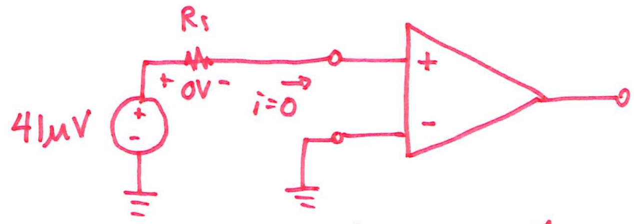
ECE3204 Lecture 3

Ideal Op-Amp (2.1)
Noninverting Gain (2.2)

Handout:
Open-Loop vs. Closed-Loop

THERMOCOUPLE → OPEN LOOP OP-AMP



$V_o = 200000(V_+ - V_-)$

$41\mu V - 0V$

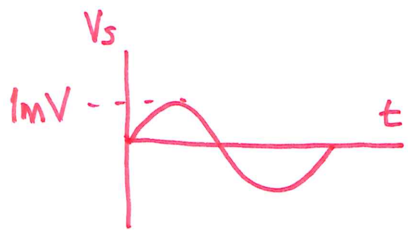
$= +8.2V$

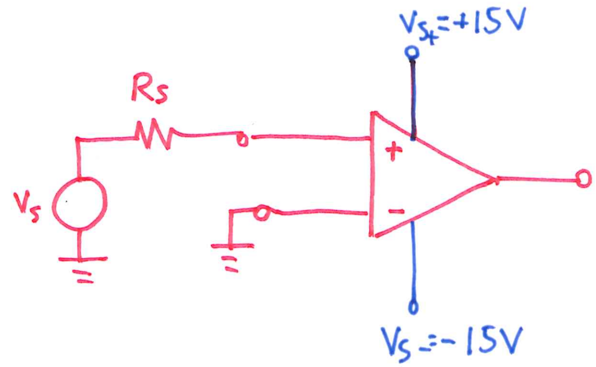
"OPEN LOOP"

BIG ENOUGH FOR DVM! ✓

ALMOST NEVER USED THIS WAY!

MICROPHONE

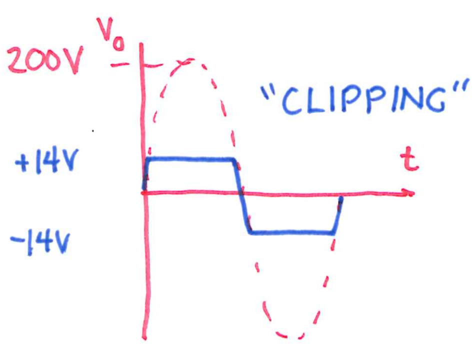




$V_o = A(V_+ - V_-)$

$= 200000(1mV \sin[2\pi f]t - 0)$

$= 200V \sin[2\pi f]t$



PROBLEM: V_o NOT SCALED VERSION OF V_s INPUT!

⇒ DISTORTION

IF INPUT EXCEEDS INPUT LINEAR RANGE: CLIPPING

NEED TO STAY INSIDE ± 70μV LINEAR RANGE

ECE3204 IDEAL OP-AMP SUMMARY

KCL ?

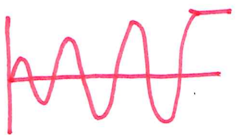
$i_- = 0 \quad i_+ = 0 \quad i_o \neq 0$?

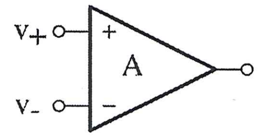
POWER SUPPLIES

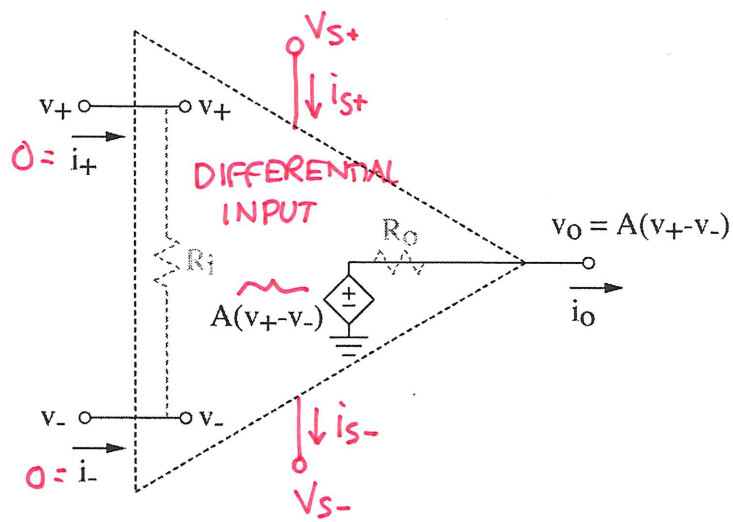
NEED V_{S+}, V_{S-}

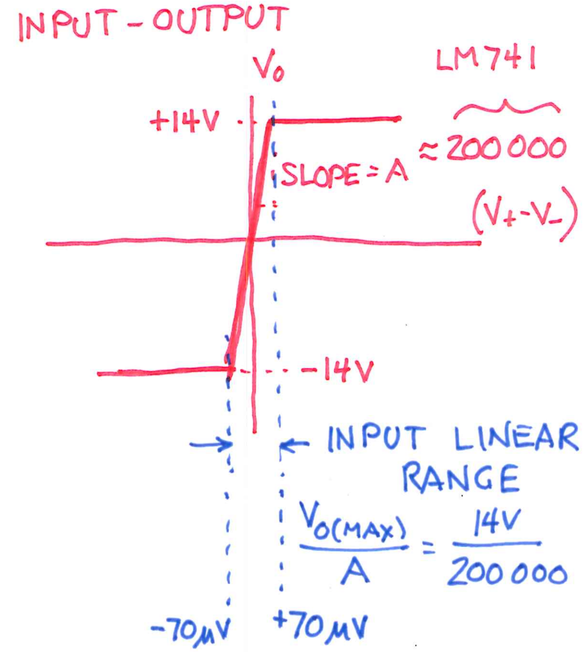
LIMITS OUTPUT VOLTAGE SWING

HOW FAR CAN VOLTAGE MOVE AT OUTPUT







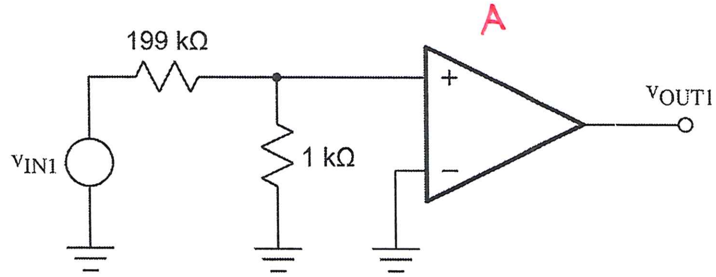


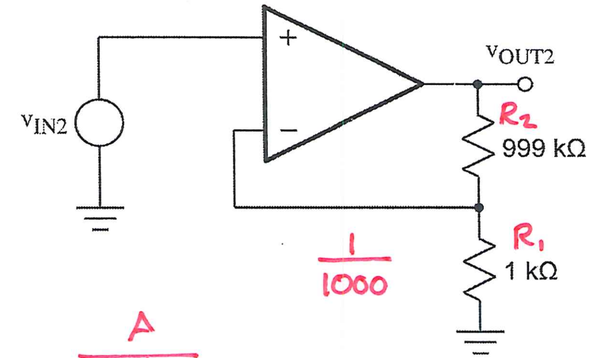
PROPERTY	INPUT RESISTANCE	OPEN LOOP GAIN	BANDWIDTH	OUTPUT RESISTANCE
IDEALIZATION	$R_i = \infty$	$A = \infty$	$BW = \infty$	$R_o = 0$
MEANING	Input currents = 0	Any v_o can be "supported" by infinitesimally small differential input (v_+ - v_-)	Signal of any frequency is OK	Output "looks like" ideal voltage source. Can drive any current required by load resistance
CONSEQUENCE	KCL at -, + terminals simplified. Always known that $i_- = 0$ and $i_+ = 0$	When negative feedback is present, $v_- = v_+$		Output current i_o determined by load

Electrical Characteristics (Note 5) (Continued)

Parameter	Conditions	LM741A			LM741			LM741C			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Large Signal Voltage Gain	$T_A = 25^\circ C$, $R_L \geq 2\ k\Omega$										
	$V_S = \pm 20V$, $V_O = \pm 15V$	50									V/mV
	$V_S = \pm 15V$, $V_O = \pm 10V$				50	200		20	200		V/mV
	$T_{AMIN} \leq T_A \leq T_{AMAX}$, $R_L \geq 2\ k\Omega$,										
	$V_S = \pm 20V$, $V_O = \pm 15V$	32									V/mV
	$V_S = \pm 15V$, $V_O = \pm 10V$				25			15			V/mV
	$V_S = \pm 5V$, $V_O = \pm 2V$	10									V/mV
Output Voltage Swing	$V_S = \pm 20V$										
	$R_L \geq 10\ k\Omega$	±16									V
	$R_L \geq 2\ k\Omega$	±15									V
	$V_S = \pm 15V$										
	$R_L \geq 10\ k\Omega$				±12	±14		±12	±14		V
	$R_L \geq 2\ k\Omega$				±10	±13		±10	±13		V
Output Short Circuit Current	$T_A = 25^\circ C$	10	25	35		25			25		mA
	$T_{AMIN} \leq T_A \leq T_{AMAX}$	10		40							mA
Common-Mode Rejection Ratio	$T_{AMIN} \leq T_A \leq T_{AMAX}$										
	$R_S \leq 10\ k\Omega$, $V_{CM} = \pm 12V$				70	90		70	90		dB
	$R_S \leq 50\Omega$, $V_{CM} = \pm 12V$	80	95								dB
Supply Voltage Rejection Ratio	$T_{AMIN} \leq T_A \leq T_{AMAX}$,										
	$V_S = \pm 20V$ to $V_S = \pm 5V$										
	$R_S \leq 50\Omega$	86	96								dB
	$R_S \leq 10\ k\Omega$				77	96		77	96		dB
Transient Response	$T_A = 25^\circ C$, Unity Gain										
Rise Time			0.25	0.8		0.3			0.3		μs
Overshoot			6.0	20		5			5		%
Bandwidth (Note 6)	$T_A = 25^\circ C$	0.437	1.5								MHz
Slew Rate	$T_A = 25^\circ C$, Unity Gain	0.3	0.7			0.5			0.5		V/μs
Supply Current	$T_A = 25^\circ C$					1.7	2.8		1.7	2.8	mA
Power Consumption	$T_A = 25^\circ C$										
	$V_S = \pm 20V$		80	150							mW
	$V_S = \pm 15V$					50	85		50	85	mW
LM741A	$V_S = \pm 20V$										
	$T_A = T_{AMIN}$			165							mW
	$T_A = T_{AMAX}$			135							mW
LM741	$V_S = \pm 15V$										
	$T_A = T_{AMIN}$					60	100				mW
	$T_A = T_{AMAX}$					45	75				mW

Note 2: "Absolute Maximum Ratings" indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is functional, but do not guarantee specific performance limits.





$\left(\frac{1}{200}\right) A$

$\frac{A}{1+\frac{A}{1000}}$

OPEN LOOP GAIN A	OPEN LOOP: GAIN v_{OUT}/v_{IN}	OPEN LOOP: $\lvert v_{OUT}\rvert$ for 10mV v_{IN}	CLOSED LOOP, NEGATIVE FEEDBACK: GAIN v_{OUT}/v_{IN}	CLOSED LOOP, NEGATIVE FEEDBACK: $\lvert v_{OUT}\rvert$ for 10mV v_{IN}
20 000	100	1V small?	952	9.52 V ✓
TYP → 200 000	1000	10V ✓	995	9.95 V ✓
2 000 000	10000	~~100V~~ CLIP!	999.5	9.995V ✓

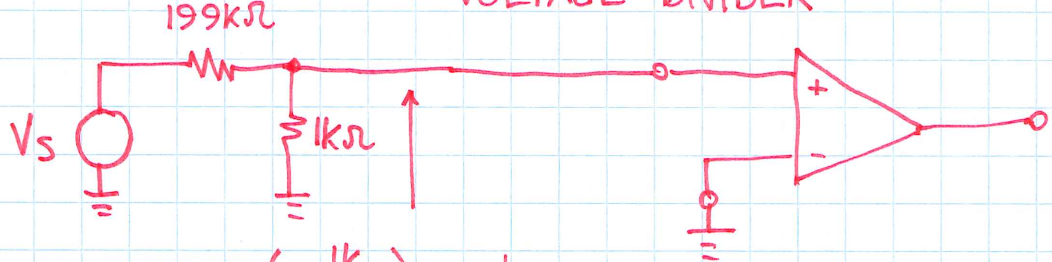
TOO SENSITIVE TO VARIATIONS IN OPEN LOOP GAIN A !

MUCH LESS SENSITIVE TO VARIATIONS IN A !

ECE3204 Open Loop vs. Closed Loop Comparison

$(V_+ - V_-)$ WAS TOO BIG: MAKE SMALLER TO STAY INSIDE $\pm 70\mu V$ LINEAR RANGE

VOLTAGE DIVIDER

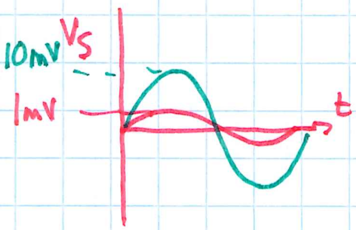


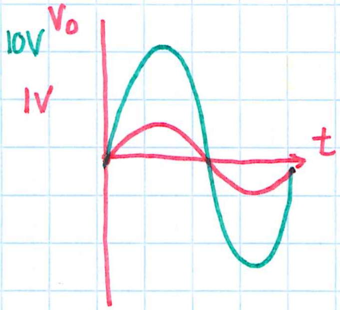
$$V_o = A\,(V_+ - V_-) = \frac{A}{200}\, 1mV \sin 2\pi f t$$

$$(V_+ - V_-) = \frac{1}{200} V_S$$

$$\left(\frac{1k}{1k + 199k}\right) = \frac{1}{200} V_S$$

$$\underbrace{\frac{200\,000}{200}\, 1mV}_{1\,V \ \sin 2\pi f t}$$

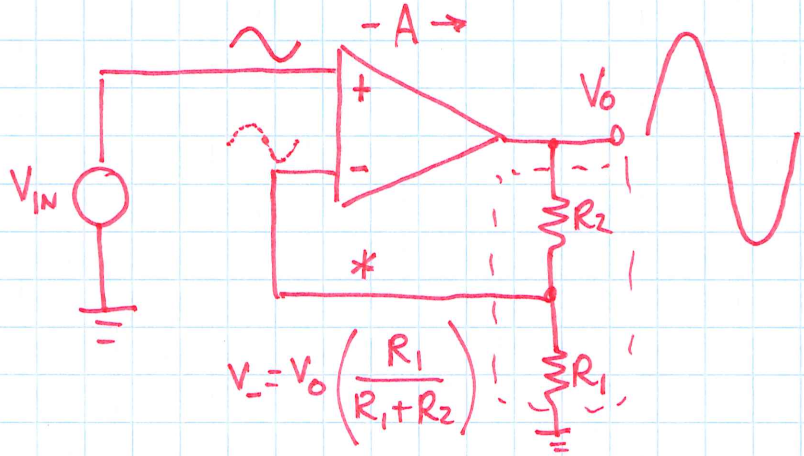




① TOO SENSITIVE TO A!

DON'T DO THIS!

② NEGATIVE FEEDBACK



$V_- = V_O\left(\frac{R_1}{R_1+R_2}\right)$

$$V_O = A(\underbrace{V_+}_{V_{IN}} - \underbrace{V_-}_{V_O\left(\frac{R_1}{R_1+R_2}\right)}) = AV_{IN} - AV_O\left(\frac{R_1}{R_1+R_2}\right)$$

SOLVE FOR V_O AS A FUNCTION OF V_{IN}

$$V_O\left[1 + A\left(\frac{R_1}{R_1+R_2}\right)\right] = A\,V_{IN}$$

GAIN $$\frac{V_O}{V_{IN}} = \frac{A}{1 + A\left(\frac{R_1}{R_1+R_2}\right)}$$

$$\frac{\cancel{A}}{\cancel{1} + \cancel{A}\left(\frac{R_1}{R_1+R_2}\right)} \quad A \to \infty \quad \frac{V_O}{V_{IN}} \approx \frac{R_1+R_2}{R_1}$$

DEPENDS ONLY ON FEEDBACK ELEMENTS!

THOUGHT PROCESS

PROBLEM: $(V_+ - V_-)$ TOO BIG
[OUTSIDE LINEAR RANGE]

APPLY ALL OF V_{IN} TO V_+

IF EVERYTHING'S WORKING:
AMPLIFIED VERSION OF V_{IN} AT OUTPUT V_O

MAKE $(V_+ - V_-)$ SMALL BY SUBTRACTING A V_- THAT IS ALMOST SAME AS V_+

SMALL DIFFERENCE;
$(V_+ - V_-)$ INSIDE LINEAR RANGE

* ATTENUATE V_O TO MAKE V_- THAT IS $\approx V_+$