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
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.
The **cathode ray tube (CRT)**, invented by [German physicist Karl Ferdinand Braun](https://en.wikipedia.org/wiki/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

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

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.
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

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

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

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

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

\[ S = \frac{H}{U} = \frac{l(l + l/2)}{2dU_0} \]
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
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.

Waveforms of (a) signal voltage, (b) sweep voltage, (c) blank pulses, and (d) signal form on the screen of the CRT.
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.
Picture (TV) tubes (kinescopes)

The sequential (progressive) and interlaced scanning
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

Imagine a TV picture where the rich red hues of a sunset contrast seamlessly with the cool blues of a moonlit night. Or consider a high-definition video where the finest details of a landscapes are captured with sharp clarity. The cathode-ray tube (CRT) television has been the standard for years, offering a wide range of colors and details, but it is facing challenges from new technologies such as liquid crystal displays (LCDs) and organic light-emitting diodes (OLEDs).

By 2014, LCD TVs will dominate the market, with more than 50% of new sets being LCDs. This transition is due to the efficiency and cost-effectiveness of LCD technology. LCDs use less power and emit less heat than CRTs, making them a more environmentally friendly option. They also have a longer lifespan and require less maintenance.

In addition, LCDs offer higher contrast ratios and faster response times, allowing for more vibrant images and smoother motion. LCDs are also more space-efficient, making them ideal for smaller living spaces.

As for plasma displays, they are still popular due to their large size and high picture quality. However, they are expensive and require more power, making them less suitable for energy-conscious consumers.

In conclusion, while the cathode-ray tube may be on its way out, there are many exciting developments in display technology that promise to make our viewing experience even more enjoyable.

*Image: LG OLED TV*
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 wight, once they’re lugged into the house, there seems to be no problem.
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
LED displays
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
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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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.
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.
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

Clever twist
How a liquid crystal display blocks light

Source: University of Colorado
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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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
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.
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.

Field emission displays

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

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
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

COLOR CONTROLLER: The color of each pixel in the TV screen is created by groups of movable ribbons, the width of which depends on the intensity of the light to be produced.
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