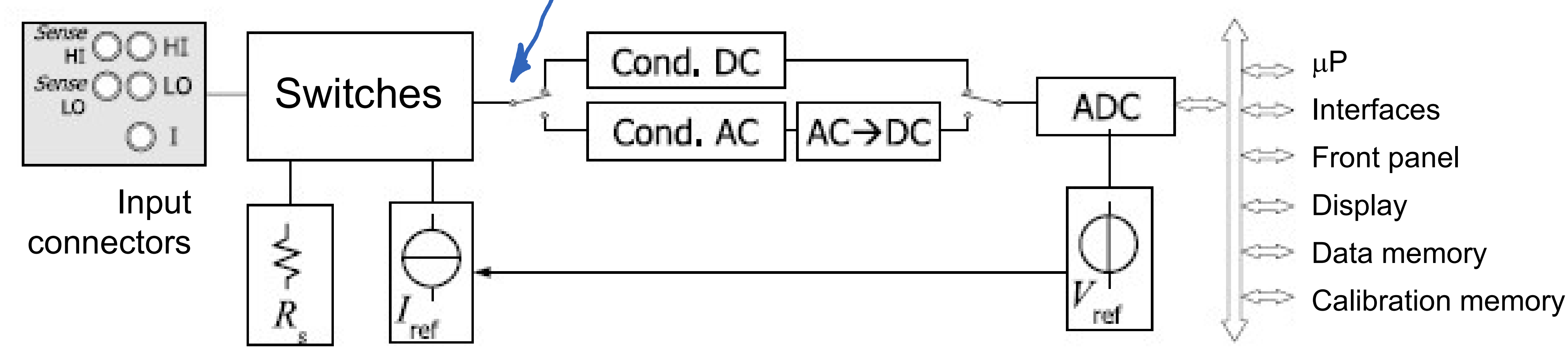
Digital Multi Meter (DMM)

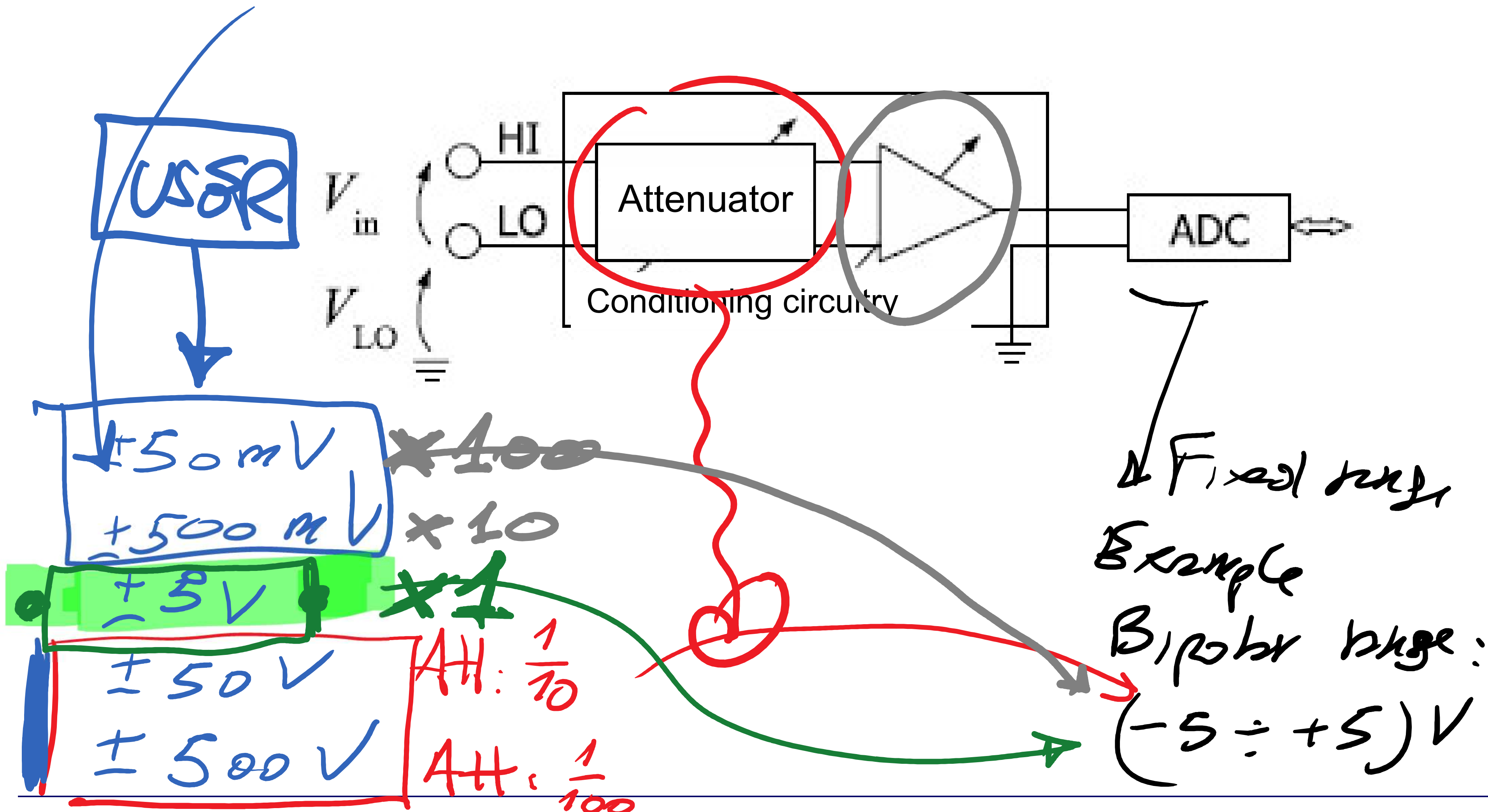
Digital Multi Meter

DMM – Block scheme

Voltage
Direct → DCV, DCI, OHM
Alternate → ACV, ACI

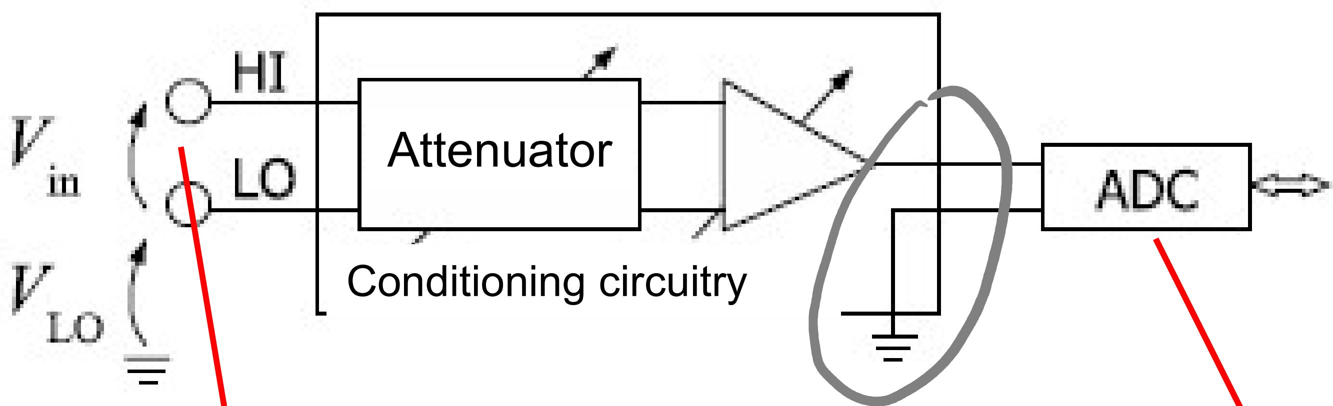


DMM – **DCV** section



Digital Multi Meter

DMM – DCV section



Measurement range up to 1 kV

Multi-range capability

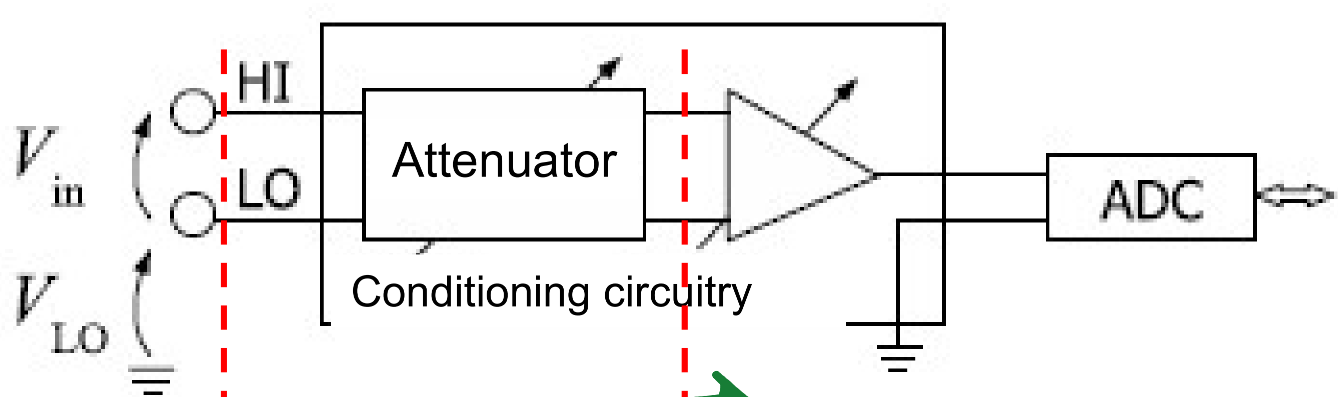
Example:

± 50 mV, ± 500 mV, ± 5 V, ± 50 V, ± 500 V, ± 1000 V

Bipolar measurement range not greater than 10 V

Example: ± 5 V

DMM – **DCV** section



±50 V
±500 V
:
±1 kV

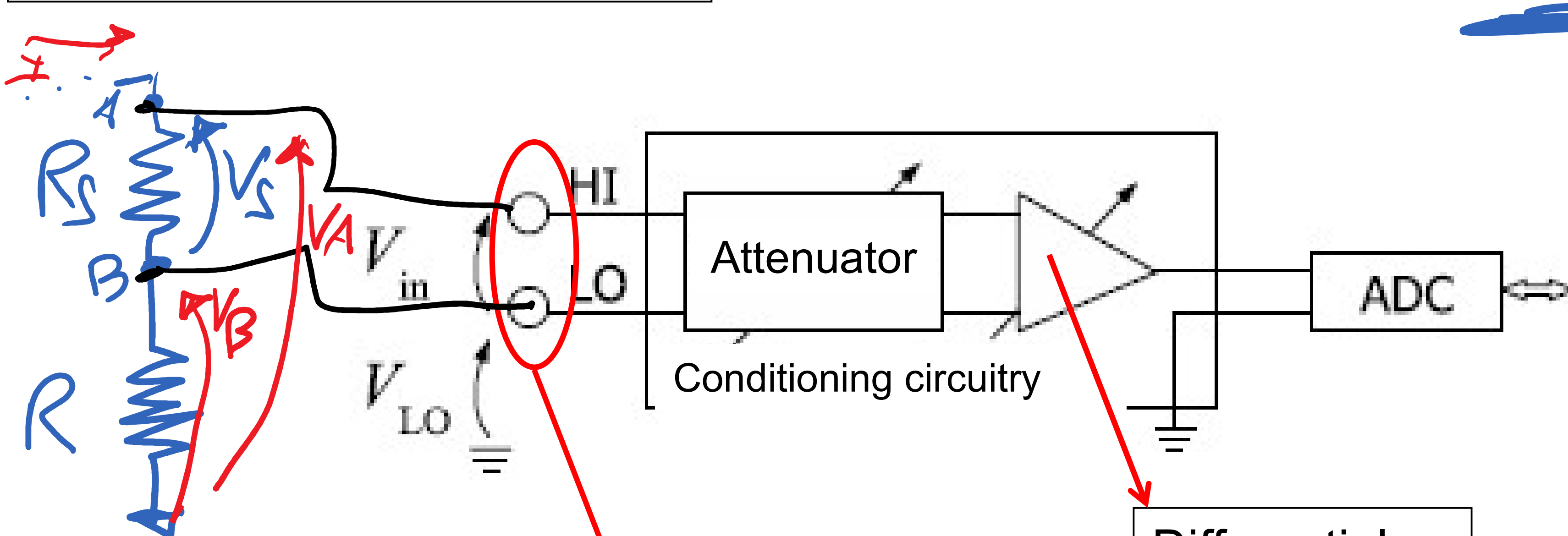
$R_{IN} = 10\ \mathrm{M\Omega}$

$R_{IN} > 10\ \mathrm{G\Omega}$

±5 V
±500 mV
±50 mV

DMM – **DCV** section

$V_S = V_A - V_B = V_{HI} - V_{LO}$



Measurement of voltages not referred to ground (low sensitivity to the voltage V_{LO})

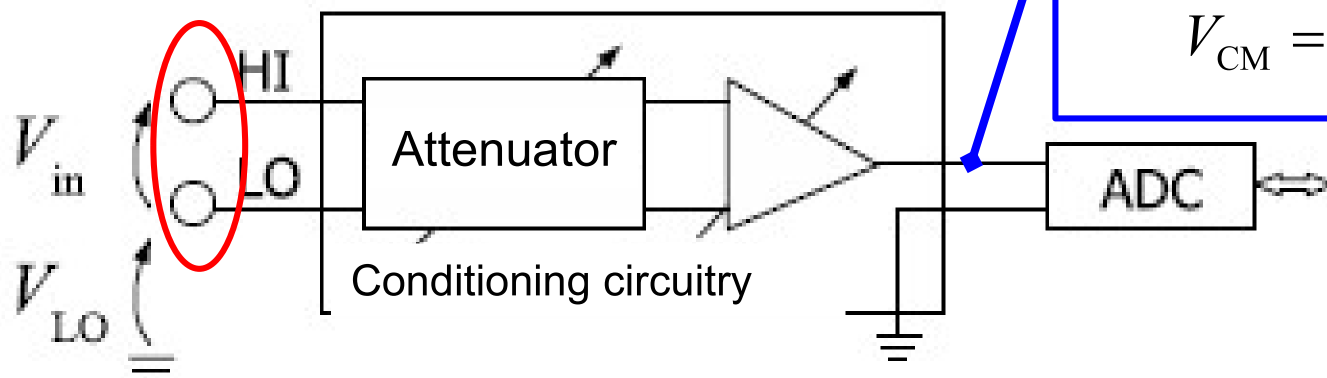
Differential amplifier

Digital Multi Meter

DMM – DCV section

IDEAL DIFF. AMPL. → $A_{cm} = 0$

REAL DIFF. AMPL. $A_{cm} \neq 0$



$$V_{out} = A_D \cdot V_{in} + A_{CM} \cdot V_{CM}$$

$$V_{in} = V_{HI} - V_{LO}$$

$$V_{CM} = \frac{V_{HI} + V_{LO}}{2}$$

Common-Mode Rejection Ratio

$$CMRR = 20 \cdot \log_{10}\left(\frac{A_D}{A_{CM}}\right)$$

A_D: Differential gain

A_{CM}: Common-mode gain

Ideal amplifier A_{CM} = 0 ⇨ $CMRR$ = ∞

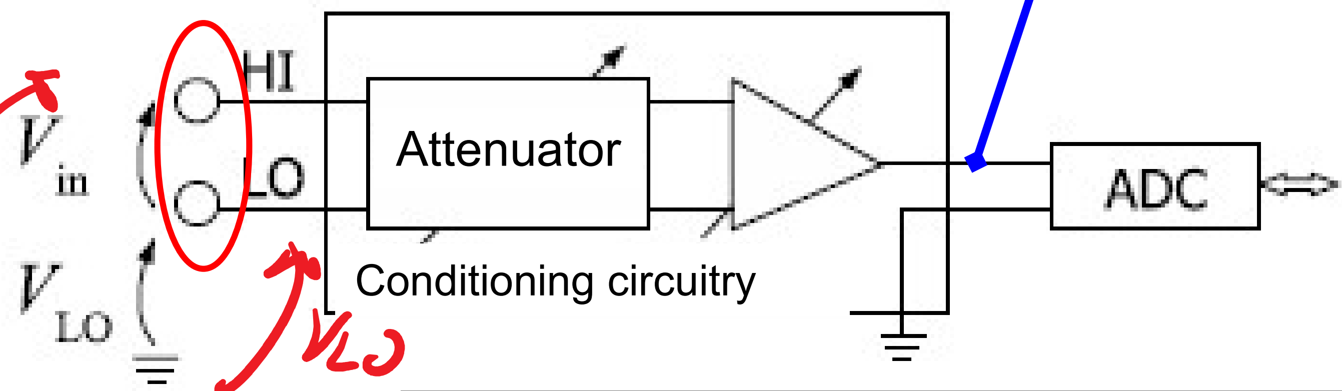
Digital Multi Meter

DMM – **DCV** section

$V_{HI} = V_{LO} \Rightarrow V_{in} = 0$

$$V_{out} = A_D \cdot \underbrace{V_{in}}_{=0} + A_{CM} \cdot V_{CM}$$

V_{HI}



$$CMRR = 20 \cdot \log_{10}\left(\frac{A_D}{A_{CM}}\right)$$

For a real amplifier $A_{CM} > 0$, then the DMM provides an indication $L_{CM} \neq 0$ event though $V_{IN} = 0$

Example: $CMRR = 100$ dB; $V_{HI} = 100$ V; $V_{LO} = 99$ V; $A_d = 1$

$$\Rightarrow \quad V_{out,V_{in}} = 1\text{ V}; \quad V_{out,V_{CM}} = V_{CM} \cdot 10^{\left(-\frac{CMRR}{20}\right)} = 0.995\text{ mV}$$

$10^2 \cdot 10^{-5} \cong 1$ mV

Digital Multi Meter

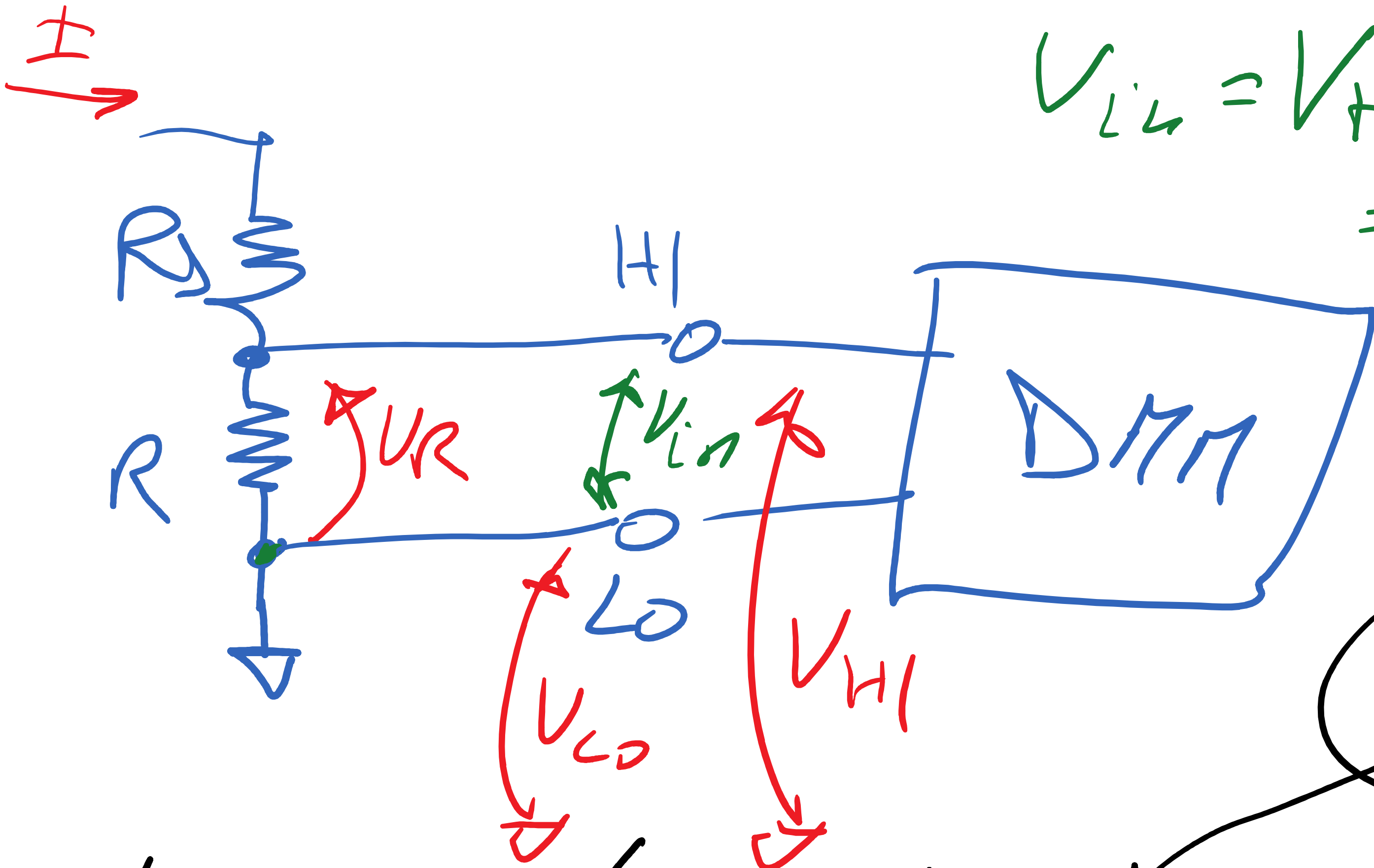
$$CMRR = 20 \log_{10}\left(\frac{A_D}{A_{CM}}\right) \quad ; \quad A_D = 1 \quad ; \quad CMRR = 100\ \mathrm{dB}$$

$$\frac{CMRR}{20} = \log_{10}\left(\frac{A_d}{A_{CM}}\right) \Rightarrow \left(\frac{A_d}{A_{CM}}\right) = 10^{\frac{CMRR}{20}}$$

$$A_{CM} = A_d \cdot 10^{-\frac{CMRR}{20}} = 1 \cdot 10^{-\frac{100}{20}} = 10^{-5}$$

A_{CM}

Digital Multi Meter



$$V_{in} = V_{HI} - V_{LO} = V_{HI} - 0$$

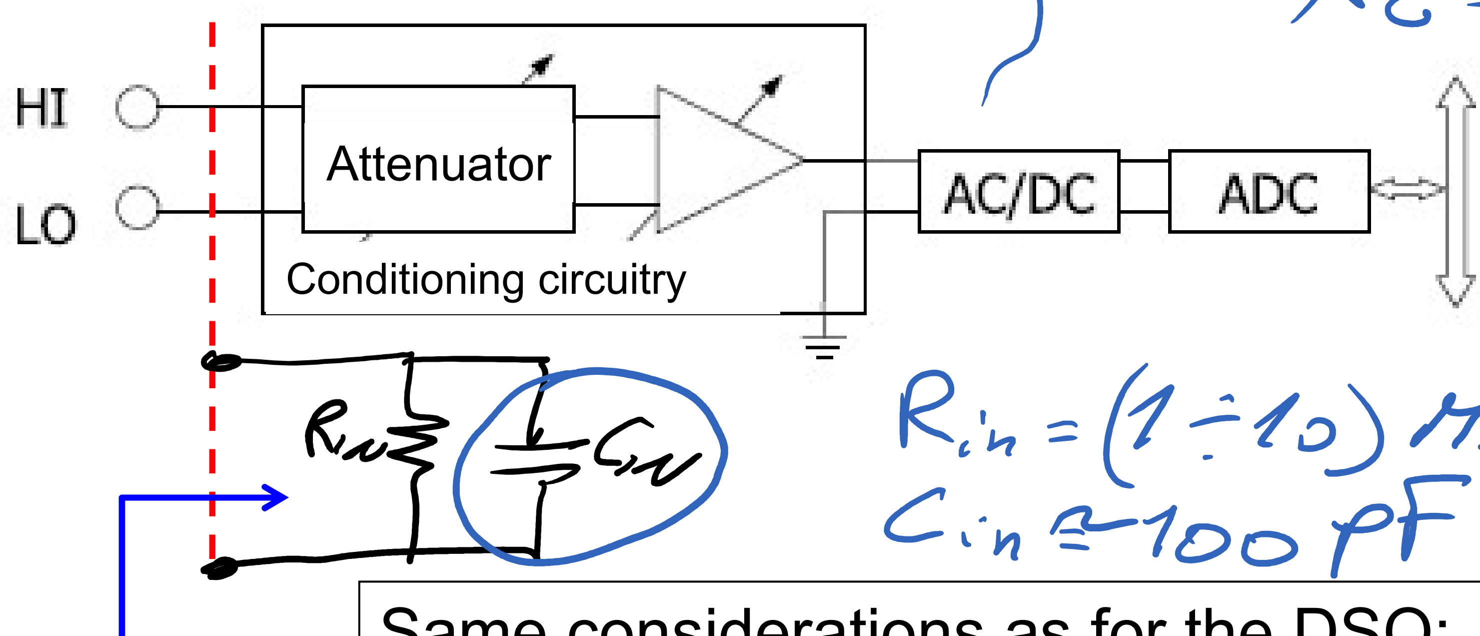
$$V_{in} = V_{HI}$$

$$V_{CM} = \frac{V_{HI} + V_{LO}}{2} = \frac{V_{HI}}{2} \neq 0$$

DMM – **ACV** section

$f_{max} \lessapprox 1\,MHz$

$X_C = \frac{1}{2\pi f C}$



$R_{in} = (1 \div 10)\,M\Omega$

$C_{in} \cong 100\,pF$

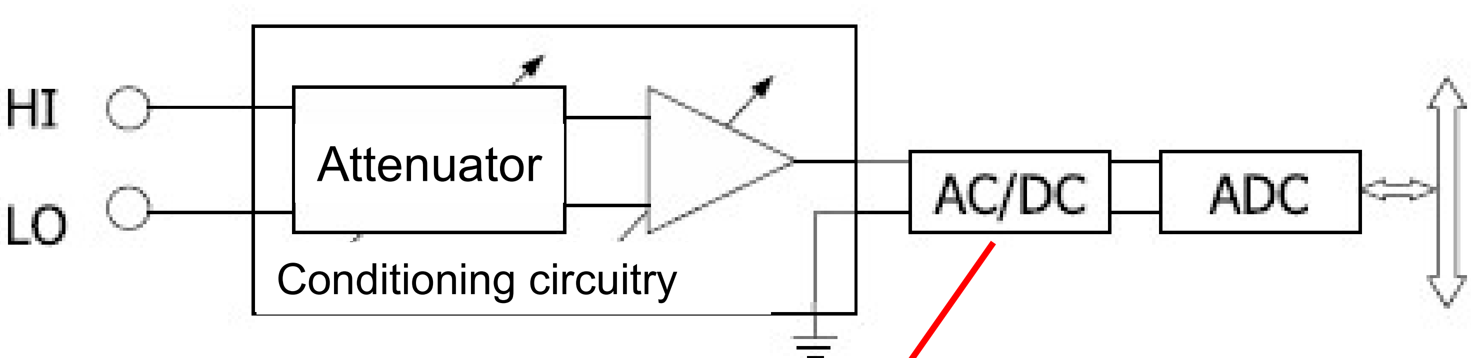
$$Z_{IN} = R_{IN} \,//\, C_{IN}$$

Same considerations as for the DSO:

load effect dependent on the frequency of the input signal

DMM – ACV section

r.m.s : root mean square



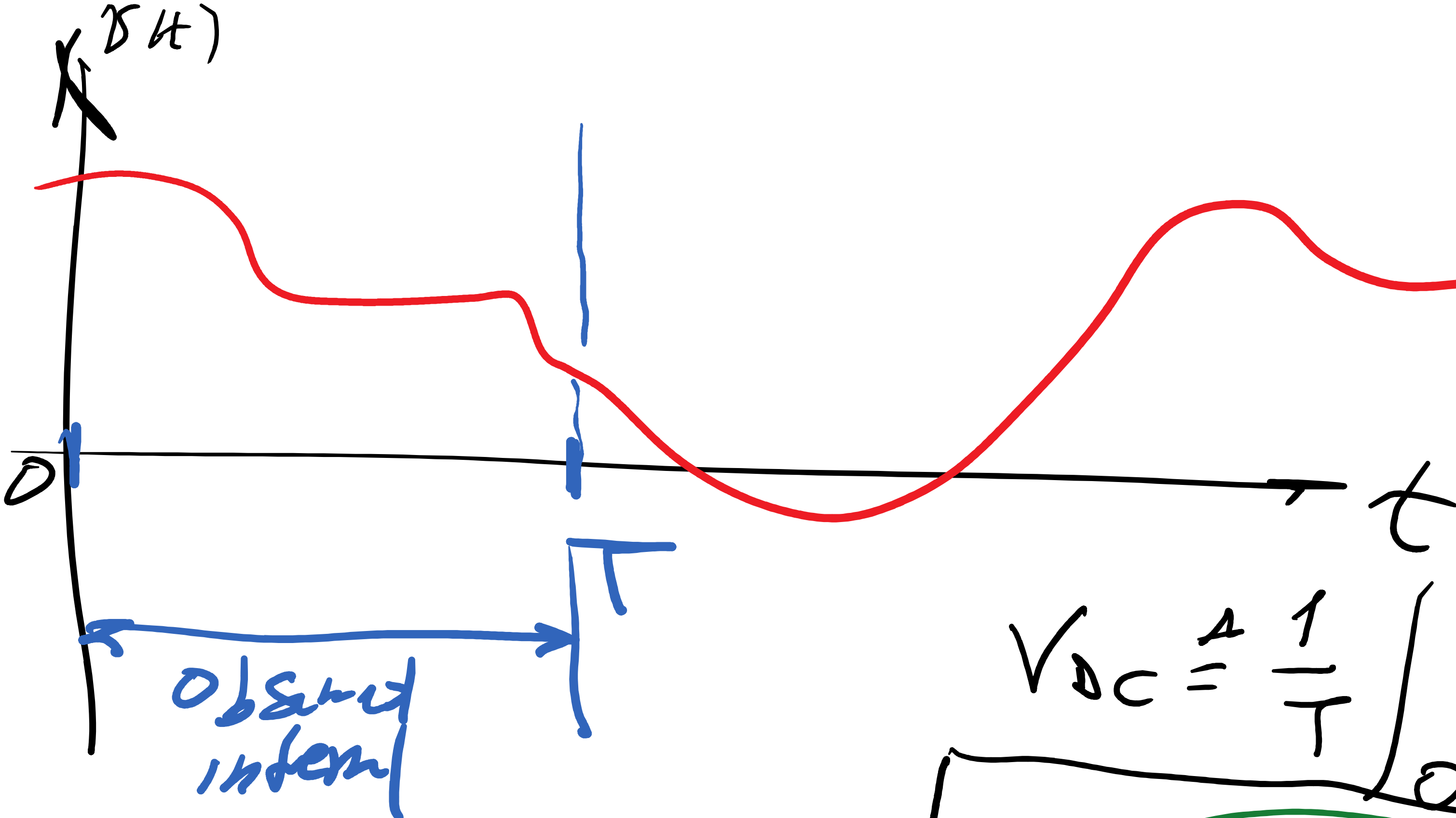
True rms AC/DC converter

- It converts the input signal into a DC voltage that is equal to the rms value of the input signal, **regardless of its waveform**

Influence quantity: crest factor of the input signal

- $$\frac{V_{pk}}{V_{rms}}$$

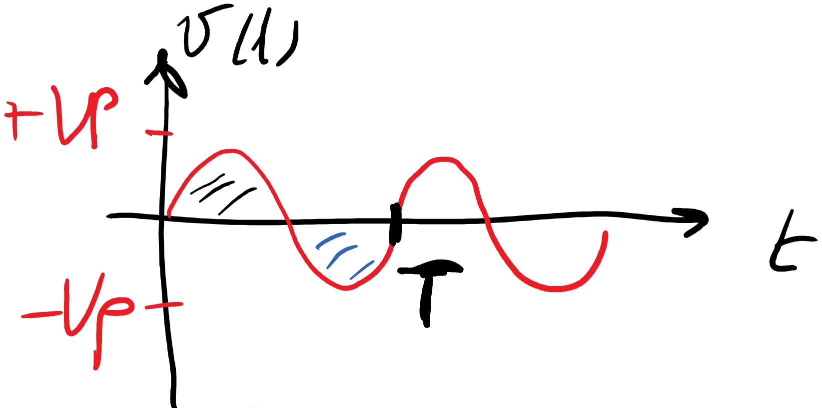
Digital Multi Meter



$$V_{DC} \triangleq \frac{1}{T}\int_0^T v(t)\,dt$$

$$V_{rms} \triangleq \sqrt{\frac{1}{T}\cdot\int_0^T v^2(t)\,dt}$$

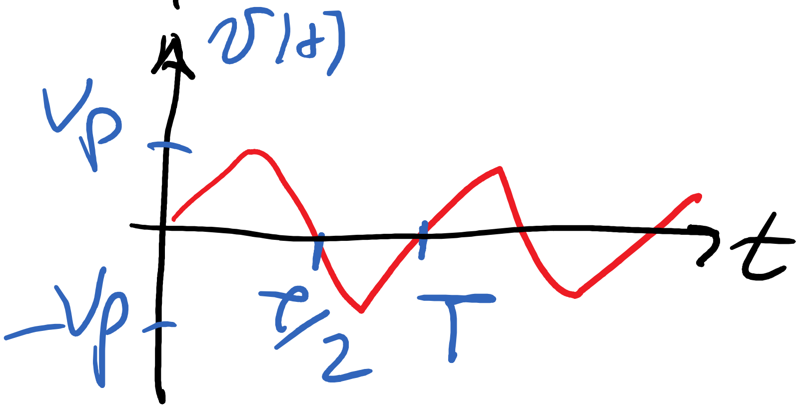
Digital Multi Meter



$$V_{DC} = 0$$

$$V_{rms} = \frac{V_p}{\sqrt{2}}$$

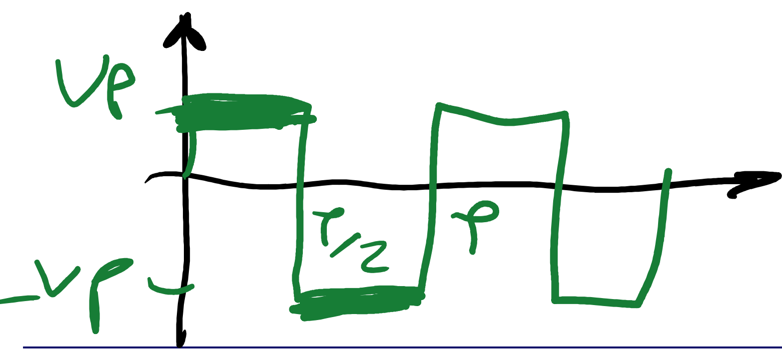
$$C.F. = \sqrt{2}$$



$$V_{DC} = 0$$

$$V_{rms} = \frac{V_p}{\sqrt{3}}$$

$$C.F. = \sqrt{3}$$

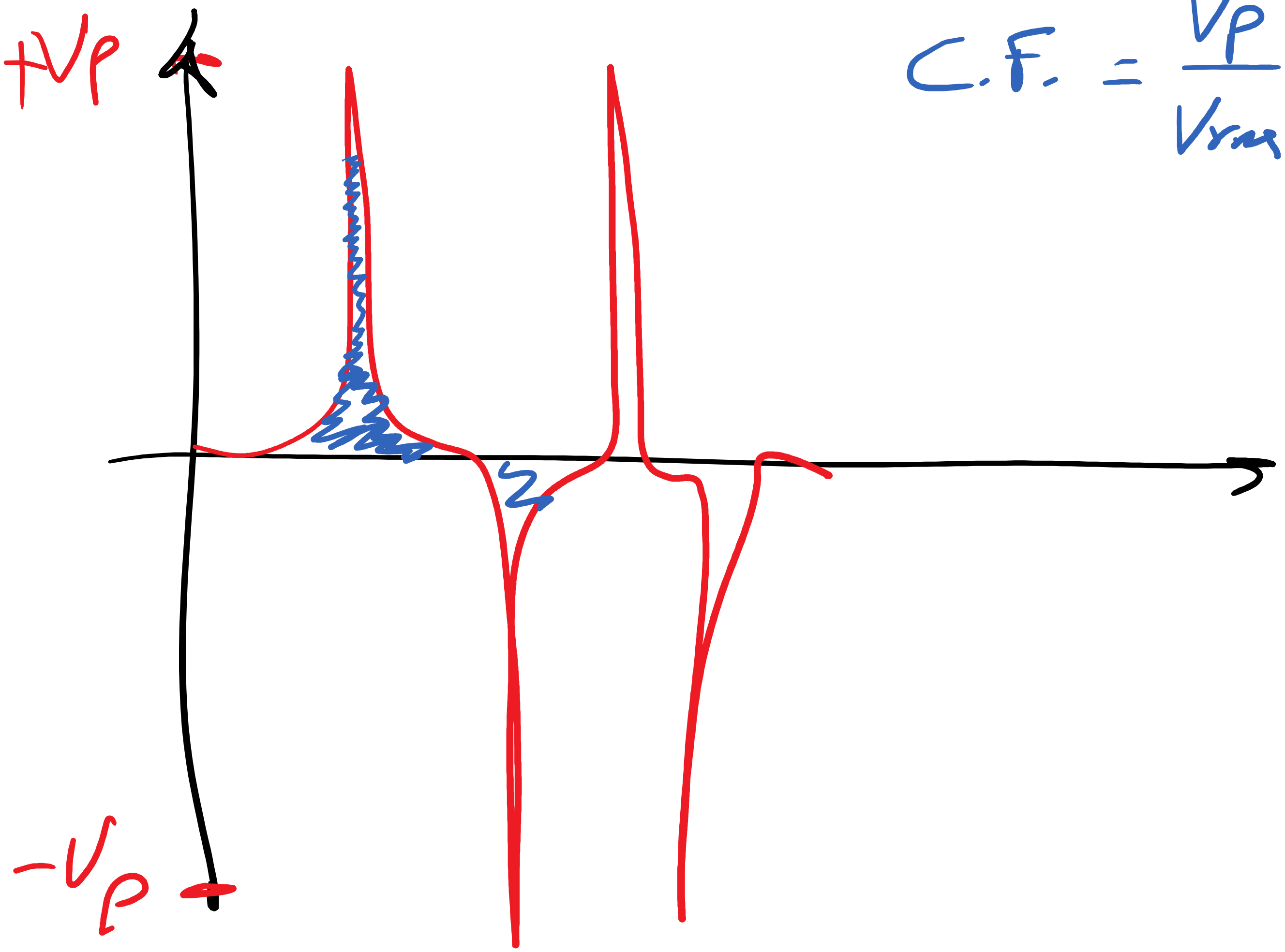


$$V_{c} = 0$$

$$\boxed{V_{rms} = V_p}$$

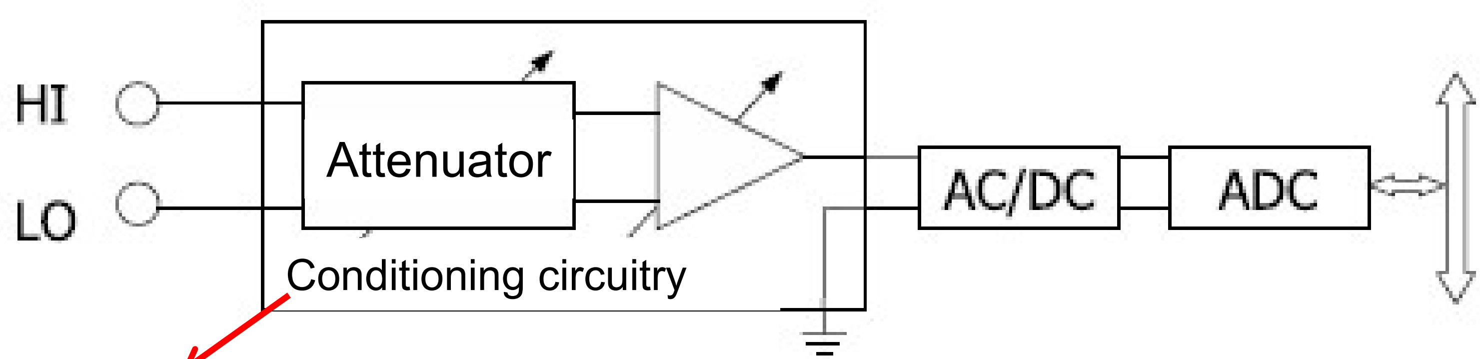
$$C.F. = 1$$

Digital Multi Meter



$$C.F. = \frac{V_p}{V_{rms}} \gg 1$$

DMM – **ACV** section



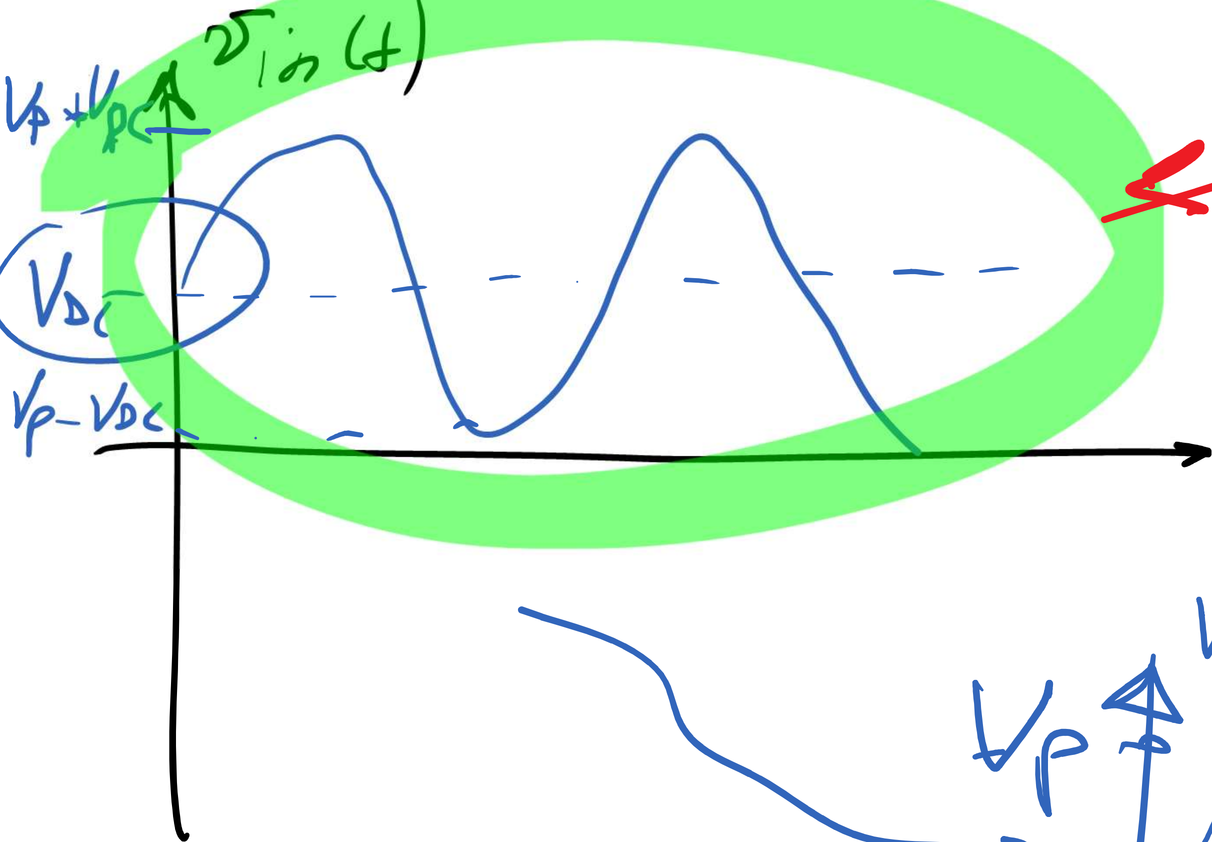
Usually AC coupled

If $v_{in}(t) = V_{DC} + v_{AC}(t)$ → only the rms value of the AC component is measured

Remember that $V_{rms} = \sqrt{V_{DC}^2 + V_{rms,AC}^2}$

CMRR for AC signal worse than the CMRR for DC signal

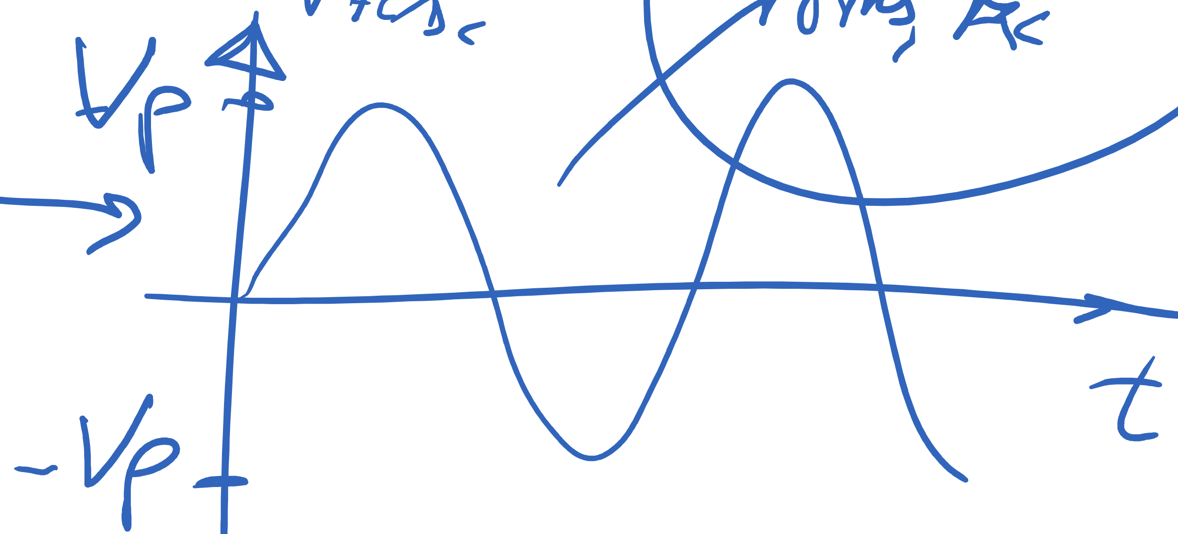
Digital Multi Meter



Vrms = ?

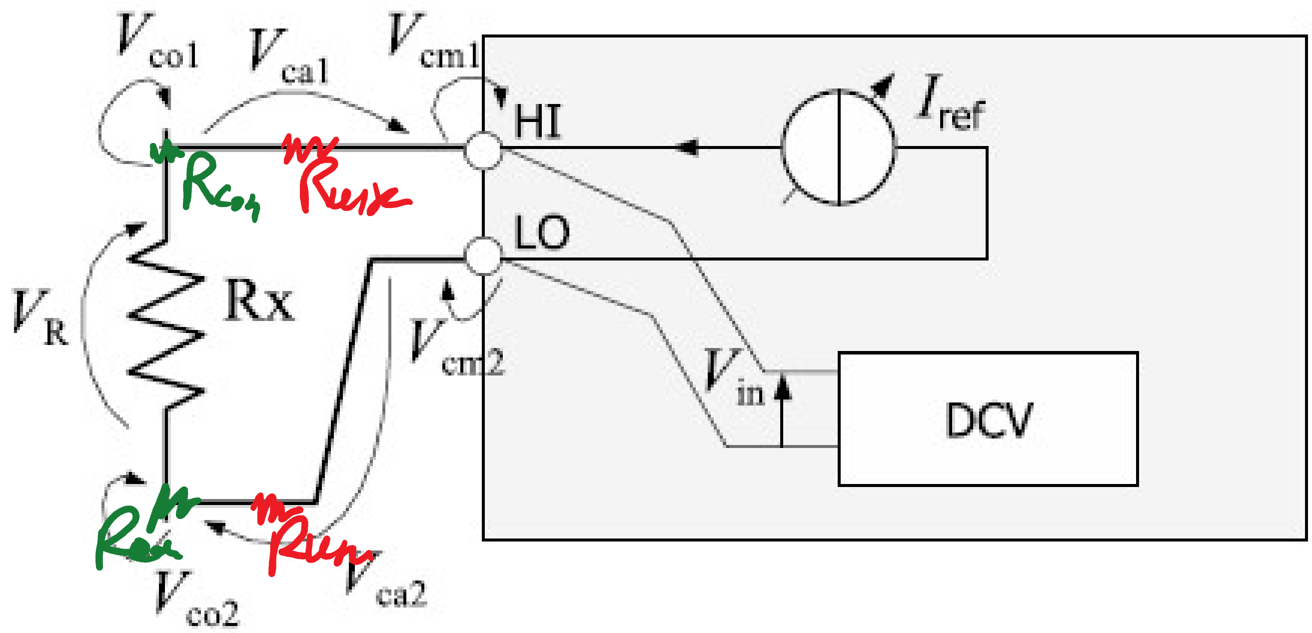
DCV → VDC

ACV → Vrms, ac



DMM – **OHM (2 wire)** section

Measurement based on the volt-ammeter method



$$R_m = \frac{V_{in}}{I_{ref}} = R_x + R_{con} + R_{wire}$$

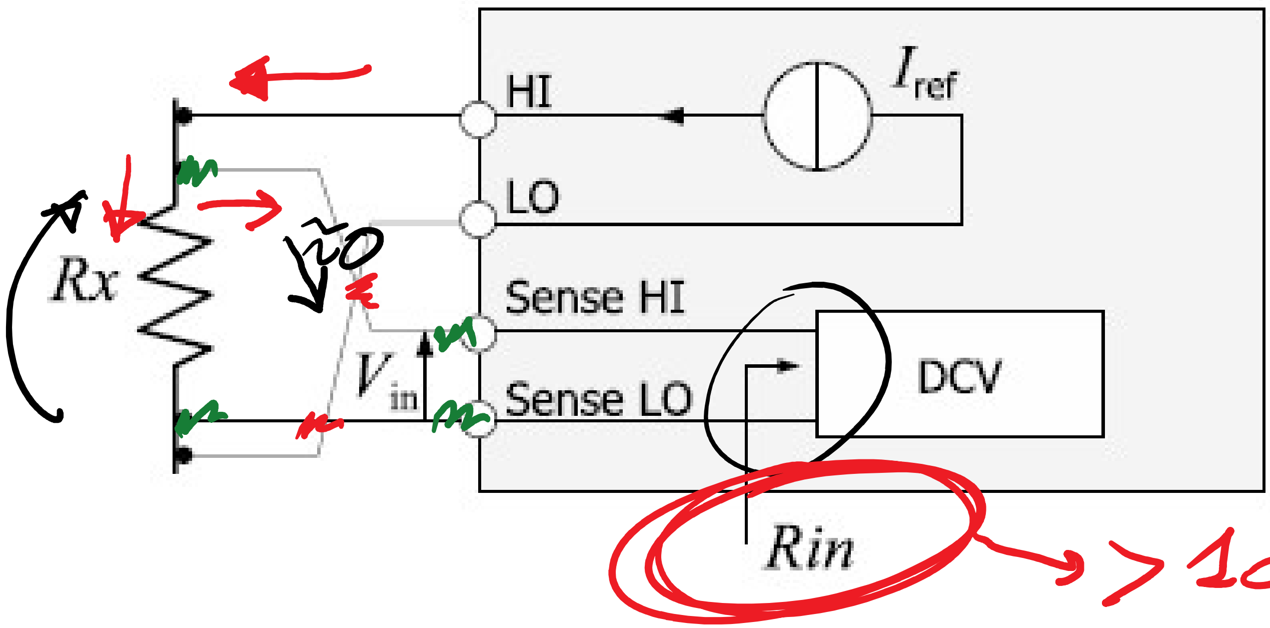
Systematic error due to cable and contact resistances

Digital Multi Meter

DMM – OHM (4 wire) section

not available in all commercial DMM

Not always available



$> 10^6 \Omega$

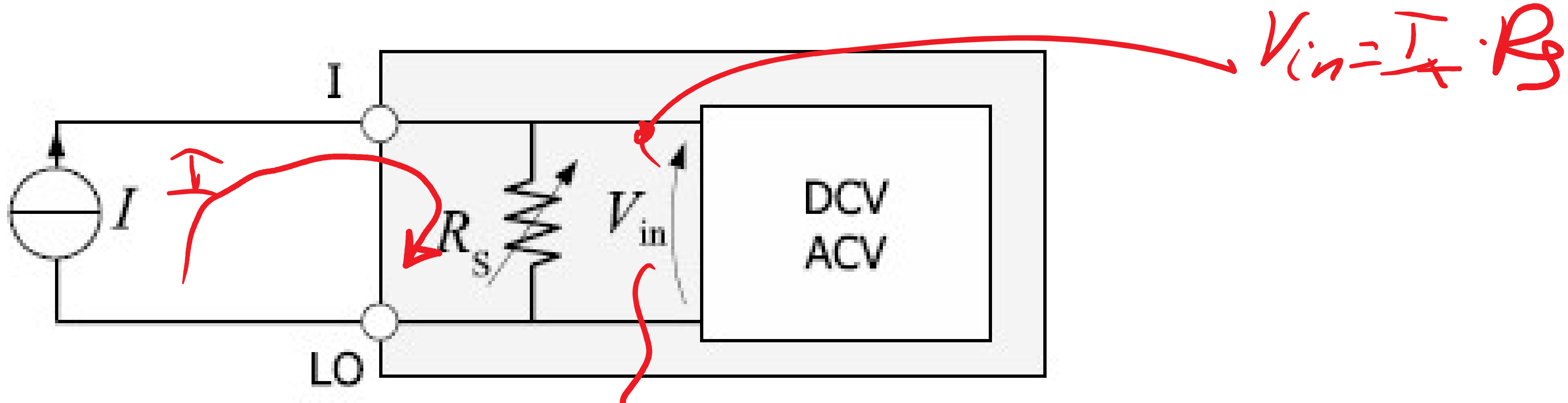
$$R_m = \frac{V_{in}}{I_{ref}}$$

$$\varepsilon_{R_m} = -\frac{R_x}{R_x + R_{in}}$$

Relative systematic error due to the input resistance of the DCV section

DMM – DCI and ACI sections

Current under measurement converted into voltage by means of internal shunts R_S



$$\boxed{I_m = \frac{V_{in}}{R_S}}$$

Digital Multi Meter

Measurement with a DSO

Menu : MEASURE

Amplitude
- Vpp
- Vp
- Vrms
- Vmean

Time
- T
- Δt
- f
- RT
- FT
- δ
- .
- .

$\delta V = ?$

$\delta T = ?$

Digital Multi Meter

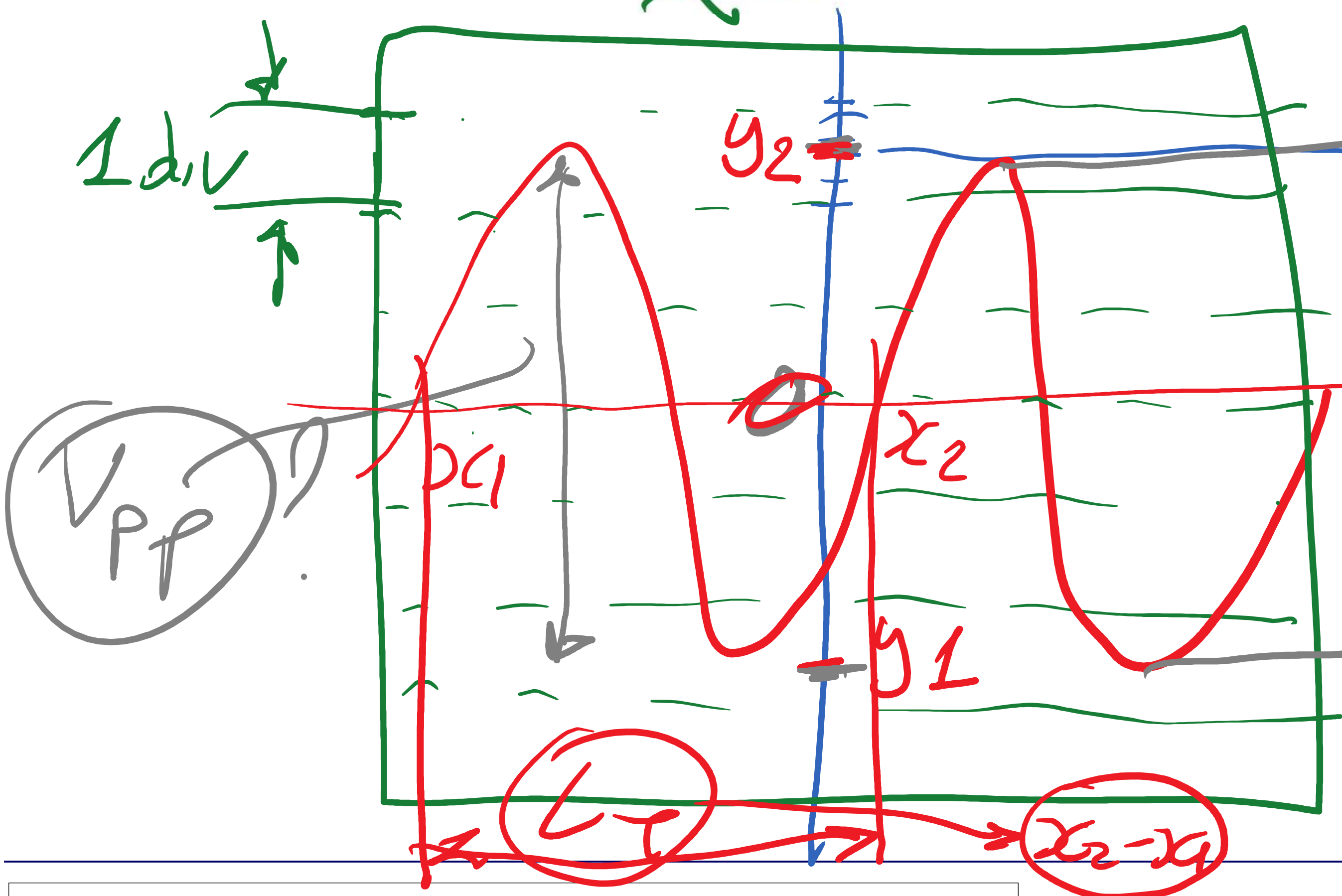
DSO → $\varepsilon_{ky\%} = 2\%$

ε_{kx}

K_v: V/div vertical calibration constant

K_o: s/div time c.c.

0.2 div



$k_y = 1\ V/div$

$y_2 = 2\ div$

$y_1 = -2.5\ V$

$L_{pp} = 5\ div$

Digital Multi Meter

$L_{pp} = 5\ div \quad ; \quad K_y = 1\ V/div$

$$\boxed{V_{pp} = L_{pp} \cdot K_y} \longrightarrow V_{pp_0} = L_{pp_0} \cdot K_{y_0} = 5 \cdot 1 = 5\ V$$

$$\boxed{V_{pp} = (y_2 - y_1) \cdot K_y} \qquad \boxed{V_{pp_0} = 5\ V}$$

$$\varepsilon_{V_{pp}} = \varepsilon_{L_{pp}} + \varepsilon_{K_y} = \varepsilon_{L_{pp}} + 0.02$$

$$L_{pp} = y_2 - y_1 \Rightarrow \varepsilon_{L_{pp}} = \frac{\delta L_{pp}}{L_{pp}} = \frac{\delta y_1 + \delta y_2}{y_2 - y_1}$$

Digital Multi Meter

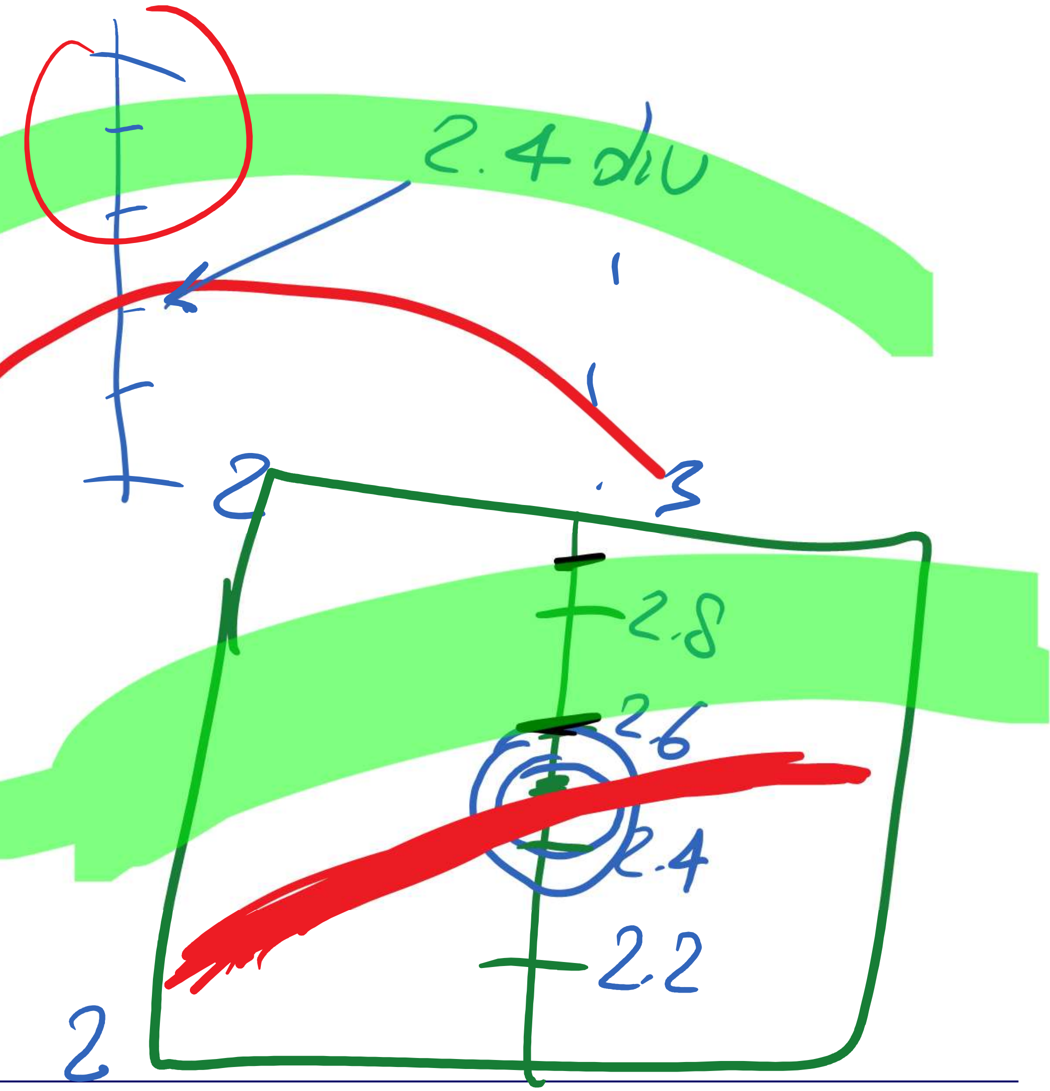
δy_1 ?

δy_2 ?

$$\frac{\text{resolution}}{2}$$

$y_2 = 2.5$ div

resolution = 0.1 div



Digital Multi Meter

$$\varepsilon_{V_{pp}} = \frac{\delta y_1 + \delta y_2}{y_2 - y_1} + \varepsilon_{K_y} = \frac{0.05 + 0.05}{5} + 0.02$$

$$\varepsilon_{V_{pp}} = \frac{0.1}{5} + 0.02 = 0.02 + 0.02 = 0.04$$

$$V_{pp}\% = 4\%$$

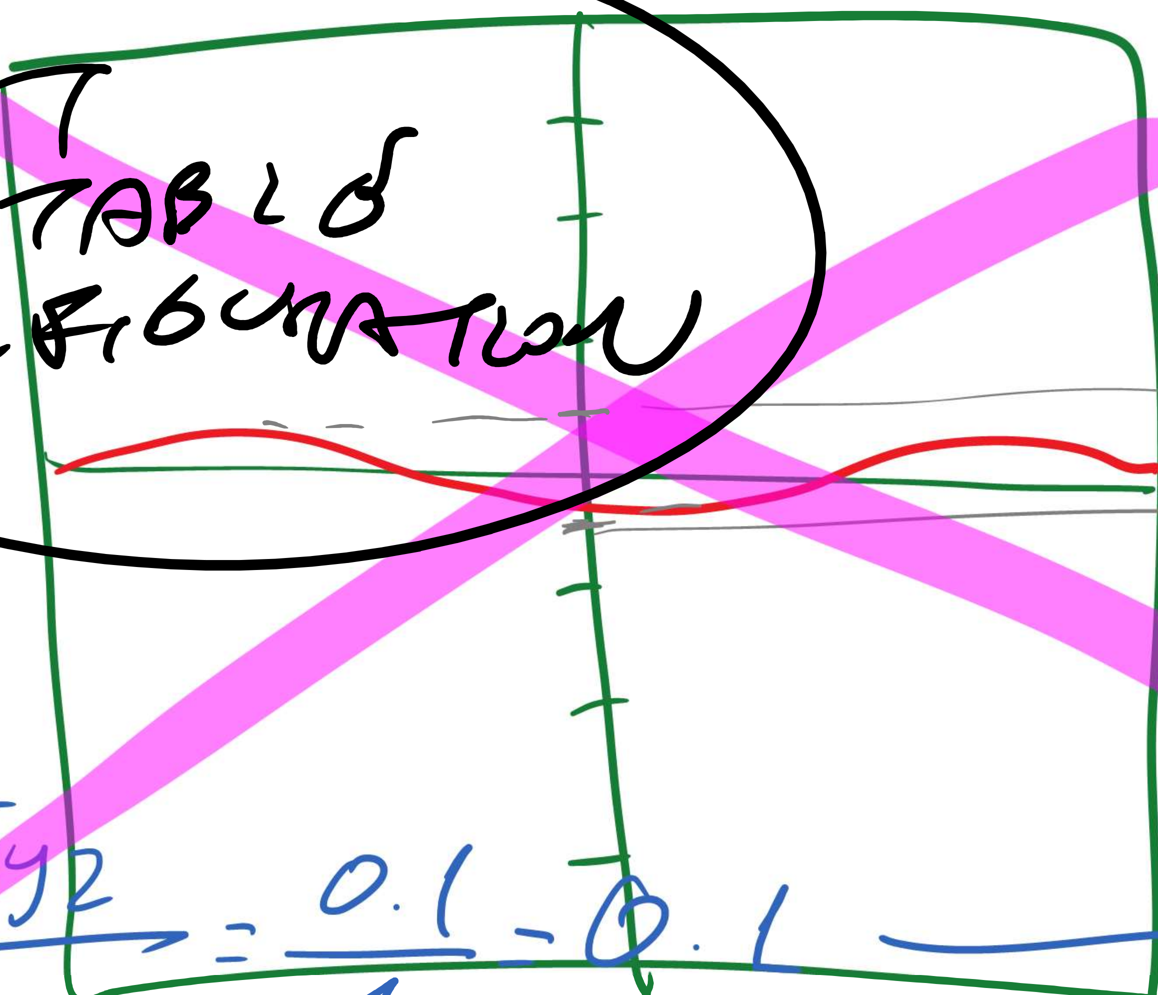
$$\delta V_{pp} = V_{pp} \cdot \varepsilon_{V_{pp}} = 5 \cdot 0.04 = 0.2\ V$$

$$\boxed{V_{pp} = (5.0 \pm 0.2)\ V}$$

Digital Multi Meter

NOT SUITABLE CONFIGURATION

$K_y = 5V/div$



$L_{pp} = 1$

$$\frac{\delta y_1 + \delta y_2}{y_2 - y_1} = \frac{0.1}{1} = 0.1 \rightarrow 10\%$$

Digital Multi Meter

$$\boxed{\delta V = 2\% \text{ of FULL SCALE}}$$

$$\delta V = 0.02 \cdot \text{FULL SCALE}$$

$$8 \text{ divisions} \cdot K_y = \text{FULL SCALE}$$

$$K_y = 1\, V/div \Rightarrow F.S. = 8\, V$$

$$\delta V = 0.02 \cdot 8 = 2 \cdot 10^{-2} \cdot 8 = 0.16\, V$$

Digital Multi Meter

$$V_{pp} = 5V \Rightarrow \varepsilon_{V_{pp}} = \frac{\delta V}{V_{pp}} = \frac{0.16V}{5V}$$

$$T = L_T \cdot K_x = (x_2 - x_1) \cdot K_x$$

$$\varepsilon_{K_x} = (50 \div 100) \cdot 10^{-6} = (50 \div 100)\, ppm$$

part per milion

$$\varepsilon_{K_{x_{2,1}}} = 100 \cdot 10^{-4} = 0.01$$

Digital Multi Meter

$V_{pp} = (5.0 \pm 0.2)\ V$

$V_{rms} = ?$

Sin wave $\rightarrow V_{rms} = \dfrac{V_{pp}}{2\sqrt{2}} = \dfrac{5}{2 \cdot \sqrt{2}} = \ldots\ V$

$\varepsilon_{V_{rms}} = \varepsilon_{V_{pp}} = 0.04$

$\delta V_{rms} = V_{rms} \cdot \varepsilon_{V_{rms}} = \ldots\ 0.04 = \ldots\ V$

Digital Multi Meter

DCV

0.05% → 0.0005 · 1 V

1. $\delta V = (A\%\ \text{reading} + B\%\ \text{range})\ V$

2. $\delta V = (A\%\ \text{reading})\ V + B\ V$

3. $\delta V = (A\%\ \text{reading})\ V + n\ \text{digits}$

→ n times the resolution

Digital Multi Meter

$\boxed{\text{DC V}}$ range 1 V $0 \div 1$ $0 \div 9$

DMM 4 e 1/2 digits $\boxed{X.XXXX}$ V

0.1 mV

reading = 0.5 V

$\delta V = 0.1\%$ reading + 3 digits =

$= 0.001 \cdot 0.5 + 3 \cdot 0.1 \cdot 10^{-3} =$

$= 0.0005 + 0.0003 = 0.0008\ V =$

$= 0.8\ mV$

Digital Multi Meter

$$\delta V = (A\,\text{ppm} \cdot \text{reading} + B\,\text{ppm range})\,V$$

$$\text{ppm} = 10^{-6}$$

$$A = 5$$

$$B = 2$$

$$\text{range} = 10\,V$$

$$\text{reading} = 5\,V$$

$$\delta V = 5 \cdot 10^{-6} \cdot 5 + 2 \cdot 10^{-6} \cdot 10 =$$

$$= 25 \cdot 10^{-6} + 20 \cdot 10^{-6} =$$

$$= 4.5 \cdot 10^{-5} \simeq 45\,\mu V$$

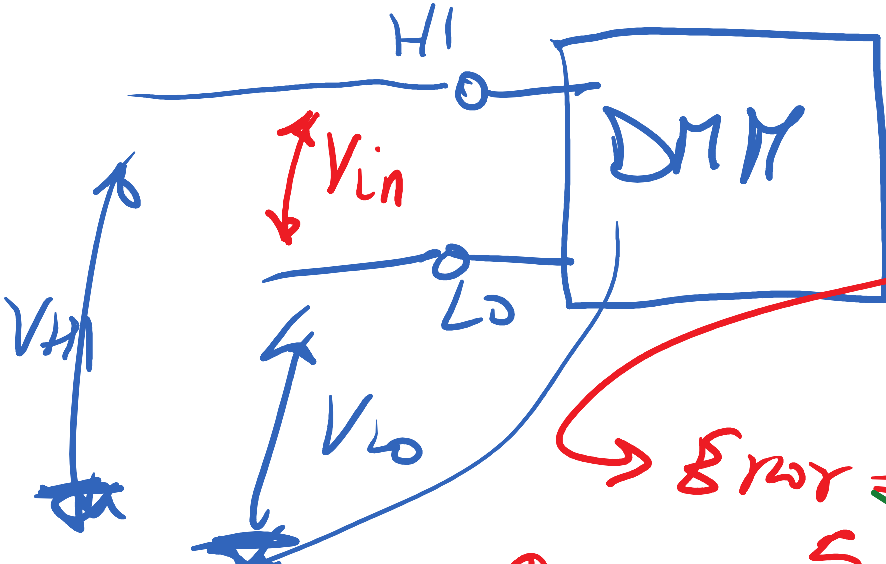
Digital Multi Meter

$\boxed{\text{DCV}}$

$CMRR = 100\ \text{dB}$

$V_{HI} = 10\ V$

$V_{LO} = 9\ V$



$V_{in} = V_{HI} - V_{LO} = 1\ V$

$V_{CM} = \dfrac{V_{HI} + V_{LO}}{2} = 9.5\ V$

$\text{Error} = V_{CM} \cdot \overset{1}{A_d} \cdot 10^{-\frac{CMRR}{20}} =$

$= 9.5 \cdot 10^{-5} \simeq 95\ \mu V$

$\delta V = 0.2\%\ \text{reading} + 1\ mV = 0.002 \cdot 1 + 1 \cdot 10^{-3} =$

$= 3\ mV$

$CMRR = 80\ dB \longrightarrow Error = 0.95\ mV$

$\approx$

$\delta V = 3\ mV$

Digital Multi Meter

OHM

DMM $\rightarrow \delta R = (0.1\%\ \text{reading} + 0.05\%\ \text{range})\ \Omega$

$\text{Range} = 100\ \Omega \longrightarrow \text{reading} = 74\ \Omega$

$R_w + R_{cont} \simeq 0.02\ \Omega = \cancel{20\ m\Omega}$

$\delta R = 0.001 \cdot 74 + 0.0005 \cdot 100 \simeq 0.12\ \Omega$

Digital Multi Meter

$\boxed{\text{OHM}}$ $\delta R = (0.01\%\,\text{reading} + 0.005\%\cdot\text{range})\,\Omega$

$\text{reading} = 74\,\Omega$

$R_{wt}\ R_{cont} \simeq 0.02\,\Omega$

$\delta R = 0.0001 \cdot 74 + 0.00005 \cdot 100 \simeq 0.012\,\Omega$

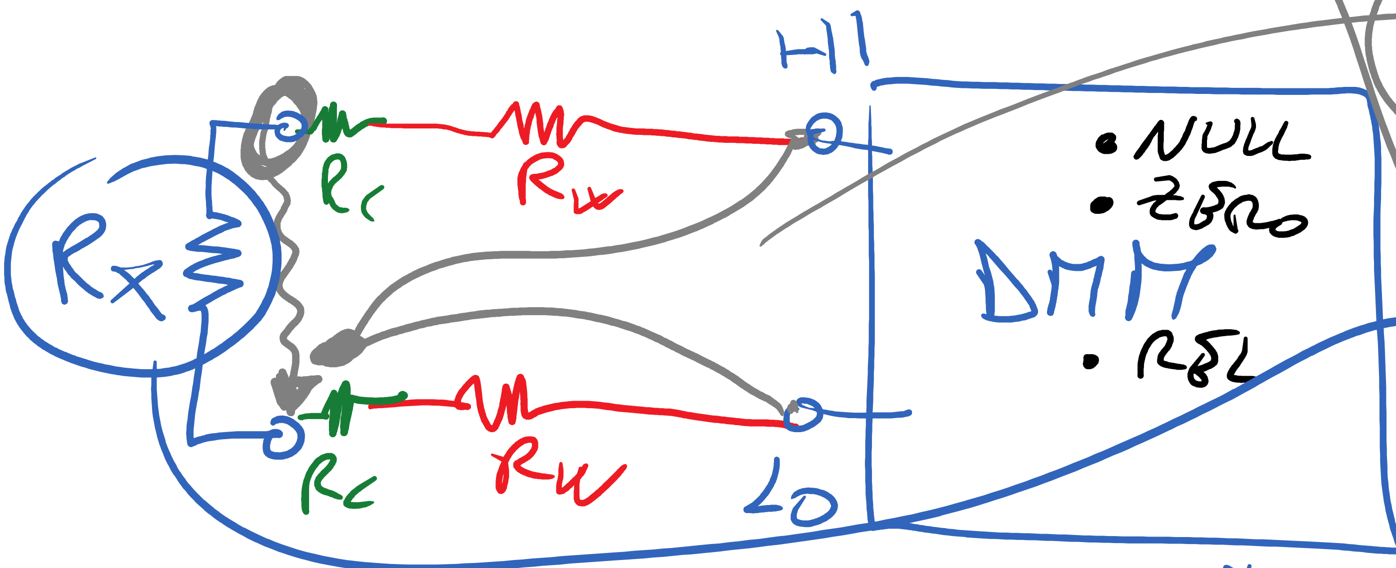
$\delta R = 12\,m\Omega$

$R_w + R_{cont} \simeq 20\,m\Omega$ → SOLUTIONS?

$(R_w + R_{cont}) > \delta R$

Digital Multi Meter

$\boxed{\text{OHM}}$ 2W : 2 wire measurement circuit



$R_{mo} = 27m$

NULL

$R_m = 74.0$

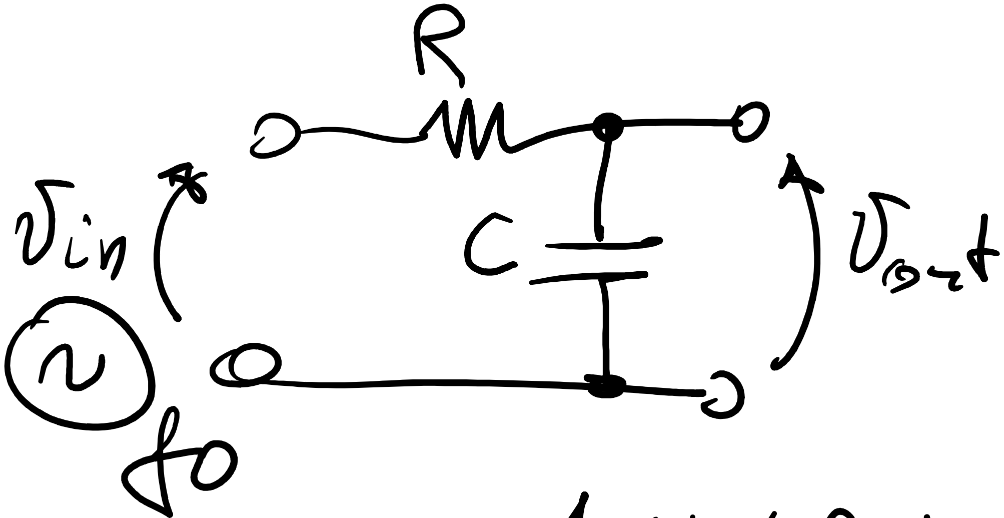
NO NULL CAPABILITY

$$R_m = R_x + \underbrace{(R_w + R_c)}_{20\,m\Omega}$$

$$R_m^* = R_m - R_{mo} =$$

$$= (74.035 - 0.027)$$

Digital Multi Meter



$$Att(f_0) = \frac{v_{out}(f_0)}{v_{in}(f_0)}$$

$$\boxed{Att_{dB}(f_0) = 20 \log_{10} \left[\frac{v_{out}(f_0)}{v_{in}(f_0)} \right]}$$

Digital Multi Meter

$$A_{dB} = 20 \cdot \log_{10}\left(\frac{v_{out}}{v_{in}}\right) \quad \sigma \quad \delta \quad f(v_{in}, v_{out})$$

$$v_{in} = (v_{in_0} \pm \delta v_{in})\ V$$

$$v_{out} = (v_{out_0} \pm \delta v_{out})\ V$$

$$\boxed{\delta A_{dB} = \left|\frac{\partial A_{dB}}{\partial v_{in}}\right| \cdot \delta v_{in} + \left|\frac{\partial A_{dB}}{\partial v_{out}}\right| \cdot \delta v_{out}}$$

Digital Multi Meter