CONDITIONING NETWORKS

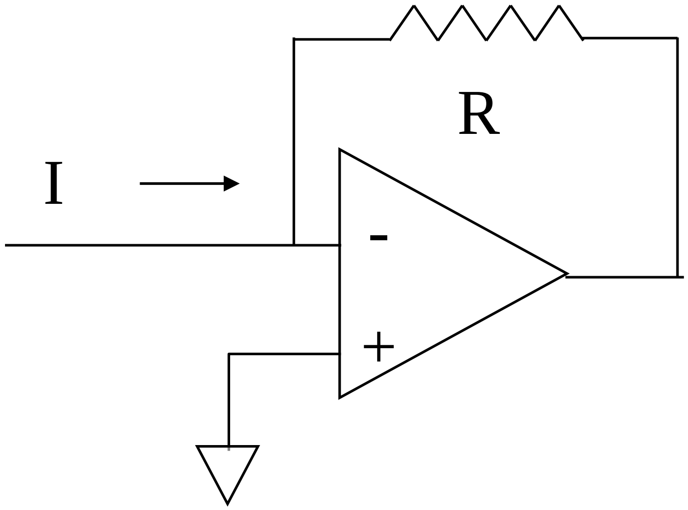
INTRODUCTION

Current/voltage signals as they come from the transducers must be converted in suitable voltages to be transmitted or converted by an ADC:

- **Charge/current conversion**
- **Impedance conversion**
- **Amplification**
- **Rectification**
- **Transmission**

CURRENT-VOLTAGE CONVERTER

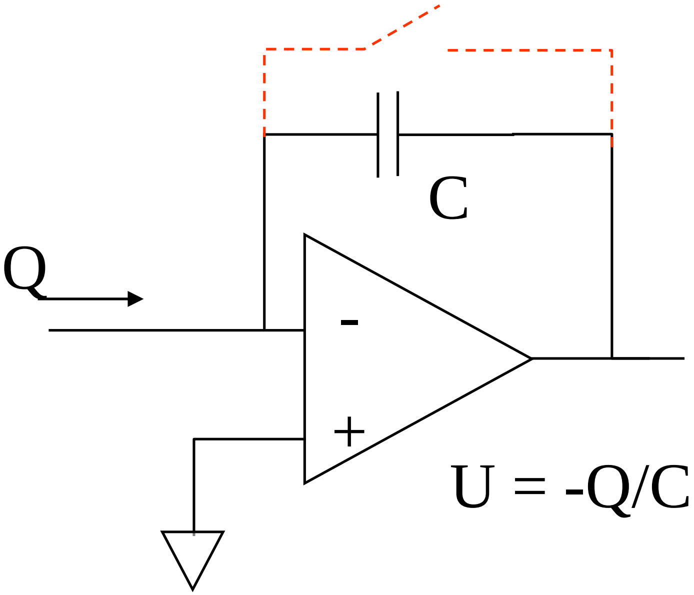
- **Suitable for transducers whose output signal is a current**
- **A resistor R can be used to convert a current I in a voltage suitabel for the ADC: the problem is the same input and ouyput impedance.**
- **Let’s use an operational amplifier**

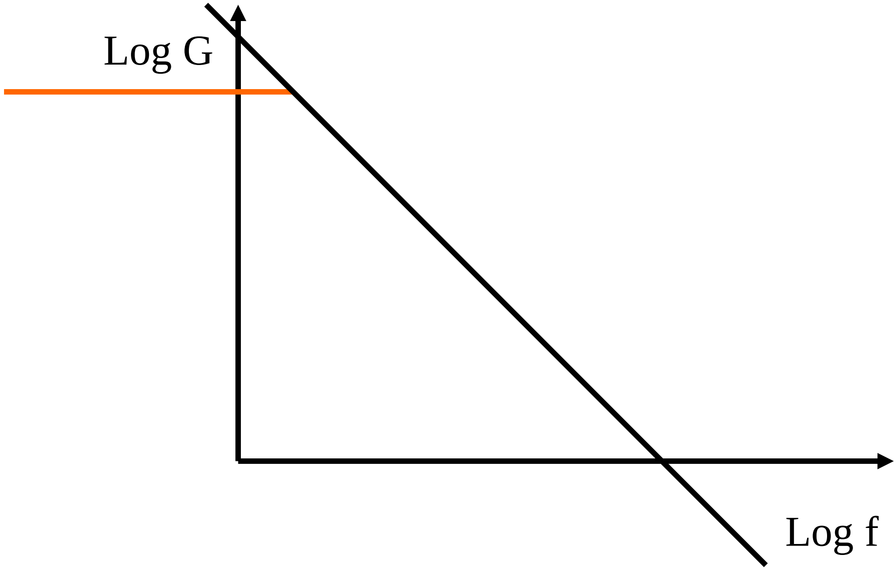


- **MOS technology OP-AMP to absorb low polarisation currents**
- **R high to minimise the OP-AMP offset effect**
- **Low cut-off frequency (parasite capacities in the operational amplifier)**
- **Possible solution: two amplification stages I/V and V/V**

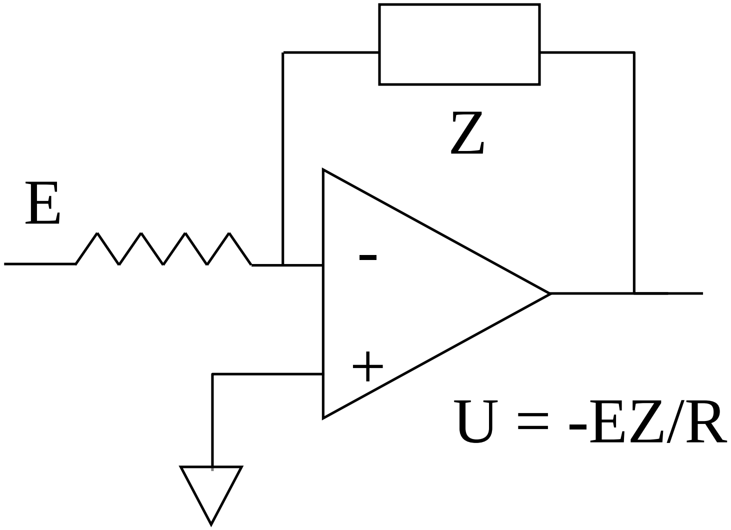
CHARGE AMPLIFIER

- **Used for the piezoelectric accelerometer**
- **A capacity in reaction to the amplifier**
- **The OP-AMP can saturate: a resistor or a switch can be put in parallel to the C**



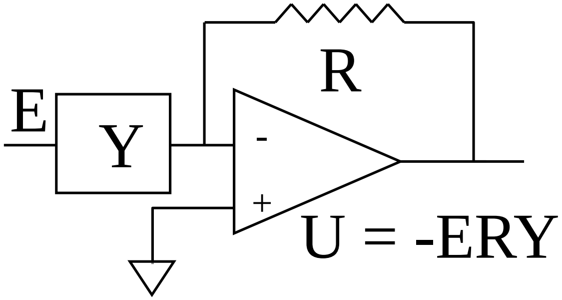


IMPEDANCE CONVERTER



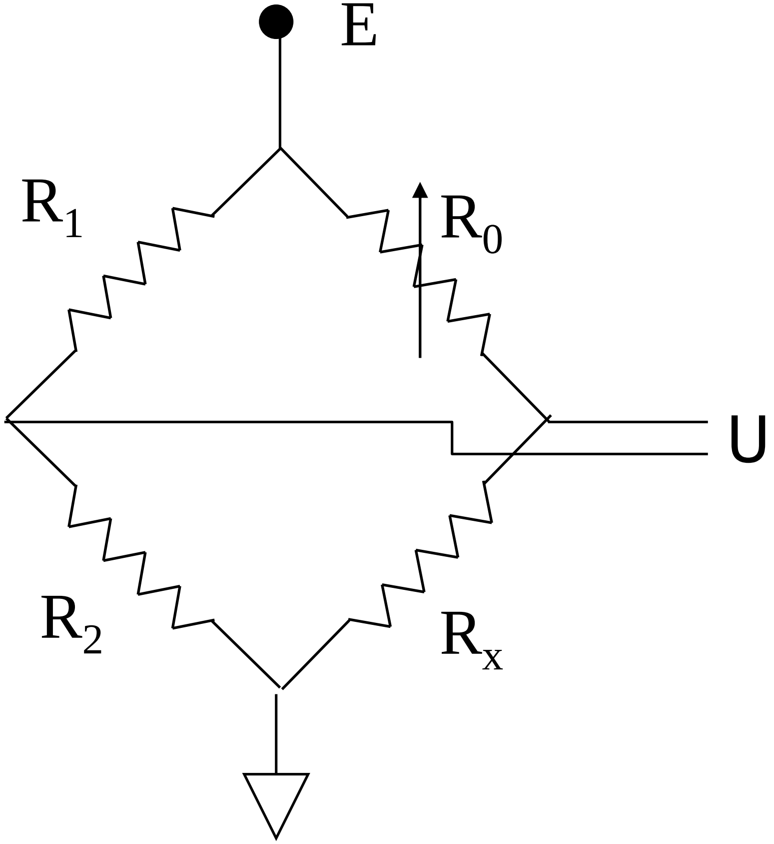
Suitable for transducers into which a resistive, capacitive or inductive parameter is proportional to a physical magnitude

$$R_x = -\frac{RU}{E} \qquad L_x = -\frac{RU}{j\omega E} \qquad C_x = -\frac{E}{j\omega RU}$$



Sometimes (variable reluctance transducer) it is necessary to convert the admittance

WHEATSTONE BRIDGE



Ok when the power supply is high and a small variation in the impedance of the transducer must be revealed or when the transducer is sensible to the temperature and/or to other environmental parameters.

The 'bridge' relates the output to 'zero' and compensates the similar effects on the same branch resistors.

$$U = \frac{ER_2}{R_1 + R_2} - \frac{ER_x}{R_0 + R_x}$$

At the beginning R_0 is set so as $U=0 \Rightarrow R_2(R_0+R_{x0}) = R_{x0}(R_1+R_2)$

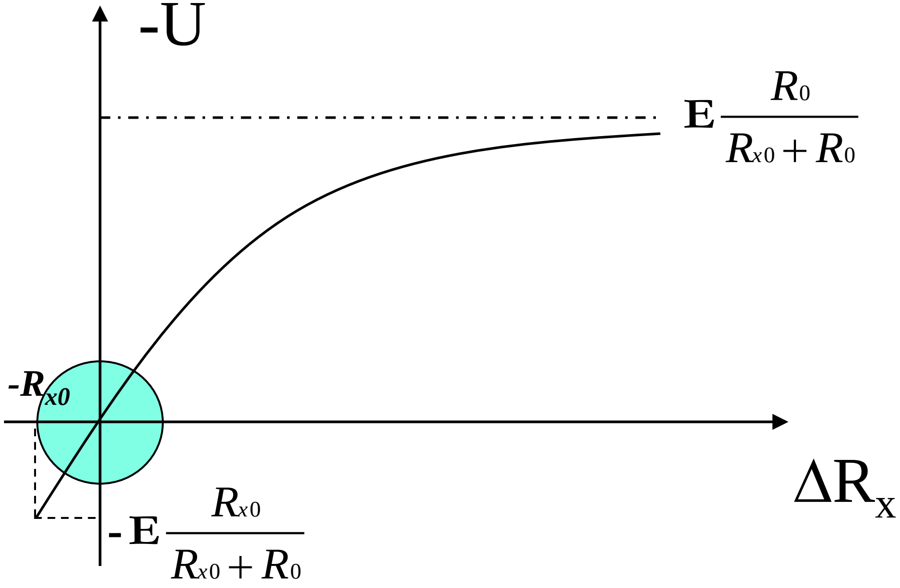
$$\Rightarrow R_2 : R_1 = R_{x0} : R_0$$

WHEATSTONE BRIDGE

Let's suppose now that the transducer resistance changes slightly

$R_x=R_{xo}+\Delta R_x$ so as $\Delta R_x << R_{0,} R_{xo}$

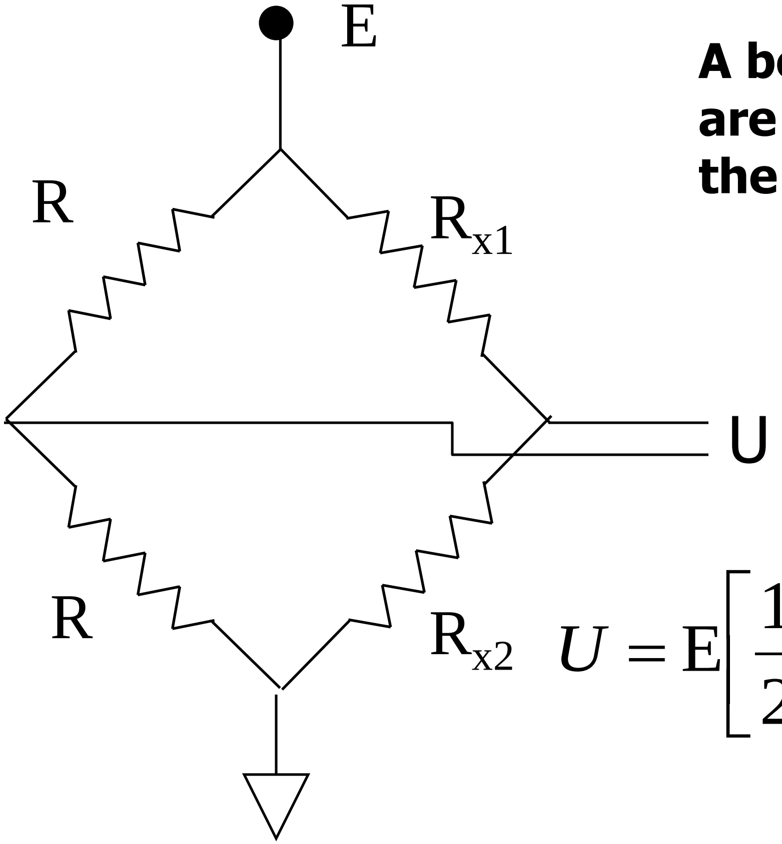
$$U = \mathbf{E}\left[\frac{R_2}{R_1+R_2}-\frac{R_{x0}+\Delta R_x}{R_0+R_{x0}+\Delta R_x}\right] \cong -\mathbf{E}\frac{R_0\Delta R_x}{\left(R_{x0}+R_0\right)^2}$$



In this case only when ΔR_x is small the answer is linear.

Just to 'balance' the output, R_{x0} and R_0 nearly = can be used (but in general this cannot be assured)

WHEATSTONE BRIDGE



A better solution is when 2 variable resistors are used that change in the opposite way with the parameter that must be measured.

$$R_{x1} = R_{x0} + \Delta R_X$$

$$R_{x2} = R_{x0} - \Delta R_X$$

$$U = E\left[\frac{1}{2} - \frac{R_{x2}}{R_{x1} + R_{x2}}\right] = E\left[\frac{1}{2} - \frac{R_{x0} - \Delta R_x}{2R_{x0}}\right] = E\,\frac{\Delta R_x}{2R_{x0}}$$

If resistors are replaced with reactive impedances the bridge can still be used with AC power supply and keeping on the same branches the components with the same phase shift.

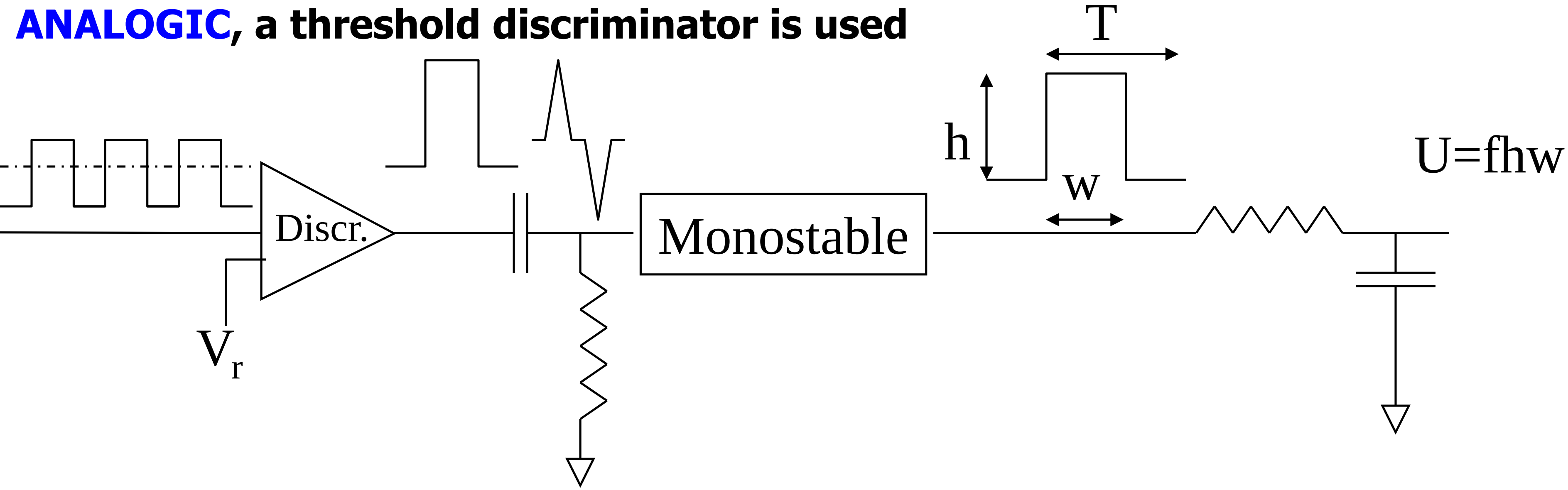
AC is useful also to limit the offset influence in case of very small ΔR.

FREQUENCY-VOLTAGE CONVERTERS

2 conversion modes:

DIGITAL, the signal is digitized and sent to a μP or to a counter/timer that counts the periods

ANALOGIC, a threshold discriminator is used



- **The first approach is more accurate**
- **The second is accurate only if a sufficient number of pulses is counted**
- **Both the techniques work well at medium frequencies, better the second at low frequencies, better the first at high ones**

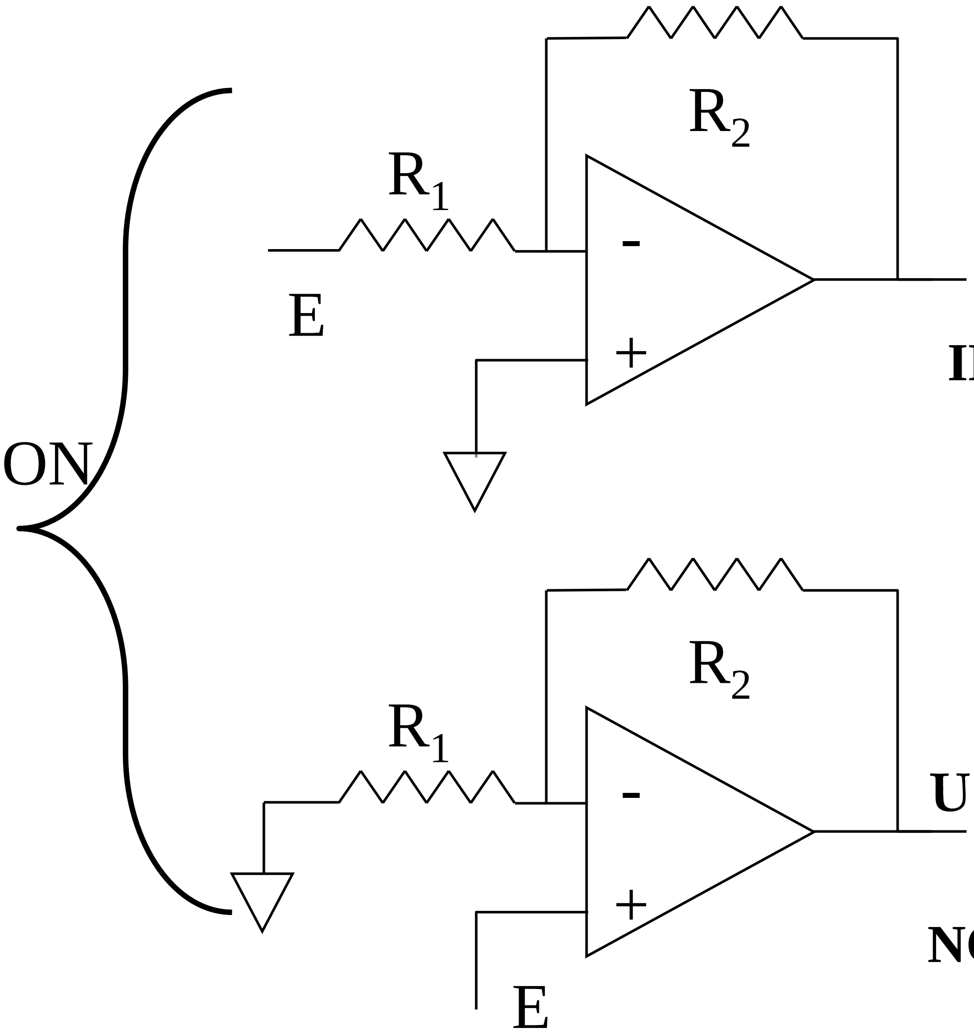
AMPLIFICATION

LINEAR

AMPLIFICATION

OF THE

SIGNAL



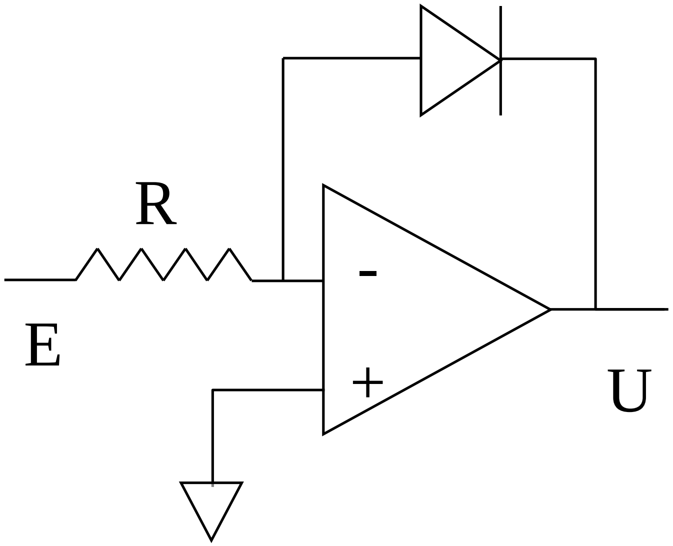
$$U = -\frac{R_2}{R_1} E$$

INVERTING

$$U = \left(1 + \frac{R_2}{R_1}\right) E$$

NOT INVERTING

NOT LINEAR AMPLIFICATION OF THE SIGNAL



$$U = -\eta V_T \ln\left[\frac{E}{RI_D}\right]$$

Often a signal does not provide an information proportional to its amplitude (sometimes it is inversely proportional) ⇒ but it is still important to keep the *relative error* constant.

That is the signal must be revealed with an error proportional not to the maximum amplitude but to the effective one.

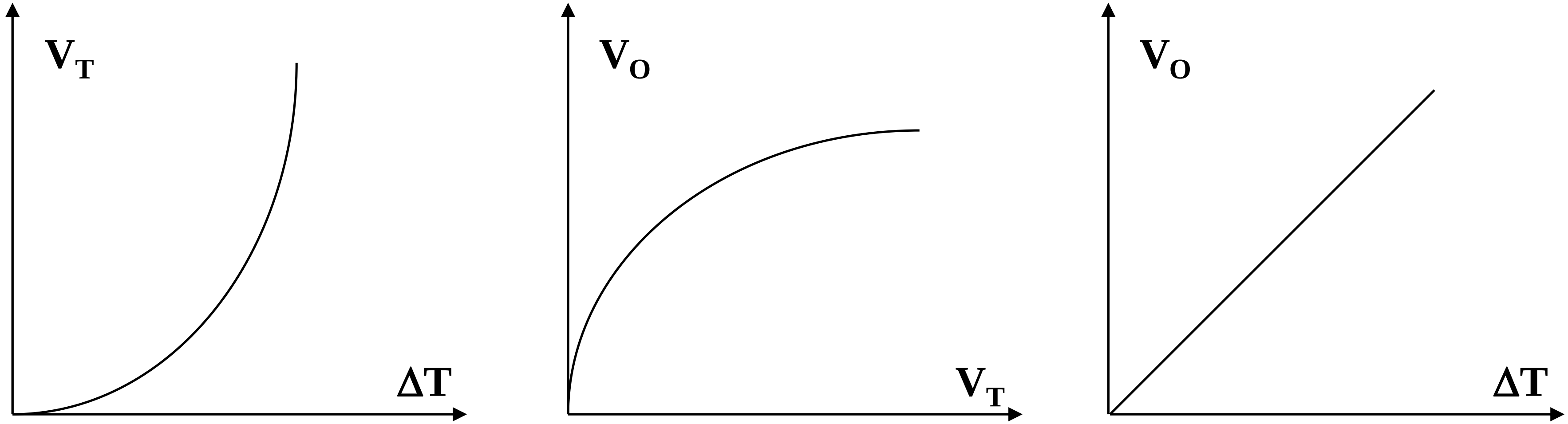
This implies to compress/expand voltage values before the conversion made by the ADC

N. B. Let's remember that the ADC quantization error is constant (Vref/2^n)

NOT LINEAR AMPLIFICATION OF THE SIGNAL

Not linear functions can be used to compensate not linear curves characterizing sensors like as thermocouples. We can implement 2 solutions:

1) Non linear amplification of the signal;

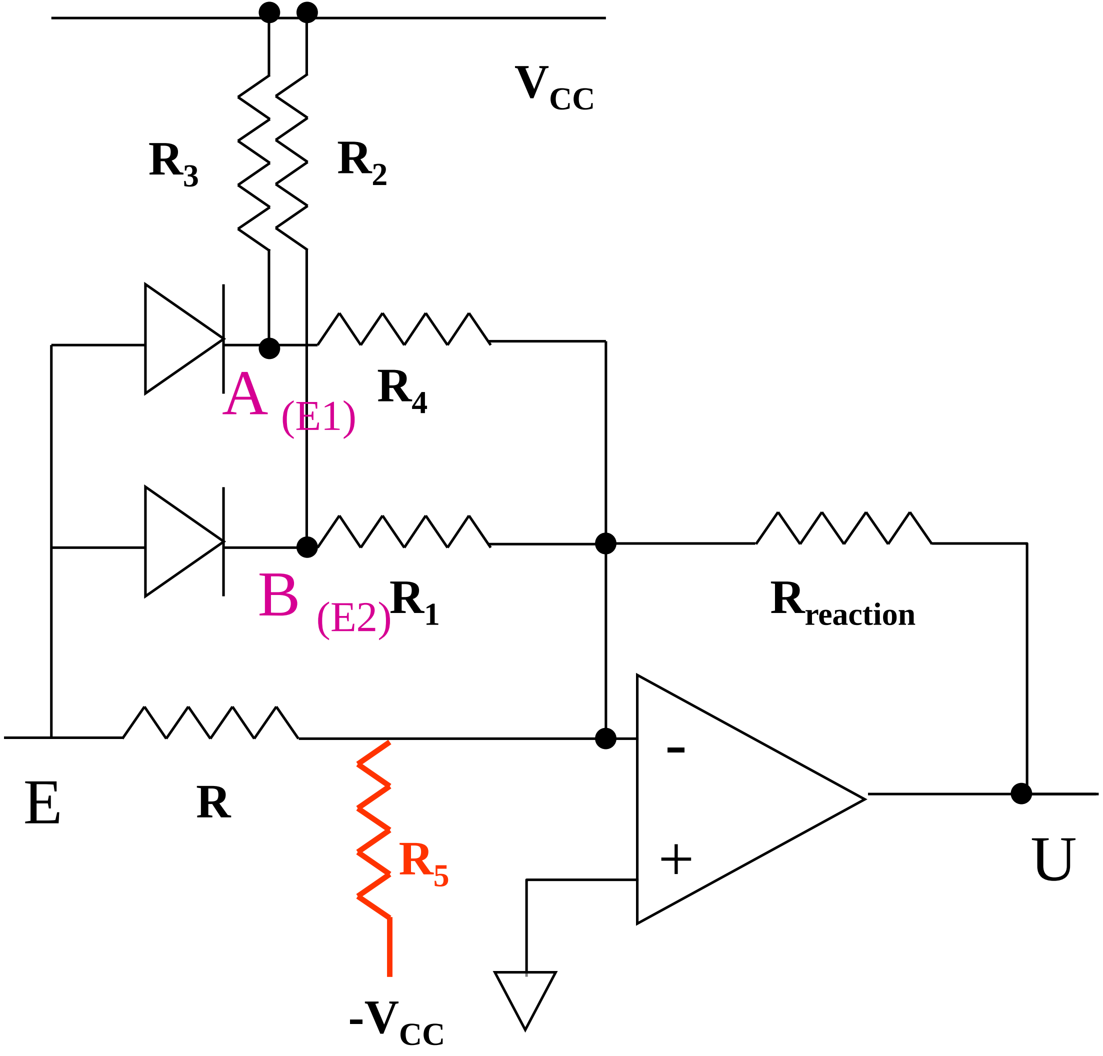


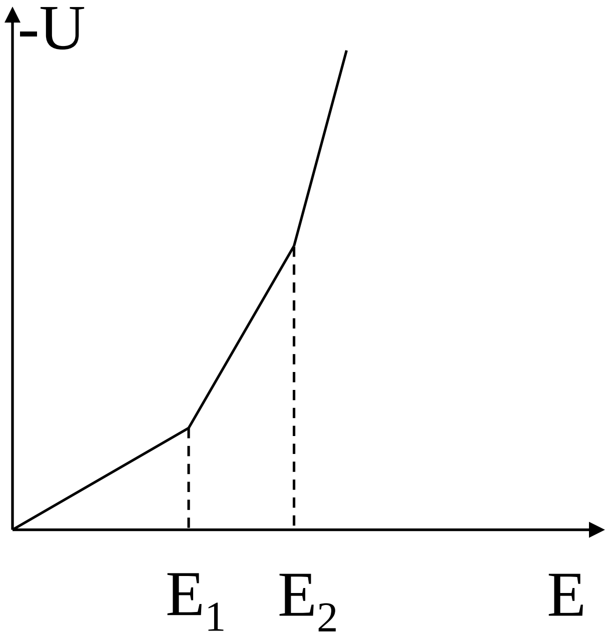
2) Linear amplification of the signal, digitization and transmission to a μP where it is adjusted on the basis of suitable values contained in a look up table

Solution 2) can be more precise, but in case 1) it is possible to achieve a linear relationship between the input and the output magnitudes (ΔT vs V_O)

NOT LINEAR AMPLIFICATION OF THE SIGNAL

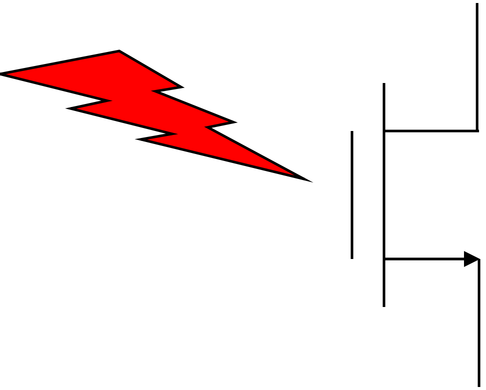
BROKEN LINES APPROXIMATION **(when difficult to find a electronic component with exactly inverse of the one provided by the transducer)**



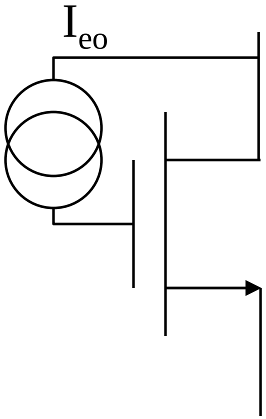


R_{1-4} are chosen to set the E_1 and E_2 thresholds in A and B so as the diodes are polarized (biased). R_5 is introduced to discharge the current crossing R_3 and R_2

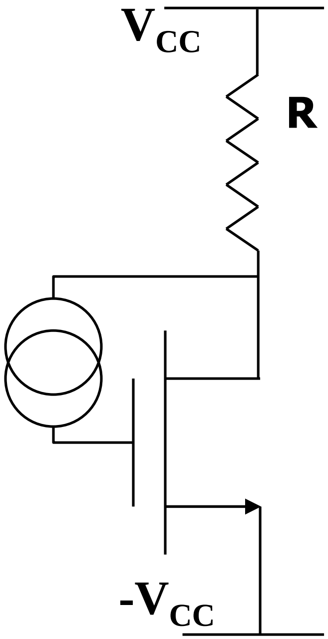
GENERATING LOGIC SIGNALS



The photo-transistor when lighted becomes active and is crossed by a current. The light produces the same effect as to insert current generator between the base and the collector.



This current (that is proportional to the light radiation striking the photo-transistor) through the voltage drop on a resistor R.



$$V = -R(1+\beta)I_{eo}$$

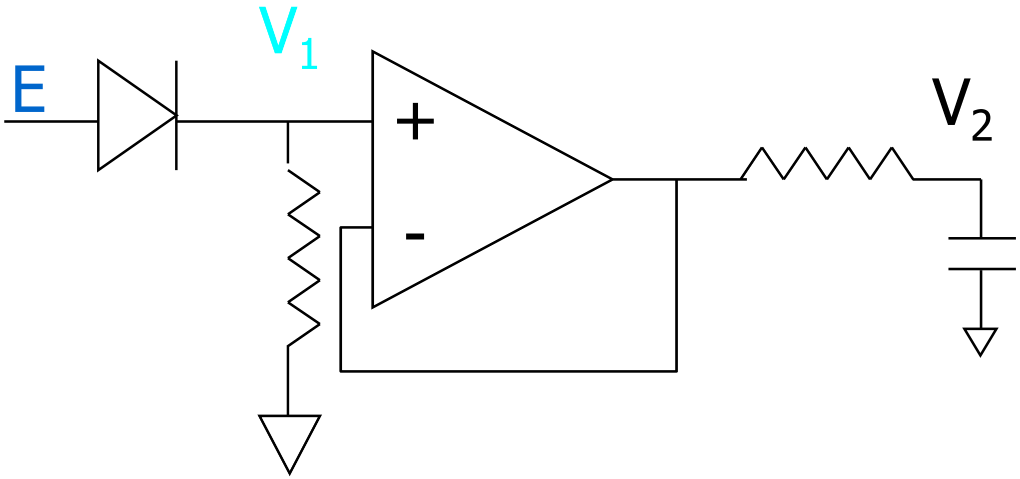
This measurement (1 or 0) can be slow since the cut-off frequency of these transistors is typically 1 kHz.

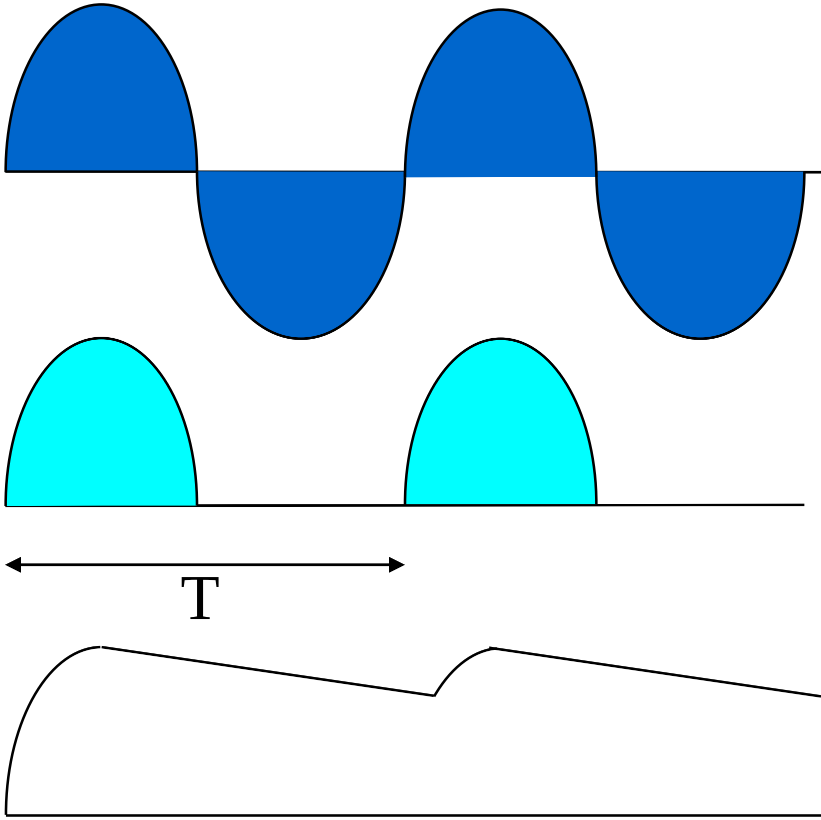
RECTIFICATION

Some transducers provide AC output signals.

The interesting information is however in the peak value (ex. differential linear position transducer).

Rectification, de-coupling and filtering stages are required.

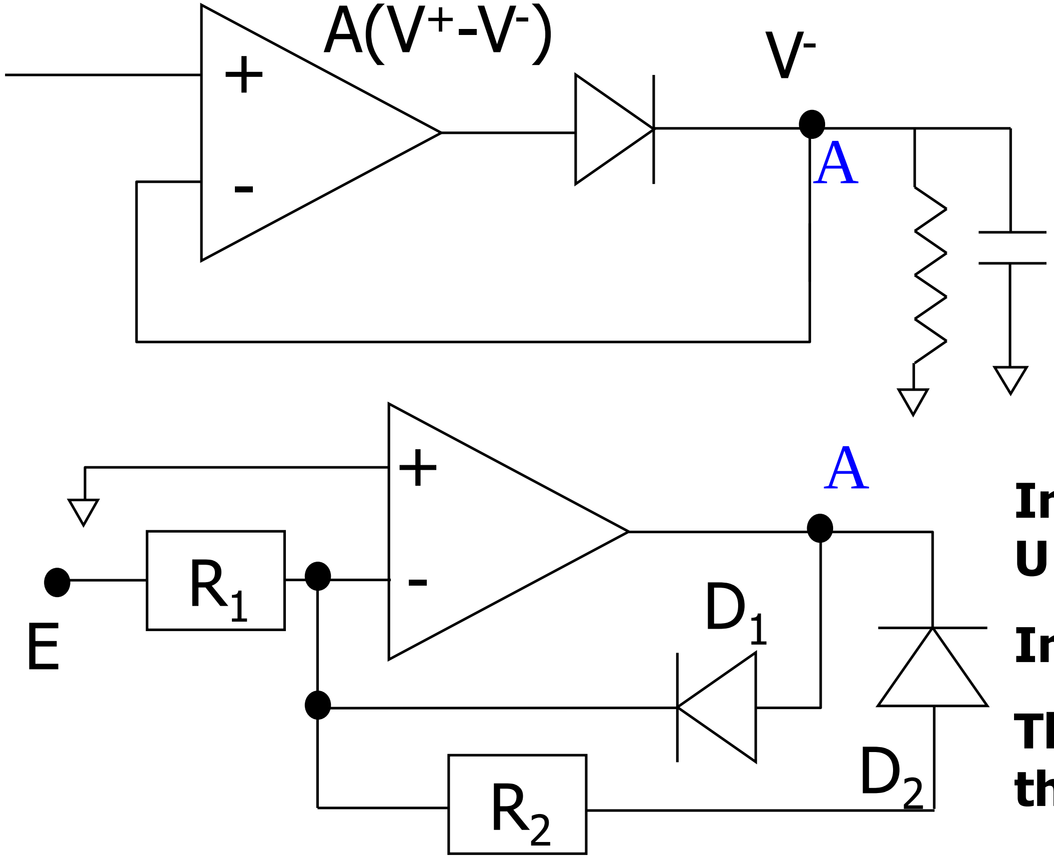




valid if $E >> V_\gamma$ and $RC >> T$

AMPLIFIED (SUPER) DIODE

To achieve more accurate measurements different networks based on operational amplifiers are used



Only in the positive wave the diode is active. In the negative one the diode is not active, the amplifier saturates ⇒ the circuit switches in a very slow way (when exits from saturation)

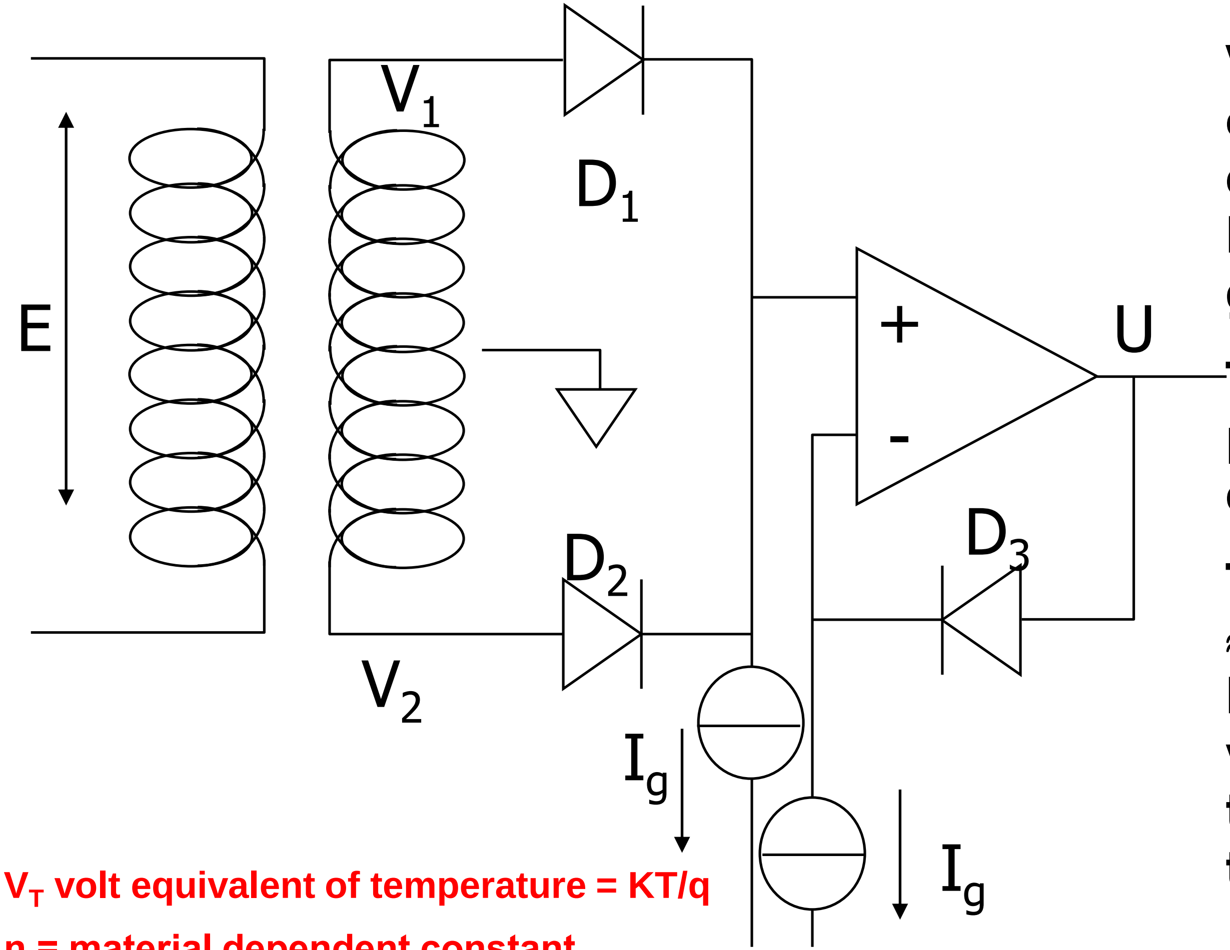
In the positive wave D_2 is active ⇒ $U=-E\,R_2/\,R_1$.

In the negative D_1 is active $U=0$.

The amplifier never saturates since the reaction is always closed.

Ok at medium/high frequencies (kHz). Ko at MHz

PRECISION RECTIFICATION



Voltage drop on D_1 e D_2 is compensated by the one on D_3. The 3 diodes are kept active by the current generators.

The primary winding is AC powered so when $V_1 >> V_2$ or viceversa $U=V_1$ or $U=V_2$

The worst case is when $V_1 \approx V_2$. Since $V_1 = -V_2$ this happens when both the values are close to zero. In this case (input = zero), the output is 0.02 (wrong).

V_T volt equivalent of temperature = KT/q

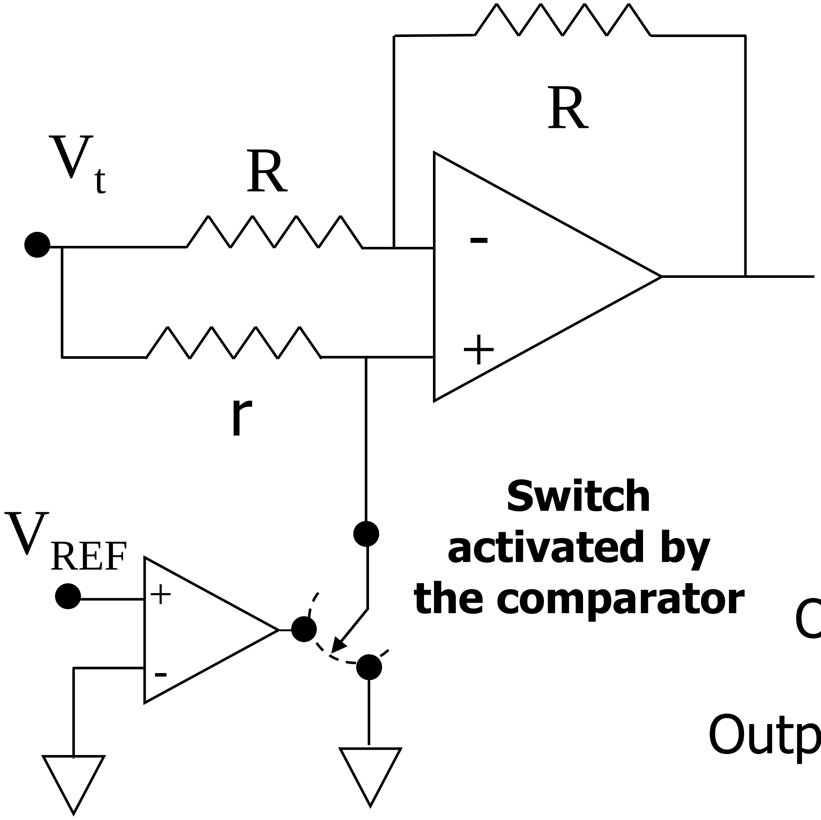
η = material dependent constant

$$U = V_1 - \eta V_T \ln\frac{I_g}{2I_0} + \eta V_T \ln\frac{I_g}{I_0} = \eta V_T \ln 2 \cong 20\text{mV}$$

SYNCHRONOUS RECTIFIER (DETECTOR)

Used when the phase is required together with the amplitude.

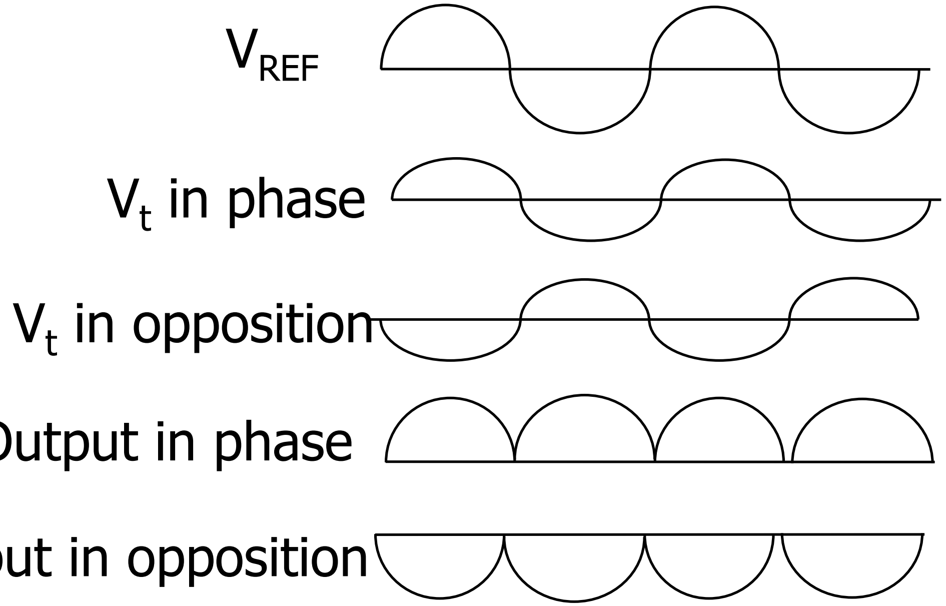
The phase is obtained through a comparison with a reference signal.



Switch activated by the comparator

$V_{REF} > 0$, open switch ⇒ output = V_t

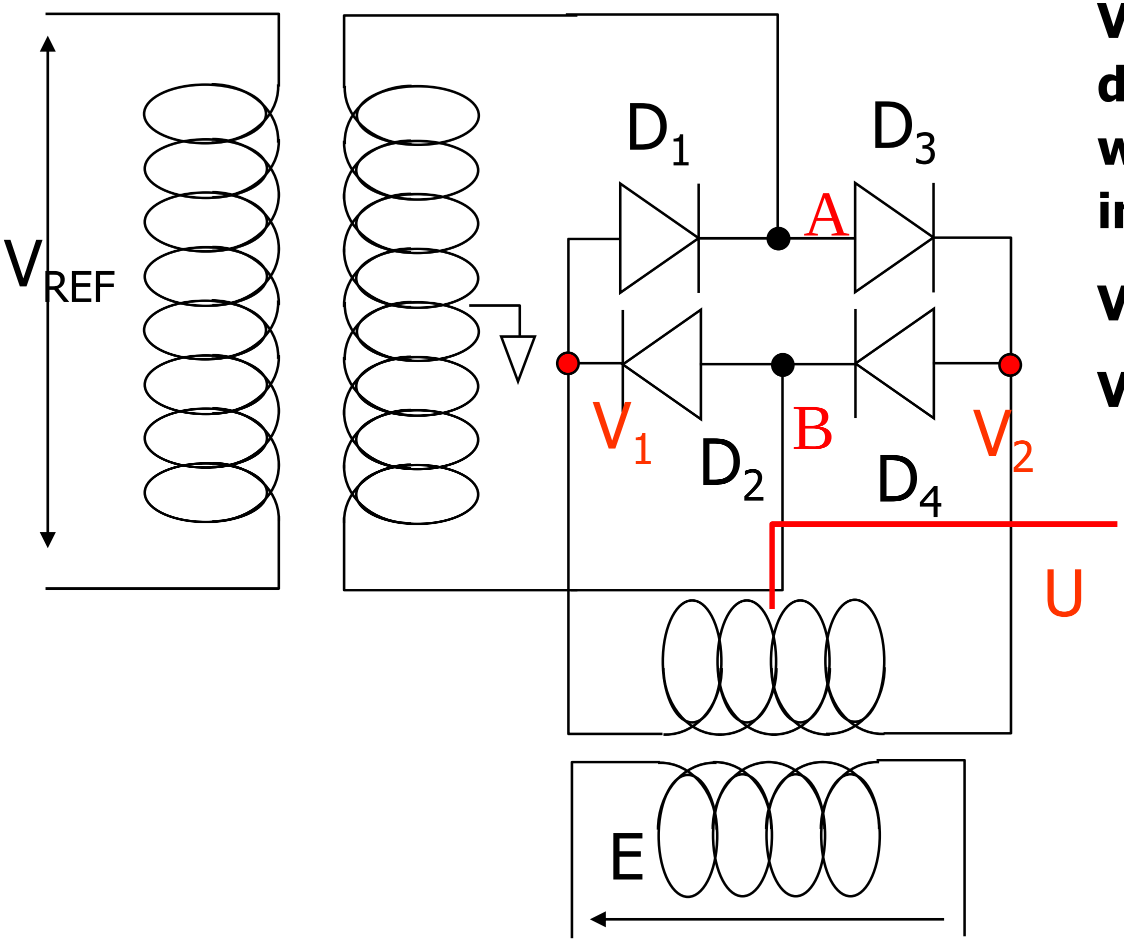
$V_{REF} < 0$, closed switch ⇒ output = $-V_t$



SYNCHRONOUS RECTIFIER (DETECTOR) WITH DIODE BRIDGE

The previous detector provides an appreciable output voltage even for low input values but could be affected by the cutoff frequency of the op. amplifier

An alternative solution exploits a 'diode bridge' configuration.

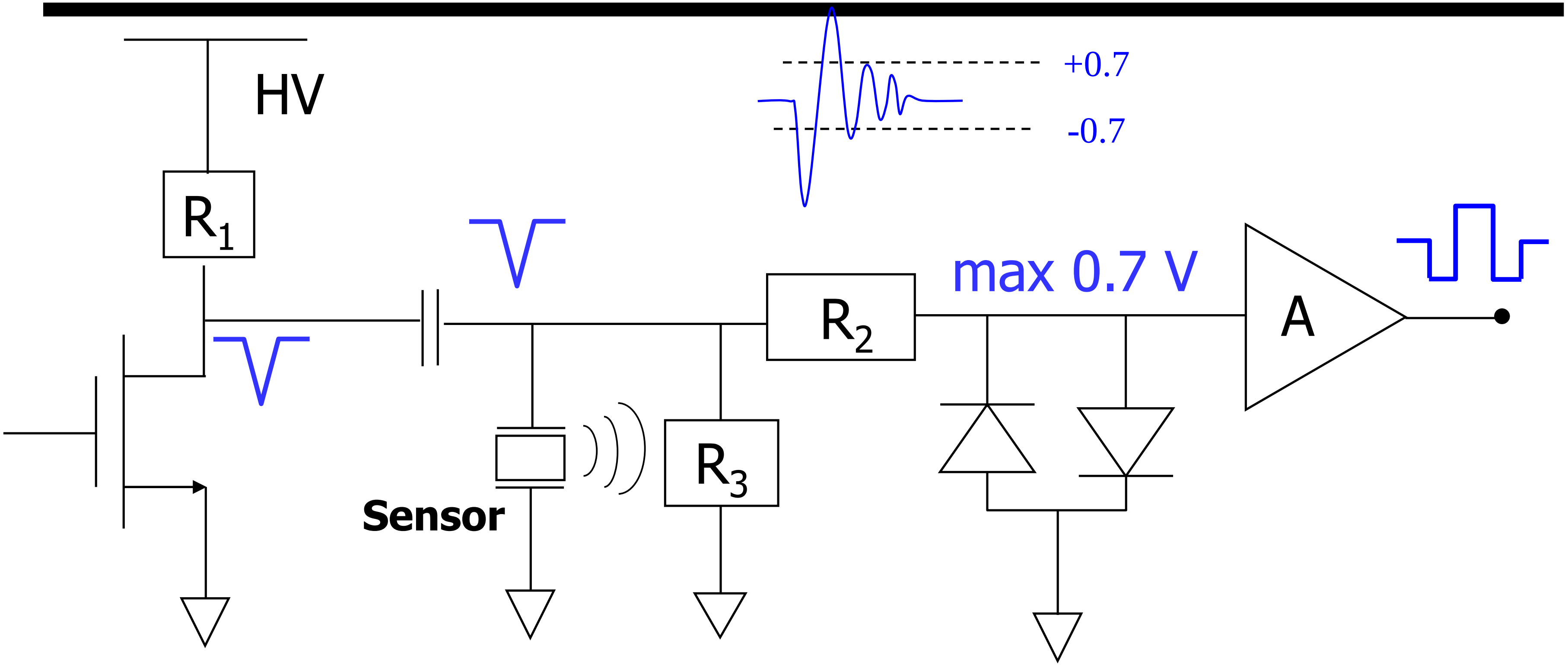


V_{REF} activates the two D_1-D_2 diodes in the negative half-wave or the two D_3-D_4 diodes in the positive one.

$V_{REF} > 0$, $V_2 = 0$; $U = E/2$

$V_{REF} < 0$, $V_1 = 0$; $U = -E/2$

ULTRASOUND MEASUREMENTS ELECTRONICS



TRANSMISSION: the pulse given to the Mosfet gate activates it and causes a spike at both the sides of the capacitor. The spike amplitude is within 10-100V enough to excite the ultrasound generator/receiver.

RECEPTION: the sensor beaten by the echo signal generates an electronic signal that is amplified by the A operational amplifier (Gain ~ 1000).

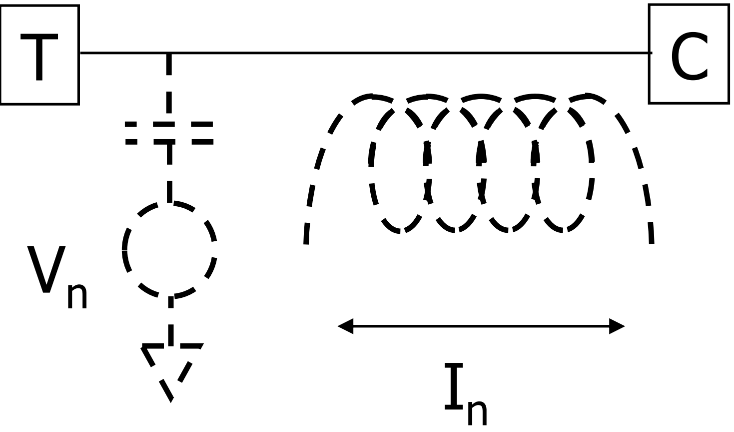
The resistor and the diodes protect A from signals too high with respect to the gain and limit its input between + V_γ and -V_γ.

SIGNAL TRASMISSION

The transmission could be affected by noise due to two kind of interactions: electrostatic or electromagnetic (if a variable magnetic field is present).

In the first case a capacitive coupling between the wire that brings the signal and a possible noise source present in the surroundings (for example when this wire is close to other ones with the 50 Hz voltage. We can say that this noise is a "parallel" noise = a charge distribution takes origin in the wire.

In the other case the proximity noise 'induces' a current in the wire, this current overlaps to the existing one. This current creates an additive voltage as small as the impedance is.

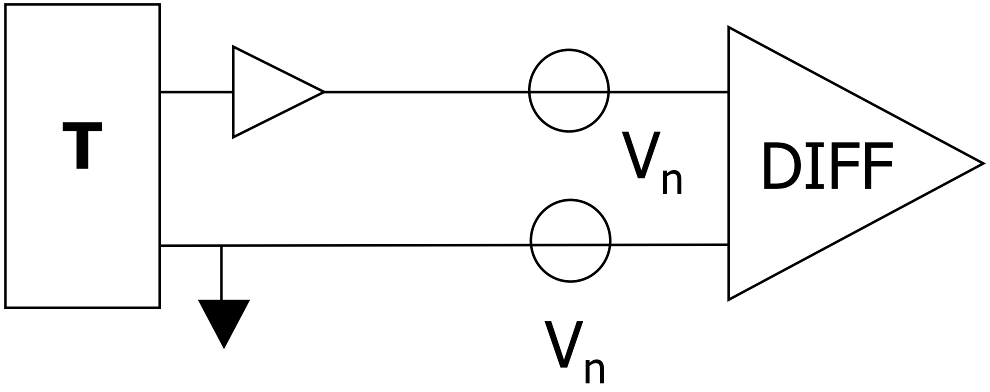


The electrostatic effect could be cancelled if a low output impedance is given in the transducer able to absorb the injected charge.

The electromagnetic disturbance instead can be limited only if the signal is much higher than it (pre-amplifier in the transducer output)

DISTURBANCES COMPENSATION

If the disturbance is known a *compensation* can be done.



CONSTRAINTS:

1) High CMRR (high A_d and low A_c)

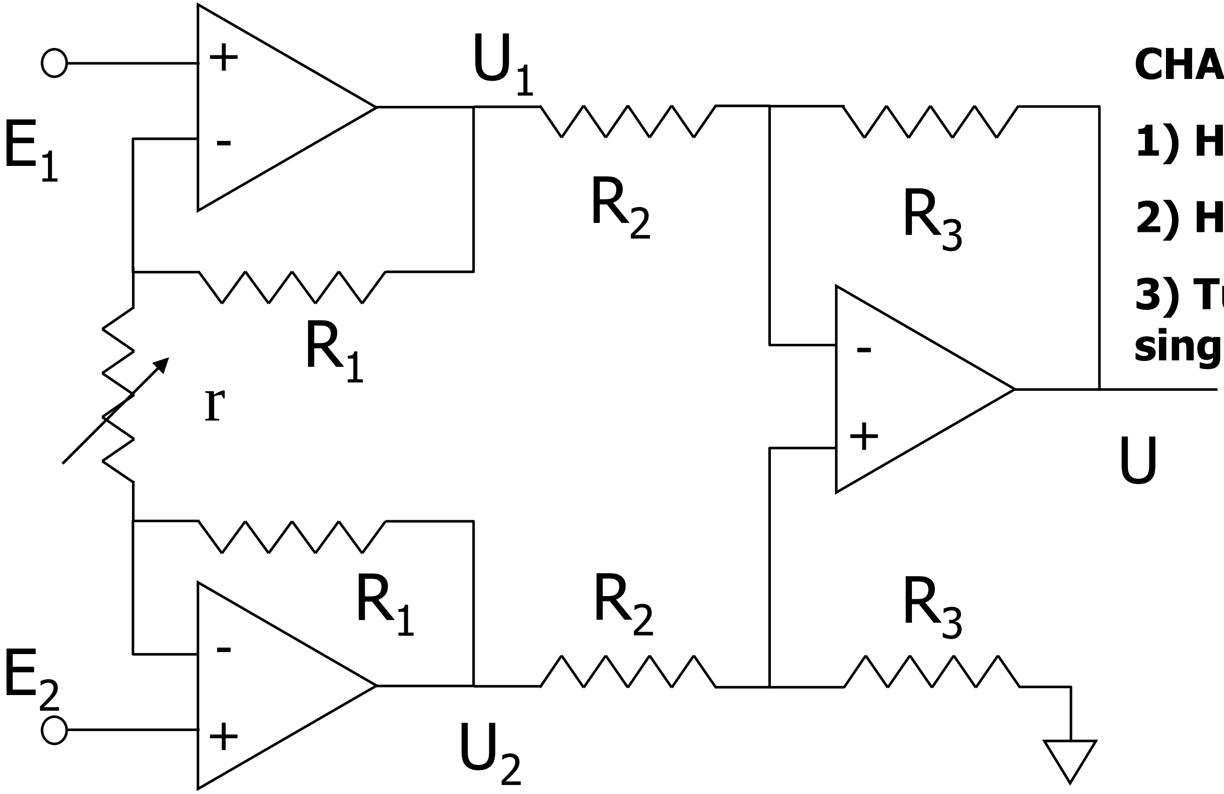
2) Stable and constant noise on a couple of twisted wires

The capacitive coupling depends on the 2 wires impedances. It is important that they are as equal as possible to collect the same amount of noise.

It will be necessary that the preamplifier and the transducer feature a low output impedance. The preamplifier also must feature a high input impedance.

As a differential amplifier the INSTRUMENTATION AMPLIFIER is typically employed

INSTRUMENTATION AMPLIFIER



CHARACTERISTICS

1) High CMRR (high A_d and low A_c)

2) High Z_{in} (300 MΩ)

3) Tunable amplification with a single resistor (gain= 1-1000)

$$U_1 = E_1\left(1+\frac{R_1}{r}\right) - E_2\frac{R_1}{r} \qquad U_2 = E_2\left(1+\frac{R_1}{r}\right) - E_1\frac{R_1}{r}$$

$$U = (U_1 - U_2)\frac{R_3}{R_2} = (E_1 - E_2)\left(1+\frac{2R_1}{r}\right)\frac{R_3}{R_2}$$

OBSERVATIONS

This kind of noise filtering is ok if no great accuracy is required. As an alternative a digital conversion is necessary close to the transducer.

If transmission on long distances is needed a serial protocol can be used (RS232/USB) since the noise immunity is better.

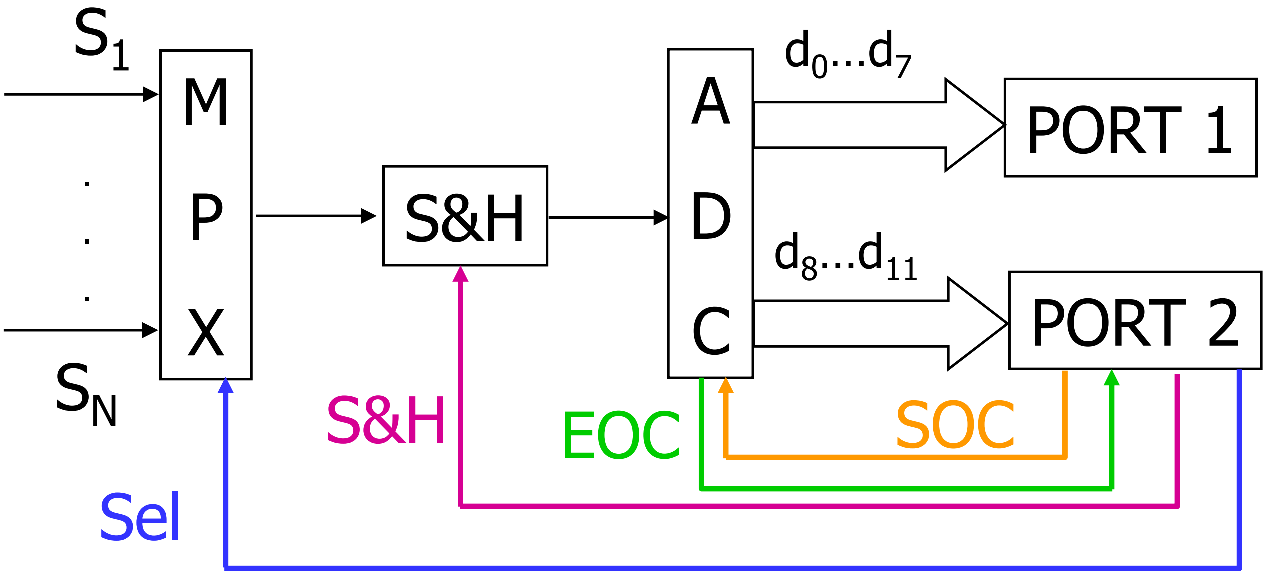
In fact the voltage recognition bands for the logic signals are larger than for TTL or ECL electronic circuits (logic «0» corresponds to 3/25 V, logic «1» to -3/-25 V).

In the RS232 format the transmission is done on a single wire: no noise compensation (instead in the RS422 format yes).

Voltage converters between parallel and serial lines are necessary when bits are generated (line drivers and receivers).

Filters can be used if noise and signal frequency bands are different. Both analog and digital filtering can be used.

FROM THE TRANSDUCER TO THE MICROPROCESSOR



SOC=start of conversion

EOC=end of conversion

Conversion TIMES

(μsec-msec)

<u>When to read the converted datum?</u>

If the ADC is fast, the μP waits for the EOC (polling)

If the ADC is slow, the μP waits for a interrupt signal when EOC will be active (the port must be programmed accordingly)

<u>When to start the conversion?</u>

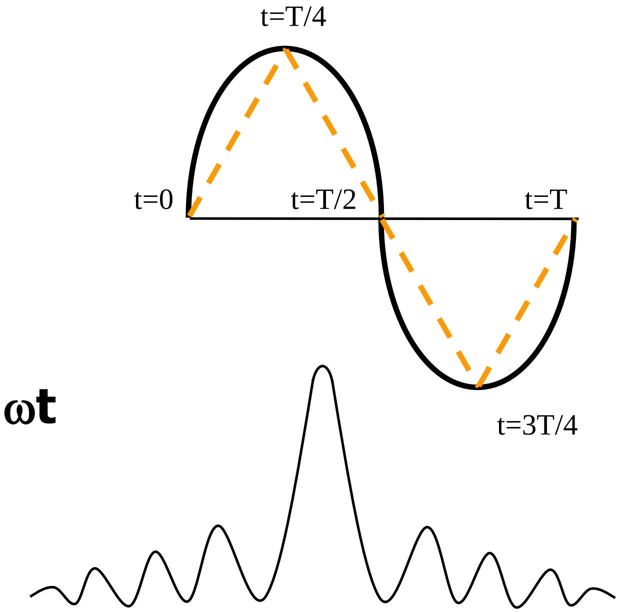
- A code with a known duration. At the end the μP sends the SOC through the port.

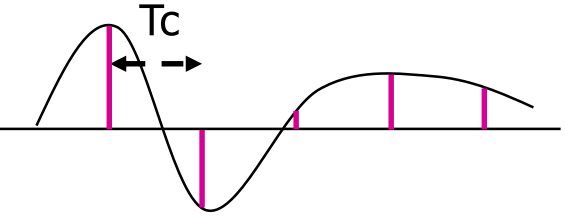
- A timer that sends a interrupt signal to the μP accordingly to a selected time interval

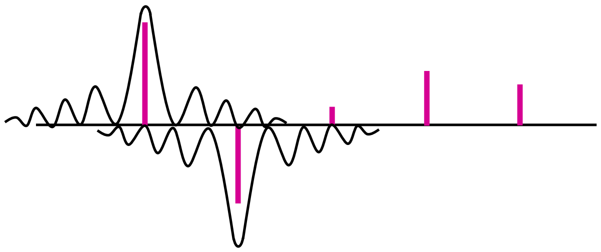
TEMPORAL QUANTIZATION

Shannon theorem (Nyqvist) $f_c > 2f_{max.}$

Does it really work? Only if sync= senωt/ωt function is used







Σ signal(kT_c) sync(ω(t-T_c))

Very heavy !!!

In practice **$f_c > 10\ f_{max.}$**

AMPLITUDE QUANTIZATION

ADC PRECISION

$$Eq = \frac{Vref(FS)}{2^n}$$

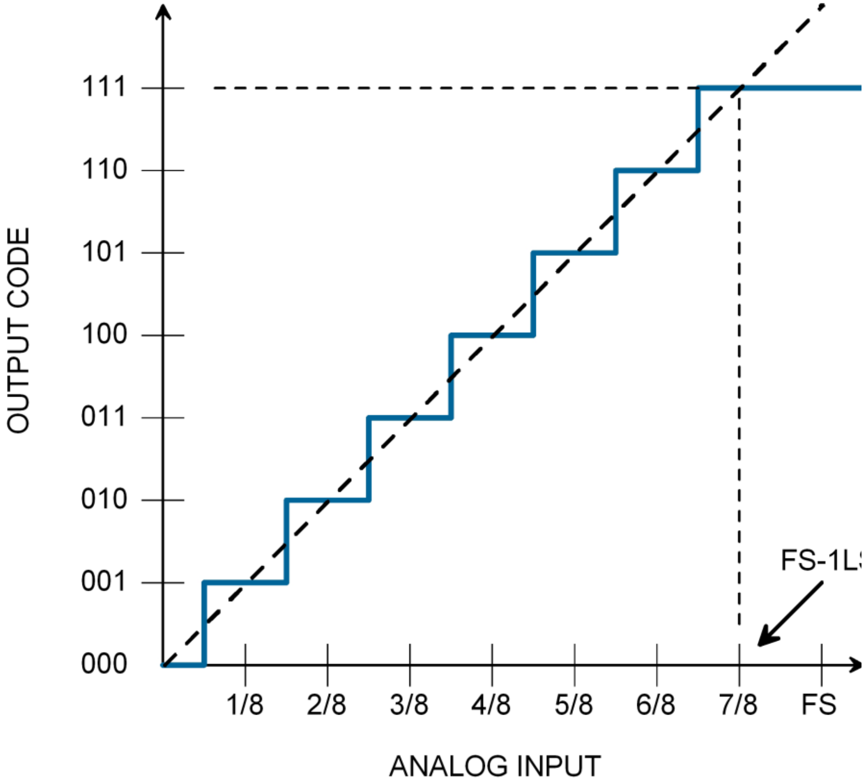
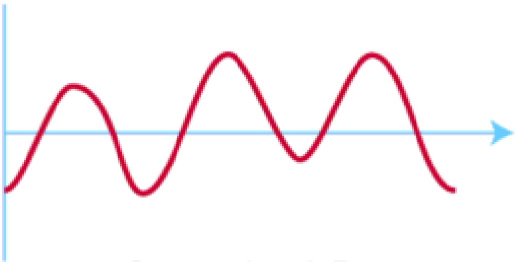
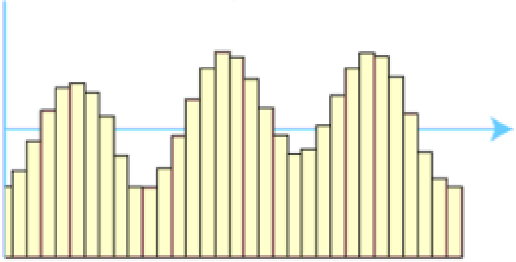


fig. 1



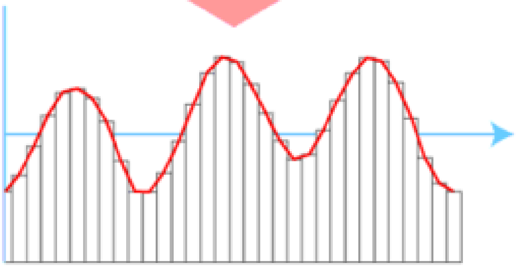
Conversion A-D

fig. 2



Conversion D-A

fig. 3



A 20 V signal to be read with 1 mV precision requires 20000 levels of conversion and requires a 15 bit ADC.

If however a 100 mV noise is overlapped only 8 bits are enough.

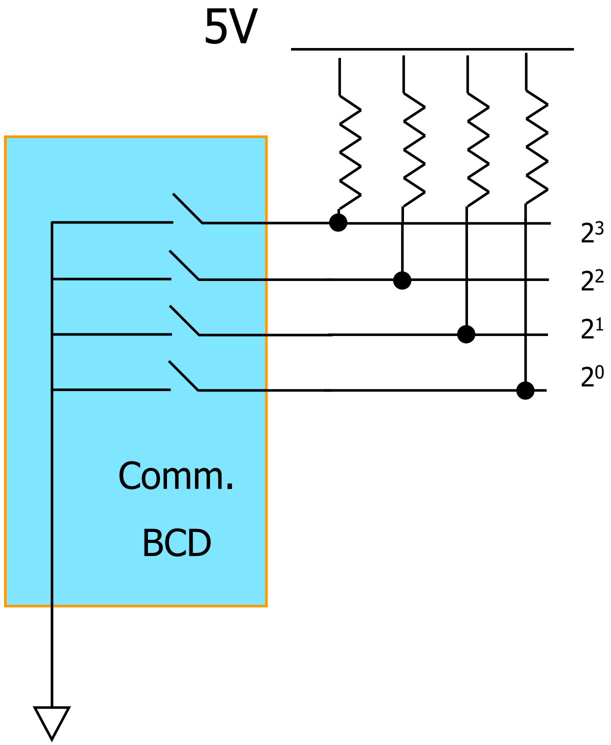
Finally if the noise is null-average a low pass filter can be used.

Typical industrial ADC feature 12-16 bits.

Usually a very fast ADC is less accurate.

N° Bit = $\log_2$ (precision)$^{-1}$ = $\log_2$ (signal FS range/max. abs. error)

DECIMAL SWITCHES - CONTRAVES

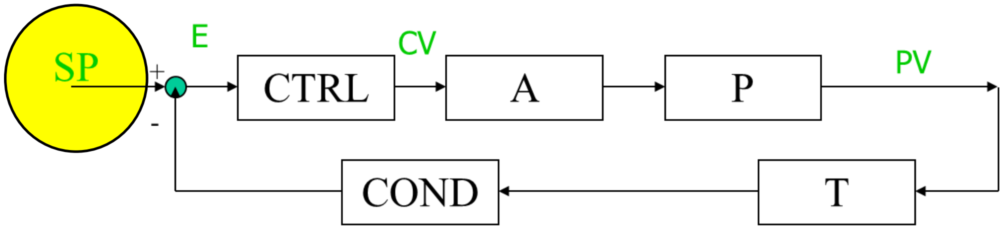


A certain number of digits must be read by the μP (i. e. the set point of a regulation chain)

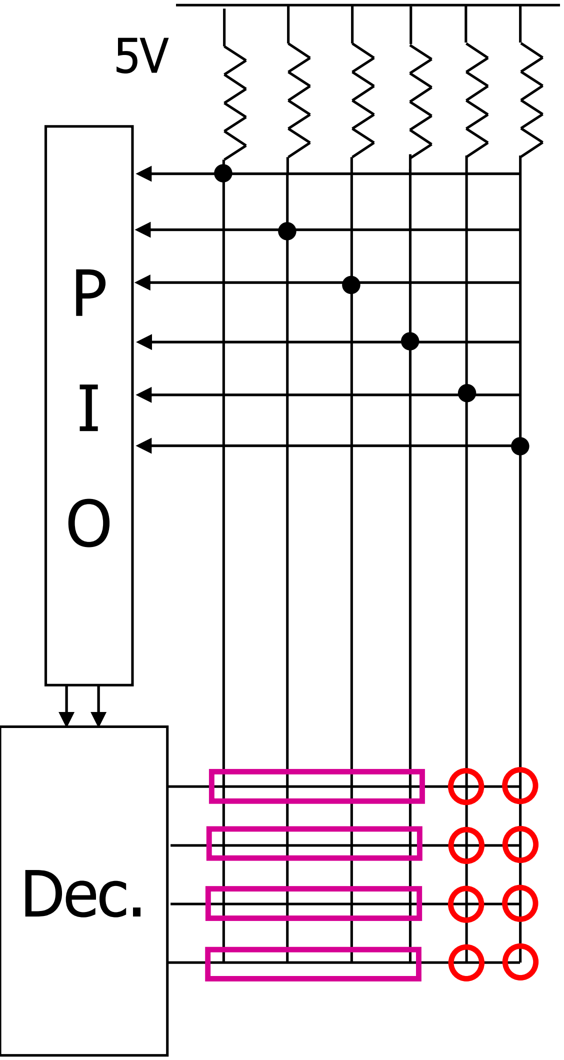
Problems due to the partitioning with other (resistive) loads

A command bit for every switch to be managed. Not suitable, many ports could be required.

A matrix mesh is better.



DECIMAL SWITCHES – CONTRAVES

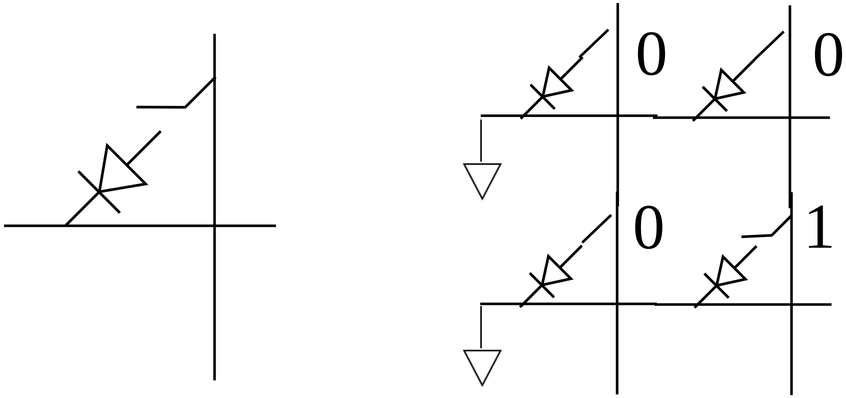


Example: 4 BCD digits (magenta) must be read together with 8 push-button connections (red). They correspond to 24 bits but instead of 3 ports, only 1 plus a decoder can be used.

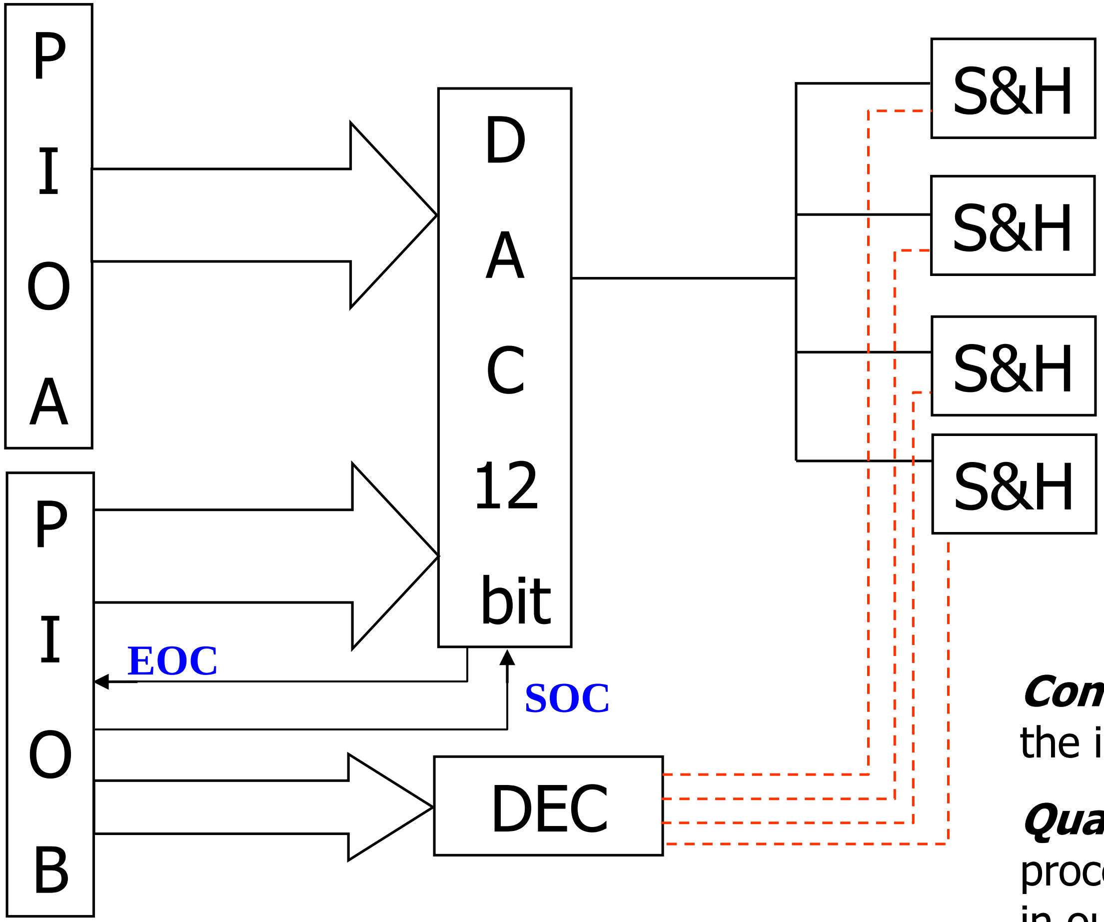
The decoder activates 1 of the 4 possible outputs (low active) each one with 6 elements. Then they are acquired through the port.

The column/raw contact is made by means of de-coupling diodes.

Acquisition time= decoder selection bit time + output decoder time + port input time



Analog Output: DAC



A S&H is required to keep the output voltage stable between a value and the successive one.

The 4 outputs repetition frequency is equal to the S&H one.

PRECISION

Conversion frequency: it depends on the input data arrival to the processor.

Quantization: if we do not know the process dynamics the variable we provide in output could be not suitable compared to what is necessary to keep the process stable; it is not a problem if the process dynamically behaves slowly.