

Aberration effects inherent in planar integrating detectors and their influence on imaging quality in diffraction experiments

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Diffraction experiments using coherent X-ray radiation from light sources, such as X-ray free-electron lasers (XFELs), are essential for investigating the structural and functional properties of materials at the nanoscale. These sources deliver highly coherent, high-brilliance, pulsed X-ray beams that enable the detailed study of physical, chemical and biological systems. A key requirement for such experiments is the accurate detection of diffraction patterns. For this purpose, large-area planar integrating pixel detectors with a high dynamic range across the full q -range are typically employed.

This simulation study investigates how aberration and charge-sharing effects inherent to a planar detector with a 500 μm -thick silicon sensor affect the achievable spatial resolution and image quality across a range of pixel sizes (from 50 $\mu\text{m} \times 50 \mu\text{m}$ to 200 $\mu\text{m} \times 200 \mu\text{m}$). We characterize and quantify these effects using our generalized point spread function (PSF) model [1, 2], which describes the spatial distribution of detected photon signals as a function of photon energy and diffraction angle.

We also analyze the effect of the PSF on the achievable signal-to-noise ratio, considering its dependence on photon energy, angle of incidence or equivalent q , image contrast and spatial resolution. Spatial resolution is assessed quantitatively through the modulation transfer function (MTF), providing a comprehensive understanding of detector performance under varying experimental conditions. Our study provides valuable insights into the design and optimization of future detector systems, particularly in terms of achieving maximum contrast, signal-to-noise and position resolution in high-resolution diffraction experiments.

[1] Kuster, M., Hartmann, R., Hauf, S et al. (2024) *On the Influence of Parallax Effects in Thick Silicon Sensors in Coherent Diffraction Imaging*, In Journal of Physics – Conference Series (JPCS), arXiv:2410.14474, accepted for publication, in press

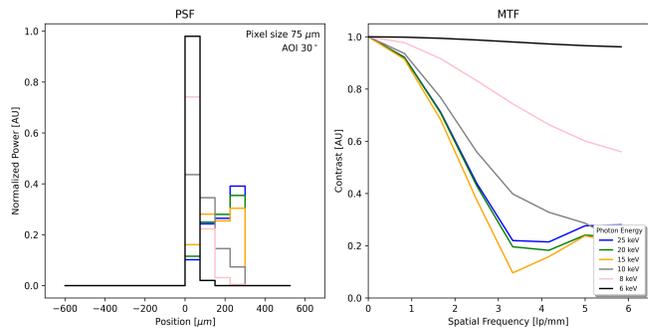


Figure 1. Exemplary point spread function (left) and corresponding modulation transfer function (right) for a planar detector with a pixel size of 75 $\mu\text{m} \times 75 \mu\text{m}$, shown as a function of X-ray photon energy at an incidence angle of 30°. The results illustrate how the shape of the PSF affects the measured spatial signal distribution, signal contrast, and consequently the position resolution.