Preliminary Design of the LWA-1 Array, Antenna, Stand, Front End Electronics, and Ground Screen

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Contents

1. Introduction

This document describes the preliminary design of the portions of the Long Wavelength Array (LWA) Array subsystem that are associated with the antennas themselves, as defined in the LWA Station Architecture [1]. Specifically, we cover:

- Array (ARR): The geometry of the antennas within the station footprint.
- Antenna (ANT): The RF design of the pair of orthogonally polarized dipole antennas that form the primary receiving elements in the station.
- Stand (STD): The mechanical structure that supports the antenna.
- Ground Screen (GND): The conductive ground screen that is positioned under each STD.
- Front-End Electronics (FEE): The electronics within the STD that convert the balanced signal from each dipole to an unbalanced signal and amplify it for transmission over the RF cables.

2. Subsystem Design

2.1. Array (ARR)

2.1.1. Geometry

The psuedo-random array geometry was chosen to provide the collecting area and field of view required while minimizing sidelobes, maintaining a minimum separation between STDs of 5.0 meters, and providing good imaging quality for northern and southern sources. The design optimization is fully described in [2]. The optimization ignores the effects of mutual coupling since the full calculation is impractical at this time, but the effects on this pseudo-random array are not expected to require changing the array layout [27]. The selected array configuration is displayed in Figure 2.1. The installation tolerances have not been studied in great detail, but initial estimates suggests that ±10 cm in the X, Y, or Z directions should be more than sufficient (B. Erickson and E. Polisensky, personal communication). This tolerance corresponds to 1/40th of a wavelength at the shortest wavelength.

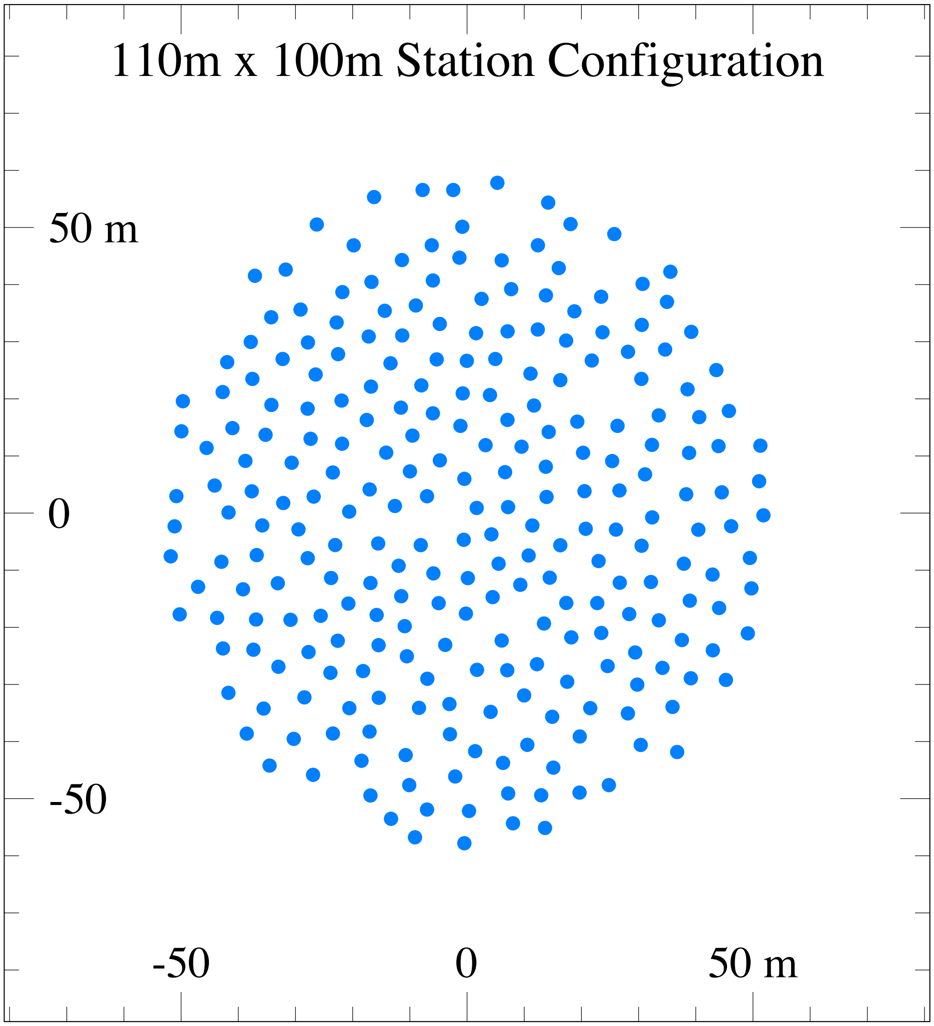

Figure 2.1. Pseudo-random array geometry planned for LWA-1. Reproduced from [2].

At each location in the array an anchor is driven into the ground to a depth such that the Oz-Post collar is at the level of the ground plane. The anchors then serve to hold up the masts (see STD description in Section 2.3) and thus must be sufficiently strong to keep the stands upright through whatever conditions are encountered at the site. They also set the height of the feedpoint above the ground, and thus must be able to be driven in to a consistent depth. The anchors chosen for the preliminary design are the Oz-Post ISW-850 [4], which cost $18/each in LWA-1 quantities [26]. The Oz-Post company estimates that delivery times for 256–300 pieces are about 8 weeks. For purchasing, we note that convenient quantities include 6-post cases and 120-post pallets [26]. The vertical and lateral load ratings of this anchor are more than sufficient for this application [4].

2.1.2. Interface to STD

The Oz-Post ISW-850 accepts a 2 3/8 inch outside diameter round post (the STD mast) into its 4 inch deep sleeve. After aligning the STD with N-S, a compression collar is hammered on, which secures the mast to the Oz-Post and prevents rotation. The compression collar is removable to allow for reorientation, replacement, or removal of the STD.

2.1.3. Installation

The ARR installation consists of surveying the locations of each of the STDs and driving the Oz-Posts. The cost and time estimates for the surveying are described in [34]. Once markers are in place for the STDs, the Oz-Posts need to be installed. The Oz-Post company recommends that 10–15 minutes per post be budgeted for a team of two people, although the actual installation time is only about 2 minutes per post. A 2-way post level is used to ensure that the post is driven in vertically. The post is driven with a jackhammer and a custom adapter. The cost of these parts required for installation are given in Table 3.1. The labor estimate for installation of 256 posts is then 53 hours × 2 people = 106 person-hours.

The STD installation described below assumes this ARR installation is completed first.

2.1.4. Pre-CDR Plan

Initial tests with one Oz-Post at the site were quite encouraging, but given the heavy reliance on them, additional testing is warranted. Tests undertaken will include:

- Test driving Oz-Posts to ground level to see how repeatable the process is and what vertical tolerance can be achieved. We will also verify the installation labor estimates.
- Attach posts to driven Oz-Posts and subject to varying loads in varying directions to see how far from vertical they can be pulled by wind loading over time.
- Test methods for dealing with soft or highly disturbed ground (such as is found where rabbits or other animals have been digging). Either repacking the soil, or reinforcing with concrete should handle these cases.
- Derive and document tolerances on surveying and installing the Oz-Posts.

2.2. Antenna (ANT)

2.2.1. Geometry

The final antenna geometry represents a tradeoff between cost, mechanical stability and RF performance. The choice of the Screen Tied Fork with an alternate of the Tied Fork was described in [3]. For the PDR design we have chosen an intermediate solution of the Tied Fork with a single crosspiece (see Figure 2.2) that increases mechanical stiffness without overly inflating the cost. The arm lengths of the dipoles are 1.50 m. The distance between the feedpoints on the FEE is 9.0 cm, while the apexes of the triangular elements are separated by about 13.2 cm (see Figure 2.3).

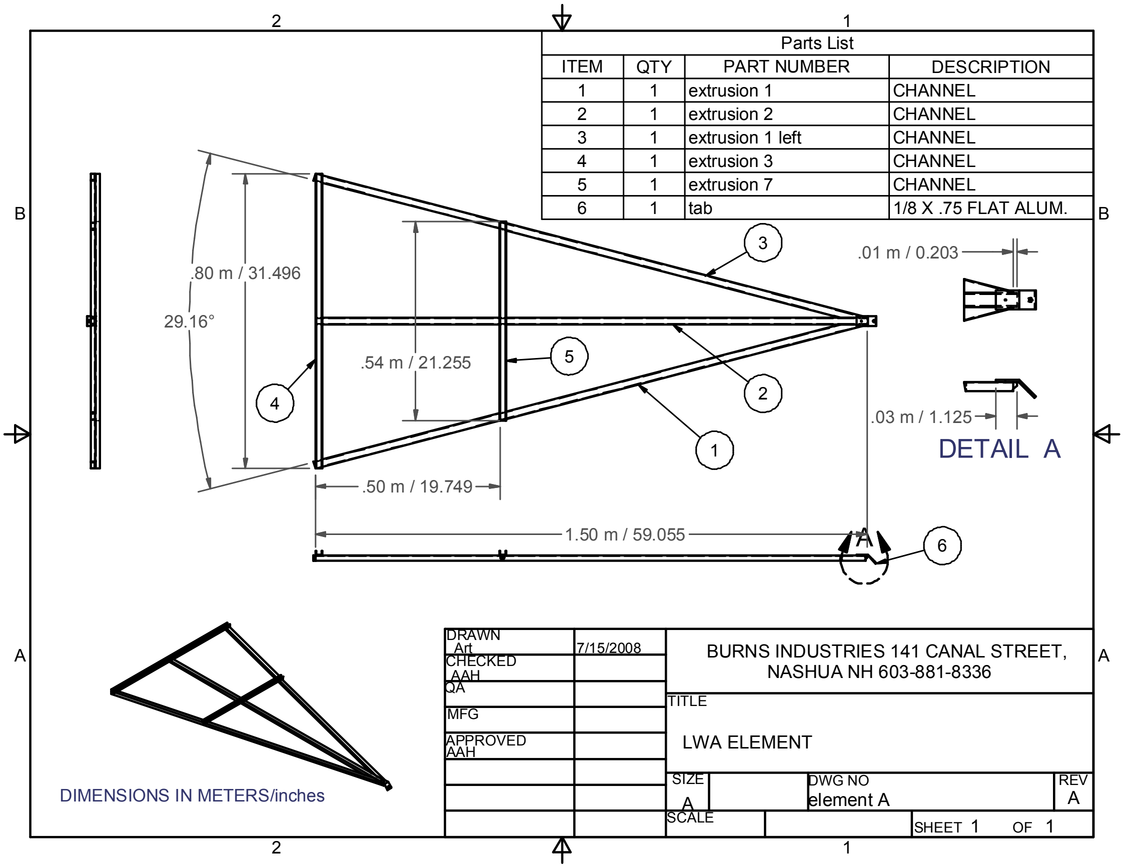

Figure 2.2. Preliminary mechanical design of a single antenna element.

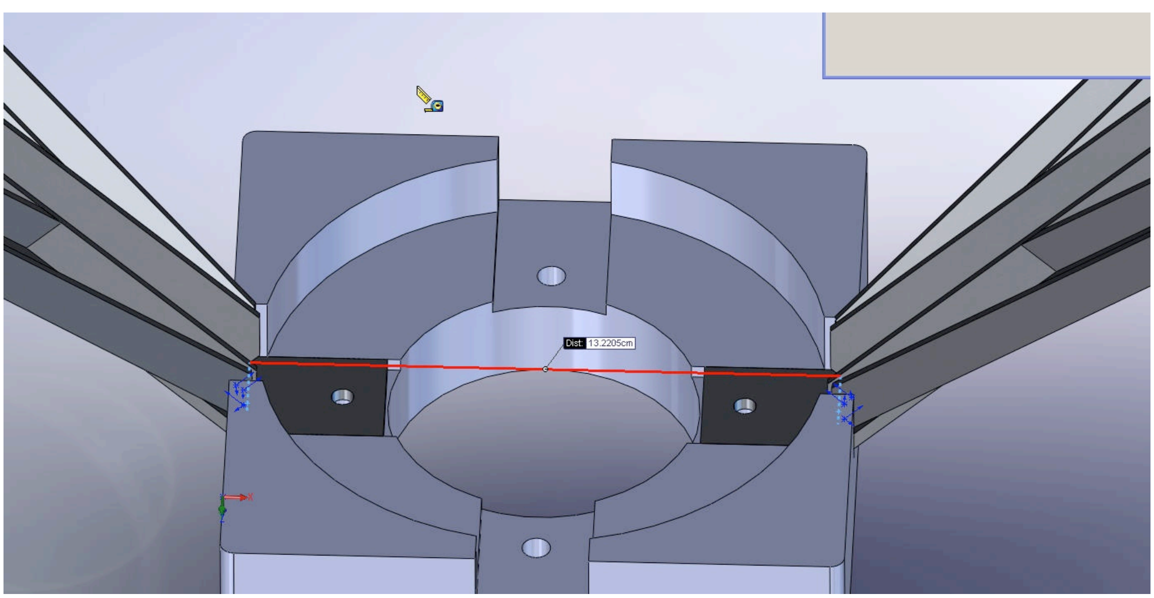

Figure 2.3: Detail of feedpoint connections on the hub. The bolts are 9.0 cm apart and the apexes of the elements are about 13.2 cm apart, with tabs welded on that cover the rest of the distance.

2.2.2. Performance

In addition to numerous simulations [24] and field tests [23] on previous similar designs, NEC-4 [19] simulations were performed to demonstrate the performance of these specific antennas. The E and H-plane patterns over a range of frequencies are shown in Figures 2.4 & 2.5 and a summarized in Table 2.1. The predicted impedance characteristics and sky noise dominance are shown in Figures 2.6 & 2.7. We note that the sky noise dominance (*D*) is >6 dB over the frequency range 24–60 MHz. Over the 60–80 MHz range, D drops to as low as +4 dB, which does not meet Technical Requirement TR-10A. However, the impact of this is modest, causing a 25% increase in required integration time to reach the same sensitivity compared to the +6 dB case [35]. At the high frequency end, the primary limitation to the sky noise dominance is the 250 K noise temperature of the FEE (see Section 2.5). An alternative design was developed [37] that has a noise temperature of ~120 K, which would meet the +6 dB requirement up to above 80 MHz. For several reasons, including complexity and system linearity analysis, this design was not adopted for LWA-1, but will be reconsidered for a future update of the FEE design.

Table 2.1. Antenna Pattern Summary. Values are zenith angles at which the pattern is down by 3 dB or 6 dB from the zenith gain.

Frequency	Gain (dBi)	E-plane		H-plane	
		–3 dB	–6 dB	–3 dB	–6 dB
20 MHz	4.0	41°	57°	51°	66°
40 MHz	6.0	45°	64°	53°	67°
60 MHz	5.9	48°	71°	55°	68°
80 MHz	5.6	45°	77°	58°	70°

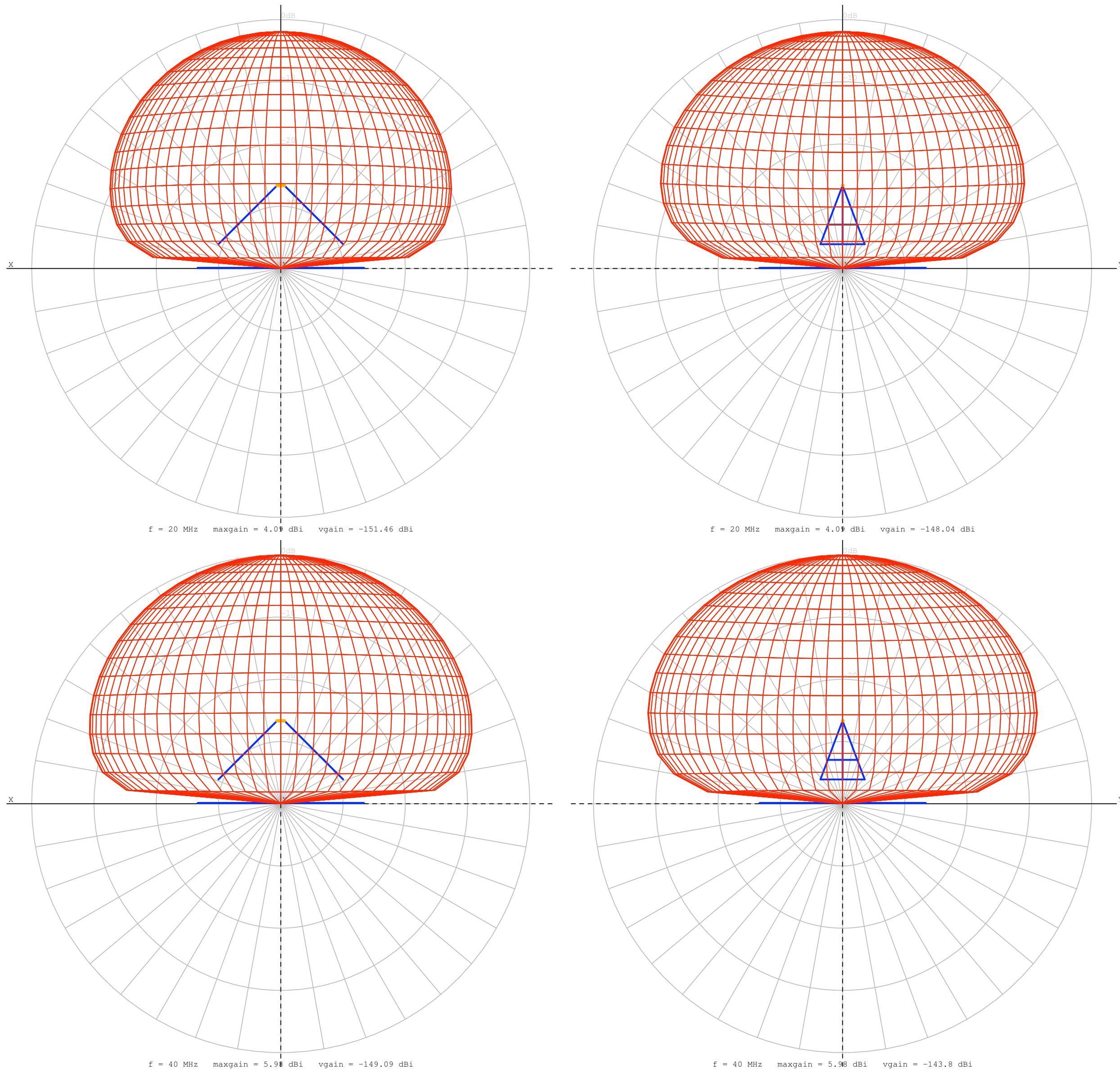

Figure 2.4. E and H plane patterns at 20 MHz (top) and 40 MHz (bottom). The scale is logarithmic total power with 10 dB per division. E-plane patterns are on the left and H-plane patterns are on the right.

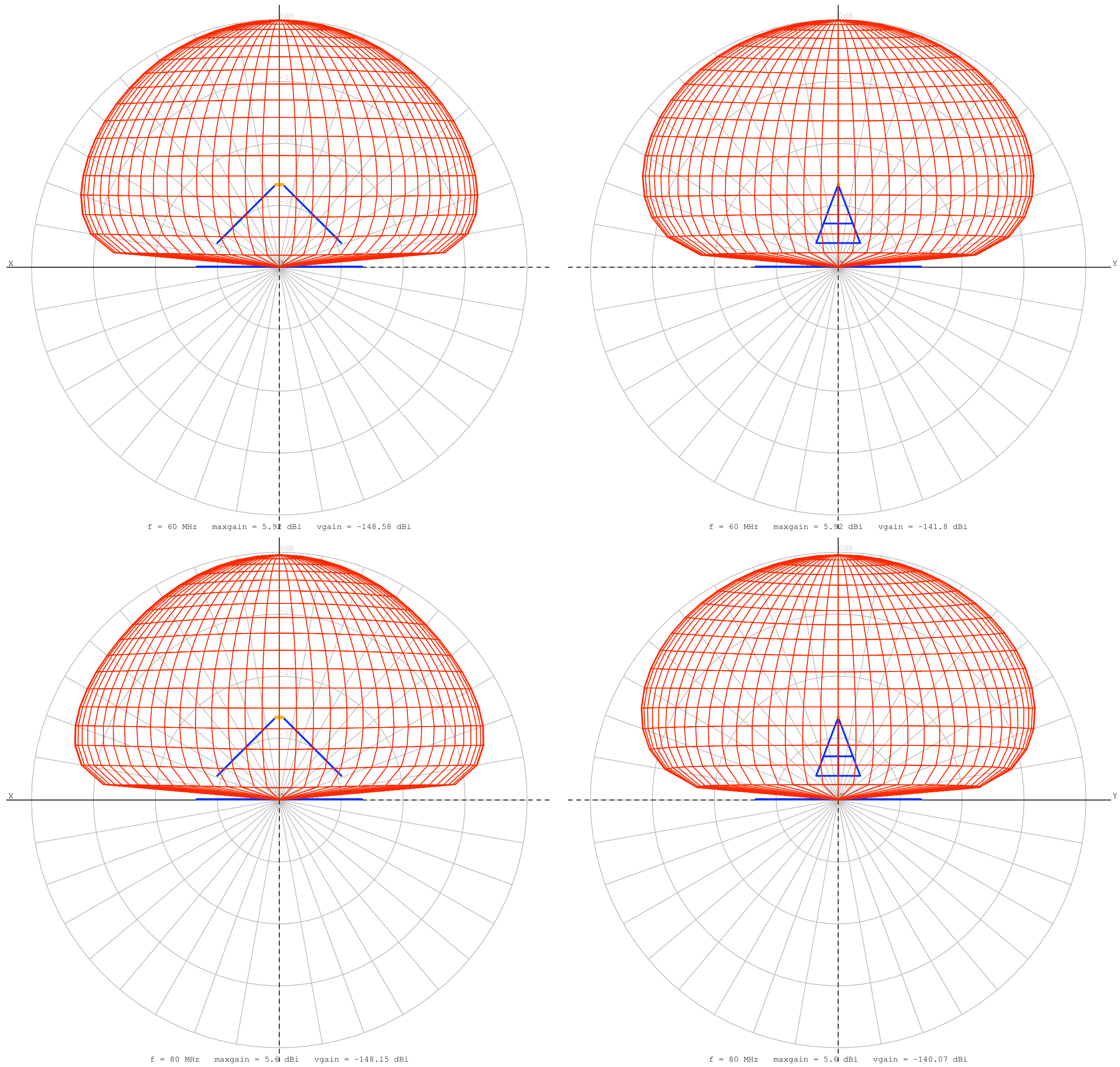

Figure 2.5: E and H plane patterns at 60 and 80 MHz. The scale is logarithmic total power with 10 dB per division.

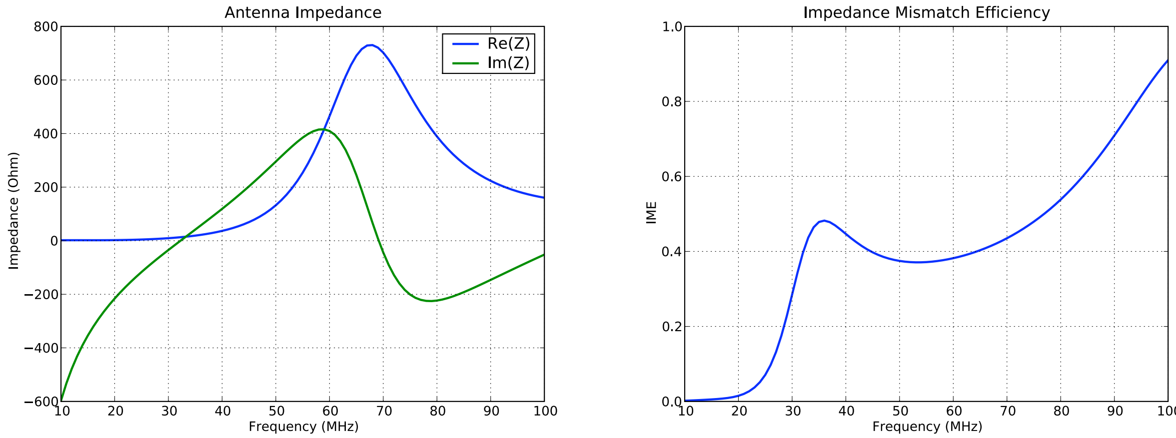

Figure 2.6: Antenna terminal impedance and impedance mismatch efficiency

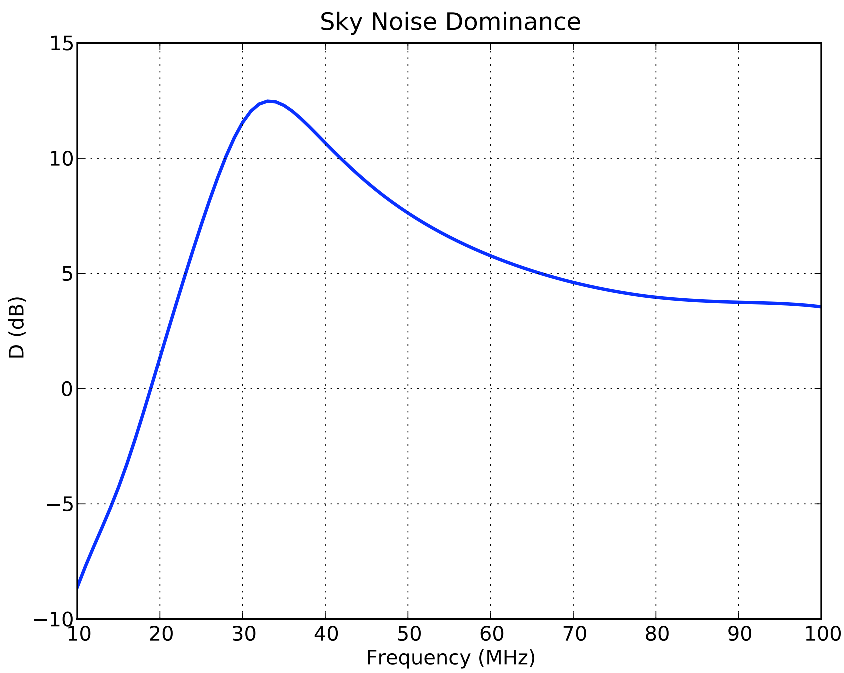

Figure 2.7: Predicted sky noise dominance (D) for ANT + GND as a function of frequency including impedance mismatch and ground losses calculated using NEC-4 and assuming T_{FEE} = 250 K and Z_{FEE} = 100 Ω. The Cane [16] model for sky noise at the Galactic pole is assumed, so this is a minimum sky noise dominance.

2.3. Stand (STD)

As described in [17], we have chosen to proceed with a central mast design for the stand, which confers several advantages:

- The antenna elements are not required to be load bearing structural elements
- They can be much easier to assemble than pyramidal designs

• Site preparation work is minimized because the STD only touches the ground in one place.
• The footprint of the design is smaller than pyramidal designs so there is more clearance between STDs.

We have developed a central mast design in collaboration with our manufacturing partner, Burns Industries, Inc. The design is shown in Figure 2.8 and fully detailed in [18]. It consists of four welded aluminum elements attached to the bottom of a solid plastic hub at the top of the mast. The FEE is mounted to the top of the hub and the solid hub prevents mechanical stresses on the elements from being transmitted to the FEE PCB. A plastic cap fits over the hub to protect the FEE from the elements and a plastic ring inserts into the bottom of the hub ensures that the feedpoint connections are also protected from dirt and moisture. A 'spider' midway down the mast supports the elements using fiberglass rods, so they don't move significantly in the wind. The mast is standard 2 3/8 inch outer diameter galvanized steel fence post, machined to accept a connection to the junction box where the connection to the RPD conduit is made.

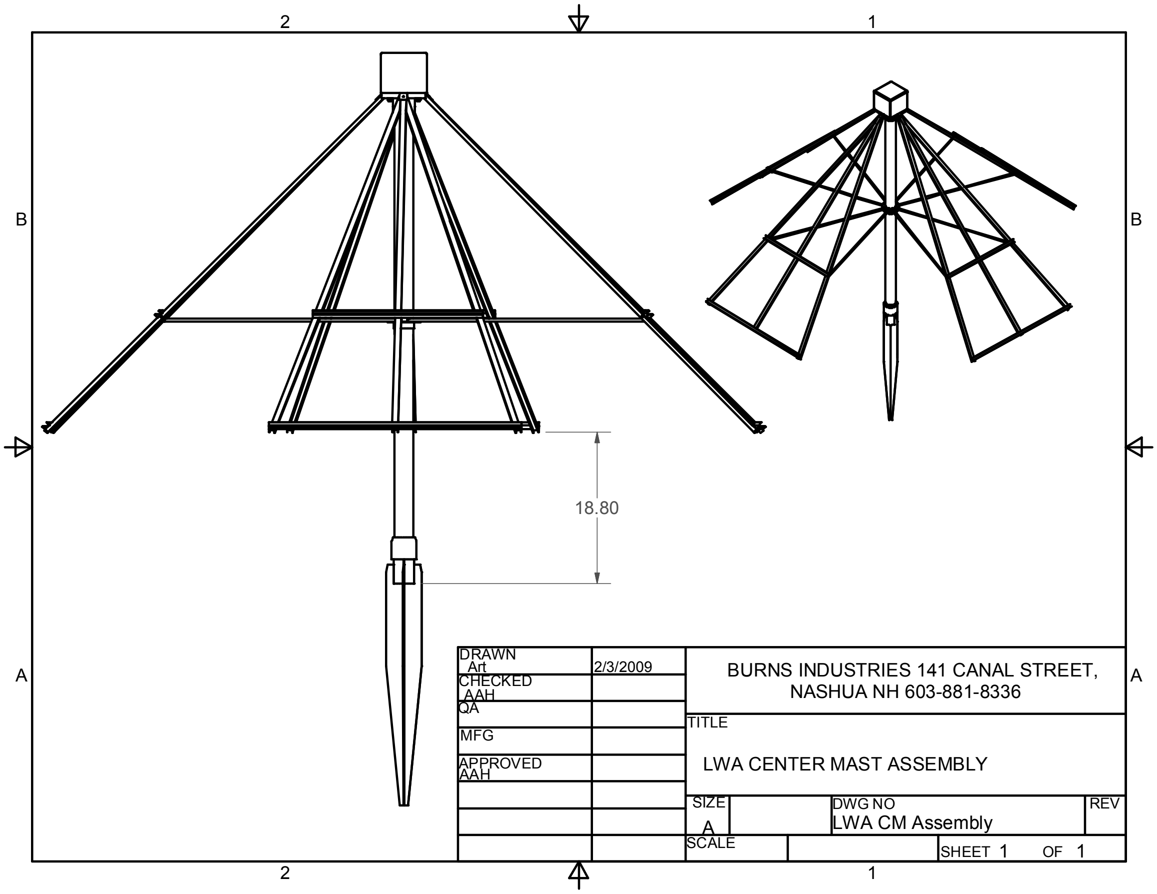

Figure 2.8. Preliminary mechanical drawing of STD assembly.

2.3.1. Installation and Alignment

The STDs will be assembled from the shipped pieces under a shelter and carried out to the mounting points. They will be fitted with a compression collar and set into the Oz-Post sleeve. A compass mounted on a bracket will be attached to the studs that will hold the FEE. Using that compass (and the measured magnetic variance at the site), the mast will be aligned with N-S to a tolerance of <5 degrees which is more stringent than required for performance [15]. Then the collar will be hammered into place with the cap driver and the installation is complete.

2.3.2. Mechanical and Environmental Survivability

The survivability requirements in [14] include survival of winds up to 80 mph (gusts to 100 mph) [EN-4A], UV lifetimes of 15 years [EN-6], and alighting of a 4 lb bird [EN-7B]. Both the fiberglass and plastic in the STD design are UV stabilized materials with long lifetimes, but this needs further verification as we refine the design for manufacturing. Wind survivability will be verified by both modeling and field testing.

2.3.3. Removal

Using Oz-Posts as the ground anchors facilitates removal of the STDs, should we need to return the site to its original condition. The Oz-Post collars are removable, so the masts may be removed, and the Oz-Post company sells a simple device, the *Oz-Puller*[1] for pulling the posts out of the ground.

2.3.4. Plans from PDR to CDR

The following activities are planned between PDR and CDR:

- Improve structural stability, particularly in the azimuthal direction by adding additional fiberglass struts.
- Try aluminum tube as an alternative to the C-channel for the elements to improve stiffness.
- Decide which parts will be injection molded and which will be machined. This is basically just a cost optimization.
- Select junction box when RPD design is finalized.
- Install one or two full prototypes in the field.
- Make deep integrations to test RF stability.
- Repeat interferometer tests to validate pattern, if possible.

2.4. Ground Screen (GND)

It has been shown [13] that there are significant benefits from deploying a ground screen beneath the antennas, including reduced ground losses and reduced susceptibility to variable soil conditions. For an antenna in isolation, it has been demonstrated that a small ground screen provides these benefits without the poor axial symmetry and significant sensitivity to RFI coming from the horizon that are caused by using a full-station ground screen [24, 25]. It is

[1] See http://www.oz-post.com/html.php?p=viewproduct.html&id=17

difficult to accurately model these effects for a full array in the presence of mutual coupling, but initial studies [27,28] indicate that the behavior should be qualitatively similar.

2.4.1. Design

For the above reasons, we have chosen a 3 m × 3 m ground screen under each STD, as detailed in [22]. Simulations indicate [22] that the mesh density is not important as long as the lattice spacing is less than 12 inches. We have chosen a 4 × 4 inch, galvanized welded wire mesh material that is structurally sound and inexpensive, made with wire width of 14Ga (~2 mm). We have identified a vendor, PennWire - EJ Darby & Sons, Inc, [29] that produces rolls of this material with dimensions of 6 × 200 ft. Considering that we will need two 6 × 10 ft pieces of mesh, overlapped by 2 ft, to make a 3 × 3 m ground screen, one of these rolls can be used to produce 10 complete ground screens. Taking into account possible mistakes and losses that can happen while cutting the mesh, we estimate that we will need 27 of these rolls in order to produce 256 ground screens. For the connection of the two ground screen sections we will use split splicing sleeves produced by Nicopress (stock number FS-2-3 FS-3-4) [20]. As indicated in [30], we will need 6 sleeves per ground screen (1,700 for a full station assuming a 10% loss). Simulations have shown [31] that the performance of such two-part ground screens is negligibly different than single ground screens. The anchoring of the ground screens also is an important issue, since this will avoid the buckling of the sides of the mesh. For this purpose we will use 12 inch plastic tent stakes, 8 per ground screen, which can be purchased from Big Game Pro Shop in buckets containing 180 pieces each (12 buckets will be needed). We note that the ground stakes are primarily needed during installation and for the first year or so. After some time, vegetation tends to grow through the screen and provide additional anchoring.

2.4.2. Installation

The installation procedure of the ground screen is the following. Unroll mesh rolls on a flat surface, cut mesh into 10 ft sections and flip each section upside down to prevent it from rolling back. Overlap two 10 ft sections of mesh by 2 ft and connect them using 6 splicing sleeves, spaced by 2 ft each. Move the ground screens to the position of each stand and place them aligning the sides in the E-W, N-S direction, and ensuring that the ground screen is centered on the Oz-Post. Also, make sure that the ground screen is put down with the sides that try to curl up facing down, to reduce the number of anchors needed. Anchor each corner of the ground screen and also put one stake in the mid point of each side, to improve the stability.

2.4.3. Costs

The cost of the materials needed for the ground screens is summarized in Table 2.2, which does not take into account labor costs. The delivery cost is included in the wire mesh quote (assuming that we will have a fork lift, or can borrow one), but is not included in the estimates of the sleeves and tent stakes.

Table 2.2: GND parts costs

Component	Company	Quantities and Unit Cost	Cost per Station
14 gauge galvanized welded wire mesh rolls of 6×200 ft, with mesh size of 4×4in	PennWire – EJ Darby & Sons, Inc.	27 rolls @ $148.00/roll	$3,996.00
Split splicing sleeves	Nicopress	1700 sleeves @ $0.20/sleeve	$340.00
12” plastic tent stakes	Big Game Pro Shop	12 buckets (180 pc/bucket) @ $66.19 per bucket	$794.28
Total			**$5,130.28**

2.4.4. Pre-CDR Activities

Pre-CDR testing will determine the time needed to build and install the ground screens, and possibly improve on the procedures described above. These tests should determine whether the splicing sleeves are an appropriate means of connecting the two ground screen sections, and if the number of sleeves is enough to guarantee the structural stability of the screen. These tests should also determine if the 12 inch tent stakes are sufficient as anchors for the ground screen.

2.5. Front-End Electronics (FEE)

The LWA FEE is an extension of the baseline active-balun design utilized for the Long Wavelength Demonstrator Array (LWDA) [5]. Improvements to the baseline design include an additional 12 dB of gain to handle additional cable losses without affecting noise performance [32], a local voltage regulator, an integral 5th order Butterworth filter, transient protection, and direct feedpoint connections. Dual polarization FEE units are formed by rotating two identical double sided FEE circuit boards 90^{o} and bolting them together with ground planes touching. This geometry was motivated by the need for isolation between polarizations and economy of fabrication.

2.5.1. Summary of Performance

The FEE serves to establish the system noise temperature, match antenna impedance, provide adequate gain to overcome cable loss, and limit out-of-band RFI presented to the analog receiver (ARX) module. The performance of a single polarization of the FEE is given in Table 2.3. A dual polarization unit will draw twice as much current as a single FEE board – a total of 460 mA. Total power consumption is ~7W per antenna stand.

Table 2.3. FEE Performance Summary

Parameter	Value
Current Draw (at +15 VDC)	230 mA
Voltage Range	± 5%
Gain	36 dB
Noise Temperature	250 K
Input 1 dB Compression Point	–18.30 dBm
Input IP3	–1.8 dBm

The single ended cascade analysis performed to determine IIP3 and noise temperature is provided in Appendix A. All other parameters were directly measured.

Filter Design. A 5th order low-pass Butterworth filter is included before the final 12 dB gain stage to define the bandpass and reject out-of-band interference that could drive the FEE into non-linear operation. The characteristics of the filter can be widely varied within the topology of the filter through component selection. Testing and prototyping has centered on the specific filter shown in Figure 2.9. The –3 dB point of the filter is at 150 MHz; at 250 MHz it achieves approximately 21 dB of attenuation (see Figure 2.10). A high cut-off frequency was chosen to minimize distortion of the working bandpass of 20 to 80 MHz.

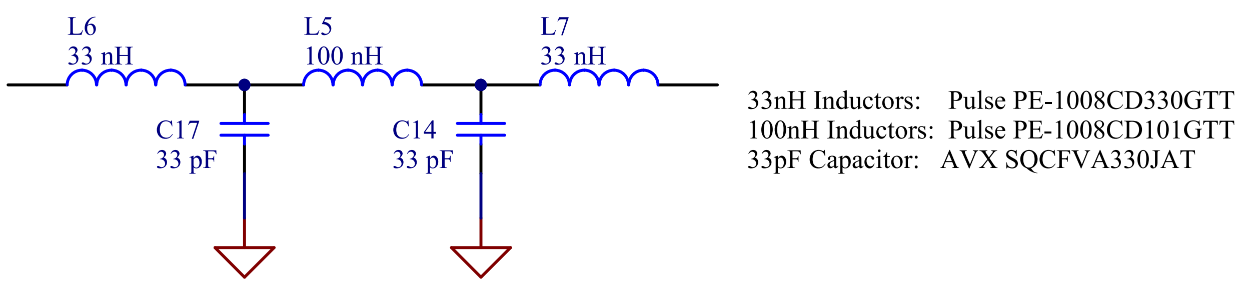

Figure 2.9. FEE filter design.

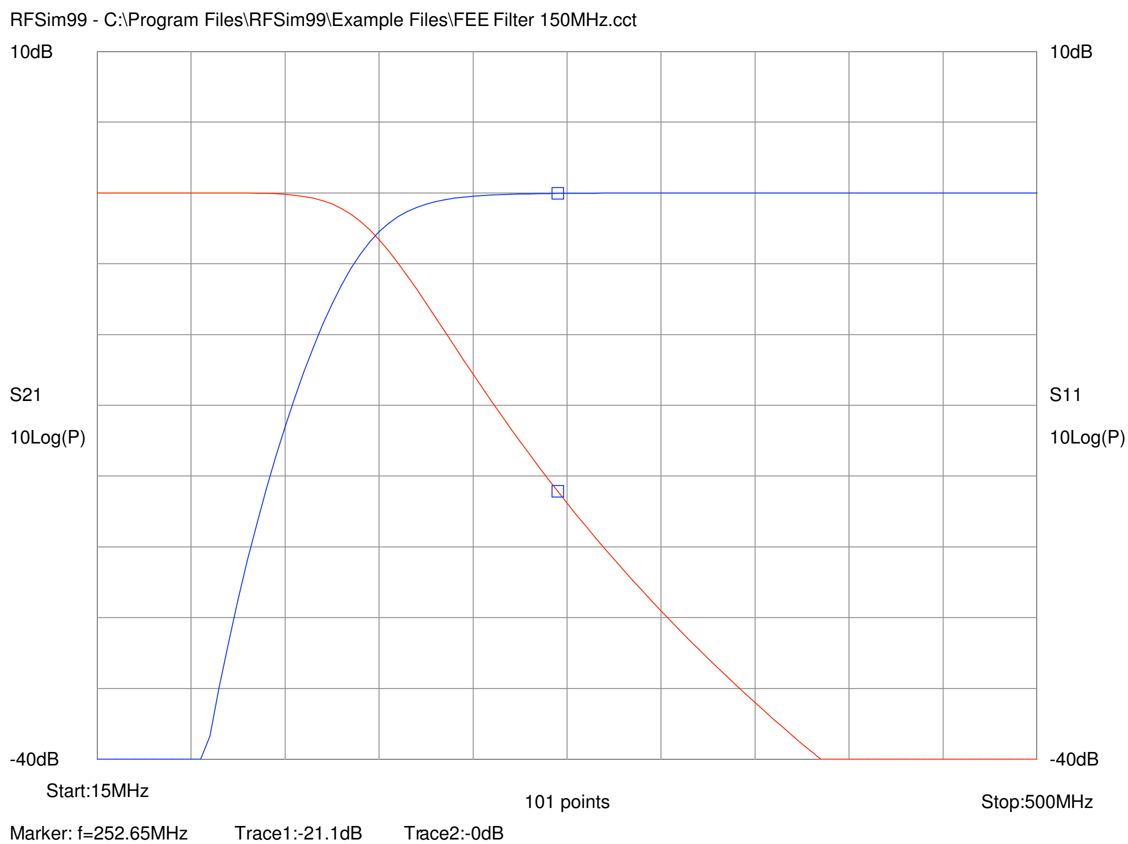

Figure 2.10. Ideal FEE filter response. Red: S21 (Forward Gain of Filter) Blue: S11 (Insertion Loss of Filter)

2.5.2. Field Measurements

Field measurements conducted to validate the performance of the FEE design [23, 33]. Figure 2.11 shows the measured performance of the LWA-1 FEE from field measurements with the Burns Dipole, a previous prototype antenna design that is very similar to the current design. A filter was not installed in the LWA FEE used for this test.

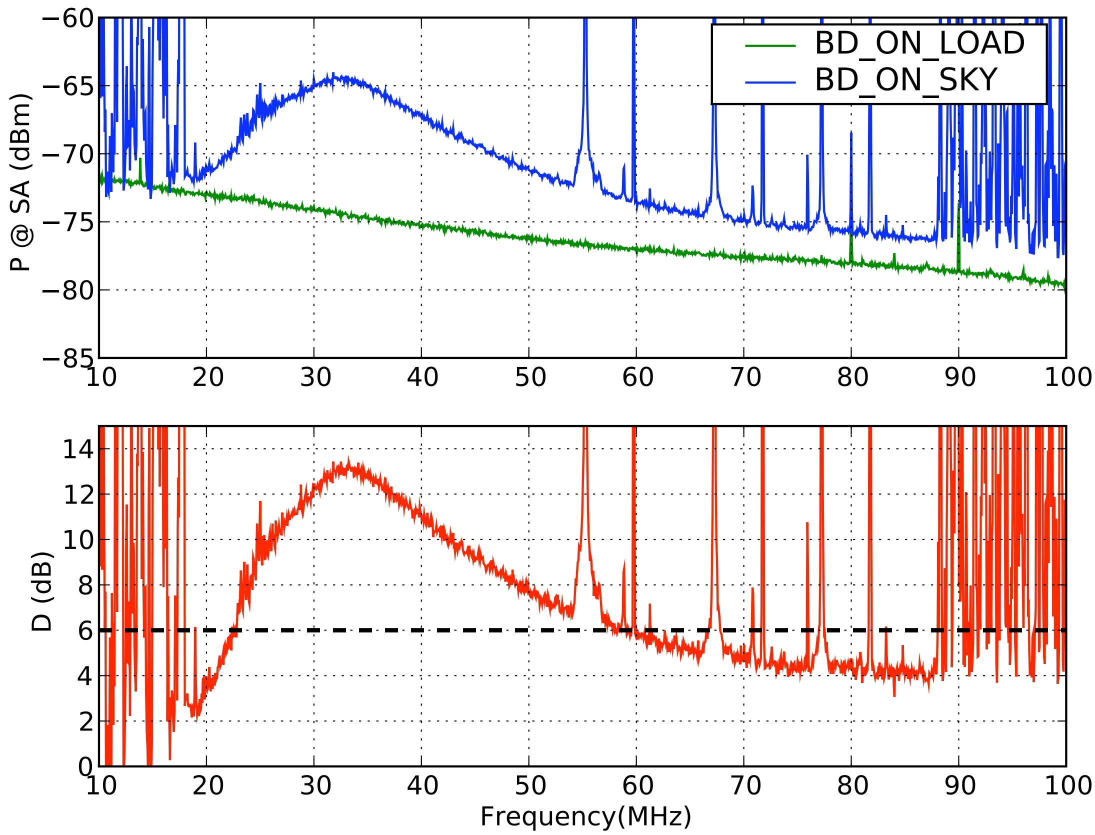

Figure 2.11 – Spectral measurements using the Burns Dipole (very similar to the LWA-1 antenna design) with an LWA-1 prototype FEE taken at the LWA site on 2009 September 9. The top frame compares the spectrum on the sky with the spectrum when the FEE inputs are loaded with 100 Ohms. The bottom frame shows the measured sky noise dominance, with +6 dB indicated by the dotted line. These data match very well with the simulated performance in Figure 2.7.

2.5.3. Manufacturing Estimates and Test Plans

Manufacturing Quotes. We have received manufacturing quotes (summarized in Table 2.4) from two companies interested in producing turnkey dual polarization units. Both quotes included printed circuit board (PCB) fabrication, assembly, and the administrative overhead associated with ordering all of the requisite parts. The quote from PCB Automation included also functional testing and assistance with the production of the necessary test fixtures.

Table 2.4: Manufacturing quotes for FEE units.

Company	Costs	Comments
PCB Automation, LLC P.O. Box 110 Mt. Sterling, KY 50353 Phone: 859-499-3455	50 units = $133.48 each 250 units = $130.40 each 500 units = $128.35 each 5000 units = $126.30 each 13000 units = $124.24 each	Dual polarization units. This company has expressed an ongoing interest in performing this work. Price also includes eyelets for the feedpoints, should this be deemed necessary.
Silicon Hills Design, Inc. 8504 Cross Park Drive Austin, TX 78754 Phone: 512-836-1088	256 units = $131.04 each 512 units = $123.91 each 13000 units = $109.24 each	Testing will add additional cost not yet determined.

Quality Control and Functional Testing. Test scripts to confirm basic functionality and conduct full characterization of an FEE are detailed in [11]. We have discussed the basic functional test (gain, stability, power consumption) described in this document with manufacturers and they agree that it can be readily implemented as an automated test procedure. The FEE includes a test point to allow proper supply voltage to be safely verified in the field after the FEE is installed on the antenna stand.

Lead Times and Schedule Concerns. All of the components in the LWA FEE are presently listed as ‘active’ with their respective vendors, but the lead time required for delivery of any given part has varied significantly over the past year.

It is recommended that six to eight weeks be allotted for the procurement of components. PCB fabrication can easily be completed at economy pricing prior to the arrival of parts. Approximately four to six weeks should be budgeted for assembly and testing of enough boards to construct a station with 256 antenna stands.

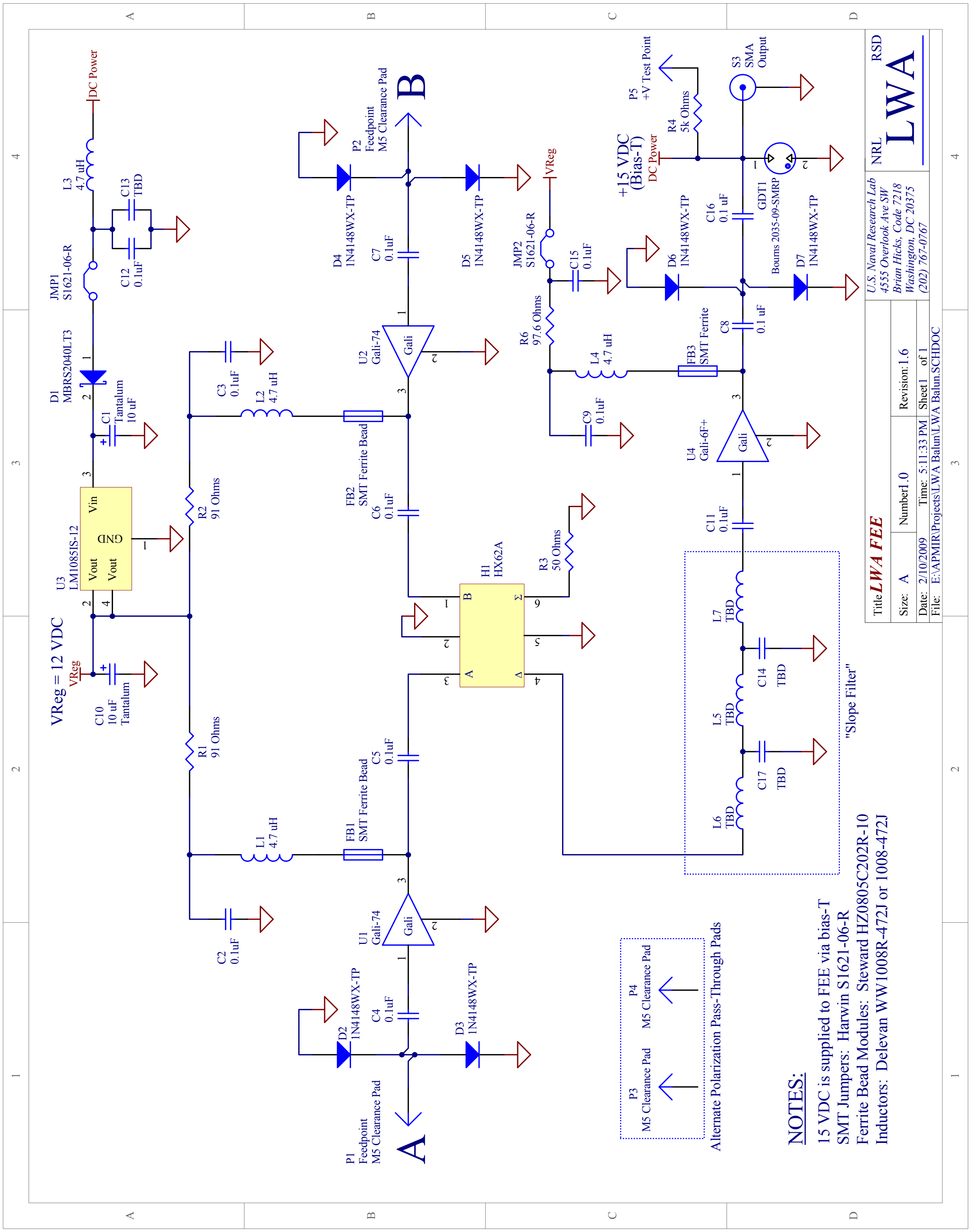

Figure 2.12. Preliminary Schematic of LWA FEE (Version 1.6)

2.5.4. PCB Layout and Mechanical Details – LWA FEE

The component side of the circuit board is given in Figure 2.13. The opposite side of the board is a solid ground plane aperiodically "stitched" to the grounded copper on the component side. The bolt circle that directly connects the FEE to the dipole elements (radius = 4.5 cm) and the outer edge of the PCB are labeled. The bolt holes are sized for 1/4-20 studs with standard clearance. The corresponding mechanical interface of the antenna stand being developed by Burns Industries of Nashua, NH, and is shown in Figures 2.14, 2.15 and 2.16.

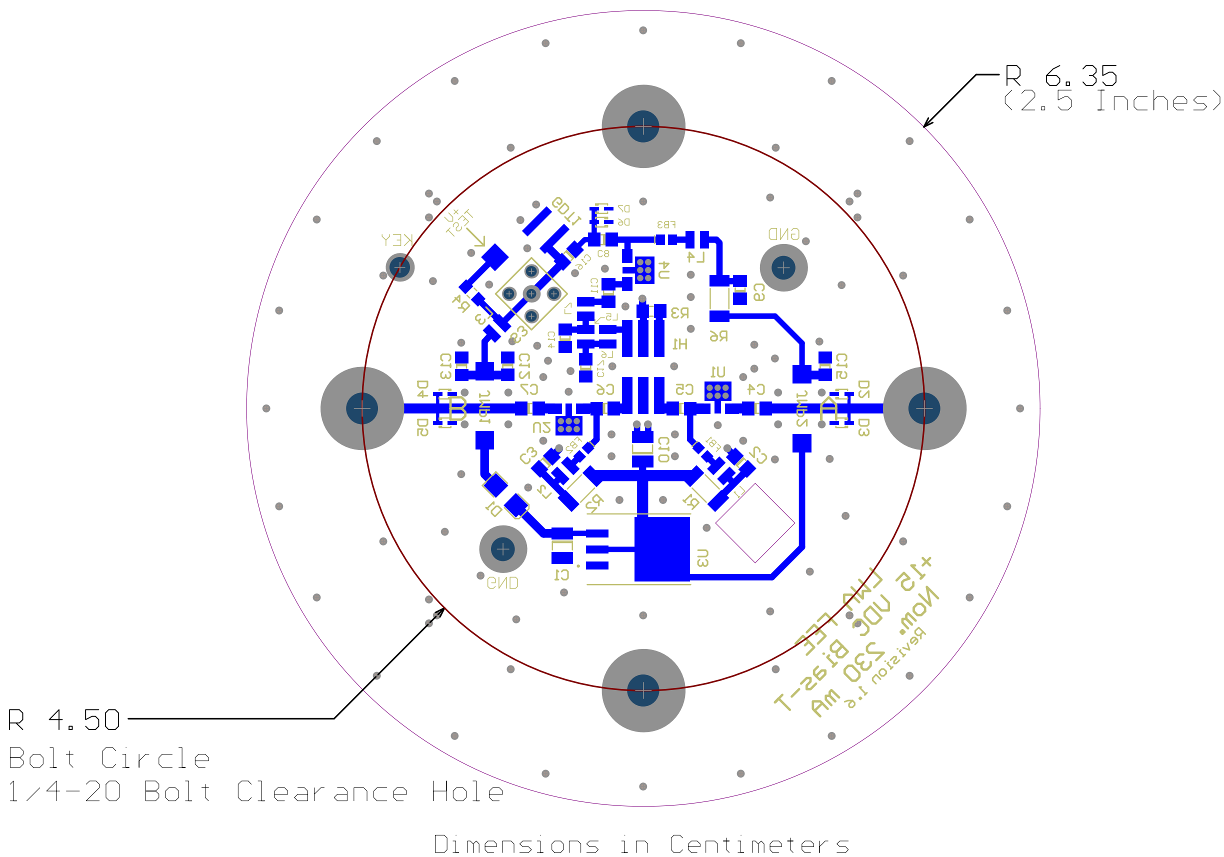

Figure 2.13 – PCB Assembly Diagram Component Side - ground plane removed for clarity.

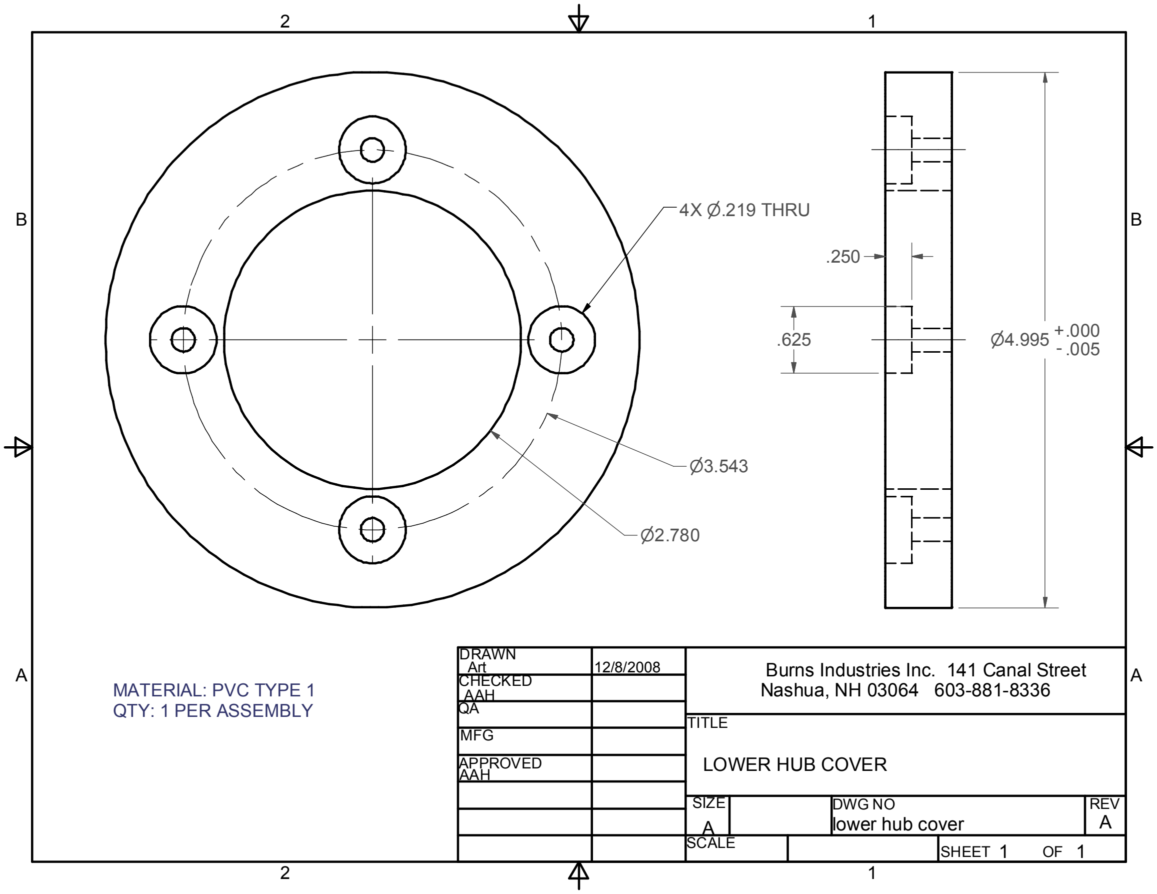

Figure 2.14 – Mechanical interface to antenna stand (STD) – Dimensions in Inches. Note that bolt holes will be resized for 1/4-20 clearance.

Parts List			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	hub base	
2	2	PWB	
3	1	cover	
4	4	stud	
5	16	ANSI B18.2.2 - 5/16 - 18	Hex Jam Nut
6	1	mast	
8	1	adapter	
9	1	oz-post 30040	
10	1	oz-cap 30040	
11	1	lower hub cover	

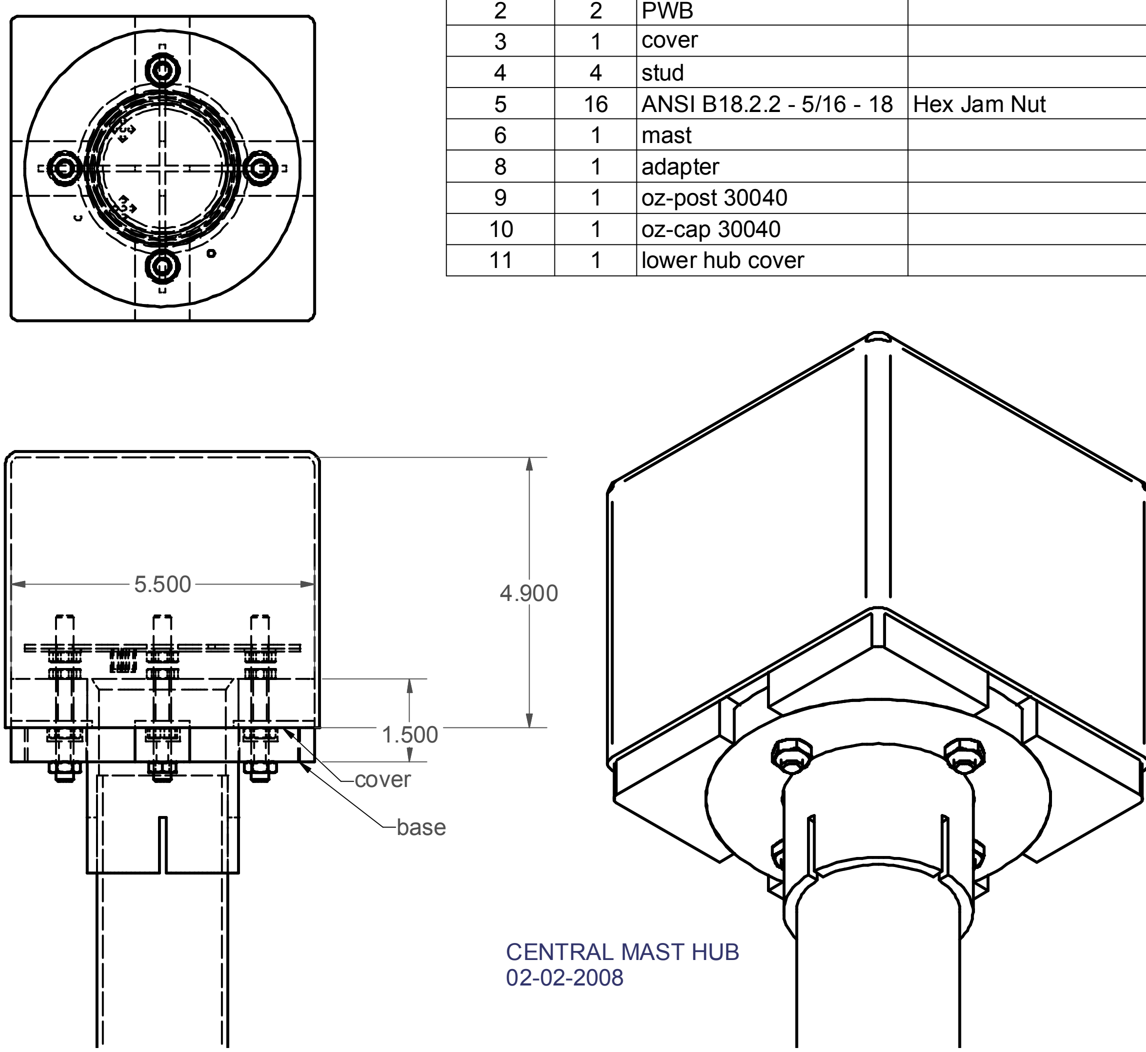

Figure 2.15 – Mechanical interface to antenna stand (STD) – Dimensions in Inches. Note: Antenna elements are welded to the tabs shown in the drawing - not bolted.

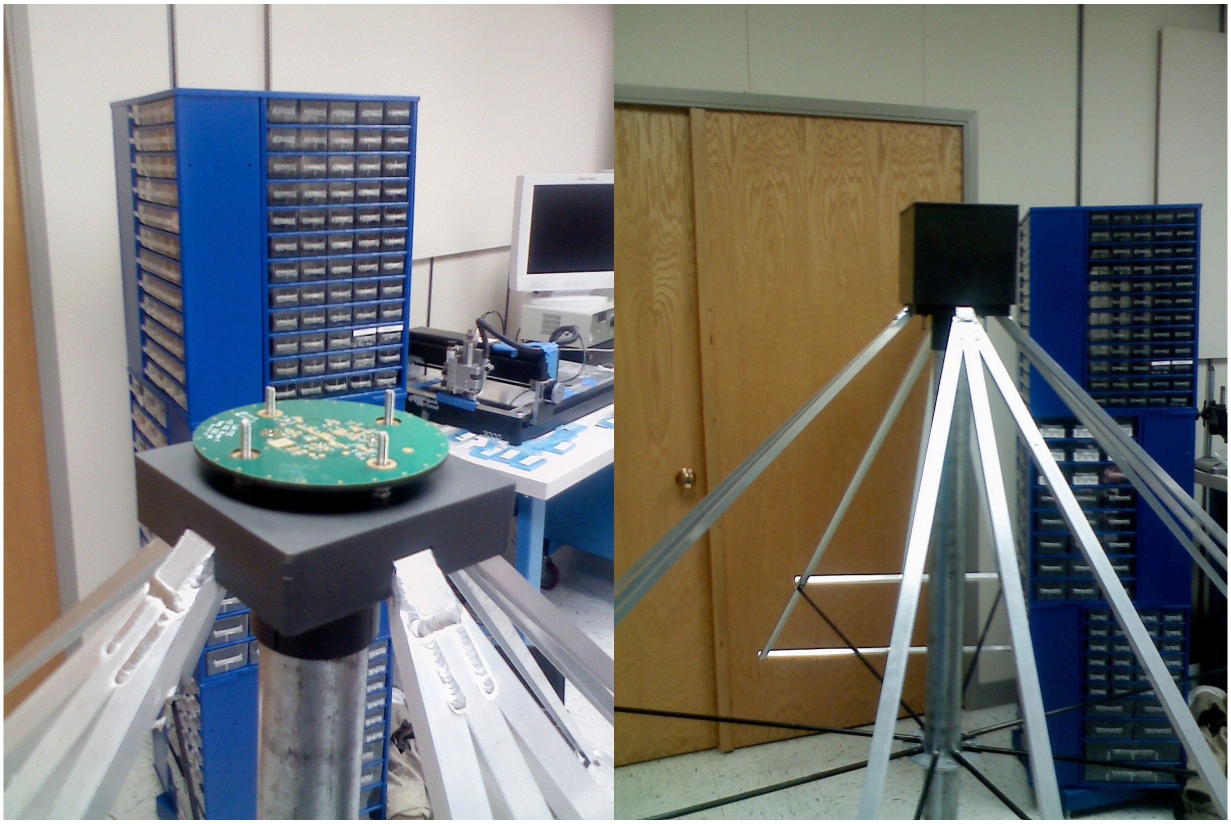

Figure 2.16 – (Left) Blank FEE PCB sitting in Burns Antenna Prototype. (Right) LWA FEE Enclosed in hub of antenna Stand

2.5.5. Bill of Material - LWA FEE

FEE Bill of Materials

Designation	Value	Tolerance	Type	Manufacturer	Part Number	Package Style	Unit Cost	Qty	Extended	Cost Bracket
L1, L2, L3, L4	4.7 µH	5% (1)	Inductor, Ceramic Core	Delevan	WW1008R-472J	1008	$0.39	4	$ 1.56	>8000
L5	100 nH	2%	Inductor, Unshielded	Pulse	PE-1008CD101GTT	1008	$0.30	2	$ 0.60	> 1000
L6, L7	33 nH	2%	Inductor, Unshielded	Pulse	PE-1008CD330GTT	1008	$0.30	2	$ 0.60	> 1000
C1, C10	10 µF	20%	Tantalum Capacitor	Nichicon	F931E106MCC	SMT-C (6.0 x 3.2 mm)	$0.33	2	$ 0.66	>250
C2..C9, C11, C12, C15	0.1 µF	10%	Capacitor, Ceramic, X7R	Panasonic - ECG	ECJ-3VB1E104K	1206	$0.06	11	$ 0.62	>4000
C14, C17	33 pF	2%	Capacitor, MLC	AVX	SQCFVA330GAT1A\500	1206	$0.59	2	$ 1.18	>1000
R1, R2	91 Ω	5%	Resistor, 1 Watt	Panasonic	ERJ-1TYJ910U	2512	$0.19	2	$ 0.38	>1000
R6	96.7 Ω	1%	Resistor, 1 Watt	Panasonic	ERJ-1TNF97R6U	2512	$0.16	1	$ 0.16	>1000
R3, R4, R5	51 Ω	5%	Resistor, 1/4 Watt	Panasonic - ECG	ERJ-P08J510V	1206	$0.04	3	$ 0.13	<4000
U3	LM1085IS-12-ND	N/A	Positive Voltage Regulator	National Semiconductor	LM1085IS-12	TO-263-3	$1.25	1	$ 1.25	>500
U1, U2	Gali-74	N/A	MMIC Amplifier	Mini-Circuits	Gali-74	DF782	$1.85	2	$ 3.70	>1000
U4	Gali-6	N/A	MMIC Amplifier	Mini-Circuits	Gali-6	DF782	$1.39	1	$ 1.39	>1000
H1	HX62A	N/A	180 degree hybrid	Tele-Tech, Corp.	HX62A	TT-HX62A	$20.00	1	$ 20.00	>500
D1	MBRS2040	N/A	Diode, Schottky, 40 V, 2A	ON Semiconductor	MBRS2040LT3G	SMB (5.59 x 3.81)	$0.16	1	$ 0.16	>500
D2, D3, D4, D5, D6, D7	1N4148	N/A	Diode	Micro Commercial Co.	1N4148WX-TP	SOD323	$0.06	6	$ 0.36	>1000
FB1, FB2, FB3	Ferrite 1.5A, SMD	N/A	Ferrite, 1.5A	Steward	HZ0805C202R-10	240-0805	$0.05	3	$ 0.15	>500
S3	SMA, Straight	N/A	SMA Connector	Emerson Network	142-0701-201	SMA	$2.55	1	$ 2.55	>500
GDT1	2035-09	20%	2 Pole Gas Discharge Tube	Bourns, Inc.	2035-09-SM-RP	SMT	$0.66	1	$ 0.66	>1500
JMP1, JMP2	S1621-06-R	N/A	SMT Jumpers	Harwin	S1621-06-R	SMT Jumper	$0.08	2	$ 0.16	>2000
Printed Circuit Board	RTA v2.0	N/A	Double Sided, Solder Mask	Galaxy Electronics	RTA-2	N/A	$7.00	1	$ 7.00	>=300
								TOTAL	**$ 43.26**	

* R7, L5, C13, and C14 are TBD

* Parts only cost for a single polarization balun. Enclosure and connectors not included.

* Price and availability verified on 11/6/2007

Note 1: High tolerance (5%) is incidental, component was selected on basis of: Max current (260 mA), Min SRF (90 MHz), and Max DCR (4 Ohms).

2.5.6. Installation

The FEE is installed onto the STD after the cables have been pulled and are ready to be connected. A keying scheme (currently TBD) will be incorporated into the FEE and STD hub such that the FEE can only be installed with the N-S polarization in the correct orientation. The connections to the coax cable must be made according to the STD-RPD ICD [36], which specifies the color coding for the two polarizations and the torque required to tighten the SMA connectors.

2.5.7. Plans from PDR to CDR

The FEE is very close to CDR readiness at this point. The remaining issues to be addressed are:

- Revise silk screen design to indicate color coding for each polarization according to the STD-RPD Interface Control Document.
- Complete phase and gain stability vs. temperature measurements over full temperature range (–20 F to 110 F according to EN-1A in [14]).
- Develop keying scheme with the hub so that FEE polarization is physically required to match the polarization of the STD.
- Add power LED to FEE.
- Produce prototypes of final PCB design and test in the lab and in the field with the STD prototype.
- Investigate alternative inductors for bias-T with higher current capacity for increased reliability.

3. Summary Schedule and Cost Estimate

3.1. Schedule

For the schedule, we are assuming a CDR in May 2009 and an authority to place orders on June 1, 2009 (see Figure 3.1). If the STD order is placed immediately, this results in a delivery to the site by September 1, 2009 and a 3-week install completing by September 18, 2009.

	Activity Name	Duration (Work Weeks)	Start Date	Finish Date
1	PDR Complete	0.00	3/2/09	3/2/09
2	Develop Build Packages	13.00	3/2/09	5/29/09
3	CDR	0.00	5/29/09	5/29/09
4	STD Procurement	**12.00**	**6/1/09**	**8/21/09**
5	STD order placed	0.00	6/1/09	6/1/09
6	STD build	8.00	6/1/09	7/24/09
7	STD ship	4.00	7/27/09	8/21/09
8	FEE Procurement	**12.00**	**6/1/09**	**8/21/09**
9	FEE parts procured	8.00	6/1/09	7/24/09
10	FEE build	4.00	7/27/09	8/21/09
11	ARR Procurement	**8.00**	**6/1/09**	**7/24/09**
12	OzPost procurement	8.00	6/1/09	7/24/09
13	GND Procurement	**7.00**	**6/22/09**	**8/7/09**
14	GND parts procured	7.00	6/22/09	8/7/09
15	Installation	**9.00**	**8/3/09**	**10/2/09**
16	OzPosts	2.00	8/3/09	8/14/09
17	GND	2.00	8/17/09	8/28/09
18	STD	3.00	8/31/09	9/18/09
19	FEE	2.00	9/21/09	10/2/09

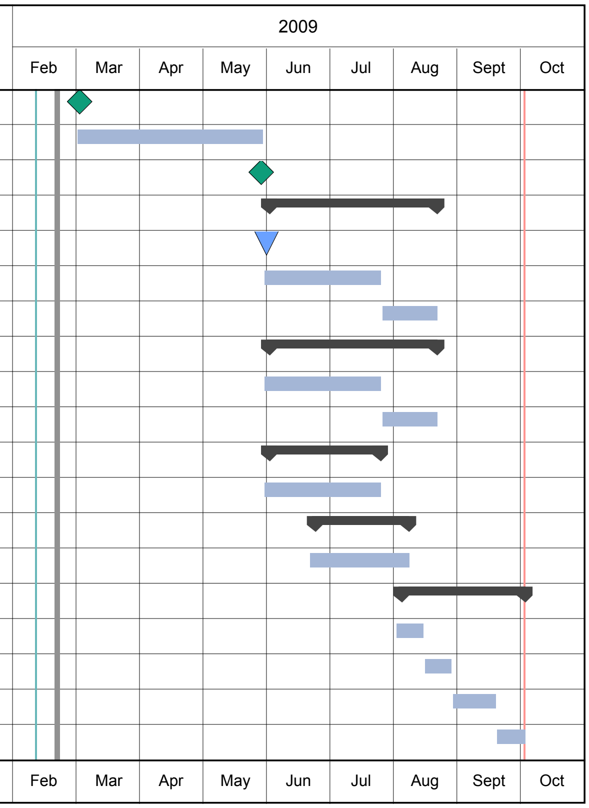

Figure 3.1: Summary schedule from PDR to installation of ARR, STD, GND, and FEE

3.2. Cost Estimates

We have estimated the total parts costs for the ARR, STD, GND and FEE as well as the costs associated with the installation (both tools and labor). For the parts costs, we have **included spares** in the estimates so these are the full costs. The TBD labor items do not have specific estimates yet, but are expected to be performed by LWA personnel, UNM students, and semi-skilled contract labor. The STD Build and Install Labor quote is from Burns Industries, Inc. [18].

Table 3.1: Summary of Parts Costs by Subsystem (including spares)

Item	Unit Cost	Qty	Subtotal
ARR			
Oz-Post	$18.13	286	$5,185
STD			
STD Assembly	$225.00	300	$67,500
GND			
Screens	$148.00	27	$3,996
Splicing Sleeves	$0.20	1700	$340
Stakes	$66.19	12	$794
FEE			
FEE Assembly	$131.00	320	$41,920
TOTAL			**$119,735**

Table 3.2: Installation Cost Estimates by Subsystem

Item	Unit Cost	Qty	Subtotal
	ARR		
Electric Jack Hammer EL-1100	$986.00	1	$986
20420 OH-01 Oz-Hammer Adapter	$200.00	1	$200
Cap Driver CDT-07	$29.09	1	$29.09
Post Level	$3.40	1	$3.40
Oz-Puller	$296.25	1	$296.25
Surveying Labor	**TBD**		
Post Driving Labor	**TBD**		
	STD		
STD Build & Install Labor	$17,500.00	1	$17,500
	GND		
Crimping Tool	$81.20	2	$162.40
Wire cutters	$30.00	4	$120
GND Install Labor	**TBD**		
	FEE		
SMA Torque Wrench	$100.00	3	$300
FEE Install & Connect Labor	**TBD**		
TOTAL			**$19,597.14**

4. Acknowledgements

Many people have made useful contributions to the STD design development. We'd like to express particular thanks to Bill Erickson, Steve Ellingson, Joe Craig, Walter Gerstle, Namir Kassim, Kurt Weiler, Emil Polisensky, and Pat Crane.

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A.Cascade Analysis of LWA FEE (Filter Bypassed)

```
***********************************************************
* CASCADE ANALYSIS *
* Version 1.4A *
* (c) 1997-2001 Dan McMahill *
* mcmahill@alum.mit.edu *
***********************************************************
Input Resistance for each Stage = 50 Ohms
Output Resistance for each Stage = 50 Ohms
Default Rho (for IIP3 calc.) = 0
***********************************************************
* Stage #1 "Gali-74" *
***********************************************************
Power Gain= 25.10 dB, Voltage Gain= 25.10 dB
NF= 2.70 dB
Input Res. = 50 Ohms, Output Res. = 50
Ohms
IIP3= 12.90 dBm ( 59.89 dBmV), RHO= 0.00
Total Power Gain = 25.10 dB
Total Voltage Gain = 25.10 dB
Total Noise Figure = 2.70 dB
Noise Figure from this stage only = 2.70 dB
IIP3 = 12.90 dBm
IIP3 from this stage only = 12.90 dBm
***********************************************************
* Stage #2 "Gali-6" *
***********************************************************
Power Gain= 12.20 dB, Voltage Gain= 12.20 dB
NF= 4.50 dB
Input Res. = 50 Ohms, Output Res. = 50
Ohms
IIP3= 23.30 dBm ( 70.29 dBmV), RHO= 0.00
Total Power Gain = 37.30 dB
Total Voltage Gain = 37.30 dB
Total Noise Figure = 2.71 dB
Noise Figure from this stage only = 0.02 dB
IIP3 = -1.80 dBm
IIP3 from this stage only = -1.80 dBm
***********************************************************

***********************************************************
* Noise Figure Contribution Summary *
***********************************************************
Stage Noise Figure Possible Noise Figure
in the system Improvement
--------------- ---------------- ----------------------
Gali-74 2.700 dB 2.689 dB
Gali-6 0.024 dB 0.013 dB
***********************************************************
* IIP3 Contribution Summary *
***********************************************************
Stage IIP3 in the system
--------------- --------------------
Gali-6 -1.800 dBm
Gali-74 12.900 dBm
***********************************************************
```