Elliptical LWA Station Configurations Optimized to Minimize Side Lobes.

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ABSTRACT

An elliptical station, elongated in the north-south axis to compensate for projected foreshortening for sources in the far north and far south, may be desirable to produce a more circular field of view over as much of the sky as possible (Clarke 2007). Here, we present elliptical station configurations that are each optimized to minimize sidelobes across the entire sky. Each design is characterized by the minimum allowed spacing between elements, and we used values of 3.5, 4.0 and 5.0 meters. Because the final size of the station is still not settled, we consider three possibilities for the major axis (100, 110 and 120m). With three possible sizes and three possible minimum element spacings, a total of nine potential station configurations are presented. Various properties of each design are examined including maximum sidelobe levels and phased-beam axis ratios. We find that the maximum side lobe increases with increased minimum spacings, while the effects of station size depend on the minimum dipole spacing. This side-lobe optimization does not take into account the effects of mutual coupling, which is far too computationally intensive to be feasible in the context of an iterative optimization scheme.

1. Overview

A circular design for the perimeter of an LWA station would produce a circular station beam at zenith, but off-zenith would be elongated in the azimuthal direction by a factor of $1/\cos(ZA)$ where ZA is the zenith angle. The elongation is minor at low zenith angles, but close to the horizon it can be quite large. The regions of the sky where it is most critical to observe near the horizon are towards the north and south. The north because sources near the celestial north pole never "leave" that region from our vantage point. The south because sources at far southern declinations only reach a high enough elevation above the horizon when they are near transit, which is always toward the south from the LWA site. Any source near the horizon at the east or west will reach a much higher elevation at some point in the day.

For this reason, we concentrate on the station beam shape along the north-south azimuth or, in other words, as a function of source declination when a source is at its transit. In Figure 1 we plot the phased-beam axis ratio (the ratio of the major axis to the minor axis of the station beam ellipse) at transit for a circular station as a function of source declination for the range of

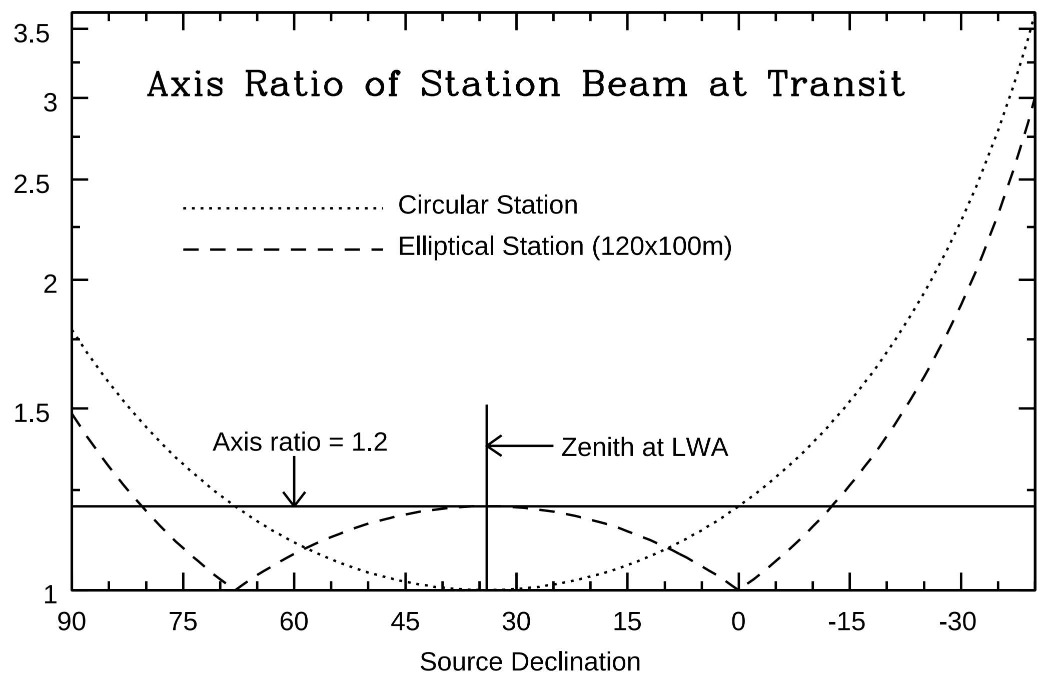

Fig. 1.— Axis ratio of station beam at transit as a function of declination for a circular and elliptical (axis ratio = 1.2) station design. The elongation is in the north-south direction everywhere except for the mid-declination region for the elliptical station which would have a station beam that is elongated in the east-west direction.

declinations visible from the LWA site. The LWA will be located near the VLA with a latitude of about 34°N. Only sources at a declination of $\delta = +34^\circ$ reach zenith, the only location where the station beam is circular (axis ratio = 1). The axis ratio increases from there and becomes especially high at the far southern declinations.

The latest science requirements (Clarke 2007) suggest a station shape that is elongated in the north-south direction so that the station beam would become circular at the celestial equator rather than at zenith. Rather than a circular design with axis ratio of 1, this would require a station axis ratio of roughly 1.2 (a factor of $1/\cos 34^\circ$). The phased-beam axis ratio for the elliptical station is also plotted in Figure 1 as a function of source declination. By symmetry this design produces a circular beam both at the celestial equator and at declination $\delta = +68^\circ$. At $\delta = +34^\circ$ (zenith) the axis ratio is larger than for a circular beam because there the elliptical station produces a station beam that is elongated east-west by a factor of 1.2.

The advantage of this design is seen in Figure 1. A low station beam axis ratio (closer to circular ratio of 1) is desired to produce a roughly symmetric a field of view. While the circular design gives a more circular station beam for the middle declinations (from about $+10 < \delta < +58$), the elliptical design produces a more circular beam outside that region. More importantly, the elliptical design has a lower axis ratio in the *difficult* places, where the axis ratio is high enough to become difficult. Where the circular design performs better, the elliptical design never has an axis ratio greater than 1.2, which is still manageable. Quantitatively, the circular design has an axis ratio less than 1.2 between $+0 < \delta < +68$, while the elliptical design achieves this for the larger region of $-12.6 < \delta < +80.6$, which is a full 30% more solid angle of sky. In addition to having a roughly symmetrical station beam throughout a larger region of the sky, the elliptical design also has a better axis ratio everywhere outside this region, including the difficult southern region.

We caution that this study is done only for sources at transit. Before proceeding with an elliptical design, it may be instructive to consider the relative costs and benefits in the case of full earth-rotation synthesis images, possibly with time-variable weighting schemes designed to keep a constant beam size as astronomical sources are tracked across the sky.

Ideally, we would produce an axis ratio of 1.2 by simply expanding the north-south axis from 100m to 120m resulting in a 120m$\times$100m ellipse. However it isn't clear that the stations can be made that big. Therefore, we consider smaller stations that would fit within the original station footprint while maintaining the axis ratio of 1.2. With the original 120m$\times$120m fence, and a 10m distance from the fence to any dipoles, the largest possible elliptical station would have outer dimensions of 100m$\times$83m. If, within this same fence, it is deemed safe to place dipoles within 5 meters of the fence, a 110m$\times$92m station would be feasible. We consider all three possible station sized in this report.

2. Optimizing for an elliptical geometry

Previously, LWA station designs have been optimized to minimize the maximum sidelobe level throughout the visible sky according to the iterative approach described in (Kogan 2000). This had been produced for a 256-element, circular, 100m$\times$100m station (Kogan & Cohen 2005). To create an elliptical station one could simply "stretch" or "compress" this station design along each axis by the amount needed to result in a north-south axis ratio of 1.2 with the desired major axis. A "stretched" or "compressed" station would still be optimized for low sidelobes because its power pattern on the sky would just be linearly compressed or expanded, respectively. However, a "stretched" station axis would no longer result in a power pattern that is optimized over the entire sky, because the power pattern would now be compressed in the north-south axis, and so the optimized region would then be smaller than the visible sky. Also, the minimum spacings would be larger in the north-south direction than along the east-west direction, which would not optimally use the space available within the station ellipse. A "compressed" station axis would still be optimized over the whole sky, but could result in minimum spacings that are too small.

Therefore we have repeated the station optimization for each case of elliptical station geometry considered, as described in Section 1. For an array phased to zenith, the optimization should minimize sidelobes all the way to the horizons by optimizing in a circle defined by the radius

$|\sin(ZA)| \leq 1$, where ZA is the zenith angle. However, in typical observing mode, LWA stations could be phased to any location above the horizon, and the sidelobes should still be optimized anywhere else above the horizon. As describe in Kogan & Cohen (2005), this can still be done with a zenith pointing provided that the optimization radius is doubled. Therefore we have conducted all optimization within the radius of $|\sin(ZA)| \leq 2$. Though counterintuitive, this is mathematically equivalent to optimizing in the normal radius $|\sin(ZA)| \leq 1$ for any pointing above the horizon.

The optimization begins with 256 elements arranged in a roughly hexagonal pattern covering the station area. An iterative process causes elements to gradually "move" so as to lower the peak sidelobe in the optimization region. The movement of the elements is restricted not only to the station area, but also by a minimum allowable separation distance between the elements. This is set not only because of the physical size of the antenna elements, but also to (hopefully) minimize mutual coupling effects. Therefore we consider a minimum spacing of 3.5 meters, the smallest allowable given the probably size of the antenna elements. However, it may be desirable to have larger minimum spacings to reduce the effects of mutual coupling. Therefore we optimized for two other minimum spacings of 4.0 meters and then 5.0 meters. In this report, we consider these three possible minimum spacings, each within three different station sizes of 120m×100m, 110m×92m, and 100m×83m. That results in a total of nine possible stations. Henceforth, we will describe each station by its minimum spacing, S, and its major axis, D. (Example: a $D = 110$m, $S = 5$m station would be the one with outer dimensions of 110m×92m and minimum dipole spacings of 5.0m.)

3. Resulting Configurations

The station configuration for each major axis, D, and minimum dipole spacing, S, were optimized separately. The optimization was performed in the usual iterative fashion until the maximum sidelobe levels stopped decreasing. At that point a "final" configuration was determined for that (D, S) combination. The resulting configurations for each of the nine cases are shown in Figure 2. These are also available in ASCII format on the LWA memo series website[1]. The maximum sidelobe levels achieved for each (D, S) combination are listed in Table 1. Figure 3 shows an example power pattern plot for the $(D, S) = (110\text{m}, 4.0\text{m})$ station. This plot demonstrates that within the optimized region of $|\sin(ZA)| \leq 2$, there are no sidelobes higher than the stated maximum of 1.45% for this station (Table 1). Outside that region the sidelobes are generally higher.

As Table 1 demonstrates, for any given major axis, D, the sidelobes decrease with smaller minimum dipoles spacings, S. This is because relaxing the minimum dipole spacing requirement allows more freedom of movement for the dipole placement and therefore greater ability to produce non-redundant baselines. This can be seen in the station configurations shown in Figure 2, where for smaller D and larger S the freedom of dipole placement is limited resulting in more a more

[1]http://www.ece.vt.edu/swe/lwa/#VTR

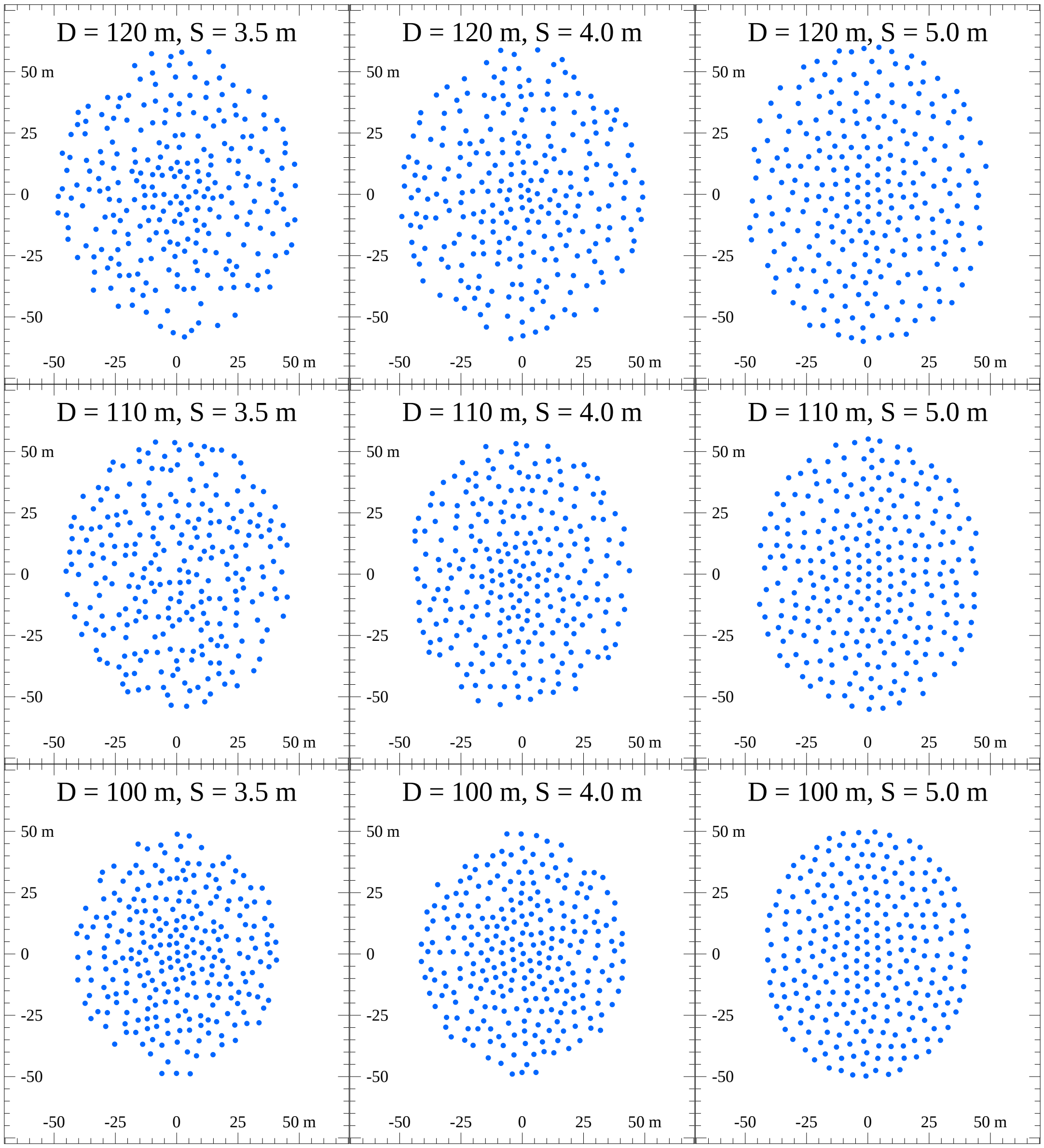

Fig. 2.— Elliptical station designs with 256 elements optimized to minimize sidelobes across the entire sky at 80 MHz. Three sizes are considered (120m×100m, 110m×92m, and 100m×83m) and each plot is labeled with the major axis, D. For each station size, three different minimum dipole spacings, S, are considered (3.5m, 4.0m, and 5.0m).

regular pattern and therefore more redundant baselines. For a given minimum spacing, S, the dependence on the station major axis, D, is more complicated. For S = 3.5m or 4.0m, there is a slight increase in sidelobe levels for larger station size. For S = 5.0m there is a much larger decrease in sidelobes with larger station size. This is because there are two, conflicting, effects

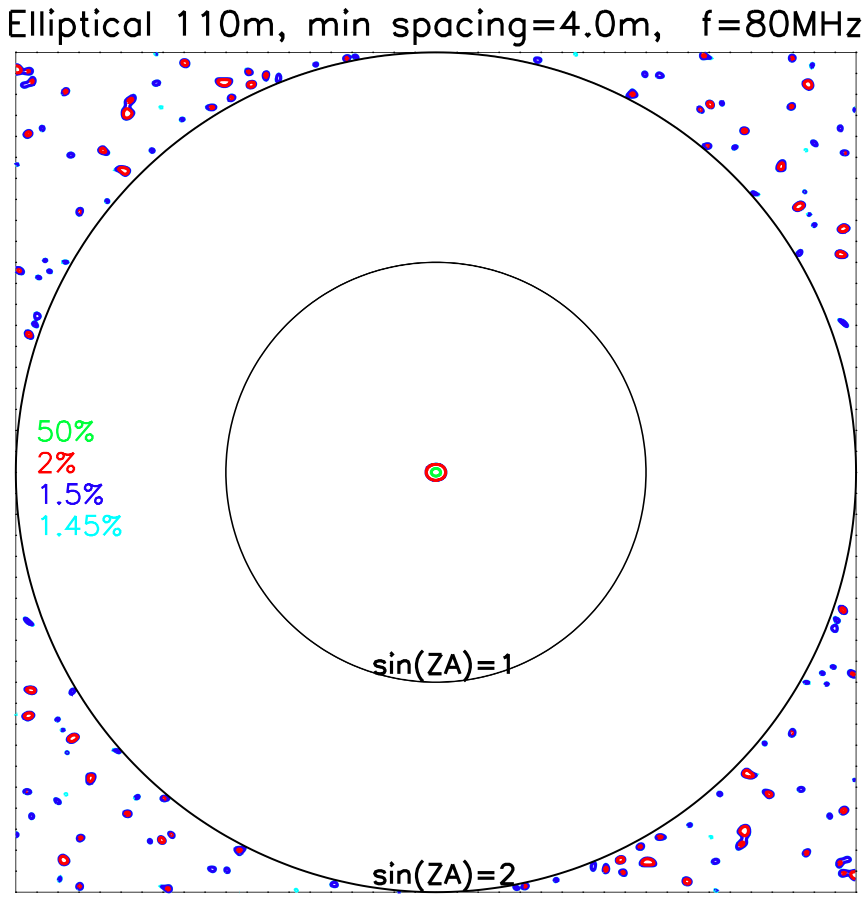

Fig. 3.— Power pattern of the elliptical station with $S = 4$m and $D = 110$m. Optimization was done to a radius of sin(ZA) = 2 at 80 MHz. Within this radius, the sidelobes have been optimized so that none are greater than 1.45% of the central beam.

associated with station size. First, as the station size increases, the effective size of the sky, in units of phased-array beam size, increases. An increased area to optimize makes the optimization less effective and the sidelobes increase. Second, as station size increases, there is more freedom of movement of the dipoles for the same minimum spacing, S. That improves the optimization and lowers sidelobes. For the $S = 5$m stations the latter effect was dominant, presumably because the large minimum spacings make freedom of movement the most important factor. For $S = 3.5$m and 4.0m, the freedom of movement is not so restricted, and here effect of sky becomes slightly more important.

While the axis ratio of the outer boundary of each station is fixed at 1.2, this is not necessarily the axis ratio of the phased beam at zenith, which depends not only on the outer boundary, but the distribution of dipoles within that boundary. While the phased beam also starts off with the desired axis ratio of 1.2, this has been found to "drift" during the optimization process. We are currently

Table 1: Maximum sidelobe levels for each station configuration (percent).

Minimum Spacing (S)	Major Axis (D) 100m	110m	120m
3.5m	1.34%	1.41%	1.44%
4.0m	1.44%	1.45%	1.47%
5.0m	2.04%	1.62%	1.55%

Table 2: Axis ratio of the phased-array beam at zenith for each station configuration.

Minimum Spacing (S)	Major Axis (D) 100m	110m	120m
3.5m	1.114	1.189	1.100
4.0m	1.124	1.225	1.124
5.0m	1.238	1.220	1.256

attempting to address this issue for future simulations. However, for now we simply report the actual simulated phased beam axis ratios for each configuration in Table 2.

4. Discussion

Which configuration should be used depends on factors beyond the scope of this report. The overall science goals will dictate whether to use the elliptical stations to improve imaging of far southern and northern sources, even though the performance for the mid-declination region might be degraded somewhat. Also practical concerns will dictate the final size of the station.

Perhaps the most important unknown is the issue of mutual coupling. It remains to be seen if mutual coupling effects are great enough to cause the sidelobe patterns to differ significantly from those presented in this report. While a larger minimum spacing results in higher sidelobes, it may also result in less mutual coupling.

Calculating the effects of mutual coupling on the power pattern of a single configuration takes considerable computing time. Therefore, it does not seem feasible to adapt the current iterative optimization scheme to take mutual coupling into account. This is because it can take thousands of iterations to create an optimized station and the power pattern must be calculated for each iteration.

What may be feasible is to test the effects of mutual coupling on the power pattern on the final station configurations from regular optimization. That will determine if the effect is significant and, if so, how much improvement remains over a simple random configuration. Also, if mutual coupling is, for example, less significant for the 5.0m station than for the 3.5m or 4.0m stations, it may turn out that the 5.0m station actually has the lowest maximum sidelobes once mutual coupling is included. The configurations presented in this report are meant as the starting point for such future studies.

REFERENCES

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