THE 65-METER HOMOLOGY TELESCOPE

1. Introduction

A fully-steerable radio telescope with a reflector diameter of 65 meters (213 feet) is being designed at the National Radio Astronomy Observatory. The instrument is intended to work at very short radio wavelengths, where there are at present no large telescopes in use or planned.

The first stage of this work, which is progressing well, should result in a design which establishes both the feasibility and the cost of the instrument. The goals of this design are to plan an instrument with the following specifications:

(a) The telescope will be an altitude-azimuth instrument 65 meters in diameter.

(b) Wheel and track azimuth bearings and conventional elevation bearings will be used.

(c) Elevation range — from the horizon to a few degrees beyond the zenith.

(d) Azimuth range — a total of 420°.

(e) Reflector system — to be used as either a prime-focus instrument with $f/D = 0.42$ or as a Cassegrain telescope.

(f) Short wavelength limit — the goal is to have operation at 3.5 mm wavelength with an RMS surface accuracy of 0.22 mm. This goal may be met only under benign wind and temperature conditions.

(g) Pointing precision — this should achieve 3 arc seconds under benign atmospheric conditions.

(h) The design should ensure no permanent deformation or damage to the telescope in winds of 100 miles/hour at the dish center.

(i) Equipment rooms, each about 10x10x12 feet, will be supplied at the vertex of the dish and just outside the prime focus.

2. General Description

Figures 1 and 2 show two outline drawings of the telescope. It is an altitude-azimuth instrument; one in which the whole structure rotates in azimuth on railroad tracks about a central pintle bearing. The reflector can be rotated about a horizontal elevation axis between two bearings carried at the top of the support tower. The telescope is driven in azimuth by electric motors geared to the wheels on the azimuth track and in elevation by motors geared to pinions which drive a gear rack on the elevation wheel. Control by a high-speed computer system will allow the telescope to slew, scan and track under servo-mechanism control at a wide range of rates and cover the whole sky.

The optics of the instrument can be either Cassegrain or prime focus. When used as a Cassegrain, the radio waves reflected from the main 65-meter parabolic reflector are reflected a second time at a much smaller diameter (12 feet or 3.7 meters) hyperboloid mirror (subreflector) which is near the focal point of the main mirror. The radio energy is thus focussed to the feed horn in the main equipment cabin in the center of the parabolic reflector.

For use as a prime focus instrument, the subreflector is removed and the energy is then collected by a feed horn in the equipment room at the vertex of the feed support legs.

This duality of methods of using the telescope is of great value, since for very short wavelength work the Cassegrain mode is most desirable while, if research is to be done at wavelengths longer than a few centimeters, the prime focus mode is generally more practical.

Much of the design work of the telescope uses classical techniques and need not be treated in detail. There are, however, a number of design features which are unique and which will permit this telescope to perform to the very high accuracy demanded by the specifications. These are now considered.

3. Special Features of the Design

The telescope design uses the principle of homologous deformation, or more shortly of "homology". Any massive structure must bend under its own weight, and if, as is true of the reflector of a radio telescope, it must be moved with respect to the gravitational force, it will bend to different amounts as it moves. Suppose, however, that the entire reflector supported at its elevation bearings could be so designed that the reflector surface is a true paraboloid of revolution both when the reflector points to the zenith and also when it points to the horizon. It would then be (no matter where it points in elevation or azimuth) a perfect radio telescope. It is known that this condition can be satisfied in practice provided we are willing to let the focal length of the reflector surface change. We also have to allow the direction of the telescope's radio beam to move in a slightly different way from the way the elevation axis rotates. When we achieve this result that the reflector surface keeps the same geometrical shape but only changes by a scale factor, we say that the deformation has been homologous.

This principle has been well-stated by S. von Hoerner and a method by which it can be applied has been developed and tested by him. It has been the basic technique by which the whole of the reflector structure has been designed. The method uses the well-established techniques by which stress and deflexion analyses of complex structures made up of elastic materials can be computed with a high accuracy. The programs developed by von Hoerner to make these computations are novel, and include many checks to ensure that the structural design which results is both practical and accurate. The results of these computations are checked independently by a firm of consulting engineers.

As a result of this design process, a reflector structure can be designed which will retain its figure despite the effects of gravity. This has been described by von Hoerner as "passing the gravitational limitation" in telescope design.

It is necessary to know very precisely (to within a few seconds of arc) where the radio beam of the telescope is pointed. Although homology neutralises the effects of gravity on the reflector performance, the whole telescope will bend under gravity, and the more conventional means of measuring its beam position — by using accurate angle measuring encoders on the azimuth and elevation axes — will show considerable differences between these axial position measures and the actual beam position. Other factors, such as wind forces, temperature differences, small movements of the telescope foundations or lack of exact levelling of the azimuth track, all result in position errors.

These gravitational, steady-wind and other position errors can be much reduced if the position of the structural axis of the parabolic reflector can be referred directly to a fixed reference system on the ground. This method has proved most useful in the Australian National Radio Astronomy Observatory's 210-foot telescope at Parkes, N.S.W., and it is also used in the NASA/JPL 210-foot at Goldstone and in the Canadian N.R.C. Algonquin Park 150-foot telescope. All these instruments have a central, independently founded tower, shielded from the sun and wind, which carries at its top the system which references the direction in which the reflector is pointing.

The same principle is being used in the design of the 65-meter telescope. The reflector axis will be referenced to a platform which is held in the position where the elevation and azimuth axes of the telescope intersect. This reference platform will itself be locked to remain fixed in azimuth and elevation as the telescope moves, and highly accurate encoders will measure the reflector position relative to this stable reference platform. Instead of mounting this reference platform on a central shielded tower, it will be held locked to the ground by a servo-control system which gets its error indications from beams of light transmitted in fixed directions from several stations on the ground around the telescope and reflected from mirrors on the reference platform back to the ground.

This position reference system is intended to reduce the pointing errors of the whole telescope to the very low values required. It has already been the subject of considerable design and test. A test stand of one element of the optical system has been built and has been operating at Green Bank for several months. This has demonstrated that the method will not fail because of irregularities in the atmosphere causing instability in the direction of the light beam. Further detailed design is in progress.

The provision of an accurate reflecting surface which will focus very short radio waves is challenging. It is accepted that, to work even adequately at a given wavelength, λ, the reflector surface must not on the average deviate from a true paraboloid by more than $\lambda/16$. (More precisely, the root mean square deviation (RMS) must be equal to $\lambda/16$.) If this performance were needed for work on the radio line of carbon monoxide (CO — which was recently discovered to exist in interstellar space by work at the NRAO 36-foot telescope on Kitt Peak), the telescope surface would have to be good to an RMS of 0.16 mm or 6 thousandths of an inch. However, the present design goal cannot reach this limit, and a figure of 0.22 mm is proposed. The telescope will work with reduced efficiency at the CO line.

Fabrication of reflector surfaces to this accuracy is possible; for example, the NRAO 36-foot telescope had an RMS accuracy of 0.1 mm when manufactured and in use appears to have an RMS of 0.15 mm as measured from its radio performance. The best manufacturing so far claimed for an antenna is an RMS of 0.05 mm (0.002") for the Aerospace Corporation 15-foot (4.6 meter) reflector. And, of course, large shapes are now quite routinely fabricated on digitally controlled machine tools to better than the accuracy required here.

Nevertheless, the challenge remains, since it is necessary to fabricate, check, install and adjust almost 40,000 square feet of reflector surface to this high accuracy. This must be achieved at a reasonable cost.

Already one method of fabrication shows promise. The telescope design allows of independent surface plates, each about 6x2-1/4 feet, to be used. Such plates have been fabricated at Green Bank; they have 36 internal adjustment screws and the surface can be set to the required accuracy (RMS about 0.06 mm) in a reasonable time. The screw adjustments are then locked in position. It is interesting to note that the recently completed RT-22 telescope (22 meters or 72 feet in diameter) recently built in the Crimea uses a similar kind of surface fabrication. An RMS of 0.12 mm is claimed for this Russian telescope.

This one approach to the panel fabrication appears to be hopeful, but a second avenue of approach is also being explored. This would accurately machine the panel support structure and then fix pre-formed metal sheets to conform in shape to the supports.

Methods for setting the surface panels on the reflector support structure to the required accuracy also seem to be within reach, although no fully-engineered and tested system yet exists. However, a fully-tested Zeiss optical method already can give a measurement RMS of 0.15 mm, and a whole new range of optical distance measuring instruments is now appearing on the market which promise to provide the required accuracy.

4. Further Factors Which Affect Precision

Two further factors which can affect the performance of a very precise radio telescope are the effects of the variability of the wind forces on the instrument and the structural deformations resulting from changes in temperature of the whole or of parts of the structure.

The telescope is planned to be exposed to the atmosphere. Although the protection of a radome would simplify some design problems, there appears to be no ways in which such a radome could be built and yet preserve the performance of the instrument over its wide range of millimeter wavelengths.

The main effects of variable wind forces on the structure are the disturbances to the pointing precision due to the inability of the servo drive to correct for the more rapidly varying wind torques and the deformations of the reflector surface due to its support structure bending in the wind. Both these effects can be calculated when the parameters of the telescope and the probable nature of the wind forces are known. Preliminary results of such calculations suggest that in winds with mean velocities below 17 miles per hour the effects will not limit the shortest wavelength performance. This in turn says that, when higher winds occur, observations must be restricted to the longer wavelengths which require less precision. Such statements can, when sites for the telescope are considered, be transformed into more quantitative estimates of the amounts of time at which the instrument can work at various wavelength ranges. For example, were the telescope now to be at Green Bank (which is, in fact, not a very probable site but is one where good wind statistics are known), winds would permit it to work at its shortest wavelength for 76% of the total time in any one year.

Thus, the wind forces limit the telescope, but in a fairly reasonable way. A similar result seems likely to be true for the effects of temperature and temperature differences.

The telescope only has its correct shape when all members are at the same temperature. Sunlight and shadow, radiation to a cold ground or from a hot ground, differences in the rate at which various parts of the telescope heat and cool, all these effects produce temperature differences across the structure. Such differences, by altering lengths of structural members, deform the dish. This shows as a loss of surface accuracy and, in some conditions, as a degradation in the pointing precision of the telescope.

Thus the basic questions are: What temperature differences are likely to occur and how would they distort the structure? Measurements have been made and are continuing on the telescopes at Green Bank which, together with calculations, will answer the first of these questions. The second can be answered by computing the changes in shape of the telescope structure when various possible regimes of temperature differences exist. Such calculations can be made using the computer programs which are used in the telescope design.

At present, results suggest that the telescope will, at its shortest wavelength, be close to a temperature difference limitation, in that no more than 2° F can be permitted to exist as a temperature difference between members before the shape of the reflector departs enough to spoil its performance at the shortest wavelength. Further work continues on these problems, both in considering ways of reducing the temperature differences and in estimating the climatic conditions under which the temperature effects will be minimized.

In general, however, it seems true that the design which is being worked out is one where the limitations due to gravitational deflexions, wind and temperature effects all begin to limit the telescope in about the same way. If this is true, it suggests that the general design goals are well-chosen and realistic.

5. The Choice of a Site

In searching for possible sites for such a telescope it is desirable to have two classes of criteria by which the location is judged. The first of these we will call "general" or "administrative" and it need not be discussed in detail. This class includes such items as proximity to cities and towns, access, availability of utilities and services, land ownership, political and administrative problems, etc.

The second class of criteria, the "specific" criteria, are those which will determine the overall performance of the instrument on its chosen site. These need careful definition and study, particularly to determine how much weight to give to the various items in the list. For example, the following criteria, and perhaps some others, need to be judged.

(a) Atmospheric clarity — i.e., radio-wave absorption, radio-sky noise and its fluctuations, cloud cover and precipitation as they affect radio observations, etc.

(b) Meteorological environment of the structure — i.e., wind and temperature effects on the telescope performance and the estimation of the fraction of the time that full-precision performance is to be expected. Possible survival limits due to wind, snow or ice.

(c) Astronomical requirements — i.e., the ability to observe well over the most important areas of the sky, such as most of the galactic plane, the galactic center and certain important extra-galactic objects.

(d) Radio interference — i.e., proximity to sources of radio noise which may now or in the future limit the telescope performance.

A site search is therefore a considerable task, since it may involve not only the collection and analysis of existing data but the development of means by which some of the criteria can be evaluated. A start has been made on this task, with most of the interest being directed to the general area of the Southwest of the United States.

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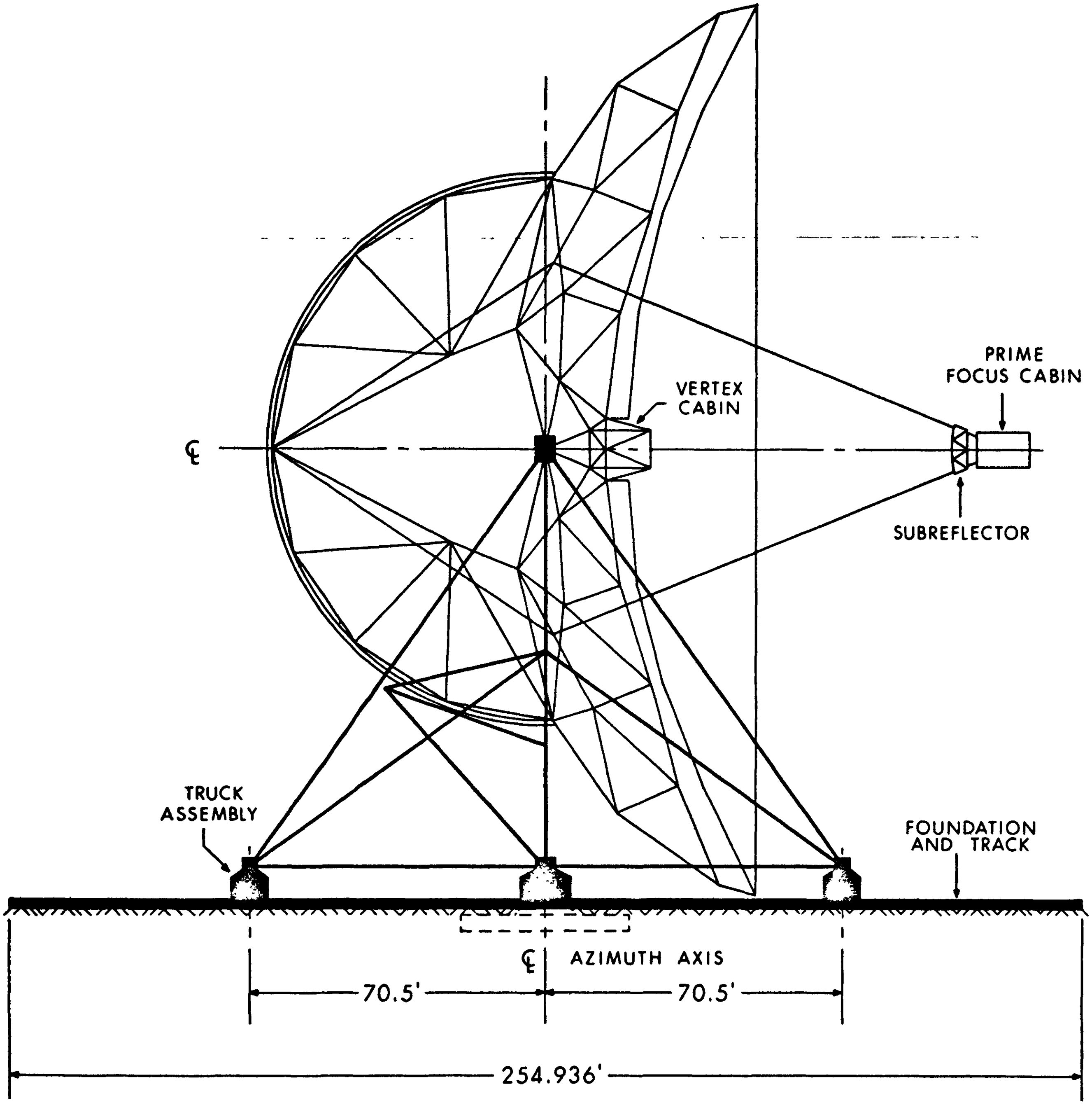

Figure 1: Outline Drawing of the 65-meter Telescope

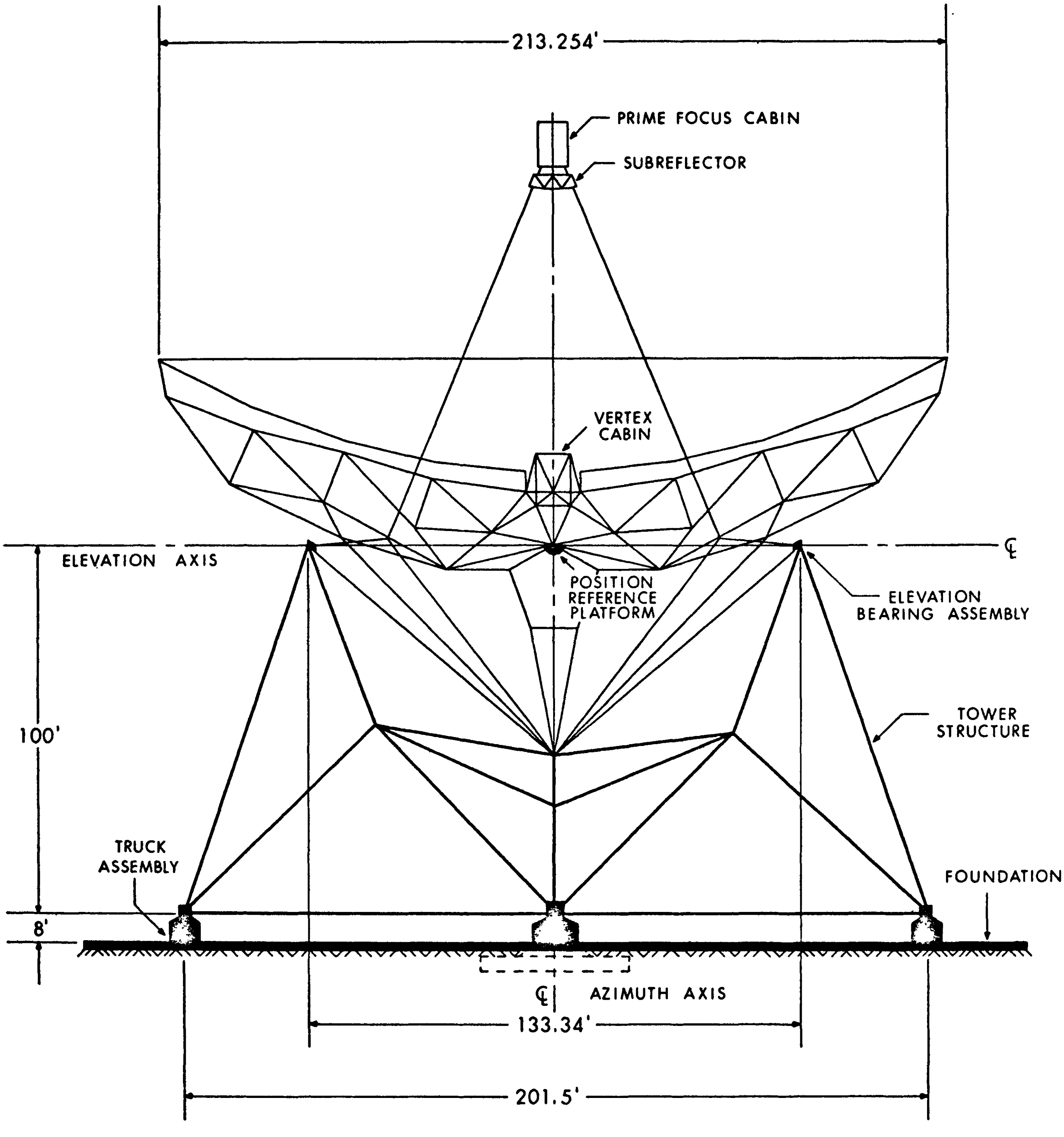

Figure 2: Outline Drawing of the 65-meter Telescope