THOUGHTS ON THE 25-METER TELESCOPE FOR 1 MM

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25 METER - MILLIMETER WAVE TELESCOPE
MEMO # 1

There are two problems associated with the atmosphere: 1) straight attenuation. 2) variable phase length due to non-uniformities. The latter cause variable phase across the telescope aperture which raises the sidelobe level (reduces η_B) and, if bad enough, noticeably broaden the main beam.

The first problem is to estimate quantitatively the size of the latter effect. Some information exists on atmospheric scale sizes. Using two detectors at 0.8 μ, Cudaback measures the correlation between their outputs while observing the sun, at variable spacings between the detectors. The correlation coefficient seems to fall to about 0.5 at separations between 500 and 1000 meters. This is roughly what Hinder and Ryle find in measurements made at Cambridge. If blob sizes are ~ 500 to 1000 meters, we should have little problem over a 25-meter aperture. For apertures smaller than the blob size, we can get away with phase measurements at a single wavelength and separation. The phase error scales linearly with separation and also with wavelength. We need to calculate precisely the effect on telescope performance of these atmospheric effects.

The problem of straight attenuation depends on the precipitable water vapor content. The Westphal IR survey indicates that White Mountain is the best site, with Mauna Kea and Mt. Lemmon not far behind. Kitt Peak is slightly worse again. The VLA site is definitely not in the same class. Furthermore, at the VLA site we won't be above inversion layers most of the time, and these layers not only imply more cloudy weather but also irregular refractive indices at the inversion. It is important to measure the atmospheric effects with regard to potential problems at λ 1 mm.

Other sites should be looked into. Besides White Mountain (which has severe access problems--we might not be able to build a road even if we had money) we should study the Redondo Peak area just outside Los Alamos. This site is at 10,000 ft. but will probably have some cloudy weather.

Paul Goldsmith and Mike Werner have used the Palomar 200" and Lick 120" at λ 1 mm. We should avail ourselves of their experience on "seeing" conditions at λ 1 mm over an aperture of 200".

<u>Projects</u>: 1) review (extensive) literature made by astronomers over the last 10 years on site selection for both optical and IR telescopes.

2) consider doing Cudaback-type measurements at various sites,

especially the VLA site. Could we use his equipment, or easily set up similar of our own?

As a general comment, a telescope operating at $\lambda/16$ is marginal. But we may not be able to do much better, at least not without considerable cost. Therefore it is vital to study the effects of atmosphere carefully, to insure that we don't over-design the telescope beyond limits set by the atmosphere. This is particularly relevant if, for other reasons, the site is chosen as the VLA site, in which case the atmosphere might well be a limiting factor.

II. RADOME VS. OPEN-AIR TELESCOPE

The strong prejudice seems to be that the telescope must be enclosed. We note there are materials (e.g. Invar, used on the Texas telescope) that have a very small thermal coefficient (the Texas dish works well at λ 2 mm under direct or partial sunlight, with regard to both efficiency and pointing). It is not yet clear from our own design people whether the 25-meter telescope could be built to work under outdoor wind and temperature conditions at least part of the time, with respect at least to aperture efficiency. Pointing apparently would be much more difficult (we need $\lesssim$ 2" pointing accuracy at λ 1 mm). Furthermore, I think we should try to work up to 300 μ (as a light-bucket) eventually. At least a partial enclosure seems essential for this. It seems likely that radome materials are available that have $\lesssim$ 10% loss to λ 1 mm. There may be no materials that work in the far-IR. Assuming we can build a rotatable dome with adequate propagation properties for λ 1 mm, it seems clear that the added improvement of performance in pointing and probably dish efficiency more than compensates the radome loss (and increase in system noise).

III. RADOME FABRIC

We envision an "astrodome" in which the observing window is covered with a particularly low-loss fabric. The window may be removable for far-IR work or other wavelengths if conditions warrant.

Resonances It seems likely that resonances will be broader in frequency than we can tolerate (e.g. placing a resonance at 120 GHz, where the atmosphere is opaque, probably would interfere with the CO line at 115.3 GHz). Therefore it is necessary to make the window fabric thin enough that all resonances lie shortward of λ 1 mm (shortward of 300 μ is impossible, so the window should be removable to do far-IR work). A new genre of nylon materials seems profitable to study. Thaddeus has studied nylons used for parachutes and balloons and thinks they would propagate well up to λ 1 mm. The material can be quite strong down to a few mills thickness. At 800 μ, the thickness must be $\lesssim$ 8 mills (for a dielectric constant of 1).*

It is apparently not uncommon for fabric materials like this to become opaque in the far-IR even though they may be good at λ 2 mm or so. Therefore we need attenuation measurements to as short a wavelength as possible. Measures of phase shift through the material (i.e. dielectric constant) will also be needed, to estimate total phase error across the telescope aperture and possible correction for it (e.g. a correcting secondary in a Cassagrain system).

Quantitative estimates are needed as to how given phase errors across the aperture affect the beam efficiency and (to smaller extent) the pointing. Such phase errors could arise either from atmosphere or from ripple in the window fabric under wind conditions, etc.

If materials cannot be found which place the resonances outside the operating wavelength range, it may be possible to make the window a sandwich of materials of different dielectric constants matched to behave like coated lenses. No single one of these could likely be resonance-inhibiting over the entire operating wavelength range.

IV. TELESCOPE SURFACE

A milled surface is generally felt to be unfeasible. Note the Rohr Corporation had to build a special machine to mill the 36 ft. surface, and even that didn't work out very well.

Even with a surface of λ/16 at 800 μ, the rms error must not exceed 0.002", and better than this would definitely be highly desirable. Other λ mm telescopes being built now operate at better than λ/16. Welch's new 20 ft antenna is at least λ/24, and Thaddeus' 8-meter dish will be λ/70 at the presently intended operating range.

Surface panels apparently can be manufactured to an rms of 0.7 mills, at least for sizes used on current telescopes. The problem seems to be whether they will hold these specs over long periods of time against effects of creep. Thaddeus used multiple annealling to minimize strain in his panels, but Philco-Ford, who built them, was reluctant to predict their behavior over many years. These panels consisted of a single aluminium casting, computer designed by a program called NASTRAN which apparently is an all-purpose generally available code. Should we use it?

* For $\varepsilon > 1$, the wavelength inside the fabric is increased, and the material must therefore be even thinner. Some trade-off between material strength and dielectric constant may be necessary.

The general feeling is that single-cast panels, machined to tolerance, are a better way to go than to use von Hoerner's design with its many screw adjusts. The latter involve too much tuning too often (at λ 1 mm) and may not anyway produce a better surface than can be made with the most recent techniques. On the other hand, tuning screws might provide a longer lifetime for the panels, if creep effects are important.

The specs which the panels must meet will of course depend on the accuracy with which we can build the back-up structure. Thus the first answer we need is the result of scaling down the 65 meter homology design (W.-Y. Wong and Co.). The more accurate the panels need to be, the smaller they would be, which means the larger the ratio of space between panels (for adjustment, at least) to panel area becomes. The effect of these spaces is to cause some diffraction; this should not be a severe effect but should not be overlooked.

Telescope Mount-= To what degree will the homology design of the backup structure depend on whether the structure is mounted on a pedestal, or on a circular azimuth track? The latter appears cheaper to build, but is less accurate. For this telescope an azimuth track could not be built accurately enough for the pointing requirements without using an optically servoed reference platform, referred to several ground points.

V. POINTING

It seems necessary to incorporate something like the optically servoed reference platform planned for the 65-meter telescope. Assuming this, do we use shaft-encoders, or inductosyns, to measure angle with respect to this platform? Either device currently seems to have enough accuracy.

Pointing might be limited by thermal warping of feed support legs and dish, unless the radome is thoroughly air-conditioned. Even then, we must avoid a temperature gradient from top to bottom of the radome caused by air-blockage by the telescope, especially when it is pointing near zenith. Such considerations might put a lower limit on the size of the radome required. Haystack has problems of this nature.

VI. OPTICS: CASSAGRAIN ONLY, OR CASSAGRAIN PLUS PRIME FOCUS?

Cassagrain optics appears necessary if we are to use cooled receiver systems when they are developed. But spectral baseline problems can be expected unless added precuations are taken. As I understand it, the baseline problems are produced by a beating of the radiation from the source (the atmosphere mainly, at λ mm wavelengths) with other reflections generated within the feed by the L.O. power, arising from small mismatches. The effect, according to Welch, is described by

$$T_{baseline} = T_{source} (1 - |\Gamma|^2)$$

where $|\Gamma|^2$, the reflection coefficient, is given by A_f / A_d, the ratio of feed area to dish area. These effects occur at prime focus as well as Cassagrain, but are much larger for the latter because the hyperbolic secondary effectively magnifies A_f by up to 10 times. (It is fair tb mention that this picture does not explain why Gregorian optics are even worse, apparently, than Cassagrain for spectral baseline problems).

We might put a sliding section into the Cassagrain secondary which alters the echo pattern depending on its position, and at some setting will minimize the effect. Alternatively, a circularly polarized feed might reduce or eliminate the effect, because the echo comes back in the oppositely polarized sense.

We should of course consider making the secondary a nutating one but possibly shaped differently from a hyperboloid to give a more uniform illumination pattern and thus a higher gain. The tri-cone arrangement on the 210 ft. Goldstone telescope is a convenient, rapid method of changing receivers. Possibly we could use this also.

VII. OTHER QUESTIONS

1) Space frame vs. astrodome. Despite what seems to be common belief, it does not appear, from observations at Haystack, that space-frames actually decrease the effective telescope size by broadening the main beam (due to phase errors across the aperture). However a space-frame clearly would have inferior transmission characteristics compared with an astrodome with specially designed window. Space-frames are much cheaper, however.

2) Receiver Development. Essentially no receiver has yet been built above 200 GHz that is suitable for anticipated research with the 25-meter telescope (the Jefferts-Philips hot-electron device is much too narrow-band even for most spectral line work). This state of affairs seems alarming in view of the fact that, if all goes well, the telescope could be ready by 1978-1979. Or more immediately, we should be prepared to show that receiver development is in good shape when we approach NSF for funds, which could be as early as next year.

VIII PRIORITIES

1) an answer to the back-up structure accuracy that is attainable inside and outside enclosures. Not much point in examining the surface panel problem until we have this in hand.

2) Measurement of transmission qualities of radome materials. It has been proposed to allot at once about $15K for a λ1.3 mm klystron and waveguide as a start. This will also provide necessary experience in making doublers and other components for future receivers. A way to measure above 230 GHz should be studied at high priority.

3) Feasibility study of pointing to better than 2". The new laser device of Findlay and Payne, shortly to be used to measure the 36 ft. surface, offers the best start.

Until we have answers to these questions, we cannot be sure what size or wavelenth telescope we are actually going to build.

IX. OUTSIDE CONSULTANTS

1) P. Goldsmith/M. Werner--atmospheric effects at λ 1mm over 200" aperture.

2) J. Mather (SPace-Flight Center, N.Y.)--can predict, theoretically, from model atmospheres, transmission qualities of the atmosphere at any wavelength for given precipitable water content.

3) Lou Becker (Philco-Ford)--built surface panels for Thaddeus' telescope.

4) Joe Frisch (U. C. Berkeley)--metallurgist, an expert on creep and strain problems.

5) Dave Morris/Emil Blum (Meudon)--problems of Cassagrain optics.

6) Univ. of California IR telescope proposal:--site selection in California.