Linear Integrated Circuit (4341105) - Summer 2023 Solution

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Question 1(a) [3 marks]

Write advantages and disadvantages of negative feedback amplifier

Solution

Advantages	**Disadvantages**
Increases bandwidth	Reduces gain
Stabilizes gain	Requires more components
Reduces distortion	Increases cost
Increases input impedance (voltage series)	May cause oscillations if improperly designed
Decreases output impedance (voltage series)	Requires careful phase compensation

Mnemonic

"GRASS Grows Better Despite Dry Soil: Gain Reduction, Amplifies Stability, Stops distortion, Better impedance"

Question 1(b) [4 marks]

Derive the equation of overall gain with negative feedback in amplifier and give application of negative feedback.

Solution

Derivation of overall gain:

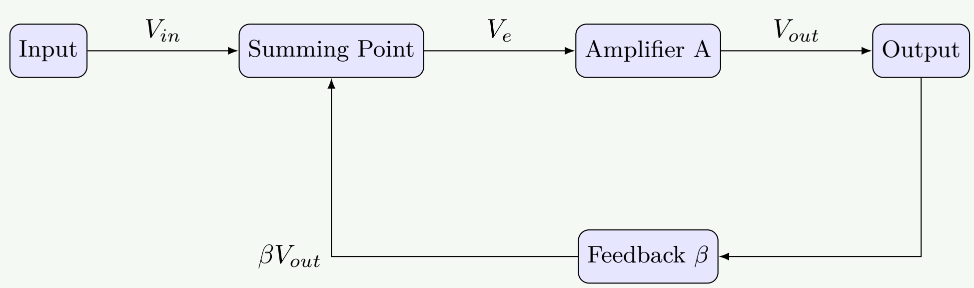


Figure 1. Negative Feedback Block Diagram

Let amplifier gain be A and feedback factor be β.

- Input signal = V_{in}
- Feedback signal = βV_{out}
- Effective input to amplifier = $V_{in} - \beta V_{out}$

- Output $V_{out} = A(V_{in} - \beta V_{out})$
- $V_{out} + A\beta V_{out} = AV_{in}$
- $V_{out}(1 + A\beta) = AV_{in}$
- **Overall Gain** $A_f = \frac{V_{out}}{V_{in}} = \frac{A}{1+A\beta}$

Applications: Operational amplifiers, Voltage regulators, Audio amplifiers, Instrumentation amplifiers.

Mnemonic

“AVOI: Amplifiers, Voltage regulators, Oscillation control, Instrumentation”

Question 1(c) [7 marks]

Draw and Explain current shunt type negative feedback amplifier and Derive the formula of input impedance and output impedance of it.

Solution

Current Shunt Negative Feedback: Output voltage is sampled and converted to current, which is subtracted from input current (Shunt mixing).

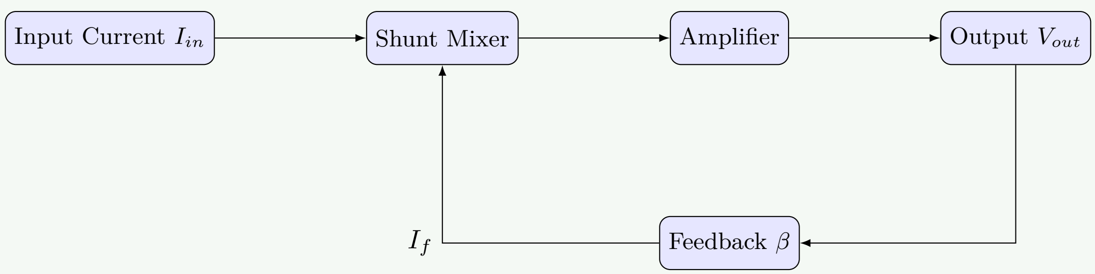


Figure 2. Current Shunt Feedback

Characteristics:

- Feedback type: Current sampling (Series), Current mixing (Shunt). *Note: The question says ”Current Shunt”. Usually means Output=Current, Input=Shunt. But description says ”output voltage sampled... subtracted from input current”. This corresponds to Voltage-Shunt topology usually. Wait. ”converted to a current”.
- MDX says: ”Output voltage is sampled...”. That's Voltage Sampling. ”subtracted from input current...”. That's Shunt Mixing. So it is **Voltage-Shunt** feedback.
- MDX Title says: ”Current Shunt type”.
- Standard texts: Current-Shunt means Output=Current sampled (Series output), Input=Current mixed (Shunt input).
- Let's check the Derivations in MDX.
- MDX Derivation: $Z'_{in} = Z_{in}/(1 + A\beta)$ (Decreases). $Z'_{out} = Z_{out}/(1 + A\beta)$ (Decreases).
- Voltage-Shunt (Transresistance) -> Z_{in} decreases, Z_{out} decreases. Matches derivation.
- So it describes **Voltage-Shunt** feedback but labels it Current Shunt. I will follow the text description characteristics.

Input Impedance: Without feedback: Z_{in}. With feedback: $Z'_{in} = \frac{Z_{in}}{1+A\beta}$. Input impedance **decreases** by factor $(1 + A\beta)$.

Output Impedance: Without feedback: Z_o. With feedback: $Z'_o = \frac{Z_o}{1+A\beta}$. Output impedance **decreases** by factor $(1 + A\beta)$.

Mnemonic

“DISCO: Decreased Impedances with Shunt Current Operation”

Question 1(c) OR [7 marks]

Draw and Explain voltage series type negative feedback amplifier and Derive the formula of input impedance and output impedance of it.

Solution

Voltage Series Negative Feedback: Output voltage is sampled and fed back in series with input voltage.

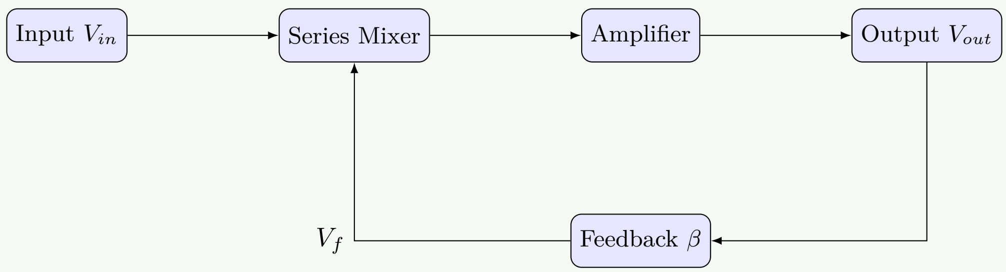


Figure 3. Voltage Series Feedback

Characteristics:

- Feedback: Voltage sampling (Output), Series mixing (Input).

Input Impedance: Without feedback: Z_{in}. With feedback: $Z'_{in} = Z_{in}(1 + A\beta)$. Input impedance **increases** by factor $(1 + A\beta)$.
Output Impedance: Without feedback: Z_o. With feedback: $Z'_o = \frac{Z_o}{1+A\beta}$. Output impedance **decreases** by factor $(1 + A\beta)$.

Mnemonic

"ISDO: Increased input impedance, Series feedback, Decreased output impedance"

Question 2(a) [3 marks]

Draw and Explain the circuit diagram of UJT as a relaxation oscillator.

Solution

UJT Relaxation Oscillator:

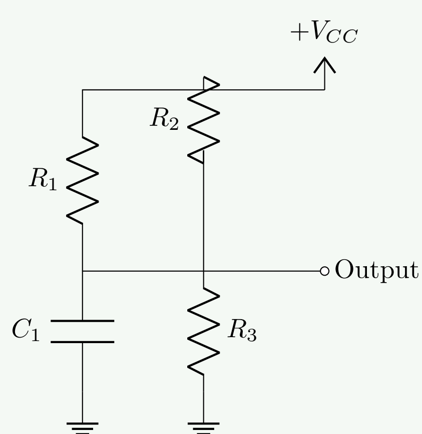


Figure 4. UJT Relaxation Oscillator

Note: If UJT symbol fails to render, use discrete representation.

Working:

- Capacitor C_1 charges through R_1.
- When voltage V_c reaches UJT peak point (V_p), UJT fires (turns ON).
- Capacitor discharges rapidly through UJT Emitter-Base1 path and R_3.
- Cycle repeats, generating sawtooth waveform at Capacitor and pulses at Output.

Mnemonic

"CURD: Capacitor charges Until Reaching Discharge point"

Question 2(b) [4 marks]

Draw circuit diagram of Colpitts oscillator and explain in brief. Give the advantages and disadvantages of it.

Solution

Colpitts Oscillator: Uses capacitive voltage divider for feedback.

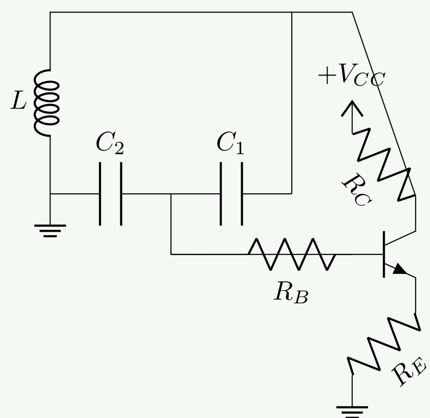


Figure 5. Colpitts Oscillator (Tank Circuit Feedback)

Working:

- Tank circuit made of L and split capacitors C_1, C_2.
- Transistor amplifies signal to sustain oscillations.
- Frequency: $f = \frac{1}{2\pi\sqrt{LC_{eq}}}$ where $C_{eq} = \frac{C_1 C_2}{C_1+C_2}$.

Advantages	**Disadvantages**
Good frequency stability	Requires two capacitors
Good for high frequencies	Harder to tune (gang tuning needed)
Simple design	Limited frequency range

Mnemonic

"FAST Circuits: Frequency stable, Appropriate for high frequencies, Simple design, Two capacitors"

Question 2(c) [7 marks]

Explain the Crystal Oscillator.

Solution

Crystal Oscillator: Uses piezoelectric crystal (Quartz) for extremely stable frequency.

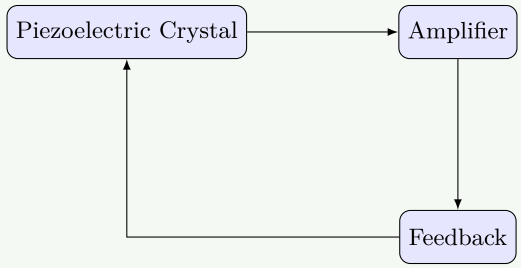


Figure 6. Concept of Crystal Oscillator

Circuit Diagram:

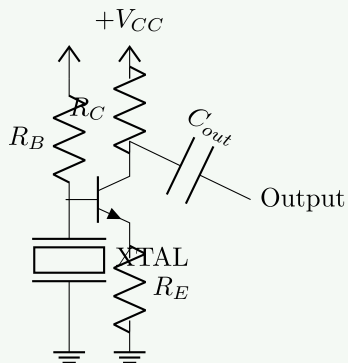


Figure 7. Pierce Crystal Oscillator

Working:

- Based on Piezoelectric effect: Crystal vibrates when voltage applied.
- Acts as high-Q Tuned Circuit. Q-factor $\approx 10,000+$.
- Provides very stable frequency $\Delta f/f \approx 10^{-6}$.

Applications: Microprocessors (Clocks), Digital watches, Radio transmitters.

Mnemonic

"STOP: Stable, Temperature-resistant, Oscillates, Piezoelectric"

Question 2(a) OR [3 marks]

Draw and explain the Hartley Oscillator.

Solution

Hartley Oscillator: Uses tapped inductor tank circuit.

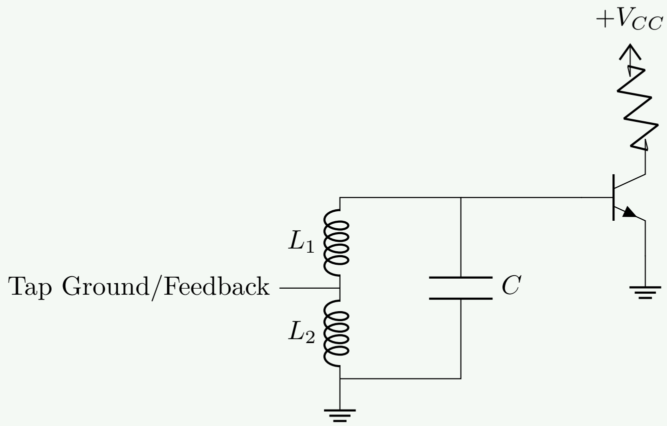


Figure 8. Hartley Tank Circuit (Tapped Inductor)

Working:

- Inductive voltage divider (L_1, L_2) provides feedback.
- Frequency: $f = \frac{1}{2\pi\sqrt{L_{eq}C}}$ where $L_{eq} = L_1 + L_2$.
- Used for RF applications.

Mnemonic

"TIC: Tapped Inductor Circuit"

Question 2(b) OR [4 marks]

Draw and explain Wien Bridge oscillator.

Solution

Wien Bridge Oscillator: Audio frequency oscillator using RC bridge.

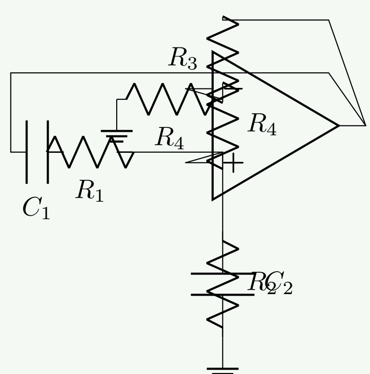


Figure 9. Wien Bridge Oscillator

Working:

- Uses series RC (Z_1) and parallel RC (Z_2) arms.
- Balance condition: $f = \frac{1}{2\pi RC}$.
- Amplifier gain must be $A \geq 3$ to sustain oscillations.
- Low distortion sine wave generator.

Mnemonic

"FEAR: Frequency selective, Equal RC, Audio Range"

Question 2(c) OR [7 marks]

Draw the Structure, symbol, equivalent circuit of UJT and explain in brief.

Solution

Unijunction Transistor (UJT):

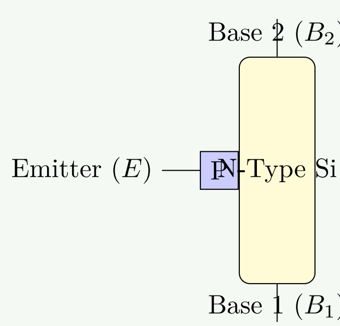


Figure 10. UJT Structure

Working Principle:

- 3-terminal device: Emitter, Base1, Base2.
- RB1 and RB2 are internal resistances of N-bar.
- **Firing Condition:** When $V_E > \eta V_{BB} + V_D$, current flows.
- Exhibits **Negative Resistance** region.

Characteristics:

- Intrinsic Standoff Ratio $\eta = \frac{R_{B1}}{R_{B1}+R_{B2}}$. Typically 0.5-0.8.
- Peak Point (V_p): Onset of conduction.
- Valley Point (V_v): Minimum voltage after firing.

Mnemonic

"NEVER: Negative resistance, Emitter-triggered, Valley/Peak points"

Question 3(a) [3 marks]

Differentiate between voltage and power amplifier.

Solution

Parameter	Voltage Amplifier	Power Amplifier
Purpose	Amplifies voltage	Delivers power to load
Output Impedance	High	Low
Input Impedance	High	Relatively low
Efficiency	Not important	Very important
Heat Dissipation	Low	High (requires heat sink)
Position	Early stages	Final stage

Mnemonic

"PEHIP: Power for Efficiency and Heat, Impedance matters, Position differs"

Question 3(b) [4 marks]

Explain class-B push pull power amplifier in detail.

Solution

Class-B Push-Pull Amplifier: Uses two complementary transistors, each conducting for 180° of the cycle.

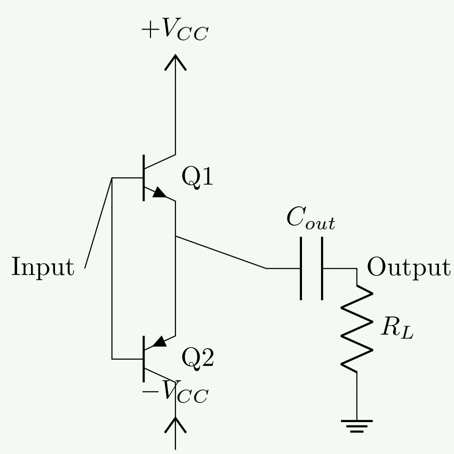


Figure 11. Class-B Push-Pull

Working:

- Q1 conducts for positive half cycle.
- Q2 conducts for negative half cycle.
- Combined output is full sine wave.
- Efficiency $\eta \approx 78.5\%$.
- Suffers from **Crossover Distortion**.

Mnemonic

"ECHO: Efficiency high, Crossover distortion, Half-cycle operation, Output high power"

Question 3(c) [7 marks]

Draw and Explain Complementary symmetry push-pull power amplifier in detail also list

the disadvantages of it.

Solution

Complementary Symmetry Push-Pull: Uses matched NPN and PNP transistors. No transformers required.

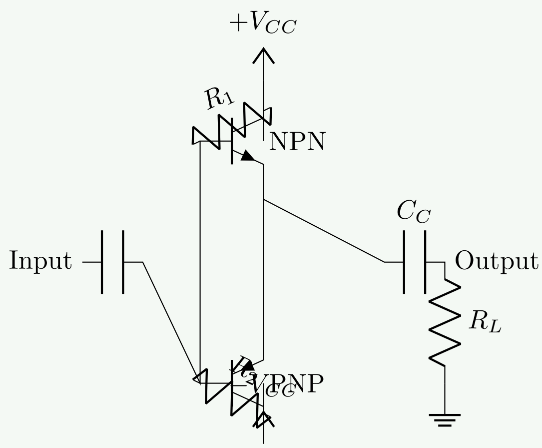


Figure 12. Complementary Symmetry Amplifier

Disadvantages:

1. Needs matched NPN/PNP pair (hard to find in high power).
2. Thermal runaway if not properly biased.
3. Crossover distortion (if pure Class B).
4. Requires dual power supply usually.

Mnemonic

"MATCH: Matched transistors, Avoids transformers, Thermal issues, Crossover distortion"

Question 3(a) OR [3 marks]

Define the terms related to power amplifier. i)Efficiency ii)Distortion iii)power dissipation capability

Solution

Term	Definition
Efficiency	Ratio of AC output power to DC input power. $\eta = \frac{P_{out}}{P_{in}} \times 100\%$.
Distortion	Unwanted alteration of output waveform (THD). Harmonics, crossover, etc.
Power Dissipation Capability	Max power the device can dissipate as heat without damage. Depends on heat sink.

Mnemonic

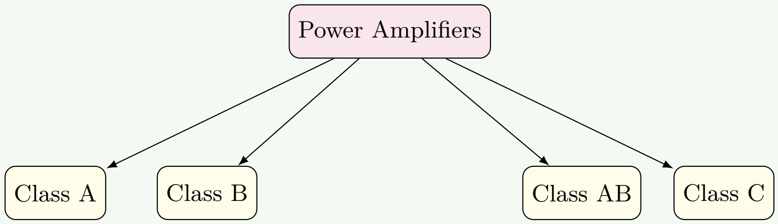
"EDP: Efficiency converts, Distortion deforms, Power capability protects"

Question 3(b) OR [4 marks]

Classify the power amplifier for mode of operation and explain working of different type power amplifier

Solution

Classification:



Class	Angle	Working
A	$360°$	Conducts full cycle. Linear, Low efficiency $(25 - 50\%)$.
B	$180°$	Conducts half cycle. High efficiency (78.5%), X-over distortion.
AB	$180° - 360°$	Trade-off. Reduced distortion, Good efficiency $(50 - 70\%)$.
C	$< 180°$	Tuned circuits. High efficiency $(> 80\%)$, High distortion.

Question 3(c) OR [7 marks]

Derive efficiency of class-B push pull power amplifier.

Solution

Efficiency Derivation:

- **DC Input Power:** $I_{dc} = \frac{2I_m}{\pi}$ (Total for full wave). $P_{dc} = V_{CC}I_{dc} = \frac{2V_{CC}I_m}{\pi}$.
- **AC Output Power:** $I_{rms} = \frac{I_m}{\sqrt{2}}$. $P_{ac} = \frac{V_m I_m}{2}$. (Ideally $V_m = V_{CC}$).
- **Efficiency:**

$$\eta = \frac{P_{ac}}{P_{dc}} \times 100\% = \frac{V_{CC}I_m/2}{2V_{CC}I_m/\pi} \times 100\%$$

$$\eta = \frac{\pi}{4} \times 100\% \approx 78.5\%$$

Mnemonic

"PIPE: Power ratio, Input DC vs Output AC, Pi in formula, Efficiency 78.5%"

Question 4(a) [3 marks]

Draw pin diagram and Schematic symbol of IC 741 and explain it in detail.

Solution

IC 741 Op-Amp:

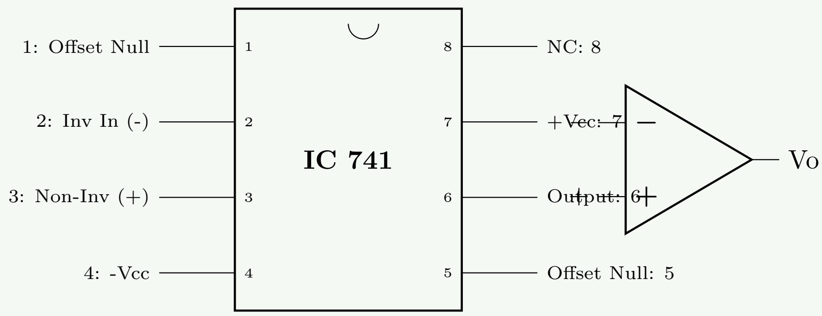


Figure 13. IC 741 Pinout and Symbol

Pin Description:

- **2, 3**: Inputs (Inverting, Non-inverting).
- **6**: Output.
- **7, 4**: Power Supply ($+V_{CC}, -V_{EE}$).
- **1, 5**: Offset Null (to remove error voltage).
- **8**: No Connection.

Question 4(b) [4 marks]

Explain differential Amplifier using OPAMP.

Solution

Differential Amplifier: Amplifies the difference between two input voltages.

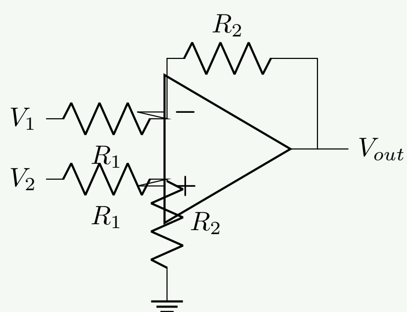


Figure 14. Difference Amplifier

Working: Output $V_{out} = \frac{R_2}{R_1}(V_2 - V_1)$. Rejects common mode signals (CMRR).

Mnemonic

"CARE: Common-mode rejection, Amplifies difference, Resistor matching"

Question 4(c) [7 marks]

Explain the following parameters of an OP-Amp: 1)Input offset voltage 2) Output Offset Voltage 3) Input Offset Current 4)Input Bias Current 5) CMRR 6) Slew rate 7) Gain.

Solution

- **Input Offset Voltage (V_{io}):** Voltage applied at input to make output zero. (Typ: 1-5mV).
- **Output Offset Voltage:** Error voltage at output when inputs are zero.
- **Input Offset Current (I_{io}):** Difference between input bias currents $|I_{b1} - I_{b2}|$. (Typ: 10nA).
- **Input Bias Current (I_b):** Average of input currents $(I_{b1} + I_{b2})/2$. required to bias transistors.
- **CMRR:** Common Mode Rejection Ratio. CMRR $= A_d/A_{cm}$. Ability to reject noise. (Typ: 90dB).
- **Slew Rate (SR):** Max rate of change of output voltage. $SR = dV_o/dt|_{max}$. Unit: V/μs. (Typ: 0.5V/μs).
- **Gain (A_{OL}):** Open Loop Voltage Gain. ratio of output to differential input. (Typ: 2×10^5).

Mnemonic

"VICS BGR: Voltage offset, Current offset, Slew rate, Bias, Gain, Rejection"

Question 4(a) OR [3 marks]

List characteristics of ideal op-amp.

Solution

Characteristic	**Ideal Value**
Open Loop Gain (A_{OL})	Infinite (∞)
Input Impedance (Z_{in})	Infinite (∞)
Output Impedance (Z_{out})	Zero (0)
Bandwidth (BW)	Infinite
CMRR	Infinite
Slew Rate	Infinite
Offset Voltage	Zero

Mnemonic

"ZINC BOSS: Zero output Z, Infinite Gain/Input Z, No noise, CMRR infinite"

Question 4(b) OR [4 marks]

Draw and explain the block diagram of the Operational Amplifier (OPAMP) in detail.

Solution

Block Diagram:

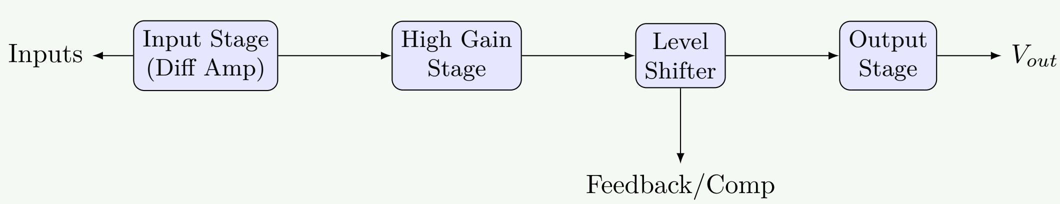


Figure 15. Op-Amp Internal Block Diagram

Stages:

1. **Input Stage:** Differential amplifier (Dual Input Balanced Output). High Z_{in}.

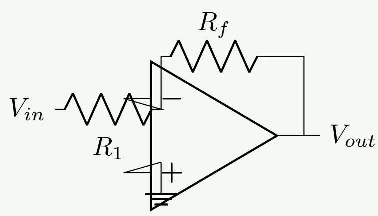
2. **Intermediate Stage:** High gain voltage amplifier (Darlington pair).
3. **Level Shifter:** Emitter follower to shift DC level to 0V.
4. **Output Stage:** Push-pull amplifier for low Z_{out} and current drive.

Question 4(c) OR [7 marks]

Draw explain Inverting and Non-inverting Op-amp amplifier with the derivation of voltage gain.

Solution

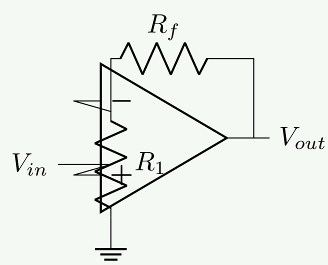
1. Inverting Amplifier:



Gain: Virtual ground at (-) input. Current $I = V_{in}/R_1$. Flows to R_f. $V_{out} = -IR_f = -(V_{in}/R_1)R_f$.

$$A_v = -R_f/R_1$$

2. Non-Inverting Amplifier:



Gain: Voltage divider feedback $V_- = V_{out}\frac{R_1}{R_1+R_f}$. Virtual short $V_- = V_+ = V_{in}$. $V_{in} = V_{out}\frac{R_1}{R_1+R_f}$.

$$A_v = 1 + R_f/R_1$$

Mnemonic

"PING-PONG: Phase Inverted Negative Gain vs Positive Output Non-inverted Gain"

Question 5(a) [3 marks]

Draw and explain integrator using Op-Amp.

Solution

Integrator:

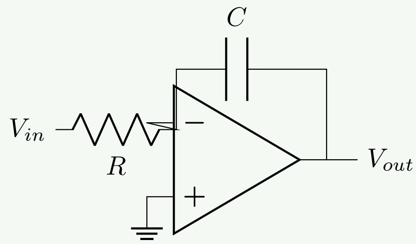


Figure 16. Ideal Integrator

Working: Output is proportional to time integral of input. $V_{out} = -\frac{1}{RC}\int V_{in}dt$. Used in analog computers and wave shaping.

Mnemonic

"TIME: Takes Input and Makes integral over time"

Question 5(b) [4 marks]

Compare different types of power amplifier.

Solution

Parameter	Class A	Class B	Class AB	Class C
Conduction	360°	180°	$180° - 360°$	$< 180°$
Efficiency	25-50%	78.5%	50-70%	>80%
Distortion	Low	High	Low	High
Usage	Audio	General	Audio	RF

Mnemonic

"CABINET: Conduction, Amplification, Biasing, Ideal apps, Noise, Efficiency, Temperature"

Question 5(c) [7 marks]

List applications of IC555 and explain any one in detail.

Solution

Applications: Timers, Oscillators, Pulse generation, PWM, Frequency divider, Tone generator.
Astable Multivibrator:

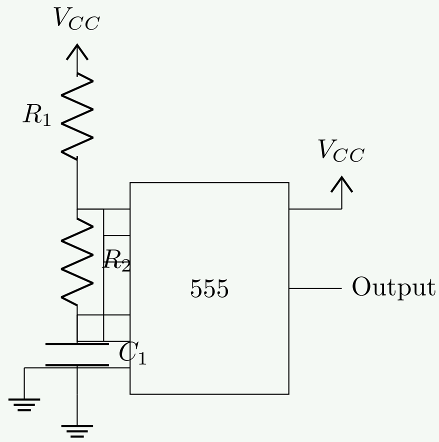


Figure 17. Astable Mode

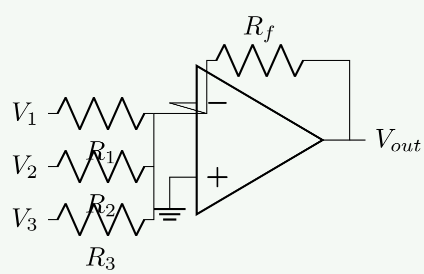
Working: Capacitor C charges through $R_1 + R_2$ and discharges through R_2. $t_{high} = 0.693(R_1 + R_2)C$. $t_{low} = 0.693R_2C$. $f = \frac{1.44}{(R_1+2R_2)C}$. Produces square wave output.

Question 5(a) OR [3 marks]

Draw and explain summing amplifier using Op-Amp.

Solution

Summing Amplifier:



Working: $V_{out} = -(\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \dots)$. If all R equal, $V_{out} = -(V_1 + V_2 + V_3)$.

Question 5(b) OR [4 marks]

Compare between push-pull amplifier and Complementary push-pull power amplifier.

Solution

Feature	Push-Pull	Complementary Push-Pull
Transistors	Same type (NPN)	Matches Pair (NPN+PNP)
Transformers	2 Required (Input/Output)	None
Size/Weight	Bulky	Compact
Cost	High	Low
Matching	Transistors only	NPN and PNP characteristics

Mnemonic

"TONIC: Transformers, One type vs Complementary, Nice frequency, Improved distortion, Cost"

Question 5(c) OR [7 marks]

Draw pin diagram and block diagram of IC555 and explain in detail.

Solution

IC 555 Block Diagram:

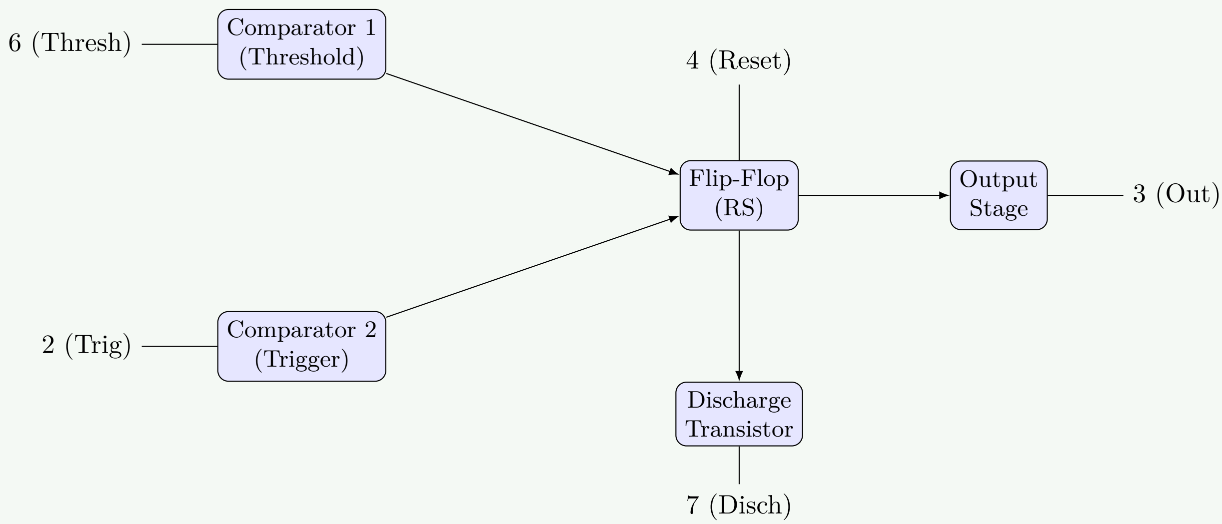


Figure 18. Internal Block Diagram of IC 555

Components:

1. **Resistor Divider:** Three 5kΩ resistors set reference voltages ($2/3V_{CC}, 1/3V_{CC}$).
2. **Comparators:** Compare inputs with references.
3. **Flip-Flop:** Set/Reset by comparators.
4. **Output Stage:** High current totem-pole output.
5. **Discharge Transistor:** Discharges timing capacitor.

Mnemonic

"VICTOR: Voltage divider, Internal comparators, Control flip-flop, Timing, Output, Reset"