

**ULTIMATE ELECTRONICS: PRACTICAL CIRCUIT DESIGN AND ANALYSIS****7.EX**

# Chapter 7 Example Circuits

63 example circuits and simulations from Chapter 7: Op-Amps.

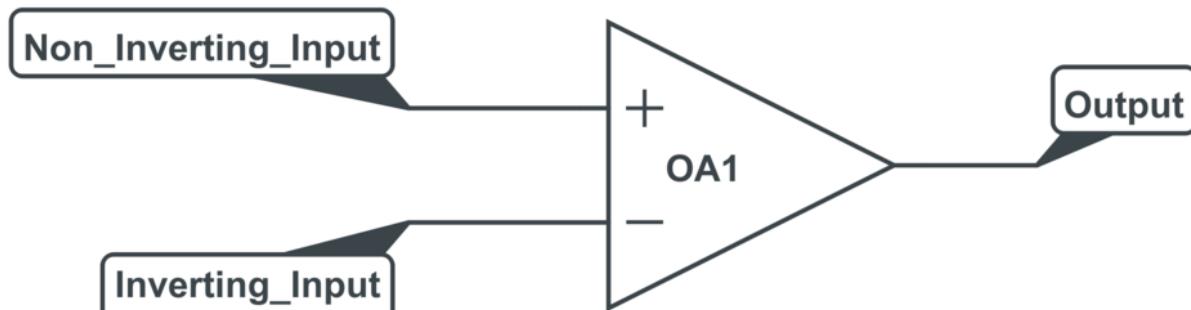
This page collects interactive circuits and simulations from Chapter 7 of [Ultimate Electronics Book: Op-Amps](#).

**Exercise**

Click any circuit to open in a new tab. Most include simulations.

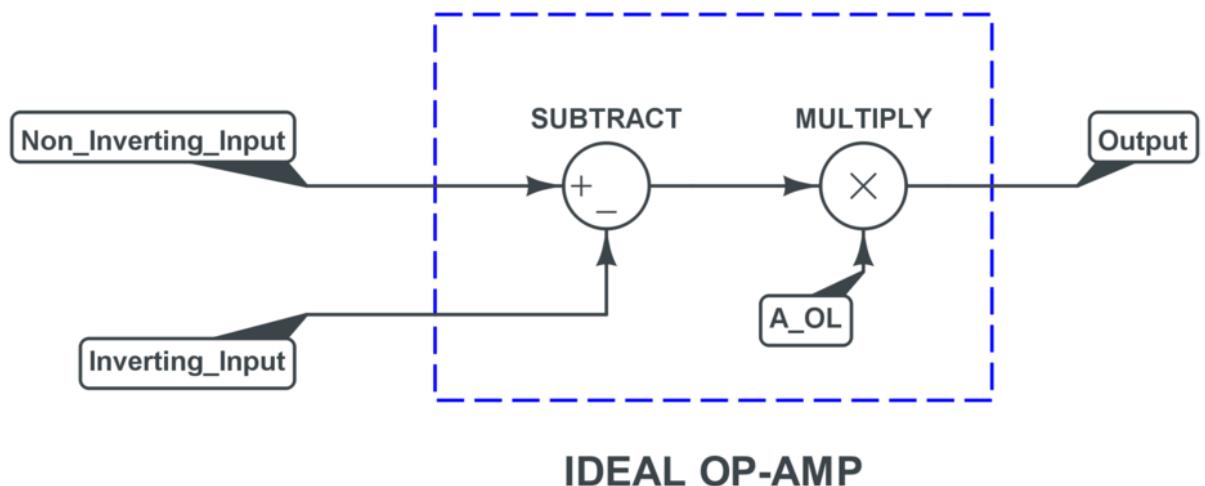
## From Chapter 7.1 The Ideal Op-Amp (Operational Amplifier):

*The ideal op-amp model is a key building block of designing analog filters, amplifiers, oscillators, sources, and more.*

**IDEAL OP-AMP**

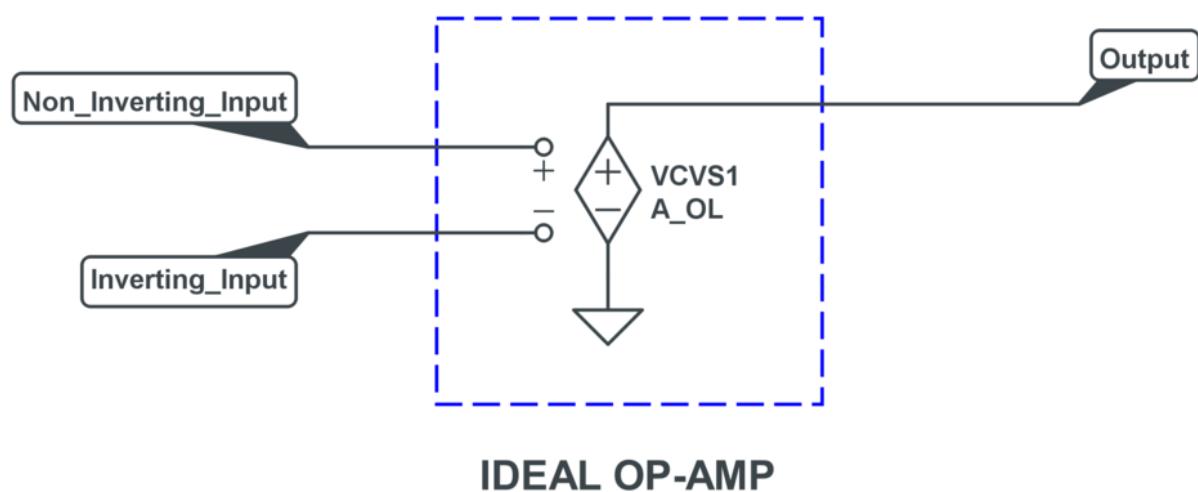
Ideal Op-Amp Symbol  
[circuitlab.com/c42kpkv8a43k](https://circuitlab.com/c42kpkv8a43k)

[Edit - Simulate](#)



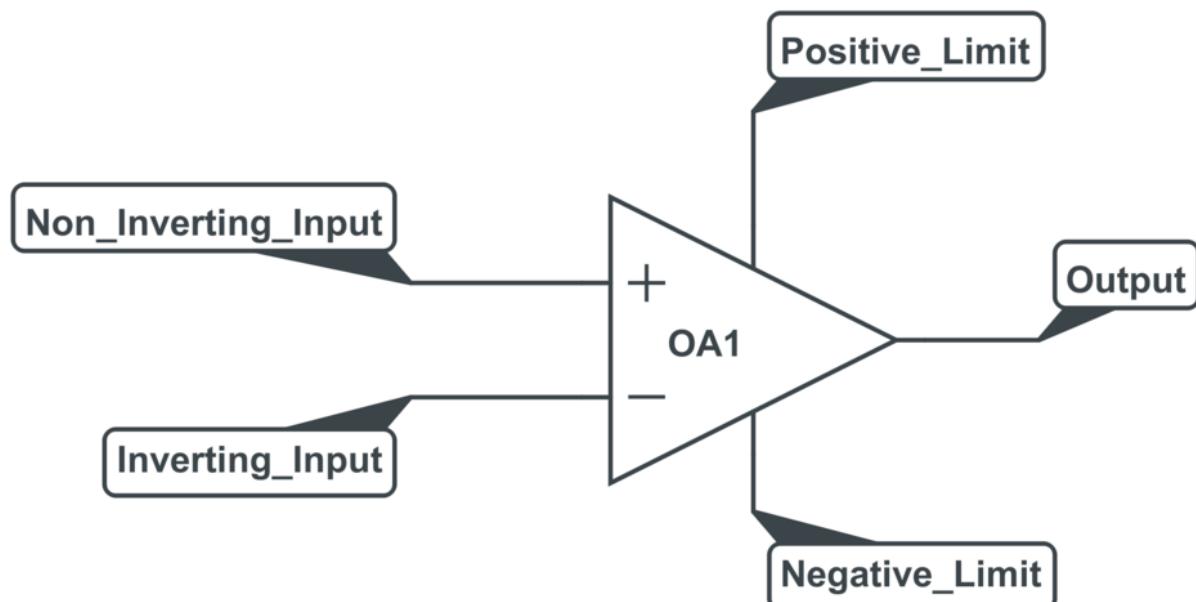
Ideal Op-Amp Subtraction and Multiplication  
[circuitlab.com/cv47d3w6nc9cs](http://circuitlab.com/cv47d3w6nc9cs)

[Edit - Simulate](#)



Ideal Op-Amp as VCVS  
[circuitlab.com/cs79ppnt7dr8f](http://circuitlab.com/cs79ppnt7dr8f)

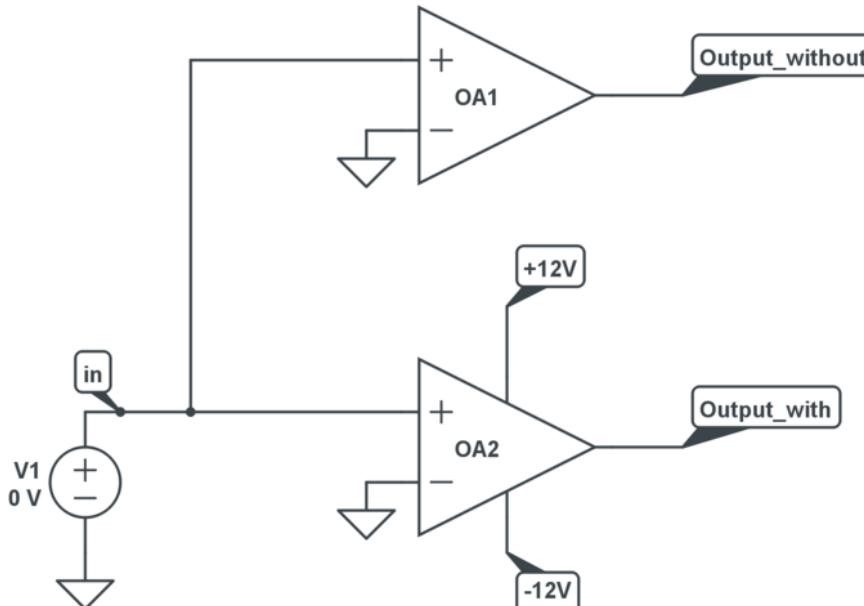
[Edit - Simulate](#)



## IDEAL OP-AMP WITH VOLTAGE RAILS

Ideal Op-Amp with Voltage Rails Symbol  
[circuitlab.com/c3nhuzcp8d3zc](http://circuitlab.com/c3nhuzcp8d3zc)

[Edit - Simulate](#)



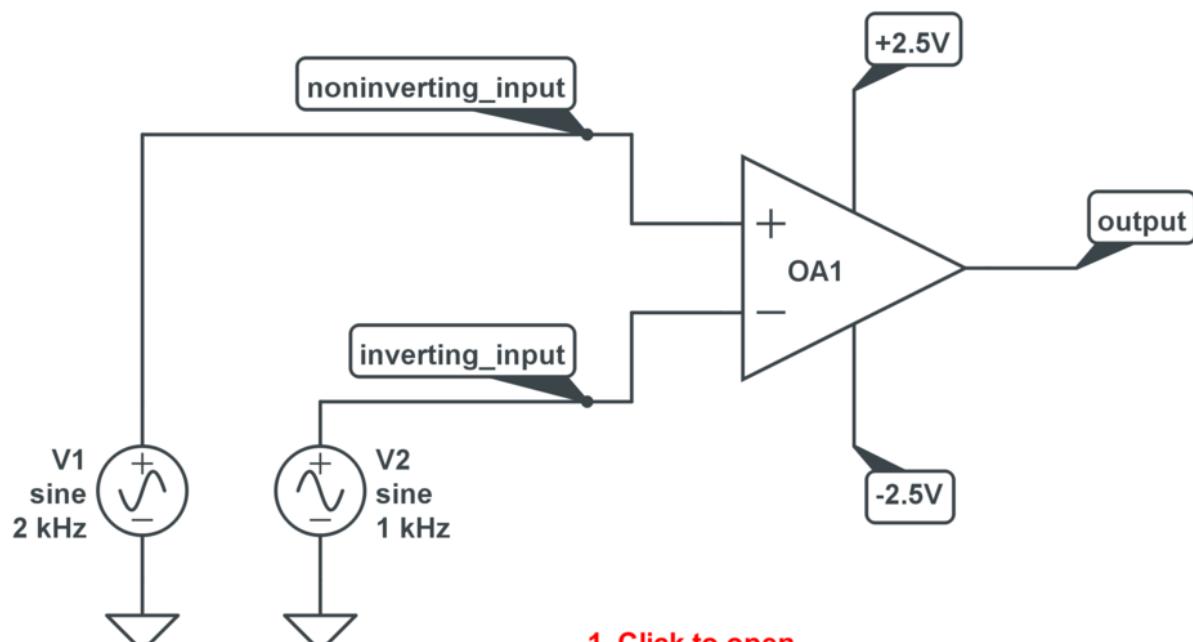
### IDEAL OP-AMP WITH & WITHOUT VOLTAGE RAILS

1. Click to open
2. Click "Simulate"
3. Click "Run DC Sweep"

Run "DC Sweep" simulation  
to see how adding supply rail limits change  
the shape of the output curve.

Op-Amp With and Without Voltage Rails DC Sweep Comparison  
[circuitlab.com/cy6wk2cksasa6](http://circuitlab.com/cy6wk2cksasa6)

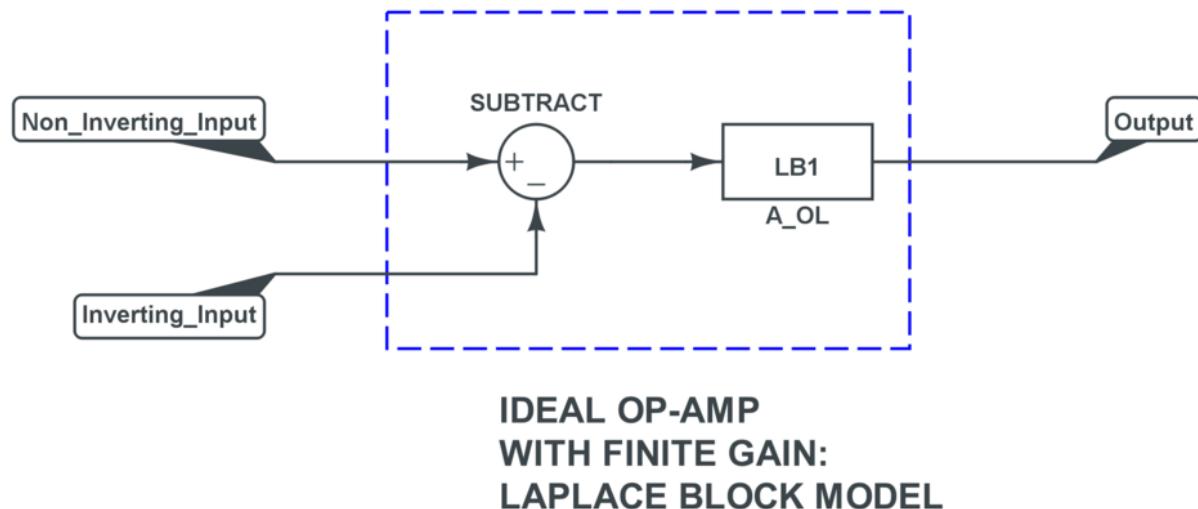
[Edit](#) - [Simulate](#)



1. Click to open
2. Click "Simulate"
3. Click "Run Time-Domain Simulation"

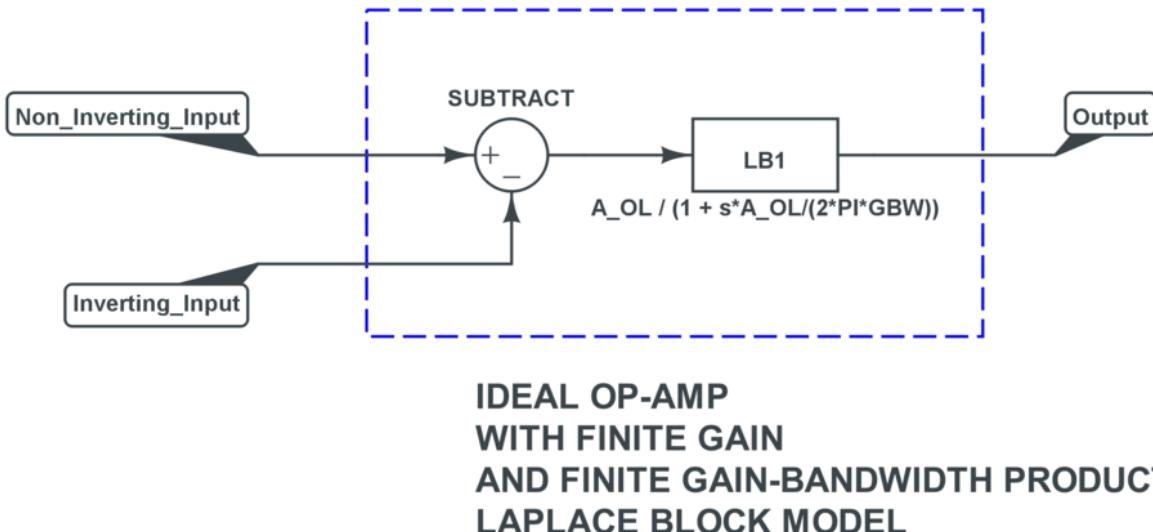
Op-Amp with Voltage Rails as Analog Comparator  
[circuitlab.com/c39z7cwks2hrz](http://circuitlab.com/c39z7cwks2hrz)

[Edit](#) - [Simulate](#)



Ideal Op-Amp with Finite Gain: Laplace Block Model  
[circuitalab.com/ctq3jgk8rqewh](https://circuitalab.com/ctq3jgk8rqewh)

[Edit - Simulate](#)

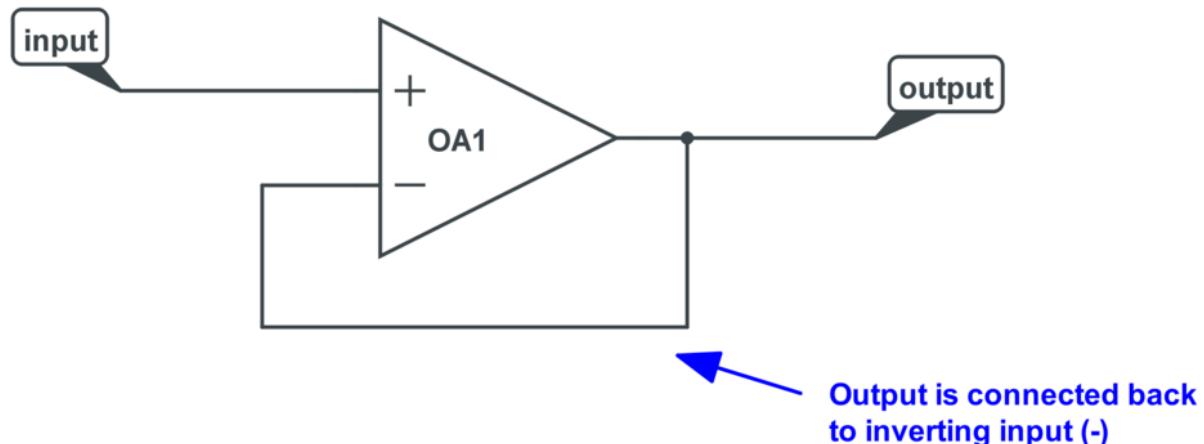


Ideal Op-Amp with Finite Gain and Gain-Bandwidth Product: Laplace Block Model  
[circuitlab.com/can8pyj7dxf2b](https://circuitlab.com/can8pyj7dxf2b)

[Edit - Simulate](#)

## From Chapter 7.2 Op-Amp Voltage Buffer:

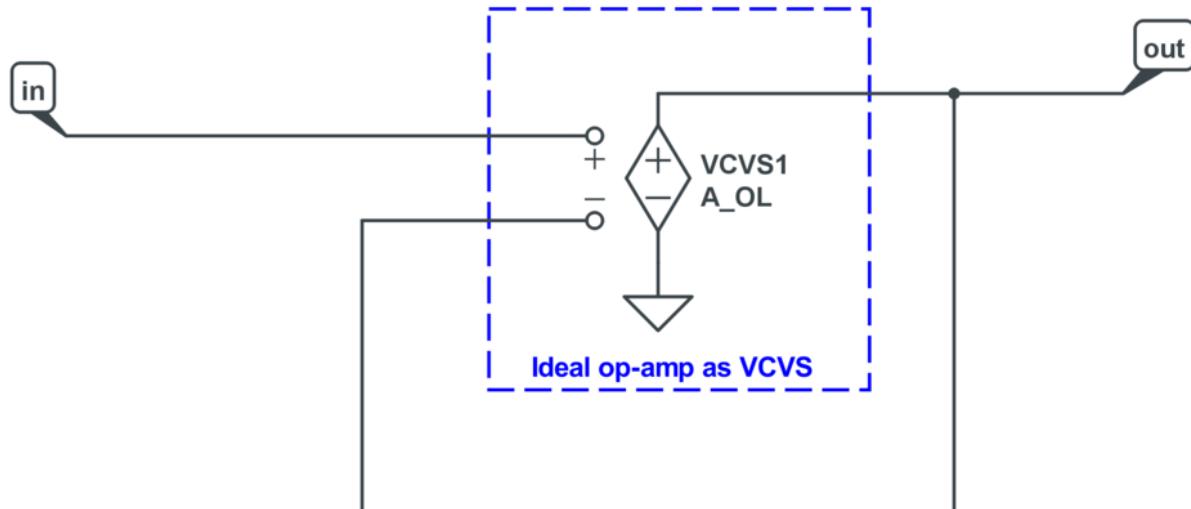
An op-amp voltage buffer mirrors a voltage from a high-impedance input to a low-impedance output.



## OP-AMP VOLTAGE BUFFER

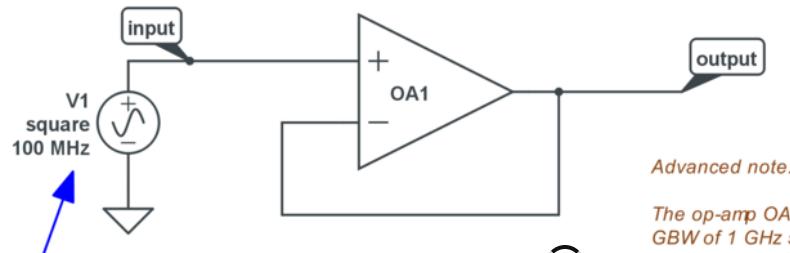
Op-Amp Voltage Buffer  
[circuitlab.com/c2gpmect8rv5e](https://circuitlab.com/c2gpmect8rv5e)

[Edit - Simulate](#)



Op-Amp Voltage Buffer VCVS Model  
[circuitlab.com/czx96fb4mmfn](https://circuitlab.com/czx96fb4mmfn)

[Edit](#) - [Simulate](#)



Square wave generator  
puts sharp-edged steps  
into the non-inverting input.

1. Click to open
2. Click "Simulate"
3. Click "Run Time-Domain Simulation"

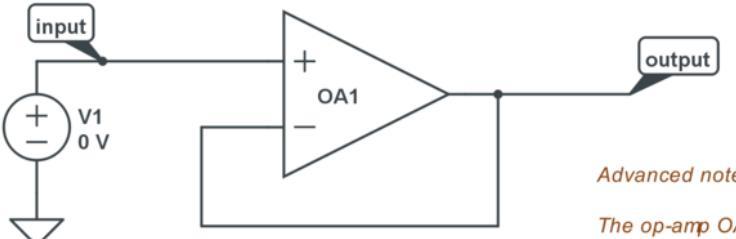
*Advanced note:*

*The op-amp OA1 is not perfectly ideal. We've given it a GBW of 1 GHz so that we can see that the step response to a 100 MHz signal takes a few hundred picoseconds to respond to the input change.*

### SQUARE WAVE INTO OP-AMP VOLTAGE BUFFER

Square Wave into Op-Amp Voltage Buffer  
[circuitlab.com/cv9xf6jpa325g](http://circuitlab.com/cv9xf6jpa325g)

[Edit - Simulate](#)



Advanced note:

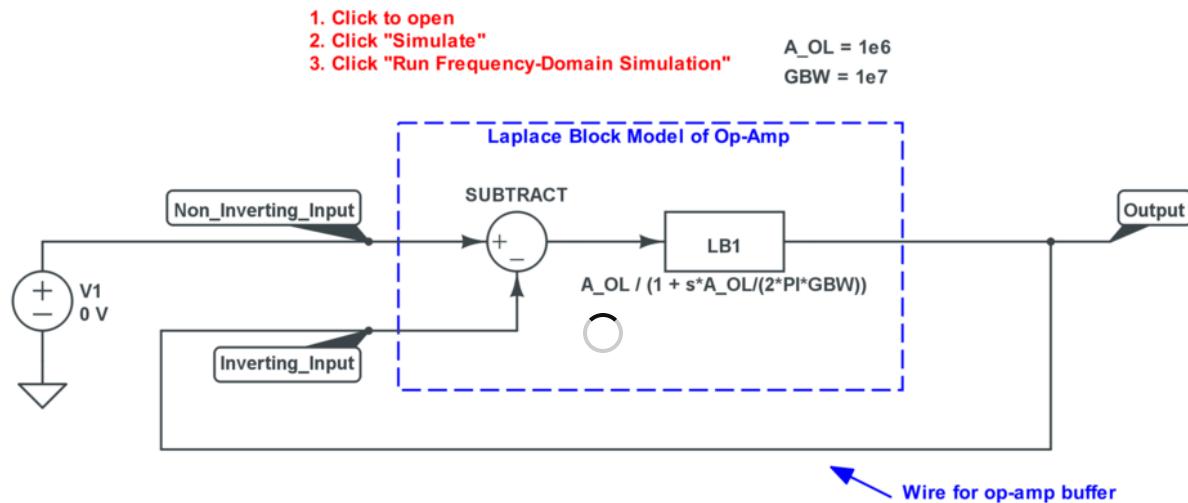
*The op-amp OA1 is not perfectly ideal. We've given it a GBW of 10 MHz so that we can see the frequency response.*

1. Click to open
2. Click "Simulate"
3. Click "Run Frequency-Domain Simulation"

## FREQUENCY RESPONSE OF OP-AMP VOLTAGE BUFFER

Frequency Response of Op-Amp Voltage Buffer  
[circuitlab.com/ct47w8u2tanx5](http://circuitlab.com/ct47w8u2tanx5)

[Edit](#) - [Simulate](#)

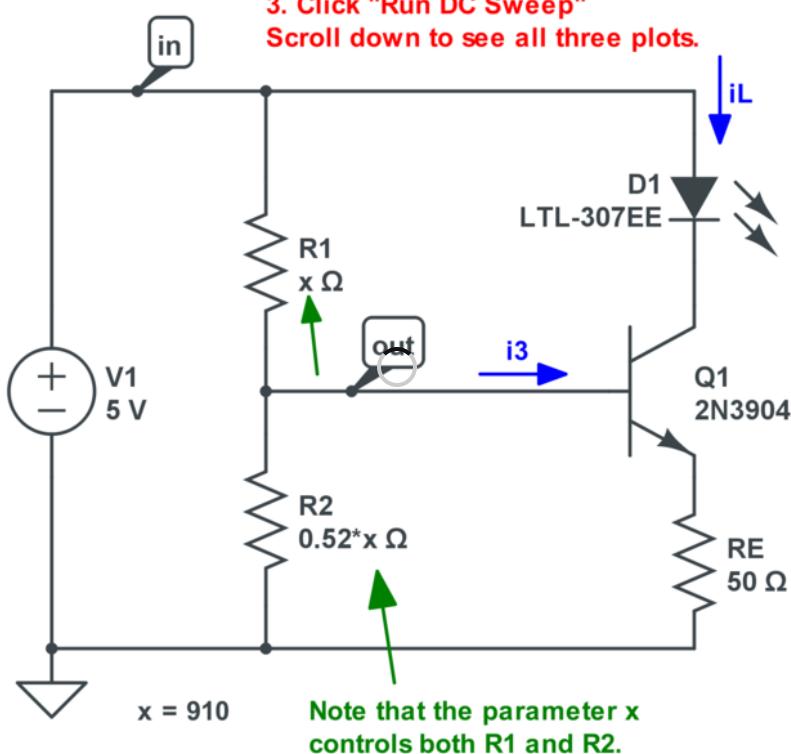


### OP-AMP VOLTAGE BUFFER AS LAPLACE TRANSFER FUNCTION MODEL

Op-Amp Voltage Buffer as Laplace Transfer Function  
[circuitlab.com/c3j294fm9929n](http://circuitlab.com/c3j294fm9929n)

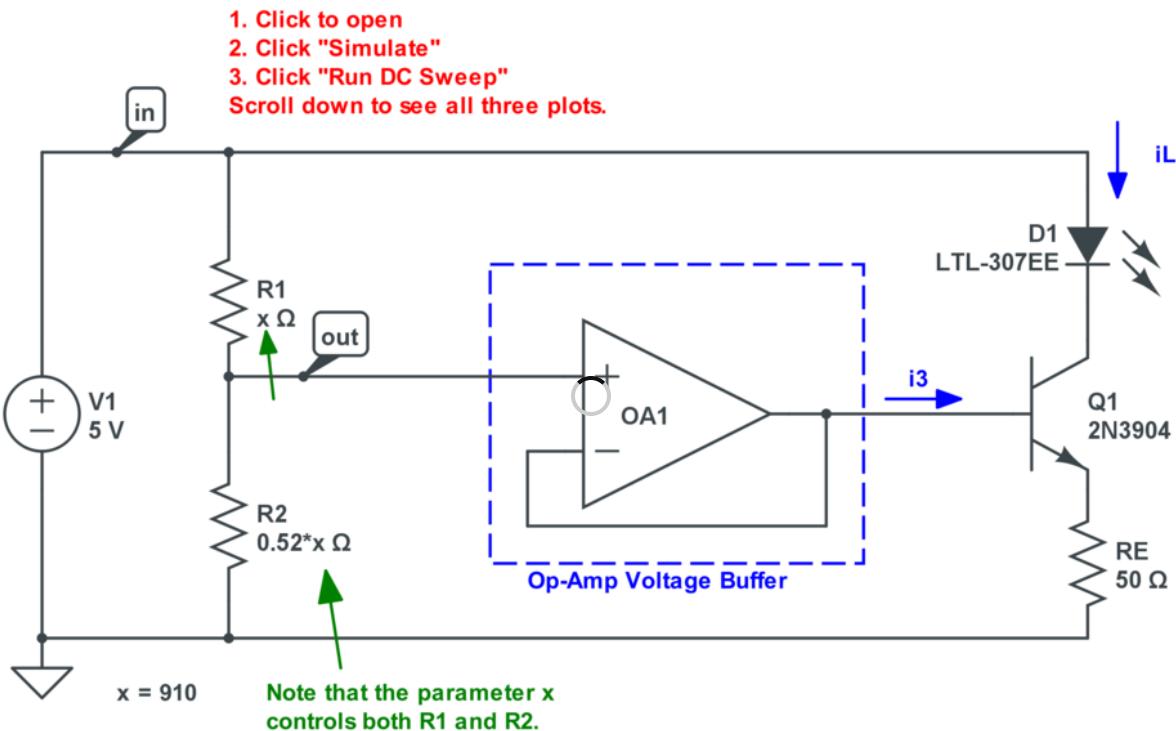
[Edit - Simulate](#)

1. Click to open
  2. Click "Simulate"
  3. Click "Run DC Sweep"
- Scroll down to see all three plots.



LED Current Control with Voltage Divider and BJT, Resistance Parameter  
[circuitlab.com/cz56bu5r8j8b9](http://circuitlab.com/cz56bu5r8j8b9)

[Edit](#) - [Simulate](#)

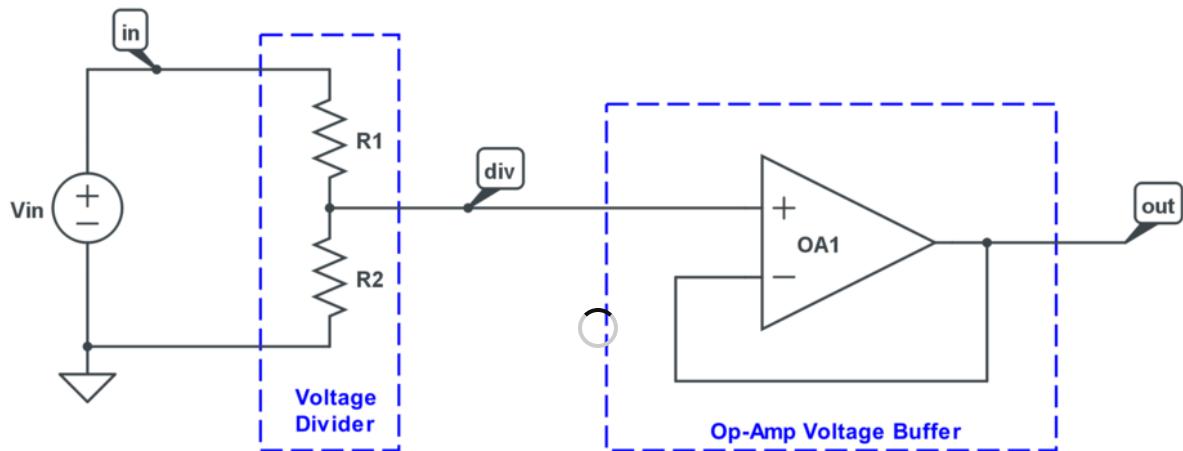


LED Current Control with Op-Amp Buffered Voltage Divider and BJT  
[circuitlab.com/c27285snky768](http://circuitlab.com/c27285snky768)

[Edit](#) - [Simulate](#)

## From Chapter 7.3 Op-Amp Voltage Reference:

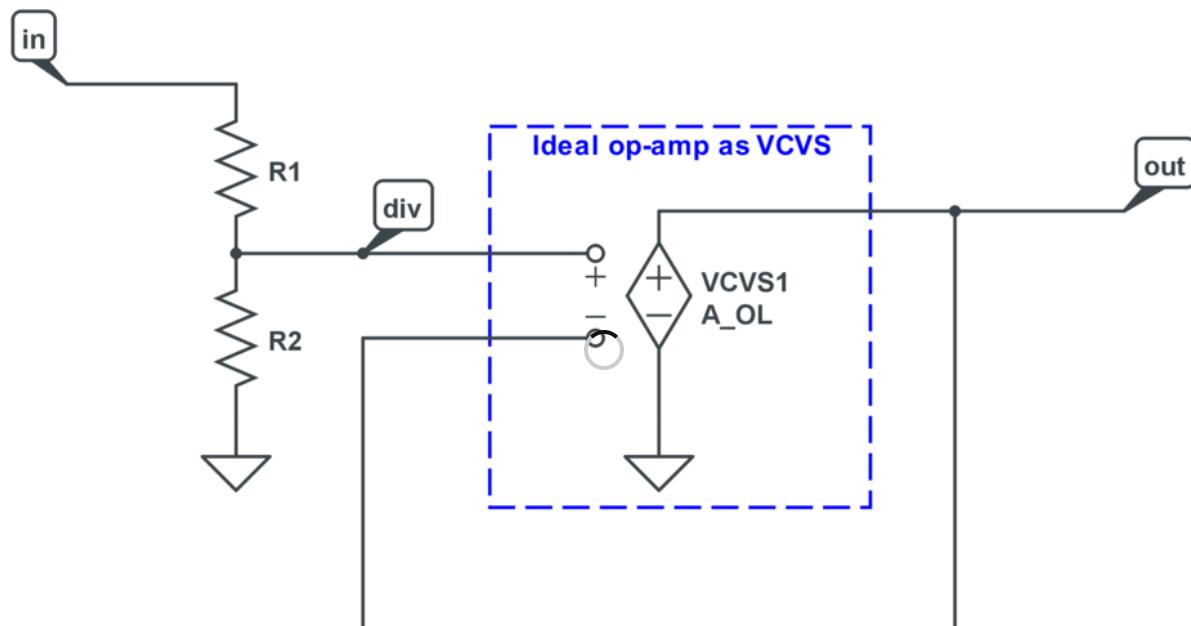
A *voltage divider* (or other reference element) plus an op-amp can create a *fixed or adjustable voltage reference*.



### OP-AMP VOLTAGE REFERENCE

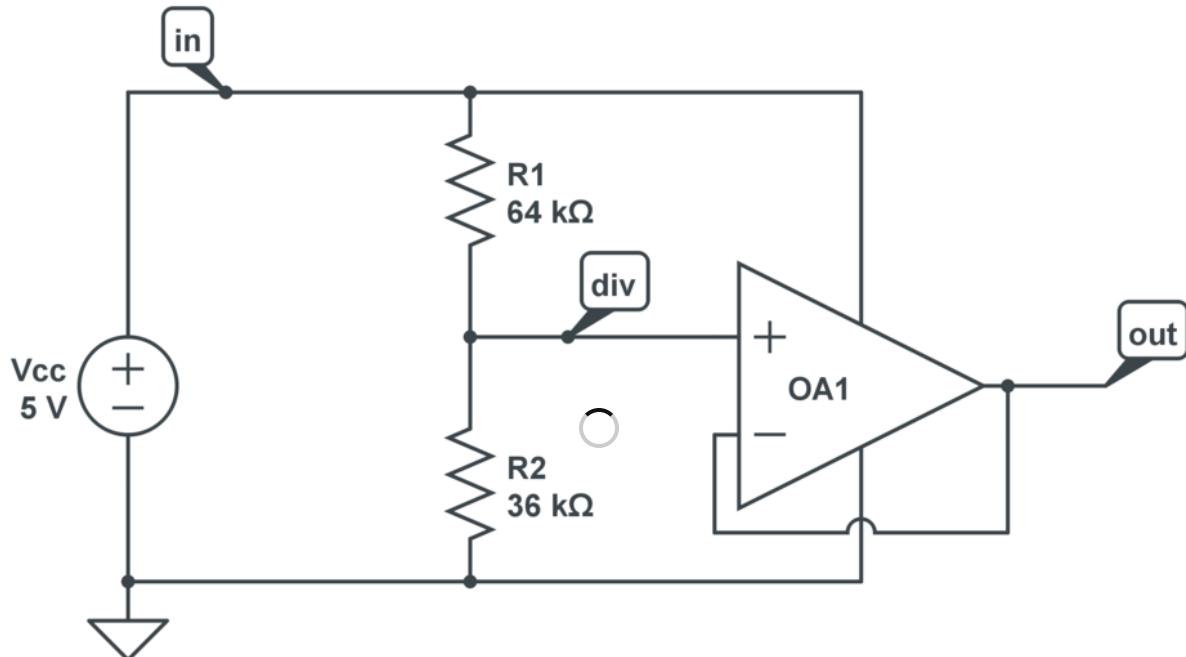
Op-Amp Voltage Reference  
[circuitlab.com/ctb9tj6thtyu4](http://circuitlab.com/ctb9tj6thtyu4)

[Edit - Simulate](#)



Op-Amp Voltage Reference VCVS Model  
[circuitlab.com/c72rfqfybptg](http://circuitlab.com/c72rfqfybptg)

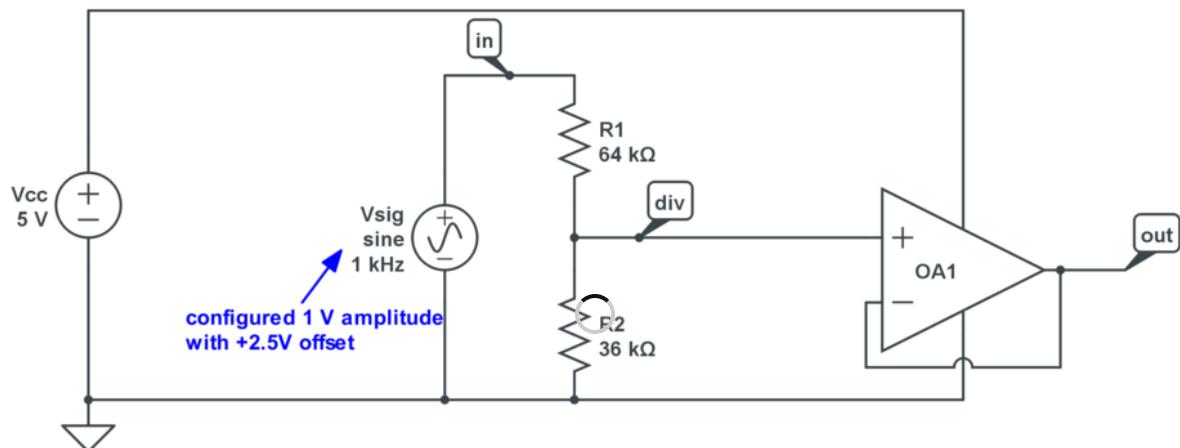
[Edit](#) - [Simulate](#)



1. Click to open
2. Click "Simulate"
3. Click "Run DC Solver"

Op-Amp Voltage Reference: 5V to 1.8V DC Example  
[circuitlab.com/c9z4mk57ap4c9](http://circuitlab.com/c9z4mk57ap4c9)

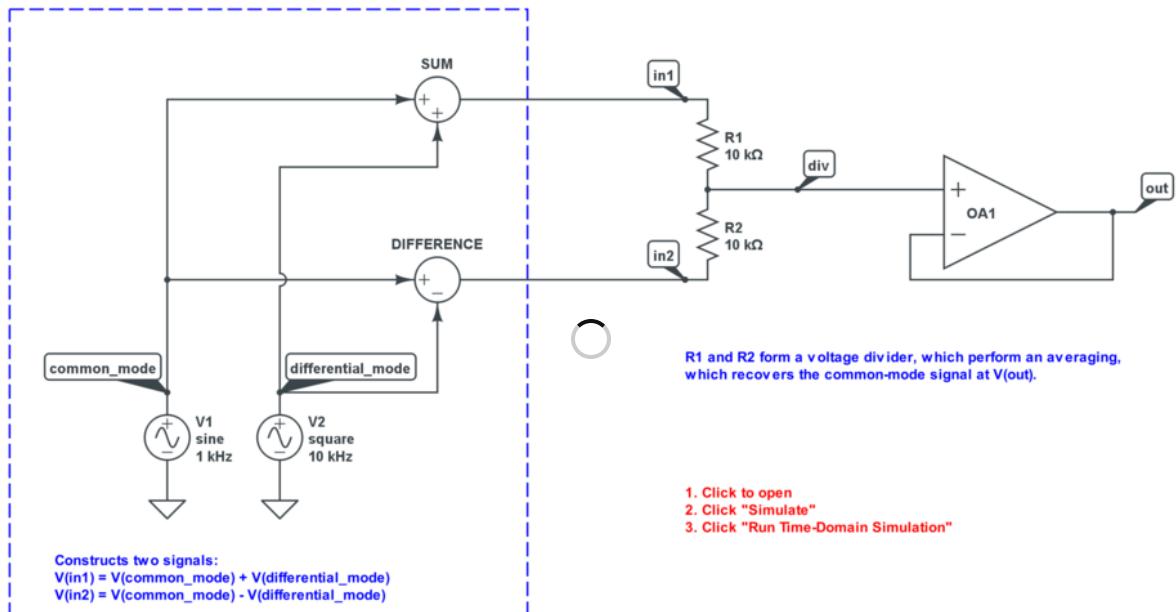
[Edit](#) - [Simulate](#)



1. Click to open
2. Click "Simulate"
3. Click "Run Time-Domain Simulation"
4. Click "Run Frequency Domain Simulation"

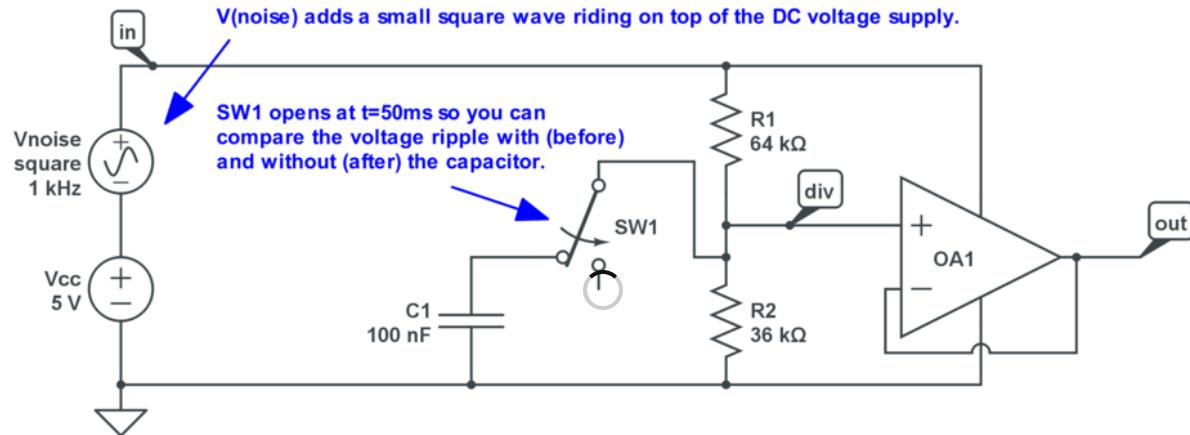
Op-Amp Voltage Reference: Signal Reducer Example  
[circuitlab.com/cvyj75jz57twc](http://circuitlab.com/cvyj75jz57twc)

[Edit](#) - [Simulate](#)



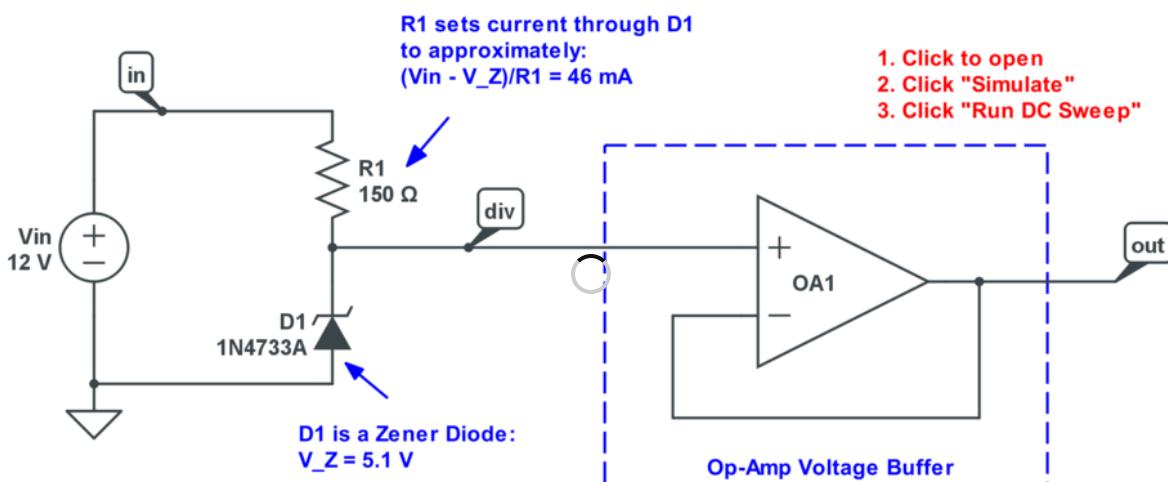
Op-Amp Voltage Averager: Common-Mode Signal Recovery  
[circuitlab.com/crtg6qf32qc9z](http://circuitlab.com/crtg6qf32qc9z)

[Edit](#) - [Simulate](#)



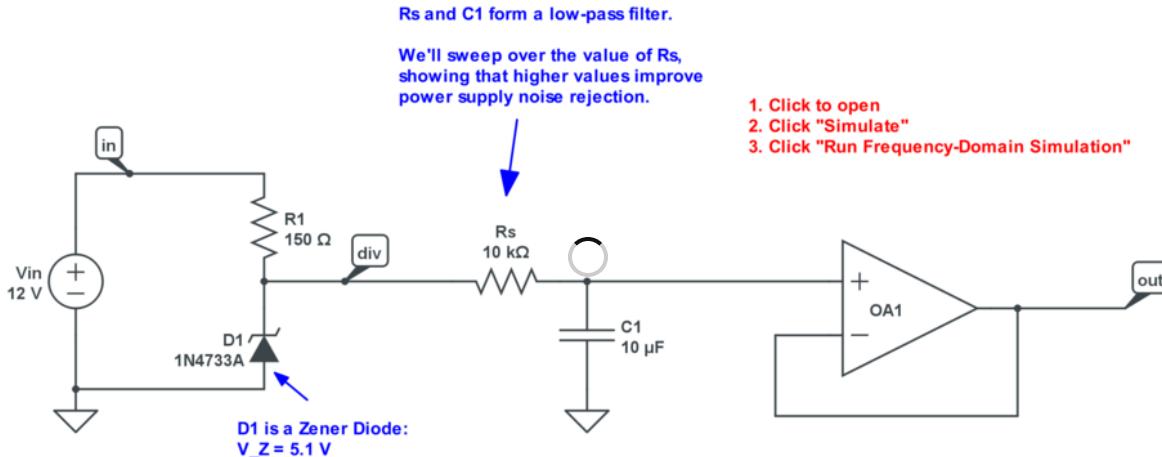
Capacitor Smoothes Op-Amp Voltage Reference  
[circuitlab.com/cjxd89bna2624](http://circuitlab.com/cjxd89bna2624)

[Edit](#) - [Simulate](#)



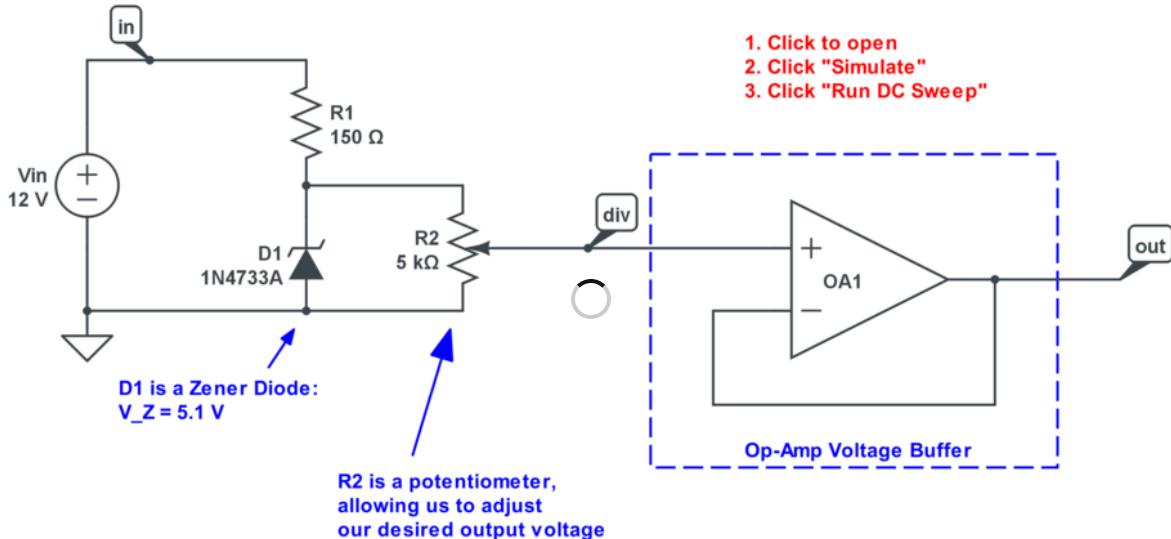
Zener Diode Op-Amp Voltage Reference  
[circuitlab.com/cn8t7824cbz47](http://circuitlab.com/cn8t7824cbz47)

[Edit](#) - [Simulate](#)



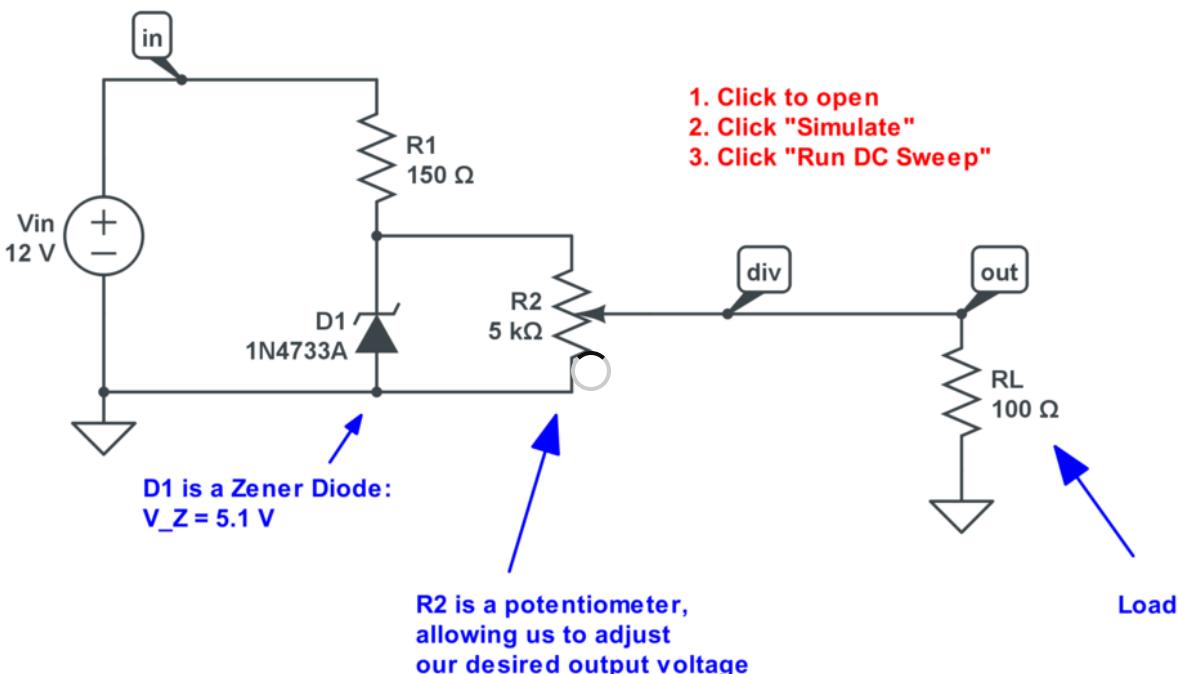
Zener Diode Op-Amp Voltage Reference with Capacitor  
[circuitlab.com/cct3dw8uz2e66](http://circuitlab.com/cct3dw8uz2e66)

[Edit](#) - [Simulate](#)



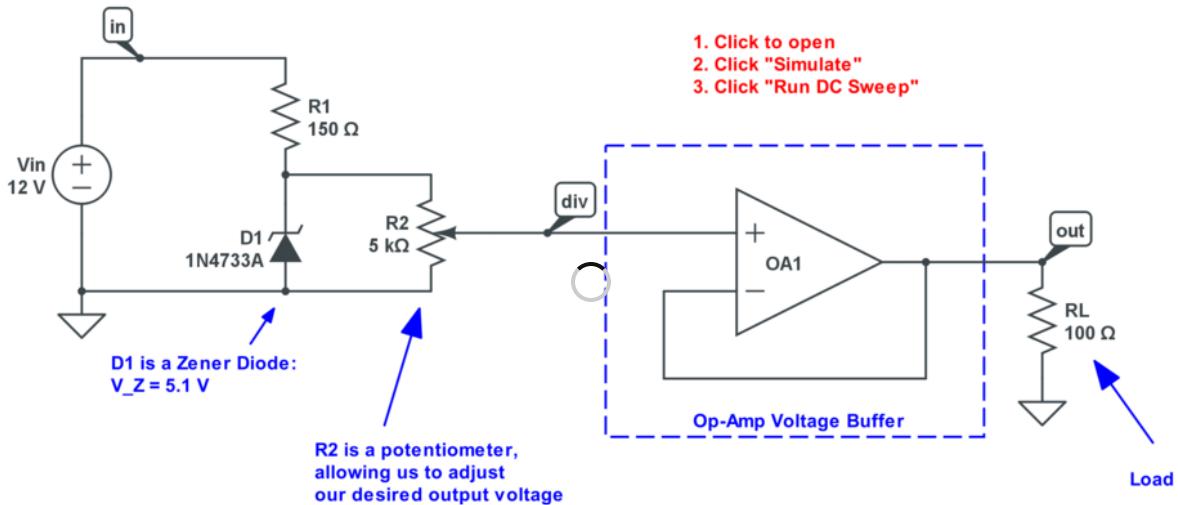
Zener Diode, Potentiometer, Op-Amp: Adjustable Voltage Reference  
[circuitlab.com/chvw343g59bd8](http://circuitlab.com/chvw343g59bd8)

[Edit](#) - [Simulate](#)



Adjustable Zener-based Voltage Reference Under Load (Unbuffered)  
[circuitlab.com/c9p4uvmmg26xz](http://circuitlab.com/c9p4uvmmg26xz)

[Edit](#) - [Simulate](#)

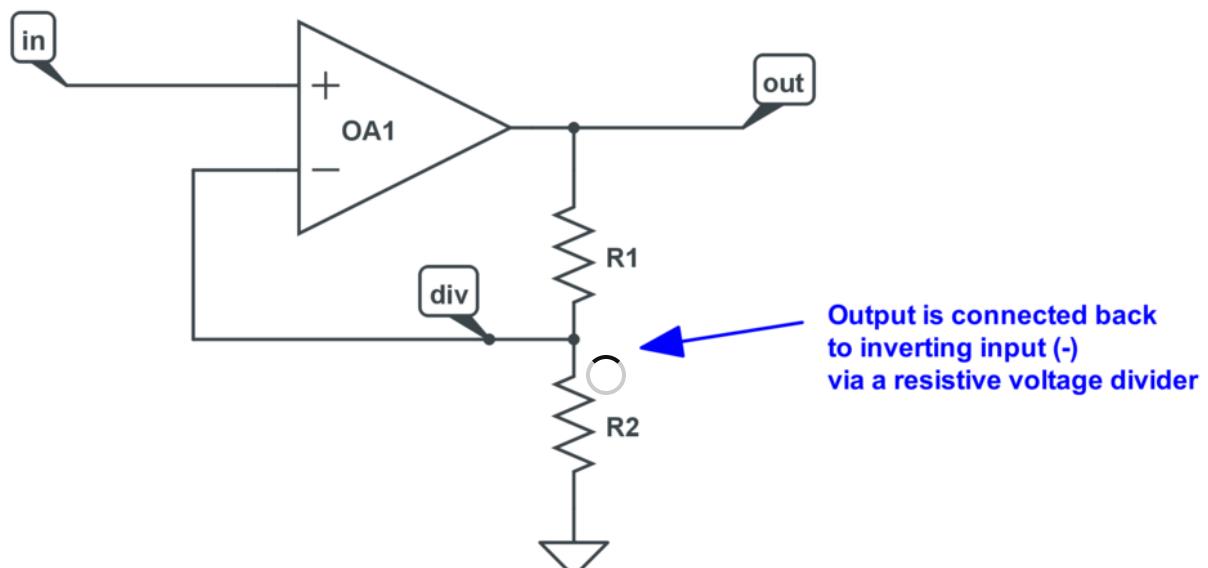


Adjustable Zener-based Voltage Reference Under Load (With Op-Amp Buffer)  
[circuitlab.com/cxskwwjv9sza4](http://circuitlab.com/cxskwwjv9sza4)

[Edit - Simulate](#)

## From Chapter 7.4 Op-Amp Non-Inverting Amplifier:

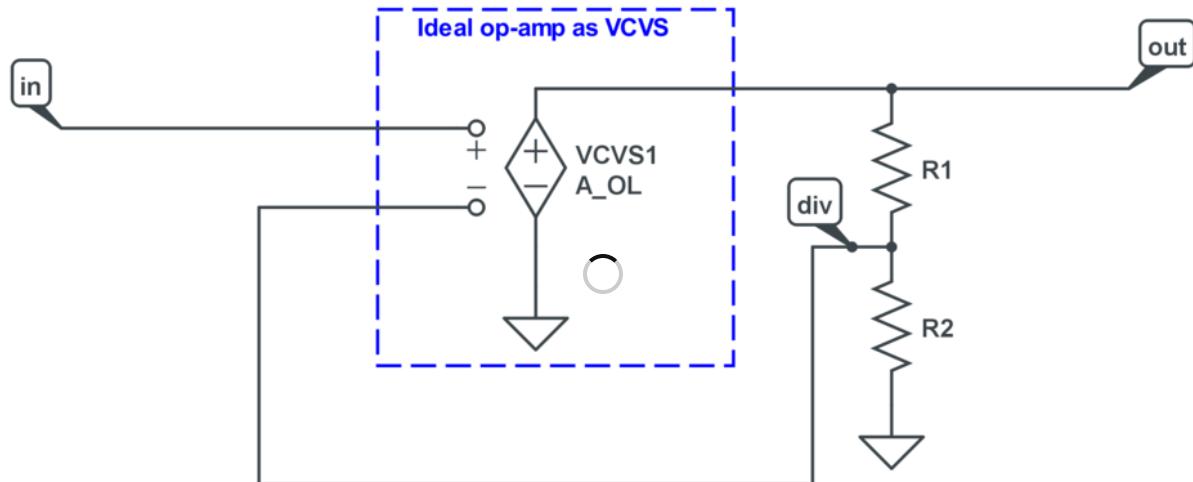
An op-amp circuit forming a voltage amplifier, using negative feedback to multiply an input signal by a positive gain set by two resistors.



## OP-AMP NON-INVERTING AMPLIFIER

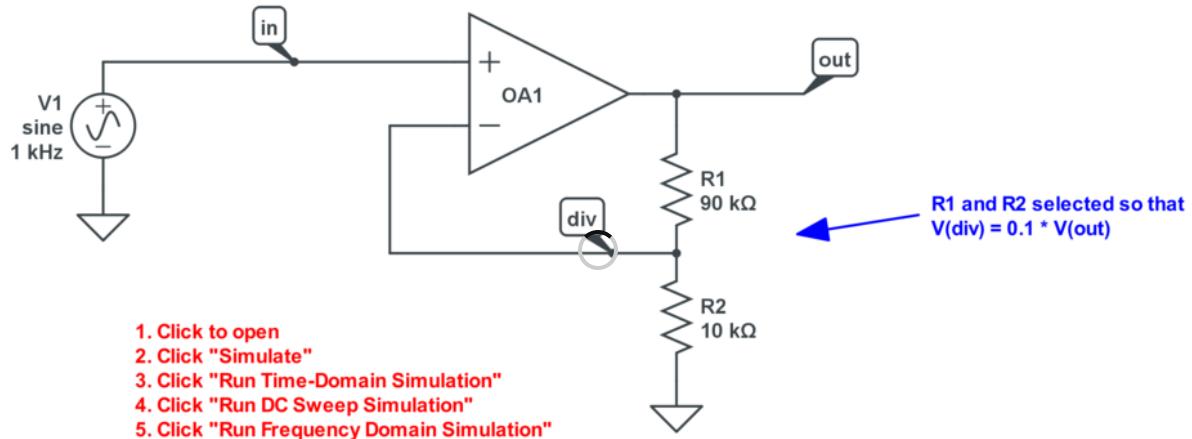
Op-Amp Non-Inverting Amplifier  
[circuitlab.com/c4wnat6ynz2ek](http://circuitlab.com/c4wnat6ynz2ek)

[Edit](#) - [Simulate](#)



Op-Amp Non-Inverting Amplifier VCVS Model  
[circuitlab.com/cq3ssz7y3pkpj](https://circuitlab.com/cq3ssz7y3pkpj)

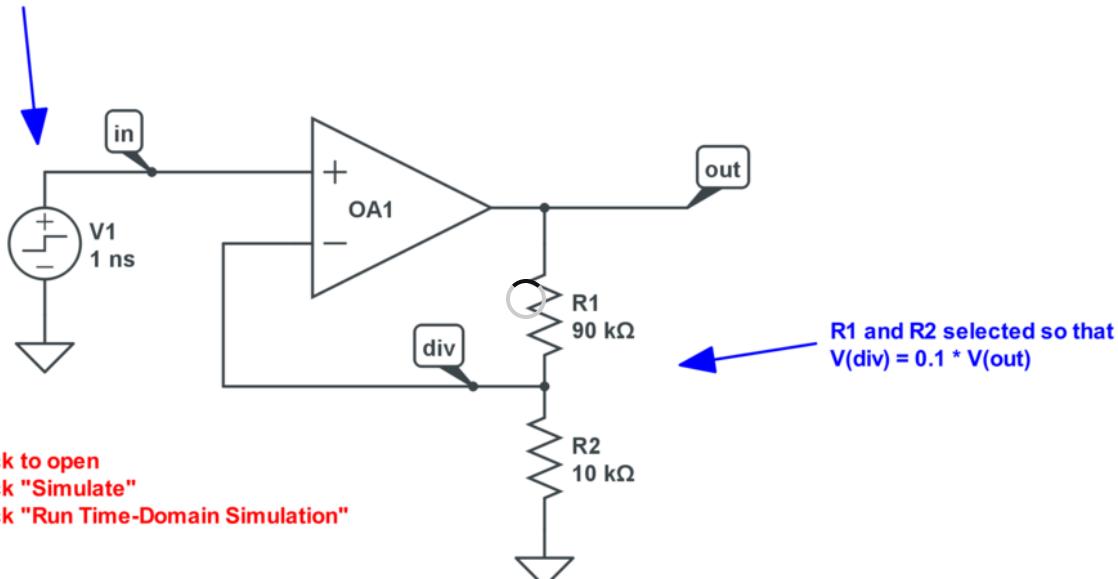
[Edit](#) - [Simulate](#)



Op-Amp Non-Inverting Amplifier Gain of 10 Example  
[circuitlab.com/cnm6354nkc2jm](http://circuitlab.com/cnm6354nkc2jm)

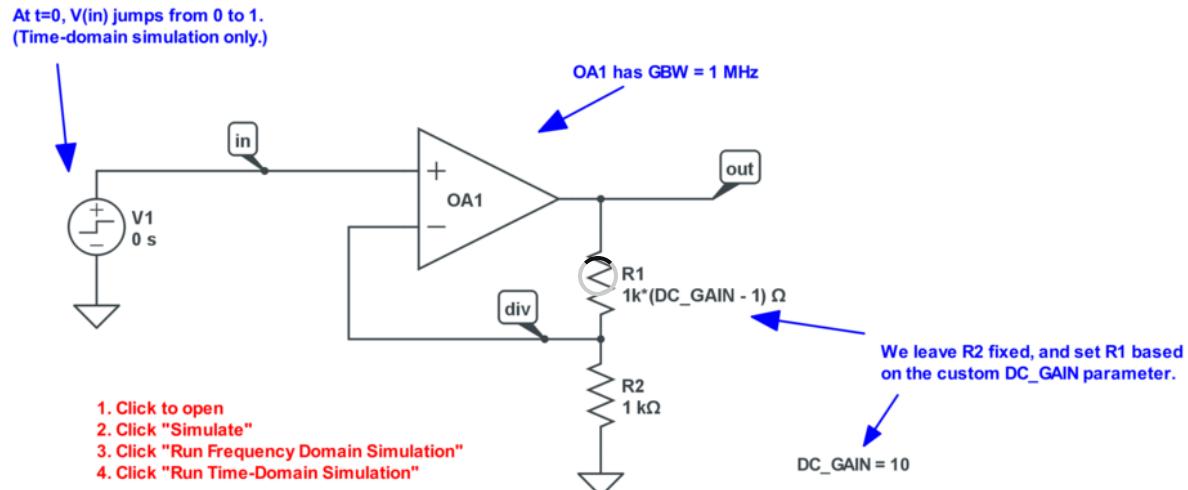
[Edit - Simulate](#)

At t=1ns, V(in) jumps from 0 to 1.



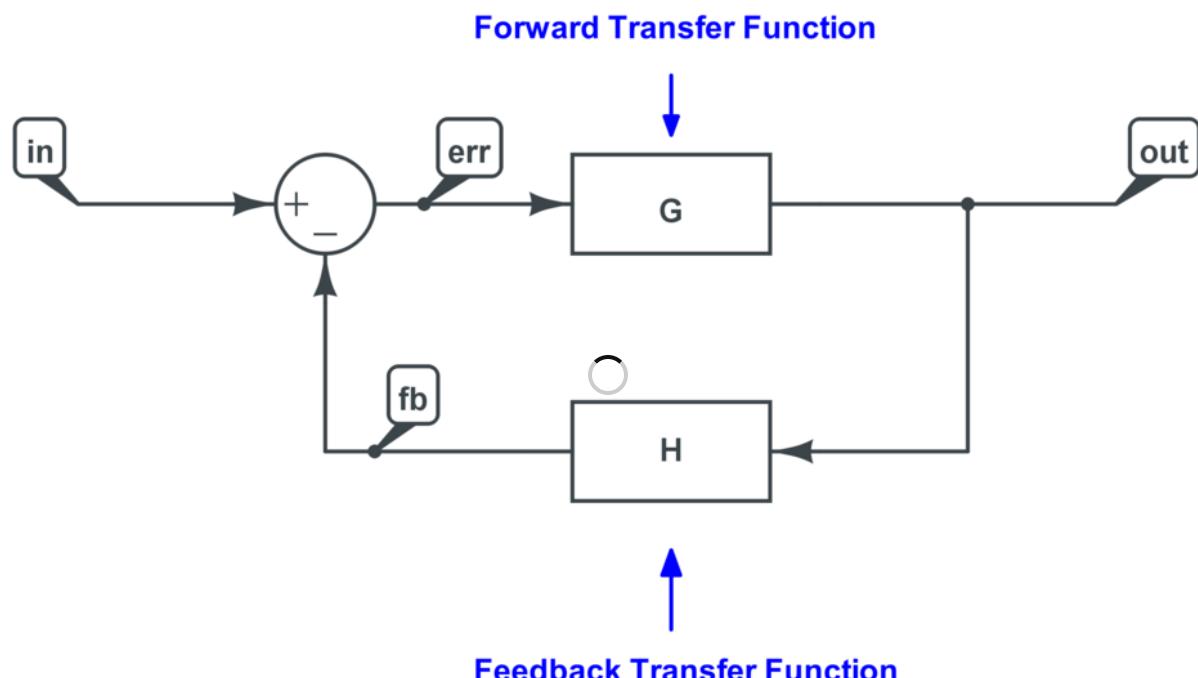
Op-Amp Non-Inverting Amplifier Gain of 10 Step Response  
[circuitlab.com/c9xykgb57wstt](http://circuitlab.com/c9xykgb57wstt)

[Edit](#) - [Simulate](#)



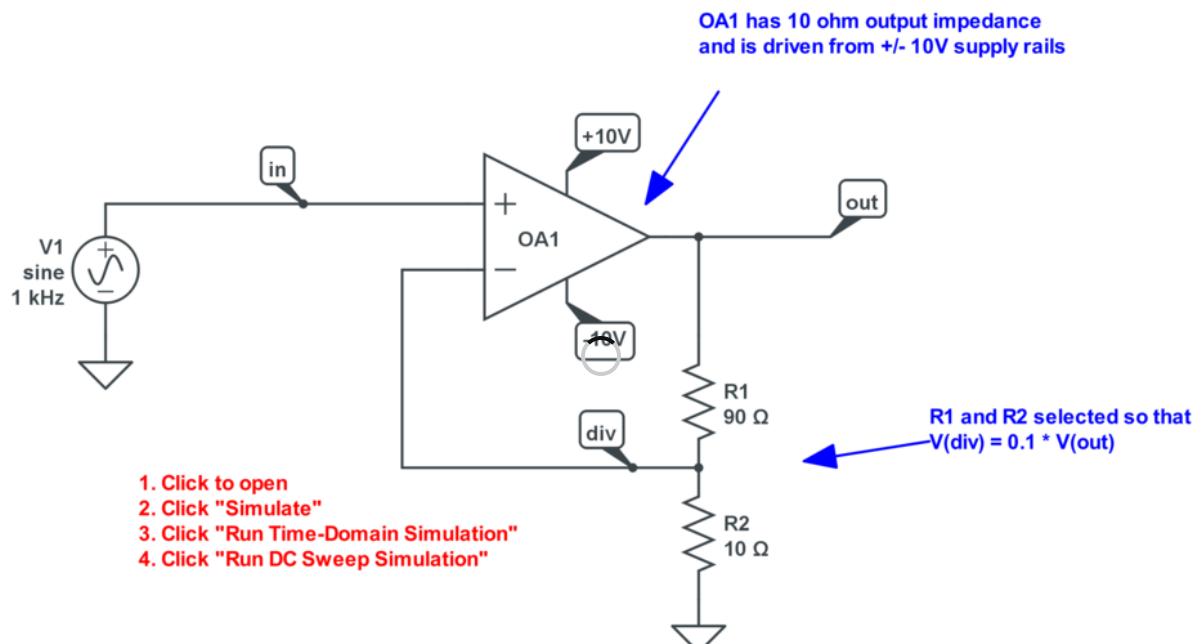
Op-Amp Non-Inverting Amplifier - Gain vs. Bandwidth Tradeoff  
[circuitlab.com/c2v2mwrld2t966](http://circuitlab.com/c2v2mwrld2t966)

[Edit](#) - [Simulate](#)



Closed-Loop Transfer Function Block Diagram  
[circuitlab.com/c42n7tesuxm2d](https://circuitlab.com/c42n7tesuxm2d)

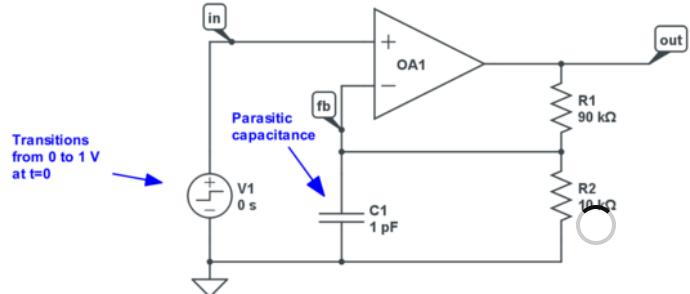
[Edit - Simulate](#)



Op-Amp Non-Inverting Amplifier - Clipping due to Output Impedance  
[circuitlab.com/c2xqt2ju44bm7](http://circuitlab.com/c2xqt2ju44bm7)

[Edit](#) - [Simulate](#)

## OP-AMP FEEDBACK CAPACITANCE AND STABILITY



OA1, R1, and R2 form a non-inverting amplifier with a gain of 10.

1. Click to open
2. Click "Simulate"
3. Click "Run Time-Domain Simulation"
4. Click "Run Frequency-Domain Simulation"

C1 represents a capacitance at the op-amp's inverting input.

This may be unintentional: there's always some capacitance from the PCB layout, or internal to the op-amp.

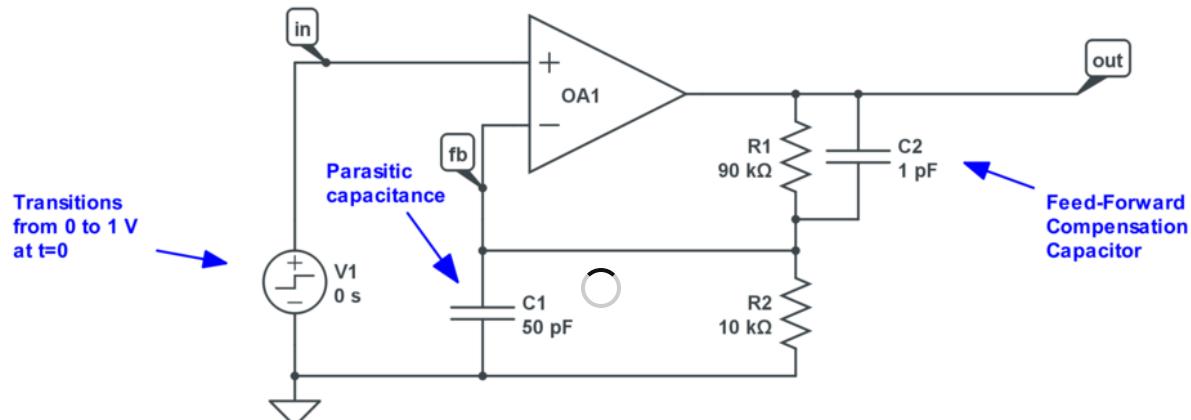
How long does it take for the output signal V(out) to settle to within 1% of its steady-state value?

How does this change as C1 increases?

Op-Amp Non-Inverting Amplifier Feedback Parasitic Capacitance Stability Issues  
[circuitlab.com/ctahy46huss23](https://circuitlab.com/ctahy46huss23)

[Edit](#) - [Simulate](#)

## OP-AMP COMPENSATION



1. Click to open
2. Click "Simulate"
3. Click "Run Time-Domain Simulation"

We've deliberately added a large parasitic capacitance C1.

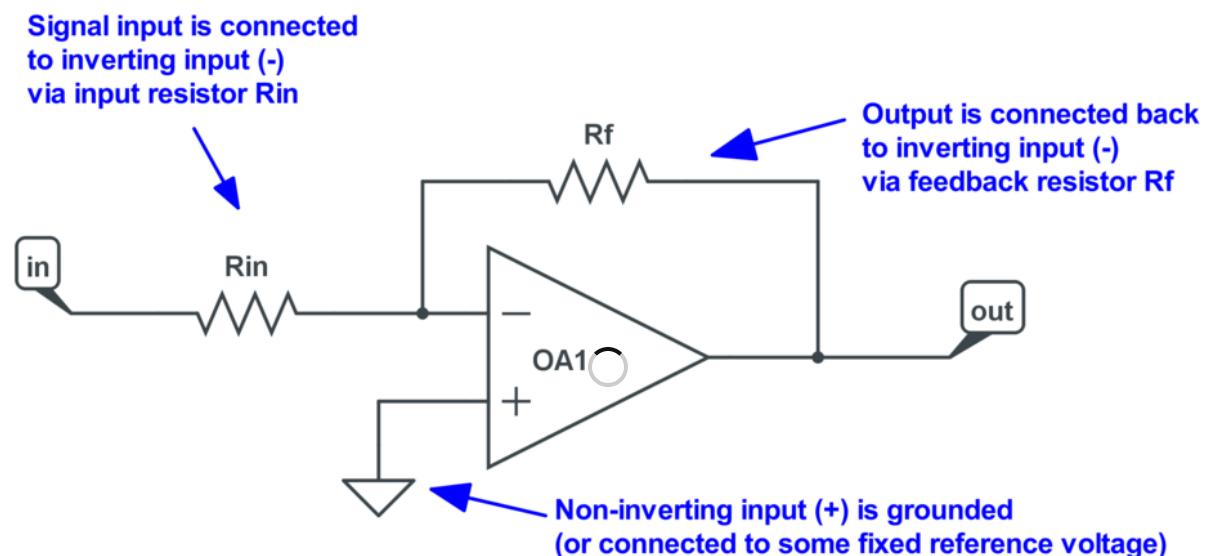
We can improve the step response (dramatically reducing overshoot) by adding a new capacitor C2.

Op-Amp Non-Inverting Amplifier - Feed-Forward Compensation Capacitor  
[circuitlab.com/c9wqubpx4g4g5](http://circuitlab.com/c9wqubpx4g4g5)

[Edit](#) - [Simulate](#)

## From Chapter 7.5 Op-Amp Inverting Amplifier:

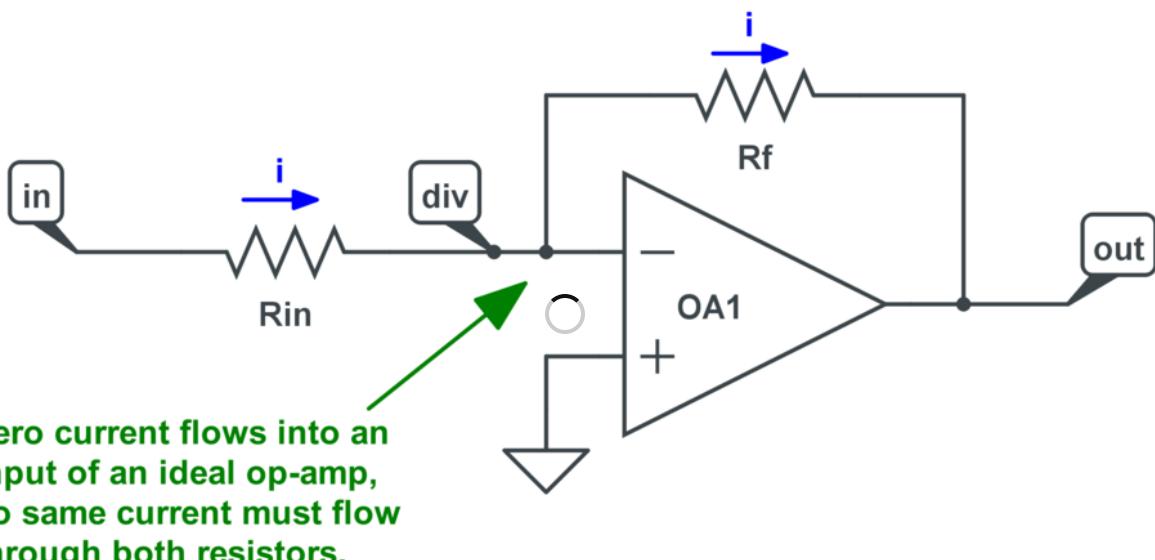
An op-amp circuit forming a voltage amplifier with negative gain set by the ratio of two resistors.



## OP-AMP INVERTING AMPLIFIER

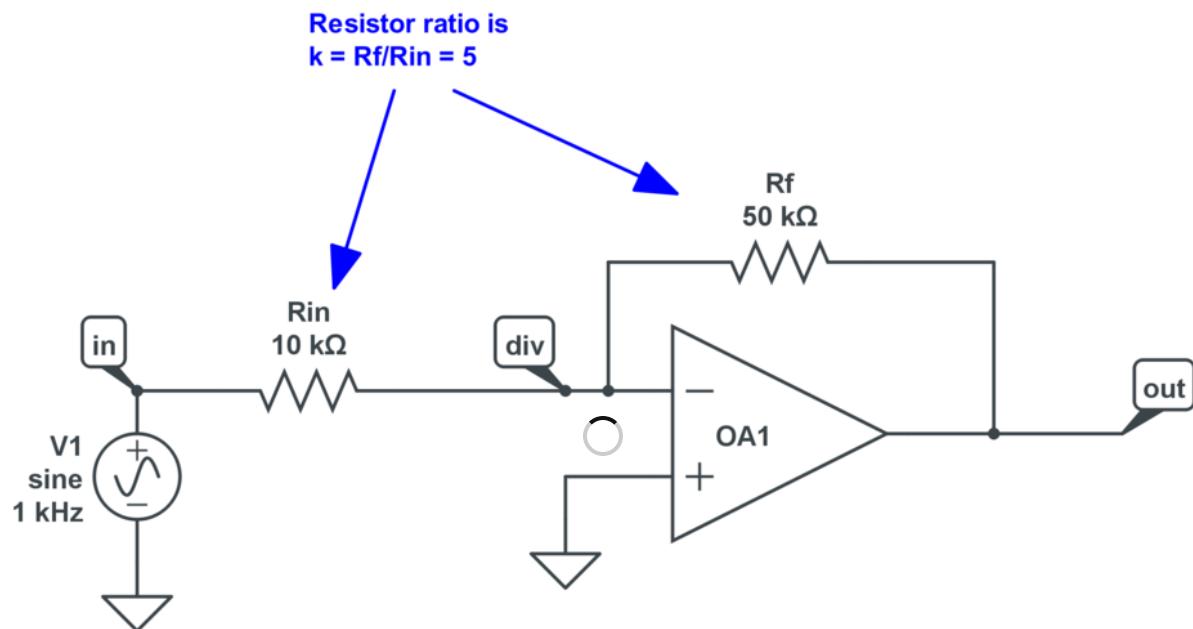
Op-Amp Inverting Amplifier  
[circuitlab.com/crb4w7egr83k](http://circuitlab.com/crb4w7egr83k)

[Edit](#) - [Simulate](#)



Op-Amp Inverting Amplifier - Labeled Inverting Input  
[circuitlab.com/c576qm3vwjhtp](https://circuitlab.com/c576qm3vwjhtp)

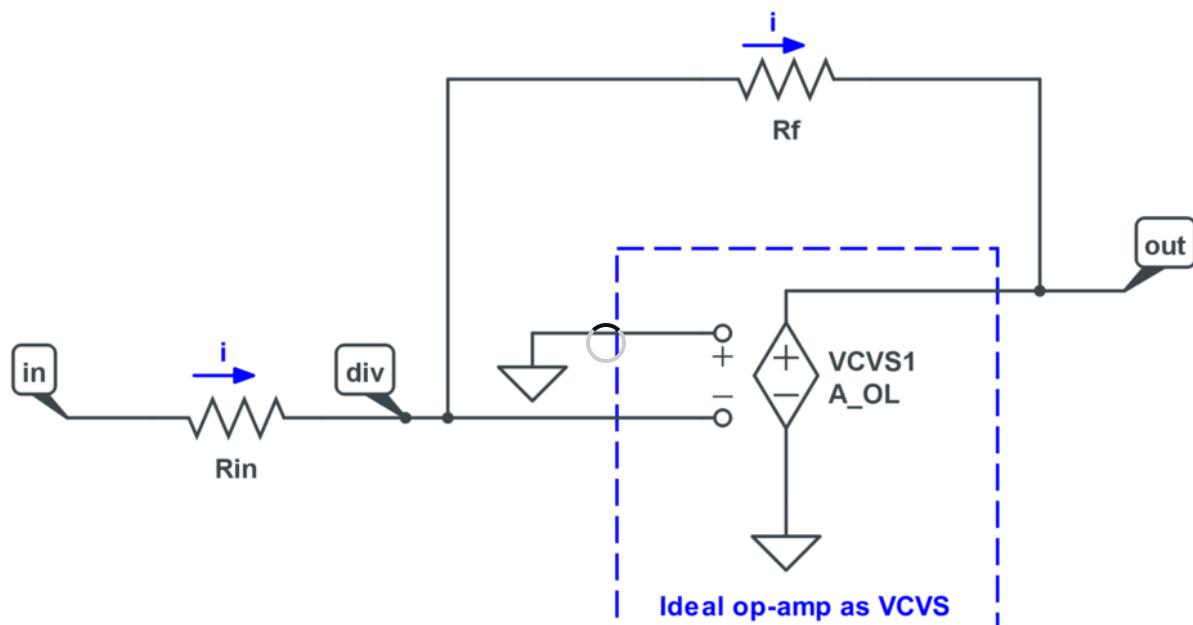
[Edit](#) - [Simulate](#)



1. Click to open
2. Click "Simulate"
3. Click "Run Time-Domain Simulation"
4. Click "Run DC Sweep Simulation"
5. Click "Run Frequency Domain Simulation"

Op-amp Inverting Amplifier - Gain of -5 Example  
[circuitlab.com/c23xfs3587jd8](http://circuitlab.com/c23xfs3587jd8)

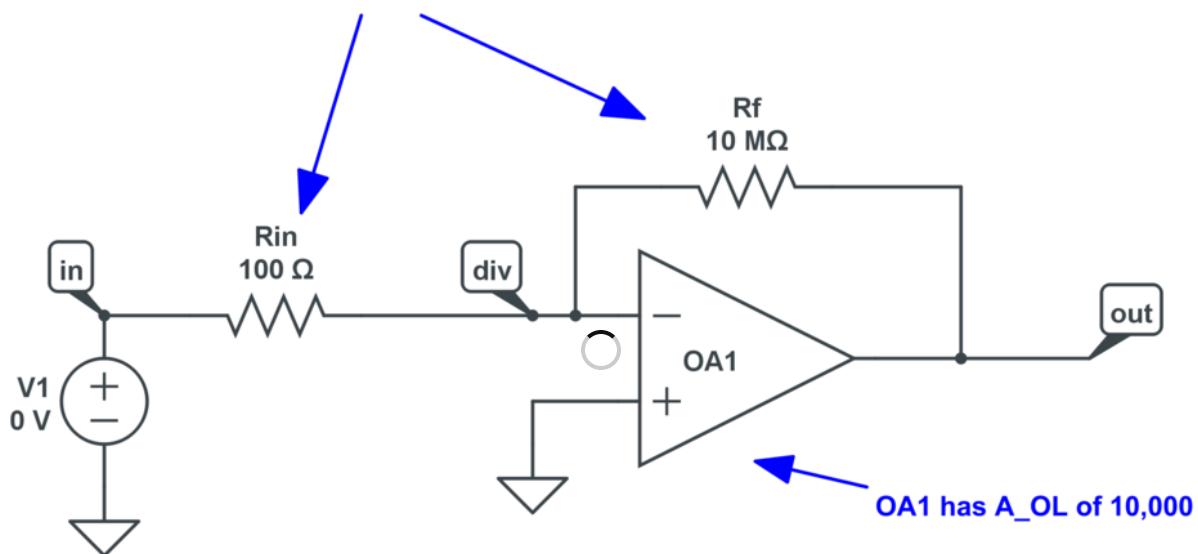
Edit - Simulate



Op-Amp Inverting Amplifier VCVS Model  
[circuitlab.com/c5kgdge4xjqq7](https://circuitlab.com/c5kgdge4xjqq7)

[Edit - Simulate](#)

Resistor ratio is  
 $k = R_f/R_{in} = 10M/100 = 1e7 / 1e2 = 1e5 = 100,000$

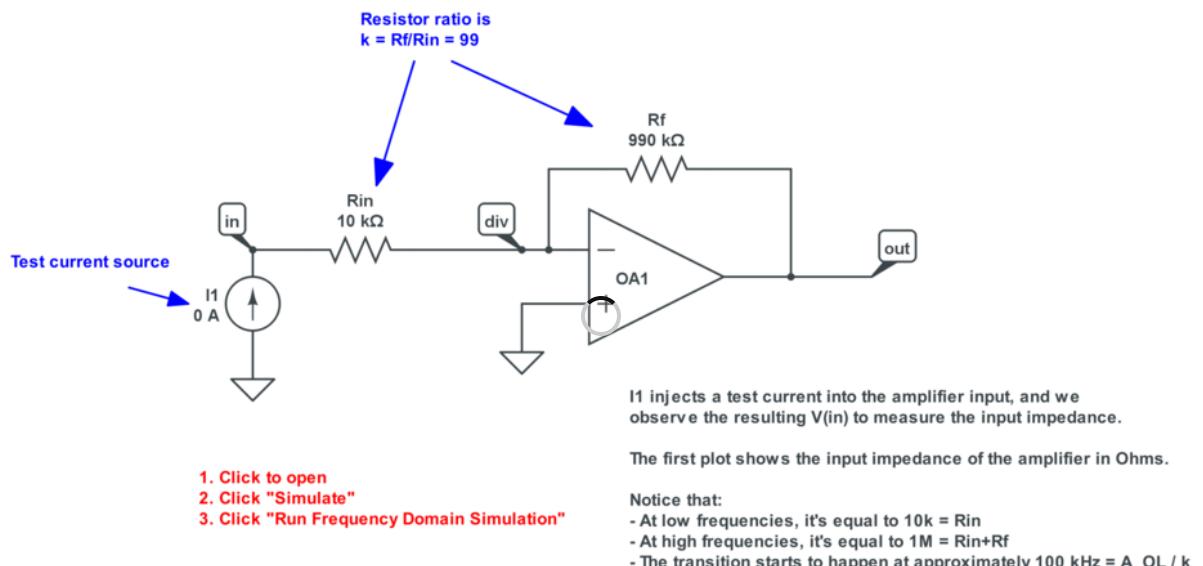


1. Click to open
2. Click "Simulate"
3. Click "Run DC Sweep"

Because  $A_{OL} < k$ , the gain of this inverting amplifier is limited by the op-amp, not the resistors.

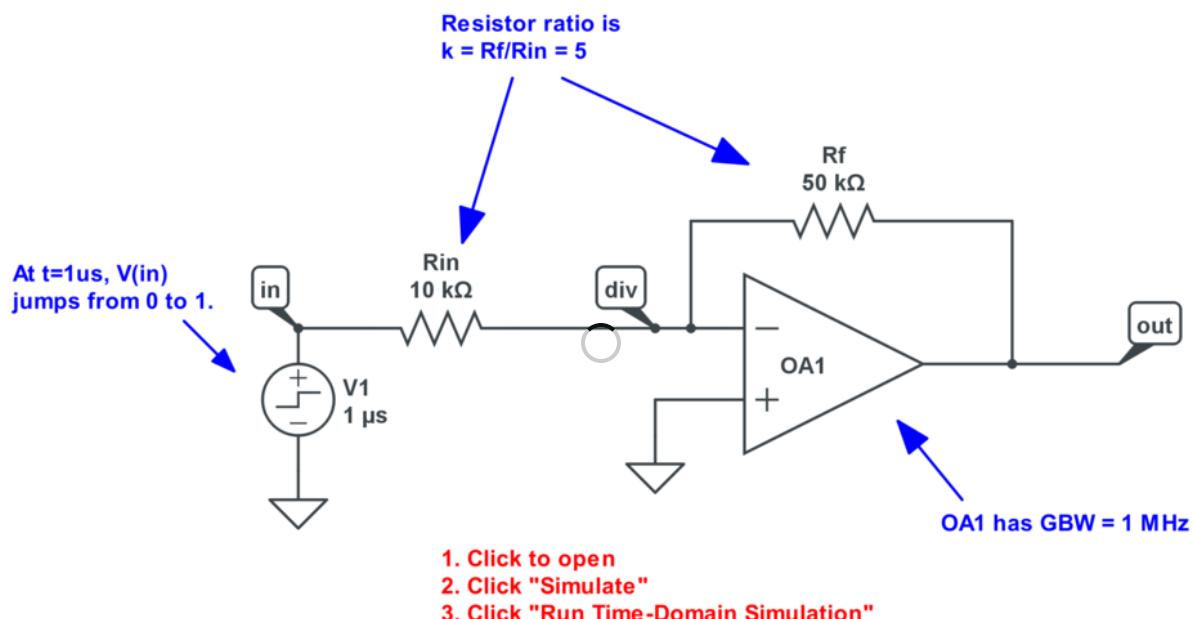
Op-Amp Inverting Amplifier - Limited by Open-Loop Gain  
[circuitlab.com/ctjm6t325a9he](http://circuitlab.com/ctjm6t325a9he)

[Edit](#) - [Simulate](#)



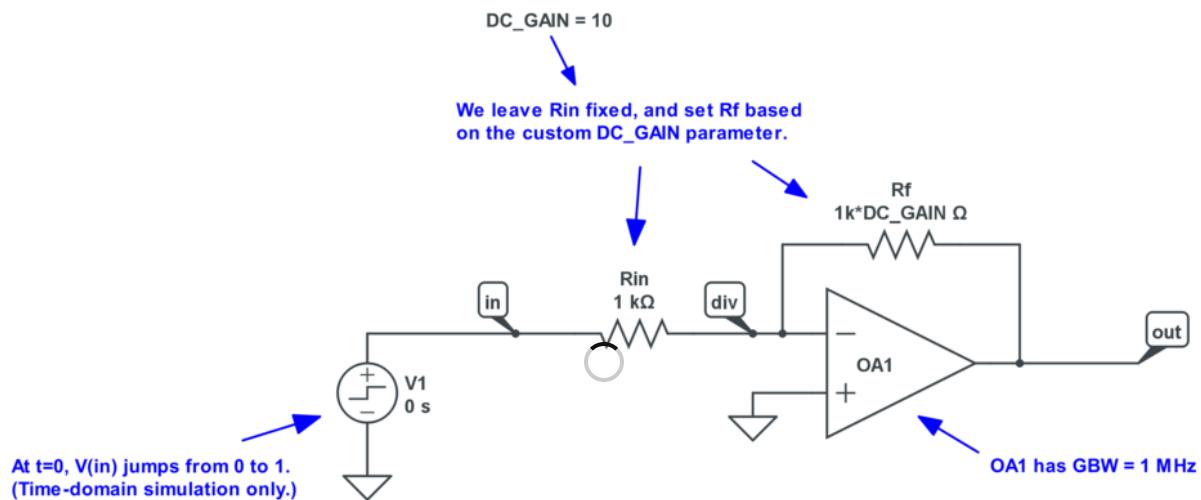
Op-Amp Inverting Amplifier - Input Impedance Simulation  
[circuitlab.com/c7gvkuez25b24](https://circuitlab.com/c7gvkuez25b24)

[Edit](#) - [Simulate](#)



Op-Amp Inverting Amplifier - Step Response  
[circuitlab.com/c5493kmczatef](http://circuitlab.com/c5493kmczatef)

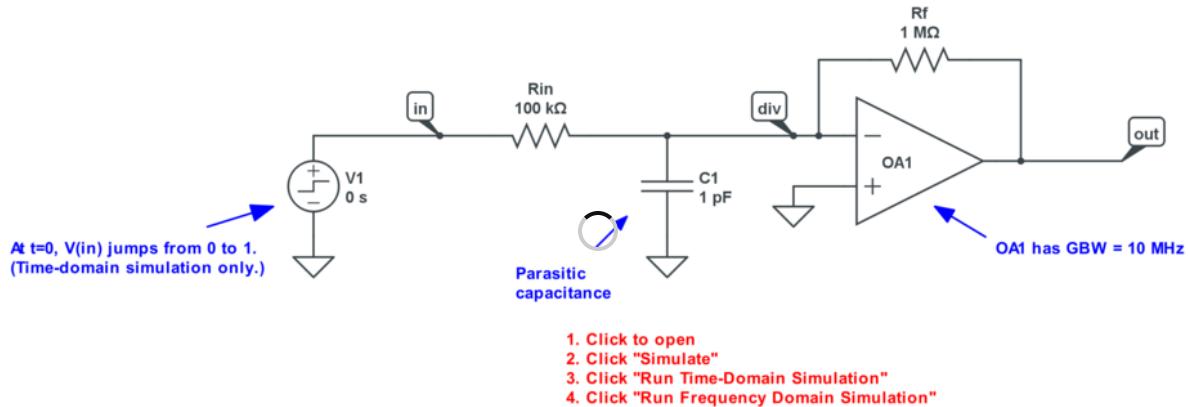
[Edit](#) - [Simulate](#)



1. Click to open
2. Click "Simulate"
3. Click "Run Frequency Domain Simulation"
4. Click "Run Time-Domain Simulation"

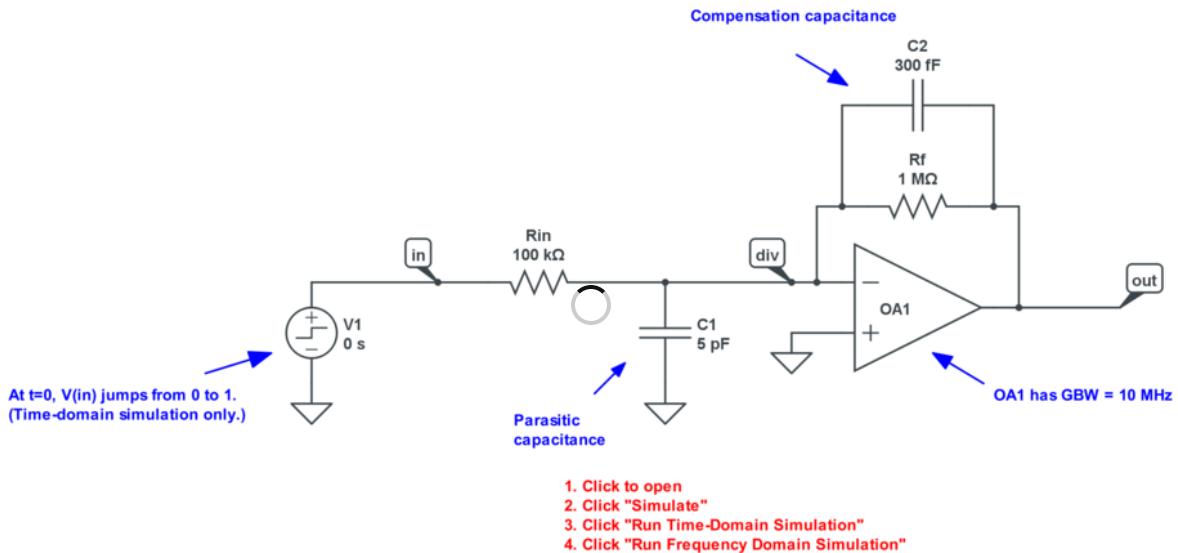
Op-Amp Inverting Amplifier - Gain vs. Bandwidth Tradeoff  
[circuitlab.com/cm5yf4gjyqf4t](http://circuitlab.com/cm5yf4gjyqf4t)

[Edit](#) - [Simulate](#)



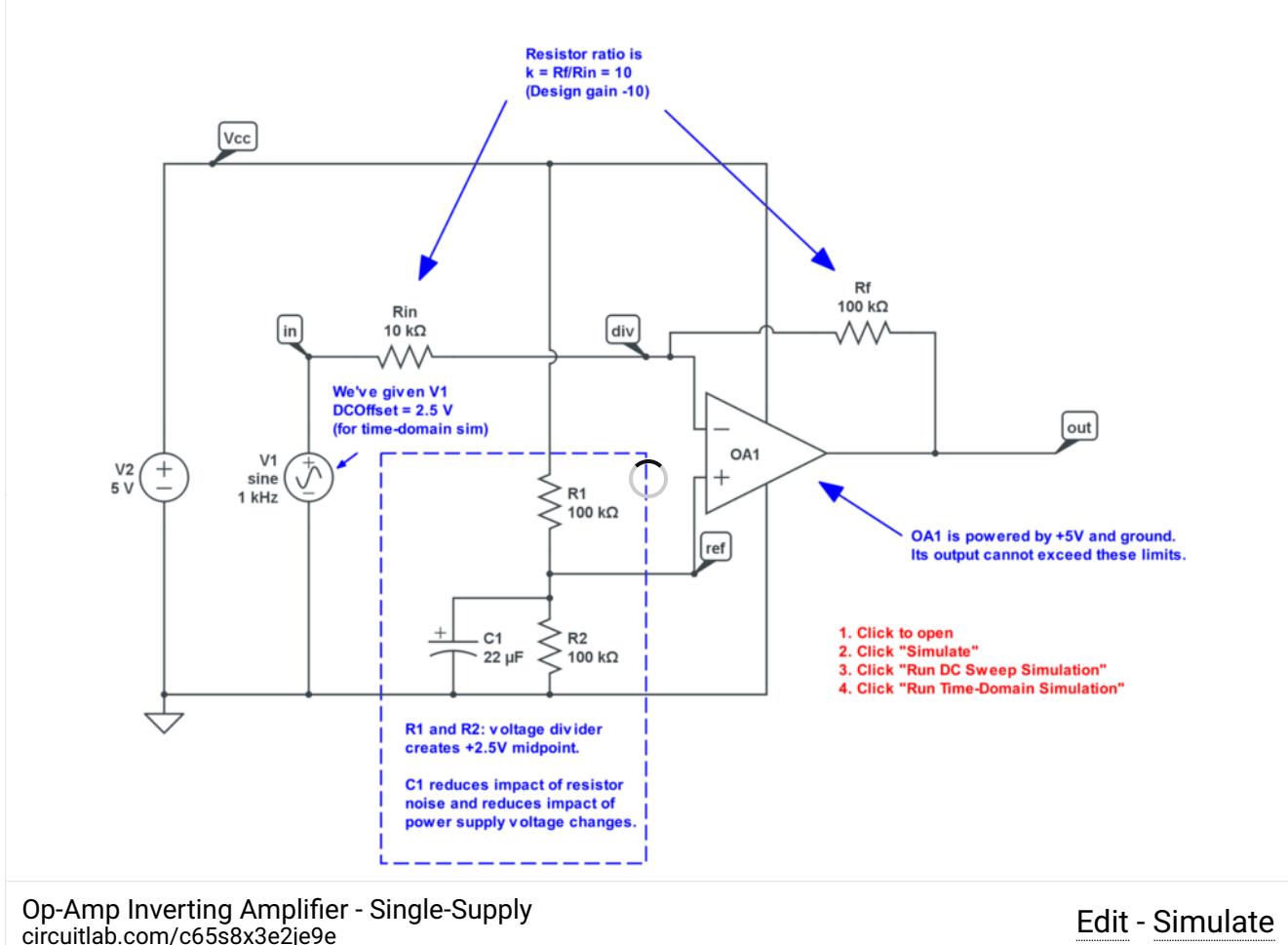
Op-Amp Inverting Amplifier - Instability due to Parasitic Capacitance  
[circuitlab.com/c8x5srsmhd6zg](http://circuitlab.com/c8x5srsmhd6zg)

[Edit](#) - [Simulate](#)



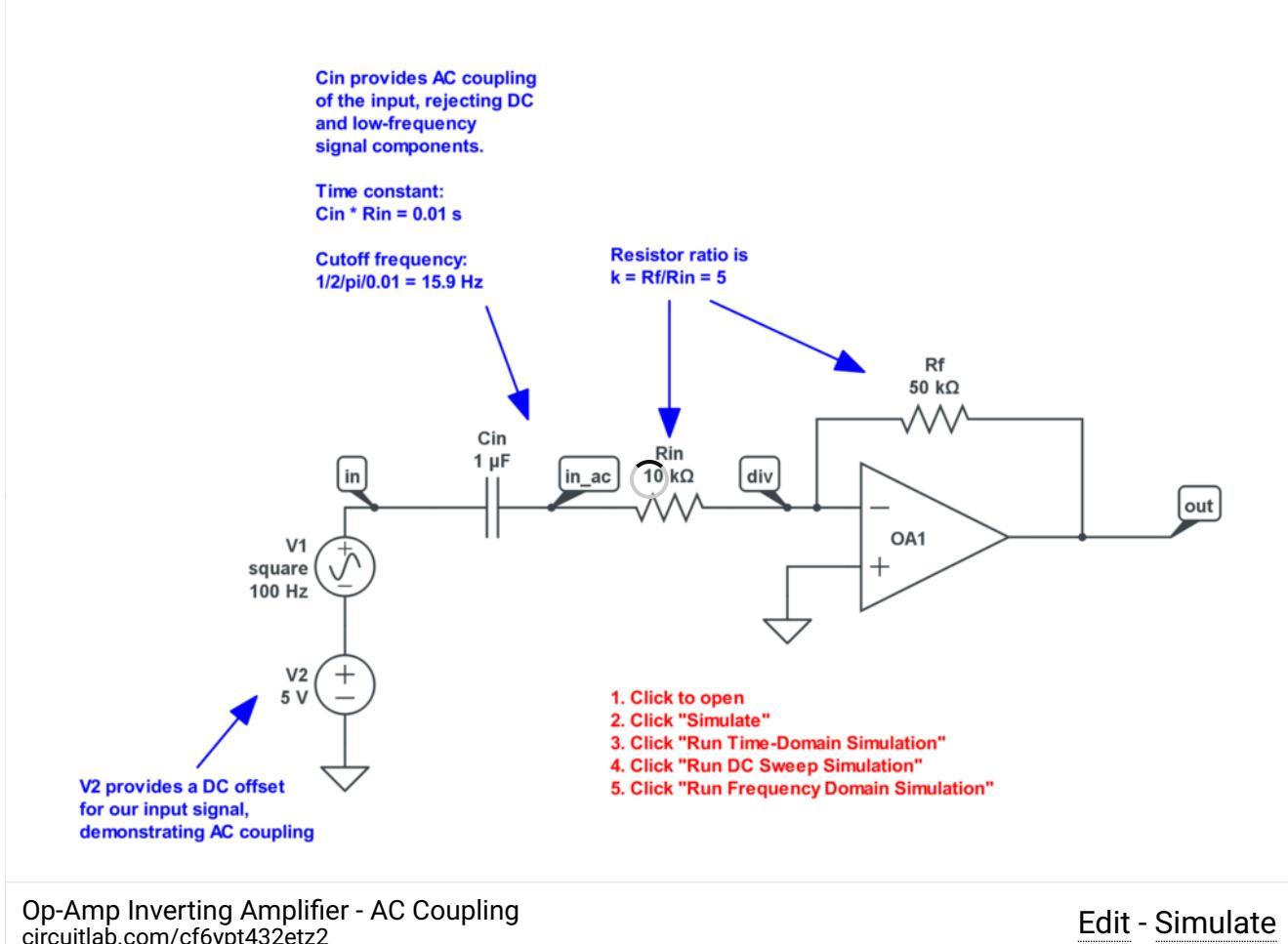
Op-Amp Inverting Amplifier - Compensation Capacitor  
[circuitlab.com/cdr6eey9rx4hn](http://circuitlab.com/cdr6eey9rx4hn)

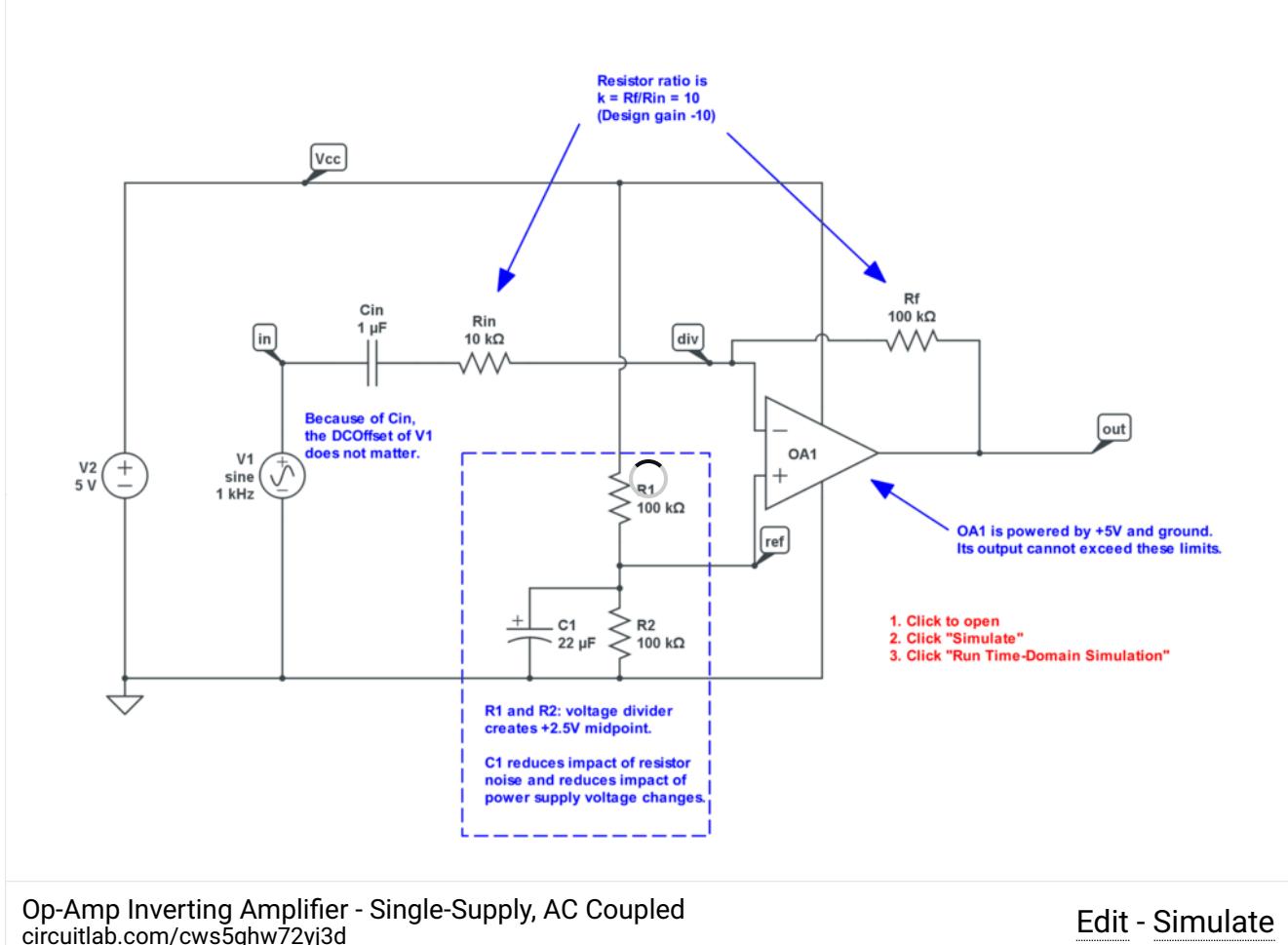
[Edit](#) - [Simulate](#)



Op-Amp Inverting Amplifier - Single-Supply  
[circuitlab.com/c65s8x3e2je9e](http://circuitlab.com/c65s8x3e2je9e)

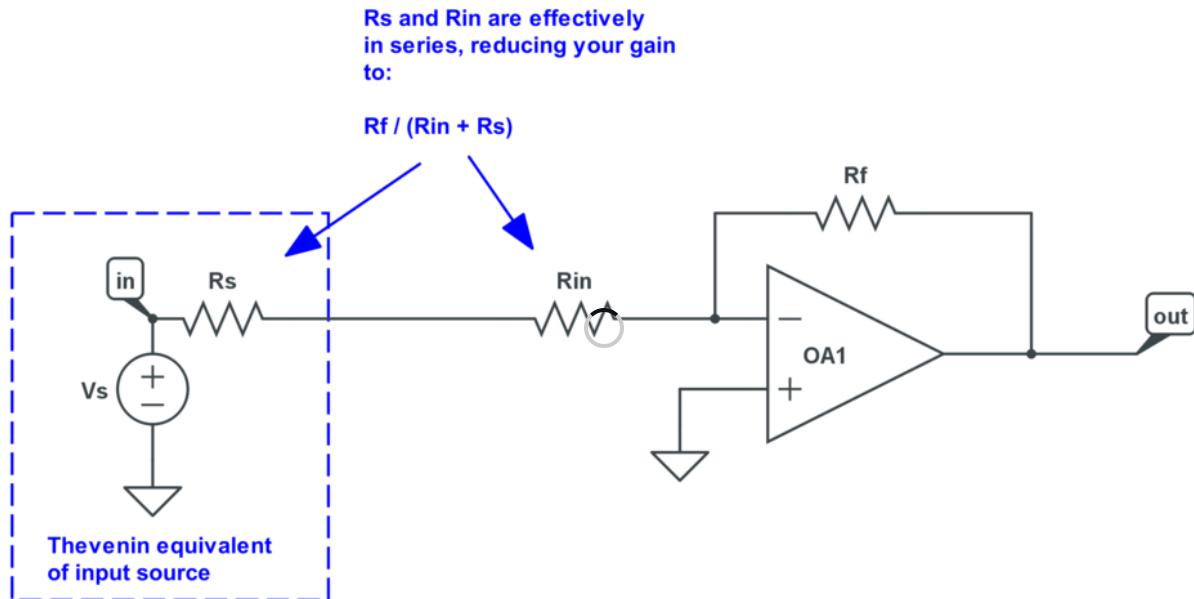
[Edit](#) - [Simulate](#)

Op-Amp Inverting Amplifier - AC Coupling  
[circuitlab.com/cf6ypt432etz2](http://circuitlab.com/cf6ypt432etz2)[Edit - Simulate](#)



Op-Amp Inverting Amplifier - Single-Supply, AC Coupled  
[circuitlab.com/cws5ghw72yj3d](http://circuitlab.com/cws5ghw72yj3d)

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Op-Amp Inverting Amplifier with Thevenin Equivalent Source Input  
[circuitlab.com/c5q537vb823cn](http://circuitlab.com/c5q537vb823cn)

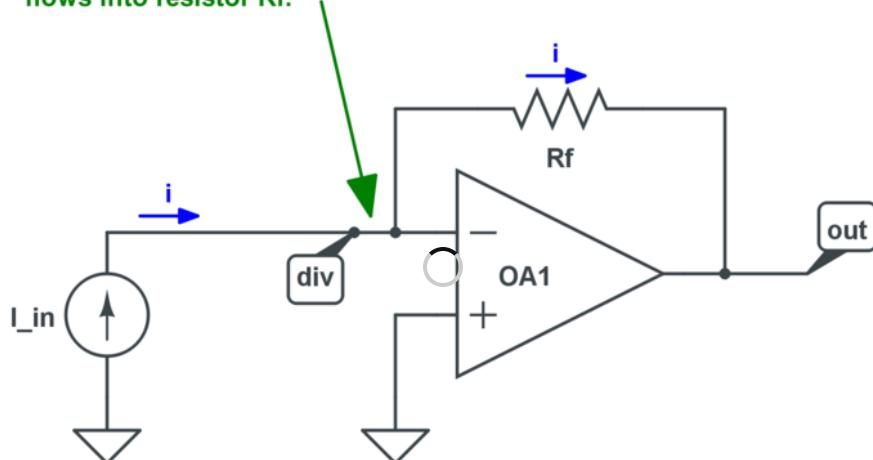
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## From Chapter 7.6 Op-Amp Transimpedance Amplifier:

A *transimpedance amplifier (TIA)* converts a current to a voltage and is often used with current-based sensors like photodiodes. It's also a common building block that helps explain the performance and stability limits of many other op-amp circuits.

**KCL at Inverting Input Node:**

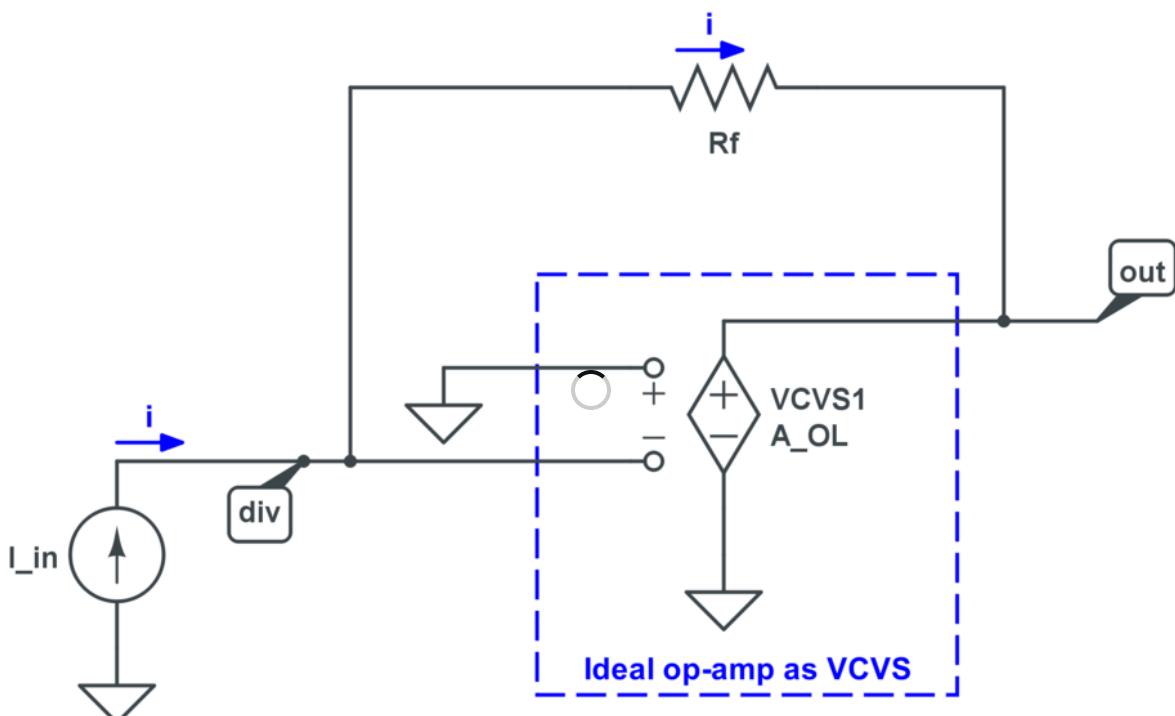
Zero current flows into an input of an ideal op-amp, so all of the input current flows into resistor  $R_f$ .



## Op-Amp Transimpedance Amplifier (Current-to-Voltage Converter)

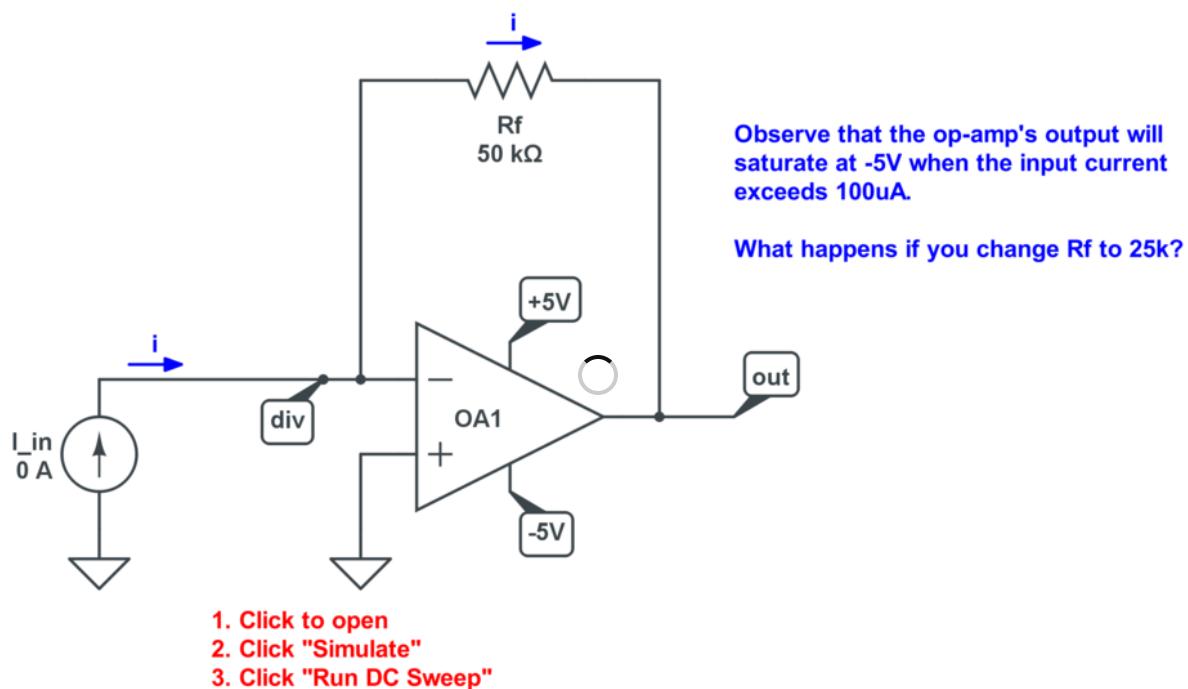
Op-Amp Transimpedance Amplifier - Labeled  
[circuitlab.com/c9c575e8ks4rq](http://circuitlab.com/c9c575e8ks4rq)

[Edit - Simulate](#)



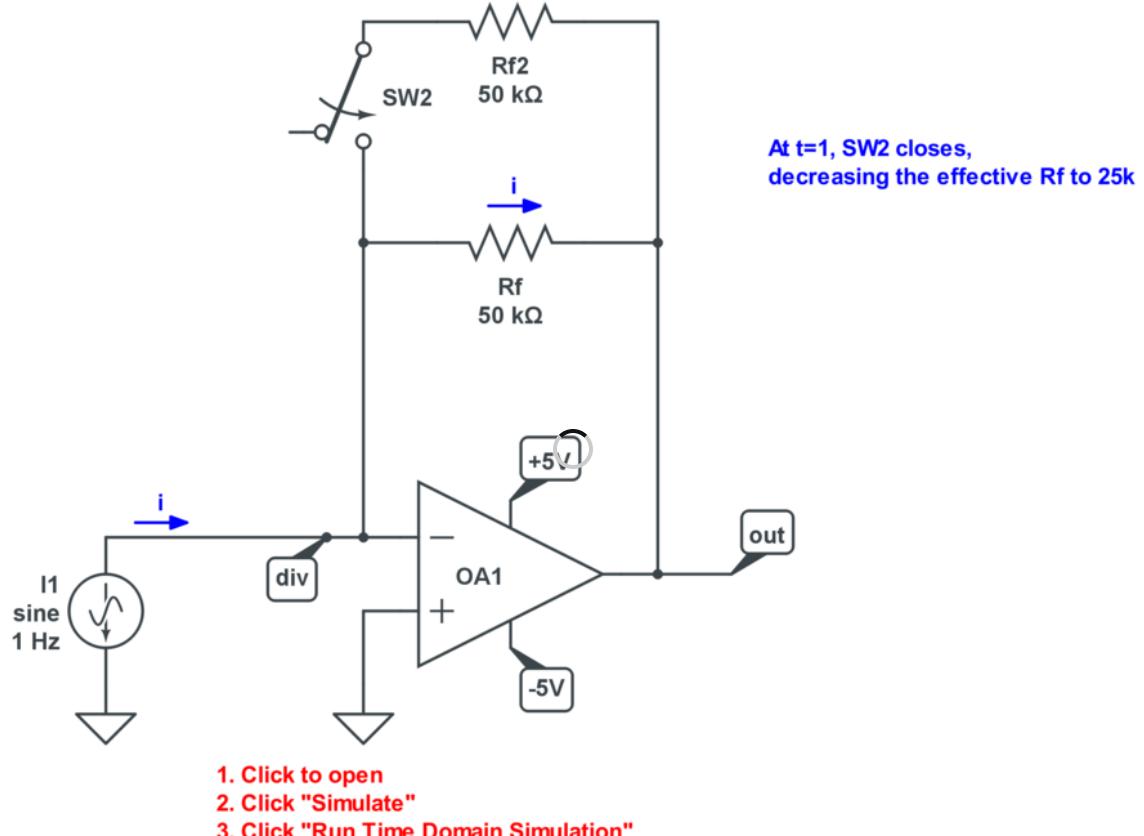
Op-Amp Transimpedance Amplifier VCVS Model  
[circuitlab.com/cd5qtq6tcn2va](https://circuitlab.com/cd5qtq6tcn2va)

[Edit](#) - [Simulate](#)



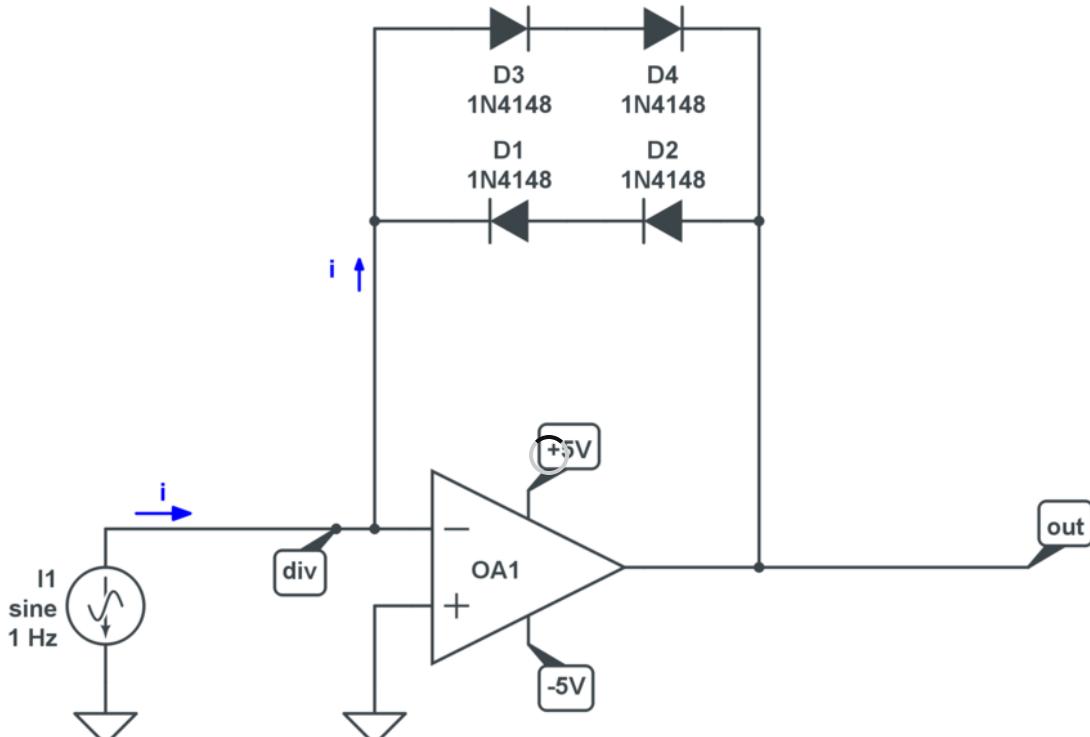
Op-Amp Transimpedance Amplifier - 50k Resistance DC Sweep Simulation  
[circuitlab.com/cy56xh92e2v57](http://circuitlab.com/cy56xh92e2v57)

[Edit](#) - [Simulate](#)



Op-Amp Transimpedance Amplifier - Switched Resistance Simulation  
[circuitlab.com/c733z7nm5fbby](http://circuitlab.com/c733z7nm5fbby)

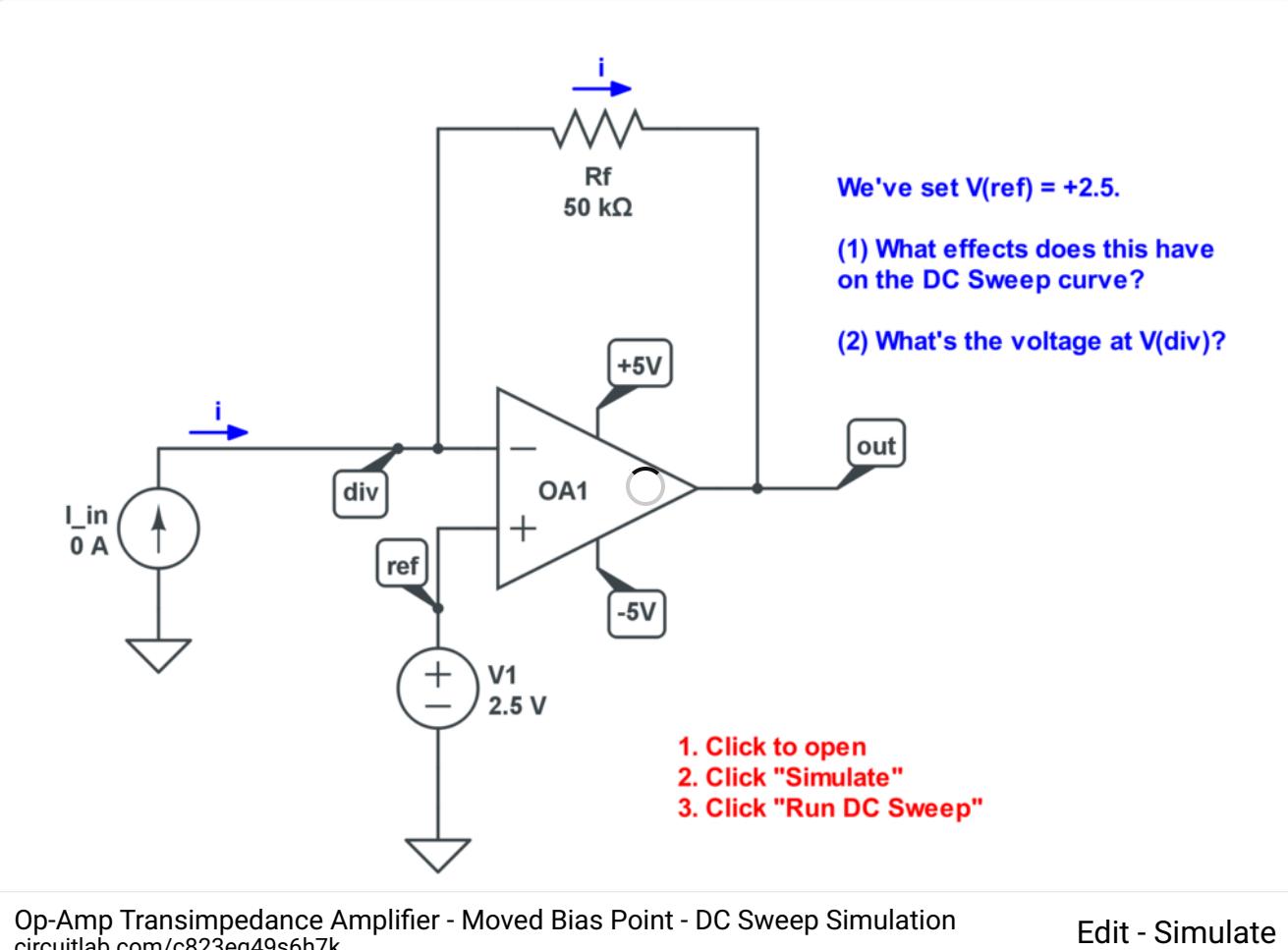
[Edit](#) - [Simulate](#)



1. Click to open
2. Click "Simulate"
3. Click "Run Time Domain Simulation"

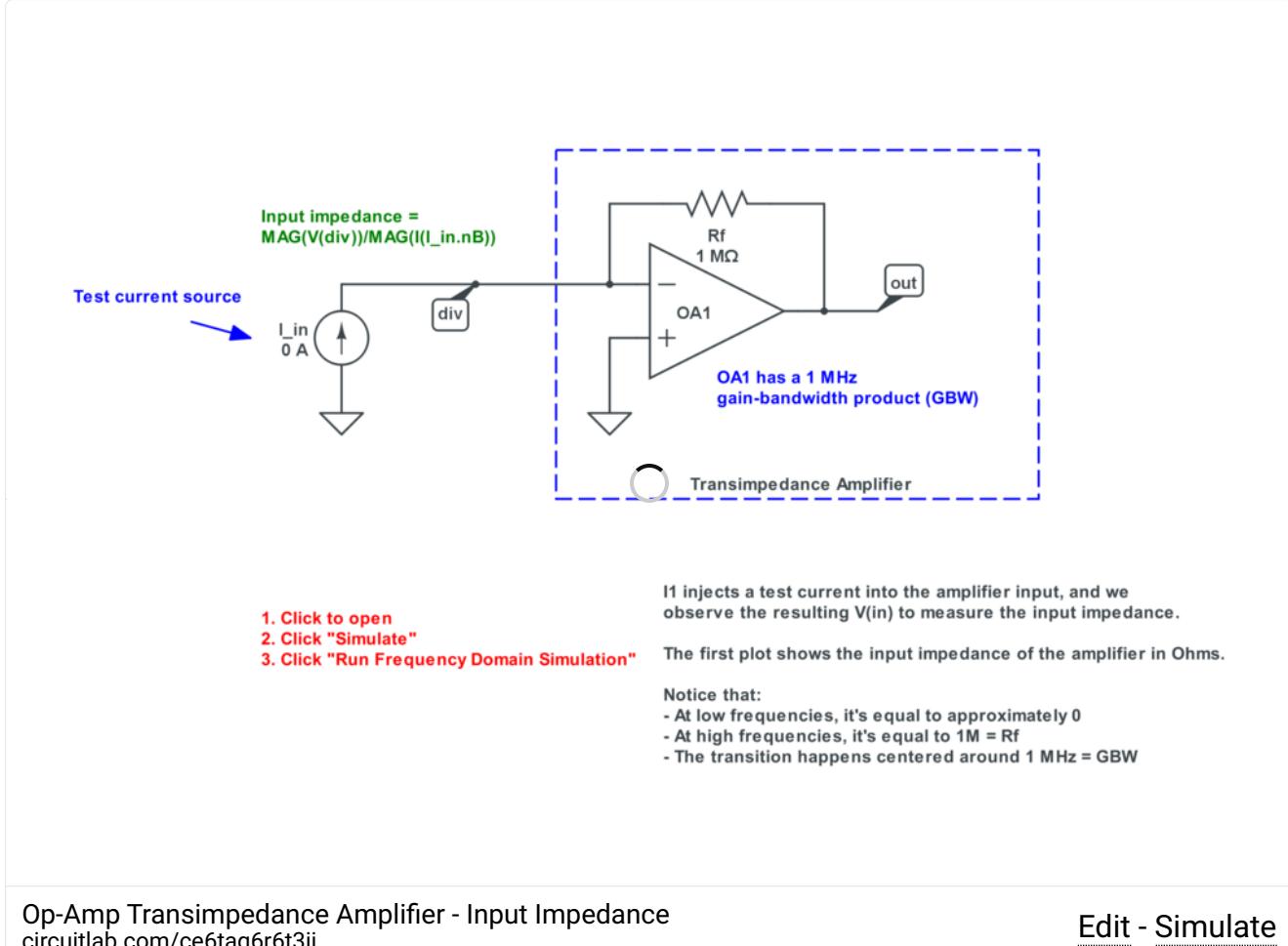
Op-Amp Transimpedance Amplifier - Logarithmic Response  
[circuitlab.com/c6gpwqp963hr7](http://circuitlab.com/c6gpwqp963hr7)

[Edit](#) - [Simulate](#)



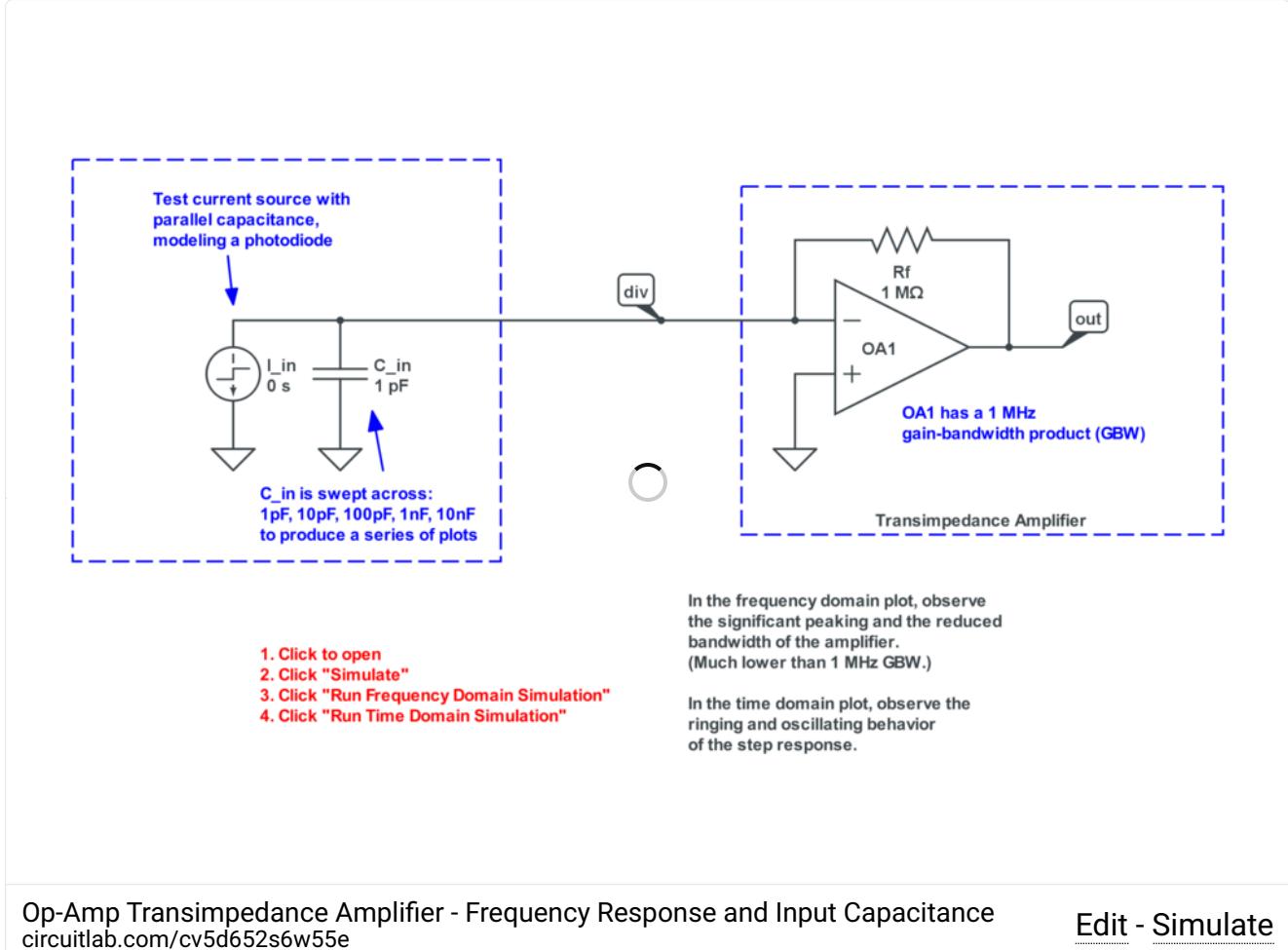
Op-Amp Transimpedance Amplifier - Moved Bias Point - DC Sweep Simulation  
[circuitlab.com/c823eq49s6h7k](http://circuitlab.com/c823eq49s6h7k)

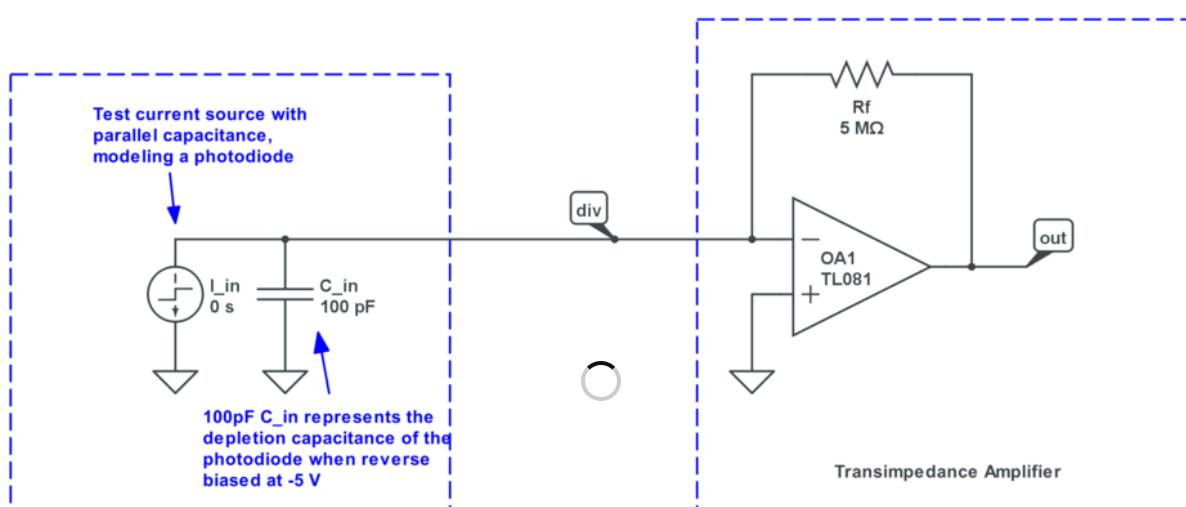
Edit - Simulate



Op-Amp Transimpedance Amplifier - Input Impedance  
[circuitlab.com/ce6tag6r6t3jj](http://circuitlab.com/ce6tag6r6t3jj)

[Edit](#) - [Simulate](#)





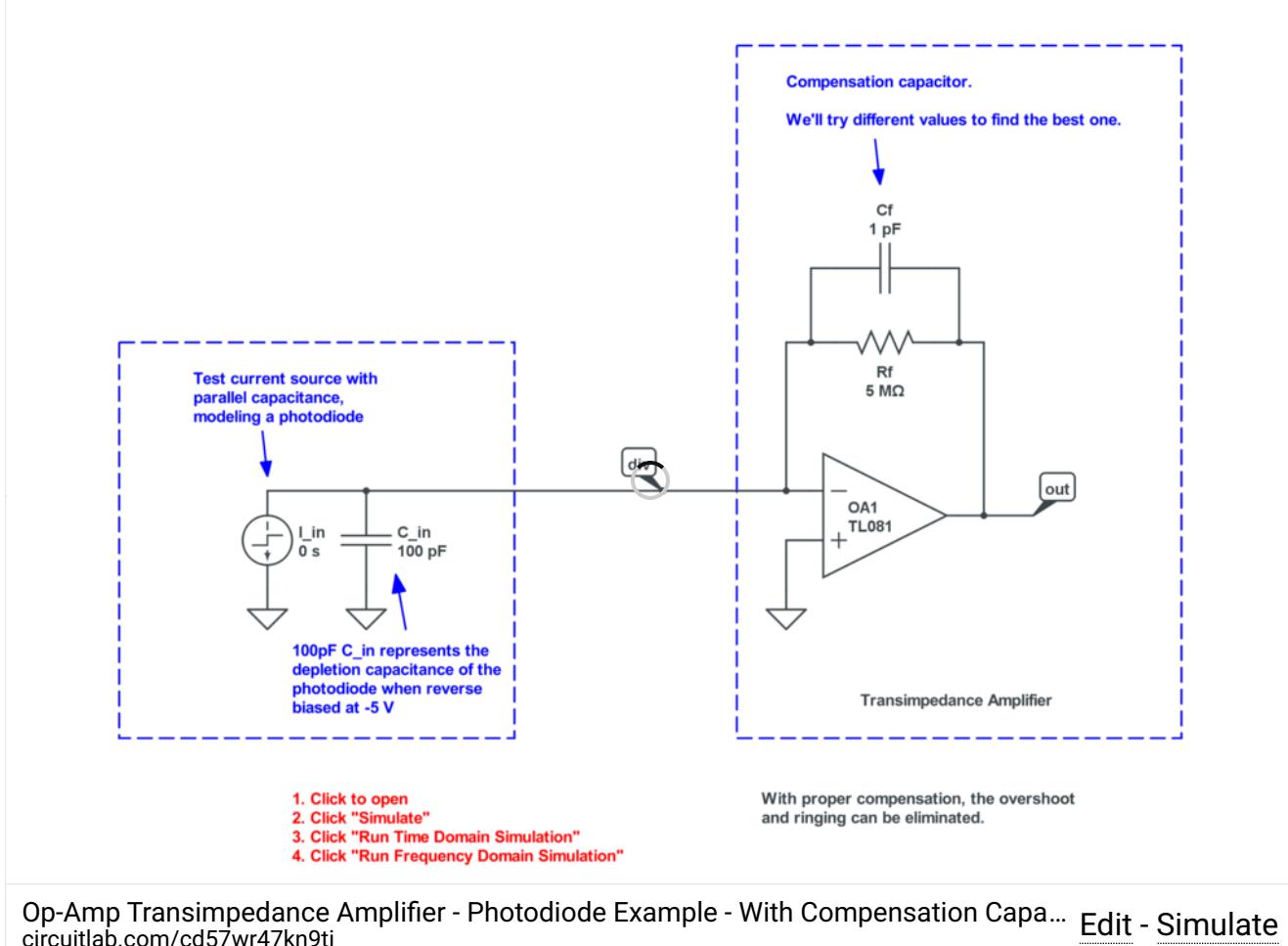
1. Click to open
2. Click "Simulate"
3. Click "Run Time Domain Simulation"
4. Click "Run Frequency Domain Simulation"

In the frequency domain plot, observe the significant peaking and the reduced bandwidth of the amplifier.  
(Much lower than the TL081's 4 MHz GBW.)

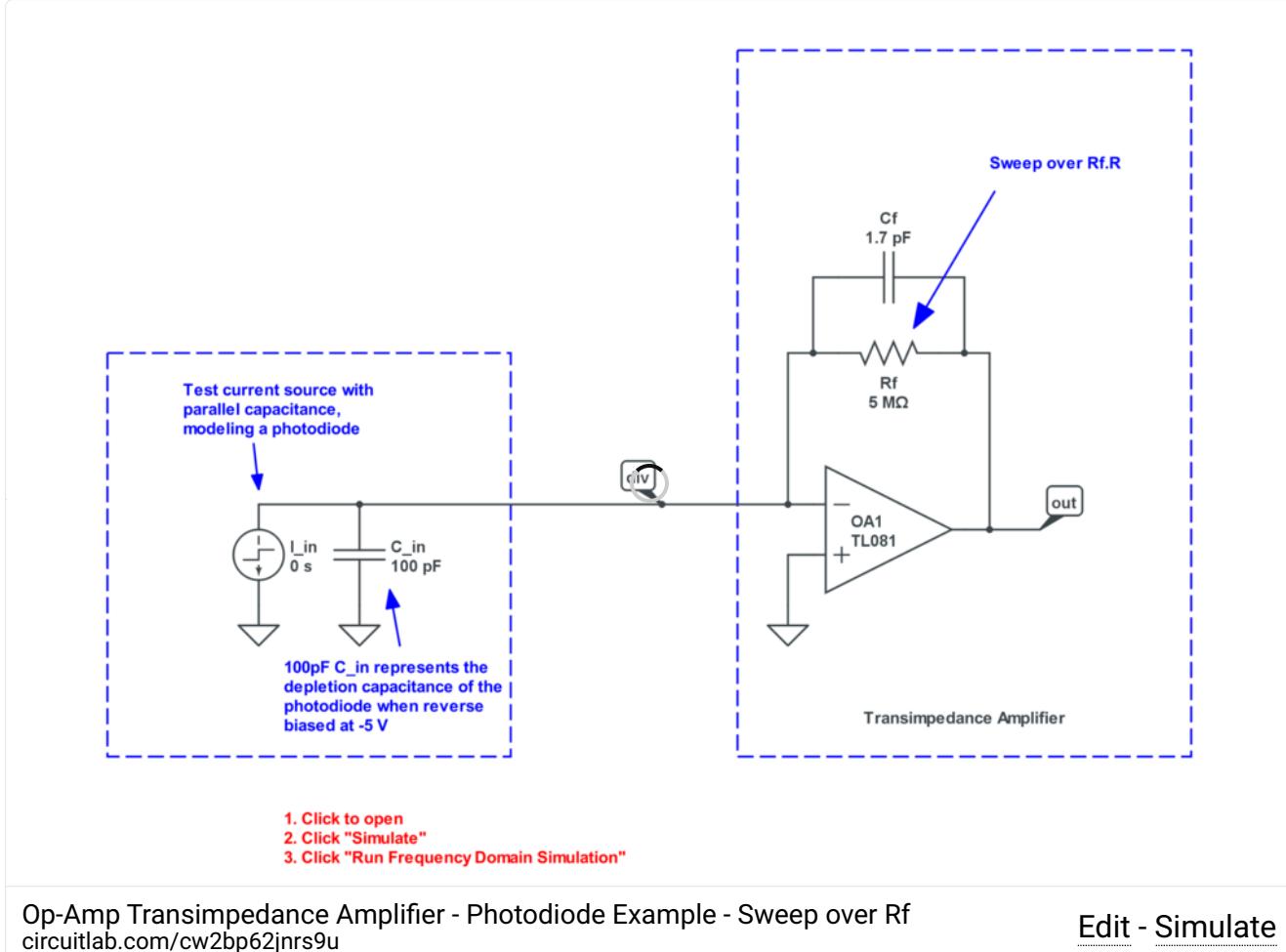
In the time domain plot, observe the ringing in the step response.

Op-Amp Transimpedance Amplifier - Photodiode Example - Uncompensated  
[circuitlab.com/cmy22d5hj37gq](http://circuitlab.com/cmy22d5hj37gq)

[Edit](#) - [Simulate](#)

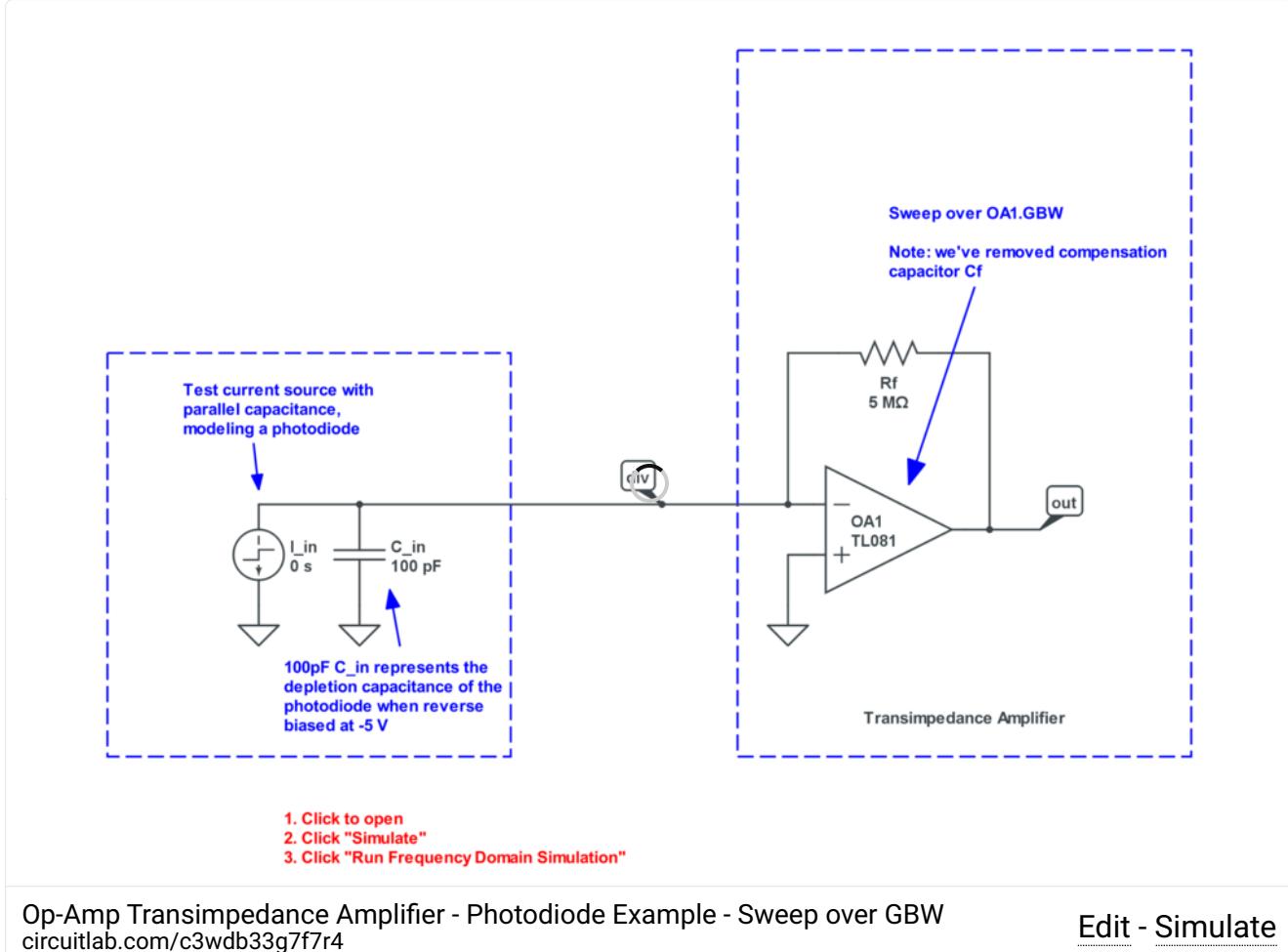


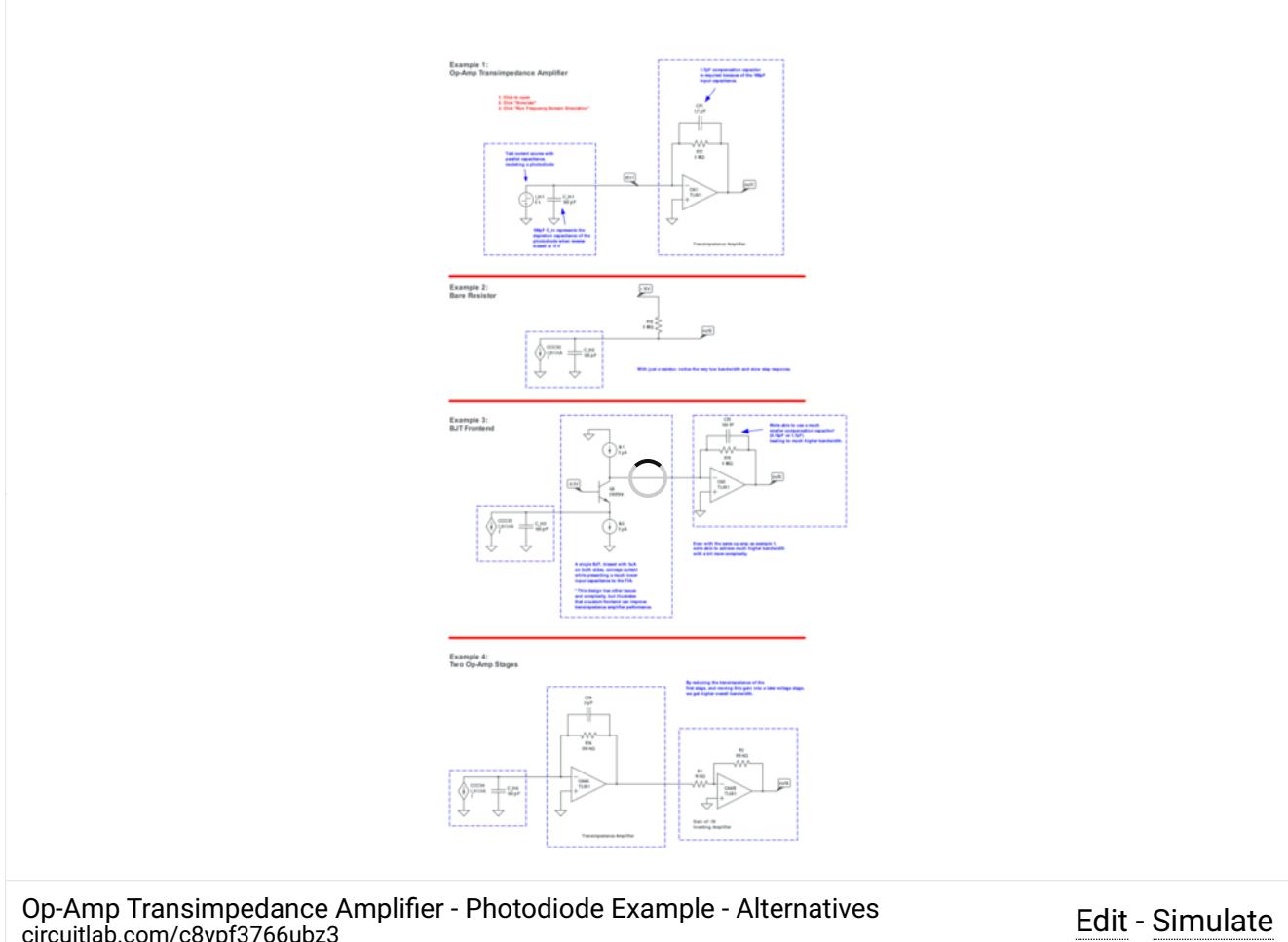
Op-Amp Transimpedance Amplifier - Photodiode Example - With Compensation Capa... [Edit](#) - [Simulate](#)



Op-Amp Transimpedance Amplifier - Photodiode Example - Sweep over Rf  
[circuitlab.com/cw2bp62jnr9u](http://circuitlab.com/cw2bp62jnr9u)

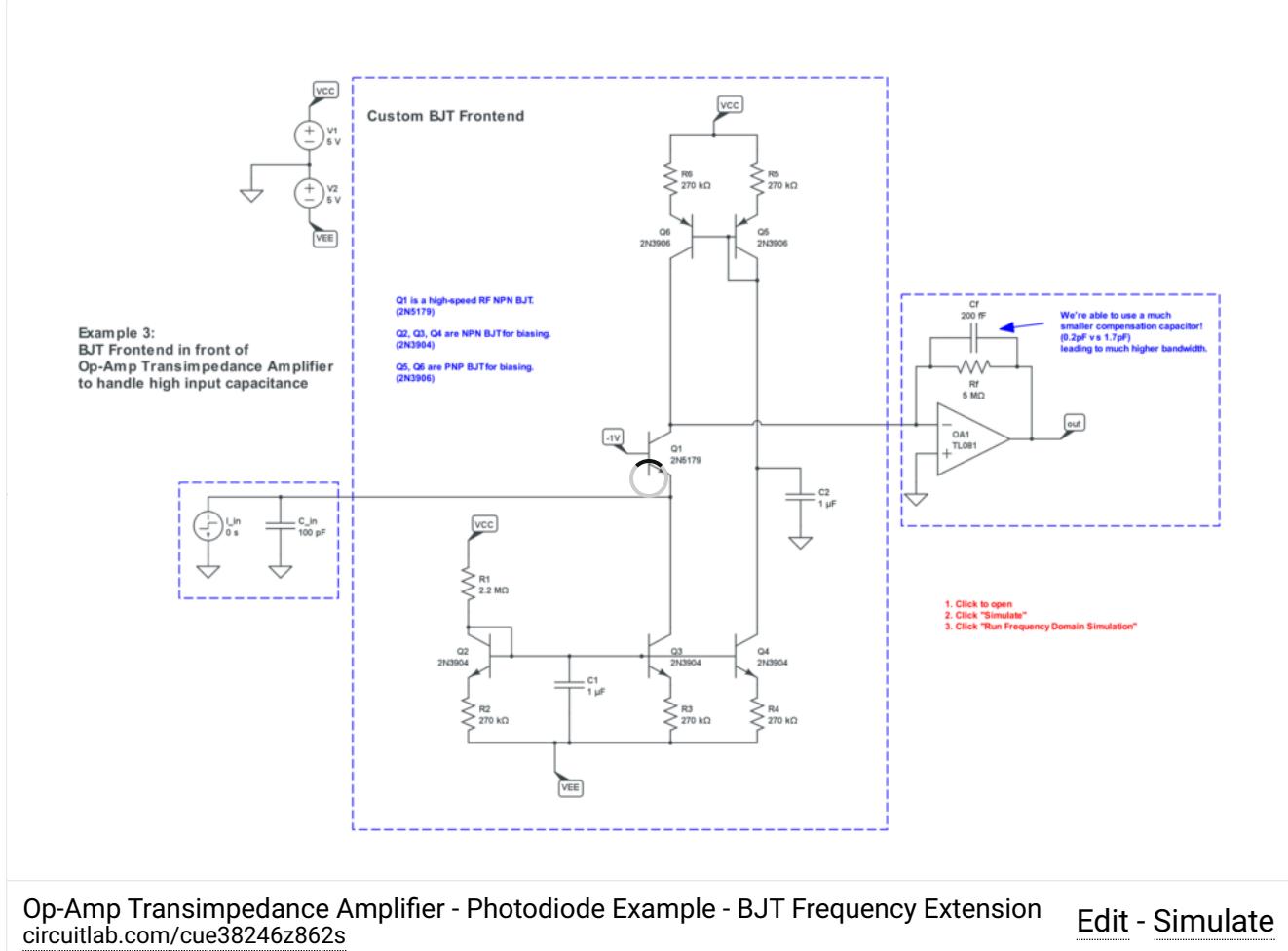
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Op-Amp Transimpedance Amplifier - Photodiode Example - Alternatives  
[circuitlab.com/c8ypf3766ubz3](http://circuitlab.com/c8ypf3766ubz3)

[Edit](#) - [Simulate](#)



Op-Amp Transimpedance Amplifier - Photodiode Example - BJT Frequency Extension

[circuitlab.com/cue38246z862s](http://circuitlab.com/cue38246z862s)

[Edit](#) - [Simulate](#)

Robbins, Michael F. **Ultimate Electronics: Practical Circuit Design and Analysis**. CircuitLab, Inc., 2021,  
[ultimateelectronicsbook.com](https://ultimateglobals.com/ultimateelectronicsbook.com). Accessed 07 Apr 2023. (Copyright © 2021 CircuitLab, Inc.)