TELEDYNE DALSA
A Teledyne Technologies Company

Application Note | Case Study | Technology Primer | **White Paper**

X-RAY IMAGING

Emerging Digital Technology - CMOS Detectors

IMAGE SENSORS | **X-RAY DETECTORS** | SCANNERS | IMAGE PROCESSING | CUSTOM SOLUTIONS

SHAD-O-BOX 1280 HS

In all domains of Medical, Dental and Scientific X-Ray imaging, the replacement of film and analog video imaging techniques with a fully digital workflow is underway.

Digital X-Ray Technology Workflow Benefits:

- increased operational efficiency resulting in higher patient comfort;
- the adoption of digital information workflow and archival infrastructure;
- opportunity for digital communication and collaboration with peers at remote sites
- advanced digital image processing capabilities;
- and lower X-Ray dose with real-time image availability

There are four primary digital X-Ray technologies in use today, these include:

Computed Radiography - uses phosphor imaging plates that are converted to digital format in a separate scanning operation (in a similar manner to traditional film-scanning) and cannot be used for real-time X-Ray imaging such as endovascular procedures.

Image Intensified CCD-cameras (II-CCD) - in which the x-ray signal is converted to electrical charges (electrons), which are multiplied and converted to visible light photons inside a high voltage glass vacuum tube. The visible light is imaged onto a CCD-camera to generate real-time images at low x-ray dose levels, e.g. to act as the surgeon's eyes during minimally invasive procedures. Although recognized for their excellent for low-dose image quality and cost-effectiveness, II-CCD cameras offer significant drawbacks in terms of physical size, inability to support challenging projections, vulnerability and shorter intervals between calibrations.

Flat Direct Detectors - Direct conversion uses either amorphous selenium (aSe), cadmium telluride (CdTe) or mercuric iodine (HgI2) layers to convert X-Ray photons directly to electrons for immediate image capture. An important drawback of selenium is the instability and mechanical vulnerability of the material over time and under normal transport temperature conditions, as well as the environmental impact during production and repair or disposal. Amorphous selenium is also suffering from 'image lag', a memory effect where information from previous images is retained during next captures, rendering the technology unsuitable for real-time imaging applications.

Flat Indirect Detectors - As the most common method, indirect detection uses scintillators (such as Gadolinium Oxides or Cesium-Iodides) to convert X-Rays to visible light. Traditionally, the light generated by the scintillator is imaged onto a CCD sensor using a bulky lens system. In modern flat-panel detectors, the scintillator output is captured by either an amorphous silicon (TFT) panel or CMOS sensor that converts the image to digital format.

Teledyne DALSA is a leader in the design and manufacture of CCD (Charge Coupled Device) and CMOS (Complementary Metal-Oxide Semiconductor) for digital medical imaging technology.

This technology primer examines the unique engineering features and panel architecture of Teledyne DALSA's advanced CMOS detectors.

CMOS Imaging Technology

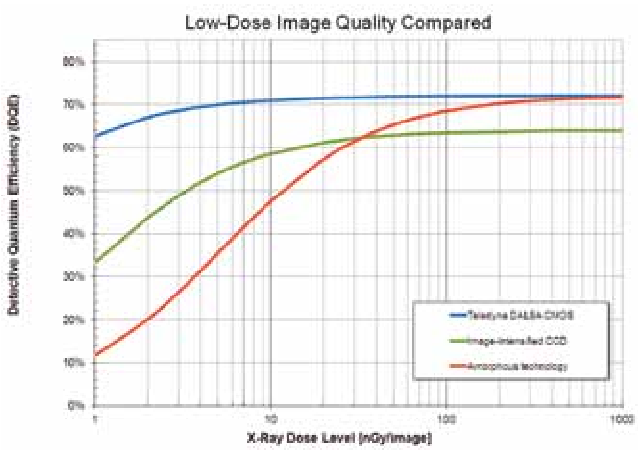
CMOS image detectors offer numerous advantages including the ability to record smaller image details at higher resolutions – allowing for the diagnostics of medical anomalies at earlier stages, and significantly increasing the probability of early intervention, patient recovery and reduced treatment costs. Current and planned wafer-scale X-Ray CMOS image sensor designs are using pixel pitches ranging from 20 to 100 microns.

Another important benefit of CMOS image sensors is the absence of so-called 'image lag', or the presence of residual image information in successive images, that is typical of amorphous TFT technologies. Image lag leads to poor quality images because of small image displacement. The image lag in Teledyne DALSA's X-Ray CMOS technology is less than 0.1%.

Low Dose Image Quality

Active Pixel Sensor technology and expertise in low noise circuit design are the hallmark's of Teledyne DALSA's CMOS X-Ray image sensors. Our CMOS image sensors exhibit unrivalled low readout noise levels and deliver superior Dynamic Range – even at low X-Ray dose, contributing to the high image quality required to support medical diagnostics. Teledyne DALSA's active pixel implementation process significantly reduces the read noise which typically dominates system noise when compared with amorphous silicon (TFT) based detectors. Our CMOS detector deliver low-dose image quality equal to or even surpassing high quality II-CCD systems, combined with the form factor and patient comfort advantages offered by flat detectors.

On system level, the low-noise raw images from Teledyne DALSA's CMOS detectors require less pre-processing before the diagnostics image enhancements, preserving image detail, and reducing system processing overhead and complexity.



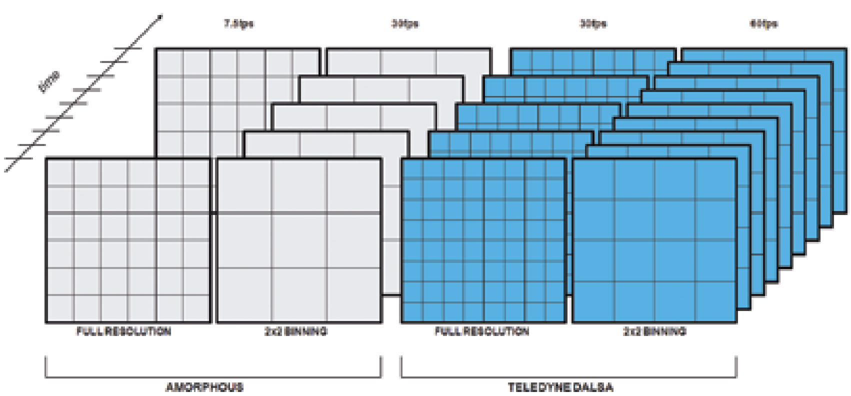
DETECTIVE QUANTUM EFFICIENCY

High DQE (the efficient use of incoming x-rays) is vital to minimizing patient dose and obtaining the best quality image to support further medical image processing and diagnostics. Teledyne DALSA's CMOS detectors deliver industry leading DQE performance as a result of our low readout noise and ability to resolve very small image details at high spatial frequencies.

High-Speed, High Resolution Readout

Taking full advantage of the high-speed capabilities of crystalline silicon material, Teledyne DALSA CMOS X-Ray detectors deliver detailed images at rates exceeding 30fps, at full resolution and each with excellent image quality. OEM system architects have a choice to achieve even higher speeds either through defining a specific region of interest (ROI or 'windowing') or by selecting one of the flexible pixel binning modes.

Thanks to the advanced processing technology and small feature size, our CMOS detectors offer the capability to create x-ray detectors with very high resolution, without sacrificing the pixel's ability to efficiently detect and convert the incoming x-ray signal. The ability to create CMOS pixels with high optical aperture (or 'fill factor") is unmatched by the resolution capabilities of either amorphous or image-intensified detector technologies.



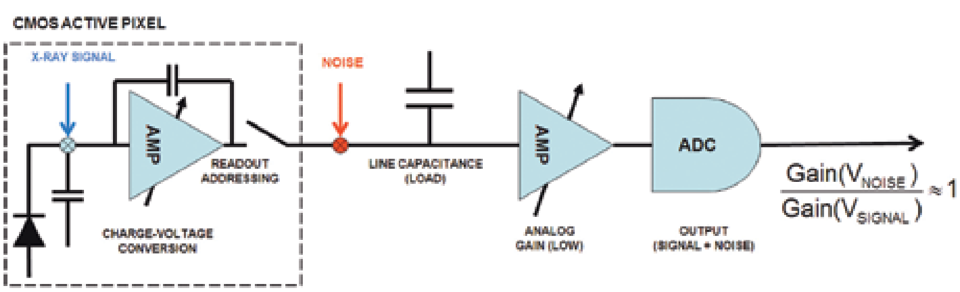
Switchable In-Pixel Gain

More and more medical modalities offer combined static (still) and dynamic (real-time) imaging capabilities. As the total X-Ray dose to which a patient can be exposed is strictly regulated, the amount of X-Ray dose available per image in dynamic mode is much less when compared to static images.

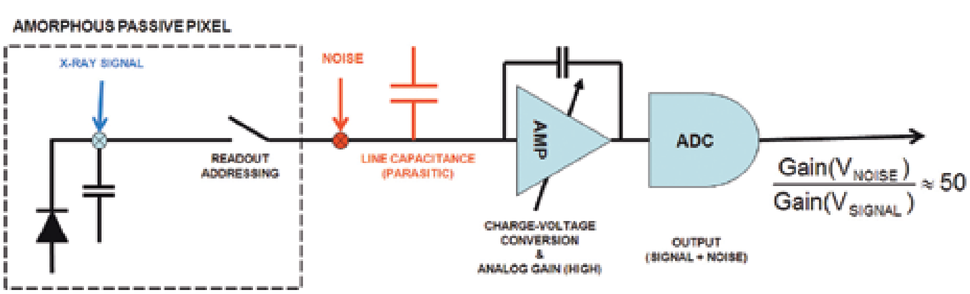
A traditional pixel with a fixed signal gain, optimized to handle the large dose required for still images, will only utilize a fraction of the dynamic range capability when operated in real-time imaging applications. Low dose results in a lower signal level which necessitates the application of higher analog gain to the output signal. In this case both the X-Ray signal and the readout noise are amplified which lowers the signal-to-noise ratio. Readout noise is one of the most important limiting factors of image quality when capturing images under low dose conditions.

The advanced Teledyne DALSA CMOS pixel design offers the ability to switch between different pixel charge capacities, each optimized for a specific imaging mode. This eliminates the need for additional gain that amplifies readout noise. Switching is done via software and can be programmed in between consecutive frames. Dynamic images for video analysis are crisp and clear, and do not suffer from low signal-to-noise ratio (SNR) after the required contrast stretching.

The switchable pixel full well capacity also has advantages for binned mode operation when higher frame rates and higher sensitivity are desired. Pixel binning can be used to increase the frame rate, but generally the sensitivity is not increased since the saturation charge is increased by the binning factor. An improvement of the SNR in binned operation would be very welcome. The Teledyne DALSA switchable pixel achieves higher frame rates and higher sensitivity when operated in binned mode. A sensitivity increase of up to a factor of 4 is within reach of the technology.

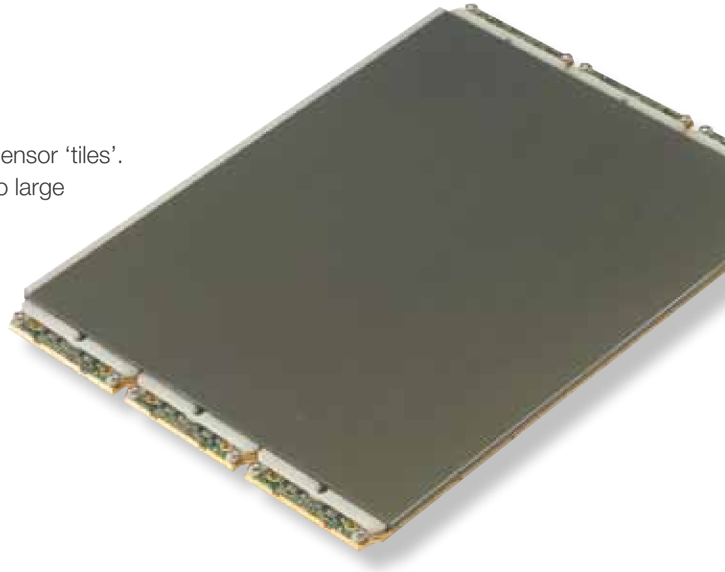


IMAGES CAPTURED @ 30fps
40kV/20uA (46nGy/FRAME)
100 FRAMES AVERAGE



Scalability

Teledyne DALSA CMOS X-Ray detectors are created from individual CMOS sensor 'tiles'. These "buttable" sensors are designed with flexibility in mind for assembly into large two-dimensional arrays with less than one pixel spacing in between individual sensors. This modularity enables multiple detectors with different active areas and resolutions to exist within the same sensor design, leveraging investments in development and production tooling while offering the same high imaging quality performance for multiple detector formats, optimized for a wide range of applications.



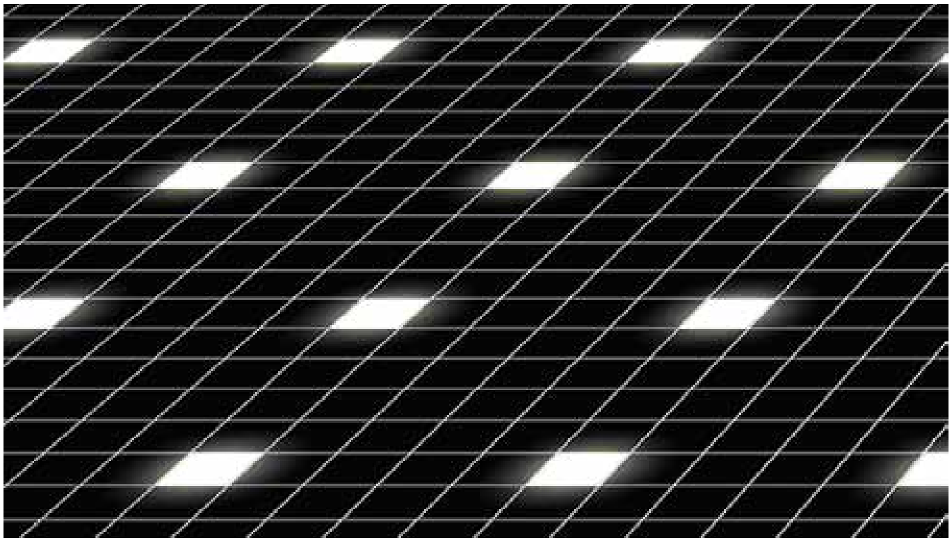
23X28CM Teledyne Dalsa FULL FIELD DIGITAL MAMMOGRAPHY CMOS DETECTOR, FEATURING A 2X3 ARRAY OF CMOS IMAGE SENSOR TILES WITH A 33 MICRON PIXEL PITCH. TOTAL RESOLUTION: 60MP

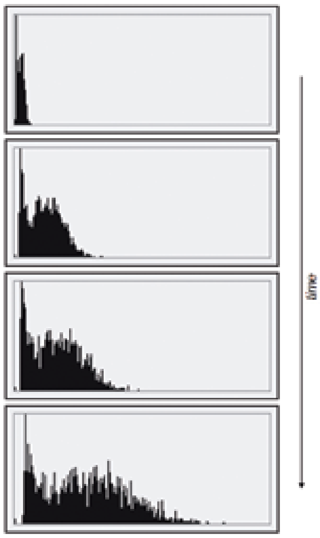
Real-Time Image Preview (RTIP)

To facilitate medical diagnostics, it's important to have access to correctly exposed X-Ray images. However, to minimize patient dose and to maximize equipment utilization, it is neither practical nor acceptable to take multiple X-Ray exposures to determine the optimal X-Ray setting. Ion chambers are most often used to achieve a better X-Ray exposure on the first attempt, but ion chambers can only report the average exposure averaged over a large area through a single analog signal.

Teledyne DALSA CMOS X-Ray detectors offer a unique way to ensure optimal X-Ray exposure for every image. A grid of dose-sensing pixels is embedded in and distributed over the full active image area, which can be read repeatedly at high speed during the actual X-Ray exposure period. Because dose sensing pixels are exactly the same as the pixels in a final image, the low-resolution dose sensing image delivers a qualitative and quantitative thumbnail preview of the final X-Ray image.

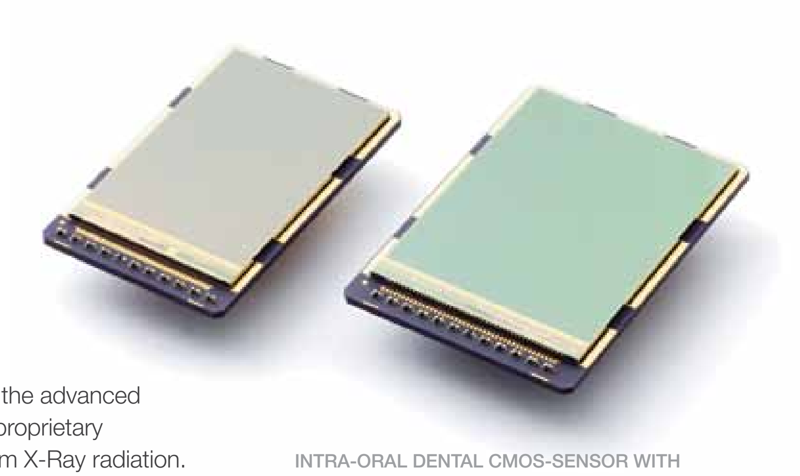
Read-out of these RTIP pixels is non-destructive and delivers highly valuable image statistics to support intelligent exposure and contrast control algorithms during the actual X-Ray exposure. By using this information to control X-Ray exposure parameters, the highest possible image quality is achieved while the patient is exposed to the lowest possible X-Ray dose in a first-time-right procedure. This is critically important for single-shot applications like mammography screening.





PERSPECTIVE ILLUSTRATION OF PIXEL ARRAY SHOWING THE UNIFORMLY DISTRIBUTED 'RTIP' PIXELS AS LIGHTER PIXELS

Lifetime Reliability



INTRA-ORAL DENTAL CMOS-SENSOR WITH INTEGRATED CIRCUIT DRIVERS AND 12-BIT ANALOG-TO-DIGITAL CONVERSION

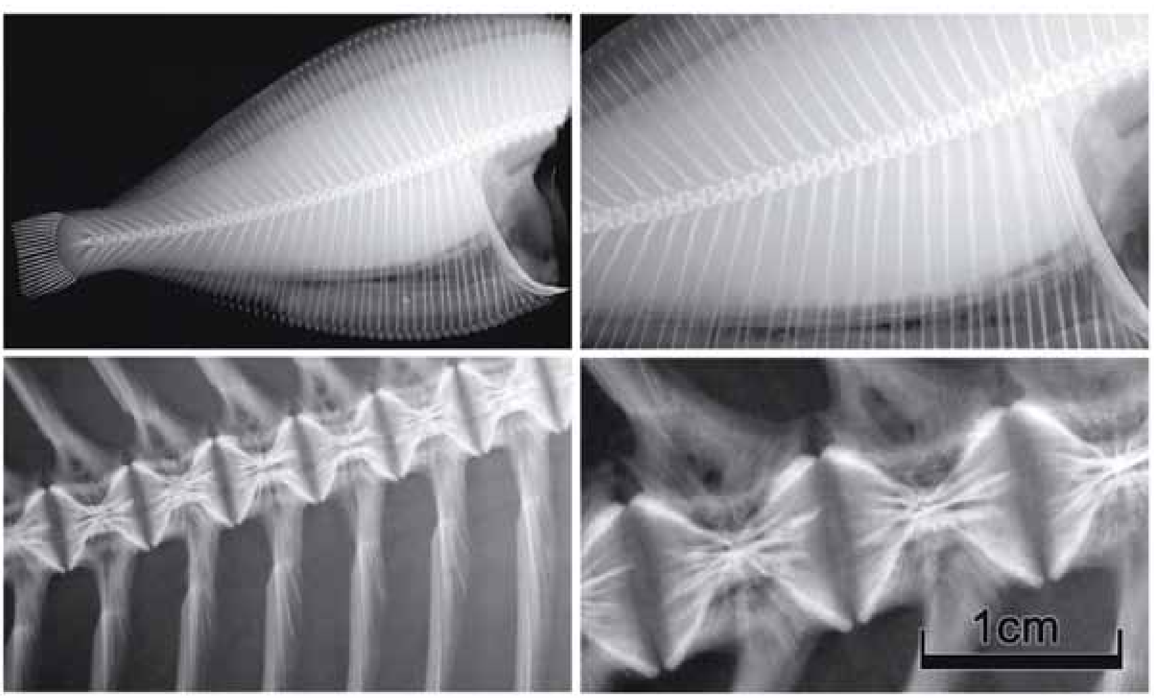
Similar to human bone and tissue, image sensor structures suffer damage from high-energy X-Ray photons, which results in increased noise (or reduced signal-to-noise ratio). This will become increasingly more apparent throughout the lifetime of the detector.

Through many years of experience and a thorough understanding of the advanced processes in CMOS manufacturing, Teledyne DALSA has created a proprietary pixel design that is far more resistant to performance degradation from X-Ray radiation. By isolating and protecting critical structures within the basic pixel cell design, the pixel performance remains constant even after high total ionization dose, enabling long operating lifetimes and less frequent calibration routines.

Unlike amorphous technology, the advanced CMOS design and manufacturing process supports the integration of sensor control, readout and signal digitization functionality from the peripheral electronics into the pixel array. This ability reduces component and interconnect count, reducing system cost and assembly complexity while improving product reliability at the same time.

The low power consumption of crystalline CMOS detectors also eliminates the need for active cooling, which allows the use of detectors in environments with less stringent temperature conditioning. Cooler-running detectors deliver better image quality over longer lifetimes.

Teledyne DALSA CMOS detectors deliver constantly high imaging performance throughout their extended product lifetime. Extended equipment lifetime and reduced maintenance downtime deliver more efficient equipment utilization and increased patient throughput without the need to reschedule appointments.



Teledyne DALSA knows the highly regulatory stringent quality requirements for medical and scientific imaging applications.

We offer OEMs more than just a technology advantage; we provide a comprehensive consultation program to meet your business model and a single point of accountability for service, support and manufacturing. Our imaging technology is backed by a field proven track record and an extensive install base; propelled by next generation R&D and delivered by a dedicated and highly trained team of imaging engineers.

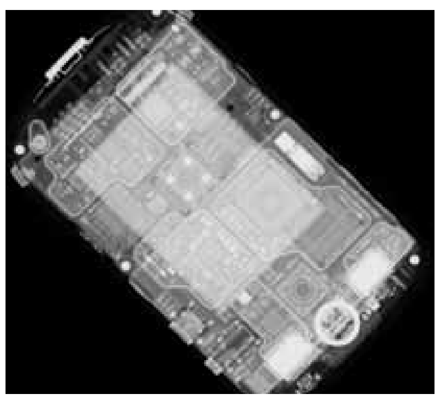
Teledyne DALSA X-Ray detectors and sensors are designed to deliver the highest imaging quality for improved diagnostics, while optimizing patient comfort and safety including:

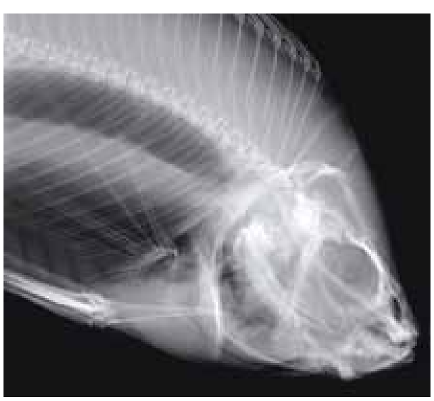
- The ability to offer lower noise and higher image quality which in-turn facilitates improved diagnostics, more accurate procedures and potentially contributes to higher patient survival rates and lower treatment costs

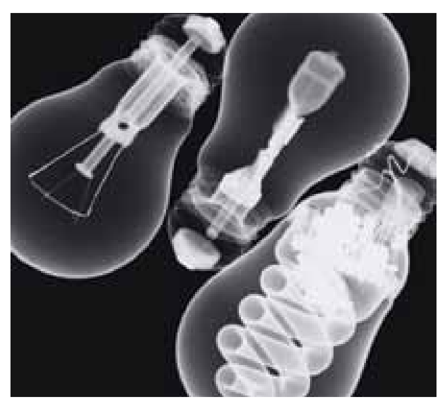
- Implementation of dose-sensing to optimize image quality in first-time-right exposures, resulting in reduced patient dose, increased patient comfort and workflow efficiency

- Optimized imaging modes for static and dynamic procedures, “best of both worlds”, offering true integration of modalities and more effective utilization of capital investments without sacrificing diagnostic quality.

- Provides radiation hard pixel technology which delivers constant and reliable operation throughout extended periods of daily use, reducing periodic re-calibration and system down-time to a minimum, optimizing patient throughput.





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Teledyne DALSA is an international leader in digital imaging and semiconductors and has its corporate offices in Waterloo, Ontario, Canada.