Subject Name Solutions

4341105 – Summer 2024

Semester 1 Study Material

Detailed Solutions and Explanations

Question 1(a) [3 marks]

State and explain the difference between positive and negative feedback with diagram.

Solution

Parameter	Negative Feedback	Positive Feedback
Signal	Output signal is fed back to input with opposite phase	Output signal is fed back to input with same phase
Gain	Decreases	Increases
Stability	Improves	Reduces
Applications	Amplifiers	Oscillators

Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Input] {-{-}{} B[Amplifier]}
    B {-{-}{} C[Output]}
    C {-{-}{} D\{Feedback Network\}}

    \%\% Negative Feedback
    subgraph Negative Feedback
    D {-{-}{}|180^ Phase Shift| E[Subtractor]}
    E {-{-}{} B}
    end

    \%\% Positive Feedback
    subgraph Positive Feedback
    D {-{-}{}|0^ Phase Shift| F[Adder]}
    F {-{-}{} B}
    end
{Highlighting}
{Shaded}
```

- **Phase relationship**: In negative feedback, signal is 180°$out of phase while in positive feedback, signal is in phase$
- **Purpose**: Negative feedback stabilizes system while positive feedback creates oscillations

Mnemonic

"Negative Needs Stability, Positive Produces Oscillations"

Question 1(b) [4 marks]

Explain the effect of negative feedback on input impedance of the Amplifier.

Solution

Type of Feedback	Effect on Input Impedance	Formula
Voltage Series	Increases	Z(in-f) = Z(in)(1+A)
Current Series	Increases	Z(in-f) = Z(in)(1+A)
Voltage Shunt	Decreases	Z(in-f) = Z(in)/(1+A)
Current Shunt	Decreases	Z(in-f) = Z(in)/(1+A)

Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Input Signal] {-{-}{} B[Input Impedance]}
    B {-{-}{} C[Amplifier]}
    C {-{-}{} D[Output]}
    D {-{-}{} E[Feedback Network]}
    E {-{-}{} F[Summing Point]}
    F {-{-}{} B}
    style B fill:\#f9f,stroke:\#333,stroke{-width:2px}
{Highlighting}
{Shaded}
```

- **Series feedback**: When feedback signal is in series with input, input impedance increases
- **Shunt feedback**: When feedback signal is in parallel with input, input impedance decreases
- **Magnitude**: Change is proportional to (1+A) where A is gain and is feedback factor

Mnemonic

"Series Soars, Shunt Shrinks"

Question 1(c) [7 marks]

List the advantages and Disadvantages of negative feedback.

Solution

Advantages	Disadvantages
Stabilizes gain	Reduces overall gain
Increases bandwidth	Requires additional components
Reduces distortion	May cause oscillation if improperly designed
Reduces noise	Requires careful phase compensation
Improves input/output impedance	Increases power consumption
Reduces temperature sensitivity	Makes circuit more complex
Controls frequency response	May reduce signal-to-noise ratio in some cases

Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph TD
    A[Negative Feedback] {-{-}{} B[Advantages]}
    A {-{-}{} C[Disadvantages]}

    B {-{-}{} D[Stable Gain]}
    B {-{-}{} E[Wider Bandwidth]}
    B {-{-}{} F[Lower Distortion]}
    B {-{-}{} G[Better Impedance]}

    C {-{-}{} H[Reduced Gain]}
    C {-{-}{} I[More Components]}
    C {-{-}{} J[Complex Design]}
{Highlighting}
{Shaded}
```

- **Performance tradeoff**: Sacrifices gain to achieve better stability and linearity
- **Frequency considerations**: May require compensation to prevent oscillations at high frequencies
- **Design complexity**: More complex to design properly but offers better long-term performance

Mnemonic

"Stability Grows As Gain Drops"

Question 1(c) OR [7 marks]

Explain Voltage series feedback amplifier in detail with block diagram and draw the Practical voltage series feedback circuit.

Solution

Parameter	Effect in Voltage Series Feedback
Input signal	Voltage
Feedback signal	Voltage
Input impedance	Increases
Output impedance	Decreases
Gain stability	Improves
Bandwidth	Increases

Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Input Vi] {-{-}{} B["{}+"]}
    B {-{-}{} C[Amplifier A]}
    C {-{-}{} D[Output Vo]}
    D {-{-}{} E[Feedback Network ]}
    E {-{-}{} F["{}{-}"]}
    F {-{-}{} B}

    style C fill:\#bbf,stroke:\#333,stroke{-width:1px}
    style E fill:\#fbb,stroke:\#333,stroke{-width:1px}
{Highlighting}
{Shaded}
```

Practical Circuit:

```
          +Vcc
            |
            R2
            |
            +{-{-}{-}{-}{-}+}
            |     |
Vin o{-{-}{-}R1{-}{-}+{-}{-}+  |}
            |  |  |
            C1 | C2
            |  |  |
            |  +{-{-}+{-}{-}{-}{-}o Vout}
            |     |
            RE   RC
            |     |
            +{-{-}{-}{-}{-}+}
            |
           GND
```

- **Sampling method**: Output voltage is sampled and fed back to input
- **Mixing method**: Feedback signal is mixed in series with input signal
- **Working principle**: Reduces gain for improved stability and linearity
- **Applications**: Audio amplifiers, instrumentation amplifiers

Mnemonic

"Voltage Series - Impedance In Up, Out Down"

Question 2(a) [3 marks]

Write short note on Colpitts oscillator circuit.

Solution

Component	Function
LC Tank	Determines oscillation frequency
Capacitive Voltage Divider	Provides feedback
Active Device	Provides gain to sustain oscillations

Diagram:

```
    +Vcc
      |
      R1
      |
      +{-{-}{-}{-}{-}+}
      |     |
      |     C3
      |     |
      +{-{-}+{-}{-}+{-}{-}{-}o Output}
      |  |  |
      L1 |  |
      |  |  |
      +{-{-}+  |}
      |     |
      C1    |
      |     |
      +{-{-}{-}{-}{-}+}
      |     |
      C2    |
      |     |
     GND   GND
```

- **Frequency formula**: f = $1/(2\sqrt(L \times (C12)/(C1 + C2)))$
- **Feedback**: Provided by capacitive voltage divider (C1 and C2)
- **Applications**: RF oscillators, communication circuits

Mnemonic

"Colpitts Contains Capacitive divider"

Question 2(b) [4 marks]

Explain requirement of oscillator. i) Barkhausen Criterion. ii) Tank circuit. iii) Amplifier.

Solution

Requirement	Function	Explanation
Barkhausen Criterion	Ensures sustained oscillation	Loop gain = 1, Phase shift = $0° or 360°$
Tank Circuit	Determines frequency	Resonant LC circuit that stores energy
Amplifier	Provides gain	Compensates for circuit losses

Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph TD
    A[Oscillator] {-{-}{} B[Barkhausen Criterion]}
    A {-{-}{} C[Tank Circuit]}
    A {-{-}{} D[Amplifier]}

    B {-{-}{} E[Loop Gain = 1]}
    B {-{-}{} F[Phase Shift = 0^ or 360^]}

    C {-{-}{} G[Energy Storage]}
    C {-{-}{} H[Frequency Determination]}

    D {-{-}{} I[Overcome Losses]}
    D {-{-}{} J[Maintain Amplitude]}
{Highlighting}
{Shaded}
```

- **Barkhausen Criterion**: Mathematical condition for sustained oscillations without damping
- **Tank Circuit**: LC circuit that determines frequency of oscillations
- **Amplifier**: Active device that provides energy to maintain oscillations

Mnemonic

"BAT - Barkhausen Amplifies Tank"

Question 2(c) [7 marks]

Explain construction, working and V-I characteristics of UJT.

Solution

Parameter	Description
Construction	Silicon bar with two base connections and one emitter
Symbol	Triangle with emitter on one side and two bases
Equivalent Circuit	Voltage divider with diode
Key Parameter	Intrinsic standoff ratio ( )

Diagram:

```
        E
        |
        v
    +{-{-}{-}{-}+{-}{-}{-}{-}+}
    |    |    |
    |    D    |
    |    |    |
B1 o+{-{-}{-}www{-}{-}{-}+o B2}
        R1    R2

UJT Symbol \& Equivalent Circuit
```

V-I Characteristic Curve:

```
  I
  \^{}
  |
  |       Peak point
  |         o
  |        /|
  |       / |
  |      /  |
  |     /   |
  |    /    |
  |   /     |
  |  /      |
  | /       |
  |/        |
  +{-{-}{-}{-}{-}{-}{-}{-}{-}{-} V}
  |
  | Valley point
```

- **Construction**: N-type silicon bar with P-type emitter junction
- **Working principle**: When emitter voltage > ( ), device conducts
- **Regions of operation**: Cut-off, negative resistance, and saturation
- **Applications**: Relaxation oscillators, timing circuits, triggering devices

Mnemonic

"UJT Peaks Then Valleys - Negative Resistance Rules"

Question 2(a) OR [3 marks]

State the advantages, disadvantages and applications of Hartley oscillator.

Solution

Advantages	Disadvantages	Applications
Easy tuning	Bulky inductors	RF generators
Wide frequency range	Mutual inductance issues	Radio receivers
Simple design	Difficult at high frequencies	Amateur radio
Good frequency stability	Requires center-tapped coil	Communication equipment

Diagram:

```
+Vcc
  |
  R1
  |
  +{-{-}{-}{-}{-}+}
  |     |
  |     C2
  |     |
  +{-{-}+{-}{-}+{-}{-}{-}{-}o Output}
  |  |  |
  L1 |  |
  |  |  |
  L2 |  |
  |  |  |
  +{-{-}+  |}
  |     |
  C1    |
  |     |
 GND   GND
```

- **Key feature**: Uses tapped inductor for feedback
- **Frequency formula**: f = $1/(2\sqrt{(C \times (L1 + L2))})$
- **Distinguishing characteristic**: Inductive voltage divider for feedback

Mnemonic

"Hartley Has tapped Inductor"

Question 2(b) OR [4 marks]

Explain UJT as relaxation oscillator.

Solution

Component	Function
UJT	Provides switching action
Capacitor	Timing element
Resistor	Controls charging rate
Output	Sawtooth waveform

Diagram:

```
     +Vcc
       |
       R
       |
       +{-{-}{-}{-}{-}{-}{-}+}
       |       |
       |       |
       +{-{-}| |{-}{-}+{-}{-}{-}{-}o Output}
       |   C   |
       |       |
       E       |
      UJT      |
      B1  B2   |
       |   |   |
       +{-{-}{-}+{-}{-}{-}+}
           |
          GND
```

Waveforms:

```
Vc
\^{}
|  /|  /|  /|
| / | / | / |
|/  |/  |/  |
+{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-} t}

Vo
\^{}
|
|  \_   \_   \_
| | | | | | |
|\_| |\_| |\_| |\_
+{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-} t}
```

- **Operating principle**: Capacitor charges until UJT firing voltage, then rapidly discharges
- **Frequency formula**: f $\approx 1/(RC(1/(1-)))$
- **Applications**: Timing circuits, pulse generators, control systems

Mnemonic

"Charge-Fire-Repeat - Sawtooth's Beat"

Question 2(c) OR [7 marks]

Explain working of weinbridge oscillator with neat diagram also state the advantage, disadvantage and application for the same.

Solution

Parameter	Description
Configuration	RC feedback network in bridge formation
Frequency Formula	f = 1/(2 RC) when R1=R3 and C2=C4
Feedback	Positive feedback through RC network
Phase Shift	$0°atresonantfrequency$

Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Amplifier] {-{-}{} B[RC Bridge]}
    B {-{-}{} A}

    subgraph "Wien Bridge Network"
    direction LR
    C[R1] {-{-}{-} D[C1]}
    D {-{-}{-} E[R2]}
    E {-{-}{-} F[C2]}
    F {-{-}{-} C}
    end
{Highlighting}
{Shaded}
```

Circuit:

```
                +Vcc
                  |
                  |
                  v
    +{-{-}{-}R2{-}{-}{-}+{-}{-}{-}{-}+{-}{-}{-}{-}+}
    |        |         |
    C2       |        R4
    |        |         |
    +{-{-}{-}+    +    +{-}{-}{-}{-}+}
    |   |    |    |    |
    |   +{-{-}{-}{-}+{-}{-}{-}{-}+    |}
    |        |         |
    R1       +        R3
    |        |         |
    C1       v        R5
    |       Op{-Amp     |}
    +{-{-}{-}{-}{-}{-}{-}{-}+         |}
             |         |
             +{-{-}{-}{-}{-}{-}{-}{-}{-}+}
                  |
                 GND
```

Advantages:

- High frequency stability
- Low distortion output
- Simple RC components
- Easy to tune

Disadvantages:

- Limited frequency range
- Amplitude stabilization needed
- Sensitive to component variations
- Difficult to start oscillations

Applications:

- Audio test equipment
- Function generators
- Musical instruments
- Laboratory signal sources

Mnemonic

"Wien Works at R1C1=R2C2 frequency"

Question 3(a) [3 marks]

Give classification of power Amplifier.

Solution

Classification Basis	Types
Based on Conduction Angle	Class A, B, AB, C
Based on Configuration	Single-ended, Push-pull, Complementary
Based on Coupling	RC coupled, Transformer coupled, Direct coupled
Based on Operation	Linear, Switching

Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph TD
    A[Power Amplifiers]
    A {-{-}{} B[Class A {-} 360^]}
    A {-{-}{} C[Class B {-} 180^]}
    A {-{-}{} D[Class AB {-} 180^{-}360^]}
    A {-{-}{} E[Class C {} 180^]}

    style B fill:\#d4f0f0,stroke:\#333
    style C fill:\#d4f0f0,stroke:\#333
    style D fill:\#d4f0f0,stroke:\#333
    style E fill:\#d4f0f0,stroke:\#333
{Highlighting}
{Shaded}
```

- **Class A**: Conducts for full $360°cycle, highestlinearity, lowestefficiency$
- **Class B**: Conducts for $180°cycle, mediumdistortion, mediumefficiency$
- **Class AB**: Conducts for $180° - 360°cycle, goodlinearity, goodefficiency$
- **Class C**: Conducts for $<180°cycle, highestdistortion, highestefficiency$

Mnemonic

"A All-time, B Bisects, AB Almost-Bisects, C Cuts-more"

Question 3(b) [4 marks]

Explain class A power amplifier.

Solution

Parameter	Class A Amplifier
Conduction Angle	$360°(fullcycle)$
Biasing	Q-point at center of load line
Efficiency	Low (25-30% max)
Distortion	Very low

Diagram:

```
        +Vcc
          |
          |
        Rcollector
          |
          +{-{-}{-}{-}{-}+}
          |     |
          |     +{-{-}{-} Output}
          |     |
      +{-{-}{-}+     |}
      |   |     |
  In {-+   Q1    |}
      |   |     |
      +{-{-}{-}+     |}
          |     |
        Remitter|
          |     |
          +{-{-}{-}{-}{-}+}
          |
         GND
```

Load Line:

```
 Ic
  \^{}
  |         Load Line
  |        /
  |       /
  |      /
  |     *  Q{-point}
  |    /
  |   /
  |  /
  | /
  |/
  |/
  +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-} Vce}
```

- **Operating principle**: Transistor conducts for entire input cycle
- **Efficiency calculation**: Maximum theoretical efficiency = 50%
- **Practical efficiency**: Typically 25-30% due to losses
- **Applications**: Audio pre-amplifiers, low-power amplifiers where quality matters more than efficiency

Mnemonic

"Class A - Always conducting, All cycle"

Question 3(c) [7 marks]

Explain the principle of push pull amplifiers and write short note on class B push pull amplifier.

Solution

Push-Pull Principle	Class B Push-Pull
Uses two complementary devices	Each transistor conducts for half cycle
Reduces even harmonic distortion	Higher efficiency (78.5% theoretical)
Cancels DC magnetization in transformer	Suffers from crossover distortion
Provides higher output power	Requires proper biasing to minimize distortion

Diagram:

```
          +Vcc
            |
            |
       +{-{-}{-}{-}+{-}{-}{-}{-}+}
       |         |
       Q1        Q2
       |         |
       +{-{-}{-}{-}+{-}{-}{-}{-}+}
            |
            +{-{-}{-}{-}{-}{-} Output}
            |
            R
            |
           GND
```

Waveforms:

```
  Input      Q1 Current    Q2 Current     Output
    \^{           \^{}             \^{}             \^{}}
    |            |             |             |
    |  /{        |  /         |    /       |  /}
    | /  {       | /          |   /        | /  }
{-{-}{-}{-}+{-}{-}{-}{-}{-}{-}     {-}+{-}{-}{-}{-}{-}{-}      {-}+{-}{-}{-}{-}{-}{-}{-}     {-}+{-}{-}
    |    {       |             |            |    }
    |     {      |             |            |     }
    |      {     |             |            |      }
    v       v    v             v       v     v       v
```

- **Working principle**: Each transistor conducts for alternate half-cycles
- **Advantages**: Higher efficiency, reduced even harmonics, lower heat generation
- **Disadvantages**: Crossover distortion at transition points
- **Applications**: Audio power amplifiers, output stages of high-power systems

Mnemonic

"Push-Pull: Pair Processes alternate Pulses"

Question 3(a) OR [3 marks]

Discuss crossover distortion in push pull amplifier. How it can be removed.

Solution

Crossover Distortion	Solution Methods
Occurs at signal crossover points	Apply small bias voltage (Class AB)
Due to transistor's non-linear region	Use diode compensation networks
Creates "dead zone" around zero	Implement feedback correction
Affects small signals more	Use complementary emitter-follower stage

Diagram:

```
  Input          Output with Distortion
    \^{                 \^{}}
    |                  |
    |  /{              |   /}
    | /  {             |  /  }
{-{-}{-}{-}+{-}{-}{-}{-}{-}{-}          {-}+{-}{-}{-}{-}{-}{-}}
    |    {             |     }
    |     {            | gap  }
    |      {           |       }
    v       v          v        v
```

Correction Circuit:

```
          +Vcc
            |
            |
       +{-{-}{-}{-}+{-}{-}{-}{-}+}
       |    |    |
       |    R    |
       |    |    |
       |    D1   |
       |    |    |
       Q1   +    Q2
       |    |    |
       |    D2   |
       |    |    |
       +{-{-}{-}{-}+{-}{-}{-}{-}+}
            |
            R
            |
           GND
```

- **Cause**: Transistors require ~0.7V to turn on, creating dead zone
- **Effect**: Distortion particularly noticeable at low volumes
- **Solution**: Class AB biasing with diodes or VBE multiplier
- **Result**: Smoother transition between positive and negative half-cycles

Mnemonic

"Cross to Class AB Smooths the Gap"

Question 3(b) OR [4 marks]

Explain complimentary symmetry push-pull amplifier.

Solution

Component	Purpose
NPN Transistor	Handles positive half-cycle
PNP Transistor	Handles negative half-cycle
Biasing Network	Reduces crossover distortion
Output Coupling	Direct coupling to load

Diagram:

```
          +Vcc
            |
            |
            Q1 (NPN)
            |
      R1    |
       +{-{-}{-}{-}+}
       |    |
Input  |    +{-{-}{-}{-}{-}o Output}
       |    |
       +{-{-}{-}{-}+}
            |
            Q2 (PNP)
            |
            |
           GND
```

Working Principle:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Input Signal] {-{-}{} B\{Voltage Polarity\}}
    B {-{-}{}|Positive| C[NPN Conducts]}
    B {-{-}{}|Negative| D[PNP Conducts]}
    C {-{-}{} E[Output]}
    D {-{-}{} E}
{Highlighting}
{Shaded}
```

- **Key feature**: Uses complementary transistors (NPN and PNP) for push-pull operation
- **Advantage**: No output transformer required, direct coupling to load
- **Efficiency**: Typically 78.5% theoretical maximum
- **Applications**: Audio amplifiers, power output stages

Mnemonic

"NPN Pulls-up, PNP Pulls-down"

Question 3(c) OR [7 marks]

Derive the equation of efficiency for class B push pull Amplifier.

Solution

Parameter	Formula	Description
DC Input Power	PDC = 2VCC	Power drawn from supply
AC Output Power	PAC = Vrms$^2/RL$	Power delivered to load
Maximum Efficiency	= (/4)×100% = 78.5%	Theoretical maximum
Practical Efficiency	60-70%	Considering losses

Mathematical Derivation:
For a sinusoidal input: v(t) = Vm sin(t)
Step 1: DC Input Power

- Input current per transistor: Im/
- Total DC input power: PDC = 2VCC/

Step 2: AC Output Power

- RMS output voltage: Vrms = Vm/$\sqrt{2}$
- Maximum output voltage: Vm = VCC
- Output power: PAC = Vrms$^2/RL = Vm^2/2RL$

Step 3: Efficiency Calculation

- = (PAC/PDC)×100%
- = ((Vm$^2/2RL)/(2VCC/)) \times 100\%$
- Since Vm = VCC and Im = VCC/RL
- = (/4)×100% = 78.5%

Diagram:

```
 Vm=VCC
    \^{}
    |         /{}
    |        /  {}
    |       /    {}
    |      /      {}
    |     /        {}
0   +{-{-}{-}{-}/{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-} t}
    |   /            {}
    |  /              {}
    | /                {}
    |/                  {}
    v
```

- **Power dissipation**: Most efficient when output voltage swing approaches VCC
- **Conduction angle**: Each transistor conducts for exactly 180°
- **Practical factors**: Biasing current, saturation voltage, and other losses reduce efficiency
- **Comparison**: Much higher than Class A (25-30%), less than Class C (>80%)

Mnemonic

"Pi-over-4 gives 78.5% - Class B's best"

Question 4(a) [3 marks]

Define.(i) CMRR (ii)slew rate.(iii)Input offset Current.

Solution

Parameter	Definition	Typical Values
CMRR	Ratio of differential gain to common-mode gain	80-120 dB
Slew Rate	Maximum rate of change of output voltage	0.5-20 V/ s
Input Offset Current	Difference between currents into the two inputs	1-100 nA

Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph TD
    A[Op{-Amp Parameters]}
    A {-{-}{} B[CMRR = Ad/Acm]}
    A {-{-}{} C[Slew Rate = dVo/dt]}
    A {-{-}{} D["IOS = |I+ {-} I{-}|"]}

    style B fill:\#f9f9f9,stroke:\#333
    style C fill:\#f9f9f9,stroke:\#333
    style D fill:\#f9f9f9,stroke:\#333
{Highlighting}
{Shaded}
```

- **CMRR**: Measures op-amp's ability to reject common-mode signals
- **Slew Rate**: Limits maximum frequency for undistorted output
- **Input Offset Current**: Causes output error even with identical inputs

Mnemonic

"Cancelling Mistakes Requires Ratios"

Question 4(b) [4 marks]

Draw and explain the basic block diagram of an operational amplifier.

Solution

Stage	Function
Differential Input	Accepts and amplifies difference between inputs
High-Gain Intermediate	Provides voltage amplification
Level Shifter	Shifts DC level for output stage
Output Buffer	Provides low output impedance

Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph LR
    A[Inverting Input] {-{-}{} B[Differential Input Stage]}
    C[Non{-inverting Input] {-}{-}{} B}
    B {-{-}{} D[High{-}Gain Intermediate Stage]}
    D {-{-}{} E[Level Shifter]}
    E {-{-}{} F[Output Buffer]}
    F {-{-}{} G[Output]}

    style B fill:\#d4f0f0,stroke:\#333
    style D fill:\#d4f0f0,stroke:\#333
    style E fill:\#d4f0f0,stroke:\#333
    style F fill:\#d4f0f0,stroke:\#333
{Highlighting}
{Shaded}
```

- **Differential input stage**: Converts differential input to single-ended output
- **High-gain stage**: Provides most of the open-loop gain
- **Level shifter**: Shifts signal level for proper output operation
- **Output stage**: Provides current gain and low output impedance

Mnemonic

"Diff-Amp Gain Shift Out"

Question 4(c) [7 marks]

Explain in detail operational amplifier as integrator.

Solution

Parameter	Description	Formula
Circuit	Op-amp with capacitor in feedback	-
Transfer Function	Output proportional to integral of input	Vo = -(1/RC)dt
Frequency Response	Acts as low-pass filter	Gain = 1/(j RC)
Phase Shift	-90°	-

Diagram:

```
             C
       +{-{-}{-}{-}{-}{-}||{-}{-}{-}{-}{-}{-}+}
       |              |
       |    +{-{-}{-}{-}{-}+   |}
       |    |     |   |
       +{-{-}{-}{-}+  {-}  |   |}
       |    |     |   |
Vin o{-{-}+{-}{-}R{-}+     +{-}{-}{-}+{-}{-}o Vout}
            |  +  |
            |     |
            +{-{-}{-}{-}{-}+}
              |
             GND
```

Input/Output Waveforms:

```
 Input Square Wave     Output Triangle Wave
       \_\_\_                    /|
      |   |                  / |
      |   |                 /  |
  \_\_\_\_|   |\_\_\_\_         \_\_\_\_/    |{\_\_\_\_}
      |   |                    |
      |   |                    |
      |\_\_\_|                       |
                               {|}
```

- **Working principle**: Capacitor integrates current over time
- **Mathematical basis**: Vo(t) = -(1/RC)(t)dt + Vo(0)
- **Limitations**: Capacitor leakage, op-amp input bias current cause drift
- **Applications**: Waveform generators, analog computers, active filters

Mnemonic

"Square-In Triangle-Out, RC sets the Slope"

Question 4(a) OR [3 marks]

Explain operational amplifier as summing amplifier.

Solution

Parameter	Description	Formula
Circuit	Multiple inputs with same feedback	Vo = -($R_1/R_{11} + R_1/R_{22} + \ldots$)
Equal Resistors	Simple addition/averaging	Vo = -($V_1 + V_2 + \ldots + V_n$)
Weighted Sum	Different input resistors	Vo = -($K_1V_1 + K_2V_2 + \ldots + K_nV_n$)
Inverting	Output inverted from inputs	-

Diagram:

```
        R1
V1 o{-{-}{-}www{-}{-}{-}+}
             |
        R2   |    +{-{-}{-}{-}{-}+}
V2 o{-{-}{-}www{-}{-}{-}+{-}{-}{-}{-}+     |}
             |    |  {-  |}
        R3   |    |     |
V3 o{-{-}{-}www{-}{-}{-}+{-}{-}{-}{-}+     +{-}{-}{-}o Vout}
                  |  +  |
                  |     |
                  +{-{-}{-}{-}{-}+}
                    |
          Rf        |
        +{-{-}{-}www{-}{-}{-}{-}{-}+}
        |
       GND
```

- **Working principle**: Each input contributes current to summing junction
- **Applications**: Audio mixers, signal processing, analog computers
- **Virtual ground**: Summing point maintains near-zero voltage
- **Variations**: Inverting, non-inverting, and differential summer

Mnemonic

"Many Inputs, One Output - Sum It All"

Question 4(b) OR [4 marks]

State the applications of operational amplifier.

Solution

Application Category	Examples
Signal Processing	Amplifiers, Filters, Buffers
Mathematical Operations	Adders, Subtractors, Integrators, Differentiators
Waveform Generators	Sine, Square, Triangle, Pulse generators
Instrumentation	Instrumentation amplifiers, Current-to-voltage converters
Comparators	Zero crossing detectors, Window comparators
Precision Rectifiers	Full-wave, Half-wave rectifiers
Voltage Regulators	Series regulators, Shunt regulators

Diagram:

Mermaid Diagram (Code)

```
{Shaded}
{Highlighting}[]
graph TD
    A[Op{-Amp Applications]}
    A {-{-}{} B[Signal Processing]}
    A {-{-}{} C[Math Operations]}
    A {-{-}{} D[Waveform Generators]}
    A {-{-}{} E[Instrumentation]}
    A {-{-}{} F[Comparators]}
    A {-{-}{} G[Rectifiers]}
    A {-{-}{} H[Regulators]}
{Highlighting}
{Shaded}
```

- **Linear applications**: Utilize op-amp in linear region for amplification, filtering
- **Non-linear applications**: Use saturation characteristics for comparison, limitation
- **Analog computation**: Perform mathematical operations on analog signals
- **Signal conditioning**: Adapt signals for analog-to-digital conversion

Mnemonic

"SMWIG-CR: Signal, Math, Wave, Instrument, Gate, Convert, Regulate"

Question 4(c) OR [7 marks]

Explain op-amp as inverting and non-inverting amplifier.

Solution

Parameter	Inverting Amplifier	Non-Inverting Amplifier
Circuit Configuration	Input to negative terminal	Input to positive terminal
Gain Formula	A = -Rf/Rin	A = 1 + Rf/Rin
Input Impedance	= Rin	Very high ($\approx 10^9 ohms$)
Phase Shift	180°	0°
Virtual Ground	At negative input	Not applicable

Inverting Amplifier:

```
            Rf
        +{-{-}{-}{-}www{-}{-}{-}+}
        |          |
        |   +{-{-}{-}{-}{-}+|}
        |   |     ||
Vin o{-{-}{-}w{-}{-}{-}+  {-}  ||}
       Rin  |     ||
            |     +{-{-}{-}o Vout}
            |  +  |
            |     |
            +{-{-}{-}{-}{-}+}
              |
             GND
```

Non-Inverting Amplifier:

```
                Rf
            +{-{-}{-}{-}www{-}{-}{-}+}
            |          |
            |   +{-{-}{-}{-}{-}+|}
            |   |     ||
Vin o{-{-}{-}{-}{-}{-}{-}+{-}{-}{-}+  +  ||}
            |   |     ||
            |   |     +{-{-}{-}o Vout}
            |   |  {-  |}
            |   |     |
            |   +{-{-}{-}{-}{-}+}
            |     |
            |    GND
            |
            +{-{-}{-}{-}www{-}{-}{-}{-}{-}+}
                 Rin     |
                        GND
```

Inverting Mode:

- **Gain equation**: Vout = -(Rf/Rin)
- **Virtual ground**: Negative input maintained at ~0V
- **Applications**: Signal inversion, controlled gain, summing

Non-Inverting Mode:

- **Gain equation**: Vout = (1 + Rf/Rin)
- **Minimum gain**: Always ≥ 1
- **Applications**: Buffering, voltage amplification with high input impedance

Mnemonic

"Invert: Negative is Input, Non-invert: Positive gets signal"

Question 5(a) [3 marks]

Give pin description of IC555.

Solution

Pin Number	Pin Name	Description
1	Ground	Connected to circuit ground
2	Trigger	Starts timing cycle when < 1/3 VCC
3	Output	Provides output signal
4	Reset	Terminates timing when LOW

5	Control Voltage	Adjusts threshold voltage
6	Threshold	Ends timing cycle when > 2/3 VCC
7	Discharge	Connected to timing capacitor
8	VCC	Positive supply voltage (5-15V)

Diagram:

```
    +{-{-}{-}{-}{-}{-}{-}{-}+}
  8 |        | 7
+{-{-}{-}+ VCC    | DISCHARGE +{-}{-}{-}+}
    |        |                |
  7 |        | 6              |
+{-{-}{-}+ DISCHARGE THRESHOLD +{-}{-}+}
    |        |                |
  6 |        | 5              |
+{-{-}{-}+ THRESHOLD CONTROL   +{-}{-}+}
    |        |                |
  5 |        | 4              |
+{-{-}{-}+ CONTROL  RESET     +{-}{-}{-}+}
    |        |                |
  4 |        | 3              |
+{-{-}{-}+ RESET   OUTPUT    +{-}{-}{-}{-}+}
    |        |                |
  3 |        | 2              |
+{-{-}{-}+ OUTPUT  TRIGGER   +{-}{-}{-}{-}+}
    |        |                |
  2 |        | 1              |
+{-{-}{-}+ TRIGGER GND       +{-}{-}{-}{-}+}
    |        |
    +{-{-}{-}{-}{-}{-}{-}{-}+}
```

- **Input pins**: Trigger, Reset, Threshold, Control Voltage
- **Output pins**: Output, Discharge
- **Power pins**: VCC, Ground
- **Internal structure**: Composed of comparators, flip-flop, discharge transistor

Mnemonic

"Ground Triggers Output Reset Control Threshold Discharges Voltage"

Question 5(b) [4 marks]

Explain op-amp as differentiator.

Solution

Parameter	Description	Formula
Circuit	Op-amp with capacitor in input	Vo = -RC(dVi/dt)
Transfer Function	Output proportional to rate of change	H(s) = -sRC
Frequency Response	Acts as high-pass filter	Gain increases with frequency
Phase Shift	+90°	-

Diagram:

```
                R
           +{-{-}{-}{-}www{-}{-}{-}{-}+}
           |           |
           |    +{-{-}{-}{-}{-}+|}
           |    |     ||
Vin o{-{-}{-}{-}{-}{-}{-}|{-}{-}{-}{-}+  {-}  ||}
           ||   |     ||
           ||   |     +{-{-}{-}{-}o Vout}
           |C   |  +  |
           ||   |     |
           |    +{-{-}{-}{-}+}
           |      |
          GND    GND
```

Input/Output Waveforms:

```
  Triangle Input       Square Output
       /{                 \_}
      /  {              | |}
     /    {             | |}
\_\_\_\_/      {\_\_\_\_    \_\_\_\_\_| |\_\_\_\_\_}
              {         | |}
               {        | |}
                {       | |}
                 {     \_| |\_}
```

- **Working principle**: Output voltage proportional to rate of change of input
- **Mathematical basis**: Vo = -RC(dVin/dt)
- **Practical limitations**: Sensitive to high-frequency noise
- **Applications**: Waveform generation, edge detection, rate-of-change indicator

Mnemonic

"Differentiator Delivers Derivatives - RC determines speed"

Question 5(c) [7 marks]

Explain IC 555 as astable and Monostable multivibrator.

Solution

Parameter	Astable Multivibrator	Monostable Multivibrator
Definition	Free-running oscillator	One-shot pulse generator
Stable States	None (continuously oscillates)	One stable state
Timing	T = 0.693(RA+2RB)C	T = 1.1RC
Trigger	Self-triggering	External trigger required
Output	Continuous square wave	Single pulse of fixed width

Astable Circuit:

```
  +Vcc
   |
   |
+{-{-}+{-}{-}+}
|     |
R1    |
|     |
+{-{-}+{-}{-}+{-}{-}{-}{-}{-}{-}{-}{-}+}
|  |           |
|  +{-{-}+        |}
|     |   8    |     7
R2    +{-{-}{-}+{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}+}
|         |       |   |
+{-{-}{-}{-}{-}{-}+  | 555   |   |}
|      |  |       |   |
C1     |  |       |   |
|      |  |       |   |
+{-{-}{-}{-}{-}{-}+{-}{-}+{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}+}
       |  |       |   |
     2 |  |   3   |   |
+{-{-}{-}{-}{-}{-}+{-}{-}+{-}{-}{-}{-}{-}{-}{-}+   |}
|         |           |
|         |           |
+{-{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+}
          |
        Output
```

Monostable Circuit:

```
+Vcc
 |
 |
 R
 |
 +{-{-}{-}{-}{-}{-}{-}+{-}{-}+}
 |        |  |
 |    8   |  |
 +{-{-}{-}{-}+{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}+}
 |    |       |     |
 |    | 555   |     |
 |    |       |     |
 |    |       |     |
 |  4 |       | 7   |
 +{-{-}{-}{-}+{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}+}
      |       |     |
    2 |       |     |
 +{-{-}{-}{-}+       |    |}
 |    |       |     |
 |  3 |       |     |
 +{-{-}{-}{-}+{-}{-}{-}{-}{-}{-}{-}+    |}
      |             |
    Output          |
      |             |
      +{-{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}+}
            |
            C
            |
           GND
```

Astable Operation:

- **Working**: Capacitor charges through RA+RB and discharges through RB

- **Duty cycle**: Can be adjusted by proper selection of RA and RB
- **Frequency**: f = 1.44/((RA+2RB)C)
- **Applications**: LED flashers, tone generators, clock pulse generators

Monostable Operation:

- **Working**: Triggered by falling edge on pin 2, outputs HIGH for time T
- **Time period**: T = 1.1RC
- **Applications**: Time delays, pulse width modulation, debouncing

Mnemonic

"Astable Always Alternates, Monostable Makes One pulse"

Question 5(a) OR [3 marks]

Explain IC555 as Bistable multivibrator.

Solution

Parameter	Description
Definition	Flip-flop circuit with two stable states
Triggering	SET by trigger pin (2), RESET by reset pin (4)
Stable States	Two (HIGH or LOW)
Time Period	No timing components needed

Diagram:

```
           +Vcc
            |
            |
       +{-{-}{-}{-}|{-}{-}{-}{-}+}
       |    |    |
       |  8 |  4 |
   +{-{-}{-}+{-}{-}{-}{-}+{-}{-}{-}{-}+{-}{-}{-}+}
   |   |         |   |
   |   |   555   |   |
   |   |         |   |
   |   |         |   |
   | 2 |         | 3 |
   +{-{-}{-}+{-}{-}{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}+}
       |         |
    Trigger    Output
       |         |
      GND       GND
```

Truth Table:

Trigger (Pin 2)	Reset (Pin 4)	Output (Pin 3)
< 1/3 VCC	HIGH	HIGH
> 1/3 VCC	HIGH	No change
Any	LOW	LOW

- **SET operation**: Occurs when trigger pin falls below 1/3 VCC
- **RESET operation**: Occurs when reset pin is pulled LOW
- **Applications**: Latching switches, memory elements, flip-flops
- **Features**: No timing components (R, C) required

Mnemonic

"Bistable Bounces Between two states"

Question 5(b) OR [4 marks]

Explain the basic operation of IC555 with internal block diagram.

Solution

Block	Function
Comparators	Monitor trigger and threshold voltages
Flip-Flop	Controls output state
Discharge Transistor	Discharges timing capacitor
Voltage Divider	Establishes reference voltages

Internal Block Diagram:

```
                     +Vcc (8)
                        |
                        v
             +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+}
             |        Voltage Divider      |
             |     +{-{-}{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}+       |}
             |     |       |       |       |
             |     R       R       R       |
             |     |       |       |       |
             |     +       +       +       |
             |     |       |       |       |
Control (5){-{-}+{-}{-}{-}{-}+       |       |       |}
             |             |       |       |
Threshold(6){-+{-}{-}{-}{-}{-}|{-}{-}{-}{-}{-}+       |       |}
             |      |+             |       |
             |    Comp2            |       |
             |      |              |       |
             |      v              |       |
             |    +{-+{-}+            |       |}
Trigger (2){-{-}+{-}{-}{-}|   |        S   |       |}
             |    |+  |{-{-}{-}{-}{-}{-}{-}{-}{-}{-}Q+{-}{-}{-}{-}{-}{-}{-}+{-}{-}Output (3)}
             |    Comp1         FF |       |
             |      |          R   |       |
             |      |          \^{   |       |}
Reset (4){-{-}{-}{-}+{-}{-}{-}{-}{-}{-}|{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}|{-}{-}{-}+       |}
             |      |          |   |       |
             |      |          |   |       |
             |      v          |   |       |
             |    Transistor   |   |       |
             |      |          |   |       |
Discharge(7){-+{-}{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}{-}{-}+{-}{-}{-}+       |}
             |                             |
             |                             |
             |                             |
             +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}+}
                        |
                      GND (1)
```

Basic Operation:

1. **Voltage divider**: Creates 2/3 VCC and 1/3 VCC reference points
2. **Comparator 1**: Triggers when pin 2 goes below 1/3 VCC
3. **Comparator 2**: Resets when pin 6 goes above 2/3 VCC
4. **Flip-flop**: Controls output state based on comparator inputs
5. **Discharge transistor**: Connects pin 7 to ground when output is LOW

- **Versatility**: Can be configured in multiple modes (astable, monostable, bistable)
- **Timing precision**: Determined by external RC components
- **Wide supply range**: Functions from 4.5V to 16V

Mnemonic

"Comparators Control Flip-flop For Timing"

Question 5(c) OR [7 marks]

Explain how class A, Class B, Class C and Class AB Power amplifier are classified based on their Q Point location on load line, with diagram.

Solution

Amplifier Class	Q-Point Location	Conduction Angle	Efficiency
Class A	Center of load line	360°	25-30%
Class B	Cut-off point	180°	78.5%
Class AB	Slightly above cut-off	$180° - 360°$	50-78.5%
Class C	Below cut-off	<180°	>80%

Diagram Load Line:

```
     Ic
      \^{}
      |
      |              Load Line
      |             /
      |            /
      |           /
   IcQ1|      A   /
      |       *  /
      |        {/}
   IcQ2|     AB * /
      |        {/}
      |      B * /
   IcQ3|        {/}
      |        /
      |    C * /
      |      /
      |     /
      |    /
      |   /
      |  /
      | /
      | /
      |/
      +{-{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}{-}
          VceC   VceB   VceAB   VceA
```

Input/Output Waveforms:

```
   Input          Class A         Class B          Class AB         Class C
     \^{              \^{}              \^{}              \^{}              \^{}}
     |              |               |                |                |
     |  /{          |  /            |  /             |  /            |  /}
     | /  {         | /             | /              | /             | /  }
{-{-}{-}{-}{-}+{-}{-}{-}{-}{-}{-}       {-}+{-}{-}{-}{-}{-}{-}       {-}+{-}{-}{-}{-}{-}{-}        {-
     |    {         |               |                |               |}
     |     {        |               |                |               |}
     |      {       |               |               |                |}
     v       v      v       v       v       v        v       v        v       v
                                    Distortion       Small Distortion
```

Class A Characteristics:

- **Q-point**: Center of load line
- **Bias**: Fixed bias maintains conduction for entire cycle
- **Linearity**: Excellent linearity, minimal distortion
- **Efficiency**: Poor (25-30%)

Class B Characteristics:

- **Q-point**: At cutoff point
- **Bias**: Biased at cutoff, each device conducts for half-cycle
- **Distortion**: Crossover distortion at zero-crossing
- **Efficiency**: Good (78.5% theoretical)

Class AB Characteristics:

- **Q-point**: Slightly above cutoff
- **Bias**: Small bias current eliminates crossover distortion
- **Linearity**: Good compromise between A and B
- **Efficiency**: Moderate (50-78.5%)

Class C Characteristics:

- **Q-point**: Below cutoff
- **Bias**: Conducts for less than half-cycle
- **Distortion**: Severe distortion, requires tuned circuit
- **Efficiency**: Excellent (>80%)

Mnemonic

"Above center, Below center, Cut-off point, Down below - ABCD order for Q-point location"