RESETTING ARECIBO'S REFLECTOR SURFACE USING PHOTOGRAMMETRY

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A program was begun at the end of 1998 to refurbish and reset the primary reflector surface of the 305 m Arecibo radio telescope. After the completion of the installation of the new dual-reflector Gregorian system to correct for the telescope's spherical aberration [*Kildal et al, 1994*], radiometric measurements indicated that the efficiency of the surface of the primary reflector at frequencies above 1 GHz was significantly lower than predicted based on the nominal 2 mm to 3 mm rms surface accuracy. This was not surprising, as the reflector had been last set in 1986. It was expected that both changes with time and the considerable damage to the approximately 1 m by 2 m reflector panels and their supporting cable system that occurred during the upgrading work on the suspended structure of the telescope would have caused considerable deterioration in the 2.2 mm rms surface accuracy achieved in 1986.

Simulations showed that a photogrammetry system taking images from the tops of the three towers from which the suspended structure of the telescope is supported would be able to locate 7.5 cm (3 inch) diameter targets on the reflector's panels to an rms accuracy of better than 1 mm in all three dimensions. However, the system would have to be a film-based one as the newer video systems would not have adequate resolution or the number of required images to cover the entire reflector surface would be unacceptably large. A refurbished photogrammetry system was purchased from Geodetic Services Inc. consisting of a 20 cm by 20 cm (8 x 8 inch) film format camera, a film measurement system, and the associated software. With this system, the measurement and resetting of the 38,800 panels was done in two stages. The overall spherical shape of the reflector is defined by 40 "main" cables of 2.5 cm (1 inch) diameter, which span the reflector as equally spaced chords. This cable system is forced into a roughly spherical shape by 1,859 steel tie-back cables that are anchored in concrete blocks to the underlying terrain. Orthogonal to the main cables are 300 diameter "light" cables of 8 mm diameter at 1 m spacing that are tied to the main cables where they cross them. The corners of four adjacent panels are attached to a "collection plate" which is connected to these light cables via an adjustable stud so that the number of adjustment studs is roughly equal to the number of panels. The first stage of the reflector alignment consisted of placing targets on the panels over each of the 1,859 tie-back cable positions and using the photogrammetry system to measure their locations. Twelve camera exposures are made from two of the towers and, because of an obstruction in the field of view, 12 made from each of two locations on the third tower. Six exposures are needed to cover the entire reflector surface and another 6 are taken with the camera rotated through 90 degrees to help calibrate focal plane distortion errors. Typically, all these exposures provide over 20 estimates of the three-dimensional location of the centroid of each target from which the mean location and its standard deviation can be obtained. For the first measurements of the targets at the tie-back locations, the standard deviations of the mean positions of the target centroids were close to 0.6 mm. The errors in the locations of the targets relative to the ideal spherical surface shape ranged up to about 30 mm with the larger errors occurring over an area of fill material underneath the reflector, which has continued to subside ever since the telescope's original construction. The rms error of the target locations relative to the ideal reflector shape was 12 mm and the width of a fitted Gaussian distribution was 7.5 mm. On the basis of these measurements, the lengths of the tie-back cables were adjusted to bring the main cables close to their required curvature. A second survey of the tie-back targets was completed in late January 2001 and gave an rms error for these targets of 5.4 mm with the width of the fitted Gaussian being 2.3 mm. While almost all the tie-back cables had been correctly adjusted, there were a few "outliers" which were corrected. Another survey gave an rms for these 1,859 targets of 2.9 mm and the width of the Gaussian fit of 2.3 mm.

By May 2001, targets had been placed on all 38,700 panels and a new set of photos taken. Given the number of films and the average number of targets on each film, approximately 500,000 target position measurements had to be made. This took approximately three months, with the last table of panel adjustments being completed in late August 2002. The targets were measured in 16 groups and panel adjustments started as soon as the adjustment tables were available for each group. Consequently, the first complete pass of panel adjustments was completed in September, shortly after the table of required adjustments was available for the last of the 16 groups. The survey gave an rms for the surface prior to the panel adjustment of 5.3 mm.

A survey of the adjusted surface was started in October 2001. Measurements of the targets at 1,859 tie-back locations gave an rms of 1.5 mm. Because of a major failure of the target location measurement machine, measurements of only 2,234 additional targets covering two sectors have been obtained to date. Their rms is 2.8 mm. If the 140 measurements that deviate more than 5 mm from the mean are clipped at 5 mm, then the rms is 1.6 mm indicating that at least 10% of the targets need a second adjustment.

The resetting of the panels of the primary reflector has made a dramatic improvement in the performance of the telescope. Prior to the resetting, the gain at 13 cm wavelength was about 7 K/Jy and highly variable with zenith and azimuth angles. The gain is now close to 10 K/Jy, relatively constant with azimuth angle and with the expected behavior with zenith angle. The improvement in the gain at 6 cm was, of course, even more impressive going from between 2 and 3 K/Jy to over 8 K/Jy.

REFERENCES

Kildal, P-S, L.A. Baker and T. Hagfors (1994), “The Arecibo Ugrading: Electrical Design and Expected Performance of the Dual Reflector Feed System”, *Proc. Inst. Elec. Eng.,* 82, 714-724.