

White Paper

Dynamic Flat-Panel Detectors in Fluoroscopy

Technology and Clinical Advantages

Dynamic Flat-Panel Detector Technology

Introduction

Today's healthcare organizations face a variety of challenges that affect the way they deliver care. Those challenges include staffing issues, reduced reimbursements, and increasing operating costs.

Striving to meet those challenges requires enhanced diagnostics and therapy results, increased efficiency, and improved patient comfort at lower costs. To address these economic realities, you need a comprehensive, integrated solution, which combines exceptional image quality with information management.

Siemens Fluoroscopy systems address the growing demand to increase equipment utilization and patient throughput per system with outstanding results.

Brilliant image quality is just one of the benefits of Siemens Fluoroscopy systems. One reason for this is the large dynamic flat-panel detector, which is an important part of the whole imaging system and has drawn major interest.

This white paper is intended to provide you with the background on this technology, giving you the information you need to make the right decision for your clinical, financial, and workflow needs.

Digital and Analog Imaging

There are two different types of X-ray imaging chains, analog and digital.

Analog imaging chains include X-ray films and analog image intensifier TV systems. Digital imaging chains include storage phosphor systems, digital image intensifier TV systems, and flat detectors. Digital imaging has considerable advantages over analog, including:

- Direct image availability.
- Digital image processing.
- Digital storage and archiving.
- Computer-aided diagnosis.

Digital

Digital means to generate an electronic image using discrete units. The binary system makes it possible to record all numerical values as a string of digits in the form of "0" and "1".

Key advantages of digitized information are its ability to be recorded, copied, reviewed, and processed without loss in quality.

Analog

An analog display of a signal generates an image that is continuously proportional to the respective value. For example, in an instrument with an analog pointer, the pointer deflection is directly proportional to the change in current.

In general, the continuously proportional nature of analog images is an advantage. However, this is offset by disadvantages such as being more affected by electronic noise or magnetic fields and limitations in the ability to record and copy images without loss of quality.

The Development of Digital Imaging

For decades, analog X-ray films and image analog image intensifier TV systems were the only media for recording and displaying images in radiology.

In the 1980s, the introduction of digital storage phosphor systems for radiography and the digitization of image intensifier TV systems in fluoroscopy were the first steps in digital imaging systems.

A decisive breakthrough for digital imaging systems was flat-panel detectors (FPD). First introduced in radiography, they resulted in a dramatic increase in patient throughput. They are now also state-of-the-art in fluoroscopy and it is only a matter of time until all fluoroscopy systems will benefit from the advantages of flat detectors.

Image Intensifier (I.I.) and FPD in Comparison

Both image intensifier and dynamic flat-panel detectors offer digital imaging. However, dynamic flat-panel detectors offer a number of advantages including:

- Higher Detective Quantum Efficiency (DQE) and contrast particularly at higher spatial resolution.
- Higher spatial resolution e.g., - 3.4 lp/mm for FPD and 1.7 lp/mm for I.I. at full field.
- Larger maximum image area to cover larger structures.
- No degradation through electro-optical distortions and artifacts.
- Lower zoom dose factors when using magnification modes.
- Shorter image chain with fewer parts and lower maintenance requirements.
- FPD is not affected by magnetic fields.
- A more compact size that frees system design to provide easier patient access.

Dynamic Flat-Panel Detector Technology

Image Intensifier Technology

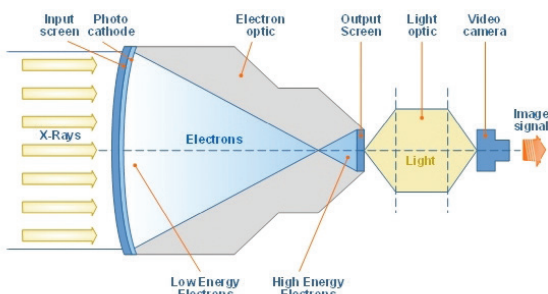
An image intensifier consists of: a vacuum tube, input window, scintillator, photocathode, electron optics, and an output phosphor screen. The addition of a video camera results in an image intensifier TV system.

X-rays enter through the input window and the scintillator converts them into light. They are then converted to electrons by the photocathode. The electrons are accelerated by a high-voltage electric field and focused by the electron optics onto the output phosphor screen, where they are converted back to visible light. The acceleration of the electrons results in about a thousand light photons at the output phosphor screen for every photon entering the input screen. This is the basis of the image intensification. The light then passes through a glass output window to a video camera. The signal from the video camera can be directly displayed on a monitor or via a digital imaging system.

Image intensifiers are a mature technology and additional improvements are unlikely. They have a number of disadvantages, including:

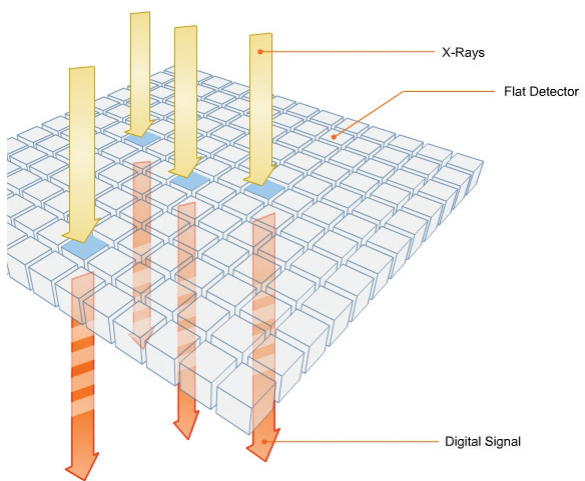
- Input window scattering with loss of edge sharpness.
- Multiple signal conversions with signal loss.
- Variation of quality, brightness, and geometric distortion across the image.
- Sensitivity to magnetic fields.
- Require regular adjustment of electrical and optical components.
- Gradual loss in image quality over time with a limited life span.

Image Intensifier



FPD Technology

With FPD technology, X-rays are converted by a matrix of photodiodes into an electrical signal, which is read out and converted into a digital signal based on a pixel structure. The principle is the same as a digital camera with the image almost immediately appearing on the display.



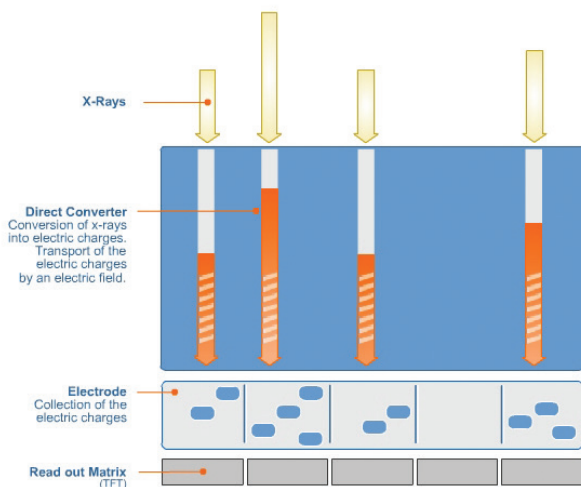
There are two different ways to convert X-rays into electrical signals. Which technology is used is dependent on the specific application.

1. Direct conversion, with no step between the X-ray and electrical conversion.
2. Indirect conversion, which converts the X-ray with a scintillator into light, which is then converted to electrical signals.

Direct Conversion

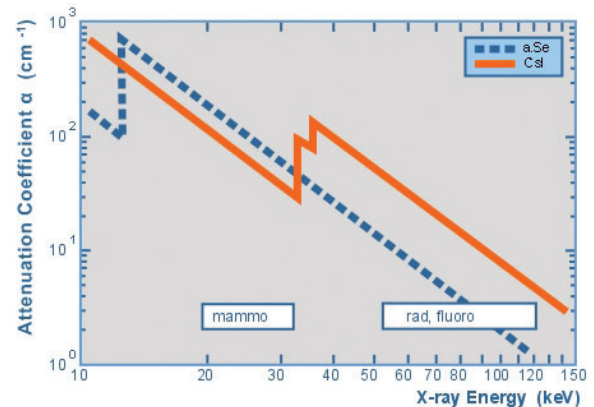
Direct conversion converts X-rays into electric charges that collect on the pixel electrodes, which are then converted into a digital signal by an AD-converter.

The material used needs to have a high X-ray absorption coefficient, and a high efficiency for the collection of generated charges and be able to be produced in a large surface area. The most common material used is amorphous selenium (Se) in conjunction with amorphous silicon.



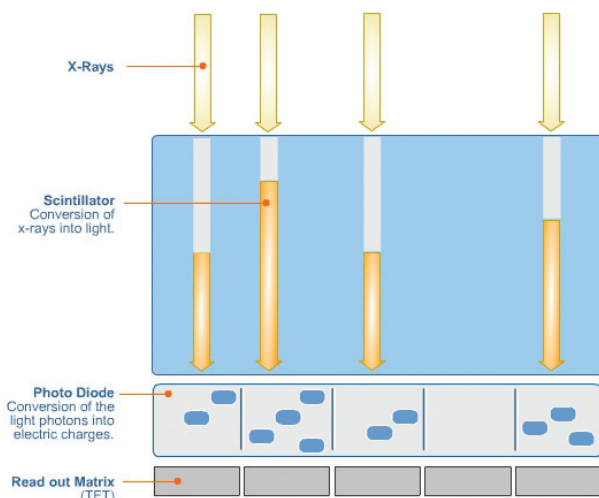
Comparison of Direct and Indirect Conversion

Direct and indirect conversion have advantages for different applications. As they perform better at low voltages, Selenium-based direct conversion detectors are commonly used in mammography. However, as Selenium has a low X-ray absorption in the voltage range used for general radiography and fluoroscopy, it is not suitable for these applications.



Indirect conversion

The most common flat-panel detectors are based on a two-step process with a scintillator converting X-rays into light, which is then converted by a photodiode into an electronic signal. The most common scintillators are Gadolinium oxysulfide (GdOx) or Cesium Iodine (CsI). Similar to direct detectors, amorphous silicon is used for the photodiodes.



Dynamic Flat-Panel Detector Technology

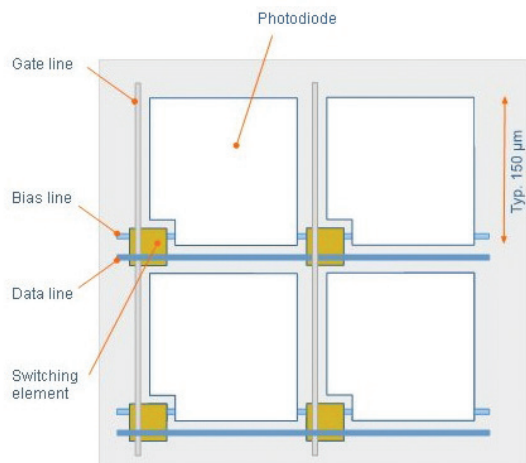
Matrix Structure

The image of a flat detector is collected by a thin film matrix of photo diodes produced using amorphous silicon (Si). These allow the charge collected at each element to be independently translated into a digital signal relating to a pixel in the image. Following an X-ray exposure (or fluoroscopy frame), the entire sensor surface is read out line by line.

Advantages of the photodiode matrix are:

- Can be produced in areas $> 40 \times 40 \text{ cm}^2$ for larger detector areas.
- Standard technology used in multiple industries.
- High resistance to X-ray radiation.

The pixels within the matrix are typically between 140 to 180 μm . This is a critical limitation to the resolution of the resulting image. The electronics used to read out the signals from each element are optimized to have low electronic noise and a high readout speed. The bit depth for the digital conversion is 14 or 16 bit.



CsI (Cesium Iodide)-FPD

The dominant FPD technology is based on indirect conversion with a cesium iodide scintillator and an amorphous silicon matrix, which is superior with respect to image quality and dose in almost all radiology applications.

A 500 μm CsI-layer is suitable for high absorption of X-ray voltages between 45 kVp and 150 kVp. The typical diameter for needles that contain the CsI crystals is 5-10 μm . This structure channels the generated light to the photodiode and keeps light scatter effects at a minimum.

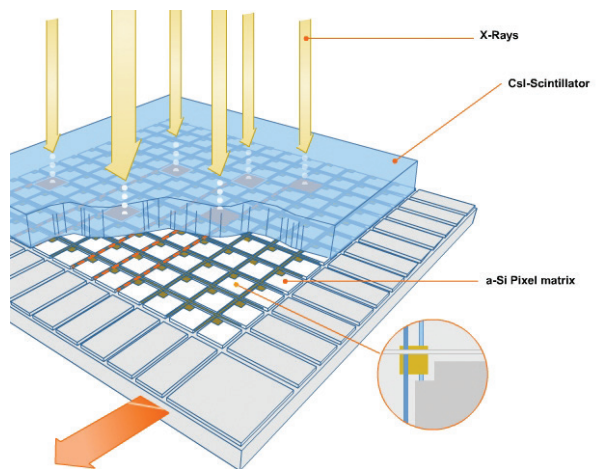


Image Quality

Image Quality

There are a number of objective parameters that can be used to characterize the image quality:

- Detective Quantum Efficiency (DQE)
- Modulation Transfer Function (MTF)
- Spatial Resolution
- Dynamic Range
- Distortions and artifacts

In addition, there are a number of other factors that influence image quality such as motion, scatter radiation, or contrast agents, which are largely independent of the imaging system used.

Detective Quantum Efficiency (DQE)

In order for a detector to transfer X-rays into an image as exactly as possible, electronic noise should be minimized for a given spatial and contrast resolution. DQE is a measure of the efficiency of this conversion.

An ideal X-ray imaging system will display all information available in the latent X-ray image without loss. Real systems fall short of this ideal, as noise introduced during the image detection processes results in the output signal to noise ratio (SNR_{out}) being lower than the input SNR (SNR_{in}).

DQE describes the degradation of the SNR at a given spatial and contrast resolution by an X-ray imaging system and is a measure to compare systems.

DQE can be defined as:

$$DQE(f) = \frac{SNR^2(f)_{out}}{SNR^2(f)_{in}}$$

$SNR_{in} \rightarrow \text{Detector} \rightarrow SNR_{out}$

f: spatial frequency.

This means that the DQE combines noise and contrast performance in a single parameter.

More efficient systems are able to display more of the information from the X-ray exposure given. As a result, for a given dose to the patient (and exposure incident to the detector) a system with a higher DQE yields higher image quality. Alternatively, a higher DQE can be used to reduce patient dose without a loss of image quality.

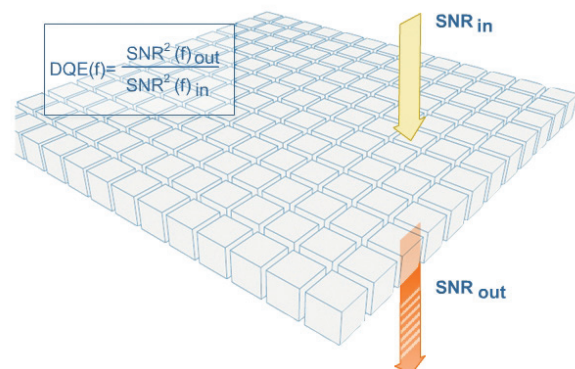


Image Quality

Noise

Unwanted variations of signal not related to the object being imaged are image noise. This is a combination of quantum noise and detector noise.

Quantum noise is caused by the physical nature of X-rays. As the number of quanta absorbed by the detector increases, the signal-to-noise ratio increases. Quantum noise is therefore dose dependent.

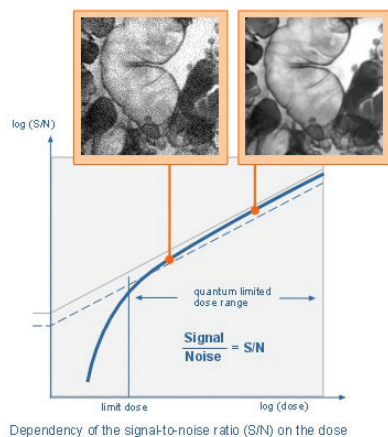
Detector noise comes from the electronic components (e.g., photodiode, switch, and amplifiers) and is independent of the dose. It cannot be reduced beyond a certain degree for technical reasons.

At very low doses, the quantum noise is low and detector noise dominates. As the dose increases and the signal becomes stronger, the detector noise becomes less relevant.

When the dose reaches the quantum-limited range, the image noise is defined by the number of X-ray quanta (dose) and detector noise is practically no longer visible.

The signal-to-noise ratio (SNR) can be used to roughly describe the ability to detect a particular object under defined exposure conditions. Of course this depends upon the observer visual system and the object shape.

In general, noise is a major limiting factor in the ability to detect the object being imaged, particularly when viewing small, low-contrast objects. Due to this, low noise is a prerequisite to good image quality.

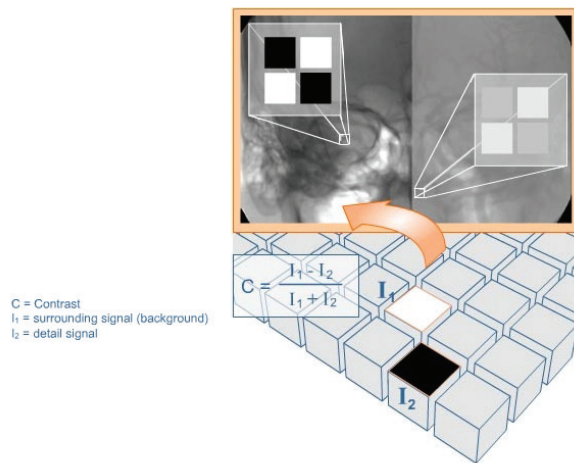


Contrast

The difference of grey values between an object and its direct surrounding describe its contrast. Contrast resolution refers to the smallest change that can be detected. It depends on various system parameters including: voltage, amount of scattered radiation, contrast media, and the parameters of pre and postprocessing.

Digital X-ray systems have a dynamic range that captures a wide variety of signal intensities and obtains a high-contrast resolution. This provides a clear image of areas that would be under- or overexposed on conventional film.

Digital systems with low noise, wide dynamic range, and high-contrast resolution improve the ability to detect low-contrast objects and can be enhanced with image processing.



Bit Depth

The bit depth determines maximum number of grey values. Increasing the bit depth increases the number of grey values as well as the memory storage capacity required for the image. When the image is reviewed, postprocessing (windowing) is used to reduce the bit depth to get the appropriate brightness and contrast. The current state-of-the-art digital systems have a bit depth of 14 or 16 bits.

MTF

The modulation transfer function (MTF) is a measure of the ability of an imaging system to preserve signal contrast as a function of spatial frequency. The MTF is presented as the contrast transfer factor 'k' dependent on the spatial frequency.

Normally, the MTF is measured under ideal laboratory conditions, using high-contrast objects and high dose while minimizing scatter radiation and noise. It is therefore not a reliable indicator of performance in real clinical situations.

Further, MTF is as relevant with digital imaging systems as postprocessing enables you to achieve the desired MTF. It can be useful for film-based systems as no postprocessing is possible.

Spatial Resolution

A measure of the line pairs in an image consisting of a series of increasing spatial frequency bar patterns is called limiting spatial resolution (LSR). It depends on the contrast of the target, the number and length of the patterns and exposure and display conditions. It is measured under laboratory rather than clinical conditions.

Dynamic Range

The dynamic range defines the exposure intensities that allow a detector to capture a useful image. A suitable range depends on the relationship between input intensity and output signal. The range between highest and lowest response is the dynamic range of the system. The advantage of a high dynamic range is the ability to record all details of the required anatomy, including areas with low and high absorption. Flat-panel detector systems obtain very high dynamic range in comparison to film-screen systems, which may require multiple exposures to obtain the same information.

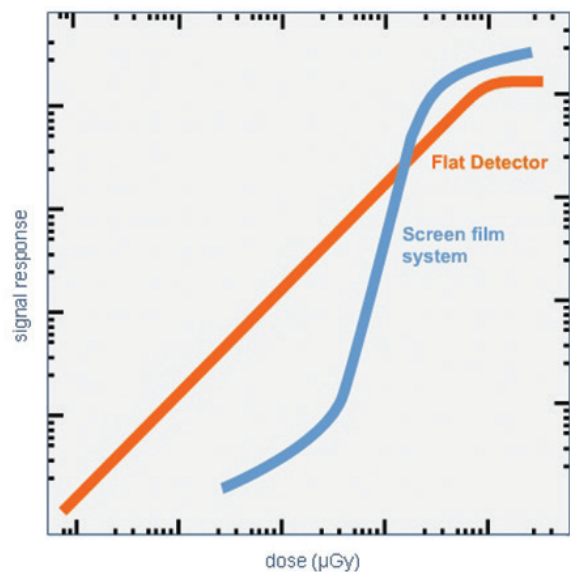


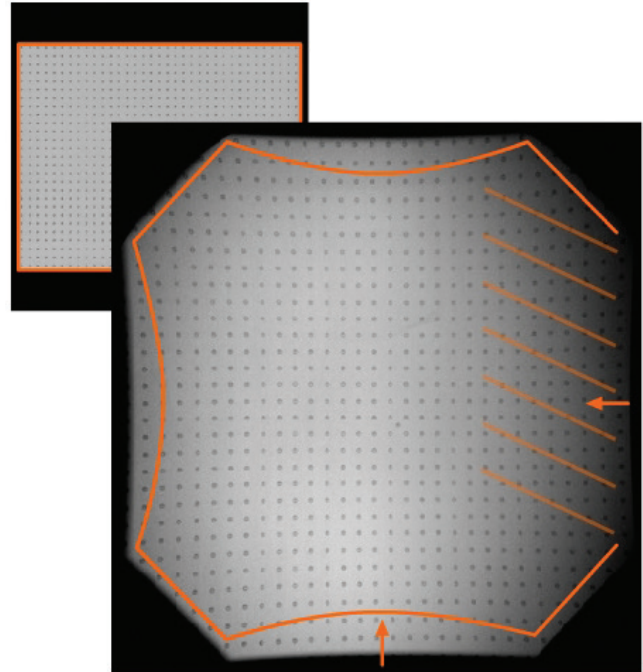
Image Quality

Image Distortions and Artifacts

An object is distorted if it is either geometrically warped or not uniform in brightness distribution compared to the original. Structures or objects that appear but are not in the original are called artifacts. All imaging systems are prone to such unwanted effects. However, because these unwanted effects can negatively influence assessment or diagnosis, the goal is to reduce them as much as possible.

Image intensifiers have characteristic distortions that are inherent to the electro-optics and can be reduced but not eliminated. They are also subject to external influences such as magnetic fields.

FPD technology is free from the distortions seen with image intensifiers. And while variations in sensitivity from pixel to pixel, or in-between lines can occur, high performance digital signal processing can counter these effects.



Clinical Advantages of FPD Technology

Clinical Advantages of FPD Technology

Compared to image intensifiers, dynamic flat-panel detectors provide many advantages in image quality and workflow. These combine to improve diagnostic results and patient care, and reduce dose in the clinical environment.

- Better detection of small structures due to improved contrast and higher DQE. This can also reduce dose while maintaining image quality or shortening examination times.
- Increased postprocessing capabilities, allowing the adaptation of image quality to suit the needs of individual examinations and operator preferences.
- The rectangular format of the flat-panel detector provides up to 50% more image area than the even the largest 40-cm, (16-in.) image intensifier. This results in better patient coverage and faster exams.
- The larger field of view can also reduce the need for additional radiography images that would be required if doing the same exam on an image intensifier system.
- The dose factor when using zoom is lower. For example from full field to zoom 3, an image intensifier has a five-time increase in dose where as the flat-panel detector increase is only three times.
- Superior image quality over image intensifier allows the more frequent use of the Last Image Hold rather than a higher dose acquisition.
- Dynamic flat-panel detectors provide the choice of three different imaging modes. Radiography, Digital fluoro-radiography (DFR) and Fluoroscopy (Last-Image-Hold) with three different dose and image quality levels, depending on the needs of the exam and operator preferences.



The rectangular format of the dynamic flat-panel detector provides up to 50% more image area than even the largest 40-cm (16-in.) image intensifier.



The same image with a simulation of the coverage of a 40-cm, (16-in.) image intensifier demonstrates the advantage of the larger image area.

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