Benha University
Faculty of Engineering (Shoubra)
Electronics and Communications Engineering

ECE 211
Electrical and Electronic Measurements
(2020-2021)

Lecture 6&7: Analog Electronic Voltmeters and Digital Voltmeters (DVM)

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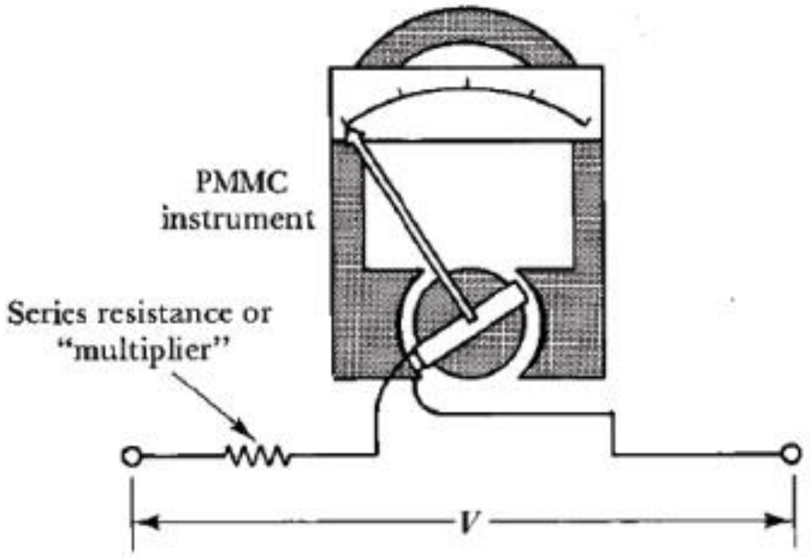
Electronics Voltmeter Outline:

1. Introduction.
2. Transistor Voltmeter Circuits.
3. Operational Amplifier Voltmeter Circuits.
4. AC Electronic Voltmeters.
5. Multimeter Probes.

Introduction:

- The electromechanical instruments have some limitations: as having low resistance (loading effect) and cannot measure very low voltages.
- The low input voltages need to be amplified to measurable levels and electronic circuits are required to offer high input resistance.
- Electronic circuits voltmeters with transistors, operational amplifiers (or op-amp) can be used to amplify small voltage and provide high input resistance .
- These analog circuits include:
    1. Emitter-Follower Voltmeter.
    2. FET-input Voltmeter.



Transistor Voltmeter Circuits.

Emitter-Follower Voltmeter:

A BJT emitter follower is used where the PMMC and R_s are connected to the Emitter.

The voltage to be measured, that is, E, is connected to the base of the transistor.

The base current, I_b is:

$$I_b = \frac{I_m}{\beta}, \qquad \beta : (\text{Transistor gain})$$

The input resistance, R_i is:

$$R_{in} \approx \frac{E}{I_b}$$

which is **much larger** than $R_s + R_m$ since I_b is small.

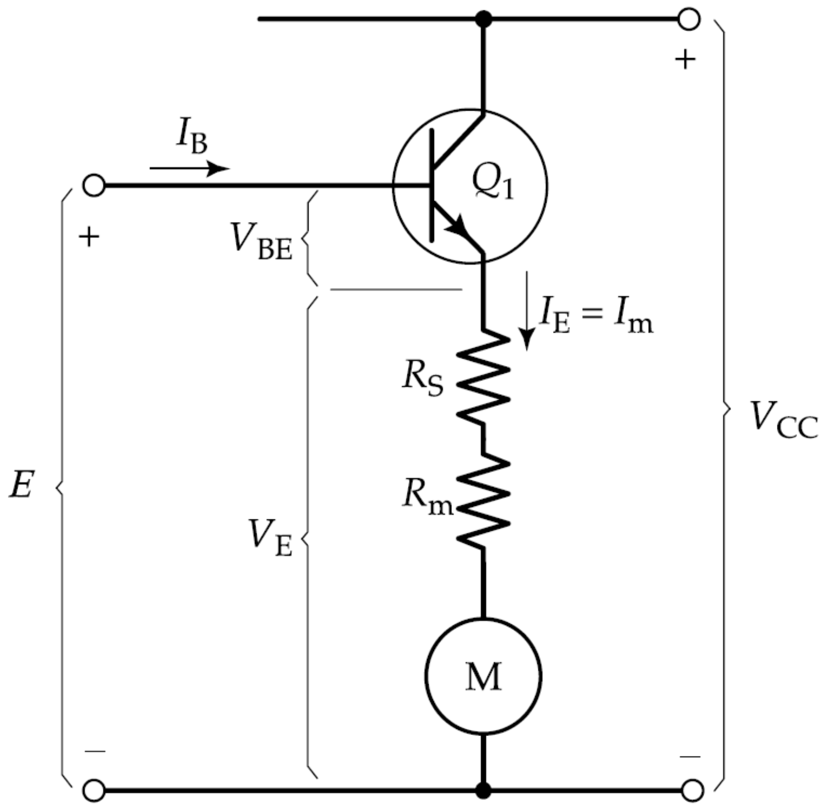
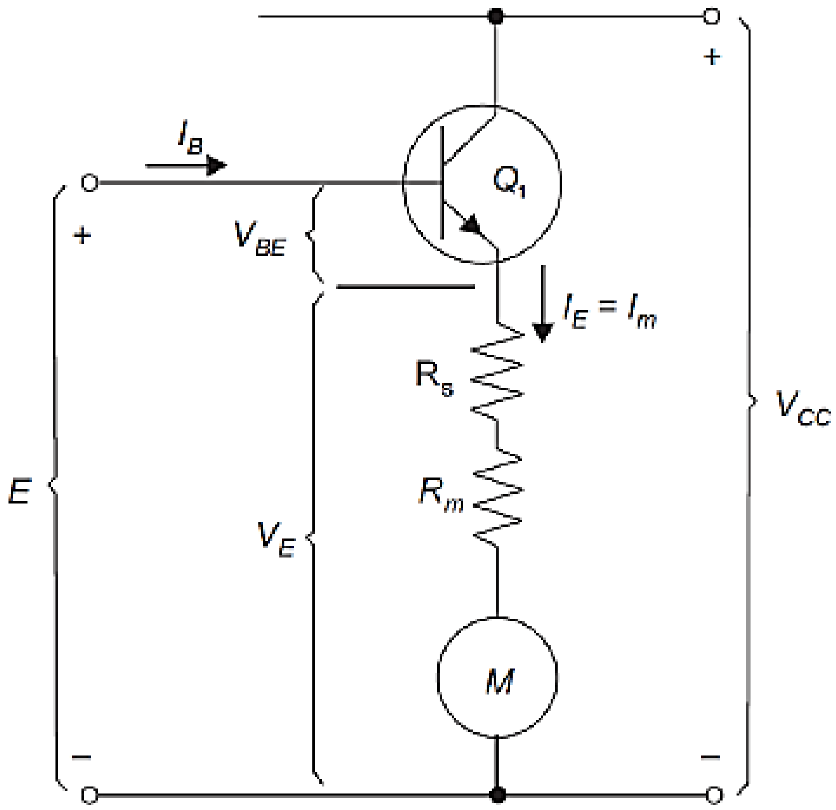


Figure 5-1 Emitter-follower voltmeter. The emitter follower offers a high input resistance to a measured voltage, and a low output resistance to a deflection meter. The base-emitter voltage drop (V_{BE}) introduces an error in the measurement.

Emitter-Follower Voltmeter (Cont.):

Example 1:

A simple emitter-follower voltmeter with: Vcc = 12 V ,
Rm = 2kΩ, 1 mA FSD meter current, and current gain = 50.
Determine :
(a) Appropriate multiplier resistance that can give FSD 5 V.
(b) Input resistance



Solu:

(a)

$$R_s = \frac{V_E}{I_m} - R_m = \frac{E - V_{BE}}{I_m} - R_m = \frac{5 - 0.7}{1\ mA} - 2 = 2.3\ k\Omega$$

(b) $$R_{in} = \frac{E}{I_b} = \beta.\frac{E}{I_m} = 50.\frac{5}{1\ mA} = 250\ k\Omega$$

Example 2:

The simple emitter-follower voltmeter circuit in Figure 4-1 has $V_{CC} = 20$ V, $R_s + R_m = 9.3$ kΩ, $I_m = 1$ mA at full scale, and transistor $h_{FE} = 100$.
(a) Calculate the meter current when $E = 10$ V,
(b) Determine the voltmeter input resistance with and without the transistor.

Solution

(a)

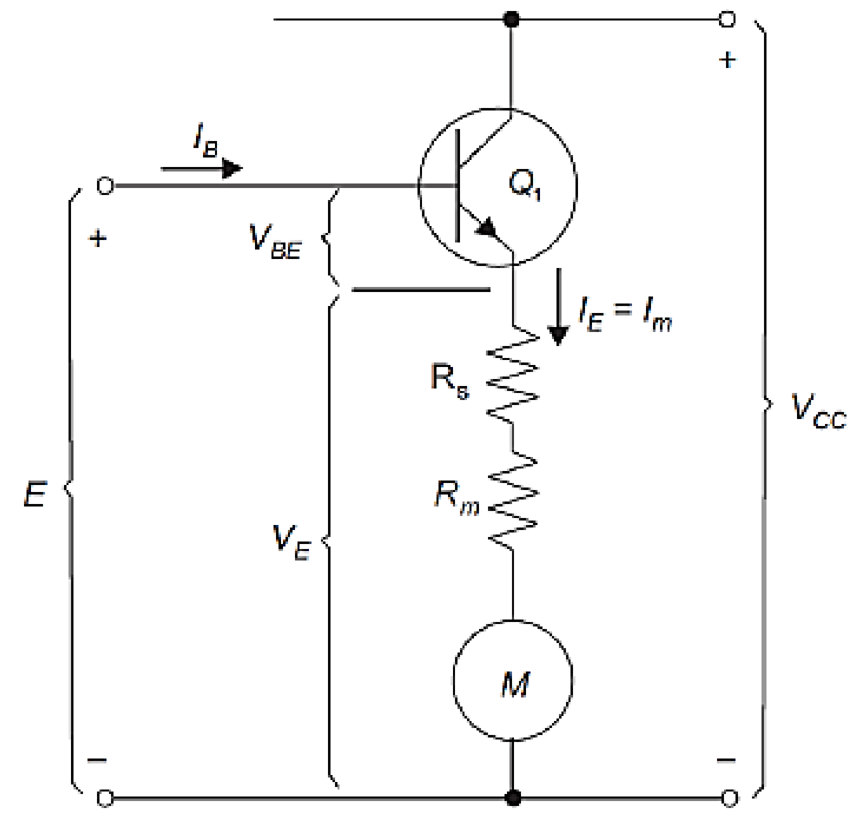
$$V_E = E - V_{BE} = 10\text{ V} - 0.7\text{ V}$$
$$= 9.3\text{ V}$$
$$I_m = \frac{V_E}{R_s + R_m} \approx \frac{9.3\text{ V}}{9.3\text{ k}\Omega}$$
$$= 1\text{ mA}$$

(b) *With the transistor,*

$$I_B \approx \frac{I_m}{h_{FE}} \approx \frac{1\text{ mA}}{100}$$
$$= 10\ \mu\text{A}$$
$$R_i \approx \frac{E}{I_B} \approx \frac{10\text{ V}}{10\ \mu\text{A}}$$
$$= 1\text{ M}\Omega$$

Without the transistor,

$$R_i = R_s + R_m = 9.3\text{ k}\Omega$$



Emitter-Follower Voltmeter (Cont.) :

- To reduce the drop V_{BE}, a one more emitter-follower and a voltage divider are used with a ± 12 V dual polarity supply is connected.
- When E = 0, the resistance R_5 is adjusted to make V_{E2} = 0.7 and V_m = 0.
- When E is exist, the PMMC voltage is:

$$V_m = E - 0.7 - (-0.7) = E$$

- So, the voltage drop is removed.

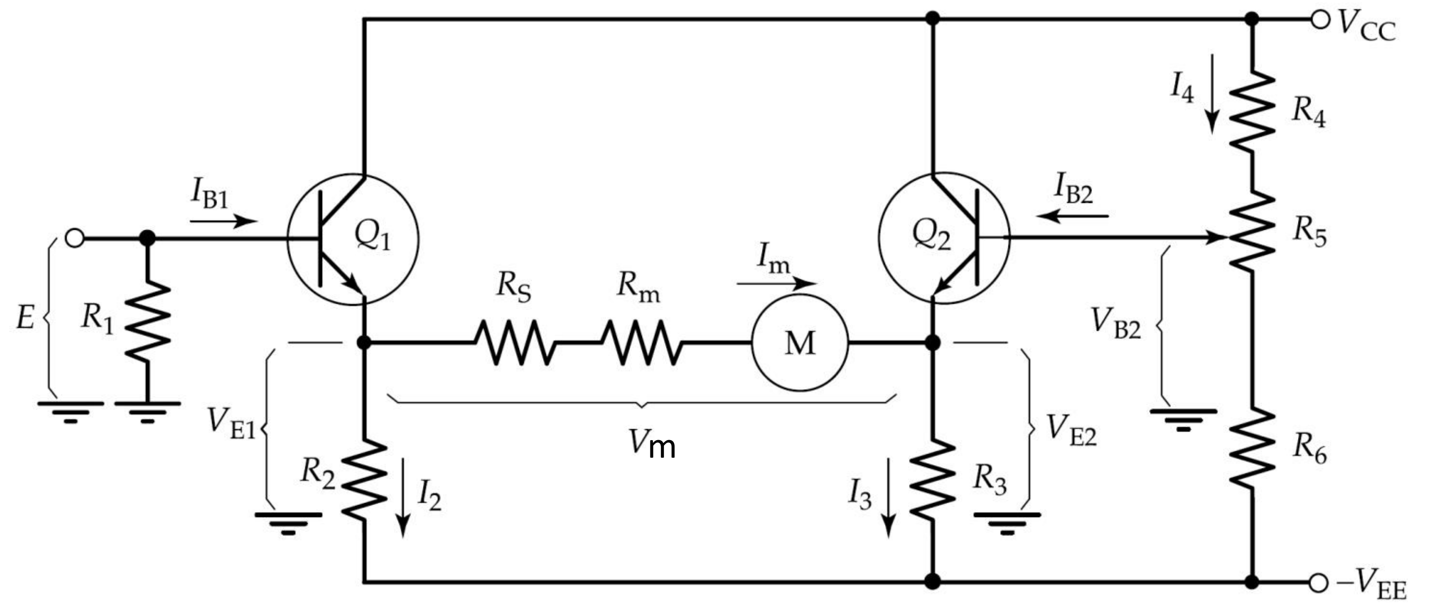


Figure 5-2 Practical emitter-follower voltmeter circuit using a second transistor (Q_2) and a voltage divider (R_4, R_5, and R_6) to eliminate the V_{BE} error introduced by Q_1.

Example 3:

An emitter-follower voltmeter circuit such as that in Figure 4-2 has $R_2 = R_3 = 3.9\ \text{k}\Omega$ and $V_{CC} = \pm 12$ V.

(a) Determine I_2 and I_3 when $E = 0$ V.

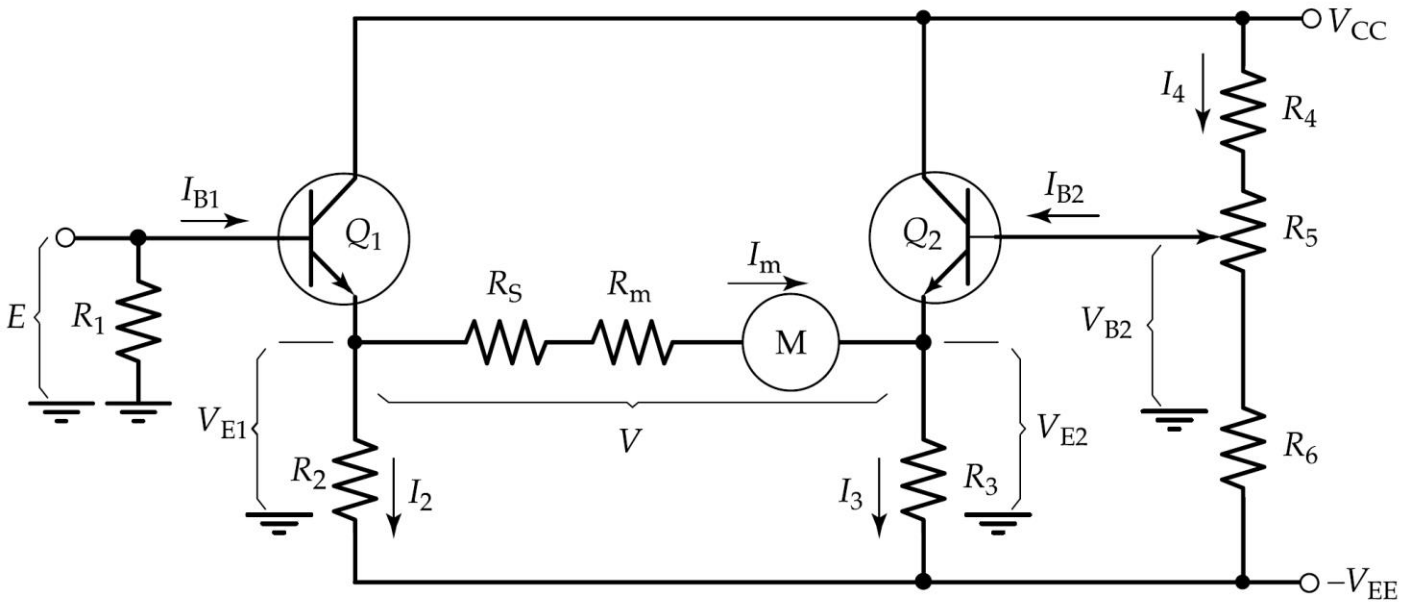
(b) Calculate the meter circuit voltage when $E = 1$ V and when $E = 0.5$ V.

Solution

(a)

$$V_{R2} = V_{R3} = 0\text{ V} - V_{BE} - V_{EE}$$
$$= 0\text{ V} - 0.7\text{ V} - (-12\text{ V})$$
$$= 11.3\text{ V}$$

$$I_2 = I_3 = \frac{V_{R2}}{R_2} = \frac{11.3\text{ V}}{3.9\text{ k}\Omega}$$
$$\approx 2.9\text{ mA}$$



(b) *When* $E = 1$ *V,*

$$V_{E1} = E - V_{BE} = 1\text{ V} - 0.7\text{ V}$$

$$= 0.3\text{ V}$$

$$V_{E2} = V_{B2} - V_{BE} = 0\text{ V} - 0.7\text{ V}$$

$$= -0.7\text{ V}$$

$$V = V_{E1} - V_{E2} = 0.3\text{ V} - (-0.7\text{ V})$$

$$= 1\text{ V}$$

When $E = 0.5$ *V,*

$$V_{E1} = E - V_{BE} = 0.5\text{ V} - 0.7\text{ V}$$

$$= -0.2\text{ V}$$

$$V_{E2} = V_{B2} - V_{BE} = 0\text{ V} - 0.7\text{ V}$$

$$= -0.7\text{ V}$$

$$V = V_{E1} - V_{E2} = -0.2\text{ V} - (-0.7\text{ V})$$

$$= 0.5\text{ V}$$

FET-input Voltmeter:

Advantage:

The Field Effect Transistor (FET) provide extremely high input resistance.

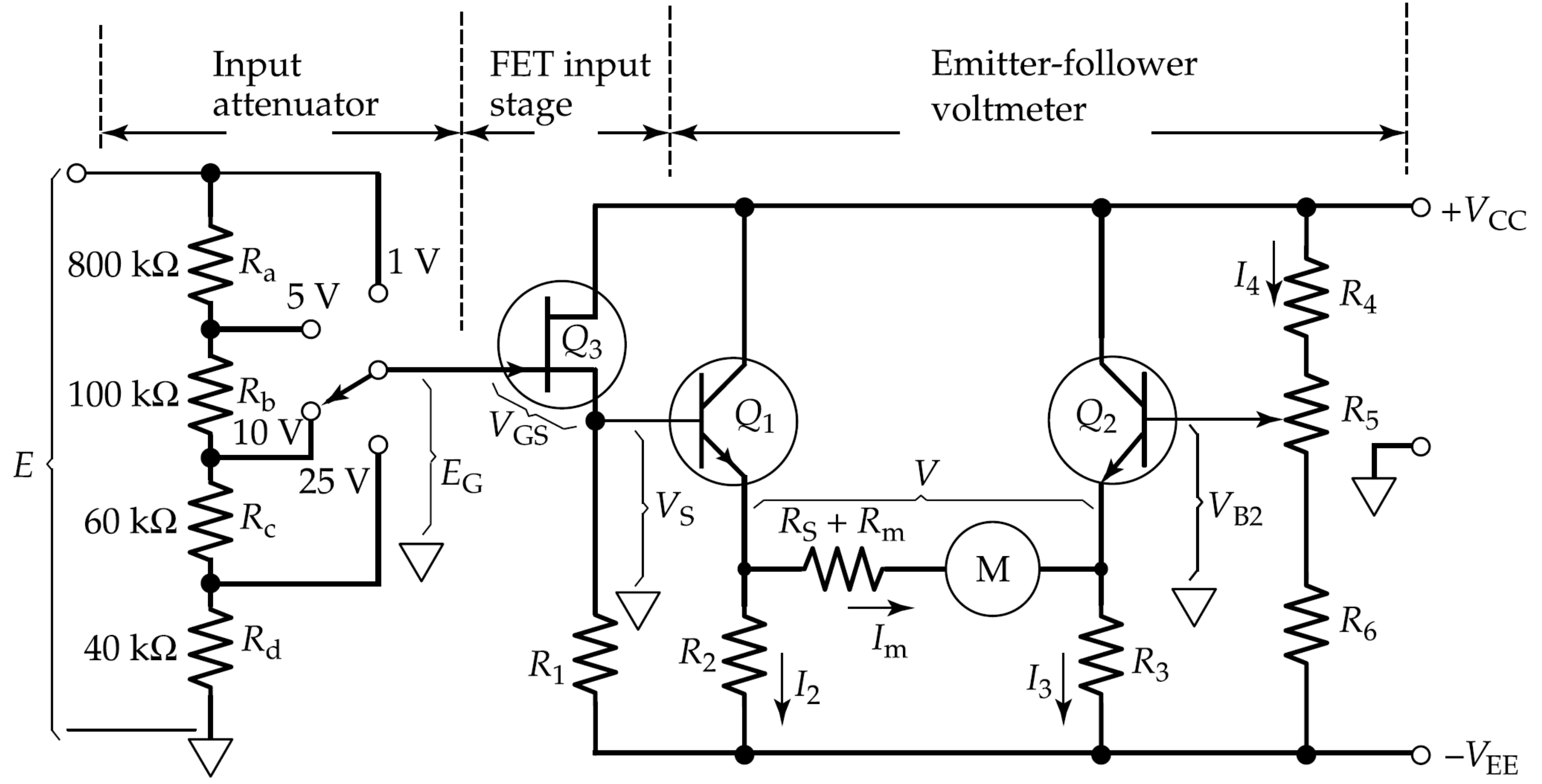


Figure 5-4 A voltmeter input attenuator is simply a voltage divider that accurately divides the voltage to be measured. The FET input stage (Q_3) gives the emitter follower a very high input resistance.

Example 4:

Determine the meter reading for the circuit in Figure 4-4 when $E = 7.5$ V and the meter is set to its 10 V range. The FET gate–source voltage is -5 V, $V_p = +5$ V, $R_s + R_m = 1$ kΩ, and $I_m = 1$ mA at full scale.

Solution *On the 10 V range:*

$$E_G = E\frac{R_c + R_d}{R_a + R_b + R_c + R_d}$$

$$= 7.5\ \text{V} \times \frac{60\ \text{k}\Omega + 40\ \text{k}\Omega}{800\ \text{k}\Omega + 100\ \text{k}\Omega + 60\ \text{k}\Omega + 40\ \text{k}\Omega}$$

$$= 0.75\ \text{V}$$

$$V_S = E_G - V_{GS} = 0.75\ \text{V} - (-5\ \text{V})$$

$$= 5.75\ \text{V}$$

$$V_{E1} = V_S - V_{BE} = 5.75\ \text{V} - 0.7\ \text{V} = 5.05\ \text{V}$$

$$V_{E2} = V_P - V_{BE} = 5\ \text{V} - 0.7\ \text{V}$$

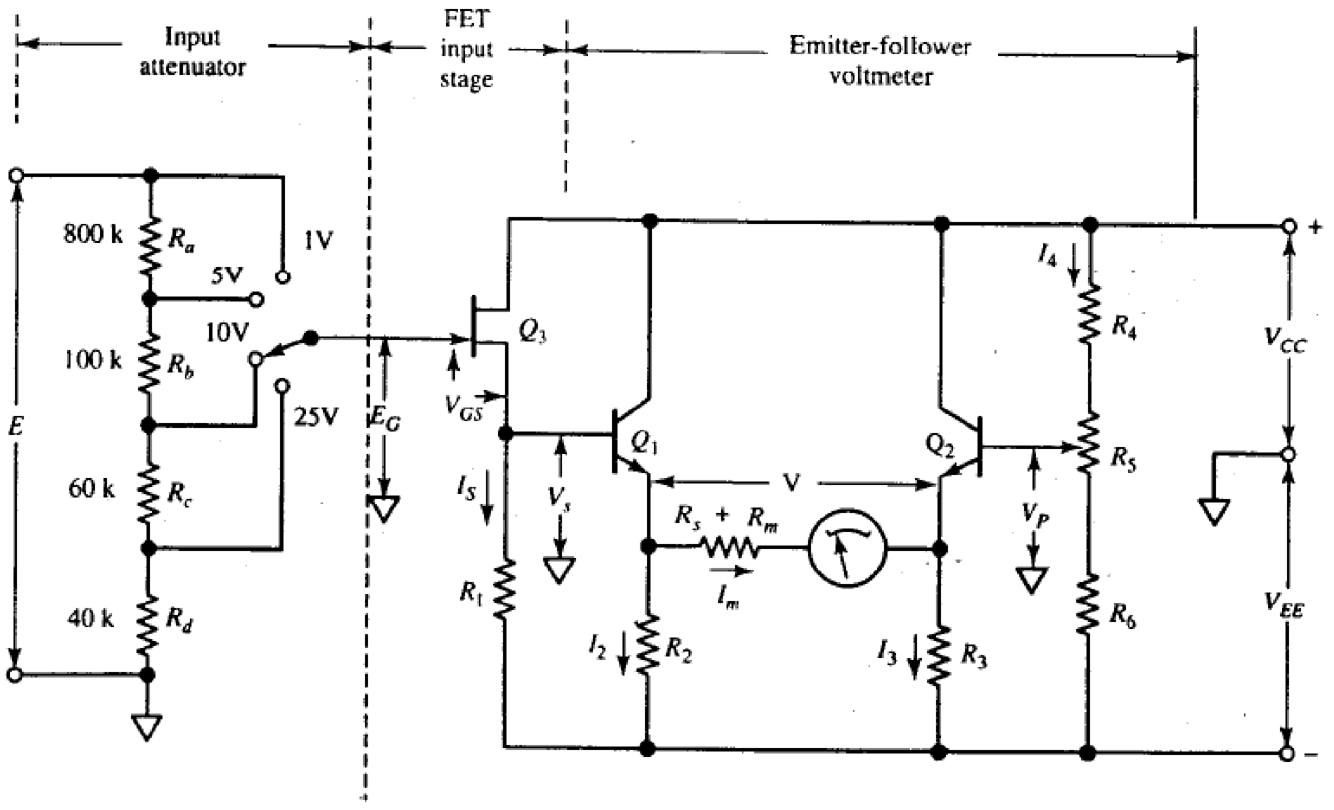
$$= 4.3\ \text{V}$$

$$V = V_{E1} - V_{E2} = 5.05\ \text{V} - 4.3\ \text{V}$$

$$= 0.75\ \text{V} = E_G$$

$$I_m = \frac{V}{R_S + R_m} = \frac{0.75\ \text{V}}{1\ \text{k}\Omega}$$

$$= 0.75\ \text{mA (75\% of full scale)}$$



On the 10 V range, full scale represents 10 V, and 75% of full scale would be read as 7.5 V.

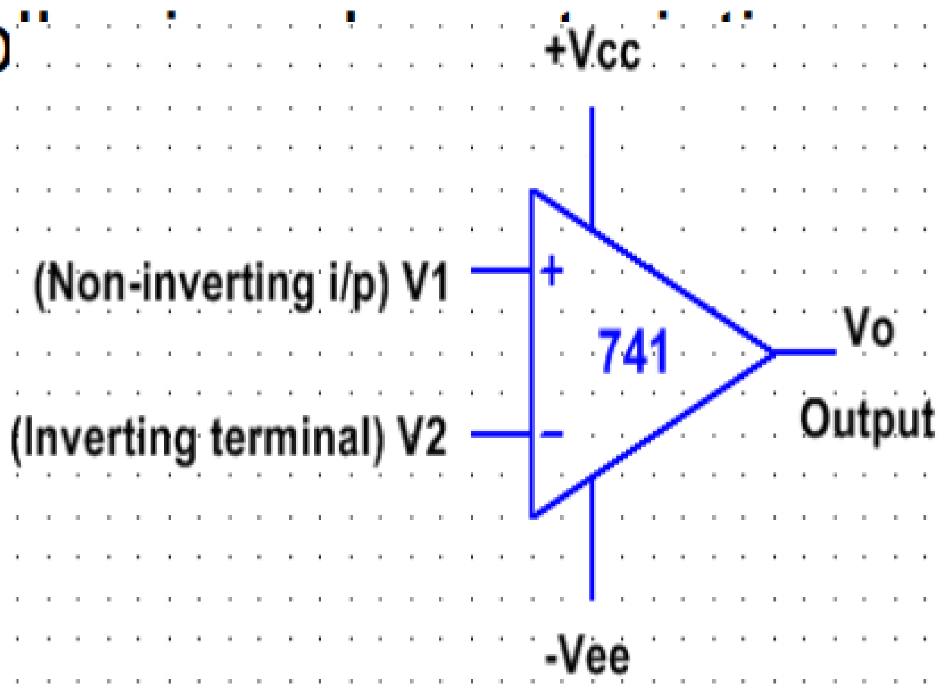
Operational Amplifier Voltmeter Circuits.

Operational Amplifier

The Op. Amp IC is a perfect choice to be used in the electronic voltmeters

- **Ideal Op. Amp** has the fo

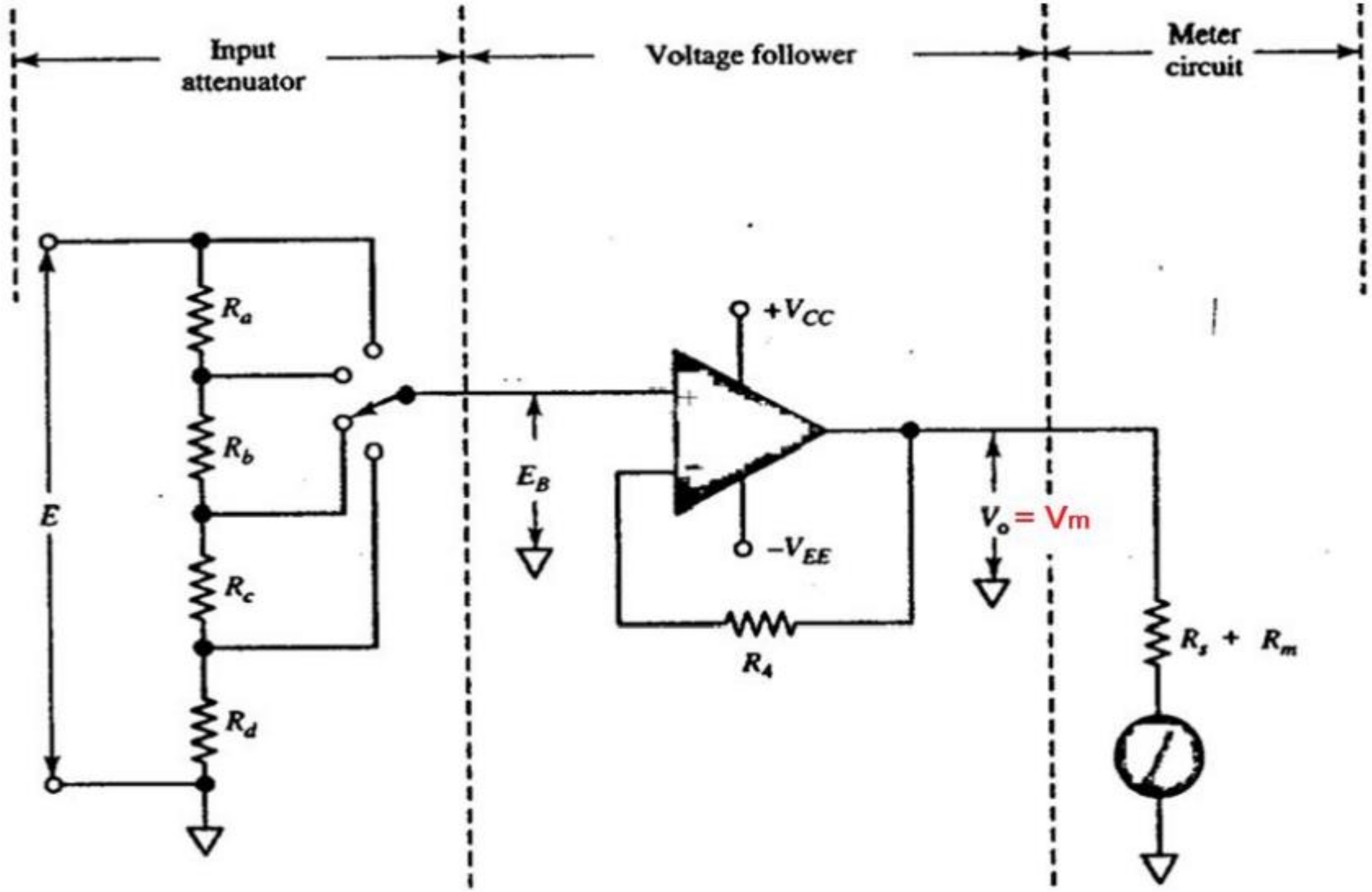
  - $R_{in} = \infty$
  - $R_o = 0$
  - $A_v = \infty$



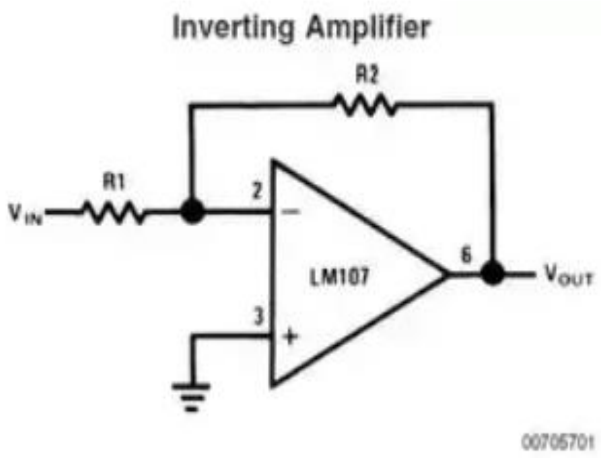
A_v is the open loop voltage gain

Operational Amplifier Voltmeter

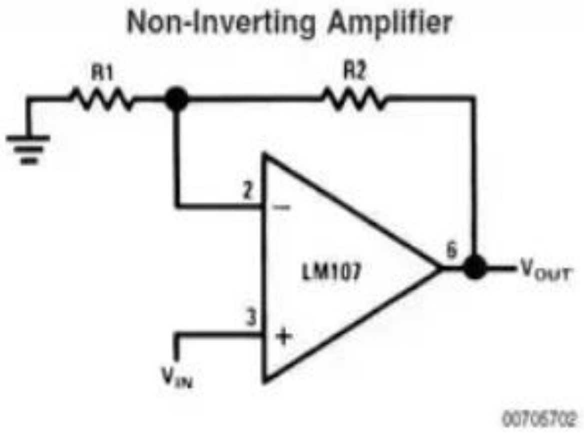
- The voltage follower has a much higher input resistance and lower output resistance than the emitter follower.
- The input voltage is applied to the op-amp noninverting input terminal, and the feedback from the output goes to the inverting input.
- The attenuator selects the voltmeter range.



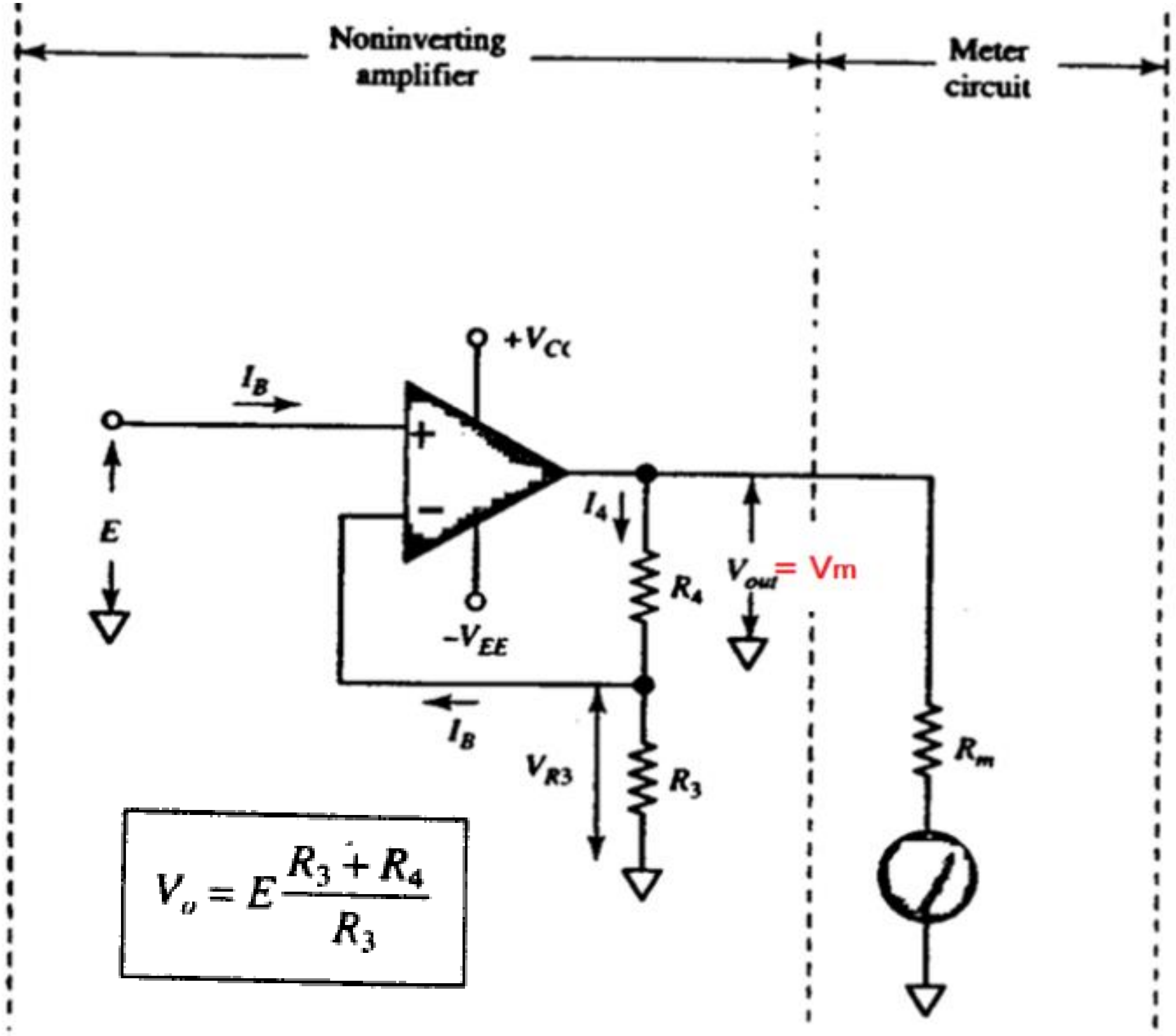
IC Operational Amplifier



$$V_{OUT} = -\frac{R2}{R1} V_{IN}$$



$$V_{OUT} = \frac{R1 + R2}{R1} V_{IN}$$



$$V_o = E\frac{R_3 + R_4}{R_3}$$

An op-amp noninverting amplifier voltmeter is very easily designed. Current I_4 through R_3 and R_4 is first selected very much larger than the op-amp input bias current (I_B). Then the resistors are calculated as

$$R_3 = \frac{E}{I_4} \quad \text{and} \quad R_4 = \frac{V_o - E}{I_4}$$

Example 5:

An op-amp voltmeter circuit as in Figure 4-7 is required to measure a maximum input of 20 mV. The op-amp input current is 0.2 μA, and the meter circuit has I_m = 100 μA FSD and R_m = 10 kΩ. Determine suitable resistance values for R_3 and R_4.

Solution

$$I_4 >> I_B$$

Select

$$I_4 = 1000 \times I_B = 1000 \times 0.2\ \mu A = 0.2\ mA$$

At full scale,

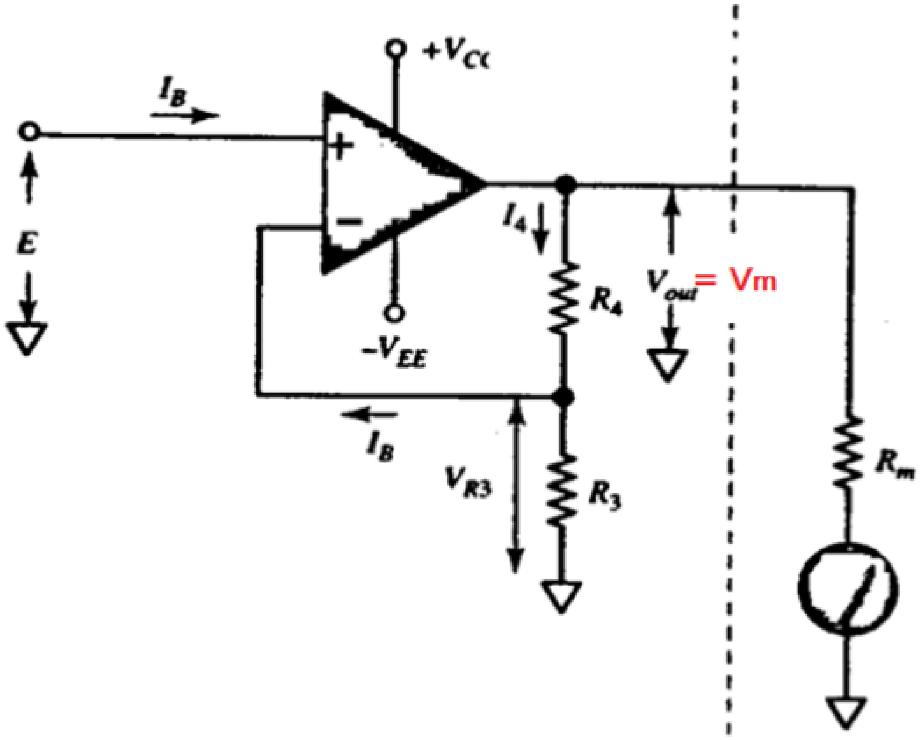
$$I_m = 100\ \mu A$$

and

$$V_{out} = I_m \times R_m = 100\ \mu A \times 10\ k\Omega = 1\ V$$

$$R_3 = \frac{E}{I_4} = \frac{20\ mV}{0.2\ mA} = 100\ \Omega$$

$$R_4 = \frac{V_o - E}{I_4} = \frac{1\ V - 20\ mV}{0.2\ mA} = 4.9\ k\Omega$$



Voltage-to-current converter Voltmeter

$$I_m = I_{R3} = \frac{E}{R_3}$$

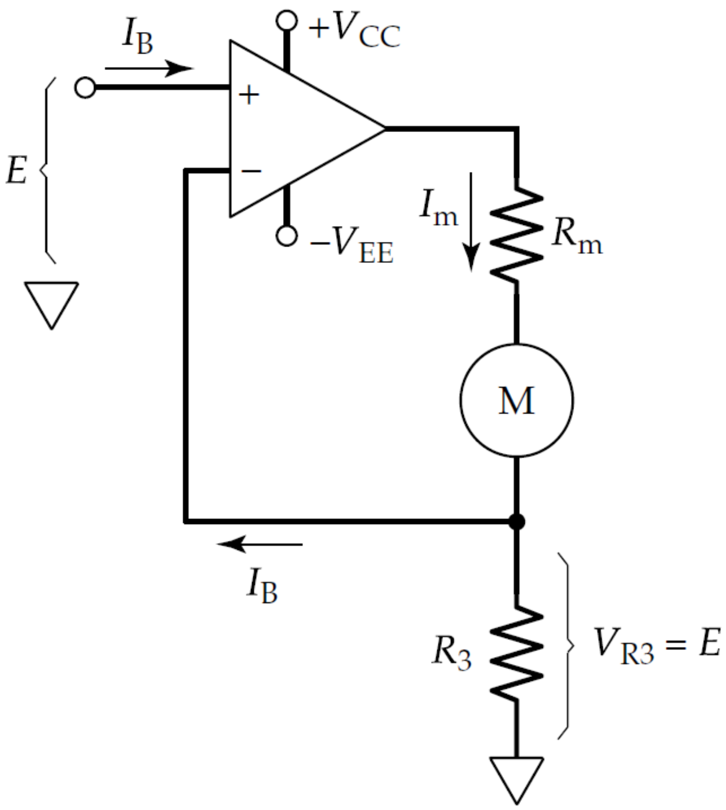
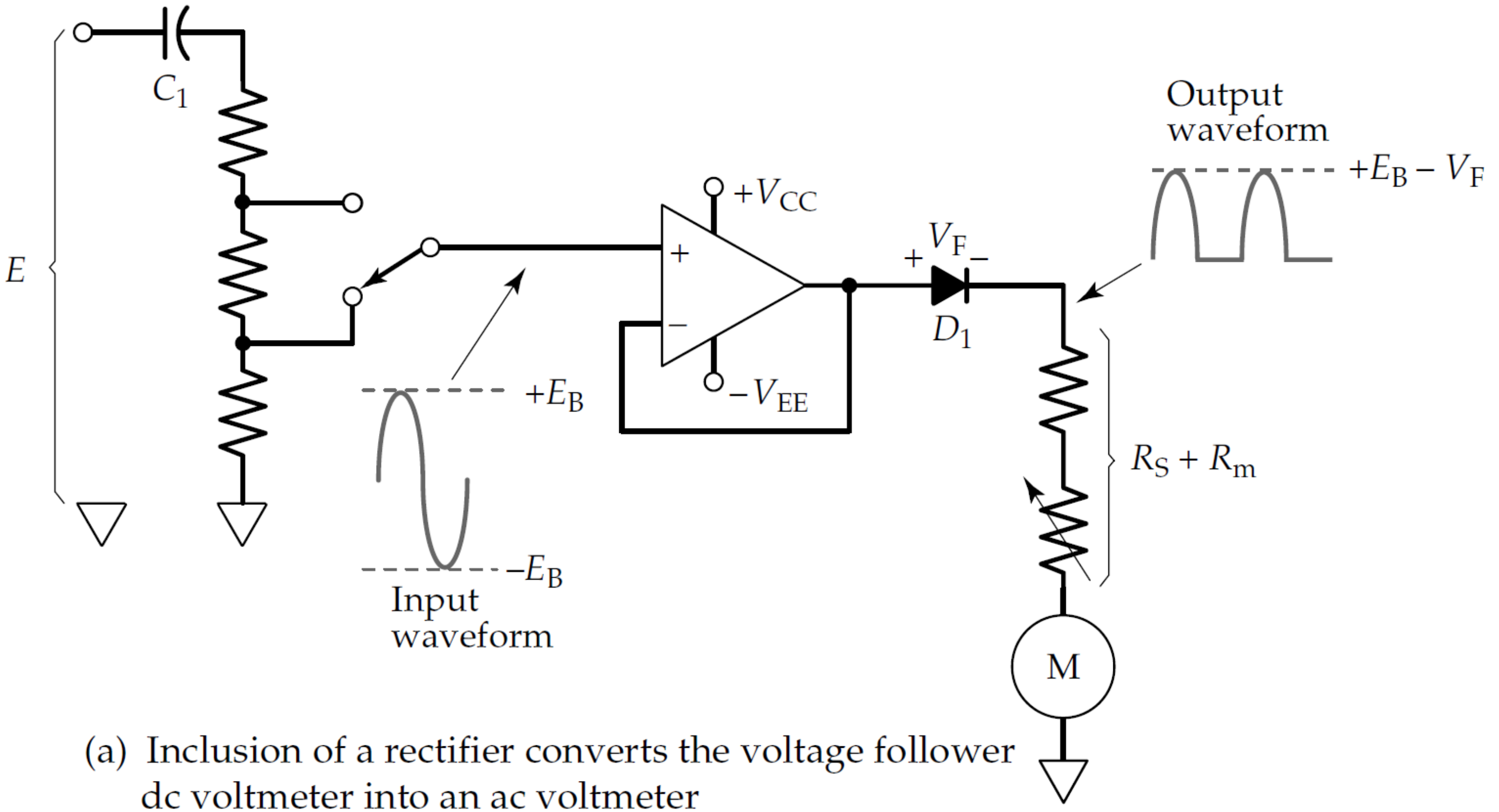


Figure 5-8 Voltmeter circuit using an op-amp voltage-to-current converter. The meter current is E/R_3.

AC Electronic Voltmeters

AC Electronic Voltmeters

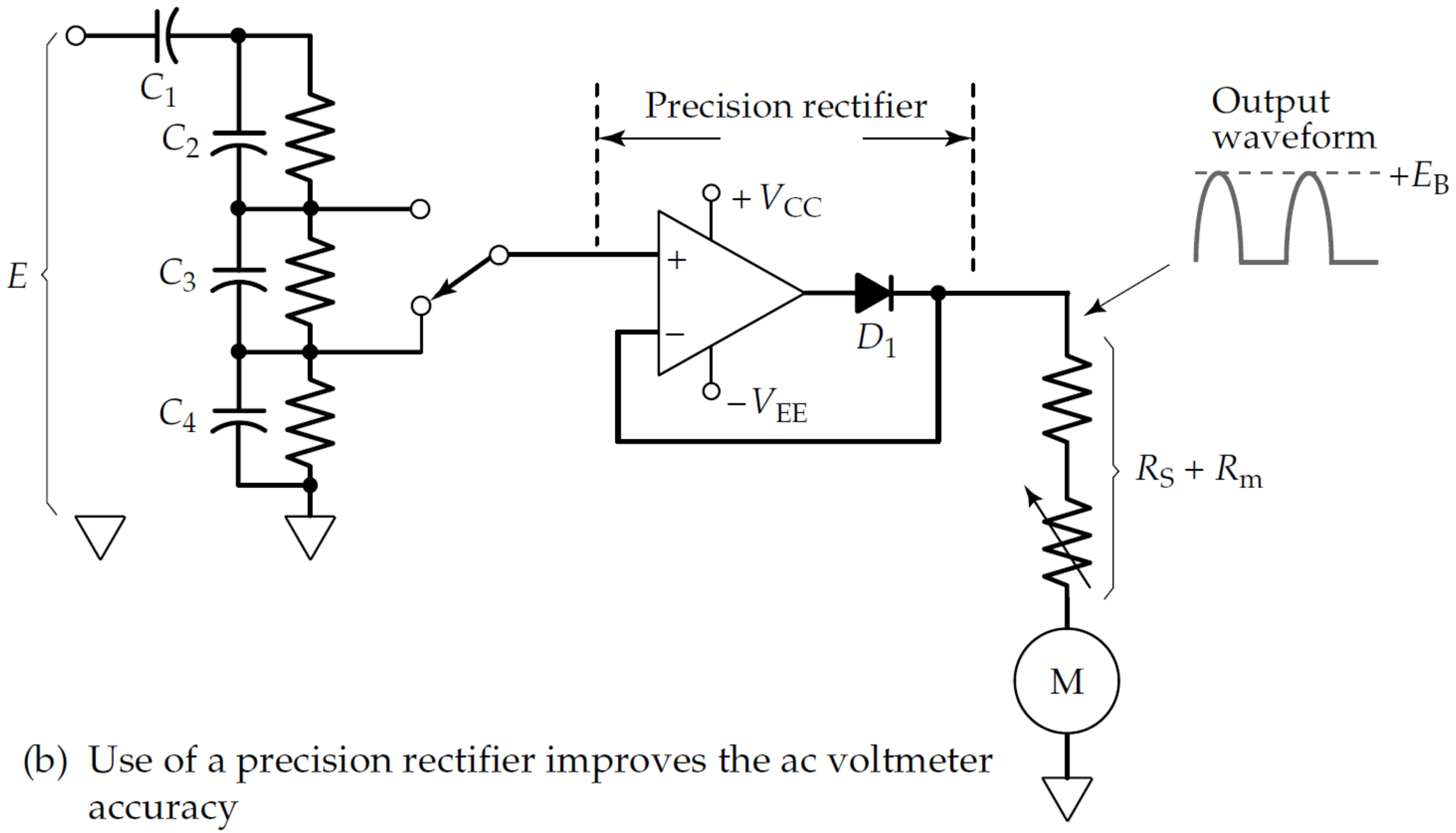
- D_1 is half-wave rectifier
- The coupling capacitor C_1 to block unwanted dc voltage.
- The voltage drop (V_F) across the rectifier is a source of error in the circuit.
- Also, the rectifier voltage drop is not always exactly 0.7 V, as usually assumed for a silicon diode and it varies with temperature change.



(a) Inclusion of a rectifier converts the voltage follower dc voltmeter into an ac voltmeter

AC Electronic Voltmeters (Cont.)

- To avoid these errors, the voltage follower feedback connection to the inverting terminal is taken from the cathode of rectifier D1 instead of from the amplifier output.



(b) Use of a precision rectifier improves the ac voltmeter accuracy

AC Electronic Voltmeters (Cont.)

- The input is amplified by factor

$$A_v = (R_2 + R_3)/R_3.$$

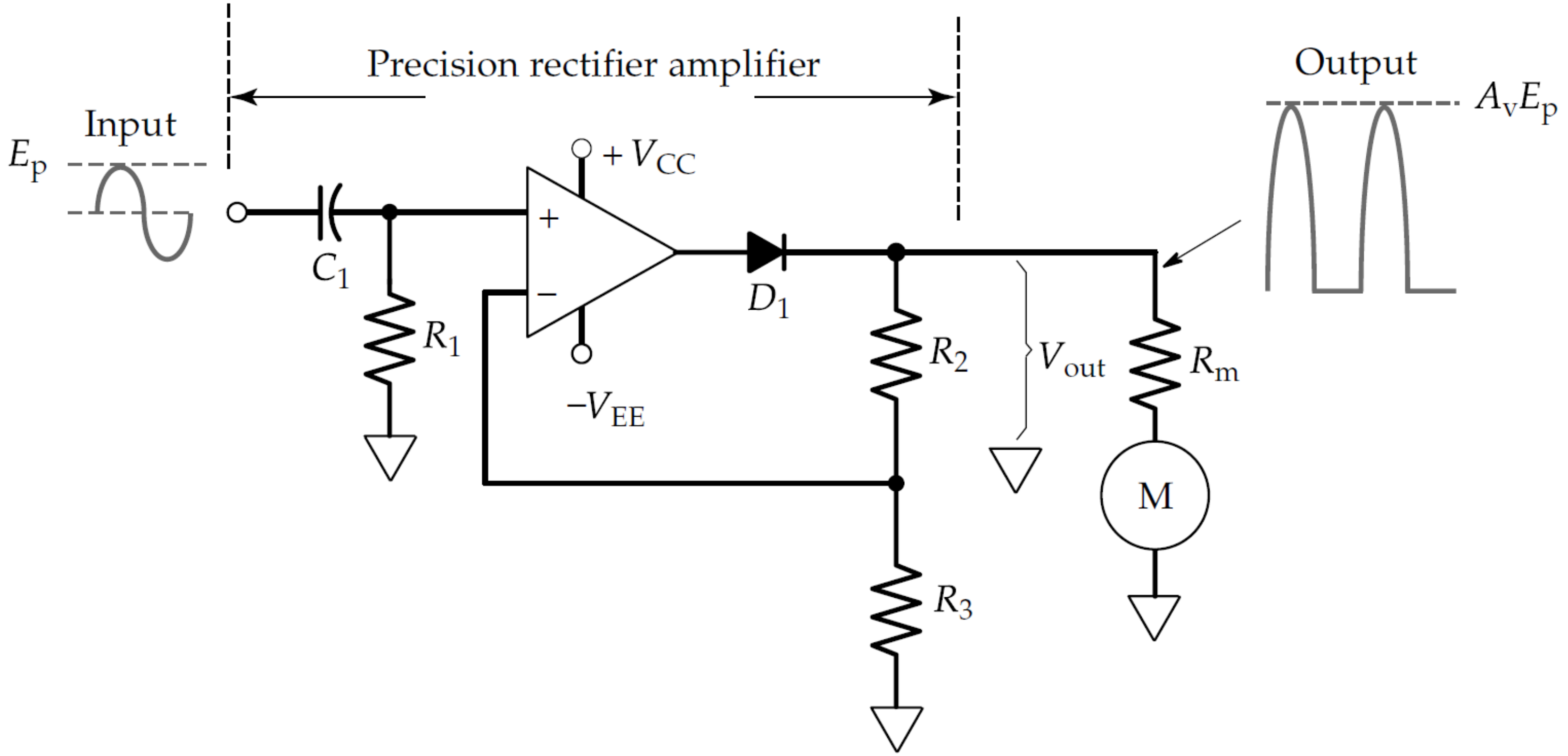
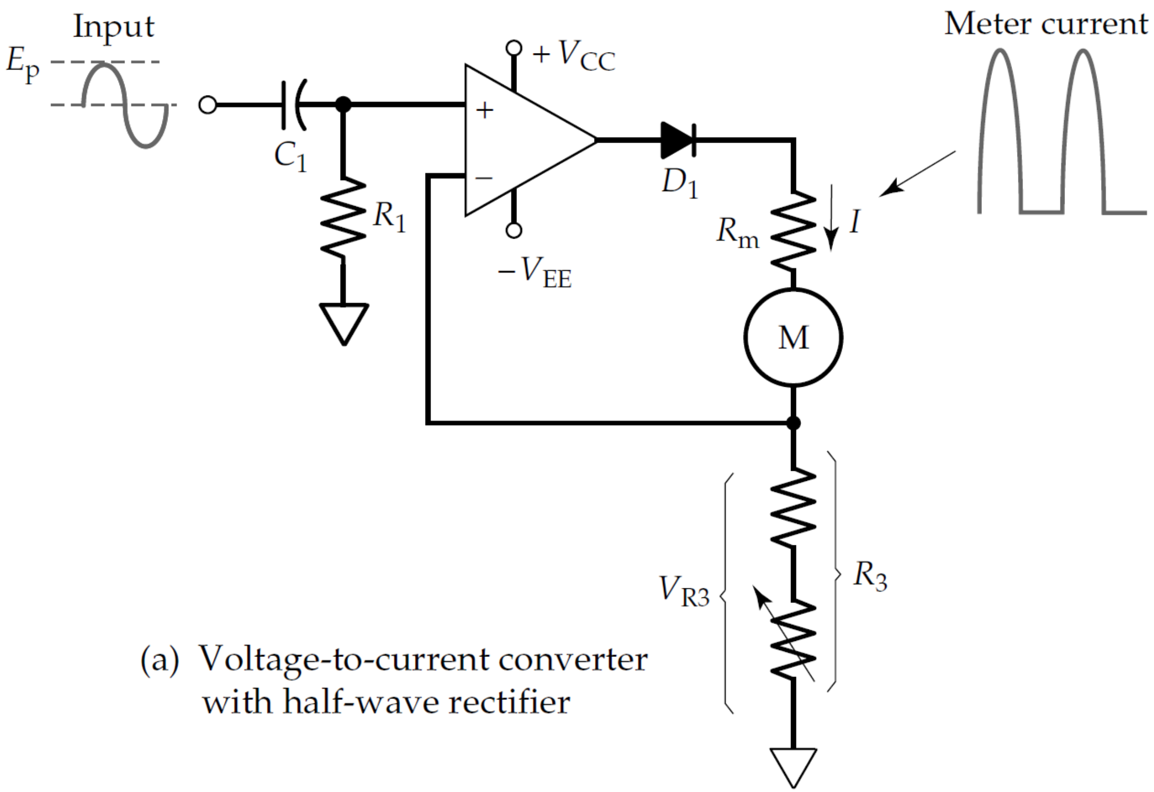
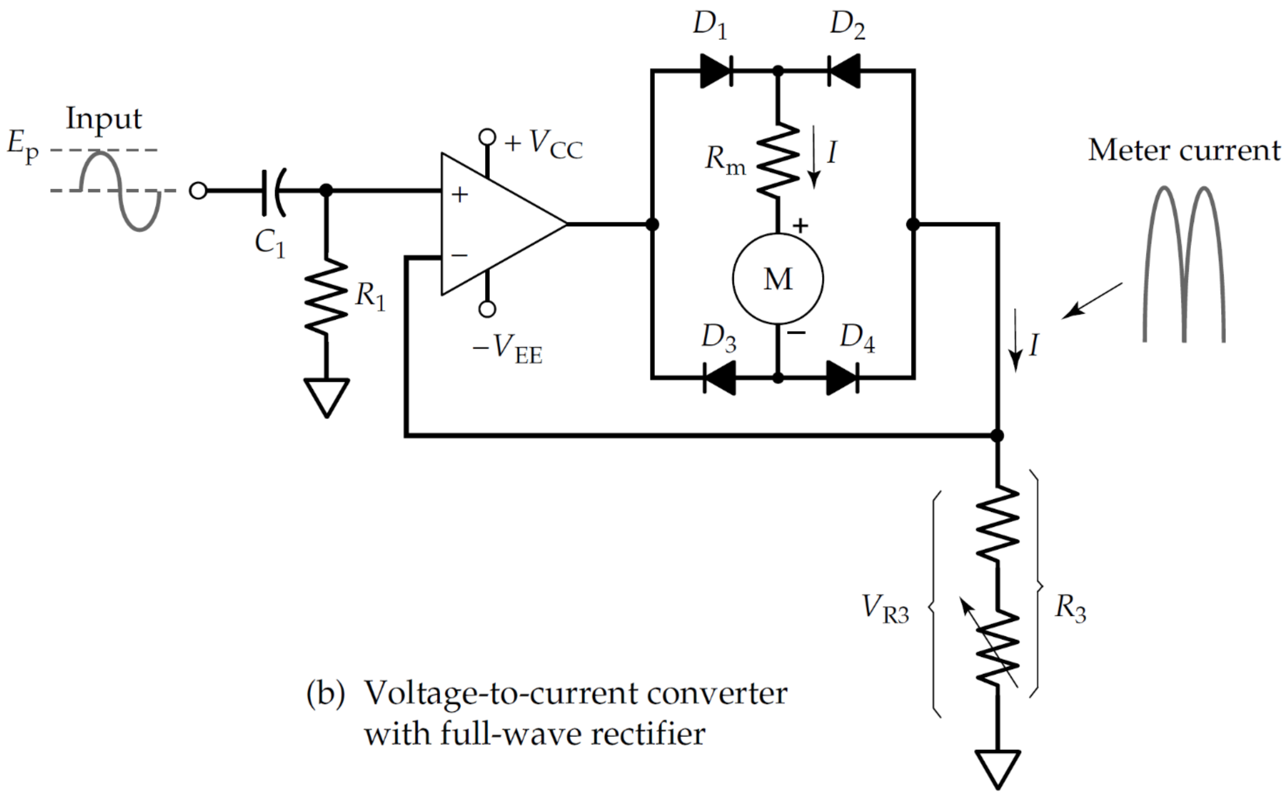


Figure 5-13 Ac voltmeter circuits using an op-amp noninverting amplifier together with precision half-wave rectification. Low-level voltages are amplified before measurement.



(a) Voltage-to-current converter with half-wave rectifier



(b) Voltage-to-current converter with full-wave rectifier

Op-amp Half-bridge Rectifier Voltmeter

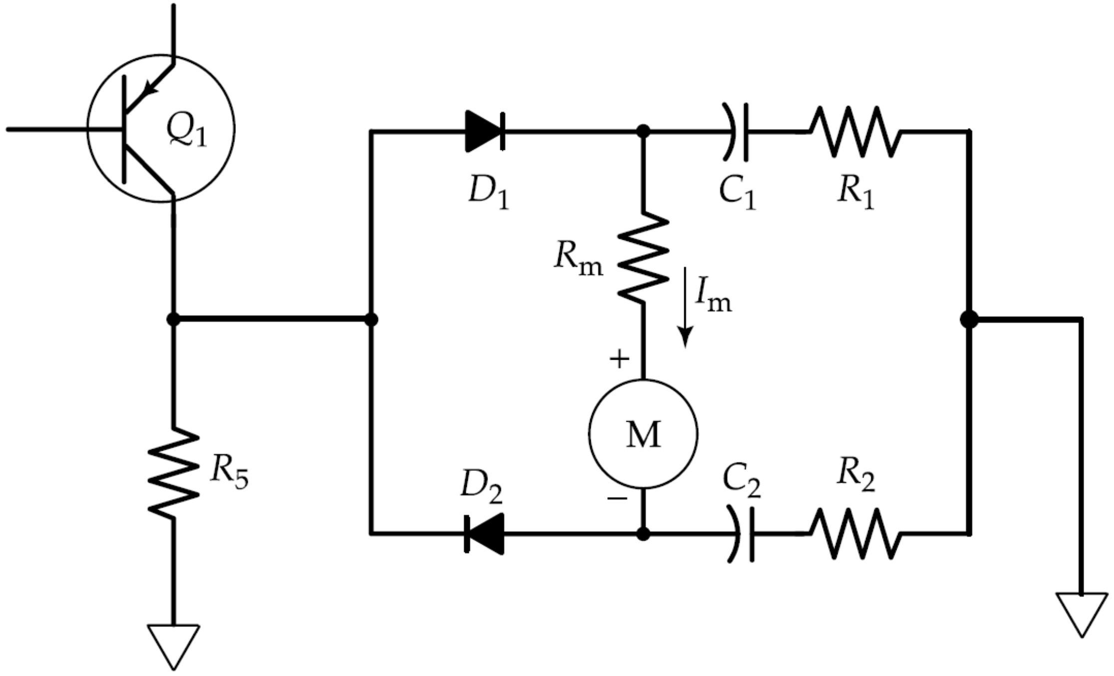


Figure 5-15 Ac electronic voltmeter using half-bridge full-wave rectification.

Voltmeter & Shunt

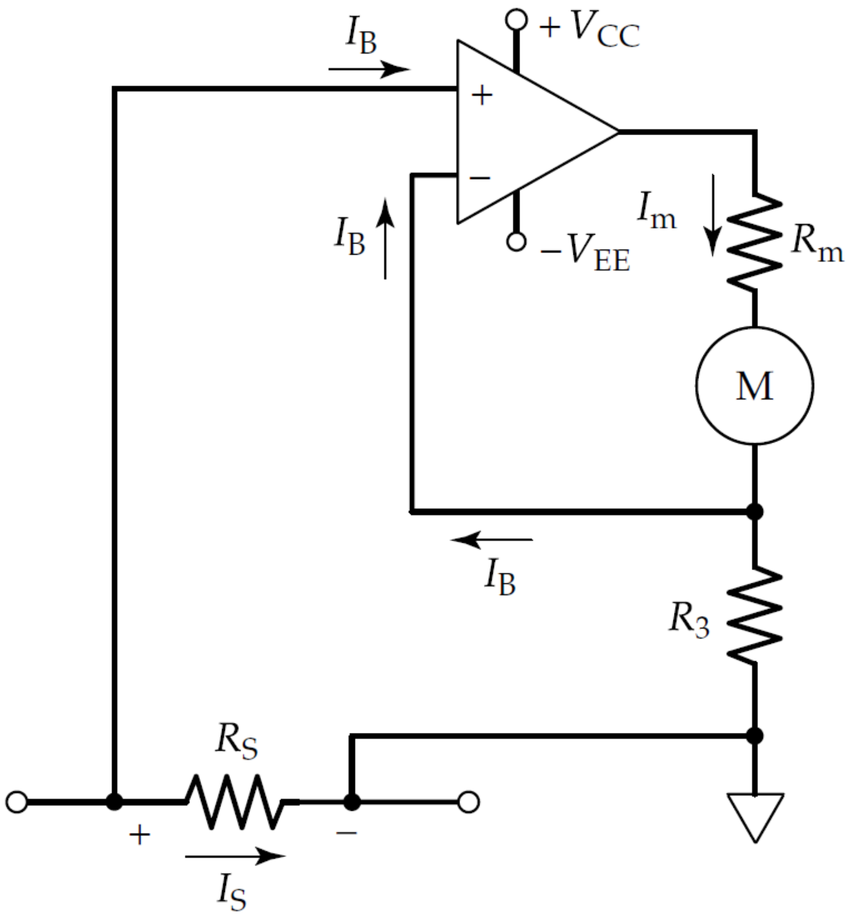
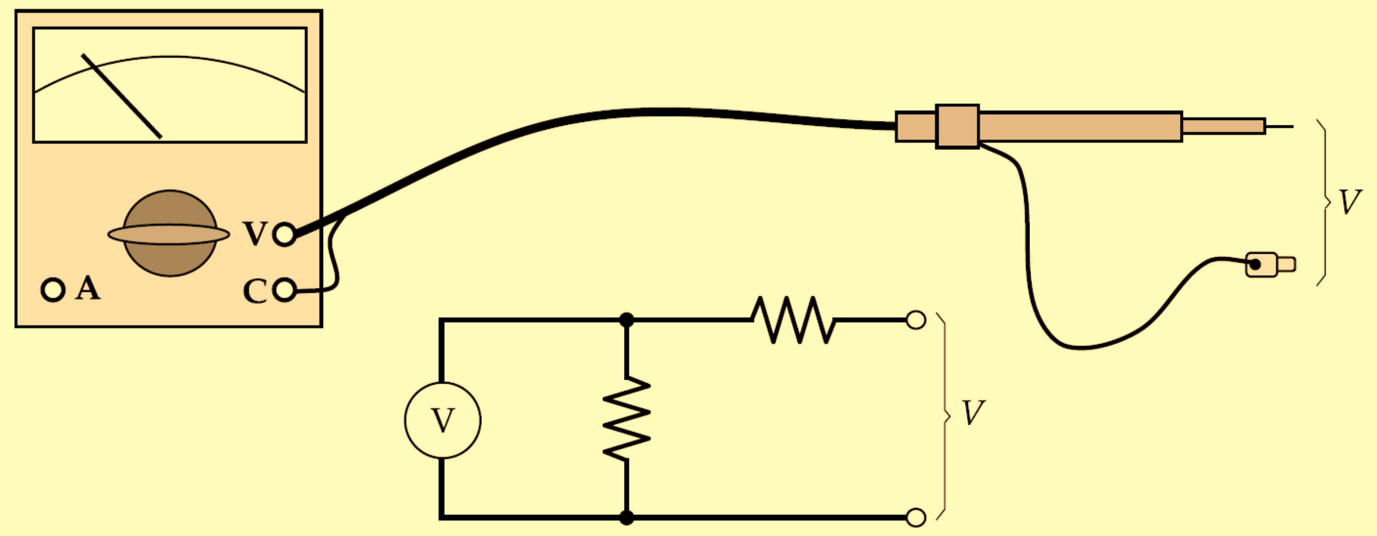


Figure 5-16 An electronic voltmeter can be used for current measurement by measuring the voltage drop across a shunt (R_S). The instrument scale is calibrated to indicate current.

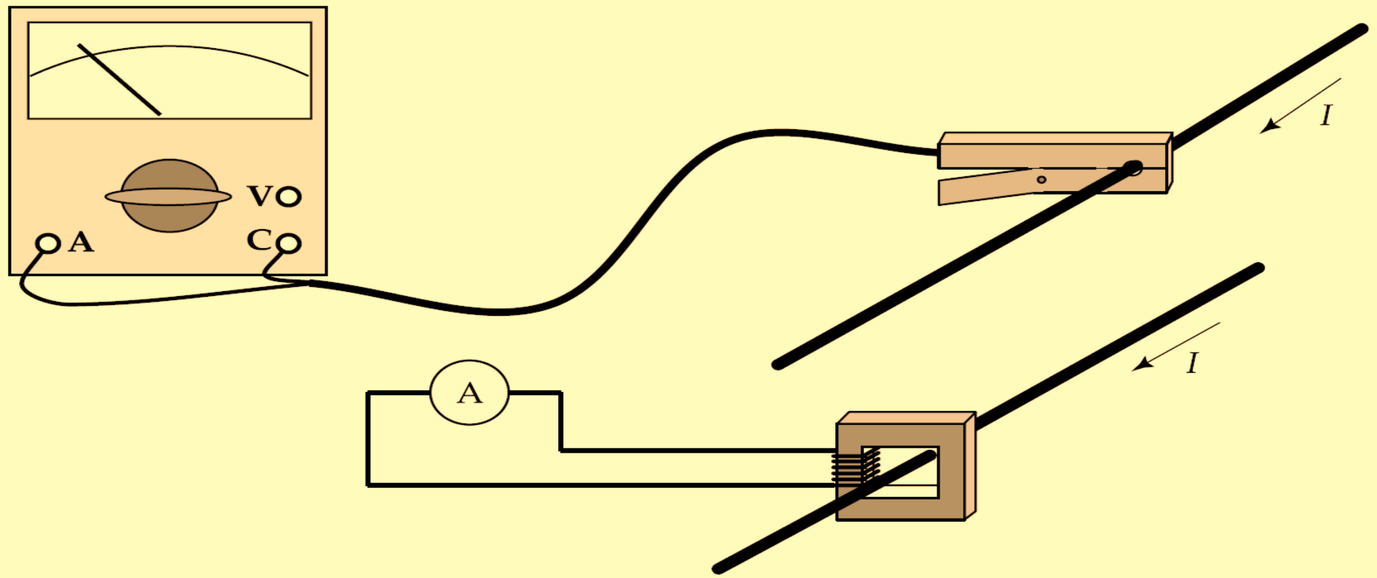
Multimeter Probes

Multimeter Probes

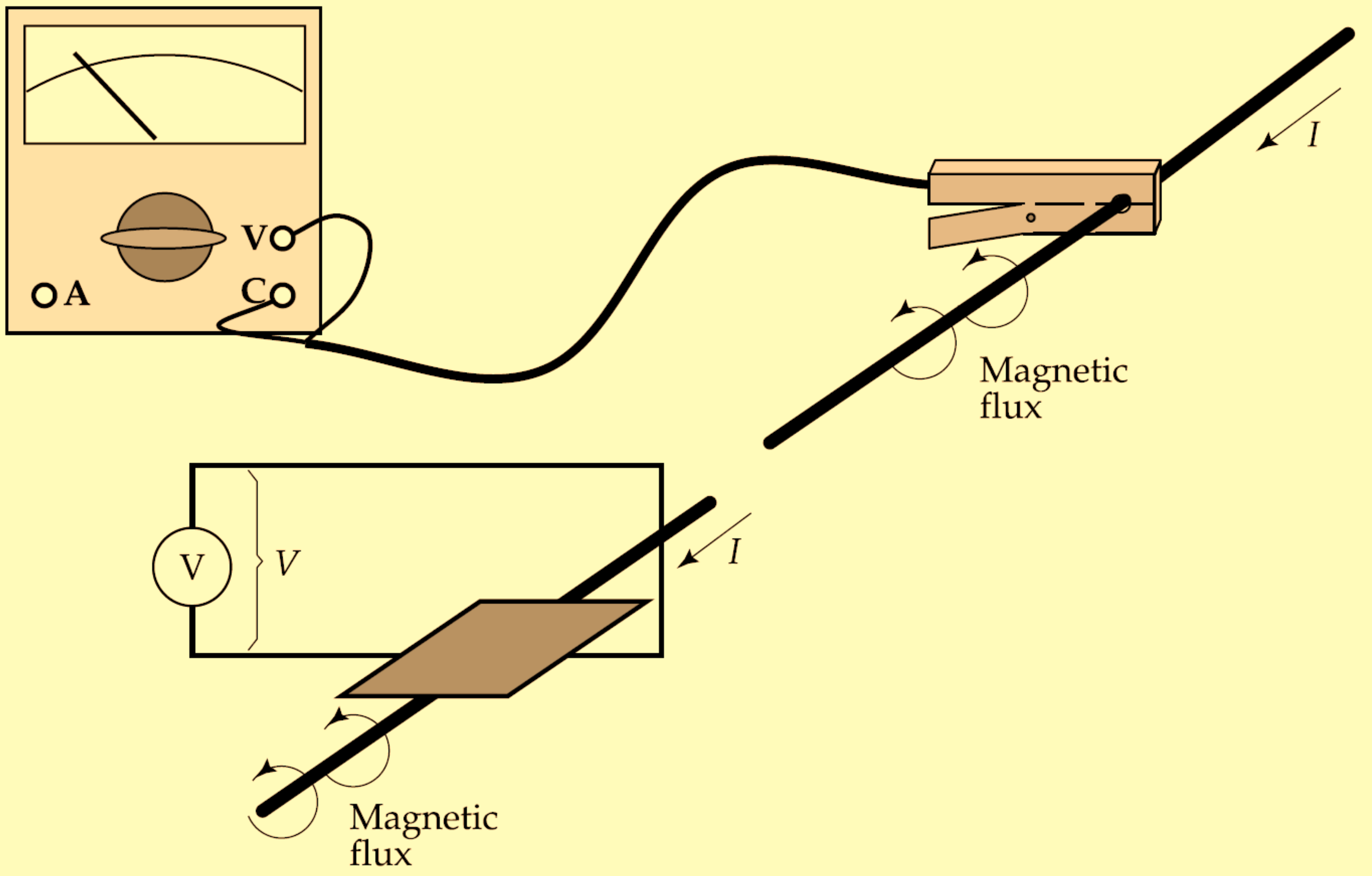
- There are many probes and adapters available to extend multimeter ranges.
  1. High-Voltage Probe
  2. High-Current Probes
  3. RF probe allows the meter to measure the voltage level of a waveform with a frequency upper its cutoff frequency.



(a) A high-voltage probe uses a voltage divider



(b) A high-current probe uses a current transformer



(c) A Hall-effect probe produces a voltage from a magnetic flux

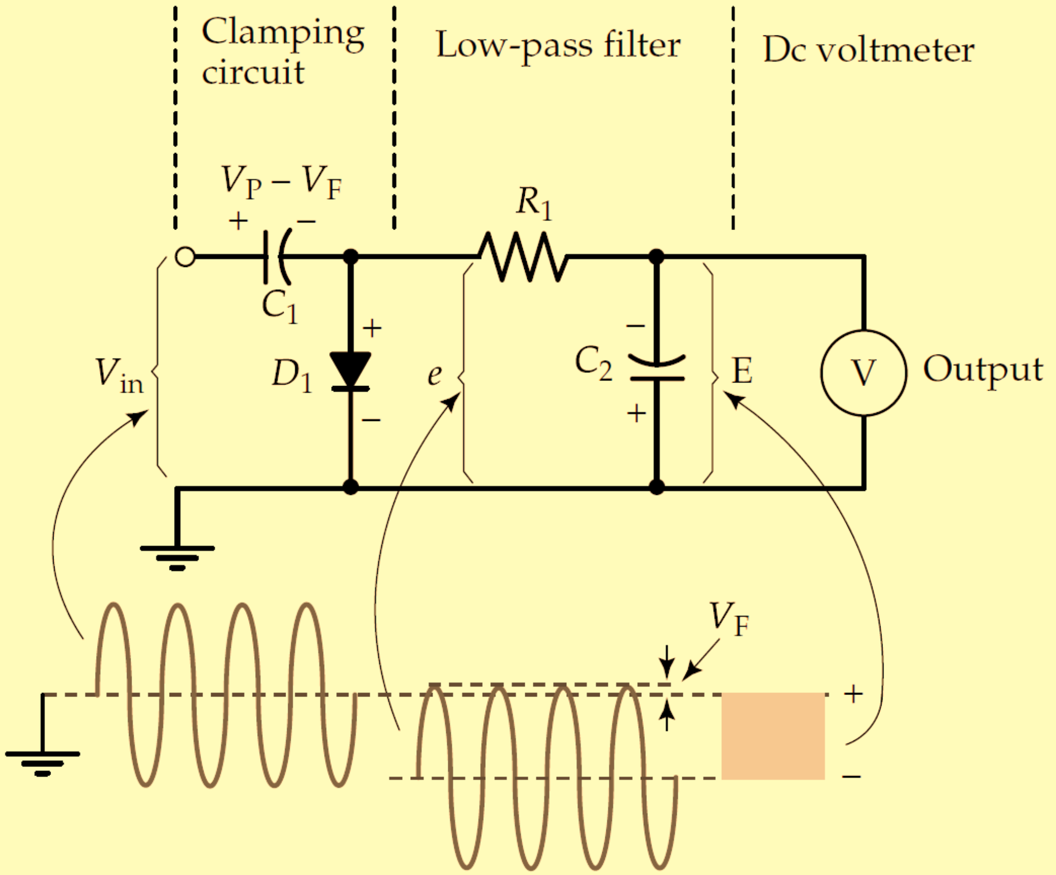


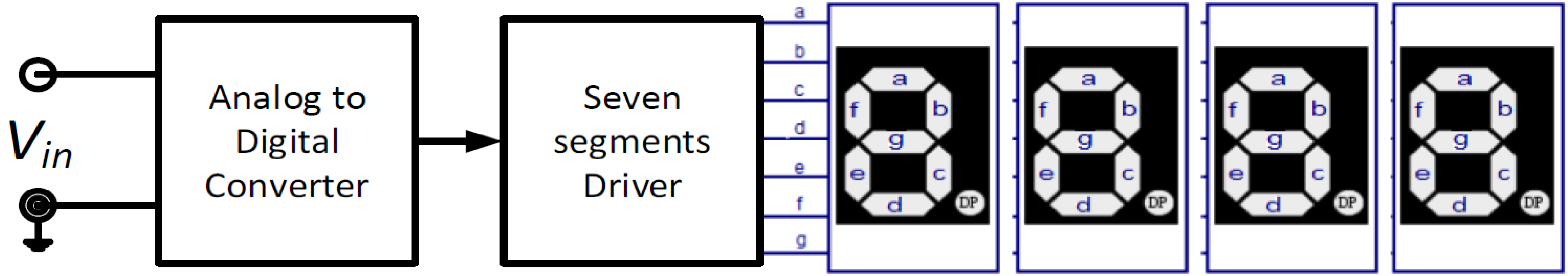
Figure 5-20 Peak detector circuit consisting of a clamper circuit and a low-pass filter. The peak voltage of a high-frequency waveform is converted to a dc quantity that can be measured on a dc voltmeter.

DVM Outline:

1. Introduction.
2. Ramp Type Digital Voltmeters.
3. Dual Slope Digital Voltmeters.
4. DVM Range Changing.
5. Digital Voltmeter Accuracy.
6. Types of Digital Multi-meters.

Introduction:

- Two types will be covered: **Ramp-type** and **Dual slope Integrator** DVMs.
- Digital voltmeters (DVM) are essentially **analog-to-digital converters** with **digital displays** to indicate the measured voltage.



Digital Voltmeter Basic Block Diagram

Seven-Segment LED Display

There are two types:

1. Common Anode
2. Common Cathode

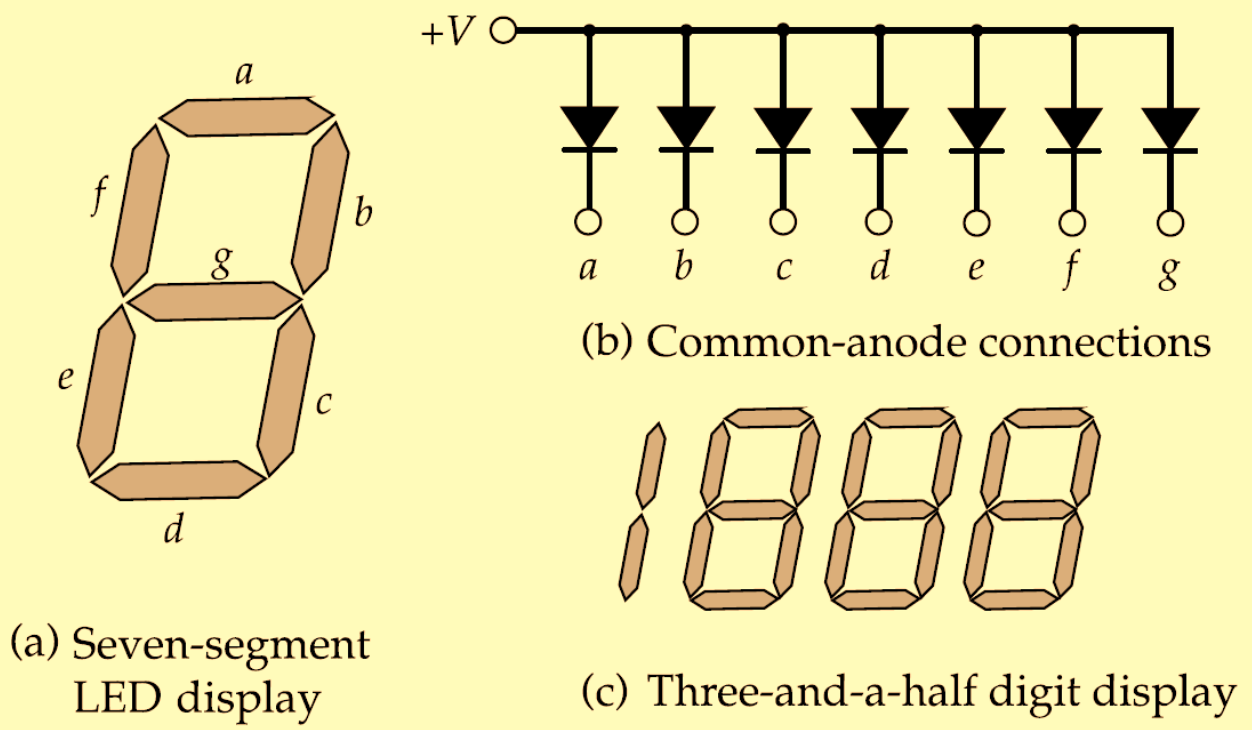


Figure 6-10 Light-emitting diodes arranged in a *seven-segment* format can display any numeral from 0 to 9.

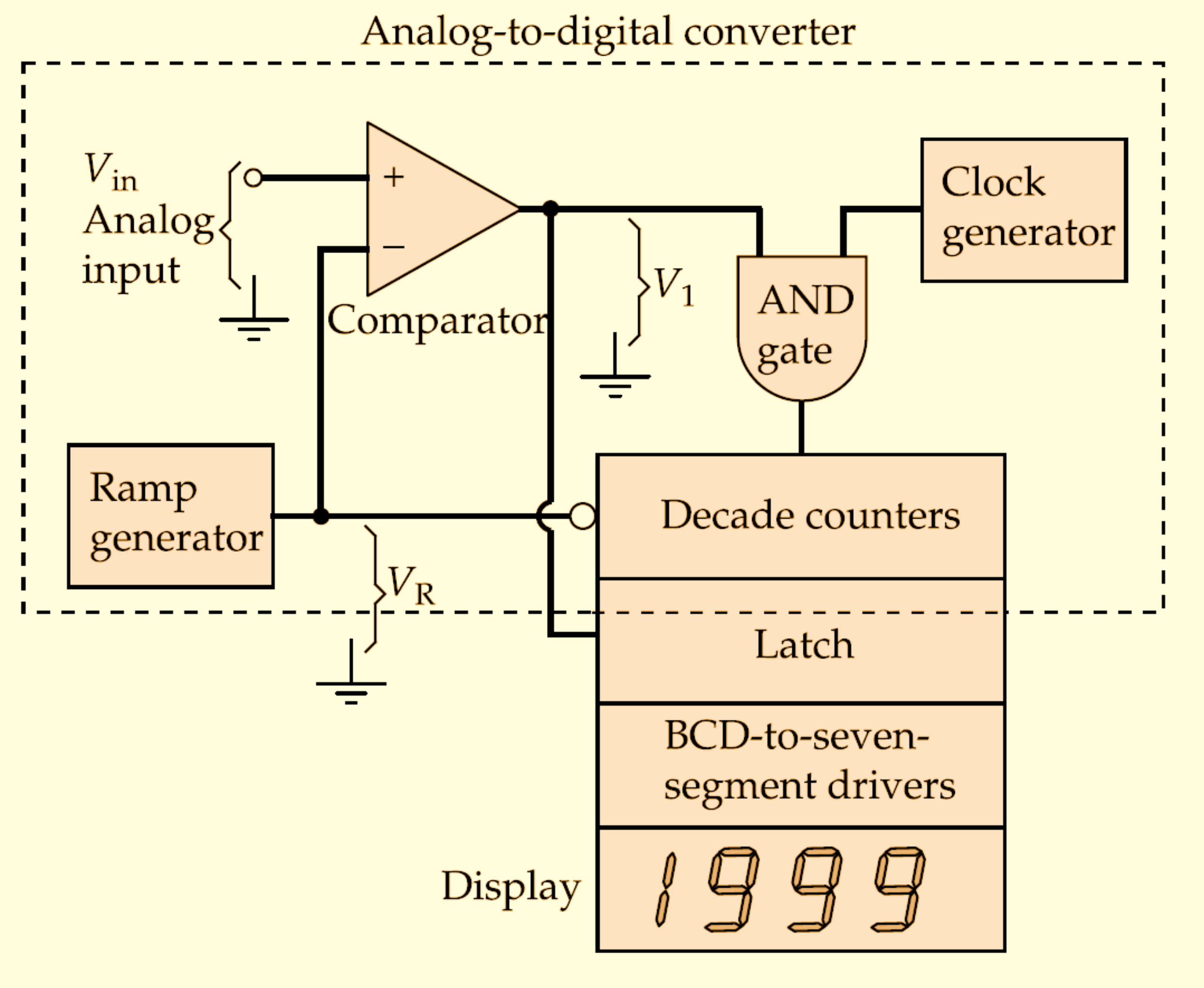
2. Ramp Type Digital Voltmeters

Ramp Type Digital Voltmeters:

- A ramp signal is generated.
- The comparator compares the input V_i with the ramp V_R.

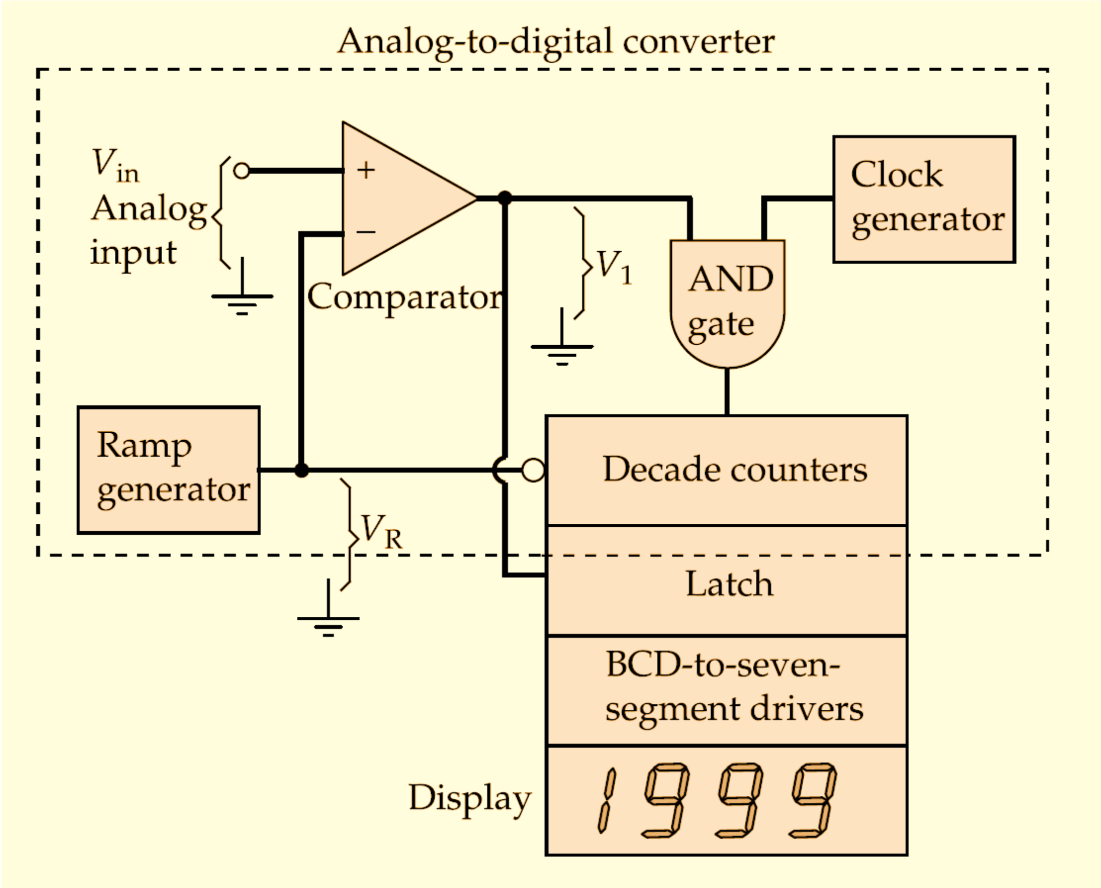
$$V_1 = \begin{cases} 1, & \text{if } V_i \geq V_r \\ 0, & \text{if } V_i < V_r \end{cases}$$

- If the comparator output V_1 is high, the counting circuit will count the pulses from clock generator.
- If the output V_1 is low, the counting will stop.
- $\boxed{N_{pulses} \propto V_i}$.
- The value of V_i will be displayed

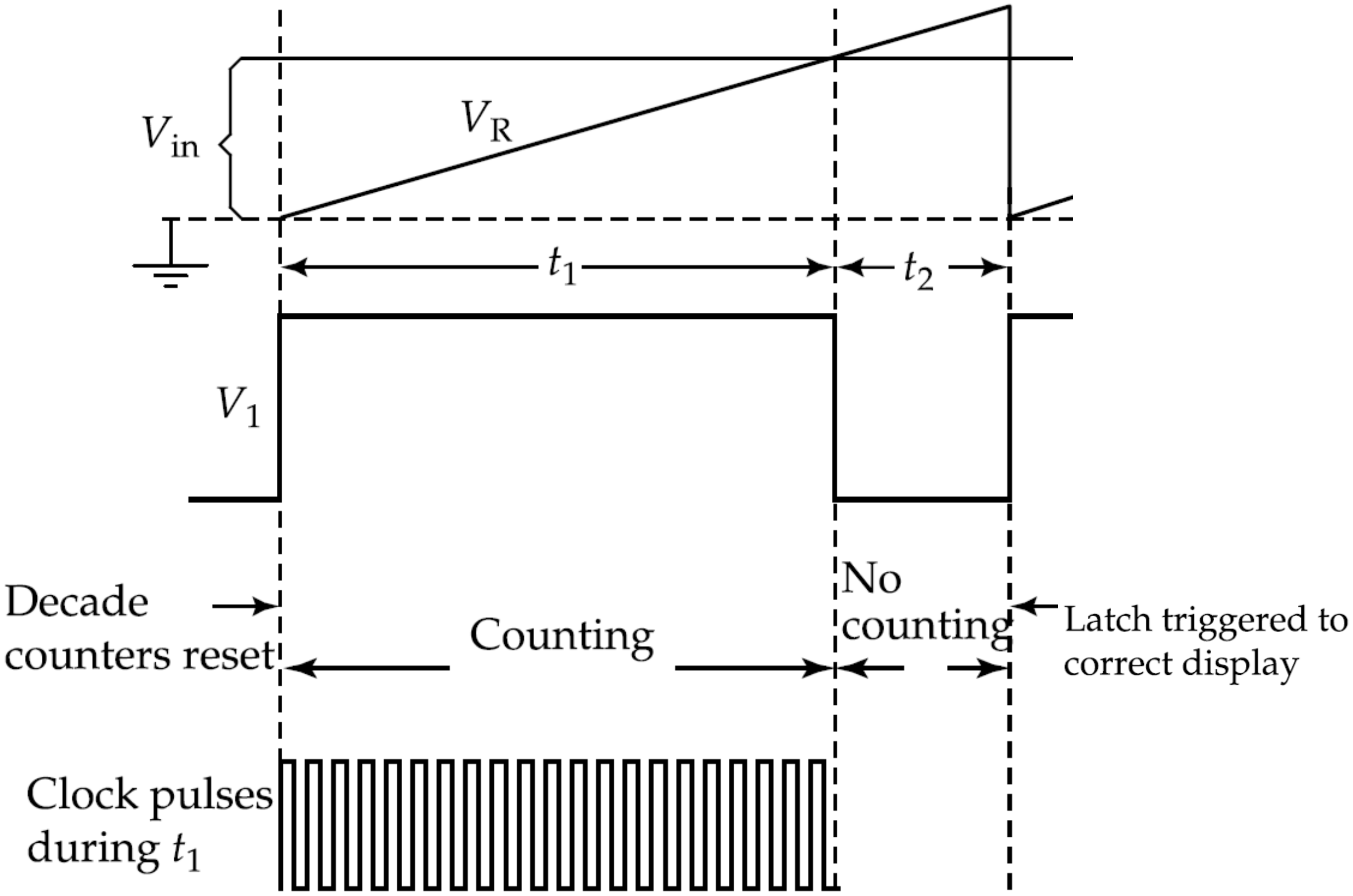


(a) Ramp-generator-type DVM

Ramp Type Digital Voltmeters (Cont.):



(a) Ramp-generator-type DVM

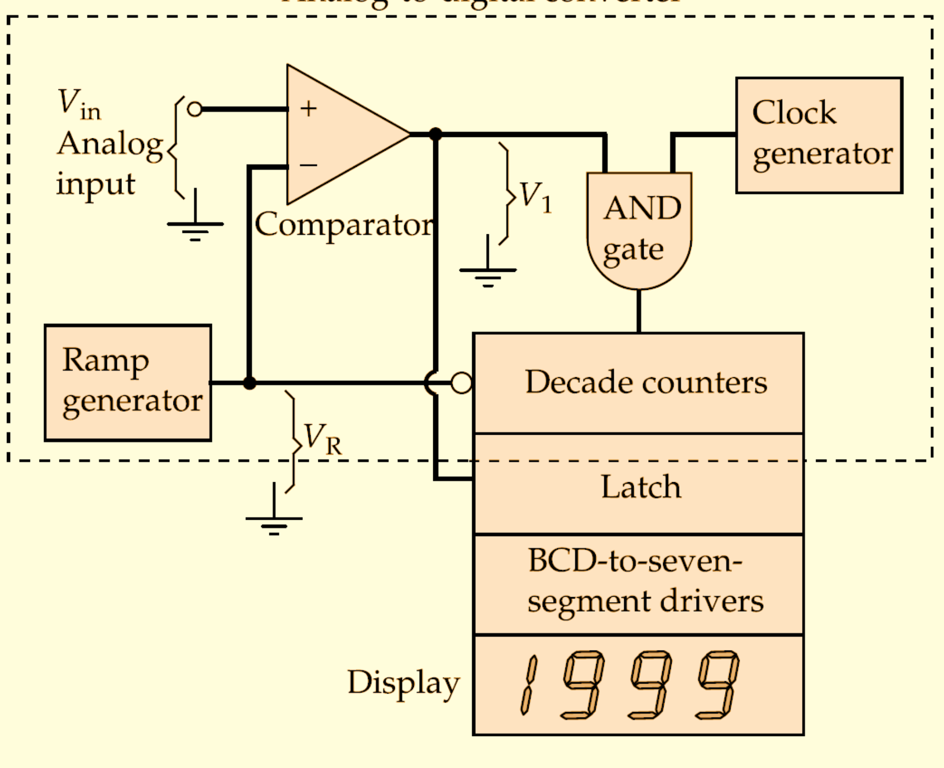


(b) DVM waveforms

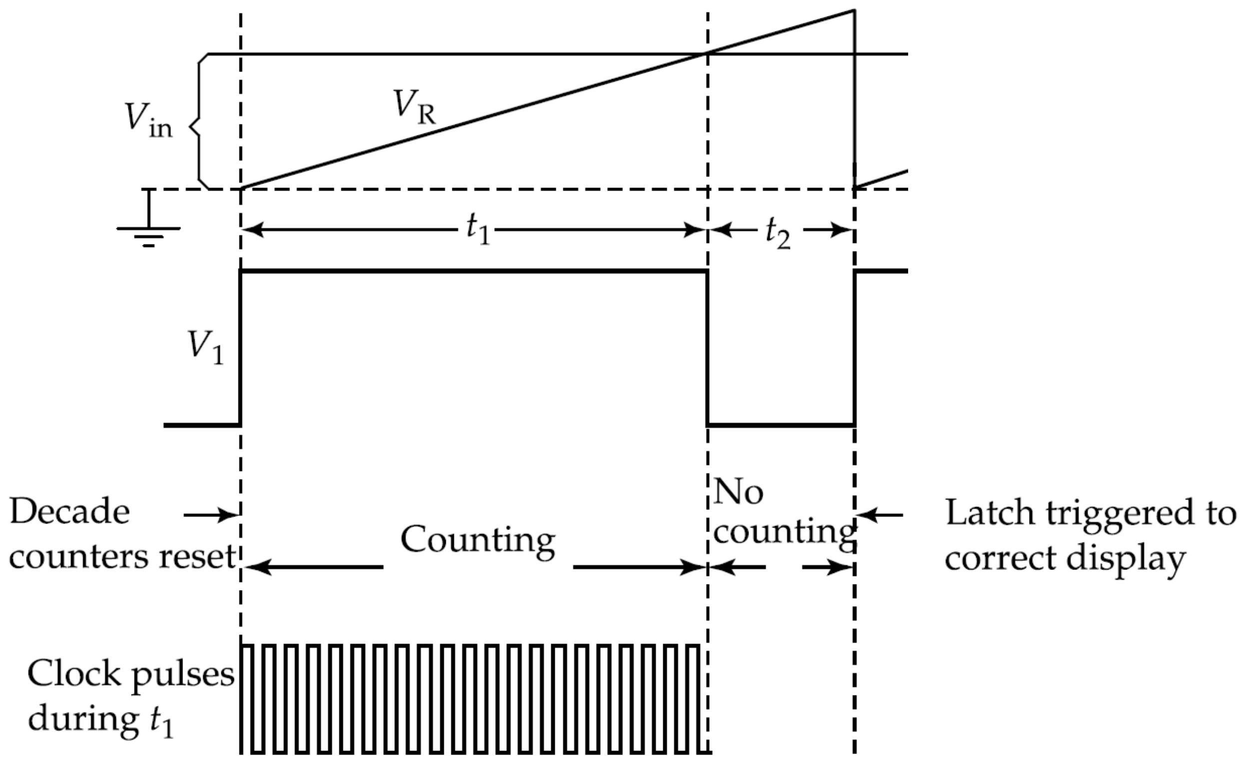
Ramp Type Digital Voltmeters (Cont.):

The use of the Latch:

1. The latch isolates the display from the counting circuit during the t1.
2. It will connect the display to the counting circuit at the rising edge of the comparator output.



(a) Ramp-generator-type DVM



(b) DVM waveforms

End of Lecture

Best Wishes