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OPTIMAL ANTENNA CONFIGURATIONS FOR THE BIMA ARRAY

NIRANJAN THATTE & WM. J. WELCH
Department of Astronomy, University of California at Berkeley, Berkeley, CA 94720

ABSTRACT We attempt to determine optimal configurations of six antennas for the proposed Berkeley Illinois Maryland Array. The instrumental response is used as a performance measure. A two dimensional sinc function is chosen as the ideal beam, supported by theoretical considerations. A mean square comparison with this ideal is used to perform optimizations for arrays of various resolutions, using the current station locations at Hat Creek. Configurations for larger fields of view are also discussed, employing two days of coverage with six antennas.

OBJECTIVES

The three element interferometer at Hat Creek is being expanded to form the six element Berkeley Illinois Maryland Association (BIMA) Array. We attempt to determine array configurations for the six antennas which would yield optimal coverage in the u-v plane. The optimization is constrained since the antennas can be placed only at the existing stations on the T shaped roadway at Hat Creek (Figure 1). The possibility of adding new stations is also explored by determining the resulting improvement in the instrumental beam. Only a marked improvement would make the addition of the new stations cost effective. We determine the optimal configurations for arrays with various beam sizes, as well as arrays involving two sets of tracks, each with six dishes, to map larger fields.

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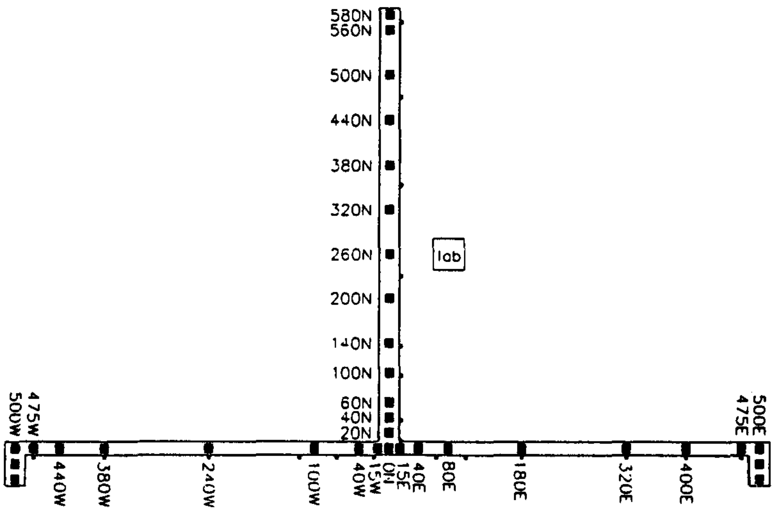

Fig. 1. Layout of stations at Hat Creek.

METHODS

No analytical techniques exist for solving the problem of antenna placement in two dimensions. We resorted to numerical techniques which would yield close to optimal solutions. The optimization is not well suited to the use of normal optimization techniques. This is because the existing stations are placed non-uniformly on the T shaped track. The other major hurdle is the definition of an objective or cost function for the optimization. The requirement that the array perform well for a variety of different source declinations further complicates the objective function.

We argue that the sinc ($sin(x)/x$) function is the ideal instrumental response function. In the visibility domain, the ideal beam would sample all the spatial frequencies (values of u and v) equally well. Since the maximum spatial frequency is limited by the size of the array, this would imply that the ideal response be unity over some restricted part of the u-v plane. A square and a circle are two strong candidates for this restricted area. We claim that the square geometry is preferable if we view only sampled versions of the maps, as is often the case.

The maximum spacing in the u-v plane is determined by the maximum extent of the interferometer. In one dimension, let this spacing be u_{max}. The choice of Δu, the distance between sample points for the FFT, is obviously the average distance between tracks. The FFT relates the product $M\Delta\xi$ to Δu, where M is the number of pixels in the map and $\Delta\xi$ is the spacing between sample points in the map plane. Since source structure upto frequencies of u_{max} can be resolved, it would be foolish to chose a $\Delta\xi$ larger than the

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reciprocal of $2u_{max}$, as it would mean throwing away information about the source. This corresponds to a choice of M which is twice the number of u-v tracks. A larger value of M would mean adding zeros values at larger u, which does not add any real information, although it does reduce the grainy nature of the map.

Using a value of $1/2u_{max}$ for $\Delta\xi$ allows us to use the periodic crossings of the sinc function to our advantage. If we assume the ideal beam to have unit value over the region of coverage (from $-u_{max}$ to u_{max}, then applying the fourier relationship gives the beam in one dimension to be

$$h(\xi) = \int_{-u_{max}}^{u_{max}} \epsilon^{i2\pi u\xi}\, du$$

Evaluating the integral yields

$$h(\xi) = 2u_{max}\frac{\sin(2\pi u_{max}\xi)}{2\pi u_{max}\xi}$$

The sinc function has a zero value when

$$2\pi u_{max}\xi = n\pi \quad \text{or when} \quad \xi = n/2u_{max}$$

But the reconstructed image is a sampled version which has a sample interval $\Delta\xi = 1/2u_{max}$. Thus, the instrumental response due to a source located at one grid point is zero at all other grid points. The sampled instrumental response is a delta function, which is the desired ideal.

The reconstruction is not perfect, as it is only the sampled beam which is the ideal delta function. Having identified the sinc function as the ideal beam, we then compare each evaluated beam with the ideal one in a mean square sense. The comparison is done in the u-v plane, but the mean square difference is the same (upto a scale factor) in the map plane too, increasing our confidence in the choice of our objective function. This objective function is evaluated for the four chosen declinations of $+45°$, $+20°$, $-5°$ and $-30°$. The four numbers for each configuration are then converted into a mean and a standard deviation. These are used as cost functions for various standard optimization algorithms, including simulated annealing to find the optimum array configuration for a given beam size.

RESULTS

Two distinct types of optimizations are possible for a given beam size. In the unrestricted version, the tracks are allowed to overflow the desired square area. In one dimension, this is equivalent to a minimum redundancy array with all spacings out to a maximum, with a few others farther out. Figure 2 shows the results of one such optimization. In the restricted version, the maximum array

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spacings are restricted so that there are no tracks outside the region of interest. The one dimensional equivalent is a minimum redundancy array with a few repeated spacings. The option results in optima of the type shown in Figure 3. The latter scheme works better for low resolution arrays, since it confines the search space much more effectively.

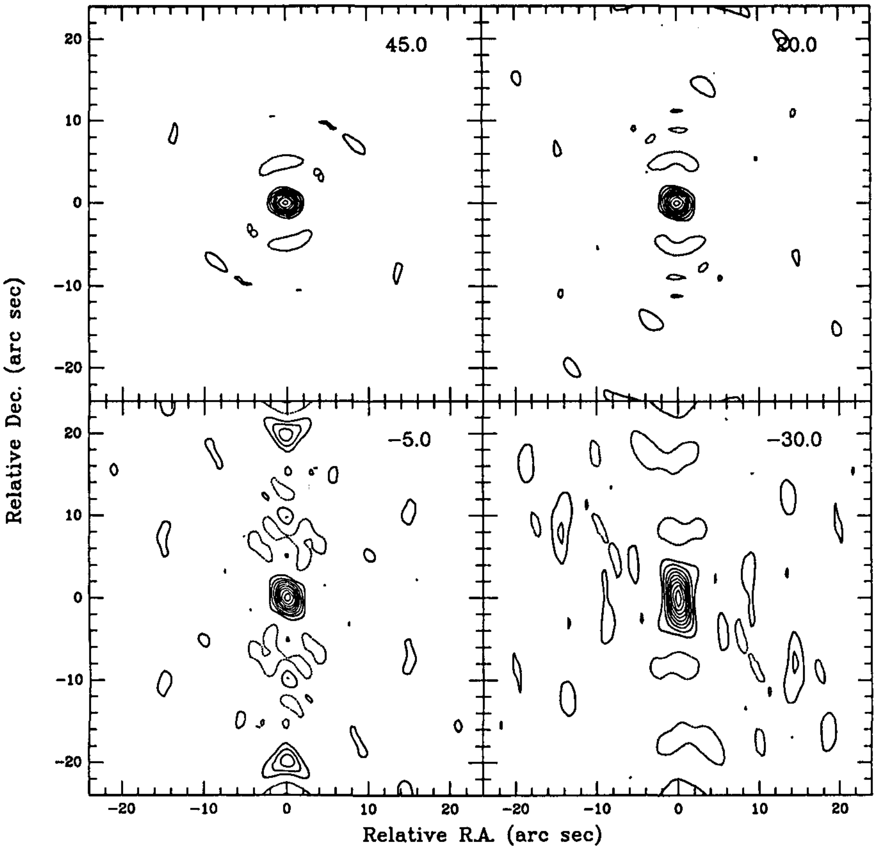

Fig. 2. Instrumental beams for four different declinations for the A array (resolution of 3 arc seconds). This optimization was performed with no restrictions on the inter-element spacings. Contour intervals are 10 percent with negative contours shown dotted.

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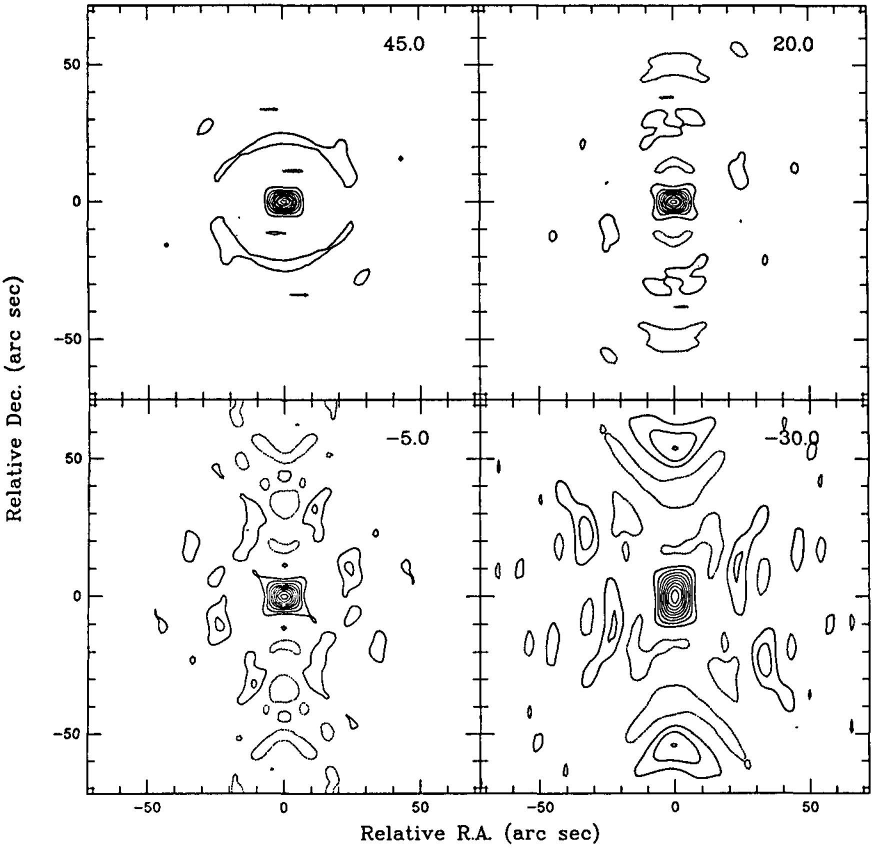

Fig. 3. Response to a point source at four different declinatios for the C array (resolution of 9 arc seconds). This optimization restricted the sizes of the u-v tracks so that they were all within the desired square area. Contour intervals are 10 percent with negative contours shown dotted.

The possibility of adding new stations was explored by performing an unrestricted optimization. A station was assumed to be located every 20 feet (the size of each antenna) on the track, and the locations of the six best stations was determined. The result is shown in Figure 4. As can be seen by comparison with Figure 2, the addition of new stations does not significantly affect the array performance. Optimizations were also performed for u-v coverage for larger fields of view, using two sets of tracks, each with six elements. The problem doubles in complexity, but some ad-hoc solutions were found, one of which is illustrated in Figure 5. These solutions perform well

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enough to serve our purpose effectively. Some future effort will be devoted to this problem and also to configurations of 9 antennas using smaller tracks.

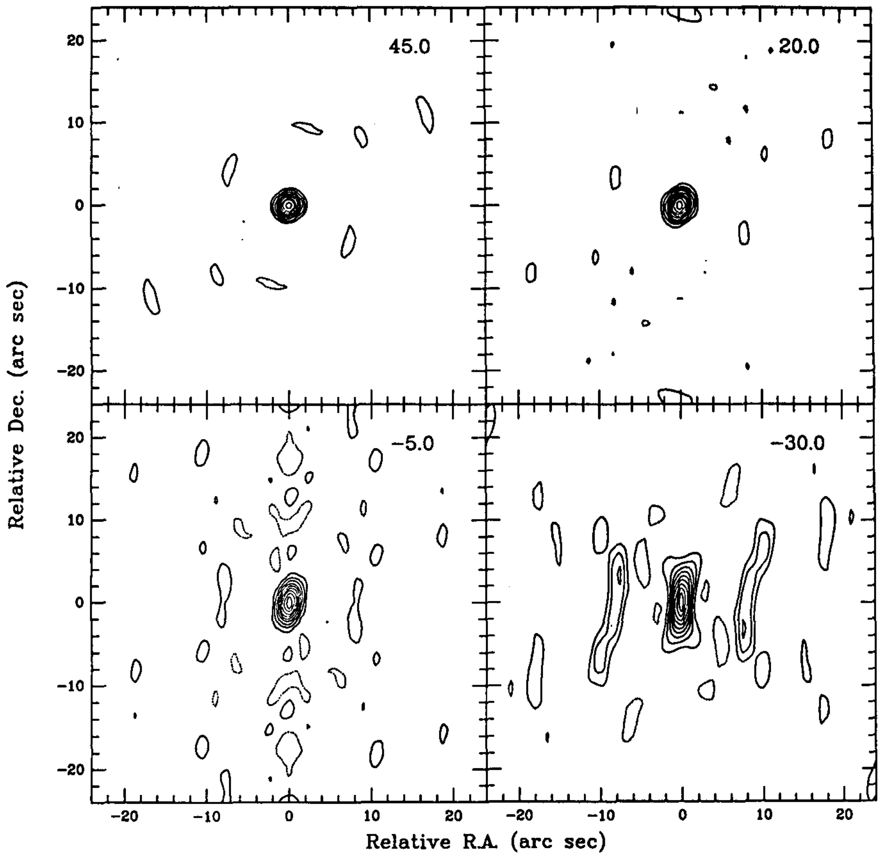

Fig. 4. The best possible instrumental responses for a beam size of 3 arc seconds are shown. Stations are assumed to exist every 20 feet on the T shaped roadway. The contour intervals are the same as Figure 2.

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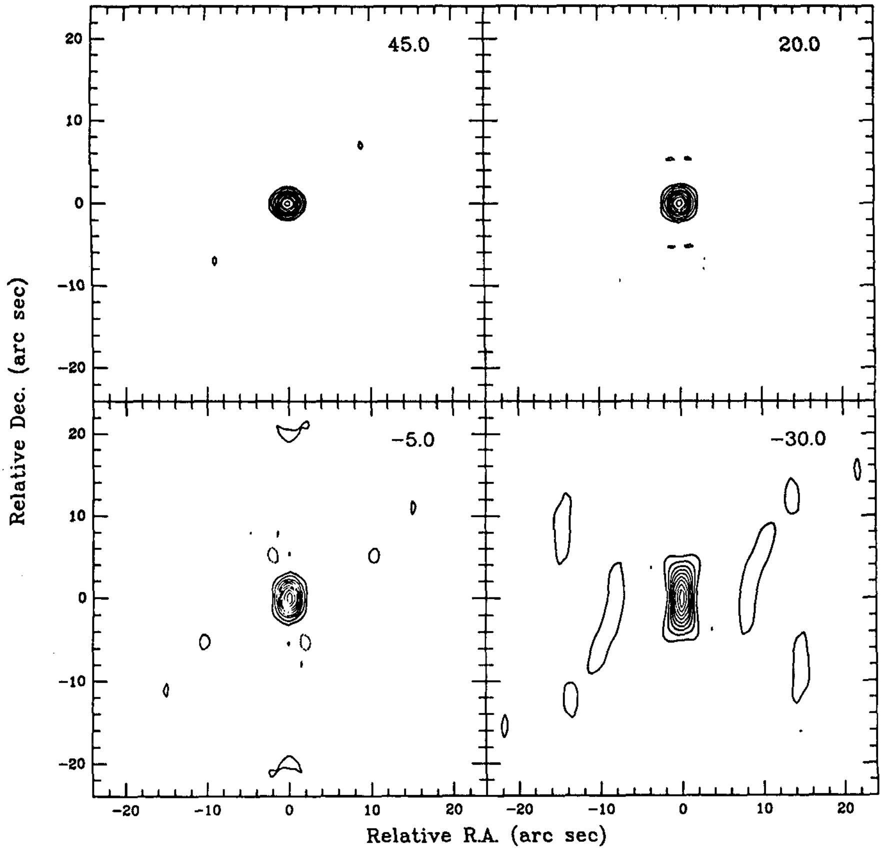

Fig. 5. Response to a point source at four different declinations for a 3 arc second resolution array. The u-v coverage consists of 2 sets of tracks, each with six antennas. The contour intervals are the same as Figure 2.

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