THE LARGEST FEASIBLE STEERABLE FILLED-APERTURE TELESCOPE

J. W. Findlay

INTRODUCTION

Discussions of the possibilities and uses of a large filled-aperture radio telescope have taken place over many years, and have been referred to for example in the report of the Pierce Committee (summarized by Keller in the Astrophysical Journal, Vol. 134, p. 927, November 1961). More recently, a report entitled "Ground-based Astronomy, A Ten-Year Program" has been prepared by the Panel on Astronomical Facilities for the Committee on Science and Public Policy of the National Academy of Sciences. This report was published in 1964 by the National Academy and is often referred to as the "Whitford Committee Report" after the name of the chairman, Prof. A. E. Whitford of the Lick Observatory. The report recommends a quite detailed plan of development for astronomy generally, and specifically (pages 56-57) proposes that a design study for a very large steerable paraboloid be undertaken.

When it was evident that the present program at the NRAO for building and bringing into use large parabolic dishes (300-foot transit telescope, completed October 1962, 140-foot equatorial nearing completion, January 1965) was approaching the end of its first phase, the time was clearly ripe to consider the possibilities of designing a very large instrument. A meeting of a representative group of radio astronomers under the chairmanship of Prof. G. Westerhout of the University of Maryland was held at Green Bank on October 30, 1964. The report of the group (reproduced as Appendix A) was brief and to the point; it concluded:

> "Summarizing, the meeting gave the NRAO a mandate to undertake a feasibility study of a steerable instrument with a circular beam, a diameter of at least 600 feet, useful down to 18 cm, and hopefully down to 10 cm."

The present note is intended to outline a plan which NRAO might follow in undertaking such a feasibility study. It is naturally evident that such an outline cannot be definitive, but can serve as a framework for work and discussion.

FACILITIES AVAILABLE AT THE NRAO

Limited funds have already been provided to the NRAO from the National Science Foundation for studying new antenna designs and concepts. These funds are needed for the present study, but must meet in addition the task (to which both the Whitford and the Westerhout Committees attach a higher priority) of developing a major high-resolution instrument. However, requests for further funding for both tasks will be included in future NRAO budget requests in the hope that funding will be continued at a satisfactory level.

The staff at the NRAO, although limited, is able to provide immediately some scientific, engineering and administrative effort. This should be sufficient, when added to the help which is available from many in the field of radio telescope building, to make a start on the plan outlined. The study work at the NRAO would be very much helped if a young, versatile engineer could be found who would be willing to join the Observatory staff for this project. Such a man might have a bachelor's degree in mechanical or structural engineering; it is possible that a qualification in aeronautical or even ship-building might be equally useful. The task would need good scientific insight, and the ability to make good "order-of-magnitude" assessments in a fairly wide variety of engineering fields.

If any of the addressees of this note know of such a person, perhaps they would ask him to write to me at Green Bank, We could locate the design study work either at Green Bank or at Charlottesville in the first instance. After about December 1, 1965, it would definitely be at Charlottesville.

THE OUTLINE PLAN FOR THE FIRST YEAR

The following list of tasks should be undertaken. These are not in strict chronological order, although they probably should be done in about the order listed. We have also, under each task, sketched some of the things to be done.

(a) Uncover all reasonable possible configurations for the antenna.

These can be listed fairly well by considering existing instruments, designs already made, or ideas already discussed. In making such a list, the exact letter of the suggested telescope performance criteria will not be adhered to, to avoid, for example, rejecting too soon a good practical design for perhaps its one poor performance feature. Table 1 is a first attempt at such a list of possible configurations.

(b) Evaluate a selected number of the configurations listed.

The first emphasis should be on making a first-order comparison between the probable performance and cost of the best-looking "unconventional" designs. The object of this should be to find, if it exists, at least one unconventional design which is generally superior to the others. Tests of superiority should rest on applying uniform standards to the estimated performance of the instrument -- sky cover, upper frequency limit, beam shape uniformity, polarization performance -- and its estimated cost.

At this stage the problems of cost-estimating arise. In a first-order study they can be met by setting up a basic cost list against which all instruments are priced. Such a list would give information of the following kind:

Cost of simple, light structural steel, erected up to k feet above the ground	\$A per ton
Cost of similar steel above k feet from the ground	\$B per ton
Cost of machinery steel	\$C per ton
Foundation costs -- reinforced concrete in the ground	\$D per c. yd.
Foundation piles	\$E per ft.
Earth moving	\$F per c. yd.
Drive machinery	\$G per H.P.

Special items, such as control and indicator equipment, in any design would have to be priced separately, but a schedule of the kind outlined would give a good first impression of the relative costs of the various concepts.

The end of (b) should be that hopefully one or more of the unconventional designs are found to be reasonably feasible.

(c) <u>Study and evaluation of the conventional designs.</u>

Some of these designs exist as telescopes; some like Sugar Grove were designed in detail and would repay a very close study. The NRAO and others have carried out considerable design work of fully steerable dishes up to 100 meters diameter. Before undertaking any further design, a uniform comparison of existing designs, giving performance and estimated costs, must be made.

(d) Ancillary information needed.

At this state of the preliminary study several items of information become necessary. For example, for radomes:

(i) What is the feasibility, performance and cost of large radomes?

(ii) To what extent is the design of the more conventional instruments dictated by wind and weather?

(iii) Is the radome worth its cost?

Such radome studies are already being undertaken by the New England group, and the results of these studies will be needed in the present work.

Considerable work and study have gone into the effects of wind on large structures (New York Academy of Sciences Conference 1964), but the results need review and there may well be a need for further experimental work.

The present information of the gravity deflection patterns of dishes needs to be unified. The accuracy of good deflection analysis by STAIR and FRAN programs has been proven, for example, on Haystack. It would be even better if a cheaper method could be found and checked against other methods and against measurements. This analysis should be applied to various dish designs to:

(i) Confirm that we can make a reasonably optimum design

(ii) Determine at what size and upper-frequency limit the need for control of the surface shape becomes critical

(e) First draft of performance specifications.

By this stage one or more of the unconventional designs should still be in the race, and it seems certain that at least one of the conventional designs will be still practicable. In the light of the information available, it should be possible to prepare performance specifications which both satisfy the astronomer and which the engineer can reasonably be expected to meet. These specifications would state the size for the dish and indicate the cost/size relationship at and above 600 feet. To get this, parametric studies are needed, but since these are expensive they would only be done for a limited number of concepts.

By this stage the study should begin to converge onto a design concept and a size and a first performance specification. Although it is difficult to determine the time scale of the study precisely, there seems reasonable hope that this stage could be reached by the early summer of 1966.

THE EVALUATION WORKING GROUP

If the plan outlined can be followed, we should be ready in the summer of 1966 to evaluate the study and to prepare the first design contract. A suggestion of how to do this would be to use an evaluation working group.

For 6-8 weeks in the summer of 1966, a group of scientists and engineers might be assembled at the NRAO. They would be drawn from those who have shown strong interest in the study phase. Their task would be:

(a) To choose the concept to be designed

(b) To make the first choice of size, upper-frequency limit, sky cover, etc., for the instrument

(c) Investigate and recommend on the choice of a suitable design contractor

(d) Prepare a report on the work, including first construction cost estimates for submission to the NSF.

J. W. Findlay

Reference LFSP/JWF/1

Green Bank, W. Va.

January 14, 1965

Table 1. Possible LFSP Configurations.

Conventional		Unconventional	
Type	Example	Type	Example
Dish on wide-based towers	Jodrell Bank 250-ft.	Spherical fixed reflector	Arecibo 1000-ft.
Dish on many large elevation wheels	Sugar Grove 600-ft.	Parabolic cylinder fixed reflector	U. of Illinois 400 x 600 ft.
Dish on floating towers	Ashton 300-ft. design for AFCRC	Kraus type antennas	Ohio State and Nancay
Dish on alidade	Rohr/JPL 210-ft.	Steerable plate antenna	AFCRC multi-plate antenna
Dish on small-hub mount	CSIRO 210-ft.	Zone plate antenna	Concept only at NRAO
Tensioned member dish and mount	Preliminary design by S. von Hoerner at NRAO	Floating sphere antenna	CSIRO suggestion--several years ago
Dish within a radome	Haystack	Luneberg lens antennas	Many military examples
		Fixed elevation az-rotating transit with spherical dish	North American Aviation proposal for Sugar Grove modification, but use spherical dish and corrected feed to give $\pm$ 1 hour of track

AD HOC MEETING OF RADIO ASTRONOMERS:

Largest feasible steerable filled-aperture telescope

Green Bank, October 30, 1964

Present:

R. N. Bracewell	A. E. Lilley
B. F. Burke	E. F. McClain
F. D. Drake	R. B. Read
J. W. Findlay	M. S. Roberts
D. S. Heeschen	G. W. Swenson
G. Keller	H. F. Weaver
J. D. Kraus	G. Westerhout

The main aim of the meeting was to discuss the question of whether this is the time to start thinking about a design study for a very large steerable telescope. The meeting was unanimous in its positive answer. A very much larger steerable telescope than those now in existence or in the design stage is certainly needed. Since the time between initial studies and the completed instrument is long (8 years?), the next step in large telescope design should be started now. The N.R.A.O. is willing, and the meeting considered the staff able, to undertake a feasibility study. It was emphasized that the studies for a very large array should not in any way suffer from this new undertaking.

After some discussion, it was decided that in order to make the telescope as universal as possible a more or less circular beam would be preferable. Thoughts will have to be concentrated mainly on some form of single-focus antenna, so that equipment from different observers can be easily interchanged. The steerability question was discussed at length and it was decided that a very considerable declination coverage would be most necessary. In particular, it was felt that both the Galactic Center and the Andromeda Nebula should be reachable, if at all possible. This requires a declination coverage of at least 70°, which in essence means a full declination coverage. The minimum coverage in right ascension should be at least one hour, in order to reach reasonable integration times. It was felt that a complete azimuth coverage was not necessary. One of the few fields in which complete sky coverage would be necessary is that of occultations. It has been shown that these can be more profitably observed at wavelengths longer than those for which the large telescope will be mainly used, and therefore would be better observed with an inexpensive special-purpose telescope.

The telescope under discussion here should still be reasonably efficient down to 10 cm, and in any case it should be fully operable at 18 cm.

The main discussion centered around the question of size. The Whitford Committee Report states that a design study should be made of the largest feasible, movable telescope; the present meeting was called to implement this point. Within the next 10 years, several telescopes with diameters of the order of 300 feet will be available. It is clear that with the present-day techniques, telescopes up to 450 feet are feasible. In fact, the initial studies of designs for this kind of diameter have been made. We are dealing with a feasibility study; therefore, our limits should be considerably higher. Although every increase in size is a step forward, the astronomers at the meeting were agreed that a step of at least a factor of 2 is a minimum for the largest instrument. Possible research projects for this telescope range through the entire field of radio astronomy and might even include a limited amount of planetary radar. In every single field, the highest possible resolution is required. It was therefore decided that the feasibility study should be of a telescope with a minimum diameter of 600 feet. This may well lead to completely new concepts in the construction.

As was said before, this study is secondary to the study of a very large array, which was the highest priority item in the Whitford Committee Report. Also, it has been assumed throughout the meeting that at least two steerable telescopes of the order of 300 feet would be available within the next five years, built either by groups of universities on the East Coast and the West Coast, and/or by the N.R.A.O.

Summarizing, the meeting gave the N.R.A.O. a mandate to undertake a feasibility study of a steerable instrument with a circular beam, a diameter of at least 600 ft., useful down to 18 cm. and hopefully down to 10 cm.