

Resistance Measurement



EIE 240 Electrical and Electronic Measurement
Class 5, February 13, 2015

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Resistance and Conductance

- Resistance, R (Ohm – Ω), is the tendency of a material to impede the flow of electric charges through it.
- The instantaneous voltage across a resistor is directly proportional to the current flowing through it. The relation was discovered by George Simon Ohm in 1836, $V = IR$ or $I = GV$ where $G = 1/R$ is called conductance (Siemens – S).



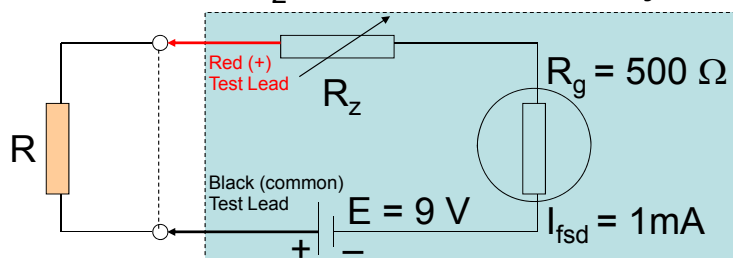
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Resistor

- Resistors are made of materials that conduct electricity but possess a large resistance compared to the resistance of the wires and the contacts, e.g. carbon composition, wirewound, metal film, steel, liquid ($\text{H}_2\text{O}+\text{CaCO}_3$).
- They are used for many purposes, e.g. electric heater, voltage dividing elements, current-limiting devices.
- Resistors of $50\mu\Omega$ -1000 $\text{M}\Omega$ are manufactured.
- Acceptable tolerances range from $\pm 20\%$ (serving as heating element) to $\pm 0.001\%$ (more precious for sensitive measuring instruments) ³

Analogue Ohmmeter

- Using permanent-magnet moving-coil (galvanometer, $\theta \propto I$) with a total internal resistance R_g
- Series type ohmmeter with battery E
- Resistance R to be measured
- Resistance R_z to be zero-ohm-adjusted

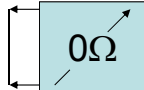


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Zero-Ohm Adjustment – First!

- Short circuit at the terminals
- Resistance reading should be zero, $R = 0$
- Adjust R_z until reach a full-scale current reading (0Ω at I_{fsd})

$$E = I_{fsd} (R_z + R_g)$$

$$I_{fsd} = E / (R_z + R_g)$$


- I_{fsd} , E and R_g are constant.
- R_z has to be adjusted every time the range is changed (current changed by any other additional resistors)

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Zero-Ohm Adjustment (Cont'd)

- for the measurement of series type ohmmeter

$$E = I (R + R_z + R_g)$$

$$I = E / (R + R_z + R_g)$$

- R increased, I decreased, θ decreased (scale $\infty \leftrightarrow 0$)
- Relationship between I and R is non-linear, it means a non-linear resistance scale.
- R_z and R_g are small, therefore for high resistances, the scale points are very close together!

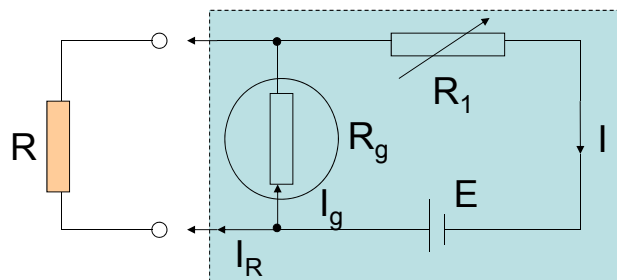
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Shunt Type Ohmmeter

- When $R \rightarrow \infty$ (open circuit), R_1 is adjusted for a full-scale reading.

$$E = I_{\text{fsd}} (R_1 + R_g)$$

$$I_{\text{fsd}} = E / (R_1 + R_g)$$



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Shunt Type Ohmmeter (Cont'd)

- When R is connected, the current passing through the meter is reduced by shunt resistor,

$$1/R_{\text{parallel}} = 1/R + 1/R_g$$

$$R_{\text{parallel}} = RR_g / (R + R_g)$$

and

$$E = I (R_1 + R_{\text{parallel}})$$

$$= I (R_1 + RR_g / (R + R_g))$$

$$= I (R_1 R + R_1 R_g + RR_g) / (R + R_g)$$

$$= I (R_1 R_g + R(R_1 + R_g)) / (R + R_g)$$

$$I = E (R + R_g) / (R_1 R_g + R(R_1 + R_g)) \quad ^8$$

Shunt Type Ohmmeter (Cont'd)

- The current I is divided into two parts,

$$I_g = I - I_R = I - I_g R_g / R, \quad I_g R_g = I_R R$$

therefore

$$I_g = E(R + R_g) / (R_1 R_g + R(R_1 + R_g)) - I_g R_g / R$$

$$I_g (1 + R_g / R) = E(R + R_g) / (R_1 R_g + R(R_1 + R_g))$$

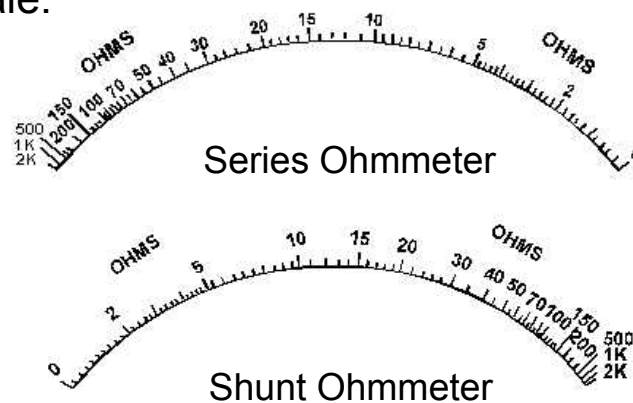
$$I_g (R + R_g) / R = E(R + R_g) / (R_1 R_g + R(R_1 + R_g))$$

$$I_g = ER / (R_1 R_g + R(R_1 + R_g)) \rightarrow \text{nonlinear}$$

- Meter reading depends on the value of R , then it is useful when R is a low resistance.
- R increased, I_g increased, θ increased ($0 \leftrightarrow \infty$)

Resistance Logarithmic Scales

The most accurate resistance measurement made by an ohmmeter is made when the needle is positioned at the center of the scale.



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Ex-1 A series type ohmmeter uses a moving coil meter with a resistance of 50Ω and a full-scale deflection of 1mA . If the battery has an e.m.f. of 2V , what should be the value of the resistor for the zero adjustment?

Short circuit at the terminals,

$$\begin{aligned} E &= I_{\text{fsd}} (R_z + R_g) \\ R_z &= E/I_{\text{fsd}} - R_g \\ &= (2\text{V})/(1\text{mA}) - 50\Omega \\ &= 1950 \Omega \end{aligned}$$

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Mid-Scale Reading

For series type,

at $0-\Omega$, $I_{\text{fsd}} = E / (R_z + R_g)$

Measure, $I = E / (R + R_z + R_g) = E / (R + E/I_{\text{fsd}})$

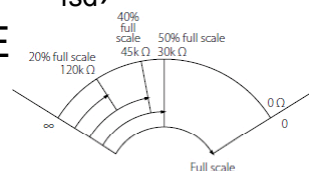
$$I_{\text{mid}} = I_{\text{fsd}}/2 = E / (R_{\text{mid}} + E/I_{\text{fsd}})$$

$$2E = I_{\text{fsd}} R_{\text{mid}} + E$$

$$R_{\text{mid}} = E/I_{\text{fsd}}$$

or $R_{\text{mid}} = R_z + R_g$

It means that a resistance to be measured should be equal to an internal resistance of the meter (to make middle scale reading).



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Mid-Scale Reading (Cont'd)

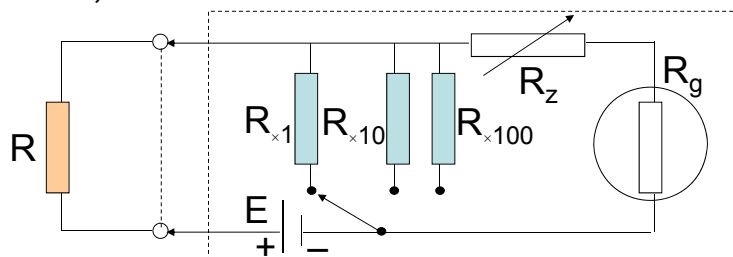
For shunt type,

$$\begin{aligned}
 I_g &= ER / (R_1 R_g + R(R_1 + R_g)) \\
 &= R / (R_1 R_g / E + R(R_1 + R_g) / E) \\
 &= R / (R_1 R_g / E + R / I_{fsd}) \\
 I_{mid} &= I_{fsd} / 2 = R_{mid} / (R_1 R_g / E + R_{mid} / I_{fsd}) \\
 2R_{mid} &= I_{fsd} (R_1 R_g / E + R_{mid} / I_{fsd}) \\
 R_{mid} &= R_1 R_g I_{fsd} / E \\
 &= (V_{fsd} / E) R_1
 \end{aligned}$$

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Ranges of Ohmmeter

Ohmmeter usually has several operational ranges indicated by $R \times 1$, $R \times 10$, $R \times 100$, $R \times 1k$, $R \times 100k$ and $R \times 1M$.



- For the mid-scale (series type),

$$\begin{aligned}
 R = R_{mid} &= R_{x1} // (R_z + R_g) \\
 &= R_{x1} (R_z + R_g) / (R_{x1} + R_z + R_g)
 \end{aligned}$$

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Ranges of Ohmmeter (Cont'd)

$$R_{\text{mid}} = R_{\times 1}(R_z + R_g) / (R_{\times 1} + R_z + R_g)$$

$$R_{\text{mid}}(R_{\times 1} + R_z + R_g) = R_{\times 1}(R_z + R_g)$$

$$R_{\text{mid}}(R_z + R_g) = R_{\times 1}(R_z + R_g - R_{\text{mid}})$$

$$R_{\times 1} = R_{\text{mid}}(R_z + R_g) / (R_z + R_g - R_{\text{mid}})$$

The shunt resistance increases for higher ohm ranges and is always equal to the center scale reading on the range.

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Ex-2 From the series type ohmmeter in Ex-1, what should be the value of the shunt required for the meter if the mid-scale reading of the ohmmeter is to be 1000Ω and 1500Ω?

$$R_{\text{shunt for } 1\text{k}\Omega} = R_{\text{mid}}(R_z + R_g) / (R_z + R_g - R_{\text{mid}})$$

$$= \frac{(1000\Omega)(1950\Omega + 50\Omega)}{(1950\Omega + 50\Omega - 1000\Omega)}$$

$$= 2000 \Omega$$

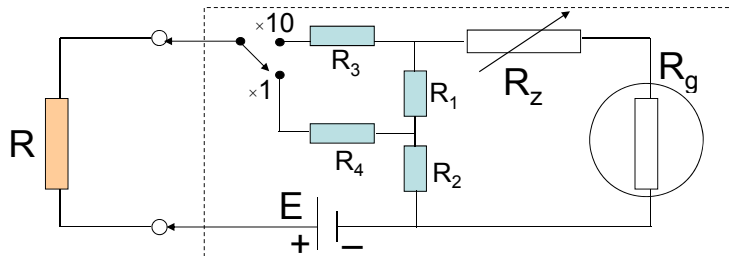
$$R_{\text{shunt for } 1.5\text{k}\Omega} = \frac{(1500\Omega)(1950\Omega + 50\Omega)}{(1950\Omega + 50\Omega - 1500\Omega)}$$

$$= 6000 \Omega$$

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Range of Ohmmeter (Cont'd)

- Another arrangement,



$$\times 10, I = E / [(R_z + R_g) // (R_1 + R_2) + R_3 + R]$$

$$= E / [(R_z + R_g)(R_1 + R_2) / (R_1 + R_2 + R_z + R_g) + R_3 + R]$$

$$\times 1, I = E / [(R_1 + R_2 + R_g) // R_2 + R_4 + R]$$

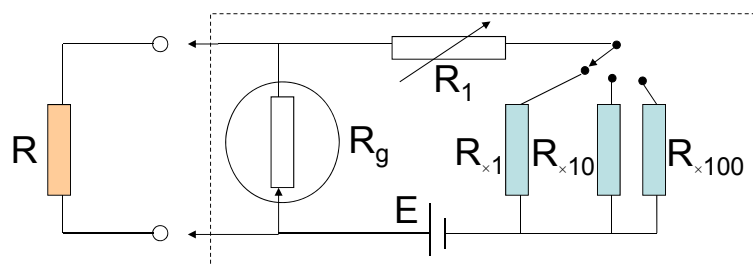
$$= E / [R_2(R_1 + R_2 + R_g) / (R_1 + R_2 + R_z + R_g) + R_4 + R]$$

More R paralleled, less total R, higher I

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Ranges of Ohmmeter (Cont'd)

- For shunt type,



$$\text{Without } R_x, I_g = ER / (R_g R_1 + R(R_1 + R_g))$$

$$\text{With } R_x, I_g = ER / (R_g(R_1 + R_{x1}) + R(R_1 + R_{x1} + R_g))$$

R_x increased, I_g decrease

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Ranges of Ohmmeter (Cont'd)

- One major problem with this ohmmeter's design is its reliance upon a stable battery voltage. If the battery voltage decreases, as all chemical batteries do with age and use, the scale will lose accuracy.
- From this fact of the logarithmic scale, this type of ohmmeter is never considered to be a precision instrument.
- One final caveat needs to be mentioned is that they only function correctly when measuring resistance that is not being powered by a voltage or current source, not for on a live circuit!

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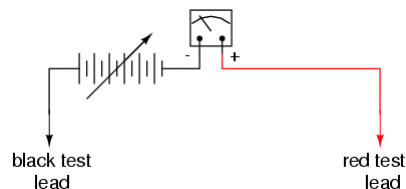
High-Voltage Ohmmeter

- Most ohmmeters of the previous design utilize a battery of low voltage. This is adequate for measuring resistances under several mega-ohms ($M\Omega$), but for extremely high resistances, a 9-V battery is insufficient for generating enough current to actuate the movement.
- Moreover, resistance is not always a stable or linear quantity, especially true of non-metals.

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High-Voltage Ohmmeter (Cont'd)

- The most direct method of high-voltage resistance measurement involves simply substituting a higher voltage battery in the same basic design of ohmmeter investigated earlier.
- Unfortunately, this would create a calibration problem for the meter.

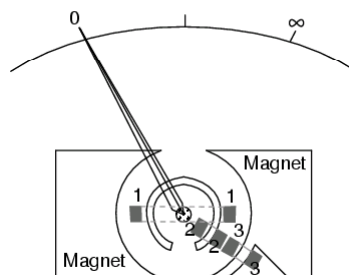


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Megger Movement

Megohmmeters

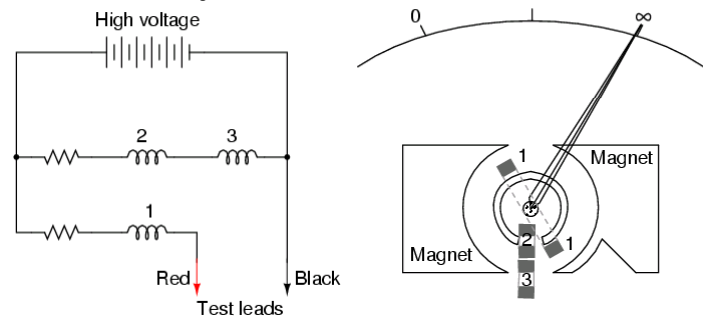
- Needle mechanism moves 3 wire coils without spring to return the needle to a set position.
- When the movement is unpowered, the needle will randomly float.



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Megger Movement (Cont'd)

- When open circuit, there will be no current through coil 1, only through coils 2 and 3.
- These two coils try to center themselves in the gap between the two magnet poles, driving the needle fully to the right of the scale where it points to infinity.



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Megger Movement (Cont'd)

- Any current through coil 1, and measured resistance between the leads, tends to drive the needle to the left of scale or zero.
- The internal resistance of the meter are calibrated so that when the leads are shorted together, the needle deflects exactly to the 0 Ω position.
- For maximum safety, most meggers are equipped with hand-crank generators for producing the high DC voltage (≥ 1 kV). If the operator receives a shock from the high voltage, he will naturally stop cranking!



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References

- http://www.faqs.org/docs/electric/DC/DC_8.html
- http://avstop.com/ac/Aviation_Maintenance_Technician_Handbook_General/10-74.html
- <http://www.wisc-online.com/Objects/ViewObject.aspx?ID=DCE7104>