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Fundamentals of Measurements & instrumentation

Measurement : trying to use an instrument to determine the quantity of a variable.

Instrument: A device which we have to measure for find out its quantity.

Acuracy: Its closeness to which an instrument reading approachs to value of variable being measured.

Precision: measure of reproducibility of measurements that is given a fixed value of variable.
Precision is measure of degree to which sucessive measurements differ from one another.

Sensitivity: the ratio of o/p signal or response of the instrument to a change of i/p for measured variable is sensitivity

Resolution: The smallest change in measured value to which the instrument will respond.

Error: Deviation of measured value to true value, that's error.

Types of Errors :

1. Gross
2. Systematic
3. Random

① Gross Error :
- human error
- wrong connection of circuit
- not using proper instrument

② Systematic error :

instrumental
- instrumenterror

Environment
- tempr
- humandity (cleaness, ~~Poor~~ room)
- electrostatic discharge can damage our circuit (By antibiotic use)
- electrical & magnetic field (By shielding)

③ Random error :
- By taking no. of readings
- By taking another different instrument

Limiting Error :
manufacture gives us knowledge or grantee the error that is limited
as example resistor having tolerance of ±10% to ±20%
(that is already limited.

Example : The voltage generated by a circuit is equally dependent on the value of resistors and is given by following equation :

$$V_{out} = \frac{R_1 R_2}{R_3}$$

if tolerance of each resistor is 0.1%. What is the max. error of generated voltage.

Sol : $V_{out} \rightarrow max \Rightarrow R_1$ & R_2 is max. & R_3 is min.

$R_1 + 0.001 R_1$

$R_2 + 0.001 R_2$

$R_3 - 0.001 R_3$

$$So;\ V_{out} = \frac{R_1 (1+0.001)\ R_2 (1.001)}{R_3 (0.999)}$$

$$= 1.003 \frac{R_1 R_2}{R_3}$$

so max. error = 0.003 = .3%.

total V_{out} = 0.003 V

Example : The current passing through a resistor of $100 \pm 2\Omega$ is to $2 \pm 0.01 A$; using $P = I^2 R$. Calculate the limiting error is computed value of power dissipation.

Sol :
$I = 2 \pm 0.01 A = 2 \pm 0.5\%$

$R = 100 \pm 2\Omega = 100 \pm 0.2\%$

$P = I^2 R$

error is $P_r = 2E_I + E_R$

$= 2 \times 0.5 + 0.2$

$= 1.2\%$

$I_r = I (1 \pm 0.002)$

$R_r = R (1 \pm 0.005)$

$P_r = I_r^2 R_r$

$= I^2 R (1.002)^2 (1.005)$

$= (1.012) I^2 R$

error = 1.2%.

BRIDGES

Ac bridges

1. Maxwell (for L)
2. Hay's (for L)
3. Wein (for frequence)
4. De saunty (for capacitance)
5. shering (for capacitor)
6. Andersm (for inductance)

Dc bridges

1. wheatstone (for R)
2. kelvin (for R)
3. kelvin double (for R)

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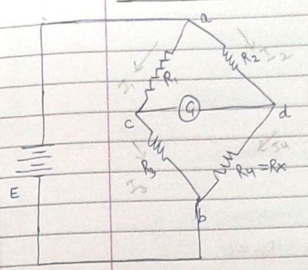
① Wheatstone Bridge :



$R_4 \rightarrow$ Unknown arm

R_1 & $R_2 \rightarrow$ ratio arm

$R_3 \rightarrow$ standard arm

- bridge is balanced when current through Galvanometer is zero $I_G = 0$

$$I_1 R_1 = I_2 R_2 \quad \text{--- (1)}$$

$$I_1 = I_3 \quad \& \quad I_2 = I_4$$

$$I_1 = \frac{E}{R_1 + R_3} \text{ --- (2)} \quad \& \quad I_2 = \frac{E}{R_2 + R_4} \text{ --- (3)}$$

$$\frac{R_1}{R_1 + R_3} = \frac{R_2}{R_2 + R_4}$$

$$R_1 R_2 + R_1 R_4 = R_1 R_2 + R_2 R_3$$

$$\boxed{R_1 R_4 = R_2 R_3} \quad \text{--- (4)}$$

if $R_4 = R_x \longrightarrow$ Unknown

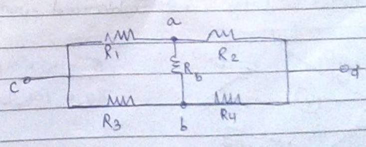
$$R_x = \frac{R_2 R_3}{R_1}$$

We don't get practically exact value of R_x, because

Measurement errors :-

- insufficient efficiency of gelvnometer
- thermal emfs
- limiting errors of resistors
- R of connecting leads [lead resistance is added, when resistance value is low]
- heating errors effect $\rightarrow I^2R$ losses

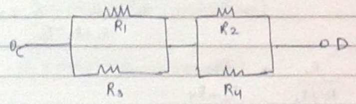
Thevnin eqn Circuit :



Drawback: lead resistance

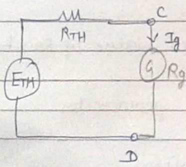
$$E_{CD} = E_{ac} - E_{ad}$$
$$= I_1R_1 - I_2R_2$$
$$= \frac{ER_1}{R_1+R_3} - \frac{ER_2}{R_2+R_4}$$
$$= E\left[\frac{R_1R_2 + R_1R_4 - R_1R_2 - R_2R_3}{(R_1+R_3)(R_2+R_4)}\right]$$
$$= E\left[\frac{R_1R_4 - R_2R_3}{(R_1+R_3)(R_2+R_4)}\right] \quad \text{— (1)}$$

when we assume R_b is very less $R_b = 0$



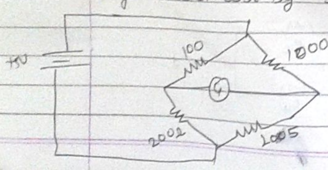
$$R_{TH} = \frac{R_1R_3}{R_1+R_3} + \frac{R_2R_4}{R_2+R_4} \quad \text{— (2)}$$

equivalent circuit:



$$I_g = \frac{E_{th}}{R_{th}+R_g}$$

Ex: Considering the fig. the Battery voltage is 5V and its internal resi. is negligible. The G has a current sensitivity of 10 mm/ µA and $R_g = 100\,\Omega$. Calculate the deflection of galvanometer cost by $5\,\Omega$ unbalanced arm BC.



$S = 10$ mm/µA
$R_g = 100\,\Omega$

Sol:

$$V_{th} = 5\left[\frac{100\times2005 - 1000\times200}{300\times3005}\right]$$
$$= 2.77\times10^{-3}\ V$$

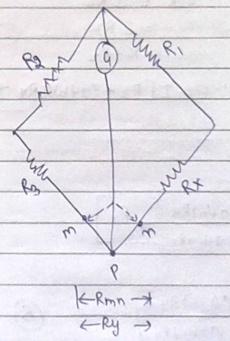
$$R_{th} = \frac{100\times200}{300} + \frac{1000\times2005}{3005} = 66.67 + 667.22 = 733.89\,\Omega$$

$$I_g = \frac{2.77\times10^{-3}}{733.89+100} = 3.72\ \mu A$$

deflection = 37.2 mm

(2) Kelvin Bridge:

for low resistance value, we used Kelvin bridge.



$$\boxed{\frac{R_{np}}{R_{mp}} = \frac{R_1}{R_2}} \quad \text{— (1)}$$

– balanced bridge

$$R_2(R_x + R_{np}) = (R_3 + R_{mp})R_1$$
$$R_x + R_{np} = \frac{R_1}{R_2}(R_3 + R_{mp}) \quad \text{— (2)}$$

in eqn (1)
$$\frac{R_{np}}{R_{mp}+R_{np}} = \frac{R_1}{R_1+R_2}$$
$$\Rightarrow R_{np} = \frac{R_1}{R_1+R_2}(R_y) \quad \text{— (3)}$$
$$\frac{R_{np}+R_{mp}}{R_{mp}} = \frac{R_1+R_2}{R_2}$$
$$R_{mp} = \frac{R_2}{R_1+R_2}(R_y) \quad \text{— (4)}$$

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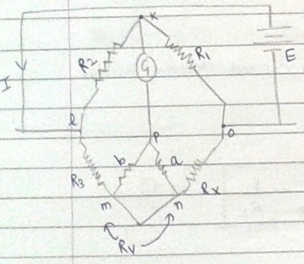
$$R_x = \frac{R_1}{R_2}\left[R_3 + \frac{R_y R_2}{R_1+R_2}\right] - \frac{R_y R_1}{R_1+R_2}$$

$$= \frac{R_1(R_1R_3 + R_2R_3 + R_yR_2)}{R_2(R_1+R_2)} - \frac{R_yR_1}{R_1+R_2}$$

$$= \frac{R_1(R_1R_3+R_2R_3) + \cancel{R_1R_2R_y} - \cancel{R_1R_2R_y}}{(R_1+R_2)R_2}$$

$$R_x = \frac{R_1R_3}{R_2}$$

③ Kelvin double bridge :



$$\frac{a}{b} = \frac{R_1}{R_2}$$

Balanced : $G = 0$

pot. at k = Pot. at p

$E_{lk} = E_{lmp}$ —— ①

$E_{lk} = I R_2$

$= \frac{E R_2}{R_1+R_2}$ —— ②

$\because E = I[R_3 + (a+b)\,||\,R_y + R_x]$ —— ③

$$E_{lk} = \frac{R_2 \cdot I}{R_1+R_2}\left[R_3 + \frac{(a+b)R_y}{a+b+R_y} + R_x\right] \quad \text{—— ④}$$

$$E_{lmp} = I\left[R_3 + \frac{b}{a+b}\left(\frac{(a+b)R_y}{(a+b)+R_y}\right)\right] \quad \text{—— ⑤}$$

④ = ⑤

$$\frac{R_2R_3}{R_1+R_2}[1] + \frac{R_2 \cdot R_x}{R_1+R_2} + \frac{R_2(a+b)R_y}{R_1+R_2(a+b+R_y)} = R_3 + \frac{b}{a+b}\frac{(a+b+R_y)}{(a+b)R_y}$$

$$\frac{R_3}{\frac{a}{b}+1} + \frac{R_x}{\frac{a}{b}+1} + \frac{(a+b)R_y}{(\frac{a}{b}+1)(a+b+R_4)} = R_3 + \frac{b(a+b+R_y)}{(a+b)^2R_y}$$

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$$\Rightarrow \frac{bR_3}{a+b} + \frac{bR_x}{a+b} + \frac{b(a+b)R_y}{(a+b)(a+b+R_y)} = \frac{R_3(a+b)}{(a+b)} + \frac{b(a+b+R_y)}{(a+b)^2R_y}$$

$$\Rightarrow b[R_3 + R_x] + b(a+b)R_y = R_3[a+b] + \frac{b(a+b+R_y)}{(a+b)R_y}$$

$$\Rightarrow [bR_x + b(a+b)R_y][(a+b)R_y] = aR_3R_y(a+b) + b(a+b+R_y)$$

$\Rightarrow$ ~~$abR_xR_y +$~~

$$\Rightarrow (bR_x + abR_y + b^2R_y)(aR_y + bR_y) = aR_3R_ya + abR_3R_y + ab + b^2 + bR_y$$

$$\Rightarrow abR_xR_y + b^2R_xR_y + a^2bR_y^2 + ab^2R_y^2 + ab^2R_y^2 + b^3R_y^2$$

$=$

$$\frac{R_2}{R_1+R_2}\left[R_3 + R_x + \frac{(a+b)R_y}{a+b+R_y}\right] = R_3 + \frac{b}{a+b}\frac{(a+b)R_y}{(a+b+R_y)}$$

$$R_2R_3 + R_2R_x + \frac{(a+b)R_y R_2}{a+b+R_y} = R_3R_1 + R_3R_2 + \frac{bR_y(R_1+R_2)}{(a+b+R_y)}$$

$$R_2R_x + \frac{aR_2R_y}{a+b+R_y} - \frac{bR_yR_1}{(a+b+R_y)} = R_1R_3$$

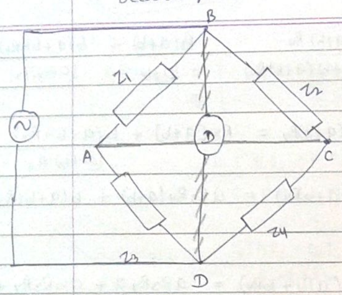
$$\boxed{R_x = \frac{R_1R_3}{R_2}}$$

assumption : ① $\frac{a}{b} = \frac{R_1}{R_2}$

② current through both branches is same.

AC BRIDGES :

- for dc, we used gelunometer, but we can't use this for ac. Because gelunometer calculate the avg. value: $(I_{avg})_{ac} = 0$



D → null detector

$Z_1 Z_4 = Z_2 Z_3$ — (1)

$Y_1 Y_4 = Y_2 Y_3$ — (2)

$$\boxed{Z_1 Z_4 \angle \theta_1 + \theta_4 = Z_2 Z_3 \angle \theta_2 + \theta_3}$$

- $Z_1 Z_4 = Z_2 Z_3$

$\angle \theta_1 + \theta_4 = \angle \theta_2 + \theta_3$

<u>Example</u>: the impedences of basic ac bridge are as follows:

$Z_1 = 100\Omega \angle 80° \rightarrow L$ $Z_2 = 250\Omega \angle 0° \rightarrow R$

$Z_3 = 400\Omega \angle 30° \rightarrow L$ find $Z_4 = ?$

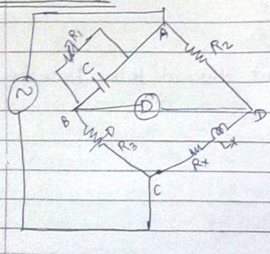
<u>Sol:</u> $Z_4 = \frac{Z_2 Z_3}{Z_1} = \frac{250 \times 400}{100} = 1000\Omega$

$80 + \theta_4 = 30°$

$\theta_4 = -50°$

so; $\boxed{Z_4 = 1000\Omega \angle -50°}$ → capacitor

(1) <u>Maxwell Bridge:</u>



at balance

$Z_1 Z_x = Z_2 Z_3$

$Z_x = \frac{Z_2 Z_3}{Z_1} = Z_2 Z_3 \cdot Y_1$

$R_x + j\omega L_x = R_2 \cdot R_3 \left[\frac{1}{R_1} + j\omega C_1\right]$

$R_x + j\omega L_x = \frac{R_2 R_3}{R_1} + R_2 R_3 j\omega C_1$

$\theta \rightarrow +ve \rightarrow L$ $L \rightarrow j\omega L_x$

$\theta \rightarrow 0° \rightarrow R$ $C \rightarrow 1/j\omega C_x$

$\theta \rightarrow -ve \rightarrow C$

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$$\boxed{R_x = \frac{R_2 R_3}{R_1}} \; ; \; \boxed{L_x = R_2 R_3 C_1}$$

- maxwell : $1 < Q < 10$ medium Q coil (inductor)

<u>Example</u> A Maxwell bridge is used to measure an inductive impedance the bridge constant are balanced $C_1 = 0.01 \mu F$; $R_1 = 470 K\Omega$; $R_2 = 5.1 K\Omega$ & $R_3 = 100 K\Omega$

<u>Sol:</u>

$R_x = \frac{R_2 R_3}{R_1} = \frac{5.1 \times 100}{470} = 1.08 \ K\Omega$

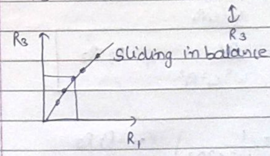
$L_x = R_2 R_3 C_1 = 5.1 \times 100 \times 0.01 \mu F = 5.1 H$

(?) Why maxwell bridge is not used for finding the Low-Q and high-Q ?

<u>Low-Q</u>

$L_x \rightarrow$ low Q

$R_3 \leftrightarrow R_1 \leftrightarrow R_3 \leftrightarrow R_1 \updownarrow R_3$



Balance convergence

<u>High-Q</u>

$\angle \theta_1 + \angle \theta_4 = \angle \theta_2 + \angle \theta_3$

$= 0$ (because of Resistance)

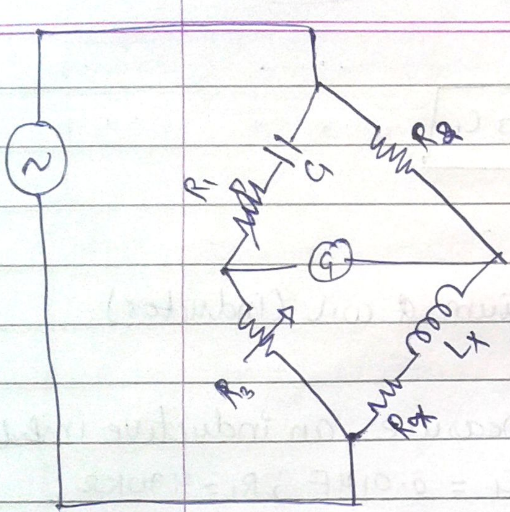
$\angle \theta_1 = -\angle \theta_4$

$\approx 90°$

for getting the $-90°$ angle we have to ↑se the value of X_C, so we have to increase the value of R_1 ($M\Omega$) so its not practically possible.

(2) <u>Hay's Bridge:</u>

- for High Q measurment



$$Z_1 = R_1 - \frac{1}{j\omega C_1}$$

$$Z_4 = R_4 + j\omega L_{x_1}$$

at balance

$$Z_1 Z_4 = Z_2 Z_3$$

$$\left(R_1 - \frac{1}{j\omega C_1}\right)\left(R_4 + j\omega L_x\right) = R_2 R_3$$

$$R_1 R_4 + j\omega L_x R_1 - \frac{R_4}{j\omega C_1} - \frac{L_x}{C_1} = R_2 R_3$$

$$R_1 R_4 - \frac{L_x}{C_1} = R_2 R_3$$

$$\boxed{C_1 (R_1 R_4 - R_2 R_3) = L_x}$$

$$\boxed{C_1 (R_1 R_x - R_2 R_3) = L_x} \quad \text{— (2)}$$

$$j\omega L_x R_1 + \frac{R_4 j}{\omega C_1} = 0$$

$$\omega R_1 L_x = \frac{R_4}{\omega C_1} \quad \text{— (1)}$$

$$L_x = \frac{R_4}{\omega^2 C_1 R_1}$$

putting the value from (1) in (2)

$$C_1 (R_1 R_x - R_2 R_3) = R_4$$

$$\left(R_1 - \frac{1}{j\omega C_1}\right)(R_x + j\omega L_x) = R_2 R_3$$

$$R_1 R_x - \frac{L_x}{C_1} - \frac{R_x}{j\omega C_1} + R_1 j\omega L_x = R_2 R_3$$

$$C_1 (R_1 R_x - R_2 R_3) = L_x \quad \text{—— ①} \qquad \& \qquad L_x = \frac{-R_x}{\omega^2 R_1 C_1} \quad \text{—— ②}$$

① = ②

$$C_1 R_1 R_x - C_1 R_2 R_3 = \frac{-R_x}{\omega^2 R_1 C_1}$$

$$R_x \left(C_1 R_1 + \frac{1}{\omega^2 R_1 C_1} \right) = C_1 R_2 R_3 \Rightarrow \boxed{R_x = \frac{\omega^2 C_1^2 R_2 R_3 R_1}{1 + \omega^2 R_1^2 C_1^2}}$$

$$\boxed{L_x = \frac{C_1 R_2 R_3}{1 + \omega^2 R_1^2 C_1^2}}$$

II. balanced condition:

$$\tan\theta_L = \frac{X_L}{R} = \frac{\omega L_x}{R_x} \quad \text{—— ⑦}$$

$$\tan\theta_C = \frac{X_C}{R} = \frac{1}{\omega C_1 R_1} \quad \text{—— ⑧}$$

$$\frac{\omega L_x}{R_x} = \boxed{\frac{1}{\omega C_1 R_1} = Q} \quad \text{—— ⑨}$$

So; $$R_x = \frac{\omega^2 C_1^2 R_1 R_2 R_3}{1 + (1/Q)^2} \simeq \omega^2 C_1^2 R_1 R_2 R_3$$

$$L_x = \frac{R_2 R_3 C_1}{1 + (1/Q)^2} \simeq R_2 R_3 C_1$$

Hay's $Q > 10 \Rightarrow \left(\frac{1}{Q}\right)^2 < \left(\frac{1}{10}\right)^2$

Example find series equivalent L_x & R_x of a n/w that ~~possess~~ causes opp. angle of Hay's bridge to null with full bridge arms

$\omega = 3000$ rad/s

$R_2 = 10 K\Omega$

$R_1 = 2 K\Omega$

$C_1 = 1 MF$

$R_3 = 1 K\Omega$

Sol:-

$$\phi = \frac{1}{\omega R_1 C_1} = \frac{1}{3000 \times 2\times10^3 \times 1\times10^6}$$

$$= 0.16\times10^{-12}$$

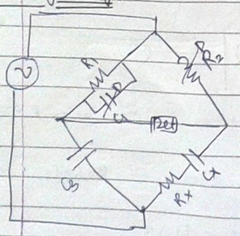
$$R_x = \frac{\omega^2 C_1^2 R_1 R_2 R_3}{1+\omega^2 C_1^2 R_1^2}$$

$$= \frac{(3000)^2 (1M)^2 (10\times2\times1\times10^9)}{1+(3000\times1M\times2\times10^3)^2}$$

$$= \frac{180\times10^{27}}{1+36\times10^{24}} = 5 K\Omega$$

$$L_x = \frac{R_2 R_3 C_1}{1+\omega^2 C_1^2 R_1^2} = \frac{10\times1\times1\times10^6\times10^6}{36\times10^{24}} = 0.027\times10^{-11} H$$

③ Schering Bridge :



$$Y_1 = \frac{1}{R_1} + j\omega C_1$$

$$Z_2 = R_2$$

$$Z_3 = \frac{-j}{\omega C_3}$$

$$Z_x = R_x - \frac{j}{\omega C_x}$$

at balance

$$Z_1 Z_x = Z_2 Z_3$$

$$Z_x = Z_2 Z_3 Y_1 \quad —①$$

$$\left(R_x - \frac{j}{\omega C_x}\right) = \frac{-R_2 j}{\omega C_3}\left(\frac{1}{R_1} + j\omega C_1\right)$$

$$= -j\frac{R_2}{\omega C_3 R_1} - \frac{R_2 j^2 C_1}{C_3}$$

$$\left(R_x - \frac{j}{\omega C_x}\right) = -j\left(\frac{R_2}{R_1 \omega C_3}\right) + \frac{R_2 C_1}{C_3}$$

$$\boxed{R_x = \frac{R_2 C_1}{C_3}} \quad —② \qquad \boxed{C_x = \frac{R_1 C_3}{R_2}} \quad —③$$

dissipation factor : (D)

$$D = \cot(\theta_c) = \omega C_x R_x \quad —④$$

put ② & ③ in ④

$$\boxed{D = \omega C_1 R_1} \quad —⑤$$

Ex:- An ac bridge has following constants ; $f = 1 KHz$

Arm AB : $C = 0.5 MF \parallel R = 1 K\Omega$

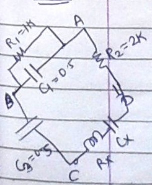
Arm AD : $R = 2 K\Omega$

Arm BC : $C = 0.5 MF$

CD : C_x & R_x in series with other

determine R_x & C_x and dissipation factor D = ?

Sol:



$$R_x = R_2 \cdot \frac{C_1}{C_3} = \frac{2\times10^3\times0.5\times10^{-6}}{0.5\times10^{-6}} = 2 K\Omega$$

$$C_x = \frac{R_1}{R_2} \cdot C_3 = \frac{1\times10^3}{2\times10^3}\times0.5 = 0.25 MF$$

$$D = \omega C_1 R_1 = 2\pi f(0.5\times10^{-6})(10^3) = \frac{10^{-3}}{10^6}\left(\frac{0.5}{2\pi}\right) = \frac{0.079}{\times10^{-9}}$$

$$= 3.14$$ Ans.

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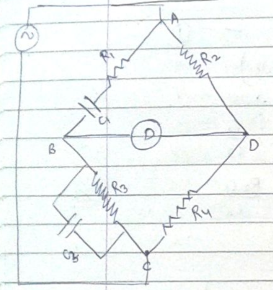
④ Wein Bridge : (for frequence)



$$Z_1 Z_4 = Z_2 Z_3$$

$$Z_2 = Z_1 Z_4 Y_3$$

$$R_2 = \left(R_1 - \frac{j}{\omega C_1}\right) R_4 \left(\frac{1}{R_3} + j\omega C_3\right)$$

$$R_2 = \frac{R_1 R_4}{R_3} + R_1 R_4 j\omega C_3 - \frac{j R_4}{\omega C_1 R_3} + \frac{C_3 R_4}{C_1}$$

Equate real terms

$$R_2 = \frac{R_1 R_4}{R_3} + \frac{C_3 R_4}{C_1}$$

$$\frac{R_2}{R_4} = \frac{R_1}{R_3} + \frac{C_3}{C_1} \quad \text{—— ①}$$

Equate imag. terms

$$R_1 R_4 \omega C_3 = \frac{R_4}{\omega C_1 R_3}$$

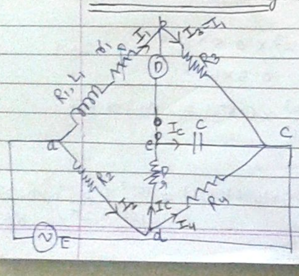
$$\omega^2 = \frac{1}{C_1 C_3 R_1 R_3}$$

$$\boxed{f = \frac{1}{2\pi\sqrt{C_1 C_3 R_1 R_3}}} \quad \text{—— ②}$$

$C_1 = C_3 = C$ & $R_1 = R_3 = R$

So freq. $f = \frac{1}{2\pi RC}$

⑤ Anderson's Bridge : (meaure the self inductance of inductor)



at balance

$$I_1 = I_3$$

$$I_2 = I_c + I_4$$

$$I_4 = I_2 - I_c$$

Date
Page

pottential at b = pottential at e

$$E_{bc} = E_{ec}$$

$$I_1 R_3 = I_c \left(\frac{1}{j\omega C}\right) \quad \text{—— ①}$$

$$\Rightarrow \quad I_c = I_1 (R_3 j\omega C) \quad \text{—— ②}$$

$$E_{ab} = E_{ade}$$

$$I_1(r_1 + R_1 + j\omega L_1) = I_2 R_2 + I_c r \quad \text{—— ③}$$

$$E_{dc} = E_{dec}$$

$$I_4 R_4 = I_c r + I_c\left(\frac{1}{j\omega C}\right)$$

$$\because I_4 = I_2 - I_c$$

$$(I_2 - I_c) R_4 = I_c\left(r + \frac{1}{j\omega C}\right) \quad \text{—— ④}$$

put ② in ③

$$I_1(r_1 + R_1 + j\omega L_1) = I_2 R_2 + I_1 (r R_3 j\omega C)$$

$$I_2 R_2 = I_1 [r_1 + R_1 + j\omega L_1 - r R_3 j\omega C]$$

$$I_2 = \frac{I_1}{R_2}[r_1 + R_1 + j\omega L_1 - r R_3 j\omega C] \quad \text{—— ⓐ}$$

put ② in ④

$$I_2 R_4 - R_4 I_1 R_3 j\omega C = I_1 (R_3 j\omega C)\left(r + \frac{1}{j\omega C}\right)$$

$$I_2 R_4 = I_1 R_3 j\omega C\left[r + \frac{1}{j\omega C} + R_4\right]$$

$$I_2 = \frac{I_1 R_3 j\omega C}{R_4}\left(r + R_4 + \frac{1}{j\omega C}\right) \quad \text{—— ⓑ}$$

By equating ⓐ & ⓑ

$$\frac{r_1}{R_2} + \frac{R_1}{R_2} + \frac{j\omega L_1}{R_2} - \frac{r R_3 j\omega C}{R_2} = \frac{R_3}{R_4} j\omega C r + R_3 j\omega C \mp \frac{R_3}{R_4}$$

real terms:

$$\frac{r_1 + R_1}{R_2} = \frac{R_3}{R_4}$$

$$R_1 = \frac{R_3 R_2}{R_4} - r_1$$

imag. Parts

$$\frac{L_1}{R_2} = \frac{R_3 C r}{R_4} + R_3 C + \frac{r R_3 C}{R_2}$$

$$L_1 = C R_3\left(\frac{r}{R_4} + 1 + \frac{r}{R_2}\right) R_2$$

$$\boxed{R_1 = \frac{R_2 R_3}{R_4} - r_1}$$

$$L_1 = C R_2 R_3 \left(1 + \frac{r}{R_2} + \frac{r}{R_4}\right)$$

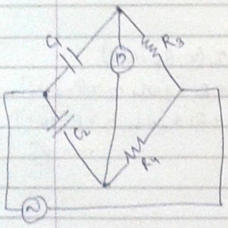
$$= \frac{C R_2 R_3}{R_2 R_4}\left[R_2 R_4 + r(R_2 + R_4)\right]$$

$$\boxed{L_1 = \frac{C R_3}{R_4}\left[r(R_2 + R_3) + R_2 R_4\right]}$$

- low Q measurement (Advantage)

⑥ **De Saunty Bridge:**

- used for measuring capacitance



$C_1 \rightarrow$ Unknown

$C_2 \rightarrow$ Standard

R_3 & $R_4 \rightarrow$ non inductive resistor

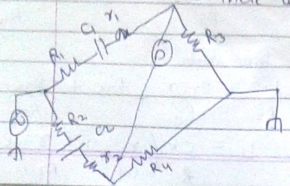
$$Z_1 Z_4 = Z_2 Z_3$$

$$\frac{1}{j\omega C_1} \times R_4 = R_3 \times \frac{1}{j\omega C_2}$$

$$\boxed{\frac{C_1}{C_2} = \frac{R_4}{R_3}} \quad \text{—— (1)}$$

eqⁿ (1) is valid when (its ideally,) when cap. has not diletric losses by capacitor

- But if diletric losses is there, then some series resistance is there with capacitor



$r_1, r_2 \rightarrow$ loss of cap. C_1 & C_2

$R_1, R_2 \rightarrow$ series resitance with capacitor

$$Z_1 Z_4 = Z_2 Z_3$$

$$\left(R_1 + r_1 + \frac{1}{j\omega C_1}\right) R_4 = R_3\left(R_2 + r_2 + \frac{1}{j\omega C_2}\right)$$

real: $\dfrac{R_1 + r_1}{R_2 + r_2} = \dfrac{R_3}{R_4}$ imag. $\dfrac{R_3}{R_4} = \dfrac{C_2}{C_1}$ $\Rightarrow C_1 = C_2 \dfrac{R_4}{R_3}$

$$\Rightarrow \boxed{\frac{C_1}{C_2} = \frac{R_2 + r_2}{R_1 + r_1}} \quad \text{—— (2)}$$

<u>dissipation factor:</u>

$$D_1 = \omega C_1 r_1$$
$$D_2 = \omega C_2 r_2$$

in eqⁿ (2)

$$C_1 R_1 + C_1 r_1 = C_2 R_2 + C_2 r_2$$
$$\omega(C_1 R_1 - C_2 R_2) = \omega(C_2 r_2 - C_1 r_1)$$
$$\omega(C_1 R_1 - C_2 R_2) = D_2 - D_1 \quad \text{—— (3)}$$

so;

$$\boxed{D_2 - D_1 = \omega C_2\left(\frac{R_1 R_4}{R_3} - R_2\right)}$$