AKTU · 1ST YEAR · AEC101A / AEC201A

Fundamentals of Electronics Engineering

Unit 2 — Transistors as Switches and Amplifiers

- Bipolar Junction Transistor (BJT): Construction & VI characteristics of BJT, NPN and PNP
- three regions of operation (cut-off, active, saturation)
- BJT as a switch (digital control of relay, buzzer, motor)
- BJT as a common-emitter amplifier (concept and gain)
- Introduction to FETs
- MOSFET: N-channel MOSFET, gate-source voltage, MOSFET as a switch



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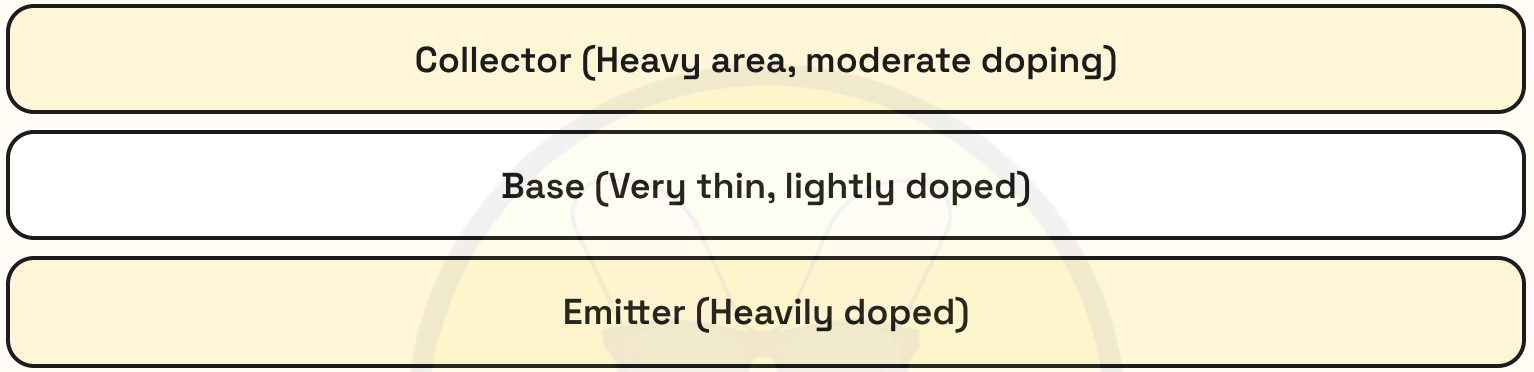
Bipolar Junction Transistor

BJT

A three-terminal semiconductor device consisting of two p-n junctions formed by sandwiching either a p-type or n-type layer between two opposite types.

- Terminals are Emitter, Base, and Collector.
- Called bipolar because conduction involves both electrons and holes.
- Used primarily for amplification and switching.

BJT Construction Layers



Physical layer structure of a BJT (NPN or PNP arrangement)

NPN vs PNP Transistor Comparison

Parameter	NPN Transistor	PNP Transistor
Sandwich structure	n-type region between two p-layers	p-type region between two n-layers
Majority carriers	Electrons	Holes
Current flow	Mainly due to electrons	Mainly due to holes
Switching speed	Faster due to electron mobility	Slower due to hole mobility

BJT VI Characteristics

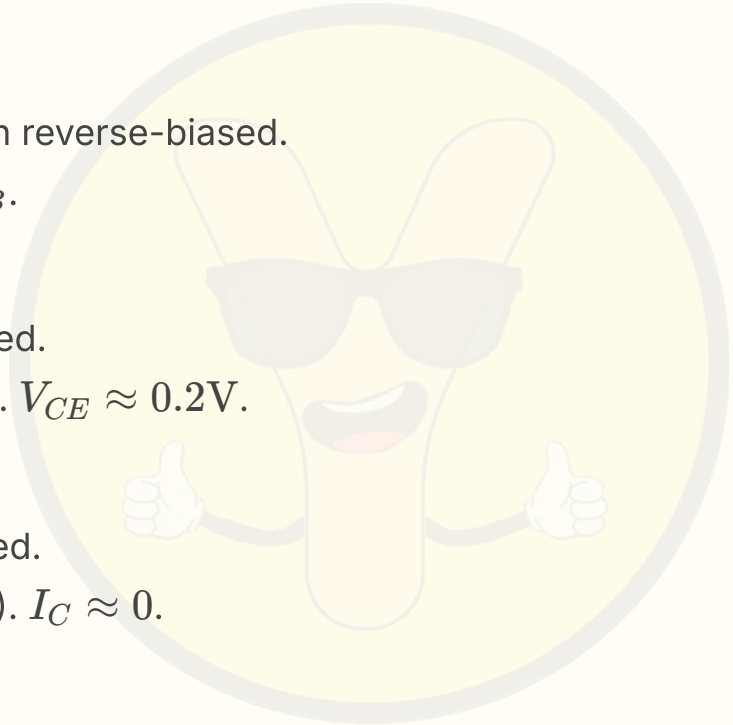
Input and output characteristics define how a BJT operates under different voltage and current conditions.

- Input characteristics plot base current I_B versus base-emitter voltage V_{BE} for a constant collector-emitter voltage V_{CE}.
- Output characteristics plot collector current I_C versus V_{CE} for various constant base currents I_B.
- Output curves show three distinct regions: Saturation, Active, and Cut-off.

Three Regions of BJT Operation

The operating region depends on the biasing of the emitter-base (EB) and collector-base (CB) junctions.

- Active Region
  - EB junction forward-biased, CB junction reverse-biased.
  - Used for linear amplification: $I_C = \beta I_B$.
- Saturation Region
  - Both EB and CB junctions forward-biased.
  - Transistor acts as a closed switch (ON). $V_{CE} \approx 0.2\text{V}$.
- Cut-off Region
  - Both EB and CB junctions reverse-biased.
  - Transistor acts as an open switch (OFF). $I_C \approx 0$.

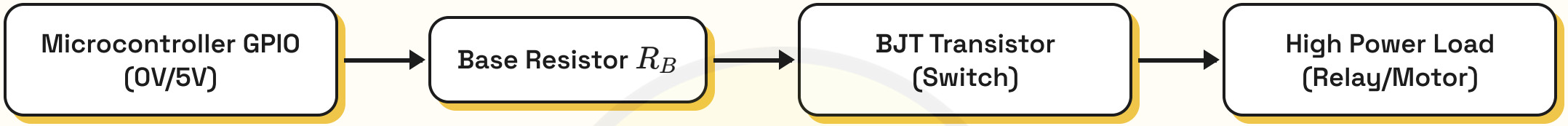


BJT as a Electronic Switch

A BJT can operate as a binary switch by toggling between cut-off and saturation.

- OFF State: Base current $I_B = 0$, keeping $V_{BE} < 0.7\text{V}$. $I_C = 0$, $V_{CE} = V_{CC}$.
- ON State: Base current I_B is large enough to drive the transistor into saturation.
- Collector-emitter voltage drops to a very small saturation voltage $V_{CE(sat)}$.
- Used extensively in digital control to interface low-power microcontrollers with high-power actuators.

Digital Control Flow using BJT



Chain of command in digital control circuits

BJT as a Common-Emitter Amplifier

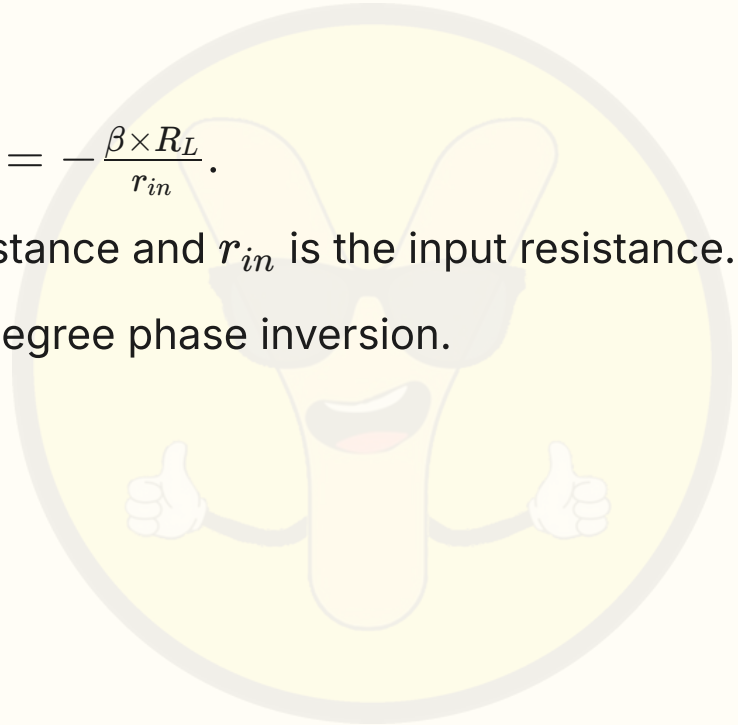
The Common-Emitter (CE) configuration provides both voltage and current amplification.

- The emitter terminal is common to both the input and output circuits.
- A small change in base current ΔI_B results in a large change in collector current ΔI_C.
- Collector current variation across load resistor R_C produces a large output voltage swing.
- The output voltage is 180 degrees out of phase with the input voltage.

CE Amplifier Voltage Gain

Mathematical expression and parameters governing amplifier performance.

- Current gain $\beta = \frac{\Delta I_C}{\Delta I_B}$.
- AC Voltage gain A_v is given by: $A_v = -\frac{\beta \times R_L}{r_{in}}$.
- Where R_L is the effective load resistance and r_{in} is the input resistance.
- The negative sign indicates a 180-degree phase inversion.



Introduction to Field Effect Transistors

FET

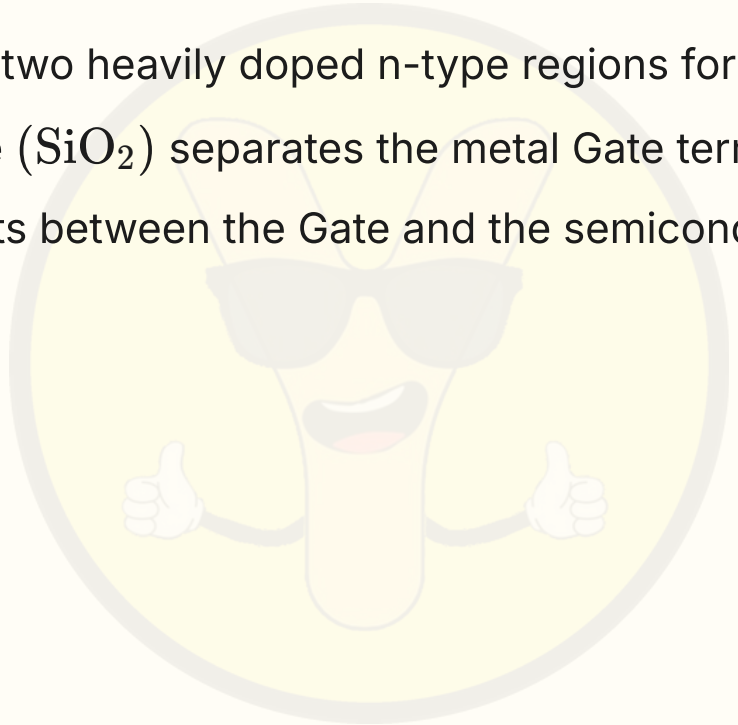
A unipolar voltage-controlled semiconductor device where current conduction is controlled by an electric field rather than injection of charge carriers.

- Terminals are Gate, Source, and Drain.
- Extremely high input impedance because the gate is isolated from the channel.
- Divided into JFET (Junction FET) and MOSFET (Metal-Oxide-Semiconductor FET).

N-Channel MOSFET Construction

Metal-Oxide-Semiconductor Field-Effect Transistor structure and layout.

- Consists of a p-type substrate with two heavily doped n-type regions forming Source and Drain.
- An insulating layer of silicon dioxide $(\mathrm{SiO_2})$ separates the metal Gate terminal from the channel.
- No direct electrical connection exists between the Gate and the semiconductor body.



Gate-Source Voltage and Operation

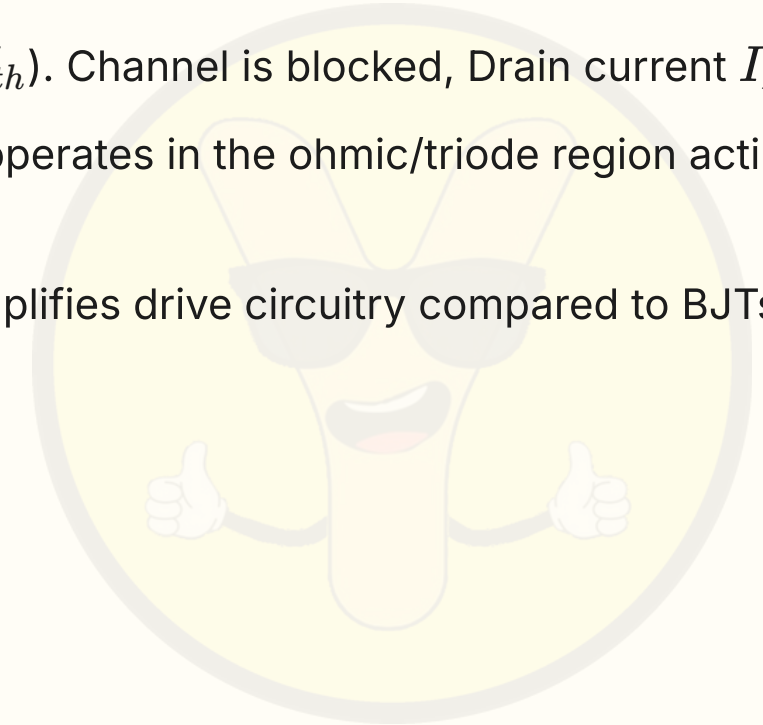
Controlling the conductive channel using the gate electric field.

- Enhancement Mode: Applying positive V_{GS} attracts electrons to the region beneath the gate, forming an inversion n-channel.
- Threshold Voltage V_{th}: The minimum V_{GS} required to create the conductive channel.
- When $V_{GS} < V_{th}$, the MOSFET is OFF.
- When $V_{GS} > V_{th}$, current flows freely from Drain to Source.

MOSFET as a Switch

Fast and efficient switching operation using voltage control.

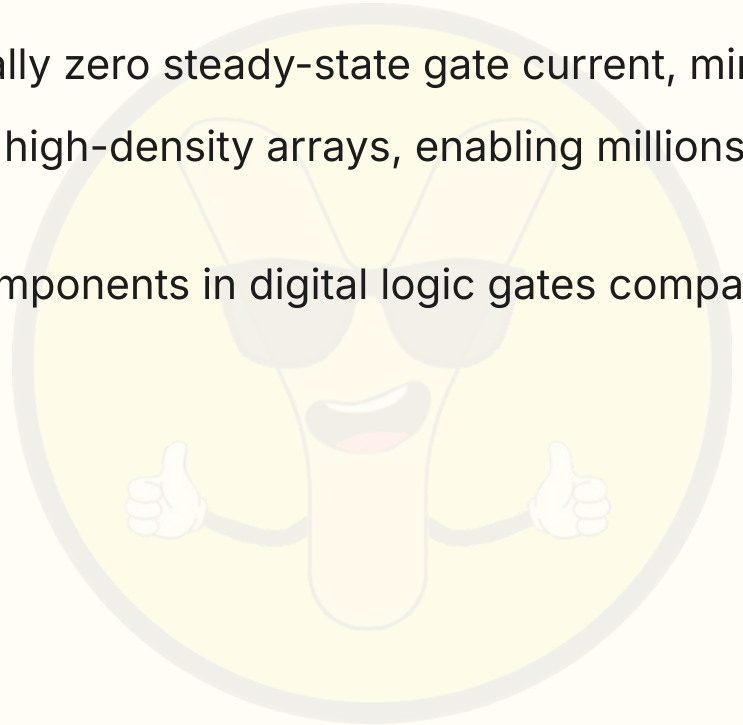
- OFF State: $V_{GS} = 0\text{V}$ (or below V_{th}). Channel is blocked, Drain current $I_D = 0$.
- ON State: $V_{GS} \gg V_{th}$. Transistor operates in the ohmic/triode region acting as a very small resistance $R_{DS(on)}$.
- Zero steady-state gate current simplifies drive circuitry compared to BJTs.



Why MOSFET is Preferred in Digital ICs

Advantages of MOSFETs in modern VLSI and digital systems.

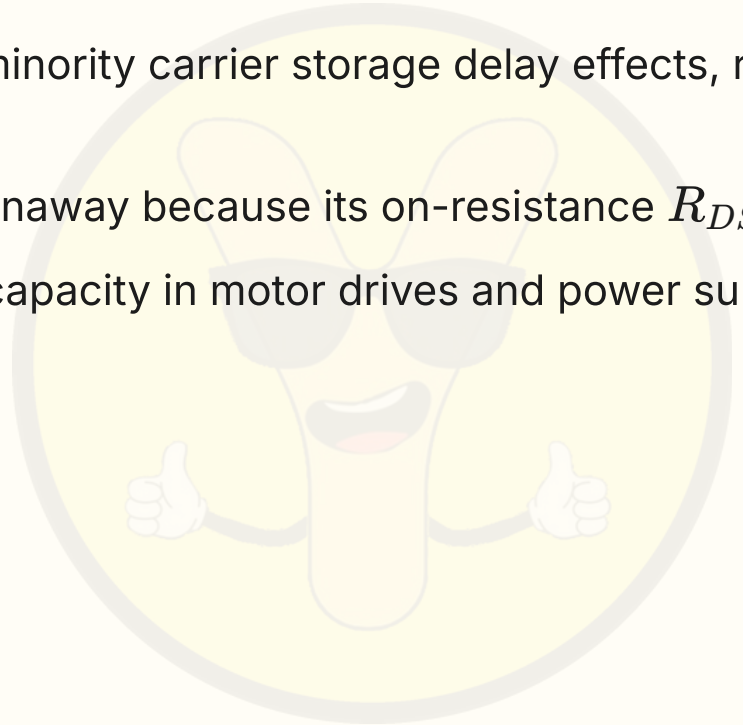
- High Input Impedance: Draws virtually zero steady-state gate current, minimizing power consumption.
- Miniaturization: Easy to fabricate in high-density arrays, enabling millions of transistors on a single chip (CMOS technology).
- Simple Circuitry: Requires fewer components in digital logic gates compared to BJTs.



Why MOSFET is Preferred in Power Electronics

Handling high voltages and currents with minimal thermal losses.

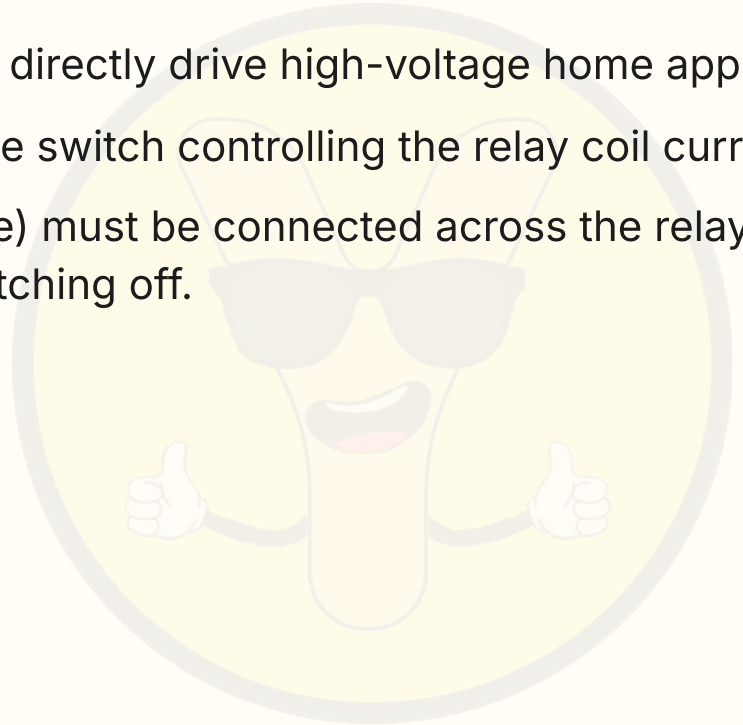
- Fast Switching Speeds: Free from minority carrier storage delay effects, reducing switching losses at high frequencies.
- Thermal Stability: Avoids thermal runaway because its on-resistance $R_{DS(on)}$ increases with temperature.
- High voltage and current handling capacity in motor drives and power supplies.



Application: Transistor Switch for Driving a Relay

Protecting control circuits while operating inductive loads in home automation.

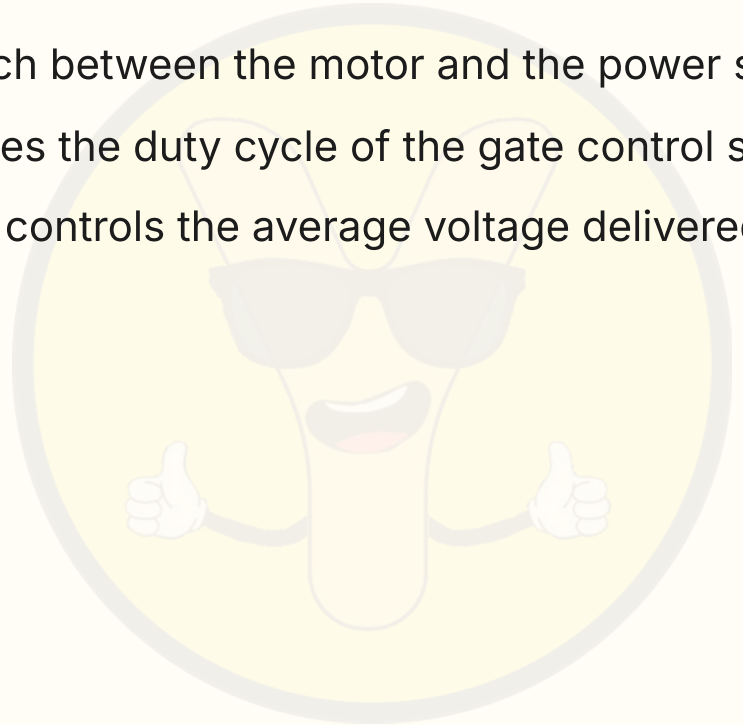
- A microcontroller output pin cannot directly drive high-voltage home appliances via a relay coil.
- A BJT or MOSFET acts as a low-side switch controlling the relay coil current.
- A flyback diode (freewheeling diode) must be connected across the relay coil in reverse bias to absorb back-EMF voltage spikes when switching off.



Application: MOSFET in Motor Speed Control (PWM)

Utilizing Pulse Width Modulation for efficient speed regulation.

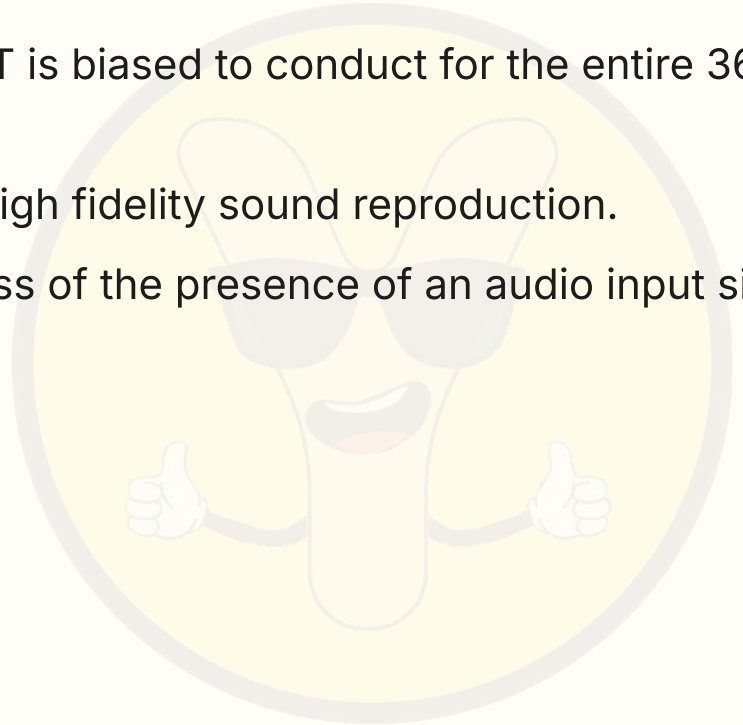
- MOSFET acts as a high-speed switch between the motor and the power supply.
- PWM (Pulse Width Modulation) varies the duty cycle of the gate control signal.
- Changing the ON-to-OFF time ratio controls the average voltage delivered to the motor without dissipating excess power as heat.



Application: Transistor in Class-A Amplifier for Audio

Linear audio amplification using a biased BJT.

- In a Class-A audio amplifier, the BJT is biased to conduct for the entire 360 degrees of the input audio signal cycle.
- Provides low signal distortion and high fidelity sound reproduction.
- Draws constant DC power regardless of the presence of an audio input signal, resulting in lower electrical efficiency.



BJT Switching Design Example

Calculate the minimum base current I_B required to saturate a BJT switch controlling a relay of resistance $R_C = 100\Omega$ connected to $V_{CC} = 12\text{V}$. Assume $\beta = 50$ and $V_{CE(sat)} = 0.2\text{V}$.

1. Step 1: Find collector saturation current $I_{C(sat)} = \frac{V_{CC} - V_{CE(sat)}}{R_C}$.
2. Step 2: $I_{C(sat)} = \frac{12 - 0.2}{100} = \frac{11.8}{100} = 0.118\text{A} = 118\text{mA}$.
3. Step 3: Calculate base current $I_B = \frac{I_{C(sat)}}{\beta}$.
4. Step 4: $I_B = \frac{118\text{mA}}{50} = 2.36\text{mA}$. (Apply a safety factor of 2 to ensure deep saturation).

Minimum base current required $I_B = 2.36\text{mA}$ (use $\approx 5\text{mA}$ practically).

Exam corner

- **Q1** Explain the construction and working of an NPN BJT with neat diagrams of input and output characteristics.
- **Q2** List and explain the three regions of operation of a BJT with respect to junction biasing conditions.
- **Q3** Explain how a BJT operates as a switch. Design a circuit to drive a relay using an NPN transistor.
- **Q4** Derive the expression for voltage gain in a Common-Emitter BJT amplifier.
- **Q5** Compare BJT and MOSFET. Why is MOSFET preferred in VLSI digital integrated circuits?
- **Q6** Explain the construction and working of an N-channel enhancement MOSFET with gate-source voltage control.
- **Q7** Describe how PWM is used with MOSFETs for motor speed control applications.

Unit 2 done. You are exam-ready.

Revise the Exam corner once more, then open Unit 3 on theycotes.com. Every AKTU subject, unit by unit, free. Notes by Chirag Jain, Ycotes.

