Op Amps

Noninverting
Input \( V_+ \)

Inverting \( V_- \)
Input

Output \( V_o \)

I deal? Op Amp

* Input currents are zero
* Input impedance \( \infty \)
* Gain \( \infty \)

\[ V_o = \lim_{R_o \to \infty} \frac{2V_i}{R_o} \left( 1 + \frac{-V_-}{V_+} \right) \]

* Output impedance is zero

All voltages are referenced to ground.

There is no output current but there is no input current.

* Virtual Short - if feedback is negative.
Inverting Amplifier

We have negative feedback.

\[ I_i = \frac{\bar{V}_i}{R_1}, \quad \bar{V}_0 = -R_F \bar{I}_i \]

\[ \bar{V}_0 = -\frac{R_F}{R_1} \bar{I}_i \]

\[ \bar{I} = \frac{\bar{V}_0}{\bar{I}_i} = -\frac{R_F}{R_1} = -A_v \]

\[ A_v = \text{the voltage gain} = \frac{R_F}{R_1} \]

Minus sign means input is 180° out of phase.

\[ \bar{I}_i = R_1, \quad \bar{V}_0 = 0 \]
Non Inverting Ampifier

\[ \overline{V_i} = \overline{V_+} = \overline{V_-} = \frac{R_i}{R_i + R_F} \overline{V_o} \]

\[ i = \frac{\overline{V_o}}{\overline{V_i}} = \left(1 + \frac{R_F}{R_i}\right) = A_v \]

\( V_i \) and \( V_o \) are in phase

\( Z_i = \infty \quad Z_o = 0 \)

Special Cases

Unity Gain Buffer

Sim Chong
Variations

\[
\bar{T} = \left(1 + \frac{R_i}{R_1}\right) \\
\bar{Z_i} = R_i \\
\bar{Z_o} = R_o
\]

\[
\bar{T} = -A_v = -\frac{RF}{R_1} \\
\bar{Z_i} = R_i \\
\bar{Z_o} = R_o
\]
$$I_c = \frac{-V_i}{R_1}, \quad V_c = \frac{-R_2}{R_1} \cdot V_i$$

$$I_3 = \frac{V_c}{R_3} = \frac{-R_2}{R_1 R_3} \cdot V_i$$

$$I_H = I_3 - I_c = -\left[\frac{R_2}{R_1 R_3} + \frac{1}{R_1}\right] V_i$$

$$V_o = R_4 \cdot I_H + V_c$$

$$V_o = -\left[\frac{R_2 R_4}{R_1 R_3} + \frac{R_4}{R_1} + \frac{R_2}{R_1}\right] V_i$$

$$T = \frac{V_o}{V_i} = -\frac{R_4}{R_1} \left[1 + \frac{R_2}{R_3} - \frac{R_2}{R_4}\right]$$

$$T = -\frac{R_4}{R_1} \left[1 + \frac{R_2}{R_3 || R_4}\right] = -AV$$
Finite Gain

\[
A(\omega) = \frac{V_o}{V_+ - V_-} = \frac{A_0}{1 + \frac{\omega}{\omega_0}}
\]

\(A_0 \equiv \text{dc gain at } 0 \text{ Hz}\)

\(\omega_0 \equiv \text{pole frequency } = \text{xBandwidth}\)

\(\omega_0 \approx 7.41\)  \(A_0 = 200 \Omega\)

\(\omega_0 = 5 \text{ Hz}\)

Gain

\[
10^A_0
\]

- \(1 \) decade / decade

\(b_x = A_0 b_0\)
\[ V_o = A(\omega) \left( V_+ - V_- \right) = A(\omega) \left( V_i - \bar{V}_i \right) \]

\[ V_- = \frac{V_o}{2} \frac{R_1}{R_1 + R_F} \]

\[ V_o = \frac{\omega x}{2} \left[ V_i - \frac{R_1}{R_1 + R_F} V_o \right] \]

\[ \left[ 1 + \frac{\omega x}{2} \frac{R_1}{R_1 + R_F} \right] V_o = \frac{\omega x}{2} V_i \]

\[ T = \frac{V_o}{V_i} = \frac{1}{\frac{\omega x}{2} + \frac{R_1}{R_1 + R_F} \left( 1 + \frac{R_F}{R_1} \right)} \]
$$T = \frac{A_o V_o}{V_i} = \frac{A_o b}{1 + \frac{b}{w_o b}}$$

$$A_o b = 1 + \frac{R_F}{R_1} \quad w_o b = \frac{w_X}{1 + \frac{R_F}{R_1}}$$

$$A_o b \times b_o b \equiv \text{gain bandwidth product}$$

Gain

$$\begin{array}{c|c|c|c}
1 & A_o & A_o b & b_o b b_x \\
+ & \frac{R_F}{R_1} & & \\
\end{array}$$
ECE 3042 Amplifier Example

(A) example.dat

Frequency

A1: (1.0000, 89.990)  A2: (165.905K, 63.909)  DIFF(A): (-165.904K, 26.081)

Date: January 19, 2000

Time: 20:47:10
ECE 3042 Amplifier Example

vi 1 0 ac 1
r1 1 2 3k
r2 2 3 45k
x1 0 2 3 OA351
x2 3 5 4 OA351
r3 4 5 10k
r4 5 0 2k
*LF351 OP AMP SUBCIRCUIT
.SUBCKT OA351 1 2 3
RIN 1 2 2E12
GM1 4 0 1 2 2.83E-4
R1 4 0 1E5
CC 4 5 15E-12
GM2 5 0 4 0 283
R01 3 5 50
R02 5 0 25
.ENDS OA351
.ac dec 30 1 10meg
.probe
.end
NAME:________________________________________  SECTION:___________________________
GT NUMBER:___________________________________  GTID:______________________________

Experiment 2: Basic Op-Amp Circuits 1

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<th>Verification (Must demonstrate circuit)</th>
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<td>5. Integrator</td>
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To be permitted to complete the experiment during the open lab hours, you must complete at least four procedures during your scheduled lab period or spend your entire scheduled lab session attempting to do so. A signature below by your lab instructor, Dr. Brewer, or Dr. Robinson permits you to attend the open lab hours to complete the experiment and receive full credit on the report. Without this signature, you may use the open lab to perform the experiment at a 50% penalty.

SIGNATURE:________________________________________  DATE:________________________________________
ECE 3042 Check-off Requirements for Experiment 2

Make sure you have made all required measurements before requesting a check-off. For all check-offs, you must demonstrate the circuit or measurement to a lab instructor. All screen captures must have a time/date stamp.

2. Non-Inverting Amplifier
   ✓ Oscilloscope screen capture showing 1 kHz input sine wave and output and Vpp measurements for each signal
   ✓ Calculation of the gain at 1 kHz.
   ✓ Oscilloscope screen capture showing input and output signals at the -3 dB frequency. Display Vpp. measurements for each signal and the frequency. Be sure to adjust the CIRCUIT OUTPUT to 1 Vpp before increasing the frequency from 1 kHz.
   ✓ Screen capture displaying input and soft clipping on output and measured positive and negative peak amplitudes (can use max and min functions on scope).
   ✓ Screen capture displaying input and hard clipping on output and measured positive and negative clipping levels (can use max and min functions on scope).

3. Inverting Amplifier
   ✓ Same as for 2.

4. Inverting Amp with T Feedback
   ✓ Same as for 2.

5. Integrator
   ✓ Oscilloscope screen capture showing input 100 Hz sine wave and output signal. Display Vpp measurements for each signal.
   ✓ Calculation of the gain at 100 Hz.
   ✓ Plot of gain versus frequency made with HPVEE, LabView, or by hand. Set input to 0.2 Vrms.
   ✓ Oscilloscope screen capture showing input and output signals and Vpp measurements for each signal for triangle wave input of 100 Hz. Dc couple the scope channels.
   ✓ Oscilloscope screen capture showing input and output signals and Vpp measurements for each signal for square wave input of 100 Hz. Dc couple the scope channels.

6. Differentiator
   ✓ Oscilloscope screen capture showing input 100 Hz sine wave and output signal. Display Vpp measurements for each signal.
   ✓ Calculation of the gain.
   ✓ Plot of gain versus frequency made with HPVEE, LabView, or by hand. Set input to 0.2 Vrms.
   ✓ Oscilloscope screen capture showing input and output signals and Vpp measurements for each signal for triangle wave input of 100 Hz. Dc couple the scope channels.
   ✓ Oscilloscope screen capture showing input and output signals and Vpp measurements for each signal for square wave input of 100 Hz. Dc couple the scope channels.