CENG2030 FUNDAMENTALS OF EMBEDDED SYSTEM DESIGN

LECTURE 5: OPERATIONAL AMPLIFIER

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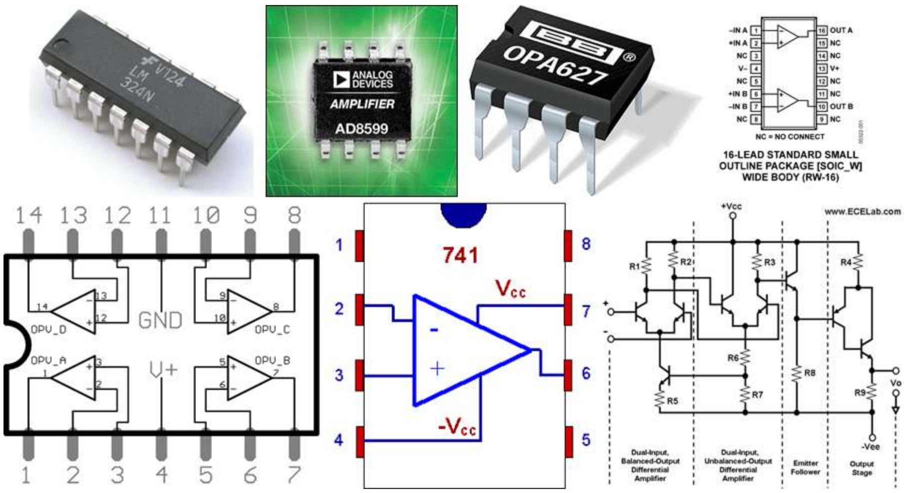
OPERATIONAL AMPLIFIER (OP-AMP)



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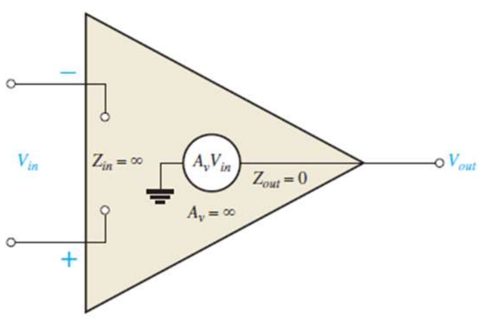
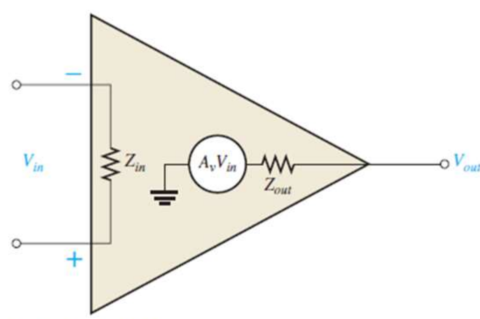
IDEAL OP-AMP



(a) Ideal op-amp representation



(b) Practical op-amp representation

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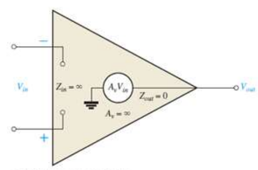
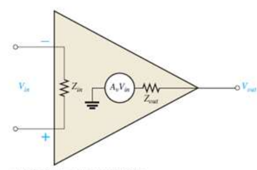
OP-AMP IDEALIZED CHARACTERISTICS

- Open Loop Gain, (Av)
  - Infinite - The main function of an operational amplifier is to amplify the input signal and the more open loop gain it has the better.

  - Open-loop gain is the gain of the op-amp without positive or negative feedback and for an ideal amplifier the gain will be infinite but typical real values range from about 20,000 to 200,000.



(a) Ideal op-amp representation



(b) Practical op-amp representation

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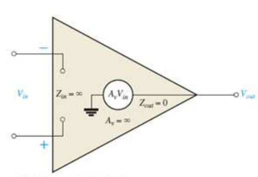
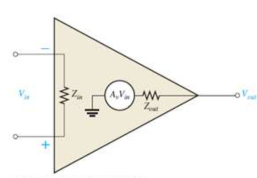
OP-AMP IDEALIZED CHARACTERISTICS

- Input impedance, (Zin)
  - Infinite - Input impedance is the ratio of input voltage to input current and is assumed to be infinite to prevent any current flowing from the source supply into the amplifiers input circuitry (Iin =0).

  - Real op-amps have input leakage currents from a few pico-amps to a few milli-amps.



(a) Ideal op-amp representation



(b) Practical op-amp representation

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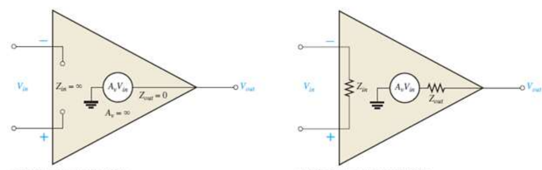
OP-AMP IDEALIZED CHARACTERISTICS

- Output impedance, (Zout)
  - Zero - The output impedance of the ideal operational amplifier is assumed to be zero acting as a perfect internal voltage source with no internal resistance so that it can supply as much current as necessary to the load. This internal resistance is effectively in series with the load thereby reducing the output voltage available to the load.

  - Real op-amps have output-impedance in the 20~100Ω range.



(a) Ideal op-amp representation (b) Practical op-amp representation

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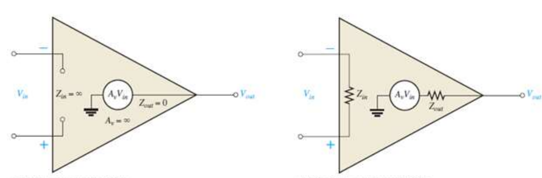
OP-AMP IDEALIZED CHARACTERISTICS

- Bandwidth, (BW)
  - Infinite - An ideal operational amplifier has an infinite frequency response and can amplify any frequency signal from DC to the highest AC frequencies so it is therefore assumed to have an infinite bandwidth.

  - With real op-amps, the bandwidth is limited by the Gain-Bandwidth product (GB), which is equal to the frequency where the amplifiers gain becomes unity.



(a) Ideal op-amp representation (b) Practical op-amp representation

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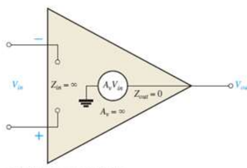
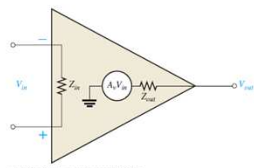
OP-AMP IDEALIZED CHARACTERISTICS

- Offset Voltage, (Vio)
  - Zero - The amplifiers output will be zero when the voltage difference between the inverting and the non-inverting inputs is zero, the same or when both inputs are grounded.
  - Real op-amps have some amount of output offset voltage.



(a) Ideal op-amp representation



(b) Practical op-amp representation

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VOLTAGE GAIN

- The Voltage Gain (A) of the amplifier can be found using the following formula:

$$\text{Voltage Gain, (A)} = \frac{V_{out}}{V_{in}}$$

- and in Decibels or (dB) is given as:

$$20\log(A) \text{ or } 20\log\frac{V_{out}}{V_{in}} \textit{ in dB}$$

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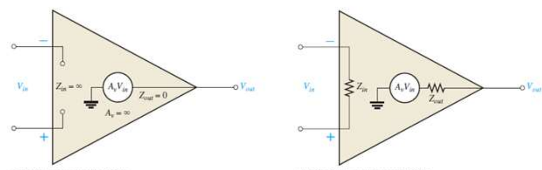
INVERTING AMPLIFIER

- In the Inverting Amplifier circuit, the operational amplifier is connected with feedback to produce a closed loop operation.

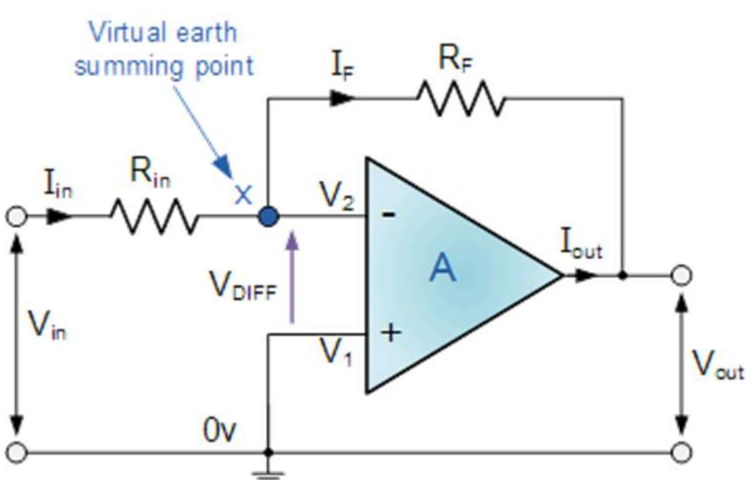
- For ideal op-amps there are two important rules to remember:
  - There is no current flows into the input terminals
  - The differential input voltage is zero,
    - V1 = V2



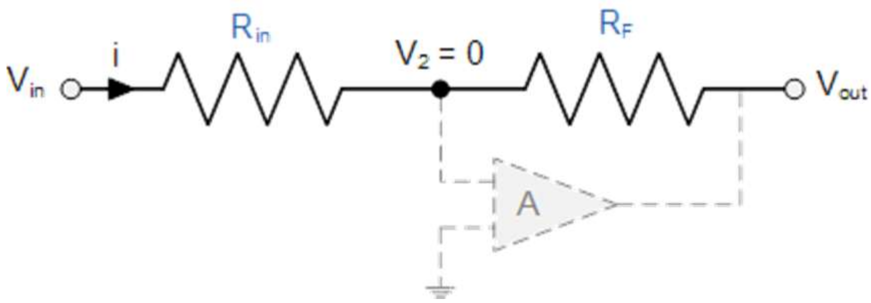
(a) Ideal op-amp representation

(b) Practical op-amp representation

INVERTING AMPLIFIER



EQUIVALENT CIRCUIT OF INVERTING AMPLIFIER



$$\text{Gain (Av)} = \frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}}$$

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CLOSED LOOP GAIN (AV) OF INVERTING AMPLIFIER

$$i = \frac{Vin - Vout}{Rin + Rf}$$

$$\text{therefore, } i = \frac{Vin - V2}{Rin} = \frac{V2 - Vout}{Rf}$$

$$i = \frac{Vin}{Rin} - \frac{V2}{Rin} = \frac{V2}{Rf} - \frac{Vout}{Rf}$$

$$\text{so, } \frac{Vin}{Rin} = V2\left[\frac{1}{Rin} + \frac{1}{Rf}\right] - \frac{Vout}{Rf}$$

$$\text{and as, } i = \frac{Vin - 0}{Rin} = \frac{0 - Vout}{Rf} \qquad \frac{Rf}{Rin} = \frac{0 - Vout}{Vin - 0}$$

$$\text{the Closed Loop Gain (Av) is given as, } \frac{Vout}{Vin} = -\frac{Rf}{Rin}$$

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NON-INVERTING AMPLIFIER

- In Non-inverting Amplifier, the input voltage signal, (Vin) is applied directly to the non-inverting (+) input terminal which means that the output gain of the amplifier becomes "Positive" in value in contrast to the "Inverting Amplifier" circuit.

- The result of this is that the output signal is "in-phase" with the input signal.

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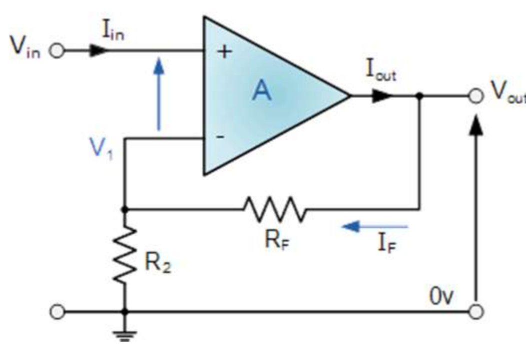
NON-INVERTING AMPLIFIER



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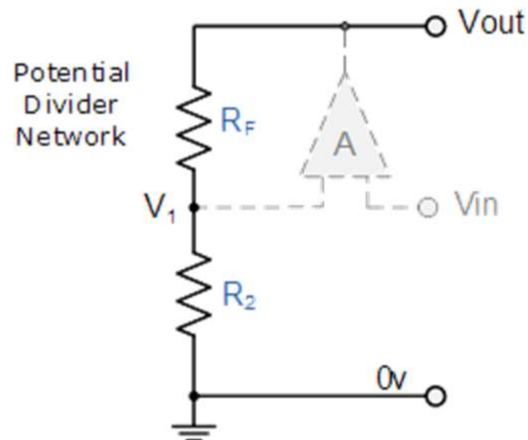
EQUIVALENT CIRCUIT OF NON-INVERTING AMPLIFIER



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CLOSED LOOP GAIN OF NON-INVERTING AMPLIFIER

$$V_1 = \frac{R_2}{R_2 + R_F} \times V_{OUT}$$

Ideal Summing Point: $V_1 = V_{IN}$

Voltage Gain, $A_{(V)}$ is equal to: $\frac{V_{OUT}}{V_{IN}}$

Then, $A_{(V)} = \frac{V_{OUT}}{V_{IN}} = \frac{R_2 + R_F}{R_2}$

Transpose to give: $A_{(V)} = \frac{V_{OUT}}{V_{IN}} = 1 + \frac{R_F}{R_2}$

$$A_{(v)} = 1 + \frac{R_F}{R_2}$$

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ACTIVE FILTERS

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ACTIVE LOW PASS FILTER (LPF)

- The principle of operation and frequency of an Active Low Pass Filter is exactly the same as passive filter.
- The only difference this time is that it uses an op-amp for amplification and gain control.

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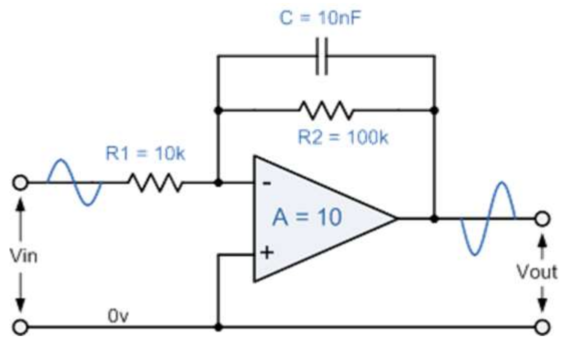
ACTIVE LPF WITH INVERTING AMPS



$$fc = \frac{1}{2\pi C R_2} \text{ Hertz}$$

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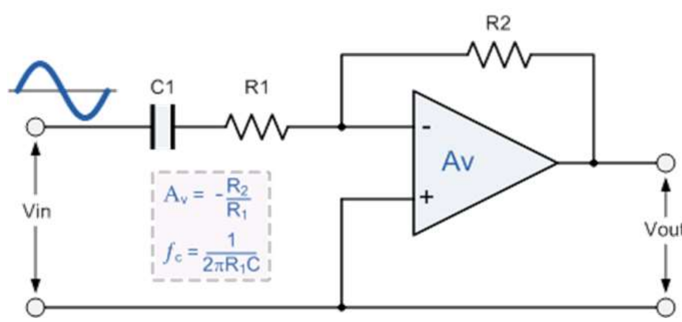
ACTIVE HIGH PASSIVE FILTER (HPF) WITH INVERTING AMPLIFIER



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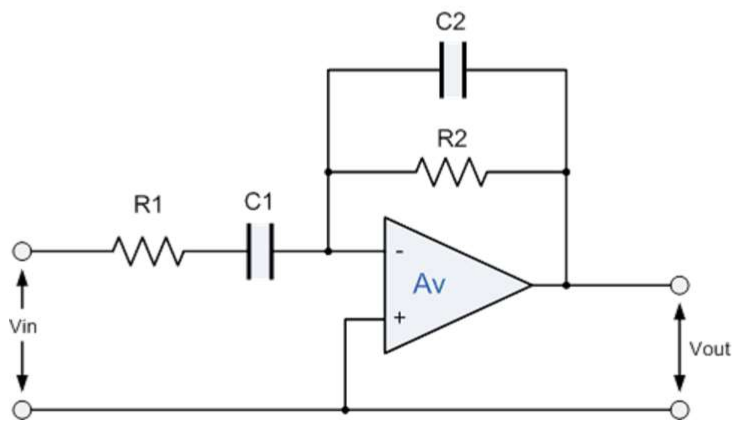
ACTIVE BAND PASS FILTER (BPF) WITH INVERTING AMPLIFIER



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ACTIVE INVERTING BAND PASS FILTER

- The voltage gain and the two cut-off frequencies of the filter are given by:

$$Voltage\ Gain = -\frac{R_2}{R_1}, \quad fc_1 = \frac{1}{2\pi R_1 C_1}, \quad fc_2 = \frac{1}{2\pi R_2 C_2}$$

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ANY QUESTIONS ?

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