Data Presentation Elements

ME 220

The data presentation element is the final element in the measurement system, its function being to communicate the measured value of the variable to a human observer. It is important that the measured value is presented as clearly and easily as possible, otherwise the value registered by the observer may be different. Consider an accurate flow measurement system where the true value of flow rate is 11.3 $m^3 h^{-1}$ and the measured value 11.5 $m^3 h^{-1}$, i.e. a **measurement system error** of 11.5 – 11.3 = 0.2 $m^3 h^{-1}$. If the observed value is 12.0 $m^3 h^{-1}$, then the **observation error** is 12.0 – 11.5 = 0.5 $m^3 h^{-1}$. This is greater than the measurement error and means that the high system accuracy is wasted.

Observation error depends on many factors:

- Distance of the element from the observer
- Ambient lighting
- Eyesight, patience and skill of the observer.

Figure 11.1 classifies data presentation elements in wide current use, showing the relevant section in the chapter where the device is covered. It begins by classifying elements into **displays** and **recorders/printers**.

If no permanent record of measured variables is required, then displays can be used. A choice must first be made between **analogue pointer–scale indicators** and **digital displays**. With the pointer–scale indicator, the observer must **interpolate** if the pointer lies between two scale marks: thus if the pointer lies between 9 and 10 the observer must decide whether the measured value is say 9.4, 9.5 or 9.6. Thus an observation error of up to ±0.5 units is possible. This problem is avoided with a two-decade digital display, which presents the number directly as 9.5.

Section 11.3 discusses the principles of **character** displays, which display numerals and letters of the alphabet, and **graphic** displays, which can also show line diagrams, graphs and waveforms, etc.

There are four types of digital display technology in wide current use: **light emitting diodes** (LED), **cathode ray tubes** (CRT), **liquid crystal displays** (LCD) and **electroluminescent displays** (EL). LEDs have high power consumption, which makes them only suitable for small-scale character displays; they are not used in graphic displays. CRTs are used for character and graphics displays, monochrome and colour, but have the disadvantage of high operating voltages and are high-volume bulky devices. LCDs are used for both character and graphics displays. LCD character displays, usually monochrome, have much lower power consumption than equivalent LED displays. LCD graphics displays, monochrome and colour, are **flat screen** panels and have lower operating voltages and power consumption than equivalent CRT devices. Electroluminescent displays are also flat screen and are used for both character and graphics monochrome displays. They have higher operating voltages and power consumption than equivalent LCD devices but greater contrast ratio and viewing angle.

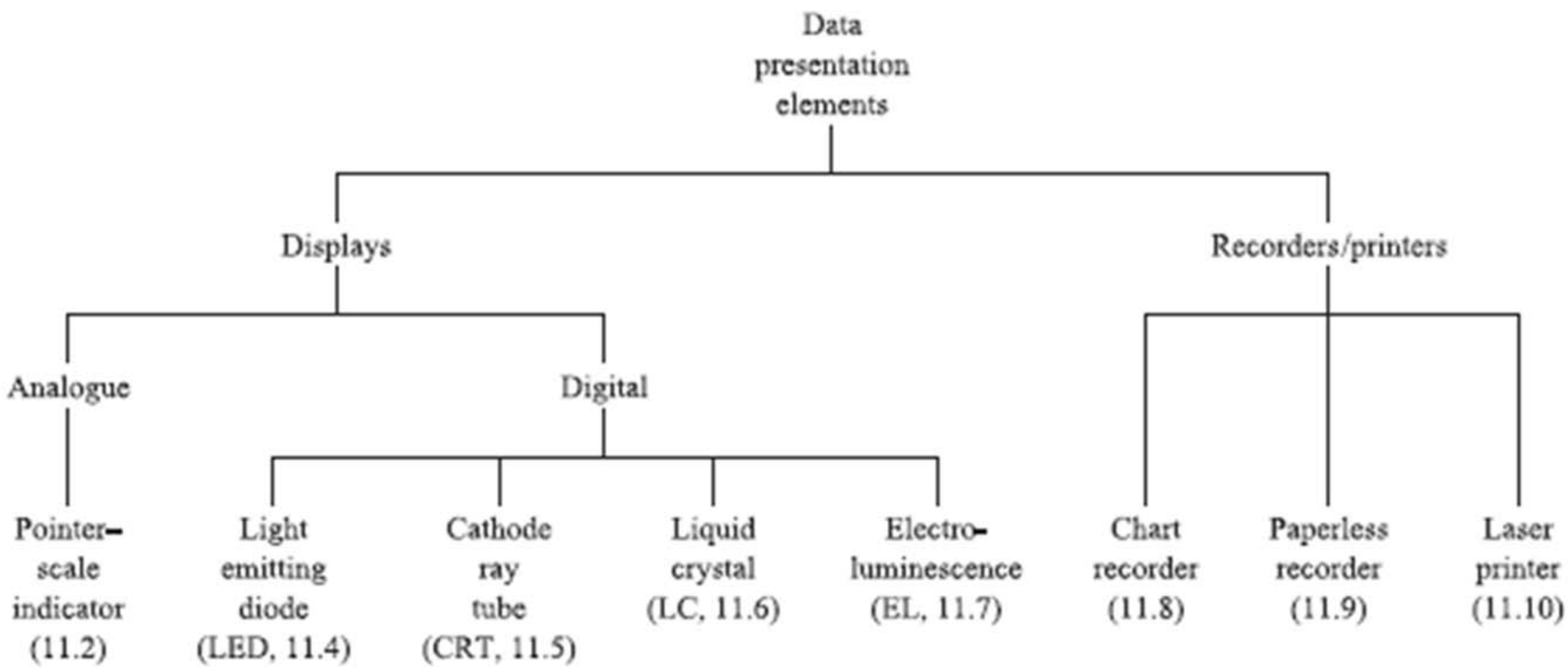
A record of the time variation of the measured variables would be essential, for example, in the following situations:

(a) High-speed events, e.g. a human heartbeat, which are too fast to be followed by a human observer. Changes in the recorded blood pressure waveform will then show clearly any irregular or abnormal behaviour.

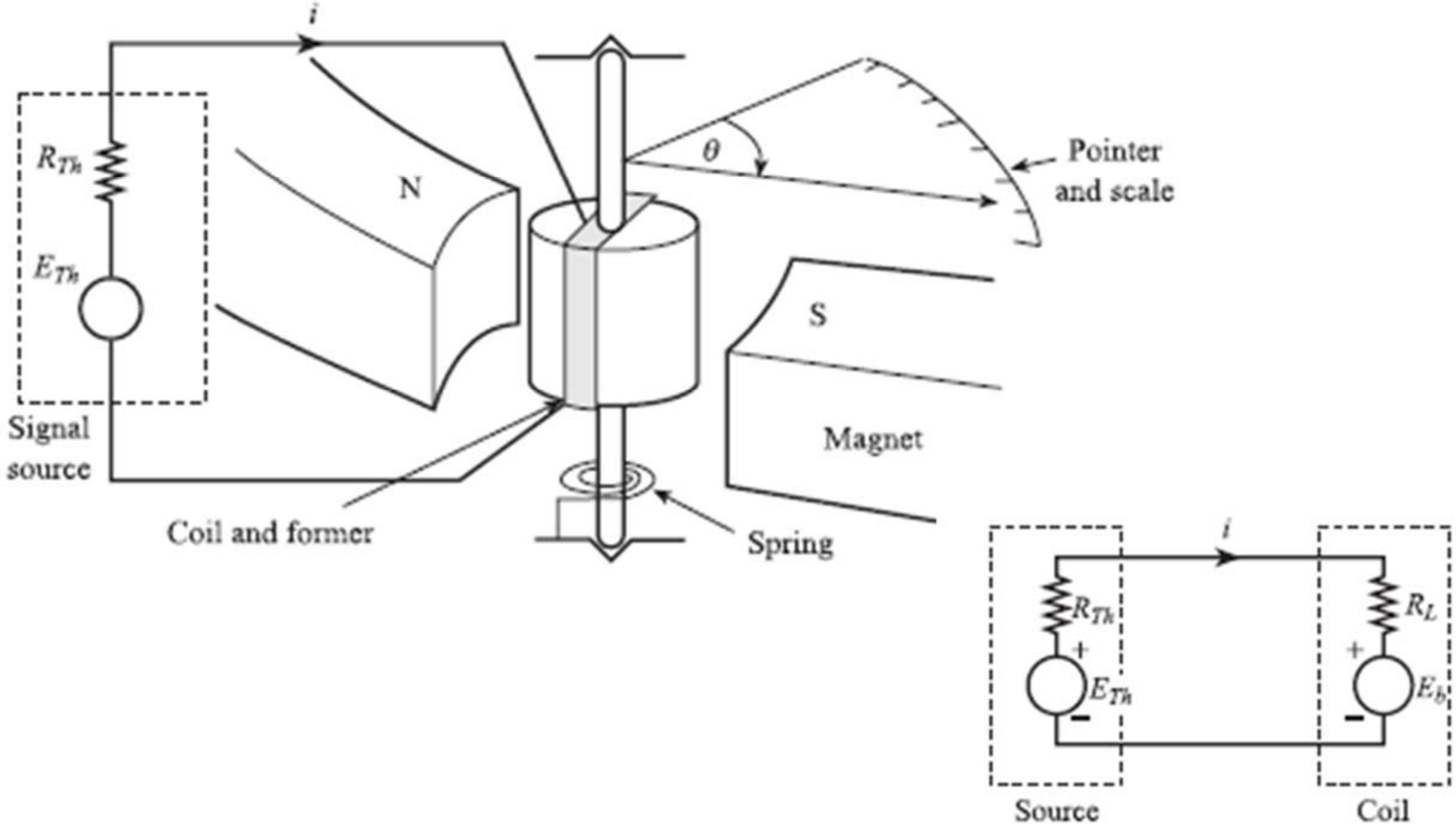
(b) The monitoring of a complex process such as a gas compressor which has a number of associated measured variables. If the compressor breaks down, then the exact sequence of events *drop in lubricating oil pressure – rise in bearing temperature – drop in delivery pressure* can be found and the cause of failure established.

(c) Large amounts of data which are to be used in numerical calculations. Examples are the calculations of the yield and efficiency of a chemical reactor from composition, temperature, pressure and flow-rate data, and the value of gas transferred from supplier to customer in a given month.

Classification of data presentation elements



Pointer–scale indicators



E_{Th}, R_{Th}. The coil is situated in a radial magnetic field of flux density B, so that a current i through the coil produces a deflecting torque:

$$T_D = BnAi \qquad [11.1]$$

where A is the cross-sectional area of the coil and n the number of turns. This deflecting torque is opposed by the spring restoring torque:

$$T_R = c\theta \qquad [11.2]$$

where c is the spring stiffness and θ the angular deflection. Assuming negligible frictional torque, the resultant unbalanced torque on the coil is $T_D - T_R$. This is equal to the product of moment of inertia I and angular acceleration $\mathrm{d}^2\theta/\mathrm{d}t^2$, i.e.

$$BnAi - c\theta = I\frac{\mathrm{d}^2\theta}{\mathrm{d}t^2} \qquad [11.3]$$

The current i is given by:

$$i = \frac{E_{Th} - E_b}{R_{Th} + R_L} \qquad E_b = nAB\frac{\mathrm{d}\theta}{\mathrm{d}t} \qquad [11.4]$$

where R_L is the resistance of the coil and E_b is the back e.m.f. induced in the coil due to its motion in the magnetic field. E_b can be calculated using Faraday's law of electromagnetic induction

Differential equation for pointer–scale indicator

$$\frac{I}{c}\frac{\mathrm{d}^2\theta}{\mathrm{d}t^2}+\frac{(nAB)^2}{c(R_{Th}+R_L)}\cdot\frac{\mathrm{d}\theta}{\mathrm{d}t}+\theta=\frac{nAB}{c(R_{Th}+R_L)}E_{Th}$$

Transfer function for pointer–scale indicator

$$\frac{\Delta\bar{\theta}}{\Delta\bar{E}_{Th}}(s) = \frac{K}{\frac{1}{\omega_n^2}s^2 + \frac{2\xi}{\omega_n}s + 1}$$

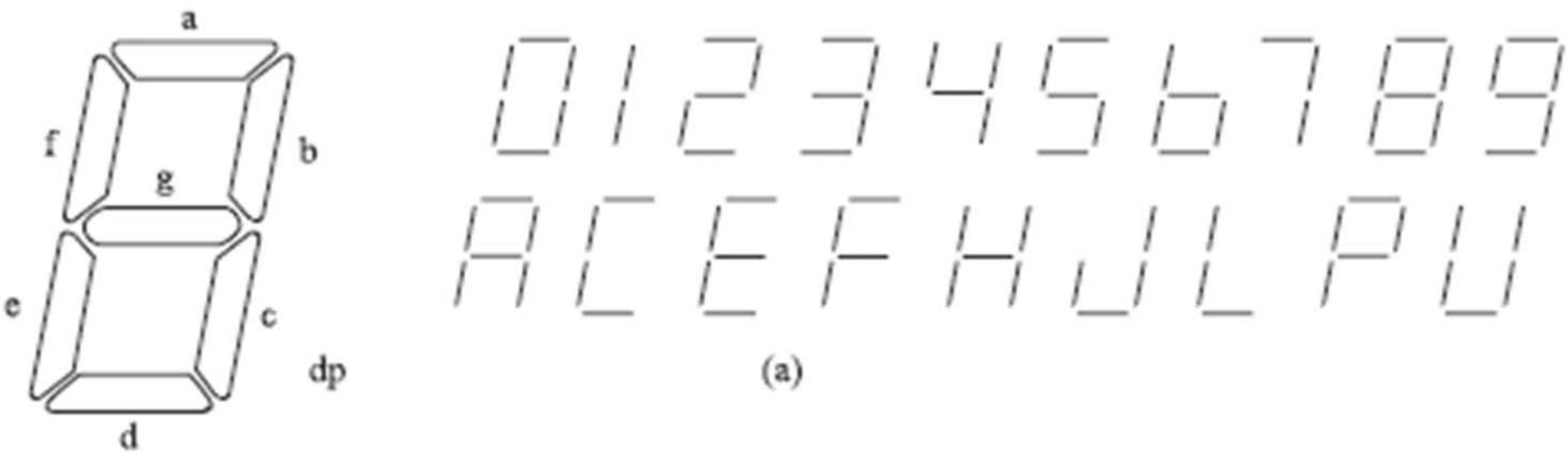
Steady-state sensitivity $K = \dfrac{nAB}{c(R_{Th} + R_L)}$ rad V^{-1}

Natural frequency $\omega_n = \sqrt{\dfrac{c}{I}}$ rad s^{-1}

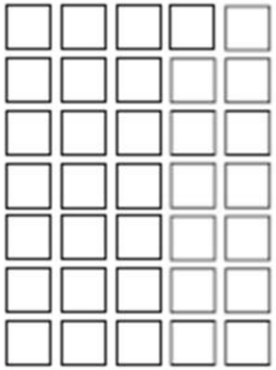
Damping ratio $\xi = \dfrac{(nAB)^2}{2\sqrt{cI(R_{Th} + R_L)}}$

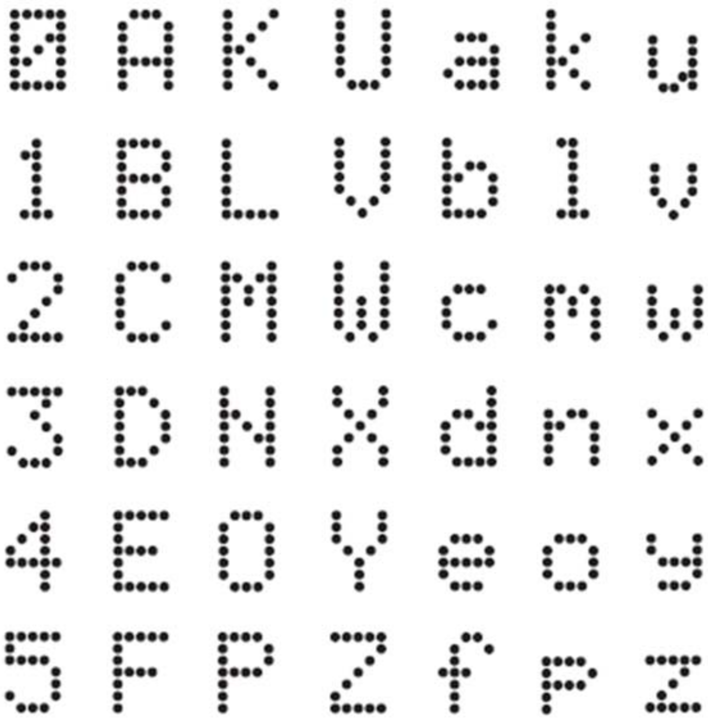
Digital display principles [Character display]

- Seven-segment character format



7 × 5 dot-matrix character format

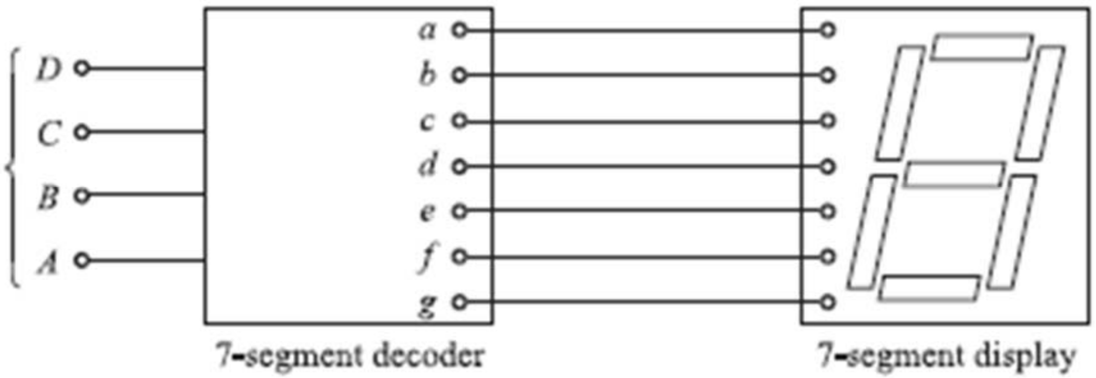




- Displays set of 192 characters -- all the numerals, upper and lower case letters, together with Greek letters and other symbols.
- 9 × 7 dot-matrix format gives a better representation of lower case letters.

Display of numerals using 7-segment format

Each character format is an array of segments or dots; these elements are referred to as **pixels.**

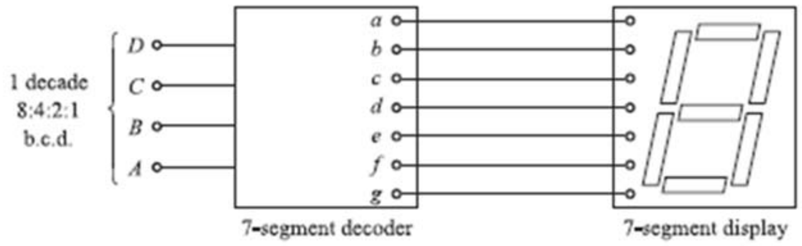


- To display a character each pixel must be separately switched 'on' and 'off' independently of the other pixels.

- When a pixel is switched on, either it is a source emitting light or it is modulating light from other sources.

- When a pixel is switched off it is either not emitting light or not modulating light.

- <u>Example:</u>
- Display the numerals 0 to 9 using the seven-segment format
- Each of the pixels ***abcdefg*** can be switched individually on or off using a seven-digit parallel binary code where a '1' corresponds to 'on' and a '0' to 'off'.
- Figure shows the seven-segment codes corresponding to the numerals 0 to 9.
- A 7- segment decoder is used to convert the input parallel digital signal, usually in binary coded decimal (b.c.d.) or ASCII format, into seven-segment code.

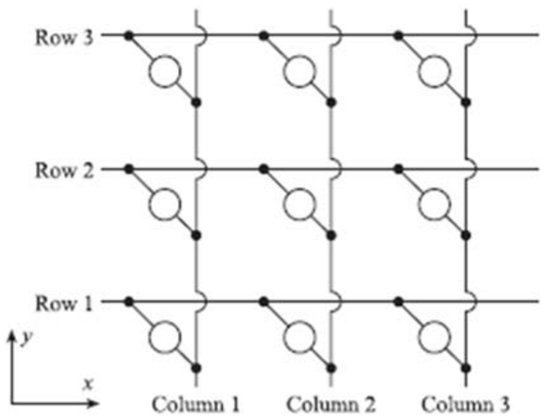


Denary number	b.c.d. code D C B A	7-segment code a b c d e f g	Displayed numeral
0	0 0 0 0	1 1 1 1 1 1 0	
1	0 0 0 1	0 1 1 0 0 0 0	
2	0 0 1 0	1 1 0 1 1 0 1	
3	0 0 1 1	1 1 1 1 0 0 1	
4	0 1 0 0	0 1 1 0 0 1 1	
5	0 1 0 1	1 0 1 1 0 1 1	
6	0 1 1 0	0 0 1 1 1 1 1	
7	0 1 1 1	1 1 1 0 0 0 0	
8	1 0 0 0	1 1 1 1 1 1 1	
9	1 0 0 1	1 1 1 0 0 1 1	

Denary number	b.c.d. code D C B A	7-segment code *a* *b* *c* *d* *e* *f* *g*	Displayed numeral
0	0 0 0 0	1 1 1 1 1 1 0	
1	0 0 0 1	0 1 1 0 0 0 0	
2	0 0 1 0	1 1 0 1 1 0 1	
3	0 0 1 1	1 1 1 1 0 0 1	
4	0 1 0 0	0 1 1 0 0 1 1	
5	0 1 0 1	1 0 1 1 0 1 1	
6	0 1 1 0	0 0 1 1 1 1 1	
7	0 1 1 1	1 1 1 0 0 0 0	
8	1 0 0 0	1 1 1 1 1 1 1	
9	1 0 0 1	1 1 1 0 0 1 1	

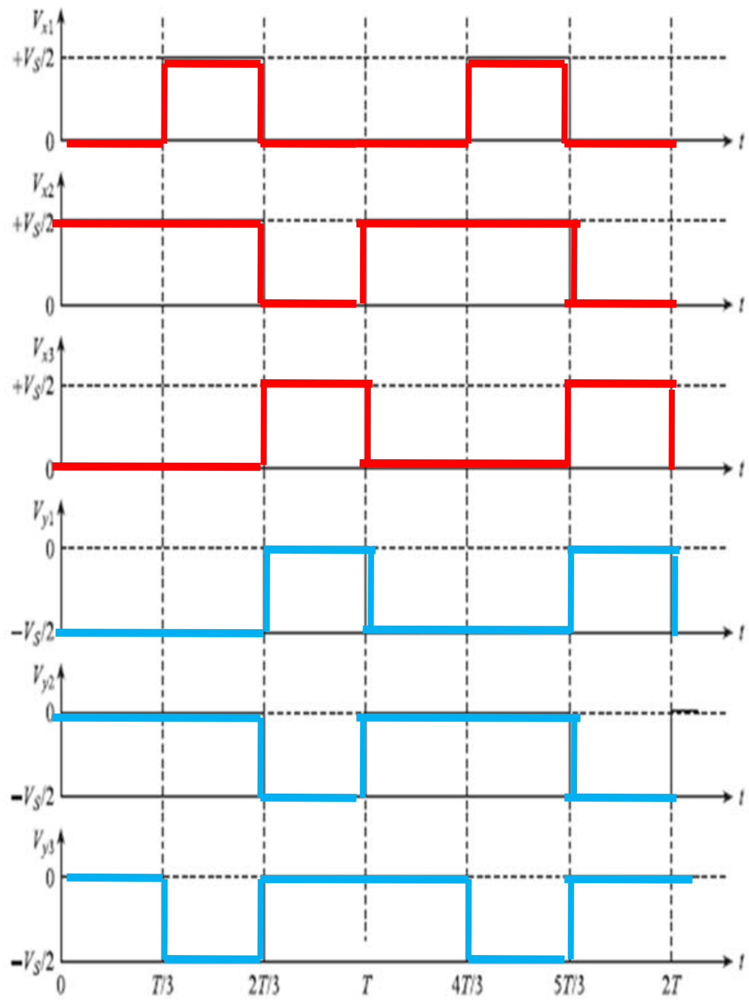
Digital display principles [Graphic display]

- To show **line diagrams, graphs, waveforms, bar charts**, etc.
- Consist of a large number of pixels arranged in **rows** (along the y-axis) and **columns** (along the x-axis).
- The pixels are arranged in a matrix of columns (x) and rows (y).
- Each column (x) and each row (y) has an **electrical conductor** giving a corresponding matrix of conductors.
- Each pixel, with position coordinates (x, y), is connected across the corresponding x and y conductors at their point of intersection

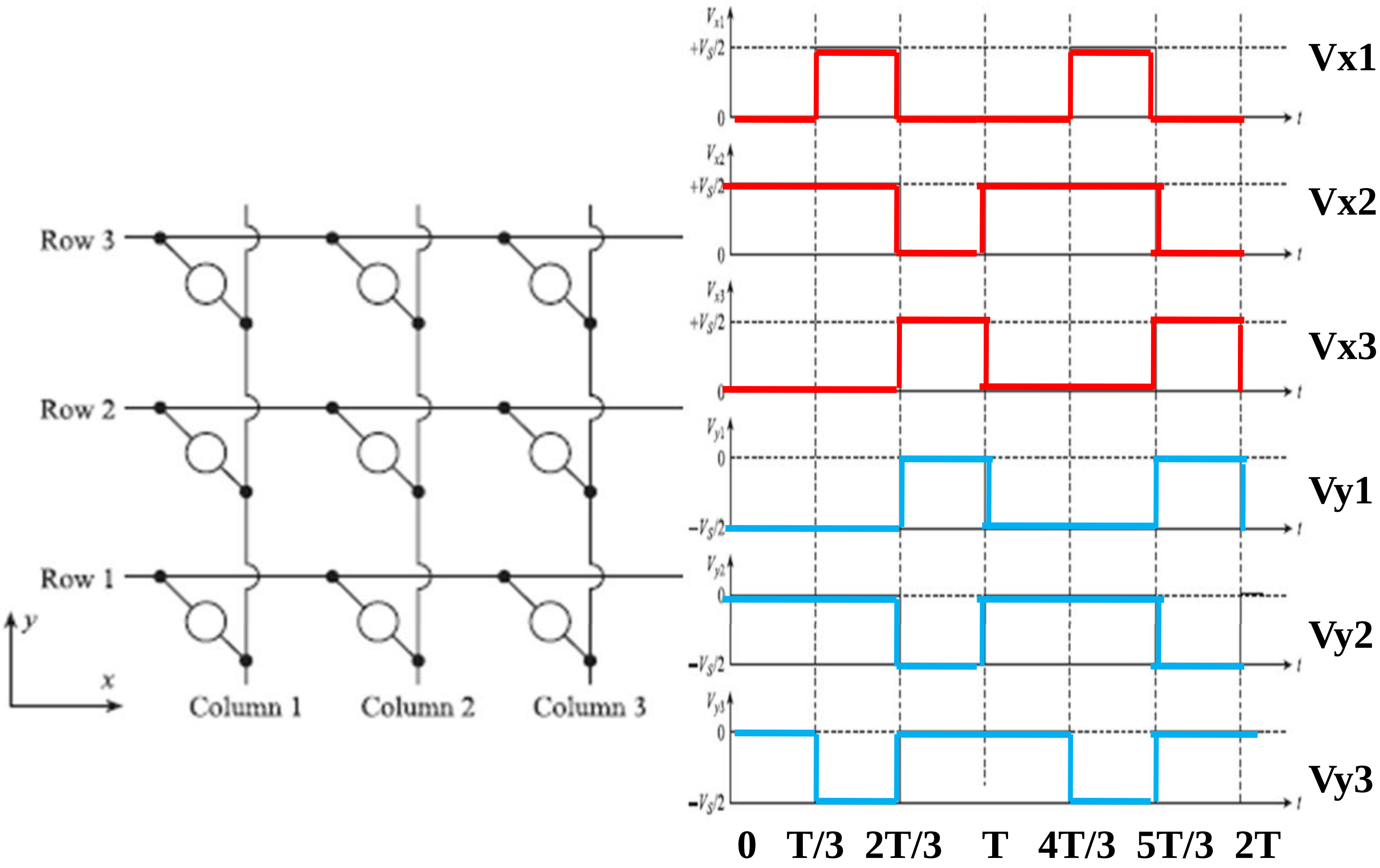


Column voltage waveforms V_x and row voltage waveforms V_y

- The pixel (2, 1) is switched on during time interval 0 to T/3.
- The pixels (1, 1), (2, 1), (1, 3) and (2, 3) are switched on during the time interval T/3 to 2T/3.
- Pixel (3, 2) is switched on during time interval 2T/3 to T.
- There are six electrical conductors for nine pixels so that the saving in external connections is small.
- All waveforms are repeated every repetition period T; this is to refresh the display.
- Provided T is sufficiently short, the brightness of the screen remains reasonably constant without flicker.



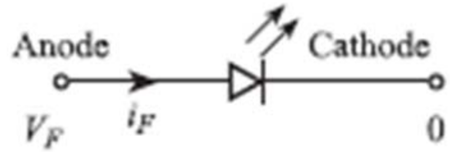
Column voltage waveforms V_x and row voltage waveforms V_y

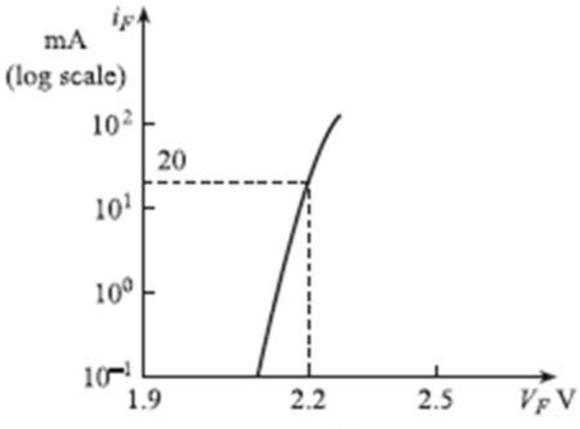


Light-emitting diode (LED) displays

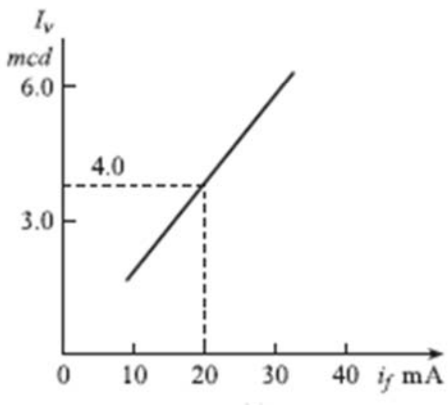
- LEDs have the special property that when forward biased they emit electromagnetic radiation over a certain band of wavelengths.
- Two commonly used LED materials are
  - **Gallium arsenide phosphide (GaAsP) -- emits red light**
  - **Gallium phosphide (GaP) -- emits green or yellow light.**

Forward biased LED

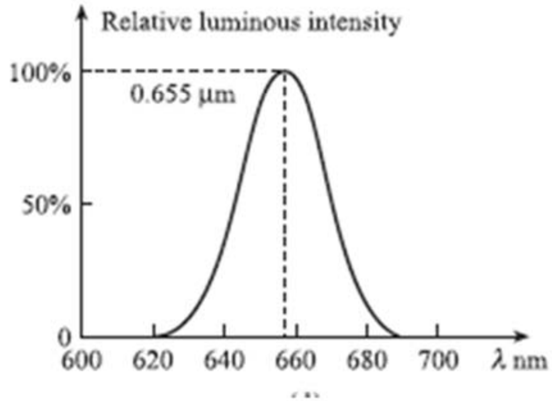




Current/voltage (GaAsP)

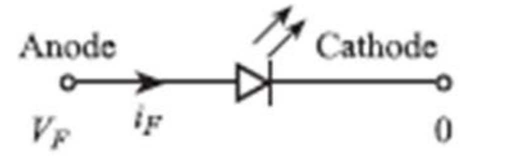


Luminous intensity/current (GaAsP)



Relative intensity wavelength (GaAsP)

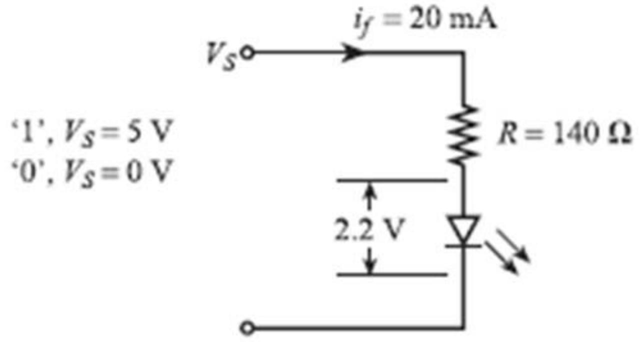
LEDs



- When switched 'on', a typical **GaAsP** diode requires a forward current i_F of around 20 mA corresponding to a luminous intensity I_v of 4.0 mcd (millicandela), and a forward voltage V_F of 2.2 V.

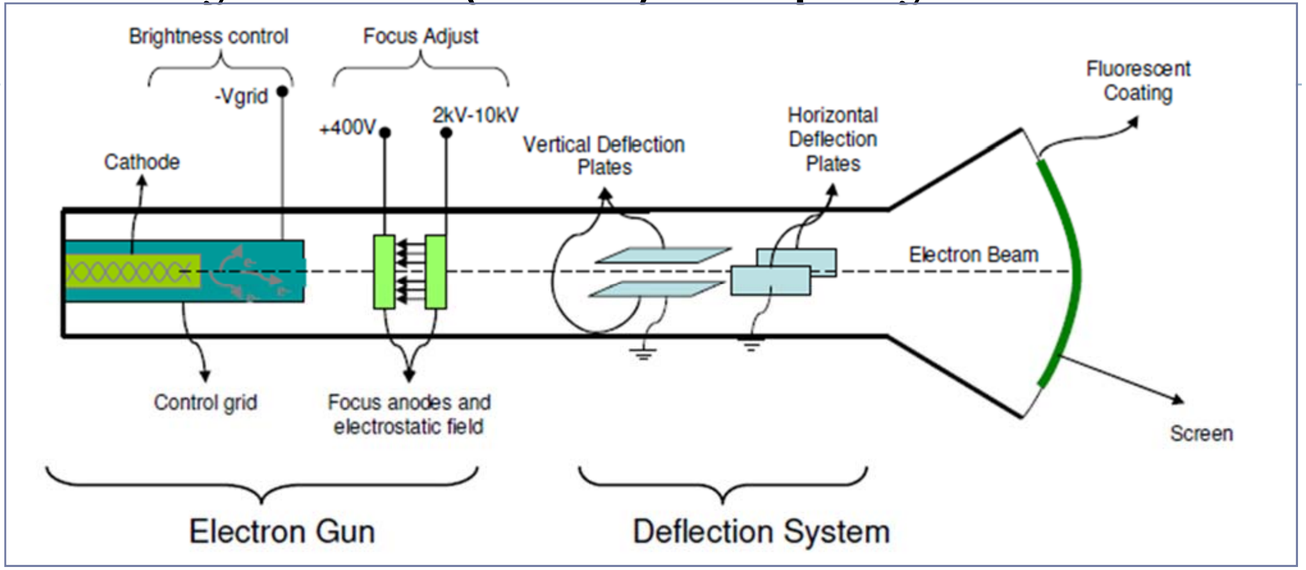
- When used as a display pixel the diode should be switched 'on' by a logic signal in the '1' state, and switched 'off' when the signal is in the '0' state.

- A simple circuit for achieving this, using a series resistor R of 140 Ω.
- For a '1' input, $V_S \approx 5$ V, $i_F = (5 - 2.2)/140 = 20$ mA and the diode is 'on'.
- For a '0' input, $V_S \approx 0$ V, i_F is negligible and the diode is 'off '.



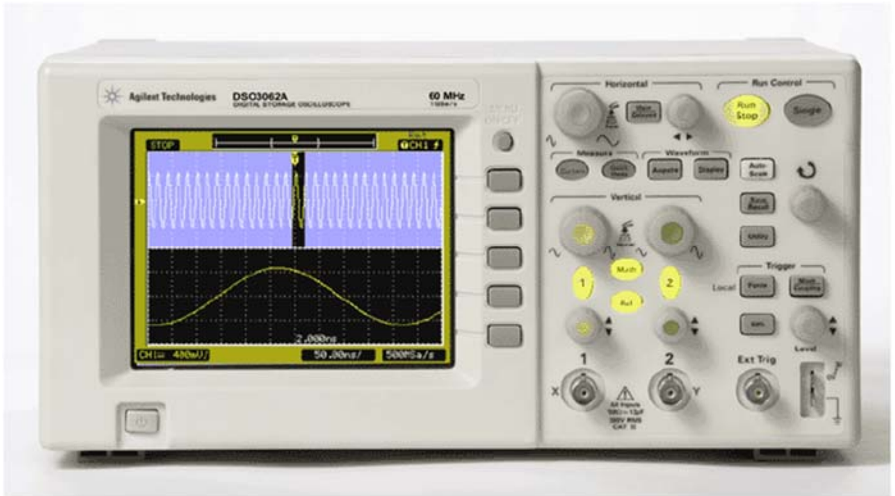
➢ The response of LEDs to step changes in i_F is extremely fast; turn-on and turn-off times of 10 ns are typical.

Cathode ray tube (CRT) displays



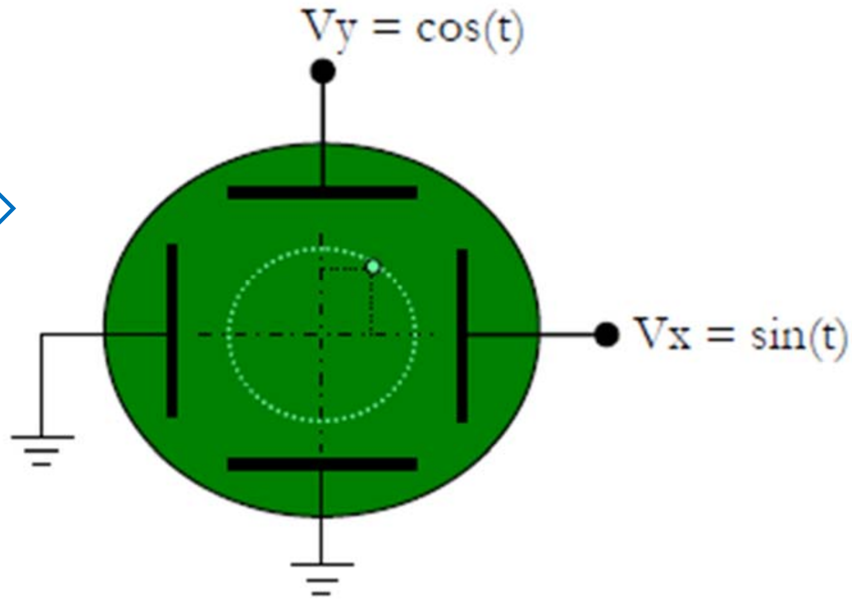
- Electrons are emitted at the cathode and accelerated towards the anode.
- A third electrode, called a grid or modulator, is placed between cathode and anode: by altering the potential of the modulator the number of electrons in the beam, i.e. the beam current, can be adjusted.
- The beam then passes through a focusing system followed by X and Y deflection systems: the focusing and deflection systems can be electromagnetic (EM), or electrostatic (ES).
- The electron beam is brought to a focus on the inside surface of the screen, which is coated with a large number of **phosphor dots.** These dots form the pixels.
- Phosphors are semiconductor materials which emit visible radiation in response to the impact of electrons: a spot of light therefore appears on the screen.

It lets you "see" electrical signals.

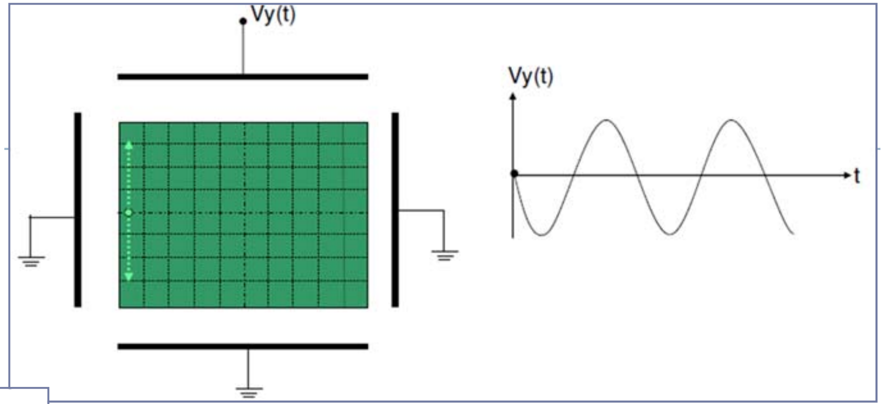


Suppose Vx = sin(t), Vy = cos(t) are applied to the horizontal and vertical deflection plates respectively. Then the bright spot would follow a circular path on the CRO screen.

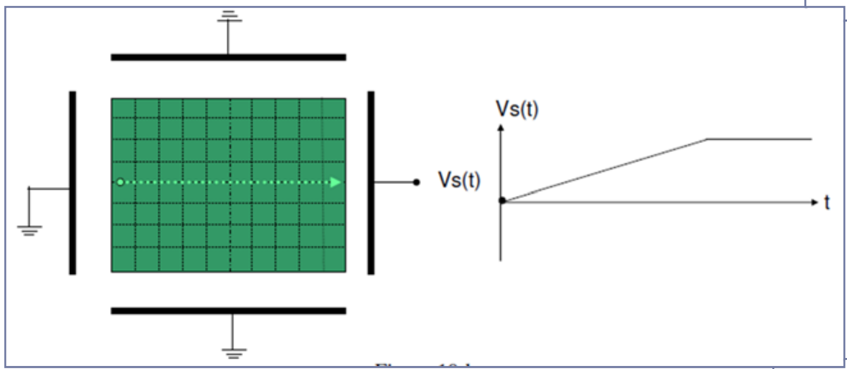
Example 1:



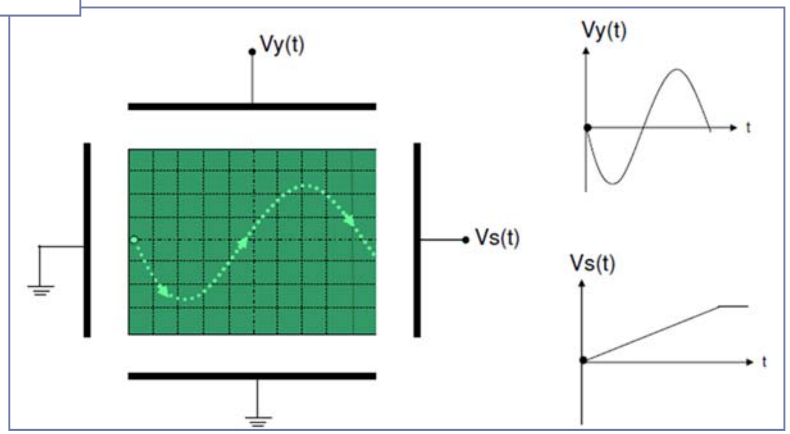
Example 2:

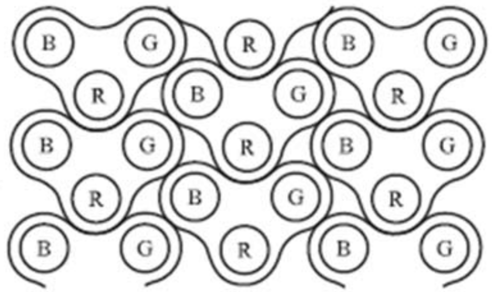


Example 3:

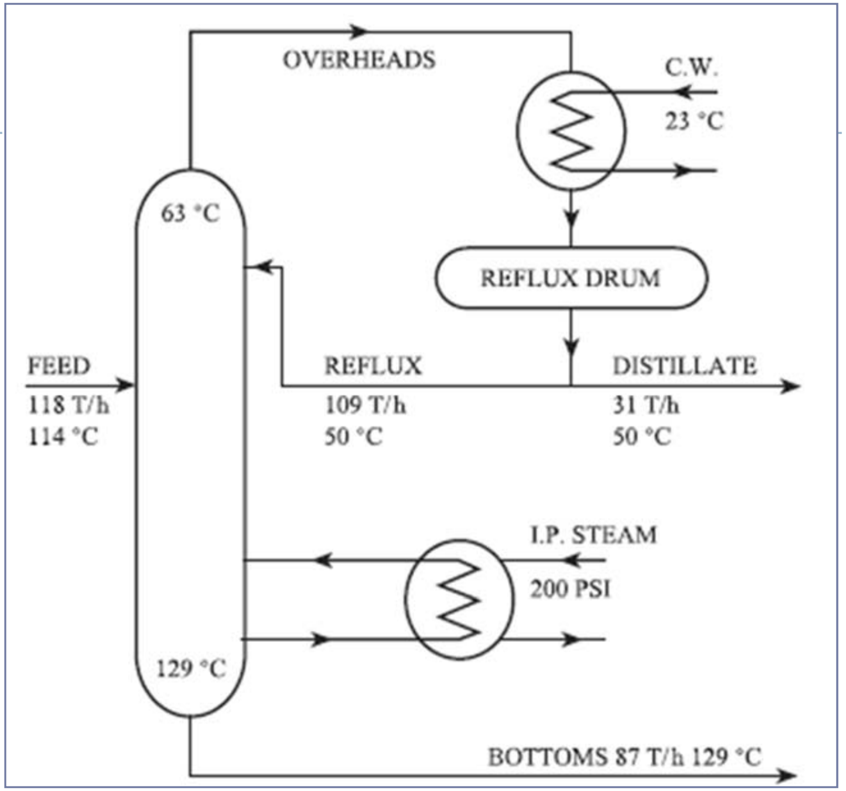


Example 4:



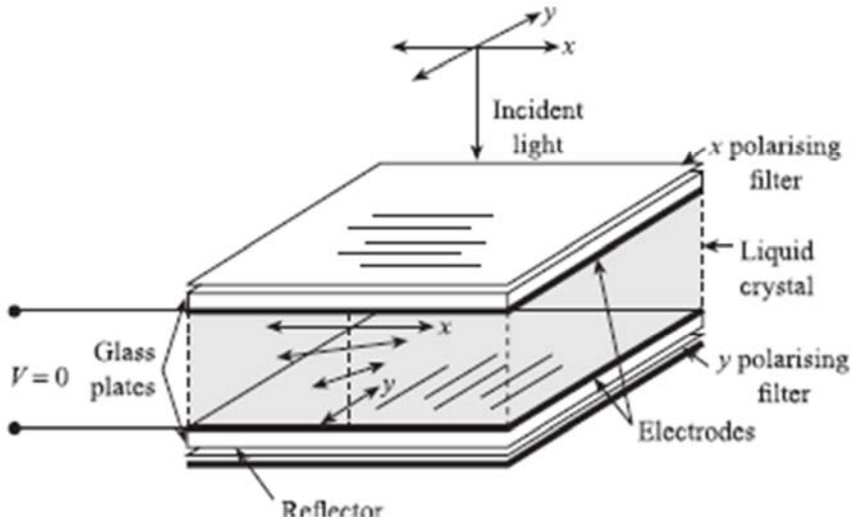


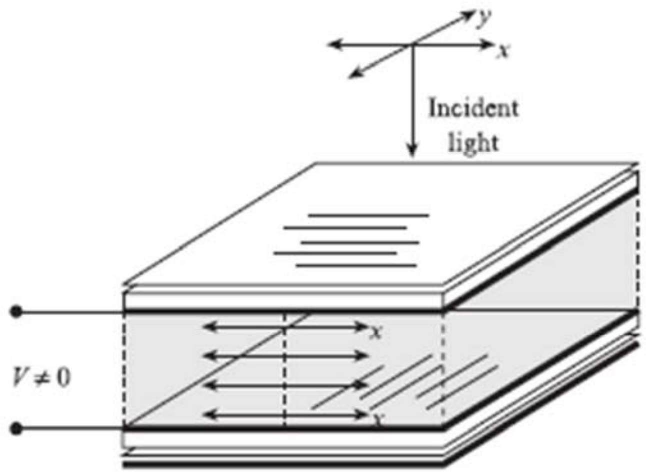
- A **colour display produces images containing a wide range of colours. The** screen of a colour CRT is coated with dots of three different types of phosphor: one type of phosphor emits red light, the second green light, the third blue light.
- Dots of each type are arranged in equilateral triangles called triads .
- The monitor has three electron guns, one for each type of phosphor.
- The corresponding electron beams are deflected horizontally and vertically to produce a raster display as in a monochrome monitor.
- As the beams traverse the screens, the intensity of each beam is varied according to the voltage applied to the corresponding modulator electrode.
- This creates varying colour intensities at the triads and colour images on the screen.



- Figure shows, in black-and white, a colour line diagram of part of a chemical plant; alphanumeric data such as descriptions of process variables and their measured values can be displayed at any appropriate point on the diagram.

Liquid crystal displays (LCDs)





Principle: *V* = *0*

Principle: *V* ≠ *0*

Liquid crystal displays (LCDs) do not emit light but use light incident on them from external sources. Consequently LCDs use significantly less power (microwatts) than LEDs (milliwatts). Liquid crystals flow under shear forces as in normal liquids but have some of the properties of solids. In **nematic** liquid crystals individual molecules have a rod-like shape. As the orientation of the molecules changes so there is a corresponding rotation of the plane of **polarisation** of the incident light. An applied electric field can alter both the orientation of the molecules and the plane of polarisation of the light, thus creating light and dark areas.

Figures 11.10(a) and (b) show the construction of a reflective **monochrome** display using **field effect** or **twisted nematic** (TN) liquid crystal material. The LC material is in contact with a pair of conducting electrodes which are transparent to light; a voltage is applied across these to create an electric field. There are glass plates above and below the electrodes. An *x* polarising filter is situated above the upper glass plate; this transmits only *x* polarised light. Similarly a *y* polarising filter below the lower glass plate transmits only *y* polarised light.

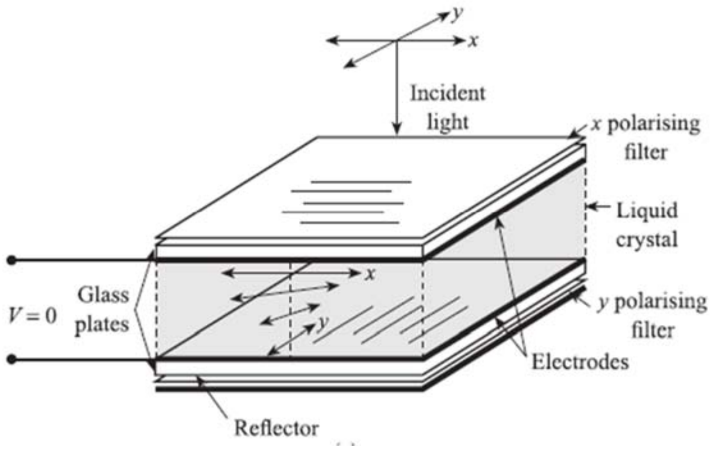
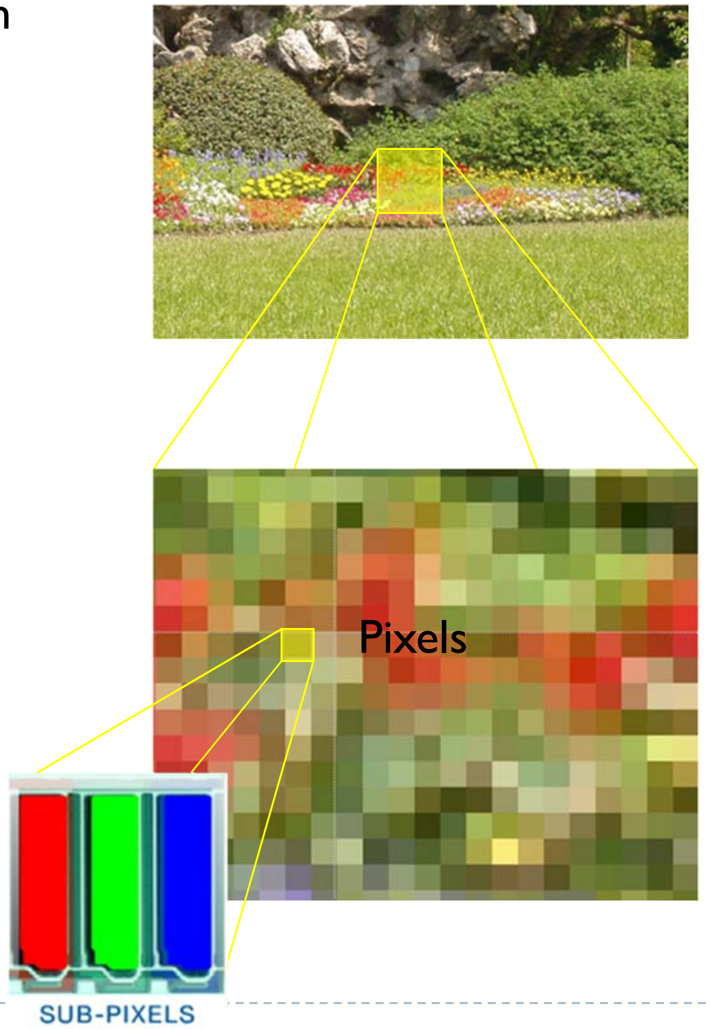


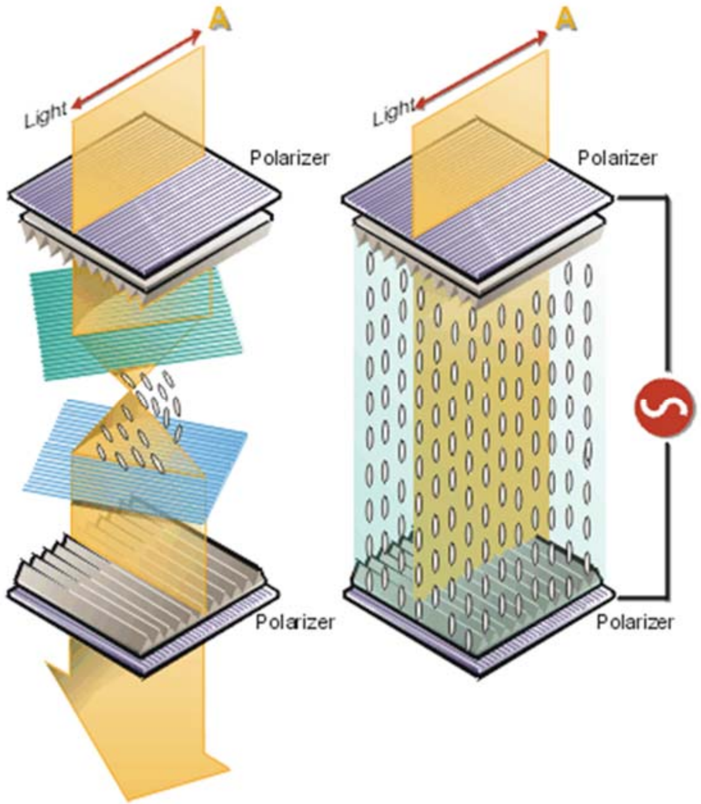
Figure 11.10(a) shows the situation when the applied voltage $V = 0$. The molecules near the top of the LC are lined up along the x-direction. Moving downwards through the liquid, their orientation gradually changes so that the molecules at the bottom are lined up along the y-direction. The light entering the liquid is x polarised; as it moves downwards the direction of polarisation rotates so that the light is y polarised on leaving the liquid. The light is therefore able to pass through the y polarising filter and is reflected back to the observer, the surface appearing pale grey or green.

Figure 11.10(b) shows the situation when the applied voltage V is non-zero. In this case the molecules remain aligned along the x direction throughout the liquid crystal: this means that the light remains x polarised as it moves downwards. The light cannot therefore pass through the lower y polarising filter and is absorbed; the surface appears black to an observer.

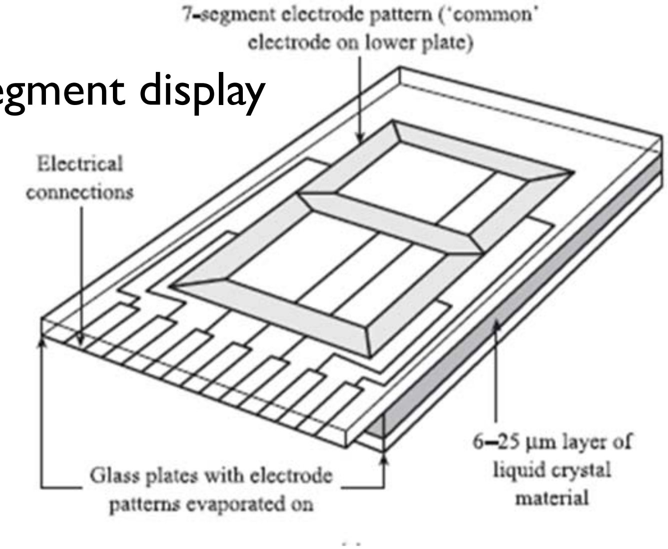
Digital Images and Pixels

- A digital image is a binary (digital) representation of a two-dimensional pictorial data.
- Digital images may have a raster or vector representation.
- Raster Images defined over a 2D grid of picture elements, called pixels.
- A pixel is the basic items of a raster image and include intensity or color value.



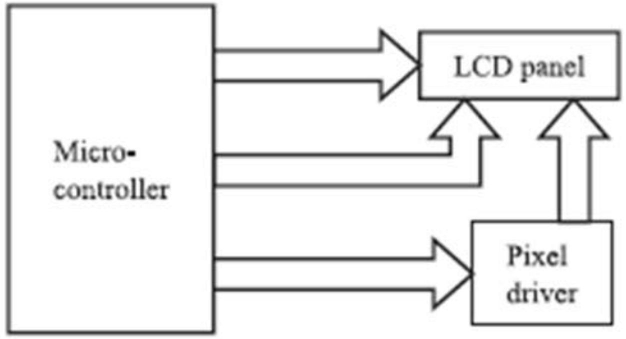

A
Light
Polarizer
Polarizer
A
Light
Polarizer
Polarizer

Seven-segment display



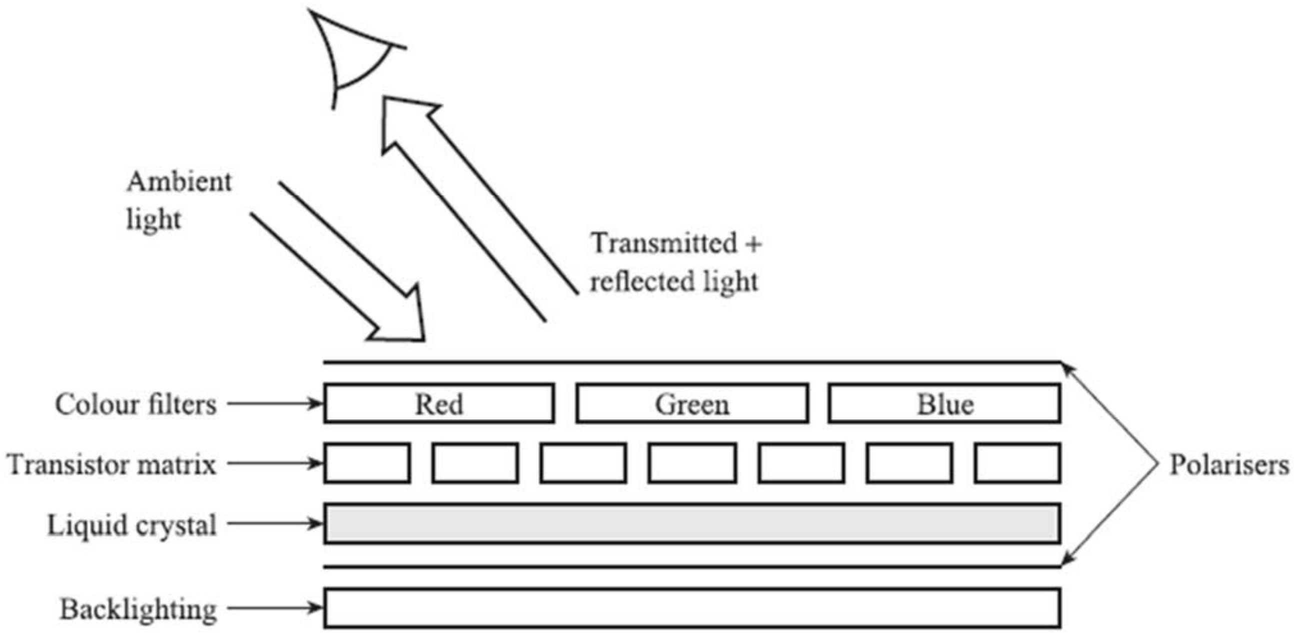
Character display

Graphics display

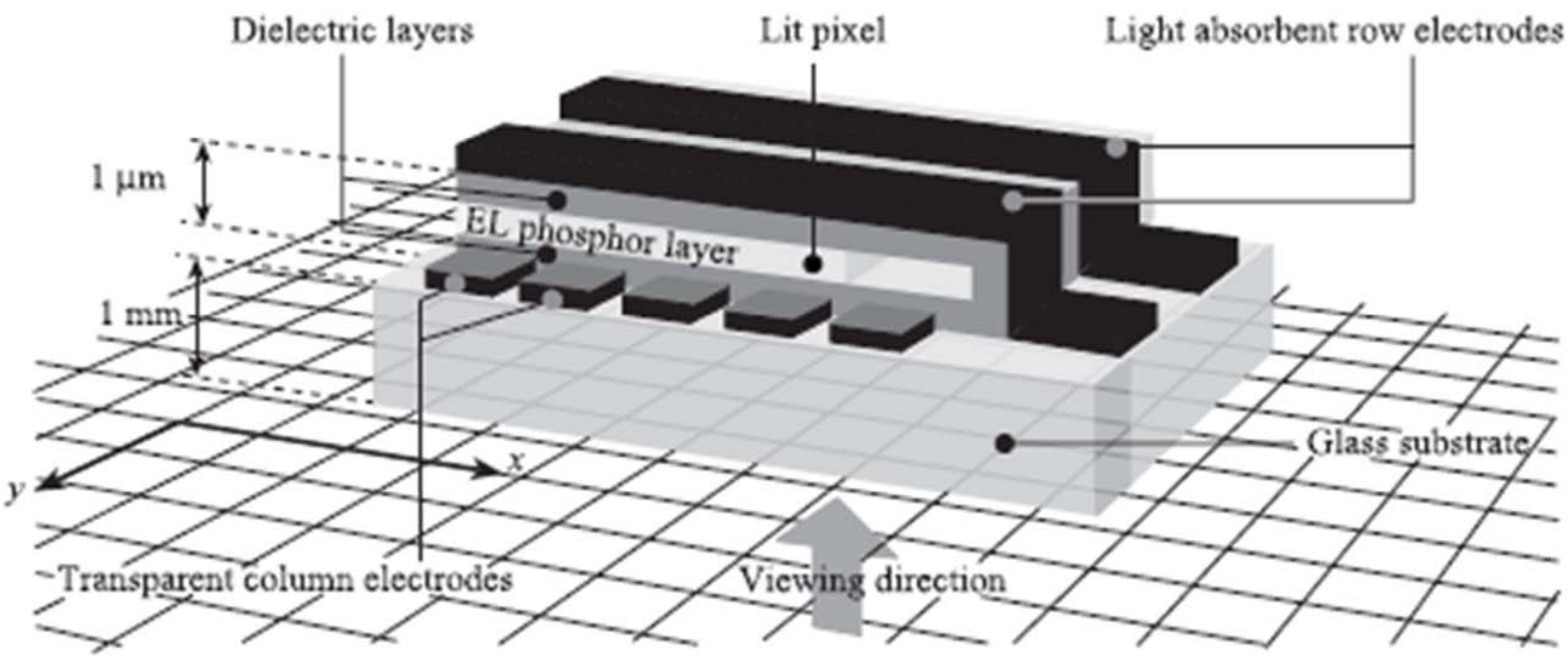


Character display system.

A more recent development is **thin film transistor** (TFT) technology. Here there is a thin film of semiconductor providing a matrix of transistors, so that there is a drive transistor associated with each individual LC pixel. This gives more effective pixel multiplexing, with all pixels in a given row or column having the same voltage. Figure 11.11(a) shows the construction of a typical TFT display.[3]



Electroluminescence displays



Construction

When a voltage is applied across a **phosphor** material, light is emitted. This effect is called **electroluminescence**. A typical electroluminescent phosphor material is zinc sulphide doped with small amounts of metals, the metals being chosen according to the required colour. For example, an amber colour light with peak wavelength $\lambda = 580$ nm is emitted if the zinc sulphide is doped with manganese and copper. Electroluminescent displays consist of a matrix of pixels, where each pixel is a phosphor element which can be switched on and off by an applied voltage.

Figure 11.12(a) shows the construction of an EL display which consists of a number of layers deposited on a glass substrate.[5] The first layer is a number of *x*-axis or column electrodes which are electrically conductive and transparent to light. Then there is the matrix of phosphor elements, which is sandwiched between two dielectric layers. Finally there are a number of *y*-axis or row electrodes which absorb light. Each pixel is located at an intersection of an *x* and a *y* electrode and connected across them. The display is viewed through the glass substrate; with no voltage across the electrodes the pixel appears black. If a voltage pulse, typically of height 100 V and duration 10 µs, is applied across the electrodes, the pixel emits light. The luminance of the pixel decays from an initial value, just after the pulse, of around 1000 cd/m^2, with a time constant of typically 500 µs. This means that the display must be continually refreshed to avoid flicker. The pulse is repeated approximately every 1000 µs, i.e. the pulse repetition frequency is 1 kHz; this enables a continuous luminance of at least 100 cd/m^2 to be obtained. Because the voltage is applied for only 1% of the time, the power required for each pixel is considerably reduced; around 100 µW per pixel is typical. The pulse repetition interval can be increased by adding memory to the pixel element.

Display of measured variable waveforms.

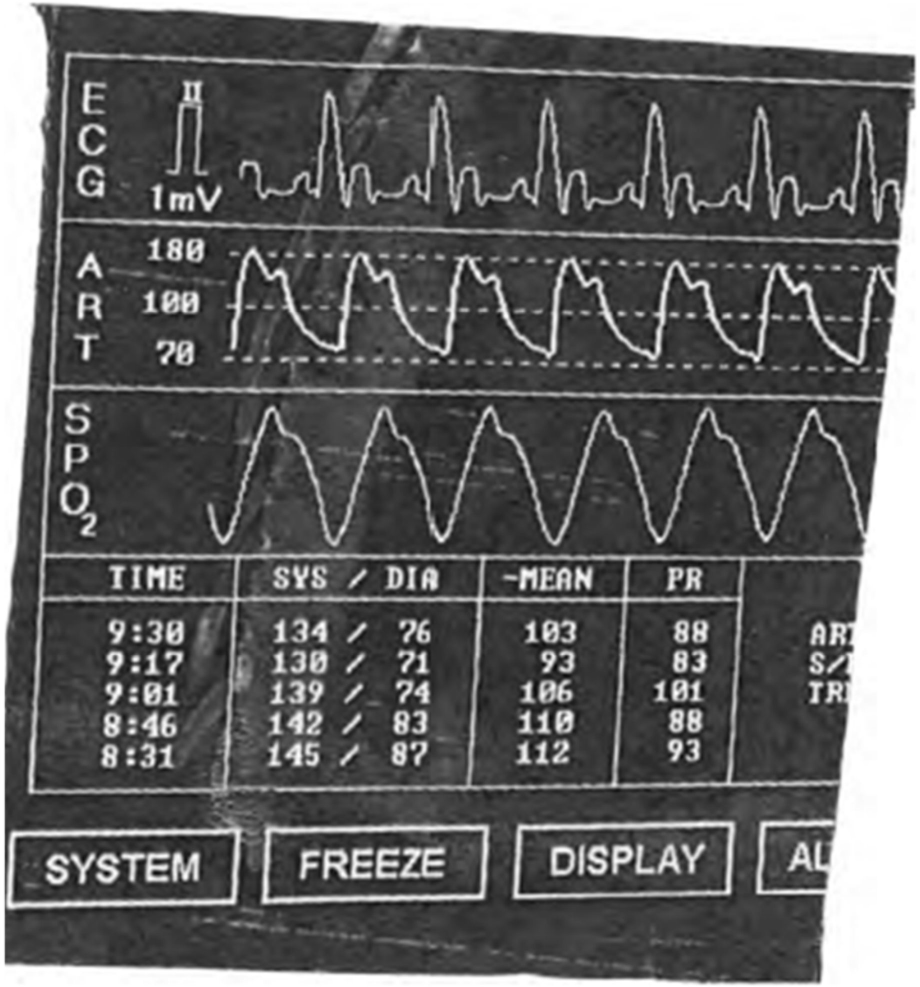
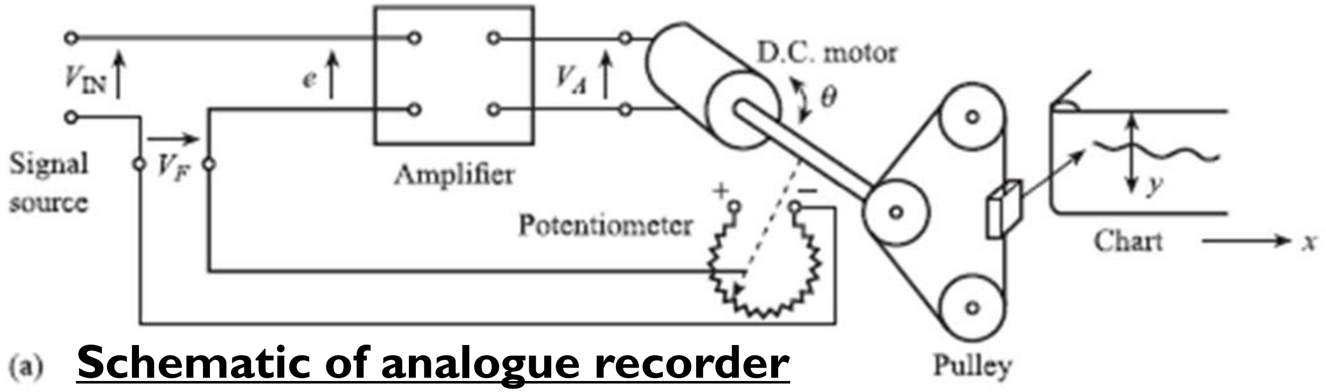
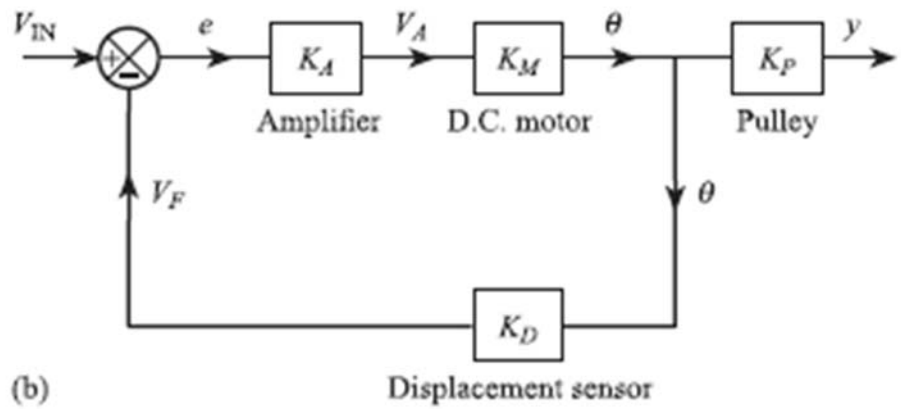


Chart recorders



(a) **Schematic of analogue recorder**



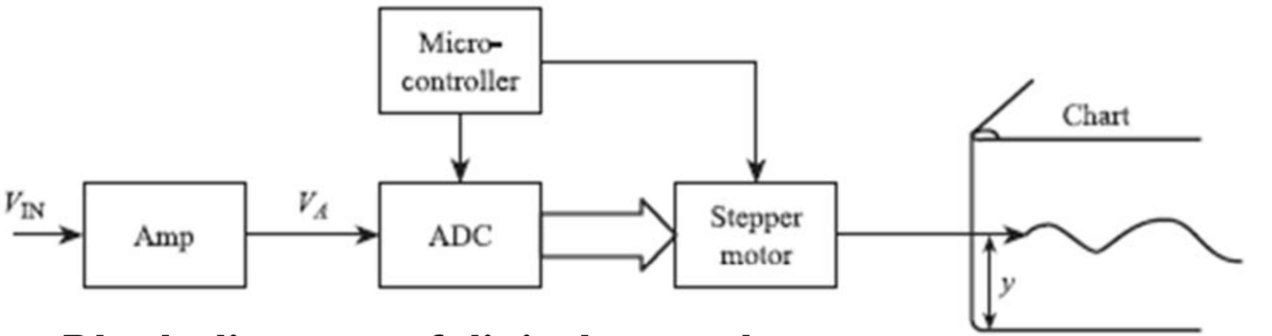
(b)

Block diagram of analogue recorder

These provide a continuous record, on paper, of the time variation of measured variables.

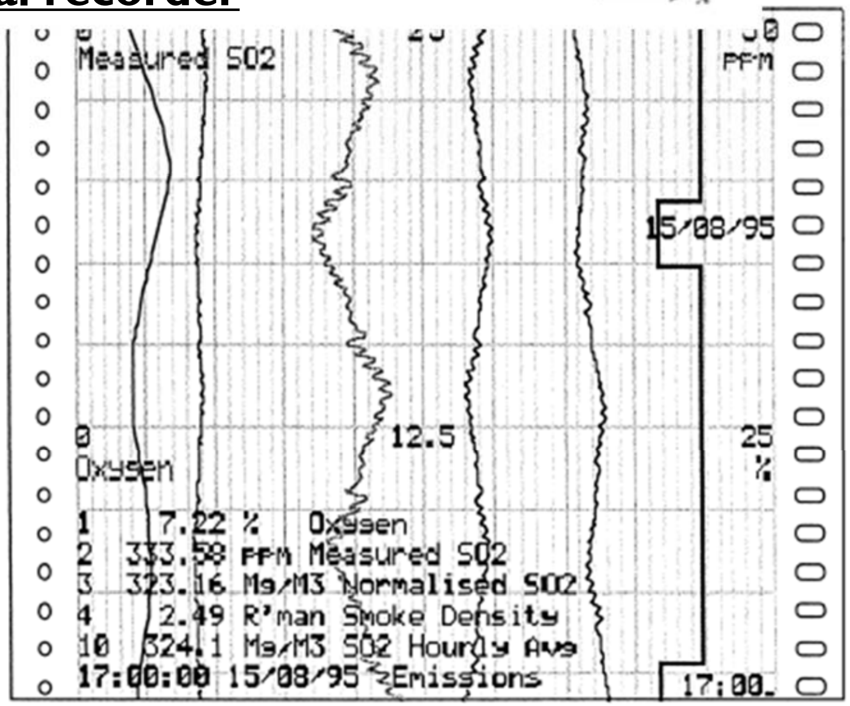
A typical analogue chart recorder has a displacement span y of 100 mm and an input range of 0 to 10 V or 4 to 20 mA d.c. The pen positioning accuracy is ±0.2%, the input impedance 250 kΩ and the response time less than 2.0 s for 100% step change.

The angular rotation θ of the
motor is converted into the vertical displacement y of the pen by a pulley system. The pen writes on a chart which is driven at a constant speed along the x-direction, i.e. the x position of the pen is proportional to time. The motor angular position θ is sensed by a displacement sensor, often a potentiometer, to provide the feedback voltage V_F, thus closing the loop. An increase in input voltage V_{IN} will cause error e to increase in the short term, causing V_A, θ and y to increase. This causes a corresponding increase in V_F which reduces e; the system settles out with the pen at a new position y such that V_F is as close as possible to V_{IN}.



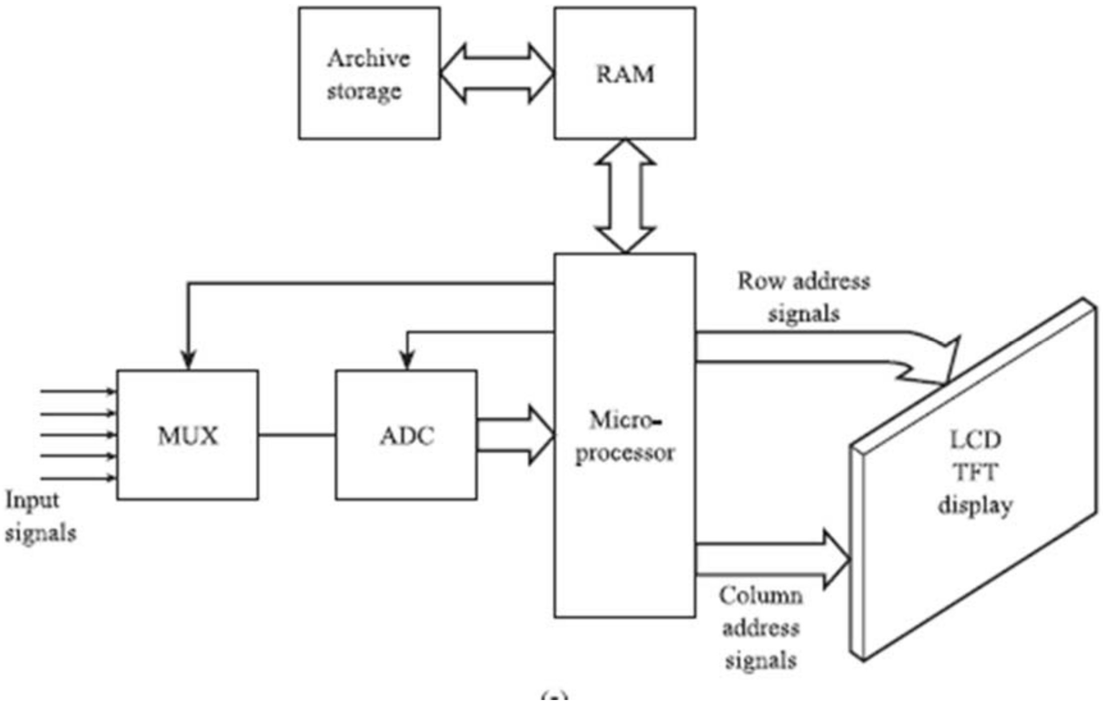
(c) **Block diagram of digital recorder**

Chart record of measured variables.

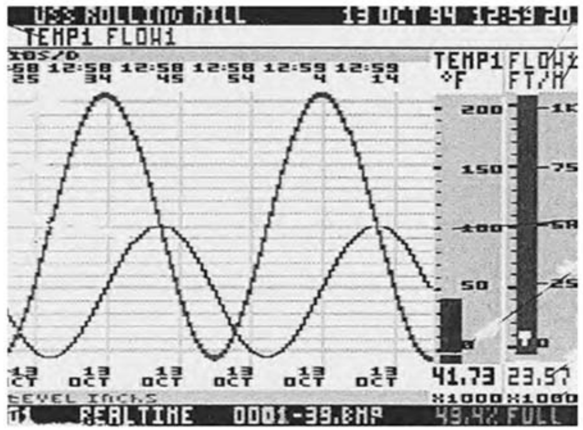


Paperless recorders

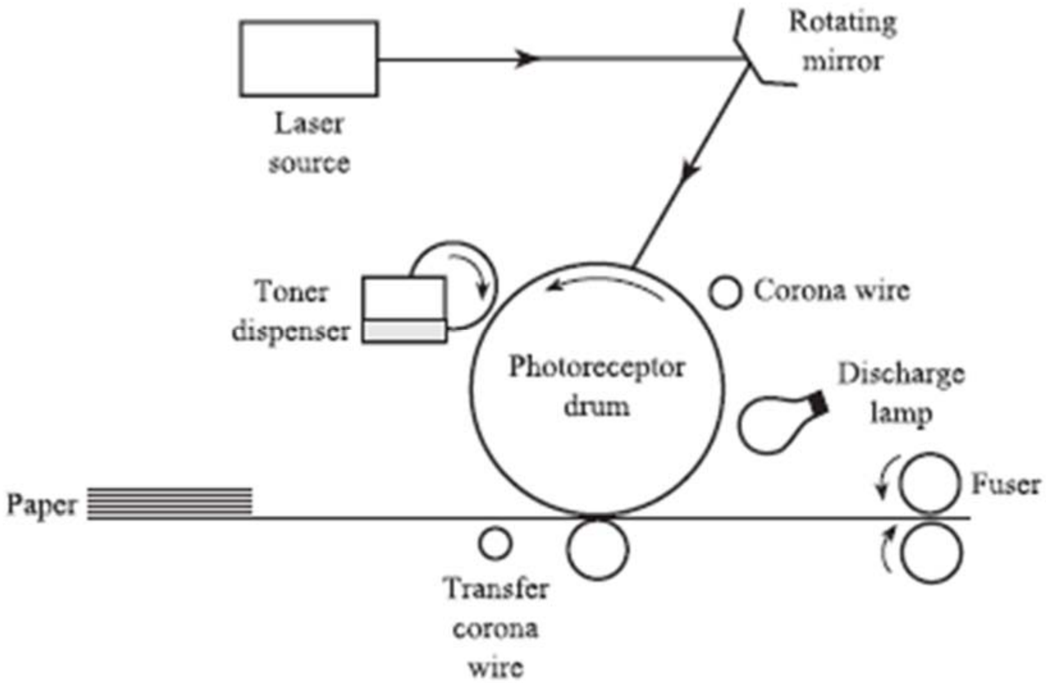
- System block diagram



Typical recording



Laser printers



The operation of the printer is controlled by a computer acting as a **print controller**. The controller converts this incoming data into **bitmap image** pages, each page corresponding to an array of black/white or coloured dots.

The **photoreceptor drum** is an array of photoconductive elements or pixels which correspond to the above bitmap image page. Initially all of the elements are given a positive charge; this is done by passing an electric current through the **corona wire**. The drum rotates and the controller directs a laser beam to move across the entire photoreceptor array in a raster pattern (Figure 11.8). The laser beam is moved by a rotating polygonal mirror and is switched on and off at high speed as it strikes each pixel. If light hits an element, its resistance falls sharply, causing the charge to fall to a negative value. If no light is incident, the pixel retains its positive charge.

The result is that the drum is an array of positively and negatively charged pixels, i.e. an **electrostatic image** of the bitmap page.

The drum is then coated with positively charged black powder toner. The toner clings to the negatively charged elements on the drum but not to the positively charged elements, thus creating a toner version of the bitmap. The sheet of paper is given a negative charge by the **transfer corona wire**; this charge is greater than the negative charge of the electrostatic image so that the paper can pull the toner powder away. The drum rolls over the sheet of paper and the paper picks up the toner to create an exact image on paper. The paper is then discharged so that it can be separated from the drum and finally passes to the **fuser**. This is a pair of heated rollers which melt any loose toner particles so that they fuse with the paper fibres. The printing process is now complete. The electrostatic image on the drum surface is then erased by passing it under the discharge lamp.