Elements of Electrical & Electronics Engineering (1313202) - Winter 2023 Solution

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Question 1(a) [3 marks]

Explain difference between Active and passive network.

Solution

Active Network	**Passive Network**
Contains at least one energy source	Contains no energy source
Can deliver power to other elements	Cannot deliver power to other elements
Examples: Transistors, Op-amps, Batteries	Examples: Resistors, Capacitors, Inductors

Mnemonic

"Active Adds Power, Passive Pulls Power"

Question 1(b) [4 marks]

State and explain Kirchhoff's voltage law (KVL).

Solution

Kirchhoff's Voltage Law (KVL): The algebraic sum of all voltages around any closed path (loop) in a circuit is zero.
Mathematical Form: $\sum V = 0$ or $V_1 + V_2 + V_3 + V_4 = 0$

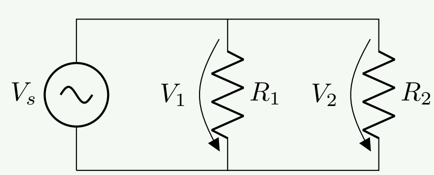


Figure 1. Closed Loop for KVL

- **Circuit Application**: When moving around a loop, voltage rises (batteries) are positive and voltage drops (components) are negative.
- **Physical Meaning**: Total energy in a closed loop is conserved.

Mnemonic

"Voltage Loop Sum Zero"

Question 1(c) [7 marks]

Define the following terms: (1) Charge (2) Current (3) Potential (4) E.M.F. (5) Inductance (6) Capacitance (7) Frequency.

Solution

Term	Definition
Charge	The basic electrical quantity measured in coulombs (C); flow of electrons creates electricity.
Current	The rate of flow of electric charge, measured in amperes (A); $I = dQ/dt$.
Potential	Electric potential energy per unit charge, measured in volts (V).
E.M.F.	Electromotive force, energy supplied by source per unit charge, measured in volts (V).
Inductance	Property of a conductor to oppose change in current, measured in henry (H).
Capacitance	Ability of a component to store electric charge, measured in farad (F).
Frequency	Number of cycles per second of an alternating quantity, measured in hertz (Hz).

Mnemonic

"Careful Currents Pass Easily Into Circuit Frequently"

Question 1(c) OR [7 marks]

State Ohm's law. Write its application and limitation.

Solution

Ohm's Law: The current flowing through a conductor is directly proportional to the potential difference across it and inversely proportional to its resistance.
Mathematical Form: $I = V/R$

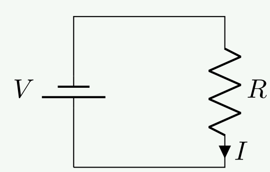


Figure 2. Ohm's Law Circuit

Applications of Ohm's Law:
- Computing current, voltage, resistance in circuits.
- Design of electrical networks.
- Power calculations ($P = VI = I^2R = V^2/R$).
- Voltage division and current division.

Limitations of Ohm's Law:
- Not valid for non-linear elements (diodes, transistors).
- Not applicable at very high frequencies.
- Not valid for non-metallic conductors like semiconductors.
- Not applicable for vacuum tubes and gaseous devices.

Mnemonic

"Voltage Drives, Resistance Restricts"

Question 2(a) [3 marks]

Draw and explain energy band diagrams for insulator, conductor and Semiconductor.

Solution

Energy Band Diagrams:

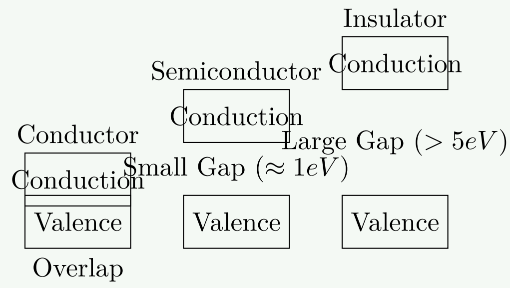


Figure 3. Energy Band Diagrams

- **Conductor**: Valence and conduction bands overlap, allowing easy electron flow.
- **Semiconductor**: Small energy gap ($\approx$ 1 eV) between bands; electrons can jump with thermal energy.
- **Insulator**: Large energy gap ($>$ 5 eV) prevents electron movement between bands.

Mnemonic

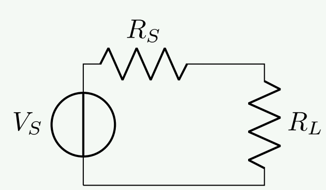
"Conductors Connect, Semiconductors Sometimes, Insulators Impede"

Question 2(b) [4 marks]

Write statement of Maximum power transfer theorem and reciprocity theorem.

Solution

Theorem	Statement
Maximum Power Transfer Theorem	Maximum power is transferred from source to load when load resistance equals the source internal resistance ($R_L = R_S$).
Reciprocity Theorem	In a linear passive network with a single source, if the source is moved from position A to B, the current at A due to source at B will equal the current at B when source was at A.



Max Power when $R_L = R_S$

Mnemonic

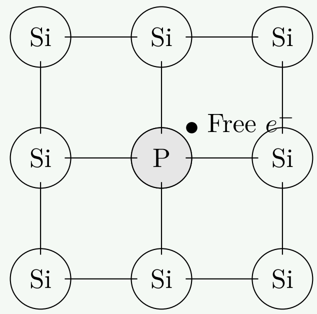
"Match Resistance to Maximize Power; Switch Source and Sink, Current Stays Same"

Question 2(c) [7 marks]

Explain the formation and conduction of N-type materials.

Solution

N-type Semiconductor Formation:



N-type Lattice

Figure 4. Pentavalent Doping (N-type)

- **Doping Process**: Silicon/Germanium (4 valence e^-) doped with pentavalent elements (P, As, Sb).
- **Extra Electron**: Each dopant atom provides 1 extra electron after covalent bonding.
- **Conduction Mechanism**:
  - **Majority Carriers**: Free electrons (negative charge carriers).
  - **Minority Carriers**: Holes (very few).
- **Electrical Properties**: Increased conductivity and negative charge carriers.

Mnemonic

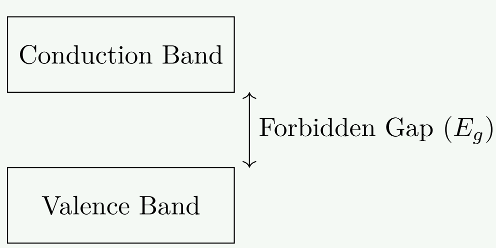
"Pentavalent Provides Plus one Electron, Negative-type"

Question 2(a) OR [3 marks]

Define valence band, conduction band and forbidden gap.

Solution

Term	Definition
Valence Band	The highest energy band filled with electrons, where electrons are bound to atoms.
Conduction Band	The band above valence band where electrons move freely and contribute to electrical conduction.
Forbidden Gap	The energy range between valence and conduction bands where no electron states exist.



Mnemonic

"Valence Holds, Forbidden Blocks, Conduction Flows"

Question 2(b) OR [4 marks]

Define the terms active power, reactive power and power factor with power triangle.

Solution

Power Terms in AC Circuits:

Term	Definition
Active Power (P)	Actual power consumed, measured in watts (W); $P = VI\cos\theta$.
Reactive Power (Q)	Power oscillating between source and load, measured in VAR; $Q = VI\sin\theta$.
Power Factor (PF)	Ratio of active power to apparent power; $PF = \cos\theta$.

Power Triangle:

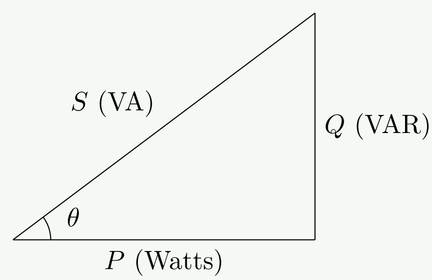


Figure 5. Power Triangle

- **Apparent Power (S)**: Vector sum of active and reactive power.
- **Power Factor**: $\cos\theta = P/S$ (0 to 1).

Mnemonic

"Active Power Works, Reactive Power Waits"

Question 2(c) OR [7 marks]

Explain the structure of atom of trivalent, tetravalent and pentavalent elements.

Solution

Atomic Structures:

Element Type	Valence Electrons	Examples	Electronic Configuration
Trivalent	3	Boron, Aluminum, Gallium	3 electrons in outermost shell
Tetravalent	4	Carbon, Silicon, Germanium	4 electrons in outermost shell
Pentavalent	5	Nitrogen, Phosphorus, Arsenic	5 electrons in outermost shell

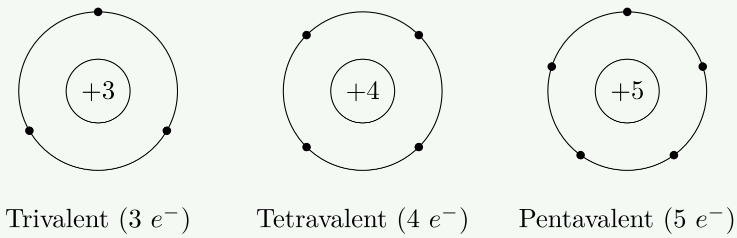


Figure 6. Valence Shell Electrons

- **Trivalent Elements**: Used as p-type dopants in semiconductors.
- **Tetravalent Elements**: Form semiconductor base materials.
- **Pentavalent Elements**: Used as n-type dopants in semiconductors.

Mnemonic

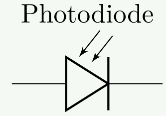
"Three Tries to Bond, Four Forms Full bonds, Five Frees an Electron"

Question 3(a) [3 marks]

Draw the symbol of photodiode and state it's application.

Solution

Photodiode Symbol:



Applications of Photodiode:

- Light sensors and detectors.
- Optical communication systems.
- Camera exposure controls.
- Barcode scanners.
- Medical instruments.
- Solar cells.

Mnemonic

"Photons Produce Current"

Question 3(b) [4 marks]

Write a Short note on LED.

Solution

LED (Light Emitting Diode):

Parameter	Description
Structure	p-n junction with special doping materials.
Working	Electrons recombine with holes, releasing energy as photons.
Materials	GaAs (red), GaP (green), GaN (blue), etc.
Voltage	Forward voltage typically 1.8V to 3.3V depending on color.

Advantages:
- High efficiency (low power consumption).
- Long life (50,000+ hours).
- Small size and durability.
- Various colors available.

Applications:
- Indicators and displays.
- Lighting systems.
- TV/monitor backlights.
- Traffic signals.

Mnemonic

"Light Emits when Diode conducts"

Question 3(c) [7 marks]

Draw and explain VI characteristic of PN junction diode.

Solution

P-N Junction Diode V-I Characteristic:

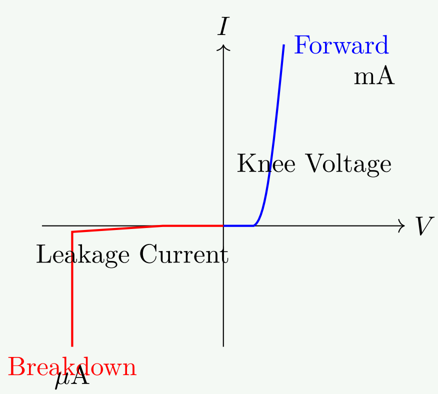


Figure 7. V-I Characteristics

Forward Bias Region:
- **Knee Voltage**: 0.3V (Ge), 0.7V (Si) where current starts flowing.
- **Current Equation**: $I = I_s(e^{qV/kT} - 1)$.
- **Conductivity**: High (low resistance).

Reverse Bias Region:
- **Leakage Current**: Very small reverse current (micro-amps).
- **Breakdown Region**: Sharp increase in current at breakdown voltage.
- **Conductivity**: Very low (high resistance).

Key Points:
- **Barrier Potential**: Decreases in forward bias, increases in reverse bias.
- **Diode Resistance**: Dynamic resistance changes with applied voltage.
- **Temperature Effect**: Voltage drop decreases with temperature increase.

Mnemonic

"Forward Flows Freely, Reverse Resists"

Question 3(a) OR [3 marks]

List the applications of PN junction diode.

Solution

Applications of PN Junction Diode:

Application Category	Examples
Rectification	Half-wave rectifier, Full-wave rectifier, Bridge rectifier.
Signal Processing	Signal demodulation, Clipping circuits, Clamping circuits.
Protection	Voltage spike protection, Reverse polarity protection.
Logic Gates	Diode logic circuits, Switching applications.
Voltage Regulation	Zener diodes for voltage references.
Light Applications	LEDs, Photodiodes, Solar cells.

Mnemonic

"Rectify, Process, Protect, Logic, Regulate, Light"

Question 3(b) OR [4 marks]

Explain the formation of depletion region in unbiased P-N junction.

Solution

Depletion Region Formation:

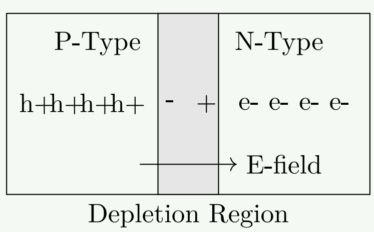


Figure 8. Depletion Region

Process:
- **Diffusion**: Electrons from n-side diffuse to p-side; holes from p-side diffuse to n-side.
- **Recombination**: Electrons and holes recombine at the junction.
- **Immobile Ions**: Exposed positive ions in n-region, negative ions in p-region.
- **Electric Field**: Forms between positive and negative ions, opposing further diffusion.
- **Equilibrium**: Diffusion current equals drift current; no net current flows.

Properties of Depletion Region:
- No free charge carriers.
- Acts as insulator.
- Width depends on doping levels.
- Contains built-in potential barrier.

Mnemonic

"Diffusion Depletes Carriers, Creating Electric barrier"

Question 3(c) OR [7 marks]

Explain construction, working and applications of PN junction diode.

Solution

Construction of PN Junction Diode:

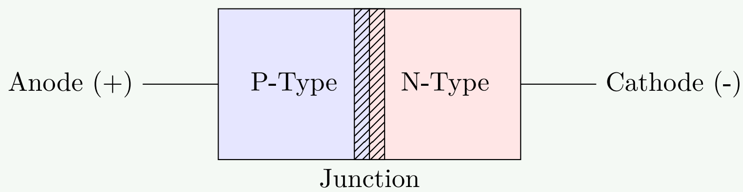


Figure 9. PN Junction Construction

- **P-Type Region**: Silicon/Germanium doped with trivalent impurities (boron, aluminum).
- **N-Type Region**: Silicon/Germanium doped with pentavalent impurities (phosphorus, arsenic).
- **Junction**: Interface between p and n regions with depletion layer.
- **Terminals**: Anode (p-side) and Cathode (n-side).

Working Principle:

Bias Condition	Behavior
Forward Bias	Depletion region narrows, current flows when $V > 0.7V$ (Si).
Reverse Bias	Depletion region widens, only small leakage current flows.

Applications:

- Rectification in power supplies.
- Signal demodulation in radios.
- Voltage regulation (Zener).
- Signal clipping and clamping.
- Logic gates and switching.
- Light emission and detection.

Mnemonic

"Forward Flow, Reverse Restrict, Convert AC to DC"

Question 4(a) [3 marks]

Define: (1) Ripple frequency (2) Ripple factor (3) PIV of a diode.

Solution

Term	Definition
Ripple Frequency	The frequency of AC component present in rectified DC output; for half-wave $f = f_{in}$, for full-wave $f = 2f_{in}$.
Ripple Factor (γ)	Ratio of RMS value of AC component to DC component in rectifier output; $\gamma = V_{ac(rms)}/V_{dc}$.
PIV of Diode	Peak Inverse Voltage - maximum reverse voltage a diode can withstand without breakdown.

Mnemonic

"Ripples Per second, Ripple Proportion, Reverse Peak Voltage"

Question 4(b) [4 marks]

Give comparison between full wave rectifier with two diodes and full wave bridge rectifier.

Solution

Parameter	Center-Tapped Full Wave	Bridge Rectifier
Diodes Used	2 diodes	4 diodes
Transformer	Center-tapped required	No center tap needed
PIV of Diode	$2V_m$	V_m
Output Voltage	$V_{dc} = 0.637V_m$	$V_{dc} = 0.637V_m$
Ripple Factor	0.48	0.48
Efficiency	81.2%	81.2%
TUF	0.693	0.812

Mnemonic

"Bridge Beats Tap with Lower PIV but Needs More Diodes"

Question 4(c) [7 marks]

Explain zener diode as voltage regulator.

Solution

Zener Diode Voltage Regulator:

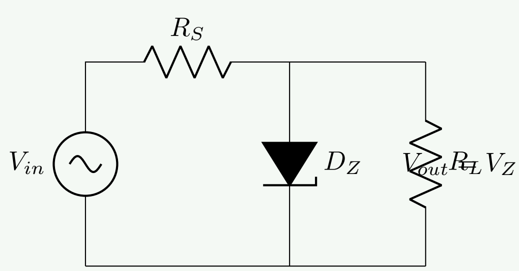


Figure 10. Zener Voltage Regulator

Working Principle:

- **Reverse Biased**: Zener operates in breakdown region.
- **Constant Voltage**: Maintains fixed voltage (V_Z) across its terminals.
- **Current Regulation**: Series resistor (R_S) limits current.
- **Load Changes**: When load current changes, Zener current changes to maintain constant output voltage.

Design Equations:

- $R_S = (V_{in} - V_Z)/(I_L + I_Z)$.
- Power rating of Zener: $P_Z = V_Z \times I_{Z(max)}$.

Mnemonic

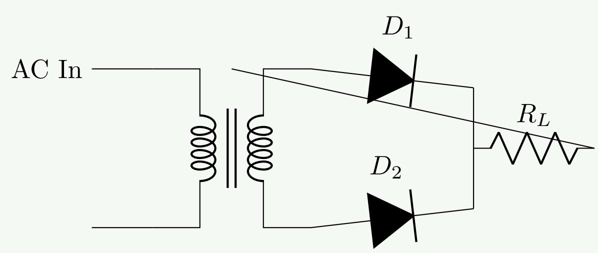
"Zener Stays at breakdown Voltage despite Current changes"

Question 4(a) OR [3 marks]

What is rectifier? Explain full wave rectifier with waveforms.

Solution

Rectifier: A circuit that converts AC voltage to pulsating DC voltage by allowing current flow in one direction only.
Full Wave Rectifier (Center-Tapped):



Waveforms:

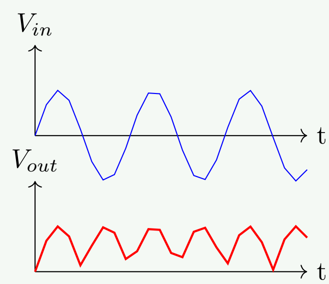


Figure 11. Full Wave Rectifier Waveforms

- **Operation**: Both half cycles of AC input are converted to same polarity.
- **Frequency**: Output ripple frequency is twice the input frequency.
- **Voltage**: $V_{dc} = 0.637V_m$.

Mnemonic

"Full Wave Forms Full Output"

Question 4(b) OR [4 marks]

Why filter is required in rectifier? State the different types of filter and explain any one type of filter.

Solution

Need for Filters: Rectifiers produce pulsating DC with large ripples; filters smooth this output to provide steady DC voltage.
Types of Filters:
- Capacitor (C) filter.

- Inductor (L) filter.
- LC filter.
- π (Pi) filter.
- RC filter.

Capacitor Filter:

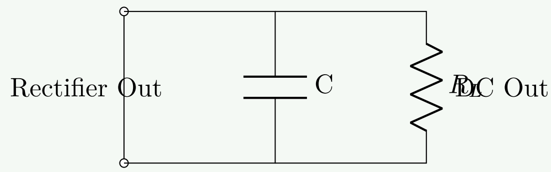


Figure 12. Capacitor Filter

Working Principle:
- Capacitor charges during voltage rise to peak.
- Discharges slowly through load during voltage fall.
- Reduces ripple by providing discharge path with time constant RC.

Mnemonic

"Capacitor Catches Charge and Releases Slowly"

Question 4(c) OR [7 marks]

Write the need of rectifier. Explain bridge rectifier with circuit diagram and draw its input and output waveforms.

Solution

Need for Rectifiers:
- Convert AC to DC for electronic devices.
- Power supplies and battery charging.
- Signal demodulation.

Bridge Rectifier Circuit:

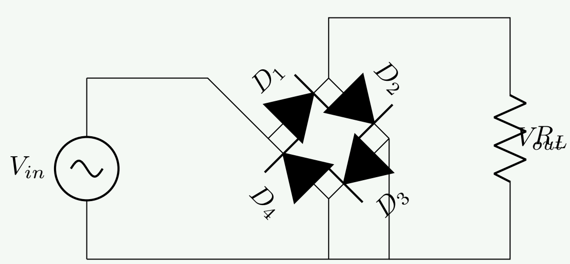


Figure 13. Bridge Rectifier

Working Principle:
- **Positive Half Cycle**: D_1 and D_3 conduct.
- **Negative Half Cycle**: D_2 and D_4 conduct.
- **Result**: Unidirectional current through R_L.

Waveforms: Input is sine wave, Output is pulsating DC (full-wave rectified).

Mnemonic

"Bridge Brings Both halves to Direct Current"

Question 5(a) [3 marks]

Explain causes of electronic waste.

Solution

Causes of Electronic Waste:

Cause	Description
Rapid Technology Change	Frequent upgrades and obsolescence of electronics.
Short Lifecycle	Devices designed with limited useful life.
Consumer Behavior	Preference for new gadgets over repair.
Manufacturing Issues	Poor quality leading to early failures.
Marketing Strategies	Promoting new models through planned obsolescence.

Mnemonic

"Upgrade, Use, Throw, Repeat"

Question 5(b) [4 marks]

Compare PNP and NPN transistors.

Solution

Parameter	PNP Transistor	NPN Transistor
Majority Carriers	Holes	Electrons
Current Flow	Emitter to Collector	Collector to Emitter
Biasing	Emitter +ve, Collector -ve	Collector +ve, Emitter -ve
Switching Speed	Slower	Faster
Usage	Less common	More common

Mnemonic

"PNP: Positive-Negative-Positive; NPN: Negative-Positive-Negative"

Question 5(c) [7 marks]

Draw the symbol, explain the construction and working of MOSFET.

Solution

MOSFET (N-Channel Enhancement):

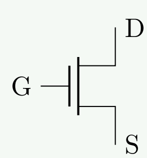


Figure 14. MOSFET Symbol

Construction:

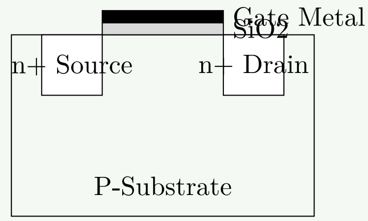


Figure 15. MOSFET Construction

Working Principle (Enhancement Mode):

- No channel exists initially.
- When positive voltage applied to Gate ($V_{GS} > V_{Th}$), electrons are attracted to surface.
- An N-channel is formed connecting Source and Drain, allowing current flow.

Mnemonic

"Gate Voltage Controls Electron Channel"

Question 5(a) OR [3 marks]

Explain methods to handle electronic waste.

Solution

Methods to Handle E-Waste:

- **Reduce**: Designing long-lasting products.
- **Reuse**: Refurbishing used electronics.
- **Recycle**: Recovering materials.
- **Recover**: Extracting energy/metals.

Mnemonic

"Reduce, Reuse, Recycle, Recover Resources"

Question 5(b) OR [4 marks]

Derive the relationship between α_{dc} and β_{dc}.

Solution

Given:

- $\alpha_{dc} = I_C/I_E$
- $\beta_{dc} = I_C/I_B$

Derivation: From KCL: $I_E = I_C + I_B$ Divide by I_C:

$$\frac{I_E}{I_C} = 1 + \frac{I_B}{I_C}$$

$$\frac{1}{\alpha} = 1 + \frac{1}{\beta}$$

$$\frac{1}{\alpha} = \frac{\beta + 1}{\beta}$$

$$\alpha = \frac{\beta}{1+\beta}$$

Similarly,

$$\beta = \frac{\alpha}{1-\alpha}$$

Mnemonic

"Alpha approaches One as Beta approaches Infinity"

Question 5(c) OR [7 marks]

Explain common collector configuration with its input and output characteristics.

Solution

Common Collector (Emitter Follower):

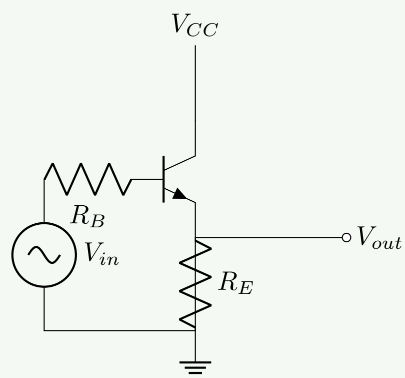


Figure 16. Common Collector Circuit

Characteristics:

- **Input**: Plot of I_B vs V_{BC}. High input impedance.
- **Output**: Plot of I_E vs V_{CE}. Low output impedance.
- **Voltage Gain**: ≈ 1.
- **Current Gain**: High $(\beta + 1)$.

Mnemonic

"Collector Common, Current amplifies, Voltage follows"