National Astronomy and Ionosphere Center

Arecibo Observatory

NEWSLETTER

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Photo: David Parker, 1997/Science Photo Library

Observing Proposal Reminder: The next proposal deadline is June 1, 2001. Please make a note to get your proposals for observations using the Arecibo Observatory facilities submitted by that date. Details can be found at our web site *http://www.naic.edu/vscience/proposal/proposal.htm.*

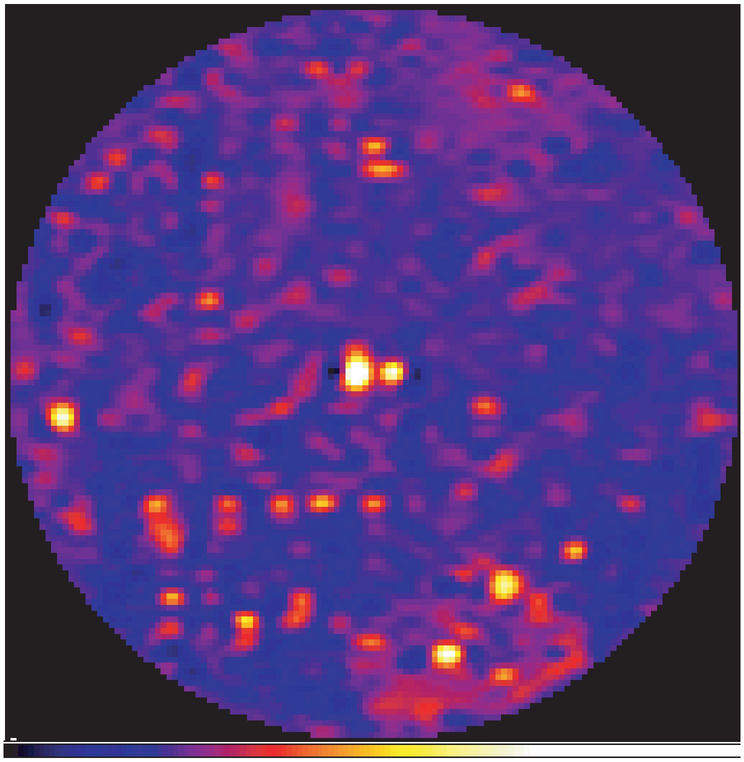

Figure 1: An image of the errors in the main reflector surface processed from Lynn Baker's photogrammetry data by Germán Cortés. Blue indicates positive devation from an ideal surface and red/yellow means negative deviation. The unweighted rms is about 15 mm. (Courtesy Germán Cortés).

Resetting the Arecibo Primary Reflector Surface

Paul Goldsmith

Although not strictly considered part of the Arecibo Upgrade project, the surface of the 305 m telescope plays a critical role in the overall system performance, particularly at the higher fre-

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The NAIC is operated by Cornell University under a Cooperative Agreement with the National Science Foundation.

quencies that is one goal of the Upgrade. The surface was last surveyed and adjusted about 15 years ago, and a lot has happened since. The main cables supporting the surface are held to the ground by about 2000 cables which connect to concrete blocks sitting on the ground beneath the reflector. Soil motions thus can directly impact the shape of the reflector surface.

Based on monitoring by surveying, José Maldonado (NAIC) had indications that these motions had been significant, particularly in the southeast quadrant of the reflector. That part of the natural "sinkhole" in which the reflector was built had been filled in extensively with dirt and construction material from other parts of the bowl and elsewhere. This area was less stable than the rest of the ground, and it was not surprising that it should be more subject to gradual movement. Puerto Rico is in a fairly active seismic zone and there are tremors that produce small motions—in particular, of this not very well compacted portion of the ground under the reflector.

In addition to the subsidence, the upgrade work itself was quite traumatic for the reflector surface. There were many panels damaged by items dropped by construction crew working on the platform and the feed arm. Also, there was one large cable that was dropped, and when this hit the dish surface, it destroyed over 100 panels, and broke some of the cables that support the dish surface. These panels and cables have long been repaired, but the process may certainly have contributed to a deterioration of the accuracy of the reflector surface.

Since one of the major goals of the upgrade was to raise the upper frequency limit of operation to 8 GHz or higher (wavelengths less than 4 cm and hopefully as short as 3 cm) it was evident that we would be pushing the accuracy of the primary reflector. Some very limited tests using the mini-Gregorian carried out by Phil Perillat (NAIC) in April 1991 showed that things were not terrific in this frequency range, with a sensitivity of 0.25 K/Jy at 10.67 GHz. And this was before the contractors started redoing the surface for us! The mini-Gregorian illuminated only a small fraction of the total surface, but the derived surface rms from those measurements was 3.3 mm—not too terrible, but higher than one would like for efficient operation.

Previous campaigns to set the primary reflector were based on optical surveys with theodolites. In this procedure, the location of targets located above the main (North-South) cables was determined by triangulation based on measurements made from several points around the reflector rim. The locations of these selected points could be measured and adjusted to an accuracy of approximately 1 mm rms. However, the panels are only 1/4 the size of the spacing of the main cables, and each of them can be adjusted. In the approach used earlier, the positions of panels between the main cables were "interpolated" between the measurements of the widely-spaced targets on the main cables. It was thought that the overall rms was on the order of 2.5 mm, only slightly less than implied by the X-band measurements mentioned above.

To perform really well, one needs the overall rms surface error to be less than 1/20 wavelength, which translates to 3 mm rms at 10 GHz. The panels themselves are thought to have an error of approximately 1 mm rms, and the secondary and tertiary reflectors contribute smaller errors. So it would be desirable to get the primary surface adjustment error below 2 mm rms. It was judged impractical to reach this level using the technique employed previously. In assessing options, we decided to adopt optical photogrammetry.

For this approach, reflective targets are put on the panels; these targets are 3 inch diameter disks of retroreflective material. Using a special camera, photographs of the dish are taken from the top of each of the towers. You can imagine each photograph as yielding the angular coordinates of the target. If you combine the angles to a given target from three or more viewing positions, you can solve for the three dimensional location of the target. This technique has been refined and turned into a commercially available combination of hardware and software by a company called Geodetic Services Inc. NAIC has been working with the president of GSI, Mr. John Brown, since 1994, and last year we finally were able to get an order in for the special equipment needed. A somewhat different version of this same approach was used to measure the secondary and tertiary reflectors—the main difference is for those relatively small reflectors, a CCD camera was used.

For the measurement of the primary, we have to use a large-format film camera. Part of the reason why is evident if you compare the number of pixels in a 6 inch by 8 inch piece of film, versus even the biggest "megapixel" CCD. My crude estimate is that we get at least a "gigapixel" format with the film camera. This is necessary if you want to measure a target 500 m away to an accuracy of 1 mm.

What happens in practice is that the camera is taken up to the top of one of the towers. It is accompanied by several intrepid NAIC staff members, typically Lynn Baker, Felipe Soberal, and sometimes others. From the tower top, they take a number of photographs of the dish surface—several photographs are necessary to cover the entire area, and they also take photographs with the camera rotated by 90 degrees to be able to isolate any distortion in the camera's imaging system, and take views from two different positions on each tower top as well. The illumination is provided by a powerful strobe lamp, which together with the retroreflective properties of the target, guarantees that the targets stand out with good contrast relative to the general dish surface. It also means that the effective exposure time is very short, minimizing any mechanical vibrations, etc. Getting all the required equipment to the tower tops is no mean feat, and we have to admire those who carried out this difficult and sometimes hazardous work.

After the photographs are taken, the film is developed, and then each image is digitized using a special scanner that is located in lab adjacent to Tony Acevedo's (NAIC) office. This scanner is a close relative to plate measuring machines used by astronomers; it measures the centroid of each of the "spots" produced by the targets to an error of no more than a few microns. These centroid positions are entered into a data file on the PC controlling the scanner.

After all the photographs are scanned, the data files are combined using a special program developed by GSI, which outputs the location of each target in three coordinates. Next, Lynn fits a sphere to the data set, and derives the errors for each target relative to the best-fit sphere. The software also gives the uncertainty in each position; this depends on where on the dish the target is located, and in how many photographs the target appears. We have been impressed that the formal uncertainty in position when we have a full set of photographs is about 0.6 mm rms. Thus, the system appears to really have the capability to measure the whole surface to the required accuracy, but then it will be up to us to adjust the panels to achieve our goal.

During the Fall of 2000, about 2,000 targets were placed on the primary surface of the antenna. Most of these were located above the points where the "tieback cables" (which connect the surface to the concrete anchors on the ground below, mentioned above) are located. Some extra targets were put in dense patches to fully sample the panel-to-panel setting errors. It was a real struggle to get the necessary data, as that was one of the rainiest Fall periods in recent memory, but this was finally accomplished. The usual learning curve for developing, scanning, and reducing data was ascended, and we obtained the first set of post-upgrade surface measurement data.

An image of the errors (processed from Lynn Baker's data by Germán Cortés—NAIC) is shown in Figure 1. Blue means high and red/yellow means low. The big surprise is that the unweighted rms is about 15 mm! This is worse than had been determined in 1991. The obvious conclusion is that all the upgrade work (plus the passage of the intervening 10 years!) severely degraded the surface accuracy. It is difficult to compare this photogrammetric rms directly with that derived radiometrically, because the Gregorian system does not illuminate the entire surface, and large scale errors of the illuminated region (linear gradients and quadratic errors) are taken out by calibration runs, appearing as pointing and focus offsets, respectively. However, there is no doubt that we have adequate explanation for the relatively poor performance we have seen at 5 GHz, and also for the variability of gain as a function of source declination and hour angle. Note in particular the large errors seen in the "fill area". The large errors seen in the panels right at the center of the dish are not surprising as those are the "new" panels recently installed by José Maldonado's team, and they have not yet been adjusted. The largest errors outside the center are on the order of 100 mm! This is even bigger than José Maldonado had expected, and shows how much that part of the dish surface had sunk.

While the first round of photogrammetry was going on, José Maldonado and his crew were undertaking to refurbish a lot of the panel support hardware that had corroded since installation in 1974. Several thousand panel supports needed to be replaced, and many more to be cleaned up and greased so that adjustment of the individual panels would be possible. This work is still ongoing, and should be completed in April 2001.

That work was interrupted by the arrival of the results of the first round of photogrammetry indicating the presence of very severe large-scale errors. We immediately started a project to adjust the 2000 or so tieback cables to get the surface closer to the desired spherical shape. This work was completed in a

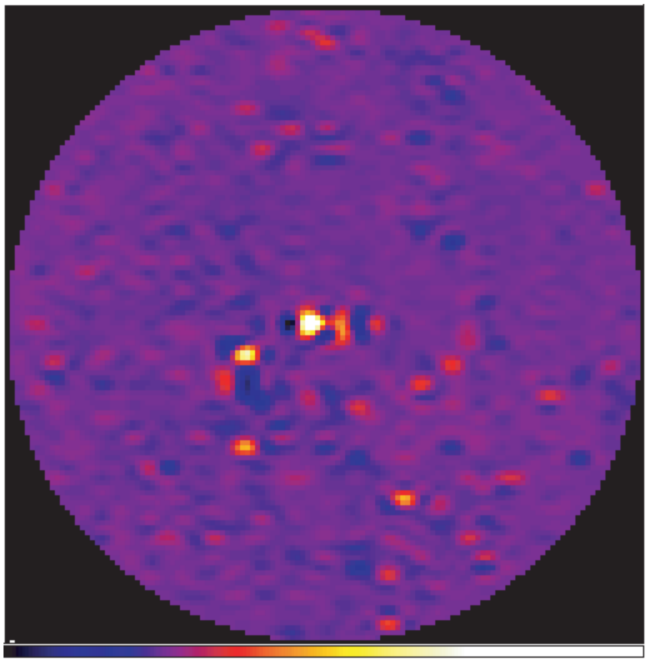

Figure 2: This image is from the second set of photogrammetry tests completed in January by Lynn Baker and Felipe Soberal. The improvement is immediately evident when compared with Figure 1, and is quantified by the reduction in the rms surface error from ~15 mm to just over 5 mm.

remarkably short time, and in January Lynn went again to Arecibo, and with Felipe obtained a second set of data, which is shown in Figure 2. The improvement is immediately evident (the color tables are the same), and is quantified by the reduction in the rms surface error from ~15 mm to just over 5 mm. The situation is really somewhat better. If one allows for fact that some of the adjustments were done in the wrong direction (something that always happens in a campaign like this, despite the best efforts of the field crews), and one excludes them, the rms is down to about 3.5 mm. Again, this does not allow for any low-order terms, and includes the entire antenna surface (except the central panels which still were not adjusted). Part of the remaining error may be due to the fact that some of the adjustments were so large that there were interactions between adjustment points and possibly even nonlinearities in the relationship between tieback cables and surface position.

Naturally, although this already represents a huge improvement, we are not satisfied, and a second set of required adjustments has been generated. As this is written, over half of the tieback cable turnbuckles have already been adjusted for the second time. The central panels will also be included in this round. So we can really hope to get the large-scale rms down to a few mm. Unfortunately, this has all happened so quickly that we have not had time to schedule the required telescope time to see what has happened to the antenna performance. In some limited time creatively obtained by John Harmon (and thanks to those who gave up their scheduled observations!) Phil Perillat and Mike Nolan (NAIC) did carry out some measurements. There are indications (but these must be considered preliminary) that the L-band gain may be up by about 10%, that the S-band gain is up from 5.5 to 7.0 K/Jy, and that at C-band (5 GHz) we have a single beam with 4 - 5 K/Jy consistently. I am going out on a limb to even put these results in print, but I know that they are what everyone wants to hear about. I caution again that these are very preliminary. However, I am confident that the photogrammetry is giving us the right answers, and that we can do better yet.

So —what happens next? After we complete the ongoing second round of tieback cable adjustments, Lynn and Felipe will do the photogrammetry for a third time. We also will be scheduling additional telescope time to define the antenna performance more completely. This is all a prelude for Phase II, in which we adjust the position of each panel individually. The first step here is to get approximately 39,000 targets out on the antenna surface. The targets themselves are currently on order and should arrive within a month or so. By that time, all of the panel support hardware should be refurbished, and the nontrivial task of putting those targets on the antenna surface will be accomplished. Then, the really demanding job of doing the photogrammetry, but measuring 39,000 rather than 2,000 targets will begin. This is conceptually not different, but in practice the amount of time and effort to scan the photographs will increase greatly, simply due to the increased number of targets.

Adjustment of the individual panels can then begin, and this too may require several iterations. Thus, this project is likely to go on for another year. In addition to the surface adjustment itself, we will be installing the tertiary actuators and computer control system, which will be necessary to make the small focus and pointing corrections necessary for operation at the shortest wavelengths. Bill Sisk (NAIC) has been working with this system extensively and it is almost ready to go, but installation needs to be synchronized with a couple of other nasty tasks including shimming the elevation rails. It does seem that efficient operation at 5 GHz is now within our grasp, and 10 GHz is not too far off. I hope that in the next newsletter we can give you some detailed results of antenna measurements at the higher frequencies, and before long, some scientific results as well.

As indicated above, many people have been working very hard on the surface adjustment project. Lynn Baker, Don Campbell (NAIC), José Maldonado, Mike Nolan, Phil Perillat, and Felipe Soberal have been extensively involved, and they have been supported by many others at Arecibo and also in the NAIC Maple Avenue laboratory. Mr. John Brown of GSI has been extremely helpful in getting us up to speed with the photogrammetry system at Arecibo. These people are the ones who deserve credit for getting Arecibo working through the entire cm wavelength range.

Radio Astronomy Highlights

Chris Salter

Pulsar Scintillations

The Oberlin/Cornell collaboration lead by Dan Stinebring (Oberlin) continues to investigate the high-Q "parabolic arcs" that they have been seen in pulsar secondary spectra (power spectra of the dynamic spectra). These arcs, which are the transform domain equivalent of the criss-cross patterns that have often been noted in pulsar dynamic spectra since the early 1970s, will be familiar to faithful readers of these pages. In fact, these arcs made their debut as "wisps" in the Spring 1999 NAIC-AO Newsletter (No. 27) after the group made intensive observations during January, 1999. It will interest some readers that that article caught the attention of none other than Ronald Bracewell, who had some interesting suggestions to make concerning further analysis of the patterns.

In addition to roughly biweekly observations — mostly performed remotely — that the group makes to monitor time variability of the phenomenon toward half a dozen strong, nearby pulsars, they are continuing to explore the effect in archival data, much of it taken at Arecibo by Jim Cordes (Cornell) during the 1980s. The most remarkable result to come out of the analysis of this earlier data is how little the arc pattern changes