Analog Electronics

Unit 2

Unit 2. Analog signals

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Thevenin/Norton equivalent

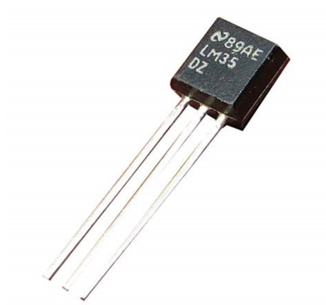
2.1 Introduction

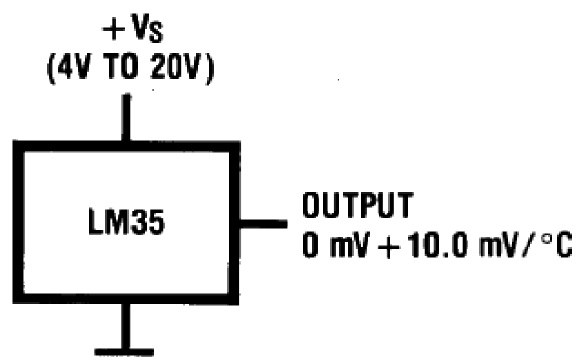
Open loop system

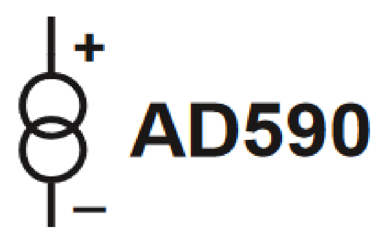
Physical signal:
Temperature,
liquid level,
pressure

→ SENSOR →

Electric Signal:
Voltage
Current



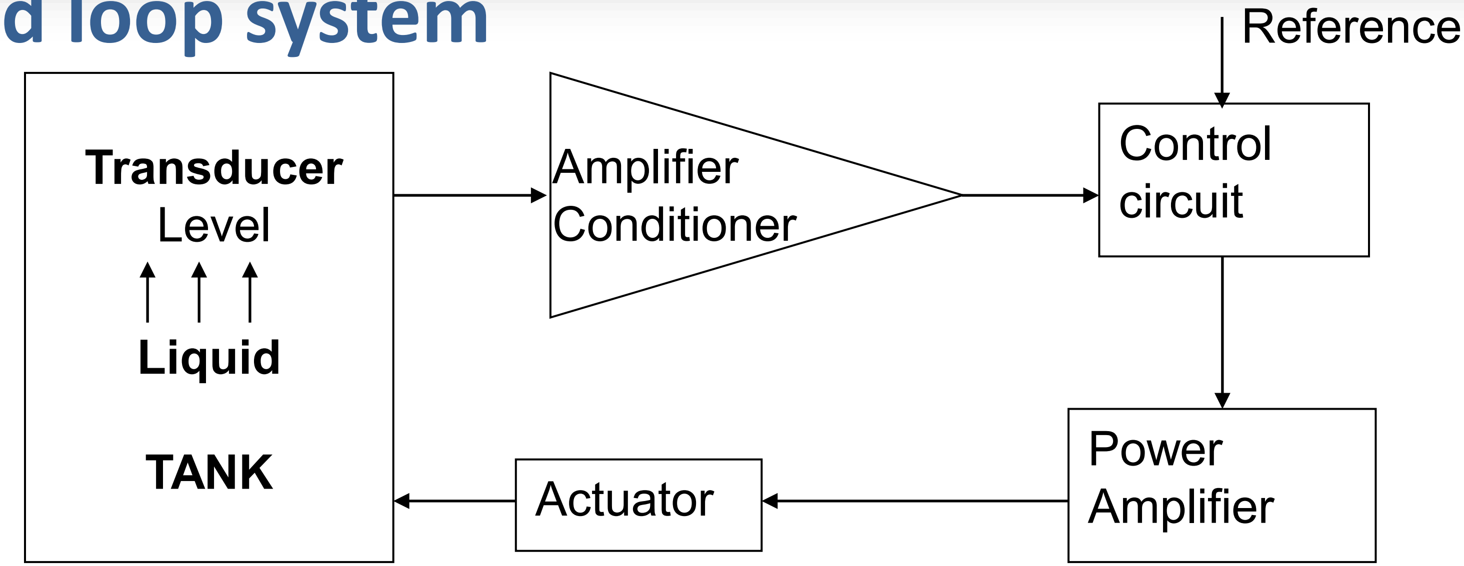


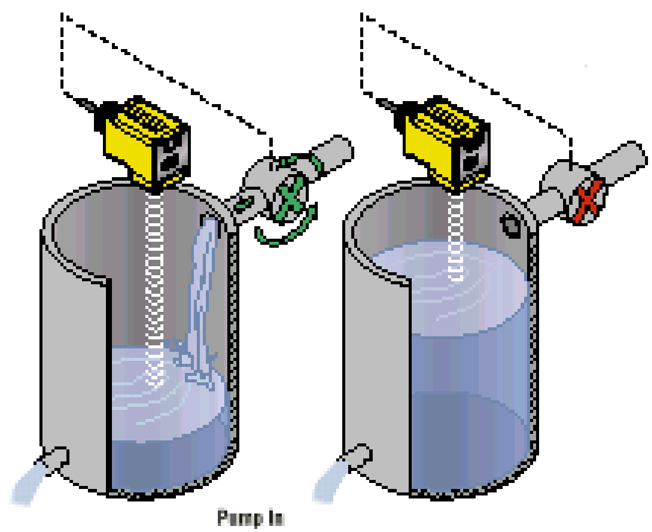


1 µA/K

2.1 Introduction

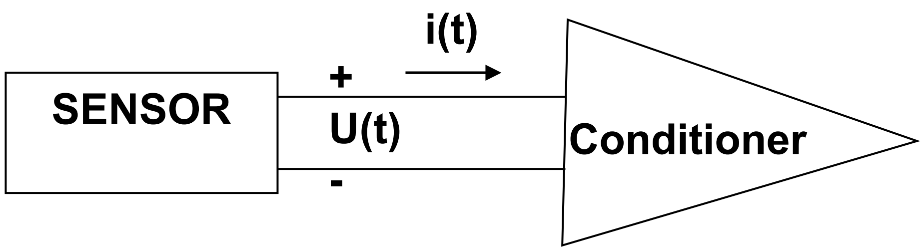
Closed loop system

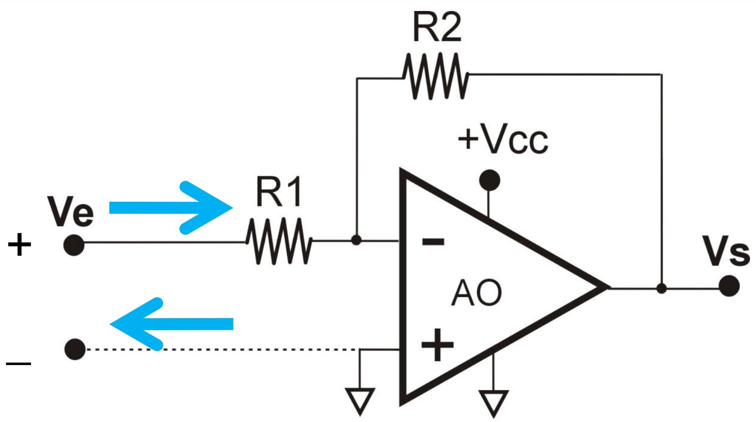


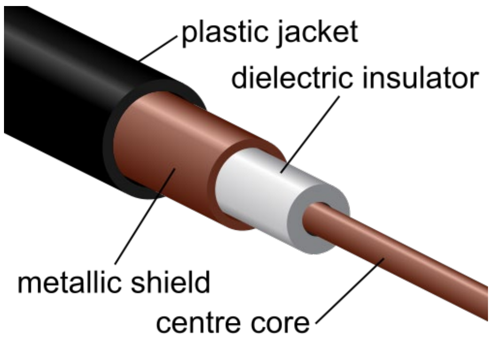


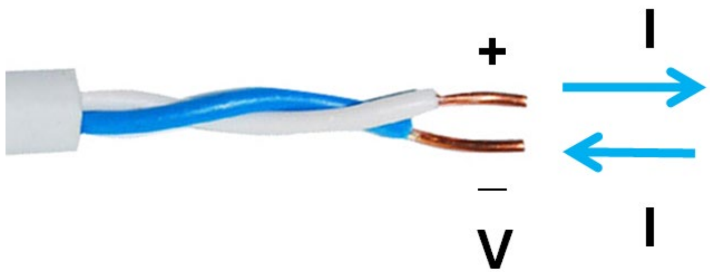
2.2 Types of signals

Conducted signals



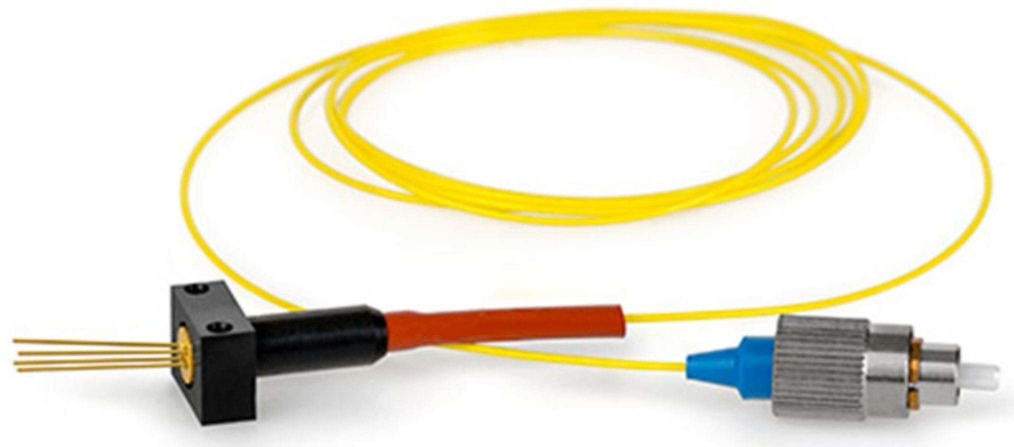


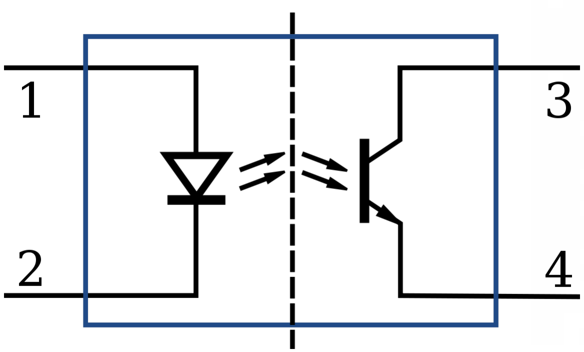


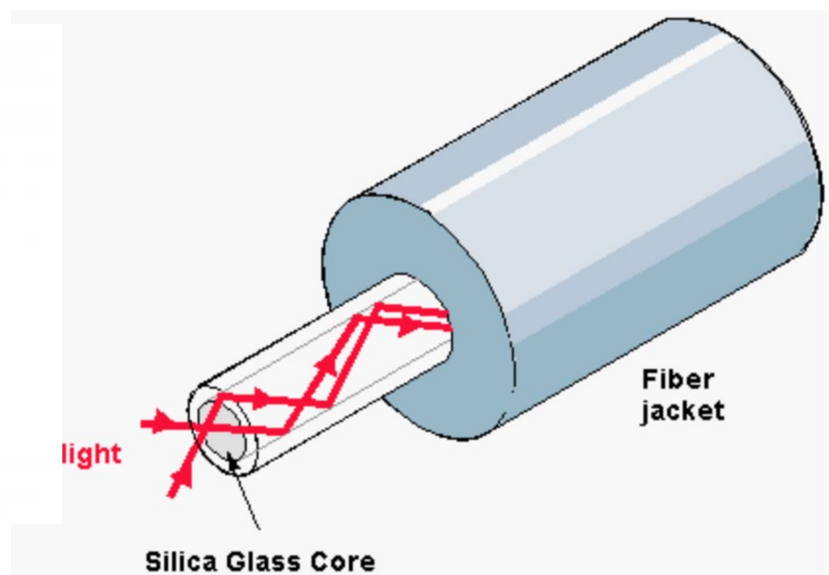


2.2 Types of signals

Optical (guided/free)

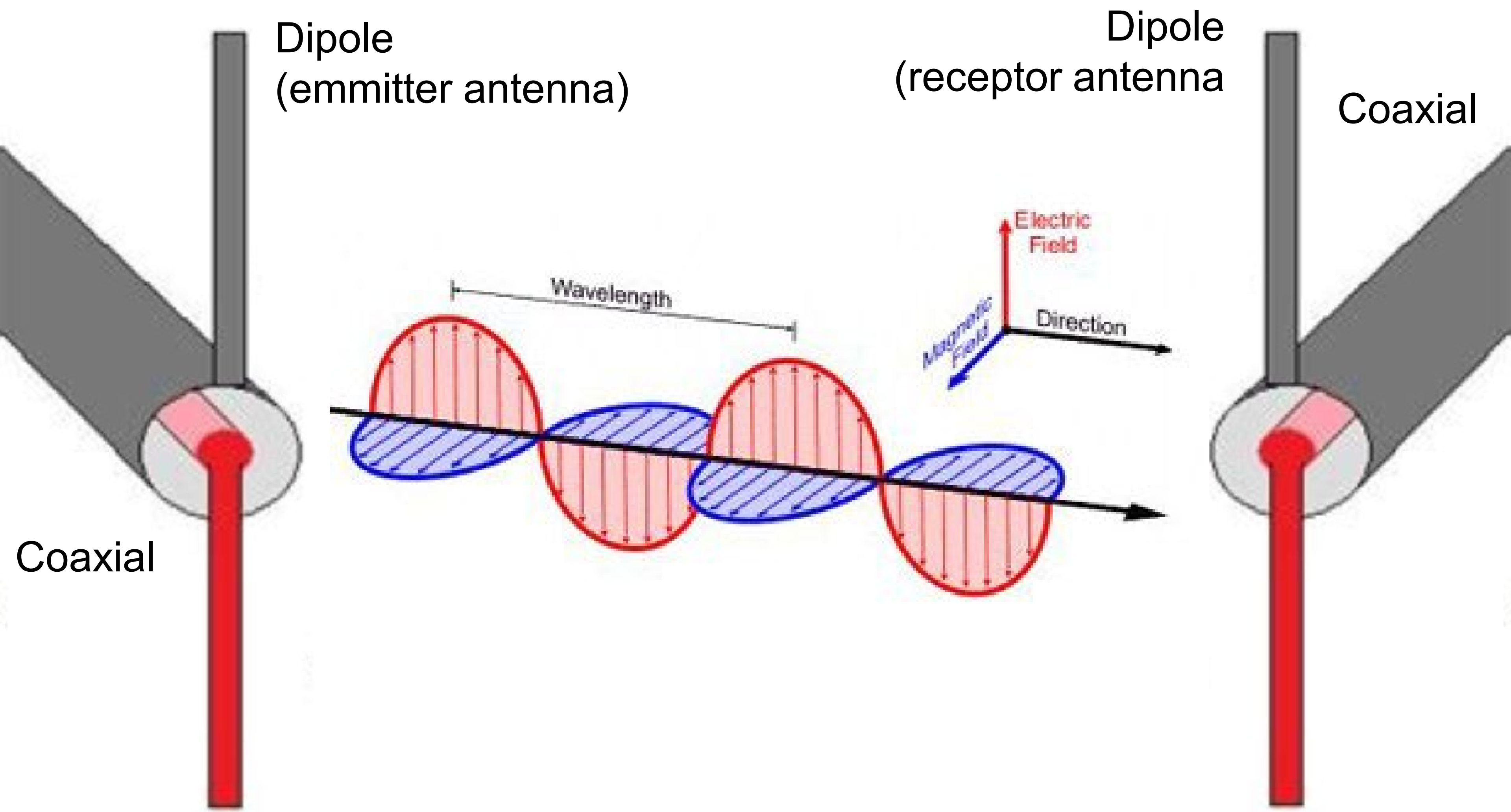






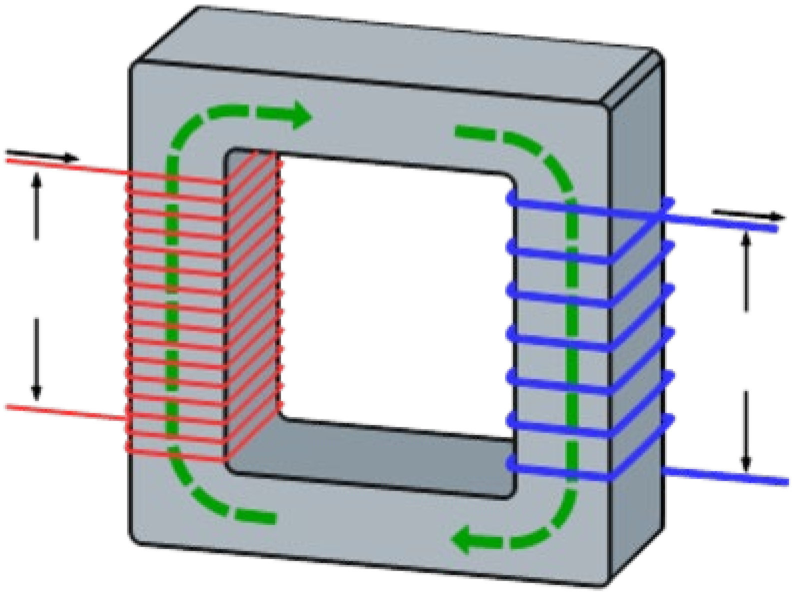
2.2 Types of signals

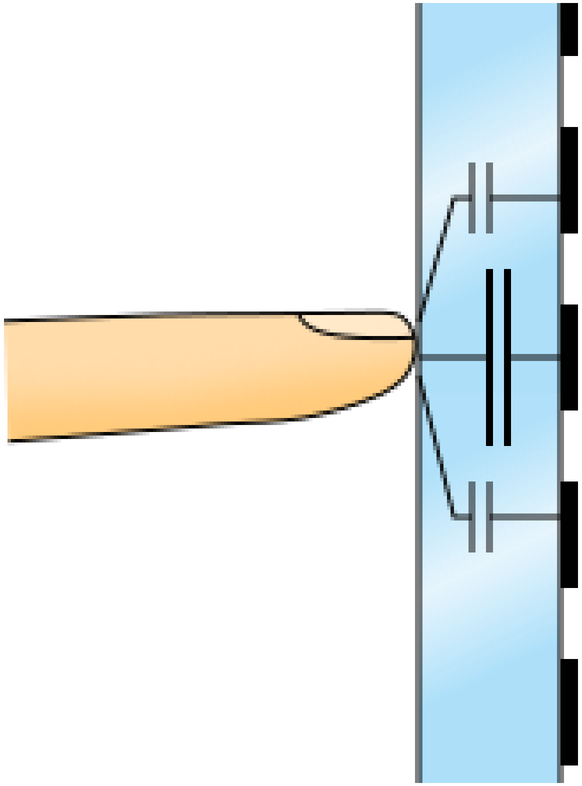
Radiated (radioelectric signals)



2.2 Types of signals

Coupled (inductive/capacitive)





2.3 Features of electric conducted signals

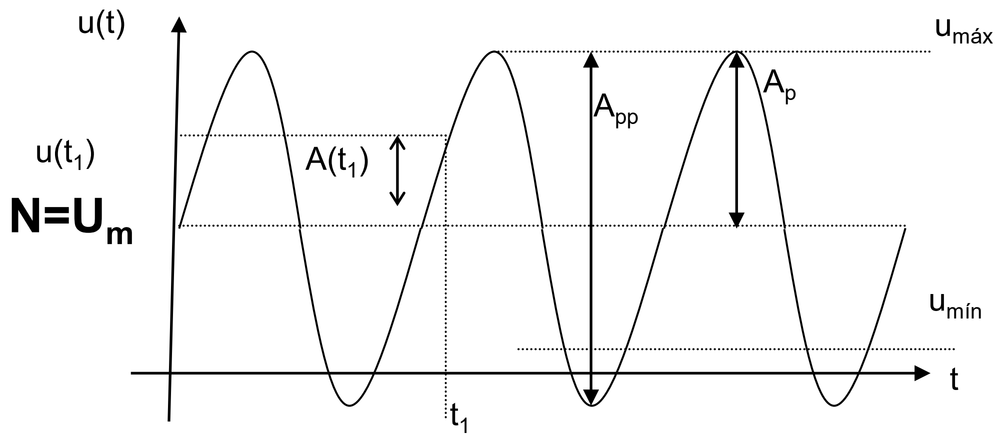
Amplitude, level, range

AC and DC components

$u(t)=A(t)+N$

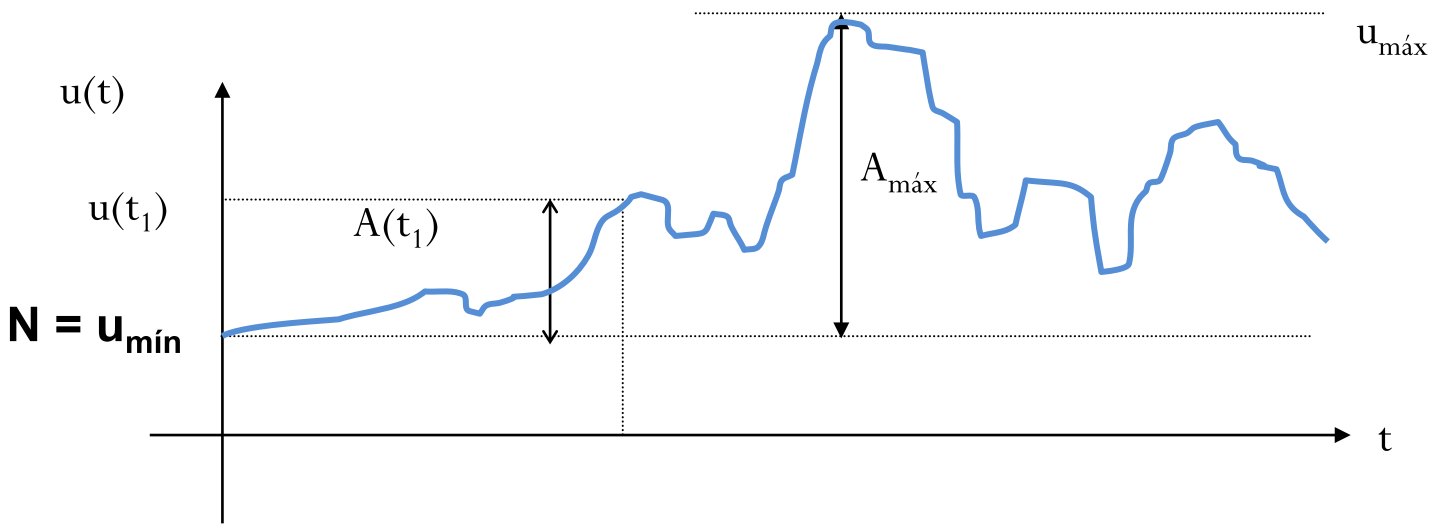
Amplitude ↓ Level ↓

Case 1: Periodic signals or with known mean value



2.3 Features of electric conducted signals

Case 2: Signals with unknown time-course and mean value. BUT Known range.

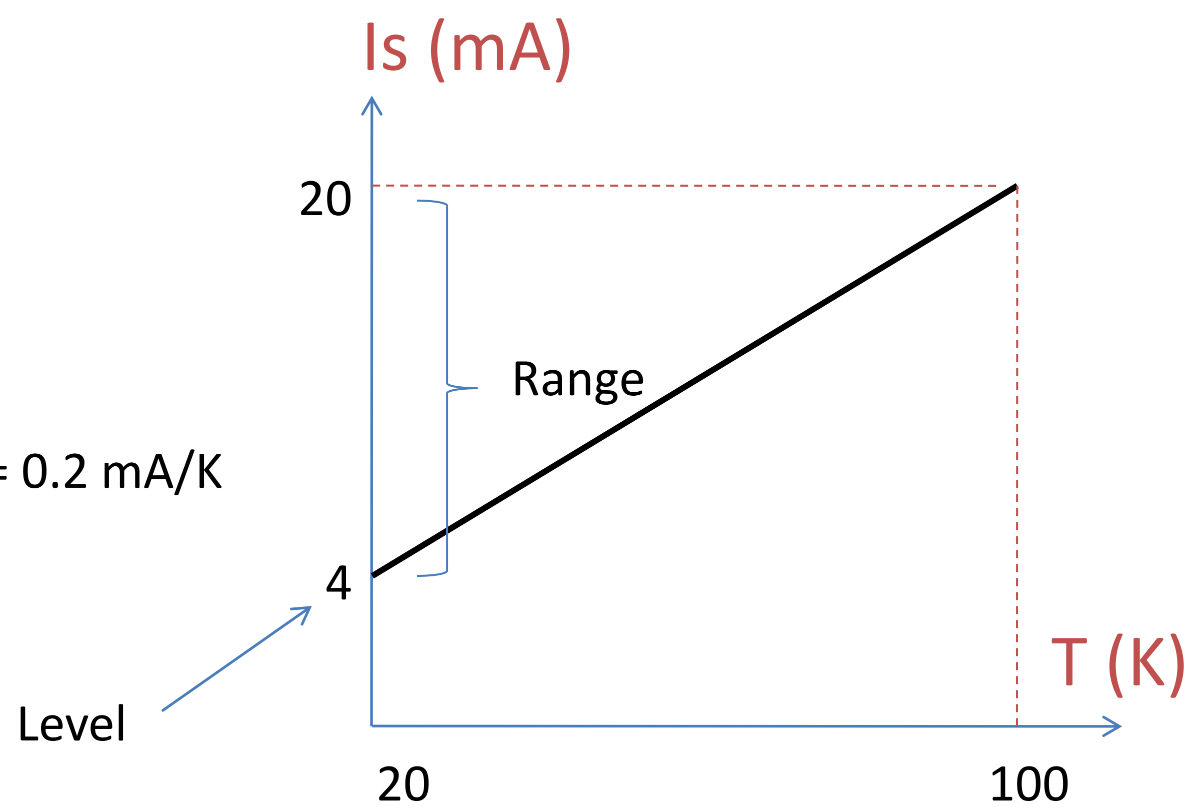


2.3 Features of electric conducted signals

Amplitude, level, range

Sensitivity:

$$\frac{20\text{-}4\ \text{mA}}{100\text{-}20\ \text{K}} = 0.2\ \text{mA/K}$$



2.3 Features of electric conducted signals

Amplitude, level, range

Calculate the level, range and maximum amplitude of the analog signal at the output of the humidity sensor HIH-4000 (Honeywell) when power supply is 5 V, and the relative humidity (RH) varies between 10 and 95%

HIH-4000 Series

Table 1. Performance Specifications (At 5 Vdc supply and 25 ºC [77 ºF] unless otherwise noted.)

Parameter	Minimum	Typical	Maximum	Unit
Voltage supply	4	–	5.8	Vdc
Current supply	–	200	500	µA
Voltage output (1st order curve fit)	V_{OUT}=(V_{SUPPLY})(0.0062(sensor RH) + 0.16), typical at 25 ºC			
Temperature compensation	True RH = (Sensor RH)/(1.0546 – 0.00216T), T in ºC			
Output voltage temperature, coefficient at 50% RH, 5 V	–	-4	–	mV/ºC

2.3 Features of electric conducted signals

Amplitude, level, range

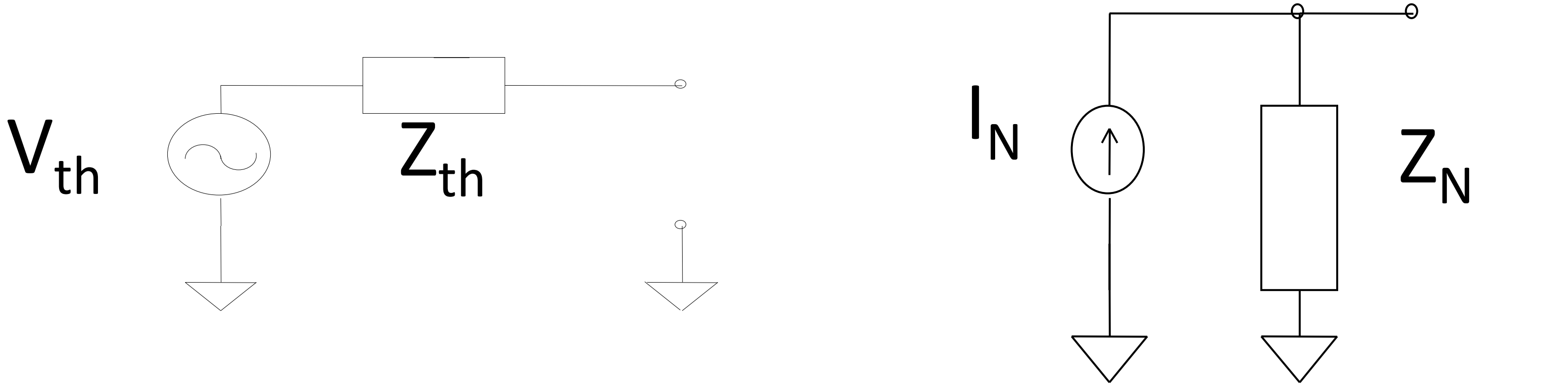
Calculate the level, range and maximun amplitude of the analog signal at the output of a flowmeter 8700 (Rosemount) when the output range has been adjusted between ± 5 m/s and the flow varies between 1 and 4 m/s

Output automatically scaled to provide 4 mA at lower range value and 20 mA at upper range value. Full scale continuously adjustable between -39 and 39 ft/s (-12 to 12 m/sec), 1 ft/s (0.3 m/s) minimum span.

2.3 Features of electric conducted signals

Impedance: Thevenin/Norton

- LOW impedance ↔ Voltage Source → Thevenin Eq.
- HIGH impedance ↔ Current Source → Norton Eq.

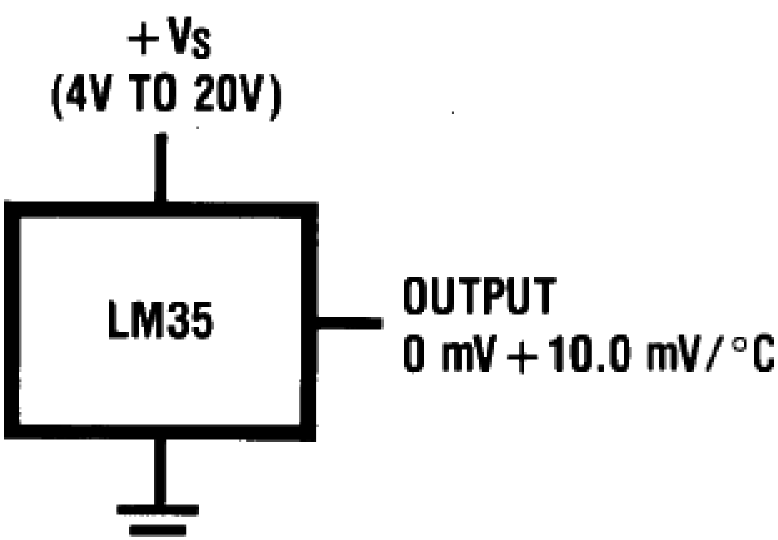


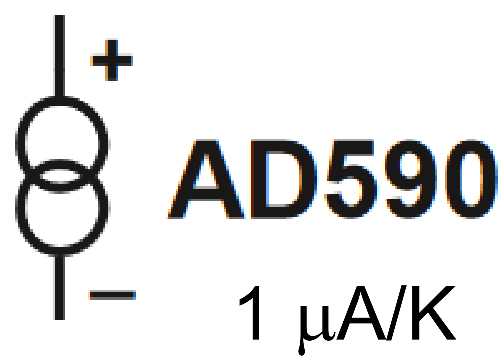
$R_{Th}=R_N$ is “the signal impedance”

2.3 Features of electric conducted signals

Impedance: Thevenin/Norton

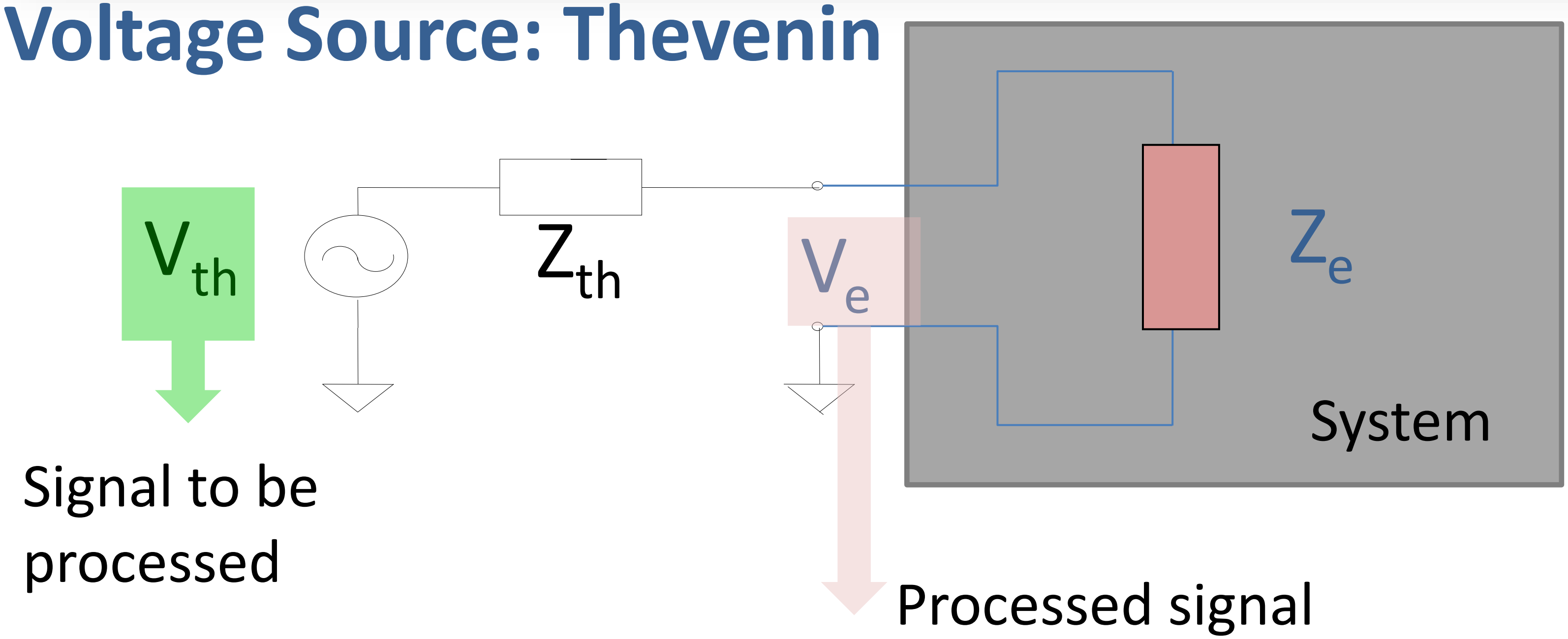
If $R_{Th}=R_N=0\ \Omega \rightarrow$ Ideal voltage source
If $R_{Th}=R_N=\infty\ \Omega \rightarrow$ Ideal current source





2.3 Features of electric conducted signals

Voltage Source: Thevenin



LOW signal impedance $Z_{th} << Z_e$

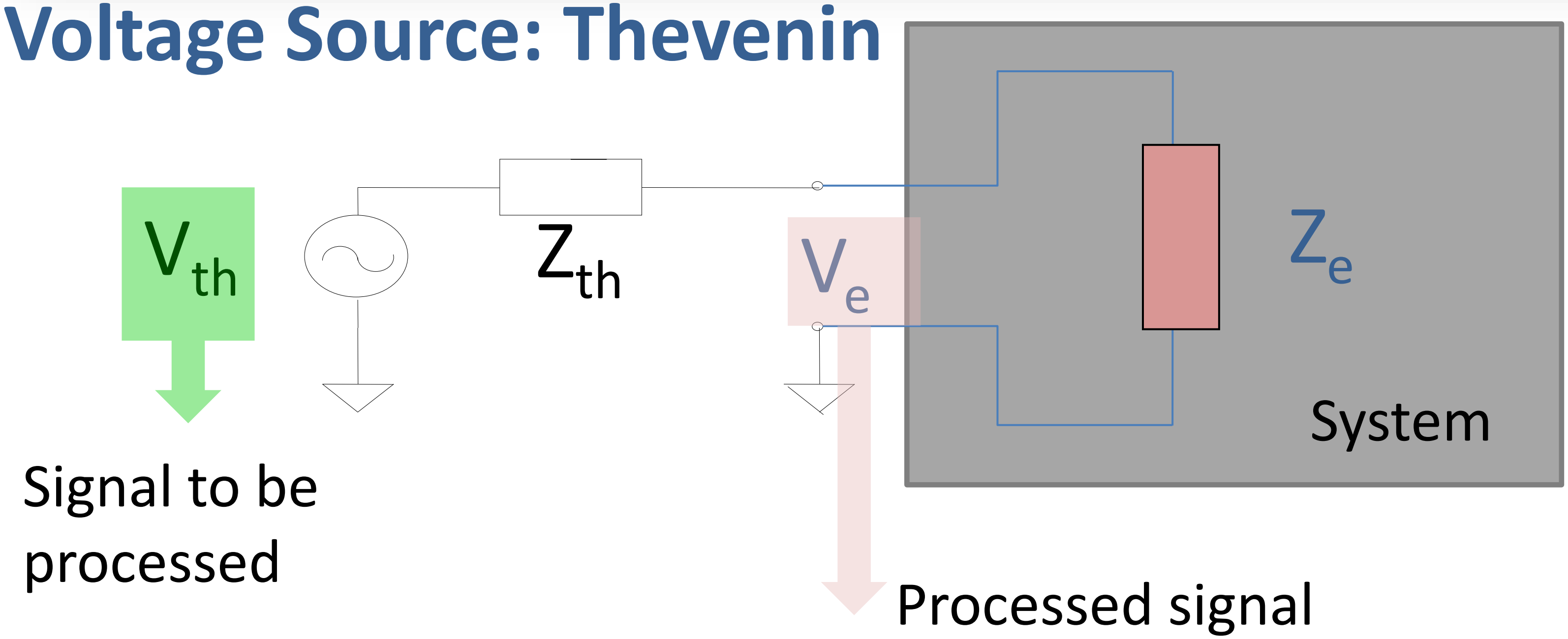
$\Leftrightarrow V_e \approx V_{th}$

$\Leftrightarrow$ Ideal Voltage Source

$\Leftrightarrow V_e \neq f(Z_e); \;\; I_e = f(Z_e)$

2.3 Features of electric conducted signals

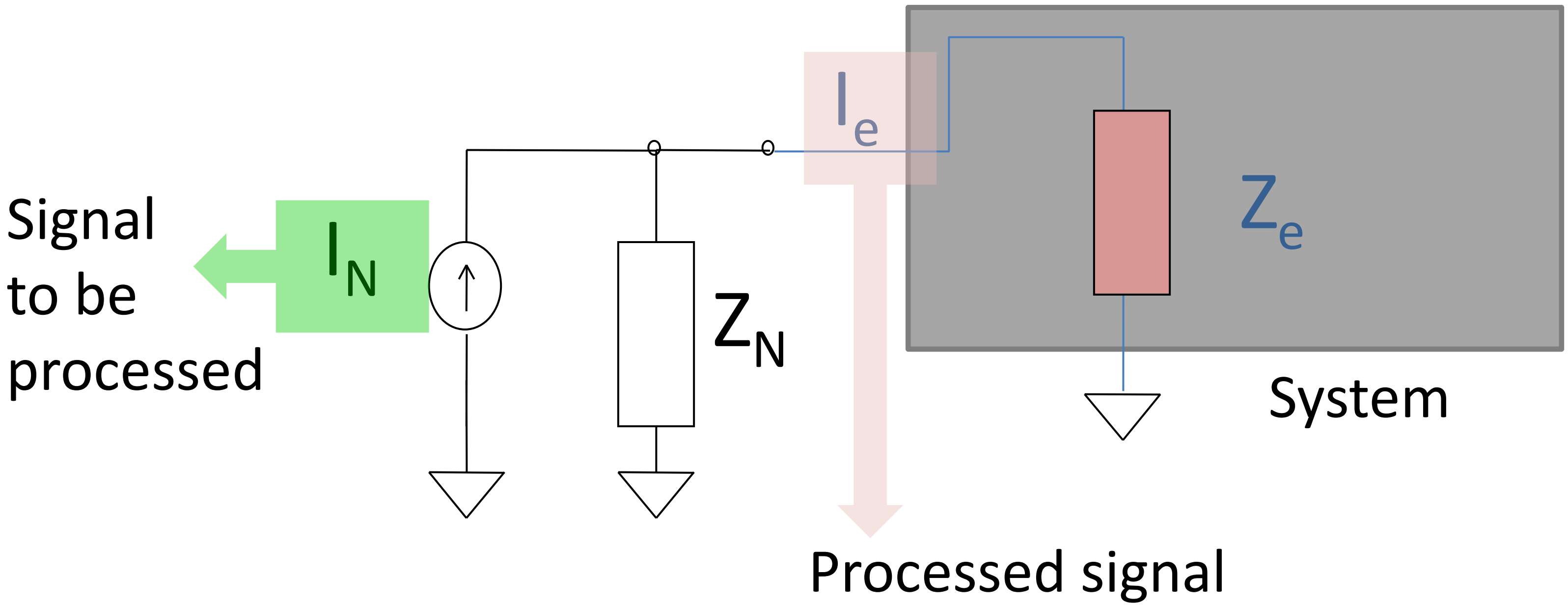
Voltage Source: Thevenin



We usually achieve $Z_e >> Z_{Th}$ because Z_{Th} is variable (within a range), and Z_e can be controlled by design

2.3 Features of electric conducted signals

Current source: Norton



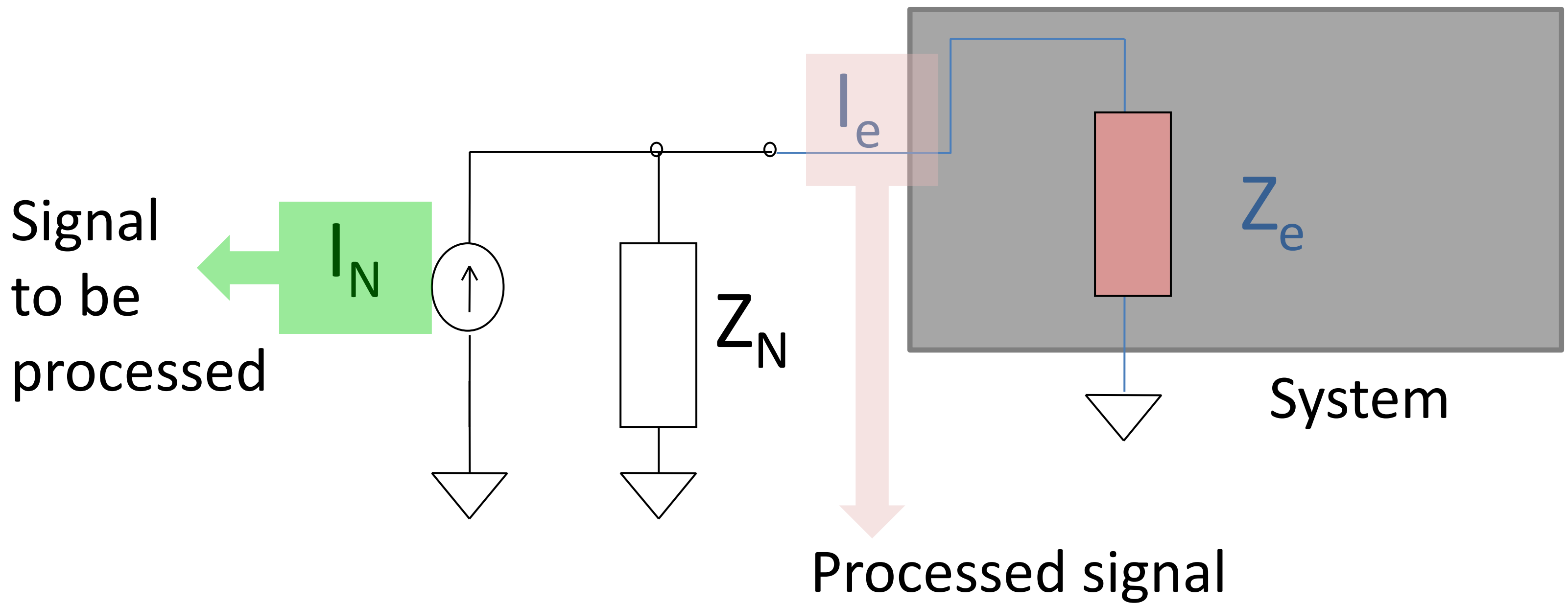
HIGH signal impedance $Z_N >> Z_e$

$\Leftrightarrow$ All the current in $Z_e \rightarrow$ Ideal current source

$\Leftrightarrow I_e \neq f(Z_e)$; $V_e = f(Z_e) = I_e \cdot Z_e$

2.3 Features of electric conducted signals

Current source: Norton

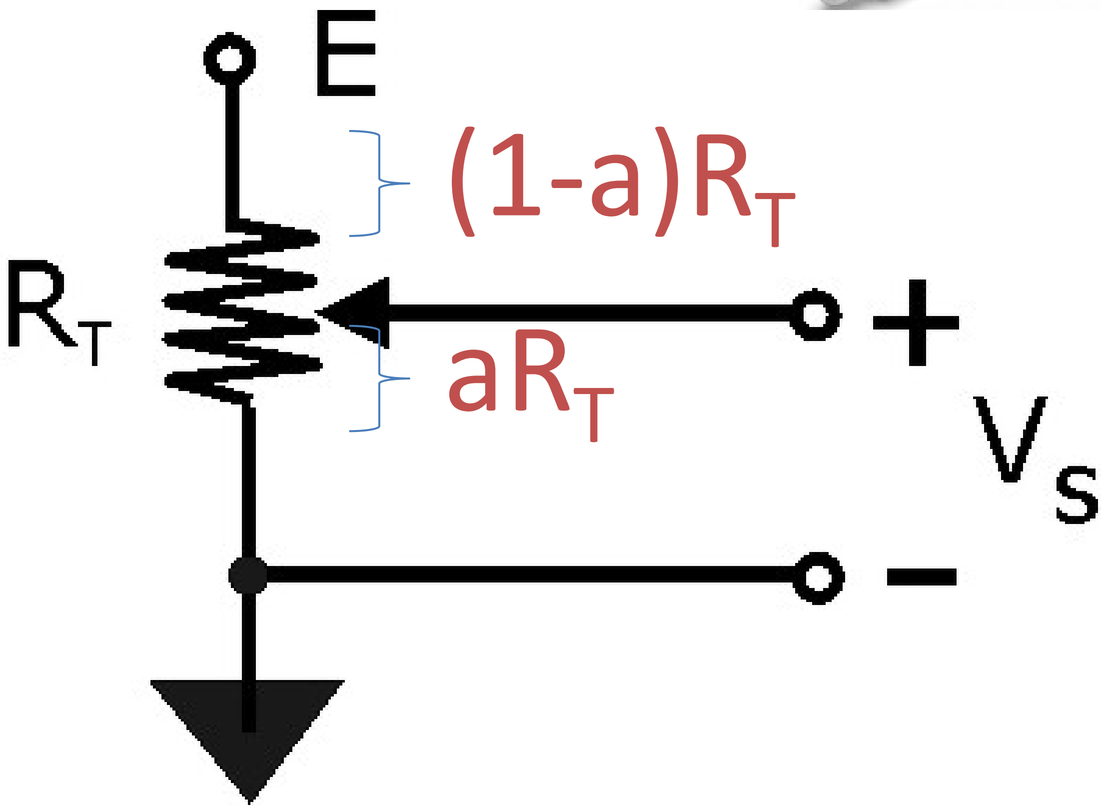


We usually achieve $Z_e << Z_N$ because Z_N is variable (within a range), and Z_e can be controlled by design

2.3 Features of electric conducted signals

Signal impedance (variable a)

Ex: potentiometer R_T



0<a<1

a	Vs
0	0
0.5	E/2
1	E

2.3 Features of electric conducted signals

Signal (output) impedance: analytical calculation

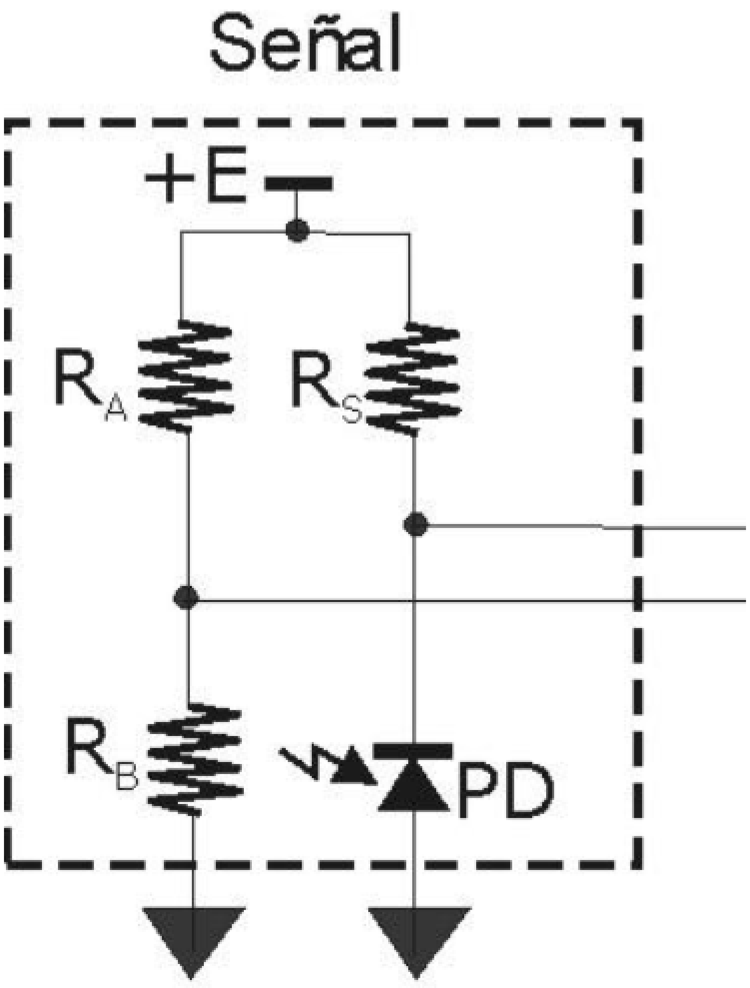
Method 1. Eliminate independent voltage and current sources and calculate the equivalent impedance seen from the terminal to the reference point.

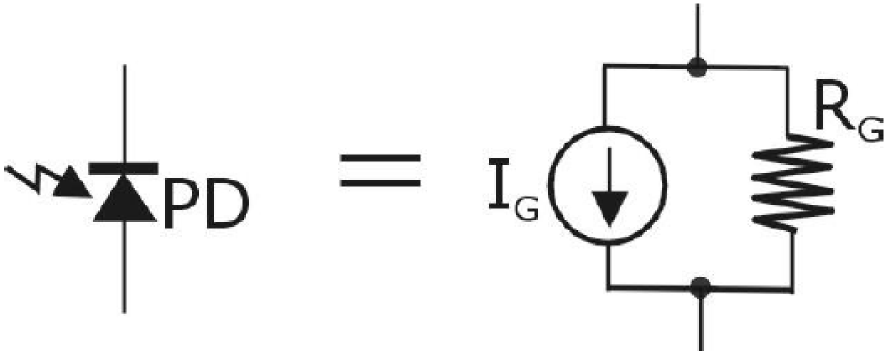
Method 2. Calculation of the open circuit voltage (V_{ca}) and the short circuit current (I_{cc}) and compute $Z_s = V_{ca}/I_{cc}$

Signal (output) impedance: experimental calculation

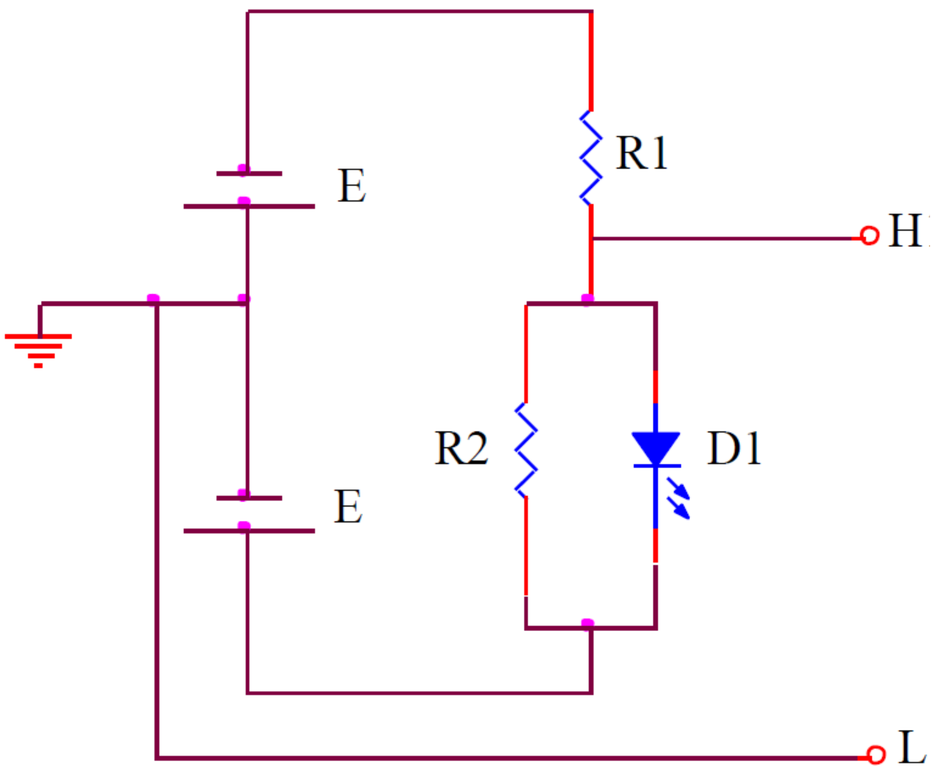
1. Measure of V_{ca}
2. Connection of the load potentiometer R_L
3. Regulation of R_L until $V_L=V_{ca}/2$
4. Measure of R_L
5. $Z_s=R_L$ measured

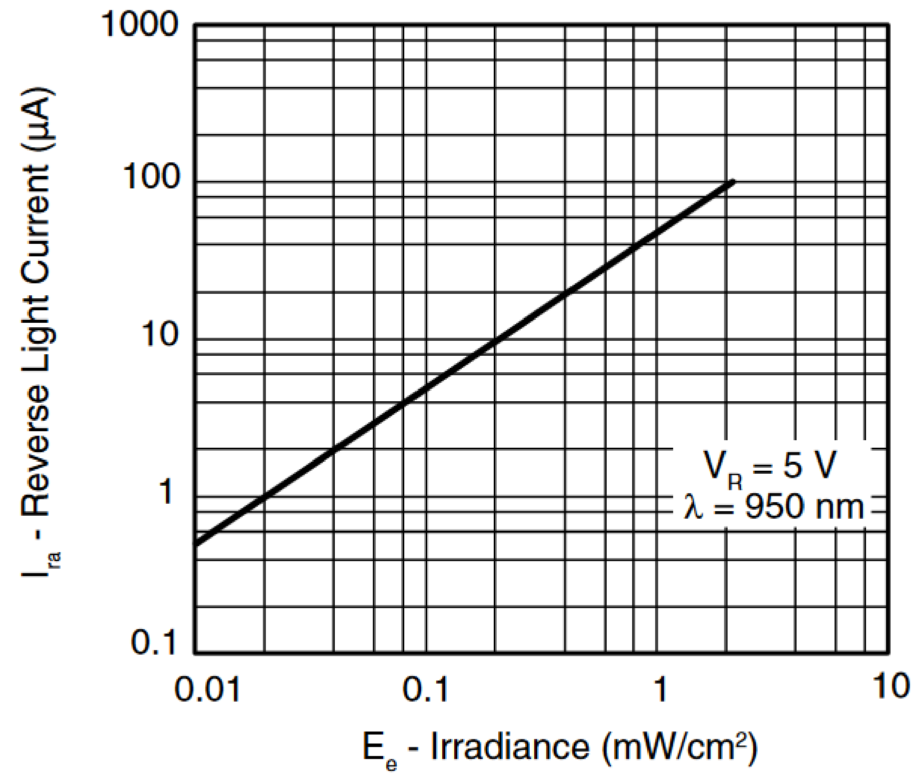
Ex January 2005. Ex1. *Signal conditioning for a photodiode (PD)*
Represent the Thevenin equivalent circuit for each terminal, indicating the values of the Thevenin resistance and voltage. IG is a current variating with light.
$R_A = R_B = R_S = 1\ k\Omega$ $R_G = 10\ M\Omega$

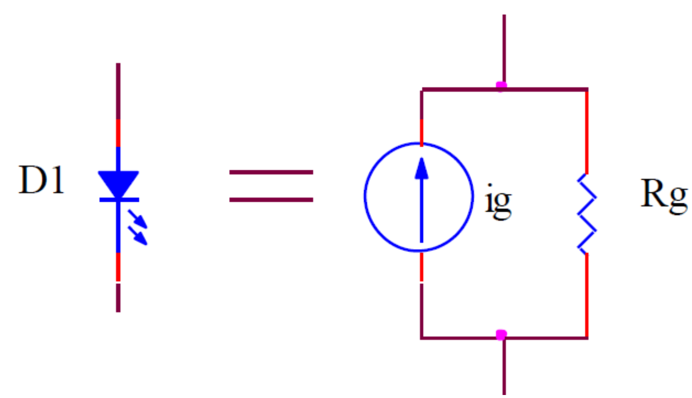




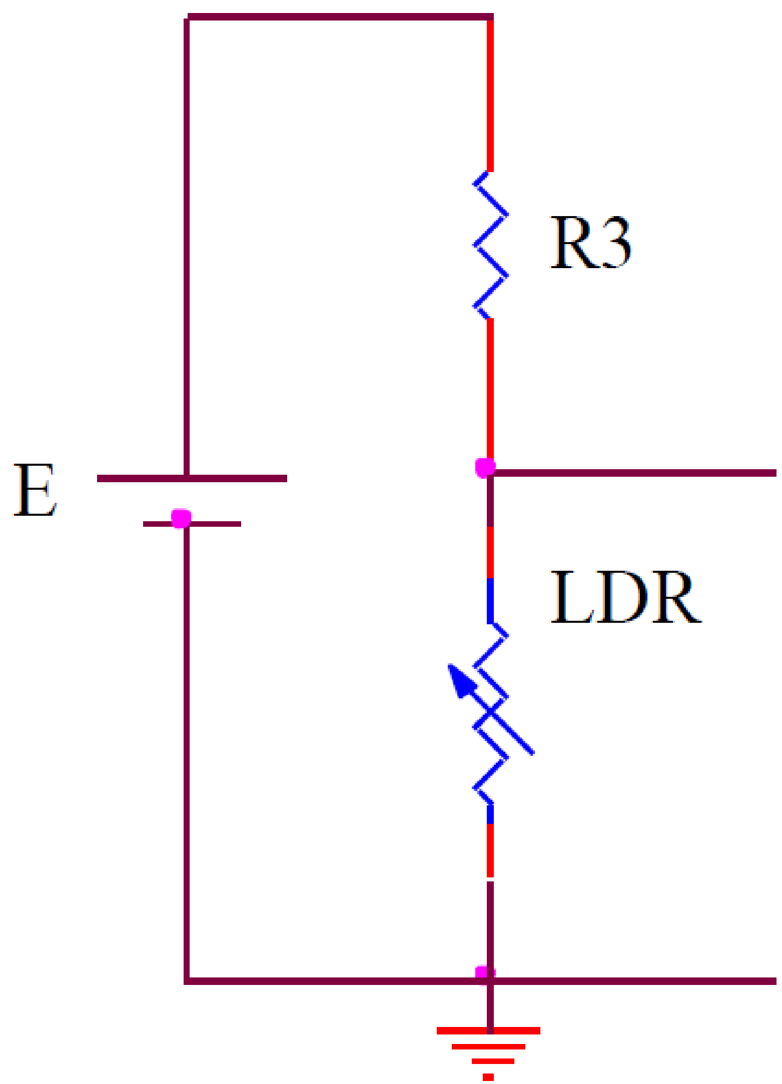
Ex January 2010. Ex1. *Represesnt the Norton equivalent circuit for each terminal, indicating the value of the Norton resitance and current. E=5 V, R1=R2=Rg=600 kΩ, The light varies between 0.01 and 1 mW/cm^2*

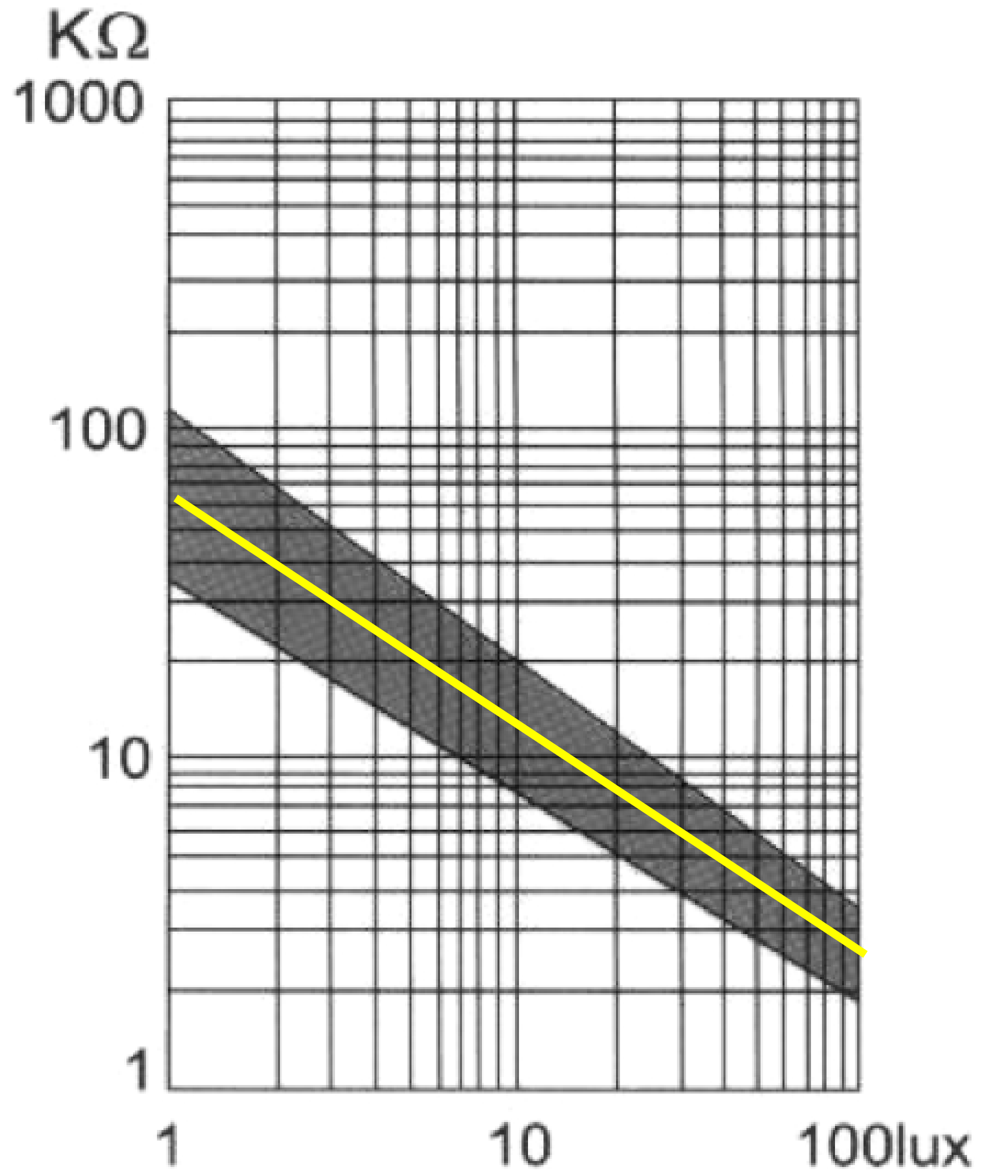




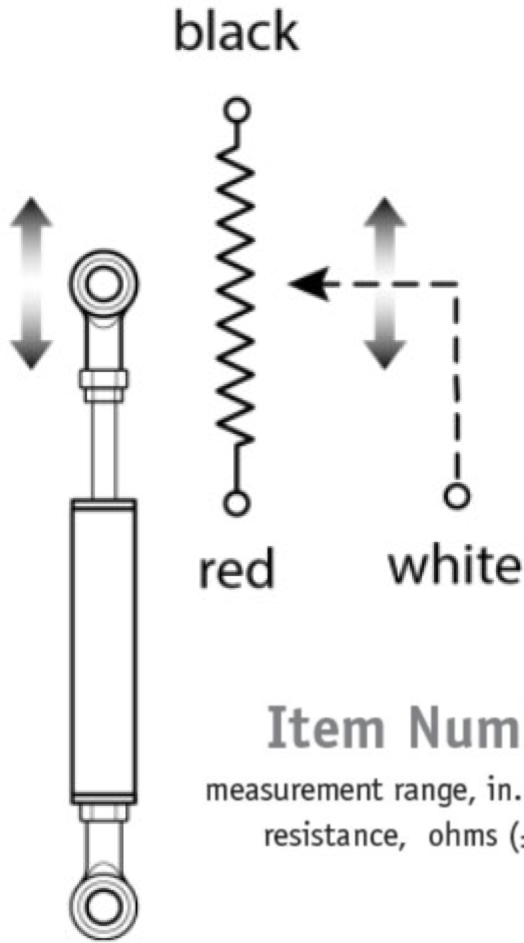


Ex January 2010. Ex1. *Represent the Thevenin equivalent circuit for each terminal, indicating the values of the Thevenin resistance and voltage. The light varies between 2 and 50 lux. E=5 V, R3=500 Ω*





Example: *The position potentiometer MLP-50 is supplied with a 10V battery (between terminals black and red) Represent the Thevenin equivalent circuit for each terminal, indicating the values of the Thevenin resistance and voltage (between White and red), when the displacement is comprised between 10 and 40 mm*



Item Number:	MLP-12	MLP-25	MLP-50	MLP-75
measurement range, in. [mm]:	0.5 [12.5]	1 [25]	2 [50]	3 [75]
resistance, ohms (±20%):	1.25K	2.5K	5K	7.5K

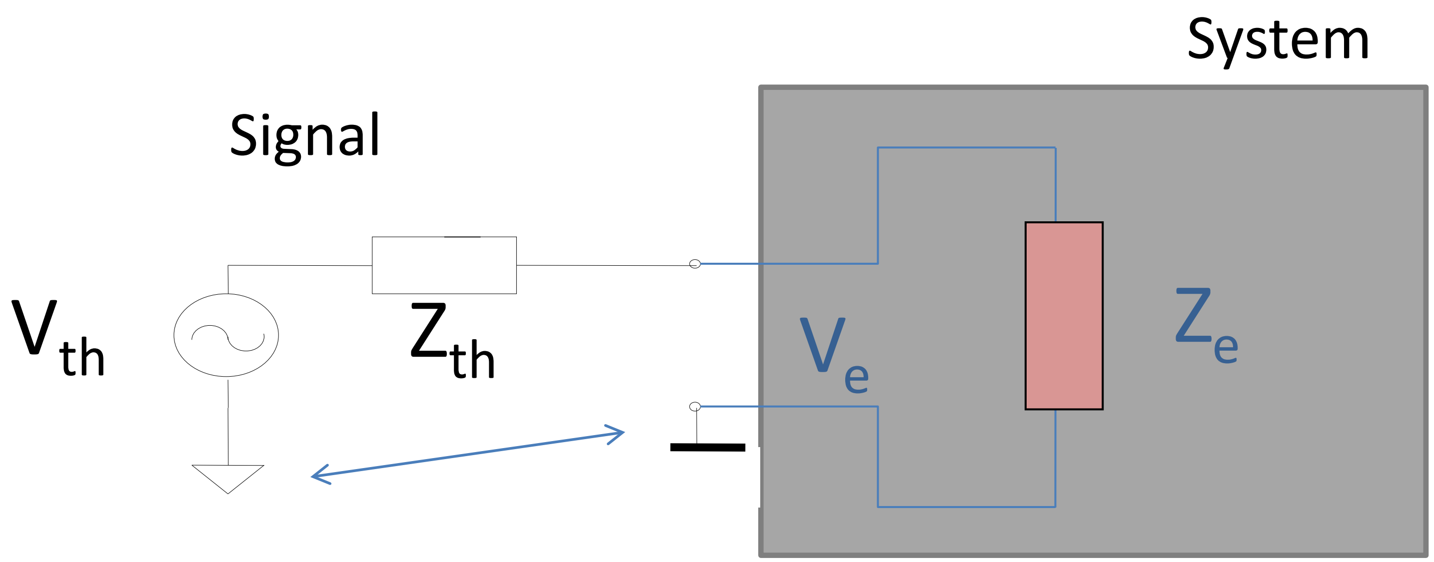
2.3 Features of electric conducted signals

Topology

- FLOATING or GROUNDED: Depending on the relationship between the reference of the signal and the system:

Grounded: Both reference points are the same.

Floating: Both reference points are different (non connected).



The system reference is:
- The lower voltage for asymmetrical supply (rail –)
- Intermediate point for symmetrical supply

2.3 Features of electric conducted signals

Topology

- SINGLE-ENDED, DIFFERENTIAL, or PSEUDO-DIFFERENTIAL: depending on the voltages in the output terminals:

Single-ended: One of the terminals is the signal reference terminal.

Differential: voltages in both terminals variate.

Pseudo-differential: one terminal has variating voltage and the other terminal has a fixed voltage $\neq 0$.

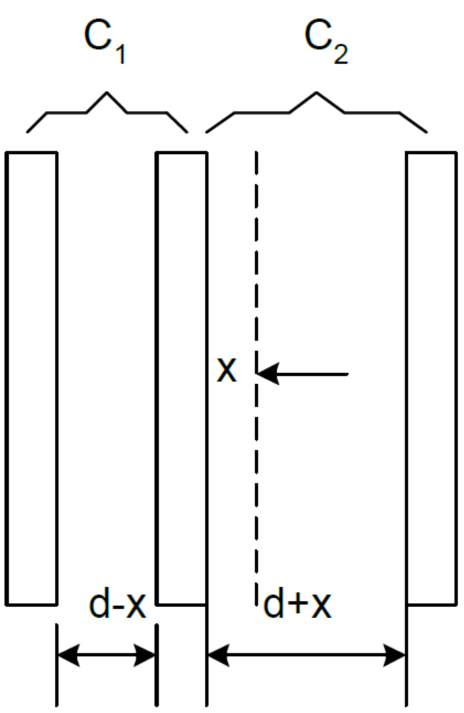
2.3 Features of electric conducted signals

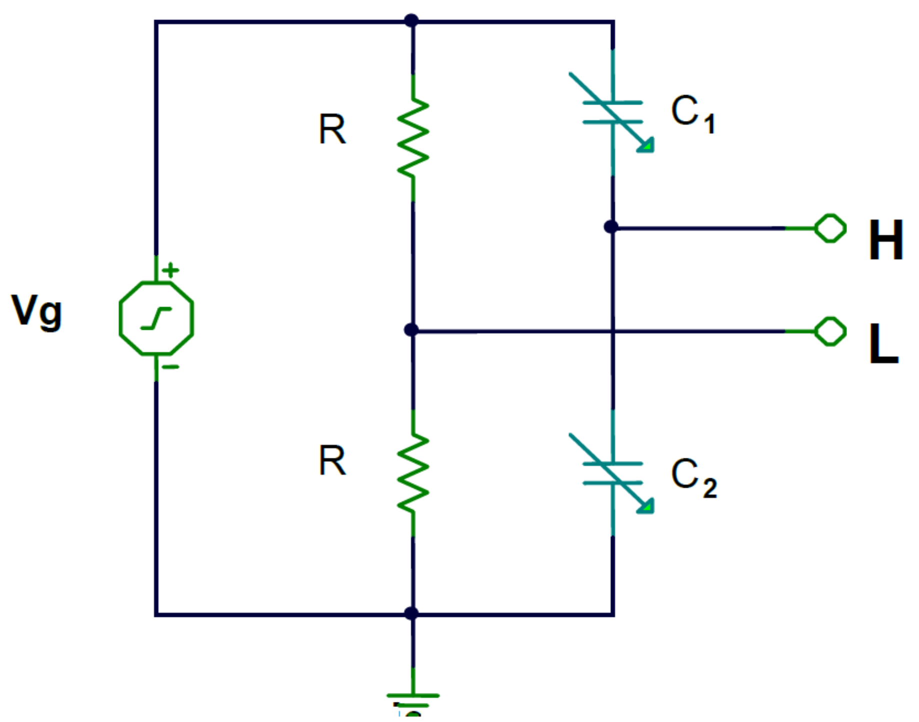
	Differential	Pseudo-differential	*Single-ended*
Floating	X	X	X
Grounded	X	X	X

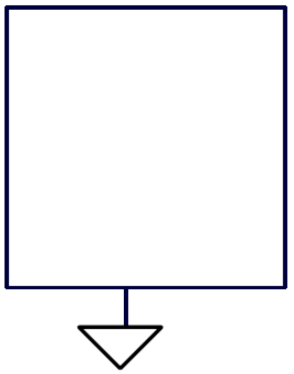
P3. *A differential capacitor has 3 parallel plates. The exterior plates are fixed and the central plate can move, in response to the variable that is measured (linear displacement). Two capacitors are thus formed with capacities C1 and C2:*

$$C_1 = \frac{\varepsilon A}{d - x} \qquad C_2 = \frac{\varepsilon A}{d + x}$$

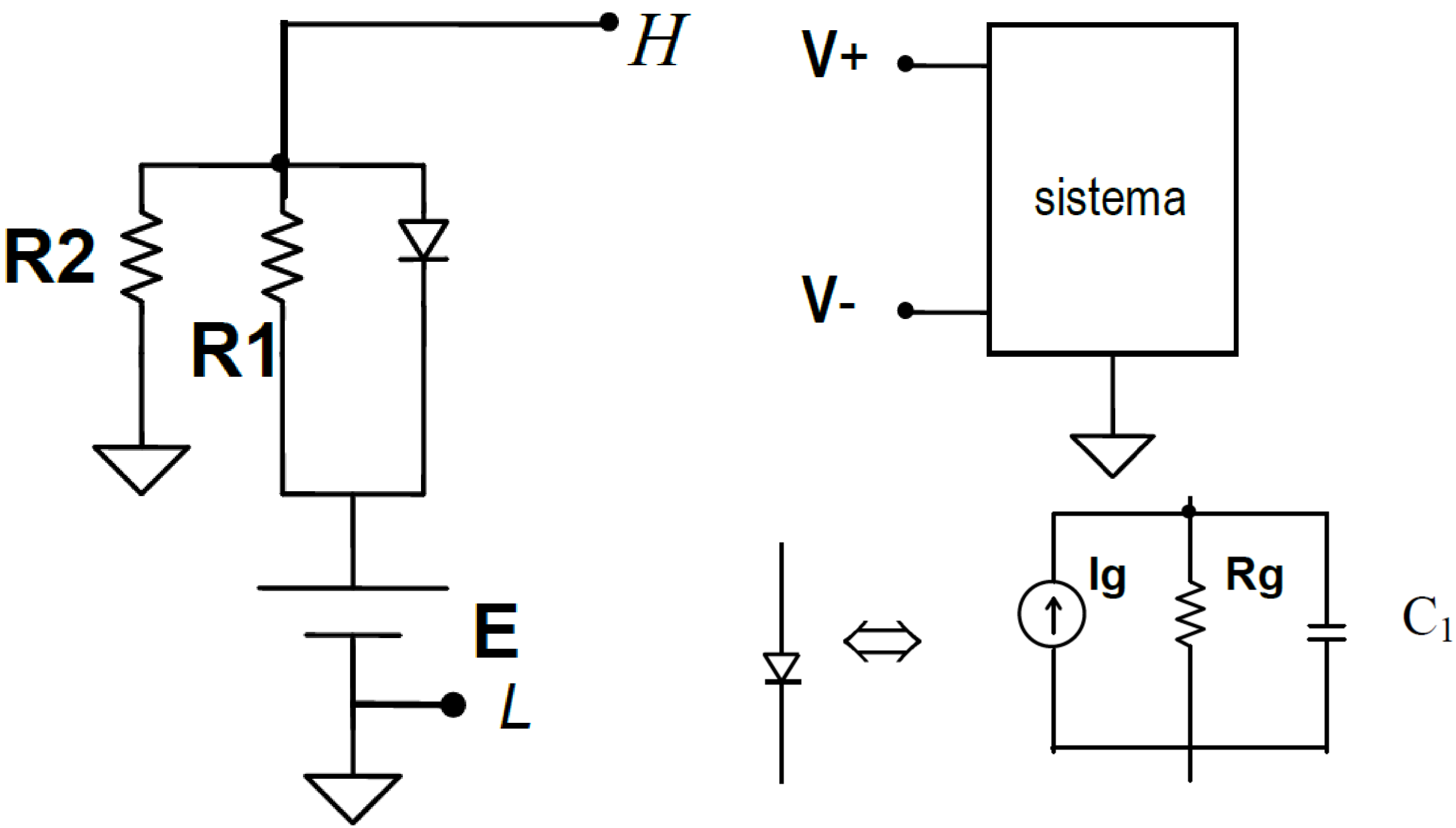
Represent the Thevenin equivalent circuit. Determine the topology of the signal. Why do we need an alternate voltage source Vg?







P4. *The circuit in the figure represents a DC biasing circuit of a ohotodiode.*
Represent the Norton equivalent circuit for terminals H and L. Consider the complex impedance for the capacitor $1/Cj\omega$. Note: use superposition method. Justify the topology of the signal.
$Ig=0\text{-}10\mu A$, $R1=3\ k\Omega$; $R2=2\ k\Omega$; $C1=1.5\ pF$; $Rg=1\ M\Omega$; $E=5\ V$

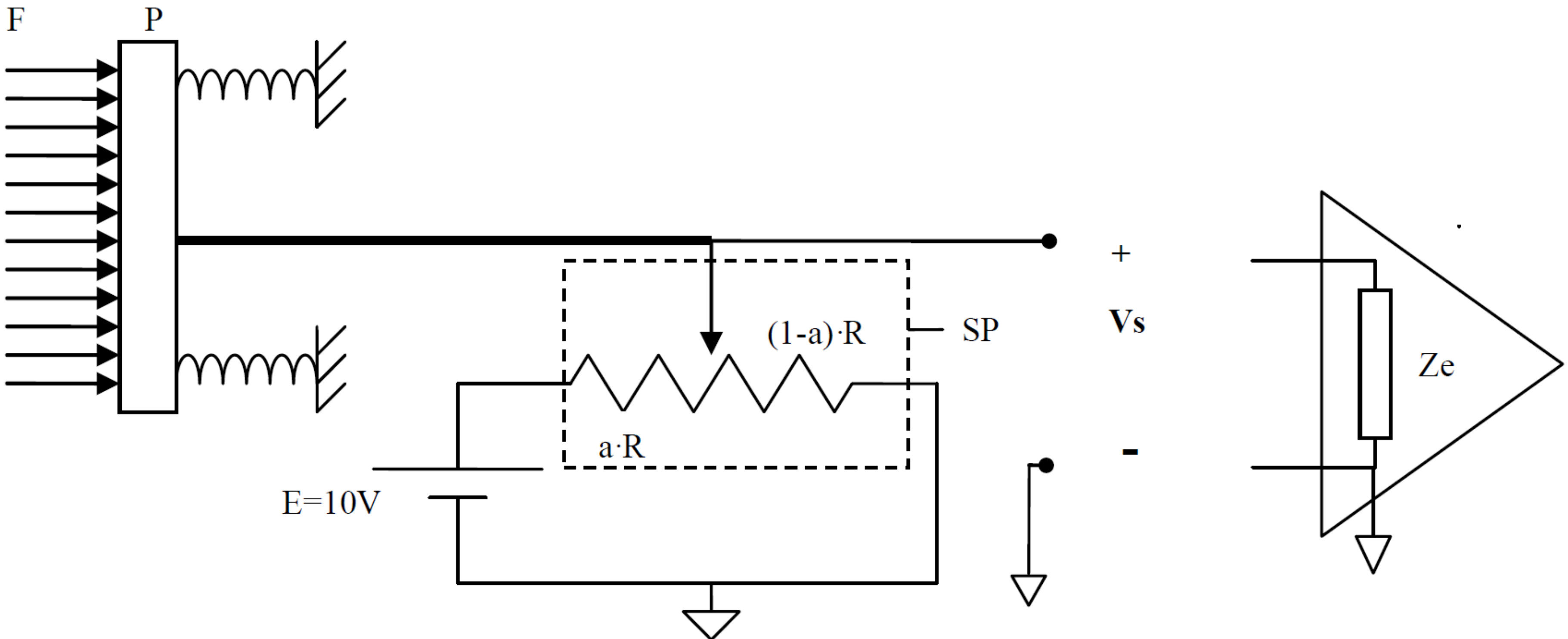


P1. *An elastic force transducer to measure the force (F) applied on a platform (P) has a position sensor based on a potentiometer (SP). If the applied force is zero then "a=0", if the force is maximum then "a=1"*

1. Represent the Thevenin equivalent circuit for the signal system.

2. Determine the topology of the signal.

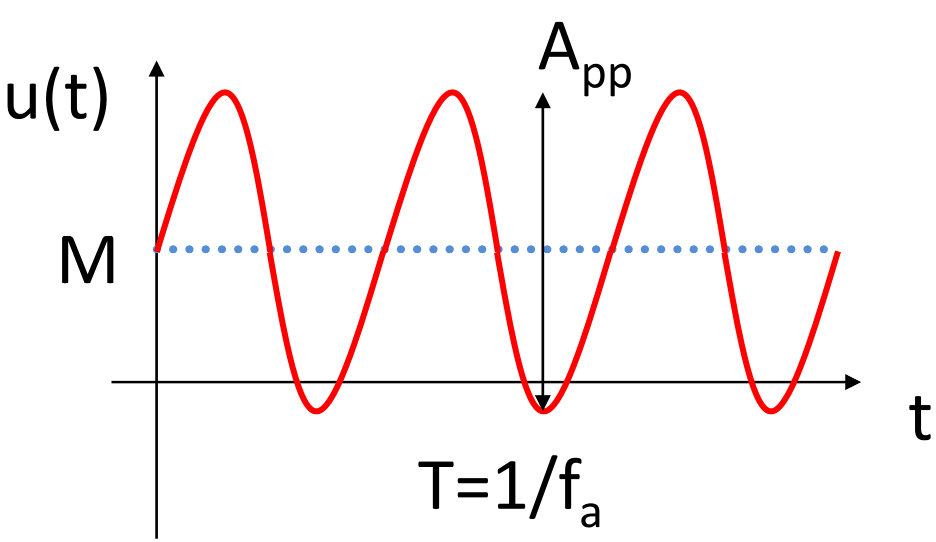
3. Represent graphically the evolution of the output impedance of the system as a function of "a" parameter.



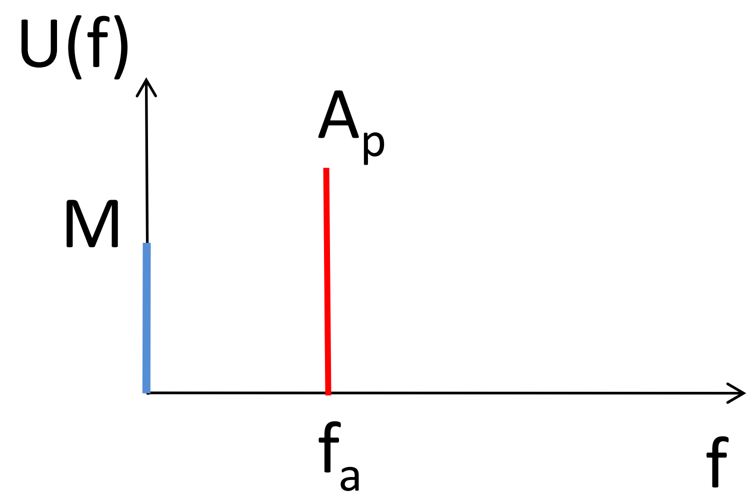
2.3 Features of electric conducted signals

Signal Bandwidth

Fourier Theorem: every periodic signal can be decomposed in a sum of sinusoidal signals of different amplitudes, frequencies and phases.



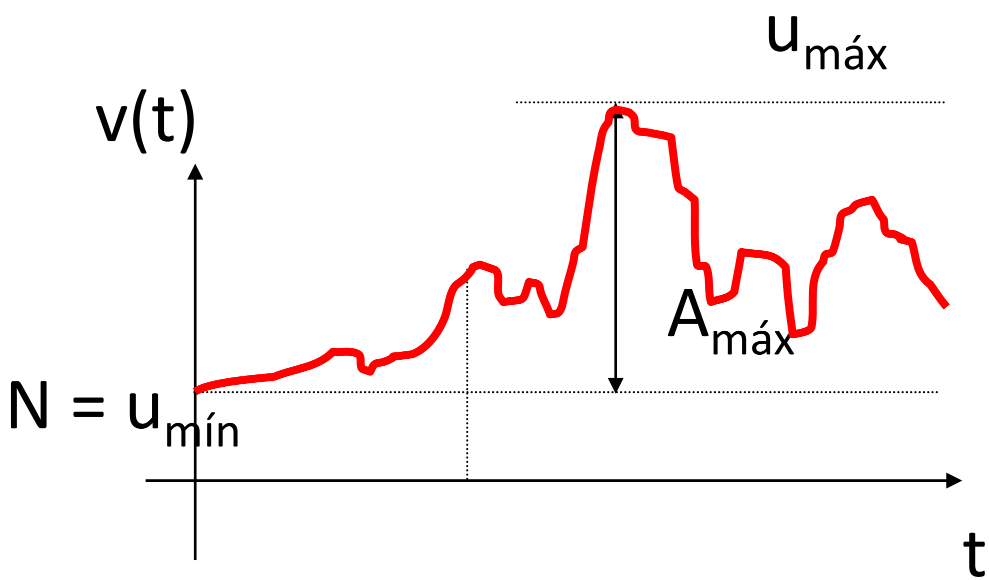
Frequency spectrum

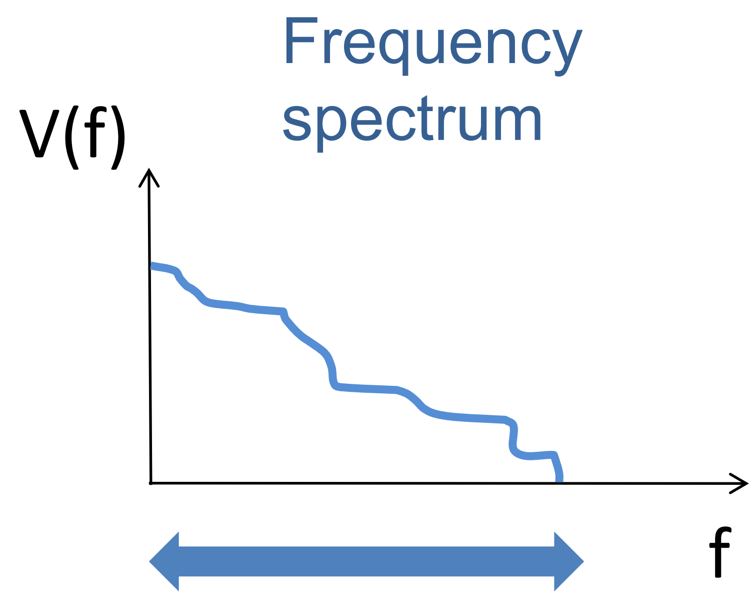


2.3 Features of electric conducted signals

Signal Bandwidth

Fourier Theorem: non-periodic signals defined over a finite time span, can be considered to be part of a periodic signal and Fourier theorem holds.

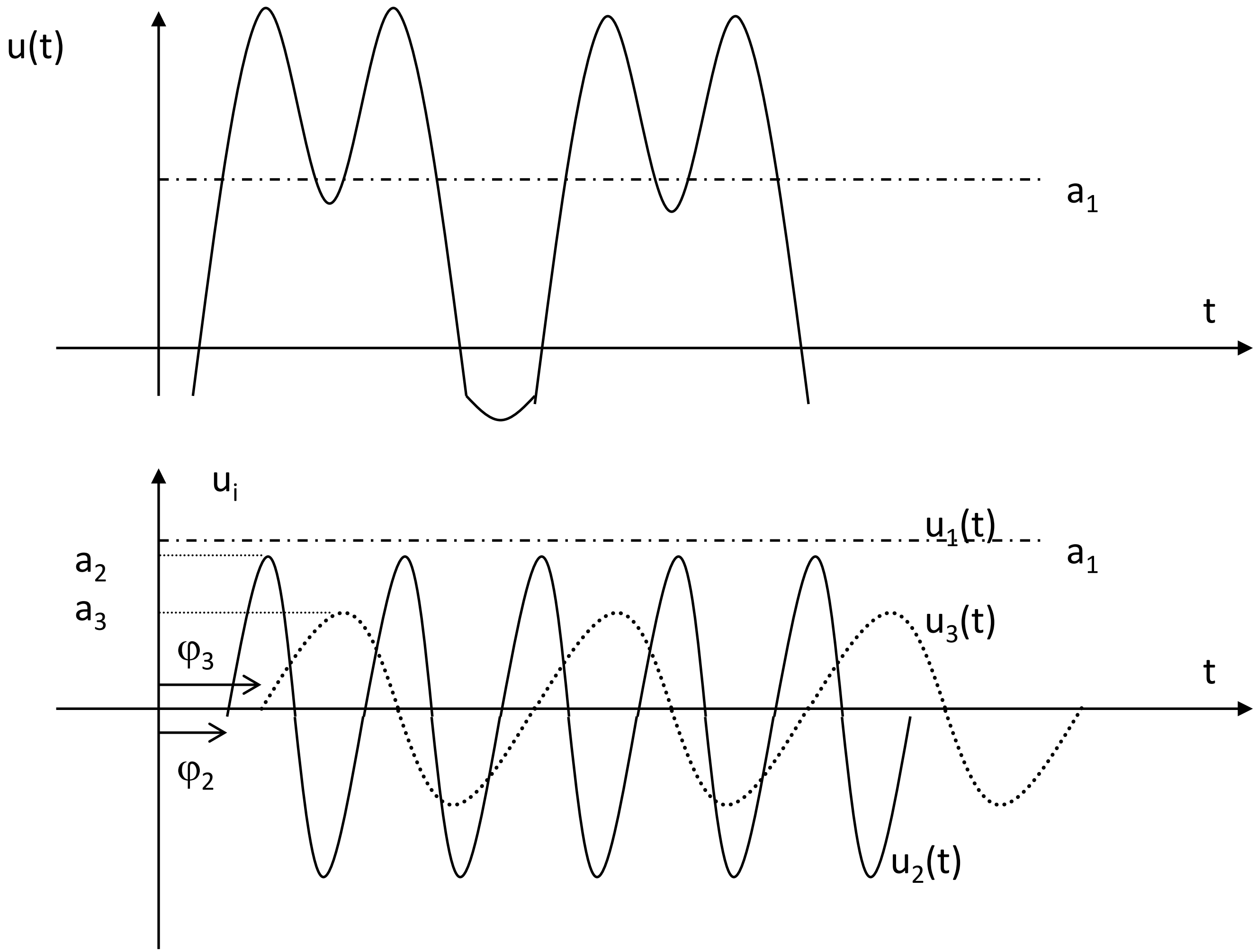




Bandwidth of the signal
$(f_{max}-f_{min})$

2.3 Features of electric conducted signals

Bandwidth: Fourier Theorem



2.3 Features of electric conducted signals

Bandwidth

Narrow BW : small frequency variations around a central frequency.

DC Signals (from 0 Hz until some Hz). Capacitive and inductive sensors.

Wide BW : a wide range of frequencies

- Sound and vibration sensors [0 Hz-10,50 kHz]
- Transient signals.
- Audiofrequency signals [20 Hz-20 kHz]
- Radiofrequency signals [20 kHz-hundreds of MHz]
- Videofrequencies signals [0 Hz-5 MHz]

2.3 Features of electric conducted signals

Bandwidth

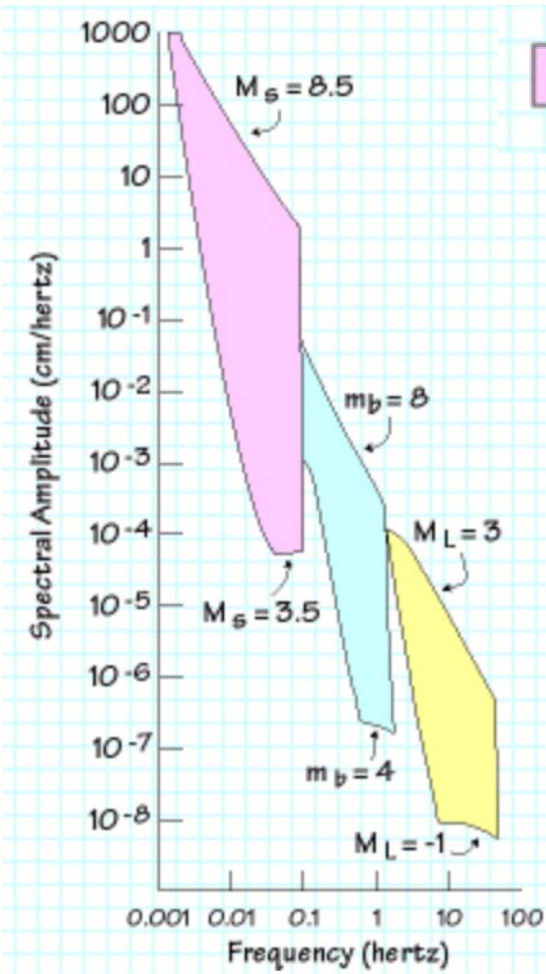
Why is it important to know the signal bandwidth?

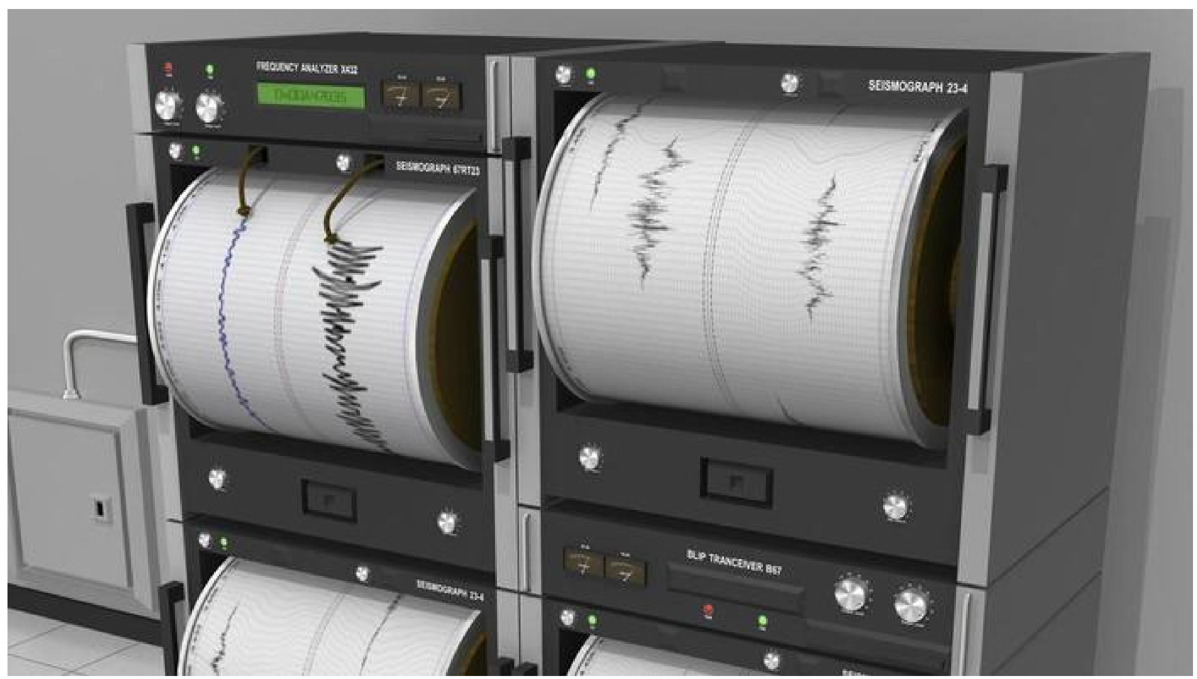
The processing system MUST consider the signal bandwidth to

1) Minimize external interferences
2) Minimize internal noise
3) To correctly process the signal of interest.

2.3 Features of electric conducted signals

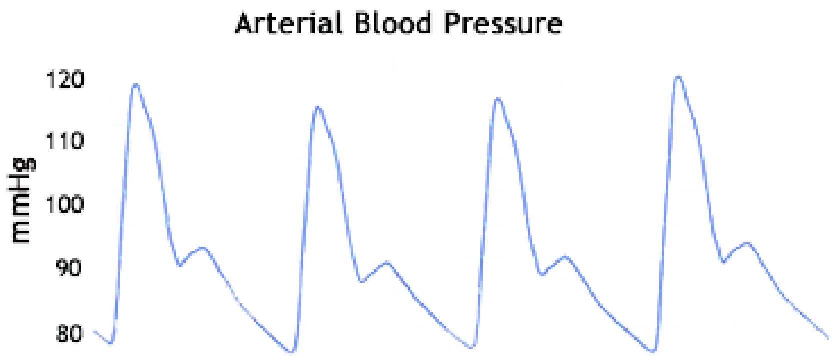
Bandwidth CASE 1: Previous information



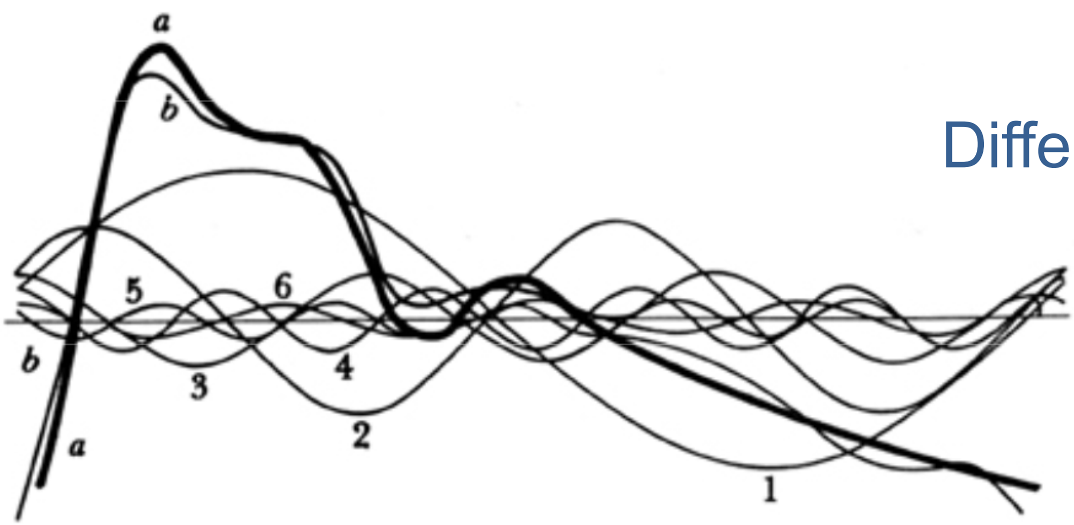


2.3 Features of electric conducted signals

Bandwidth CASE 2: Estimation



120 beats/min → 2 Hz



Different harmonics