

Predicting and Finding Your Limits!

By Jan-Hein Broeders, Healthcare Business Development Manager, Europe

IDEA IN BRIEF

In the past, vital signs have been monitored mostly on people with physical complaints or detected diseases, but today we are interested in monitoring these parameters to anticipate unexpected situations. Heart rate is often monitored to measure the condition of a person or to find our physical limits. This article describes a new integrated circuit from Analog Devices (ADI) that can help monitor heart rate. It can also monitor the behavior of the heart to provide cardiac feedback and an ECG waveform.

Among all biopotential measurements, ECG and heart rate are measured the most, as they provide a good indication of your physical condition. This allows you to exercise safely, as well as providing feedback about your physical improvement and success during exercising. Heart rates taken during exercise encourage you to exert yourself enough without overexerting or overstressing. Keeping track of your heart rate allows you to monitor your cardiac output to show whether you are in a safe operating mode during the entire fitness program or not. In addition, monitoring heart rate over a longer period of time gives feedback about long-term progress. If you are able to exercise at a more intense level without increasing your heart rate, you're becoming stronger and more efficient.

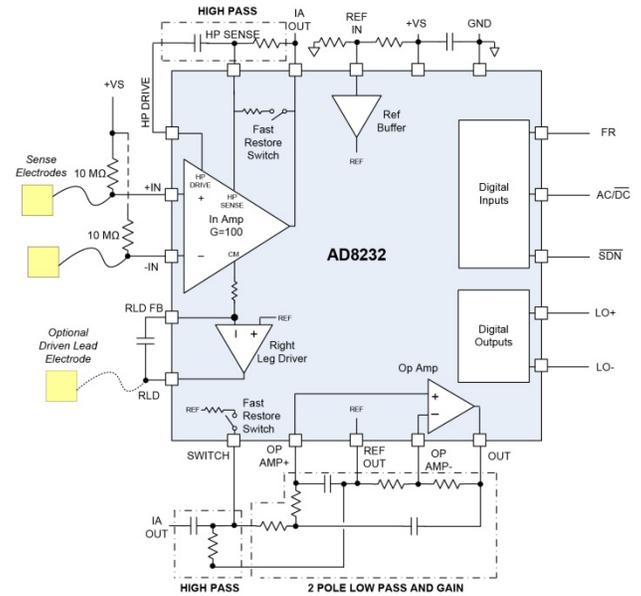


Figure 1.

Heart rate can be monitored by contact or contactless measurements. The [AD8232](#) is a new low power integrated signal conditioning front end, developed for ECG and other biopotential measurements. It uses two or three electrodes to obtain the cardiac signals from the human body.

The chip converts the small, noisy signals from the electrodes into a large, filtered signal that can be easily digitized by a standalone analog-to-digital converter (ADC) integrated in a microcontroller.

SIGNAL CHAIN DESCRIPTION

Figure 2 shows a simplified circuit diagram of the [AD8232](#), which, in principle, can be seen as four individual sub-functions. It contains an instrumentation amplifier, an amplifier stage that supports low-pass filtering, a right leg drive (RLD) amplifier, and an on-chip reference buffer.

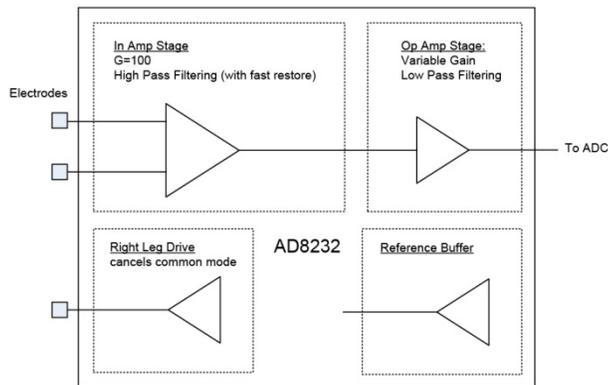


Figure 2. Simplified Block Diagram of the AD8232

The key function in the signal chain is the instrumentation amplifier. Its balanced input stage provides a common-mode rejection ratio of at least 80 dB. The electrodes from the body are connected directly into the high impedance input nodes of this amplifier, which features an input impedance of 100 mΩ. A fixed gain of 100 V/V is integrated in this stage to amplify the small signals that are applied to the input. As dc offset at this high gain could easily saturate the input amplifier, it is coupled with a 2-pole high-pass filter, which rejects the half-cell potential of the electrodes, in addition to filtering the motion artifacts.

The second stage consists of an operational amplifier that adds an additional gain of 11 V/V to the signal, setting the total gain to 1100 V/V and limiting the maximum differential input signal to 2.7 mV p-p. However, the device is protected against overvoltage so input voltages exceeding the maximum level will distort the output but will not damage the part. The operational amplifier can be configured as a 2-pole low-pass filter to remove line noise and other interference. The output signal represents a clean, amplified version of the ECG signal as provided at the input of the AD8232. Depending on how the signal is processed, it can be used as a “heart rate monitor” device or as a moderate performance ECG system.

The AD8232 is designed for low power, single-supply operation, so its ground must be lifted to a fixed reference level (pseudo ground), preferably midscale or the common-mode voltage level of the ADC that is used further down the signal chain. The integrated reference amplifier buffers this voltage to set the common reference point inside the AD8232. Two resistors can be used to set the reference to any preferred level, or the reference voltage output from the ADC could be used. If the ADC doesn't have a built-in reference voltage, the REF output of the AD8232 could be used to provide the reference for the ADC. This ratiometric measurement provides a high level of accuracy without immediate need for absolute accuracy.

IMPORTANCE OF FILTERING

The signals obtained from the body are weak and noisy, making them sensitive to motion related artifacts. For this reason, filtering is important to get a useful signal. The input amplifier provides gain and high-pass filtering simultaneously. It adds a gain of 100 V/V to the small ECG signals, while rejecting the electrode offsets, which can be as high as ± 300 mV.

The -3 dB cutoff frequency of the first filter is $FHP1 -3 \text{ dB} = 100/(2\pi R1C1)$. Due to the gain and feedback architecture of the amplifier, the filter cutoff is 100 times higher than would typically be expected. Figure 3 shows a circuit diagram of the amplifiers and various filter stages for optimum signal transfer.

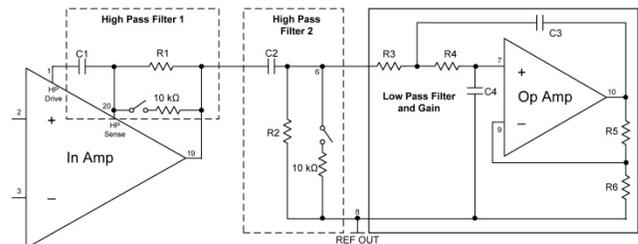


Figure 3. Filtering Section in the AD8232

The first stage is followed by an ac-coupled network that represents the second pole. The cutoff is set as a regular first-order high-pass filter, $FHP2 -3 \text{ dB} = 1/(2\pi R2C2)$. The two combined high-pass filters yield a total roll-off of -40 dB per decade.

The next filter stage supports a second-order low-pass filter, using a Sallen Key configuration. This filter is important to remove motion artifacts and correct the base line. The suggested cutoff frequency is around 25 Hz. The output of this amplifier stage is able to swing within 100 mV from $+V_S$ and ground, so nearly the entire dynamic range of the ADC following the AD8232 can be used, maximizing the system resolution if the ADC and the AD8232 are powered from the same supply voltage.

RIGHT LEG DRIVE AMPLIFIER

Another amplifier, called right leg drive, is integrated to provide the connection to the third electrode. The RLD can be used to condition the common voltage between the patient/user and the AD8232. This RLD helps to optimize the performance of the AD8232 but is not a mandatory function. RLD connection makes the application more immune to disturbances from outside, like 50 Hz/60 Hz noise coming from the mains, switch mode power supplies, and radiation from new LED lights, fluorescent lamps, and other lighting systems.

LEAD-OFF DETECTION AND FAST RESTORE MODE

The AD8232 monitors when an electrode is disconnected from the patient or user. A user-selectable option allows either dc or ac lead-off detection. In dc lead-off detection mode, the system senses the input potential of the electrodes. When one of the electrode inputs goes high, the corresponding LO- or LO+ pin gets flagged to warn the operator or user. Also, ac lead-off detection mode can be selected in case the AD8232 is operating with just two electrodes (without the RLD). The device detects when an electrode is disconnected by sourcing a small 100 kHz excitation current into the electrodes. Since only two electrodes are being used, the AD8232 won't be able to detect which electrode has been disconnected from the body. During ac lead-off detection, only the LO+ pin will be flagged.

Another very helpful feature on the AD8232 is the fast restore mode. To support this, the AD8232 automatically adjusts to a higher filter cutoff when one of the leads shows an abrupt change at its input. For example, the AD8232 could be built in to the bar of an exercise machine, such as a cross trainer or a treadmill. When the user takes the bar, this feature will help the device to recover and provide valid measurements faster.

Once the signal is settled, the filter action automatically changes to improve the overall noise behavior of the system. Figure 4 shows the settling with and without fast restore mode enabled.

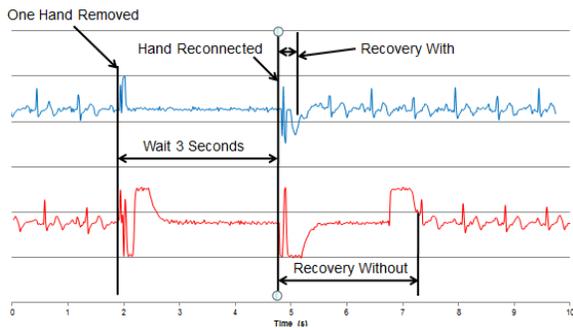


Figure 4. Settling of the AD8232 with and Without Fast Restore Mode Enabled

WHERE TO USE THE AD8232

This ECG measurement or heart rate front end is developed for a variety of applications. It can be used for healthcare applications, as well as for sports and activity applications. Many healthcare systems require low-lead-count ECG measurement such as portable ECG monitors, medical heart rate monitors, and lower end defibrillators and automated external defibrillators (AED). These require ECG monitoring to measure heart activity and to synchronize the moment before providing the defibrillator pulse.

A completely different market that is growing rapidly is the sports and exercising market. Measuring heart rate during sports activities can help athletes improve exercise routines and to determine their optimum exercise level. The AD8232 brings the solution there.

Its analog output allows system integrators to select an ADC and microcontroller of their choice. Analog Devices offers ARM Cortex™-M3 processors with built-in ADCs ranging from 12 bits to 24 bits of resolution. One of the recommended parts is the ADuCRF101. In case a standalone ADC is required, however, there are other options like the low power 12-bit AD7170 or 16-bit AD7171, dissipating 125 μA and 135 μA, respectively. These devices can be operated from the same supply voltage as the front end to minimize the overall power dissipation and to extend battery life. Once the application is operated from the mains, a galvanic isolation barrier is needed to maintain patient or user safety. The Analog Devices iCoupler® family provides galvanic isolation including isolated power up to 5 kV and could be of help to meet those requirements.

CONCLUSION

In summary, the AD8232 is a very handy, full-featured building block that can be used for a wide range of cardiac applications. It comes in a small 4 mm × 4 mm package, is low power, and priced attractively to support healthcare, home care, and sports markets.

REFERENCES

www.analog.com/healthcare

RESOURCES

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