enter an invalid state. This hypothesis is consistent with the intermittent and seemly non-deterministic failures, as the DLL locking process is about the only random process involved in power up. However, simulation of the Verilog code, including repeated pathological triggering of the bitslew_req flag, failed to reproduce any erroneous results. The ultimate cause is unknown, and this problem will need further debugging.

The final LWDA maintenance task performed was a thorough examination of the LWDA hardware, focusing on the outdoor components and looking for any signs of degradation. Nearly an hour on Monday was spent removing patch panel, antenna, and enclosure covers looking for anything unusual. Aside from a slight deterioration of the adhesive on the GPS antenna cable guide, all of the LWDA hardware appears to be in excellent condition. No action is warranted at the present time.

2) Ground Screen Performance Measurements

This work was led by Nagini Paravastu, Brian Hicks, and Eduardo Gonzales. Prior to the site visit, Nagini and Walter Gerstle had organized a short meeting at UNM to discuss plans for the ground screen field measurements. Walter and Eduardo had secured sufficient ground screen material to allow us to make tests over a range of sizes. Walter also brought in an example of ground screen material that had resided in his Albuquerque backyard for approximately 10 years and showed surprisingly little wear or deterioration.

A report written by Paravastu et. al (LWA Memo 90) documents the measurements made as well as some conclusions based on a preliminary look at the data. We made impedance measurements from 0 MHz to 150 MHz on one of the Big Blade antennas (BB1) over bare ground and over various sizes of ground screen, starting with a "postage stamp" screen ~3 m by 3 m. Similar measurements were made on the fork antenna. On Thursday it rained so we were "lucky" enough to be able to obtain data over wet ground to compare with our dry ground data obtained earlier.

Bill Erickson was moderately surprised by the very significant difference in impedance between the dry ground data taken on Tuesday and the wet ground data taken on Thursday. This differed significantly from what he had found on Bruny Island, possibly indicating that the ground there is never, or at least rarely, really "dry". The wet ground impedance data are intermediate between the dry ground and ground screen data, leading us to the preliminary conclusion that ground screens are quite necessary for a stable system.

Impedance measurements were made with screens ~3 m by 3 m, ~6 m by 7 m, and ~6 m by 12 m (with the larger dimension in the E-plane). Aside from an error in our first measurement, all of these data are essentially identical, i.e. the "postage stamp" screen appears to be quite adequate to stabilize impedance the variations. Bill commented that ASTRON must have reached similar conclusions leading them to adopt similar “postage stamp” ground screens for their low-band antenna systems. Bill’s preliminary recommendation was that small ~3m by 3m screens be employed throughout LWA stations, and we subsequently deployed as many postage stamp systems under the standalone antennas at the LWDA site as possible based on the material in hand. Figures 1-2 document some of the ground screen activities conducted during our visit.

In addition to the impedance measurements, the ground screen activities included obtaining as many long (mostly nighttime) uninterrupted drift scans on the sky. The data were recorded on the SPECMASTER system and will be discussed in further detail in a forthcoming report.

3) Review of RFI Survey Protocol

This work was led by Pat Crane, John Dickel, and Bill Erickson. A key challenge to LWA receiver design is to incorporate sufficient dynamic range to digitally sample the full band while at the same time avoiding receiver saturation. Thus a key measurement is to understand the level of RFI at potential LWA station sites. To achieve this, RFI surveying, led by Pat Crane and John Dickel, has commenced at candidate LWA station sites. The mobile measurements utilize a standalone LWA prototype antenna coupled with a spectrometer based backend developed by Ted Jaegar and Bob Mutel at U. Iowa. The RFI surveying is only useful as guidance for LWA receiver design if the absolute calibration of the measurement system is suitably characterized.

The procedure for the RFI testing at remote sites is outlined in the User's Manual for the Iowa Portable RFI Monitor (IPRM) written by T. Jaeger and R.Mutel (see also LWA Memo 76). Here we describe only the modifications currently being implemented as part of the measurement protocol:

- The antenna and balun used are Big-Blade and Teletech (i.e. Gali-74 based), respectively.
- The low pass filter supplied is not used.
- The spectrum analyzer now utilized is an Advantest.
- Prior to April 2007, the frequency range was 10 - 110 MHz. In April 2007 - June 2007 the frequency range was expanded to 0.1 - 210 MHz. In summer 2007 plans are to increase this to 0.001 - 210 MHz.
- The GPS interface does not work so the latitude, longitude, and time are entered by hand using hand-held GPS units.
- Typical scan lengths are 500 cycles that take about 2 hours.

- The data (in FITS format) are archived in the IPRM IBM laptop and also regularly transferred to the LWA Wiki pages. As well as FITS copies, color gif files are also prepared to show the spectrum as a function of time for each record.

To ensure confidence in the RFI measurement protocol, John Dickel and Pat Crane visited the LWDA site to perform a mock "remote" RFI survey measurement. Bill Erickson observed the procedure in order to offer comments or suggestions for improvement. At the conclusion of the mock run, Bill expressed confidence that the measurement techniques being employed were sound and quite valid for characterizing RFI at remote sites with the mobile system, and he planned to pass this information on to the LWA system engineer.

4) LWDA Interferometer

This work was led by Johnathan York and Bill Erickson with assistance from Brian Hicks and Namir Kassim. Shortly after LWDA installation was completed in Fall 2006, the 16-element, relatively compact (B_{max}~ 25m) array successfully achieved first-light (LWA Memo 68). The initial operating mode was as a zenith-staring cross-correlating interferometer, allowing the LWDA to do impressive all-sky imaging. A number of movies illustrating this capability have been made that show the sky rotating as a function of time, and a few discrete emission regions (e.g. Cas A, Cyg A, the sun, inner Galactic plane) can be detected. Nevertheless, the LWDA is normally so strongly confusion limited that only a handful of sources can be decently observed. Proposed background subtraction schemes to enable all-sky transient monitoring are being developed, but even if successful the limit on viable transient candidates will likely be at the few thousand Jy level, at best.

In light of the high level of confusion due to the short baselines of the LWDA, it was clear that an interferometer extending to longer baselines would be required to resolve out most of the large scale Galactic structure and permit more sensitive source observations. A goal of this site visit was to implement an outrigger element to work with the LWDA to realize this capability. Two standalone Big Blades (BBs) were available at the LWDA site, and while one of these was being routinely utilized for remote RFI measurement campaigns, the second was a candidate to utilize as an outrigger interferometer element for LWDA. Johnathan was able to swap out a signal into the LWDA digital receiver chain from one of the 16 LWDA antennas and substitute a signal from the candidate BB outrigger. The LWDA receive system does include a capability to handle a 17th digital signal chain, and eventually the required modifications will be completed so that a 17 antenna system (16 in the LWDA plus one outrigger) can operate on a routine basis (see discussion of extra receive module partly installed on this trip in section 1).

In the discussion that follows, we note that the speed and efficiency at which the interferometer work proceeded owed to the excellent pre-trip preparation by Johnathan York and Brian Hicks. The necessary cabling (LM-400) to establish a longer baseline was shipped ahead of time from NRL, already outfitted with the proper connectors, and as activities began Brian was able to configure the bias-T powered balun for the outrigger quite quickly. At the same time, the impressive flexibility of the LWDA digital backend and Johnathan's ability to quickly reconfigure it on the fly were also key to the success of our efforts. With just a few minutes at the keyboard of the control computer in the LWDA trailer, Johnathan was able to implement

Bill's advice in dialing in new settings, such as delays and bandwidth, and to otherwise reconfigure the system, e.g. between drift scan and tracking modes, so that "first light fringes" in "long baseline" interferometer mode were achieved after only a few hours of work. Most of the time was actually spent laying the infrastructure and dragging the outrigger antenna from various candidate locations.

As a first attempt to establish a longer baseline, we transported BB2 to the western edge of the LWDA site (see Figure 3), establishing a baseline of ~ 100 m. We tried to make the baseline as close to purely EW as possible, to maximize the frequency of the fringe oscillations. Fringes on Cas A (~20,000 Jy at 74 MHz) were thereafter readily detected by multiplying the signal from BB2, suitably delayed, against the phased array response from the central 16-element LWDA. The first detections were obtained by pointing the interferometer, whose field of view is defined by the phased array beam of the LWDA, ahead of Cas A and allowing the source to drift through the fixed fringe pattern on the sky (Figure 4a). However the level of confusion indicated that an even longer baseline was needed to effectively resolve out the Galactic emission, so we then moved the outrigger further west outside the periphery of the LWDA site (Figure 4b). The individual fringes on the long drift scan run on Cyg A are lost in the myriad of individual data points, but the envelope nicely maps out the effective "primary" beam pattern of the interferometer. It is defined by the "station beam" of the phased LWDA antennas.

After we returned home, we used the recorded interferometer measurements to refine our estimates of the various baseline lengths and fringe spacings using the well know relationship:

$$\nu_F = \omega_e * u * \cos(\delta)$$

Here ν_F is the fringe frequency (Hz^{-1}), λ is the observing wavelength (m), ω_e is the angular rotation rate of the Earth (7.29×10^{-5} rad/sec), and u is the EW component of the baseline B measured in wavelengths. Under the assumption that the measurements were made at transit so that baseline foreshortening could be ignored, we thereafter determined that our EW baselines and sky resolutions were [129,185] m and [1.2,1.8]°, respectively, for the first two set-ups west of the LWDA. We eventually settled on a location for the outrigger on NRAO property ~300 m east of the LWDA, and recent interferometer measurements conducted after the visit indicate u~287 m.[1] For protection, a small fence was erected around the outrigger once it was set up (see Figure 5)

The increase in sensitivity with increasing baseline length was spectacular, and drift scan fringes on Cas A and Cyg A (also ~20,000 Jy at 74 MHz) were soon readily detected at signal to noise ratios (S/N) approaching 50/1 in integration times as short as 1 second. It should be straightforward to integrate for ~1000 seconds and obtain S/N ratios approaching 1000/1 on these sources. Thereafter we were able to obtain fringes on a number of weaker sources with

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[1] John Dickel recorded the location of the outrigger on May 17, 2007 as measured by his handheld GPS receiver as 34º 04.160' N 107º 37.501' W, ~1010 feet from the LWDA central stake at azimuth 80º degrees east of north. On June 28, 2007 Masaya Kuniyoshi (UNM) measured the length of the cable from the outrigger to the spectrum analyzer in the LWDA trailer at 840 feet or ~250 m - a somewhat shorter run than to the LWDA phase center. After the trip, Henrique Schmitt (NRL) & NEK utilized follow-up observations of Cas A to estimate u~260 m..

typical flux densities of a few hundred to a few thousand Jy. Examples of fringes on Cas A and Virgo A (~2000 Jy at 74 MHz) on the longer baselines we tested are shown in Figure 6.

Observing sources such as Cas A and Cyg A at high S/N brings an enormous advantage to the LWDA, and Bill Erickson commented that based on his experience it will allow us to detect, diagnose, and characterize many other aspects of the system. Phase and absolute flux density calibration are now readily accessible, as the Baars et al. scale itself is tied to the flux density of these objects, and their positions are well known. As another example, shortly after detecting Cas A for the first time via drift scans, Johnathan configured the system to track the source as it moved across the sky, typically in incremental scan lengths of ~1 minute. When this tracking mode was first implemented, we immediately noticed phase jumps at scan boundaries readily attributed to an error in our definition of the LWDA phase center (Figure 7a). Johnathan was thereafter able to refine the position of the phase center to remove the phase jumps, essentially employing a self-calibration-like technique to tune up the system (Figure 7b).

Another example of the type of useful system measurements now routinely available are provided in Figure 8, in which Johnathan utilized drift scan measurements of Cas A to make a preliminary map of the LWDA phased array beam. This was done by acquiring drift scans of Cas A as it passed through the interferometer beam at successively different right ascensions, thereby obtaining adjacent slices through the primary beam as defined by the phased array beam of the LWDA. Additional system measurements permitted by the interferometer may include the ability to constrain the effects of mutual coupling between individual elements in the LWDA.

Despite the ability of the interferometer to detect fringes from sources much weaker than Cas A and Cyg A, the system remains strongly confusion limited, as indicated by the additional bumps and wiggles superimposed on the fringes of the weaker sources shown in Figure 9. Thus while the confusion due to the extended Galactic emission has been largely removed, the interferometer is now sidelobe confusion limited by the myriad of discrete sources that it now partially detects. Thus even in "blank sky" directions, e.g. those away from sources at the few hundred Jy level or higher, we see lower level, distorted fringes that preclude our ability to unambiguously detect weaker sources. An even longer baseline of ~500-600 m might help resolve this confusion to some extent, but the limited effective collecting area, equivalent to $\sim(1*16)^{0.5}$ or ~4 dipoles, precludes pushing our sensitivity much further.

Despite its limited resolution and sensitivity, the LWDA interferometer can now allow new observing programs to be considered. Daily or more frequent determinations of the total solar flux density could be made, similar to the Canadian 10 cm observations. As another example, it should now be able to implement a search for longer time scale transients that would compliment the all-sky cross-correlation search for rapid transients. Since the system is so quickly confusion limited, we could scan repeatedly down the meridian at 1/2 beamwidth intervals, spending a few seconds at each position, and making the scans rapidly enough that each position is observed several times as the sky goes by. In 24 hours this would provide a fairly sensitive map of the whole sky that might be useful to detect longer period transients and to gain experience with ionospheric problems, operations during high winds and thunderstorms, and any secular variations in antenna performance.

One odd event was that after fringes had first been detected they were "lost" for a period of several hours for unknown reasons. Several other periods of odd behavior were experienced and at first we guessed it must be due to our "operator error" with respect to the way the system was set up. However our feelings grew that external effects such as RFI from lightning or a highly disturbed ionosphere might have played a role. There was considerable thunderstorm activity throughout the length of our trip, typically rolling in each late afternoon, and often corresponding to periods of "wild" activity. As a database of routine interferometer measurements are built up, it will become possible to understand to what extent external, e.g. tropospheric or ionospheric effects may disrupt the stability of the system.

At the conclusion of our site visit, the interferometer was clearly valuable enough that we left it in operation. Johnathan implemented an observing script in which the system would automatically track one of a handful of bright 3C objects that would be at the highest elevation at any given local sidereal time. The signal from BB2 is now being split and sent both to the SPECMASTER and to the LWDA system. (A 3 dB splitter was installed about 11 AM MDT on May 18.) The second SPECMASTER channel was left on the FORK dipole. Based on the preliminary ground screen test results, we left the FORK dipole on a 6 m by 7 m screen, and BB2 on a 3 m by 3 m screen, work is ongoing to install ground screen under all the LWDA antennas to enhance the stability of the whole system. BB1 remains independent and is available for mobile RFI measurements, and there are also plans to send a 3rd BB (aka BB3) to the site to provide a backup to BB1 for remote RFI survey work.

The development of the interferometer as an additional useful mode led us to hold a discussion at NRL shortly after the visit with the aim of defining the scientific and technical advantages of the various modes now available to the system. These are listed briefly below along with their nominal scientific and technical utility. Dan Wood attended the meeting, so that he could familiarize himself with the type of observational modes that the radio astronomers felt were most useful. He thereafter visited ARL-UT to work with Johnathan York to develop the higher level software needed to permit him to remotely implement an observing schedule routinely from NRL via the internet.

5) Summary of Current Observing systems at the LWDA Site:

Standalone Systems:

FRK1 and one of two signals from BB2: available for standalone antenna, balun tests, and sky-noise measurements via SPECMASTER system.

LWDA observational modes:

Mode 1: Original zenith-staring, cross-correlating mode that includes all antennas in the LWDA (inclusion of outlier antenna optional.) Most useful for all-sky transient monitoring, albeit at a relatively insensitive level due to confusion from the diffuse Galactic emission.

Mode 2: 2-element interferometer formed between phased array LWDA and BB2. This might serve as a useful default mode, since the sensitivity is highest and data rate the lowest. Useful technically for a variety of purposes e.g. for amplitude and phase calibration, primary beam holography, etc. Scientifically useful for targeted observations of isolated sources, and for possible programs such as a meridian transient survey that could map the entire sky on a daily basis (as suggested above), or for rapid pointed observations of sources based on external triggers (e.g. quick follow ups to SWIFT GRB detections).

Mode 3: Tracking phased array mode – utilizing a formed phased array beam from the LWDA (inclusion of outrigger antenna optional). The mode is useful for pulsar or radio recombination line observations, although the latter would only be useful as a pilot program since the sensitivity is probably insufficient to detect RRLs with the number of antennas currently deployed.

The LWDA digital electronics allows for spatial, frequency, and polarization multi-beaming, and discussion of the available options for utilizing these to enhance both technical and scientific observations were also discussed. As we move forward, we anticipate a scenario in which radio astronomers at NRL will develop an observing schedule that Dan Wood will implement, perhaps bi-weekly, on the telescope, including routine calibration observations.

6) Miscellaneous remarks: the small LWDA control trailer has become so crowded with equipment that it is not possible to organize equipment efficiently. We therefore strongly recommended the addition of new storage space at the site, and Eduardo Gonzales has since installed a shed at the site to address that need (Figure 10a). We also recommended installation of a small fence around the outrigger antenna, that Eduardo has already installed (Figure 5b). Oddly enough, the long run of unburied, unprotected co-axial cable running from the fenced confines of the LWDA site to the distant outrigger has yet to show any signs of "nibbling" or other effects of animals as was experienced on one of our first site visits. During the course of our visit, Eduardo was also able to install steps to the LWDA control trailer (Figure 10b).

7) Summary: Our LWDA site visit was very successful and one of the most efficient site trips we have conducted. We conducted useful ground screen measurements, successfully reviewed RFI measurement protocol, conducted routine maintenance on the LWDA receive system, and implemented an outrigger interferometer capability for the telescope. The success of the trip can be attributed to the excellent preparation of all involved prior to the trip, especially that of Johnathan York, Brian Hicks, Nagini Paravastu, and Eduardo Gonzales, allowing us to accomplish all of our planned tasks. The exercise demonstrated that given sufficient planning, a Sunday – Saturday travel schedule for those coming from outside NM permits adequate time to execute a number of separate, well defined tasks at the site.

Basic research in radio astronomy at the Naval Research Laboratory is supported by 6.1 base funding. NEK thanks Henrique Schmitt for assistance in estimating the final EW component of the outrigger baseline from recent interferometer measurements of Cas A.

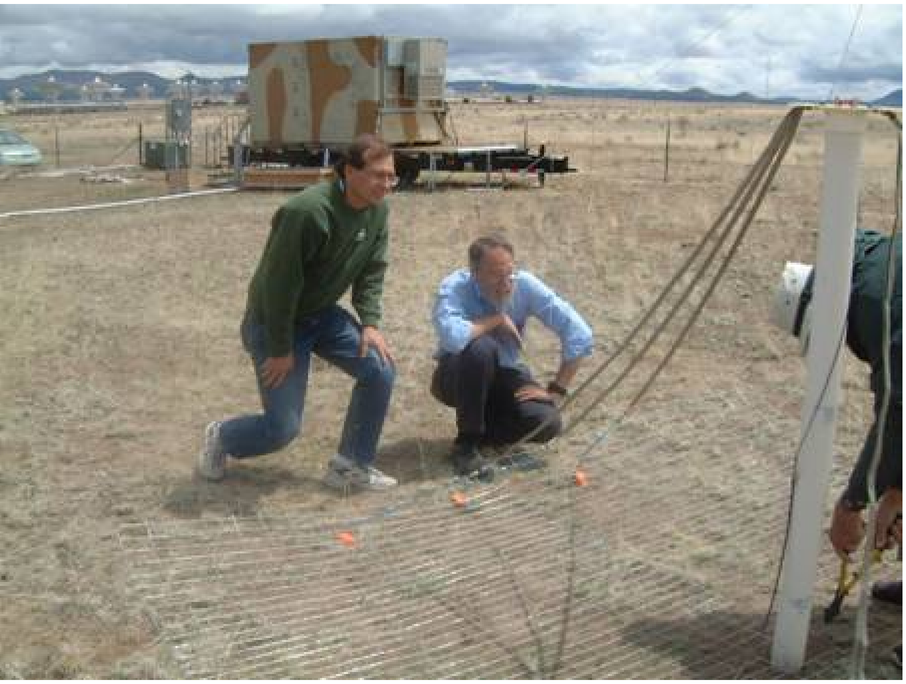


Figure 1: (a) – top left: Big Blade antenna atop a "postage stamp" ground screen. The ground screen material came in 500'x5' rolls at about $80 each; the unused portion of the roll can be seen at the upper right. The 16 small blade antennas of the LWDA can be seen in the background; (b) – top right: close up from (a) showing details of the ground screen material – 14 gauge welded wire with a 2"x4" cell size, see LWA Memo 90; (c) – bottom left - Rickard and Taylor examining Erickson's installation of ground screen under the FORK antenna. The project normally requires two supervisors per worker, in adherence to a strict regimen of quality control. The LWDA antenna can be seen in the near background, and the VLA in its D configuration in the distant background; (d) - bottom right - Bill Erickson over a nearly completely installed ground screen underneath the FORK antenna. One arm of the FORK antenna has yet to be reconnected. The U. Iowa RFI monitoring system is in the background.

Figure 2: (a) – top left – fully assembled FORK antenna atop postage stamp ground screen. The fence in the background marks the southern perimeter of the LWDA site; (b) top right – Brian Hicks replacing normal FORK balun with special unit for making impedance measurements in the presence and absence of a ground screen; (c) bottom left – Hicks and Paravastu recording impedance measurements. The equipment included a mobile network analyzer and power supply used in conjunction with a laptop computer configured with dedicated measurement software. (d) bottom right – same as (c) after the experimental assembly was moved from the trunk of a smaller car into the back of a 4x4 where it was much better protected from afternoon thunderstorms. The ability to make measurements in the rain was very beneficial, allowing us to compare dry and wet ground conditions with respect to the presence, absence, and size of ground screen material.

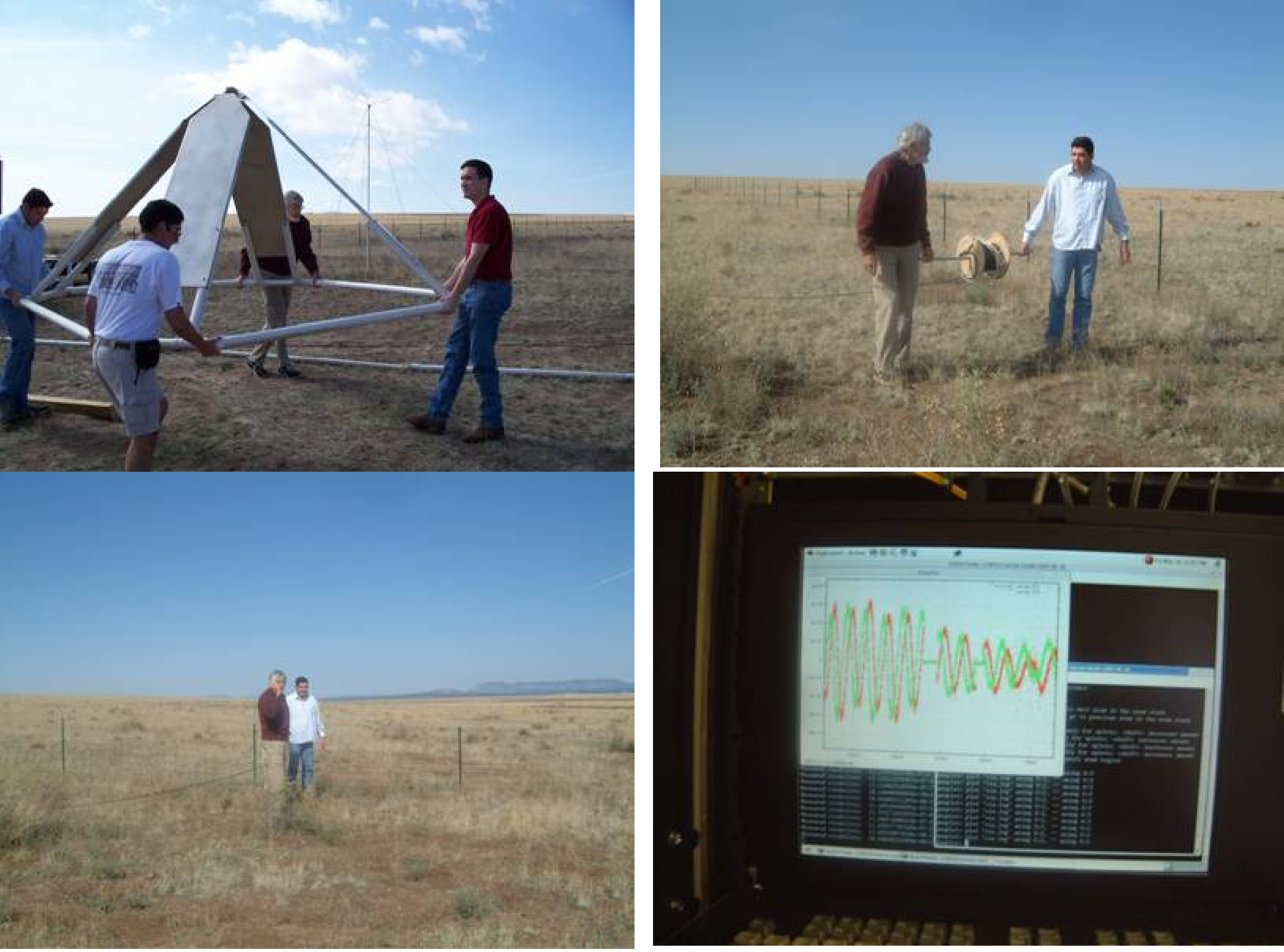
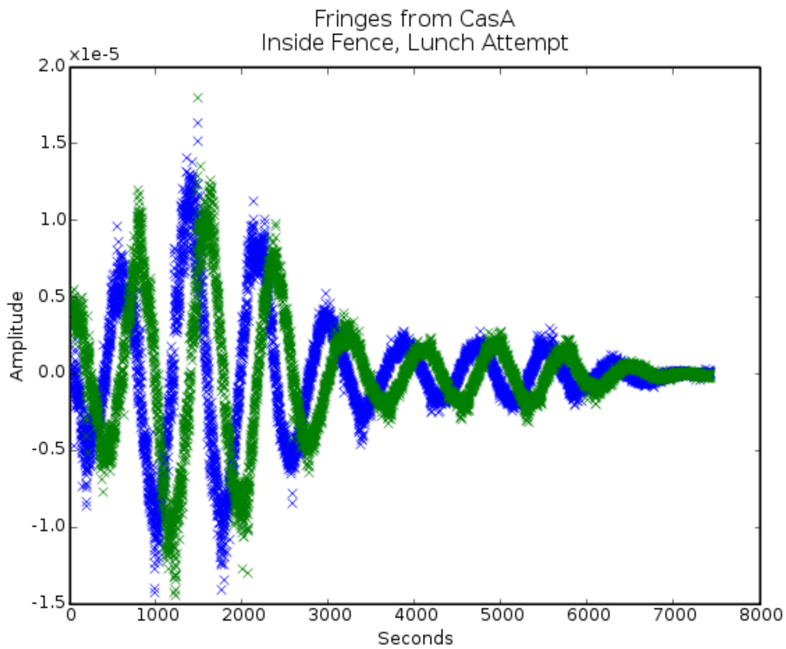


Figure 3: (a) – top left – Kassim, Gonzalez, Erickson, and York transporting Big Blade 2 (BB2) to the first outrigger location at the eastern periphery of the LWDA site; (b) – top right -Erickson and Gonzales paying out cable for the outrigger; (c) – bottom left – Erickson and Gonzales with the end of the outrigger cable at the eastern edge of the LWDA site; (d) – bottom right – some of the first fringes acquired by Johnathan York as displayed on the LWDA control computer inside the LWDA control trailer.



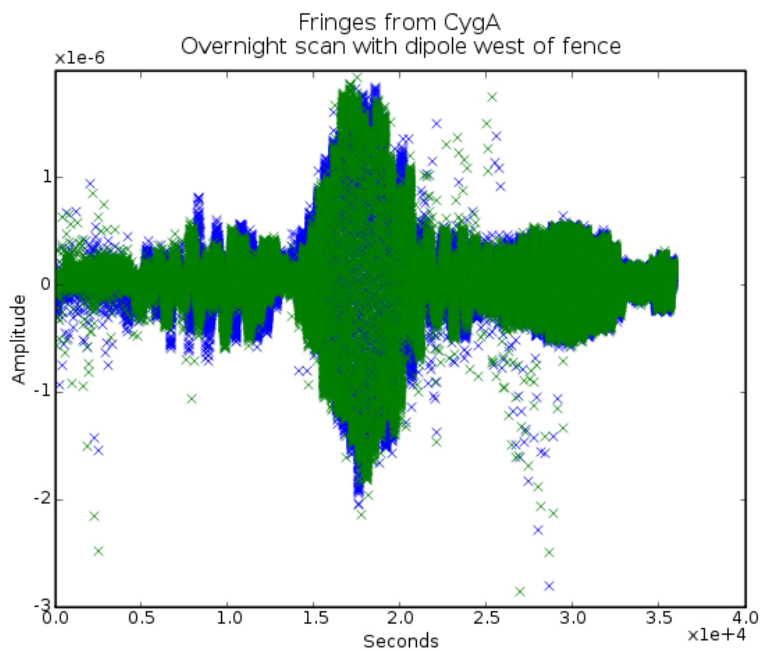


Figure 4: Drift scan fringes obtained on (a) Cas A (top) and (b) Cyg A (bottom) before and after the outrigger was moved from inside to beyond the western periphery of the LWDA site, respectively. The measured fringe frequency for Cas A indicates the EW component of the baseline length was ~129 m. The fringes on Cyg A were obtained over a nearly 12 hour period and hence the ~1s sampling of the individual data points has washed out the detail. The envelope of both patterns maps out the effective primary beam and sidelobes of the interferometer, defined by the phased array beam of LWDA. Each point represents 1 second of data at 1.6 MHz instantaneous bandwidth.

Figure 5: (a) – top – panoramic view of the outrigger antenna after it was moved about 300 m east of the LWDA (still on NRAO property); (b) – bottom – small fence erected by Eduardo outside the outrigger antenna shortly after our trip. Oddly enough, at the time of the writing of this memo (> 1 month after the installation of the outrigger) little or no damage has been noted with respect to the long run of unprotected co-axial cable from the LWDA to the outrigger.

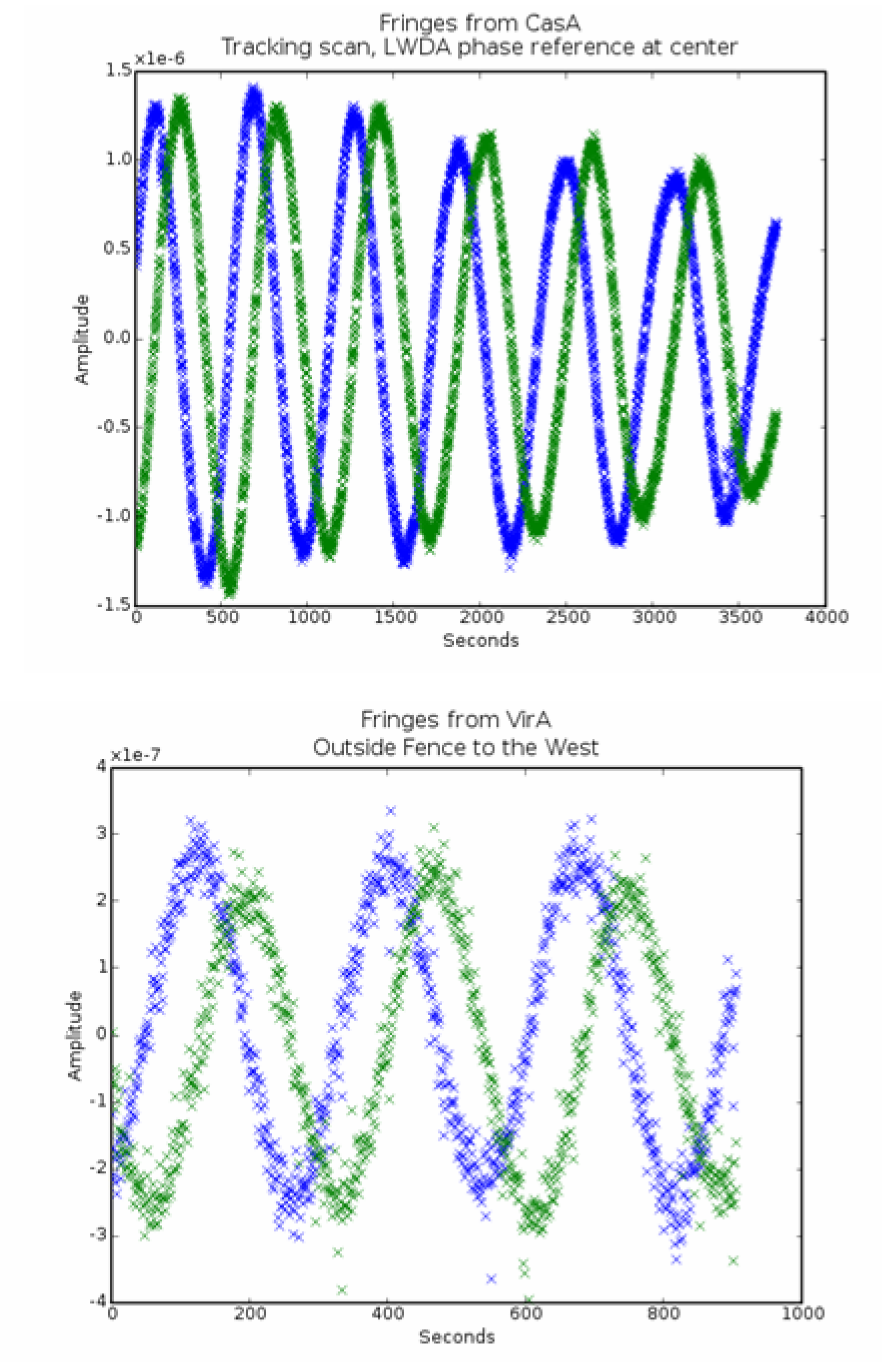


Figure 6: SINE and COSINE interferometer fringes on (a) Cas A (above) and (b) Virgo (A) (bottom) from outrigger located outside western periphery of LWDA site. The operational mode employed was a tracking two element interferometer between the outlier Big Blade antenna (BB2) and the phased array LWDA. Each point represents 1 second of data at 1.6 MHz instantaneous bandwidth.

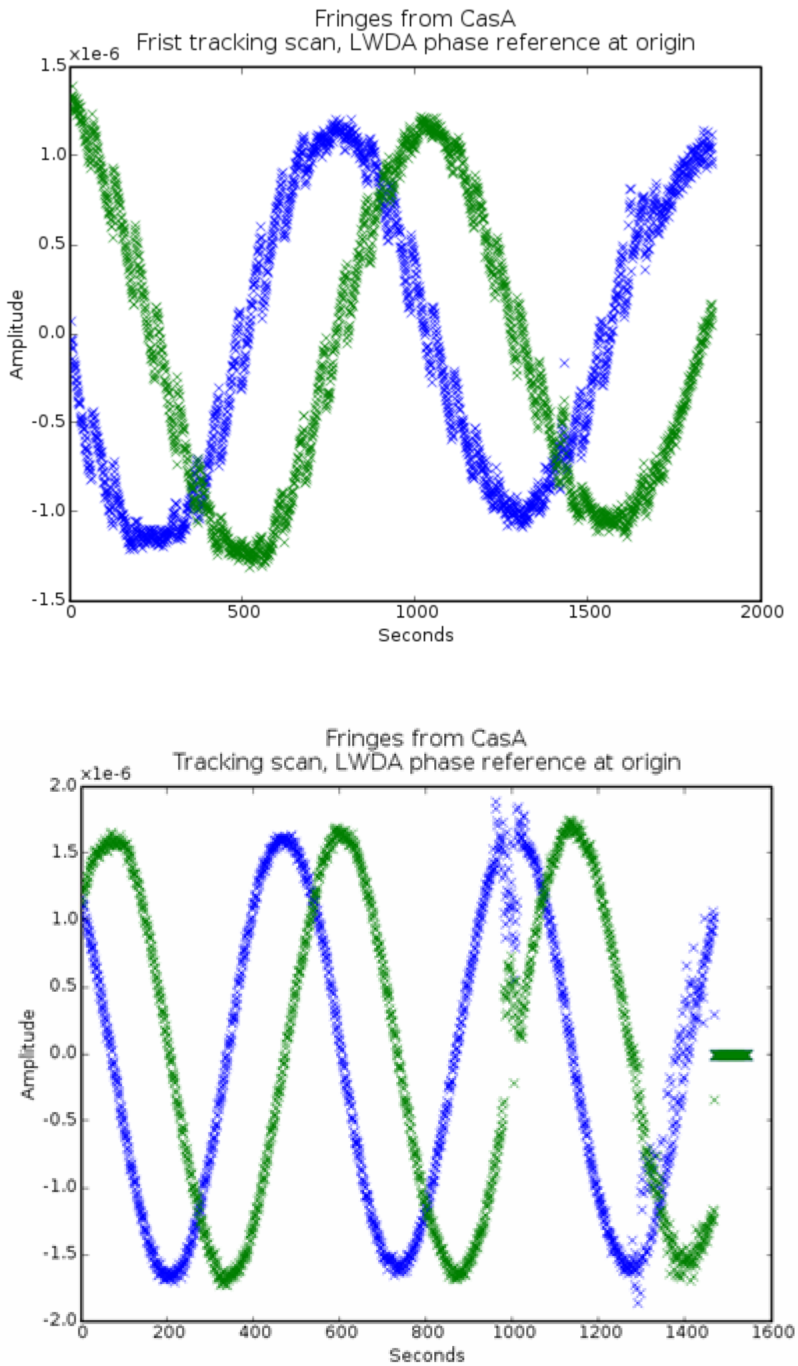
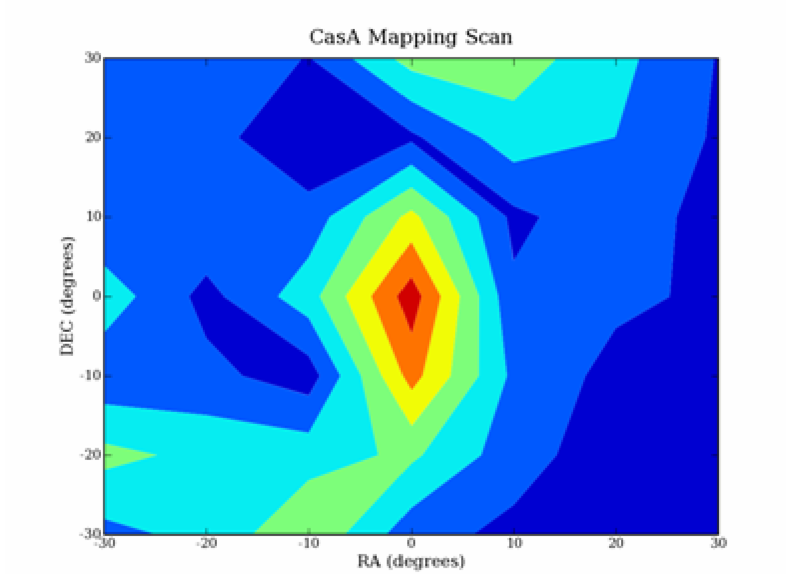


Figure 7: Fringes on Cas A when tracking mode was first implemented and the interferometer was re-pointed after each 1 minute scan. (a) The top panel shows "jumps" at scan boundaries corresponding to an error in our assumed phase center of the LWDA phased array. (b) In the bottom panel, Johnathan York corrected the assumed phase center of the LWDA to remove the jumps.



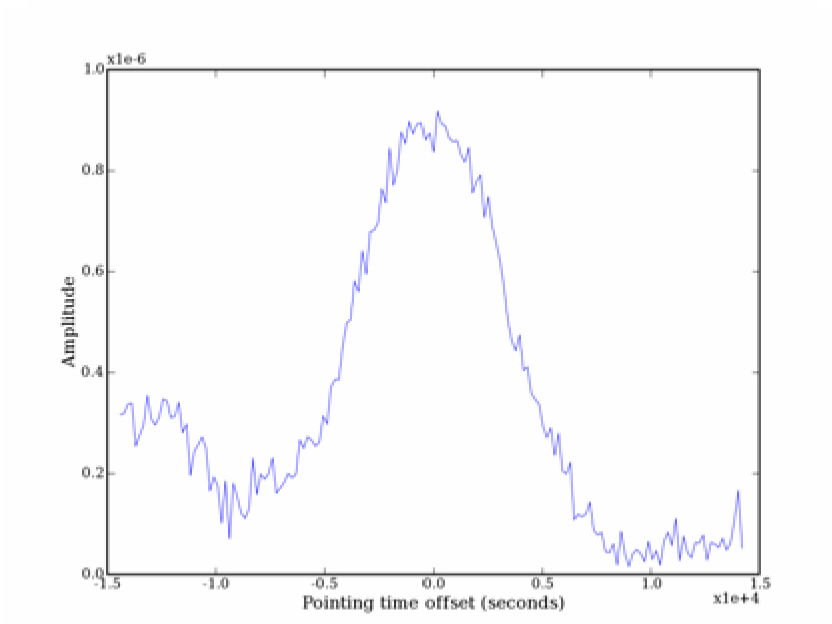


Figure 8: (a) – top – using successive drift scans of Cas A to map out the primary beam of the LWDA phased array station beam in RA and Dec; (b) 1-D cut through the primary beam showing amplitude as a function of time. The tic mark at "0.5×10^4"seconds corresponds to ~10° on the sky at the declination of Cas A. This reflects the relatively small size of the LWDA, whose ~25 m footprint translates to a primary beam on the sky ~$(180/\pi)*(\lambda/25\ \mathrm{m}) \sim 9.2°$at $\lambda = 4$ m wavelength (74 MHz).

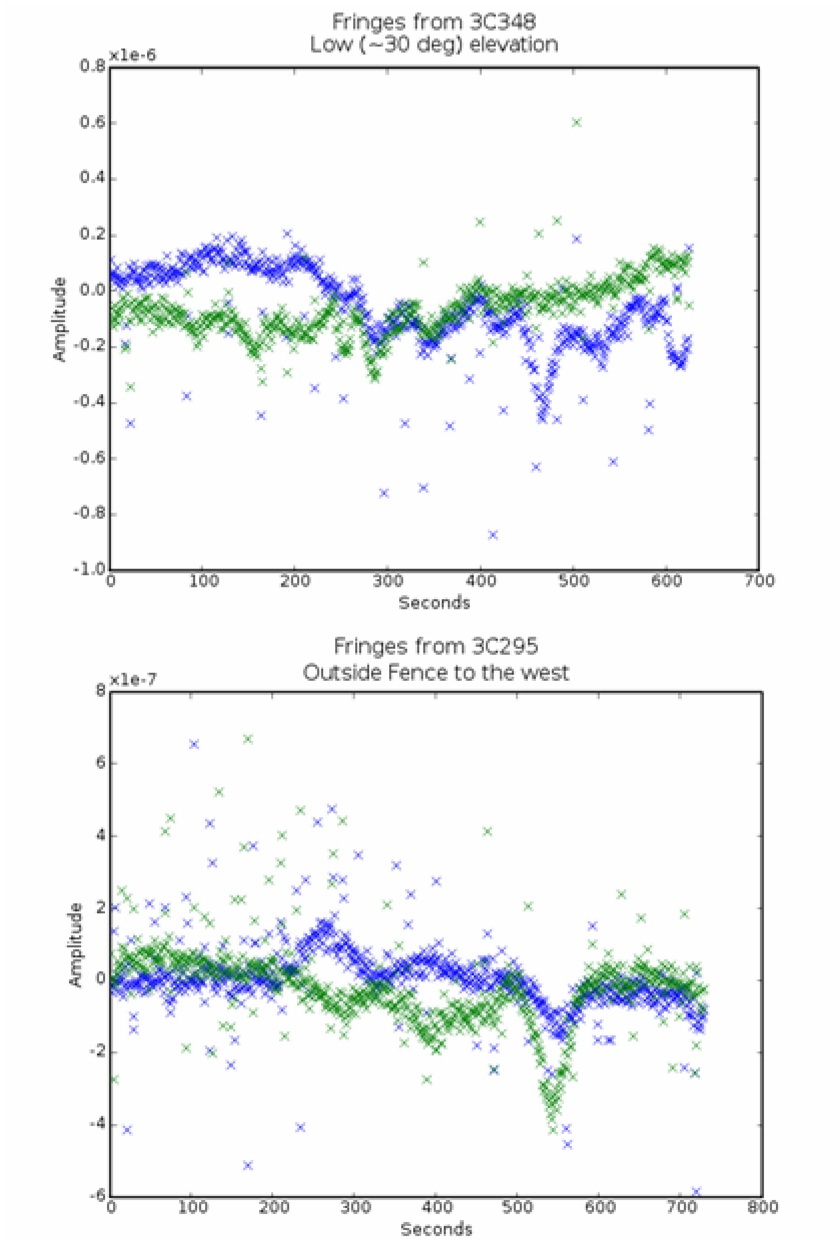


Figure 9: (a) – top – fringes on 3C348 (Her A), heavily distorted by the sidelobe confusion from many other discrete sources; (b) – bottom – same as (a) for the radio source 3C295. The sidelobe confusion comes from the superimposed fringe patterns from the myriad discrete sources that the interferometer is sensitive to, although the main effects are probably dominated by the pathologically brightest sources (e.g. Cas A, Cyg A, Vir A, & Tau A).

Figure 10: (a) – top – equipment shed installed by Eduardo next to the LWDA control trailer shortly after our trip; (b) – bottom - steps installed outside the LWDA control trailer (also by Eduardo) during our visit.