Interoffice

National Radio Astronomy Observatory

Very Large Array

11 February 1980

To: H. Hvatum

From: W. Horne

25 METER MILLIMETER WAVE TELESCOPE
MEMO No. 132

Subject: Review of 25 Meter Status

In our conversation in Charlottesville in early December you asked that I review the information in my possession, the information that Buck Peery would send me concerning the 25 meter, and submit my evaluation of the status of the 25 meter project and my recommendations relative to the work to be performed, in order for NRAO to be ready to aggressively pursue the 25 meter project when construction funding is available. The data I have received from Buck consists of the Engineering reports issued, Woon Yin's antenna structure analysis G 5425 and Lee King's review of the analysis which I have skimmed through. My comments will be based on my interpretation of that data. I will beg your indulgence if I use information which has been modified or changed but which changes I either overlooked in the reports or am unaware of.

I. Resolution of the Design Program - It is my impression that the homolgy group realizes that there is much engineering effort yet to be done on this antenna, but I also get the impression that there really is not an appreciation of the magnitude of the engineering work yet to be done. AUI has expended a sizeable amount of engineering effort in analysis (primarily structural), research, and feasibility studies, but the detailed structural design, drive analysis and design, servo analysis and design, mechanical design, surface plate design, preparation of procurement specifications for components, selection of components as well as the myriad of construction, assembly, test and acceptance specifications and tolerance documents must be prepared. Even assuming that there is no review of alternate methods, materials or requirements (that we have decided what we are going to do and how we are going to do it), I estimate a total of over 25,000 direct engineering hours, not counting program management hours, in order to complete the engineering to the point of procurement of the hardware. This is the antenna and its foundation only and does not include the astrodome, astrodome drive and synchronization or support buildings and facilities.

With an estimate of this size for antenna engineering plus astrodome engineering, plus program management, it appears obvious to me that AUI, while it may possess the engineering capability, certainly does not possess the engineering capacity in its own organization for the performance of the required design work. The conclusion then is that we will have to contract out for the performance of the actual final detailed engineering. The questions then become the following:

1. Who do we get to do the engineering?
2. How many separate contracts and contract engineering firms do we use and what elements of work are in each?
3. When must we be prepared to request proposals for the engineering?
4. When must the engineering for each item be complete?
5. Can NRAO now define exactly the parameters and objectives of the various elements of the design in order to not require the contract engineering firm to do feasibility studies, comparative analysis or make management decisions? I don't think we can now, and will discuss particular problems further in this dissertation.
6. What will NRAO's role be during the time of performance of contract engineering?
7. What are NRAO's tasks between now and the time that engineering contracts are let, and do we have time, the capacity and the capability to do those tasks?

Since I am sure that you wanted answers from me far more than you wanted questions, I will try to give my answers to the questions, noting that the questions have probably been asked in the inverse order to which they will have to be answered timewise. Questions 1 and 2 can be finally answered at the time that first project money is available, but it appears to me that we will need separate firms for (a) the Astrodome, (b) the antenna structure and drives (probably an antenna firm), (c) dome and antenna foundation, (d) servo and controls (both antenna and astrodome), (e) surface plate design (maybe also manufacture), (f) support buildings and facilities.

Questions 3 and 4 are answered by the pert chart presently prepared and applicable to whatever funding plan in approved by NSF and budget restrictions, except that Question 3's answer also is impacted by AUI's capability to properly answer Questions 5 and 7 prior to times set forth for 3 and 4 and perform the work required by 5 and 7.

My answer to Question 5 I have already given in the negative; the particular problems which must be resolved prior to issuance of design contracts I will discuss in Section II of this letter. My answer to Question 6 is that NRAO's role during performance of contract engineering is that NRAO will be providing information and analysis which it has developed over the years of its studies, to the contractor; reviewing the contractor's design and drawings; helping develop and reviewing the contractor's procurement specifications, assembly and test specifications; and preparing the bid documents for hardware procurement. My point with reference to Question 6 is that we cannot postpone to this time frame work necessary to arrive at decisions, because NRAO engineers will be fully employed supervising and checking the design contractors work, and the lack of those decisions will delay the contractors work and increase the cost of the

design contractors effort. My answer to Question 7 is contained in Section II of this letter.

II. Specific Design Areas Which Need Attention

A) Foundation Investigation and Preliminary Design

The need for the investigation is probably recognized by all, along with its urgency which will require it to be performed in 1980. Results should be available for use in foundation design and servo design. The soil characteristics reflect on pointing accuracy due to spring rate, servo response for the same reason, pointing accuracy if differential settlement occurs and stability of the dome if settlement occurs, as well as size and cost of foundations.

B) Wind Operating Parameters

I note in Woon-Yin's Memo No. 107 that present telescope is designed for 18 mph (30 km/hr) but also note that Mark Gordon (Memo 106) thinks it should operate in winds to 50 mph (80 km/hr) which would produce forces approximately eight times as high with roughly the same ratio of increases in distortions and pointing error. I recall from my rapid scanning of the memorandums that Buck Peery sent, that Sebastion and Woon-Yin have performed some additional analysis and proposed some additional tests to determine actual wind velocities inside an astrodome. A final decision must, however, be made on wind velocities at which the astrodome will be closed, since wind environment on the antenna affect reflector distortion, pointing, structural wind forces on members, drive forces, as well as foundation and truck reactions.

C) Position Indicating System & Pointing Error

As I have previously commented to you, I question the adequacy of a position indicating system for the requirements of this antenna and believe we will have to go to a position reference system. I am convinced we will have to prepare a realistic pointing error budget to replace that shown on page 38 of Volume II proposal and then enforce on our design and component selection the requirements of that error budget. I note that on page 1 of Volume II we state an operating wavelength of 1.2 mm (or shorter) and state a pointing accuracy of 0.6 arc sec. which is 1/20 of the half power beam width. I had always thought of 1/10 of B as design goal with 1/5 B as minimally acceptable. Design of VLA antennas was based on 1/8.8 of half power beam width. The error budget on page 38, Volume II, shows 0.1 arc seconds for wind pointing error rms, while Woon-Yin in Memo 107 quotes 3.2 arc seconds (I assume peak; we're in worse trouble if it isn't) for 30 km/hr. with a pointing error of 23 arc seconds

for 80 km/hr. You will recall the purpose of the position reference system arrived at by the agonizing efforts of Sebastion and Otto for the 300 ft. project, was to eliminate some of the structural distortion influence in pointing by placing it within the servo loop and therefore measurable and correctable.

I have already given you verbally my comments on the angle encoder portion of the error budget in which an accuracy of 0.2 arc seconds is used for an inductosyn with a resolution of 0.31 arc seconds (22 bit). I pointed out that I thought someone was confusing the terms resolution and accuracy, and we should define the error used in the budget in terms of rms error (usually 3 LSB), peak error (probably around 6 LSB) or peak to peak error (about 8 LSB). I suspect that the thermal pointing error contribution listed in this error budget as 0.2 arc seconds may have been arrived at by considering that the antenna was in a closed astrodome and the dome is preventing the sun from differential heating of the structure. Now with a dome door open and parts of the antenna (particularly the azimuth structure) being differentially heated during daytime, the thermal effect on pointing error will greatly exceed 0.2 arc seconds (again I don't know if the figure of 0.2 arc seconds represents peak, some rms figure or half of the peak). The position reference system would place some of this error within the servo loop and thus correct.

No allowance is made in the pointing error budget for mechanical alignment tolerances, elevation and azimuth bearing error and non-repeatability.

With the use of a pintle bearing at the center of the antenna base to take some thrust load and the radial load of the antenna, this bearing will have sizeable friction (particularly when we put seals on it). We will connect the antenna to the bearing with essentially a torque tube and the position indicator below that. What effects will wind-up on the tube due to the friction of the bearing (which will vary and therefore be non-repeatable), have on pointing error? I don't know, but it should be analyzed and accounted for or else assigned a value and that value enforced on the final design.

I recall that some place in the memos a track level of .0025 inches (65 microns) is set out. I'm not sure this can be achieved even with careful shimming and measuring but of equal importance (and much more difficult to obtain) is the specification we will place on the out-of-roundness of the track (175 lb. crane rail which is difficult to bend), which will cause lateral movement or forces on the pintle bearing, some wandering of the trucks

with consequent elevation change due to wheel and rail shapes, bending on the torque tube due to lateral forces and probably some error in position indication. Another similar problem is thermal expansion of the antenna base frame due to day-to-night temperature differentials. With a diagonal dimension of approximately 95 feet and a probable daily excursion of temperature of 40°F, expansion will be in the order of 0.300 inches which if it isn't symmetrical,and it probably won't be, will change pointing due to wheel contact change.

In summary, we have a lot of analysis and painful decisions yet to be made relative to pointing before we can assign the project to a contract design firm. I started off with the intention of including in this letter an estimate of manhours required for resolution of these problems, but am getting tired of writing, want to get these comments to you in preliminary form, so will put those estimates in another letter.

D) Servo Design and Drive Design

In reviewing existing status of the 25 meter, it appears to me that a complete drive analysis or servo analysis has not been done for this antenna since Otto Heine did the work for the 300 ft. and the 65 meter. I note that John Payne did review the problem (Memo 15, dated November 13, 1974), but since operating parameters have changed considerably since that time, I believe a much more extensive design analysis and system design should now be performed. As one example, I have not found the motor horsepower for each axis spelled out. First, of course, we must resolve the wind velocities in which the telescope will operate with the astrodome open and the wind forces on the antenna due to that decision. Another question to be resolved is the slew velocity. I note that in general we have set forth 20°/min. elevation velocity and 40°/min azimuth velocity, but somewhere in the memorandums I believe that Ulich recommended (or required) velocities of 60°/min in each axis. I don't recall seeing either an acceptance or rejection of Ulich's memo, but this must be resolved in that the increase in velocity would triple the horsepower of the motors because of the change in reduction ratio of the gear boxes will decrease the stiffness of the system affecting servo response, increase servo overshoot, change the design of the motors, in that the tracking velocity of the antenna remains the same, but due to the reduced reduction ratio, the minimum motor speed will be 1/3 of that previously required.

The present design of the 25 meter shows a linkage mechanism in the elevation drive system which in my opinion is the same mistake the Germans made in the 100 meter elevation drive which caused their

limit cycle excitation due to hunting of the servo system; this should be eliminated. The azimuth track and azimuth drive system must be reviewed to determine the rail size required (smaller rails are easier to bend), how many drive wheels are actually required, whether we should drive at all four corners of the azimuth base and whether the truck design is overdone.

After NRAO has reviewed the drive design, I recommend that we contact a servo design company for a design of the servo system for about four reasons: 1) to determine if a servo system can be designed to meet the error budget we will have established; 2) to determine the best type of servo and servo components presently available for our purpose; 3) to determine the most practical data format for controlling the servo system; d) to arrive at a better estimate of cost for the servo system.

E) Bore Sighting

Probably not a problem but a question which was raised and should be answered because at present I question whether this antenna can reach horizon, let alone depress some three to five degrees below horizon. The requirement for depression below horizon would require some structural alterations (possibly raising the elevation axis), but we should not consider offsetting the elevation axis from the azimuth axis since we may have to use a position reference system which requires axis intersection. I believe our specifications still say that the antenna goes 35 degrees over zenith but I question the need for this in an astrodome.

F) Surface Plate Design and Manufacture

I don't really have much to say about this phase of the project except to say that I recognize its importance, that I conclude (probably along with everyone else) that the machined panel approach will be satisfactory, although expensive, and that we do need to remove any doubt as to the stability of the panels. I, at present, have seen nothing on the Harris panels, but agree with what John Findlay is evidently going to do in taking another look at one or two alternate methods of making the panels. This should be done rather quickly, and if we need money to have sample panels made, or to secure measuring devices, it should be provided.

G) Surface Plate Setting and Adjustment

I think John Findlay has this pretty well in hand. He has sent me additional information recently which I have reviewed, commented on, and will work with him further on. I believe his stepping process will work and will assist him in preparing final plans, specifications and procedures necessary for the actual setting of the panels.

H) Comprehensive Estimate of Costs

I think we need to firm up our design in the various areas I have covered above and by the end of this year (we can, of course, be working on an estimate as various elements of the design are completed) prepare an itemized estimate for all features of the program so that we will know whether we have to adjust our funding plans prior to commitment of any construction or manufacturing funds. The present estimates represent extensions of estimates made over the years for various portions of the project which may no longer be applicable due to the design changes which have been made. It is probable that estimates for operating, costs, support facilities and perhaps even the antenna structure, are fairly accurate, but with the limited information I have, I would recommend we re-estimate the balance.

As I remarked previously, I am growing weary of writing, so will end this here and get it typed and sent to you. I will continue, however, to prepare a manhour estimate for NRAO effort the remainder of the year and a proposed budget for those items which I think should be done the remainder of the year.

If you have any questions on what I have submitted so far, I will try to answer them.

WH/dl