GBT MEMO 120

NATIONAL RADIO ASTRONOMY OBSERVATORY

GREEN BANK, WV

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To: Distribution
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This note intended to be the first step in defining the astronomical requirements of the GBT's active surface. It also considers some consequences of those requirements.

As the GBT moves in elevation, its surface will deform under gravity. If the telescope were perfectly "homologized", the deformations would move the surface smoothly from one paraboloid to another and there would be no change in aperture efficiency or gain with elevation. The GBT is only partially homologized, however, so even though there is a "best fit" paraboloid at each elevation which minimizes the overall rms error, unless the telescope is at the "rigging angle", there will be portions of the dish which will not be at the optimum location. For the GBT the rigging angle will be at 44 deg elevation.

To correct for these residual gravitational deformations, the GBT will have an active surface in which panel corners are mounted on motor driven actuators that can move in a direction normal to the surface. The actuators have a travel range of about 2 inches. To appreciate the effects of the partial homology, note that as the telescope moves from horizon to zenith the "floppiest" panel corner support is expected to move by >2 inches. In terms of the best-fit paraboloid, however, the maximum deviation of any point at any elevation is <0.2 inches. The structural models used to derive these numbers suggest that to correct for gravitational deformations the worst-case actuator will need to be moved by as much as ±0.15 inches between horizon and zenith, or about ±4 mm. There are also areas of the surface (~10%) over which the actuators will almost never have to be used to correct for gravitational deformations. Calculated surface contour maps with respect to the best fit paraboloid are given in GBT Memo 119 for the antenna pointed at the zenith and at the horizon.

The instantaneous length of each actuator relative to the backup structure is sensed by an LVDT to a resolution of about 25 microns. In principle therefore, we could continually adjust the surface to keep it within 25 microns of the exact shape. In practice this may not be a desirable strategy because actuators will be awkward to replace if broken; from operational considerations we should minimize wear and tear on the actuators. The following discussion is an attempt to develop criteria and consequences of various modes of active surface use, and to estimate the demands on the actuators caused by such use.

For the purposes of this discussion I adopt the following two rules:

1. There will be no attempt to adjust the surface continuously at the resolution limit of the LVDT. Instead, an actuator will be moved by a discrete amount whenever the panel corner it is attached to differs from its desired location by some specified tolerance.
2. The tolerance, Δy, will be given by the observer in units of the observing wavelength, e.g., $\Delta y = \lambda/32$.

The following general information will be useful in this discussion. Assuming uncorrelated surface irregularities with an rms deviation σ, the Ruze formula indicates that the surface aperture efficiency will have the following values:

σ/λ	η(surf)
1/16	0.54
1/25	0.78
1/32	0.86
1/40	0.91
1/55	0.95

For a surface with a random distribution of errors with a mean of zero and a peak $\pm\Delta y$, the rms error $\sigma = 0.4\ \Delta y$. If the surface is a "squarewave" with a single amplitude $\pm\Delta y$ then $\sigma = \Delta y$. Because the actuators are located at the panel corners this second state will not ever be achieved, so for now I will assume random errors. This topic will be revisited at the end of this note. Errors in the surface are only one term in the equation for overall aperture efficiency; other terms, including illumination efficiency and subreflector irregularities, are discussed in GBT Memo 119.

Several examples of the use of the active surface during observing can be considered.

Slewing in elevation: The most intensive use of the active surface will occur while the telescope is continually moved from horizon to zenith and back again at the slew rate and the surface is maintained at the best possible figure all the while. At the elevation slew rate (20 deg/min) the "worst case" panel corner will need to be moved on average 1.7 mm per minute. To maintain a surface to $\lambda/32$ against random errors at 7 mm observing wavelength implies that $\Delta y = 0.5$ mm and thus the worst case actuator will have to be moved about 3 times a minute. Observations of this type are expected to be fairly rare, but they will tax the active surface system while they are being done.

Tracking: While tracking an object at a fixed celestial position, the GBT moves most rapidly in elevation if the object has a declination of about 38 degrees so that it goes through the zenith. In this case, horizon to zenith motion takes 6 hours and the average elevation rate will be 0.25 deg/min, or about 1% of the elevation slew rate. Using criteria from the previous example, the worst case actuator will have to be moved about 0.04 times per min or about twice an hour. Thus one could expect to integrate for at least 20 minutes while tracking at $\lambda = 7$ mm without having to adjust even the worst-case actuator from its initial setting.

Position-switching: A more strenuous use of the system is for brief integrations followed by substantial moves in elevation. An example would be a 5 min "on-source" followed by a 5 min "off" at the same elevation, then a move of 20 degrees in elevation to a new source for a repeat of the procedure. This is equivalent to operating at about 0.1 of slew, on average. The 5 min integration would not ever require an actuator move (even at 2.7 mm) beyond its initial setting, and since the "off" will most likely be at the same elevation as the "on", no actuator move would be required between them. A change of elevation of 20 degrees every ten minutes, however, would require an actuator adjustment, on the same time scale, of 1.7 mm, which is significant for observing wavelengths of ≤ 3 cm. A surface readjustment would have to be made only when moving between sources, and thus once every 10 minutes at most.

For the following discussion I assume that the GBT will move in elevation at an average rate of 0.1 slew, equivalent to the position-switched example above, and that the telescope is in use for astronomy 90% of the time.

The maximum total distance traveled by an actuator over its lifetime can be estimated for the case in which it is continually adjusted as $\mathbf{Y} = 100\ \mathbf{s}\ \epsilon\ \mathbf{T}\ \mathbf{f}$ mm hr^{-1}, where **s** is the average elevation rate expressed as a fraction of the slew rate 20 deg/min, ϵ is the fraction of the time the telescope is making astronomical observations, **T** is the life expectancy of an actuator and **f** is the fraction of the time that the telescope is using the active surface when it is in operation. I will adopt $\mathbf{T} = 20$ years, $\mathbf{s} = 0.1$, and $\epsilon = 0.9$.

The quantity **f** depends on the distribution of observing frequencies. For the purposes of discussion I assume that about 40% of the time the telescope will operate at $\lambda \geq 11$ cm, and that the active surface will not be in use. Recall that the maximum deviation of the worst-case panel corner from the correct location is of order 4 mm, which is $\lambda/28$ at 11 cm wavelength. Even if the active surface were turned on at a $\lambda/50$ threshold, it would move only rarely for the typical experiment at 3 GHz and below. Thus I take $\mathbf{f} = 0.60$, and the total travel of the "worst case" actuator is estimated to be $\mathbf{Y} = 10^6$ mm over 20 years of antenna operation.

The estimated number of actuator steps can be derived as a function of observing wavelength. During a single motion from horizon to zenith the worst case actuator needs to be moved by 8 mm to remain in the correct position. If we move an actuator only when it exceeds a 2.5σ threshold, where $\sigma = \lambda/32$, for example, then the actuator would be moved when its position was in error by more than $\lambda/13$, and the move would be a distance of $\lambda/13$. To cover the 8mm motion needed from horizon to zenith, the actuator would have to move $\mathbf{n} \approx 100/\lambda$(mm) times. The following table gives estimates of the number of times the worst case actuator would have to be adjusted during a track from horizon to zenith, and the average length of the adjustment. The table also includes guesses as to the relative percentage of time that the GBT will spend at each observing wavelength, guesses that I would not like to have to defend at this time.

λ(cm)	% observing	n(λ)	Δy (mm)
≥11	40	0	0
6	10	3	2.5
3	5	5	1.5
2	5	8	1.0
1.3	25	11	0.7
0.7	15	27	0.3
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		<8 moves>	<0.7mm>

In summary, the worst-case actuator is estimated to move on average 8 times during a horizon to zenith track, at an average move distance of ~0.7 mm. Assuming that the GBT will operate at an average elevation slew rate of 0.1 max (see the "position-switched example above), then over a 20 year span the worst-case actuator will make a total of ~1.7×10^6 moves, and travel a total distance of ~1.2×10^6 mm. I estimate that about 40% of the time the active surface will not be in use, though there is considerable uncertainty in this figure.

Before the active surface is implemented we need to consider several other factors:

1. Most of the gravitational deformations will be locally correlated and not randomly distributed across the surface (see GBT Memo 119). Because of this it may be useful to adjust portions of the dish more frequently than implied by the above arguments, and some criteria for surface goodness other than overall rms will have to be devised. These situations can and should be numerically simulated.
2. It might be worthwhile to implement "feed-forward" algorithms that take into account knowledge of the projected telescope position to optimize the surface setting for an entire integration, rather than just optimize the surface for the elevation of the beginning of an observation.
3. At some stage we will try to use the active surface to correct for thermal deformations detected by the laser ranging system. This will increase the demand on the actuators.