Analog Engineer's Circuit
Low-Level Voltage-to-Current Converter Circuit

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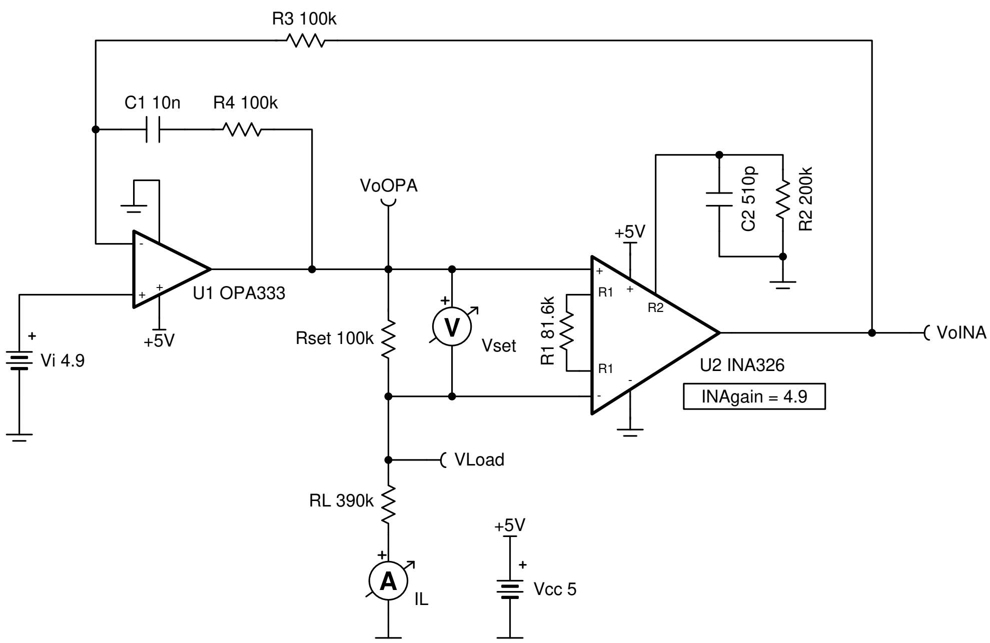
Design Goals

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	1µA	10µA	5V	0V	0Ω	390kΩ

Design Description

This circuit delivers a precise low-level current, I_L, to a load, R_L. The design operates on a single 5V 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 *Analog engineer's calculator* 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 are 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

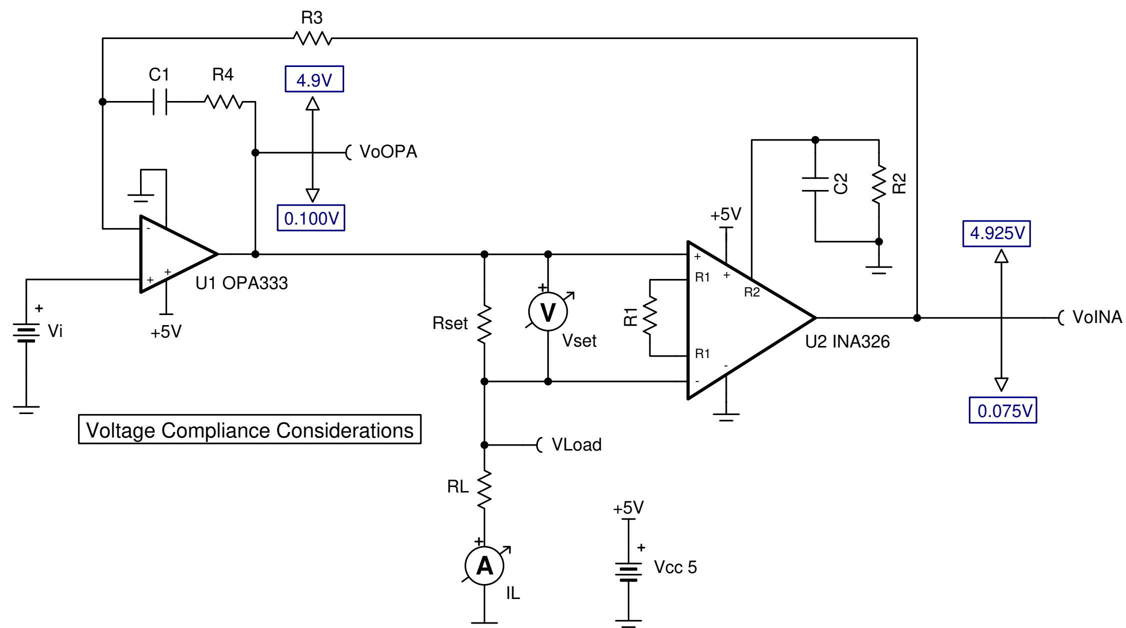
1. Select R_{set} and check I_{LMin} based on voltage compliance.

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

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

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

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



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 = 200kΩ 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:

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

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

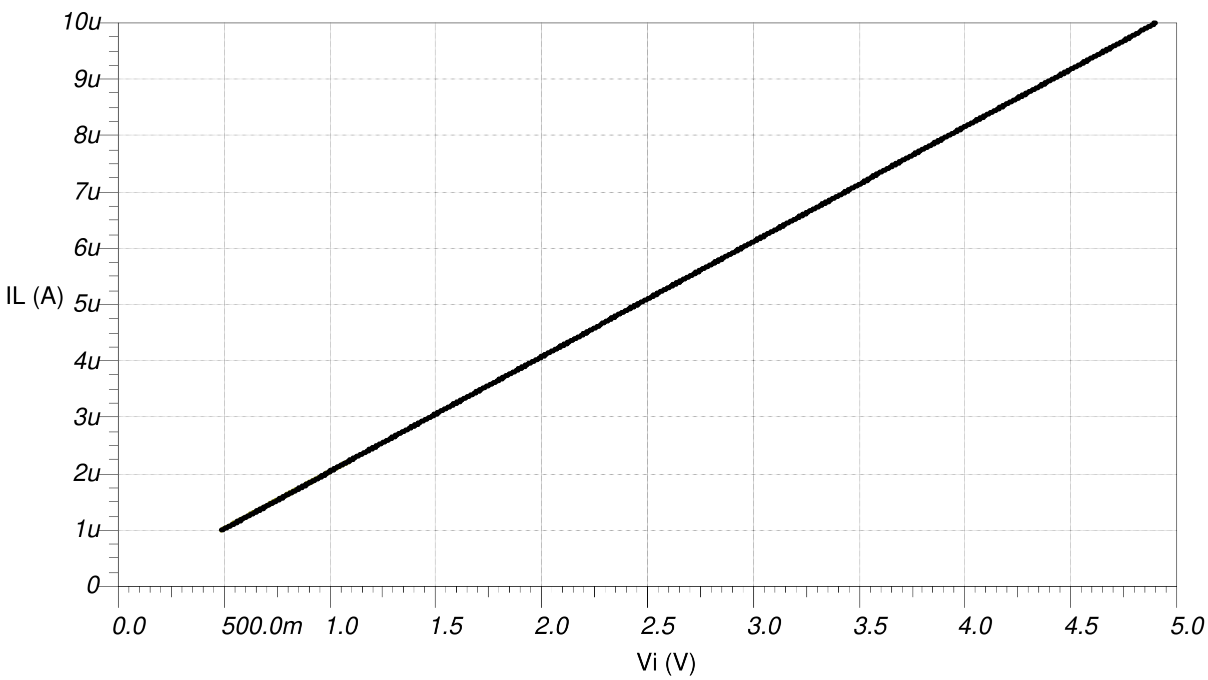
$$V_i = 0.49V \rightarrow I_L = 1\mu A$$

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

Design Simulations

DC Simulation Results

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



Design References

Texas Instruments, *SBOMAT8 TINA-TI™ circuit simulation*, file download

Texas Instruments, *Low-Level V-to-I Converter Reference Design, 0V to 5V Input and 0µA to 5µA Output*, product page

Texas Instruments, *Solving Op Amp Stability Issues*, E2E™ amplifiers forum

Design Featured Op Amp

OPA333	
V_{ss}	1.8V to 5.5V
V_{inCM}	Rail-to-rail
V_{out}	Rail-to-rail
V_{os}	2µV
I_q	17µA/Ch
I_b	70pA
UGBW	350kHz
SR	0.16V/µs
#Channels	1 and 2
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}	20µV
I_q	2.4mA
I_b	0.2nA
UGBW	1kHz (set by 1kHz filter)
SR	0.012V/µs (set by 1kHz filter)
#Channels	1
INA326	

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