LWA Memo 226: LWA-NA Construction

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1 Introduction

This memo provides an overview of the construction of the LWA-NA station. This includes a description of the work carried out along with estimates of the labor and materials. This memo ends with first light and does not describe commissioning activities.

2 Site Description

The LWA North Arm site is located on state land near the end of the North Arm of the Karl G. Jansky Very Large Array (VLA) at (34° 14′ 49″ N, 107° 38′ 21″ W). The site is a fenced in 120 m x 120 m (3.54 acre) lot. Structures at the site include the LWA-NA electronics shelter, a 20' storage container, and the old LWDA trailer which is used as a mobile workshop and cafe. The site is connected at 1 Gbps via fiber that runs to the nearby VLA:N72 pad and then to the VLA control building. Figure 1 presents annotated satellite imagery from Google Maps.

3 Part List

The list of parts needed for the LWA-NA station is provided in Table 1.

Table 1: Parts List

Part	Cost	Manufacturer
Shelter		
Shelter	44559	American Products
Power line filters	495.4	TE/Corcom
250 ft 1 inch liquid tight conduit	339	homedepot.com
gasketting for shelter	2000	Holland Shielding

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PDU	569	APC
ASP Rack box	6845	Premier Enclosures
concrete pad	925	home depot
Antennas		
33 Ant	8910	Burns Industries
33 FEE	8745	Burns Industries
128 cables to SEP	9480	Burns Industries
outrigger cable extension	1690	TXM manufacturing
bulk LMR 195 cable	914	TXM manufacturing
ozposts	1353	OZCO
ground screens	660	fencerwire.com
shipping	6300	Burns Industries
machine shop	444	UNM
Analog Signal Processing		
power supply	2848	Acopian
cabling	4157	Readytogocables
chassis	950	elma.com
Waterjet rack-entry panels	204	waterjet in Albuquerque
sandblast paint on panels	209	Albuquerque Powder Coating
ARX boards	14363	Caltech
Waterjet doors on ASP box	364	waterjet in albuquerque
Digital Processor		
Timing	12000	Oriola and UNM, see Craig Taylor memo
SNAP2 boards	25819	Chiphop.cn
Digitizer boards	4728	Caltech
chassis	650	elma.com
PDU	568	APC
cabling	5104	Readytogocables
servers	46981	Silicon Mechanics
switches	595	Arista
4 data recorders	8944	Silicon Mechanics
drives for DRs	2520	Western Digital
Monitor and Control		
computers	4915	Silicon Mechanics
switches (network)	799	HP
Smart UPS	1525	APC
Miscellaneous		
Monuments	125	Bernsten International
lightning detector	2598	Boltek
weather station	899	Davis Instruments
lightning arrestors	5390	Polyphaser
sensors - enviromux	381	NTI
Oz-puller	488	OZCO
extra collars	105	OZCO
power line, pvc pipe and ground rods	375	home depot

RF parts	447	digikey
field supplies	210	home depot
Machine shop	562	UNM
travel to site	1914	UNM
generator (20 kW) rental	140	Frank's Supply
electric hookup (parts)	310	home depot
fiber hookup (parts)	123	fiber.com
flatbead rental for Shelter install	150	Frank's Supply
as-built survey	160	home depot
sealcon boxes and pass throughs	947	Sealcon
trencher rental1	189	Frank's Supply
trencher rental2 and 3	702	Acosta Rentals
trencher rental4	350	Acosta Rentals
trencher rental5	400	Acosta Rentals

4 Preliminary Survey

The preliminary survey of antenna and shelter locations was conducted in May of 2022 using a Northwest Instruments NTS02B total station borrowed from AFRL[1]. Two monuments were set for the survey with one located at the center of the array and the other ∼5 outside the fence and due north of the center marker. It would be a good idea to make sure that no antenna ends up withing 5 meters of the center monument, otherwise the survey at the end could be challenging.

Mast positions were first mapped using an antenna location optimizer (seen in Figure 2), located on site using the ARFL total station and reflector, then marked using labelled wooden stakes pounded into the ground. Similarly the electronics shelter and weather station were outlined on the ground with hi-visibility marking spray paint. Following the survey to place markers for structures, future trenches were labelled on the ground using thick dashed lines of marking paint. This would allow for masts to be placed with their junction boxes facing towards their respective trench during the installation of masts discussed in Section 6.

A sighting was also determined for the reference point of the alignment jig. This jig can be placed on the antenna (where the FEE will eventually sit) and lined up with a distant point on the horizon. For LWA-NA we used the Antenna Assembly Building on the VLA site. This reference point should ideally be over 10 km distant such that the parallax across the 100 m site is less than 1 degree.

5 Electronics Shelter

The electronics shelter was purchased from American Products and is the AP Freedom 78x90x42 (126RU) model for $44,558. Options include door alarms, rail sets for all three

[1]A weekly rental is available from VectorsInc.com in Albuquerque for $1260.

Figure 1: LWA-NA site and VLA pad N72 at right. North is up and east is to the right. The imagery from Google Maps' "satellite" layer.

bays, two AC units with 20,000 BTU (≈1.5 tons) cooling capacity each, a center panel to divide the two-bay from the cable entry bay, and a 100 amp load center. The rail set for the cable entry bay was not needed and could have been omitted. In order to properly shield the the shelter all the gaskets had to be removed for the two-bay and shielded gaskets installed. The most labor intensive part of this was grinding off the paint using an angle grinder with flap discs and a wire wheel. In the future it would be preferable to leave the interior of the shelter unpainted and provide instructions not to install gaskets on the two bay doors.

Other improvements to shielding were the addition of honey comb panels on the HVAC entry/exit, closing the cable routing holes between the two-bay and the cable entry bay, installing an EMI filter (TE Connectivity 30VK6C) on the power cable to the 120 VAC outlets in the cable entry bay, and installing powerline filters on all circuits (TE Connectivity 30VK6C).

The as-modified shielding level was obtained by placing a discone antenna inside the shelter transmitting a broadband signal, and then measuring the power levels with a directional log periodic antenna (see Figure 3). The system was calibrated with the door open and the log periodic at a distance of 3 meters such that the average received power was 0 dB. With the door closed the shielding at 3 meters achieved was roughly 40 dB at 120 MHz. Measuring the shielding at frequencies below 100 MHz was challenging given the performance of the antennas used. Larger antennas may have worked better but would have been difficult to fit inside the AmPro shelter.

The shelter was installed by crane with help from NRAO. It was placed on a concrete pad that had been previously built in November. We then trenched in power, fiber, and

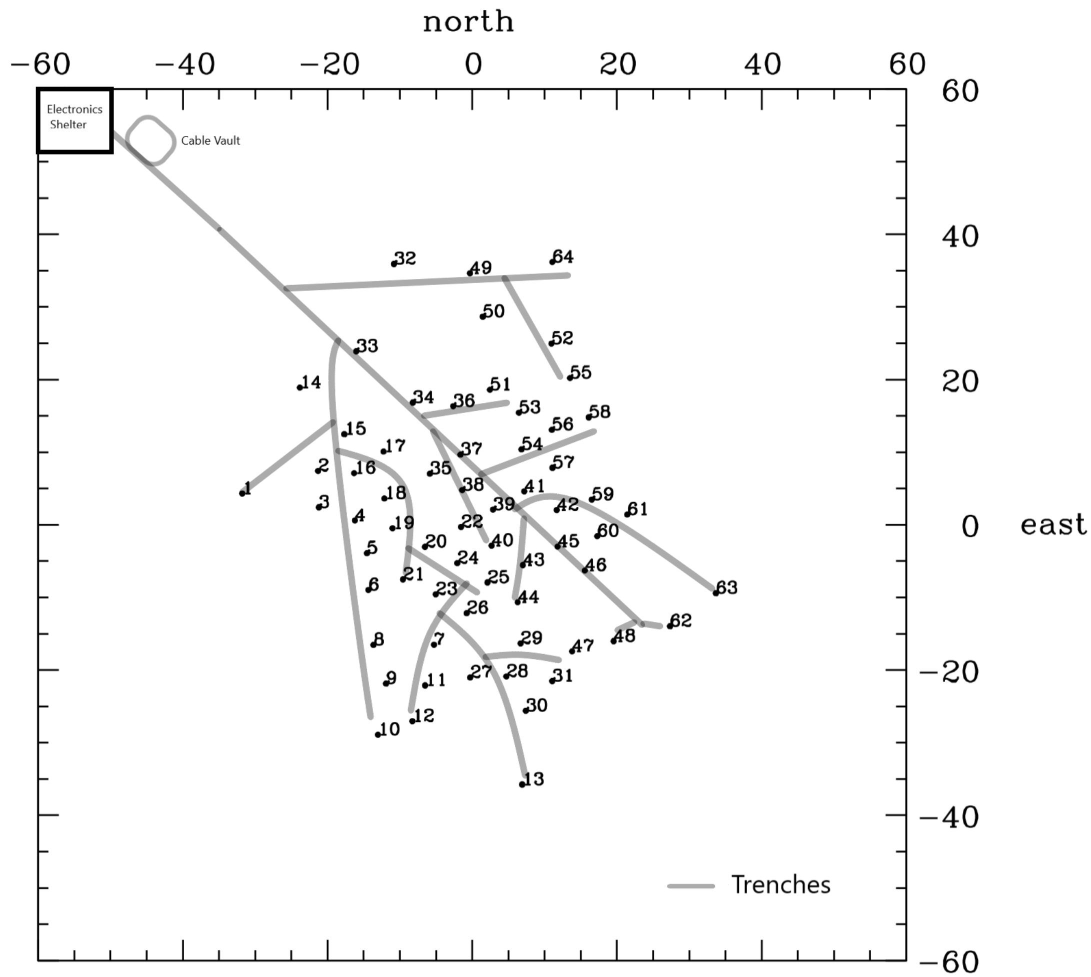

Figure 2: Diagram of the LWA North Arm site as constructed. Antenna positions were distributed using an optimization code (see LWA Memo #210 and supplemental materials), grey lines indicate where trenches were dug during the construction phase, and the borders of the plot effectively serve as a reference to the fence enclosure. Note that the outrigger temporary structure is located due South-East of the fence and it's trench extends out of the array at Antenna #58.

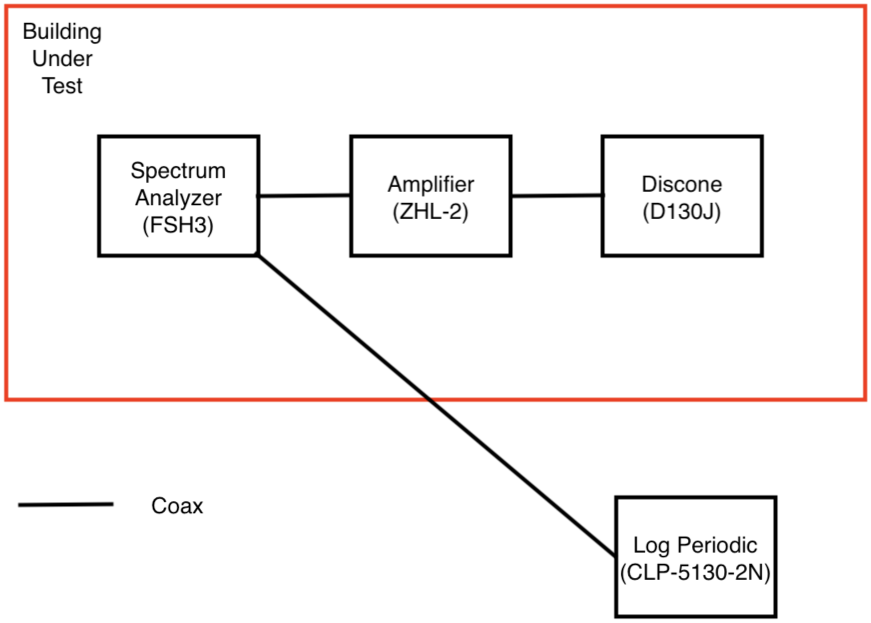

Figure 3: Block diagram of the setup for the building shielding test. The discone is used as the transmitting antenna inside the building and the log periodic as the receiver outside the building.

GPS/weather station trenches using a walk-behind trencher was obtained from Frank's Supply at a daily cost shown in Table 1. Cables were ran over the course of three site trips with 2-3 people at each one.

6 Oz-Posts and Masts

Mast locations were first mapped as described in the preliminary survey (see §4), then installed over the course of 3 site trips. This consisted of pounding Oz-Posts into the ground at the marked locations using an electric jackhammer, a two way level, and a cap driving tool per the recommended installation instructions. After placing a mast into the Oz-Post assembly, each mast was rotated to point the junction box opening towards their respective future trench location as labelled on the ground with marking paint. Small corrections to the leveling were also made prior to pounding the compression collar into place. Masts were installed into the recess left from removing the marker stake from the ground to best replicate the survey design, then relabeled by placing the same marker stake in the ground adjacent to newly installed masts. Each mast assembly takes about 5 minutes to install, not including the time required to move tools between mast locations, and 2-3 persons were able to install 20-30 masts per day.

During assembly of antennas, it was discovered that several Oz-Post compression collars were not properly fastening when installed. Leaving behind a small gap in the housing that allowed for the affected masts to free rotate in their Oz-Post anchor, creating problems in retaining alignment during service. This was likely due to mixing old antenna masts with new collars or vice-versa and is not expected to be a problem with new installations with uniform parts. To remedy this at the NA site we had a set of aluminum 3003 shims at $\frac{1}{16}$ by $\frac{3}{8}$ by $2\frac{3}{4}$ inches through the UNM machine shop. These shims were then molded by hand into a semi-circular shape using a spare Oz-Post compression collar. On site we used a combination of hammer and chisel as well as the Oz-Post collar hammer to drive our aluminum shims into the gap between collar and mast. The pliability of the 3000s series aluminum made installation easy and we found this an adequate solution to antennas who had rotational freedom in their Oz-Post.

7 Trenching

Trenching for array cabling was done of the course of 3 site trips with a combination of ride-on and walk-behind trenchers, plus a fourth day to backfill open trenches. Previously marked trench locations (see §4) were repainted using marking paint to improve visibility, then dug according to the site map shown in Figure 2. During the cable laying phase of construction, several inches of dirt will likely accumulate in the bottoms of trenches due to foot traffic and cables interacting with the trench walls. *To help support integrity during construction and thermal stability of station cables, diligent attention should be given to ensure trenches are dug to the proper depth to account for such considerations.* Below is a brief outline of the aforementioned heavy equipment rentals used in the construction of the North Arm mini-station. For each of the days listed the rented equipment was used for approximately 5-6 hours to complete the described tasks.

Day 1: On May 23rd a ride-on trencher was obtained from Acosta Equipment at a daily cost of $350. This trencher was used to dig the main trench and the trench to the outrigger.

Day 2: On May 25th a ride-on trencher was obtained from Acosta Equipment to finish the main trench, dig some auxiliary trenches, and dig the cable vault.

Day 3: On May 30th a walk-behind trencher was obtained from Acosta Equipment at a daily cost of $300. The trencher was used to cut short side trenches that branch from the main trenches. Note that some short channels from the antenna to the trench had to be dug by hand when there was not sufficient room to get the trencher in. This effort was done partially on this day and mostly during cabling (see §8).

Day 4: On August 3rd a ride-on trencher was obtained from Acosta Equipment to backfill the open trenches in the array and to cover the cable vault.

8 Cables, TDR, Labeling

Cables used were LMR195 type with a combination of store-bought cables and custom (both recycled and fixed length purchases). The outrigger (to be placed roughly 400 meters from the center of the array to the east or west) should employ LMR400 type cable to reduce voltage drop and signal loss. Note, however that the LMR400 cable is too thick to be run up the mast so a junction box (see Table 1 for the price of that made by sealcon) needs to be installed about 7 meters from the outrigger antenna and LMR195 cable used from the junction box to the FEE. Note that the junction box must be completely waterproof and well sealed to avoid damage to the connection between the LMR400 and LMR195 cables. For thermal stability the junction box should be placed under a 19″ x 14″ irrigation box buried near the end of the trench with the lid of the irrigation box roughly level with the ground. Flexible conduit should be run from the irrigation box to the J-box on the antenna mast.

An issue with the recycled cables is that they were not measured with sufficient accuracy so some of these cables came up short. The store-bought cables from Burns Industries came with connectors on spools with two cables/spool. These are quite easy to install but require a cable vault area where excess (typically about 10') cable can be stored. Custom cabling can eliminate the need for a cable vault, but requires connectorizing the cables in the field which is more time consuming. Store-bought cables can be installed by 3 people at the rate of about 12/day. Custom cables can be run at the rate of about 8/day. In addition to running the cables, some effort is required to hand-dig short trenches to the closest trench, install flexible conduit from the J-box to the trench, place a cap over the exposed cable, and then label the antenna cap. About 7 inches of cable should be present above the top of the mast. This cable should be secured using tape or equivalent means such that it is not accidentally pulled down the mast. This is particularly important for the backfill stage of trenching where cables will undergo increased strain. These steps are included in the time estimations above for laying cable for LWA stations, but nevertheless should be considered when preparing to install cable at new stations.

Note that cables can get hung up on the side-walls of the trenches. When these cables were later buried this can pull the cable down the mast by between 6 and 18 inches leading to cables that were no longer long enough to reach the FEE. This can also put undue strain on the cables at the SEP. At the SEP proper strain relief should be provided and several inches of excess cable should be available for each connection.

After all cables had been laid in trenches, we carried out time domain reflectometry (TDR) in order to acquire the cable lengths as-built and check for possible damage incurred during the installation. We used a TAPR Vector Network Analyzer Model 6000, following the associated software set-up on a portable computer running Windows XP (most recent stable release is for 32-bit windows OS only up to Windows 8.1). Station cables to be measured must be a clean open (no FEE installed) and we were able to complete these measurements over the course of approximately 6-hours with three workers. One at the computer taking measurements, and the other two taking off FEEs and re-installing them as we had already completed construction. For a clean mini-station build, this could be done in the same amount of time with one person if all cables have been laid and are a clean open at each stand. Measurements were verified in the lab using a set of manually measured cables and the hardware manual, then corrected using a linear fit to more accurately represent the field cable lengths for preliminary calibration.

9 Populating Electronics Racks

At this point one may want to begin populating the racks in the electronics room. Basic equipment includes the UPS and two PDUs, enviromux for environmental monitoring, GPS receiver (with its antenna placed outside and clear of the array), lightning detector, weather station, fiber switch, network switch, MCS servers, GPU servers, ARX boards, FPGA boards, and timing distribution box. Even with only one antenna built it is then possible to begin evaluating the RFI environment. As additional antennas are constructed signal integrity can be evaluated.

10 Building Antennas

Antenna building took place over the course of 6 site trips (8/3/2023-9/12/2023) and assembly followed along with the *LWA Antenna Field Assembly Instructions - LWA Memo 225*. We implemented two types of construction strategies during this stage of the project. The first was small group trips of 2-4 students working collaboratively to build one or two antennas simultaneously (4 of 6 site trips). The second approach utilized a larger group of 10-16 workers in an 'assembly line' fashion. Where pairs of workers were assigned one of the build phases outlined in the field assembly guide, then progressively build their assigned stage on available antennas.

Strategy #1 seemed to prevail in the long run as the more successful scheme for building antennas. Mostly due to the fact that efficiency rapidly improves in construction after the first several antennas. The main drawbacks of this approach are that extra time must be allocated to assembling the required components at each antenna site for construction, and the need to move a potentially cumbersome amount of tools and hardware from antenna to antenna. Strategy #2 alleviates some of the strain in moving parts between antennas during assembly, but adds stagger to each stage of assembly which can itself cause delays or many antennas to be partially complete after a work day. For example, if the pair constructing fiberglass supports is slow there will be a large backup down the line as groups may have to wait to perform later building steps.

For these reasons, we suggest the following compromise of the two strategies that may alleviate some of the pitfalls of each. Before beginning assembly of antennas en masse, start first by building all of the ground screens, placing them over each existing mast, then collecting the remaining parts (fiberglass supports, flanges, antenna wings, etc.) and place them adjacent to each mast. This will save time in the long run of walking back and forth between an arbitrary pile of supplies likely located outside the core of antennas. After this is complete, break workers into teams of 2-4 and assign them to perform the remaining assembly tasks outlined in the manual onward from ground screen installation. This will hopefully eliminate large sets of partially complete antennas after a work day, preserve the efficiency developed in fully constructing antennas, and give workers a better understanding of the hardware. This strategy is also likely to deliver better build quality. With large groups it can be easy for some important step (e.g. properly placing the hose clamp on the hub and tightening it down after alignment). At LWA-NA several antennas were found to be insufficiently tightened following alignment.

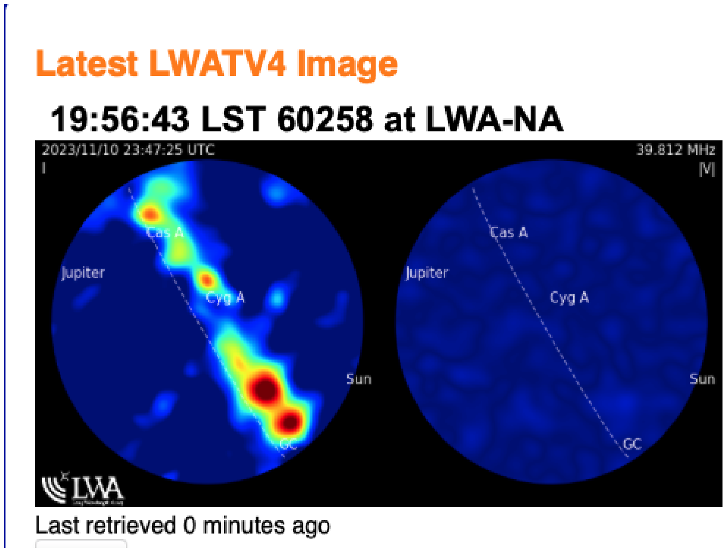

Figure 4: LWA-NA first light image of the sky with approximately 56 good dipoles. Calibration is very preliminary which is why the galactic center falls to the right of where it should be (dashed line).

11 As-Built Survey

After all antennas have been built and cabled up it is time to perform the final TDR measurements and carry out the as-built survey. The as-built survey was again done using the same total station as was used for the pre-construction survey and station layout. The total station was placed on top of the array center monument and then a reflector was placed on a custom mount that fits snugly over the top of each antenna. Antennas were measured 1 through 64, taking a back-site reading to the reflector placed at the back-site monument every 8 antennas. After all measurements have been taken they are downloaded to a USB drive.

12 Summary

With proper planning it should be possible to build an LWA mini station (64 dipoles) as described here in roughly 3 months time, assuming site preparation and purchasing of long lead items has been started early enough. Long lead items (3+ months) for construction of the station include preparation of the ground and electronics shelter, connection of power and fiber to the shelter, as well as the purchase of the monuments, antennas, racks, power supplies, ARX boards, and timing distribution box. Medium lead items (1-3 months) include the digitizer boards, GPU server, and imaging server. Note that as of the time of this writing we are looking to transition to the VCU102 boards as a replacement for the SNAP2 boards. The VCU102 boards have a much shorter lead time (1 week) compared to the SNAP2 boards (3+ months).

Most of the tools needed are readily available hand tools (see LWA memo #225), but there are a few less common tools. These include the total station used for surveying, the ride-on trencher and walk behind trenchers that are generally available for rent, the jackhammer to put in the oz-posts, the oz-post collar pounder to seat the collars on the masts, the nicopress tool to clamp the two ground screen pieces together, and the TDR measurement box and suitably ancient laptop computer with the TDR software installed.

In Figure 4 is the first light image for LWA_NA obtained on November 10, 2023 after the final TDR measurements had been entered into the SSMIF. There are still some issues with the calibration and a handful of antennas still have problems with FEEs or cabling, or possibly a bad connection on the digitizer board. These issues and others will be sorted out during commissioning.

References

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[2] O. Leone Jr., "A Standalone High Frequency Receiver System." May 2014. [online] https://digitalrepository.unm.edu/ece$_e tds$/157

[3] C. Taylor, S. Chastain, G. B. Taylor & J. Dowell, " LWA Antenna Field Assembly Instructions" Long Wavelength Array Memo 225, Nov 6, 2023. [online] http://www.phys.unm.edu/ lwa/memos/index.html.