

## FEATURES

- **Extremely Easy to Use—A Single Resistor Value Sets the Cutoff Frequency ( $256\text{kHz} < f_c < 256\text{kHz}$ )**
- **Extremely Flexible—Different Resistor Values Allow Arbitrary Transfer Functions with or without Gain ( $256\text{Hz} < f_c < 256\text{kHz}$ )**
- Supports Cutoff Frequencies Up to 360kHz Using FilterCAD™
- LTC1563-2: Unity-Gain Butterworth Response Uses a Single Resistor Value, Different Resistor Values Allow Other Responses with or without Gain
- LTC1563-3: Unity-Gain Bessel Response Uses a Single Resistor Value, Different Resistor Values Allow Other Responses with or without Gain
- Rail-to-Rail Input and Output Voltages
- Operates from a Single 3V (2.7V Min) to  $\pm 5\text{V}$  Supply
- Low Noise:  $36\mu\text{V}_{\text{RMS}}$  for  $f_c = 25.6\text{kHz}$ ,  $60\mu\text{V}_{\text{RMS}}$  for  $f_c = 256\text{kHz}$
- $f_c$  Accuracy  $< \pm 2\%$  (Typ)
- DC Offset  $< 1\text{mV}$
- Cascadable to Form 8th Order Lowpass Filters
- Available in Narrow SSOP-16 Package

## APPLICATIONS

- Discrete RC Active Filter Replacement
- Antialiasing Filters
- Smoothing or Reconstruction Filters
- Linear Phase Filtering for Data Communication
- Phase Locked Loops

## DESCRIPTION

The LTC®1563-2/LTC1563-3 are a family of extremely easy-to-use, active RC lowpass filters with rail-to-rail inputs and outputs and low DC offset suitable for systems with a resolution of up to 16 bits. The LTC1563-2, with a single resistor value, gives a unity-gain Butterworth response. The LTC1563-3, with a single resistor value, gives a unity-gain Bessel response. The proprietary architecture of these parts allows for a simple resistor calculation:

$$R = 10\text{k} (256\text{kHz}/f_c); f_c = \text{Cutoff Frequency}$$

where  $f_c$  is the desired cutoff frequency. For many applications, this formula is all that is needed to design a filter. By simply utilizing different valued resistors, gain and other responses are achieved.

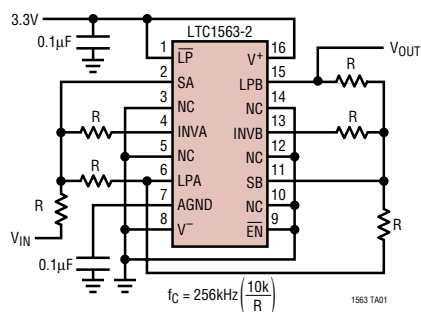
The LTC1563-X features a low power mode, for the lower frequency applications, where the supply current is reduced by an order of magnitude and a near zero power shutdown mode.

The LTC1563-Xs are available in the narrow SSOP-16 package (Same footprint as an SO-8 package).

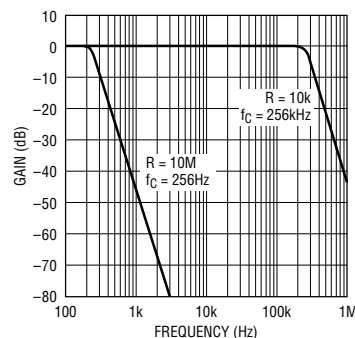
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## TYPICAL APPLICATION

Single 3.3V, 256kHz to 256kHz Butterworth Lowpass Filter



Frequency Response



# LTC1563-2/LTC1563-3

## ABSOLUTE MAXIMUM RATINGS

(Note 1)

|                                               |                                               |
|-----------------------------------------------|-----------------------------------------------|
| Total Supply Voltage ( $V^+$ to $V^-$ ) ..... | 11V                                           |
| Maximum Input Voltage at<br>Any Pin .....     | $(V^- - 0.3V) \leq V_{PIN} \leq (V^+ + 0.3V)$ |
| Power Dissipation .....                       | 500mW                                         |
| Operating Temperature Range                   |                                               |
| LTC1563C .....                                | 0°C to 70°C                                   |
| LTC1563I .....                                | -40°C to 85°C                                 |
| Storage Temperature Range .....               | -65°C to 150°C                                |
| Lead Temperature (Soldering, 10 sec) .....    | 300°C                                         |

## PACKAGE/ORDER INFORMATION

|                                                                                                                                                                                                                                                                    |                                                              |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------|
| <p>TOP VIEW</p> <p>GN PACKAGE<br/>16-LEAD PLASTIC SSOP</p> <p><math>T_{JMAX} = 150^\circ\text{C}</math>, <math>\theta_{JA} = 135^\circ\text{C/W}</math></p> <p>NOTE: PINS LABELED NC ARE NOT CONNECTED INTERNALLY AND SHOULD BE CONNECTED TO THE SYSTEM GROUND</p> | ORDER PART NUMBER                                            |
|                                                                                                                                                                                                                                                                    | LTC1563-2CGN<br>LTC1563-3CGN<br>LTC1563-2IGN<br>LTC1563-3IGN |
|                                                                                                                                                                                                                                                                    | GN PART MARKING                                              |
|                                                                                                                                                                                                                                                                    | 15632<br>15633<br>15632I<br>15633I                           |
| <p><b>Order Options</b> Tape and Reel: Add #TR<br/>Lead Free: Add #PBF Lead Free Tape and Reel: Add #TRPBF<br/>Lead Free Part Marking: <a href="http://www.linear.com/leadfree/">http://www.linear.com/leadfree/</a></p>                                           |                                                              |

Consult LTC Marketing for Military grade parts.

## ELECTRICAL CHARACTERISTICS

The ● denotes specifications which apply over the full operating temperature range, otherwise specifications are  $T_A = 25^\circ\text{C}$ .

$V_S$  = Single 4.75V, EN pin to logic "low," Gain = 1,  $R_{FIL} = R_{11} = R_{21} = R_{31} = R_{12} = R_{22} = R_{32}$ , specifications apply to both the high speed (HS) and low power (LP) modes unless otherwise noted.

| PARAMETER                                                               | CONDITIONS                                                                                             |   | MIN  | TYP   | MAX  | UNITS |
|-------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------|---|------|-------|------|-------|
| Specifications for Both LTC1563-2 and LTC1563-3                         |                                                                                                        |   |      |       |      |       |
| Total Supply Voltage (V <sub>S</sub> ), HS Mode                         |                                                                                                        | ● | 3    |       | 11   | V     |
| Total Supply Voltage (V <sub>S</sub> ), LP Mode                         |                                                                                                        | ● | 2.7  |       | 11   | V     |
| Output Voltage Swing High (LPB Pin)<br>HS Mode                          | V <sub>S</sub> = 3V, f <sub>C</sub> = 25.6kHz, R <sub>FIL</sub> = 100k, R <sub>L</sub> = 10k to GND    | ● | 2.9  | 2.95  |      | V     |
|                                                                         | V <sub>S</sub> = 4.75V, f <sub>C</sub> = 25.6kHz, R <sub>FIL</sub> = 100k, R <sub>L</sub> = 10k to GND | ● | 4.55 | 4.7   |      | V     |
|                                                                         | V <sub>S</sub> = ±5V, f <sub>C</sub> = 25.6kHz, R <sub>FIL</sub> = 100k, R <sub>L</sub> = 10k to GND   | ● | 4.8  | 4.9   |      | V     |
| Output Voltage Swing Low (LPB Pin)<br>HS Mode                           | V <sub>S</sub> = 3V, f <sub>C</sub> = 25.6kHz, R <sub>FIL</sub> = 100k, R <sub>L</sub> = 10k to GND    | ● |      | 0.015 | 0.05 | V     |
|                                                                         | V <sub>S</sub> = 4.75V, f <sub>C</sub> = 25.6kHz, R <sub>FIL</sub> = 100k, R <sub>L</sub> = 10k to GND | ● |      | 0.02  | 0.05 | V     |
|                                                                         | V <sub>S</sub> = ±5V, f <sub>C</sub> = 25.6kHz, R <sub>FIL</sub> = 100k, R <sub>L</sub> = 10k to GND   | ● |      | −4.95 | −4.9 | V     |
| Output Swing High (LPB Pin)<br>LP Mode                                  | V <sub>S</sub> = 2.7V, f <sub>C</sub> = 25.6kHz, R <sub>FIL</sub> = 100k, R <sub>L</sub> = 10k to GND  | ● | 2.6  | 2.65  |      | V     |
|                                                                         | V <sub>S</sub> = 4.75V, f <sub>C</sub> = 25.6kHz, R <sub>FIL</sub> = 100k, R <sub>L</sub> = 10k to GND | ● | 4.55 | 4.65  |      | V     |
|                                                                         | V <sub>S</sub> = ±5V, f <sub>C</sub> = 25.6kHz, R <sub>FIL</sub> = 100k, R <sub>L</sub> = 10k to GND   | ● | 4.8  | 4.9   |      | V     |
| Output Swing Low (LPB Pin)<br>LP Mode                                   | V <sub>S</sub> = 2.7V, f <sub>C</sub> = 25.6kHz, R <sub>FIL</sub> = 100k, R <sub>L</sub> = 10k to GND  | ● |      | 0.01  | 0.05 | V     |
|                                                                         | V <sub>S</sub> = 4.75V, f <sub>C</sub> = 25.6kHz, R <sub>FIL</sub> = 100k, R <sub>L</sub> = 10k to GND | ● |      | 0.015 | 0.05 | V     |
|                                                                         | V <sub>S</sub> = ±5V, f <sub>C</sub> = 25.6kHz, R <sub>FIL</sub> = 100k, R <sub>L</sub> = 10k to GND   | ● |      | −4.95 | −4.9 | V     |
| DC Offset Voltage, HS Mode<br>(Section A Only)                          | V <sub>S</sub> = 3V, f <sub>C</sub> = 25.6kHz, R <sub>FIL</sub> = 100k                                 | ● |      | ±1.5  | ±3   | mV    |
|                                                                         | V <sub>S</sub> = 4.75V, f <sub>C</sub> = 25.6kHz, R <sub>FIL</sub> = 100k                              | ● |      | ±1.0  | ±3   | mV    |
|                                                                         | V <sub>S</sub> = ±5V, f <sub>C</sub> = 25.6kHz, R <sub>FIL</sub> = 100k                                | ● |      | ±1.5  | ±3   | mV    |
| DC Offset Voltage, LP Mode<br>(Section A Only)                          | V <sub>S</sub> = 2.7V, f <sub>C</sub> = 25.6kHz, R <sub>FIL</sub> = 100k                               | ● |      | ±2    | ±6   | mV    |
|                                                                         | V <sub>S</sub> = 4.75V, f <sub>C</sub> = 25.6kHz, R <sub>FIL</sub> = 100k                              | ● |      | ±2    | ±6   | mV    |
|                                                                         | V <sub>S</sub> = ±5V, f <sub>C</sub> = 25.6kHz, R <sub>FIL</sub> = 100k                                | ● |      | ±2    | ±7   | mV    |
| DC Offset Voltage, HS Mode<br>(Input to Output, Sections A, B Cascaded) | V <sub>S</sub> = 3V, f <sub>C</sub> = 25.6kHz, R <sub>FIL</sub> = 100k                                 | ● |      | ±1.5  | ±3   | mV    |
|                                                                         | V <sub>S</sub> = 4.75V, f <sub>C</sub> = 25.6kHz, R <sub>FIL</sub> = 100k                              | ● |      | ±1.0  | ±3   | mV    |
|                                                                         | V <sub>S</sub> = ±5V, f <sub>C</sub> = 25.6kHz, R <sub>FIL</sub> = 100k                                | ● |      | ±1.5  | ±3   | mV    |

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## ELECTRICAL CHARACTERISTICS

The ● denotes specifications which apply over the full operating temperature range, otherwise specifications are  $T_A = 25^\circ\text{C}$ .

$V_S$  = Single 4.75V,  $\overline{\text{EN}}$  pin to logic "low," Gain = 1,  $R_{\text{FIL}} = R_{11} = R_{21} = R_{31} = R_{12} = R_{22} = R_{32}$ , specifications apply to both the high speed (HS) and low power (LP) modes unless otherwise noted.

| PARAMETER                                                                     | CONDITIONS                                                                      |   | MIN  | TYP     | MAX     | UNITS                        |
|-------------------------------------------------------------------------------|---------------------------------------------------------------------------------|---|------|---------|---------|------------------------------|
| DC Offset Voltage, LP Mode<br>(Input to Output, Sections A, B Cascaded)       | $V_S = 2.7\text{V}$ , $f_C = 25.6\text{kHz}$ , $R_{\text{FIL}} = 100\text{k}$   | ● |      | $\pm 2$ | $\pm 7$ | mV                           |
|                                                                               | $V_S = 4.75\text{V}$ , $f_C = 25.6\text{kHz}$ , $R_{\text{FIL}} = 100\text{k}$  | ● |      | $\pm 2$ | $\pm 7$ | mV                           |
|                                                                               | $V_S = \pm 5\text{V}$ , $f_C = 25.6\text{kHz}$ , $R_{\text{FIL}} = 100\text{k}$ | ● |      | $\pm 2$ | $\pm 8$ | mV                           |
| DC Offset Voltage Drift, HS Mode<br>(Input to Output, Sections A, B Cascaded) | $V_S = 3\text{V}$ , $f_C = 25.6\text{kHz}$ , $R_{\text{FIL}} = 100\text{k}$     | ● |      | 10      |         | $\mu\text{V}/^\circ\text{C}$ |
|                                                                               | $V_S = 4.75\text{V}$ , $f_C = 25.6\text{kHz}$ , $R_{\text{FIL}} = 100\text{k}$  | ● |      | 10      |         | $\mu\text{V}/^\circ\text{C}$ |
|                                                                               | $V_S = \pm 5\text{V}$ , $f_C = 25.6\text{kHz}$ , $R_{\text{FIL}} = 100\text{k}$ | ● |      | 10      |         | $\mu\text{V}/^\circ\text{C}$ |
| DC Offset Voltage Drift, LP Mode<br>(Input to Output, Sections A, B Cascaded) | $V_S = 2.7\text{V}$ , $f_C = 25.6\text{kHz}$ , $R_{\text{FIL}} = 100\text{k}$   | ● |      | 10      |         | $\mu\text{V}/^\circ\text{C}$ |
|                                                                               | $V_S = 4.75\text{V}$ , $f_C = 25.6\text{kHz}$ , $R_{\text{FIL}} = 100\text{k}$  | ● |      | 10      |         | $\mu\text{V}/^\circ\text{C}$ |
|                                                                               | $V_S = \pm 5\text{V}$ , $f_C = 25.6\text{kHz}$ , $R_{\text{FIL}} = 100\text{k}$ | ● |      | 10      |         | $\mu\text{V}/^\circ\text{C}$ |
| AGND Voltage                                                                  | $V_S = 4.75\text{V}$ , $f_C = 25.6\text{kHz}$ , $R_{\text{FIL}} = 100\text{k}$  | ● | 2.35 | 2.375   | 2.40    | V                            |
| Power Supply Current, HS Mode                                                 | $V_S = 3\text{V}$ , $f_C = 25.6\text{kHz}$ , $R_{\text{FIL}} = 100\text{k}$     | ● |      | 8.0     | 14      | mA                           |
|                                                                               | $V_S = 4.75\text{V}$ , $f_C = 25.6\text{kHz}$ , $R_{\text{FIL}} = 100\text{k}$  | ● |      | 10.5    | 17      | mA                           |
|                                                                               | $V_S = \pm 5\text{V}$ , $f_C = 25.6\text{kHz}$ , $R_{\text{FIL}} = 100\text{k}$ | ● |      | 15      | 23      | mA                           |
| Power Supply Current, LP Mode                                                 | $V_S = 2.7\text{V}$ , $f_C = 25.6\text{kHz}$ , $R_{\text{FIL}} = 100\text{k}$   | ● |      | 1.0     | 1.8     | mA                           |
|                                                                               | $V_S = 4.75\text{V}$ , $f_C = 25.6\text{kHz}$ , $R_{\text{FIL}} = 100\text{k}$  | ● |      | 1.4     | 2.5     | mA                           |
|                                                                               | $V_S = \pm 5\text{V}$ , $f_C = 25.6\text{kHz}$ , $R_{\text{FIL}} = 100\text{k}$ | ● |      | 2.3     | 3.5     | mA                           |
| Shutdown Mode Supply Current                                                  | $V_S = 4.75\text{V}$ , $f_C = 25.6\text{kHz}$ , $R_{\text{FIL}} = 100\text{k}$  | ● |      | 1       | 20      | $\mu\text{A}$                |
| $\overline{\text{EN}}$ Input<br>Logic Low Level                               | $V_S = 3\text{V}$                                                               | ● |      |         | 0.8     | V                            |
|                                                                               | $V_S = 4.75\text{V}$                                                            | ● |      |         | 1       | V                            |
|                                                                               | $V_S = \pm 5\text{V}$                                                           | ● |      |         | 1       | V                            |
| $\overline{\text{EN}}$ Input<br>Logic High Level                              | $V_S = 3\text{V}$                                                               | ● | 2.5  |         |         | V                            |
|                                                                               | $V_S = 4.75\text{V}$                                                            | ● | 4.3  |         |         | V                            |
|                                                                               | $V_S = \pm 5\text{V}$                                                           | ● | 4.4  |         |         | V                            |
| $\overline{\text{LP}}$<br>Logic Low Level                                     | $V_S = 3\text{V}$                                                               | ● |      |         | 0.8     | V                            |
|                                                                               | $V_S = 4.75\text{V}$                                                            | ● |      |         | 1       | V                            |
|                                                                               | $V_S = \pm 5\text{V}$                                                           | ● |      |         | 1       | V                            |
| $\overline{\text{LP}}$<br>Logic High Level                                    | $V_S = 3\text{V}$                                                               | ● | 2.5  |         |         | V                            |
|                                                                               | $V_S = 4.75\text{V}$                                                            | ● | 4.3  |         |         | V                            |
|                                                                               | $V_S = \pm 5\text{V}$                                                           | ● | 4.4  |         |         | V                            |

### LTC1563-2 Transfer Function Characteristics

|                                                              |                                                        |   |       |           |      |                       |
|--------------------------------------------------------------|--------------------------------------------------------|---|-------|-----------|------|-----------------------|
| Cutoff Frequency Range, $f_C$<br>HS Mode<br>(Note 2)         | $V_S = 3\text{V}$                                      | ● | 0.256 |           | 256  | kHz                   |
|                                                              | $V_S = 4.75\text{V}$                                   | ● | 0.256 |           | 256  | kHz                   |
|                                                              | $V_S = \pm 5\text{V}$                                  | ● | 0.256 |           | 256  | kHz                   |
| Cutoff Frequency Range, $f_C$<br>LP Mode<br>(Note 2)         | $V_S = 2.7\text{V}$                                    | ● | 0.256 |           | 25.6 | kHz                   |
|                                                              | $V_S = 4.75\text{V}$                                   | ● | 0.256 |           | 25.6 | kHz                   |
|                                                              | $V_S = \pm 5\text{V}$                                  | ● | 0.256 |           | 25.6 | kHz                   |
| Cutoff Frequency Accuracy, HS Mode<br>$f_C = 25.6\text{kHz}$ | $V_S = 3\text{V}$ , $R_{\text{FIL}} = 100\text{k}$     | ● | -2.0  | $\pm 1.5$ | 3.5  | %                     |
|                                                              | $V_S = 4.75\text{V}$ , $R_{\text{FIL}} = 100\text{k}$  | ● | -2.0  | $\pm 1.5$ | 3.5  | %                     |
|                                                              | $V_S = \pm 5\text{V}$ , $R_{\text{FIL}} = 100\text{k}$ | ● | -2.0  | $\pm 1.5$ | 3.5  | %                     |
| Cutoff Frequency Accuracy, HS Mode<br>$f_C = 256\text{kHz}$  | $V_S = 3\text{V}$ , $R_{\text{FIL}} = 10\text{k}$      | ● | -5    | $\pm 1.5$ | 2.5  | %                     |
|                                                              | $V_S = 4.75\text{V}$ , $R_{\text{FIL}} = 10\text{k}$   | ● | -5    | $\pm 1.5$ | 2.5  | %                     |
|                                                              | $V_S = \pm 5\text{V}$ , $R_{\text{FIL}} = 10\text{k}$  | ● | -5    | $\pm 1.5$ | 2.5  | %                     |
| Cutoff Frequency Accuracy, LP Mode<br>$f_C = 25.6\text{kHz}$ | $V_S = 2.7\text{V}$ , $R_{\text{FIL}} = 100\text{k}$   | ● | -3    | $\pm 1.5$ | 3    | %                     |
|                                                              | $V_S = 4.75\text{V}$ , $R_{\text{FIL}} = 100\text{k}$  | ● | -3    | $\pm 1.5$ | 3    | %                     |
|                                                              | $V_S = \pm 5\text{V}$ , $R_{\text{FIL}} = 100\text{k}$ | ● | -3    | $\pm 1.5$ | 3    | %                     |
| Cutoff Frequency Temperature Coefficient                     | (Note 3)                                               | ● |       | $\pm 1$   |      | ppm/ $^\circ\text{C}$ |

## ELECTRICAL CHARACTERISTICS

The ● denotes specifications which apply over the full operating temperature range, otherwise specifications are  $T_A = 25^\circ\text{C}$ .

$V_S$  = Single 4.75V,  $\overline{\text{EN}}$  pin to logic "low," Gain = 1,  $R_{\text{FIL}} = R_{11} = R_{21} = R_{12} = R_{22} = R_{32}$ , specifications apply to both the high speed (HS) and low power (LP) modes unless otherwise noted.

| PARAMETER                                                                                               | CONDITIONS                                            |   | MIN   | TYP   | MAX   | UNITS |
|---------------------------------------------------------------------------------------------------------|-------------------------------------------------------|---|-------|-------|-------|-------|
| Passband Gain, HS Mode, $f_C = 25.6\text{kHz}$<br>$V_S = 4.75\text{V}$ , $R_{\text{FIL}} = 100\text{k}$ | Test Frequency = $2.56\text{kHz}$ ( $0.1 \cdot f_C$ ) | ● | -0.2  | 0     | 0.2   | dB    |
|                                                                                                         | Test Frequency = $12.8\text{kHz}$ ( $0.5 \cdot f_C$ ) | ● | -0.3  | 0     | 0.3   | dB    |
| Stopband Gain, HS Mode, $f_C = 25.6\text{kHz}$<br>$V_S = 4.75\text{V}$ , $R_{\text{FIL}} = 100\text{k}$ | Test Frequency = $51.2\text{kHz}$ ( $2 \cdot f_C$ )   | ● |       | -24   | -21.5 | dB    |
|                                                                                                         | Test Frequency = $102.4\text{kHz}$ ( $4 \cdot f_C$ )  | ● |       | -48   | -46   | dB    |
| Passband Gain, HS Mode, $f_C = 256\text{kHz}$<br>$V_S = 4.75\text{V}$ , $R_{\text{FIL}} = 10\text{k}$   | Test Frequency = $25.6\text{kHz}$ ( $0.1 \cdot f_C$ ) | ● | -0.2  | 0     | 0.2   | dB    |
|                                                                                                         | Test Frequency = $128\text{kHz}$ ( $0.5 \cdot f_C$ )  | ● | -0.5  | 0     | 0.5   | dB    |
| Stopband Gain, HS Mode, $f_C = 256\text{kHz}$<br>$V_S = 4.75\text{V}$ , $R_{\text{FIL}} = 10\text{k}$   | Test Frequency = $400\text{kHz}$ ( $1.56 \cdot f_C$ ) | ● |       | -15.7 | -13.5 | dB    |
|                                                                                                         | Test Frequency = $500\text{kHz}$ ( $1.95 \cdot f_C$ ) | ● |       | -23.3 | -21.5 | dB    |
| Passband Gain, LP Mode, $f_C = 25.6\text{kHz}$<br>$V_S = 4.75\text{V}$ , $R_{\text{FIL}} = 100\text{k}$ | Test Frequency = $2.56\text{kHz}$ ( $0.1 \cdot f_C$ ) | ● | -0.25 | 0     | 0.25  | dB    |
|                                                                                                         | Test Frequency = $12.8\text{kHz}$ ( $0.5 \cdot f_C$ ) | ● | -0.6  | -0.02 | 0.6   | dB    |
| Stopband Gain, LP Mode, $f_C = 25.6\text{kHz}$<br>$V_S = 4.75\text{V}$ , $R_{\text{FIL}} = 100\text{k}$ | Test Frequency = $51.2\text{kHz}$ ( $2 \cdot f_C$ )   | ● |       | -24   | -22   | dB    |
|                                                                                                         | Test Frequency = $102.4\text{kHz}$ ( $4 \cdot f_C$ )  | ● |       | -48   | -46.5 | dB    |

### LTC1563-3 Transfer Function Characteristics

|                                                                                                         |                                                        |   |       |         |       |                       |
|---------------------------------------------------------------------------------------------------------|--------------------------------------------------------|---|-------|---------|-------|-----------------------|
| Cutoff Frequency Range, $f_C$<br>HS Mode<br>(Note 2)                                                    | $V_S = 3\text{V}$                                      | ● | 0.256 |         | 256   | kHz                   |
|                                                                                                         | $V_S = 4.75\text{V}$                                   | ● | 0.256 |         | 256   | kHz                   |
|                                                                                                         | $V_S = \pm 5\text{V}$                                  | ● | 0.256 |         | 256   | kHz                   |
| Cutoff Frequency Range, $f_C$<br>LP Mode<br>(Note 2)                                                    | $V_S = 2.7\text{V}$                                    | ● | 0.256 |         | 25.6  | kHz                   |
|                                                                                                         | $V_S = 4.75\text{V}$                                   | ● | 0.256 |         | 25.6  | kHz                   |
|                                                                                                         | $V_S = \pm 5\text{V}$                                  | ● | 0.256 |         | 25.6  | kHz                   |
| Cutoff Frequency Accuracy, HS Mode<br>$f_C = 25.6\text{kHz}$                                            | $V_S = 3\text{V}$ , $R_{\text{FIL}} = 100\text{k}$     | ● | -3    | $\pm 2$ | 5.5   | %                     |
|                                                                                                         | $V_S = 4.75\text{V}$ , $R_{\text{FIL}} = 100\text{k}$  | ● | -3    | $\pm 2$ | 5.5   | %                     |
|                                                                                                         | $V_S = \pm 5\text{V}$ , $R_{\text{FIL}} = 100\text{k}$ | ● | -3    | $\pm 2$ | 5.5   | %                     |
| Cutoff Frequency Accuracy, HS Mode<br>$f_C = 256\text{kHz}$                                             | $V_S = 3\text{V}$ , $R_{\text{FIL}} = 10\text{k}$      | ● | -3    | $\pm 2$ | 6     | %                     |
|                                                                                                         | $V_S = 4.75\text{V}$ , $R_{\text{FIL}} = 10\text{k}$   | ● | -3    | $\pm 2$ | 6     | %                     |
|                                                                                                         | $V_S = \pm 5\text{V}$ , $R_{\text{FIL}} = 10\text{k}$  | ● | -3    | $\pm 2$ | 6     | %                     |
| Cutoff Frequency Accuracy, LP Mode<br>$f_C = 25.6\text{kHz}$                                            | $V_S = 2.7\text{V}$ , $R_{\text{FIL}} = 100\text{k}$   | ● | -4    | $\pm 3$ | 7     | %                     |
|                                                                                                         | $V_S = 4.75\text{V}$ , $R_{\text{FIL}} = 100\text{k}$  | ● | -4    | $\pm 3$ | 7     | %                     |
|                                                                                                         | $V_S = \pm 5\text{V}$ , $R_{\text{FIL}} = 100\text{k}$ | ● | -4    | $\pm 3$ | 7     | %                     |
| Cutoff Frequency Temperature Coefficient                                                                | (Note 3)                                               | ● |       | $\pm 1$ |       | ppm/ $^\circ\text{C}$ |
| Passband Gain, HS Mode, $f_C = 25.6\text{kHz}$<br>$V_S = 4.75\text{V}$ , $R_{\text{FIL}} = 100\text{k}$ | Test Frequency = $2.56\text{kHz}$ ( $0.1 \cdot f_C$ )  | ● | -0.2  | -0.03   | 0.2   | dB                    |
|                                                                                                         | Test Frequency = $12.8\text{kHz}$ ( $0.5 \cdot f_C$ )  | ● | -1.0  | -0.72   | -0.25 | dB                    |
| Stopband Gain, HS Mode, $f_C = 25.6\text{kHz}$<br>$V_S = 4.75\text{V}$ , $R_{\text{FIL}} = 100\text{k}$ | Test Frequency = $51.2\text{kHz}$ ( $2 \cdot f_C$ )    | ● |       | -13.6   | -10   | dB                    |
|                                                                                                         | Test Frequency = $102.4\text{kHz}$ ( $4 \cdot f_C$ )   | ● |       | -34.7   | -31   | dB                    |
| Passband Gain, HS Mode, $f_C = 256\text{kHz}$<br>$V_S = 4.75\text{V}$ , $R_{\text{FIL}} = 10\text{k}$   | Test Frequency = $25.6\text{kHz}$ ( $0.1 \cdot f_C$ )  | ● | -0.2  | -0.03   | 0.2   | dB                    |
|                                                                                                         | Test Frequency = $128\text{kHz}$ ( $0.5 \cdot f_C$ )   | ● | -1.1  | -0.72   | -0.5  | dB                    |
| Stopband Gain, HS Mode, $f_C = 256\text{kHz}$<br>$V_S = 4.75\text{V}$ , $R_{\text{FIL}} = 10\text{k}$   | Test Frequency = $400\text{kHz}$ ( $1.56 \cdot f_C$ )  | ● |       | -8.3    | -6    | dB                    |
|                                                                                                         | Test Frequency = $500\text{kHz}$ ( $1.95 \cdot f_C$ )  | ● |       | -13     | -10.5 | dB                    |
| Passband Gain, LP Mode, $f_C = 25.6\text{kHz}$<br>$V_S = 4.75\text{V}$ , $R_{\text{FIL}} = 100\text{k}$ | Test Frequency = $2.56\text{kHz}$ ( $0.1 \cdot f_C$ )  | ● | -0.2  | -0.03   | 0.2   | dB                    |
|                                                                                                         | Test Frequency = $12.8\text{kHz}$ ( $0.5 \cdot f_C$ )  | ● | -1.0  | -0.72   | -0.25 | dB                    |
| Stopband Gain, LP Mode, $f_C = 25.6\text{kHz}$<br>$V_S = 4.75\text{V}$ , $R_{\text{FIL}} = 100\text{k}$ | Test Frequency = $51.2\text{kHz}$ ( $2 \cdot f_C$ )    | ● |       | -13.6   | -11   | dB                    |
|                                                                                                         | Test Frequency = $102.4\text{kHz}$ ( $4 \cdot f_C$ )   | ● |       | -34.7   | -32   | dB                    |

**Note 1:** Absolute Maximum Ratings are those value beyond which the life of a device may be impaired.

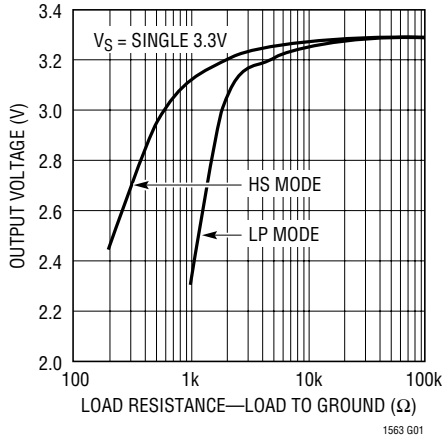
**Note 2:** The minimum cutoff frequency of the LTC1563 is arbitrarily listed as 256Hz. The limit is arrived at by setting the maximum resistor value limit at  $10\text{M}\Omega$ . The LTC1563 can be used with even larger valued resistors. When using very large values of resistance careful layout and thorough

assembly practices are required. There may also be greater DC offset at high temperatures when using such large valued resistors.

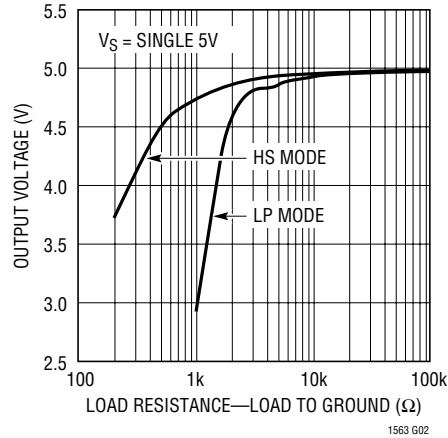
**Note 3:** The cutoff frequency temperature drift at low frequencies is as listed. At higher cutoff frequencies (approaching 25.6kHz in low power mode and approaching 256kHz in high speed mode) the internal amplifier's bandwidth can effect the cutoff frequency. At these limits the cutoff frequency temperature drift is  $\pm 15\text{ppm}/^\circ\text{C}$ .

# TYPICAL PERFORMANCE CHARACTERISTICS

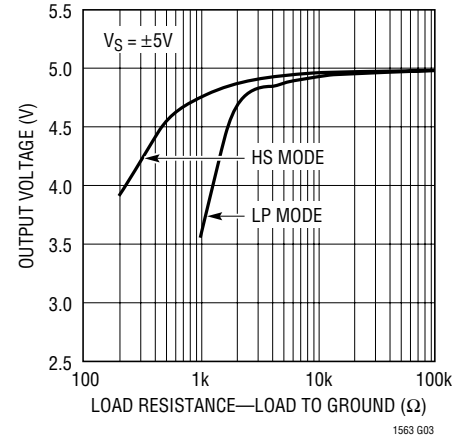
Output Voltage Swing High vs Load Resistance



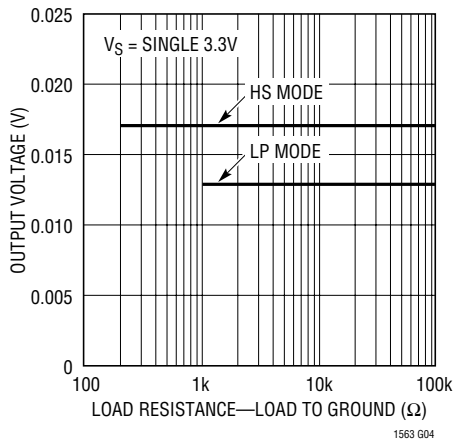
Output Voltage Swing High vs Load Resistance



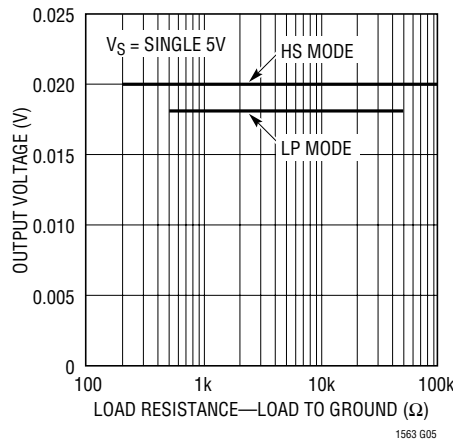
Output Voltage Swing High vs Load Resistance



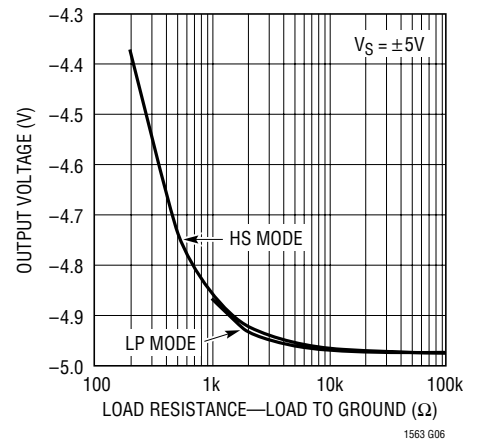
Output Voltage Swing Low vs Load Resistance



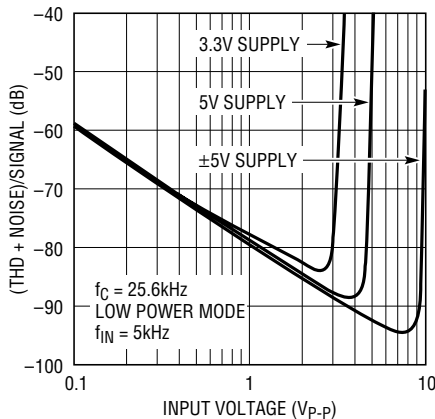
Output Voltage Swing Low vs Load Resistance



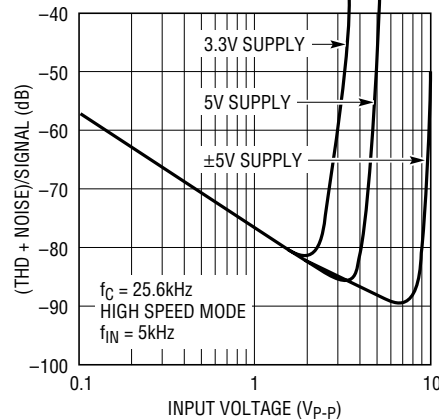
Output Voltage Swing Low vs Load Resistance



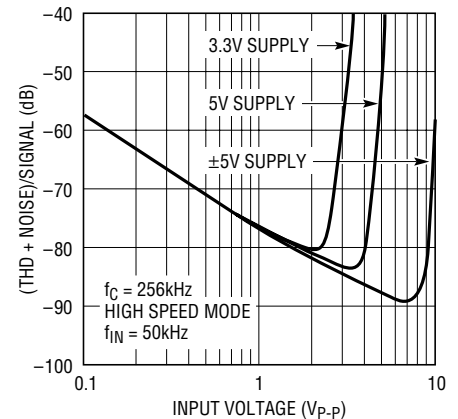
THD + Noise vs Input Voltage



THD + Noise vs Input Voltage

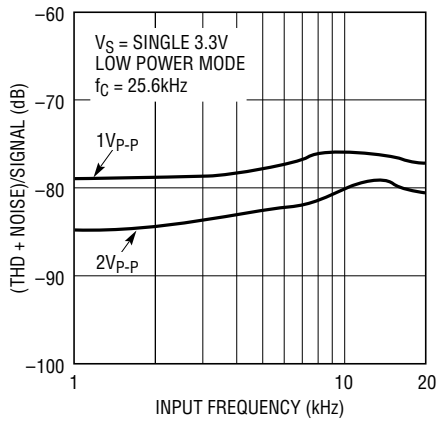


THD + Noise vs Input Voltage

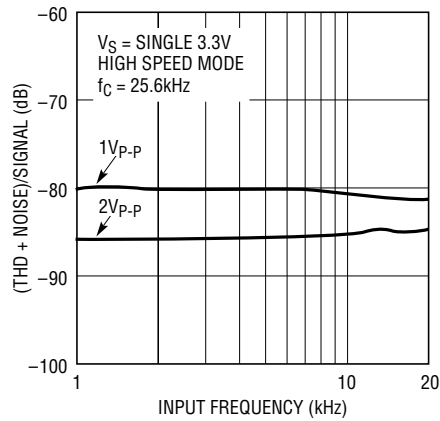


## TYPICAL PERFORMANCE CHARACTERISTICS

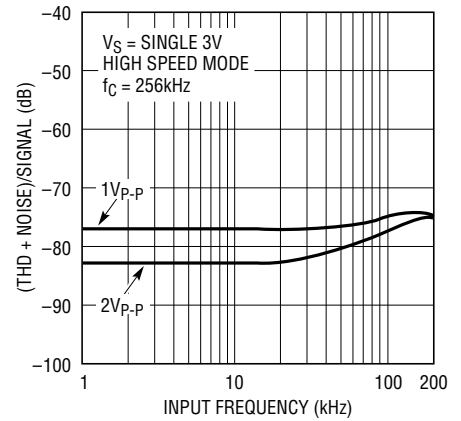
THD + Noise vs Input Frequency



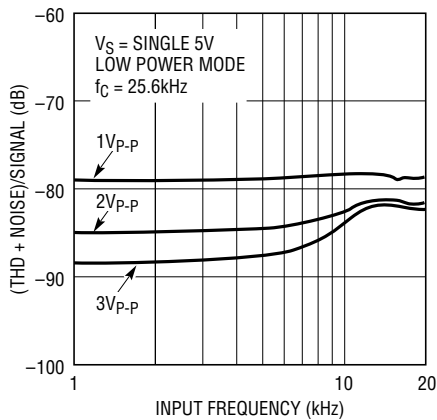
THD + Noise vs Input Frequency



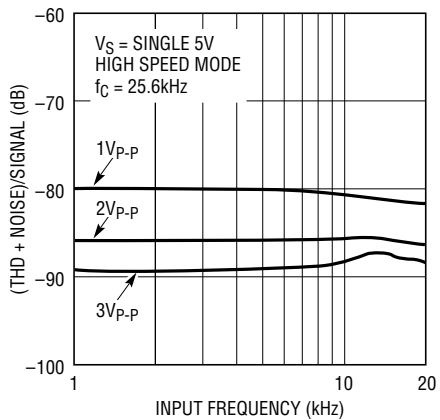
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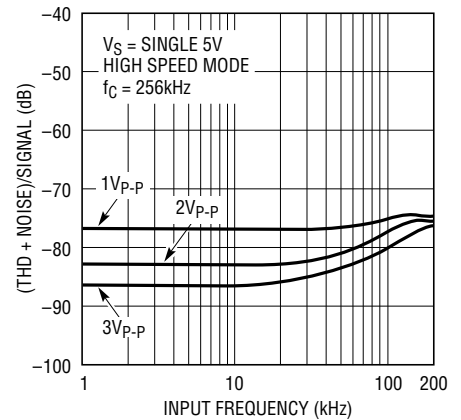
THD + Noise vs Input Frequency



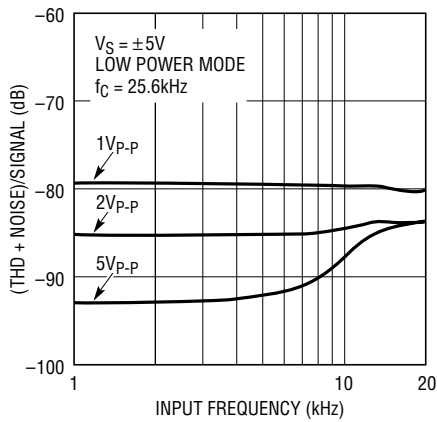
THD + Noise vs Input Frequency



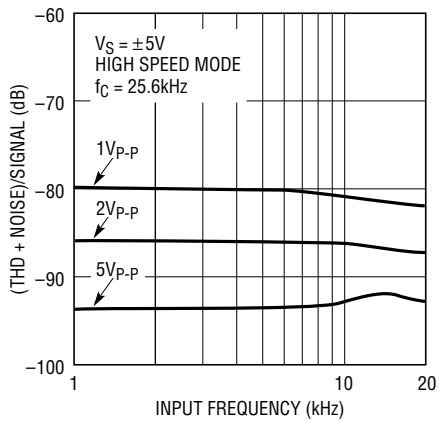
THD + Noise vs Input Frequency



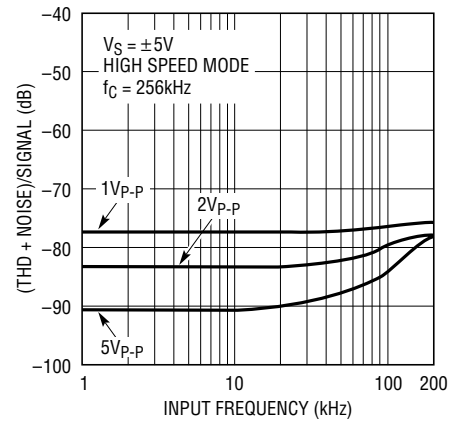
THD + Noise vs Input Frequency



THD + Noise vs Input Frequency

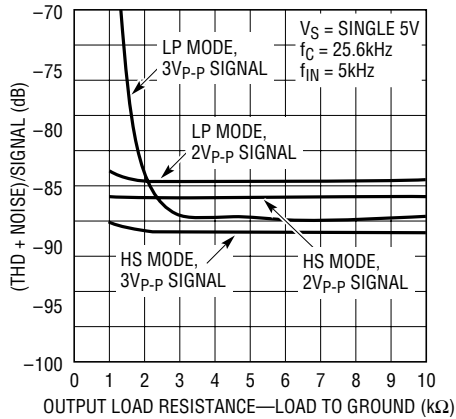


THD + Noise vs Input Frequency



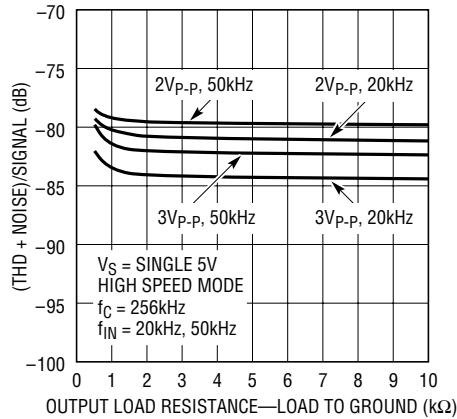
## TYPICAL PERFORMANCE CHARACTERISTICS

THD + Noise vs Output Load



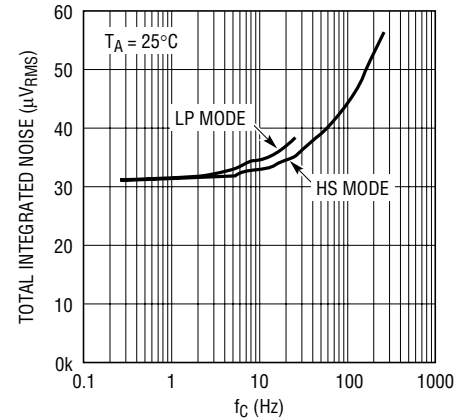
1563 G19

THD + Noise vs Output Load



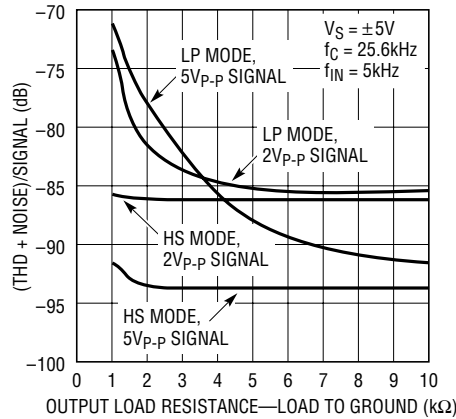
1563 G20

Output Voltage Noise vs Cutoff Frequency



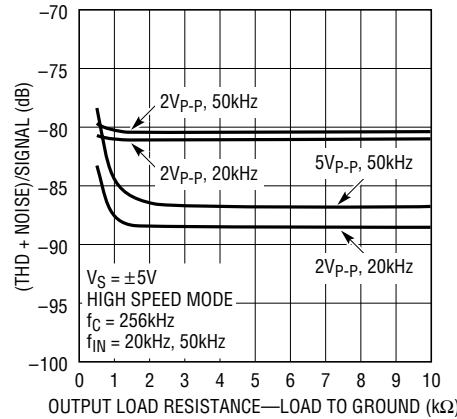
1563 G21

THD + Noise vs Output Load



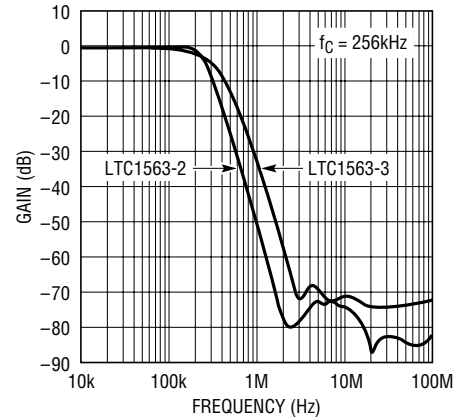
1563 G22

THD + Noise vs Output Load



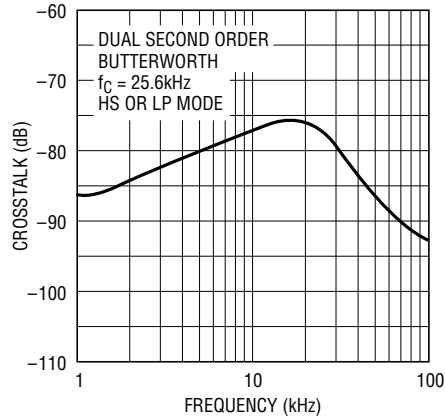
1563 G23

Stopband Gain vs Input Frequency



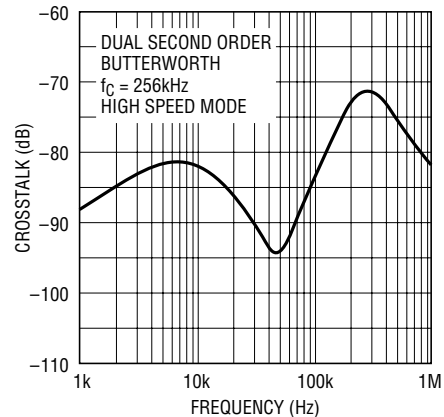
1563 G24

Crosstalk Rejection vs Frequency



1563 G25

Crosstalk Rejection vs Frequency



1563 G26

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## PIN FUNCTIONS

**$\overline{\text{LP}}$  (Pin 1):** Low Power. The LTC1563-X has two operating modes: Low Power and High Speed. Most applications will use the High Speed operating mode. Some lower frequency, lower gain applications can take advantage of the Low Power mode. When placed in the Low Power mode, the supply current is nearly an order of magnitude lower than the High Speed mode. Refer to the Applications Information section for more information on the Low Power mode.

The LTC1563-X is in the High Speed mode when the  $\overline{\text{LP}}$  input is at a logic high level or is open-circuited. A small pull-up current source at the  $\overline{\text{LP}}$  input defaults the LTC1563-X to the High Speed mode if the pin is left open. The part is in the Low Power mode when the pin is pulled to a logic low level or connected to  $V^-$ .

**SA, SB (Pins 2, 11):** Summing Pins. These pins are a summing point for signals fed forward and backward. Capacitance on the SA or SB pin will cause excess peaking of the frequency response near the cutoff frequency. The three external resistors for each section should be located as close as possible to the summing pin to minimize this effect. Refer to the Applications Information section for more details.

**NC (Pins 3, 5, 10, 12, 14):** These pins are not connected internally. For best performance, they should be connected to ground.

**INVA, INVB (Pins 4, 13):** Inverting Input. Each of the INV pins is an inverting input of an op amp. Note that the INV pins are high impedance, sensitive nodes of the filter and very susceptible to coupling of unintended signals. Capacitance on the INV nodes will also affect the frequency response of the filter sections. For these reasons, printed circuit connections to the INV pins must be kept as short as possible.

**LPA, LPB (Pins 6, 15):** Lowpass Output. These pins are the rail-to-rail outputs of an op amp. Each output is designed to drive a nominal net load of 5k $\Omega$  and 20pF. Refer to the Applications Information section for more details on output loading effects.

**AGND (Pin 7):** Analog Ground. The AGND pin is the midpoint of an internal resistive voltage divider developing a potential halfway between the  $V^+$  and  $V^-$  pins. The equivalent series resistance is nominally 10k $\Omega$ . This serves as an internal ground reference. Filter performance will reflect the quality of the analog signal ground. An analog ground plane surrounding the package is recommended. The analog ground plane should be connected to any digital ground at a single point. Figures 1 and 2 show the proper connections for dual and single supply operation.

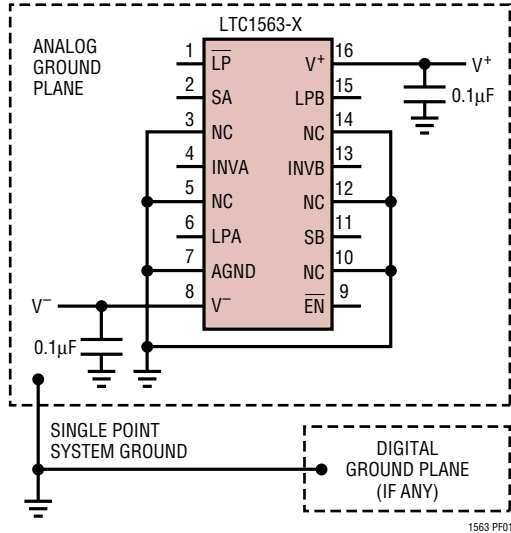
**$V^-$ ,  $V^+$  (Pins 8, 16):** The  $V^-$  and  $V^+$  pins should be bypassed with 0.1 $\mu\text{F}$  capacitors to an adequate analog ground or ground plane. These capacitors should be connected as closely as possible to the supply pins. Low noise linear supplies are recommended. Switching supplies are not recommended as they will decrease the filter's dynamic range. Refer to Figures 1 and 2 for the proper connections for dual and single supply operation.

**$\overline{\text{EN}}$  (Pin 9):**  $\overline{\text{ENABLE}}$ . When the  $\overline{\text{EN}}$  input goes high or is open-circuited, the LTC1563-X enters a shutdown state and only junction leakage currents flow. The AGND pin, the LPA output and the LPB output assume high impedance states. If an input signal is applied to a complete filter circuit while the LTC1563-X is in shutdown, some signal will normally flow to the output through passive components around the inactive part.

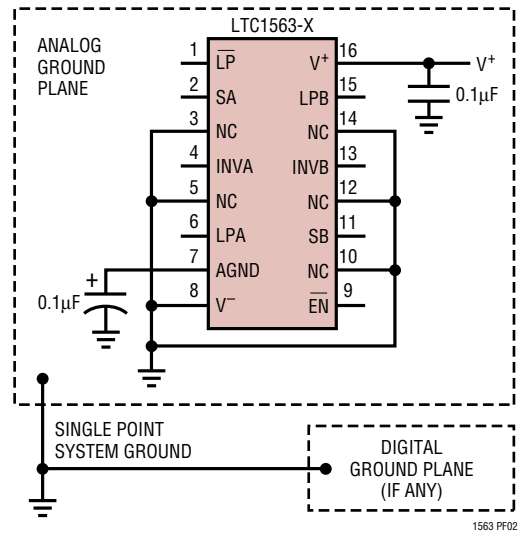
A small internal pull-up current source at the  $\overline{\text{EN}}$  input defaults the LTC1563 to the shutdown state if the  $\overline{\text{EN}}$  pin is left floating. Therefore, the user *must* connect the  $\overline{\text{EN}}$  pin to  $V^-$  (or a logic low) to enable the part for normal operation.

## PIN FUNCTIONS

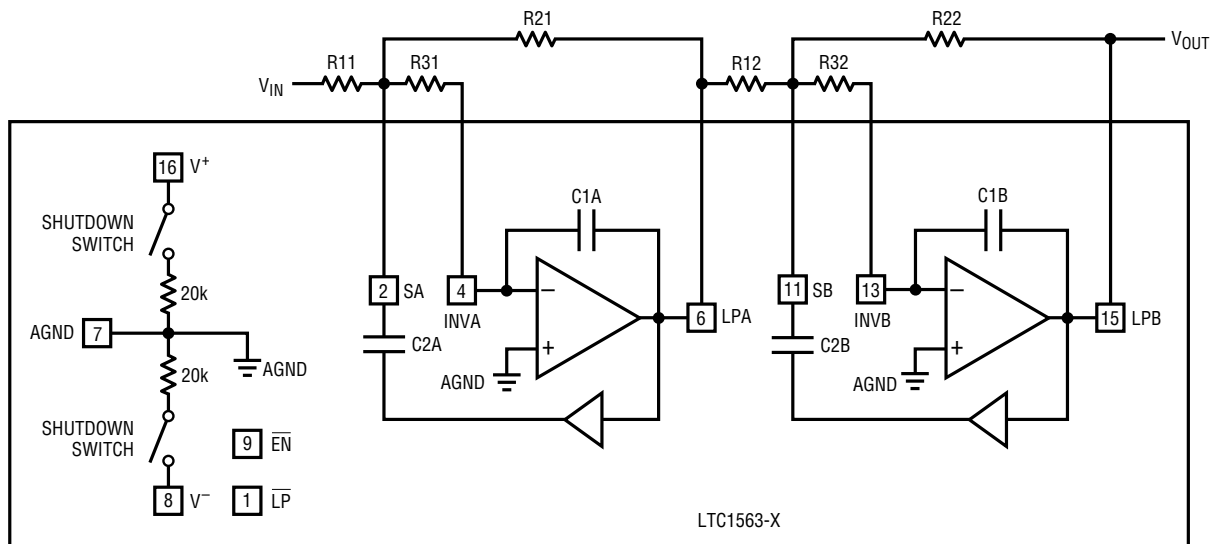
Dual Supply Power and Ground Connections



Single Supply Power and Ground Connections



## BLOCK DIAGRAM



PATENT PENDING

1563 BD

## APPLICATIONS INFORMATION

### Functional Description

The LTC1563-2/LTC1563-3 are a family of easy-to-use, 4th order lowpass filters with rail-to-rail operation. The LTC1563-2, with a single resistor value, gives a unity-gain filter approximating a Butterworth response. The LTC1563-3, with a single resistor value, gives a unity-gain filter approximating a Bessel (linear phase) response. The proprietary architecture of these parts allows for a simple unity-gain resistor calculation:

$$R = 10k(256kHz/f_C)$$

where  $f_C$  is the desired cutoff frequency. For many applications, this formula is all that is needed to design a filter. For example, a 50kHz filter requires a 51.2k resistor. In practice, a 51.1k resistor would be used as this is the closest E96, 1% value available.

The LTC1563-X is constructed with two 2nd order sections. The output of the first section (section A) is simply fed into the second section (section B). Note that section A and section B are similar, but not identical. The parts are designed to be simple and easy to use.

By simply utilizing different valued resistors, gain, other transfer functions and higher cutoff frequencies are achieved. For these applications, the resistor value calculation gets more difficult. The tables of formulas provided later in this section make this task much easier. For best results, design these filters using FilterCAD Version 3.0 (or newer) or contact the Linear Technology Filter Applications group for assistance.

### Cutoff Frequency ( $f_C$ ) and Gain Limitations

The LTC1563-X has both a maximum  $f_C$  limit and a minimum  $f_C$  limit. The maximum  $f_C$  limit (256kHz in High Speed mode and 25.6kHz in the Low Power mode) is set by the speed of the LTC1563-X's op amps. At the maximum  $f_C$ , the gain is also limited to unity.

A minimum  $f_C$  is dictated by the practical limitation of reliably obtaining large valued, precision resistors. As the desired  $f_C$  decreases, the resistor value required increases. When  $f_C$  is 256Hz, the resistors are 10M. Obtaining a reliable, precise 10M resistance between two points on a printed circuit board is somewhat difficult. For example, a 10M resistor with only 200M $\Omega$  of stray, layout related

resistance in parallel, yields a net effective resistance of 9.52M and an error of -5%. Note that the gain is also limited to unity at the minimum  $f_C$ .

At intermediate  $f_C$ , the gain is limited by one of the two reasons discussed above. For best results, design filters with gain using FilterCAD Version 3 (or newer) or contact the Linear Technology Filter Applications Group for assistance.

While the simple formula and the tables in the applications section deliver good approximations of the transfer functions, a more accurate response is achieved using FilterCAD. FilterCAD calculates the resistor values using an accurate and complex algorithm to account for parasitics and op amp limitations. A design using FilterCAD will always yield the best possible design. By using the FilterCAD design tool you can also achieve filters with cutoff frequencies beyond 256kHz. Cutoff frequencies up to 360kHz are attainable.

Contact the Linear Technology Filter Applications Group for a copy the FilterCAD software. FilterCAD can also be downloaded from our website at [www.linear.com](http://www.linear.com).

### DC Offset, Noise and Gain Considerations

The LTC1563-X is DC offset trimmed in a 2-step manner. First, section A is trimmed for minimum DC offset. Next, section B is trimmed to minimize the total DC offset (section A *plus* section B). This method is used to give the minimum DC offset in unity gain applications and most higher gain applications.

For gains greater than unity, the gain should be distributed such that most of the gain is taken in section A, with section B at a lower gain (preferably unity). This type of gain distribution results in the lowest noise and lowest DC offset. For high gain, low frequency applications, all of the gain is taken in section A, with section B set for unity-gain. In this configuration, the noise and DC offset is dominated by those of section A. At higher frequencies, the op amps' finite bandwidth limits the amount of gain that section A can reliably achieve. The gain is more evenly distributed in this case. The noise and DC offset of section A is now multiplied by the gain of section B. The result is slightly higher noise and offset.

## APPLICATIONS INFORMATION

### Output Loading: Resistive and Capacitive

The op amps of the LTC1563-X have a rail-to-rail output stage. To obtain maximum performance, the output loading effects must be considered. Output loading issues can be divided into resistive effects and capacitive effects.

Resistive loading affects the maximum output signal swing and signal distortion. If the output load is excessive, the output swing is reduced and distortion is increased. All of the output voltage swing testing on the LTC1563-X is done with  $R_{22} = 100k$  and a 10k load resistor. For best undistorted output swing, the output load resistance should be greater than 10k.

Capacitive loading on the output reduces the stability of the op amp. If the capacitive loading is sufficiently high, the stability margin is decreased to the point of oscillation at the output. Capacitive loading should be kept below 30pF. Good, tight layout techniques should be maintained at all times. These parts should not drive long traces and must never drive a long coaxial cable. *When probing the LTC1563-X, always use a 10x probe. Never use a 1x probe.* A standard 10x probe has a capacitance of 10pF to 15pF while a 1x probe's capacitance can be as high as 150pF. The use of a 1x probe will probably cause oscillation.

For larger capacitive loads, a series isolation resistor can be used between the part and the capacitive load. If the load is too great, a buffer must be used.

### Layout Precautions

The LTC1563-X is an active RC filter. The response of the filter is determined by the on-chip capacitors and the external resistors. Any external, stray capacitance in parallel with an on-chip capacitor, or to an AC ground, can alter the transfer function.

Capacitance to an AC ground is the most likely problem. Capacitance on the LPA or LPB pins does not affect the transfer function but does affect the stability of the op amps. Capacitance on the INVA and INVB pins will affect the transfer function somewhat and will also affect the stability of the op amps. Capacitance on the SA and SB pins alters the transfer function of the filter. These pins are the most sensitive to stray capacitance. Stray capacitance on these pins results in peaking of the frequency response

near the cutoff frequency. Poor layout can give 0.5dB to 1dB of excess peaking.

To minimize the effects of parasitic layout capacitance, all of the resistors for section A should be placed as close as possible to the SA pin. Place the R31 resistor first so that it is as close as possible to the SA pin on one end and as close as possible to the INVA pin on the other end. Use the same strategy for the layout of section B, keeping all of the resistors as close as possible to the SB node and first placing R32 between the SB and INVB pins. It is also best if the signal routing and resistors are on the same layer as the part without any vias in the signal path.

Figure 1 illustrates a good layout using the LTC1563-X with surface mount 0805 size resistors. An even tighter layout is possible with smaller resistors.

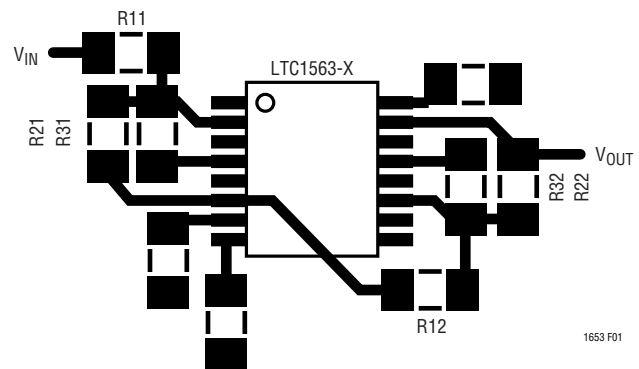


Figure 1. PC Board Layout

### Single Pole Sections and Odd Order Filters

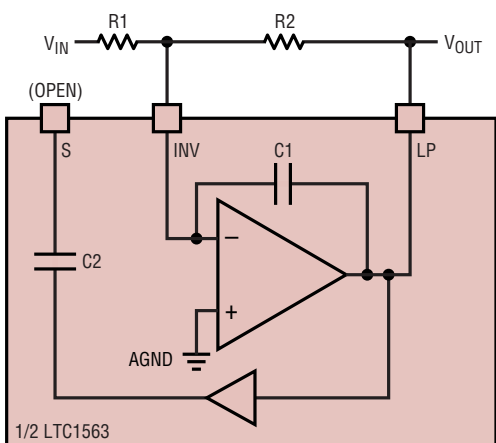
The LTC1563 is configured to naturally form even ordered filters (2nd, 4th, 6th and 8th). With a little bit of work, single pole sections and odd order filters are easily achieved. To form a single pole section you simply use the op amp, the on-chip C1 capacitor and two external resistors as shown in Figure 2. This gives an inverting section with the gain set by the  $R_2$ - $R_1$  ratio and the pole set by the  $R_2$ -C1 time constant. You can use this pole with a 2nd order section to form a noninverting gain 3rd order filter or as a stand alone inverting gain single pole filter.

Figure 3 illustrates another way of making odd order filters. The R1 input resistor is split into two parts with an additional capacitor connected to ground in between the resistors. This "TEE" network forms a single real pole. RB1

156323fa

## APPLICATIONS INFORMATION

should be much larger than RA1 to minimize the interaction of this pole with the 2nd order section. This circuit is useful in forming dual 3rd order filters and 5th order filters with a single LTC1563 part. By cascading two parts, 7th order and 9th order filters are achieved.



$$\text{DC GAIN} = \frac{-R2}{R1}$$

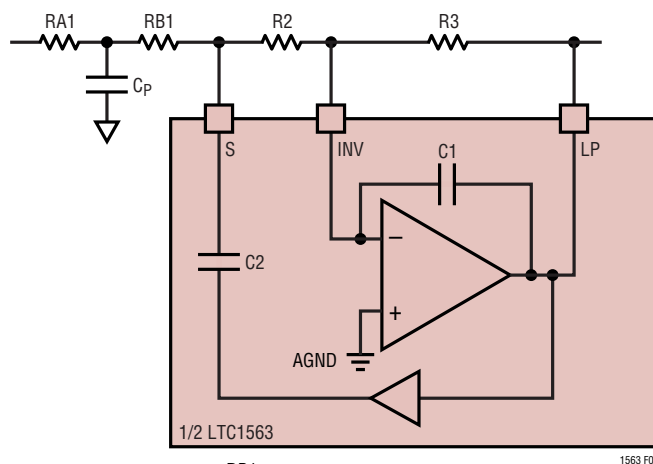
$$F_p = \frac{1}{2\pi \cdot R2 \cdot C1}$$

LTC1563-2: C1A = 53.9pF, C1B = 39.2pF  
LTC1563-3: C1A = 35pF, C1B = 26.8pF

1563 F02

Figure 2

You can also use the TEE network in both sections of the part to make a 6th order filter. This 6th order filter does not conform exactly to the textbook responses. Textbook responses (Butterworth, Bessel, Chebyshev etc.) all have three complex pole pairs. This filter has two complex pole pairs and two real poles. The textbook response always has one section with a low Q value between 0.5 and 0.6. By replacing this low Q section with two real poles (two real poles are the same mathematically as a complex pole pair with a Q of 0.5) and tweaking the Q of the other two complex pole pair sections you end up with a filter that is indistinguishable from the textbook filter. The Typical Applications section illustrates a 100kHz, 6th order pseudo-Butterworth filter. FilterCAD is a valuable tool for custom filter design and tweaking textbook responses.



$$RA1 = \frac{RB1}{10}$$

$$F_p = \frac{1}{2\pi \cdot \left( \frac{RA1 \cdot RB1}{RA1 + RB1} \right) C_p}$$

Figure 3

### What To Do with an Unused Section

If the LTC1563 is used as a 2nd or 3rd order filter, one of the sections is not used. Do not leave this section unconnected. If the section is left unconnected, the output is left to float and oscillation may occur. The unused section should be connected as shown in Figure 4 with the INV pin connected to the LP pin and the S pin left open.

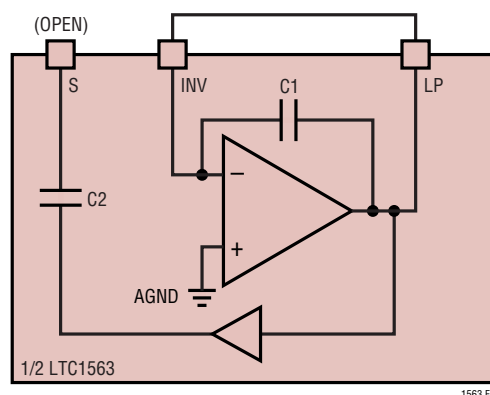


Figure 4

## APPLICATIONS INFORMATION

## 4th Order Filter Responses Using the LTC1563-2

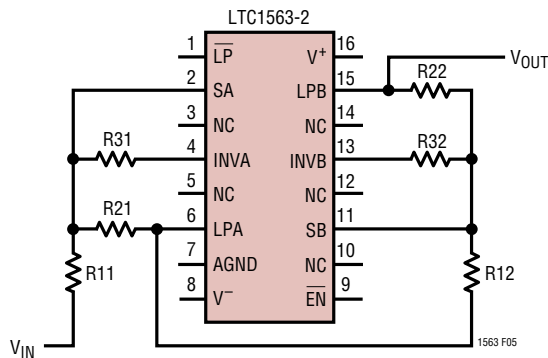


Figure 5. 4th Order Filter Connections (Power Supply, Ground, EN and LP Connections Not Shown for Clarity). Table 1 Shows Resistor Values

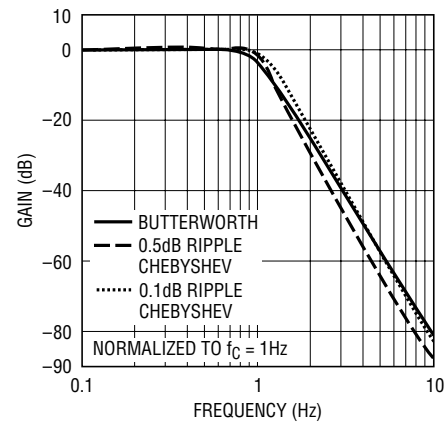


Figure 5a. Frequency Response

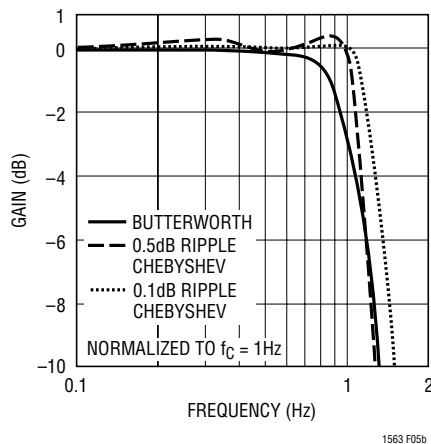


Figure 5b. Passband Frequency Response

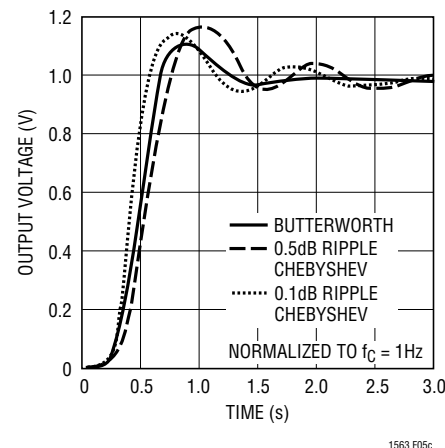


Figure 5c. Step Response

Table 1. Resistor Values, Normalized to 256kHz Cutoff Frequency ( $f_C$ ), Figure 5. The Passband Gain, of the 4th Order LTC1563-2 Lowpass Filter, Is Set to Unity. (Note 1)

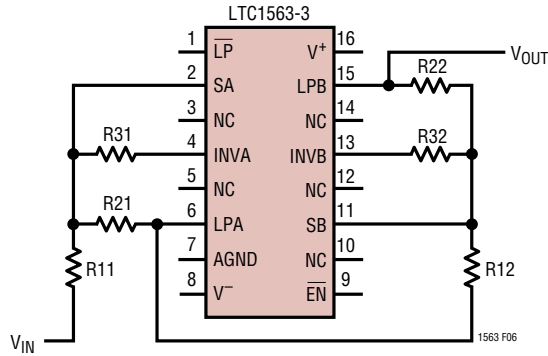
|                   | BUTTERWORTH       | 0.1dB RIPPLE<br>CHEBYSHEV | 0.5dB RIPPLE<br>CHEBYSHEV |
|-------------------|-------------------|---------------------------|---------------------------|
| LP Mode Max $f_C$ | 25.6kHz           | 15kHz                     | 13kHz                     |
| HS Mode Max $f_C$ | 256kHz            | 135kHz                    | 113kHz                    |
| R11 = R21 =       | $10k(256kHz/f_C)$ | $13.7k(256kHz/f_C)$       | $20.5k(256kHz/f_C)$       |
| R31 =             | $10k(256kHz/f_C)$ | $10.7k(256kHz/f_C)$       | $12.4k(256kHz/f_C)$       |
| R12 = R22 =       | $10k(256kHz/f_C)$ | $10k(256kHz/f_C)$         | $12.1k(256kHz/f_C)$       |
| R32 =             | $10k(256kHz/f_C)$ | $6.81k(256kHz/f_C)$       | $6.98k(256kHz/f_C)$       |

Example: In HS mode, 0.1dB ripple Chebyshev, 100kHz cutoff frequency,  $R_{11} = R_{21} = 35k \approx 34.8k$  (1%),  $R_{31} = 27.39k \approx 27.4k$  (1%),  $R_{12} = R_{22} = 256k \approx 255k$  (1%),  $R_{32} = 17.43k \approx 17.4k$  (1%)

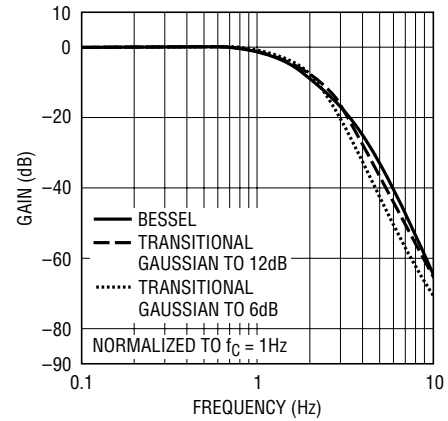
**Note 1:** The resistor values listed in this table provide good approximations of the listed transfer functions. For the optimal resistor values, higher gain or other transfer functions, use FilterCAD Version 3.0 (or newer) or contact the Linear Technology Filter Applications group for assistance.

# APPLICATIONS INFORMATION

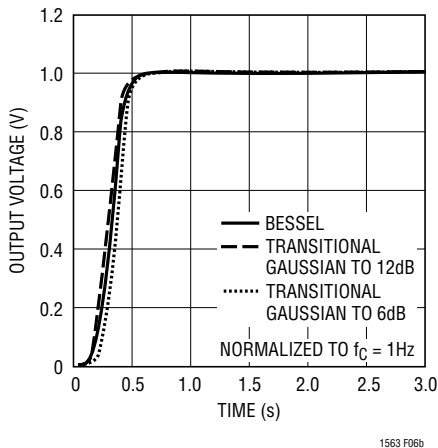
## 4th Order Filter Responses Using the LTC1563-3



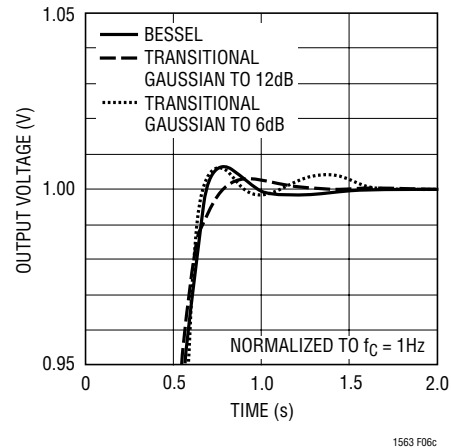
**Figure 6. 4th Order Filter Connections (Power Supply, Ground, EN and LP Connections Not Shown for Clarity). Table 2 Shows Resistor Values**



**Figure 6a. Frequency Response**



**Figure 6b. Step Response**



**Figure 6c. Step Response—Settling**

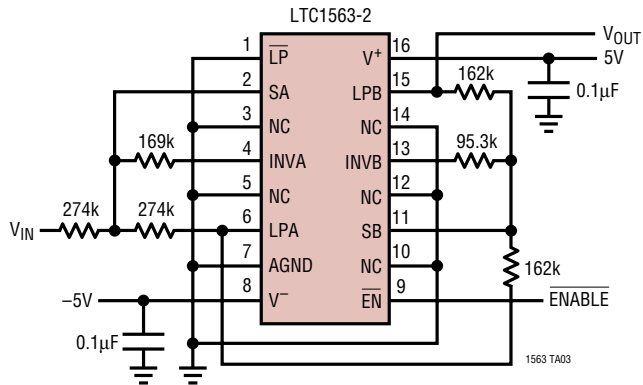
**Table 2. Resistor Values, Normalized to 256kHz Cutoff Frequency ( $f_C$ ), Figure 6. The Passband Gain, of the 4th Order LTC1563-3 Lowpass Filter, Is Set to Unity. (Note 1)**

|                   | BESSEL            | TRANSITIONAL<br>GAUSSIAN TO 6dB | TRANSITIONAL<br>GAUSSIAN TO 12dB |
|-------------------|-------------------|---------------------------------|----------------------------------|
| LP Mode Max $f_C$ | 25.6kHz           | 20kHz                           | 21kHz                            |
| HS Mode Max $f_C$ | 256kHz            | 175kHz                          | 185kHz                           |
| R11 = R21 =       | $10k(256kHz/f_C)$ | $17.4k(256kHz/f_C)$             | $15k(256kHz/f_C)$                |
| R31 =             | $10k(256kHz/f_C)$ | $13.3k(256kHz/f_C)$             | $11.8k(256kHz/f_C)$              |
| R12 = R22 =       | $10k(256kHz/f_C)$ | $14.3k(256kHz/f_C)$             | $10.5k(256kHz/f_C)$              |
| R32 =             | $10k(256kHz/f_C)$ | $6.04k(256kHz/f_C)$             | $6.19k(256kHz/f_C)$              |

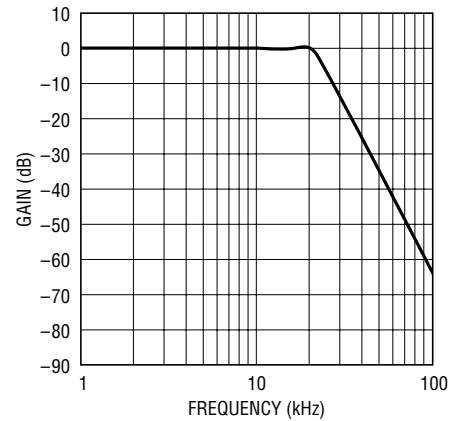
**Note 1:** The resistor values listed in this table provide good approximations of the listed transfer functions. For the optimal resistor values, higher gain or other transfer functions, use FilterCAD Version 3.0 (or newer) or contact the Linear Technology Filter Applications group for assistance.

## TYPICAL APPLICATIONS

**$\pm 5V$ , 2.3mA Supply Current, 20kHz, 4th Order, 0.5dB Ripple Chebyshev Lowpass Filter**

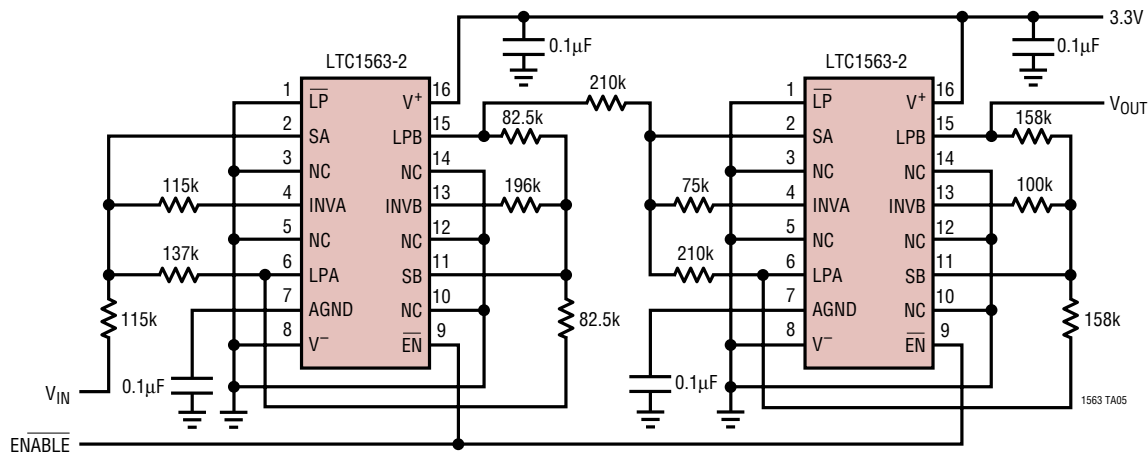


**Frequency Response**

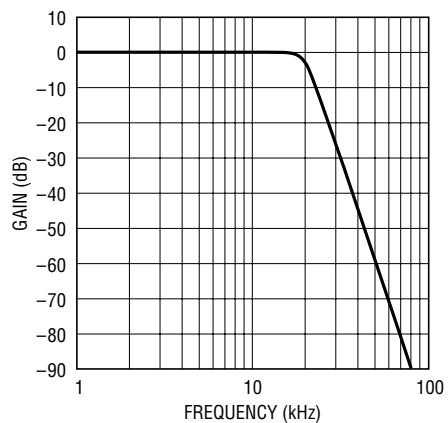


1563 TA04

**Single 3.3V, 2mA Supply Current, 20kHz 8th Order Butterworth Lowpass Filter**



**Frequency Response**

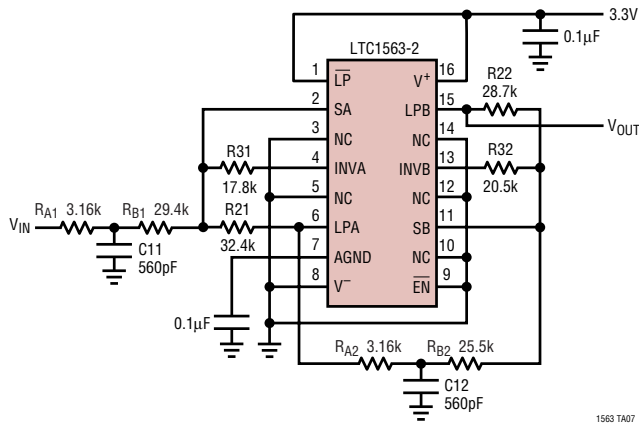


1563 TA06

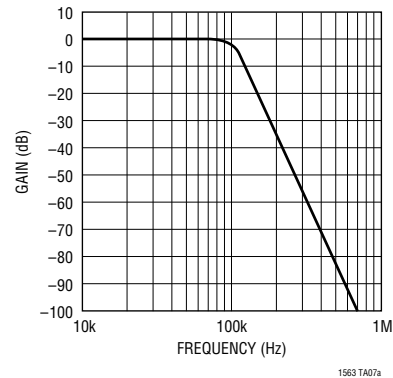
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## TYPICAL APPLICATIONS

100kHz, 6th Order Pseudo-Butterworth



Frequency Response



| TEXTBOOK BUTTERWORTH                   | PSEUDO-BUTTERWORTH                     |
|----------------------------------------|----------------------------------------|
| $f_{01} = 100\text{kHz}$ $Q1 = 1.9319$ | $f_{01} = 100\text{kHz}$ $Q1 = 1.9319$ |
| $f_{02} = 100\text{kHz}$ $Q2 = 0.7071$ | $f_{02} = 100\text{kHz}$ $Q2 = 0.7358$ |
| $f_{03} = 100\text{kHz}$ $Q3 = 0.5176$ | $f_{03} = 100\text{kHz}$ Real Poles    |
|                                        | $f_{04} = 100\text{kHz}$ Real Poles    |

The complex, 2nd order section of the textbook design with the lowest Q is replaced with two real first order poles. The Q of another section is slightly altered such that the final filter's response is indistinguishable from a textbook Butterworth response.

Other Pseudo Filter Response Coefficients (All  $f_0$  Are Normalized for a 1Hz Filter Cutoff)

|          | BESSEL | 0.1dB RIPPLE CHEBYSHEV | 0.5dB RIPPLE CHEBYSHEV | TRANSITIONAL GAUSSIAN TO 12dB | TRANSITIONAL GAUSSIAN TO 6dB |
|----------|--------|------------------------|------------------------|-------------------------------|------------------------------|
| $f_{01}$ | 1.9070 | 1.0600                 | 1.0100                 | 2.1000                        | 1.5000                       |
| $Q1$     | 1.0230 | 3.8500                 | 5.3000                 | 2.2000                        | 2.8500                       |
| $f_{02}$ | 1.6910 | 0.8000                 | 0.7200                 | 1.2500                        | 1.0500                       |
| $Q2$     | 0.6110 | 1.0000                 | 1.2000                 | 0.8000                        | 0.9000                       |
| $f_{03}$ | 1.6060 | 0.6000                 | 0.5000                 | 1.2500                        | 0.9000                       |
| $f_{04}$ | 1.6060 | 1.0000                 | 0.8000                 | 1.2500                        | 0.9000                       |

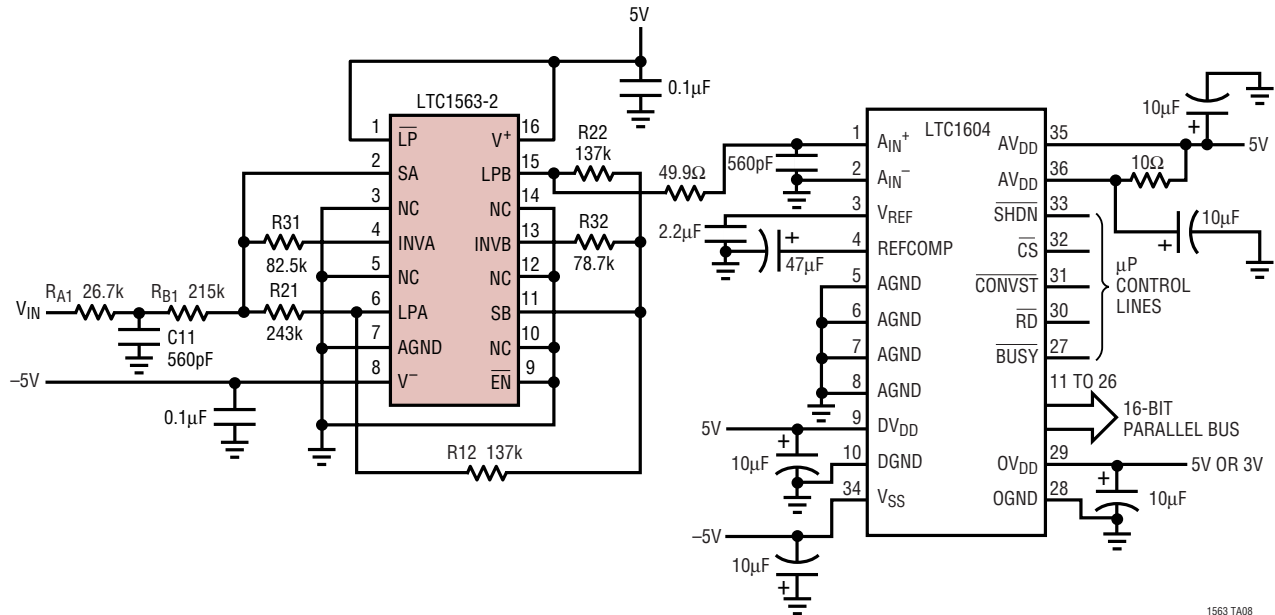
The  $f_0$  and Q values listed above can be entered in FilterCAD's Enhanced Design window as a custom response filter. After entering the coefficients, FilterCAD will produce a schematic of the circuit. The procedure is as follows:

1. After starting FilterCAD, select the Enhanced Design window.
2. Select the Custom Response and set the custom  $F_C$  to 1Hz.
3. In the Coefficients table, go to the Type column and click on the types listed and set the column with two LP types and two LP1 types. This sets up a template of a 6th order filter with two 2nd order lowpass sections and two 1st order lowpass sections.
4. Enter the  $f_0$  and Q coefficients as listed above. For a Butterworth filter, use the same coefficients as the example circuit above except set all of the  $f_0$  to 1Hz.
5. Set the custom  $F_C$  to the desired cutoff frequency. This will automatically multiply all of the  $f_0$  coefficients. You have now finished the design of the filter and you can click on the frequency response or step response buttons to verify the filter's response.
6. Click on the Implement button to go on to the filter implementation stage.
7. In the Enhanced Implement window, click on the Active RC button to choose the LTC1563-2 part. You are now done with the filter's implementation. Click on the schematic button to view the resulting circuit.

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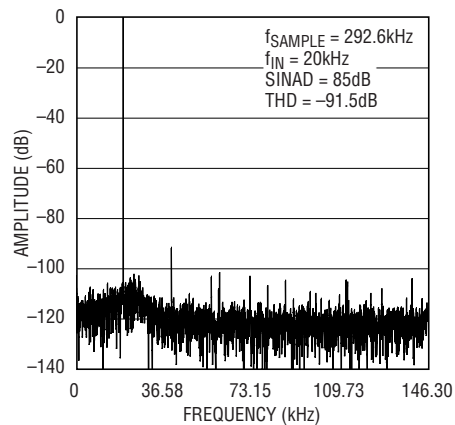
## TYPICAL APPLICATIONS

22kHz, 5th Order, 0.1dB Ripple Chebyshev Lowpass Filter  
Driving the LTC1604, 16-Bit ADC



1563 TA08

4096 Point FFT of the Output Data

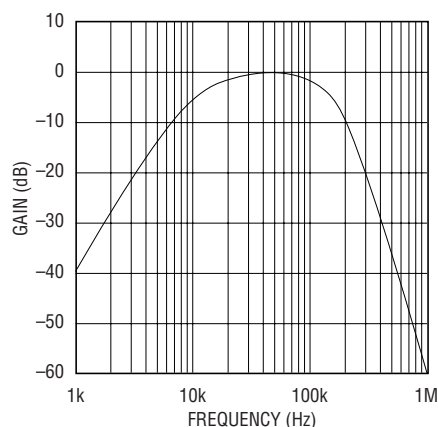
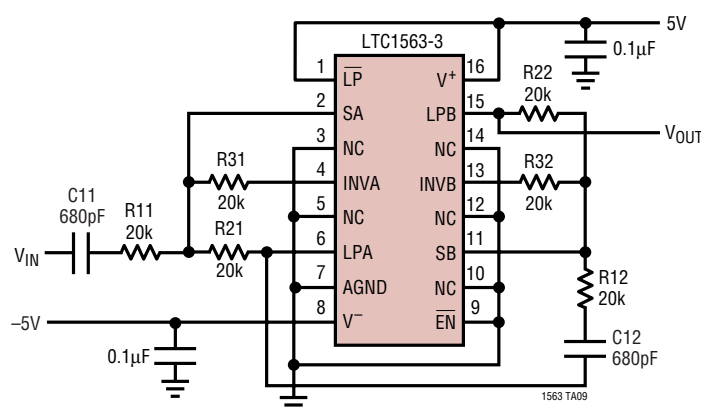


1563 TA08a

## TYPICAL APPLICATIONS

## 50kHz Wideband Bandpass

4th Order Bessel Lowpass at 128kHz with Two Highpass Poles at 11.7kHz Yields a Wideband Bandpass Centered at 50kHz



To design these wideband bandpass filters with the LTC1563, start with a 4th order lowpass filter and add two highpass poles with the input, AC coupling capacitors. The lowpass cutoff frequency and highpass pole frequencies depend on the specific application. Some experimentation of lowpass and highpass frequencies is required to achieve the desired response. FilterCAD does not directly support this configuration. Use the custom design window in FilterCAD get the desired response and then use FilterCAD to give the schematic for the lowpass portion of the filter. Calculate the two highpass poles using the following formulae:

$$f_0(\text{HPA}) = \frac{1}{2 \cdot \pi \cdot R11 \cdot C11}, f_0(\text{HPB}) = \frac{1}{2 \cdot \pi \cdot R12 \cdot C12}$$

The design process is as follows:

1. After starting FilterCAD, select the Enhanced Design window.
2. Choose a 4th order Bessel or Butterworth lowpass filter response and set the cutoff frequency to the high frequency corner of the desired bandpass.
3. Click on the custom response button. This copies the lowpass coefficients into the custom design Coefficients table.
4. In the Coefficients table, the first two rows are the LP Type with the  $f_0$  and Q as previously defined. Go to the third and fourth rows and click on the Type column (currently a hyphen is in this space). Change the Type of each of these rows to type HP1. This sets up a template of a 6th order filter with two 2nd order lowpass sections and two 1st order highpass sections.
5. Change the frequency of the highpass (HP1) poles to get the desired frequency response.
6. You may have to perform this loop several times before you close in on the correct response.
7. Once you have reached a satisfactory response, note the highpass pole frequencies. The HP1 highpass poles must now be removed from the Custom design coefficients table. After removing the highpass poles, click on the Implement button to go on to the filter implementation stage.
8. In the Enhanced Implement window, click on the Active RC button and choose the LTC1563-2 part. Click on the schematic button to view the resulting circuit.
9. You now have the schematic for the 4th order lowpass part of the design. Now calculate the capacitor values from the following formulae:

$$C11 = \frac{1}{2 \cdot \pi \cdot R11 \cdot f_0(\text{HPA})}, C12 = \frac{1}{2 \cdot \pi \cdot R12 \cdot f_0(\text{HPB})}$$

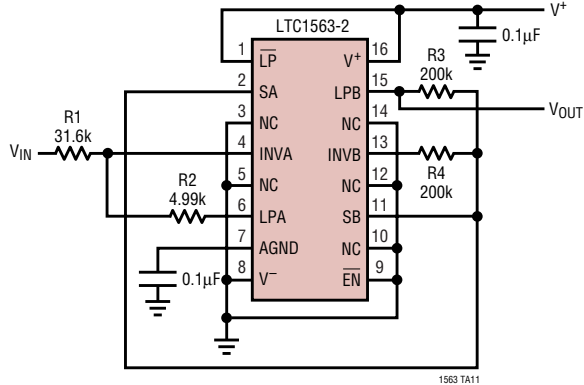
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## TYPICAL APPLICATIONS

### Single Supply, 10kHz, Bandpass Filter

Maximum  $f_{\text{center}} = 120\text{kHz}$  ( $-3\text{dB}$  Bandwidth =  $f_{\text{center}}/10$ )

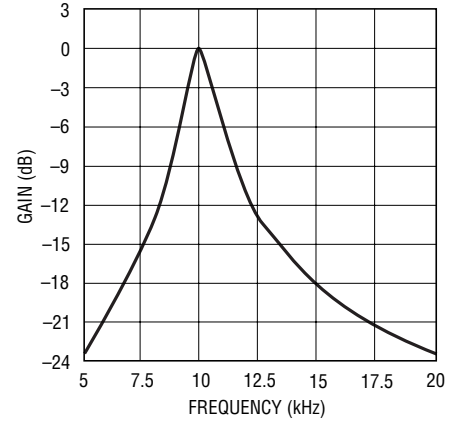


$$\text{GAIN AT } f_{\text{CENTER}} = \frac{31.6k}{R_1} \quad \text{MAXIMUM GAIN} = 120\text{kHz}/f_{\text{CENTER}}$$

$$R_2 = 4.99k \quad R_3 = R_4 = R$$

$$R = \frac{10^{21}}{f_{\text{CENTER}} \cdot (f_{\text{CENTER}}^2 + 5 \cdot 10^{11})}$$

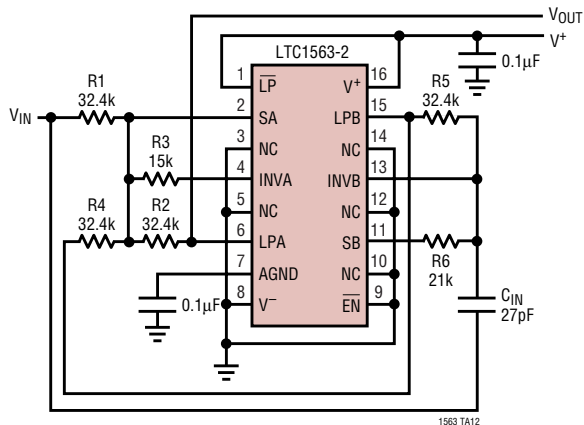
### Frequency Response



1563 TA11a

### Single Supply, 100kHz, Elliptic Lowpass Filter

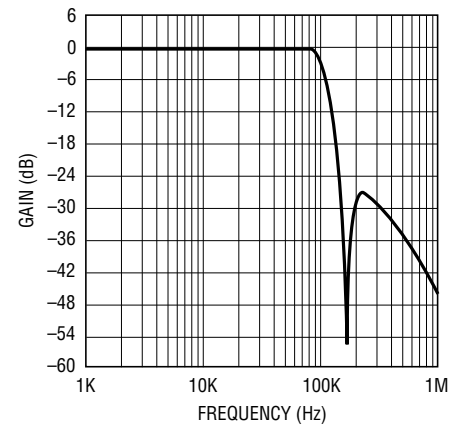
Maximum  $f_{\text{cutoff}} = 120\text{kHz}$



PASSBAND GAIN = 0dB  
STOPBAND ATTENUATION = 26dB AT  $1.5 \times f_{\text{CUTOFF}}$   
 $C_{\text{IN}} = 27\text{pF}$   $R_2 = R_4 = R_5 = R_1$

$$R_1 = \frac{3.24 \cdot 10^9}{f_{\text{CUTOFF}}} \quad R_3 = \frac{R_1}{2.16} \quad R_6 = \frac{R_1}{1.54}$$

### Frequency Response



1563 TA12a

## RELATED PARTS

| PART NUMBER | DESCRIPTION                                                | COMMENTS                                               |
|-------------|------------------------------------------------------------|--------------------------------------------------------|
| LTC1560-1   | 5-Pole Elliptic Lowpass, $f_c = 1\text{MHz}/0.5\text{MHz}$ | No External Components, SO-8                           |
| LTC1562     | Universal Quad 2-Pole Active RC                            | $10\text{kHz} < f_0 < 150\text{kHz}$                   |
| LTC1562-2   | Universal Quad 2-Pole Active RC                            | $20\text{kHz} < f_0 < 300\text{kHz}$                   |
| LTC1569-6   | Low Power 10-Pole Delay Equalized Elliptic Lowpass         | $f_c < 80\text{kHz}$ , One Resistor Sets $f_c$ , SO-8  |
| LTC1569-7   | 10-Pole Delay Equalized Elliptic Lowpass                   | $f_c < 256\text{kHz}$ , One Resistor Sets $f_c$ , SO-8 |
| LTC1565-31  | 650kHz Continuous Time, Linear Phase Lowpass               | $f_c = 650\text{kHz}$ , Differential In/Out            |
| LTC1568     | Very Low Noise 4 <sup>th</sup> Order Filter Building Block | $f_c < 10\text{MHz}$                                   |

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