Subject Name Solutions

4311102 – Summer 2023

Semester 1 Study Material

Detailed Solutions and Explanations

Question 1(a) [3 marks]

Define Active and Passive components.

Solution

Active Components	Passive Components
• Require external power source to operate • Can amplify and process electrical signals • Examples: transistors, diodes, ICs	• Do not need external power source • Cannot amplify or process signals • Examples: resistors, capacitors, inductors

Mnemonic

"APE" - Active needs Power to Enhance signals

Question 1(b) [4 marks]

State types of capacitors based on materials used.

Solution

Table 1: Types of Capacitors Based on Materials

Material Type	Capacitor Type	Typical Applications
Ceramic	Ceramic disc, multilayer	Bypass, coupling, high frequency
Plastic Film	Polyester, Polypropylene, Teflon	Timing, filtering, precision
Electrolytic	Aluminum, Tantalum	Power supply, DC blocking, high capacitance
Paper	Paper dielectric	Old equipment, not common now
Mica	Silvered mica	High precision RF circuits
Glass	Glass dielectric	High voltage applications

Mnemonic

"CEPPMG" - Ceramic Electrolytic Paper Plastic Mica Glass

Question 1(c) [7 marks]

Explain resistor color coding technique with example.

Solution

The resistor color code uses colored bands to indicate resistance value, tolerance, and reliability.

Table 2: Standard Resistor Color Code

Color	Digit Value	Multiplier	Tolerance
Black	0	$\times 10^0 (1)$	-
Brown	1	$\times 10^1 (10)$	$\pm 1\%$
Red	2	$\times 10^2 (100)$	$\pm 2\%$

Orange	3	$\times 10^3 (1,000)$	-
Yellow	4	$\times 10^4 (10,000)$	-
Green	5	$\times 10^5 (100,000)$	$\pm 0.5\%$
Blue	6	$\times 10^6 (1,000,000)$	$\pm 0.25\%$
Violet	7	$\times 10^7 (10,000,000)$	$\pm 0.1\%$
Grey	8	$\times 10^8 (100,000,000)$	$\pm 0.05\%$
White	9	$\times 10^9 (1,000,000,000)$	-
Gold	-	$\times 0.1 (0.1)$	$\pm 5\%$
Silver	-	$\times 0.01 (0.01)$	$\pm 10\%$

Example 1: Red-Violet-Orange-Gold

- 1st band (Red) = 2
- 2nd band (Violet) = 7
- 3rd band (Orange) = $\times 1,000$
- 4th band (Gold) = $\pm 5\% tolerance$
- Value: 27 $\times 1,000 = 27,000 = 27k \pm 5\%$

Example 2: Brown-Black-Yellow-Silver

- 1st band (Brown) = 1
- 2nd band (Black) = 0
- 3rd band (Yellow) = $\times 10,000$
- 4th band (Silver) = $\pm 10\% tolerance$
- Value: 10 $\times 10,000 = 100,000 = 100k \pm 10\%$

```
flowchart LR
    A[1st Band{br /First Digit] {-}{-} B[2nd Bandbr /Second Digit]}
    B {-{-} C[3rd Bandbr /Multiplier]}
    C {-{-} D[4th Bandbr /Tolerance]}
    style A fill:\#f96,stroke:\#333
    style B fill:\#69f,stroke:\#333
    style C fill:\#f90,stroke:\#333
    style D fill:\#fc0,stroke:\#333
```

Mnemonic

"BBROY Great Britain Very Good Wife" for colors 0-9 (Black Brown Red Orange Yellow Green Blue Violet Gray White)

Question 1(c) OR [7 marks]

Explain construction, working Characteristic and application of LDR.

Solution

Light Dependent Resistor (LDR)

Aspect	Description
Construction	• Semiconductor material (cadmium sulfide) deposited in zigzag pattern • Packaged in transparent case to allow light exposure • Two terminals connected to the semiconductor
Working Principle	• Resistance decreases when light intensity increases • Photons release electrons in semiconductor material • More light = more free electrons = lower resistance
Characteristics	• High resistance in darkness (MΩ range) • Low resistance in bright light (100-5000Ω) • Non-linear response to light intensity • Slow response time (tens of milliseconds)
Applications	• Automatic street lights • Light meters in cameras • Burglar alarm systems • Automatic brightness control in displays

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[More Light] {-{-}{}|Releases electrons| B[More Free Electrons]}
    B {-{-}{} C[Lower Resistance]}
    D[Less Light] {-{-}{}|Fewer electrons released| E[Fewer Free Electrons]}
    E {-{-}{} F[Higher Resistance]}
{Highlighting}
{Shaded}
```

Mnemonic

"MOLD" - More light On, Less resistance Down

Question 2(a) [3 marks]

Classify Resistors based on materials.

Solution

Table 3: Resistor Classification Based on Materials

Material Type	Characteristics	Examples
Carbon Composition	Low cost, noisy, poor tolerance	General purpose resistors
Carbon Film	Better stability than carbon composition	Audio equipment, general circuits
Metal Film	Excellent stability, low noise	Precision circuits, instrumentation
Metal Oxide	High stability, heat resistant	Power supplies, high-voltage circuits
Wire Wound	High power rating, inductive	Power circuits, heating elements
Thick & Thin Film	Small size, good stability	Surface mount applications

Mnemonic

"CMMWTF" - Carbon Makes Much Wire To Form resistors

Question 2(b) [4 marks]

Calculate value of resistor for a given color code. – (i) Brown, Black, Yellow, Golden (ii) Yellow, Violet, Red, Silver

Solution

Part (i): Brown, Black, Yellow, Golden

- 1st Band (Brown) = 1
- 2nd Band (Black) = 0
- 3rd Band (Yellow) = $\times 10,000$
- 4th Band (Golden) = $\pm 5\% tolerance$

Calculation: Value = 10 $\times 10,000 = 100,000 = 100k \pm 5\%$

Part (ii): Yellow, Violet, Red, Silver

- 1st Band (Yellow) = 4
- 2nd Band (Violet) = 7
- 3rd Band (Red) = $\times 100$
- 4th Band (Silver) = $\pm 10\% tolerance$

Calculation: Value = 47 $\times 100 = 4,700 = 4.7k \pm 10\%$

Mnemonic

"BBROY Great Britain Very Good Wife" for the color sequence 0-9

Question 2(c) [7 marks]

Illustrate construction and operation of Electrolytic capacitors.

Solution

Electrolytic Capacitor Construction and Operation

Component	Description
Anode	Aluminum or tantalum foil with oxide layer (dielectric)
Cathode	Electrolyte (liquid, paste or solid) and metal foil
Separator	Paper soaked in electrolyte
Casing	Aluminum can with insulating sleeve
Terminals	Positive (+) and negative (-) leads

Operation Principle:

1. The oxide layer on the anode acts as an extremely thin dielectric
2. The large surface area and thin dielectric create high capacitance
3. When connected to DC voltage (with correct polarity), charges accumulate
4. Positive plate (+) attracts negative charges; negative plate (-) attracts positive charges

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Aluminum Foil{br /{}Anode] {-}{-}{} B[Oxide Layer{}br /{}Dielectric]}
    B {-{-}{} C[Electrolyte{}br /{}Cathode]}
    C {-{-}{} D[Aluminum Foil{}br /{}Terminal Connection]}
    style A fill:\#fc9,stroke:\#333
    style B fill:\#9cf,stroke:\#333
    style C fill:\#cfc,stroke:\#333
    style D fill:\#fc9,stroke:\#333
{Highlighting}
{Shaded}
```

Key Characteristics:

- **Polarity**: Must be connected correctly (+/-)
- **High capacitance**: 1 F to thousands of F
- **Voltage limitations**: Breakdown if exceeded
- **Leakage current**: Higher than other capacitor types

Mnemonic

"PAVE" - Polarized Aluminum with Very high capacitance and Electrolyte

Question 2(a) OR [3 marks]

State the importance of filter circuit in rectifier.

Solution

Importance of Filter Circuit in Rectifier

Function	Description
Smoothing	Converts pulsating DC to smooth DC by reducing ripples

Voltage Stabilization	Maintains steady output voltage despite input fluctuations
Ripple Reduction	Decreases unwanted AC components in DC output
Load Protection	Protects electronic devices from voltage variations

Mnemonic

“SVRL” - Smoothens Voltage by Reducing ripples for Load

Question 2(b) OR [4 marks]

Differentiate between P type semiconductor and N type semiconductor.

Solution

Table 4: P-type vs N-type Semiconductor

Characteristic	P-type Semiconductor	N-type Semiconductor
Dopant used	Trivalent elements (B, Al, Ga)	Pentavalent elements (P, As, Sb)
Majority carriers	Holes (positive charge carriers)	Electrons (negative charge carriers)
Minority carriers	Electrons	Holes
Conductivity	Due to movement of holes	Due to movement of electrons
Energy level	Acceptor atoms near valence band	Donor atoms near conduction band
Electrical charge	Overall neutral, but accepts electrons	Overall neutral, but donates electrons

Mnemonic

“HELP-NED” - Holes Exist in Large quantities in P-type, Negative Electrons Dominate N-type

Question 2(c) OR [7 marks]

Illustrate working of Bridge Rectifier with waveforms.

Solution

Bridge Rectifier Working Principle

Component	Function
Diodes (D1-D4)	Four diodes arranged in bridge configuration
Input	AC voltage from transformer secondary
Output	Pulsating DC voltage across load resistor
Operation	Converts both halves of AC cycle to same polarity

Working in Positive Half Cycle:

- Diodes D1 and D3 conduct
- Diodes D2 and D4 are reverse biased (off)
- Current flows: AC+ $\rightarrow D1 \rightarrow Load \rightarrow D3 \rightarrow AC-$

Working in Negative Half Cycle:

- Diodes D2 and D4 conduct
- Diodes D1 and D3 are reverse biased (off)
- Current flows: AC- $\rightarrow D2 \rightarrow Load \rightarrow D4 \rightarrow AC+$

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    AC[AC Input] {-{-}{} D1[D1]}
    AC {-{-}{} D3[D3]}
    D1 {-{-}{} Load[Load]}
    D3 {-{-}{} Load}
    Load {-{-}{} D2[D2]}
    Load {-{-}{} D4[D4]}
    D2 {-{-}{} AC}
    D4 {-{-}{} AC}
    style AC fill:\#fcf,stroke:\#333
    style Load fill:\#cfc,stroke:\#333
    style D1 fill:\#9cf,stroke:\#333
    style D2 fill:\#9cf,stroke:\#333
    style D3 fill:\#9cf,stroke:\#333
    style D4 fill:\#9cf,stroke:\#333
{Highlighting}
{Shaded}
```

Waveforms:

```
AC Input:      \_/{      \_/      \_/      }
              /    {   /       /       }
    0 \_\_\_\_\_\_/      {\_/      \_/      \_\_}
             {    /       /       /}
              {\_\_/     \_\_/     \_\_/}


DC Output:     \_       \_       \_
              / {     /      /      }
    0 \_\_\_\_\_\_/   {\_\_\_/   \_\_\_/   \_\_\_\_\_}
```

Advantages:

- Utilizes both half cycles of AC input
- Higher output voltage and efficiency compared to half-wave
- No center-tapped transformer required

Mnemonic

"FBRO" - Four diodes, Both cycles, Rectified Output

Question 3(a) [3 marks]

Define (1) PIV (2) Ripple Factor.

Solution

Term	Definition
PIV (Peak Inverse Voltage)	• Maximum voltage a diode can withstand in reverse bias condition • Important rating to prevent diode breakdown • Must be higher than maximum reverse voltage in circuit
Ripple Factor (r)	• Measure of effectiveness of a rectifier filter • Ratio of RMS value of AC component to DC component in output • Lower ripple factor indicates better filtering

Formula: Ripple Factor (r) = V$_{(ms)a\cdot k}/V_{()}$

Mnemonic

"PIR" - Peak Inverse voltage Restricts, Ripple indicates Rectification quality

Question 3(b) [4 marks]

Illustrate VI characteristics of PN junction diode.

Solution

V-I Characteristics of PN Junction Diode

Region	Behavior	Characteristics
Forward Bias	Conducts current easily	• Exponential increase in current after threshold • Threshold voltage: ~0.7V for silicon, ~0.3V for germanium
Reverse Bias	Blocks current	• Very small leakage current (A) • Breakdown at reverse breakdown voltage

```
        Current (I)
            ↑
            |            /
            |           /
            |          /
            |         /
            |        /
    {-{-}{-}{-}{-}{-}{-}{-}{-}|{-}{-}{-}{-}{-}{-}{-}/{-}{-}{-}{-}{-} Voltage (V)}
            |    0.7V
            |/
     \_\_\_\_\_\_\_\_|\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
            |
            | Small leakage current
            |
            |       Breakdown
            |          ↓
            |          |
            |          |
```

Key Points:

- **Forward threshold**: ~0.7V for Si, ~0.3V for Ge
- **Forward region**: High conductivity
- **Reverse region**: Very high resistance
- **Breakdown region**: Sudden increase in reverse current

Mnemonic

"FBRL" - Forward Bias Resists Little, reverse blocks lots

Question 3(c) [7 marks]

Explain the working of capacitor input and choke input filter with waveforms.

Solution

1. Capacitor Input Filter

Component	Function
Capacitor	Connected in parallel with load resistance
Working Principle	• Charges during voltage peaks • Discharges during voltage dips • Acts as charge reservoir
Waveforms	• Reduces ripple significantly • Output has slight discharge slope

Advantages:

- Higher DC output voltage
- Simple and economical
- Good ripple reduction

Limitations:

- Poor voltage regulation
- High peak diode currents
- Suitable for low current applications

2. Choke Input Filter

Component	Function
Inductor (Choke)	Connected in series with load
Capacitor	Connected in parallel with load
Working Principle	• Inductor opposes current changes • Capacitor smooths remaining ripples
Waveforms	• More constant current • Lower but more stable output voltage

Advantages:

- Better voltage regulation
- Lower peak diode currents
- Suitable for high current applications

Limitations:

- Lower DC output voltage
- More expensive
- Bulkier than capacitor filter

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Rectifier Output] {-{-}{} B[Capacitor/Choke Input]}
    B {-{-}{} C[Filtered Output]}
    style A fill:\#f96,stroke:\#333
    style B fill:\#69f,stroke:\#333
    style C fill:\#6f9,stroke:\#333
{Highlighting}
{Shaded}
```

Waveform Comparison:

```
Rectifier output:     \_\_      \_\_      \_\_
                     /  {    /      /  }
                    /    {  /      /    }
           0 \_\_\_\_\_\_/      {/      /      \_\_\_\_}

Capacitor filter:    \_\_\_     \_\_\_     \_\_\_
                     {              }
                      {              }
           0 \_\_\_\_\_\_\_\_\_\_{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_}

Choke filter:         \_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_
                     /          /
                    /          /
           0 \_\_\_\_\_\_/          /\_\_\_\_\_\_\_\_\_\_\_\_
```

Mnemonic

"VOICE" - Voltage Output Is Constant with Either filter, but choke gives better regulation

Question 3(a) OR [3 marks]

State the function and importance of Zener diode.

Solution

Function and Importance of Zener Diode

Function	Description
Voltage Regulation	Maintains constant output voltage despite input variations
Voltage Reference	Provides precise reference voltage in circuits
Voltage Protection	Prevents voltage spikes from damaging circuits
Voltage Limiting	Clips signal voltages to predetermined levels
Waveform Clipping	Shapes waveforms by limiting voltage levels

Mnemonic

"VPRVW" - Voltage Protection, Regulation, and Voltage Waveform control

Question 3(b) OR [4 marks]

Describe Light emitting diode (LED) with its characteristic.

Solution

Light Emitting Diode (LED) Characteristics

Characteristic	Description
Construction	• P-N junction made from direct bandgap semiconductors • Common materials: GaAs, GaP, AlGaInP, InGaN
Working Principle	• Electroluminescence: electrons recombine with holes • Energy released as photons (light)
Forward Voltage	• Red: 1.8-2.1V • Green: 2.0-3.0V • Blue/White: 3.0-3.5V
Colors Available	• Depends on semiconductor material • Red, green, yellow, blue, white, IR, UV
I-V Characteristics	• Conducts when forward biased above threshold • Requires current-limiting resistor • Damaged by reverse bias above 5V
Applications	• Indicators, displays, lighting, optocouplers

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Voltage Applied] {-{-}{}|Forward Bias| B[Electron{-}Hole Recombination]}
    B {-{-}{} C[Energy Released]}
    C {-{-}{} D[Light Emission]}
    style A fill:\#f96,stroke:\#333
    style B fill:\#69f,stroke:\#333
    style C fill:\#fc9,stroke:\#333
    style D fill:\#6f9,stroke:\#333
{Highlighting}
{Shaded}
```

Mnemonic

"CRAVE" - Current Regulated And Voltage Emits light

Question 3(c) OR [7 marks]

Illustrate the working of capacitor input and choke input filter.

Solution

Capacitor Input Filter:

Component	Function
Circuit Structure	Capacitor connected in parallel with load
Operation	• Capacitor charges to peak voltage • Discharges slowly through load when voltage drops • Acts as reservoir of charge
Performance	• Good ripple reduction • Higher output voltage • Poor regulation under varying loads

Circuit Diagram:

```
    +{-{-}{-}{-}{-}{-}||{-}{-}{-}{-}{-}{-}+}
    |      D1       |
AC  |               | Load
In  |               | RL    +
    +{-{-}{-}{-}{-}{-}||{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}||{-}{-}{-}+}
    |      D2       |     C    |
    +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+}
```

Choke Input Filter:

Component	Function
Circuit Structure	Inductor (choke) in series, capacitor in parallel
Operation	• Inductor opposes change in current • Smooths current flow • Capacitor further filters voltage ripples
Performance	• Better voltage regulation • Lower output voltage • Good for high-current applications

Circuit Diagram:

```
    +{-{-}{-}{-}{-}{-}||{-}{-}{-}{-}{-}{-}+}
    |      D1       |
AC  |               +{-{-}{-}{-}LLLLL{-}{-}{-}{-}+}
In  |                     L        |
    +{-{-}{-}{-}{-}{-}||{-}{-}{-}{-}{-}{-}+         RL +}
    |      D2       |     C        |
    +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}||{-}{-}{-}{-}{-}{-}{-}+}
```

Comparison:

Parameter	Capacitor Input	Choke Input
Output Voltage	Higher ($\approx 1.4Vm$)	Lower ($\approx 0.9Vm$)
Ripple Factor	Higher	Lower
Voltage Regulation	Poor	Good
Diode Current	High peak currents	Lower peak currents
Cost & Size	Lower, smaller	Higher, larger
Applications	Low current needs	High current needs

Mnemonic

"CHEER" - Capacitor Holds Energy, inductor Ensures Regulated current

Question 4(a) [3 marks]

Discuss characteristics of PN junction diode.

Solution

Characteristics of PN Junction Diode

Characteristic	Description
Forward Bias	• Conducts when voltage > threshold (0.7V for Si, 0.3V for Ge) • Current increases exponentially with voltage • Low resistance state
Reverse Bias	• Blocks current flow • Small leakage current (A) • High resistance state
Breakdown	• Occurs at specific reverse voltage • Current increases rapidly • Can damage diode if current not limited
Temperature Effects	• Forward voltage decreases with temperature • Reverse leakage current doubles every 10
Capacitance	• Junction capacitance varies with applied voltage • Higher in forward bias

Mnemonic

"FRBCT" - Forward conducts, Reverse blocks, Breakdown destroys, Capacitance changes, Temperature affects

Question 4(b) [4 marks]

Compare between P-N junction diode and Zener diode.

Solution

Table 5: P-N Junction Diode vs. Zener Diode

Parameter	P-N Junction Diode	Zener Diode
Symbol	⟨	⟨
Forward Operation	Conducts above 0.7V	Conducts above 0.7V (similar)
Reverse Operation	Blocks current until breakdown	Designed to operate in controlled breakdown
Breakdown Voltage	Higher, not specified precisely	Lower, precisely specified (2-200V)
Reverse Breakdown	Destructive if not limited	Non-destructive, used for operation
Applications	Rectification, switching	Voltage regulation, protection
Doping Level	Normal doping	Heavily doped to control breakdown

Mnemonic

"FORBAR" - Forward Operation is Regular, Breakdown Application is the Real difference

Question 4(c) [7 marks]

Illustrate the function of Zener diode as a voltage regulator.

Solution

Zener Diode as Voltage Regulator

Component	Function
Zener Diode	Maintains constant voltage in breakdown region
Series Resistor (Rs)	Limits current and drops excess voltage
Load Resistor (RL)	Represents the circuit being powered

Working Principle:

1. Zener diode is connected in reverse bias
2. When input voltage rises above Zener voltage, diode conducts
3. Excess voltage is dropped across series resistor
4. Output voltage remains constant at Zener voltage

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Input Voltage] {-{-}{} B[Series Resistor]}
    B {-{-}{} C[Output Voltage]}
    C {-{-}{} D[Load]}
    C {-{-}{} E[Zener Diode]}
    E {-{-}{} F[Ground]}
    style A fill:\#f96,stroke:\#333
    style B fill:\#69f,stroke:\#333
    style C fill:\#6f9,stroke:\#333
    style D fill:\#fc9,stroke:\#333
    style E fill:\#f9f,stroke:\#333
{Highlighting}
{Shaded}
```

Circuit Diagram:

```
     +{-{-}{-}{-}[Rs]{-}{-}{-}{-}{-}+{-}{-}{-}{-}+}
     |             |    |
Vin  |             +   RL   Vout = Vz
     |             |    |
     +{-{-}{-}{-}{-}{-}{-}{-}||{-}{-}+{-}{-}{-}{-}+}
              Zener
```

Regulation Cases:

Condition	Response
Input Voltage Increases	• More current through Zener • More voltage dropped across Rs • Output remains at Vz
Input Voltage Decreases	• Less current through Zener • Less voltage dropped across Rs • Output remains at Vz (until minimum operating voltage)
Load Current Increases	• Less current through Zener • Output voltage stable until minimum Zener current
Load Current Decreases	• More current through Zener • Output voltage remains stable

Limitations:

- Power dissipation in Zener and Rs
- Minimum input voltage requirement (Vin > Vz + Voltage drop across Rs)
- Limited current capability

Mnemonic

"VISOR" - Voltage In Stays Out Regulated

Question 4(a) OR [3 marks]

Discuss transistor in brief.

Solution

Transistor Overview

Aspect	Description
Definition	• Semiconductor device that amplifies/switches electrical signals • Three-terminal device: emitter, base, collector
Types	• Bipolar Junction Transistor (BJT): NPN, PNP • Field Effect Transistor (FET): JFET, MOSFET
Working Principle	• Current/voltage controlled device • Small base current controls larger collector current (BJT) • Gate voltage controls channel conductivity (FET)
Applications	• Amplification: audio, RF, power • Switching: digital circuits • Oscillators and signal generation
Importance	• Foundation of modern electronics • Enabled miniaturization of electronic devices

Mnemonic

"TAWAI" - Transistors Amplify, Work As switches, and are Integral to electronics

Question 4(b) OR [4 marks]

Derive relation between and for transistor amplifier.

Solution

Relation Between and

Parameter	Definition	Formula
(Alpha)	• Common Base (CB) current gain • Ratio of collector current to emitter current	= IC/IE
(Beta)	• Common Emitter (CE) current gain • Ratio of collector current to base current	= IC/IB

Derivation Steps:

1. We know that emitter current is the sum of base and collector currents: IE = IB + IC
2. Alpha definition: = IC/IE
3. Beta definition: = IC/IB
4. From step 1, we can write: IB = IE - IC
5. Substituting into beta definition: = IC/(IE - IC)
6. Using alpha definition, IC = $\times IE$:

$= (\times IE)/(IE - \times IE)$

7. Simplifying: = /(1 -)
8. Conversely, we can also express in terms of : = /(+ 1)

Relationship Table:

(Alpha)	(Beta)
0.9	9
0.95	19
0.98	49
0.99	99
0.995	199

Mnemonic

"ABR" - Alpha and Beta are Related by = /(+1) or = /(1-)

Question 4(c) OR [7 marks]

Explain in detail the construction of NPN and PNP transistor.

Solution

Construction of NPN and PNP Transistors

Parameter	NPN Transistor	PNP Transistor
Structure	• N-type (Emitter) • P-type (Base) • N-type (Collector)	• P-type (Emitter) • N-type (Base) • P-type (Collector)
Symbol		
Materials	• Silicon or Germanium • Emitter: Heavily doped N-type • Base: Lightly doped P-type • Collector: Moderately doped N-type	• Silicon or Germanium • Emitter: Heavily doped P-type • Base: Lightly doped N-type • Collector: Moderately doped P-type
Thickness	• Base: Very thin (1-10 m) • Collector: Thickest region	• Base: Very thin (1-10 m) • Collector: Thickest region
Doping Level	• Emitter: Highest • Base: Lowest • Collector: Medium	• Emitter: Highest • Base: Lowest • Collector: Medium

NPN Transistor Construction:

```
    Emitter (N)   Base (P)   Collector (N)
       |             |             |
       v             v             v
    +{-{-}{-}{-}{-}{-}+     +{-}{-}{-}+     +{-}{-}{-}{-}{-}{-}{-}{-}+}
    |  N+  |     | P |     |    N     |
    +{-{-}{-}{-}{-}{-}+     +{-}{-}{-}+     +{-}{-}{-}{-}{-}{-}{-}{-}+}
       |           |           |
       |           |           |
       E           B           C
```

PNP Transistor Construction:

```
    Emitter (P)   Base (N)   Collector (P)
       |             |             |
       v             v             v
    +{-{-}{-}{-}{-}{-}+     +{-}{-}{-}+     +{-}{-}{-}{-}{-}{-}{-}{-}+}
    |  P+  |     | N |     |    P     |
    +{-{-}{-}{-}{-}{-}+     +{-}{-}{-}+     +{-}{-}{-}{-}{-}{-}{-}{-}+}
       |           |           |
       |           |           |
       E           B           C
```

Manufacturing Process:

1. Start with semiconductor substrate (N or P type)
2. Create layers through epitaxial growth
3. Form junctions through diffusion or ion implantation
4. Add metal contacts for terminals
5. Package in protective case

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Silicon Wafer] {-{-}{} B[Epitaxial Layer Growth]}
    B {-{-}{} C[Diffusion of Dopants]}
    C {-{-}{} D[Oxide Insulation]}
    D {-{-}{} E[Metallization]}
    E {-{-}{} F[Packaging]}
    style A fill:\#fc9,stroke:\#333
    style B fill:\#69f,stroke:\#333
    style C fill:\#f9f,stroke:\#333
    style D fill:\#cfc,stroke:\#333
    style E fill:\#f96,stroke:\#333
    style F fill:\#9cf,stroke:\#333
{Highlighting}
{Shaded}
```

Mnemonic

"ENB-CPM" - Emitter has N in NPN, Collector is Proportionally Medium-doped

Question 5(a) [3 marks]

Explain e-waste in brief.

Solution

Electronic Waste (E-Waste)

Aspect	Description
Definition	• Discarded electronic devices and equipment • Contains both valuable materials and hazardous substances
Sources	• Computers, phones, TVs, appliances • Circuit boards, batteries, displays • Office equipment, medical devices
Concerns	• Contains toxic materials (lead, mercury, cadmium) • Environmental contamination if improperly disposed • Health risks to humans and wildlife
Importance	• Fastest growing waste stream globally • Resource recovery potential (gold, silver, copper) • Requires specialized handling

Mnemonic

"TECH" - Toxic Electronics Create Hazards when improperly disposed

Question 5(b) [4 marks]

Illustrate operation of NPN transistor with figure.

Solution

NPN Transistor Operation
Symbol and Basic Operation:

```
       Collector (C)
           |
           |
           v
     +{-{-}{-}{-}{-}+{-}{-}{-}{-}{-}+}
     |     |     |
     |    / {    |}
Base |{-{-}{-}|   |{-}{-}{-}| Collector}
(B)  |    { /    |}
     |     |     |
     +{-{-}{-}{-}{-}+{-}{-}{-}{-}{-}+}
           |
           |
           v
        Emitter (E)
```

Basic Operating Principle:

- Base-Emitter junction is forward biased
- Base-Collector junction is reverse biased
- Small base current controls larger collector current

Operating Mode	Biasing Conditions	Description
Active Mode	• B-E: Forward biased • B-C: Reverse biased	• Normal amplification mode • IC = $\times IB$
Cutoff Mode	• B-E: Reverse biased • B-C: Reverse biased	• Transistor OFF • No collector current
Saturation Mode	• B-E: Forward biased • B-C: Forward biased	• Transistor fully ON • Maximum collector current

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Base Current Injected] {-{-}{} B[Electrons from Emitter Enter Base]}
    B {-{-}{} C[Most Electrons Reach Collector]}
    C {-{-}{} D[Small Change in Base Current Controls Larger Collector Current]}
    style A fill:\#f96,stroke:\#333
    style B fill:\#69f,stroke:\#333
    style C fill:\#f9f,stroke:\#333
    style D fill:\#cfc,stroke:\#333
{Highlighting}
{Shaded}
```

Current Flow in NPN Transistor:

- Electrons flow from emitter to collector
- Small base current controls larger collector current
- Amplification factor ( ) = IC/IB

Mnemonic

"BECAN" - Base current Enables Collector-to-emitter current Amplification in NPN

Question 5(c) [7 marks]

Illustrate common emitter (CE) configuration of Transistor with input and output characteristics.

Solution

Common Emitter (CE) Configuration

Component	Description
Circuit Configuration	• Emitter is common to both input and output • Input between base and emitter • Output between collector and emitter
Input Parameters	• Base current (IB) • Base-emitter voltage (VBE)
Output Parameters	• Collector current (IC) • Collector-emitter voltage (VCE)

Circuit Diagram:

```
                 +Vcc
                   |
                   |
                  RL
                   |
                   |
    +{-{-}{-}{-}{-}+    +{-}{-}{-}o{-}{-}{-} Vout}
    |     |    |   |
Vin o{-{-}{-}{-}{-}o{-}{-}{-}{-}|B  C}
    |     |    |   |
    RB    |    |   |
    |     |    |E  |
    |     |    |   |
    +{-{-}{-}{-}{-}+{-}{-}{-}{-}+{-}{-}{-}o{-}{-}{-} GND}
                   |
                  RE
                   |
                   +
```

Input Characteristics:

- Plots IB vs VBE for different VCE values
- Resembles forward-biased diode characteristic
- Threshold voltage ~0.7V for silicon transistors

```
    IB ( A)
      ↑
      |                /
      |               /
      |              /
      |             /
      |            /
      |           /
      |          /
      |         /
    {-{-}|{-}{-}{-}{-}{-}{-}{-}/{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-} VBE (V)}
      |     0.7V
```

Output Characteristics:

- Plots IC vs VCE for different IB values
- Shows three regions: Active, Saturation, Cutoff

```
    IC (mA)
      ↑
      |                 \_\_\_\_\_\_\_\_ IB = 50 A
      |                /
      |               /\_\_\_\_\_\_\_\_\_ IB = 40 A
      |              /
      |             /\_\_\_\_\_\_\_\_\_\_ IB = 30 A
      |            /
      |           /\_\_\_\_\_\_\_\_\_\_\_ IB = 20 A
      |          /
      |         /\_\_\_\_\_\_\_\_\_\_\_\_\_ IB = 10 A
      |        /
      |       /
    {-{-}|{-}{-}{-}{-}{-}{-}/{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-} VCE (V)}
      |  Saturation   Active
      |  Region       Region
```

Characteristics:

- Current gain ( ) = IC/IB (typically 50-200)
- Input resistance: 1-2 kΩ
- Output resistance: 40-50 kΩ
- Phase shift: 180°*betweeninputandoutput*

Mnemonic

"CASIO" - Common emitter Amplifies Signals with Inverted Output

Question 5(a) OR [3 marks]

State types of e-waste.

Solution

Types of Electronic Waste (E-Waste)

Category	Examples
IT & Telecommunications	• Computers, laptops, printers • Mobile phones, tablets • Servers, networking equipment
Consumer Electronics	• TVs, monitors, audio equipment • DVD/Blu-ray players • Cameras, video recorders
Home Appliances	• Refrigerators, washing machines • Microwave ovens, air conditioners • Small kitchen appliances
Lighting Equipment	• Fluorescent lamps, LED lights • High-intensity discharge lamps
Electrical & Electronic Tools	• Drills, saws, soldering equipment • Lawn mowers, gardening tools
Medical Devices	• Diagnostic equipment • Treatment equipment • Lab equipment
Monitoring Instruments	• Smoke detectors • Thermostats • Control panels
Electronic Components	• Circuit boards • Batteries • Cables and wires

Mnemonic

"CLIMATE" - Computing, Lighting, Industrial, Medical, Appliances, Telecommunications, Electronic components

Question 5(b) OR [4 marks]

Illustrate different categories of Electronics waste.

Solution

Categories of Electronic Waste

Category	Description	Examples
Large Household Appliances	• Bulky items with high metal content • Often contain refrigerants	• Refrigerators, freezers • Washing machines • Air conditioners
Small Household Appliances	• Portable household devices • Mixed material composition	• Vacuum cleaners • Toasters, coffee machines • Electric fans
IT & Telecom Equipment	• Data processing/communication devices • High precious metal content	• Computers, laptops • Printers, copying equipment • Mobile phones, telecom equipment
Consumer Equipment	• Entertainment/media devices • Often with display screens	• TVs, monitors • Audio/video equipment • Musical instruments
Lighting Equipment	• Contains mercury and other metals • Special handling required	• Fluorescent lamps • High-intensity discharge lamps • LED lighting
Electrical & Electronic Tools	• Portable or fixed power tools • High motor content	• Drills, saws • Sewing machines • Construction equipment

Toys & Sports Equipment	• Electronic games and recreational items • Mixed plastic and electronic components	• Video game consoles • Electric trains/racing sets • Exercise equipment with electronics
Medical Devices	• Specialized healthcare equipment • Often contains valuable and hazardous materials	• Diagnostic equipment • Radiation therapy equipment • Laboratory equipment

```
pie
    title "Typical E{-Waste Composition by Category"}
    "IT \& Telecom" : 25
    "Large Appliances" : 29
    "Small Appliances" : 14
    "Consumer Electronics" : 17
    "Lighting" : 5
    "Other Categories" : 10
```

Mnemonic

"LIMCEST" - Large appliances, IT equipment, Medical devices, Consumer electronics, Electronic tools, Small appliances, Telecom equipment

Question 5(c) OR [7 marks]

Explain transistor as a switch in cutoff and saturation region.

Solution

Transistor as a Switch

Region	State	Conditions	Characteristics
Cutoff Region	OFF	• VBE $<$ 0.7V • IB $\approx$ 0	• IC $\approx 0 VCE \approx VCC Highimpedance$
Saturation Region	ON	• VBE $>$ 0.7V • IB $>$ IC/	• IC $\approx IC(sat) VCE \approx 0.2V Lowimpedance$

Circuit Diagram:

```
                  +Vcc
                    |
                    |
                    R
                    |
                    |
                    C
           +{-{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}{-}+}
           |                 |
Input o{-{-}{-}{-}+{-}{-}{-}{-}[RB]{-}{-}{-}{-}+B   |}
           |        |E  |    |
           |        |   |    |
           +{-{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}+{-}{-}{-}{-}o Output}
                    |
                    |
                   GND
```

Cutoff Operation (OFF State):

- Input voltage is below 0.7V (typically 0V)
- Base-emitter junction is not forward biased
- No base current flows (IB ≈ 0)
- No collector current flows (IC ≈ 0)
- Collector-emitter voltage is approximately VCC
- Transistor acts as an open switch

Saturation Operation (ON State):

- Input voltage is above 0.7V
- Base-emitter junction is forward biased
- Sufficient base current flows (IB > IC/)
- Collector current reaches maximum (IC(sat))
- Collector-emitter voltage drops to minimum (VCE(sat) $\approx 0.2V$)
- Transistor acts as a closed switch

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Input Signal] {-{-}{} B\{Voltage Level?\}}
    B {-{-}{}|V {} 0.7V| C[Cutoff Region{}br /{}Switch OFF]}
    B {-{-}{}|V {} 0.7V| D[Saturation Region{}br /{}Switch ON]}
    C {-{-}{} E[High V\_CE{}br /{}No Current]}
    D {-{-}{} F[Low V\_CE{}br /{}Maximum Current]}
    style A fill:\#f96,stroke:\#333
    style B fill:\#69f,stroke:\#333
    style C fill:\#f9f,stroke:\#333
    style D fill:\#cfc,stroke:\#333
    style E fill:\#9cf,stroke:\#333
    style F fill:\#fc9,stroke:\#333
{Highlighting}
{Shaded}
```

Applications:

- Digital logic circuits
- Relay and motor drivers
- LED and lamp control
- Power converters
- Signal conditioning

Key Design Considerations:

- Base resistor (RB) limits base current
- Collector resistor (RC) limits collector current
- Saturation requires IB > IC/ for reliable switching
- Fast switching requires consideration of charge storage effects

Mnemonic

"COSVL" - Cutoff means Off State with Vce Large, saturation means low Vce