

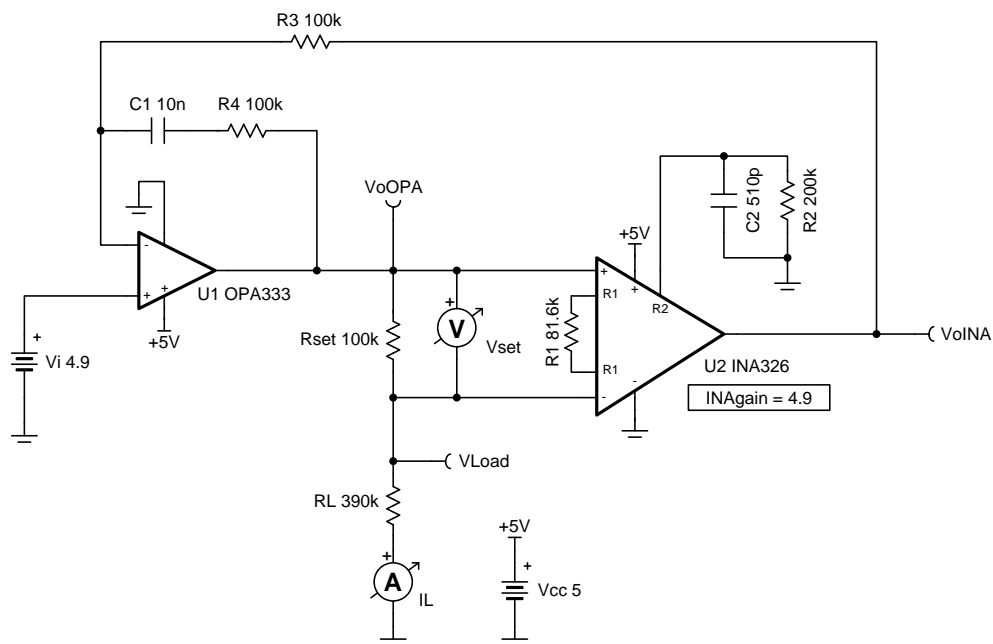
Low-level voltage-to-current converter circuit

Design Goals

Input		Output		Supply		Load Resistance (R_L)	
V_{iMin}	V_{iMax}	I_{LMin}	I_{LMax}	V_{cc}	V_{ee}	R_{LMin}	R_{LMax}
0.49V	4.9V	1 μ A	10 μ A	5V	0V	0 Ω	390k Ω

Design Description

This circuit delivers a precise low-level current, I_L , to a load, R_L . The design operates on a single 5-V supply and uses one precision low-drift op amp and one instrumentation amplifier. Simple modifications can change the range and accuracy of the voltage-to-current (V-I) converter.



Design Notes

1. Voltage compliance is dominated by op amp linear output swing (see data sheet A_{OL} test conditions) and instrumentation amplifier linear output swing. See the [Common-Mode Input Range Calculator for Instrumentation Amplifiers](#) for more information.
2. Voltage compliance, along with R_{LMin} , R_{LMax} , and R_{set} bound the I_L range.
3. Check op amp and instrumentation amplifier input common-mode voltage range.
4. Stability analysis must be done to choose R_4 and C_1 for stable operation.
5. Loop stability analysis to select R_4 and C_1 will be different for each design. The compensation shown is only valid for the resistive load ranges used in this design. Other types of loads, op amps, or instrumentation amplifiers, or both will require different compensation. See the **Design References** section for more op amp stability resources.

Design Steps

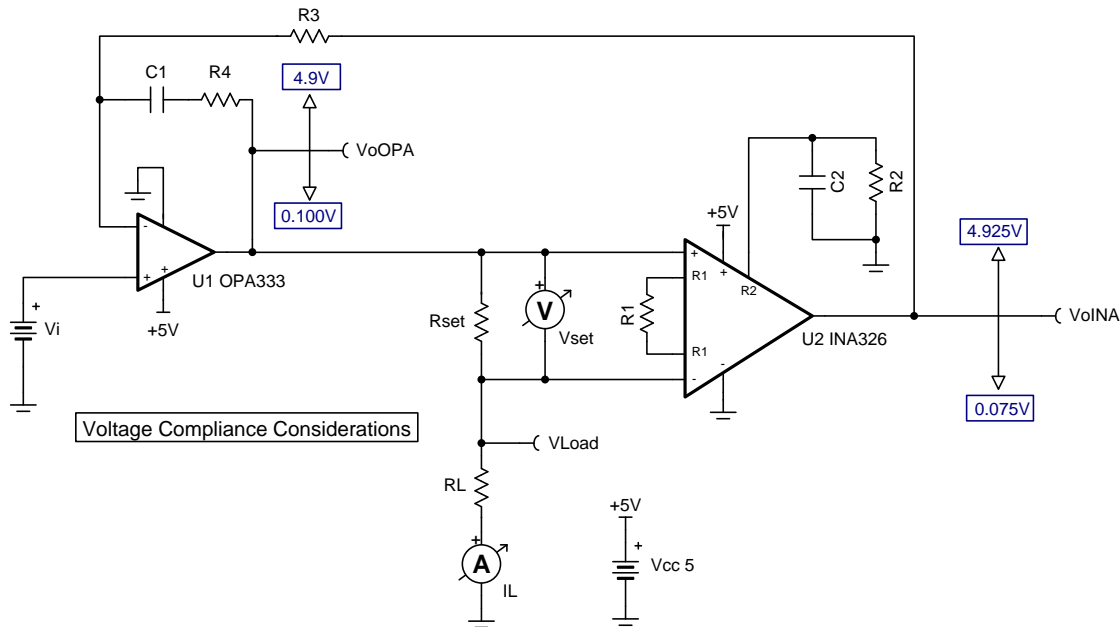
1. Select R_{set} and check I_{LMin} based on voltage compliance.

$$I_{LMax} = \frac{V_{oOPAMax}}{R_{set} + R_{LMax}}$$

$$10\mu A = \frac{4.9V}{R_{set} + 390k\Omega} \rightarrow R_{set} = 100k\Omega$$

$$I_{LMin} = \frac{V_{oOPAMin}}{R_{set} + R_{LMin}}$$

$$I_{LMin} = \frac{0.1V}{100k\Omega + 0\Omega} = 1\mu A$$



2. Compute instrumentation amplifier gain, G .

$$V_{setMin} = I_{LMin} \times R_{set} = 1\mu A \times 100k\Omega = 0.1V$$

$$V_{setMax} = I_{LMax} \times R_{set} = 10\mu A \times 100k\Omega = 1V$$

$$G = \frac{V_{iMax} - V_{iMin}}{V_{setMax} - V_{setMin}}$$

$$G = \frac{4.9V - 0.49V}{1V - 0.1V} = 4.9$$

3. Choose R_1 for INA326 instrumentation amplifier gain, G . Use data sheet recommended $R_2 = 200k\Omega$ and $C_2 = 510pF$.

$$G = 2 \times \left(\frac{R_2}{R_1} \right)$$

$$R_1 = \frac{2 \times R_2}{G}$$

$$R_1 = \left(\frac{2 \times 200k\Omega}{4.9} \right) = 81.6327k\Omega \approx 81.6k\Omega$$

4. The final transfer function of the circuit follows:

$$I_L = \frac{V_i}{G \times R_{set}}$$

$$I_L = \frac{V_i}{4.9 \times 100k\Omega} = \frac{V_i}{490k\Omega}$$

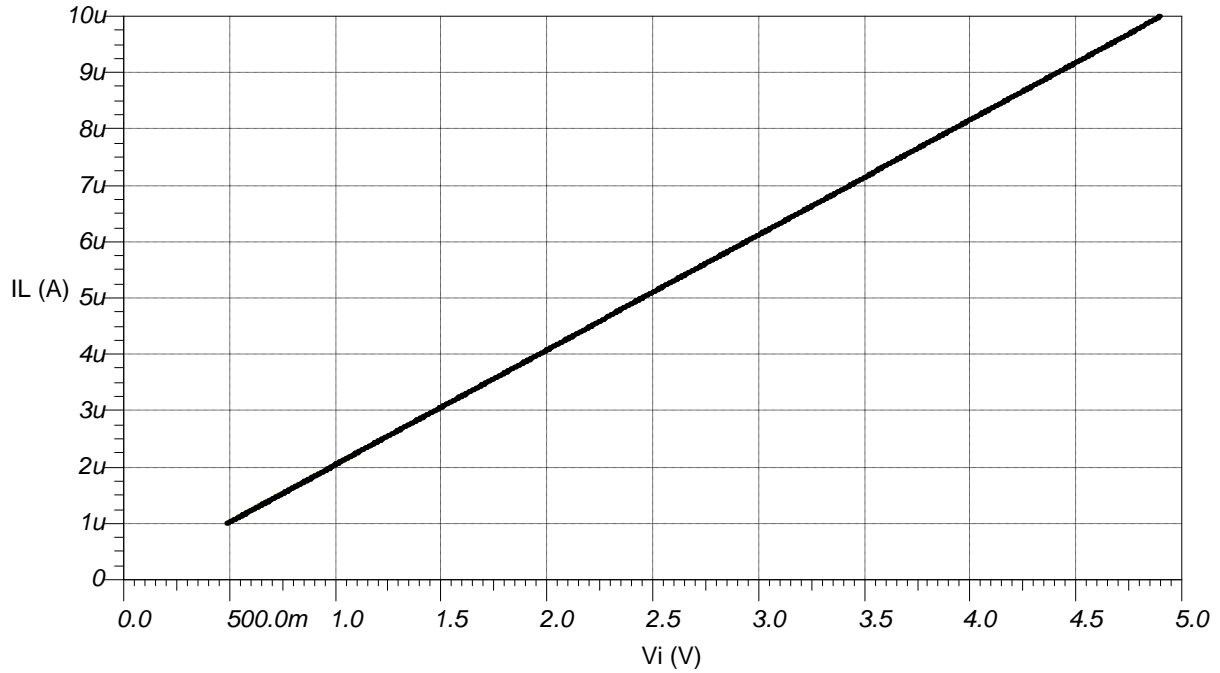
$$V_i = 0.49V \rightarrow I_L = 1\mu A$$

$$V_i = 4.9V \rightarrow I_L = 10\mu A$$

Design Simulations

DC Simulation Results

V_i	R_L	I_L	V_{oOPA}	V_{oOPA} Compliance	V_{oINA}	V_{oINA} Compliance
0.49V	0 Ω	0.999627 μ A	99.982723mV	100mV to 4.9V	490.013346mV	75mV to 4.925V
0.49V	390k Ω	0.999627 μ A	489.837228mV	100mV to 4.9V	490.013233mV	75mV to 4.925V
4.9V	0 Ω	9.996034 μ A	999.623352mV	100mV to 4.9V	4.900016V	75mV to 4.925V
4.9V	390k Ω	9.996031 μ A	4.898075V	100mV to 4.9V	4.900015V	75mV to 4.925V



Design References

See [Analog Engineer's Circuit Cookbooks](#) for TI's comprehensive circuit library.

See the TINA-TI™ circuit simulation file, [SBOMAT8](#).

See TIPD107, <http://www.ti.com/tool/TIPD107>.

See [Solving Op Amp Stability Issues - E2E FAQ](#).

See [TI Precision Labs - Op Amps](#).

Design Featured Op Amp

OPA333	
V_{SS}	1.8V to 5.5V
V_{inCM}	Rail-to-rail
V_{out}	Rail-to-rail
V_{os}	2 μ V
I_q	17 μ A/Ch
I_b	70pA
UGBW	350kHz
SR	0.16V/ μ s
#Channels	1,2
http://www.ti.com/product/opa333	

Design Featured Instrumentation Amplifier

INA326	
V_{SS}	2.7V to 5.5V
V_{inCM}	Rail-to-rail
V_{out}	Rail-to-rail
V_{os}	20 μ V
I_q	2.4mA
I_b	0.2nA
UGBW	1kHz (set by 1kHz filter)
SR	0.012V/ μ s (set by 1kHz filter)
#Channels	1
http://www.ti.com/product/INA326	

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATA SHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES "AS IS" AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to [TI's Terms of Sale](#) or other applicable terms available either on [ti.com](#) or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products.

TI objects to and rejects any additional or different terms you may have proposed.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2021, Texas Instruments Incorporated