RadioGraphics

AAPM/RSNA Physics Tutorial for Residents: Physics of Flat-Panel Fluoroscopy Systems

Survey of Modern Fluoroscopy Imaging: Flat-Panel Detectors versus Image Intensifiers and More[1]

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TEACHING POINTS
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This article reviews the design and operation of both flat-panel detector (FPD) and image intensifier fluoroscopy systems. The different components of each imaging chain and their functions are explained and compared. FPD systems have multiple advantages such as a smaller size, extended dynamic range, no spatial distortion, and greater stability. However, FPD systems typically have the same spatial resolution for all fields of view (FOVs) and are prone to ghosting. Image intensifier systems have better spatial resolution with the use of smaller FOVs (magnification modes) and tend to be less expensive. However, the spatial resolution of image intensifier systems is limited by the television system to which they are coupled. Moreover, image intensifier systems are degraded by glare, vignetting, spatial distortions, and defocusing effects. FPD systems do not have these problems. Some recent innovations to fluoroscopy systems include automated filtration, pulsed fluoroscopy, automatic positioning, dose-area product meters, and improved automatic dose rate control programs. Operator-selectable features may affect both the patient radiation dose and image quality; these selectable features include dose level setting, the FOV employed, fluoroscopic pulse rates, geometric factors, display software settings, and methods to reduce the imaging time.

Abbreviations: CsI = cesium iodide, DEL = detector element, FOV = field of view, FPD = flat-panel detector, SNR = signal-to-noise ratio

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Introduction

Current fluoroscopy systems fall into two distinct categories: image intensifier and flat-panel detector (FPD). The more conventional and older design is the image intensifier system, which is coupled with a television camera and displays. This system has been utilized for radiology imaging since the 1960s. FPD fluoroscopy systems represent more modern solid-state detector arrays used as the image receptor. FDP receptors have a number of advantages over image intensifier fluoroscopy systems including better stability, lower patient radiation doses, and wider dynamic ranges. However, image intensifier systems are widely used, especially for mobile C-arms and gastrointestinal fluoroscopy. The displayed images have differences in their visual appearances on the two fluoroscopy systems. Each system has its own specific characteristics, advantages, and disadvantages. In this article, the engineering design, operation, and image quality features of both image intensifier and FPD fluoroscopy systems are reviewed, compared, and contrasted.

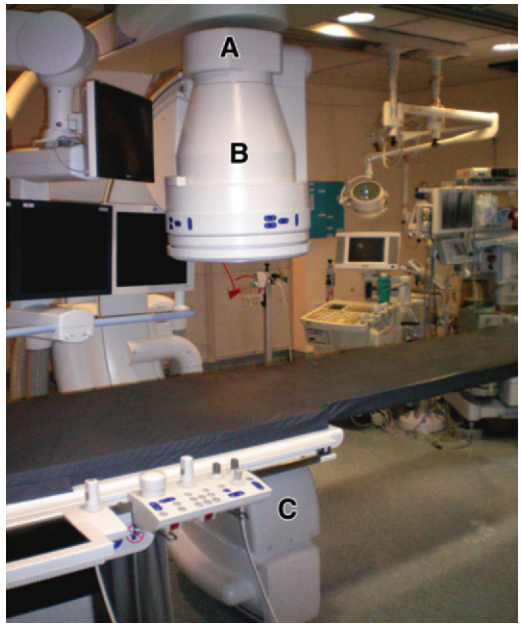


Figure 1. Photograph of an angiography room shows a fluoroscopy system with an image intensifier (*B*) (field of view [FOV], 40 cm) and television camera (*A*). *C* = x-ray tube.

Design and Operation of Fluoroscopy Systems

Image Intensifier Fluoroscopy Systems

Soon after their development in the late 1950s, image intensifiers were coupled with television systems to enable viewing of fluoroscopic images (Fig 1) (1–3). These fluoroscopy systems may be used to assess dynamic processes such as swallowing and cardiac function, to provide a road map for the positioning of catheters in angioplasty, to assess vascular function of contrast material–filled vessels in digital subtraction angiography (DSA), and to detect gastrointestinal abnormalities in barium enema studies. Image intensifier and fluoroscopy television systems have undergone significant technological improvements over the past 50 years (1–3). Large field-of-view (FOV) image intensifiers may cover a 40-cm diameter, and multiple magnification modes have been developed (4,5). Fluoroscopy television systems have progressed from using camera tubes such as bulky orthicons and vidicons to charge-coupled devices (CCDs) (6,7). In some fluoroscopy systems, 1023–raster line television systems with liquid crystal display (LCD) monitors are used. Despite these advances, image intensifier fluoroscopy systems have many disadvantages.

An image intensifier is a very large vacuum tube that captures the pattern of x-ray radiation transmitted through the patient and converts it into a light image of sufficient brightness to be seen on the television camera (Fig 2). After entering the curved input surface of the image intensifier, the x-rays interact with and deposit energy into the layer of phosphor (which is composed of cesium iodide [CsI]); a portion of this energy is converted into light. The light from the phosphor is then absorbed by the photocathode layer of the image intensifier, which uses the light energy to emit electrons: The number of electrons emitted is in direct proportion to the amount of light that was absorbed. The electrons are then accelerated by a high voltage

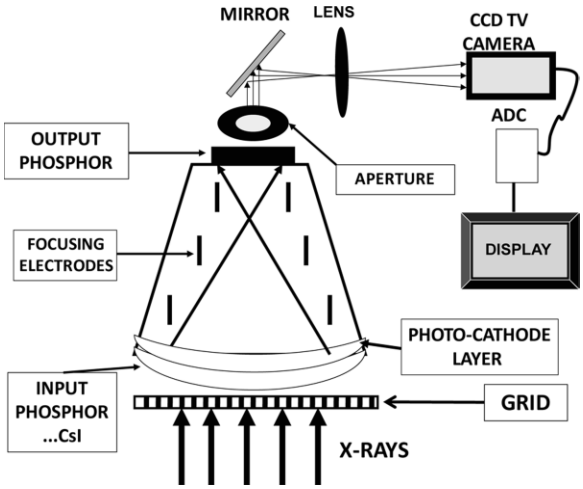


Figure 2. Schematic shows the internal structures of an image intensifier. *ADC* = analog-to-digital converter, *CCD* = charge-coupled device.

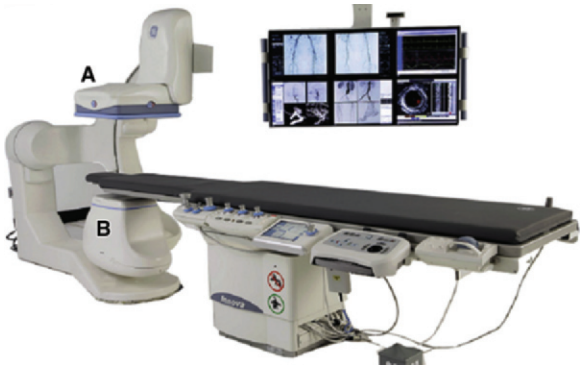


Figure 3. Photograph shows a large FPD fluoroscopy system. *A* = flat-panel image receptor, *B* = x-ray tube.

(25,000–35,000 V) placed between the input cathode of the image intensifier and the output phosphor. As they move from the photocathode to the output phosphor of the image intensifier, the emitted electrons gain substantial kinetic energy and travel at a high velocity. Electrostatic plates are used to focus the electrons and direct them to the output phosphor, which has a much smaller surface area. Upon impacting the output phosphor, a portion of the energy is converted back to a light image. Because the electron flux from a large input surface area is concentrated onto a much smaller output surface area at the output phosphor, the light image that emerges from the output phosphor is much brighter than it would be at the input phosphor layer (minification gain). Moreover, the high kinetic energy gained by the electrons, a result of the high voltage applied across the image intensifier, also increases the emitted light from the output phosphor (flux gain). After passing through a lens system and an aperture, the television camera tube intercepts this light image and converts the light pattern into a series of electrical signals that may be displayed on the television monitor.

FPD Fluoroscopy Systems

FPD fluoroscopy systems have begun to dominate angiography and cardiac catheterization laboratories (Fig 3) (8–10). Currently, only their high purchase cost is preventing their utilization with low-end fluoroscopy equipment such as gastrointestinal fluoroscopy systems and C-arm mobile units. The smaller size of the FPD imaging chain allows for more flexible movement during patient examinations. Moreover, FPD systems do not require a television camera to produce an electronic signal for the display monitor. By its design, the image receptor (FPD) produces a digital electronic signal, which represents the intensity of the x-rays that impinge on each detector element (DEL) in the solid-state FPD array (8–10). Moreover, the entire process is digital, which reduces image noise caused by electronic components.

The FPD consists of an array of individual DELs (Fig 4a). The typical size of those in fluoroscopy systems ranges from 200 μm to about 140 μm per side, depending on the manufacturer and model. The size of the entire array ranges from 25 × 25 cm to 40 × 40 cm. However, some manufacturers specify the size of the FPD by providing a diagonal measurement, and others quote the edge dimension. A FPD may contain 1.5–5.0 million individual DELs; a challenge of manufacturing is to make a uniform array with few defective or degraded DELs.

Currently, most FPD arrays are indirect solid-state systems, meaning that the x-ray energy is first converted to light and then to an electronic signal. An individual DEL consists of a

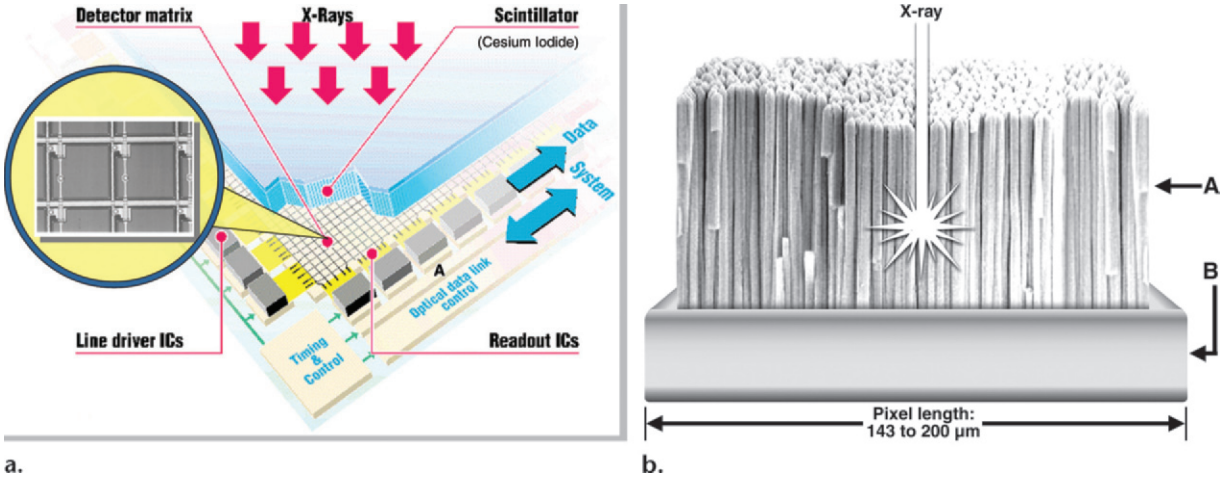


Figure 4. Construction of an FPD array. **(a)** Drawing shows a section of the FPD and many individual DELs. *A* = 14-bit A/Ds, *IC* = integrated circuit. **(b)** Drawing shows one DEL in the FPD array. *A* = CsI needle scintillator layer, *B* = photodiode and transistor layer.

scintillation layer, which usually is composed of thallium-activated CsI (Fig 4b). The scintillation layer attenuates the incident x-rays and produces light. The CsI scintillation layer is composed of many needle-like crystals, which are grouped together to cover the surface of the DEL. These needle-like structures help direct light toward the photodiode located below. The amount of light produced is directly related to the amount of x-ray flux that is incident on the DEL. When light hits the surface of the low-noise photodiode and transistor below, it acts like a switch, allowing the diode to conduct electricity. In the absence of light on its surface, the photodiode acts like an insulator, preventing the flow of electrons.

Each DEL is able to quantify the amount of x-ray radiation incident upon its surface. First, an electronic switch is closed and the capacitor is charged (Q_0) (Fig 5a). Next, the electronic switch is opened (Fig 5b). Because no light is incident upon the surface of the DEL, the charge remains on the capacitor, which stores the initial charge, similar to the way a bank stores money. The interaction of x-rays with the scintillator produces light in proportion to the x-ray flux. This light causes the photodiode to conduct to different degrees, depending on the intensity of the light: As more light is produced, more charge is drained from the capacitor (ε), like a bank withdrawal of money (Fig 5c, 5d). Finally, another electronic switch is closed and the remnant charge ($Q_0-\varepsilon$) is withdrawn from the storage capacitor and sent to the display system (Fig 5e). The loss in charge (ε) is related to the amount of x-ray radiation incident upon the DEL. By reading each DEL in the FPD array row by row, an electronic image of the distribution of x-rays that are incident upon the FPD can be formed. In this way, an FPD array may be used to create an image without the use of a television camera.

Advantages and Limitations of Image Intensifier Systems

There are a number of limitations associated with the use of an image intensifier and a television camera tube for formation of fluoroscopic images. First, image intensifiers are fairly large in size, which may make it difficult to position the unit during fluoroscopy procedures. The internal structure of the image intensifier must be under high vacuum. Air leakage into the image intensifier would interfere with the transit of electrons between the photocathode layer and the output phosphor and would degrade image quality. If the voltage of each electrostatic plate is not adjusted correctly, the electrons will not pass through the appropriate focal point of the image intensifier, causing the image to be blurry with a loss of spatial resolution; this blurriness is referred to as a

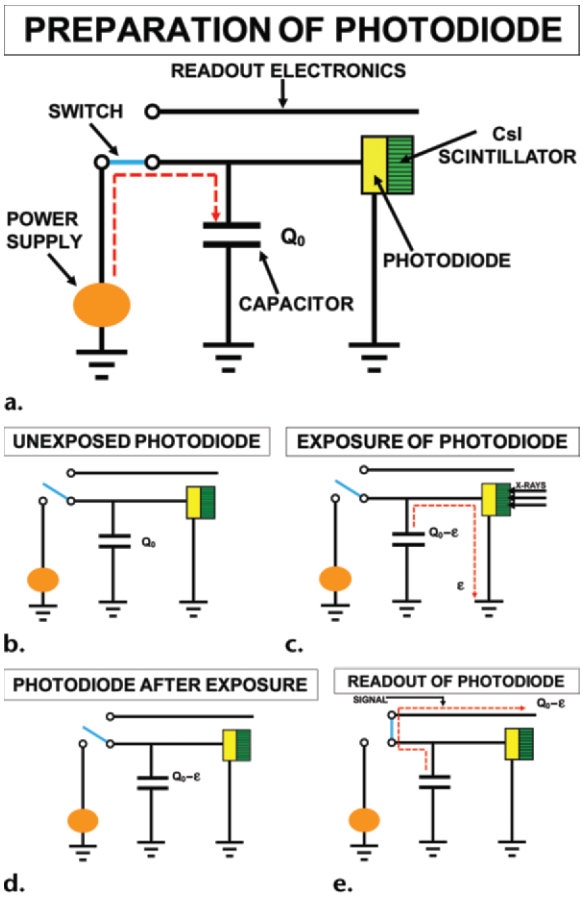


Figure 5. Diagrams show the manner in which each DEL records the x-ray flux incident upon its surface. **(a)** The initial preparation of a photodiode involves charging the capacitor attached to the DEL. **(b)** The switch is opened, and the charge (Q_0) remains on the capacitor or DEL. **(c)** X-rays interact with the scintillator layer and produce light, which causes the photodiode to conduct. Some of the charge on the capacitor (ε) is discharged, leaving a remaining charge of ($Q_0-\varepsilon$). **(d)** After x-ray exposure, the capacitor on the DEL has a remaining charge of ($Q_0-\varepsilon$). **(e)** The switch closes, and the charge remaining on the capacitor flows to the readout electronics, which measure the change in the charge caused by x-ray radiation. A light then flashes to totally discharge the capacitor on the DEL. This entire process is repeated many times per second.

defocusing effect. The focusing voltages may drift over time, requiring readjustments to achieve the desired spatial resolution. Other defocusing effects may be attributed to magnetic field variations such as rotation of the image intensifier within the earth's magnetic field (or due to the

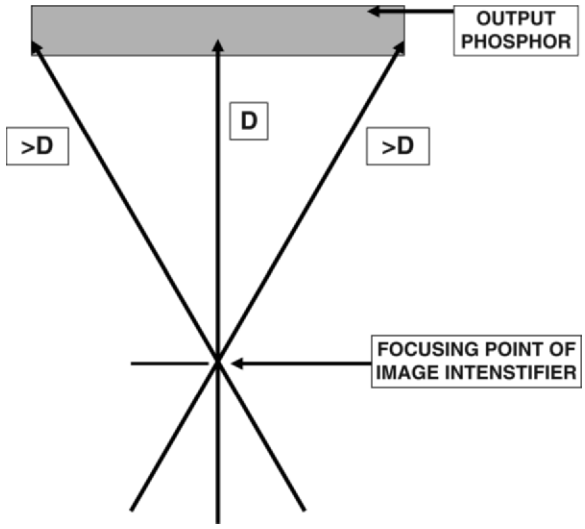
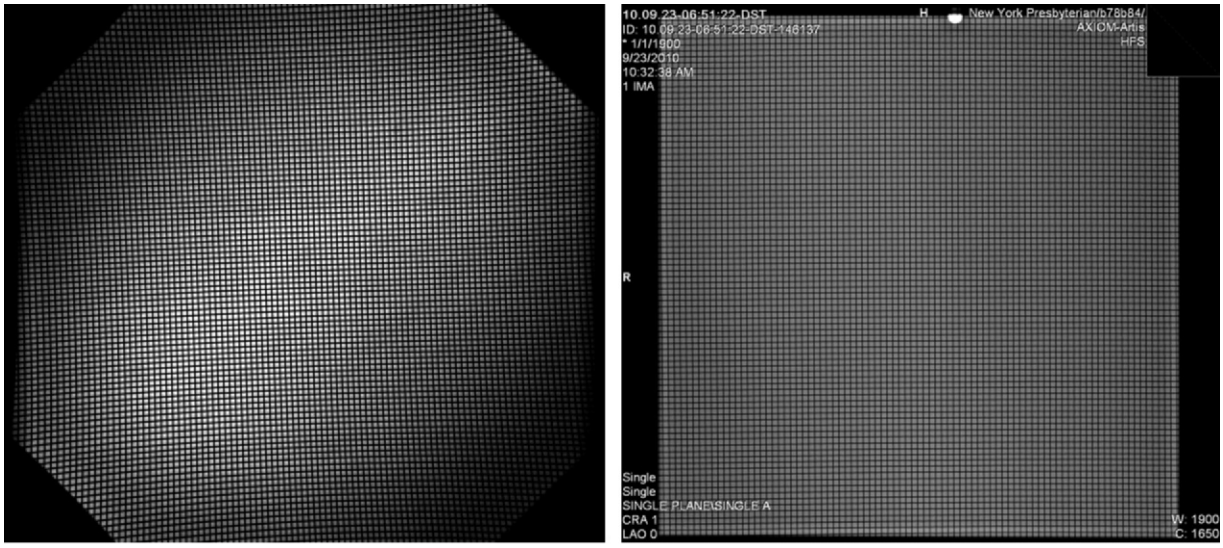


Figure 6. Drawing shows the geometry of the image intensifier from its focusing point to output phosphor. Longer distance *(D)* to the surface leads to distortion and less light at the periphery, an effect known as vignetting.

presence of a nearby magnetic device such as a magnetic resonance imager) and variations of stray electromagnetic fields from other electronic devices such as power supplies. Image intensifiers often are shielded with mu-metal to minimize the distortions caused by magnetic and electromagnetic fields; however, these degradations are seldom completely eliminated.

Geometric features of the image intensifier also may cause distortion. Engineering design may allow the path lengths from the curved input surface of the image intensifier to the focus to remain constant. However, because the output phosphor surface is flat, the distances from the focal point of the image intensifier to its output surface are not the same; distances to the periphery of the output surface are longer than they are to the center (Fig 6). Because the path lengths to the periphery of the output phosphor are longer, images of linear structural lines such as wire screens (a mesh test tool) appear curved. These deformations are referred to as *pincushion effects* and *S distortions*. Moreover, these longer paths reduce the concentration of electrons that impact



a. b.

Figure 7. Comparison of images depicting a uniform wire mesh pattern obtained with image intensifier and FPD fluoroscopy systems. **(a)** Image obtained with an image intensifier fluoroscopy system shows distortion of the lines and vignetting, in which the center of the image is brighter than the periphery. **(b)** Image obtained with an FPD fluoroscopy system accurately depicts the straight lines, and the background intensity is uniform.

the periphery of the output phosphor, which causes the center of the output phosphor to be brighter than the periphery. This phenomenon is referred to as *vignetting* (Fig 7).

The television system itself is another limitation of image intensifier fluoroscopy systems. The spatial resolution that is directly measured at the output phosphor of the image intensifier is inherently good, at 5 line pairs per millimeter or more. However, the resolution of the television system is limited by the number of display raster lines and its bandwidth frequency. When a large FOV (eg, 40 cm) is used, the visible spatial resolution obtained through the television system is approximately 0.5–0.8 line pair per millimeter for a 525–raster line television system and approximately 1.0–1.5 line pairs per millimeter for a 1023–raster line system. However, the spatial resolution of image intensifier fluoroscopy systems increases with the use of higher magnification modes (smaller FOVs). For instance, with a 12-cm FOV, the spatial resolution that results from the television raster line limitations dramatically improves to approximately 1.8–2.5 line pairs per millimeter for a 525–raster line television system and approximately 3.5–4.5 line pairs per millimeter for a 1023–raster line television system. (The values for spatial resolution are for the surface of the image receptor. Because focal spot blur and geometric magnification of the object affect the spatial resolution, values obtained at the patient's position are slightly different.) In other words, the spatial resolution of an image intensifier fluoroscopy system varies depending on the magnification mode (the selected FOV) that is used. Figure 8a is a graph that plots the spatial resolution at the surface of the image receptor for two different image intensifier systems (525 and 1023 raster line–systems). Smaller FOVs provide better spatial resolution, which enables visualization of smaller anatomic structures and vessels (Fig 8a).

Because smaller FOVs of the image intensifier have less minification gain, patient radiation dose rates usually are increased to maintain similar image noise (mottle) for all magnification modes. The radiation dose rates into the image intensifier usually increase at a rate of $1/(\text{FOV})^2$. However, the magnitude of the radiation dose rates depends on the engineering design of the fluoroscopy system; various combinations of increases in kilovolt peak, milliampere, x-ray beam filtration, and fluoroscopy pulse width may be used to increase the radiation to the input surface of the image intensifier (11,12). In general, increases in patient radiation dose range from approximately 1.4 to 2.0 times for each decrease in FOV (magnification mode). To achieve better spatial resolution with an image intensifier fluoroscopy system, patient radiation doses must be substantially increased and the FOV reduced. The relationship between FOV and patient entrance radiation dose is illustrated in the graph in Figure 9 and compared with a FPD system.

Another limitation of the image intensifier fluoroscopy system is its dynamic range, the ratio of the highest input radiation level to the image receptor (without saturating) to that of the lowest

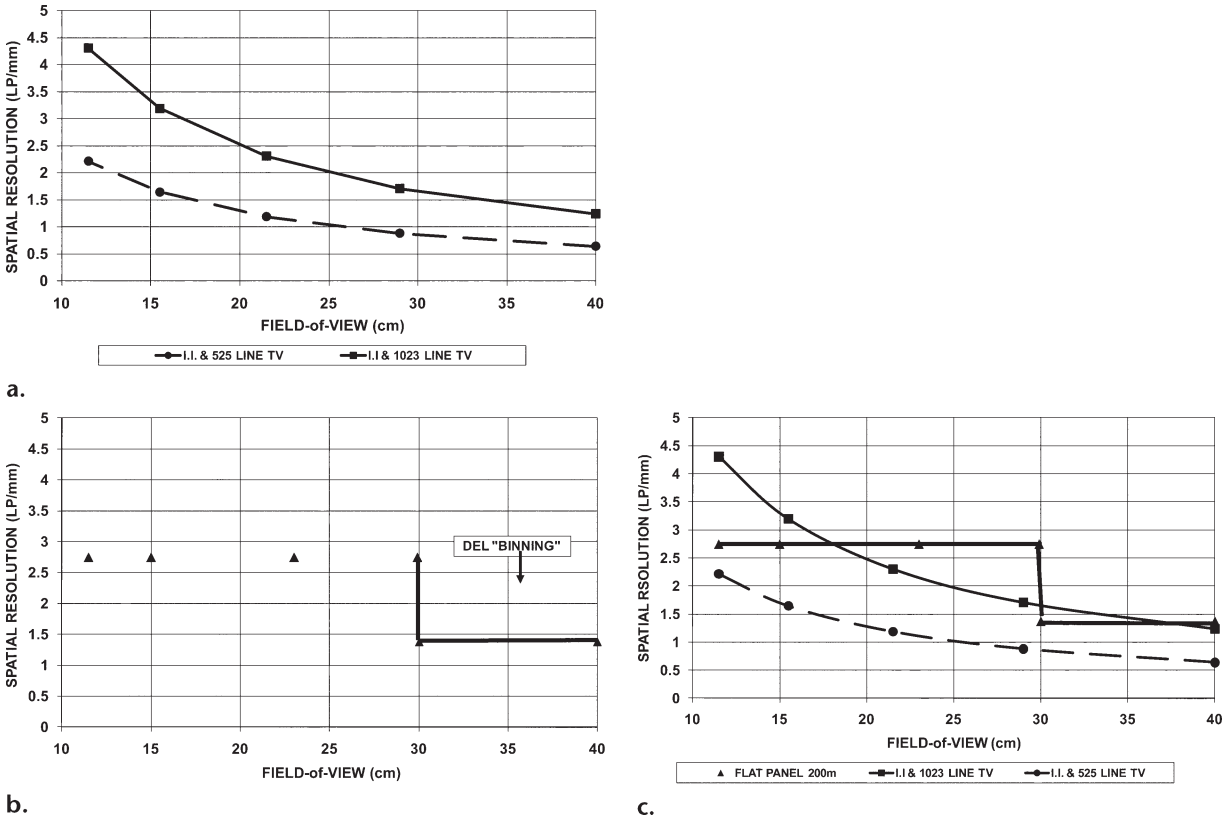


Figure 8. Comparison of measured spatial resolution of image intensifier and FPD fluoroscopy systems. **(a)** Graph plots the spatial resolution at the surface of the image receptor for a 525–raster line (dashed line) and 1023–raster line (solid line) fluoroscopy system as a function of the selected FOV. Spatial resolution for an image intensifier fluoroscopy system depends on the FOV (magnification mode) selected and the number of raster lines of the television system. Use of a small FOV and a large number of raster lines improves spatial resolution. **(b)** Graph plots the spatial resolution of an FPD system (pitch, 200 μm). Spatial resolution decreases with the use of large FOVs and binning, which reduces the data rate. When binning is not employed, the spatial resolution is the same for all FOVs because it is related to the size of the DEL. **(c)** The graphs in parts **a** and **b** are superimposed to show the spatial resolution of both image intensifier (dashed line, solid line with squares) and FPD (solid line with triangles) systems.

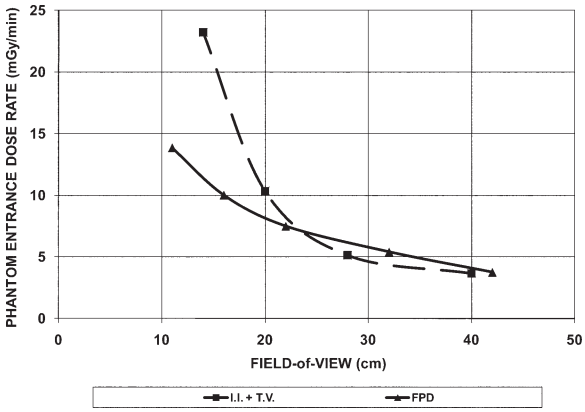


Figure 9. Graph plots the entrance radiation dose rates to a phantom of the image intensifier (dashed line) and FPD (solid line) fluoroscopy systems as a function of the selectable FOVs for a fluoroscopy pulse rate of 15 pps in normal dose mode. The phantom simulates a typical patient.

level (just above the noise level) at which the unit can operate properly. If a portion of the incident x-ray beam passes through low-density anatomy such as the lung or air external to the body, the higher x-ray flux into the image intensifier will cause the system to saturate. Image intensifier systems have a much lower dynamic range than FPD systems.

The bright areas of saturation in the display make it difficult to visualize adjacent structures, a phenomenon referred to as *flare* or *veiling glare* (Fig 10). Because both the image intensifier and television system utilize analog (continuously variable) electronic signals, their images contain more electronic noise than those of digital systems. Some analog fluoroscopy systems use an analog-to-digital converter to digitize the television output signal; however, noise is already present in the signal before it is digitized. In combination with the limited dynamic range, image noise also affects the visualization of very-low-contrast structures in the body.

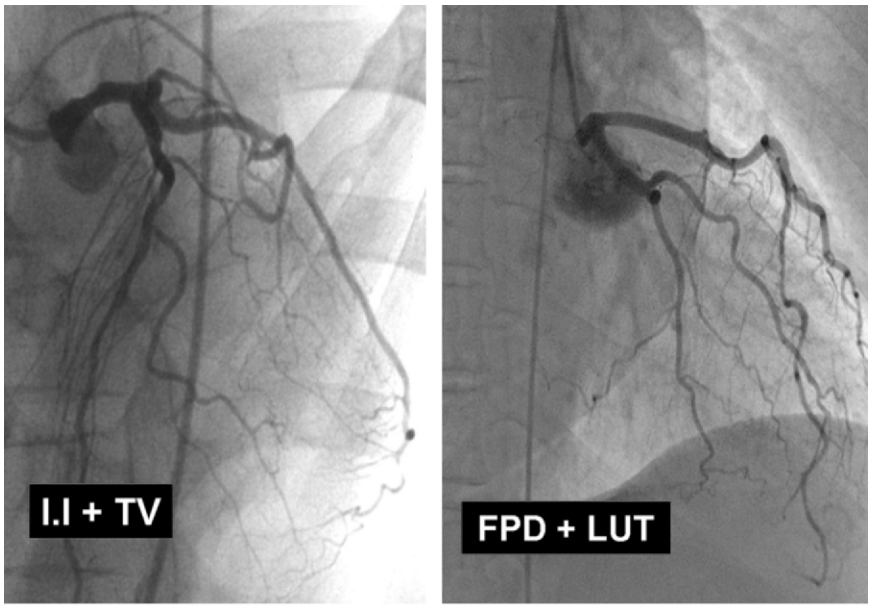


Figure 10. Brightness saturation. **(a)** Image obtained with an image intensifier fluoroscopy system clearly shows glare. Image intensifier systems have limited dynamic range. **(b)** Image obtained with an FPD fluoroscopy system shows a decrease in glare, which is achieved by using a look-up table *(LUT)*.

Considering all these limitations, it is amazing that the older technology of image intensifier fluoroscopy systems have performed so well clinically for many decades. Modern FPD fluoroscopy systems have overcome many of these limitations, but they have their own unique deficiencies.

Advantages and Limitations of FPD Systems

Many of the degradations associated with the use of combined image intensifier and television camera systems are not present in images obtained with FPD fluoroscopy systems. Images obtained with FPD systems also do not exhibit geometric deformation such the "pincushion" effect and S distortion because the individual DELs in the FPD array are manufactured in straight rows and columns. Consistent production techniques and appropriate software calibration ensure excellent uniformity; the vignetting that occurs with the use of image intensifier systems is not present in images obtained with FPD systems. In addition, because each DEL is fixed in a constant position, images obtained with FPD systems do not exhibit defocusing effects.

Other advantages of the FPD system include its smaller size, which makes it easier to position during clinical studies, and its solid-state design, which makes it more reliable. FDP systems do not require a television camera to convert the x-ray intensity distribution into an electronic signal; an electronic signal automatically emerges from the image receptor. Moreover, the video signal emerges from the device in a digital format, which reduces electronic noise.

Teaching Point

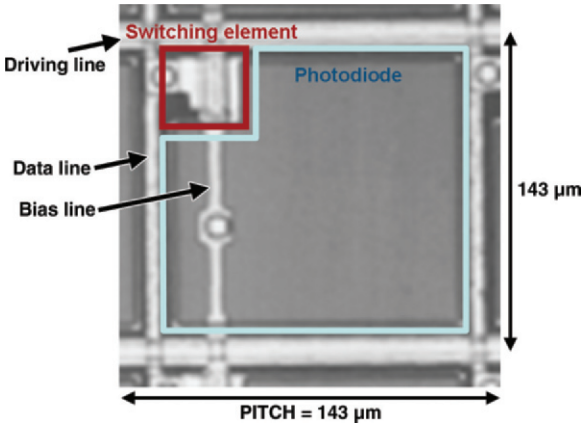


Figure 11. Illustration shows the layout of the switching mechanism on the photodiode surface of an individual DEL in an FPD array. The sensitivity and efficiency of the detector depend on the size of the area subtended by the switching transistors and conductor lines.

FPD fluoroscopy systems have their own unique limitations. As was previously mentioned, it is difficult to manufacture an FPD array that contains no defective or degraded DELs; if there are too many defective DELs, image quality suffers. Manufacturers of FPD systems often compensate for defective DELs by using software to interpolate values for those defective elements. However, this interpolation may introduce artifacts. Moreover, FPD systems usually are temperature sensitive, and the im-

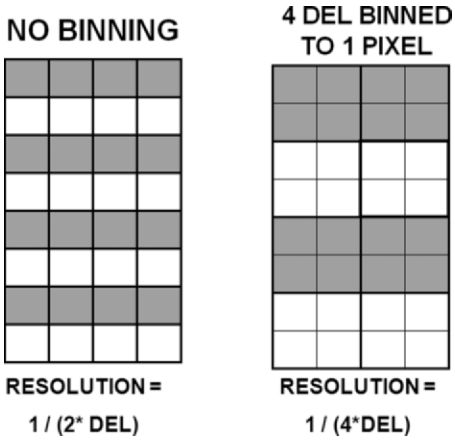


Figure 12. Diagrams illustrate binning. By grouping four DELs together, the data rate is reduced and the surface area is increased. However, the spatial resolution to display line pairs is also reduced.

Amount of Data and Data Rates for FPD Arrays of Different Sizes

FOV (cm)	No. of DELs* (Pixels)†	Image Size* (MB)	Data Rate‡ (MB/sec)
10 × 10	0.25	0.5	15
20 × 20	1.0	2.0	60
30 × 30	2.25	4.5	135
40 × 40	4.0	8.0	240

*Assumes 2 bytes per DEL. DEL size is 200 μm on each side.
†Data are in millions.
‡All data rates are at 30 frames per second.

ages may be affected by changes in temperature. FPD detector arrays also are sensitive to mechanical shocks, which can permanently damage the device. Damaged FPD systems can be expensive to replace.

Teaching Point

Another limitation of the FDP system is its spatial resolution, which is influenced by the size of its DEL (pitch) and by a process called *binning*. The pitch is the actual distance between the centers of two adjacent DELs. The best spatial resolution that may be obtained by an FPD is related to the size of the DEL; this spatial resolution is equal to 1 divided by twice the DEL size (in millimeters):

$$\text{maximum spatial resolution} = 1 \div (2 \times \text{pitch}).$$

In actual practice, the maximum spatial resolution is about 75%–80% of this value because of misalignment of the line-pair pattern with the individual pixels during measurement procedures. By rotating the test pattern to 45° with respect to the rows of the FPD, the spatial resolution lost to misalignment is regained. The typical spatial resolution of most FPD arrays is approximately 2.5–3.2 line pairs per millimeter if the test pattern is placed at 45° (13).

One may conclude that manufacturers of FPD arrays should reduce the size of the DEL to improve spatial resolution. However, the switching and readout electronics plus the etched data lines on the circuit occupy a portion of each DEL; only a fraction of the total surface area is used to form the image (Fig 11). Some of the x-ray radiation is incident on readout electronic elements and is not used in image formation. The actual fraction of the incident radiation that is available for image formation is called the fill factor:

$$\text{fill factor} = \frac{\text{sensitive area of DEL}}{[(\text{pitch}) \times (\text{pitch})]}.$$

As the pitch of the DEL decreases, the readout electronics constitute a larger portion of the total surface area, and the efficiency (fill factor) of the DEL drops dramatically. Even normal-sized DELs have an efficiency of only 60%–80% for the use of incident x-rays, and smaller-sized DELs are much less efficient. In addition, the amount of radiation incident upon each DEL decreases as its size decreases. For these reasons, although smaller-sized DELs improve the achievable spatial resolution, the images would have more mottle (noise) and would thus require more radiation to reduce this mottle.

Another factor to consider is that large FPD fluoroscopy systems have considerable data rates. For instance, a 40 × 40-cm FPD system may produce an image composed of 4 million pixels (DELs), an image size of 8 MB, and a data rate as high as 240 MB/sec (Table). Large data rates such as these are difficult for electronic systems to handle. To reduce the size of data rates, manufacturers group the data from four DELs together for larger FOVs, a process called binning (Fig 12). Grouping four DELs together reduces the data rate to 25% of the ungrouped rate for large FOVs. Binning has the disadvantage of less spatial resolution because the effective area of each image pixel is four times larger, and it has the advantage of lower data rates and less image mottle than ungrouped DELs.

For smaller FOVs, collimation is used to select only the central portion of the FPD for imaging, which is similar to the process used with image intensifier fluoroscopy systems; thus, information from a smaller anatomic area is spread across the display monitor or magnified (Fig 13). When smaller FOVs are used, the data rate is lower, and binning is no longer required. Unlike image intensifier fluoroscopy systems, the spatial resolution of FPD fluoroscopy systems is the same for all FOVs—if no binning is employed. For those larger FOVs when binning is employed, the spatial resolution dramatically decreases to 50% of the value without binning; this process is illustrated in Figure 8b for a system with a pitch of 200 μm. Figure 8c compares the spatial resolution at the surface of the image receptor for an FPD fluoroscopy system with an image intensifier system. For FPD systems, there is a dramatic, discrete step change in spatial resolution between small and large FOVs.

In addition, for FPD systems, the radiation dose levels to the patient could potentially be the same for all FOVs. The size of pixels (DELs) is the same for all FOVs (provided that binning is not employed); therefore, the amount of x-ray flux on each DEL is the same for all FOVs. Unlike with image intensifier systems, which progressively use more radiation as the FOV decreases, there is no reason to increase the radiation to the image receptor as the FOV is changed. Nevertheless, most vendors of FPD fluoroscopy systems increase the radiation to the image receptor at a rate of approximately 1/FOV (Fig 9). With the selection of smaller FOVs, the dose rates are gradually increased by the FPD system. With smaller FOVs, magnification of the surface area makes the image noise more apparent to the eyes of the observer. In FPD systems, increased radiation for smaller FOVs is used to reduce the optical perception of noise. However, this increase in radiation is substantially less than that used with image intensifier systems (Fig 9). Unlike in image intensifier systems, the thickness of the CsI layer may be increased without substantially degrading spatial resolution of images obtained with FPD systems. For these reasons, FPD fluoroscopy systems are more efficient and tend to require less radiation than image intensifier systems.

Teaching Point

Finally, FPD systems have a large operational dynamic range, about 60 times larger than that of image intensifier systems (Fig 14). For this reason, FPD systems do not exhibit flare or veiling glare, which degrade image quality.

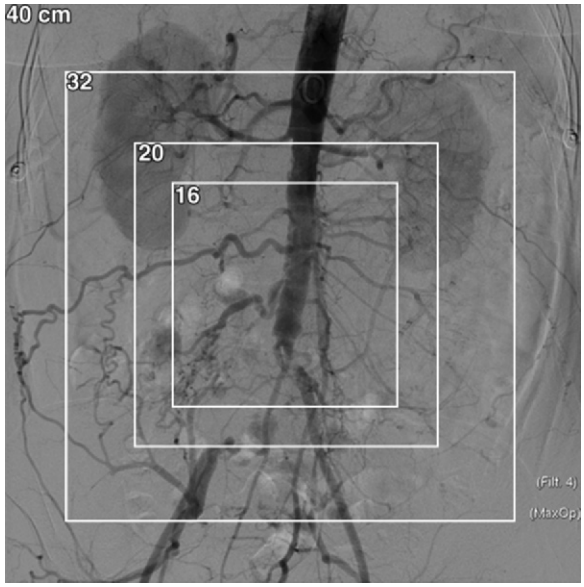


Figure 13. Use of smaller FOVs in an FPD fluoroscopy system. Image obtained with an FPD system shows several possible FOVs. To achieve a smaller FOV, the x-ray collimator blades close to select data from a smaller central portion. These data are then displayed across the entire viewing monitor.

Additional Important Features of Image Intensifier and FPD Systems

There are a number of features that are common to both image intensifier and FPD fluoroscopy systems, some of which are detrimental and some of which are beneficial. Both systems exhibit image persistence or "ghosting" (14). Because the phosphorescent light of the scintillation surfaces undergoes a period of decay, light emissions from a previous image may persist as a "ghost" and degrade image quality. FPD systems use a bright internal light source that flashes to reset the scintillation surface to background levels and an offset current to neutralize the ghost signal. Another source of ghosting in both types of fluoroscopy systems is recursive software filtration of the sequential fluoroscopy images, which adds a portion of several previous fluoroscopy frames to the current image (15). However, image mottle (noise) is a random process, and the image signal often is at a fixed location. Thus, the final result is more signal and less noise because the signal from various image frames adds together while the noise tends to cancel itself and is reduced. Selectable software parameters allow different weighting factors to be used when adding previous images to the current image (Fig 15). For static anatomy, the use of recursive filtration

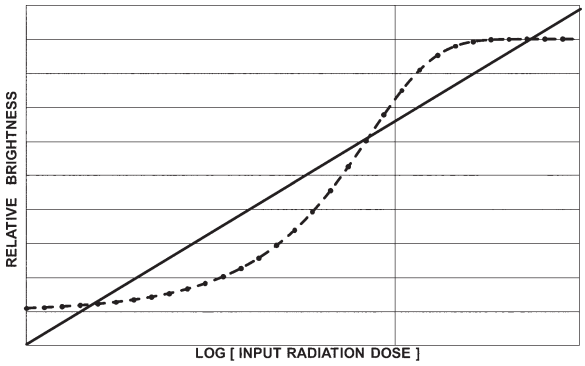


Figure 14. Graph plots the dynamic ranges of an image intensifier (dashed line) and FPD (solid line) fluoroscopy system; the dynamic range of the image intensifier system is smaller than that of the FPD system, which better displays the various radiation levels transmitted to the patient. Image intensifier systems saturate at high radiation levels and display all low radiation levels at the same minimum density on the monitor.

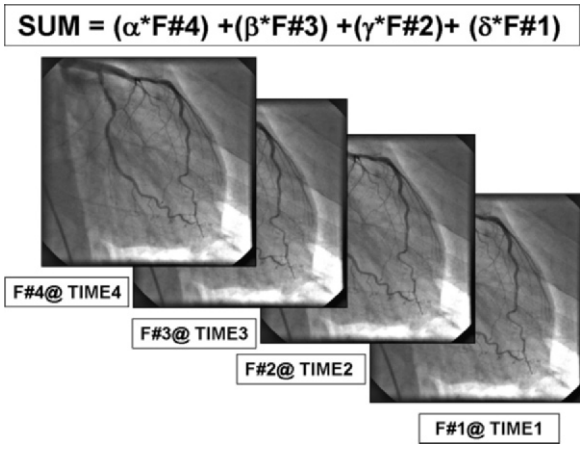


Figure 15. Recursive filtration. Successive fluoroscopy images show recursive filtration, in which a portion of the signal from several previous fluoroscopy frames is added to the signal of the current image to improve SNR without increasing radiation dose.

improves the signal-to-noise ratio and improves image quality. For moving anatomic structures or contrast media, recursive filtration may add objects from a previous image that are now at a different location, creating "ghost" images.

Modern fluoroscopy systems have a number of software features that are critical to reaching the achievable image quality. The use of edge enhancement software may improve visualization of vessels and other anatomic structures, and density equalization software has selectable parameters to reduce the contrast of bright areas, reduce flare, and boost the brightness of dark areas (11,16,17). Other software include selectable parameters that modify the manner in which the contrast of imaged structures is displayed, a feature similar to a continuously adjustable characteristic curve for the display system.

Modern fluoroscopy systems also have a number of features intended to reduce patient radiation dose rates. Pulse fluoroscopy may reduce radiation levels to the patient and image degradation caused by motion blur (11–13,18,19). Copper filtration is used to preferentially remove the lower-energy x-rays that do not effectively penetrate the patient's tissues (20,21). New automatic dose rate control (ADRC) systems modulate milliampere, kilovolt peak, pulse width, and filtration in a manner aimed at minimizing patient dose rates while maintaining good image quality (22). Moreover, different ADRC programs are available to optimize the imaging of different anatomic regions. Modern fluoroscopy systems also have automatic positioning systems, which eliminate the amount of fluoroscopy time required to properly position the system for various imaging procedures (23). Dose-area product (DAP) meters that display cumulative dose are required on all new fluoroscopy systems in the United States (24). These meters measure the product of the dose and the size of the x-ray field at a point in space that represents the patient's entrance surface for the entire fluoroscopy procedure. Even though the imaging device is rotated and moved to various anatomic locations, DAP meters and other dose-calculating systems monitor the total amount of radiation delivered; physicians performing long and complex procedures can use such devices to avoid delivering excessive radiation to the patient.

The newest innovation to modern fluoroscopy systems is rotational three-dimensional imaging, in which the gantry of an angiography system rapidly rotates through 180° while continuously acquiring images (25). The resultant cine display resembles a volume-rendered computed tomographic image and may be used by physicians to better understand the geometric location of various contrast material–filled vessels.

Summary

Modern fluoroscopy systems have undergone many significant advances. One major improvement is the introduction of FPD arrays, which

replace image intensifiers and television cameras. FPDs are smaller than image intensifiers, a characteristic that allows for more flexible positioning of the angiography and cardiac fluoroscopy systems. Solid-state FPD image receptors generally have better stability, lower radiation dose rates, and improved dynamic range, and they eliminate glare and geometric distortions such as vignetting and defocusing effects.

Teaching Point

Teaching Point

The disadvantages of FPD systems include higher costs, lower spatial resolution with very small and very large FOVs, and a different appearance of the displayed image compared with that of images from image intensifier fluoroscopy systems.

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AAPM/RSNA Physics Tutorial for Residents: Physics of Flat-Panel Fluoroscopy Systems

Survey of Modern Fluoroscopy Imaging: Flat-Panel Detectors versus Image Intensifiers and More

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Page 598
FDP systems do not require a television camera to convert the x-ray intensity distribution into an electronic signal; an electronic signal automatically emerges from the image receptor.

Page 599
Another limitation of the FDP system is its spatial resolution, which is influenced by the size of its DEL (pitch) and by a process called *binning*.

Page 600
For these reasons, FPD fluoroscopy systems are more efficient and tend to require less radiation than image intensifier systems.

Page 602
Solid-state FPD image receptors generally have better stability, lower radiation dose rates, and improved dynamic range, and they eliminate glare and geometric distortions such as vignetting and defocusing effects.

Page 602
The disadvantages of FPD systems include higher costs, lower spatial resolution with very small and very large FOVs, and a different appearance of the displayed image compared with that of images from image intensifier fluoroscopy systems.