

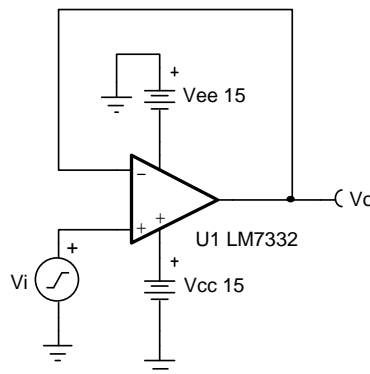
## Buffer (follower) circuit

### Design Goals

Input		Output		Freq.	Supply	
$V_{iMin}$	$V_{iMax}$	$V_{oMin}$	$V_{oMax}$	f	$V_{cc}$	$V_{ee}$
-10V	10V	-10V	10V	100kHz	15V	-15V

### Design Description

This design is used to buffer signals by presenting a high input impedance and a low output impedance. This circuit is commonly used to drive low-impedance loads, analog-to-digital converters (ADC) and buffer reference voltages. The output voltage of this circuit is equal to the input voltage.



### Design Notes

1. Use the op-amp linear output operating range, which is usually specified under the  $A_{OL}$  test conditions.
2. The small-signal bandwidth is determined by the unity-gain bandwidth of the amplifier.
3. Check the maximum output voltage swing versus frequency graph in the datasheet to minimize slew-induced distortion.
4. The common mode voltage is equal to the input signal.
5. Do not place capacitive loads directly on the output that are greater than the values recommended in the datasheet.
6. High output current amplifiers may be required if driving low impedance loads.
7. For more information on op-amp linear operating region, stability, slew-induced distortion, capacitive load drive, driving ADCs, and bandwidth, see the *Design References* section.

## Design Steps

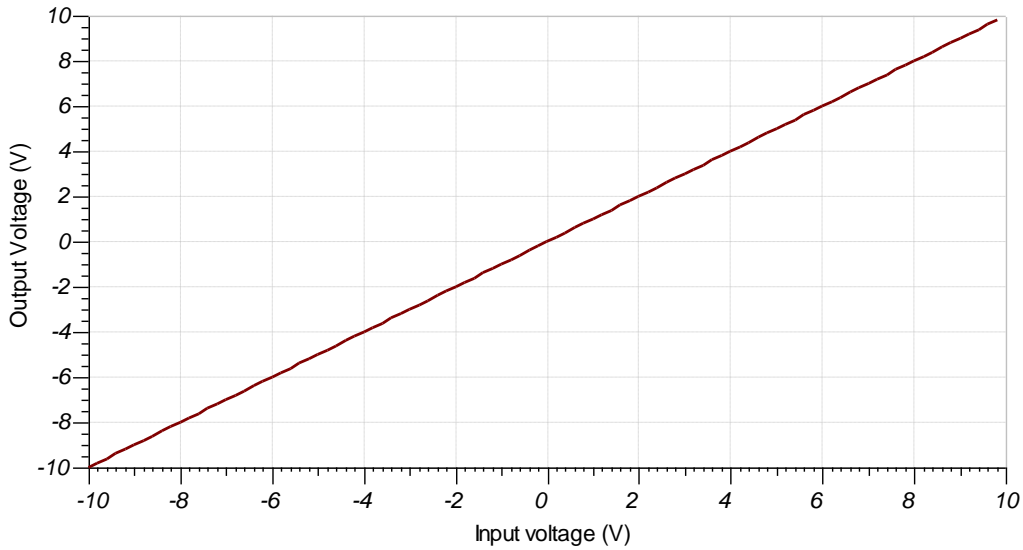
The transfer function for this circuit follows:

$$V_o = V_i$$

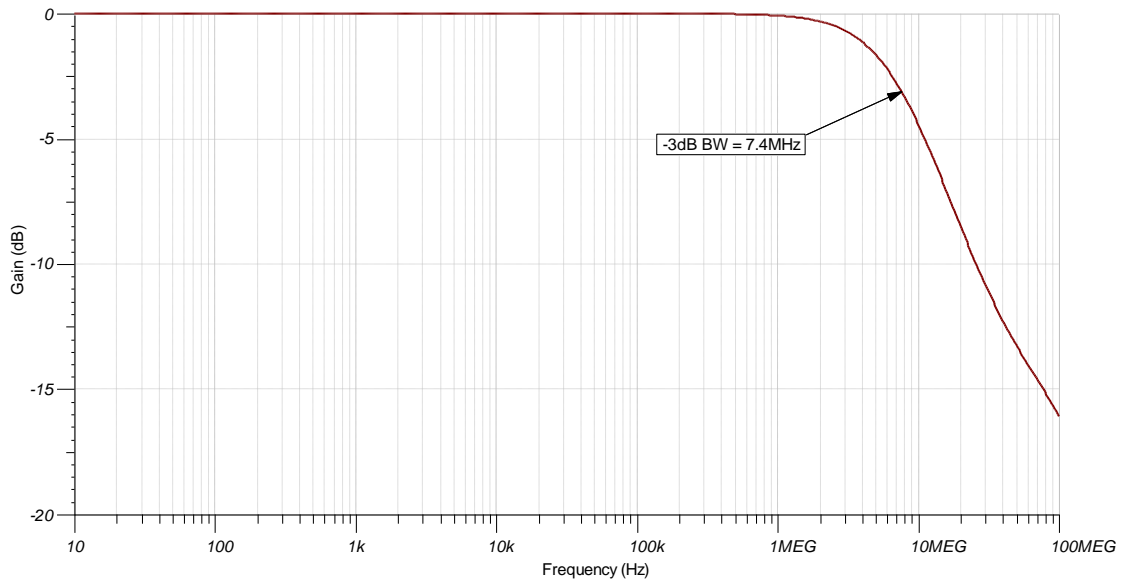
- Verify that the amplifier can achieve the desired output swing using the supply voltages provided. Use the output swing stated in the  $A_{OL}$  test conditions. The output swing range of the amplifier must be greater than the output swing required for the design.
  - $-14V \leq V_o \leq 14V$ 
    - The output swing of the LM7332 using  $\pm 15V$  supplies is greater than the required output swing of the design. Therefore, this requirement is met.
    - Review the Output Voltage versus Output Current curves in the product datasheet to verify the desired output voltage can be achieved for the desired output current.
- Verify the input common mode voltage of the amplifier will not be violated using the supply voltage provided. The input common mode voltage range of the amplifier must be greater than the input signal voltage range.
  - $-15.1 V \leq V_{icm} \leq 15.1 V$ 
    - The input common-mode range of the LM7332 using  $\pm 15V$  supplies is greater than the required input common-mode range of the design. Therefore, this requirement is met.
- Calculate the minimum slew rate required to minimize slew-induced distortion.
  - $SR > 2 \times \pi \times V_p \times f = 2 \times \pi \times 10V \times 100kHz = 6.28V / \mu s$ 
    - The slew rate of the LM7332 is  $15.2V/\mu s$ . Therefore, this requirement is met.
- Verify the device will have sufficient bandwidth for the desired output signal frequency.
  - $f_{signal} < f_{unity}$
  - $100kHz < 7.5MHz$ 
    - The desired output signal frequency is less than the unity-gain bandwidth of the LM7332. Therefore, this requirement is met.

**Design Simulations**

**DC Simulation Results**



**AC Simulation Results**



**Design References**

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

For more information, see the [Capacitive Load Drive Verified Reference Design Using an Isolation Resistor](#) TI Design.

See the circuit SPICE simulation file SBOC491 – <http://www.ti.com/lit/zip/sboc491>.

For more information on many op amp topics including common-mode range, output swing, bandwidth, slew rate, and how to drive an ADC, see [TI Precision Labs](#).

### Design Featured Op Amp

LM7332	
$V_{SS}$	2.5V to 32V
$V_{inCM}$	Rail-to-rail
$V_{out}$	Rail-to-rail
$V_{os}$	1.6mV
$I_q$	2mA
$I_b$	1 $\mu$ A
<b>UGBW</b>	7.5MHz ( $\pm$ 5-V supply)
<b>SR</b>	15.2V/ $\mu$ s
<b>#Channels</b>	2
<a href="http://www.ti.com/product/LM7332">www.ti.com/product/LM7332</a>	

### Design Alternate Op Amp

OPA192	
$V_{SS}$	4.5V to 36V
$V_{inCM}$	Rail-to-rail
$V_{out}$	Rail-to-rail
$V_{os}$	5 $\mu$ V
$I_q$	1mA
$I_b$	5pA
<b>UGBW</b>	10MHz
<b>SR</b>	20V/ $\mu$ s
<b>#Channels</b>	1, 2, 4
<a href="http://www.ti.com/product/opa192">www.ti.com/product/opa192</a>	

The following device is for battery-operated or power-conscious designs outside of the original design goals described earlier, where lowering the total system power is desired.

LPV511	
$V_{SS}$	2.7V to 12V
$V_{inCM}$	Rail-to-rail
$V_{out}$	Rail-to-rail
$V_{os}$	0.2mV
$I_q$	1.2 $\mu$ A
$I_b$	0.8nA
<b>UGBW</b>	27KHz
<b>SR</b>	7.5V/ms
<b>#Channels</b>	1
<a href="http://www.ti.com/product/lpv511">www.ti.com/product/lpv511</a>	

### Revision History

Revision	Date	Change
A	January 2019	Downscale title. Added LPV511 table in the <i>Design Alternate Op Amp</i> section.

## 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](http://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 © 2021, Texas Instruments Incorporated