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Conference on Large Antennas
Held at the N.A.C.A. Building, Washington, D.C.
October 26, 1957

I. Purpose of Conference

The joint session of Commissions V and VI at the Boulder meetings of URSI made it clear that future conferences between scientists interested in radio astronomy and those interested in antenna design would be mutually helpful. Discussions took place between Dr. Van Atta and members of the National Radio Astronomy Observatory staff with the result that an informal conference was held to discuss the following questions:

1. What are the design considerations for large parabolic reflectors used as radio telescopes?

2. What better antennas than large paraboloids might be available when very large apertures and gains are required?

II. List of Those Attending

R.W. Bickmore	Hughes Aircraft Corp., Culver City, California
Russell Brown	Naval Research Laboratories, Washington, D.C.
J.T. Bolljahn	Stanford Research Institute, Menlo Park, California
R.M. Emberson	Associated Universities, Inc., 10 Columbus Circle, New York
J.W. Findlay	National Radio Astronomy Observatory, Green Bank, West Va.
D.P. Flood	Andrew Alford, 299 Atlantic Avenue, Boston, Massachusetts
T. Gold	Harvard College Observatory, Cambridge, Massachusetts
D.S. Heeschen	National Radio Astronomy Observatory, Green Bank, West Va.
H. Jasik	Jasik Laboratories, 300 Shanes Drive, Westbury, New York
C.H. Mayer	Naval Research Laboratories, Washington, D.C.
J.L. Pawsey	c/o ASLO, 1907 K Street, Washington 6, D.C.
C. Seeger	Leiden Observatory, Leiden, Holland

S. Silver — Electronics Research Laboratory, Div. of Electrical Engineering, University of California, Berkeley 4, California

L.C. Van Atta — Hughes Aircraft Corp., Culver City California

III. Plan of Conference

The morning session of the conference was devoted to considerations of large steerable paraboloids, and the afternoon session to the study of arrays of large aperture.

IV. Main Radio Astronomical Requirements for Large Paraboloids

Dr. Pawsey suggested that the main needs for large paraboloids in radio astronomy were to measure the following quantities:

1. The flux density from a small isolated source; this requires that the antenna have a gain which is both high and well-determined.

2. The surface brightness of a radio source; this requires that the antenna should have a known polar diagram.

3. The flux density from confused radio sources; to separate the flux densities from a number of confused sources requires that the antenna system should have high resolution and small side lobes. An estimate of the size of side lobes which would be acceptable in a dish of about 140-feet in diameter was given as.....

   a. for angles less than 30° away from the main antenna beam, the side lobes should be lower than 30 db. below the main lobe;

   b. for angles greater than 30° from the main beam, the side lobes should be 40 db. below the main lobe.

4. The polarization of radiation from a radio source; to measure polarization requires that the polar diagram of the antenna should not differ when different polarizations are being received. It is also necessary that the antenna should be receptive to only one type of polarized wave and should exclude all others to the extent of about 30 db. rejection.

5. The measurement of positions of radio sources; the antenna system should be capable of isolating and measuring positions of radio sources to an accuracy consistent with

the signal strength of the source and the beam width of the antenna.

V. Antenna Patterns for Large Paraboloids

Considerable discussion was directed to the problems of what is a desirable antenna pattern and on which particular design features this pattern depends. Mr. Seeger suggested that if it were possible to design a paraboloid feed such that the antenna efficiency was as high as 90 per cent, near-in side lobes about the 20 db. level might be acceptable. Conversely, efficiency might be sacrificed to as low a figure as 40 per cent if this resulted in side lobes as low as 60 db. The opinion seemed to be that no features as yet known for paraboloids could give such a low side lobe figure, but that as the afternoon session would show, better side lobes were possible with arrays than with paraboloid antennas.

In discussing side lobes, the conference agreed that there were three separate classifications of radiation from the antennas that were being discussed. These might be separated as:

1. side lobes which exist close to the main lobe and which are similarly polarized;

2. side lobes which are often referred to as "cross polarization" lobes and which have a polarization orthogonal to that in the main lobe;

3. the radiation which is often referred to as "spill-over" and which to radio astronomers is generally very important because it is all that radiation which may enter the feed horn from the ground and other objects near the radio telescope.

The ways in which these three characteristics of a dish might be modified by the dish and feed design were discussed in some detail. First, it was agreed that practical methods of illuminating a dish to reduce the side lobes near the main beam were well-known. These methods generally involve the use of an illumination suitably tapered in amplitude. The question as to whether variations in phase as well as in amplitude in the illumination might helpfully modify the antenna pattern was not clearly resolved. Other methods for reducing the near side lobes of dishes, such as fitting the dishes with short cylindrical tubes around the edge, were mentioned as possible practical solutions.

The subject of "cross polarized" lobes was described by Dr. Van Atta. For a lineally polarized feed and a parabolic dish, four "cross polarized" side lobes were radiated with their maxima in the direction of the first minimum of the dish radiation. In space, the direction of these lobes lie along the lines 45^{o} to the principal planes of the polarization of the emitted radiation. In addition to these "cross polarized" lobes, four other lobes (the Condon lobes) exist at fairly large angles away from the main beam. If short focus paraboloids are used, the near-in cross polarized lobes may be as large as 12 db. down from the main lobe. The flatter the dish is made, the smaller these lobes can become. In fact, both for the reduction of "cross polarization" and for the reduction of "spill-over", dishes of long focal length are to be preferred to those of short focal length.

The reduction of "spill-over" in radio telescopes was discussed on the assumption that the main components arise from direct radiation which enters the horn feed without having been reflected by the dish surface. This neglects diffraction effects, which is obviously only a first approximation, but it leads to the fairly obvious decision, such that the illumination of the dish should be arranged to fall to a low value at the edge. Present practical designs provide such illumination which can be between 10 db. to 18 db. less than the main lobe. If the "spill-over" problem becomes serious, as it may with the advent of receivers of low noise figure, then it may be necessary to reduce the illumination at the edge of the dish to a still lower value. Various practical attempts have been made, such as scalloping the edge of a dish, fitting a quarter wave trap at the edge, or adding absorbing material. None of these has shown much success in reducing "spill-over". This subject is one in which experimental knowledge is not very adequate, and some fairly straightforward suggestions were made for possible experiments:

1. It might be worth adding additional area to the dish in the form of a fairly crude reflecting screen; this would be designed only to insure that as little radiation as possible from outside the dish edge could enter the feed horn;

2. The use of reflecting screens placed over the ground near a big radio telescope would insure that the radiation entering the horn would be radiation from the cool sky rather than from the hot ground;

3. In order to estimate the magnitude of the problem, a simple experiment in measuring the signal injected into the horn from a small transmitter placed at various points on the ground near a radio telescope might be of value.

VI. The Present Characteristics of Large Parabol 'ds

The following table shows what, in the opinion of the members of the conference, appeared to be the best figures which were presently achieved in current parabolic radio telescopes:

Characteristics	Present Figures
Efficiency of dish and feed	65%
Spill-over	It was estimated that for a good feed with an efficiency of 65%, about 10% of the energy entering the feed came from "spill-over"
Side lobes within about 5 beam widths	30 db. down
Side lobes far from the main lobe	40 db. down
Purity of polarization	30 db. down
Band width for a simple feed	10%
Best form of feed support	unknown

VII. The Need for Larger Aerials.

Dr. Emberson opened the afternoon session by saying that although studies have suggested that paraboloids of two or three thousand feet in size seemed to be structurally possible, it also appeared that to gain collecting area in this way might prove extremely expensive. For example, a 600-foot steerable dish might cost as much as $50 million. A short study of the costs of existing dishes showed that because of their diverse characteristics, it was not possible to extrapolate safely to determine the costs of larger dishes. It would obviously be valuable to consider other alternatives to large dishes when collecting areas of the order of 10^6 or 10^7 square feet were being discussed.

VIII. Electrically Scanned Arrays

Dr. Van Atta outlined the main differences between large dishes and electrically scanned arrays. It seemed that the dish would become very expensive when apertures above 250 feet were considered. Because of the difficulties of feed design and because the obstruction of the aperture for feed supports could become more serious with larger dishes, it might be difficult to keep side lobes lower than about 17 db. The main advantage of the big dish was the flexibility in the frequency at which it could be operated. Electrically scanned arrays allow of large aperture to be used with only an increase in cost proportional to the aperture. Control of the feeding of the array could result in side lobes as low as 40 db. below the main lobe, and, of course, a considerable reduction in the problems of "spill-over". The large array would be fairly simple to build and align, and additions could be made to it if future needs required a larger aerial. The main and obvious disadvantage of the array was the comparatively narrow range of frequencies at which it could be operated. At present, Dr. Van Atta said that a frequency range of about 10 per cent was practical. Careful attention to various features in the design of the array should allow of this figure being increased to about 25 percent. The important factor of cost had been estimated by making some rough cost estimates of various sizes of arrays and parabolic dishes. These estimates are reproduced in the attached figure. The curve #1 in this figure is the estimated cost of a parabolic dish in which the accuracy of the dish is about one inch for a 250 foot dish, and varies lineally with the area to about 12 inches on the 10^6 square foot dish. The array costs were figured for arrays of individual elements mounted on posts on flat land and fed through a system which would permit the beam of the array to be scanned both in declination and in azimuth. The declination scan would be about $\pm 45^o$ and the azimuth scan about $\pm 15^o$. This scan would be achieved either by phase shifters or by variable length lines. It was generally agreed that scanning such an array by changing frequency would not be acceptable to radio astronomers, nor would any scanning system be acceptable which limited the band width over which the array had a satisfactorily narrow beam width to much lower than those which radio astronomers presently use. As an example, the use of a 1420 mc array with a band width of 6 mc should not impair the sharpness of the array polar diagram. There was some discussion on the best way in which a given area of array might be disposed on the ground. It seemed generally agreed that when areas of the order of 10^6 square feet or greater were considered, it would be best to make a square or circular array and not to attempt increased resolution by the use of systems akin to the Mills Cross.

IX. Arrays of Paraboloids

Some brief consideration was given to achieving large collecting areas by making arrays from steerable parabolic dishes. About 100 dishes giving a total collecting area of 10^6 square feet, could be bought, erected, interconnected and phased for about $20 million. However, the cost of the best design for arrays of dishes led to some difficulties. The dishes would have to be spaced closely enough to avoid unwanted lobes in their combined pattern, and yet far enough apart to avoid one dish shadowing its neighbor. Finally, the phase of the correct illumination for each dish is important if the over-all pattern is not to include large side lobes. The problems of such arrays of dishes were not fully explored at the meeting.

X. Conclusion

It was agreed at the conclusion of the conference that this draft report of the proceedings should be transmitted to all those who had attended. Comments on this report and any additions would be welcomed. It was hoped that those attending might wish to suggest subjects which ought to be studied further. Dr. Findlay said that the National Radio Astronomy Observatory would be continuing a study of the problems of large radio astronomy aerials, and so he would be glad to receive any comments that were made. He would hope to make a final report of the conference in about four weeks time, and include in this report any observations which had been sent to him.

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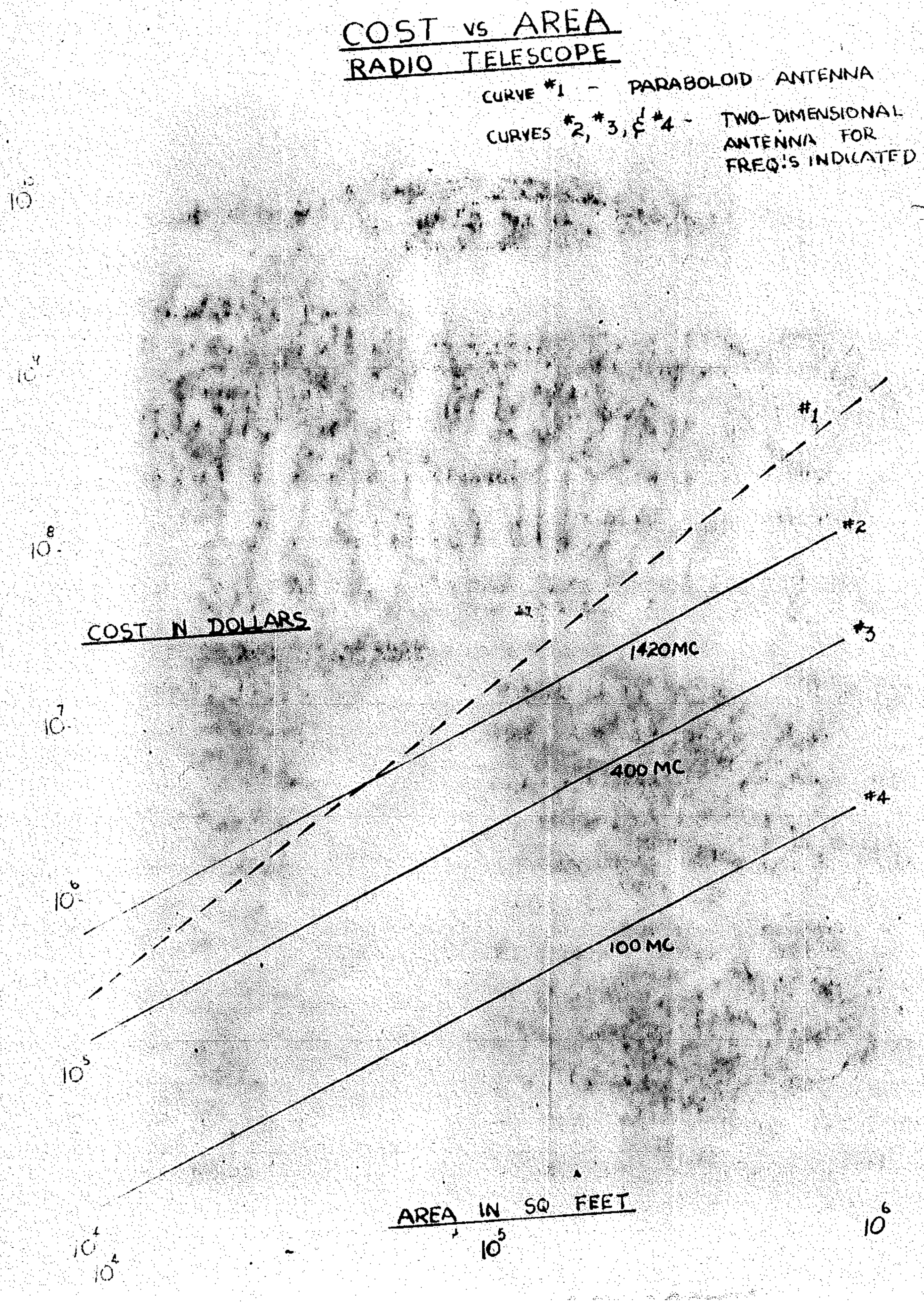
October 28, 1957


COST VS AREA
RADIO TELESCOPE
CURVE #1 - PARABOLOID ANTENNA
CURVES #2, #3, & #4 - TWO-DIMENSIONAL ANTENNA FOR FREQ'S INDICATED
COST IN DOLLARS
AREA IN SQ FEET
#1
#2
#3
#4
1420MC
400 MC
100 MC
10^9
10^8
10^7
10^6
10^5
10^4
10^5
10^6