Measurements

Summer017

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Measurements 5/6/2017

Overview :-

1. statisistical measurements (mean, variance) helpful for control & planning
   ex. voltage of house to monitor drop
   ex. controling home devices like fridge, microwave...
2. effective sample : how many readings needed & for how long to get gaussian curve
3. state estimation, since measurement for all houses is costy & objected to error due to communication or meas. devices
4. meters (voltmeters, ameters) whether analog/digital in terms of design & possible errors
   - wattmeter measures energy watt/hour
   - all meters will change to smart meters
5. bridges ex. temperature $\xrightarrow{\text{transducer}}$ voltage
6. earthing systems

Grading :-

First 20%
Second 30%
Final 50%
Bonus Project 5% → Labview, transducer

6/6/2017

Characteristics of Measurement Instruments :

1. Accuracy : how close is the measured value to the true value $\overset{\text{meas.}}{x}$ - - - - - - - $\overset{\text{true}}{x}$

   ± x % tolerance/inaccuracy → the smaller the better

   ↳ percentage % of the measured / full scale

Ex a voltmeter measured 10 V , accuracy 10% full scale, range is 0-15 V, find true value ??

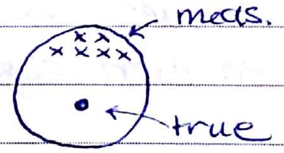
sol : true value = $10 \pm (10\% * 15) = 8.5 - 11.5$ V

* analog meas. devices work thru torque of current

* digital meas. devices work thru A/D converters sampling, quantization ...

2. Precision : reproduce ability in the measurements shown

   we note low accuracy & high precision



?? what's the metric used to describe low/high

Precision → mean (from min to max)

→ standard deviation σ تباعد القراءات عن بعض

$$\sigma^2 = E[(x - \bar{x})^2]$$

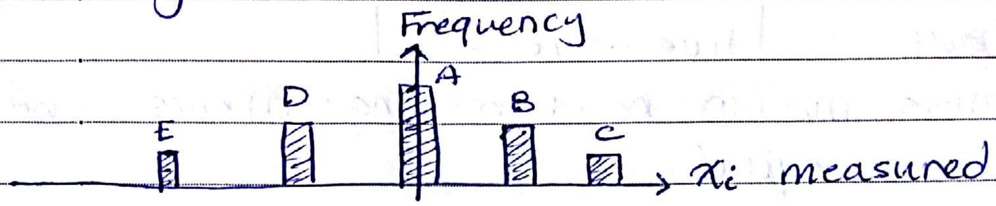
σ² → variance تبعثر القراءات عن ال mean

E → expectation (integration)

$\bar{x}$ → mean value

$$\bar{x} = E[x] = \frac{1}{N} \sum_{i=1}^{N} x_i$$

⊛ Histogram:



to get the mean:

$$\bar{x} = \sum_{i=1}^{N} x_i * Pr(x_i)$$

where $Pr(<1) = \text{Freq} / \#\text{ total measurements}$

to get standard deviation:

$$\sigma^2 = \sum_{i=1}^{N} (x_i - \bar{x})^2 * Pr(x_i)$$

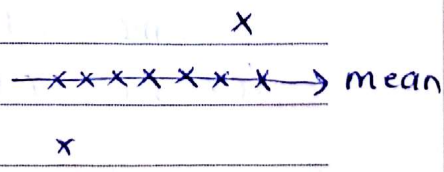
assume uniform

$$\sigma^2 = \frac{1}{N} \sum_{i=1}^{N} (x_i - \bar{x})^2$$

⊛ comparison btwn (mean & standard deviation):

if 1 million readings were taken, & only 2 readings were far from mean

mean metric → conservative
low precision
takes highest & lowest only



σ metric → high precision
considers their probabilities

Accuracy → $|\text{true value} - \bar{x}|$

percentile, median: no of readings above and below are equal

* note: accuracy cares about true value while precision cares about mean value.

3 Resolution: detection of small changes that could happen, minimum step change that can be captured

Ex a digital voltmeter A/D uses 12-bits how much is the resolution knowing that the full scale is 5 V ??

sol levels = $2^{12} = 4096$

resolution = $5/2^{12} = 1.221 \times 10^{-3}$

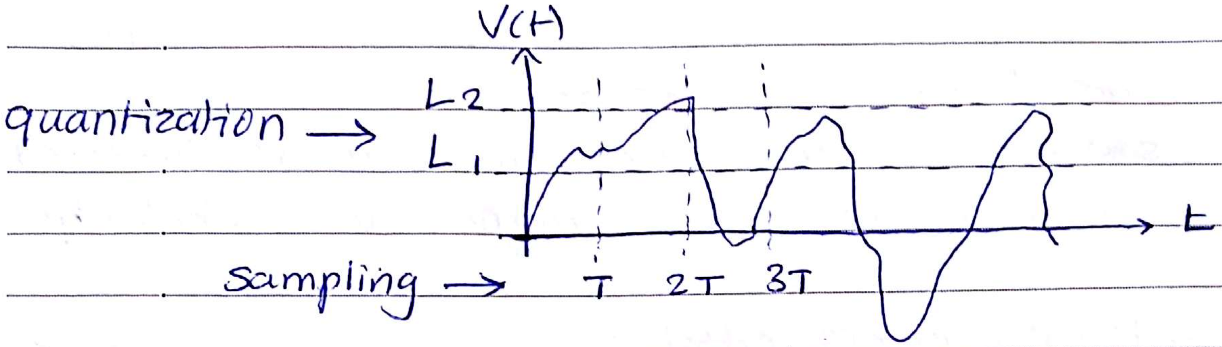
* remember (A/D): analog → $\boxed{\text{sample}}$ → $\boxed{\text{quantization}}$ → $\boxed{\text{Encoder}}$ → bits

assume 2 bits → we have 4 encoded levels

(00) L_1 (01) L_2 (10) L_3 (11) L_4

$$\#\text{of Levels} = 2^{\#\text{ of bits}}$$

the closer the levels to each other, the higher the resolution



step size/resolution = full scale / # of levels

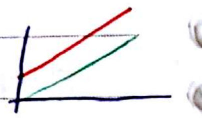
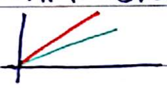
$\boxed{4}$ Sensitivity : how does change in input change the output

Sensitivity = Δ output / Δ input

ex. $C = \frac{\epsilon A}{d}$ how does C change when A & d change ??

Error Definition & Types :-

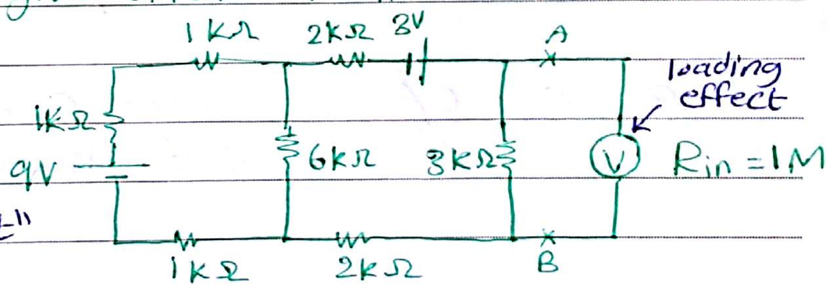
1. systematic errors : cause is known, can be eliminated
2. random errors : cause is unknown, use probability

* systematic errors offsets :
  - → constant like zero offset : shift starts @ zero 
  - → % reading like scale offset 

Slide 8 $\boxed{\text{Ex}}$ in the ckt shown find :

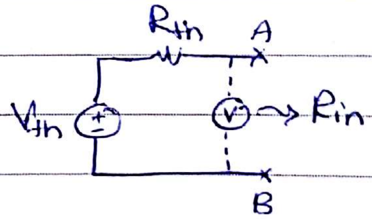
1. error in the measurement
2. $R_{\text{volt meter (in)}}$ that will give error smaller than 1%

here we have systematic error due to "loading effect"



<u>Sol</u> find true value

1. $R_{th} = 2\,k\Omega$
   - → ideal / no error / expected $R_{in} = \infty$
   - → measured $R_{in} = 1M$



$V_{expected} = V_{th}$

$V_{measured} = V_{th} * \frac{1M}{1M + 2k}$

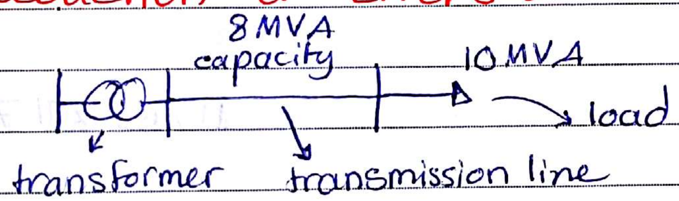
* types of errors → relative
→ absolute

$$\text{error \%} = \frac{V_{th} - 0.998\,V_{th}}{V_{th}} * 100\% = 0.2\%$$

② $$\frac{V_{th} - \left(R_{in}/R_{in}+2k\right)V_{th}}{V_{th}} * 100\% \leq 0.1\%$$

$R_{in} \gg 198\,k\Omega$

Reduction of Errors :-

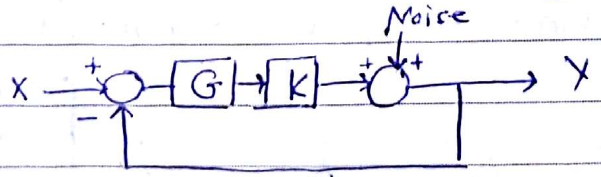


Active Network Management (ANM)

*increase in demand → Reinforce Network
add transformers, T.L ...
~~costly & takes time~~
→ ANM
control room to control
2MVA out of 10 MVA

here we note the importance of measurement in decision making & safety of network.

Negative Feedback: the target is to minimize error



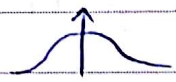
transfer function:

$$y = (x - y)GK + N$$

$$y(1 + GK) = xGK + N$$

$$y = x \frac{GK}{1 + GK} + \frac{N}{1 + GK}$$

here we reduced effect of Noise by dividing it on gain

* assume noise is white gaussian 

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* Random Errors :-

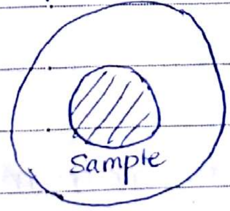
measured $x(t) \longrightarrow (+) \longrightarrow y(t)$

↑ Noise error due to channel
↳ wireless
↳ fiber

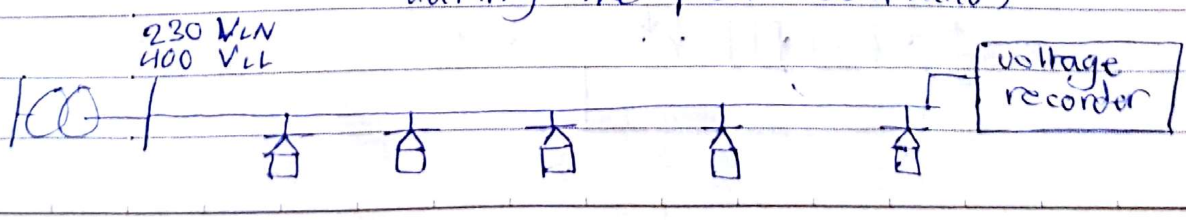
use probability calculate
↳ BER
↳ symbol error rate

* when the sample is small its hard to get gaussian curve

population



ex. when trying to reinforce a power grid, we cant take measurement for all the houses, we take a sample (preferrably at the end during the peak demand)



from sample ($\bar{X}$ mean, σ^2 variance) where $X \to$ voltage

$\alpha \triangleq$ standard mean error (expansion for all population)

$\alpha = \dfrac{\sigma}{\sqrt{n}}$ σ ⇝ standard deviation, n ⇝ number of readings

X ?? which range of reading to choose ?

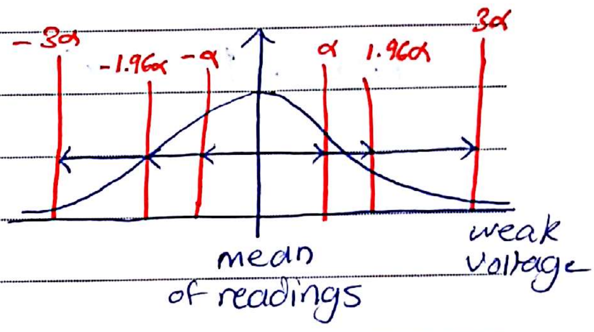
confidence level :

mean $\pm \alpha \to$ 68%

mean $\pm 1.96\alpha \to$ 95%

mean $\pm 3\alpha \to$ 99.7%

↓ memorize these numbers



* confidence level : if you're 100% sure about your readings we take the biggest range ($\pm 3\alpha$).

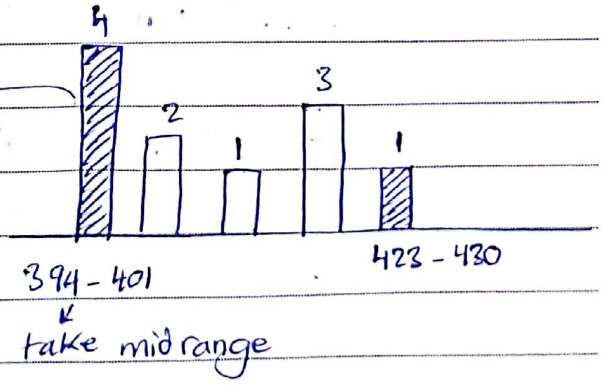
* now we want to know if we need to reinforce the network based on readings :

-6% voltage drop $\leqslant V \leqslant +10\%$ voltage rise

$215 \leqslant 230 \leqslant 253$

* if given a histogram to find $\bar{X}$ & σ^2

$\dfrac{394 + 401}{2} \times \left(\dfrac{4}{11}\right)$

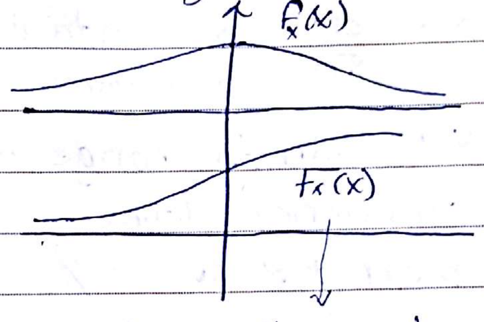


Cumulative Distribution Function CDF

$f_x(x)$ pdf

$F_x(x)$ cdf

for gaussian



$$F_x(x) = \int_{-\infty}^{x} f_x(x)\,dx$$

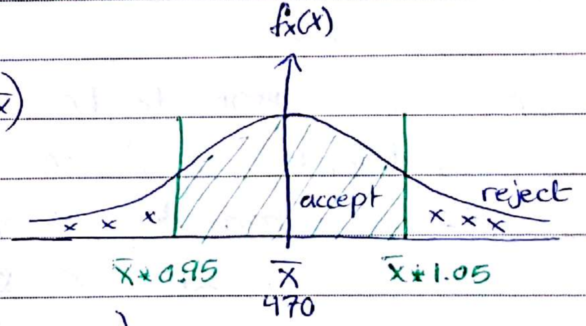
$$F_x(x_0) = Pr(x \leq x_0)$$

non-decreasing

12/6/2017

$\boxed{Ex}$ 10000 resistors, $R = 470\,\Omega$, tolerance $= \pm 5\%$

sample $\rightarrow$ $\bar{X} = 470\,\Omega$, $\sigma = 23.5\,\Omega$



$$Pr(\text{accepted}) = Pr(0.95\bar{X} < X < 1.05\bar{X})$$

$$= \int_{0.95\bar{x}}^{1.05\bar{x}} f_x(x)\,dx$$

from table

$$= Pr(X \leq 1.05\bar{x}) - Pr(X \leq 0.95\bar{x})$$

$$= F_x(1.05\bar{X}) - F_x(0.95\bar{X})$$

$$= F_Z\left(\frac{1.05\bar{x} - \bar{x}}{\sigma}\right) - F_Z\left(\frac{0.95\bar{x} - \bar{x}}{\sigma}\right)$$

$$= F_Z(1) - F_Z(-1) \rightarrow -ve$$

$$= F_Z(1) - (1 - F_Z(1))$$

$$= 2F_Z(1) - 1 = 0.68$$

$$Pr(\text{rejected}) = 1 - 0.68 = 0.32$$

# of rejected $= 10{,}000 * 0.32 = 3200$

Scanned by CamScanner

t-test
chi-square

* remember to use table:

$F_x(x_o) \doteq F_z\left(\frac{x_o - \bar{x}}{\sigma}\right)$

$\boxed{Ex}$ 10 readings from a voltmeter, express voltage reading as a range with 95.4%.

$X = \{$

find mean $\bar{X} = \frac{1}{10} \sum X = 35.93\,\Omega$

$\sigma^2 = \frac{1}{N} \sum (x_i - X)^2 = 0.365$

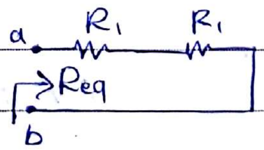
$\alpha = \frac{\sigma}{\sqrt{n}} = 0.115$

confidence level = 95.4% $\longrightarrow$ $\bar{X} \pm 2\alpha = 35.95 \pm 2(0.115)$

Aggregation of Errors

* to measure variable of interest as function of other variables.

* to find Req → measure terminals a & b
  → find R_1 and R_2



$\underset{error}{R_{eq}} = \underset{error}{R_1} + \underset{error}{R_2}$

Error → limiting error (max, min)
→ most likely error

addition:

$u = v + w$ where error: $v \pm m\%$, $w \pm n\%$

↳ limiting error

$u = (v+w) \pm (m\% * v + n\% * w)$ → error is absolute

$\boxed{Ex}$ $V = 10V$ $e = \pm 10\%$, $W = 5V$ $e = \pm 10\%$

$y = V + W$, what's the limiting error

max $y \rightarrow (10 + 10\% * 10) + (5 + 10\% * 5) = 16.5V$

min $y \rightarrow (10 - 10\% * 10) + (5 - 10\% * 5) = 13.5$

error $= \pm(10\% * 10 + 10\% * 5) = \pm 1.5$

$y = 15 \pm 1.5$

multiplication

$u = v * w$

↳ limiting error

$u = v.w\,(1 \pm e)$ → error is percentage

$= v.w\,(1 \pm (m+n))$

if we have $f = f(V_1, V_2, V_3 \cdots V_n)$ → complicated

use partial derivatives

$\boxed{Ex}$ $F = \frac{EAd}{\ell}$, variables (A, d, ℓ)

$$\Delta F = \Delta A * \frac{\partial F}{\partial A} + \Delta d * \frac{\partial F}{\partial d} + \Delta \ell * \frac{\partial F}{\partial \ell}$$

$$= \Delta A * \frac{F}{A} + \Delta d * \frac{F}{d} + \Delta \ell * \frac{F}{\ell}$$

$$\left|\frac{\Delta F}{F}\right|_{max} = \frac{|\Delta A|}{A} + \frac{|\Delta \ell|}{\ell} + \frac{|\Delta d|}{d} \qquad \left|\frac{\Delta F}{F}\right|_{min} = -\frac{\Delta A}{A} - \frac{\Delta \ell}{\ell} - \frac{\Delta d}{d}$$

13/6/2017

Probable Values

$R_1 = 10\,\Omega \pm 10\%$ $\quad\quad 9\,\Omega \leqslant R_1 \leqslant 11\,\Omega$

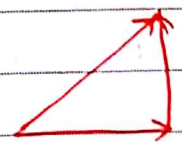
$R_2 = 10\,\Omega \pm 10\%$ $\quad\quad 9\,\Omega \leqslant R_2 \leqslant 11\,\Omega$

→ Limiting error (assuming $R = R_1 + R_2$)

$R_{max} = 22\,\Omega \quad R_{min} = 18\,\Omega$

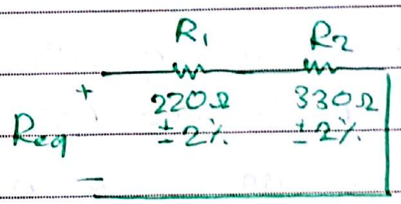
→ Probable error

$R_1 + R_2 \pm e$



$20 \pm \sqrt{1^2 + 1^2} = 20 \pm \sqrt{2}$

$\boxed{Ex}$ find Req & most likely error



$R_{eq} = R_1 + R_2 \pm e$

$= 550 \pm \sqrt{(220 * 0.02)^2 + (330 \times 0.02)^2}$

$= 550 \pm 7.93\,\Omega$ → actual error

$= 550 \pm 1.44\% * 550\,\Omega$ → relative error

↘ $7.93/550$

$\boxed{Ex}$ $P = VI$ find most likely error if

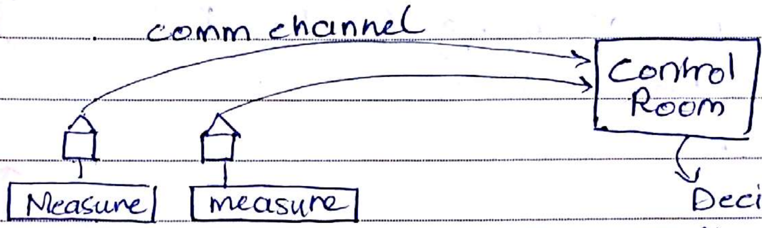
$V = \pm 1\% \quad I = \pm 2\%$

$P = VI\,(1 \pm e\%)$

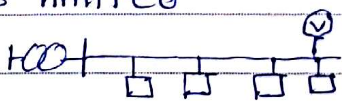
$e\% = \sqrt{(0.01)^2 + (0.02)^2}$

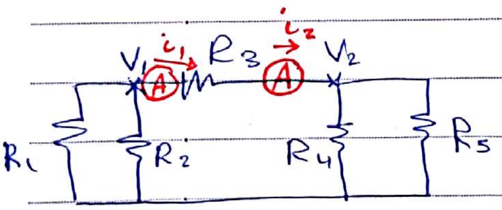
State Estimation (not in the slides)

assume the power transmission network :-



Decision-making Algorithm
ex. open/close switch...

* What's wrong with these measurements?
  - errors in readings
  ex. assume reading for power consumption of a house was 200kW (too large) usually it ranges (5-10kW)
  - high cost, number of readings is limited
  ex. only measure at end of T.L 



states → voltages
→ angles

which current (i_1 or i_2) is the correct one?
by estimating V_1 & V_2 we can calculate i between V_1 & V_2 then decide which reading is correct

→ black box

real measurements → $\boxed{\text{State Estimation Algorithm}}$ → error in meas.

V, I, P

* Measurements → Real
→ Pseudo (historical)

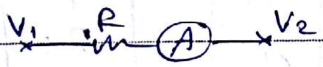
* Black box function:-

$$\text{Min} \sum_{i=1}^{m} \frac{[Z_i - h_i(x)]^2}{\sigma_i^2}$$

where Z_i : measurements
$h(x)$: model
~~x : system state~~
e : error
m : # of measurements

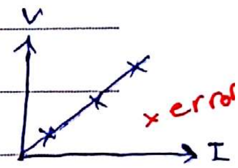
$$Z_i = h_i(x) + e$$

steps → find x (the states)
→ find model h(x)

ex. 

states : V_1 , V_2

model : A = $V_1 - V_2 / R$



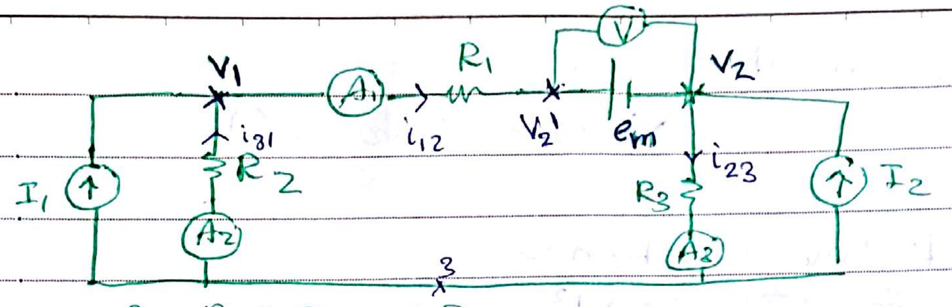
*almost like when we know that a reading outside straight line of V-I of resistor was an error

1. system model : measurements = h(states)
2. sum squared error : write the summation

(2') solution : hard, using matrices

3. find errors in measurements

Ex



where $R_1 = R_2 = R_3 = 1\Omega$

known: states V_1, V_2, e_m

measurements $A_1 = 1A$ $A_2 = -3.2A$

$A_3 = 0.8A$ $V = 1.1V$

system model

$$\underbrace{\begin{bmatrix} 1 & -1 & -1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}}_{h_i(x)} \underbrace{\begin{bmatrix} V_1 \\ V_2 \\ e_m \end{bmatrix}}_{\text{states}} = \underbrace{\begin{bmatrix} A_1 \\ A_2 \\ A_3 \\ V \end{bmatrix}}_{\text{measured}} = \begin{bmatrix} 1 \\ -3.2 \\ 0.8 \\ 1.1 \end{bmatrix}$$

* note that the measured readings have error (check using KVL or KCL)

$-3.2 + 1 + 1.1 + 0.8 = -0.3 \neq 0$

* to get the matrix $h_i(x)$:

$z_i = h(x) + e$ → purpose: write with respect to states

(A2) $i_{31} = \frac{V_1}{R_2} = V_1 = -3.2$

(A3) $i_{23} = \frac{V_2}{R_3} = V_2 = 0.8$

(V) $V = e_m$

14/6/2017

* note that we have 4 equations & 3 unknowns thus we will not get 1 solution

solution (states)

$$\underbrace{\begin{bmatrix} 1 \\ -3.2 \\ 0.8 \\ 1.1 \end{bmatrix}}_{\text{measured}} - \underbrace{\begin{bmatrix} 1 & -1 & -1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ e_m \end{bmatrix}}_{\text{model}} = \text{error}$$

$\hookrightarrow Z_i - h(x) = e$

$\text{Min}(\text{error})^2 \rightarrow$ minimum square error

$$\text{Min}\left\{(1 - V_1 + V_2 + e_m)^2 + (-3.2 - V_1)^2 + (1.1 - e_m)^2 + (0.8 - V_2)^2\right\}$$

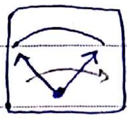
$$X = \begin{bmatrix} 3.125 \\ 0.875 \\ 1.175 \end{bmatrix} \begin{matrix} \rightarrow V_1 \\ \rightarrow V_2 \\ \rightarrow e_m \end{matrix}$$ ← مش مطلوب كيف نطلعه

$$\text{error} = \begin{bmatrix} 1 \\ -3.2 \\ 0.8 \\ 1.1 \end{bmatrix} - \begin{bmatrix} 1 & -1 & -1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 3.125 \\ 0.875 \\ 1.175 \end{bmatrix}$$

Meters :-

DC Meter

Analog "Galvanometer"



FULL scale

- → Ammeter
- → Voltmeter

* calibration : to decide what is the full scale

AC Meter

Digital Voltmeter

15/6/2017

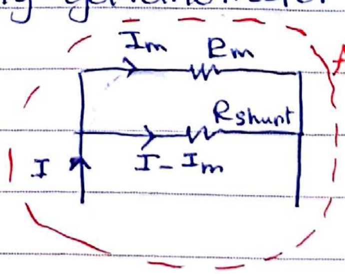
* Analog DC Meter

Permanent Magnet Moving Coil (PMMC)

* Full scale pointer
- → internal resistance R_m
- → I_m: full scale deflection current usually small ≈ 1mA

How to measure large current using galvanometer ??

we add resistance in parallel to increase the scale



$$I_m R_m = (I - I_m) R_{shunt}$$

$$R_{shunt} = \frac{I_m R_m}{I - I_m}$$

$$\boxed{R_{shunt} = \frac{R_m}{\frac{I}{I_m} - 1}}$$

Ex find R_{shunt} to measure 10mA using 1mA meter with internal resistance $R_m = 100\Omega$

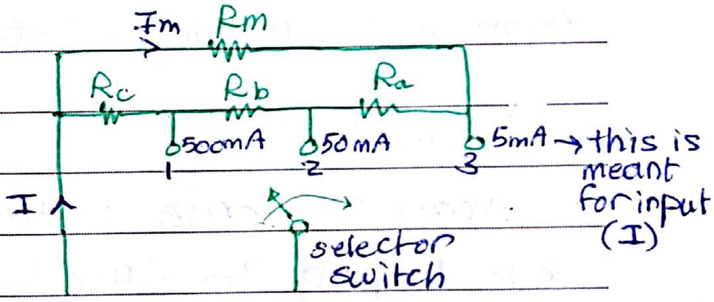
sol: $R_{shunt} = \dfrac{100}{\frac{10m}{1m} - 1} = 11.11\Omega$

* Multiple Range Ammeter

Ex $I_m = 50\mu A$

$R_m = 2400\Omega$

3 ranges $\begin{cases} 5mA \\ 50mA \\ 500mA \end{cases}$



sol: 5mA is when switch closes at position 3

↳ biggest shunt resistance

$* \; I_m R_m = (I - I_m)(R_a + R_b + R_c)$

$50\mu \times 2400 = (5m - 50\mu)(R_a + R_b + R_c)$ ---- $\boxed{1}$

at position 2 we read 50mA

$* \; (R_c + R_b)(I - I_m) = I_m(R_m + R_a)$

$(R_c + R_b)(50m - 50\mu) = 50\mu(2400 + R_a)$ --- $\boxed{2}$

at position 1 we read 500mA

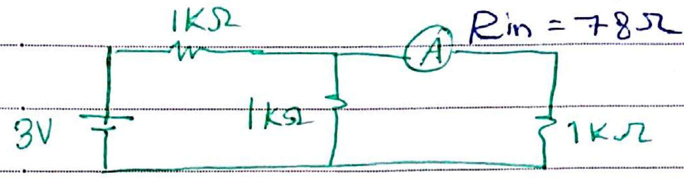
$* \; (I - I_m)R_c = I_m(R_m + R_a + R_b)$

$(500m - 50\mu) = 50\mu(2400 + R_a + R_b)$ ---- $\boxed{3}$

3 unknowns: $R_c = 2.18\Omega$ $R_b = 9\Omega$ $R_a = 21.81\Omega$

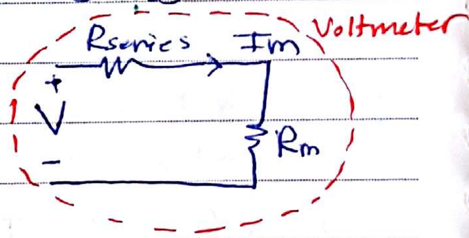
* Ammeter loading effect → due to internal resistance
what is the effect when adding R_{shunt}?

Ex



sol:
using current division solve once with 78Ω and then without it, the difference between them is the loading effect.

* DC Voltmeter
to measure large voltage we add R_{series} while keeping I_m within limits



Ex measure voltage = 10V
$R_m = 650\,\Omega$ $\quad I_m = 1mA$
whats the suitable R_{series}?

sol: $-10V + I_m R_{series} + I_m (650\,\Omega) = 0$
$R_{series} = 9.35\,k\Omega$

* for multi-range voltmeter we add selector switch & many resistances

* note: we might have ammeter & voltmeter in the same circuit

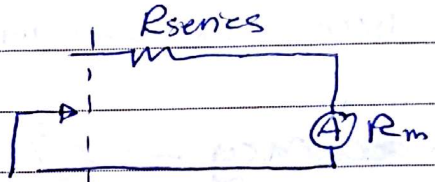
* Sensitivity of Analog Meters

an ammeter measuring 50 μA is more sensitive than that measuring 1 mA.

(S) sensitivity = $1/I_{FSD}$ Ω/V

FSD : full scale deflection

$I_{FSD} \downarrow$ sensitivity $\uparrow$



$R_{series} = S * Range - R_m$

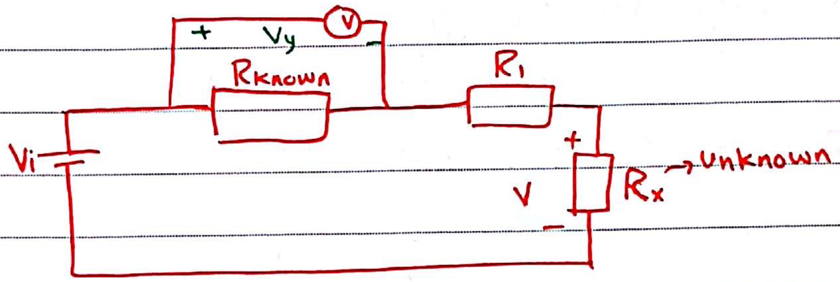
↳ for voltmeter

$R_{in} = \frac{1}{I_{FSD}} * Range$

Scanned by CamScanner

2016

*Ohmmeter → Analogue (Galvanometer) $R = \frac{V}{i}$

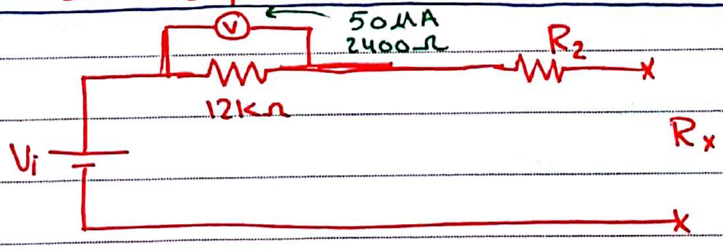


~~V = Vi~~

- Reverse Scaling - Non-linear

$$V_y = V_i \times \frac{R_{known}}{R_1 + R_x + R_{known}}$$

* The Relationship between them is not linear.



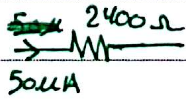
Ex:

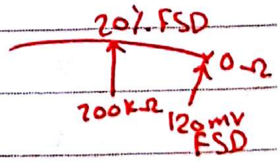
Desired ⇒ $R_x = 0$ (Full-Scale)

$R_x = 200\,k\Omega$ (20% Full Scale)

find R_2, V_i??

* FSD 50 µA





$V(FSD) = 2400 \times 50\mu$

$= 120\,mV = 0.12\,V$

$20\%\ V(FSD) = 0.024\,V$

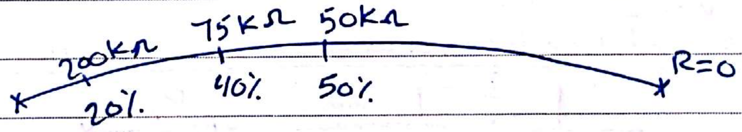
$$V_y = V_i \frac{(12k \parallel 2.4k)}{(12k \parallel 2.4k) + R_2 + R_x}$$

@ $R_x = 0 \Rightarrow$ FSD $\Rightarrow V_y = 0.12$

$$\boxed{0.12 = \frac{V_i(12k \parallel 2.4k)}{(12k \parallel 2.4k) + R_2}} \quad (1)$$

@ $R_x = 200k\Omega \Rightarrow 20\%$ FSD $\Rightarrow V_y = 0.024$

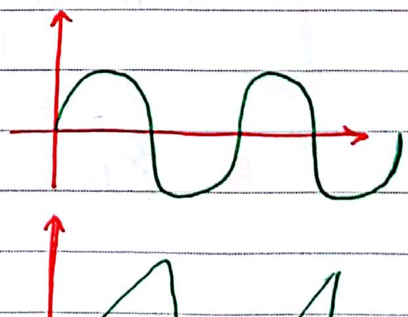
$$\boxed{0.024 = \frac{V_i(12k \parallel 2.4k)}{(12k \parallel 2.4k) + R_2 + 200k}} \quad (2)$$



- Reverse
- Non-linear.

* AC Voltmeter "Analogue"

$\rightarrow V_{rms} = \sqrt{\frac{1}{T}\int_T v^2(t)\,dt}$

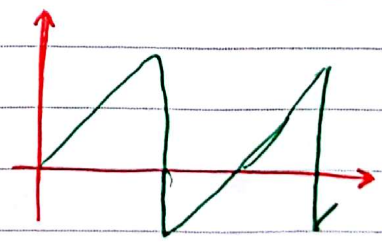


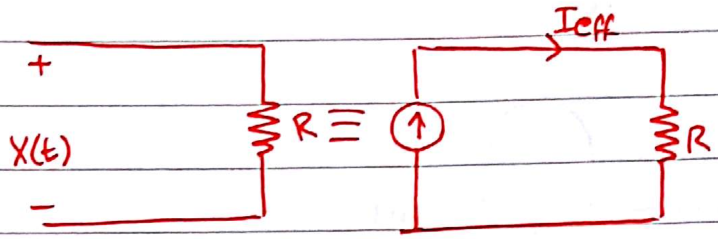
RMS ≡ Effective

V_{avg}

$= \frac{1}{T}\int v^2(t)\,dt$ * $\boxed{\frac{1}{2}\frac{V_m^2}{R} = \frac{1}{2} I_m^2 R}$

Power





$P = I_{eff}^2 * R$

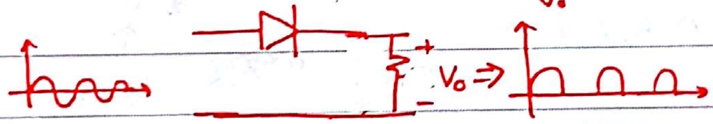
dc

Pure AC Signal ⇒ $I_{rms} = \frac{I_m}{\sqrt{2}} = 0.707\, I_m$

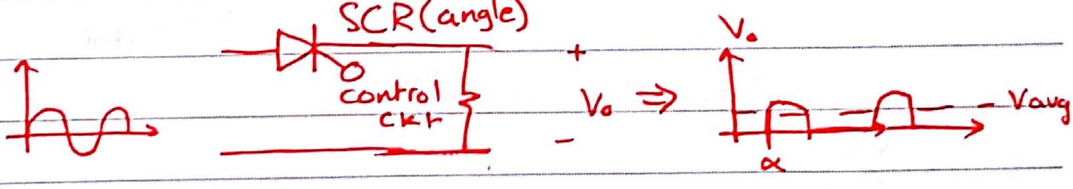
↳ for Sinusoidals.

$\underline{\underline{rms}}$ ∼ → $\boxed{\text{Rectifier}}$ $\xrightarrow{dc}$ $\boxed{\text{Calibration}}$

"Uncontrolled"



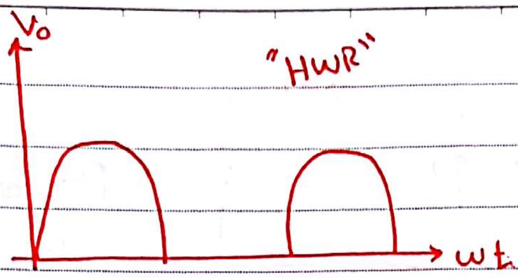
"Controlled"



Pure AC ⇒ $V_{rms} = 0.707\, V_m$

$\underline{\underline{rms}}$ ∼ → $\boxed{\text{Rectifier}}$ $\xrightarrow{dc}$ $\boxed{\text{Calibration}}$

↳ $V_o = \begin{cases} 0.318\, V_m, & HWR \\ 0.636\, V_m, & FWR \end{cases}$



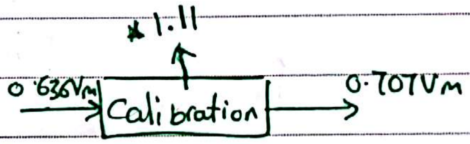
Galvanometer (average) $\longrightarrow V_o = \frac{1}{T}\int x(t)\,dt$

$$= \frac{1}{2\pi}\int_0^{\pi} V_m \sin\theta \, d\theta$$

$$= 0.318 V_m$$

* Calibration for Pure AC

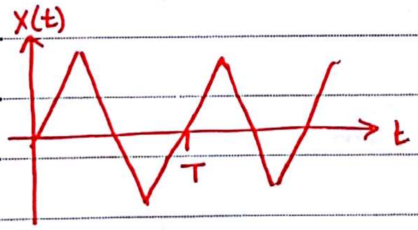
$V_{o_{FWR}} = 0.636 V_m$



$V_{rms} = 0.707 V_m \rightarrow$ Desired

SF = 1.11
↳ Safe factor

* For Triangular wave form



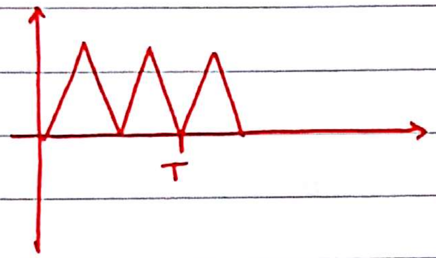
$$V_{rms} = \frac{V_m}{\sqrt{3}}$$

$$V_{avg} = \frac{1}{T}\int x(t)\,dt = \frac{V_m}{2}$$

$$\text{Error} = \frac{\frac{V_m}{2} * 1.11 - \frac{V_m}{\sqrt{3}}}{V_m/\sqrt{3}} * 100\%$$

$$\text{Error} = -3.81\%$$

V_{avg} for FWR Triangular waveform



Fluke

22/6/2017

Digital Meter :-

* $4\frac{1}{2}$ digit display → 4 digits display from 0~9
  ↳ 1 digit displays only 0/1

ex. 19,999 → $4\frac{1}{2}$ digits maximum value

* $4\frac{3}{4}$ digits → 4 digits from 0~9
  ↳ 1 digit from 0~3

here maximum value (count) = 39,999

* accuracy → ± % * full-scale (analog)
  ↳ (digital) ± % * reading ± x counts
  ↳ go to LSD
  Least Significant Digit
  LSD * x

ex. 1.99 ± 2 :

accuracy = 1% * 1.99 ± 2 * $\underbrace{0.01}$ → LSD weight

ex. 1.999 ± 2 :

accuracy = 1% * 1.999 ± 2 * 0.001

* counts : when we increase the range, LSD weight will increase (resolution decreases)

ex. $3\frac{1}{2}$ digits

200 V	_ 2 0 0 (0,1)	LSD = 10^0 = 1 V
20 V	_ 2 0 . 0	LSD = 0.1 V
2 V	_ 2 . 0 0	LSD = 0.01 V → highest resolution biggest # of digits after (.)

Ex Digital (0.6 % ± 1) 3 ½ digit
Analog (2 % + full scale) 25 V
find accuracy when reading 20 V

sol ① digital : _ 20.0
0, 1

accuracy = 0.6 % * 20 ± 1 × 0.1

counts LSD weight

/ _ _ _ _ _ _ _

29/6

Digital Multimeter - Counts

4digits Multi meter

1000 → _ _ _ _ $\underbrace{\quad\quad\quad}_{0-9}$ → weight 1 Volt

Digital Multimeter - Range

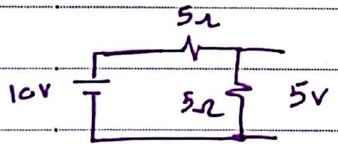
Digital

reading 001.8

Accuracy 5% ± 1 count

error 5% reading ± 1 count ⇒ 5% redding ± 0.1 count

*



* error range 10V

* error range 100v (bigger error)

$3\frac{1}{2}$ _ _ _ _ (0, 1) (0-9)

Range 10 V → _ _ . _ _ 0.01 count

Range 100V → _ _ _ . _ 0.1 count

Range 20V → _ _ _ . _ 0.1 count

Analogue → 5% of Full Scale.
Digital → 5% of Reading.

Ex : Analogue | Digital

Scale → 25 V

Accuracy → 2% | 0.6 % reading ± 1 counts

error = 2% × 25 = ± 0.5 V | $\frac{0.6}{100} \times 20 \pm 1 \times 0.1$

error = $\frac{0.5}{20}$ = 2.5%

$3\frac{1}{2}$ → _ 2 5. _

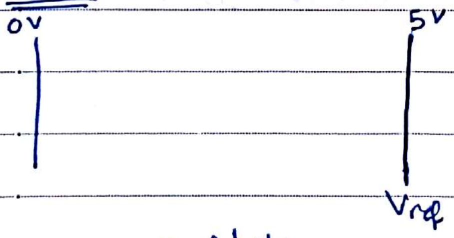
25 V full Scal

error = 0.12 ± 0.1

=

* Analogue to Digital Converter

ADC



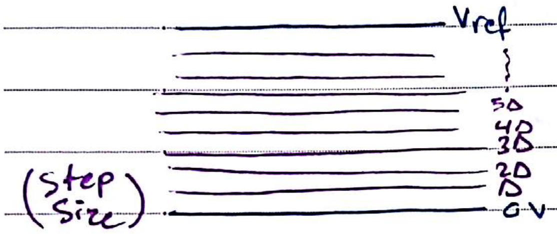
S/H → sample & hold

# of bits

each Sample → n bits

3 bits → 8 levels

n bits → # of levels = 2^n



$$\boxed{\Delta = \frac{V_{ref}}{2^n}}$$

3 bits

111
⋮
011
010
001
000

~~error =~~

$$\boxed{\text{Quantization Error} = \frac{\Delta}{2}}$$

$$\boxed{\text{Quantization Error} = \frac{V_{ref}}{2^{n+1}}}$$

$$\boxed{\text{Quantization Error\%} = \frac{V_{ref}}{2^{n+1} * V_{ref}} * 100\% = \frac{1}{2^{n+1}} * 100\%}$$

$$\boxed{QE\% = \frac{\Delta/2}{V_{ref}}}$$

Ex

Signal → [ADC, 8 bit] → level 80, level 150 , find Step Size??

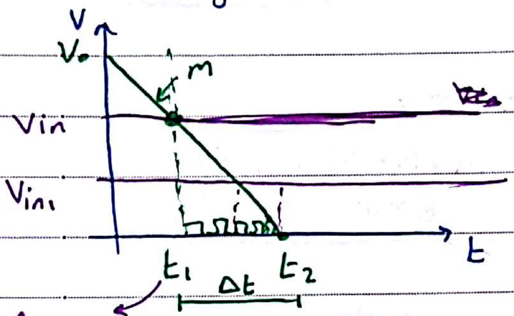
800–1500 mV

800 mV → level 80 (80 Δ)
1500 mV → level 150

800 mV = 80Δ → $\boxed{\Delta = 10\ mV}$

* Ramp - Type Digital Voltmeter

"Voltage to time Conversion"



conversion time

$V_o - mt$ "ramp"

$V_o - m t_1 = V_{in}$

$V_o - m t_2 = 0$

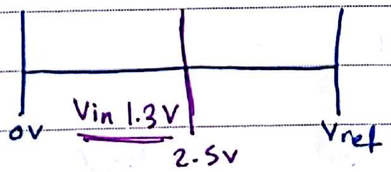
$-m(t_2 - t_1) = -V_{in}$

$t_2 - t_1 = \Delta t = \frac{V_{in}}{m}$

$\boxed{V_{in} = m \Delta t}$ → counter

* Successive Approximation Digital Voltmeter

$V_{in} \Rightarrow$ digital



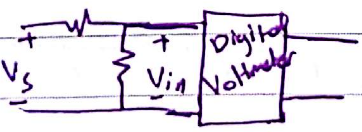
Compare Vin with 2.5V ⇒ Vin < 2.5V ⇒ 0

" Vin with 1.25 V ⇒ Vin > 1.25 v ⇒ 1

" Vin with 2.

bits

010

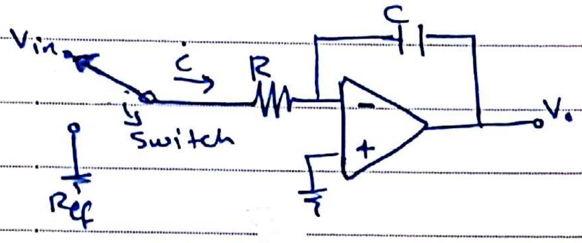


Step Size $= \frac{5}{8} = \frac{V_{ref}}{2^n}$

$= \frac{5}{8} \times 2 = \frac{5}{4} = 1.25$

Vin | Voltmeter

* Dual Slope Digital Voltmeter



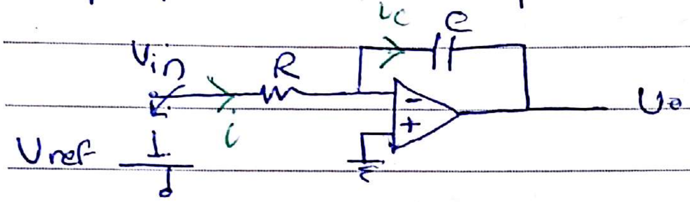
$$i = \frac{V_{in}}{R}$$

$$\frac{1}{C}\int i\,dt + V_o = 0 \Rightarrow V_o = -\frac{1}{RC}\int V_{in}\,dt$$

2/7/2017

Dual-slope Digital Voltmeter → 3rd type

↪ purpose: reads input



$i = V_{in}/R$

$V_c = \int i\,dt + V_{initial}$

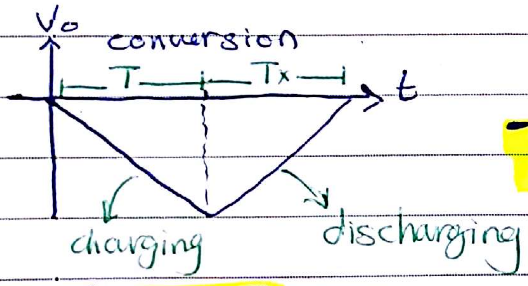
$\frac{1}{C}\int i\,dt + V_o = 0$

$V_o = \frac{-1}{RC} V_{in} * T$

(unknown) V_{in} ⇒ T (known)

(known) V_{ref} ⇒ T_x (unknown)

Conversion Time = $T + T_x$



$T_x = \frac{V_{in}\,T}{V_{ref}}$

slope = $\frac{-T}{RC}$

*if Vin bigger needs more conversion time

$\boxed{Ex}$ $R = 100\,K\Omega$ $C = 0.01\,\mu F$ $T = 10\,mS$ $V_{ref} = 10V$

find T_x & conversion time if $V_{in} = 6.8V$

<u>sol</u> $T_x = \frac{V_{in} * T}{V_{ref}} = 6.8ms$

conversion time $= 6.8 + 10 = 16.8\,mS$

R, C are used when drawing

in the question: Vin (input voltage)

Vref (known voltage)

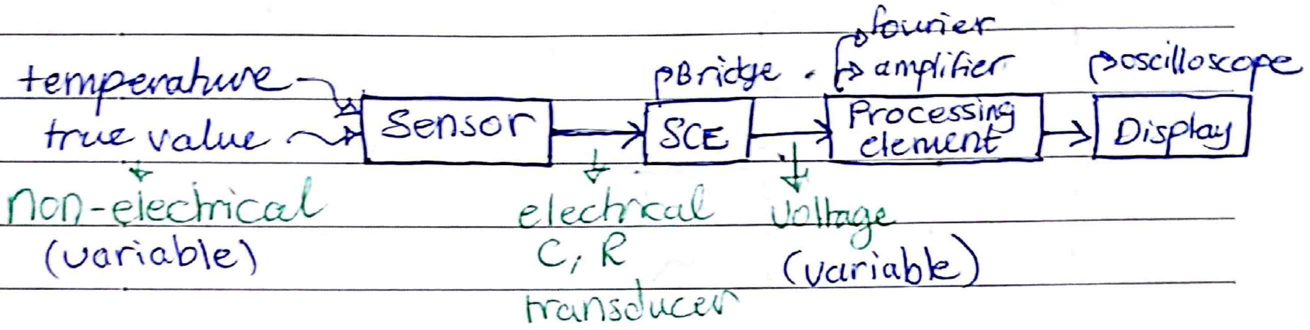
بيجي وصف
مش رموز

Scanned by CamScanner

→ how to check errors in energy & wattmeters
→ smart meters with internet & communication
* wattmeter will be given at end of the semester.

* في سؤال على نظام الشرائح

Bridges

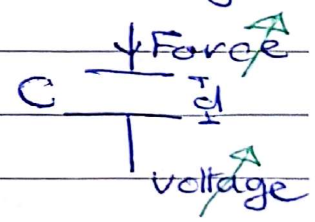


* Bridge: produce output in voltage form that changes as measured quantity changes

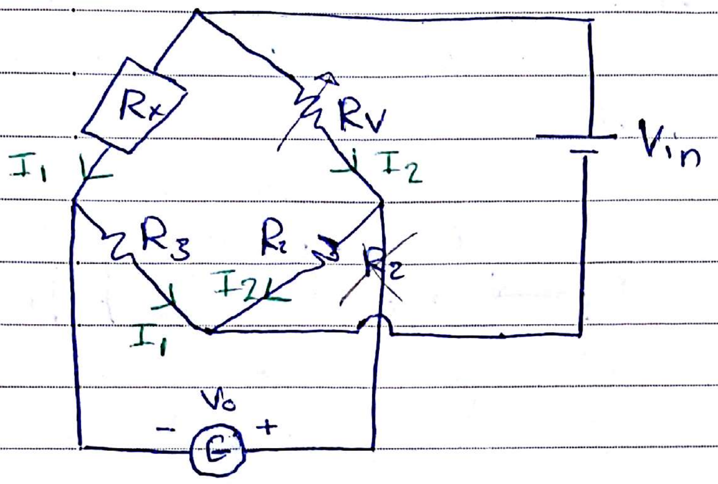
AC → R
→ C
→ L
→ f

DC → R

ex. when sensing capacitance, distance changes & bridge reads change in voltage



DC bridge → doesnt have different freq.
wheatstone bridge
→ Null method صفر (Voltage = 0)
→ Deflection method
④ V = f(R)
→ function of resistance



ممكن موقع ال G
بتغير المهم نعرفا
مين series وكيف
توزيع ال current

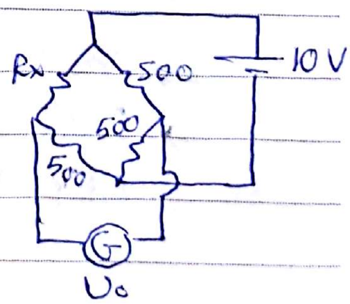
Rx → from non-electrical
Rv → variable resistance

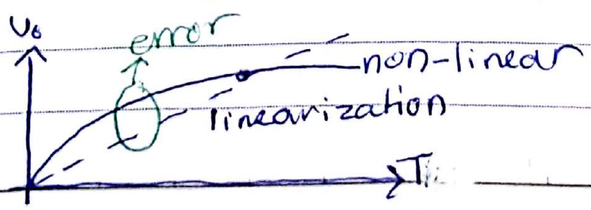
Null → $\vec{R_V}$ $V_o = 0$ (balanced) $R_2 R_x = R_3 \vec{R_V}$
set Rin of galvanometer = ∞ so $i_g = 0$

$$V_o = \frac{V_{in}}{R_x + R_3} * R_x - \frac{V_{in}}{R_V + R_2} * R_V$$ → voltage division

Ex a thermometer (0 → 50°c)
R = 500 Ω @ 0°c
ΔR = 4 Ω/°c   Vin = 10 V
$R_1 = R_2 = R_3 = 500\ \Omega$ → no variable R

deflection ; purpose is to see relationship between Rx & Vo as Rx changes with temperature





$V_o = f(R_x) \approx f(T)$ ⇒

sol $\quad 0^\circ C \Rightarrow R_x = 500\ \Omega$

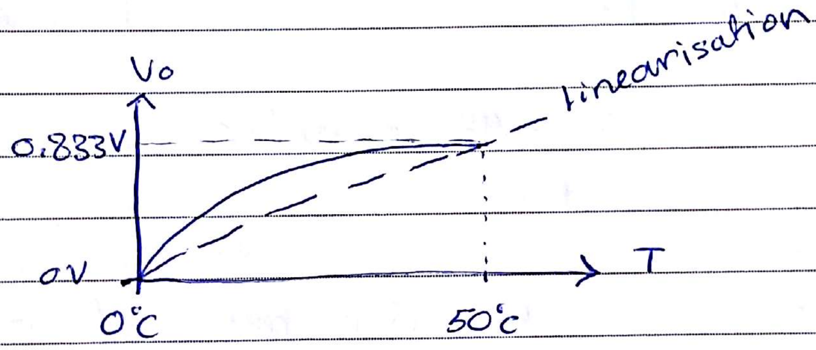
$$V_o = V_{in}\left(\frac{R_x}{R_x+500} - \frac{500}{1000}\right) = 0$$

$50^\circ C \Rightarrow R_x = 500 + 4\times 50 = 700\ \Omega$

$$V_o = 10\left(\frac{700}{700+500} - \frac{500}{1000}\right) = 0.833$$

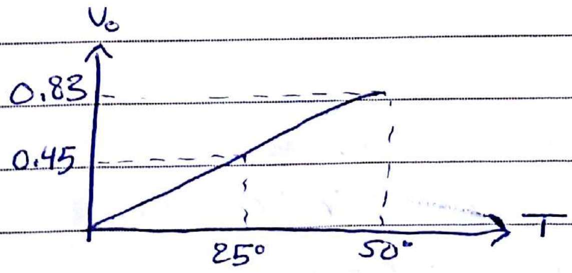
note V_o & R_x are non-linearly related

actual



linearisation : $V_o = \text{slope} * T = 0.016 * T$

approximation



actual : $R_x = 500 + 4T$

$$V_o = V_{in}\left(\frac{500+4T}{500+4T+500} - \frac{500}{1000}\right)$$ غيرمباشر

approx : $V_o = 0.016\ T$

error : actual − approx.

max error : $\frac{d}{dT} = 0$ (maximum value المشتقة)

3/7/2017

Project → note: may be included in final exam

1) Piezo Electrical tiles
2) Lab view (basics) + demonstration + example
3) Power Quality analyzer (harmonics)
4) Energy Meters (single & three phase)
   - ↳ electro mech
   - ↳ electronic
   - ↳ smart

group of 4-5 students

bonus 5 marks

* slides
* presentation 30 – 45 minutes
* examples & maths
* Simulation

presentations will be after material is finished (maybe 11-12-13/7)

* search youtube : 3 min PhD UK

$\boxed{Ex}$ same as previous example

a resistance thermometer ($0° - 50°C$)

$R = 500\,\Omega$ @ $0°C$ $\Delta R = 4\,\Omega/°C$

$V_{in} = 10V$ $R_1 = R_2 = R_3 = 500\,\Omega$

Bridge $V_o = V_{IN}\left(\frac{R_x}{R_x + R_3} - \frac{R_1}{R_1 + R_2}\right)$

$R_x = 500 + 4T$

actual : $V_o = V_{in}\left(\frac{500+4T}{500+4T+500} - \frac{500}{1000}\right)$

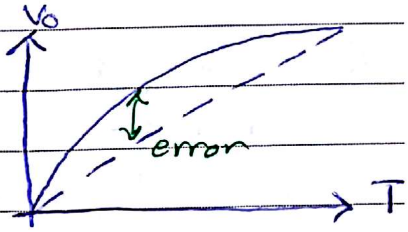
approximation : linearization

$0°C \rightarrow V_o = 0\ V$

$50°C \rightarrow V_o = 0.833\ V$

$V_o = 0.016\ T$

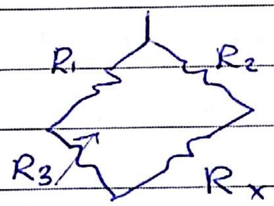
$$error = \underbrace{10 * \left(\frac{125 + T}{250 + T} - 0.5 \right)}_{actual} - \underbrace{0.016\ T}_{approx}$$



max error $\frac{d(error)}{dT} = 0$

Ans: max error @ $T = 23.86°C$ $e = 37.96\ mV$

* measurement errors



(Null, balanced) $V_o = 0$

$R_1 R_x = R_2 R_3$

$\Rightarrow R_x = \frac{R_2 R_3}{R_1}$

where $R_2 = R_2 \pm \Delta R_2 \rightarrow$ tolerance

$R_3 = R_3 \pm \Delta R_3$

$R_1 = R_1 \pm \Delta R_1$

remember Limiting error $\rightarrow$ max (take +), $\rightarrow$ min (take −)

$$R_x = \frac{(R_2 \pm \Delta R_2)(R_3 \pm \Delta R_3)}{R_1 \pm \Delta R_1}$$

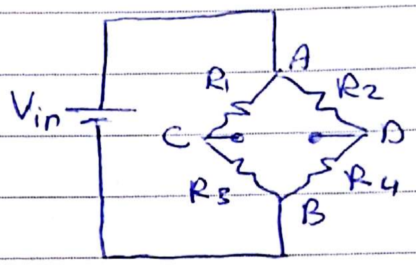
approx. $\Delta R_2 \times \Delta R_3 \approx 0$

$$\underbrace{R_x}_{\text{Range of } R_x} = \underbrace{\frac{R_3 R_2}{R_1}}_{\text{nominal value without error}} \left(1 \pm \frac{\Delta R_1}{R_1} \pm \frac{\Delta R_2}{R_2} \pm \frac{\Delta R_3}{R_3} \right)$$

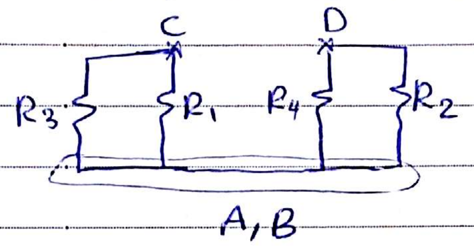
Sensitivity of Galvanometer

for unbalanced wheatstone find thevinin equiv.

$V_{th} = V_{in} * \left(\frac{R_1}{R_1+R_3} - \frac{R_2}{R_2+R_4} \right)$



$R_{th} = (R_3 // R_1) + (R_4 || R_2)$



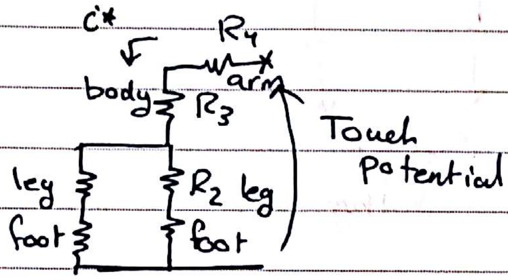
* note if it was current source instead of Vin we will get $(R_1 + R_3) // (R_2 + R_4)$

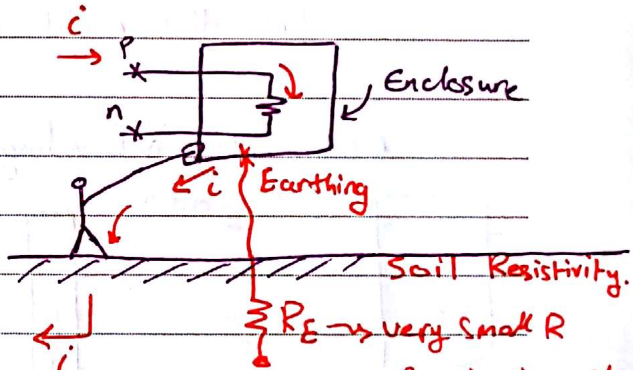
8 slides 126, 131 only the circuits & their names

Earthing ~~Grounding~~:

~~Tach~~ Touch & Step Voltage

touch Voltage



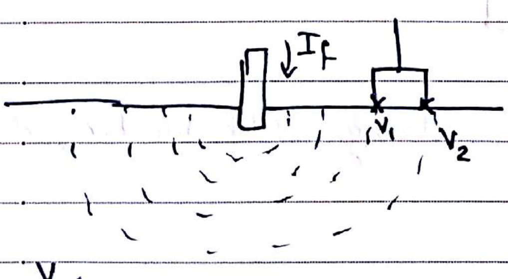


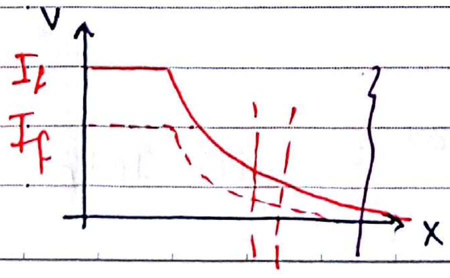
So that most I would go through it.

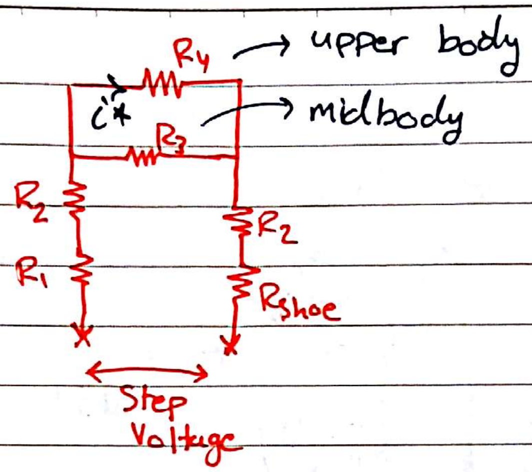
*Step Voltage

One leg has more Potential than the other which will produce current in your body.

this happens when a fault occur is P system.



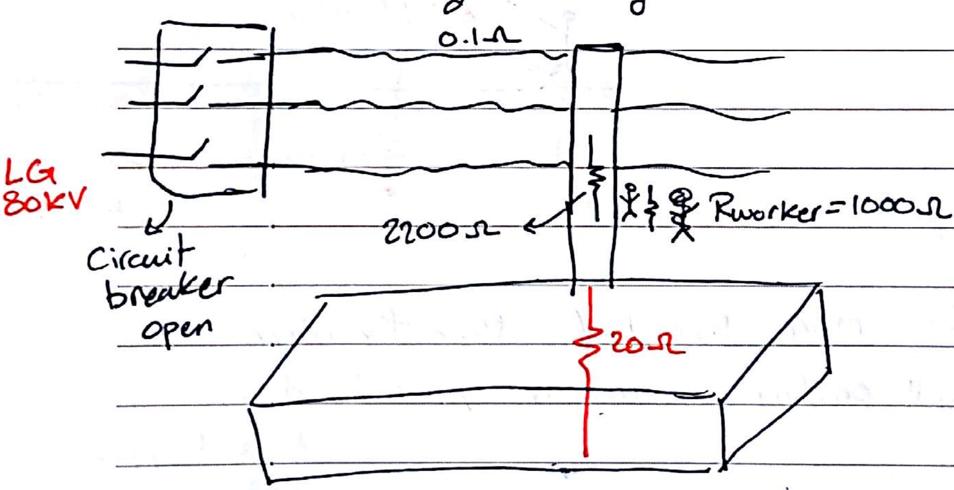




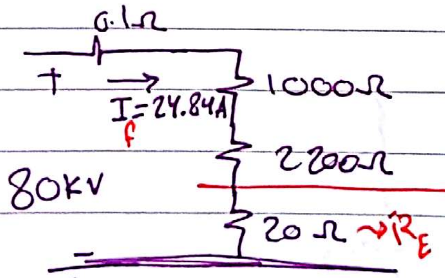
current, time
⇓ fault ⇓ protection system.
{ detects error, clear the faulted part of the entire system by o.c the breaker. }

* if current fault is there for a long time this might cause fires. $\boxed{I^2 R * t = \text{Energy}}$

* Grounding & Bonding

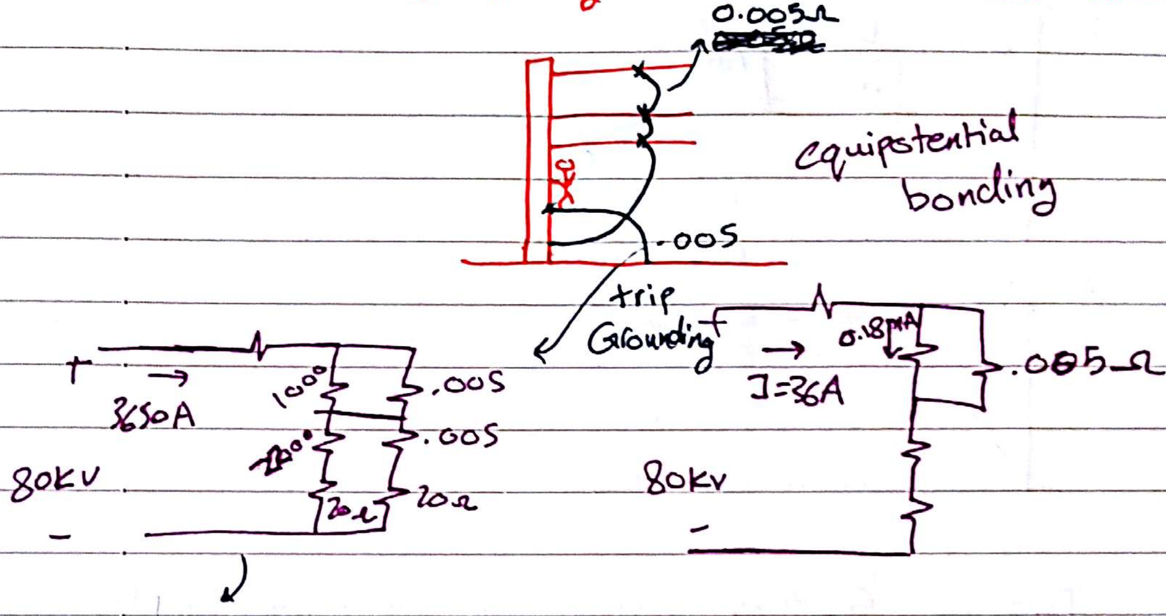


A problem could occur by closing ckt breaker, due to lack of coordination.



$GPR = I_f R_E$

Solution : by putting R parallel to the worker

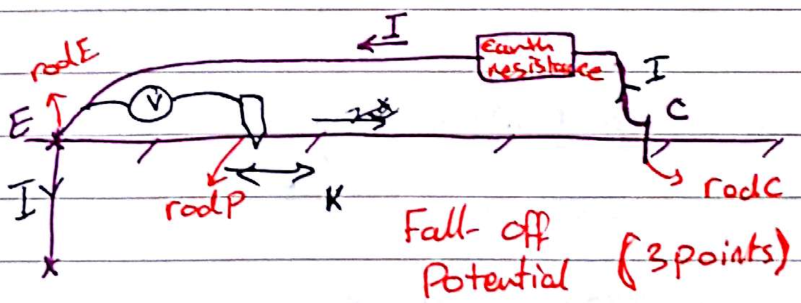


that is to increase I_f so that the protection system can detect it.

~~and by~~

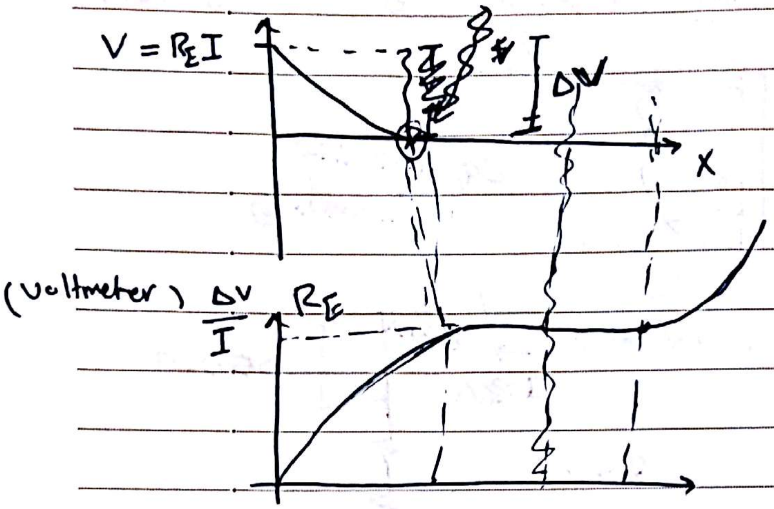
* Measurement of Earthing
Earth Resistance

$R_E = \frac{V}{I}$

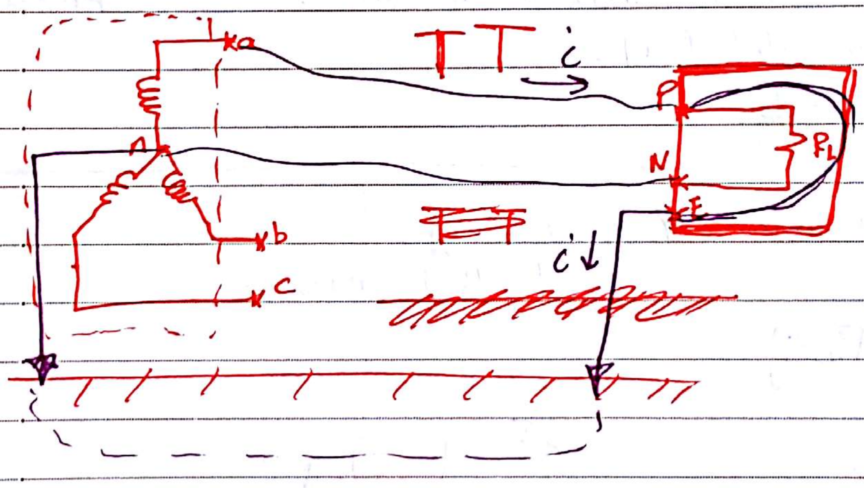


~~$R_E = \frac{V}{I}$~~

when Ⓥ = 0V



* Types of Earthing System, for electricity Supplies.



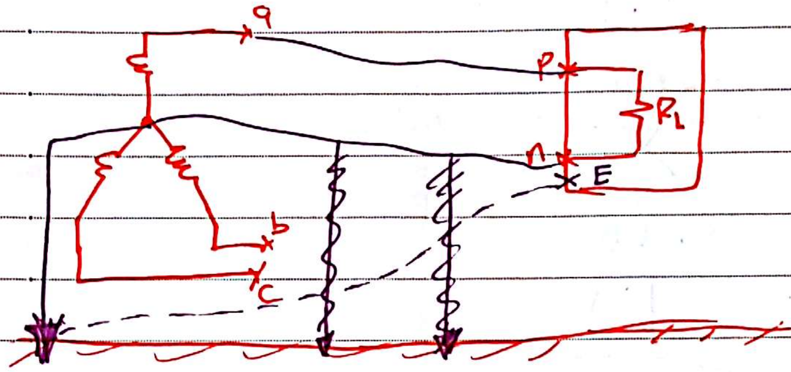
Ground loop resistance

$\simeq 20\,\Omega$

$I_{LG} = \dfrac{230V}{20\,\Omega} = \underline{11.5\,A}$ → Small Current {MCB will not trip}

اعرف الجهاز اللي بيحسب الفرق بين الcurrents
بال n و ال P lines ؟؟

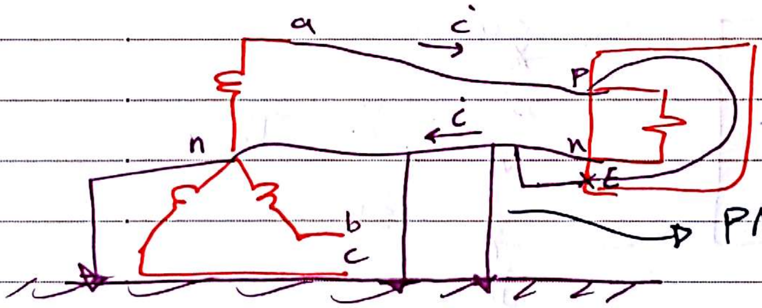
TN-S → seperate



{The wire can be cut which is a problem because consumers will not have earthing system

$$I_{LG} = \frac{230}{0.8\Omega} = \cancel{278A}\ 287A$$

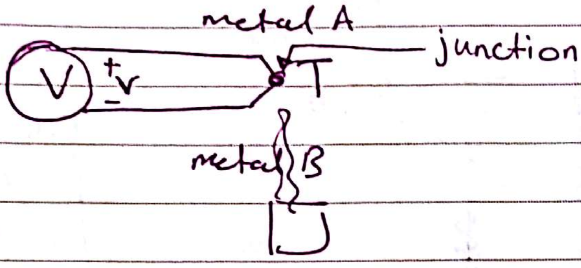
~~TSN~~ TN-CS (combined, separate consumer)

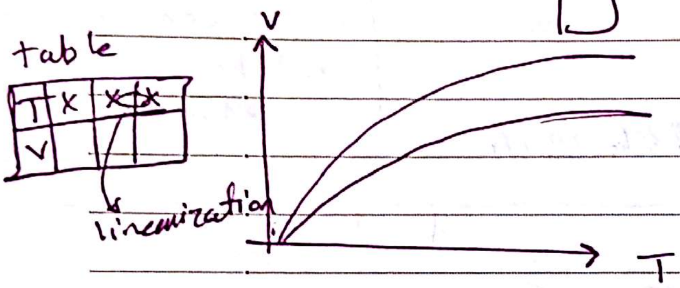


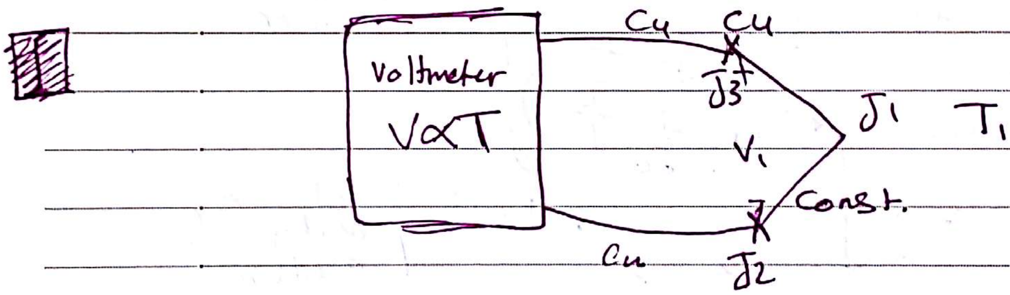
PME {Protective multiple earthing}

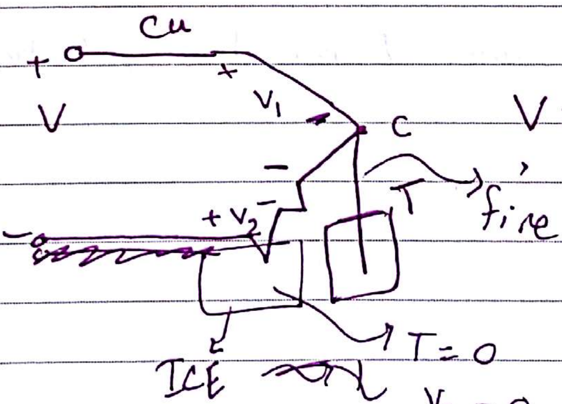
we do PME because E now has potential difference.

Thermocouple < type J, type K, type T









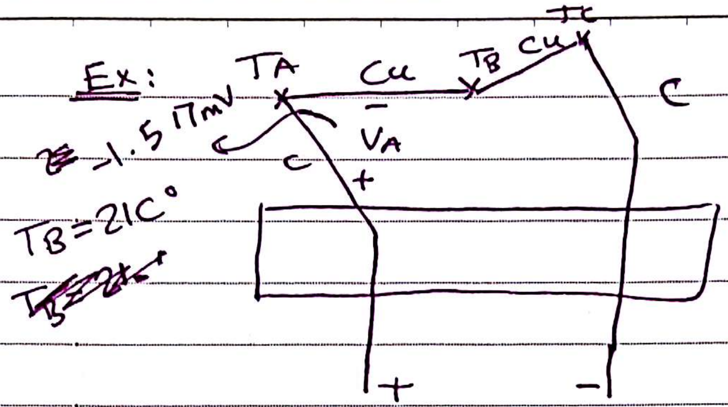
$V = V_1 - V_2$

$V_2 = 0$

$\downarrow$

$V = V_1$

Ex:



V_C ??
V_B
T_A !!
T_C

Cu-C $\qquad E_T = 2.05\,mV$

T	
E	

$V_B = 0V$ (Cu-Cu)

$-E_T + V_A + V_C = 0$

$V_C = E_T - V_A$

$= 3.567\,mV$

from Table

$T_A = 37.78°C$

$T_C \rightarrow$ you need linearization

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