

TELEVISION CAMERAS AND DISPLAYS

1.0 CAMERA IMAGE SENSORS

The television camera is a device that employs light-sensitive image sensors to convert an optical image into a sequence of electrical signals—in other words, to generate the primary components of the picture signal. The first sensors were mechanical spinning disks, based on a prototype patented by the German Paul Nipkow in 1884. As the disk rotated, light reflected from the scene passed through a series of apertures in the disk and entered a photoelectric cell, which translated the sequence of light values into a corresponding sequence of electric values. (See the animation.) In this way the entire scene was scanned, one line at a time, and converted into an electric signal.

Large spinning disks were not the best way to scan a scene, and by the mid-20th century they were replaced by vacuum tubes, which utilized an electron beam to scan an image of a scene that was focused on a light-sensitive surface within the tube. Electronic camera tubes were one of the major inventions that led to the ultimate technological success of television. Today they have been replaced in most cameras by smaller, cheaper solid-state imagers such as charge-coupled devices. Nevertheless, they firmly established the principle of line scanning (introduced by the Nipkow disks) and thus had a great influence on the design of standards for transmitting television picture signals.

2.0 ELECTRON TUBES

The first electronic camera tubes were invented in the United States by Vladimir K. Zworykin (the Iconoscope) in 1924 and by Philo T. Farnsworth (the Image Dissector) in 1927. These early inventions were soon succeeded by a series of improved tubes such as the Orthicon, the Image Orthicon, and the Vidicon. The operation of the camera tube is based on the photoconductive properties of certain materials and on electron beam scanning. These principles can be illustrated by a description of the Vidicon, one of the most enduring and versatile camera tubes. (See the diagram.)

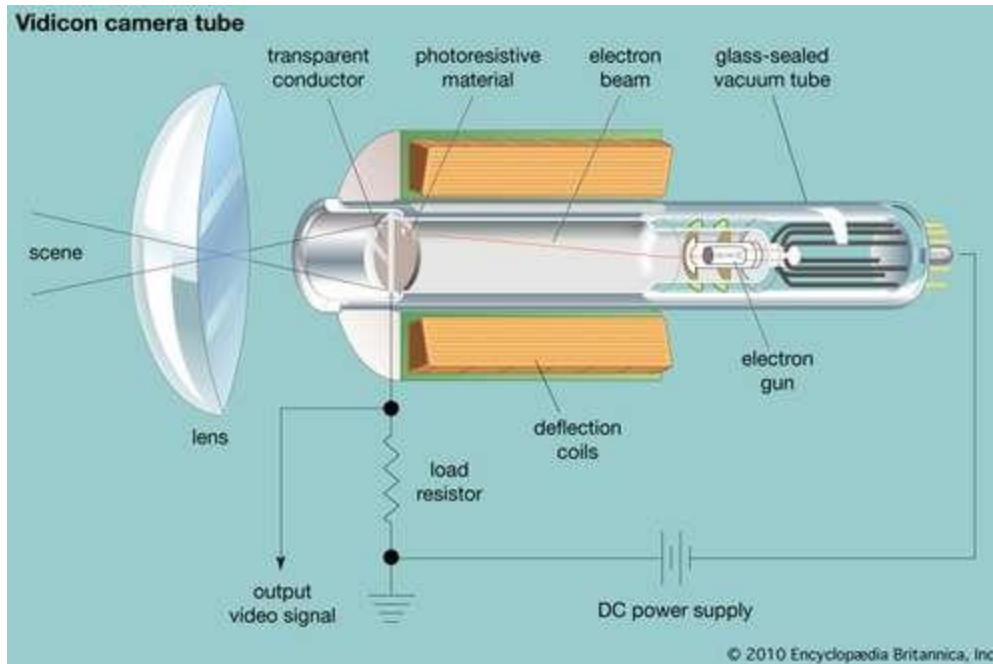


Figure 1. Vidicon television camera tube The image of the scene is focused on a transparent conductor coated with a photoresistive material, creating a matrix of spots of varying electrical charge. An electron beam then scans the material, creating a video signal that represents the varying amounts of light in the image.

The tube elements of the Vidicon are relatively simple, being contained in a cylindrical glass envelope that is only a few centimetres in diameter and is hence quite adaptable to portable cameras. At one end of the envelope, a transparent metallic conductor serves as a signal plate. Deposited directly on the signal plate is a photoresistive material (e.g., a compound of selenium or lead) the electrical resistance of which is high in the dark but becomes progressively less as the amount of light increases. The optical image is focused on the end of the tube and passes through the signal plate to the photoresistive layer, where the light induces a pattern of varying conductivity that matches the distribution of brightness in the optical image. The conduction paths through the layer allow positive charge from the signal plate (which is maintained at a positive voltage) to pass through the layer, and this current continues to flow during the interval between scans. Charge storage thus occurs, and an electrical charge image is built up on the rear surface of the photoresistor.

An electron beam, deflected in the vertical and horizontal directions by electromagnetic coils, scans the rear surface of the photoresistive layer. The beam electrons neutralize the positive charge on each point in the electrical image, and the resulting change in potential is transferred by capacitive action to the signal plate, from which the television signal is derived.

The typical colour television camera contained three tubes, with an optical system that cast an identical image on the sensitive surface of each one. The optics consisted of a lens and four mirrors that reflected the image rays from the lens onto the three tubes. Two of the mirrors were of a colour-selective type (a dichroic mirror) that reflected the light of one colour and transmitted the remaining colours. The mirrors, augmented by colour filters that perfected their colour-selective action, directed a blue image to the first tube, a green image to the second, and a red image to the third. The three tubes were designed to produce identical scans of the scene, so that their respective picture signals represented images of the same geometric shape, differing only in colour. The respective primary-colour signals were passed through video preamplifiers associated with each tube and emerged from the camera as separate entities.

3 CHARGE-COUPLED DEVICE (CCD) CAMERA

Camera tubes need frequent adjustment and replacement, are sensitive to mechanical vibration and shock, are large and bulky, and suffer from various image problems, such as blooming with bright lights, smearing, and retained images. For this reason modern television cameras utilize solid-state image sensors, which are small in size, rugged, and reliable and offer excellent light sensitivity and high resolution.

Solid-state image sensors are charge-coupled devices (CCDs) constructed as large-scale integrated circuits on semiconductor chips. The basic sensor element includes a photodiode and field-effect transistor. Light falling on the junction of the photodiode liberates electrons and creates holes, resulting in an electric charge that accumulates in proportion to the intensity and duration of the light falling on the diode. A typical CCD sensor has more than 250,000 sensor elements, organized into 520 vertical columns and 483 horizontal rows. This two-dimensional matrix analyzes the image into a corresponding number of pixels. In one type of image sensor, the charges accumulated by the sensor elements are transferred one row at a time by a vertical shift register to a horizontal register, from which they are shifted out in a bucket brigade fashion to form the video signal.

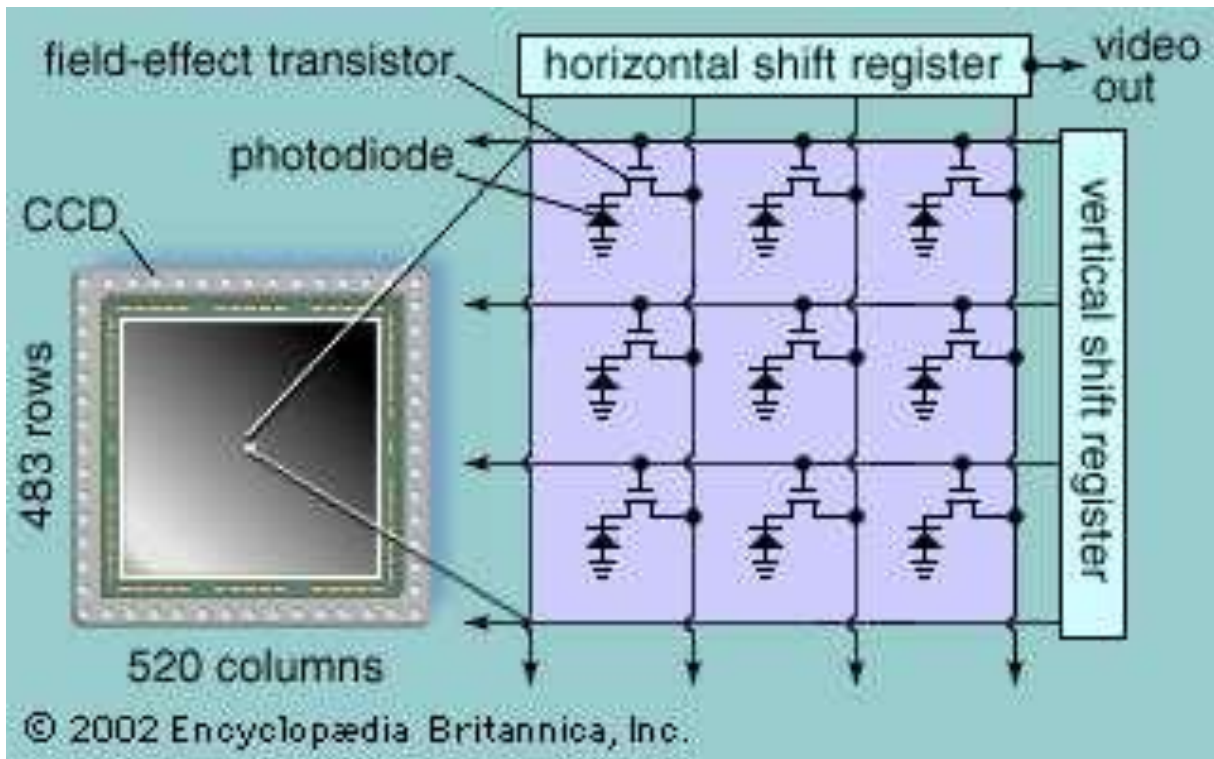


Figure 6. Elements of a charge-coupled device (CCD) image sensor. A typical CCD sensor has more than 250,000 sensor elements; each sensor element corresponds to one of 250,000 picture elements, or pixels, making up the image.

A colour CCD image sensor uses a checkerboard pattern of transparent colour filters. These filters can represent the three primary colours of red, green, and blue, thereby generating three electrical signals corresponding to the three primary colours. Alternatively, prisms can be used to separate the image into its three primary colours; in that case three separate CCD sensors are used, one for each primary colour.

4. TELEVISION DISPLAYS

The cathode-ray tube (CRT) television screen is the oldest display technology, with a history extending back to the late 1890s. It is still difficult to better, although its considerable depth, weight, and high voltage requirements are disadvantages. Liquid crystal displays (LCDs) are perfect for small laptop computers and are also being used more commonly for desktop computers; but large-screen LCDs for television are costly and difficult to manufacture, and they do not have the brightness and wide field of view of the CRT. The basic concepts of plasma display panels (PDPs) are decades old, but only recently have they begun to find commercial use for television. There are many other display technologies, such as ferroelectric liquid crystal, field emission, and

vacuum fluorescent, but they have not reached the commercial viability of the CRT, LCD, and PDP, which are described in turn below. Improvements may well occur in the CRT, renewing the life and utility of this old technology. However, LCDs and PDPs seem more appropriate for the new digital and compression technologies, and so their future in television seems bright.

5. PICTURE TUBES

5.1 Basic structure

A typical television screen is located inside a slightly curved glass plate that closes the wide end, or face, of a highly evacuated, funnel-shaped CRT. Picture tubes vary widely in size and are usually measured diagonally across the tube face. Tubes having diagonals from as small as 7.5 cm (3 inches) to 46 cm (18 inches) are used in typical portable receivers, whereas tubes measuring from 58 to 69 cm (23 to 27 inches) are used in table- and console-model receivers. Picture tubes as large as 91 cm (36 inches) are used in very large console-model receivers, and rear-screen projection picture tubes are used in even larger consoles.

The screen itself, in monochrome receivers, is typically composed of two fluorescent materials, such as silver-activated zinc sulfide and silver-activated zinc cadmium sulfide. These materials, known as phosphors, glow with blue and yellow light, respectively, under the impact of high-speed electrons. The phosphors are mixed, in a fine dispersion, in such proportion that the combination of yellow and blue light produces white light of slightly bluish cast. A water suspension of these materials is settled on the inside of the faceplate of the tube during manufacture, and this coating is overlaid with a film of aluminum sufficiently thin to permit bombarding electrons to pass without hindrance. The aluminum provides a mirror surface that prevents backward-emitted light from being lost in the interior of the tube and reflects it forward to the viewer.

The colour picture tube (shown in the figure) is composed of three sets of individual phosphor dots, which glow respectively in the three primary colours (red, blue, and green) and which are uniformly interspersed over the screen. At the opposite, narrow end of the tube are three electron guns, cylindrical metal structures that generate and direct three separate streams of free electrons, or electron beams. One of the beams is controlled by the red primary-colour signal and impinges on the red phosphor dots, producing a red image. The second beam produces a blue image, and the third, a green image.

5.2 Electron guns

At the rear of each electron gun is the cathode, a flat metal support covered with oxides of barium and strontium. These oxides have a low electronic work

function; when heated by a heater coil behind the metal support, they liberate electrons. In the absence of electric attraction, the free electrons form a cloud immediately in front of the oxide surface.

Directly in front of the cathode is a cylindrical sleeve that is made electrically positive with respect to the cathode (the element that emits the electrons). The positively charged sleeve (the anode) draws the negative electrons away from the cathode, and they move down the sleeve toward the viewing screen at the opposite end of the tube. They are intercepted, however, by control electrodes, flat disks having small circular apertures at their centre. Some of the moving electrons pass through the apertures; others are held back.

The television picture signal is applied between the control electrode and the cathode. During those portions of the signal wave that make the potential of the control electrode less negative, more electrons are permitted to pass through the control aperture, whereas during the more negative portions of the wave, fewer electrons pass. The receiver's brightness control applies a steady (though adjustable) voltage between the control electrode and the cathode. This voltage determines the average number of electrons passing through the aperture, whereas the picture signal causes the number of electrons passing through the aperture to vary from the average and thus controls the brightness of the spot produced on the fluorescent screen.

As the electrons emerge from the control electrode, each electron experiences a force that directs it toward the centre of the viewing screen. From the aperture, the controlled stream of electrons passes into the glass neck of the tube. Inside the latter is a graphite coating, which extends throughout the funnel of the tube and connects to the back coating of the phosphor screen. The full value of positive high voltage (typically 15,000 volts) is applied to this coating, and it therefore attracts and accelerates the electrons from the sleeve, along the neck and into the funnel, and toward the screen of the tube. The electron beam is thus brought to focus on the screen, and the light produced there is the scanning spot. Additional focusing may be provided by an adjustable permanent magnet surrounding the neck of the tube. The scanning spot must be intrinsically very brilliant, since (by virtue of the integrating property of the eye) the light in the spot is effectively spread out over the whole area of the screen during scanning.

5.3 Deflection coils

Scanning is accomplished by two sets of electromagnet coils. These coils must be precisely designed to preserve the focus of the scanning spot no matter where it falls on the screen, and the magnetic fields they produce must be so distributed that deflections occur at uniform velocities.

Deflection of the beam occurs by virtue of the fact that an electron in motion through a magnetic field experiences a force at right angles both to its direction of motion and to the direction of the magnetic lines of force. The deflecting magnetic field is passed through the neck of the tube at right angles to the electron-beam direction. The beam thus incurs a force tending to change its direction at right angles to its motion, the amount of the force being proportional to the amount of current flowing in the deflecting coils.

To cause uniform motion along each line, the current in the horizontal deflection coil, initially negative, becomes steadily smaller, reaching zero when the spot passes the centre of the line and then increasing in the positive direction until the end of the line is reached. The current is then reversed and very rapidly goes through the reverse sequence of values, bringing the scanning spot to the beginning of the next line. The rapid rate of change of current during the retrace motions causes pulses of a high voltage to appear across the circuit that feeds current to the coil, and the succession of these pulses, smoothed into direct current by a rectifier tube, serves as the high-voltage power supply.

A similar action in the vertical deflection coils produces the vertical scanning motion. The two sets of deflection coils are combined in a structure known as the deflection yoke, which surrounds the neck of the picture tube at the junction of the neck with the funnel section.

The design trend in picture tubes has called for wider funnel sections and shallower overall depth from electron gun to viewing screen, resulting in correspondingly greater angles of deflection. The increase in deflection angle from 55° in the first (1946) models to 114° in models produced nowadays has required corresponding refinement of the deflection system because of the higher deflection currents required and because of the greater tendency of the scanning spot to go out of focus at the edges of the screen.

5.4 Shadow masks and aperture grilles

The sorting out of the three beams so that they produce images of only the intended primary colour is performed by a thin steel mask that lies directly behind the phosphor screen. This mask contains about 200,000 precisely located holes, each accurately aligned with three different coloured phosphor dots on the screen in front of it. Electrons from the three guns pass together through each hole, but each electron beam is directed at a slightly different angle. The angles are such that the electrons arising from the gun controlled by the red primary-colour signal fall only on the red dots, being prevented from hitting the blue and green dots by the shadowing action of the mask. Similarly, the "blue" and "green" electrons fall only on the blue and green dots, respectively. The colour dots of which each image is formed are so small and so

uniformly dispersed that the eye does not detect their separate presence, although they are readily visible through a magnifying glass. The primary colours in the three images thereby mix in the mind of the viewer, and a full-colour rendition of the image results. A major improvement consists in surrounding each colour dot with an opaque black material, so that no light can emerge from the portions of the screen between dots. This permits the screen to produce a brighter image while maintaining the purity of the colours.

This type of colour tube is known as the shadow-mask tube. It has several shortcomings: (1) electrons intercepted by the mask cannot produce light, and the image brightness is thereby limited; (2) great precision is needed to achieve correct alignment of the electron beams, the mask holes, and the phosphor dots at all points in the scanning pattern; and (3) precisely congruent scanning patterns, as among the three beams, must be produced. In the late 1960s a different type of mask, the aperture grille, was introduced in the Sony Corporation's Trinitron tube. In Trinitron-type tubes the shadow-mask is replaced by a metal grille having short vertical slots extending from the top to the bottom of the screen (see the figure). The three electron beams pass through the slots to the coloured phosphors, which are in the form of vertical stripes aligned with the slots. The slots direct the majority of the electrons to the phosphors, causing a much lower percentage of the electrons to be intercepted by the grille, and a brighter picture results.

6. LIQUID CRYSTAL DISPLAYS

The CRT offers a high-quality, bright image at a reasonable cost, and it has been the workhorse of receivers since television began. However, it is also large, bulky, and breakable, and it requires extremely high voltages to accelerate the electron beam as well as large currents to deflect the beam. The search for its replacement has led to the development of other display technologies, the most promising of which thus far are liquid crystal displays (LCDs).

The physics of liquid crystals are discussed in the article liquid crystal, and LCDs are described in detail in the article liquid crystal display. LCDs for television employ the nematic type of liquid crystal, whose molecules have elongated cigar shapes that normally lie in planes parallel to one another—though they can be made to change their orientation under the influence of an electric field or magnetic field. Nematic crystal molecules tend to be influenced in their alignment by the walls of the container in which they are placed. If the molecules are sandwiched between two glass plates rubbed in the same direction, the molecules will align themselves in that direction, and if the two plates are twisted 90° relative to each other, the molecules close to each plate will move accordingly, resulting in the twisted-nematic layout shown in the figure. In LCDs the glass plates are light-polarizing filters, so that polarized

light passing through the bottom plate will twist 90° along with the molecules, enabling it to emerge through the filter of the top plate. However, if an external electric field is applied across the assembly, the molecules will realign along the field, in effect untwisting themselves. The polarization of the incoming light will not be changed, so that it will not be able to pass through the second filter.

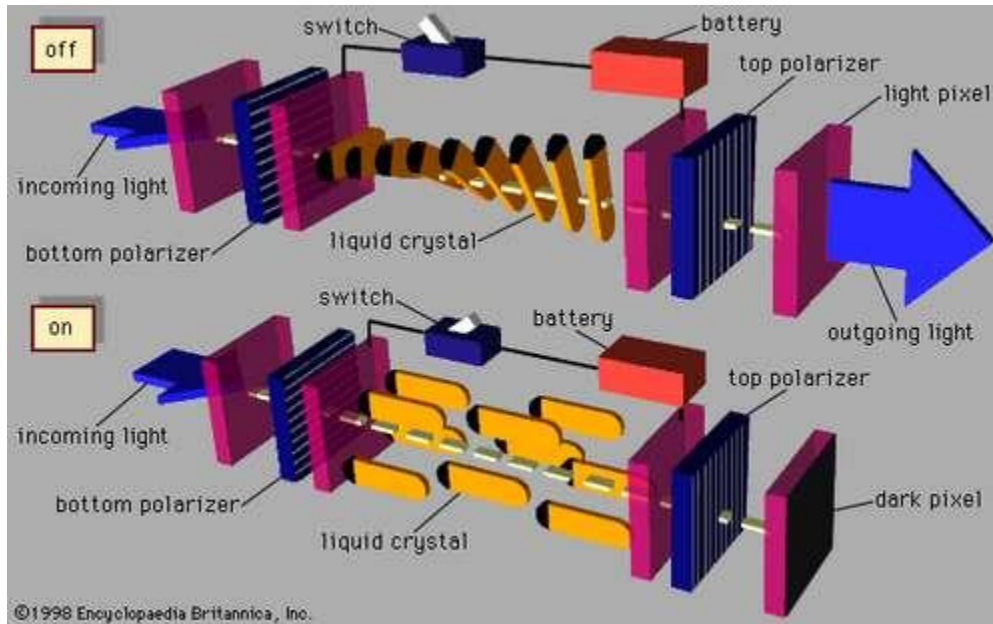


Figure A twisted nematic cell In the “off” state, in the absence of an electric field, the assembly is transparent to light. In the “on” state, an applied field destroys the twist of the nematic, rendering the assembly opaque.

Applied to only a small portion of a liquid crystal, an external electric field can have the effect of turning on or off a small picture element, or pixel. An entire screen of pixels can be activated through an “active matrix” LCD (see the figure), in which a grid of thousands of thin-film transistors and capacitors is plated transparently onto the surface of the LCD in order to cause specific portions of the crystal to respond rapidly. A colour LCD uses three elements, each with its own primary-colour filter, to create a colour display.

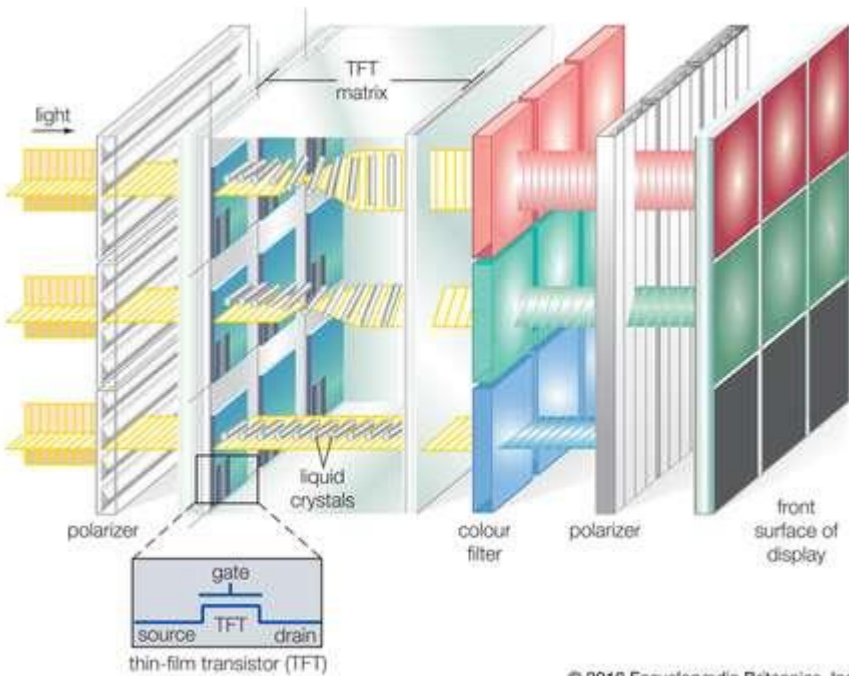


Figure Basic architecture of an active-matrix thin-film transistor liquid crystal display. Associated with each picture element, or pixel, of the display screen is a thin-film transistor, or TFT. The TFTs are subjected to varying voltages, which produce a varying orientation of molecules in the liquid crystal suspension. This varying orientation in turn varies the amount of light allowed to pass through the TFT matrix and colour filter, thereby changing the colour picture on the display screen.

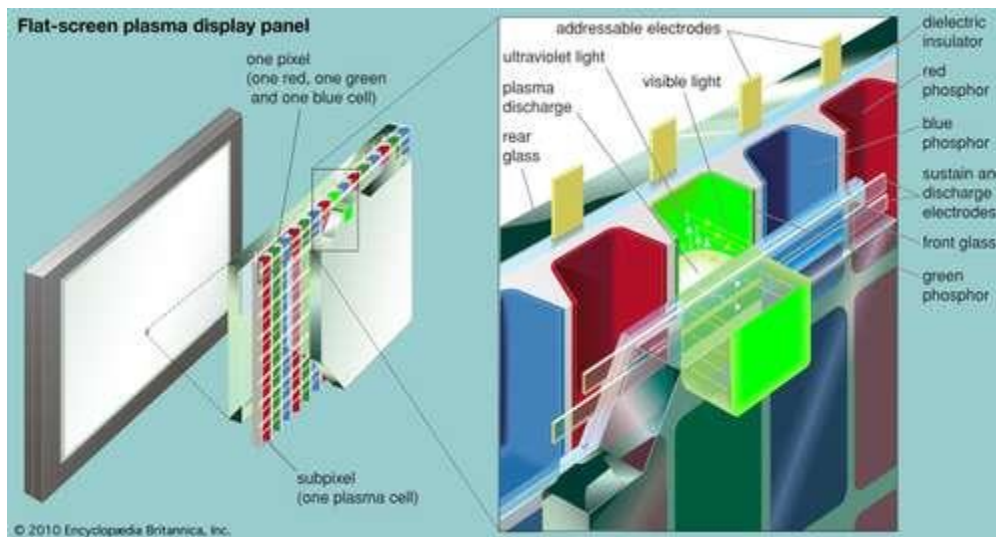
Because LCDs do not emit their own light, they must have a source of illumination, usually a fluorescent tube for backlighting. It takes time for the liquid crystal to respond to electric charge, and this can cause blurring of motion from frame to frame. Also, the liquid nature of the crystal means that adjacent areas cannot be completely isolated from one another, a problem that reduces the maximum resolution of the display. However, LCDs can be made very thin, lightweight, and flat, and they consume very little electric power. These are strong advantages over the CRT. But large LCDs are still extremely expensive, and they have not managed to displace the picture tube from its supreme position among television receivers. LCDs are used mostly in small portable televisions and also in handheld video cameras (camcorders).

Plasma display panels

Plasma display panels (PDPs) overcome some of the disadvantages of both CRTs and LCDs. They can be manufactured easily in large sizes (up to 125 cm, or 50 inches, in diagonal size), are less than 10 cm (4 inches) thick, and have wide horizontal and vertical viewing angles. Being light-emissive, like CRTs, they produce a bright, sharply focused image with rich colours. But much

larger voltages and power are required for a plasma television screen (although less than for a CRT), and, as with LCDs, complex drive circuits are needed to access the rows and columns of the display pixels. Large PDPs are being manufactured particularly for wide-screen, high-definition television.

The basic principle of a plasma display, shown in the diagram, is similar to that of a fluorescent lamp or neon tube. An electric field excites the atoms in a gas, which then becomes ionized as a plasma. The atoms emit photons at ultraviolet wavelengths, and these photons collide with a phosphor coating, causing the phosphor to emit visible light.



Cross section of a flat-panel plasma display for wide-screen, high-definition colour television. A pulse of electricity between the addressable electrodes and the transparent sustain and discharge electrodes causes gas sealed in a subpixel to form a plasma and discharge ultraviolet light. This discharge in turn causes the phosphor coating of the subpixel to flash visible light through the front glass panel. A red, green, and blue subpixel together form one pixel, which is perceived by the human eye as a single spot of one combined hue. Through complex circuitry, each subpixel is discharged in series multiple times per second, creating a moving television image. Encyclopædia Britannica, Inc.

As is shown in the diagram, a large matrix of small, phosphor-coated cells is sandwiched between two large plates of glass, with each cluster of red, green, and blue cells forming the three primary colours of a pixel. The space between the plates is filled with a mixture of inert gases, usually neon and xenon (Ne-Xe) or helium and xenon (He-Xe). A matrix of electrodes is deposited on the inner surfaces of the glass and is insulated from the gas by dielectric coatings. Running horizontally on the inner surface of the front glass are pairs of transparent electrodes, each pair having one "sustain" electrode and one "discharge" electrode. The rear glass is lined with vertical columns of

“addressable” electrodes, running at right angles to the electrodes on the front plate. A plasma cell, or subpixel, occurs at the intersection of a pair of transparent sustain and discharge electrodes and an address electrode. An alternating current is applied continuously to the sustain electrode, the voltage of this current carefully chosen to be just below the threshold of a plasma discharge. When a small extra voltage is then applied across the discharge and address electrodes, the gas forms a weakly ionized plasma. The ionized gas emits ultraviolet radiation, which then excites nearby phosphors to produce visible light. Three cells with phosphors corresponding to the three primary colours form a pixel. Each individual cell is addressed by applying voltages to the appropriate horizontal and vertical electrodes.

The discharge-address voltage consists of a series of short pulses that are varied in their width—a form of pulse code modulation. Although each pulse produces a very small amount of light, the light generated by tens of thousands of pulses per second is substantial when integrated by the human eye.