Solar-B **EIS** * EUV Imaging Spectrometer	Potential charge spreading in the Solar-B EIS CCDs -initial discussion

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1 Introduction

The EUV Imaging Spectrometer (EIS) is a component of the Solar-B satellite, due for launch in August 2004 and the camera head detector for EIS will comprise a number of EEV 42 series CCDs. The nominal plate scale of the EIS telescope is 13.5µm, to match with the pixel size of the 42 detector (which is 13.5µm by 13.5µm).

The low count rates commonly encountered in spectroscopic applications (due to image dispersion) require the Quantum Efficiency (QE) of the CCDs to be as high as possible. However, at EUV wavelengths, the absorption depth in silicon is very small. Therefore, in the conventional operation of CCDs, in which the incoming light falls onto the front side of the CCD, a very large proportion of the photons (about 80%) will be absorbed within the gate structure of the CCD and hence will not be detected by the CCD.

There are a number of CCD fabrication methods adopted to minimise the effect of this absorption and hence increase the number of photons detected. For example, the virtual phase CCD removes the need for two of the three CCD gates using suitable implants in the silicon to create a series of potential steps, and thus confine the generated charge within the pixel. As the majority of the CCD front surface does not now need to be covered with a gate electrode, the quantum efficiency will be greatly improved.

A second way of maximising the QE is to use the back side of the CCD to detect the incoming photons. This backside is then thinned down to within a few microns of the depletion depth. As this depth is similar to the photon absorption depth, the QE is dramatically increased. However, as a consequence of the back-illuminated mode of operation, the effective resolution of each pixel may be decreased.

The reason for this potential lowering of resolution is shown in figure one, which shows (in a very simplified way) the physical structure of a backthinned CCD. Initially, there is a small accumulation layer at the backside surface, heavily p+ doped; then a (field free) undepeleted region; a depleted region; and the "pixels" themselves (i.e the potential wells within the Silicon). Unfortunately, it is not possible to completely thin the backside region right up to the depletion region as is it not possible to calculate exactly the dimensions of the depletion depth. In addition, even if it were possible to thin the depletion region completely, the depletion region would now come into contact with the backside surface of the CCD, and would be exposed to a vastly increased dark signal from electrons generated in the backside surface states.

Consequently, any photon-induced electrons will have to diffuse through the field free region before being collected in a potential well. During the diffusion through the field free region, there will be expansion of the charge cloud. This expansion is sufficient that some of the charge which would be collected in the illuminated "pixel" will in fact be collected in adjacent pixels. In addition, the Silicon itself will be arbitrarily divided into pixel boundaries which will have the effect of splitting some charge packets (depending on their position) into a number of adjacent pixels.

This charge spreading can lead to an effective reduction in the CCD resolution, is highly dependent on the absorption depths in Silicon at the relevant wavelengths, and can be significant (For example, it could be over 50% at the wavelengths we are interested in).

2 The effect of charge spreading on the EEV CCDs

Definition of charge spreading

The effect of charge spreading can be defined by calculating the Mean Charge Capture (MCC) coefficient. The MCC factor defines the percentage of the charge that is captured in the pixel of interest. The remainder of this charge appears in the electronic image of surrounding pixels. Thus, the higher the MCC, the more charge will occur in a single pixel. MCC itself is signal dependent as the presence of electrons within the potential well will modify the structure of the depletion region (due to charge compensation). Consequently, as the signal level increases, the size of the depletion depth will decrease and hence the size of the field free region will increase. For a device detecting smaller signals (i.e substantially less than full well) the effect of the MCC on the Point Spread Function (PSF) is more-or-less constant over a range of signal strengths.

Modelling of charge spreading

A number of simulations exist which can be used for calculating the effect of charge spreading. The simplest simulations assume a uniformly illuminated CCD and calculate the MCC by using geometrical relationships of the depletion depth to the pixel pitch. More detailed models exist which model the shape and the subsequent diffusion of the charge cloud. For example, Leisa Townsley (Penn State University) models the device as a number of "slabs" with the propagation through each slab dependent on the properties of that layer.

Generally however, either method produces similar results unless detailed predictions need to made. For example, the presence of a channel stop will make the MCC a bit asymmetric and is not included in the simple flat field simulations. However, there is only a small difference between the results using this method and those using more detailed simulations.

The effect of charge spreading on the MTF

Figure two shows the variation in the MTF (a combination of geometric and diffusion MTFs) with depletion depth and pixel size. This figure is only valid for absorption of photons very near the backsurface (for the EIS CCDs, the absorption depth is about 0.3-0.5μm and so this figure should be reasonably applicable). For the EEV 42-10s, the pixel size is 13.5μm, and the depletion depth is typically between 3 and 4µm, yielding a ratio of between 0.22 and 0.3. Thus, the appropriate MTF corresponding to the appropriate normalised spatial frequency can be found. For example, at the Nyquist limit, the MTF due to charge spreading is expected to be about 50%.

No actual simulations have yet been run using EIS CCD data to estimate the MCC that would be expected for 42-10s. However, results seen by the author for other projects suggest that we can anticipate an MCC of between 0.35 and 0.45. An MCC factor of 45% would produce the following charge distribution matrix in the CCD pixels:

4.25	9.5	4.25
9.5	45	9.5
4.25	9.5	4.25

The resultant profile between pixels is shown in figure three.

Measurement of Charge Spreading

Charge spreading is usually measured using an Fe55 source. Providing the intensity of the source is low, then the probability is high that any event registered in a CCD pixel will come from only one gamma ray. Consequently, charge measured in a group of pixels can be assumed to be as a result of a single charge spreading event. By varying the voltage on the integrating electrode phases, it should be possible to vary the depth of the depletion layer, and hence simulate the effect of different well depths (as the depletion depth will be minimum at full well).

3 Mitigation of potential charge spreading effects

Charge spreading is related to the device geometry (i.e the pixel size width compared to the depth of Silicon substrate) and also to the device structure such as resistivity. Consequently, it is possible to some extent to tailor the design of the CCD to minimise charge spreading.

For example, possible approaches include:

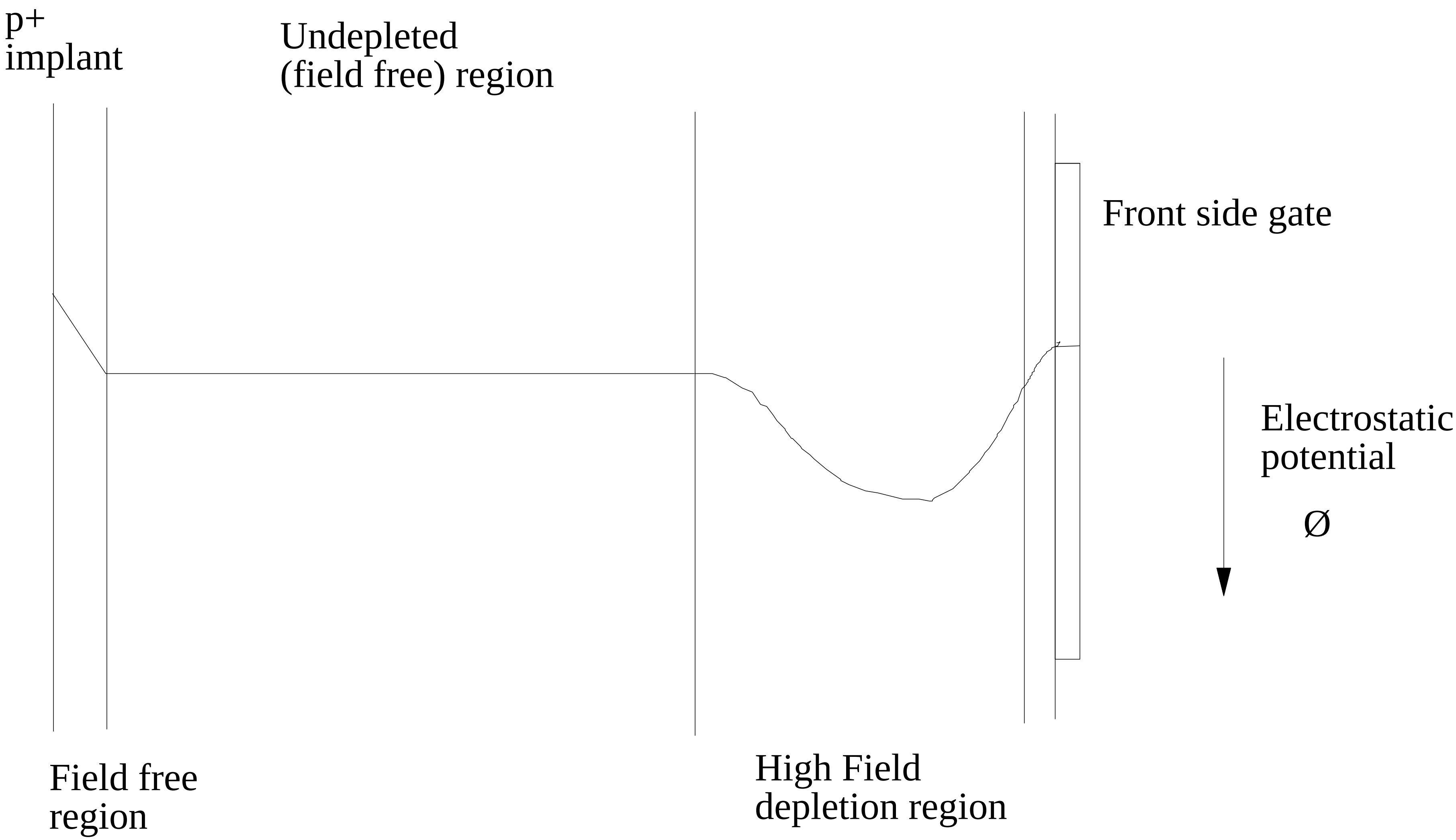
- limiting the field free region by thinning closer to the depletion depth - this may present yield problems;
- by using a lower resistivity silicon so that the device can be thinned nearer to the depletion depth - this could increase the device’s potential susceptibility to radiation due to greater penetration of ionising radiation through the Silicon.

Initial discussions with EEV suggest that a 20 ohm/cm device may be most applicable to minimise charge spreading. However, this choice was made assuming that the majority of signals detected would be well below full well, and further information will be required before a firm decision can be made.

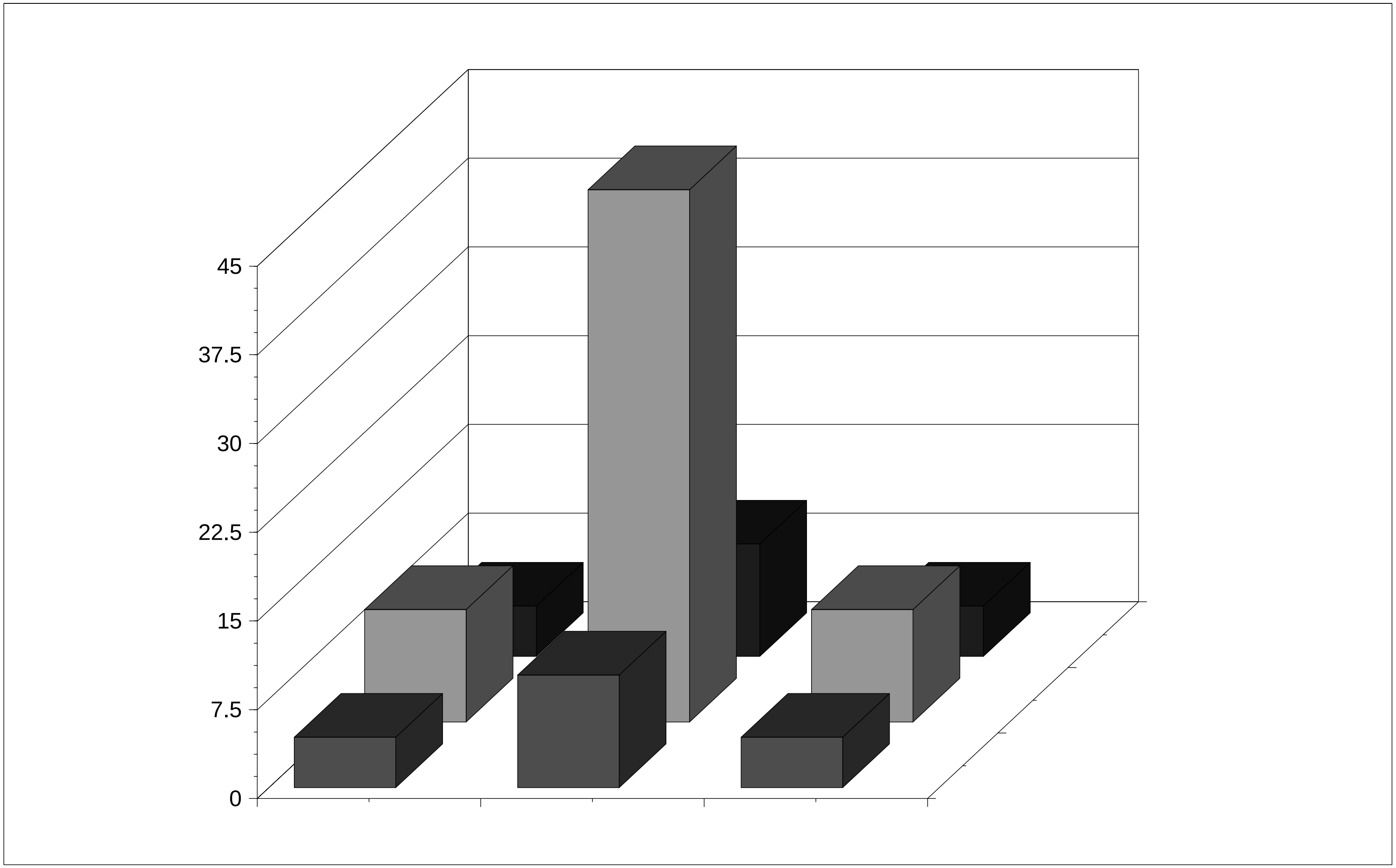
4 Further research

Further research will be required:

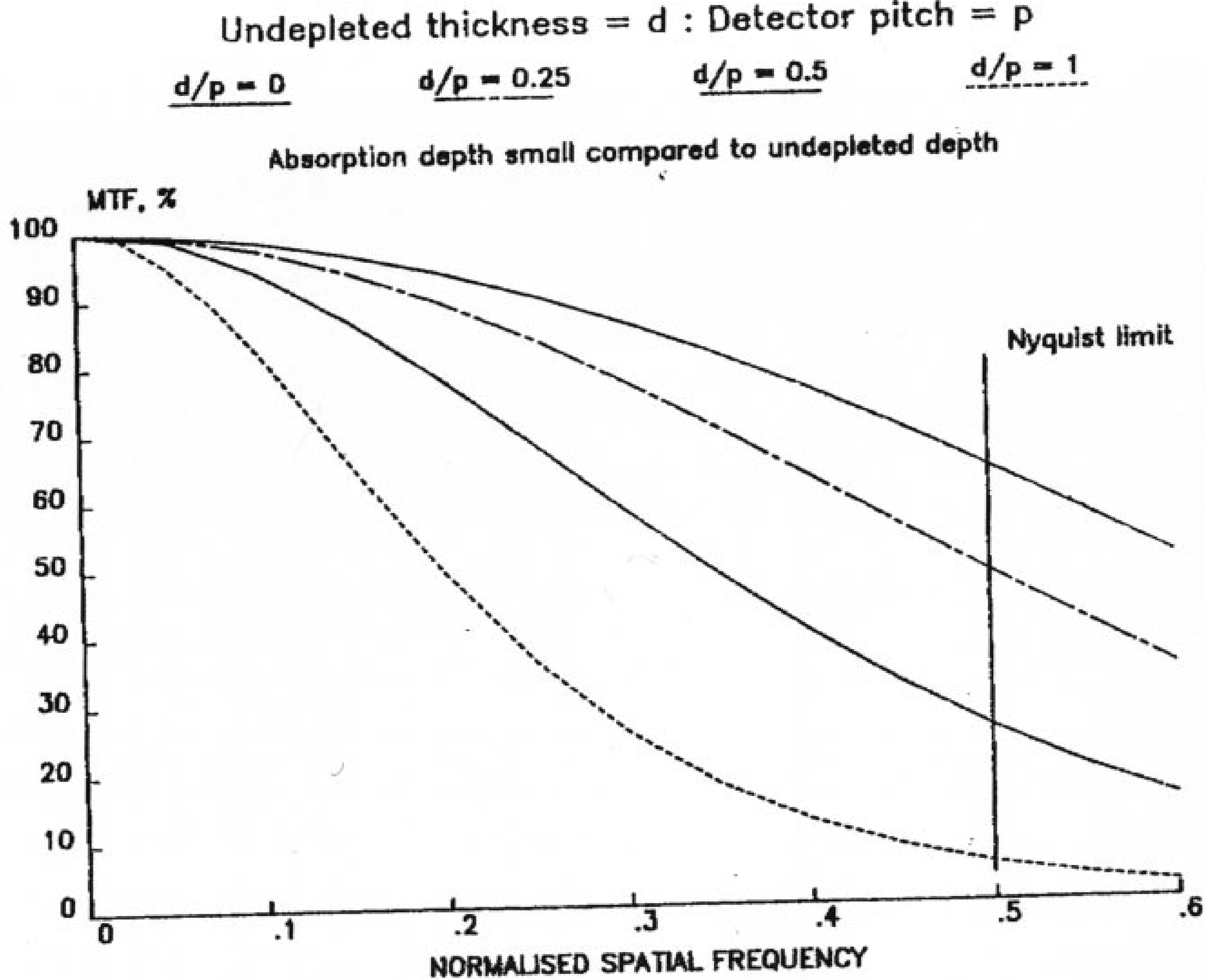
- to gain a better understanding of the effect of charge spreading on the EIS CCDs, it will be necessary to simulate the effect of charge spreading using the actual CCD parameters. This value can they be used to calculate a PSF for the spectrometer;
- further discussion is necessary with EEV to identify the most appropriate device structure to minimise charge spreading given the number of photons likely to be detected per exposure;
- the detailed relationship between MCC and the PSF needs to be investigated so that we can be more confident in estimating the potential loss of resolution due to charge splitting.



A simplified diagram of a back-illuminated CCD structure



The approximate distribution of charge for an MCC factor of 0.45


Undepleted thickness = d : Detector pitch = p
d/p = 0
d/p = 0.25
d/p = 0.5
d/p = 1
Absorption depth small compared to undepleted depth
MTF, %
100
90
80
70
60
50
40
30
20
10
0
Nyquist limit
0
.1
.2
.3
.4
.5
.6
NORMALISED SPATIAL FREQUENCY