Analog Electronics

DIPLOMA WALLAH

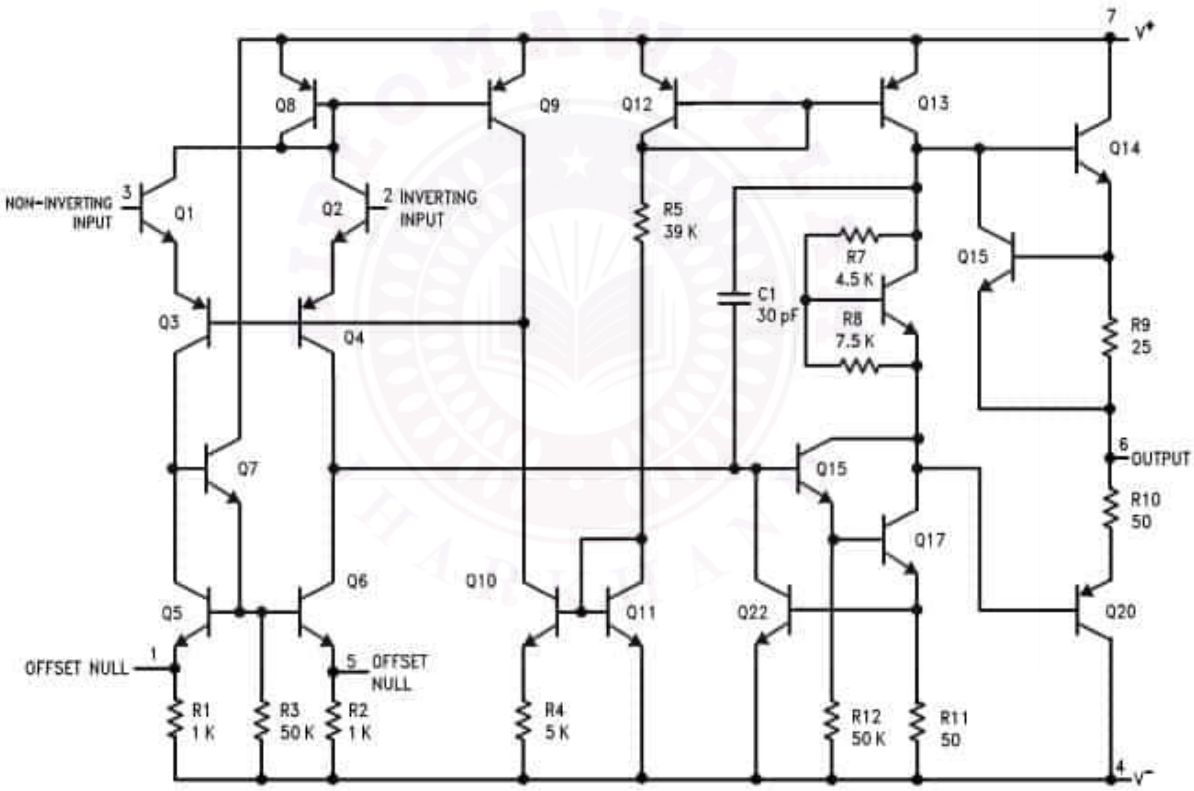
EE/EEE

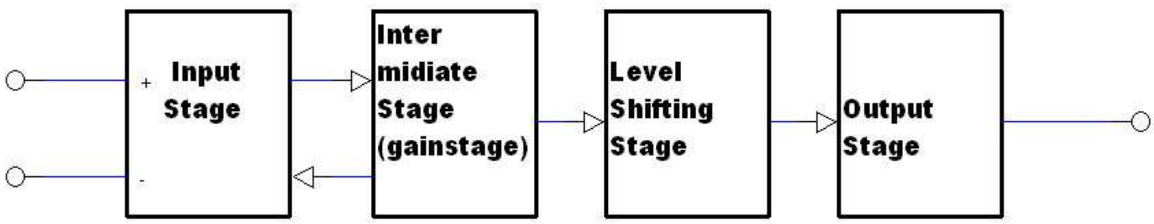
Jharkhand University Of Technology (JUT)

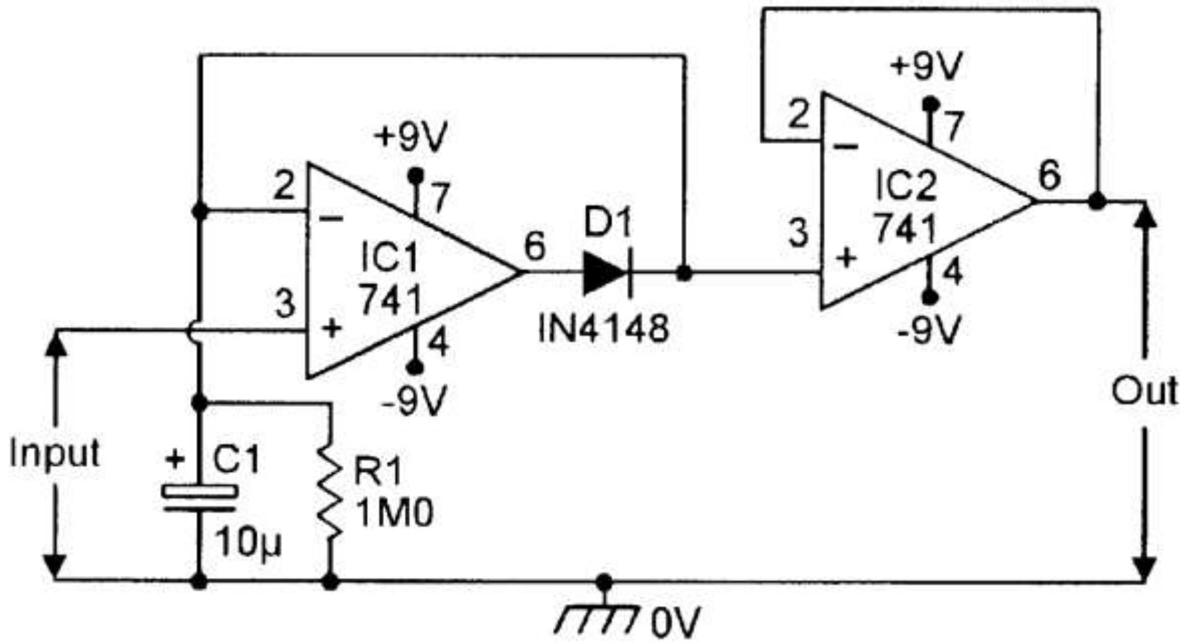
Unit 06

1. OP-AMP — Block Diagram, Operation, Characteristics, Applications, LM741 Pin Diagram

1.1 Internal Structure & Block Diagram







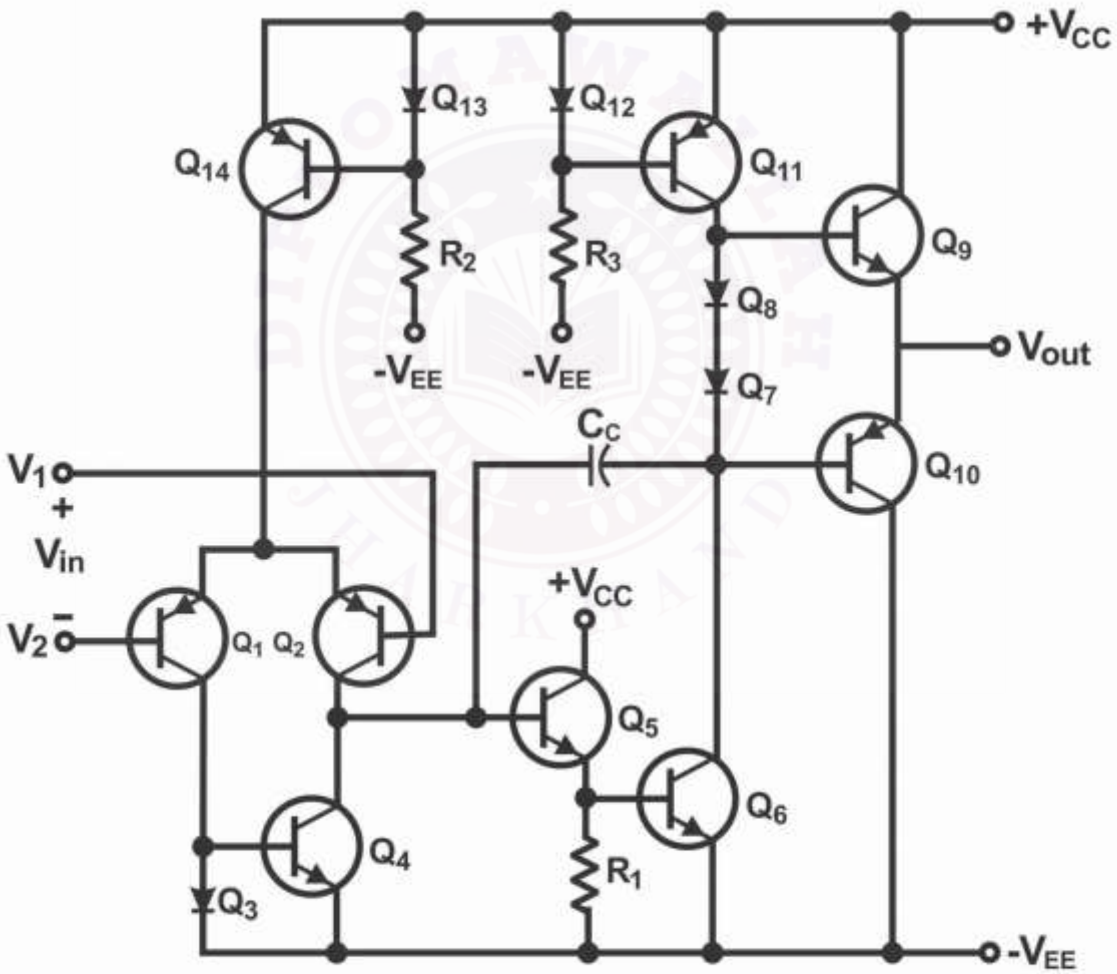
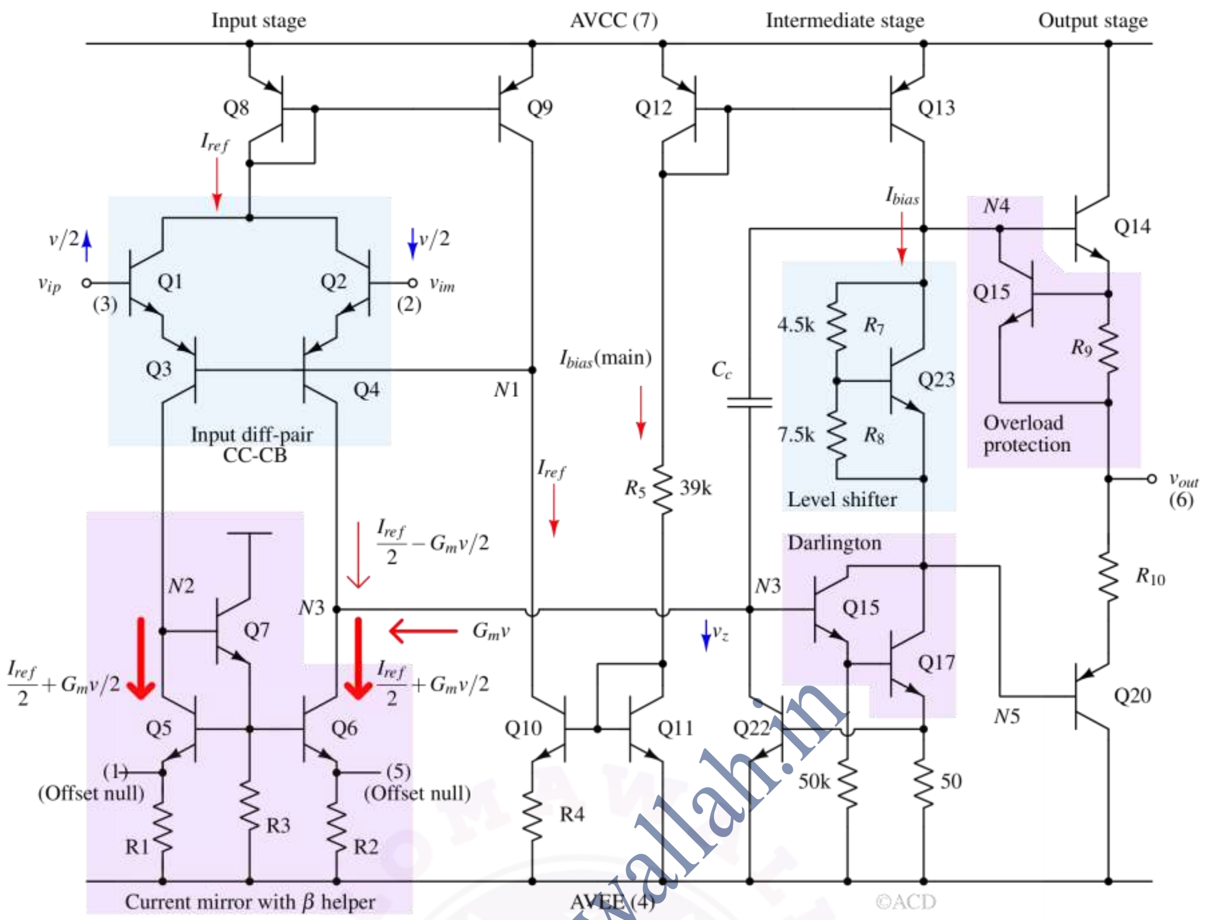


Fig 8.64: Simplified schematic diagram of 741



- The LM741 (and many similar op-amps) are built from several internal stages. According to a detailed reference:

"A detailed circuit schematic of the 741 op-amp … consists of five main parts: (i) bias circuit, (ii) the input gain stage, (iii) the second gain stage, (iv) the output buffer, and (v) the short-circuit protection circuit." (Electrical and Computer Engineering)

- Breaking that down:
  1. **Bias Circuit / Current Sources & Mirrors**: Provide stable operating currents to various internal transistors, keep inputs stable, supply rails separated. For example the 741 uses current-mirror arrangements and internal compensation capacitor. (righto.com)
  2. **Differential Input Stage**: Two inputs (inverting "–" and non-inverting "+") feed a long-tailed pair (transistors) so the device amplifies the *difference* (V_{+} - V_{-}). The input stage also provides high input impedance and fairly good common-mode rejection. (Basic Electronics Tutorials)

3. **Second / Gain Stage**: The differential signal is converted into a single-ended signal and then amplified further (voltage amplification). Internal capacitor (compensation) creates a dominant pole for stability. (cdn.evilmadscientist.com)
4. **Output Stage (Buffer / Power Stage)**: Provides enough current/voltage to drive loads; low output impedance ideally. In the 741 there are push-pull emitter follower stages in the output. Also some protection circuits against overload/short. (Texas Instruments)

- Why this structure matters: It allows a single integrated chip to meet many requirements: high gain, stable behaviour with feedback, capability to drive loads, tolerance to input & load changes.

1.2 Operation (How it works)

- In open-loop configuration, the op-amp amplifies the difference between its inputs:
$$V_{\text{out}} = A_{\text{OL}} \times (V_{+} - V_{-})$$
Where (A_{OL}) (open-loop gain) can be very large (e.g., 10^5 or more) for the 741-type. (righto.com)
- In practical circuits, feedback (usually negative feedback) is applied so that the closed-loop gain is controlled by external resistors, rather than being uncontrolled and very large. This feedback forces the op-amp to operate in linear region (not saturation).
- For example: In an inverting amplifier configuration: the negative input receives input via resistor, the output is fed back via another resistor; the non-inverting input is grounded (or at reference). The closed-loop gain becomes:
$$V_{\text{out}} = - \frac{R_f}{R_{in}} \, V_{\text{in}}$$
(for ideal conditions)
- Key requirement: The op-amp must remain in its active region (not saturate or cut-off) during the full swing of the input signal so that

amplification remains “faithful”. If input pushes base into saturation or transistor stages saturate, distortion occurs.

1.3 Characteristics — Ideal vs Practical

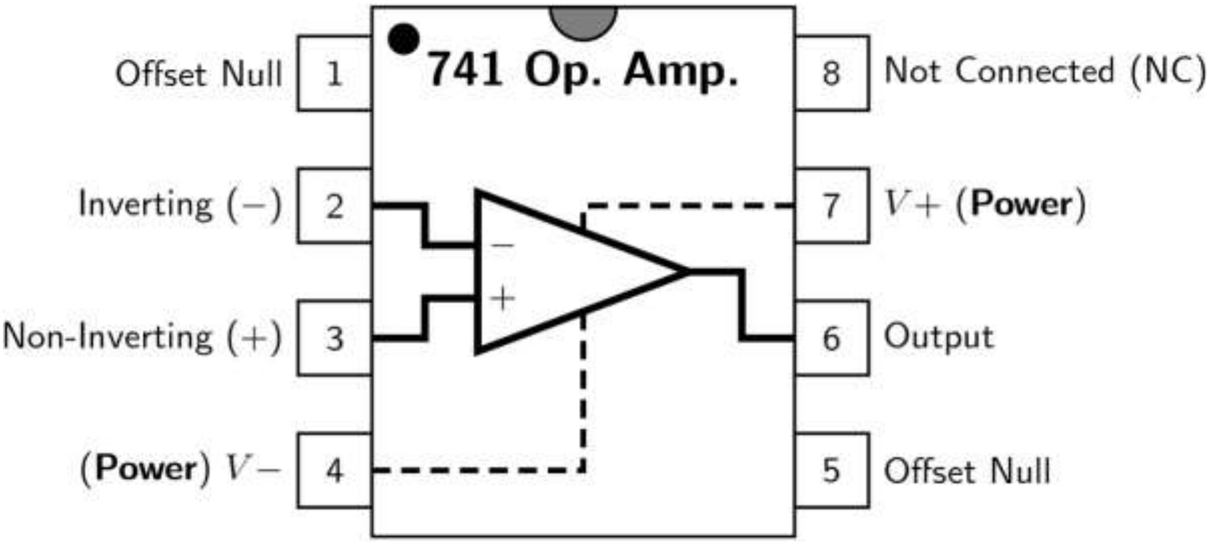
Ideal op-amp characteristics:

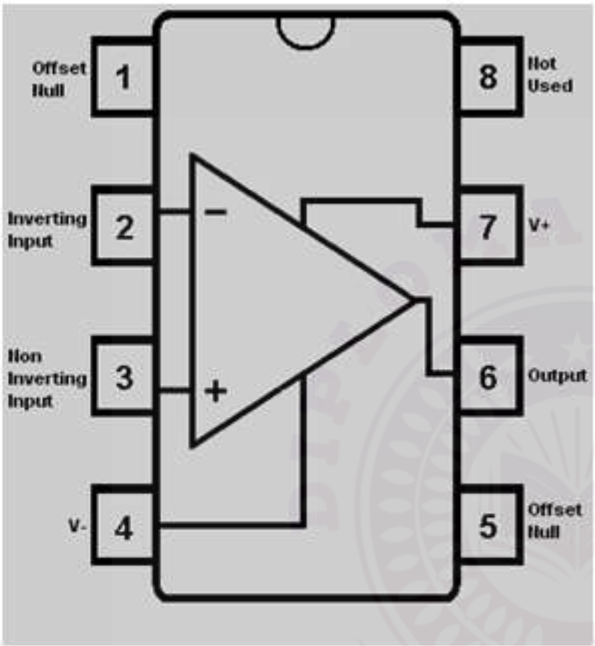
- Infinite open-loop gain
- Infinite input impedance (so no input current)
- Zero output impedance
- Infinite bandwidth (gain constant for all frequencies)
- Zero offset voltage, infinite slew rate, perfect common-mode rejection

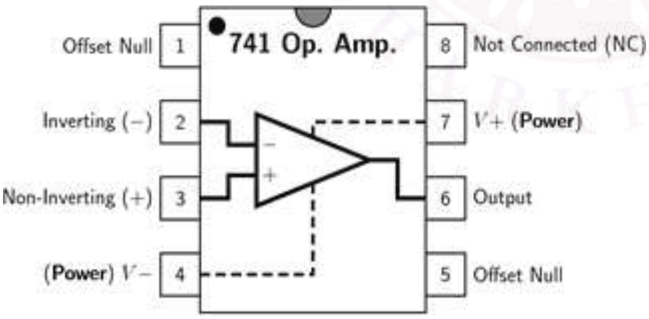
Practical characteristics (e.g., LM741/μA741)

- Finite open-loop gain (maybe 10^4–10^6) and gain reduces with frequency (gain-bandwidth product is limited). (Basic Electronics Tutorials)
- Finite input impedance (maybe several MΩs) and there is input bias current, input offset voltage.
- Non-zero output impedance — so output cannot always drive very heavy loads without drop in gain or increased distortion.
- Limited bandwidth; there is a dominant pole (due to internal compensation capacitor) so above some frequency gain drops. (righto.com)
- Finite slew rate (how fast output can change) — this limits how quickly the output can respond to fast changing inputs without distortion.
- Input voltage range and output swing are limited by the supply rails and internal transistor saturation margins.
- Need for dual-supply rails (for 741) typically ±12 V or ±15 V. (learninglink.oup.com)
- Additional features like overload protection, short-circuit protection, no latch-up behaviour. (Texas Instruments)

1.4 Pin Diagram of LM741 / Typical Usage







- A typical 741 (8-pin DIP) has pins:
  - Pin 1: Offset Null
  - Pin 2: Inverting Input (–)

- Pin 3: Non-Inverting Input (+)
- Pin 4: (V_{CC−}) (Negative supply)
- Pin 5: Offset Null (or other config)
- Pin 6: Output
- Pin 7: (V_{CC+}) (Positive supply)
- Pin 8: Not connected or sometimes compensation/unused depending version. (Electrical 4U)

- Important practical notes:
  - The offset null pins allow you to adjust (via small potentiometer) the output offset when input is zero or inputs are shorted, to compensate internal mismatches.
  - The supply rails must be symmetric for many applications (for example ±15 V) so that input and output can swing both positive and negative about ground. If one uses single supply, the input and output must be shifted accordingly.
  - Because of internal design, the input common-mode voltage must stay within some margin of the rails (cannot go to rails). The output cannot swing fully to the supply rails — there is a "headroom" required.

1.5 Applications of Op-Amps

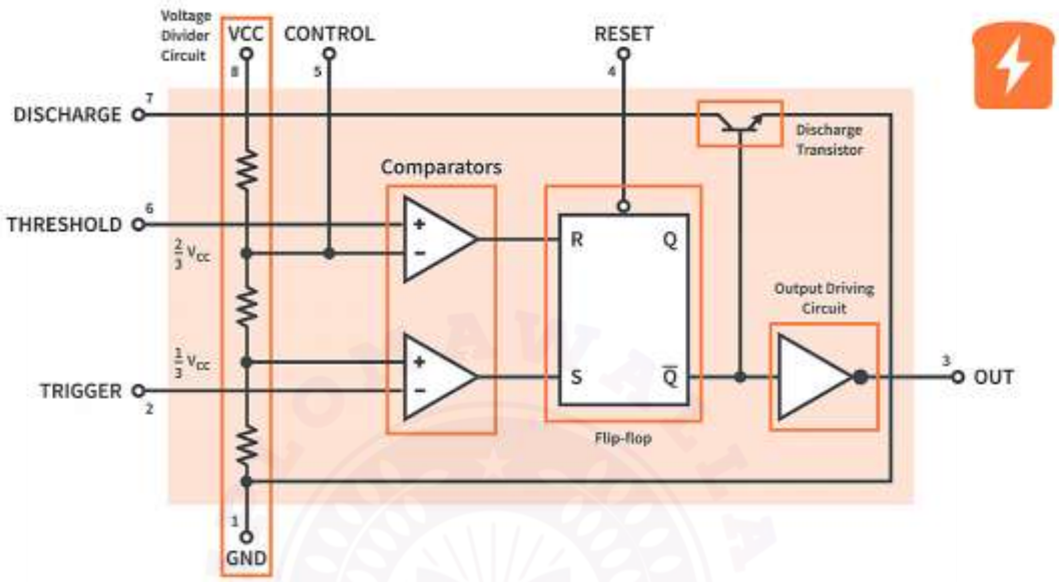
- As amplifiers in signal conditioning: e.g., small sensor output amplified to usable voltage.
- Feedback control systems (PID controllers).
- Active filters (low-pass, high-pass, band-pass).
- Mathematical operations: adder (summer), subtractor, integrator, differentiator (important in analog computing).
- Voltage followers / buffers for impedance matching.
- Comparators (though dedicated comparator ICs often used nowadays) where the op-amp compares two voltages and switches output accordingly.
- Instrumentation amplifiers (with multiple op-amps) for accurate low-level signal amplification in medical, industrial devices.

- Oscillators, waveform generators (with feedback networks).
- Digital-to-analog and analog-to-digital front ends.

---

2. 555 Timer IC — Block Diagram, Pin Diagram, Duty Cycle/Time Delay, Applications, Astable & Monostable Multivibrators

2.1 Internal Structure & Block Diagram



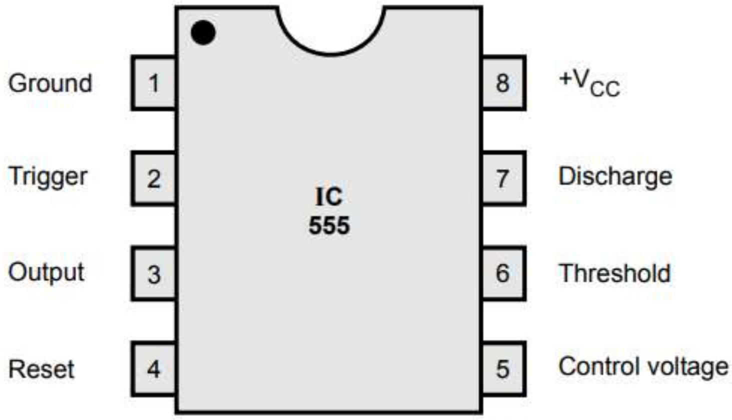


Fig. 4.1.5 (a) Pin diagram

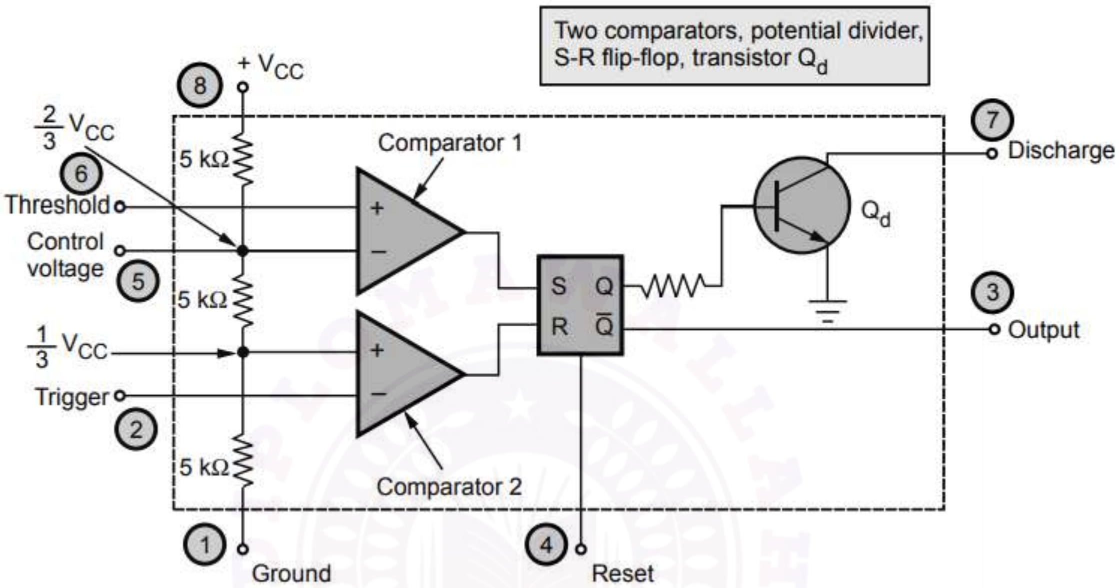
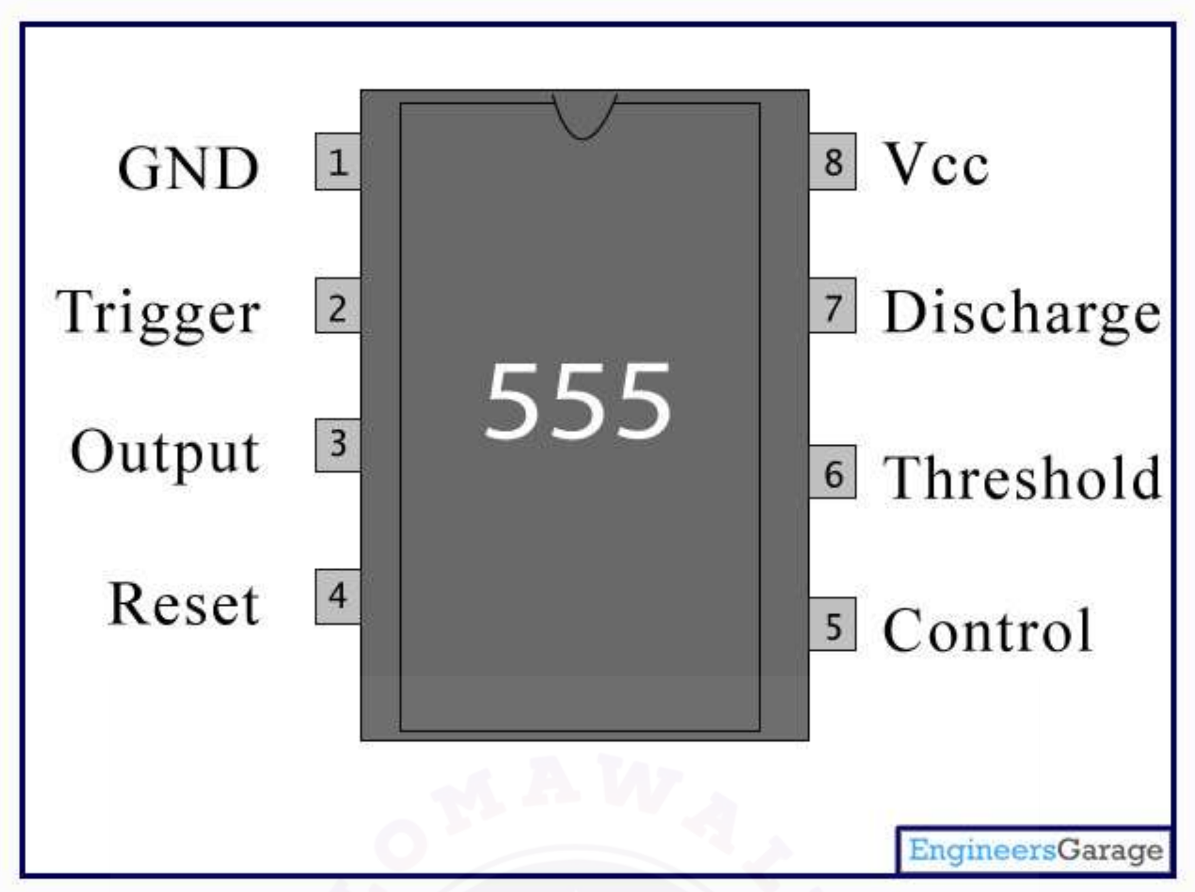
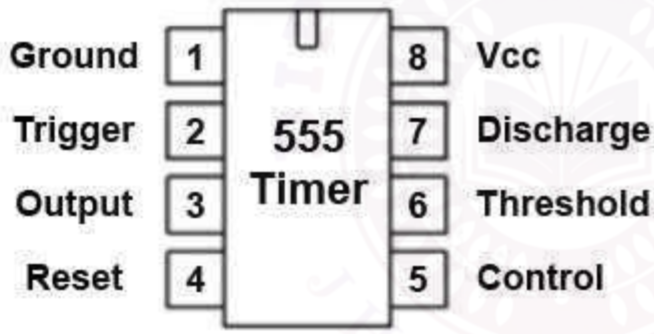


Fig. 4.1.5 (b) Block diagram of IC 555 timer





- The 555 timer IC is built using roughly 15 resistors, 2 diodes, and around 20 transistors internally (depending on manufacturer). (me.psu.edu)
- Key internal blocks:
  1. **Three equal resistors** forming a voltage divider between supply rails (typically each ~5 kΩ) – these create two reference voltages: (V_{CC}/3) and (2V_{CC}/3). (ElecCircuit.com)
  2. **Two voltage comparators**:

    - Upper comparator compares the threshold input (pin 6) to (2V_{CC}/3).
    - Lower comparator compares the trigger input (pin 2) to (V_{CC}/3). (Basic Electronics Tutorials)

  3. **SR flip-flop**: The outputs of comparators set or reset the internal flip-flop which drives the output stage and controls the discharge transistor.
  4. **Discharge transistor**: Internally connected to pin 7. When this transistor is ON it pulls the external timing capacitor to ground (discharging it).
  5. **Output stage**: Provides the output at pin 3, capable of sourcing or sinking current, able to drive loads or other circuits.
  6. **Control pin (pin 5)**: Allows external control of the reference voltages (optional).

- Working principle: depending on external RC network and trigger/threshold signals, the 555 toggles output and controls discharge transistor accordingly.

2.2 Pin Diagram & Description

- Standard 8-pin DIP:
  - Pin 1: GND (0 V)
  - Pin 2: TRIG (Trigger) – when voltage falls below (V_{CC}/3), sets flip-flop
  - Pin 3: OUT (Output)
  - Pin 4: RESET – active low, when pulled low resets the flip-flop (output low)
  - Pin 5: CTRL (Control) – externally adjust threshold voltages
  - Pin 6: THR (Threshold) – when voltage rises above (2V_{CC}/3), resets flip-flop
  - Pin 7: DISCH (Discharge) – transistor to ground to discharge timing capacitor

- Pin 8: VCC (Positive supply) (Electronics For You)

- The supply voltage range is typically +4.5 V up to ~+18 V for the standard bipolar 555. (Electronics For You)
- The device is widely popular for timing, pulse generation and oscillator circuits. (Wikipedia)

2.3 Working Modes: Monostable (One-Shot) & Astable (Oscillator) & Duty Cycle / Time-Delay

Monostable Mode

- In this mode, the 555 has **one stable state** (usually output low). On a trigger (negative-going pulse on TRIG pin), the output goes high for a duration (set by R and C) then returns to the stable state. (circuitbread.com)
- Timing equation:
  [
  T = 1.1,R,C
  ]
  (approximately) where R is the timing resistor and C is the timing capacitor. (Basic Electronics Tutorials)
- During the timing interval, the discharge transistor is off, allowing the capacitor to charge up via R. Once the voltage at THR pin hits (2V_{CC}/3), the comparator resets the flip-flop, output goes low, discharge transistor turns ON, capacitor discharges quickly, ready for next trigger.
- Applications: delays, pulse stretching, push-button debouncing, missing pulse detection, sensor trigger circuits.

Astable Mode

- Here, the 555 has **no stable state**; the output continuously toggles between high and low, forming a free-running oscillation (square-wave) without external trigger. (Basic Electronics Tutorials)
- External components: two resistors (R_A) and (R_B), and capacitor (C). The capacitor charges through (R_A + R_B) and discharges through (R_B) (via discharge transistor).

- Equations:
  $$T_{\text{high}} = 0.693,(R_A + R_B),C$$
  $$T_{\text{low}} = 0.693,R_B,C$$
  $$T = T_{\text{high}} + T_{\text{low}} \implies f = \frac{1}{T}$$
  $$\text{Duty cycle } D = \frac{T_{\text{high}}}{T}$$
  (All About Circuits)
- Because $(R_A + R_B)$ appears in (T_{high}) but only (R_B) in (T_{low}), the duty cycle is always >50 % (unless modified with diodes etc).
- Applications: clock generation, square-wave sources, LED flashers, PWM circuits, tone generation, waveform generation.

2.4 Duty Cycle & Time Delay Considerations

- For monostable: the time delay (T) is directly proportional to R and C. Choose R large and C large for long delays (but note large C may have leakage and tolerance issues) (All About Circuits)
- For astable: if you want duty cycle closer to 50%, you may use a diode in parallel with (R_B) or other modifications so that charging and discharging paths are symmetric.
- The accuracy of timing depends on tolerance of R/C, temperature, supply voltage variation, leakage currents, and external trigger/spurious noise.
- The output amplitude is from nearly 0 V to nearly VCC (minus small saturations) depending on load and supply.

2.5 Applications & Multivibrator Modes

- **Monostable multivibrator** (one-shot): Output pulse of fixed duration on each trigger. Use for timers, delay circuits. (555-timer-circuits.com)

- **Astable multivibrator**: Output continuously oscillates; used for clocks, PWM, LED blinkers. (ae-iitr.vlabs.ac.in)
- **Bistable multivibrator**: Using 555 (or dual versions) you can make flip-flop behaviour (two stable states) though pure 555 needs external wiring. (GeeksforGeeks)
- Other uses: PWM motor speed control, light dimmers, tone generators, sensor interface delays, waveform shaping.

Summary & Exam Tips

- For the op-amp section: make sure you understand the internal structure (bias, differential input, gain stage, output buffer), the difference between ideal vs practical characteristics, how feedback influences gain and behaviour, and know the pin-out + supply requirements of LM741.
- For the 555 timer section: understand the internal functional blocks (voltage divider → comparators → flip-flop → discharge transistor → output), the pin functions, how the timing works (charging/discharging of external RC), how to derive the formulas for monostable and astable modes, and typical applications of each mode.
- In your answers, include diagrams: pin-diagrams, block diagrams, circuit diagrams for monostable/astable, waveform sketches. Label everything.
- Use the formulas when required (e.g., derive time delay, or duty cycle) and mention limitations (accuracy, external component tolerances, supply voltage effects).
- When describing op-amp behaviour, emphasise the need for negative feedback for stability and how biasing ensures linear operation (not saturating).
- When describing 555 circuits, make sure you mention trigger/threshold levels (⅓ VCC, ⅔ VCC) because that's often asked in exams.

Diploma Wallah

Made with 💗 by Sangam