# RECTANGULAR PANELS FOR OFFSET MMA ANTENNAS

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Abstract

A previous memorandem [1] has outlined the advantages of the slant axis antenna for the MMA. Easy receiver access, light weight and small gravity induced deformations are the main advantages over a conventional design.

This memo explores a further possible advantage of the slant axis offset design. The use of rectangular panels rather than the conventional pie shaped panels leads to cost savings both in the panels and the backing structure. Fewer panels with fewer adjustment points will result in a reduction in labour costs for both panel installation and setting.

For the proposed MMA antenna the adoption of rectangular panels reduces the panel count by 23% and the number of joints in the backing structure by 29%. The number of members needed in the backing structure is also reduced.

## 1.0 Introduction.

Fan shaped panels have been used extensively for radio and millimeter wave antennas, including some offset designs such as the Crawford Hill 7-m millimeter wave antenna[2]. There are two advantages in applying the fan shaped panels in the antenna design. First, the fan shaped panels exhibit a perfect symmetry about an axis. This makes it much easier to design a homologically deformed backup structure. Second, all the panels within the same ring are identical. So the panel type number reduces and the panel manufacture and maintenance are easier, especially when only one antenna is concerned. However, fan shaped panels have a disadvantage of a smaller average area. For the same aperture surface, using the fan shaped panels requires many more panels than rectangular or hexagonal shapes. More panels require more panel adjusters and more joints on the backup structure. These contribute to a higher cost in manufacture and panel adjustment. For this reason, the 10.4-m Caltech antennas[3] and the recently proposed Large Millimeter Wave Radio Telescope(LMT)[4] use or will use hexagonal shaped panels. Hexagonal panels retain, to some extent, the symmetrical property about an axis and reduce the panel number needed for a same antenna surface. The hexagonal panels are supported on three corners only, so a small supporting error may cause some surface discontinunity if the other three corners are not connected. For the mmA offset design, the backup structure requires no symmetry about an axis. Therefore, other panel shapes, such as a rectangular one, may be applied in reducing the cost of the project.

## 2.0 Panel shape and backup structure.

As mentioned before, the panel shape is related to the backup strucural design. For fan shaped panels, the top support joints on the backup structure have to be lined along the radial directions around an axis. This creates an axial symmetrical loading condition when the antenna is pointing to zenith. In this case, the surface deflection is always serious. If the backup structure has the same axial symmetrical property, the deflection pattern will be symmetrical about the same axis. The task of optimization of the backup structure would be easier as the variables considered are reduced.

For hexagonal shaped panels, the axial symmetrical property disappears if more than two rings of panels are involved. However, it retains a cyclical symmetry about an axis. The cyclical angle is 60 degrees.For the case of only three corners are supported, the angle is 120 degrees. This creates the same loading condition to the backup structure when the antenna is pointing to zenith. Therefore, optimization of surface deflections will be not easy. For LMT project, active panel adjustment is required.

If a square panel shape is used, the cyclical angle of symmetry is 90 degrees. In this memo, the rectangular shape is recommended, for which the cyclical angle is 180 degrees. The design of a symmetrical homologically deformed backup structure under these loading conditions will be very difficult. However, the backup structure of an offset mmA antenna is different. The homology of its backup structure is achieved by reducing the magnitude of loads which are applied perpendicular to the dish surface. The backup structure itself has no axial symmetry, and requires no symmetrical loading condition. The only symmetry required is a mirror symmetry about the meridian plane, of which using both square or rectangular panel shapes preserves. So it is possible to use these non conventional panel shapes for the offset mmA antennas. In the previous memo, the backup structure designed is basically a double layer space truss. Using rectangular panels, the structure will be very much the same except the surface joints are evenly spaced along two coordinate direction. Usually, the number of grids is reduced. The double layer truss is even simple.

To accomodate the rectangular panel shape, a new backup truss for mmA offset concept was generated. It is shown in Figure 1. For a CFRP truss structure, joints are mostly made of steel(or stainless steel, invar), they are very heavy and may have a larger thermal expansion coefficient. Reducing the joints number will improve the truss performance and may reduce the thermal distortion. For a panel size of 950 X 750 mm there are 101 surface joints for a rectangular panel structure, comparably, there are 141 joints for a fan shaped panels with the same maximum panel size. Using few joints also reduces the number of structure members and results a smaller total member length. Since all the surface joints are equally spaced and are aligned in two coordinate directions, the length of CFRP members and the shape of joints are all uniform in few groups. All these simplify the structure design and will rusult some cost savings.

### 3.0 Cost analysis.

There are two candidates for the mmA antenna panels: one is a surface machined cast aluminum panel and the other is a duplicated CFRP panel with a zero thermal expansion coefficient. The poor durability of the CFRP panels will result in high maintainence cost. The cast aluminum panels are generally prefered. The steps involved in making cast aluminum panels are: making a panel model for each set of panels; casting panels from a production line; panel rough machining; panel heat treatment; panel final machining and panel inspection.

The detailed cost of cast aluminum panels ordered in large quantity can be expressed as:

$$C=C_m*n_m+(C_c+C_r+C_h+C_s+C_i)*n*m+C_c*A*m+C_e$$

The cost of the backup structure is:

$$C=C_a*m+(C_b*L_b+C_j*n_j)*m+C_e$$

where:

$C_m$ = average modelling cost
$C_c$ = average panel casting cost
$C_r$ = average panel rough machining cost
$C_h$ = average panel heat treatment cost
$C_s$ = panel machining handing cost
$C_i$ = average panel inspection cost
$C_c$ = panel net cutting time cost
$C_e$ = engineering cost
$C_a$ = the assembly cost of truss
$C_b$ = the cost of CFRP tube per unit length
$C_j$ = the cost of the joints
$n$ = the number of panels of an antenna
$n_m$ = the number of panel models needed
$m$ = the number of antennas
$n_j$ = the number of joints
$A$ = the dish surface area
$L_b$ = the length of CFRP members required.

The backup structure of mmA antennas are formed by CFRP tube members and coated steel joints. The surface joints have panel adjuster on their top, and some of bottom joints will connect the truss to slant bearing disk.

From the expression for the panel cost, it is clear that part of the cost of the panels is directly proportional to the number of panels involved. Only panel net cutting cost is related to the panel surface area. Larger surface area per panel may not affect the net cutting cost of panels as the total panel area of an antenna remains unchanged for different panel shapes. For an 8-m offset antenna, using traditional panels, a typical number for n is 120 and for $n_m$ is 9. For rectangular panels, n is 90 and $n_m$ may be much smaller, as discussed below. The panel number is reduced by 23% and the model number may be reduced by as much as 89% (a typical panel model costs about $12,000.) At this stage the exact savings are uncertain, but should be at least 5%.

For a truss structure, the cost of CFRP members and joints form the main part of total cost. The truss for a rectangular panel shape has a smaller joint number and shorter CFRP member total length per antenna. Both of these reduce the truss cost. The joint number reduction by using rectangular panels is about 29 %. The total CFRP member length reduction is expected to be about 10%, with a corresponding reduction in total cost.

Further cost savings will result from less labour being required in the panel setting process, due to fewer adjustment points.

### 4.0 Panel stability and size.

The panel shape also affects its stability. In order to reduce the panel weight, the panel and its ribs should be thin (5 mm for SMA panels). During manufacture and over time, the panel surface shape will tend to deform slightly, so stiffening ribs are desirable. For rectangular panels, the stiffening ribs form 4 strong balanced triangles, giving a stiffer, more stable structure than panels which have a fan-shaped outline. Experience with heat treatment and panel machining indicate that the fan shaped panels of the innermost ring are worst in stability. Figure 2 shows SMA panels for different rings. The ribs of the inner panels form only a single triangle and tend to twist more than other panels.

Panel size is determined by thermal distortion. For mmA antennas, Lamb[5] indicates that the dimension should be about 1 m for the cast aluminum panels. Another restriction of panel size comes from the size of vacuum casting container used in production. One panel manufacturer has a container size of 1000mm X 800mm, which matches well the limit set by thermal distortion. By using these criteria, we chose panels of maximum dimension of 950 mm X 750 mm for the mmA offset antenna. The arrngement for both fan shaped and rectangular panels is shown in Figure 3. In this figure, the total number of fan shaped panels is 119, while there are only 92 rectangular panels, a reduction of 23%; the number of joints in the backing structure is correpsondingly reduced.

## 5.0 Casting moulds needed for an 8-m offset antenna.

The number of casting moulds needed depends on the surface profile difference between each panels. For rectangular panels, every panel will have a different surface profile due to the lack of axial symmetry. However, if the surface shape difference is small, panels in different position could share a single mould in the casting process. The panel surface profile difference can be estimated from the radius of curvature on the paraboloid surface. The radius of curvature along the x or y direction of a paraboloid can be expressed as:

$$r = 2*f*[1+(\frac{t}{2*f})^2]^{3/2}$$

where t is the value of x or y coordinate, and f is the focal length. When t = 0 the smallest radius of curvature is 2*f. For f=5m, the radii of curvature at different t values are listed in Table 1. In Table 1, d is the sagitta for an arc which has a cord length of 1 m(ref Figure 4).

Table 1. Radii of curvature and sagitta

| t (m) | r (m) | d (mm) |
|---|---|---|
| 0. | 10. | 12.5 |
| 1. | 10.15 | 12.3 |
| 2. | 10.60 | 11.7 |
| 3. | 11.38 | 10.9 |
| 4. | 12.49 | 10.0 |
| 9. | 24.35 | 5.1 |

From this table, it is easy to estimate the surface profile difference along the x or y direction for an 8 m offset antenna. Along the x axis, from t = 1m to t = 9 m, the sagitta difference is only about $d_x$=7.2 mm and in the y direction from t = 0 to t =4 m, the saggitta difference is only about $d_y$=2.5 mm. These saggitta differences represent the maximum panel profile differences. When two panels are not aligned with the coordinate axis, the sagitta differences along two coordinate directions have to be added together in estimating the panel profile difference. The maximum difference between panels of an 8-m offset antenna is $d_x+d_y$=9.7 mm. This is a peak to peak difference. If the cast model has a profile of an intermediate curve, the differnce between any of panels and the casting model surface will be only half of this value(4.8 mm), which is a small.

For confirming this, a computer program was written to fit the panel with a plane and calculate the shape difference between panels on an offset antenna. The resultant surface differences between panel 1a and 9a(ref. Figure 3) are ploted in Figure 5. The maximum value of difference calculated is only 6.56 mm, even smaller than 7.2 mm from the sagitta estimation. The biggest profile difference between panels happens between panels 9a and 2d. The estimation of this difference from Table 1 is 8.8 mm. The computer calcutation is 8.03 mm. For such a small peak to peak difference, all the panels on the surface may be cast from a single mould. Of course, for reducing the cutting time, more casting shapes are prefered. Because all the panels have a single outline, it may be possible to cast panels with different surface profiles by applying different inserts. The cost of making these inserts will be very small compared to the cost of making different casting moulds.

It may be useful to mention that only the offset design offers this unique advantage of being able to share a single casting mould. For a symmetrical 8-m antenna, the focal length is about 3.2 m. Using the same expression mentioned, for t = 0, r = 6.4 m and the calculated d = 19.5 mm and while t = 4m, r = 10.49 m and the calculated d = 6.6 mm, the profile difference between center and edge panels will be 13mm, which is a much larger value than that for the offset design. In this case, a single model for all the panels may be not feasible.

## 6.0 Other panel shapes and arrangements

R. Hills had suggested a fan shaped arrangement from the center of the elliptical dish surface for the offset mmA antenna design. The arrangement is shown in Figure 6. The advantage of this arrangement is that the backup structure could be designed with high rigidity radially and circumferentially. However, as with fan shaped panels, this arrangement will require more panels and more panel moulds.

The hexagonal arrangement shown in Figure 6 may have both advantages of fan shaped and rectangular panels. The panel number will be small and the model number is small too. Therefore it is a viable alternative to rectangular panels. The only problem of the hexagonal panel is some surface discontinunity when the adjustment has small error.

The square panel is the same as the rectangular one. There is no reason to reject a square panel arrangement if the casting cost does not increase.

**References**

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[3] Woody, D., Vail, D. and Schaal, W., Design, construction, and performnance of the 10.4-m-diameter radio telescope, Proc. of IEEE, VOl. 82, 673-686(1994).
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[5] Lamb, J., Thermal considerations for mmA antennas, mmA memo(1992).

**Figure captions**

Figure 1 Backup structure design for rectangular surface panels.

Figure 2 SMA panels in perspective view.

Figure 3 Rectangular and fan-shaped panel arrangement for an offset 8-m mmA antenna.

Figure 4 Sagitta of a curve and a typical contour profile of a rectangular panel for mma offset antenna.

Figure 5 The surface profile difference between the first and the last rectangular panels in the center row.

Figure 6 Hexagonal panel arrangement and another fan-shaped arrangement which starts from the center of the ellipsed dish.

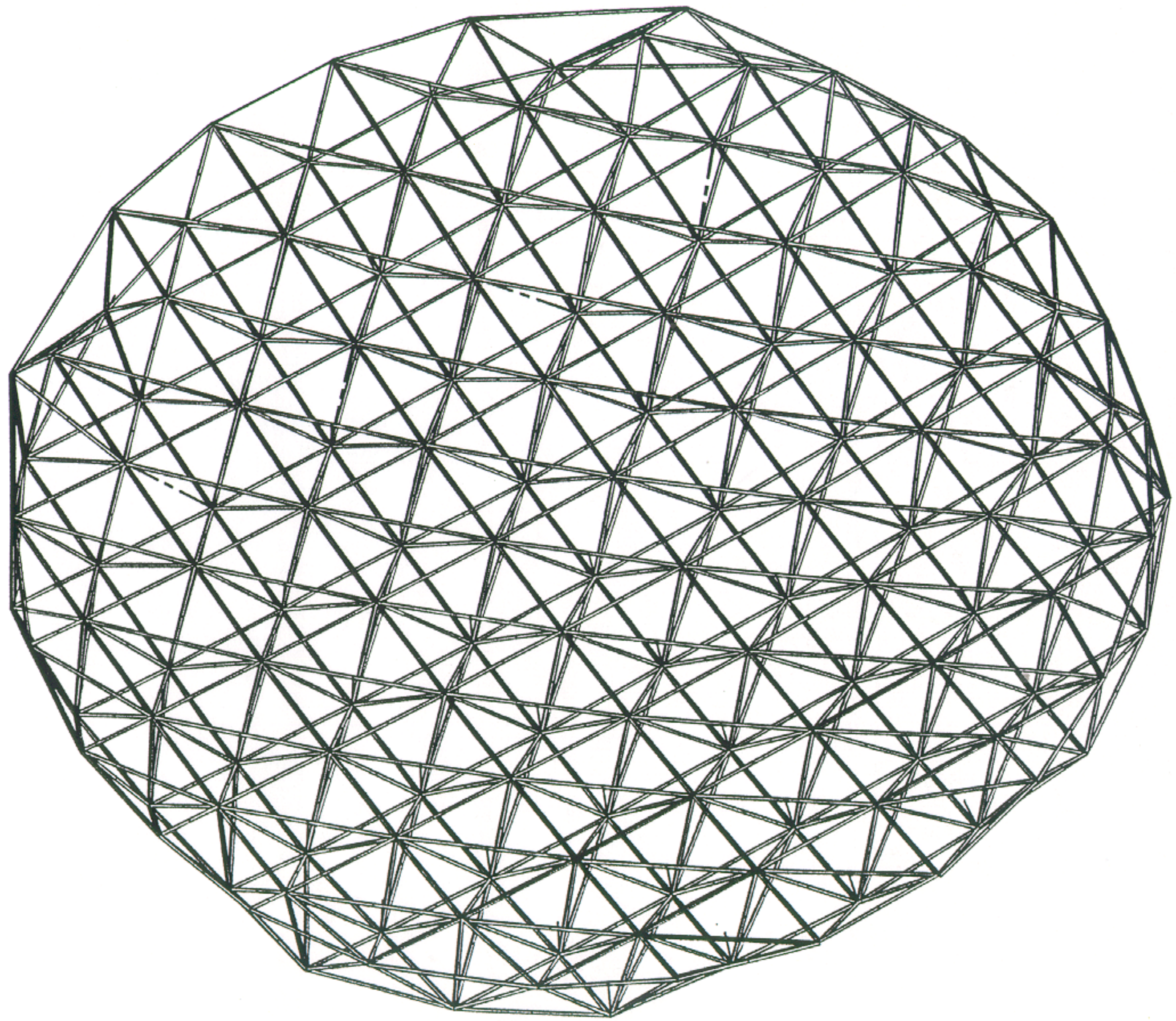

Figure 1 Backup structure design for rectangular surface panels.

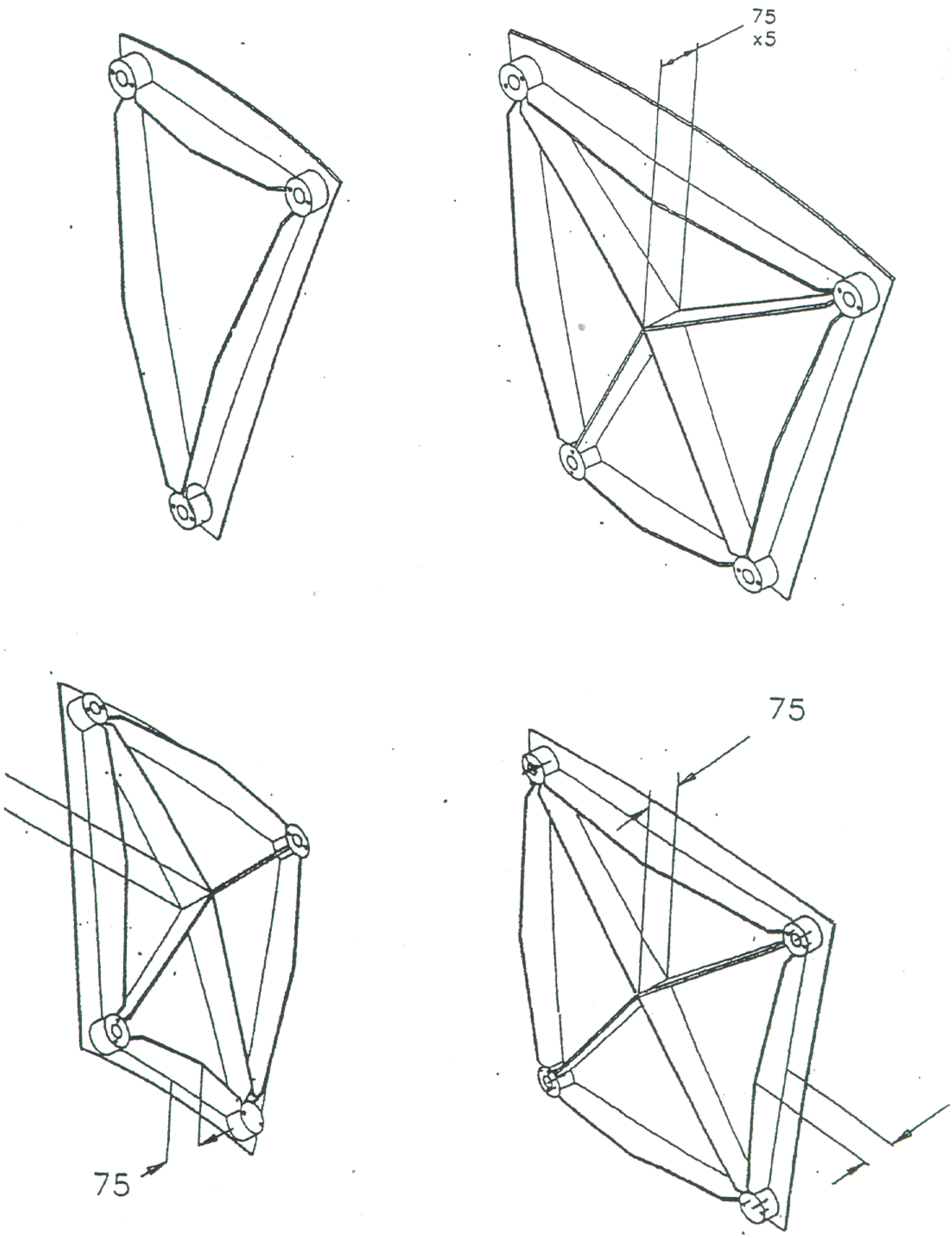


Figure 2 SMA panels in perspective view.

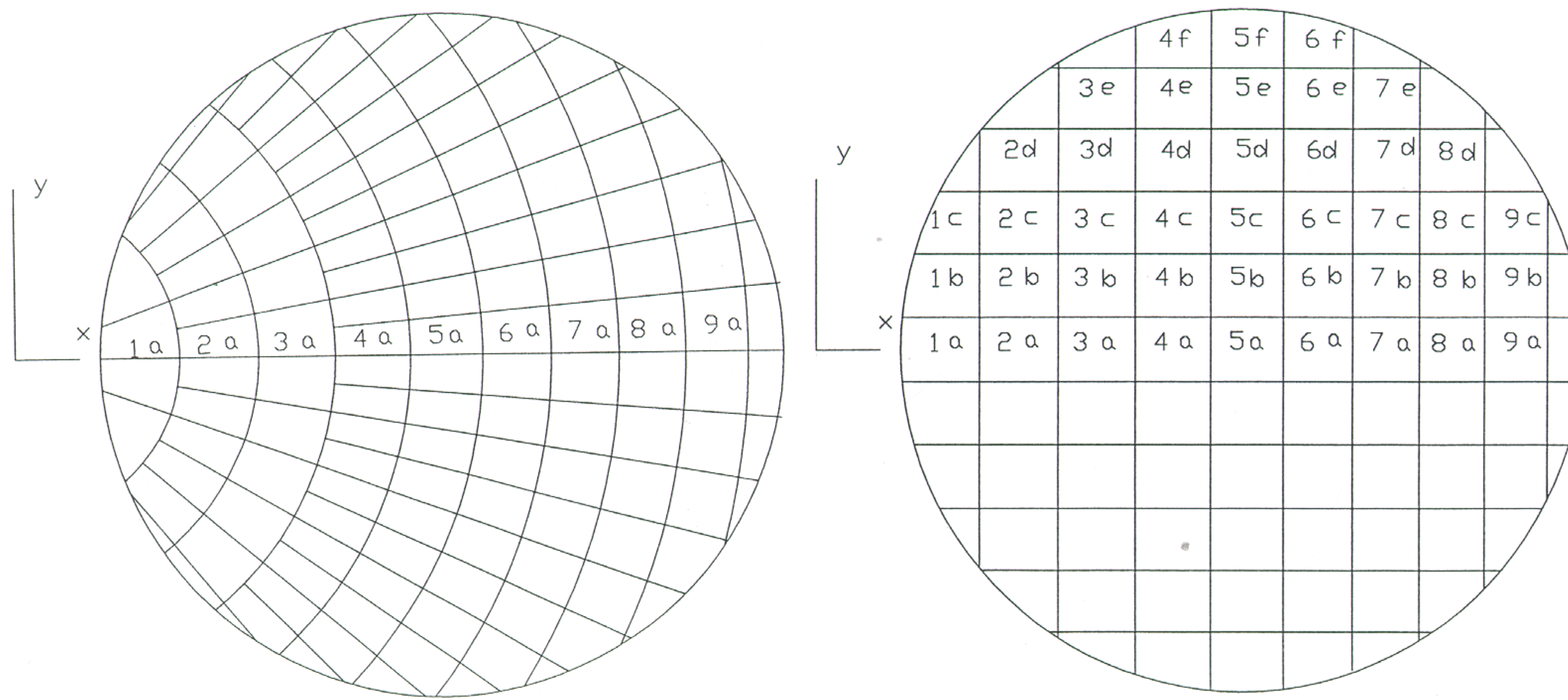


Figure 3 Rectangular and fan-shaped panel arrangement for an offset 8-m mmA antenna.

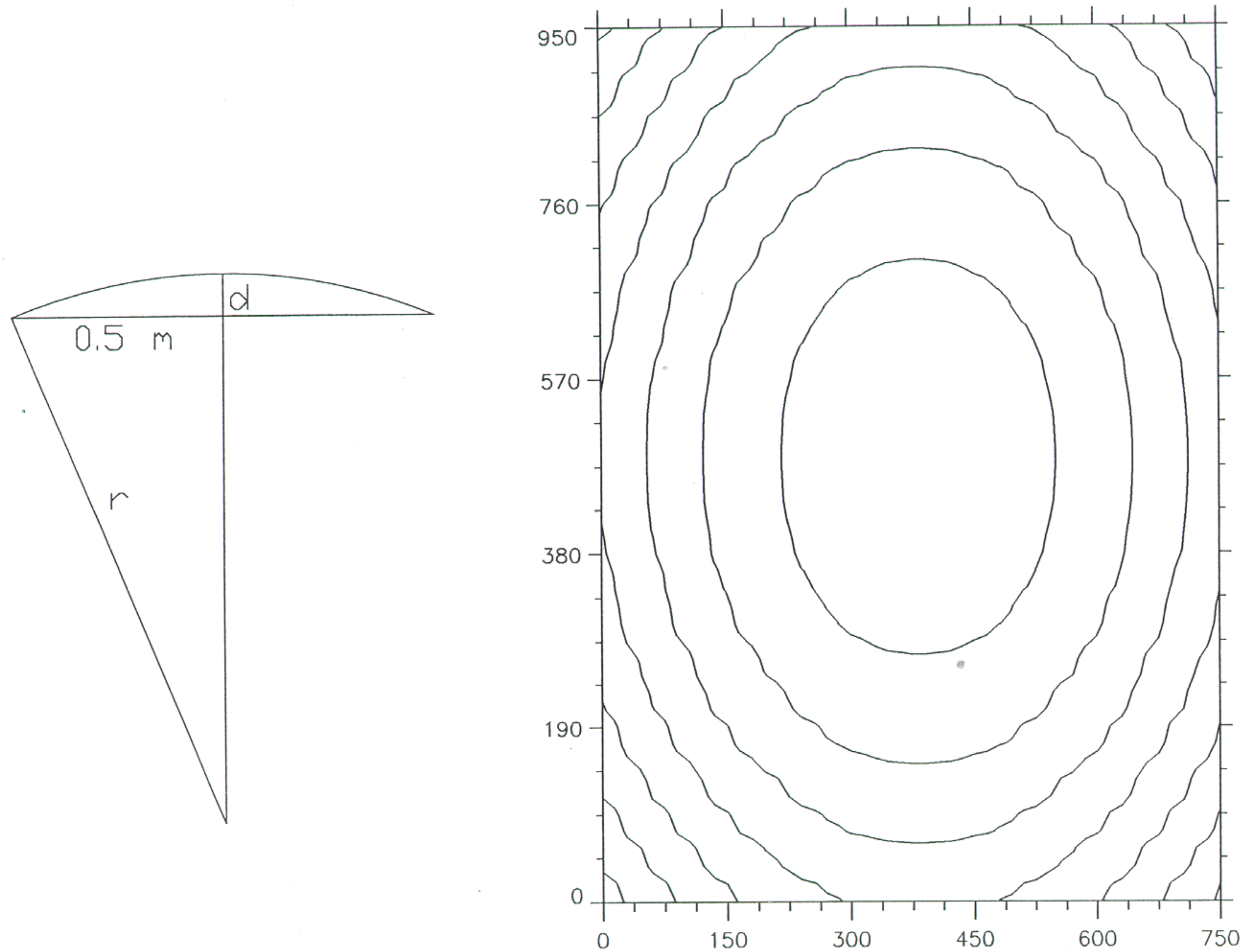


Figure 4 Sagitta of a curve and a typical contour profile of a rectangular panel for mma offset antenna.

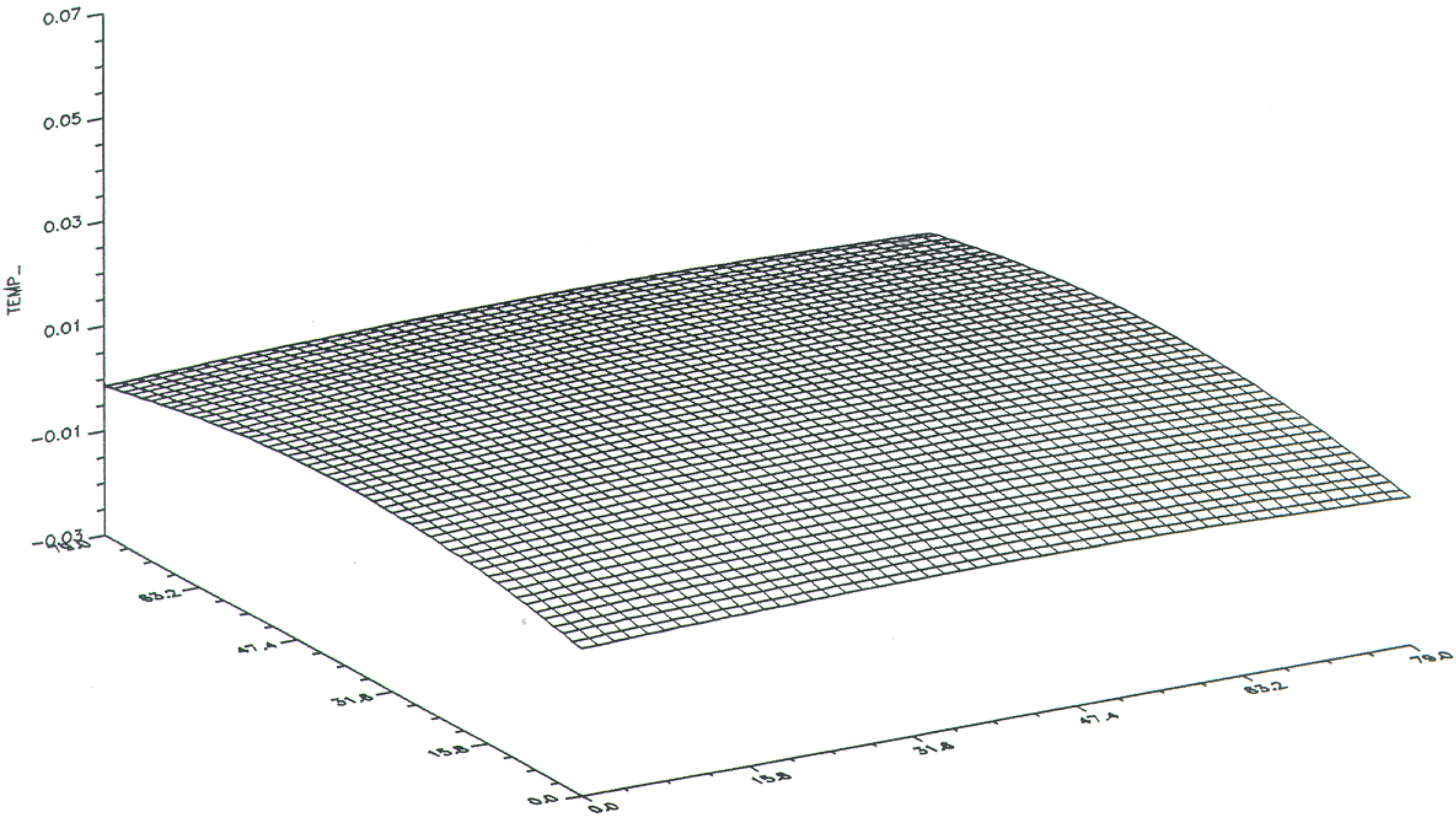


Figure 5 The surface profile difference between the first and the last rectangular panels in the center row.

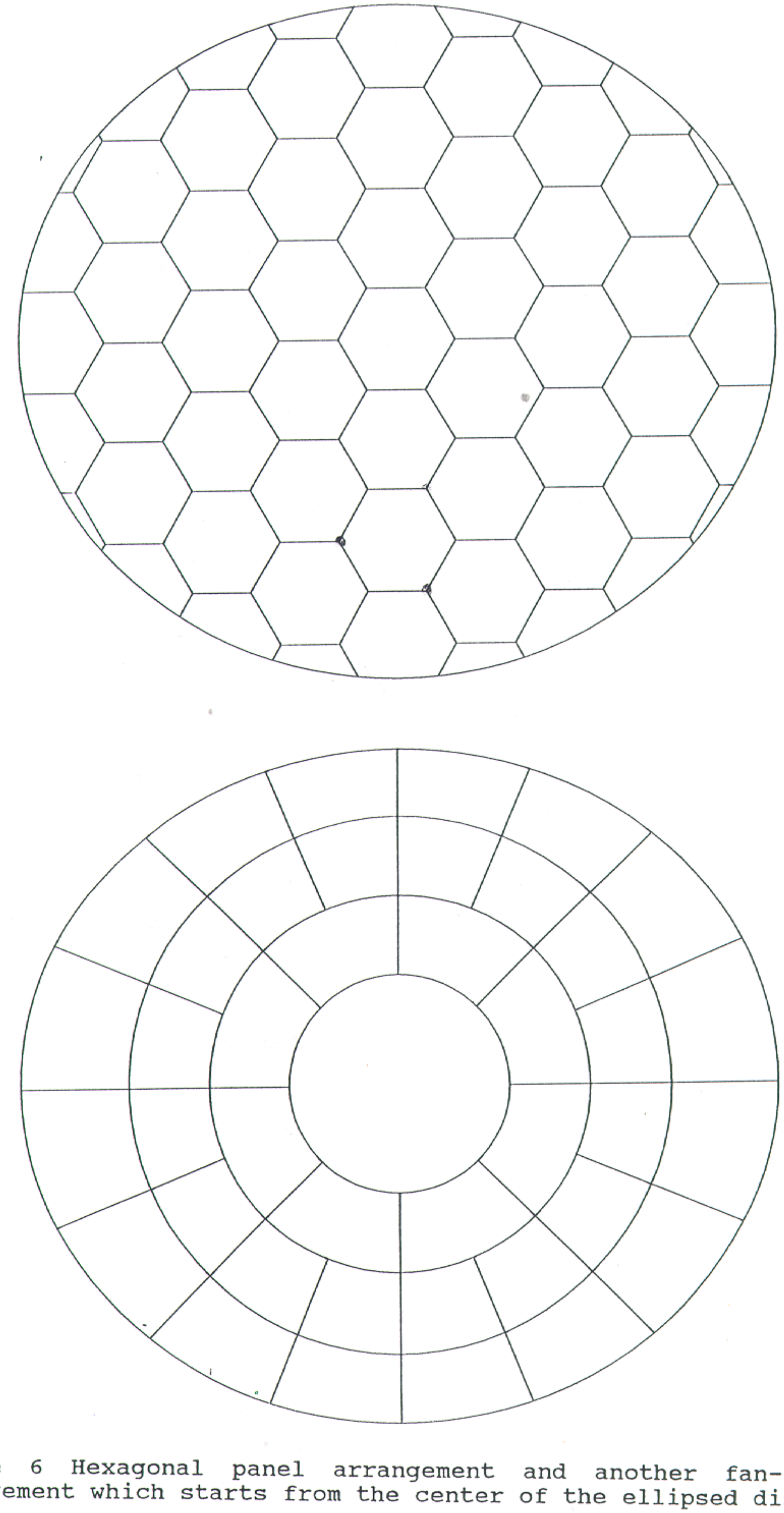

Figure 6 Hexagonal panel arrangement and another fan-shaped arrangement which starts from the center of the ellipsed dish.