<< Variation of resolution, position and brightness along a CCD pixel >>

Calibration Report

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1. Introduction

The blue detector of the UV-optical telescope (XMM-OM) employs centroding technique to achieve large pixel format with a small CCD. Each CCD pixel is divided into 8x8 subpixels, therefore only 256x256 physical CCD pixel is necessary to create pixel format of 2048x2048.

There are, however, several potential problems associated with the centroiding. For instance, the centroiding accuracy changes with event position within a CCD pixel. The accuracy is better at CCD pixel boundaries with the parabola algorithm, which will be used for the flight model electronics. The accuracy is better at CCD pixel centre with the centre of gravity algorithm, which was used for EOB-1 model.

The size of a photo-event splash is typically 1.1 CCD pixel. If event occurs at the pixel corner, only quarter of the total energy falls into a CCD pixel. While at the centre, almost all energy falls into a CCD pixel. The threshold level for the photo-event detection is constant, 30 ADU nominal, wherever an event occurs. Therefore event detection probability is higher at the pixel centre and is lower at the pixel corner. This causes D.Q.E. non-uniformity within a CCD pixel.

The centroiding inaccuracy miss-positions an event, therefore it does not cause only image blurring but also position displacement of an pinhole image. As the centroiding inaccuracy may have position dependence within a CCD pixel, the displacement of a spot position may be systematic.

Undersampling by MCP1 pores and by subpixels (8.86um) potentially creates inaccuracies in resolution, position and photometry. XMM-OM/MSSL/TC/0022 (March 1991 M. Oldfiled et al) reported the effect of undersampling by MCP1 pores for pinhole image with the Imperial College's superb 40mm image tube, which employed 12 on 15um 1st plate and had excellent resolution for all visual wavelengths. While the simulation on the undersampling by 10 on 12um 1st plate ("XMM-OM/MSSL/TC/0043.01", 15 May 1997) showed only small effect if image blurring due to centroiding inaccuracy is 10um and image blurring due to photocathode gap is 19um.

A fine pinhole image (~5um) was delivered to a CCD pixel and was scanned along the pixel 1.8um by 1.8um. Then, the brightness, position and point spread function (PSF) of the pinhole were investigated. The two light sources were used, red 630nm and blue 460nm. This experiment was carried out with the DEP tube TYPE-PP0370B (SN B9710003), whose 1st plate is 10 on 12um and centroiding accuracy is worse than 8um. Because of poor centroiding accuracy and fine pore in the 1st plate, the effect of the 1st plate is expected to be small.

2. Set-up of experiment

An 11(H)x9(V) pinhole array image was projected onto the intensifier through a Nikon 50mm lens with F/8 (see Figure 1 of "XMM-OM/MSSL/SP/0067, 20 March 1995"). The minification of the optics is 1/5 to allow a small spot image, 5um at the detector, and fine positioning by a x-y stage. The light sources was a red LED (630nm max) and a blue LED (460nm max). Their brightnesses are tuneable by changing the applied voltage (8-15V).

As the light box is too small, the illumination of the pinholes is not uniform, therefore the brightness on the detector varies pinhole by pinhole by a factor of 5.

A CCD camera format of 256x256 was employed, which provided a frame rate of 100Hz. 1/8 pixel centroiding was then employed to obtain the 2048x2048 area from which the 512x512 stored sections were obtained. Figure 1 shows an example of the stored section. Figure 2 is its magnified image. The central pinhole scanned along a CCD pixel (256H, 224V) with 1.77um step. One scan contains 40 points and 8 scans were carried out to cover the whole pixel area, hence 320 frames were stored for a set of measurements. The integration time was 300 sec per frame. The 11x9 pinhole array around the central pinhole was used for calibrating brightness of the light source and position of the xy stage. Since a set of experiment takes 27 hours, the average of PSFs from 11x9 pinholes was used for monitoring the quality of focus.

Fig.3a shows positions of the central pinhole within the CCD pixel (256,224) for red light experiment, and Fig 3b for the blue. The relative position of the central pinhole to the other 11x9 pinholes are derived by analysing 320 frames. And then the position of the central pinhole was calculated from those of 11x9 pinholes for the individual frame. The xy stage must be kept power on to keep high precision. The communication between the xy stage and IBM-PC broke down at the end of 1st scan during the red light measurement. The DSP-VME crate got a trouble near the end of 6th scan during the blue light measurement. After the both troubles, the xy stage delivered the pinhole to wrong positions.

Figures 4a and 4b show the averaged brightnesses from 11x9 pinholes and raw brightness of the central pinhole (total counts per frame) during the red and the blue lights measurements. The voltage applied to the red LED was increased after the communication break down. The voltage applied to the blue LED was also increased after the DSP-VME crate trouble. As the non-uniformity of illumination was large in blue LED, the intensity of the central pinhole had to be uncomfortably low, 0.7 count/(pinhole sec). But it could be brighter by twice.

Fig. 5a shows the averaged PSFs from 11x9 pinholes throughout the 27 hours red light experiment. The averaged width was nearly constant, ~17um. Fig. 5b shows the averaged PSFs for blue light experiment. The averaged width is nearly constant, ~20um.

3. Point Spread Function and Asymmetry of Profile

Figure 6 shows profiles of the central pinhole along x-direction at 10 different positions. The top 5 profiles are from the edge of the CCD pixel in y-direction and bottom 5 are from the centre in y-direction. The light source is the red LED. As the photocathode gap effects least in red, the undersampling effects by CCD pixel, subpixel, and 1st plate are most noticeable. The displacement of the pinhole is only 1.8um between the two consecutive profiles. The width does not look changing among the 10 profiles. While, outlooks are changing gradually. For instance, the sense of asymmetry flips from N=444 to N=445 profiles. It is most likely the effect of undersampling by subpixels. The undersampling effect due to the 1st plate is not noticeable in this level of S/N. The widths (point spread function) of the central pinhole at different positions are shown in figures 7a and 7b, which are from boundary scan and central scan. Both show large scatters, but the width is smaller than 20um. The large scatter may be due to the undersampling by 8.9um subpixel and caused calculation inaccuracy. Poor photon statistics may be another reason. It is necessary to scan only small area with longer exposure time for identifying the cause of the large scatter.

Figures 8a and 8b show widths scanning along CCD pixel boundary and pixel centre for blue light. The width is smaller than 25um.

4. Position Accuracy

was preliminary measured using a photographic sky image ("XMM-OM/MSSL/SP/0067", 20 March 1995). Because the stellar image size was larger than 40um in the test, high position accuracy was obtained, 1-2um. But, the real stellar image in the orbit is expected to be ~20um, therefore the undersampling by subpixels may reduce the position accuracy. As the red light produces the smallest image size, the experiment with red light shows the worst case. The experiment with blue light may represent typical case.

Figure 9 shows measured positions for red light and figure 10 for blue light. Small dots denote the calculated positions from 11x9 pinhole positions. The deviation of the measured position is nearly same in both colours and is less than 2um. The accumulated photons in the central pinhole are 350-650 for the red experiment and 200-250 for the blue. The accumulated photon is not extremely large and the pinhole size is reasonably small, but almost same accuracy as March 1995 was obtained.

5. Photometric Accuracy

The detectable Q.E. can change with event positions along a CCD pixel. For an event at the pixel corner, only quarter of the total energy falls into a CCD pixel. While at the centre, almost all energy falls into a CCD pixel. Therefore, the D.Q.E. can be lowest at the corner subpixels and be highest at the central subpixels, this is particularly true for the DEP TYPE-PP0370B tube as it has very small event size, 15um on the CCD. Even the DQE varies subpixel by subpixel, the total photon from a star can be fairly constant if the stellar size is very large because it may cover both of corner subpixel and central subpixel. While, photometric accuracy of a star faces with problem if stellar image covers only few subpixels. As the red light creates smallest pinhole size, ~17um, the pinhole brightness shows worst variation in red light. The experiment with blue light may represent typical case.

Figure 11 shows averaged pulse height distribution of the DEP tube. The threshold level for the event detection is 30 ADU in nominal. The PHD shrinks toward left by half for pixel corner events compared with that for central events. This causes the effective threshold to be 60ADU for the corner events, therefore many events are lost. Since the PHD of the DEP tube has very deep valley, the threshold can be set lower without increasing noise. The lower threshold allows less DQE loss along a CCD pixel. The experiment was carried out with the threshold of 13ADU to enjoy the beauty of the intensifier. This, of course, causes loss of centroiding accuracy, hence loses resolution. But, it should be noted that all of the image throughout the experiments were acquired with threshold=13ADU and pinhole size in red was 17um. Therefore, this low threshold value is proven to be adequate in the orbit.

The undersampling of photo-electron by 1st plate pores also can create local DQE variation. However, the simulation with 10 on 12um pores and with 19um input photo-electron showed negligible effect. The effect is larger if the size of photo-electron input is smaller. As the size of input photo-electron is 17um in red, the situation in red is a little worse than the simulation. The red light experiment again should show worst variation, and the blue light experiment represents typical case of the real observation.

Figures 12a,b and c show brightness of the central pinhole at different positions with red LED. Fig. 12a and c are from the scans at y-boundary and Fig. 12b is from the scan at y-centre. The LED brightness was monitored by other 11x9 pinholes and brightness of the central pinhole was corrected. The photon shot noise is 5.8%(rms) for figure 12a and 3.7%(rms) for figures 12b,c. There is no clear systematic variation within the accuracy of 20%. It is difficult to mention about small systematic variation due to the unbrilliant S/N.

photon shot noise for the 3 figures are 6.7%(rms).

6. Summary

1) Point spread function of pinhole is smaller than 20um for all position within a CCD pixel with red light, and is smaller than 25um for all positions with blue light. The large scatter may be associated with calculation error due to the undersampling by subpixels. The averaged PSF is 17um for red and 20um for blue.
2) Position accuracy is better than 2um with both colours even if accumulated photons are only 200-650.
3) No systematic variation in DQE was detected within the accuracy of 20%

This is the start of calibration of the blue detector. It, however, is essential to improve photon statistics to clarify systematic variation and its quantities. To do so, the illumination of the mask pattern must be more flattened to allow more intensity to the central pinhole. The CCD camera format of 256(H)x64(V) should be employed to increase the frame rate to 400Hz. The LED should be tuned as bright as possible, namely 40 counts/(sec pinhole). Even if exposure time is kept same 300sec, each pinhole can acquire 12,000 counts. The photon shot noise can be 0.9%(rms), and it is low enough to detect 5% systematic variation. If phosphor is slow, it causes uncertainty of counts in a bright spot (e.g. 40 counts/sec). Therefore, the DEP TYPE-PP0370B tube, which has fast phosphor, is ideal for this test.

Acknowledgement. The author wish to express grateful thanks to DEP for loan of the new intensifier. This work was carried out as part of the XMM-OM program for the calibration of the blue detector.

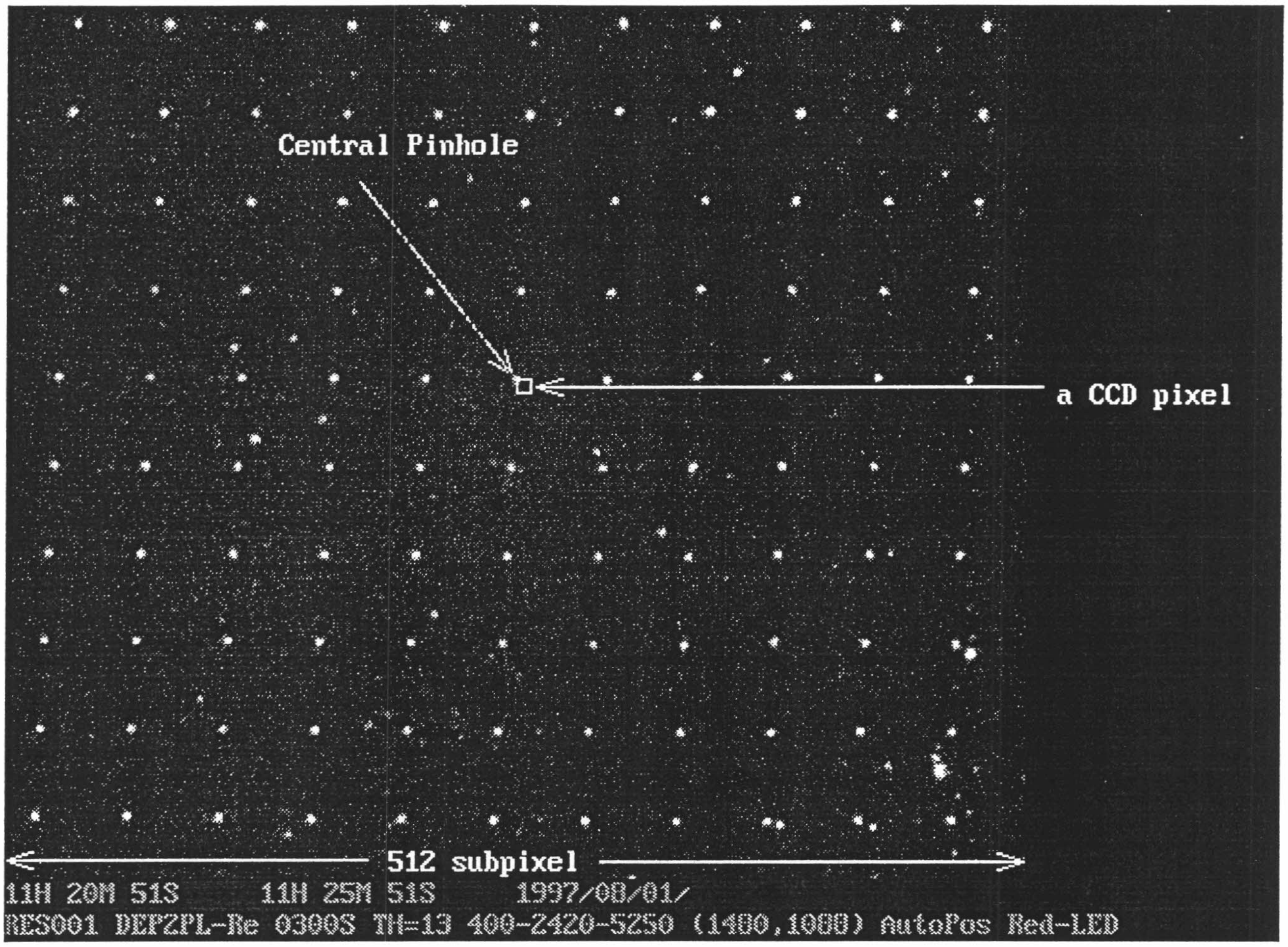

Central Pinhole
a CCD pixel
512 subpixel
11H 20M 51S 11H 25M 51S 1997/08/01/
RES001 DEPZPL-Re 0300S TH=13 400-2420-5250 (1400,1080) AutoPos Red-LED

Fig. 1

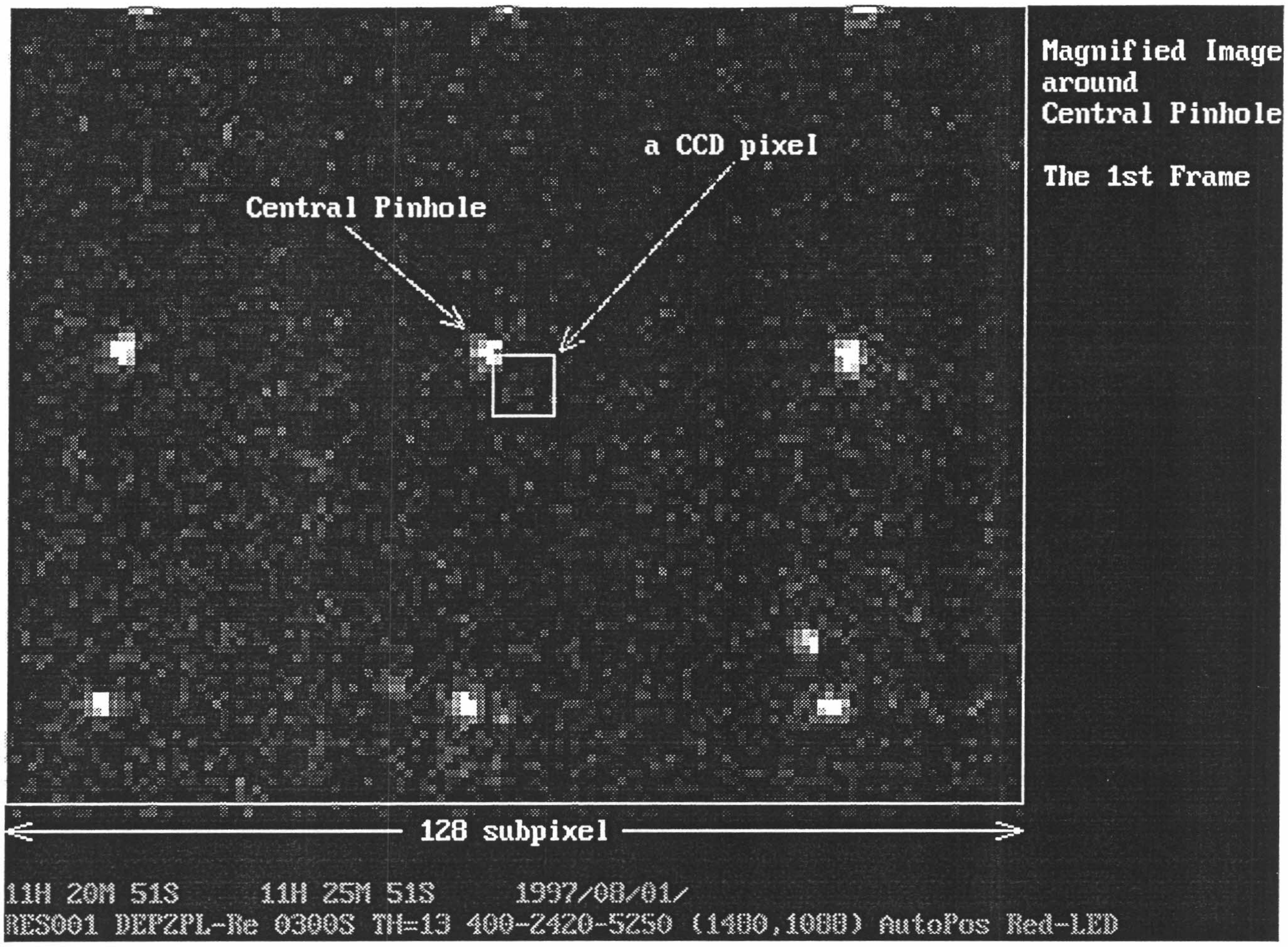

Magnified Image around Central Pinhole
The 1st Frame
a CCD pixel
Central Pinhole
128 subpixel
11H 20M 51S 11H 25M 51S 1997/08/01/
RES001 DEPZPL-Re 0300S TH=13 400-2420-5250 (1480,1080) AutoPos Red-LED

Fig. 2

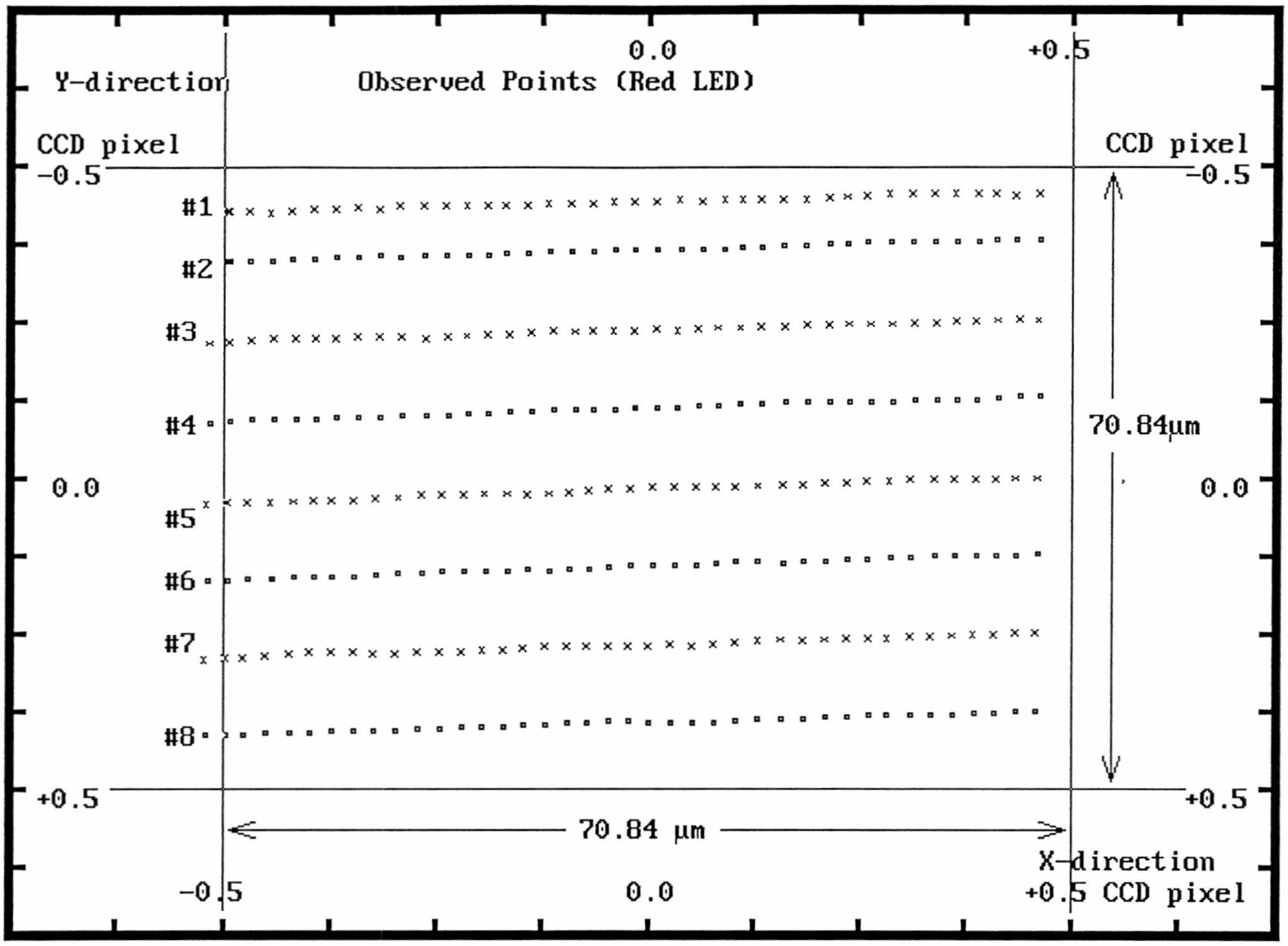

0.0
+0.5
Y-direction
Observed Points (Red LED)
CCD pixel
-0.5
CCD pixel
-0.5
#1
#2
#3
#4
70.84μm
0.0
0.0
#5
#6
#7
#8
+0.5
+0.5
70.84 μm
X-direction
-0.5
0.0
+0.5 CCD pixel

Fig. 3a

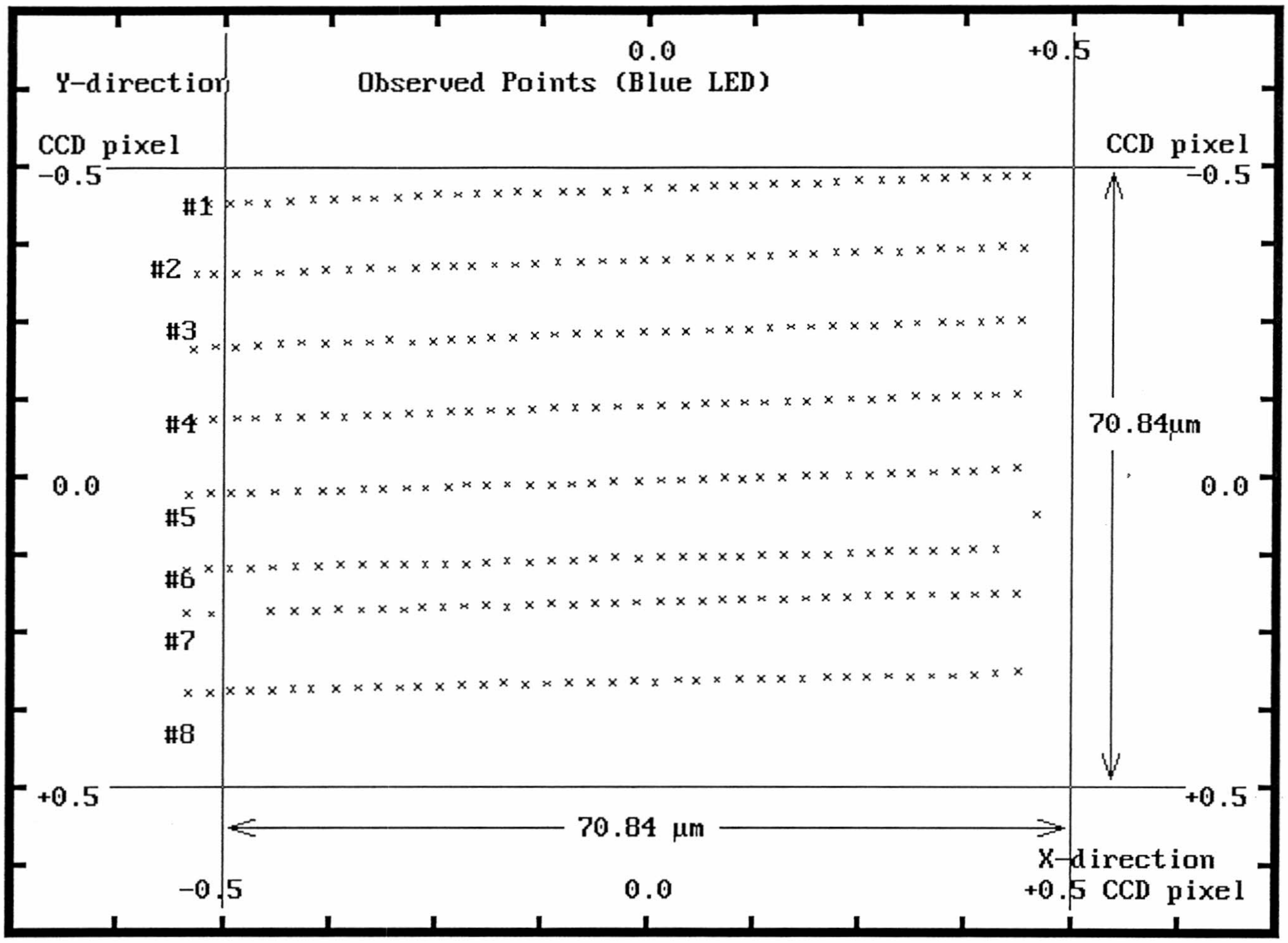

0.0
+0.5
Y-direction
Observed Points (Blue LED)
CCD pixel
-0.5
CCD pixel
-0.5
#1
#2
#3
#4
70.84µm
0.0
0.0
#5
#6
#7
#8
+0.5
+0.5
70.84 µm
X-direction
-0.5
0.0
+0.5 CCD pixel

Fig. 3b

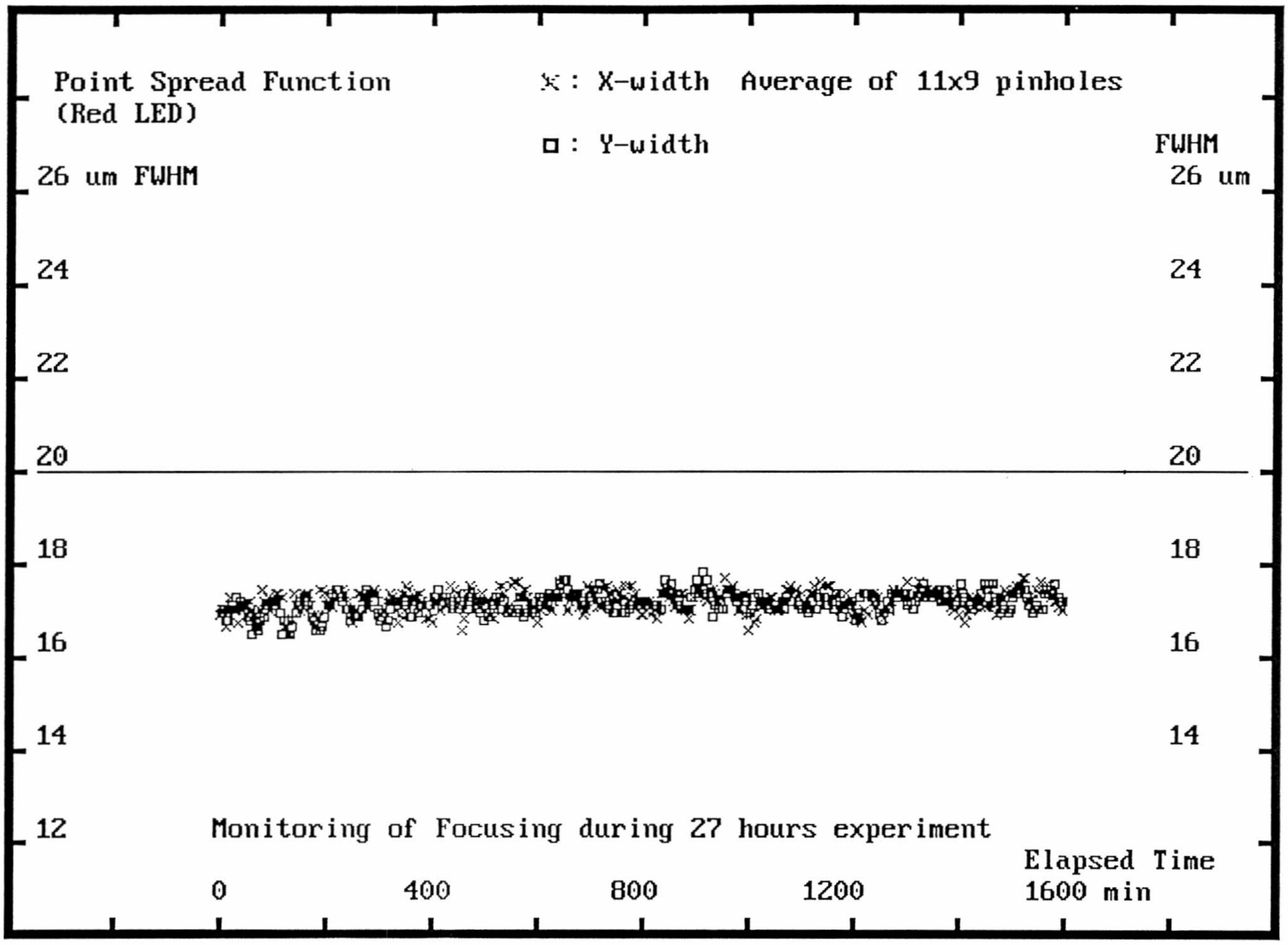

Point Spread Function
(Red LED)
⋇ : X-width
Average of 11x9 pinholes
□ : Y-width
26 um FWHM
FWHM
26 um
24
22
20
18
16
14
12
Monitoring of Focusing during 27 hours experiment
Elapsed Time
0
400
800
1200
1600 min

Fig. 4a

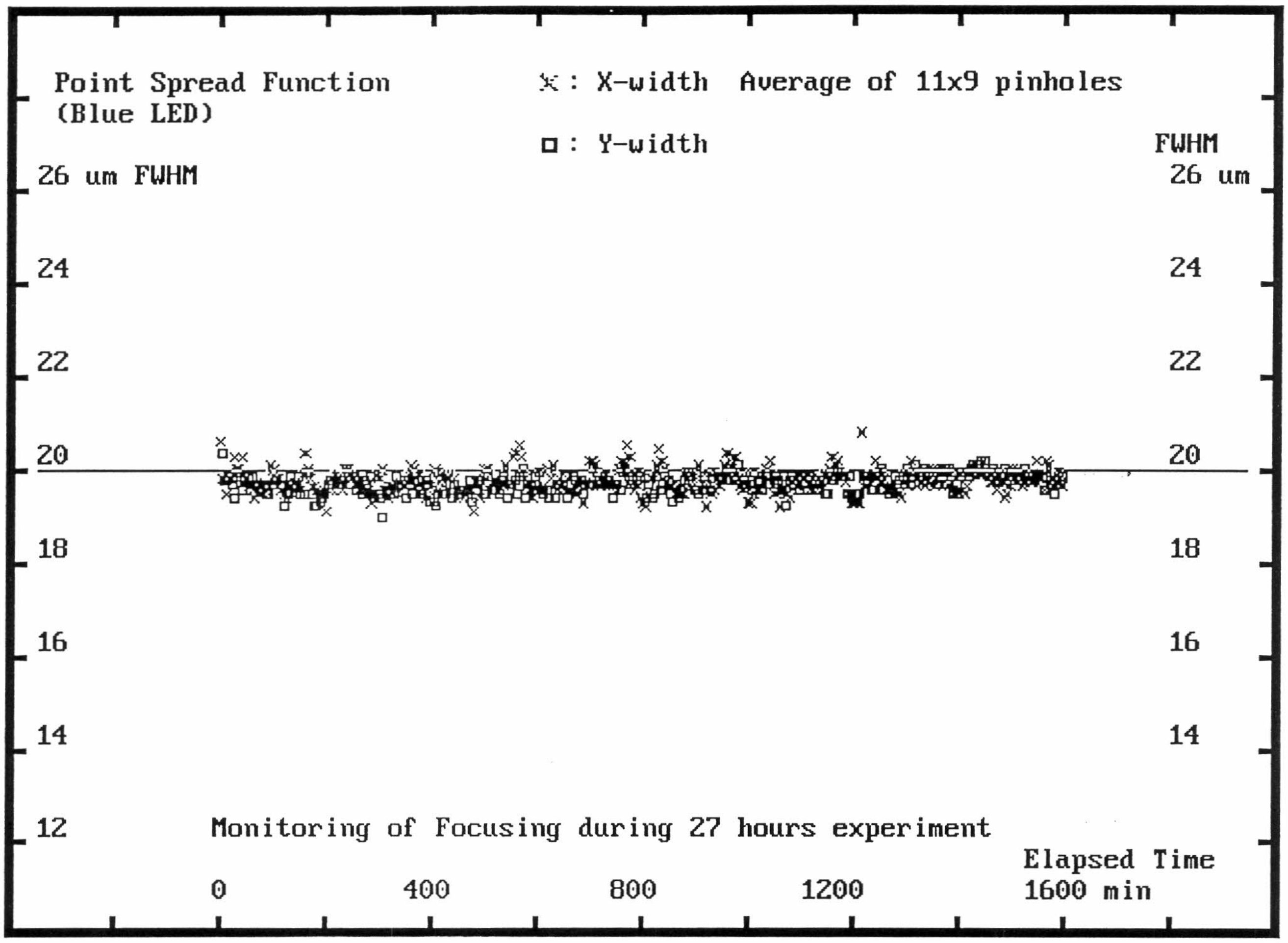

Point Spread Function
(Blue LED)
X : X-width
Average of 11x9 pinholes
□ : Y-width
26 um FWHM
FWHM
26 um
24
22
20
18
16
14
12
Monitoring of Focusing during 27 hours experiment
Elapsed Time
0
400
800
1200
1600 min

Fig. 4b

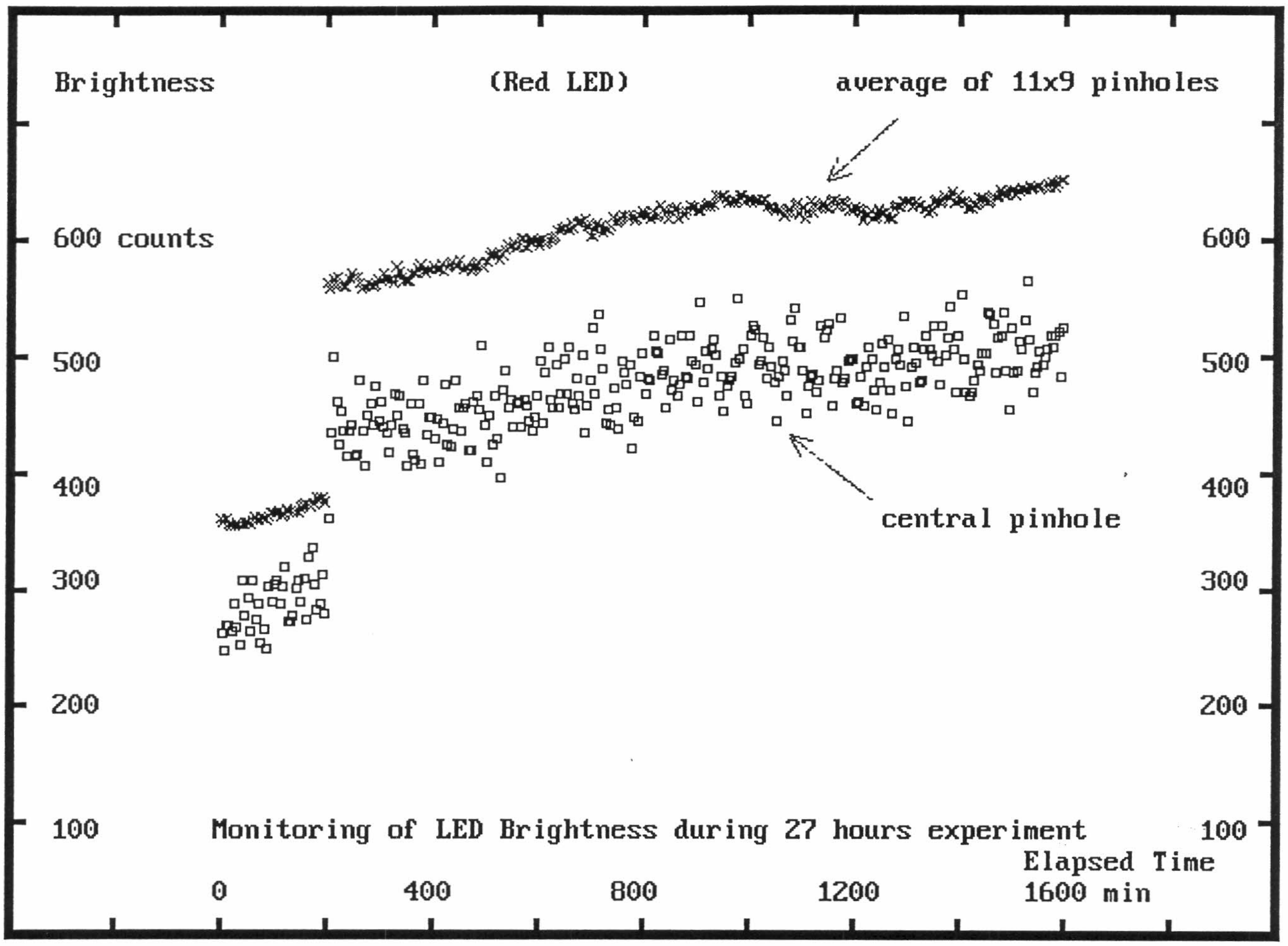
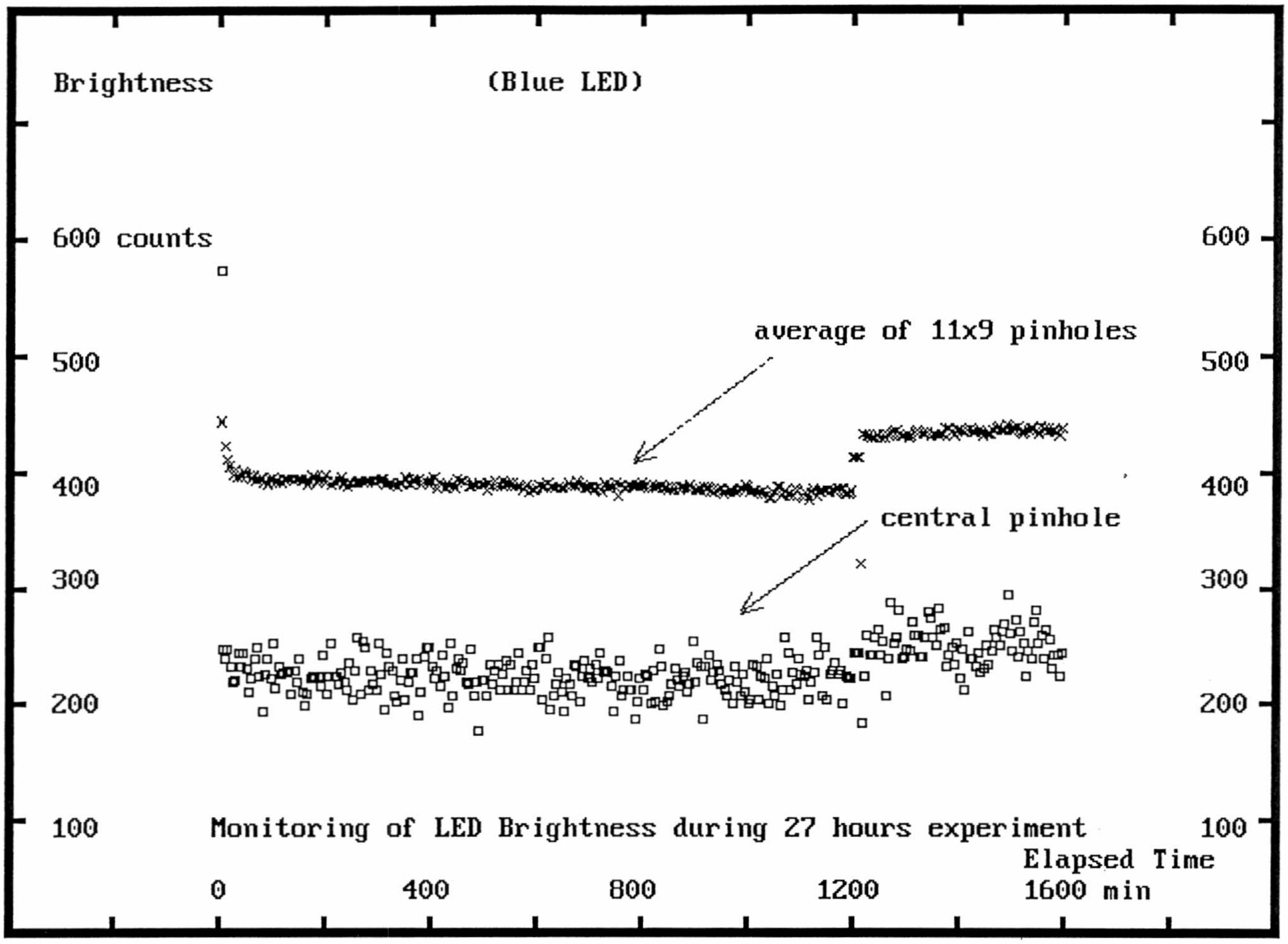
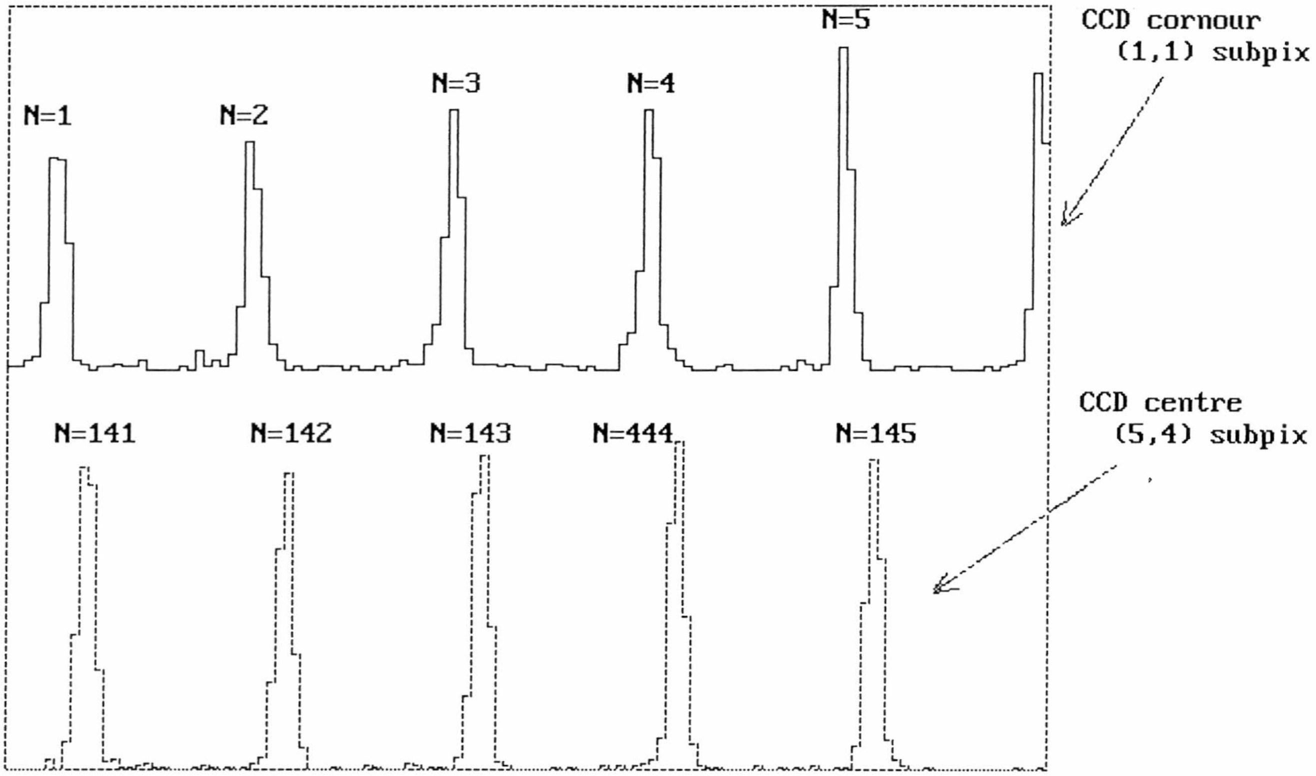

Brightness
(Red LED)
average of 11x9 pinholes
600 counts
500
400
300
200
100
600
500
400
300
200
100
central pinhole
Monitoring of LED Brightness during 27 hours experiment
Elapsed Time
0
400
800
1200
1600 min

Fig. 5a



Brightness
(Blue LED)
600 counts
600
average of 11x9 pinholes
500
500
400
400
central pinhole
300
300
200
200
100
Monitoring of LED Brightness during 27 hours experiment
100
Elapsed Time
0
400
800
1200
1600 min

Fig. 5b



Profiles of central pinhole in different positions within a CCD pixel
Asymmetries seem to be simply due to under sampling.

Red LED (630nm) PSF=17μm typical 1 subpixel = 8.86μm

Fig. 6

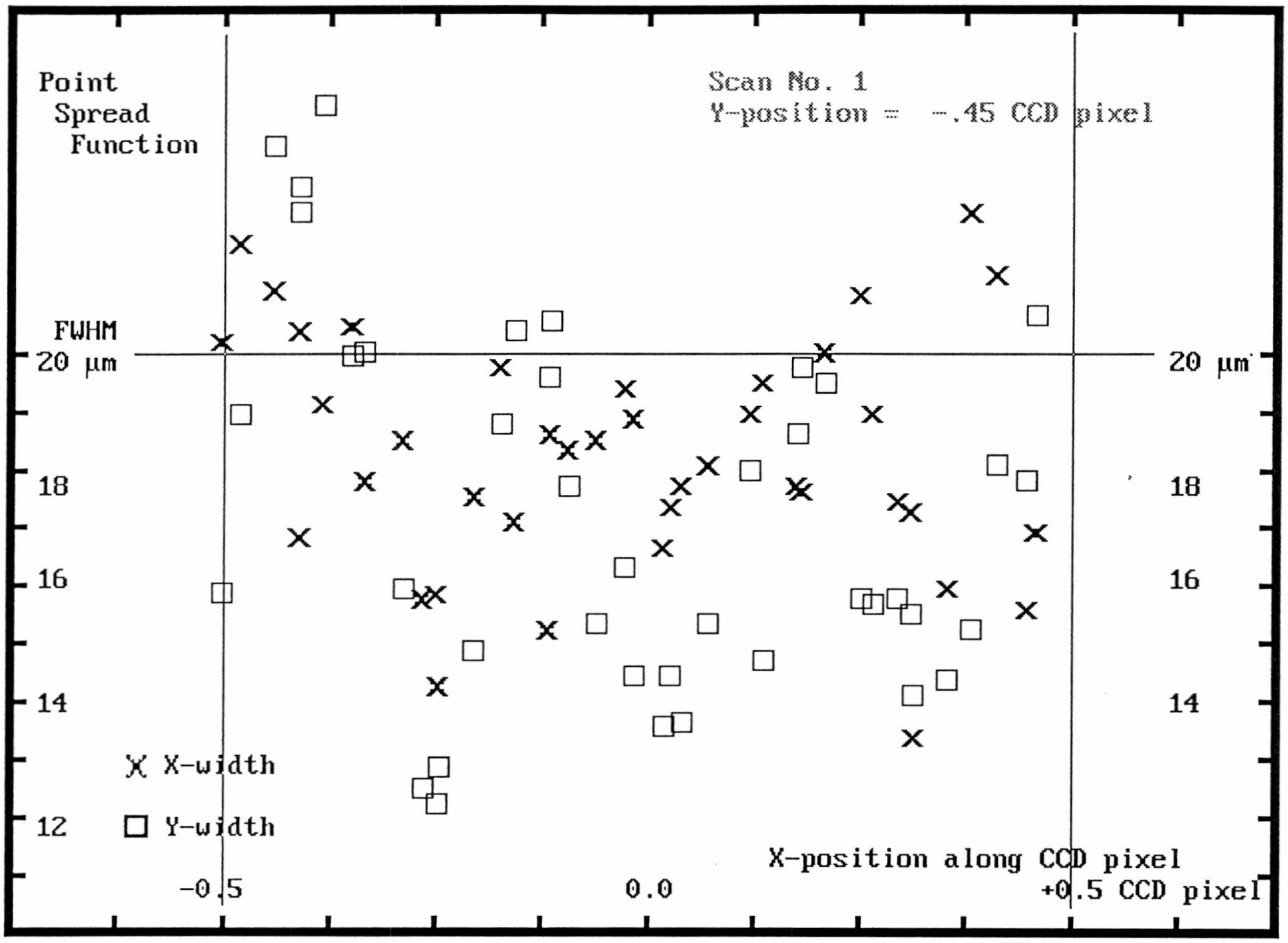


Fig. 7a Y-boundary

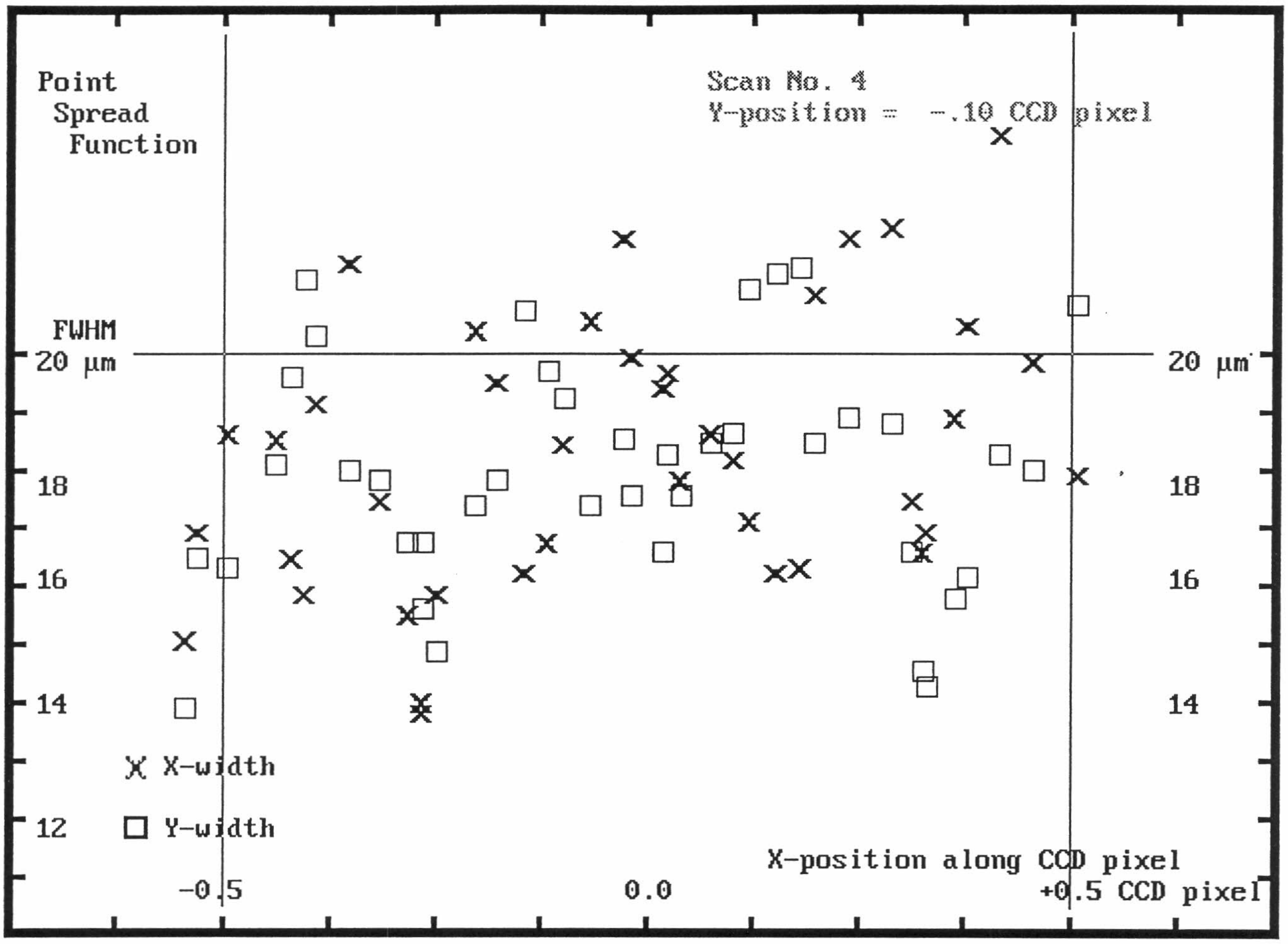


Fig. 7b Y-centre

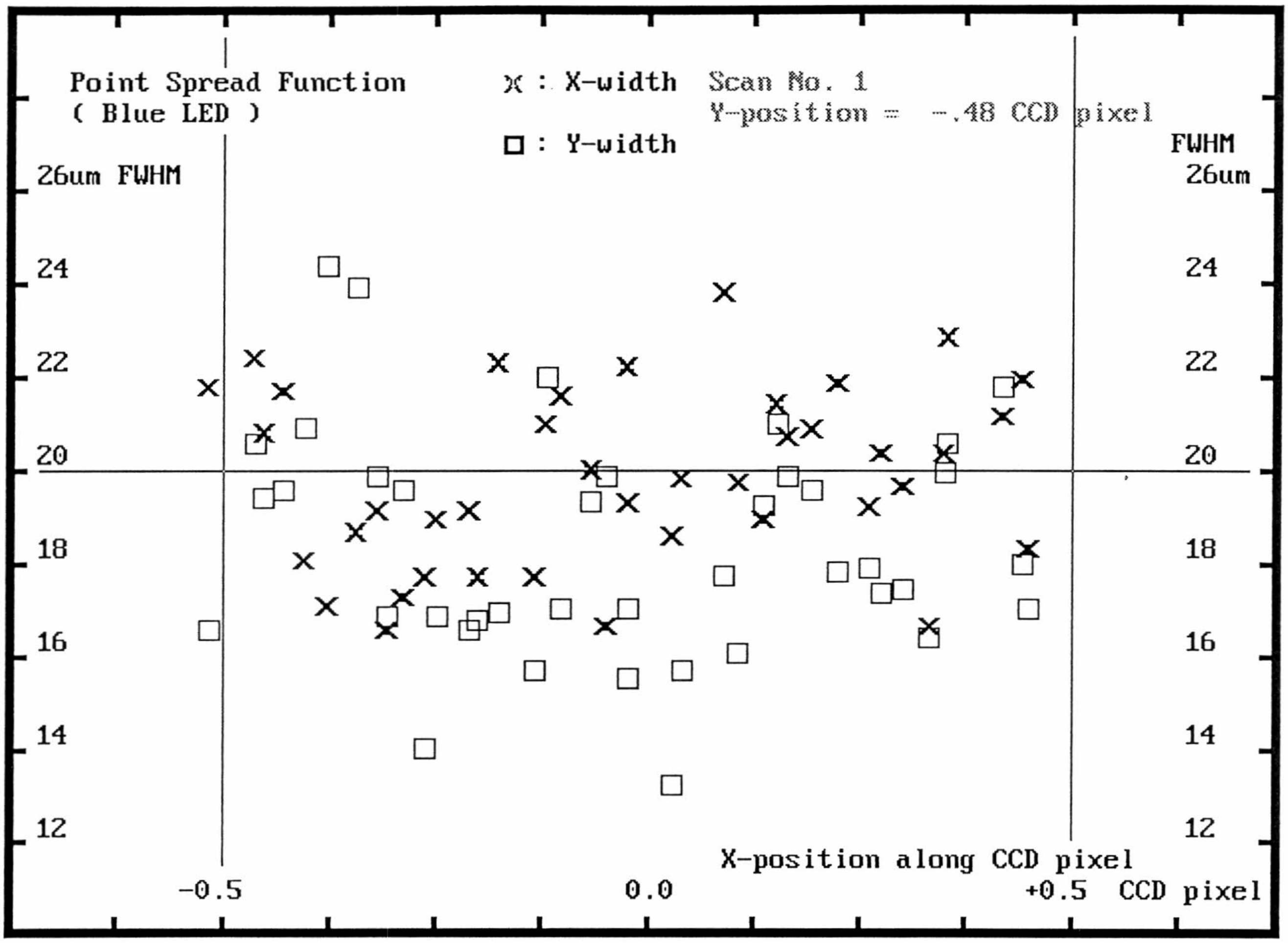


Fig. 8a Y-boundary

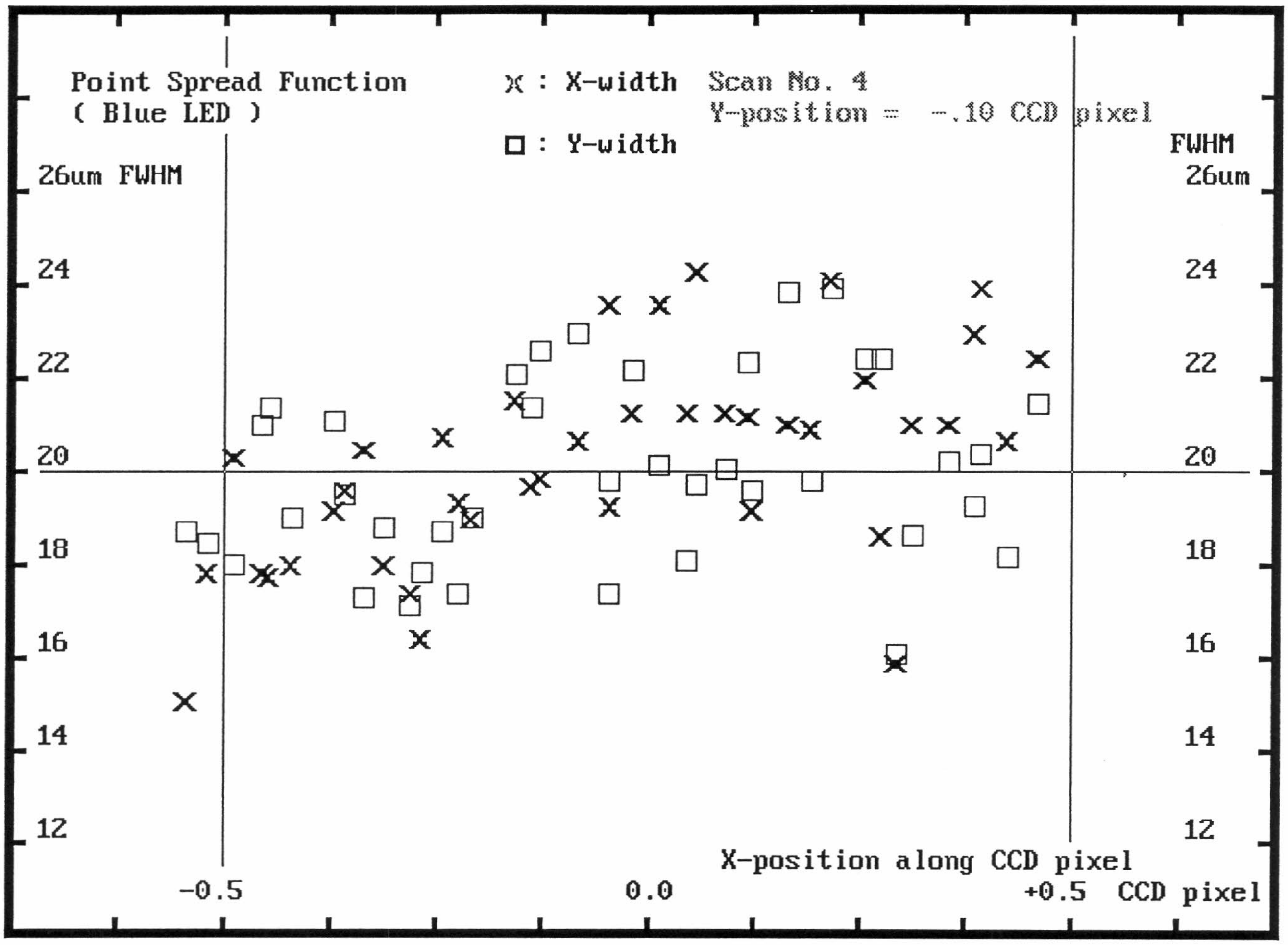


Fig. 8b Y-centre

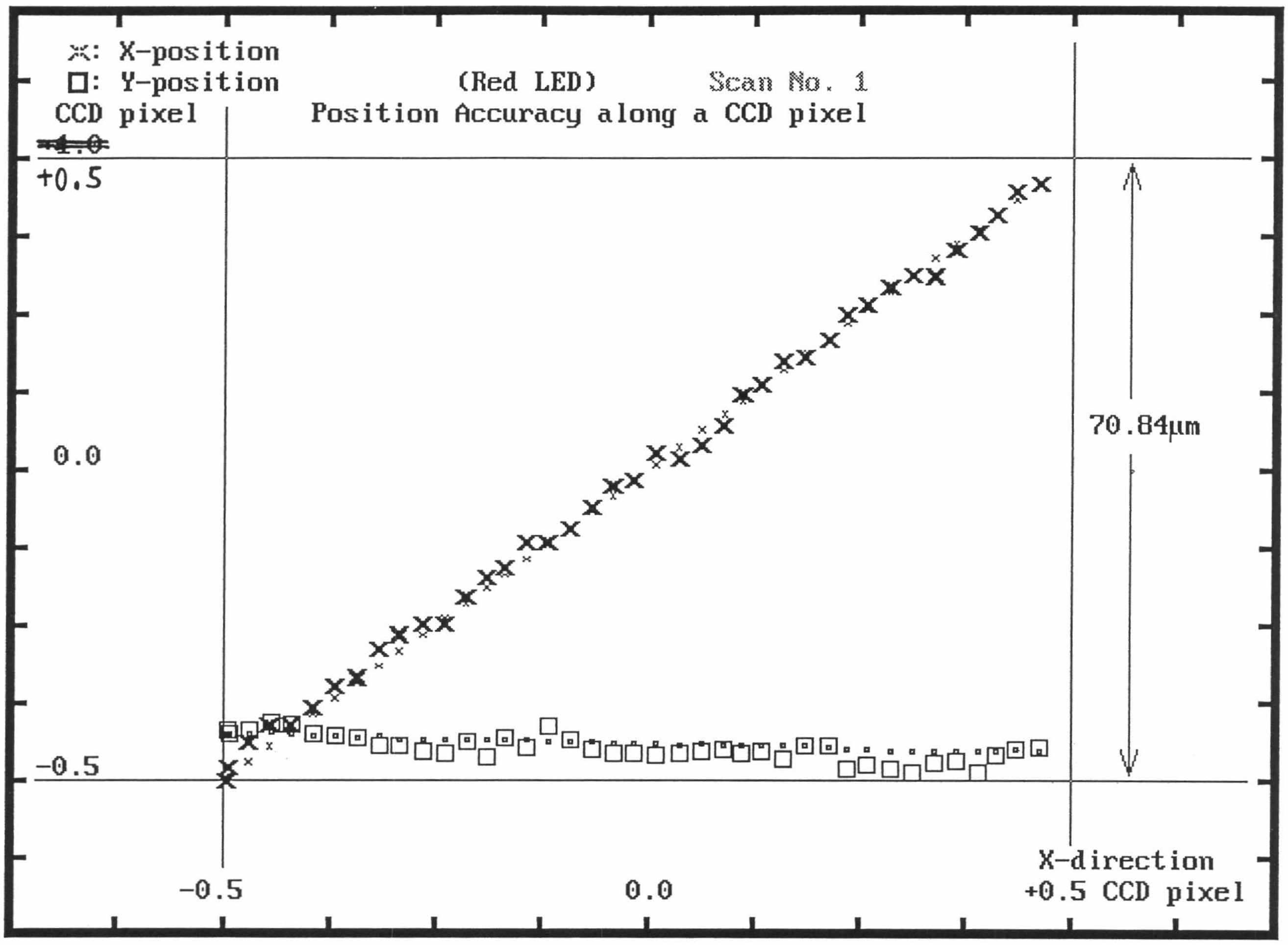

×: X-position
□: Y-position
(Red LED)
Scan No. 1
CCD pixel
Position Accuracy along a CCD pixel
+1.0
+0.5
0.0
-0.5
70.84µm
-0.5
0.0
X-direction
+0.5 CCD pixel

Fig. 9

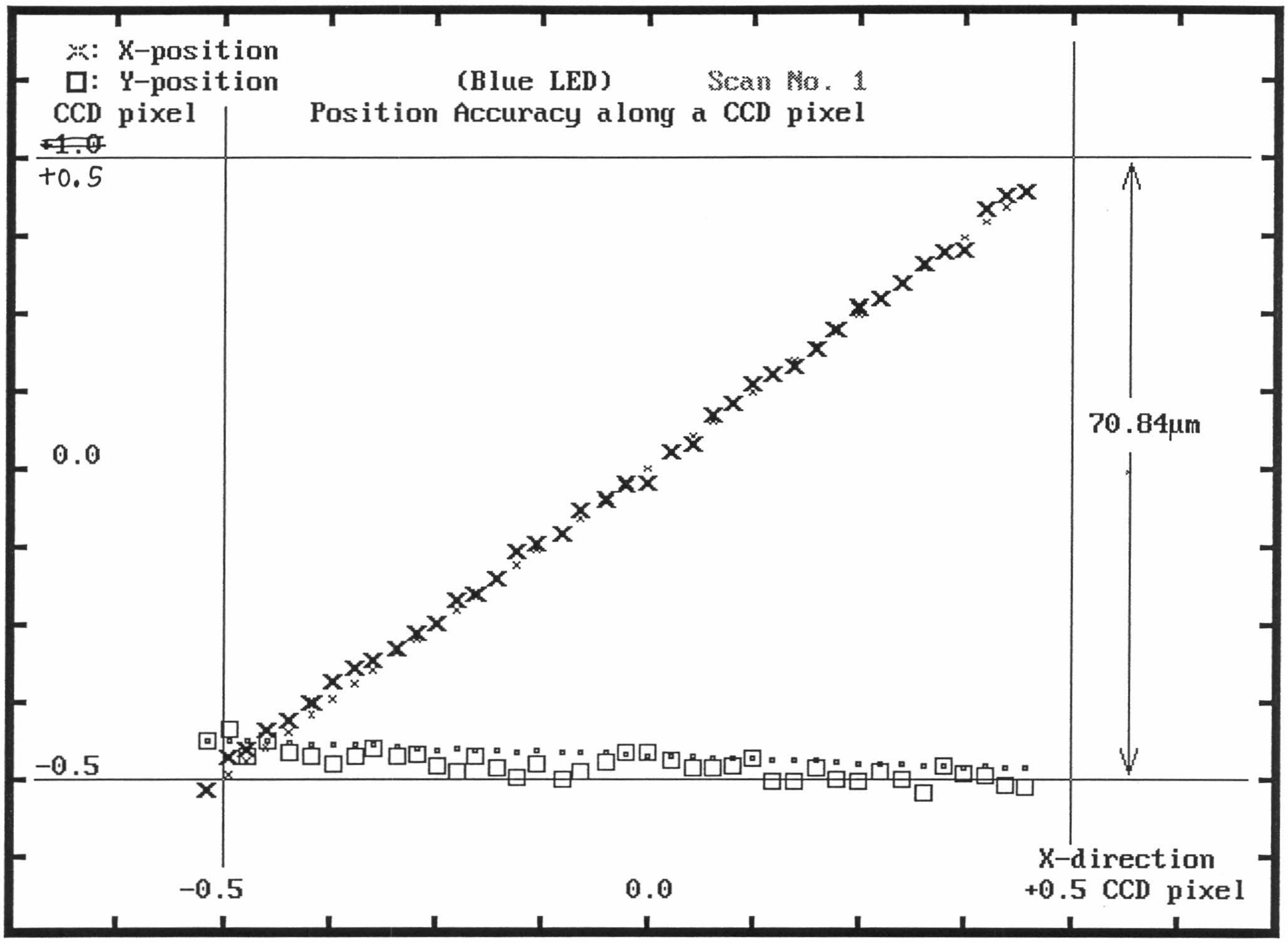

✕: X-position
□: Y-position
(Blue LED)
Scan No. 1
CCD pixel
Position Accuracy along a CCD pixel
+1.0
+0.5
0.0
-0.5
70.84μm
-0.5
0.0
X-direction
+0.5 CCD pixel

Fig. 10

PHD from all subpixel positions at detector centre

Fig. 11

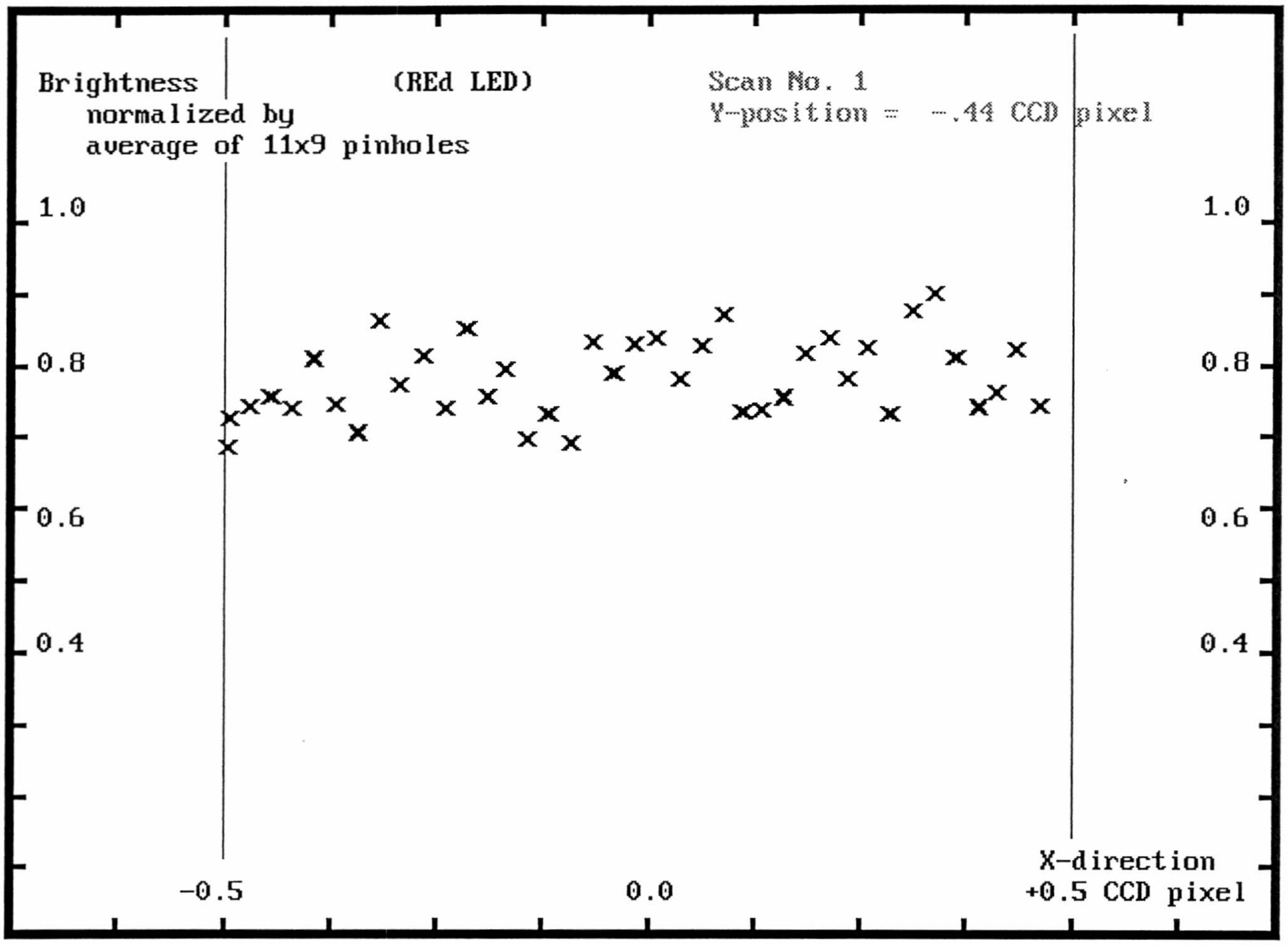


Fig. 12a Y-boundary

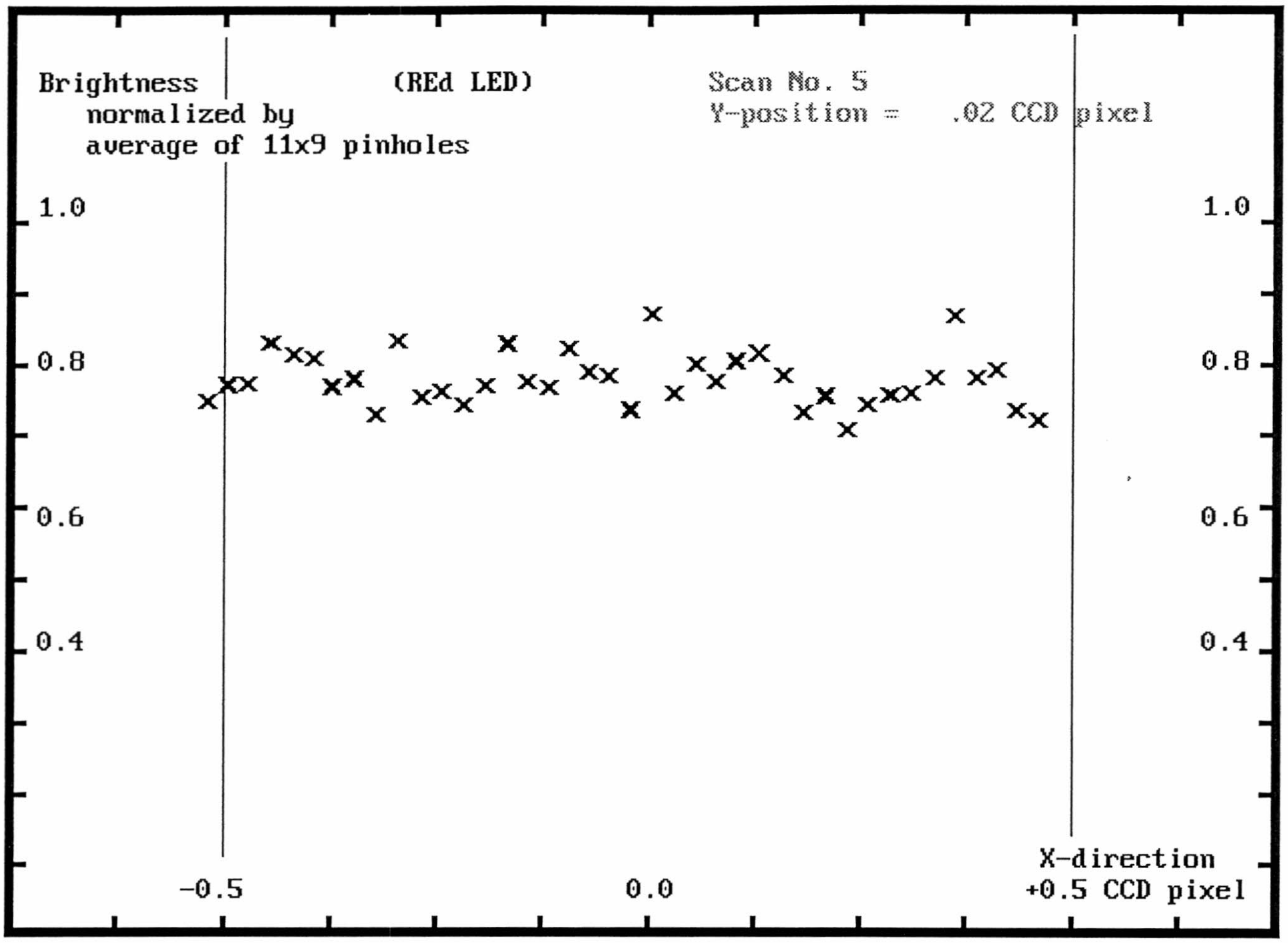


Fig. 12b Y- centre

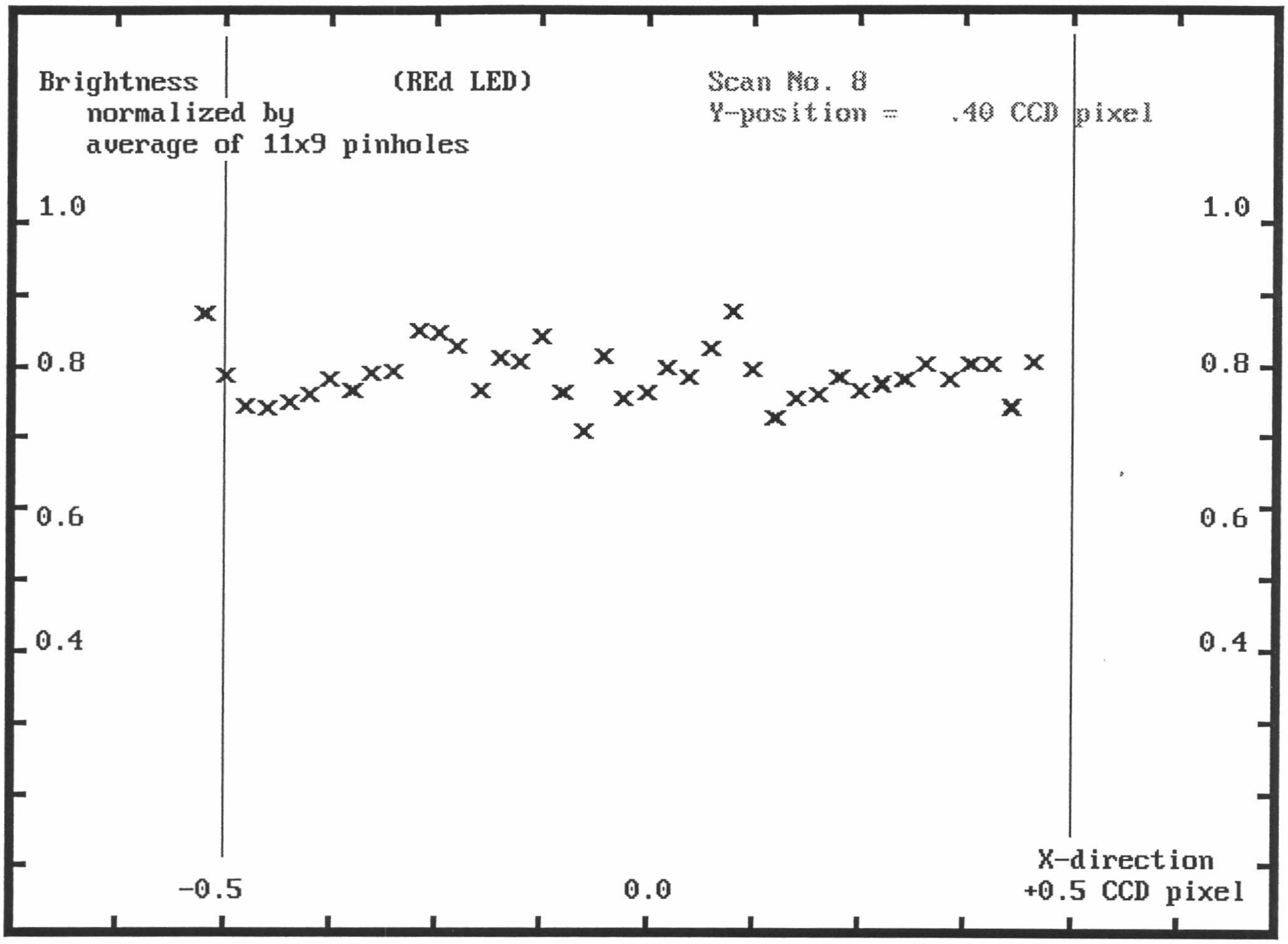


Fig 12c Y- boundary

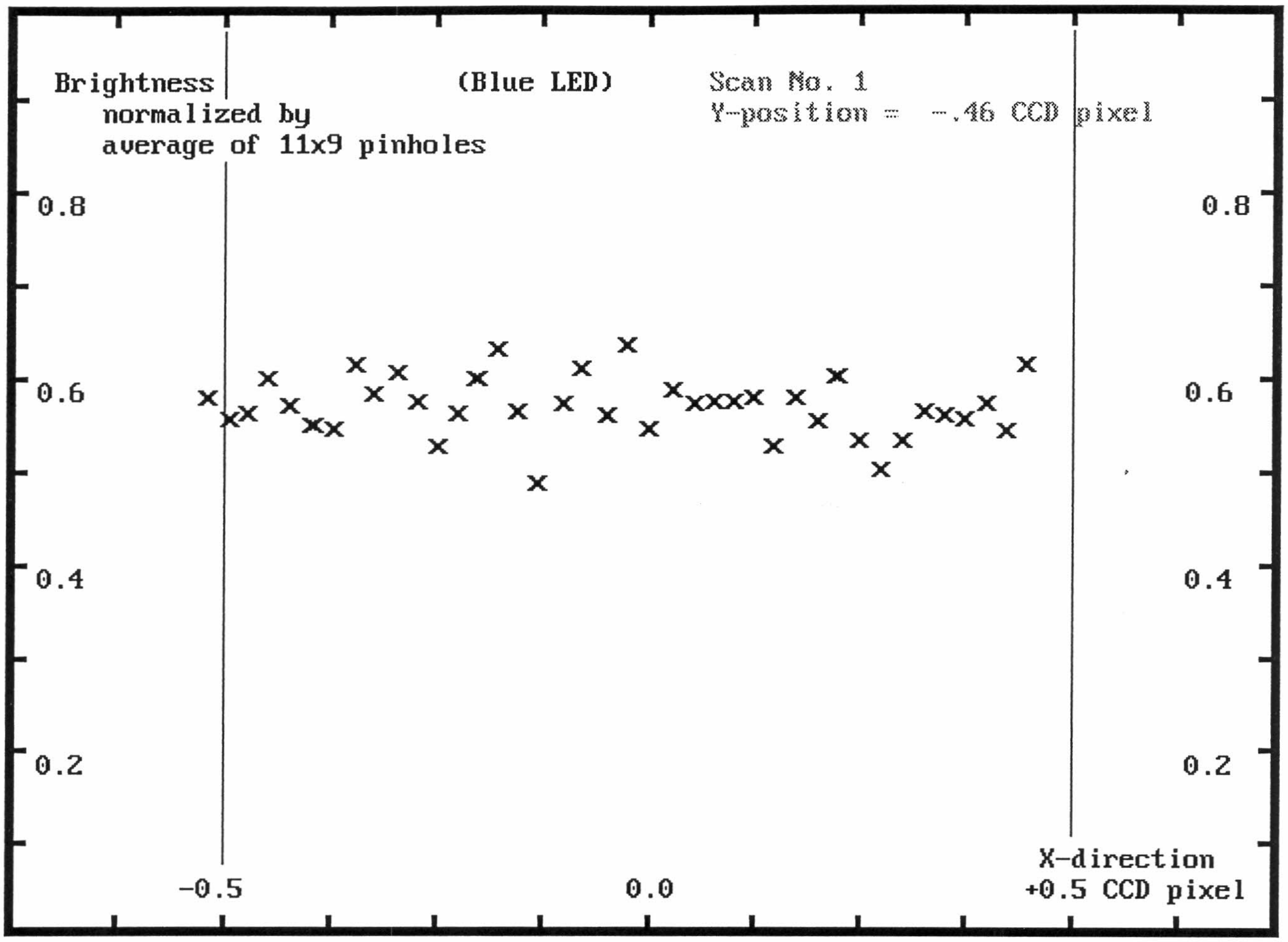


Fig. 13a Y-boundary

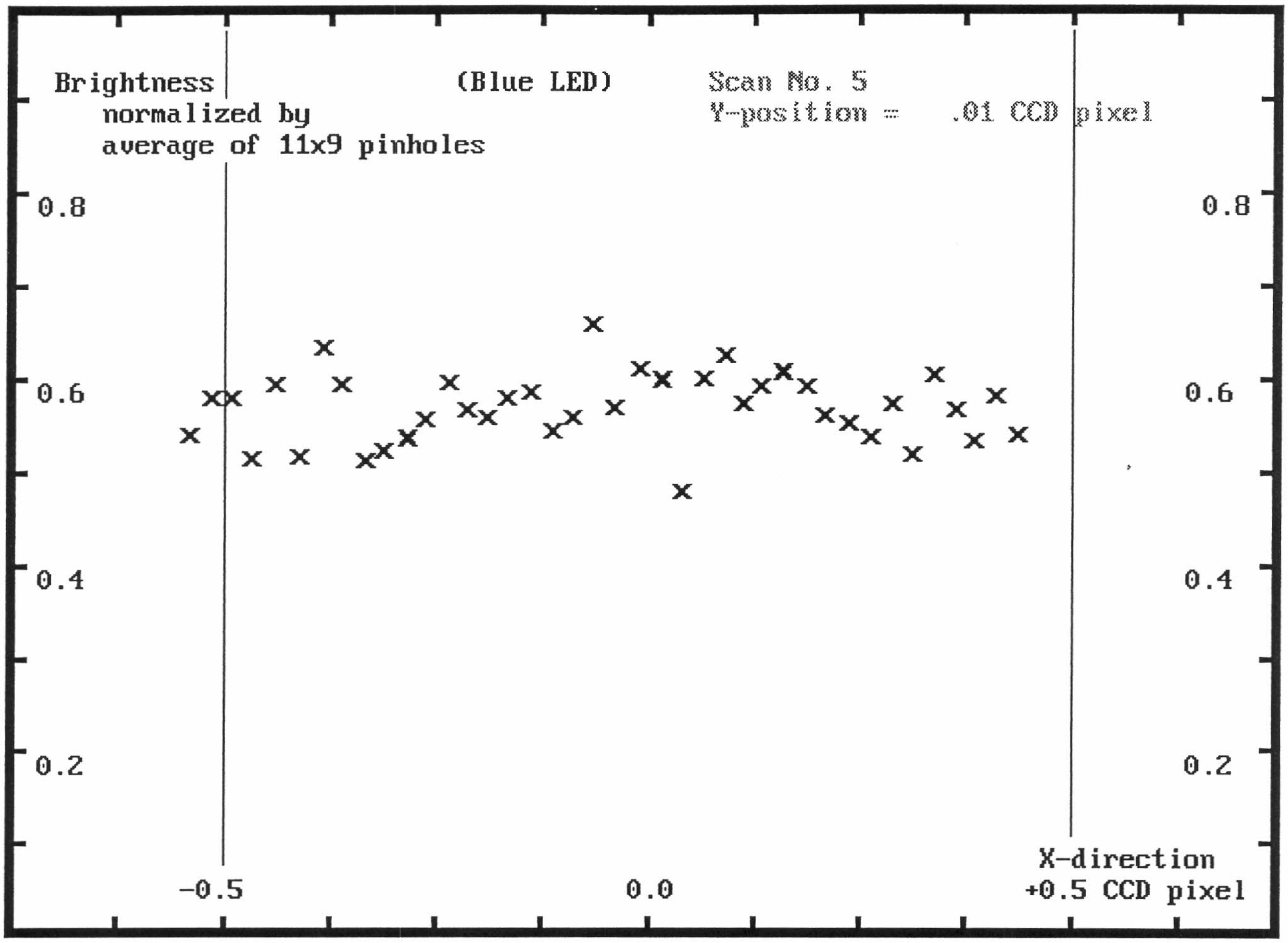


Fig. 13b   Y-centre

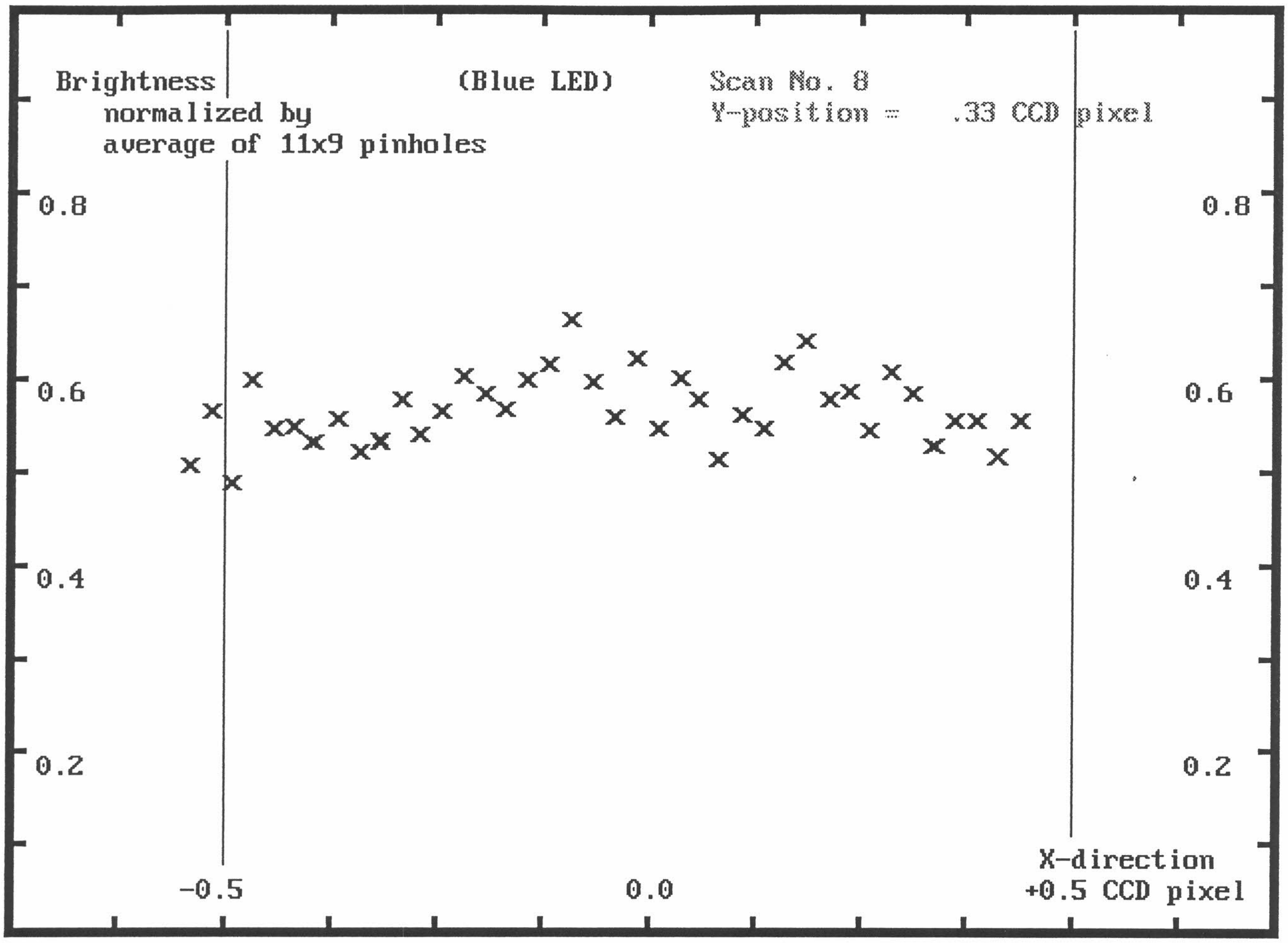


Fig. 13c Y- boundary