Collected LWA Engineering Memos
from the Development of the Ground Screen Subsystem (GND)

2008 April 23 – 2009 October 14

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LWA Engineering Memo GND0001
Baseline Design of Station Ground Screen

April 23, 2008

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Summary

This document describes the 3 ground screen designs being considered for LWA-1: (1) a full station ground screen; (2) a postage stamp ground screen, and; (3) a hybrid configuration. We discuss issues related to each of the designs, and also present a comparison between the observations of different antenna designs on a 3x3m ground screen with those from a Big Blade antenna on top of a 10x10m ground screen. These measurements show that a large ground screen collects much higher levels of RFI, consistent with their simulated beam patterns.

Motivation

For the basic "dipole mounted above the ground" geometry being considered for the LWA, the dipole angular response pattern, the terminal impedance of the dipole as a function of frequency, and the ground loss are all impacted by the electrical properties of the ground plane. The option of using just the natural soil as the ground plane is attractive for cost reasons and the basic performance would probably be acceptable. However, impedance measurements over varying ground conditions (particularly soil moisture content) at the LWDA site (LWA Memo 90) demonstrate that a ground screen is probably required to stabilize the performance (antenna impedance and gain) and facilitate station calibration. Further, LWA Memo 90 demonstrates that a small (3m x 3m) ground screen is all that is required to achieve this stabilization.

Therefore, in this memo, we begin with the assumption that some kind of ground screen will be required and look at several aspects of the implementation of various design options. The simplest and least expensive option is a small (nominally 3m x 3m) "postage stamp" ground screen associated with each stand, which may even be an integral part of the stand support structure. However, it is possible that the calibratibility of the full LWA-1 station will depend on the ability to accurately electromagnetically simulate the response of every element in the station, in the presence of mutual coupling among all the dipoles. It is hypothesized, though not yet demonstrated, that such simulations may be easier and more accurate if the entire surface of the ground beneath the array can be treated as a perfect electric conductor (PEC). If a full station ground screen implementation can be developed that is affordable and close enough to a PEC ground to allow improved array simulation capability, this may be the preferred option.

Survey of Other Projects

In this section, we briefly review the ground screen choices made by several comparable projects. This information is not easily available online and can usually be obtained from personal communications or from presentations available in the web.

- LOFAR: The low frequency part of this project is using postage stamp ground screens with dimensions of 3X3 m, with cell sizes of 15X15 cm, made of thick wire (Weiler, private communications).
- MWA: This project is using a single ground screen under each 16 dipole stand. This is easy to do in their case, because their dipoles are small, separated by ~1 m. The ground screen is a 5X5 m mesh with a cell size of 5X5 cm. The mesh is made with 4mm thick galvanized wire and is used as a support structure for the antennas (Steve Burns presentation at the pre-PDR meeting).
- Deuterium: This project uses a single ground screen under each 25 element dipole stand. The stands have a dimension of 4X4 m. The ground screen is a wire mesh with a 2.5X2.5 cm cell size (measured on photos available in memo #68 of the Deuterium Array www.haystack.mit.edu/ast/arrays/deut/deut_memos/memoindex.html).
- PAPER: Information about the ground screen being used by this array is harder to obtain. In a recent talk by Chris Carilli (April 2008), we've learned that they are using a ground screen under the dipole, as well as ground screen around it. The end result is what can be called a "poor man's parabola". We don't have any information about the specifications of this ground screen.

Ground Screen Designs

Here we describe the three basic ground screen designs that are being considered for the LWA-1 station. The issues to be considered when comparing these designs are the cost of the materials and installation, durability, maintenance, and effects such as beam shape, which can affect the sensitivity of the system. In the current document we touch briefly on some of these issues, however, a more detailed analysis will be presented in a future document after we do a vendor survey for materials. In the following we assume that the cables will be buried underground in conduit before the ground screen and antennas are put in place, though the final decision on whether to use conduit or directly buried cable, as well as whether the conduit will be above or below the ground (and thus the ground screens) will be made as part of the RPD work plan. For now, we assume the cables will be routed through buried conduit and will penetrate the ground screens directly below the feed point of each stand.

Full Station Ground Screen

This design consists of "carpeting" the entire station with a ground screen using the same material that would be used for postage stamp ground screens. As described above, the motivation for this design is to enable accurate simulation of the response of each element when embedded in the array. Additional work is required to derive the requirements on the mesh density, conductivity, and extent for such a ground screen to have the desired effect, but we defer this to a later task.

Based simply on area arguments, if we assume that the station will have a diameter of 110m and the ground screen will extend 5 m beyond that (120m), we get that we will need a total of 11,300 m^2 of ground screen material. This is approximately 5 times the area of material needed from the postage stamp design (2,300 m^2), not counting the fact that we will need some extra material to overlap different sections of ground screen. If the cost scales by area, the full station ground screen will cost 5 times more than the postage stamp ones.

Maintenance of the station, cables and conduits will be a major issue, independent of the RPD scenario. In the case something breaks underground and digging of the conduits/cables is required, it will be necessary to cut through a large portion of the ground screen and remove stands in order to be able to access the affected parts of the system. Once the problem is fixed it will be necessary to stitch the ground screen back together. Another issue related to the full station ground screen is changes in elevation, vegetation and irregularities of the terrain in a region of 120 x 120 m. This may require the removal of the vegetation and leveling of the station, which will cause erosion, thus requiring the stabilization of the site with gravel. However, grading of the site is *forbidden* by the terms of the categorical exclusion that allows us to develop the sites without a more extensive environmental study.

The antenna beam pattern and increased sensitivity to RFI may also become an issue for this design, as discussed below and in the ANT0004 Engineering Memo (Paravastu). One potential advantage of the full station ground screen is the improved ability to do electromagnetic modeling of the array. However, the ground screen mesh density and extent required for EM simulations using PEC boundary conditions at the ground has not been established and requires additional study.

Postage Stamp ground screens

This is the design that is currently being used at the LWDA, consisting of a 3x3 m ground screen, aligned in the E-W N-S direction, under each stand (see Figure 1). We chose this size as the baseline because tests (LWA Memo #90 – Paravastu et al.) show that there is no significant difference in the measured impedance of the antenna on top of a screen this size compared to antennas on top of larger ground screens (up to 13X6 m). Furthermore, a ground screen this size is currently being considered by Steve Burns as the structure support for the antennas. The postage stamp design has the advantage of using much smaller amounts of material, thus potentially being cheaper. It will also result in easier maintenance of cables and conduits, independent of the RPD scenario. In case something breaks underground and digging is needed to fix it, one needs to move a few stands and ground screen patches. Unlike the full ground screen carpet, it will not be necessary to cut through patches of ground screen and stitch them back together. Another advantage of this design is the fact that it does not require the leveling of the full station, since the terrain irregularities are much smaller on 3X3 m patches, and it is easier to guarantee the connection between different parts of the ground screen, in case it is composed of multiple sections. The smaller ground screen results in a more "regular" antenna beam pattern (smooth variations as a function of elevation and azimuth), and the detection of smaller amounts of RFI because of reduced response at the horizon compared to larger ground screens.

A future task will address the specific optimization of the parameters of the postage stamp ground screen, including mesh spacing and ground screen size, based on electromagnetic performance. The wire thickness will be largely determined by the required mechanical properties to ensure its durability and functionality as part of the STD support. This will be done as part of the STD design work once the vendor is funded for that work. All current designs have been based on square ground screens. A circular option could also be considered, but the fabrication cost is likely to be higher and we don't believe there will be a significant performance difference or reduction in complexity of installation.

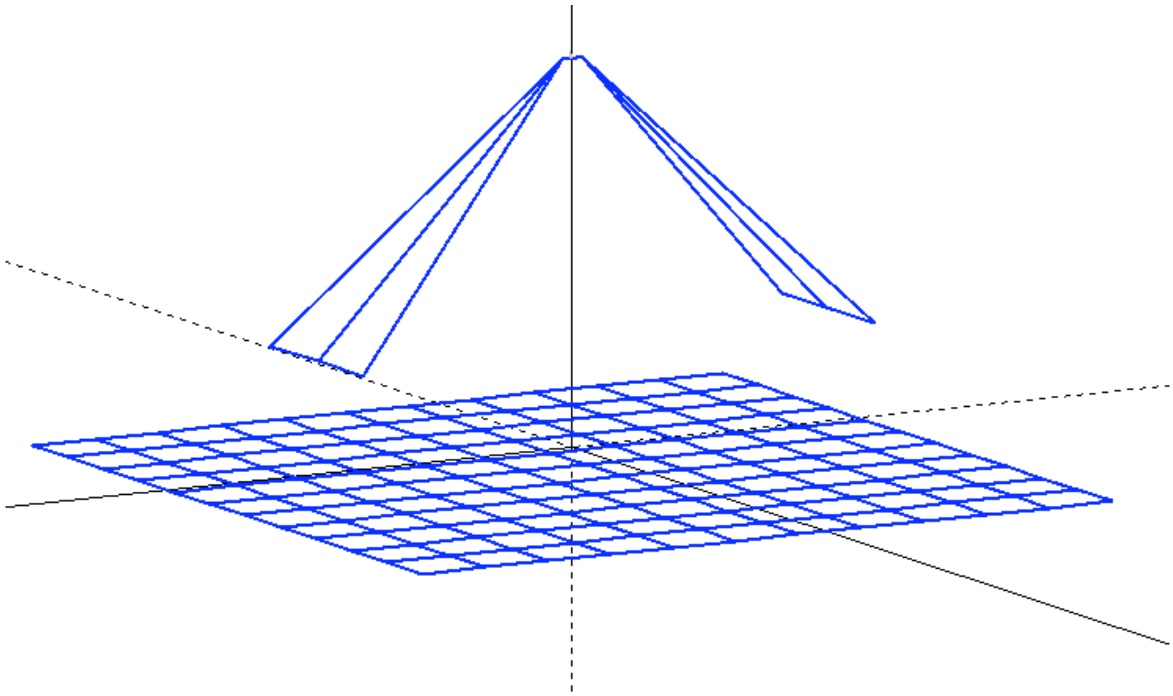


Figure 1: Example of postage stamp ground screen configuration.

Hybrid Configuration

This design consists of using a 3x3m postage stamp ground screens under each stand, plus a coarse ground screen covering the entire LWA-1 station. The motivation for this option is to maintain the structural benefits of the postage stamp ground screen, and keep that as an option for the only ground screen, but also provide the potential improvement in simulatability of a full-station ground screen.

A possibility that is being considered is to build the coarse ground screen using wire, tied down with pegs. The separation between the individual wires is under consideration, as well as the use of different materials. Based on the simulations presented in the LWA Memo #83 (Stewart), we find that a wire grid with a separation of 30cm would reflect back >90% of the incident radiation at 80MHz, with even higher percentages at lower frequencies, suggesting that this wire separation may be a good initial assumption. One advantage of this design is the fact that one can start with the deployment of 3x3 m ground screens under each stand, test the performance of the array under these conditions, and, if necessary, deploy the coarse ground screen afterwards. Maintenance of cables and conduits will be harder than in the case of postage stamp ground screens, but not as complicated as in the case of a full station ground screen. One important issue to be considered in the hybrid configuration is how to obtain a good connection between the different pieces of wire, which may require welding all the connections (time consuming and likely to be expensive). Safety of the people working around the site will also be an issue, since it will be easy to trip and fall on the 30X30 cm grid. The effect of the hybrid ground screen on the antenna beam patterns is not very well known, but one would expect it to be similar to that of a full station ground screen.

Ground Screen Material

Just for reference, the current ground screens that are being used at the site are made of galvanized welded wire mesh with a thickness of 2mm. This material has cell sizes of 5x10 cm and comes in rolls of 5x100 ft. It is laid out in double layers to ensure a good connection between the different sections, and anchored to the ground with bent pieces of rebar. Although this material was good enough for the tests performed at the LWDA site, it will probably not survive for a 10+ years period. We noticed that the welded connections can be easily broken by people stepping on them, and that the material tends to buckle up, resulting in the loss of connection between the different sections. During the pre-PDR meeting Steve Burns suggested the use of a ground screen made of stainless steel wire with a thickness of 4 mm, similar to the material used by MWA. This material is heavy enough that a single layer weighs 100-200 lb and the antennas can be mounted directly on them, thus reducing the amount of support material needed in their structure. In a conversation with Walter Gerstle (UNM), he mentioned that such a material is used to reinforce concrete, and can probably be fabricated to our specifications (3x3m). Alternatively, it is possible to build 3X3 m postage stamp patches by overlapping 2 pieces of mesh with 3X1.7m. In the case of a full station ground screen on should use pieces as long and as wide as possible, overlapping them in a similar way. An overlap region of 15-20 cm between different sections will guarantee their connection. It will be necessary to stitch the different pieces together and a solution is being investigated. Although this material is heavier than the one currently being used at the LWDA, we still plan to anchor the ground screens with pieces of bent rebar (4 to 6 per 3X3 m postage stamp), for safety and stability reasons. Our experience obtained with tests done with LWA antennas, as well as the first stages of the RTA, indicate that rebar rods with a length of 18 inches, which can be easily bent into an U shape and pounded into the ground, are the most effective way to anchor the ground screens. Tent stakes are too light, can be easily removed from the ground and are not as effective. For safety reasons it is necessary to use bent pieces of rebar, to avoid having pieces of metal sticking out of the ground at ankle level, like it was done with the first ground screens at the LWDA site. The use of rebar rods is a cheap alternative, and it may be possible to buy these pieces already bent. We suggest anchoring all the ground screens in the same way, always putting the rebar in the same positions. In this way, in the event some of these pieces get lose, people walking around the site will know where to look for them and avoid accidents.

Another issue to be considered in the ground screen is the size of the cells in the mesh. The current material and technique being used results in cells of 5x5 cm. However, LWA Memo #83 (Stewart) indicates that cell sizes of 10x10 cm would reflect >98.7% of the incident radiation, so the use of a 5x5 cm mesh is not necessary. In fact, even a 15x15cm mesh would reflect more than 96% of the incident radiation. Furthermore, this memo indicates that even using stainless steel, which is not as good a conductor as aluminum or copper, will not affect these numbers. We will investigate the price of ground screen material with different mesh sizes and determine what is a safe weight to support the antennas under strong wind conditions that can happen in New Mexico.

Future Issues To Address

One issue that needs to be addressed in future work is the electrical potential of the ground screen. Options include letting it float without making any extra effort to ensure a good connection to the earth ground, grounding it to the local earth ground with grounding stakes, or connecting it to the shelter ground via the outer conductors of the RF cable. The current baseline is to make no special provisions for grounding the screen, but other options should be investigated.

It is possible in the case of postage stamps screens, and highly likely in the case of full station screens, that the ground screens will have to be fabricated out of multiple sections. An issue needing further study is what amount of overlap, and how much "stitching" together of the individual sections is required to get the needed ground screen performance?

Appendix: Comparison of RFI and Antenna Beam on Different Ground Screens

In the following we present the results of drift scan measurements performed at the LWDA site on February 20-28, 2008 (see Paravastu's memo for a more detailed description of the results). Throughout this period we dedicated one specmaster input to a

Big Blade antenna on top of a 10X10m ground screen (BBLGS). The other inputs were used for other antenna types on top of a 3X3m ground screen. We tested a Big Blade (BBSGS), a Tied Fork (TF) and a 1.5m Blade Frame Design (BD). In Figures 2 and 3 we show 16 samples of the 50-65MHz spectrum of BBSGS and BBLGS, covering a period of 24 hours. Each panel is separated by ~1.5 hours, with the BBSGS and BBLGS spectra being observed within 1 minute of each other. Similarly, we show the spectral region 65-80MHz in Figures 4 and 5. The comparison of the spectra of these 2 sets of measurements shows that the RFI is much stronger on BBLGS. We can easily see broader and stronger RFI on the observations done on top of the 10X10m ground screen. These results are confirmed in Figure 6 where we show the average and standard deviation of the difference BBLGS-BBSGS. These values were determined by first calculating the difference between BBLGS and BBSGS in each 30 second scan cycle, then calculating the average and standard deviation over a 24 hours period. This figure shows that BBLGS always collects a much higher level of RFI, as high as 10 dB, on average, for some of the peaks. The enhanced RFI level may represent a threat to the system linearity and should be further investigated.

In order to understand the reason for the higher RFI levels on BBLGS, Figure 7 shows the modeled 80MHz beam patterns of a Big Blade antenna on top of a 3X3m and a 10X10m ground screen. Here we can see that the antenna on top of a 3X3m ground screen has a more "regular" beam pattern, meaning that there is a steady loss of ~3 dB from zenith to a zenith angle of 70 degrees. On the other hand, putting the antenna on top of a 10X10m ground screen creates a beam pattern with strong side lobes and large gain variations. As we can see in this figure, the beam pattern drops by ~3 dB from zenith to a zenith angle of 20 degrees and remains at these levels until a zenith angle of 40 degrees. After that the gain rises again, reaching levels of ~ -1 dB for zenith angles between 50 and 70 degrees. This beam pattern results in higher sensitivity close to the horizon, which explains the higher RFI levels detected with BBLGS. A better description of the beam patterns and their effects are presented in the ANT0004 Memo (Paravastu).

Finally, in Figures 8 and 9 we compare the BBLGS measurements with those of the Tied Fork (TF) and 1.5m Blade Frame Design (BD) on top of a 3X3m ground screen. As in Figure 6, we see much higher RFI levels on BBLGS than on TF and BD.

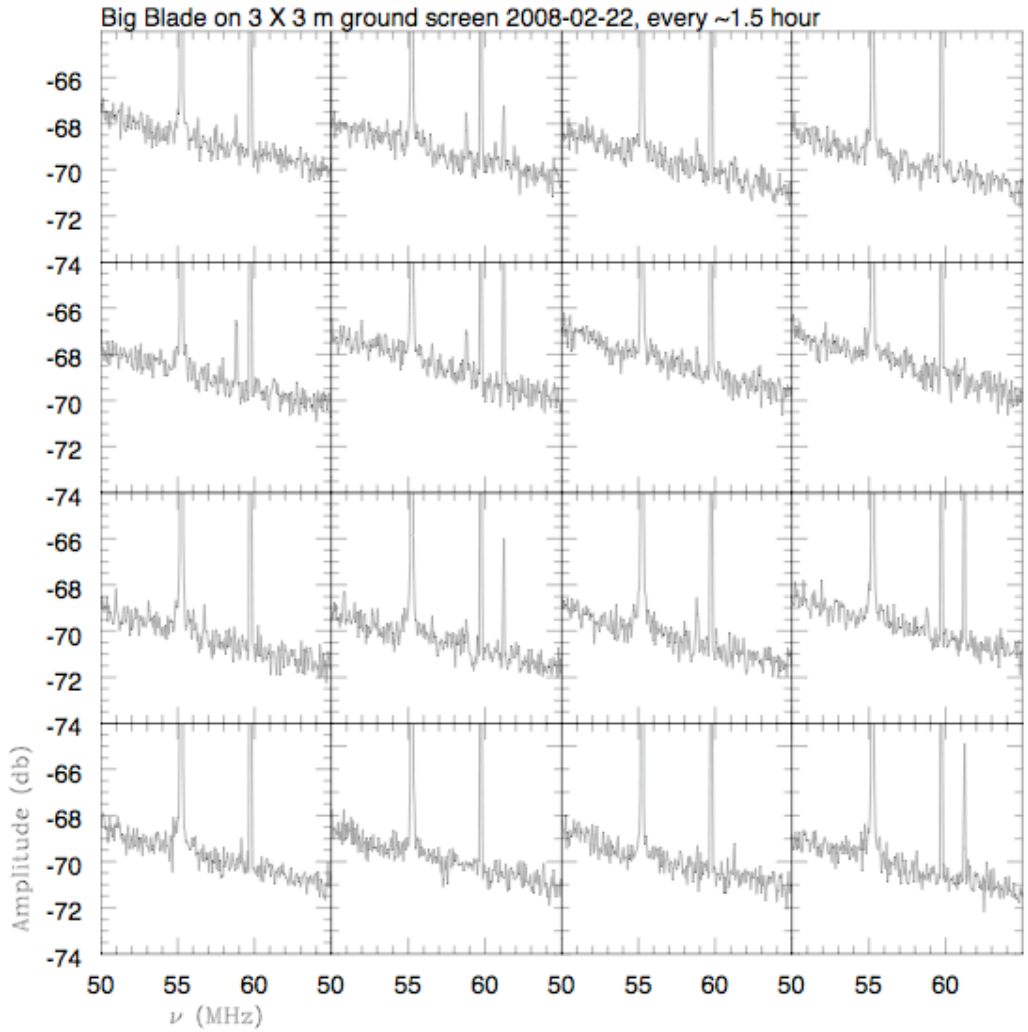


Figure 2: Sample spectra of BBSGS over the frequency range 50-65MHz, covering a time range of 24 hours (~1.5 hours separates each panel).

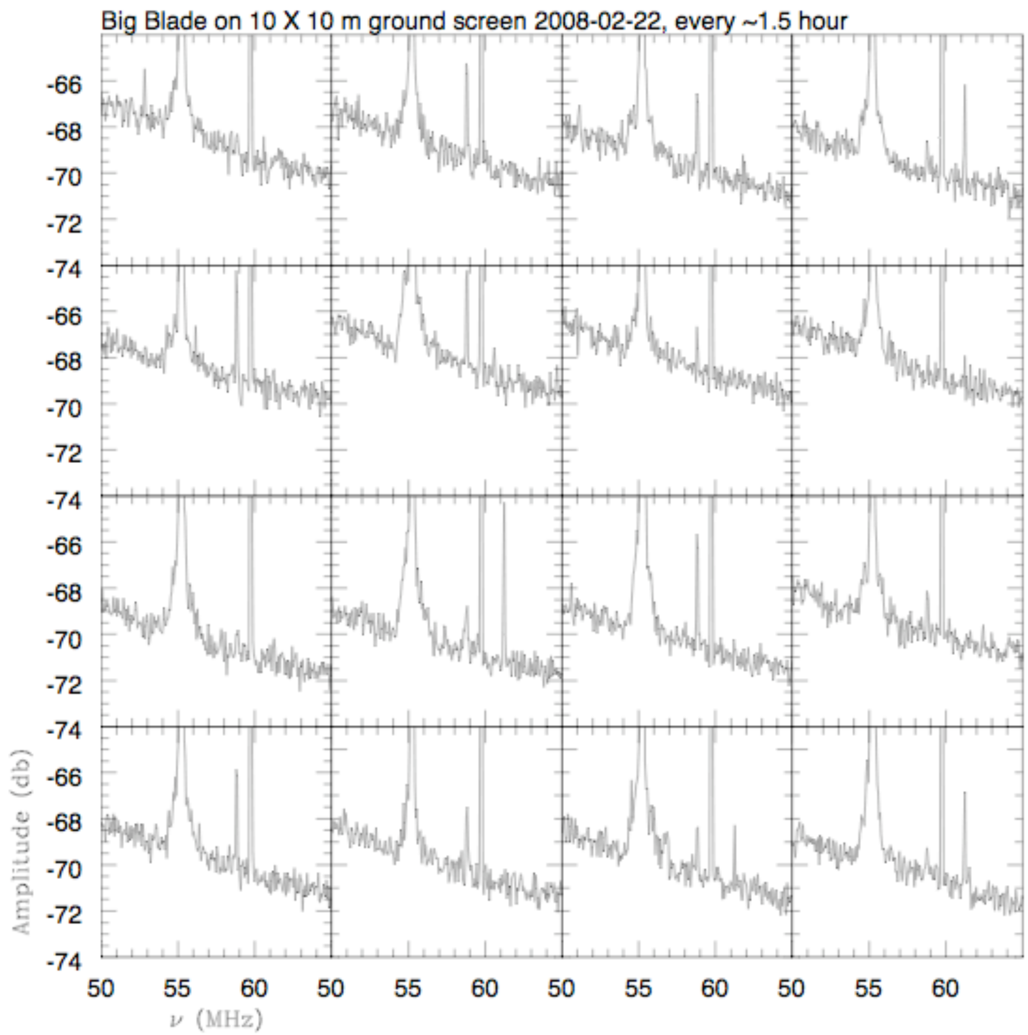


Figure 3: Sample spectra of BBLGS over the frequency range 50-65MHz, covering a time range of 24 hours (~1.5 hours separates each panel).

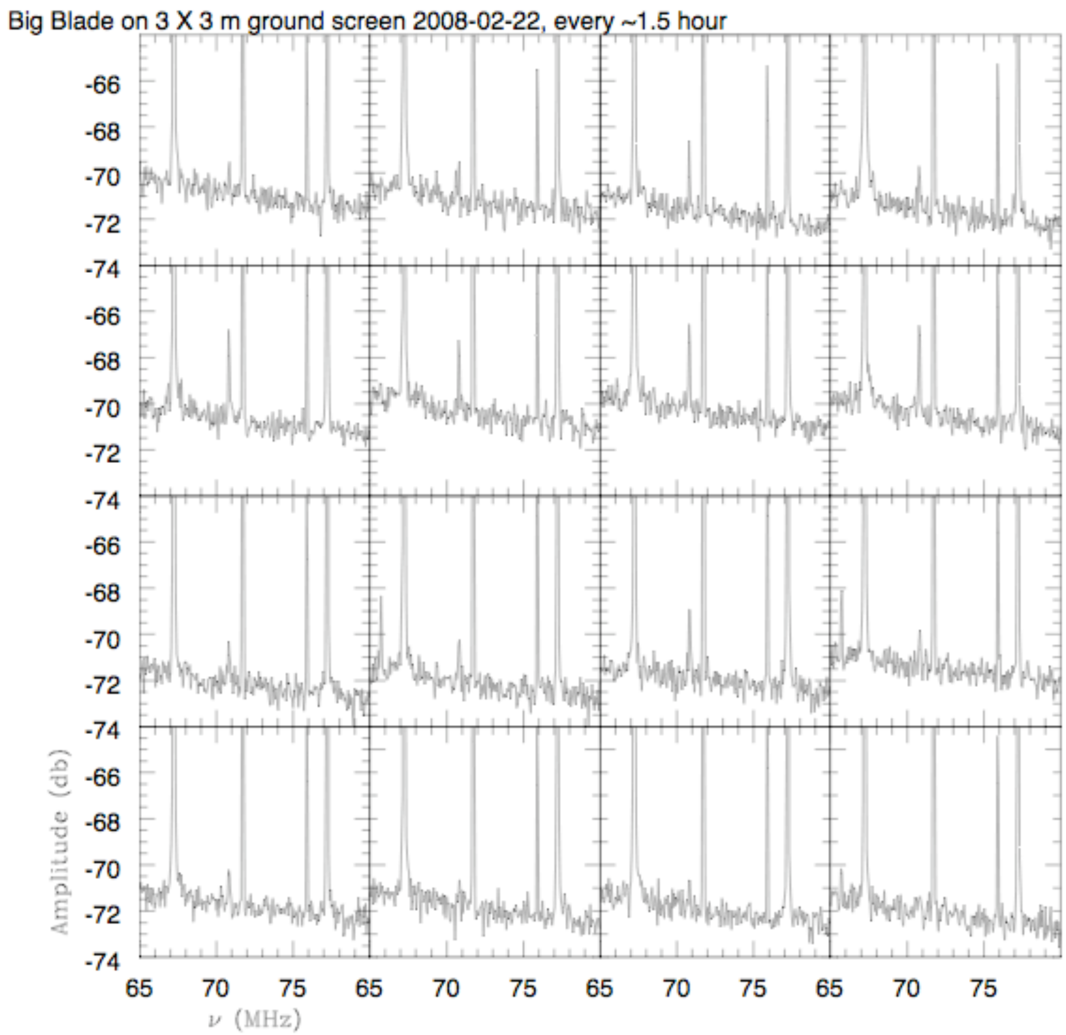


Figure 4: Sample spectra of BBSGS over the frequency range 65-80MHz, covering a time range of 24 hours (~1.5 hours separates each panel).

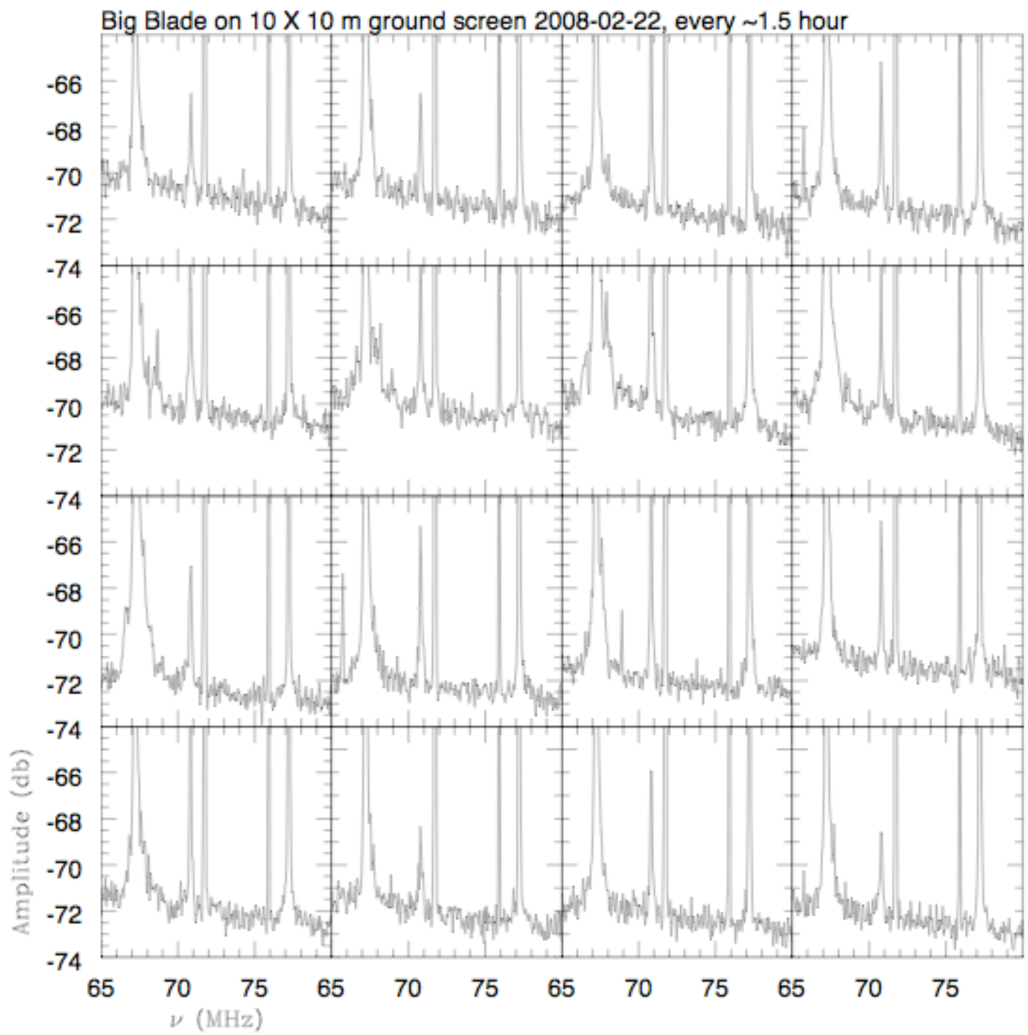


Figure 5: Sample spectra of BBLGS over the frequency range 65-80MHz, covering a time range of 24 hours (~1.5 hours separates each panel).

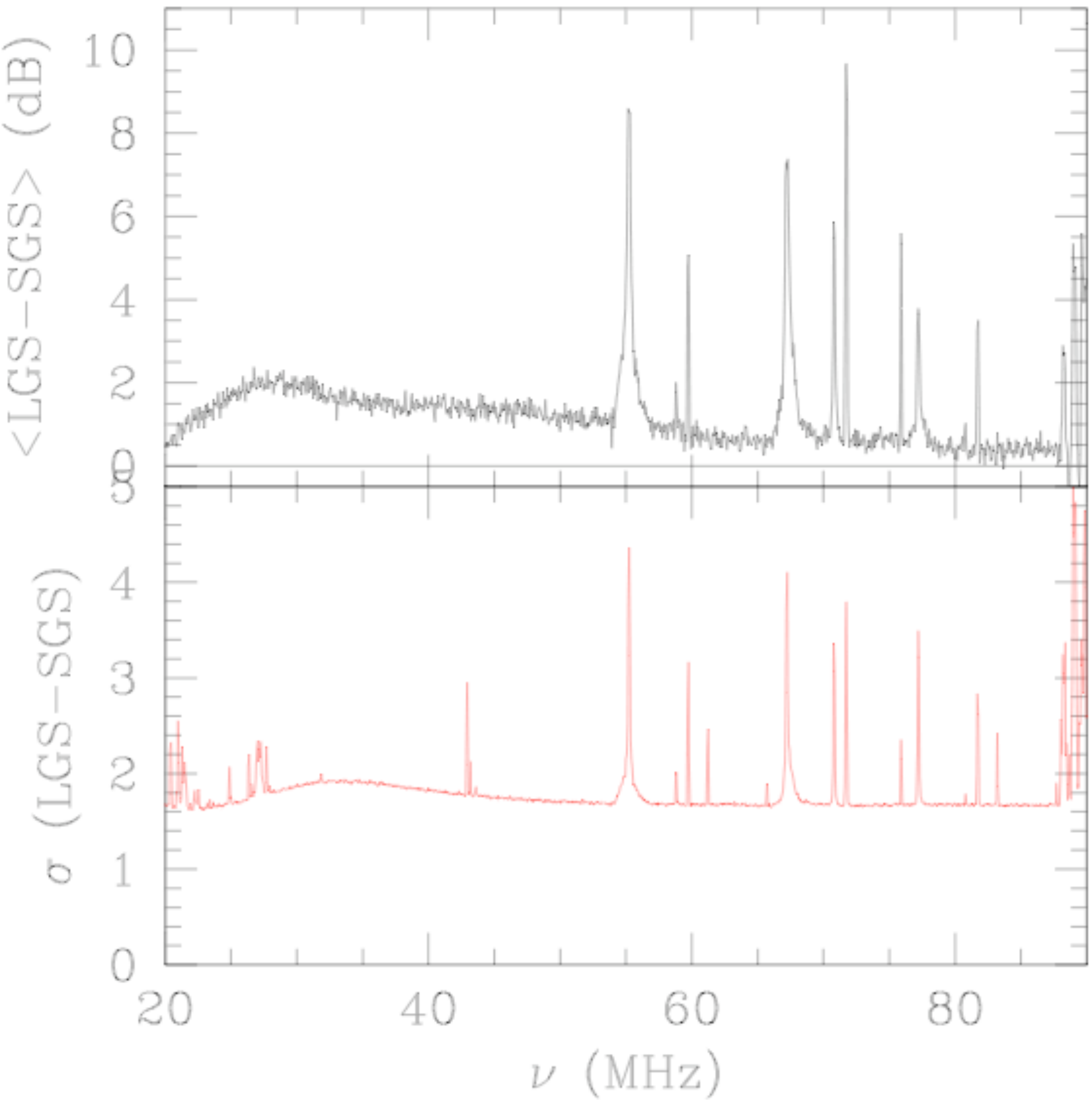


Figure 6: Average difference spectra of BBLGS and BBSGS (top), and standard deviation (bottom).

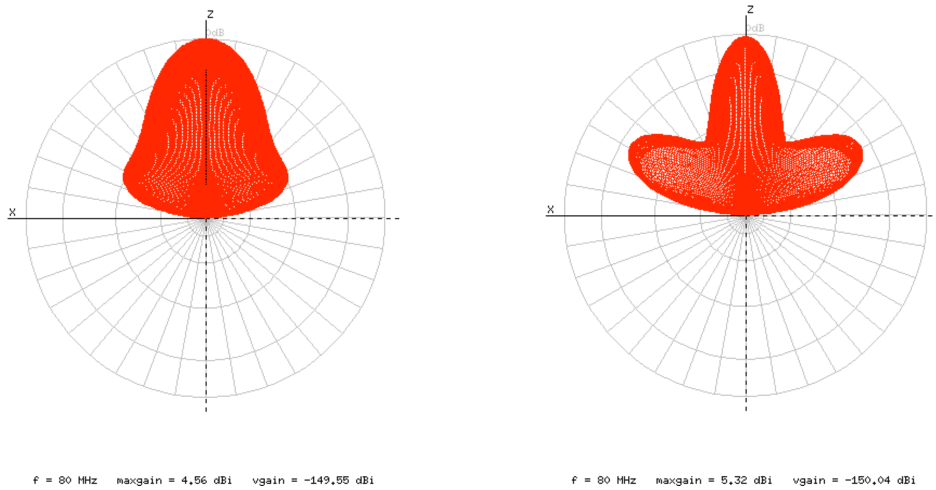


Figure 7: Simulated 80MHz beam patterns for a Big Blade antenna over a 3X3m ground screen (left) and a 10X10m ground screen (right). The outermost circle corresponds to 0dB, decreasing inwards to –1, -3, -6 and –10 dB each per circle.

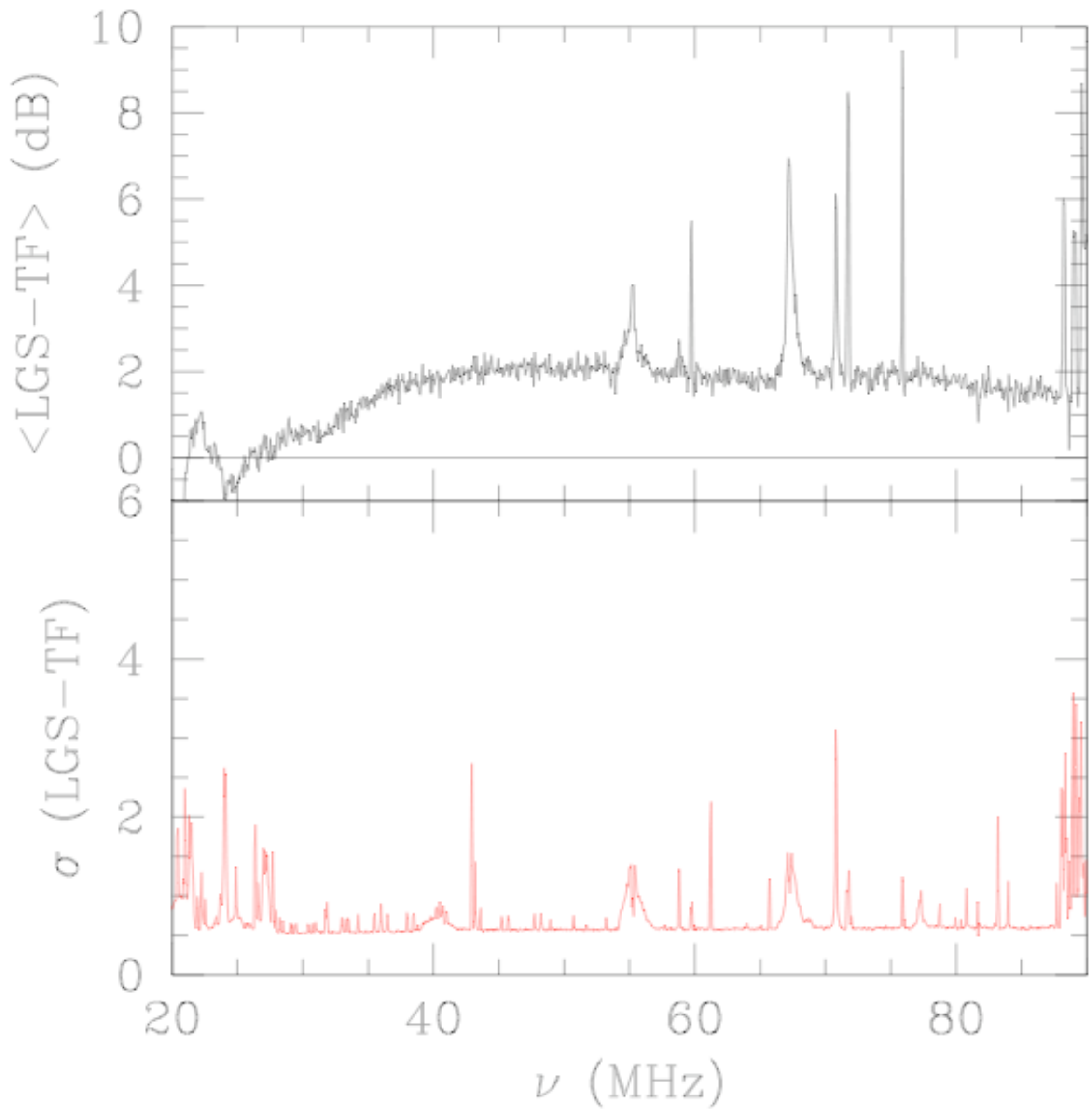


Figure 8: Average difference spectra of BBLGS and Tied Fork (top), and standard deviation (bottom).

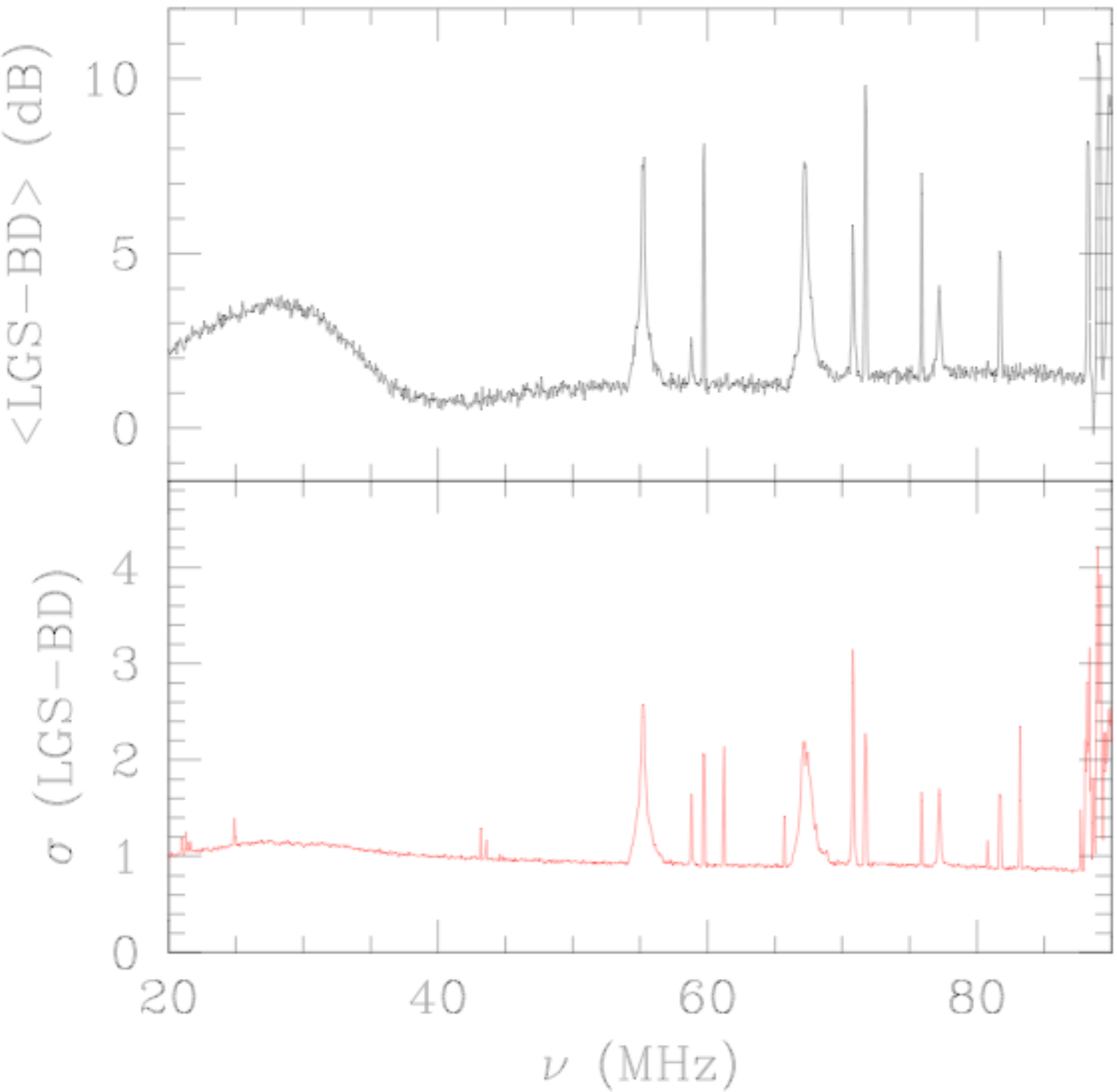


Figure 9: Average difference spectra of BBLGS and 1.5m Big Blade Frame Design (top) and standard deviation (bottom).

LWA Engineering Memo GND0002
Quotes for Ground Screen Material

May 21, 2008

Henrique R. Schmitt (NRL/Interferometrics Inc.)

Summary

This memo lists quotes for different ground screen materials. We study two ground screen designs, postage stamp and full station. In the case of the postage stamps we explore two scenarios, one in which the ground screen is used as a support structure for the antenna, and one where the antenna is supported by a PVC structure, not attached to the ground screen. At the end of the memo we summarize the different options and their costs in a table, for easy comparison. We also suggest that at this point the antenna manufacturer should be consulted, since the choice of ground screen will influence the design and cost of the antennas.

Details about the quotes requested:

At the current stage we are just requesting quotes for the price of the material and have not tried to request quotes for delivery costs or any applicable taxes. Another detail about the quotes is that we had to adapt the requests to what the companies produce, since different companies produce different products. In a first attempt we tried to request quotes for the exact materials and cell sizes we need, but no quotes were returned. Once we have a better idea of which ground screen design will be adopted the search can be refined.

Full station Ground Screen:

In the case of a full station ground screen we got quotes on the same kind of material currently used at the LWDA. We got prices for rolls of galvanized welded wire mesh from Academy Fence Company and from Lowe’s in Albuquerque (they sell Redbrand welded wire fence). These rolls are made with 14 gauge wire (~2mm thick), have cells of 2”X4” and come in rolls of 6X100 ft or 4X100 ft. Based on the experience obtained at the LWDA site we should overlap the rolls by 8” (2 cells), to improve the connection between them. The calculations presented below were done assuming that the ground screen will cover an area of 110X110m with a single layer of material. In case one assumes that we will only cover a circular area with a diameter of 110m the numbers below can be reduced by 20%. Just for comparison we also got a quote from Academy fence for rolls with a cell size of 1”X1” (much denser than needed, but this company does not produce rolls with cell sizes of 2”X2” or 4”X4”). The results are presented in Table 1. We have also requested quotes from Deacero, for rolls with cell sizes of 2”X2”, but after a week we were told that they no longer produce meshes with this cell size.

Quantity (rolls)	Size (ft)	Cell size (in)	Wire width (gauge-mm)	Total Weight (lb)	Cost per station ($)	Manufacturer
250	6X100	2X4	14 – 2	23,000	27,655	Academy Fence
400	4X100	2X4	14 – 2	24,500	25,600	Lowe’s
400	4X100	1X1	14 – 2	64,800	84,084	Academy Fence

Table 1: Quotes from Academy Fence Company.

In order to connect the different rolls of mesh together we propose to use split splicing sleeves from Nicopress (http://www.nicopress.com), which are made specifically to connect wire fences (stock number FS-2-3 or FS-3-4) at a cost of $0.20 each. These sleeves are crimped with a tool sold by this company (tool number 64-2345), which costs approximately $100. Assuming that we will put one connector every 2ft, we will need approximately 20,000 connectors ($4,000) in the case of the 4X100 ft rolls, or 12,500 connectors ($2,500) in the case of the 6X100 ft rolls. Here we do not take into account the man power needed to put these connectors in place.

Besides connecting the individual rolls of mesh together it will also be necessary to anchor the borders of the ground screen to avoid buckling. We propose to do this by using bent pieces of rebar, like it was done on the LWDA. We propose to use 1/2”X18” pieces of rebar which is sold at Lowe’s by $0.88 a piece. Assuming that we will put one piece every meter we will need 440 pieces of rebar, which will cost $387.

Postage Stamp Ground Screen:

Here we consider two scenarios. In the first one we assume that the ground screen will be used as a support structure for the antenna, while the second one assumes that the antenna will be supported by a PVC structure, not connected to the ground screen.

In the case of the first option, we got quotes for 2 kinds of galvanized welded wire mesh from McNichols CO. Both kinds have cell sizes of 2”X2” and come in sheets of 6X12 ft. One is made with 3mm wire and the other with 4mm wire. Two of these sheets will be needed for each postage stamp, allowing a 1 ft overlap. Along the other direction the screen is 2ft longer than the 3X3 m (10X10 ft) postage stamps mentioned in GND0001. We are assuming that this is a detail that can be solved in the future. Furthermore, assuming the cost of the screen scales with the area we expect the final cost to be 20% smaller than the ones quoted in Table 2. We also got a quote from Direct Metals, which is shown in Table 3. One detail to be noticed in the two quotes. The quotes from McNichols is only for meshes galvanized after the welding, while in the case of Direct Metals we have quotes for galvanized before and after welding (in the case of the 3.4mm wire they don't offer galvanized after because the process causes the sheets to warp). Taking into account the difference in the area of the material in the two quotes we get that both of them have similar costs.

Quantity (sheets)	Size (ft)	Cell size (in)	Wire width (mm)	Total Weight (lb)	Cost ($)	Details
512	6X12	2X2	3.0	19,538	42,025	Galv. After
512	6X12	2X2	4.0	30,966	60,826	Galv. After

Table 2: Quotes from McNichols CO.

Quantity (sheets)	Size (ft)	Cell size (in)	Wire width (mm)	Total Weight (lb)	Cost ($)	Details
768	4X10	2X2	3.4	17,080	30,359	Pre galvanized
768	4X10	2X2	4.1	30,106	40,182	Pre galvanized
768	4X10	2X2	4.1	27,985	51,802	Galv. After

Table 3: Quotes from Direct Metals

Just for comparison, we contacted Brian Corey from MIT Haystack about the cost of the ground screens used for MWA. Their ground screens are made with galvanized welded wire with a thickness of 3.15 mm and cell sizes of 5X5 cm (2"X2"). Each one of their tiles used 3 sheets with 2X5 m, overlapping by 50cm to make a 5X5m tile. This cost them $AU357 per tile, which translates to approximately US $338 using today's exchange rate, but does not take into account the change in the price of metals, which has gone up over the last few months. Making the proper area conversion from their tiles to our postage stamps (using an overlap of only 30cm between sheets like we propose in our case), we get that one postage stamp would cost $113 if we used the MWA materials, at the cost from a few months ago. From the first quote in Table 2, which is a similar material to the MWA, we get that a 3X3m postage stamp cost $139.

In order to attach the different ground screen sections together we will need between 6 and 12 splicing sleeves (for the case of 2 or 3 sheet per postage stamp, respectively), which add up to 1,550 or 3,100 sleeves per station ($310-620). We will also need to anchor the ground screens to the ground, which we propose to do using 6 pieces of rebar per ground screen (1/2"X18" rebar like in the case of full station ground screen). We propose to put one piece of rebar on each corner of the ground screen, plus one on each side where the ground screen is composed of more than one sheet (these pieces of rebar will be placed at equidistant points from the corners). This will require 1,536 pieces of rebar which will cost $1,352.

We did not ask for quotes for a full station ground screen made of the materials presented in Tables 2 and 3, but the area argument suggests the cost would be approximately 4-5 times the ones quoted in the Table. One issue that has to be kept in mind is the thickness of the wires, if the ground screen is to be used as the support structure for the antennas.

In the case of the second postage stamp option, where the ground screen does not support the antenna, we assume that we will use the rolls of mesh with 2"X4" cells. Table 4 shows the number of rolls and the cost of the ground screen for the two types of mesh being considered. In the case of the 6X100 ft rolls we will use 2 sections of 6X10 ft per ground screen, overlapped by 1ft. In the case of the 4X100 ft rolls we will use 3 sections of 4X10 ft overlapped by 1 ft. The connection between the different sections of mesh will be done in the same way as above, using between 6 and 12 splicing sleeves, which will cost between $300 and $600 per station. The ground screens will be anchored to the ground using 4 pieces of rebar, one on each corner of the ground screen, which will require 1024 pieces and will cost $901.

Quantity (rolls)	Size (ft)	Cell size (in)	Wire width (gauge-mm)	Total Weight (lb)	Cost per station ($)	Manufacturer
52	6X100	2X4	14 – 2	4,780	5,752	Academy Fence
77	4X100	2X4	14 – 2	4,720	4,968	Lowe's

Table 4: Quotes from Academy Fence Company.

Comparison of designs:

In Table 5 we present the costs of the different ground screen designs. In the case of the postage stamp designs we also give the cost per stand. These numbers take into account the cost of the materials to connect the different sections of ground screen and to anchor them to the ground. As was previously discussed, we do not need ground screens with mesh sizes of 2"X2", so we are assuming that we will be able to find a manufacturer who can produce postage stamp meshes with 4"X4" cells. We converted the numbers presented in Tables 2 and 3 to this cell size, assuming that the cost will scale by a factor of 0.5 due to the amount of material. Also, in the case of the sheets produced by McNichols (Table 2), we assume that we will be able to purchase sheets of 6X10ft so the numbers in that table are converted to this size by dividing by an additional factor of 1.2.

Design	Manufact.	Cell Size (in)	Sheet/Roll Size (ft)	Wire	Cost Station ($)	Cost Stand ($)
PS- Sup	McNichols	4X4	6X10 – ga	3.0 mm	19,170	75
PS- Sup	McNichols	4X4	6X10 – ga	4.0 mm	27,010	105
PS- Sup	Direct Met	4X4	4X10 – ga	3.4 mm	17,150	67
PS- Sup	Direct Met	4X4	4X10 – gb	4.1mm	22,060	86
PS- Sup	Direct Met	4X4	4X10 – gb	4.1mm	27,848	109
PS	Academy	2X4	6X100	14 ga	6,960	27
PS	Lowe's	2X4	4X100	14 ga	6,490	25
FS	Academy	2X4	6X100	14 ga	30,540	---
FS	Lowe's	2X4	4X100	14 ga	29,990	---

Table 5: Comparison of the costs of different designs (PS- Sup = Postage Stamp used as support; PS= Postage Stamp; FS= Full Station). ga= galvanized after; gb= galvanized before. The costs per stand were rounded.

Study of Ground Screens for LWA – a Civil Engineering Perspective

Walter Gerstle

July 15, 2008

Summary

This document was requested by Joe Craig, LWA system engineer. He requested a "civil engineer's view of LWA ground screens". This document addresses this request. Two scenarios are contemplated: (1) a 3mx3m postage stamp ground screen under each of 256 antennas per station, and (2) covering the entire station with a 120m diameter ground screen. We consider the conceptual design, construction and fabrication issues, and the estimated cost of each alternative.

Background

Henrique Schmidt wrote "LWA Engineering Memo GND0001 Baseline Design of Station Ground Screen" dated April 18, 2008. In his memo, he considers the comparison of RFI and antenna beam between three different ground screen configurations. He states that some sort of ground screen is probably required, with the full-station ground screen being preferred, from an electromagnetic radiation perspective, over the postage stamp ground screen. He also considers a hybrid scenario, in which there is a 3mx3m postage stamp ground screen under each antenna, plus a coarse ground screen covering the entire LWA station. We do not consider the latter scenario further in this document.

On May 21, 2008, Henrique Schmidt wrote "LWA Engineering Memo GND0002 Quotes for Ground Screen Material". I provided input for and reviewed both of these documents and find them to be reasonable, accurate and error-free.

Conceptual Design

From a civil engineering perspective, the postage stamp configuration is certainly preferable, as it involves approximately one-fifth as much material as the full-station ground screen and would be much easier to install and maintain. The postage stamps could be more easily moved out of the way in the event that buried cables need maintenance. In addition, the postage stamp configuration could be more easily fabricated in the shop and transported to the station in modular units. Finally, in the event that some of the ground screen needs to be replaced after a number of years of operation, it would be much easier to replace isolated postage stamps as required than the ground screen over the entire station.

It appears to be unlikely that the antennas could be anchored directly to the ground screen in either configuration without auxiliary support members. For this reason, it is recommended that the ground screen not be considered as a structural support member for the antennas.

From memo GND001, it is clear that 4”x4” mesh spacing reflects about 99% of incident radiation, while 6”x6” mesh spacing reflects more than 96% of incident radiation. We would prefer 6”x6” mesh spacing in our conceptual designs, with 12 gage (0.1084” diameter) galvanized steel wires running in both directions. Thinner gage wires would probably be inadequate from a durability standpoint, and galvanization is required to prevent corrosion over a period of years. We will assume the wires in each direction are welded together in the factory. However, our research shows mesh with 6”x6” 12 Ga wire spacing is not readily available. Such mesh can be ordered from the factory, if we decide we need it for our design. A phone conversation with a salesman at McNichols Products in Dallas (http://www.mcnichols.com) revealed that they can order custom mesh to be fabricated for us. For example, they can order 100’x6’ rolls of 6”x6” 11 Ga (0.1233” diameter) welded wire mesh. However, for handling reasons, they were unwilling to order 6”x6” 12 Ga welded wire mesh, because they think it would be damaged during transport. Thus, the limiting wire spacing and wire thickness could be dictated more by handling considerations than by any other consideration.

Fabrication

McNichols (http://www.mcnichols.com) products is willing to work with us to custom-order from the factory mesh of our design. Let us assume 6”x6” 11 Gage hot-dip galvanized welded wire mesh can be ordered (see Quote on next page. This quote seems very high, at $3.02 per pound of steel, and possibly it could be lowered if we ordered mesh in larger quantities.).

McNICHOLS CO.

Quotation: **4453332-01**
Reference: Inq#: 4453332
Date: 7/14/2008
Ship Date: 12 WEEKS
F.O.B.: YOUR DOOR
Account: 676102
Terms:

Customer Information:

University Of New Mexico

2301 Central Ave Ne
Albuquerque, NM 87131

Contact: Mr Walter Gerstle
E-mail: gerstle@unm.edu
Phone: 505-277-7470
Fax: 1-505-277-0304

McNICHOLS Information:

MCNICHOLS CO.
3540 Miller Rd, #240
Garland, TX 75041

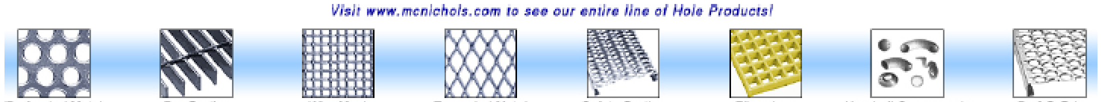
Contact: Rustin Corsentino
E-mail: Rustin.Corsentino@mcnichols.com
Phone: 214-349-3150
Fax: 214-553-8529

Thank you for your inquiry for McNichols quality products. We are pleased to quote as follows:

LINE	McNICHOLS PRODUCT DESCRIPTION	QUANTITY	UNIT	UNIT PRICE	AMOUNT (USD)
1	Wire Mesh Square Mesh Major Material: Galvanized Minor Material: Pre-Galvanized Construction Type: Welded Untrimmed Mesh Size1: 6.000" Wire Diameter Parallel Width: .120 Width: 72.0000 Length (Span for Grating): 1200.0000 Weight: 13860 lbs	150			$41909.09
	We appreciate the opportunity to quote on your requirements and look forward to the pleasure of serving you.				

The information contained in this quotation is subject to change without notice and will not be binding on McNichols unless it is verified in writing by authorized personnel of McNichols at the time an order is placed. This quotation is subject to McNichols standard terms and conditions and are available upon request. Prices quoted for stock items are valid for 10 days subject to availability, unless otherwise stated. Prices quoted for specials and nonstandard items are "Price in Effect at Time of Order." All materials quoted are industrial in nature and may not be suitable for architectural applications. All materials quoted come in a mill finish. Mill Finish - not cleaned, oil on sheet, raw material can have inherent cosmetic flaws, scratches, burrs, sharp edges, and material can also have color distortions due to heat or welding processes. Any material cut-to-size cannot be returned.

Visit www.mcnichols.com to see our entire line of Hole Products!



Service, Quality, and Perfomance - That's The Hole Story!®

As suggested by Henrique Schmidt in GND001, the mesh can be connected using split splicing sleeves from Nicopress (http://www.nicopress.com). Such connectors cost $0.20 each. We might be able to make our own connectors at much lower cost. The electrical behavior of such connectors will need to be investigated. Field-welding of the mesh sections might also be an option hat needs to be considered.

The mesh will probably need to be anchored periodically to the ground using earth anchors of some sort. Schmidt suggested 18” long hooked reinforcing bars (costing about $0.88 apiece), but in my opinion we can fabricate much less expensive anchors such as 3/4”x3/4”x1/8” angles or even gun-inserted soil nails or similar. Again, these anchors should be optimized for the application.

Cost Estimate

The cost of ground screen includes cost of material and cost of installation. Because of the remote locations of the stations, I suspect travel and labor will be a major component of the cost. Let us assume the ground screens are installed by UNM staff, so that labor costs are pre-paid. Travel, however, will be extra, and will cost approximately, say, \$200 per person per day. Assuming that ground-screen installation takes 16 man-days per station, travel would cost \$3,200 per station for installation.

According to Schmidt's analysis (GND0002) ground screen materials (including connectors and ground anchors) will cost approximately \$7,000 per station for the postage stamp scenario, and \$30,000 per station for the full station ground screen. Thus, the total cost, excluding labor but including travel is estimated to be \$10,200 per station for the postage stamp scenario and \$33,200 per station for the full station scenario.

Construction

All materials will need to be transported to the site. In the case of the postage stamp scenario, the postage stamps would likely be pre-assembled and trucked to the station as flat 3mx3m sections of mesh, stacked on a flat bed truck. In the case of the full-station ground screen, the mesh would be transported as 250 100'x6' rolls to the station.

In the postage stamp case, each postage stamp would be hand-carried to its pre-determined location, and set on the ground. Then soil anchors will be installed. Estimated time to install each postage stamp is 15 minutes for two people. Thus with 256 postage stamps per station, the total man-hours required is 0.25 hours x 256 x 2 men = 128 man-hours = 16 man-days per station.

In the full-station case, mesh would be rolled out into position, connected together, and anchored. Likely installation time: 16 man-days per station. This is just an educated guess.

Conclusions

Custom galvanized mesh can be ordered; this might produce some savings from the estimates in GND0002. We can probably save money by developing our own connectors and soil anchors for the mesh segments. Likely labor requirements to install ground screen is estimated to be 16 man-days per station plus travel time and cost (which will be significant).

LWA Engineering Memos GND0005
Simulations and Final Choice of Ground Screen Material

February 11, 2009

W. J. Robbins, H. R. Schmitt, P.S. Ray& N. Paravastu

Summary

We present the results of Numerical Electromagnetics Code (NEC) simulations of ground screens. We use these simulations to evaluate different choices of ground screen sizes, mesh densities and wire gauges, and guide us in the determination of the parameters to be adopted by the project, as well as tolerances. We recommend a 3X3m ground screen, with 4"X4" mesh lattice, made out of 14 Ga (~2mm) wire.

Introduction

Some fieldwork has been done on the determination of the need of ground screens, as well as on the study of the effects of the ground screen size on the antenna impedance, radiation pattern and sensitivity to RFI (Paravastu et al. 2007 – LWA Memo #90, Schmitt 2008 – GND0001). These tests have shown that a ground screen will reduce ground losses and stabilize the gain of the antennas, which in the case of Earth ground can vary depending on the moisture content. In order to show some of these effects, Figures 1 and 2 present two projections of the antenna beam pattern for models calculated using a single polarization Tied Fork antenna over Earth ground, over infinite PEC ground and over a 3X3m ground screen (on top of Earth ground). These simulations show that the peak response of an antenna over Earth ground is only 56% relative to the one obtained over PEC ground, while in the case of a 3X3m ground screen the peak response is 83% relative to the one from PEC ground. Another important result obtained from these models is the shape of the beam presented in the Figures. In the case of PEC ground the antenna develops a low elevation side lobe, which will enhance the collection of ground RFI signals, as seen in field tests (Schmitt 2008 – GND0001). Here we present the results of a set of simulations designed to compare a wide range of ground screen sizes, mesh lattice densities and wire gauges, that will be used to guide our choice of ground screen materials.

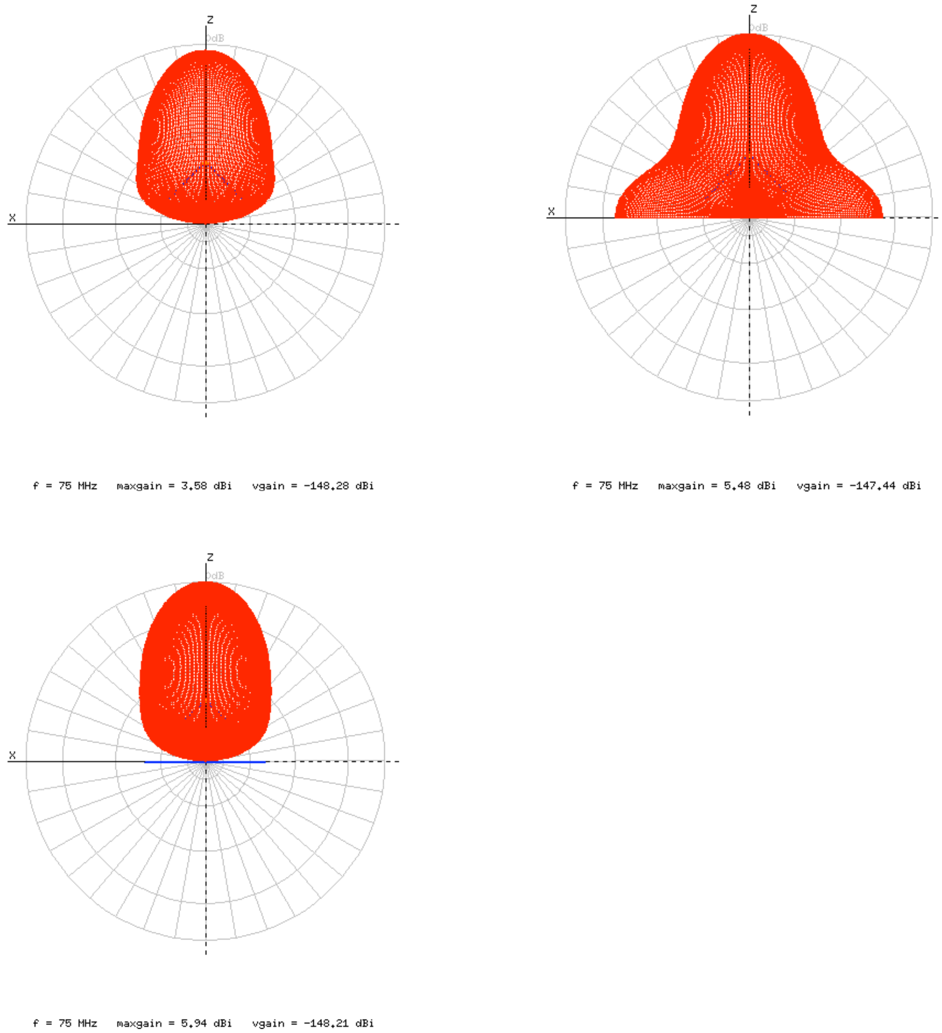


Figure 1: Simulated 75MHz beam patterns for a single polarization Tied Fork Antenna on top of Earth ground (top left), PEC ground (top right) and a 3X3m ground screen (bottom left). The outermost circle corresponds to 0 dB, decreasing inwards to –1, -3, -6 and –10 dB. The beam pattern is shown in linear scale.

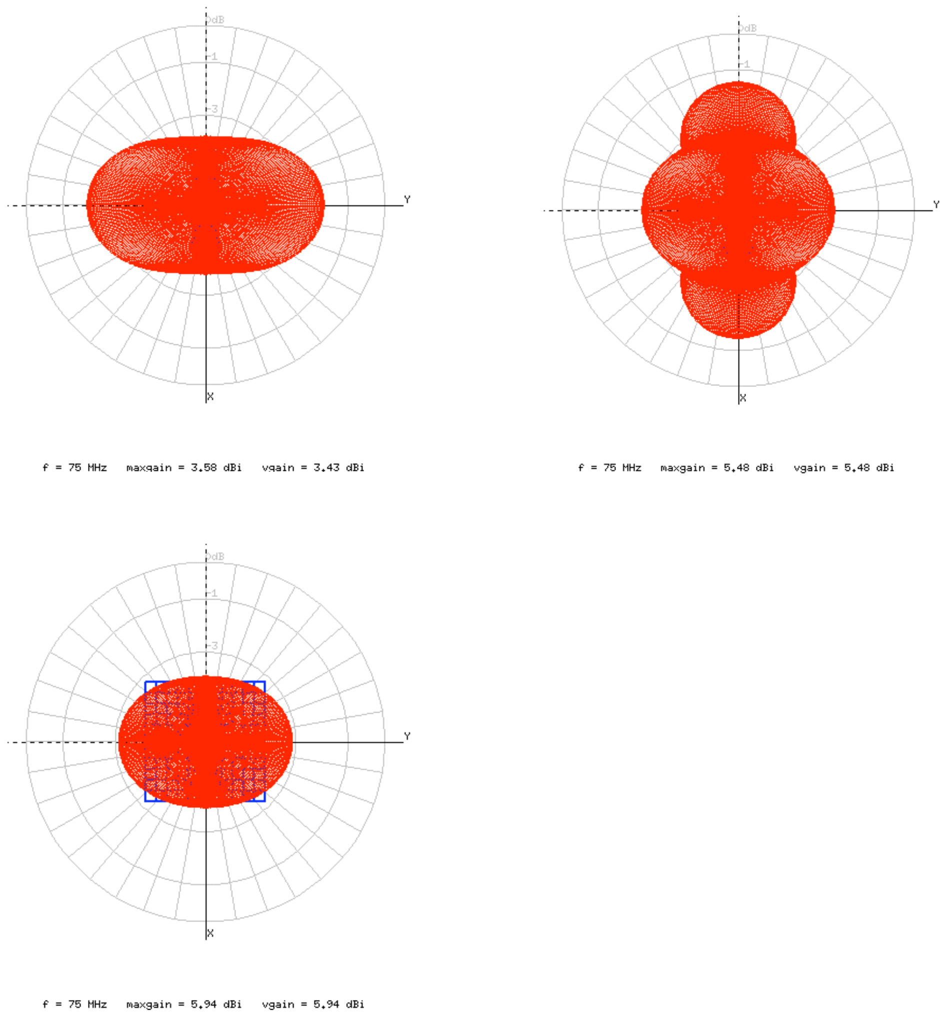


Figure 2: Same as Figure 1 for the simulated 75MHz beam patterns, seen from the Z-axis, for a single polarization Tied Fork Antenna on top of Earth ground (top left), PEC ground (top right) and a 3X3m ground screen (bottom left).

Simulations

Our simulations follow the method used by Robbins et al. (2009) on the study of the tolerances of the Tied Fork Antennas, adopting the antenna parameters presented by Paravastu 2008 in the Memo ANT0006 (Figure 3). The antenna was modeled with cylindrical wires with an effective diameter of 12.5mm and a bulk conductivity of 25 Mega-Siemens per meter. The antenna was stimulated by a voltage source of magnitude √2 volts in the feedline. The frequency of excitation was swept in increments of 1 MHz between 5 MHz and 111 MHz. As a means to determine the performance of the different ground screen simulations, we compare them to an infinite PEC model. The ground screen is made of parallel wires organized in a square lattice, raised by 3cm from Earth ground. The quantities of merit presented here are the impedance, Z, and the impedance mismatch efficiency, IME (presented as a unit-less fraction $\in [0,1]$).

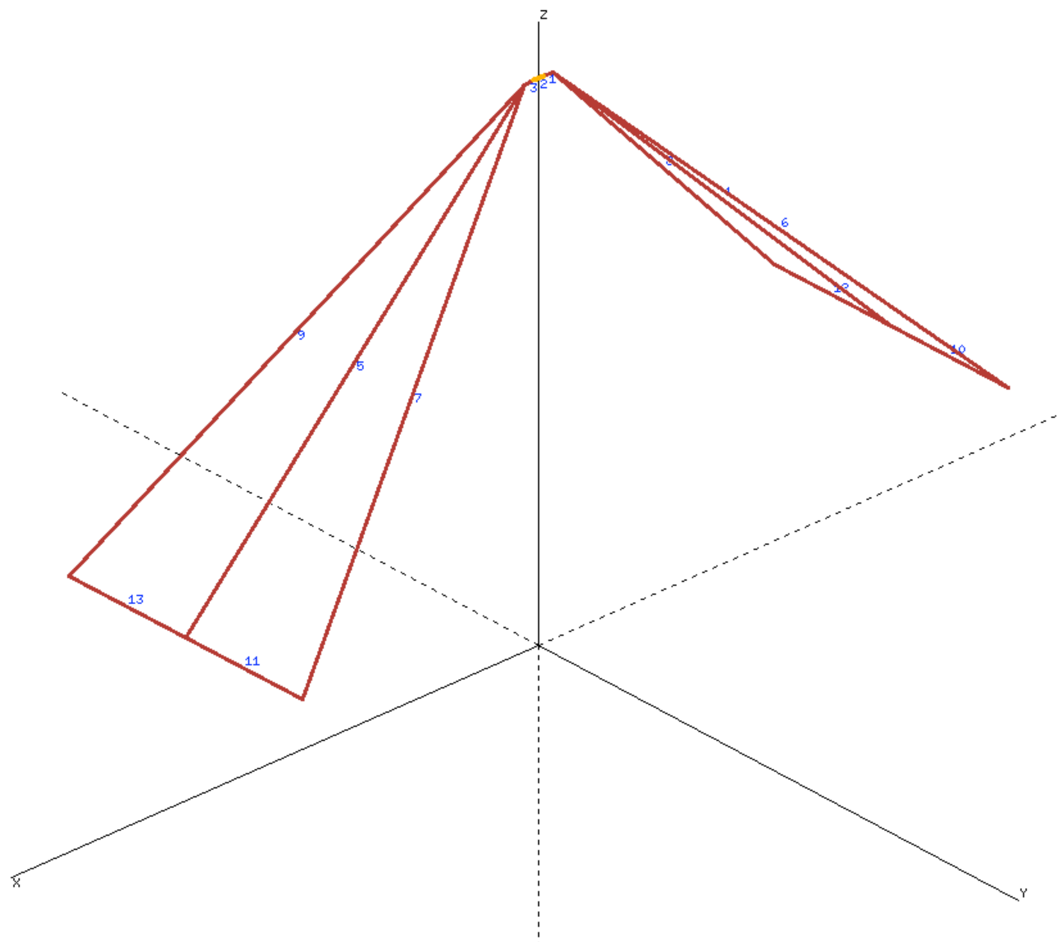


Figure 3: Antenna model with wire segments numbered.

Ground Screen Size

The effects of the ground screen size on the antenna performance were tested using 7 square ground screen models with side dimensions of 1, 2, 3, 5, 10, 15 and 20m. For these models we used a 6” mesh lattice and wires with a width of 1mm. The comparison of these models with the one calculated using a PEC ground are presented in Figures 4 and 5. The simulations show that for ground screens smaller than 3X3 m, there is a large deviation of the simulated impedance relative to that of a PEC ground screen. The best agreement occurs for ground screens with 3X3m and 5X5m, while those with sizes of 10X10m or larger start to deviate significantly from the PEC ground models. Comparing the ground screens with 3X3m and 5X5m we find that at certain frequencies one is a better match to the PEC model than the other, making it difficult to recommend one size based only on these results and making it necessary to take into account the cost and infrastructure. Based on the area of the 2 ground screens, the cost of the 5X5m option will be ~2.7 times that of the 3X3m one. This does not take into account the extra labor needed to stitch different pieces of ground screen together and to anchor the screen to the ground, which will most likely make the final cost much higher. The 5X5m ground screen also presents an infrastructure problem. Since the closest separation between two stands is 5m, a 5X5m ground screen means that different ground screens will possibly overlap, especially if two stands are separated by 5m along the diagonal. Besides changing the properties of the ground screen, this overlap, and in most of the cases the close proximity of ground screens, will not leave a lot of space between stands for people to walk around the site, making maintenance hard, if not dangerous. Taking all these factors into account we recommend a 3X3m ground screen.

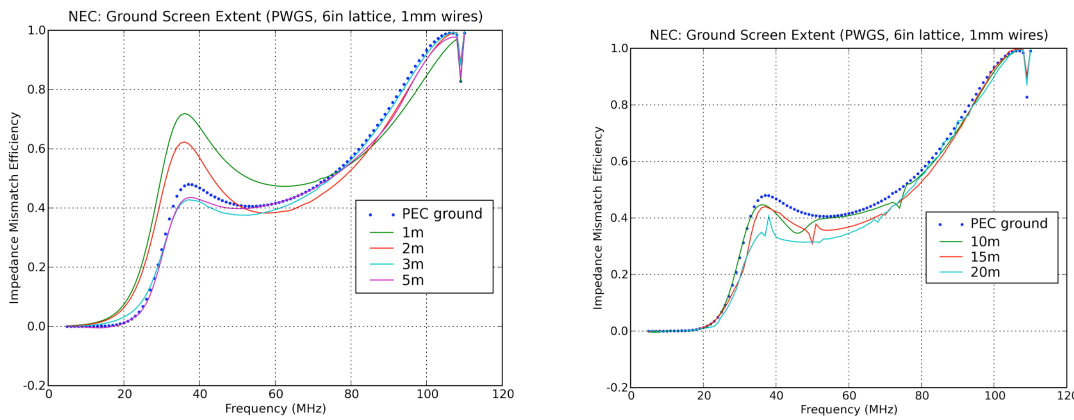


Figure 4: The antenna IME versus frequency, for several ground screen sizes.

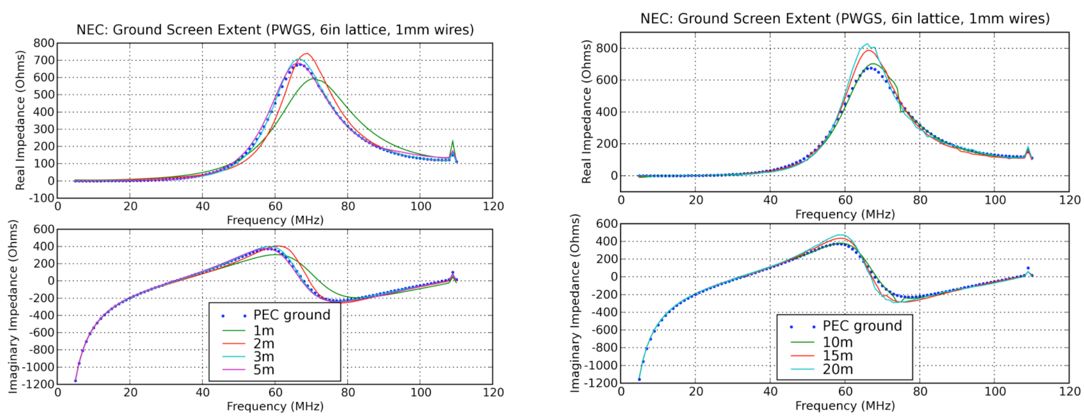


Figure 5: Antenna impedance versus frequency, for several ground screen sizes.

Mesh Density

We tested the effects of 6 lattice sizes: 1”, 2”, 4”, 6”, 8”, and 10”. All these simulations used a 3X3m ground screen with 1mm wires. The results are presented in Figure 6. The simulations show that there is not a lot of differences between ground screens with mesh sizes between 1”X1” and 10”X10”. The impedances obtained for the different mesh densities cluster together and are very similar to that of the PEC model. We suggest using a material that can be easily and cheaply obtained on the market. The best option identified in the Memo GND0006 is the fencing material with 4"X4" cells, produced by Penn Wire.

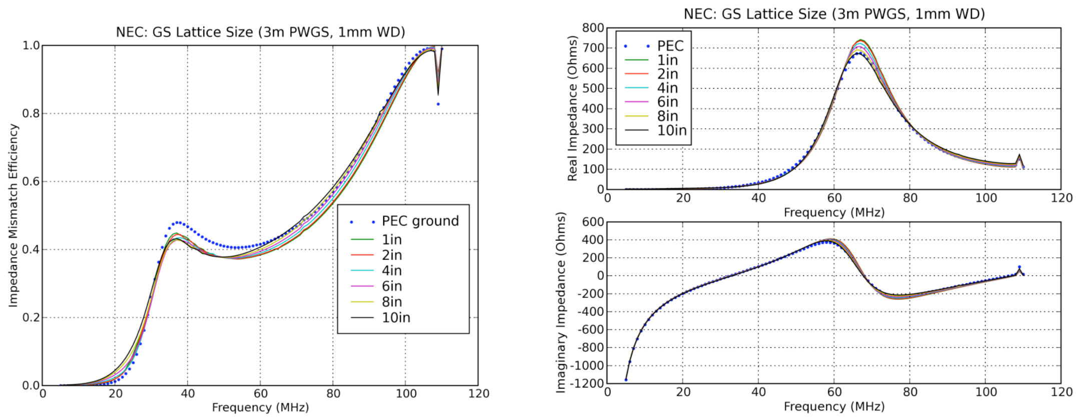


Figure 6: The antenna IME (left) and impedance (right) versus frequency, for several ground screen lattice sizes.

Wire Diameter

A last set of simulations tested the effect of the mesh wires. We tested wires with 1, 3 and 4 mm. The results are shown in Figure 7, where we can see that there is basically no difference between the 3 models. These models were calculated for a 3X3m ground screen with a 6" mesh lattice. We suggest using a material that is easily available, a mesh made with 14Ga wire. Experience at the site indicates that ground screens made with 14 Ga galvanized wire (~2mm in diameter) can last for a long period in the LWA environment.

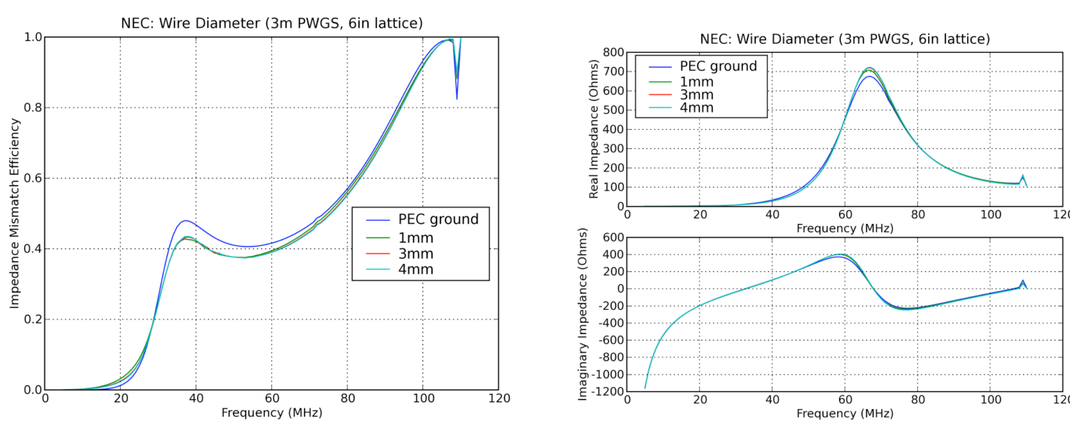


Figure 7: The antenna IME (left), and impedance (right) versus frequency for several ground screen wire diameters.

Tolerances:

As pointed out above, the simulations show that in order to get a significant change in the impedances one needs to make large changes to the set of ground screen parameters chosen here. Keeping this in mind we suggest that tolerances of 10% in the ground screen size should not make a significant difference to the performance. In the case of the mesh density, one can go up or down a couple of inches (2"X2" or 6"X6"), in case some cheaper equivalent product is found, without incurring a significant change to the properties of the system. In the case of the wire diameter we recommend that one should not go thinner than 14 Ga. Experience at the site indicates that anything thinner will be easily bent and may even break, which is not desirable for a ground screen.

Conclusion

Our simulations show that the ground screen performance is not significantly affected by the width of the wires they are made. The best performance, compared to PEC ground, is obtained for ground screens of 3x3 or 5X5m. As for the mesh density, there is not a lot of difference for lattice sizes between 1" and 10". We recommend using postage stamp ground screens with a dimension of 3X3m, with lattice sizes of 4"X4", made with 14Ga galvanized wire.

LWA Engineering Memo GND0006
Quotes for Ground Screen Material Custom Materials

June 19, 2008

Henrique R. Schmitt (NRL/Interferometrics Inc.)

Summary

This memo lists quotes for "custom" ground screen materials, with cell sizes of 4"X4", made with galvanized wire. We obtained quotes for materials that can be used for the antenna support as well as a lighter material that would require the antennas to have a different support structure. We considered only postage stamp ground screens.

Ground Screen NOT supporting antenna:

We found that Pennsylvania Wire Works produces rolls of welded utility "fabric" with cell sizes of 4"X4". This material is made of 14 ga (~2mm) galvanized wire and comes in rolls of 6'X200'. Each postage stamp would need 2 sections of 6'X10', overlapping them by 1', so we would need 26 rolls for 256 of them. At a cost of $120 per roll this option will cost $3,120 for one station. These numbers do not take into account the cost of transport and installation (cutting the rolls, stitching the sections together and anchoring them).

Ground Screen as a support structure for the antenna:

We got quotes from McNichols and Direct Metals for sheets of 6'X10', with cells of 4"X4", made of galvanized wire with a diameter of 0.162" (~4mm). We will need 2 sheets per postage stamp, overlapped by 1'. The price quoted by McNichols for 512 sheets is $65,975, while Direct Metals quotes $29,259 for 512 sheets made with 0.162" wire, or $21,752 in the case the sheets are made with 0.135" (3.4 mm) wire.

Comparison of designs:

In Table 1 we present the costs of the different postage stamp ground screen designs, per station and per stand. Based on the numbers presented in the Memo GND0002, we expect that we will need an extra $1,500 to connect the different sections together and anchor the postage stamps down. Notice that in the case of the design where the ground screen is not used to support the antenna we do not take into account the cost of the materials necessary to anchor the antennas to the ground.

Design	Manufac.	Cell Size	Sheet/Roll Size (ft)	No.	Wire	Cost Station ($)	Cost Stand ($)
PS- Sup	McNic.	4”X4”	6X10	512	4.1 mm	65,975	258
PS- Sup	Direct Met.	4”X4”	6X10	512	4.1 mm	29,259	114
PS- Sup	Direct Met.	4”X4”	6X10	512	3.4 mm	21,752	85
PS	PennWire	4”X4”	6X200	26	14 ga	3,120	12

Table 1: Comparison of the costs of different designs (PS- Sup = Postage Stamp used as support; PS= Postage Stamp NOT used for support). The costs per stand were rounded.

Connection Requirement for Two-Part Ground Screens

Ken Stewart

11 February 2009

Because there is no commercial source for 3-m wide wire mesh, the ground screens beneath the LWA antennas will need to be constructed from two separate pieces of the material. If two 6-ft wide sections are used to make a 3-m square ground screen, they will overlap by approximately 60 cm. This memo answers the question of how well the two sections need to be electrically connected to prevent degradation of the antenna performance.

I compared two different NEC-4 models:

1. The ground screen is a single 3-m square mesh.

2. The ground screen consists of two parts which overlap by 60 cm. One section is 1 or 2 cm above the other with varying numbers of electrical connections between the two.

In both cases the screens are made of 2 mm diameter wires in a 10 cm square mesh. Fig. 1 shows the NEC-4 model used to evaluate how well the two parts need to be connected.

Although this is a difficult situation to simulate accurately due to the many closely-spaced, parallel wires, the two-part ground screen models consistently have slightly higher gain (< 0.5 dB) than the single screen model regardless of the number or positions of electrical connections between the two sections. The shape of the pattern does not change: the 3-dB beam widths are identical in all simulations (Fig. 2). The small asymmetry visible in the figure is due to the necessity of modeling the left section of the ground screen at least 1 cm above the right section. It would not be present in the real case in which both sections would be lying directly on the soil. This result is consistent with lower ohmic losses due to doubling the number of conductors in the high current area below the feedpoint. The feedpoint impedance increases or decreases slightly depending on the frequency and the details of the model.

The differences between the two ground screen models are minor, and changes due to adding one or more connections between the sections of the two-part model are smaller still. Exact numerical values are not presented here because they are very sensitive to the details of the model. The separation between the two layers needs to be at least several times the diameter of the ground screen wires, so an accurate simulation of the real case in which the wires will be very close together and touching in many places is not possible.

The qualitative picture that emerges from many models with varying ground screen parameters is that good electrical connection between the screens seems to be unimportant for the electromagnetic performance of the antenna system. Therefore, I recommend that the number of physical connections be whatever is sufficient to ensure structural integrity of the ground screens while minimizing the labor involved.

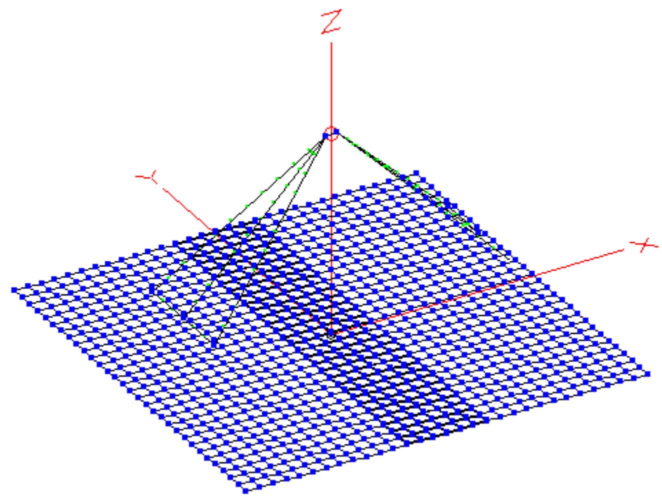


Figure 1: NEC model of antenna + two-part ground screen.

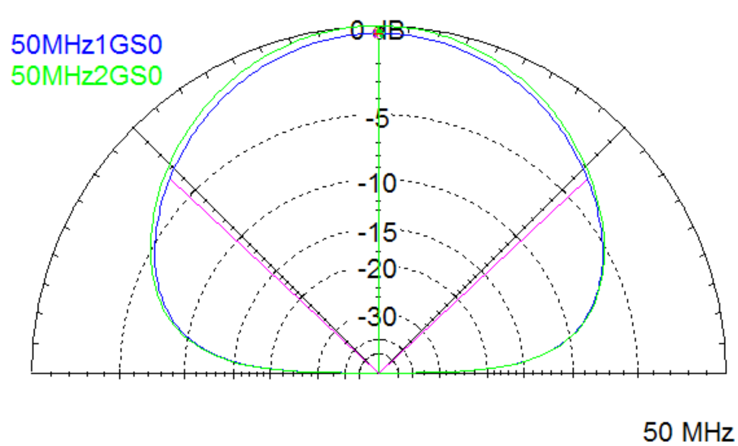


Figure 2: E-plane antenna response pattern: single ground screen (blue), two-part ground screen (green).

How to Fabricate Ground Screens for an LWA Station

Joe Craig, Steve Tremblay
10/14/09

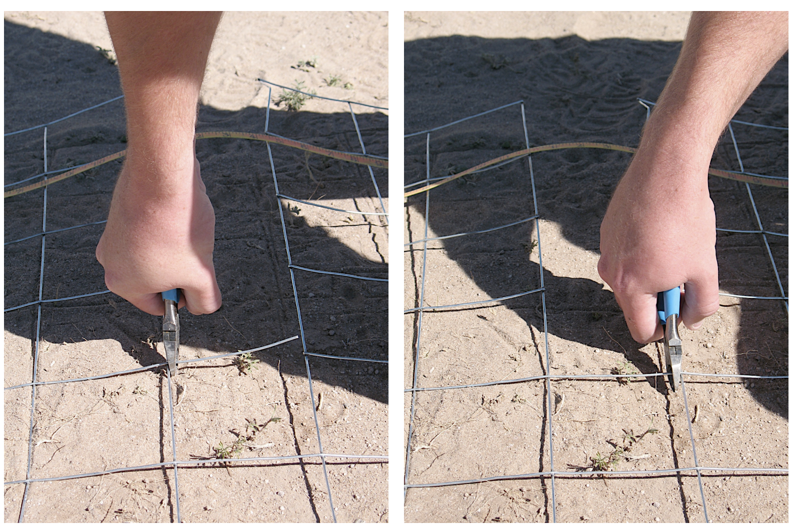
The ground screen material for an entire station is packaged in 27 rolls of 6 ft x 200 ft. Two rolls are overlapped by 2 ft to create 10 ft x 10 ft squares. The most efficient way of fabricating these 10 ft x 10 ft squares is to roll out two rolls, one overlapping the other by 2 ft as shown in figure 1.

Figure 1: Two 6 ft sections rolled out to overlap by 2 ft. A piece of wood was used to secure the ends and prevent the screen from rolling up.

It is important to keep count of the squares to make sure they overlap by 2 ft. A bit of straightening is required to get the squares to line up exactly (figure 2).

Figure 2: Lining up the squares for the overlap. It is very easy to jump squares and misalign the overlap.

Once the overlap is aligned, the screen can be cut into 10 ft sections. The recommended procedure is to cut out a full square so the screen won't have wire protruding from the edge. This is illustrated in figures 3 and 4.



Figures 3 and 4: Cutting out the wires for 10 ft pieces. Dykes were used, but bolt-cutters or similar are recommended.

6 nicopress splice sleeves are used for every 10 ft section. 2 sleeves are placed on each edge, one on each side of the overlap, and 2 in the middle on each side of the overlap. They are crimped with the tool shown in figure 5.

Figure 5: Nicopress tool used to crimp the sections together.

When each section is complete, it can be rolled easily and carried out to each antenna location (figure 6).

Figure 6: Carrying the rolled ground screen to the antenna location.