Choosing x-ray detectors

Issues

Using Digital Radiographic imaging to view moderate- or large-size objects

To see fine detail in small object scanning with either DR or CT

Using Computed Tomography (CT) to see fine object detail at different imaging output rates

CT production and other applications with high duty factor considerations

Extremely low signal rates through dense objects

Detector technical descriptions

Discrete detectors

Area detectors

Semiconductor chips

Flat panels

Image intensifiers

Linear Detector Array, top off

Imaging Requirements.
In choosing a detector to be able to see the kind of image detail you require, it's important to know that there is no single type of detector that is best for every requirement. Which detector to choose depends on:

- The size of the object you want to scan
- The material the object is made of
- The level of fine detail or density differences you want to see
- How fast you want to see the results
- The voltage, current, and spot size of the x-ray source
- The scanning technique (2D or 3D), DR or CT

Using Digital Radiographic (DR) imaging to view moderate- or large-size objects.
If the object to be scanned is moderate in size, less than 45 cm in its largest dimension, and cannot be panned during examination, a scan can be accomplished with one panel; if more than 45 cm, butted CMOS flat panels are required. (Single or multiple panel configurations are possible, depending upon object size.)

BIR, Inc., 425 Barclay Boulevard, Lincolnshire, IL 60069 TEL: 847.279.5100 FAX: 847.279.4900 EML: marketing@birinc.com WEB: www.birinc.com

ACTIS CT System with amorphous silicon Flat Panel

If the object is not very dense, so it requires less than 300 kV of x-ray source penetrating power, an image intensifier is a good choice because it will provide longer life vs. radiation damage, as well as well defined images.

Image Intensifier, side view

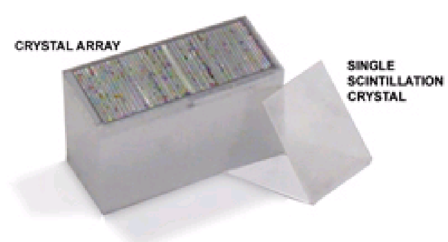
For large or denser objects which need to be imaged so that fine differences in density or thickness can be seen, higher voltages are required. Consider scanning with a scintillator-photodiode linear array detector.

Back to top

To see fine detail in small object scanning with either DR or CT.
Choose a flat panel or image intensifier in combination with either a mini- or micro-focus x-ray source. Use magnification where the source-to-detector distance is greater than the source-to-object distance.

Back to top

Using Computed Tomography (CT) to see fine object detail at different imaging output rates.
If sensitivity to small density differences is required, use a scintillator-photodiode linear array or multiple-row array to get high dynamic range.



When speed (but less dynamic range) is required, and at moderate x-ray source voltages (130 kV to 225 kV), an image intensifier offers up to ten times faster data collection than a flat panel.

For larger or denser objects requiring higher penetrating voltages, over 300 kV, a scintillator-photodiode linear array detector may actually be faster because it can capture 30 to 60 times more photons than the evaporated scintillator coatings on flat panels, image intensifiers, or than the intrinsic detectors using amorphous selenium. Also, in Si-based flat panels, photons that stop in the silicon rather than the scintillator cause excess image "noise."

Back to top

CT production and other applications with high duty factor considerations.
Radiation damage to the detector is the problem in high duty factor applications. Scintillator-photodiode detector arrays often have the advantage with performance unaffected by megarads. The same is true of CCD detectors which by design are kept out of the x-ray beam utilizing fiber-optics couplers. If a flat panel is chosen, it is important to make sure its design shields its electronic components from the x-ray beam. Even then, sensitive flat panel semiconductors may degrade with time.

Back to top

Extremely low signal rates through dense objects.
Scan times need to be increased. A detector array utilizing scintillator crystals with photodiodes allows counting of individual photons and essentially infinite dynamic range. Images with greater detail and contrast accuracy can be generated.

Back to top

Detector technical descriptions.

There are two main detector categories: discrete detectors and area detectors. Each category has many different application specific variations.

Discrete detectors.
In CT, the earliest scanners used pressurized xenon. Ions created in the gas by x rays were collected on parallel plates connected to amplifiers. Some recent versions use tungsten plates in which the x rays knock out electrons, which in turn gives rise to ion currents in the gas; others use bundles of gas-filled, small-diameter tubes.

Today, almost all discrete detectors consist of many individual scintillators that convert x-rays to light; these are coupled to photoconverters that convert the light to an electrical signal. Where the x-ray signal is weak, individual photons can be counted in photomultiplier tubes or avalanche diodes. More commonly, the current in photodiodes is sensed. Originally available only in linear arrays with a single row, they are now obtainable in area arrays with dozens of rows.

Dual-slice Linear Detector Array

The advantages of discrete detectors are:

• Their scintillators can be as deep as desired along the x-ray path, so that most of the x rays are captured, this shortens acquisition times, especially at higher energies

- Because of the individual scintillators, they have very little optical crosstalk
- The scintillators are separated by absorptive septa of tungsten or other heavy metals, so x-ray crosstalk is also low
- By extending the septa forward of the scintillators to form collimators, x-ray scatter is almost completely eliminated
- All components have high dynamic range, 16 to 21 bits. Since the dynamic range is not degraded by scatter or crosstalk, it is possible to see small density changes—as little as 0.1%
- System readout is fast, as short as a microsecond. It can also be gated to ignore noise between the pulsed outputs of linear accelerators (LINACs)
- They are less susceptible to radiation damage

The disadvantages of discrete detectors are:

- Since they are individually made, pixels cannot be as small as those from area detectors. The smallest linear arrays have a pitch of 75 microns, and the smallest 2D arrays have a pitch of 1000 microns
- They often (but not always) cost more

Back to top

Area detectors.

There are three main types: high-resolution semiconductor chips, flat panels, and image intensifiers. The semiconductor chips are usually CCD or CMOS. CMOS chips can convert x rays directly, but CCDs cannot, so they must be preceded by a scintillator.

Back to top

Semiconductor chips.
These chips have pixel pitches as little as 7 microns (13 microns is more common), and arrays of up to 4080 by 6120 pixels. Pixels can be grouped 2 by 2 or more to increase signal. Though the area of CCD chips is small (up to 51 mm by 76 mm), their effective area can be increased if their scintillator is coupled to them through lenses or tapered fiber optics. Such optical arrays can be used to form large areas, like replacements for medical film cassettes. As mentioned previously, they can be protected from radiation degradation if kept out of the x-ray beam by slanted linear fiber optics. Slanted linear fiber optics also permit optical butting, so detectors can be 76 mm wide by any length. Readout times for chips depends on size and the extent to which pixels are grouped, but 15 or 30 frames/second is common.

The advantages of semiconductor chip detectors are:

• Smallest available pixel size

• Can be completely out of the x-ray beam, for no radiation damage

• Relatively fast readout

• With linear optical butting, can form arrays thousands of pixels wide by millions of pixels long

• With lenses or tapered optical butting, can form arrays of any size

• Can tradeoff resolution and readout time by grouping pixels; this can be under software control for versatility

The disadvantages of semiconductor chips are:

• Linear optical butting can only form strip arrays not wider than their greatest dimension

• When optically butted with tapered fiber optics or lenses, require software for both distortion and edge correction

• Scintillators are limited to screens or vacuum-deposited CsI, with reduced x-ray efficiency above 150 kV

• Larger arrays are physically fragile

Back to top

Flat panels.
These detectors are usually amorphous silicon or amorphous selenium, or CMOS based. The former require a scintillator, commonly evaporated columnar cesium iodide, obtainable up to 400 microns deep; the latter can be used as an intrinsic detector.

Pixels sizes are 127 and 200 microns, though smaller pixels are on the horizon. Sizes range from 10 by 15 cm to 35 by 45 cm; some CMOS panels can be butted. For lower energy, the data collection and amplification electronics are under the panel; for higher energy, they must be off to the side to avoid radiation damage. Readout times are 3 to 7.5 frames/second.

Flat panel detector with shielded electronic components

The advantages of flat panels are:

• Simple assembly and readout

• No image distortion

• Mechanically rugged

The disadvantages of flat panels are:

• Relatively slow readout time

• Scintillators are limited to screens or vacuum-deposited CsI with reduced x-ray efficiency above 150 kV

• Limited dynamic range, often further reduced by crosstalk and scatter

• Susceptibility to radiation damage

Back to top

Image intensifiers.
These vacuum devices are available from 10 cm to 50 cm diameter. Light from their scintillator coating causes cesium inside the top surface to emit electrons that are concentrated onto a fluorescent output screen; the latter is viewed by a camera, via a mirror that keeps the camera out of the x-ray beam. Resolution in 15 cm and 23 cm models can be 6 to 7 line pairs per mm, corresponding to pixel sizes of 83 or 70 microns. Readout rate is 15 or 30 frames/sec, and it is easy to add frames to reduce noise.

The advantages of image intensifiers are:

• Very good resolution

• Simple assembly and readout

• Fast readout

• Not susceptible to radiation damage

The disadvantages of image intensifiers are:

• Physically fragile

• Scintillators are limited to screens or vacuum-deposited CsI with reduced x-ray efficiency above 150 kV

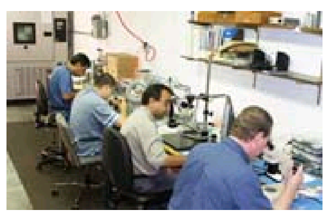
• Limited dynamic range

• Require software for distortion correction

Back to top

Conclusion.
BIR has more experience than anyone else in building systems with image intensifiers, photodiodes, flat panels, and dozens of different types and geometries of discrete detectors. We have covered the range from 60 kV to 9 MV, and from millimeter-sized specimens to entire truck trailers. Our systems and their detectors will give you what need—images you can trust—not a compromise based on a single product line. If your application is different from any of the above examples, or if you aren't sure how to get the most out of a CT or DR system, ask BIR.

Back to top



BIR detector laboratory