From NRAO

August 3, 1959

Mr. G. A. Miller, Head
Microwave Section
National Research Council
Ottawa, Ontario, Canada.

Dear Mr. Miller,

Enclosed is a recent copy of an old memorandum I drew up before the present NRAO operation was undertaken. I haven't had time to make up any more sketches mentioned on page 8, but the description seems adequate.

During the past two years I have developed a design given on the enclosed synopsis. The size may be over ambitious. Perhaps a smaller one should be tried first. If the linear dimensions are divided by N the material in mirror will be divided by N^2 and volume of hole by N^3.

If you are interested further, perhaps we can get together and discuss details at a future date.

Sincerely,

Grote Reber

Encl.

APPENDIX

A-14-1

"Large Mirror Design"

by Grote Reber

12 March 1955

General Discussion

If a given structure is scaled up linearly N times, the mass of material required will be N^3 times and the bending encountered will be N^2 times. My design scaled up to 500 feet diameter will require 7600 tons and the roughness will be ± 1.3 inches. Thus, for a relatively small improvement in resolving power, a severe reduction in top working frequency will be imposed and a huge increase in material and cost will be encountered. Scaling up the Manchester design will produce even more absurd results; There are only five possible escapes from this situation.

I. Employ a material with a higher ratio of modulus of elasticity to density.

II. Use a deeper structure to give a better ratio of moment of inertia divided by length.

III. Incorporate more supports.

IV. Devise equalizers which will automatically compensate for changes in frame deformation with position and thereby retain the figure of the mirror at all positions.

V. Restrict the motion of the carriage so that less than the entire celestial hemisphere is available for observation.

I. Materials

Steel and aluminum are practically equal and are by far the best of the common materials. Some ceramics and carbides are immensely better than steel but such things cannot be used as structural materials. A slight gain may be secured by making the dead weight parts such as parapet, mirror skin and ribs from aluminum. This reduces the fixed load on the carriage.

II. Structure Depth.

This feature has been carried to about as large a ratio as possible in my design. It accounts for most of the improvement in performance over the Manchester design. A further increase will require disproportionately large side circles.

III. Supports

The swinging bill board on two pivots is the worst possible and only suitable for small mirrors. Some improvement is incorporated in my design which uses four supports.

IV. Equalisers

Equalizers may readily be designed to correct the mirror surface properly when the carriage is at positions 90° apart. However they must be checked at intermediate carriage positions to be sure they don't under or over correct. They are tricky, complex and expensive. Any appreciable use of them is fraught with uncertainty. An exact large scale working model should be built of any structure which proposes to incorporate equalisers to be sure they function in fact as expected on paper. My design uses two elementary varieties. They are not shown on the small model but their effects are included in the calculations.

V. Motion Restriction

Carried to an extreme, we have the fixed wire dish of Manchester. Any increase in mobility has to be paid for in complexity, mass and cost. Sometimes small parts of the celestial sphere may be left out of the observing area with relatively small loss in performance and a substantial reduction in cost.

A wide variety of compromises may be observed in the mounts used by optical astronomers since Galileo rested his hand instruments on a convenient wall. Huygens' long telescopes must have been shaky in the extreme. Herschel used a system where the sky swept by. Ross was able to track objects for a brief periodby moving the eye piece. Even the Hooker telescope omits the north polar region and the Hale telescope cannot reach the circumpolar stars at lower culmination. If any region is to be omitted in radio astronomy, it seems best to omit the first ten or twenty degrees of altitude where atmospheric vagaries are the greatest. Throughout the many years of optical astronomy the ratio of size of mount to size of objective has steadily increased, as larger and larger objectives have been produced. The same may be expected to occur in radio astronomy.

Focal Length

When the mirror is only a few wave lengths in diameter, it is necessary to keep the focal point apparatus small to prevent a big scatterer in front. A small focal apparatus can only produce a dipole field. This requires a short focal length and inherent poor efficiency of mirror. If a long focal length is used, the mirror efficiency increases but the focal apparatus efficiency decreases and a lot of radiation leaks in the sides of mirror. The system efficiency is the product of the mirror efficiency and the focal apparatus efficiency. I have discussed this in the literature over ten years ago.

When the mirror is many wave lengths in diameter a much larger focal device may be tolerated. A larger device may be designed to have an acceptance pattern with quite sharp edges. These edges may conform to the solid angle subtended by the mirror at the focal point. Thus the system has a high overall efficiency because the mirror is looked at uniformly over its entire surface and the focal apparatus looks only at the mirror. Very little energy can leak in around the edges of mirror. Such a combination may be more readily secured with a large focal ratio system, say f = 0.6 to 0.8, than when f < 0.5. The long focal length also makes the mirror more flat and easier to build. The ideal focal device should not look at all outside the mirror, look most strongly at edges of mirror and somewhat less strongly at center of mirror. The edge to center ratio will depend upon focal ratio and be larger for small focal ratios. Note: This produces high efficiency and high side lobes also!

Wind

Any design which has enough steel in it to provide small bending will be so strong that it cannot fail and so heavy that it cannot overturn even in a cyclone. However these matters should be checked on the final calculations. High winds are transient phenomena but they introduce large unbalanced forces. Consequently the mirror should always remain clamped tightly when not in use. Winds above 30 m.p.h. are rare in most places. Thus if the drive has sufficient power to control the mirror in a 30 m.p.h. wind, the machine may be operated for over 99% of the annual hours.

Considerable thought has been given to mesh versus solid skin. At velocities below 20 m.p.h. the air flow through a mesh will be laminar and considerable reduction in wind resistance will be achieved. At higher velocities the flow becomes increasingly turbulent. A blanket of slow moving air covers the mesh. A great mound of air piles up in front of the blanket and most of the oncoming air slides off the sides of the mound. Thus the entire structure looks like a dome to the wind, exactly the same as if the mirror were solid. In effect the mesh reduces the wind loading at low velocities when it is not needed and does no good at high velocities when it is needed. Any mesh fine enough to be effective at centimeter waves will be worthless for wind load reduction. To keep the bending small the mesh must be thick and supplied with many ribs. Altogether it seems best to use a skin of solid plate and simplify things.

Snow

Snow is a great menace because it introduces huge unbalanced forces. If the snow could be dumped off easily there would be little harm. However, often the snow is sticky and won't flow. I nearly wrecked my Wheaton mirror once this way. Several times I had dumped off a foot or more of loose snow. However in due time a heavy wet snow came down and froze tight. When I unclamped the mirror it became uncontrollable and ran through the stops at the end breaking off two legs of the parapet. After this experience the mirror was allowed to remain clamped in whatever position it happened to be until the snow went away. Any large mirror should be placed south of where there are frequent heavy snows or much time will be lost.

Corrosion

It is customary to cover buried line pipe in a tar and cloth wrap. This will not be satisfactory for above ground protection because the sunlight drives off the most volatile components and hardens the tar. Changes in temperature cause the tar to crack and water gets in with accompanying corrosion. The tar and cloth wrap also introduces a large dead load which is objectionable. Painting is an endless job as may be seen on any large bridge.

The best scheme of protection seems to be to thickly galvanize the whole framework. Then it should not require any attention for 30 years or more. Inquiry shows that members at least three feet in diameter and 40 feet long may be galvanized in one dip. There is also a portable kit which does a very nice on the spot job of galvanizing. It may be used to cover all the welds, touch up scars and provide general maintenance.

Corrosion is primarily due to two causes: industrial pollution (sulphur) and salt particles. Any large mirror should be kept away from large cities and the seacoast, or else taken up to a high altitude.

In Hawaii the salt content in the air decreases at 2000 feet to 1/10 the sea level value, to a small fraction of a percent at 5000 feet, and nil above this. At 10,000 feet black iron banding lying out for two years remained black. At sea level it would be a mass of rust in a few months. At 14,000 feet the climate is like the Gobi desert.

220-Feet Design

This design was worked out in detail. The size, weight, moment and bending of each member and every joint was determined both when the carriage was on its side and upright. The entire structure was checked for balance, wind stress and overturning. A complete parts list was drawn up and sketches made of fittings at each joint. All that needed to be done was make shop drawings. Inquiry was made to find out where the materials would come from, their approximate cost and who might be interested in erecting the structure and the best means. About 100 pounds of literature on this matter reposes in the attic at Wheaton, Illinois. I also carried the model around to about a dozen different government agencies and foundations. In general the response I obtained was "He's harmless, be kind to him and he will go away!"

The design of a structure like this is done by successive approximations. First each member is assumed either as an outright guess, or on the basis of previous information. Then the whole structure is worked through to see what the stresses and bending are. Suitable corrections to member size, shape and length are made and the process repeated. Finally a satisfactory design is secured. Unfortunately, for any major change in size or structure configuration, all the numbers change. Thus the old figures are only suitable for building a 220-foot mirror or to show the general method of procedure.

500-Foot Possibilities

The most practical scheme seems to be the application of more supports in conjunction with a restriction in motion. I have a modification of the 220-foot design which uses three vertical tracks for motion in altitude. The center track is somewhat larger than the outside ones. Each of the three tracks has three tracks of many wheels making a continuous row of wheels under each track. Thus three line supports are achieved, and the amount of material in the rim of the tracks may be greatly reduced. The turntable has a fixed pivot at the center and runs on two horizontal circular tracks respectively 350 and 500 feet diameter. The motion in altitude is limited from 15° to 90°. This should not be serious as the lowest angles near the horizon are subject to lots of atmospheric vagaries and are not particularly useful. No model has been built, nor details worked out. However, it appears that such a machine would probably weigh between 2500 and 3000 tons. The surface roughness should not be worse than the 220-foot design.

Possibilities Over 500 Feet

To get into this class it seems that an entirely different approach is necessary. Escape III must be exploited to a maximum. If the number of supports increases as N^2, then the mass of material increases as only N^2 for a design of constant bending. The situation is equivalent to building a table where the legs are all the same distance apart, however large the table may be. With this scheme the size appears to be unlimited. The attached sketches show a design for a 750-foot mirror. The hole in the ground is a hemisphere 3000 feet in diameter. Many circular concentric horizontal tracks line the side of the hole 50 feet apart in horizontal projection. A cradle pivoted at the center bottom of hole runs along the tracks and provides motion in azimuth. The top of cradle has many parallel circular vertical tracks also 50 feet apart. The mirror mounts on a carriage which runs up and down the tracks atop the cradle and provides motion in altitude from 15° to 90°. By this combination of interlocking tracks the mirror is actually supported every 50 feet both ways underneath.

Fixed Mirror

A parabola is reasonably approximated by a sphere with a radius of curvature twice the focal length of the parabola. The bottom of the hole may be lined with a conducting sheet like chicken wire for about 2/3 of the diameter of the hole. The focal equipment may be supported at one-half the depth of the hole by cables from the rim. Thus a fixed mirror 2000 feet in diameter may be secured in addition to an adjustable one 750 feet in diameter. The fixed mirror will have considerable roughness due to the tracks. These may be made to depart from a hemisphere to approximate a parabola of revolution over the bottom of the hole and thus improve the figure. Suitable changes will be needed in the underpart of the cradle. However the fixed mirror should be useful at meter and decameter waves both for radio astronomy and ionosphere experiments. Moving the position of the focal apparatus by adjusting the cables will provide beam swinging over an angle equal to about ten beam widths of the main pattern each side of the zenith. The beam will break up at greater angles. A graph of hole diameter/mirror diameter versus minimum altitude for a hemispherical hole is provided.

Hole in Ground

If a ready-made hole can be used the expense of the project will be greatly reduced. A number of possibilities exist. The meteor crater near Winslow, Arizona, is about 4500 feet in diameter and 600 feet deep. The bottom is full of loose rock and dirt which could be readily excavated. A somewhat better meteoric hole is Crater Elegante just across the border in Mexico. Both of these are dry all year around. Numerous volcanic craters are available. Puu Makanaka on the side of Mauna Kea, Hawaii, is a very symmetrical cone of about the right size. Equally nice ones could probably be found in continental America. Old quarries offer another possibility. The extra material removed to produce the correct shape may be piled around the outside top to build up the edge. It is even possible to make some money by selling the rock, if it is any good.

I favor the hole in the ground design because there is no wind problem and it is easy to build.

Whatever kind of an installation is made, it should be kept far away from electrical disturbances; at least two miles from highways and many miles from steel mills, tin can factories, carborundum works, television stations, etc.

Grote Reber

SYNOPSIS OF DISH DESIGN

Diameter = 1,000 feet, Focal length 300 feet. Motion ± 40° from zenith

Hole in ground = 1350 feet diameter, 550 feet deep, 700 feet radius.

Members		Tons Weight	Inches Maximum Deflection
Skin: #12 U.S. guage blackiron		1986	.159
Grid: U.S. section TCBJ6 and U.S. section CBJ-12		1145	.158
Cross Beams: U.S. section CB241		1380	.114
Longitudinal Beams: Built up beam 36" deep 134.6# 1 ft. similar to U.S. section CB361		1221	.100
	Totals	5732	.531

Weight on each 18" diameter wheel = 16 tons

360 pairs of wheels run on ASCE #4040 rail.

Each wheel driven by separate small motor.

45,000 ft. of rail required = 300 tons

200# / wheel = 72 tons.

Cost of steel work in place less than $500/ton

Cost of hole less than 10¢/cu. yd using nuclear explosives.

Parapet, foundation for rail and drive extra.

Grote Reber