VLB ARRAY MEMO No. 3

A 25-m RADIO TELESCOPE DESIGN

FOR

THE VLB ARRAY PROJECT

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CONTENTS

SUMMARY

A new 25-m telescope design for the Very Long Baseline Array project is proposed. It is an instrument specifically designed for wavelength $\lambda = 7$ mm. Except at the most unfavorable condition when the sun is shining on one part of the tower, the pointing error due to wind or temperature is sufficiently small for the short wavelength observations. The design concept is similar to the proposed 25-m mm-wavelength telescope: an al.-az. instrument supported by a wheel and track tower, with the elevation bearings located at a large distance apart, so that the thermal and wind pointing characters are intrinsically better than the compacted design. The dish structure is light in weight, simple in geometry, and consists of mainly two types of steel tubings, suggesting that it might be relatively inexpensive to build. There is a large space behind the vertex for the instrument cabin. With some further design effort, it might be possible to keep this cabin stationary in elevation motion.

A TELESCOPE DESIGN FOR THE VLBA PROJECT

In 1967, S. von Hoerner pointed out the natural limits defining the best accuracies which radio telescopes could achieve through the means of "conventional" designs. He also stated that, in order to exceed those limits, one must use homologous optimization to overcome the gravitational limit, and use environmental controls to overcome the thermal limits. A quick review of this thesis showed that it is possible to design a 25-m diameter radio telescope to operate satisfactorily in wavelengths of 6 mm to 7 mm range without the extra investments in design optimization and environmental control. Of all existing 25-m radio telescopes in this country, the VLA design is the best in terms of operating wavelength. But the demand on the proposed VLBA telescope is about a factor of 2 more than the VLA telescope can provide. Hence, in order to have telescopes capable of observing in wavelength λ = 7 mm, a new design is needed.

There are two concurrent thoughts for the VLBA 25-m telescope design. The first is to use the existing VLA telescope basic structure and upgrade the surface plates and setting accuracies; the second is to have an entirely new design.

This report advocates the second approach, and proposes a new 25-m telescope design with better surface and pointing, which could be built with a cost less than the VLA telescope.

To compare with the VLA telescope design, the new design has about 30% less in gravity distortion, and about a factor of 3 less in thermal pointing. It could be less expensive to build by virtue of its simplicity in design and light weight. Again, in comparison with the VLA design, it has about 80% less in structural joints, 70% less in structural connections, and 40% less in weight. The dish structure consists of only two major types of steel tubing; both are standard catalogue items (there are some items, such as feed supports, elevation gear, etc., which would require special design efforts).

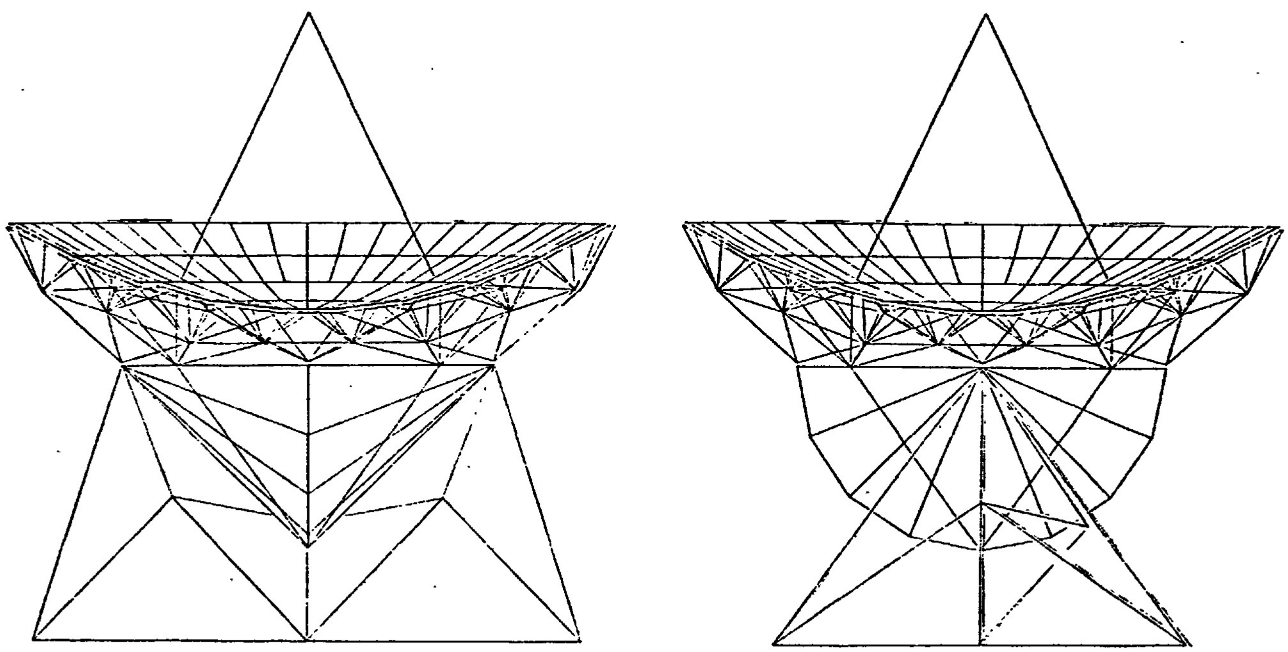


Figure 1. Two views of the proposed 25-m VLBA radio telescope. It is an al.-az. instrument, with the azimuth motion determined by a tower on wheels travelling on a circular track. It is designed to observe effectively in wavelengths λ = 7 mm during part of the day time with the normal thermal wind conditions. The vertex room, not shown in the drawings, is located below the vertex, between the two elevation bearings.

Figure 1 shows the two views of the proposed telescope with its tower structure. The design concept is influenced by the proposed 25-m mm-wavelength telescope, but the design is entirely new. The analytical model is done in detail, showing the acceptable gravitational distortion behavior and its ability to withstand heavy snow and high wind. The thermal and wind analyses are taken from the 25-m mm-wavelength telescope studies. These two telescopes have identical optical arrangements and overall physical dimensions. The thermal and wind behaviors should be similar. These analyses will be made in the future if the effort is justified.

The design provides a large space, approximately 4 meters in diameter and 2 meters high, to house the receivers in the Cassegrain system. The access to the vertex room should be easy due to the simple design of the base structure. With some further design effort, the room could be kept stationary in elevation motion.

To account for the surface plate thickness and adjustment screws, a distance of 200 mm is allowed between the parabolic surface and the structure.

In spite of its better surface and pointing characters, this new design would still be a pointing-limited instrument. In a typical sunny day, a four- to five-hour period during which the thermal condition is most unfavorable, the observations in λ = 7 mm would be possible only with a reduced efficiency. The peak thermal pointing is estimated to be about 15 arcsec, 25% the HPBW at λ = 7 mm, when the sun heats up half of the tower structure, with the other half in the shade. It is the tower which contributed most of the thermal pointing problem. Insulation of the tower would reduce this problem if the short wavelength observations are needed during the daytime.

THE ERROR BUDGET

Item	RMS Surface Error	
Surface Plate	0.28 mm	
Fabrication		0.20 mm
Temperature, dead wt.		0.20 mm
Deflection, etc.		
Measuring and Setting	0.20 mm	
Back-up Structure	0.27 mm	
Dead weight		0.20 mm
Wind		0.10 mm
Temperature		0.10 mm
Construction error		0.10 mm
RSS Total	0.44 mm	

Item	Worst situation noon, clear & calm sunny day	Average 0800 2100 hr sunny, no wind	Windy night 2200 0700 hr clear sky	Clear evening 2200-0700 hr calm
Servo and all corresponding error	4.0 sec	4.0 sec	4.0 sec	4.0 sec
18 mpd wind	--	--	7.1 sec	--
Temperature effects	13.9 sec	10.0 sec	0.5 sec	0.5 sec
RSS Total	14.5 sec	10.8 sec	8.1 sec	4.0 sec

THE SURFACE ERROR

The Back-up Structure's Gravitational Distortion

From the budget table, the surface distortion due to the gravity effects should be kept less than 0.20 mm rms. The two-step analysis, with the structure in stow position (g=-z) and in horizontal position (g=+y), showed the following results.

Table II. The departure from a paraboloid due to the gravity effects on the back-up structure.

Back-up str. position	rms surface error	dx	dy — mm —	dz	ϕx x10^{-5}	ϕy rad	ΔF mm
Zenith (g = -z)	0.26 mm	0	0	-6.06	0	0	+2.87
Horizon (g = +y)	0.26 mm	0	-1.19	0	-51.	0	0

The Calibration

If the telescope surface plates are set at zenith position Θ, the total surface error $H(\phi,\Theta)$ at any zenith position ϕ has the following expression:

$$H(\phi,\Theta) = \sqrt{H_z^2\,(\cos\phi - \cos\Theta)^2 + H_y^2\,(\sin\phi - \sin\Theta)^2} \qquad (1)$$

where H_z = 0.26 mm, H_y = 0.26 mm from Table II. Arbitrarily, the setting position is chosen at 40°. Then, the surface error due to gravity effects at each zenith position is predicted and listed in Table III.

Table III. The departure from a paraboloid due to gravity effect alone, but adding an advantage of setting the surface at 40° zenith angle.

Zenith angle (degree)	Surface distortion from the back-up structure (mm)
0	0.18
10	0.14
20	0.09
30	0.05
40	0.00
50	0.05
60	0.09
70	0.13
80	0.18
90	0.22
	rms error = 0.13 mm

Note that the gravity effect over the range of 90° is 0.13 rms after the calibration; it is smaller than the budget allows. The data in Table III are plotted in figure 2 as the solid line. The dotted line is the corresponding distortion curve of the VLA telescope, included for comparison purposes. The rms error of the VLA structure after the calibration in the same way is 0.21 mm. The proposed VLBA design is 38% better.

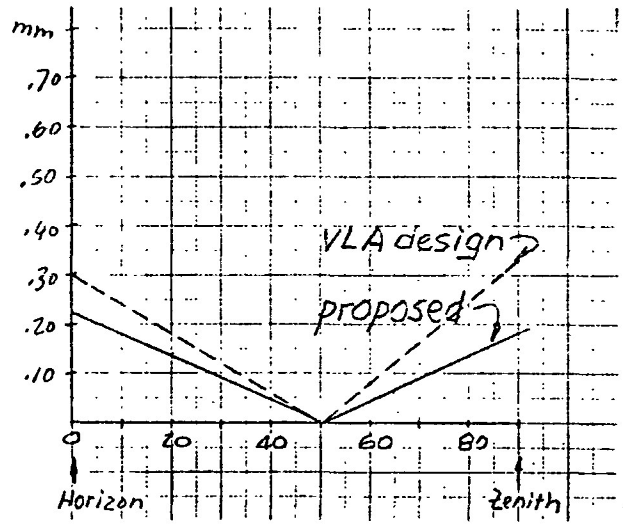


Figure 2. The distortion of the surface due to the weight of the back-up structure as the telescope tilts. The distortion is calibrated away at zenith angle of 40° by setting the surface plate to a "perfect" paraboloid. The dotted line is the VLA design, included for comparison purposes.

The Temperature Effects on the Structure

1) Temperature data - Two kinds of temperature data are required for the study of the thermal effects on the structure: temperature difference (ΔT) between any parts over the structure, and the time derivative of ambient air temperature ($\dot{T}$). Based on the past collections of these data, the highly stylized thermal data over a period of 24 hours are shown in figure 3. It is considered representative for a normal, typical cloudless day.

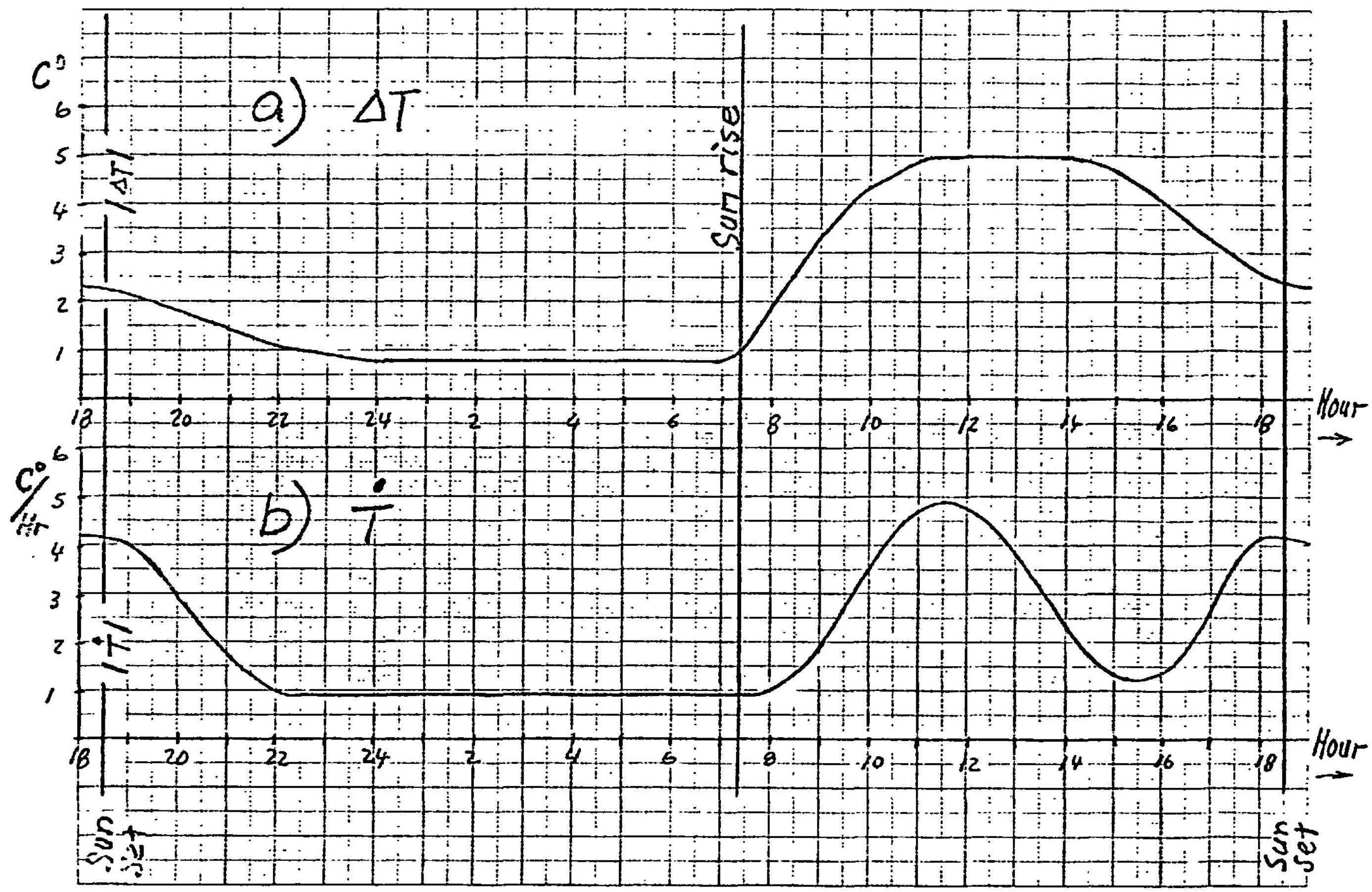


Figure 3. a) ΔT = Vertical temperature difference for the telescope structure.

b) $\dot{T}$ = The derivative of ambient air temperature.

2) Surface deformation due to 1° C temperature difference on the structure

Quoted directly from the analytical results of the 25-m mm-wavelength telescope studies, the result is summarized in Table IV. It is assumed that the telescope is not equipped with a temperature measuring device during operation, and that the defocusing effect is not adjusted away, but the telescope is calibrated before each observation.

Table IV. Influence of thermal gradient on the back-up structure without focal adjustment.

Loading	Surface error	dx	dy	dz	ϕx	ϕy	ΔF
			— mm —		10^{-5} rad		mm
$\Delta T_z = 1°$ C	0.016 mm	0	0	−0.01	0	0	--
$\Delta T_y = 1°$ C	0.000 mm	0	−0.02	0	−0.1	0	--

Taking half of the peak value (0.016 mm/°C) as the rms value, the surface error induced by a temperature difference of 1°C over the structure is

$$\text{rms } (\Delta z) = 0.008 \text{ mm/°C} \tag{2}$$

3) Surface deformation due to 1°C/hr change of ambient air temperature - Again, since this part of the analysis was not done, the closest information available is from the analysis of the 25-m mm-wavelength telescope. It is well justified for its similarity in size and design criteria. The new design consists of only 2 types of tubing, with the difference of wall thickness of 4 mm, which is within the design criteria (4.8 mm) of the mm-wavelength telescope to keep the thermal time constant less than 30 minutes. Table V shows the analytical data.

Table V. Influence of $\dot{T}$ effect on the back-up structure without focal adjustment.

Loading	rms surface error	dx	dy	dz	ϕx	ϕy	ΔF
			— mm —		10^{-5} red.		mm
$\dot{T}$ = 1°C/hr	0.040 mm	0	0	+0.013	0	0	0

Or,

$$\mathrm{rms}(\Delta z) = 0.040 \text{ mm/°C/hr} \qquad (3)$$

4) Surface error due to the combined temperature effects over a 24-hour period - Figure 3 represents the ΔT on a structure and variation of ambient air temperature on a typical day with clear sky. The temperature-induced surface error is a combination, based on these data and those analytical results given in equations (2) and (3). The following table shows the hour by hour surface error on such a typical day.

Table VI. Temperature effects on the surface on a typical day.

Hour	$\lvert\Delta T\rvert$	x8μm/°C	$\lvert\dot{T}\rvert$	x40 $\frac{\mu m.hr}{°C}$	combined surface error (mm)
18	2.3	18	4.2	168	0.17
19	2.1	17	4.0	160	0.16
20	1.8	14	3.0	120	0.12
21	1.4	11	1.8	72	0.07
22	1.1	9	1.0	40	0.04
23	0.9	7	0.9	36	0.04
24	0.8	6	0.9	36	0.04
1	0.8	6	0.9	36	0.04
2	0.8	6	0.9	36	0.04
3	0.8	6	0.9	36	0.04
4	0.8	6	0.9	36	0.04
5	0.8	6	0.9	36	0.04
6	0.8	6	0.9	36	0.04
7	0.8	6	0.9	36	0.04
8	1.9	15	1.0	40	0.04
9	3.3	26	2.0	80	0.08
10	4.4	35	3.5	140	0.14
11	4.9	39	4.7	188	0.19
12	5.0	40	4.8	192	0.20
13	5.0	40	3.8	152	0.16
14	5.0	40	2.4	96	0.10
15	4.7	38	1.4	56	0.07
16	4.0	32	1.4	56	0.06
17	3.3	26	2.7	108	0.11

In summary:

$$\begin{aligned} \mathrm{rms}(\Delta z) &= 0.10 \text{ mm} \\ \mathrm{pk}\ (\Delta z) &= 0.20 \text{ mm} \end{aligned} \qquad (4)$$

Structural Deflections Due to an 18 mph Steady Wind

The wind loadings are computed on the 25-m telescope design. Five cases with different wind directions were analyzed, and the results are listed in Table VII. The wind data were based on the wind tunnel test results published by JPL in 1962 (Internal Memorandum CP-4, "Load Distributions on the Surface of Paraboloidal Reflector Antenna" by Normal L. Fox).

Table VII. Effects on telescope surface due to an 18 mph steady wind.

Angle of Attack	RMS Surface Error
0°	0.02 mm
60°	0.05 mm
90°	0.01 mm
120°	0.02 mm
180°	0.03 mm

The averaged surface error over a range of 180^{o} elevation angle is

$$\mathrm{rms}\ (\Delta z) = 0.03\ \mathrm{mm} \qquad (5)$$

Surface Deformation Due to Construction Inaccuracy

Studies were made on the effects of fabrication tolerance, or the builder's inability to assemble a structure exactly as the plan called for. This is a practical problem, causing the telescope to differ from the analytical model by a distance. As a result, the surface accuracy also is affected. Analytical cases were made to simulate this problem.

A case for the proposed 65-m telescope was made so that all joints were mis-located in a random direction with a peak value up to 6 mm. Another case for the proposed 25-m telescope was made with the geometry error progressively increased from ground level in a random way in magnitude and direction, up to maximum values of 9 mm. Both cases showed that the effects on the surface are small.

Table VIII. Effect on the surface due to construction inaccuracy.

Case Study	Effect on the Surface
On 65-m telescope, with joints randomly mis-located up to 6 mm maximum.	0.03 mm rms
On 25-m telescope, with joints randomly mis-located, and progressively worse as a function of distance from ground level, up to 9 mm maximum.	0.01 mm rms

For this 25-m design, the error contribution due to constructional error adapts a value of 0.01 mm rms. The results in Table VIII shows that even for a precise instrument like the proposed mm wavelength telescope, the usual industrial practice is sufficient for the construction.

The Surface Plates

Referring to the error budget, a rms error of 0.20 mm was allowed for the fabrication tolerance, and another 0.20 mm for the deflections due to temperature and its own weight.

A review of surface plates of similar kinds showed that the demands of the plates are reasonable according to today's standard in both accuracy and size. Table IX summarizes the data on various plates.

Table IX. Surface plates of various designs.

Description	Surface Area of Each Plate (m^2)	Unit Wt. kg/m^2	Tolerance rms
ESSCO plate for the U-Mass 14-m telescope. Al. skin and rib construction.	2.36	10	0.10 mm
ASI deform. subreflector of fiberglass. Al. honey-comb epoxy construction.	7.90	10	0.19 mm
RSI plate for VLA tele-scopes. Al. skin-rib construction.	3.27		0.38 mm
Proposed VLBA plate.	4.42	10	0.20 mm

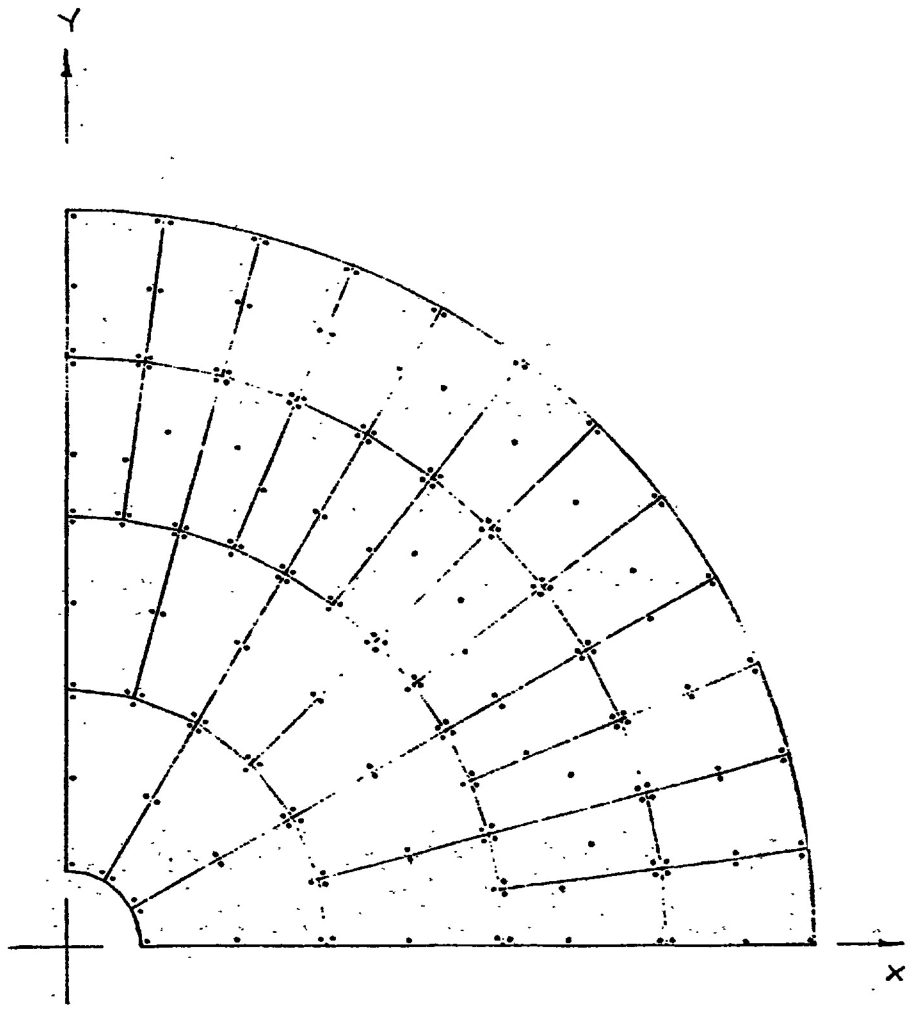


Figure 4. The surface plate arrangement shown in one quadrant. Each plate is supported at the four corners and at its mid-span. The adjustment screws, shown in dots, are arranged depending on the available supports from the back-up structure. There are 132 plates, and 788 adjustments in total. All adjustments are done behind the plates.

A proposed surface plate arrangement is shown in figure 4. Gaps of 1 to 1.5 mm should be provided between plates. The arrangement of adjustment screws, shown as dots, is also suggested. The suggested surface plate is large in size (about 1.6 m x 3.0 m) so that mid-span supports are needed to reduce the plate thickness without causing large dead weight deflections. Unlike the usual corner supports, the mid-span supports are located at the edge in some cases, and in the middle in other cases. These might add to the fabrication difficulties, but simplify the back-up structure design. All adjustments are done on the back side of the plates, made possible by the relatively simple and unobtrusive structure underneath.

It is suggested that the plates be fabricated of fiberglass epoxy-aluminum honeycomb construction. This kind of reflecting surface is common among the military and communication industries. It is light in weight, with a high stiffness-weight ratio. The 140-foot's deformable subreflector shows no noticeable sign of deterioration after two years of exposure to the environment plus constant flexure when used. On the other hand, it is suggested that an experimental plate should be made some time in the future to reassure the fabrication technique, accuracy, adjustment method, and the durability of the plate.

Measuring and Setting of the Parabolic Surface

The measuring and setting accuracies of ±0.20 mm required for a 25-m diameter telescope require no further research or development effort. A review of the existing measuring techniques used on various telescopes showed that the given demand is a reasonable and attainable one. If the new technique of stepping method is developed into a working version, the measuring error could be reduced by a factor of 4, or to ±0.05 mm.

Table X. Surveying method used on various telescopes.

Telescope	Method	Accuracy
140-foot	Stepping method	0.40 mm
36-foot	Stepping method	0.05 mm
25-m VLA	Theodolite, tape	0.46 mm
25-m Raisting	Range-angle	0.20 mm
34-m Werthoven	Range-angle	0.20 mm
Proposed 65-m	Range-angle	0.13 mm
Proposed 25-m	Stepping method	0.04 mm
Proposed 30-m	Laser interferometer	0.05 mm
Proposed 15-m	Laser interferometer	0.02 mm

The most attractive approach for the telescope would be the stepping method. The more conventional way of using pentaprism and tape could be considered as an alternative. The error of ±0.20 mm allowed for the measuring is a pessimistic one if the stepping method is used.

Once again, it is interesting to review the telescope's surface error by including all the contributions (shows as the solid curve in figure 5) over the range from zenith to horizontal positions. The VLA telescope structure with upgraded plates and better setting accuracies is shown as the dotted curve in figure 5. As far as the surface accuracy is concerned, the VLA design is an acceptable one.

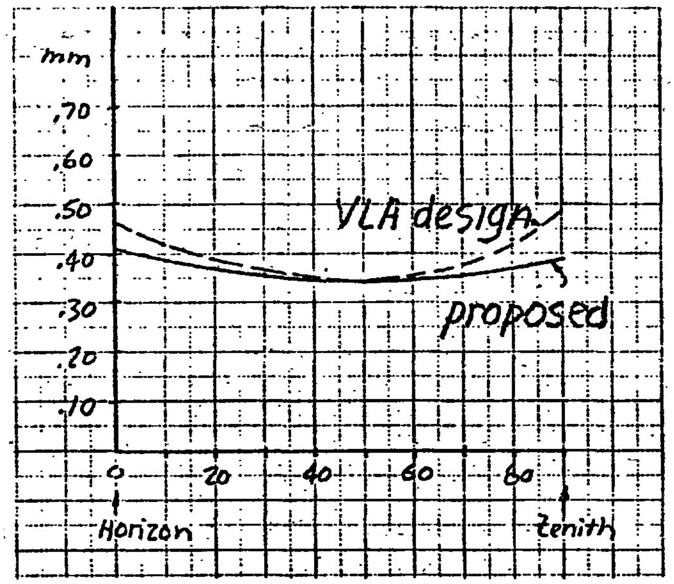


Figure 5. The telescope surface error under no temperature effects and no wind loading. Even with the combined temperature or wind error of 10 μm rms included, the change of the curve would be very slight. The solid curve denotes the behavior of the new design, and the dotted one corresponds to the VLA design.

THE POINTING ERROR

The Wind Pointing

The following analytical results on the tilts of the beam caused by wind were based on the detailed studies of the exposed 25-m mm-wavelength telescope. These results are considered acceptable because of the similarity of the two telescope designs, plus their identical towers. The wind data were based on the wind tunnel tests published by JPL in 1962 (Internal Memorandum CP-4, "Load Distributions on the Surface of Paraboloidal Reflector Antenna" by Norman L. Fox). Five wind loading conditions were computed and the results are summarized in Table XI. All studies were made with the elevation and tower structures as separate problems.

Table XI. The mechanical deflections and optical tilts of beam under 18 mph wind conditions on the reflector alone.

Angle of attack (deg)	Mechanical Deflections				
	Δm (mm)	αm (sec)	Δs (mm)	αs (sec)	αT (sec)
0	+0.076	+0.4	0.0	0.0	-1.6
60	-0.457	-4.8	+0.241	+18.2	-0.6
90	-0.330	-0.4	+0.278	+21.0	-1.4
120	-0.762	-4.0	+0.241	+18.2	-1.1
180	0.0	0.0	0.0	0.0	-1.0

Table XI (ctd.)

Angle of attack (deg)	Corresponding Optical Beam Tilts Δm (sec)	αm (sec)	Δs (sec)	αs (sec)	Sum	Mech. deflection of tower (sec)	Resultant beam tilt (sec)	Abs. value analytical results of VLA (sec)
0	- 1.2	+0.7	0.0	0.0	-0.5	-1.6	-2.1	16.0
60	+ 7.2	-8.6	+3.5	-1.6	+0.5	-0.6	-0.1	12.4
90	+ 5.2	-0.7	+4.1	-1.9	+6.7	-1.4	+5.3	*
120	+12.0	-7.2	+3.5	-1.6	+6.7	-1.1	+5.6	10.8
180	0.0	0.0	0.0	0.0	0.0	-1.0	-1.0	*

where

Δm = lateral shift of the main reflector

αm = rotation of the main reflector

Δs = lateral shift of the subreflector

αs = rotation of the subreflector

αT = rotation of the tower

* = data not available

J. Ruze formulated the tilts of the beam due to the optical characters and the mechanical deflections of the telescope parts. It was discussed in detail in his paper ("Small Displacements in Parabolic Reflectors", MIT, Lincoln Lab., Feb. 1, 1969). A summary of these formulas is included in Appendix 1 for reference.

It could be summarized from the above table that the 25-m telescopes' beam tilts in a steady 18 mph wind in the following ways:

$$\begin{aligned} &\text{rms (18 mph wind pointing)} = 4.1 \text{ sec} \\ &\text{peak(18 mph wind pointing)} = 5.6 \text{ sec} \end{aligned} \qquad (6)$$

The Temperature Pointing

The detailed analysis on the 25-m mm-wavelength telescope produced the mechanical deflections on various parts of the structure due to a unit thermal gradient across the dish structure. These results are listed in the following table. The results were then further expanded into the corresponding RF beam tilt according to J. Ruze's formulas given in Appendix 1. The following results represent only one idealized thermal gradient case: a ΔT across the aperture of the telescope between two extreme points.

Table XII. The deflection of the dish structure with the supporting point held undeformed.

Lateral shift of the main reflector	Δm = -0.022 mm/°C
Rotation of the main reflector	αm = $-9 \times 10^{-}$ rad/°C or -0.19 sec/°C
Lateral shift of the subrelfector	Δs = +0.056 mm/°C
Rotation of the subreflector	αs = +1.7 sec/°C

Referring to Table VI, the temperature difference over a 24-hour period on a typical sunny day can be separated into the following cases:

$$\begin{aligned} &\text{Case 1:} \quad \Delta T \text{ (peak)} = 5.0^{\circ}\text{C} && \text{day, noon} \\ &\text{Case 2:} \quad \Delta T \text{ (avg. over 0800–2100 hr)} = 3.6^{\circ}\text{C} && \text{day, average} \\ &\text{Case 3:} \quad \Delta T \text{ (avg. over 2200–0700 hr)} = 0.8^{\circ}\text{C} && \text{night, avg} \end{aligned} \tag{7}$$

From Appendix 1, Table XII, and equation (7), the beam tilt θ_T on the reflector alone is as follows:

Case 1: θ_T = 3.4 sec rms peak

Case 2: θ_T = 2.4 sec rms daytime average (8)

Case 3: θ_T = 0.5 sec rms nighttime average

Additionally, the analysis of the tower structure yielded the following results:

$$\alpha T = 2.1 \text{ sec/°C} \qquad (9)$$

By combining (7) and (9), the mechanical deflections αT on the tower alone are:

Case 1: αT = 10.5 sec peak

Case 2: αT = 7.6 sec day, average (10)

Case 3: αT = 0 sec night

During a calm evening, the temperature difference on the structure appears to lie in a vertical direction due to the air temperature stratification. Hence, Case 3 produces no differential deflection on the tower's bearing supports, but could still affect the dish structure since the dish is most unlikely in stow position.

The thermal pointings of the telescope could then be summarized and listed in Table XIII.

Table XIII. Thermal pointing of the telescope during a typical sunny day.

Case	Beam tilt dish structure (8)	Beam tilt tower structure (10)	Combined
Peak, at noon, worst case	3.4	10.5	13.9 sec
Average during day (0800-2100)	2.4	7.6	10.0 sec
Average during night (2200-0700)	0.5	0	0.5 sec

Steven Spangler's measurement on the tilt of yoke on the VLA structure showed at the peak ($\Delta T = 5°C$), the amount of tilt was 50 arcsec, compared with the corresponding 10.5 arcsec tilt. The worst thermal pointing of the VLA telescope is about 5 times higher.

APPENDIX 1

Pointing Error of Cassagrain System for the 25-m

The pointing error of a Cassegrain System is a combination of beam tilting caused by

1) Lateral shift of the best fit paraboloid Δm, the tilt of beam is

$$\theta_{\Delta m} = -(BDF) \frac{\Delta m}{fm} \tag{1}$$

2) Rotation of the best fit paraboloid αm, the tilt of beam is

$$\theta_{\alpha m} = + (1+BDF) \quad \alpha m \tag{2}$$

3) Lateral shift of the subreflector ΔS, causing the tilt of beam,

$$\theta_{\Delta s} = +(BDF) \frac{\Delta S}{fm} (1 - \frac{fs}{L}) \tag{3}$$

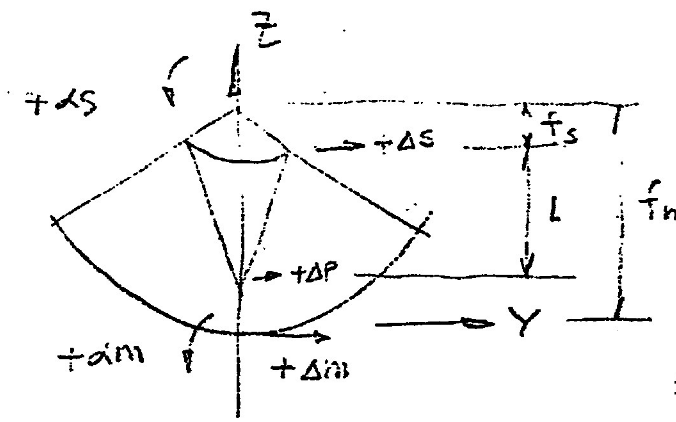
4) Rotation of the subreflector αS causing a tilt of the beam

$$\theta_{\alpha s} = -2 \times BDF \times \alpha S \times \frac{fS}{fm} \tag{4}$$

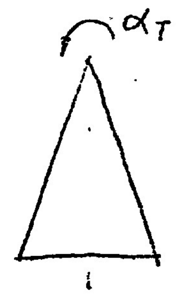
5) Lateral displacement of the Cassegrain receiver and its corresponding tilt of beam,

$$\theta_{\Delta p} = -BDF \quad \frac{\Delta P}{L} \frac{fs}{fm} \tag{5}$$

The geometry and the sign convention are shown in the following figure:



Reflector



Tower

fm = 10,500 mm

fs = 589.3 mm

L = 9,310.7 mm

BDF= 0.8

With the given geometry and equation (1) through (5), the combined tilt of beam is as follows, with displacement in mm and sec.

$$\theta_T = \theta_{\Delta m} + \theta_{\alpha m} + \theta_{\alpha s} + \theta_{\Delta P} + \theta_{\Delta S}$$

$$= -15.695\ (\Delta m) + 1.8\ (\alpha m) + 14.702\ (\Delta S) - 0.09(\alpha S) - 0.993(\Delta P)$$

APPENDIX 2 - WEIGHT OF VARIOUS COMPONENTS

Estimated weight of the 25-m VLBA Telescope

Elevation structure	Kg	
Surface plate	5,800	
Back-up structure	54,600	
Counter weight	10,500	
Subreflect and focal adj.	1,000	
Subtotal		71,900 Kg
Azimuth structure		
Tower	37,300	
Elev. brg.	500	
Elev. drive	1,800	
Az. drive	1,800	
Subtotal		41,400 Kg
		113,300 Kg
		(250,000#)