Op-Amp Circuits Part One

∴ last time: single <u>active</u> (three-terminal) device could make a linear amplifier.

∴ huge development!

∴ several shortcomings; big one is that overall performance (<u>actual</u> linearity, amount of gain, etc.) depended heavily on device itself and a high level of <u>variability</u> unit-to-unit

huge invention: <u>negative feedback</u>

Harold Black, Western Electric (1928)

concept: output, or <u>fraction</u> of the output of an amplifier, is <u>subtracted</u> from the input

∴ reduces voltage gain; but <u>corrects</u> errors in gain, linearity, etc.

Operational Amplifier

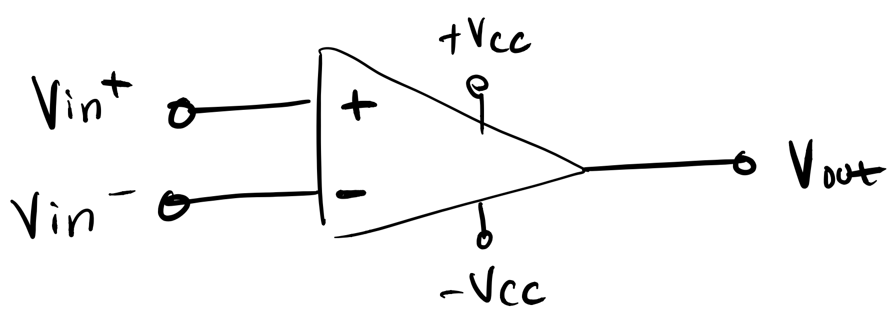
- multistage voltage amplifier with extremely high voltage gain, whose final performance is determined by negative feedback.

    - results in "near-perfect" processing of signals, without variability due to individual devices such as transistors.

    - developed in 1940s for use in analog computers

    - by 1960's: monolithic integrated circuit (I.C.) chip

Ideal Op-Amp



key features:

- $\underline{\text{differential input}}$ $(V_{in}^{+} - V_{in}^{-})$
  w/ infinite R_{in} and therefore zero input current, like an ideal voltmeter

- infinite voltage gain

$$\underbrace{A_{v(o.L.)}}_{\text{open-loop}} = \infty$$

- perfect frequency response
  (i.e., no high- or low-pass filter)

- zero R_{out}; i.e. perfect voltage source @ output, drive any load

- **no** such thing as ideal op-amp, but they are perfect enough for our applications!

Two Rules:

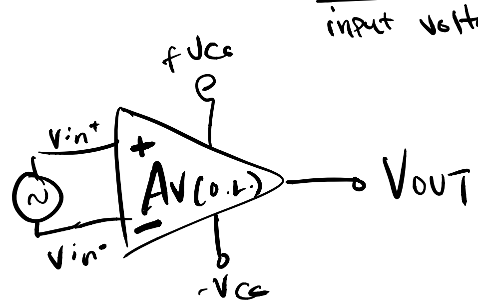
- these will allow us to develop a <u>transfer function</u> $\left(\frac{V_{OUT}}{V_{SOURCE}}\right)$ for many negative-feedback circuits using an ideal op-amp:

1.) $V_{in}^{+} = V_{in}^{-}$

what?

- an ideal op-amp has <u>infinite</u> open-loop gain
- by definition:

$$V_{OUT} = \underbrace{\left(V_{in}^{+} - V_{in}^{-}\right)}_{\text{differential input voltage}} \cdot A_{V(O.L.)}$$



∴ as $A_{v(o.L.)} \to \infty$, $V_{in}^{+} - V_{in}^{-} \to 0$

∴ $V_{in}^{+} = V_{in}^{-}$

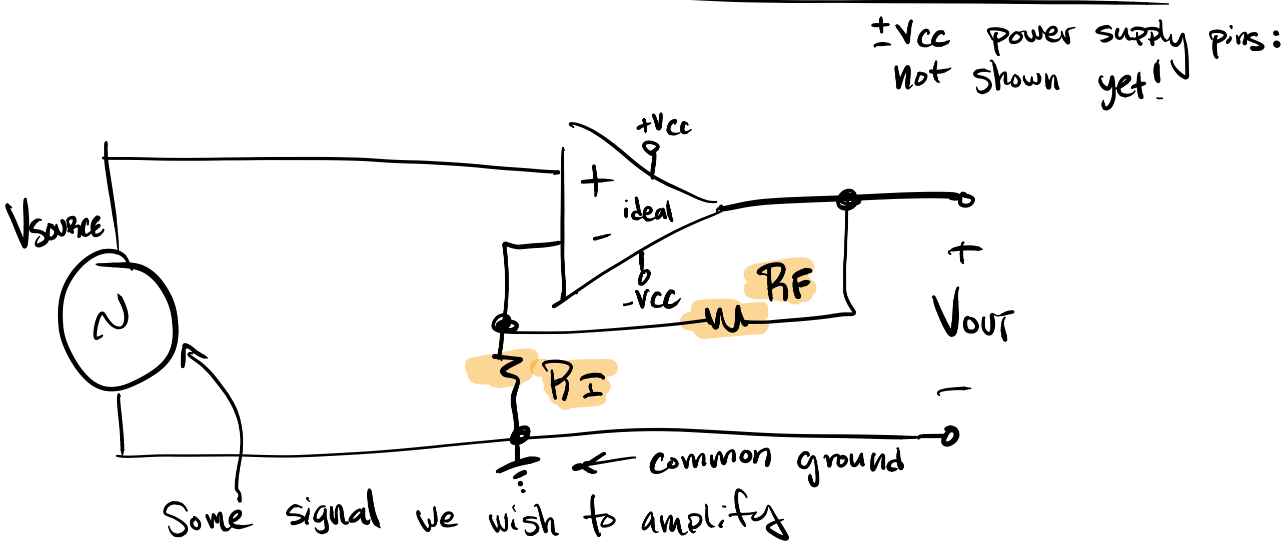
2.) $i_{in}^{+} = 0$

$i_{in}^{-} = 0$

∴ this is because $R_{in} = \infty$

∴ how do we use these rules?

Non-inverting Voltage Amplifier



- R_F and R_I constitute a negative feedback loop!

- thus a voltage-divided fraction of V_{OUT} is subtracted from V_{SOURCE}!

- ideal: $V_{in}^{+} = V_{in}^{-}$ (rule #1)

$$\underbrace{V_{in}^{+} = V_{SOURCE}}$$

$$V_{in}^{-} = V_{OUT}\left[\frac{R_I}{R_F + R_I}\right]$$

$$\therefore V_{SOURCE} = V_{OUT}\left[\frac{R_I}{R_F + R_I}\right]$$

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

voltage gain of non-inverting amplifier

$$\therefore A_V = 1 + \frac{R_F}{R_I}$$

- Voltage gain of circuit - if we assume op-amp is ideal - is based on the ratio of a couple resistors and not active device characteristics!

HUGE !!!!!

- we can use cheap, high-precision resistors and get very precise amplification

ex: $R_F = 100\ k\Omega$

$R_I = 10\ k\Omega$

$$A_v = 1 + \frac{R_F}{R_I}$$

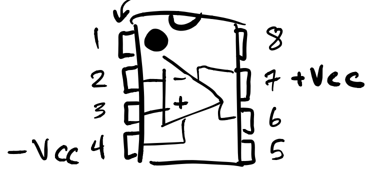
$$= 1 + \frac{100k}{10k} = 11 \quad \left[\text{or } 20\log_{10}(11) = 20.8\ \text{dB}\right]$$

ex: if $V_{SOURCE} = 5\ mV_{p\text{-}p}$ @ 1 kHz, $V_{OUT} = 55\ mV_{p\text{-}p}$ @ 1k

if $V_{SOURCE} = -1\ VDC$, $V_{OUT} = -11\ VDC$

- Many small-signal op-amps use the 8-pin DIP package

- pins go CCW from top, starting here



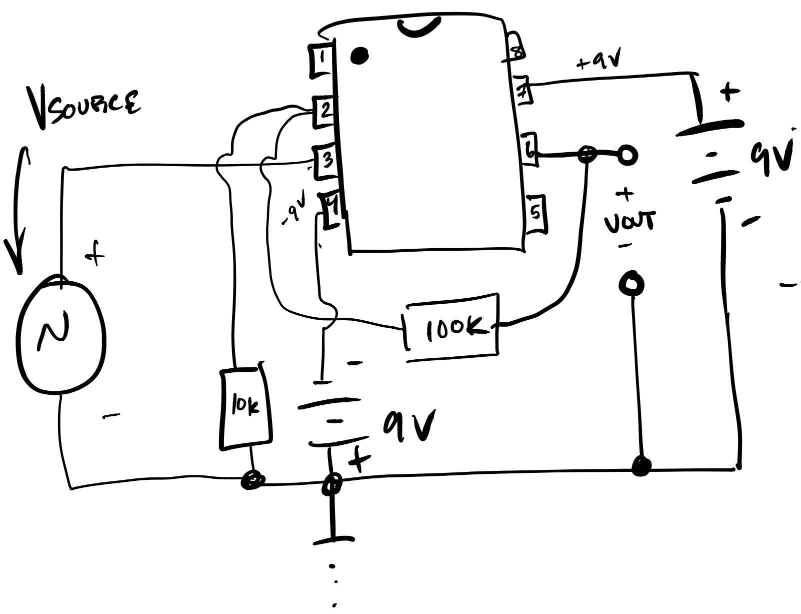
Wrong pinout in video lecture!!!

Corrected here!

Classic op-amp:

μA741

- introduced in 1968
- cheap! \$3 then, more like 25¢ now
- cpi calculator online: \$3 in 1968 money is how much in 2020 dollars?



- μA741 works with up to ± 18V Vcc
- need bipolar power supply so Vout can go pos. or negative!