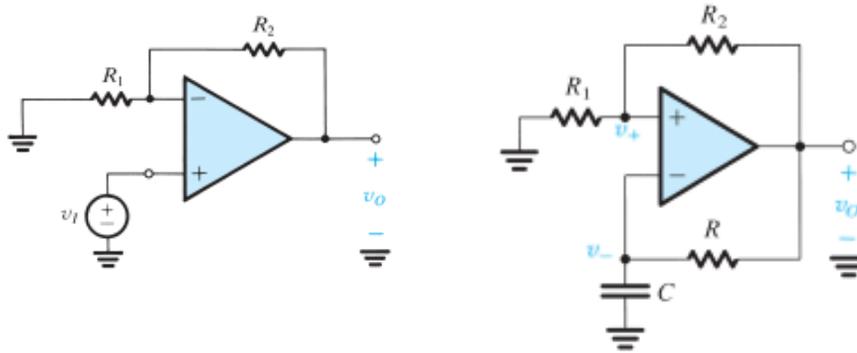


Op Amp Discovery

Fast & Flexible Experimenter and Learning Board



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2	Fast & Flexible Prototyping	2
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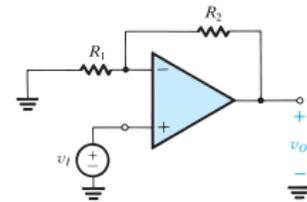
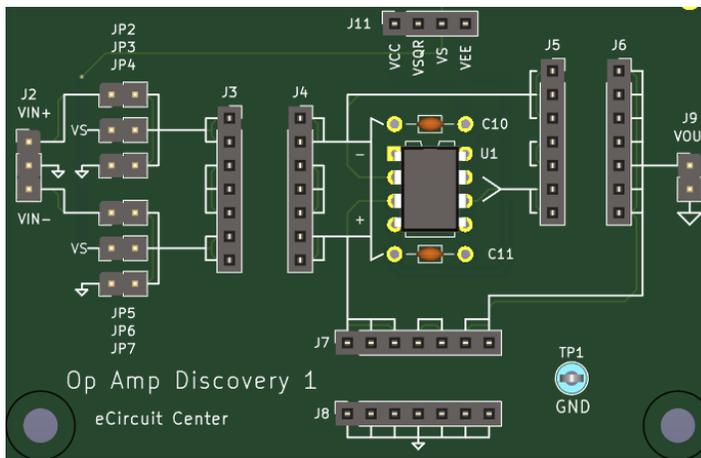
1 Intro

The Op Amp Discovery Board allows students, engineers and DIYers to quickly build and experiment with a variety of op amp configurations. **Hands-on learning boosts understanding and intuition!**

- Easy-to-use hybrid (solderless breadboard / PCB)
- Explore 20+ classic op amp circuits
- Create your own circuits
- Supply Rails & Signal Source Included on-board

2 Fast & Flexible Prototyping

Quickly build and explore many classic op amp circuits with component headers and configurable circuits. Follow self-directed or guided learning.



- Flexible - **easily install Rs, Cs or jumpers across any headers.**
- Fun problem solving - *How-to-build circuit on headers?*
- Configurable signal - *DC, AC, square-wave, level trimpot*

3 Problems Solved

Standard breadboards can be frustrating:

- Prone to opens, shorts, intermittent connections
- Confusing, difficult to probe and debug
- Requires expensive, bulky supplies and signal generators

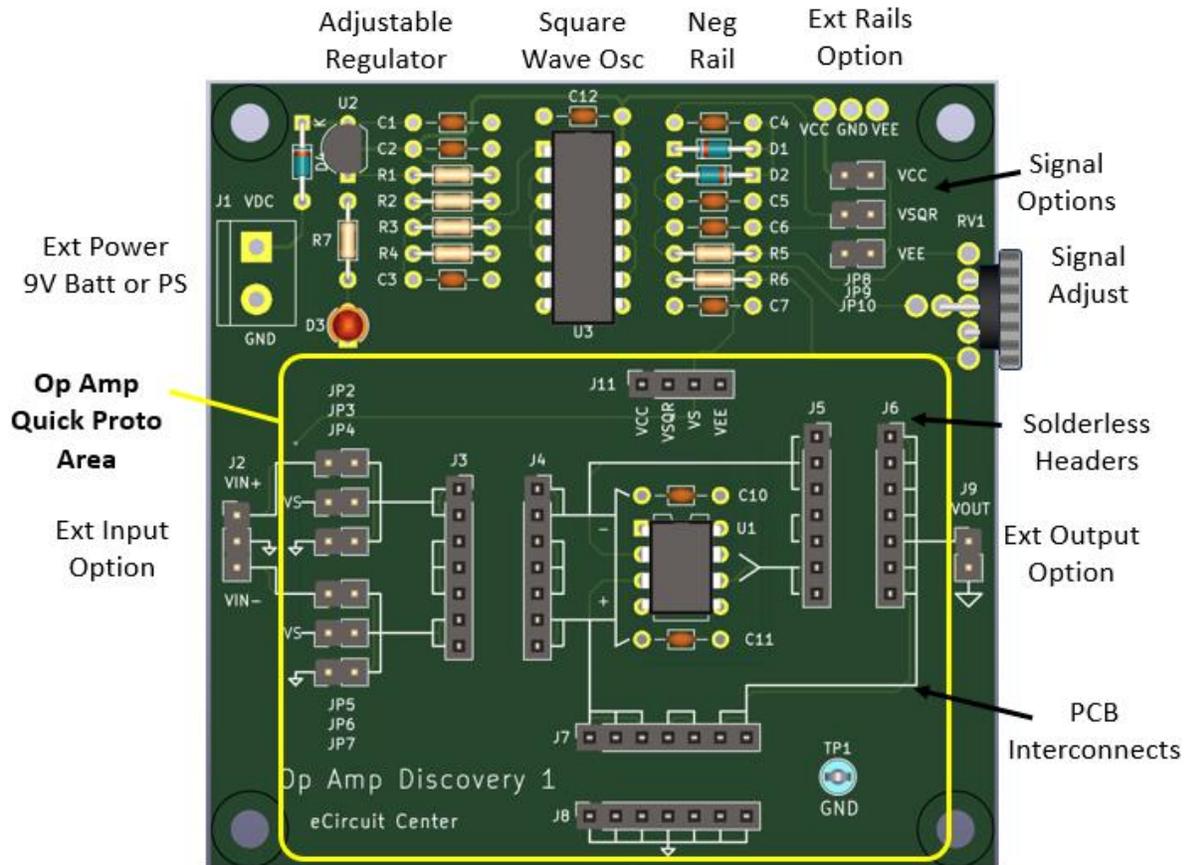
Op Amp Discovery:

- PCB provides solid, versatile connections, power and a signal source.
- Layout arranged like schematic to reinforce learning.
- Minimal cost and PCB space - an affordable & portable learn-anywhere lab.
- Learning possible with a \$10 DMM only.

4 Overview

The Op Amp Discovery provides essential support circuitry for a **stand-alone learning lab**. Circuit flexibility allows for custom or more complex setups.

The “Schematic” style of the PCB layout helps build understanding and intuition.



Overview

- Solderless Headers for easy install of components.
- PCB interconnects for versatile circuit options.
- Op Amp socket for DIP (or SMD on 8-pin header).
- Power from single source (9V battery)

Signal Source

- Scalable Square Wave (0 to 5V)
- Selectable DC or AC coupling.
- Adjustable Amplitude (Trimpot RV1)
- External Input / Outputs (Optional)

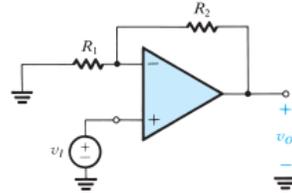
Power Rails

- Positive Rail VCC: Adjustable Regulator (5V default)
- Negative Rail VEE: Cap Charge Inverter (-4.5V)
- Solder pads for External Rails option.

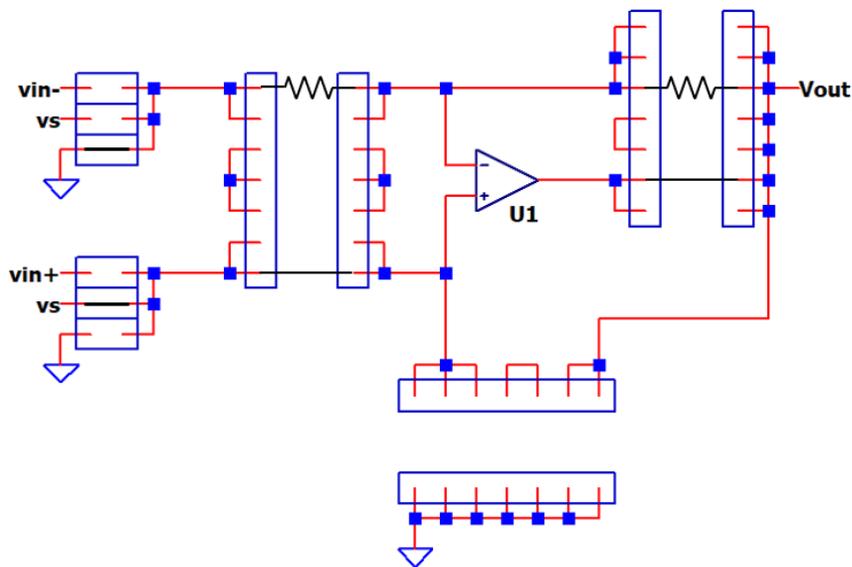
5 Quick Start Guide

5.1 Inverting Amplifier

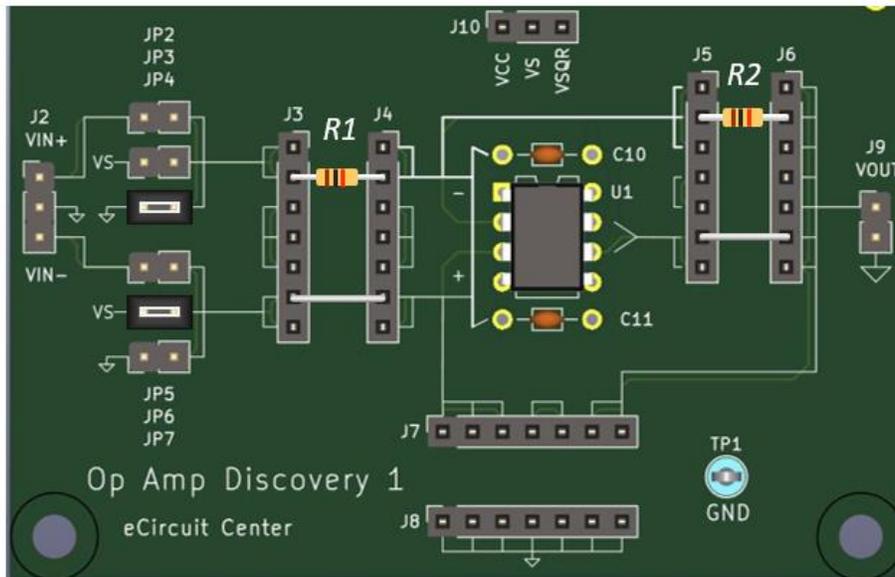
Let's jump in with the Non-Inverting Amplifier. From the circuit diagram, how can you build the amplifier on the Op Amp Discovery board?



First, sketch out a possible build on the proto-area schematic.

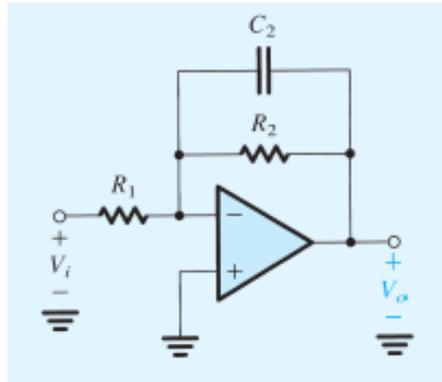


Then, simply install the resistors and wire jumpers - and the circuit's ready to explore!

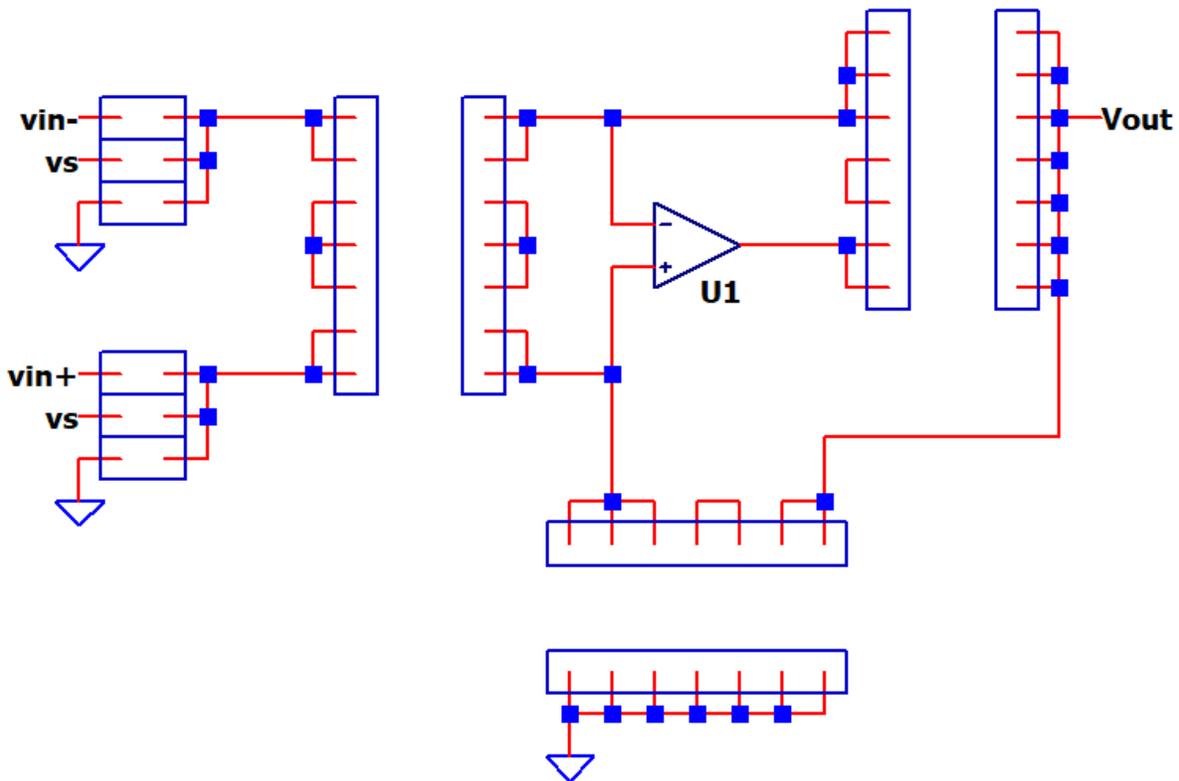


5.2 Your Turn!

How can you prototype the Inverting Low-Pass Filter?



Grab a pencil and solve the quest of how-to-build the circuit on the blank proto schematic! More than one solution typically possible.



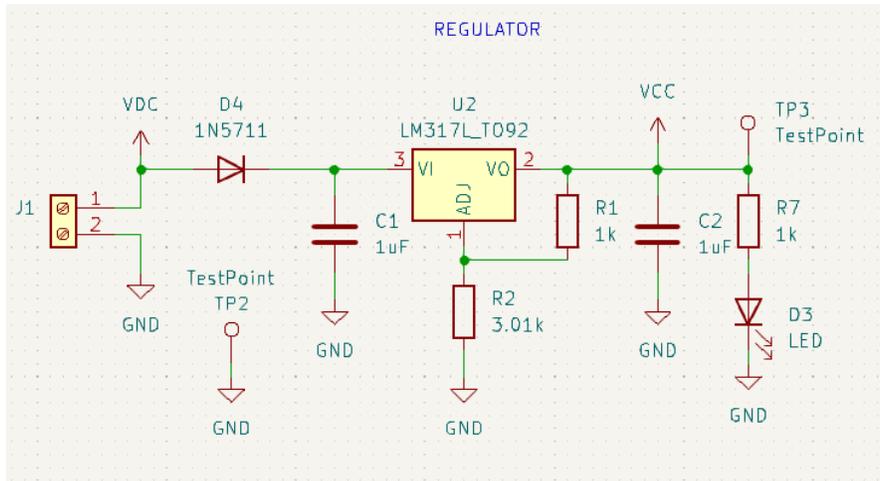
Next step: install the components, jumpers and then power up and explore the circuit.

Print out blank Proto Area Schematics from Section 10.

6 Schematic

The Op Amp Discovery is created using standard parts and straightforward circuits.

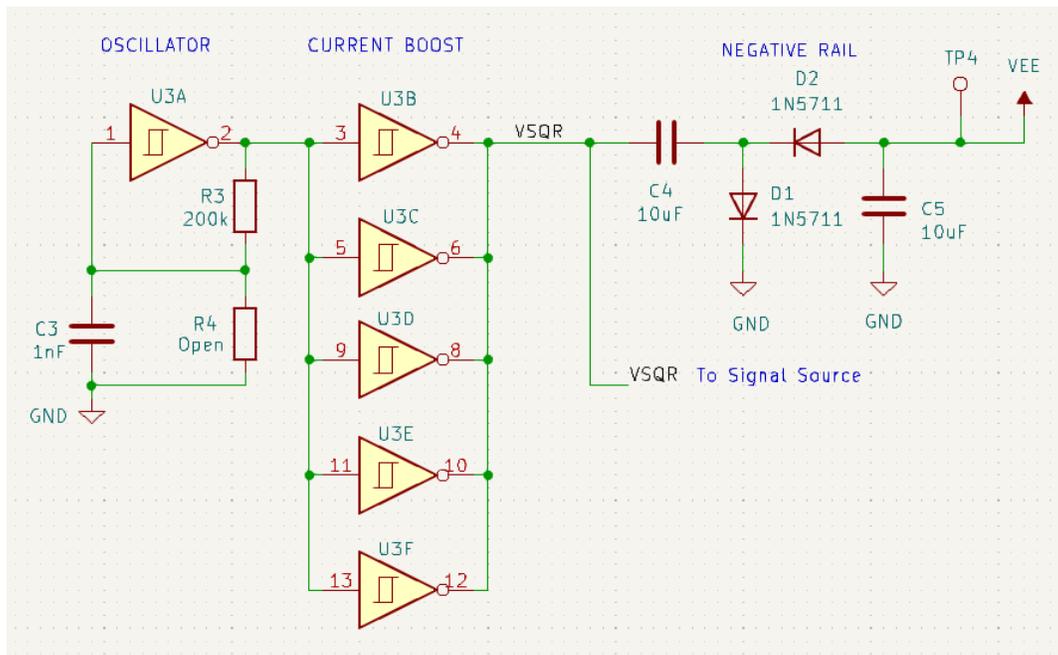
6.1 Positive Adjustable Supply



- U1 regulates external battery or power source to 5V
- R1, R2 adjust output $VCC = 1.25V \times (R1+R2)/R1$
- D4 prevents V_{in} reverse bias damage.
- D3 provides visual power indicator

6.2 Square-Wave Oscillator and Negative Rail

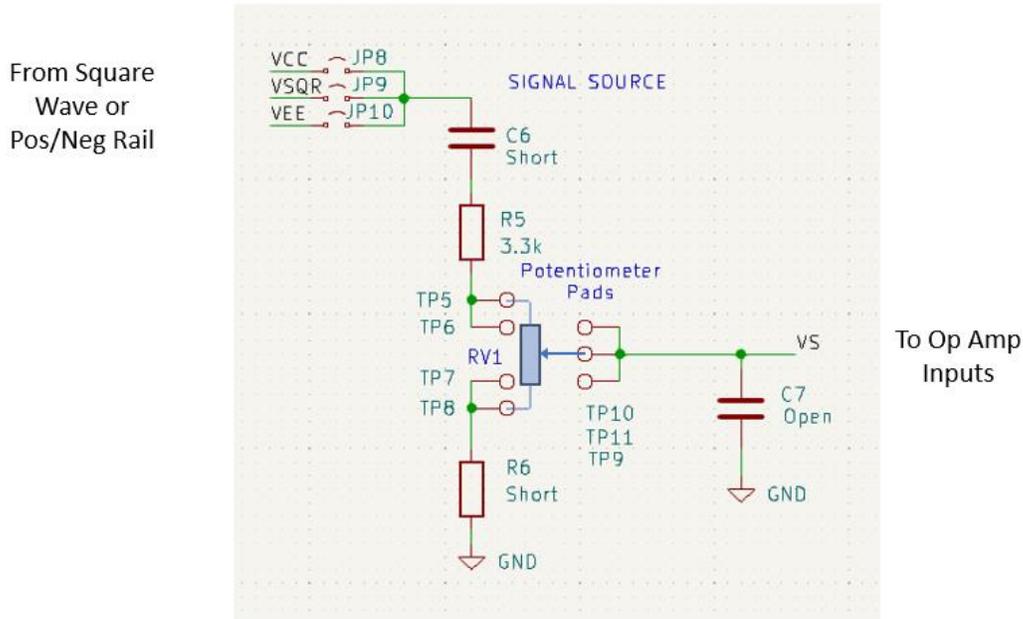
Square Wave provides Signal Source and drives Neg Rail Generator.



- Square-Wave Oscillator (U3A, R3, R4) creates 0-5V, 200kHz signal.
- Negative Rail developed by Capacitive Charge Pump (C4, C5, D1, D2).

6.3 Signal Source and Scaling

Signal components C6, R5, R6 and C7 easily changed on 4-pin solderless headers for user flexibility.



RV1's multi-pad PCB layout accommodates a wide variety of Trim Pot types.
Flexible signal options.

- Select Signal Source (JP8-10): Square Wave (VSQR) or DC Level (VCC, VEE).
- Choose DC Coupling (C6=short) or AC Coupling (C6=cap)
- Scale signal between 0 and 5V (Resistor Divider R5, RV1 and R6).
- Adjust signal level (RV1)
- Apply Low-Pass Filter (C7 optional).

DC Signal Scaling (R-Divider)

- VS Minimum

$$VS_{min} = Vin \cdot \frac{R6}{R5 + RV1 + R6}$$

- VS Maximum

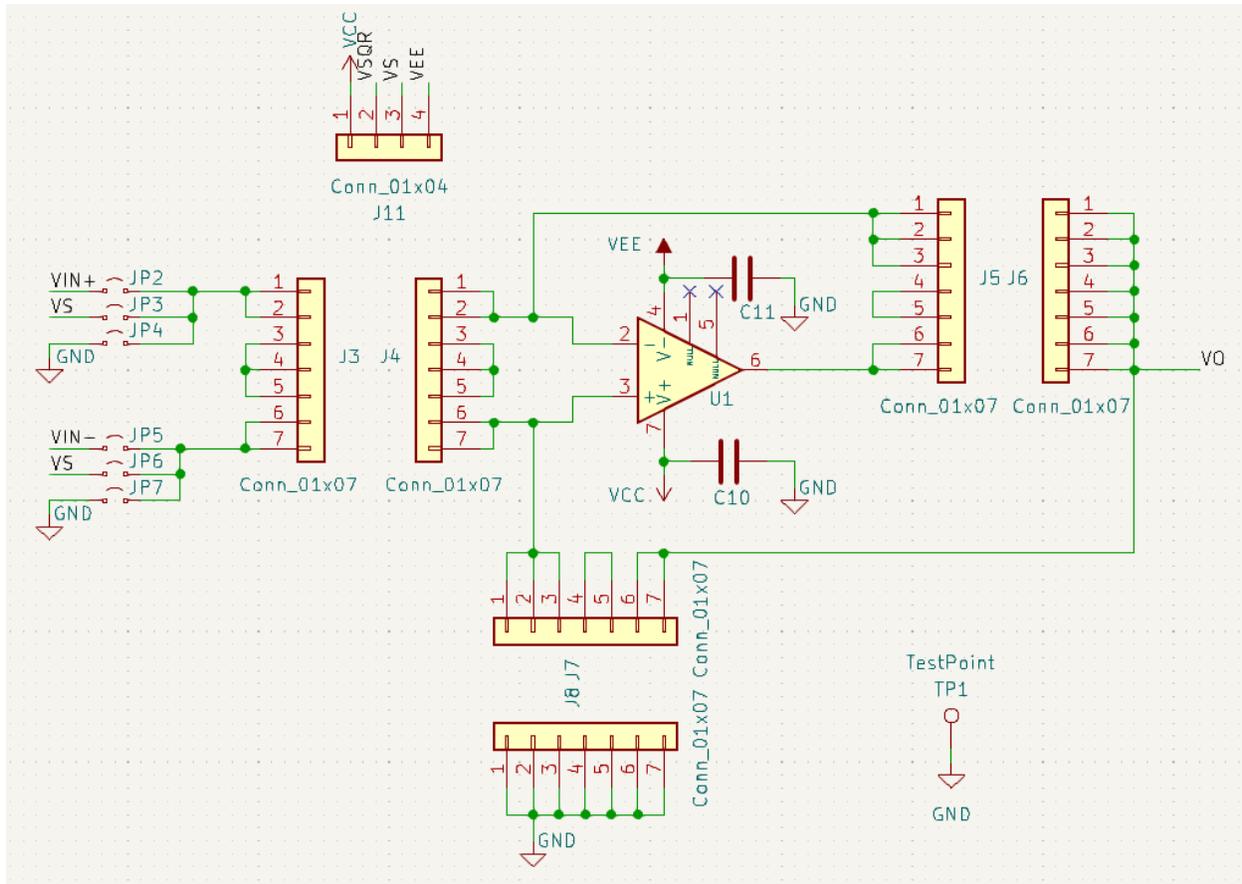
$$VS_{max} = Vin \cdot \frac{R6 + RV1}{R5 + RV1 + R6}$$

Default Signal Settings

- C6=short, R5=3.01k, RV1=1k, R6=short, C7=open, JP9=ON.
- RV1 adjusts VS for a 0 to 1.25V Square-Wave.

6.4 Op Amp Proto Area

Component headers and jumpers create a flexible and intuitive proto lab for exploring op amp circuits.



Prototyping

- Easily install components (Rs, Cs, etc.) *across or within* any Header Sockets (J3 - J8).

Input Signals

- Select VS, GND or VIN- (ext) to U1 NEG input path (JP2-4).
- Select VS, GND or VIN+ (ext) to U1 POS input path (JP5-7).

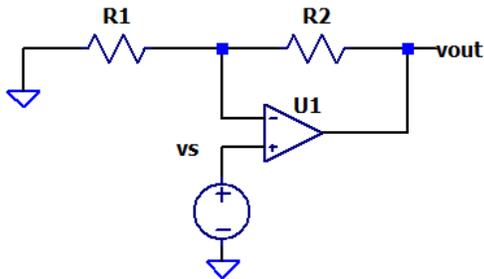
Advanced Circuits

- Connect to VCC, VSQR, VS or VEE (J11) for more advanced circuits.
- Install alternate op amps into U1 socket.
- PCB and GND plane allows for wider bandwidths than standard solderless breadboards.

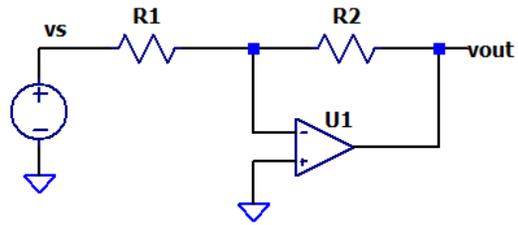
7 Op Amp Basic Circuits

- Fast prototyping of key topologies.
- Basic to advanced applications.
- More op amp circuits possible!

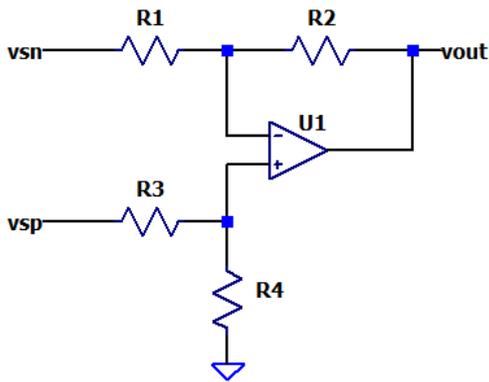
Non-Inverting



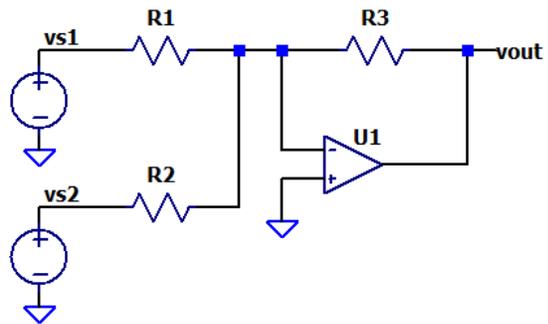
Inverting



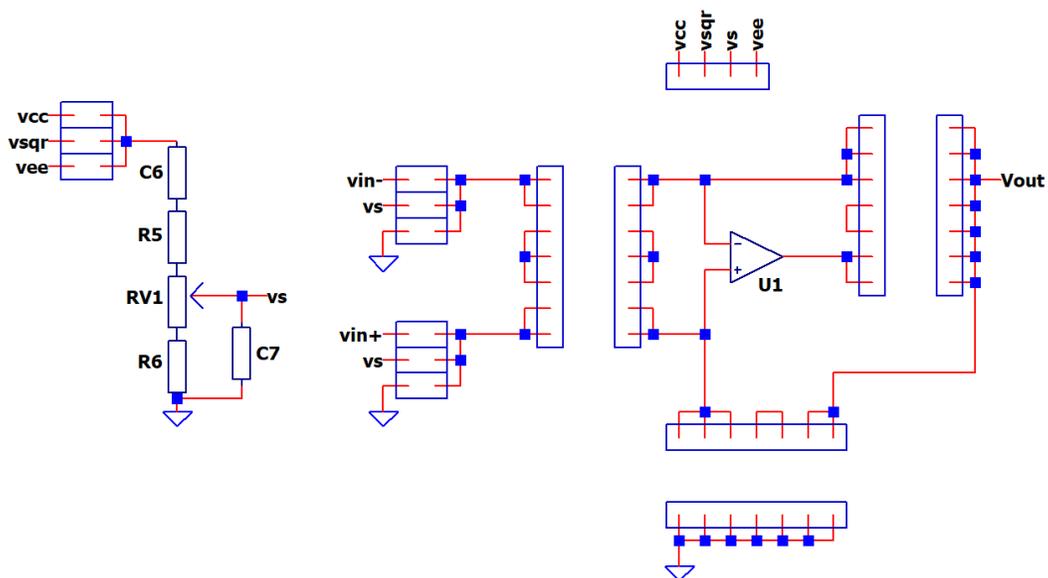
Differential



Summing



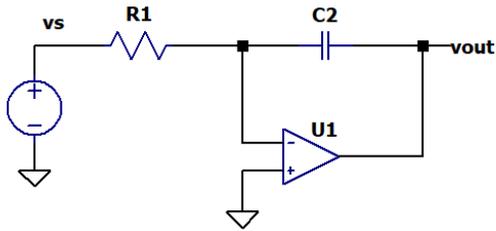
- Grab a pencil - find a way to create the circuit on the Proto Area!



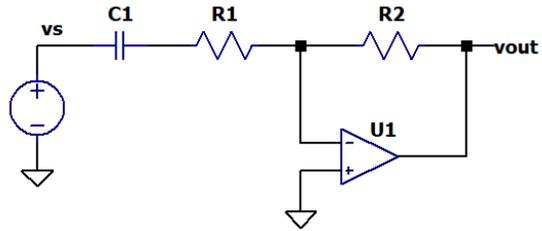
- Print out more Proto Area Schematics (Section 10).

8 Op Amp Circuits II

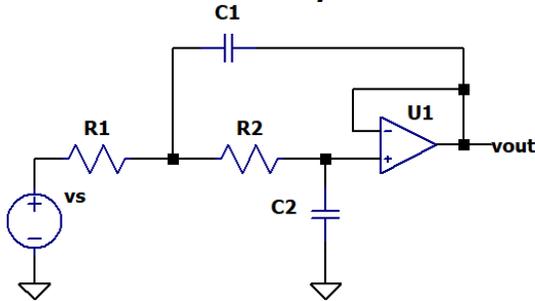
Integrator



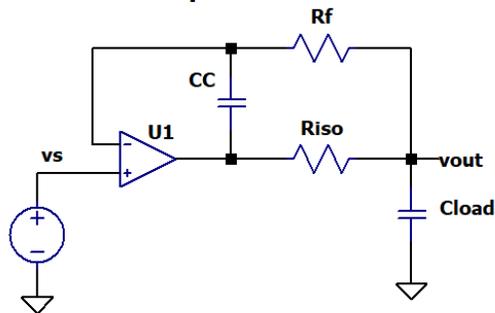
Differentiator



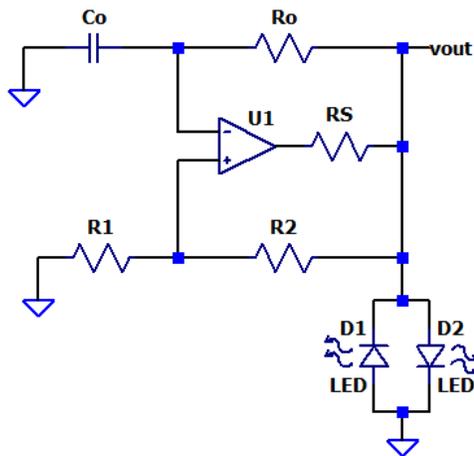
Sallen-Key Filter



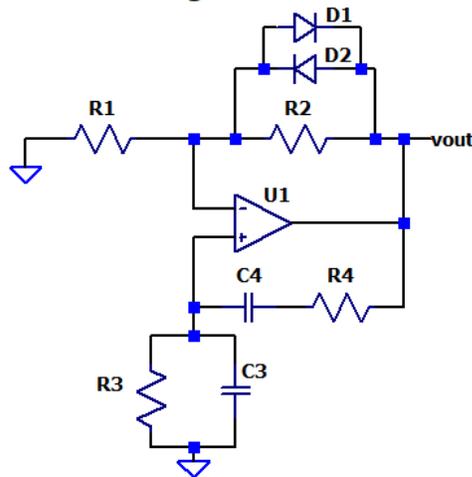
Capacitive Load



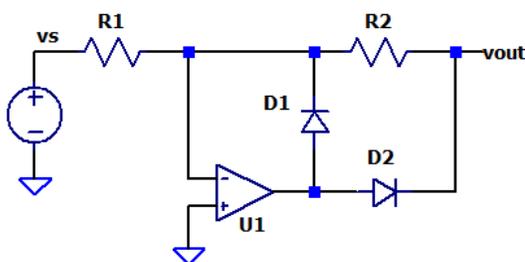
Square-Wave Oscillator



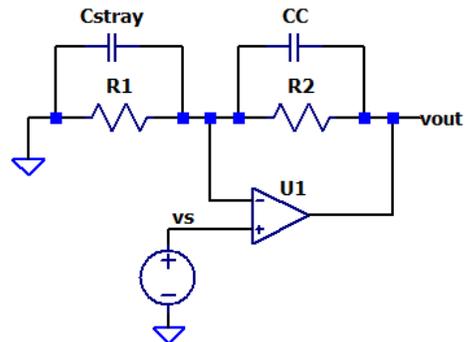
Wien-Bridge Oscillator



Precision Rectifier

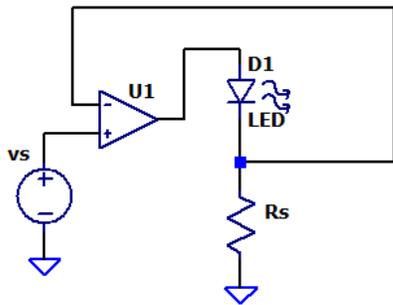


Stray Capacitance

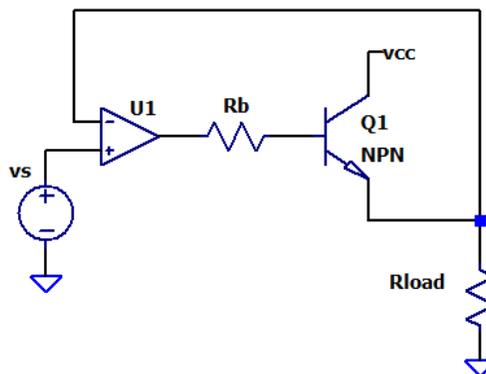


9 Op Amp Circuits III

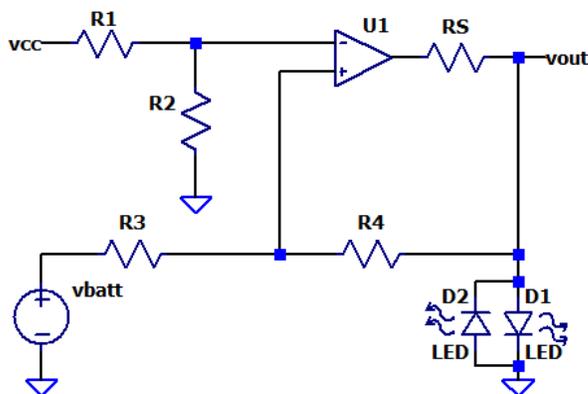
LED Current Drive



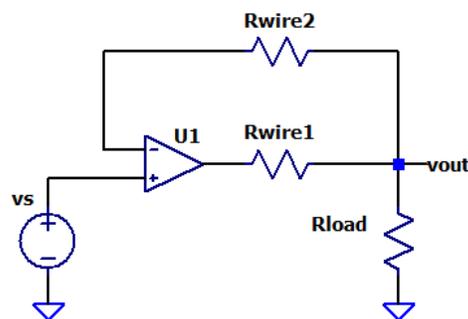
Voltage Regulator



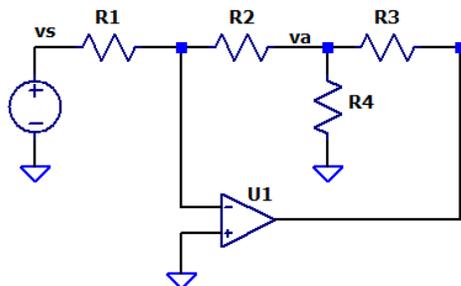
Comparator (Lo-Batt)



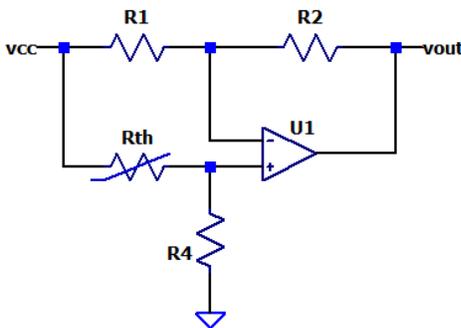
Buffer (Remote Sense)



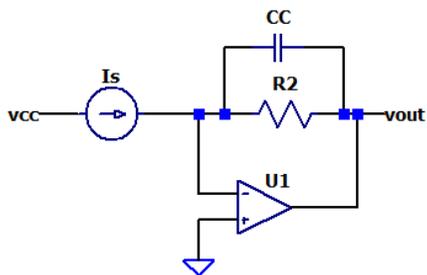
T Feedback



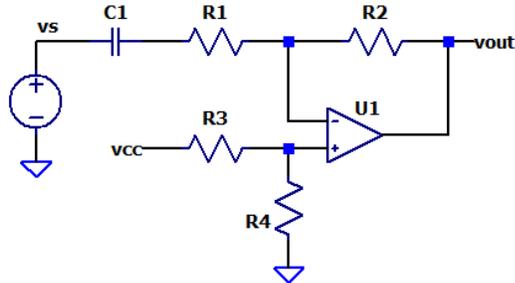
Temperature Sense



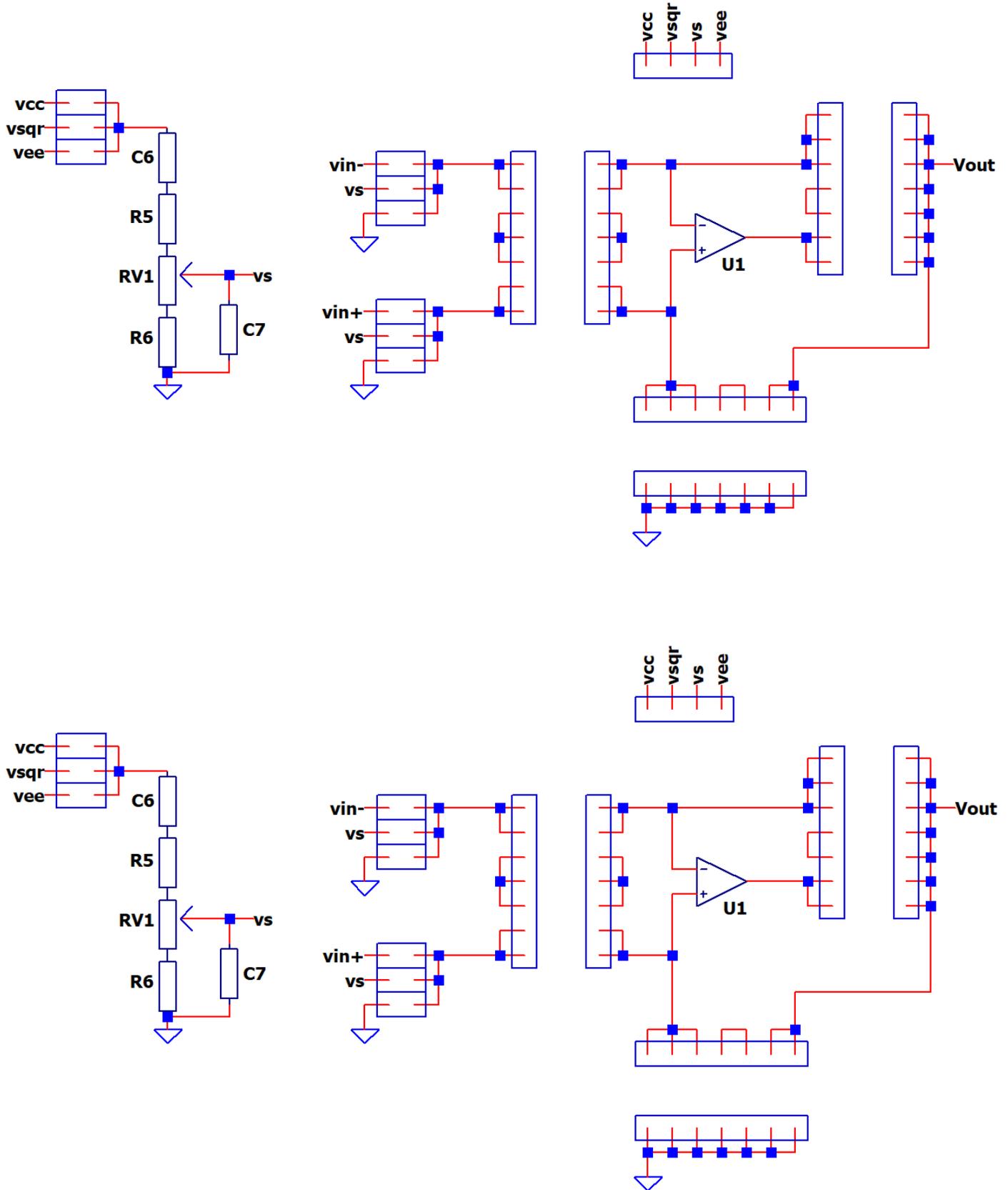
I-to-V Converter



Single Supply Amp

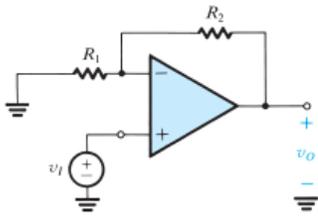


10 Proto Area Schematics



11 Non-Inverting Amp Walk-Thru

1. **Define It** – Draw Schematic, choose gains, signal levels, etc.



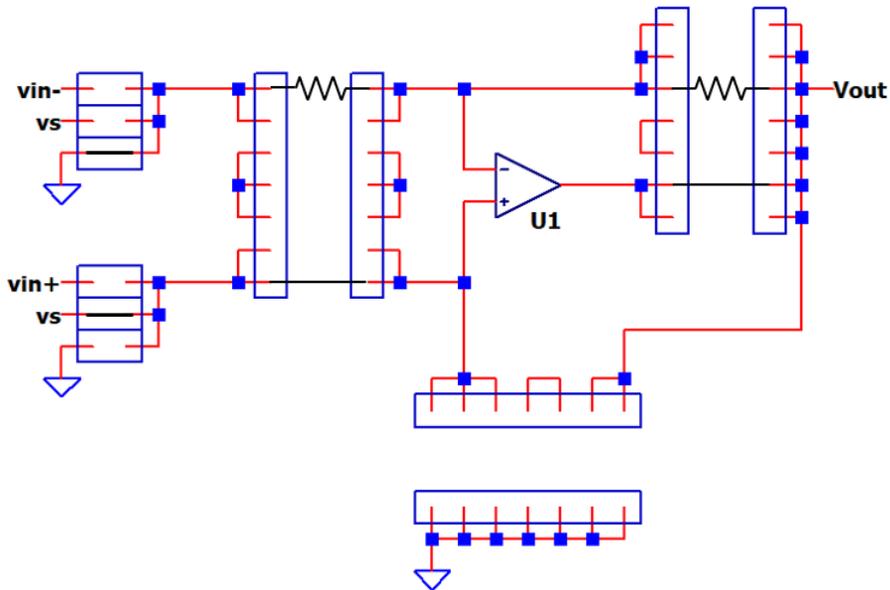
Let's amplify a signal by +3.
 $K = V_{out}/V_s = R_1/R_2 + 1 = 3$
 Choose $V_s = 0.5V$

2. **Design It** – Calculate component values, signal levels.

Choose $R_1 = 10k$,
 Calc $R_2 = (K-1) * R_1 = 20k$

$V_{out} = V_s * K$
 $= 0.5V * 3$
 $= 1.5V$

3. **Build It** - Find a way to create it (sketch circuit below, install parts on Discovery Bd.)



4. **Test & Learn It** – Plan setup, make measurements, verify levels, observe, connect to theory.

Power up the circuit (connect 9V Battery).
 Connect Probe 1 to V_S (Jumper at J3,4).
 Connect Probe 2 to V_{OUT} (R_2 at V_{out} side).
 Verify a unipolar square wave at V_S .

Adjust RV_1 for $V_s = 0.5V$ max.
 Did V_{out} achieve the goal?

Move Probe 2 to U_1 input- (R_1 at U_1 side).
 Does $U_1.in-$ follow V_S ?

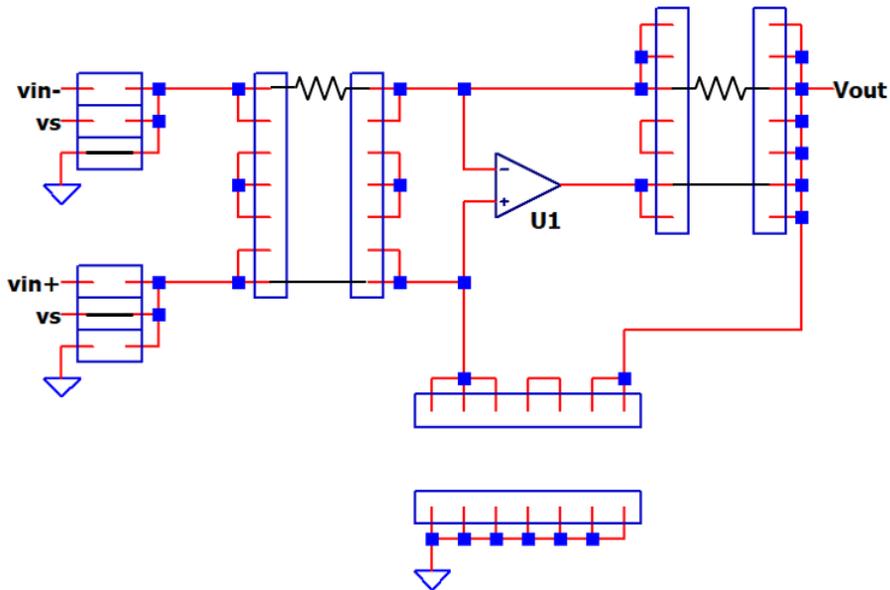
What happens if you double R_1 or R_2 ?

12 Op Amp Discovery Sheets

1. **Define It** – Draw Schematic, choose gains, signal levels, etc.

2. **Design It** – Calculate component values, signal levels.

3. **Build It** - Find a way to create it (sketch circuit below, install parts on Discovery Bd.)



4. **Test & Learn It** – Plan setup, make measurements, verify levels, observe, connect to theory.

13 Parts List

Here's the default Bill of Materials. Modify and build for your own learning goals.

Reference	Qty	Value	Part #	Comment
C1, C2	2	1uF		All caps ceramic, $\geq +25V$
C3	1	1nF		
C4, C5	2	10uF		
C6, R6	2	Short		Short wires or resistor leads.
C7, R4	2	Open		
C10, C11, C12	3	0.1uF		
D1, D2, D4	3	Diode	1N5711	
D3	1	LED Yel	LTL-4253	Any color you prefer.
J1	1	2-pin Terminal Block screw type		Optional: Solder 9V Battery Leads or Power Supply Leads directly to pads.
J2	1	3-pin Header	TSW-103-08-T-S	Optional: for external inputs.
J9	1	2-pin Header	TSW-102-08-T-S	Optional: for external output.
JP2, JP3, JP4, JP5, JP6, JP7, JP8, JP9, JP10	9	2-pin Header	TSW-102-08-T-S	3 Shunts needed typically SNT-100-BK-T
J3, J4, J5, J6, J7, J8	6	7-pin Socket Header	SSW-107-01-T-S	Sockets for circuit prototyping.
J11, J12, J13	3	4-pin Socket Header	SSW-104-01-T-S	J12,13 sockets for signal scaling components C6, R5, R6, C7.
R1, R7	2	1k		All resistors 1/4W
R2	1	3.01k		
R3	1	200k		
R5	1	3.01k		
RV1	1	1k trimpot side adjust	3352W-1-102LF	5 PCB pads available for various pin styles.
TP1	1	TestPoint	5011	
U1	1	Op Amp	LMC6081IN/NOP8	Single op amp, rail-to-rail output, +/-7.5V supply max, DIP.
U1 socket	1	DIP-8 Socket	4808-3000-CP	
U2	1	Linear Regulator	LM317LZ	
U3	1	Hex Inverters Schmidt Trigger	74HC14APF	
U3 socket	1	DIP-14 socket	4814-3000-CP	

14 Bonus Sections

14.1 Revision & Notes

Op Amp Discovery User's Guide: Rev 1c

I was looking to clear some roadblocks to the hands-on learning of op amps: *driving to a limited-hours lab, clearing a work space at home, buying expensive / bulky supplies / generators or struggling with messy circuit wiring on breadboards.*

A bit of research and brainstorming led to the idea of the Op Amp Discovery Board - *the best of both the solderless breadboard and PCB worlds.* A small board with handy component headers, PCB interconnections, supply rails and a square wave generator is where anyone could learn on their kitchen table, in the library or coffee shop.

In a short time, you can get up and running 20+ classic op amp circuits **rediscovering the fun and joy of learning about circuits**, developing understanding and intuition about their topologies and device behaviors.

Rick Faehnrich

<https://www.linkedin.com/in/rick-faehnrich-2671a911/>

14.2 Excel Op Amp Design Calculator

A handy Design and Analysis Toolkit for 20 Op Amp Circuits.

<https://ecircuitcenter.com/op-amp-discovery/op-amp-discovery.html>

1. Calculate gains, signal levels and frequencies.
2. Modify, customize for your own projects.

Enter circuit			
R1	100,000	ohms	
R2	100,000	ohms	
R3	100,000	ohms	
R4	100,000	ohms	
Enter input			
Vsp	5.000	pos input	
Vsn	4.500	neg input	
Calc Gains Pos and Neg			
Kp	1.000	R4/(R3+R4) * (R2+R1)/R1	
Kn	-1.000	-R2/R1	

14.3 Learning Styles

Dive in any way that propels your learning with Open or Guided learning (or combinations of both).

1. Explore circuits entirely on your own with *Self-Directed Learning*.
2. Follow *Guided Examples of circuits to observe op amp functions and behaviors.*
3. Borrow ideas from circuit examples and follow-through on your own.

14.4 DMM Only Learning (No Scope)

A Digital Multi-Meter (DMM) serves a low cost alternative to an oscilloscope. Budget DMMs are available from \$10 and up. See the Guided Examples document for tips on getting the most from a DMM.

14.5 Circuit Options

External Inputs / Outputs

- Install header pins J2 (input) and J9 (output).
- Install 2-pin shunts at JP2 or JP5.

External Power Supplies

- Un-install U2, R1, C2, R7, C5, D2
- Connect external supplies to PCB plated holes labeled VCC, GND and VEE.

Linear Regulator and Square-Wave Oscillator

- Modify regulator voltage output or oscillator frequency.
- Use the Excel Design Calculator.

14.6 KiCAD Software

KiCad is a free and open-source software suite that provides a complete EDA toolset including schematic capture, PCB layout, 3D visualization, and circuit simulation.

<https://www.kicad.org/>

14.7 GitHub

The Op Amp Discovery Bd is an open-source project intended to make op amp learning as accessible and affordable as possible. You can download the documentation and KiCAD project files at <https://github.com/rick-ecircuit>

14.8 Experimenters Parts List

Here's a suggested selection of parts to explore the circuits.

Reference	Qty	Value
Resistors	3 each	100, 1k, 3.3k 10k, 20k, 33k, 39k, 47k 100k, 200k, 330k, 390k, 470k 1M, 4.7M
Capacitors	2 each	100pF, 1nF, 10nF, 100nF, 1uF
Seniconductors	2 each	BJT 2N3904 Diode 1N5711
LEDs	2 each	RED, GRN
Sensors	1 each	Thermistor 10k Photodiode
Jumpers	10 each	Use cut resistor leads

14.9 Feedback eCircuitCenter

Feedback on eCircuit Center

- ✓ How is Op Amp Discovery helpful for you?
- ✓ What circuits could be added?
- ✓ What needs clarity?

Send your thoughts on the feedback form at eCircuit Center.

<https://ecircuitcenter.com/op-amp-discovery/form/feedback1.html>

eCircuit Center strives to provide informal, hands-on and fun experiences that lead to a deeper, more intuitive understanding of circuit design and analysis.

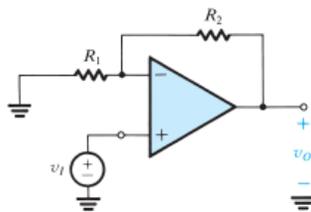
14.10 Advanced Topics

The Discovery Board allows learning of advanced characteristics and limitations!

- Bandwidth
- Slew-Rate
- Stability
- Voltage / Current Limits
- Linear Regulator and Capacitive Charge Pump
- Heat (Thermal) Management
- RC Oscillators

14.11 The Power of Play

- Key to analog success: *play, play, play with circuits!*



- Analog circuits appear more inviting (and less intimidating) when playing and tinkering.
- Learning and passion grow when you
 - Ask “what if” questions
 - Play with component values - *Predict the outcome!*
 - Small discoveries and learning fuel motivation and the joy of learning.