Operational Amplifiers

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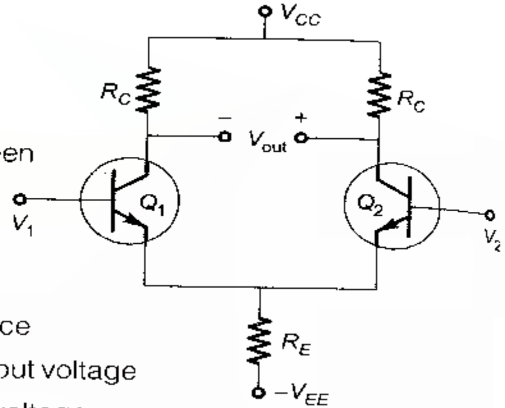
Differential Amplifier



- Here,

  $V_{out} = A(V_1 - V_2)$

  where, V_{out} = Voltage between collectors

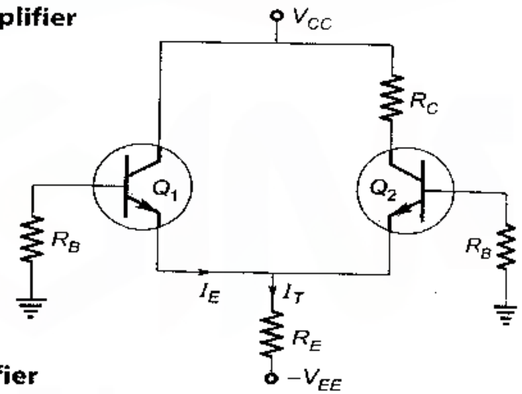
  $$\boxed{A = \frac{R_C}{R_E}}$$

  where, R_E = Emitter resistance

  V_1 = Noninverting input voltage

  V_2 = Inverting input voltage

DC Analysis of a Differential Amplifier



- Emitter bias current

  $$\boxed{I_E = \frac{V_{EE} - V_{BE}}{2R_E}}$$

- Tail current

  $$\boxed{I_T = \frac{V_{EE} - V_{BE}}{R_E}}$$

AC Analysis of a Different Amplifier

1. Non-inverting input
   - AC emitter current

     $$\boxed{I_E = \frac{V_1}{2R_E}}$$ where, R_E = emitter resistance

   - AC output voltage is $\boxed{V_{out} = I_C R_C = \frac{V_1}{2R_E} R_C}$

   - Voltage gain for noninverting input is $\boxed{\frac{V_{out}}{V_1} = \frac{R_C}{2R_E}}$

2. Inverting input
   - AC emitter current is $\boxed{I_E = \frac{V_2}{2R_E}}$

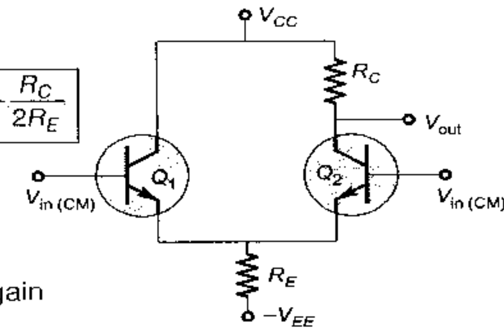
   - AC output voltage is $\boxed{V_{out} = -I_C R_C = -\frac{V_2}{2R_E} R_C}$

   - Voltage gain for inverting input is $\boxed{\frac{V_{out}}{V_2} = \frac{R_C}{2R_E}}$

   - Differential Voltage gain $\boxed{A = \frac{R_C}{2R_E}}$

   - Input impedance $\boxed{R_{in} = 2\beta R_E}$

Common Mode Voltage Gain



$$\boxed{A_{CM} = \frac{V_{out}}{V_{in\,(CM)}} = -\frac{R_C}{r_e + 2R_E} \cong -\frac{R_C}{2R_E}}$$

$$\boxed{\text{CMRR} = \frac{A}{-A_{CM}}}$$

where, $A_{CM} \rightarrow$ common mode gain

Note: ....

$$\boxed{R_E >> r_e}$$

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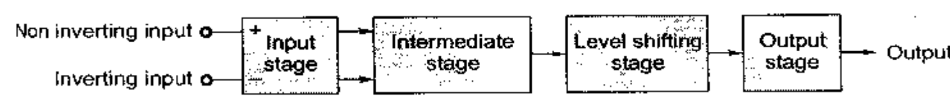
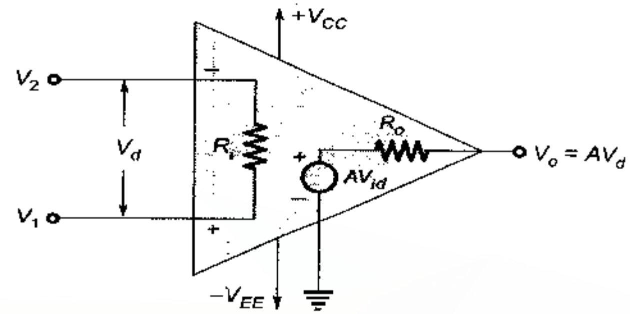
Operational Amplifier

An op-Amp is basically a very high gain, direct-coupled amplifier with high input impedance and low output impedance.



Equivalent circuit of an Op-Amp

Op-amp amplifies the difference between the two input signals applied at non inverting and inverting input terminals.



Equivalent circuit of op-amp

where,

Difference input voltage $V_d = V_1 - V_2$

A = Open loop gain of op-amp

Output voltage $V_o = A\,V_d$

R_i = Differential input resistance

R_o = Output resistance

Properties of Op-Amp

Parameters	Ideal value	Practical value
Voltage gain	∞	10^6
Input resistance	∞	10^6 Ω or 1 MΩ
Output resistance	0	10 Ω to 100 Ω
B.W.	∞	10^6 Hz or 1 MHz
CMRR	∞	10^6 or 120 dB
Slew rate	∞	80V/μ sec.

Slew rate

For input $V_m \sin \omega t$

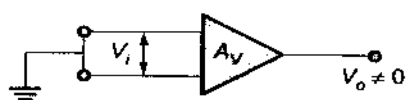
$$f_{max} = \frac{SR}{2\pi A_{CL} V_m}$$

where, SR = Slew rate

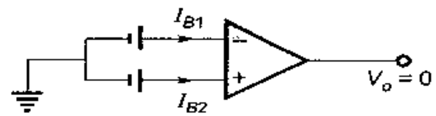
f_{max} = Maximum frequency of operation

A_{CL} = Closed loop gain of OP-AMP.

Bias Currents and Voltage



$V_0 \neq 0 \rightarrow$ Called O/P offset voltage.



Balanced condition.

Input bias current (I_B)

$$I_B = \frac{I_{B_1} + I_{B_2}}{2}$$

Input offset current

$$I_{io} = (I_{B1} - I_{B2})$$

Note: ....

Input offset voltage is the voltage which must be applied between input terminals to balance amplifier ($V_0 = 0$).

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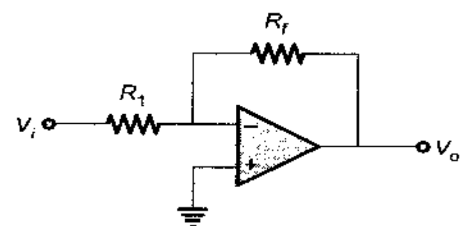
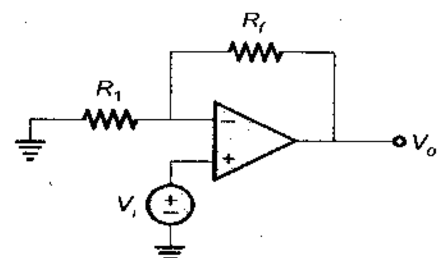
Linear Op-Amp Circuits

Inverting Amplifier



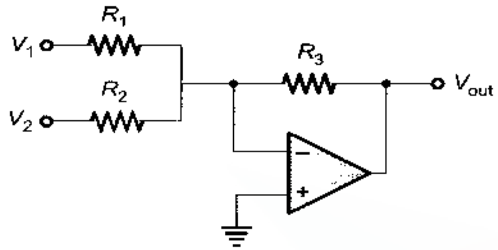
$$A_V = -\frac{R_f}{R_1}$$

Non-inverting Amplifier



$$A_V = \left(1 + \frac{R_f}{R_1}\right)$$

Summing Amplifier



Output voltage

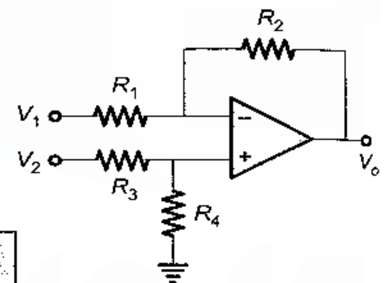
$$V_{out} = \frac{R_3}{R_1}V_1 - \frac{R_3}{R_2}V_2$$

Differential Amplifier

$$V_0 = -\frac{R_2}{R_1}V_1 + \left(\frac{R_4}{R_3 + R_4}\right)\left(1 + \frac{R_2}{R_1}\right)V_2$$

if $\boxed{\frac{R_2}{R_1} = \frac{R_4}{R_3}}$

then, $$V_0 = \frac{R_4}{R_3}[V_2 - V_1] = \frac{R_2}{R_1}(V_2 - V_1)$$



Note: ....

In this case when $\frac{R_2}{R_1} = \frac{R_4}{R_3}$,

$A_c = 0 \rightarrow$ Common mode gain and CMRR $= \infty$

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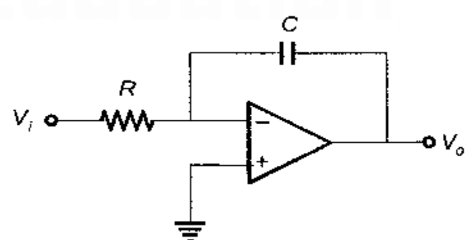
Nonlinear Op-Amp circuits

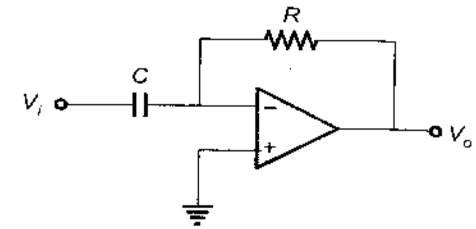
Integrator

$$V_0 = -\frac{1}{RC}\int V_i\,dt + V_c(0+)$$



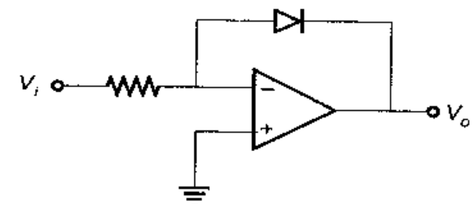
Differentiator

$$V_0 = -RC\frac{dV_i}{dt}$$



Logrithemic Amplifier

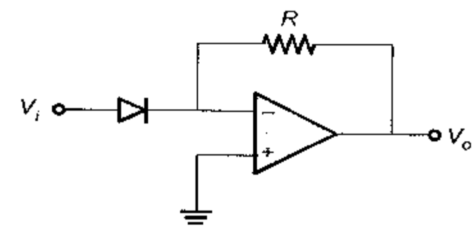
$$V_0 = -\eta V_T \ln \frac{V_i}{I_0 R}$$



where, η = Recombination factor
V_T = Thermal voltage
I_o = Reverse saturation current of diode

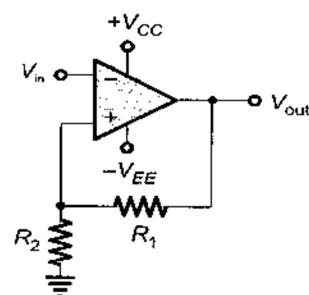
Antilog Amplifier

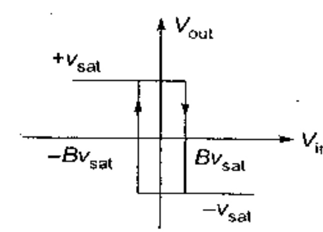
$$V_o = -I_o R \text{ antilog} \frac{V_i}{\eta V_T}$$



where, I_0 = Reverse saturation current of diode
η = Recombination factor
V_T = Thermal voltage

Schmitt Trigger





$$V_{Th} = \frac{R_1}{(R_1 + R_2)} V_H$$

$$V_{TL} = \frac{R_1}{(R_1 + R_2)} V_L \qquad \text{(where } V_L << V_H\text{)}$$

Remember:

- The complete transfer characteristics of Schmitt trigger shows a hysteresis effect.
- The width of hysteresis is the difference between the two cross-over voltages V_{Th} and V_{TL}.

Op-Amp as a Multivibrator

Square Wave Generator or Astable Multivibrator

Time period of output waveform generated is

$$\boxed{T = 2RC \ln 3} \qquad \text{(For } R_1 = R_2\text{)}$$

$$\boxed{T = 2RC \ln\left[\frac{1+B}{1-B}\right]} \qquad \left(\text{where } B = \frac{R_2}{R_1 + R_2}\right)$$

Monostable Multivibrator

Width of pulse generated at output is

$$\boxed{T = RC \ln\left(1 + \frac{R_2}{R_1}\right)}$$

if $R_2 = R_1$,

then $\boxed{T = RC \ln 2}$

Note:

- Astable multivibrator is a square wave generator.
- Monostable multivibrator is used as pulse stretcher and missing pulse detector.

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