Notes on Measuring Distances

by John W. Findlay

1. Introduction.

It may well be that both the pointing and the surface tasks for the GBT will be based on the development of a system which locates many points on the telescope with respect to a coordinate system fixed to the ground. If there were such a system and, for example, the location of many surface points and points on the sub-reflector were known, the surface and pointing tasks would, in principle, be solved. I do not here look toward such a final solution but I do suggest that we should review briefly various ways by which such a system could be set up. In what follows I am thinking of position accuracy of points in the system of the order of 100 microns. I do not consider angle-measuring because I believe distance measuring is the better choice. The physics behind this choice lie mainly in the difficulties of measuring angles of light rays in an atmosphere which has both regularities and irregularities in its refractive index. I leave it to the reader (for the moment) to consider this point in detail. However it should be noted that over the last thirty years first order surveying has moved from triangulation (the theodolite) to trilateration (the geodimiter and other range-measurers).

2. Optical Ranging.

The most precise ranging using light is by an interferometer (the Hewlett- Packard laser interferometer is the typical instrument). However the wavelength of light is so short that such techniques are too sensitive for our purposes. The earliest instruments which used a modulation impressed on a light beam were derived from precise measurements of the velocity of light made by Bergstrand soon after WWII (The Geodimiter and the Mekometer). The way in which this principle could be developed for measuring telescopes was described by Payne in ([1]) and also in the 65-meter telescope design book. Although this work was not continued in NRAO it was further developed by the Max Planck Institute (for possible use on the 30-meter) and by V. Herrero who planned and tested a system for measuring and setting the 300-meter Arecibo surface.

In the original NRAO work the light from a helium neon laser was modulated at 550 MHz, transmitted over the path to be measured and returned by a corner cube reflector. The phase of the returned modulation was compared to the transmitted phase - the phase difference is a measure of the path length, except for a range ambiguity of about 27 cms (half the modulation wavelength). Tests of the instrument suggested that ranges of up to 60 meters could be measured with errors of about 50 microns. Let us consider the errors in more detail.

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[1]. "An Optical distance Measuring Instrument", J.M. Payne, Rev. Sci. Instr. 44, 304 - 306, 1973.

The range ambiguities will not be important in practice. It can be assumed that all paths will be defined and known to a few centimeters. In a modern instrument the modulation frequency would become one or two GHz (to improve sensitivity to range changes) so the ambiguities would be 15 or 7.5 cms apart. However, the question of the stability of the "zero-point" of such a instrument is vital. This was tested in 1972 by observing on a 60-meter range to see how the readings changed over an hour. The results were good. However, it would seem wise to incorporate a "zero-check" in future tests. This is fairly easy, but may use time in a busy reading cycle. The tests in which the path length was changed showed the instrument read correctly over an 80-cm range of path change, but that insufficient care had been taken to isolate the return signal from the sent signal. This was noted as something to be watched in future designs. The last point to note from this early work is that the measurement time per target was slightly less that 3 seconds. For a present-day system this is too long.

3. Some possible new systems.

This paragraph has been written after informal talks with.John Payne, who has suggested various possibilities. Let us stay for the present with the task of locating a thousand or so points on the dish surface with respect to a coordinate system carried in the dish support structure. (This coordinate system has eventually to be related to ground). There seem to be at least two ways of locating the surface, I can call these "floodlight" or "beamed".

(a) The Floodlight method.

Floodlight the whole dish surface with light from a source modulated at (say) one GHz. Place a retro-reflector at each point to be measured to return the light to its own receiver. Avoid cross-talk. Then at each receiver compare the phase of the returned light with the phase of the sent light. This gives a continuous measure of the range to every target. In its simplest form the system would have one floodlight source near the subreflector. To give good trilateration, use three more such sources placed around the dish edge.

(b) The Beam method.

Payne says there can be simple, modulated lasers which can be steered. So, steer the lasers in the above system and read the receivers only when lit by the lasers. To speed the data, use more lasers.

(c) Possible modifications.

If the modulation frequency is changed linearly with time and the receiver mixes the returned signal with a sample of the sent signal, we have an up-to-date version of the way the ionosphere was discovered in

1925. (See references [2],[3]). The method can measure the total time of travel to the target and back, and also the changes of the travel time. The accuracy of the total travel time is too poor for our use, but the changes are measured with the same sensitivity as in (a) and (b) above. To illustrate the method, let us assume a modulation frequency which starts at one GHz and changes linearly to 1.1 GHz in 100 microseconds. It then repeats this cycle. (This will be recognised as "chirp" radar, much used in defense systems). If our target is 150 meters distant, the signal returned from it will be delayed by one microsecond, so it will be mixing with a sent signal of
1.001 GHz to give an output of one MHz. Thus during our 100 microsecond chirp we see one hundred cycles of one MHz output. To get the actual range, Appleton just measured the number of these cycles in the chirp. But he also noted that the phase of the chirp waveform changed as the path changed, by one wavelength for each path change of one wavelength. In our example, if the target distance changes by 15 cms we see our one MHz output move through one cycle. So by using some method such as locating zero crossings we can measure target motions of the same order as in (a) or (b) above. (The methods are, of course, fundamentally phase sensitive systems, with phase changes detected slightly differently). It is not clear whether this system is any better or worse than the others It might be easier in practice to avoid cross-talk. Its ability to discrininate in absolute range to a few centimeters might possibly be of use.

In this same category of systems we should include any pulsed radar method which allows of the determination of the phase of the radiofrequency within the pulse. Again, this was done in ionospheric research [4] but does not seem to be easy to apply here. One would like to maintain phase coherence within a pulse of long infra-red radiation, but I do not see a way.

4. Relationship to the GBT Project.

At this early stage it is only possible to make rather general statements as to how the whole surface and pointing systems are likely to interface with the structural and mechanical areas of the project plan. However, it may be useful to attempt to set down some thoughts -bearing in mind that these have to be modified as work progresses.

I believe the surface shape and the pointing systems will turn out to be connected, insofar as the fine pointing of the telescope is concerned. It does not seem to me to be essential to define the exact systems immediately, but it does seem to me to be vital to define the "first" GBT as far as structural and mechanical properties are concerned. I picture a

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[2]. Appleton and Barnett, Proc.roy.Soc. A, 109,621, 1925

[3]. Appleton E.V., Proc.roy.Soc. A, 126, 548, 1930.

[4]. Findlay, J.W., "The phase and group paths or radio waves returned from region E of the ionosphere". J. Atm. and Terr. Phys., 1, pp 353 - 366, 1951.

strong, stiff structure driven by good well-tested machinery but not incorporating special or expensive devices to meet a pointing specification. This "first" design should be good enough to allow of a careful dynamic analysis to be made of all the major parts of the design, so that good predictions can be made as the the actual tasks which the surface and pointing systems have to meet. I should demand that this "first" design should be at least as good as the Efflesburg 100-meter with respect to its predicted performance. (I would not accept anecdotal information about the 100-meter, but take steps to find out its pointing performance under various wind and thermal conditions).

During the time that these tasks take I would concentrate on the design and test of a range-measuring system. The tasks of deciding the layout of a ranging system and the computing needed to derive the information of the surface and sub-reflector locations can be attacked by computation. There may be some constraints on structural geometry but these should be slight. One problem might be the fact that the range systems need a lot of GHz radiation around.

The step from the surface and sub-reflector (which essentially define the beam) to earth-based coordinates could come from a stable platform, but I prefer to think of it being made by another ranging system.

My last point is to ask whether it is really essential to point the telescope beam at all times to two or three arc seconds. I can envisage the surface and pointing systems knowing where the beam is at all times to this sort of precision. But there are many observing modes (mapping in particular) where the data handling could put the data into the correct box as determined by the fine pointing system rather than asking thousands of tonnes to move four arc seconds. The answer to this partly lies on the time structure of the motion of the telescope beam on the sky. I can see very good tracking and pointing in the face of effects due to thermal and steady winds, since here the fine pointing could control the beam. But when pointing errors with time scales of less than a minute occur, it might be better to control the data flow rather than the beam.

5. Conclusion.

It will be clear that the opinions in this note are my own. However, the paragraphs on ranging have been written after discussions with John Payne. If there are errors in these, I can be blamed. If there any good ideas, he can have the credit.

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