BENHA UNIVERSITY
FACULTY OF ENGINEERING (SHOUBRA)
ELECTRONICS AND COMMUNICATIONS ENGINEERING

CCE 304

Measurements and Instrumentations

(2022 - 2023) term 231

Lecture 4: Electromechanical Instruments (part3).

Dr. Ahmed Samir
https://bu.edu.eg/staff/ahmedsaied

Chapter Outline:

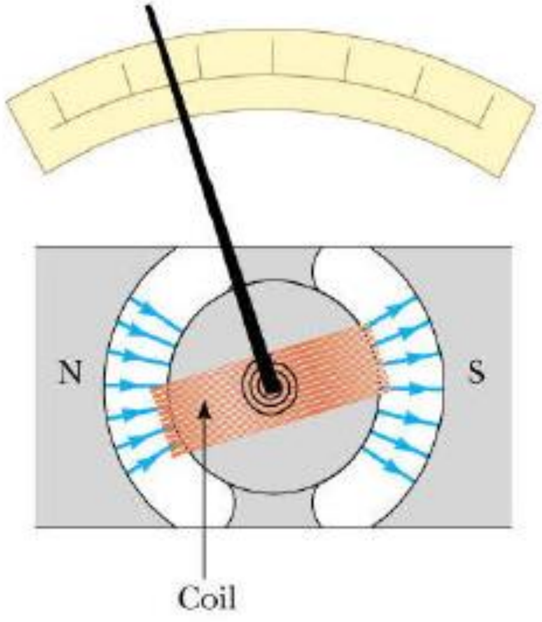
1) **Permanent Magnet Moving Coil (PMMC).**
2) **Galvanometer.**
3) **DC Ammeters**
4) **DC Voltmeters**
5) **Ohmmeters**
6) **AC Voltmeters**
7) **AC Ammeters**

3.6 AC Voltmeter:

Introduction:

PMMC as AC instrument:

- When an alternating current with **a very low frequency 0.1 Hz)** is passed through a PMMC, the **pointer will follow the instantaneous level** of the ac signal.
- Since the PMMC is polarized, **the pointer will move when ac goes positive only** and will stop when ac goes negative.
- With higher frequencies, the PMMC will **not be able to follow** the changing ac level and the pointer will stop on the **average level** (zero for pure sinusoidal wave).
- So, a modification has to be done on PMMC to measure alternating current and voltage.



Construction of PMMC

3.6 AC Voltmeter:

[1] Full-Wave Rectifier Voltmeter:

- Four diodes rectifiers are added to the PMMC to convert the AC signal into a series of uni-directional current pulses that pass through the PMMC instrument to cause positive deflection.
- **On positive half cycle:** Diodes **D1** and **D4** conduct and the current flows through the PMMC meter from top to bottom.
- **On negative half cycle**: Diodes **D2** and **D3** to conduct causing the current to flow again through the meter in the same direction.
- The multiplier resistance Rs is connected to allow higher voltage to the meter in the same way as in the case of DC voltmeter.

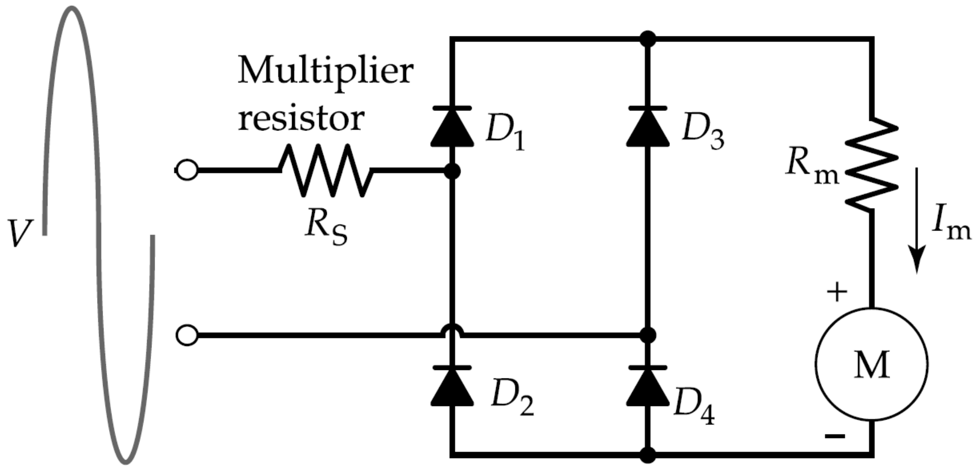
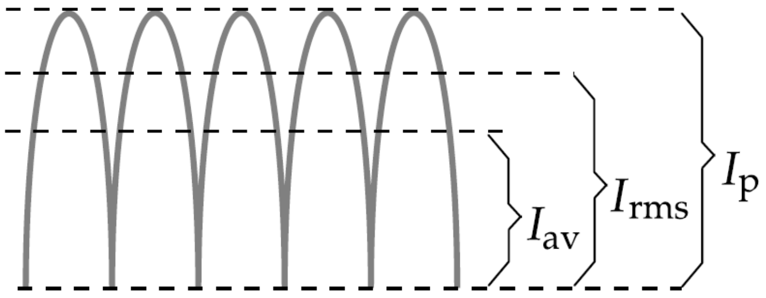


Figure 4-7 An ac voltmeter may be constructed of a PMMC instrument, a multiplier resistor, and a full-wave bridge rectifier.

3.6 AC Voltmeter:

[1] Full-Wave Rectifier Voltmeter:

- The rectifier meter will deflect in proportional to the average value of the current (0.637 peak current).
- However, the meter must indicate the RMS value, (that is, 0.707 peak value) of the voltage.
- Therefore, the linear scale of the meter can be calibrated accordingly to indicate the RMS value (1.11 average value).
- Limitation: The diodes drop will limit the measurement of low levels of AC signals.



Example 3.9

A PMMC instrument with FSD = 100 μA and R_m = 1 kΩ is to be employed as an ac voltmeter with FSD = 100 V (rms). Silicon diodes are used in the bridge rectifier circuit of Figure 3-17. Calculate the multiplier resistance value required.

Solution

At FSD, the average current flowing through the PMMC instrument is

$$I_{av} = 100\ \mu A$$

$$\textit{peak current}\ I_m = \frac{I_{av}}{0.637} = \frac{100\ \mu A}{0.637} \simeq 157\ \mu A$$

$$I_m = \frac{(\text{applied peak voltage}) - (\text{rectifier volt drop})}{\text{total circuit resistance}}$$

$$\textit{rectifier volt drops} = 2V_F\ (\text{for } D_1 \text{ and } D_4 \text{ or } D_2 \text{ and } D_3)$$

$$\textit{applied peak voltage} = 1.414V_{rms}$$

$$\textit{total circuit resistance} = R_s + R_m$$

$$I_m = \frac{1.414V_{rms} - 2V_F}{R_s + R_m}$$

$$R_s = \frac{1.414V_{rms} - 2V_F}{I_m} - R_m$$

$$= \frac{(1.414 \times 100\ V) - (2 \times 0.7\ V)}{157\ \mu A} - 1\ k\Omega$$

$$= 890.7\ k\Omega$$

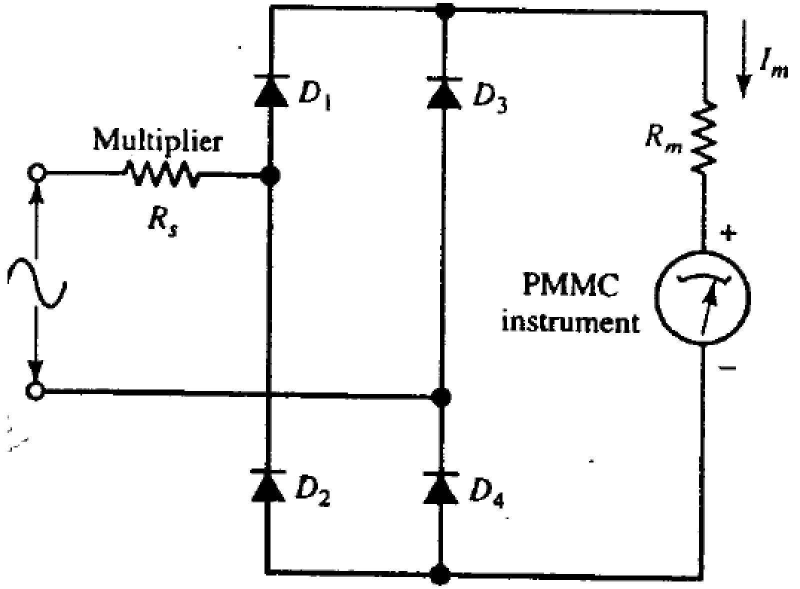


Fig. 3-17

Example 3.10:

- Calculate the pointer indications for the voltmeter in the previous example, when the rms input voltage is: (a) 75 V and (b) 50 V

Solution

(a)

$$I_{av} = 0.637 I_m = 0.637\left(\frac{1.414 V_{rms} - 2V_F}{R_s + R_m}\right)$$

$$= 0.637\left[\frac{(1.414 \times 75\text{ V}) - (2 \times 0.7\text{ V})}{890.7\text{ k}\Omega + 1\text{ k}\Omega}\right]$$

$$\simeq 75\ \mu\text{A} = 0.75\text{ FSD}$$

(b)

$$I_{av} = 0.637\left[\frac{(1.414 \times 50\text{ V}) - (2 \times 0.7\text{ V})}{890.7\text{ k}\Omega + 1\text{ k}\Omega}\right]$$

$$\simeq 50\ \mu\text{A} = 0.5\text{ FSD}$$

The previous two examples demonstrate that:
100V rms at Full scale, 75V rms at 0.75 FSD and 50V rms at 0.5 FSD.
Then, the instrument has a linear scale

3.6 AC Voltmeter:
[2] Half-Wave Rectifier Voltmeter:

- D1 is used to rectify the ac signal into the PMMC.
- On positive half cycle: Diodes D1 conducts and the current flows through the PMMC.
- On negative half cycle: Diodes D1 is OFF and no current flows.

- RSH is added in parallel to increase the current in diode D1 when a positive half-wave appears at the input (to operate in the linear region of the diode).
- D2 is added to protect the meter against any reverse voltages.
- The rectifier meter will deflect in proportional to the average value of the current (0.5 * 0.637 *peak current).

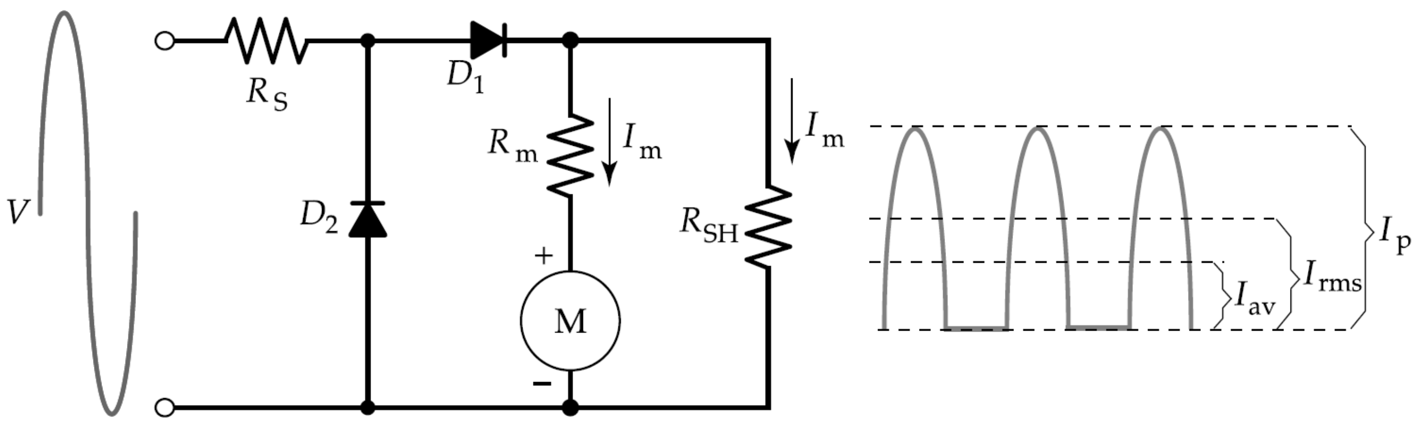


Figure 4-8 Half-wave rectification may be used with a PMMC instrument and a multiplier resistor for ac voltage measurements. A shunt resistor (R_{SH}) is included to ensure a satisfactory rectifier forward current level. The additional rectifier (D_2) minimizes reverse leakage current through D_1.

Example 3.11:

A PMMC instrument with FSD = 50 μA and R_m = 1700 Ω is used in the half-wave rectifier voltmeter circuit illustrated in Figure 3-18. The silicon diode (D_1) must have a minimum (peak) forward current of 100 μA when the measured voltage is 20% of FSD. The voltmeter is to indicate 50 V rms at full scale. Calculate the values of R_s and R_{SH}.

Solution At FSD, I_{av}=50 μA

Meter peak current: $\mathbf{I_m = \pi I_{av} = \pi(50\ \mu A) = 157\ \mu A}$

At 20% of FSD, *diode peak current I_F must be at least 100* μA; *therefore, at 100% of* FSD,

$$I_{F(\text{peak})} = \frac{100\%}{20\%} \times 100\ \mu\text{A} = 500\ \mu\text{A}$$

$$I_{F(\text{peak})} = I_m + I_{SH}$$

$$I_{SH(\text{peak})} = I_{F(\text{peak})} - I_m$$

$$= 500\ \mu\text{A} - 157\ \mu\text{A} = 343\ \mu\text{A}$$

$$V_{m(\text{peak})} = I_m R_m = 157\ \mu\text{A} \times 1700\ \Omega$$

$$= 266.9\ \text{mV}$$

$$R_{SH} = \frac{V_{m(\text{peak})}}{I_{SH(\text{peak})}} = \frac{266.9\ \text{mV}}{343\ \mu\text{A}} = 778\ \Omega$$

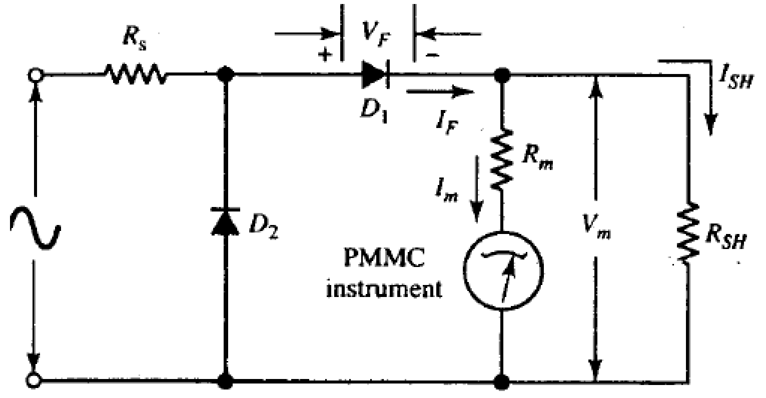


Fig. 3-18

Solution (Cont.)

$$I_{F(\text{peak})} = \frac{(\text{applied peak voltage}) - V_{m(\text{peak})} - V_F}{R_s}$$

$$I_{F(\text{peak})} = \frac{1.414V_{\text{rms}} - V_{m(\text{peak})} - V_F}{R_s}$$

$$R_s = \frac{1.414V_{\text{rms}} - V_{m(\text{peak})} - V_F}{I_{F(\text{peak})}}$$

$$= \frac{(1.414 \times 50\ \text{V}) - 266.9\ \text{mV} - 0.7\ \text{V}}{500\ \mu\text{A}}$$

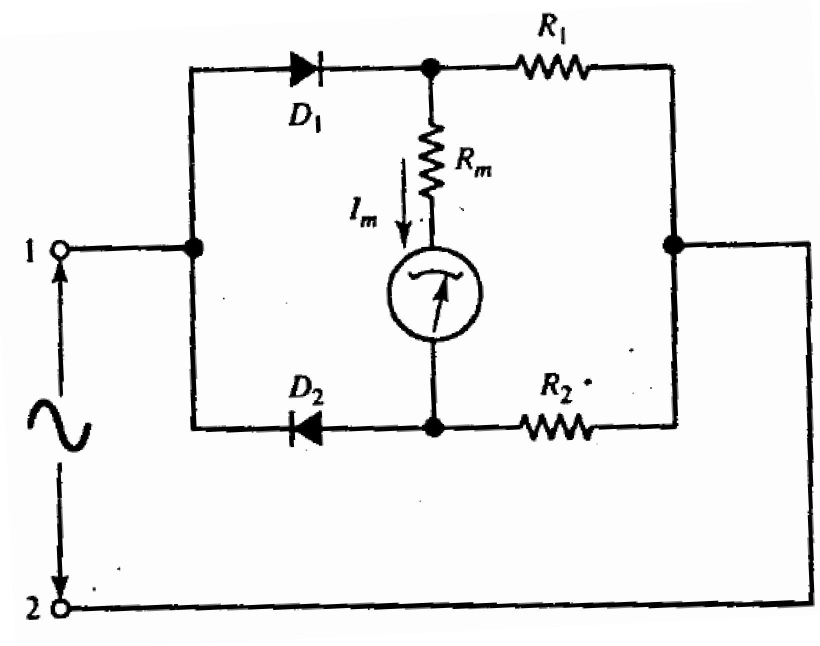
$$= 139.5\ \text{k}\Omega$$

3.6 AC Voltmeter:

[3] Half-bridge full-wave rectifier Voltmeter

- Two diodes and two resistors are used instead of the four diodes used in a full-wave bridge rectifier.
- During the positive half-cycle, D1 is forward and D2 is reverse. Current flows from terminal 1 through D1 and the meter, and then through R2 to terminal 2
- R1 is in parallel with the meter and R2.

- During the negative half-cycle, D2 is forward biased and D1 is reverse biased. Current now flows from terminal 2 through R1 and the meter, and through D2 to terminal 1.
- R2 is in parallel with the series-connected meter and R1.



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3.7 AC Ammeter:

- The requirement of the AC ammeter is to have very low resistance which implies that a very low (typically less than 100 mV) voltage drop.
- Thus, a rectifier PMMC circuit is not suitable to directly measure AC currents.
- A step-up transformer is used to measure AC current:

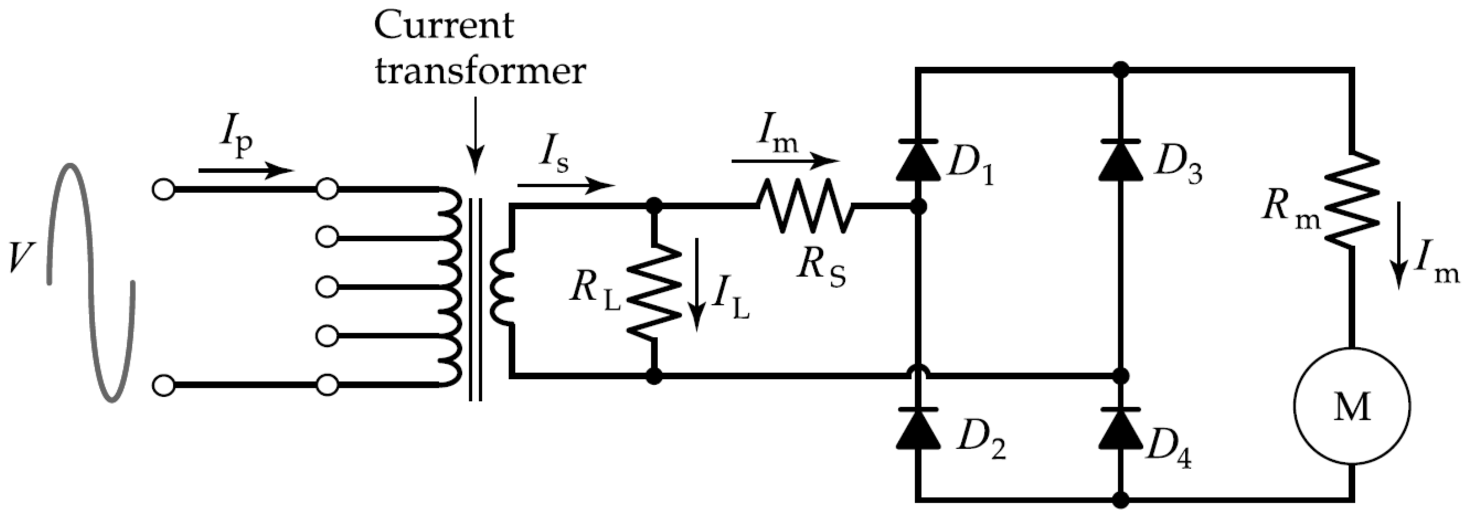
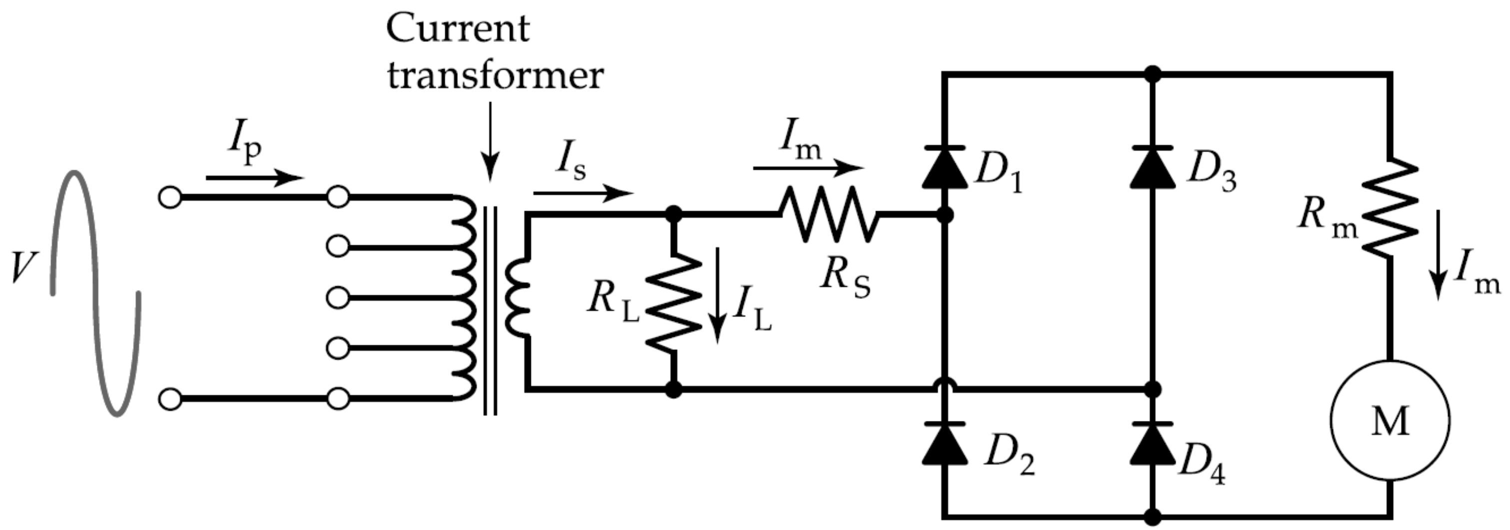


Figure 4-10 Ac ammeter circuit consisting of a current transformer, full-wave bridge rectifier, and a PMMC instrument.

3.7 AC Ammeter:



- Using a current transformer with a rectifier instrument provides a very low terminal resistance and low voltage drop.
- In step-up transformer, the input voltage gets stepped up so that sufficient voltage can be provided for rectifier operation.
- Since the transformer is used in an ammeter circuit, the current transformation ratio $I_P/I_S = N_S/N_P$ is very important.
- A multi-range AC ammeter could be provided by changing the number of primary turns in the transformer or using different values of load resistance (R_L)

Example 3.12:

A rectifier ammeter with the circuit shown is to give FSD for a primary current of 250 mA (rms). The PMMC meter has FSD = I mA and R_m = 1700 Ω The current transformer has N_S = 500 and N_P = 4. The diodes each have V_F = 0.7 V, and the series resistance is R_S = 20 kΩ ***Calculate*** the required value of R_L.

Solution:

Peak meter current $I_m = \dfrac{I_{av}}{0.637} = \dfrac{1\text{ mA}}{0.637}$

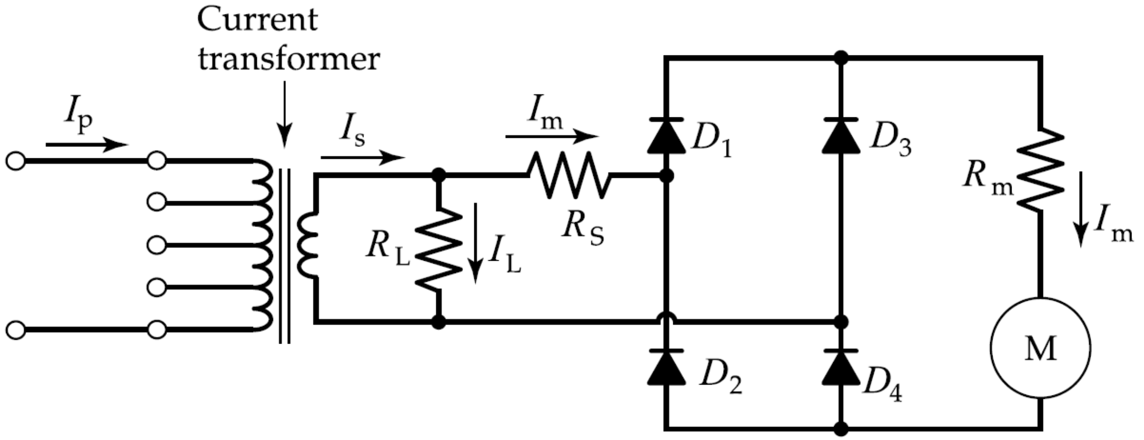
$= 1.57\text{ mA}$

Transformer secondary peak voltage,

$E_m \doteq I_m(R_s + R_m) + 2V_F$

$= 1.57\text{ mA }(20\text{ k}\Omega + 1700\ \Omega) + 1.4\text{ V}$

$\simeq 35.5\text{ V}$



or secondary voltage $E_s = (0.707 \times 35.5\text{ V})\text{ rms}$

$\simeq 25.1\text{ V}$

and *rms meter current* $= 1.11\ I_{av}$

$= 1.11\text{ mA}$

Solution (Cont.)

Transformer rms secondary current,

$$I_s = I_p \frac{N_p}{N_s}$$

$$= 250 \text{ mA} \times \frac{4}{500} = 2 \text{ mA}$$

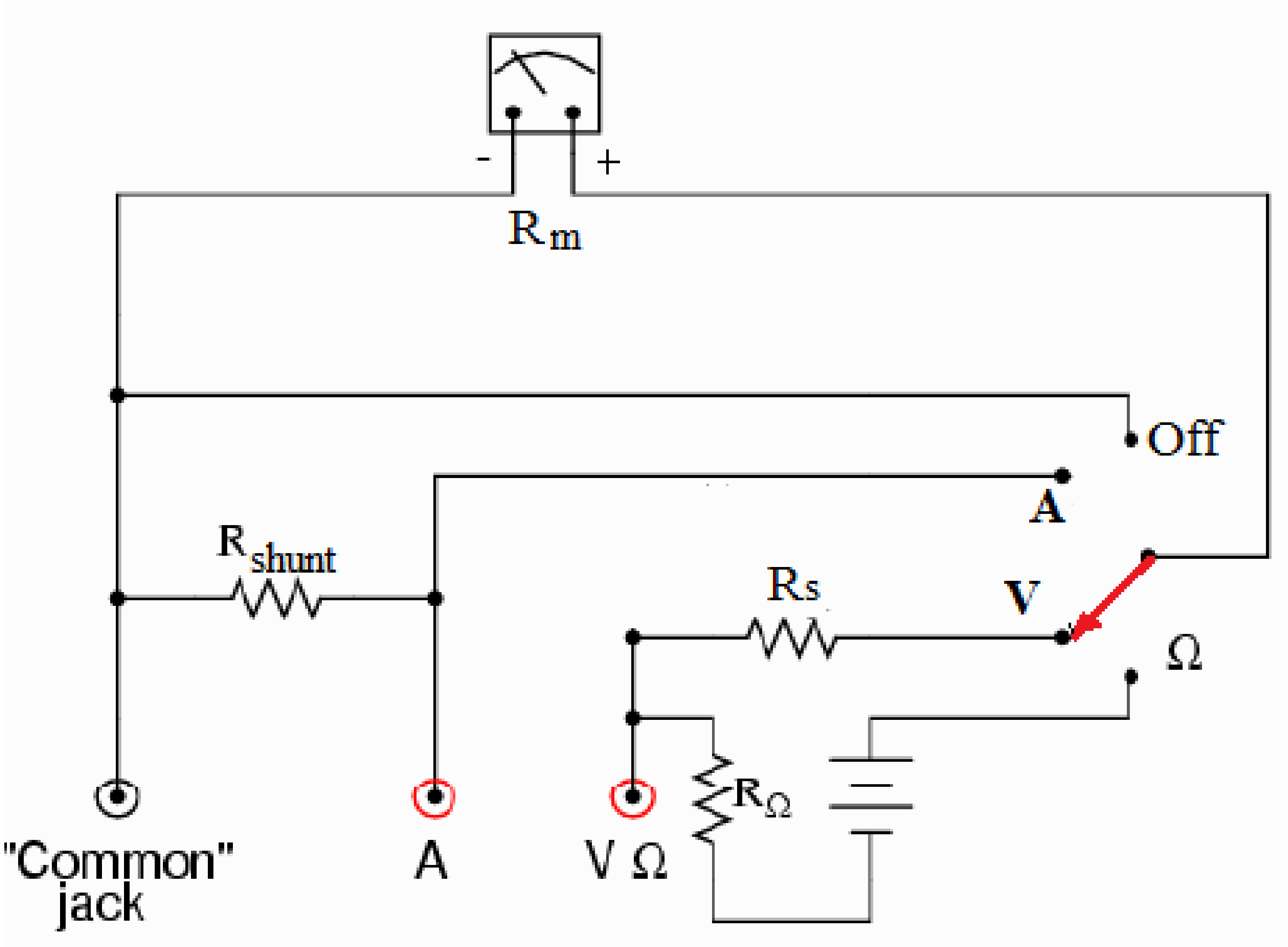
$$I_L = I_s - I_m$$

$$= 2 \text{ mA} - 1.11 \text{ mA} = 0.89 \text{ mA}$$

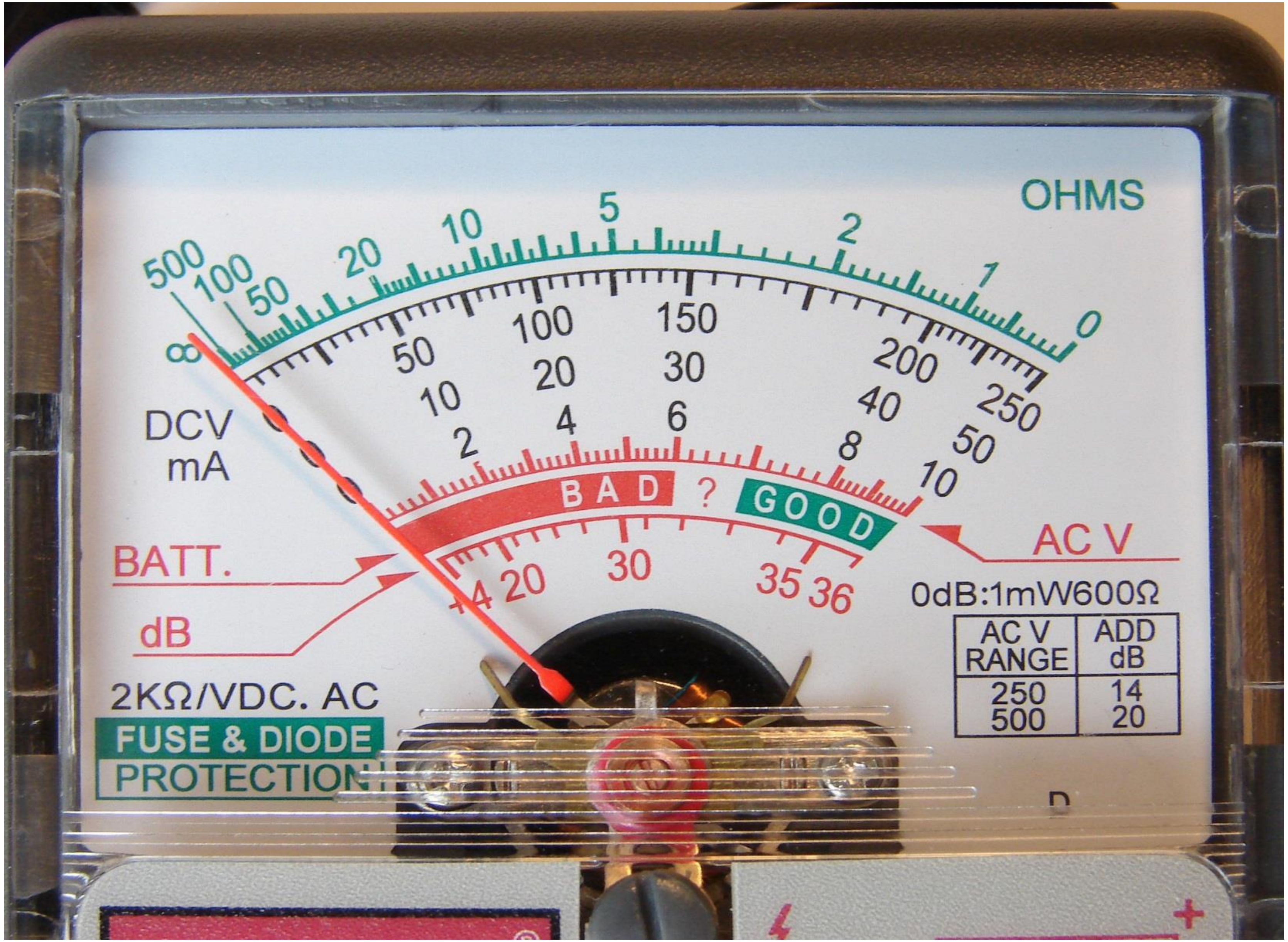
$$R_L = \frac{E_s}{I_L} = \frac{25.1 \text{ V}}{0.89 \text{ mA}}$$

$$= 28.2 \text{ k}\Omega$$

Analogue Multi-meter circuit



Scale of ohm, volt and ampere in analogue multi-meter



END OF LECTURE

BEST WISHES