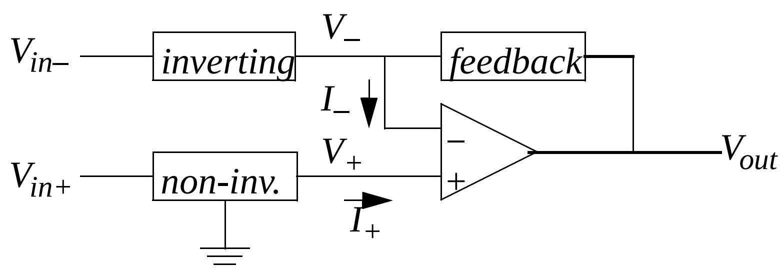
Amplifier Circuits

Two Rules for Op-amp Circuits

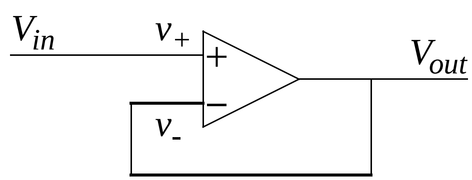
1. $I_+ = I_- = 0$. ***The input currents are 0.***

2. $V_+ - V_- = 0$. ***The input voltage difference is 0 when there is negative feedback.***



Buffer/Follower

- The simplest buffer is a non-inverting amplifier without resistors.



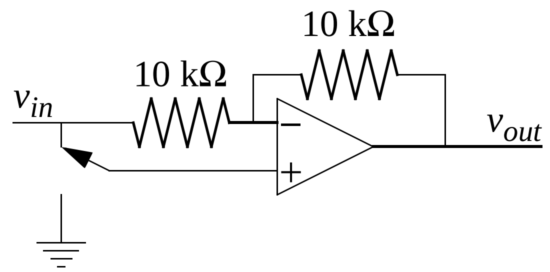
- Effectively, $R_1 = \infty$, and $R_2 = 0$. So, $A = 1 + \frac{R_2}{R_1} = 1$.

Switchable Inverter/Follower

- An inverter can be combined with a follower to provide either function.

Switch up for follower

Switch down for inverter

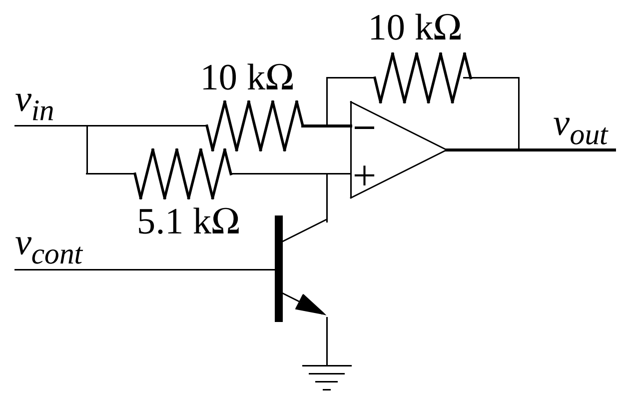


- The inverter has a gain of -1.
- The follower shorts the input resistor for a gain of 1 + 0/10k = 1.

- A transistor can be used for the switch:

v_{cont} is low for follower

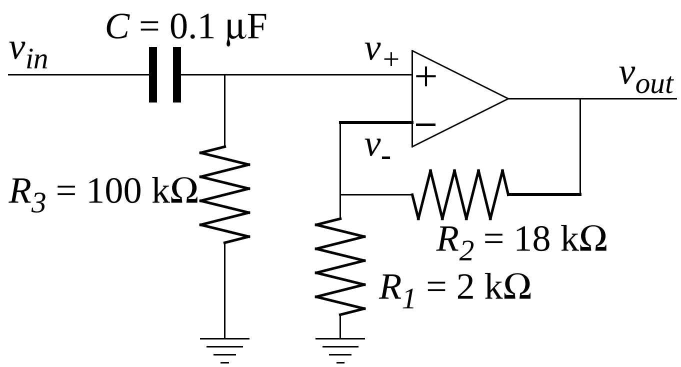
v_{cont} is high for inverter



- The follower setting has $v_+ = v_{in}$, since Z_{in+} is very large; v_-, and v_{out} must follow v_+.

Follower with Input Filter

- High-pass input filter can be added to a non-inverting amplifier to buffer only high frequencies.

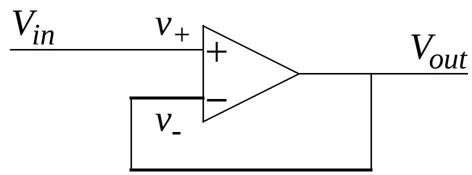


- From the op-amp rule no current flows into v_+.
- The input current needs a path to ground through R_3.
- The input impedance is set by the filter $Re(Z_{in}) = Re(1/j\omega C + R_3) = R_3$.
- As a complex divider the gain at v_+ is $A = \dfrac{1/j\omega C}{1/j\omega C + R_3} = \dfrac{1}{1 + j\omega R_3 C}$.
- The breakpoint frequency is $f_B = 1/2\pi R_3 C = 16$ Hz.
- The gain for high frequencies is the same as the remaining follower.

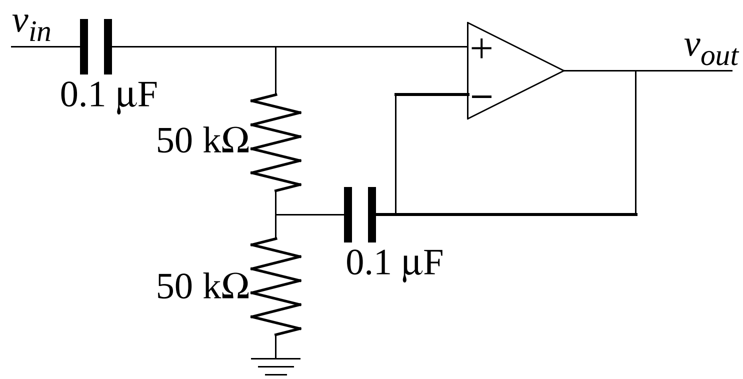
$$A = 1 + \frac{R_2}{R_1} = 1 + \frac{18}{2} = 10$$

Bootstrapped Follower

- The simple buffer/follower has a gain of 1 and large input impedance.



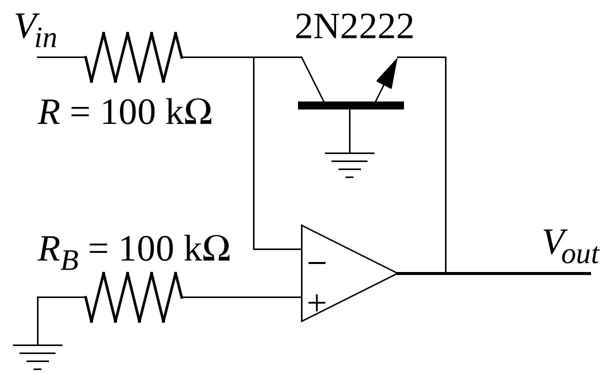
- A high-pass input filter reduces the impedance to be only the impedance of the filter.
- The op-amp follower can add a *bootstrap* capacitor.



- For low frequencies the gain is zero. At high frequencies, the capacitors look like wires. Since v_- = v_+ from op-amp rule 2, the voltage across the 1 MΩ resistor is nearly 0, so the current through the resistor is nearly 0. Since input impedance is v_{in}/i_{in} and i_{in} is nearly 0, the input impedance is very high.

Logarithmic Amplifier

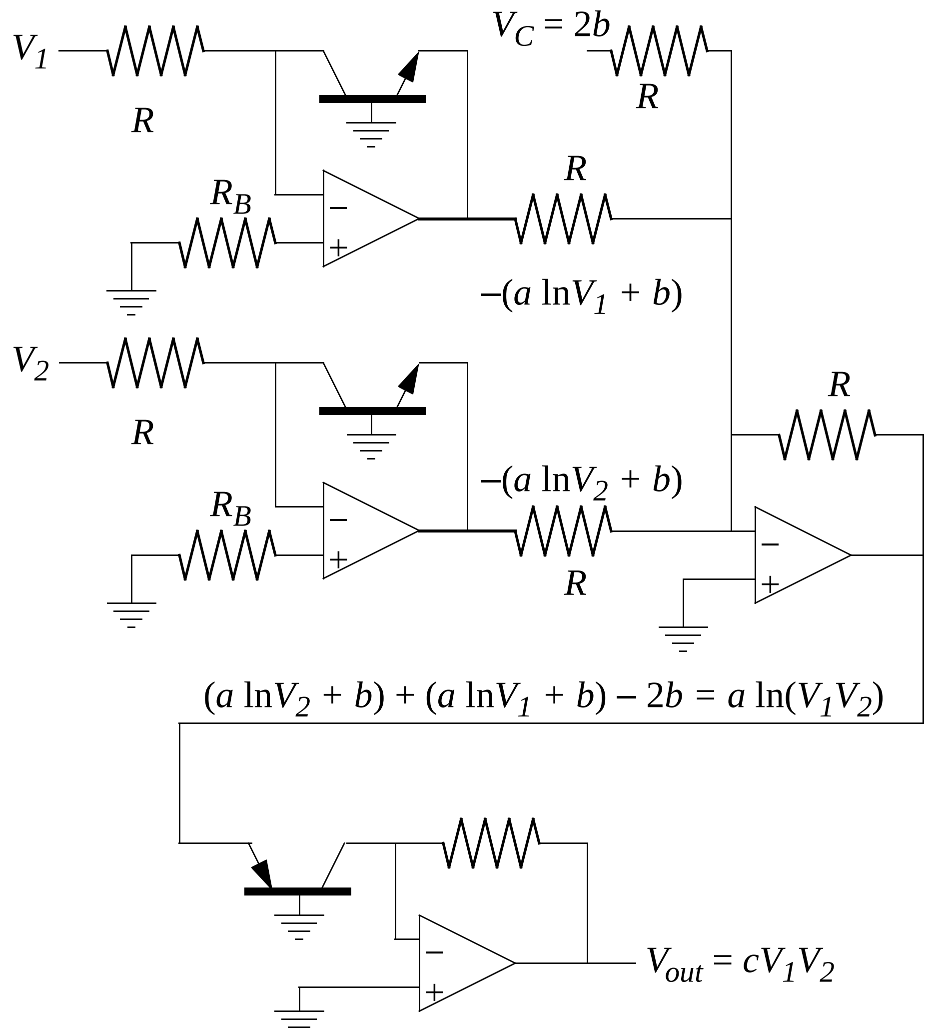
- A transistor in the feedback network of an inverting amplifier creates a logarithmic amplifier.



- R_B compensates for the bias current.
- The current I_{in} is given by $I_{in} = \frac{V_{in}}{R}$.
- This current must flow into the collector of the transistor $I_C = I_0 e^{V_{BE}/V_T} = \frac{V_{in}}{R}$.
- The base-emitter voltage is equal to the negative of V_{out}; $V_{out} = -V_T \log \frac{V_{in}}{I_0 R}$.
- The output depends on the logarithm of the input voltage.

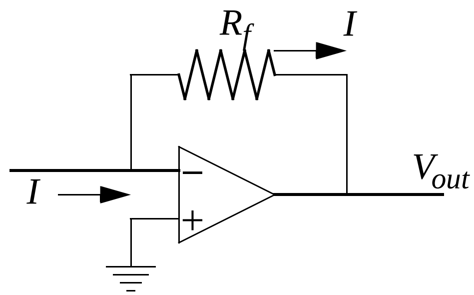
Analog Product

- The output of two logarithmic amplifiers can be summed through an inverter.
- An adjustable control voltage compensates for the offsets in the log amplifiers.
- An antilog amplifier reverses the input and feedback stages.
- The result is proportional to the product of the two input voltages.



Current-to-Voltage Converter

- Operational feedback relies on current.



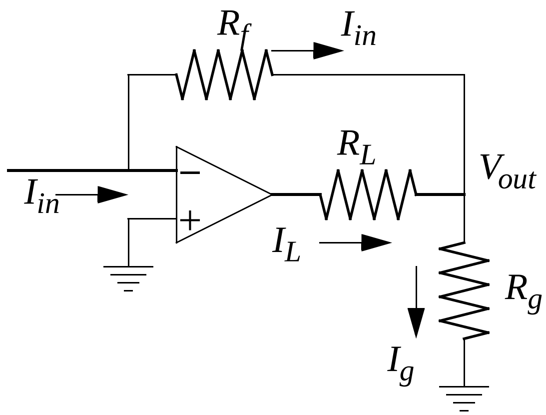
$$V_{out} = -R_f I$$

- The output is usually measured in V/μA.

- The op-amp provides low output impedance, hence higher power.

Current-to-Current Converter

- An extra resistor to defines the output current.



$$V_{out} = -R_f I_{in}$$

From Kirchoff's Laws:

$$I_g = I_L + I_{in}$$

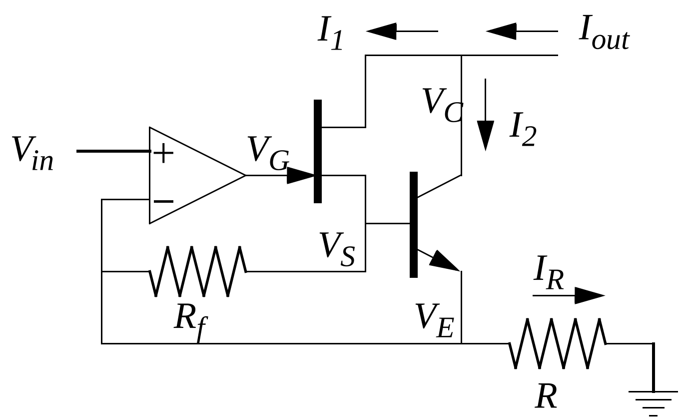
$$V_{out} = R_g I_g$$

Combine the equations:

$$I_L = -I_{in}\left(1 + \frac{R_f}{R_g}\right)$$

Voltage-to-Current Converter

- An op-amp follower can be used to drive a conventional transistor current source.



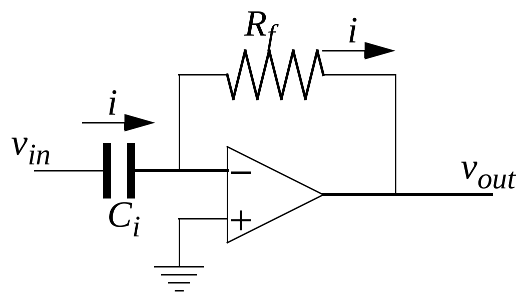
- The current I_{out} splits through the FET and BJT.
- No current passes through the gate of the FET or the v_- op-amp input.
- All current I_{out} is present through the resistor I_R.
- $V_E = V_{in}$ from the op-amp voltage rule.

$$I_{out} = -\frac{V_{in}}{R}$$

Differentiator

- An amplifier can utilize the relation between charge and current.

$$I = \frac{dQ}{dt} = C\frac{dV}{dt}$$



- The current is converted to a voltage.

$$v_{out} = -iR_f = -R_f C_i \frac{dv_{in}}{dt}$$

- For a sinusoidal input $v_{in} = V_0 \sin\omega t$,

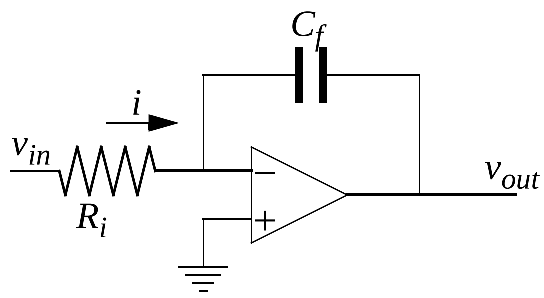
$$\frac{dv_{in}}{dt} = V_0 \omega \cos\omega t$$

$$v_{out} = -R_f C_i V_0 \omega \cos\omega t = -R_f C_i \omega v_{in}$$

- The amplitude increases with increasing frequency.

Integrator

- The input current can be converted into a charge



$$i = \frac{v_{in}}{R_i} = -C_f\frac{dv_{out}}{dt}$$

- Solving for v_{out}:

$$v_{out} = \frac{-1}{R_iC_f}\int v_{in}dt + K$$

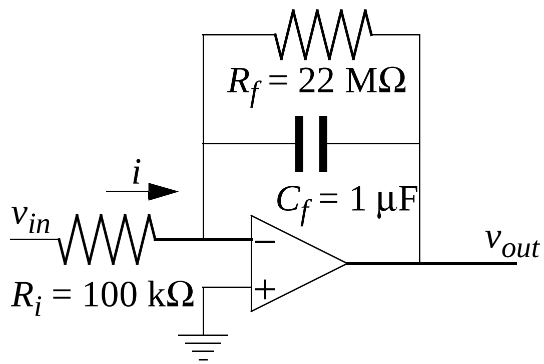
- With a sine wave input

$$v_{out} = \frac{-1}{\omega R_iC_f}v_{in} + K$$

- The amplitude decreases with frequency.

Stabilized Integrator

- The constant term from the integral is undesirable on the output.
- A switch can be used to discharge the capacitor.
- The circuit can provide a path for the capacitor to discharge.



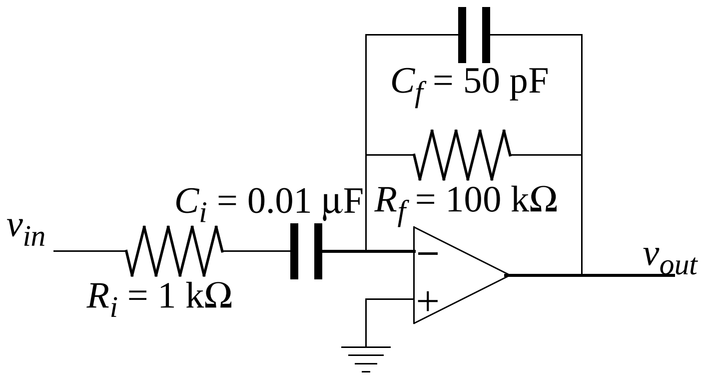
- The feedback resistor and capacitor have a parallel impedance

$$Z_f = \frac{R_f}{1 + j\omega R_f C_f}$$

- The breakpoint frequency is $f = 1/2\pi RC = 0.007$ Hz .
- Only DC can feedback for amplification.

Limited Differentiator

- Differentiator has large amplification at high frequencies.
- A high frequency cutoff above the signal range is often needed.
- Combine an integrator and differentiator.



- The differentiator has a low cutoff

$$v_{out} = -R_f C_i \frac{dv_{in}}{dt} \qquad f_B = \frac{1}{2\pi R_f C_i} = 160\,Hz$$

- The integrator begins working at

$$v_{out} = \frac{-1}{R_i C_f}\int v_{in}\,dt \qquad f_B = \frac{1}{2\pi R_i C_f} = 3\,MHz$$

- The differentiator will perform well between those two frequencies.