Low-Level Voltage-to-Current Converter Circuit



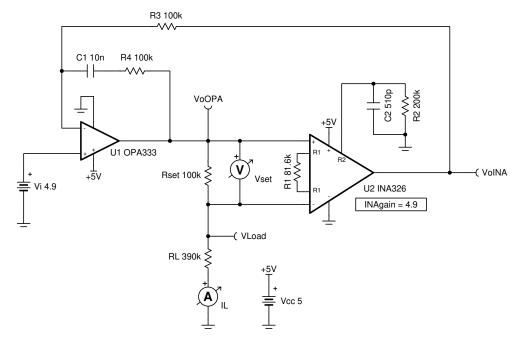
Masashi Miyagawa

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	10μΑ	5V	0V	Ω0	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

- 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 R₄ and C₁ for stable operation.
- 5. Loop stability analysis to select R₄ and C₁ 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

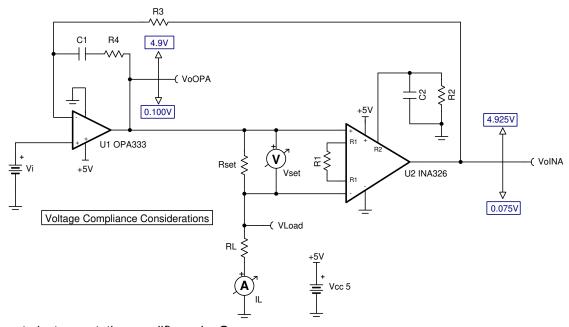
1. Select R_{set} and check I_{LMin} based on voltage compliance.

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

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

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

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



2. Compute instrumentation amplifier gain, G.

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

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

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

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

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

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

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

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



4. The final transfer function of the circuit follows:

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

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

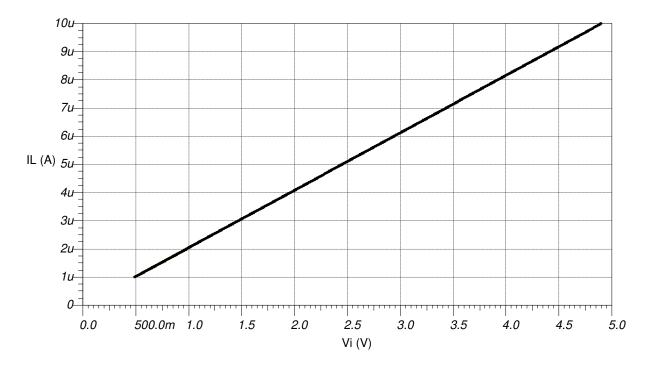
$$V_i = 0.49V \rightarrow I_L = 1\mu A$$

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

Design Simulations

DC Simulation Results

Vi	R _L	IL	V _{oOPA}	V _{oOPA} Compliance	V _{oINA}	V _{olNA} Compliance
0.49V	Ω0	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, E2ETM amplifiers forum

Trademarks Superior Instruments

Www.ti.com

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		
Iq	17μA/Ch		
I _b	70pA		
UGBW	350kHz		
SR	0.16V/µs		
#Channels	1 and 2		
OPA333			

Design Featured Instrumentation Amplifier

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

Trademarks

All trademarks are the property of their respective owners.

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 © 2024, Texas Instruments Incorporated