APPENDIX A-11-1
MINUTES AUI RADIO ASTRONOMY
COMMITTEE MEETING
MARCH 26-27, 1956

Carnegie Institution of Washington
Department of Terrestrial Magnetism
Washington 15, D.C.

March 14, 1956

Dr. R. M. Emberson
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350 Fifth Avenue
New York 1, New York

Dear Dick:

I have received the folio of drawings from Dr. Feld for the 140 foot altazimuth mount. I note the next to the last paragraph in his Description of Design, namely, that "Complete servo-mechanism operation ...... is outside this contract ......" This confirms the position I took on the telephone with you in the middle of February, that the altazimuth designs are incomplete in a vital and essential way. No comparison between equatorial and altazimuth suitability can be made unless at least one of them is a complete design. The MIT Servo Laboratory has told you of their inability to visualize a solution to the servo problem in terms of the specifications set by AUI. As far as I can see, this is a first-order difficulty which has not been resolved. You should not seek the judgment or approval of the Steering Committee on the merits of these mounts with such a principal factor not only undetermined but challenged by us for nearly a year as impractical and probably impossible in terms of the specifications presented.

I should probably be specific about the principal difficulties we visualize. An altazimuth mount can of course be driven like a remote "synchro indicator," and this can be done with very high torque. Operating this way (sometimes called an "open-ended servo"), and without rapid feedback from the final driven unit, the dish is simply allowed to go where the wind blows it, except for perhaps very slow corrections fed back with a period of minutes. A truly rigid altazimuth mount with a very stiff "position indicator" drive, and without rapid feedback, can of course be operated to some tolerances which can be estimated. These angular tolerances are likely to be much larger than the two to ten seconds of arc in the AUI specifications. In much the same way a rigid equatorial mount with a very stiff synchronous mount can be operated to angular tolerances which can also be estimated. The rigidity of the structure and the "stiffness" of the drive mechanism are essential elements in calculating these angular tolerances for these two quite separate structural systems. An added feature of the altazimuth design which is not yet included in your fact gathering for the Steering Committee is the angle solver or computer. The cost of a computer which would meet the AUI specifications for accuracy and flexibility and be suitably reliable in use is unknown. This is a major added complexity of the altazimuth design, and unless a second independent computer is added there is no reliable way of knowing at all times where the dish is actually pointing (errors in a single computer may go undetected for a long time). A principal difficulty arises when corrections for gusty winds are attempted using a direct servo, namely with feedback from the driven dish, to the computer output, for comparison and continuous rapid correction. Major difficulty in this situation can be encountered with oscillations, if anything like a one to four second period is attempted. The stars move in the sky 15 seconds of arc in one second of time, and, depending on the rigidity of the altazimuth mount, especially the towers, changes in the wind can make changes of many seconds of arc in one or several seconds of time. We encountered these oscillation difficulties with gun mounts during the war, and that experience led us here to strongly favor the avoidance of servos and to prefer a simple synchronous motor drive, hence an equatorial mount. One additional point is the inherent rigidity of an equatorial mount based entirely on the intrinsic rigidity of tetrahedral structures, as exampled by the sketches sent herewith.

I replied to Dr. Seeger at the NSF three weeks ago concerning your letter to him about equatorial mount designs. I trust that my reply, or the gist of it, including some suggested specifications of a much less stringent character, has been forwarded to you.

In order to set the record straight, please note again that since before Christmas I have said that we would give our Carnegie equatorial design ideas to any engineering firm you might select to make an examination for the AUI. The Kennedy Company has been informed about our ideas for some time, but they seem to have missed the point, or at least they have done practically no calculation.

I am enclosing herewith two sets of photographs of the rough model of our Type 7 equatorial mount. I am also enclosing prints of a couple of sketches, dated November 20 and 29, 1955, indicating the approximate dimensions of this mount for an 84 foot dish. The basic notion of this design, largely due to Dr. Tatel, is to avoid bending moments on structural elements by utilizing tetrahedral structures throughout. Almost the only bending moments in any structural element of this design are the bearings on the declination axis and the polar axis, where the moment arms are less than one foot. These moments arise because the stationary and movable tetrahedrons cannot be exactly coincident in space, and the apex of one must clear the other by something less than one foot. With these minor exceptions, all of the stresses from gravity and from winds in any direction are converted to simple compression or tension. Furthermore, redundancy of elements has been to a large degree avoided, and nearly every stress is determined and calculable. The drive mechanism calls for tolerances between one-tenth and one-twentieth of an inch, because the gears are so large, and simple synchronous motors with gear reduction will handle 99% of the observing. A special computer, or special programming, would be needed to follow the Moon, for example, with precision. The large tetrahedrons make this design intrinsically very rigid.

I am enclosing two sets of these prints and an extra copy of this letter. I should like to suggest that you give one set of prints and a copy of this letter to Dr. Jacob Feld for his thoughtful consideration. If you have anybody on your engineering advisory list who has examined the problems of drives as well as structures, you might show them these sketches and pictures.

It is our hope that if any company undertakes to build a structure based on these designs they will at least advise us first and call it the Carnegie equatorial mount, to avoid a repetition of the hiatus in our activities which came about last summer. For the same reason we would prefer, at least for a few months, that this design should not be broadcast indiscriminately.

I am frankly not much interested in attending sessions March 26 and 27 to hear only about structural calculations for an alt-azimuth mount. Unless you are prepared to face the problem of drive and servo limitations frankly and openly I would be inclined to let this letter and these prints be our contribution to that meeting. I do not believe a choice can be made between altazimuth and equatorial mounts when the altazimuth has been only half worked out (the drive difficulty being the unresolved half) and the equatorial mount has not been examined at all by your engineers.

We have a consulting engineering firm now working on a detailed design of this mount for the 84 foot size. At present we see no reason to think that it would not be applicable to the 140 foot size as well.

Very truly yours,

/s/

M. A. Tuve, Director

P.S. I am enclosing a copy of the suggested specification tolerances for 140 to 180 foot dish and mount which were part of my letter of February 23 to Dr. Seeger. It was the opinion of our Advisory Panel that if your engineers start with less rigid specifications, such as these, the cost of the equipment might be greatly reduced, and perhaps the size increased above 140 feet, thus giving appropriate emphasis to the hydrogen line work and the longer wavelengths, as recommended by our Panel.

February 23, 1956 (M.A. Tuve)

Suggested specification tolerances for 140 ft to 180 ft parabolic dish on mount, with drive (and with computer if alt-azimuth type)

Note: These tolerances are intended to represent reasonable limits, to be attained without extreme (and hence very costly) design provisions. Design engineers should request authorization for modest revisions of these tolerances if certain of the indicated limits cannot be achieved without "exaggerated" investment in materials or construction time or design complication.

Ask for the primary design effort on

(a) a 140 foot dish for use at 10 cm wavelength,

with accompanying estimates on design changes (cost changes) for

(b) 140 foot dish for 20 cm wavelength
(c) 180 foot dish for 20 cm wavelength
(d) 180 foot dish for 10 cm wavelength

Note that a 170 foot dish at 21 cm wavelength gives a beam width to half power points of about 15 minutes of arc (one minute of arc is 1/4 inch at approximately 70 feet).

Specifications as follows: (suitable for either size, 140 or 180 ft)	Satisfactory for 7 cm	Satisfactory for 10 cm	Satisfactory for 20 cm
1) Construction accuracy in figure of dish, measured when horizontal (about ± 1/8 wavelength). (Note: These construction errors are not to be systematically related to gravity distortion errors.)	(± 3/8 inch) ± 1/4 inch	(± 1/2 inch) ± 3/8 inch	(± 1 inch) ± 3/4 inch
1a) Reflecting surface (if expanded metal) hole size.	1/4 inch "Squarex"	3/8 inch "Squarex"	3/4 inch "Squarex"
2) Maximum distortion of average dish figure under gravity. (Note: The dish may take a new average figure, resulting in some pointing error.)	± 1/4 inch	± 3/8 inch	± 3/4 inch

<u>Specifications as follows:</u> (suitable for either size, 140 or 180 ft)	Satisfactory for 7 cm	Satisfactory for 10 cm	Satisfactory for 20 cm
3) Maximum shift of average pointing direction for dish and feed when under distortion by gravity (here allowing about 1/8 of beam width, but expect to compensate to closer limits by non-feedback corrector).	± 1 min of arc	± 1 min of arc	± 2 min of arc
4) Maximum distortion of dish figure under pressures of 20 mph steady wind. (It is not clear that a servo corrector will improve this in a gusty wind. Request designers to comment fully.)	± 1 min of arc	± 1 min of arc	± 2 min of arc
5) Maximum shift of average pointing direction of dish (and feed) and mount when under pressures of 20 mph steady wind. Specify if compensation planned.	± 1 min of arc	± 1 min of arc	± 2 min of arc
6) Expected accuracy with which dish can be set on a desired point in the sky, probably with angularly programmed compensators.	± 1 min of arc	± 1 min of arc	± 2 min of arc
7) Steadiness and precision of drive (<u>after</u> being locked on a point): When originally set on any arbitrary "fixed star" position the center of the beam is to follow the motion of this "fixed star" during any one hour period:			
a) When within 30° of the meridian	within ± 15 sec of arc (± 4% of beam width)	within ± 20 sec of arc (± 4% of beam)	within ± 40 sec of arc (± 4% of beam)

Specifications as follows: (suitable for either size, 140 or 180 ft)	Satisfactory for 7 cm	Satisfactory for 10 cm	Satisfactory for 20 cm
b) When within 60° of the meridian	± 30 sec of arc	± 40 sec of arc	± 80 sec of arc
c) For any sky region accessible to the dish and mount	± 45 sec of arc	± 1 min of arc	± 2 min of arc (1/8 lambda)

Note: Any programming calculator for following the sun, moon, or planets is <u>not</u> to be included in this specification. Separate cost estimates on such an item are to be made and stated separately.