Charge Sharing Corrections for a Photon-Counting Detector (PCD) and its Impact on PCD-CT

James Day, PhD[1]; Kris Iniewski, PhD[2]; Alison Deng, PhD[1]; Magdalena Bazalova-Carter, PhD[1]
[1]University of Victoria, [2]Redlen Technologies

MEDICAL PHYSICS COMMUNITY · INSPIRATION · INNOVATION · IMPACT
2026 JULY 19–22 VANCOUVER, BC
JOINT AAPM | COMP MEETING

UVIC CITE

ABSTRACT

Purpose:
To compare digital coincidence detection (DCD) with analog charge summation (ACS) for a cadmium zinc telluride (CZT) photon counting detector (PCD) and evaluate the impact on spatial resolution in PCD computed tomography (CT) as a function of imaging beam energy.

Methods:
A CZT PCD with 330 µm pixels, equipped with DCD and ACS, and six energy bins was used with a 120 kVp x-ray source. Charge-sharing effects were quantified by acquiring PCD-CT images of a spatial resolution piece featuring 0.25 mm-1 mm hole patterns on a tabletop system. The thresholds were set at 25, 33, 41, 50, 59, and 68 keV, first balancing the number of counts in each bin without additional filtration. To simulate the human body, 0-25cm of acrylic slabs at an air gap of 64cm were added, with the tube current increasing proportionally. Spatial resolution was quantified using the modulation transfer function (MTF) for DCD and ACS.

Results:
Bins 3 and 4 were omitted from the study because of a 50% and 100% discrepancy in MTF in comparison to the other bins for the same energy thresholds. Overall, both DCD and ACS experienced up to a 25% loss in MTF as attenuation increased to 25cm of acrylic. Without additional filtration, the MTF trends were consistent between DCD and ACS, with the MTF decreasing with energy. With thicker filtration, DCD showed higher MTF values at the higher spatial frequencies by 10% to 20% for energy bin 1 where charge sharing is more prominent. Additionally, the overall spatial resolution for all energies was maintained between DCD and ACS.

Conclusions:
Both ACS and DCD are comparable in MTF and spatial resolution across most energy bins. However, DCD shows a distinct advantage in higher-flux environments, maintaining 87.5% of the ideal count rate at maximum tube current, whereas ACS maintains only 23.4%.

CONTACT

James Day
University of Victoria
3800 Finnerty Rd
jamesday@uvic.ca

INTRODUCTION

Charge sharing is a well-characterized limitation of photon-counting detectors (PCD), arising when the charge cloud from a single interaction spreads across multiple pixels and divides the deposited energy among multiple pixels. The fragmented signal degrades both spectral and spatial resolution, particularly in detectors with small pixels where the charge cloud width is more comparable in size.

Real-time correction strategies such as analog charge summation (ACS) and digital count summation (DCD) use coincident information to combine signals from adjacent pixels into one. This is done by either summing adjacent pulse heights or by aggregating digitized energy window outputs. Although effective, both ACS and DCS do this at the expense of detector performance, raising the dead times from 15 to 25 ns up to 140ns for ACS and 210 ns for DCS.[1]

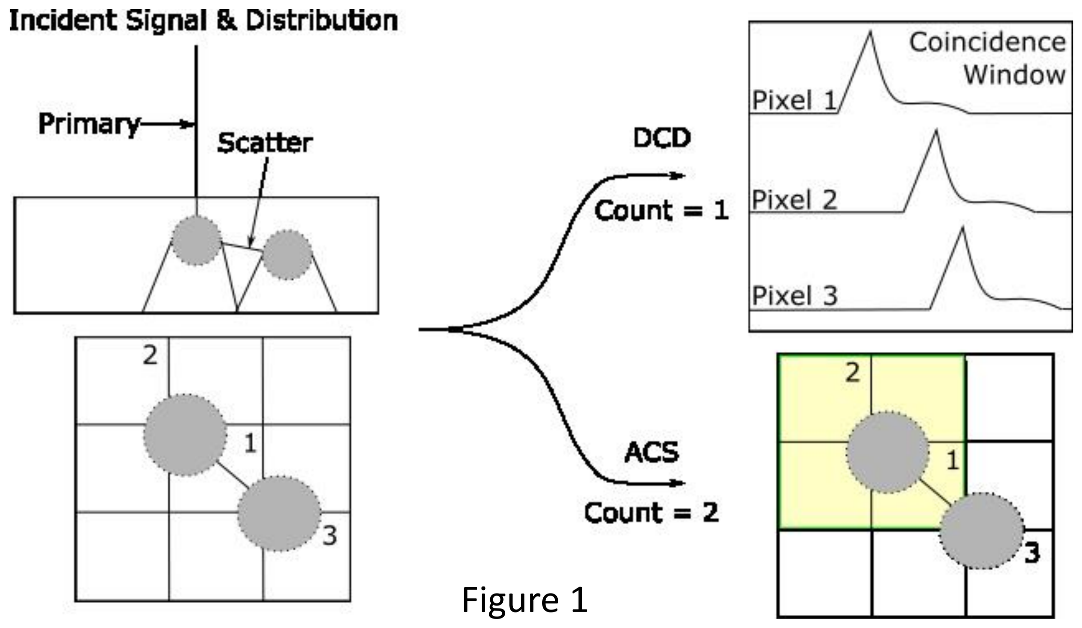

Figure 1

More recent archetypes, such as Fujifilm's multi-energy inter-pixel coincidence counters, record coincident information without modifying the primary count stream, enabling charge-sharing characterization with a dead time of around 20 ns. Redlen recently added a similar correction method to their detectors using a digital coincident detection (DCD) method.

A Redlen prototype detector [2] was acquired by our group for scientific exploration. This detector, while not equipped with single-pixel detection, was properly equipped with both ACS and the new DCD logic.

Impact/innovation: The choice of charge-correction logic affects the detector's resolution and may improve performance depending on the application. This study compares the detector's performance between ACS and DCD.

MATERIALS & METHODS

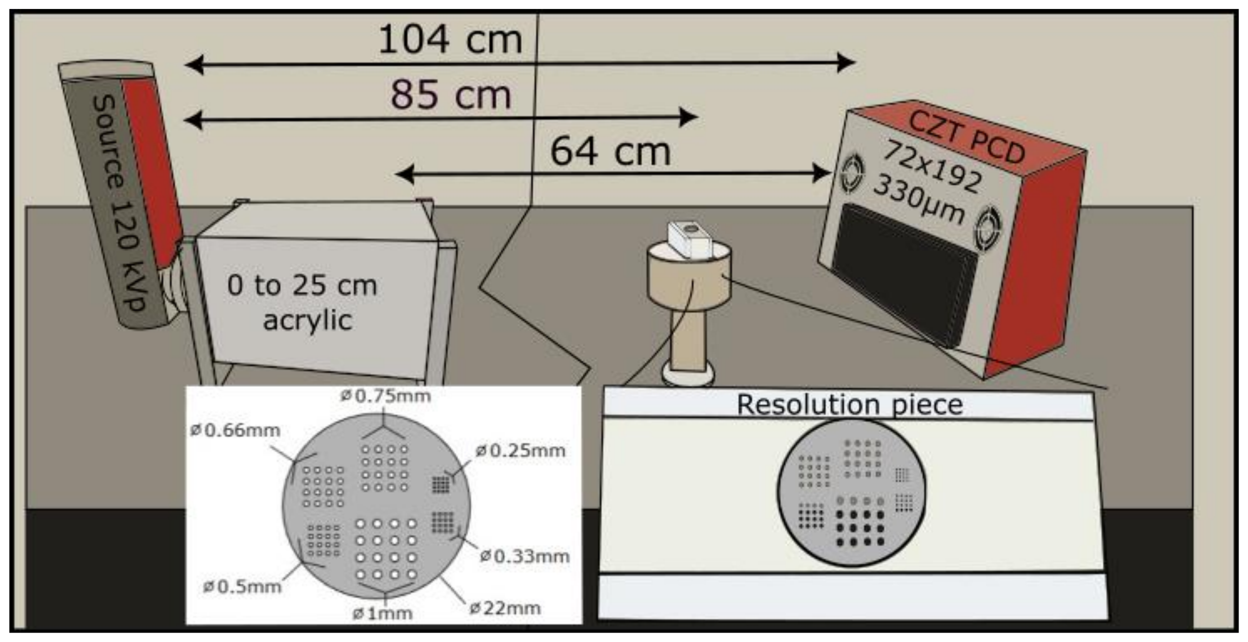

FIGURE 2: This setup is used to measure spatial resolution. The resolution piece was placed on a block of Styrofoam and leveled to be parallel to the incoming X-ray source and centered with the detector, with a slight vertical offset to avoid the center ASIC boundary.

The modulation transfer function was measured as: [3]

$$TF(\omega) = \frac{\pi\sqrt{2}M(\omega)}{4M_0}$$

Where

$$M(\omega) = \sqrt{M'^2 - N_{ac}^2}; \quad M_0 = \frac{|CT_{ac} - CT_{air}|}{16}\pi\sqrt{\frac{16}{\pi} - 1}$$

Variables
M' is the standard deviation of the region
N_{ac} is the standard deviation of an acrylic-only area
M_0 is the expected voxel ratio of holes to acrylic
CT_{ac}& CT_{air} are the respective CT values of acrylic and air

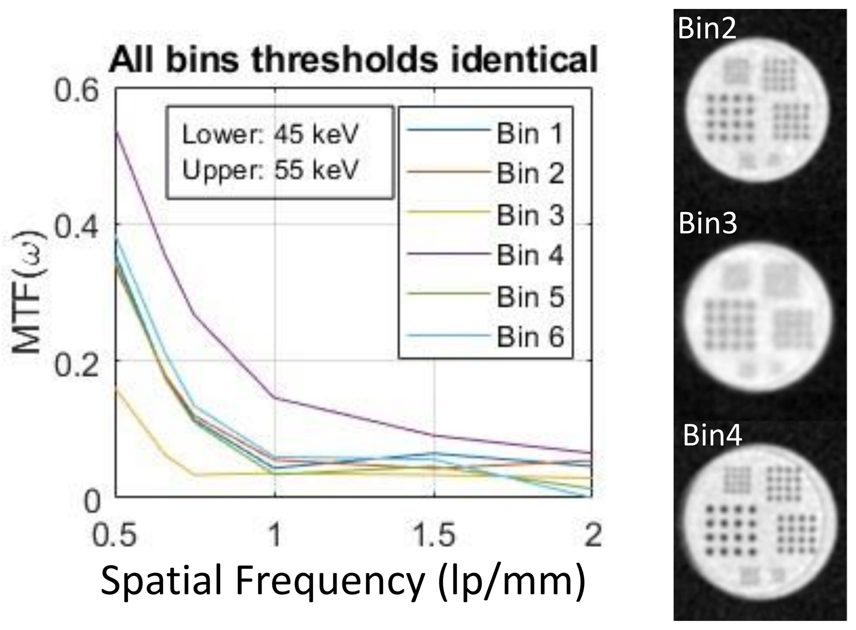

FIGURE 3: Spatial resolution comparison between ASIC bins revealed inconsistencies in performance.

Bins 3 and 4 were under- and overperforming, as visualized in the photos on the left. These bins were thus removed from the study

- g

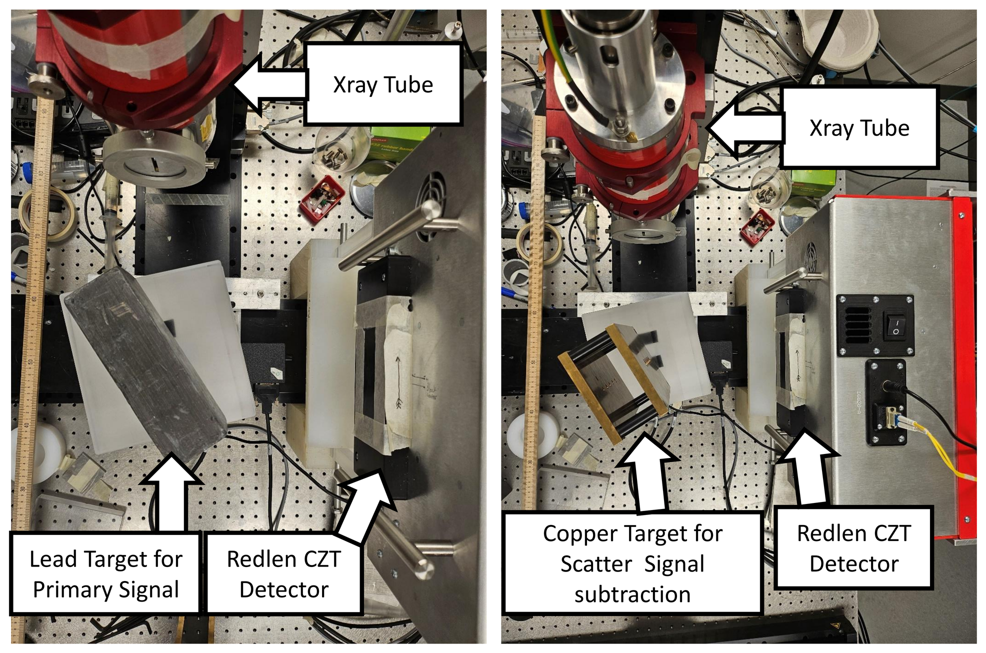

FIGURE 4: Setups for measuring the energy resolution of the detector. This can be done through a pair of threshold sweeps between materials of similar density.
The spectral sweeps were combined as:

$$Pb_{char}(E) = Pb_{sweep} - \frac{\rho_{pb}}{\rho_{Cu}}Cu_{sweep}(E)$$

This method normalizes the spectrum by removing much of the Compton component.

RESULTS & DISCUSSION

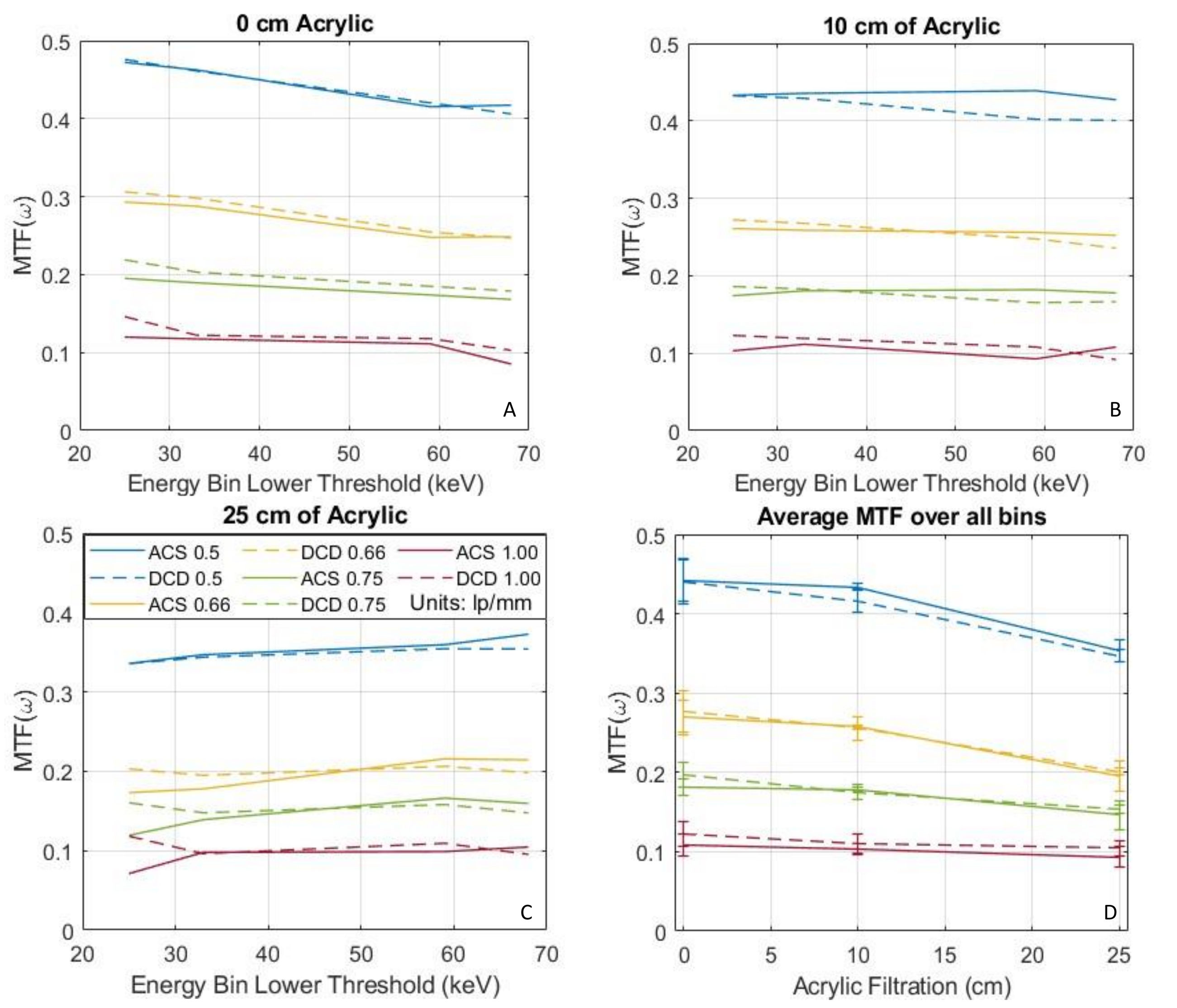

FIGURE 5: Quantification of spectral distortions observed in a PCD and the effects of different correction logic. A) At low levels of charge sharing, both logic sets behaved similarly. B) & C) For a moderately sized object, ACS still shows similar MTF values across the different energy bins, while DCD shifts the MTF towards the configuration when no object is present, but only for one of the data sets.

D) Overall, both DCD and ACS experienced up to a 25% loss in MTF as attenuation increased to 25cm of acrylic. Without additional filtration, the MTF trends were consistent between DCD and ACS, with the MTF decreasing with energy. With thicker filtration, DCD showed higher MTF values at higher spatial frequencies by 10% to 20% in low-energy bins, where charge sharing is more prominent. Additionally, the overall spatial resolution for all energies was maintained between DCD and ACS.

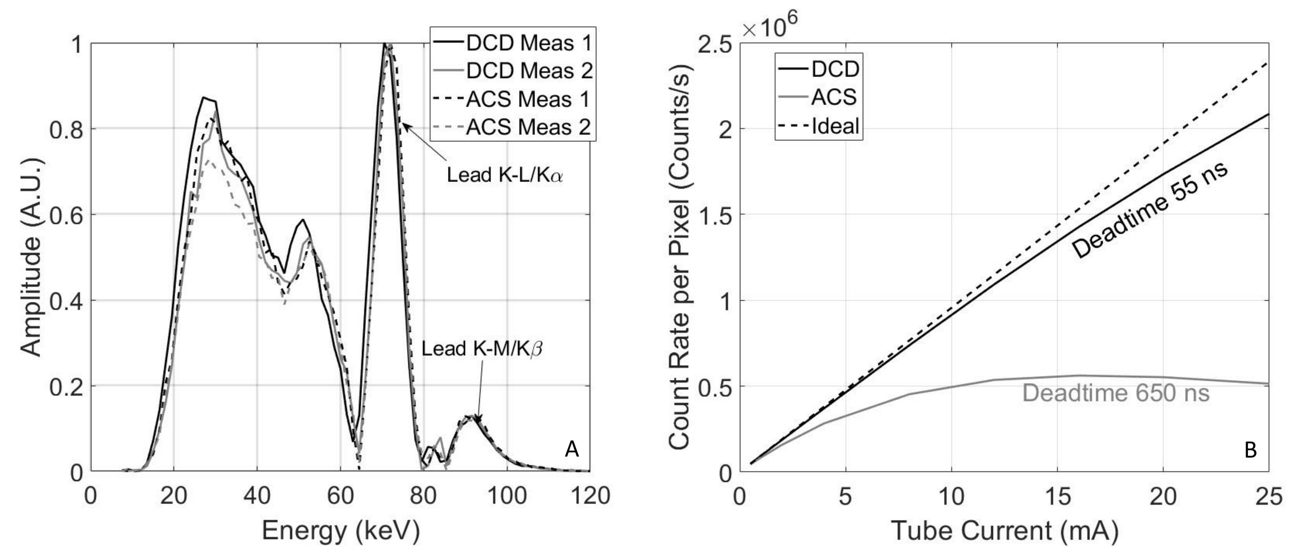

FIGURE 6: a) Both ACS and DCD also demonstrated similar energy resolution over multiple energy bins. This is evident not only in the two characteristic X-ray photo-peaks (K-L and K-M) but also in the charge-sharing tail.

b) Between the two charge correction algorithms, a remarkable difference in dead time emerges as the tube current increases from 0.5 to 25 mA at a frame rate of 10 Hz, with an 87.5% counting efficiency.

CONCLUSIONS

A direct comparison between digital coincidence detection (DCD) and analog charge summation (ACS) in the same detector system demonstrated:

Similar spatial-frequency qualities, with only minor differences between ACS and DCD at high spatial frequencies, with increased attenuation in bins containing primarily charge-sharing photons, where DCD was shown to be advantaged.

Both ACS and DCD showed similar energy resolutions, with no significant differences between them.

As counting rates increased, DCD maintained a counting efficiency of at least 87.5% while ACS was reduced to 23.5%. Overall, the DCD setting showed 1/12 of the dead time of ACS.

REFERENCES

1. Taguchi, K. et al. Assessment of multi-energy inter-pixel coincidence counters for photon-counting detectors at the presence of charge sharing and pulse pileup: A simulation study. Medical Physics. 2021; 48:4909-4925
2. Deng X, Day J, Masella O et al. Dual-Sontrast Arthrography Using Photon-Counting Detector Computed Tomography with Gadolinium and Iodine Contrast. Phys Med Biol 2026
3. Breitkreutz D et al. A 3D printed modular phantom for quality assurance of image-guided small animal irradiators: Design, imaging experiments , and Monte Carlo simulations. Medical Physics 2019; 46 (5): 2015-2024