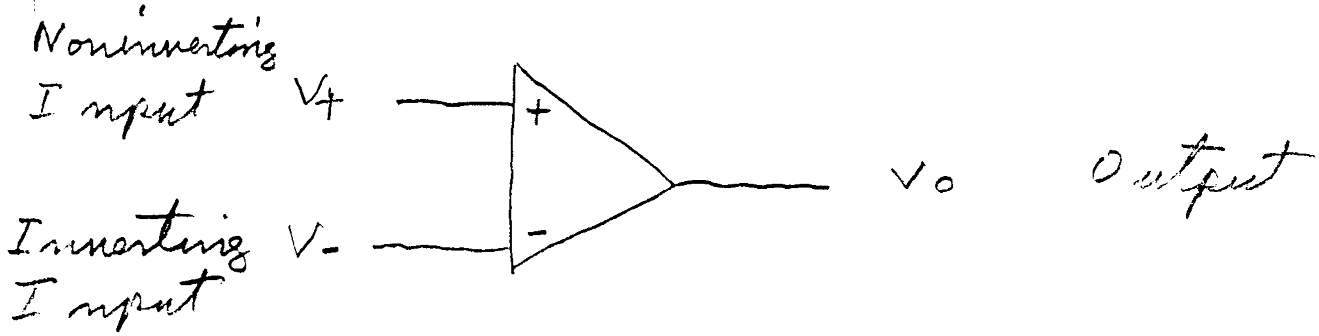
Op Amps



Ideal Op Amp

* Input currents are zero
* Input Impedance ∞
* Gain ∞.

$$V_o = \lim_{A_o \to \infty} A_o(V_+ - V_-)$$

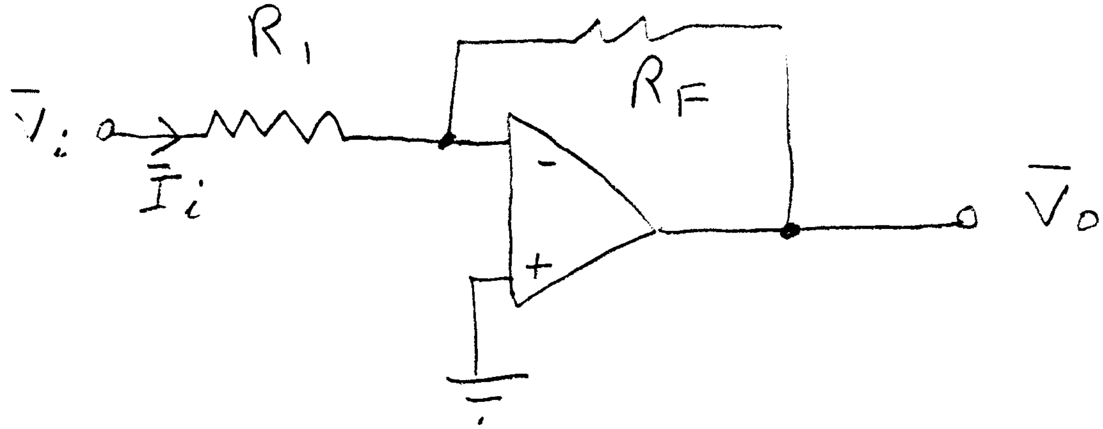
* Output Impedance is zero

All voltages are referenced to ground.

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

* Virtual Short - if feedback is negative

Inverting Amplifier



We have negative feedback

$$\bar{I}_i = \frac{\bar{V}_i}{R_1}, \quad \bar{V}_o = -R_F \bar{I}_i$$

$$\bar{V}_o = -\frac{R_F}{R_1}\bar{V}_i$$

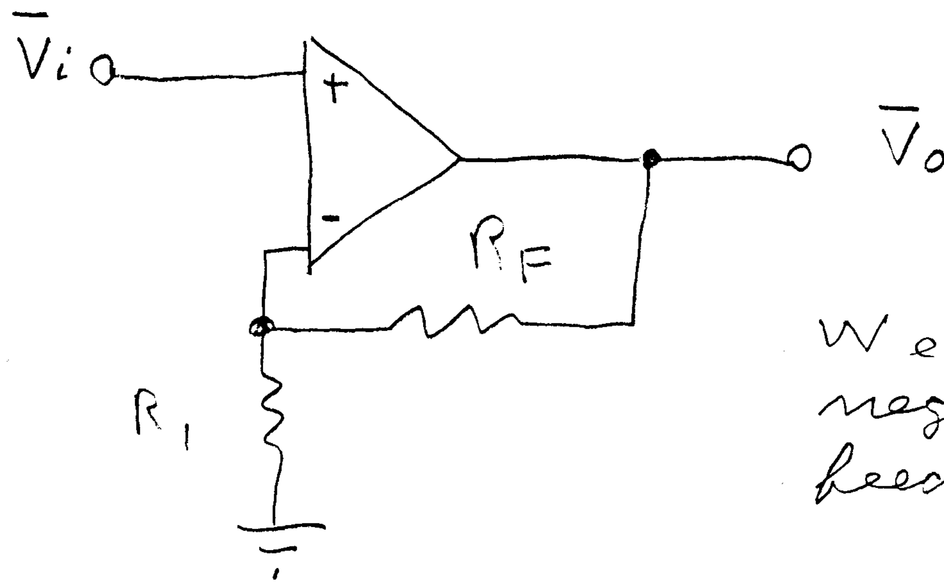
$$\bar{T} = \frac{\bar{V}_o}{\bar{V}_i} = -\frac{R_F}{R_1} = -A_v$$

$A_v \equiv$ the voltage gain $= \frac{R_F}{R_1}$

Minus sign mean input & output sine wave are 180° out of phase.

$$\bar{Z}_i = R_1, \quad \bar{Z}_o = 0$$

Non Inverting Amplifier



We have negative feedback

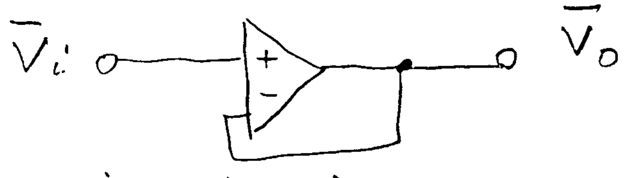
$$\bar{V}_i = \bar{V}_+ = \bar{V}_- = \frac{R_1}{R_1 + R_F}\bar{V}_o$$

$$\bar{T} = \frac{\bar{V}_o}{\bar{V}_i} = \left(1 + \frac{R_F}{R_1}\right) = A_V$$

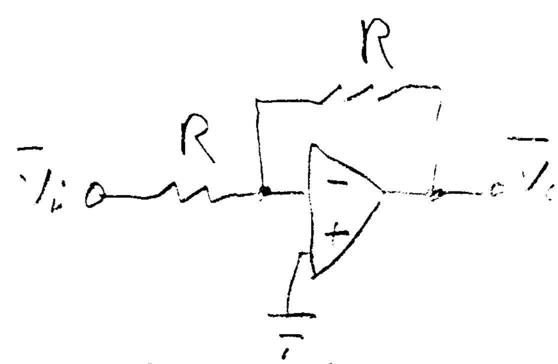
$\bar{V}_i$ & $\bar{V}_o$ are in phase

$\bar{Z}_i = \infty \qquad \bar{Z}_o = 0$

Special Cases

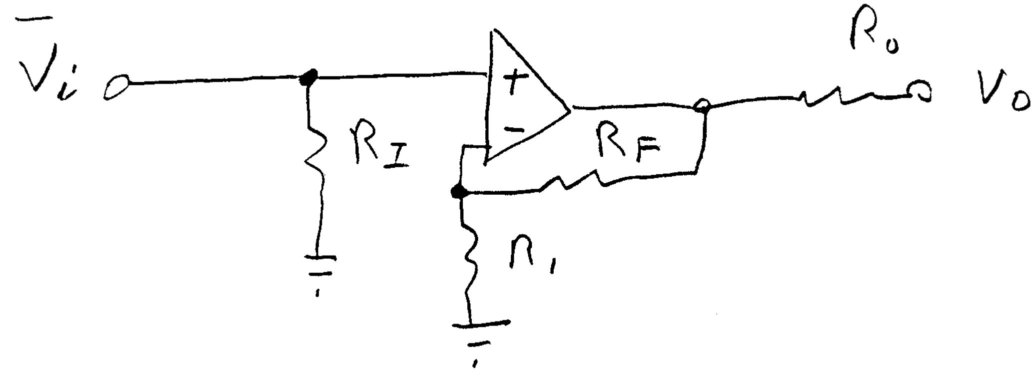


Unity Gain Buffer



Sign Changer

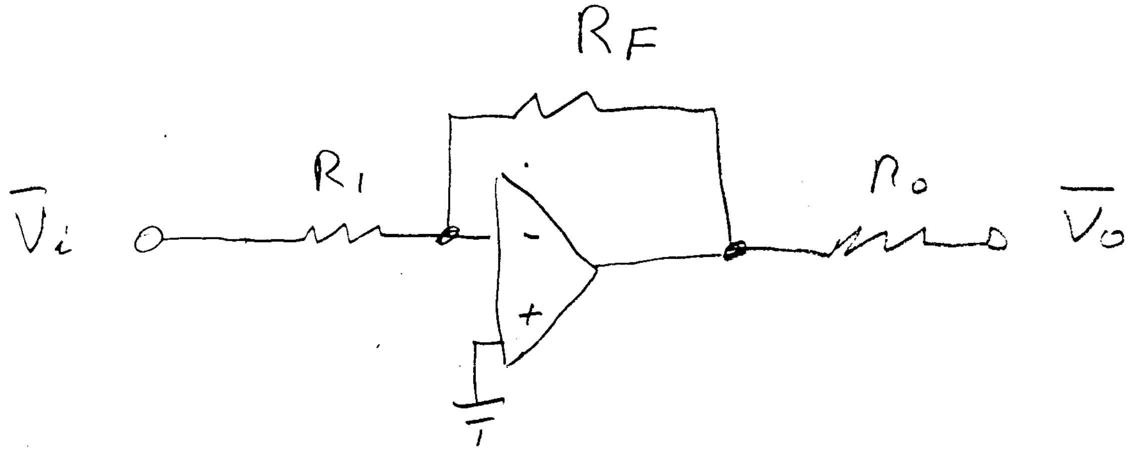
Variations



$$\bar{T} = \left(1 + \frac{R_F}{R_1}\right)$$

$$\bar{Z}_i = R_I$$

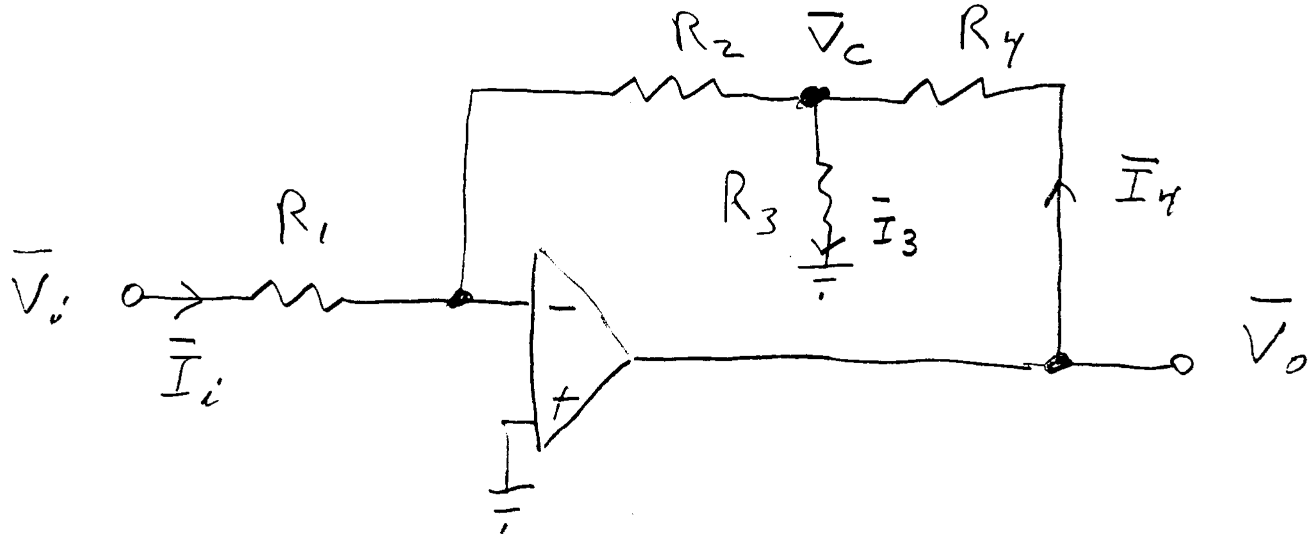
$$\bar{Z}_o = R_o$$



$$\bar{T} = -A_V = -\frac{R_F}{R_1}$$

$$\bar{Z}_i = R_1 \qquad \bar{Z}_o = R_o$$

T Feedback



$$\bar{I}_i = \frac{\bar{V}_i}{R_1}, \quad \bar{V}_c = -\frac{R_2}{R_1}\bar{V}_i$$

$$\bar{I}_3 = \frac{\bar{V}_c}{R_3} = -\frac{R_2}{R_1 R_3}\bar{V}_i$$

$$\bar{I}_4 = \bar{I}_3 - \bar{I}_i = -\left[\frac{R_2}{R_1 R_3} + \frac{1}{R_1}\right]\bar{V}_i$$

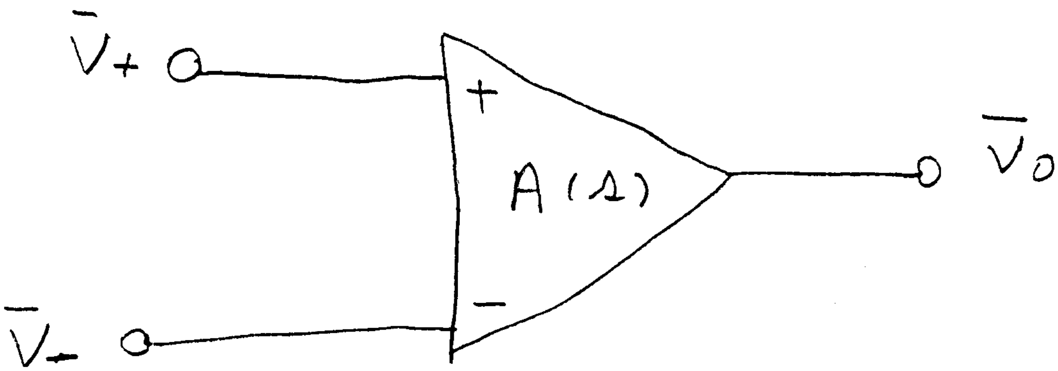
$$\bar{V}_o = R_4 \bar{I}_4 + \bar{V}_c$$

$$\bar{V}_o = -\left[\frac{R_2 R_4}{R_1 R_3} + \frac{R_4}{R_1} + \frac{R_2}{R_1}\right]\bar{V}_i$$

$$\bar{T} = \frac{\bar{V}_o}{\bar{V}_i} = -\frac{R_4}{R_1}\left[1 + \frac{R_2}{R_3} + \frac{R_2}{R_4}\right]$$

$$\bar{T} = -\frac{R_4}{R_1}\left[1 + \frac{R_2}{R_3 \| R_4}\right] = -A_V$$

Finite Gain



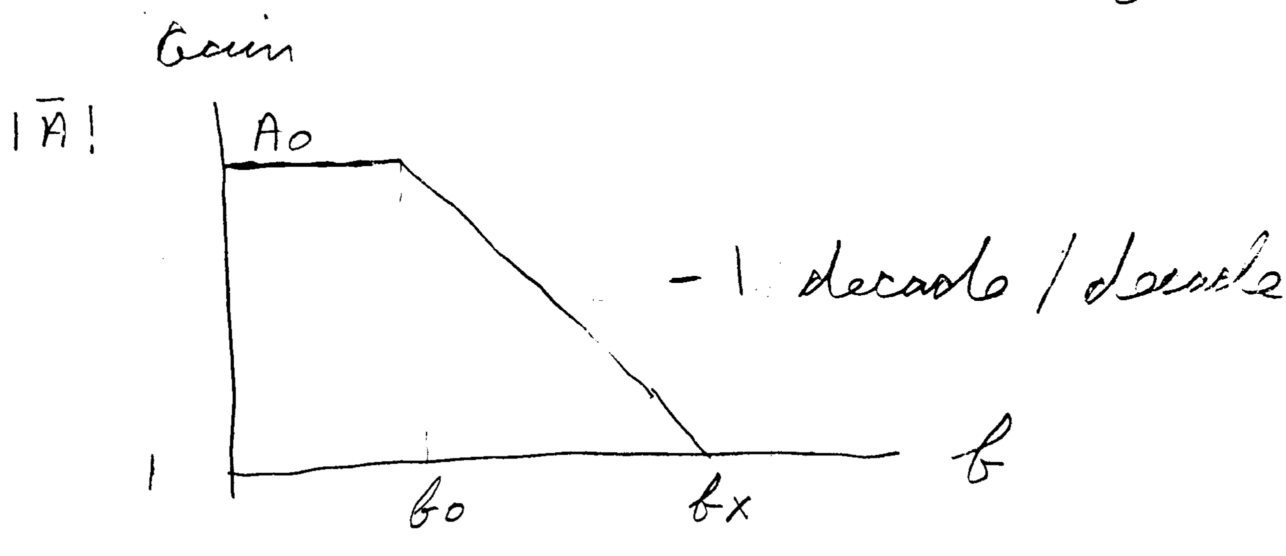
$$A(s) = \frac{\bar{V}_o}{\bar{V}_+ - \bar{V}_-} = \frac{A_o}{1 + \frac{s}{\omega_o}}$$

$A_o \equiv$ dc gain

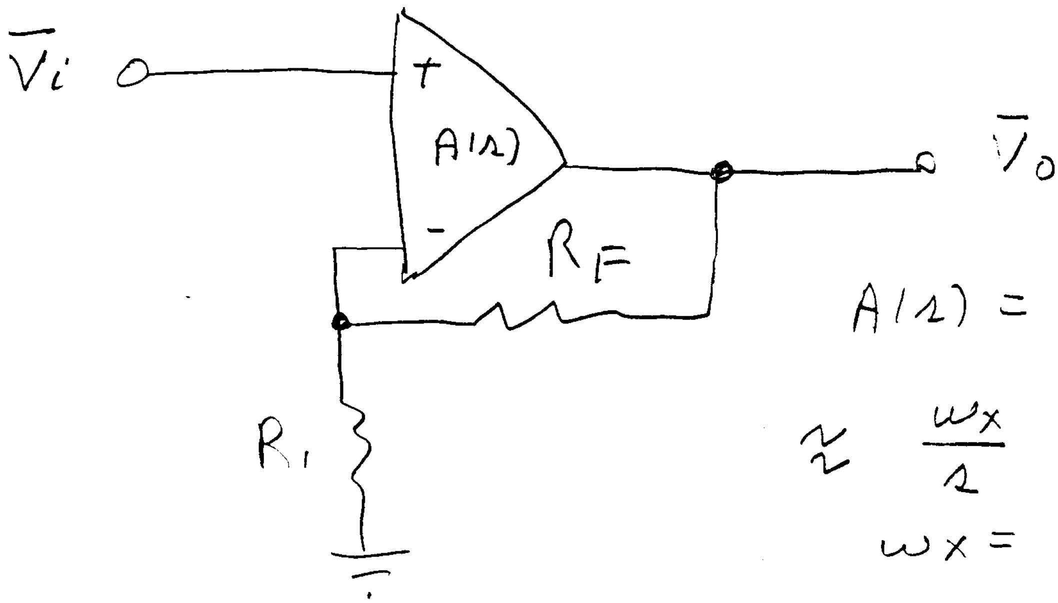
$f_o \equiv$ pole frequency $\equiv$ bandwidth

for 741 $\quad A_o = 200\,k$

$\qquad\qquad f_o = 5$ Hz



$$f_x \approx A_o f_o$$



$$A(s) = \frac{A_0}{1 + \frac{s}{\omega_0}}$$

$$\approx \frac{\omega_x}{s} \quad \text{large } s$$

$$\omega_x = A_0 \omega_0$$

$$\bar{V}_o = A(s)\left[\bar{V}_+ - \bar{V}_-\right] = A(s)\left[\bar{V}_i - \bar{V}_-\right]$$

$$\bar{V}_- = \bar{V}_o \frac{R_1}{R_1 + R_F}$$

$$\bar{V}_o = \frac{\omega_x}{s}\left[\bar{V}_i - \frac{R_1}{R_1 + R_F}\bar{V}_o\right]$$

$$\left[1 + \frac{\omega_x}{s}\frac{R_1}{R_1 + R_F}\right]\bar{V}_o = \frac{\omega_x}{s}\bar{V}_i$$

$$\bar{T} = \frac{\bar{V}_o}{\bar{V}_i} = \frac{1}{\frac{s}{\omega_x} + \frac{R_1}{R_1 + R_F}} =$$

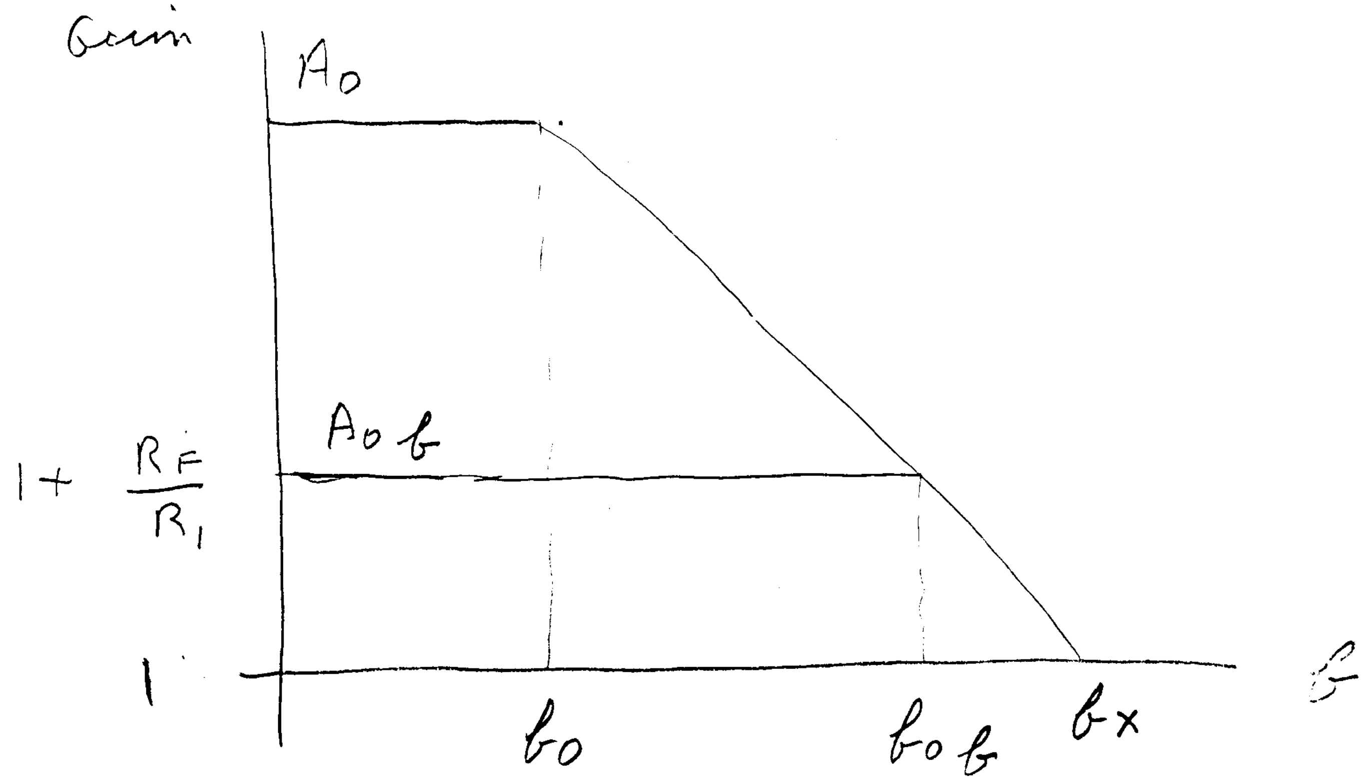
$$\left(1 + \frac{R_F}{R_1}\right)\frac{1}{1 + \frac{s}{\omega_x}\left(1 + \frac{R_F}{R_1}\right)}$$

$$T = A_f(s) = \frac{\bar{V}_o}{\bar{V}_i} = \frac{A_{of}}{1 + \frac{s}{\omega_{of}}}$$

$$A_{of} = 1 + \frac{R_F}{R_1}, \quad \omega_{of} = \frac{\omega_x}{1 + \frac{R_F}{R_1}}$$

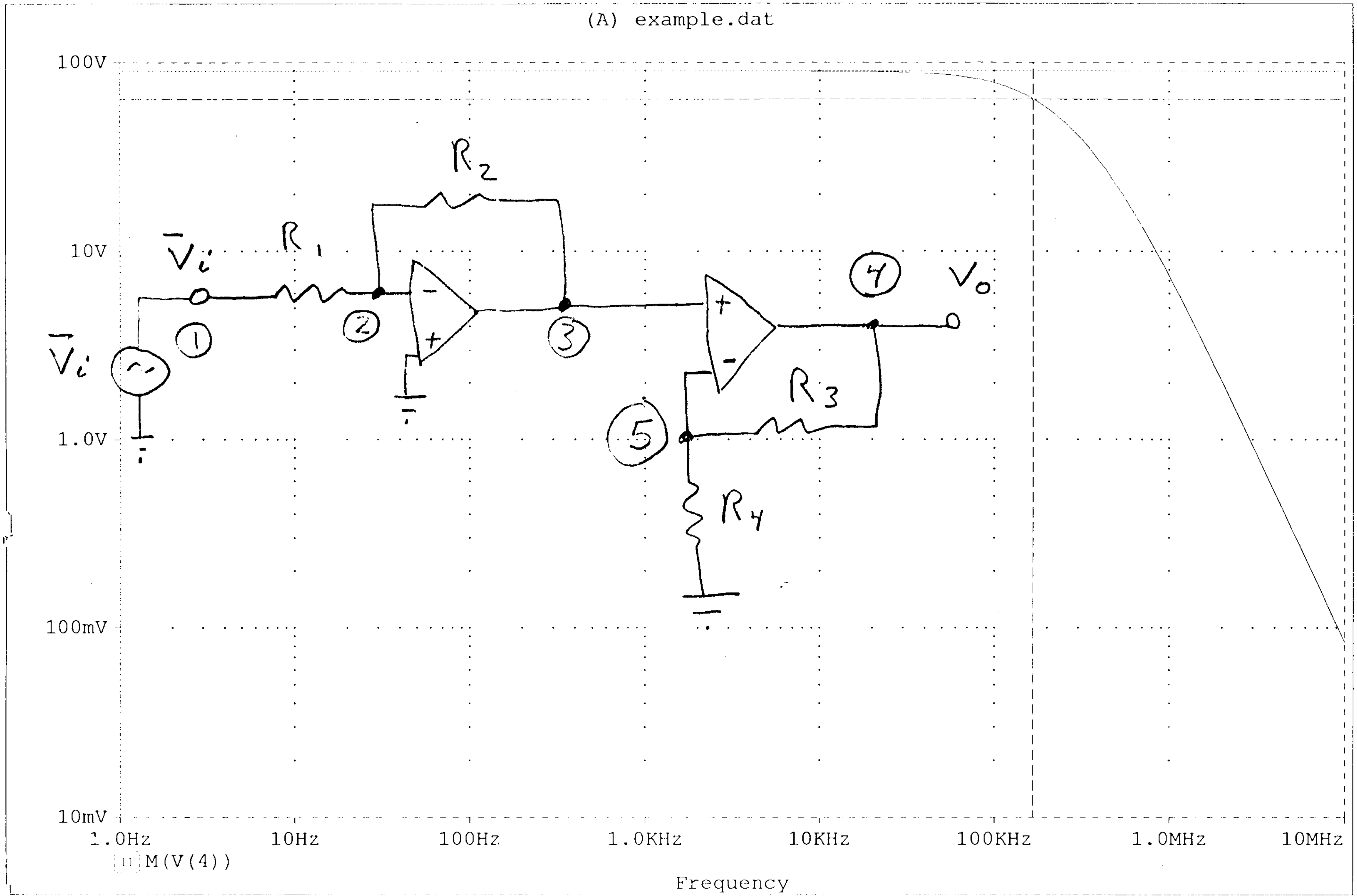
$A_{of} f_{of} \equiv$ gain bandwidth product

$= f_x$



ECE 3042 Amplifier Example

Date/Time run: 01/19/100 20:45:37 Temperature: 27.0



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

Date: January 19, 2000 Page 1 Time: 20:47:10

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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
```

Georgia Institute of Technology

School of Electrical and Computer Engineering

ECE 3042 Microelectronic Circuits Laboratory Verification Sheet

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NAME:____ SECTION:_____________________________

GT NUMBER:____________________________________ GTID:________________________________

Experiment 2: Basic Op-Amp Circuits 1

Procedure	Time Completed	Date Completed	Verification (Must demonstrate circuit)	Points Possible	Points Received
2. Non-Inverting Amplifier				20	
3. Inverting Amplifier				20	
4. Inverting Amp with T Feedback				20	
5. Integrator				20	
6. Differentiator				20	

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 100Hz.
   - ✓ 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.