Resistance Measurement

EIE 240 Electrical and Electronic Measurement
Class 6, January 19, 2012

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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.

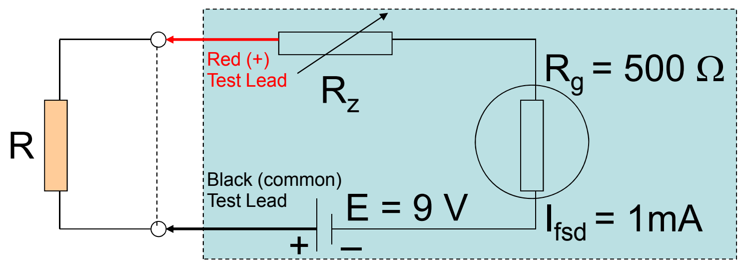
- The instantaneous voltage across a resistor is directly proportional to the current flowing through it. The relation was discovered by George Simon Ohm in 1836, V = IR or I = GV where G = 1/R is called conductance (siemens – S).

Resistor

- Resistors are made of materials that conduct electricity but posses a large resistance compared to the resistance of the wires and the contacts, e.g. carbon composition, wirewound, metal film, steel, liquid (H_2O+$CaCO_3$).
- They are used for many purposes, e.g. electric heater, voltage dividing elements, current-limiting devices.
- Resistors of $50\mu\Omega$-1000 $M\Omega$ are manufactured.
- Acceptable tolerances range from $\pm$20% (serving as heating element) to $\pm$0.001% (more precious for sensitive measuring instruments)

Analogue Ohmmeter

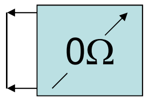
- Using permanent-magnet moving-coil (galvanometer, $\theta \propto I$) with a total internal resistance R_g
- Series type ohmmeter with battery E
- Resistance R to be measured
- Resistance R_z to be zero-ohm-adjusted



Zero-Ohm Adjustment

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

$$E = I_{fsd}\,(R_z + R_g)$$
$$\color{red}{\mathbf{I_{fsd}}} = E \,/\, (\color{red}{\mathbf{R_z}} + R_g)$$



- 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)

Zero-Ohm Adjustment (Cont'd)

- for the measurement of series type ohmmeter

$$E = I\,(R + R_z + R_g)$$
$$\color{red}{\mathbf{I}} = E \,/\, (\color{red}{\mathbf{R}} + R_z + R_g)$$

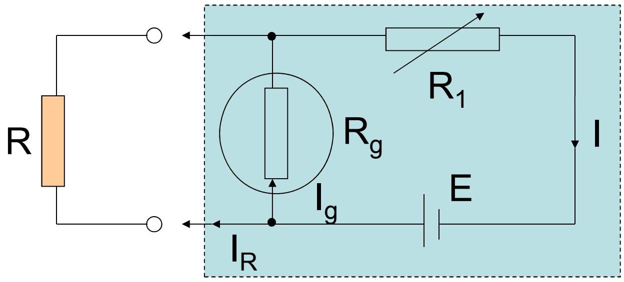
- R increased, I decreased, θ decreased (scale ∞ ↔ 0)
- Relationship between I and R is non-linear, it means a non-linear resistance scale.
- R_z and R_g are small, therefore for high resistances, the scale points are very close together!

Shunt Type Ohmmeter

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

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

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



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Shunt Type Ohmmeter (Cont'd)

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

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

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

and

$$\begin{aligned} E &= I\,(R_1 + R_{parallel}) \\ &= I\,(R_1 + RR_g/(R + R_g)) \\ &= I\,(R_1R + R_1R_g + RR_g) / (R + R_g) \\ &= I\,(R_1R_g + R(R_1 + R_g)) / (R + R_g) \end{aligned}$$

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Shunt Type Ohmmeter (Cont'd)

- The current I is divided into two parts,

$$I_g = I - I_R = I - I_gR_g/R \qquad , I_gR_g = I_RR$$

therefore

$$I_g = E(R + R_g)/(R_1R_g + R(R_1 + R_g)) - I_gR_g/R$$

$$I_g(1+R_g/R) = E(R + R_g)/(R_1R_g + R(R_1 + R_g))$$

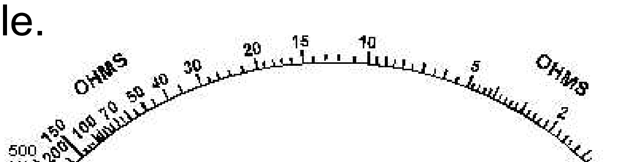
$$I_g(R+R_g)/R = E(R + R_g)/(R_1R_g + R(R_1 + R_g))$$

$$\mathbf{I_g} = E\mathbf{R} / (R_1R_g + \mathbf{R}(R_1 + R_g)) \rightarrow \text{nonlinear}$$

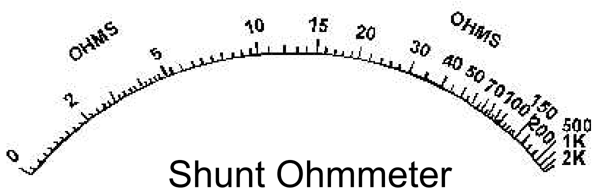
- Meter reading depends on the value of R, then it is useful when R is a low resistance.
- R increased, I increased, θ increased ($0 \leftrightarrow \infty$)

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.



Series Ohmmeter



Shunt Ohmmeter

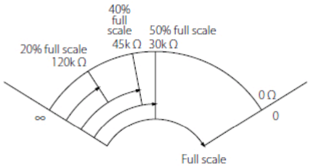
Mid-Scale Reading

For series type,

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

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

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



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

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

or $R_{mid} = R_z + R_g$

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,

$I_g = ER / (R_1R_g + R(R_1 + R_g))$

$= R / (R_1R_g/E + R(R_1 + R_g)/E)$

$= R / (R_1R_g/E + R/I_{fsd})$

$I_{mid} = I_{fsd}/2 = R_{mid} / (R_1R_g/E + R_{mid}/I_{fsd})$

$2R_{mid} = I_{fsd} (R_1R_g/E + R_{mid}/I_{fsd})$

$R_{mid} = R_1R_gI_{fsd}/E$

$= (V_{fsd}/E) R_1$

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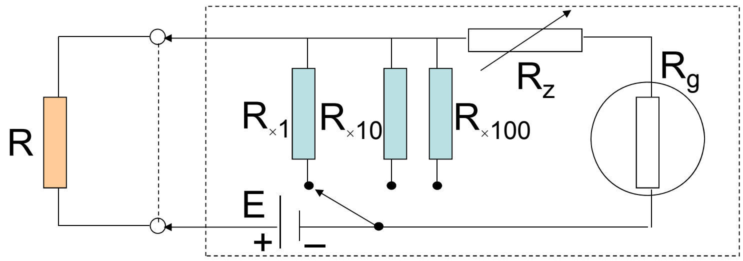
Ranges of Ohmmeter

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



- For the mid-scale (series type),

$$R = R_{mid} = R_{\times 1} \; // \; (R_z+R_g)$$
$$= R_{\times 1}(R_z+R_g) \, / \, (R_{\times 1}+R_z+R_g)$$

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Ranges of Ohmmeter (Cont'd)

0-Ω adjust (short circuit to R),

$$I = E \, / \, R_{mid}$$
$$V_{Rz+Rg} = V_{R\times 1}$$
$$I_{fsd}(R_z+R_g) = (I - I_{fsd})R_{\times 1} \quad \text{, if } R_\times \uparrow \text{ then } I \uparrow$$
$$R_{\times 1} = I_{fsd}(R_z+R_g) \, / \, (I - I_{fsd})$$
$$= I_{fsd}(R_z+R_g) \, / \, (E/R_{mid} - I_{fsd})$$
$$= I_{fsd}R_{mid}(R_z+R_g) \, / \, (E - I_{fsd}R_{mid})$$

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

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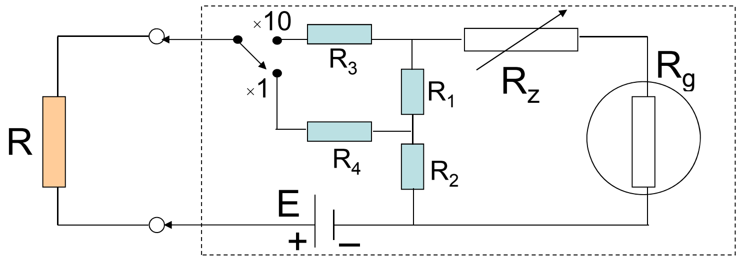
Range of Ohmmeter (Cont'd)

- Another arrangement,



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

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

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

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

More R paralleled, less total R, higher I

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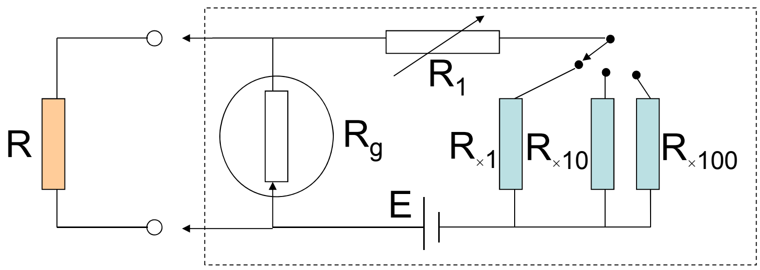
Ranges of Ohmmeter (Cont'd)

- For shunt type,



Without $R_\times$, $I_g = ER / (R_gR_1 + R(R_1 + R_g))$

With $R_\times$, $I_g = ER / (R_g(R_1+R_{\times 1}) + R(R_1+R_{\times 1}+R_g))$

$R_\times$ 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 (MΩ), 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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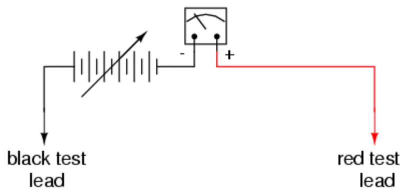
High-Voltage Ohmmeter (Cont'd)

- 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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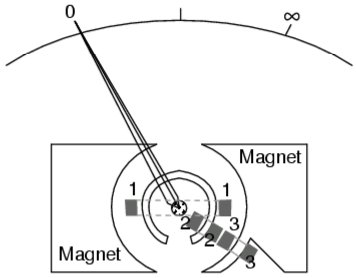
Megger Movement

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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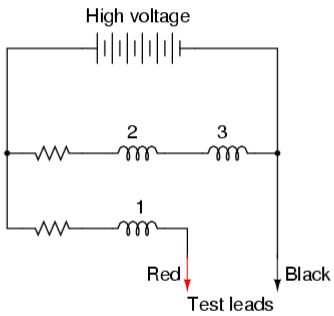
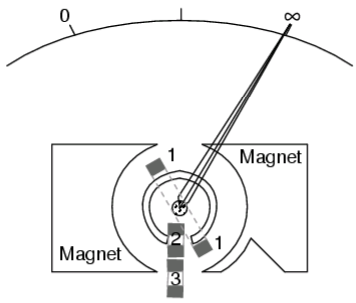
Megger Movement (Cont'd)

- 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.





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!

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