LOOKING INTO THE FUTURE

PHOTOGRAPH BY JIM KARAGEORGE

Digital X-Ray Imaging

Digital technology has revolutionized our lives. We are collecting, storing, analyzing, and using more and more information at a faster and faster pace. X-ray imaging is no exception, whether it is for medical diagnosis, security screening, or industrial inspection. The benefits of digital X-ray imaging are clear. Doctors are already using it to see "real-time" movies of their patients' anatomy and physiology. They can watch blood flowing through vessels and into organs or monitor the gastrointestinal tract to diagnose conditions that require treatment. Better still, doctors are using this imaging capability during treatment to see exactly where to target cancerous tumors with radiotherapy beams or where to place the instruments and devices that will cure their patients.

The value of this real-time X-ray vision goes beyond medicine to many other scenarios, including industrial inspections in which technicians take instant snapshots of the internal structures of objects such as electronic circuits and mechanical parts.

While progress has been rapid in recent years, companies like Varian Medical Systems are now using solid-state digital technology in the form of amorphous silicon flat-panel X-ray detectors to achieve even more dramatic improvements that will extend the utility of digital X-ray imaging systems. These panels obtain instant high-resolution "still" X-ray images (radiographs) as well as "live," or moving, X-ray images (fluoroscopy) for display on computer monitors or storage in electronic archives.

Today, most medical centers are still hampered by a continuing reliance on film for obtaining, displaying, and storing radiographic X-ray images. In the digital age, this technological relic of the analog age is viewed as inefficient; it requires processing chemicals, storage space, and perhaps most important – time. Other centers are digitizing X-ray images using computed radiography, which requires several time-consuming steps before an image can be viewed. Furthermore, many centers rely entirely on separate systems for obtaining fluoroscopic images.

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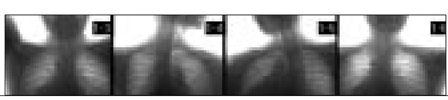


Hospitals have been generating live fluoroscopic images for years, using X-ray systems equipped with image-intensifier tubes. This now-common approach, which has been evolving since the first image intensifiers were introduced in the 1960s, has resulted in an annual multi-million dollar image-intensifier tube industry. The technology has some drawbacks, however. Image-intensifier tubes generate circular images that suffer from a loss of resolution at their periphery. Furthermore, the up-to-100-pound heft and barrel-shaped bulkiness of these tubes require large supports that are cumbersome to work around when doctors are treating patients. This can be particularly difficult in trauma centers, for instance, or in surgery, where doctors need very close access to their patients and the ability to maneuver around them.

By comparison, flat-panel imagers are 90 percent smaller and weigh 60 percent less than image-intensifier tubes. These new imagers cover the same anatomical area as image-intensifier tubes, but present a uniform, undistorted, high-resolution image throughout a rectangular field of view with superior contrast resolution. Flat-panel imagers exhibit smaller objects in greater detail than is possible with image intensifiers.

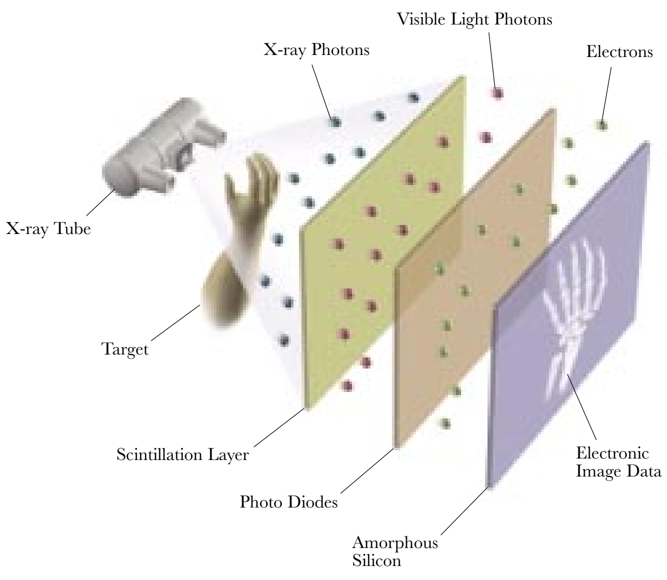
HOW FLAT-PANEL X-RAY IMAGERS WORK

Varian first introduced its flat-panel detectors to the medical world in 1998 with its VIP-9 system, making use of technology developed a few years earlier by Xerox Corporation. In this approach, the flat-panel detector consists of a sheet of glass covered with a layer of silicon that is in an amorphous, or filmlike, state. If your eyes could magnify this layer of silicon film a thousand times, you'd see that it has been imprinted with millions of transistors

Flat panels present a uniform, undistorted, high-resolution image throughout the rectangular field of view. With superior contrast resolution, they show smaller objects in greater detail than is possible with image intensifiers.

arranged in a highly ordered array, like the grid on a sheet of graph paper.

Each of these thin-film transistors (TFTs) is attached to a light-absorbing photodiode making up an individual pixel (picture element). Photons striking the photodiode are converted into carriers of an electrical charge, either negatively charged electrons, or positively charged holes (vacant energy spaces that act as if they were positively charged electrons). Since the number of charge carriers produced will vary with the intensity of incoming light photons, an electrical pattern is created that can be swiftly read and interpreted by a computer to produce a digital image.



With indirect digital X-ray imaging, an X-ray tube sends a beam of X-ray photons through a target. X-ray photons not absorbed by the target strike a layer of scintillating material that converts them into visible light photons. These photons then strike an array of photodiodes which converts them into electrons that can activate the pixels in a layer of amorphous silicon. The activated pixels generate electronic data that a computer can convert into a high-quality image of the target, which is then displayed on a computer monitor.

Although silicon has outstanding electronic properties, it is not a particularly good absorber of X-ray photons. For this reason, Varian, like some other flat-panel detector manufacturers, takes an indirect approach to creating electrical charge carriers. X rays first impinge upon scintillators made from either gadolinium oxysulfide or cesium-iodide. The scintillators absorb the X rays and convert them into visible light photons that then pass onto the photodiode array. Because cesium-iodide is such an excellent absorber of X rays, and converts them to visible light photons at energies that amorphous silicon is best able to convert to charge carriers, the combination of these two materials has the highest-rated Detective Quantum Efficiency (DQE) in use today. DQE is the yardstick by which the performance of photoconductors is measured. A high DQE rating means that superior images can be obtained with low dosages of X rays.

REAL-TIME IMAGING

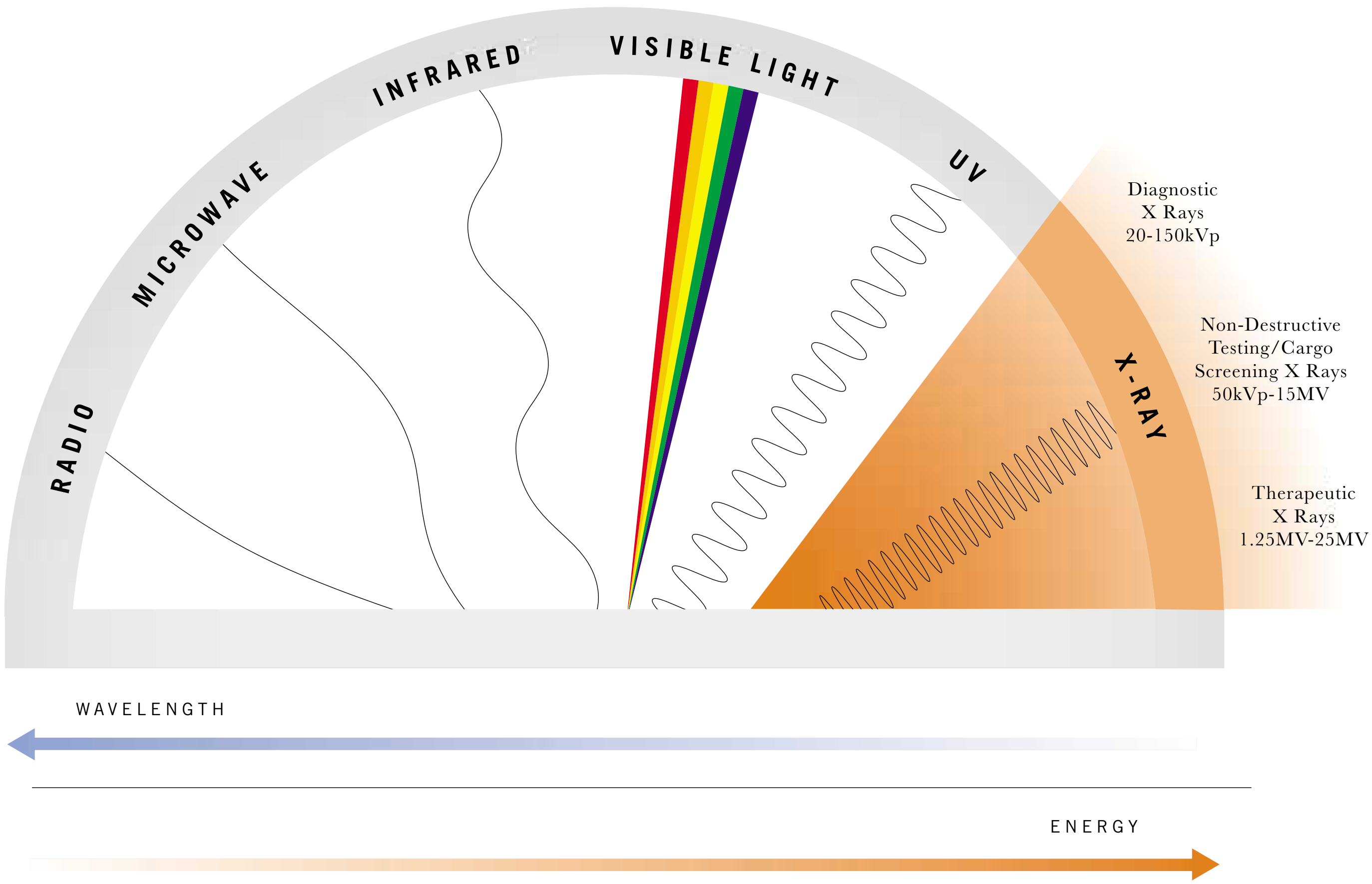
Varian's PaxScan® flat-panel detectors can acquire high-resolution radiographs at up to seven frames per second (FPS) and moving fluoroscopic images at up to 30 FPS. The PaxScan® 4030A also has been incorporated into Varian's radiotherapy products, including its Acuity™ and PortalVision™ systems (see IMRT: Targeting Cancer) that enable radiation oncology teams to properly position patients, target tumors, and verify treatment accuracy. Acuity's flat-panel imager, for example, can be used during brachytherapy procedures to image cancer patients, develop treatment plans, and precisely place radioactive isotopes within tumors.

As a new technology, the flat-panel imagers remain relatively expensive compared to the more traditional X-ray imaging systems. However, the technology can be expected to become more cost-competitive as more users move to take advantage of the substantial cost and time savings offered by digital X-ray imaging.

Varian's engineers have been working with several imaging equipment manufacturers to incorporate flat-panel detectors into a variety of different imaging systems. The PaxScan panel has already been incorporated into commercially available systems for gastrointestinal and vascular diagnostic procedures. Varian's flat-panel detectors are also being investigated for use in orthodontic applications. It is hoped that they will play a role during surgery by generating images that can help to guide doctors as they work. The flat-panel imagers also have potential as a noninvasive means of evaluating the structural integrity of bridges, rocket motors, and shipping containers, as well as the quality of multilayer microchips.

New market opportunities for flat-panel detectors have grown significantly in the past year, according to Chuck Blouir, marketing manager for Varian's imaging products. "We are still finding new applications for our digital flat-panel technology in medical, industrial, and homeland security markets where speed, image quality, and cost-efficiency are essential. I fully expect this to become the new standard in X-ray imaging." ■

The Electromagnetic Spectrum



We "see" images through light – the radiation emitted by electrons when they lose energy. This radiation is carried in massless particles called photons, and travels in waves that move through a vacuum at a constant speed of 186,282 miles per second. Scientists speak about the dual nature of light because it behaves both as a stream of photon particles and as the rippling motion of pure energy waves through space. Although most of us think of light in terms of what we see with our eyes, scientists consider light in a broader sense, as electromagnetic radiation.

Electromagnetic radiation is categorized either according to the energy of its photons, or by the frequency or length of its waves. This spectrum of electromagnetic radiation extends from radio waves, with energies of less than a billionth of an electron volt per photon and wavelengths measuring more than 10,000 kilometers (6,220 miles), to gamma rays, with energies topping a billion electron volts per photon and wavelengths of less than 10 trillionths of a meter. Visible light, the electromagnetic radiation that can be seen with our eyes, constitutes less than a millionth of one percent of the electromagnetic spectrum.

Depending upon the energy and wavelength of the incoming electromagnetic radiation, matter can either be transparent, or it can absorb or reflect light back. The surface of the human body absorbs and reradiates photons at energies ranging between 1.61 and 3.18 electron volts. This is the visible light region of the electromagnetic spectrum and explains why we can see people but cannot see beneath their skin. To look beneath the skin at the body's internal structure you need photons at energies high enough to penetrate tissue and bone. Photons at energies between 20 thousand and 150 electron volts are ideal for diagnostic imaging purposes. These photons are X rays.

Diagnostic imaging depends not only upon the ability of photons to penetrate deep below the skin but also upon their ability to "see," or resolve, small details. This is a function of wavelength. For example, visible light waves, ranging in wavelengths from 700 nanometers (red) to 400 nanometers (violet), are simply too large to ever resolve images of structures the size of a typical protein molecule. No matter how high the magnification, visible light waves would pass over such molecules unaffected. It would be like trying to determine the size and shape of a tennis ball by observing its impact on the movement of ocean waves.

X rays have wavelengths several thousand times shorter, some even less than an angstrom, which is the unit of scale for measuring atoms. This makes X-ray photons ideal for imaging the structures of atoms common in the human body: hydrogen, carbon, oxygen, and calcium. X rays are also ideal for imaging nitrogen, which is a key component, along with hydrogen, carbon, and oxygen, of most chemical explosives. ■