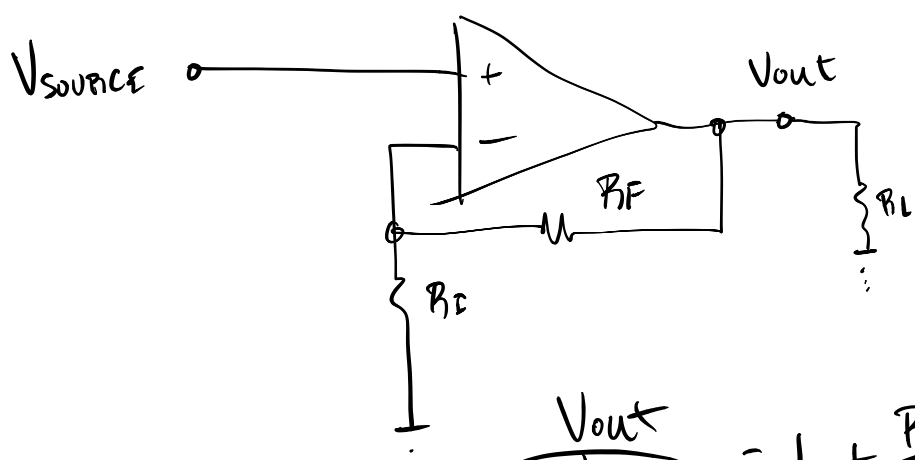
Homework: design op-amp circuit that will acheive a gain of 36

∴ determine max. V_{SOURCE} if $V_{CC} = \pm 12V$

∴ determine min. R_L if $I_{OUT(max)} = \pm 40\,mA$

∴ gain of 36 implies non-inverting configuration; no negative sign!



$$\frac{V_{out}}{V_{SOURCE}} = 1 + \frac{R_F}{R_I} = 36$$

$A_V \Rightarrow$ gain

$$\therefore \frac{R_F}{R_I} = 35$$

∴ Choose $R_F = 10\ k\Omega$ ← $k\Omega$ range is good for R_F; won't load op-amp too heavily

$$\therefore R_I = \frac{10k}{35}$$

$$= 285.7\ \Omega$$

∴ need standard value; nearest E24 value is

$$R_I = 300\ \Omega$$

[actual gain: $1 + \frac{10k}{.3k} = 34.33$ (ok)]

∴ if you need more precision, use E96 1% value!

$V_{CC} = \pm 12V$ means Vout may range

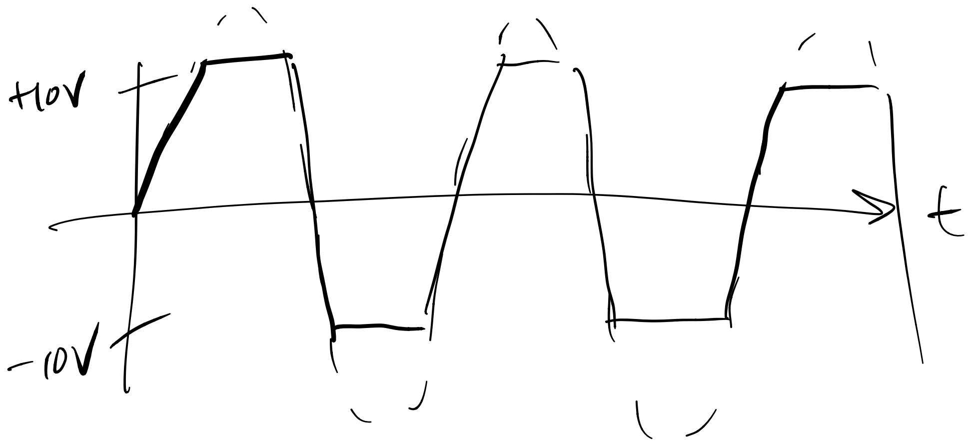
$$\pm(12-2) = \pm 10V$$

$\therefore$ max. positive $V_{SOURCE} = \frac{10}{36} = 0.2778$

or 277.8 mV

max. negative $V_{SOURCE} = \frac{-10}{36} = -277.8\ mV$

∴ V_{SOURCE}, whether DC voltage or peak AC voltage, may range up to ± 277.8 mV



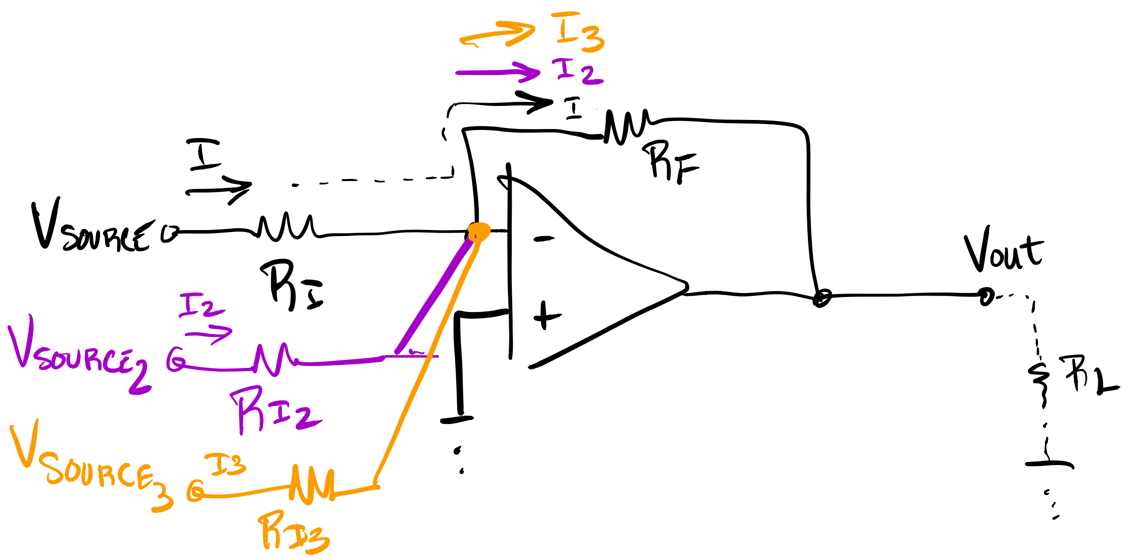
∵ max. output current ± 40mA

∴ $R_{L(min.)}$ @ $V_{out} = \pm 10V$:

$$R = \frac{V}{I} = \frac{10}{.04} = 250\,\Omega$$

Summing Amplifier

∴ starts w/ inverting configuration!



∴ we analyzed inverting amp by considering input current $\underline{I}$ to be required to flow R_F by KCL

∴ What if we add more inputs and thus more currents?

∴ they all flow through R_F by KCL!

$\because$ $V_{in}^{+} = 0$ [it's grounded]

$\because$ $V_{in}^{-} \approx 0$ ["virtual ground"]

($V_{in}^{+} = V_{in}^{-}$ for ideal op-amp)

virtual ground

$$\therefore \quad I_1 = \frac{V_{SOURCE_1} - 0}{R_{I_1}}$$

$$I_2 = \frac{V_{SOURCE_2} - 0}{R_{I_2}}$$

$$I_3 = \frac{V_{SOURCE_3} - 0}{R_{I_3}}$$

@ R_F: $$\frac{0 - V_{out}}{R_F} = I_1 + I_2 + I_3$$

$$V_{out} = -R_F \left(I_1 + I_2 + I_3 \right)$$

$$V_{out} = -R_F \left(\frac{V_{SOURCE_1}}{R_{I_1}} + \frac{V_{SOURCE_2}}{R_{I_2}} + \frac{V_{SOURCE_3}}{R_{I_3}} \right)$$

$$V_{OUT} = V_{SOURCE1}\left(\frac{-R_F}{R_{I_1}}\right) + V_{SOURCE2}\left(\frac{-R_F}{R_{I_2}}\right) + V_{SOURCE3}\left(\frac{-R_F}{R_{I_3}}\right)$$

.. if $R_{I_1} = R_{I_2} = R_{I_3} = R_I$

(not required, but common!)

then
$$V_{OUT} = \frac{-R_F}{R_I}\left(V_{SOURCE1} + V_{SOURCE2} + V_{SOURCE3}\right)$$

.. hence, summing amplifier

.. note: "virtual ground" isolates the inputs!

.. avoids interaction between sources of different signal magnitudes and impedances homework: design a circuit using ideal op-amps that acheives

$$V_{out} = 3V_A + 2V_B - 5V_C$$

∴ use as few op-amps as possible

∴ sketch V_{out} if $V_A = 1V$ [D.C.]

$V_B = 10\,mV$ [D.C.]

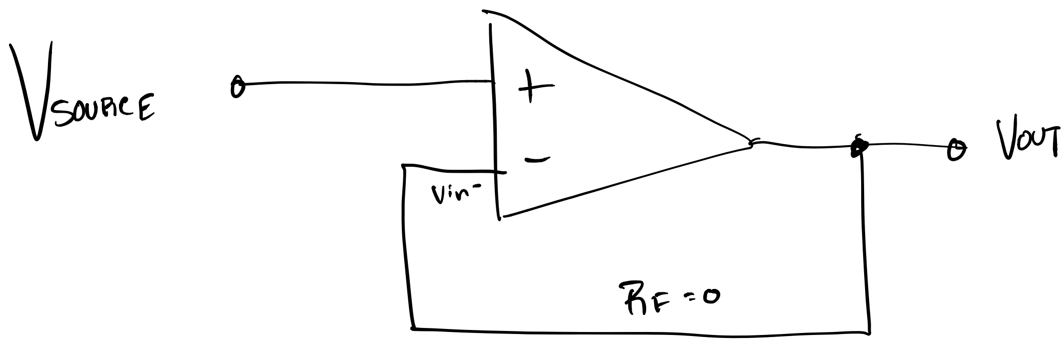
$V_C = 50\,mV_{p\text{-}p}$ [sine, 1 kHz]

Unity-Gain Buffer (Non-Inverting)

∴ what if we took a non-inverting amplifier and made $R_F = 0$ and $R_I = \infty$?

$$A_v = \frac{V_{OUT}}{V_{SOURCE}} = 1 + \frac{R_F}{R_I} = 1 + \cancel{\frac{0}{\infty}}_{\,0} = \underline{1}$$

(hence, unity gain)



$R_I = \infty$ (not there!)

∴ <u>another</u> way to analyze circuit:

ideal op-amp: $V_{in}^+ = V_{in}^-$

$$V_{SOURCE} = V_{in}^+ = V_{in}^- = V_{OUT}$$

$$\therefore V_{SOURCE} = V_{OUT}$$

∴ this circuit uses <u>100% negative feedback</u>

∴ often called "voltage follower" because output "follows" input

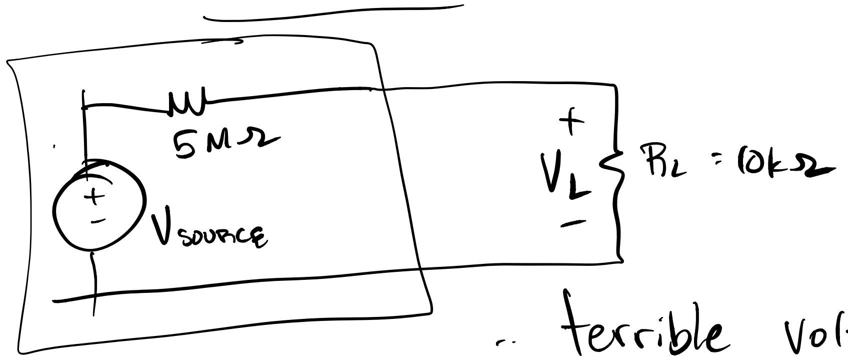
∴ what is it good for if it doesn't provide voltage gain ??

∴ buffer !

∴ remember, ideal opamp has infinite input impedance due to zero input current, and zero output impedance; perfect voltage source

∴ what if we have a very sensitive source;

ex: piezoelectric transducer w/ 5MΩ internal impedance and we must drive 10kΩ load at input to computer sound card.



∴ terrible voltage divider !

$$V_L = V_{SOURCE}\left[\frac{R_L}{R_L + R_{int.}}\right]$$

$$V_L = V_{SOURCE}\left[\frac{10k}{10k + 5M}\right]$$

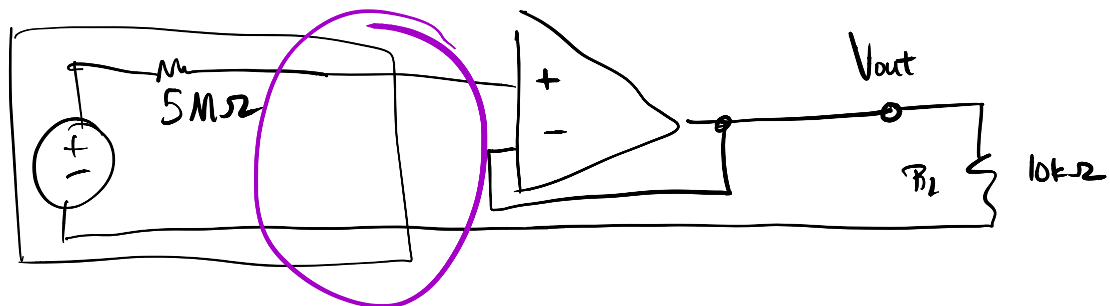
$$V_L = V_{SOURCE}\left[0.002\right]$$

99.8% of our signal is gone!

$$20\log_{10} 0.002 = -54 \text{ dB}$$

terrible!

∴ insert unity-gain buffer :



no voltage division here!

[real op-amps like μA741 do have finite R_{in}; alternatives are available with GΩ input resistances!]

∴ $V_{int} = V_{SOURCE} = V_{OUT}$

∵ op-amp can easily drive 10kΩ and possibly lower; just check output current