Principles and types of analog and digital ammeters and voltmeters
Electrical voltage and current are two important quantities in an electrical network.

The voltage is the effort variable without which no current is available. It is measured across an electrical circuit element or branch of a circuit. The device that measures the voltage is the voltmeter.

The current is the flow variable that represents net motion of the charged particles (electrons in solids, ions in a liquid) in a given direction.

The product of the two yields the instantaneous electrical power. The ratio of the voltage to the current is the impedance.
The current is measured by an **ammeter** (also called an **ampermeter**). Ammeters are connected **in series** with the load to measure the current in the load.

Eventually, the ammeters require breaking the current loop to place it into the circuit.

The voltmeter connection is rather easy since it is connected without disturbing the circuit layout. Voltmeters are connected **in parallel** with the load to measure the voltage across the load.
Moving-Coil Meter

- Two Types of Multimeters

VOM (analog)

DMM (digital)
Types of Meters

– **Analog meter:**
  - Uses a moving pointer and a printed scale to indicate values of voltage, current, or resistance.

– **Volt-Ohm-Milliammeter (VOM):**
  - Allows all three kinds of measurements on a single scale or readout.

– **Digital multimeter:**
  - Uses a numerical readout to indicate the measured value of voltage, current or resistance.
Moving-Coil Meter

• Direct Current Meters
  – Direct current in a moving-coil meter deflects the pointer in proportion to the amount of current.
  – A current meter must be connected in series with the part of the circuit where the current is to be measured.
  – A dc current meter must be connected with the correct polarity.
Moving-Coil Meter: principle of operation

Where, $B$ is magnetic flux density

$i$ the current passing through the wire

$\Phi$ the angle between $B$ and $I$

$I$ is the length of the conductor

\[ F = Bli \sin \phi \]
Right-hand rule for a current-carrying wire in a magnetic field $B$
Moving-Coil Meter

Analog instruments use a moving coil meter movement.

Current flow in the coil moves the pointer up-scale.
Moving-Coil Meter: principle of operation

The length of each side of the coil is perpendicular to the magnetic field, that is $\Phi=0$

\[ F = 2LBi \]

for n turn coil

\[ F = 2LNBi \]

the torque generated by passing the current through the N turns(Tm)

\[ Tm = F \times h / 2 \]

where h is the width of the coil

\[ Tm = 2LNBi \times h / 2 \]

= $LhNBi = ANBi$

Note: $L \times h = \text{area}$

B: flux density

I : Current

F : Force
Moving-Coil Meter: principle of operation

- The deflection torque causes the moving system to move from zero position when the instrument is connected to the circuit to measure the given electrical quantity.

The Torque is given by,

\[ T = BiNA \]

where

- \( T \) = Torque in unit Newton meter (N.m)
- \( B \) = Flux density in unit Tesla (T) or wb/m\(^2\)
- \( i \) = Current through coil in unit Ampere (A)
- \( N \) = Numbers of coil
- \( A \) = Area (length x wide), m\(^2\)
Moving-Coil Meter: principle of operation

At equilibrium (at balance)

\[ Tm = Ts \]

Where \( Ts \) is the spring torque and \( Ts \)

\[ Ts = K\theta \]
Moving-Coil Meter: principle of operation

At equilibrium (at balance)

\[ BNAi = K \theta \]

\[ \theta = \frac{BNA}{k} i \]

the sensitivity \( S \),

\[ S = \frac{\partial \theta}{\partial I} = \frac{BNA}{k} \]

which is constant for a specific equipment provided that \( B \) is constant.
Example

- A moving coil has following parameters: Area $A = 2 \text{ cm}^2$, $N = 90$ turns, $B = 0.2 \text{ Tesla}$, coil resistance $= 50 \Omega$, current $I = 1 \text{ mA}$. Calculate the electromagnetic torque ($T_m$) established:

$$T_m = NBAI = 90 \times 0.2 \times 2 \times 10^{-4} \times 10^{-3}$$

$$= 3.6 \times 10^{-6} \text{ N.m}$$

- Assume that the electromagnetic torque of the coil is compensated by a spring torque and the spring constant $k = 3.6 \times 10^{-8} \text{ N-m/degrees}$. Find the angle of deflection of the coil at equilibrium.
Example

- $\theta = \frac{T_M}{k} = 100^\circ$
The moving coil instrument can be considered as a transducer that converts the electrical current to angular displacement. The linear relation between $\theta$ and $I$ indicate that we have a linear (uniform) scale.
Example

• A moving coil instrument has the following data: number of turns of the coil = 100, width of the coil = 2 cm, length of the coil = 3 cm, flux density in the air gap = 0.1 Tesla. Calculate the deflection torque when carrying a current of 10 mA. Also calculate the deflection (angle) if the control spring constant is $20 \times 10^{-7}$ N-m/degree.

• Solution
• $A = 6 \text{ cm}^2$, therefore, $T_M = NBAI$
• $T_M = 60 \times 10^{-6}$ N-m

$\theta = \frac{T_{EM}}{k} = 30$
Meter Shunts

• Meter Shunts
  – **Meter shunts** are low-value precision resistors that are connected in parallel with the meter movement.
  
  – Meter shunts bypass a portion of the current around the meter movement. This process extends the range of currents that can be read with the same meter movement.
Meter Shunts

• Using Shunts to Increase Ammeter Range

Example of meter shunt $R_S$ in bypassing current around the movement to extend range from 1 to 2 mA. (a) Wiring diagram.
Meter Shunts

$V_M = I_M \times r_M \quad I_S = I_T - I_M \quad R_S = \frac{V_M}{I_S}$

$V_M = 50 \text{mV} \quad I_S = 1 \text{mA} \quad R_S = 50 \Omega$

(b) Schematic diagram showing effect of shunt. With $R_S = r_M$, the current range is doubled. (c) Circuit with 2-mA meter to read the current.
Calculating the resistance of a meter shunt. $R_S$ is equal to $V_M/I_S$.

$V_M = 0.001 \times 50 = 0.05 \text{V or } 50 \text{ mV}$
Meter Shunts

Calculating the resistance of a meter shunt. $R_S$ is equal to $V_M/I_S$.

$I_S = 0.005 - 0.001 = 0.004 \text{ A or } 4 \text{ mA}$
**Meter Shunts**

Divide \( V_M \) by \( I_S \) to find \( R_S \).

\[
R_S = \frac{0.05 \text{ V}}{0.004 \text{ A}} = 12.5 \ \Omega
\]

This shunt enables the 1-mA movement to be used for an extended range from 0-5 mA.
Voltmeters

– A **voltmeter** is connected across two points to measure their difference in potential.

– A voltmeter uses a high-resistance **multiplier** in series with the meter movement.

– A **dc voltmeter** must be connected with the correct polarity.
Voltmeters

A multiplier resistor is a large resistance in series with a moving-coil meter movement which allows the meter to measure voltages in a circuit.
Voltmeters

Using Multipliers to Increase Voltmeter Range

\[ V_M = I_M \times r_M = 0.1 \text{ V} \]

Sensitivity = \( \frac{r_M}{V_M} = 1000 \text{ } \Omega \text{ per volt} \)

\[ R_{\text{mult}} = \frac{V_{FS}}{I_M} - r_M \]

For a 25 V range, change \( R_{\text{mult}} \) to 24.9 kΩ.

Note: sensitivity is not affected by the multipliers.
Voltmeters

- Typical Multiple Voltmeter Circuit

A typical voltmeter circuit with multiplier resistors for different ranges.
Voltmeters

Voltmeter Resistance

- The high resistance of a voltmeter with a multiplier is essentially the value of the multiplier resistance.
- Since the multiplier is changed for each range, the voltmeter resistance changes.
Voltmeters

• Ohms-per-Volt Rating
  – Analog voltmeters are rated in terms of the ohms of resistance required for 1 V of deflection.
  – This value is called the **ohms-per-volt rating**, or the **sensitivity** of the voltmeter.
  – The ohms-per-volt rating is the same for all ranges. It is determined by the full-scale current $I_M$ of the meter movement.
  – The voltmeter resistance $R_V$ can be calculated by multiplying the ohms-per-volt rating and the full-scale voltage of each range.
Loading Effect of a Voltmeter

– When voltmeter resistance is not high enough, connecting it across a circuit can reduce the measured voltage.

– This effect is called loading down the circuit, because the measured voltage decreases due to the additional load current for the meter.
Loading Effect of a Voltmeter

– High resistance circuits are susceptible to Voltmeter loading.

How loading effect of the voltmeter can reduce the voltage reading. (a) High-resistance series circuit without voltmeter. (b) Connecting voltmeter across one of the series resistances. (c) Reduced $R$ and $V$ between points 1 and 2 caused by the voltmeter as a parallel branch across $R_2$. The $R_{2V}$ is the equivalent of $R_2$ and $R_V$ in parallel.
Negligible loading effect with a high-resistance voltmeter. (a) High-resistance series circuit without voltmeter. (b) Same voltages in circuit with voltmeter connected, because \( R_V \) is so high.
Loading Effect of a Voltmeter

- The loading effect is minimized by using a voltmeter with a resistance much greater than the resistance across which the voltage is measured.

- The loading effect of a voltmeter causes too low a voltage reading because $R_V$ is too low as a parallel resistance.

- The digital multimeter (DMM) has practically no loading effect as a voltmeter because its input is usually 10 to 20 MΩ on all ranges.

- The following formula can be used to correct for loading:
  \[ V = V_M + \frac{R_1 R_2}{R_V (R_1 + R_2)} V_M \]
Ohmmeters

– An ohmmeter consists of an internal battery in series with the meter movement, and a current limiting resistance.

– Power in the circuit being tested is shut off.

– Current from the internal battery flows through the resistance being measured, producing a deflection that is:
  • Proportional to the current flow, and
  • Displayed on a back-off scale, with ohm values increasing to the left as the current backs off from full-scale deflection.
Ohmmeters

How meter movement $M$ can be used as an ohmmeter with a 1.5-V battery. (a) Equivalent closed circuit with $R_1$ and the battery when ohmmeter leads are short-circuited for zero ohms of external $R$. (b) Internal ohmmeter circuit with test leads open, ready to measure an external resistance.
Ohmmeters

Resistance $R_T$ is the total resistance of $R_X$ and the ohmmeter’s internal resistance. NOTE: $R_X$ is the external resistance to be measured.

The ohmmeter’s internal resistance $R_i$ is constant at $50 + 1450$, or $1500 \, \Omega$ here. If $R_X$ also equals $1500 \, \Omega$, $R_T$ equals $3000 \, \Omega$.

The current then is $1.5 \, \text{V}/3000 \, \Omega$, or $0.5 \, \text{mA}$, resulting in half-scale deflection for the 1-mA movement.
Multimeters

- **Multimeters** are also called multitesters.
- Multimeters are used to measure voltage, current, or resistance.
- Main types of multimeters are:
  - Volt-ohm-milliammeter (VOM)
  - Digital multimeter (DMM)
# Multimeters

## Comparison between VOM and DMM

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<th>DMM</th>
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<td>$R_V$ is 10 or 22 MΩ, the same on all ranges</td>
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<td>Ohm ranges up to $R \times 10,000$ Ω, as a multiplying factor</td>
<td>Ohm ranges up to 20 MΩ; each range is the maximum</td>
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</table>
Multimeters

Analog VOM that combines a function selector and range switch.

Portable digital multimeter (DMM).
Multimeters

The problem of opening a circuit to measure current can be eliminated by using a probe with a clamp that fits around the current-carrying wire.

The clamp probe measures only ac, generally for the 60-Hz ac power line.

DMM with amp clamp accessory.
Digital Multimeters (DMMs)

• The **digital multimeter** has become a very popular test instrument.

• The digital value of the measurement is displayed automatically with decimal point, polarity, and the unit for V, A, or Ω.
Digital Multimeters (DMMs)

- Digital multimeters are generally easier to use.

- They eliminate the human error that often occurs in reading different scales on an analog meter with a pointer.
• **Table 8-4** (next slide) summarizes the main points to remember when using a voltmeter, ohmmeter, or milliampmeter.
# Meter Applications

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<td>Has internal series</td>
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How to insert a current meter in different parts of a series-parallel circuit to read the desired current $I$. At point A, B, or C the meter reads $I_T$; at D or E the meter reads $I_2$; at F or G the meter reads $I_3$. 
With 15 V measured across a known $R$ of 15 $\Omega$, the $I$ can be calculated as $V/R$ or $15 \text{ V} / 15 \text{ $\Omega$} = 1 \text{ A.}$
Voltage tests to localize an open circuit. (a) Normal circuit with voltages to chassis ground. (b) Reading of 0 V at point D shows $R_3$ is open.
Checking Continuity with the Ohmmeter

• The ohmmeter is a great tool for checking the continuity between two points.

• When checking for continuity, make sure the ohmmeter is set on the lowest ohms range.

• If continuity exists between two points, the ohmmeter will read a very low resistance such as zero ohms.

• If there is no continuity between two points, the ohmmeter will read infinite ohms.
Checking Continuity with the Ohmmeter

Continuity testing from point A to wire 3 shows this wire is connected.
Checking Continuity with the Ohmmeter

Temporary short circuit at one end of a long two-wire line to check continuity from the opposite end.