Operational Amplifier Circuits

Called operational amplifier due to the use of this amplifier to perform specific electronic circuit functions or operations, such as summation, integration, differentiation, etc.

We studied applications of op amp. Now we analyze and design the circuitry of the op-amp to determine how the various configurations can be combined to form a nearly ideal op amp!

The 741 has been produced since 1966. The 741 is widely used as general-purpose op-amp
General block diagram of an operational amplifier
The 741 Op-Amp Circuit
Circuit Description

• The 741 consists of three circuits
  – The input differential amplifier (Q₁ through Q₇)
  – The gain stage
  – The output stage (low output resistance)
  – There is also a separate bias circuit, which establishes the bias currents throughout the op amp (Q₈ through Q₁₂).
  – The 741 is biased by both positive and negative supply voltages (typical values ±15 V).
  – The 741 is a DC and small-signal amplifier.
  – The DC output voltage is zero when the applied differential input signal is zero.
Input Differential Amplifier

- Q₁ and Q₂ act as emitter followers causing the input resistance to be high.
- The differential output currents from Q₁ and Q₂ are the inputs to the common-base amplifier formed by Q₃ and Q₄, which provides a relatively large voltage gain.
- Transistors Q₅, Q₆, and Q₇, with associated resistors R₁, R₂, and R₃ form the active load for the diff amplifier.
- A single sided output at the common collectors of Q₄ and Q₆ is the input signal to the following gain stage.
- The DC output voltage at the collector of Q₆ is at lower potential than the inputs at the bases of Q₁ and Q₂.
- As the signal passes through the op-amp, the DC voltage level shifts several times. By design, when the signal reaches the output terminal, the DC voltage should be zero if a zero differential input signal is applied.
• The two null terminals on the input stage are used to make appropriate adjustment to accomplish this design goal.
• The DC current biasing is initiated by transistors $Q_{12}$ and $Q_{11}$ and resistor $R_5$.
• Transistor $Q_{11}$ and $Q_{10}$, with resistor $R_4$ form a Wildar current source that establishes the bias currents in the common-base transistors $Q_3$ and $Q_4$ as well as the current mirror formed by $Q_9$ and $Q_8$.
• $Q_3$ and $Q_4$ are pnp transistors. They provide added protection against voltage breakdown.
Gain Stage

- The second, or gain, stage consists of transistors $Q_{16}$ and $Q_{17}$.
- Transistor $Q_{16}$ operates as an emitter follower (high input resistance).
- $Q_{13}$ is effectively two transistors connected in parallel with common base and emitter terminals. The area of $Q_{13A}$ is effectively one-fourth the area of $Q_{12}$, and the area of $Q_{13B}$ is effectively three-fourths that of $Q_{12}$.
- Transistor $Q_{13B}$ provides the bias current for $Q_{17}$ and also acts as an active load to produce high voltage gain.
- Transistor $Q_{17}$ operates in a common-emitter configuration.
- The voltage at the collector of $Q_{17}$ is the input signal to the output stage.
- $C_C$ acts as a feedback capacitor between the output and input terminals of the gain stage.
Output Stage

• The output stage of an op-amp provides a low output resistance as well as current gain. It is a class AB circuit with the emitter follower pair $Q_{14}$ and $Q_{20}$.

• The output of the gain stage is connected to the base of $Q_{22}$, which operates as an emitter follower and provides a very high input resistance.

• Transistor $Q_{13A}$ provides a bias current for $Q_{22}$, $Q_{18}$, and $Q_{19}$.

• Transistors $Q_{15}$ and $Q_{21}$ are referred to as short-circuit protection devices. They are normally off; they conduct only if the output is connected to the ground, resulting in a very large output current.
(a) The emitter follower  
(b) Class B Output Stage
The output of a class B output stage fed with an input sinusoid
DC Analysis

• The bias portion of the Op Amp circuit must be identified. A reference current must be calculated and then the bias currents in the individual building blocks of the overall circuit can be determined.
• To determine the DC bias current:
  – We assume both the non-inverting and inverting input terminals are at ground potential and that the DC supply voltages are ±15 V.
  – We may assume $V_{BE} = 0.7$ V.
• In most DC calculation we may ignore DC base currents.
The DC Analysis of the 741 input stage

\[ I_{REF} = \frac{V_{CC} - V_{EB12} - V_{BE11} - (-V_{EE})}{R_5} \]

\[ V_{BE11} - V_{BE10} = I_{C10}R_4 \]

\[ V_T \ln \frac{I_{REF}}{I_{C10}} = I_{C10}R_4 \]

\[ I_{C1} = I_{C2} = I_{C3} = I_{C4} = \frac{I_{C10}}{2} \]
The AC Analysis of the 741 Input Stage
Gain Stage

\[ IC_{13B} = 0.75 I_{REF} \]

\[ IC_{16} = I_{E16} = I_{B17} + \frac{I_{E17} R_8 + V_{BE17}}{R_9} \]
Output Stage

\[ I_{C13A} = 0.25I_{REF} = I_{Bias} \]

\[ I_{C18} = \frac{V_{BE19}}{R_{10}} \]

\[ I_{C19} = I_{Bias} - I_{C18} \]
Short Circuit Protection Device

- Resistor $R_6$ and transistor $Q_{15}$ limit the current in $Q_{14}$ in the event of a short circuit.
- If the current in $Q_{14}$ reaches 20 mA, the voltage drop across $R_6$ is 540 mV, which is sufficient to bias $Q_{15}$ in the conducting stage.
- As $Q_{15}$ turns on, excess base current into $Q_{14}$ is shunted through the collector of $Q_{15}$. The base current into $Q_{14}$ is then limited to a maximum value, which limits the collector current.
- The maximum current in $Q_{20}$ is limited by components $R_7$, $Q_{21}$, and $Q_{24}$ in much the same way.