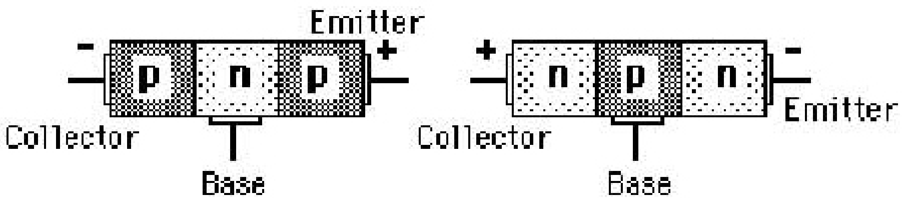
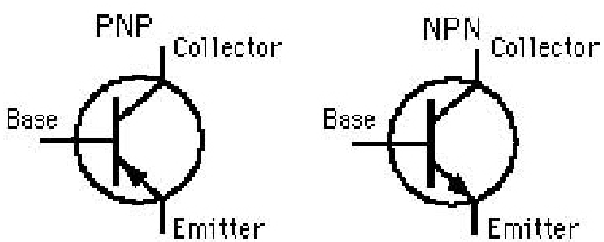
Bipolar Junction Transistors

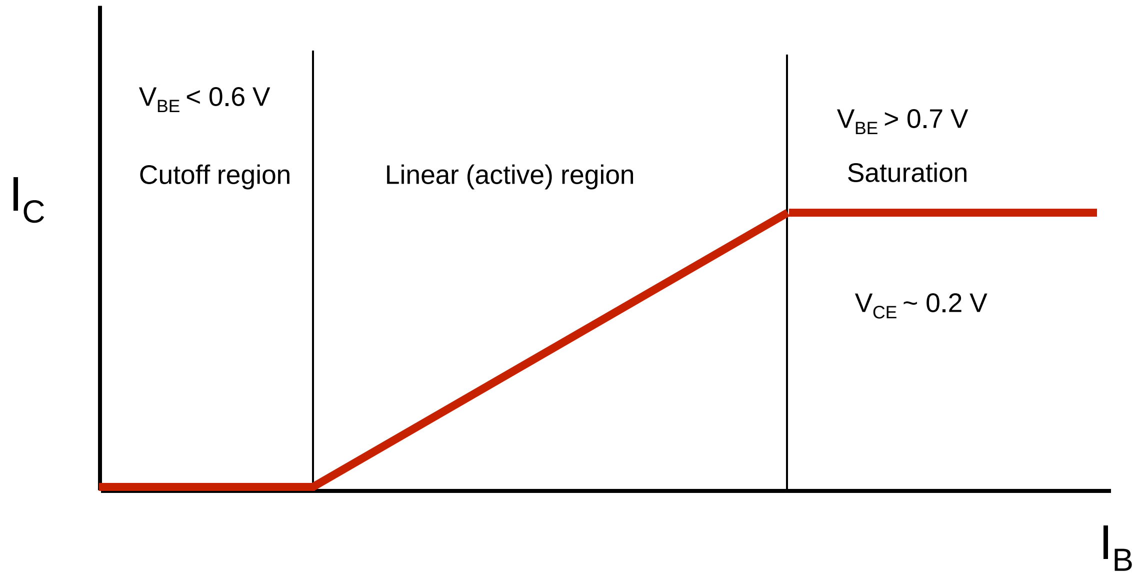
- A three terminal device that allows a small current to control a much larger one
- Essentially two junction diodes





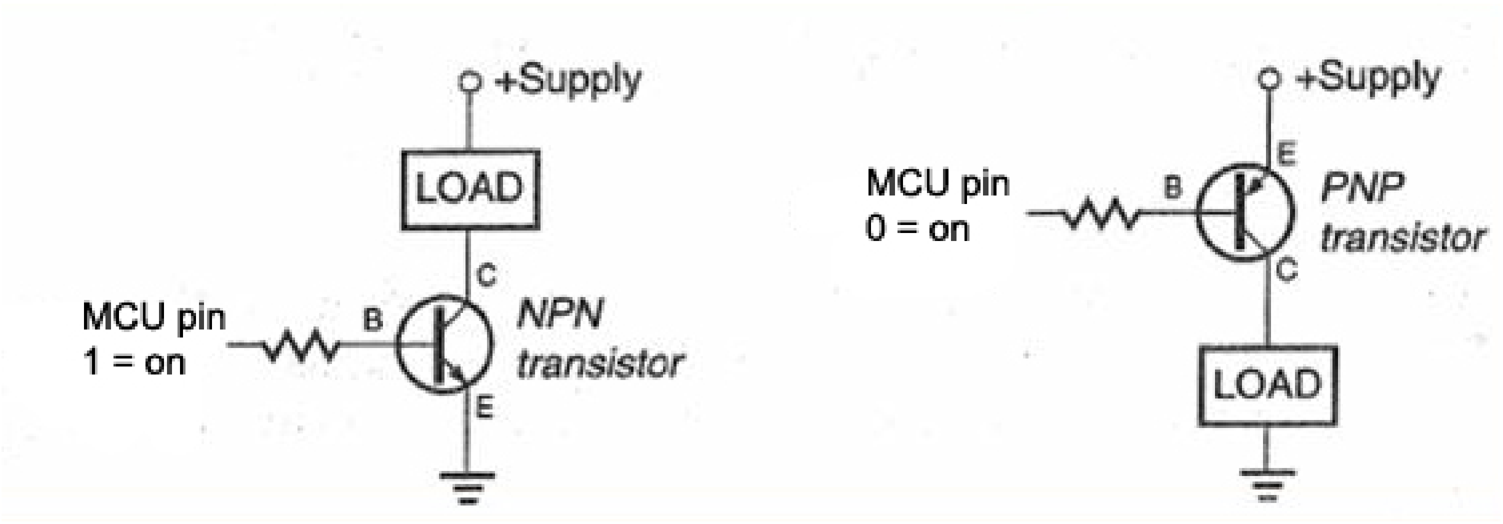
Bipolar Junction Transistors

- What's going on?
  - BE diode doesn't turn on until forward biased to ~ 0.6 V
  - In the linear region $I_C = \beta * I_B$ (β is a bad design parameter!)
  - Eventually saturate and I_C depends solely on the attached load.



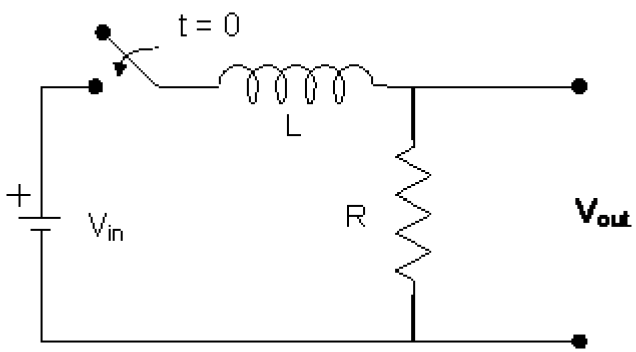
Bipolar Junction Transistors

- Be sure “switch side” is opposite the load side.

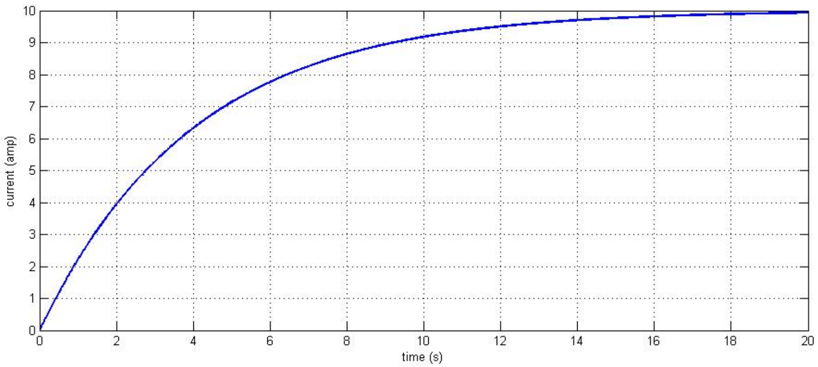


Circuit Dynamics

- Frequency dependence of impedance is important



- Current through an inductor cannot change instantaneously.



- What happens when the switch is closed?

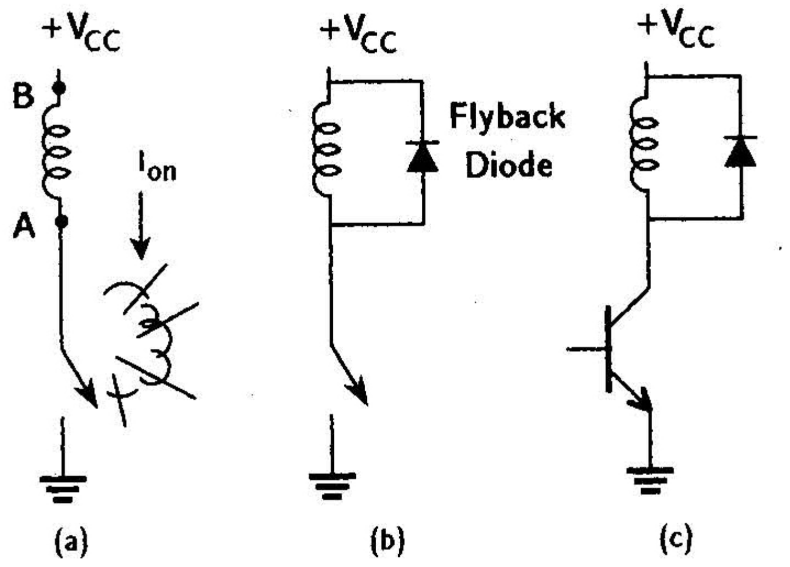
$$\text{KVL: } V = L\frac{dI}{dt} + IR \quad \rightarrow \quad I(t) = \frac{V}{R}\left[1 - e^{-t/\tau}\right]$$

where τ = L/R is the time constant

So, as $t \rightarrow \infty$, $V_L \rightarrow 0$ and the inductor behaves as a short circuit.

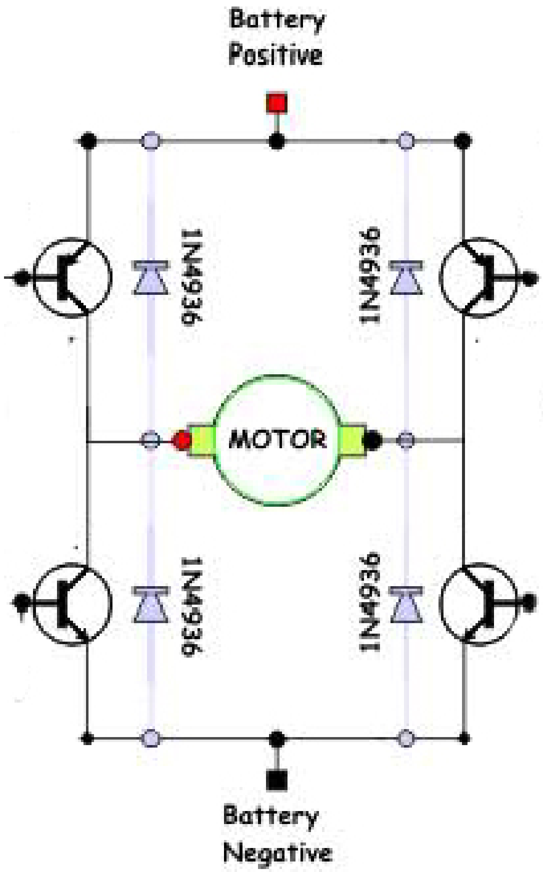
Junction Diodes

- Inductive kickback
  - Big problem when switching inductive loads (motors, solenoids)
  - A changing current induces a voltage across the inductor, making the potential at A greater than at B.
  - This can cost you the price of a new switch.
  - Flyback diodes protect against this.



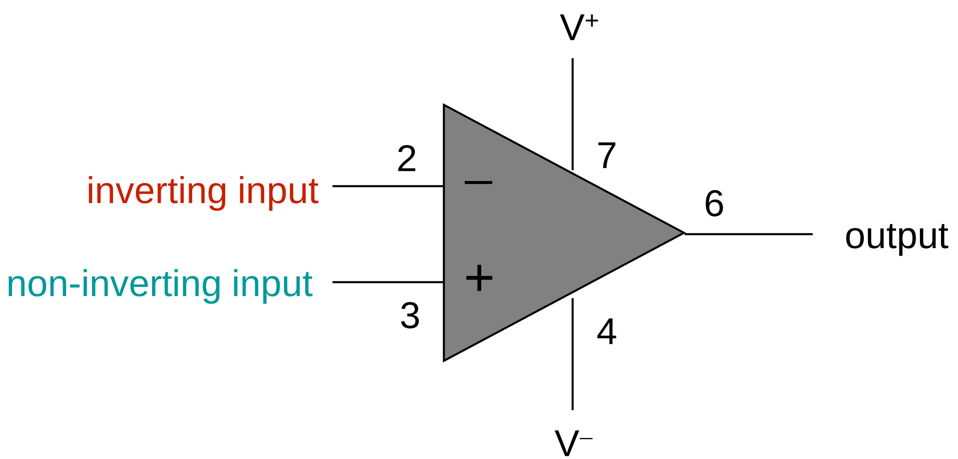
Bipolar Junction Transistors

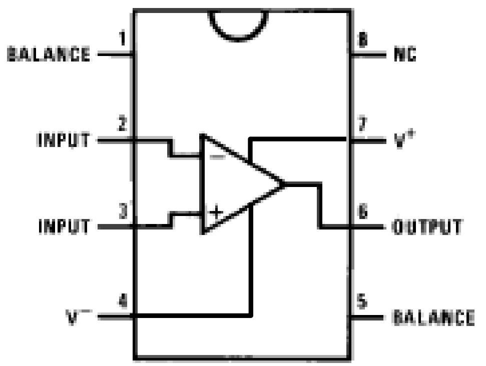
- H-Bridge motor drivers



Operational Amplifier

- Two inputs
  - inverting
  - non-inverting
- One output
- External power connections

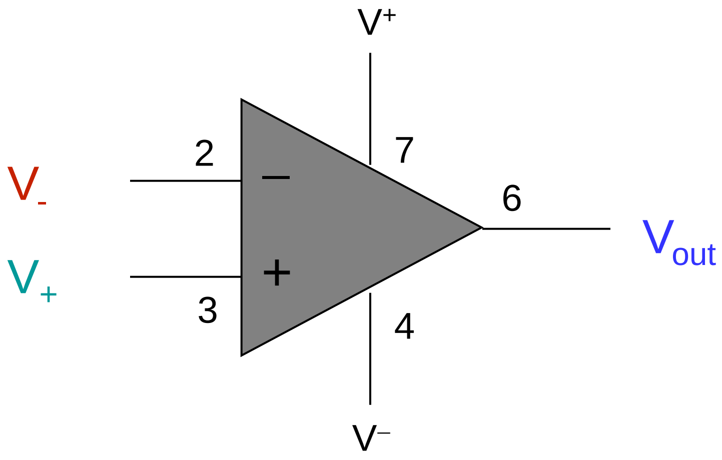




Operational Amplifier (w/o feedback)

- The internal op-amp formula is

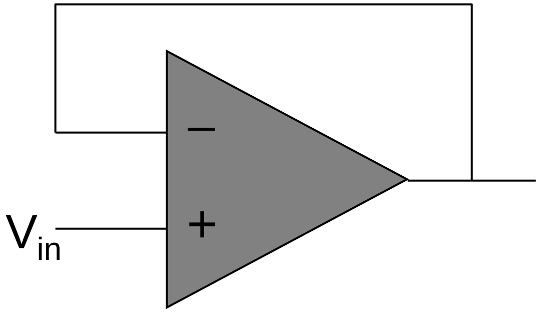
  $V_{out} = Gain * (V_+ - V_-)$



- So if V_+ is greater than V-, the output goes positive
- If V_+ is less than V-, the output goes negative
- A Gain of ~200,000 (for a real op-amp) makes this device practically useless (at least as shown here…)

Operational Amplifier (negative feedback)

- Infinite gain is not generally useful unless used with negative feedback
- Imagine hooking the output to the inverting input

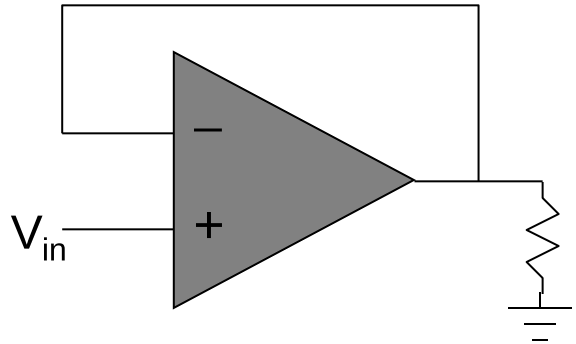


- If the output is less than V_{in}, it must go positive
- If the output is greater than V_{in}, it must go negative

The result is that the output quickly forces itself to be exactly V_{in}.

Operational Amplifier (negative feedback)

- What happens under load?

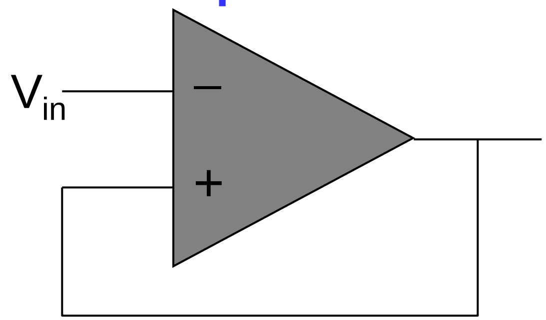


- Load wants to pull output to GND
- Op-Amp will do all it can (within current limitations) to drive output to V_{in}
  - In this case, the op-amp drives (or sinks, if V_{in} is negative) a current through the load until $V_{out} = V_{in}$

  The result is that we have a buffer that can apply V_{in} to a load without worrying about the characteristics of the source of V_{in}.

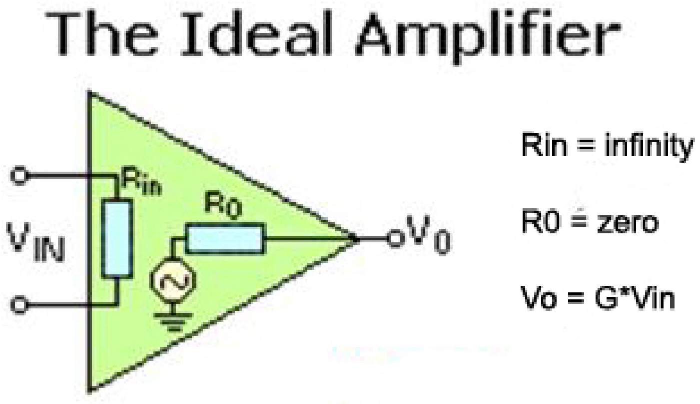
Operational Amplifier (positive feedback)

- What happens under positive feedback?



- Now if the non-inverting input is more positive by even a tiny amount, the output tries to drive it still more positive
- The system will immediately “rail” at the supply voltage
  - This could be either positive or negative, depending on the initial offset

Golden Rules



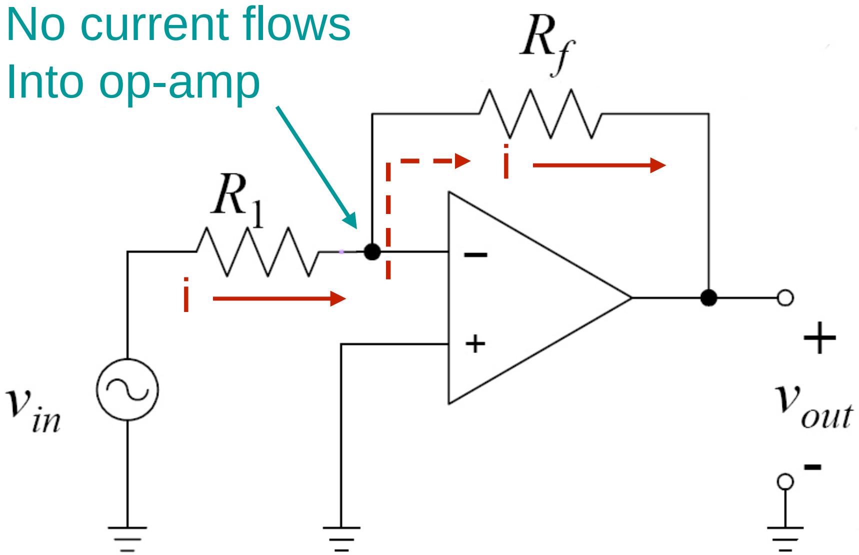
- The inputs draw no current
- When wired with negative feedback the output does whatever is necessary to make the difference between the input voltages zero.

→ Only KCL, KVL, and Ohm's Law are necessary to completely analyze op amp circuits.

Inverting Amplifier

- Resistor R_f is connected to the inverting input and forms a negative feedback loop:

No current flows Into op-amp



Using KCL: $\dfrac{V_{in} - V_-}{R_1} = \dfrac{V_- - V_{out}}{R_f}$

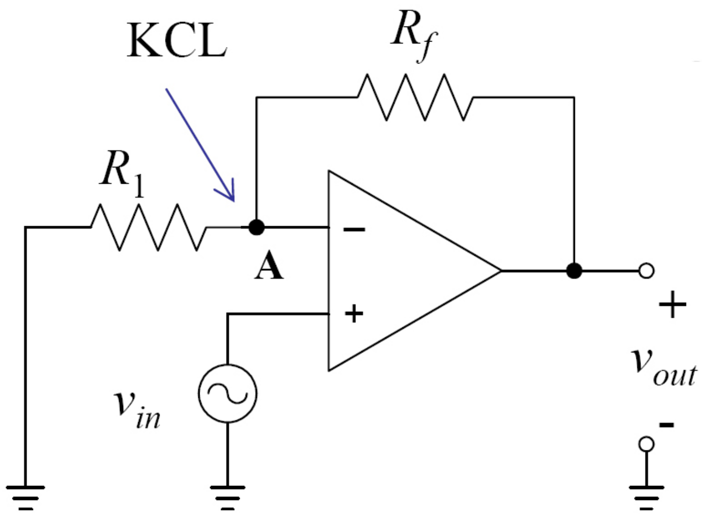
Also: $V_{out} = G*\left(V_+ - V_-\right)$ and $V_+ = 0$

$$\rightarrow \frac{V_{in} + \left(-V_{out}/G\right)}{R_1} = \frac{\left(-V_{out}/G - V_{out}\right)}{R_f}$$

$$\rightarrow V_{out}/V_{in} = -R_f/R_1$$

Non-Inverting Amplifier

- Positive input is held at V_{in}



$$V_{out} = G\left(V_+ - V_-\right)$$

$$V_+ = V_{in} \text{ and } V_- = \frac{R_1}{R+R_f} V_{out}$$

$$V_{out} = G\left(V_{in} - \frac{R_1}{R+R_f} V_{out}\right)$$

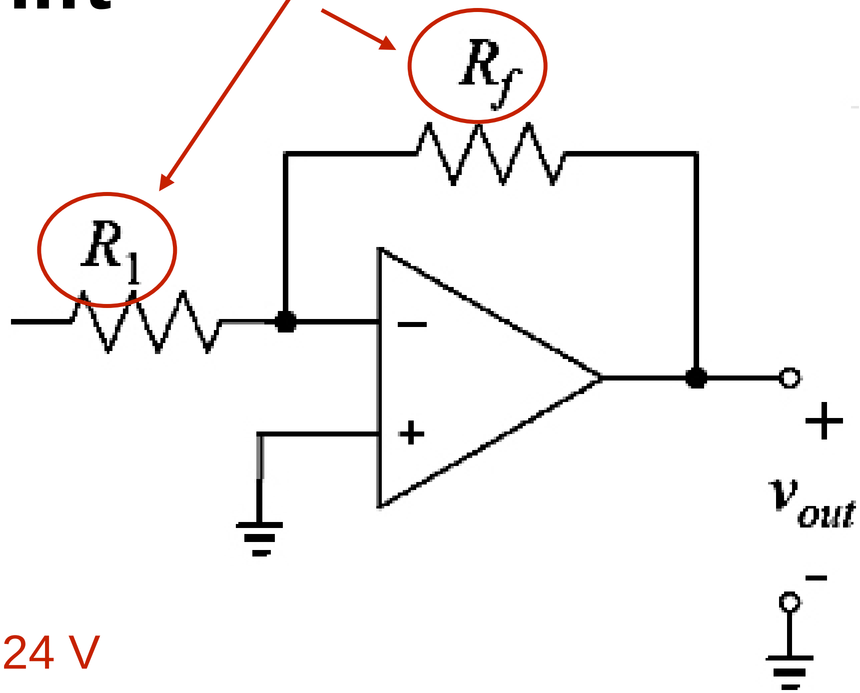
$$\rightarrow \quad \frac{V_{out}}{V_{in}} = \frac{G}{\left(1 + \frac{GR_1}{R_1+R_f}\right)} \approx 1 + \frac{R_f}{R_1}$$

Gain & Shift

Choose $R_f / R_1 = 1/8$

$$V_{out} / V_{in} = -R_f / R_1$$

V_{in} (±12 V)



$$V_{out} = \pm 1.5\ V$$

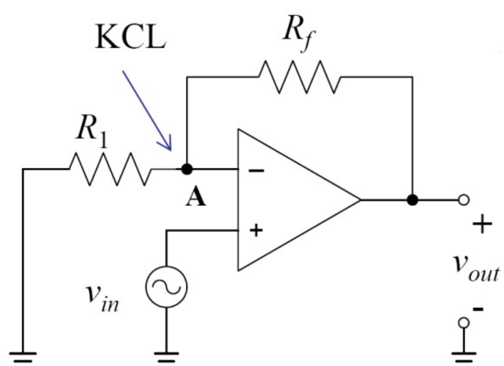
Now what?

Limited to 0-3 V

Full-range is 24 V

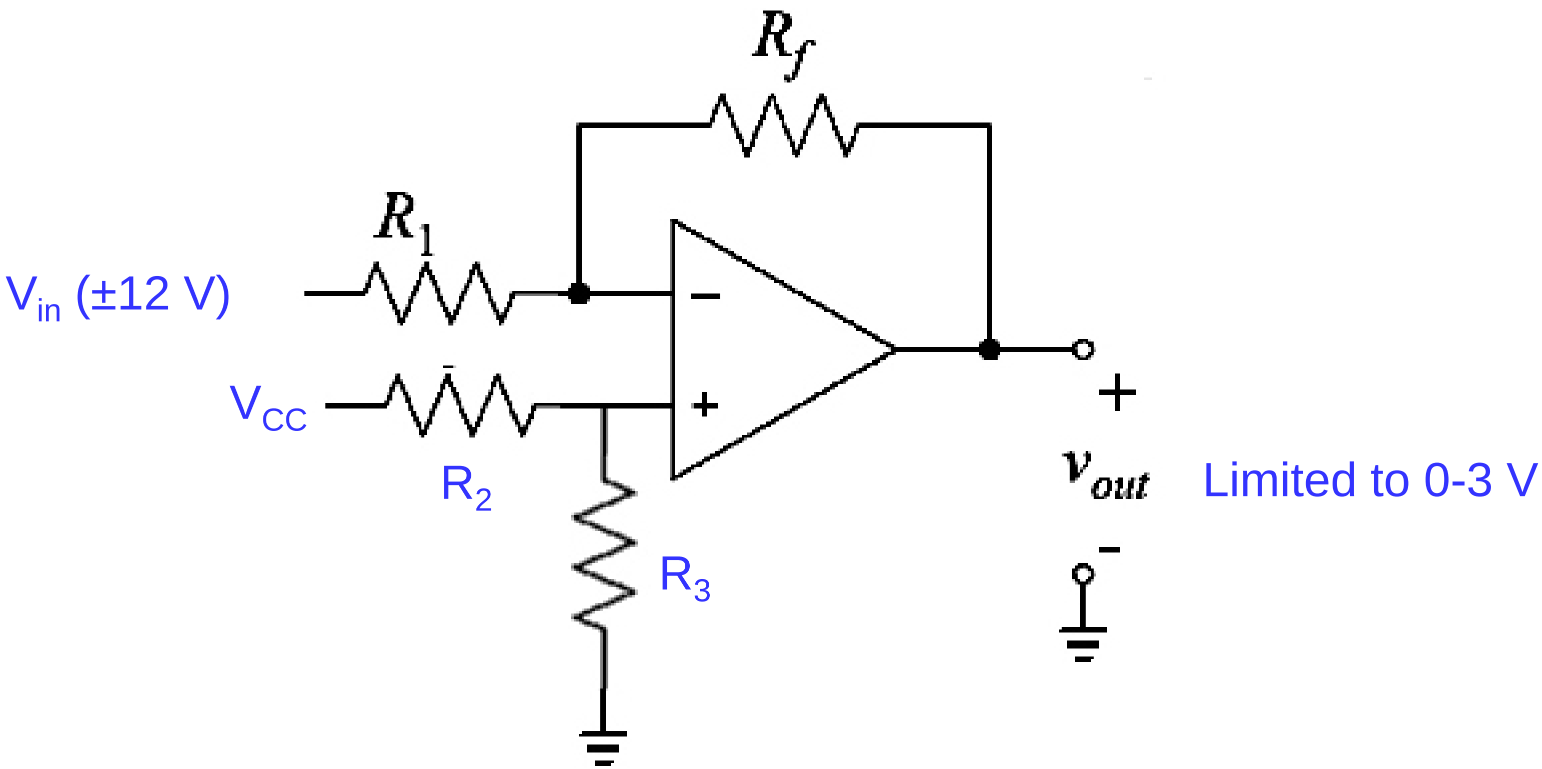
Full-range is 3 V

Recall:



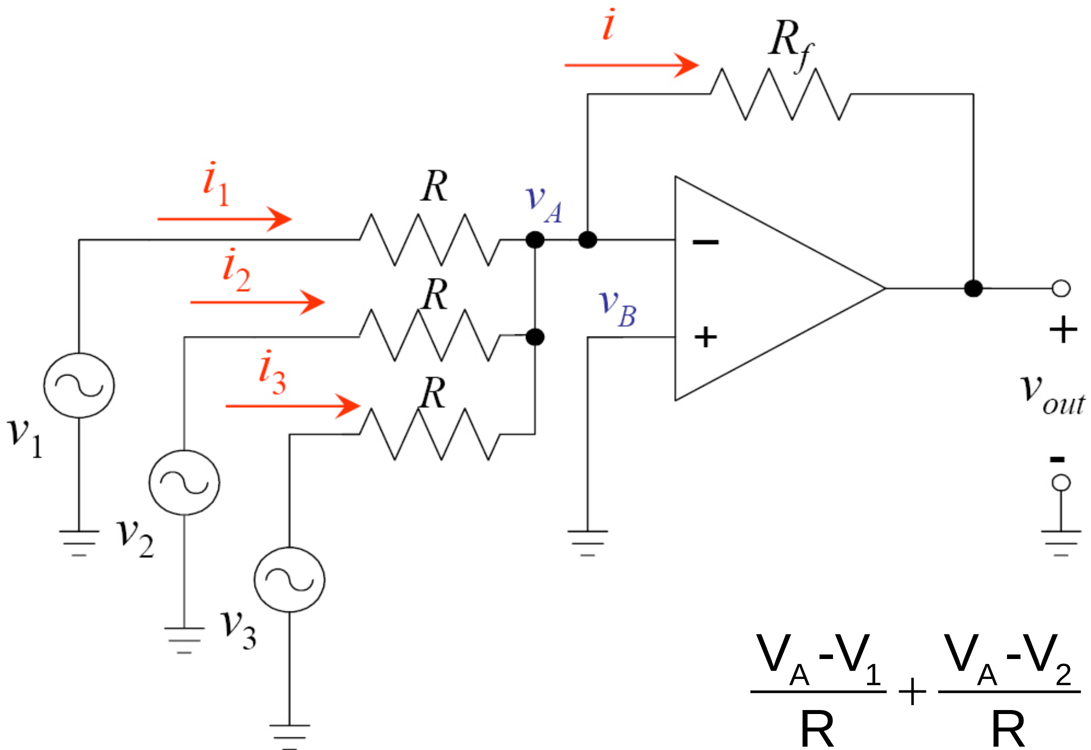
$$\frac{V_{out}}{V_{in}} = 1 + \frac{R_f}{R_1}$$

Gain & Shift



$$V_{out} = \underbrace{-\frac{R_f}{R_1}}_{\text{Gain on input voltage}} V_{in} + \underbrace{\left(\frac{R_3}{R_2+R_3} + \frac{R_3}{R_2+R_3}\frac{R_f}{R_1} \right) V_{CC}}_{\text{Shift on reference voltage}}$$

Summing Amplifier

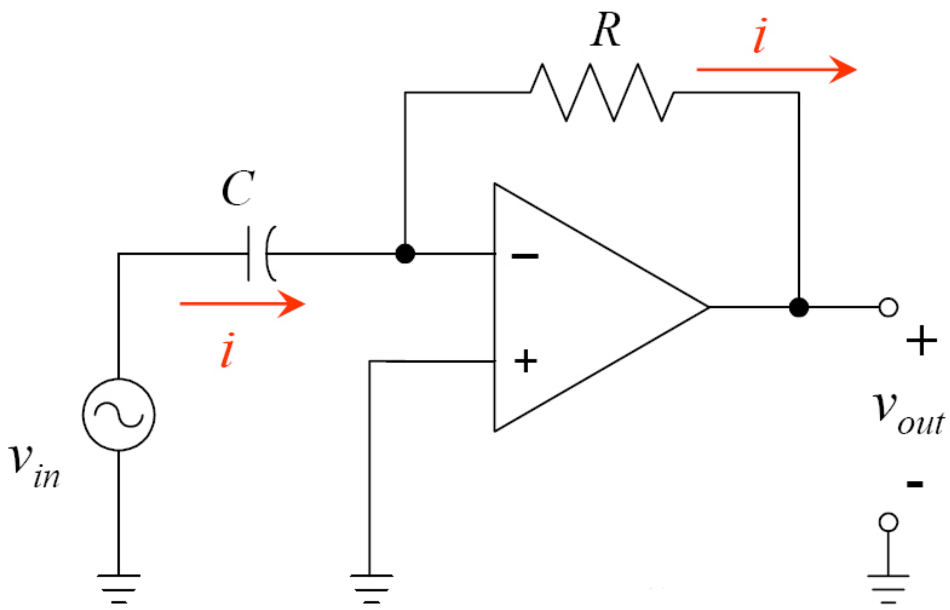


$$\frac{V_A - V_1}{R} + \frac{V_A - V_2}{R} + \frac{V_A - V_3}{R} + \frac{V_A - V_{out}}{R_f} = 0$$

$$\longrightarrow \quad V_{out} = -\frac{R_f}{R}\left(V_1 + V_2 + V_3\right)$$

Differentiator

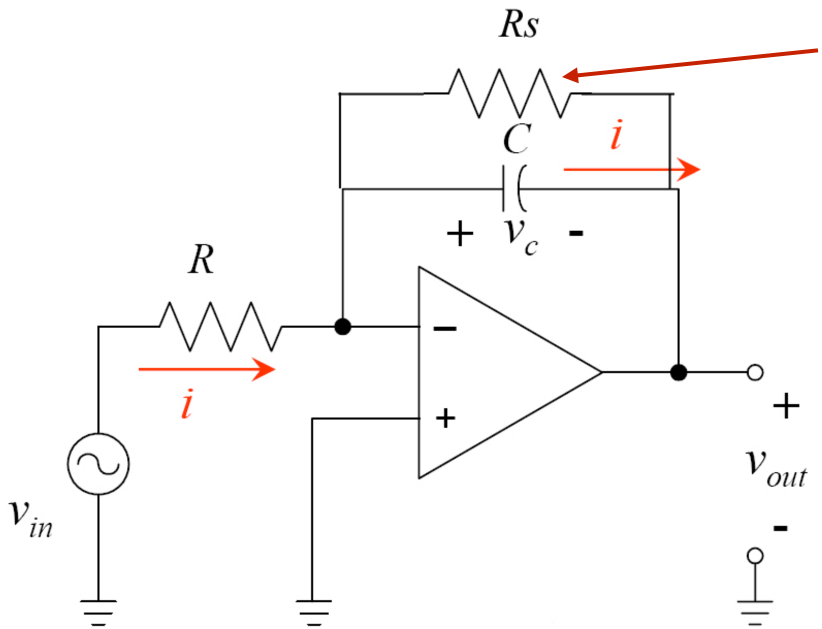
- High-Pass filter
- Tends to accentuate the effects of noise



$$V_{out} = -RC\frac{dV_{in}}{dt}$$

Integrator

- Low-pass filter
- Tends to smooth signals over time.



Why the shunt resistor?

Without R_s

$$V_{out} = -\frac{1}{RC}\int V_{in}(t)\,dt$$

