SIEMENS

White Paper

The Stellar Detector

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First fully integrated detector

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Siemens has continually evolved its technology for the most critical components in the CT scanner, including the X-ray tube, detector array, and efficient image reconstruction algorithms. Back in 2002, Siemens introduced a revolutionary concept for a new X-ray: the STRATON® tube. The STRATON tube's compact design led to the development of fast rotation speeds and Dual Source technology. STRATON X-ray tubes have a high power output, small focal spot sizes, and virtually no cooling delays, thanks to unique technology that cools the anode directly. [1] Siemens also has continuously improved its image reconstruction methods. While other vendors still use single-slice techniques which require compromises between image quality and speed, Siemens has developed SureView™ for the first generation of multi-slice detectors, offering optimal dose utilization and excellent image quality at arbitrary pitch values. Extensive research and development have fueled the latest generation of iterative reconstruction approaches, which include IRIS, and SAFIRE – Siemens' raw-data-based iterative reconstruction application.

High absorption, fast decay, and low afterglow

CT scanner detectors convert the attenuated X-ray beam into a digital signal that can be processed by computers. To achieve very high dose efficiency, the detector's capacity for X-ray absorption must be as high as possible. After decades of using Xenon gas detectors in CT, Siemens introduced the first solid-state detector in 1999 (Fig. 1).

Based on the proprietary scintillator material Ultra Fast Ceramics (UFC™), the detector offered high X-ray absorption, short decay times, and extremely low afterglow. The UFC layer used in Siemens CT scanners converts almost 100% of the X-rays into visible light, whereas Xenon detectors can only convert between 60% to 90% of the X-ray into a usable signal. A direct comparison of Xenon detectors and UFC-based detectors indicated an increase of 23% in dose efficiency. [2] Two additional properties of scintillator materials that are also very important: decay time and afterglow, both of which characterize the light output of the scintillator after the X-rays are switched off. Decay refers to the short-term behavior of the signal directly after the X-ray is switched off and afterglow is the longer-term composition of the signal output due to luminescence. UFC has set an industry standard with a consistent decay time of 2.5 microseconds, and an afterglow below 10^{-4} after 1 millisecond and 10^{-5} after 10 milliseconds. Until recently, other vendors still had to use afterglow correction mechanisms [3] since long decay time and high afterglow can completely ruin spatial resolution. Siemens has continued its dedication to innovation by developing the first fully integrated detector, which is designed to dramatically reduce electronic noise, extend the dynamic range, and increase spatial resolution in combination with new reconstruction methods.

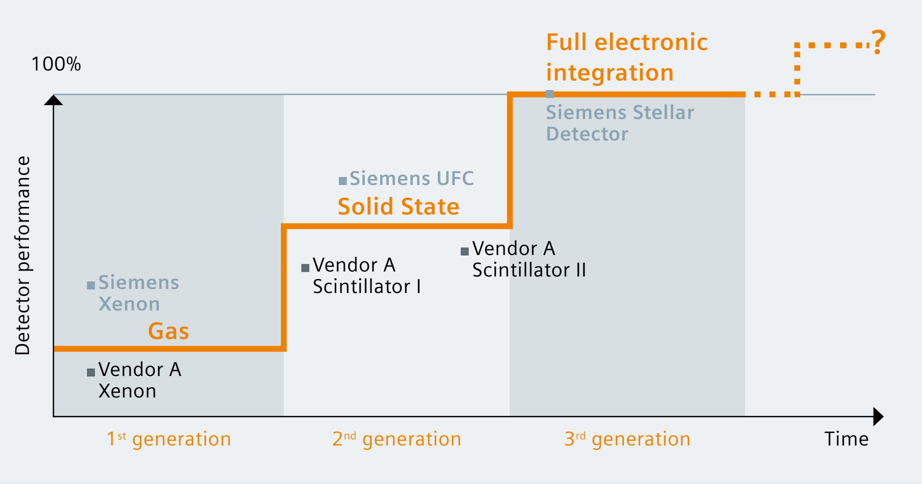

Figure 1: First-generation detectors still used Xenon gas under high pressure to convert the incoming X-rays into electric current that can be processed further. Second-generation detectors use solid-state ceramic scintillators to convert X-rays into light, photodiodes to convert the light into current and analog-digital converters to digitize the signal. The Stellar Detector is the first third-generation detector that for the first time combines the photodiode and the ADC in one application specific integrated circuit (ASIC) dramatically reducing electronic noise, power consumption and heat dissipation.

Figure 2: The new Stellar Detector as it is implemented in the CT scanner.

Revolutionary new detector design

Detector performance is not only measured by fast and high X-ray absorption, short decay times, and low afterglow. Low electronic noise levels and a high dynamic range are also important goals in designing effective detectors. With the new Stellar Detector (Fig. 2), Siemens is pioneering the first fully integrated CT detector. Conventional solid-state detectors consist of a scintillator layer that converts the incoming X-rays into visible light, a photodiode array that converts the visible light into an electric current, and an analog-to-digital converter (ADC) which digitizes the signal on a separate electronic board (Fig. 4a).

The number of electronic components and relatively long conducting paths increase power consumption, and add to the electronic noise produced by the detector. In the Stellar Detector, Siemens has combined the photodiode and the ADC in one application-specific integrated circuit (ASIC) for the first time in the history of CT, thus reducing the path of the signal. Fig. 3a shows the new Stellar Detector configuration. The light from the UFC scintillator reaches the back-illuminated photodiode on top of the complementary metal oxide semiconductor (CMOS) wafer, which houses the ADC. A digital signal is then produced on the other side of the wafer. This geometry consists of a 3D package of electronic circuits in a through-silicon via (TSV) – a high performance technique for creating vertical connections that pass completely through the silicon wafer. Fig. 3b shows the complete configuration of the compact Stellar Detector array with the ADC positioned entirely underneath the photodiode array.

This small module replaces all boards and electronic components previously present on the detector module electronic boards (Fig. 4b). The Stellar Detector transfers

Figure 3: The schematic drawing illustrates the principle setup of a detector element of the new Stellar Detector. The light from the UFC scintillator reaches the backside illuminated photodiode. The photodiode sits on top of a complementary metal oxide semiconductor (CMOS) wafer. Within this CMOS wafer the analog-to-digital converter (ADC) is included. The fully digital signal is then available on the other side of the wafer (Fig. 3a). A picture of the compact Stellar Detector array with the ADC sitting completely underneath the photodiode array. (Fig. 3b)

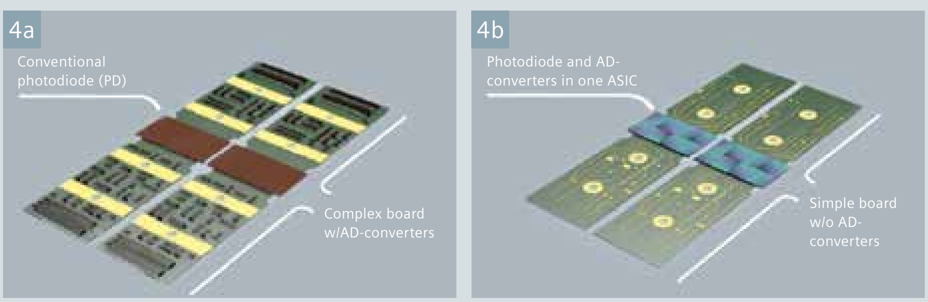

Figure 4: On second-generation solid-state detectors a separate electronic board with analog digital converters was necessary (Fig. 4a). In the Stellar Detector these components are completely integrated with the photodiode eliminating the need for these additional electronic components (Fig. 4b).

the digitized signal without any losses while the electronic noise produced by the detector is reduced by TrueSignal Technology, which transfers to a reduction of image noise in low signal situations. The Stellar Detector consumes approximately 70% less power and dissipates less heat than conventional detectors , further reducing electronic noise. Fig. 5 shows the reduced noise produced by the new Stellar Detector compared to a conventional second-generation detector.

Low electronic noise and high dynamics

In clinical CT, the attenuation of the measured object varies dramatically and so do the signal levels at the detector. The dynamic range describes the range of the input signal levels that can be reliably measured simultaneously without saturation. HiDynamics has an exceptionally high dynamic range of up to 102 dB, which is an increase of more than 200% compared to conventional detector systems. This eliminates the need to modify amplification and avoids detector saturation. Combined with the noise reduction provided by TrueSignal, Stellar Detectors can measure smaller signals over a wider dynamic range which directly reduces the noise in CT images (Fig. 6) and enhances CT image quality (Fig. 7, 8). Applications with extremely low signal levels at the detector benefit especially from HiDynamics and TrueSignal, such as scanning large patients and low dose scans, as well as the low-kV datasets produced with CARE kV [4–6], CARE Child or Dual Energy examinations. With CARE kV Siemens developed an automated tube potential adaption enabling dose reductions of up to 60%. CARE kV proposes the optimal kV setting taking into

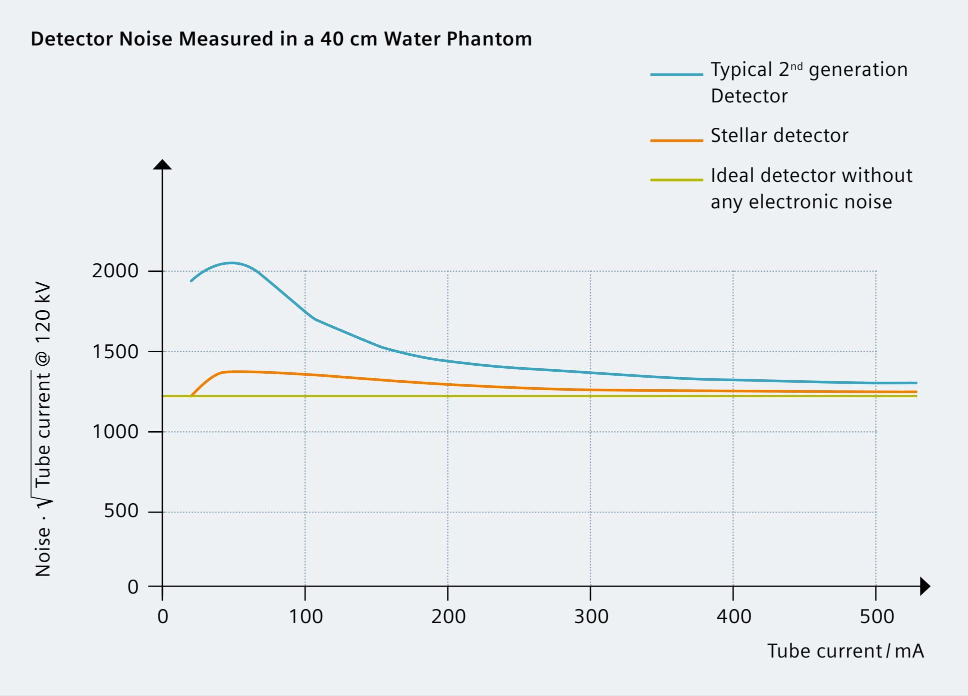

Figure 5: This graph demonstrates the reduced noise of the new Stellar Detector measured with a 40 cm water phantom compared to a conventional second-generation detector. Stellar is very close to an ideal detector with no electronic noise (green line). Especially for low dose applications and obese scanning where the signals are very low this provides a significant advantage.

account the individual patient, the examination type and the requirements of the clinical institution. An internal analysis showed that in clinical practice the kV setting was not adapted very often as this can be complex and time-consuming. So the standard kV setting was used in most cases. With CARE kV the adaption can be done automatically and clinical results show that now different kV settings – and depending on the patient population in a remarkable number of cases lower kV settings – are used [5]. With its ability to process low level signals, Stellar detector may be of benefit in comparison to conventional detector systems. CARE Child provides a full package of tools for matching the special requirements when imaging pediatric patients, among these the possibility to scan with 70 kV.

Model-based and detector-optimized reconstruction

With SAFIRE* (Sinogram Affirmed Iterative Reconstruction), Siemens has introduced the first model-based and raw data-based iterative reconstruction application capable of reducing spiral artifacts, suited for a broad range of applications in clinical routine. [7, 8] SAFIRE* can thus model the Stellar Detector precisely, including the cross talk between detector elements, detector aperture, detector grid, and the focal spot of the STRATON X-ray tube. This approach – the Edge Technology – delivers a much sharper slice profile and makes possible the reconstructing of true 0.5 mm slices and unmatched spatial resolution in routine clinical protocols with excellent dose efficiency (Fig. 8).

*In clinical practice, the use of SAFIRE may reduce CT patient dose depending on the clinical task, patient size, anatomical location, and clinical practice. A consultation with a radiologist and a physicist should be made to determine the appropriate dose to obtain diagnostic image quality for the particular clinical task. The following test method was used to determine a 54 to 60% dose reduction when using the SAFIRE reconstruction software. Noise, CT numbers, homogeneity, low-contrast resolution and high contrast resolution were assessed in a Gammex 438 phantom. Low dose data reconstructed with SAFIRE showed the same image quality compared to full dose data based on this test. Data on file.

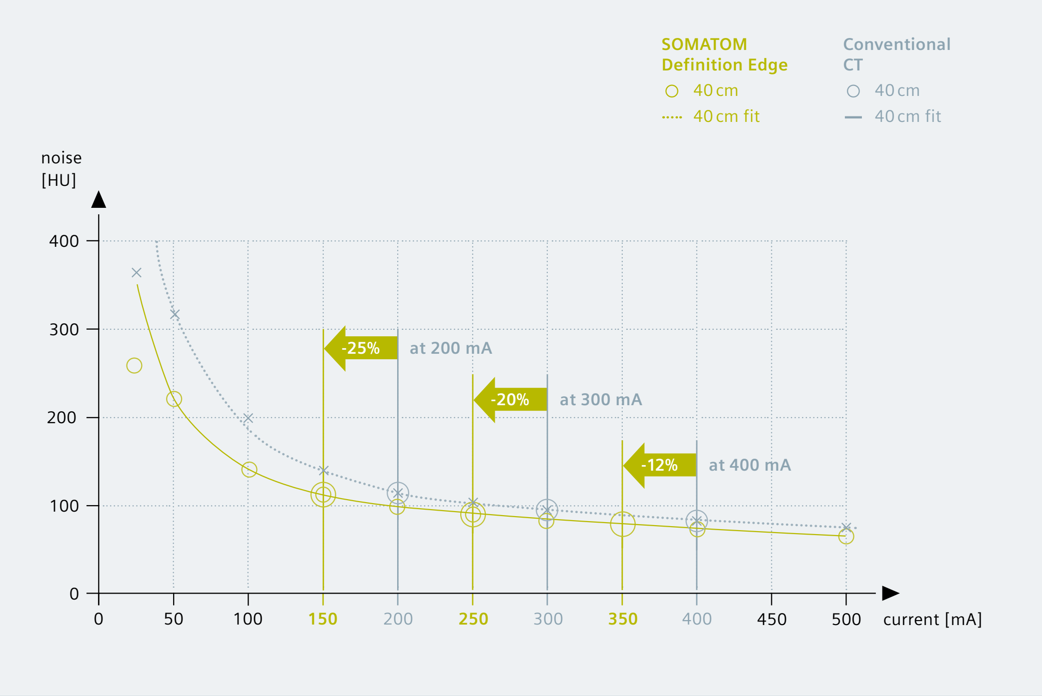

Figure 6: Image noise is measured in a 40 cm water phantom for various mAs settings. When the mAs decreases image noise is increased. With the new Stellar detector image noise increases more slowly when the mAs is reduced compared to a conventional detector. The same image noise level can now be achieved with e.g. a 25% lower mAs at an image noise level of 100 HU in a 40 cm water phantom.

SOMATOM Definition Edge and SOMATOM Definition Flash now equipped with next-generation detector technology

Siemens' high-end scanners, both in the single source and dual source category, are now equipped with the latest Stellar Detector enabling them to push the limits in resolution and dose reduction even further.

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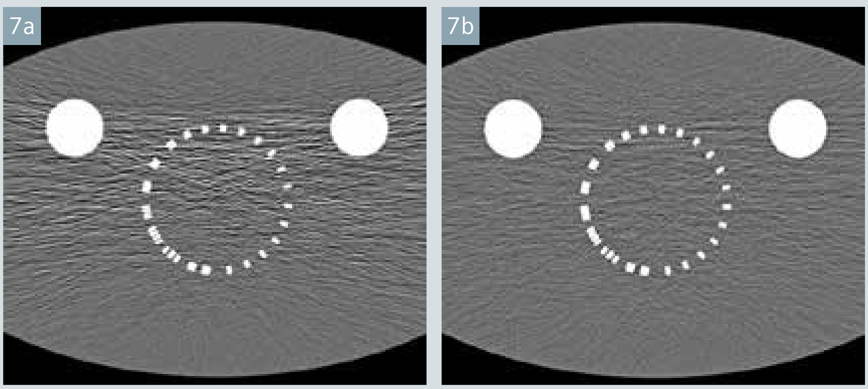

Figure 7: These simulation of a hip phantom with resolution insert once for conventional detector technology and once for the new Stellar Detector show the advantages of the new detector. With conventional technology low signal levels in projections with high attenuation transfer to typical streak noise pattern in clinical images (Fig. 7a). With the Stellar Detector and TrueSignal technology these unwanted noise patterns are eliminated (Fig. 7b).

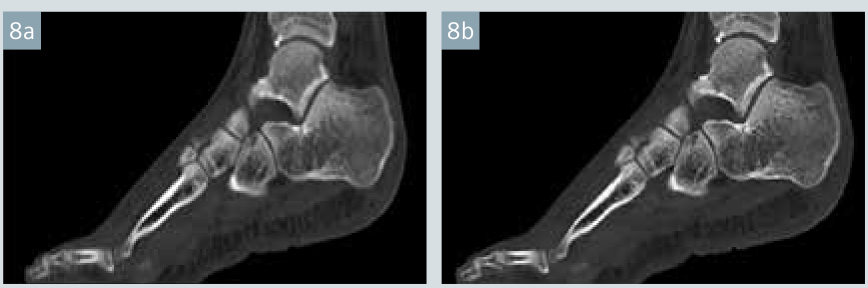

Figure 8: A foot has been scanned once and reconstructed with conventional technology (Fig. 8a) and the new Stellar Detector reconstructed with optimized SAFIRE model based reconstruction (Fig. 8b).

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