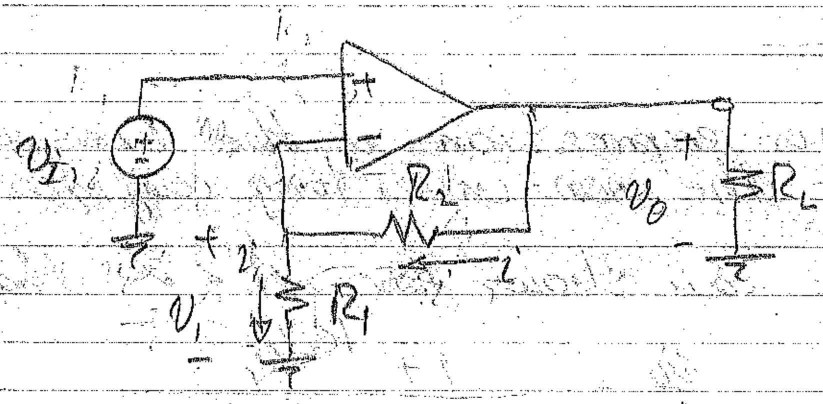
NON-INVERTING CONFIGURATION

we can also apply a signal to the non-inverting input. we still want negative feedback, however. Let's look at the following circuit...



ANALYSIS

Virtual Short $\Rightarrow v_1 = v_I$

Hence $i = \frac{v_1}{R_1} = \frac{v_I}{R_1}$

KVL: $v_0 - v_I - i R_2 = 0$

$$v_0 = v_I + \frac{v_I}{R_1} R_2$$

$$\boxed{\frac{v_0}{v_I} = 1 + \frac{R_2}{R_1}}$$

NOTE: gain is POSITIVE, hence NON-INVERTING

Alternative Derivation:

By voltage divider rule,

$$v_{in} = v_1 = v_0 \cdot \frac{R_1}{R_1 + R_2}$$

$$A_V = \frac{v_0}{v_{in}} = \frac{R_1 + R_2}{R_1} = 1 + \frac{R_2}{R_1}$$

This expression is the CLOSED LOOP gain for the non-inverting configuration.

We can show for $A < \infty$ that

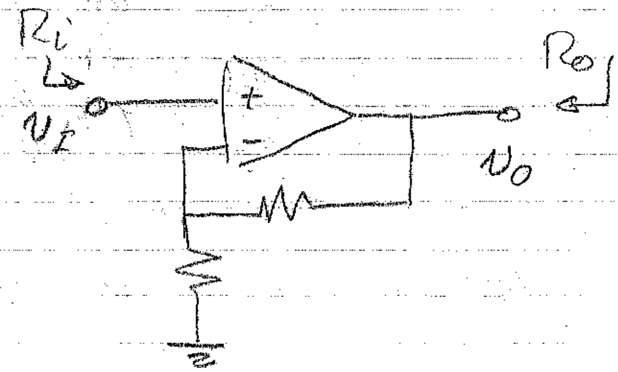
$$\frac{v_O}{v_I} = \frac{1 + R_2/R_1}{1 + \frac{1 + R_2/R_1}{A}}$$

for the non-inverting configuration.

NON-INVERTING CONFIGURATION:

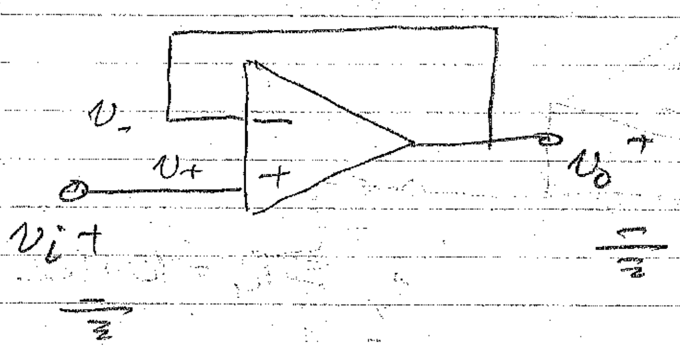
$R_i = \infty$

$R_o = 0$



BUFFER AMPLIFIER

What about this?

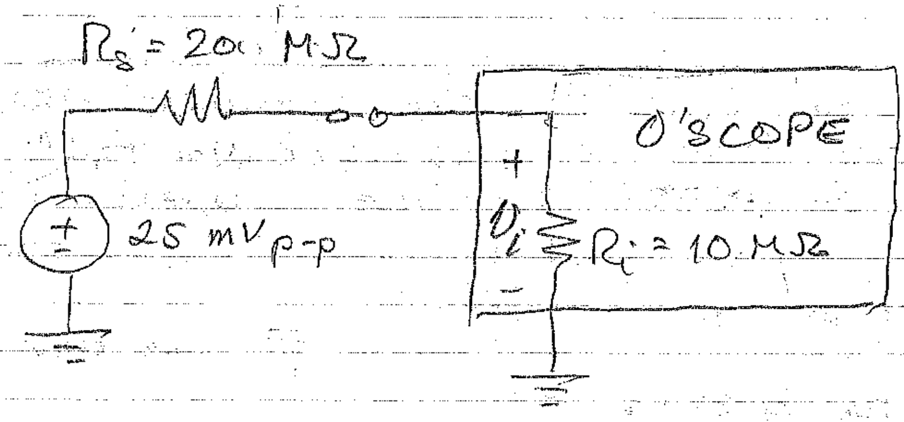


$v_+ = v_- = v_i$

$\underline{v_o = v_i}$!

Is this useful? Yes! The important property of this configuration is that $R_i = \infty$ (and $R_o = 0$).

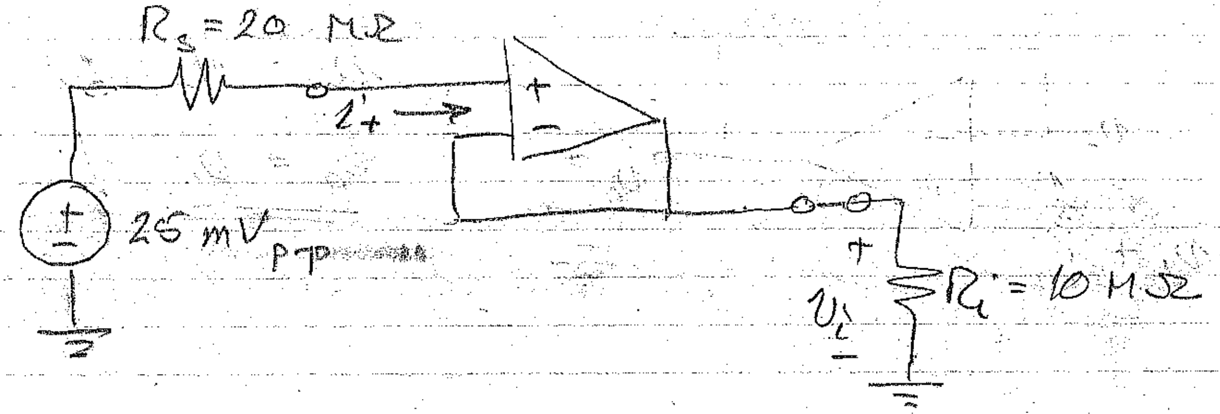
Suppose we had a source with the following Thevenin equivalent:



We have connected a source having large R_s to an oscilloscope with a $10\ M\Omega$ input. The signal to the scope is

$$v_i = 0.025 \frac{10M}{10M + 20M} = 0.0083\ V_{p-p}$$

In this case the scope isn't go to show us much. But if we insert a buffer amp:



Now $v_i = 25\ mV_{p\text{-}p}$. If that still isn't enough, we can amplify before going to the scope, and our amplifier will not need a large R_i.

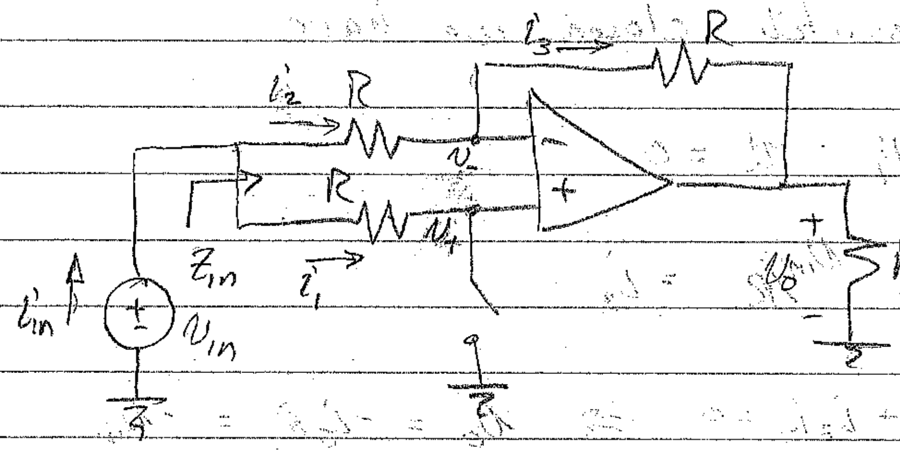
Because $i_+ \simeq 0$, the power drawn from the load is negligible. But the power delivered to the scope is

$P_{del\ to\ R_i} = v_i^2 / R_i$

$P_{del\ by\ source} \sim 0$

$\Rightarrow$ power gain $\sim \infty$!

HAMBLEY 2ed. EXERCISE 2.4



a) To start, note that we do have negative feedback, so we can say $v_- = v_+$.

With switch open and the op amp input resistance very large (∞), we have $i_1' = 0$. Therefore

$$v_+ = v_- = v_{in}$$

This is a curious result, since it means that $i_2' = 0$ and $i_3' = 0$! So

$$v_o = v_{in} \Rightarrow \boxed{A_v = 1}$$

The impedance Z_{in} can be found by considering v_{in} to be a test source. Then

$$\underline{Z_{in}} = \frac{v_{in}}{i_{in}} = \frac{v_{in}}{0} = \underline{\infty} \quad !$$

b) With the switch closed, we have

$$v_+ = v_- = 0$$

$$\therefore \quad i_1' = i_2' = v_{in}/R = i_3'$$

KVL: $\quad v_o + i_3' R = 0 \Rightarrow v_o = -i_3' R = -v_{in}$

So $\boxed{A_v = -1.}$

We have $i_{in}' = i_1' + i_2'$

$$= \frac{v_{in}}{R} + \frac{v_{in}}{R} = v_{in}\,\frac{2}{R}$$

$$\therefore \quad \frac{v_{in}}{i_{in}} = \boxed{Z_{in} = \frac{R}{2}}$$

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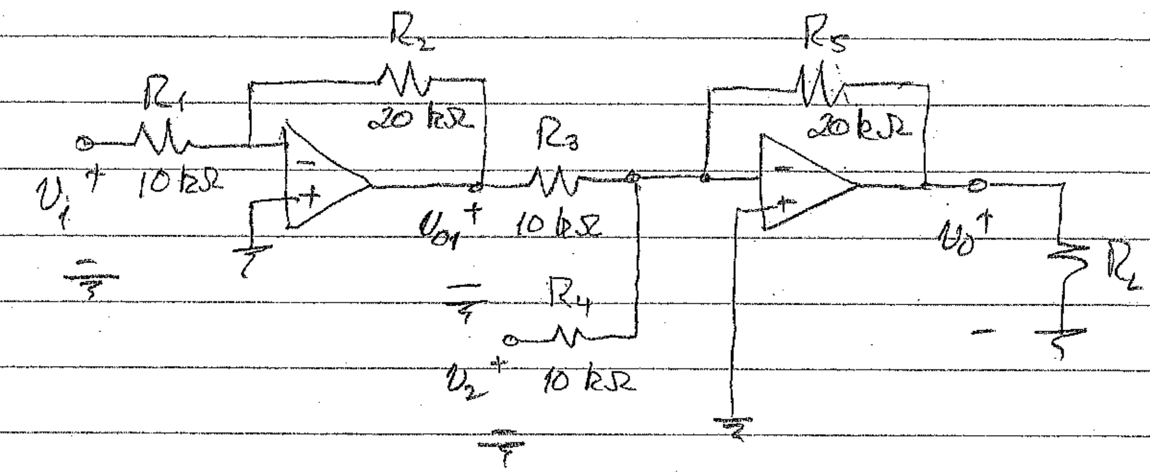


As is often the case in op-amp circuits, this problem is much easier than it looks. Note that the second "stage" is a summing configuration, and the first is a simple inverter. So...

$$v_0 = -\frac{R_5}{R_4} v_2 - \frac{R_5}{R_3} v_{01}$$

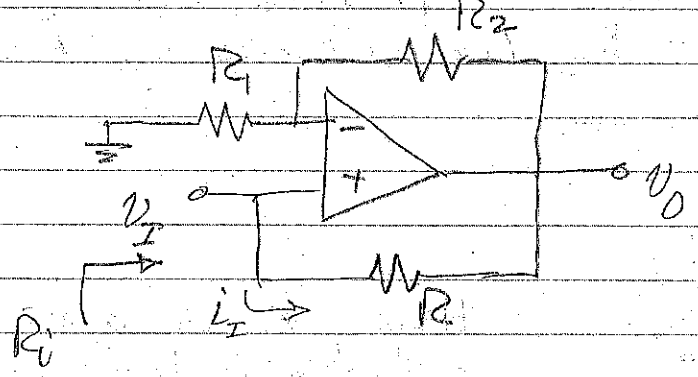
$$v_{01} = -\frac{R_2}{R_1} v_1$$

$$\therefore \quad v_0 = \frac{-R_5}{R_4} v_2 + \frac{R_5}{R_3}\frac{R_2}{R_1} v_1$$

Plugging in numbers...

$$v_0 = -2v_2 + 4v_1$$

NEGATIVE IMPEDANCE CONVERTER



The analysis of v_O/v_I is the same as for the simple non-inverting configuration - the resistor R has no effect on that. So,

$$v_O/v_I = 1 + R_2/R_1$$

But the input resistance R_i is interesting...

$$R_i = v_I/i_I$$

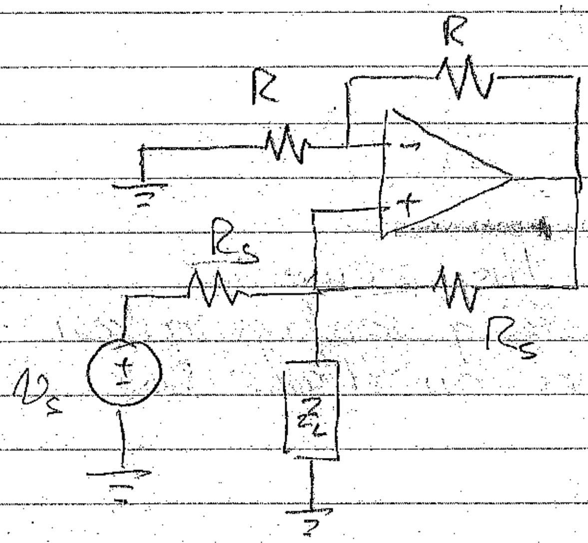
$$i_I = \frac{v_I - v_O}{R} = \frac{v_I - (1 + R_2/R_1)v_I}{R}$$

$$= -\frac{1}{R}\frac{R_2}{R_1}v_I$$

So $R_i = -\frac{RR_1}{R_2}$ which is negative!

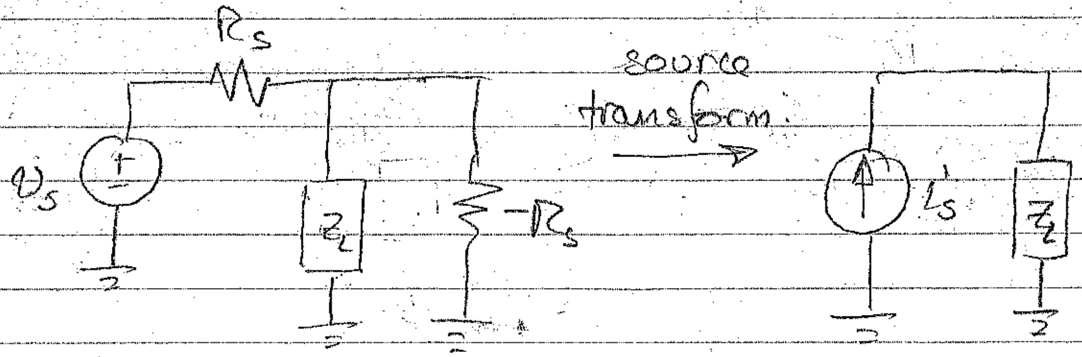
What can we do with this? $\rightarrow$

If we take the entire op amp circuit as a resistance $-R_s$ (by setting $R_2 = R_1$), we have



Here, Z_L is an arbitrary load, and we have attached a source with series resistance R_s.

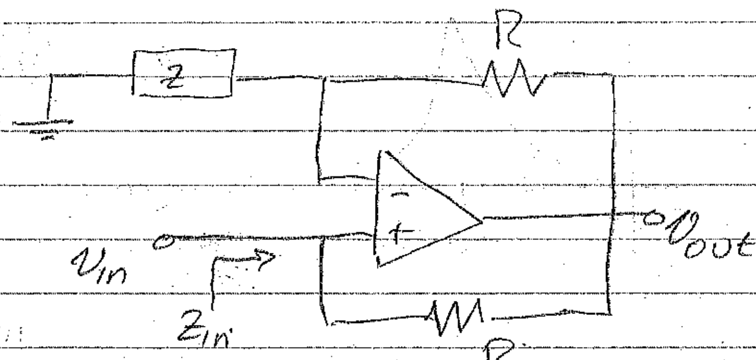
We can re-draw as



In the last step we have combined R_s and $-R_s$ in parallel ($R_s // -R_s \to \infty$).

So we have constructed an IDEAL CURRENT SOURCE, i.e., one with $R_s = \infty$.

Something else:



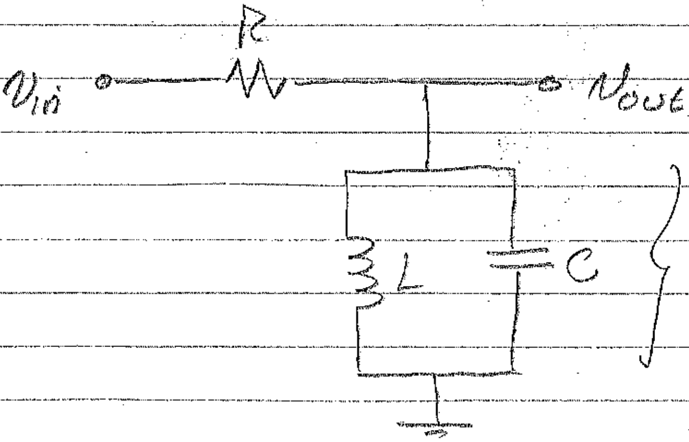
In this circumstance, $Z_{in} = -Z$. So if

$$Z = 1/j\omega C \quad \text{(a capacitor)}$$

Then $Z_{in} = j/\omega C$

which looks like an inductor. An inductor cannot be produced on an integrated circuit, but this will simulate one.

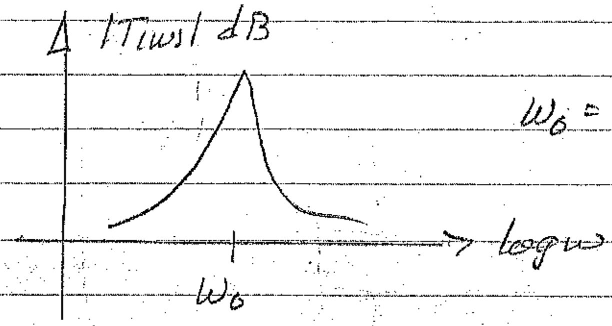
With both capacitors and inductors available, we can make a special class of filters.



$$Z = j\omega L \,//\, 1/j\omega C = \frac{1/C}{j(\omega L - 1/\omega C)}$$

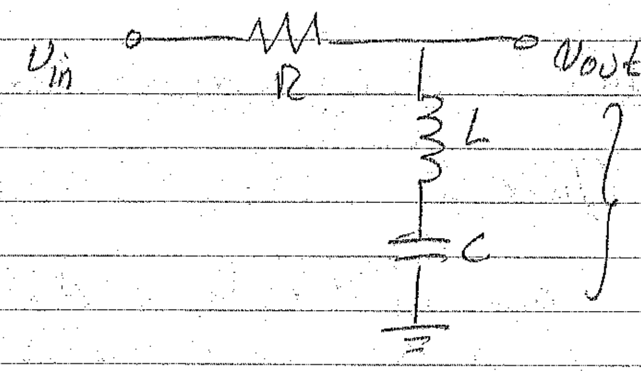
At $\omega = 1/\sqrt{LC}$, $Z \to \infty$ and $v_{out} = v_{in}$.

BODE:



$\omega_0 = 1/\sqrt{LC}$

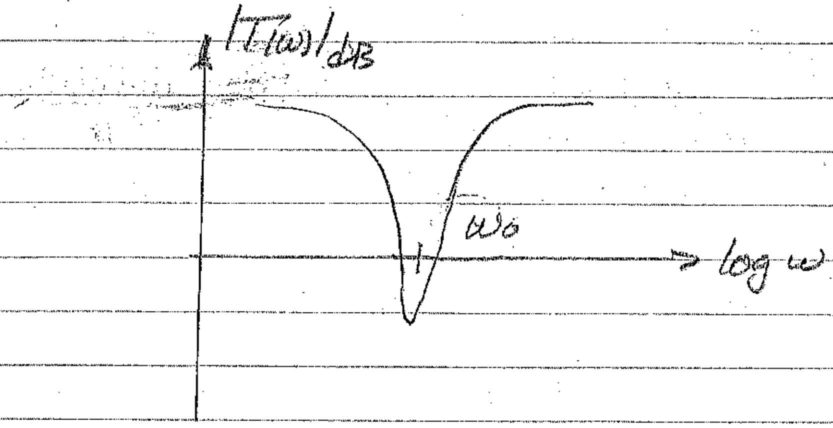
Alternatively, we can do this:



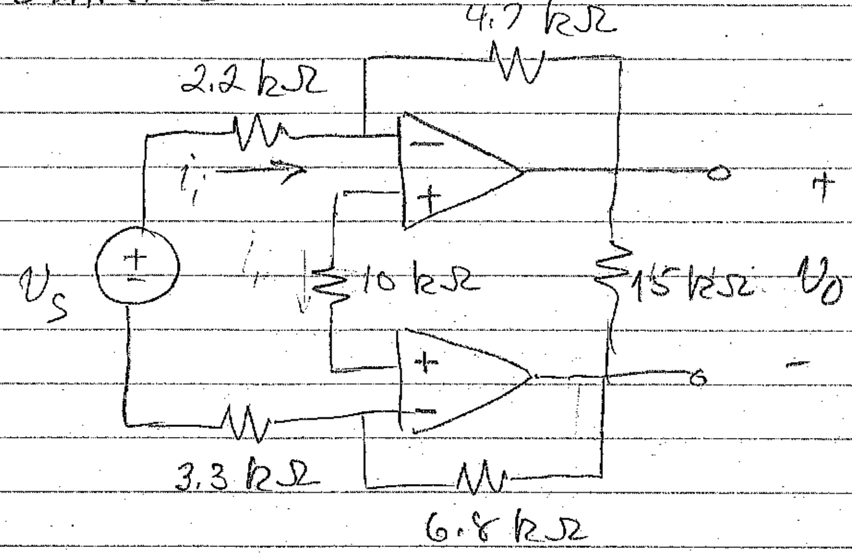
$Z = 1/j\omega C + j\omega L$

$\to 0$ at ω_0

BODE:



EXAMPLE



FIND

- v_O/v_S
- R_i

By KVL,

$$-v_S + 2200\,i + 3300\,i = 0$$

because there is no current in the 10 kΩ resistor.

So $$i = \frac{v_S}{5500}$$

KVL around outside gives

$$-v_S + i\cdot(2200 + 4700) + v_o + i\,(6800 + 3300) = 0$$

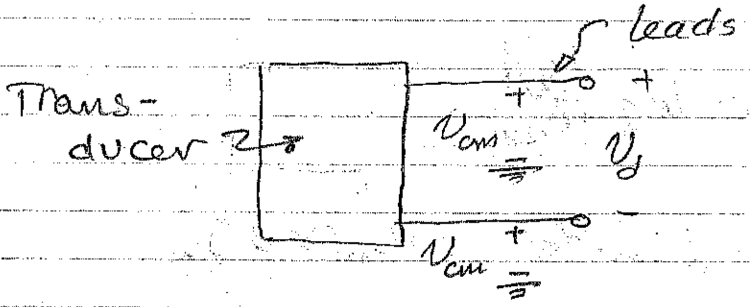
$$v_s\left(-1 + \frac{6900}{5500} + \frac{10100}{5500}\right) = -v_o$$

$$\frac{v_o}{v_s} = -2.09$$

Also $R_i = \dfrac{v_i}{i} = 5500\ \Omega.$

DIFFERENCE AMPLIFIER

We sometimes have the following situation.



Transducer: a measuring device, e.g. for temperature or sound intensity...

v_d is the difference in potential between the two leads; we want to amplify this.

v_{cm} is a voltage (the "common mode" voltage) between each lead and ground, which may be large compared to v_d and which we do not want to amplify.

We need a DIFFERENCE AMPLIFIER here.

In general,

$$v_O = A_d v_{Id} + A_{cm} v_{Icm}$$

where v_{Id} and v_{Icm} are the differential and common mode input signals and A_d and A_{cm} are the differential and common mode gains.

We would like the difference amplifier to reject the common mode signal; i.e.

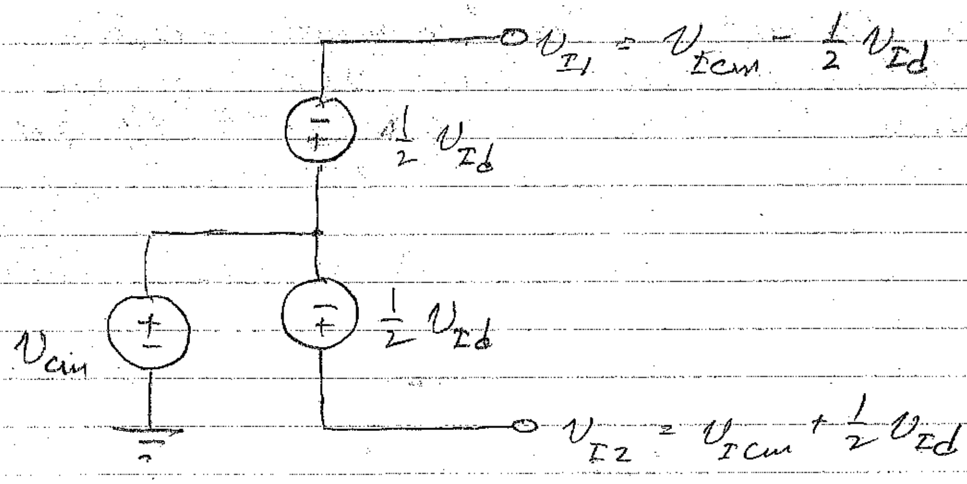
We would like $A_{cm} \cong 0$. A measure of an amplifier's ability to do this is the "common mode rejection ratio" CMRR:

$$CMRR \equiv 20 \log \frac{|A_d|}{|A_{cm}|}$$

Ideally this is infinite ($A_{cm} = 0$).

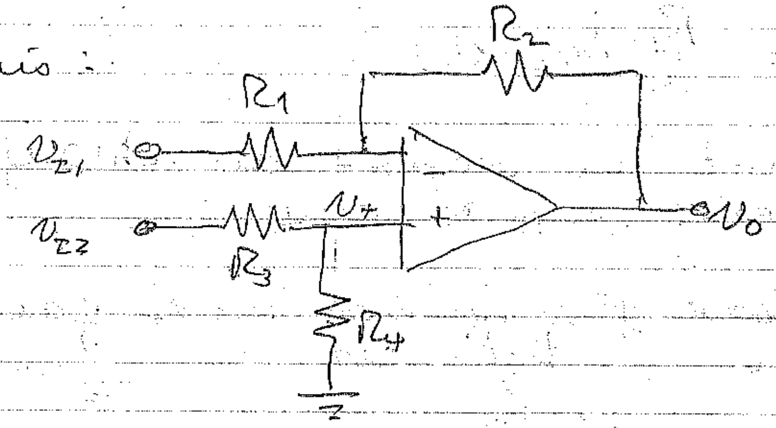
ANALYSIS of a difference amplifier:

We can represent the total signal (difference and common mode) as



Let's look at a configuration that will amplify v_{Id} and reject v_{Icm} ...

Try this:



So $v_{Id} = v_{I2} - v_{I1}$. What is the output?

Superposition:

$$v_{I2} \to 0 \Rightarrow v_{o1} = -v_{I1}\frac{R_2}{R_1}$$

$$v_{I1} \to 0 \Rightarrow v_{o2} = \left(1+\frac{R_2}{R_1}\right)v_+$$

$$= \left(1+\frac{R_2}{R_1}\right)\frac{R_4}{R_3+R_4}v_{I2}$$

So $v_o = v_{o1} + v_{o2} = v_{I1}\left(-\frac{R_2}{R_1}\right) + v_{I2}\left(1+\frac{R_2}{R_1}\right)\frac{R_4}{R_3+R_4}v_{I2}$

This is complicated, and for arbitrary values of R_1, R_2, R_3, R_4, it is not what we want.

However, if we choose $\frac{R_4}{R_3} = \frac{R_2}{R_1}$, we get

$$\left(1+\frac{R_2}{R_1}\right)\left(\frac{R_4}{R_3+R_4}\right) = \left(1+\frac{R_2}{R_1}\right)\left(\frac{1}{R_3/R_4+1}\right)$$

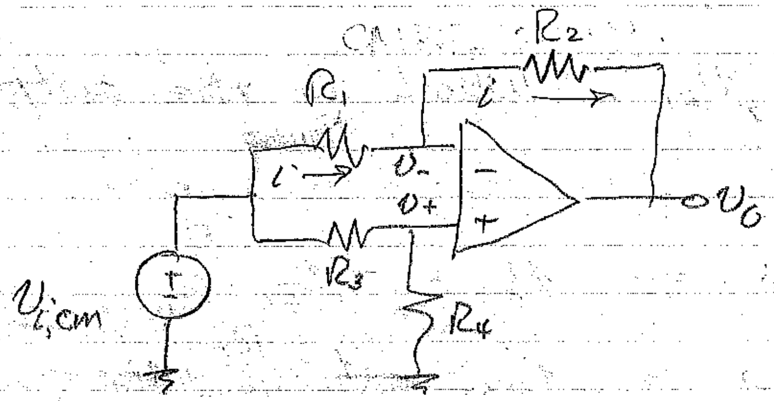
$$= \left(1+\frac{R_2}{R_1}\right)\left(\frac{1}{R_1/R_2+1}\right)$$

$$= \left(\frac{R_1+R_2}{R_1}\right)\left(\frac{R_2}{R_1+R_2}\right) = \frac{R_2}{R_1}$$

So $\quad v_0 = \frac{R_2}{R_1}(v_2 - v_1)$

This is what we want: an amplification of the difference signal only.

But what about the common mode gain of this circuit? Let's see:



$$v_- = v_+ = v_{i,cm}\,\frac{R_4}{R_3+R_4}$$

$$i = \frac{v_{i,cm}\left(1 - \frac{R_4}{R_3+R_4}\right)}{R_1}$$

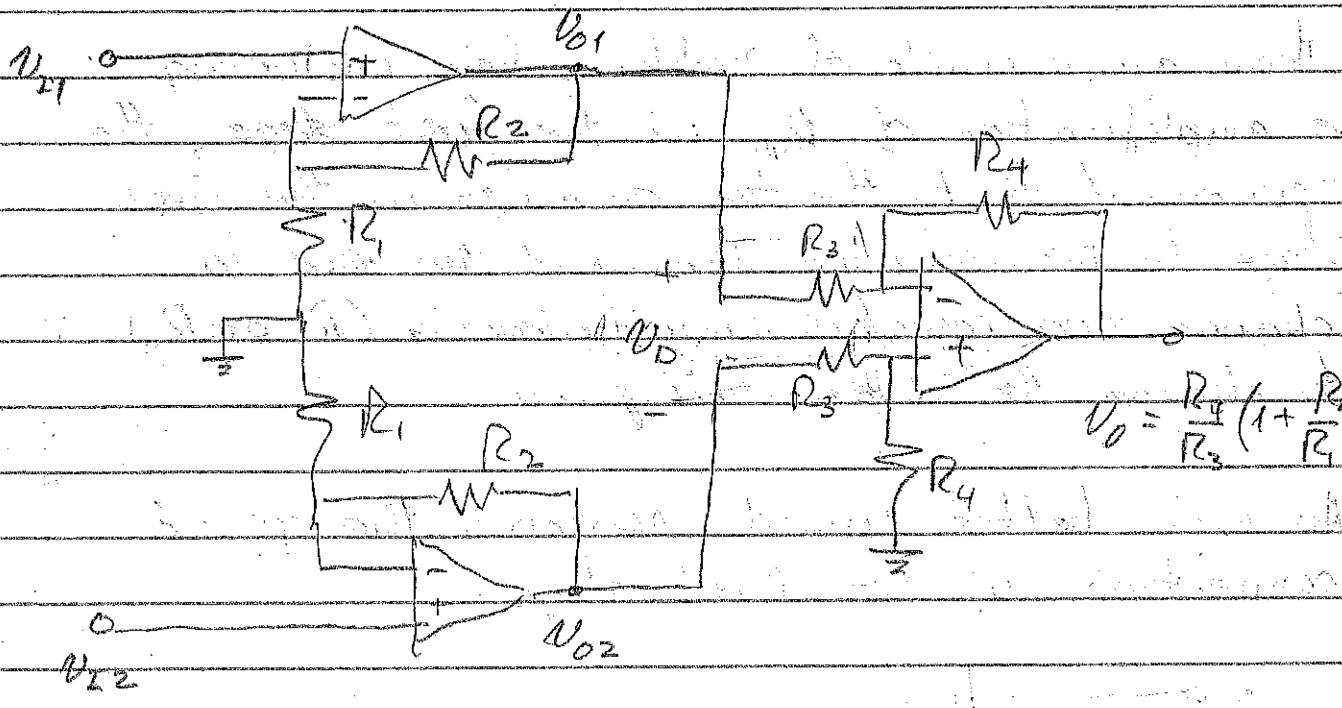
$$v_0 = v_{i,cm}\,\frac{R_4}{R_3+R_4} - i_2 R_2$$

and $\quad A_{cm} = \frac{v_0}{v_{i,cm}} = \frac{R_4}{R_4+R_3}\left(1 - \frac{R_2}{R_1}\frac{R_3}{R_4}\right)$

If we choose $\frac{R_4}{R_3} = \frac{R_2}{R_1}$ as before, then $A_{cm} = 0$, as desired.

INSTRUMENTATION AMPLIFIER

A potential problem with the difference amplifier we just considered is the finite input resistance. We can improve this with the instrumentation amplifier:



$$v_O = \frac{R_4}{R_3}\left(1+\frac{R_2}{R_1}\right)v_{Id}$$

The non-inverting op amps at the input provide high input resistance and gains of

$$v_{O1} = \left(1+\frac{R_2}{R_1}\right)v_{I1} \qquad v_{O2} = \left(1+\frac{R_2}{R_1}\right)v_{I2}$$

Then $v_D = v_{Id} = \left(1+\frac{R_2}{R_1}\right)(v_{I2}-v_{I1})$ is amplified by the configuration we looked at previously.

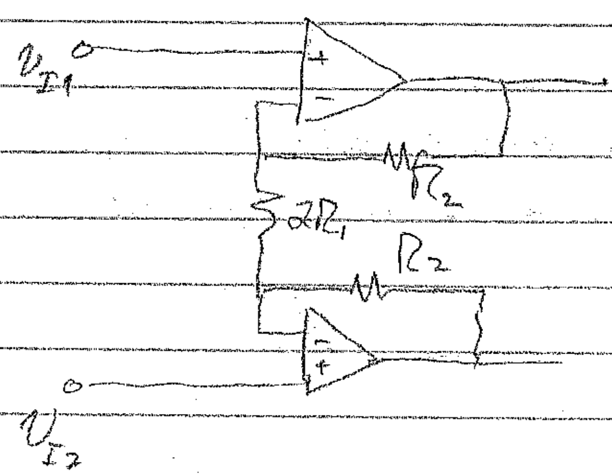
This second stage gives

$$v_O = \frac{R_4}{R_3}\left(1+\frac{R_2}{R_1}\right) v_{Id}$$

So we have high R_{in}, and high CMRR.

There are a couple of problems here, including the amplification of v_{cm} in the first stage, the requirement that the two op amps in the first stage be precisely matched, and the need to change two resistors simultaneously (R_2 or R_1) to change the differential gain.

An even better circuit removes the ground connection in the first stage:



The resulting v_O is the same.