

Analog Engineer's Circuit

3-Decade, Load-Current Sensing Circuit

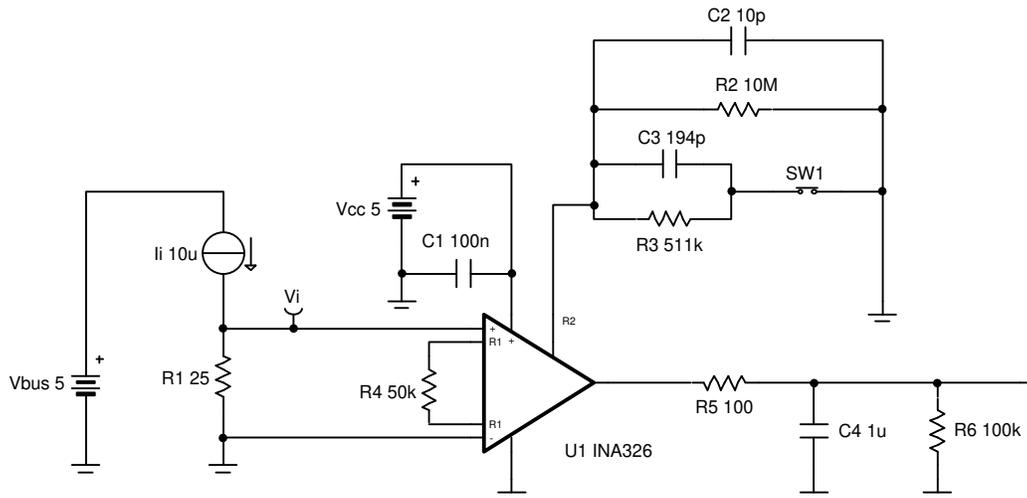


Design Goals

Input		Output		Supply		
I_{iMin}	I_{iMax}	V_{oMin}	V_{oMax}	V_{cc}	V_{ee}	V_{ref}
10 μ A	10 mA	100 mV	4.9 V	5.0 V	0 V	0 V

Design Description

This single-supply, low-side, current-sensing solution accurately detects load current between 10 μ A and 10 mA. A unique yet simple gain switching network was implemented to accurately measure the three-decade load current range.



Design Notes

1. Use a maximum shunt resistance to minimize relative error at minimum load current.
2. Select 0.1% tolerance resistors for R_1 , R_2 , R_3 , and R_4 in order to achieve approximately 0.1% FSR gain error.
3. Use a switch with low on-resistance (R_{on}) to minimize interaction with feedback resistances, preserving gain accuracy.
4. Minimize capacitance on INA326 gain setting pins.
5. Scale the linear output swing based on the gain error specification.

Design Steps

1. Define full-scale shunt resistance.

$$R_1 = \frac{V_{iMax}}{I_{iMax}} = \frac{250mV}{10mA} = 25\Omega$$

2. Select gain resistors to set output range.

$$G_{IiMax} = \frac{V_{oMax}}{V_{iMax}} = \frac{V_{oMax}}{R_1 \times I_{iMax}} = \frac{4.9V}{25\Omega \times 10mA} = 19.6 \frac{V}{V}$$

$$G_{IiMin} = \frac{V_{oMin}}{V_{iMin}} = \frac{V_{oMin}}{R_1 \times I_{iMin}} = \frac{100mV}{25\Omega \times 10\mu A} = 400 \frac{V}{V}$$

$$R_2 = \frac{R_4 \times G_{IiMin}}{2} = \frac{50k\Omega \times 400 \frac{V}{V}}{2} = 10M\Omega$$

$$R_2 \parallel R_3 = \frac{R_4 \times G_{IiMax}}{2} = \frac{50k\Omega \times 19.6 \frac{V}{V}}{2} = 490k\Omega$$

$$R_3 = \frac{490k\Omega \times R_2}{R_2 - 490k\Omega} = 515.25k\Omega \approx 511k\Omega \text{ (Standard Value)}$$

3. Select a capacitor for the output filter.

$$f_p = \frac{1}{2 \times \pi \times R_5 \times C_4} = \frac{1}{2 \times \pi \times 100\Omega \times 1 \mu F} = 1.59kHz$$

4. Select a capacitor for gain and filtering network.

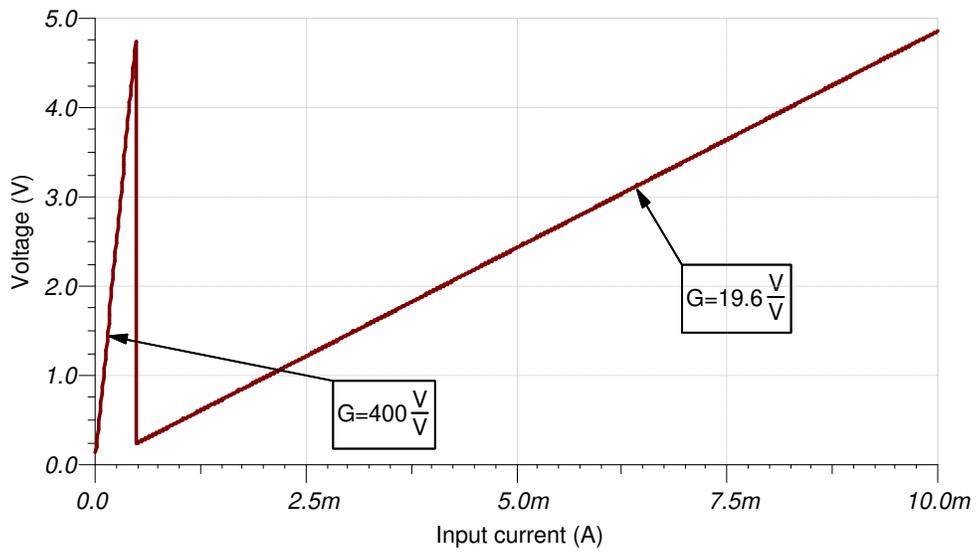
$$C_2 = \frac{1}{2 \times \pi \times R_2 \times f_p} = \frac{1}{2 \times \pi \times 10M\Omega \times 1.59kHz} = 10pF$$

$$C_3 = \frac{1}{2 \times \pi \times (R_2 \parallel R_3) \times f_p} - C_2 = \frac{1}{2 \times \pi \times (10M\Omega \parallel 511k\Omega) \times 1.59kHz} - 10pF$$

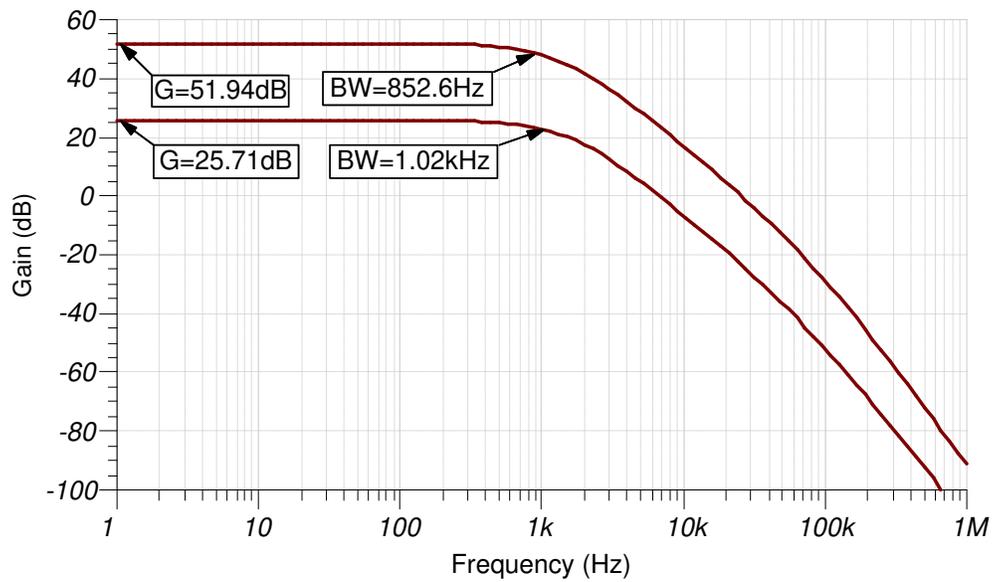
$$C_3 = 196pF \approx 194pF \text{ (Standard Value)}$$

Design Simulations

DC Simulation Results



AC Simulation Results



Design References

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

See circuit SPICE simulation file [SBOC498](#).

See TIPD104, [Current Sensing Solution, 10 \$\mu\$ A-10 mA, Low-Side, Single Supply](#).

Design Featured Op Amp

INA326	
V_{SS}	1.8 V to 5.5 V
V_{inCM}	Rail-to-rail
V_{out}	Rail-to-rail
V_{os}	0.1 mV
I_q	3.4 mA
I_b	2 nA
UGBW	1 kHz
SR	Filter limited
#Channels	1
INA326	

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from January 28, 2018 to February 1, 2019

Page

- Downscale the title and changed title role to 'Amplifiers'. Added link to circuit cookbook landing page.....1
-

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](https://www.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 © 2023, Texas Instruments Incorporated