DISPLAY DEVICES
Display devices

Display devices are used for the visual presentation of information.

1. Analog display devices (cathode-ray tubes)
   - Oscilloscope tubes
   - TV CRTs

2. Digital display devices
   - LED (including OLED) displays
   - VF (vacuum fluorescent) displays
   - LCD (liquid crystal) displays
   - Nixie tube displays and PDPs (plasma display panels)
   - Electroluminescent displays (ELDs)

3. Others:
   - Electronic paper
   - Using principles of nanoelectronics (carbon nanotubes, nanocrystals)
   - Laser TV
Classification of electronic information technologies with high information content; highlighted technologies are treated in this article.

w4.siemens.de/.../heft2_97/artikel08/index.html
Display devices

Electronic display devices based on various principles were developed.

Active display devices are based on luminescence.

*Luminescence* is the general term used to describe the emission of electromagnetic radiation from a substance due to a non-thermal process. Luminescence occurs from a solid when it is supplied with some form of energy.

*Photoluminescence* arises as a result of absorption of photons.

In the case of *cathodoluminescence* material is excited by bombardment with a beam of electrons.

*Electroluminescence* is a result of excitation from the application of an electric field.

*Fluorescence* persists for a short lifetime of the transition between the two energy levels.

*Phosphorescence* persists for much longer time (more than $10^{-8}$ s).

Passive display devices reflect or modulate light...
Display devices. Content and objectives

Cathode ray tubes
- Electron gun
- Principles of focusing
- Deflection of the beam
- Cathodoluminescence
- Oscilloscope tubes
- Picture tubes

Flat panel displays
- LED displays
- Vacuum fluorescent displays
- Gas discharge displays and plasma display panels
- Electroluminescent displays
- Liquid crystal displays
- Field emission displays

Other displays

Objectives: overview structures, principles of operation and general properties of display devices.
Cathode-ray tubes

**Karl Ferdinand Braun** a German physicist, interested in the just discovered Cathode rays, ... developed the first cold Cathode Ray tube with magnetically beam deflection ... and a mica screen covered with phosphor to produce a visible spot. This tube, build for him by Franz Müller ... was called after its inventor, the Braun tube. JJ.Thomson used a similar tube design in his experiments to show the existence of the electron almost at the same time. Braun used this tube as an indicator tube for studying the effects of Cathode rays and described this 1897, this was in fact the first oscilloscope. **Harris J Ryan** introduced this tube in 1903 in the USA as an alternating current wave indicator, known as the Braun-Ryan tube.

The Braun tube, this early 1900 tube is in fact a cold Cathode Crookes tube with an **internal mica screen** covered with phosphorescent paint. The neck contains **glass diaphragm** with a small 2mm hole to let only a tiny **electron beam go through** (focus) which can be deflected by an (electro) magnet to produce a **spot on the screen**.
Cathode-ray tubes

The cathode ray tube (CRT), invented by German physicist Karl Ferdinand Braun in 1897, is an evacuated glass envelope containing an electron gun (a source of electrons) and a fluorescent screen, usually with internal or external means to accelerate and deflect the electrons. When electrons strike the fluorescent screen, light is emitted. The electron beam is deflected and modulated in a way which causes it to display an image on the screen. The image may represent electrical waveforms (oscilloscope), pictures (television, computer monitor), echoes of aircraft detected by radar, etc.

A cathode ray tube (CRT) contains four basic parts:

• electron gun,

• focusing and accelerating systems,

• deflecting systems, and

• evacuated glass envelope with a phosphorescent screen that glows visibly when struck by the electron beam.
Cathode-ray tubes. Electron gun

An electron gun consists of a series of electrodes producing a narrow beam of high-velocity electrons.

Electrons are released from the indirectly heated cathode.

The intensity of the beam is controlled by variation of the negative potential of the cylindrical control grid surrounding the cathode. This electrode is called the modulator.

The control grid has a hole in the front to allow passage of the electron beam.

The electrons are accelerated and focused.
Cathode-ray tubes. Electron gun

Modulation characteristic

Focusing:
- electrostatic
- electromagnetic

Deflection:
- electrostatic
- electromagnetic
Cathode-ray tubes. Electrostatic focusing

Two or more electrodes at different potentials are used to focus the electron beam. The electrostatic field set up between the electrodes causes the beam to converge.

The focusing effect is controlled by varying the potential of the focusing electrode. Due to the focusing action electrons of the gun bombard the screen of the cathode ray tube at the same point.

The system of converging and diverging lenses
Cathode-ray tubes. Electrostatic focusing
Cathode-ray tubes. Electromagnetic focusing

The focusing magnetic field is inhomogeneous and axial symmetrical.

Cathode ray tube employing electromagnetic focus and deflection
Cathode-ray tubes. Electrostatic deflection

Sensitivity

\[ S = \frac{H}{U} \]

\[ E = \frac{U}{d} \]

\[ \frac{d^2 y}{dt^2} = \frac{q}{m} E \]

\[ H = vt_2 + h = \frac{qE}{m} \left( t_1 t_2 + \frac{t_1^2}{2} \right) = \frac{qE}{m} \frac{l(L + l/2)}{v_0^2} \]

\[ S = \frac{H}{U} = \frac{l(L + l/2)}{2dU_0} \]
Cathode-ray tubes. Electromagnetic deflection

\[ S = \frac{H}{NI} = k \frac{l(L + l/2)}{\sqrt{U_0}} \]

NI is the number of ampere-turns

The sensitivity of a CRT with electrostatic deflecting system is in inverse ratio to \( U_0 \). In the case of electromagnetic deflection it is in inverse ratio to \( \sqrt{U_0} \).

Using electromagnetic deflection we can obtain relatively great sensitivity and great deflection angle at high accelerating voltage. For this reason electromagnetic deflection is used in television picture tubes, requiring high-velocity electron beams necessary for bright display.
Cathode-ray tubes. Electromagnetic deflection
Cathode-ray tubes. Electromagnetic deflection
Cathode-ray tubes. Electromagnetic deflection
Cathode-ray tubes. Cathodoluminescence

The deflected and accelerated electron beam strikes a phosphorescent material on the inside face of the tube. The phosphor glows and the visible glow can be seen at the front of the tube. So cathodoluminescence is used in cathode ray tubes.

Cathodoluminescent efficiency increases with increasing beam voltage.

As a result of the screen bombardment free electrons are knocked out. To collect these electrons the inside surface of the glass balloon is coated by conducting aquadag layer. Usually this layer is connected to the accelerating anode.

The screen of the CRT may be coated with aluminium on the inside and this coating is held at anode potential. Such an aluminized screen prevents the accumulation of charge on the phosphor and improves its performance increasing the visible output and reducing the effects of ion bombardment.
Oscilloscope tubes

Electrostatic focusing and electrostatic deflection
Oscilloscope tubes

The most important characteristics of an oscilloscope tube are deflection sensitivity (deflection on the screen per volt), bandwidth (or rise time of the step-function response), spot diameter, useful scan and maximum writing speed.

The high sensitivity and super-wide-band of CRTs are achieved using traveling-wave deflecting systems. Electrons of the beam in the travelling-wave deflecting system are deflected by the incident electromagnetic wave propagating along the system with the same velocity as electrons of the beam.
Picture (TV) tubes (kinescopes)

Electrostatic focusing and electromagnetic deflection are usually used in picture tubes.

Due to the rectilinear scanning the electron beam traverses the screen area in both the horizontal and vertical directions.

The electron beam is intensity modulated by the transmitted video signal that is applied to the modulator.
Picture (TV) tubes (kinescopes)

The horizontal direction is termed the line and the vertical direction the field. Saw-tooth current waveforms are used to produce the deflection of the beam. The fly-back period is blanked out.

The number of lines traversed per second is the line frequency. The number of vertical scans per second is the field frequency.

A method of scanning that produces the entire picture in a single field (or raster) is termed sequential scanning.

Most broadcast television systems use a system of interlaced scanning. In this system the lines of successive rasters are not superimposed on each other but are interlaced.

Two rasters constitute a complete picture or frame. The number of complete pictures per second is the frame frequency which is half the number of rasters per second, i.e. half the field frequency.

The field frequency needs to be relatively slow to allow as many horizontal lines as possible but sufficiently fast to eliminate flicker.
The sequential (progressive) and interlaced scanning
Color picture tubes

The colored image is produced varying the intensity of excitation of the three different phosphors that produce the three primary colors (red, green and blue) and reproduce the original colors of the image by an additive color process.

The triangular arrangement of electron guns are used. The phosphors are arranged as triangular sets of coloured dots.

A metal shadow mask is placed directly behind the screen in the plane of intersection of the electron beams to ensure that each beam hits the correct phosphor. The mask acts as a physical barrier to the beams as they progress from one location to the next and minimizes the generation of spurious colours by excitation of the wrong phosphor.
Color picture tubes

Slot matrix tube

Traditional mask

Trinitron
The cathode-ray tube is on the way out.

What will replace it? (Hint: it won’t be plasma)

GOODBYE, CRT

By Paul O’Donovan
1. CRT TV displays are the highest quality display: “...the CRT, still the benchmark of all displays.”

2. CRTs last longer than any other type of display (our 27-inch JVC is 18 years old and runs great).

3. CRTs have a wider viewing angle than any other display (plasmas are on the way out, I agree).

4. CRTs have higher imaging bandwidth, which is important for rapidly changing scenes in, for example, televised sports.

5. CRTs cost about half as much as short-lived LCDs and one-fourth as much as complex LCD/LED models.

6. CRTs have greater reliability than any other type of display.

7. CRTs are more easily viewable in daylight than models of any other technology.

Admittedly, CRTs use more energy than LCDs and maybe even LCD/LED models. In most parts of the country, this is not objectionable; the extra heat is not wasted. They are acceptable even in Phoenix, where I live, which is the hottest large city in the United States. As to weight, once they’re hauled into the house, there seems to be no problem.
FLAT PANEL DISPLAYS

CRTs are relatively fragile and bulky.

Other types of thinner displays were developed. They are often called flat panel displays.

Most flat-panel displays form digits or characters with combination of segments or dots. The arrangement of these elements is called the display font.

The most common format for numeric display is the seven-segment font.

Graphic displays are like very large dot matrices. Each dot in a graphic display is called picture element, pixel or pel. The capabilities of a graphic display depend on number of pixels horizontally and vertically.
Flat panel displays requiring continuous refresh:

**DLP** (Digital Light Processing)

Plasma displays

Liquid crystal displays (LCDs)

Organic light-emitting diode displays (OLEDs)

Light-emitting diode display (LED)

Electroluminescent displays (ELDs)

Surface-conduction electron-emitter displays (SEDs)

Field emission displays (FEDs)

Nano-emissive display (NEDs)

Only the first five of these displays are commercially available today, though OLED displays are beginning deployment only in small sizes (mainly in cellular telephones).

http://en.wikipedia.org/wiki/Flat_panel_display
LED displays

Light emitting diodes are used in LED displays. Operation of the LED displays is based on the injection luminescence. LED displays are available in many different sizes and shapes. Usually LED displays radiate red, orange, yellow or green light. They have a wide operating temperature range, are inexpensive, easily interfaced to digital logic, easily multiplexed, do not require high voltages and have fast response time.

The viewing angle is good and display of arbitrary numbers of digits is easily assembled.
The amazing new VAIO TX3 is the smallest and lightest fully featured notebook around. Developed for ultimate mobility using advanced carbon-fibre materials, TX3 includes a range of brilliant design innovations including a super-thin LED display panel and postcard-sized motherboard.
High LED Technology Displays & Giant Screens
High LED Technology for the Visual Communication in the XXI Century

Select Your Giant Screen and Ask Now For an Online Quotation. It Takes 30 Seconds!

280,000,000,000 Colours
3 LEDs: Red+Green+Blue Colour White: Yes Indoor-Outdoor (IP65) Plug&Play Technology High Brightness

LED displays

The World Largest 3D LED Display

static.flickr.com

stanislovas.staras@el.vgtu.lt
LED displays

![Diagram of an OLED display structure with layers including substrate, hole transport layer, electron transport layer, metal electrode, and transparent electrode.](image)
Vacuum fluorescent displays are a variation on the triode vacuum tube. The filament of thin, oxide-coated tungsten is heated enough to emit electrons. The control grid is an open wire mesh placed between the filament and the anode. The anode is divided into individual display segments or dots. It is formed by depositing conductive material on a glass base. The anode is then covered by a phosphor. If an anode segment is more positive than the filament, it attracts electrons. When electrons strike the phosphor on the anode, light is produced.
Vacuum fluorescent displays

Filament consists of tungsten coated with the oxidized Ba, Sr and Ca. Powered filament generates heat and emits thermal electrons which are dispersed and selected by the grid electrode and reach the anode electrode. On the anode electrode, display pattern is formed with phosphor which emit light.

Most vacuum fluorescent displays emit a blue-green light which is a nearly optimum colour because it is near the peak of the human eye’s response. Some extra indicators may use a phosphor that produces a different color of light, for example, orange.
Some displays can show only digits or alphanumeric characters. They are called segment displays, because they are composed of several segments that switch on and off. There are several types:

- Seven segment display (most common, digits only)
- Fourteen segment display
- Sixteen segment display
Gas discharge displays and plasma display panels

A neon bulb is the simplest gas discharge display. Two electrodes are scaled in a glass bulb filled with a mixture of neon and argon gas. When high enough voltage is applied (typically 100 to 200 V), an electrical discharge begins in the gas. Free electrons acquire high kinetic energies from the electric field. When they collide with gas atoms they transfer this energy to the atoms, thereby exciting them into energy levels above the ground state. The atoms may then lose energy radiatively and return to the ground state. Then the gas emits orange-red light. The ionised gas is called plasma and gas displays are therefore often called plasma displays.

... the nixie tube was a numerical display technology used in scientific instruments and calculators in the 1960s and 70s, before seven segment LED displays were invented.

A nixie tube is an electronic device for displaying numerals or other information, in the form of a glass tube containing multiple cathodes and a wire mesh anode, filled with neon and often a little mercury and/or argon ... at a small fraction of atmospheric pressure. It is a cold-cathode tube (a form of gas filled tube), or a variant of neon lamp.
Gas discharge displays and plasma display panels

The most common form of nixie tube has ten cathodes in the shapes of the numerals 0 to 9 (and occasionally a decimal point or two), but there are also types that show various letters, signs and symbols. Each cathode can be made to glow in the characteristic neon red-orange color by applying about 170 volts DC at a few milliamps between a cathode and the anode.

Most gas discharge displays are dot matrix. The cathode is divided into stripes in one direction and the anodes are stripes in the perpendicular direction. The display is then driven in a multiplexed fashion driving one cathode at a time. Controlling the anode voltages dots are formed at the desired intersections due to the discharge through the holes in the intermediate plate.
Gas discharge displays and plasma display panels

There are many varieties of gas discharge displays. The most basic type is called dc plasma, but the future of gas discharge displays lies in ac plasma technology.

The structure of the ac plasma display cell
Gas discharge displays and plasma display panels

A grid of tiny electrodes applies an electric current to the individual cells, causing the gas (a mix of neon and xenon) in the cells to ionize. This ionized gas (plasma) emits high-frequency UV rays, which stimulate the cells' phosphors, causing them to glow the desired color.
Gas discharge displays and plasma display panels

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Gas discharge displays and plasma display panels

PDP is composed of the front substrate and the rear substrate. The front substrate is formed by transparent electrode, bus electrode, dielectric layer, protective layer and the rear substrate is formed by address electrode, dielectric layer, barrier rib phosphor. The two substrates are sealed with electric discharge gas filled inside.
Gas discharge displays and plasma display panels

Two HDTV-capable plasma panel designs

http://www.plasmadepot.com/plasmatv/howplasmaworks.html
Gas discharge displays and plasma display panels

High Performance – 9th Generation Panel

Panasonic has completely redesigned all major components of this ninth generation plasma panel. The phosphors and other panel materials have been upgraded to improve light output efficiency; the ribs and electrodes have been reconfigured with new shapes; and the gas mixture has been altered. The result is a dramatic improvement in picture performance, even when viewed in a bright living room.
Electroluminescent displays

EL was first observed in 1907 by Captain Henry Joseph Round in silicon carbide (SiC), although ELD technology was not made commercially available until the 1980s.

The electroluminescent display is similar in idea to an ac plasma display, except that the gas-filled area is replaced by a thin film of electroluminescent material.

http://www.indiana.edu/~hightech/fpd/papers/ELDs.html
Electroluminescent displays

When sufficiently large ac voltage (typically 150 to 200 V) is applied between the front and rear electrodes, the material between them emits light.

One material commonly used is zinc sulphide doped with manganese.

The advantages of electroluminescent displays include very thin and rugged constructions, very high brightness, high resolution, wide operating temperature range, and moderate power consumption.
Electroluminescent displays

ELDs are particularly useful in applications where full color is not required but where ruggedness, speed, brightness, high contrast, and a wide angle of vision is needed.
Liquid crystal displays

The heart of all liquid crystal displays (LCDs) is a liquid crystal itself. A liquid crystal is a substance that flows like a liquid, but its molecules orient themselves in the manner of a crystal.

There are three basic types of ordering in liquid crystals which are termed nematic, cholesteric and smectic.

In the cholesteric crystals molecules form planes. A plane has nematic-like structure, but with each plane molecules change their direction.

As a result the molecules display a helical twist through the material.
Liquid crystal displays

When a nematic liquid crystal material comes into contact with a solid surface molecules become aligned either perpendicular to the surface (homeotropic ordering) or parallel to the surface (homogeneous ordering). These two forms can be produced by suitable treatment of the surface.

The most important electrical characteristic of liquid crystal materials is that the direction of the molecules can be controlled by the electric field. Usually the molecules tend to be orientated along the electric field.
Liquid crystal displays

Most of the LCDs use twisted nematic cells.

When a beam of polarised light is incident on the cell the liquid causes rotation of polarisation plane.

A strong enough electric field changes orientation of molecules and in this state the molecules have no effect on an incident light beam.

\[ E = 0 \]

\[ E \rightarrow \]

![Diagram of liquid crystal states](image-url)
Liquid crystal displays

In the most common type of LCD cell based on twisted nematic field effect, two sheets of glass form the main structure. Between the sheets of glass there is a very thin layer of liquid crystal material. The inner surface of each piece of glass is coated with a transparent, conductive layer of metal oxide. The sandwich is completed with a polarizer on the outside of each piece of glass and a reflector on the back of the display.
Liquid crystal displays

Transmission LCD displays do not have the reflector and must be provided with rear illumination. They operate in a very similar fashion to the reflective displays.

Colour displays are possible by incorporating colour filters.

An LCD cell consumes only microwatts of power over a thousand times less than LED displays.

LCDs can operate on voltages as low as 2 to 3 V and are easily driven by MOS IC drivers.

LCDs also have their disadvantages. They cannot be seen in the dark, have a limited viewing angle and a limited temperature range.
Liquid crystal displays

Source: University of Colorado
Liquid crystal displays

The left column electrode is at the same potential level as the row electrode. To the right column electrode (red), a different voltage is applied. In this way, an electric field is generated in the right pixel oriented perpendicular to the glass surfaces. On the picture one can see that the rubbing direction of the alignment layers (green) on top and bottom substrate are chosen perpendicular to each other. Due to this choice, the director in the left pixel makes a homogeneous turn of 90° from bottom to top. Therefore, this type of LCD is called a 'Twisted Nematic LCD' (TN-LCD). If a voltage is applied to the electrode, the director reorients to become perpendicular to the surfaces (right pixel).

Liquid crystal displays

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ONE (LCD) PIXEL

Viewer

Polarizing filter

Red Filter

Green Filter

Blue Filter

Liquid crystals

Thin-film transistors

Polarizing filter

Backlight

VGTU EF ESK
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The very first types of LCDs were called DSM (dynamic scattering mode), but TN (twisted nematic) has become the standard today. Almost all active matrix drive displays use TN type LCDs, and numerous types of active elements are being developed. The use of TN type LCDs in simple matrix drive displays causes the contrast to drop as the number of scan lines of the image displayed is increased. To compensate for this, new types of LCDs are being researched and developed. Advances in LCD R&D have already led to the development of STN (super twisted nematic) type LCDs, which offer high contrast, even on large screens; and TSTN (triple STN) and FSTN (film STN) LCDs, which feature a lightweight and thin body design that are optimal for large black-and-white LCDs and precise color imaging when equipped with a color filter.

http://sharp-world.com/sc/library/lcd_e/s2_4_4e.htm
Liquid crystal displays

**TFT-LCD** (Thin Film Transistor-Liquid Crystal Display) is a variant of Liquid Crystal Display (LCD) which uses Thin-Film Transistor (TFT) technology to improve image quality. TFT LCD is one type of active matrix LCD, though it is usually synonymous with LCD. It is used in both flat panel displays and projectors.

Normal Liquid Crystal Displays like those found in calculators have direct driven image elements – a voltage can be applied across one segment without interfering with other segments of the display. This is impractical for a large display with a large number of picture elements (pixels), since it would require millions of connections - top and bottom connections for each one of the three colors (red, green and blue) of every pixel.

To avoid this issue, the pixels are addressed in rows and columns which reduce the connection count from millions to thousands.
Liquid crystal displays

...The solution to the problem is to supply each pixel with its own transistor switch which allows each pixel to be individually controlled.
Liquid crystal displays

The TFT-array and color-filter substrates are made into an LCD panel by assembling them with a sealant (hermetikas).

http://www.plasma.com/classroom/fabricating_tft_lcd.htm
Liquid crystal displays

http://www.plasma.com/classroom/fabricating_tft_lcd.htm
Field emission displays

The field emission display (FED) is a product of vacuum microelectronics. The gap between two glass plates is filled with vacuum. Arrays of small cathodes (emitters) and grids (gates) are formed on one plate using microelectronics technology. A transparent anode layer and phosphor layer are made on the other glass plate. The apex of a cathode is very sharp, less than 20 nm in radius. Then at relatively low voltage between the anode and cathodes the field emission of electrons occurs. Electrons are attracted by a positive anode. They bombard the phosphor layer and cause cathodoluminescence. The current across the cell is controlled by anode and grid voltages.
Field emission displays

The application of a small voltage to a metal or semiconductor surface containing nanometer scale protrusions produces a large electric field which causes electrons to be emitted. Using an extractor grid, less than 80 volts is sufficient to produce up to 5mA of emission current from a single tip.

A single tip in girded configuration. An array of such a unit cell forms a pixel in a display application.
Field emission displays

Works like a CRT with multiple electron guns at each pixel.
Carbon nanotube displays

Carbon nanotube displays

CNT can be metallic or semiconducting and offers amazing possibilities to create future nanoelectronics devices, circuits, and computers.
Nanopicture of the Day

November 28, 2003

Carbon Nanotube Display
Source: Samsung Display Technology, courtesy of Choi et. al.

www.nanopicoft heday.org
Carbon nanotube displays

The promise of Motorola's new Nano Emissive Display (NED) technology is sweet for anyone that covets a flat screen HDTV, but doesn't want to pony up big bucks.

Imagine a 40 inch HDTV panel less than an inch thick.

Now imagine it costing less than $400.

Motorola Labs unveiled a prototype of NED technology in the form of a functioning 5-inch color segment of a 1280 x 720, 16:9, 42-inch HDTV.

A prototype model was demonstrated by Motorola in May 2005. Nano-emissive display (NED) is Motorola's term for their Carbon Nanotubes (CNTs)-based display technology.
Laser TV

IEEE Spectrum | April 2004 |
Laser TV

LASER TV: Ribbons of light from three lasers—red, green, and blue—is partially diffracted by Grating Light Valves. A Fourier filter distinguishes diffracted red, green, and blue light from reflected light and the colors are combined to make up the colors of the pixels in the video image, 1080 pixels at a time. The pixels change at 115 kilohertz a second as the resulting high-resolution image is painted across the screen, one vertical line at a time.
E-paper

Electronic paper, also sometimes called e-paper or electronic ink, is a display technology designed to mimic the appearance of regular ink on paper. Unlike a conventional flat panel display, which uses a backlight to illuminate its pixels, electronic paper reflects light like ordinary paper and is capable of holding text and images indefinitely without drawing electricity, while allowing the image to be changed later.
E-paper
THE END