Analog Engineer's Circuit

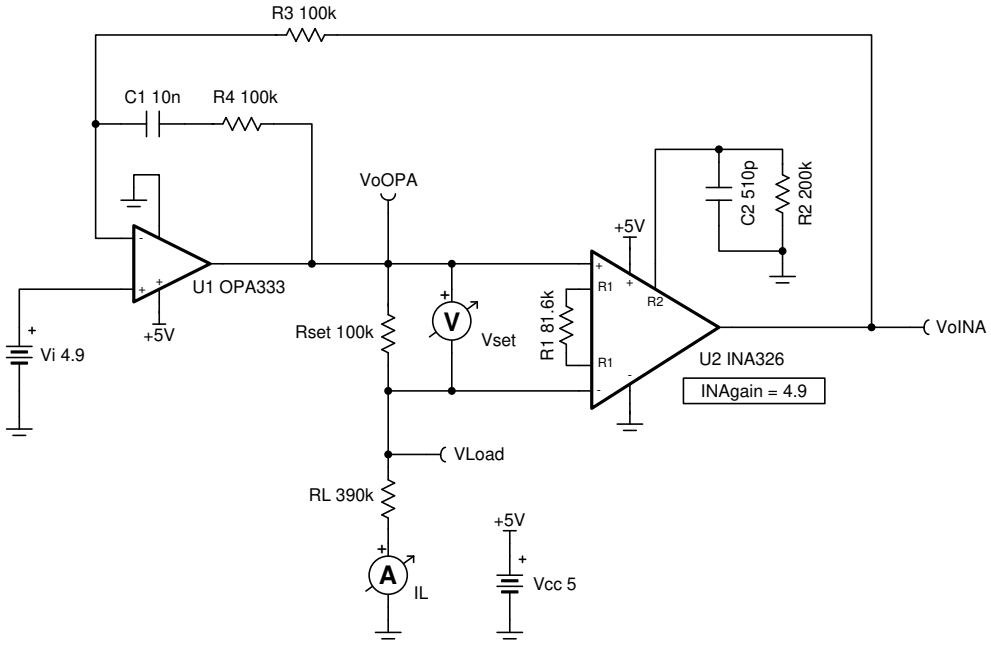
Low-Level Voltage-to-Current Converter Circuit

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}
0.49 V	4.9 V	1 µA	10 µA	5 V	0 V	0 Ω	390 kΩ

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

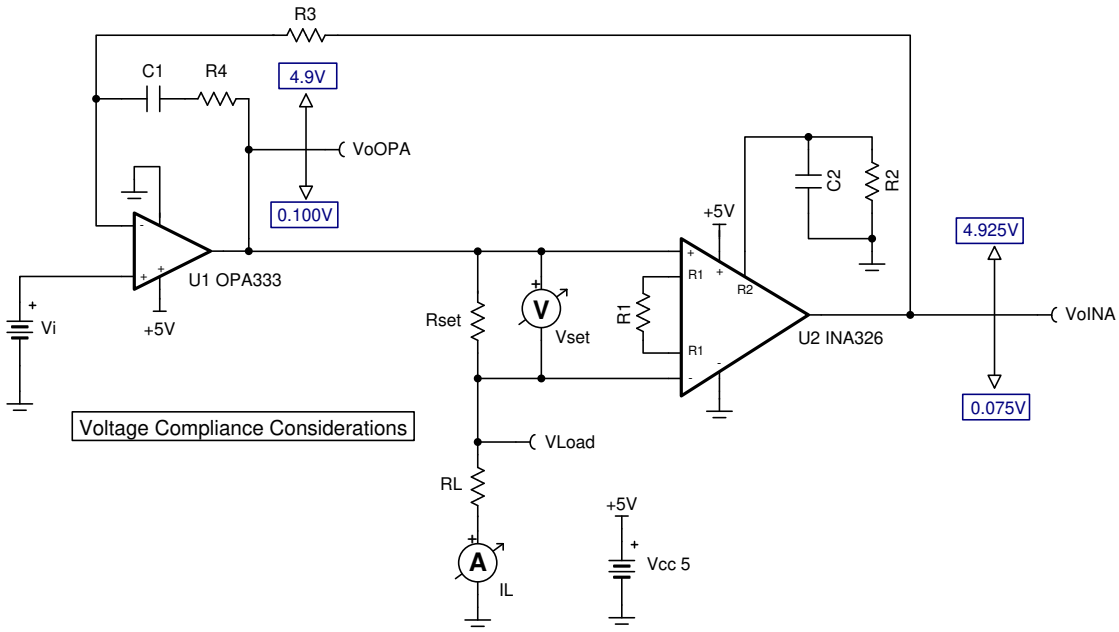
1. Select R_{set} and check I_{LMin} based on voltage compliance.

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

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

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

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



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 = 200 kΩ and C_2 = 510 pF.

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

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

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

4. The final transfer function of the circuit follows:

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

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

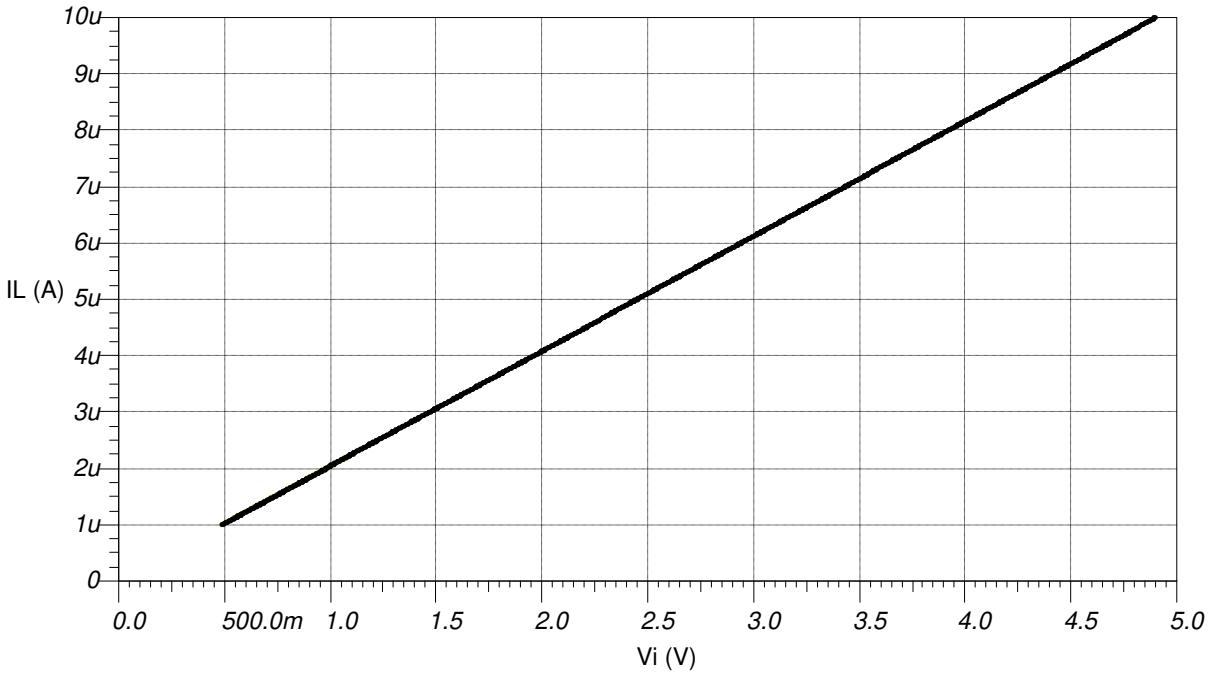
$$V_i = 0.49V \rightarrow I_L = 1\mu A$$

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

Design Simulations

DC Simulation Results

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



Design References

See *Analog Engineer's Circuit Cookbooks* for TI's comprehensive circuit library.

See the TINA-TI™ circuit simulation file, SBOMAT8.

See TIPD107.

See Solving Op Amp Stability Issues - E2E FAQ.

See TI Precision Labs - Op Amps.

Design Featured Op Amp

OPA333	
V_{ss}	1.8 V to 5.5 V
V_{inCM}	Rail-to-rail
V_{out}	Rail-to-rail
V_{os}	2 µV
I_q	17 µA/Ch
I_b	70 pA
UGBW	350 kHz
SR	0.16 V/µs
#Channels	1 and 2
OPA333	

Design Featured Instrumentation Amplifier

INA326	
V_{ss}	2.7 V to 5.5 V
V_{inCM}	Rail-to-rail
V_{out}	Rail-to-rail
V_{os}	20 µV
I_q	2.4 mA
I_b	0.2 nA
UGBW	1 kHz (set by 1 kHz filter)
SR	0.012 V/µs (set by 1 kHz filter)
#Channels	1
INA326	

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