参考資料

# *デザイン・ガイド: TIDA-060021*
# *高インピーダンス・アプリケーション向けの、カスケード接続された高ゲインのアクティブ・ローパス・フィルタのリファレンス・デザイン*

TEXAS INSTRUMENTS

## 概要

このデザインは、OPA2810 高速アンプを使用して、カットオフ周波数が 1MHz の 2 つのマルチ帰還 (MFB) ローパス・フィルタ基板を提供します。4 次の基板により、ゲインが大きくロールオフが鋭い 4 次フィルタを実現します。高インピーダンス基板 (High-Z) は、前段の出力インピーダンスが大きいシステムに適した 2 次フィルタです。このリファレンス・デザインに使用されている基板はどちらも、大きなゲインと広い電源電圧範囲を持つフィルタで、ノイズと歪みを最小化することに特化されています。OPA810 は、OPA2810 デバイスのシングル・チャネル版です。

## リソース

| | |
|---|---|
| TIDA-060021 | デザイン・フォルダ |
| OPA2810 | プロダクト・フォルダ |
| OPA810 | プロダクト・フォルダ |
| TINA-TI | ツール・フォルダ |
| Filter-Pro | ツール・フォルダ |

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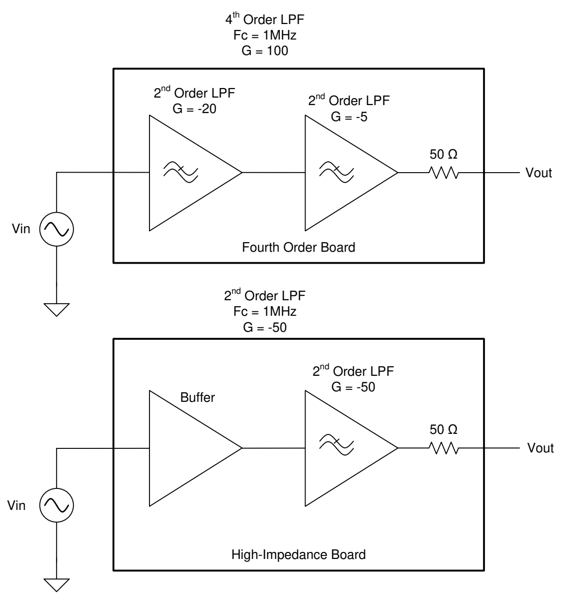
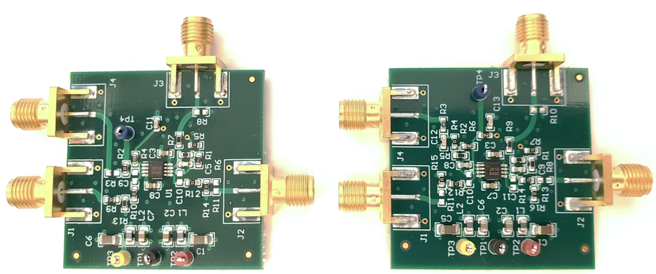
## 特長

- カスケード接続されたローパス・フィルタで、最大 40dB のゲインと、1MHz のカットオフ周波数を実現
- 複数帰還トポロジによる 4 次および 2 次のデザイン
- 小型の 2 段設計による高ゲインと 2 次または 4 次のフィルタ
- オーバーシュートとリンギングが最小で、高い安定性を達成
- 歪みとノイズの低い設計
- JFET 入力の OPA2810 を使用し、低い入力ノイズ、高い同相除去率 (CMRR)、高速なスルーレートを実現
- 広い電源電圧範囲と高い出力電圧に対応した設計

## アプリケーション

- データ・アクイジション (DAQ)
- スペクトラムおよびネットワーク・アナライザ
- オシロスコープ
- アクティブ・プローブ





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# 1 System Description

With improvements in amplifier capabilities over time, active filters have become more common in higher frequency applications. Compared to passive filters, active filters can provide gain and also improve the size, cost, and flexibility of a design. With the right amplifier and configuration, active filters can prove useful in many filter applications.

Texas Instruments' FilterPro™ software tool was used in the design of both active filters featured in the TIDA-060021 boards. Each board has a different emphasis on its design, but both boards are made up of two stages:

- The High-Z board is made up of a buffer, followed by a 34-dB gain, MFB filter. The original input signal is inverted because the High-Z board only uses one MFB filter. The use of a buffer for the first stage allows the filter to have a large input impedance.
- The fourth-order design uses an MFB filter for both stages, leading to a greater gain of 40 dB, steeper roll-off and no inversion of the input. This design, however, does not use a buffer and therefore has an input impedance of only 412 Ω.

## *1.1 Key System Specifications*

**表 1. Key System Specifications**

| PARAMETER | SPECIFICATIONS (High-Z) | SPECIFICATIONS (4th Order) |
|---|---|---|
| Filter order | 2nd-order | 4th-order |
| Gain | 34 dB | 40 dB |
| Input impedance | 12 GΩ | 412 Ω |
| Cutoff frequency | 1.04 MHz | 1.04 MHz |
| Pass-band ripple | < 1 dB | < 1 dB |
| Stop-band attenuation | 34 dB | 40 dB |
| Stop-band cut-off frequency | 15.16 MHz | 4.53 MHz |
| Q-factor (first stage) | n/a | 0.556 |
| Q-factor (second stage) | 0.599 | 1.06 |
| Total supply voltage (min) | 4.75 V | 4.75 V |
| Total supply voltage (max) | 27 V | 27 V |



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# 2 System Overview

## 2.1 Block Diagrams

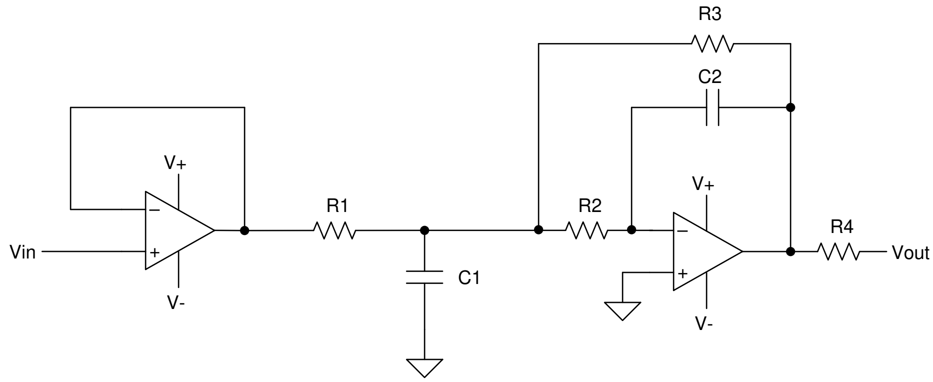


図 1. High-Z, 2nd-Order Filter Circuit

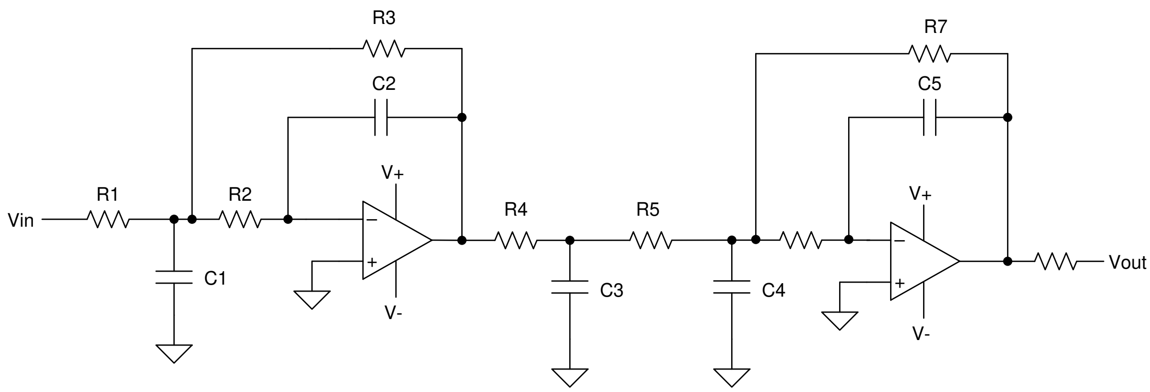


図 2. 4th-Order Filter Circuit

## 2.2 Design Considerations

### 2.2.1 Filter Topology

A multiple-feedback (MFB) topology was chosen for both designs because of its reliability in high-gain and high-frequency applications. To provide gain to a Sallen-Key filter, two resistors must be added to the typical configuration. However, an MFB filter uses fewer components to provide both higher gains and better stop-band rejection. Another issue with Sallen-Key filters is their high-pass like effects at higher frequencies. To mitigate this effect, larger resistances are needed, leading to greater noise in the overall system.

Both designs are given topologies where a combination of the desired filter gain, quality factor, and corner frequency determine the component values of the design. 式 1 shows the transfer function of a low-pass MFB filter using the second stage of the High-Z board in 図 1.

$$A(s) = \frac{\frac{-1}{C_1 C_2 R_1 R_2}}{S^2 + \frac{R_1 + R_2\left(1 + \frac{R_1}{R_3}\right)}{C_1 R_1 R_2} + \frac{1}{C_1 C_2 R_2 R_3}} \quad (1)$$


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### 2.2.2 Filter Properties

A 0.05° equiripple linear phase filter was chosen for the type of response for both the High-Z and fourth-order designs. A linear phase filter displays characteristics between that of a Bessel and Butterworth response. By introducing slight ripple into the phase response of the filter, a faster roll-off rate and bandwidth than that of a Bessel filter can be achieved. This linear-phase filter has more overshoot than a Bessel filter but less than that of a Butterworth response. 表 2 shows the quality factors of each filter stage. For more information on the types of low-pass filter responses and their comparisons, see the *How to compare your circuit requirements to active-filter approximations* technical brief.

**表 2. Quality Factor of Filter Designs**

| BOARD | STAGE 1 | STAGE 2 |
|---|---|---|
| High-Z | — | 0.599 |
| 4th-order | 0.556 | 1.06 |

### 2.2.3 Noise

In order to minimize the total noise of each filter, op amp noise must be the dominating factor in both designs. The OPA2810 voltage noise is the dominant source of amplifier noise because the OPA2810 is a FET-input device. Components are the largest factor in achieving a lower noise solution because the properties of the OPA2810 are fixed. As a result, noise must be considered when determining component values, along with the quality factor, gain, and cutoff frequency of the filter. 図 3 and 図 4 compare the total simulated integrated noise results of both filters, with an equivalent circuit using noiseless resistors. This comparison provides insight to the noise contribution of both the amplifiers and components to the overall system noise.

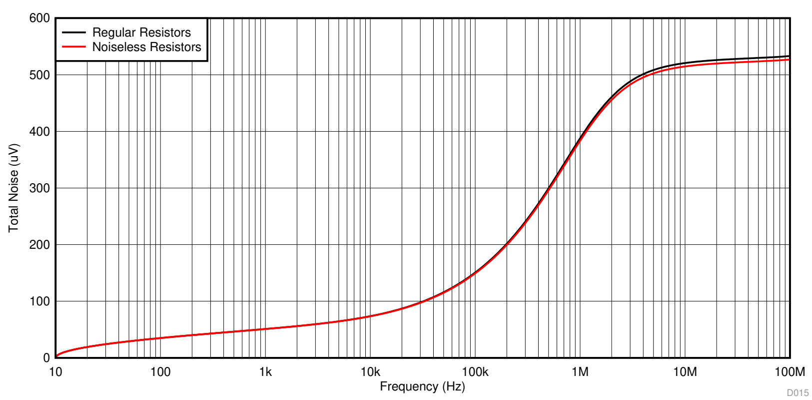


**図 3. Noise Comparison for the High-Z Board**


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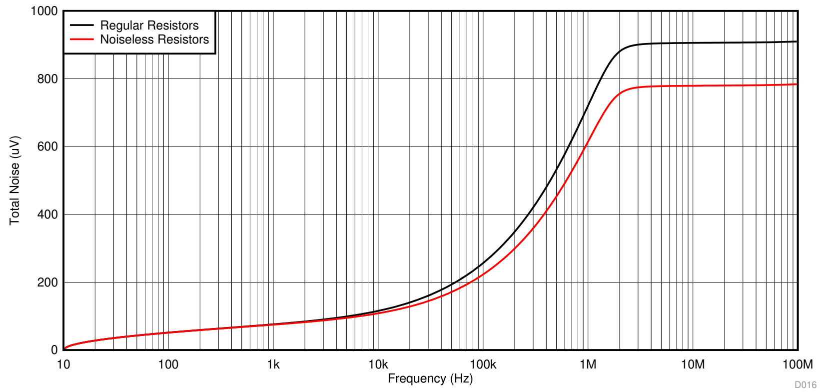


**図 4. Noise Comparison for the 4th-Order Board**

Appendix A of *Design Methodology for MFB Filters in ADC Interface Applications* application report describes the effect of each noise source on the final output of an MFB filter. The noticeable resistor noise in the fourth-order filter is a cause of the feedback resistance of the first stage. By lowering this resistance, resistor R1 must also be lowered, reducing the input impedance of the filter even further. If low input impedance is not a concern, the noise of the fourth-order board can be reduced by reducing these gain resistors and adjusting other components of the first stage to maintain the same quality factor and cutoff frequency.

## 2.3 Highlighted Products

### 2.3.1 OPA2810

The OPA2810 is a dual-channel, field-effect transistor (FET)-input, voltage-feedback operational amplifier with low input bias current. The OPA2810 is unity-gain stable with a small-signal unity-gain bandwidth of 105 MHz, and offers excellent DC precision and dynamic AC performance at a low quiescent current ($I_Q$) of 3.6 mA per channel (typical). The OPA2810 is fabricated on Texas Instrument's proprietary, high-speed silicon germanium (SiGe) bipolar CMOS (BiCMOS) process and achieves significant performance improvements over comparable FET-input amplifiers at similar levels of quiescent power. With a gain-bandwidth product (GBWP) of 70 MHz, slew rate of 192 V/µs, and low voltage noise of 6 nV/$\sqrt{Hz}$, the OPA2810 is well suited for use in a wide range of high-fidelity data-acquisition and signal-processing applications.

The OPA2810 is characterized to operate over a wide supply range of 4.75 V to 27 V, and features rail-to-rail inputs and outputs. The OPA2810 amplifier delivers 75 mA of linear output current, suitable for driving optoelectronics components and analog-to-digital converter (ADC) inputs or buffering digital-to-analog (DAC) outputs into heavy loads.

### 2.3.2 OPA810

The OPA810 is a single-channel variant of the OPA2810, and could also be used in this design.


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# 3 Hardware, Software, Testing Requirements, and Test Results

## 3.1 Required Hardware and Software

### 3.1.1 Hardware

The various hardware inputs and outputs of the TIDA-060021 boards are provided below:

- Terminals TP1, TP2, and TP3 provide inputs to power the board (GND, VCC, and VEE, respectively)
- SMA connectors J1 and J4 provide filter inputs for the High-Z and fourth-order boards, respectively
- SMA connector J3 provides the filter output

## 3.2 Testing and Results

### 3.2.1 Test Setup

3.1.1 describes the inputs and outputs required to power and run each of the TIDA-060021 boards. Each board is powered with a dual power supply of ±12 V with output swings dependent on the type of test. The test results are taken at a free-air operating ambient temperature value ($T_A$) of 25°C with no forced air regulating temperature of the EVM, unless otherwise noted in the results.


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### 3.2.2 Test Results

#### *3.2.2.1 Frequency Response*

As shown in 図 5 and 図 6, the frequency response results closely resemble the data returned during simulations. A large-signal response with an output voltage of 6 $V_{PP}$ is used for the measured data whereas the simulated curve is a small-signal response. Both responses illustrate that at larger outputs, the OPA2810 slew limit is not reached and there is minimal loss in the frequency response of both filters. This minimal loss illustrates that the measured response also matches simulations at lower output levels.

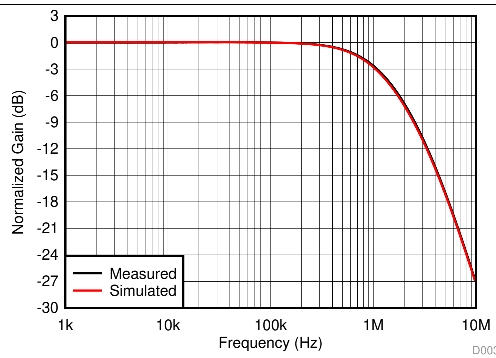


**図 5. Frequency Response for the High-Z Board**

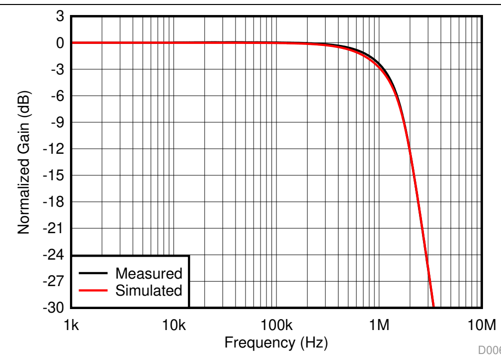


**図 6. Frequency Response for the 4th-Order Board**

#### *3.2.2.2 Noise*

For both boards, the measured noise matched the simulated results. Differences in noise can be attributed to a deviation from of the OPA2810 typical noise specifications and from component tolerances that are then amplified by the high gain of the board. 図 7 and 図 8 show noise test results for the High-Z and fourth-order boards, respectively.

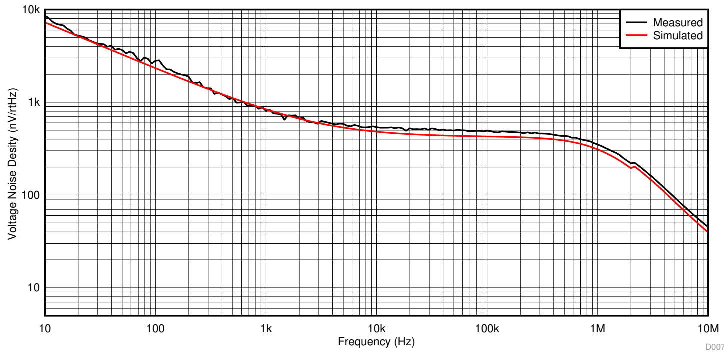


**図 7. Noise Test Results for the High-Z Board**


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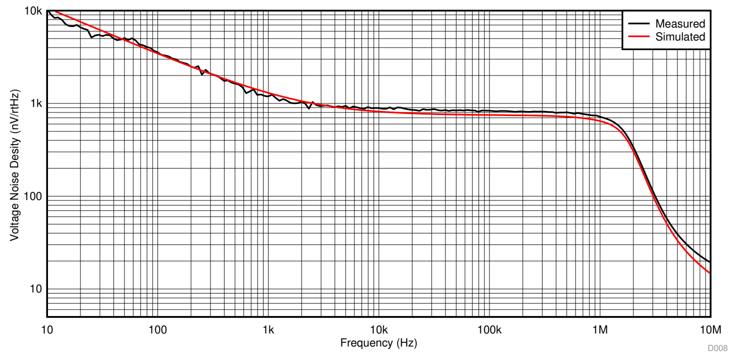


**図 8. Noise Test Results for the 4th-Order Board**

#### 3.2.2.3 Distortion

図 9 through 図 12 show the harmonic distortion of both boards. There is increased distortion between these figures and the distortion figure of the OPA2810 data sheet. The data sheet results, however, use a low-gain-test configuration to measure distortion. 図 13 and 図 14 display the total harmonic distortion plus noise (THD+N) results of each board, which remain relatively constant over the measured frequency range. This constant result represents the noise floor of each board and illustrates that noise is the dominating factor of THD+N in the frequency range of these figures. 図 13 and 図 14 also illustrate that THD+N is improved at larger output voltages because the signal-to-noise ratio (SNR) increases when noise is kept constant when the output signal level increases.

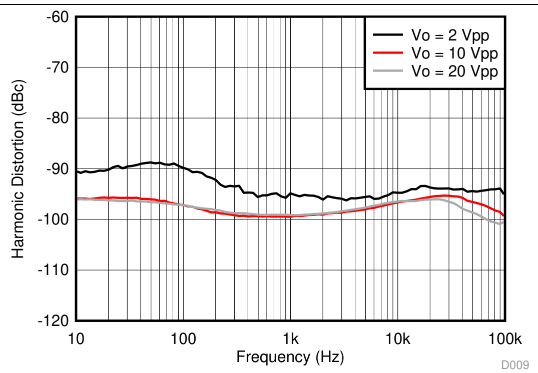


**図 9. 2nd-Harmonic Distortion for the High-Z Board**

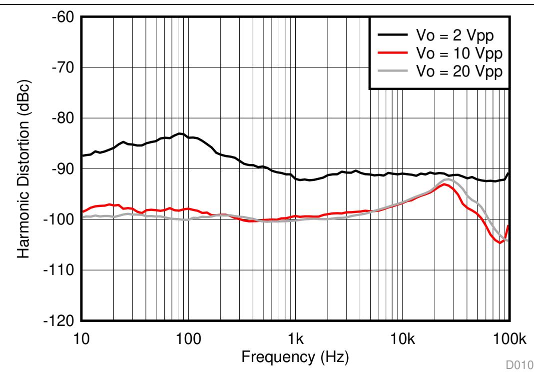


**図 10. 2nd-Harmonic Distortion for the 4th-Order Board**

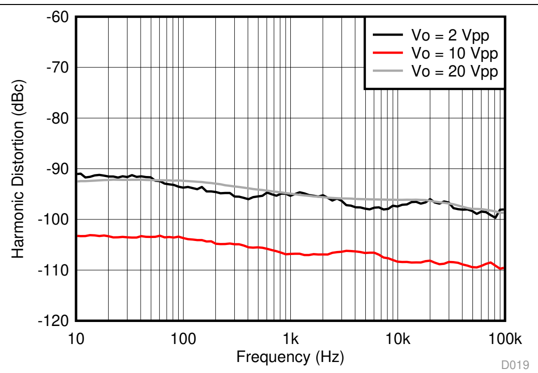


**図 11. 3rd-Harmonic Distortion for the High-Z Board**

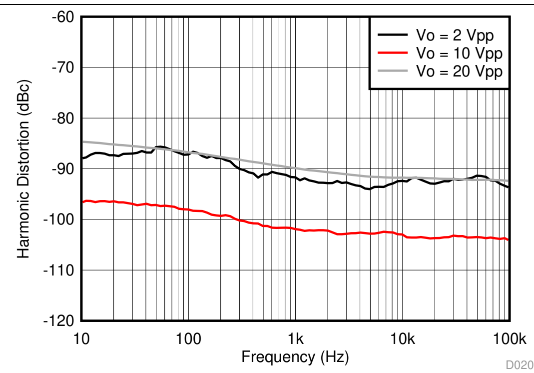


**図 12. 3rd-Harmonic Distortion for the 4th-Order Board**


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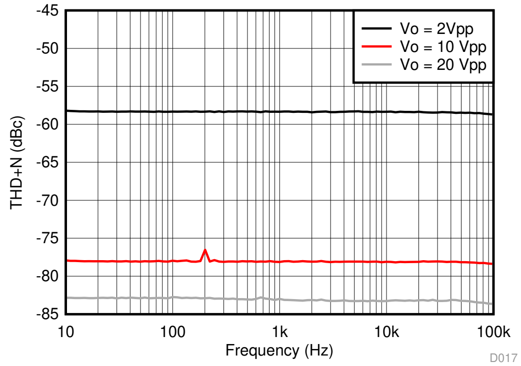


**図 13. THD+N Results for the High-Z Board**

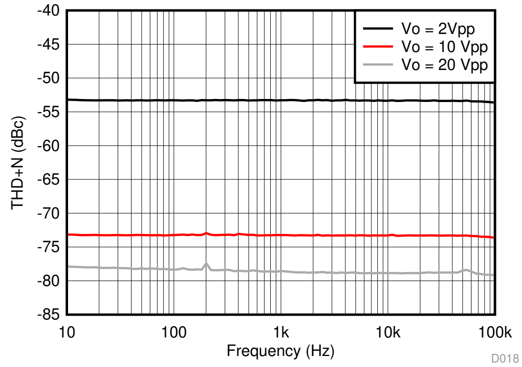


**図 14. THD+N Results for the 4th-Order Board**


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### *3.2.2.4 Step Response*

図 15 through 図 18 show the step responses for the High-Z and fourth-order boards. Although the High-Z board displays an underdamped response, the fourth-order board response is slightly overdamped. In both cases, the quality factor is between that of a Bessel and Butterworth response. The difference in the type of response can be attributed to constraints in component selection and tolerances. This design used FilterPro™ software and E96 resistors. If tighter tolerance resistors are used, similar responses can be achieved for both boards.

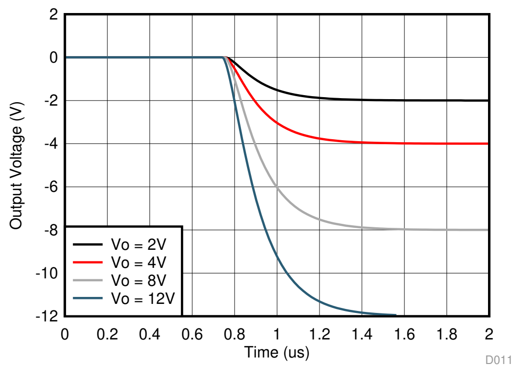


**図 15. Step Response Simulations for the High-Z Board**

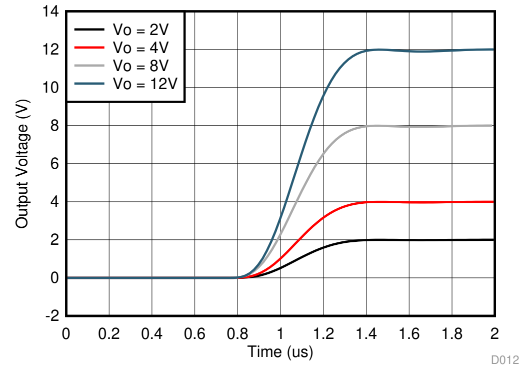


**図 16. Step Response Simulations for the 4th-Order Board**

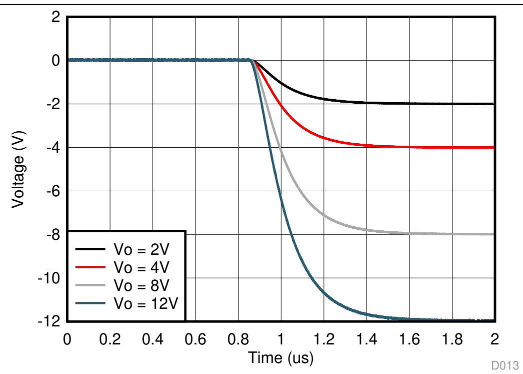


**図 17. Step Response Results for the High-Z Board**

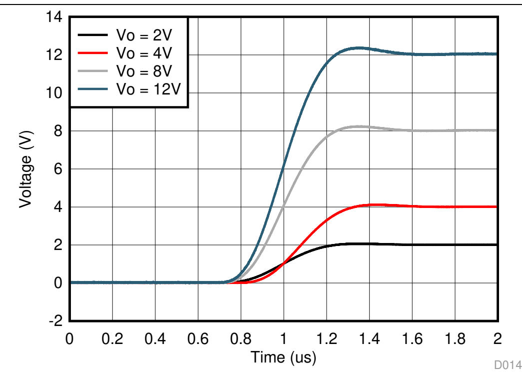


**図 18. Step Response Results for the 4th-Order Board**


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# 4 Design Files

## 4.1 Schematics

To download the schematics, see the design files at TIDA-060021.

## 4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-060021.

## 4.3 PCB Layout Recommendations

This design follows the guidelines found in the *Layout* section of the OPA2810 data sheet.

### 4.3.1 Layout Prints

To download the layer plots, see the design files at TIDA-060021.

## 4.4 Altium Project

To download the Altium Designer® project files, see the design files at TIDA-060021.

## 4.5 Gerber Files

To download the Gerber files, see the design files at TIDA-060021.

## 4.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-060021.

# 5 Software Files

To download the software files, see the design files at TIDA-060021.

# 6 Related Documentation

1. Texas Instruments, *How to compare your circuit requirements to active-filter approximations* technical brief
2. Texas Instruments, *Active low-pass filter design* application report
3. Texas Instruments, *Design methodology for MFB filters in ADC interface applications* application report
4. Texas Instruments, *OPA2810 Dual-channel, 27-V, rail-to-rail input/output FET-input operational amplifier* data sheet

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