Universal Operational Amplifier Evaluation Board for Designing a Two-Stage Bandpass Filter

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Universal Operational Amplifier Evaluation Board for Designing a Two-Stage Bandpass Filter

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ABSTRACT

This application report describes the Universal Operational Amplifier board and how to use it to demonstrate and evaluate the performance of TI's surface-mounted two-stage operational bandpass filters.

1 Introduction

This report uses the design goal of a band-pass filter with a bandwidth from 100 Hz to 10 kHz and unity gain as an example for other two-stage bandpass filters. A Butterworth configuration with a Q of 0.707 is chosen to obtain a maximally flat pass-band response. Beyond cutoff frequencies of 100 Hz and 10 kHz, the attenuation of the filter is 40 dB/dec. The amplifier is implemented in a gain block by cascading a two-pole, high-pass Sallen-Key stage with a two-pole low-pass Sallen-Key stage. The operational amplifier (op amp) chosen for this design is the TLV2442. The TLV2442 is a dual low-voltage operational amplifier from Texas Instruments. For the operational amplifier, the most essential design parameters are the bandwidth and the slew rate. The unity gain bandwidth of the TLV2442 is 1.8 MHz, which far exceeds the cut-off frequencies of the band-pass filter and will not be a limiting factor in the design. Since the maximum input amplitude is not specified, the input signal is assumed to swing to the rails. The output swing of the TLV2442 at 5 V and 10 kHz requires a maximum slew rate of 0.15 V/μS. The TLV2442 has a typical slew rate of 1.4 V/μS at a 5 V. Therefore the bandwidth and slew rate requirements are well within the capabilities of the TLV2442. For this particular application, the high input impedance and low noise of the device make the TLV2442 excellent for cascading active filter stages.

2 Description

The EVM board consists of four separate circuit development areas. The four areas are provided to evaluate specific op amp package options. Voltage references, capacitors, and resistors are not area dependent, and can be either surface-mount or through-hole devices. For this particular design a TLV2442 in an SOIC package is used, therefore all design references for the remainder of this report refer to area 100-SOIC of the EVM board. Figure 1 shows the layout of area 100 for the EVM. Area 100 uses the 1xx-reference designators and is compatible with dual op amps packaged as an 8-pin SOICs.

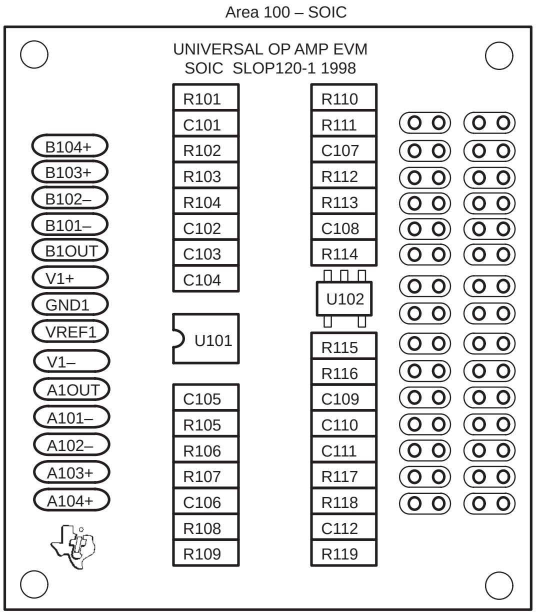


Figure 1. Layout of Area 100 of the EVA

The first stage will be the high-pass stage to take advantage of the capacitive input of the high-pass stage, which alleviates dc biasing of the source.

Determine the cut-off frequency and Q for the circuit by using: $f_c = \dfrac{1}{2\pi C\sqrt{R_1 R_2}}$

and $Q = \dfrac{1}{2}\sqrt{\dfrac{R_1}{R_2}}$

Where C= $C_1 = C_2$. Use the relation for Q to determine the R_1/R_2 ratio. A Q of 0.707 leaves R_1 twice as large as R_2. One can now choose any convenient set of standard values for these resistors. R_2 = 10 kΩ and R_2 = 20 kΩ will satisfy the Q of 0.707. In order to determine the value for C, solve the cut-off frequency equation and plug in f_c = 100 Hz and the resistor values obtained above into:

$$C = \frac{1}{2\pi f_c\sqrt{R_1 R_2}}$$

Choosing the closest standard value, $C_1 = C_2$ = 0.1 µF. The second stage of the band-pass filter is a low pass filter with a cut-off frequency of 10 kHz and a Q of 0.707. The relationship for the low-pass filter Q and cut-off frequency are respectively: $Q = \dfrac{1}{2}\sqrt{\dfrac{C_2}{C_1}}$ and $f_c = \dfrac{1}{2\pi R\sqrt{C_2 C_1}}$

Where $R = R_1 = R_2$. Solving for C_1 and C_2 with a Q = 0.707 reveals that C_2 is twice as large as C_1. One can now choose any convenient combination that satisfies this condition.

Choosing C_1 = 330 pF, and C_2 = 680 pF as standard capacitor values, R can be determined by:

$$R = \frac{1}{2\pi f_c \sqrt{C_1 \times C_2}}$$

A standard value of R = R_1 = R_2 = 33 kΩ can be used. The circuit schematic and the results of the simulation for the band-pass filter are shown in Figures 2 and 3 respectively.

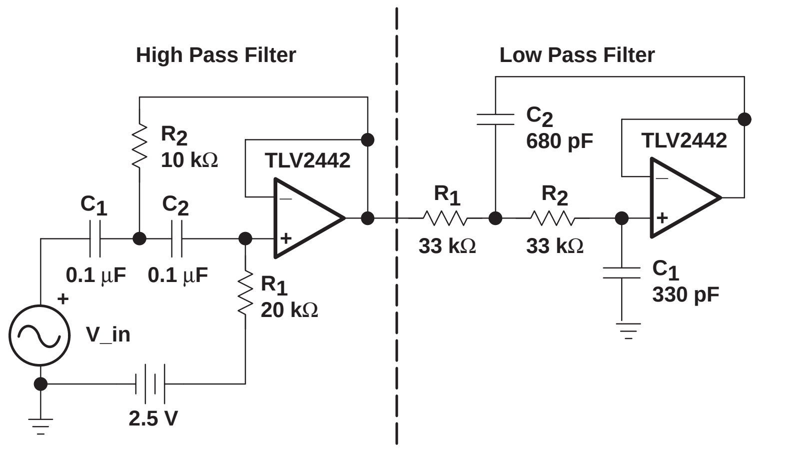


Figure 2. Equivalent Circuit for the Bandpass Filter

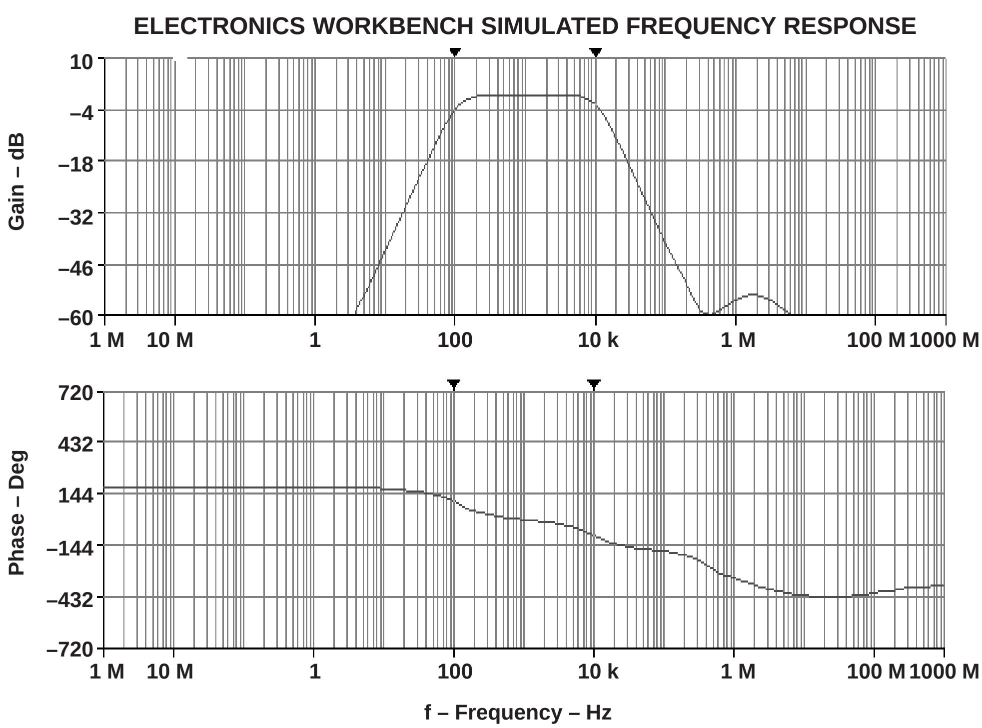
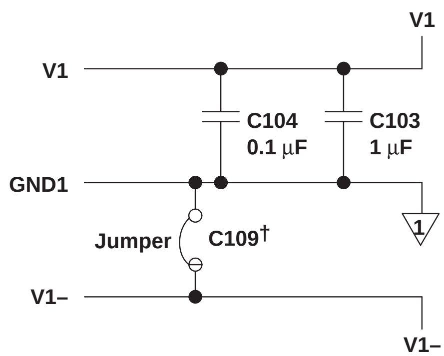


Figure 3. Simulated Frequency Response

After analysis and simulation the circuit is constructed on area 100 of the EVM board using the Sallen-Key op amp example from the *Universal Op Amp User's Guide*. The power supply bypass circuit is configured for single supply operation, using a jumper from the V1-to ground across reference designator C109. A 0.1 µF capacitor for high frequency bypassing and a 1 µF capacitor for low frequency bypassing are connected from ground to V1+ using reference designators C104 and C103 respectively. The bypass circuit and the corresponding reference designators for the EVM board are shown in Figure 4. The layout of the band-pass filter as seen on the EVM board with the corresponding reference designators is shown in Figure 5. Biasing of the circuit is accomplished using a TL431ACLP adjustable precision shunt regulator to generate VREF1. The TL431, configured as shown, provides a low impedance reference for the circuit of 2.5 V (1/2 V1+ in a 5 V system). VREF1 is jumped to B104+. This biases the positive input of the high-pass filter op amp and thus the entire circuit, see Figure 5.

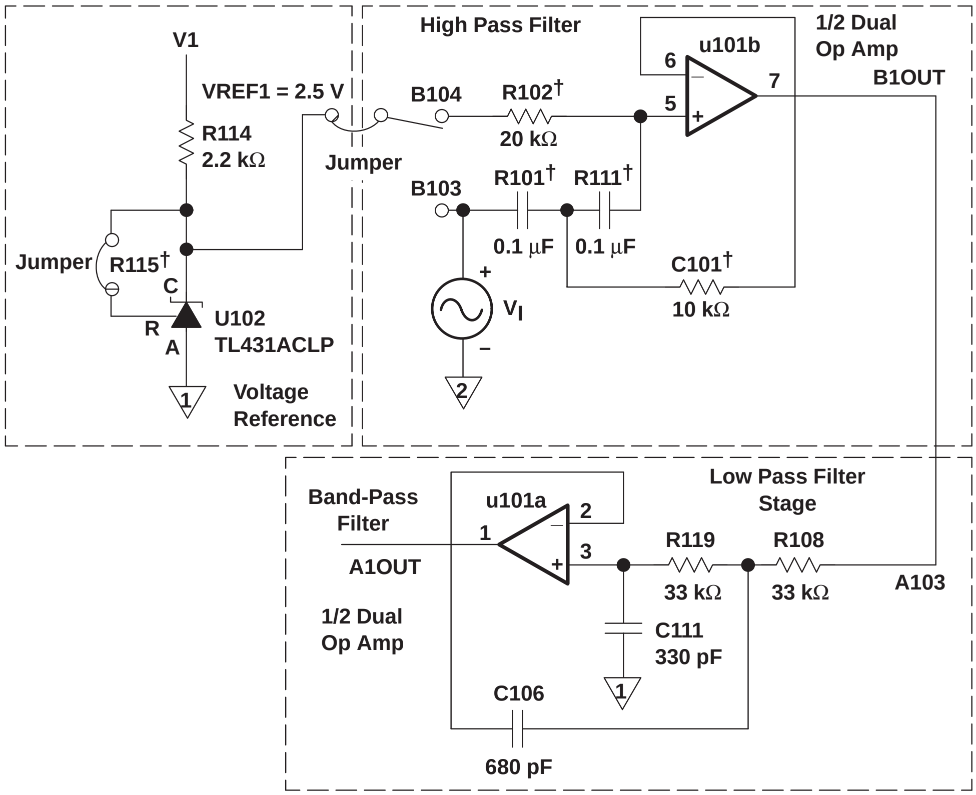


† The Universal Operational Amplifier board was designed for various configurations. These on-board reference designators have different components inserted/deleted for the two-stage bandpass filter.

Figure 4. Power Supply Bypass

The 0.1 µF capacitors for the high-pass filter stage are soldered in place at reference designators R101 and R111. The input resistor (20 kΩ) is soldered in place at R102 and the feedback resistor (10 kΩ) at C101. A jumper that is not shown in Figure 5, placed across R104 completes the connection from the output to the negative input. The output is jumped from B1 out to A103+, the input to the low-pass filter stage.

The 33-kΩ resistors for the low-pass stage are soldered at R119 and R108. The 330-pF capacitor is soldered at C111 and the 680-pF capacitor is soldered at C106. Also, a jumper that is not shown in Figure 5, is placed across R105 to complete the connection from the output to the negative input. The output of the band-pass filter is taken from A1out. The TLV2442 is U101.



† The Universal Operational Amplifier board was designed for various configurations. These on-board reference designators have different components inserted/deleted for the two-stage bandpass filter.

Figure 5. Bandpass Filter Layout on the Universal Op Amp Board

The circuit was tested and the frequency response of the circuit was measured on an AP Instruments Model 102B analog network analyzer. The output of the network analyzer is shown in Figure 6. The lower cut-off frequency is at 100 Hz and the upper cut-off frequency is at 10 kHz. This response shows a flat pass-band region with 40-dB roll-off beyond both cut-off frequencies. Comparing the actual circuit frequency response in Figure 6 to the simulated frequency response shown in Figure 3 shows good correlation between the two graphs.

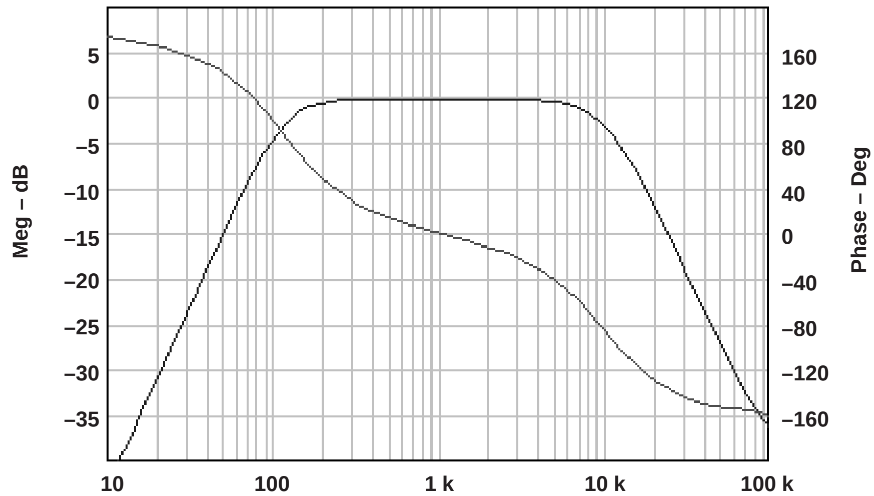


Figure 6. Frequency Response of the Bandpass Filter Measured on a Network Analyzer

3 References

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