Electrical Measurements

Code: EPM1202

Lecture: 4 Tutorial: 2 Total: 6

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Moving Iron instruments

Moving Iron instruments

Measuring instruments whose operation is based on the interaction between a magnetic field and a ferromagnetic-material core

The magnetic field is proportional to the quantity to be measured

Moving Iron instruments

The measured current is connected to the stationary coil producing a magnetic field that interacts with the moving iron element

The field pulls the core into the coil

A torque proportional to the square of the current is produced on the shaft

A spring is used to produce a counter torque proportional to the rotation angle

The shaft and pointer rotate with an angle proportional to the square of the quantity to be measured

The pointer comes to the steady-state when the torque and the counter torque are equal

Moving Iron instruments

Moving-iron voltmeter

the field coil is connected in parallel with the circuit

Moving-iron ammeter

The field coil is connected in series with the circuit

They are constructed mainly for measurements in

50 Hz circuits

Moving Iron instruments

Types of moving-iron instruments

- Attraction (or single-iron) type
- Repulsion (or double iron) type

Construction of moving iron instruments

Moving element (a piece of soft iron: a vane or rod)

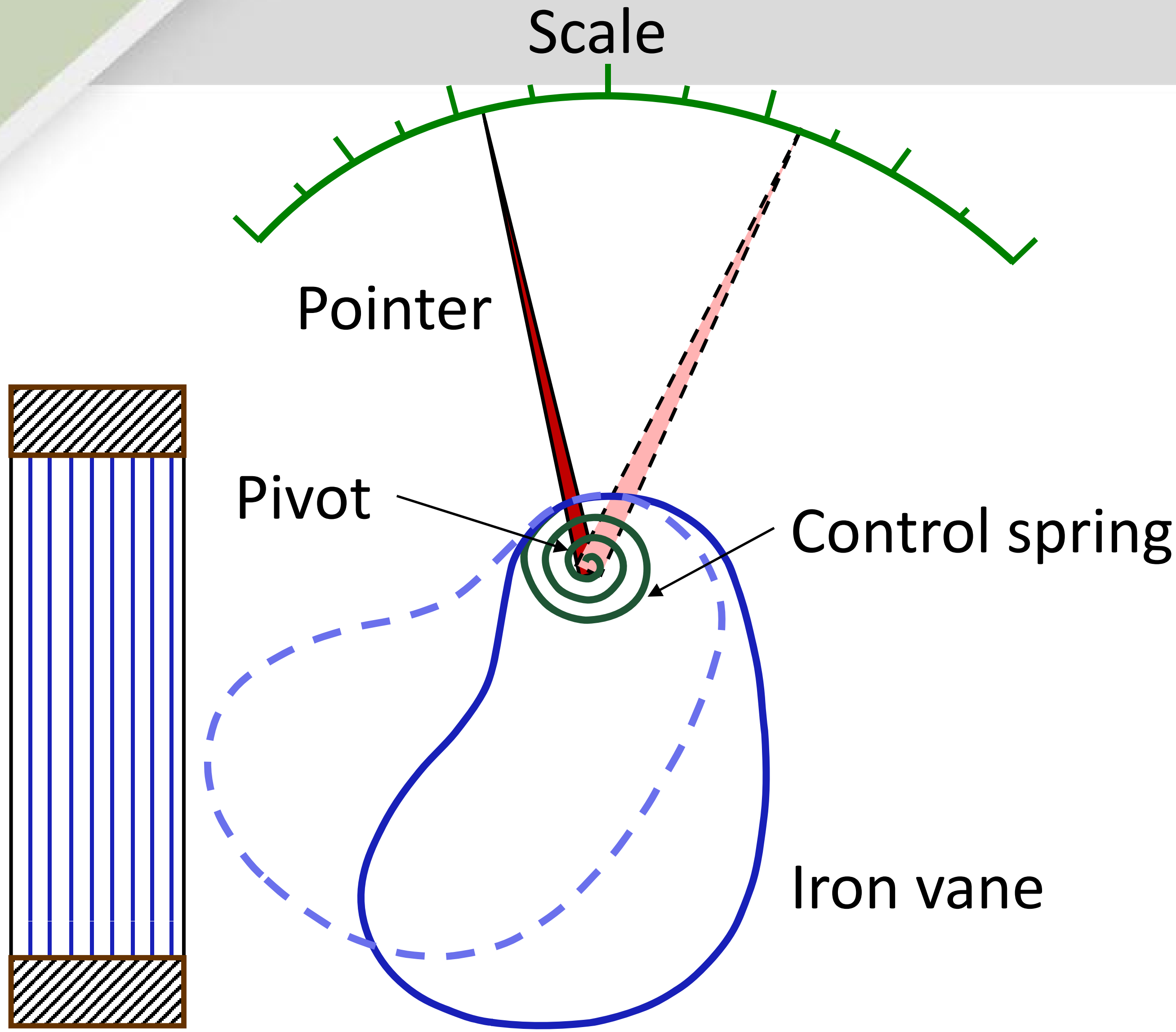
Stationary coil: to produce the magnetic field

Fixed vane or rod magnetized with the same polarity (In repulsion type only)

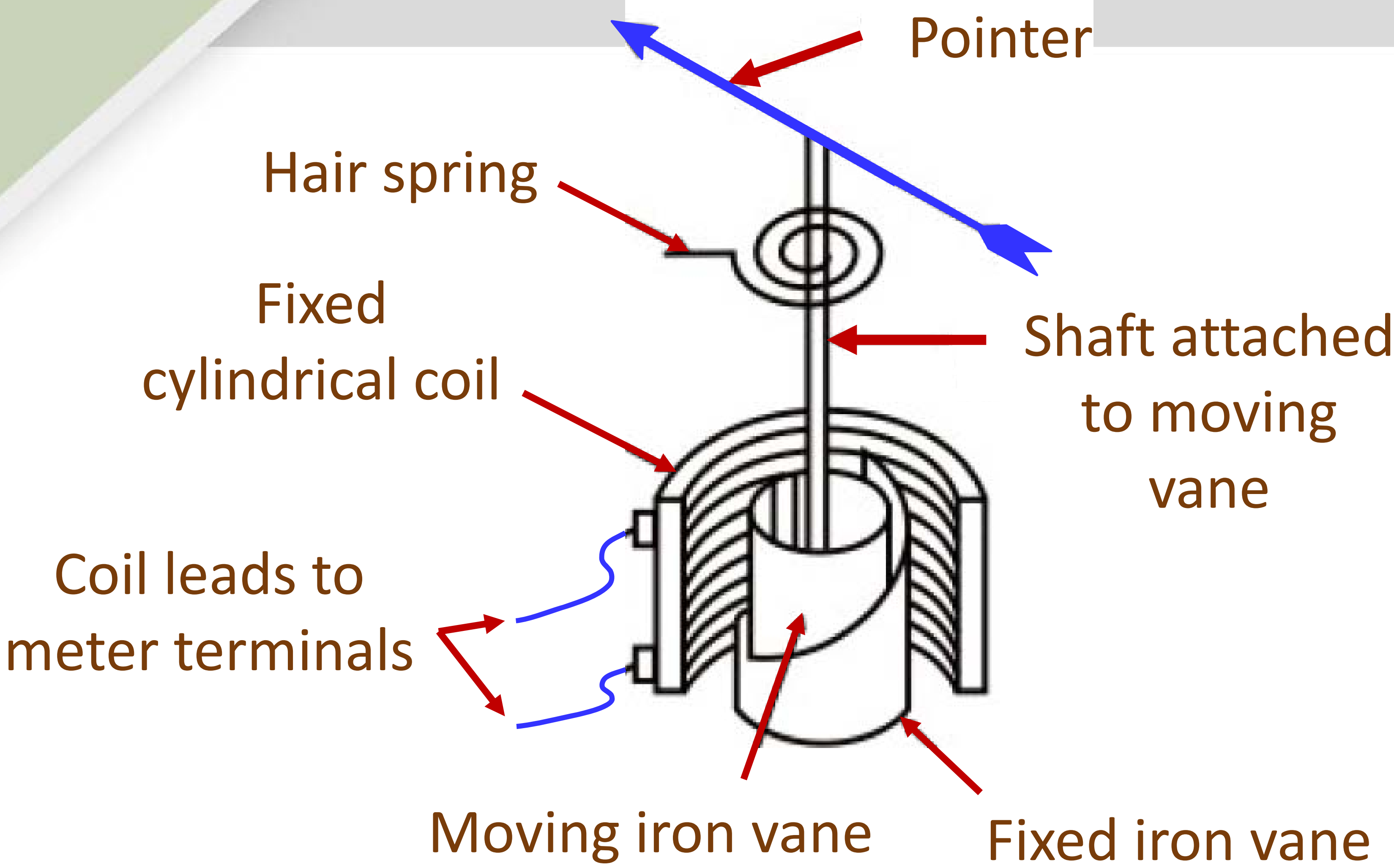
Air chamber and a moving vane to produce damping torque

A spring or weight (gravity)

Moving Iron instruments



Moving Iron instruments

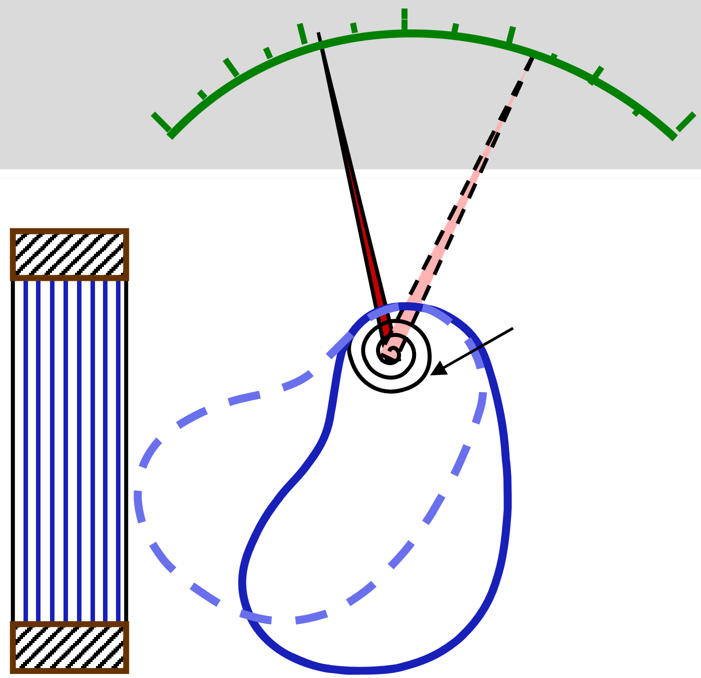


Moving Iron instruments

Attraction type

The operation depends on the attraction of a piece of soft iron into the magnetic field

When current flows in the coil, a pivoted soft-iron disc is attracted towards the solenoid and the movement causes a pointer to move across a scale

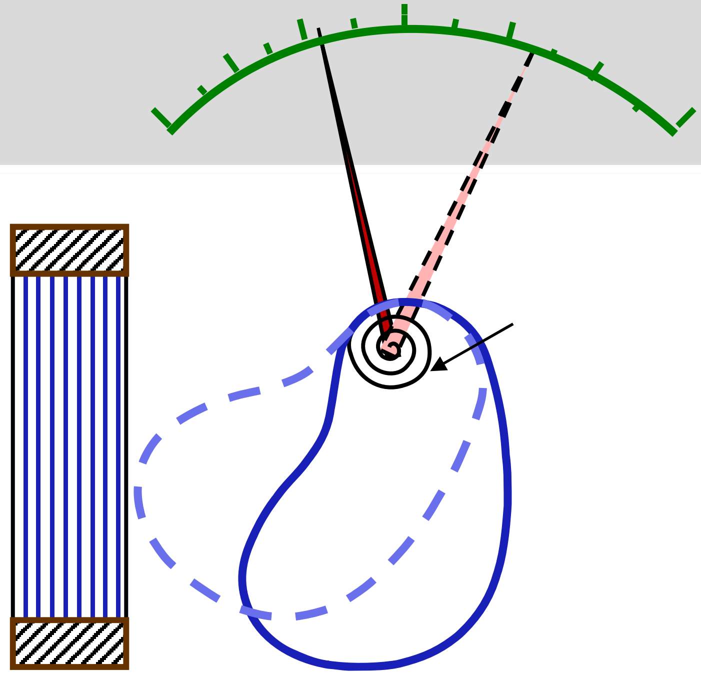


This is attributed to need for reducing the reluctance by attracting the piece of un-magnetized soft iron to the current-carrying coil

Moving Iron instruments

Attraction type

The soft iron is shaped as an oval disc to swings into the coil



The irregular shape is to enable the greatest bulk of iron to move to the coil centre, where the field is maximal

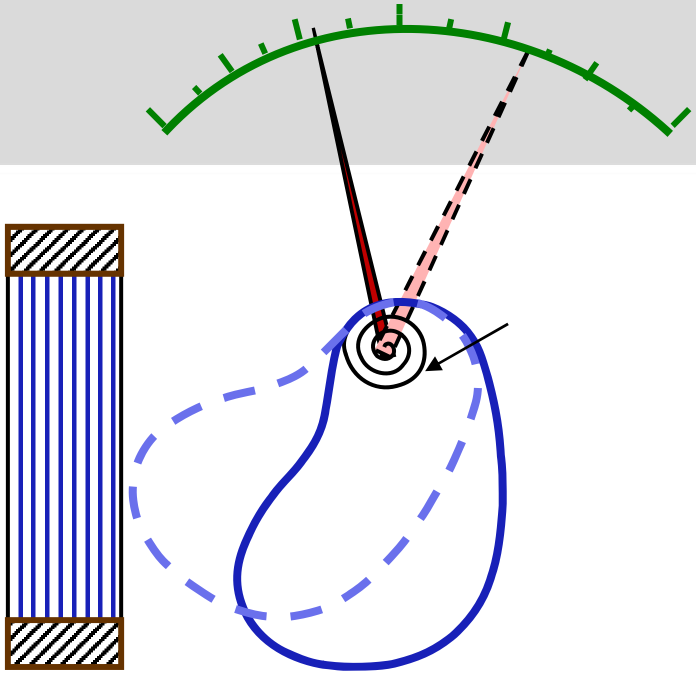
The deflection “angle” depends on the current

There is no restriction on the current direction on the coil “the instrument is used for ac and dc”

Moving Iron instruments

Attraction type

The deflection angle is defined based on the balance between the control torque and the deflection torque



$$T=T_c$$

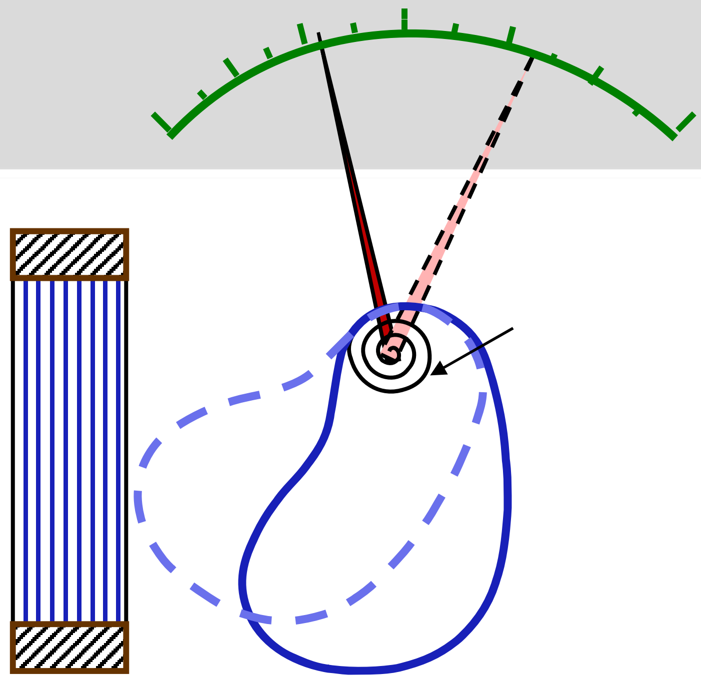
The deflecting torque is proportional to the product of the magnetic field intensity "H" and the current

The produced magnetic field intensity is proportional to the flowing current

Moving Iron instruments

Attraction type

$$T \propto I_{rms} H \;\Rightarrow\; T \propto I_{rms}^2$$



If control torque is proportional to the deflection angle “θ”:

$$T_c \propto \theta$$

$$\theta \propto I_{rms}^2$$

The scale of the instrument is not uniform

Moving Iron instruments

Repulsion type

Two pieces of iron are placed inside the solenoid, one being fixed, and the other is attached to the spindle carrying the pointer

When current passes through the solenoid, the two pieces of iron are magnetized in the same direction and therefore repel each other

The pointer moves across the scale

The force moving the pointer is proportional to I^2

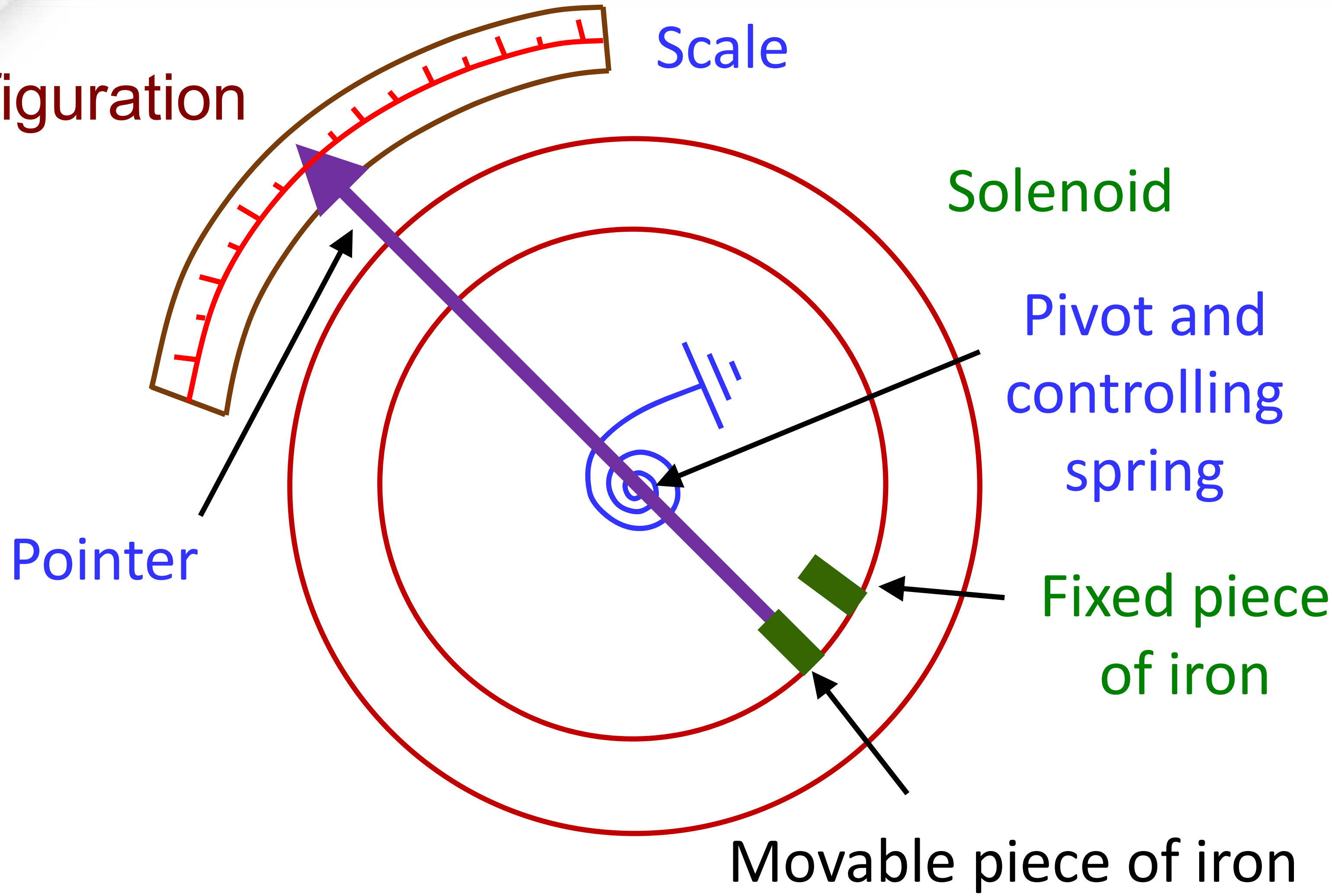
The direction of current does not matter

This type can be used for d.c. and a.c measurements

Moving Iron instruments

Repulsion type

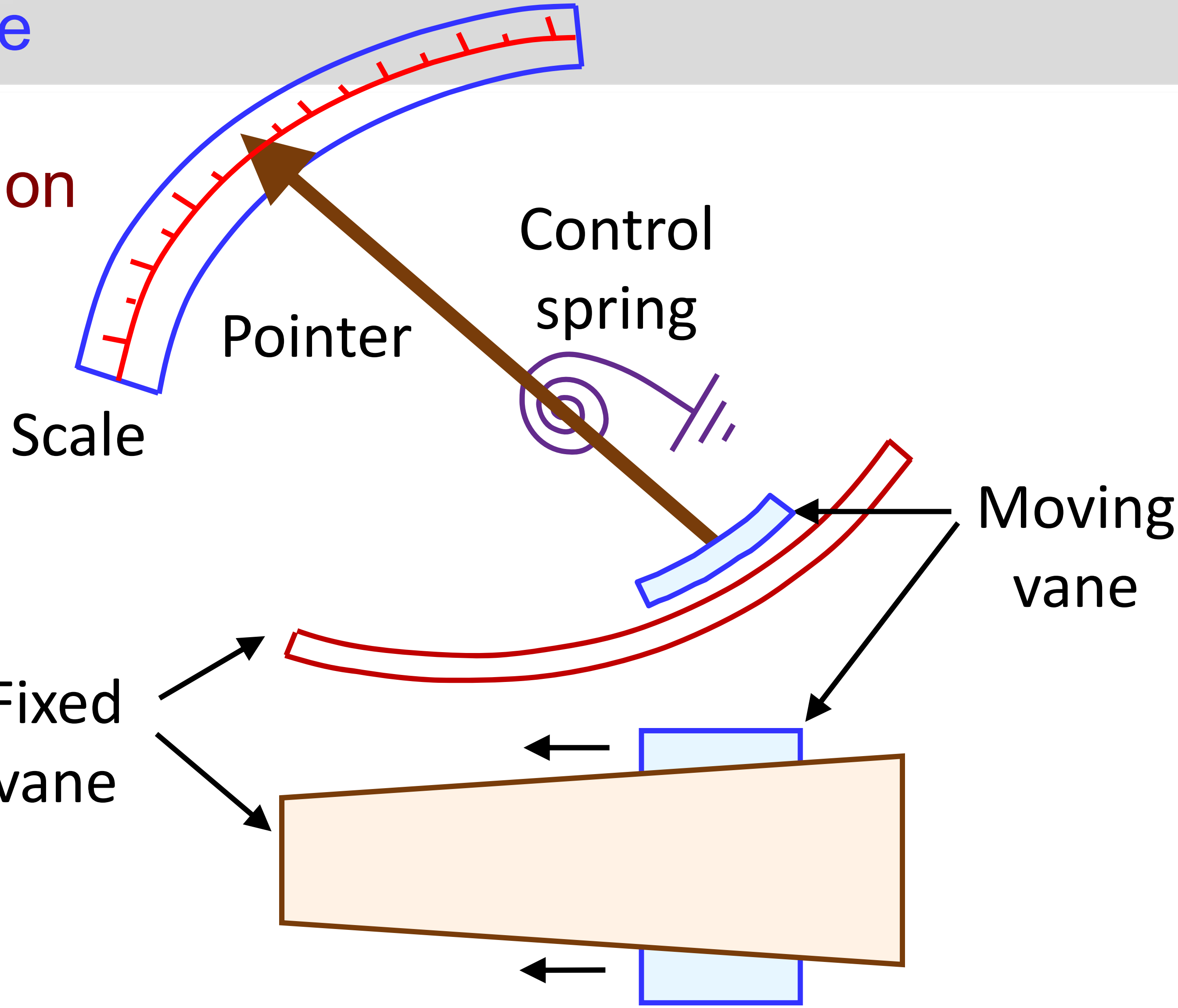
1st configuration



Moving Iron instruments

Repulsion type

2nd configuration



Moving Iron instruments

Repulsion type

The coil consists of few turns if the instrument is an ammeter and many turns for a voltmeter

Due to the error caused by magnetic hysteresis when DC current is measured, these devices are used almost exclusively for AC measurements

Normally, the instruments are shielded from external magnetic fields by enclosing their parts, except the pointer, in a laminated iron cylinder with laminated iron end covers

Advantages of the moving iron measurements

- Cheap and robust
- Depends on r.m.s. values (AC and DC)
- Easy change of range by changing the number of coil turns
- Simplicity of the design

The moving coil instruments

Disadvantages of electrodynamic instruments

Relatively large power consumption (0.1–1 VA)

Relatively high errors in dc measurements

Small sensitivity in comparison with moving coil device

Comparing moving-coil, moving-iron and moving-coil rectifier instruments

Suitability for measurement

Moving-coil	Moving-iron	Moving-coil rectifier
Direct current and voltage	Direct and alternating current and voltage (reading in rms value)	Alternating current and voltage (reads average value but scale is adjusted to give rms value for sinusoidal waveforms)

Comparing moving-coil, moving-iron and moving-coil rectifier instruments

Scale

Moving-coil	Moving-iron	Moving-coil rectifier
Linear	Non linear	Linear

Method of control

Moving-coil	Moving-iron	Moving-coil rectifier
Hairsprings	Hairsprings	Hairsprings

Comparing moving-coil, moving-iron and moving-coil rectifier instruments

Method of damping

Moving-coil	Moving-iron	Moving-coil rectifier
Eddy current	Air	Eddy current

Frequency limits

Moving-coil	Moving-iron	Moving-coil rectifier
-	20-100 kHz	20-100 kHz

Comparing moving-coil, moving-iron and moving-coil rectifier instruments

Advantages

Moving-coil	Moving-iron	Moving-coil rectifier
Linear scale High sensitivity Well shielded Lower power consumption	Robust construction Relatively cheap Measures dc and ac Frequency range 20-100Hz Reads rms regardless of supply waveform	Linear scale High sensitivity Well shielded Low power consumption Good frequency range

Comparing moving-coil, moving-iron and moving-coil rectifier instruments

Disadvantages

Moving-coil	Moving-iron	Moving-coil rectifier
Only suitable for dc More expensive than moving iron type Easily damaged	Non-linear scale Affected by stray magnetic fields Hysteresis errors in dc circuits Liable to temperature errors Reading is affected by variation of frequency due to the solenoid inductance	More expensive than moving iron type Errors caused when supply is non-sinusoidal

DC and AC bridges

Used to measure values of all electric components including, resistance, inductance and capacitance

They are the most accurate devices for the measurements of resistance and impedance

Bridges are commonly used as impedance to voltage converters

Bridges have four arms with different elements, an indicator and a dc or ac source

They depend on the use of a null-balance meter to compare two voltages

DC and AC bridges

It is a simple, accurate and widely used measurement method that depends on an instrument reading being adjusted to read zero current only

If there is a deflection, then some current is flowing

If there is no deflection, no current flows (a null condition)

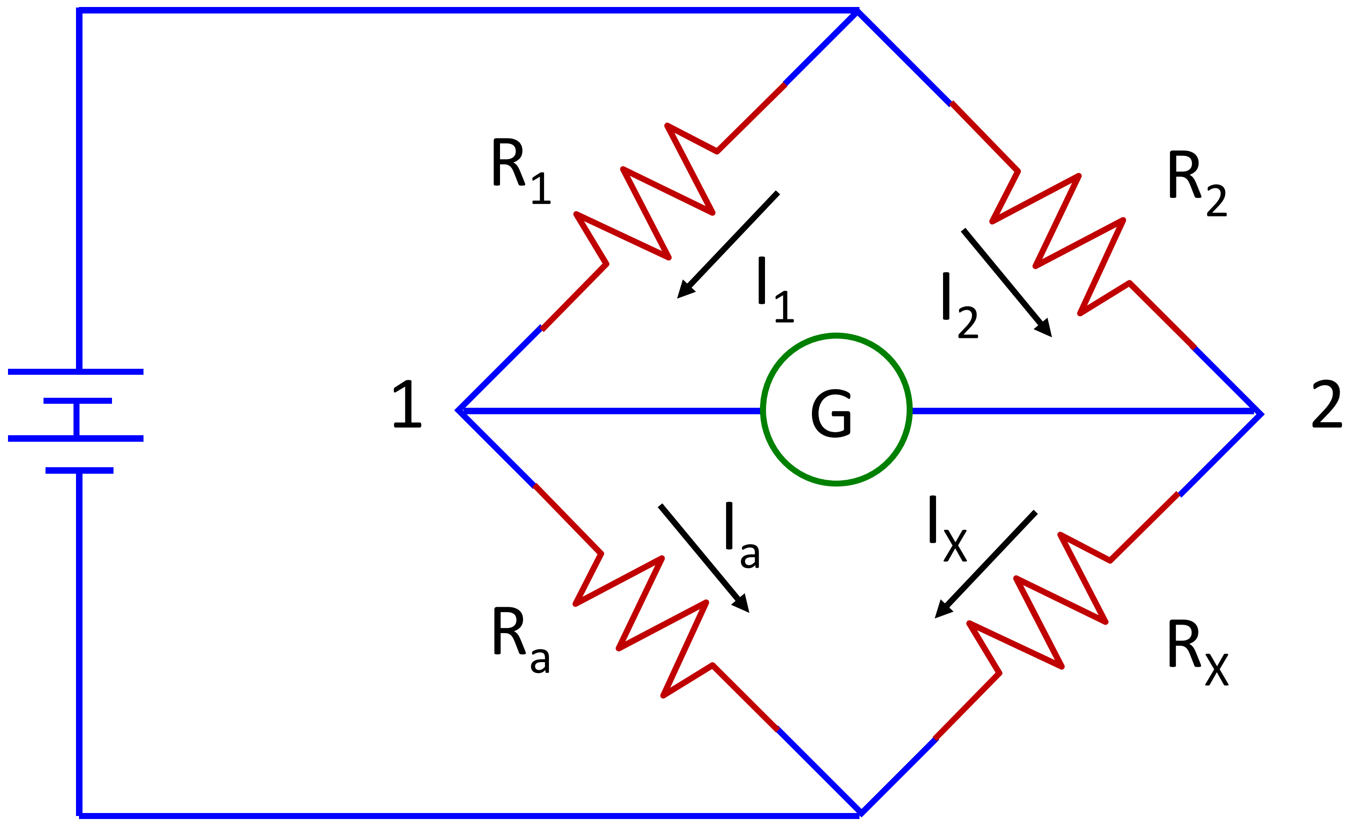
It is unnecessary for a meter sensing current flow to be calibrated

A sensitive milliammeter or microammeter with centre zero position setting, called a galvanometer, are used

DC bridges

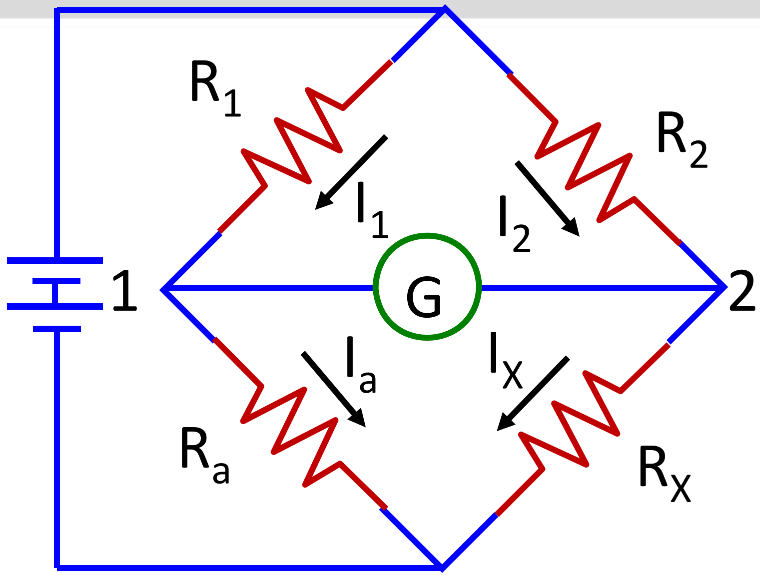
Wheatstone bridge

It is used for medium resistance measurements



Wheatstone bridge

It is used for medium resistance measurements



Zero indication occurs when V-R_a is equal to V-R_X
The balance is independent on the supply voltage

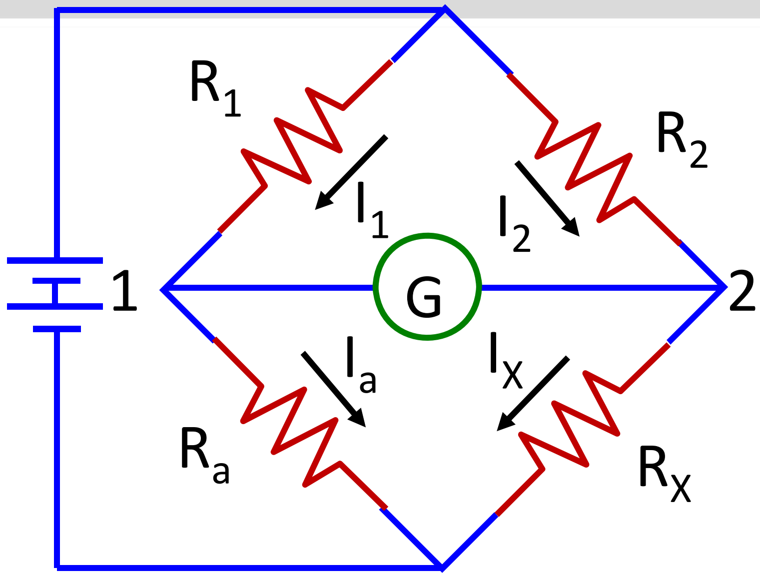
The resistances R_1 and R_2 are precision devices of known value
The resistance “R_a” is an adjustable resistance to reach the bridge-balanced condition

Wheatstone bridge

Under balanced conditions:

$$I_1 R_1 = I_2 R_2$$

$$I_a R_a = I_X R_X$$



The current "I_1" is equal to "I_a"

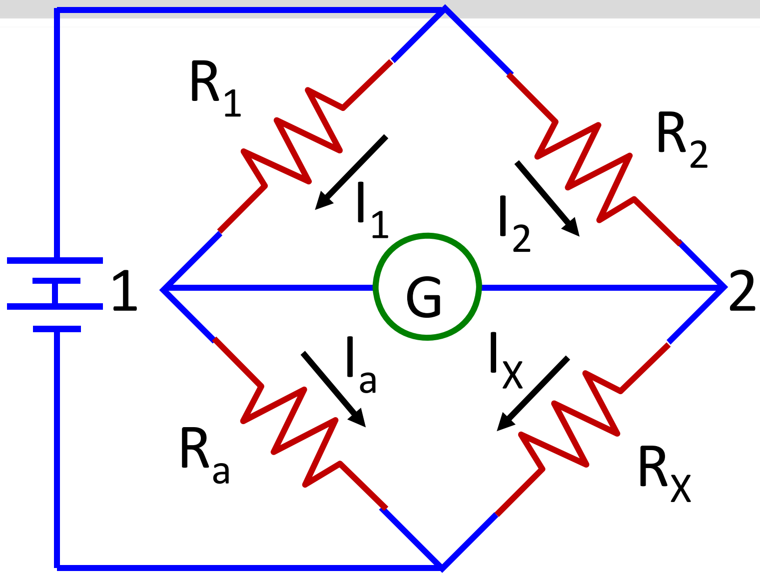
The current "I_2" is equal to "I_X"

$$I_1 R_a = I_2 R_X$$

$$\frac{R_1}{R_a} = \frac{R_2}{R_X}$$

Wheatstone bridge

$$R_X = \frac{R_a \; R_2}{R_1}$$



The standard adjustable resistor is called the rheostat

The other two resistors are called the ratio arms

A number of known variable resistors is required

The accuracy of the resistance measurement can reach 99.5%

Errors of the Wheatstone bridge

Limiting errors of the three known resistors

Temperature variation affects resistor values With different resistors, the power loss and the variation is not the same

The resistances of connectors and leads are added to the total circuit resistance

The inadequate sensitivity of the null detector

These factors limit the measurements of Wheatstone bridge for resistances higher than 1.0 Ω

Wheatstone bridge

Example:

In a Wheatstone bridge ABCD, a galvanometer is connected between A and C, and a battery between B and D. A resistor of unknown value is connected between A and B. When the bridge is balanced, the resistance between B and C is 100 Ω, that between C and D is 10 Ω and that between D and A is 400 Ω. Calculate the value of the unknown resistance.

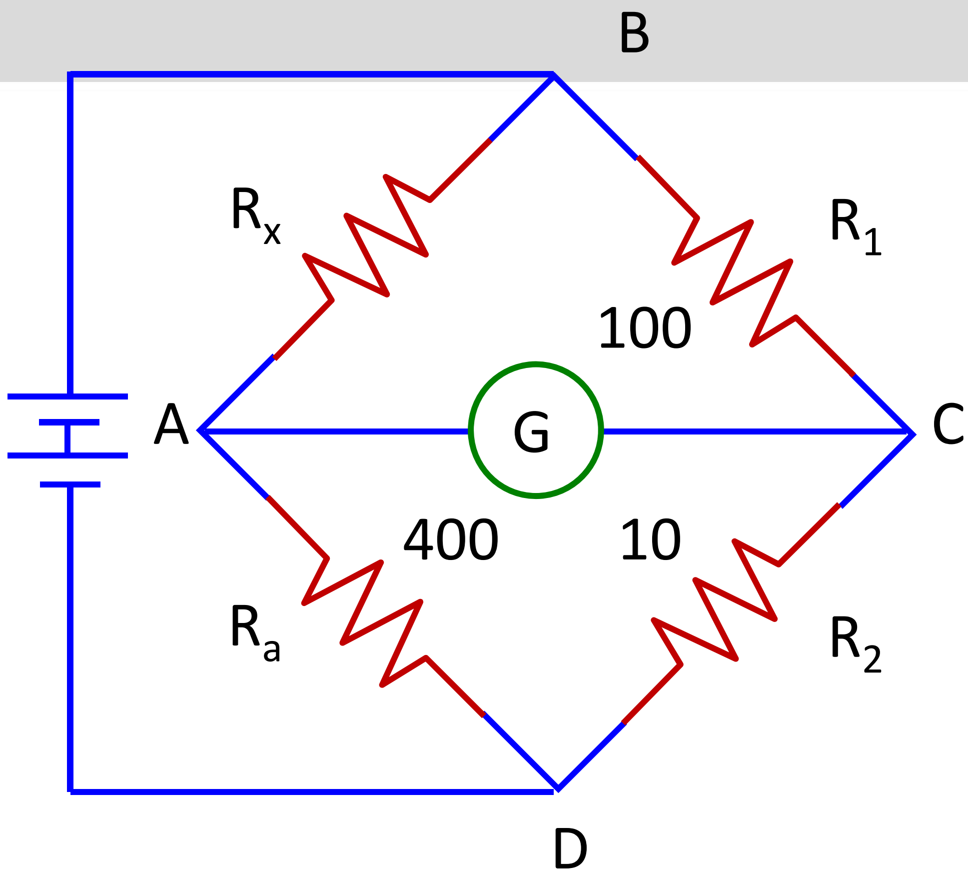
Wheatstone bridge

Solution:

The balance equation is given as:

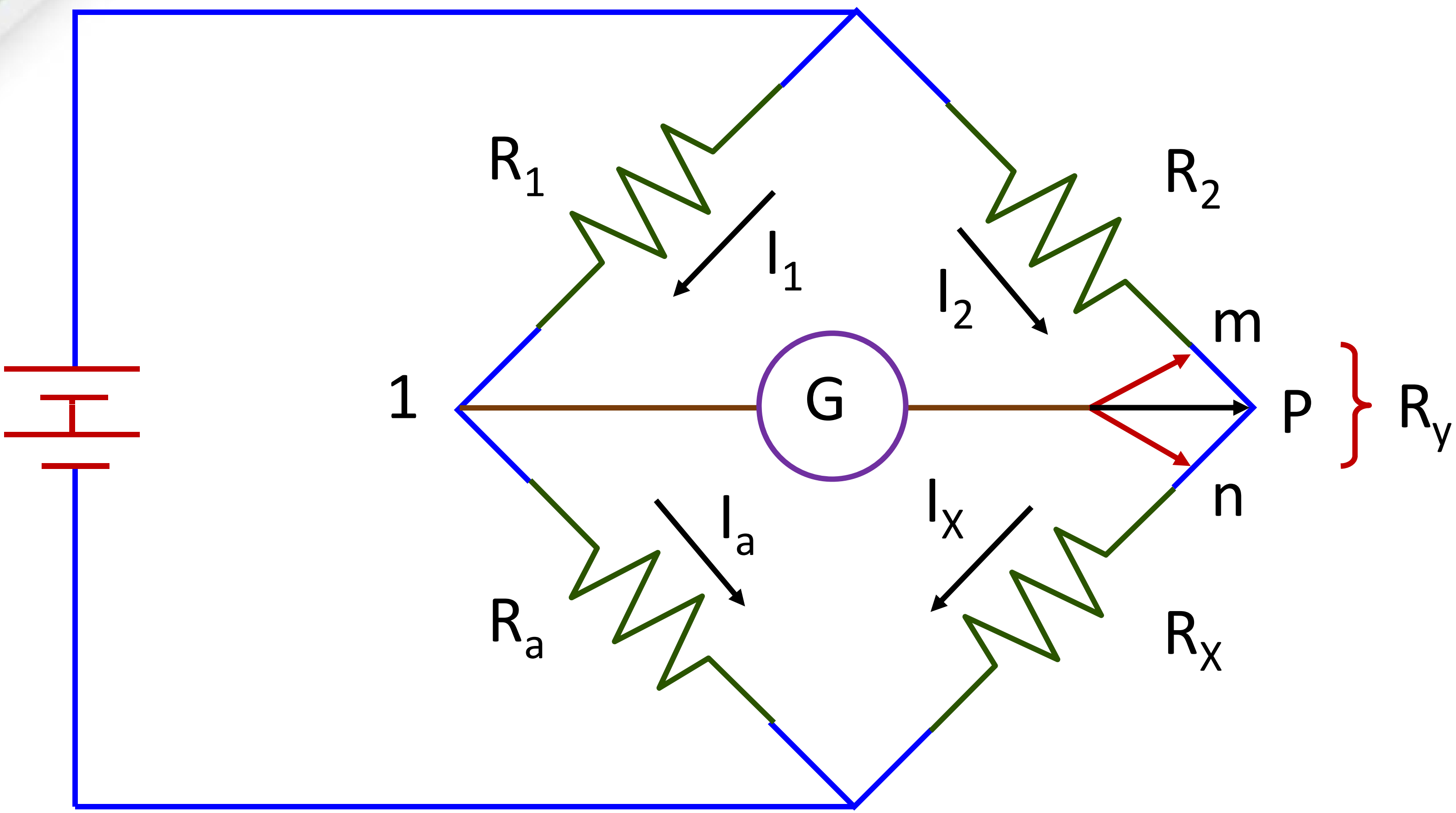
$R_x * 10 = 100 * 400$

$R_x = 4000\ \Omega$



Kelvin Bridge

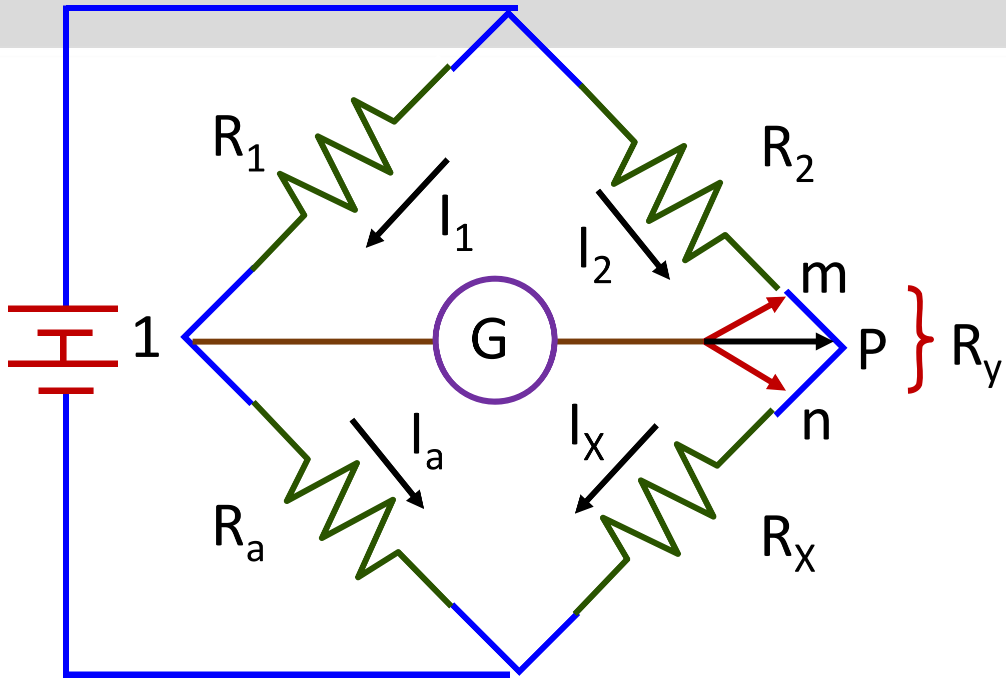
If the measured resistance is low, the resistance of the connecting wires affect the measurement



Kelvin Bridge

“R_y” is the resistance of the connecting lead from “R_2” to “R_X”

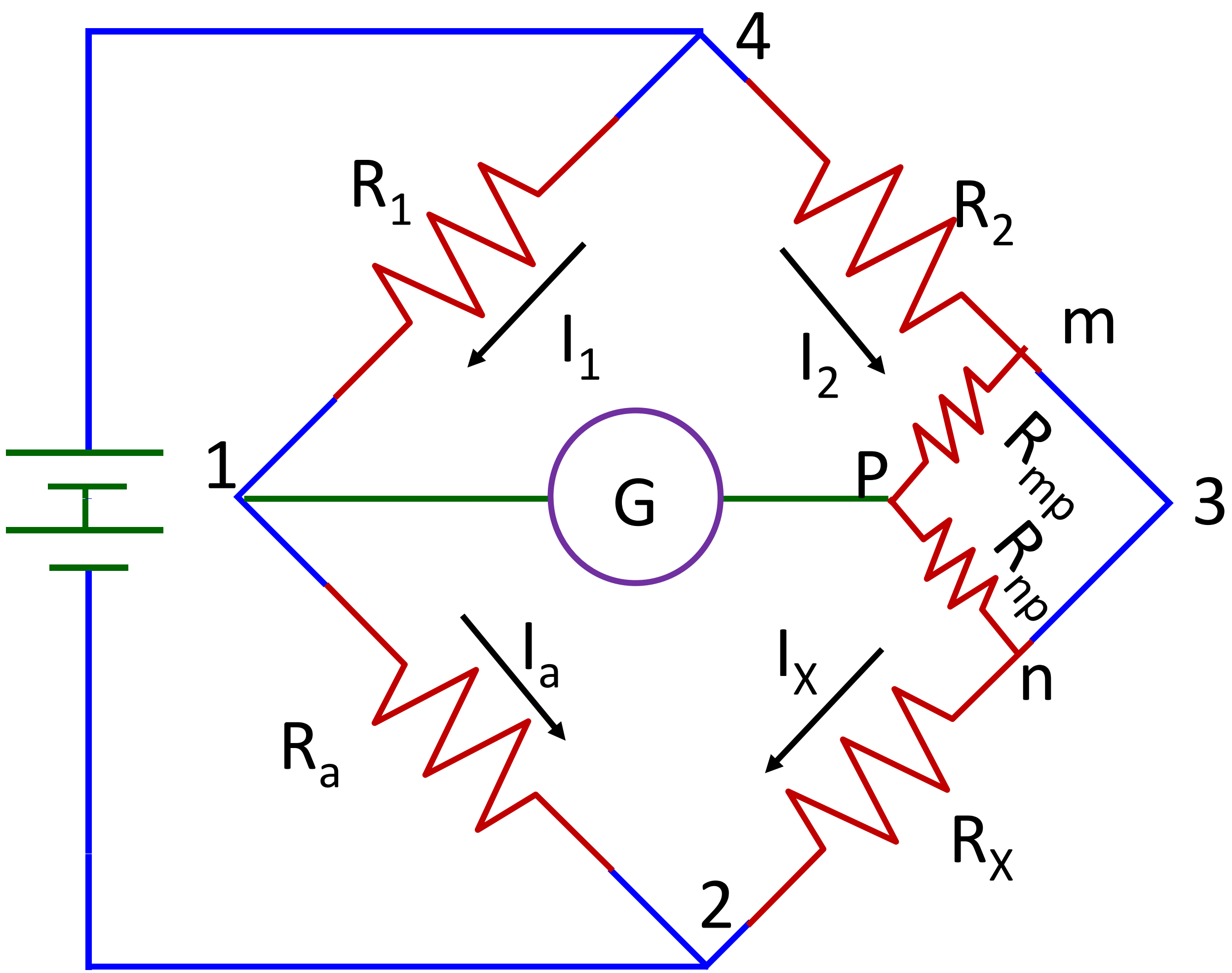
At point “m”, the resistance “R_y” is added to the “R_X”, giving higher value



At point “n”, “R_y” is added to “R_2” decreasing “R_X”

Kelvin Bridge

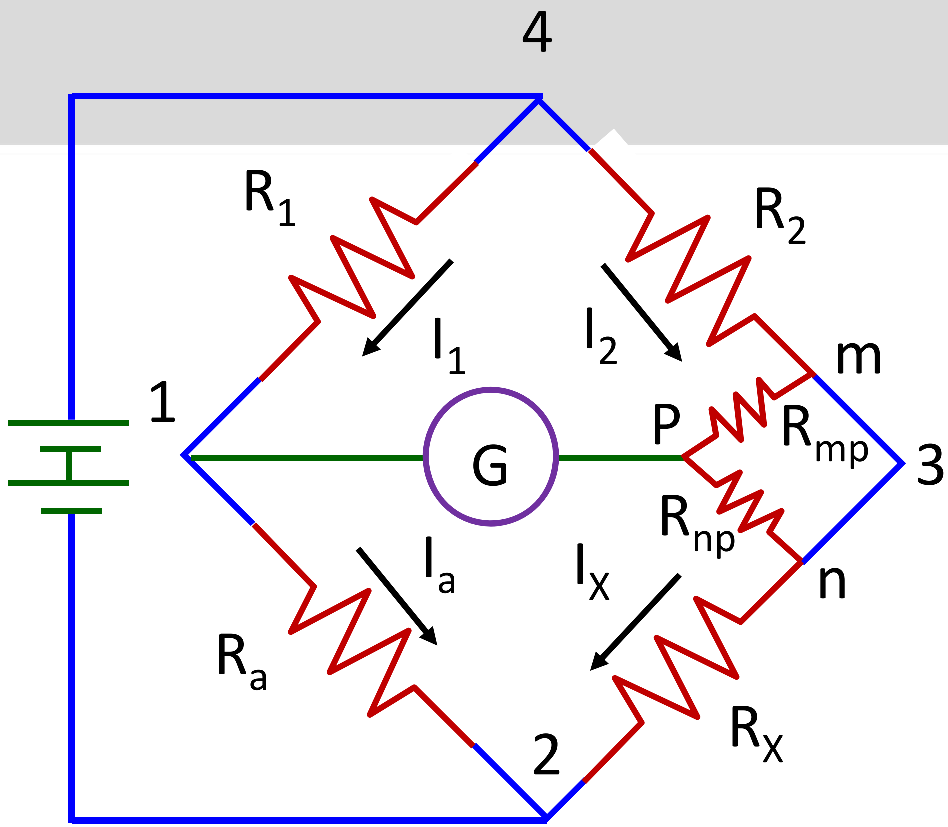
Two resistances are added to Wheatstone bridge to form Kelvin double bridge to measure resistance below 1 Ω



Kelvin Bridge

"R_{mp}" and "R_{np}" are firstly adjusted

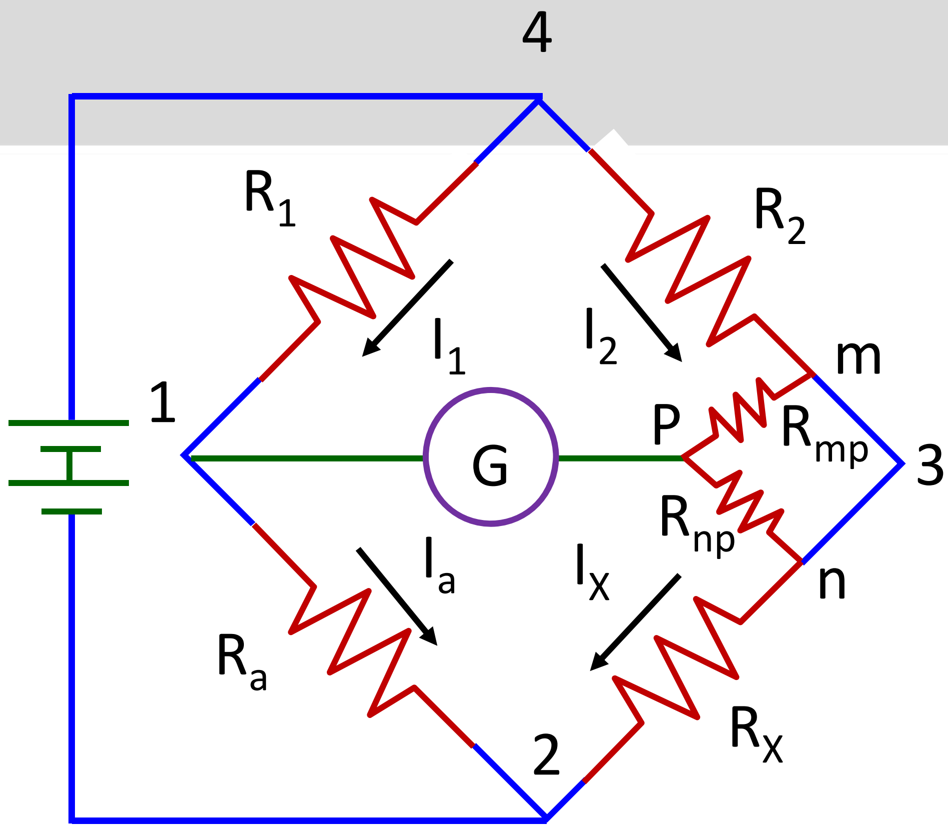
$$\frac{R_a}{R_1} = \frac{R_{np}}{R_{mp}}$$



The stray voltage drops between R_a and R_X are adjusted by sizing "R_{mp}" and "R_{np}" with ratio equal to the two ratio arms

Kelvin Bridge

The balance occurs when the voltage across the resistance "R_a" is equal to the voltage across the two resistances "R_X" and "R_{np}" in series



The unknown Resistor R_X in a balanced Kelvin Bridge is given by

$$R_X = \frac{R_a \, R_2}{R_1}$$

Ac Bridges

The magnitude and the angle have to be considered

The balance gives two equations to get two unknowns

The ac bridge consists of four impedance arms, ac source and a null detector

Two conditions should be fulfilled: the first is related to the magnitude and the other is related to phase angle

Two independent adjusting elements are necessary in order to balance such bridge circuit

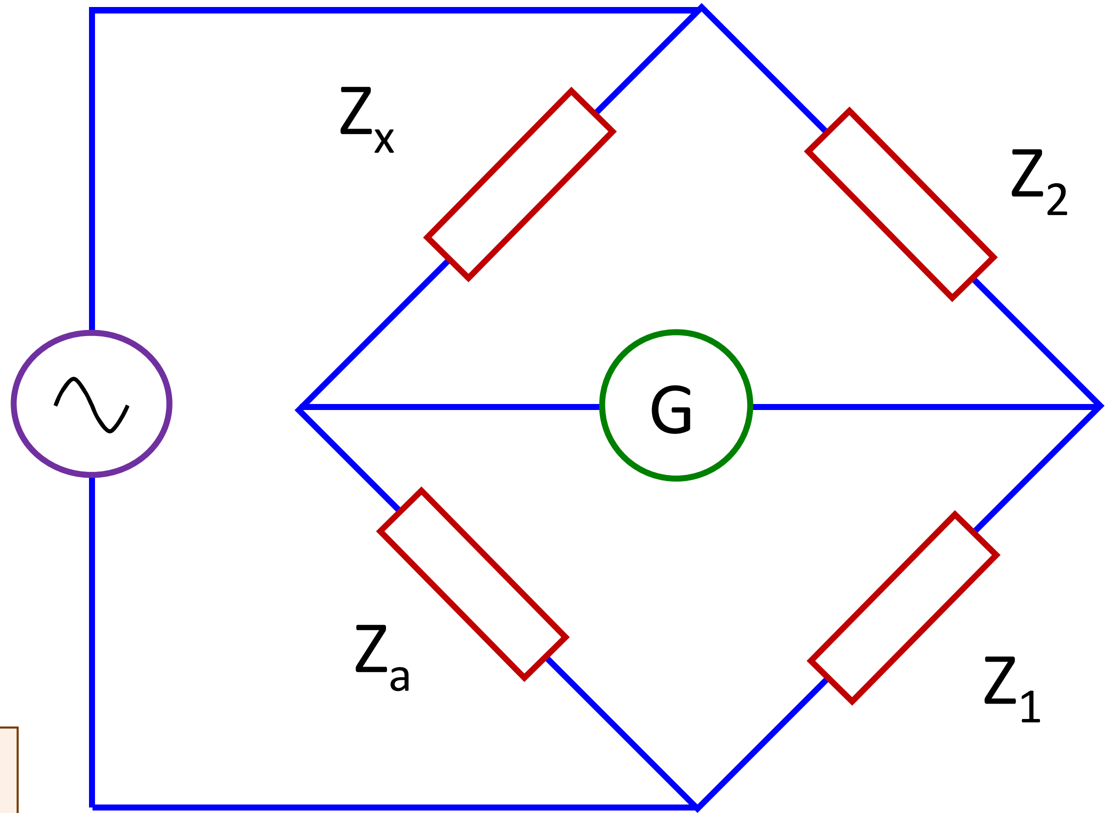
Ac Bridges

$$Z_1 Z_X = Z_a Z_2$$

$$Z_X = \frac{Z_a Z_2}{Z_1}$$

$$|Z_X| = \frac{|Z_a||Z_2|}{|Z_1|}$$

$$\theta_{Z_X} = \theta_{Z_a} + \theta_{Z_2} - \theta_{Z_1}$$



Ac Bridges

It will not be enough to achieve a balance regarding only the impedance magnitudes without phase angles

In this case, there will still be voltage across the terminals of the null detector

The standard component has to be adjusted until the null detector device indicates zero reading

The value of the unknown component can be determined directly from the setting of the calibrated standard using some mathematical calculations

Ac Bridges

To get the balance equations of ac bridges circuits:

(i) Determine the impedance in each arm in complex form and write down the balance equation

(ii) You may need to use X_L and X_C instead of "ωL" or "$1/(\omega C)$"

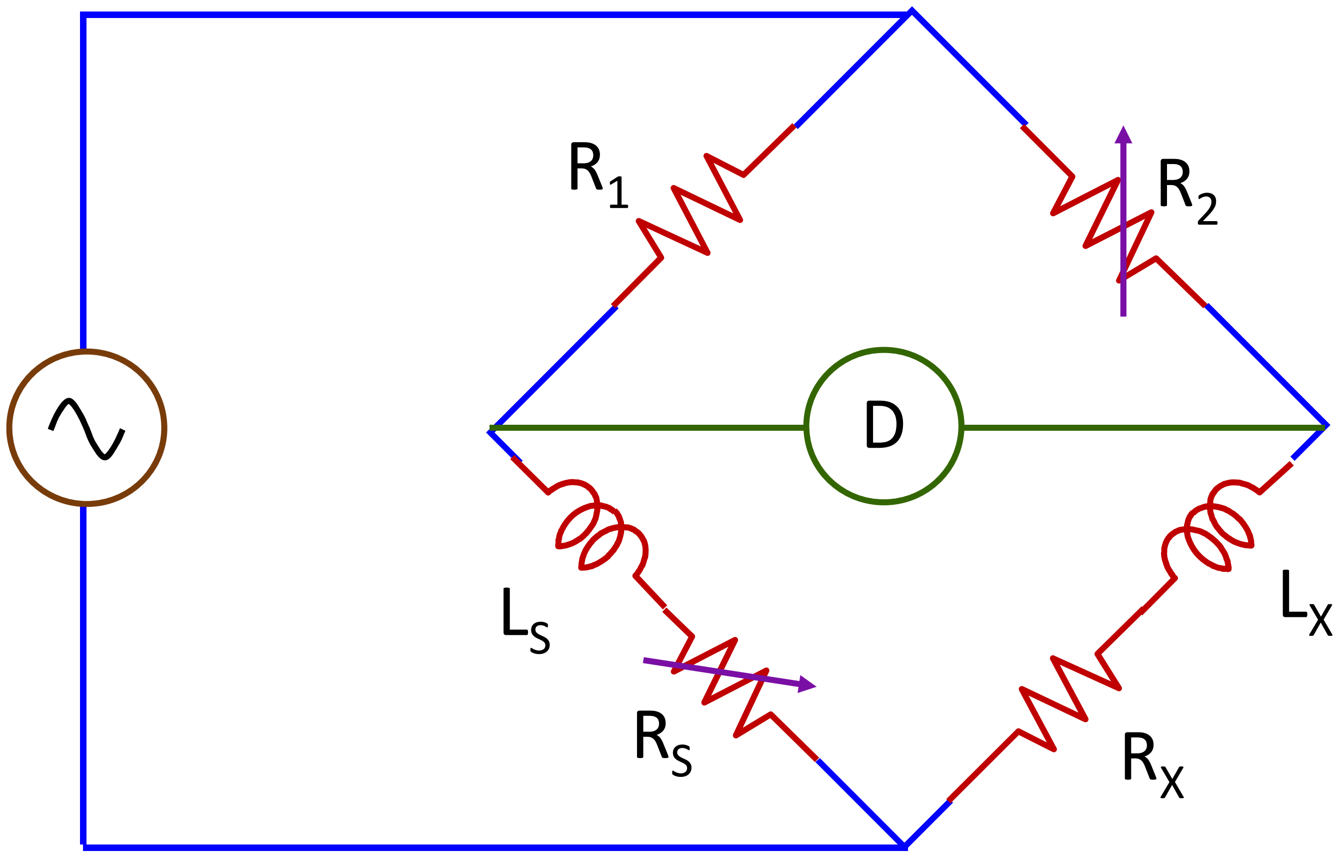
(iii) Isolate the unknown terms on the left-hand side of the equation in the form "a + j b"

(iv) Augment the terms on the right-hand side of the equation into the form "c + j d"

(v) Equate the real parts "a = c", and the imaginary parts "b = d"

Inductive comparison bridge “simple Maxwell bridge”

Used to determine the value of unknown impedance containing an inductance



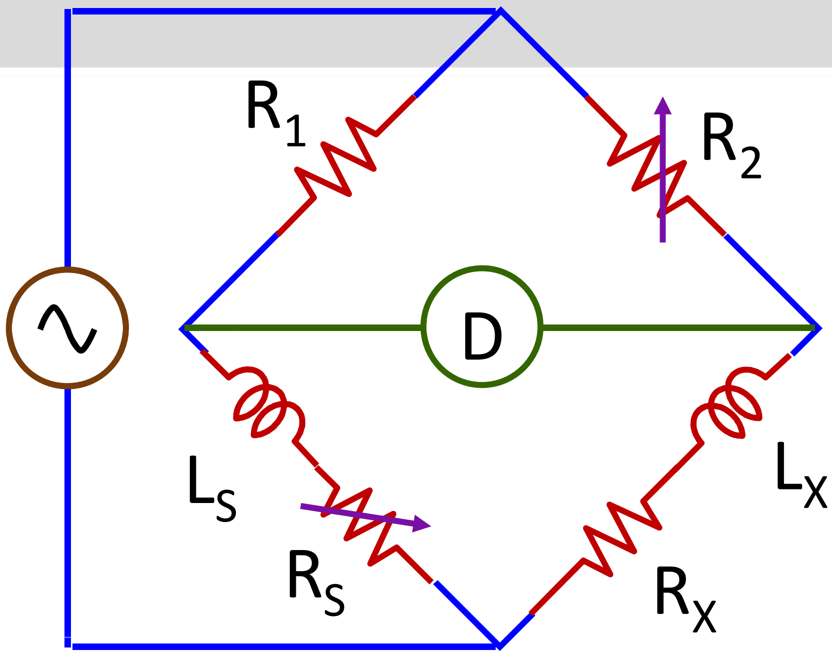
Simple Maxwell bridge

$$Z_1 = R_1$$

$$Z_2 = R_2$$

$$Z_3 = R_s + j\omega L_s$$

$$Z_4 = R_X + j\omega L_X$$



$$Z_1 * Z_4 = Z_2 * Z_3$$

$$R_1 \left(R_X + j\omega L_X \right) = R_2 \left(R_s + j\omega L_s \right)$$

$$\boxed{R_1 R_X + j\omega R_1 L_X = R_2 R_s + j\omega R_2 L_s}$$

Simple Maxwell bridge

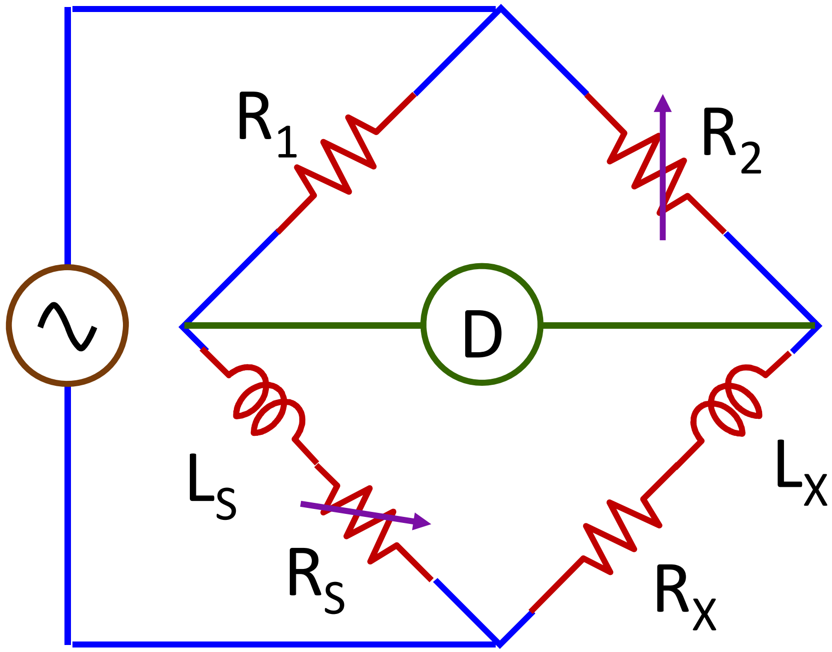
$$R_1 R_X + j\omega R_1 L_X = R_2 R_s + j\omega R_2 L_s$$

$$R_1 R_X = R_2 R_s$$

$$\omega R_1 L_X = \omega R_2 L_s$$

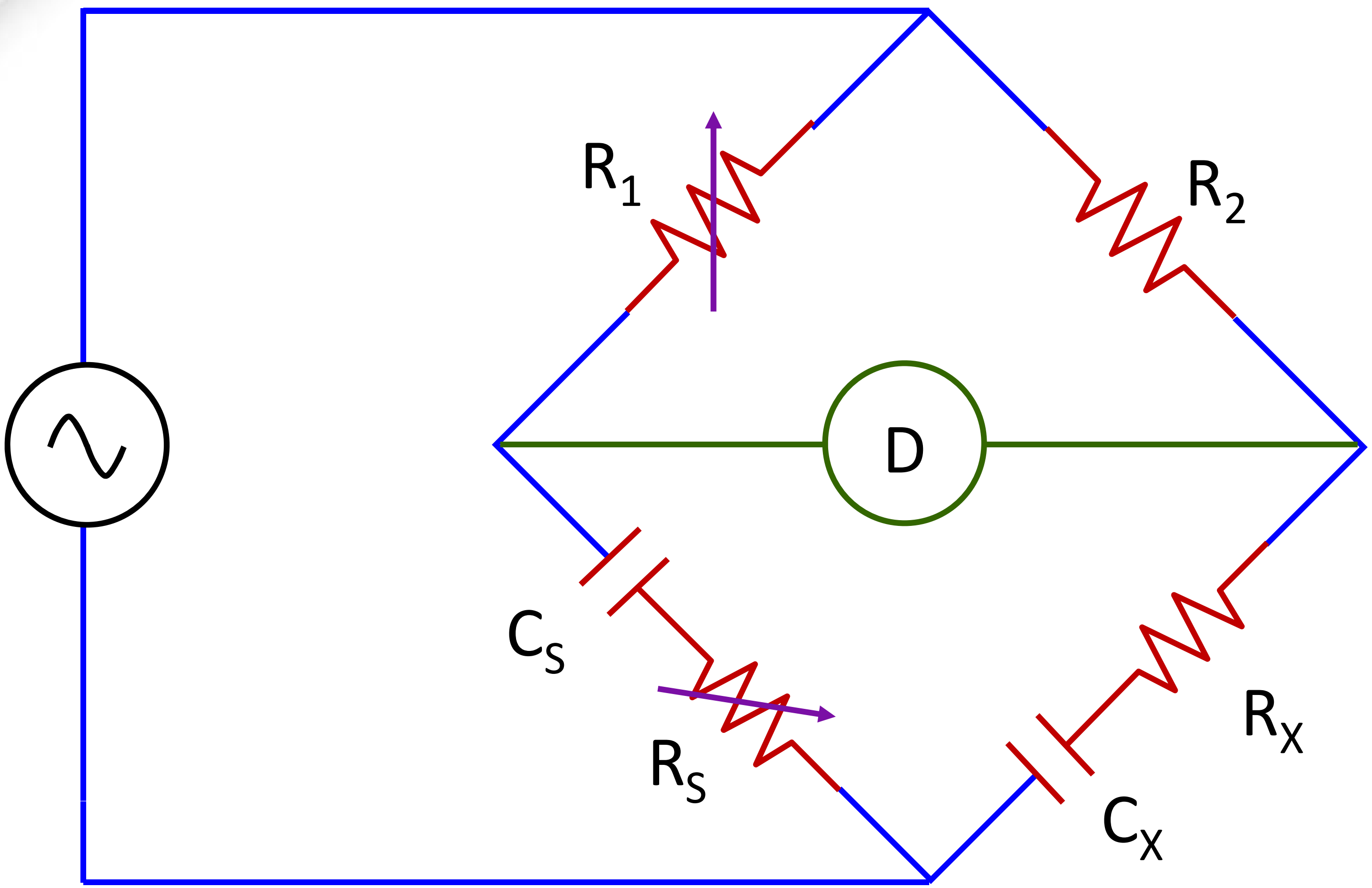
$$R_X = \frac{R_2}{R_1} R_s$$

$$L_X = \frac{R_2}{R_1} L_s$$



Capacitance Comparison Bridge

Used to measure the value of unknown impedance comprising a resistance and capacitance in series



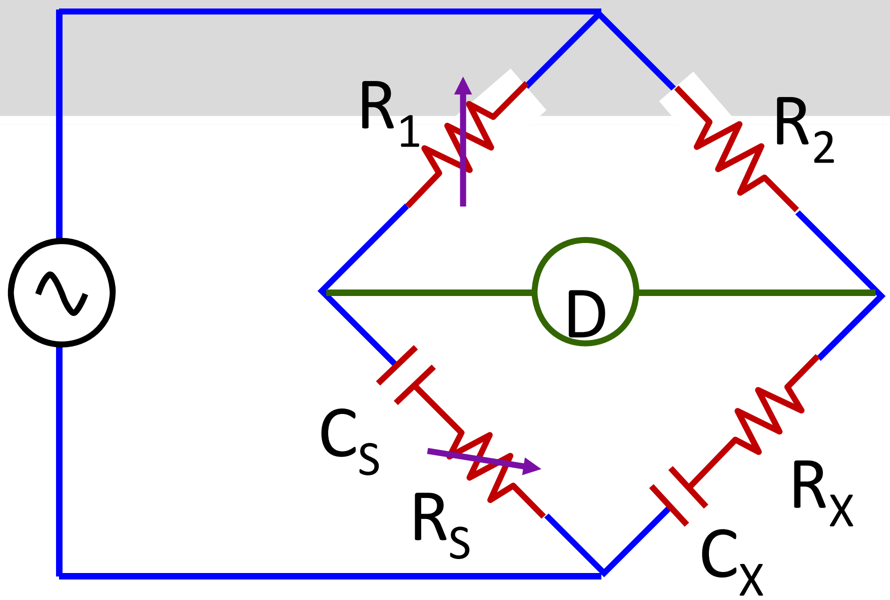
Capacitance Comparison Bridge

$$Z_1 = R_1$$

$$Z_2 = R_2$$

$$Z_3 = R_s - j\frac{1}{\omega C_s}$$

$$Z_4 = R_X - j\frac{1}{\omega C_X}$$



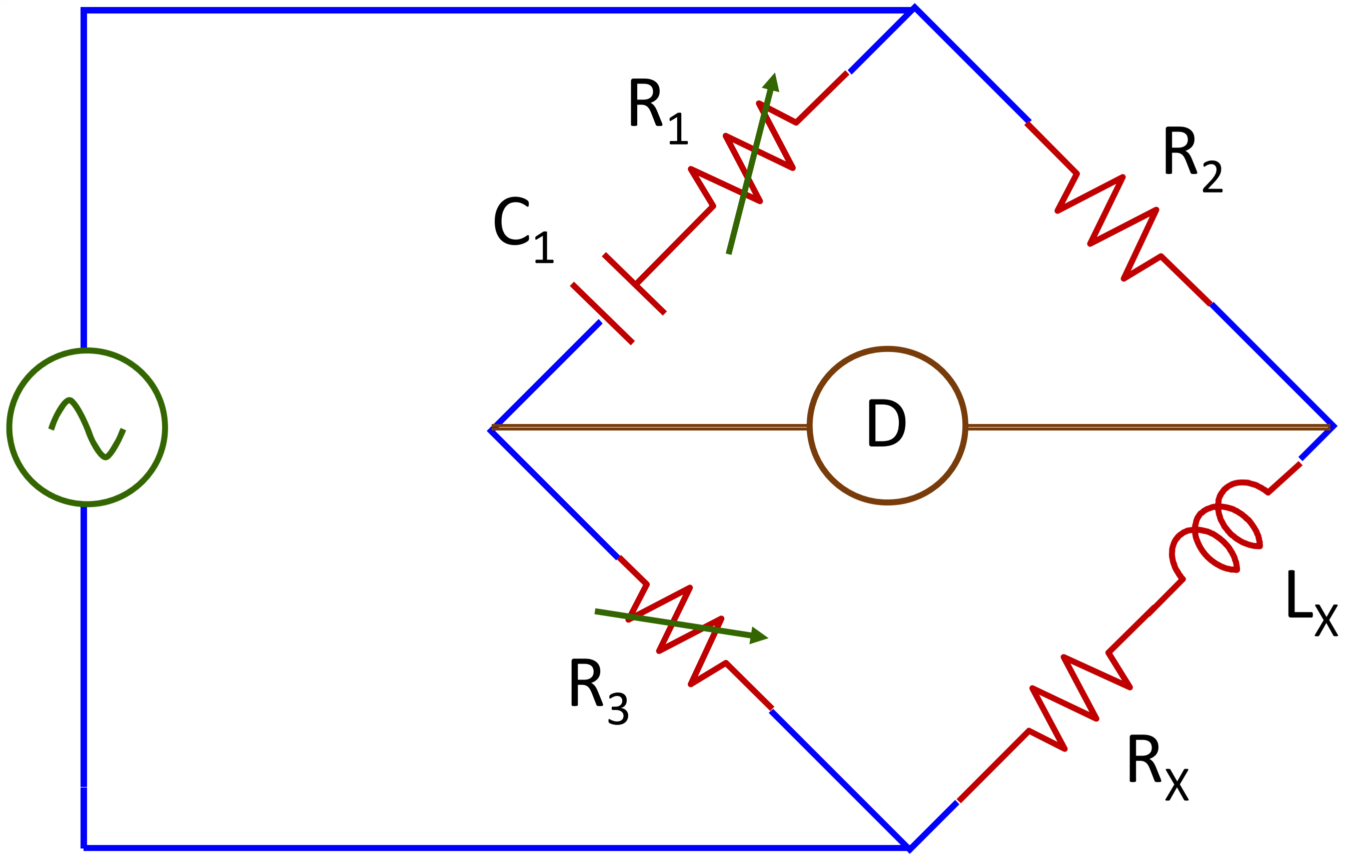
$$R_1(R_X - j\frac{1}{\omega C_X}) = R_2(R_s - j\frac{1}{\omega Cs})$$

$$\boxed{R_X = \frac{R_2}{R_1} R_s}$$

$$\boxed{C_X = \frac{R_1}{R_2} C_s}$$

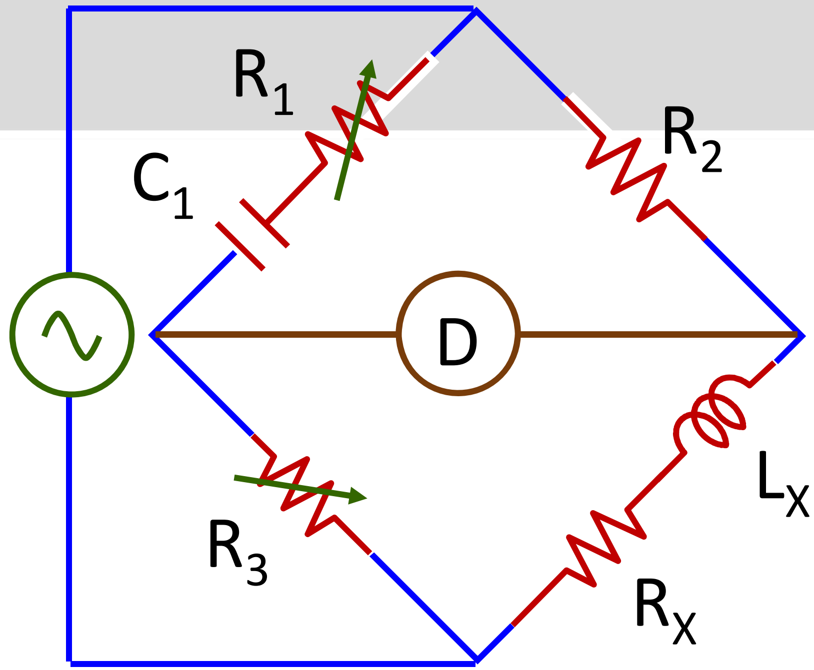
The Hay bridge

It is used to measure the resistance and inductance of a coil having a very high "ωL / R" ratio



The Hay bridge

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



$$Z_2 = R_2$$

$$Z_3 = R_3$$

$$Z_4 = R_X + j\omega L_X$$

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

$R_1 R_X + L_X / C_1 = R_2\ R_3$

$\omega\ L_X\ R_1 - R_X / \omega\ C_1 = 0$

$R_1\ R_X\ C_1 + L_X = R_2\ R_3\ C_1$

$L_X = R_X / \omega^2\ C_1\ R_1$

The Hay bridge

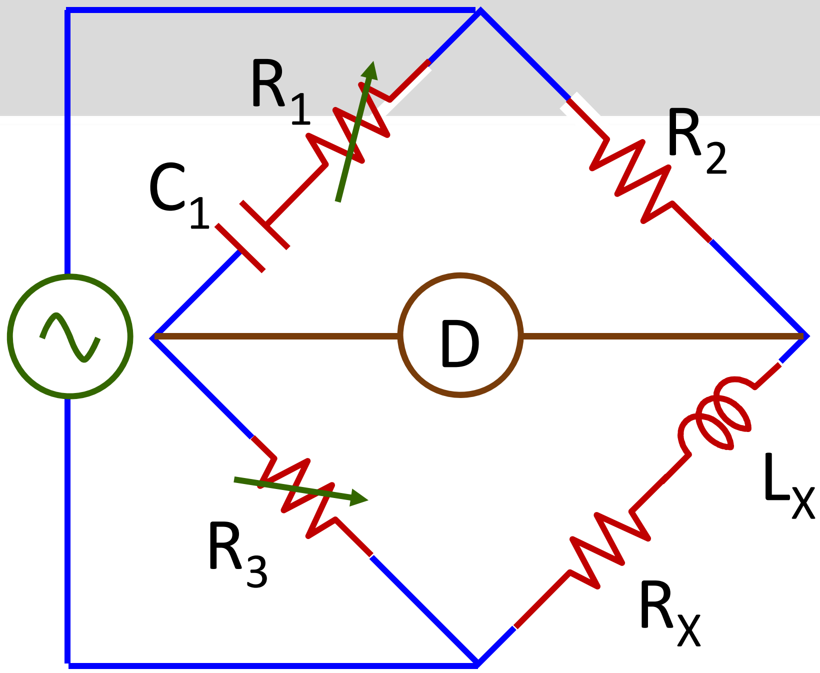
$R_1 R_X C_1 + R_X / \omega^2 C_1 R_1$

$= R_2 R_3 C_1$

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

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

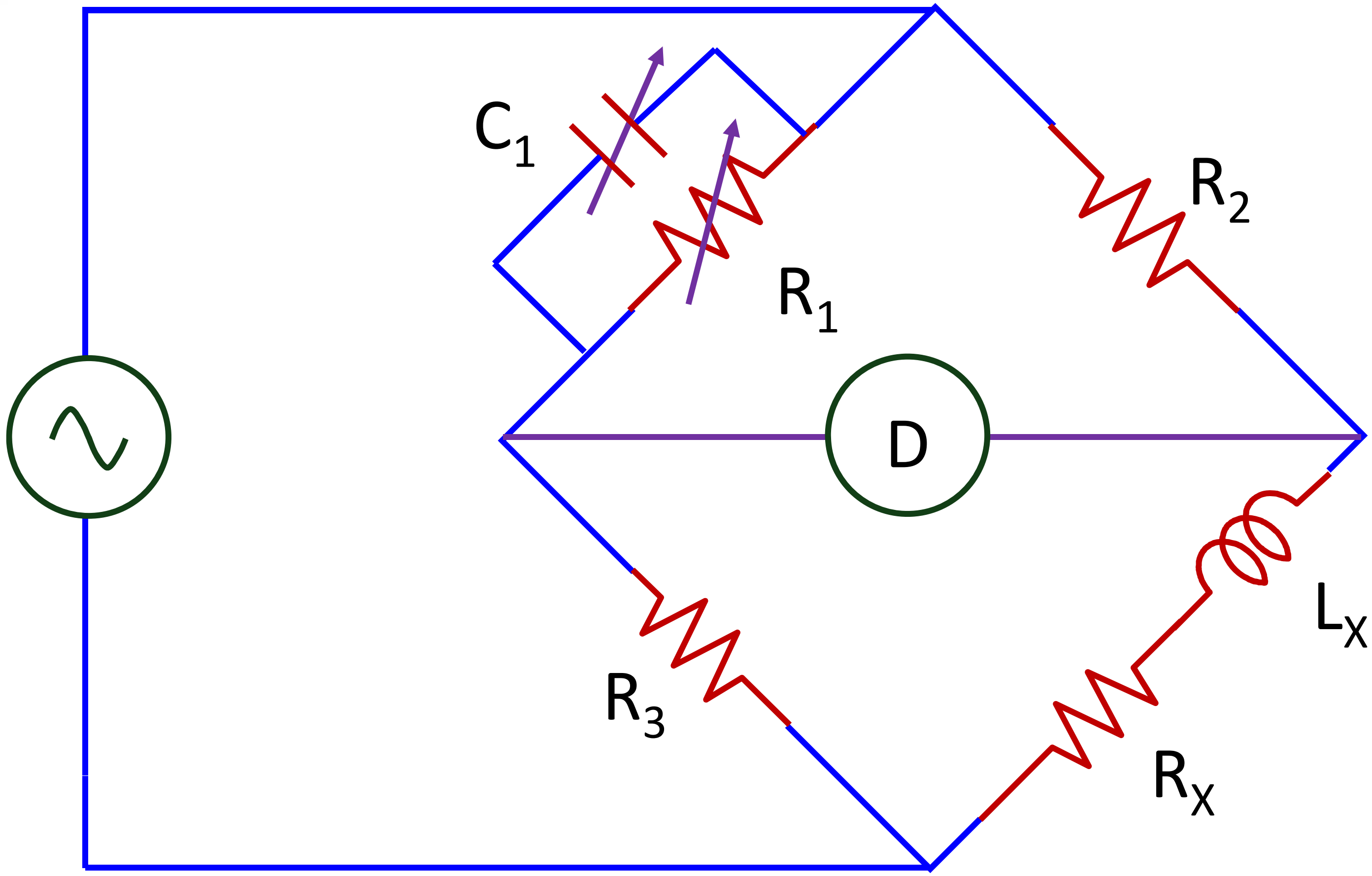
$$L_X = \frac{C_1 R_2 R_3}{1 + \omega^2 C_1^2 R_1^2}$$



The bridge is frequency dependant

The Maxwell-Wien Bridge

It is used to measure the resistance and inductance of a coil having a low or medium "ωL / R" ratio



The Maxwell-Wien Bridge

$$Z_1 = R_1 \,//\, (\text{-j}X_C)$$

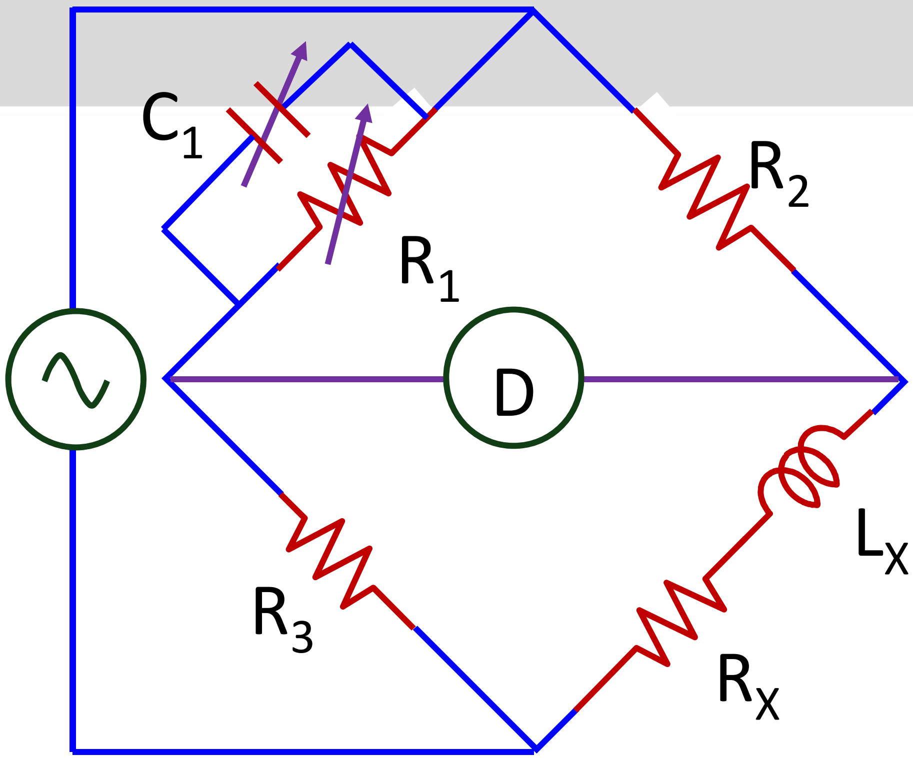
$$Z_2 = R_2$$

$$Z_3 = R_3$$

$$Z_4 = R_X + j\omega L_X$$

$$Y_1 = \frac{1}{R_1} + \text{j}\omega \text{C}_1$$

$$\text{Z}_4 = \text{Z}_2\ \text{Z}_3 \text{Y}_1$$



$$R_X + j\omega L_X = R_2\ R_3 \left(\frac{1}{R_1} + \text{j}\omega \text{C}_1 \right)$$

The Maxwell-Wien Bridge

$$R_X + j\omega L_X = R_2\, R_3 \left(\frac{1}{R_1} + j\omega C_1 \right)$$

$$\boxed{R_X = \frac{R_2\, R_3}{R_1}}$$

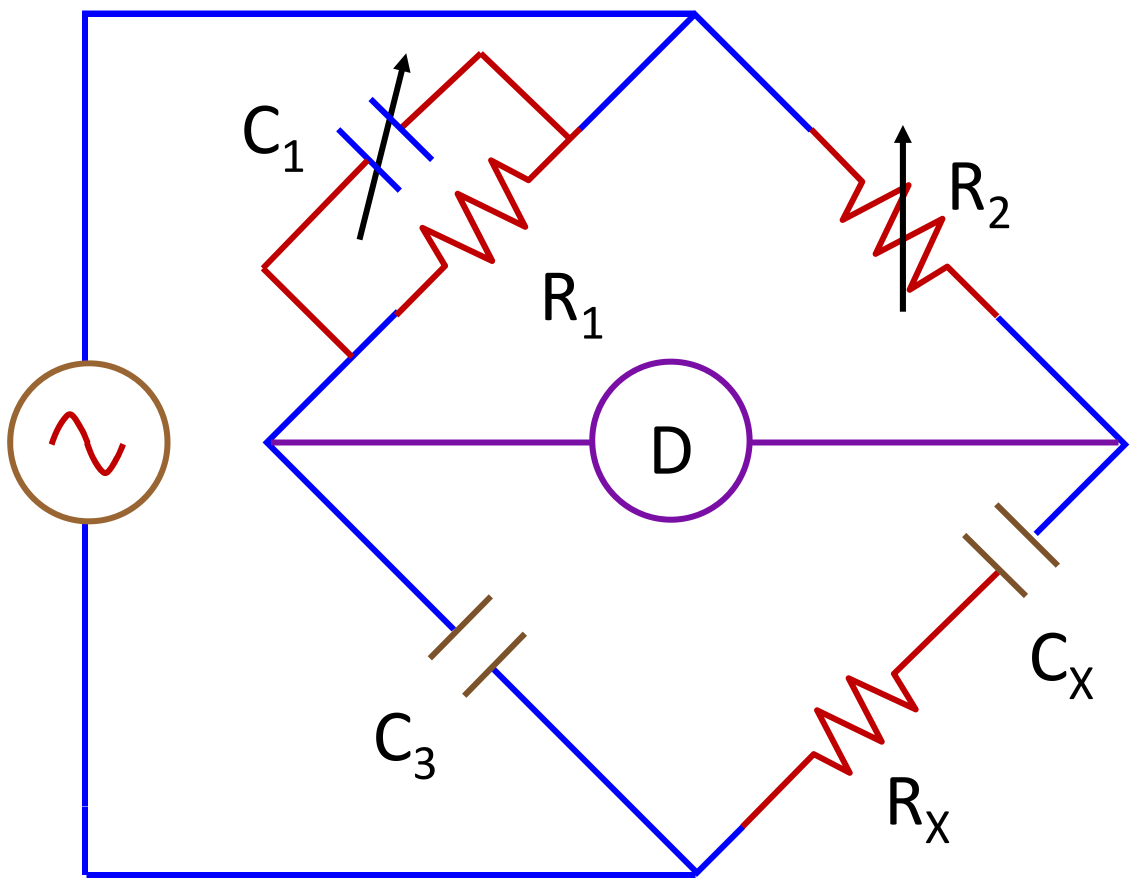
$L_X = R_2\, R_3\, C_1$

The Schering Bridge

It is used to measure the capacitance and equivalent series resistance of a capacitor

It can be used also to measure the power factor of an insulating materials

The dielectric loss may be determined for any insulating materials from these calculations



The Schering Bridge

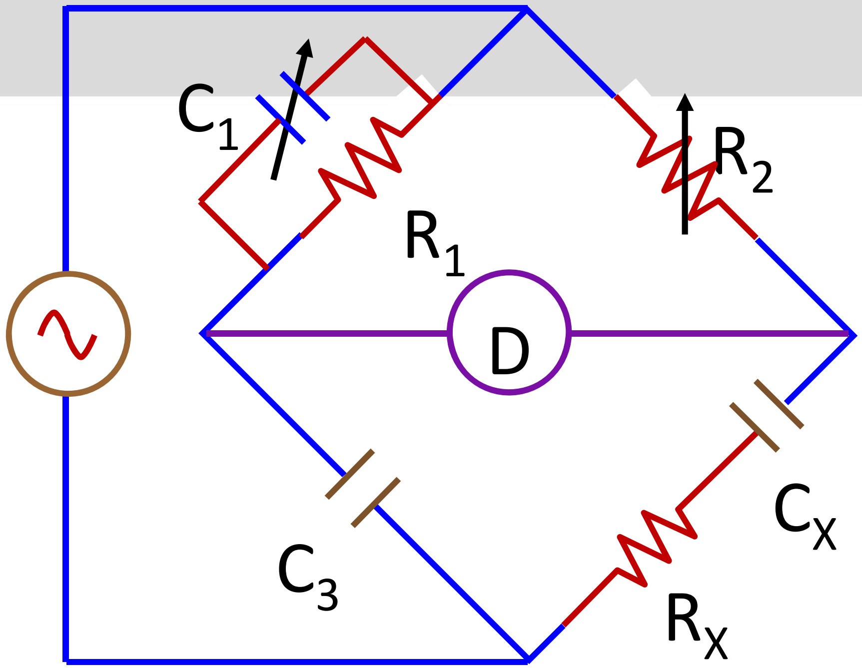
$$Z_1 = R_1 // (-jX_C)$$

$$Z_2 = R_2$$

$$Z_3 = \frac{1}{j\omega C_3}$$

$$Z_4 = R_X + \frac{1}{j\omega C_X}$$

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



$$Z_4 = Z_2 Z_3 Y_1$$

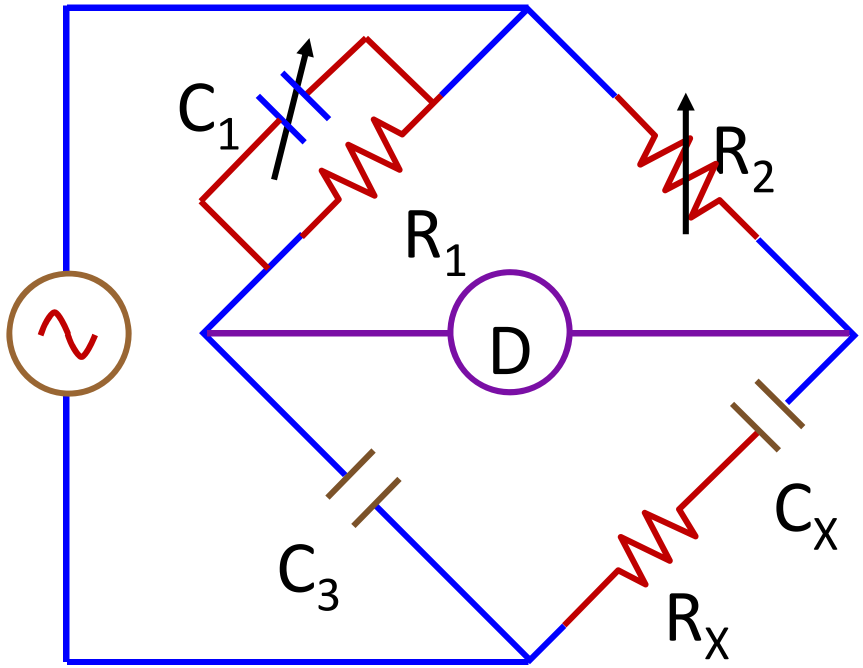
The Schering Bridge

$$R_X + \frac{1}{j\omega C_X} = \frac{R_2}{j\omega C_3}\left(\frac{1}{R_1} + j\omega C_1\right)$$

$$R_X = \frac{C_1}{C_3} R_2$$

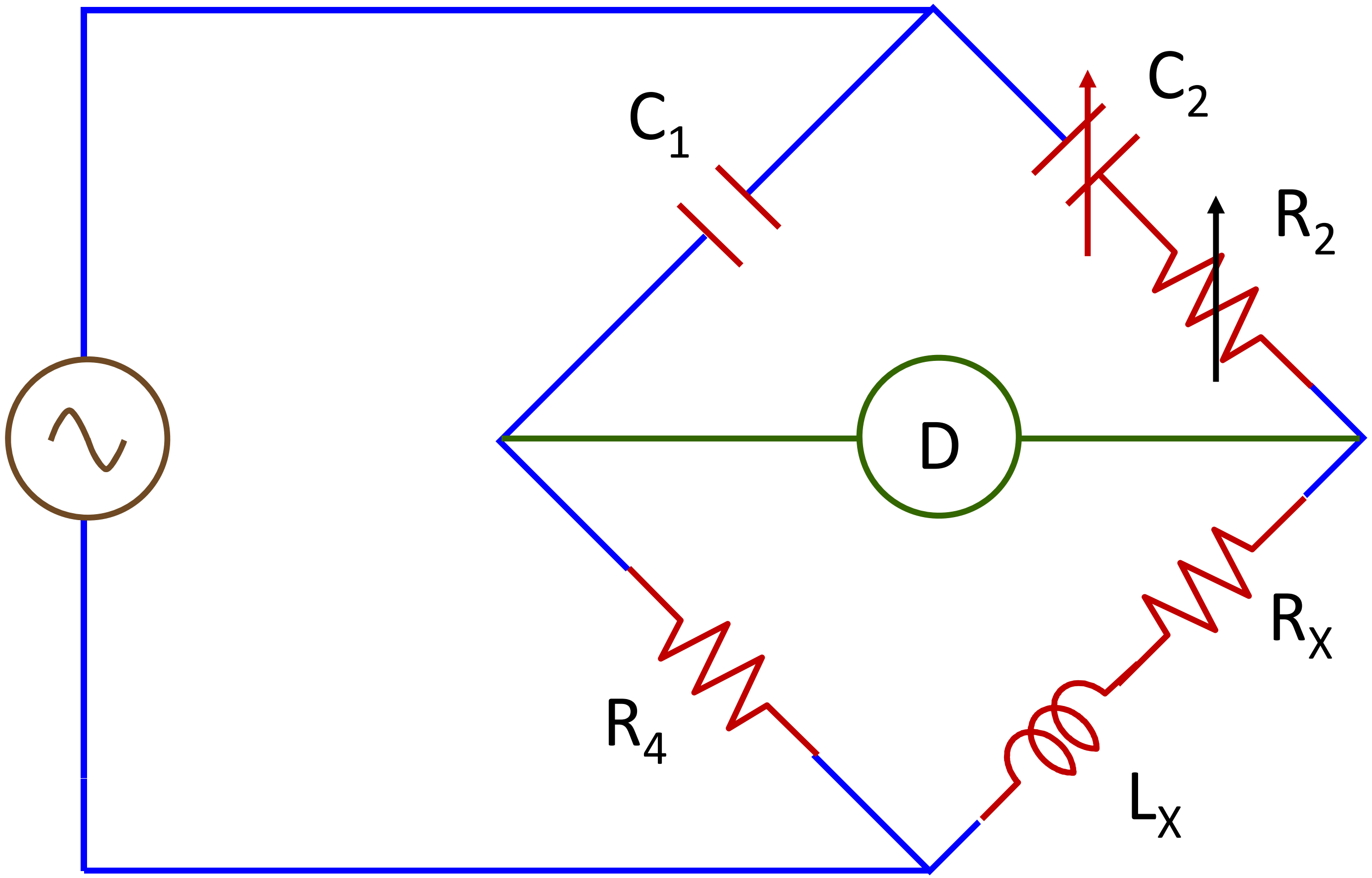
$$\frac{1}{j\omega C_X} = \frac{R_2}{j\omega R_1 C_3}$$

$$C_X = \frac{R_1}{R_2} C_3$$



The Owen Bridge

It is used to measure the resistance and inductance of coils possessing a large value of inductance



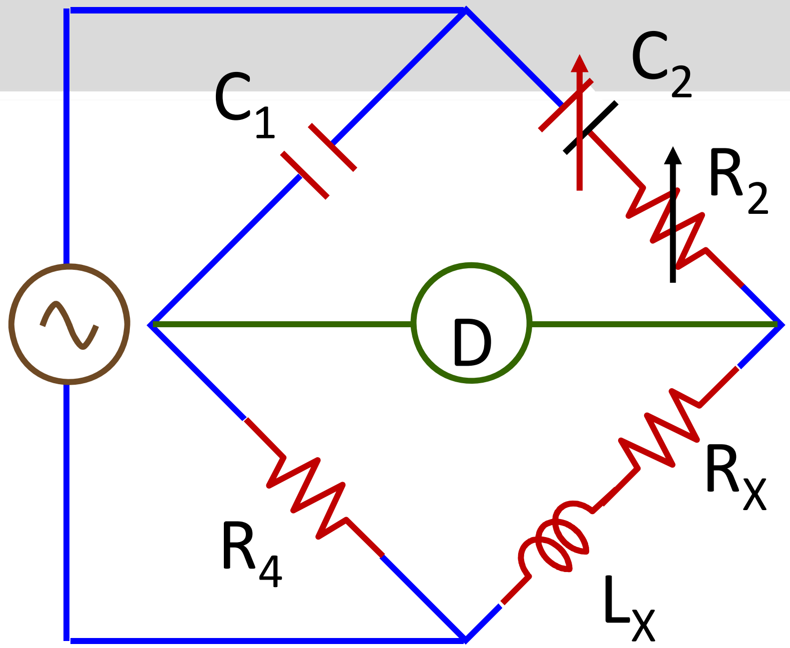
The Owen Bridge

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

$$Z_2 = R_2 + \frac{1}{j\omega C_2}$$

$$Z_3 = R_x + j\omega L_x$$

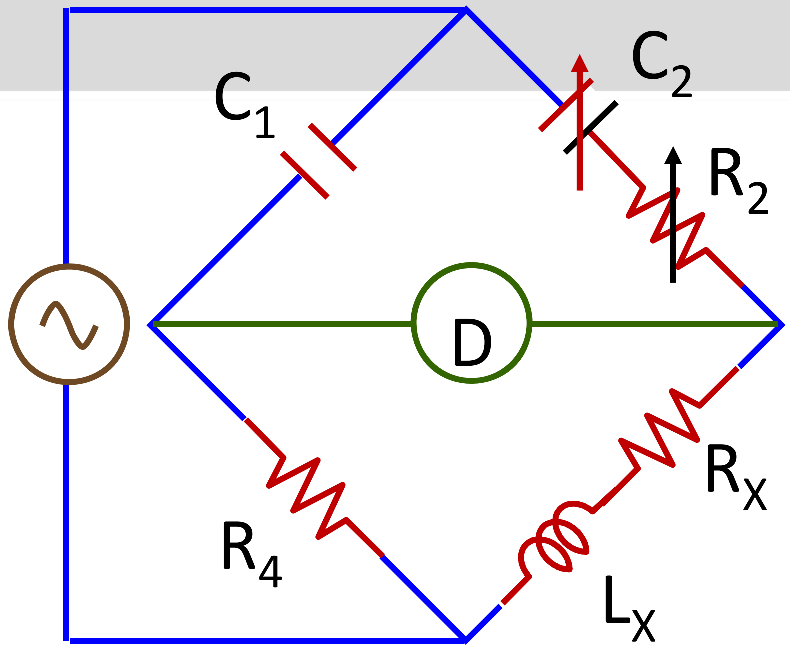
$$Z_4 = R_4$$



$$\frac{1}{j\omega C_1}(R_x + j\omega L_x) = \left(R_2 + \frac{1}{j\omega C_2}\right) R_4$$

The Owen Bridge

$$(R_x + j\omega L_x) = (j\omega C_1 R_2 + \frac{C_1}{C_2})R_4$$



$$R_x = \frac{C_1}{C_2} R_4$$

$$L_x = C_1 R_2 R_4$$