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A COMPUTER SIMULATION FOR EVALUATING THE ARRAY PERFORMANCE OF THE 10-mϕ 5-ELEMENT SUPER-SYNTHESIS TELESCOPE

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Abstract

The array performance in several successive configurations was examined for the 10-mϕ 5-element super-synthesis telescope. The number of (u,v) samples was used as a criterion of optimum (u,v) coverages. The optimum solution for a given declination were obtained by a random trial method. The performance was evaluated through a computer simulation by use of model brightness distributions.

1 Introduction

A 45-mϕ telescope and a 10-mϕ 5-element super-synthesis telescope are under construction at Nobeyama Radio Observatory, Tokyo Astronomical Observatory, University of Tokyo. The super-synthesis telescope has two baselines which are EW 560m long(EW-arm) and 33° from NS 520m long(NS-arm), as shown in Figure 1. 30 stations are arranged on these baselines with a quasi MRA distribution(Ishiguro, 1978). Antennas are 10-mϕ paraboloids with Cassegrain coudé optics, and are movable from station to station on a transporter.

With this telescope, the aperture synthesis is performed as follows: First, 5 element antennas are set on the appropriate stations. As the earth rotates, the spatial autocorrelation

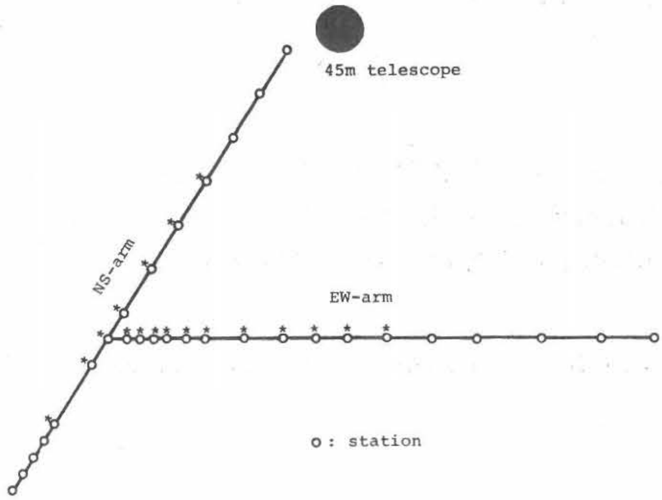


Figure 1. The baseline configuration and the arrangement of the stations of the 10-mϕ 5-element super-synthesis telescope. Stations with a symbol, * in the figure were used for the array configurations in Section 3.

function, B(u,v) which is the two-dimensional Fourier transform of the sky brightness distribution, b(l,m), is measured as a function of the hour angle and the declination of the source and the baseline vectors between the two antennas. During an observing period of some days, this measurement is repeated with different array configurations until sufficient (u,v) samples of B(u,v) are obtained. The two-dimensional Fourier transform of these samples provides an estimate of b(l,m)(Ryle and Hewish, 1960).

The arrangement of the stations on the two baselines were determined so as to give optimum (u,v) coverages when antennas are set on all stations(Ishiguro, 1978). The problem how to set 5 antennas on these stations has been left unsolved. Effective use of the telescope depends on the determination of the optimum array configurations. In this paper an optimum set of array configurations which gives maximum (u,v) samples for the given observing period of some days, was searched by a random trial method. To evaluate the array performance in several successive configurations thus determined, we performed the computer simulation of aperture synthesis using four kinds of model brightness distributions, consisting of several elliptical Gaussian components.

In Section 2, a random trial method for determining the optimum array configurations and the computer simulation of aperture synthesis are described. Results are shown and discussed in Section 3.

2 Random Trial Method and the Simulation of Aperture Synthesis

We used a following random trial method for determining the optimum array configurations for a given declination. First, 5 element antennas are set on the appropriate stations at random. Then 10 baselines between two of these antennas are determined. According to the aperture synthesis technique(Ryle and Hewish, 1960), the spatial autocorrelation function B(u,v) measured with one of these baselines, is given by

$$B(u,v) = \iint_{-\infty}^{+\infty} b(l,m)\exp(j(lu + mv))\,dl\,dm, \tag{1}$$

where u and v are projected baselines and given by,

$$u = (D/\lambda)\cos(d)\sin(H - h), \tag{2}$$

$$v = (D/\lambda)(\sin(d)\cos(\delta) - \cos(d)\sin(\delta)\cos(H - h). \tag{3}$$

Other quantities are

b(l,m) = the brightness distribution of the radio source,

H = hour angle of the source,

δ = declination of the source,

h = hour angle of the baseline vector,

d = declination of the baseline vector,

D = length of the baseline,

and

λ = wave length of the observation.

From equations (2) and (3),

$$\left\{\frac{u}{(D/\lambda)\cos(d)}\right\}^2 + \left\{\frac{v - (D/\lambda)\sin(d)\cos(\delta)}{(D/\lambda)\cos(d)\sin(\delta)}\right\}^2 = 1. \tag{4}$$

Therefore the track of the projected baseline in the (u,v) plane gives an ellipse as the earth rotates. After the (u,v) tracks of 10 baseline vectors are calculated from equations (2) and (3), the

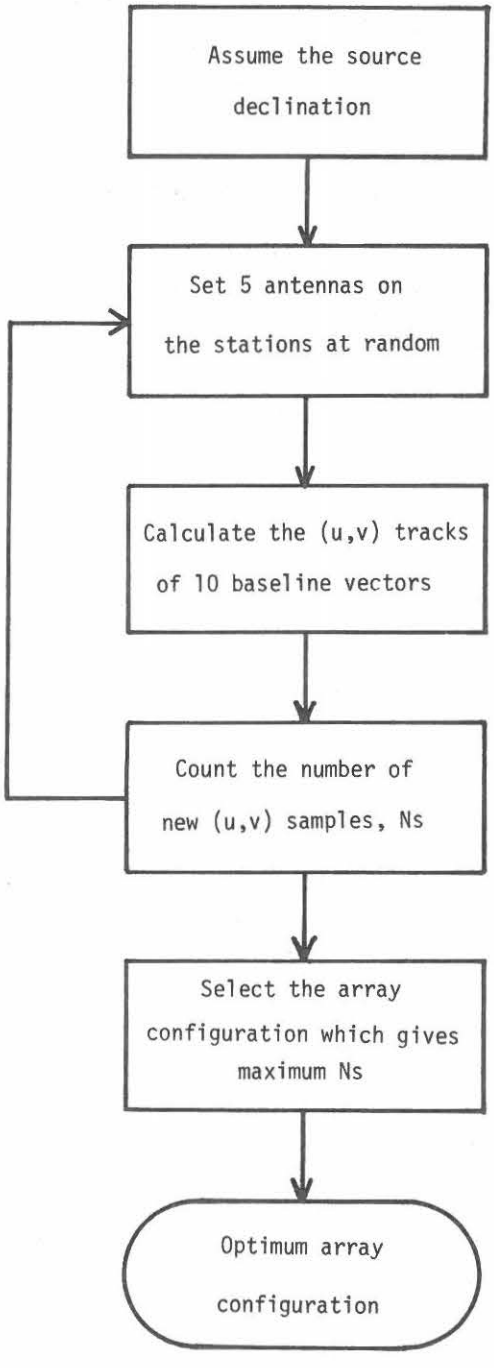


Figure 2. Flow diagram of a random trial method for determining the optimum array configurations.

sample points on these tracks are represented by the nearest grid points in the (u,v) plane, which are sometimes called as "(u,v) cells". Samples of B(u,v) measured at those points are called as (u,v) samples. The (u,v) samples thus obtained are compared with those obtained for previous days, and the number of new (u,v) samples, Ns is calculated. The above mentioned process is repeated many times and the array configuration which gives maximum Ns is selected as an optimum one at each successive stage. The flow diagram of this method is shown in Figure 2.

The performance of the array configurations thus obtained was evaluated through a computer simulation by use of model brightness distributions. First an appropriate source model consisting of several elliptical Gaussian components is constructed. The (u,v) samples which can be measured with these configurations for an assumed source declination, are calculated from equations (1), (2), and (3), and the two-dimensional Fourier transform of these data provides the observed brightness distribution. Those maps which are the results of convolution with a synthesized beam are compared with original models to evaluate the array performance.

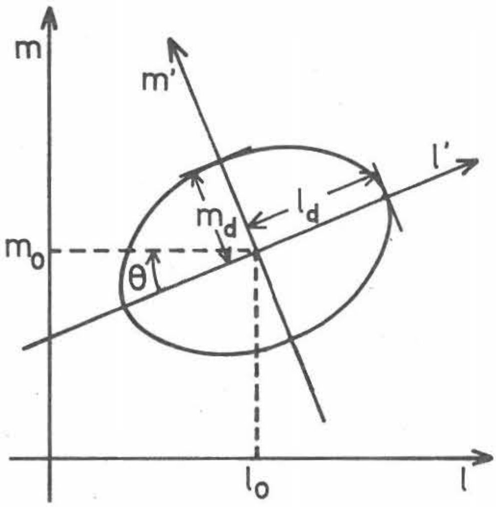


Figure 3. Parameters of an elliptical Gaussian component.

We constructed the model brightness distributions consisting of several elliptical Gaussian components, which are similar to those observed actually. An elliptical Gaussian component is given by

$$f(l,m) = A \exp(-(1/2)((l'/l_d)^2 + (m'/m_d)^2)), \tag{5}$$

where A is amplitude of the brightness and

$$l' = (l - l_0)\cos(\theta) + (m - m_0)\sin(\theta),$$

$$m' = -(l - l_0)\sin(\theta) + (m - m_0)\cos(\theta),$$

and other parameters are shown in Figure 3. From equation (5), F(u,v), the two-dimensional Fourier transform of f(l,m), is given by

$$F(u,v) = 2\pi l_d m_d A \exp[-(1/2)((l_d u')^2 + (m_d v')^2) - j(l_0 u + m_0 v)], \quad (6)$$

where

$$u' = u \cos(\theta) + v \sin(\theta),$$

$$v' = -u \sin(\theta) + v \cos(\theta).$$

Therefore analytical form of B(u,v) can be easily obtained.

3 Results and Discussions

For the array configurations described in the previous section, we restricted to the observational mode using 12 stations on EW-arm and 6 stations on NS-arm near the cross-point of the two linear baselines(see Figure 1). Although the resolution for these configurations is lower than that for those using full stations, aperture-synthesis observations can be completed in a short period. The (u,v) coverage for the source of 60° declination which might be obtained with a single configuration of 18 antennas is shown in Figure 4. This is considered as the goal for optimization. The

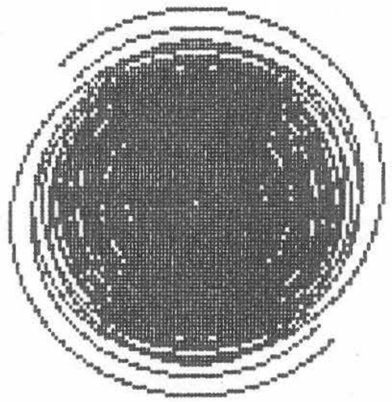


Figure 4. The (u,v) coverage for the source of 60° declination obtained with a single configuration of 18 antennas.

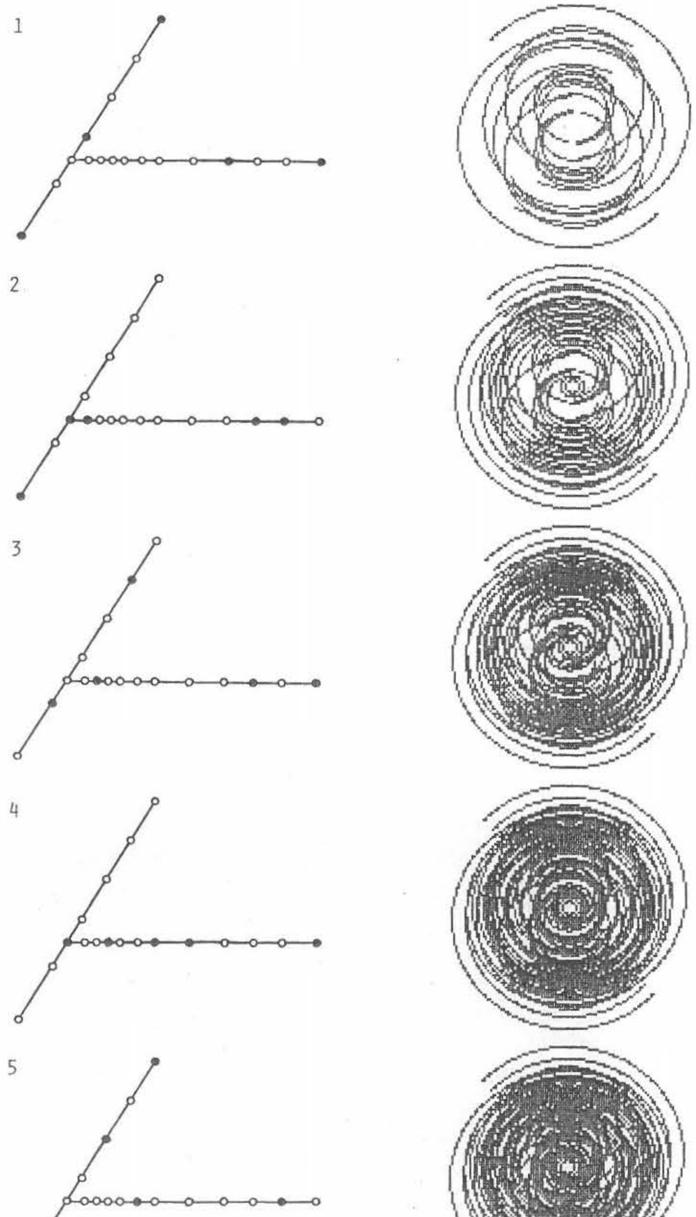


Figure 5. The successive array configurations(left) and the integrated (u,v) coverages for the source of 60° declination completed at each stage(right). 5 antennas are arranged to the stations represented by the solid circles at each stage.

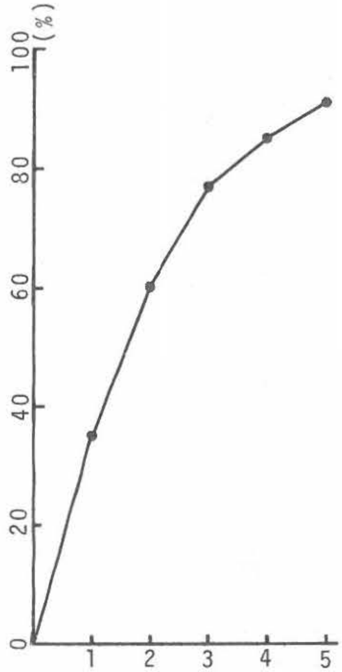


Figure 6. The ratio of the number of (u,v) samples in successive integrated (u,v) coverages shown in Figure 5 to that obtained with a single configuration of 18 antennas.

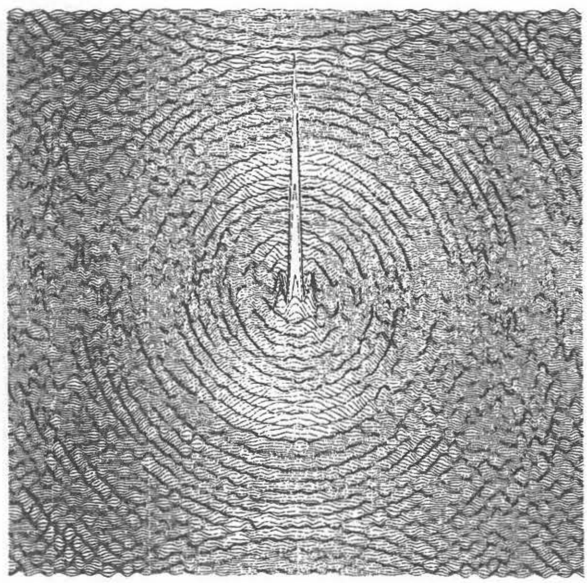


Figure 7. The synthesized beam completed with 5 configurations of 5 antennas.

number of (u,v) samples contained on the (u,v) plane is 6010.

The optimum 5 successive configurations are obtained with the random trial described in Section 2. Figure 5 shows the successive array configurations and the integrated (u,v) coverages for the source of 60° declination completed at each stage. Figure 6 shows the ratio of the total number of (u,v) samples contained in the (u,v) coverages shown in Figure 5 to that obtained with a single configuration of 18 antennas. From Figure 6, it is evident that 90% of the (u,v) samples in Figure 4 can be obtained with 5 configurations. The corresponding synthesized beam is shown in Figure 7. Note that it needs, at least, 14 configurations to reach the goal.

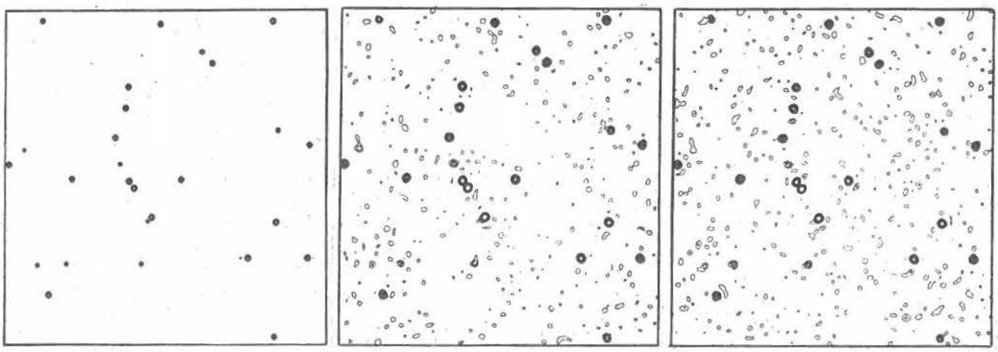
We now discuss the results of the computer simulation of aperture synthesis. In Figures 8 - 11, (a) shows the map of the model brightness distribution, (b) and (c) show the maps obtained with a single configuration of 18 antennas and with 5 configurations of 5 antennas, respectively. Models used for this simulation are as follows:

Figure 8   Many point sources,
Figure 9   Extented source with strong and nearby compact source,
Figure 10 Double source,
Figure 11 Shell source.

Source declination of 60° was assumed.

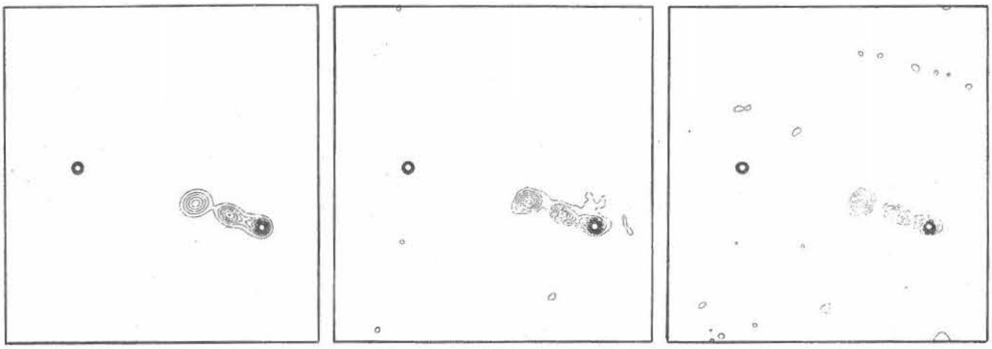
In Figure 8 and Figure 9, there are no appreciable differences between (b) and (c) except for the lowest contours. In Figure 10 (c), however, the large structure is not well reconstructed. It is much more serious in the example of Figure 11. This is caused by the presence of large holes near the center of (u,v) plane.

It was made clear that the random trial method by use of number of (u,v) samples as a criterion can give the array configurations which attain more than 90% of possible (u,v) coverage in a short period. This method, however, tends to select the array configurations, for which (u,v) coverage has some holes near the center of the (u,v) plane. The computer simulation of aperture synthesis showed that such array configurations are not optimum for the case of extended radio sources. It appears that the more preferable criterion is the one which can sensitively indicate the uniformity of (u,v) coverages. For the design of the correlator supersynthesis array, Mathur(1969) used the number of weighted (u,v) samples as such a criterion, and Swenson(1977) proposed a "Figure of Merit" for the VLBI network, which is the parameter of the area of holes in the (u,v) coverage. Therefore it is necessary to evaluate these



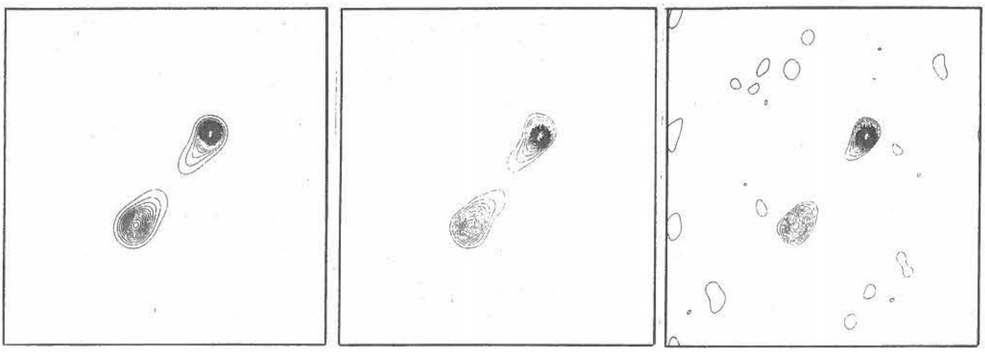
(a) (b) (c)

Figure 8. Results of the simulation of aperture synthesis for the model of many point sources. (a) shows the map of the model brightness distribution, (b) and (c) show the maps obtained with a single configuration of 18 antennas and with 5 configurations of 5 antennas, respectively. Contour levels: 5%, 10%, 15%, ···· , 50% of the peak brightness.



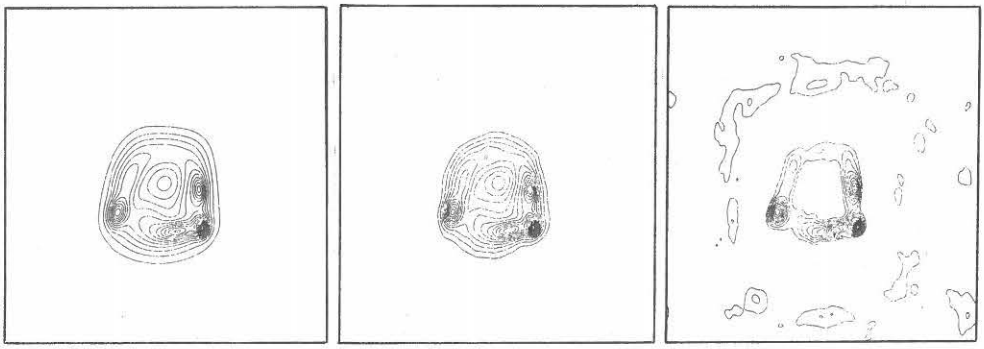
(a) (b) (c)

Figure 9. Results of the simulation of aperture synthesis for the model of extended source with strong and nearby compact source. (a), (b), and (c) show the maps in like manner with Figure 8. Contour levels: 5%, 10%, 15%, ···· , 50% of the peak brightness.



(a) (b) (c)

Figure 10. Results of the simulation of aperture synthesis for the model of double source. (a), (b), and (c) show the maps in like manner with Figure 8. Contour levels: 5%, 10%, 15%, ···· , 95% of the peak brightness.



(a) (b) (c)

Figure 11. Results of the simulation of aperture synthesis for the model of shell source. (a), (b), and (c) show the maps in like manner with Figure 8. Contour levels: 5%, 10%, 15%, ···· , 95% of the peak brightness.

quantities for our array. Since the optimum array configuration for one declination is not always optimum for other declinations, it is important to develope the criterion which meets the practical operational conditions.

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