# PHOTOGRAMMETRIC DETERMINATION OF THE FORM OF A 10m DIAMETER RADIO ANTENNA

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## Abstract

NPL has a programme for satellite power measurement. This requires the form (and hence gain) of the receiving antenna to be known accurately. For a wavelength of about 3cm, sub-millimetre accuracy is required, and photogrammetry was chosen as being the easiest method to achieve this.

Also discussed is the design of a measuring machine to assist the measurement of single photographs of randomly targeted, or approximately known form objects (such as the dish antenna).

## Introduction

The National Physical Laboratory has a programme for satellite transmitter power measurement. To get accurate results one needs both a receiver and an antenna of known gain. To this end NPL has bought a 10m diameter parabolic dish antenna, which the manufacturers claim to be 'good to 1mm'. The photogrammetry section at NPL was asked to verify the shape of the dish in order to substantiate the manufacturer's claims, and to give a theoretical value for the gain of the antenna.

Initially a simple survey, using four camera positions, to give an accuracy of about 1mm was planned, but this was modified to surveying the dish in two orientations, to check on gravitational deformation as well, if any exists. It is intended that the dish should be re-surveyed every year or so to check for long term stability. The experiment was also useful for the Photogrammetry Section as it provided an opportunity to carry out a 'real' survey (as against laboratory surveys of test objects), and so test out both hardware and software under 'real' conditions.

## Targeting

The dish consists of 24 individual 'petals', each made of 14 separate aluminium panels riveted to a frame. The petals are delivered separately, and bolted together on site. As all 24 'petals' are made on the same former, one might expect that they would all be similar in general shape, but that stresses might be introduced that would distort the shape on bolting them together. As the surface of the dish is painted matt white to reduce thermal effects, and the 'pop' rivets used in the manufacture are raised from the surface, it was necessary to target the surface in some way. Fortunately the dish was being removed from its mount to fit motor drives to the two axes, and during this period it was possible to walk on the surface of the dish and target it.

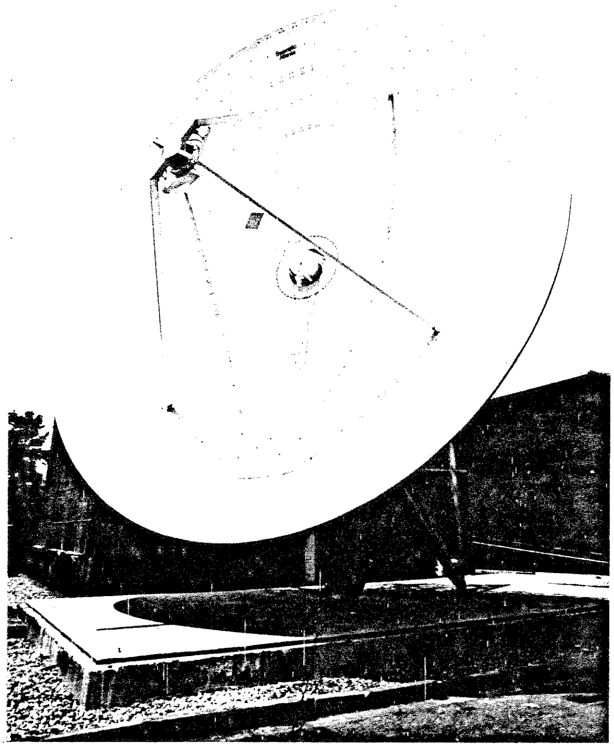
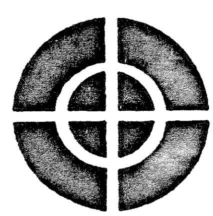


Plate 1: The dish

One sheet of 35 targets was drawn up by hand, and Letraset Ltd. then produced 15 copies of this on their 'rub down' material in about 10 days. This method produces a target which is black on clear, so that when applied to the white surface, a very high contrast target of negligible (a few micrometres) thickness results. All the targets were varnished with a matt finish varnish to protect them from the effects of weather. After 9 months, during which the dish has been subjected to temperatures between about -10°C and 30°C, and also driving rain and hail, all the targets are still in usable condition.

As all 24 petals were made on the same former, it was decided to target heavily only two petals, to give a shape for the former, and then target randomly the rest of the surface to give an overall picture of the surface shape. In this way 464 targets were placed on the dish itself, 16 on the rear of the secondary mirror and its supports, and several on the frame supporting the dish. Targeting took about one man-day

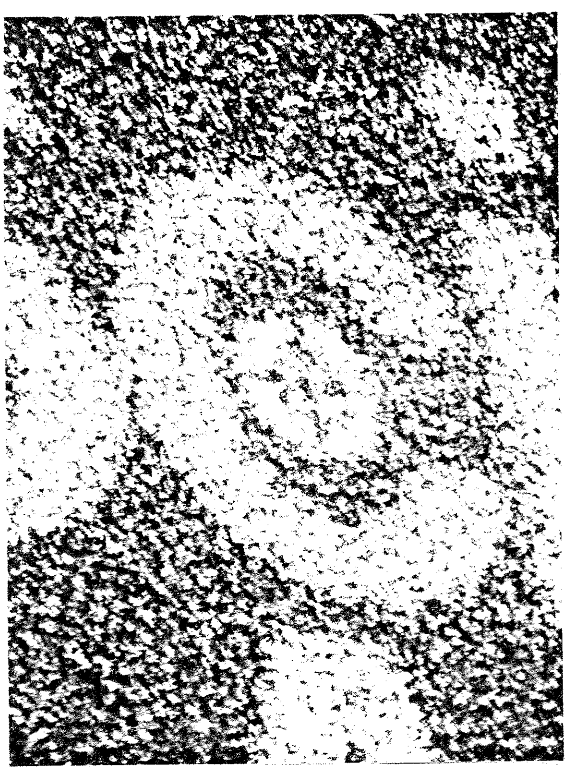


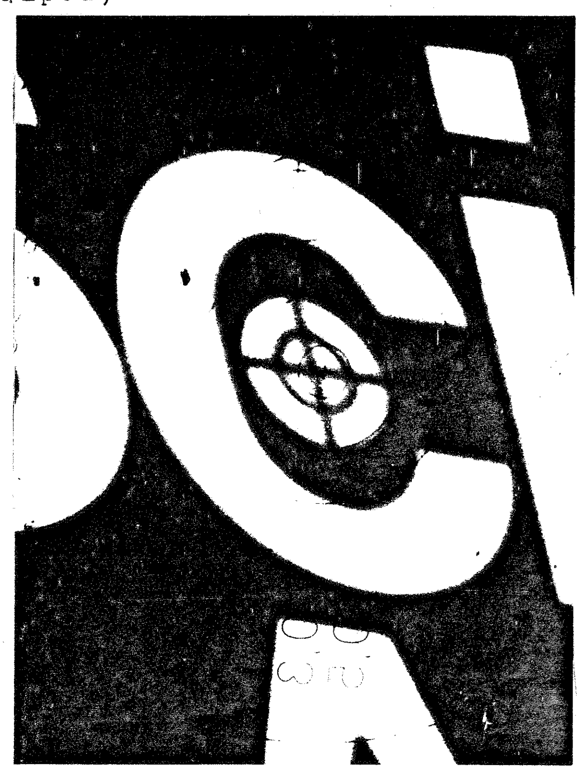
Actual size target

Nine 'ground points' were also positioned, with a view to their remaining stable with time and being used as control points. Four of these were stainless-steel sockets let into the surface of the dish's supporting plinth, and two different brass targets were then plugged into these - depending on whether one wished to view from the side or from above. A further target of the same type was fastened to the roof of a nearby building, and the remaining four were on the frame supporting the dish. These nine points were surveyed with one-second theodolites, using a 10m invar survey tape as a length standard. This gave coordinates for the control with an RMS uncertainty of 0.5mm.

<u>Photography</u>

Photography took one day, with a total of 14 photographs being taken from 7 different camera stations - 4 with the dish at minimum elevation (about $5^{o}$) and 3 with the dish at maximum elevation (about $85^{o}$). The camera used was a Zeiss Jena UMK 10 NF (the special close range version of the lens) which had been modified to enable remote cocking and firing of the shutter. Two different types of plates were used, Agfa Aviphot Pan 100 (exposure 1/60 sec at f/8) and Agfa 10E75 (exposure 1 sec at f/8). For the ground based photographs the camera was mounted on a standard survey tripod, and for the elevated





300 μm

Plate 2: Target imaged on Aviphot Pan 100

Plate 3: The same target on 10E75

photographs a 15m hydraulic platform hoist (cherry picker) was used. Fortunately the day was very calm and no camera shake could be detected with the elevated photographs, even with a 1 sec exposure. All precautions were taken, such as shutting off the truck engine, and operating the camera remotely.

The resolution of the Agfa Aviphot Pan 100 was much inferior to the 10E75, and these plates were rejected as unusable (see plates 2 and 3). Agfa 10E75 has the added advantage of being available on thicker, and hence more stable, glass (3mm instead of 1.5mm for Aviphot). It does not have a specification for flatness, is not available in 13x18cm, and so has to be cut from 20.3x25.4cm sheets.

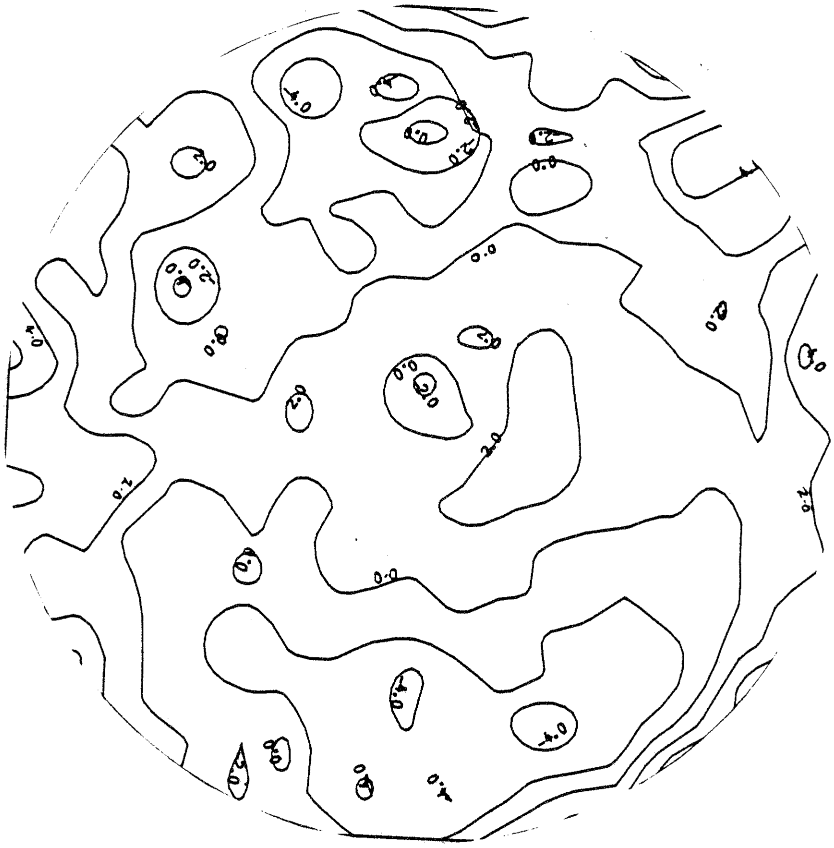
## Measurement

All plates were measured on a Zeiss Jena ZKM 01-250-D measuring microscope with a repeatability of about 2μm (limited by operator fatigue, rather than intrinsic measuring machine accuracy), with the individual targets being given serial numbers at a later stage. Plate measurement took about 2/3 man-day per plate (about 450 points), with the target size being chosen to give a central ring of 30μm in radius, which is the size of the smallest ring of the microscope graticule at x100 magnification. Numbering of the targets was initially done using a small micro-computer (BBC model B) to display a graphical representation of the plate on the screen, and prompt the operator for the serial numbers. This worked reasonably well, but the numbering still had to be checked by producing large scale annotated plots of each plate. With hindsight all targets on the dish should have been labelled with a serial number which would image onto the plate, but the opportunity for doing this was missed. A method of overcoming this difficulty will be discussed later in the paper.

## Results

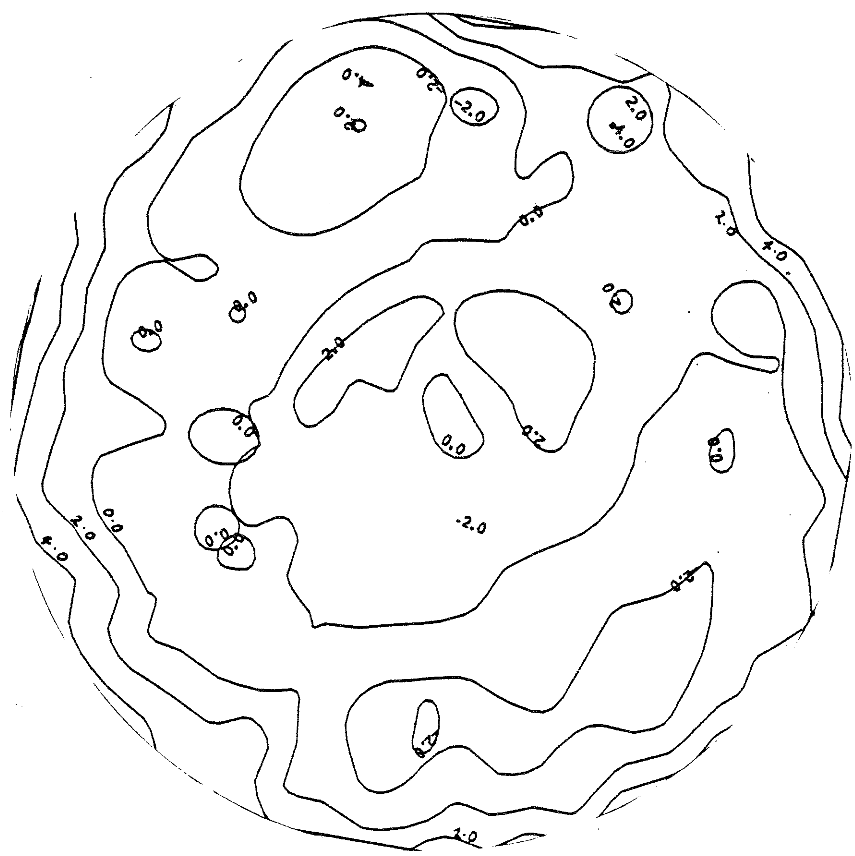
The data were processed by a pilot version of the NPL bundle solution 'PHOTOPAK', with the camera principal point allowed to vary, but otherwise assuming the camera to be perfect. The survey coordinates for the ground points were used solely to provide a starting camera orientation, though two points, and a single coordinate from a third, were used to define the coordinate system. This method gave plate residuals of the order of 5μm (this would have been much lower if the full self-calibration procedure had been used), which corresponds to about 0.3mm on the dish. This is well within the 1mm tolerance, and about 1/100 wavelength of the normal operating frequency. A best fit paraboloid was then subtracted from the coordinates, and then transformed into the xy plane, so that a contour map of departures from the best fit paraboloid could be generated.

For the low angle (about $5^{\circ}$) case, this contour map shows



Contour plot of the difference between the true surface of the dish, and the best fit paraboloid

Dish axis 5° from the horizontal.



Contour plot of the difference between the true surface of the dish, and the best fit paraboloid

Dish axis 85° from the horizontal.

Contour interval 2mm
Negative numbers are towards the secondary mirror

quite clearly that the dish is not circular, but that the top and bottom lips are closer together, and the sides further apart than would be expected. This is the general form of the deformation expected if the structure has deformed due to gravity. The maximum difference in profile between the vertical and horizontal axes is about 5mm.
The contour plot with the dish axis at $85^{o}$ to the horizontal has a much more circular pattern, showing good overall rotational symmetry (if the axis of the best fit paraboloid were tilted slightly towards the 7 O'clock position, then the circularity would be much better - this is a function of the non-uniform point density affecting the least squares fit), but with 'humps' of about 2mm height at 11 O'clock and 5 O'clock positions. These 'humps' can also be seen on the horizontal axis plot, but are confused by the general gravitational distortion. Also quite clear from the contour plot is the fact that the dish, which is supposed to be a distorted paraboloid, cannot be within the 1mm specification, as there is about 3mm of non-circularity in its shape. Once the manufacturers specified shape is known, a more detailed comparison can be made. The circular contours on the vertical axis plot are probably due to the designed shape being deliberately not a paraboloid.

## Improvements to the plate measuring procedure

At present motor drives are being fitted to the ZKM 01-250 D measuring machine, to enable it to be driven remotely, and automatically, by a small computer. This should considerably speed up the process of measuring plates, and greatly facilitate the numbering of points. This can be done in several ways:-

i) If the object has a totally unknown surface, but with at least four known control points imaged on at least two photographs, then the first camera can have its position resected, and all target coordinates measured and arbitrary serial numbers allocated. The second photograph can then be resected, and attention turned to the unknown points. Each point on the first plate would correspond to a line on the second, and the computer could be instructed to search along this line, until the operator finds the target in the field of view. In general several images may appear on the second plate close to the chosen line, but only one would give a reasonable intersection. The computer now has approximate XYZ coordinate for all targets, and the third and subsequent plates become easier to measure as the computer can drive the machine to the required point.

ii) If the object surface shape is approximately known, but not the actual target locations (as was the case with the dish, where one knew the approximate form of the paraboloid), then the above situation applies, but the computer can find an approximate intersection from the first camera alone.

iii) If all the targets have approximate coordinates (as in a re-survey of the dish), then once the camera position has been resected, the computer can generate expected plate coordinates for all points, and drive to those positions.

iv) If no control points are known, then from a measurement of a minimum of 7 identifiable points, it is possible to establish a relative orientation between two cameras. This would then form the basis for a solution of the same form as i) above.

It is also envisaged that, at any stage in the measurement cycle, the operator could request the system to do a refinement of its estimates for camera and object positions based on information gained since the last update.

It is also envisaged that, either the ZKM, or a larger machine could handle two or more plates simultaneously (the ZKM could cope with two plates from a Wild P31, but not a UMK), and thus become rather like an analytical plotter, but with only monoscopic viewing optics. The accuracy achievable would also be much higher than with most analytical plotters, as the ZKM has a resolution of 0.1µm, and an uncertainty of about +/-0.5µm overall.

It is estimated that with a modified version of the ZKM measuring machine, the time taken to re-survey the dish, to check for variations with time, would amount to about 1/2 day for the photography, and then about 2 days for plate measurement and computation. Also, with a self-calibrating bundle solution to restitute the data, the accuracy should be of the order of 1 in $10^5$, which would mean a measurement uncertainty of +/-0.1mm on the dish surface.

Acknowledgements

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