

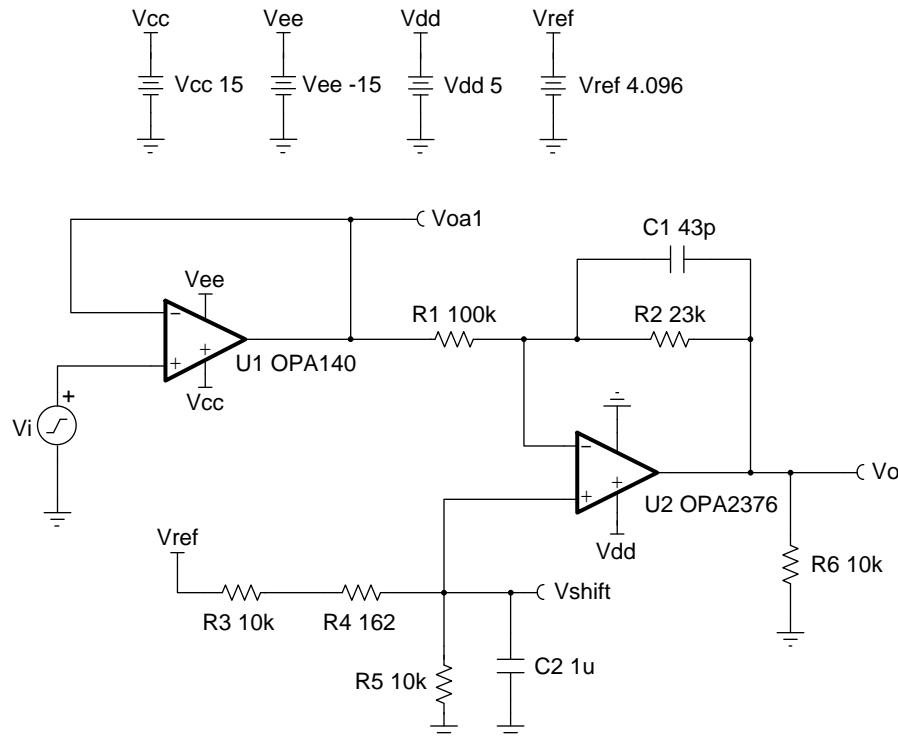
## Inverting dual-supply to single-supply amplifier circuit

### Design Goals

Input		Output		Supply			
$V_{iMin}$	$V_{iMax}$	$V_{oMin}$	$V_{oMax}$	$V_{cc}$	$V_{ee}$	$V_{dd}$	$V_{ref}$
-10V	+10V	+0.2V	+4.8V	+15V	-15V	+5V	+4.096V

### Design Description

This inverting dual-supply to single-supply amplifier translates a  $\pm 10\text{-V}$  signal to a 0-V to 5-V signal for use with an ADC. Levels can easily be adjusted using the given equations. The buffer can be replaced with other  $\pm 15\text{-V}$  configurations to accommodate the desired input signal, as long as the output of the first stage is low impedance.



### Design Notes

1. Observe common-mode limitations of the input buffer.
2. A high-impedance source will alter the gain characteristics of  $U_2$  if buffer amplifier  $U_1$  is not used.
3.  $R_6$  provides a path to ground for the output of  $U_1$  if the  $\pm 15\text{-V}$  supplies come up before the 5-V supply. This limits the voltage at the inverting pin of  $U_2$  through the voltage divider created by  $R_1$ ,  $R_2$ , and  $R_6$  and prevents damage to  $U_2$  as well as to any converter that may be connected to its output. To best protect the devices a transient voltage suppressor (TVS) should be used at the power pins of  $U_2$ .
4. A capacitor across  $R_5$  will help filter  $V_{ref}$  and provide a cleaner  $V_{shift}$ .

## Design Steps

The transfer function for this circuit follows:

$$V_o = -\frac{R_2}{R_1} \times V_i + \left(1 + \frac{R_2}{R_1}\right) \times V_{\text{shift}}$$

1. Set the gain of the amplifier.

$$\frac{\Delta V_o}{\Delta V_i} = \frac{V_{o\text{Max}} - V_{o\text{Min}}}{V_{i\text{Max}} - V_{i\text{Min}}} = \frac{4.8\text{ V} - 0.2\text{ V}}{10\text{ V} - (-10\text{ V})} = 0.23$$

$$\frac{\Delta V_o}{\Delta V_i} = \frac{R_2}{R_1}$$

$$R_2 = 0.23 \times R_1$$

Choose  $R_1 = 100\text{k}\Omega$  (standard value)

$R_2 = 23\text{k}\Omega$  (for standard values use  $22\text{k}\Omega$  and  $1\text{k}\Omega$  in series)

2. Set  $V_{\text{shift}}$  to translate the signal to single supply.

At midscale,  $V_{\text{in}} = 0\text{V}$

$$\text{Then } V_o = \left(1 + \frac{R_2}{R_1}\right) \times V_{\text{shift}}$$

$$V_{\text{shift}} = \frac{V_o}{\left(1 + \frac{R_2}{R_1}\right)} = \frac{2.5\text{V}}{1.23} = 2.033\text{V}$$

3. Select resistors for reference voltage divider to achieve  $V_{\text{shift}}$ .

$$V_{\text{ref}} = 4.096\text{V}$$

$$V_{\text{shift}} = V_{\text{ref}} \times \frac{R_5}{(R_3 + R_4) + R_5}$$

$$\frac{V_{\text{shift}}}{V_{\text{ref}}} = \frac{2.033\text{V}}{4.096\text{V}} = \frac{R_5}{(R_3 + R_4) + R_5}$$

$$R_3 + R_4 = 1.0161 \times R_5$$

Select a standard value for  $R_5$

$$R_5 = 10\text{k}\Omega$$

$$R_3 + R_4 = 10.161\text{k}\Omega$$

$$R_3 = 10\text{k}\Omega$$

$$R_4 = 162\Omega \text{ (standard 1\% value)}$$

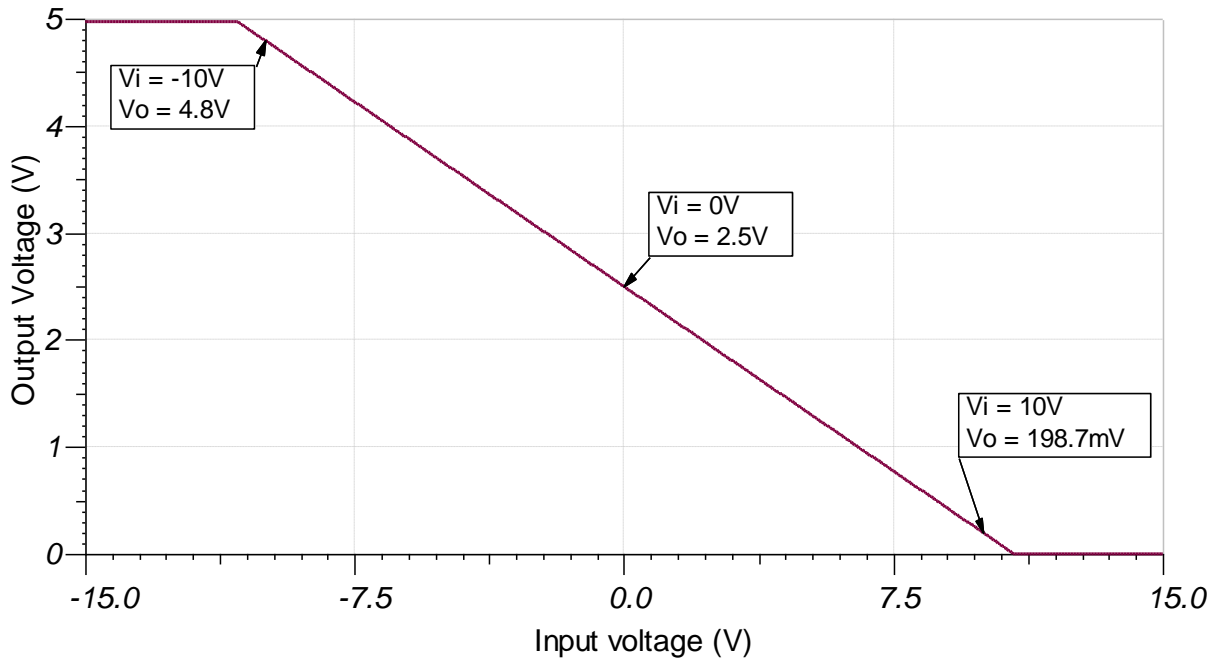
4. Large feedback resistors can interact with the input capacitance and cause instability. Choose  $C_1$  to add a pole to the transfer function to counteract this. The pole must be lower in frequency than the effective bandwidth of the op amp.

$$C_1 = 43\text{pF}$$

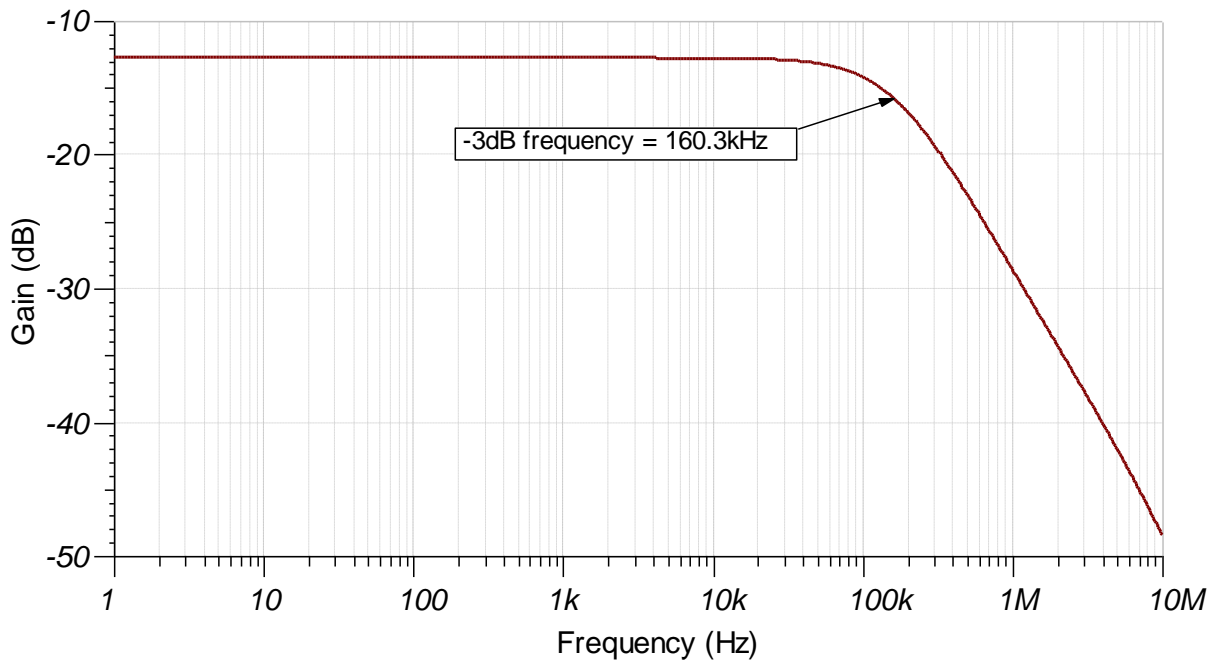
$$f_p = \frac{1}{2\pi \times R_2 \times C_1} = 160.3\text{kHz}$$

**Design Simulations**

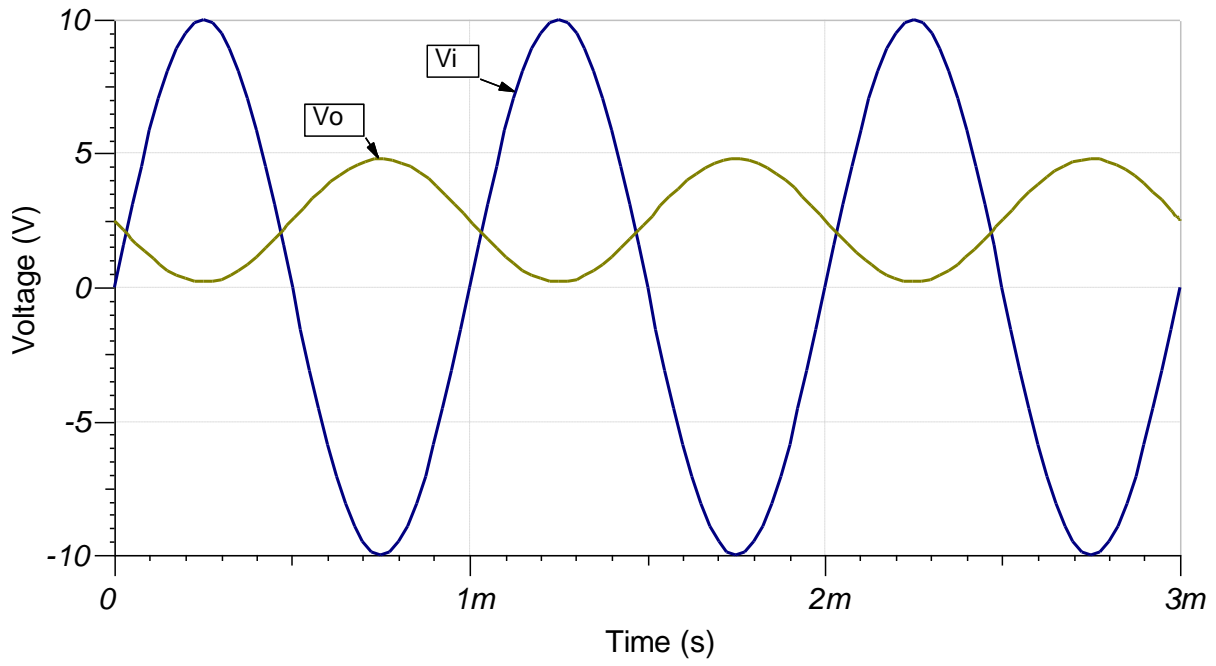
**DC Simulation Results**



**AC Simulation Results**



Transient Simulation Results



### Design References

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

See TINA-TI™ circuit simulation file, [SBOMAT9](#).

See TIPD148, <http://www.ti.com/tool/TIPD148>.

### Design Featured Op Amp

OPA376	
$V_{SS}$	2.2V to 5.5V
$V_{inCM}$	Vee to Vcc-1.3V
$V_{out}$	Rail-to-rail
$V_{os}$	5 $\mu$ V
$I_q$	760 $\mu$ A/Ch
$I_b$	0.2pA
UGBW	5.5MHz
SR	2V/ $\mu$ s
#Channels	1,2,4
<a href="http://www.ti.com/product/opa376">http://www.ti.com/product/opa376</a>	

### Design Featured Op Amp

OPA140	
$V_{SS}$	4.5V to 36V
$V_{inCM}$	Vee-0.1V to Vcc-3.5V
$V_{out}$	Rail-to-rail
$V_{os}$	30 $\mu$ V
$I_q$	1.8mA/Ch
$I_b$	$\pm$ 0.5pA
UGBW	11MHz
SR	20V/ $\mu$ s
#Channels	1,2,4
<a href="http://www.ti.com/product/opa375">http://www.ti.com/product/opa375</a>	

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