25 METER -- MILLIMETER WAVE TELESCOPE

MEMO # 3

THE NRAO 25-METER TELESCOPE: 2ND STATUS REPORT

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A committee was formed at NRAO in March 1974 to consider the feasibility of building a 25m telescope which would operate well at λ 1mm. The first report of the committee (March 27, 1974) summarized the initial problems requiring solution. In this second report, we summarize areas of progress, and remaining questions, as they appear after one month's work by members of the committee.

The basic conclusions reached after one month are as follows:

1) we can achieve a 25m telescope good to λ/16 at 1 mm wavelength, although just marginally, and at present only under conditions of no wind and no thermal gradients (i.e. inside a radome).

2) we anticipate, with further stiffening of the telescope structure, that λ/16 performance at 1 mm wavelength can be achieved under 18 mph winds, and under the temperature gradients that exist at night, but not under sunlit conditions.

3) we are investigating a novel form of astrodome which appears to meet structural requirements. There are questions about how to support the fabric over its 80 x 100 ft aperture, and whether or not the aperture fabric could be made removable for some observations.

4) if the above astrodome proves unfeasible, spaceframes larger than we need can be easily built and deliever no more than 1 db loss (blockage + fabric loss) at λ 1mm.

5) several fabrics have been tested and look satisfactory both electrically and structurally. One fabric may yield no more than 1 db loss to 400 GHz or beyond.

6) the best sites appear to be Mt. Lemmon or Kitt Peak, when a compromise is made between adequate atmospheric conditions and good logistics.

I. TELESCOPE MECHANICAL DESIGN

The telescope, a scaled down version of the homologous 65m NRAO design, consists of five distinct components. 1) tower 2) backup structure 3) intermediate structure 4) surface plates 5) feed

W.-Y. Wong has made calculations for some of these components, based on a scaled-down version of the 65m homology telescope. We summarize the results for each component. More details can be found in Wong's report of 4/17/74.

TOWER

This structure supports the elevation ring and also provides the azimuth motion. At the intersection of the az and el axes we contemplate an optically-servoed platform that will compensate all of the deflections of the tower but not those caused by wind on the feed and dish itself, nor those arising from thermal deformations of the dish and feed which produce non-repeatable pointing and focus errors. A tower design is immediately available by scaling down the 65m design, which was for operation under winds up to 18 mph and temperature gradients typical of outdoor sunlit conditions. A somewhat lighter tower structure might be feasible if the telescope is protected by a dome.

BACKUP STRUCTURE

This includes the elevation wheel and all major suspension members (581 of them connected by 172 joints) that together define the 62 homology points for the present design. The backup structure design has been scaled down from the 65m design, not in a trivial sense, but in the sense that an initial scaled design has been optimized by computer with respect to the size, weight, number of structural members, etc.; in this study all the deflections due to gravity, wind, and thermal gradients are newly determined. These deflections depend partly on some of the input constraints of the geometry and so in a sense define a "stiffness" for the structure. If this stiffness is desired to be increased, a different homology structure must be analysed, with significant additional computational effort.

The present design is only for Cassagrain optics.

The backup structure design is governed by three factors: a) homology solution; b) survival in a 120 mph wind; c) elastic stability of each structural member. In a straight scaling, the sizes of the individual members turn out to be reasonable. The cross-sectional areas of these members are well-defined in the sense that, to satisfy homology, they are determined largely by the chosen dish size and accuracy and little by the survival load. Thus the telescope will maintain about the same weight (and cost) whether inside or outside a dome. So far, errors in the spherical joints which connect the members have not been included and estimates of these errors are taken directly from the 65m design (see below).

Under an 18 mph wind, directed at the most unfavorable angle (attack angle = 120°), the induced pointing error due to rotation of best-fit main reflector structure + lateral translation of subreflector + rotation of subreflector + rotation of tower is 9.5". This is a 3-sigma value, defined as the difference in pointing with and without wind. Thus the rms pointing error under 18 mph wind is 3.2". This is inadequate, since at λ 1mm the 25m telescope beamwidth is 10".

The surface rms error of the backup structure due to the same 18 mph wind at 120° is calculated to be 0.0007 in.

Should we desire an outdoor telescope, it is possible to further stiffen the entire backup structure to reduce wind errors. We plan to do the appropriate calculations shortly, although they are quite extensive. We expect that the wind-pointing error will be reducable by a factor of over 2, as required.

INTERMEDIATE (PANEL) STRUCTURE

This refers to the structure upon which the surface plates rest, and which in turn rests on the backup structure. The intermediate structure has not yet been calculated as a separate part of the homology problem for the 25 m design. Instead, for error estimates, we have only scaled down the 65m intermediate structure. A full homology-type scaling down study will require a major effort. For initial feasibility studies a simple scaling down is adequte in the sense that the errors derived for the 65m telescope design can be directly taken over as a worst case. This worst case is used in the total surface rms error budget below.

One possible problem we may encounter in simply scaling down the 65m intermediate structure is that the member sizes may become too small (below standard manufactured tubing). If so a new structure with fewer, larger members may need to be developed. However, such a new structure will probably emerge from our subsequent detailed design of the intermediate structure, in which we anticipate that improvements in accuracy over the 65m structure will be attainable with fewer members and lower cost.

SURFACE PLATES

The deformation and initial achievable accuracy of this item is an independent question from the foregoing, in that surface plate accuracy cannot be designed, it must be achieved by advanced manufacturing techniques. The areas of concern are the initial machining accuracy, and how well the initial surface maintains itself over long periods of time against effects of creep. Philco-Ford claims they can initially achieve 0.7 mils rms for 5 ft plates such as used on Thaddeus' telescope. They are non-committal about what tolerances can be maintained over many years. For our error budget we have assumed 1.4 mils accuracy (see tables below). Note this does not include the effects of temperature gradients; however tests at Green Bank indicate a ΔT of 4 K produces $\sim$1 mil rms error. It also does not include limitations of setting accuracy on the telescope. Findlay and Payne are developing new measurement techniques which should allow no more than, and hopefully better than, 2 mils rms setting accuracy.

FEED

The feed motion due to deformation of support legs is an inherent part of the detailed homology calculation already performed. These errors are listed in the tables below. As mentioned above, we will do stiffening calculations on the feed as well as backup structure to reduce the pointing and focus errors caused by wind.

SUBREFLECTOR

The size of the subreflector is presently an open question. For at least some continuum work the subreflector must be able to nutate; a rate of 5 Hz is probably sufficient but this already limits the size. The subreflector must also be capable of being locked in position, to high accuracy, for some types of observing. The question of reflections of LO power from the subreflector, which cause baseline problems in spectral line work, may impose conditions on the subreflector size.

SUMMARY OF ERRORS FOR 25m HOMOLOGY TELESCOPE
(present "non-stiffened" design)

A) Wind-induced Pointing Error at 18 mph (worst angle) for Cassagrain Optics

--rotation of best-fit on main reflector	(3σ)	+7.0"
--lateral translation of subreflector	(3σ)	-1.6"
rotation of subreflector	(3σ)	+1.3"
--rotation of tower	(3σ)	+2.8"
total rms = sum/3		$\boxed{3.2''}$

This error is unacceptable for λ 1mm operation. However it can be significantly reduced by further stiffening of the backup structure and feed support (see above).

B) ERRORS in the Surface Accuracy

1) Deviations from Homology

	zenith	horizon (in.)
--structural design through homology optimization	0.00021	0.00010
--spherical joint errors	0.00060	0.00020
--manufacturing error (any homology pt. off by ± 0.25 in.)	0.00053	0.00033
--replacement with commercially available tubing	0.00024	0.00011
RSS	0.00086	0.00041
average rms	0.00067 in.	

2) Further Contributions to Surface Errors

		remarks
--deviations from homology (as above)	0.00067	
--gravity deformation of intermediate structure	0.0010	(a)
--fabrication tolerance of surface plates	0.0007	(b)
--gravity deformation of surface plates	0.0014	(a),(d)
--setting accuracy of surface plates	0.0020	(c)
--subreflector surface accuracy	0.0010	
total 1) + 2) RSS	0.00298 in.	

(a) taken conservatively from 65m design. With optimization this can be improved, probably by 50% , giving a total RSS of 0.00258 in.
(b) current specs stated by Philco-Ford
(c) Findlay-Payne machine under development (preliminary estimate)
(d) a recent calculation adding a third (midpoint) support gives 0.0008 in.

The above RSS should be compared with $\lambda/16$ at λ1mm, which is 0.00246 in.

3) Deformation due to 18 mph Wind at 120°

--sum of above no-wind contributions	0.00~~0~~298	
--surface rms due to steady wind	0.0007	(e)
--wind deformation of intermediate structure	0.0008	(f)
wind deformation of surface plates	0.0006	(f)
--wind deformation of subreflector	0.0002	(f),(g)
Total 1) + 2) + 3) RSS	0.00322 in.	

(e) calculated directly from homology optimization (a hard number

(f) assumed from 65m design; these are conservative estimates; although the 25m panels are presently expected to be the same size as the 65m plates, more homology points and intermediate structure points per unit area of surface plate apply to the 25m case.
(g) the focus deforms both radially and laterally, but the lateral contribution is included in the pointing error.

The total RSS so far (under wind load) is 1.288 times what we need for $\lambda/16$ at λ 1mm. Thus the RSS is $\lambda/16$ at λ1.29mm under an 18 mph wind.

4) Thermal Deformation (Effect on Pointing)

--clear sunny day	($\Delta T = 9^\circ$ F, $\dot{T} = 1.5^\circ$ F/hr)	3.3"
--clear night	($\Delta T = 1.5^\circ$F, $\dot{T} = 1.5^\circ$ F/hr)	0.9"

ΔT = largest temperature difference over entire structure.
These results are not calculated by Monte Carlo methods.
$\Delta T = 1.5^\circ$F is typical best conditions at night for 36 ft.

We will consider an optically-servoed coordinate reference platform (either of the type designed for the 65m telescope or possibly the type used at Parkes). Such a system will remove the errors due to tower motion but none of the other errors. In catagory A) of the Summary of Errors we see that the tower contribution is relatively small. Removing it reduces the total wind pointing error from 3.2" to 2.3", while we need to point to ~1" at λ1mm.

Both because of the large pointing errors and the rather large rms surface deformation, our current scaled-down 65m design will not operate as a 25m telescope at λ 1mm outside a dome. Further stiffening of the overall structure along with entirely realistic parallel improvements under catagory 2) above may well allow us to realize an outdoor λ 1mm telescope as far as effects of wind are concerned. There is at present reason to believe this will be possible. However, the thermal effects appear insurmountable. The telescope might be usable at λ 1mm at night outdoors but not during the day.* Thus, without a dome, contingency scheduling featuring rapidly interchangeable receivers (and multiple observing teams) would seem unavoidable.

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* the thermal time constant of the major telescope structure members is estimated to be 40 minutes to 1 hour. Three time constants are needed to insure stable operation.

II. DOMES

Provided that transmission losses through a dome are not excessive at λ1mm (e.g. $\lesssim$ 2 db) then a dome of some kind seems desirable as protection against thermal gradients, wind (and other weather elements), and even radio interference. A controlled enviroment is highly desirable even for purposes of setting the telescope surface.

P. Napier (NRAO) has been experimenting at 90 GHz with several modern fabrics obtained from a number of different companies. Loss measurements at 90 GHz together with an extrapolation to 300 GHz which assumes that the losses are strictly geometric (i.e. reflection only) indicate that the best materials suffer no more than 10% loss at 300 GHz. Several of them, such as Griffolyn, also seem to be structurally strong enough to be used at least on a spaceframe, and possibly on an 80 ft. astrodome aperture with minimal support structure. There is no evidence to suggest that the above assumption could be wrong, i.e., it is unlikely that resonance-type absorption occurs in such materials at frequencies as low as 300 GHz.

This optimistic outlook is further enhanced by a recent fabric made at Dupont and examined for radome properties by Esco. Measurements show a total loss of $<$ 1 db up to 400 GHz, and perhaps little more up to 1000 GHz. This material is also structually strong enough for spaceframe use.

It therefore appears that transmission losses suffered by radomes which can presently be built, are small enough to warrant placing the 25m telescope in a radome. Nevertheless, we briefly discuss additional factors.

W.-Y. Wong's calculations show that, should additional stiffening of the telescope structures overcome the pointing and surface accuracy problems under wind load, this will be accomplished at the expense of very little added steel. Thus if the stiffening calculations are successful, placing the telescope outdoors means negligible added cost for the telescope itself. It is also probable that we would not choose a site where a dome was essential to shield against radio interference. Such a dome would necessarily need to be of the spaceframe variety, and the panel size of such could probably not be made small enough to shield well against UHF without introducing too much blockage at λ mm wavelengths. Thus the principle argument in favor of a dome is to avoid large thermal gradients which render the telescope useless during the daytime for wavelengths shorter than λ 2.5mm. von Hoerner (1974) points out that a strong temperature-equalizing effect is provided by winds of only a few mph. However we doubt the wisdom of prejudicing telescope performance on factors such as this, and consider a dome the safe route to take. Even at night the warmer ground heats part of the telescope differently than the part that looks at cold sky. Inside a dome, efficient air-conditioning should reduce this effect also.

SPACEFRAME VS. ASTRODOME

Spaceframe		Astrodome	
Advantages	Disadvantages	Advantages	Disadvantages
-easily built without design study	-higher blockage loss	-lower blockage loss	-costlier,needs design study
-cheaper	-reflections off spaceframe	-removable aperture?	higher maintenance?
-shield against interference?			

We regard the better transmission characteristics of the astrodome as a decisive advantage and therefore, to keep options open, we intend to pursue a design study of a suitable astrodome.

The conventional astrodome would be a spherical structure 120 ft in diameter containing an aperture 85 ft wide which extends from the horizon to several degrees past the zenith. The aperture would hopefully have negligible supporting members across it (except a few to suppoort the fabric). It is not presently clear that such a structure can be built to withstand, say, 120 mph winds. At the least, it would require a detailed design study, of a structure with which NRAO has no experience. Therefore NRAO would have to solicit outside design studies.

As an alternative, W.-Y. Wong has suggested a structure similar to that shown in the figure. This structure does not preserve the conventional spherical shape but is structurally adequate against 120 mph winds and is relatively simple to analyse and build. Structural analysis is not yet complete, but we fully expect no structural problems. The aperture is 80 x 100 ft. Such an aperture is probably too large to support existing fabrics that are electrically suitable, without some supporting members. The necessary number of such members will not be large enough to cause appreciable blockage (two such members, in line with the feed support legs, may be sufficient, and would cause virtually no extra blockage). Note that the aperture covering must have a fold in it because of the non-spherical shape. This has two potential disadvantages: 1) the incident wavefront is not normal to all sections of the fabric except when pointing at the zenith. However The effects of variously retarded wavefronts over the aperture should not be noticeable for the very thin fabrics we are considering;[*] 2) removal of the aperture fabric for certain types of observing (e.g. 350 μ, or at the longest wavelengths where wind and thermal gradients do not seriously affect telescope performance) will be difficult. Taking up the aperture fabric on a roller may be feasible.

To minimize the number of supporting members across the aperture, should the number otherwise be too large, part of the dome might be supported by air pressure (e.g. the area shown shaded in the figure). In such a case, a removable aperture covering is probably not feasible, because of the expected difficulty of making reasonably air-tight roller fittings. Thus some compromise between the amount of aperture blockage and the desirability of removing the aperture covering might be required. We plan structural tests in the near future on the electrically-best materials to determine what member-support across the aperture will be required. At some stage, probably with these test results in hand, we will consult outside firms (e.g. Esco) on the technical details of this structure, such as how to fasten the fabric, the feasibility of fitting a sliding aperture panel which might be air-pressure supported, etc.

If the astrodome structure just described should be impractical in some fundamental way, a conventional spaceframe will probably be resorted to. Esco claims they can build spaceframes considerably larger than we need, and cover them with fabrics of the sort of strength we expect our selected material to have.

For either astrodome or spaceframe, it is probably not necessary to design carefully against tearing of the fabric. These fabrics are quite cheap (a 120 ft spaceframe would cost $10K to cover), so that frequent replacing of damaged sections is not a significant economic consideration.

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[*] Similar effects are shown by Ruze to be negligible for the Haystack radome, where the pathlength through the dome is longer at the edge of the dish than in the center. This effect scales inversely as the wavelength and directly as the fabric thickness, two effects which compensate each other and produce for our case the same (negligible) effect as for Haystack.

III. SITES

Information for a dozen or more sites is quite extensive with regard to % of cloudy days, daily averages of W_v (integrated water vapor), temperature and wind. Some basic references are

1) McDonald, J. E. 1958, Univ. of Arizona Inst. of Atm. Physics Sci. Report #7 ("Cloudiness over the SW United States and its Relation to Astronomical Observing").
2) Kuiper, G. P. and Randić, L. 1972, Comm. of the LPL No. 193, ("Water Vapor Measures, Mt. Lemmon Area").
3) Kuiper, G. P. 1972, Comm. of the LPL NO. 142, ("High Altitude Sites and IR Astronomy").
4) Westphal, J. A. 1972, Preliminary Report of the 10 u IR Sky Noise Survey
5) VLA Report, Volume III.

Much of this material has been summarized in the NRAO publication "A 65m Telescope for λ mm Wavelengths" by Findlay and von Hoerner. Following these authors, it seems reasonable to evaluate sites in terms of

A) Primary Criteria (freedom from clouds, low and stable atm. water vapor, meteorological factors (wind and temperature), and the radio environment.

B) Secondary Criteria (good construction and working site, good access and utility supply, reasonable living conditions, freedom from natural hazards, land acquisition and local governments).

It is naturally difficult without further information, such as the time scale on which we desire the telescope, and potentially available funds, to decide how to weight hhe primary and secondary criteria. Some compromises are probably necessary.

We first discuss data relevant to criteria A). At the outset it is necessary to state that no uniform data exist for all the sites of interest. For one list of sites (table 1) the W_v values (from Kuiper) have been calculated from radio-sonde data collected 1961 - 1966 and contained in the "Atmospheric Humidity Atlas--Northern Hemisphere" (Gringorten et al 1966). In the second table, I list W_v data from the Westphal IR site survey (collected 1971 - 1972). Here, W_v is derived from the difference of the solar extinction at 1.65 μ and 1.87 μ wavelength. Finally, data for some of the VLA sites are given in table 3 (collected 1966 - 1968). The W_v data here is also measured by tracking the sun at two IR wavelengths, but this time at 0.88 μ and 0.935 μ.

Table 1. W_v Values from Radio-sonde Data

SITE	Jan.		Apr.		July		Oct.		
	5%	50%	5%	50%	5%	50%	5%	50%	No. Cloudless Days
Mt. Palomar	1.8	3.4	1.9	4.4	3.5	9.5	2.6	6.1	200
White Mt.	0.44	1.1	0.49	1.2	1.1	1.9	0.7	1.3	260
Kitt Peak	1.7	4.4	1.8	3.7	5.5	10.9	2.3	7.1	260
Mt. Lemmon	1.0	2.7	1.3	2.8	5.0	9.1	1.8	5.0	260
Pikes Peak	0.40	1.0	0.7	1.3	1.6	4.2	0.81	1.9	160
Baja Calif.	1.2	2.6	1.35	2.8	3.5	8.2	1.9	4.7	240
Mauna Kea	1.2	1.5	1.0	1.8	1.3	2.0	1.2	2.3	230
Green Bank	1.2	4.3	2.6	8.0	12	20	3.4	10	80

Table 2. W_v Values from the Westphal IR Survey

Mt. Paolomar	2.8	3.0	6.0	4.2	200
White Mt.	0.6	0.8	2.2	1.2	260
Kitt Peak	1.45	1.9	---	2.7	260
Mt. Lemmon	1.0	1.4	---	---	260
Baja Calif.	1.4	1.7	---	1.7	240
Mauna Kea	1.3	1.9	2.1	1.7	230

Table 3. W_v Values from the VLA Site Survey

Y-15 (N.M.)	2.9	3.1	11.0	6.1	220
Y-23 (Ariz.)	4.4	4.9	14.5	7.6	260
Y-27 (Texas)	3.9	5.9	14.6	6.9	180
South Baldy (N.M.)		probably slightly better than Y-15			210

Several points should be noted in comparing the values of W_v in these tables.

1)tables 2 and 3 might intercompare more reliably than table 1 with either, because of the similar method used. It may be argued that overall weather patterns could have changed between the periods of the two IR surveys. While this is possible, we note that the W_v vlues for each of the three VLA sites were the same within a factor of 1.5 at most for the 3 years data was collected. Thus the larger W_v values in table 3 compared to those in table 2 are either real or are due to different calibration methods in the two surveys.

2) relative values between sites in a given table should be reliable. If the

ratios between two sites differ from one table to another, it probably reflects year-to-year differences, since different years are represented in the 3 tables.

3) whenever site A is better than site B in both tables 1 and 2, it suggests a reliable conclusion, as it spans different methods and different years.

4) in table 1, the 5% and 50% levels in the W_v distributions are given; these may be read as the "average best" and "median" values.

5) the 5% values in table 1 are conservative for at least two reasons. a) the radio-sonde data does not record relative humidities below 20 - 35 %, and there the AFCRL Atlas uses an average; b) in quiet nights there will be subsidence over the summit. For one high site, Pikes Peak, direct measures subsequently gave W_v values typically 1.6 times lower than the 5% values here.

6) the number of cloudless days is taken from the survey by McDonald (1958). By "cloudless" is meant days when the average cloud cover is less than 3/10. This study is averaged over the period 1899 - 1938, and refers to days, not nights. However, optical site studies of most of the sites discussed here indicate that cloudless days are followed by cloudless nights. There are no known cases where we might expect the daytime weather to be uncorrelated with the nighttime patterns.

The data indicate only mean values of W_v, often recorded only once per day, typically at noon. Of importance to λ mm observations are the variation of W_v over short time intervals and short distance intervals. Little data exist on these quantities. Measurements of $\Delta W_v(s)$, i.e. variations over distance s, have been made by Hinder and Ryle in Cambridge, by Cudaback at California sites including White Mt, and by NRAO at a few VLA sites and at Green Bank. All such studies seem to agree that the typical distance over which atmospheric extinction becomes uncorrelated is 500 to 1000 m. This then is the typical "cell size" and appears not to differ much for the above-mentioned topologically very different types of sites.

Almost no data on $\Delta W_v(s)/W_v$ exists for $s < 500$ m, but indications are that it varies linearly from 0 at $s = 0$ to ~ 0.05 (typical) for $s \gtrsim 1000$ m. The dependence of $\Delta W_v(s)/W_v$ on W_v is not apparently known, but experience at Green Bank indicates the dependence is not noticeable for $1 \text{ mm} \lesssim W_v \lesssim 40$ mm. Taking a phase retardation of 200° per cm of water vapor at λ11 cm and assuming a linear dependence with wavelength, we conclude that for $W_v = 2$ mm there will be a phase jitter of 220° at λ1mm over a 1 km baseline. Thus λ1mm phase-stable interferometry looks doubtful except under unusually good conditions. On the other hand $\Delta W_v(s{=}25\text{m})$ should be ~ 0.005 mm over the 25 m telescope aperture, which can be shown to shift the pointing at worst 0.35".

The behavior of $\Delta W_v(t)$, i.e. variations over time, is poorly known. NRAO measured $\Delta W_v(t)$ at several VLA sites during the months of May and June, 1969, when W_v was high (typically $\gtrsim$8mm). The results indicate W_v could vary by as much as 1 mm in a 10 minute period, and perhaps 0.2 mm in 10 seconds. These results do not look encouraging but there are at least two mitigating circumstances. 1) the quality of this data is poor, and some of the variations could even have been caused by instrumental effects. 2) some people believe that $\Delta W_v(t)/W_v$ may increase significantly with increasing W_v. Thus during winter months, when λ1mm would be done, $\Delta W_v(t)$ may well be <u>much</u> lower than these results suggest.

Not only are data on $\Delta W_v(s)$ and $\Delta W_v(t)$ fragmentary, but obtaining reliable data of this sort would require at least two years in order to avoid the much-quoted criticism that variations in W_v and ΔW_v from year to year for a given site often exceed variations in W_v and ΔW_v from site to site for a given year. Therefore, as is usual, we will assume that a low value of W_v is associated with a low variability of W_v, and accept a low W_v as the main criterion A).

With this criterion (and weighting only lightly the number of cloudless days, as this is quite similar for all sites), the order of ranking of the sites is

White Mt.	Pikes Peak	Mauna Kea
Mt. Lemmon	Baja Calif.	Kitt Peak
Y-15	Y-23	Y-27

There appears to be a significant break between the three groups arranged here. One site, Mt. Hopkins, also has extensive W_v data, but it is in terms of surface absolute humidity and thus requires a model atmosphere to convert to W_v. A rough estimate of this places it between Kitt Peak and the VLA sites. Being further east (by $\sim$100 mi) than Kitt Peak, it has more cloudy days per year and an expected higher W_v since it is close to the edge of the Bermuda High weather pattern, which is responsible for the larger W_v and more cloudy days of the VLA site.

There is little to distinguish the sites with regard to factors other than W_v in criteria A). Wind and temperature values are acceptable for all sites the year around, as is probably the radio environment. South Baldy, 30 mi from the VLA site Y-15, has no detailed W_v data, but it cannot be overlooked that the Langmuir Laboratories, whose principle function is the study of thunder storms, are located on the summit. Because South Baldy is $\sim$3000ft higher than Y-15, its W_v values may be somewhat lower, but this has not been established.

Present thinking is that it is unfeasible to consider undertaking measurements to try to improve on these existing data, in any reasonable time scale (under 3 years). Therefore, if criteria A) are to be weighted heavily, we must choose between the above sites on the basis of the above data.

Secondary Criteria.

Besides those secondary criteria listed above, it should be considered that we might want to build a λ mm interferometer at the 25 m telescope site. The longest necessary baseline would probably be $\sim$1000 m for line work (but possibly longer for continuum studies). The interferometer might use the 25 m dish as one element. The site need not necessarily have a level area of $\sim$1000 m in extent, but would need suitable spots for $\gtrsim$ 4 small telescopes within $\sim$1000 m of the 25 m dish.

The secondary criteria are not well met by White Mt., Pikes Peak, or Mauna Kea. All are relatively inaccessible by road (Mauna Kea will soon have a good road but travel from continental U.S. is probably unfeasible for a national observatory of our setup). All are at extreme altitude, making construction, observing, and maintenance inconvenient. White Mt. and Pikes Peak offer potentially severe problems for land acquisition and road access. It appears that these sites fail criteria B) at least sufficiently to make them no more attractive overall than the next group of sites, provided we decide on the basis of time-scale and expected funds that we do not want to undertake a major new site development.

Among the next group of sites, we defer discussion of the Cerro Diablo site in Baja California because it is outside the U.S. and offers no advantage over Mt. Lemmon except it is more radio quiet. (Among foreign sites, Baja has W_v values typically 2 times lower than Cerro Tololo and perhaps 4 times lower during Dec. through Feb. according to the Westphal survey. It is also much closer for travel, although it is more inaccessible in other ways).

Mt. Lemmon and Kitt Peak satisfy criteria B) well. Mt. Hopkins is severely compromised by lack of a suitable access road; transportation of fabricated parts of the telescope over the present 18 mile rough mountain road would be impossible. An additional road from the present SAO site to the 25 m telescope site would also be needed. Mt. Hopkins also has a Channel 11 television transmitter, although this should not be a problem for λ mm operations.

Mt. Lemmon has potentially bad radio environment. The main television aerials serving Tucson are on the mountain, and also other radio installations.

Power levels are very high. Although the wavelength being transmitted is much below the λ mm region, the environment should clearly be studied further before any decision is made. The road up Mt. Lemmon is good, but is heavily travelled both summer and winter.

Kitt Peak may offer problems for an interferometer but none for the 25 m dish. The radio environment, although not controlled, is good because the mountain top blocks Tucson to the east and Phoenix to the north is also shielded by distant mountains. Because the site is on the Papago Indian Reservation, future nearby industrial growth should be at least partly curtailed.

Site Y-23 lies in the Aguirre Valley just north of Kitt Peak. The radio environment is probably even better than Kitt Peak, because of local terrain shielding. An improved access road would likely be needed from Route 86 about 15 mi to the site but the terrain is quite level. The site lies on the Papago Indian Reservation so acquisition could be a problem. There would be no difficulty building an interferometer here. All in all, this site would seem inferior to Kitt Peak and Mt. Lemmon, however, in both criteria A) and B). It is also inferior to Y-15 in both criteria, assuming that the most favorable aspect of criteria B) for site Y-15 is its proximity to the VLA.

Similar comments can be made for Y-27, in extreme southwest Texas, as apply to Y-23. There would seem to be no advantage of Y-27 over Y-15 in either criteria A) or B).

Site Y-15 and nearby environs are of course a special case. Definitely inferior to Mt. Lemmon or Kitt Peak in criteria A), it offers unique advantages under criteria B) because of its proximity to the VLA. Site Y-15 may be divided into several possibilities:

a) Socorro Mt (alt. 7284 ft) lies just outside Soccoro ($\sim$4 mi). This puts it in the river valley running north-south through Soccoro, hence the W_v content is probably not low.

b) Mt. Withington (alt.$\sim$8500 ft) is the second highest nearby peak, after South Baldy. It has a fire tower on top, though accessibility is quite limited. It lies a few miles south of the VLA.

c) South Baldy (alt. 10983 ft) lies $\sim$ 30 mi east of the VLA and would seem to be the best local site because of altitude. However, only a $\sim$ 20 mi dirt mountain road exists from Route 60. This would have to be rebuilt for telescope construction. No W_v data are available, but the same sort of annual variations of W_v as are found at the VLA site could be expected. The radio environment should be satisfactory, although Baldy has direct line distances of 30 km from Socorro and 125 km from Albequerque. The Langmuir Labs operate radar transmitters when thunderstorms are in the vicinity.

Conclusions.

Mt. Lemmon appears to be the best compromise site if we decide to weight criteria B) significantly. This, provided the TV transmitters there don't cause excessive problems.

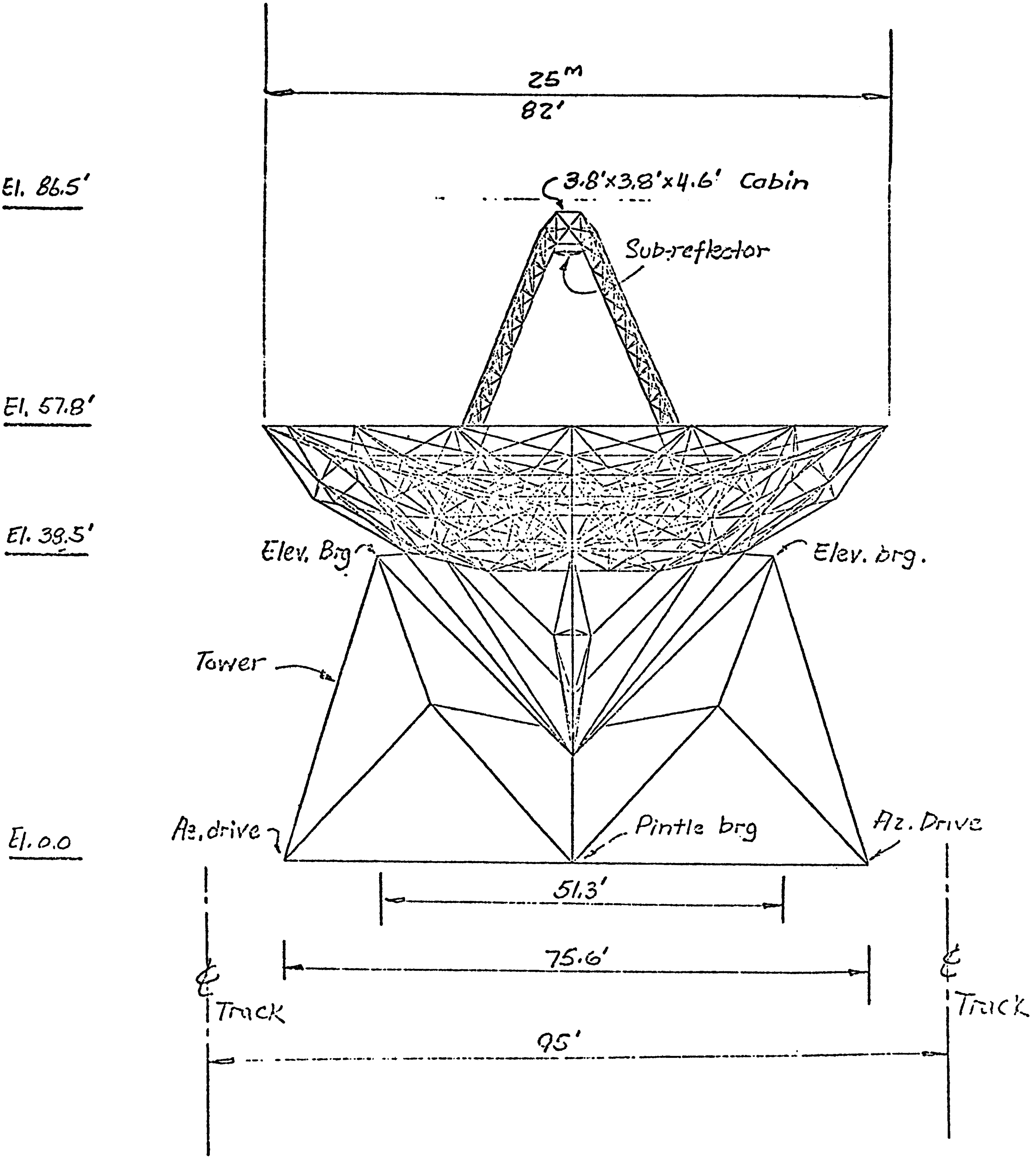
Regarding criteria A), Clegg, Ade, and Rowan-Robinson find a typical zentih opacity in a band covering 0.8 to 1.2 mm wavelength of 0.55 at Kitt Peak during February 1973. The mean value of W_v was apparently typical for the month of January. Thus, under expected good-to-best conditions at Kitt Peak the % transmission at zenith is $\sim$58% near λ1 mm. If site Y-15 is really a factor of 2 worse in W_v, and Mt. Lemmon a factor of 1.45 better, as tables 2 and 3 suggest, then the corresponding zenith % transmissions would be 33% at Y-15 and 68% at Mt. Lemmon. This would seem to be a very significant argument in favor of Mt. Lemmon, or at least against Y-15.

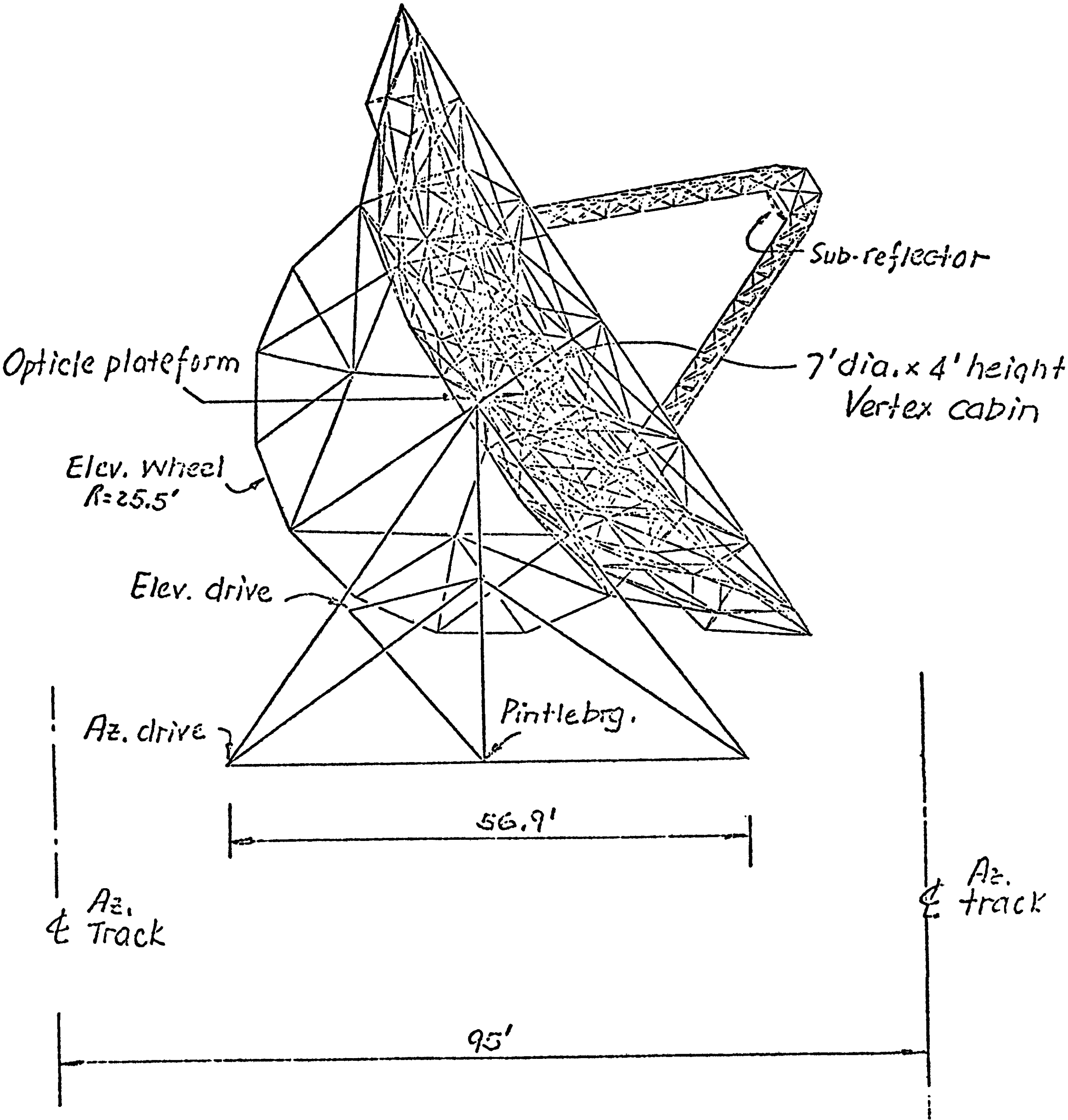
If NRAO should want to build a λmm interferometer in the future, only Mt. Lemmon or Kitt Peak, among the compromise sites, would appear to be possibilities, and even these are very marginal. However, should we decide to reject the VLA sites for the 25 m telescope, then we certainly should place a future interferometer on the 25 m telescope site and not only the VLA site.

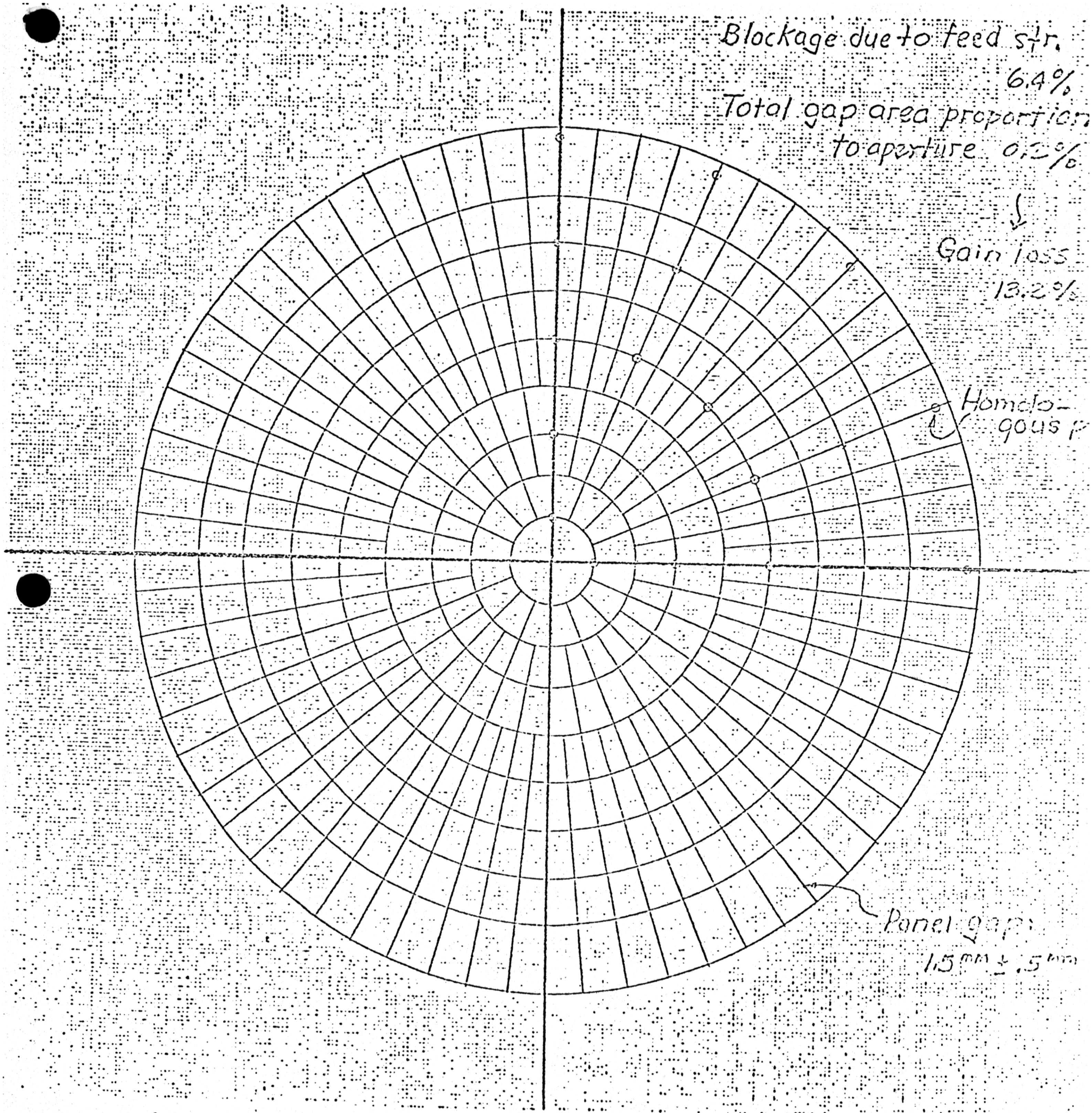
Regarding logistics, a Mt. Lemmon site does not consitute an additional site for NRAO as far as management is concerned, because the 36 ft staff could be moved over. Because of better access, Mt. Lemmon is also a cheaper site than Y-15 (i.e. South Baldy) at least as far as construction is concerned.

A thorough check of the radio environment of Mt. Lemmon is required. If this turns out favorably, Mt. Lemmon is the best compromise site. If not, then Kitt Peak appears to be the best alternative. A trip is planned in June or July to examine Mt. Lemmon, the VLA sites, and possibly others. Electrical tests on Mt. Lemmon are planned.

To end on a personal note, I do not think at this early stage we should restrict ourselves to compromise sites. Especially if it is resurfaced, as has been discussed, the present 36 ft telescope is capable of remaining at the forefront of λmm research for several years more. Therefore I see no great rush to complete the 25 m telescope on an accelerated timescale. Because it will undoubtedly be the definitive instrument in the U.S. for λmm research for a long time, I think it should be built with a minimum of compromises. Above all, this means a good site. I would hope that the good sites, particularly White Mt., whose accessibility is somewhat better than other excellent locations, will receive very serious consideration.


25m
82'
El. 86.5'
3.8'x3.8'x4.6' Cabin
Sub-reflector
El. 57.8'
El. 38.5'
Elev. Brg
Elev. brg.
Tower
El. 0.0
Az. drive
Pintle brg
Az. Drive
51.3'
75.6'
℄ Track
℄ Track
95'


Sub-reflector
Opticle plateform
7'dia. x 4' height Vertex cabin
Elev. wheel R=25.5'
Elev. drive
Az. drive
Pintle brg.
56.9'
Az. ℄ track
Az. ℄ Track
95'



Blockage due to feed str.
6.4%

Total gap area proportion to aperture 0.3%

↓

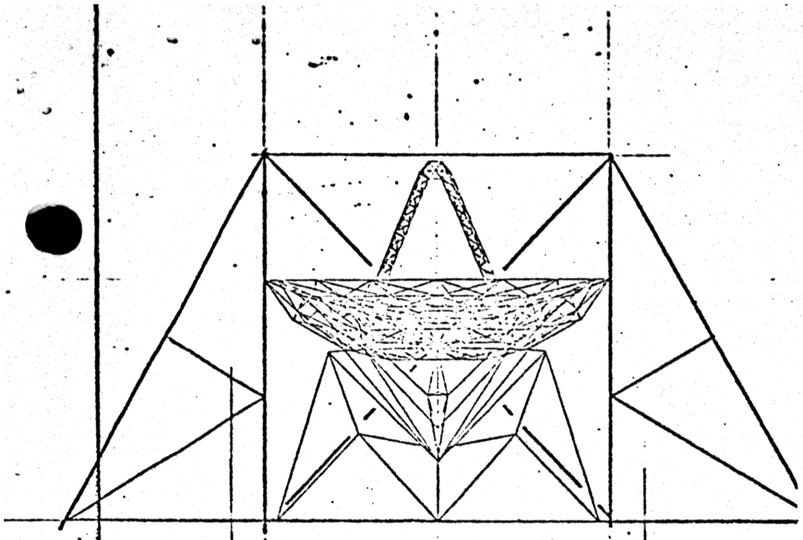
Gain loss
13.2%

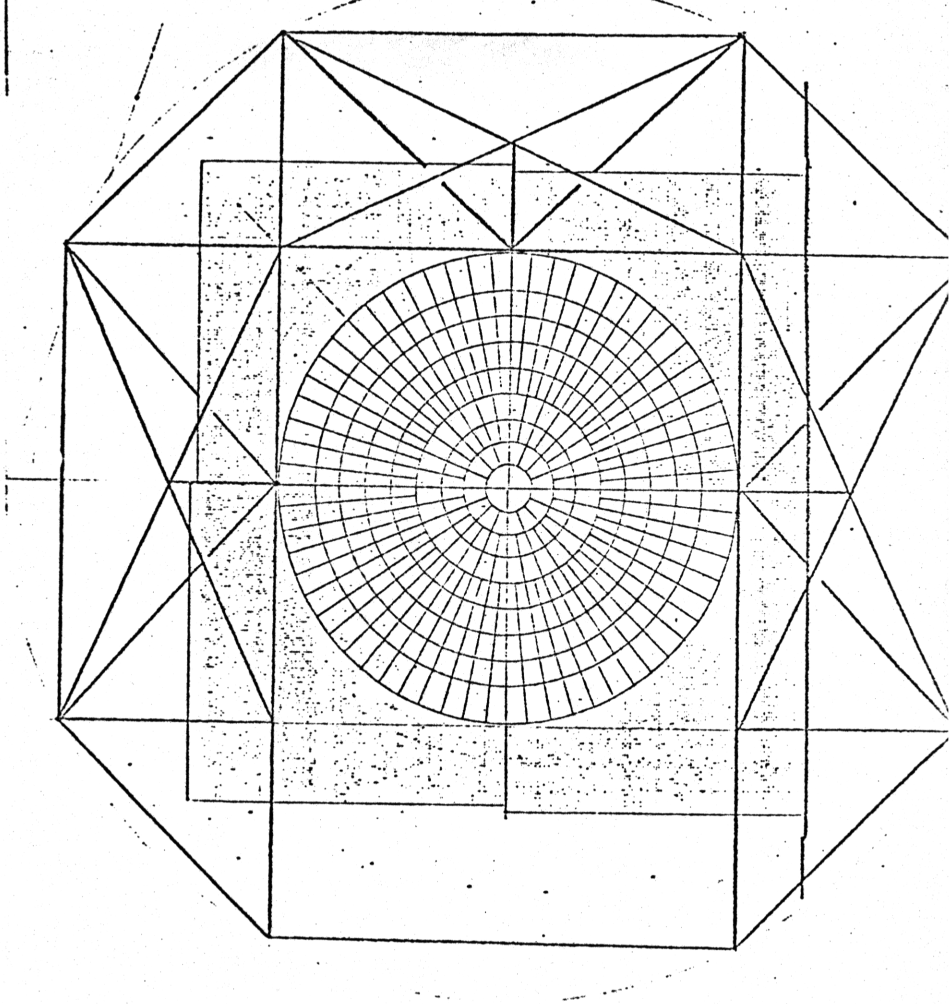
Homolo-
gous p

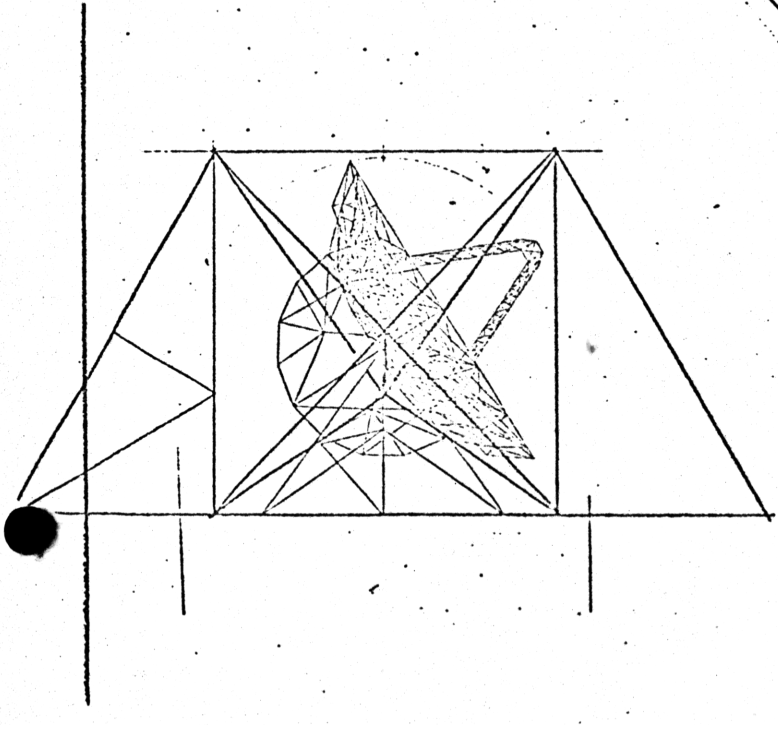
Panel gap
1.5mm ± .5mm

Surface plates arrangement for the 25m telescope.

Avg. size : 65" × 30"
Total no. : 400 plates
Total surface area : 5830 s.f.







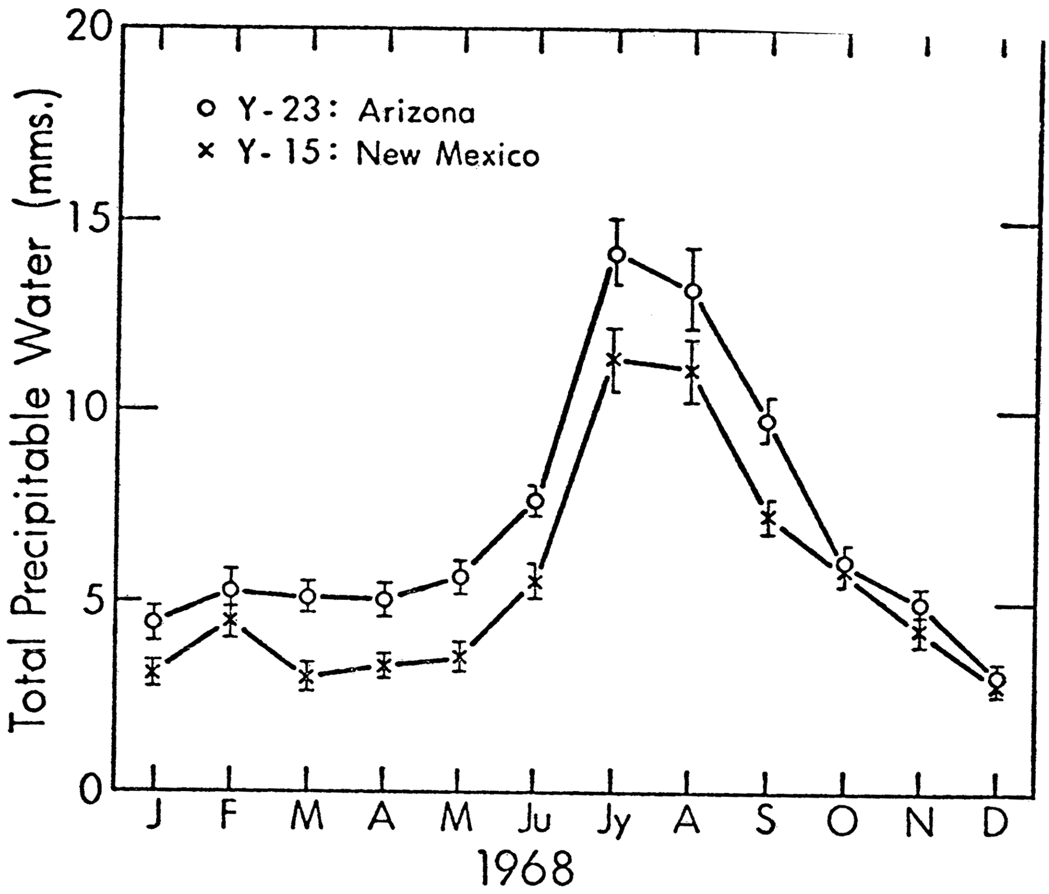


Figure 1 Precipitable water over VLA sites Y15 (New Mexico) and Y23 (Arizona).
(Findlay and von Hoerner 1972)

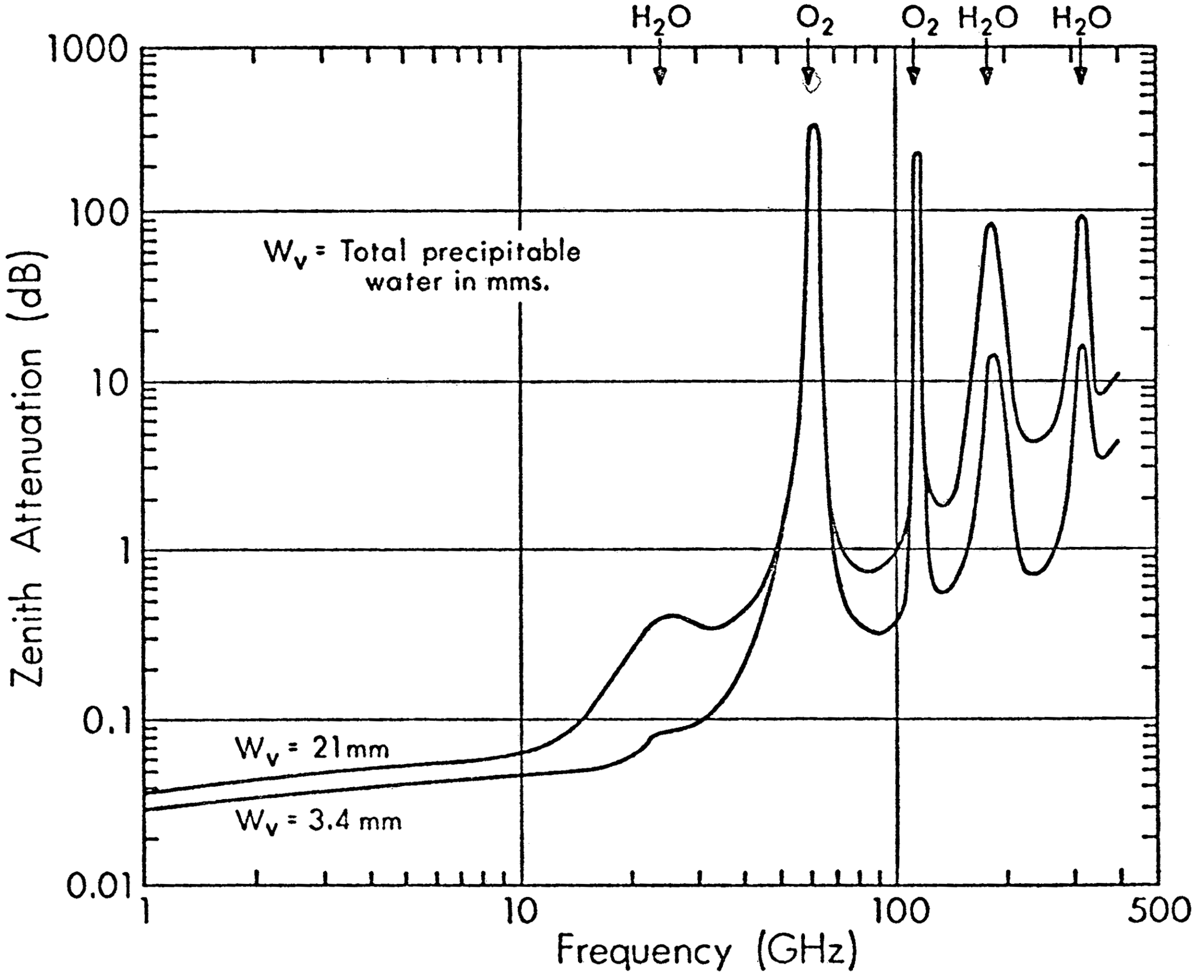


Figure 2 One-way zenith absorption of radio waves in the atmosphere.
von Hoerner 1972)