ANALOG DEVICES

AD8232-EVALZ User Guide
UG-514

One Technology Way • P.O. Box 9106 • Norwood, MA 02062-9106, U.S.A. • Tel: 781.329.4700 • Fax: 781.461.3113 • www.analog.com

Evaluating the AD8232 Single-Lead Heart Rate Monitor Front End

EVALUATION BOARD FEATURES

Ready to use heart rate monitor (HRM) front end
Operates in two electrode or three electrode configurations
Directly interfaces to data acquisition and analog-to-digital converters (ADCs)
Easy feature selection with switches
Allows various circuit configurations

EVALUATION KIT CONTENTS

AD8232-EVALZ Evaluation Board

ONLINE RESOURCES

Documents Needed
AD8232 Data Sheet
AD8232-EVALZ User Guide
FAQs and Troubleshooting

EVALUATION BOARD PICTURE

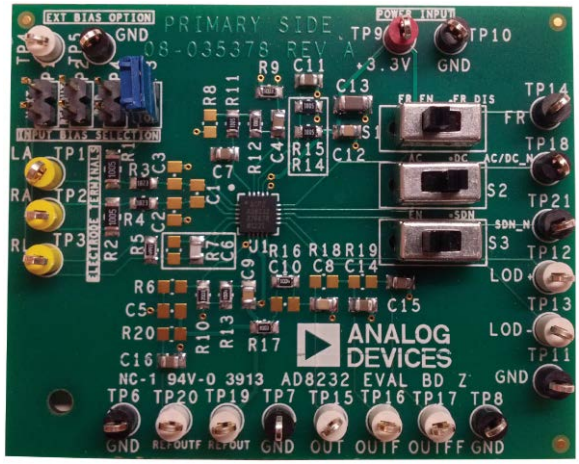

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Figure 1.

GENERAL DESCRIPTION

The AD8232-EVALZ evaluation board contains an AD8232 heart rate monitor front end conveniently mounted with the necessary components for initial evaluation in fitness applications. Inputs, outputs, supplies, and leads off detection terminals are routed to test pins to simplify connectivity. Switches and jumpers are available for setting the input bias voltage, shutdown (SDN), fast restore (FR), and ac/dc, leads off detection mode.

QUICK START

The AD8232-EVALZ evaluation board ships with a default configuration of a three electrode system that connects to the hands of the subject. For three electrode configuration, verify that the switches and jumpers are set to the default values shown in Table 1. For two electrode configuration, verify that the switches and jumpers are set to the default values shown in Table 2.

Table 1. Default Switch and Jumper Settings

Label	Position	Setting
S1	FR_EN	Fast restore enabled
S2	DC	DC leads off detection
S3	EN	Operation enabled
INPUT BIAS SELECTION	P3	Input bias set by RLD and +VS

Setup Procedure

Take the following steps to set up the AD8232-EVALZ evaluation board:

1. Connect the power supply common to the GND terminal on the board. Connect a 3.3 V supply voltage at the +3.3 V terminal.
2. Connect the left arm (LA) terminal and the right arm (RA) terminal to the signal source.
3. Connect the right leg (RL) terminal to the source reference. The right leg drive is available via the RL terminal.
4. The output signal is available on the OUT terminal.

Important Notice

For safety reasons, Analog Devices, Inc., recommends evaluating the device with an electrocardiogram (ECG) signal source instead of a live subject. Although the LA, RA, and RL electrode terminals are equipped with current-limiting resistors (R3, R4, and R5), these resistors are not a comprehensive patient protection system. The resistors may not protect against supply line transients or leakage currents coming through power and acquisition systems. The user is fully responsible for understanding and applying all the safety guidelines and regulations that apply to medical equipment.

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REVISION HISTORY

8/14—Revision 0: Initial Version

EVALUATION BOARD CONFIGURATION

A simplified schematic is shown in Figure 2 of the default configuration. See the Evaluation Board Schematic and Component Selection section for the full schematic.

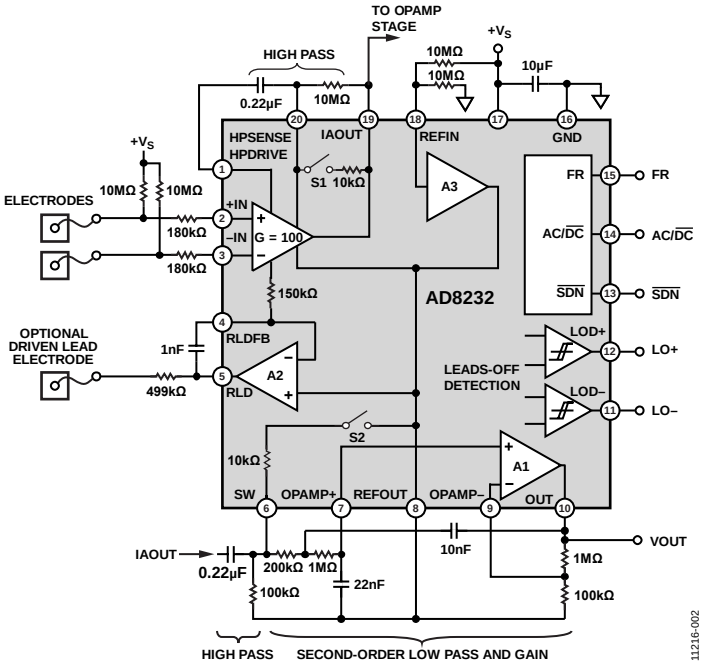

Figure 2. AD8232-EVALZ Default Configuration

SIGNAL PATH: INSTRUMENTATION AMPLIFIER AND FILTERS

The AD8232-EVALZ evaluation board ships with a default configuration for applications that involve three electrodes connected to the hands. The LA, RA, and RL terminals serve as the signal inputs and the right leg drive electrode connections, respectively.

The in-amp has a fixed gain of 100, and the op amp is set for a gain of 11. The overall gain is 1100 V/V, which limits the maximum differential input signal to approximately 2.7 mV p-p. Exceeding this amplitude does not damage the AD8232; however, the signal at the output appears distorted. Due to the high-Q of the filter, additional peaking sets the maximum observed gain more than 1100 V/V at approximately 15 Hz. The total gain can be changed by adjusting the R16 and R17 resistors, but doing so has a direct impact on the Q of the low-pass filter. Note that the in-amp has a fixed gain of 100.

A single-supply configuration is used to implement the entire signal chain. For this purpose, the reference buffer is set to a ratiometric level at midsupply using two 10 MΩ resistors (R14 and R15). The integrated reference buffer output provides a midsupply dc level for the system. The signal at the output rides on top of this midsupply level. This voltage is available at the REFOUT pin (TP19) to serve as a reference level for the subsequent signal acquisition stages.

The circuit implements a two-pole high-pass filter for eliminating motion artifacts and the electrode half-cell potential. Additionally, the integrated op amp creates a two-pole low-pass filter to remove line noise and other interference signals. The frequency cutoff of all filters can be adjusted by changing component values.

The AD8232-EVALZ evaluation board components selection is shown in Table 3, and the AD8232-EVALZ evaluation board schematic is shown in Figure 8.

RIGHT LEG DRIVE AMPLIFIER

The integrated right leg drive (RLD) amplifier senses the common-mode voltage present at the signal inputs and can drive an opposing signal into the patient. This driven electrode functionality maintains a constant voltage between the patient and the AD8232, greatly improving the common-mode rejection ratio (CMRR).

The board configures the RLD amplifier as an integrator, formed by an internal 150 kΩ resistor and an external 1 nF capacitor (C6). This configuration results in a loop gain of approximately 20 at line frequencies, with a crossover frequency of approximately 1 kHz.

In the two-lead configuration, the RL pin can be used to drive the bias current resistors on the inputs. To create this connection, place a jumper at P4.

FILTER CONFIGURATIONS

The resistor and capacitor values for the filters were selected to provide effective noise rejection in applications that involve pulse detection while the subject is in motion. The filter parameters can be adjusted to fit other applications.

High-Pass Filters

The in-amp in the AD8232 applies gain and high-pass filtering simultaneously. This capability allows the in-amp to amplify a small ECG signal by 100 while rejecting electrode offsets as large as ±300 mV. The cutoff frequency of this filter is given by the following equation:

$$f_C = \frac{100}{2\pi \times R11 \times C7}$$

In this particular case, with R11 = 10 MΩ and C7 = 0.22 µF, place the pole of the first high-pass filter at 7 Hz. Note that the filter cutoff is 100 times higher than is typically expected because of the feedback architecture of the in-amp.

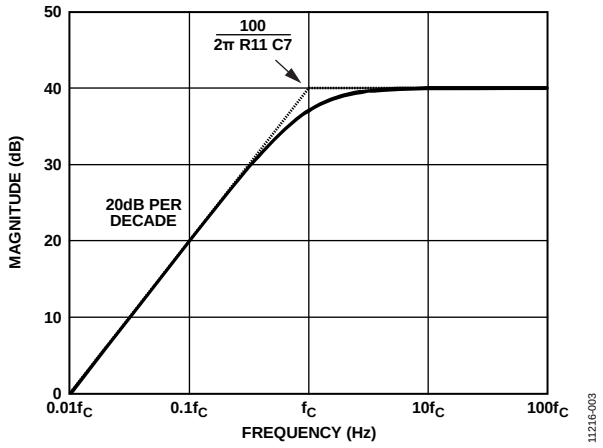

Figure 3. Frequency Response Instrumentation Amplifier Filter

An ac coupling network (C4 and R9) at the output of the in-amp introduces a second pole. The cutoff frequency is that of a regular passive first-order high-pass filter.

$$f_C = \frac{1}{2\pi \times R9 \times C4}$$

This results in a 7 Hz cutoff frequency for 0.22 µF and 100 kΩ. Both high-pass filters together yield a total roll-off of 40 dB per decade. Be aware that setting the same pole location for both high-pass filters results in 6 dB attenuation at the corner frequency. In addition, because the output of this filter is unbuffered, the in-amp exhibits higher output impedance at the input of the subsequent low-pass filter. The component values selected on the AD8232-EVALZ evaluation board yield good results without the need of a buffer. Keep this in mind when changing component values.

Low-Pass Filters

The internal uncommitted op amp is used to build a two-pole low-pass filter with gain, using a Sallen-Key configuration. The following design equations set the low-pass cutoff frequency, gain, and Q.

$$f_C = \frac{1}{2\pi\sqrt{R10 \times C8 \times R13 \times C9}}$$

$$Gain = 1 + \frac{R16}{R17}$$

$$Q = \sqrt{\frac{R10 \times C8 \times R13 \times C9}{R10 \times C9 + R13 \times C9 + R13 \times C8(1 - Gain)}}$$

Note that changing the gain or the cutoff frequency has an effect on Q, and vice versa.

The AD8232-EVALZ evaluation board components place the cutoff frequency for the low-pass filter at approximately 25 Hz and the gain to 11. Keep the sum of R16 and R17 more than 50 kΩ to save power and to avoid excessive loading of the output.

Figure 4 shows the transfer function of the signal from the differential input of the in-amp to OUT with the default filter configuration.

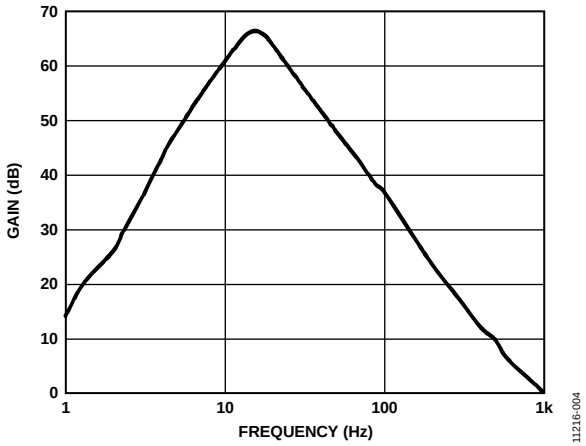

Figure 4. Gain vs. Frequency

Additional Low-Pass Filters

The R18, C14, R19, and C15 components offer additional filtering options. The OUTF terminal is located after the first filter (R18 and C14). The OUTFF terminal is located after both filters.

LEADS OFF DETECTION

The AD8232 includes a leads off detection feature. It provides modes optimized for either two electrode or three electrode configurations for the device.

DC Leads Off Detection

To use dc leads off detection mode, the position of the S2 switch must be the same as the dc label on the board. This mode works by sensing when either input goes high. Note that the system must be a three electrode configuration to operate properly. Therefore, the RLD output terminal must be connected to a driven electrode.

In dc leads off mode, the AD8232 checks each input individually and, therefore, is able to indicate which electrode is disconnected. The AD8232 indicates which electrode is disconnected by setting the corresponding LOD– or LOD+ pin high.

AC Leads Off Detection

To use ac leads off detection mode, the position of the S2 switch must be the same as the ac label on the board. To maintain the inputs inside the common-mode range of the amplifier, the bias level for the inputs can be set to REFOUT or RLD by placing the jumper at P2 or P4, respectively.

This mode is only useful when using the two electrode configuration, that is, when there is no separate driven electrode. The AD8232 detects when an electrode is disconnected by sourcing a small 100 kHz current into the electrodes. As opposed to the dc detection mode, the AD8232 is only able to determine that an electrode has lost its connection, not which electrode it is specifically. During such an event, the LOD+ pin goes to a high state. In this mode, the LOD– pin is not used and remains in a low state.

FAST RESTORE

The fast restore function (FR) reduces the duration of otherwise long settling tails of the high-pass filters. After an abrupt change that rails the amplifier, such as a leads off condition, the AD8232 automatically adjusts to a higher filter cutoff frequency. This function allows the AD8232 to recover quickly and, therefore, to take valid measurements soon after reconnecting the electrodes to the subject. To enable this function, set the S1 switch to the FR_EN position.

EVALUATION BOARD SETTINGS FOR TWO ELECTRODE CONFIGURATION

The AD8232-EVALZ evaluation board can be configured to suit two electrode applications, as is shown in Table 2.

Table 2. Two-Electrode Configuration

Label	Position	Setting
S2	AC	AC leads off detection
INPUT BIAS SELECTION	P4	Input bias set by RLD

Alternatively, the inputs can be biased to midsupply by placing a jumper on P2.

Note that the gain and filtering may need to be adjusted depending on the location of the electrodes. Narrow bandwidths offer the highest rejection to motion artifacts and other external interferences; however, these bandwidths can introduce distortion into the ECG signal. For more information, refer to the AD8232 data sheet.

EVALUATION BOARD LAYOUT

The AD8232-EVALZ evaluation board is a 2-layer board with components mounted on the primary side only. Rubber feet are available on the secondary side for mechanical stability. The layout diagrams are provided as a visual aid and reference design. The printed circuit board (PCB) was designed following standard practices to ensure signal integrity and reduce manufacturing costs.

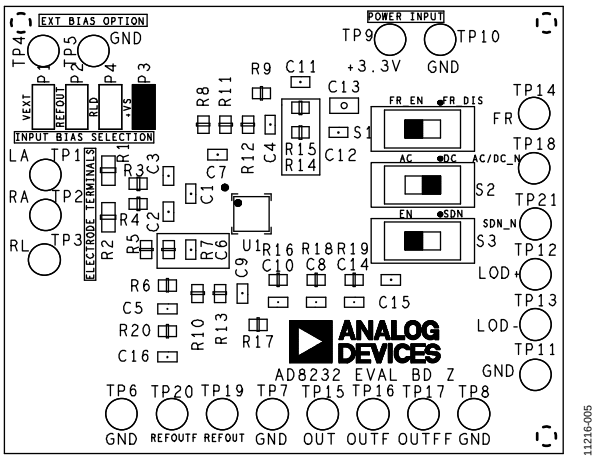

Figure 5. AD8232-EVALZ Evaluation Board Top Assembly

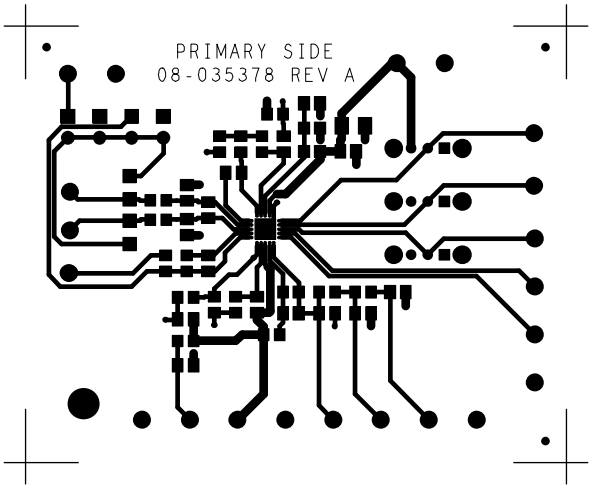

Figure 6. AD8232-EVALZ Evaluation Board Primary Side Copper

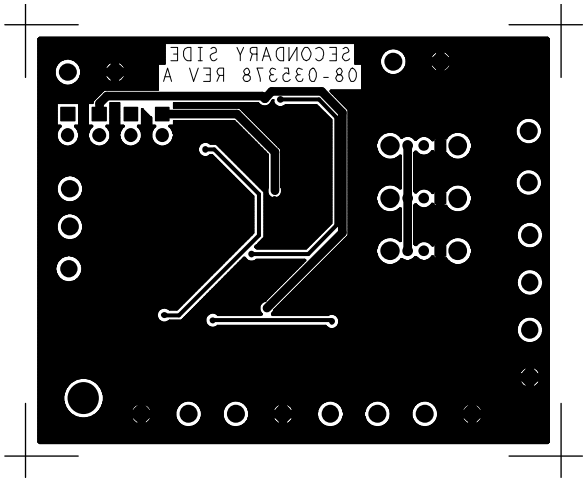

Figure 7. AD8232-EVALZ Evaluation Board Secondary Side Copper

EVALUATION BOARD SCHEMATIC AND COMPONENT SELECTION

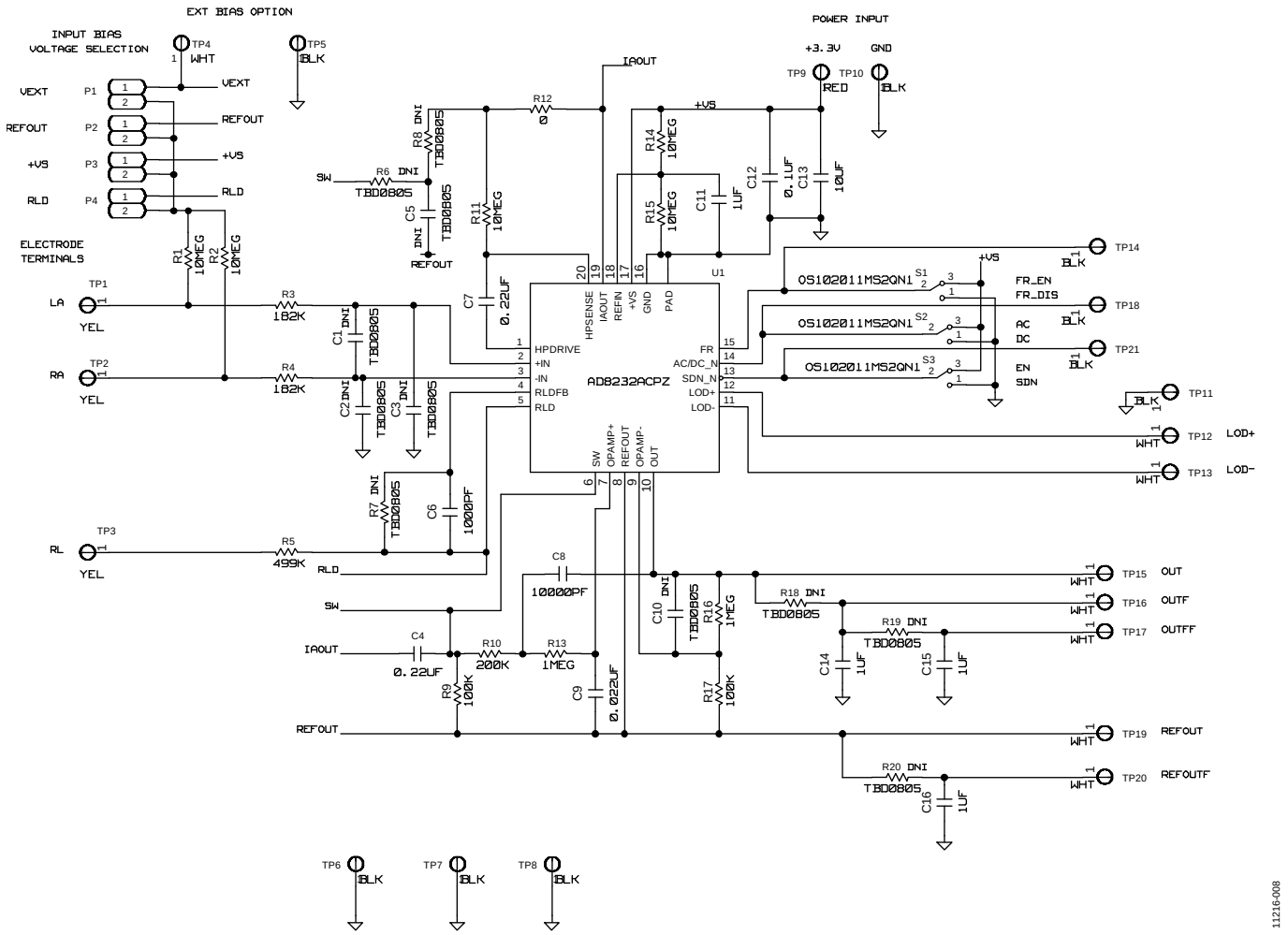

Figure 8. AD8232-EVALZ Schematic

Table 3. AD8232-EVALZ Component Selection

Designators	Section	Comments and Recommendations
P1, P2, P3, P4, R1, R2	Input bias selection	In the three electrode configuration, pull-up resistors are necessary for the leads off functionality to work correctly. In two electrode configurations, biasing the inputs within the input range of the AD8232 is necessary for the in-amp to work. R1 and R2 are 10 MΩ on the AD8232-EVALZ evaluation board. The resistors can be pulled up to four different values, depending on the jumper position. Connect only one jumper at a time. For the two electrode configuration, choose one of the following options: Connect the pull-up resistors to the RLD amplifier output through P4. Connect the pull-up resistors to REFOUT through P2 (which is typically at midsupply). For the three electrode configuration, choose one of the following options: Connect the pull-up resistors to +VS through P3. Connect the pull-up resistors to a signal provided by the user through P1. This is useful in systems that expect high power line noise (50 Hz or 60 Hz). An external signal can help in maintaining the inputs within the common-mode range of the amplifier. Apply this signal between TP4 and ground.
C7, R11	High-pass filter of the in-amp	The cutoff frequency is set to 7.2 Hz. Refer to the High-Pass Filters section for more information.

Designators	Section	Comments and Recommendations
C4, R9	AC coupled filter	The cutoff frequency of this high-pass filter is set to 7.2 Hz. Because this is a dc-blocking circuit, connecting R9 to the REFOUT voltage is necessary to allow negative signal swings. Refer to the High-Pass Filters section for more information.
R16, R17, R10, R13, C8, C9, C10	Low-pass filter (Sallen-Key)	This circuit provides two functions: a dual pole low-pass filter and gain. On the AD8232-EVALZ evaluation board, the cutoff of this filter is set at 25 Hz, and the gain to 11. This brings the total gain of the AD8232 to 11 × 100 = 1100. Refer to the Low-Pass Filters section for more information.
R18, R19, R20, C14, C15, C16	Additional low-pass filters	Not populated. These filters provide pads for the user to add additional filtering on the output and the reference voltage. Refer to the Additional Low-Pass Filters section for more information.
R14, R15, C11	Midsupply level	R14 and R15 form a supply ratiometric reference voltage for the system. The AD8232 buffers this voltage and makes it available at the REFOUT terminal. Select high resistor values for R14 and R15 to reduce power consumption. The AD8232-EVALZ evaluation board uses 10 MΩ for both. C11 is required for filtering and stability. Power line noise may be considerably worse without C11. Due to the large resistor and capacitor values used on the AD8232-EVALZ evaluation board, the time constant for this voltage is 5 seconds and takes about half a minute to observe a stable voltage at the output of REFOUT after power-up. Shutting down the device through S3 does not discharge C11 and there is no settling time related to this voltage.
C6, R5, R7	Right leg drive	C6 is 1 nF, which, together with an internal 150 kΩ resistor, results in a loop gain of 20 around the typical line frequencies and a crossover frequency of 1 kHz. The value of R5 is set to 499 kΩ to avoid stability problems. For more information, refer to the Right Leg Drive Amplifier section. R7 is not populated. It can be used to limit the loop gain at low frequencies and to shift the dominant pole of the amplifier.
R3, R4, C1, C2, C3	Optional RFI filter	Pads are provided for capacitors to implement additional RFI filtering. C2 and C3 must be the same value and well matched. C1 must be a larger value than C2 and C3. This minimizes degradation of CMRR at higher frequencies from tolerance mismatch of C2 and C3. If C2 = C3 = C and R3 = R4 = R, the common mode signal cutoff frequency is 1/ (2πRC) and the differential signal cutoff frequency is 1/(2πR(2 × C1 + C)). A lower common-mode signal cutoff frequency improves RFI rejection; however, it may increase the risk of instability with a right leg drive feedback loop. Thoroughly clean the AD8232-EVALZ evaluation board after any rework. Leaving contaminants such as residual flux from the soldering has a negative impact on the input impedance and operation of the AD8232-EVALZ evaluation board.

ESD Caution

ESD (electrostatic discharge) sensitive device. Charged devices and circuit boards can discharge without detection. Although this product features patented or proprietary protection circuitry, damage may occur on devices subjected to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.

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