Medical signal processing

signal: contains information (information: new knowledge, that decreases the uncertainty).

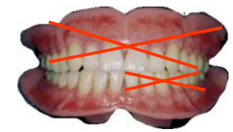
noise: everything, that is not signal.

Relative!

Information content

32 possible answers! The uncertainty is enough large.

1. Upper? - not. Only 16 possible places. Decreasing uncertainty.
2. On the left? - not. 8 possible places.



Five right questions are necessary to indentify the place!

Information content: **5 *bit*** ($2^5 = 32$)

Bit: unit of the information.

Classification of the signals 1.

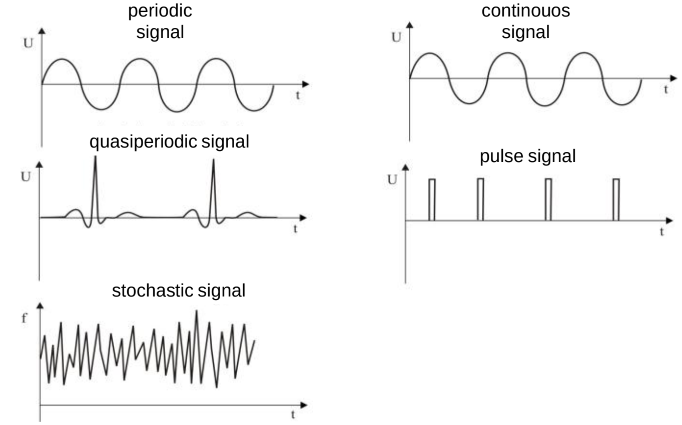
Electric signals (e.g. ECG, EEG, EMG, etc.) → electric signal

Non electric signals (e.g. blood pressure, temperature, etc.) → transformation → electric signal

Equipments are based on electricity!.

electric signal → processing

Classification of the signals 2.



Signal and noise

Noise is random normally!

Ideal case: there is no noise!

Real measurements: noise is always present!

Signal to noise ratio:

The ratio of the quantity used to characterize the strength of the signal and the noise.

Higher value is better!

How can we increase?

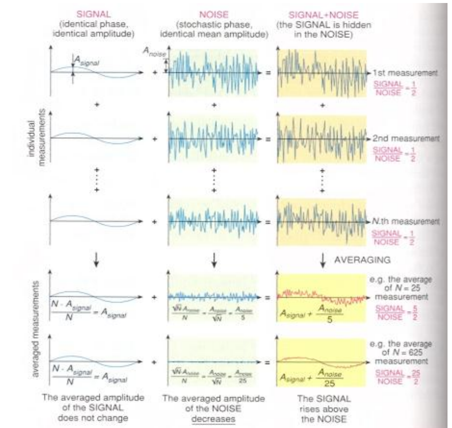
increasing the signal

decreasing the noise

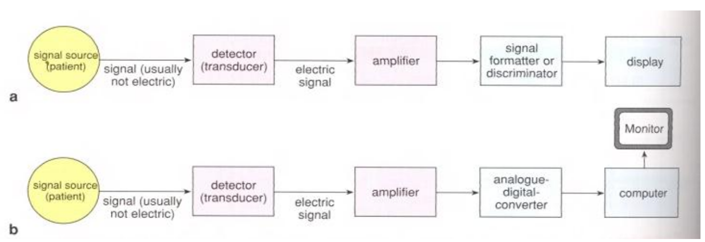
Decreasing the noise by averaging

Base:

Noise is random, while the signal is not.

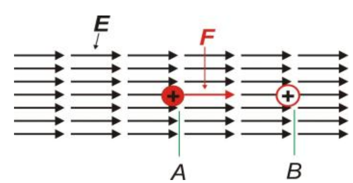


Signal processing



Electric field

Force arises on charges. (*E* – electric field strength)
Static (constant in time) field is produced by charges in rest.



$$\vec{F} = \vec{E} \cdot Q$$

Work:

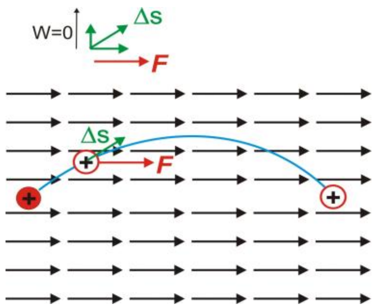
$$W_{AB} = \sum \vec{F} \cdot \overrightarrow{\Delta s} = Q \cdot \sum \vec{E} \cdot \overrightarrow{\Delta s}$$

Voltage (*V*):

unit: volt (V)

$$U_{AB} = \frac{W_{AB}}{Q}$$

Electric potential



In static field the work is independent from the path.

Let *B* is in the infinity:

$$U_A = U_{A\infty}$$

U_A – the potential at A, and:

$$U_{AB} = U_A - U_B$$

Conductors and insulators

conductors: contain movable charges.

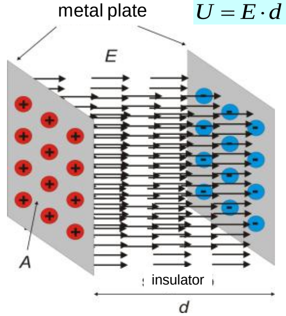
Metals: electrons

Electrolytes: ions

insulators: contain immobile charges.

The best insulator is the vacuum.

Capacitor



$$U = E \cdot d$$

There is a homogenous electric between plates if they are charged.

The strength of the electric field depends on the voltage (V) between plates and the charges (Q) on them.

$$C = \frac{Q}{U}$$

$$C = \varepsilon \frac{A}{d}$$

C is the capacitance.

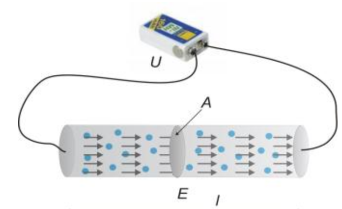
unit: farade (F)

Electric current

Definition: Ordered, unidirectional motion of charges. Its stength is the ***I***. Unit: amper (A)

$$I = \frac{\Delta Q}{\Delta t}$$

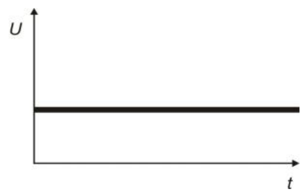
$$E = \frac{U}{l}$$



Depends on the material, *A* cross-section and *E* field strength.

Direct current (DC)

The direction of the current doesn't change.



Electric power (P):

According to the definition of the voltage: $W = QV$.

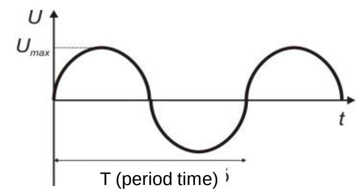
The currint is: $Q = It$.

The result:

$$P_{electric} = \frac{W_{el}}{t} = U \cdot I$$

Alternating current (AC)

The direction of the current changes periodically.



frequency: No. of periods during unit time.

$$f = \frac{1}{T}$$

$$U = U_{\max} \cdot \sin(\omega t)$$

$$\omega = 2 \cdot \pi \cdot f$$

Resistance

The average speed of the charges is determined by the E and the structure of the material.
The current depends on the no. of electrons passing through the cross-section during unit time that is influenced by the average speed.
This property of the cuductor is called resistance (R).
unit: ohm (Ω)

Ohm's law: $R = \frac{U}{I}$

The *R* depends on the material, the cross-section and on the length.

(ρ = resistivity.)

$$R = \rho \frac{l}{A}$$

Conductance

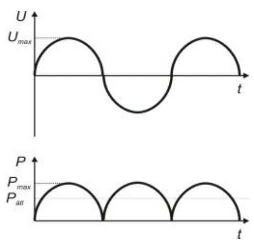
This is reciprok to the resistance. Unit is the siemens (S).

The conductivity (σ) is reciprok to the resistivity.

$$\sigma = \frac{1}{\rho}$$

Effective voltage, effective current

Definition: These are the value of a direct current, that has the same power than the given alternating current.

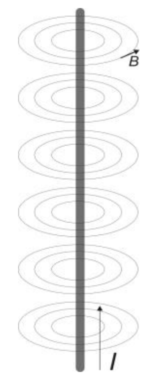


$$P = U \cdot I = I^2 \cdot R = \frac{U^2}{R}$$

$$U_{eff} = \frac{U_{max}}{\sqrt{2}} \quad \text{or} \quad I_{eff} = \frac{I_{max}}{\sqrt{2}}$$

(The equations above are valid only for sinusoidal current.)

Magnetic field

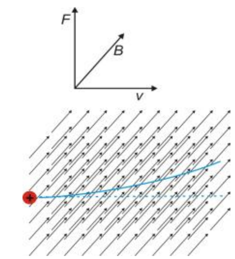


Force is exerted on moving charges only.

Its strength is characterized by the B (magnetic field vector).

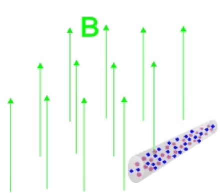
Lorentz force:

proprotional to the Q, the speed of the charge and the B.



Electromagnetic induction

Motion of a conductor in magnetic field.



The Lorentz force is exerted on the moveable electrons. The motion of the electrons produces charge separation in the material. This separation generates voltage.

Inductance

Permanent current produces a magnetic field in a coil. The resistance of the coil is zero in ideal case and so the voltage drop is also zero.

Alternating current produces periodically changing magnetic field. The consequence of this magnetic field is an induced voltage.

The produced voltage is proportional to the speed of the current changing in time. The proportionality factor is the inductivity (L).

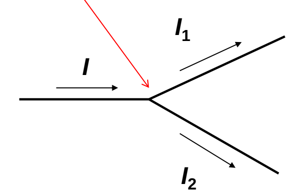
Unit: H – henry.

The impedance (X) („resistance” in the case of the alternating current)

resistance:	$X_R = R$	doesn't depends on the frequency
capacitor:	$X_C = \dfrac{1}{\omega C}$	depends on the frequency
inductance:	$X_L = \omega L$	depends on the frequency

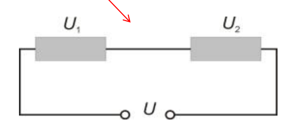
Kirchoff's laws

junction rule (current law)



$I = I_1 + I_2$

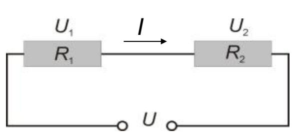
loop rule (voltage law)



$U = -(U_1 + U_2)$

Serial, parallel circuit

Serial circuit

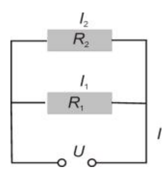


$U = U_1 + U_2$

$IR = IR_1 + IR_2$

$R = R_1 + R_2$

Parallel circuit



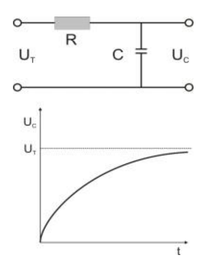
$I = I_1 + I_2$

$\frac{U}{R} = \frac{U}{R_1} + \frac{U}{R_2}$

$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$

DC behavior of a RC-circuit

charging

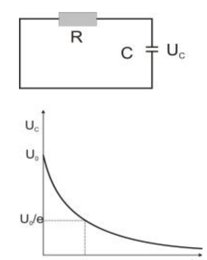


$U_C = U_T \cdot \left(1 - e^{-\frac{t}{RC}}\right)$

$\tau = RC$

τ = time constant

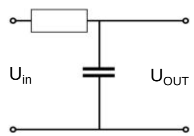
discharging



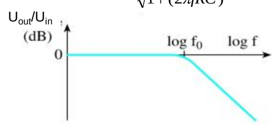
$U_C = U_0 \cdot e^{-\frac{t}{RC}}$

AC behavior of a RC-circuit

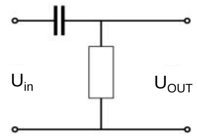
Lowpass filter



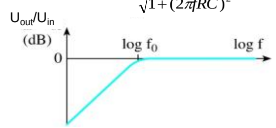
$$U_{out}=U_{in}\frac{1}{\sqrt{1+(2\pi fRC)^2}}$$



Highpass filter

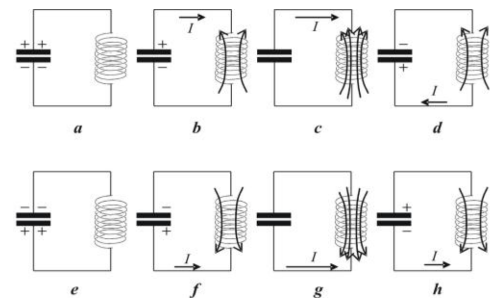


$$U_{out}=U_{in}\frac{2\pi fRC}{\sqrt{1+(2\pi fRC)^2}}$$



Resonant circuit (LC-circuit)

Electric (in the capacitor) and magnetic (in the coil) field



The electric and the magnetic field peridically are built up and destroyed.

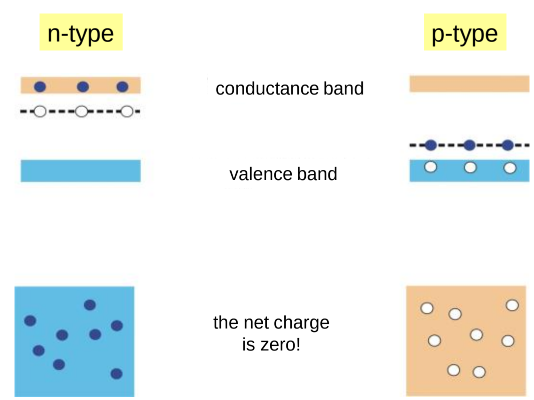
$$f=\frac{1}{2\pi\sqrt{LC}}$$

Resonance

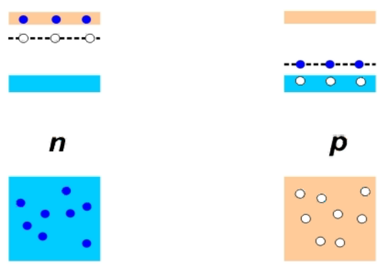
Energy excange between two oszcillating systems is possible only if the resonant frequency of the two systems is enough close to each other.

Tacoma bridge (1940)

Semiconductors



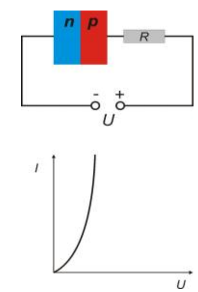
Diode



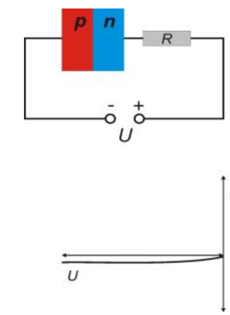
Consist of a n- and p-type semiconductors very close to each other.

Working of a diode

forward direction

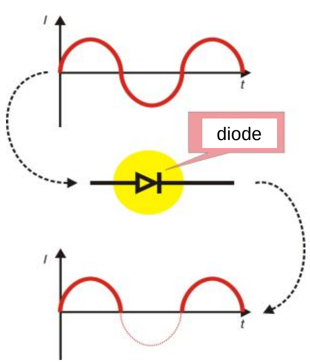


reversed direction

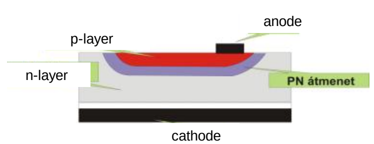


Application (examples)

rectification



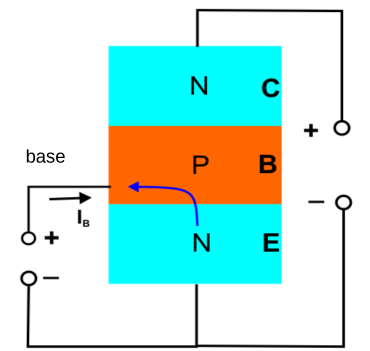
radiation detector



The radiation produces free charges and current in the case of reversed direction.

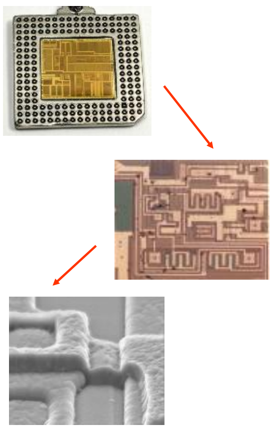
The transistor

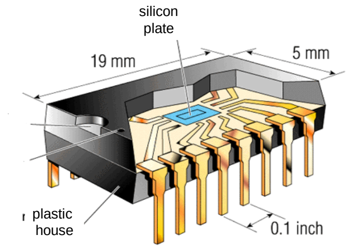
It is built up from 3 layers.



NPN transistor (there is PNP too)

Integrated circuits (IC)

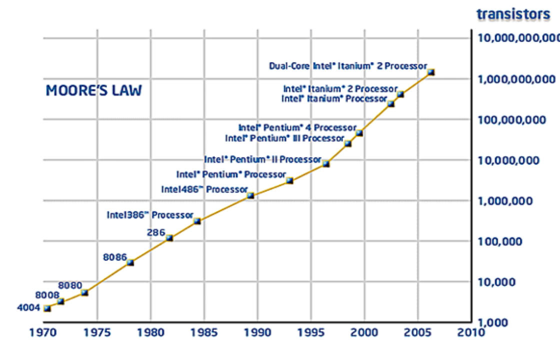




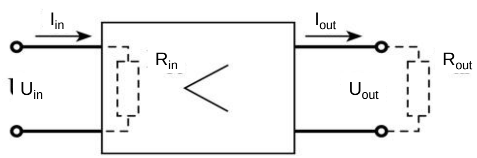
Transistors, diodes, resistors and capacitors are formed on a semiconductor plate producing a complicated electric circuit.

The development

There are about 10^{11} neurons in the brain.



Amplifier



Amplifier if $P_{out} > P_{in}$

Power gain: (A_P)

Voltage gain: (A_U)

$$A_P = \frac{P_{out}}{P_{in}}$$

$$A_U = \frac{U_{out}}{U_{in}}$$

The decibel scale

Frequently instead of the simple proportion we use the logaritmic of them. Decibel-scale.

$$n = 10 \cdot \lg \frac{P_{out}}{P_{in}} \ \text{(dB)}$$

$$P = \frac{U^2}{R}$$

$$A_P = \frac{U_{out}^2 / R_{out}}{U_{in}^2 / R_{in}} = \frac{U_{out}^2}{U_{in}^2} \cdot \frac{R_{in}}{R_{out}} = A_U^2 \cdot \frac{R_{in}}{R_{out}}$$

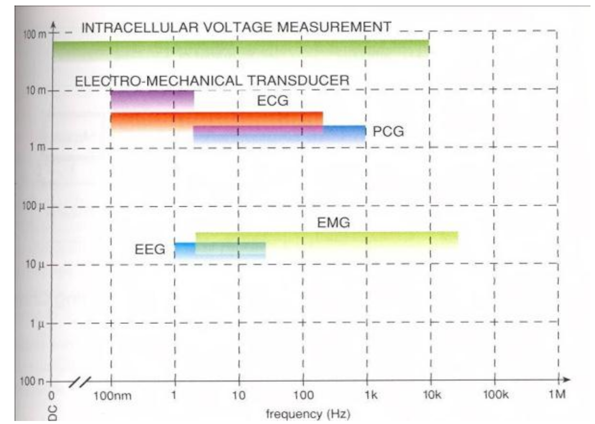
$$n(dB) = 10 \cdot \lg A_U^2 + 10 \cdot \lg \frac{R_{in}}{R_{out}} = 20 \cdot \lg A_U \left(+ 10 \cdot \lg \frac{R_{in}}{R_{out}} \right)$$

Fourier theoreme

$$y(t) = \sum_k a_k \sin(k \cdot \omega_0 \cdot t + \Phi_k)$$

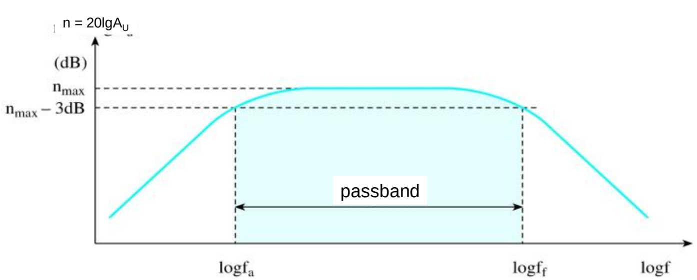
Every periodic signal may be decomposed into the sum of sinusiodal signals.

Biological signals

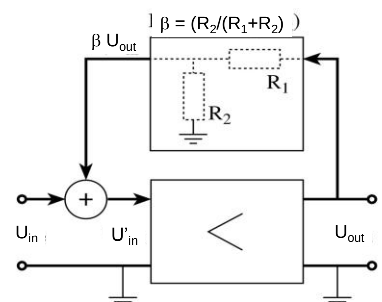


Transfer characteristics

The amplification in decibel as the function of the frequency.



Feed-back



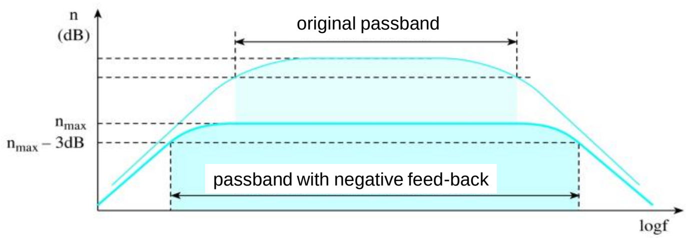
$$U'_{in} = U_{in} \pm \beta \cdot U_{out}$$

$$A_{U,F} = \frac{U_{out}}{U_{in}} = \frac{A_U}{1 \pm \beta \cdot A_U}$$

Negative feed-back

The feed-backed part of the output is added to the input after inversion.

$$A_{U,NF}=\frac{U_{out}}{U_{in}}=\frac{A_U}{1+\beta\cdot K_U}$$



Pozitive feed-back

The feed-backed part of the output is added to the input.

$$A_{U,PF}=\frac{U_{out}}{U_{in}}=\frac{A_U}{1-\beta\cdot A_U}$$

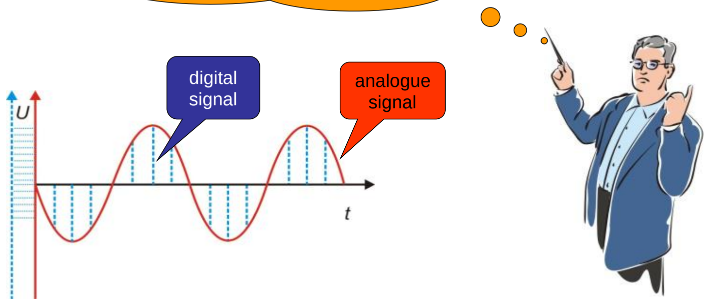
if βA_U = 1 the system is unstable, oscillation.

↓

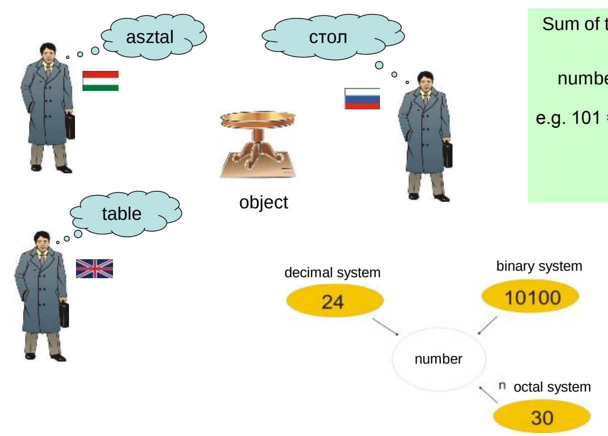
Oscillators: used to produce electric signal.

Digitazing the signal

Digital signal: a signal characterized by digital value and determined at a given time peridically (sampling).



Binary system of the numbers



Sum of the powers op 2.

numbers: 0 and 1.

e.g. 101 = $1\cdot 2^2$
$+\ 0\cdot 2^1$
$+\ 1\cdot 2^0$

Displays

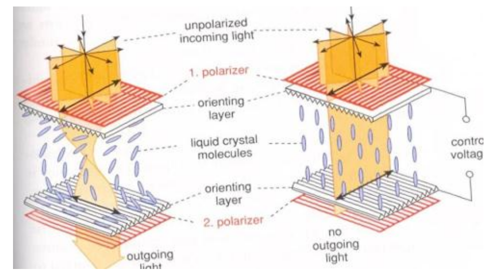
CRT (not used nowadays)

LCD

OLED

LCD (Liquid Crystal Display)

Structure and working of a single pixel (cell)



Types, resolution

Pixel: is a single point in a raster image.

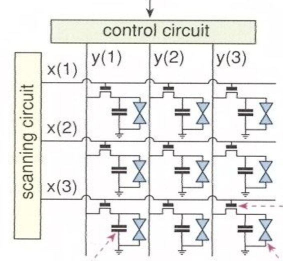
raster image: pixels arrenged in rows and columns.

Resolution: n x m
n: no. of pixels horizontally
m: no. of pixels verticaly

Types:

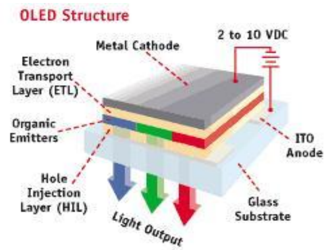
LCD : simple cell. Too slow, not used.
TFT: LCD + a thin transistor layer
LED: TFT + a LED backlight layer

TFT (-LCD) display



A very thin (transparent) transistor layer switches each pixel. This improves the speed.

O(rganic)*LED displays*



LED: Light Emitting Diode