Application Brief

Space-Grade, 100-krad, Discrete, Three Op Amp Instrumentation Amplifier Circuit

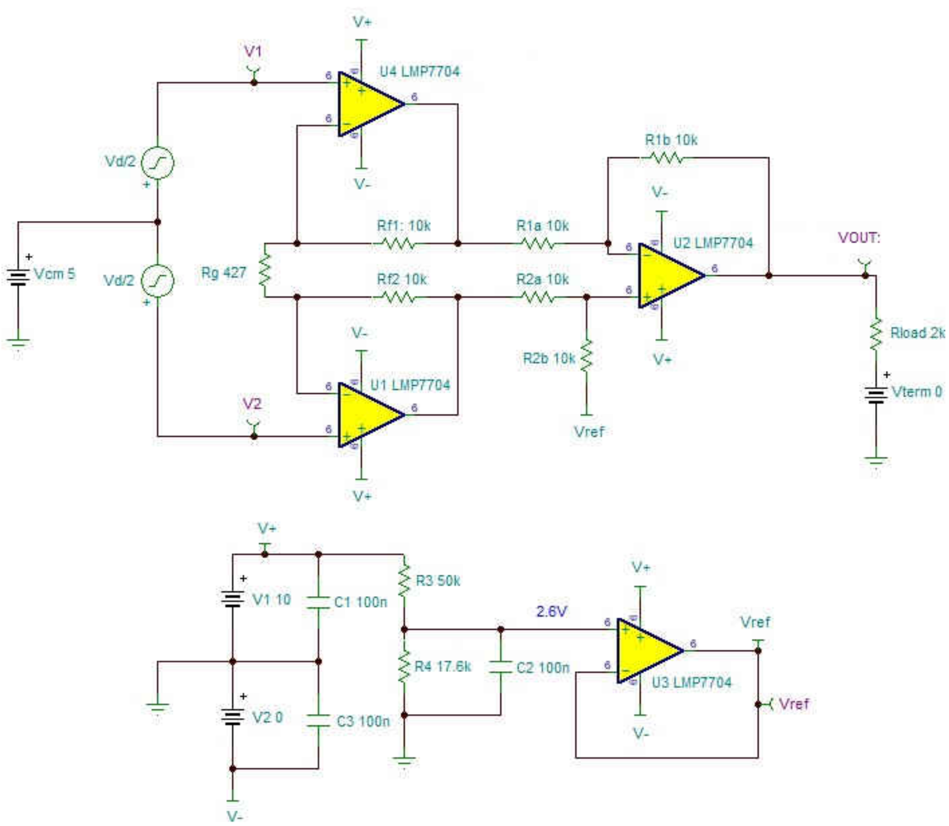
Nicholas Butts

Design Goals

Input		Output		Common-mode Voltage	Supply			Total Ionizing Dose	SEL Immunity
V_{d_min}	V_{d_max}	V_{out_min}	V_{out_max}	V_{cm}	V_+	V_-	V_{ref}	≥ 100krad(Si)	≥ 85 MeV·cm^2/mg
–50 mV	50 mV	0.2 V	5 V	5 V	10 V	0 V	2.6 V		

Design Description

This design uses discrete op amps to implement an instrumentation amplifier (IA) design using space-grade (SP) components for use in space applications. The circuit converts a differential signal to a single-ended output signal. Linear operation of an instrumentation amplifier depends upon linear operation of its building block: op amps. An op amp operates linearly when the input and output signals are within the respective input common-mode and output swing ranges of the device. The supply voltages used to power the op amps define these ranges.



Design Notes

1. Use low-tolerance resistors to achieve high DC CMRR performance. Mismatching of resistors can also lead to errors in gain and output accuracy.
2. All resistors and capacitors must be verified space-grade for this design.
3. R_g sets the gain of the input stage. R_{1a} and R_{1b} can be used to set the gain of the second stage (see Design Steps).
4. R_{f1} and R_{f2} are nominally matched in this design. In general, R_{f1} and R_{f2} do not need to be matched – it may be desirable in some cases to have R_{f1} and R_{f2} unmatched so that the top amplifier and bottom amplifier in the input stage have different gains. For example, if V_{cm} is not at mid-supply but is closer to one of the rails, R_{f1} and R_{f2} can be tuned so that neither of the input stage amplifiers run out of headroom.
5. Integrated instrumentation amplifiers normally have a fixed minimum gain. In addition to using an IA in high-gain configurations, constructing a discrete IA like this affords the flexibility to achieve any gain less than 1 V/V.
6. High-value resistors can degrade the phase margin of the circuit and introduce additional noise in the circuit.
7. Add an isolation resistor to the output stage to drive large capacitive loads.
8. Linear operation is contingent upon the input common-mode and the output swing ranges of the discrete op amps used. For best performance, choose $V_{cm} = (V_+ + V_–) / 2$ (mid-supply).
9. C_2 along with $R_3 \parallel R_4$ forms a low-pass filter with a corner frequency of 147.16 Hz.
10. The V_{ref} pin must be supplied by a low-impedance reference that can sink and source current, such as a buffer. Using a high-impedance reference, such as a resistor divider with no buffer, may result in a mismatch and degradation of CMRR.
11. V_{out_min} is chosen as 0.2 V for this design to avoid nonlinearities associated with the output of LMP7704-SP swinging too close to the rail. If this design is done with a different op amp, be sure to check the data sheet to determine the minimum and maximum output values allowed.
12. The LMP7704-SP supply voltage of 10 V was selected according the derating specifications provided by the National Aeronautics and Space Administration (NASA) in document EEE-INST-002 (April 2008) and the European Cooperation for Space Standardization (ECSS) in document ECSS-Q-ST-30-11C Rev.1 (4 October 2011). The documents specify an 80% and 90% derating of the absolute maximum supply voltage for linear ICs, respectively.
13. This design can be implemented with a single 4-channel LMP7704-SP or a similar device. See Design Alternative Op Amp for a wider supply op amp (36 V). Note that the listed alternative device meets TID = 50 krad(Si).

Design Steps

1. Calculate the output voltage V_{out} for this circuit using the following equation:

$$V_{out} = \left(1 + \frac{R_{f1} + R_{f2}}{R_g}\right) \times \frac{R_{1b}}{R_{1a}} \times V_d + V_{ref}$$

In this equation, $V_d = V_2 - V_1$ is the differential input voltage, V_{ref} is set by R_3 and R_4 to level shift the output, and it is assumed that $R_{1a} = R_{2a}$ and $R_{1b} = R_{2b}$. Integrated instrumentation amplifiers normally fix R_{f1}, R_{f2}, R_{1a}, R_{2a}, R_{1b}, and R_{2b}, leaving only R_g to set the gain of the circuit. In this discrete implementation, the designer has the freedom to alter all of these resistors, but the transfer function can be simplified by using standard values, such as $R_{f1} = R_{f2} = R_{1a} = R_{1b} = R_{2a} = R_{2b} = 10k\Omega$, and using only R_g to set the gain. In this case, R_g can be calculated using the following simplified equation:

$$V_{out} = \left(1 + \frac{20k\Omega}{R_g}\right) \times V_d + V_{ref}$$

2. Set V_{ref}. For this design, V_{ref} has been set as shown in the following equation so that a symmetric input voltage range of –50mV to +50mV results in an output voltage range of 0.2V to 5V.

$$V_{ref} = 2.6V = \frac{V_{out\_max} + V_{out\_min}}{2} = \frac{5V + 0.2V}{2}$$

$$V_{ref} = 2.6V = V_+ \times \frac{R_4}{R_3 + R_4} = 12V \times \frac{R_4}{50k\Omega + R_4}$$

$R_4 = 13.83k\Omega \approx 13.8k\Omega$ (standard value)

Note

The magnitudes of R_3 and R_4 were chosen such that $R_3 \parallel R_4$ is close to 10kΩ so that the low-pass filter formed by $R_3 \parallel R_4$ and C_2 is close to the common low-pass filter with R = 10kΩ and C = 100nF.

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3. Choose R_g to set the required gain using the simplified transfer function.

$$5V = \left(1 + \frac{20k\Omega}{R_g}\right) \times 50mV + 2.6V$$

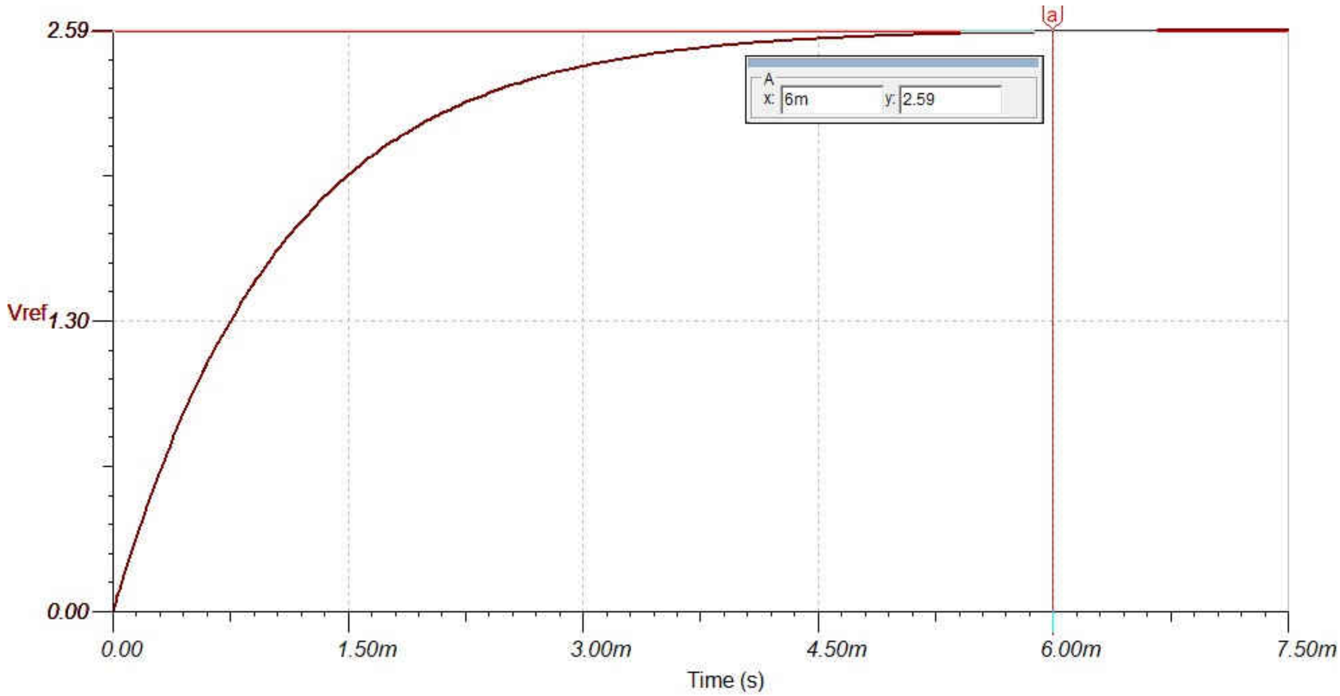
$R_g = 425\Omega \approx 427\Omega$ (standard value)

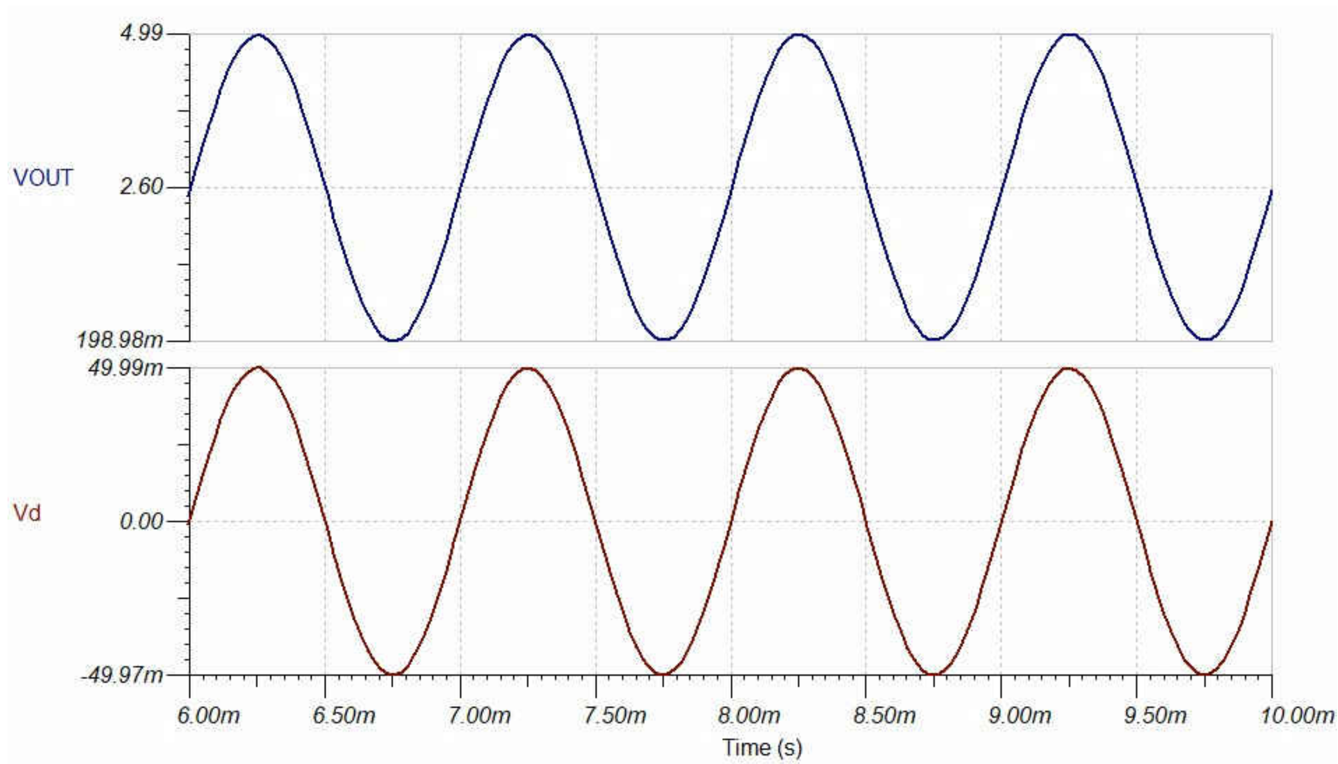
This corresponds to a gain of:

$$G = 1 + \frac{20k\Omega}{427\Omega} = 47.84V / V$$

Transient Simulation Results

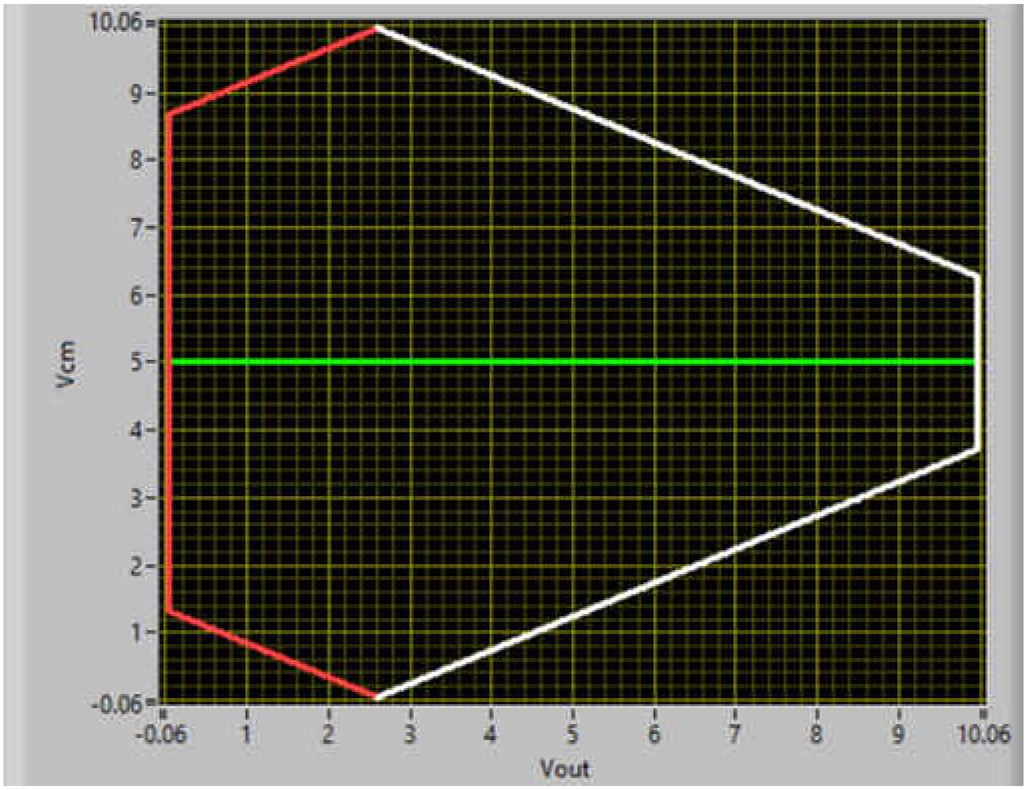
With the low-pass filter formed by R_3, R_4, and C_2, V_{ref} takes about 6ms to come up to its target value:





Vcm versus Vout Limitations

The following figure shows the allowable output voltage range for a given V_{cm}.



Design References

1. FAQ - How do Instrumentation Amplifiers (INAs) fit into my design?
2. TI Precision Labs - Online training course discussing instrumentation amplifier theory and application
3. Instrumentation Amplifier V_{cm} vs. V_{out} Plots
4. Analog Engineer's Calculator

Design Featured Op Amp

LMP7704-SP	
V_{supply}	±1.35V to ±6V
V_{inCM}	$(V_{–})$ – 0.2V to (V_{+}) + 0.2V
V_{out}	$(V_{–})$ – 120mV to (V_{+}) + 120mV
V_{os}	±32µV
I_q	725µA per channel
I_b	±200fA
UGBW	2.5MHz
SR	0.9V/µs
#Channels	4
Total Ionizing Dose	100krad(Si)
SEL Immunity to LET	85MeV·cm^2/mg
www.ti.com/product/LMP7704-SP	

Design Alternate Op Amp

OPA4277-SP	
V_{supply}	±2V to ±18V
V_{inCM}	$(V_{–})$ + 2V to (V_{+}) – 2V
V_{out}	$(V_{–})$ + 1.5V to (V_{+}) – 1.5V
V_{os}	±20µV
I_q	790µA per channel
I_b	±17.5nA
UGBW	1MHz
SR	0.8V/µs
#Channels	4
Total Ionizing Dose	50krad(Si)
SEL Immunity to LET	85MeV·cm^2/mg
www.ti.com/product/OPA4277-SP	