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CHARLOTTESVILLE, VA.

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To: Lee King
From: James Lamb and John Payne
Subject: Preliminary Optics Design for the Millimeter Array Antennas

Introduction

This memo presents a preliminary design for the optics of the Millimeter Array antennas. The philosophy behind the design is to outline a scheme for bringing the antenna beam to a convenient focus for coupling into the receiver. For reasons of convenience and reliability, the receivers should be mounted in fixed positions within the plinth of the antenna.

Fig. 1 illustrates the proposed design. It is a conventional Cassegrain except that the secondary focus is brought right down into the plinth (Coudé focus). The receivers are located in fixed positions in the base of the antenna which has the following advantages:

- (1) They are easy to get access to.
- (2) Telescope balance is not affected by removing or installing receiver.
- (3) Effects of cable and compressor line drag on the pointing are eliminated.

Primary Mirror

It is assumed that the diameter, D , of the primary reflector will be 8.0 m. The primary will be a symmetric paraboloid with a focal length, f , of 3.2 m giving a primary f-ratio (f/D) of 0.4. This value gives a compact antenna. It could be reduced further (to $f/D = 0.35$, say) but the tolerances in locating the secondary are more stringent (both for pointing and beam quality). The primary mirror requires a central hole to pass the beam from the secondary to the receivers. Its size is determined by the field of view and the required secondary focal length. A diameter, d , of 1.0 m is close to optimum.

Secondary Mirror

The secondary mirror will be a symmetrical hyperboloid. Its size is set principally by the field of view (~ 10 arcseconds) and the requirement to have the secondary focus in the receiver room. It should be as small as possible within these constraints in order to minimize blockage and allow for the possibility of nutation for beam switching at some stage.

A diameter of 800 mm and a distance between foci of 9.79 m gives an effective f-ratio at the secondary focus of 12 which is convenient for most quasi-optical systems. With some more thought, the secondary diameter could be reduced but probably could not be made much less than 750 mm. Similarly, the focal ratio could be changed, but is fairly tightly constrained and will probably be in the range 11 to 13.

Mirrors M1 - M4

Four mirrors are used to remove the rotations produced by azimuth and elevation movements and produce a constant beam in the receiver cabin. M1 is fixed to the primary mirror structure, and M2 - M4 to the rotating part of the azimuth bearing. As envisaged now, these are all plane mirrors for the following reasons.

- (1) They are cheaper to fabricate than focused reflectors.
- (2) They are simple to align.
- (3) The imaging properties of shaped mirrors for off-axis beams is unknown.

The sizes of these mirrors varies from about 1.4×0.95 m to 1.0×0.74 m.

Receiver Room

The receiver room is located in the base of the antenna mount. Five receiver bays are planned (Figs. 1 and 2). One is in the center of the room and is intended for a focal plane array at frequencies down to about 200 GHz. It receives the signal directly from M4, through the azimuth bearing. Note that the image of the sky rotates relative to this receiver position so that either the receiver has to be rotated, or software correction needs to be applied.

For the other receiver positions the beam is deflected by selection mirror S1 to one of the receiver focusing mirrors R1 - R4. These receivers may be single beam at any frequency from 43 - 500 GHz, or possibly an array at the higher frequencies (300 GHz or higher).

The receiver front ends should be about $0.75 \times 0.75 \times 1$ m. Although this is smaller than the receivers on the 12-m telescope, some of the associated electronics can be removed to racks at the side of the receiver room.

Discussion

Table I summarizes the main parameters of the design. The specification that the secondary focus be brought to the receiver puts quite stringent conditions on the geometry and dimensions. The values given here therefore cannot be changed very much. As far as the telescope performance is concerned, the main consequence is the relatively large central blockage leading to increased sidelobes and reduced aperture efficiency. The reduction in gain is about 5.4% due to the 1m diameter hole in the primary. In order to reduce the size of the central blockage significantly, the secondary focus would need to be brought much closer to the vertex and M1 and M4 (for example) would need to be focusing reflectors. Because of the disadvantages listed earlier, this should be considered only if the blockage is shown to be unacceptable.

Fig. 2 gives the main dimensions set by the choice of the optics. Figs. 3 - 5 show how the beams of different receivers couple to the telescope. A Gaussian beam giving an edge taper of 11 dB is assumed and the 1 and 2 beam radii contours are plotted. The 2 beam radii contour are a fairly conservative estimate of the clearance required, but this should not be reduced, if possible.

Distribution: MMA Memo Series
D. Emerson
R. Brown
M. Balister

Specifications

Primary Mirror

Shape		Paraboloidal
Diameter	D	8.00 m
Focal length	f	3.20 m
Focal ratio	f/D	0.4
Edge angle	θ_p	64.01°
Central hole diameter	d_h	1.00 m

Secondary Mirror

Shape		Hyperboloidal
Diameter	d_s	0.80 m
Distance between foci, f_1	$f_1 = 2c$	9.7908 m
Additional path length	2a	9.18409 m
Eccentricity	e	1.06897
Magnification	M	30
Paraxial focal length	$f_1 = a(e^2 - 1)/2$	0.655 m

Equivalent Paraboloid

Focal length	$F = Mf$	96.0 m
Focal ratio	F/D	12.0
Edge angle	$\theta_e = 2 \cot^{-1} 4F$	2.39°
Plate scale	1/F	2.15 arcsec.mm ⁻¹

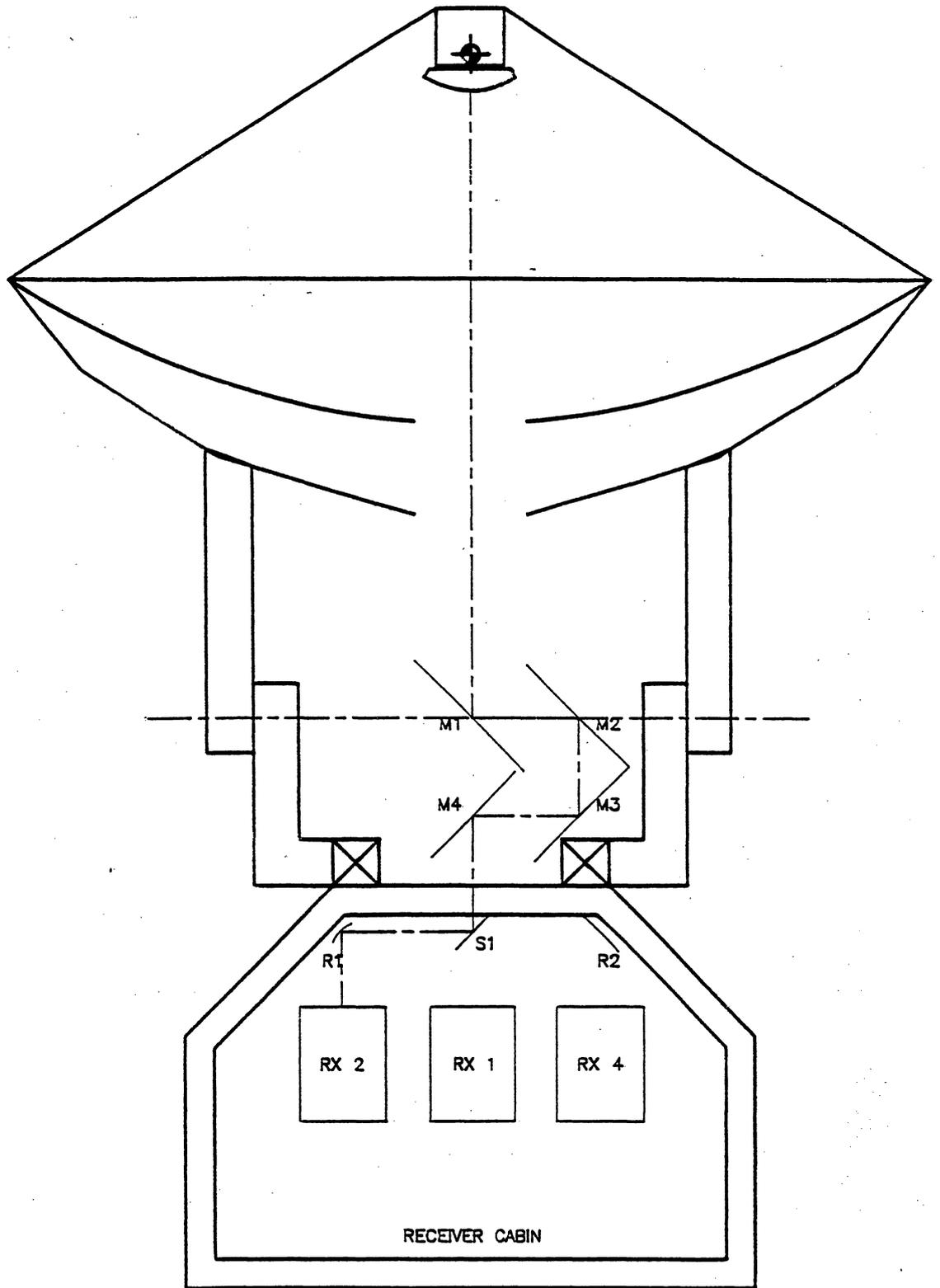


Figure 1. Proposed optics for the MMA antennas.

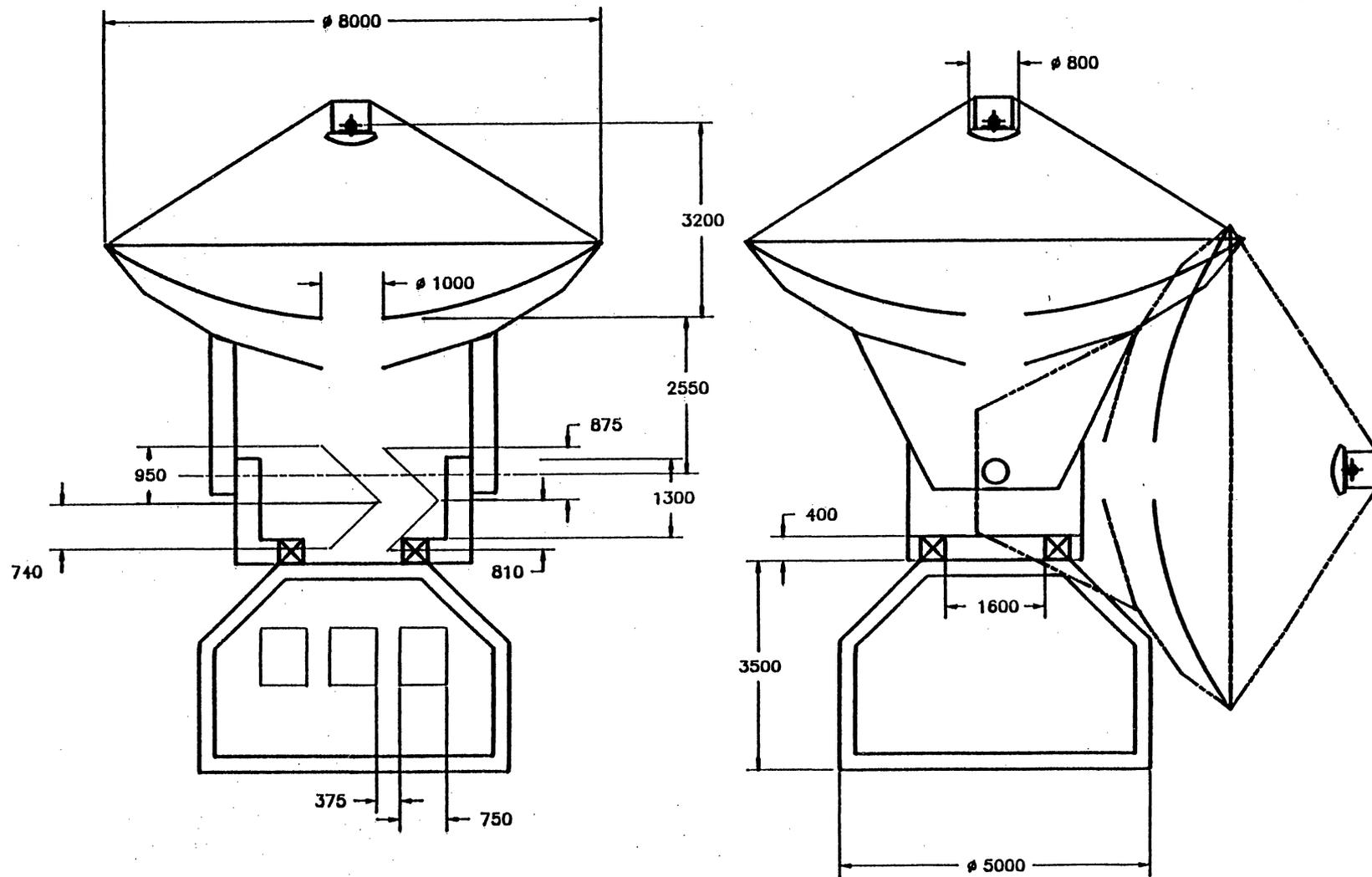
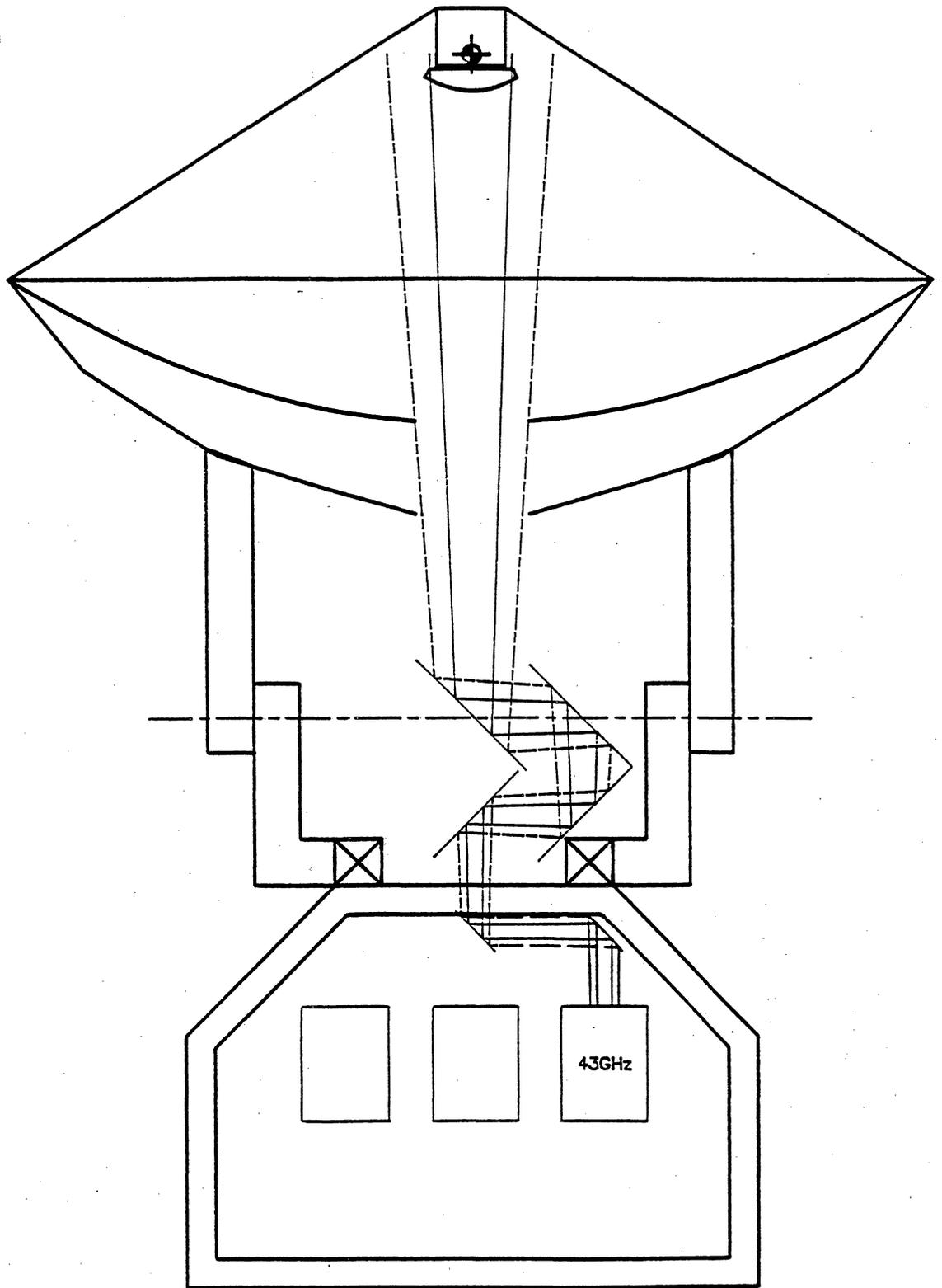
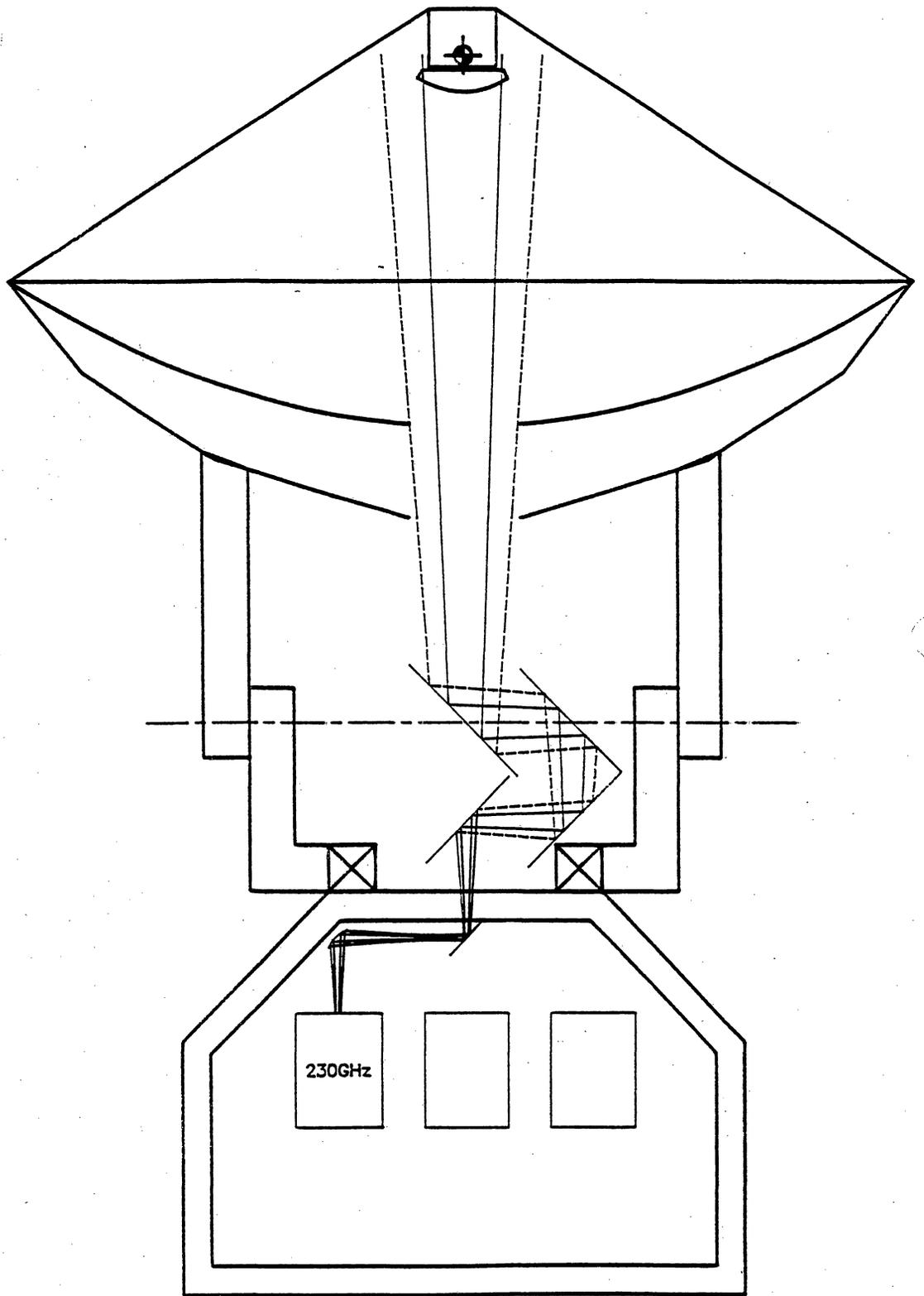


Figure 2. Preliminary dimensions of antenna (millimeters).



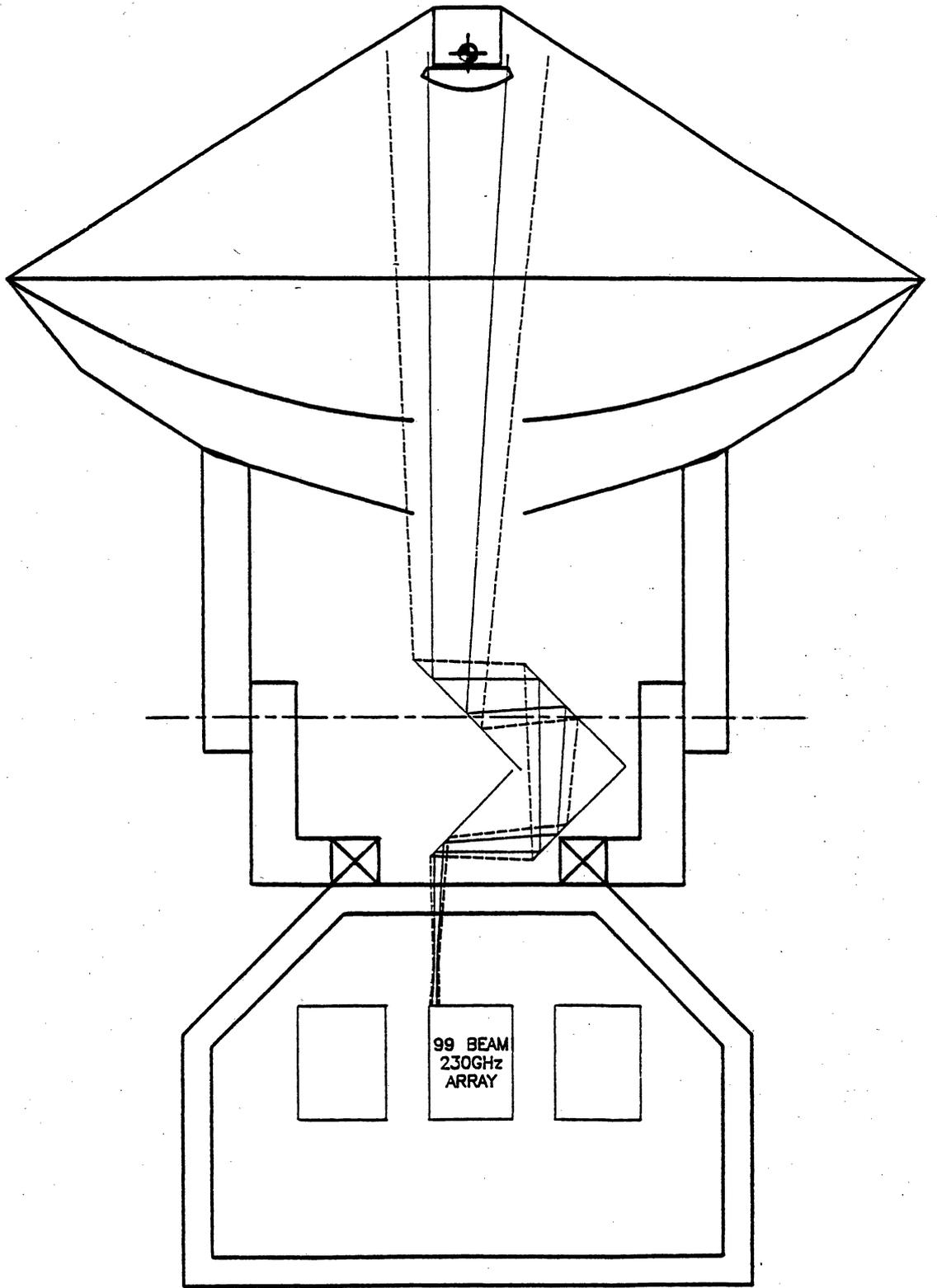
——— 1 beam radius contour
 - - - 2 beam radii contour
 (beam radius = $1/e$ amplitude contour)

Figure 3. 43GHz beam path.



——— 1 beam radius contour
 - - - - 2 beam radii contour
 (beam radius = 1/e amplitude contour)

Figure 4. 230GHz beam path



——— 1 beam radius contour
 - - - - 2 beam radii contour
 (beam radius = $1/e$ amplitude contour)

Figure 5. 230GHz offset beam