

# Dual-Supply, Discrete, Programmable Gain Amplifier Circuit



## Design Goals

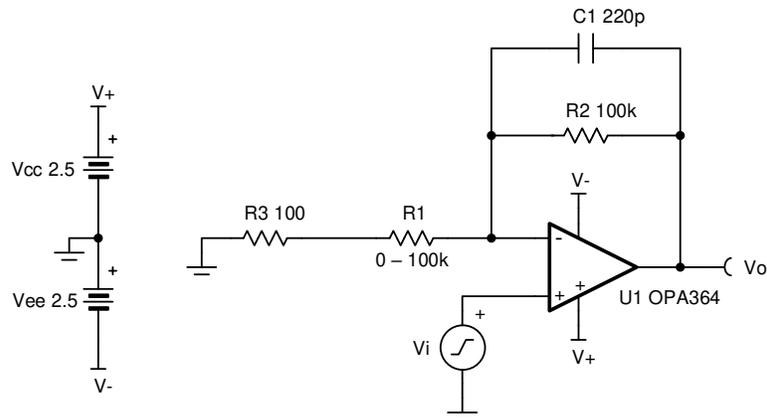
Input		Output		Supply	
$V_{iMin}$	$V_{iMax}$	$V_{oMin}$	$V_{oMax}$	$V_{cc}$	$V_{ee}$
-1.25 V	+1.25 V	-2.4 V	+2.4 V	+2.5 V	-2.5 V

Gain	Cutoff Frequency
6 dB (2 V/V) to 60 dB (1000 V/V)	7 kHz

## Design Description

This circuit provides programmable, non-inverting gains ranging from 6 dB (2 V/V) to 60 dB (1000 V/V) using a variable input resistance. The design maintains the same cutoff frequency over the gain range.



## Design Notes

1. Choose a digital potentiometer, such as TPL0102 for  $R_1$  to design a low-cost digital programmable gain amplifier.
2.  $R_3$  sets the maximum gain when  $R_1$  approaches  $0 \Omega$ .
3. A feedback capacitor limits the bandwidth and prevent stability issues.
4. Stability should be evaluated across the selected gain range. The minimum gain setting will likely be most sensitive to stability issues.
5. Some digital potentiometers can vary in absolute value by as much as  $\pm 20\%$  so gain calibration may be necessary.

## Design Steps

1. Choose  $R_2$  and  $R_3$ , to set the maximum gain when  $R_1$  approaches 0:

$$G_{\max} = 1 + \frac{R_2}{R_3}$$

$$G_{\max} - 1 = \frac{R_2}{R_3} \rightarrow R_2 = (G_{\max} - 1) \times R_3$$

$$\text{Set } R_3 = 100 \Omega$$

$$R_2 = \left(1000 \frac{V}{V} - 1\right) \times 100 = 99 \text{ k}\Omega \rightarrow R_2 = 100 \text{ k}\Omega \quad (\text{Standard value})$$

2. Choose the potentiometer maximum value to set the minimum gain:

$$G_{\min} = 1 + \frac{R_2}{R_{1,\max} + R_3}$$

$$G_{\min} - 1 = \frac{R_2}{R_{1,\max} + R_3}$$

$$R_{1,\max} + R_3 = \frac{R_2}{G_{\min} - 1}$$

$$R_{1,\max} = \frac{R_2}{G_{\min} - 1} - R_3 = \frac{100 \text{ k}\Omega}{2 - 1} - 100 \Omega = 99.9 \text{ k}\Omega \rightarrow R_{1,\max} = 100 \text{ k}\Omega \quad (\text{Standard value})$$

$$R_{1,\min} = 0 \Omega \quad (\text{Wiper resistance, typically } 25 \Omega, \text{ will introduce some error})$$

3. Choose the bandwidth with a feedback capacitor:

$$f_c = \frac{\text{GBW}}{G_{\max}} = \frac{7 \text{ MHz}}{1000 \frac{V}{V}} = 7 \text{ kHz}$$

$$f_c = 7 \text{ kHz} \rightarrow C_1 = \frac{1}{2\pi \times R_2 \times f_c} = 227 \text{ pF} \rightarrow C_1 = 220 \text{ pF} \quad (\text{Standard Value})$$

4. Check for stability at minimum gain ( $2V/V$ ), which is when  $R_1=100 \text{ k}\Omega$ . To satisfy the requirement  $f_c$  (circuit bandwidth) must be less than  $f_{\text{zero}}$  (zero created by the resistive feedback network and the differential and common-mode input capacitances).

$$f_c = \frac{1}{2\pi \times C_1 \times R_2} = 7 \text{ kHz}$$

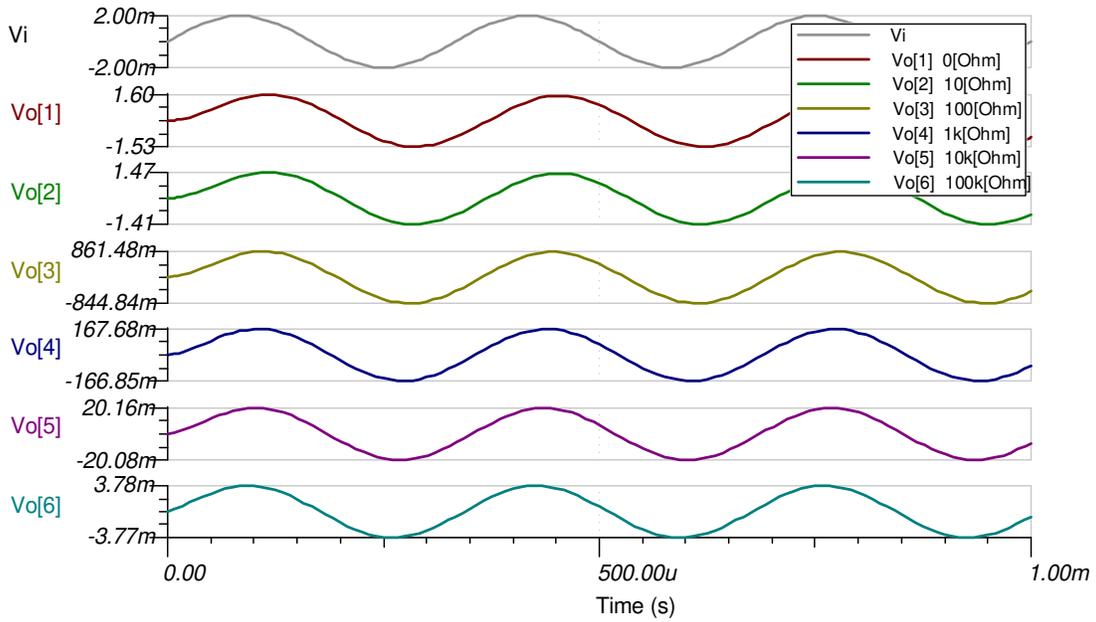
$$f_{\text{zero}} = \frac{1}{2\pi \times (C_{\text{cm}} + C_{\text{diff}}) \times (R_2 \parallel R_1)} = \frac{1}{2 \times \pi \times (3 \text{ pF} + 2 \text{ pF}) \times \left(\frac{100 \text{ k}\Omega \times 100 \text{ k}\Omega}{100 \text{ k}\Omega + 100 \text{ k}\Omega}\right)}$$

$$f_{\text{zero}} = 637 \text{ kHz}$$

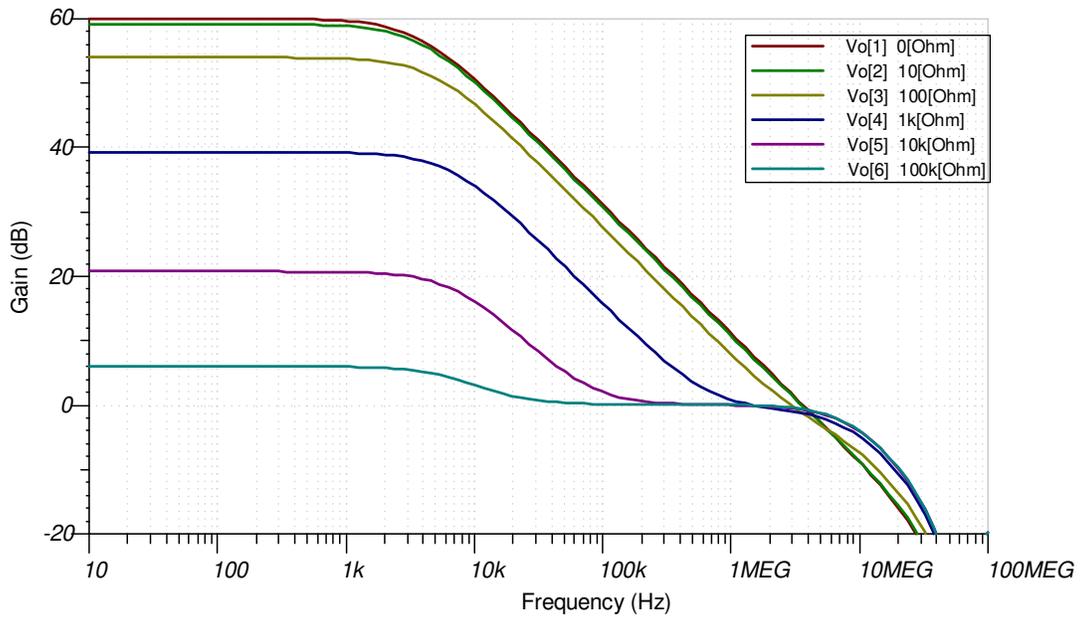
$$7 \text{ kHz} < 637 \text{ kHz} \rightarrow f_c < f_{\text{zero}}$$

## Design Simulations

### Transient Simulation Results



### AC Simulation Results



**References:**

1. [Analog Engineer's Circuit Cookbooks](#)
2. SPICE Simulation File [SBOC521](#)
3. TI Precision Designs [TIPD204](#)
4. [TI Precision Labs](#)

**Design Featured Op Amp**

OPA364	
$V_{ss}$	1.8 V to 5.5 V
$V_{inCM}$	Rail-to-rail
$V_{out}$	Rail-to-rail
$V_{os}$	1 mV
$I_q$	1.1 mA
$I_b$	1 pA
UGBW	7 MHz
SR	5 V/ $\mu$ s
#Channels	1, 2, and 4
<a href="#">OPA364</a>	

**Design Alternate Op Amp**

OPA376	
$V_{ss}$	2.2 V to 5.5 V
$V_{inCM}$	Rail-to-rail
$V_{out}$	Rail-to-rail
$V_{os}$	5 $\mu$ V
$I_q$	760 $\mu$ A
$I_b$	0.2 pA
UGBW	5.5 MHz
SR	2 V/ $\mu$ s
#Channels	1, 2, and 4
<a href="#">OPA376</a>	

## 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