ECE3204 Lecture 7

Gain-bandwidth product relationship

Op-Amp as a classical feedback system

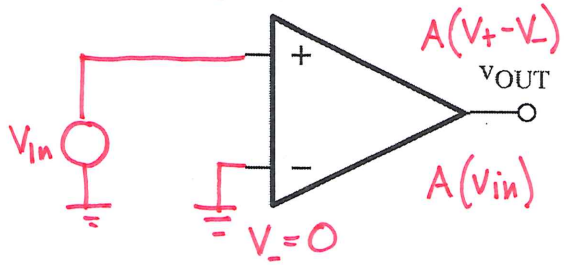
Op-Amp Design Example

Handouts:
Design Example
Op-Amp Error Matrix

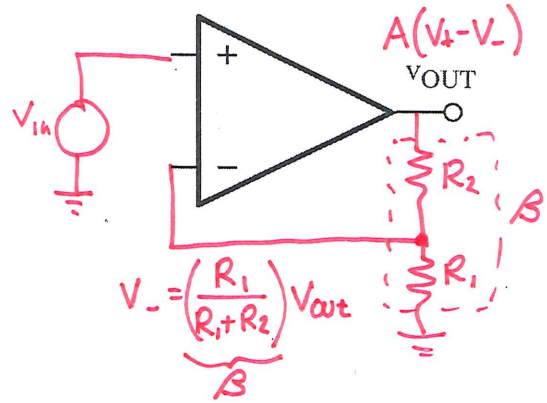
What's the difference between

OPEN LOOP GAIN ? CLOSED LOOP GAIN

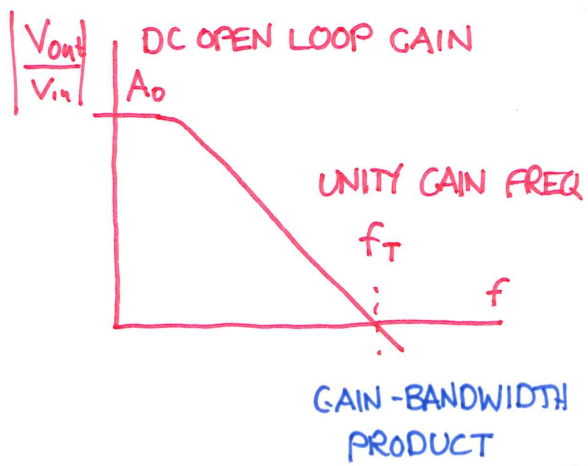
NO FEEDBACK



FEEDBACK

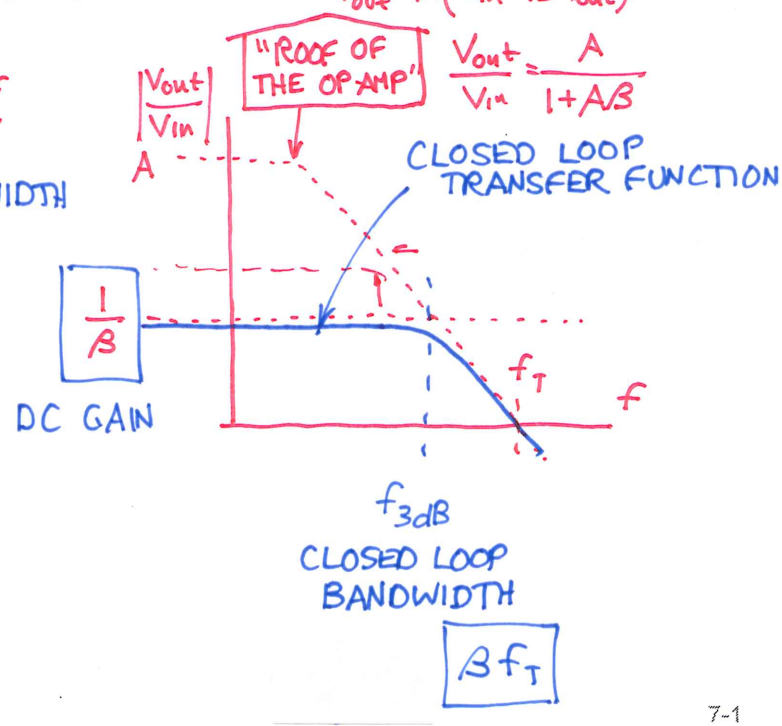


$V_- = \underbrace{\left(\frac{R_1}{R_1+R_2}\right)}_{\beta} V_{out}$



$V_{out} = A(V_{in} - \beta V_{out})$

$\frac{V_{out}}{V_{in}} = \frac{A}{1+A\beta}$



Op-Amp Design Example

a) Design an inverting amplifier with an input resistance of 1kΩ and a gain of -100

b) If an LM741 (f_T = 1MHz) is used, determine the closed loop transfer function, and express in the form showing the DC gain and closed loop 3-dB frequency (bandwidth) f_{3dB}

c) Determine $v_{OUT}(t)$ for an input step of 0 to 100mV. At what time will the output $v_{OUT}(t)$ reach within 100mV of its final value?

d) Determine $v_{OUT}(t)$ for an input sine wave of (100mV)sin(2π[100Hz]t)

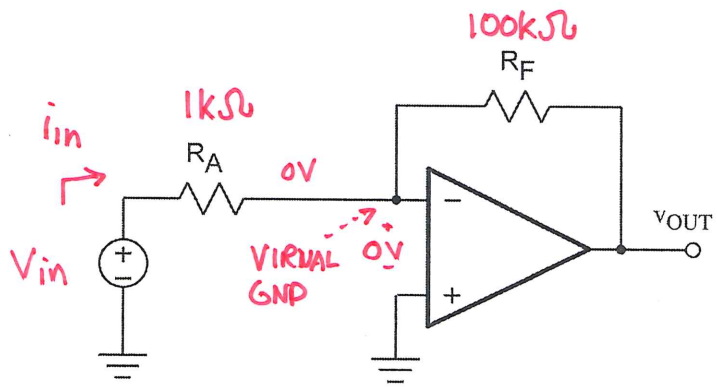
e) Determine $v_{OUT}(t)$ for an input sine wave at the upper edge of the audio frequency range (100mV)sin(2π[20kHz]t)

f) If we want a closed loop 3-dB frequency (bandwidth) f_{3dB} = 20kHz for an audio application, determine the op-amp unity gain frequency f_T required

INVERTING CONFIGURATION

$i_{in} = \frac{V_{in}}{R_A}$

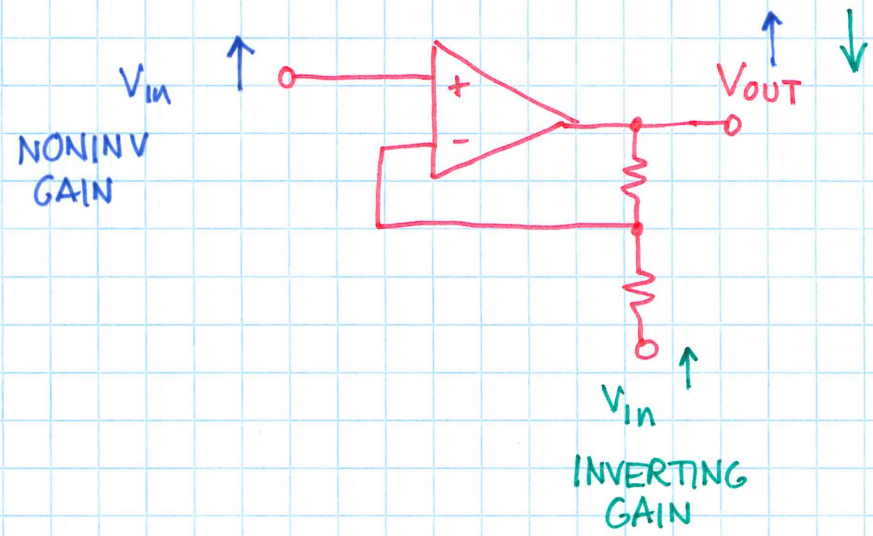
$\underbrace{\frac{V_{in}}{i_{in}}}_{\text{CIRCUIT}} = R_A = \underbrace{1k\Omega}_{\text{WANT}}$

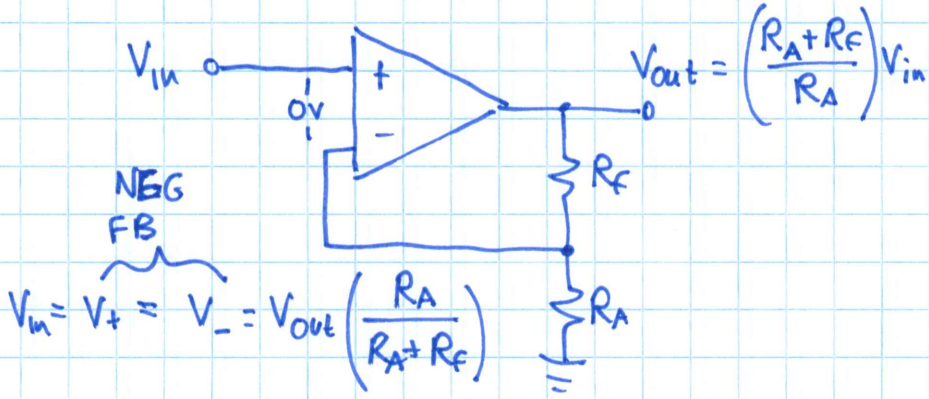


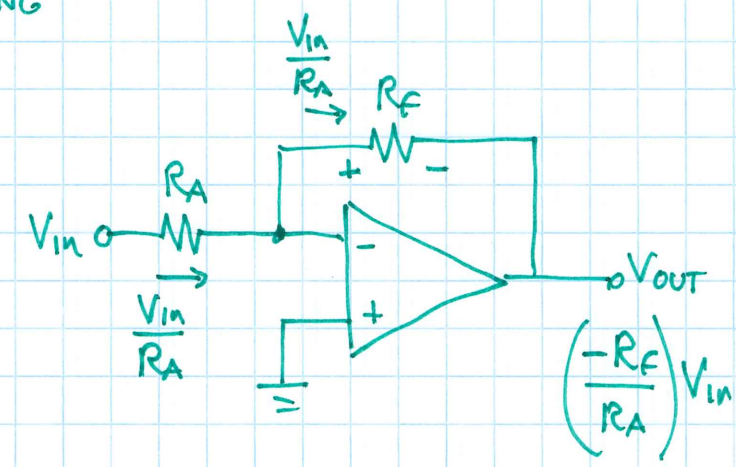
$\text{GAIN} = \underbrace{\frac{-R_F}{R_A}}_{\text{CIRCUIT}} = \underbrace{-100}_{\text{WANT}}$

$R_F = 100\underbrace{R_A}_{1k\Omega} = 100k\Omega$

WHY -100 ?


V_{in}
NONINV GAIN
+
−
V_{OUT}
V_{in}
INVERTING GAIN


V_{in}
0V
+
−
R_F
R_A
$V_{out} = \left(\frac{R_A + R_F}{R_A}\right) V_{in}$
NEG FB
$V_{in} = V_+ = V_- = V_{out}\left(\frac{R_A}{R_A + R_F}\right)$


$\frac{V_{in}}{R_A}$
R_F
+
−
R_A
V_{in}
$\frac{V_{in}}{R_A}$
−
+
V_{OUT}
$\left(\frac{-R_F}{R_A}\right) V_{in}$

b) If an LM741 (f_T = 1MHz) is used, determine the closed loop transfer function, and express in the form showing the DC gain and closed loop 3-dB frequency (bandwidth) f_{3dB}

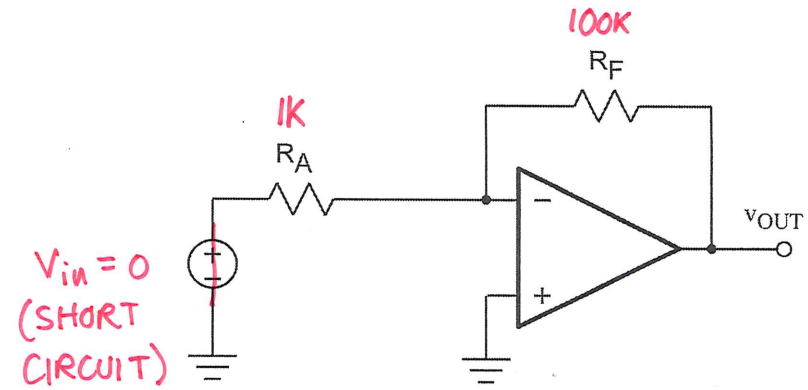
Gain-bandwidth product procedure:

1. Redraw circuit with all inputs suppressed (set = 0)
2. Find feedback factor β (fraction of output fed back to inverting input)
3. Closed loop bandwidth $f_{3\text{-}dB}$ will be unity gain frequency f_t multiplied by β

(2) $$\beta = \frac{R_A}{R_A + R_F} = \frac{1K}{1K + 100K} = \frac{1}{101}$$

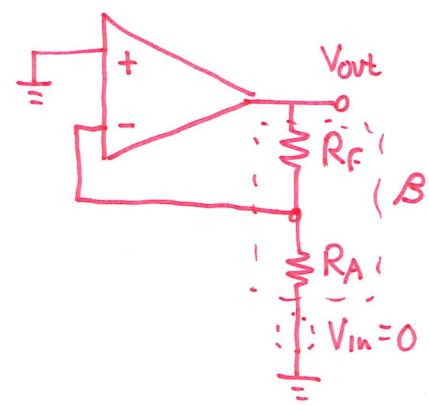
(3) $$f_{3dB} = \beta f_T = \left(\frac{1}{101}\right) 1MHz$$

$$f_{3dB} = 9.9\ kHz$$



$$\frac{V_{out}}{V_{in}} = \frac{\text{DC GAIN}}{1 + j\left(\frac{\omega}{\omega_{3dB}}\right)} = \frac{\text{DC GAIN}}{1 + j\left(\frac{f}{f_{3dB}}\right)} = \boxed{\frac{-100}{1 + j\left(\frac{f}{9.9kHz}\right)}}$$ (1)

$$1 + j\left(\frac{2\pi f}{2\pi f_{3dB}}\right)$$



GRAPHICAL REPRESENTATION

$$\frac{V_{out}}{V_{in}} = \frac{-100}{1 + j\left(\frac{f}{9.9\text{kHz}}\right)} \qquad \frac{\text{NUM}}{\text{DEN}}$$

DC GAIN = -100

$$\left|\frac{V_{out}}{V_{in}}\right|_{DC} = 100$$

$$20\log(100) = +40\text{ dB}$$

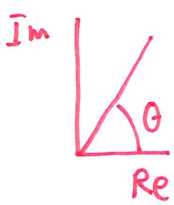
UNITY GAIN

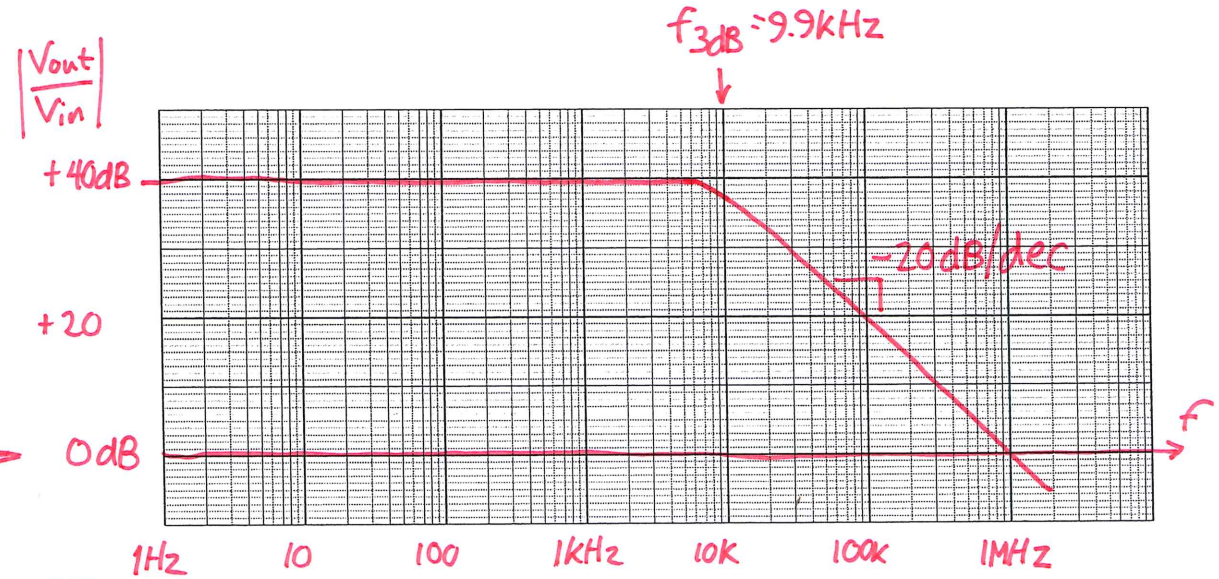
$$20\log(1) = 0\text{ dB}$$

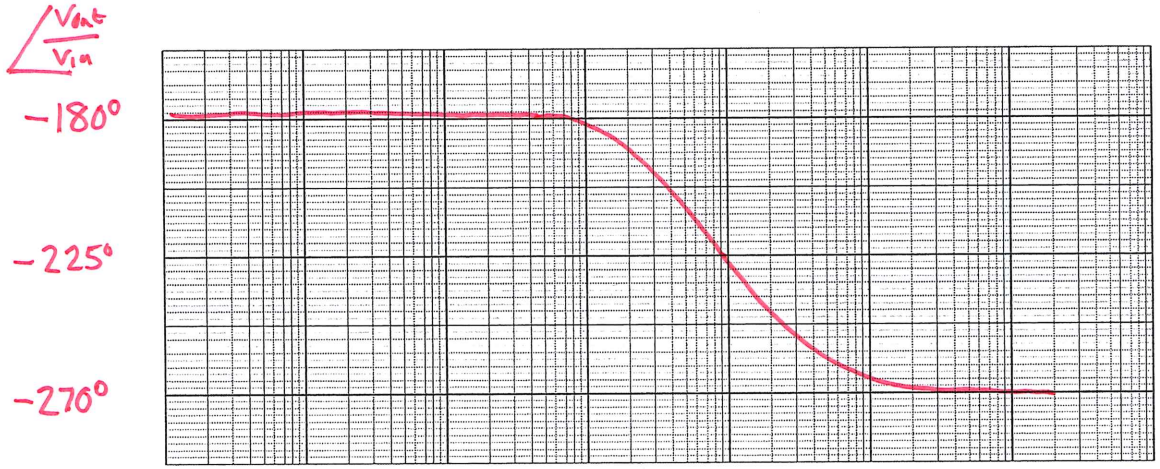
$$\angle\frac{V_{out}}{V_{in}} = \angle\text{NUM} - \angle\text{DEN}$$

$$\underbrace{-180^\circ}_{\text{FROM } - \text{ SIGN}} \underbrace{- \tan^{-1}\left(\frac{f}{9.9\text{kHz}}\right)}$$

$$\angle x + jy = \tan^{-1}\left(\frac{y}{x}\right) \quad \frac{\text{Im}}{\text{Re}}$$







c) Determine $v_{OUT}(t)$ for an input step of 0 to 100mV.

What is the 10%-to-90% rise time? $BW \times t_R = 0.35 \Rightarrow \frac{0.35}{9.9\text{kHz}} = 35\mu\text{sec}$

At what time will the output $v_{OUT}(t)$ reach within 100mV of its final value?

$$V(t) = V_F - (V_F - V_I)e^{-t/\tau}$$

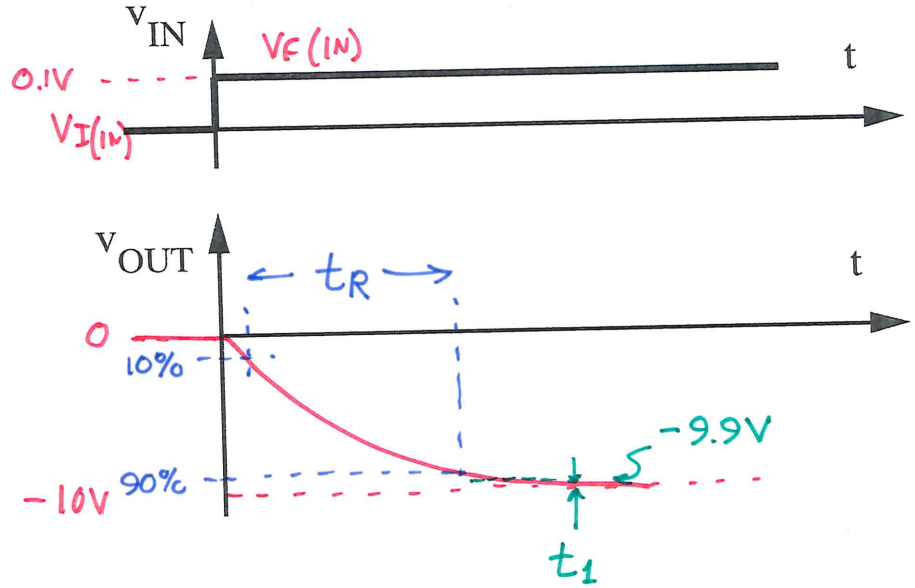
GEN'L 1ST ORDER

V_F, V_I FROM DC BEHAVIOR

$$\tau = \frac{1}{2\pi f_{3dB}} = \frac{1}{2\pi(9.9\text{kHz})} = 16\mu s$$

$\times(-100)$

V_{IN}	$\rightarrow$ V_{OUT}
0	0
0.1V	-10V



GENERAL

$$V(t) = -10V + 10V\, e^{-t/16\mu\text{sec}} \quad \} \text{ FOR ALL } t > 0$$

AT $t = t_1$, $V(t_1) = -9.9V$

$$-9.9V = -10V + 10V\, e^{-t_1/16\mu\text{sec}} \Rightarrow 73.7\mu\text{sec} = t_1$$