Telescope Consultation

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SUGGESTIONS AFTER THE MEETING ON MAY 22 AT CHARLOTTESVILLE

I. GENERAL REMARKS

It certainly was a good meeting, but with too many words and **not enough numbers**. Many items need quantitative treatment before they can be meaningfully discussed.

A project of this size and importance needs a **full-time leader**. To delegate single items to others, to summarize results from time to time, to schedule it all, and to be responsible.

All basic items, especially new ones, must be worked out first **in-house**. Lee King must get a full-time good programmer as help. After basic ideas have been tried and sorted, use outside firm.

The success of the Haystack Upgrade (100 GHz, funding granted) was achieved by the very good cooperation, and the frequent and open-minded communication, between Haystack's engineer (R.Ingalls) and the engineering firm **Simpson Gumpertz & Heger**. During our two German projects, I have seen good (Krupp-MAN) and bad (Dornier) communication. This is an extremely important factor for any new development. NRAO had already good experience with SGH (65-m).

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II. SYMMETRIC VERSUS OFFSET

1. <u>The Goal</u>

We want a first-class, unique telescope.- Unique which way? **Shortest wavelengths**: too late, Pico Veleta 30-m, Mt Graham 10-m. **Largest Size**: 100-m Effelsberg is hard to beat. 120 m would be 44% more area, nice but not really unique. Still larger is financially possible only for meter-wavelenths, with wide open mashwire surface, in a hot climate without ice rain.

Lowest noise, best baseline: we have already the unique Quiet Zone as a starter. And no offset telescope above 11.5 m exists or is planned. (Please don't ever again mention this against it!)

The importance of an offset telescope has been well discussed and documented by J. Lockman, NLSRT Memo 60. And some quantitative treatments have started, for example by R. Norrod, No.54, and J. Coe No.61. There is no question that it can be built, the question is only: how much smaller for the same money. If not too small, the **Offset Telescope** looks like a very good choice.

2. Support Tower and Cassegrain

This drawing of a long slender tower (Fig.5 of Memo No.51) was very unfortunate for the resulting discussions. Regarding the slenderness, Lee King suggested meanwhile a tripod instead, to give the required stiffness against wind and sunshine.

The length was fixed by the wanted F/D=0.6. But is this final? I would like to see a graph showing gain, cross polarization, and field of view, all as functions of F/D. To be compared with the turn-over wavelength, from Cassegrain to prime focus (at a specified maximum feed size), if the receiver cabin is at the base of the tower. Using, say, D = 90 m, Cassegrain = D/10 = 9 m. Because lifting the cabin up, to 1/2 the tower height, would be structurally rather awkward (though possible). And what, actually, is this turn-over wavelength at several existing telescopes?

How do we decide: whether the tower is above or below the dish, when pointing at horizon? Does it matter for observation? If not, ask Lee King wether there is much cost difference. And if not, then take "below" for much easier maintenance and change to prime focus (tilt down of Cassegrain).- The cost difference may be small or zero, if the elevation axis is located not below the center of the dish, but at a better balanced place, more toward the tower.

It was mentioned that large Cassegrains cannot rock fast enough for beam switching. Question for Lee King: What is the fastest, for diameters between 5 and 10 m? I had suggested a small flat tertiary, fast rocking in front of the feed, but this was nonsense: if tilting enough to get off source, a lot of illumination would go far beyond the secondary rim!

3. Suggested Procedure

Symmetric versus offset seems our most important open question. It cannot be decided without cost estimates, which cannot be done without a basic design of each type. Suggestion:

First, make a symmetric design for 100 m. Specify only survival stability (90 mph, or 20 lb/ft^2 of snow). Use a guess about the weight/ft^2 of the surface panels, and about the panel size (see Memo 5, Equ. 5, 6) which tells how many structural support points are needed. For elevation towers and drive, and for the azimuth drive, wheels and foundations, just take the NRAO 65-m design, scaled to 100 m. Get a cost estimate. Worry about all else later.

The offset 100 m. Same foundations and drives, towers higher if needed. Leave the topography of the dish as it is, just squeeze and pull where needed (see Lee Kings "Half & Half" model). Add a good tower tripod, with stiff supports under the dish to elevation bearings and wheel. Specify survival stability, and in addition: tower stiffness for wind deformations during observation (15 mph as explained in next Memo). Get a cost estimate.

Call P = (offset cost)/(symmetric cost). Assume costs to scale with the power 2.6 of the diameter. Then, for equal cost, the diameter of the offset one will be smaller than the symmetric one by the factor $(1/P)^{1/2.6}$. And its area is smaller by $(1/P)^{1/1.3}$. But if the symmetric one has 3% geometrical blockage, giving 6% loss, then, for equal cost, the efficiency of the offset telescope is reduced by the factor

$$E = (\text{offset eff.})/(\text{symmetric eff.}) = 1.06 * (1/P)^{1/1.3}. \qquad (1)$$

As an example, I use Table 6 of Memo 51, with $ 50.3 M for the symmetric case, and $ 62.4 M for the offset one, thus P = 1.24. And with two more values, we have diameters and efficiency losses:

P	D[m]	E	Loss
1.20	93.2	0.921	7.9 %
1.24	**92.1**	**0.898**	**10.2 %**
1.30	90.4	0.866	13.4 %

(2)

III. ACTIVE SURFACE

1. Keep Range Small

Surface support studs should not be long, because of dead load deformations when pointed at horizon. Also because several motors of their large number may always be out of order.

By far the largest deformation (beyond tilt and focal change) is gravitational astigmatism, and this is easily corrected by a deformable subreflector. It reduced the effect of gravity by a factor three at the 140-ft (see Memo 48). Astigmatism was then ± 8.7 mm at the rim, or a range of 17 mm (IEEE Trans. AP-26, 315, 1978). Scaled to D = 100 m, with D^2 for gravity, this is

$$\text{Range} = 17 * (100/42.7)^2 = 93 \text{ mm} = 3.7 \text{ inch}. \qquad (3)$$

The Effelsberg 100-m approached homologous deformations just by trial and error. We might use that, at least a bit, for our dish design as well. But only as an approach to "equal softness", and only for smaller-scale deformations (leaving the astigmatism for the subreflector). This may give a further reduction, say, of 1/2. The range left to the actuators may then be 1/2 to 3/4 inch.

2. Count on Gravity Only

Thermal and wind deformations are unknown. Unless we had real-time surface measurments during observation, taking a few minutes only. For which I see no chance.

For comparison: the new NNT telescope at La Silla, 3.5 m diameter, has 99 active adjusters. At changes of pointing, it uses a brighter nearby star and measures its focal surrounding during 60 sec, the computer grinds for another 60 sec, then all actuators get busy. Out of the question for us.- Maybe in a very far future: a range finder near focus, and a thousand little reflectors on the surface. Which may be added when available, if ever.

IV. THE THERMAL LIMIT

1. Exposed, Uncorrected

If the telescope is fully exposed, without corrections for its thermal deformations, the thermal limts of Memo 2, Fig.1 apply, with temperature differences in the backup of 1°C at night and 5°C in sunshine and calm. For details, see our NRAO 65-m design book. Deformation and shortest wavelength go in proportion with D:

$$D = 100 \text{ m} \quad \lambda = 5 \text{ mm, Night,} \quad \lambda = 25 \text{ mm in Sun} \tag{4}$$
$$60 \quad\quad 3 \quad\quad 15$$

Question: is Green Bank really good enough a site, to demand a good performance at 3 mm? If not, we might settle for the **6 mm** atmospheric window instead. But if yes, and even for 6 mm all day, we need some shielding. (Carbon fiber, as used for the 10-m MPI design, is much too expensive for a large telescope.)

2. Shielded

The 30-m MPI telescope on Pico Veleta has its backup structure completely enclosed in a thermally insulated skin. It uses strong ventilators for effective air circulation inside, which produce much heat, needing a cooling system, too. Jaap Baars claims that observers do not feel the difference between night and sun, and that the additional cost of all this was 10% only.

Should we consider this also for our much larger telescope? Somehow I think we shouldn't, although I have no quantitative argument against it.

Maybe there is some milder, chaeper type of shielding, in the way of **venetian blinds**, with white paint outside and a thin foam insulation inside each blade. The blades just keep the sunshine away, but they let any wind or breeze go through. Even in a dead calm, a slight warming up of the structure will cause convection. Regarding the efficiency, we need some (simple) experiments.

The blades may be either tiltable (with the changing angle of the sun) as we use it for windows, or V-shaped and fixed:

3. Central Part of Dish

I was asked whether the central part will have smaller rms surface deformations. I am rather sure that this is the case: the outer parts are more directly exposed and the rim is cantilevering; whereas the center is a bit shielded by structures and has a compact support.

Thus, instead of paying for shielding, we might sacrifice area, and observe 3 mm only with a more narrow illumination (good against sidelobes, too). But this again needs a quantitative treatment before decisions. A cost estimate for the shielding, and structural analysis for the size of the usable aperture without shielding. (At Effelsberg, only a smaller aperture can be used for shorter wavelengths, but the MPI would not do this again.)

V. POINTING ERRORS

1. Scaling for Various Diameters

For telescopes at their thermal limit, the shortest wavelength goes with D, thus the beamwidth is constant, independend of the diameter. Along the 1°C limit, we have about

$$\text{beamwidth } \beta = \text{constant} = 12 \text{ arcsec.} \qquad (5)$$

Regarding the pointing, thermal deformations go as $\Delta L \sim L$, and angles as $\Delta L/L$, where L is the length of a member; thus the pointing error, $\Delta\Phi$, does not depend on D (but depends on design and shielding); the same then holds for the ratio which matters, the error as a fraction of the beam:

$$\Delta\Phi = \text{const} \qquad \text{and} \qquad \Delta\Phi/\beta = \text{const.} \qquad (6)$$

For wind deformations, the force is $F \sim D^2$, and the deformation is $\Delta L = L*F/(E*A)$, with A = bar area and E = elasticity. If the cost goes as $D^{2.6}$ and is defined mainly by the weight which goes as $D*A$, then the bar areas scale as $D^{1.6}$. Altogether, the wind induced deformations are $\Delta L \sim D^{1.4}$. The angle again is $\Delta L/L$, thus

$$\Delta\Phi \sim D^{0.4} \qquad \text{and} \qquad \Delta\Phi/\beta \sim D^{0.4}. \qquad (7)$$

In summary: the pointing errors, and their fraction of the beam, are about constant for thermal deformation, and increase only slightly with the diameter for wind induced deformations.

If a structure is stable against survival, it is mostly also stiff enough for observational winds (Memo 5, Equ. 4). If not quite so, we must either beef up the elevation wheel and azimuth towers, or live with what we've got and observe 3 mm only during calmer times (summer, and nights; see next Memo).

2. Feed Legs, or Tower

Thermal deformation may be too large. For our old NRAO 100-m design, each leg consisted of three pipes of 4 inch diameter. We planned to spray the outside with a thin foam layer, and to blow ambient air through these pipes, using motors of 0.5 horse-power. We estimated a reduction of about a factor three for thermal differences between legs.

Another possibility is to measure these deformations by some optical means, as seen from the vertex, and to correct for it.

3. The Pointing System

Cam Wade had started to work on the pointing system, and we had discussions about this at Green Bank. We agreed that the following possibilities should be looked into, listed here in the order of decreasing desirability:

1) North-seeking gyroscope
2) Optical gyroscope + tiltmeter
3) Optical connections to ground (65-m)
4) Optical telescope at vertex, fixed at bright star
5) Transmitters on ground, receivers at dish rim

Methods 1) to 3) are meant to provide a stable small platform at the very center of the backup structure, from where on the pointing is measured; bypassing all deformations or deviations below, of fondations, azimuth rails, azimuth towers, elevation axis, and elevation wheel. Method 4) seems to work also in daylight, and it should also measure several angles to the dish rim. Method 5) may have to deal with multiple paths from reflections.

Method 1) would by far be the nicest, provided it is available, accurate, declassified, and affordable. At previous NRAO designs, John Findlay had suggested this method, but nothing useful could be found at this time.

4. Epilogue

Radio astromomers have been spoiled in the past, by being able to observe "day and night in any weather". Gradually we have got more humble when going to shorter wavelengths. If we now may be driven to design a telescope which is at its best only during calm nights with exceptionally clear sky, we should be reminded at the optical astronomers who are even more limited by external conditions, and who still have done excellent work.

One could make it a rule that at the telescope there is always a long-wave program, waiting for those times, when the scheduled program gets bad observing conditions.