Spring017

POWERUNIT

MEASUREMENTS

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Powerunit-ju.com

Measurements

second semester
(2017)

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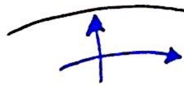
※ Instrument:
- → Device Collect Data.
- → Display.
- → Optional (Analysis)

* Instruments → Analog
- → Digital.
  - → Store data.
  - → A/D, D/A.

Ammeter.
$T \propto i$



Deflection.

EN50160 standard
Distribution code

1 week
10-min $\Rightarrow$ 95% within voltage Limit.
$-6\% \leq \Delta V \leq 10\%$

* Does this instrument provide true value?

true value $\triangleq$ theoritical value based on models.

* Characteristics of measurement instruments:

① Accuracy: How close is the reading from the true value.

Ex. Volt meter:
measured value = 10 V.
accuracy = 10% (close to the true value)
Range 0-15V
find true value?

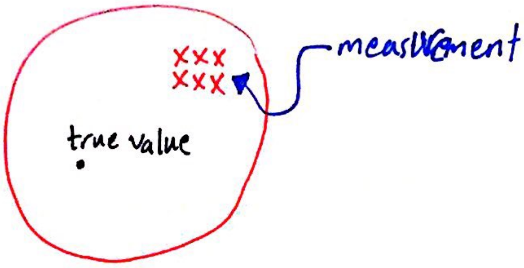
True value $= 10 \pm (10\% * 15)$
$= 8.5 \text{ volt} \rightarrow 11.5 \text{ volt}.$

*Accuracy (expressed inaccuracy)

Scanned by CamScanner

② Precision: $\Rightarrow$ Reproducibility.

Ex.



for Ex. $\Rightarrow$

* High precise.
* Low accuracy.

③ Sensitivity: it is the ability to respond to the changes in the measured quantity. (inputs).

$$S = \frac{\Delta\, output}{\Delta\, input}$$

④ Threshold: minimum input that could be measured.

⑤ Resolution: —.

Precision:

metric.

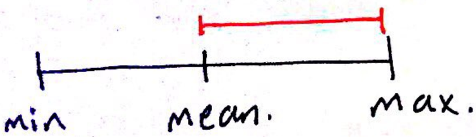
$\sigma \triangleq$ standard deviation.

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

Expectation. Mean.

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

Reading. mean "average" Sample size.



$|max - mean| \longrightarrow$ precision.

we use it to compare between two devices to know which one has better precision.

$\Rightarrow$ the smallest value $|max-mean|$ is ~~higher~~ higher precision.

Ex. A voltmeter is used to read voltage of 5V. "DC Load" "snapshot"

A: " 5.03, 4.97, 5, 5.02, 4.99, 4.98, 5.03, 5.02, 5.01, 4.97"

B: " 5.2, 5.2, 5.2, 5.2

⇒ Compare accuracy, precision ?

Accuracy:

A true = 5V.
mean = 5V.

B true = 5V.
average = 5.2 V.

A is more accurate than B.

Note:

reading	10	8	20
freq.	100	20	80

$$\bar{X} = E[X]$$
$$= 10 * \left(\frac{100}{200}\right) + 8 * \left(\frac{20}{200}\right) + 20 * \left(\frac{80}{200}\right)$$
$$= 13.8$$

mean
average.

precision:

the precision in B is higher than in A.

A

4.97 5 5.03

⇒ |max − mean| = 0.03.

B

5.2

⇒ |max − mean| = 0.

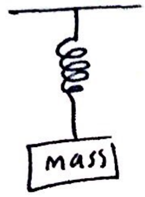
Ex. (Resolution) A digital system (A/D) uses a specific # of bits
How much is the resolution ? (Full scale = 5 V).
12 bits

12 bits ⇒ # of levels = 2^{12}

$$\text{Resolution} \equiv \text{step size} = \frac{5}{2^{12}} = 1.221 * 10^{-3}$$

Ex. (Sensitivity)

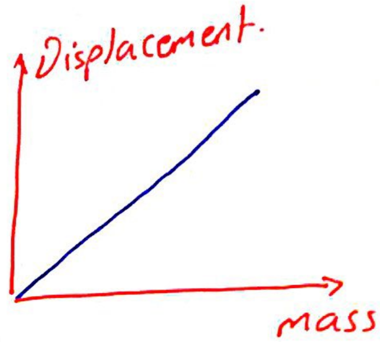
measurent system aims to measure the mass



$\Rightarrow$ mass $\propto$ Displacement.

always like these table it must have operating condition.

input (Kg)	0	50	100
o/p (cm)	0	10	20

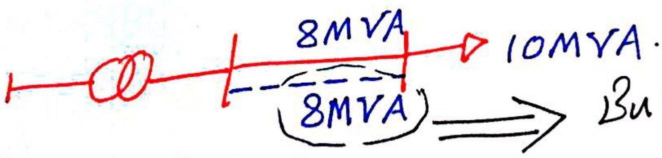


sensitivity $\triangleq$ slope $= \frac{10}{50}$ cm/Kg.

$\Rightarrow$ power-system single line diagram.

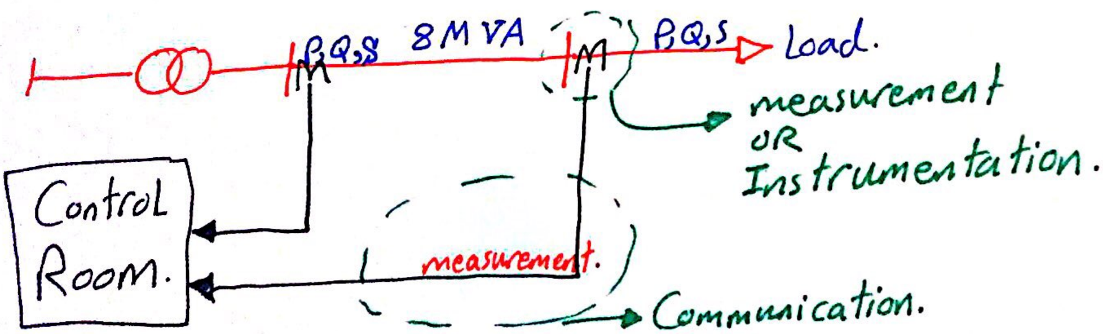
we can't do this.

$\Rightarrow$ Solution ①: install new line.



$\Rightarrow$ But This need time and cost.

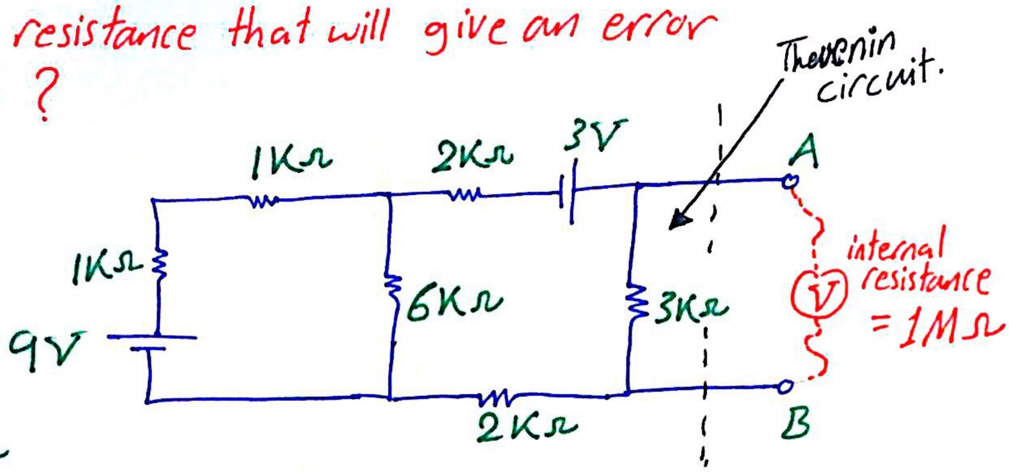
$\Rightarrow$ Solution ②: Control load $\Rightarrow$ "Active Network Management".



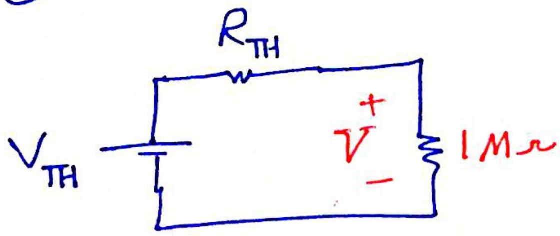
Example:

For the shown circuit:

1. Find the error in the measurement ?
2. Find the internal resistance that will give an error Smaller than 1% ?



(1) $R_{TH} = 2K\Omega$



$V_{real} = V_{th}$ (when $R_V \to \infty$)

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

$$= 0.998\, V_{th}.$$

$$Error = \frac{V_{real} - V_{measured}}{V_{real}} * 100\%$$

$$= \frac{V_{th} - 0.998 V_{th}}{V_{th}} * 100\% = \boxed{0.2\%}$$

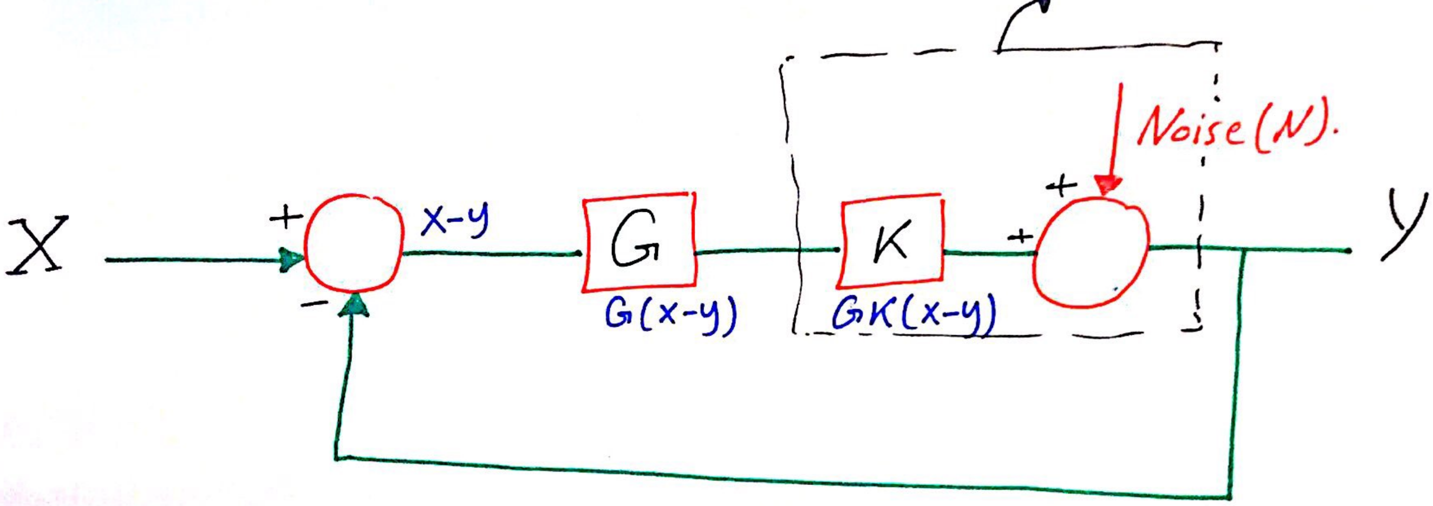
(2) final Answer:

$R_V \geq 198K\Omega$ To achive error smaller than 1%

$$\Rightarrow \left[1 - \frac{R_V}{R_V + 2K}\right] * 100 \leq 1 \quad \Rightarrow \quad 0.01 R_V \geq 1980$$

so $R_V \geq 198K\Omega$

* Transfer Function:



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

$$\Rightarrow y = \frac{X\,GK}{1+GK} + \frac{N}{1+GK}$$

if G is very large:

$\Rightarrow$ Eliminate the noise

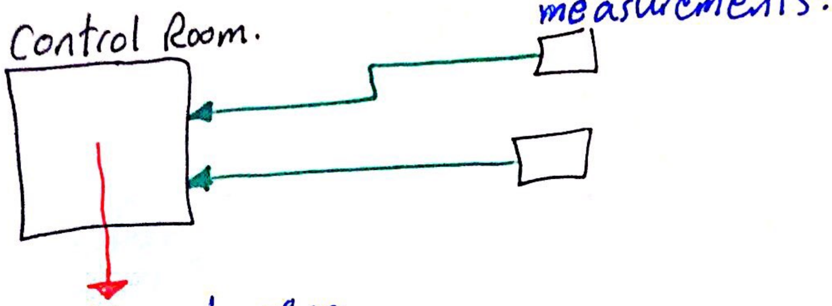
$$y = x$$

Note:
with No feedback
$y = XGK + N$
"open loop" system

Note:

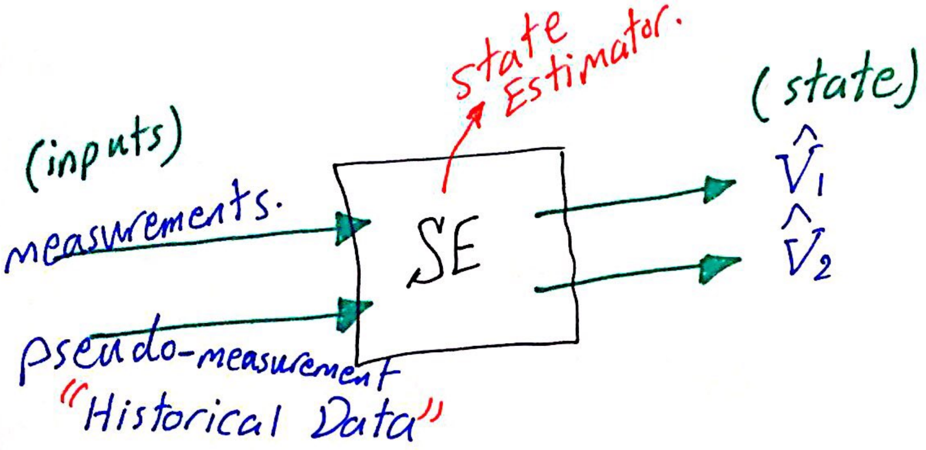
There is a Time Constant for the measurement.

※ State Estimation:



1] Monitoring.

2] Decision-making algorithm.



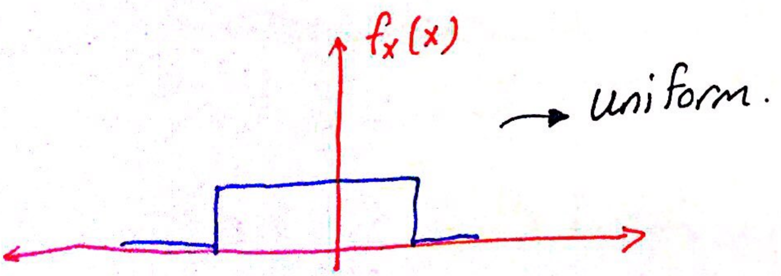
**

$$\sigma^2 = \frac{1}{n} \sum (x - \bar{x})^2$$

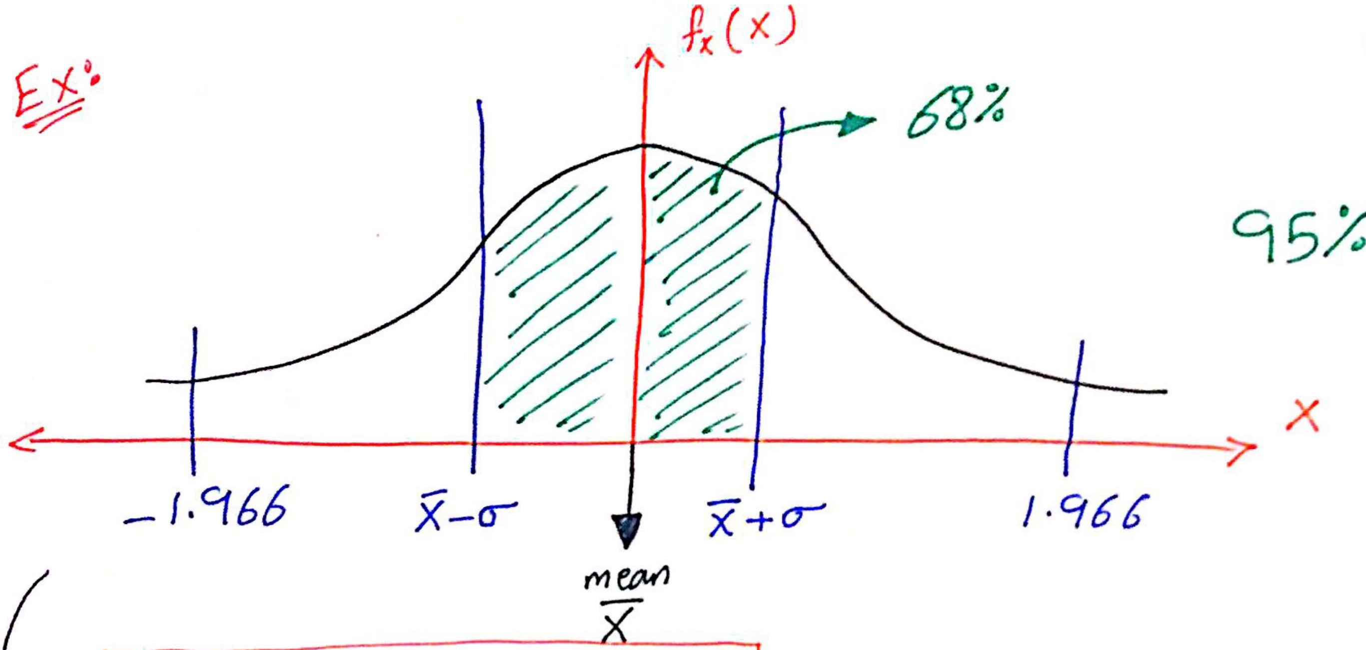
σ^2 → Variance.
n → sample.
x → measurement
$\bar{x}$ → mean.

$\sigma \triangleq$ standard deviation.

*
$$\text{mean} = \frac{1}{n} \sum X$$
$$\text{mean} = \sum x_i \, P_r(x_i)$$
*



Ex:



$$\boxed{f_x(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{\frac{-(x-\bar{x})^2}{2\sigma^2}}}$$

$$Pr(\bar{x} - 1.966 \leq X \leq \bar{x} + 1.966) = 95\%$$

$$Pr(\bar{x} - 6 \leq X \leq \bar{x} + 6) = 68\%$$

※ Pdf: "probability density function".

symbole $\rightarrow$ $f_x(X)$.

$$\Rightarrow Pr(X_1 \leq X \leq X_2) = \int_{X_1}^{X_2} f_x(x)\,dx.$$

※ cdf: "comulative distribution function".

$$\Rightarrow F_X(X_0) = Pr(X \leq X_0)$$

↳ it is called non decreasing.

$$\Rightarrow \int_{-\infty}^{X_0} f_x(x)\,dx.$$

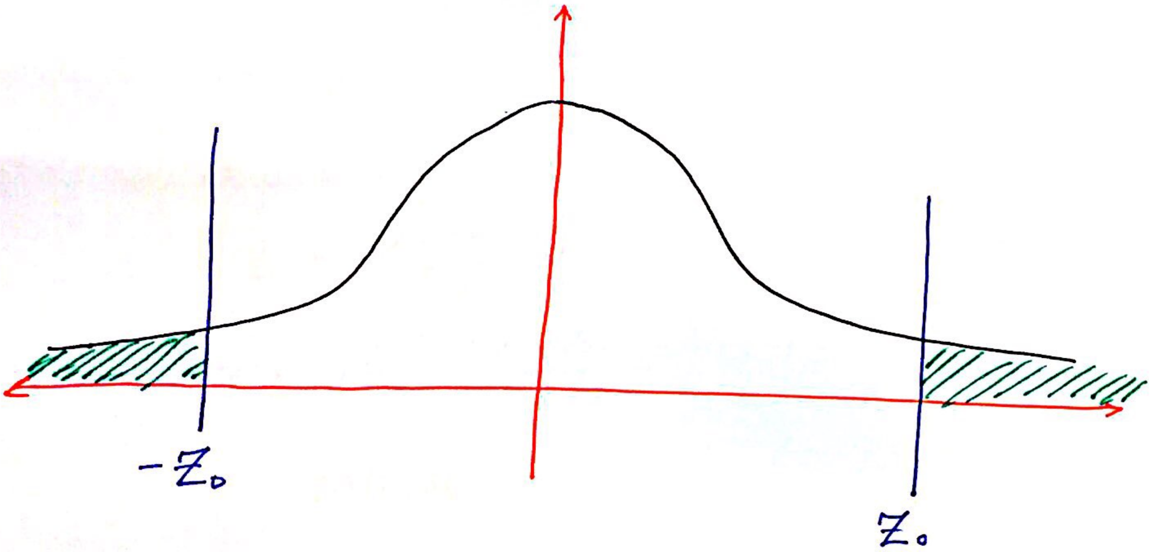
(9)

$F_X(X_0) = P_r(X \leq X_0)$

$Z_0 = \dfrac{X_0 - mean}{\sigma}$

from table.

* How to find Z_0 from table:



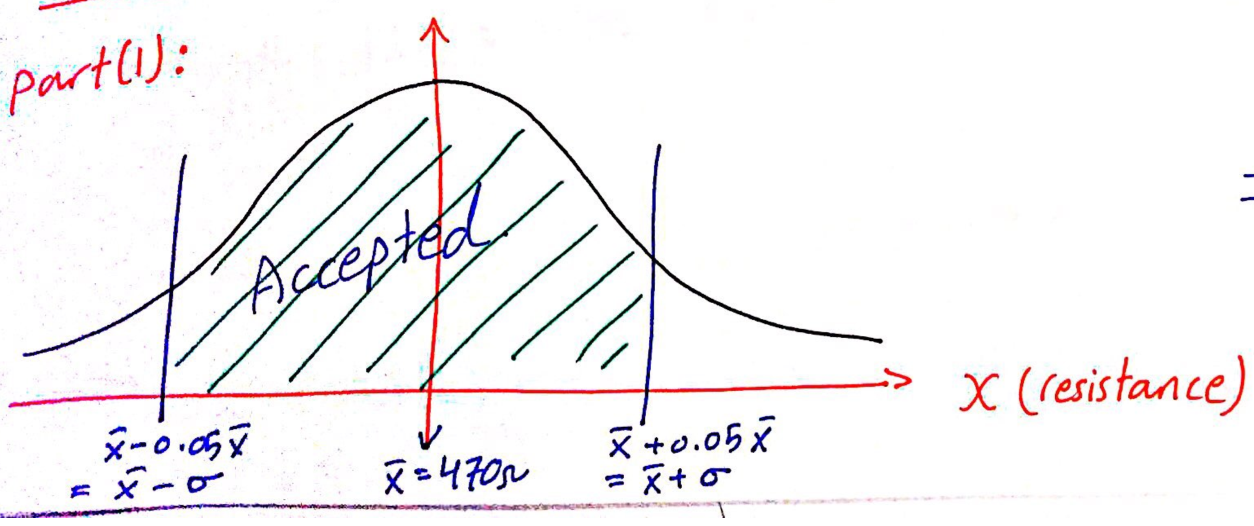
if we want to find $f(-Z_0)$:

$f(-Z_0) = 1 - F(Z_0)$

Example: slide 21

$0.05\bar{x} = 23.5 = \sigma$

part(1):



$\Longrightarrow$

$\Rightarrow$ accepted:

$$[\bar{x}-\sigma \leq x \leq \bar{x}+\sigma] = \underline{\underline{68\%}}$$

But assume we don't Know that is $= 68\%$!!

$$\Rightarrow \quad P_r(\bar{x}-0.05\bar{x} \leq x \leq \bar{x}+0.05\bar{x})$$

$$= P_r(x \leq \bar{x}+0.05\bar{x}) - P_r(x \leq \bar{x}-0.05\bar{x})$$

$$= F_x(\bar{x}+0.05\bar{x}) - F_x(\bar{x}-0.05\bar{x})$$

$\Rightarrow$ Now from table:

$$z = \frac{x - \text{mean}}{\sigma}$$

$$\Rightarrow \quad F_z\left(\frac{\bar{x}+0.05\bar{x}-\bar{x}}{\sigma}\right) - F_z\left(\frac{\bar{x}-0.05\bar{x}-\bar{x}}{\sigma}\right)$$

substitue $\bar{x} = 470$, $\sigma = 23.5$

so $\Rightarrow \quad F_z(1) - F_z(-1) = 68\%$ Acceptance value.

* For rejection:

$P_r(\text{rejection}) = 1 - 68\% = \underline{\underline{32\%}}$

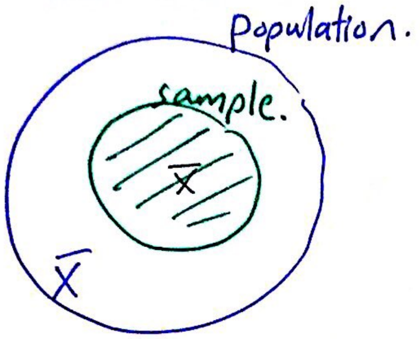
$\Rightarrow \quad 32\% * 10,000 = \boxed{3174}$ resistors will be rejected.

Part(2):

$\bar{x} = 475\,\Omega$ $\quad$ +5 $\quad$ +5 $\quad$ cancel each other. so standard deviation doesn't change.

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

※ Standard Error of the mean:



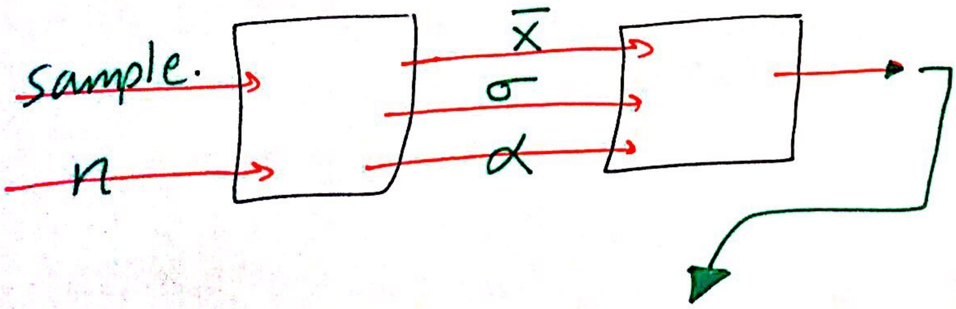
$\Rightarrow$ Confidence Level.

2.2	3.25	68%
2.5	3.5	95%
2.25	3.75	$\boxed{99\%}$

$\alpha \equiv$ standard error of the mean.

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

$X|_{\text{population}} = \alpha \pm X_{mean}$ under condition confidence level 68%



$\bar{X} \pm \alpha$ (confidence level 68%)

$\bar{X} \pm 2\alpha$ (confidence level 95.4%)

$\bar{X} \pm 1.96\alpha$ (confidence level 95%)

Example: slide (26)

Sample : $\bar{x} = \frac{\sum x_i}{N} = \boxed{35.93}\,\Omega$

$$\sigma_{n-1} = \sqrt{\frac{1}{N-1}\left[\sum_{i=1}^{N} (x_i - \bar{x})^2\right]}$$

$$= 0.365$$

$$\Rightarrow \alpha = \frac{\sigma}{\sqrt{n}} = \frac{0.365}{\sqrt{10}} = 0.115$$

confidence level 95.4%

$\rightarrow$ we have $\bar{x} \pm 2\alpha$

So mean true value is:

$35.93 \pm 2(0.115)$

※ Aggregation of Errors:

* Addition:

Assume two measurements with sum $= u$:

$u = V + W$

$V \rightarrow$ tolerance $\pm m\%$

$W \rightarrow$ tolerance $\pm n\%$

$\Rightarrow$ Ex.

Ex. $V = 10$ volt.
$\omega = 5$ volt.

$\Rightarrow u = v + w = 15$ volt. (No error).

with error:

Given: $v = 10 \pm 10\%$ & $w = 5 \pm 10\%$

for U_{max}:

$$U_{max} = 10 * 1.1 + 5 * 1.1 = 11 + 5.5 = 16.5 \text{ volt.}$$

for U_{min}:

$$U_{min} = 10 * 0.9 + 5 * 0.9 = 13.5 \text{ volt.}$$

* Multiplication:

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

Example: slide (32)

constant.

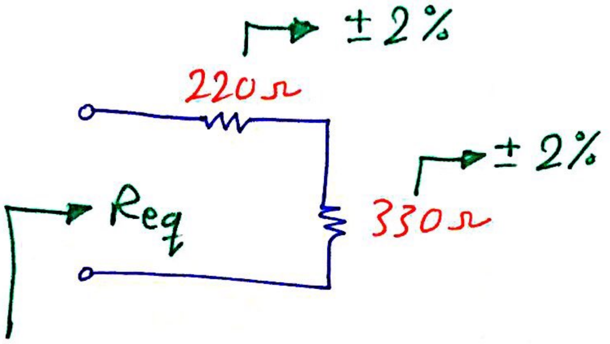
$$F = \frac{E\, A d}{l}$$

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

$$\left|\frac{\Delta F}{F}\right|_{min} = \frac{\Delta A}{A} + \frac{\Delta l}{l} + \frac{\Delta d}{d}$$

$$\left|\frac{\Delta F}{F}\right|_{max} = -\frac{\Delta A}{A} - \frac{\Delta l}{l} - \frac{\Delta d}{d}$$

Example: slide (36)



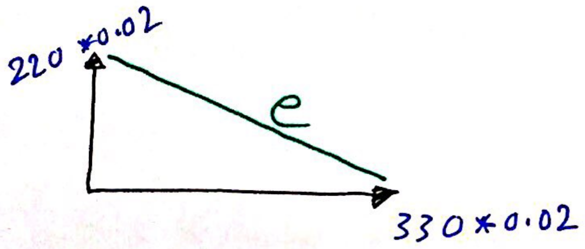
* using Limiting error:

$220 * 0.02 \longrightarrow 330 * 0.02 \longrightarrow$

$220(1+2\%) + 330(1+2\%)$

$= \boxed{561}\,\Omega$

* Using Probable error:



probable error:

$e = \sqrt{(220 * 0.02)^2 + (330 * 0.02)^2}$

$= \underline{7.93}\,\Omega$

for $R_{series} = 220 + 330 = 550\,\Omega$

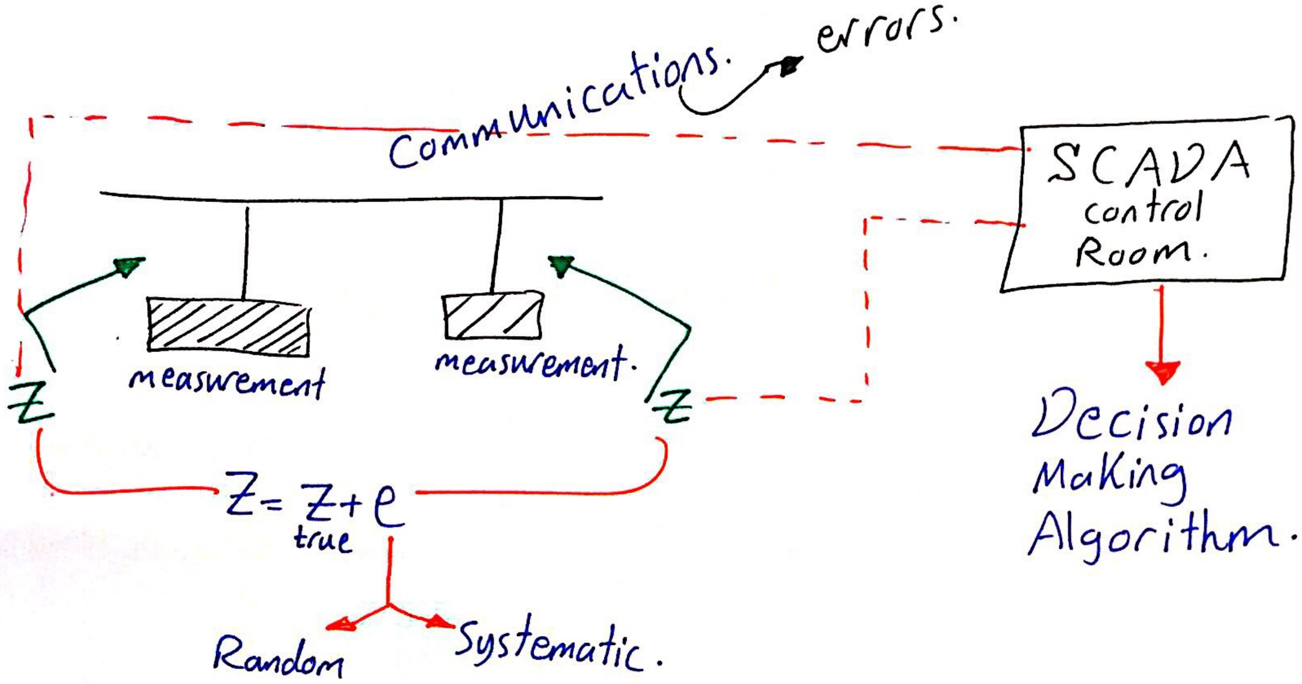
as a relative error:

$\text{Tolerance} = \frac{7.93}{550} * 100\% = 1.44\%$

so $R = 550 \pm (1.44\% * 550) = 557.92\,\Omega$

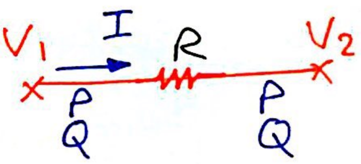
** The value in Probable error best than in Limiting error:
since Limiting error always take the worst case that both measurements had errors in same time.

※ State Estimation:



⟹ Know values of system states (voltages & angles at each node)

↳ from them you find current, P, Q.



[1] ** errors in measurments
in measurments/comms/SCADA.

[2] ** Not enough real measurements.

$$\underline{\underline{Z_i}} = h_i(x) + e$$

Z_i → measurements [Known.]

h_i → mathematical model.

x → states [UnKnown.]

e → error [UnKnown.]

* Random errors (assumptions)
  - Gaussian.
  - measurements are independent.

* Weighted lease square error: (WLSE)

$\Rightarrow$ minimization:

$$\min \sum_{i=1}^{m} \frac{[z_i - h(x)]^2}{\sigma_i^2}$$

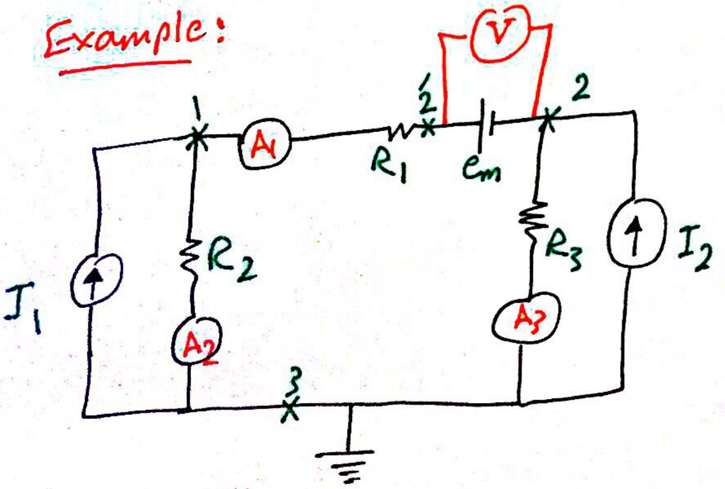
emphasis trusted measurements.

$\Rightarrow$ we solve it by Numerical Analysis "Newton-Raphson-Method"

* Pseudo measurements $\Longrightarrow$ Historical Data.

* linear Least Squares estimation:

Example:



I_1, I_2, e are all unknown

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

Measurements:

A_1 : $i_{12} = 1A$.

A_2 : $i_{31} = -3.2A$.

A_3 : $i_{23} = 0.8A$.

V : $e = 1.1$ volt.

$\Longrightarrow$

states $\begin{bmatrix} V_1 \\ V_2 \\ e_m \end{bmatrix}$??

$Z_i = h(x) \rightarrow \begin{matrix} V_1 \\ V_2 \\ e \end{matrix}$

* $i_{12} = \dfrac{V_1 - V_2'}{R_1}$; $V_2' = e_m + V_2$

$\Rightarrow i_{12} = \dfrac{V_1 - e_m - V_2}{1} \Rightarrow i_{12} = \boxed{V_1 - e_m - V_2 = 1}$ --- $\boxed{1}$

* $i_{31} = \dfrac{V_3 - V_1}{1} = -3.2 = \dfrac{0 - V_1}{1} \Rightarrow \boxed{-V_1 = -3.2}$ --- $\boxed{2}$

* $i_{23} = \dfrac{V_2 - V_3}{1} \Rightarrow \dfrac{V_2 - 0}{1} = 0.8 \Rightarrow \boxed{V_2 = 0.8}$ --- $\boxed{3}$

* $\boxed{e = 1.1\ v}$ --- $\boxed{4}$

As a matrix:

$$\begin{bmatrix} 1 & -1 & -1 \\ -1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ e \end{bmatrix} = \begin{bmatrix} 1 \\ -3.2 \\ 0.8 \\ 1.1 \end{bmatrix}$$

$$A \cdot \underline{X} = Z$$

↳ ?? since 4 equations & 3 variables.

$\Rightarrow$ "Best Solution"

Error $= Z - AX$

↳ minimize WLSE.

$A\underline{\underline{x}} = b \rightarrow$ measurements.

$\underline{\underline{x}} \rightarrow$ Best estimate.

$\Rightarrow$ minimize error between measurements & values resulting from the model.

$A_1 = 1A + e$

$\Rightarrow e = 1A - (h(x))$ → model.

$$[\text{Error}] = \begin{bmatrix} 1 \\ -3.2 \\ 0.8 \\ 1.1 \end{bmatrix} - \left\{ \begin{bmatrix} 1 & -1 & 1 \\ -1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ e_m \end{bmatrix} \right\} = \begin{bmatrix} 1 - V_1 + V_2 + e_m \\ -3.2 + V_1 \\ 0.8 - V_2 \\ 1.1 - e_m \end{bmatrix}$$

WLSE

$$\Rightarrow \min_{V_1, V_2, e_m} (1 - V_1 - V_2 + e_m)^2 + (-3.2 + V_1)^2 + (0.8 - V_2)^2 + (1.1 - e_m)^2$$

or use the following relation:

$$X = G^{-1} A^T b \quad \Rightarrow \quad X = \begin{array}{c} \begin{bmatrix} 3.125 \\ 0.875 \\ 1.175 \end{bmatrix} \end{array} \begin{array}{l} V_1 \\ V_2 \\ e_m \end{array}$$

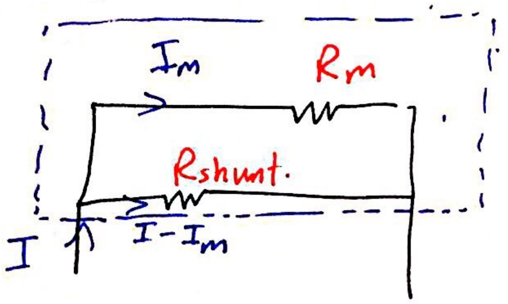
$G \rightarrow$ Gain Matrix. $G = A^T \cdot A$.

* residual: $r = b - AX = \begin{bmatrix} 1 \\ -3.2 \\ 0.8 \\ 1.1 \end{bmatrix} - \begin{bmatrix} 1 & -1 & 1 \\ -1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 3.125 \\ 0.875 \\ 1.175 \end{bmatrix}$

$$= \underline{\underline{\begin{bmatrix} -0.075 \\ -0.075 \\ -0.075 \end{bmatrix}}}$$

※ meters:

*Basic DC ammeter:



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

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

$\Rightarrow \boxed{R_{shunt} = \dfrac{R_m}{n-1}}$

Example: slide ( ) :

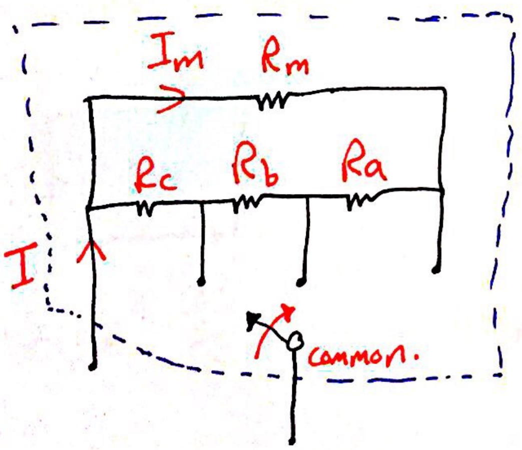
$R_m = 100\ \Omega$

$I_m = 1mA$

$I = 0 - 10mA.$

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

*Multiple Range Ammeter:



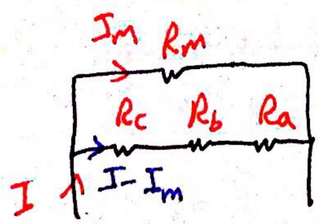
Example: slide ( ):

$I_m = 50\mu A.$

$R_m = 2400\ \Omega$

3 ranges → 5mA
→ 50mA
→ 500mA

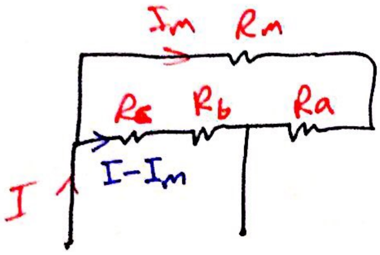
* 5mA



$R_a + R_b + R_c = \dfrac{\overset{50\mu}{I_m}\ \overset{2400}{R_m}}{\underset{5mA}{I} - \underset{50\mu}{I_m}}$ ------ $\boxed{1}$

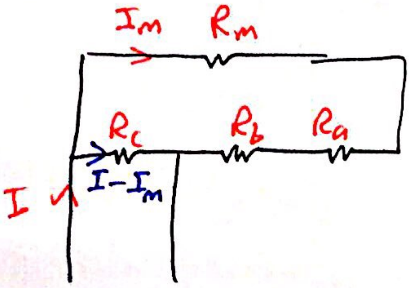
⟹

* 50mA.



$$\Rightarrow \quad \frac{I_m(R_m+R_a)}{I-I_m} = R_c+R_b \quad ----\boxed{2}$$

* 500 mA.



$$\Rightarrow \quad \frac{I_m(R_m+R_a+R_b)}{I-I_m} = R_c \quad ----\boxed{3}$$

solving 3 equations:

$$\boxed{\begin{aligned} R_a &= 21.81\,\Omega \\ R_b &= 0.94\,\Omega \\ R_b &= 2.18\,\Omega \end{aligned}}$$

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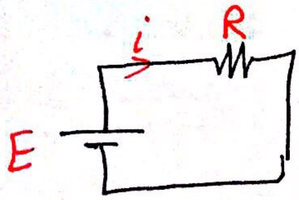
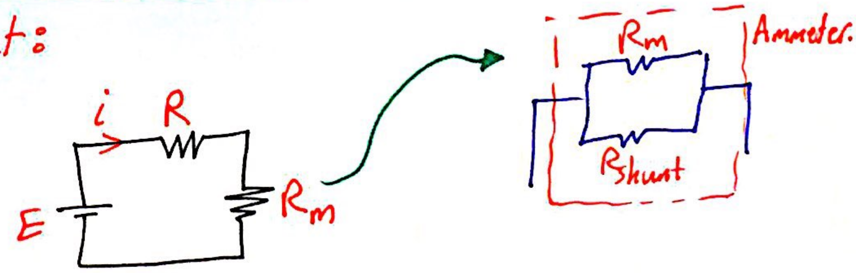
* Ammeter Loading Effect:



$\Rightarrow$

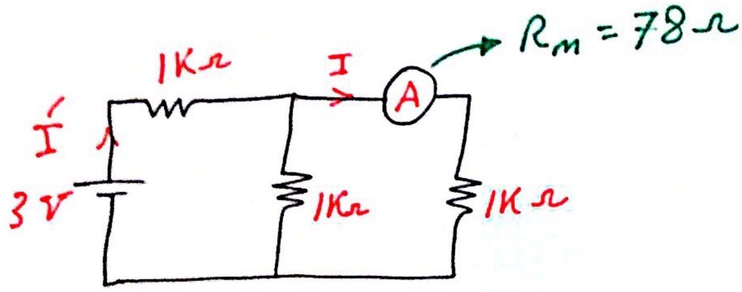


$$i_{expected} = \frac{E}{R} \qquad i_{measured} = \frac{E}{R+R_m}$$

R_m → Ammeter Resistance.

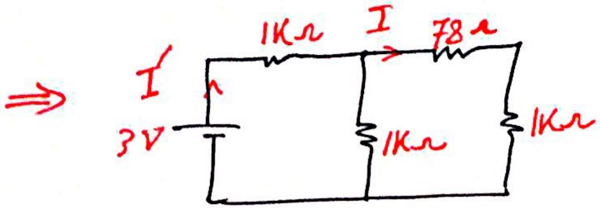
$$\text{Insertion Error} = \frac{I_{expected} - I_{measured}}{I_{expected}} * 100\%$$

Example: slide ( ):



$I'_{expected} = \frac{3}{1.5K} = 2mA.$

$I_{expected} = 1mA.$



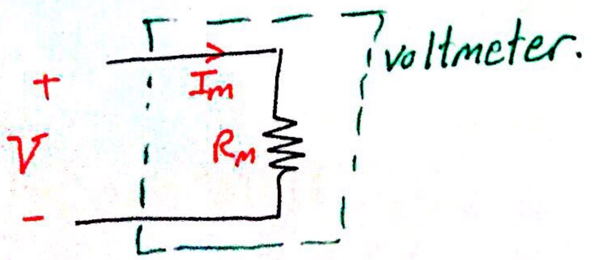
$R_{eq} = (1K+75) // 1K + 1K$

$I'_{measured} = \frac{3}{R_{eq}} = 1.97mA.$

$I_{measured} = I' \frac{1K}{1K+1K+78} = 0.95mA.$

$$\text{error}\% = \frac{1-0.95}{1} * 100\% = \underline{\underline{5\%}}$$

※ Basic DC voltmeter:



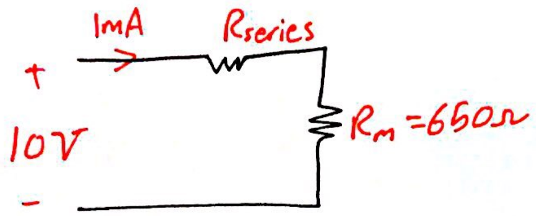
$V_{\text{full scale deflection}} = I_m R_m$

I_m → maximum that voltmeter can handle.

* To extend the $V_{\text{full scale deflection}}$ we have to add R_s series with R_m.

Example. ⟹

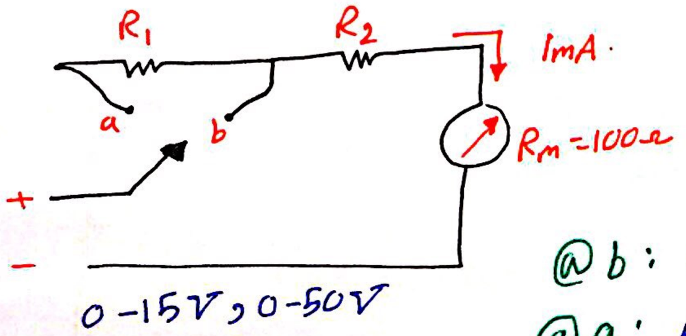
Example: slide ( ):



$\Rightarrow -10 + 1m(R_s + R_m) = 0$

$\boxed{R_s = 9.35K\Omega}$

Example: slide ( ):



Design $\Rightarrow$ $R_1, R_2 = ?!$

@b: $15 = I_m(R_2 + R_m)$ ---- $\boxed{1}$

@a: $50 = I_m(R_1 + R_2 + R_m)$ --- $\boxed{2}$

solving: $R_1 = 35K\Omega$
$R_2 = 14.9K\Omega$

※ Sensetivity:

$$\text{Sensetivity} = \frac{1}{I_{\text{fullscale deflection}}} \left(\frac{\Omega}{V}\right) \Rightarrow S = \frac{1}{I_m}$$

* for the last example what is the sensetivity?

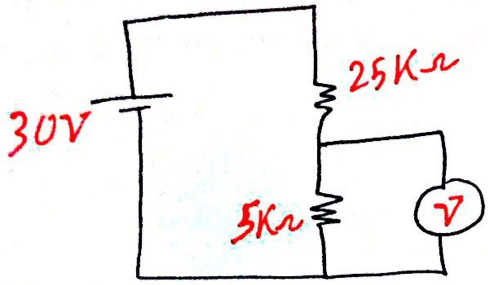
$$S = \frac{1}{I_m} = \frac{1}{1m} = \boxed{1000\ \Omega/V.}$$

Total series resistance	$= 15 * 1000 = 15k\Omega$	15V
" " "	$= 50 * 1000 = 50K\Omega$	50V

$15K = R_2 + R_m$
$50K = R_1 + R_2 + R_m$

solving, it will give same results.

Example : slide (58) :

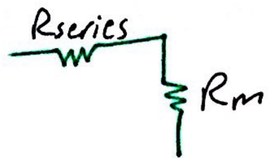


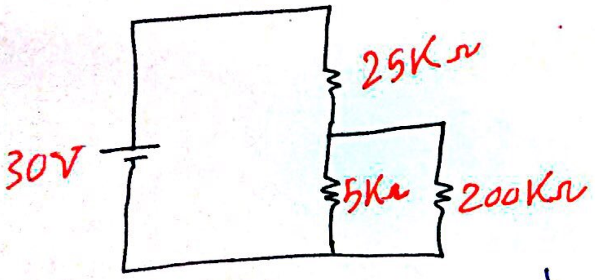
meter A :

$$R_{voltmeter} = 10 * \frac{1K\Omega}{V}$$

$$= \boxed{10K\Omega}$$

represent R_{series} & R_m

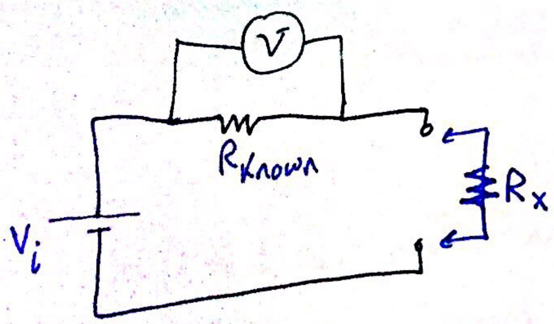




meter B :

$$R_V = 10 * \frac{20K\Omega}{V} = \boxed{200K\Omega}$$

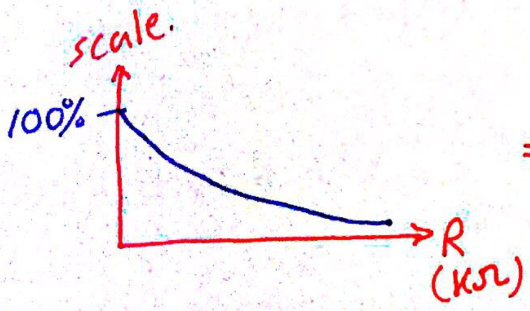
find voltage by voltage division.



when $R_x = 0$

voltmeter will read maximum voltage. (full scale).

as long as R_x increasing voltmeter reading decrease.

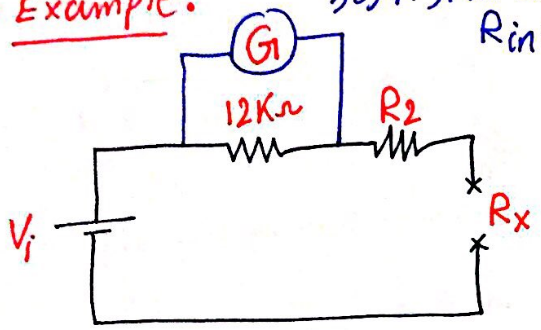


⇒ This type called:

Reversed - Nonlinear scale.

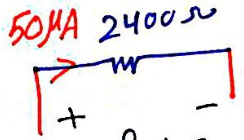
* Example:

50μA, Full scale deflection
$R_{in} = 2400\ \Omega$



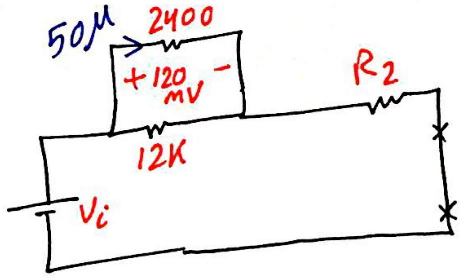
Find V_i, R_2 ?

under these conditions:
→ Fullscale deflection, $R_x = 0$
→ 20% Full scale deflection, $R_x = 200\ K\Omega$.

⇒ 

full scale deflection voltage $= 50\mu * 2400 = \underline{120mV}$

$$120mV = V_i * \frac{12K // 2400}{(12K//2400) + R_2}$$

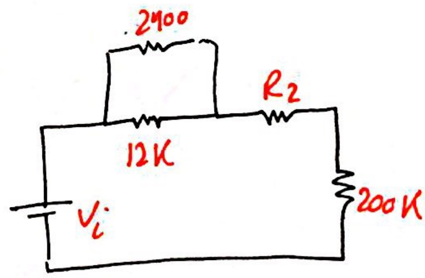


$$\Rightarrow \boxed{240 + 0.12R_2 = 2000V_i} \text{ - - - } \boxed{1}$$

Now:

20% full scale deflection :

$20\% \ (2400 * 50\mu) = \underline{0.024}$ Volt.



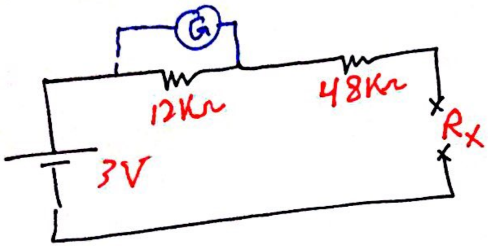
$$\Rightarrow 0.024 = V_i \ \frac{(12K // 2400)}{(12K//2400) + R_2 + 200K}$$

$$\Rightarrow \boxed{4848 + 0.024R_2 = 2000V_i} \text{ - - - } \boxed{2}$$

continue. ⇒

solving $\boxed{1}$ & $\boxed{2}$: $R_2 = 48K\Omega$, $V_i = 3$ volt.

Now find the deflection when $\begin{cases} R_x = 450\,K\Omega : \\ R_x = 75\,K\Omega \\ R_x = 50\,K\Omega \end{cases}$



full scale deflection = 120 mV.

$$\%d * 120m = 3 * \frac{(2400 // 12K)}{(2400//12K) + 48K + \underline{\underline{450K}}}$$

$\underline{\underline{75K}}$

$\underline{\underline{50K}}$.

!?

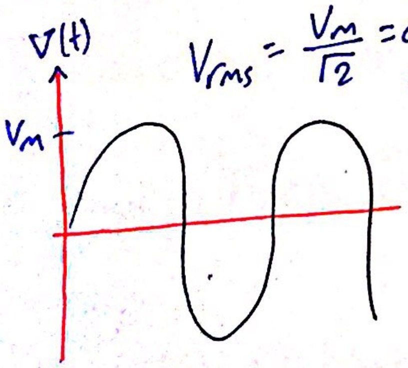
Answers:

450 K → 10 %
75 K → 40%
50 K → 50%

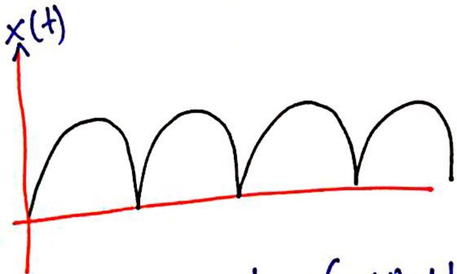
⇒ Test for the slope to Know if it is linear or Not.

※ AC voltmeter:

$V_{rms} = \frac{V_m}{\sqrt{2}} = \underline{\underline{0.707 V_m}}$



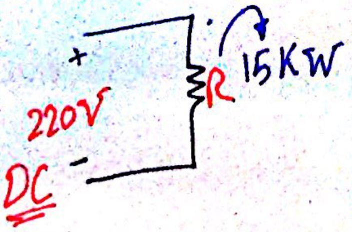
fullwave rectifire.

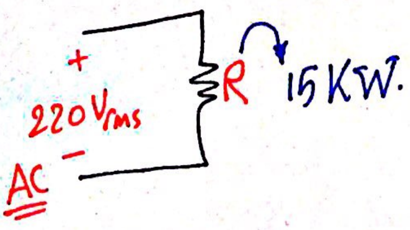


$$\text{average} = \frac{1}{T}\int x(t)\,dt$$

$$= \underline{\underline{0.636\, V_m}}$$

Example:





⇒ same rated power in DC & AC.

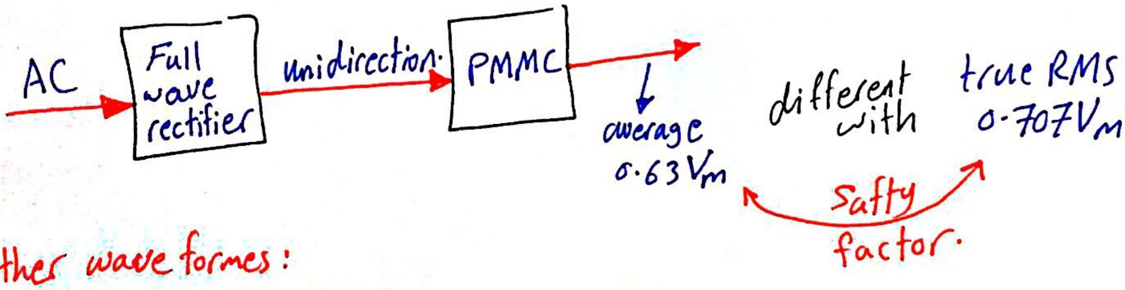
* AC signal: $V_{rms} = 0.707\,V_m$.
* Half-wave-Rectifier: $V_{av.} = 0.5\,V_m$.
* Full-wave-Rectifier: $V_{av} = 0.636\,V_m$.

* Average for any signal: $\frac{1}{T}\int_T x(t)\,dt$.

* Safe Factor $(SF) = \frac{V_{rms}}{V_{avg}}$.

  ↳ for pure sinusoidal: $SF = \frac{0.707 V_m}{0.636 V_m}$

  $\Rightarrow \boxed{SF = 1.1}$



* for other wave formes:

Correction Factor $(CF) = \frac{SF_{waveform}}{SF_{sinusoidal}}$

* if we have: Accuracy = 3% Full scale.
  Full scale = 10 V

  $\Rightarrow$ Accuracy $= 10 * 0.03 = 0.3$ Volt.

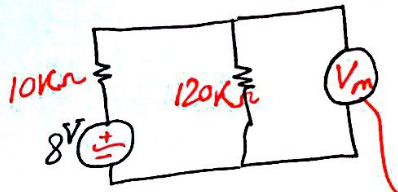
$\Rightarrow$ reading = 9 V $\Rightarrow 9 \pm 0.3$ V better than
reading = 1 V $\Rightarrow 1 \pm 0.3$ V

the best is to choose the full scale close to the expected readings.

Example: slide (73): find $V_{measured}$ & %e ?

$$\underbrace{V_{true}}_{\text{Voltage}} (\text{ideal}) = 8 * \frac{120K}{120K+10K} = \boxed{7.38 \text{ Volt}}$$

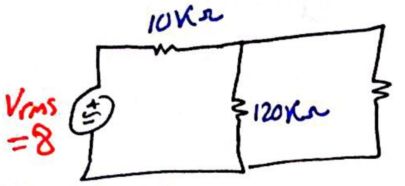
→ V_m o/c.



Analogue (0—10V)
sensitivity = 10 KΩ/V

V_m → calibrated to read V_{rms} for sinusoidal.

*measured value:



$$\frac{10 K\Omega}{V} * 10V = 100K\Omega$$

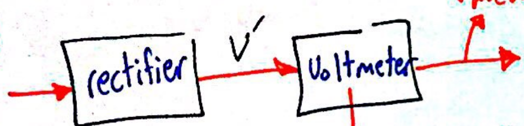
$$\Rightarrow V_{measured} = \frac{8 * (120K // 100K)}{10K + (120K//100K)} = \boxed{6.76 \text{ volt}}$$

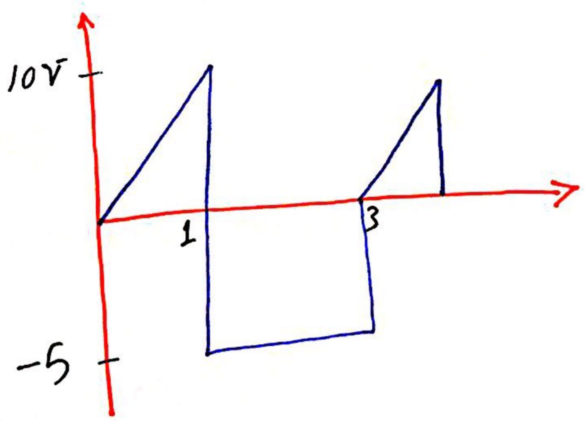
$$\% error = \frac{6.76 - 7.38}{7.38} * 100\% = -8.4\%$$

Example: slide (73):

1) find V_{rms} ?

2)



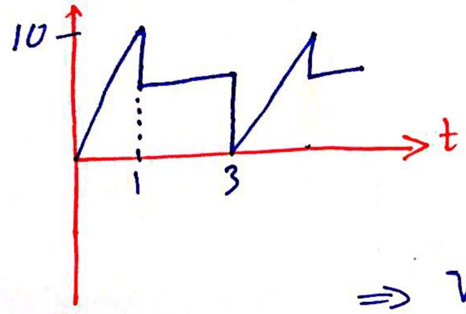


3) error in the RMS reading ?

solution. ⟹

Solution:

1) $V_{rms} = \sqrt{\frac{1}{3}\left[\int_0^1 (10t)^2 dt + \int_1^3 (-5)^2 dt\right]} = \boxed{5.27 \text{ volt.}}$

2) 

$\Rightarrow V_{average} = \frac{1}{3}\left[\int_0^1 10t\,dt + \int_1^3 5\,dt\right]$

$= \boxed{5 \text{ volt.}}$

$\Rightarrow V_{measured} = 5 * SF$

$= 5 * 1.11 = \boxed{5.55 \text{ volt.}}$

we multiply by SF since the voltmeter calibrated to measure sinusoidal signal.

3) $\%error = \frac{5.55 - 5.27}{5.27} * 100\%$

$= \boxed{5.31\%}$

Example:

Need the correction factor given that

$V_{rms} = 28.87\,V$, $\underset{\text{(rectified) signal}}{V_{average}} = 25\,V$, correction factor = ?!

$28.87 = 25 * 1.11 *$ correction factor

$\Rightarrow \boxed{CF = 1.04}$

also we could use $CF = \frac{SF_{waveform}}{SF_{sinusoidal}}$ $\frac{V_{rms}}{V_{avg}}$

※ Digital multimeter:

the type could be: 4 ½ digit.

↳ This means : _ _ _ _ _

depend on quantization

0 or 1   9 9 9 9

↑ highest.

Accuracy = ±0.1% ± 1

↳ * LSd.

↳ Least significant digit.

*For the resolution:

as long as we increase the range ⇒ it will cause the resolution to be worse.

** 4 ½ digit

count 1.9999 (decimal point)

if max voltage < 2 :

⟹ 1.9999 (max display)

↳ resolution:

⟹ 0.0001 = $\underline{\underline{100\,\mu V}}$.

if we want to display 2 :

02.000 ⟹ resolution = 0.001 = $\underline{\underline{1\,mV}}$

so increasing in range cause a decreasing in resolution.

$3\frac{1}{2}$ digit reads 20 Volt:

0 2 0 . _ → resolution = 0.1 volt.

0,1   0 → 9

Example : slide(81) :

4 ½ digit.

reading: 1.8000

Accuracy: (±0.05% + 1)

0,1 _ _ _ _ _ 0 → 9

*Range: → max = $1.8000 * \frac{1.05}{100} = \underline{1.8009V}$

→ min = $1.8000 * \frac{0.95}{100} = \underline{1.7991V}$

±0.05% + 1

1 ⇒ LSD.

1.8000 → LSD = 0.0001

→ we add it to the max.

→ we subtract it from the min.

*expected readings:

1.8009 + 0.0001 = $\underline{1.8010}$ V.

1.7991 − 0.0001 = $\underline{1.7990}$ V.

Example: slide(83) :

4 digit:

reading: 1.8 V.

Accuracy: ±0.1 % + 5

Range: 1000 V. ⇒ need it: (< 1000 V.)

max. display: $\underline{999.9}$

_ _ _ . _

resolution = 0.1

0.1 % * 1.8 almost zero.

⇒ 0.1 * 5 = $\underline{0.5 V.}$

range: 1.8 + 0.5 = 2.3

1.8 − 0.5 = 1.3

$\underline{1.3 \rightarrow 2.3 \text{ V.}}$

---

* End of first Material. *

Summary

"First"

***Accuracy:**

accuracy = A%

True = measured ± A% * range.

***resolution:** $= \dfrac{\text{full scale}}{2^{\#\text{of bits}}}$.

***Guassian Curve:**

$$f_x(x) = \frac{e^{-\frac{(x-\bar{x})^2}{2\sigma^2}}}{\sqrt{2\pi\sigma^2}}$$

***standard error of mean:**

$\alpha = \dfrac{\sigma}{\sqrt{n}}$

$\bar{x} \pm \alpha$ (68%)
$\bar{x} \pm 1.96\alpha$ (95%)
$\bar{x} \pm 2\alpha$ (95.4%)
$\bar{x} \pm 3\alpha$ (99.7%)

***limiting error:**

Addition: $u = \overset{\to n}{V} + \overset{\to m}{W}$

$\Rightarrow u = V*(1 \pm n) + W(1 \pm m)$

Subtraction:

$u = V*(1 \pm n) - W(1 \pm m)$

multiplication & division:

$u = V \div W \cdot (1 \pm (m+n))$

***precision:**

[1] $\sigma^2 = \dfrac{\sum (x-\bar{x})^2}{N \text{ or } (N-1)}$

[2] $|\text{max} - \text{mean}|$.

***Error** $= \dfrac{\text{real} - \text{measured}}{\text{real}} * 100\%$

***pdf:** $P_r(x_1 \le x \le x_2) = \int_{x_1}^{x_2} f_x(x)\,dx$.

***cdf:** $P_r(x \le x_0) = \int_{-\infty}^{x_0} f_x(x)\,dx$.

$\rightarrow Z_0 = \dfrac{x_0 - \text{mean}}{\sigma}$

***Probable error:**

Addition:

$u = V + W \pm \sqrt{(nV)^2 + (mW)^2}$

Subtraction:

$u = V - W \pm \sqrt{(nV)^2 + (mW)^2}$

Division & multiplication:

$u = V \div W * \left(1 \pm \sqrt{m^2 + n^2}\right)$

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WLSE:

$Z_i = h_i(x) + e$

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

$\Rightarrow$ How to find X!?

$X = G^{-1} A^T b$

$\downarrow$

$G^{-1} = A^T \cdot A$

---

* Residual: $r = b - A \cdot X$

---

* DC ammeter:

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

* sensitivity:

$$S = \frac{1}{I_m}$$

* Ammeter loading effect!

$$\text{insertion error} = \frac{I_{expected} - I_{measured}}{I_{expected}} * 100\%$$

Total series Resistance $\equiv$ sensitivity * full voltage Range.

R_m R_s

* full-rectified signal:

$V_{avg} = 0.636 V_m$

for sinusoidal:

$V_{rms} = 0.707 V_m$

* Half-rec:

$V_{ag} = 0.3 V_m$

form factor

* Safe factor:

$SF = V_{rms}/V_{av}$.

$\hookrightarrow$ for sinusoidal $SF = 1.11$

$$\boxed{\begin{aligned} V_{ind} &= SF * V_{meas.\,av.} \\ V_{ind} * CF &= V_{rms} \end{aligned}}$$

* Error:

$$e = \frac{V_{av} - V_{rms}}{V_{rms}} * 100\%$$

* Correction Factor:

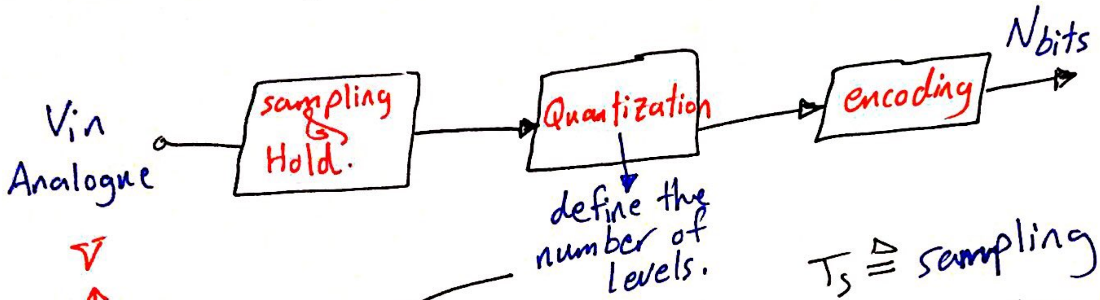
$$CF = \frac{SF_{waveform}}{SF_{sinusoidal}}.$$

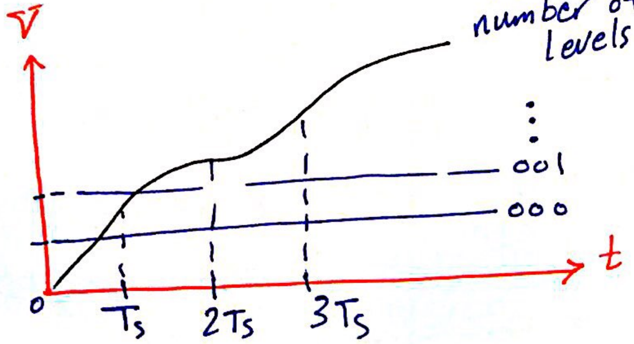
* error: $= \dfrac{1 - CF}{CF}$

* Triangular: full-rec: $V_{av} = 0.5 V_m$, $V_{rms} = 0.577 V_m$, $SF = 1.155$

* Analogue & Digital:

Basic for digital ⇒ (ADC) analogue to digital convertor.





$T_s \triangleq$ sampling Time.

$f_s \triangleq$ sampling frequancy.

$$f_s = \frac{1}{T_s} \text{ HZ}.$$

$$\boxed{\#\text{of Levels} = 2^N}$$

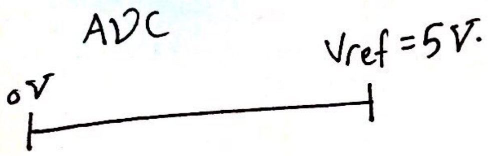
$$\text{step size} = \frac{V_{max} - V_{min}}{\#\text{of levels}}$$

"Resolution"

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

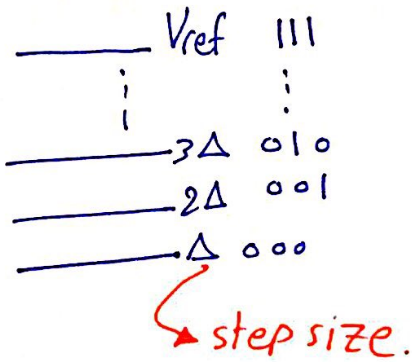
$$V_{in} = \frac{V_{ref}}{2^N} * R$$ → digital code.

Example:



#of bits = 3.

$V_{in} = ?$



3 bits ⇒ 8 Levels.

$$\Delta = \text{step size} = \frac{V_{ref}}{2^N}$$

→ resolution.

$$\text{Max Quantization error} = \frac{\Delta}{2}$$

$$\text{Quantization error \%} = \frac{\Delta/2}{V_{fullscale}} * 100\% = \frac{\left(\frac{V_{fullscale}}{2^N}\right)/2}{V_{full\ scale}} * 100\%$$

$$\text{Quantization error \%} = \frac{1}{2^{N+1}} * 100\%$$

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Example: slide (89):

800mV → 150mV.

ADC code: 80 → 150

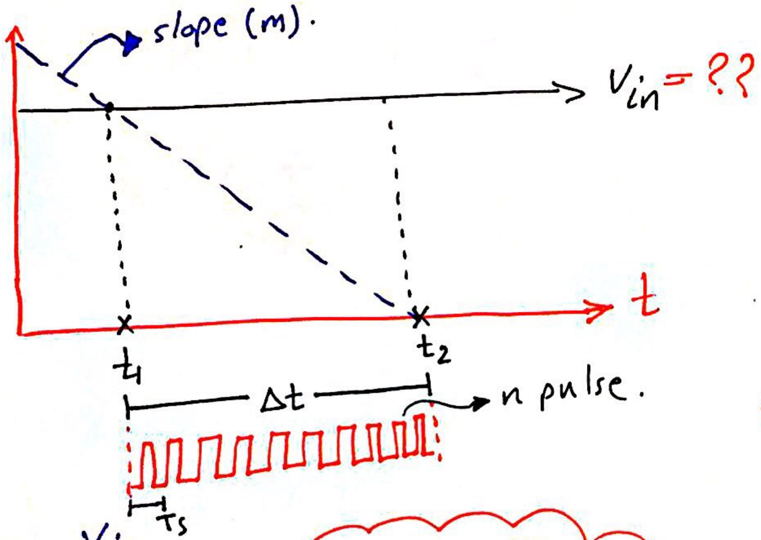
$\Delta = ??$

$\Rightarrow$ $800mV = 80\Delta$

$\Delta = 10mV$

* Ramp-Type Digital Voltmeter:

"Voltage to Time Conversion".



$V(t) = V_0 - mt$

@ t_1:

$V_{in} = V_0 - mt_1 \cdots \boxed{1}$

@ t_2:

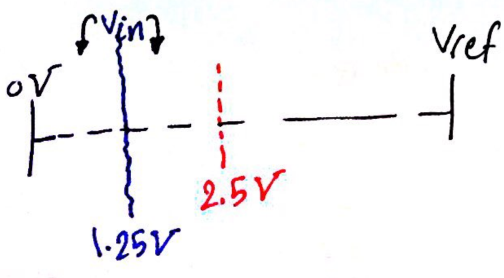
$V_{in} = V_0 - mt_2 = 0 \cdots \boxed{2}$

from $\boxed{1}$ & $\boxed{2}$:

$V_{in} = m\underbrace{(t_2 - t_1)}_{\Delta t}$

* $\Delta t = \frac{V_{in}}{m}$ $\Rightarrow$ $V_{in} = mnT_s$
* $\Delta t = nT_s$

* Successive Approximation Digital Voltmeter:



let $V_{ref} = 5V$ & # of bits = 3

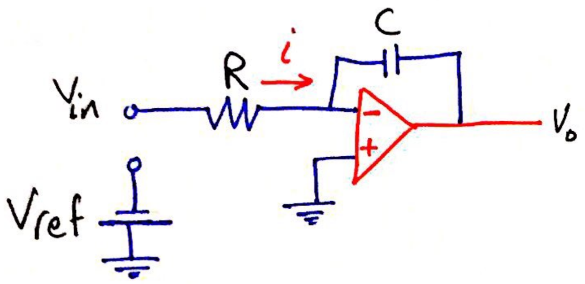
suppose V_{in} is between 0 & 2.5V.

	bit
* Compare with 2.5V ⇒	0
* Compare with 1.25V ⇒	1
* Compare with ___ ⇒	0

MSB

010

Dual-Slope Digital Voltmeter:



$$i_c = C\frac{dV}{dt}$$

$$\Rightarrow V_c = \frac{1}{C}\int i\,dt = \frac{1}{C}\int \frac{V_{in}}{R}\,dt$$

$$V_c = \frac{1}{RC}\int V_{in}\,dt \qquad V_c + V_o = 0$$

$$\Rightarrow V_o = \frac{-1}{RC}\int_{T} V_{in}\,dt$$

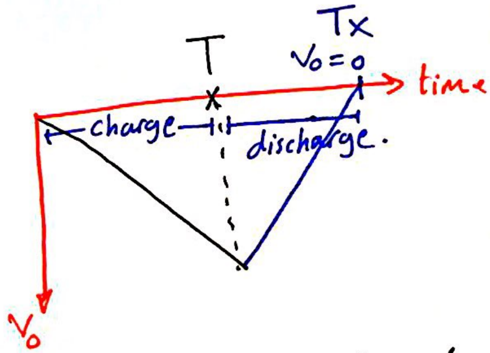
T → defined.

when we connect it to V_{ref}:

$$V_o = \frac{-1}{RC}\int -V_{ref}\,dt + V_{initial} = 0$$

$$0 = \frac{V_{ref}}{RC}T_x - \frac{V_{in}}{RC}T$$

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



$$\Rightarrow \boxed{V_{in} = \frac{T_x V_{ref}}{T}}$$

→ advantage: doesn't depend on R & C.

→ disadvantage: slow.

Example: slide (102):

$V_{ref} = 10V$

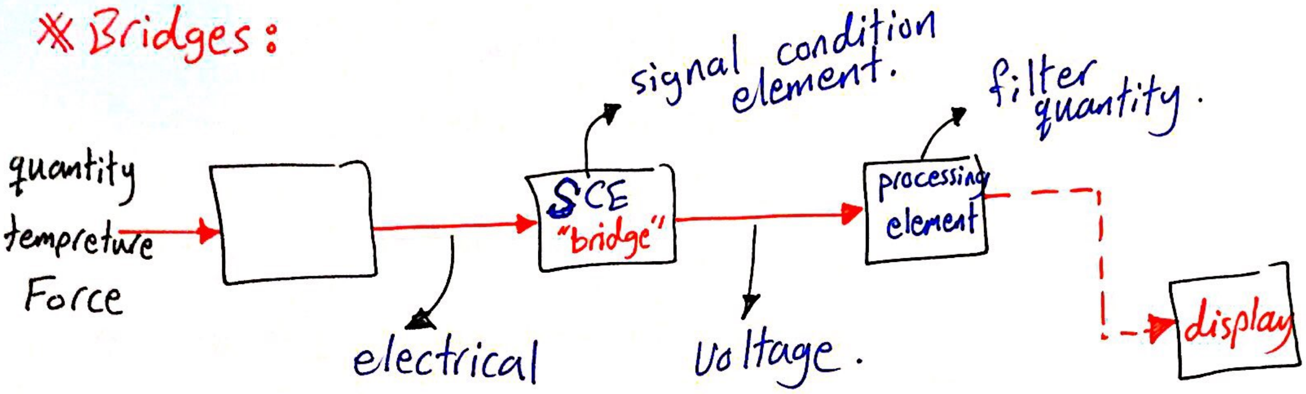
$T = 10mS$

$$\Rightarrow T_x = \frac{V_{in}T}{V_{ref}} = \frac{6.8 * 10m}{10} = 6.8\,msec.$$

if he asked about $T_{conversion}$:

$$T_{conversion} = T + T_x = 10m + 6.8m = 16.8\,msec.$$

※ Bridges:

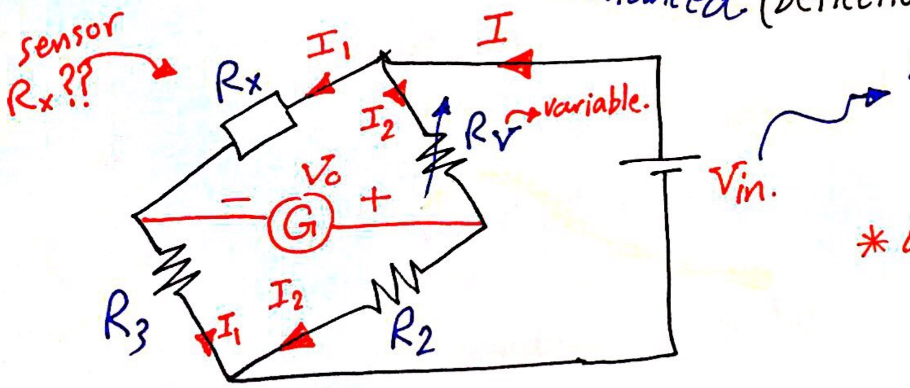


- Resistance.
- Inductor.
- Capacitor.

- frequancy.
- phase.

*** Bridge** → DC Bridge. → R.
→ AC Bridge. → L. / C. / f.

* Wheatstone Bridge: → Balanced. (Null)
→ Unbalanced. (Deflection)



Excitation Voltage.

* ideal voltmeter:

$*R_{in} \rightarrow \infty$

By using voltage division:

$$V_o = V_{in}\left(\frac{R_x}{R_x+R_3}\right) - V_{in}\left(\frac{R_v}{R_v+R_2}\right)$$

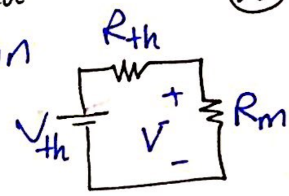
*Null method: $R_v \Rightarrow V_o = 0$ so $V_{in}\left(\frac{R_x}{R_x+R_3} - \frac{R_v}{R_v+R_2}\right) = 0$

$$\Rightarrow \frac{R_x}{R_x+R_3} = \frac{R_v}{R_v+R_2} \Rightarrow \cancel{R_xR_v} + R_xR_2 = \cancel{R_vR_x} + R_vR_3$$

$$R_xR_2 = R_vR_3$$

$$R_x = \frac{R_vR_3}{R_2}$$ "balanced"

*if the internal resistance of the voltmeter considered
Obtaining the thevenin circuit would be a solution



* Deflection method:

$R_V \xrightarrow{\text{replaced}} R_1$ (Nominal R_x)

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

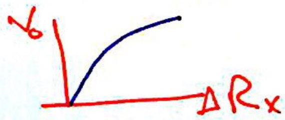
⇒ Case: $R_2 = R_3$

$R_x = R_1$ (Nominal) ⇒ $V_o = 0$

$R_x = R_1 \pm \Delta R_x$ → V_o +ve, → V_o -ve

$V_o = f(R_x)$

→ one of the problem of this method:
that is the relation isn't a linear between V_o & R_x.



Example: pressure sensor measures pressure (0-10 bar)

$R = 120 + \frac{338\,m\Omega}{bar}$, $R_{voltmeter} \to \infty$

max current sensor $\leq 30mA$
"R_x"

Find V_o when pressure is 10 bar & max V_{in} is used?

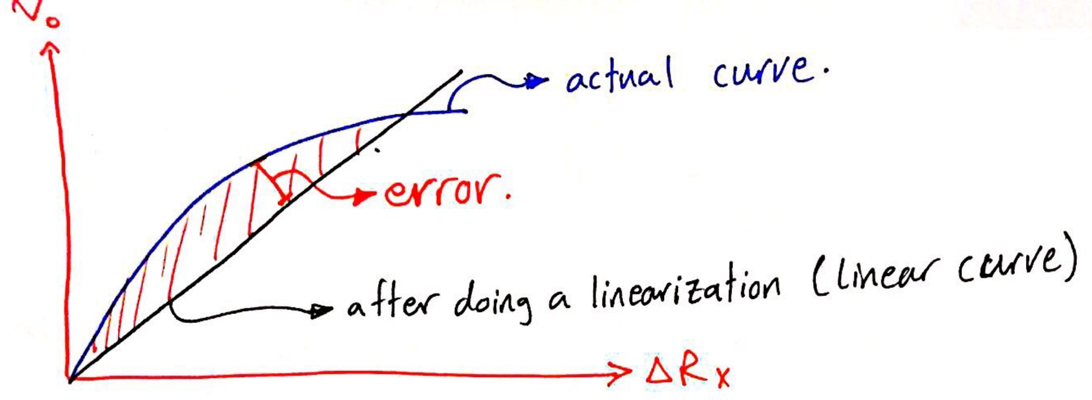
given $R_1 = R_2 = R_3 = 120\,\Omega$

$I_1 \leq 30mA$.

$$\frac{V_{in}}{R_x+R_3} \leq 30mA \Rightarrow \frac{V_{in}}{120+120} \leq 30mA \Rightarrow V_{in} \leq 7.2 \text{ volt.}$$

@ 10 bar: $R_x = 120 + 0.338 * 10 = 123.38\,\Omega$

$$V_o = V_{in}\left(\frac{R_x}{R_x+R_3} - \frac{R_1}{R_1+R_2}\right) \Rightarrow V_o = 50\,m\,volt.$$



*An illustration case: ΔR_x is small compared to nominal.

$$V_o = V_{in}\left(\underbrace{\frac{R_x}{R_x+R_3} - \frac{R_1}{R_1+R_2}}_{\boxed{1}}\right) \Rightarrow V_o = V_{in}\left(\underbrace{\frac{R_x+\delta R_x}{R_x+\delta R_x+R_3} - \frac{R_1}{R_1+R_2}}_{\boxed{2}}\right)$$

$\delta V_o = f(\delta R_x)$

subtracting $\boxed{1}$ from $\boxed{2}$ & approximate:

$\rightarrow R_x + \underbrace{\delta R_x}_{\text{smal}} \simeq R_x$. just for the Dominator.

$\delta V_o = V_o - V_o$

$$\Rightarrow \delta V_o = V_{in} \frac{\delta R_x}{R_x + R_3}$$

*Sensetivity Bridge: $\dfrac{\delta V_o}{\delta R_x} = \dfrac{V_{in}}{R_x + R_3}$

Example:

A resistance thermometer (0°C $\rightarrow$ 50°C), $R_{nominal} = 500\,\Omega$ @ 0°C

& $\Delta R = \frac{4\,\Omega}{1°C}$, $R_1 = R_2 = R_3 = 500\,\Omega$ & $V_{in} = 10$ volt.

$\Rightarrow R_x = 400 + 4T$

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

$$V_o = 10\left(\frac{125+T}{250+T} - 0.5\right)$$

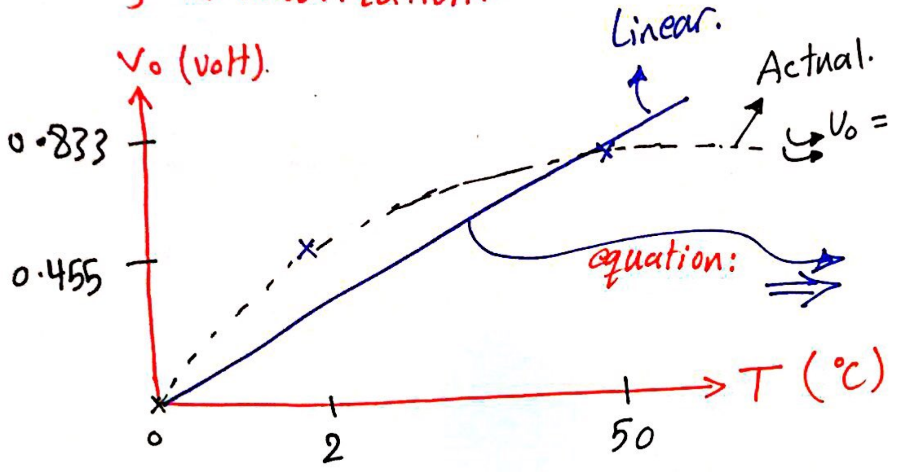
$\Rightarrow$ @ $T=0$ $\Rightarrow V_o = 0$

@ $T=2$ $\Rightarrow V_o = 0.455$ volt.

@ $T=50$ $\Rightarrow V_o = 0.833$ volt.

$\Longrightarrow$ continue.

doing a linearization:



Actual. $V_o = 10\left(\dfrac{125+T}{250+T} - 0.5\right)$

equation: $\Rightarrow$ $\boxed{V_o = 0.016T}$

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* Measument errors:

<u>Balanced:</u>

$R_2 R_3 = R_x R_1$

$\Rightarrow R_x = \dfrac{R_2 R_3}{R_1}$ $\Rightarrow$ Tolerance.

$R_2 = R_2 \pm \Delta R_2$

$R_3 = R_3 \pm \Delta R_3$

$R_1 = R_1 \pm \Delta R_1$

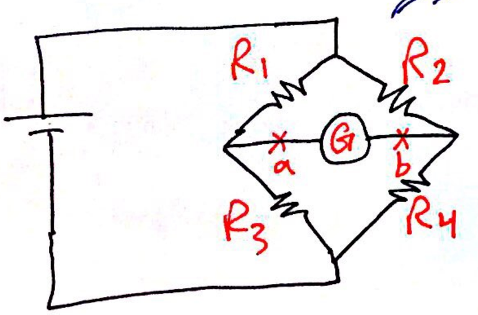
↳ * limiting error:

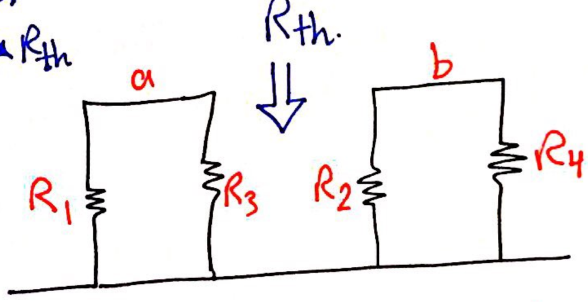
$$R_x = \frac{(R_2 \pm \Delta R_2)(R_3 \pm \Delta R_3)}{(R_1 \pm \Delta R_1)}$$

↳ Do an approximation: $R_x = \dfrac{R_3 R_2}{R_1}\left(1 \pm \dfrac{\Delta R_1}{R_1} \pm \dfrac{\Delta R_2}{R_2} \pm \dfrac{\Delta R_3}{R_3}\right)$

* Sensitivity of Galvanometer:

$\Rightarrow$ Thevenin $\begin{cases} V_{th} \\ R_{th} \end{cases}$



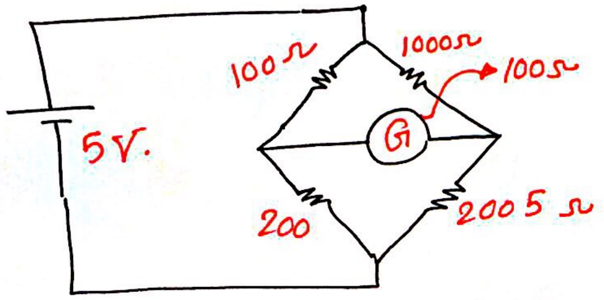


$\Rightarrow$

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

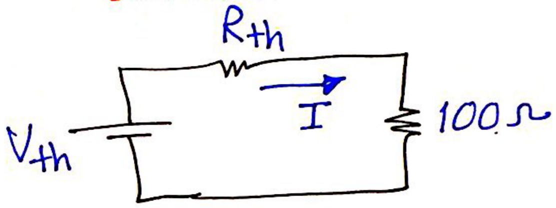
$$V_{th} = V_1 \left(\frac{R_1}{R_1+R_3} - \frac{R_2}{R_2+R_4} \right)$$

Example: slide (121):



sensitivity = $\frac{10mm}{1\mu A}$

* Deflection by the Galvanometer:



$R_{th} = 734\Omega$

$V_{th} = 2.77$ m Volt.

$I = 3.32 \mu A$.

$\Rightarrow$ deflection = I * sensitivity = $3.32\mu * \frac{10mm}{1\mu A}$

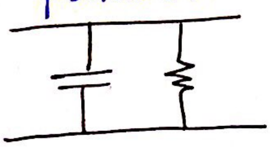
$= \boxed{33.2mm}$.

※ Capacitor:

* any capacitor has:

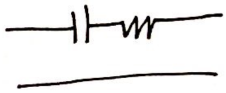
ϵ, σ

parallel.



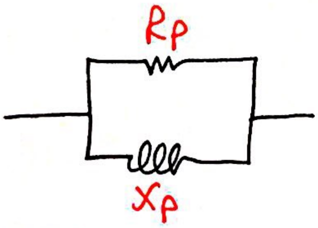
or

series.



* Quality Factor $= \dfrac{\text{Energy stored}}{\text{Average Energy Dissapated}}$.

* Dissipation factor $= \dfrac{\text{Energy Lost}}{\text{Energy stored}}$



→ Need it in series:

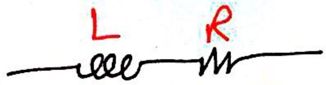
$$Z_{eq} = R_p // X_p$$

$$= \frac{\overbrace{R_p X_p^2}^{R_s} + j\,\overbrace{R_p^2 X_p}^{X_s}}{R_p^2 + X_p^2}$$

$$Z_{eq} = R_s + j\,X_s$$

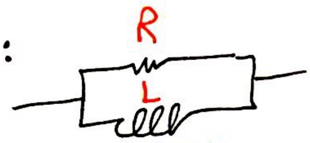
* Quality factor of inductance:

in series:



$$Q = \frac{|I|^2 * X_L}{|I|^2 * R} = \boxed{\frac{\omega L}{R}}$$

in Parallel:



$$Q = \frac{V^2/X_L}{V^2/R} = \boxed{\frac{R}{\omega L}}$$

* AC Bridge (Balanced Condition):

Balanced:

$$Z_1 Z_4 = Z_2 Z_3$$

→ magnitude balance. $Z_1 Z_4 = Z_2 Z_3$

→ phase. balance. $\angle\theta_1 + \angle\theta_4 = \angle\theta_2 + \angle\theta_3$

*Oscilloscope Fundementals:

10:1 voltage divider Probe.

↳ it is reduce the input signal if it was 10 volt signal, make it 1 volt.

*Why the internal resistance of oscilloscope very high (in MΩ)?

→ To Reduce the high loading effect.

* Oscilloscope consists R&C, at Low frequancy C become open circuit.

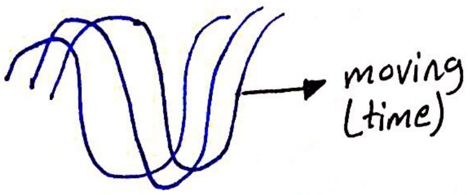
* for a 1 μs/Div & 1 V/Div:

→ max Vpp is 8 volt.

→ max period is 10 μsec.

* Trigger: we use it to have the signal stable on the oscilloscope screen.

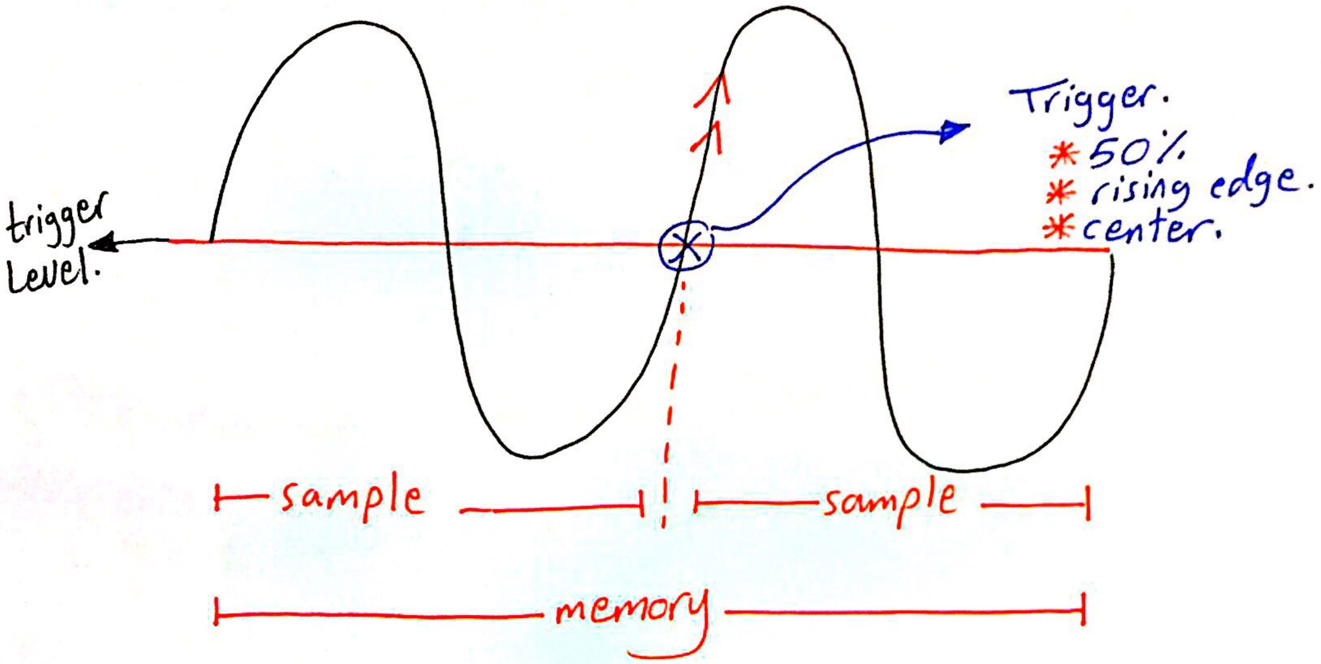
* if the trigger was above the peak voltage Then the picture will be unsynchronized.



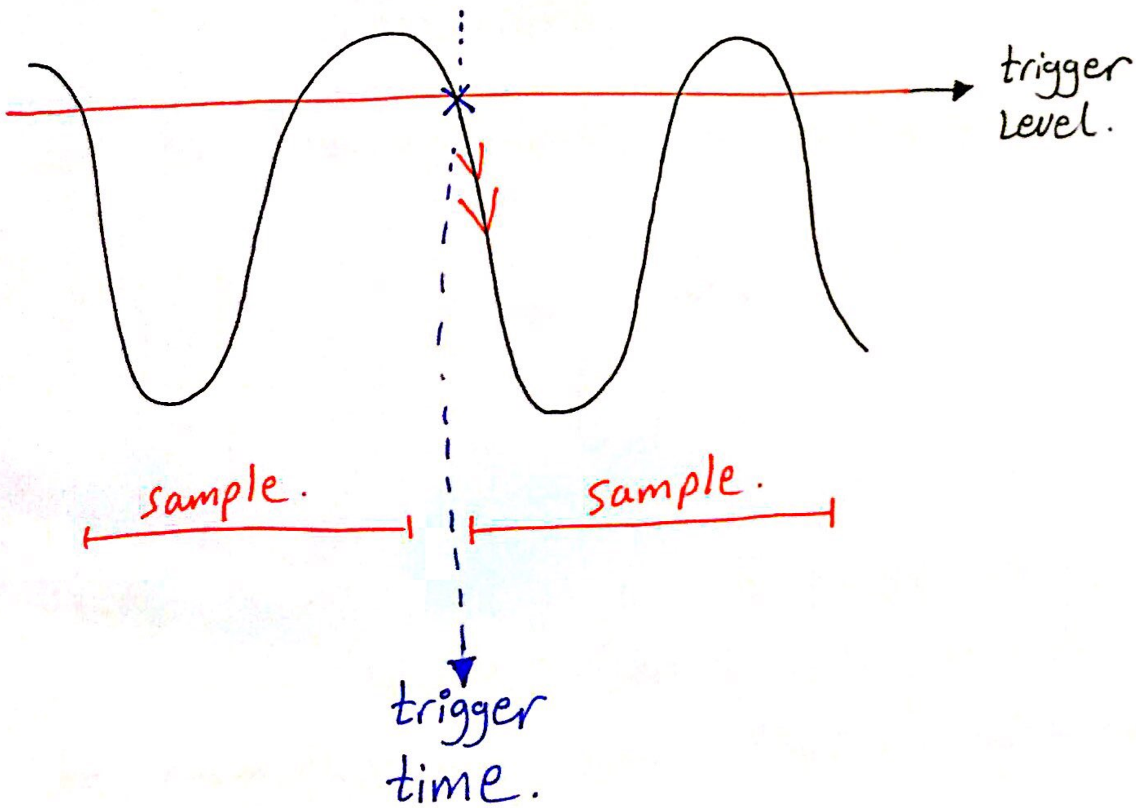
⇒ Trigger Level > V_{max}

** If the oscilloscope was ANALOGUE, then the picture will be shown starting from the trigger point.

* Trigger level in a DIGITAL oscilloscope:



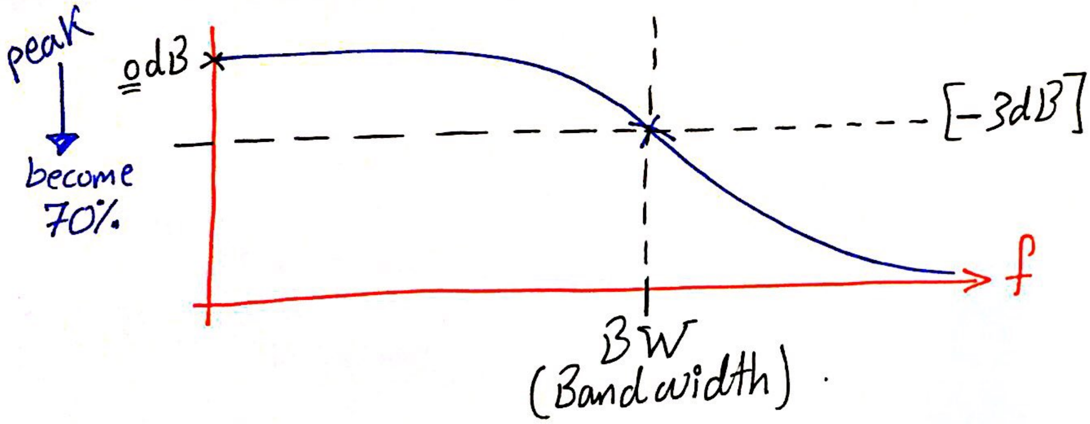
* in the following we have falling edge:



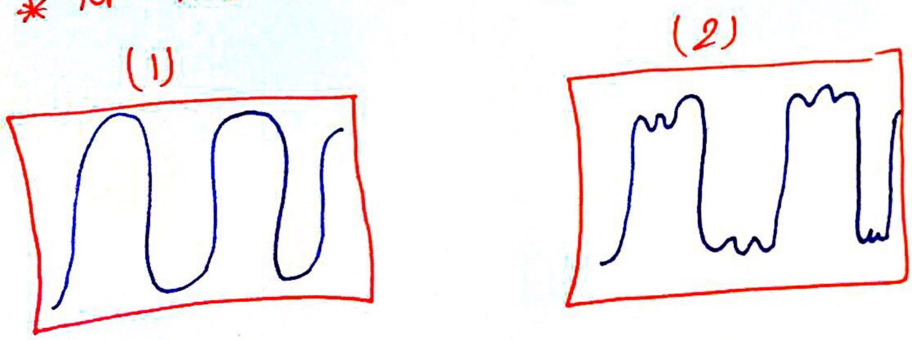
*Always when determine trigger point we need the following:
1] Determine Trigger Level.
2] Centre of the screen.
3] Determine if it is falling edge or Rising edge.

※ Oscilloscope Performance Specifications:

* for a Low pass frequancy response:



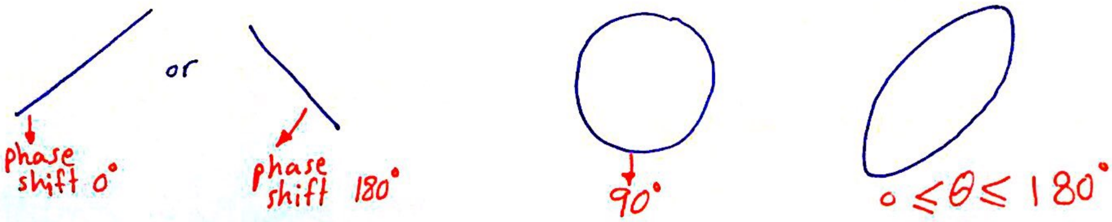
* for the two following signals on oscilloscope:



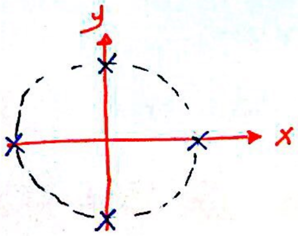
(2) is better than (1) since it is with higher BW.
and (2) is more accurate than (1) since you will see the harmonics in the signal so that it is distorted.

※ Oscilloscope (x-y mode):

if we insert a sinusoidal signal, 3 possible cases in the x-y mode:



Ex. $x = \sin\omega t$, $y = \cos\omega t$



* Zero crossing $(x=0)$

$x = \sin\omega t = 0 \Rightarrow \omega t = 0, \pi$

$y(\omega t = 0) = 1$ & $y(\omega t = \pi) = -1$

$\Downarrow$ $(0,1)$ $\Downarrow$ $(0,-1)$

* $(y=0)$

$\cos\omega t = 0 \Rightarrow \omega t = \frac{\pi}{2}, \frac{3\pi}{2}$

$x(\frac{\pi}{2}) = 1$ & $x(\frac{3\pi}{2}) = -1$

$\Downarrow$ $(1,0)$ $\Downarrow$ $(-1,0)$

* Max x :

max $\sin\omega t \Rightarrow \omega t = \frac{\pi}{2}$

$x(\frac{\pi}{2}) = 1$
$y(\frac{\pi}{2}) = 0$ $\Rightarrow (1,0)$

* Max y : max $\cos(\omega t) \Rightarrow \omega t = 0$

$x(0) = 0$
$y(0) = 1$ $\Rightarrow (0,1)$

* Min x :

Min $\sin\omega t \Rightarrow \omega t = \frac{3\pi}{2}$

$y(\frac{3\pi}{2}) = 0$
$x(\frac{3\pi}{2}) = -1$ $(-1,0)$

* Min y :

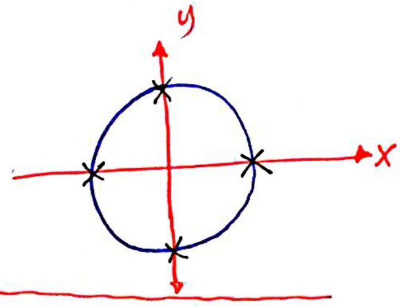
min $\cos\omega t \Rightarrow \omega t = \pi$

$x(\pi) = 0$
$y(\pi) = -1$ $(0,-1)$

$\Longrightarrow$

$\Rightarrow$ so we have:

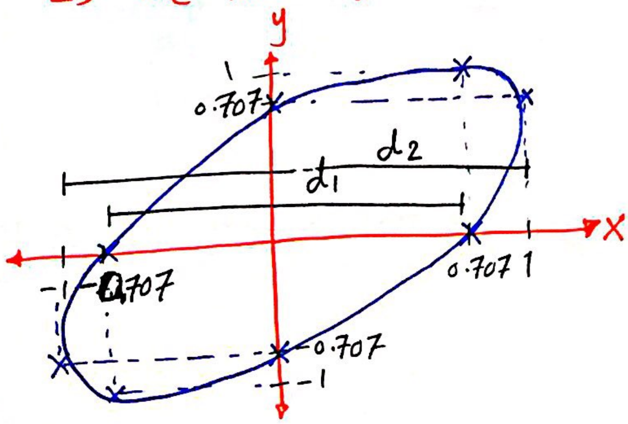
$(0,1)$, $(1,0)$, $(0,-1)$, $(-1,0)$



Ex. $x = \cos(\omega t)$
$y = \cos(\omega t - 45°)$

Do the same steps as the previous example.

$\Rightarrow$ The final figure would be:



$d_1 \equiv$ Zero crossing.

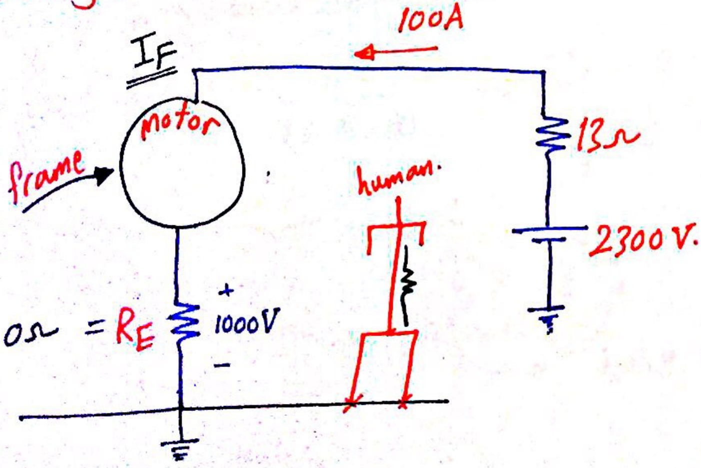
$d_2 \equiv$ peak-to-peak.

from d_1 & d_2 we evaluate the phase shift:

$$\theta = \sin^{-1}\left(\frac{d_1}{d_2}\right)$$

Note: also we could use the y-axis to find the phase-shift with the same way.

※ Earthing:



if the human touch the motor after a fault happend we protect him:

- by wearing a safty shoes.
- by using Tire to clear fault.
- by reducing R_E.

* The conductor between motor & the earth $\Rightarrow$ must be able to carry the fault current.

0 → 10 mA (NO Impact)

150mA → 200mA (Dead).

* Current relation that related to human to has No impact from the current:

$$I = \frac{116\,mA}{\sqrt{t}}$$

I: Max Safe Current.

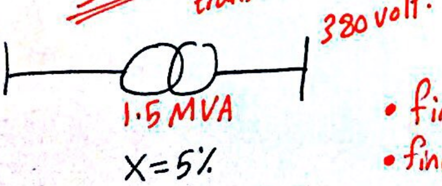
t: Time to clear fault.

* Electrical ShocK:

Difference in the voltage & will create a path of the current.

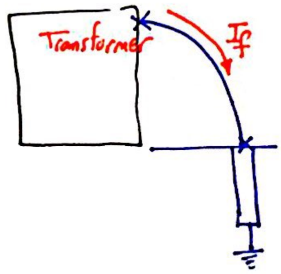
* The worst path for the current passing through the human, that between human hands (since it will pass through the heart).

<u>Ex.</u> <u>3-phase.</u> transformer



• find I_f ?!

• find cross section ?!



with stand fault current: cross section.

$$I_f = \frac{1}{X\%} * \text{Full Load current.}$$

$$\text{full load current} = \frac{1.5M}{\sqrt{3} * 380} \Rightarrow I_f = 20 * \text{full load}$$

$$\boxed{I_f \simeq 45KA}$$

$$\text{cross section } (mm^2) = 9 * \sqrt{t} * I_f$$

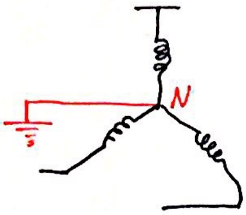
t: time to clear fault.

assume t=0.5 sec.

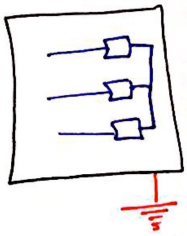
$$\text{cross section} = 9 * \sqrt{0.5} * 45K = \boxed{286\ mm^2}$$

* Grounding:

→ Connect a network point to the ground through an impedance.

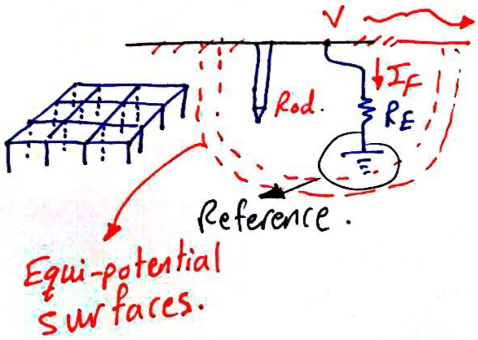


Enclosure.

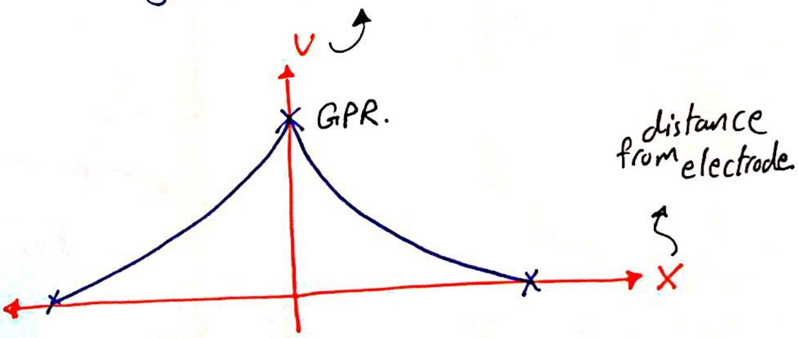


Grounding → Safty [Unenergized element.]
→ performance of the network.

* How to do the earthing?
By using Rod or a mesh of Rods.



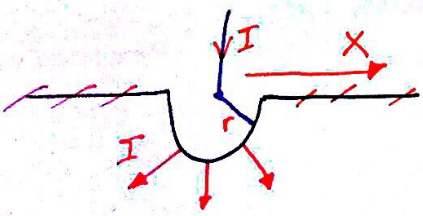
V → This voltage called: ground potential rise. (GPR)



* Safty:

- Insolation (Gloves, boots).
- Grounding → Reduce GPR.
- Equi-potential rise → Reduce voltage difference in the site.

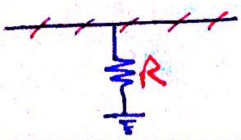
* Hemispherical electrode.



where R:

$$R = \frac{\rho}{2\pi r} \quad \Omega$$

ρ → soil Resistivity.



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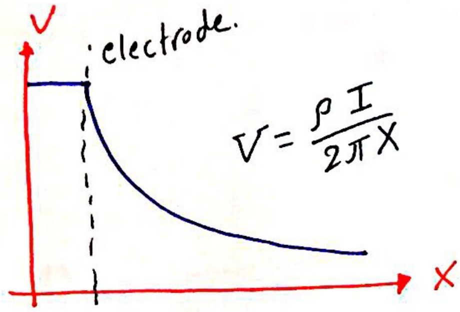
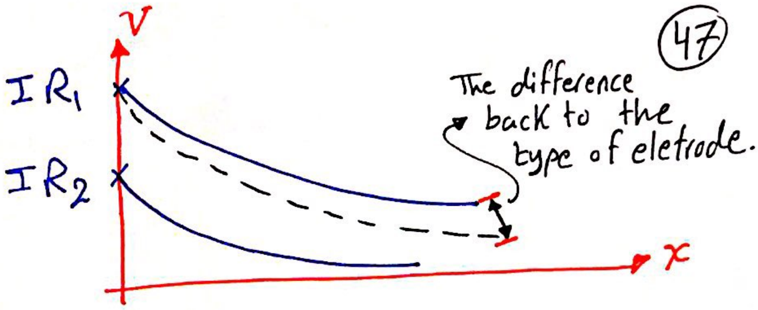
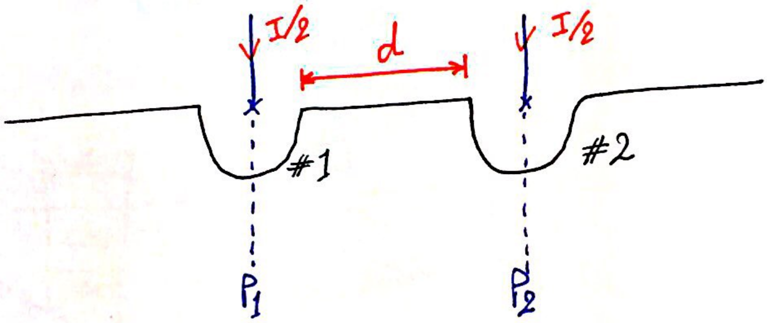


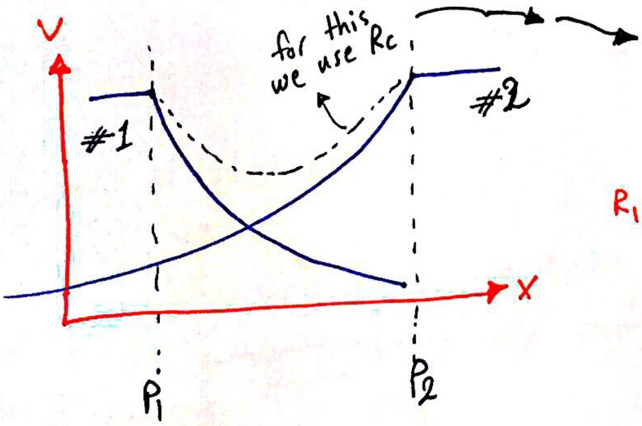


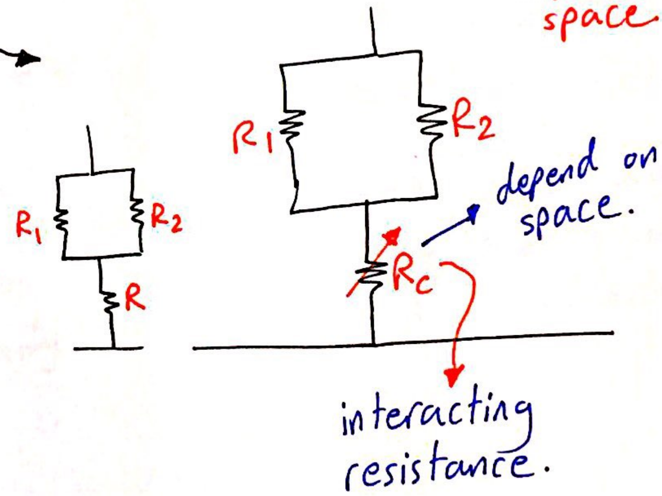
* using 2 - electrode:



$$R_{eq} = \frac{R}{N * M}$$

depend on space

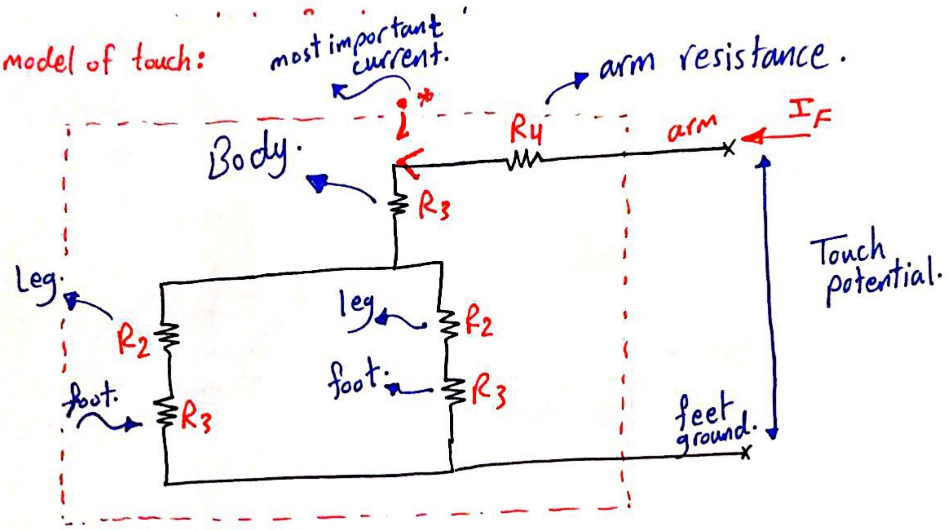


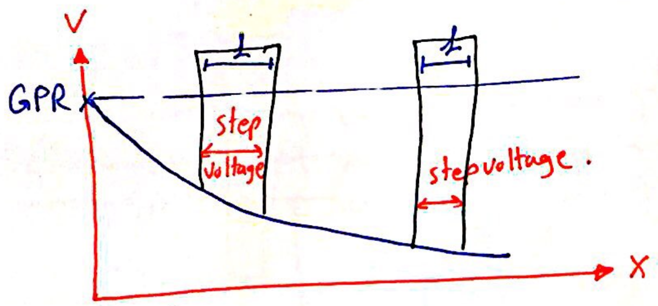


* Touch & Step voltage:

- Touch: voltage difference between your hands & your feets.
- step voltage: voltage difference between your feets.

* model of touch:

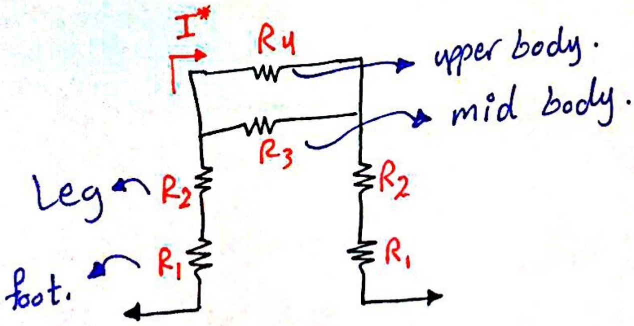




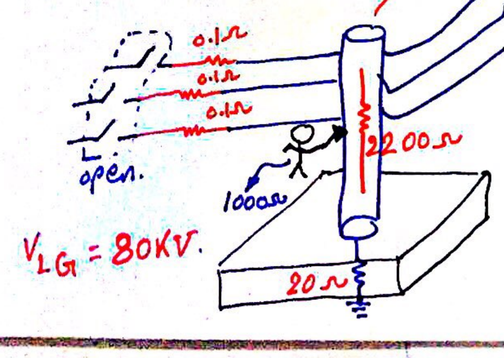
* IEEE

< 1mA	No sensation.
1–8mA	sensation of shock.
8–15mA	painful shock
15–20mA	loss of muscle control.
20–50mA	muscles failure
50–200mA	heart failure
> 200mA	death & burns.

* model of step voltage:

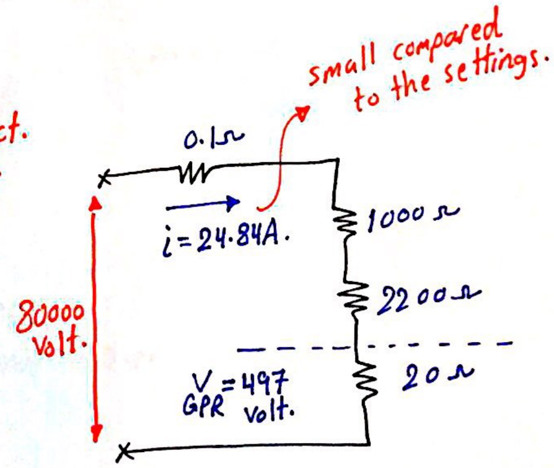


* Grounding & Bonding:

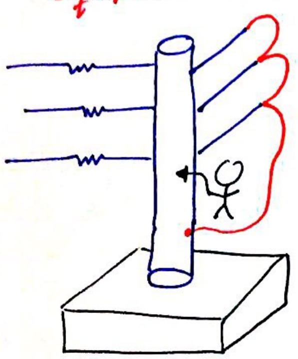


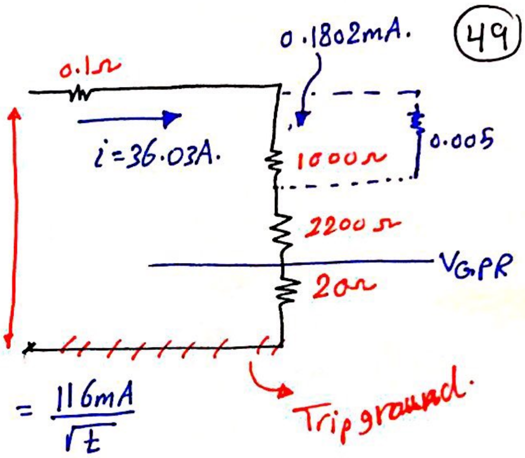
$V_{LG} = 80KV$.

equ. cct. ⟹

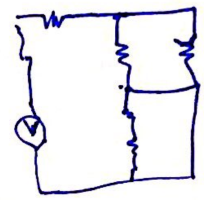


equipotential bonding.

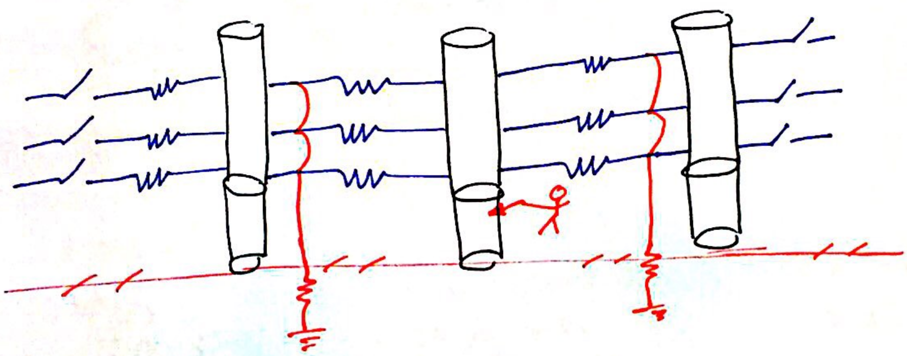




safe current $(I) = \frac{116mA}{\sqrt{t}}$

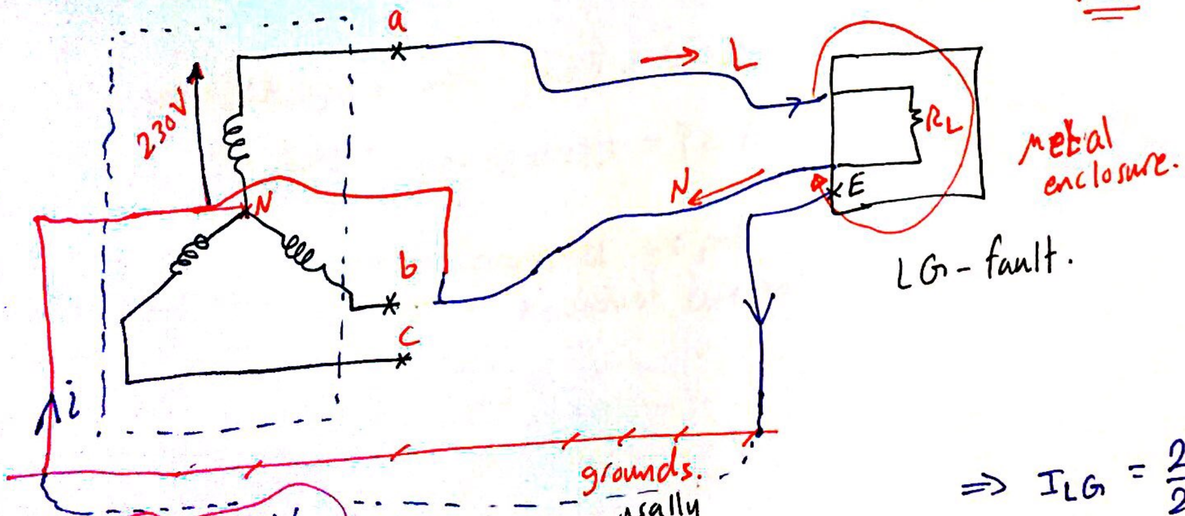


brackets grounding.



* Types of earthing systems:

T.T.



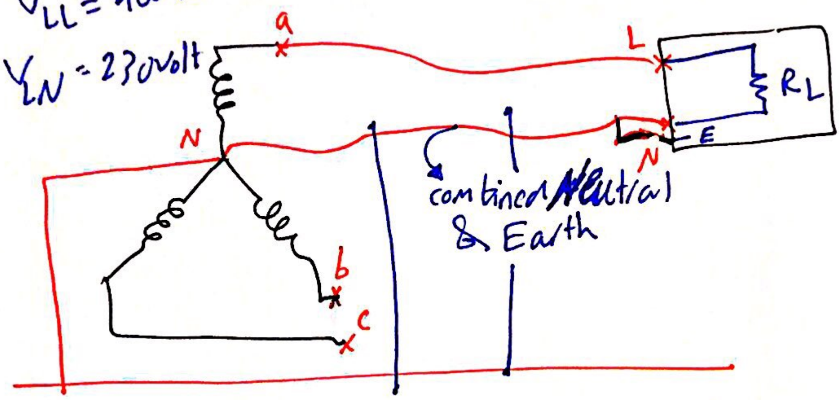
$I_{LG} = \frac{V}{R}$ ground loop resistance.

usally I_{LG} small.
ground loop $\simeq 20\ \Omega$

$\Rightarrow I_{LG} = \frac{230}{20}$
$= 11.5A.$

$V_{LL} = 400$ volt.

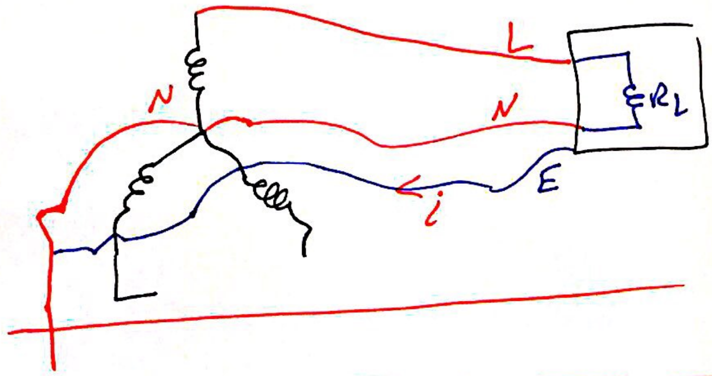
$V_{LN} = 230$ volt



⇒ TN – C – S

- C → combined.
- S → seperate

PME (protective multiple) earthing.



⇒ TN – S → seperate.

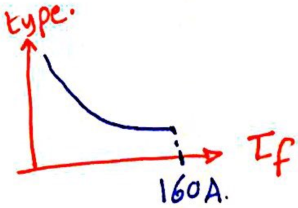
---

* ground loop:

TNS	≃ 0.8 Ω	⇒	$I_{LG} = 230/0.8 = 287A$.
TN-C-S	≃ 0.35 Ω	⇒	$I_{LG} = 657A$.
TT	= 21Ω	⇒	$I_{LG} = 11A$.
	or 100Ω	⇒	$I_{LG} = 2.3A$.

MCB 32A type B ⇒ 32 * 5 = 160A.

MCB 32A type C ⇒ 10 * 32A = 320A.

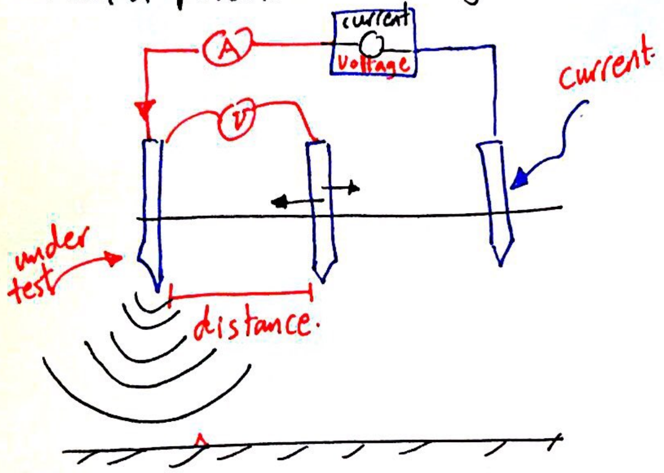


⇒ To be connected we put RCD

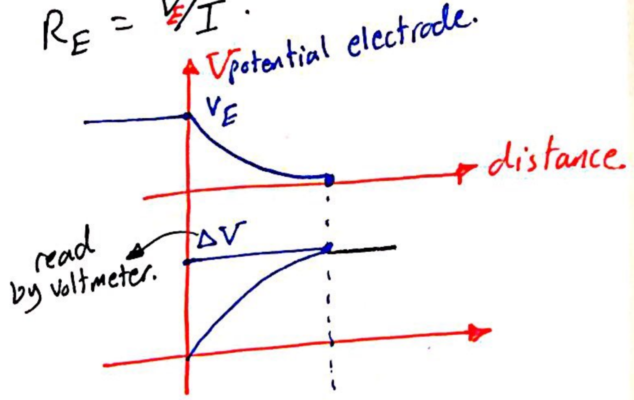
Residual current Device.

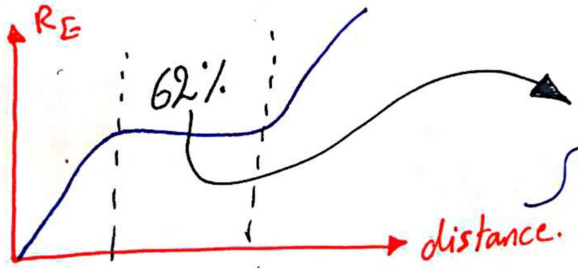
* Ground Testing:

Fall of potential – Testing:



$R_E = V_E / I$.

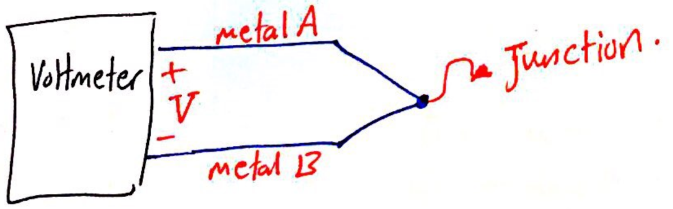




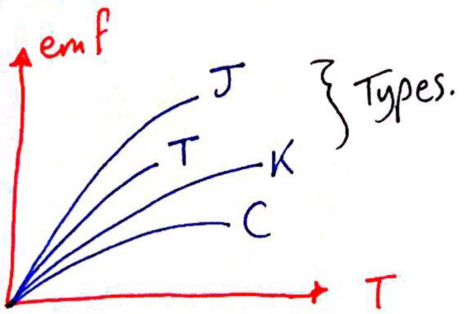
it is the distance between Electrode under Test & potential electrode.

* Transducer:

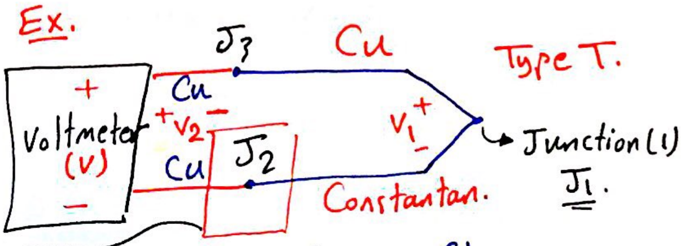
* ThermoCouple: ⇒ Temprature $\xrightarrow{\text{convert to}}$ Voltage.



$\boxed{V = \alpha T}$ → emf.



Ex.



J_3 ⇒ Cu with Cu (No emf).

J_2 ⇒ Cu with C (emf). ⇒ $V = V_1 - V_2$ By KVL.

ice $\left\{ \begin{array}{l} \text{ref} \Rightarrow T = 0 \\ V_2 = 0 \end{array} \right\}$

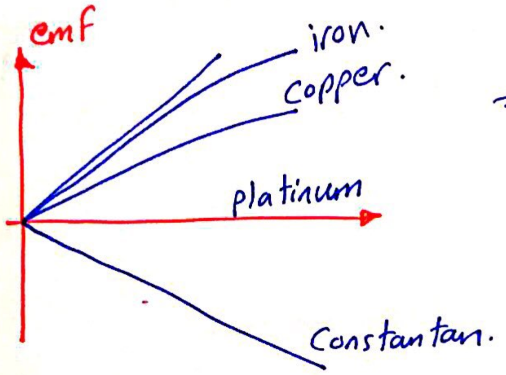
Continue.

⇒ * Reference Junction:

$J_2 \Rightarrow$ reference (ice) $\Rightarrow 0^\circ C \Rightarrow V_2 = 0$

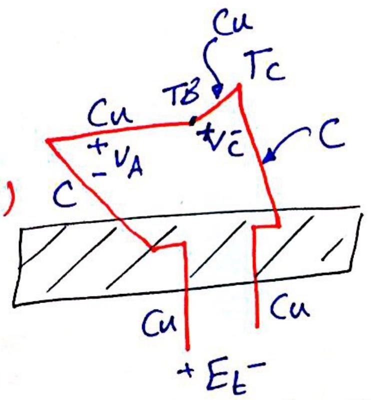
since $V_2 = \alpha T$

$V = V_1 = \alpha T_{J_1}$



⇒ depend on the junction between. the two material.

Example:



$T_D = 0^\circ C$.

given: $T_B = 121.1^\circ C$

$V_A = +1.517 mV$.

$E_t = 2.05 mV$.

curve Cu, C is given.

① find Emf (B, C)

② find T_A, T_C.

solution:

①

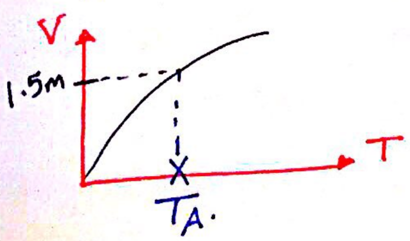
$\boxed{V_B = 0}$ (Cu-Cu Junction).

for C: KVL: $-E_t - V_A + V_C = 0$

so $V_C = E_t + V_A \Rightarrow \boxed{V_C = 3.567 mV}$

②

$T_A \Rightarrow$ from Curve.



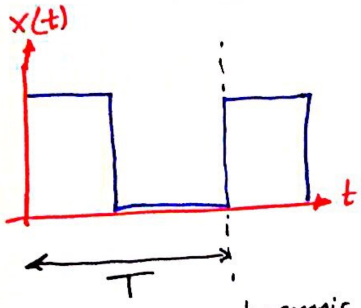
if a table is given for V & T & we didn't find the needed point. ⇒ we do a linearization and find that point.

※ Signal Analysers:

Time domain $\xrightarrow{\quad}$ Frequancy Domain.
⇓
fourier series.

$\Rightarrow x(t) = a_0 + \sum_{n=1}^{N} (a_n \cos n\omega_0 t + b_n \sin n\omega_0 t)$

$\omega_0 \equiv$ Fundemental Frequancy.



$f_0 = \frac{1}{T}$ HZ.

f_0
$2f_0$ Harmonics.
$3f_0$
$4f_0$
⋮

$a_0 \equiv$ DC signal Average.

$a_0 = \frac{1}{T} \int x(t)\, dt.$

harmonic order.

for a_n & b_n:

$a_n = \frac{2}{T} \int x(t) \cos n\omega_0 t\, dt.$

$b_n = \frac{2}{T} \int x(t) \sin n\omega_0 t\, dt.$

※ Power Quality Analysers:

This device can read:
voltage, current, power, Accumulated Energy, magnitude, frequancy
, THD "Total Harmonics Distortion".
It also has a memory.

$dB = 20 \log \frac{V_2}{V_1}$
$= 10 \log P_2/P_1$

$dB_m \rightarrow mW$.

End of Material

* * *