BOL	FIRST Bolometer	Doc No: BOL/RAL/N/0013.01
	Region of FIRST telescope beam used by BOL Prepared by: Martin Caldwell	Date: 27-8-97

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CONTENTS.

Summary.
This analysis determines the region of the FIRST telescope beam which is used by the BOL instrument. It concerns mainly the telescope region between the back of the interface primary mirror and the first focal plane, and the purpose is to define an optical interface between FIRST & BOL.

In this region the needed beam envelope is determined by analysing the largest detector-defined signal beam, this being for the following case:

- PHOT-BOL instrument.
- Incoherent detector response (Airy pattern sensitivity function).
- Longest wavelength (0.64 mm).
- Beam centred on outside edge of the outermost detector in array.

The analysis includes the effect of diffractive beam propagation, and it is assumed that within the BOL instrument the components can be sized such that no beam clipping occurs (i.e. beam is defined by the telescope & detector alone).

The results are used to define the region outside which the used beam is at < -30 dB in intensity relative to the on-axis beam. This is given in the table.

This first edition of the analysis is made for a telescope with 3.5m diameter, F/9.6 output beam, and with BOL occupying a position in the telescope focal plane which is 80mm off-axis. The data will need to be updated as the FIRST telescope design is updated.

1. Optical system model

1.1 Telescope prescription.

The optical model used is shown in fig.1. The co-ordinate system has its origin at the pole of the primary mirror, with the z-axis parallel to the telescope symmetry axis. All beam envelope data (e.g. appendix) are given in this co-ordinate system.

The model is based on the previous Cassegrain telescope design (3m aperture, F/7.76 beam, Ref.1), modified for the new baseline in the following ways:

1. Aperture of primary increased to 3.5m.
2. Mirror separation unchanged.
3. Obscuration factor unchanged. This, plus the new F/# of F/9.6, determines the focal plane position.

The new position of the BOL optics bench relative to the focal plane is not needed here.

N.B. this model needs to be further updated to the new FIRST telescope design once this is agreed in detail.

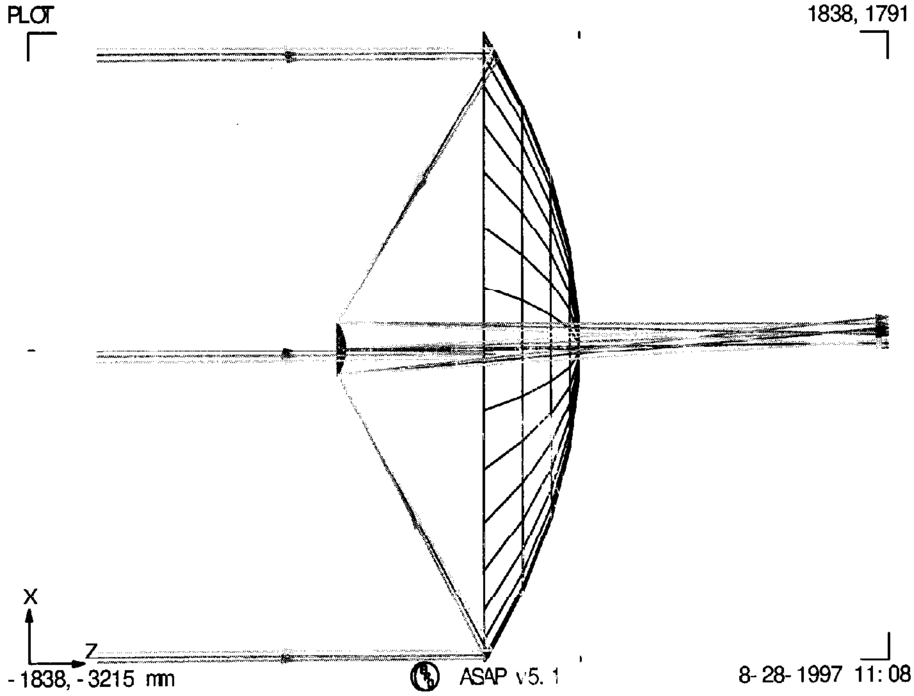


Fig.1. Current telescope model. Window dimensions are given in mm at bottom left & upper right corners of plot.

2. Beam definition.

2.1 Shape.

The wanted beam incident at a given field angle has a shape determined by type of detector used in BOL. This has a response which is intermediate between that of a coherent point detector (antenna horn) ,and an incoherent extended detector (e.g. bare photodetector). To determine needed beam sizes in detail it is necessary to analyse both extremes, i.e. far-field beam shapes of gaussian and top-hat functions respectively (Ref.3).

In the region of current interest, however, it is the top-hat case which leads to the larger beam sizes. This is because the top-hat beam fully fills the system aperture stop, which is at the telescope secondary mirror, whereas the gaussian beam case under-fills it. Therefore the top-hat case is used here to size the wanted envelope.

We are concerned mainly with far-field portions of the beam. At the longest BOL wavelength λ=0.64mm, the beam confocal distance is given by

$$z_o = \pi w_o^2 / \lambda$$

where w_o is the beam waist radius (approx. the Airy disc radius, i.e. $w_o \approx \lambda F$). This gives $z_o = 0.19$ m.

2.2 **Field-of-view.**

The beams analysed are those at the extremes of the wanted field-of-view (FOV). The FOV is currently sized around detectors with (horn) apertures of diameter 2Fλ with 0.5mm between apertures (Ref.2). The longest wavelength array has 480μm band centre wavelength, and 5 detectors in diameter. The edges of the outermost detectors are therefore separated by 5(2*9.6*0.48)+4*0.5 = 48 mm.

An additional allowance must be made for the imaging aberrations in the instrument. It is assumed that these geometric aberrations amount to less than one Airy disc radius at the longest wavelength, and therefore the amount Fλ is added to each edge of the wanted FOV to give a worst-case size.

The wanted FOV is therefore taken as having this diameter 48+2*4.6=57.2mm at the telescope focal plane. Although the detector array is hexagonal, it is assumed circular here for simplicity. The lateral displacement of the BOL FOV from the telescope axis is taken as 80mm, as per ref.2, although this data may change in the updated design.

Fig.2 shows the FOV region at the telescope focal plane, in the same co-ordinate system as fig.1.

The PHOT-BOL FOV is chopped by scanning it in the y-direction , as shown in the figure. Therefore the wanted FOV in the y-direction is 2*57.2 = 114.4mm.

In addition, the FOV region required by the SPEC instrument must be included. This is done by assuming for the whole BOL instrument a rectangular FOV as shown, giving space for the SPEC instrument FOV, e.g. as shown in the figure.

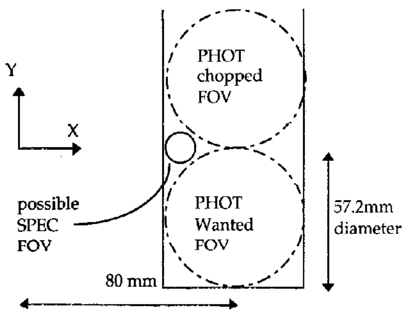


Fig.2 Wanted FOV region at telescope focal plane.

3. Results.
To describe the wanted beam corresponding to this FOV, the telescope F/9.6 top-hat beam is traced, from the system aperture stop (secondary mirror), to the focal plane, at field positions corresponding to the extremes of FOV in the x and y directions (2 beams are traced for each direction). The total flux in each beam is set at one energy unit (units e.g. pico-watts). The beam pattern is then analysed in x-y planes at several z positions, and the results are given in terms of flux per unit area (irradiance, units e.g. pW/mm^2), versus position (see appendix). Rather than compute the full two-dimensional beam pattern, only one-dimensional slices are made, in the x-direction and the y-direction, along the centre-line of the beam pattern. To see the effect of diffraction, the computation is made at both a short wavelength, and the longest wavelength relevant to BOL, i.e. 0.64mm.

The resulting series of plots show how the two beams describing each edge of the FOV, are co-incident at the telescope secondary, and then gradually separate as they propagate, becoming separate focussed spots by the time they reach the focal plane. Where the beams overlap partially, their interference is assumed to be incoherent, and a central 'stepped' peak is seen in the profile due to intensity summing.

To allocate a definite boundary to the needed beam envelope, the -30dB point of relative irradiance is used, i.e. the point where beam irradiance is 1000 times less than it is in the centre of the beam (the flat region of the top-hat beam profile). Reading these points from the data in the appendix gives the following approx. sizes for the wanted beam envelope:

Z-position	**X-envelope in mm**		**Y-envelope in mm**
Secondary mirror z=-1372.895	-160	+160	+- 160
Primary mirror z=0	-100	180	+- 150
z=293.4	-90	190	+-150
z=2*293.4	-70	170	+-130
z=3*293.4	-30	150	+-120
z=4*293.4	-0	150	+-100
Focal plane z=1467.115	30	130	+-70

4. References.

Ref.1 "Beam patterns in PIIOT-BOL design" M Caldwell. BOL/RAL/N0006.1

Ref.2 "Size of PHOT-BOL detector arrays" M Griffin & B Maffei 21-3-97.
Ref.3 Minutes of BOL meeting 27-6-97 BOL/RAL/M/0018.1 section 2.

Appendix. Beam pattern data.

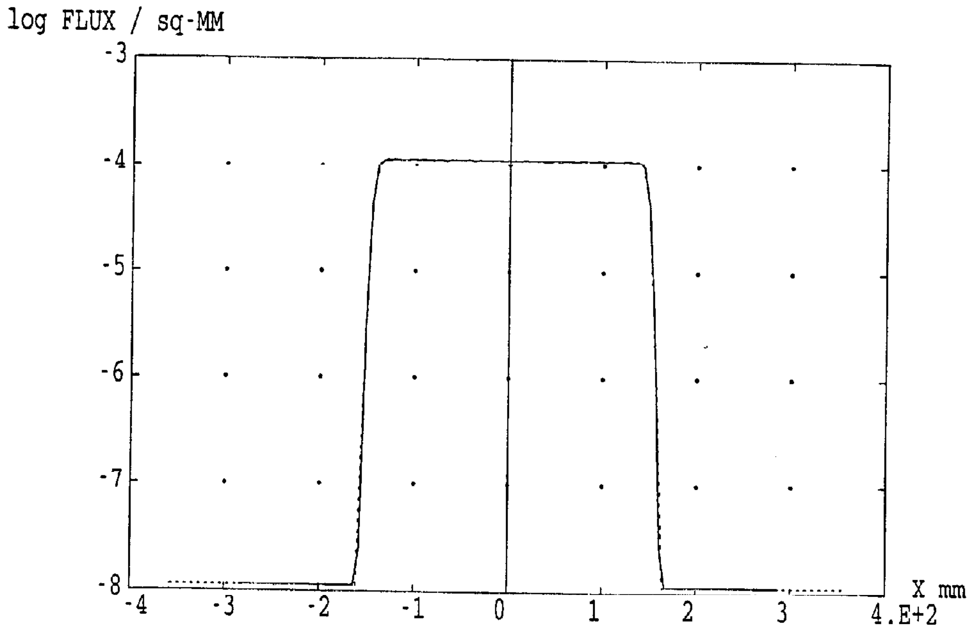
The following plots show beam patterns through the region of interest. There are two series of 7 plots each. The first series is the X-direction slice, the 2nd is the y-direction.

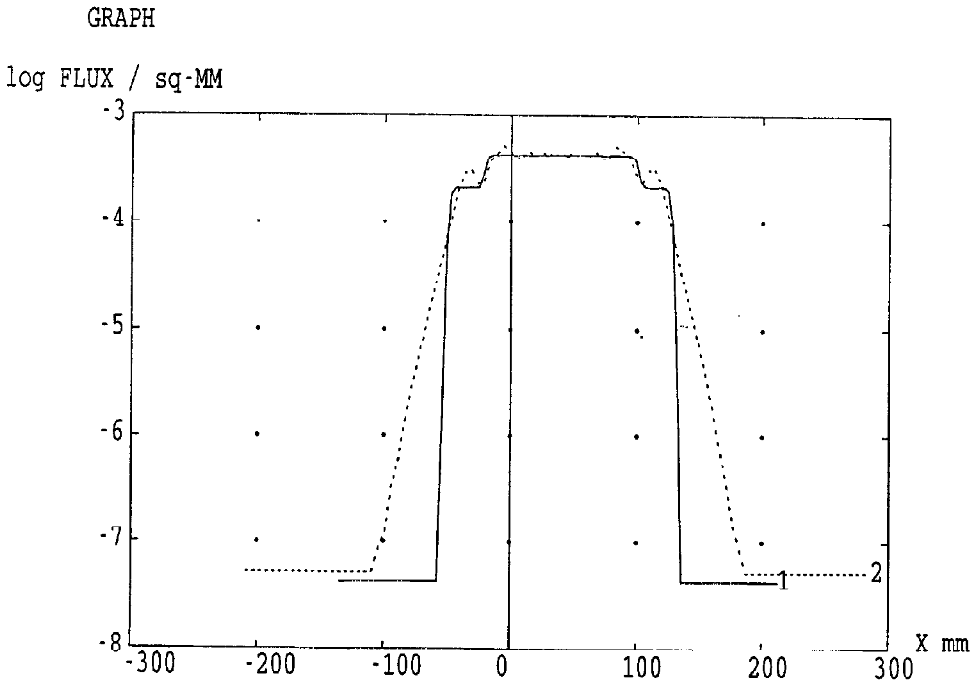
The z-positions of the plots are:

Plot 1. Secondary mirror
Plot 2. Primary mirror (beam passing through cut-out)
Plots 3 plane between primary and focal plane, z=2*293.4
Plot 4 Focal plane.

In each plot the pattern is given at both the longest required wavelength (0.64mm), and at a short wavelength (0.0025mm).

Series 1: X-direction slices





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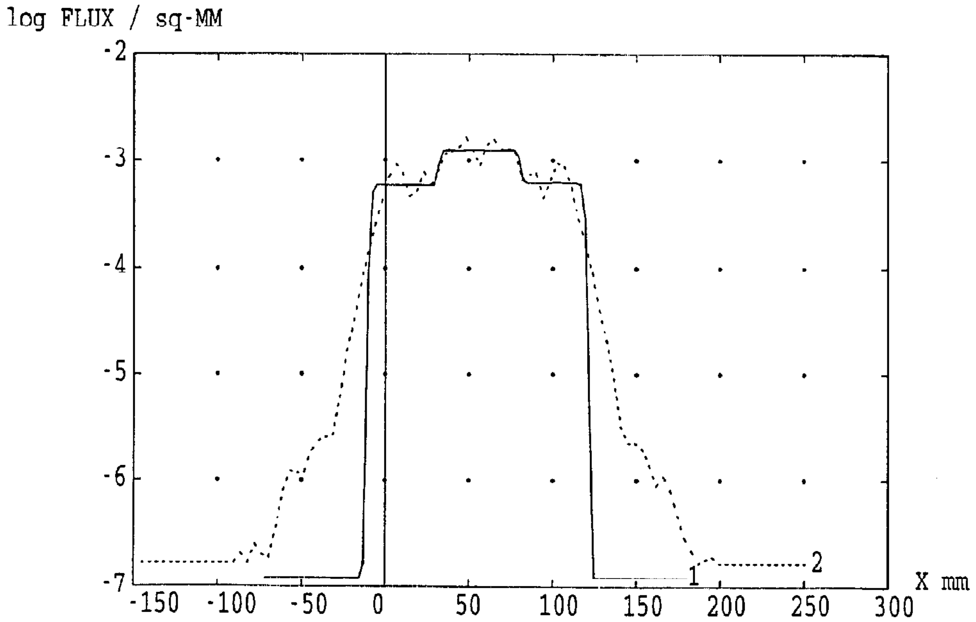

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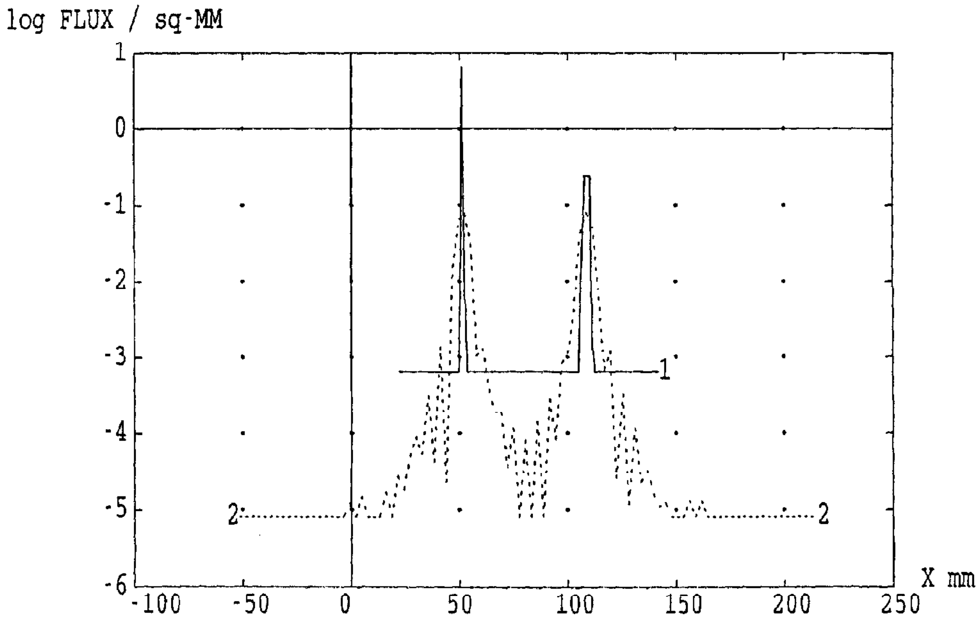
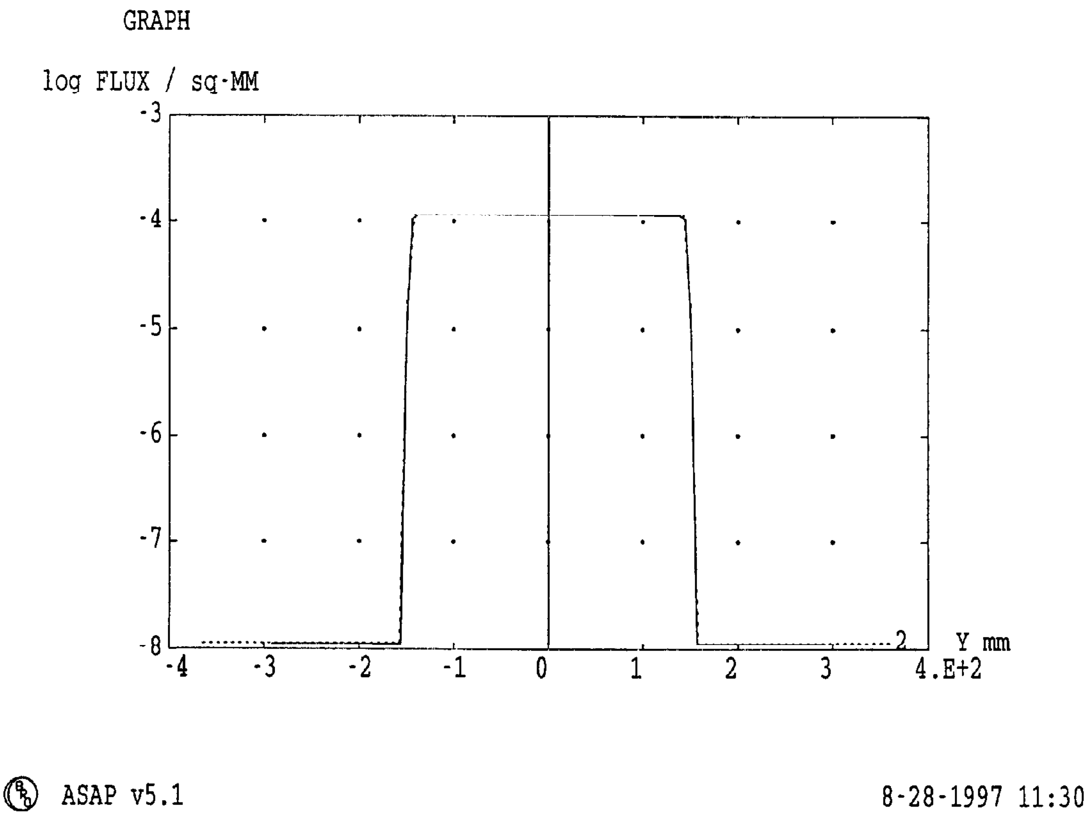


Series 2: Y-direction slices



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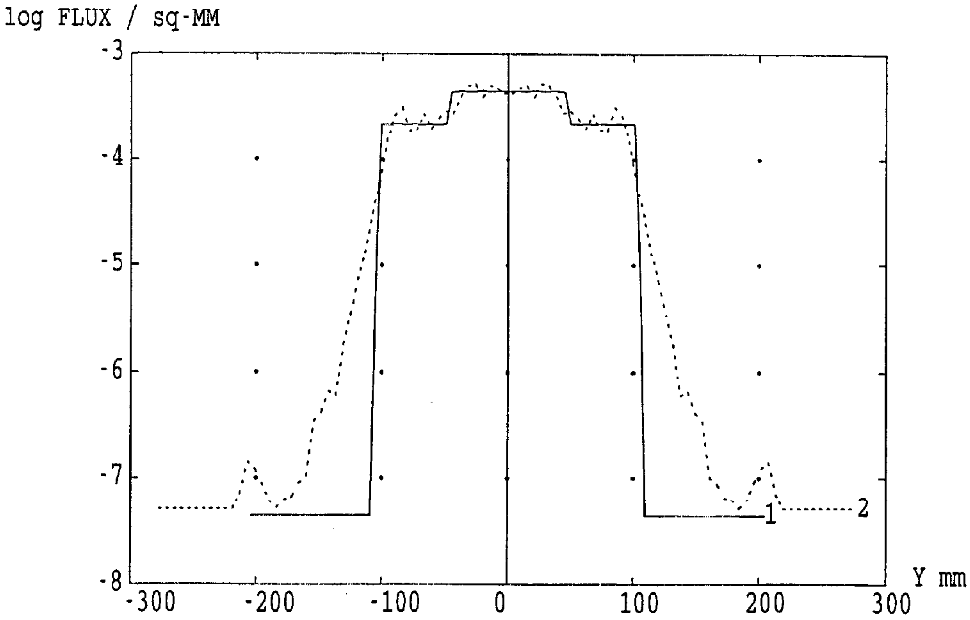

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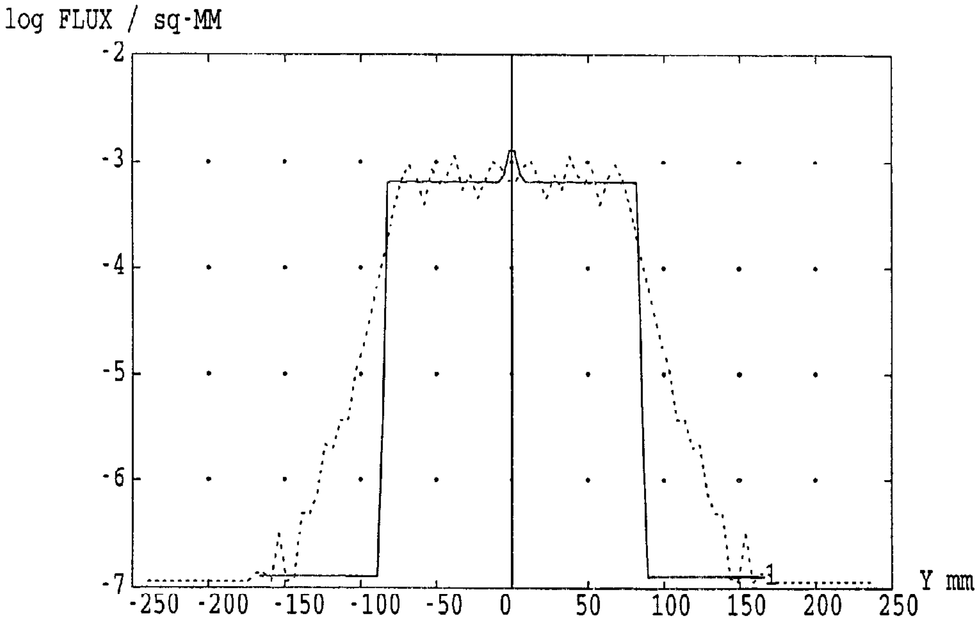

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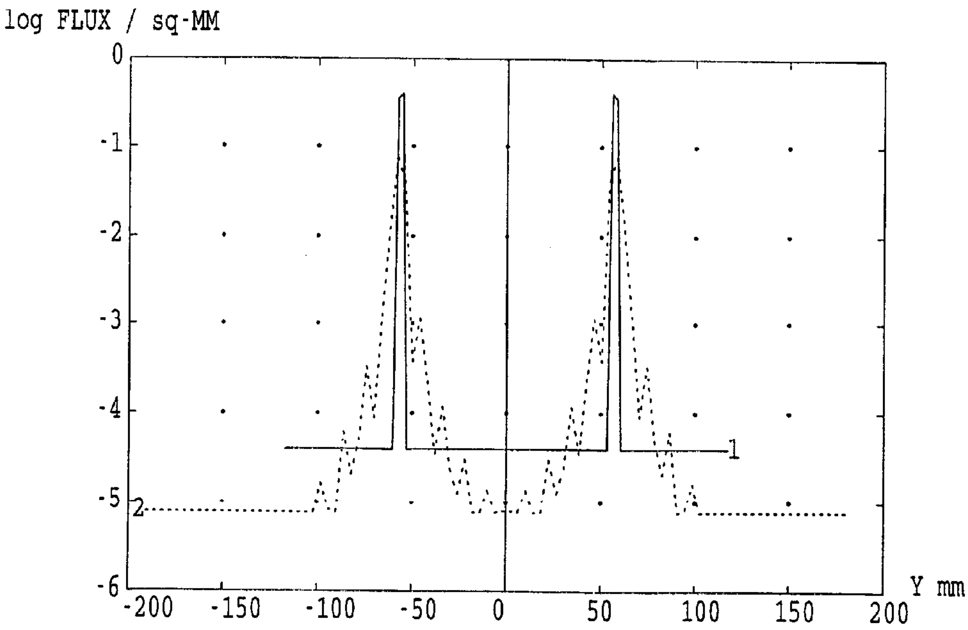

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