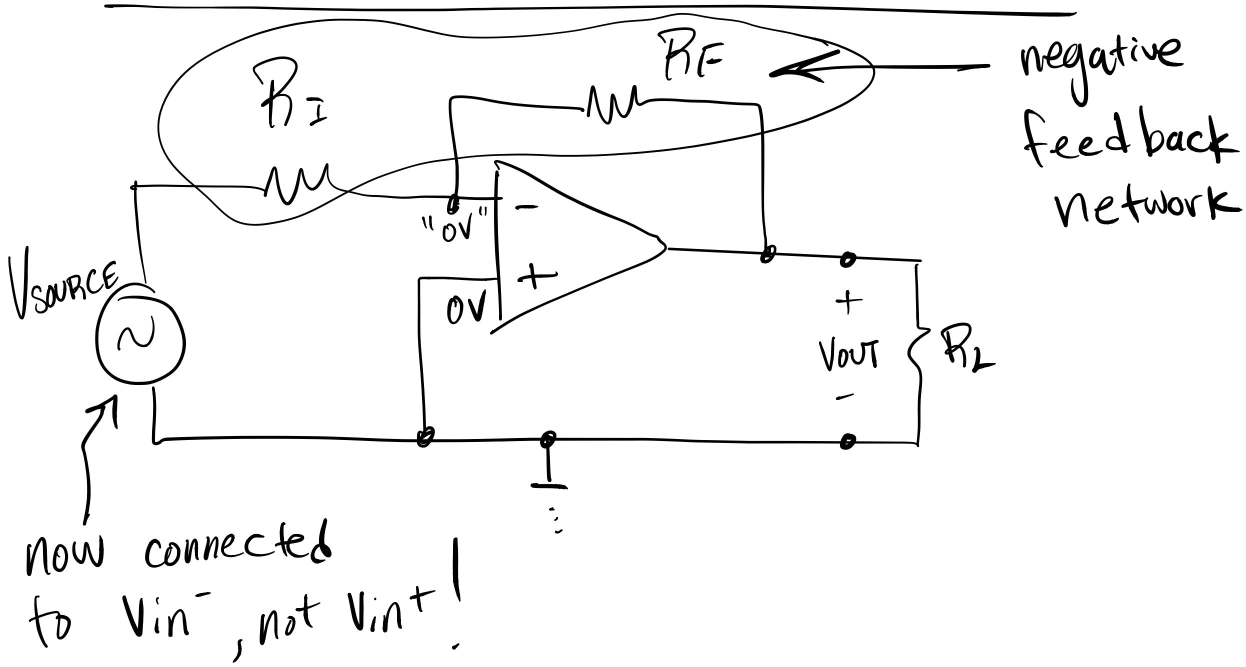
Inverting Voltage Amplifier



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

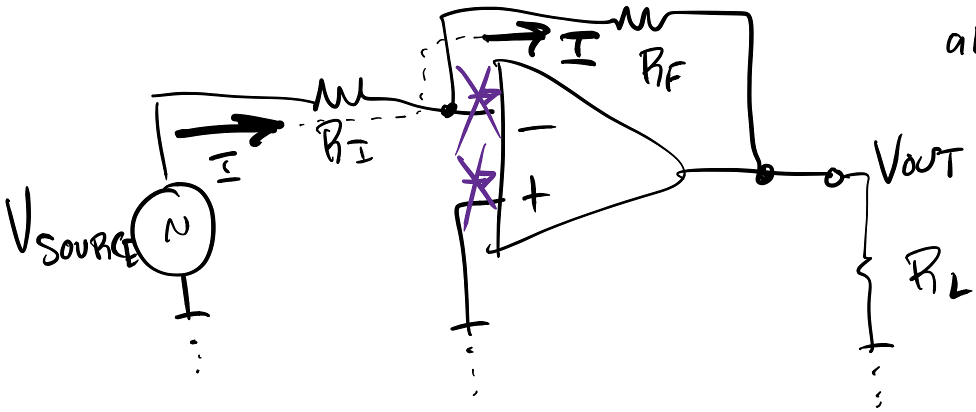
∵ V_{in}^+ is connected to <u>ground</u>.

∴ $V_{in}^+ = 0$

$\longrightarrow V_{in}^- = V_{in}^+ = 0$

∴ V_{in}^- is at <u>virtual ground</u>.

∴ not directly connected to ground, but effectively at <u>very</u> close to 0V!



alt. way of drawing common-ground circuits!

$\pm V_{CC}$ not shown!

∵ no input current to op-amp itself;
∴ I must flow through R_F due to KCL!

$$I = \frac{V_{SOURCE} - 0}{R_I} \quad \text{(at input)}$$

$$I = \frac{0 - V_{out}}{R_F} \quad \text{(through } R_F\text{)}$$

$$\frac{V_{SOURCE}}{R_I} = \frac{-V_{OUT}}{R_F}$$

$$\frac{V_{OUT}}{V_{SOURCE}} = \frac{-R_F}{R_I}$$

∴ so, once again, gain of circuit is determined by the ratio of two resistors; fantastic!

∴ note: no "1 +" term, like non-inverting circuit; and there is a negative sign, so this circuit inverts like single-device amplifier we talked about first

ex: if $R_F = 100k\Omega$

$R_I = 10k\Omega$

$$\therefore \frac{V_{OUT}}{V_{SOURCE}} = -\frac{100\cancel{k}}{10\cancel{k}} = -10$$

or $20\log_{10}(10)$

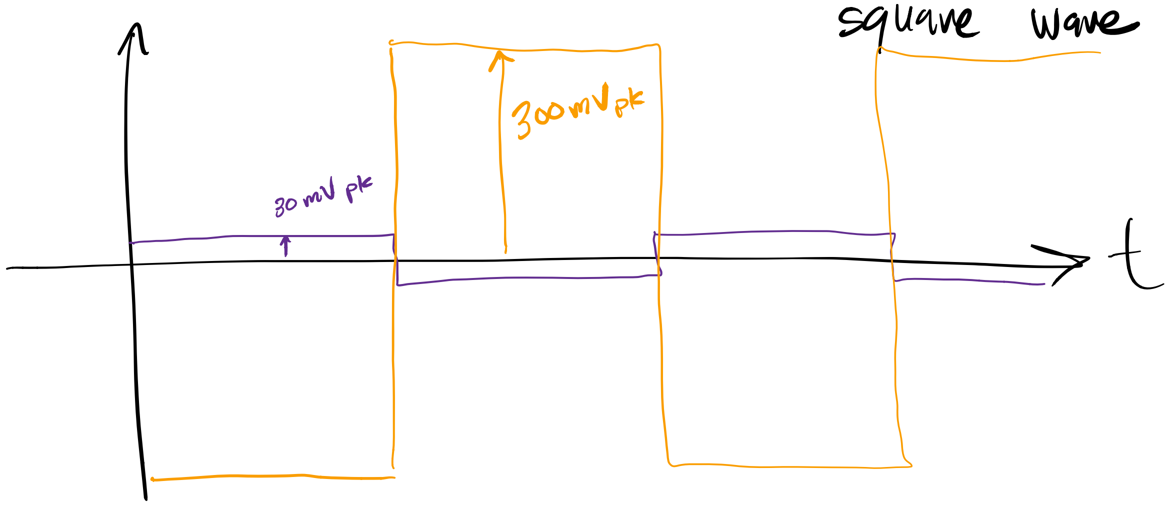
$= \boxed{20\text{ dB, inverting}}$

∴ if $V_{SOURCE} = 1.2V$, then

$V_{OUT} = -12\,V$

∴ if $V_{SOURCE} = 30\ mV_{RMS}$ @ 1 kHz, square wave

then $V_{OUT} = 300\ mV_{RMS}$ @ 1kHz inverted square wave



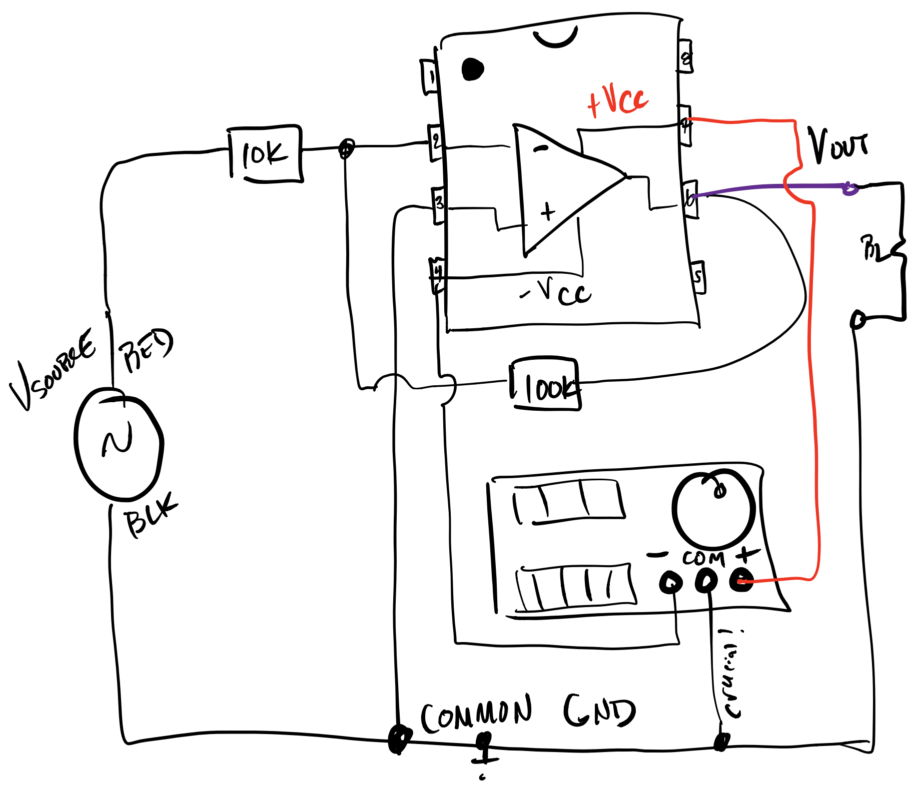
remember: $V_{RMS} = V_{pk}$ for square wave!

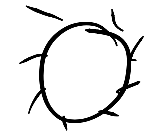
also: unlike non-inverting amplifier, can achieve fractional gain if $R_F < R_I$

[non-inverting: $A_v \geq 1$]

.. practical circuit using $\mu A741$ op-amp
ca. 1968, still used

DIP8





good layout practice:
R_F directly between Vout and V_{in}^- to avoid instability

.. $\mu A741$: max. Vcc of $\pm 18V$

lab: $\pm 15V$

.. it turns out the magnitude of Vcc determines the maximum output voltage of circuit.

∴ in general, for most practical op-amps:

$$\boxed{V_{out\,(max.)} = \pm (V_{cc} - 2)}$$

... so if $V_{cc} = \pm 15V$ [15V "rails"],

$V_{out\,(max.)} = \pm 13V$

ex: non-inverting amplifier w/ $R_F = 33\,k\Omega$
$R_I = 6.2\,k\Omega$

$$\frac{V_{OUT}}{V_{SOURCE}} = 1 + \frac{33k}{6.2k} = 6.323$$

∴ let's input $V_{SOURCE} = 1V$ (D.C.)
then $V_{OUT} = 6.323V$

$< +V_{out\,max}$ (fine)

- what if $V_{SOURCE} = 5V$ (D.C.)

then $V_{OUT} = 5 \cdot 6.323 = \cancel{31.61}\,V$

$> +13V$

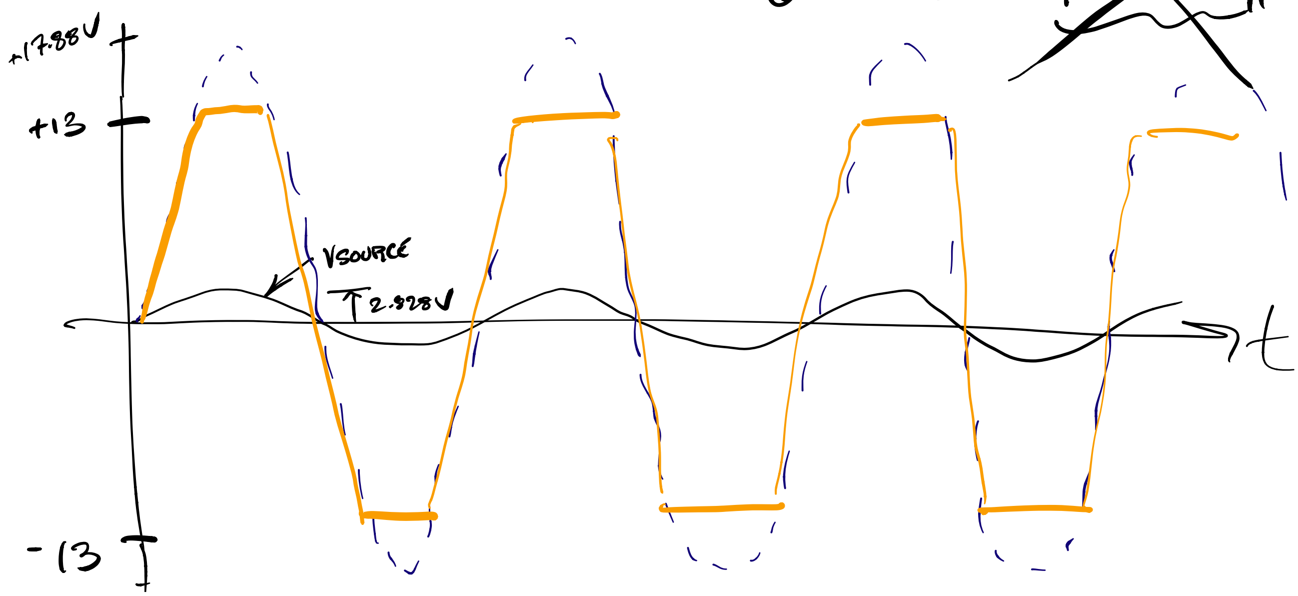
V_{out} will in fact saturate at $V_{out} = 13V$.

(error)

ex: $V_{SOURCE} = 2V_{RMS}$ sine wave

$$V_{SOURCE\,(peak)} = 2 \cdot \sqrt{2} = 2.828\,V_{pk}$$

$$\text{then } V_{OUT} = 2.828 \cdot 6.323 = \cancel{17.88}_{pk}$$



- waveform would saturate every time it exceeds $\pm 13V$
  - called clipping of waveform

- in addition to output voltage limitations of practical op-amp circuits, real op-amps also have finite current capability.

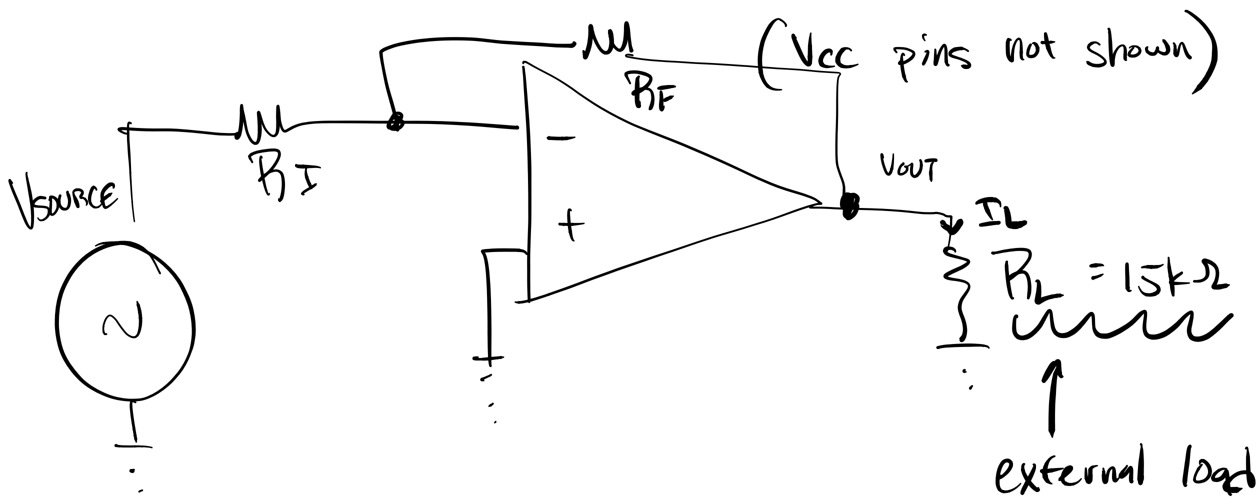
$$\mu A741 : i_{out\,(max)} = \pm 25\,mA$$

ex: inverting configuration, $R_F = 8.2\,k\Omega$

$R_I = 1\,k\Omega$

$$\therefore \frac{V_{OUT}}{V_{SOURCE}} = \frac{-R_F}{R_I} = -\frac{8.2k}{1k} = -8.2$$

- let's say $V_{SOURCE} = 1\,V$, $R_L = 15\,k\Omega$



$$V_{OUT} = 1V \cdot -8.2 = -8.2V$$

$$I_L = \frac{V_{OUT}}{R_L} = \frac{-8.2}{15k} = -0.5467 \text{ mA}$$

$$|-.5467| < 25 \text{mA} \checkmark$$

.. what if $R_L = 120\Omega$?

then $I_L = \dfrac{-8.2}{120} = -0.06833 A$

or $-68\cancel{.33}$ mA

$68.33 > 25\,mA$

∴ op-amp will saturate at $I_L = 25mA$

actual V_{OUT} will be

$-25\,mA \cdot 120\,\Omega = -3V$ (error!)

∴ in general: small op-amps like $k\Omega$-range resistors

∴ also: op-amp must drive current in R_F!

∴ $k\Omega$-range for R_F also good idea!

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 $I_{OUT(max)} = \pm 40\,mA$