IoT 4211: Sensor Technology

SIGNAL CONDITIONING

Contents

Bridge Circuits

Used to measure change in resistance, capacitance and inductance of passive transducers.: converts non-electrical energy into electrical energy

ΔR ΔC ΔL

A passive transducer is a device that converts non-electrical energy into electrical energy by external force. It requires an external power source for its operation. It produces an output signal in the form of some variation in resistance, capacitance, or any other electrical parameter. Examples:
Photocell (LDR) - It varies the resistance with light intensity
Resistance strain gauge - It changes the resistance with applied force

DC or AC

DC and **AC bridge circuits** both are used to measure resistance, while for measuring capacitance and inductance, only AC bridge circuit is used.

ΔR

ΔC AC ΔL

DC Bridge Circuit: Wheatstone Bridge

Balanced condition

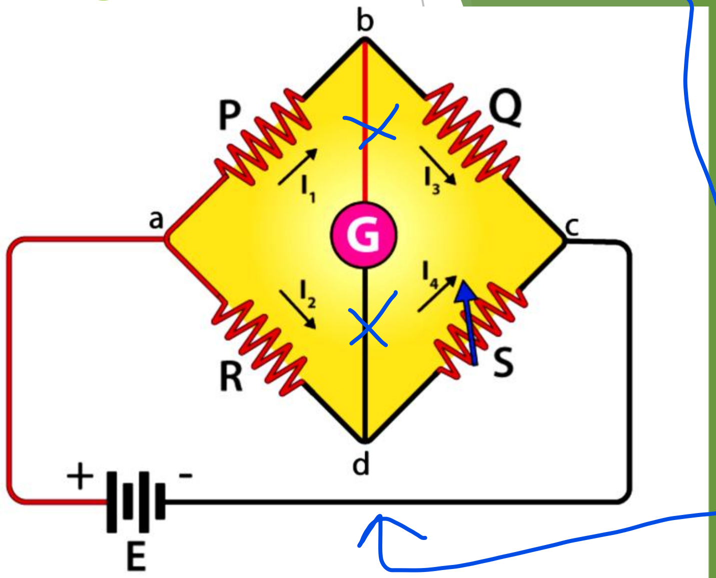
$V_1 = V_2$

When Galvanometer reading is zero, $I_1 P = I_2 R$ (1)

Current in the bridge at balanced condition,

$$I_1 = I_3 = \frac{E}{P+Q}$$

$$I_2 = I_4 = \frac{E}{R+S}$$



$V_G = 0$

$I_G = 0$

From Eq. (1),

$$\frac{PE}{P+Q} = \frac{RE}{R+S}$$

$$\frac{P}{P+Q} = \frac{R}{R+S}$$

$$P(R+S) = R(P+Q)$$

$$PR + PS = RP + RQ$$

$$\boxed{PS = RQ}$$

A Wheatstone bridge is an electrical circuit used to precisely measure an unknown resistance by balancing two legs of a bridge circuit. The circuit consists of four resistors arranged in a diamond shape with a voltage source applied across the bridge and a galvanometer (sensitive ammeter) placed in between two midpoints.

Galvanometer vs Ammeter: Key Differences

Attribute	Galvanometer	Ammeter
Measurement	Small currents, magnitude direction	Larger currents, only magnitude
Sensitivity	More sensitive	Less sensitive
Accuracy	Lower accuracy	Higher accuracy
Current Type	Direct current (DC) only	Both DC and AC
Applications	Scientific experiments, bridges	Electrical circuits

DC Bridge Circuit: Wheatstone Bridge

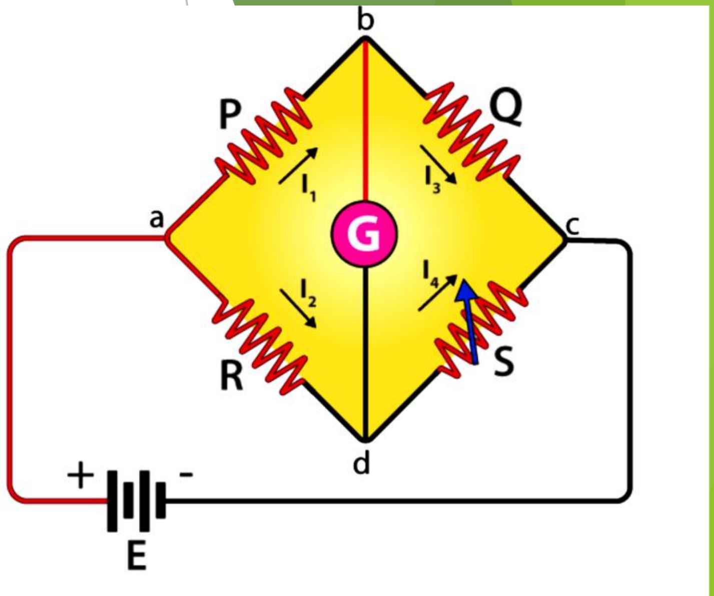
Applications

•**Measuring small resistances**: Especially useful in scenarios where high precision is needed.

•**Strain gauges and sensors**: Wheatstone bridges are often used in sensors where changes in resistance (due to pressure, force, or temperature) are converted into measurable electrical signals.

•**Temperature measurements**: With thermistors in one arm, the bridge can measure temperature.

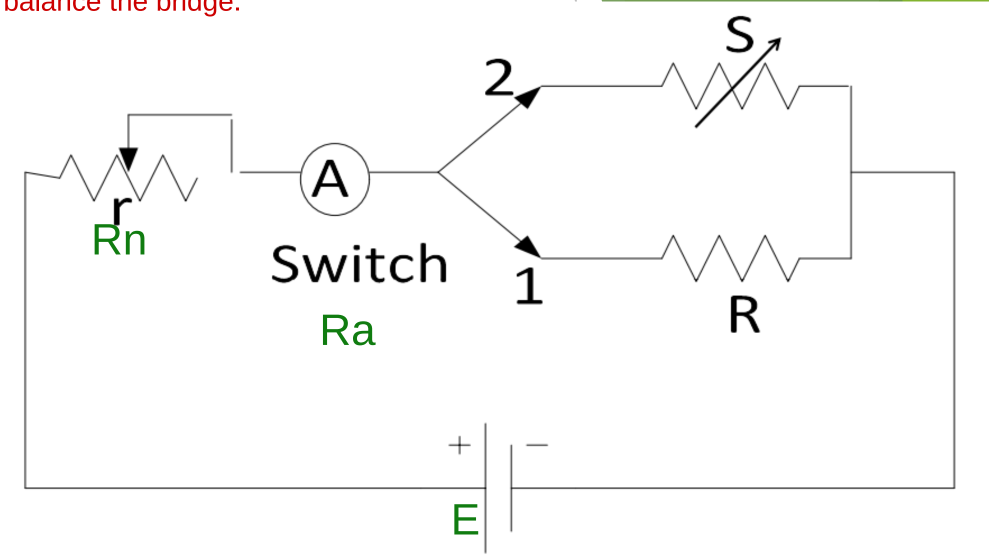
A thermistor is a semiconductor type of resistor whose resistance is strongly dependent on temperature, more so than in standard resistors. The word thermistor is a portmanteau of thermal and resistor. Thermistors are categorized based on their conduction models. Negative-temperature-coefficient thermistors have less resistance at higher temperatures, while positive-temperature-coefficient thermistors have more resistance at higher temperatures.



DC Bridge Circuit: Substitution

In a DC bridge circuit, the substitution method is a technique used to determine the value of an unknown resistor by substituting it with a known resistor.

This method is particularly useful in situations where precision is required, and it provides an effective way to balance the bridge.



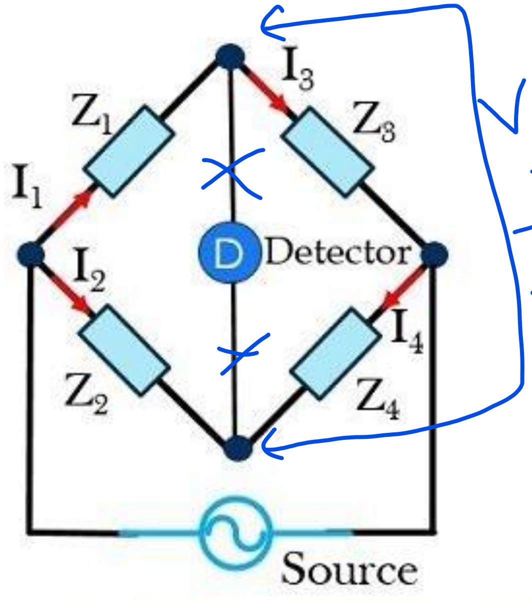
KVL

E-i1Rn-i1Ra-i1R=0
=>E=i1(Rn+Ra+R)-------------(i)

E-i2Rn-i2Ra-i2S=0
=> E= i2(Rn+Ra+R)-----------------------(ii)

i1(Rn+Ra+R)=i2(Rn+Ra+s)
.'. R = {i2(Rn+Ra+s)-i1(Rn+Ra)} / i1

AC Bridge Circuit



AC bridge network

- An AC bridge consists of 4 nodes with 4 arms, a source excitation and a balanced detector. Each of the 4 arms of the bridge consists of impedance.

$V_D = 0$

- there are 2 conditions in order to balance the bridge-

  (a) The detector current Id should be zero. $I_D = 0$

  (b) The potential difference between the detector node should be zero.

- **Applications:**

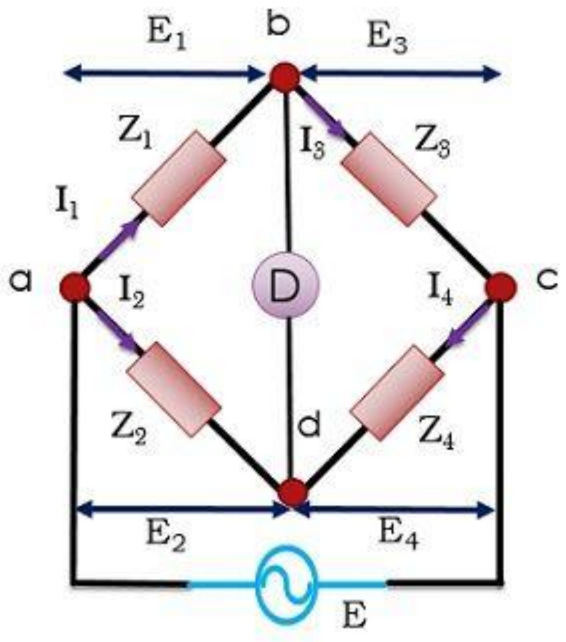
i. AC bridges are used to find unknown impedances along with associated parameters.

ii. Communication system and complex electronics circuitry majorly make use of AC bridges.

iii. AC bridge circuits are used in phase shifting and for the filtration of undesirable signals.

iv. It is also used to measure the frequency of audio signals.

AC Bridge Circuit: General Balance Equation



$E_1 = E_2$

Applying ohms' law

$$I_1 Z_1 = I_2 Z_2$$

At balance,

$$I_1 = I_3 = \frac{E}{Z_1 + Z_3}$$

And

$$I_2 = I_4 = \frac{E}{Z_2 + Z_4}$$

Substituting the value of I_1 and I_2

$$\frac{E}{Z_1 + Z_3} Z_1 = \frac{E}{Z_2 + Z_4} Z_2$$

$$\frac{Z_1}{Z_1 + Z_3} = \frac{Z_2}{Z_2 + Z_4}$$

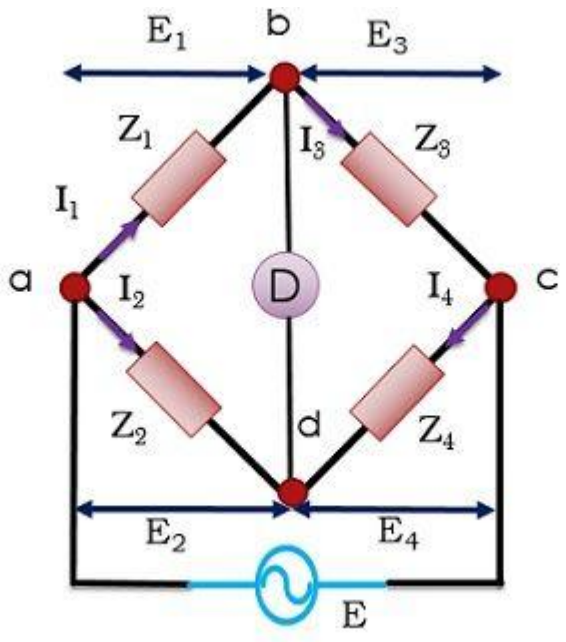
$$Z_1 (Z_2 + Z_4) = Z_2 (Z_1 + Z_3)$$

$$Z_1Z_2 + Z_1Z_4 = Z_1Z_2 + Z_2Z_3$$

Hence,

$$Z_1Z_4 = Z_2Z_3$$

AC Bridge Circuit: General Balance Equation



Let us now consider impedance in its polar form

$$\mathbf{Z = Z\angle\theta}$$

: **Z** represents the magnitude and

θ represents the phase angle of complex impedance.

The above equation can be written as

$$\mathbf{(Z_1\angle\theta_1)\ X\ (Z_4\angle\theta_4) = (Z_2\angle\theta_2)\ X\ (Z_3\angle\theta_3)}$$

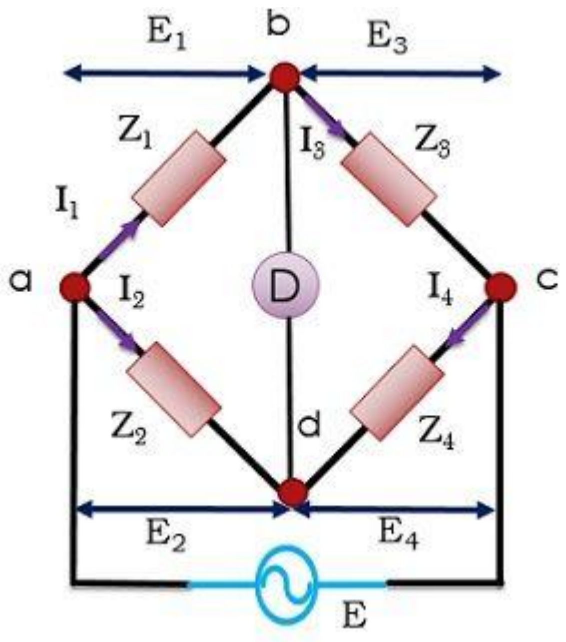
: $Z_1 = (Z_1\angle\theta_1)$

$Z_2 = (Z_2\angle\theta_2)$

$Z_3 = (Z_3\angle\theta_3)$

$Z_4 = (Z_4\angle\theta_4)$

AC Bridge Circuit: General Balance Equation



So, here impedance parameters will get multiplied and angles will be added.

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

Separately we can write magnitude and phase equation as-

$$Z_1 Z_4 = Z_2 Z_3$$

The condition in above equation is called **magnitude criteria** and

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

This condition is known as **phase criteria**.

AC Bridge Circuit: Maxwell's Inductance Bridge

The Maxwell's Inductance Bridge is an AC bridge circuit used to measure the inductance of an inductor by balancing it against a known standard inductance or resistance.

Let:

L1 = Unknown inductance with resistance R1
L2 = Variable inductance with fixed resistance r2
R2 = Variable resistance connected in series with inductor L2
R3,R4 = Known non-inductive resistances
At balance, the bridge is balanced and the following condition is met…

$$Z_1Z_4 = Z_2Z_3$$

$\Rightarrow (R_1+j\omega L_1)^* \ R_4 = ((R_2+r) + j\omega L_2)^* \ R_3$

$\Rightarrow R_1 \ R_4 + j\omega L_1 \ R_4 = (R_2+r) \ R_3 + j\omega L_2 \ R_3$

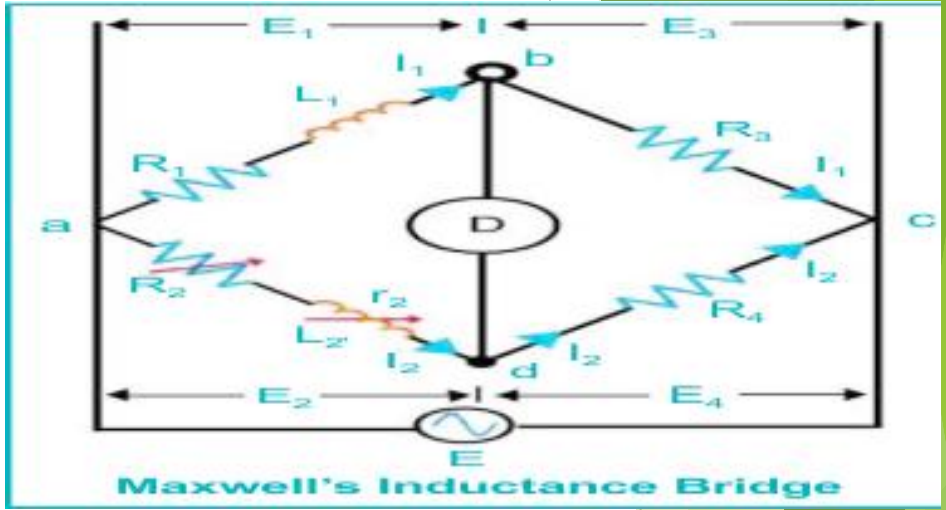
Equating real and imaginary part.

$R_1 \ R_4 = (R_2+r) \ R_3$

$\Rightarrow R_1 = \frac{(R_2+r) \ R_3}{R_4}$ ✓

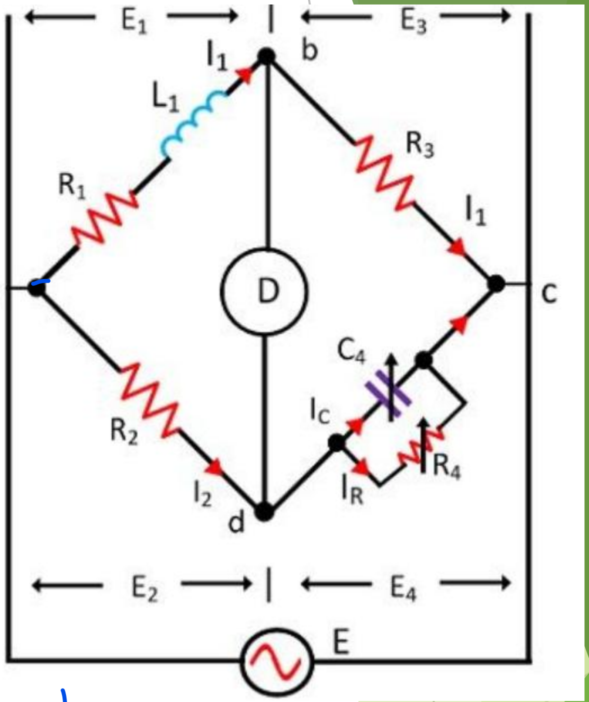
And $L_1 = \frac{L_2 R_3}{R_4}$ ✓

$Z_L = j\omega L$



Maxwell’s Inductance capacitance Bridge

The Maxwell’s Inductance-Capacitance Bridge is a type of AC bridge circuit used for measuring the inductance of an unknown inductor. It is similar to the Maxwell’s Inductance Bridge but uses a standard capacitor instead of a standard inductor,



Let, L1 – unknown inductance of resistance R1.
R1 – Variable inductance of fixed resistance r1.
R2, R3, R4 – variable resistance connected in series with inductor L2.
C4 – known non-inductance resistance

$Z_C = \frac{1}{j\omega C_4}$

$Z_R = R_4$

$\therefore \left(\frac{1}{R_4} + \frac{1}{\frac{1}{j\omega C_4}}\right)^{-1}$

$= \left(\frac{1}{R_4} + j\omega C_4\right)^{-1}$

$= \left(\frac{1 + R_4 j\omega C_4}{R_4}\right)^{-1}$

$= \frac{R_4}{1 + j\omega C_4 R_4}$

For balance condition,

$$(R_1 + j\omega L_1)\left(\frac{R_4}{1 + j\omega C_4 R_4}\right) = R_2 R_3$$

$$R_1 R_4 + j\omega L_1 R_4 = R_2 R_3 + j\omega C_4 R_4 R_2 R_3$$

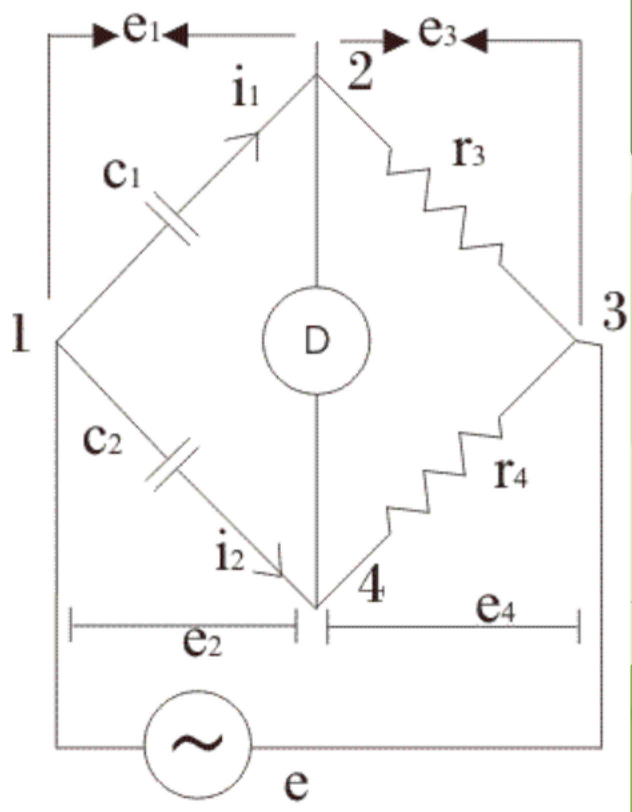
By separating the real and imaginary equation we get,

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

$$L_1 = R_2 R_3 C_4$$

De Sauty’s Bridge

The **De Sauty’s Bridge** is an AC bridge circuit used to compare two capacitors. It is a simple bridge that measures the ratio between two capacitances but does not directly measure the value of the capacitance.



At balance condition we have,

$$\frac{1}{j\omega c_1} \times r_4 = \frac{1}{j\omega c_2} \times r_3$$

It implies that the value of capacitor is given by the expression

$$c_1 = c_2 \times \frac{r_4}{r_3}$$