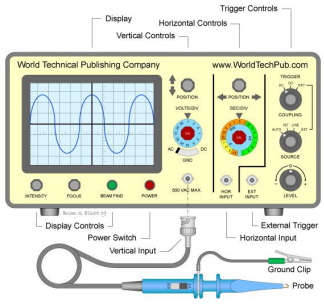
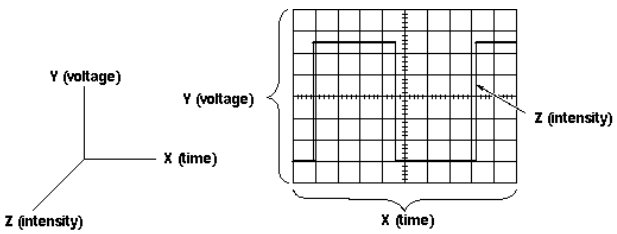
The oscilloscope



220

The oscilloscope

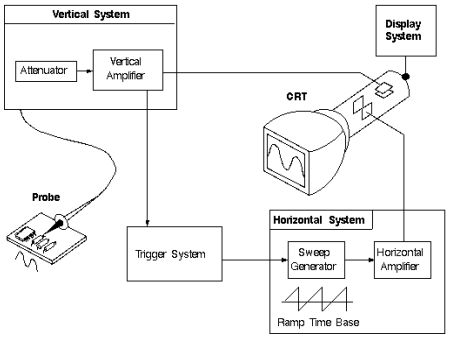
- A device that draws the graph of an electrical signal
- It can be used to:
  - Measure voltage (ac or dc), frequency
  - View the wave shape of the input signal
- There are **analogue** and **digital** oscilloscopes

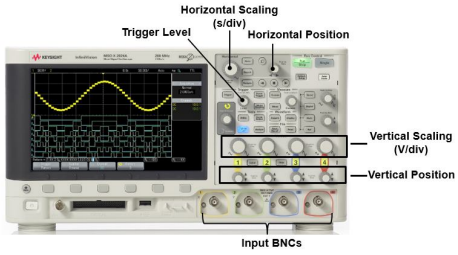


X, Y, and Z Components of a Displayed Waveform

221

Oscilloscope Setup Controls

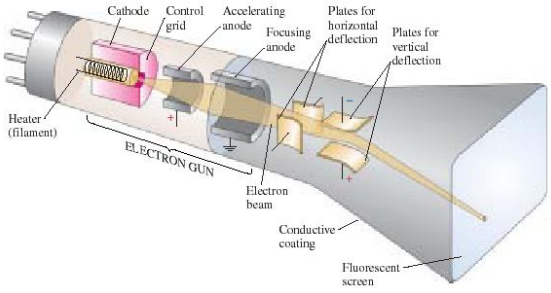


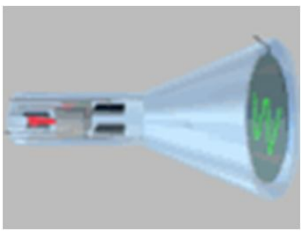


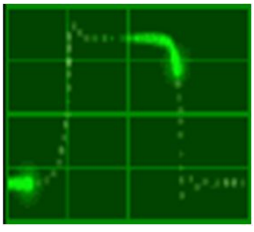
- Vertical Scaling System (Attenuation or amplification of the signal).
  - Use the **volts/div and vertical position** controls to adjust the amplitude of the signal before it is applied to the vertical deflection plates.
- Horizontal Scaling System (The time base unit).
  - Use the **sec/div and Horizontal position** control to set the amount of time per division represented horizontally across the screen.
- The Triggering System
  - Use the **Trigger Level** to stabilize a repeating signal, as well as triggering on a single event.
  - The **Trigger section** determinates when the oscilloscope begin drawing by starting the horizontal sweep across the screen

222

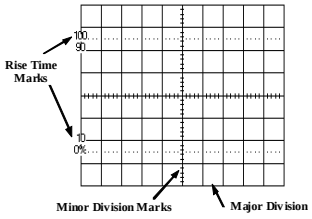
The Cathode Ray (CRO) Tube





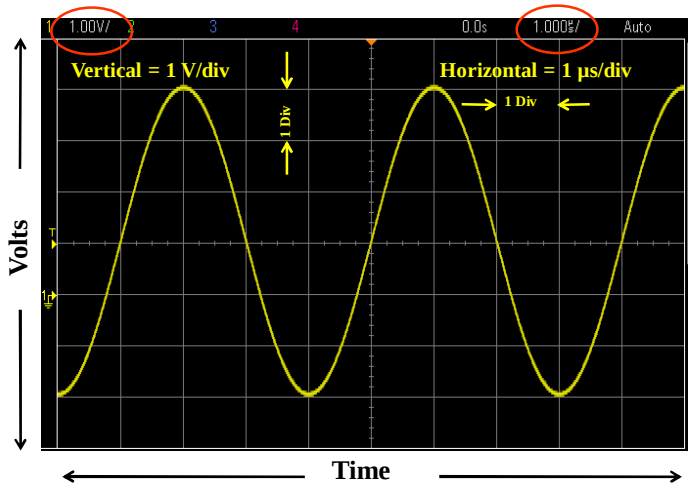


- CRT its a vacuum tube
- The electron beam is emitted by the heated cathode
- A cylindrical control electrode (Wehnelt grid-G) surrounds the cathode → **INTENSITY** brilliance of the spot
- The inner face of the screen is coated with **fluorescent material** The fluorescent radiation remains even after the excitation is stopped (phosphorescence)
- On the inner surface of the screen, horizontal and vertical lines are dawn → graticule (8 div x 10 div)



223

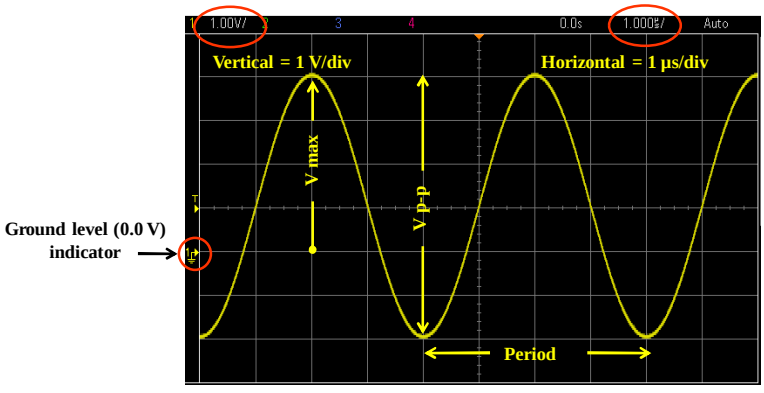
Understanding the Scope's Display



224

Making Measurements

Visual estimation – The most common measurement technique

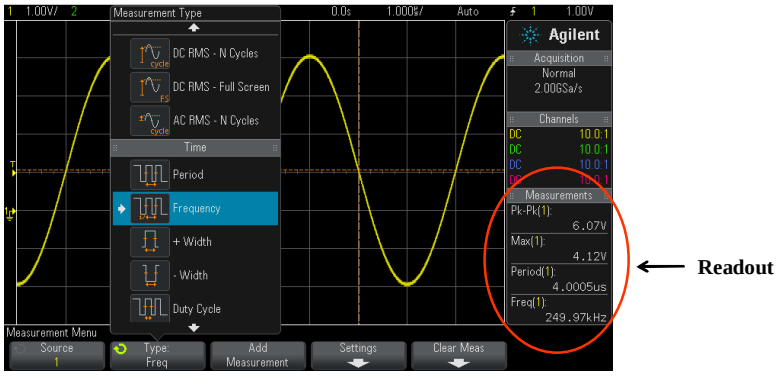


- Period (T) = 4 divisions x 1 µs/div = 4 µs, Freq = 1/T = 250 kHz.
- V p-p = 6 divisions x 1 V/div = 6 V p-p
- V max = +4 divisions x 1 V/div = +4 V → V min = ?

225

Making Measurements

Using the scope's automatic parametric measurements



- Select up to 4 automatic parametric measurements with a continuously updated readout.

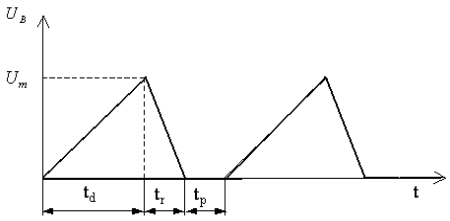
226

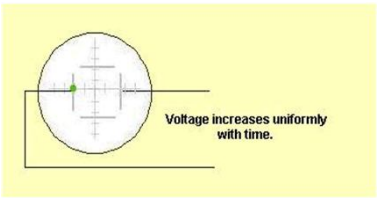
226

Horizontal or Time Base Channel

•Horizontal axis is usually the **time axis**

•The horizontally deflection plates are fed with a **periodic saw tooth signal** generated by a circuit called the time base (sweep) generator.





•t_d direct trap (trace) -a complete deflection of the beam takes place (from left to right) with a constant speed.

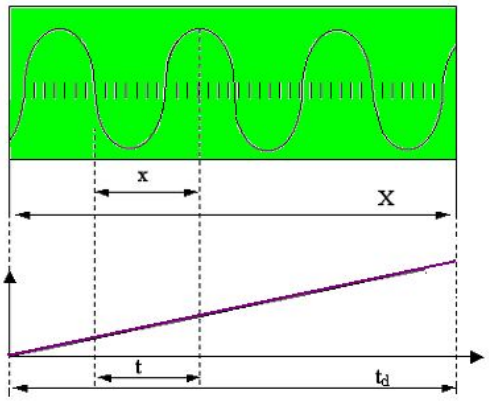
•t_r return trap (retrace) -the beam returns back in the left part of the screen.

•t_p pause time -the beam is blocked in the left part.

•U_m the maximum value of the saw-tooth signal. It is a constant for a certain oscilloscope.

227

The Horizontal deflection coefficient



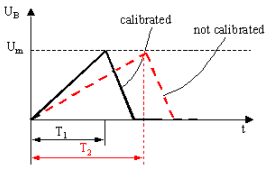
X- the screen width

x-the measured value

The horizontal deflection take place with a constant speed:

$$\frac{X}{t_d} = \frac{x}{t} \Rightarrow t = \frac{t_d}{X} \cdot x$$

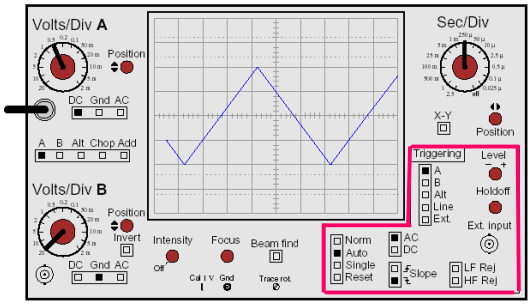
$$\frac{t_d}{X} = C_x \Rightarrow \boxed{t = C_x \cdot x}$$

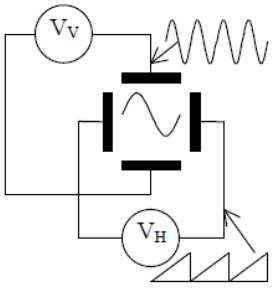


C_x is the horizontal deflection coefficient . We can select sweep speeds (TIME/DIV) in a 1-2-5 sequence. Most oscilloscopes have the variable timebase control.

228

Sweep control (triggering)





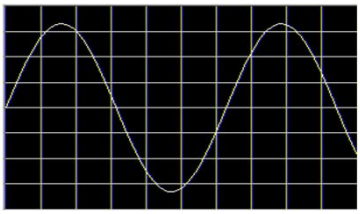
Sweep mode operation

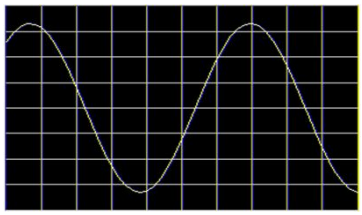
Control modes

- Automatic (Auto)
- Normal (Norm)
- Single shot (SINGLE)

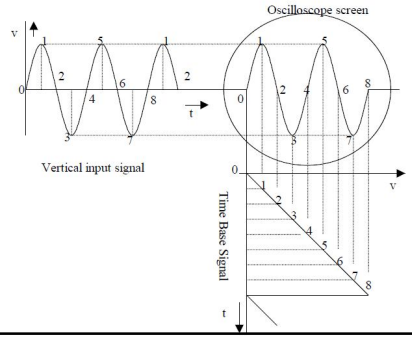
229

Sweep control modes





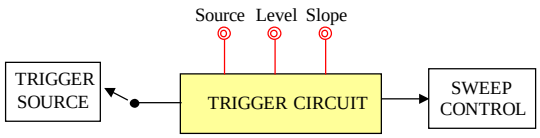
- **Automatic mode**
  - The sweep will periodically trigger even if no signal is present in the vertical amplifier.
  - The signal is **unstable** on the screen
- **Normal mode**
  - It requires a vertical signal to begin the sweeping.
  - The signal is **stable** on the screen
- **Single mode**
  - The CRT beam will seep only once.

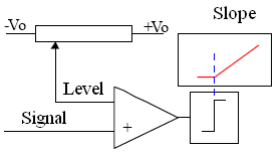


230

The trigger controls

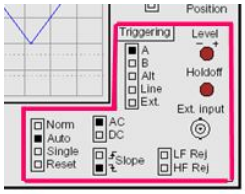
- They are active at NORMAL and SINGLE modes





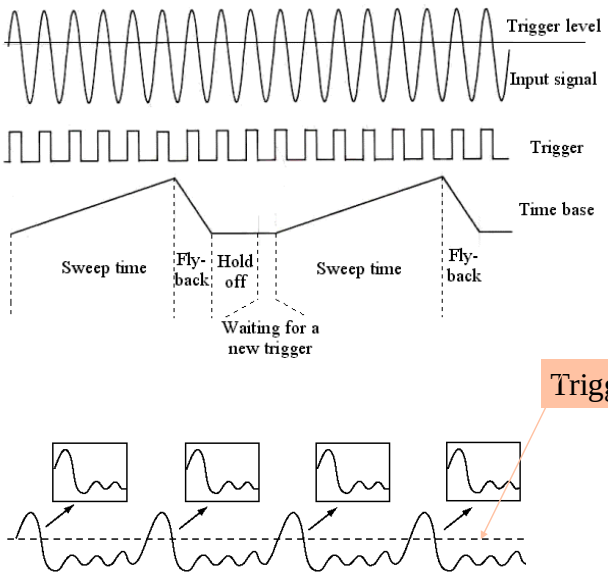
Trigger source: determinates where the trigger signal comes from.

Sources
- **INT** (input signal itself on ch. A or B)
- **EXT** (external trigger input)
- **LINE** (the 50 Hz ac line will cause triggering)



231

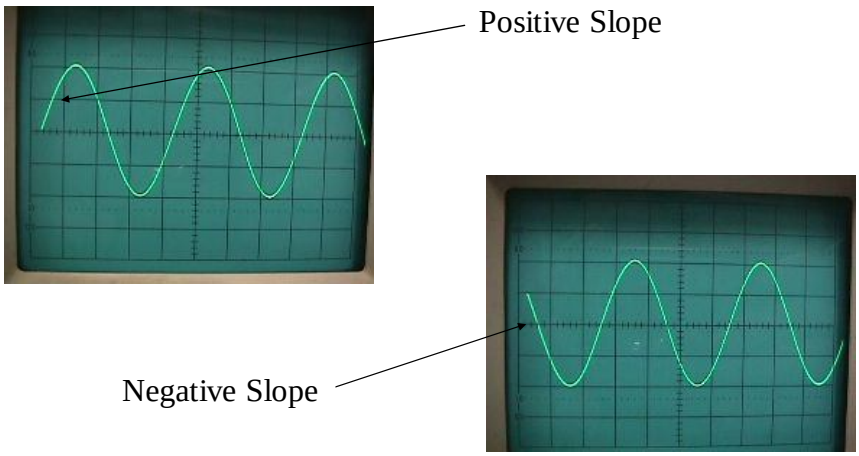
Triggering



232

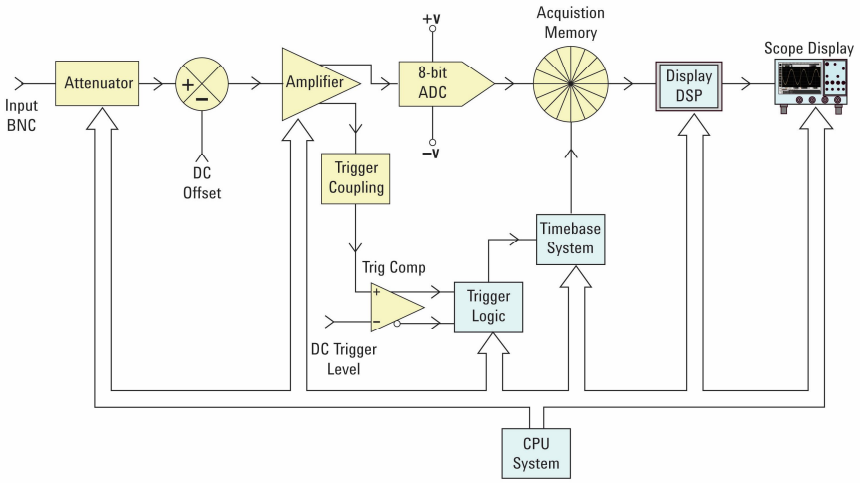
Trigger slope

The control determinates whether the trigger occurs on a negative or on a positive-going edge of the input signal



233

Digital storage oscilloscope (DSO)

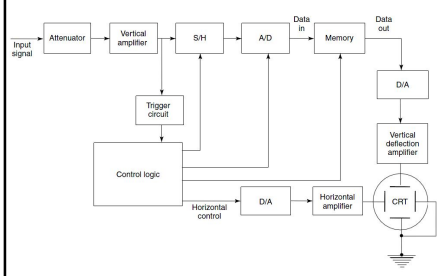


DSO: serial-processing architecture to capture, display, and analyze signals

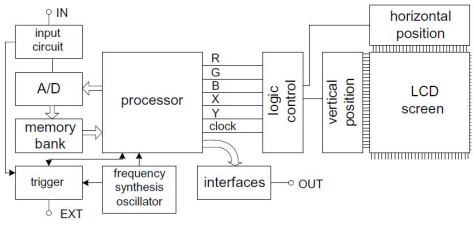
234

https://www.youtube.com/watch?v=Bf3547WB5qs

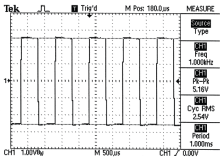
Digital storage oscilloscope (DSO)



With CRT



With LCD screen

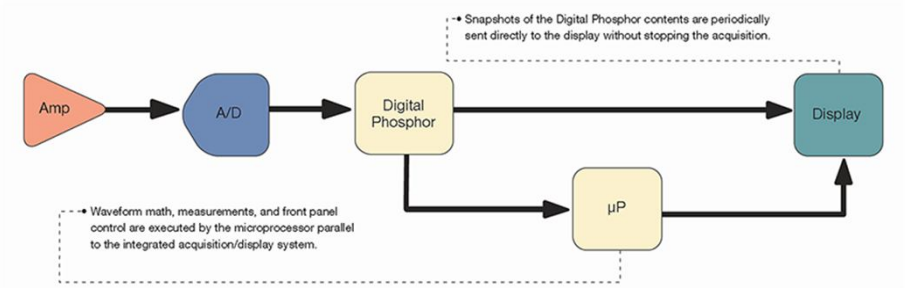


- all operations (signal processing) are performed digitally
- there is **storage function** enabling simple recording and reproduction of signals
- additional functions: FFT analysis, statistical functions

235

Digital Phosphor Oscilloscope (DPO)

DPO: parallel-processing architecture to capture, display, and analyze signals



Tektronix DPO70000

- The DPO displays signals in three dimensions (3D): **amplitude, time and the distribution of amplitude over time (interpretation of signal dynamics)**.

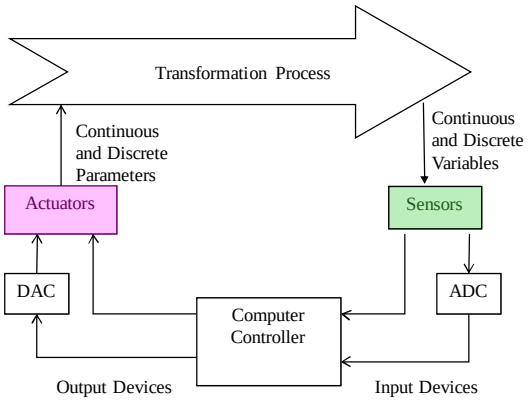
They simulate phosphor persistence with various post processing techniques

236

Sensors and Actuators

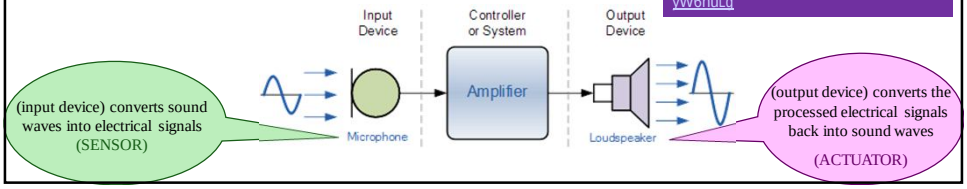
237

Transducers. Sensors. Actuators.



- **Transducer**
  - a device that converts a primary form of energy (mechanical, thermal, electromagnetic, optical, chemical, etc) into a corresponding signal with a different energy form
  - take form of a **sensor** or an **actuator**
- **Sensor** (e.g., thermometer)
  - a device that detects/measures a signal or stimulus
  - acquires information from the "real world"
- **Actuator** (e.g., heater)
  - a device that generates a signal or stimulus

https://www.youtube.com/watch?v=k8fsyW6huLg



238

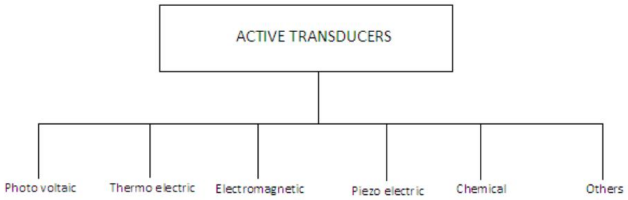
Transducers classification

Quantity being Measured	Input Device (Sensor)	Output Device (Actuator)
Light Level	Light Dependent Resistor (LDR) Photodiode Photo-transistor Solar Cell Charge-Coupled Device (CCD)-imaging applications (cameras)	Lights & Lamps LED's & Displays Fiber Optics (https://www.youtube.com/watch?v=0MwMkBET_5I)
Temperature	Thermocouple, Thermistor, Thermostat Resistive temperature detectors (RTD)	Heater Fan
Force/Pressure	Strain Gauge Pressure Switch Load Cells	Lifts & Jacks Electromagnet Vibration
Position	Potentiometer Encoders Reflective/Slotted Optical-switch (Optocouplers) LVDT (Linear Variable Differential Transformer) Infrared Proximity sensors (Play store…Proximity counter app)	Motor Solenoid Panel Meters
Speed	Tacho-meter (tacho-generator) Reflective/Slotted Optical-coupler Doppler Effect Sensors	AC and DC Motors Stepper Motor Brake
Sound	Carbon Microphone Piezo-electric Crystal	Bell Buzzer Loudspeaker

239

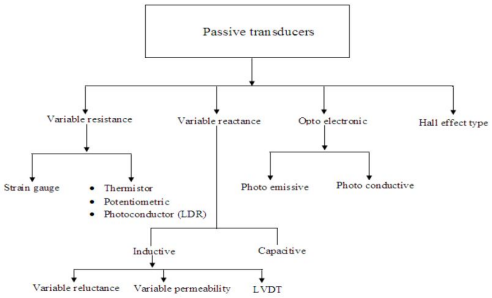
Sensors classification

- *Active*
  - They generate output voltages or currents relative to the quantity being measured
  - They require no auxiliary energy source
- *Pasive*
  - They change their physical properties (capacitance, resistance, inductance) relative to the quantity being measured
  - They require an auxiliary energy source.

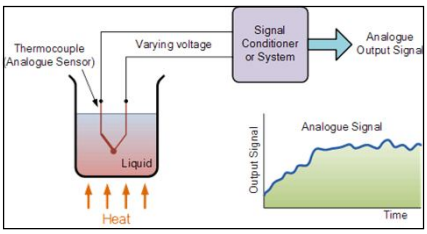


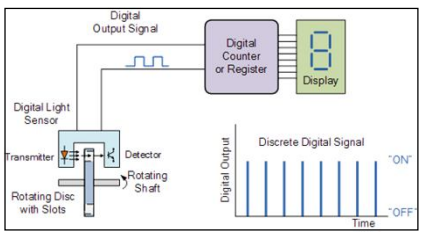
240

Sensors classification



Sensors can be *analog* (e.g. thermocouples, potentiometers) or *digital* (e.g. digital tachometer)

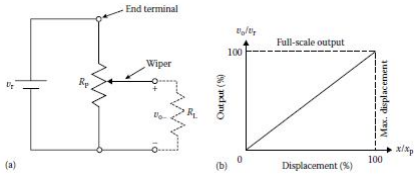


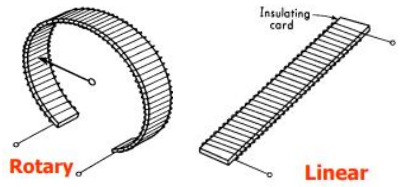


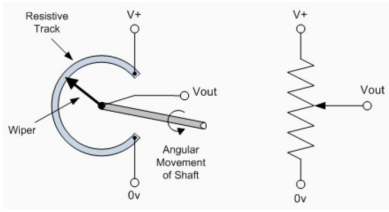
241

Resistive Displacement Sensors

- Potentiometer (Pot) -An electrically conductive wiper that slides against a fixed resistive element (linear or rotary).
- To measure displacement, a potentiometer is typically wired in a voltage divider configuration.
- A known voltage is applied to the resistor ends. The contact is attached to the moving object of interest.
- The output voltage at the contact is proportional to the displacement.







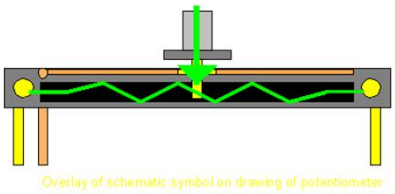
Position sensor
The output signal (Vout) is proportional to the angular position of the shaft.

242

Resistive Displacement Sensors

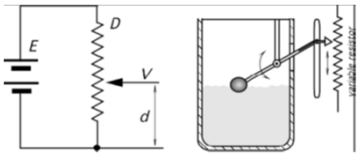
Linear potentiometers application

https://www.youtube.com/watch?v=v3ag-bGVt9I



Fluid level sensor

As the liquid level changes either on upward direction or downward direction than float position changes. This results into variation in the wiper arm across the resistance. This results into measurement of level position.

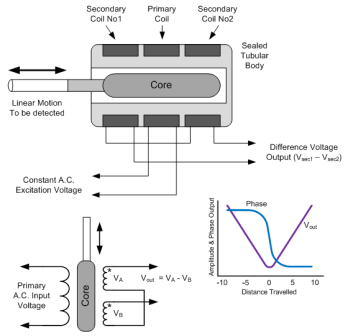


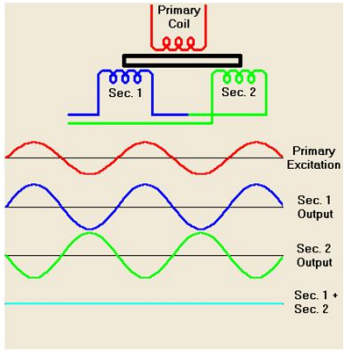
$$V = \frac{d}{D}E$$

243

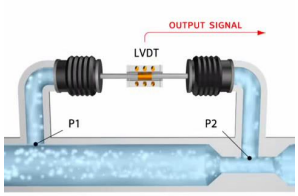
Inductive position sensors

Linear Variable Differential Transformer (LVDT)





- 3 coils; a primary and two secondaries.
- The transfer of current between the primary is controlled by the position of a magnetic core (armature)
- The two secondaries are connected in opposition.
- No electrical contact across the transducer position sensing element
- Useful application: **pressure measurement**

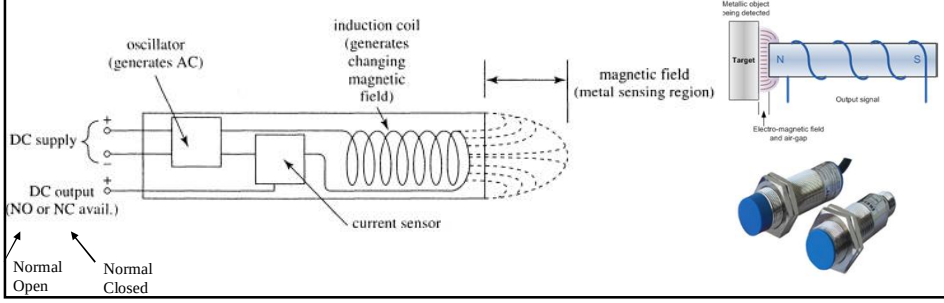


https://www.youtube.com/watch?v=i_tSHYHiDdw

244

Position Sensors: Inductive Proximity Switches

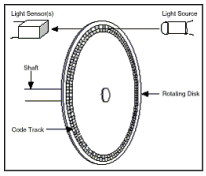
- Sensors operate under the electrical principle of inductance.
- Sensor has four components: the coil; the oscillator; the detection circuit; output circuit.
- When a metal object moves, Eddy circuits build up in the metallic object, magnetically push back, and finally reduce the inductive sensor's own oscillation field.
- The sensor's detection circuit monitors the oscillator's strength and triggers an output from the output circuitry when the oscillator becomes reduced to a sufficient level.
- Used in **traffic lights** (inductive loop buried under the road). Sense objects in dirty environment. (**https://www.youtube.com/watch?v=VsZIYj7evaA**)
- Does not work for non-metallic objects. Solution: capacity proximity sensors , ultrasonic proximity sensors
- Other commonly available magnetic position sensor include: reed switches, Hall effect sensors and variable reluctance sensors. (**https://www.youtube.com/watch?v=wpAA3qeOYiI**)



245

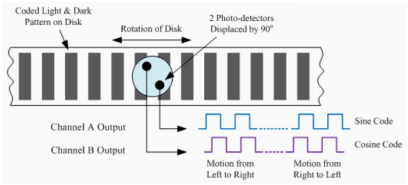
Position Sensors: Rotary Encoders

- Encoder→ electro-mechanical device that converts linear or rotary displacement into digital or pulse signals. (motion, direction, or position).
- Optical encoder→a rotating disk, a light source, a photo detector (light sensor).
- As the disk rotates, the patterns interrupt the light emitted onto the photo detector, generating a digital or pulse signal output.



Incremental encoder

generates a pulse for each incremental step in it's rotation. (tachometer)

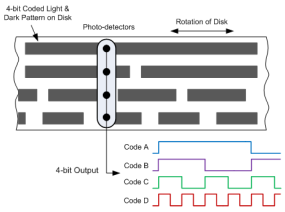


To determine both the position and direction, a two-channel, or quadrature, encoder uses two detectors and two code tracks with sectors positioned 90° out of phase

https://www.youtube.com/watch?v=zzHcsJDV3_o

Absolute encoder

They provide a unique output code for every single position of rotation indicating both position and direction.



In CD/DVD drives

246

Temperature Sensors

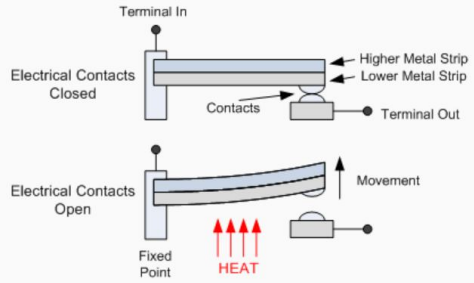
- They gather ***temperature*** by sensing some change in a physical characteristics

- Two basic physical types:
  - With ***direct contact*** with the heating source (solids, liquids or gases)
  - ***No direct contact*** with the source→ they use radiated energy
- Three groups of sensors
  - ***Electro-mechanical***
  - ***Resistive***
  - ***Electronic***

247

The thermostat

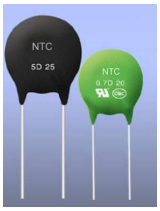
- ***Contact type*** electro-mechanical temperature sensor or switch,
- Two different metals (nickel, copper, wolfram or aluminum) are bonded together to form a ***bi-metallic strip***.
- ***Different linear expansion rates*** of the two metals → *a mechanical twisting movement when the strip is subjected to heat.*
- It's used as a switch in the thermostat in order to control:
  - hot water heating elements (boilers, furnaces, hot water storage tanks)
  - vehicle radiator cooling systems.

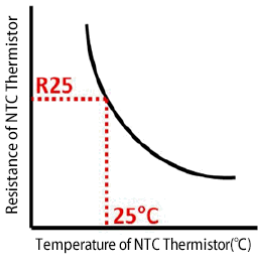


248

248

The thermistor



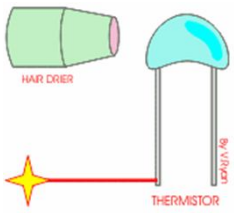


- It's a temperature sensitive resistance device made of semiconductor material (manganese, cobalt and nickel).
- It's the most sensitive temperature sensor.
- NTC (negative temperature coefficient) thermistor: the resistance decreases when the temperature rises (most used)
- PTC (positive temperature coefficient)
- Strong non-linearity→The main disadvantage

The transfer characteristic of a thermistor is given by the Stein-Hart equation:

$$\frac{1}{T} = A + B\,\ln R + C(\ln R)^3$$

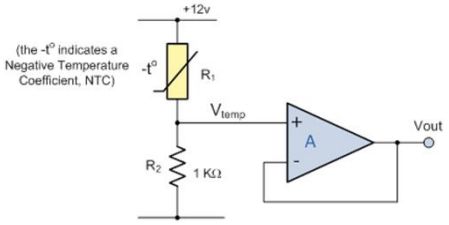
T: temperature [K]
R: resistance of the thermistor [Ω]
A, B, C: Steinhart–Hart coefficients



249

Application

- The following thermistor has a resistance value of 10KΩ at 25°C and a resistance value of 100Ω at 100°C.
- Calculate the voltage drop across the thermistor and hence its output voltage (V_{out}) for both temperatures when connected in series with a 1kΩ resistor across a 12V power supply.

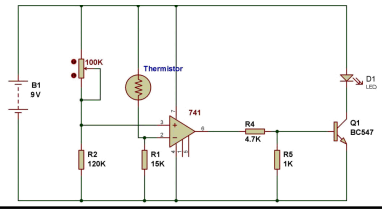


At 25°C

$$V_{out} = \frac{R_2}{R_1 + R_2} V = \frac{1000}{10000 + 1000} \cdot 12V = 1.09V$$

At 100°C

$$V_{out} = \frac{R_2}{R_1 + R_2} V = \frac{1000}{100 + 1000} \cdot 12V = 10.9V$$



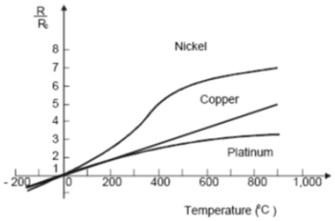
250

Resistive Temperature Detectors (RTD)

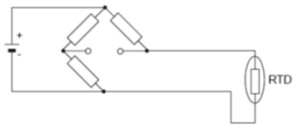
RTD is a temperature sensor whose resistance changes with temperature.

$$R_T = R_0 [1 + A\,T + B\,T^2 + C\,(T - 100)^3]$$

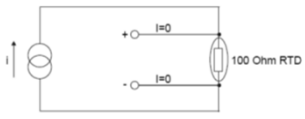
- The metals used are: nickel, platinum, and certain alloyed forms of copper.
- Platinum is probably used most frequently because it has a linear output.
- A very common probe is the Pt100: designed to have 100Ω of resistance at 0°C.



Two wire connection (Wheastone Bridge)



Four wire connection (High accuracy)

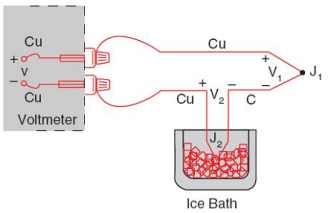


251

Thermocouples

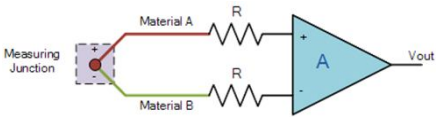
- Thermocouples also have the widest temperature range of all the temperature sensors from below -200°C to well over 2000°C.

$$\Delta e_{AB} = S\Delta T$$



- The cold-junction compensation

- The output voltage from TC is very small, few mV for a ΔT=10°C →some form of amplification is generally required

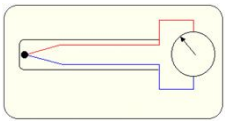


252

252

Thermocouple Sensor Colour Codes

Code Type	Conductors (+/-)	Sensitivity	British BS 1843:1952
E	Nickel Chromium / Constantan	-200 to 900ºC	
J	Iron / Constantan	0 to 750ºC	
K	Nickel Chromium / Nickel Aluminium	-200 to 1250ºC	
N	Nicrosil / Nisil	0 to 1250ºC	
T	Copper / Constantan	-200 to 350ºC	
U	Copper / Copper Nickel Compensating for "S" and "R"	0 to 1450ºC	



253

Light Sensors

Light (infrared –visible-ultraviolet) → Light sensor (Photoelectric Device) (Photo Sensor) → Electrical signal

- Two main categories,
  - ***Photo-voltaic* or *Photo-emissive*** (those which generate electricity when illuminated)
  - ***Photo-resistors* or *Photo-conductors*** (those which change their electrical properties in some way)
- Classification:
  - Photo-emissive Cells →They release free electrons from a light sensitive material (cesium) when struck by a photon.
  - Photo-conductive Cells (IR photoconductive detectors, photoresistor),
  - Photo-voltaic Cells (solar cells)
  - Photo-junction Devices (photodiodes)

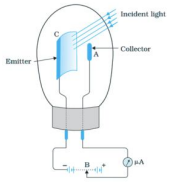


Photo-emissive Cells

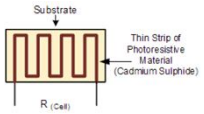
IR Photoconductive Cells

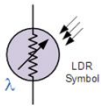
The photoconductive material exhibits a decrease in electrical resistance when illuminated with IR radiation

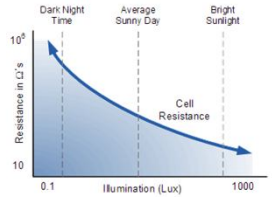
254

Photoconductive cells

- Photoresistor→ Light dependent resistor (LDR) cell
- Semiconductor material (Cd sulphide-most popular) →changes its electrical resistance from thousand Ohms (dark) to only a few hundred Ohm (light) by creating hole-electron pairs in the material.→ conductivity improvement





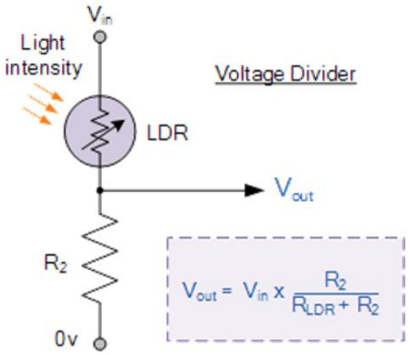


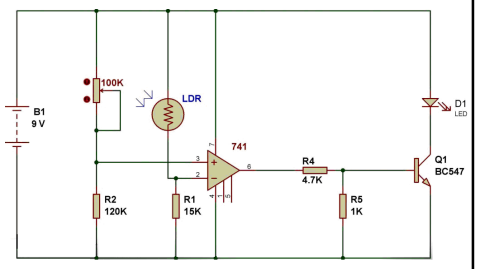
To increase the dark resistance (reduce the dark current), the resistive path forms a zigzag pattern across the ceramic substrate

255

255

Light level sensitive switch





256

Photojunction devices

- Light sensors (silicon semiconductor PN-junction) which:
  - are sensitive to light
  - can detect both visible light and infrared light levels.

Photodiode

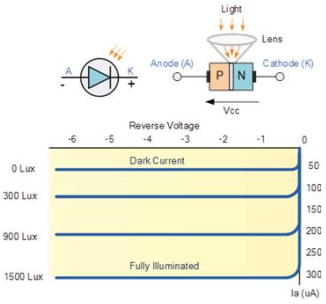
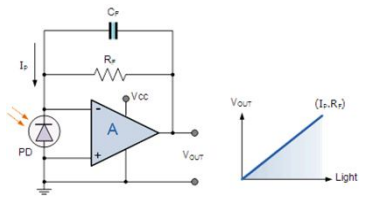
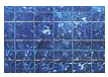


Photo-diode Amplifier Circuit

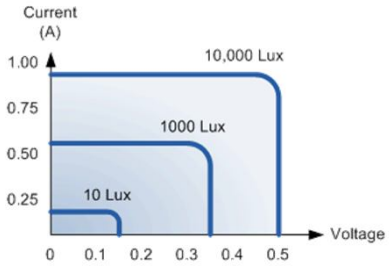


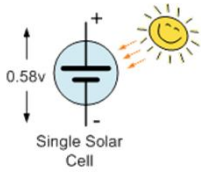
257



Photovoltaic Solar Cells

- They convert light energy directly into DC electrical energy in the form of a voltage or current to a resistive load such as a light, battery or motor.
- They are made from **single crystal silicon PN junctions**, but are used without the reverse bias.
- An individual solar cell can generate an open circuit voltage of about 0.58V
- They have a "Positive" and a "Negative" side just like a battery.





https://www.youtube.com/watch?v=L_q6LRgKpTw

258