Chapitre3 : Passive Sensor Conditioners

3.1 General characteristics of passive sensor conditioners

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3.1 General characteristics of passive sensor conditioners

3.1.1 Main types of conditioners

The variations of the impedance Z_C of a passive sensor linked to the evolutions of a measurand *m* can only be translated in the form of an electrical signal by associating with the sensor a voltage source e_s or a current source i_s and generally other impedances Z_K.

We can distinguish two main groups of conditioners according to the information they transfer and which is related to the impedance of the sensor:

- Either on the amplitude of the measurement signal:

$$Vm = e_s F(Z_K, Z_C)$$

This is the case for potentiometric ("**pot**") assemblies and bridges;

- Either on the frequency of the measurement signal:

$$Fm = G(Z_K , Z_C)$$

These are then oscillators.

The pot assembly (fig.1) has the advantage of simplicity, but its major drawback is its sensitivity to interference.

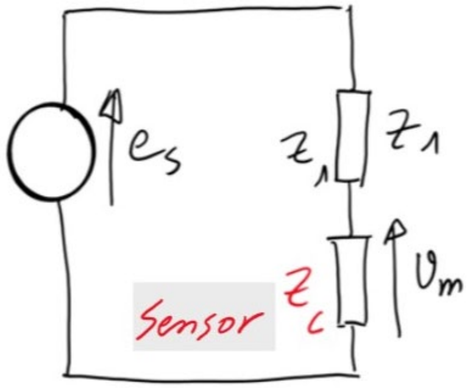


Fig.1

It is the same for the supply by current source (fig.2) which can be considered as an extreme case (Z_1 very large compared to Z_C) of the pot assembly.

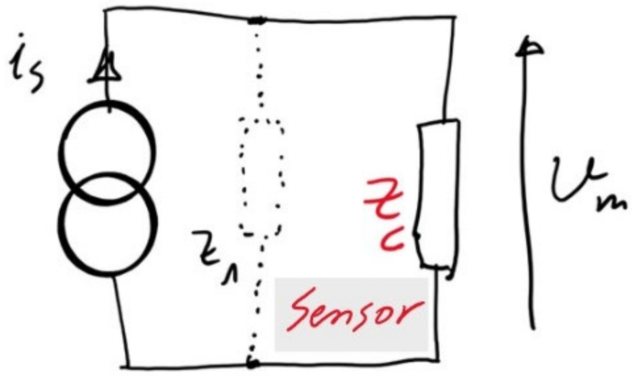


Fig.2 $z_1 \gg z_c$

The bridge on the other hand (fig.3) which is effectively a double potentiometer allows a differential measurement, significantly reducing the influence of interference.

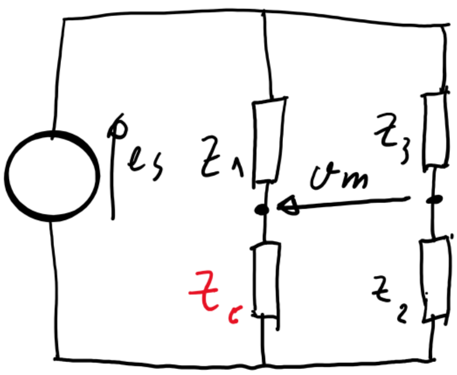


Fig.3

The oscillators used as conditioners can be of the sinusoidal or relaxation type (fig.4).

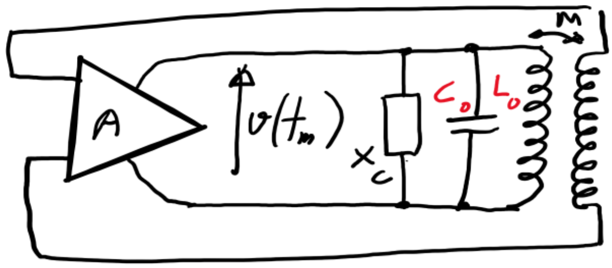


Fig.4

They deliver a signal whose frequency is modulated by the information, which gives it good protection against interference, particularly in the case of telemetry. In addition, the conversion of information into digital form is facilitated by just counting the periods.

3.2 Potentiometer Circuit

3.2.1 Resistor Measurements (Tutorial 1)

The sensor, of resistance R_C in series with a resistance R_1 is supplied by a source of internal resistance R_S and emf e_s, continuous or alternating (fig.1).

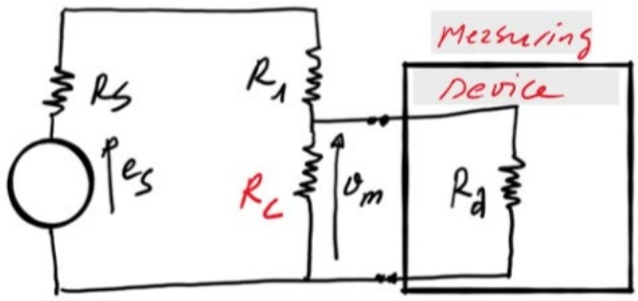


Fig.1

The voltage *Vm* is measured across the sensor terminals by a device that has an input resistance *Rd*.

We can write:

$$Vm = \frac{\mathrm{Rc}\ \mathrm{Rd}}{\mathrm{Rc}(\mathrm{Rs}+\mathrm{R1})+\mathrm{Rd}(\mathrm{Rs}+\mathrm{R1}+\mathrm{Rc})}$$

The voltage at the sensor terminals is independent of the measuring device provided that: Rd >>Rc

In this case :

$$Vm = \frac{\mathrm{Rc}}{(\mathrm{Rs}+\mathrm{R1}+\mathrm{Rc})} \quad (1)$$

It can be noticed that the voltage *Vm* is not a linear function of *Rc*.

Measurement linearization

We want the variation ΔVm of the measured voltage to be proportional to the variation ΔRc of the resistance of the sensor.

• *First solution: operation in "small signals"*

The resistance of the sensor varying from R_{C0} to $R_{C0} + \Delta RC$

The voltage *Vm* varying from *Vmo* to *Vmo* + *ΔVm*

From (1), we can write:

$$v_{m_0} + \Delta v_m = e_S \frac{R_{C0}+\Delta R_C}{(R_{C_0}+R_1+R_S)} \frac{1}{[1+\frac{\Delta R_C}{RC_0+R_1+R_S}]}$$

Provided that $\Delta R_C \ll R_{CO} + R_1 + Rs$, we can write:

$$\Delta v_m = e_s \frac{\Delta R_C}{R_{C_0} + R_1 + R_s}$$

• *Second solution: power supply by current source*

The assembly is powered by a current source, i.e. having a very high internal impedance R_S:

$$R_s >> R_{C_0} + R_1$$

In this case, the condition $\Delta R_C \ll R_{CO} + R_1 + R_s$ is always verified.

If we make $i_s = \frac{e_s}{R_s}$, we get:

$$\Delta v_m = i_s \cdot \Delta R_C$$

• *Third solution: push-pull assembly*

The fixed resistor R1 is replaced by a second sensor, identical to the first, but whose resistance variations have opposite signs:

$$R_1 = R_{C_0} - \Delta R_C$$

This association of two sensors operating in opposition is called push-pull.

Example: Two identical extensometer gauges undergoing equal deformations with opposite signs.

We then have:

$$v_{m_0} + \Delta v_m = e_s \frac{R_{C_0} + \Delta R_C}{R_{C_0} + \Delta R_C + R_s + \left(R_{C_0} - \Delta R_C\right)}$$

With $\Delta v_m = e_s \frac{\Delta R_C}{2R_{C_0}+R_s}$

3.3 Bridge Circuit (Tutorial 3)

The advantage of bridges results from the differential nature of the measurement which makes it less sensitive to noise and source drift.

This general property of bridges is highlighted in the following example of a resistive bridge (fig.1).

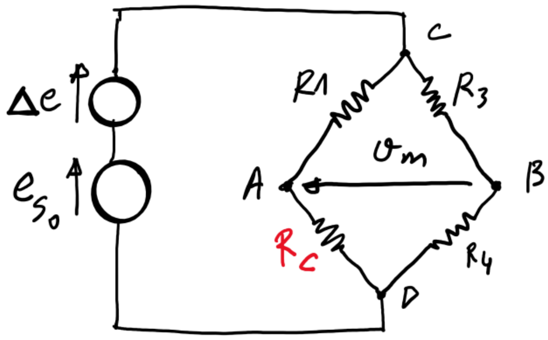


Fig1 : *resistive bridge*

Influence of supply voltage fluctuations

The bridge is initially balanced: $v_A = v_B$

And $\frac{R_{C_0}}{R_1+R_{C_0}} = \frac{R_4}{R_3+R_4}$

When there is a fluctuation Δe added to e_{s_0} of the source, we can write:

$$v_A = e_{s_0}\frac{R_{C_0} + \Delta R_C}{R_1 + R_{C_0} + \Delta R_C} + \Delta e\frac{R_{C_0} + \Delta R_C}{R_1 + R_{C_0} + \Delta R_C}$$

$$v_B = e_{s_0}\frac{R_4}{R_3 + R_4} + \Delta e\frac{R_4}{R_3 + R_4}$$

The measurement voltage v_m has the expression:

$$v_m = v_A - v_B = e_{s_0}\left(1 - \frac{\Delta e}{e_{s_0}}\right)\frac{R_1 \Delta R_C}{\left(R_1 + R_{C_0} + \Delta R_C\right)\left(R_1 + R_{C_0}\right)}$$

$$v_m \approx \frac{e_{s_0}\Delta R_C}{4R_{C_0}}\frac{1}{1 + \frac{\Delta Rc}{2Rc_0}}$$

It can be seen that the influence of the fluctuation Δe on v_m is considerably reduced as soon as $\Delta R_c \ll R_{c_0}$

3.3.1 Resistance measurements – Wheatstone bridge (reminder)

a) *General equation. Equilibrium condition (Tutorial 2)*

e_s and R_s characterize the source (fig.2) ;

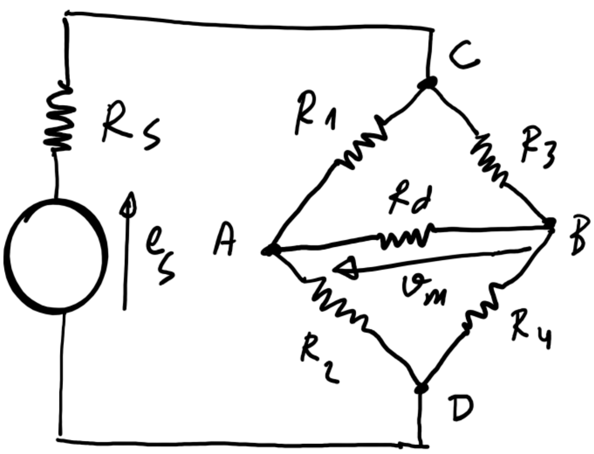


Fig.2 *Wheatstone Bridge, general structure*

Rd is the resistance of the device for detecting the balance of the bridge or measuring its unbalance.

Kirchhoff's equations make it possible to calculate i_d :

$$i_d = \frac{R2R3 - R1R4}{[R1R4(R2+R3) + R2R3(R1+R4) + Rs(R1+R3)(R2+R4) + Rd(R1+R2)(R3+R4) + RsRd(R1+R2+R3+R4)]}$$

The bridge is said to be balanced when $v_A = v_B \Rightarrow i_d = 0$

Which gives the condition :

$$R1R4 = R2R3$$

The equilibrium condition depends only on the resistances of the bridge: it is independent of the resistances of the source and of the unbalance detector.

b) Unbalance voltage

The bridge is generally powered by a source whose resistance *Rs* is low: *Rs << R1, R2, R3, R4, Rd*

If we put *Rs = 0*, that implies:

$$i_d = e_s \frac{R_2R_3 - R_1R_4}{R_1R_4(R_2+R_3) + R_2R_3(R,+R_4) + R_{c^1}(R_1+R_2)(R_3+R_4)}$$

When the measuring device has a high input impedance (voltmeter, amplifier, etc.) we have: *Rd >> R1, R2, R3, R4*

In these conditions

$$i_d = \frac{R_2R_3 - R_1R_4}{R_d(R_1+R_2)(R_3+R_4)}$$

And since $v_m = R_d i_d$

That implies

$$v_m = e_s \frac{R_2R_3 - R_1R_4}{(R_1+R_2)(R_3+R_4)}$$

(3.4) Oscillators

(3.4.1) Sinusoidal Oscillators

The frequency of a sinusoidal oscillator (fig.3) can be fixed, in particular by the resonance of a circuit consisting of an inductance coil L_0 and a capacitor of capacitance C_0 associated in series or in parallel ;

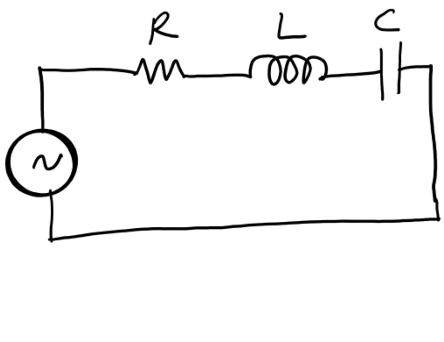


Fig.3 *Circuit RLC*

The circuit has a purely resistive impedance at the resonance frequency F_0 whose expression is:

$F_0 = \frac{1}{2\pi\sqrt{L_0C_0}}$ for a series circuit;

$F_0 = \frac{1}{2\Pi\sqrt{L_0C_0}}\sqrt{1-\frac{1}{Q_L^2}}$ for a parallel oscillating circuit.

Where Q_L is the quality factor of the coil:

$$Q_L = L_0\Omega_0 \,/\, R_S$$

R_S being its series resistance and $\Omega_0 = 2\pi F_0$

In general $Q_L^2 \gg 1$, and we can put $F_0 = \frac{1}{2\pi\sqrt{L_0C_0}}$

When an inductive or capacitive sensor is one of the elements of a resonant circuit, its reactance variations lead to a change in the frequency of the oscillations.

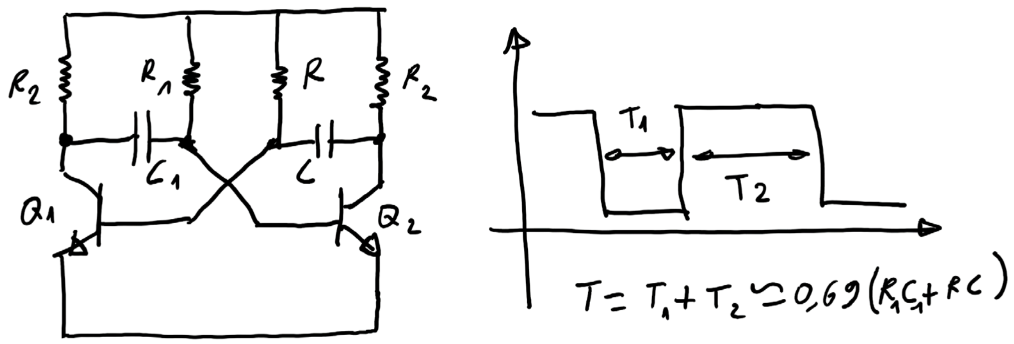
Depending on the type of sensor, and assuming the amplitude of variation of its reactance is low, the variation in frequency is as follows:

$\frac{\Delta F}{F_0} = -\frac{\Delta L}{2L_0}$ or $\frac{\Delta F}{F_0} = -\frac{\Delta C}{2C_0}$ (*log*.)

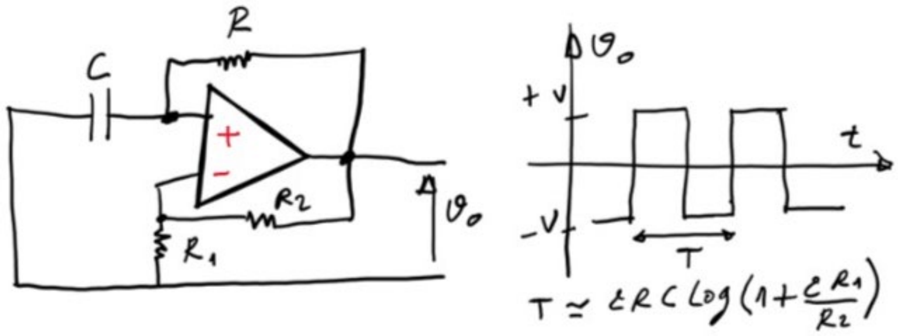
Either $F = F_0\left(1-\frac{\Delta L}{2L_0}\right)$ or $F = F_0\left(1-\frac{\Delta C}{2C_0}\right)$

(3.4.2) Relaxation Oscillators

The most commonly used device is the astable multivibrator (fig2) which is a generator of rectangular signals.



a) *With two transistors with collector coupling.* $T = T_1 + T_2 \approx 0{,}69(RC_1 + RC)$



b) *With an operational amplifier*. $T = 2RC\,log\left(1 + \frac{2R_1}{R2}\right)$

Fig2: *Astable multivibrator circuits*.

The frequency *F* of these signals is linked to the value of the components by a relation of the form:

$$F = \sim \frac{a}{R_c}$$

The constant ***a*** depends on the particular setup.

Capacitance *C* or resistance *R* can be those of a sensor:

$C = C_0 + \Delta C$ ou $R = R_0 + \Delta R$

We then have:

$\frac{\Delta F}{F_0} = -\frac{\Delta C}{C_0}$ or $\frac{\Delta F}{F_0} = -\frac{\Delta R}{R_0}$

Either $F = F_0\left(1 - \frac{\Delta C}{C_0}\right)$ or $F = F_0\left(1 - \frac{\Delta R}{R_0}\right)$

Like the sinusoidal oscillator, the frequency of the multivibrator is modulated by the variations of the impedance of the sensor.

Important Note

Depending on the type of conditioner associated with the sensor, the measured voltage, the information carrier, comes in different forms and each of these poses a double problem:

1 Adaptation of the bandwidth of the processing equipment to the frequency spectrum of the measurement signal.

2 Determination of the method and the circuits allowing the detection of the information carried by the measurement signal (next chapter).

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