Opamps

From a tinkerer’s point of view

Traditional Lesson

- Golden Rules
  -
  -
- Assumes you know Ohms law
- Emphasis on math

Traditional Lesson

- Golden Rules
  - the minus input tries to be what the plus input is
  - neither input draws current
- Assumes you know Ohms law
- Emphasis on math

Traditional Lesson

- Golden Rules
  - th[illegible]nput is
  - n[illegible]
- Assumes you know Ohms law
- Emphasis on math

The traditional Golden Rules help you
derive opamp mathematics

In This Lesson

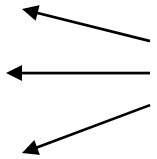
- Different Golden Rules
  -
  -
  -

In This Lesson

- Different Golden Rules
  -
  -
  -
- Lots of examples
- Assumes you know which end of a soldering iron to hold on to.

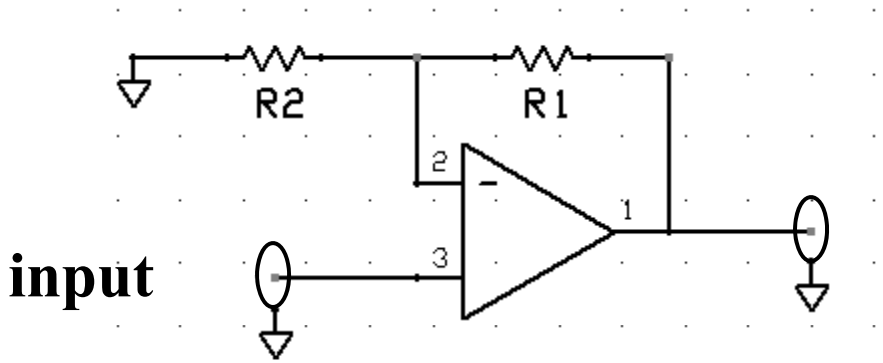
In This Lesson

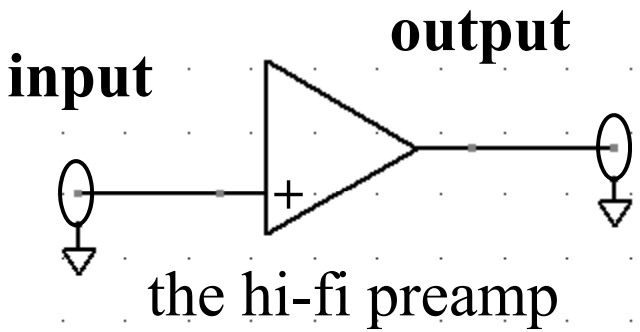
- Different Golden Rules
  -
  -
  -



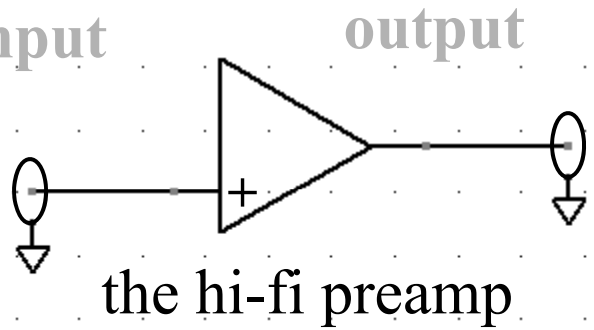
useful for circuit design, not math

- Lots of examples
- Assumes you know which end of a soldering iron to hold on to.


R2
R1
2
3
1
input
output
the opamp


output
input
+
the hi-fi preamp

- high impedance,
- microvolts,
- Audio frequency



the hi-fi preamp

- low impedance,
- about a volt
- Audio frequency

- high impedance,
- micro volts,
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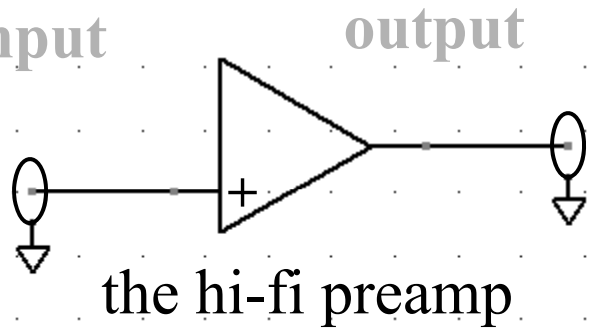
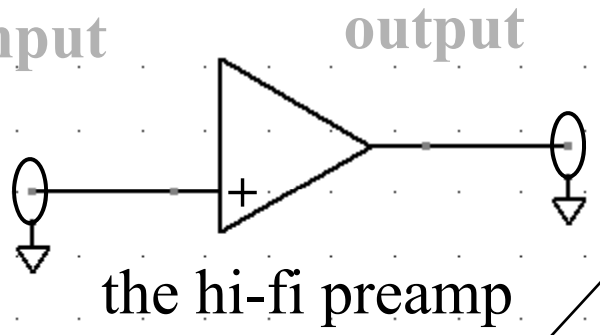


- low impedance,
- about a volt
- Audio frequency

This means it will not drag down a weak source.

- high impedance,
- microvolts,
- Audio frequency

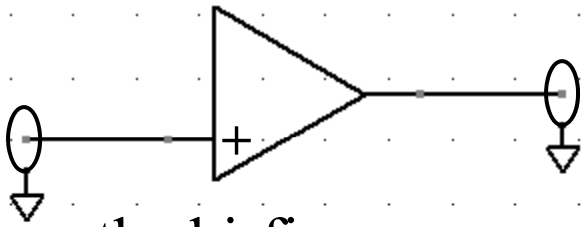


- low impedance,
- about a volt
- Audio frequency

This means sufficient power to handle any load.

Opamp Compared to Preamp

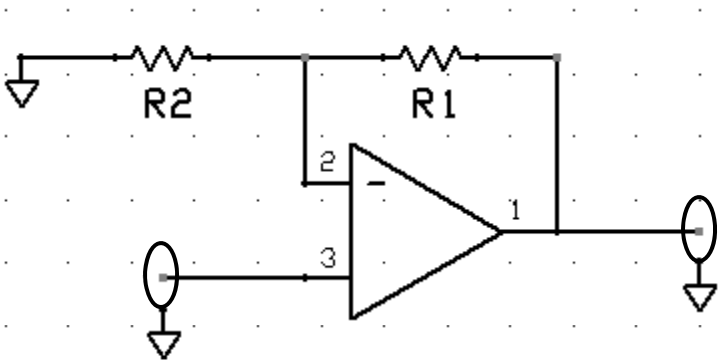
- high impedance,
- microvolts,
- Audio frequency



the hi-fi preamp

- low impedance,
- about a volt
- Audio frequency

- same as above
-
-



the opamp

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Opamp Compared to Preamp

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- microvolts,
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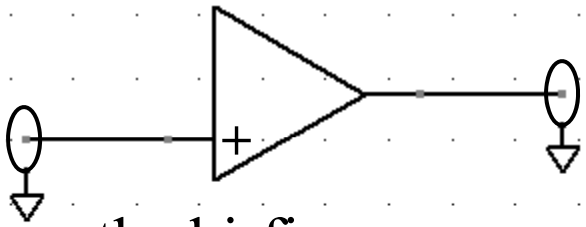
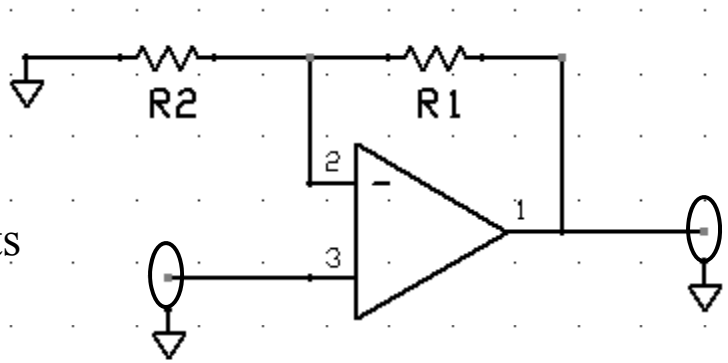


the hi-fi preamp

- low impedance,
- about a volt
- Audio frequency

- same as above
- microvolts to volts
-



the opamp

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Opamp Compared to Preamp

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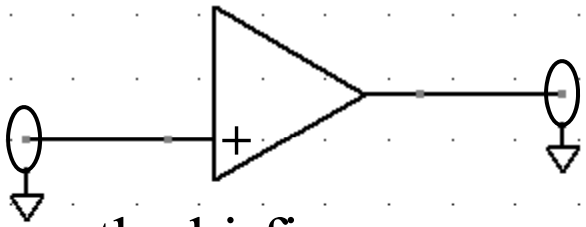
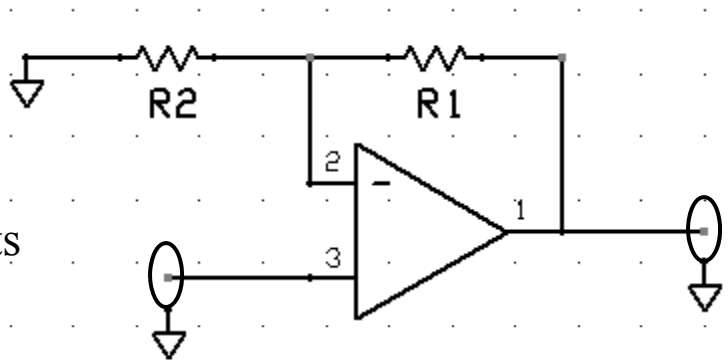


the hi-fi preamp

- low impedance,
- about a volt
- Audio frequency

- same as above
- microvolts to volts
- Audio frequency down to DC



the opamp

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Opamp Compared to Preamp

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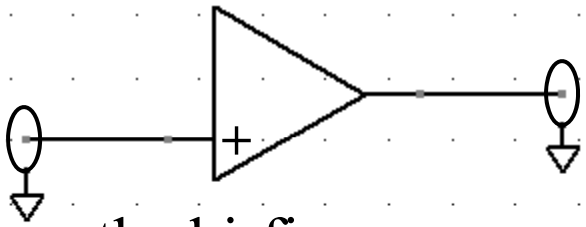

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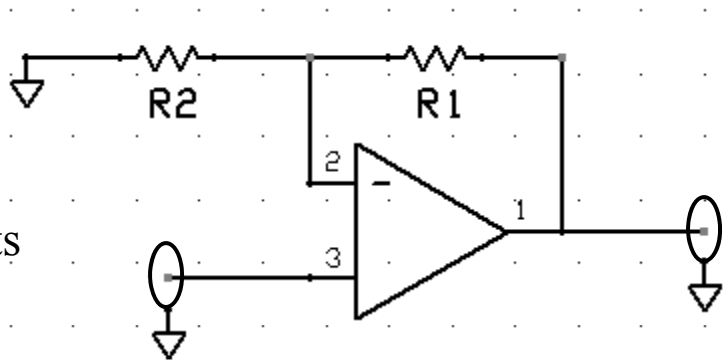

the opamp

- same as above
- same as above
- Audio frequency down to DC

There are opamps that go into the MHz, but generally it is a DC to high AF device.

Opamp Compared to Preamp

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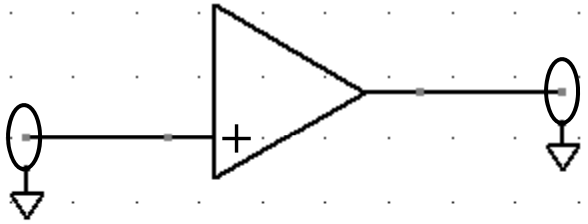
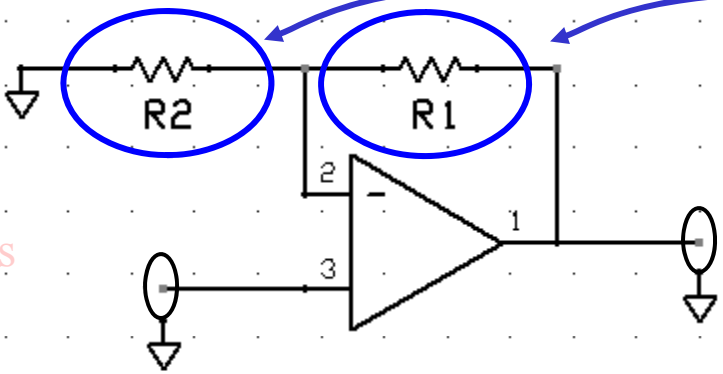
- microvolts,
- Audio frequency



- low impedance,
- about a volt
- Audio frequency

the most important difference is access to these

- same as above
- microvolts to volts
- Audio frequency down to DC



the opamp

- same as above
- same as above
- Audio frequency down to DC

Opamp Compared to Preamp

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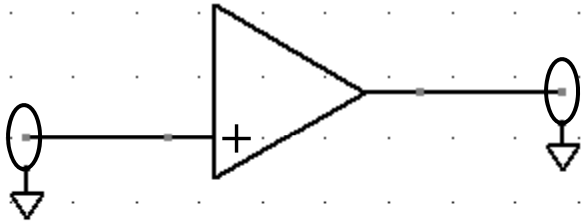

- low impedance,
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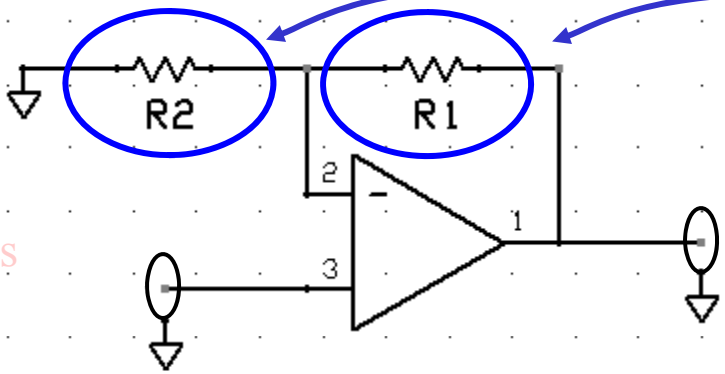
the most important difference is access to these



- same as above
- microvolts to volts
- Audio frequency down to DC

- same as above
- same as above
- Audio frequency down to DC

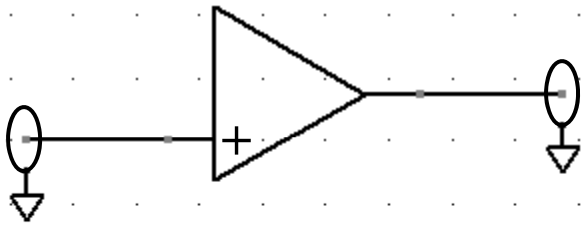
Feedback

(More on that later)

What It Means to Include DC

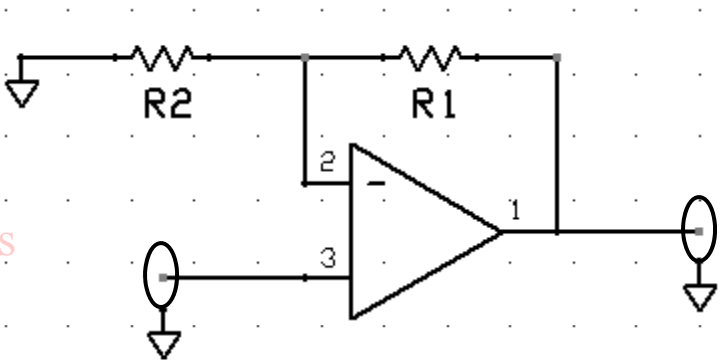
What It Means to Include DC

- high impedance,
- microvolts,
- Audio frequency



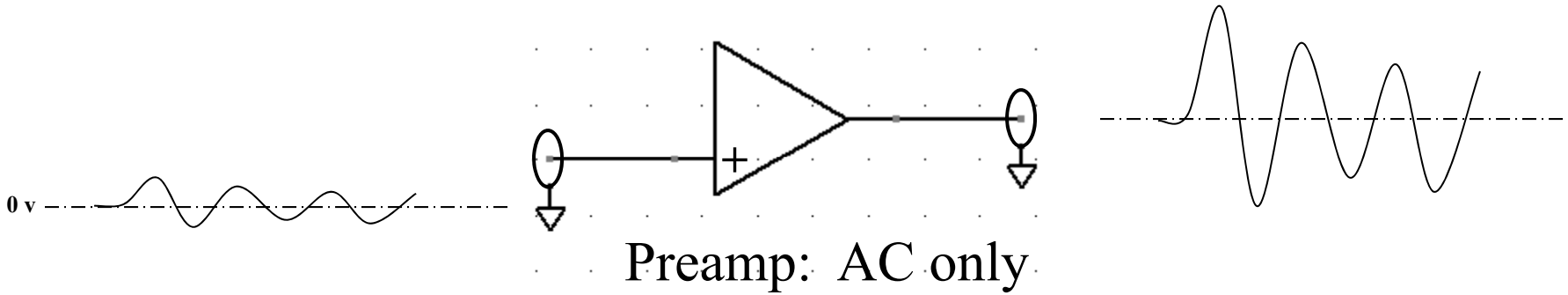
- low impedance,
- about a volt
- Audio frequency

- same as above
- microvolts to volts
- **Audio frequency down to DC**

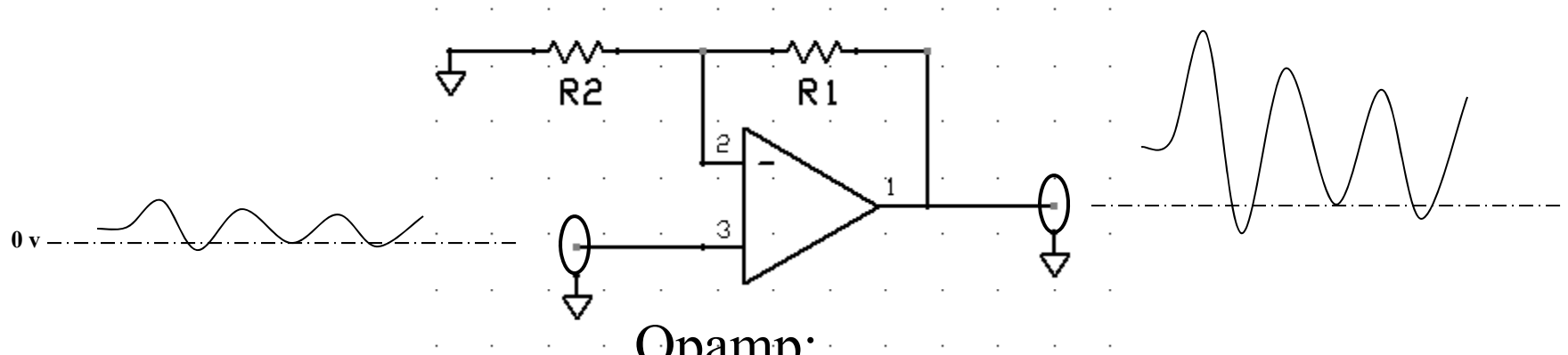


- same as above
- same as above
- **Audio frequency down to DC**

What It Means to Include DC



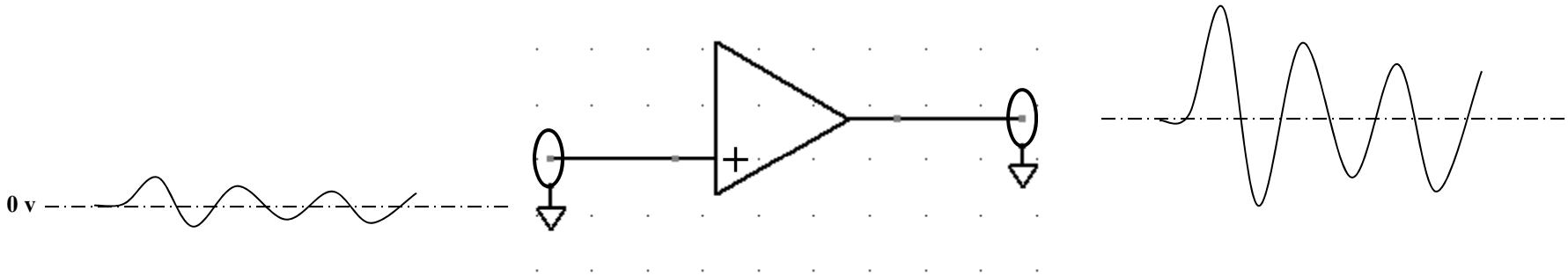
Preamp: AC only

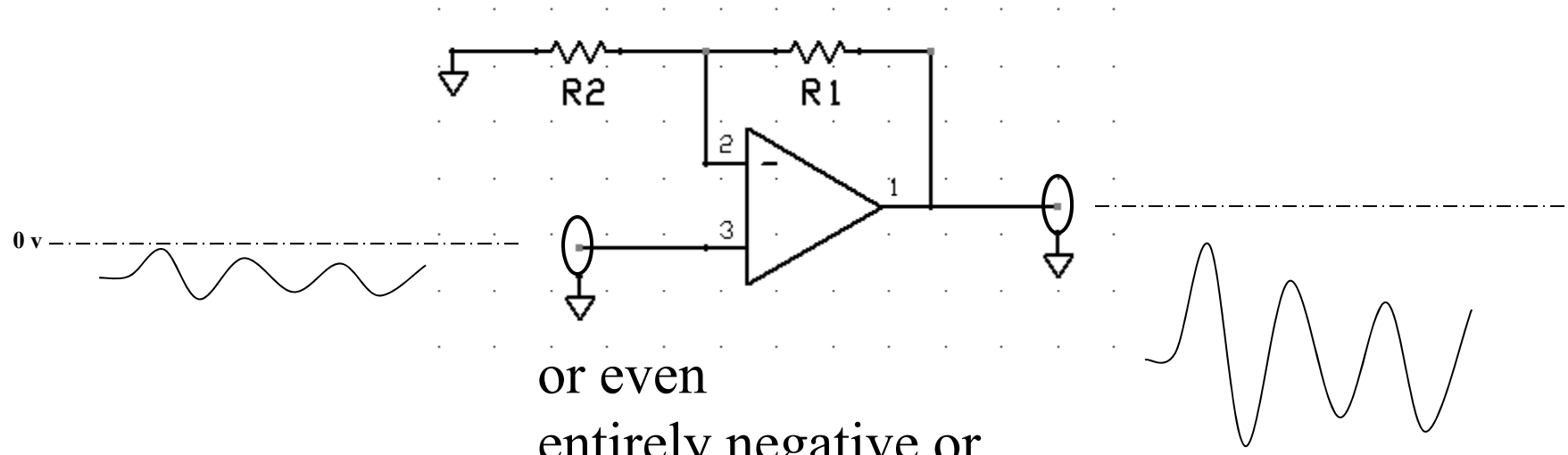


Opamp:

- AC or DC
- or both… AC with DC bias

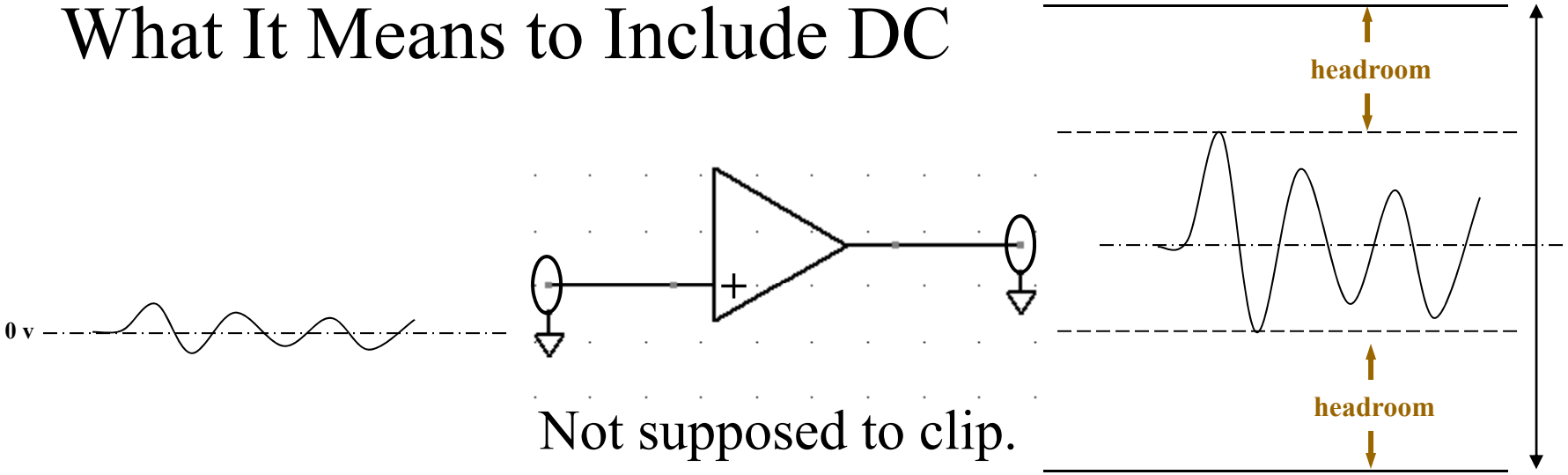
What It Means to Include DC



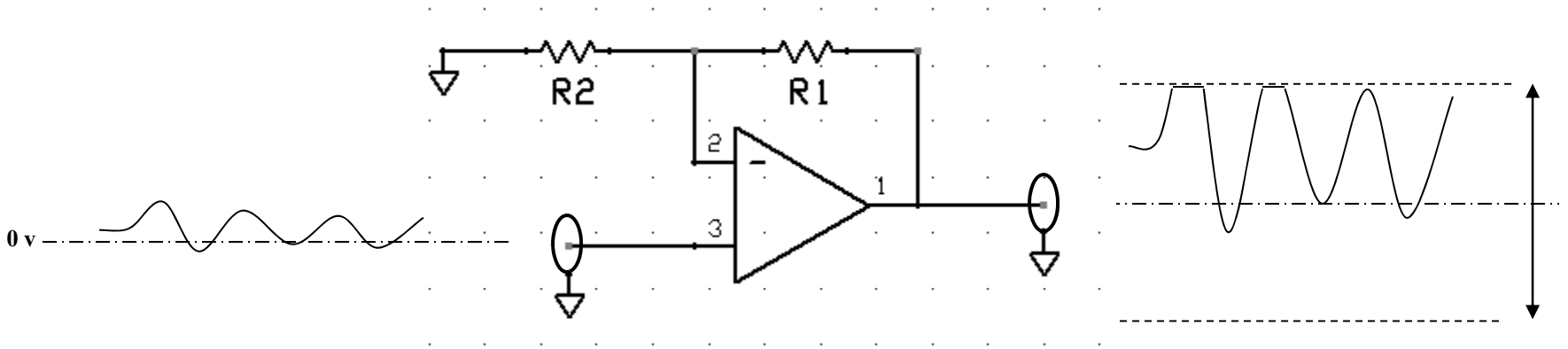


or even
entirely negative or
entirely positive

What It Means to Include DC



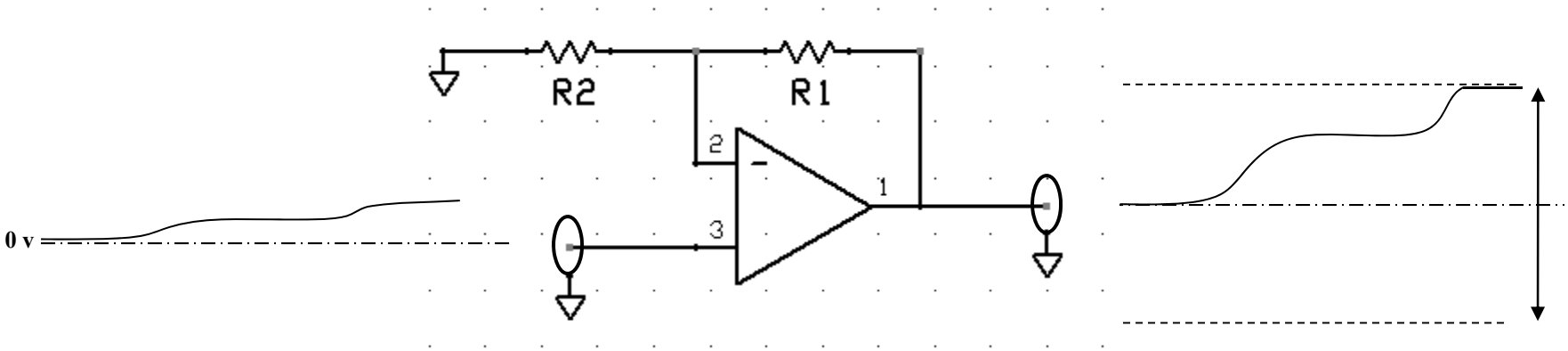
Not supposed to clip.



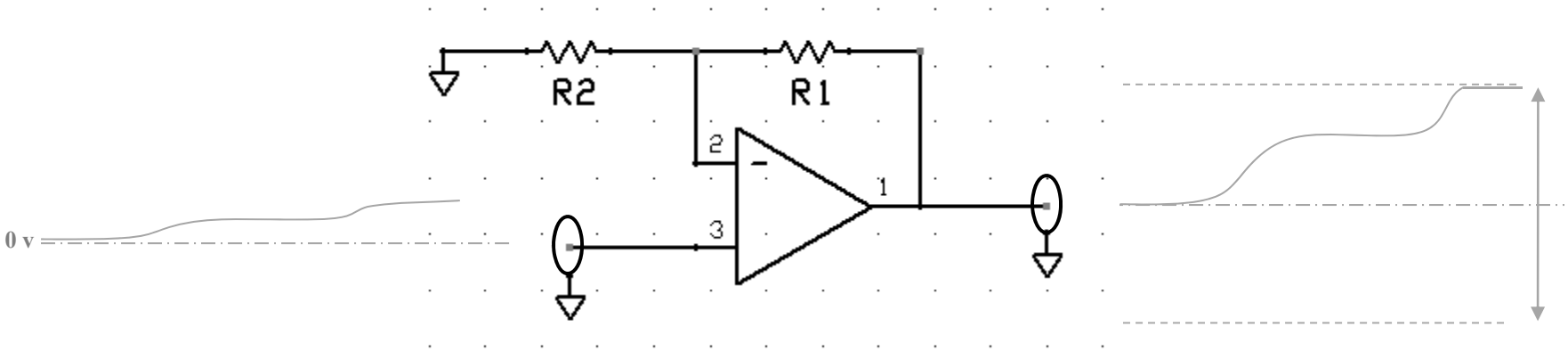
Often “run to the rails” as they say.

What It Means to Include DC

Most of the time when “DC” is associated with an amplifier, it means slow changes; like minutes held at some voltage.



Oh yea,
and there's no way you
can burn out an opamp.



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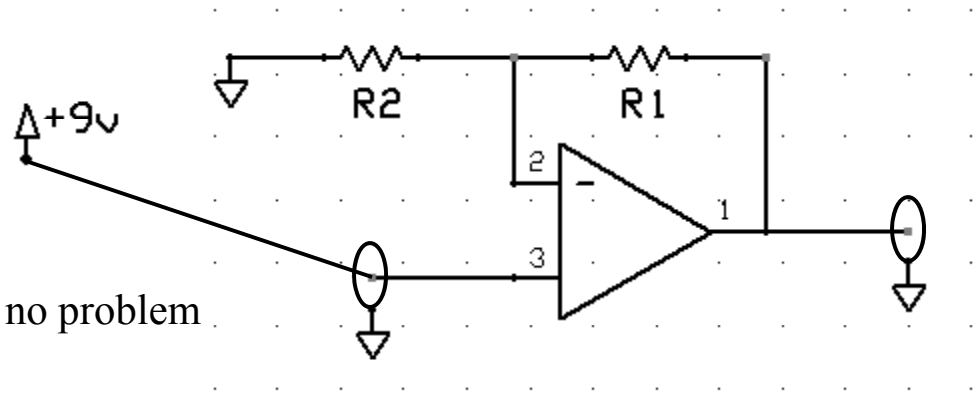
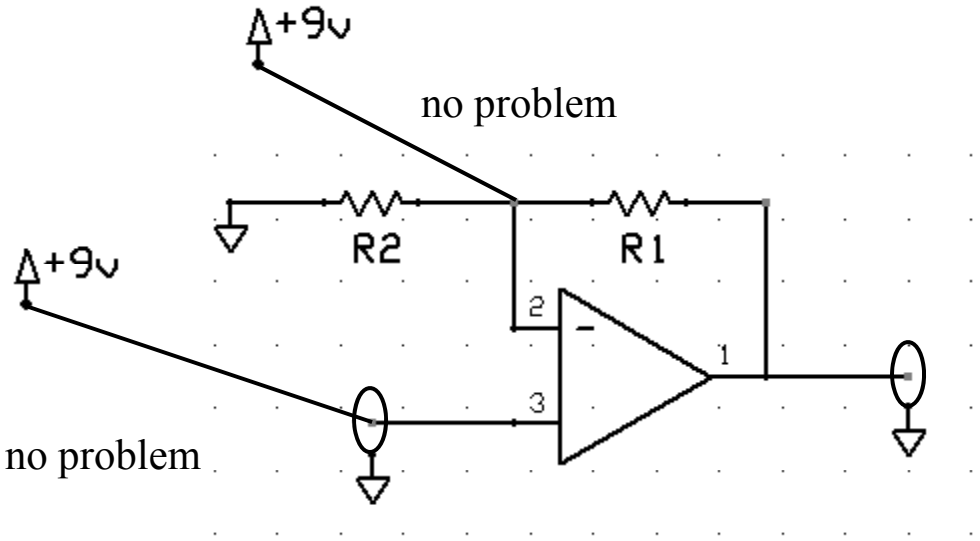
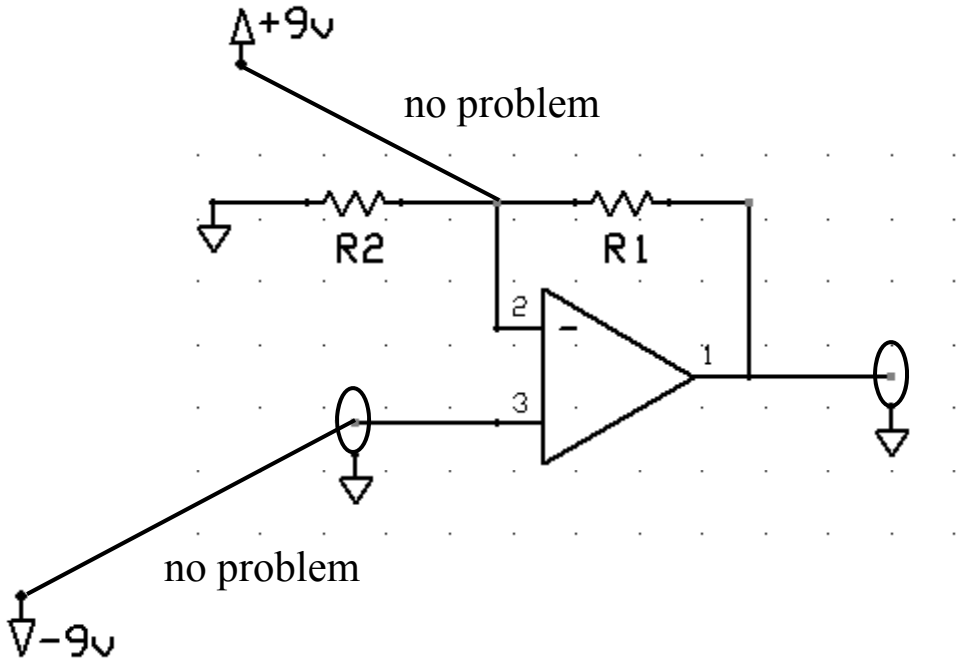
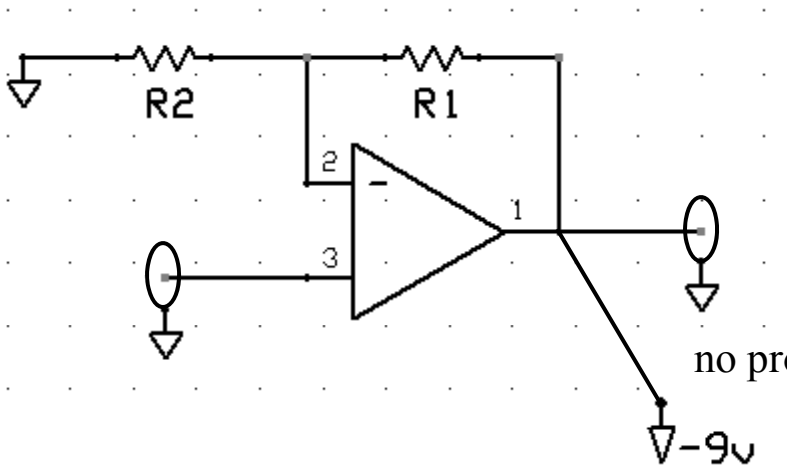
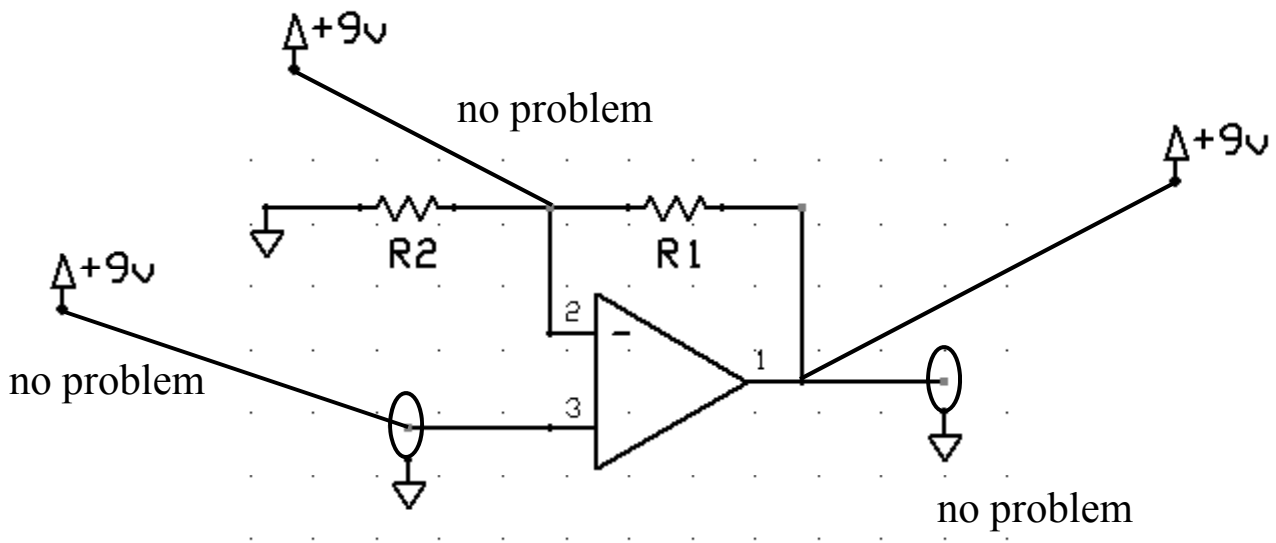



+9v
no problem
R2
R1
+9v
2
3
1
no problem

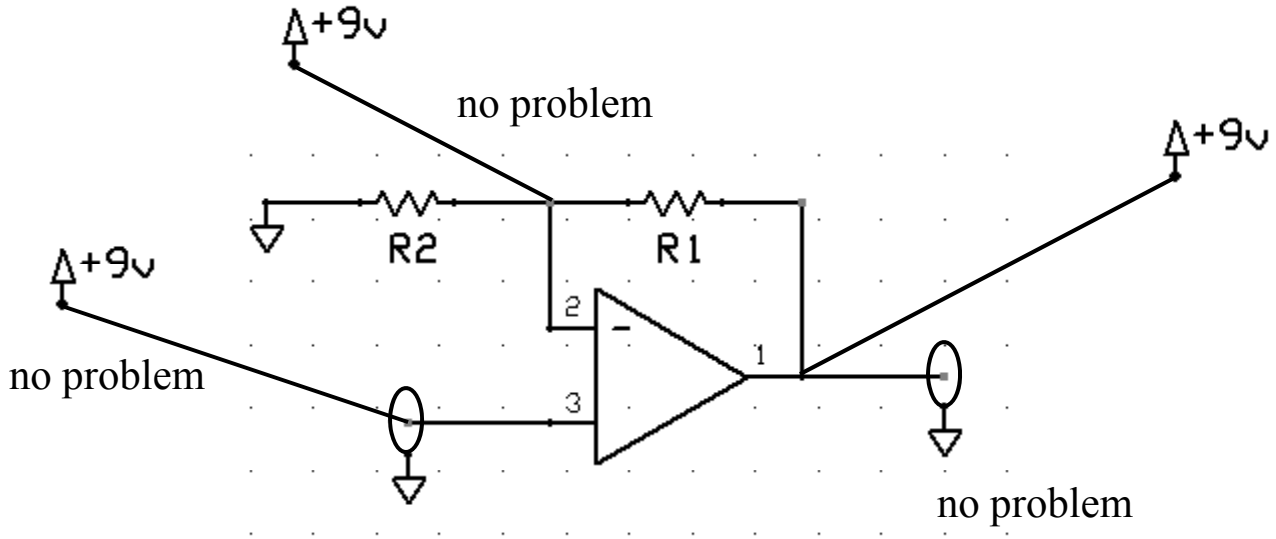

+9v
no problem
R2
R1
2
3
1
no problem
-9v



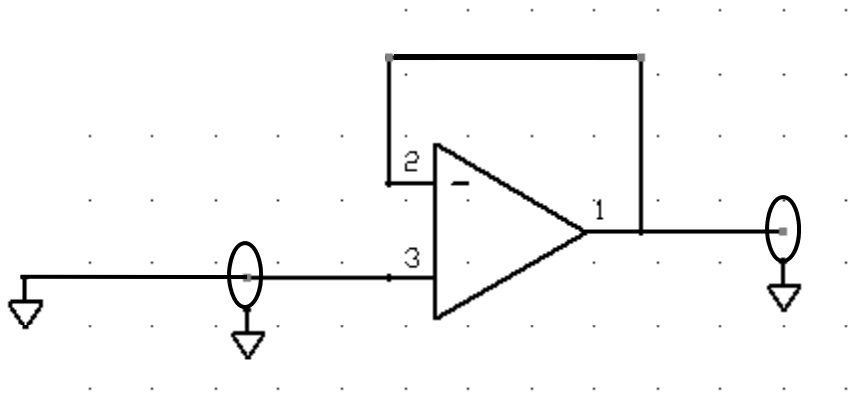
no problem


+9v
no problem
+9v
R2
R1
+9v
2
1
3
no problem
no problem

The worst that can happen is that the amplifier will be wasting battery power through R1.



How to “Disable” an Opamp



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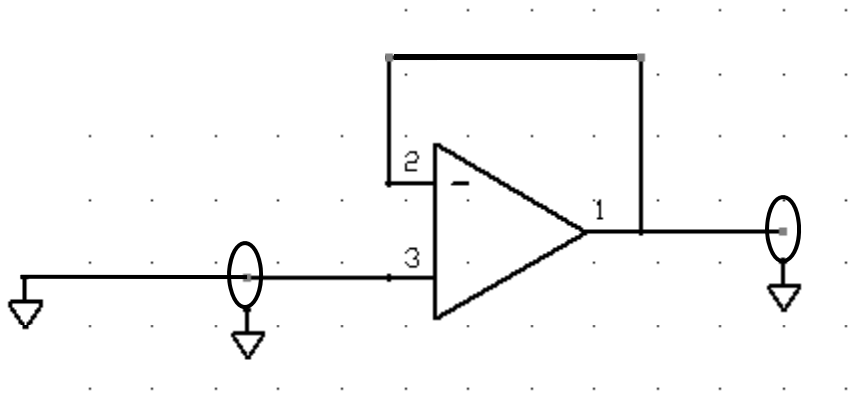
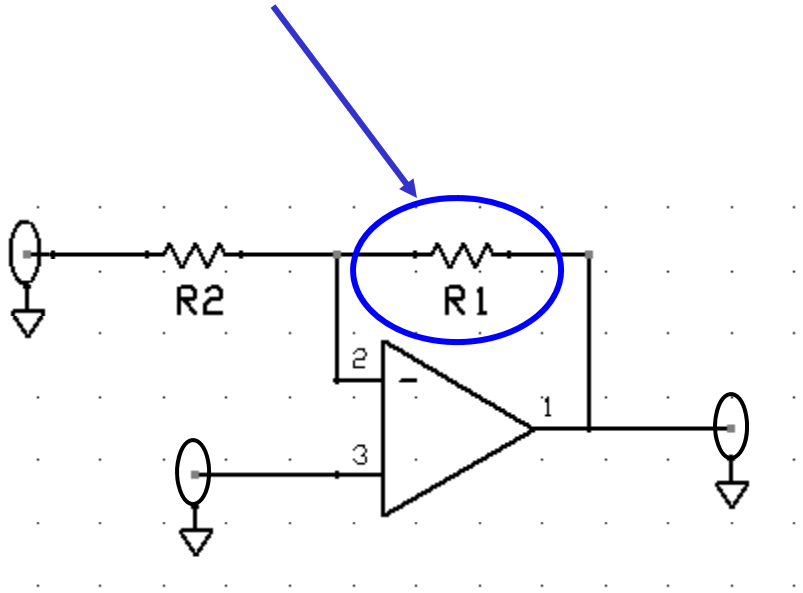


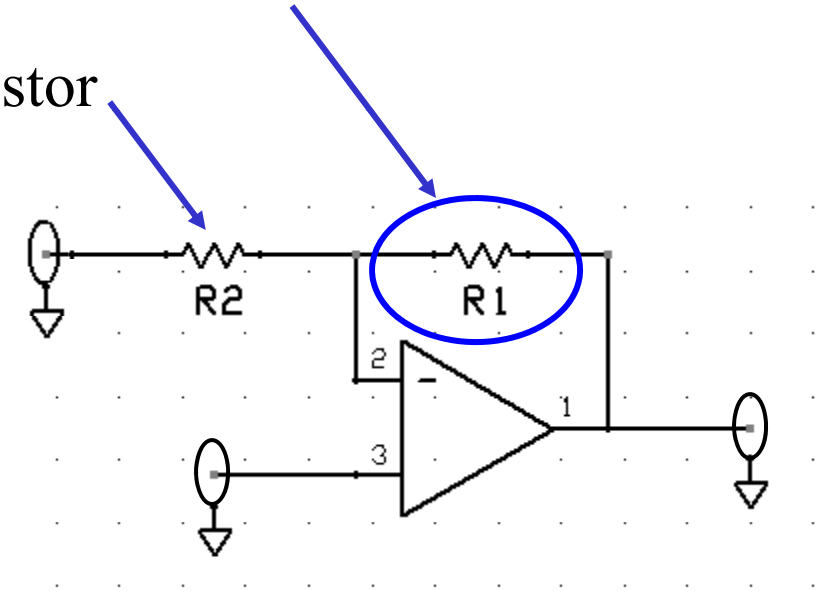
(Opamps come several to a package and often you can’t use them all.)

by the way,
this is called the feedback resistor



by the way,
this is called the feedback resistor and

this the input resistor



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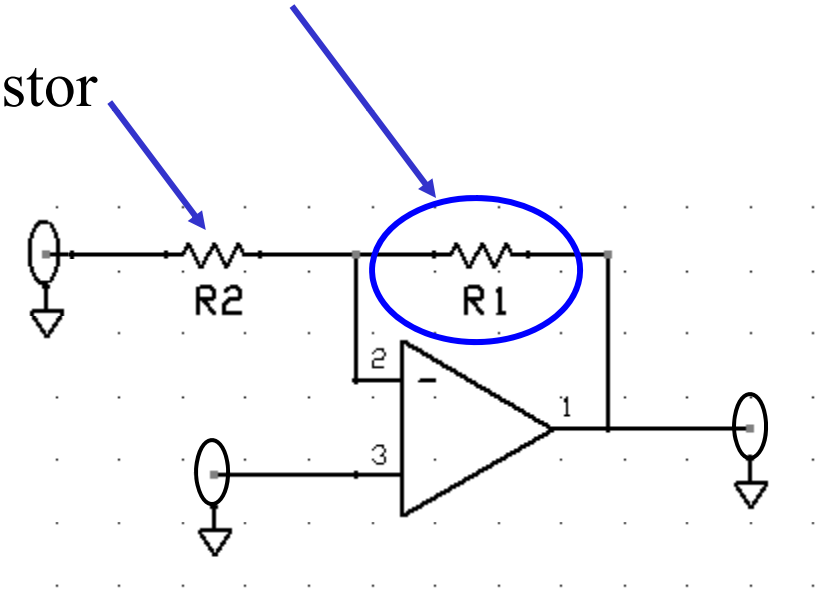

Common usage but misleading

by the way,
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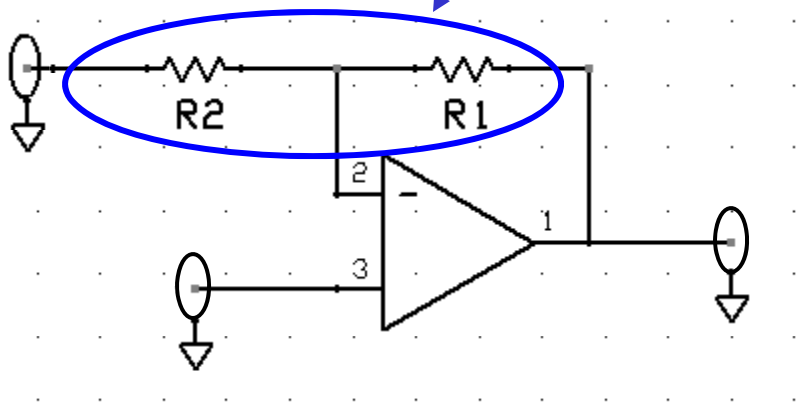
The feedback is actually both of these operating as a divider.



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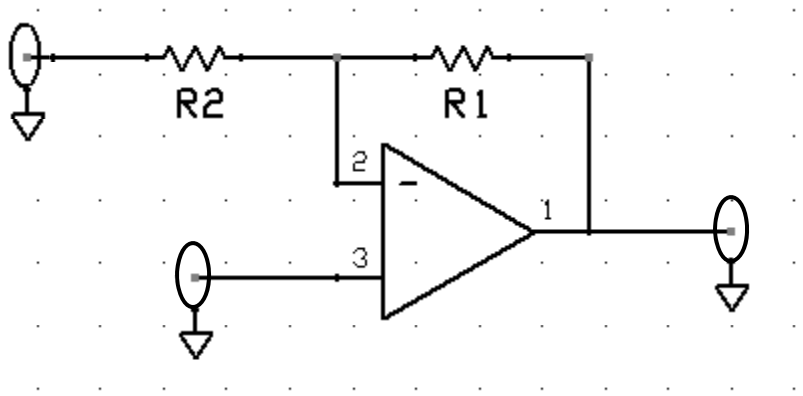
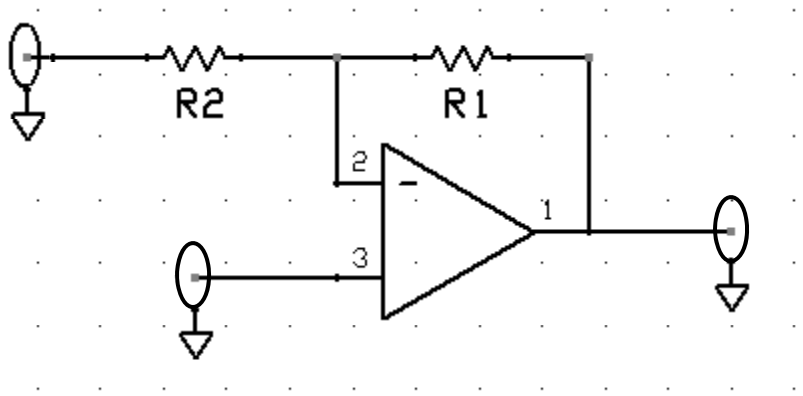
More on “feedback” later

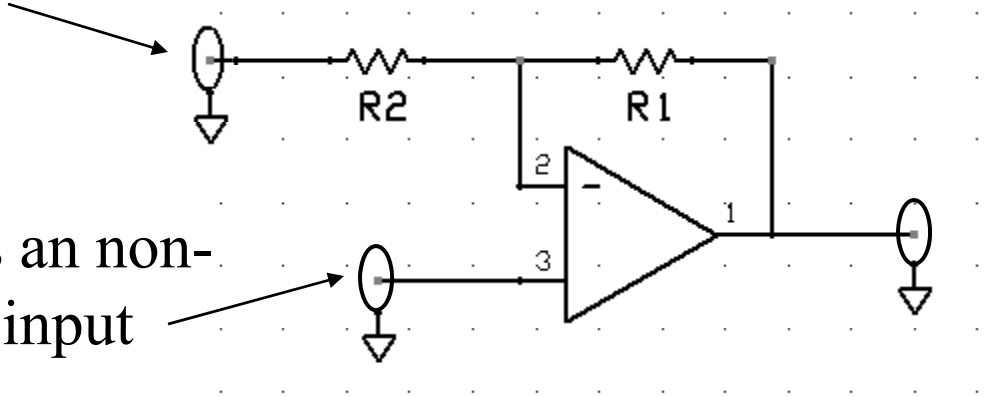


The most famous thing about opamps…



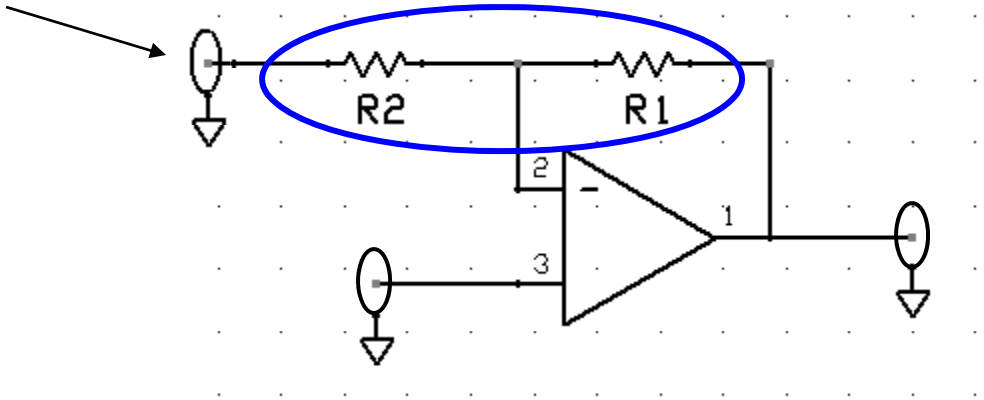
The most famous thing about opamps…

an inverting input



as well as an non-inverting input

an inverting input and this “feedback pair” = analog computer



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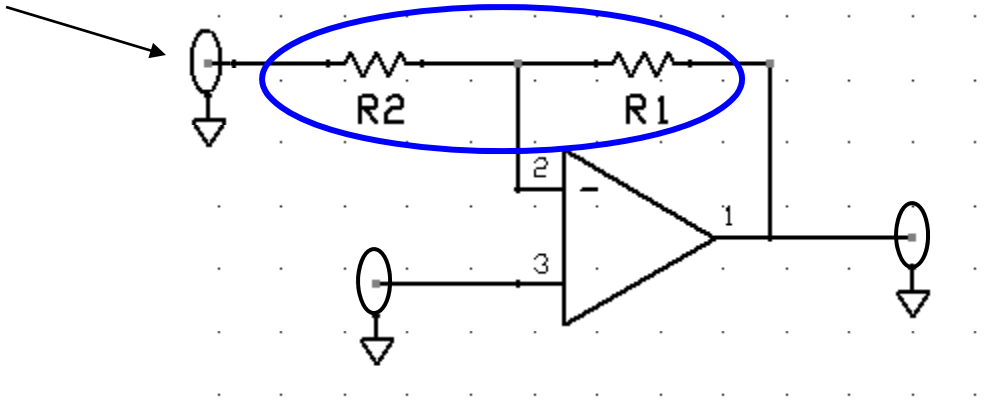

The name “operational amplifier” is because their first use was doing mathematical **operations** in analog computers.

Analog Computers…

- invert a signal
- offset (add) your signal with a DC level
- multiply DC or AC by a fixed amount
- integrate, differentiate
- logs, antilogs

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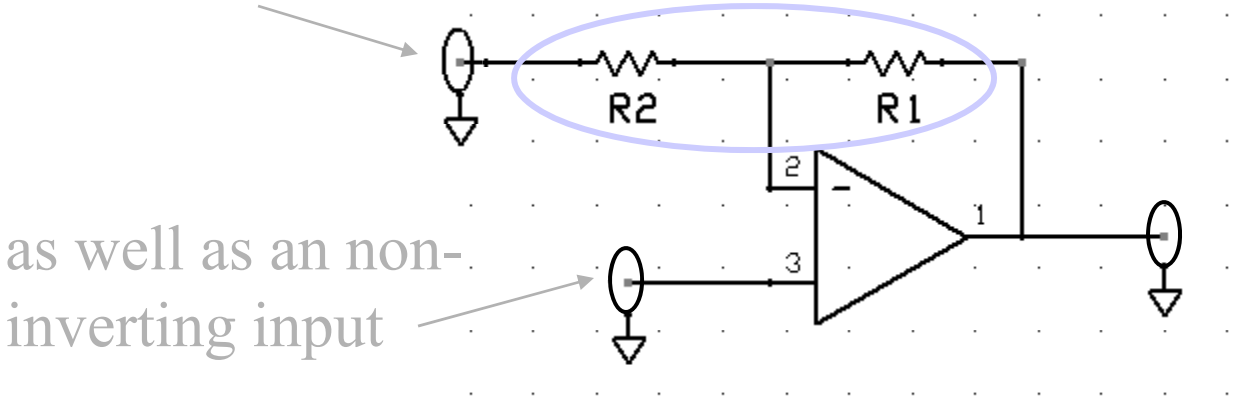

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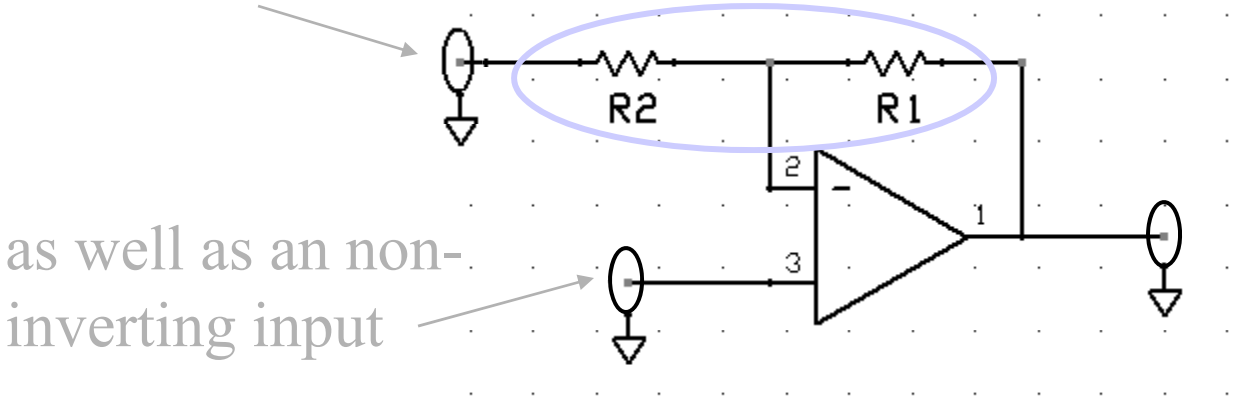


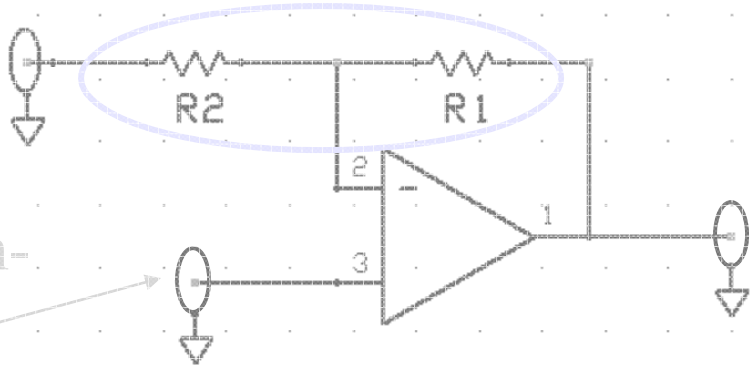
as well as an non-inverting input

The name "operational amplifier" is because their first use was doing mathematical **operations** in analog computers.

most useful for circuit designers

- invert a signal
- offset (add) your signal with a DC level
- multiply DC or AC by a fixed amount
- integrate, differentiate
- logs, antilogs

an inverting input and this "feedback pair" = analog computer



as well as an non-inverting input

The name "operational amplifier" is because their first use was doing mathematical **operations** in analog computers.

- invert a signal
- offset (add) your signal with a DC level
- multiply DC or AC by a fixed amount
- integrate, differentiate
- logs, antilogs

Why not get a fast A-to-D and do it all in software?

1.

2.

3.

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Why not get a fast A-to-D and do it all in software?

1. **you still need an opamp to get the signal at an amplitude to fill the dynamic range of the A-to-D**
2.
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Why not get a fast A-to-D and do it all in software?

1. **you still need an opamp to get the signal at an amplitude to fill the dynamic range of the A-to-D**
2. **some operations (like filtering) are difficult to do in software**
3. **remember an A-to-D needs a D-to-A as well as a microprocessor. So if you have just one thing to do; amplify with bias for example, do it with an opamp.**

- invert a signal
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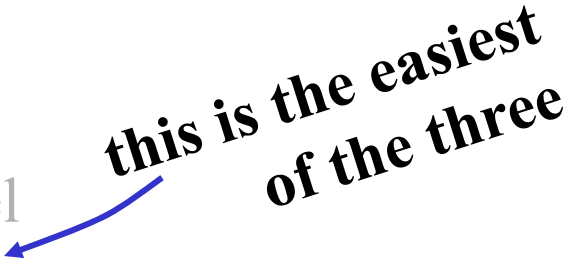
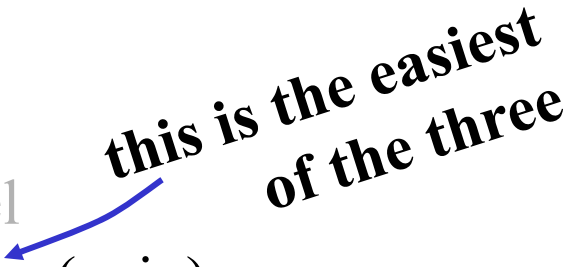


- invert a signal
- offset (add) your signal with a DC level
- multiply DC or AC by a fixed amount (gain)



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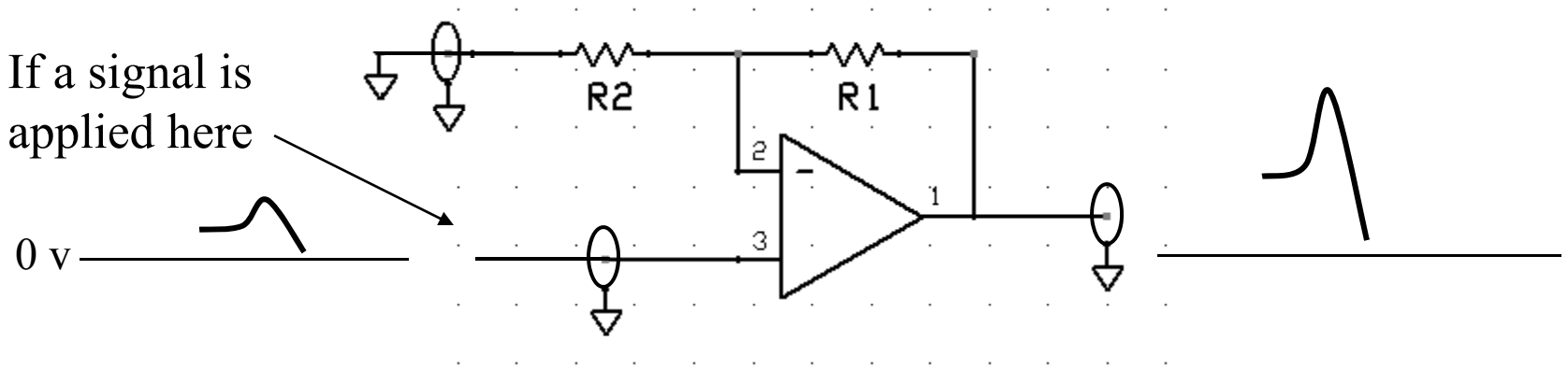
this is the easiest of the three



- invert a signal
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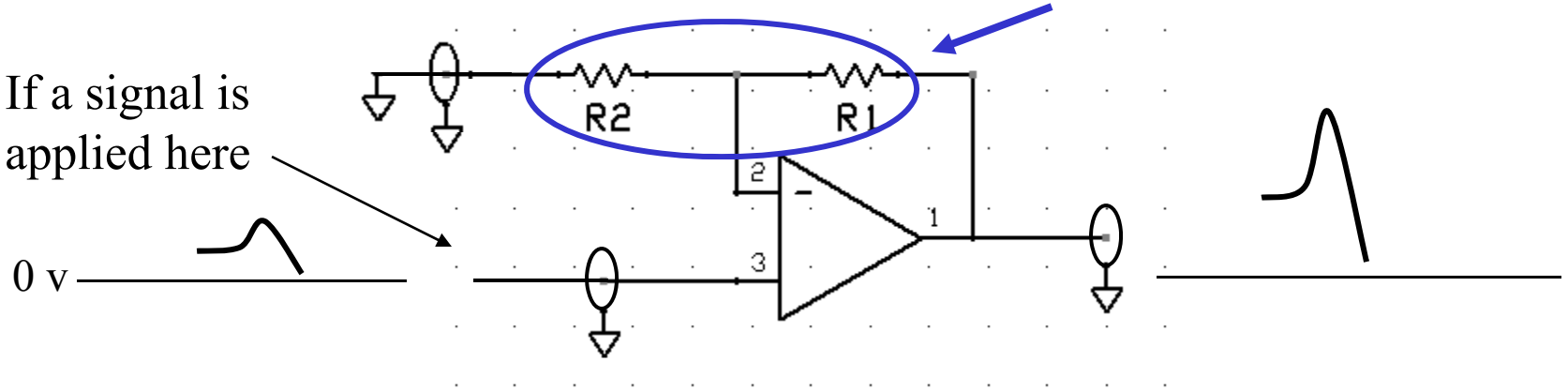
"gain" is set by the feedback resistor ratio.



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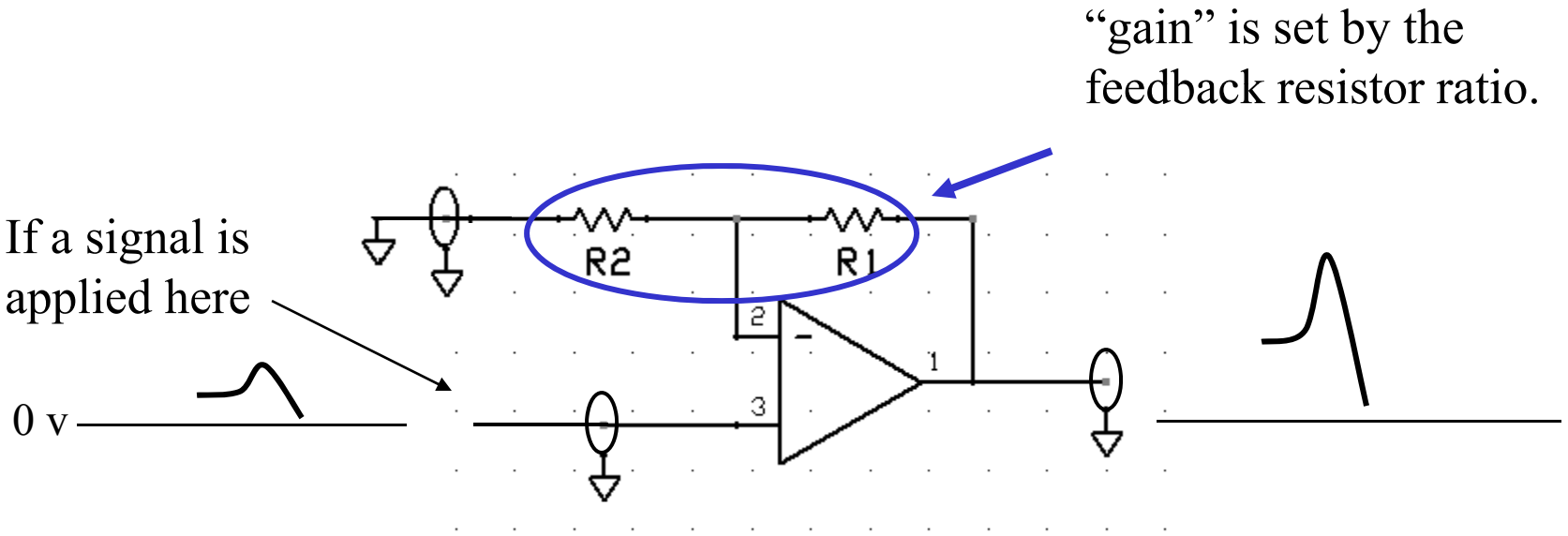

- not the amplifier's internal gain
- not the battery voltage

- invert a signal
- offset (add) your signal with a DC level
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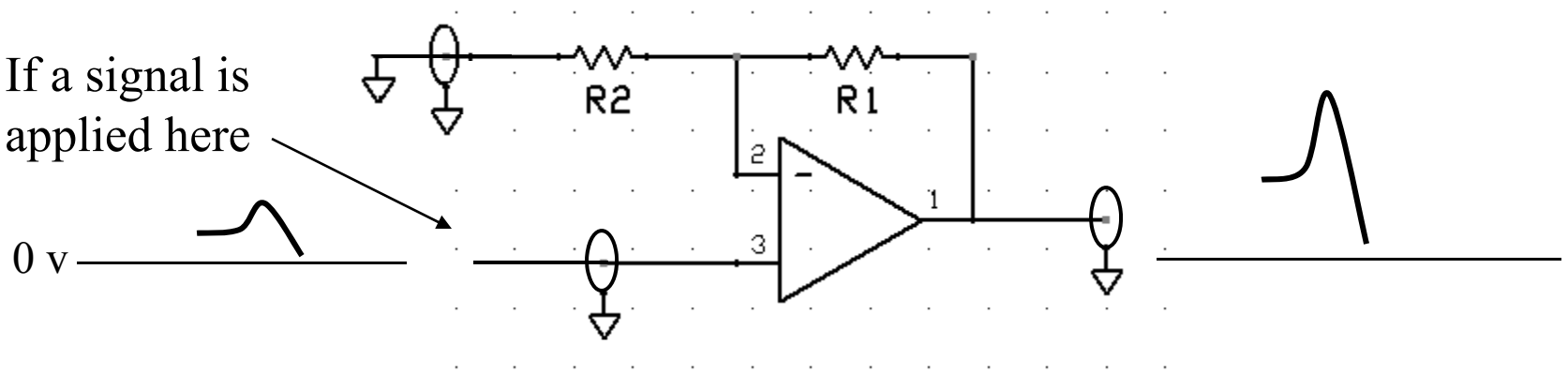

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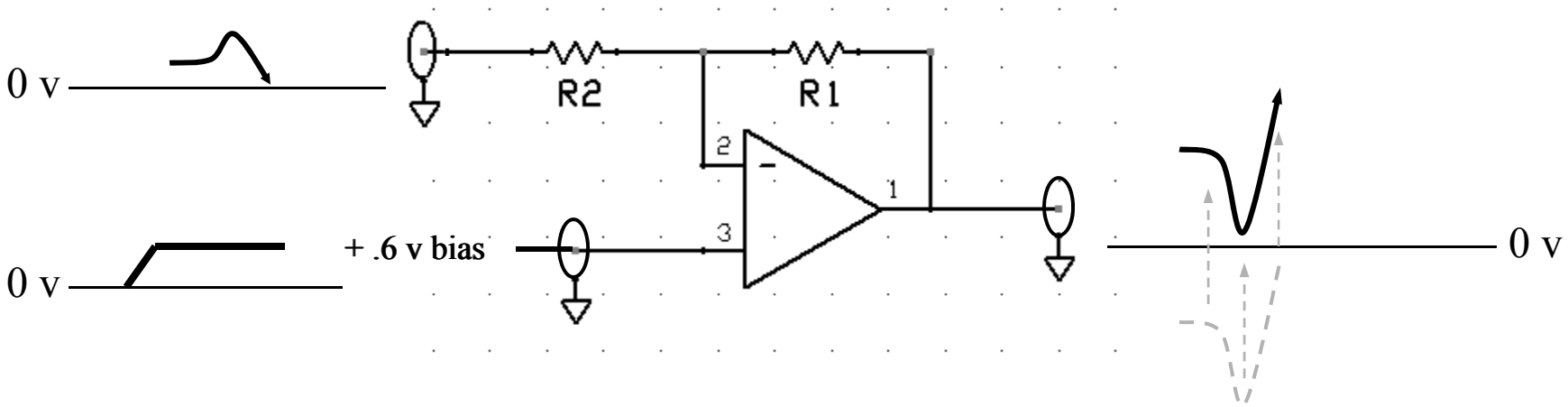
hardest of the three



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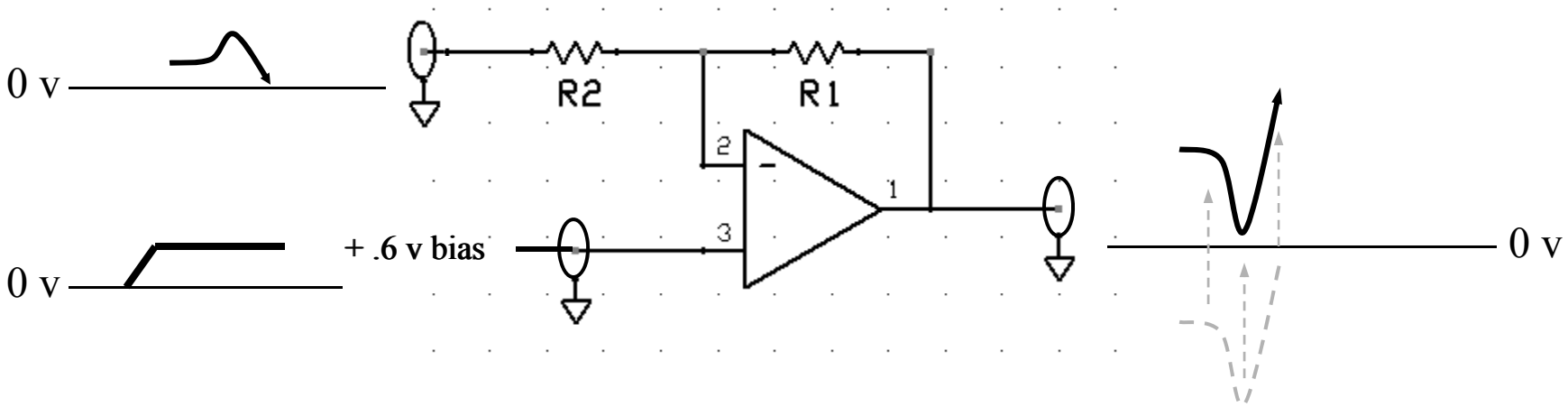
This is explored in detail in another presentation.



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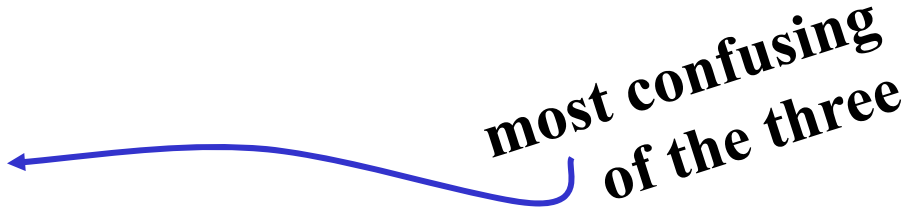

- invert a signal
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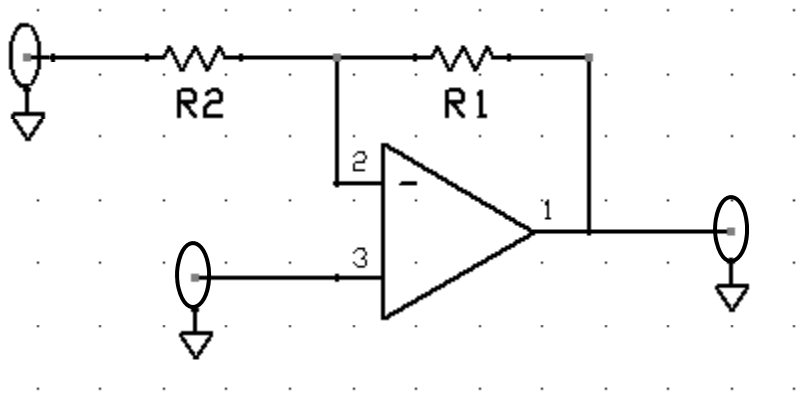
most confusing of the three

If the normal input…



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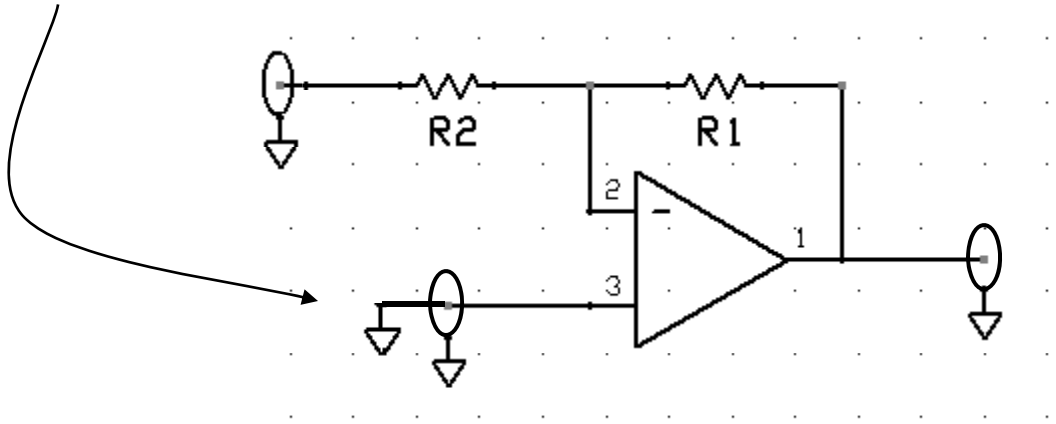
If the normal input is grounded . . .



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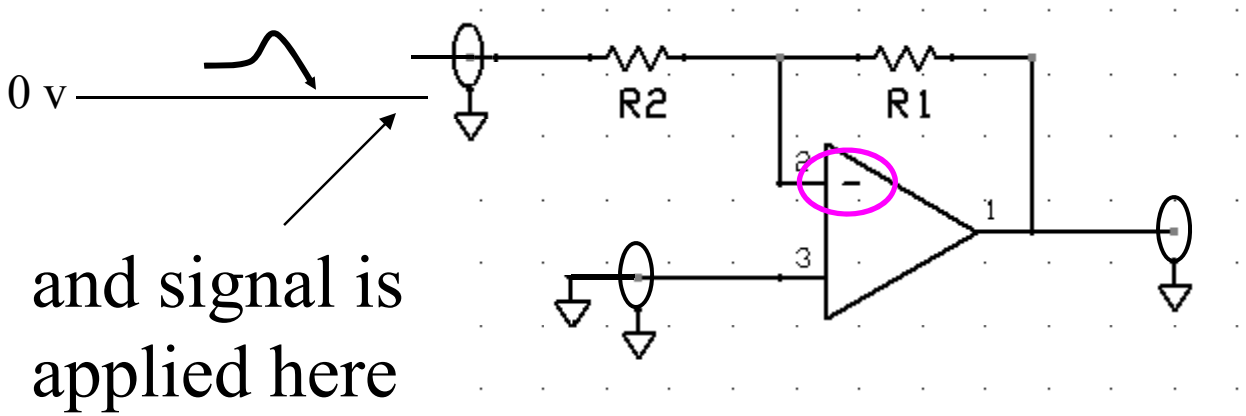

and signal is applied here

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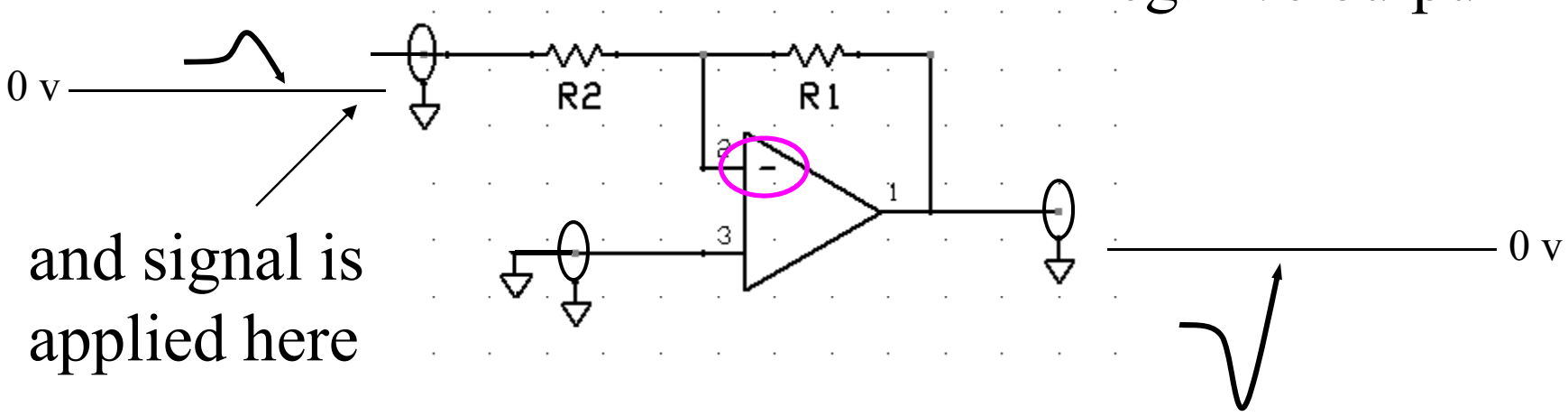
If the normal input is grounded . . .

…it will create a negative output



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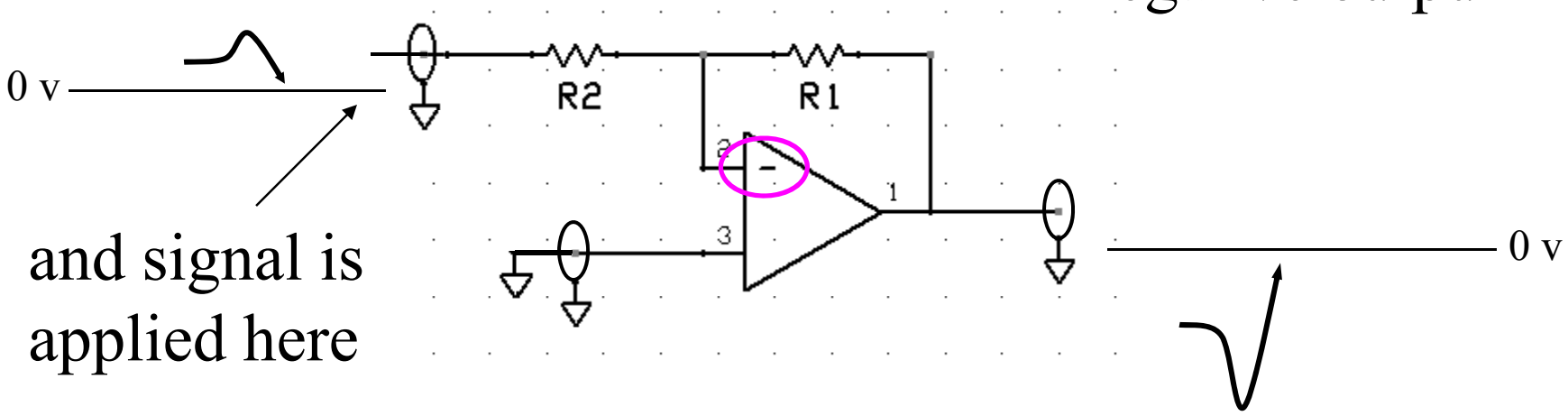
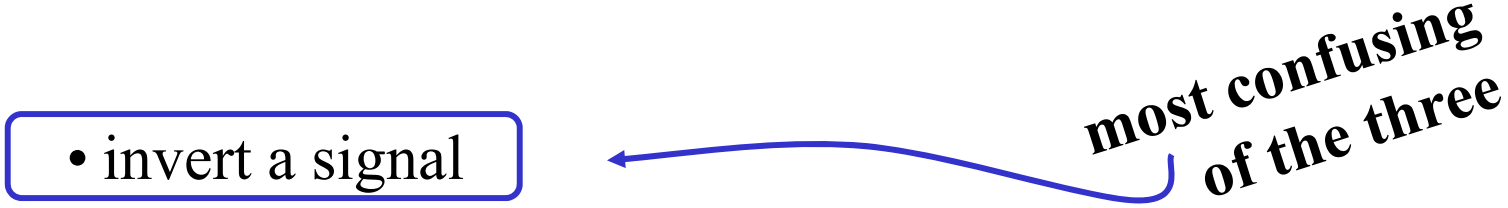


and signal is applied here

(It is confusing because it goes on the other side **and** changes direction.)



Memorize This about the "Inverting Input"

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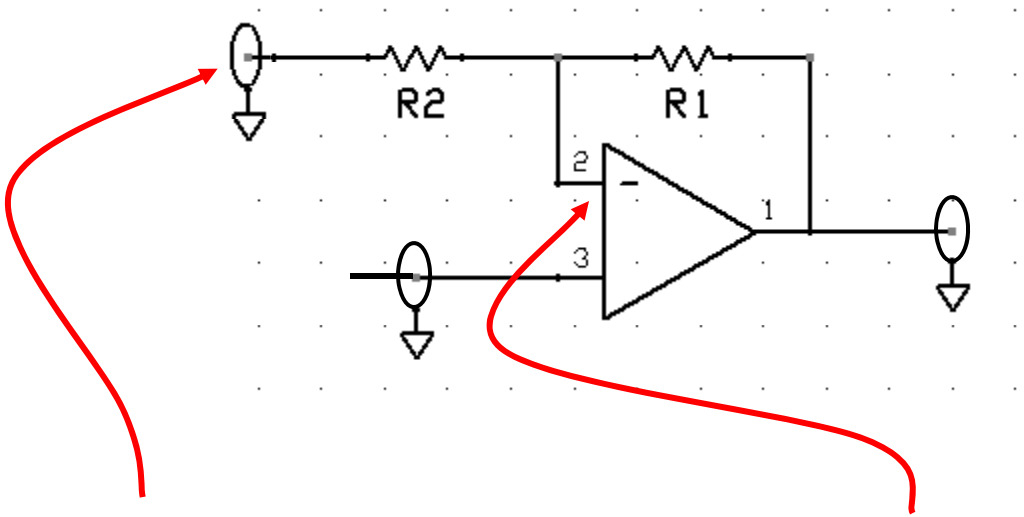
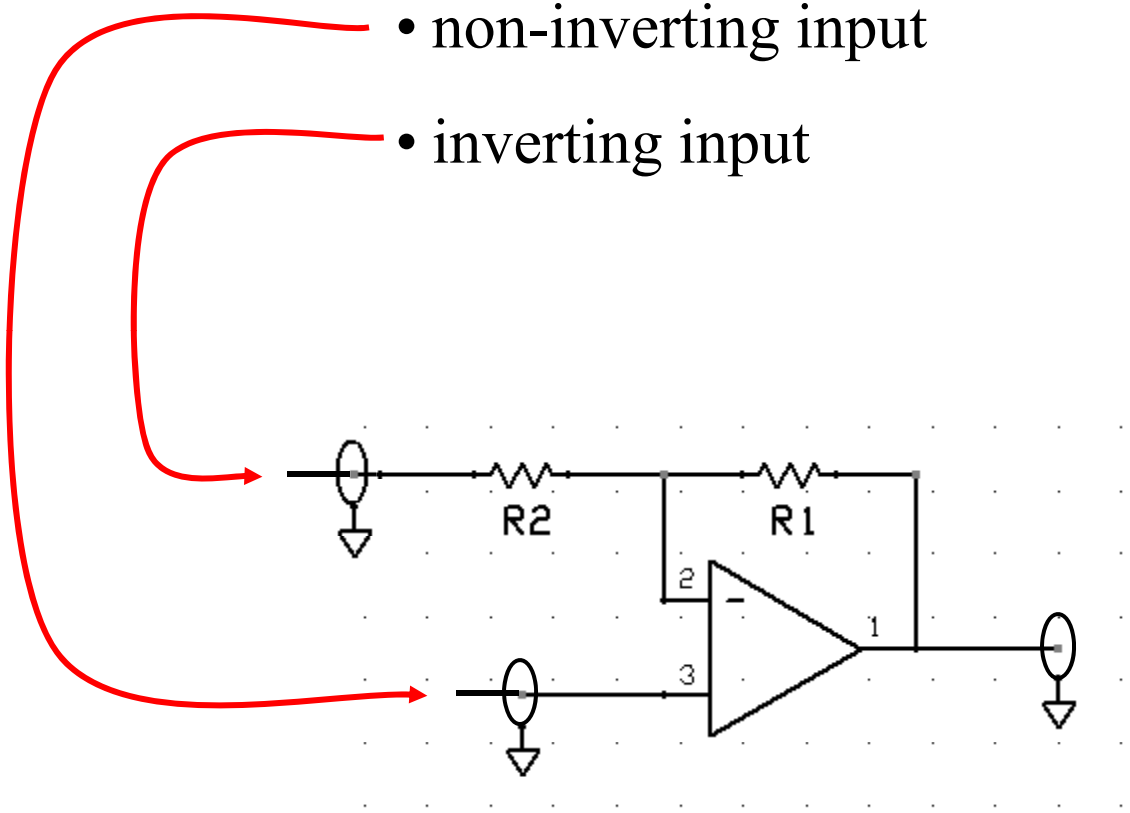


This is the input, not this.

The difference between…

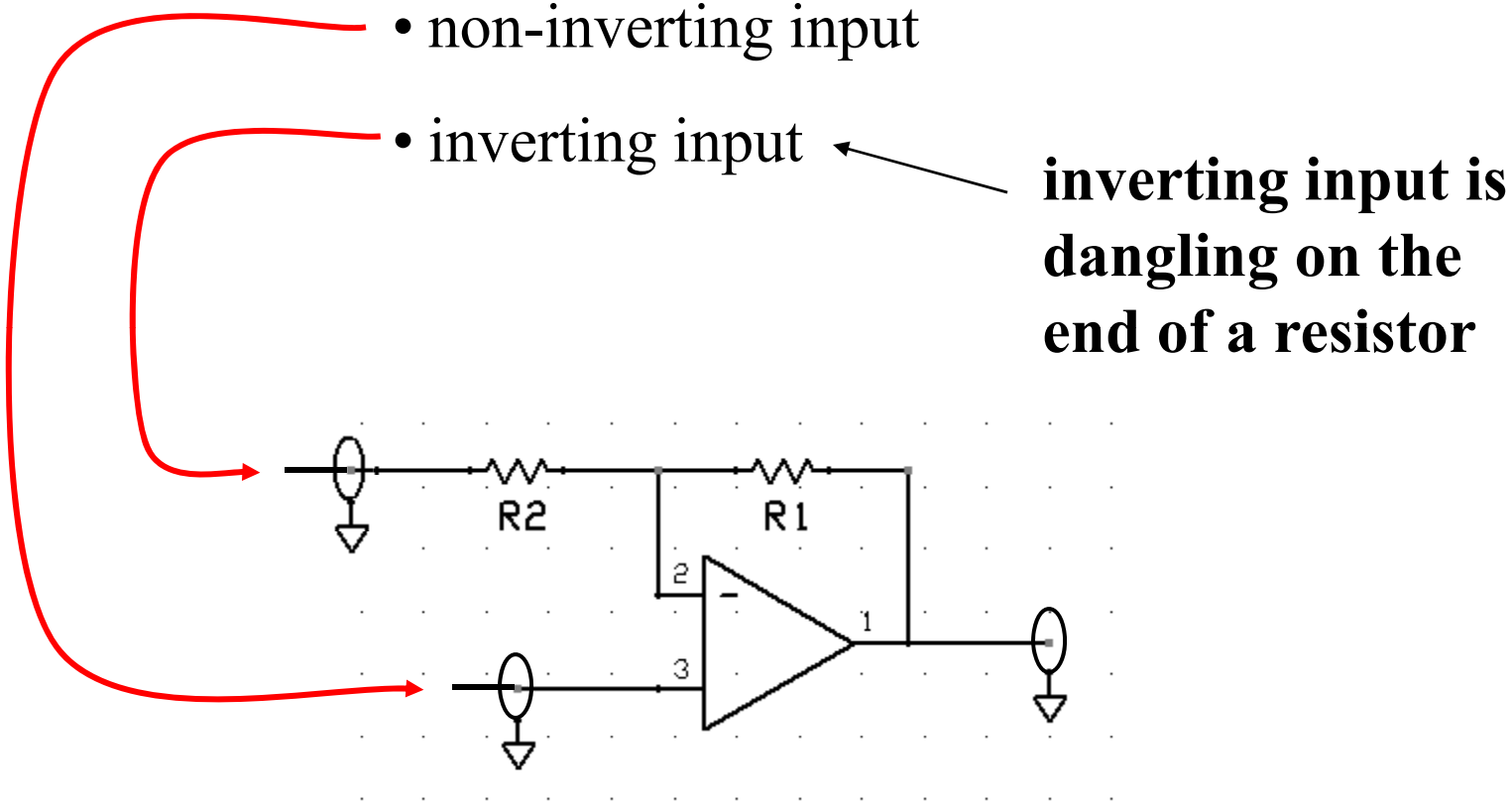
- non-inverting input
- inverting input



The difference between…

- non-inverting input
- inverting input

inverting input is dangling on the end of a resistor



One other thing…

The difference between…

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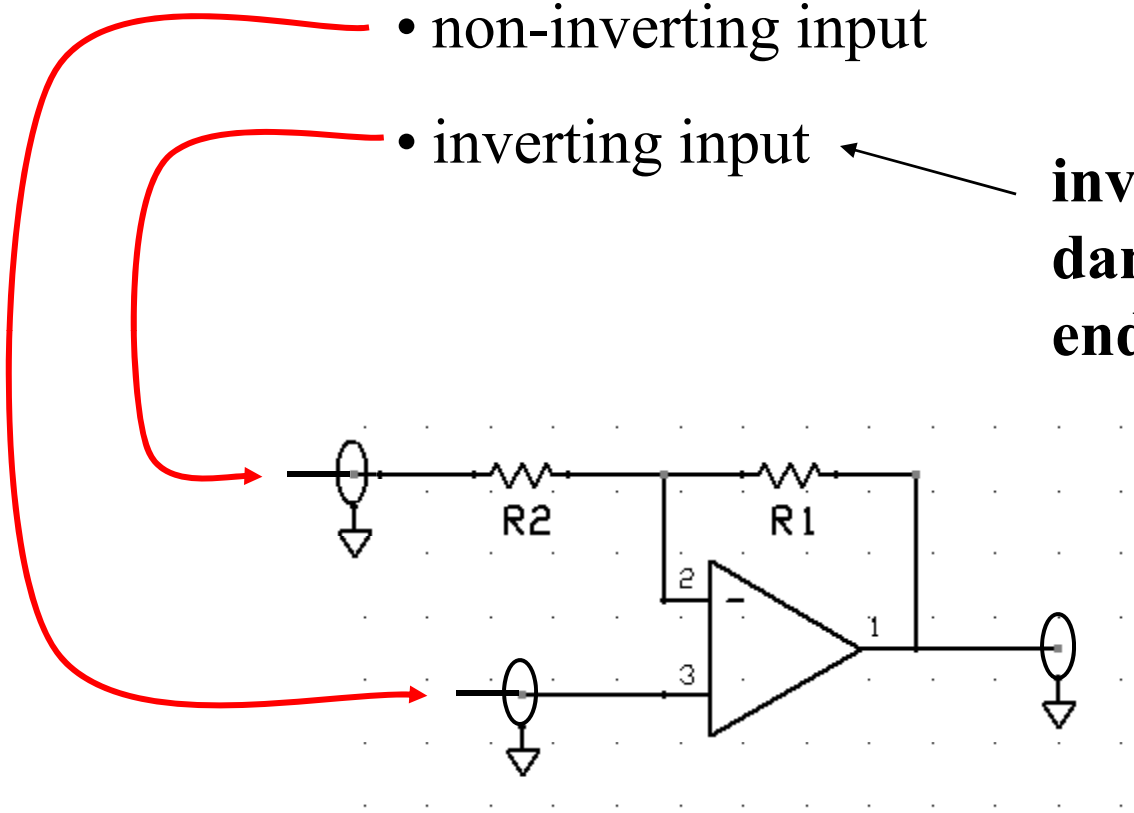

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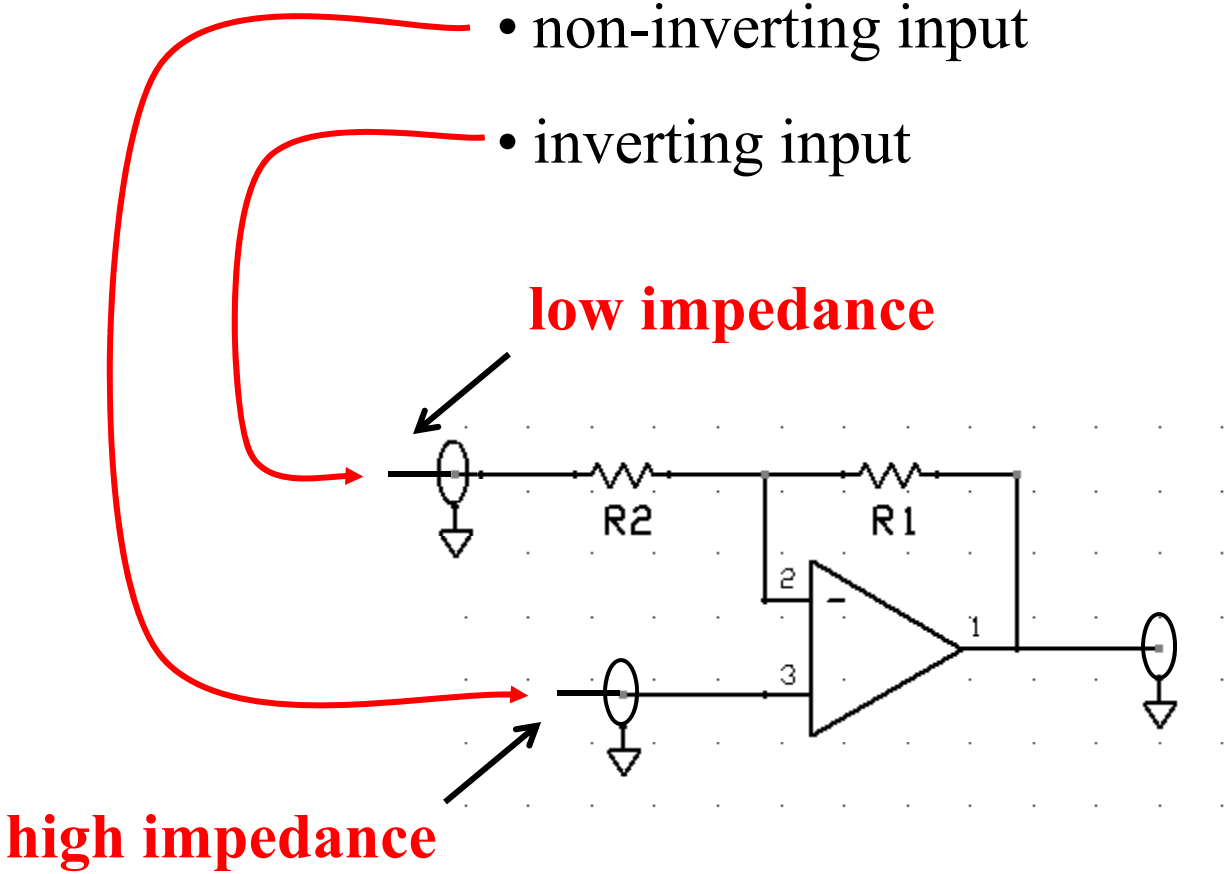
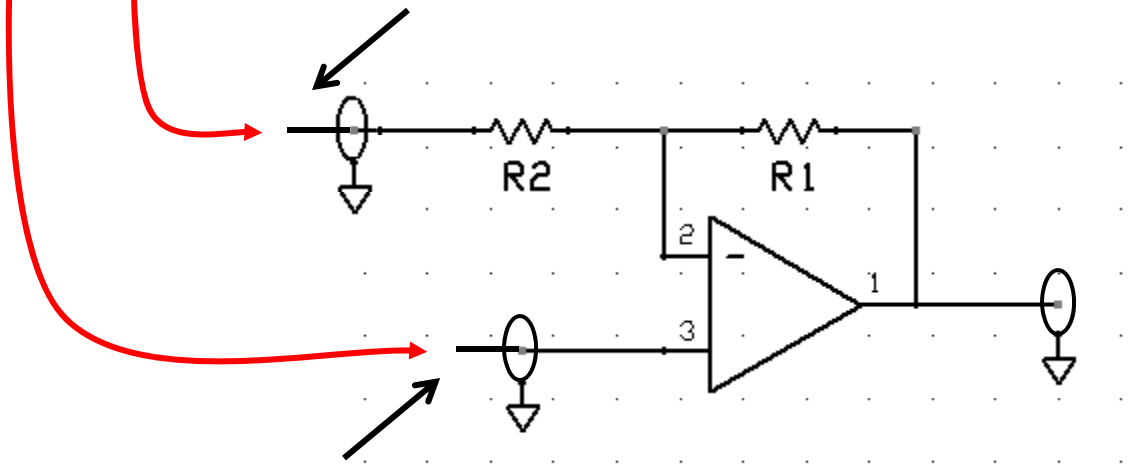


One other thing…

The difference between…

- non-inverting input
- inverting input

low impedance (actually it is whatever R2 is)



high impedance

One other thing…

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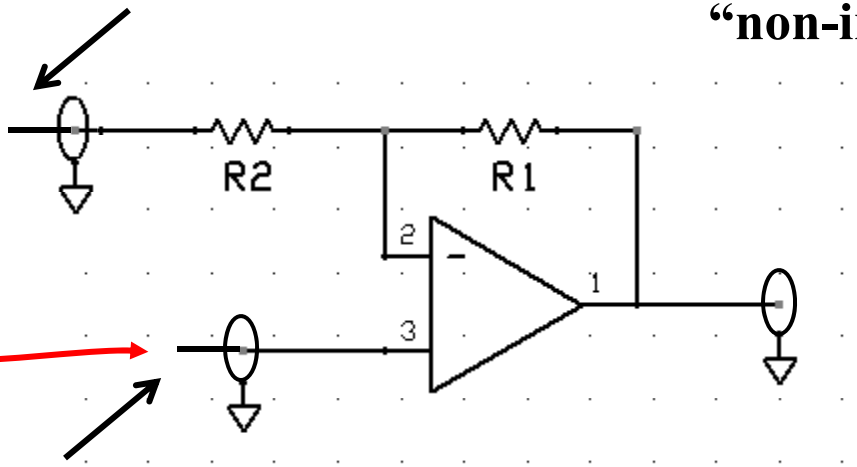
- inverting input

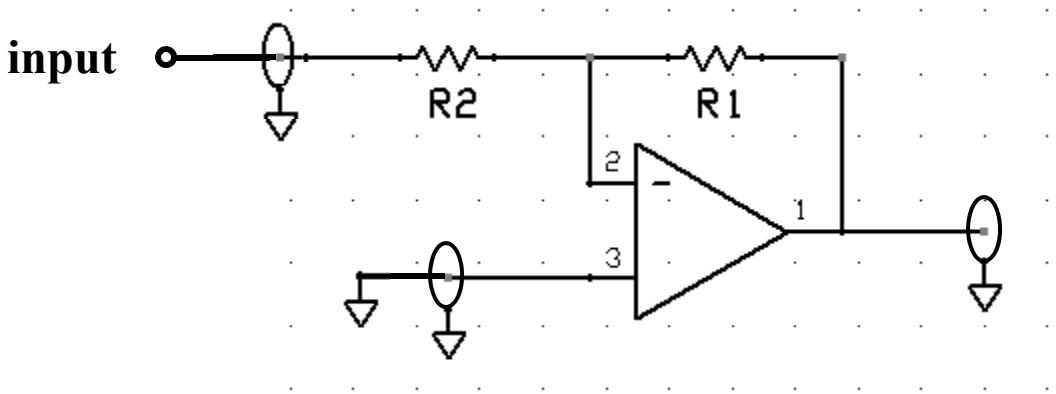
low impedance



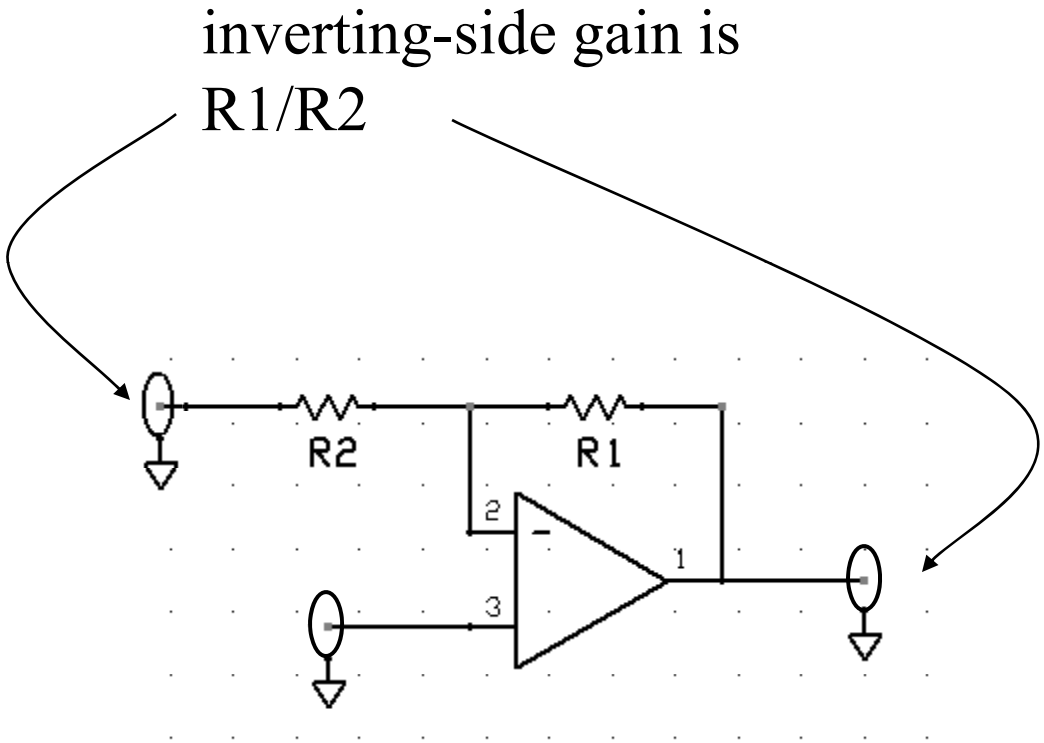
high impedance

This means extremely weak sources (micro-phones) should go into the "non-inverting" input.

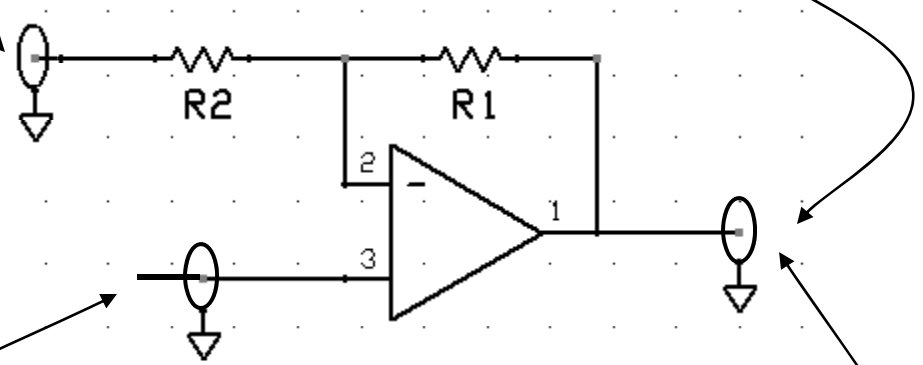
The Only Math You Must Know



Memorize this…



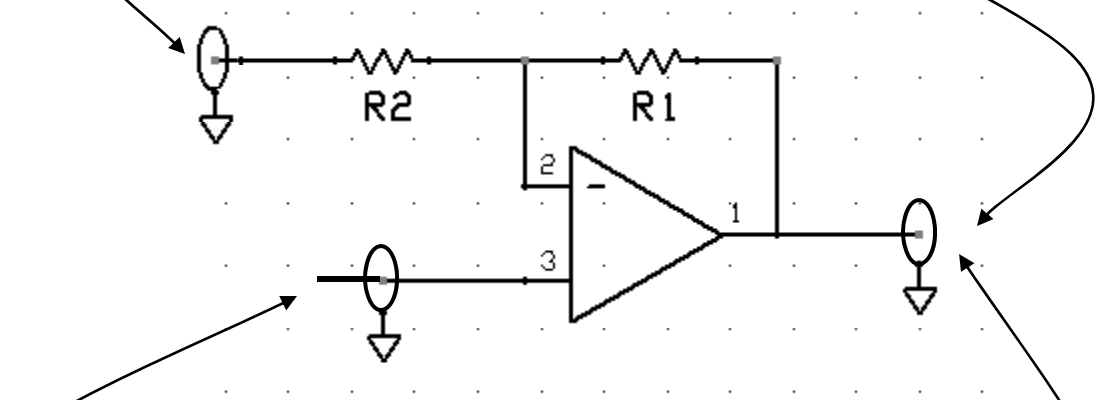
inverting-side gain is
R1/R2



And This

non-inverting-side gain is
R1/R2 + 1

inverting-side gain is
R1/R2



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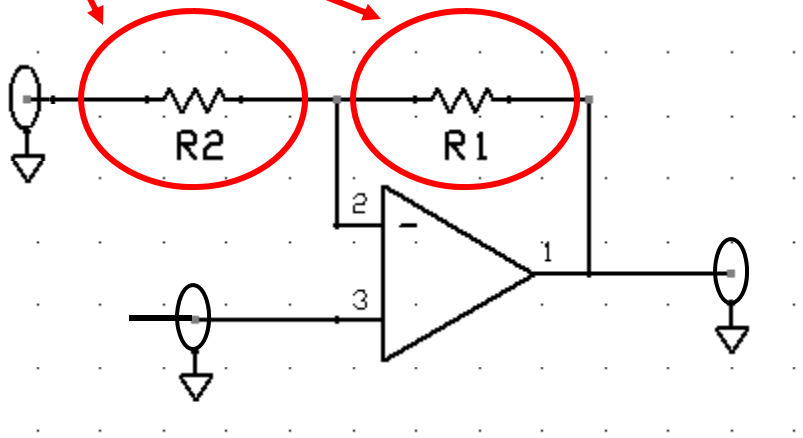

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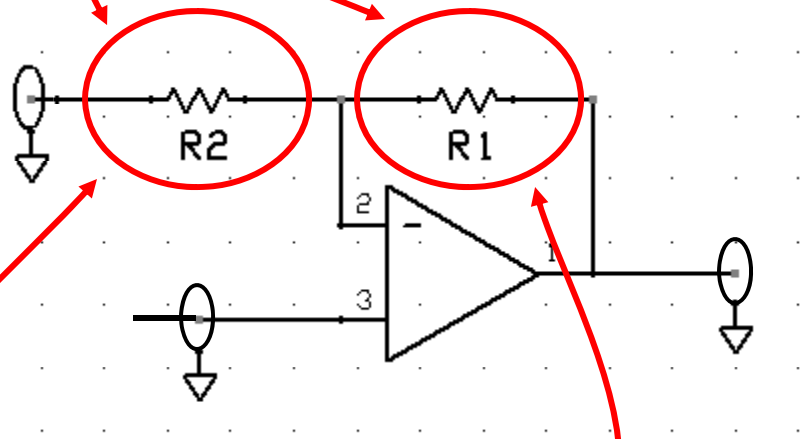
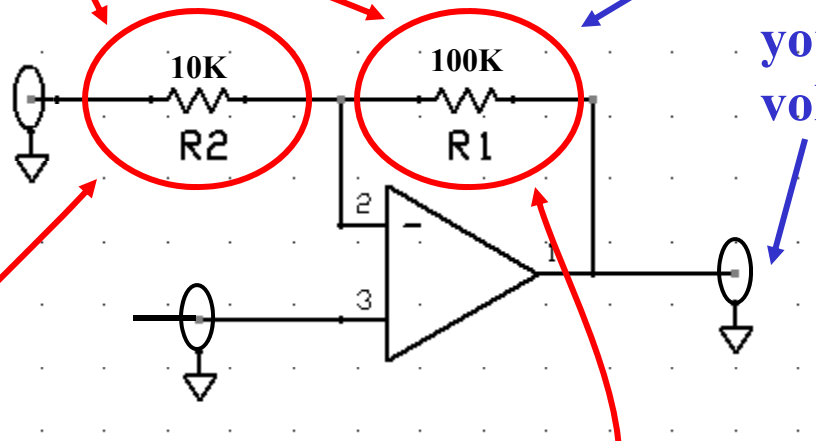


same resistors!

non-inverting-side gain is
R1/R2 + 1

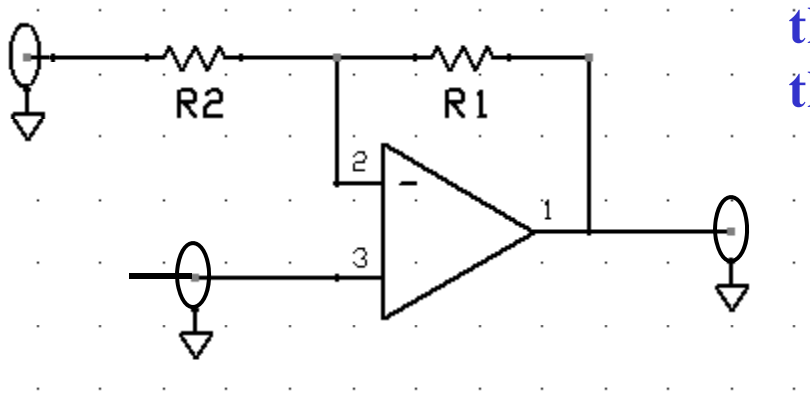
inverting-side gain is
R1/R2



How to remember that R1 is on top…
The bigger one is closer to the output because you want "more" voltage there.

non-inverting-side gain is
R1/R2 + 1

inverting-side gain is
R1/R2

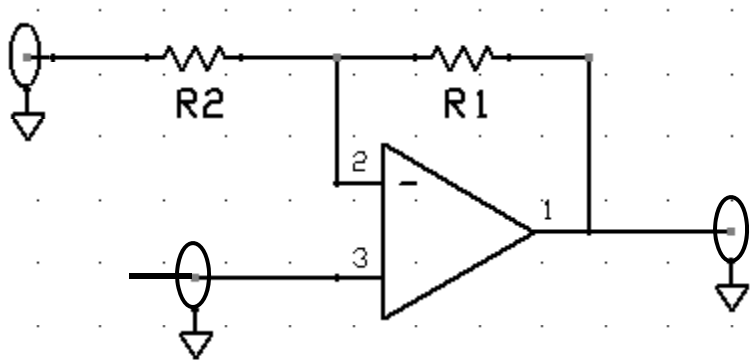


Another Trick

Note that if R2 is larger, the gain is less than one. Sometimes that's handy.

non-inverting-side gain is
R1/R2 + 1

inverting-side gain is
R1/R2



Another Trick

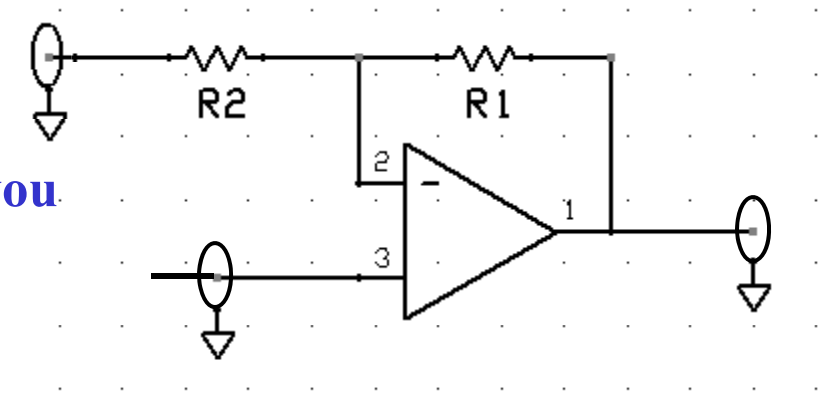
Note that if R2 is larger, the gain is less than one. Sometimes that's handy.

But the "+1" means you can never use that trick here.

non-inverting-side gain is
R1/R2 + 1

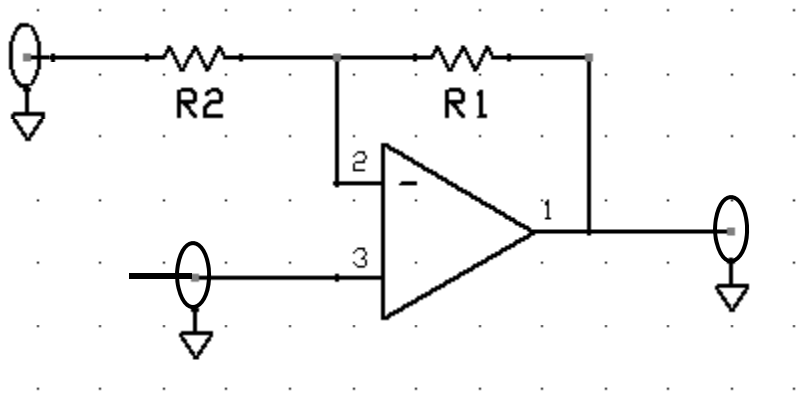
inverting-side gain is
R1/R2

How to remember which one has the +1 …
The non-inverting use the " + " side. That will remind you to "+" 1



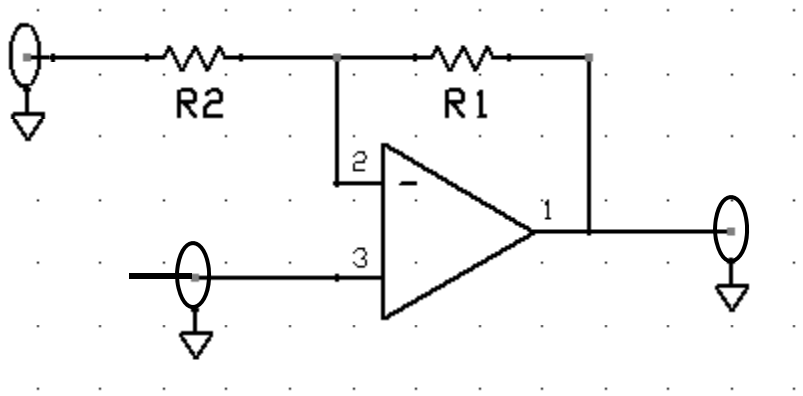
non-inverting-side gain is
R1/R2 + 1

You can either memorize R1/R2 and R1/R2 + 1



You can either memorize R1/R2 and R1/R2 + 1

Or derive R1/R2 and R1/R2 + 1 from the traditional “Golden Rules”



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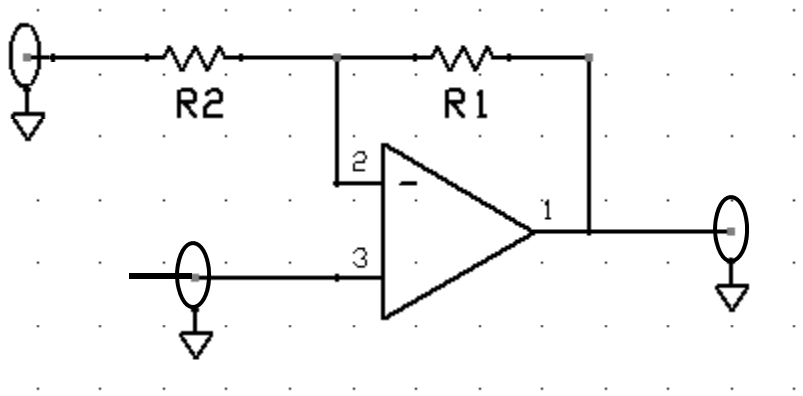
Golden Rules

1. the minus tries to be what the plus is
2. neither input draws current



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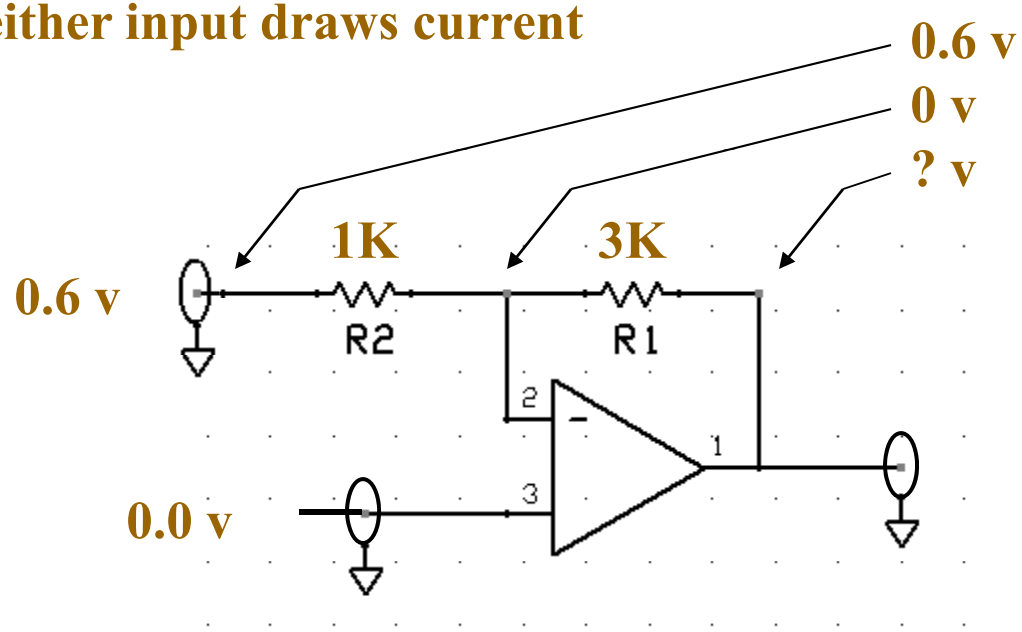

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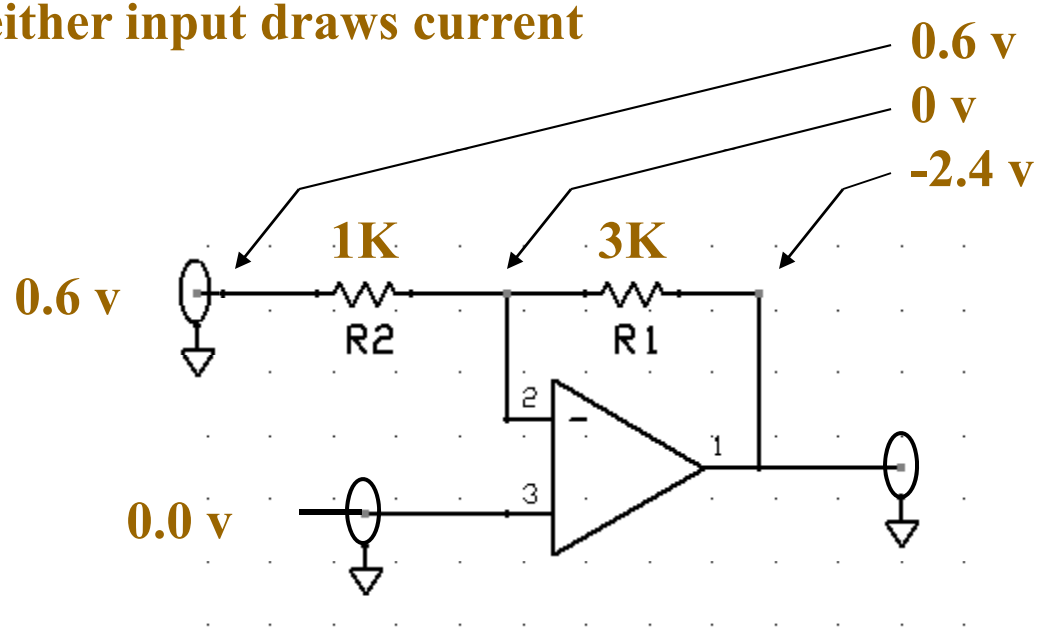

If you put +0.6 v to the inverting input, according to Rule 1, the minus input wants to be 0. So the output has to go past zero to -2.4 V to get the - input to be the same as the + input.

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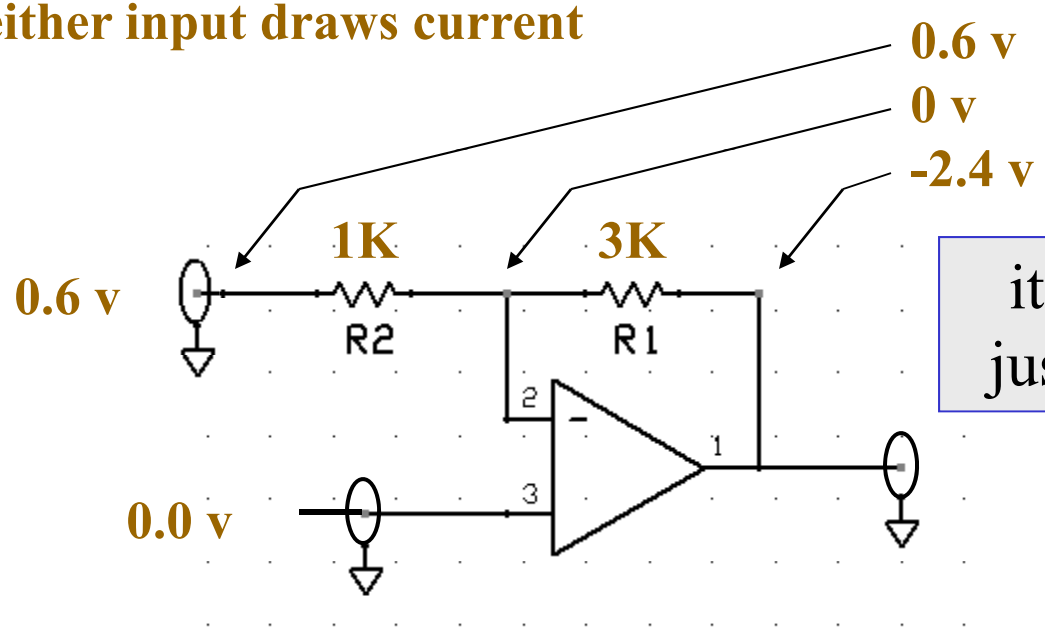

it is easier to just memorize

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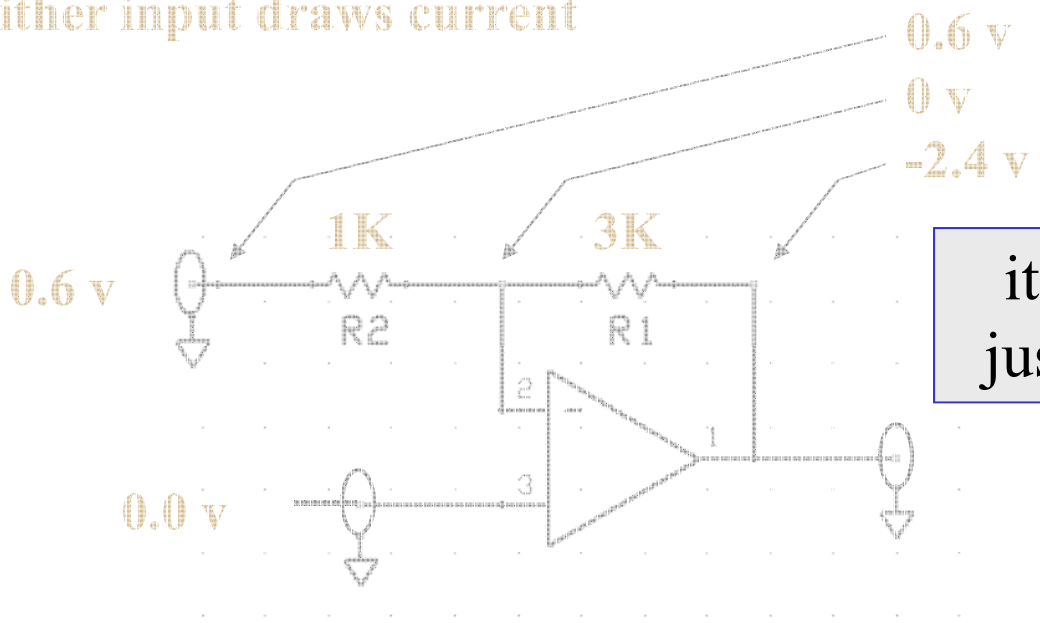

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There's a 3rd traditional Golden Rule…

Golden Rules

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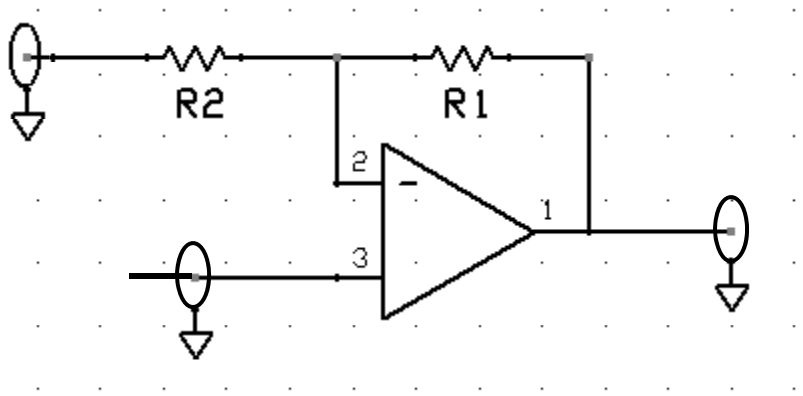
3.



There's a 3rd traditional Golden Rule…

Golden Rules

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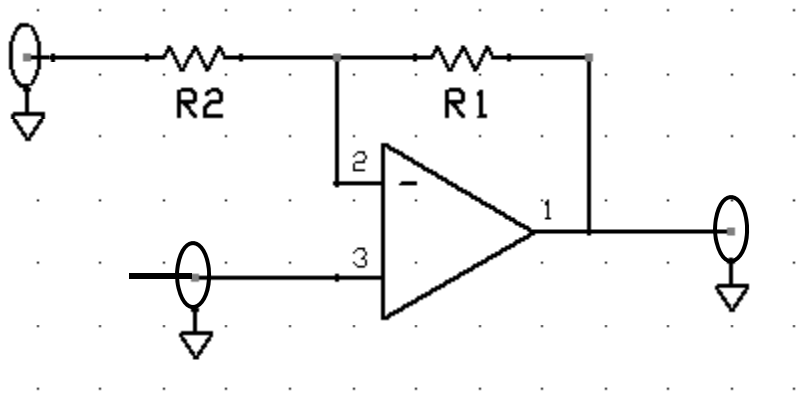
2. **neither input draws current**
3. **but the minus "acts" like it is zero impedance to ground**



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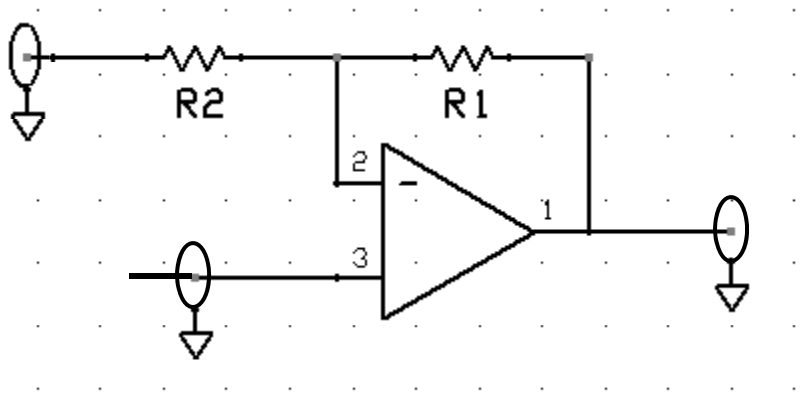
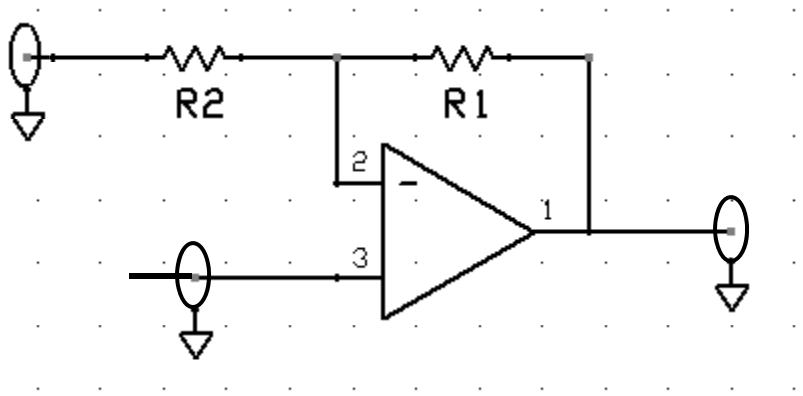


The current comes out of (or goes into) the output of course.

There's a 3rd traditional Golden Rule…

Golden Rules

1. **the minus tries to be what the plus is**
2. **neither input draws current**
3. **but the minus "acts" like it is zero impedance to ground**



The consequence of this rule is that the impedance the source sees is equal to R2.

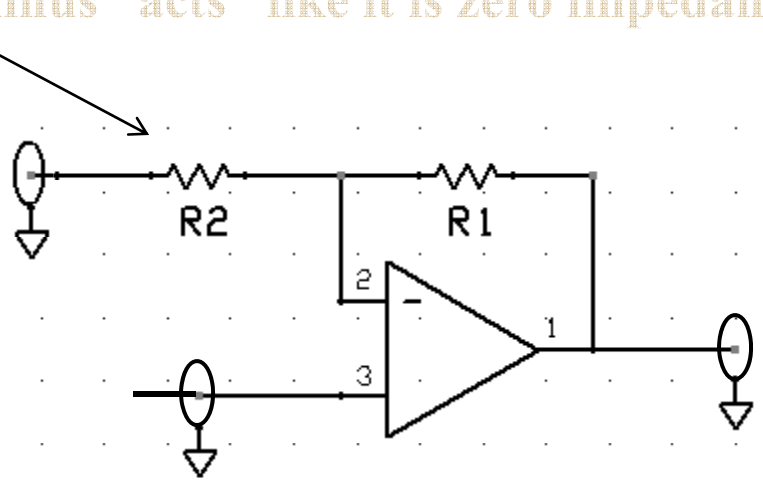
The current comes out of (or goes into) the output of course.

There's a 3rd traditional Golden Rule…

Golden Rules

If the source is high impedance, it won't create much of voltage drop here. . .

3. but the minus "acts" like it is zero impedance



The consequence of this rule is that the impedance the source sees is equal to R2.

for the amplifier to sense.

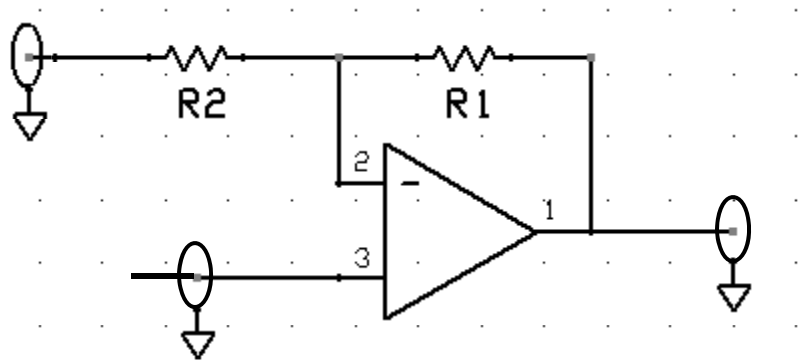
The amplifier will seem to have low gain.

Time Out

It can be confusing when the word “impedance” is used as if it was signal.

Two Tricks:

- think upside down and
- exaggerate



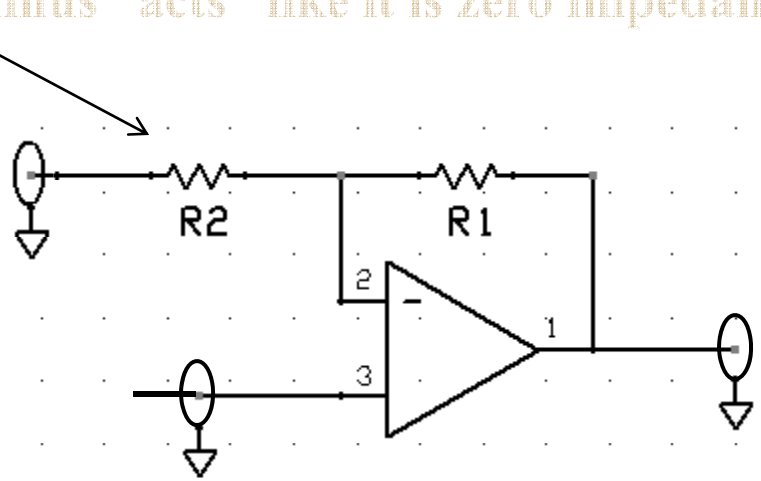
A low impedance source means it will provide that voltage no matter what. A high impedance source will be unable to maintain that voltage if the load (R2 here) is low. (R2 would draw down the source lowering its voltage.)

There's a 3rd traditional Golden Rule…

Golden Rules

If the source is high impedance, it won't create much of voltage drop here. . .

3. but the minus "acts" like it is zero impedance



The consequence of this rule is that the impedance the source sees is equal to R2.

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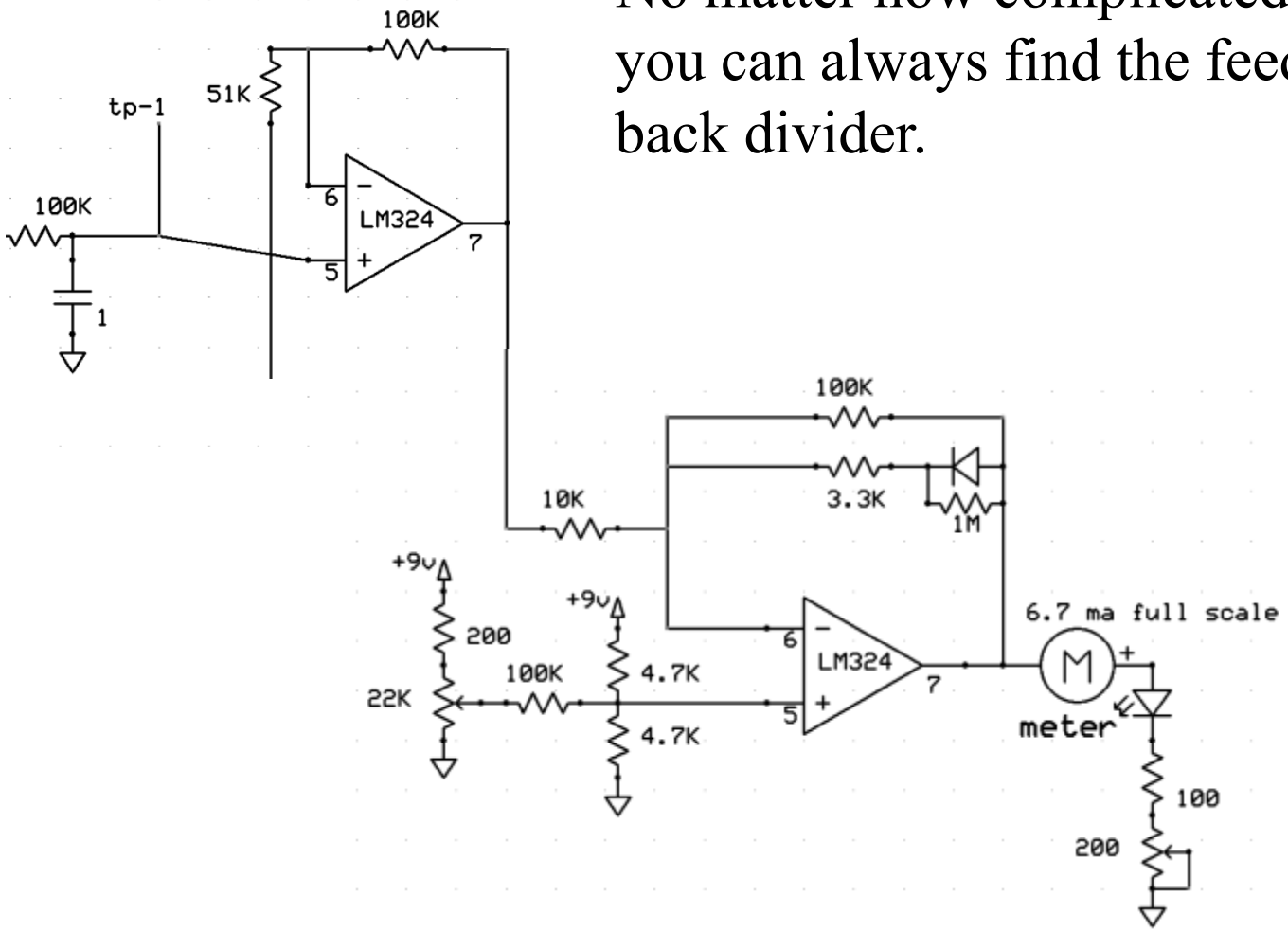
No matter how complicated… you can always find the feed-back divider.



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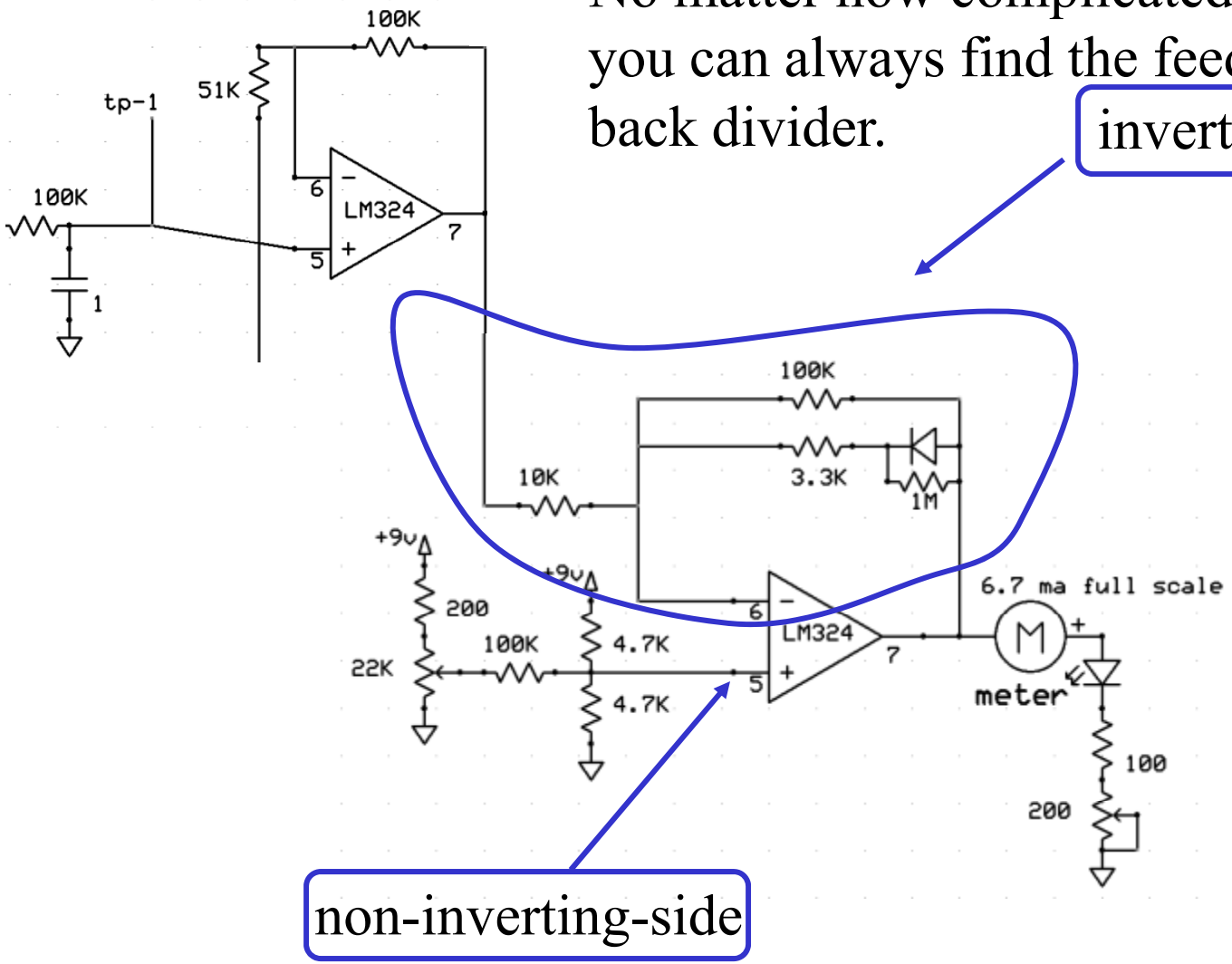
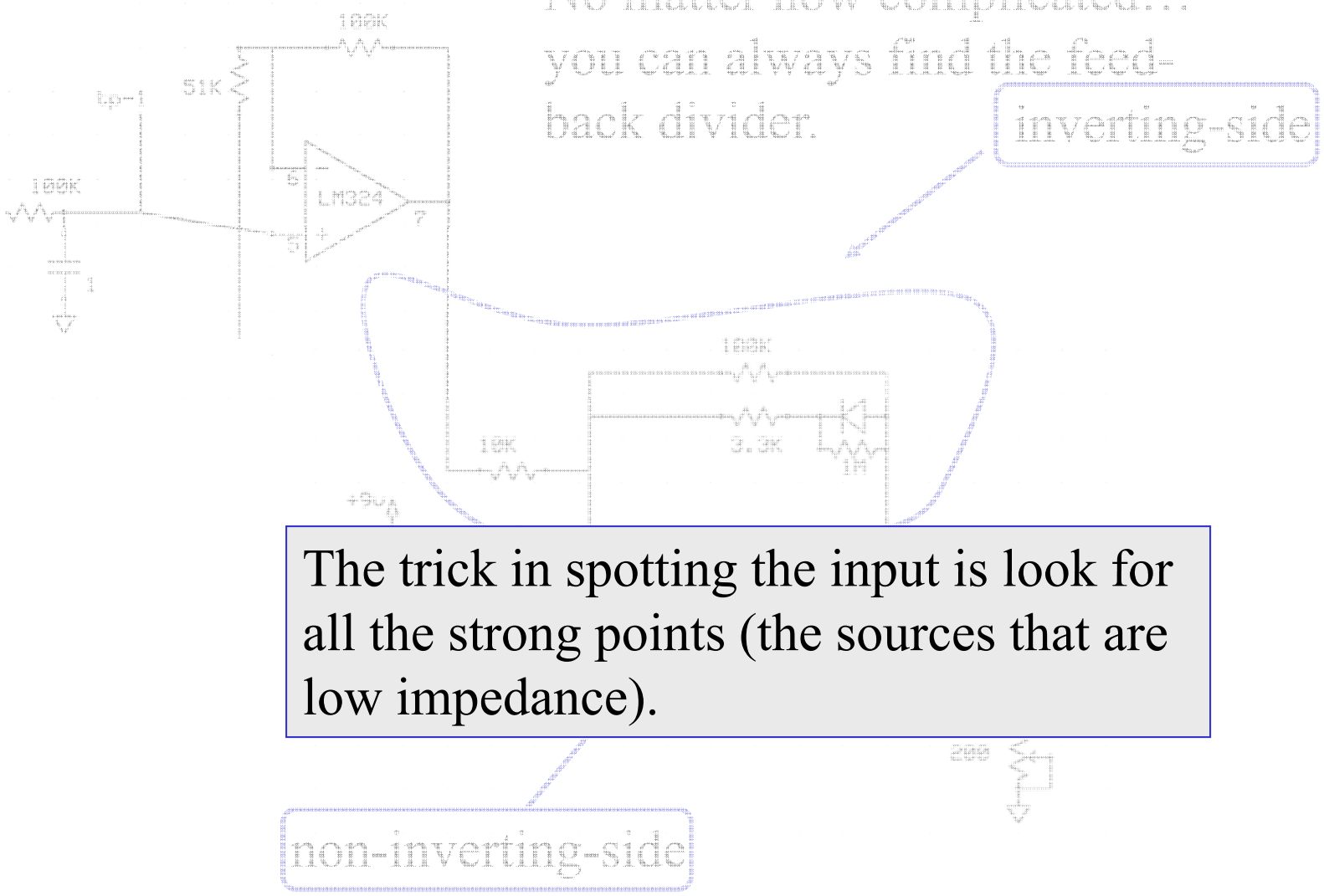
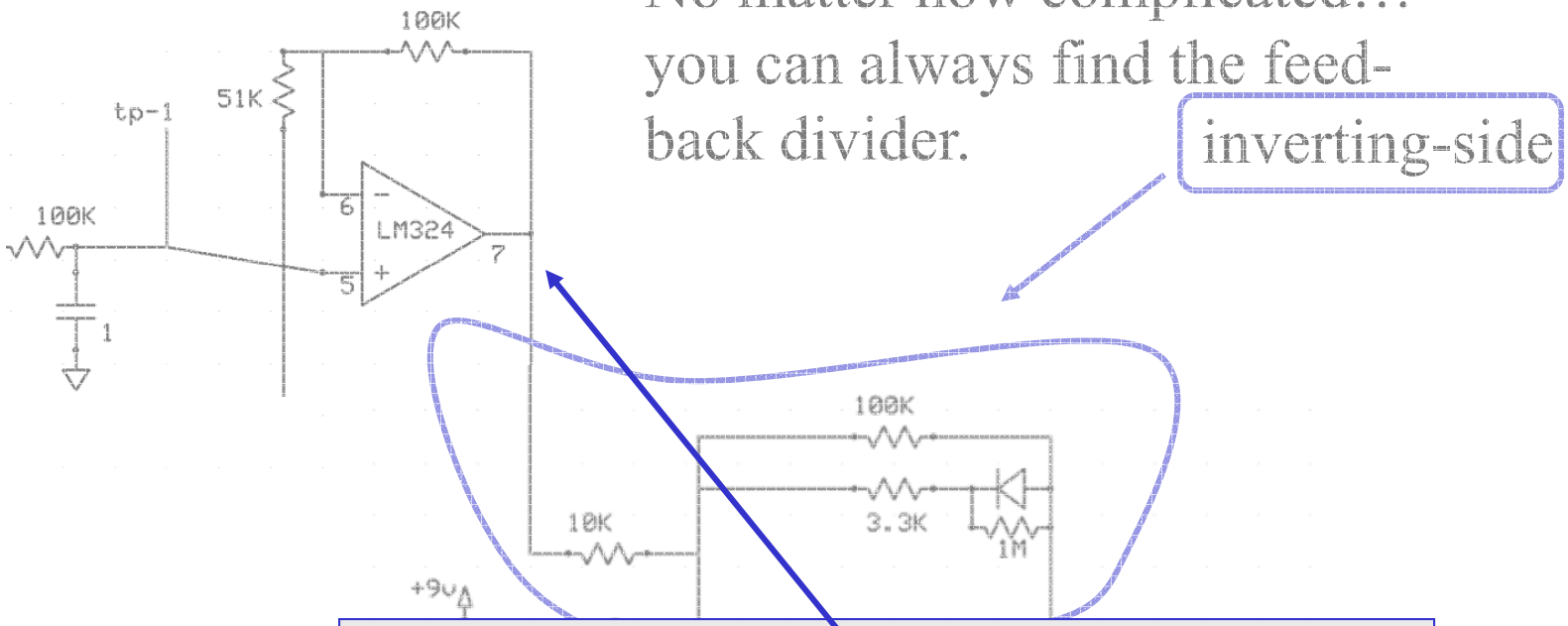




The trick in spotting the input is look for all the strong points (the sources that are low impedance).

No matter how complicated… you can always find the feed-back divider.



inverting-side

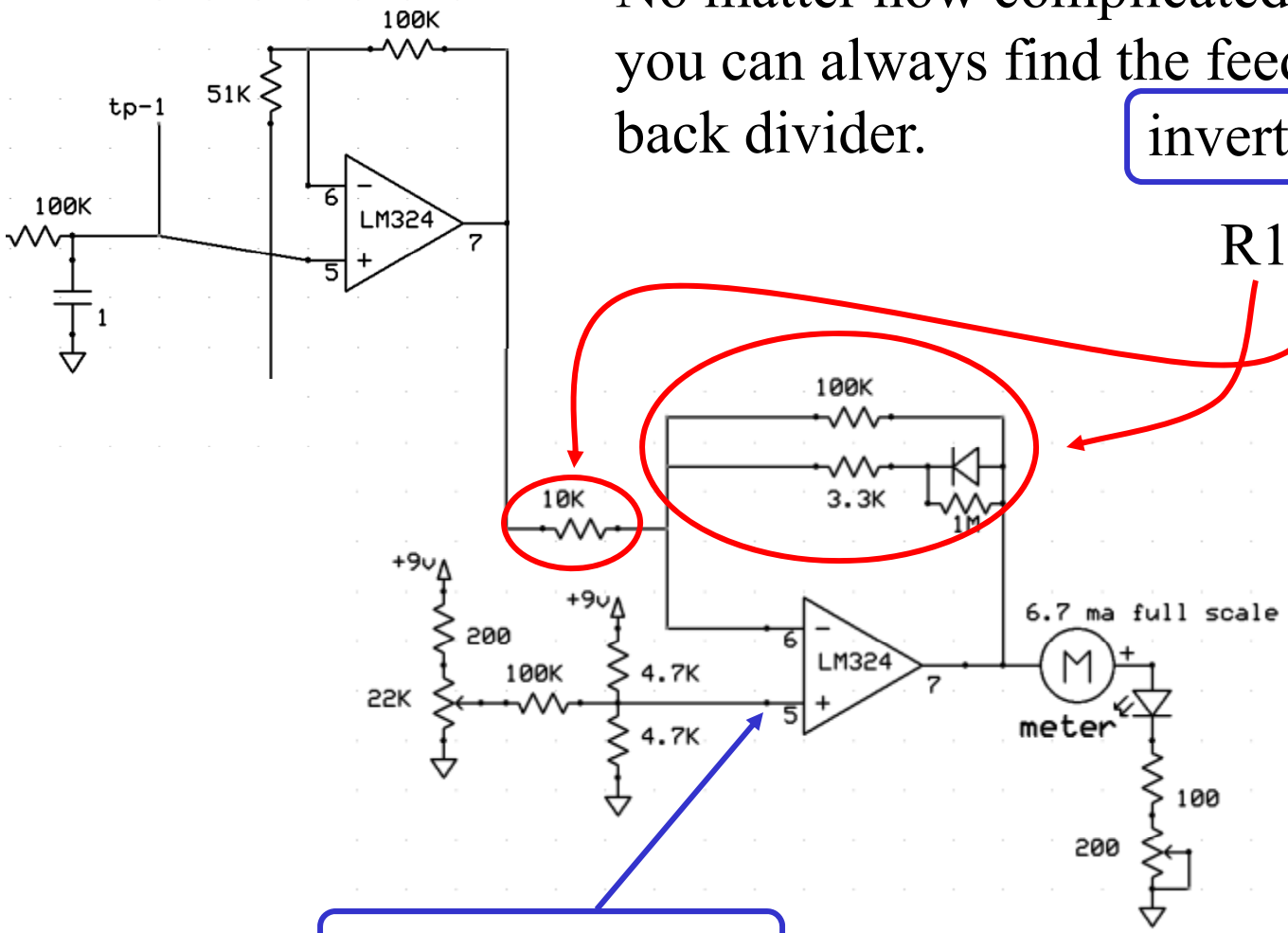
The trick in spotting the input is look for all the strong points (the sources that are low impedance). The output of an opamp is low impedance.

non-inverting-side

No matter how complicated…
you can always find the feed-
back divider.

inverting-side

R1/R2



non-inverting-side

R1/R2 + 1

No matter how complicated…
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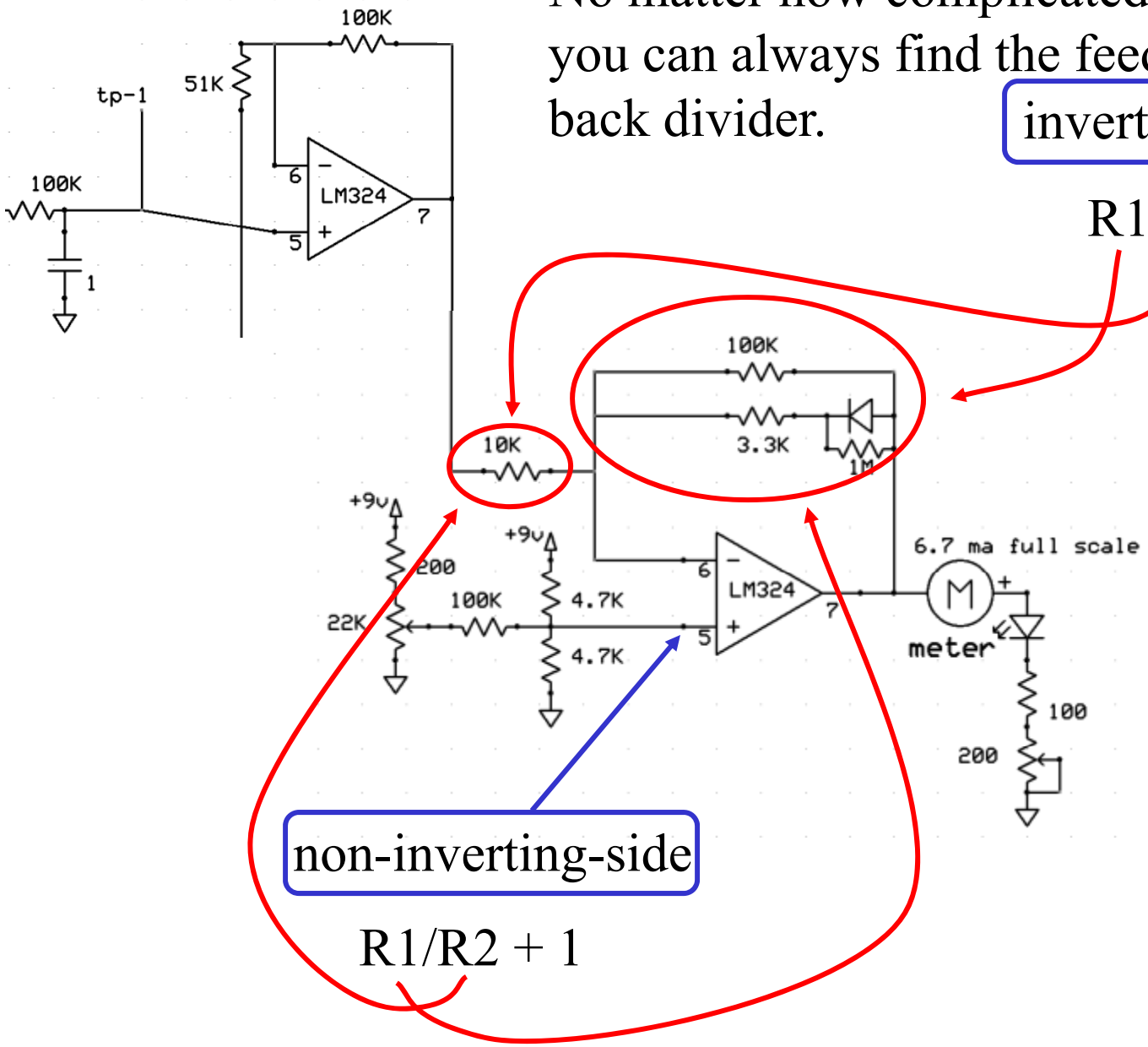
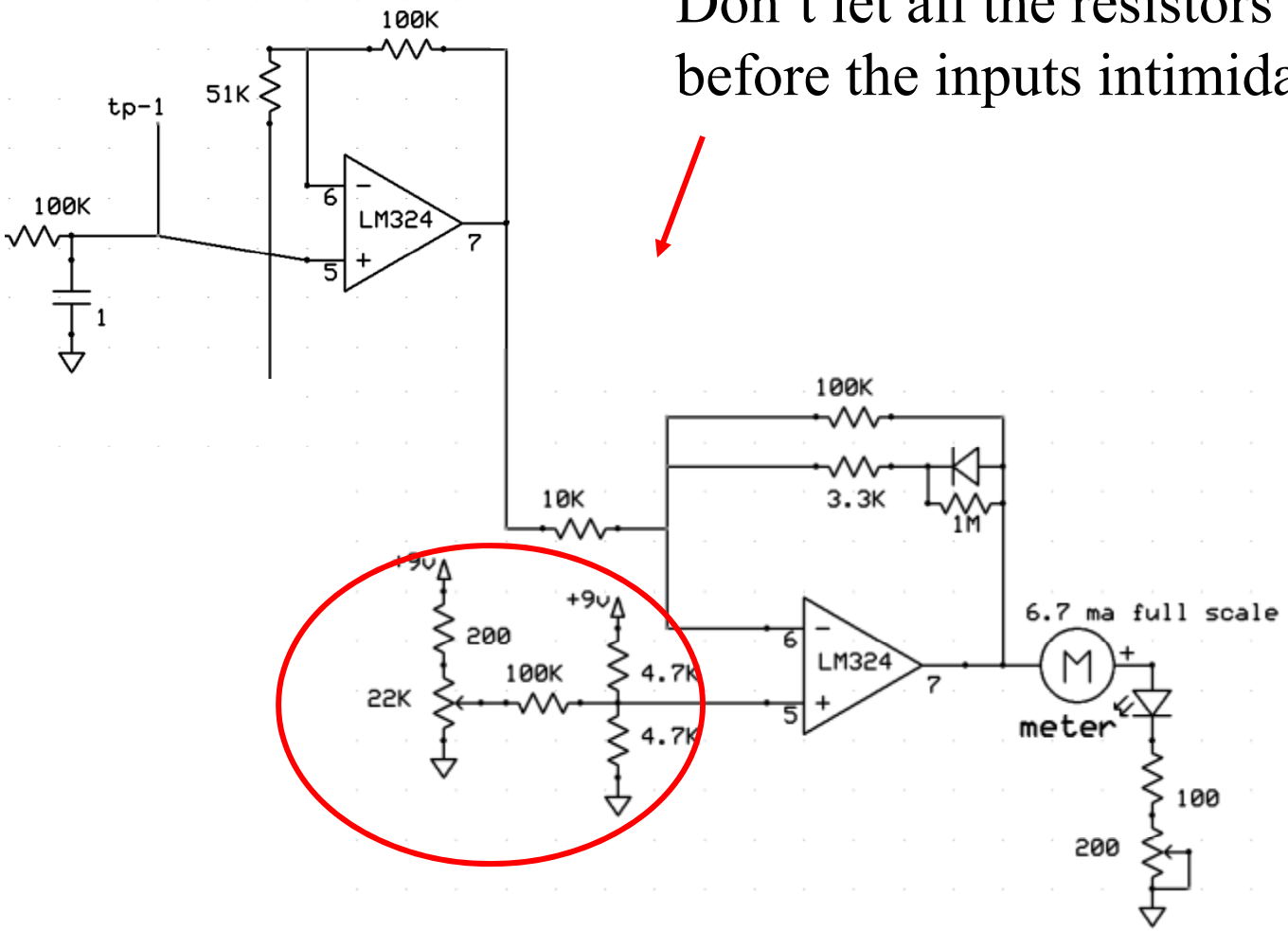
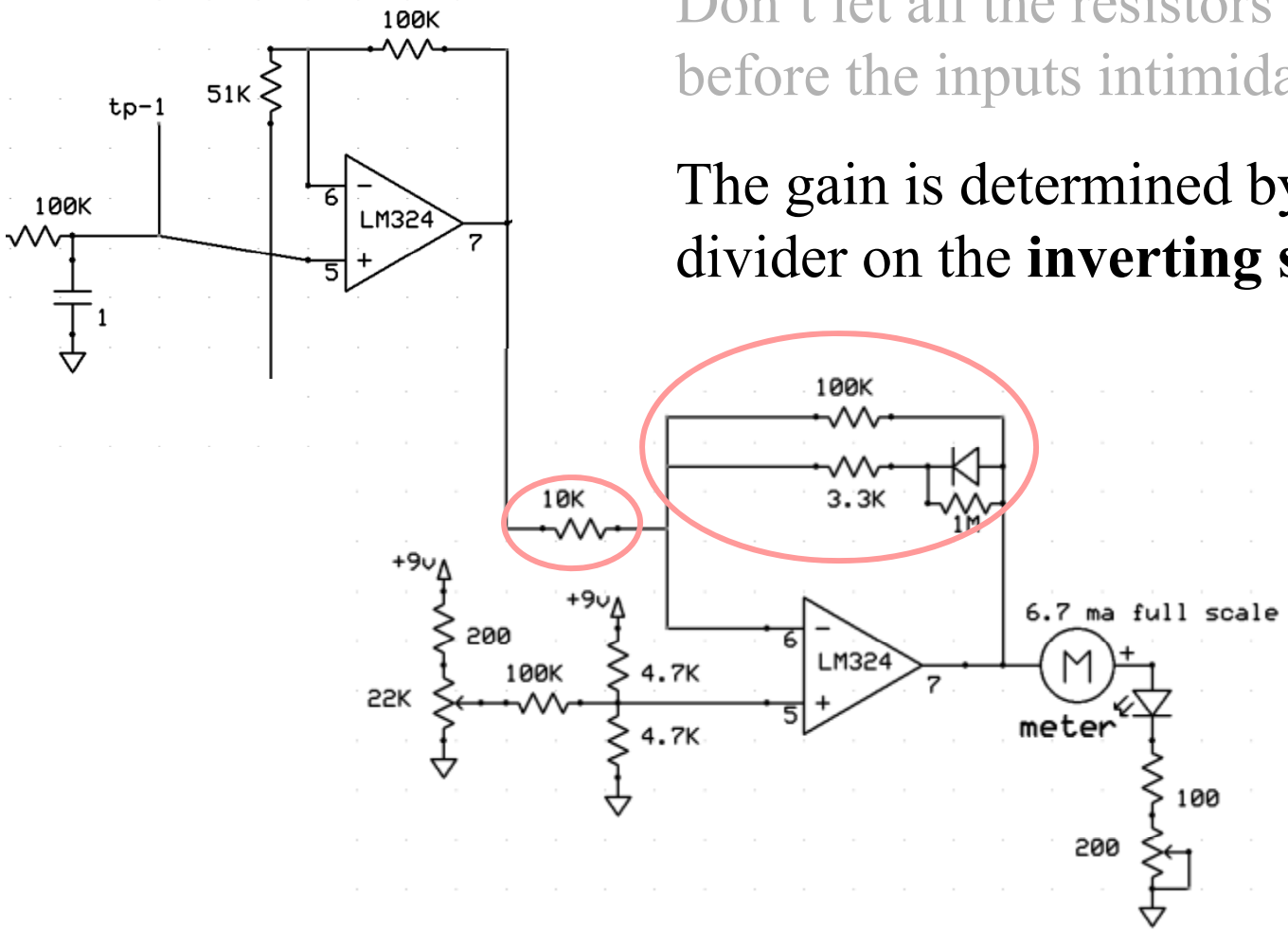


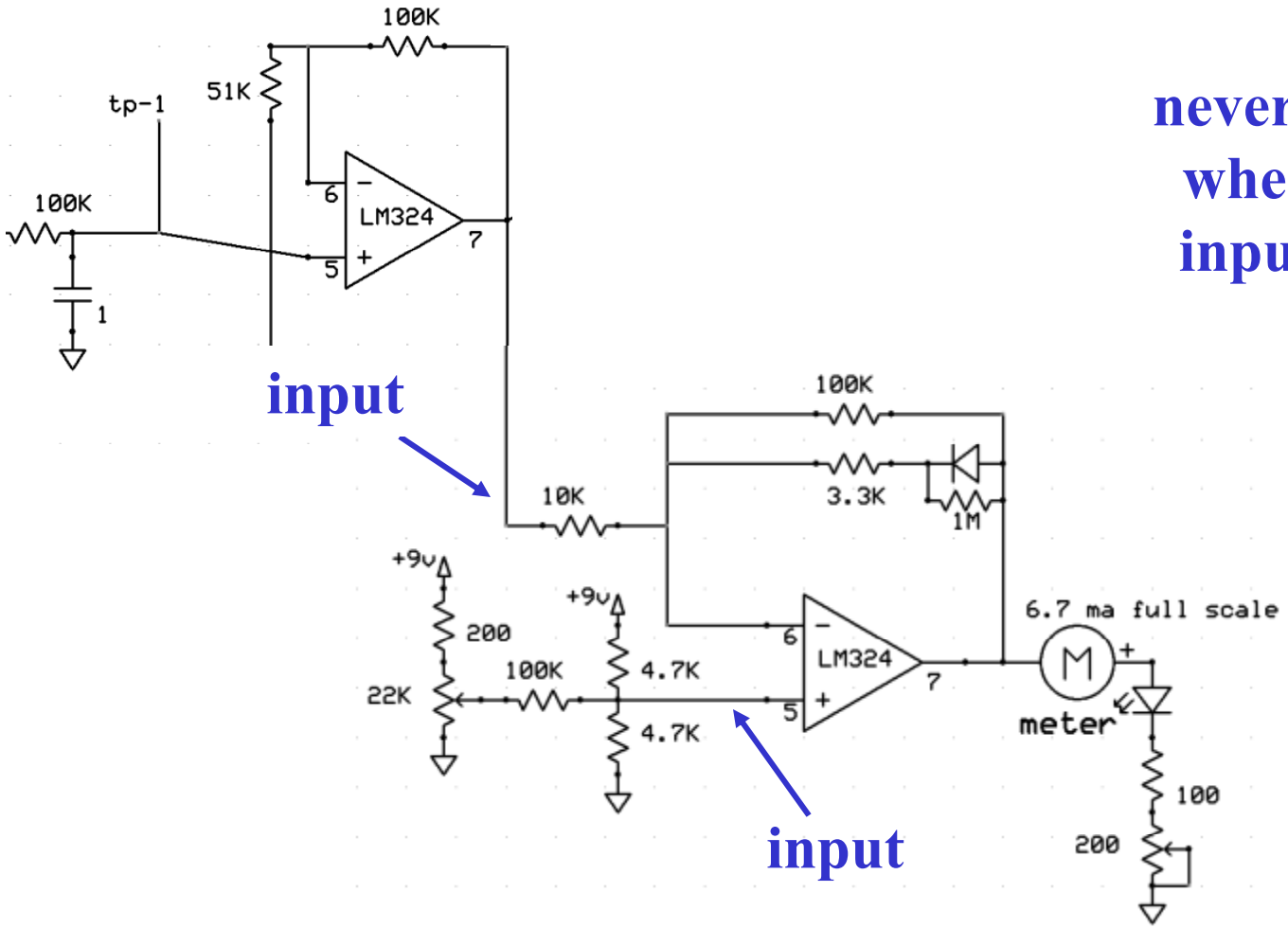
Don’t let all the resistors that come before the inputs intimidate you.



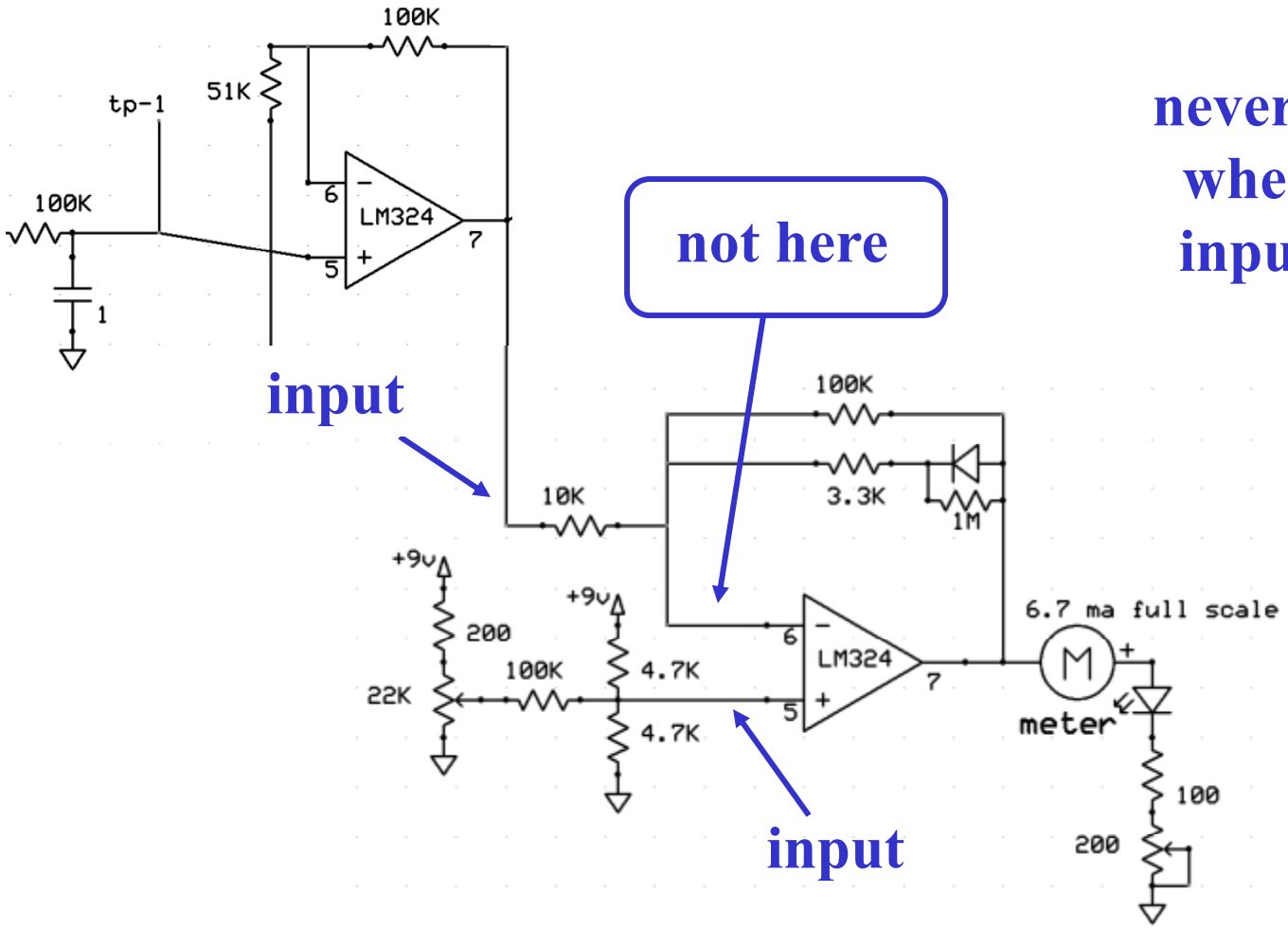


Don’t let all the resistors that come before the inputs intimidate you.

The gain is determined by the voltage divider on the **inverting side**.



never forget where the inputs are



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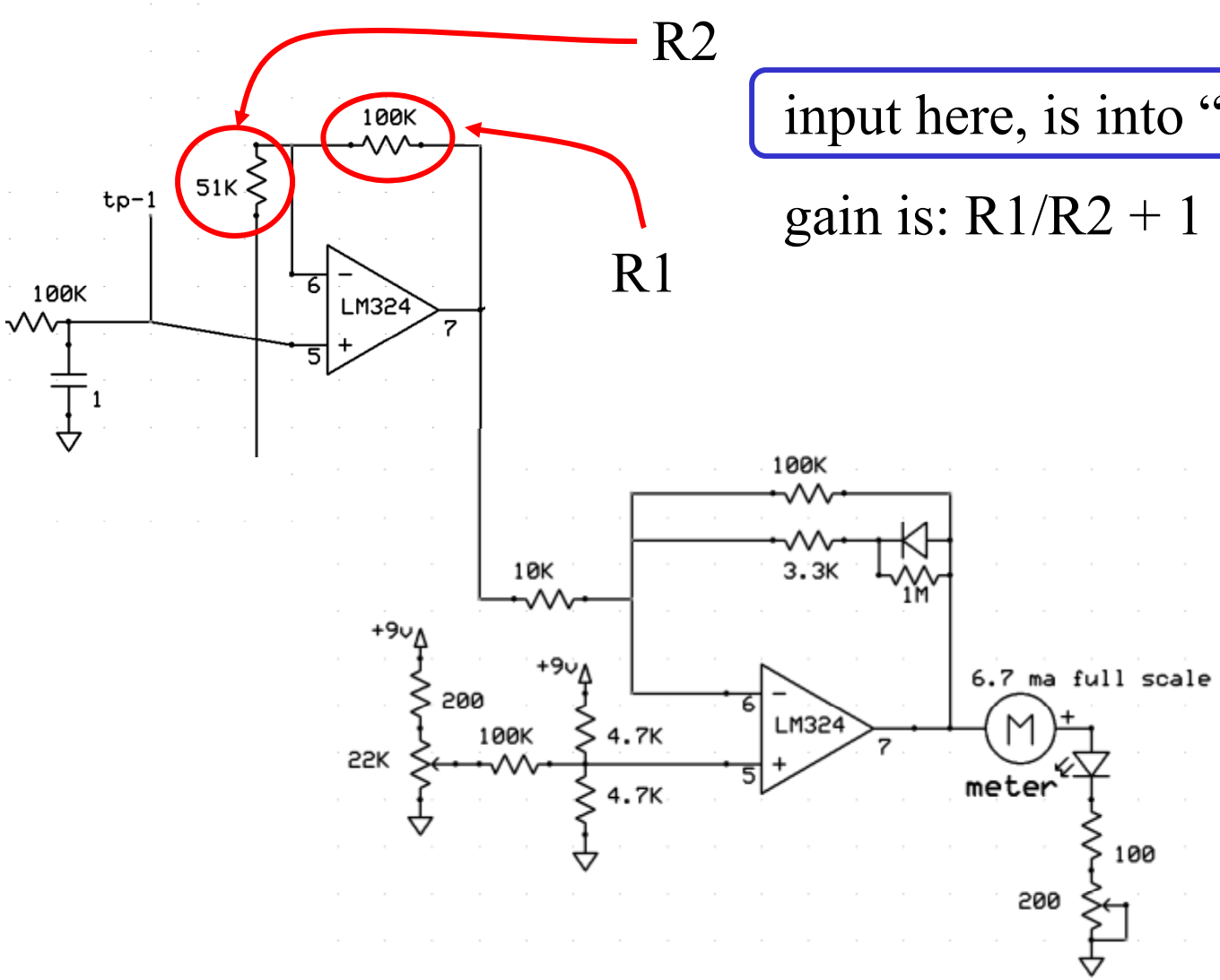
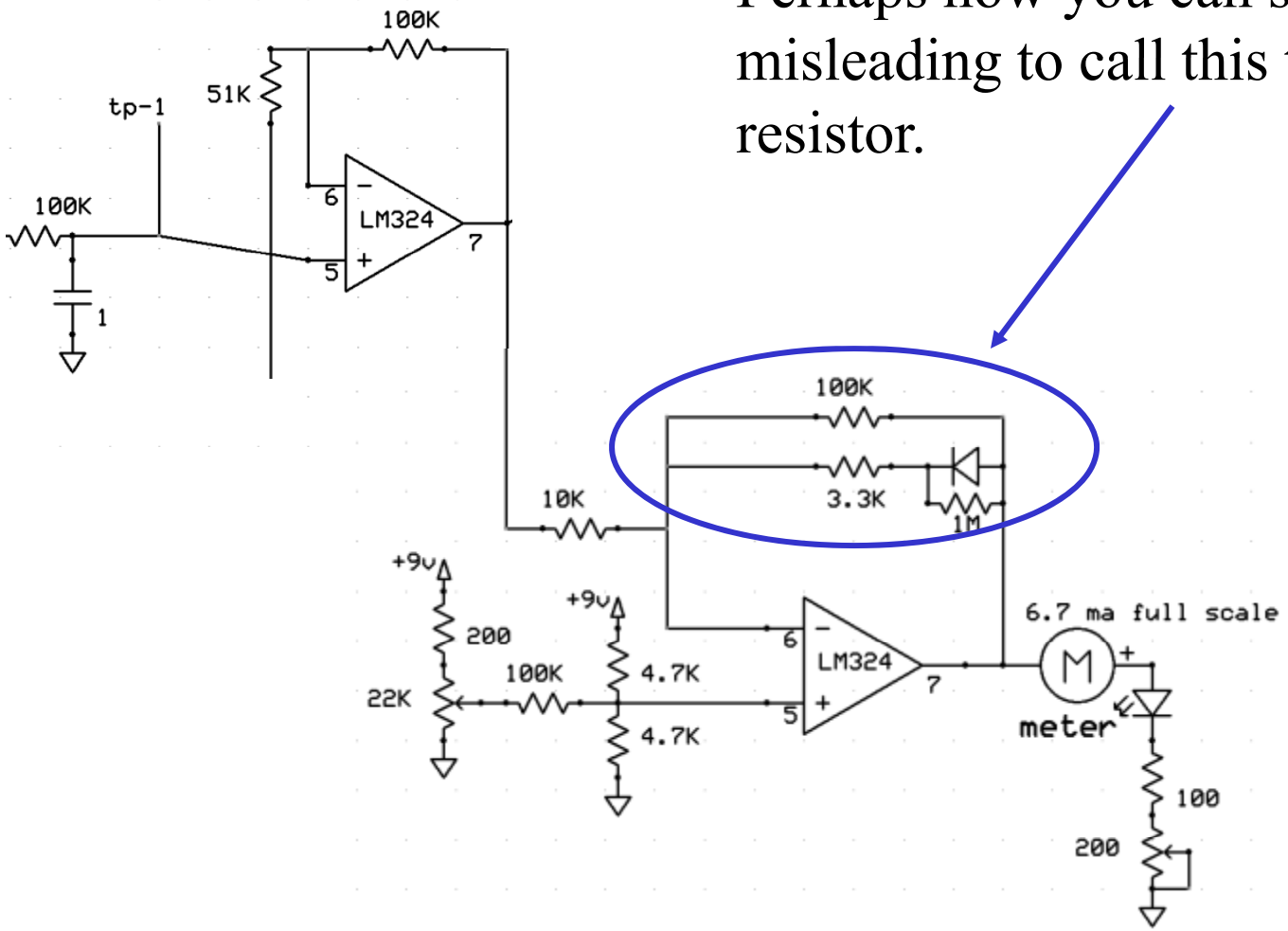
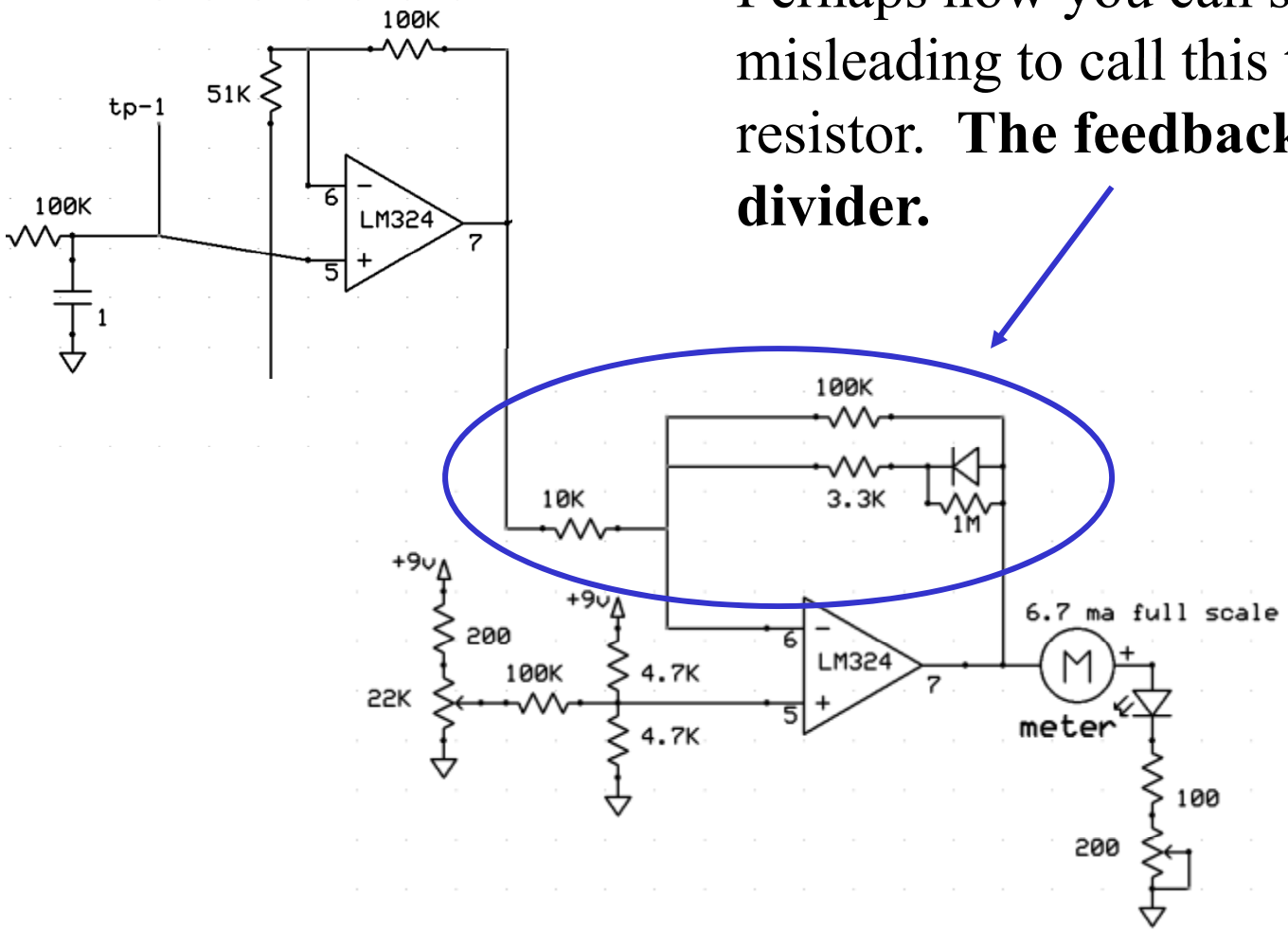


input here, is into “non” inverting

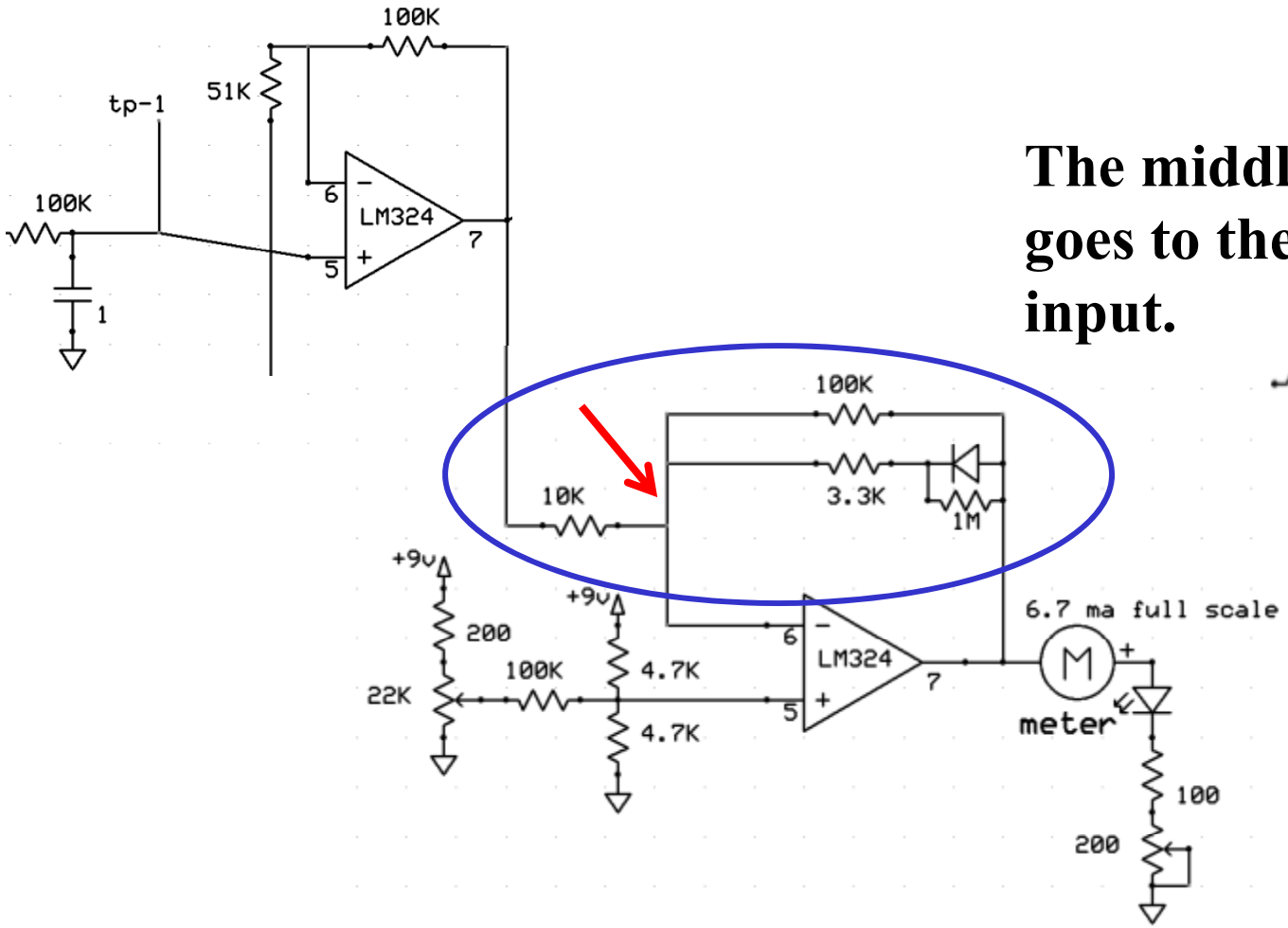
gain is: R1/R2 + 1

Perhaps now you can see why it is misleading to call this the “feedback” resistor.

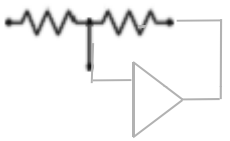


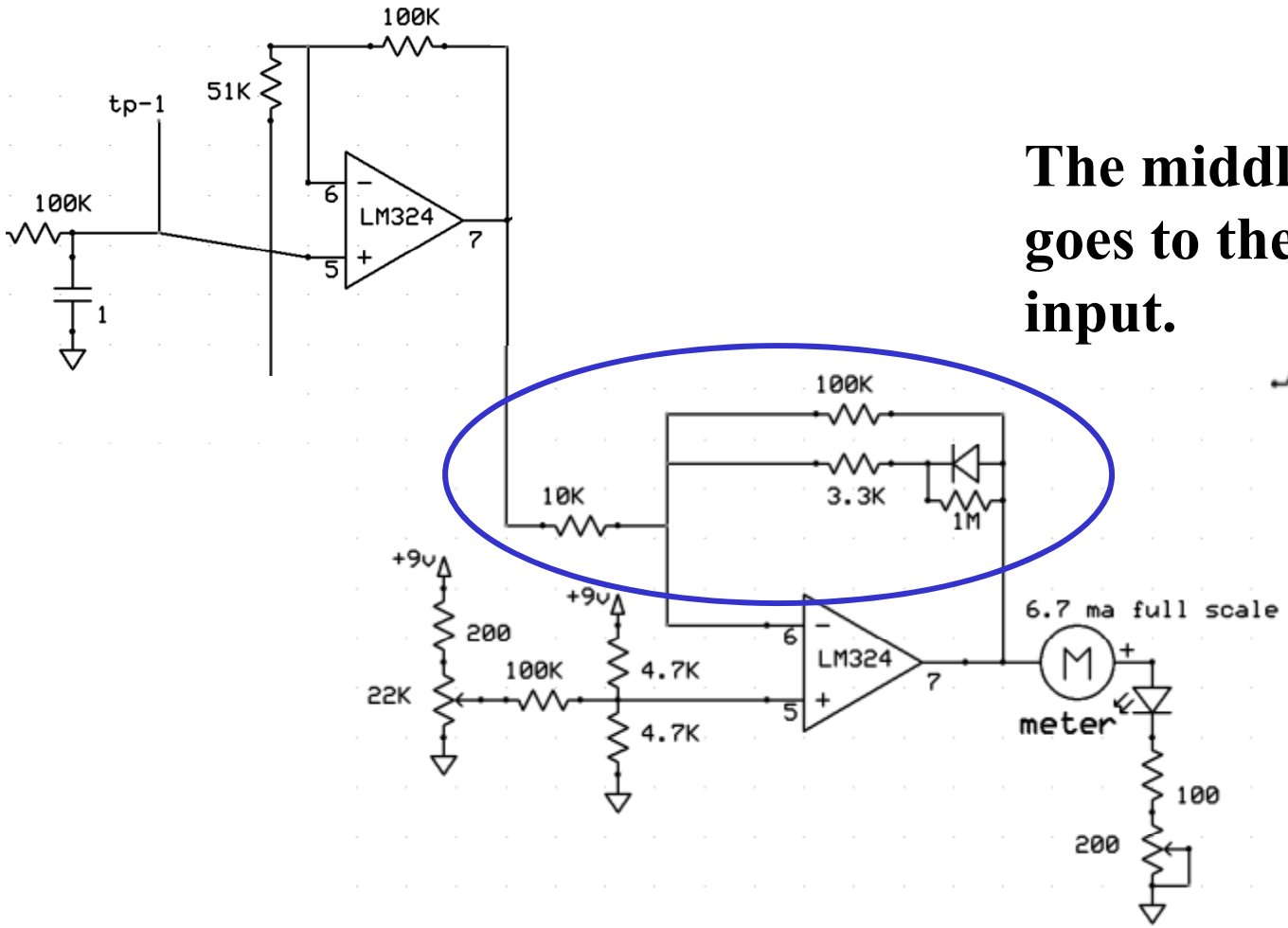


Perhaps now you can see why it is misleading to call this the “feedback” resistor. **The feedback is a voltage divider.**



The middle of the divider goes to the inverting input.





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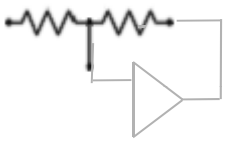


If the voltage in the middle of the divider is 1/10th of the output side, that means the output has to change a factor of ten more than the input to balance the opamp inputs.

Traditional Golden Rules

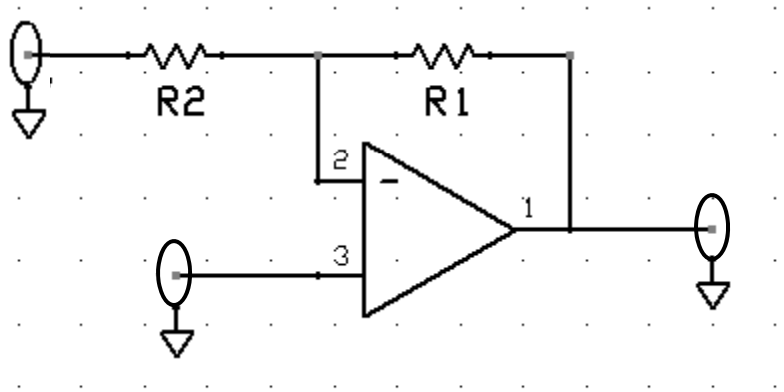
1. the minus tries to be what the plus is
2. neither input draws current
3. the minus input “acts” like a dead short to ground

Used to Derive Formulas

The More Useful Rules

The More Useful Rules

inverting
R1/R2 and non-inverting R1/R2 + 1 ← merely memorize

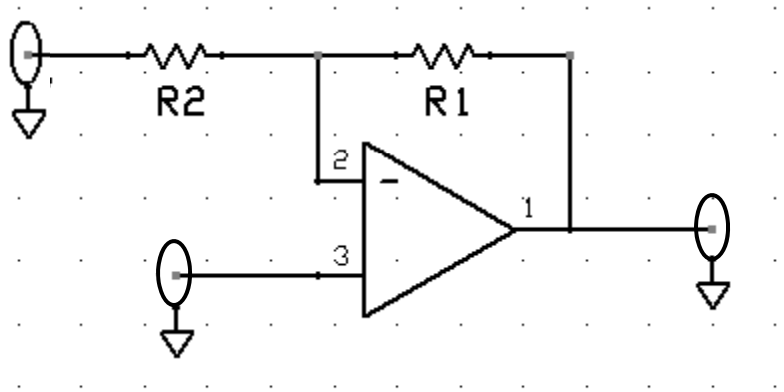


The More Useful Rules

- the resistors in the gain calculation are those connected to the inverting side…

inverting non-inverting

R1/R2 and R1/R2 + 1

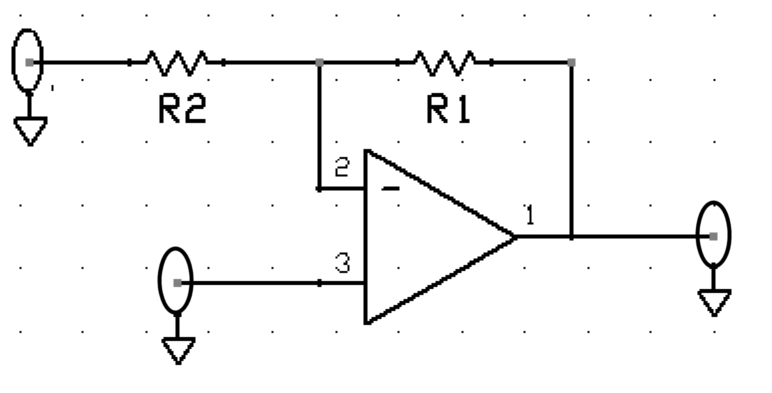


The More Useful Rules

- the resistors in the gain calculation are those connected to the inverting side…

  inverting: R1/R2 and non-inverting: R1/R2 + 1

- the inverting side input is dangling on the end of a resistor.



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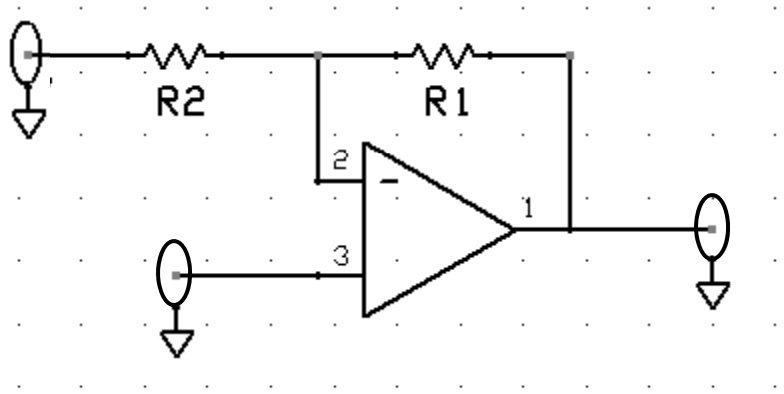

- the output from the inverting input is subtracted from the output from the non-inverting input.

The More Useful Rules

- the resistors in the gain calculation are those connected to the inverting side…

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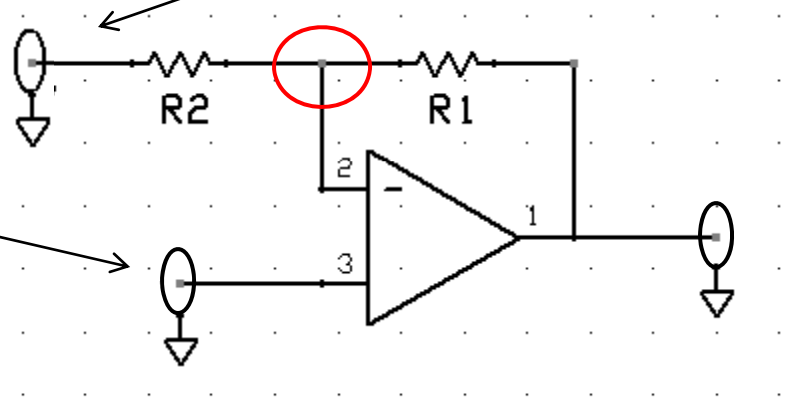
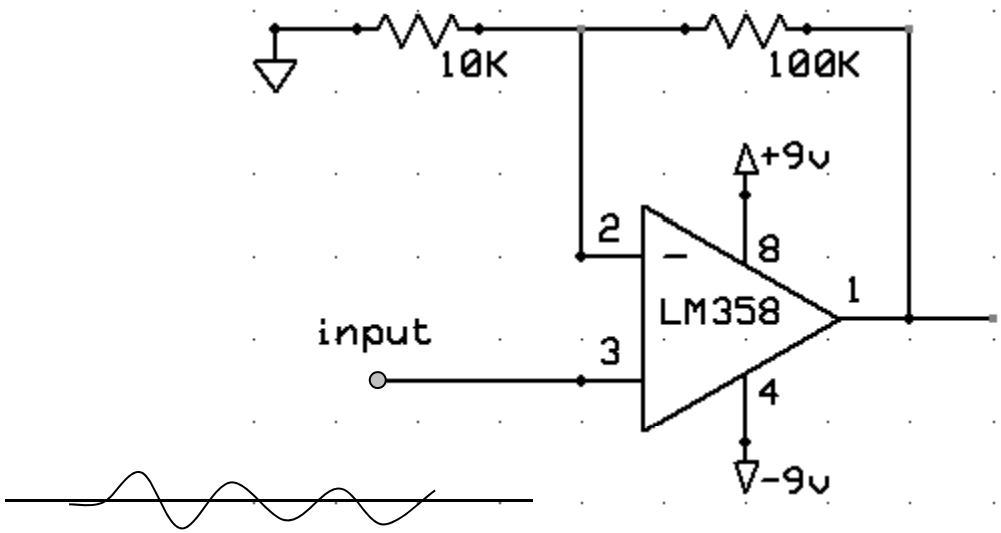


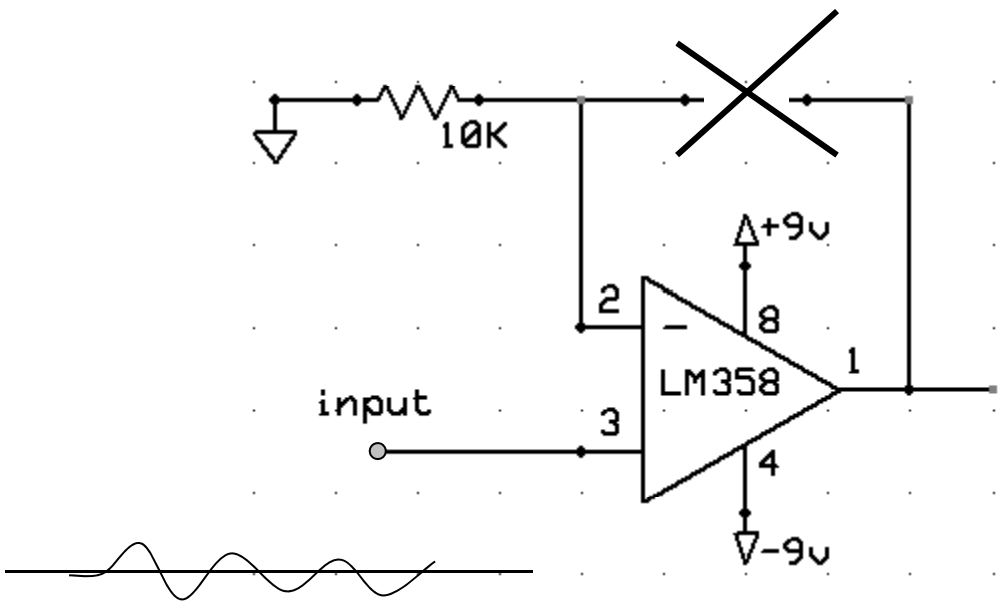
Inverting input impedance = R2

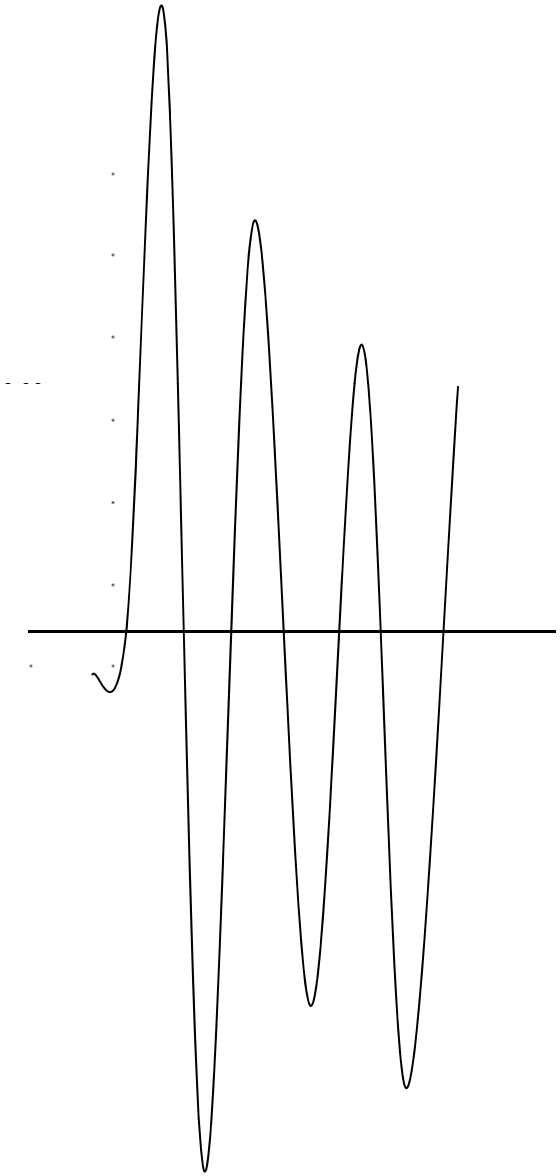
Non-inverting, is like a voltmeter (draws no current)

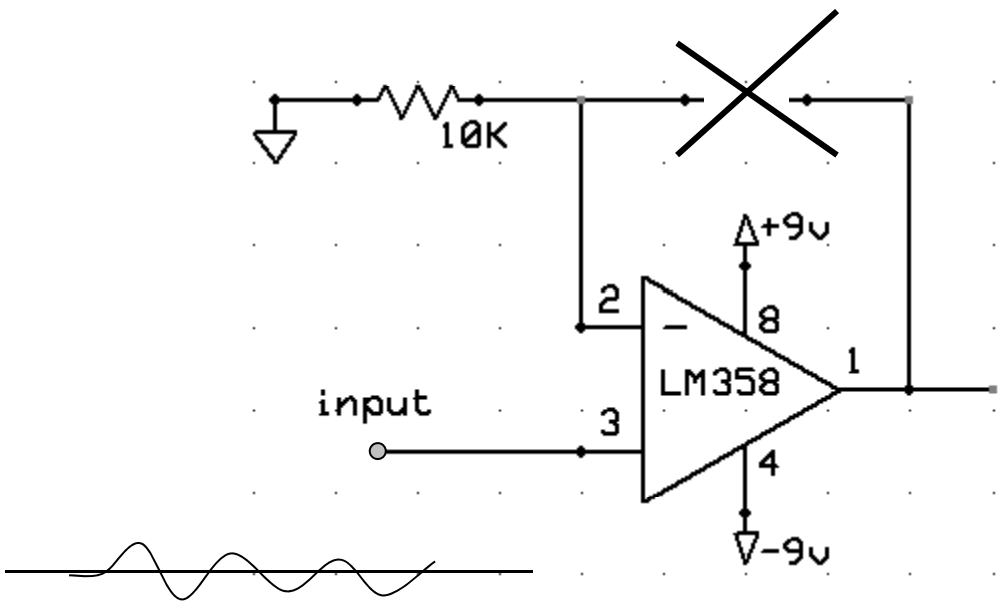
- the output from the inverting input is subtracted from the output from the non-inverting input.

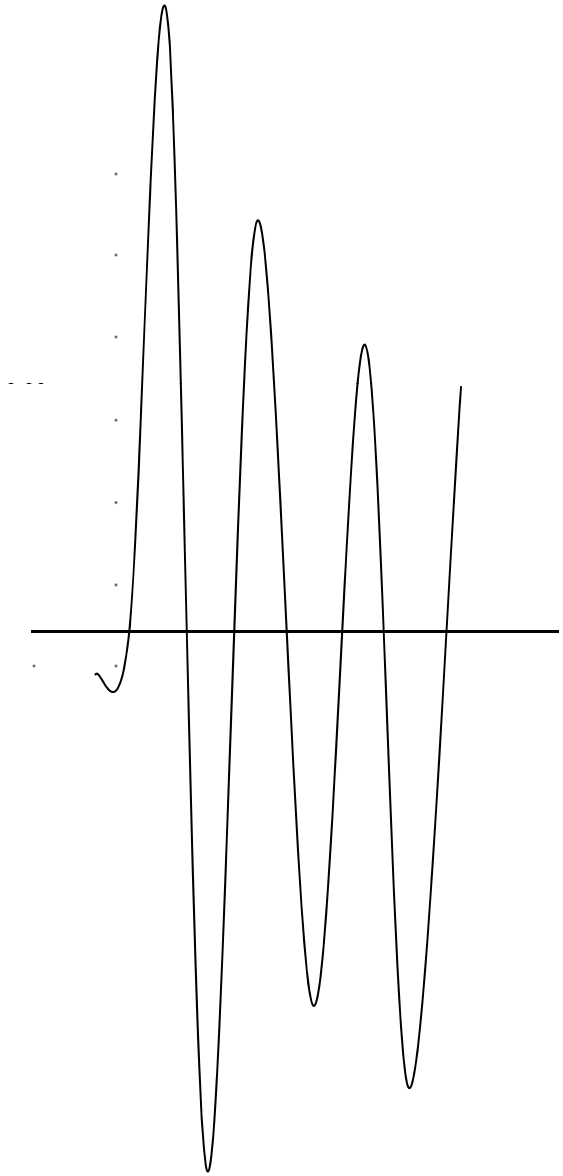


Watch this about the "Normal" Input.


10K
+9v
2
8
1
LM358
input
3
4
-9v





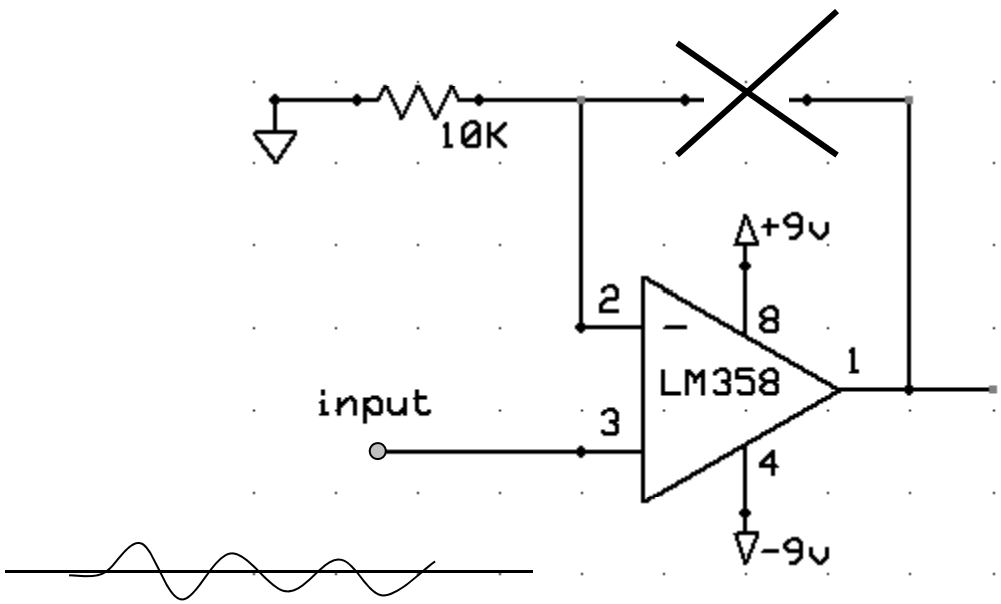


Gain calculation:

$$R1 / R2 + 1$$

$$\infty / R2 + 1$$

$$= \infty$$



Gain calculation:

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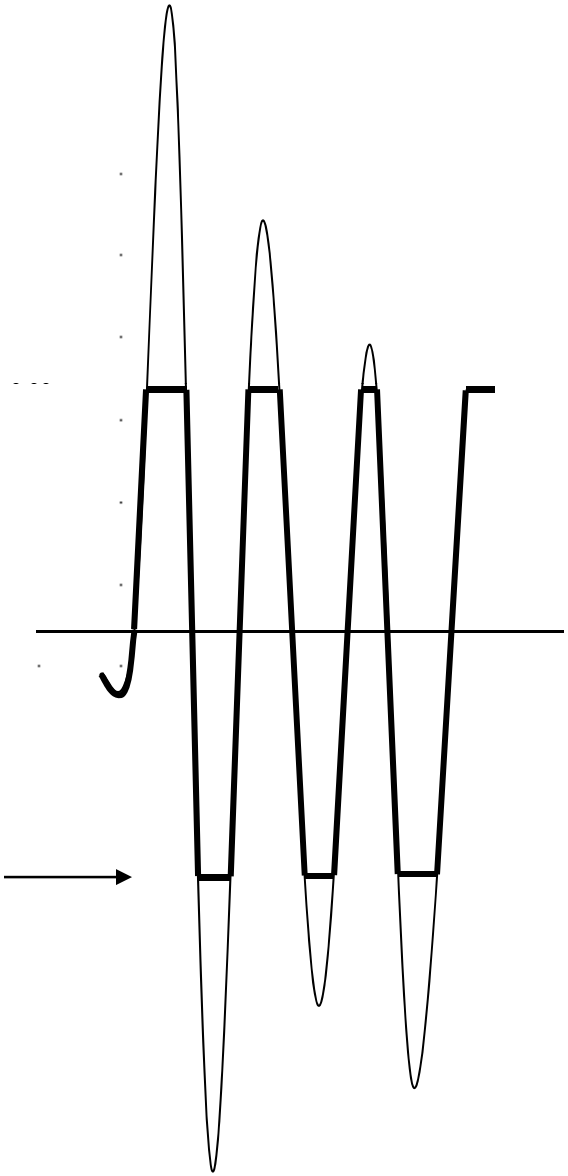
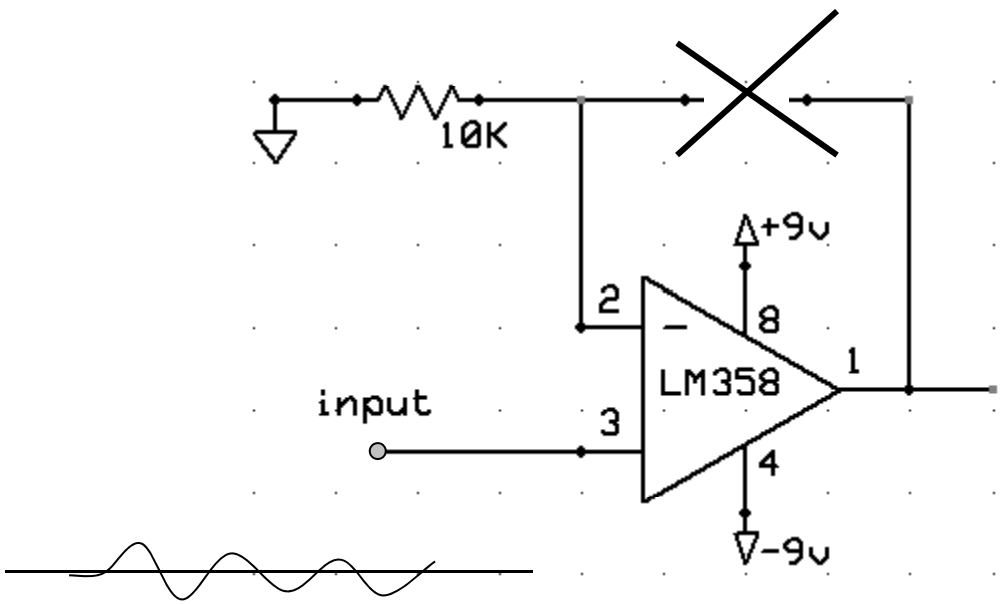
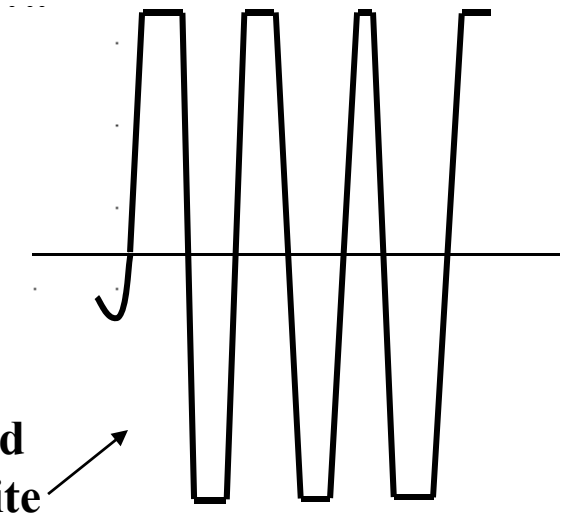
actually, it clips at the plus and minus battery voltage →







Gain calculation:

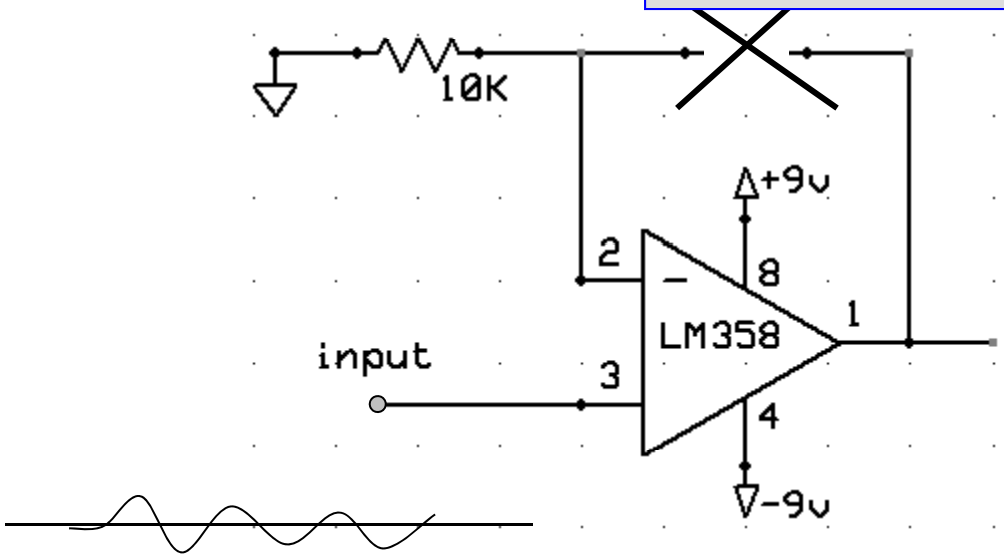
$$R1 / R2 + 1$$

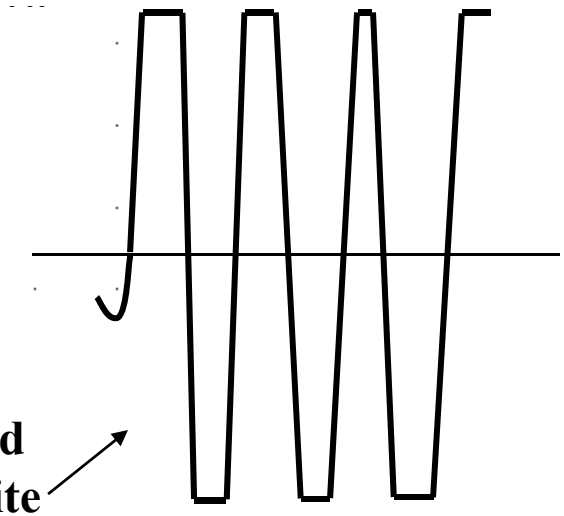
$$\infty / R2 + 1$$

$$= \infty$$

gain is said to be infinite even though it's clipping

not a problem; sometimes very useful… a zero crossing detector





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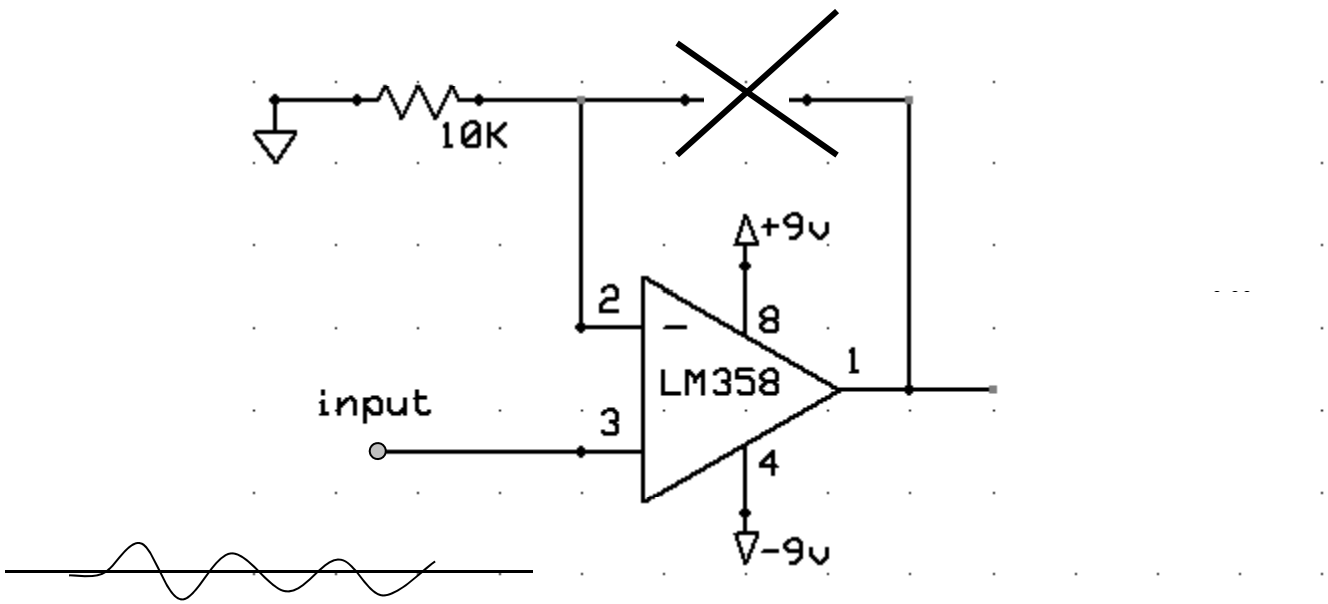

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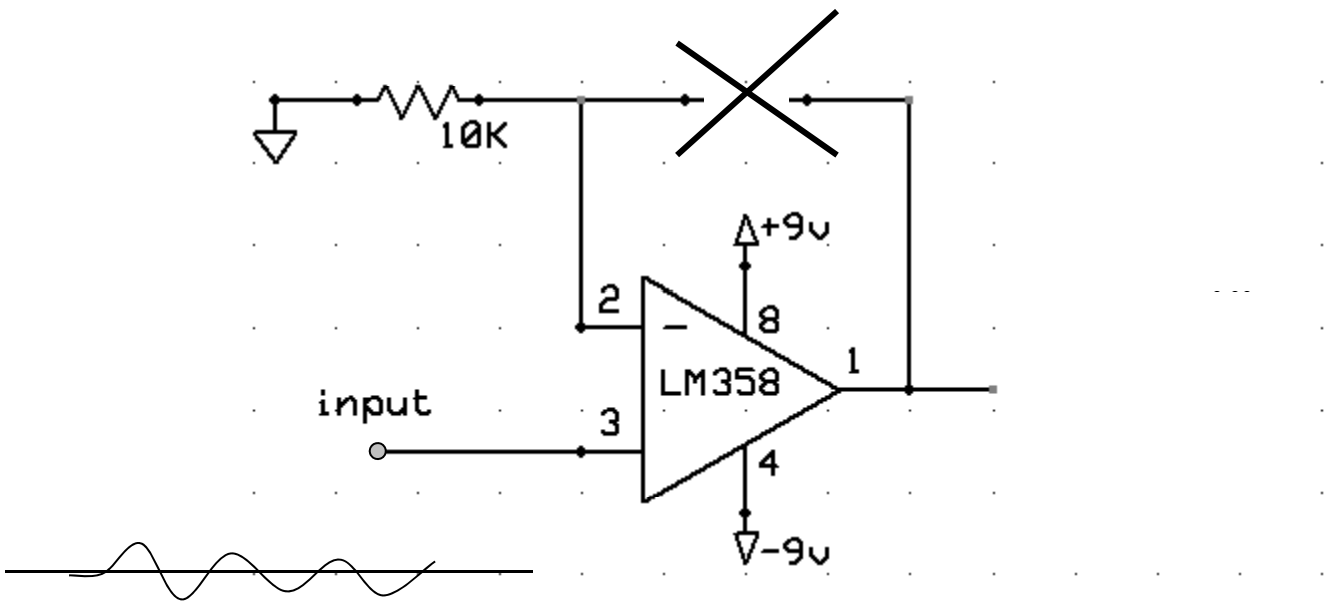

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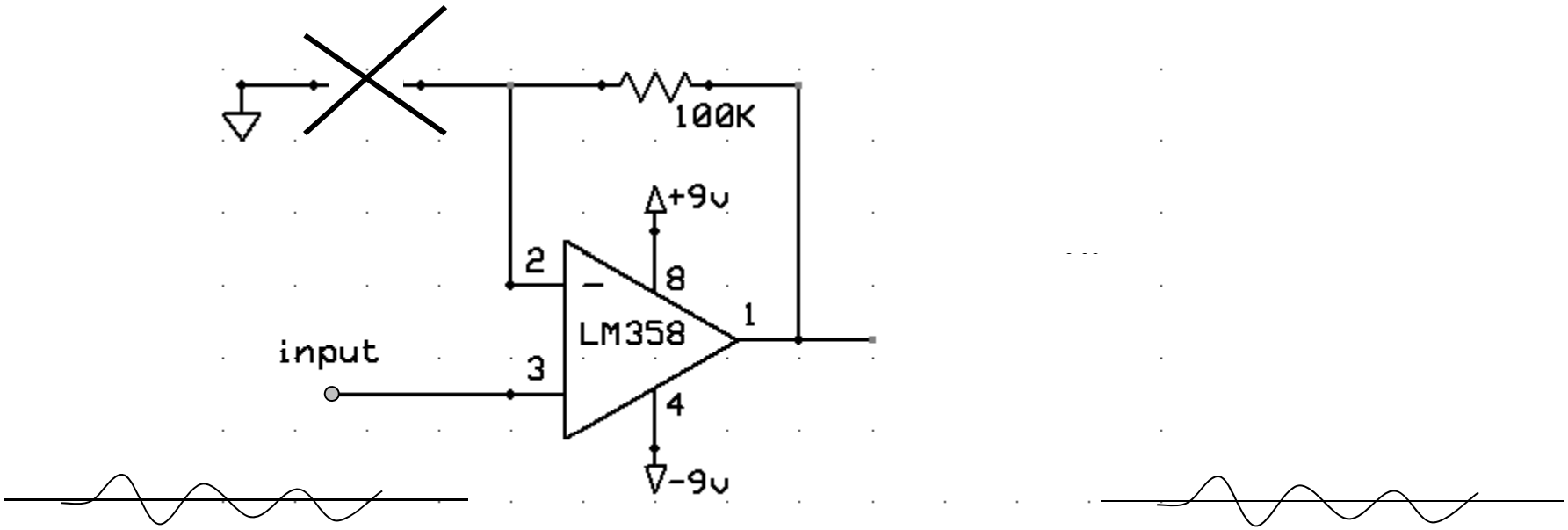

Gain calculation:

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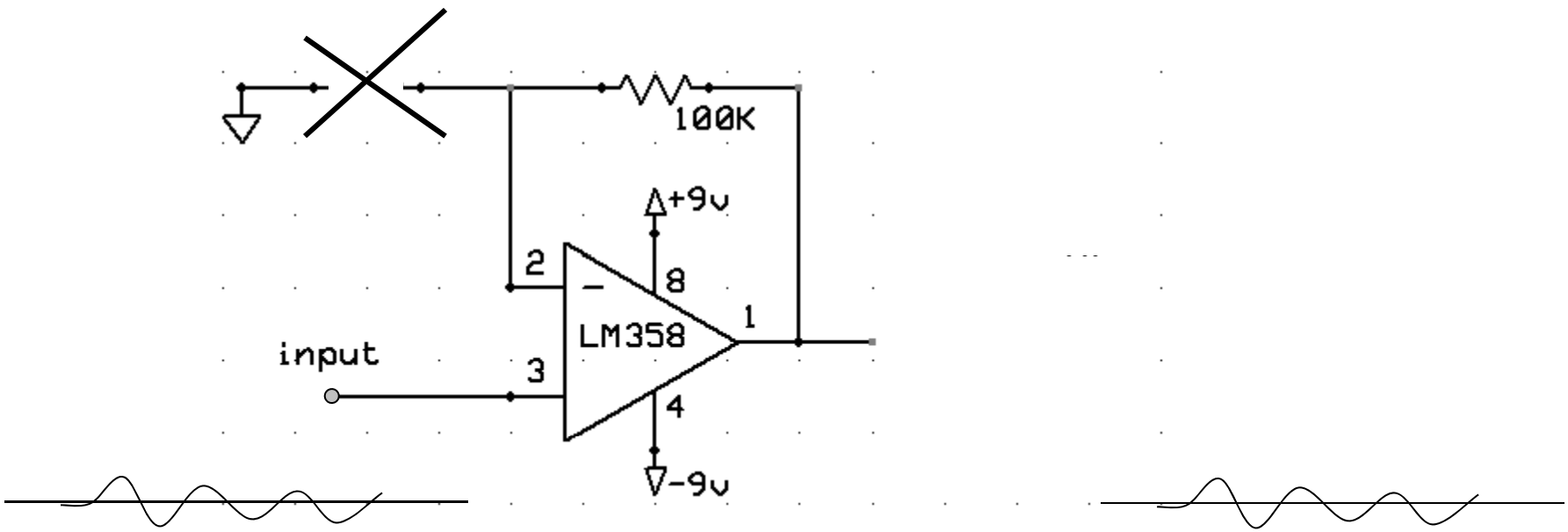
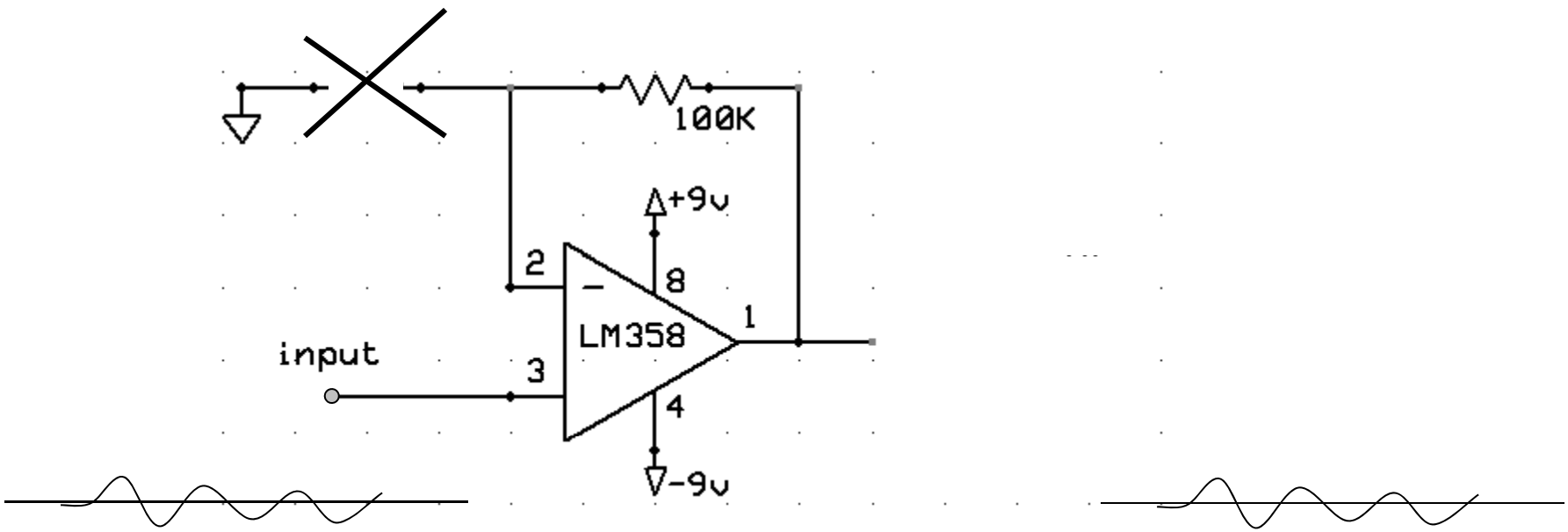


Gain calculation:

$$R1 / R2 + 1$$

$$R2 / \infty + 1$$

$$0 + 1$$



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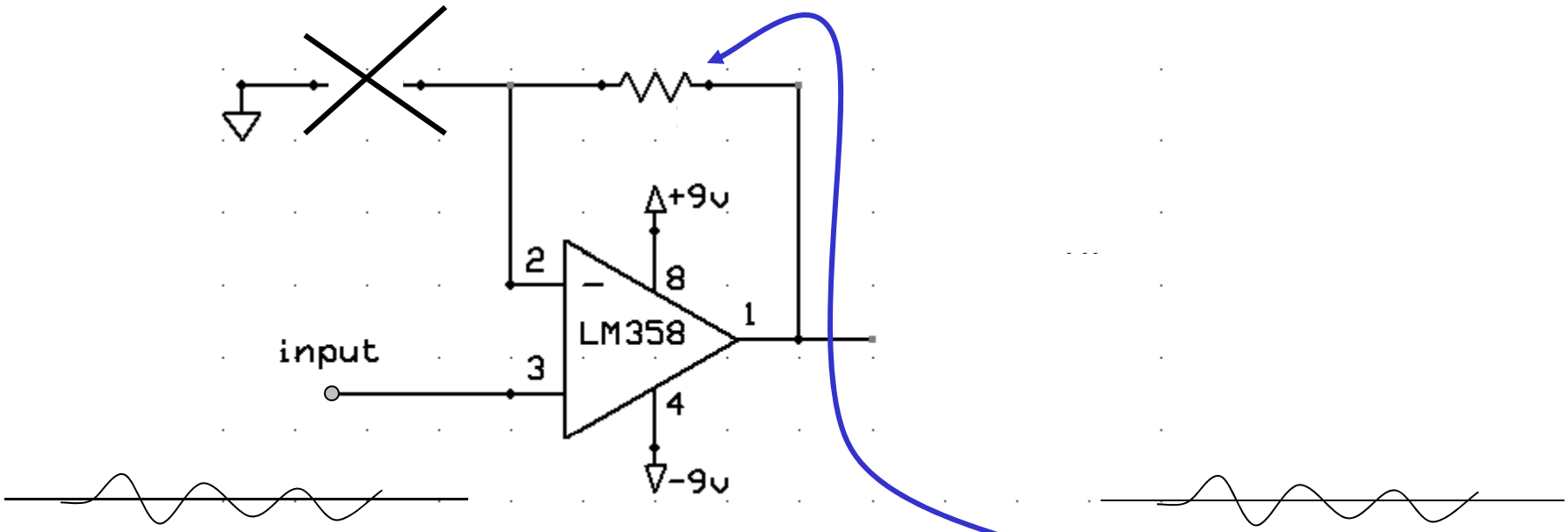
Did you remember the plus 1?



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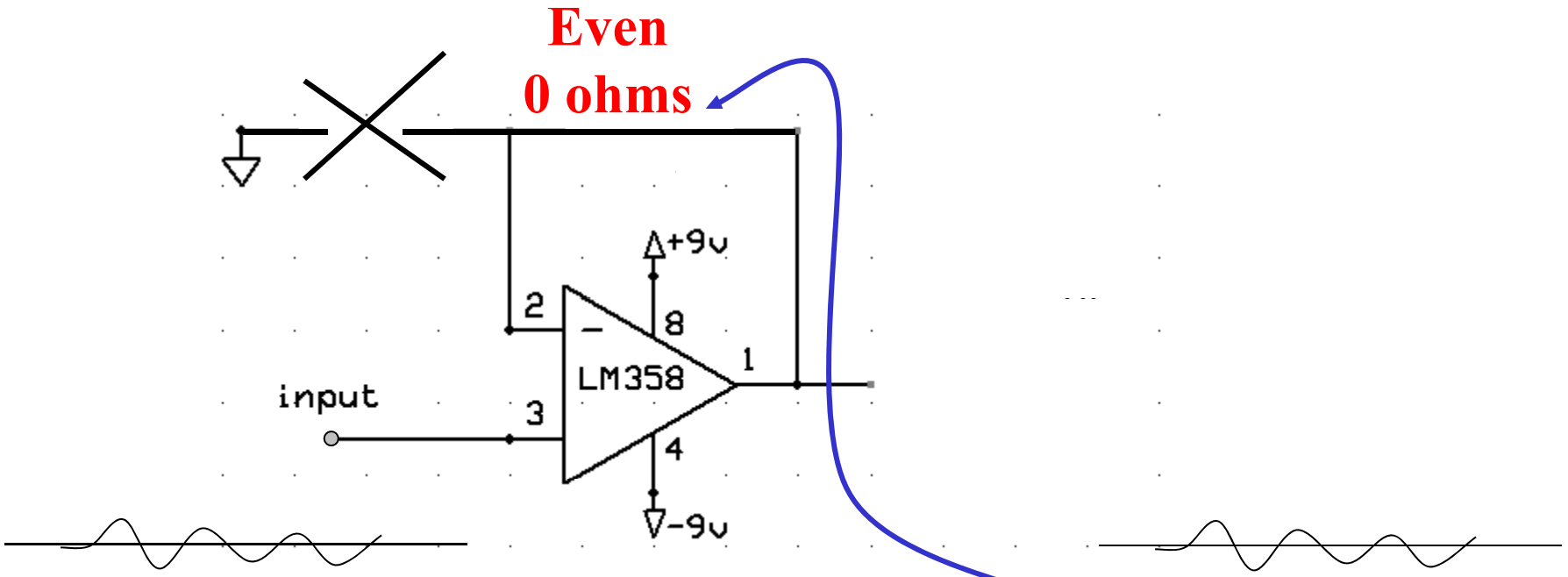
$$R2 / \infty + 1$$

$$0 + 1$$

doesn't matter what value goes here it is no less than…

unity gain



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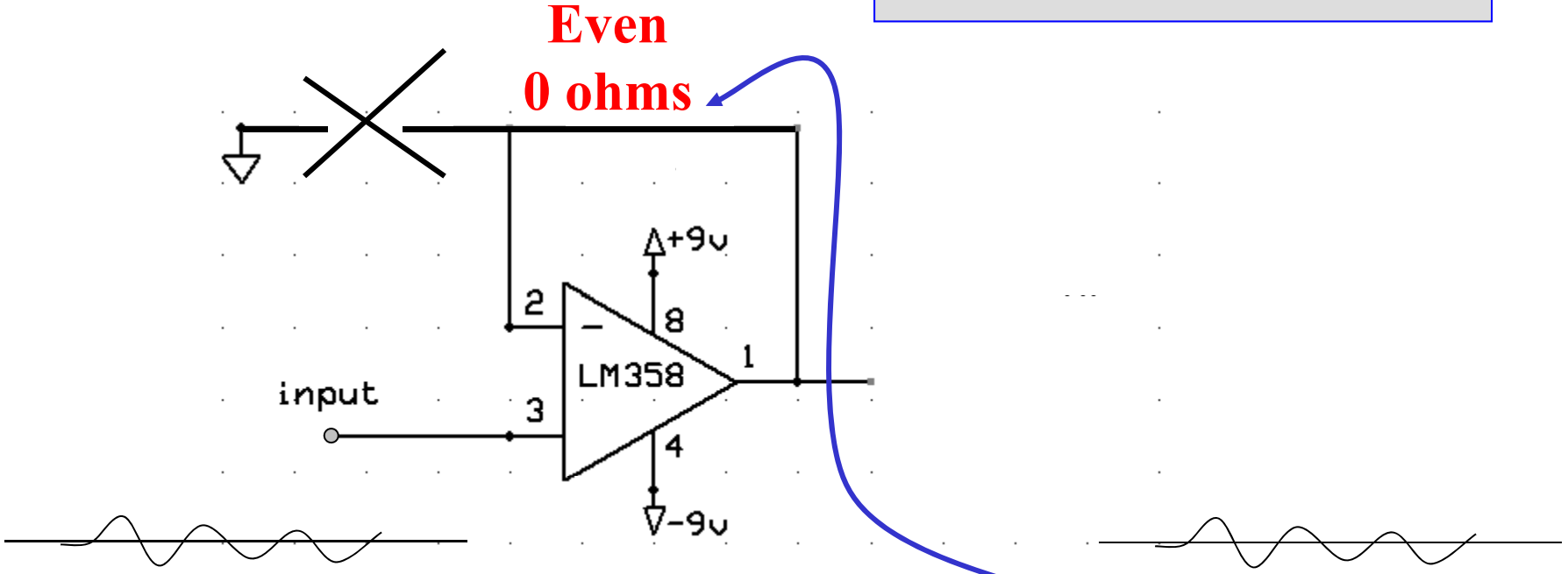
unity gain

also normal operation



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unity gain

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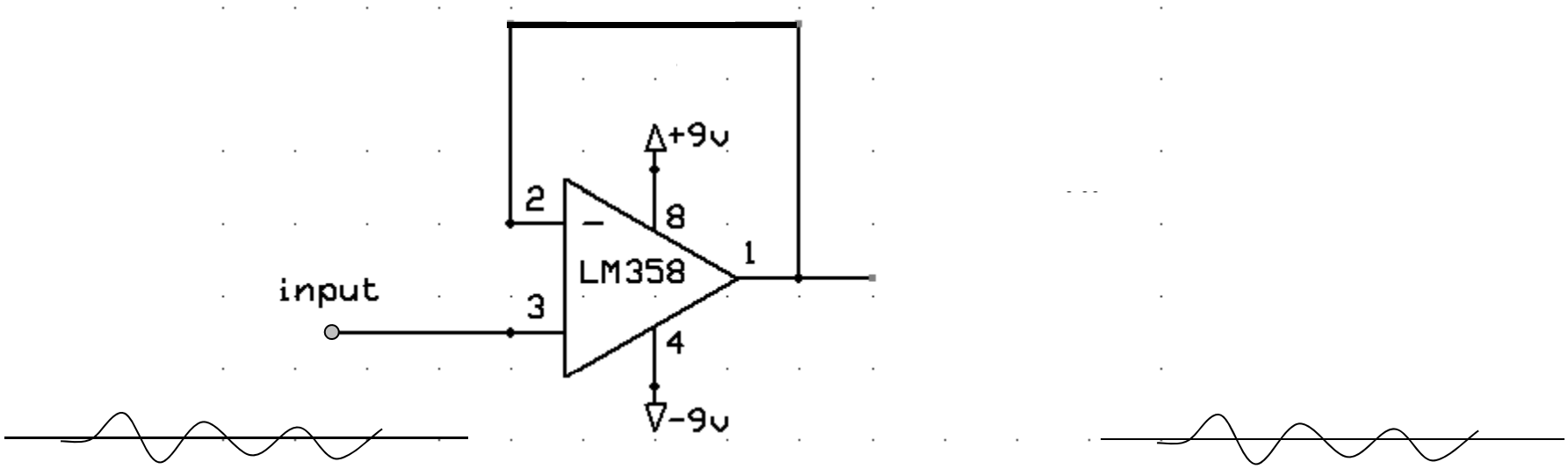
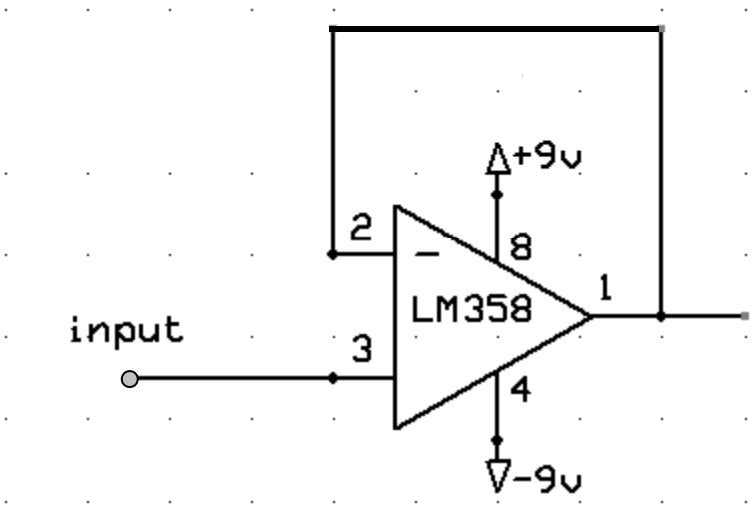
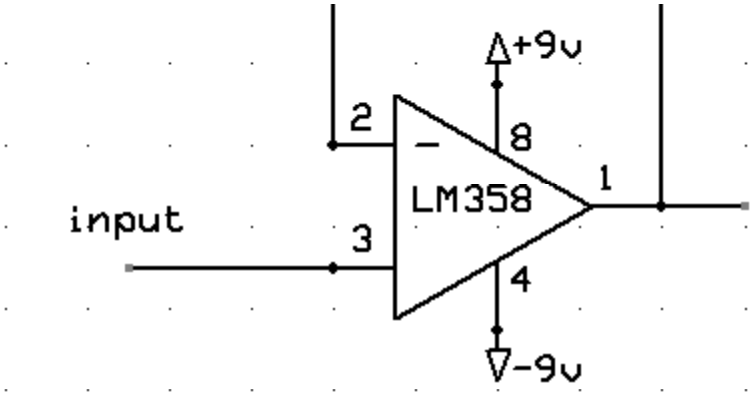


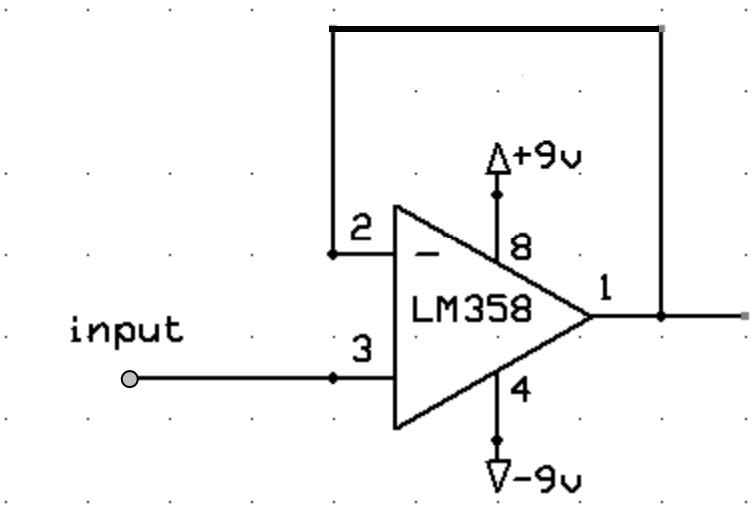
unity gain called a voltage follower



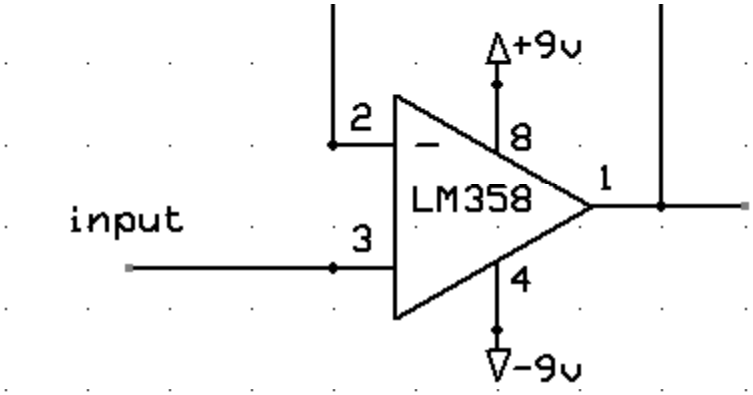
voltage follower



zero crossing detector

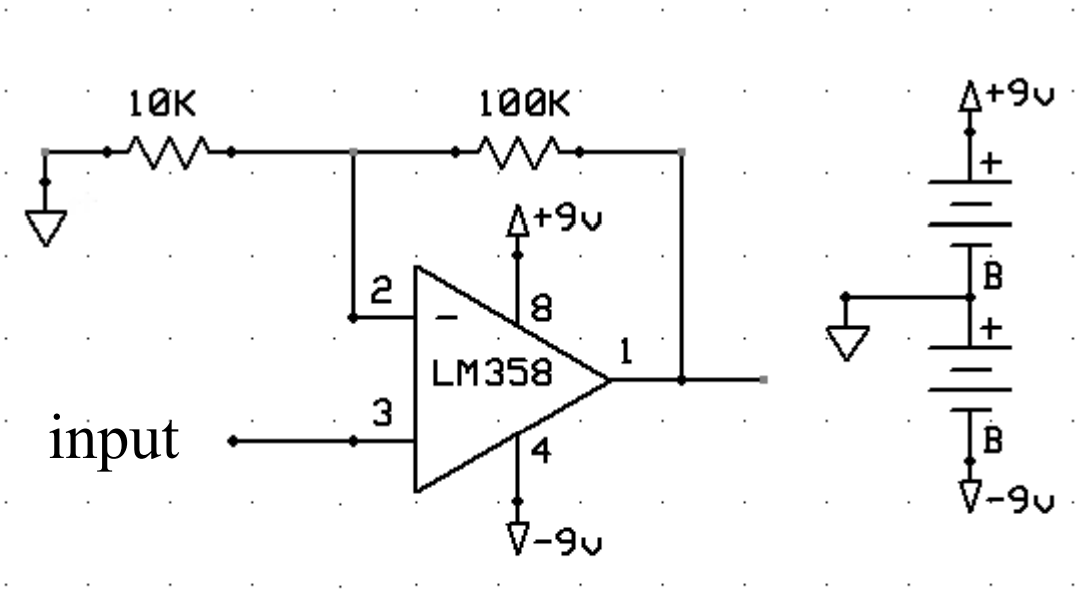


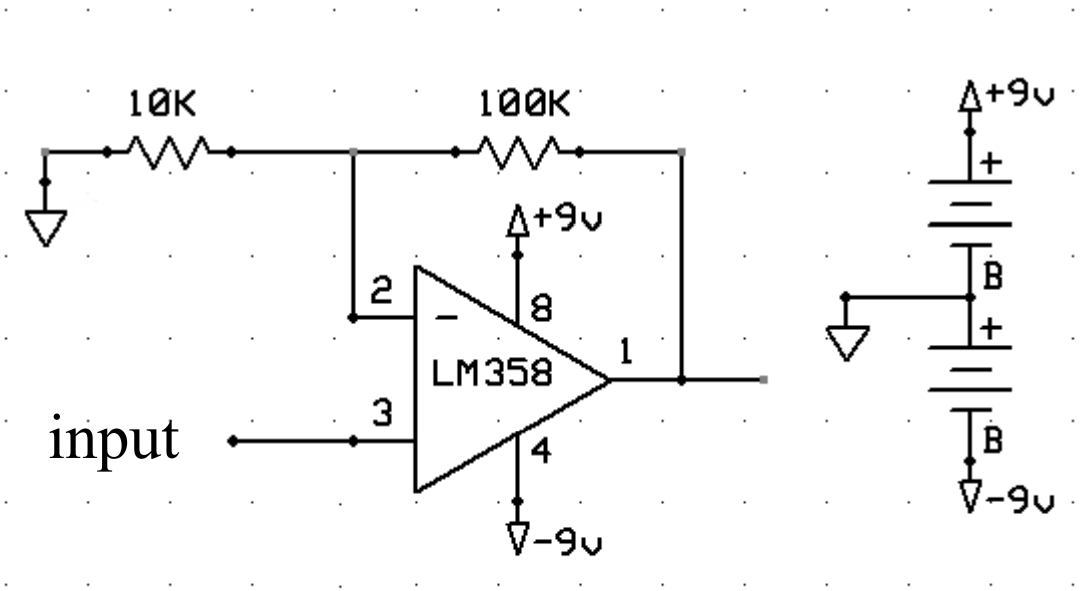
voltage follower
You will see this a lot.

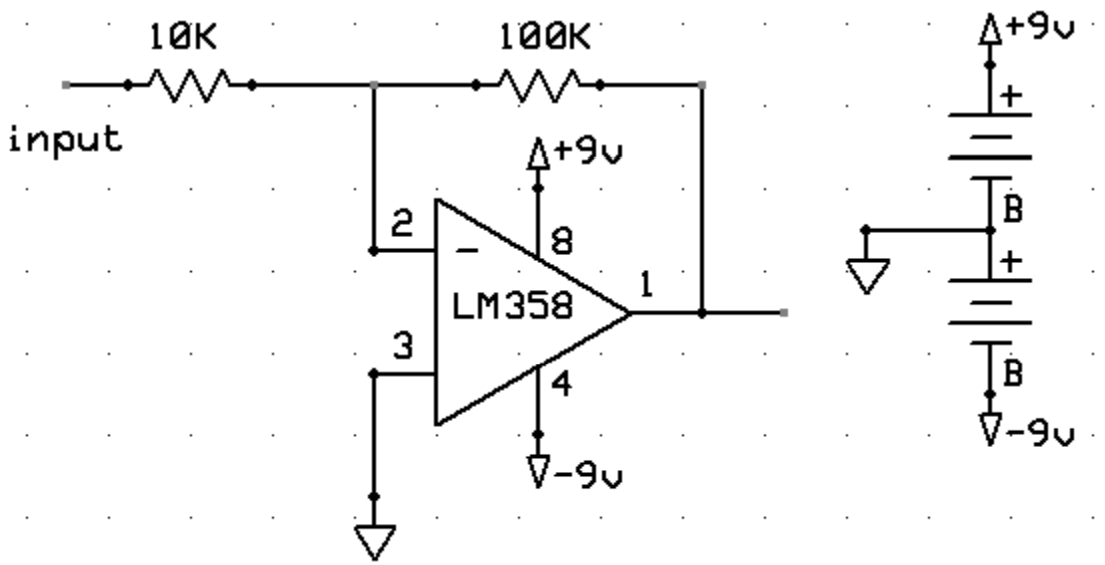


zero crossing detector

This is the “Normal” Opamp




10K
100K
+9v
2
8
LM358
1
3
4
input
-9v
+9v
+
B
+
B
-9v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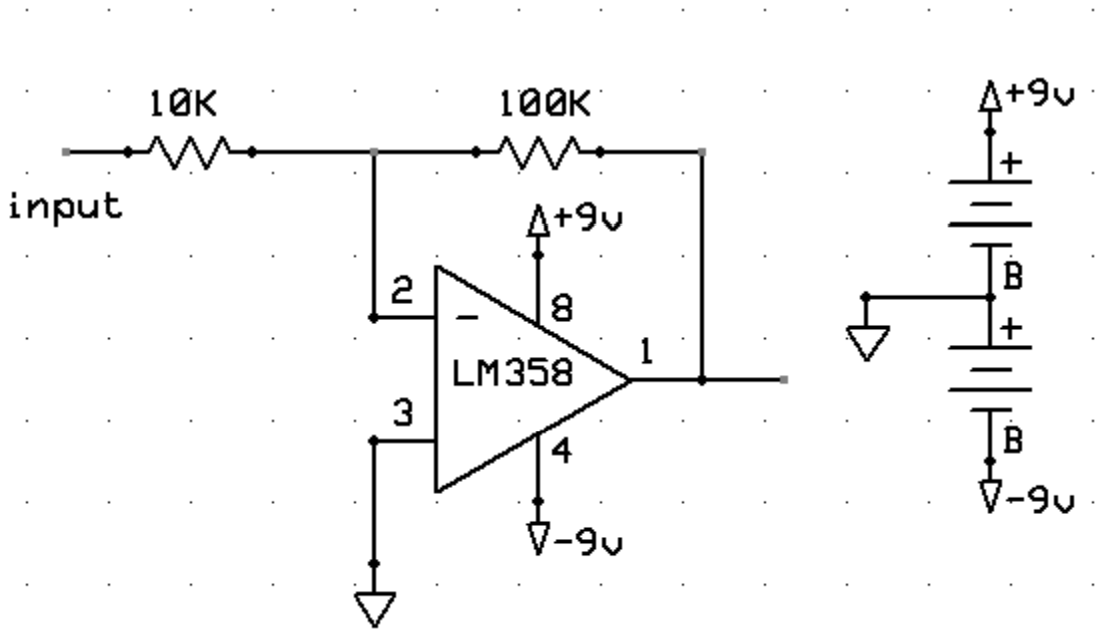
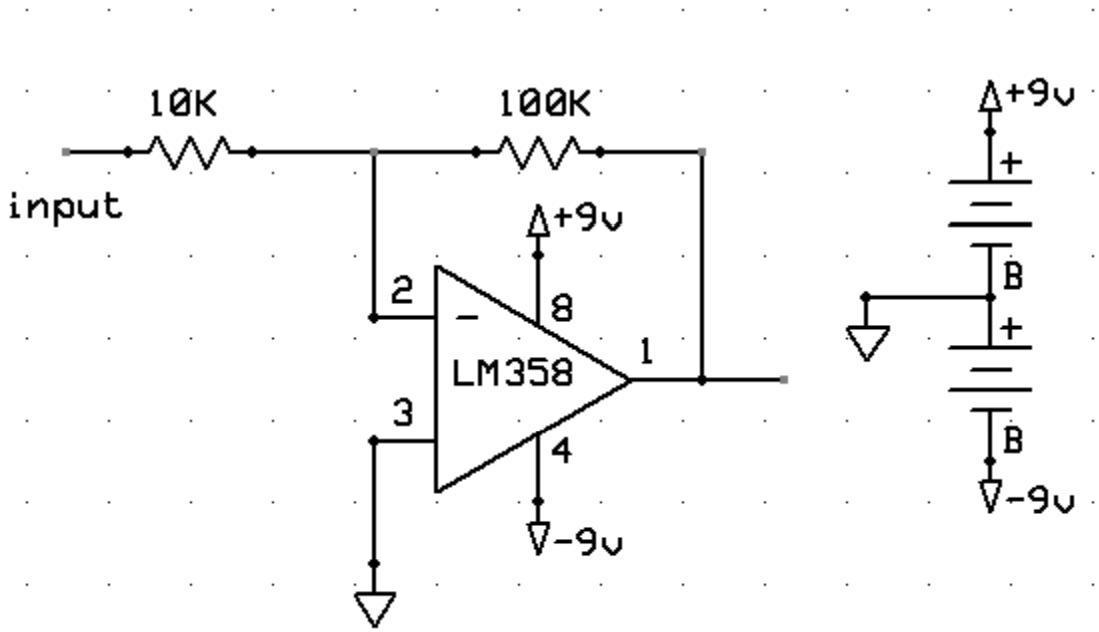


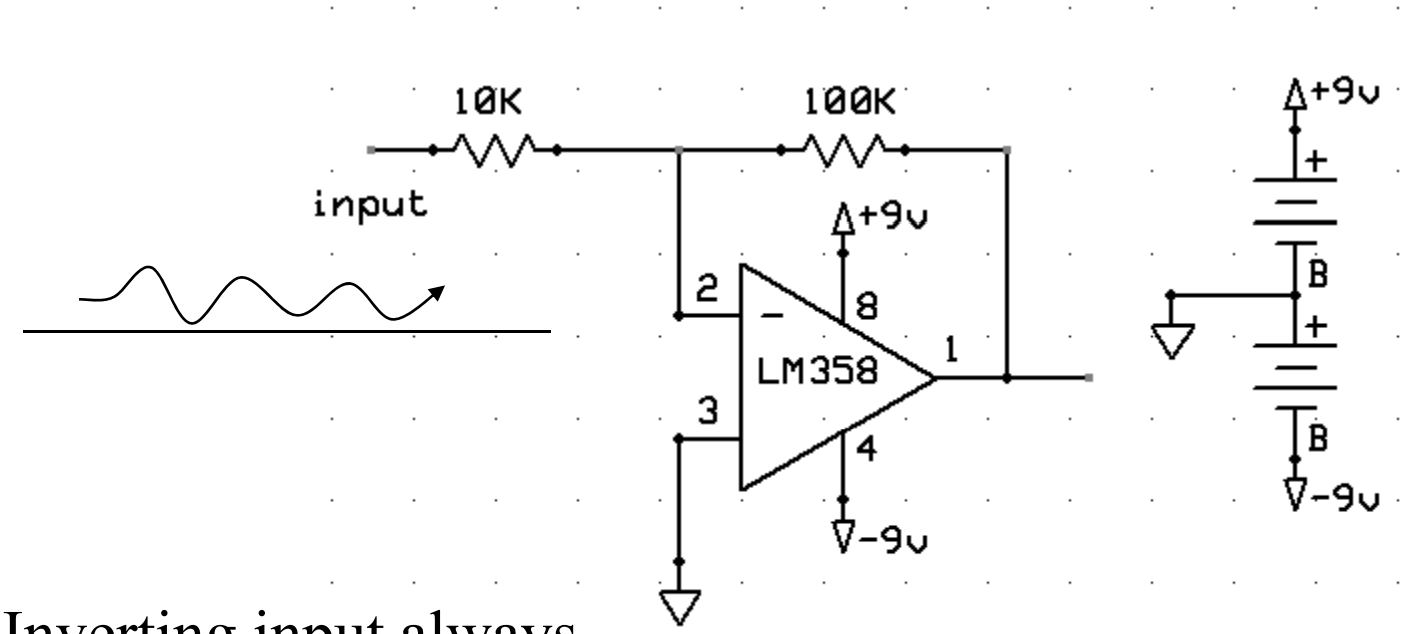
Now, More About The “Other” Input

The Inverting Input

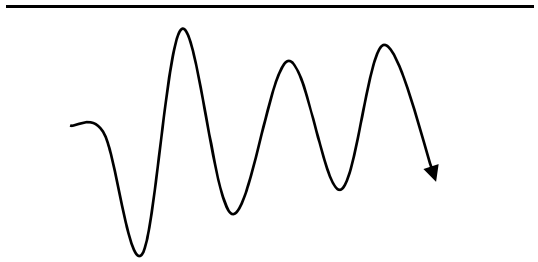


Now, More About The “Other” Input

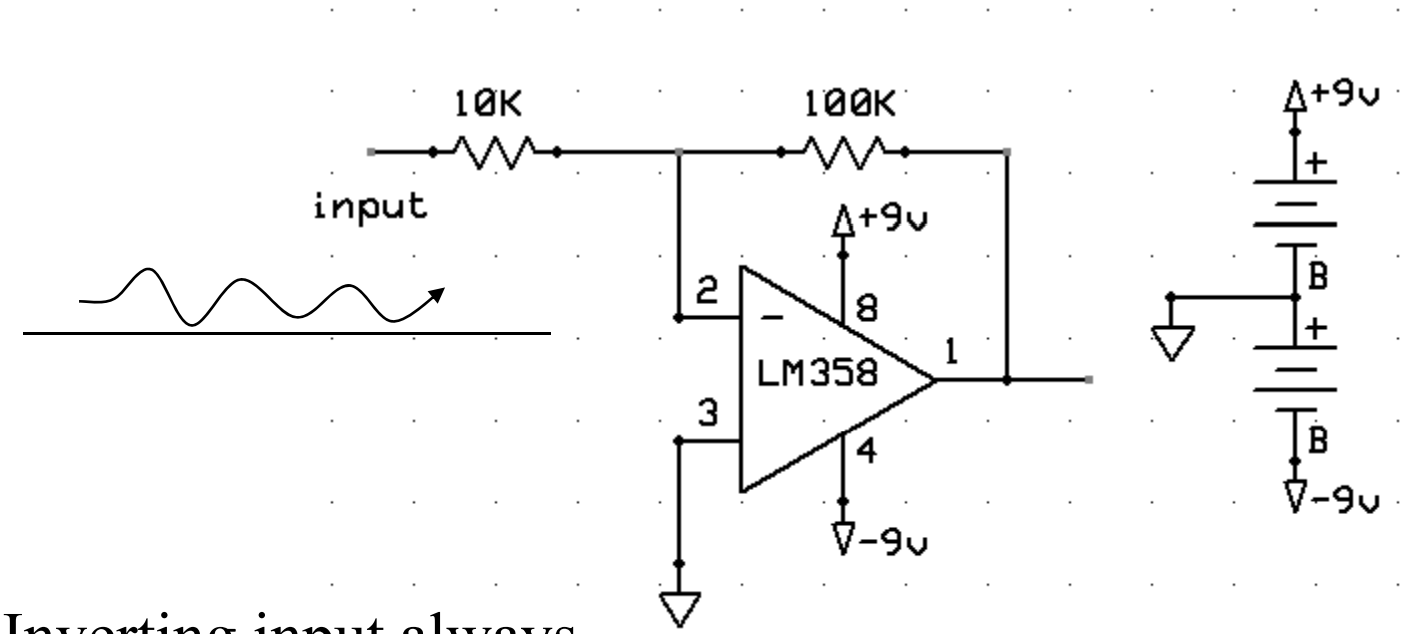
The Inverting Input



Inverting input always needs two batteries.

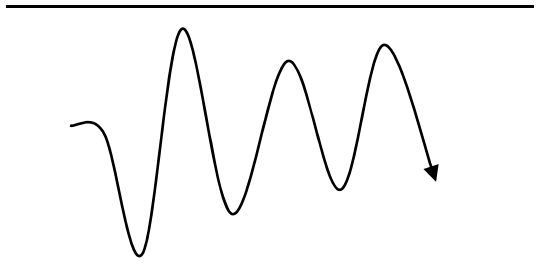


The Inverting Input



Inverting input always needs two batteries.

Do you see why? It's because the output is **always** on the other side of ground.



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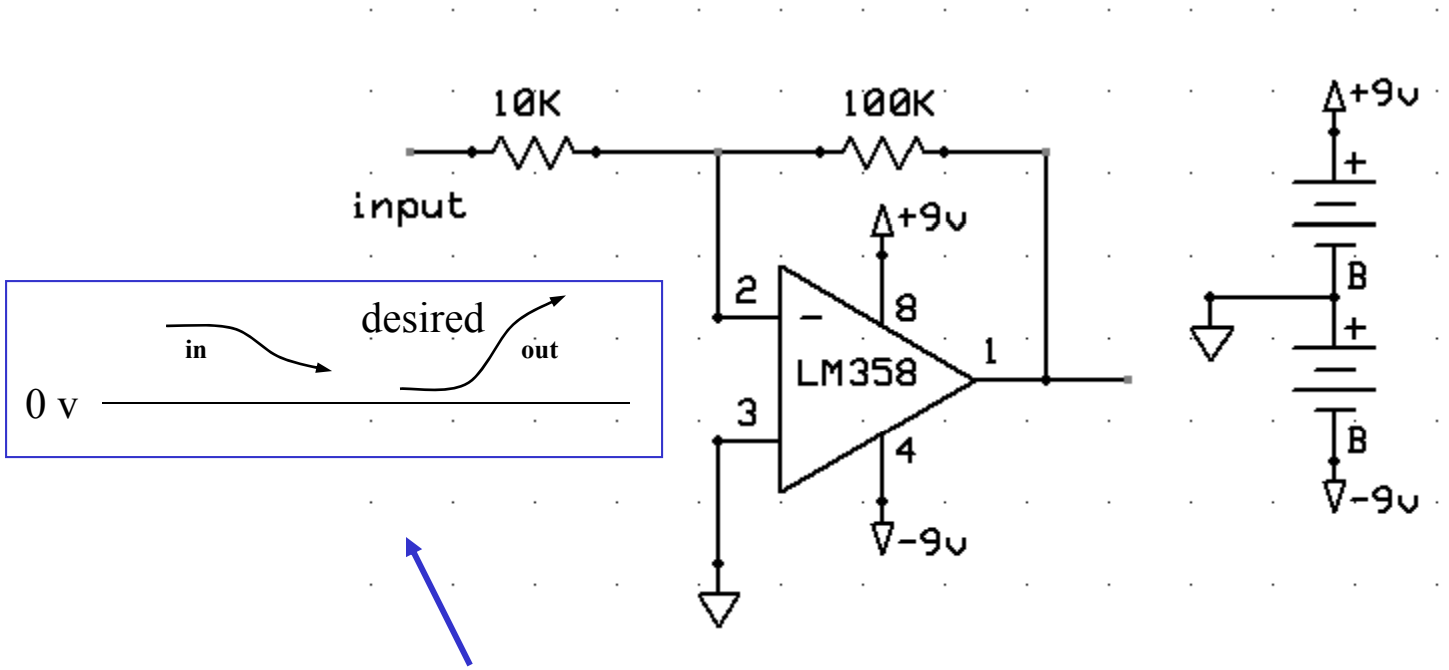
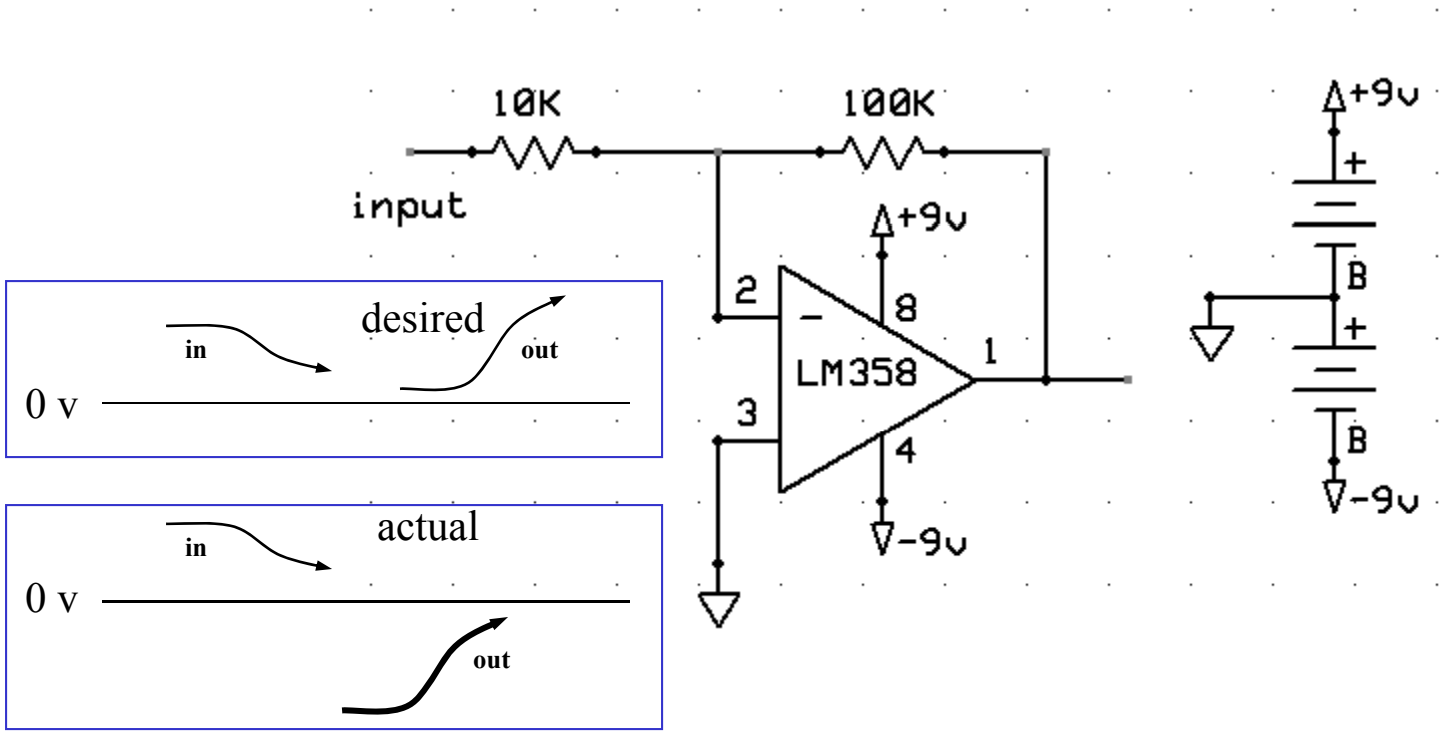


The “Inverting” input amplifier can be confusing. For example: if you wanted to drive a meter up when the input signal is going down…

The Inverting Input



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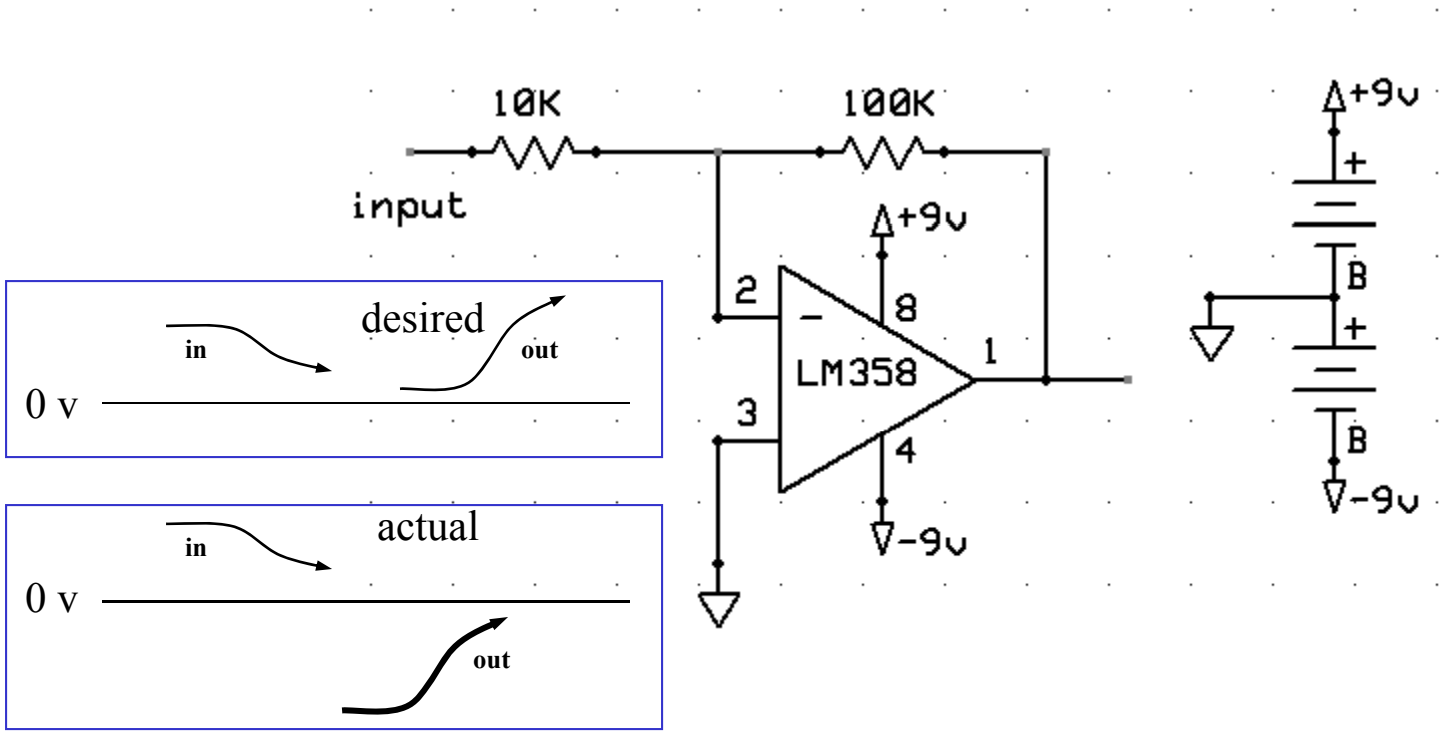
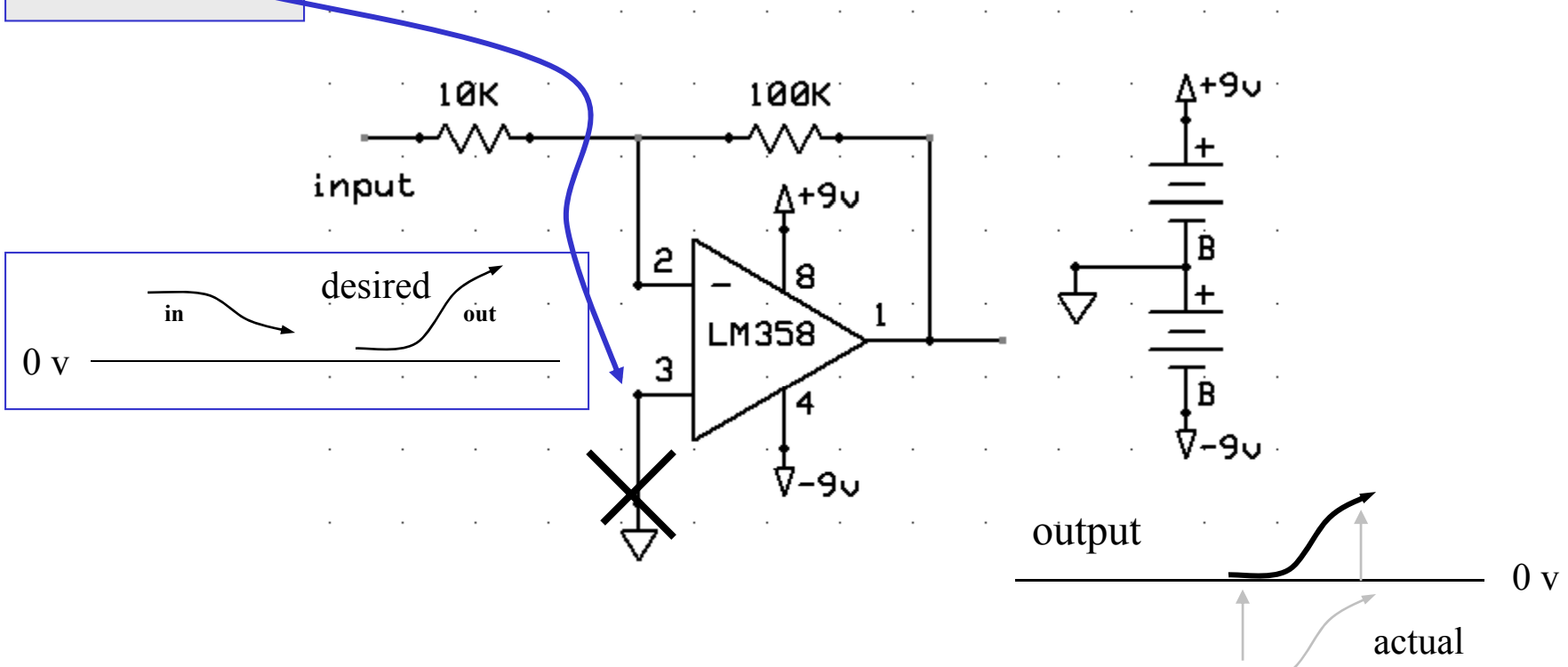
The Inverting Input



The "Inverting" input amplifier can be confusing. For example; if you wanted to drive a meter up when the input signal is going down... You'll need to do more than just invert.

The Inverting Input

It requires a DC offset here.



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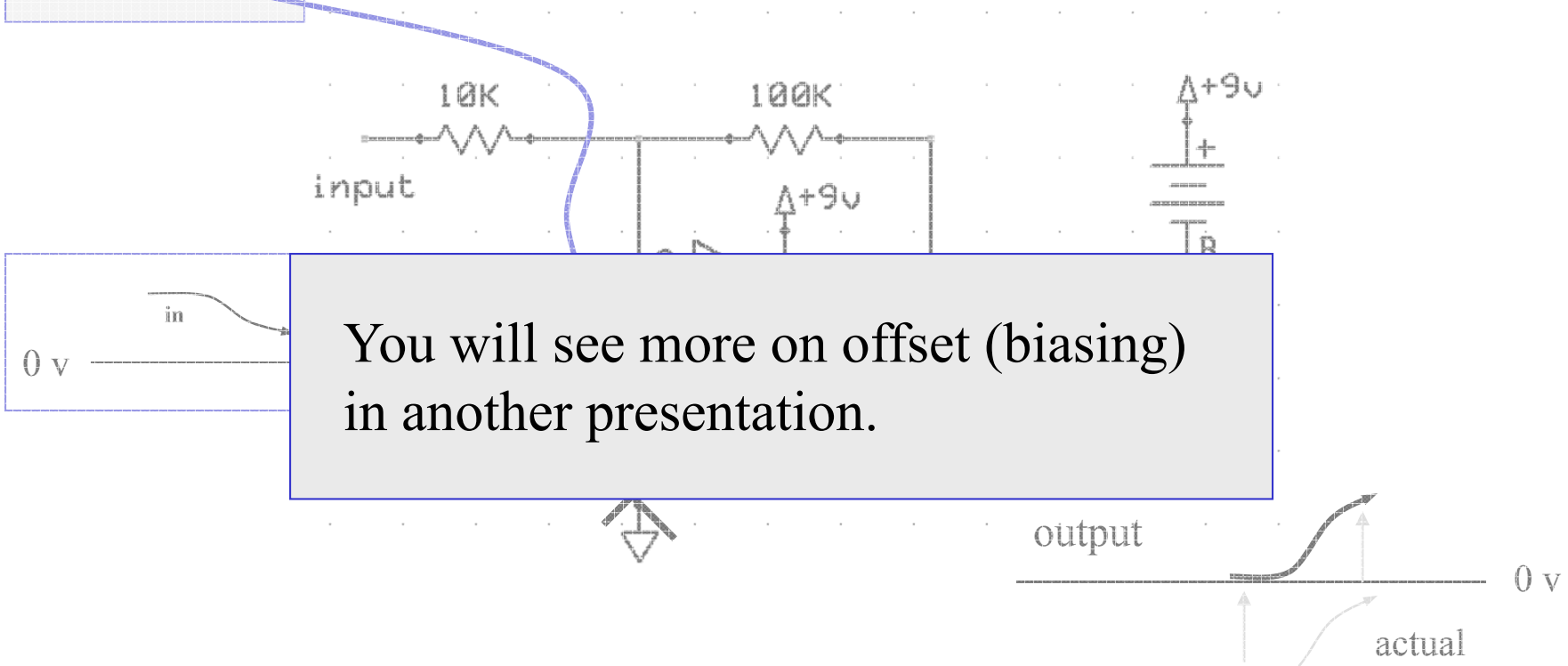
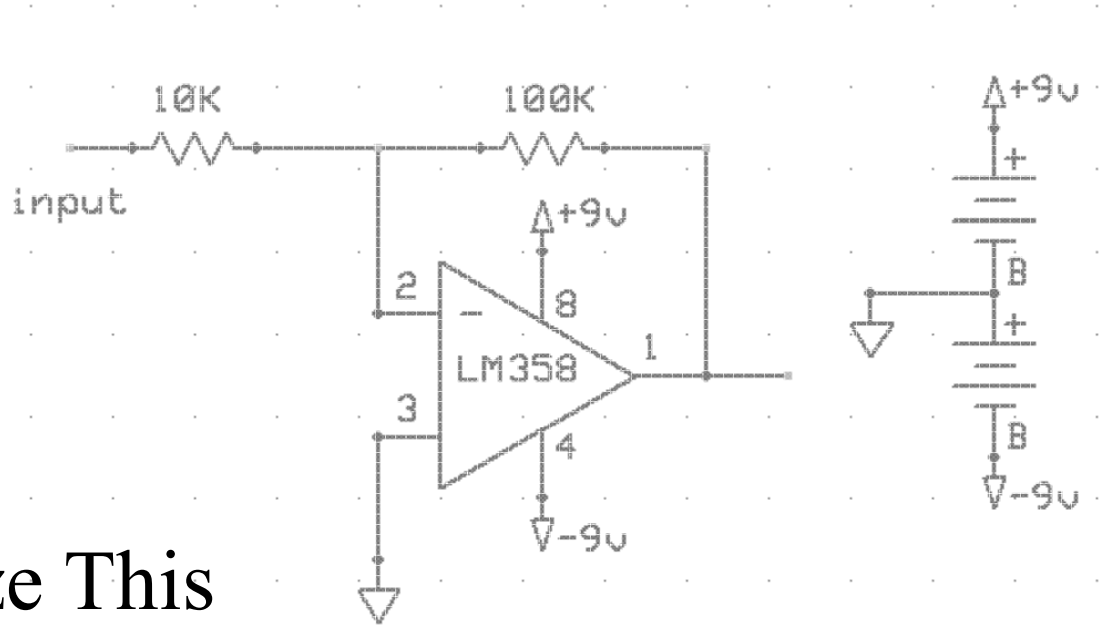


You will see more on offset (biasing) in another presentation.

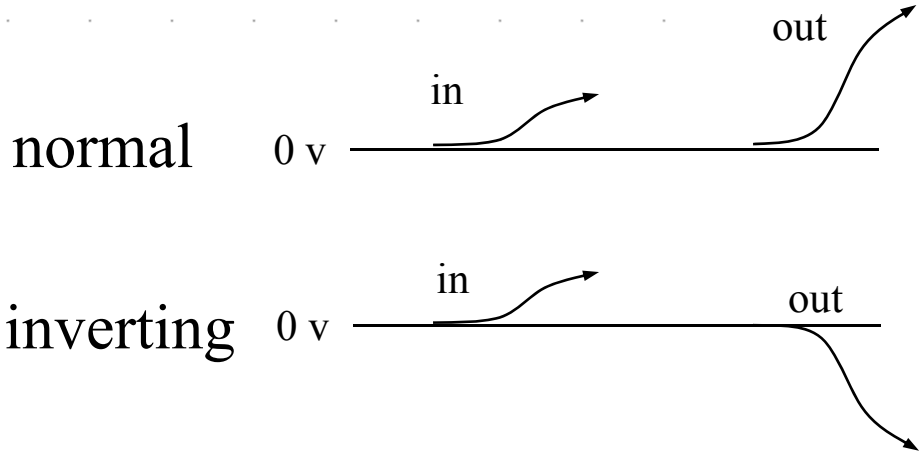
The “Inverting” input amplifier can be confusing. For example; if you wanted to drive a meter up when the input signal is going down... You’ll need to do more than just invert.

The Inverting Input



Memorize This

The output of an Inverting Input always crosses ground.



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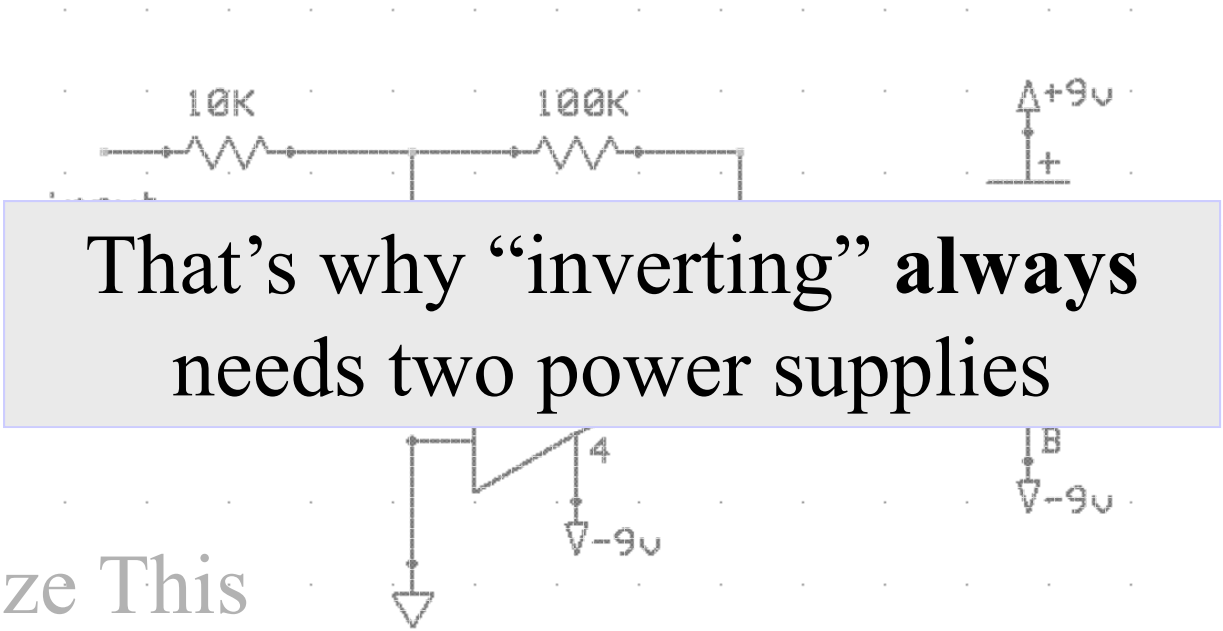
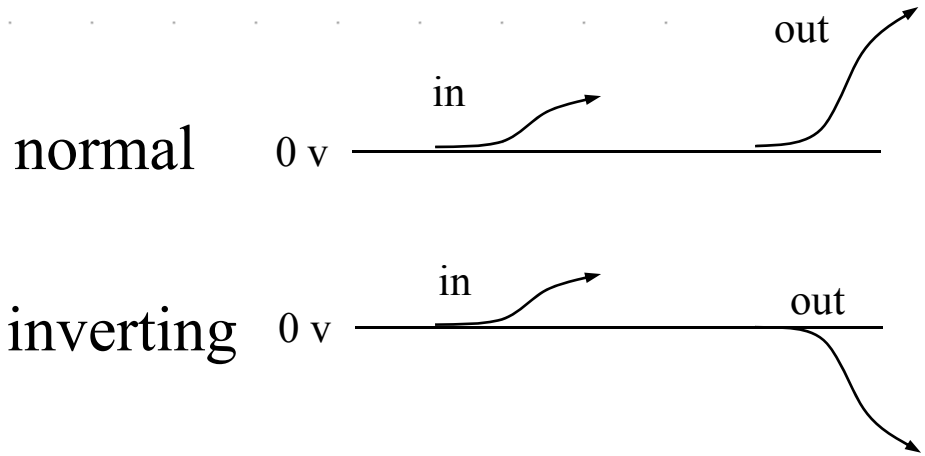


That's why "inverting" **always** needs two power supplies

Memorize This

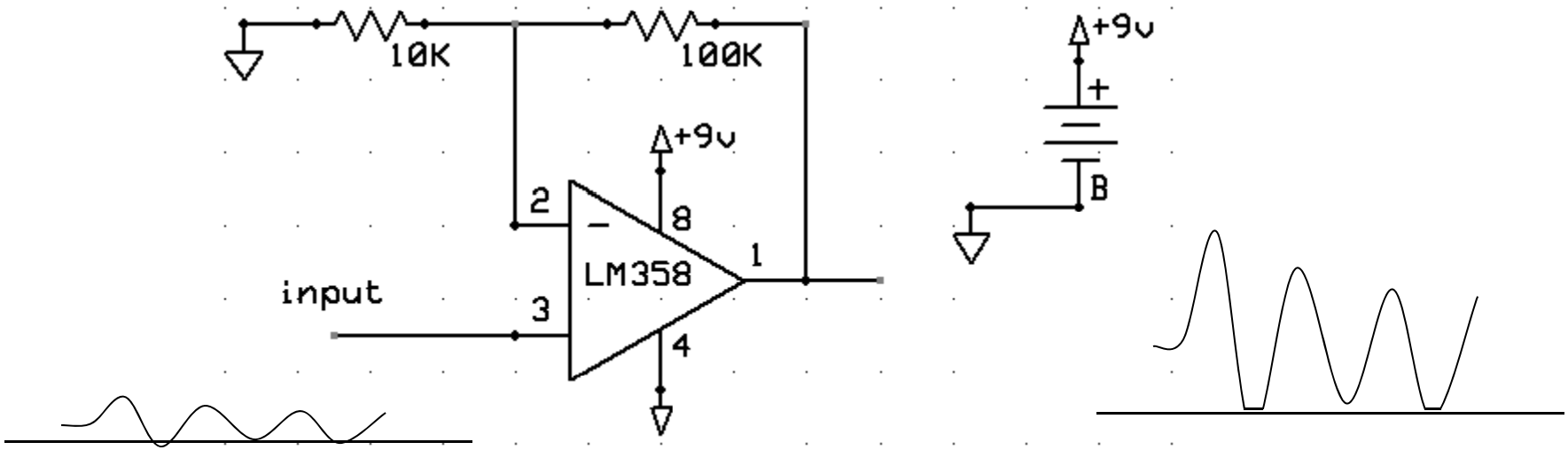
The output of an Inverting Input always crosses ground.



The Two Opamp Types

- **The Normal (Non-Inverting)**
  - easier input to use
  - can use a single battery if you are careful (more on that later)
  - gain is same as "inverting" but +1
- **The "Other" Input (the Inverting)**
  - must use two batteries
  - more confusing to debug than the non-inverting input.
  - gain is R1/R2

The Normal Input “Can” Use a Single Battery



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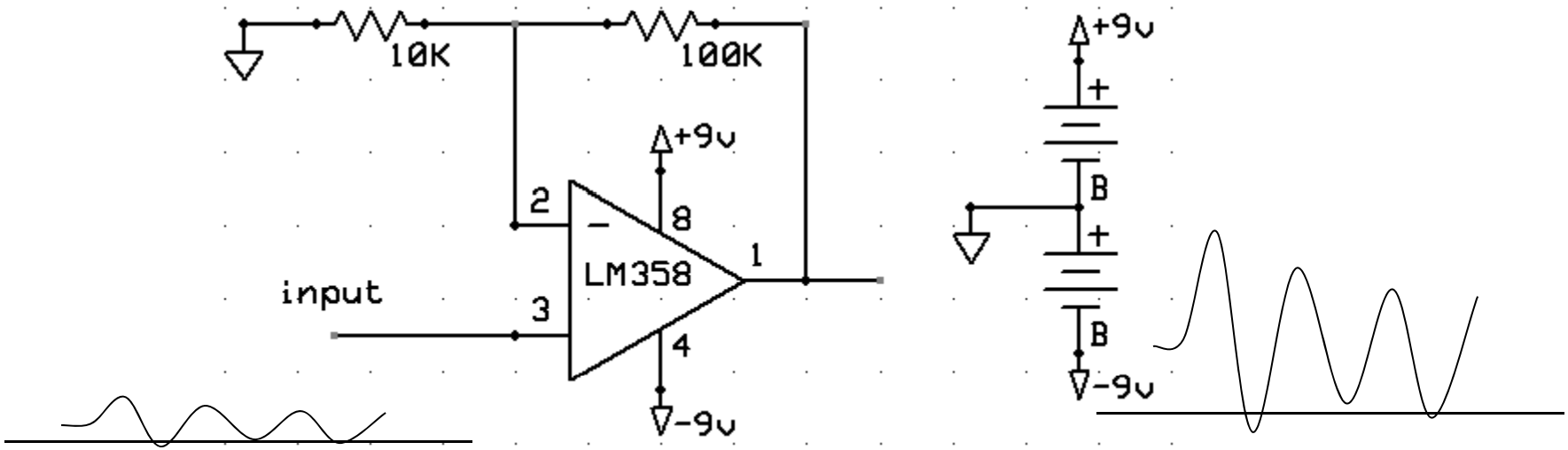
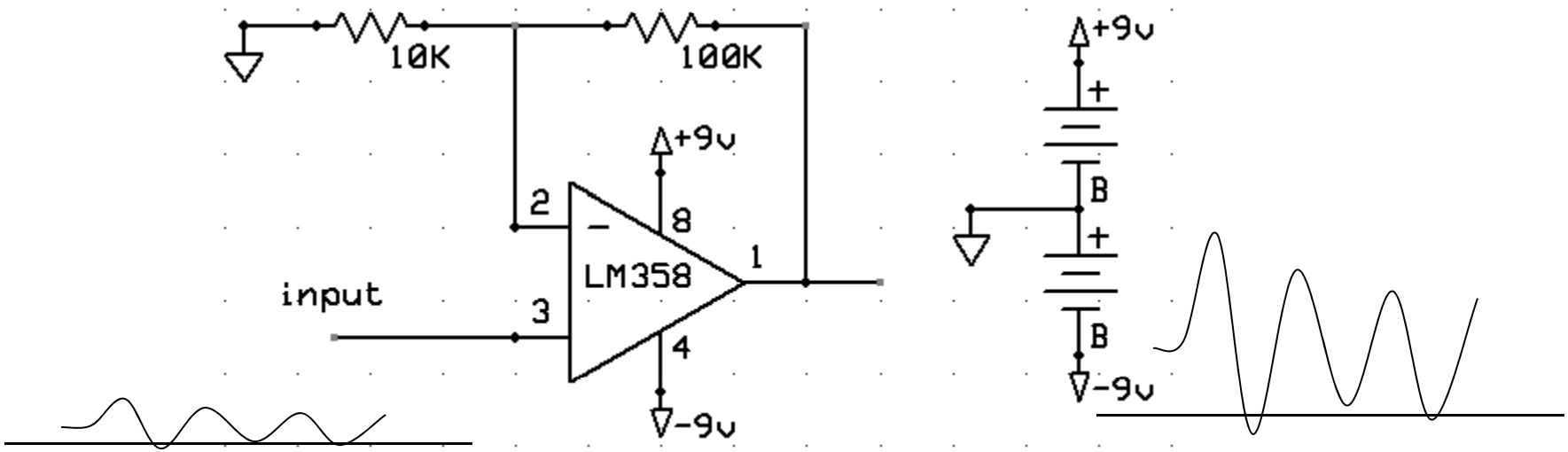


Better, fewer problems with two.

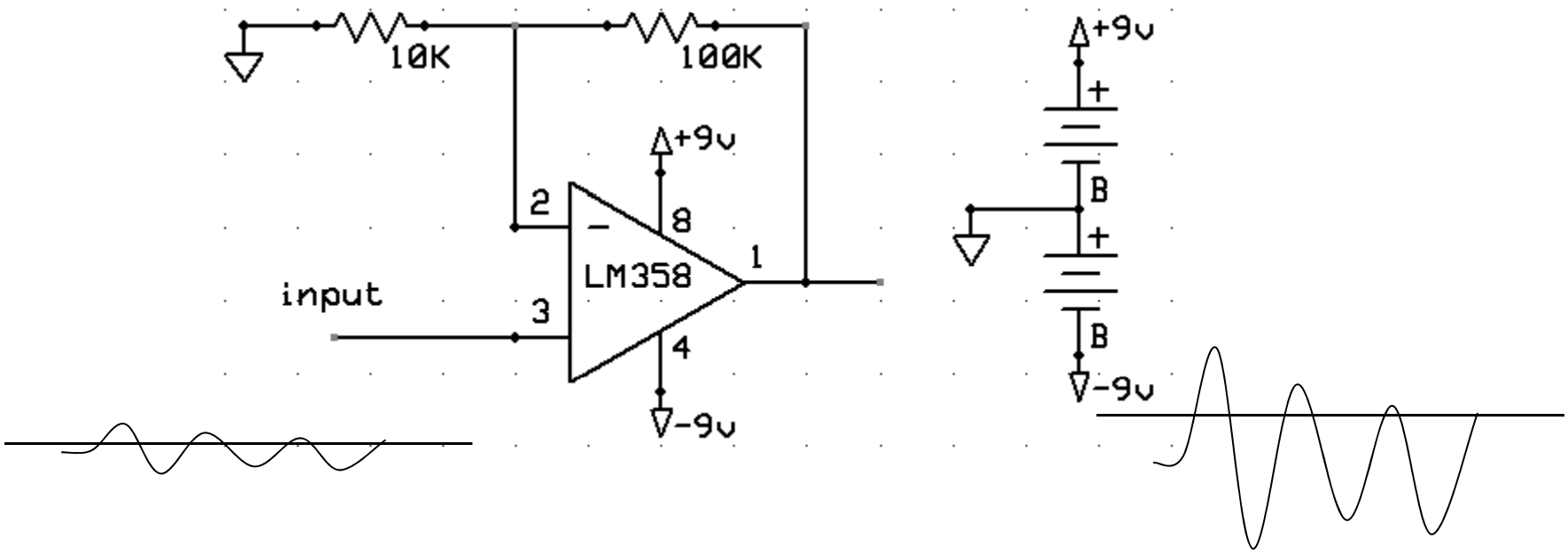
The Normal Input "Can" Use a Single Battery



Better, fewer problems with two.

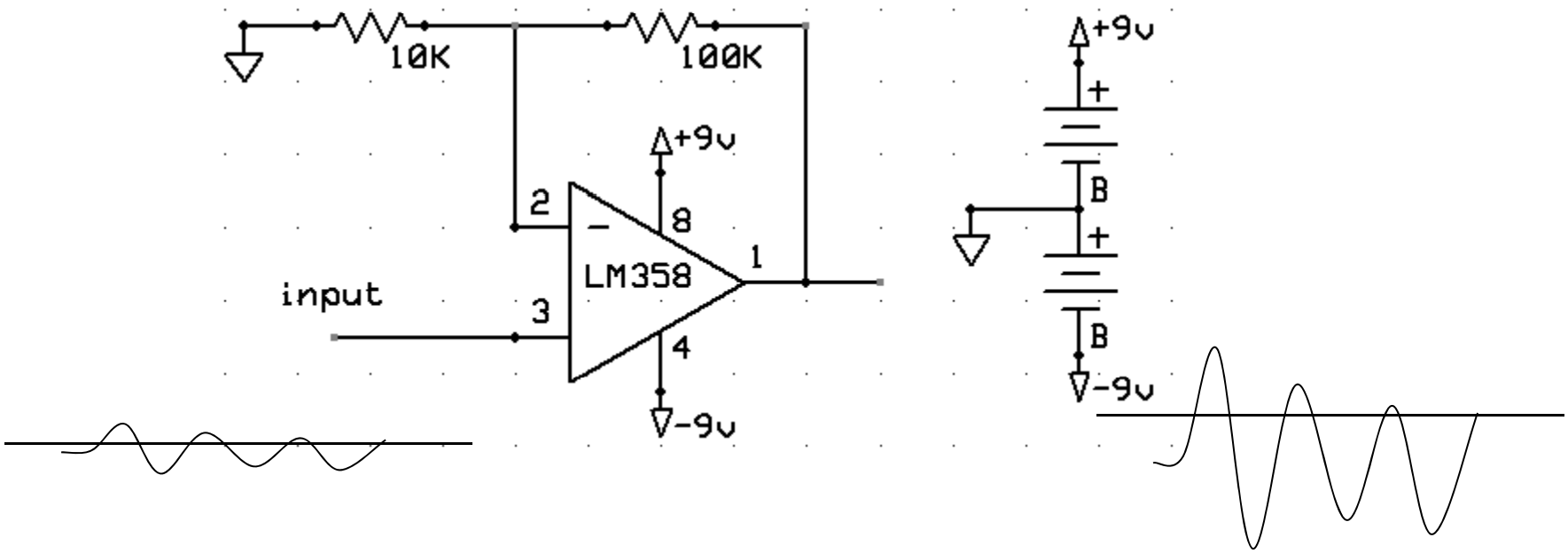
You will see more on single battery operation in another presentation.

The Normal Input "~~Can~~ Can't" Use a Single Battery

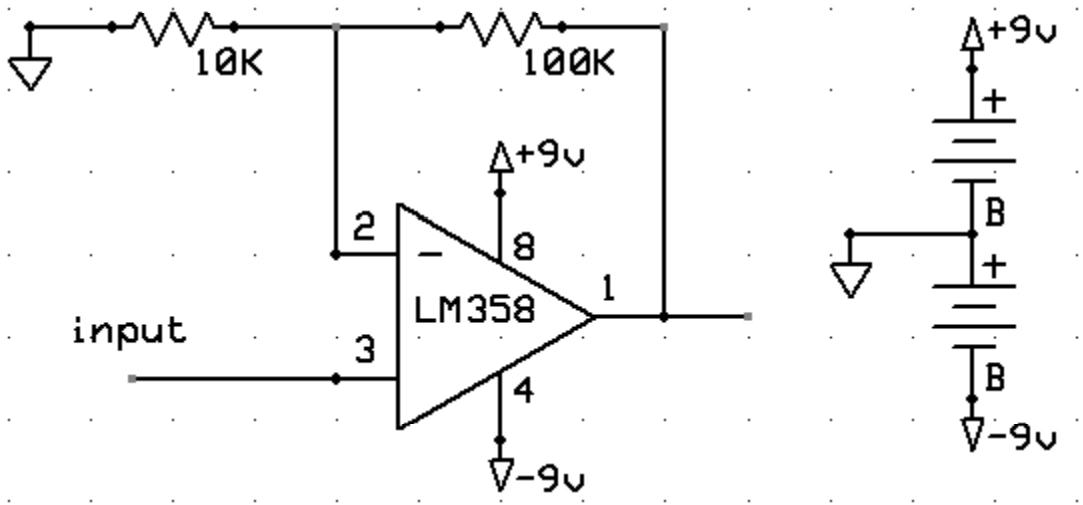


if the Signal is on Both Sides of Ground

The Normal Input

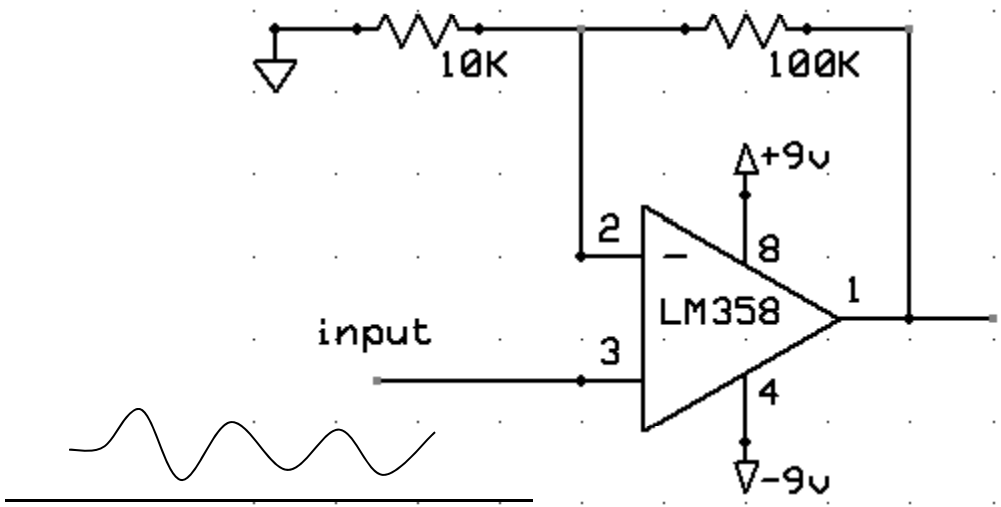


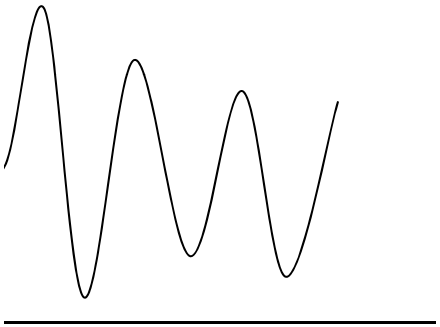
Your first thought should be to use this one rather than the inverting input. And with two batteries.



This Circuit You Should Memorize

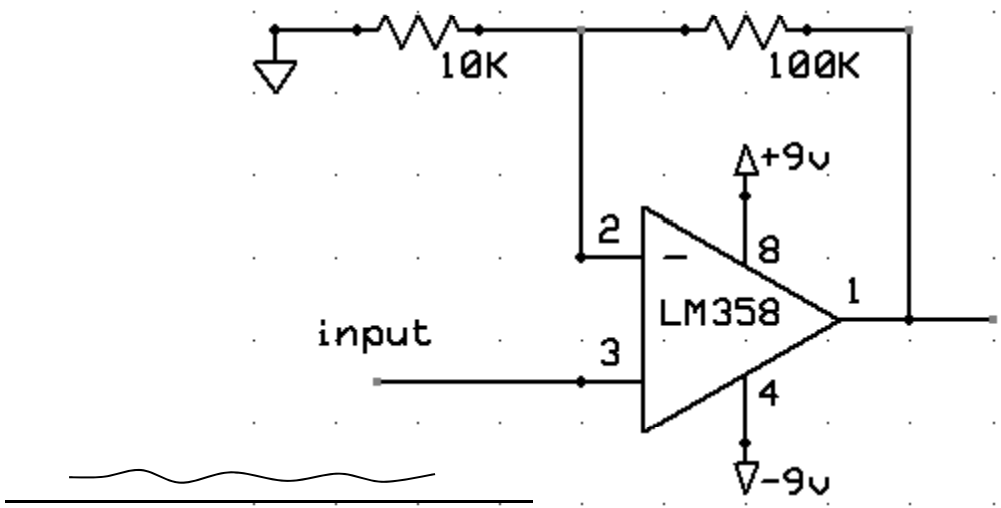
What is the Limit to the Amount of Gain?

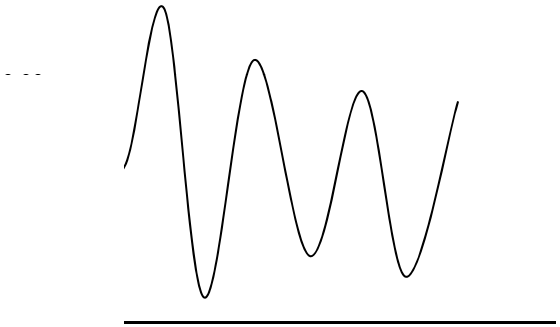




What is the Limit to the Amount of Gain?

(How weak a signal can we see?)





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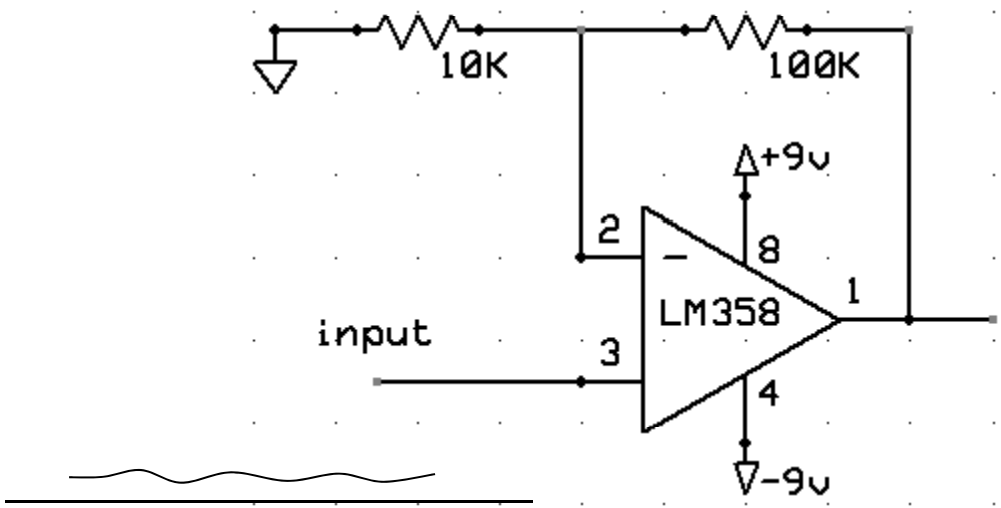
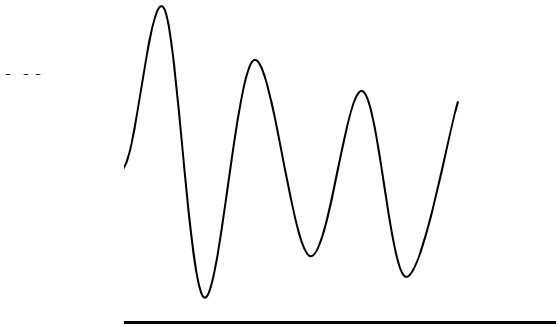
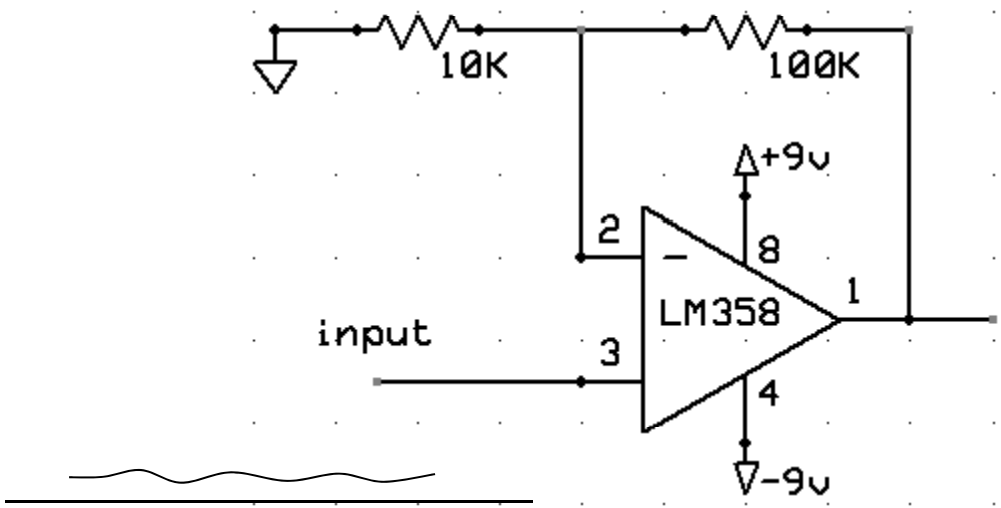


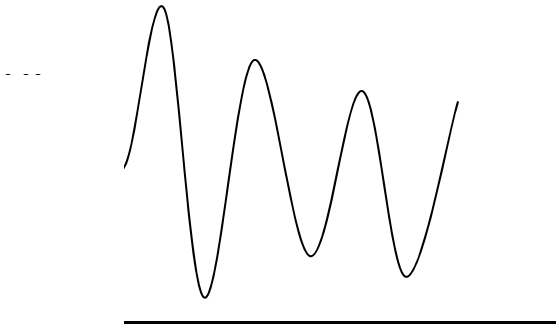


100X is typical, 10,000X is a lot

What is the Limit to the Amount of Gain?

(How weak a signal can we see?)



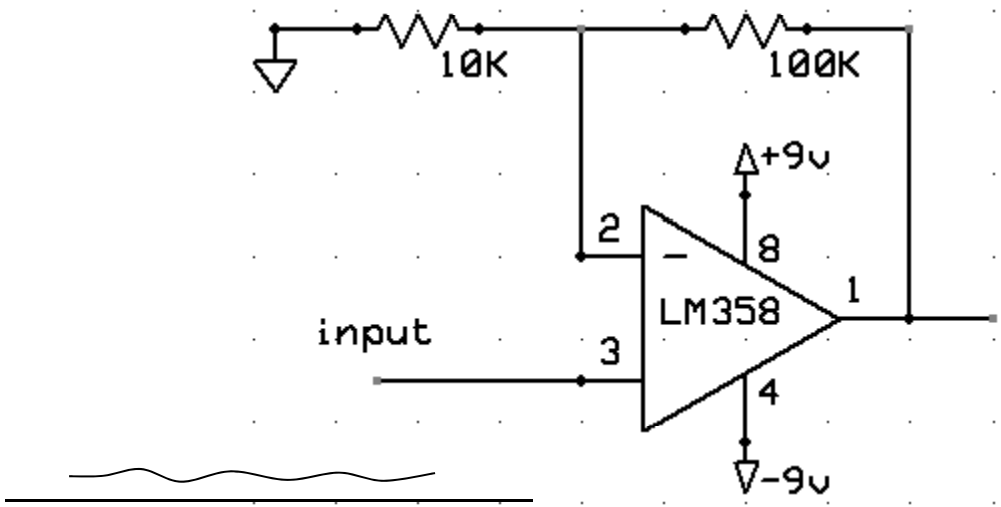


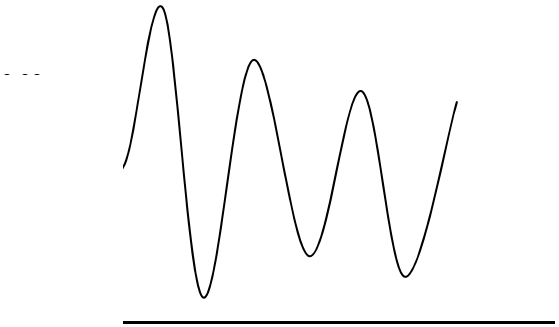
100X is typical, 10,000X is a lot

(That's DC. For AC it depends on the frequency. The gain must be reduced in proportion to the frequency. At 60KHz, 100x is a lot.)

What is the Limit to the Amount of Gain?

(How weak a signal can we see?)

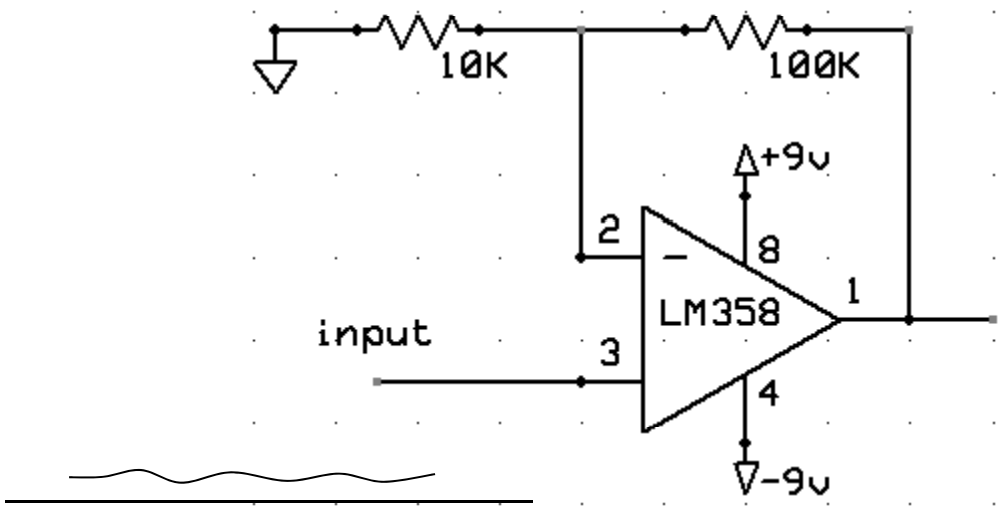


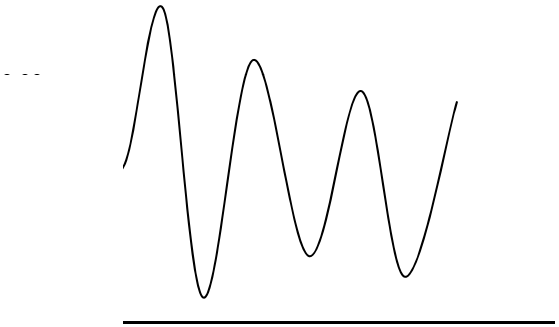


For most applications, the limit is the noise in the signal you are looking at. With gains more than a thousand it can be the noise of the opamp that dominates. You have to worry about filtering and bypass capacitors.

What is the Limit to the Amount of Gain?

(How weak a signal can we see?)





Two stages makes it a little easier.

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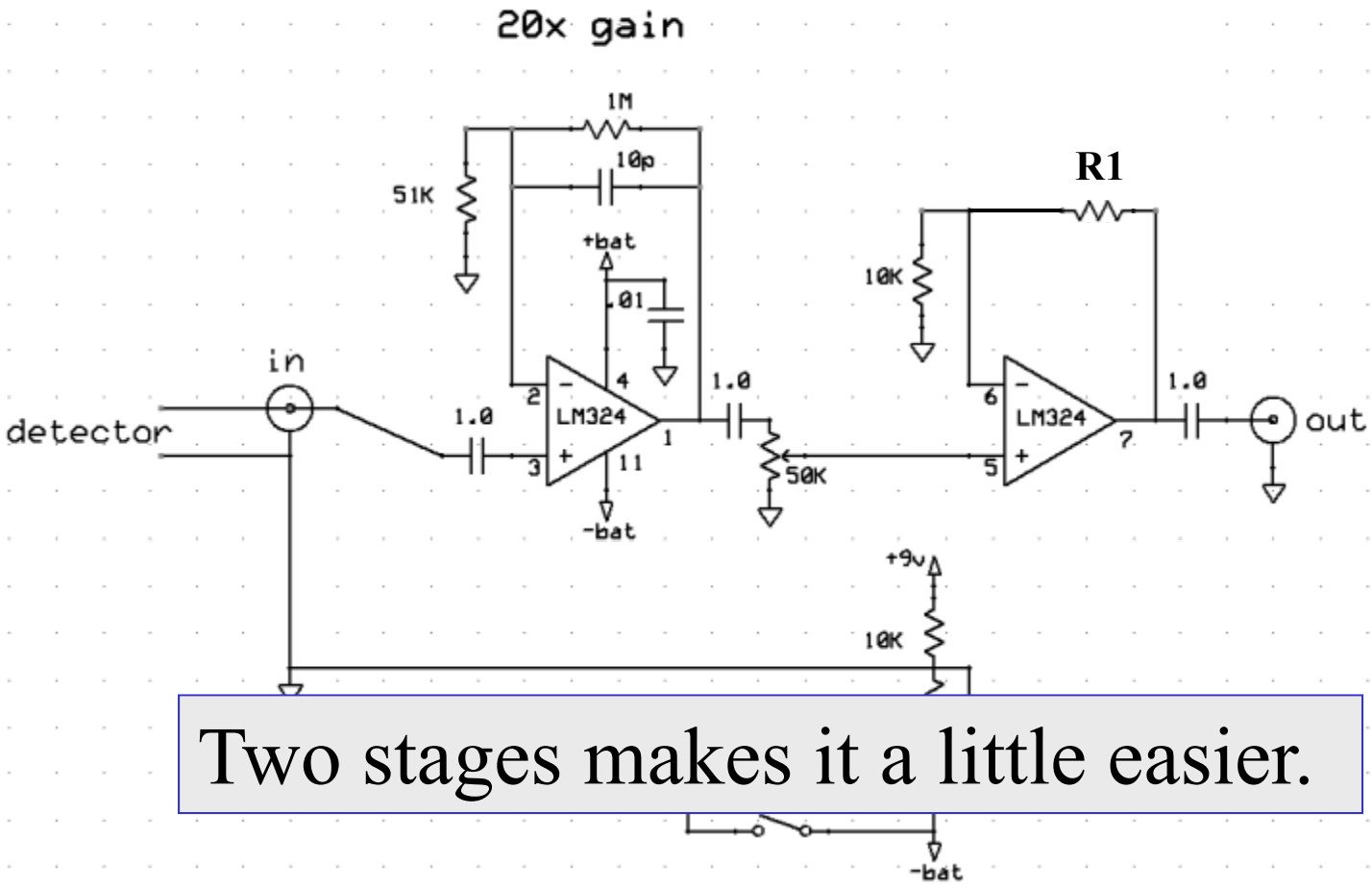

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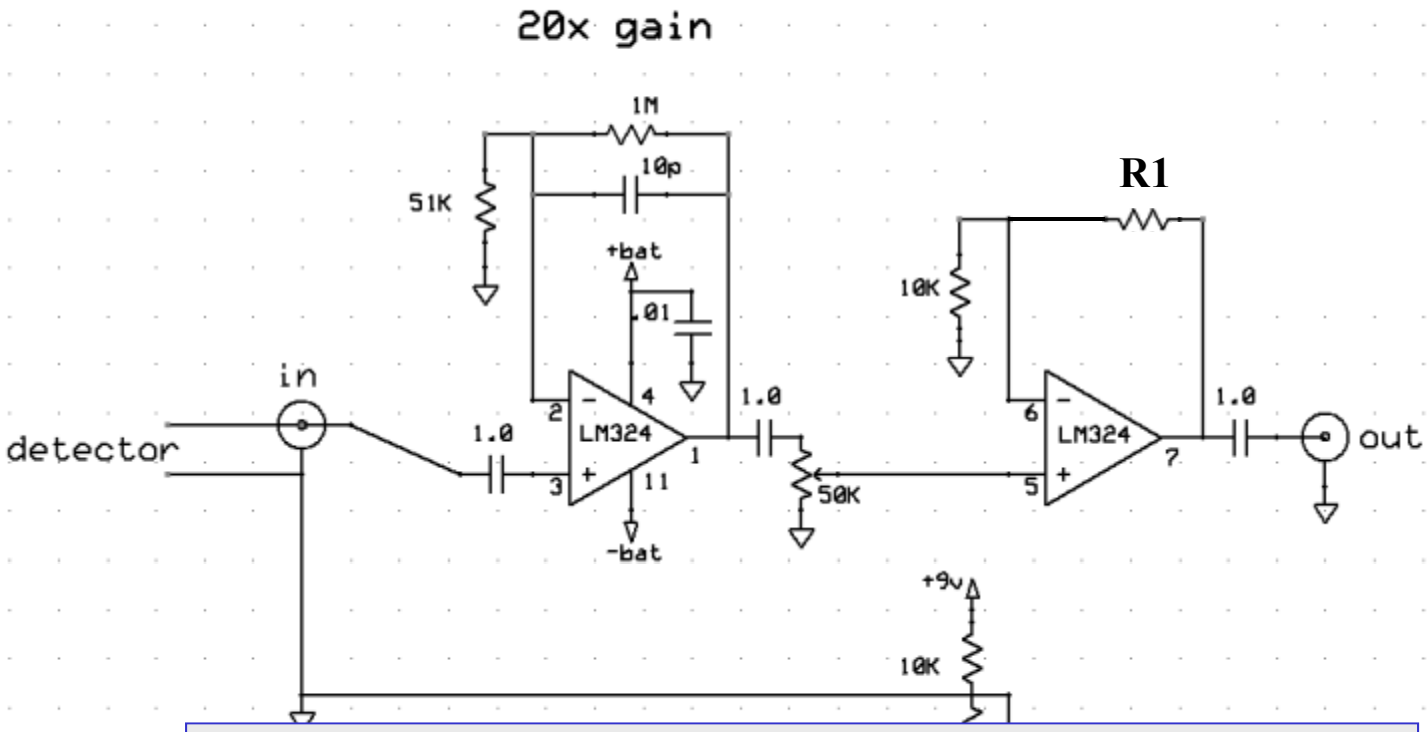
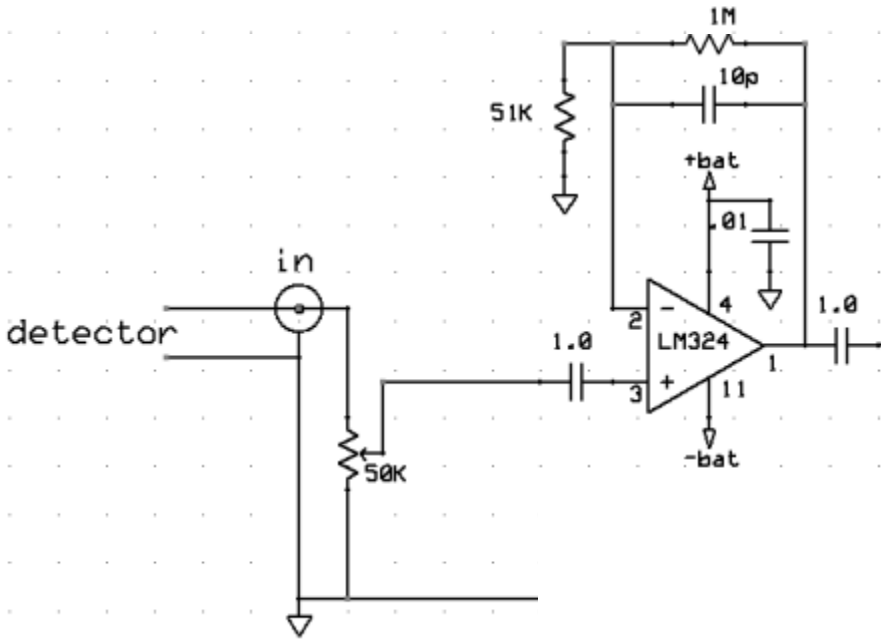


Two stages makes it a little easier.

If you are going to make variable gain adjust the second amplifier so the first one can have short leads.

Variable Gain Examples



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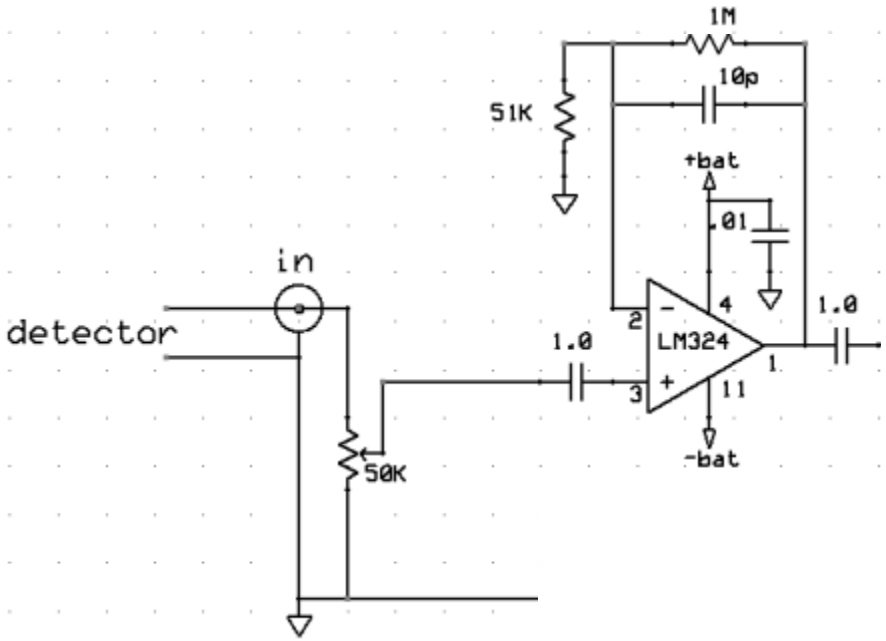
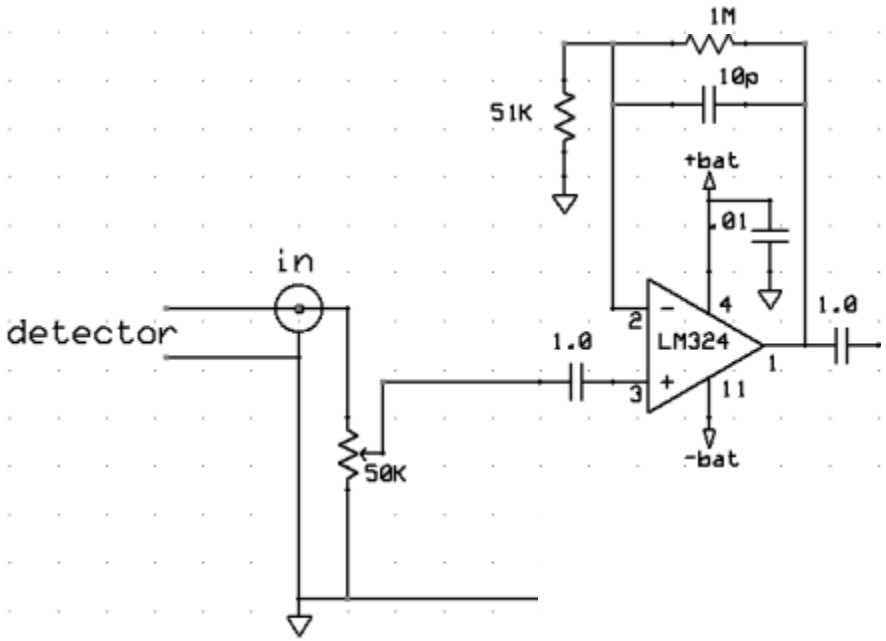


Here's a front end attenuator on the non-inverting.

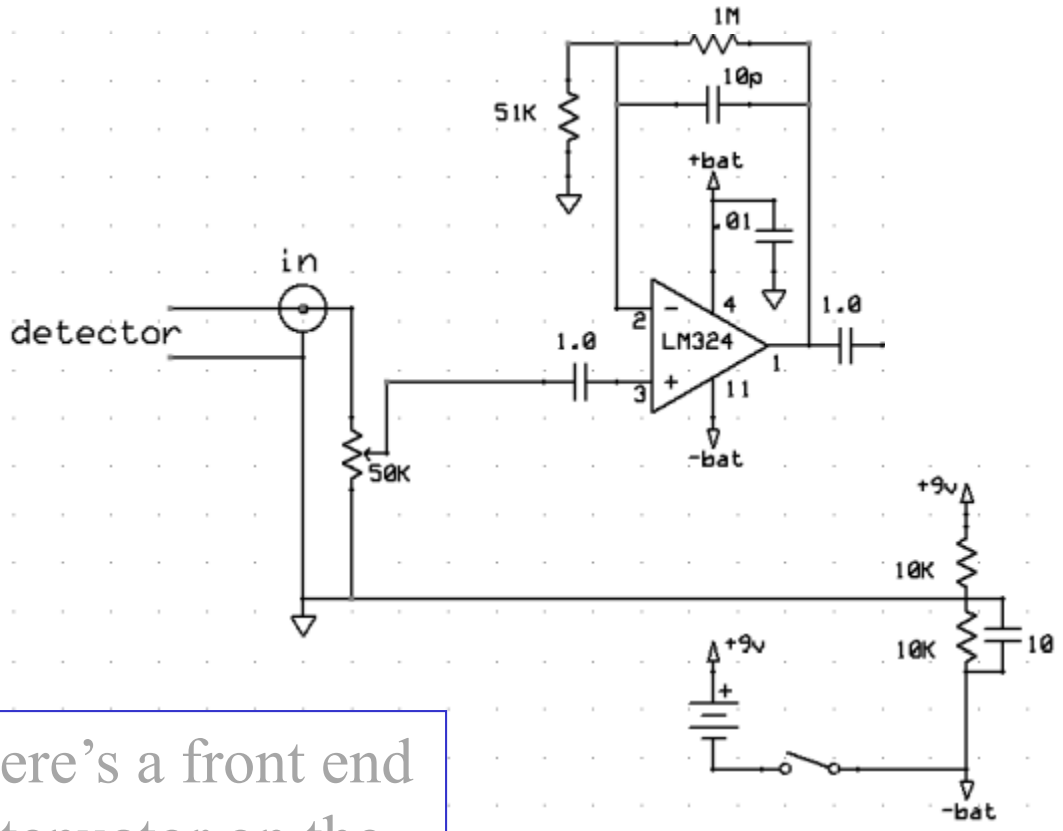
Variable Gain Examples



Here's a front end attenuator on the non-inverting.

A front-end pot would be appropriate if the signal could be more than would saturate the minimum gain.

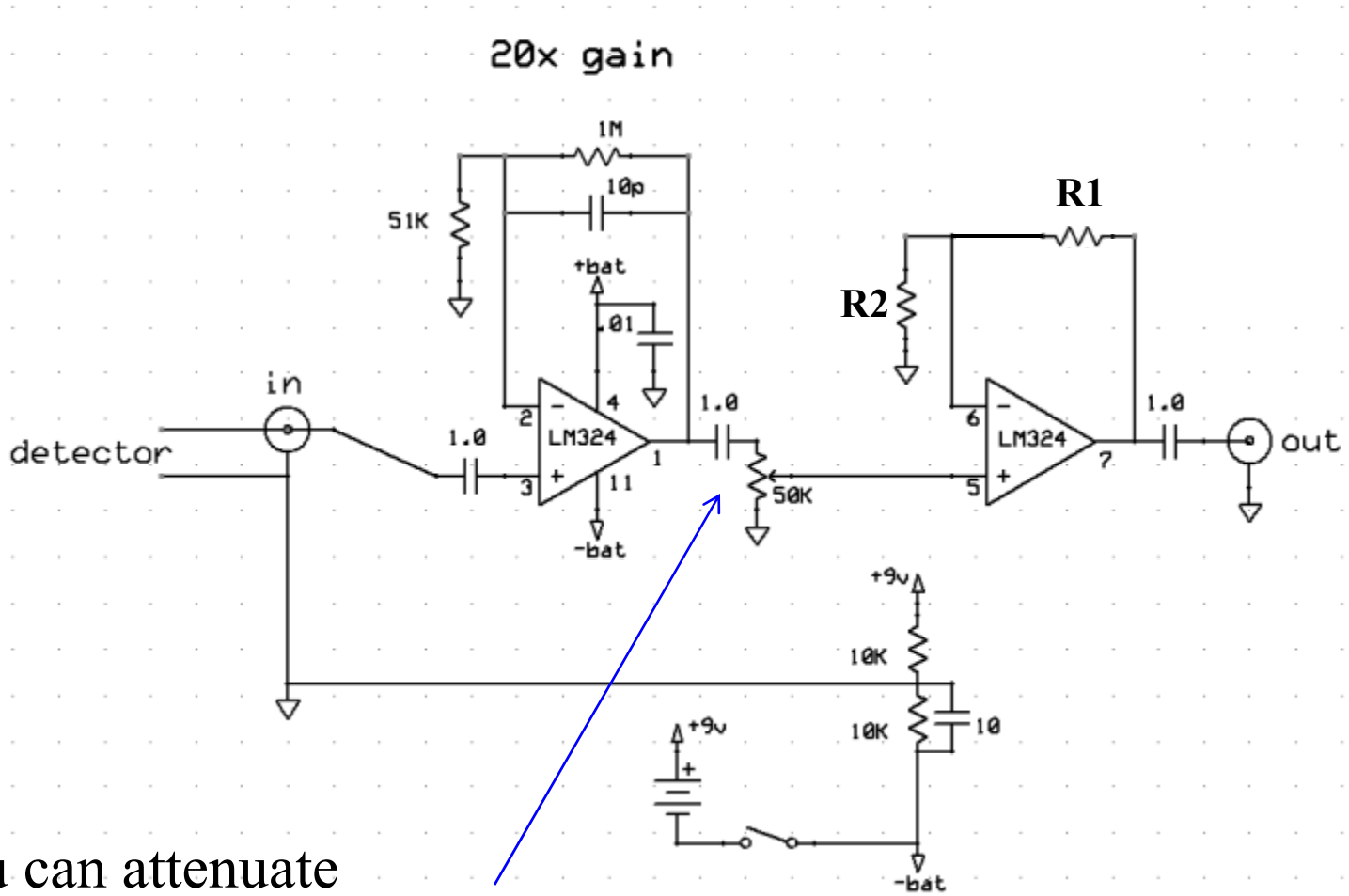
Variable Gain Examples



Here's a front end attenuator on the non-inverting.

Here's a trick for getting a single battery to behave like two. (More on this in another presentation.)

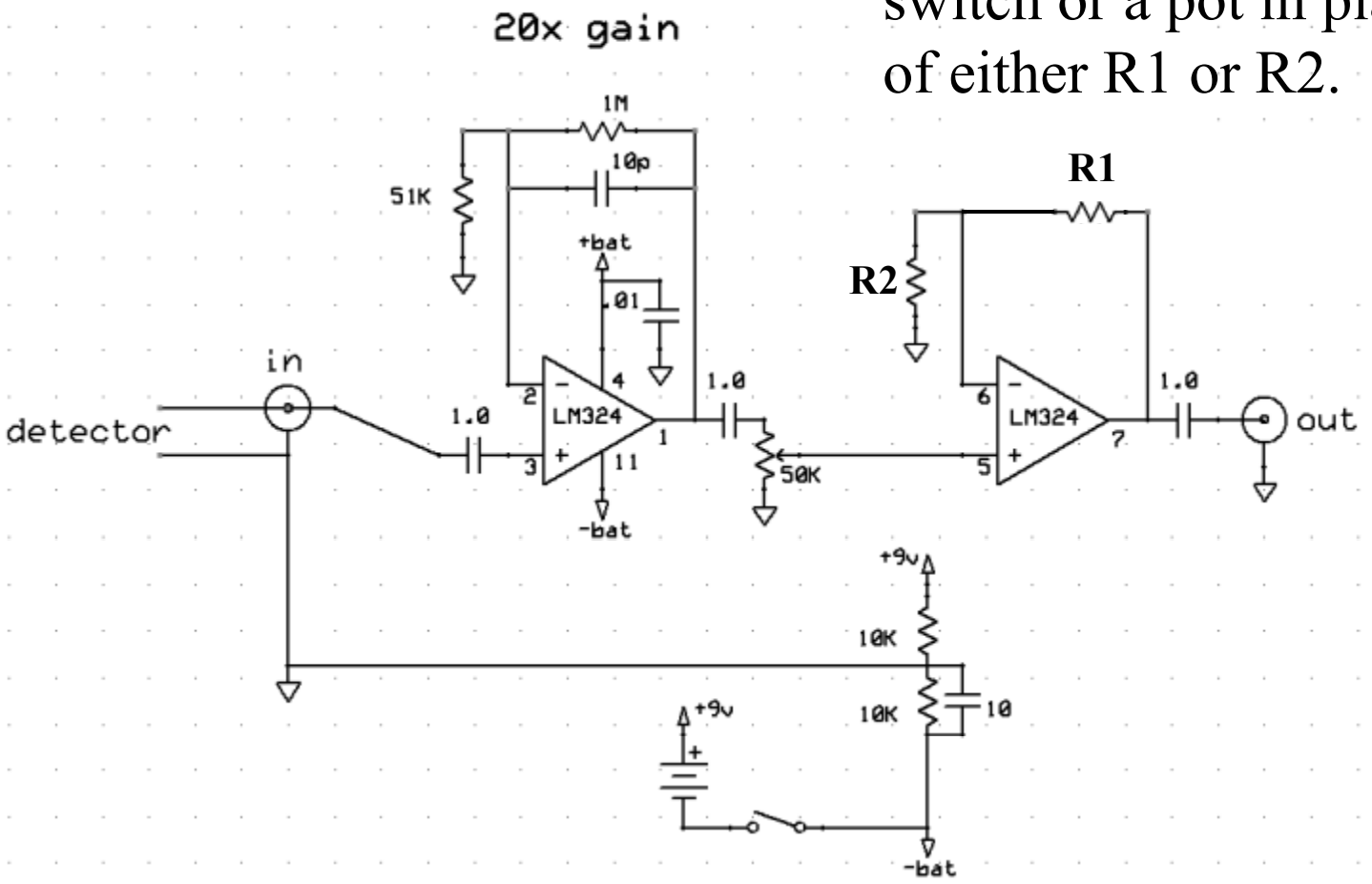
Variable Gain Examples



You can attenuate between stages with a pot here.

Variable Gain Examples

You can put a rotary switch or a pot in place of either R1 or R2.



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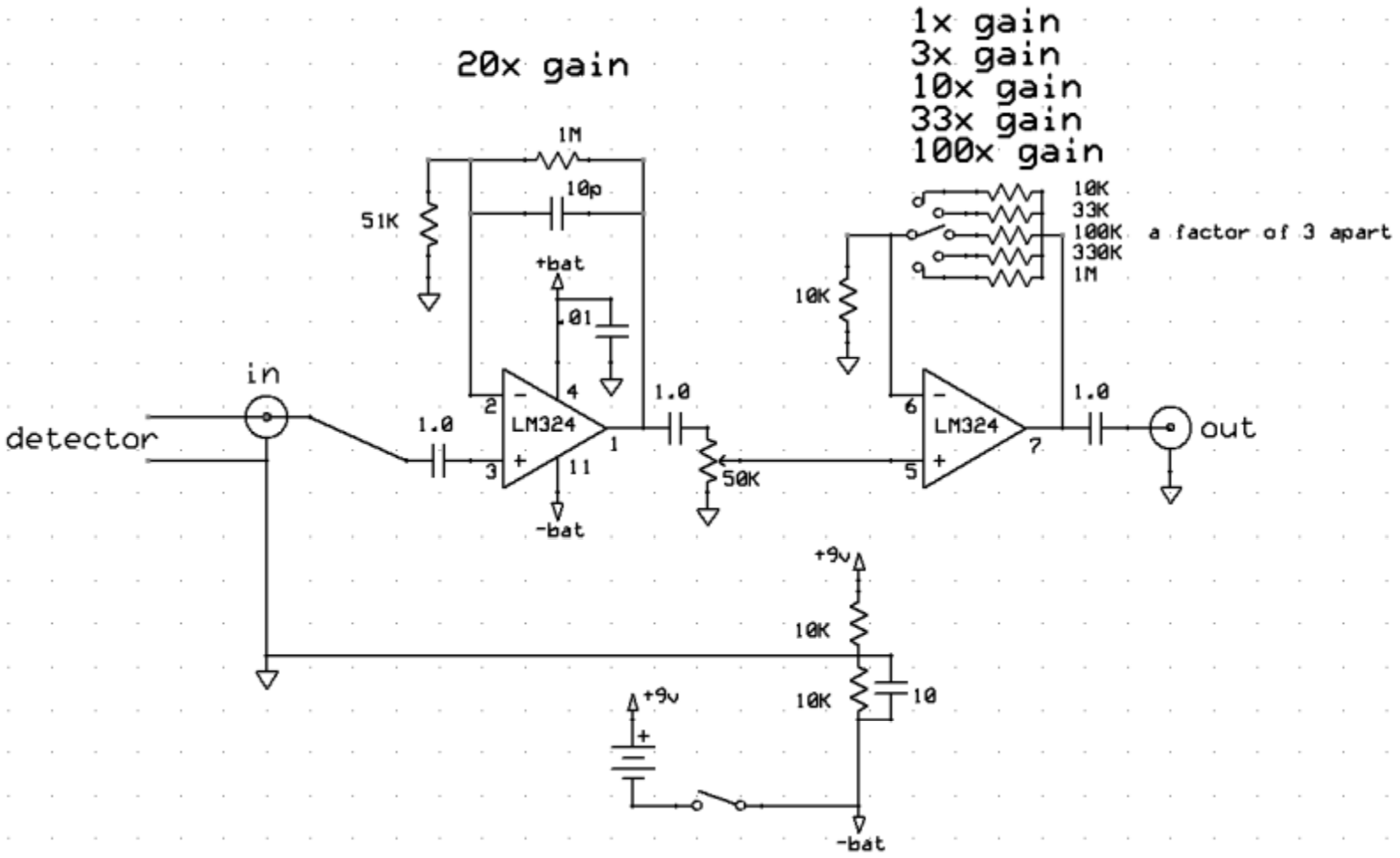

Input Impedance

Input Impedance

- **input** impedance is what the source (the detector or previous stage) sees; the higher the input impedance the more sensitive it is.
- high **source** impedance (like a diode detector) means very weak current capability. (It needs an amplifier that is also high impedance.)
- low **source** impedance of the same amount of power as the above diode detector, is more current but less voltage; microvolts (instead of millivolts) from a microphone, for example

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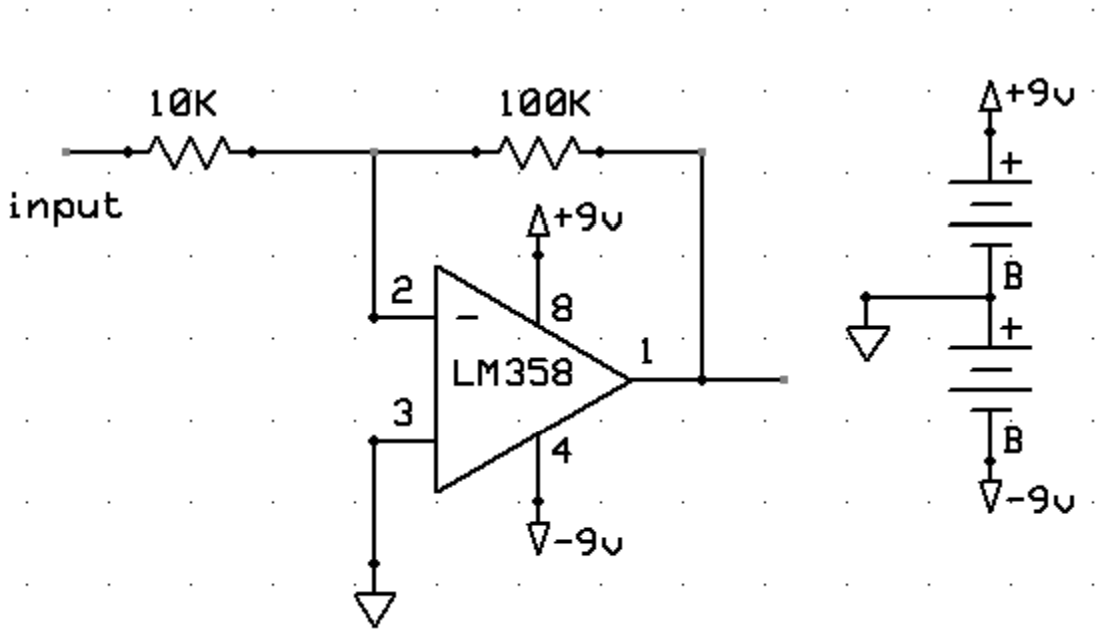
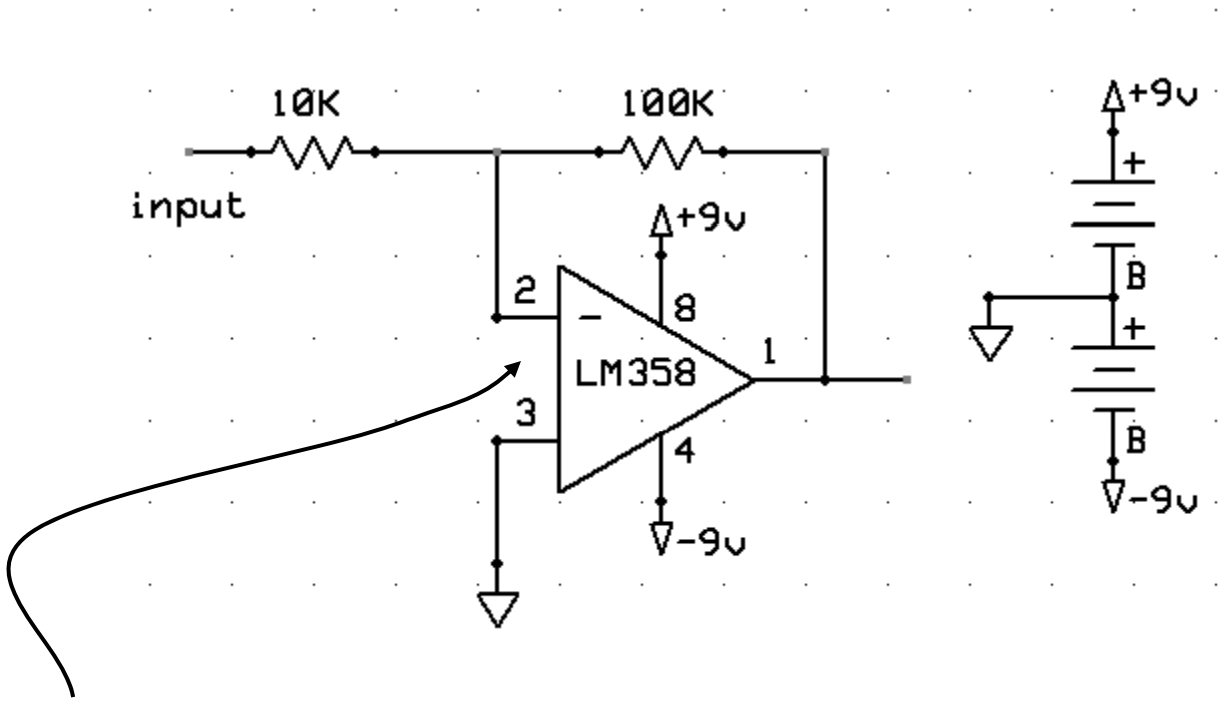
What you need to memorize is that it is more expensive for the input of an amplifier to be of high input impedance. Note that if the amplifier input impedance is low, it can drag down a high impedance (weak) source.

The Inverting Input Impedance



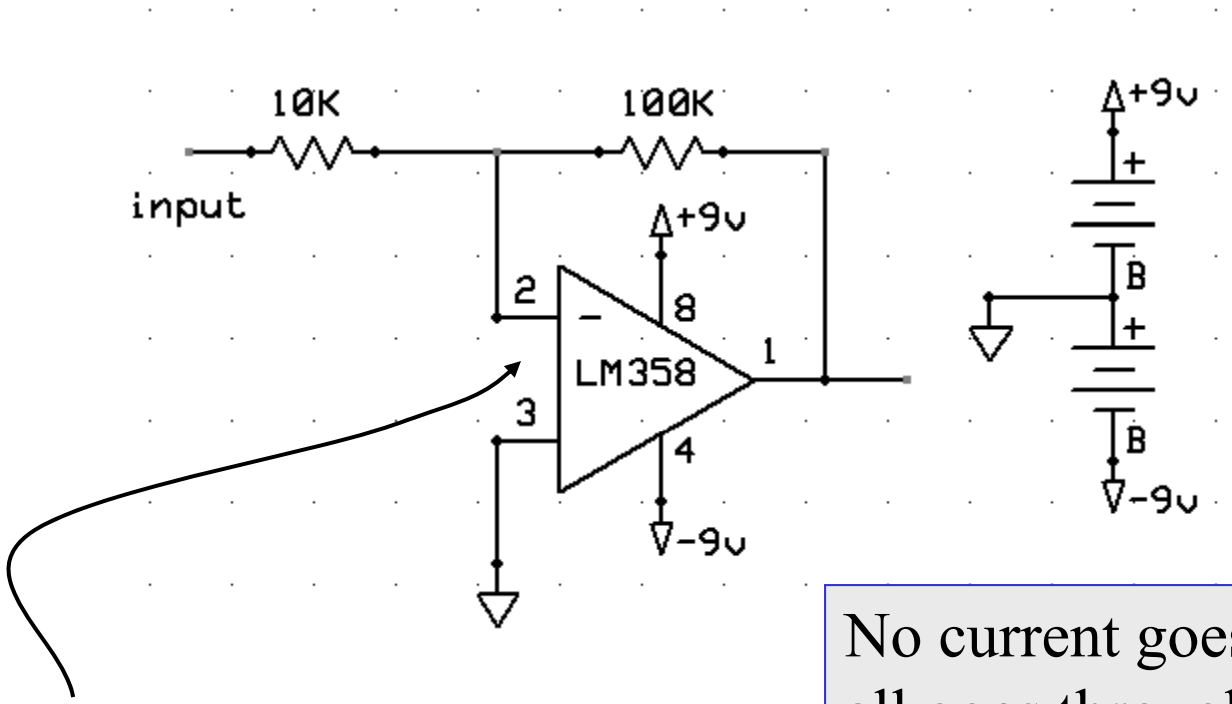
The 10K resistor is what the source will see as its load.
That's pretty low and might drag down a weak signal source.

The Inverting Input Impedance



Remember Golden Rule #3
This point acts like a ground
(it wants to be zero volts like
the other input.)

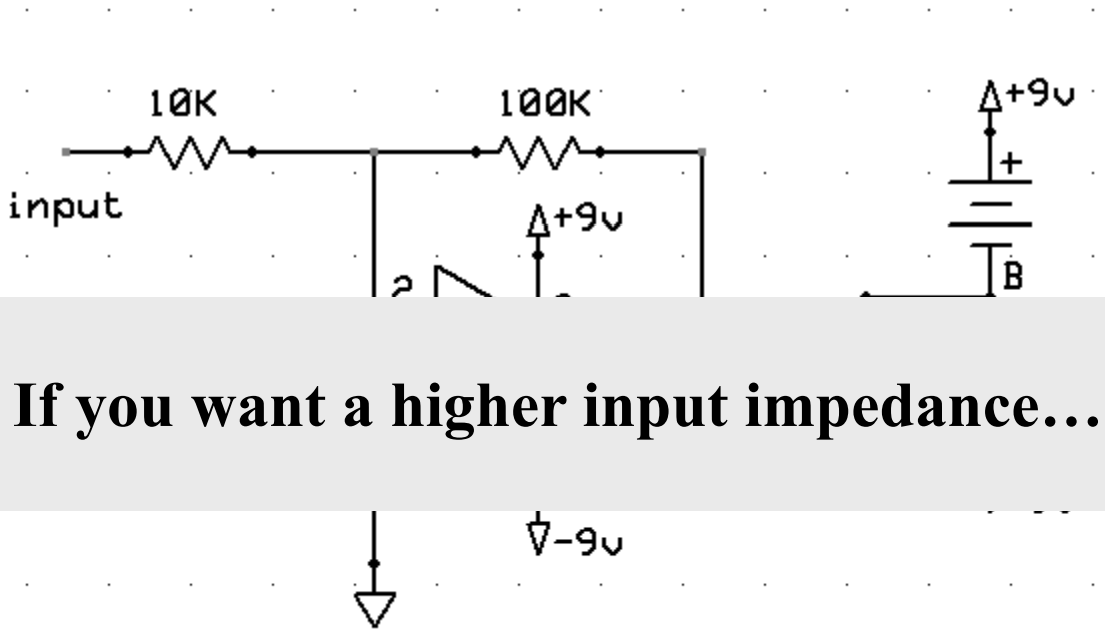
The Inverting Input Impedance



Remember Golden Rule #3
This point acts like a ground
(it wants to be zero volts like
the other input.)

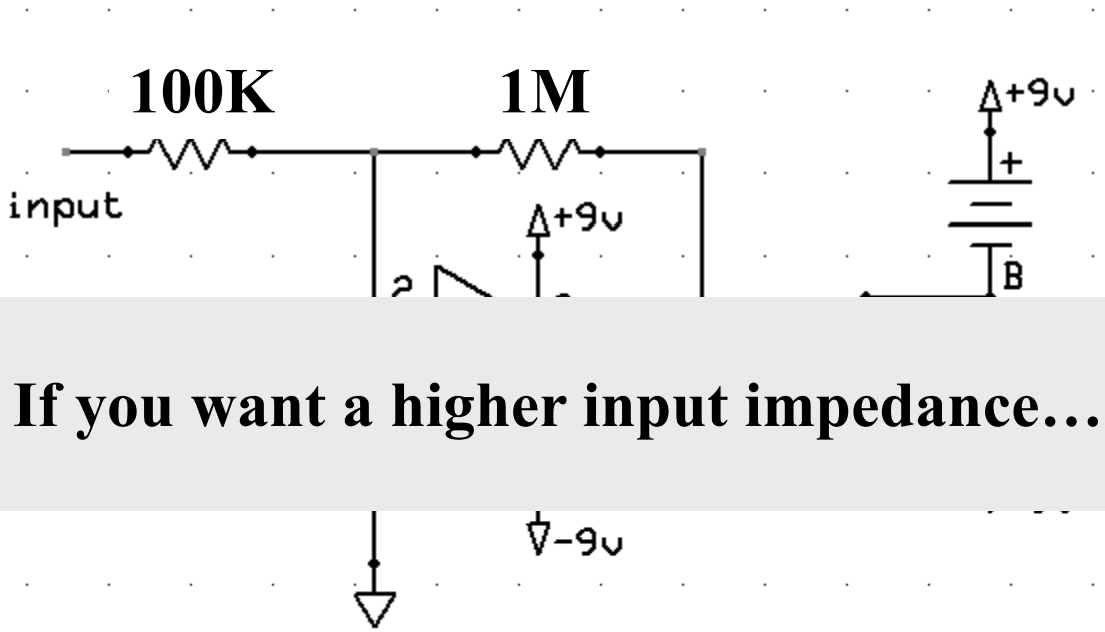
No current goes in there. It all goes through the 100K resistor. But the opamp makes it appear to be a sink at ground.

The Inverting Input Impedance



If you want a higher input impedance…

The Inverting Input Impedance



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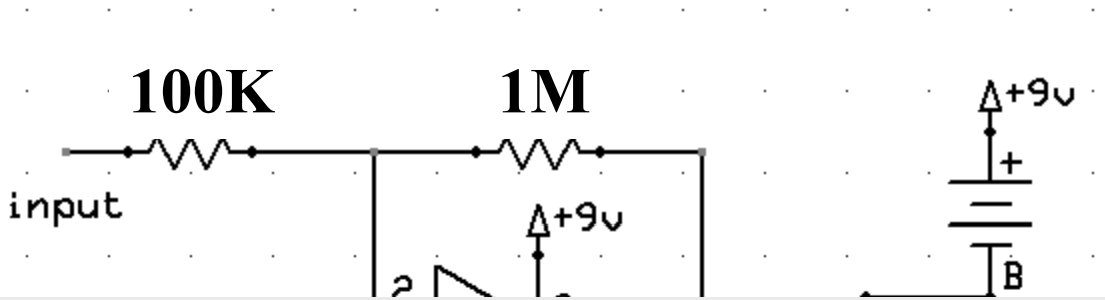
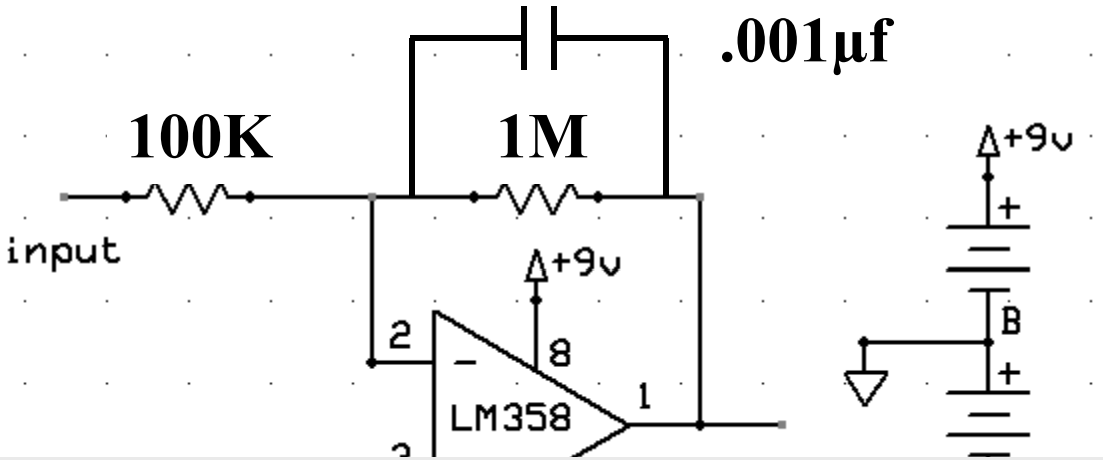


If you want a higher input impedance.

The cost is that any internal capacitance lowers the bandwidth.

The Inverting Input Impedance



The cost is that any internal capacitance lowers the bandwidth.

In fact, you can force the time constant higher (lower bandwidth) by adding capacitance.

The Non-Inverting Input Impedance

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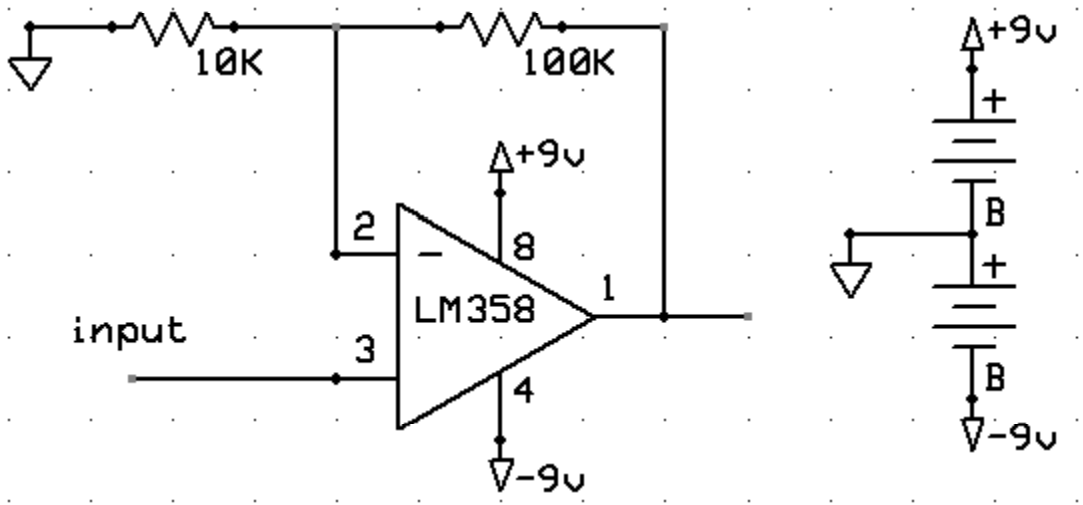

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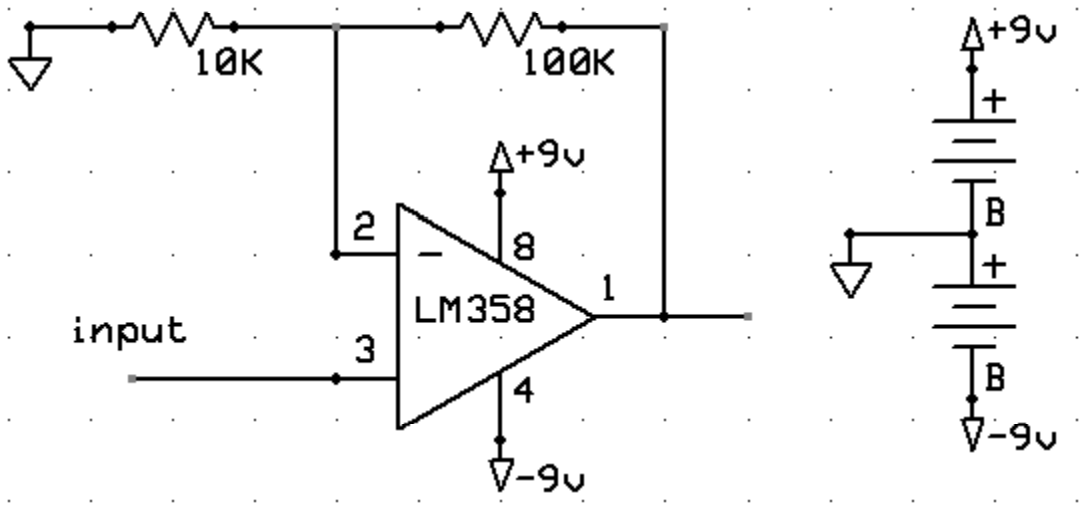
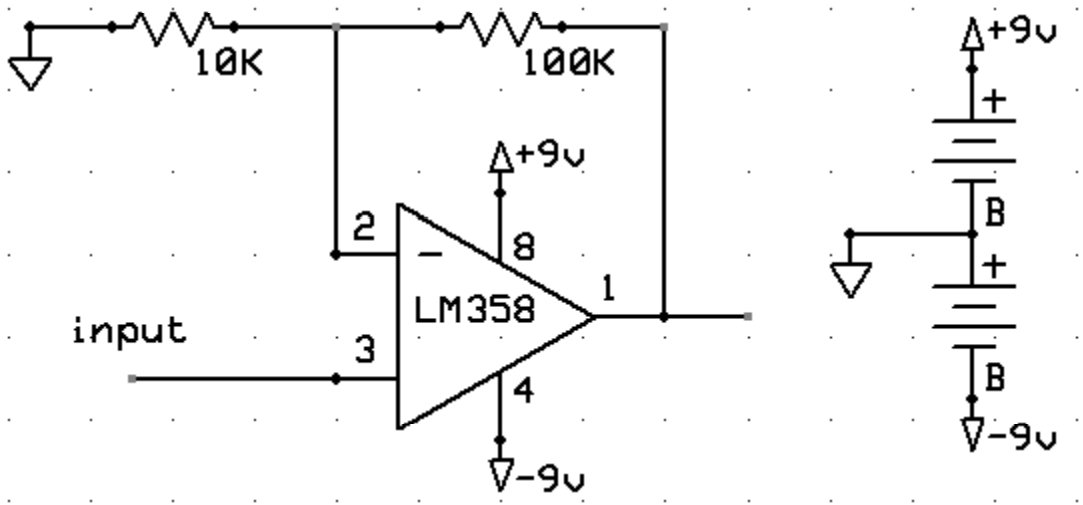


The raw input impedance of some opamps are in the millions of meg ohms.

The Non-Inverting Input Impedance



The source into the non-inverting side can be very high impedance.
(The opamp will not drag down even the lowest of current sources.)

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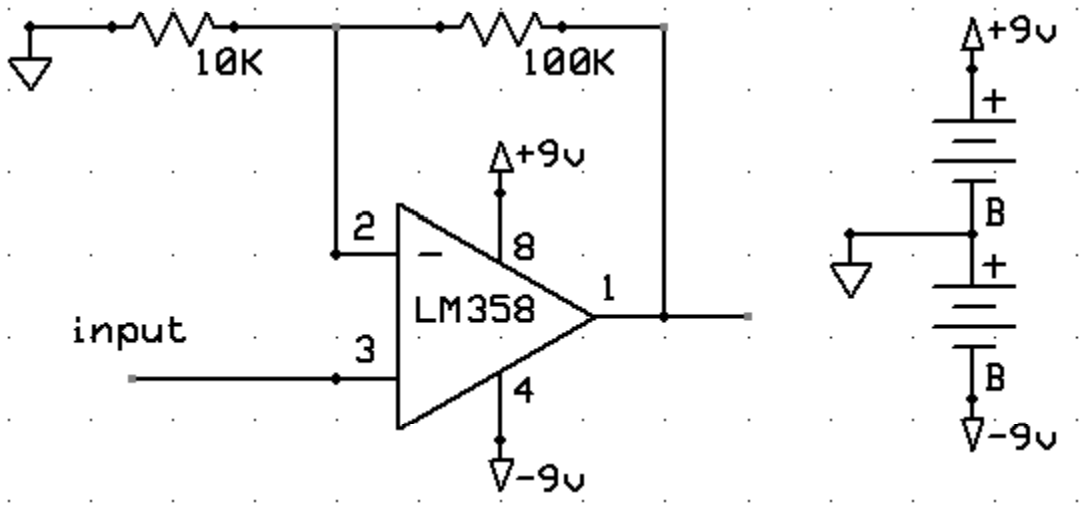

The source into the non-inverting side can be very high impedance (The opamp will not drag down even the lowest of current sources.) But with super high gains and very high input impedance sources… the opamp's "input-offset-voltage" error can bias the output when the input signal is near zero.

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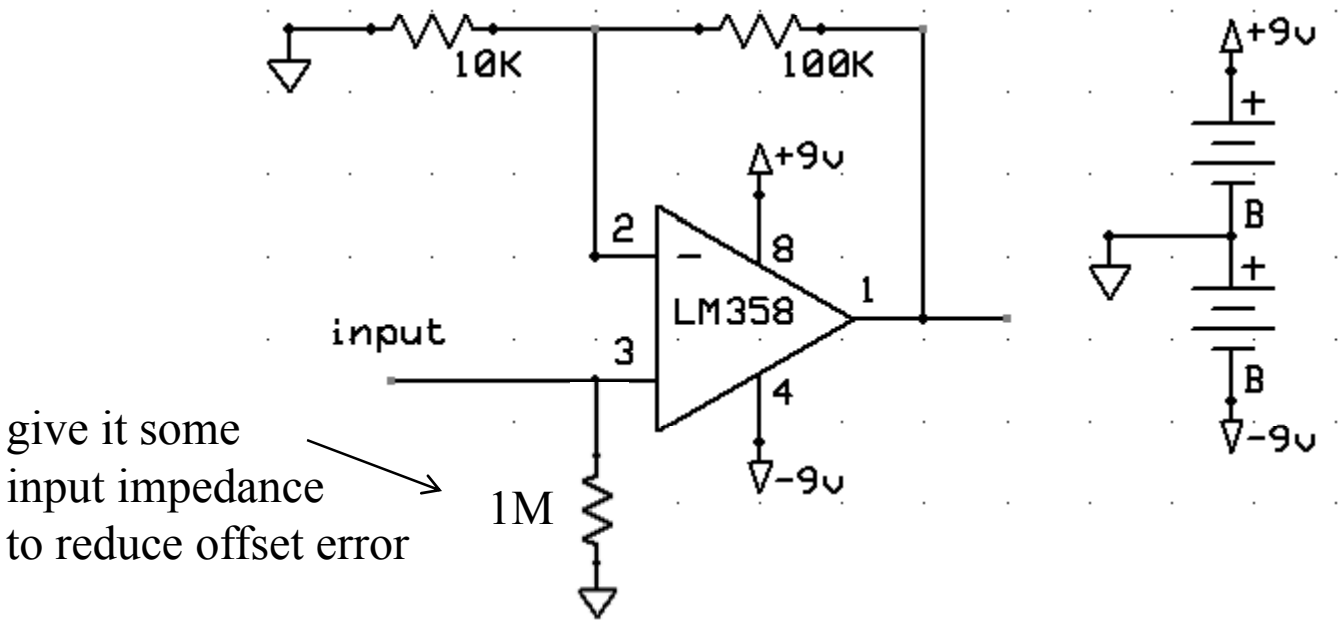

give it some
input impedance
to reduce offset error

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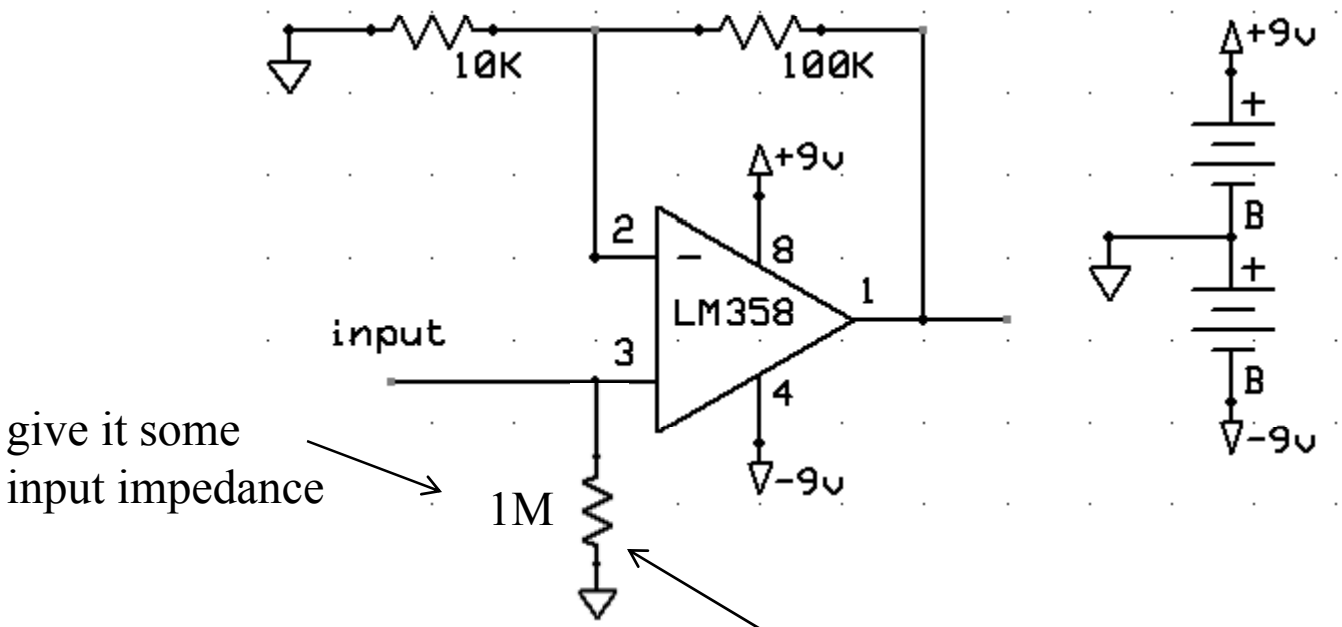

(This can be higher if opamp input offset current is very low.)

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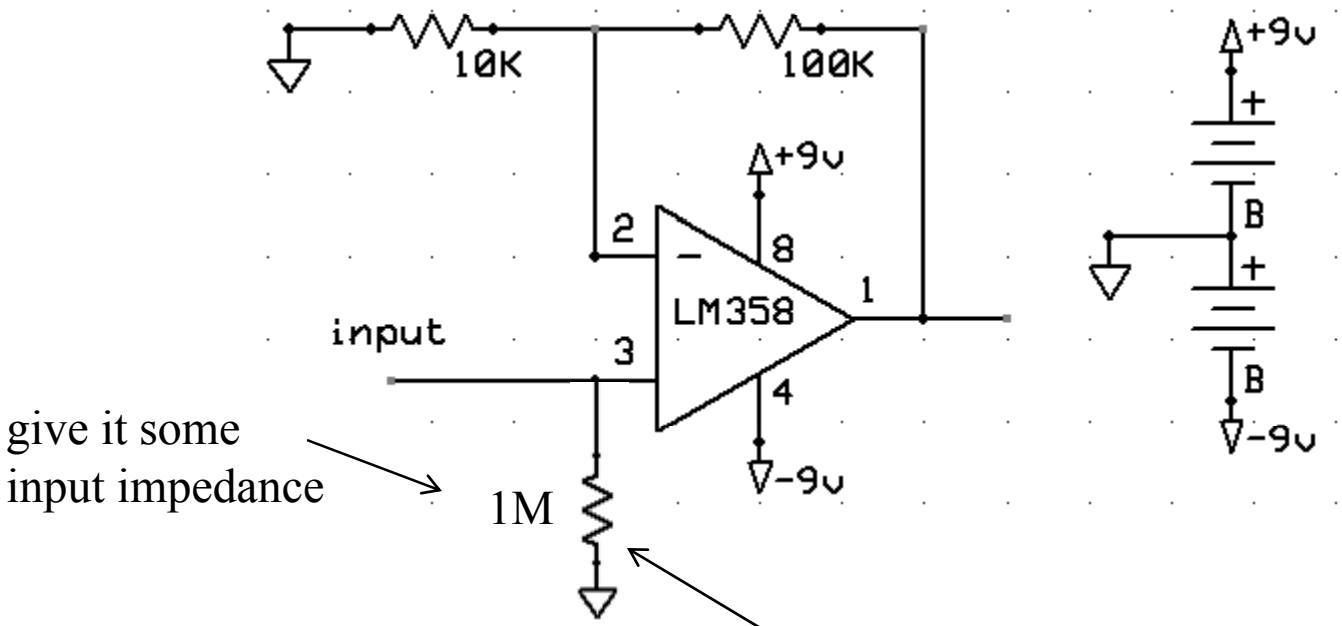

This does not affect the gain. It only lowers the input impedance. If the source is capable of providing milliamps you could lower it to 10K, the same as the other input. A balanced input cancels the effect of the input offset voltage spec.

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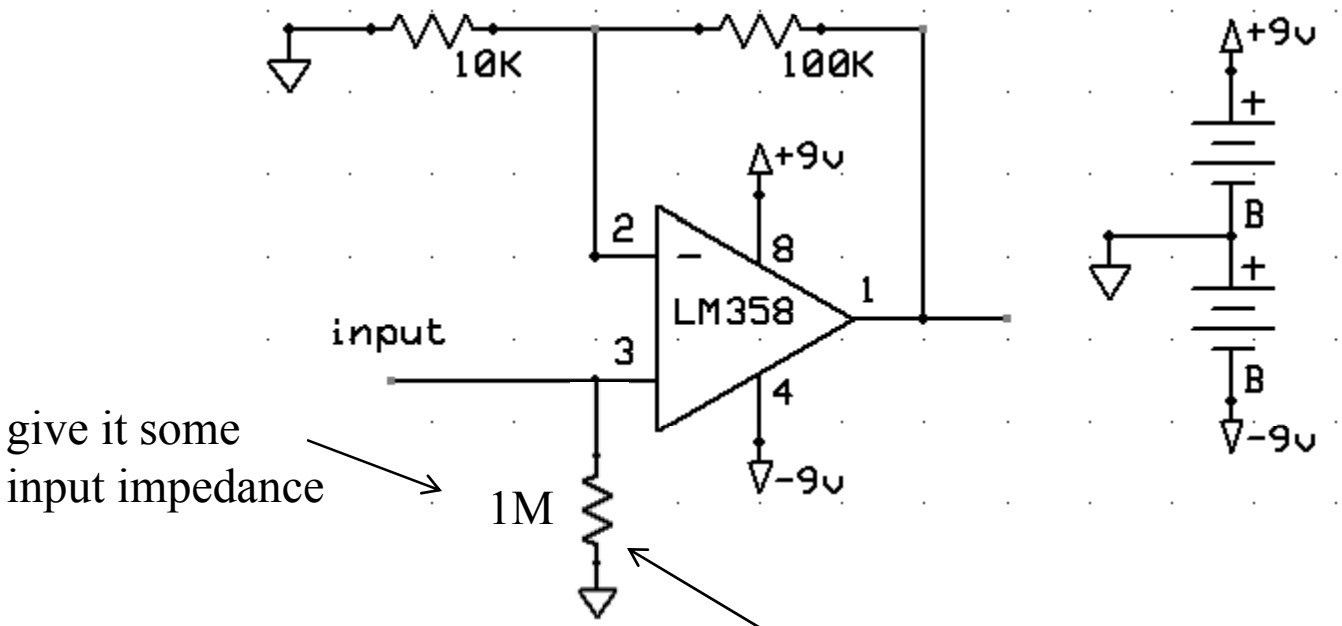

give it some
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1M

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More about zero offset
in another presentation.

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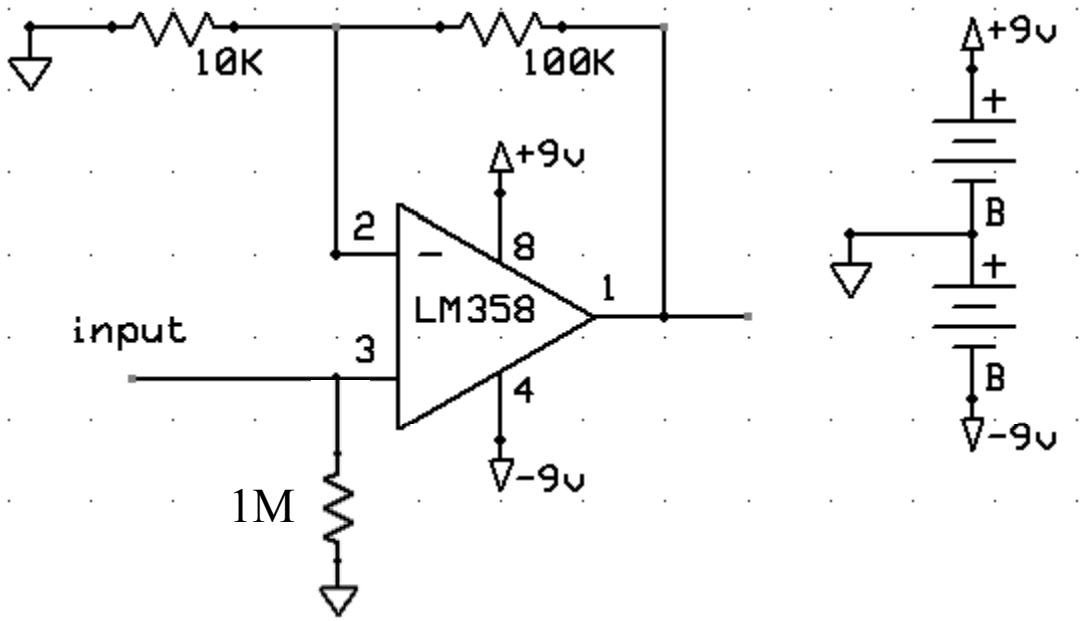

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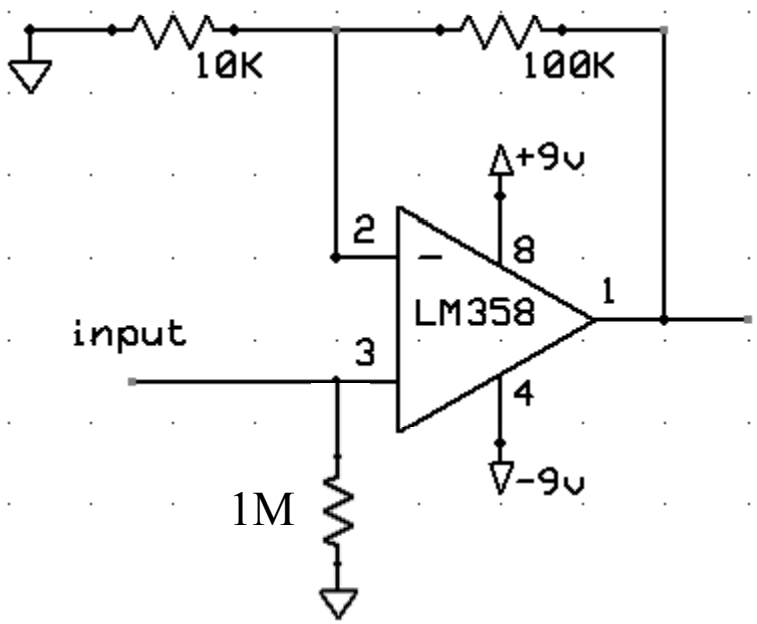

And you can lower the bandwidth on the non-inverting the same way you lowered it on the inverting. By "bypassing" the high frequencies in the feedback.

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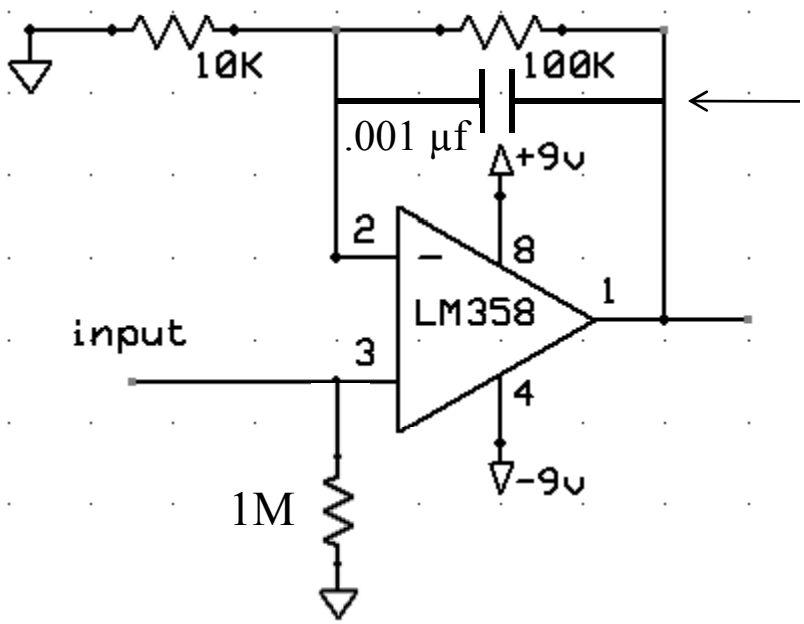

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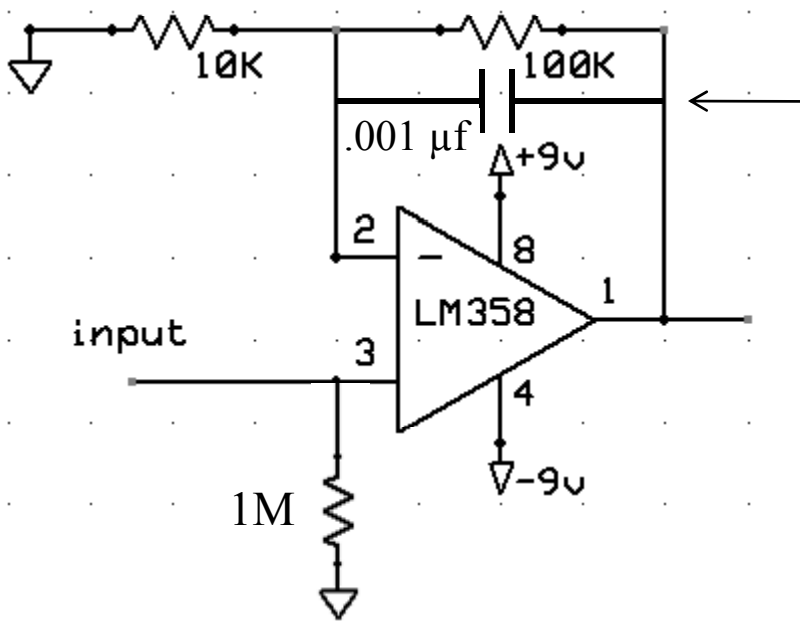

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.001 times 100K = .1 sec
One over tc is bandwidth;
20 Hz. Which would lower the noise substantially.

Stuff to Know

- **The Normal Input (The Non-Inverting)**
  - **can use single batteries**
  - **easier to work with than the inverting input.**
- **The "Other" Input (The Inverting)**
  - **must use two batteries**
  - **can't use extremely high impedance sources (weak sources)**

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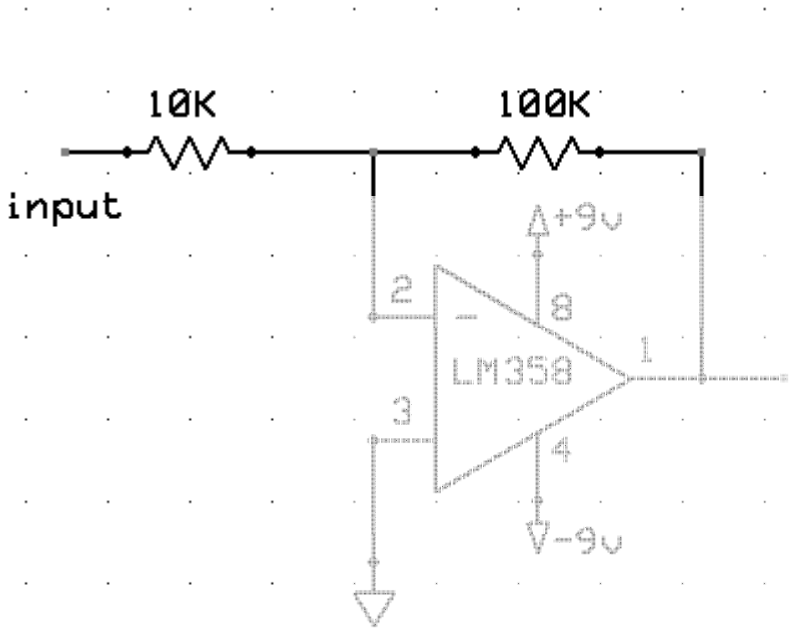

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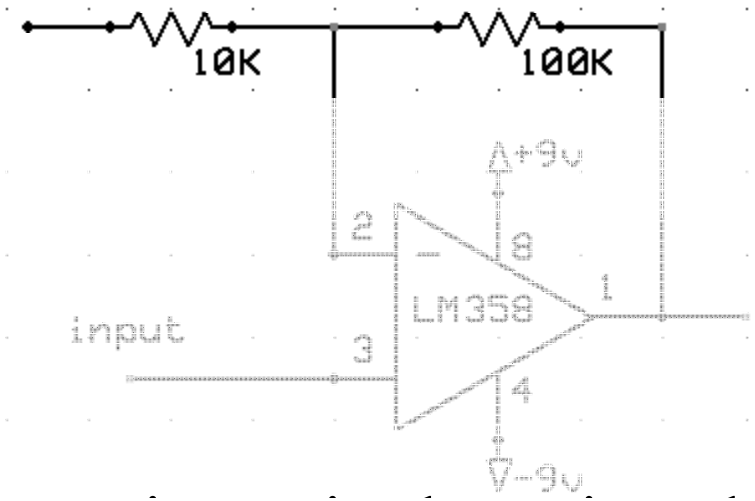

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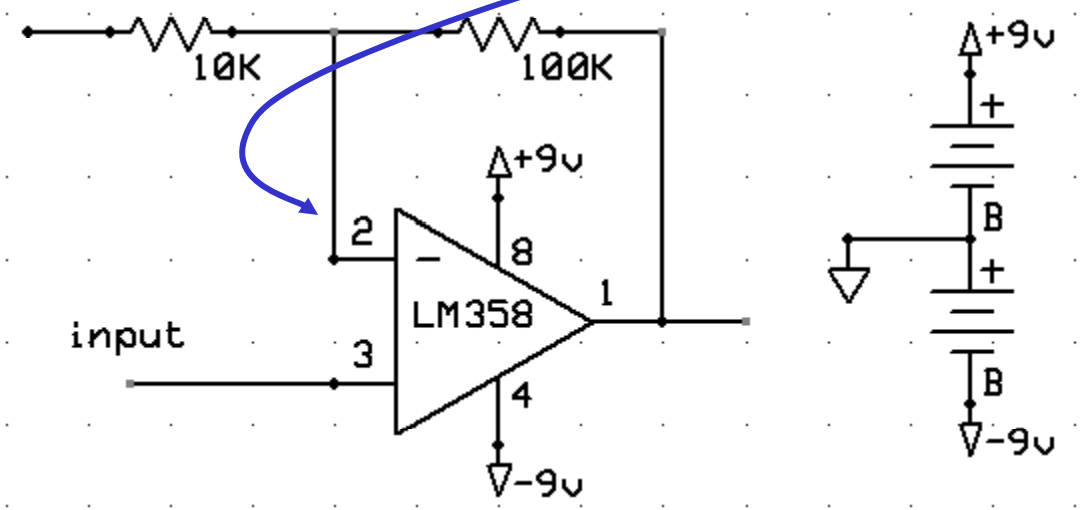

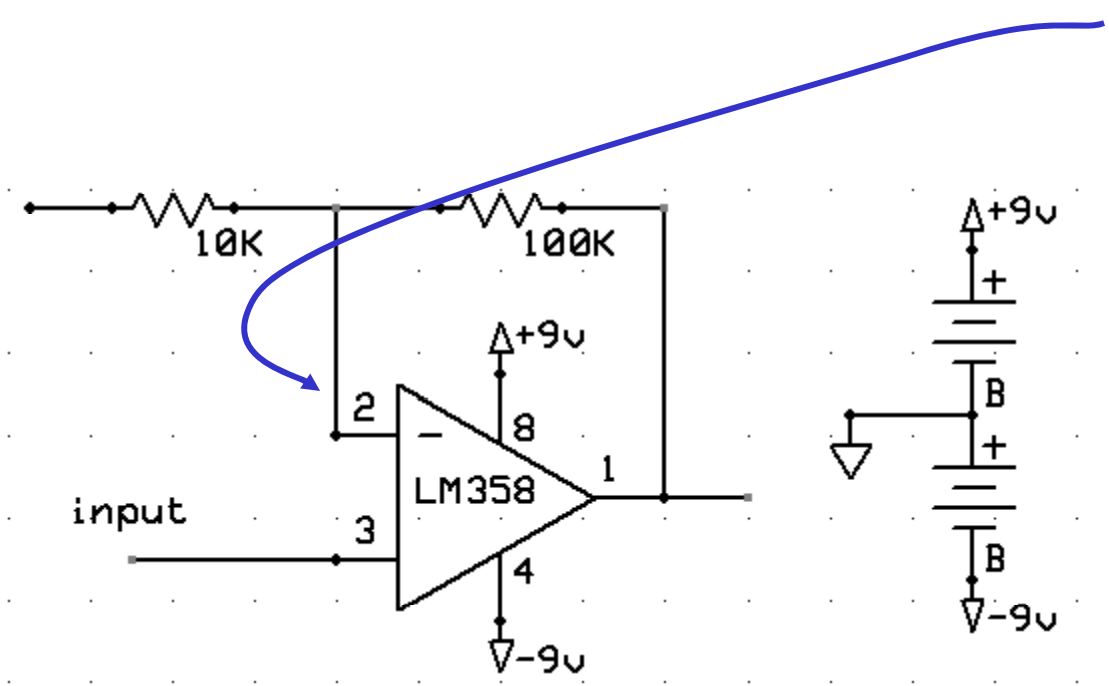

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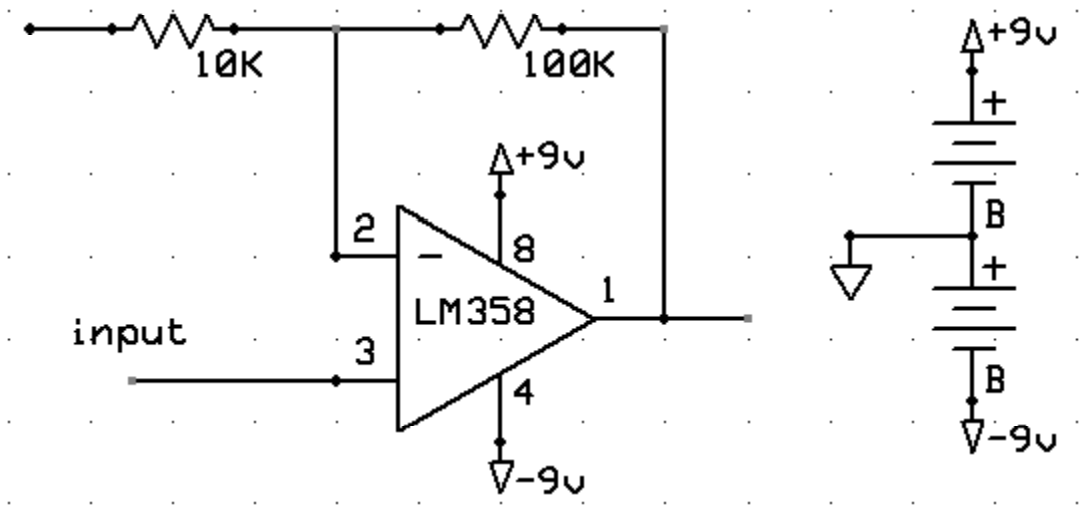
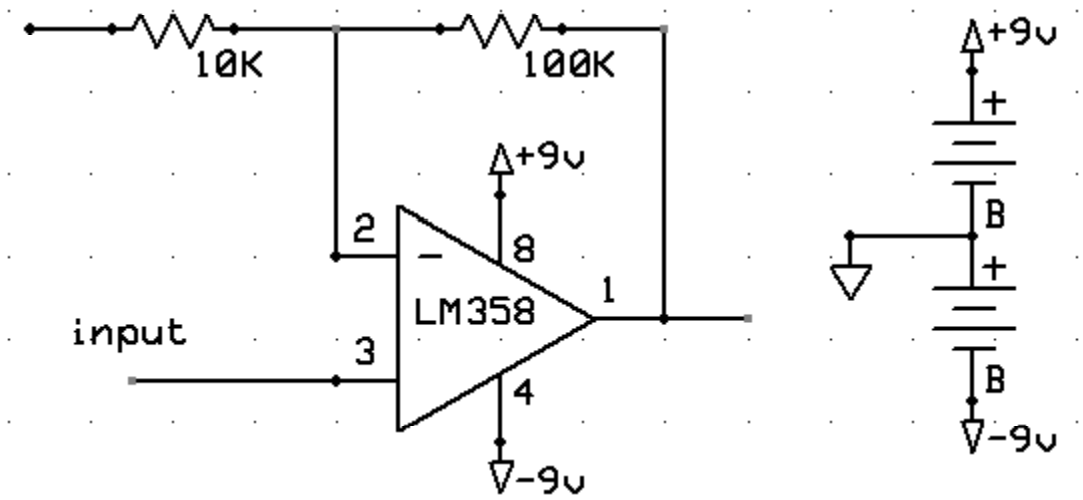
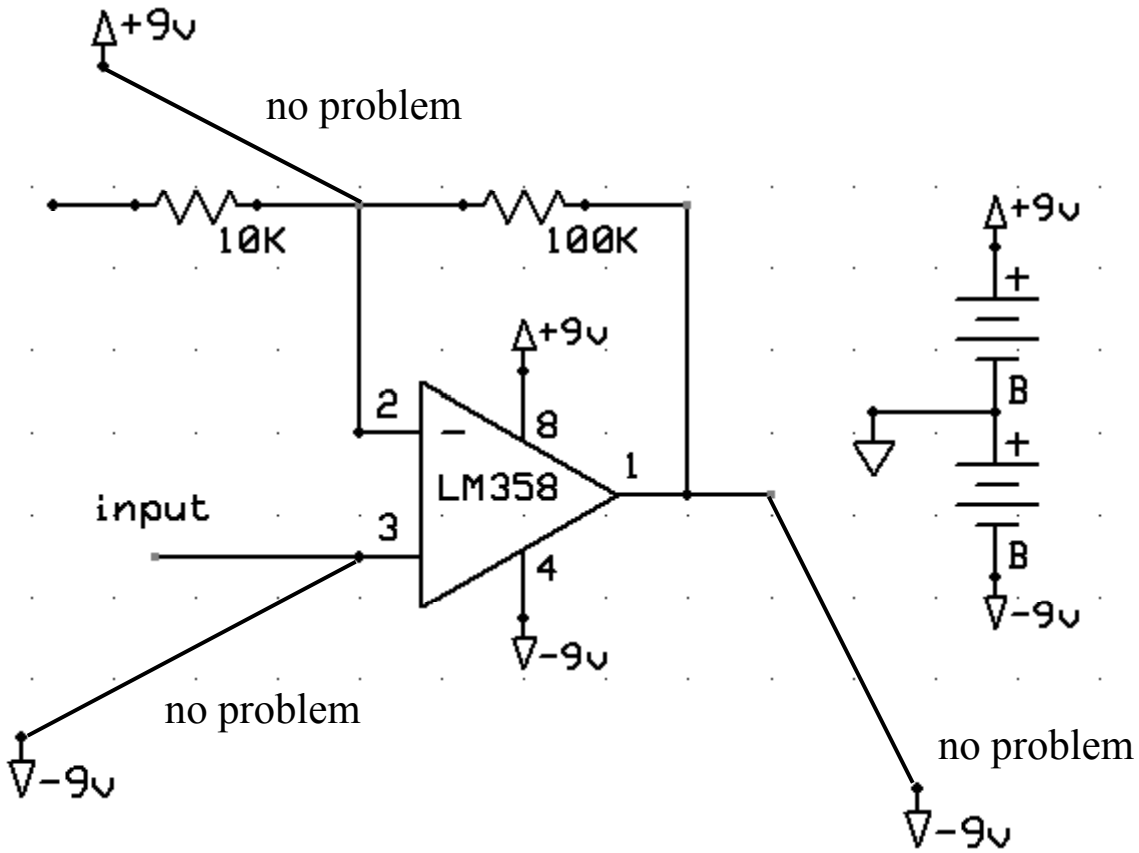
It can be very confusing if you put your VOM probe here.



Notice that both can be inputs. Ground is in reality, just some level between the battery's terminals.



Oh… and a final word of advice:



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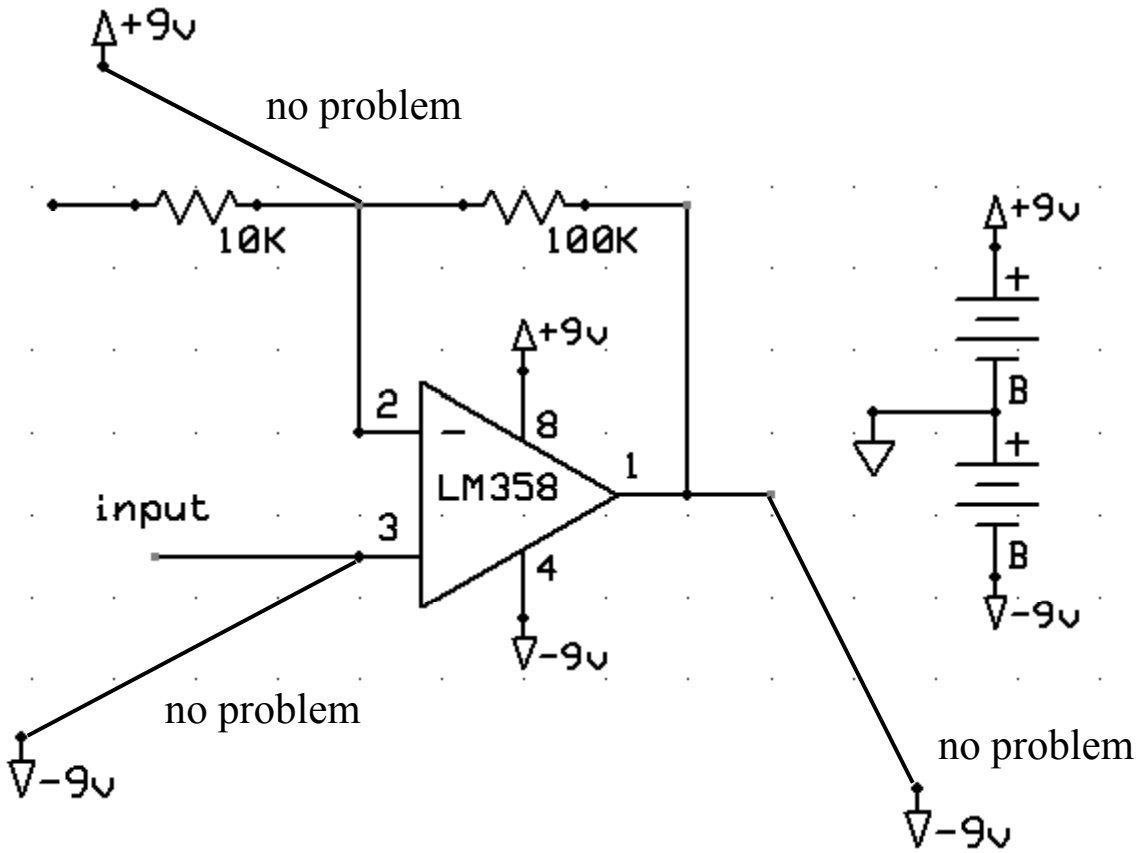
You can’t hurt it



Oh… and a final word of advice:

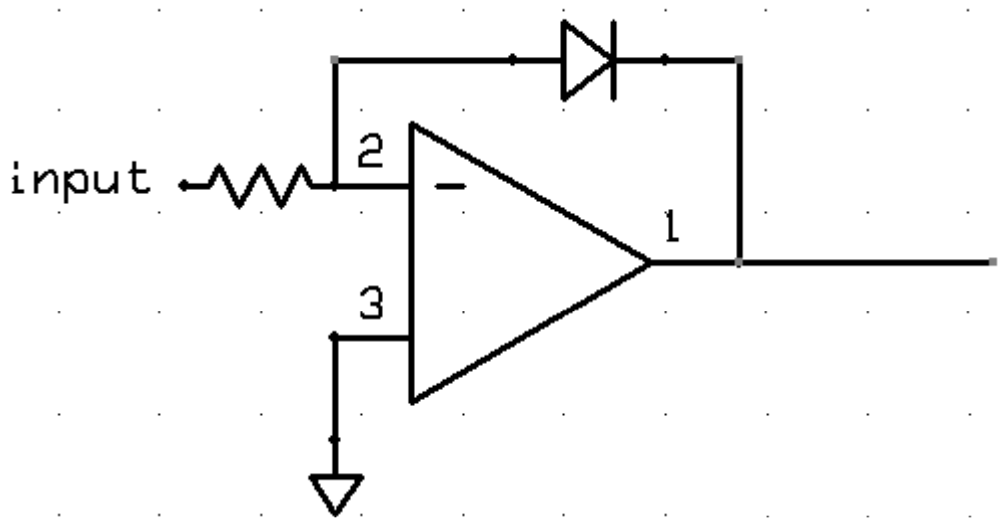
You can't hurt it, so play with it all you want.

Applications

National Semiconductors or Linear Devices Application Notes are your best resource

Applications

the “Precision Rectifier” is a good lesson in the use of non-linear elements



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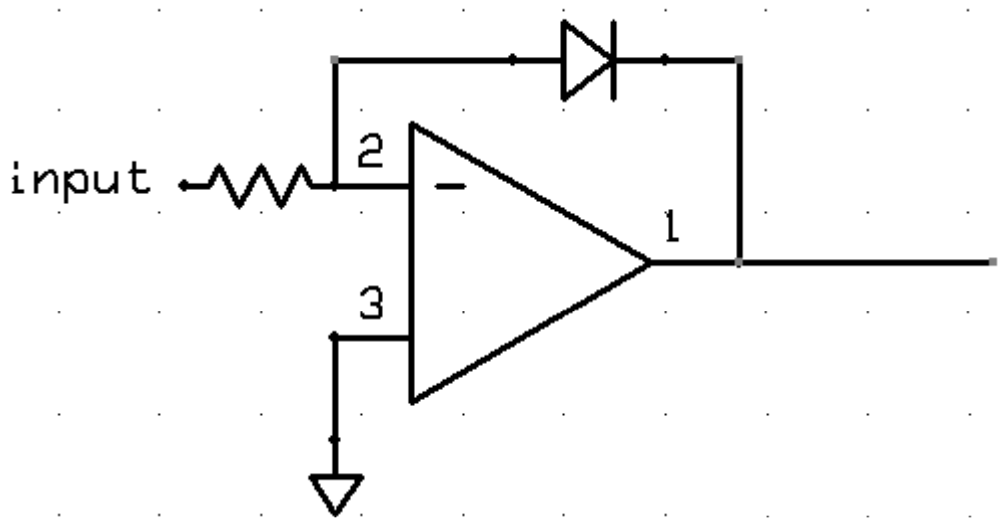

Feedback exaggerates and does the opposite.