NATIONAL RADIO ASTRONOMY OBSERVATORY
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25 METER - MILLIMETER WAVE TELESCOPE
REPORT # 8

# SURFACE PANELS AND MEASUREMENTS

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# SURFACE PANELS AND MEASUREMENTS

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## 1. History

The following telescopes which already exist work satisfactorily at wavelengths of 3 mm or less.

Table 1

Some Existing Millimeter-Wave Telescopes

| Telescope | Built by: in: | Surface Type | Accuracy | Notes |
|---|---|---|---|---|
| Aerospace 4.6 m | Rohr 1963 | Aℓ surface back-up. Machined whole surface. | 50 μ | Measured on machine. RMS checked by aperture efficiency. |
| U. Texas Mt. Locke 4.9 m | Philco-Ford WDL[1] 1963 | Invar sheet on Aℓ. Swept epoxy, gold plated. | 80 μ | Shape from sweeping. Checked by ground-range and source measurements. |
| NRAO Kitt Peak 11 m | Rohr 1965 | Integral Aℓ. surface and back-up. Whole surface machined (special machine). | 200 μ (using 10 dB illumination taper) | Measured on machine. RMS at manufacture about 150 μ. Edges of dish later were accidentally deformed. |
| Onsala Sweden 20 m | ESSCO[2] 1976 | Formed Aℓ sheet on A support | 160 μ | Panels each have 6 support points. whole telescope in radome. Panels measured at ESSCO. Set by tape and transit. |

Continued -

*Operated by Associated Universities, Inc., under contract with the National Science Foundation.

Table 1, continued

| Telescope | Built by: in: | Surface Type | Accuracy | Notes |
|---|---|---|---|---|
| Bell Labs Crawford Hill 7 m | Ford-Aerospace[1] 1977 | A356 Aℓ. Castings for panels and support. Surface numerically controlled machined. | 100 μ | Panels form an off-set paraboloid. Set in place using large template. |
| Cal Tech. OVRO 10 m | R.Leighton 1978 | Thin Aℓ on machined Aℓ honeycomb panels. Hexagonal panels all machined together. | 25 μ | Measured on the machine by various clever methods. Checked on site after erection. |

[1] Philco-Ford Western Development Laboratory, Palo Alto, California has changed its name a number of times. It is now Aeroneutronics-Ford.

[2] ESSCO, Electronic Space Systems Corporation of Concord, Massachusetts has built a number of telescopes, all in radomes. I list here only the largest.

## 2. Methods of Making Surfaces

The following general methods have been used in making surfaces:

(a) A conventional aluminum panel - This is a pre-formed Aℓ skin reinforced by a gridwork of structural members which are either pre-formed or machined to the correct curvature. The sheet may be fixed to the support members by rivets or by an epoxy bond.

As an example of this technique, which has been used by several manufacturers, the ESSCO panels can be quoted. ESSCO has devoted much time and effort on the manufacture of such panels. These panels, as measured in the plant, can achieve an RMS surface accuracy of about 60 microns.

(b) Machined contour Aℓ panel - This is the panel at present preferred by NRAO for the 25-meter telescope. A casting of the panel and stiffening ribs is made, stress-relieved and machined to shape on a numerically controlled (N/C) machine. NRAO has bought and tested several panels made this way. The Bell Labs (and some other dishes) have used such panels.

Tests show that a panel RMS of 40 microns has already been achieved. Good N/C machines may do better.

(c) Bonded Aℓ honeycomb panel - This uses an Aℓ honeycomb core sandwiched between Aℓ face plates. The panel edges are sealed. This construction has been much used on less precise telescopes, the basic technique being as follows:

(1) Locating the pre-formed aluminum face skin onto the mold.
(2) Applying a layer of adhesive to the skin.
(3) Locating the core to the skin.
(4) Applying a layer of adhesive to the back skin.
(5) Locating the back skin.
(6) Vacuum bagging the assembly.
(7) Placing the bagged assembly into an autoclave.
(8) Curing the assembly at 100 psi and 250° F to 350° F for about two hours, depending on adhesive selected.

The methods proposed by the UK and the MPI should be quoted here, since they are improvements of this basic techniques.

(i) The UK method. An accurate mold (made, for example, from cast iron) is machined for each ring of panels. It can, if necessary, be hand-finished. A typical panel is only 50x80 cm.

Rough machine the honeycomb to about the correct shape on one surface and crush this onto the mold using a flat plate.

Lift off the crushed honeycomb, stretch the Aℓ surface over the mold, release tension, put on a cold-setting adhesive.

Replace crushed honeycomb, then a thicker Aℓ skin, a second honeycomb slab and a final skin. Add adhesive at each step.

Put in a vacuum bag and let it set for ~12 hours.

The results, though not final, look good. Replication (to 10-20 $\mu$) has been achieved. Thermal cycle tests have been made with satisfactory results.

(ii) The MPI panel. The panels chosen by MPI for the 30-meter telescope are fairly large (1x1.5 meters) and two are to be carried on a single mounting frame. Each panel has a 4 mm thick Aℓ surface skin on the front, with a 40 mm thick core of Aℓ honeycomb. All bonds are by epoxy resin. The panels are formed in a conventional way (similar to that described at the start of paragraph 2(c)). Each panel is mounted onto its support frame at 9 adjustable points, so that there is some control of panel shape after manufacture and before erection. The frame with two panels is erected as one unit on the telescope.

(d) Mold-formed fiberglass panels - These are made by laying-up fiberglass on an accurate mold and curing the material while in contact with the mold. The reflector surface may be flame-sprayed Aℓ, put first onto the mold.

No very precise panels have been made this way, and the thermal behavior may be poor.

(e) The von Hoerner panel - This is fully described in Findlay and von Hoerner (1972). It would have been satisfactory in all respects (effects of wind, thermal behavior, etc.) for a $\lambda$ = 3.5 mm telescope (an RMS of 60 microns was easily achieved). There are doubts whether it can be used to get a 40 micron RMS.

(f) Panels based on carbon-fiber materials - Over the last ten years the use of carbon-fiber has greatly grown, and it is an attractive material for use in various parts of a millimeter-wave telescope. For surface panels its chief values seem to be:

(i) It is a high-strength material of moderate density.
(ii) It can be arranged in lay-up to have a very low thermal expansion (in at least two orthogonal directions).
(iii) It can start as a woven material and then be layed-up on a mold and cured in place.

NRAO has had some experience with small reflectors made in this way. A sub-reflector for the Kitt Peak 11-meter telescope was made using a carbon-fiber surface on an Aℓ honeycomb base.

The surfaces were bonded to the Aℓ with epoxy. The whole reflector is only 46 cm in diameter. Its shape conformed well to the mold. Its RMS of 25 microns is probably set mainly by the mold accuracy. It is light and of low inertia--important characteristics since it is used as a beam-switching device at 10 Hz.

To examine the problems and costs of manufacture of carbon-fiber panels for the NRAO 25-meter telescope, the Harris Corporation of Melbourne, Florida has been working on the design and fabrication of a typical 25-meter panel. The material chosen is a core of nylon honeycomb. Both surfaces are carbon fiber and the reflecting surface is 50 micron thick Aℓ. The process has been to lay-up the panel on a mold and cure the entire panel.

To reduce the cost of the experiment, only a moderately precise mold was made. The questions of greatest interest were therefore the degree to which the panels replicated the mold and each other.

Results suggest that for the three panels made from one mold:

(i) No panel replicated (agreed with) the mold.
(ii) The 3 plates did not replicate each other.
(iii) But two plates did replicate each other to about 30 microns.

(g) The Leighton surface - This is well-known and is a proven success. Basically it is 2(c) above, with the many improvements in machining and measuring introduced by Leighton. The method has resulted in 10-meter telescopes with a surface good at least to 1-mm wavelength and probably better.

## 3. Effects of Gravity, Wind, and Temperature on the Surface

Here I will restrict the discussion to effects on the surface panels or the surface itself and not deal with effects on the surface support structure. These latter effects are most important for millimeter-wave telescopes and must be analyzed separately for each case.

(a) Gravity and wind - Generally the effects of gravity and wind distorting the surface itself are small. They can easily be computed accurately enough. This may not be the case for panels with only three-support points in place of four since the rigidity of a plate against a twist is not high. (The use of triangular and rectangular plates has been studied by Von Hoerner.)

As an example, we give the expected departures from a perfect shape for a plate (N/C machined Aℓ casting) for the NRAO 25-meter telescope.

Table 2

Effects on a Cast Aℓ Panel of Gravity and Wind

| Condition | Change in RMS |
|---|---|
| Turn on gravity | 16 microns |
| Apply a 100 km/hr normal wind | 7 microns |

(b) Thermal behavior - The types of thermal environment which are most likely to distort surface panels are:

(i) Direct sunlight on the panel surface.
(ii) The surface facing a cold sky and the reflector rear facing a warm ground.
(iii) A rapidly changing ambient temperature environment.

To study the behavior of surfaces we should in principle transform (i), (ii), and (iii) above into:

(i) The temperature differences which are set up across the surface due to direct sunlight.
(ii) As (i) above--due to radiation to the cold sky and from the warm ground.
(iii) As (i) above--for likely changes of ambient temperature.

It will be realized that general answers cannot be given which describe the behavior of all types of surface. The treatment of the surface itself (by a temperature control paint), the thermal conductivity of the surface and its radiation and convection heat interchange properties all differ from surface to surface.

However, quite considerable work at NRAO and elsewhere has shown that for quite a variety of surfaces some values can be chosen for the temperature differences which arise which may be correct enough (within a factor of 2) to make a preliminary thermal analysis for any reasonable surface.

The types of measurement which have been made are:

Table 3

Temperature Differences on Telescopes

| Measurement | | Reference |
|---|---|---|
| (i) | Measurements on a spare 140-ft panel in sunlight and shade | (i)-(vi) are in: "Thermal Deformations of the 65-m Telescope", S. von Hoerner and V. Herrero, NRAO 65-m Report No. 37, Feb. 20, 1971 |
| (ii) | Sugar Grove, WVa temperature measurements | |
| (iii) | Thermistor measurements on the NRAO 140-ft | |
| (iv) | Thermistor measurements on the 85-ft | |
| (v) | Measurements on the Kitt Peak 11-m antenna | |
| (vi) | Measurements on a "von Hoerner" 65-m surface plate at Green Bank | |
| (vii) | Simulated radome tests at Green Bank Feb-Nov 1976 | 25-m Memo No. 86, S. von Hoerner, April, 1977 |
| (viii) | A 36-hour set of measurements made in the 22-m radome of the 13.7-m Brazilian (ESSCO) telescope | 25-m Memo No. 92, W-Y. Wong, May, 1977 |
| (ix) | Temperature measurements on aluminum with different surface treatments | B. Ufer and J.W.M. Baars, MPI Memo No. 34, 1978 |

Table 4

Skin to Rib Temperature Differences

| Condition | Front-Back Temperature: $\Delta T$ |
|---|---|
| Sunlight on surface | +2° C |
| Surface exposed to clear, cold sky | -2° C |
| Ambient changes in a radome at ±5°/hr | ±0.3° C |

We again note that these values are not correct for any panel, but may be used for first estimates of a panel behavior.

We can now compute the RMS errors arising from a given $\Delta T$. For a 25-meter plate we find a contribution of 18 microns/°C for the additional RMS due to a given $\Delta T$. Table 4 thus shows that some errors may be apparent in the NRAO 25-meter panels if they are in fact exposed to the sun or the cold sky.

We should also note experiments made by the MPI 30-meter designers at Stockert. They exposed test panels to radiant heat and found that the RMS increased by 6 microns per °C of $\Delta T$. This is in reasonable agreement with NRAO experience--bearing in mind the depth differences. (The MPI panel is about 4 cm deep and the NRAO plate about 8 cm deep.)

Finally, the control of temperature differences on surface panels by the use of a suitable paint is possible. However, some such paints can cause increased losses at millimeter wavelengths.

## 4. Methods of Measuring and Setting Surfaces

A summary of many methods is given in Appendix A. It is generally agreed* that to set the surface of a large telescope where individual panels have to be put in place on site, surface measuring and setting is a two-stage process. Stage one is to use one of the standard methods (range-angle, for example) to get a first order placement of the surface. Subsequent to this various methods are used or planned--each to suit the specific telescope to be set.

(a) Measuring individual plates -

(i) By an optical level.
(ii) By commercial three-dimensional machines.
(iii) The NRAO machine now under test.

* Leighton's method and others, such as the NRAO 11-m dish, are exceptions to this statement.

(c) The MPI system for the 30-m telescope

(d) Leighton's method

(e) The NRAO stepping method

(f) Radio-holographic methods

(i) Ryle and Scott
(ii) Anderson *et al.*
(iii) The NRAO 140-foot (August 3-10, 1980). Used 19.04 GHz from the Comstar satellite--elevation angle about 45° almost due south. Results not yet reduced.

## APPENDIX A

The following is a summary of most methods proposed or used for measuring antenna surfaces. Some general references are:

Mar and Liebowitz, "Structures Technology for Large Radio and Radar Telescope Systems", MIT Press, 1969.

IEE Conference: "Design and Construction of Large Steerable Aerials", Inst. Elect. Eng. (GB) Conference Pub. No. 21, 1966.

John W. Findlay (NRAO), "Filled Aperture Antennas for Radio Astronomy", Ann. Rev. Astr. & Astrophys., 9, 271-292, 1971.

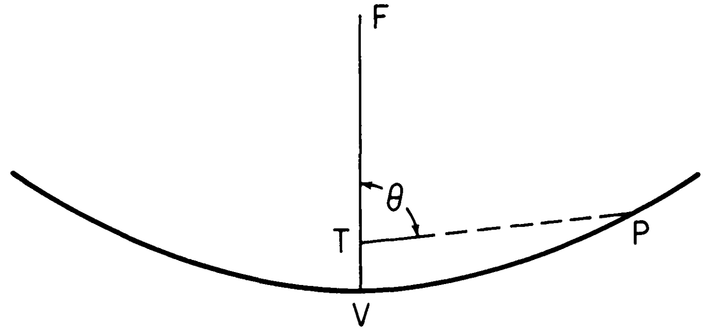
John W. Findlay and S. von Hoerner (NRAO) "A 65-Meter Telescope for Millimeter Wavelengths", NRAO Report, April 1972 (Library of Congress Catalog Card No. 72-90554).

A. Greve (MPI, Bonn), "Conventional Methods for Surveying Radio Reflector Surfaces", submitted to Zeitschrift fur Vermessungswesen.

# MEASURING ANTENNAS

1. Range Angle Measurements:

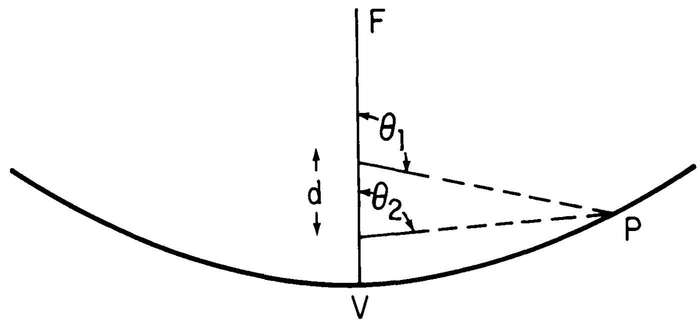
   Precision at best ~$10^{-5}$ D, where D is the reflector diameter.




| Method | Example |
|---|---|
| Tape and Transit. Measure θ and either TP or VP along the surface | Algonquin 150-ft antenna. M. H. Jeffrey in Mar and Liebowitz, pp. 226-230. |
| Tape and Pentaprism. Use several pentaprisms, one for each θ. Use tape as as above. | Raisting, Germany, 25-m antenna, C. Kuhne, IEE Conference, pp. 187-198 |
| Tape and Mirror. Photograph targets reflected in a mirror set at known angles. Automatic and rapid method. | Parkes 210-ft antenna. M. J. Puttock and H. C. Minnett, Proc. IEE, 113, 1723-30, 1966 |
| Tape and Photo-Theodolite. Photograph targets with photo-theodolite. | Effelsberg 100-m antenna. A. Greve, Kern & Co., Ltd., CH-5001 Aarau, Switzerland. Technical Report |

2. Angle Measuring Alone

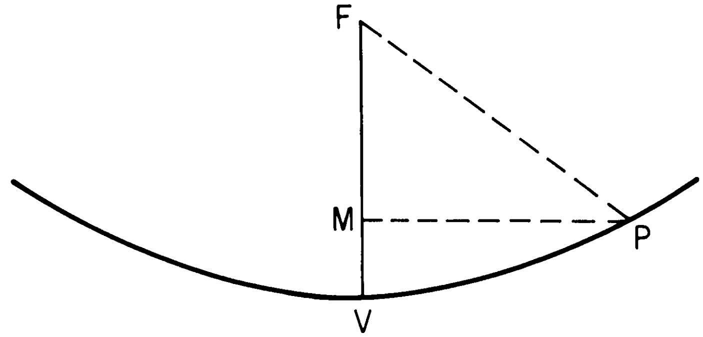
Photographic precision of $2 \times 10^{-5}$ D is possible. $10^{-5}$ D may be achievable. Range-finding precision is no greater.




| Method | Example |
| --- | --- |
| Range-Finding   Measure $\theta_1$ and $\theta_2$ and d. | A. V. Robinson, IEE Conference, pp. 75-79 |
| Photogrammetry. Photograph the reflector surface, after placing suitable targets on it, from several different points. Reduce the results from measurements of the photographic plates by high-quality photogrammetric techniques. | J. W. Findlay. Ann. N. Y. Acad. of Sciences, 116, 25-40, 1964.<br><br>Dba Systems Inc., P. O. Drawer 550, Melbourne, Florida 32901. |

3. Range Measuring Alone

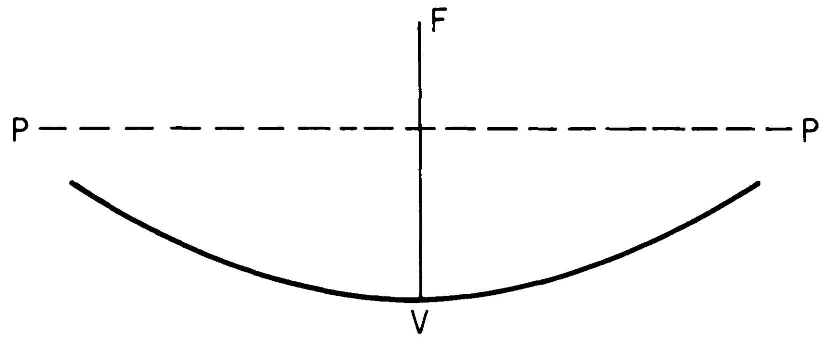
Modulated laser ranging can approach precisions of $2 \times 10^{-6}$ D. The laser interferometer may do twice as well.




| Method | Example |
|---|---|
| Measure ranges to P from a fixed point (V for example) over two paths of known but different geometry. For example, measure VMP and VFP. | System for the Arecibo 304-m reflector described by L. M. LaLonde, Science, 186, 213-218, 1974. |
| Has not yet been used for a full reflector survey, but a system has been built at Arecibo. | A modulated laser ranging system built and tested; J. M. Payne, Rev. Sci. Instr. 44, 304-306, 1973. |
| The UK proposal to measure a 15-m reflector describes a range-only system (one angle is held constant) using a Hewlett-Packard laser interferometer. | The UK system is described in B. D. Shenton and R. E. Hills "A Proposal for a UK mm-wave Astronomy Facility", Science Research Council, London 1976. |

## 4. Holographic Methods

General Principle. Radiate from a point source at F and measure the phase and amplitude of the reflected wavefront as it crosses an aperture plane PP.




| Method | Example |
|---|---|
| Holography. From a hologram by scanning the antenna through a point source and combine the output with that from a reference antenna. | J. C. Bennett et al. IEEE Trans. Ant. and Prop. AP-24, 295-303, 1976.<br>A. P. Anderson, J. C. Bennett, A. J. T. Whitaker and M. P. Godwin. Paper at 1978 URSI General Assembly, Helsinki.<br>See also M. P. Godwin et al. Electronics Letters 14, No. 5, March 1978, pp. 134-136. |
| Interferometry. Scan the antenna over<br><br>antenna combined as an interferometer, measure the complex reception pattern. The Fourier transform is the aperture amplitude and phase of the scanned antenna. | P. G. Scott and M. Ryle, Mon. Not. R. astr. Soc., 178, 539-545, 1977. |
| Two-Feed Interferometry. Measure the phase and amplitude around the focus in the focal plane using two feeds and a distant source. | Described in Shenton and Hills in the UK 15-m proposal, November, 1976.<br>S. von Hoerner, IEEE Trans. Ant. & Prop. AP-26, 857-860, 1978. |

5. Other Methods

| Method | Example |
|---|---|
| Phase-Sensitive Radar Ranging. Measure range by the phase of a returned radar signal sent over the path to be measured. | J. W. Findlay and J. M. Payne, IEEE Trans. Instrum. Measur. 23, 221, 1974. (Method used to measure range changes--not absolute range.) |
| Phase-Sensitive Sonar-Ranging. Essentially as above, using 40 kHz ultrasonic radiation. | C. G. Parini and P.J.B. Clarricoats, Electronic Letters, July 3, 1980, Vol. 16, No. 14, pp. 544-546. |
| Template or Machine Measures. Use a precise template or use the machine on which the reflector is made. | Often used successfully for reflectors of up to 11 meters in size. |
| Curvature Measurement. Measure the curvature of the surface along a radius and integrate twice to get the profile. | J. M. Payne, J. M. Hollis, and J. W. Findlay, Rev. Sci. Instrum. 47, 50-55, 1976. |
| Stepping Method. Measure the inclination of a bar of known length as it is stepped along a radius. | This paper. |