

Analog Engineer's Circuit Amplifiers

Discrete Wide Bandwidth INA Circuit

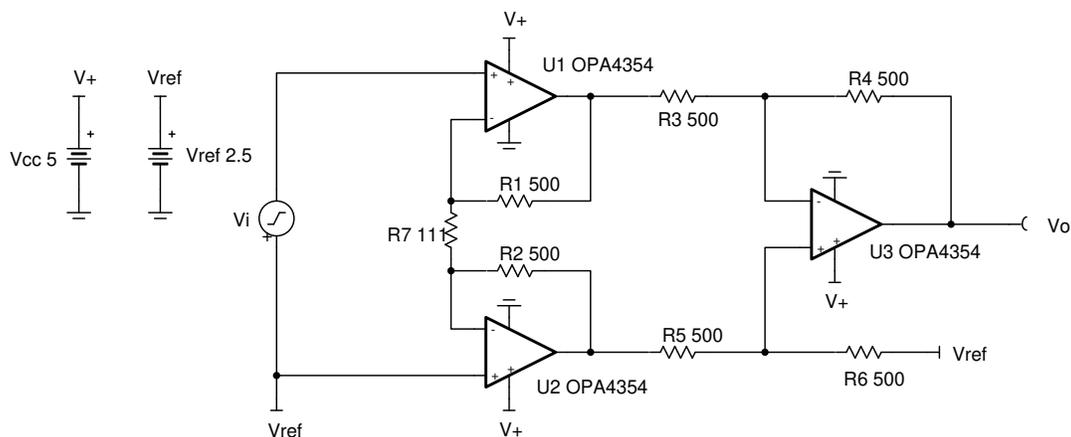


Design Goals

Input		Output		Bandwidth	Supply		
V_{iMin}	V_{iMax}	V_{oMin}	V_{oMax}	BW	V_{cc}	V_{ee}	V_{ref}
-0.24V	+0.24V	+0.1V	+4.9V	10MHz	+2.5V	0V	2.5V

Design Description

This design uses 3 op-amps to build a discrete wide bandwidth instrumentation amplifier. The circuit converts a differential, high frequency signal to a single-ended output.



Design Notes

1. Reduce the capacitance on the output of each op amp to avoid stability issues.
2. Use low gain configurations to maximize the bandwidth of the circuit.
3. Use precision resistors to achieve high DC CMRR performance.
4. Use small resistors in op-amp feedback to maintain stability.
5. Set the reference voltage, V_{ref} , at mid-supply to allow the output to swing to both supply rails.
6. Phase margin of 45° or greater is required for stable operation.
7. R_7 sets the gain of the instrumentation amplifier.
8. Linear operation depends upon the input common-mode and the output swing ranges of the discrete op amps used. The linear output swing ranges are specified under the A_{oI} test conditions in the op amps datasheets.
9. V_{ref} also sets the common-mode voltage of the input, V_i , to ensure linear operation.

Design Steps

1. The transfer function of the circuit is given below.

$$V_o = V_i \times \left(1 + \frac{2 \times R_1}{R_7}\right) \times \left(\frac{R_6}{R_5}\right)$$

where V_i is the differential input voltage

V_{ref} is the reference voltage provided to the amplifier

$$Gain = \left(1 + \frac{2 \times R_1}{R_7}\right) \times \left(\frac{R_6}{R_5}\right)$$

2. To maximize the usable bandwidth of design, set the gain of the diff amp stage to 1V/V. Use smaller value resistors to minimize noise.

Choose $R_3 = R_4 = R_5 = R_6 = 500 \Omega$ (Standard value)

3. Choose values for resistors R_1 and R_2 . Keep these values low to minimize noise.

$R_1 = R_2 = 500 \Omega$ (Standard value)

4. Calculate resistor R_7 to set the gain of the circuit to 10V/V

$$G = \left(1 + \frac{2 \times R_1}{R_7}\right) = 10 \frac{V}{V} \rightarrow \frac{2 \times 500 \Omega}{R_7} = 9 \frac{V}{V}$$

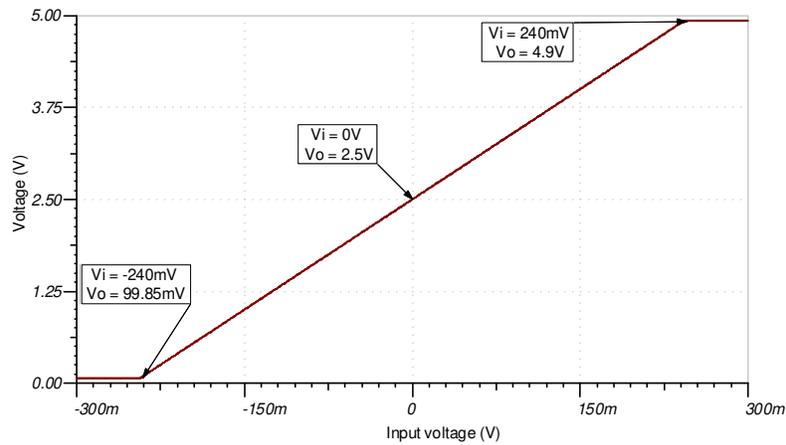
$$R_7 = \frac{1000 \Omega}{9 \frac{V}{V}} = 111.11 \Omega \rightarrow R_7 = 111 \Omega \text{ (Standard Value)}$$

5. Calculate the reference voltage to bias the input to mid-supply. This will maximize the linear output swing of the instrumentation amplifier. See References for more information on the linear operating region of instrumentation amplifiers.

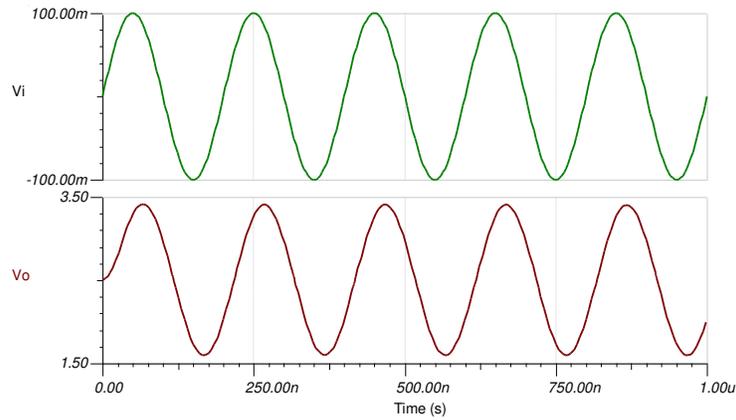
$$V_{ref} = \frac{V_s}{2} = \frac{5 V}{2} = 2.5 V$$

Design Simulations

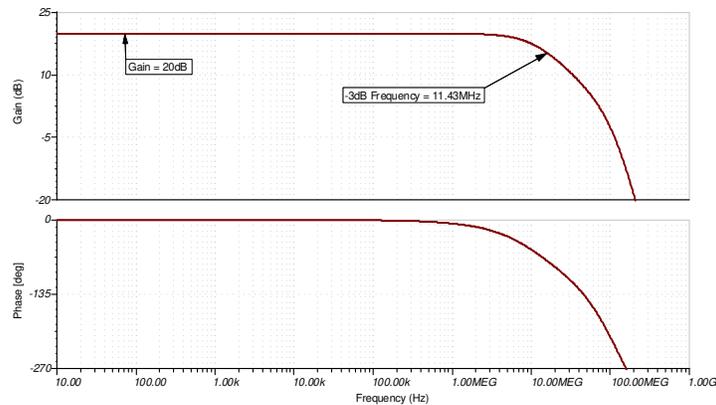
DC Simulation Results



Transient Simulation Results



AC Simulation Results



References

1. [Analog Engineer's Circuit Cookbooks](#)
2. SPICE Simulation File [SBOMAU6](#)
3. [TI Precision Labs](#)
4. [Instrumentation Amplifier \$V_{CM}\$ vs. \$V_{OUT}\$ Plots](#)
5. [Common-mode Range Calculator for Instrumentation Amplifiers](#)

Design Featured Op Amp

OPA354	
V_{SS}	2.5V to 5.5V
V_{inCM}	Rail-to-rail
V_{out}	Rail-to-rail
V_{os}	2mV
I_q	4.9mA/Ch
I_b	3pA
UGBW	250MHz
SR	150V/ μ s
#Channels	1,2,4
www.ti.com/product/opa354	

Design Alternate Op Amp

OPA322	
V_{SS}	1.8V to 5.5V
V_{inCM}	Rail-to-rail
V_{out}	Rail-to-rail
V_{os}	500 μ V
I_q	1.6mA/Ch
I_b	0.2pA
UGBW	20MHz
SR	10V/ μ s
#Channels	1,2,4
www.ti.com/product/opa322	

Revision History

Revision	Date	Change
A	December 2020	Updated R11 to R7 for resistor number consistency

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 © 2022, Texas Instruments Incorporated