*Analog Engineer's Circuit Amplifiers*

# *Discrete Wide Bandwidth INA Circuit*

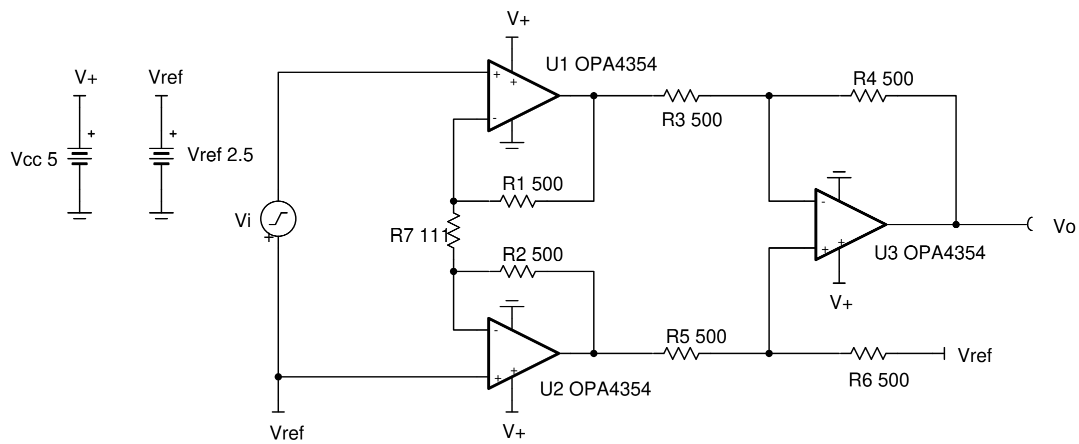
TEXAS INSTRUMENTS

## 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 $A_{ol}$ 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

Vref 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

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

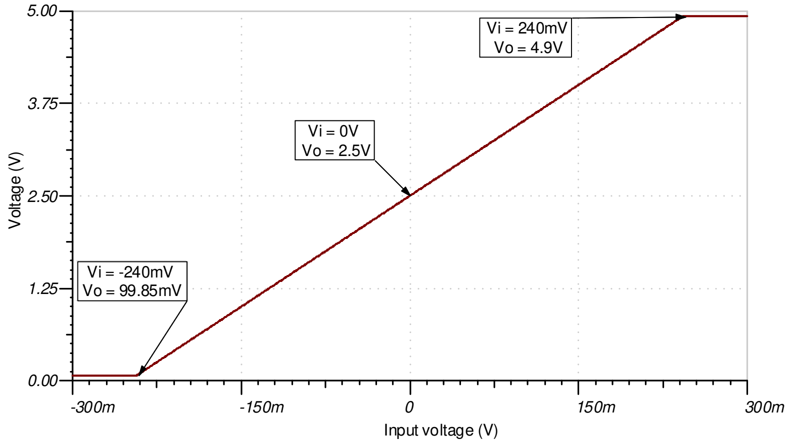
$$R_7 = \frac{1000\Omega}{9\frac{V}{V}} = 111.11\Omega \rightarrow R_7 = 111\Omega\ (Standard\ Value)$$

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.

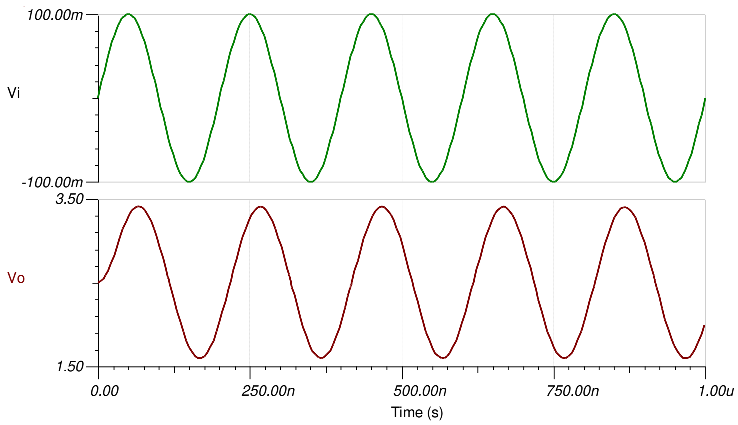
$$V_{ref} = \frac{V_s}{2} = \frac{5\ V}{2} = 2.5\ V$$

## Design Simulations

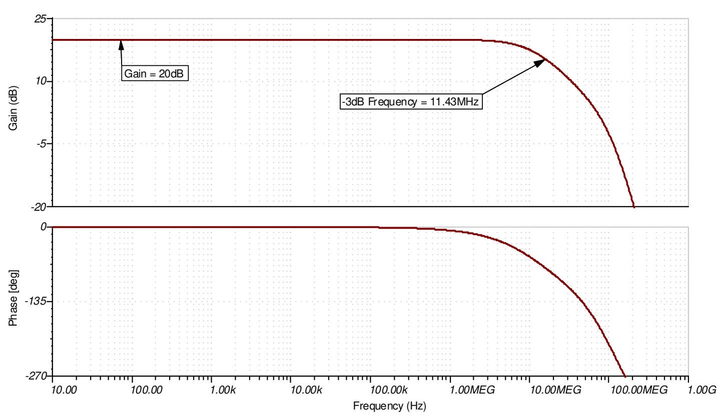
### DC Simulation Results




### 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/µs |
| **#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 |
| **$V_{os}$** | 500µV |
| **$I_q$** | 1.6mA/Ch |
| **$I_b$** | 0.2pA |
| **UGBW** | 20MHz |
| **SR** | 10V/µs |
| **#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 |