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Which 128 Elements For LWDA Phase 1?

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ABSTRACT

The positions of elements in the Long Wavelength Development Array (LWDA) will be the same as the elements in a full Long Wavelength Array (LWA) station, however Phase 1 of the LWDA will consist of only 128 elements. Which of the 256 elements should be included in LWDA Phase 1? This is the question addressed here.

1. Introduction

The configuration of the 256 elements in a LWA station was studied in my report "Station Configuration Studies III". The elements of the LWDA will be arranged as in a LWA station, but the LWDA will be built in 2 phases. Phase 1 of the LWDA (LWDA-1) will consist of only half the elements. This raises the question, which 128 of the 256 elements should be built first? This question cannot be answered without first choosing a figure of merit to judge configurations. Given that the 256 elements of the LWA were configured to minimize the peak sidelobe level, I choose the peak sidelobe of the 128 element configuration as the figure of merit to minimize. The question then becomes, which group of 128 elements has the lowest peak sidelobe?

Removing elements from the configuration increases the amount of power in the sidelobes. The ideal solution would put an equal amount of power into each individual lobe. The ideal case is unlikely to be achieved because the configuration was not optimized for 128 elements. The best solution in practice will be one that distributes power evenly to as many lobes as possible. There are $\approx 6 \times 10^{75}$ unique ways of choosing 128 elements from a 256 element set. In theory one of these possibilities has a peak sidelobe lower than the rest, but to test each possibility in a realistic period of time is an intractable problem. Nevertheless, algorithmic approaches can be taken to find good solutions, with the caveat that there is no guarantee any of the solutions found will be the theoretical best solution.

I approach the problem in two ways. The first approach is to start with all 256 elements and test the removal of each element one at a time (with replacement). When all elements have been tested, the element which gave the lowest peak sidelobe when it was removed is permanently excluded and the process repeated until only 128 elements remain. My second approach to the problem is to first randomly remove 128 elements and then try swapping each of the eliminated elements with one of the remaining. Swaps that lower the peak sidelobe are kept and the process repeats until all possible swaps have been tested. This approach is similar to the simulated annealing type algorithms developed for traveling salesman problems.

Solutions are compared against a sample of configurations whose elements were chosen randomly. Both approaches to the problem are found to give solutions whose peak lobes are within a few tenths of a dB, and significantly better than any of the randomly chosen sets. In section 4 metrics plots are given comparing the best 128 element configuration to the full 256 element station.

2. Random Sample

A sample of 5000 sets of 128 elements chosen randomly from the 256 element set was created for statistical comparisons. The peak sidelobe of each set was calculated and is shown in Figure 1. The peak sidelobes were also sorted into bins and Figure 2 shows the resulting histogram. The sample has an average peak sidelobe of -11.25 dB with a standard deviation of 0.46 dB. The distribution also has a skew with more points at higher values. This is understandable because there are more configurations that put large amounts of power into a few lobes than configurations that put small amounts of power into many lobes.

3. Results From Algorithms

The final result from the "one-by-one" removing algorithm had a peak sidelobe of -13.2 dB. Four runs of the simulated annealing-type algorithm resulted in -13.3, -13.3, -13.1, and -13.3 dB. There is a close agreement between both algorithms and between multiple runs of the same algorithm. Therefore, I pick one of the solutions with -13.3 dB as the final design for LWDA-1. This set is 4.4 standard deviations below the mean of the random sample and 0.8 dB below the lowest set of that sample. The layout is shown in Figure 3 and its power pattern in Figure 4. For reference, the full 256 element station has a peak sidelobe of -17.7 dB and its layout and power pattern are shown in Figures 5 and 6. Refer to "Station Configuration Studies III" for a discussion of the coordinate systems used in the plots.

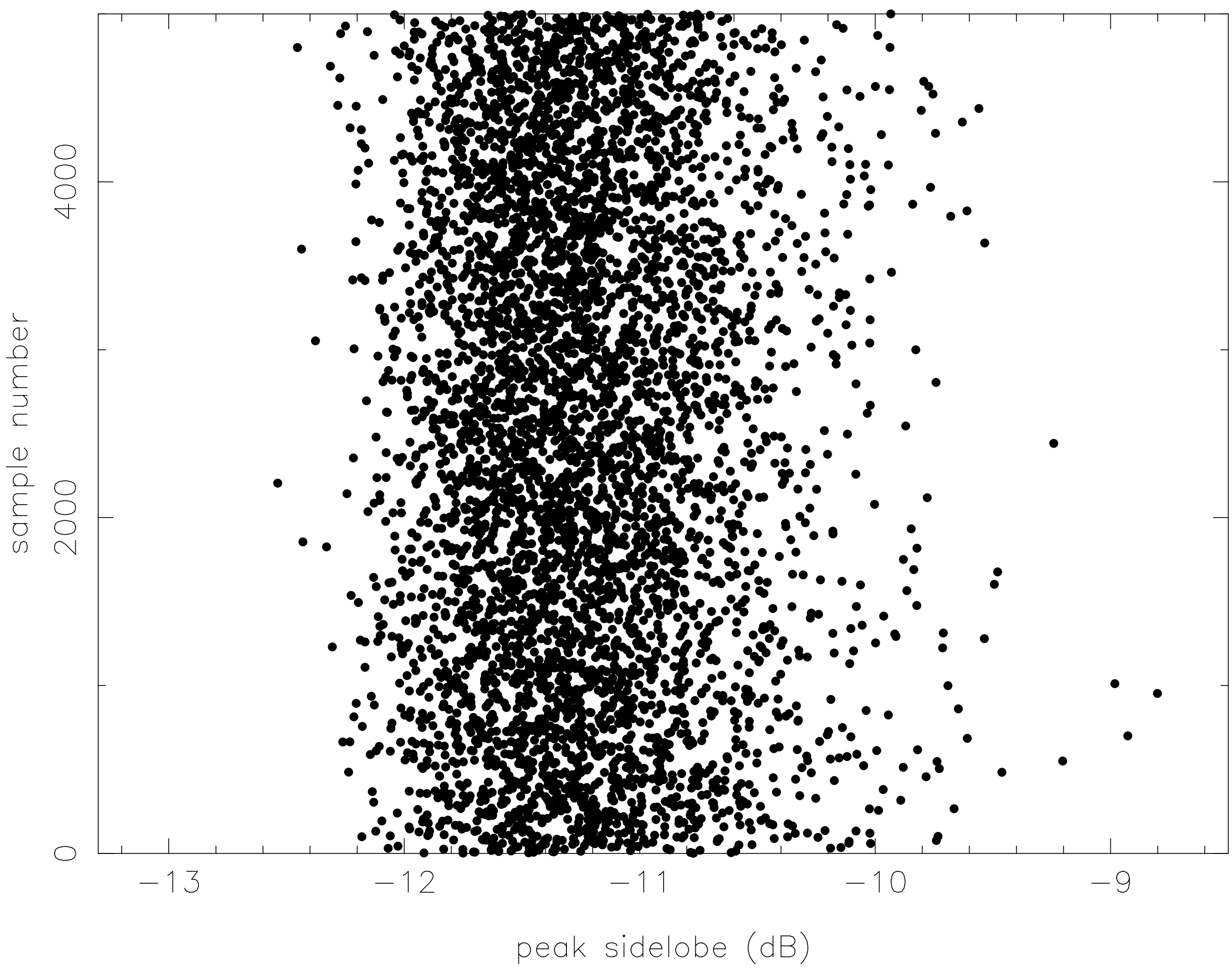

Fig. 1.— The peak sidelobes for a sample of 5000 sets of 128 elements chosen randomly from the 256 element set. The lowest set in the sample has a peak lobe of -12.5 dB.

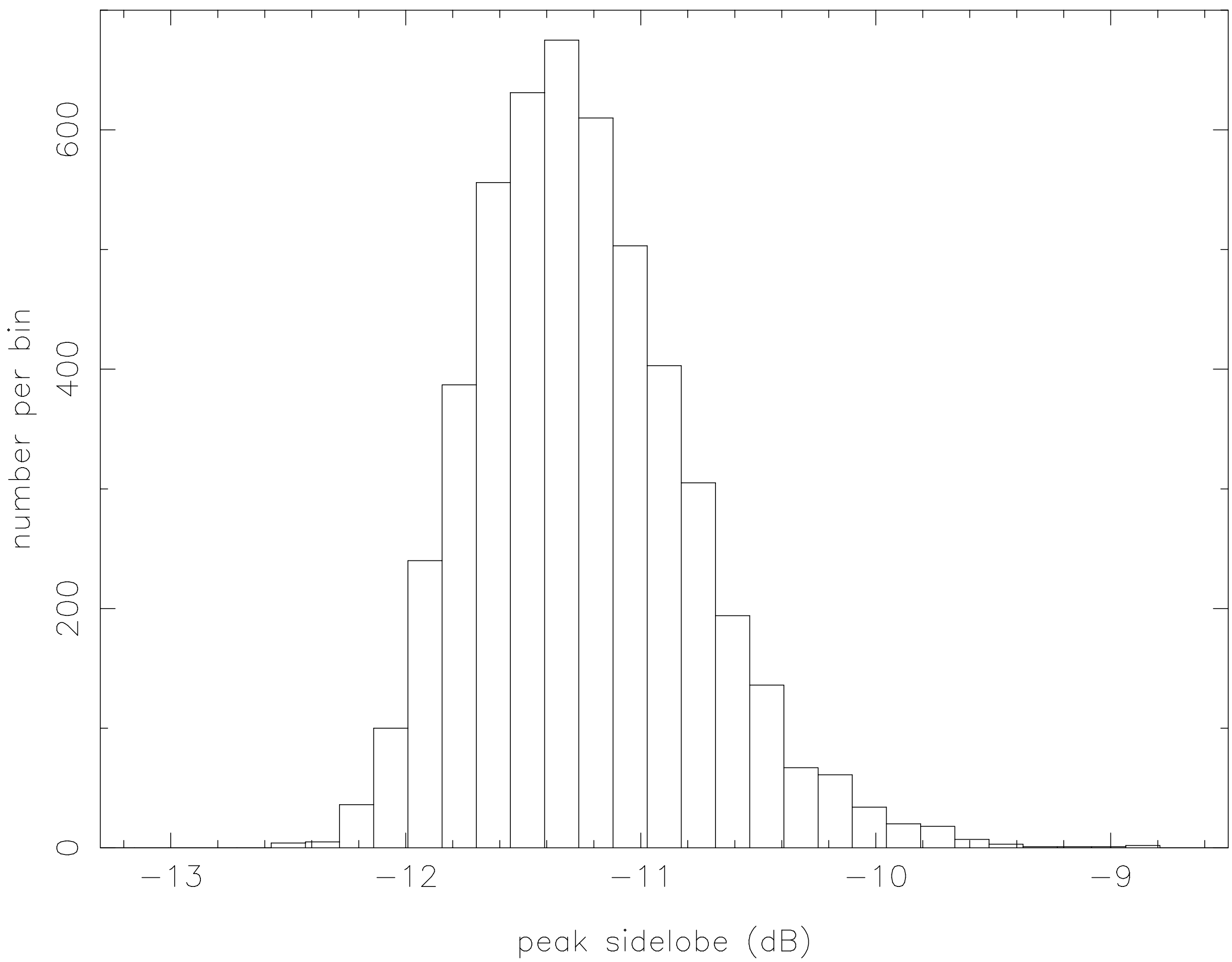

Fig. 2.— The sample when sorted into bins. The average is -11.25 dB with a standard deviation of 0.46 dB.

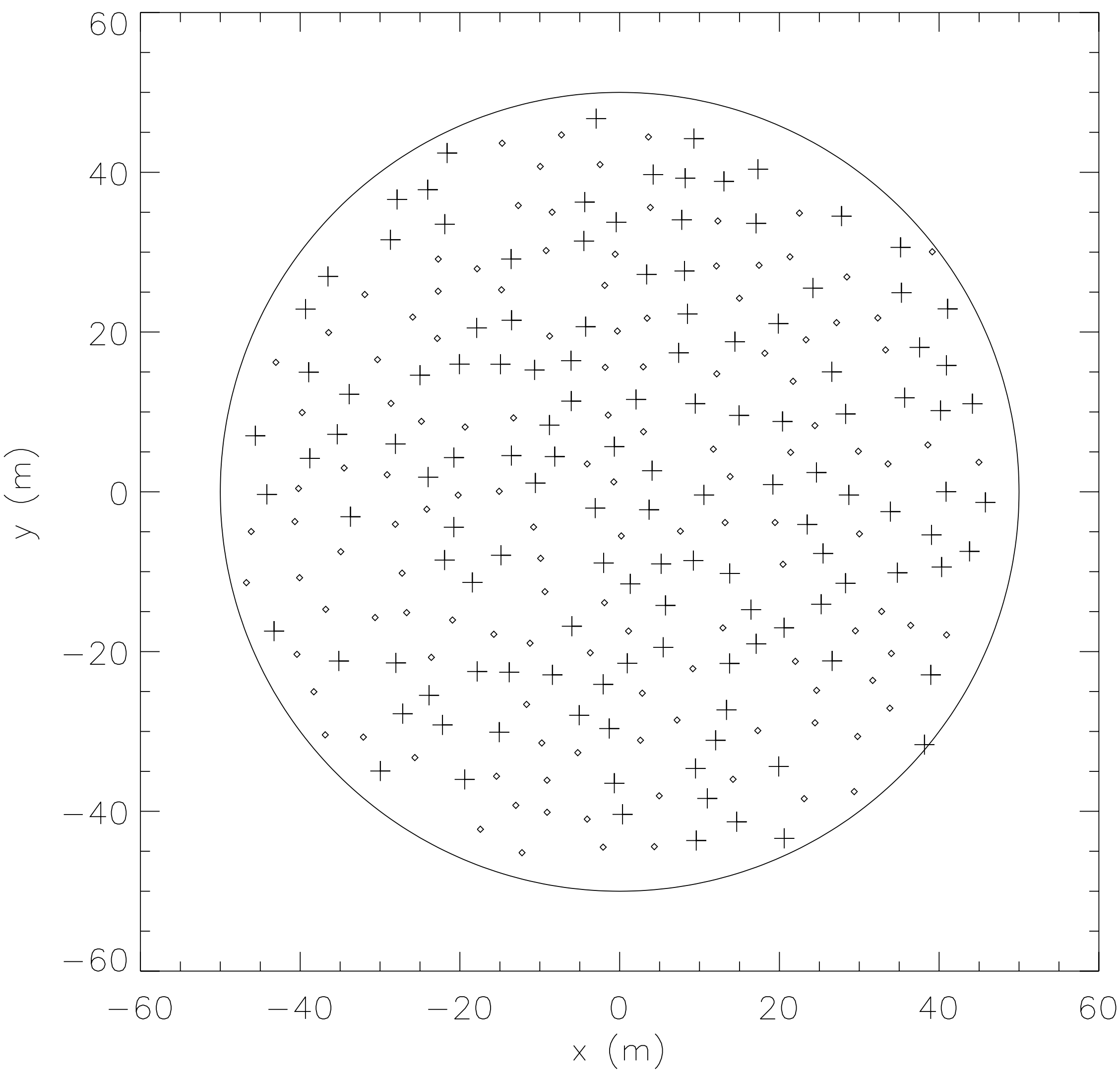

Fig. 3.— Layout of the LWDA Phase 1. Crosses represent elements with antennas, open diamonds represent empty post holes.

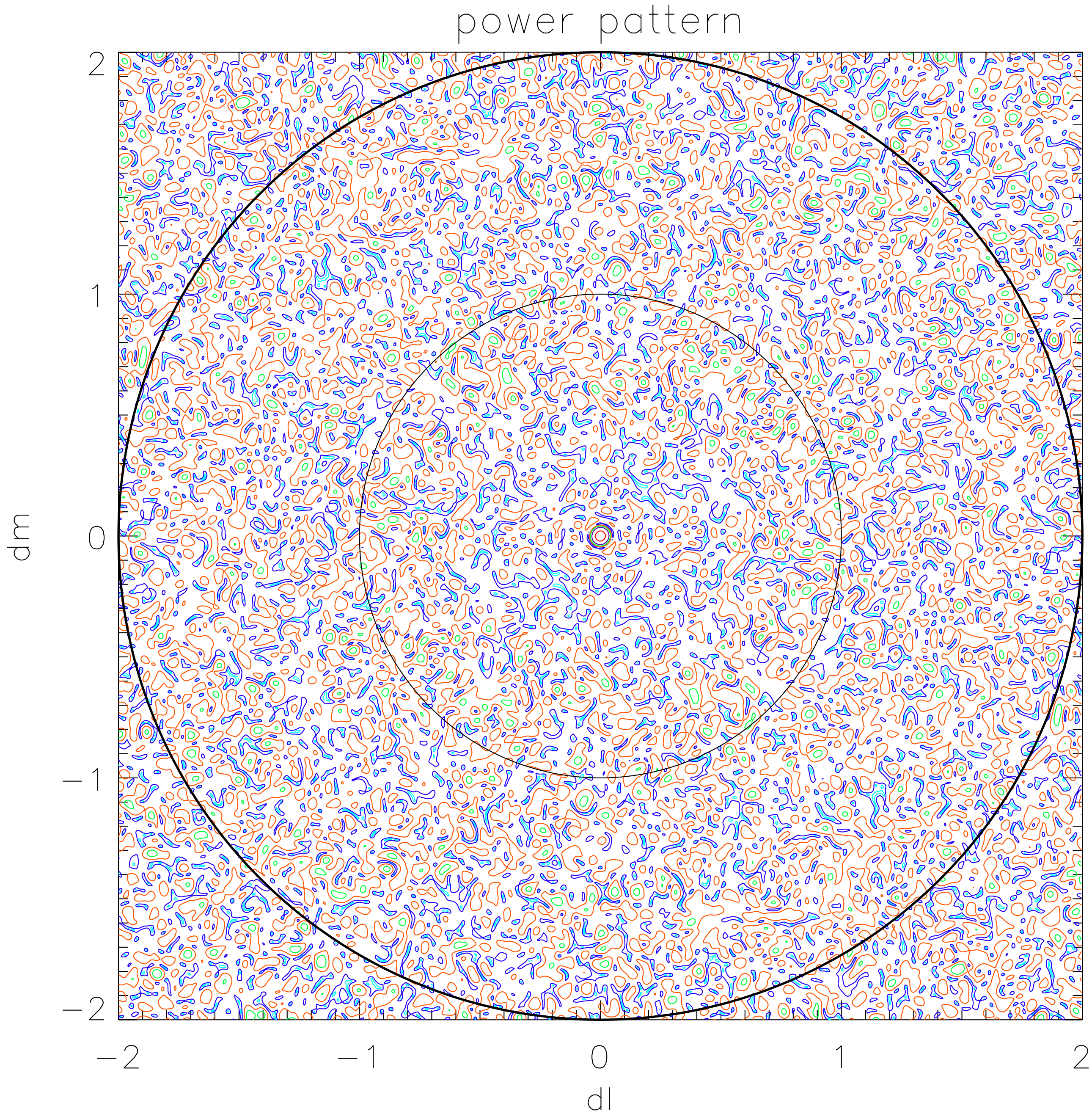

Fig. 4.— Power pattern of the 128 element LWDA-1 at 80 MHz calculated in parameter space. The peak sidelobe level is -13.3 dB. Light blue = -40 dB, Dark blue = -30 dB, Orange = -20 dB, Green = -15 dB, Purple = -10 dB, Red = -3 dB

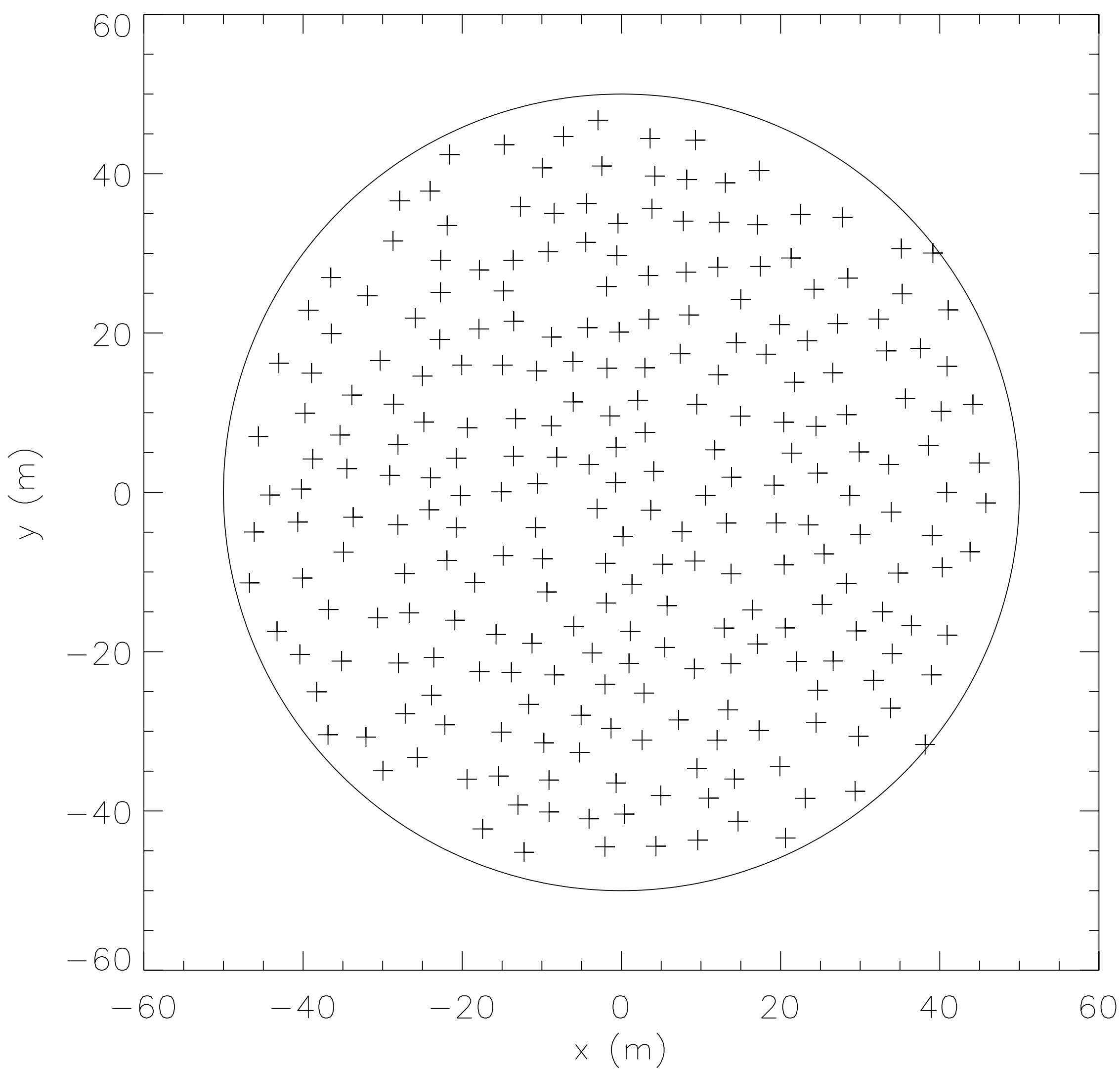

Fig. 5.— The full, 256 element, LWA station.

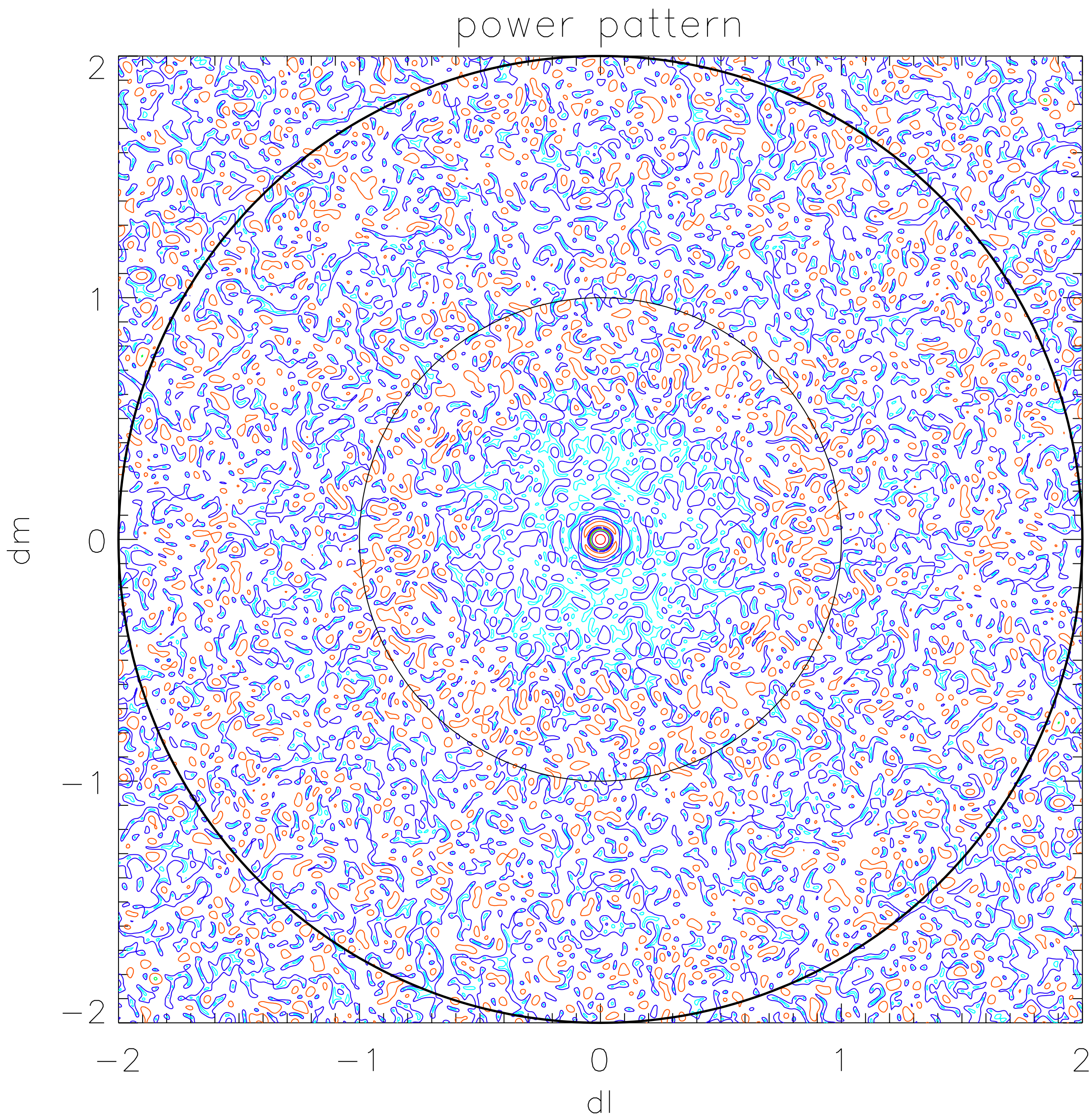

Fig. 6.— Power pattern of the full 256 element LWA station at 80 MHz. The peak sidelobe level is -17.7 dB. Light blue = -40 dB, Dark blue = -30 dB, Orange = -20 dB, Green = -15 dB, Purple = -10 dB, Red = -3 dB

4. Metrics

Plots of the metrics for the LWA and LWDA-1 are shown in the following figures. The **LWA** is plotted in **black** and the **LWDA-1** in **red**. The plots are shown with emphasis on the frequency range of the LWDA-1 (60-80 MHz). Refer to my "Station Configuration Studies III" for definitions of the metrics. It is important to remember the metrics are calculated assuming isotropic dipoles. The antennas actually used will not be isotropic. These metric plots are for comparative purposes and not meant to be taken as literal theoretical predictions for the LWA or LWDA-1.

Figures 7, 8, & 9 show the beam size and ellipticity of the LWA and LWDA-1 at three different pointing elevations. At all elevations the beam size and shape of the LWDA-1 are nearly identical to those of the LWA. This indicates elements were not preferentially removed from the inner or outer parts of the station but were removed uniformly across the area of the station.

Figure 10 shows the peak sidelobe level for both stations pointed at the horizon. The plots are similar for higher pointing elevations and thus not shown. The peak sidelobe level is constant for both stations over the frequency range. Reducing the number of elements by a factor of 2 has increased the peak sidelobe level by a factor of 2.75.

Figures 11 through 14 show the integration of the power pattern over various parts of the sky and the metrics that depend on these integrals (i.e. effective area, beam and aperture efficiencies). At all elevation angles reducing the number of elements by a factor of 2 has increased the sidelobe sky integral by a factor of 2. The solid angle of the main beam is about the same for both stations and makes a minor contribution to the all-sky integral of the power pattern. The all-sky integral is dominated by the sidelobes, hence the effective area and beam and aperture efficiencies are all decreased by factors of 2.

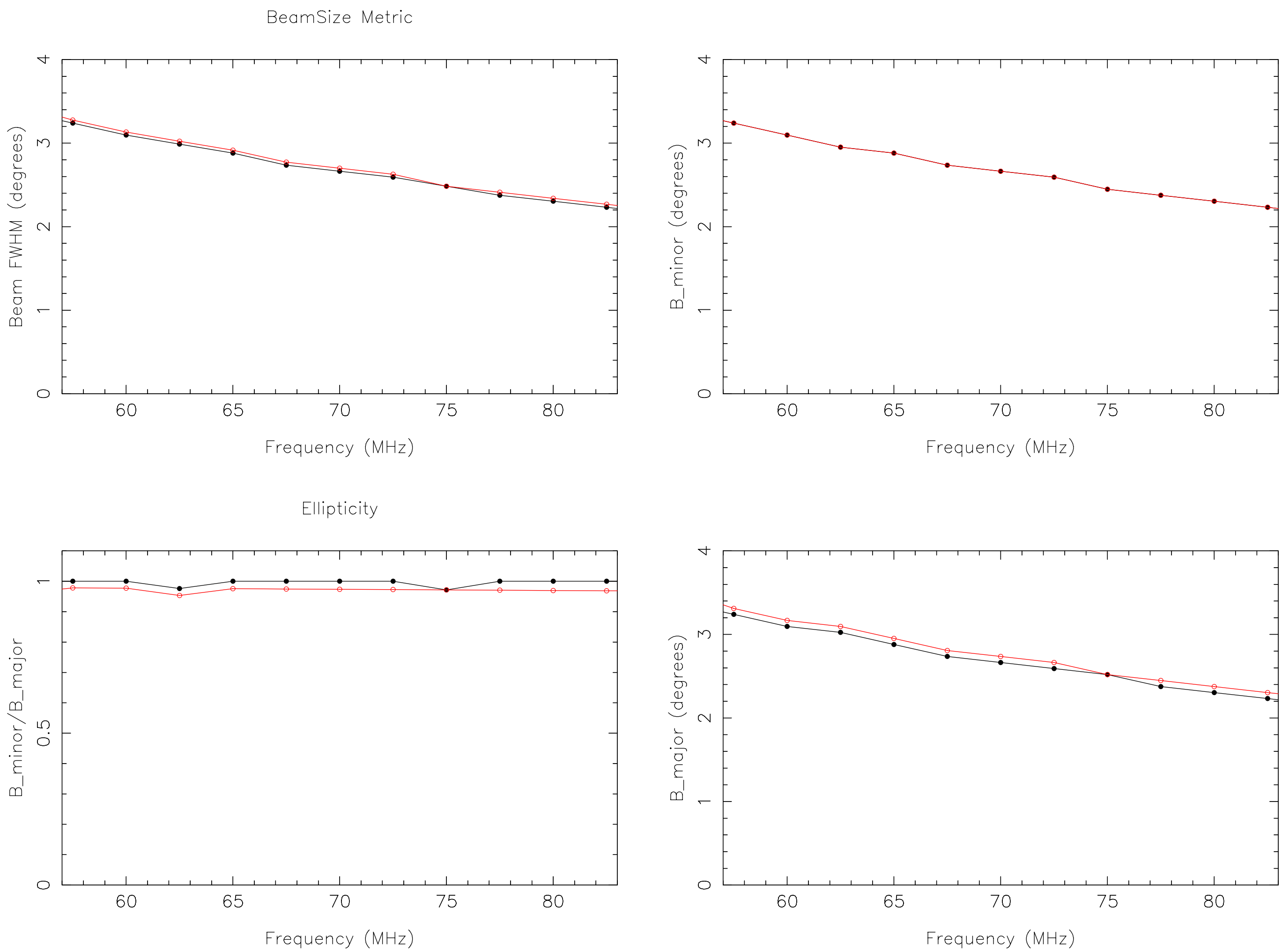

Fig. 7.— Beam Size and Ellipticity, main beam pointed at zenith. The size and shape of the main beam for the LWDA-1 is nearly the same as that for the LWA indicating elements have been excluded uniformly across the area of the station.

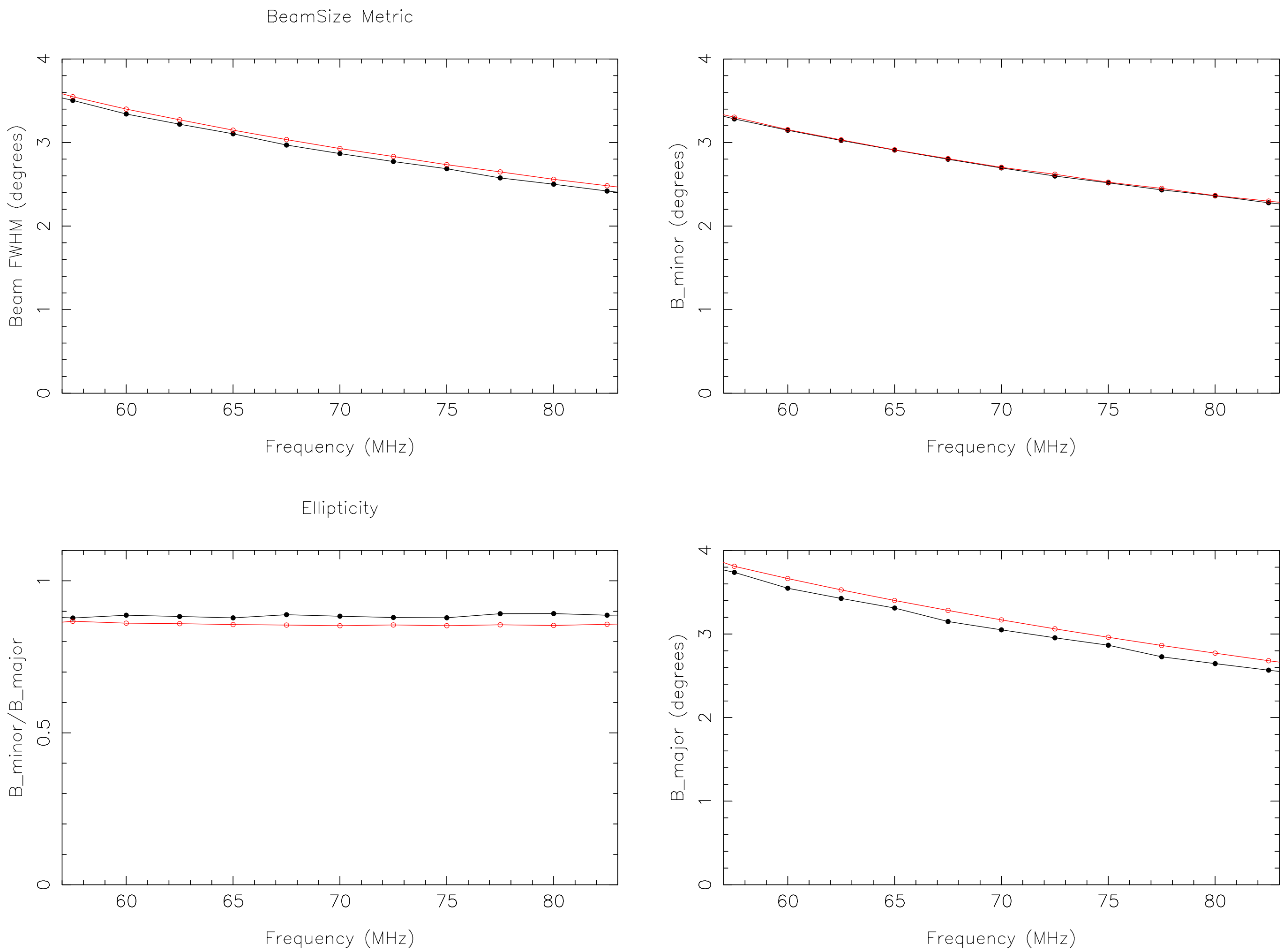

Fig. 8.— Beam Size and Ellipticity, main beam pointed at azimuth = 0°, elevation = 60°.

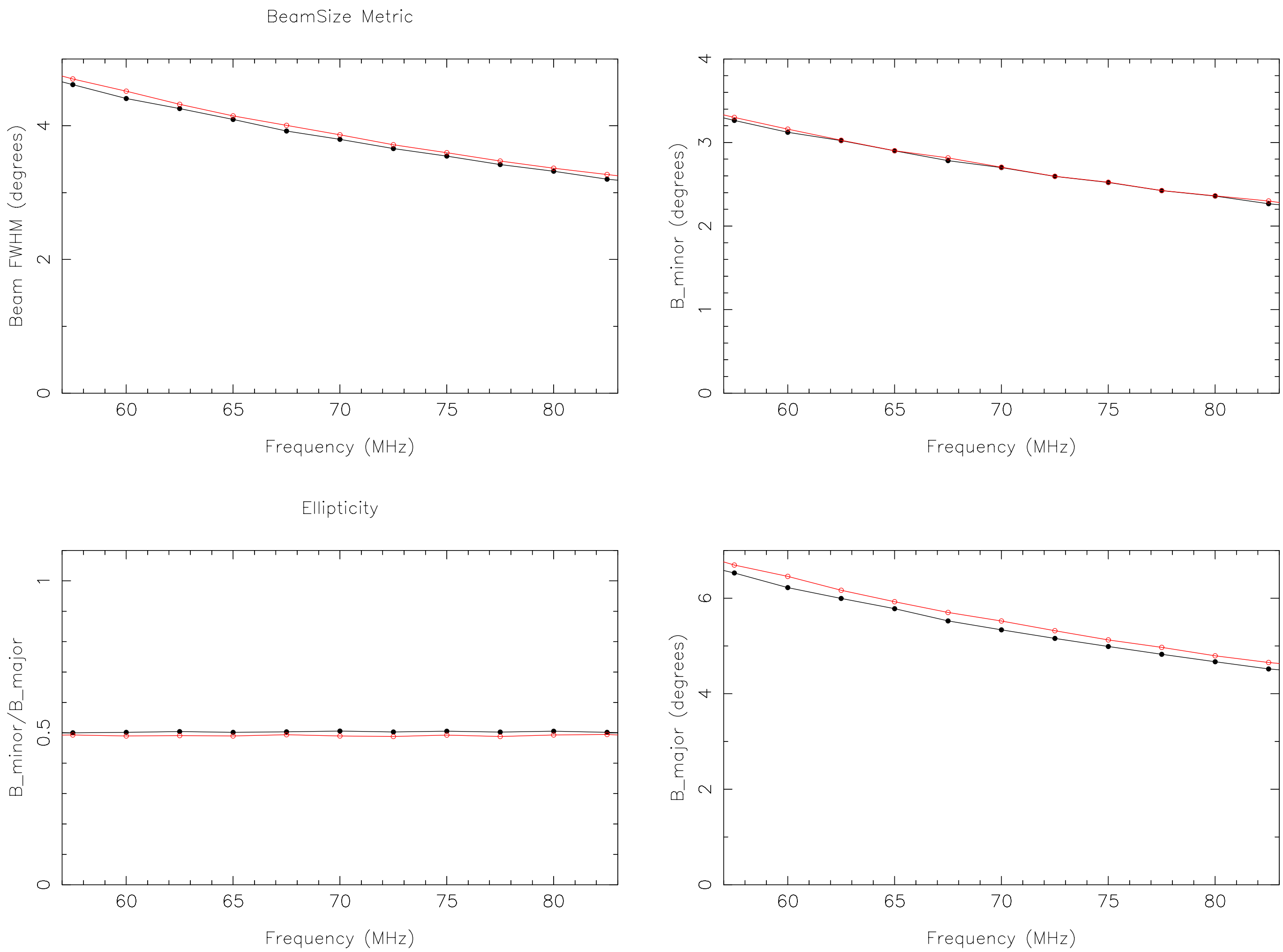

Fig. 9.— Beam Size and Ellipticity, main beam pointed at azimuth = 0°, elevation = 30°.

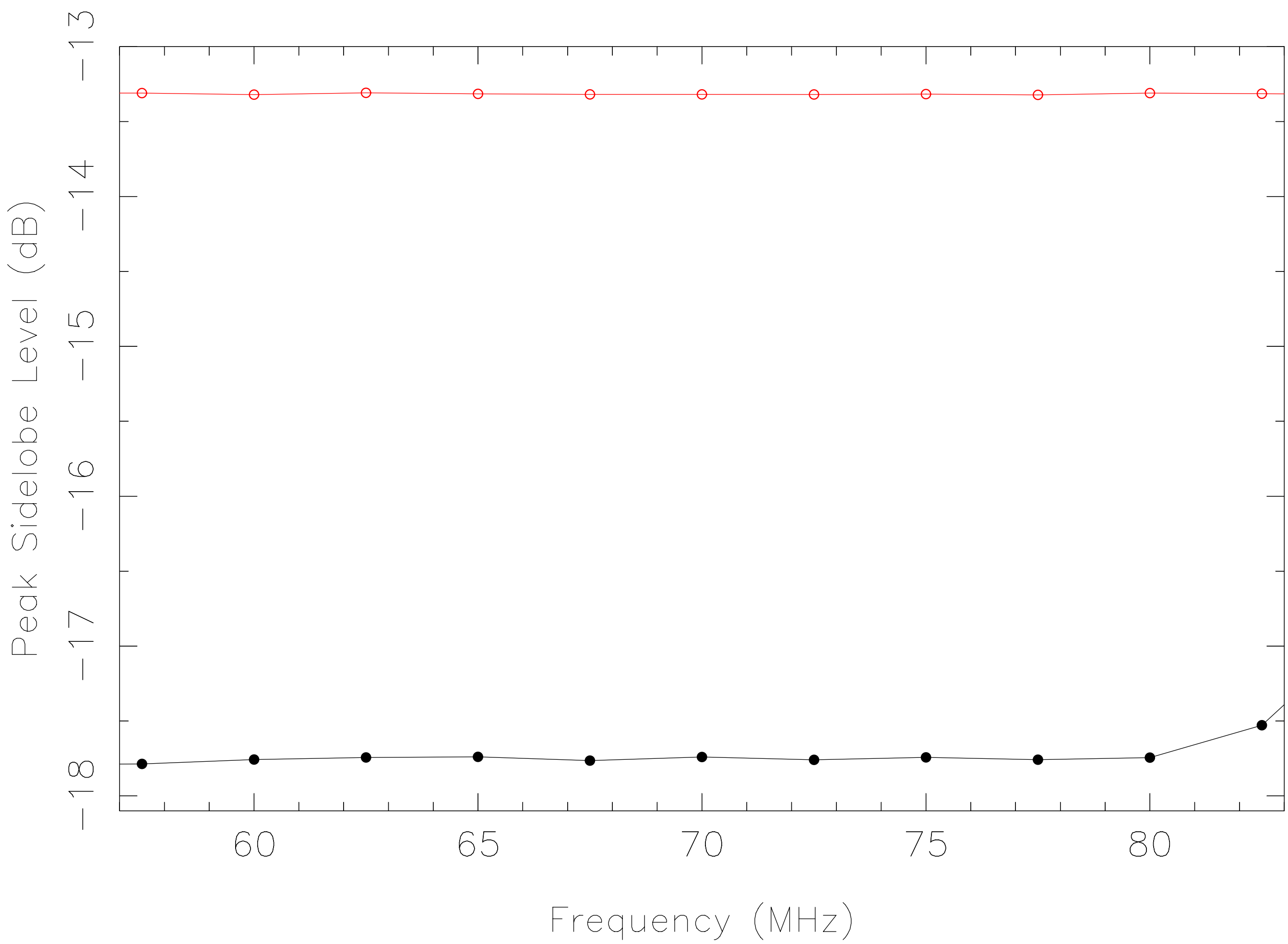

Fig. 10.— Peak sidelobe, main beam pointed at azimuth = 0°, elevation = 0°. The peak sidelobe of the LWDA-1 is 4.4 dB higher than the LWA. The LWDA-1 has half as many dipoles as the LWA but a 2.75 times higher peak sidelobe level.

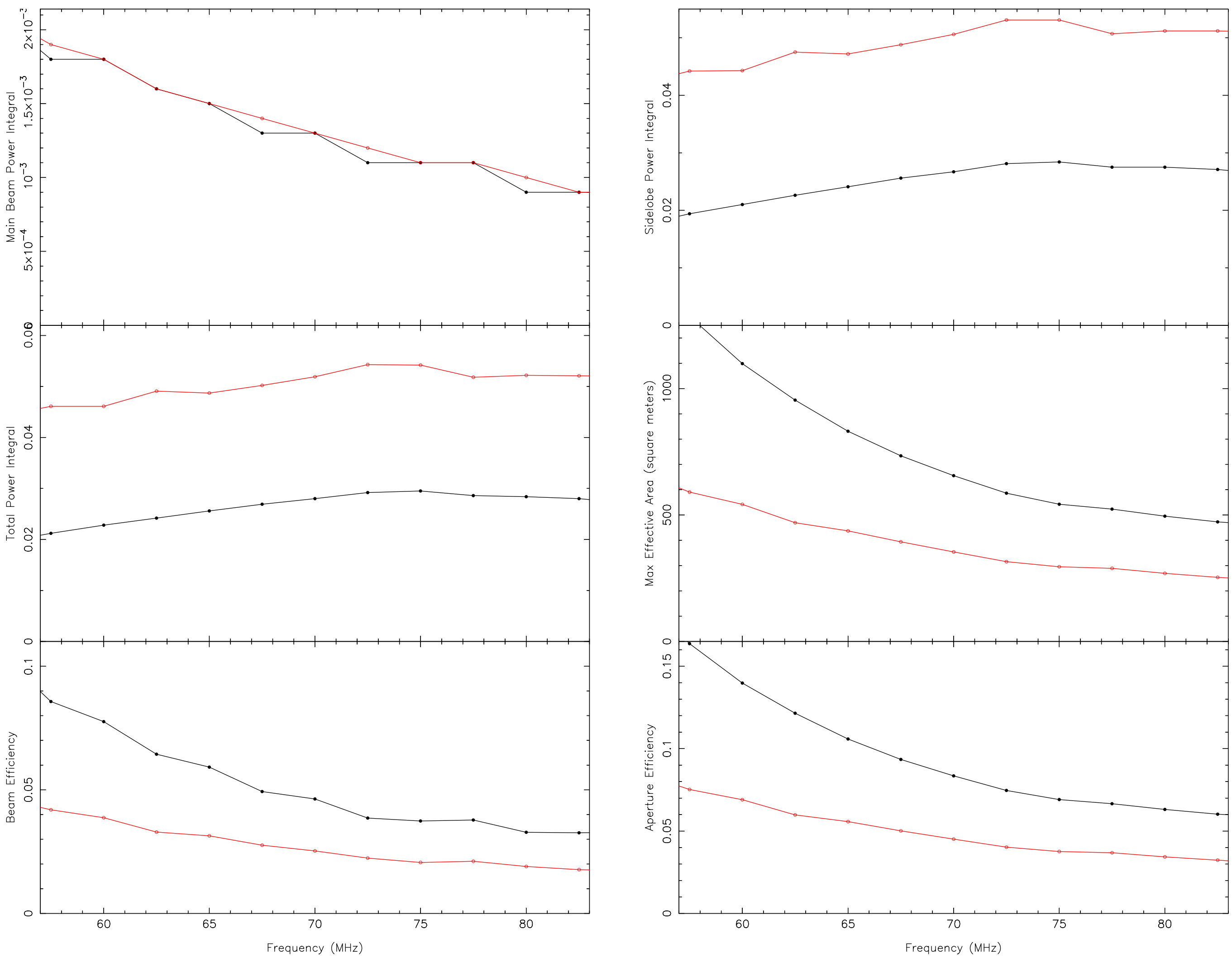

Fig. 11.— Metrics, main beam pointed at zenith. ***Top left***: Main beam power integral. ***Top right***: Sidelobe power integral. ***Middle left***: The all-sky integral, equal to the sum of the main beam and sidelobe integrals. ***Middle right***: The maximum effective area, proportional to the inverse of the all-sky integral. ***Bottom left***: The beam efficiency, equal to the main beam integral divided by the all-sky integral. ***Bottom right***: The aperture efficiency, proportional to the effective area. The proportionality constant depends on the physical size of the station and is the same for both the LWDA-1 and LWA.

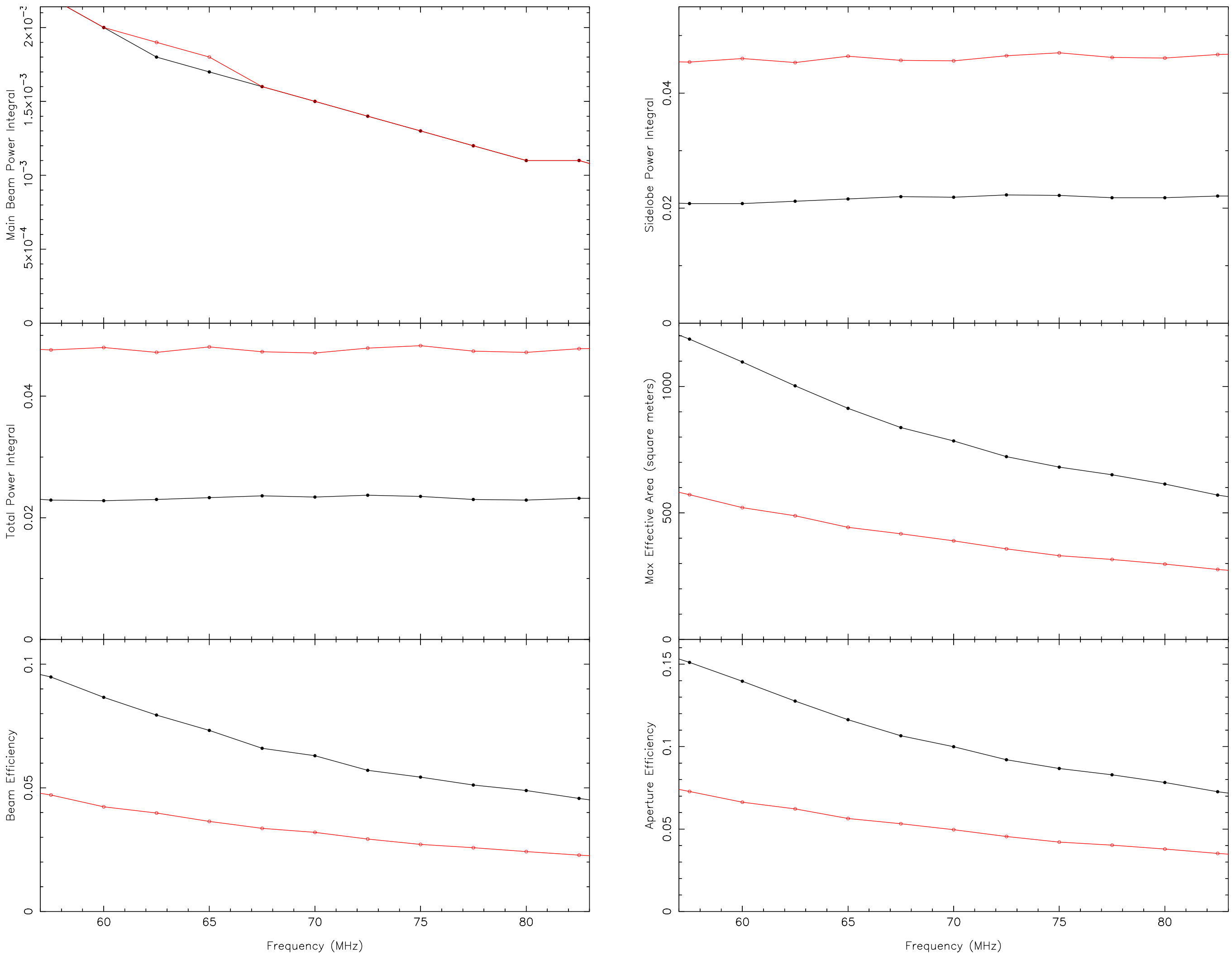

Fig. 12.— Metrics, main beam pointed at azimuth = 0°, elevation = 60°.

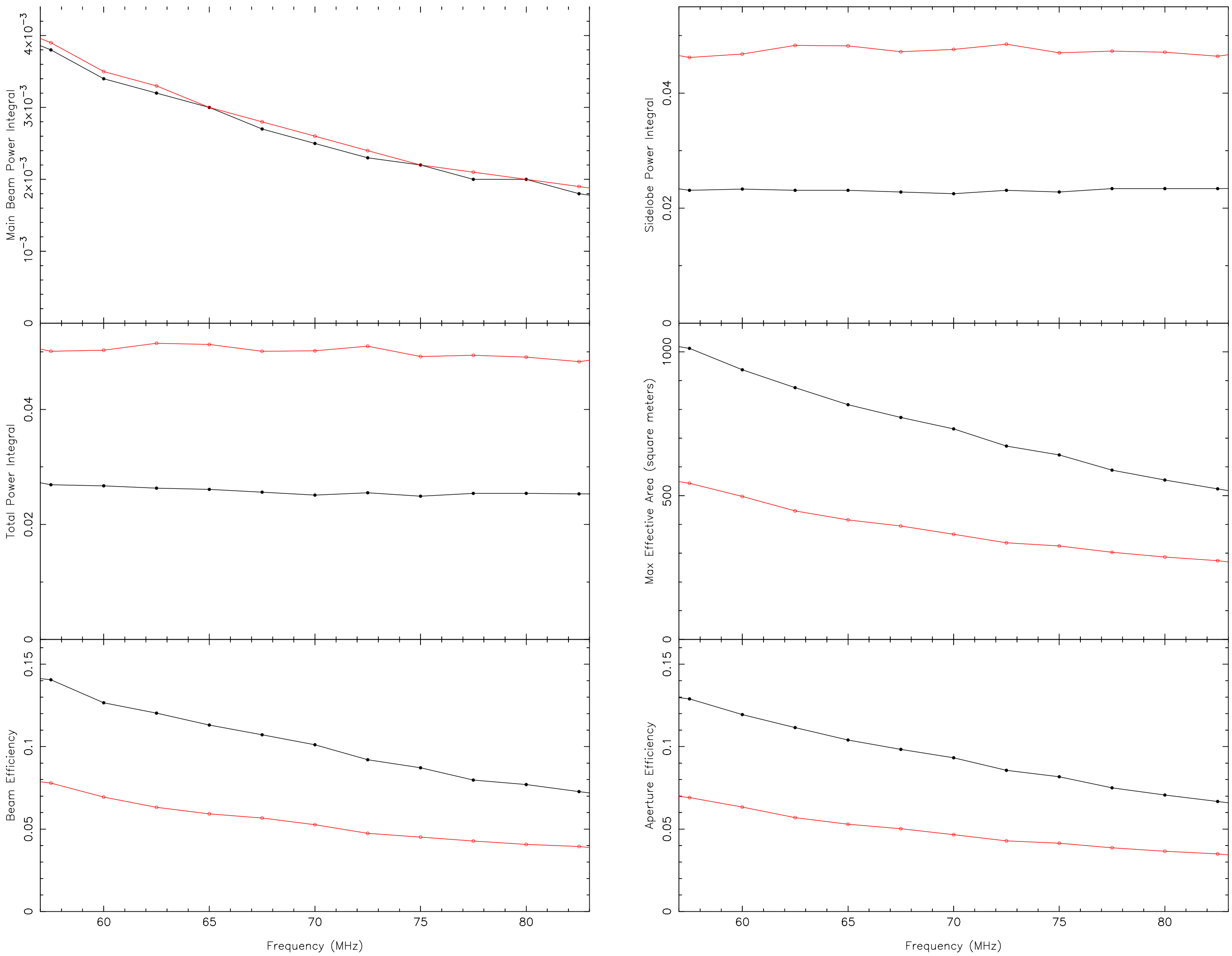

Fig. 13.— Metrics, main beam pointed at azimuth = 0°, elevation = 30°.

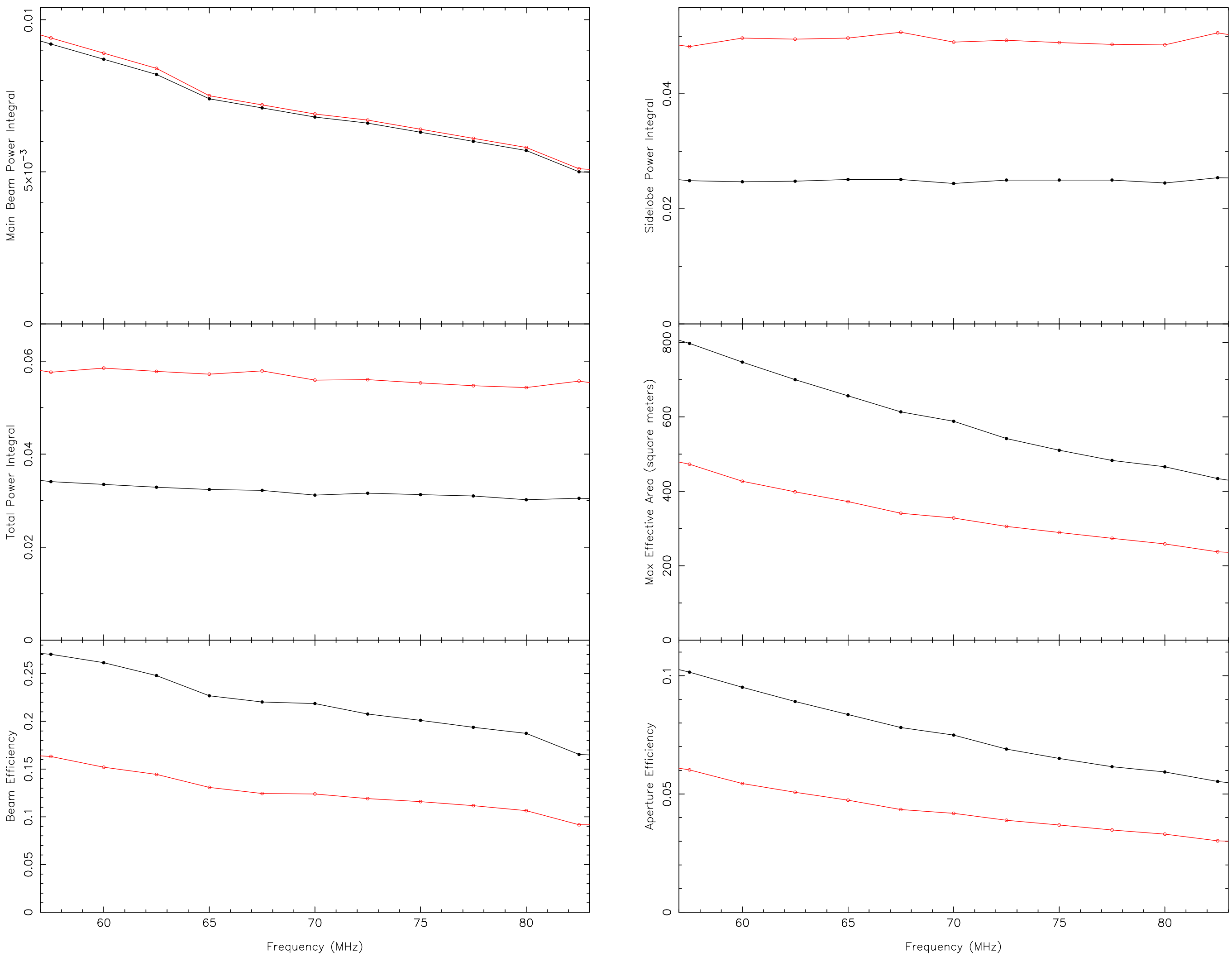

Fig. 14.— Metrics, main beam pointed at azimuth = 0°, elevation = 0°. Even when pointed at small elevation angles with large beam widths, the main beam makes an insignificant contribution to the all-sky power integral of the LWDA-1. This integral is dominated by the sidelobes, with about twice as much power per solid angle as the LWA. The effective area, beam and aperture efficiencies of the LWDA-1 are reduced by a factor of 2 compared to the LWA.

5. Summary

I tried to find a good set of elements to use for the LWDA Phase 1. The sheer number of possibilities made a direct search for the best configuration with the lowest possible peak sidelobe level impractical. I implemented algorithms to search for good solutions on reasonable timescales. My trials found sets that had significantly lower peak sidelobes than randomly chosen sets. The effects of reducing the number of elements by a factor of 2 left the beam size and ellipticity unaffected, but increased the peak sidelobe by a factor of 2.75 (4.4 dB). The power in the sidelobes per unit solid angle **increased** by a factor of 2 which **decreased** the beam and aperture efficiencies and effective area by a factor of 2.