GBT Memo No. 60

Active Correction at the Primary Reflector or the Subreflector?

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The following thoughts are a quick response to a request that I have received from John Payne for comments on a memo by R. Fisher, R. Norrod, and J. Payne dated Oct. 10, 1990, concerning the question in the title above.

The 100 m diameter main reflector surface of the GBT will consist of approximately 2000 panels of size 2 m x 2 m. The size of the subreflector is approximately 7 m diameter, so the size of a panel of the subreflector that would illuminate just one primary panel would be approximately 14 cm on each side. This is too small to provide effective compensation except at very short wavelengths (see discussion in the next paragraph). I shall therefore consider a subreflector panel size about three times larger. Thus there would be about 200 such subreflector panels, adjusted by a similar number of positioners. Each one would illuminate approximately nine primary surface panels. Now suppose that at some elevation angle such as 45 deg. it is possible to bring all the primary panels into exact adjustment. When the elevation angle is changed the surface will distort. The distortion over any area of 3x3 panels of the primary surface must be a continuous and monotonic function of position if it is to be compensated by adjusting the subreflector panels. To put it another way, any distortion on the surface must have a wavelength along the surface greater than 12 m if it is to be compensated. This condition will be fulfilled so long as the panels are mounted in such a way that the support for each one does not distort independently, that is, that the structural members that provide the panel support points are sufficiently stiff and are continuous over three or more panels in any direction. This is likely to be the case.

Compensation of the primary surface by adjustment of the subreflector depends upon the radio wavelength being small enough with respect to the subreflector panels that the radiation paths are approximately those of geometrical optics. Consider a single panel on the subreflector that illuminates a group of 3x3 panels on the main surface. This panel area on the main reflector subtends an angle of approximately 0.1 radians at the subreflector. Thus for the subreflector panel to put almost all of its reflected energy into the corresponding 3x3 primary panel patch, the divergence of the beam of reflected radiation resulting from diffraction must be much less than 0.1 radians. Thus the size of the subreflector panel must be much greater than 10 wavelengths. The subreflector panel size considered above is approx. 3x14 = 42 cm on a side, so the wavelength must be much less than 4 cm. The overall antenna structure is being designed so that compensation is required only for wavelengths less than approx. 2 cm, for which the above requirement is only marginally fulfilled. Thus perhaps the subreflector panels should be larger than the 42 cm that I have considered, which would, of course, increase the minimum (mechanical) wavelength of distortion that can be compensated. A second requirement is that the adjustment required for the subreflector panel must be such that the angle of any resulting tilt of the panel must be small compared with 0.1 radians, or else the reflected radiation will not be aimed in the direction of the primary panels for which it is intended. For a subreflector panel of dimension 42 cm the difference in the adjustment at the edges must be no more than about 42/100 = 0.42 cm. This in turn requires that the difference in distortion of the main reflector at the edges of the 3x3 panel group, which are 6 m apart, should be no more than 4.2 mm. This tilt condition would probably be met, but a careful examination of the predicted gravitational distortion is required to be certain.

The simple considerations given above indicate that for compensation at the subreflector to be effective there must be limits on the magnitude of the distortion and the frequency with which it varies across the surface of the main reflector. Distortion by thermal effects and wind should be included in any consideration, but I see no reason to think that they would vary much more rapidly across the surface than gravitational distortions, the effects or sun and shadow being blurred by motion of the antenna and the sun. If compensation at the subreflector is to be seriously considered, there is a need for a more thorough optical analysis, taking account of diffraction, and based on the predicted mechanical distortion. This would need to be done for various radio frequencies.

Now suppose that a detailed analysis confirms that the adjustable subreflector would be satisfactory. Consider the problem of setting the primary surface. There would be no positioners for the primary surface, and I assume that the panels would be supported at each corner by screws that are adjustable from the top surface. The use of the laser ranging device being developed by John Payne would appear to offer the most straightforward means of determining the required settings. Reflectors would be needed at each of the adjustment points of the 2000 panels. I envisage that each adjustment point would have an identification number, and the control computer for the measuring system would produce a listing of each point with the required angle of turn of the adjustment screw. This measurement would probably be done at night for temperature uniformity. Applying the measured corrections to the screws could be done during the daytime. It would take perhaps two minutes for a technician to move from one point to the next, identify it on the list, and make the adjustment. Two men would adjust 2000 points in about four working days, and perhaps in somewhat less time with practice. Note that this time corresponds to the case of just one adjustment screw at each point where four panel corners come together. If there are independent adjustments for each panel corner, it will take four times as long to set them all. To maintain accuracy, readjustment might have to be done periodically, so it is not clear that manual adjustment of the surface would result in less walking on the primary surface as the memo by Fisher et al suggests. This is a minor consideration, however, since the surface adjustment crew would be properly equipped to prevent damage.

The big advantage of compensation by an active subreflector is that it eliminates the need to service positioners located behind the primary surface. In my opinion, the problem of access of the positioners behind the main reflector has not been addressed satisfactorily in the present design. As I understand it, the proposal is to remove surface panels to get at the positioners. Removing a whole panel of area 4 sq. m in order to access a positioner beneath it seems to me to be impractically clumsy. It would require several men to handle such a panel, it would require care to make sure that the removed panel does not damage other parts of the surface when it is set aside, and it would be difficult if not dangerous to handle a panel if there is any wind at the height above ground of the antenna surface. When replacing the panel each corner would have to be replaced to an accuracy of better than 200 microns relative to the other panel corners at each positioner-supported point. The idea of removing a small panel, or a small portion of a normal panel, to access a positioner (see NLSRT Memo No. 50) is the only practicable solution that I know of for changing positioners on an antenna of the 100 m size, and it seems that this suggestion has to be rejected because it is would be too expensive.

The adjustable subreflector approach would require additional weight at the end of the subreflector support arm, because of both the more complicated subreflector structure, and also the requirement for some kind of working platform with access ladders, etc. to provide a safe and convenient working area for maintenance of the subreflector adjusters. (Structures to provide access could be omitted if the subreflector location could be brought down to the ground or to an access tower.) Adittional loading the arm could present serious structural problems, so this is a disadvantage of correction at the subreflector. It would certainly be easier to provide protection of the control wiring against lightning strikes if it is all in a relatively confined area than if it is distributed over the whole back surface of the antenna. The loss of the possibility of changing from a parabolic to a shaped surface for the main reflector does not seem to me to be a major problem since the increase in gain is no more than 2 dB, and in any case it may be possible to implement the effect of shaping in the future with some kind of tertiary reflector system.

My conclusions are as follows. 1) It seems possible that correction by an active subreflector would be satisfactory, but a detailed study is required to be sure. 2) If it were found to be satisfactory, and the additional weight on the arm is tolerable, the active subreflector would offer a very important advantage with regard to accessibility of positioners, and also the possibility of removing the whole active subreflector assembly and replacement with a spare, if desired. In addition there should be a very significant cost saving as pointed out in the memo by Fisher et al. 3) When the lifetime of maintenance of the telescope is considered, the best solution might be to accept a slightly lower degree of surface compensation, as provided by an active subreflector, in return for the advantages outlined.