DESIGN SOLUTIONS

HEALTHCARE

Take the Stress Out of Wearable Heart Monitoring

Introduction

Advances in semiconductor technology have made it possible for nearly all human body signals—even those traditionally monitored in a clinical environment—to be measured and recorded by a wearable device (Figure 1). Some of the most important signals to be measured are those of the cardiorespiratory (heart and lungs) system. Designers of wearables are challenged by the need to reduce size and power consumption as much as possible to extend battery life. While there are several ways in which heart and respiration measurements can be made, two of the lowest power techniques measure the heart's electrical signals (biopotential) and the resistance of the thoracic cavity (bioimpedance).

In this design solution, we review the concepts of biopotential and bioimpedance and the challenges encountered when measuring both in a wearable device. We then introduce an innovative approach that significantly simplifies how these measurements are made while reducing both device size and power consumption.

Figure 1. Medical Monitoring Using a Wearable Device

Biopotential and Bioimpedance

Biopotential measurements require placing two or more electrodes in contact with the skin of a patient's body to detect the small electrical signals generated by the heart. The signals are then conditioned and sent to a microprocessor for storage, calculation and/or display. Three important cardiac parameters are recorded using this technique: ECG, R-R intervals and PACE detection. An electrocardiogram (ECG or EKG) is the measurement and graphical representation, with respect to time, of the electrical signals associated with the heart muscles. The R-R interval is the time between the peak amplitudes of the heart's periodic electrical signal, also known as R peaks (Figure 2).

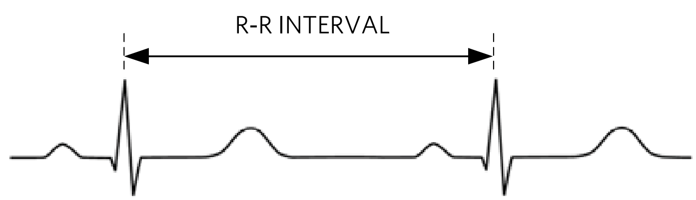

Figure 2. R-R Interval in a Typical ECG Waveform

ECG and R-R measurement can be used for heart-rate monitoring to assist in the diagnosis of specific heart conditions, such as arrhythmias. However, these conditions can be difficult to diagnose because they do not always present themselves in a clinical environment. Wearable devices provide medical professionals with the ability to monitor patients over an extended period, outside the hospital environment. This provides them with more information to assist detection and diagnosis. In addition to the biological signal from the heart itself, an ECG must also detect a separate man-made signal in patients with implanted pacemakers. This signal is referred to simply as "PACE." The PACE signal is relatively short—tens of microseconds to a couple of milliseconds—with an amplitude ranging from a few millivolts to nearly a volt. An ECG must detect the presence of a PACE signal while simultaneously preventing it from distorting the signals from the heart.

Bioimpedance (also referred to as BioZ) is the response of a living organism to an externally applied electric current. It is a measure of the opposition to the flow of that electric current through the tissues via two electrodes placed in contact with the skin. It is used in the measurement of respiration rate and hydration levels in a patient.

Design Challenges for Medical Wearables

Designers of portable medical devices are faced with several conflicting challenges. While their device must be capable of accurately recording, storing, and processing the desired measurements, it needs to be as small as possible to make it portable and comfortable without compromising functionality. To maximize portability and comfort of the device, a key design goal is to reduce the number of electrodes to a minimum. Also, since portable devices must be powered by batteries with a finite charge, they must consume as little current as possible to maximize the time interval between battery changes or recharges. Along with the requirement to reduce size and power consumption, designers are required to ensure that the functionality of the equipment meets exacting clinical standards. For example, parts used in ECG recording equipment must meet the IEC60601-2-47 standard and provide ESD protection compliant with IEC61000-4-2. Importantly, the device must be able to detect when an electrode has become detached from a patient (even when in standby mode), the complexity of which is proportional to the number of electrodes required.

Systems designers have not had the luxury of choosing a single IC that could achieve these goals. Some ICs offer the possibility of using single ECG and BioZ channels but require external circuitry to detect PACE signals and measure R-R. Other ICs can detect PACE signals as well as BioZ but require three pairs of electrodes (channels) to accurately record ECG while still requiring extra external circuitry to measure R-R.

An Integrated Solution

A new IC which successfully overcomes these limitations is the MAX30001 single-channel ultra-low power analog front-end (AFE). This part requires input from only one pair of electrodes (ECGP, ECGN) for biopotential measurements and another pair (BP, BN) for BioZ (as shown in Figure 3). However, it also incorporates PACE detection and R-R measurement functionality into a single integrated 30-pin WLP.

Even with the additional functionality, the MAX30001 consumes substantially less current than other solutions. It has a typical power consumption of 232µA, with all functions enabled, and 95µA for just ECG and R-R. This is almost a 50% improvement when compared to other solutions, which typically consume 450µA or more. Part of this power saving is achieved by incorporating the algorithm for heart-rate detection into the MAX30001 itself. This eliminates the need for the back-end microprocessor, which consumes up to 100µW in performing the calculation. In standby mode, it consumes only 0.63µW of power while still providing the necessary lead on/off detection. The MAX30001 is fully compliant with the IEC60601-2-47 ECG standard for all relevant specifications and is also compliant with the IEC61000-4-2 ESD standard on its input pins.

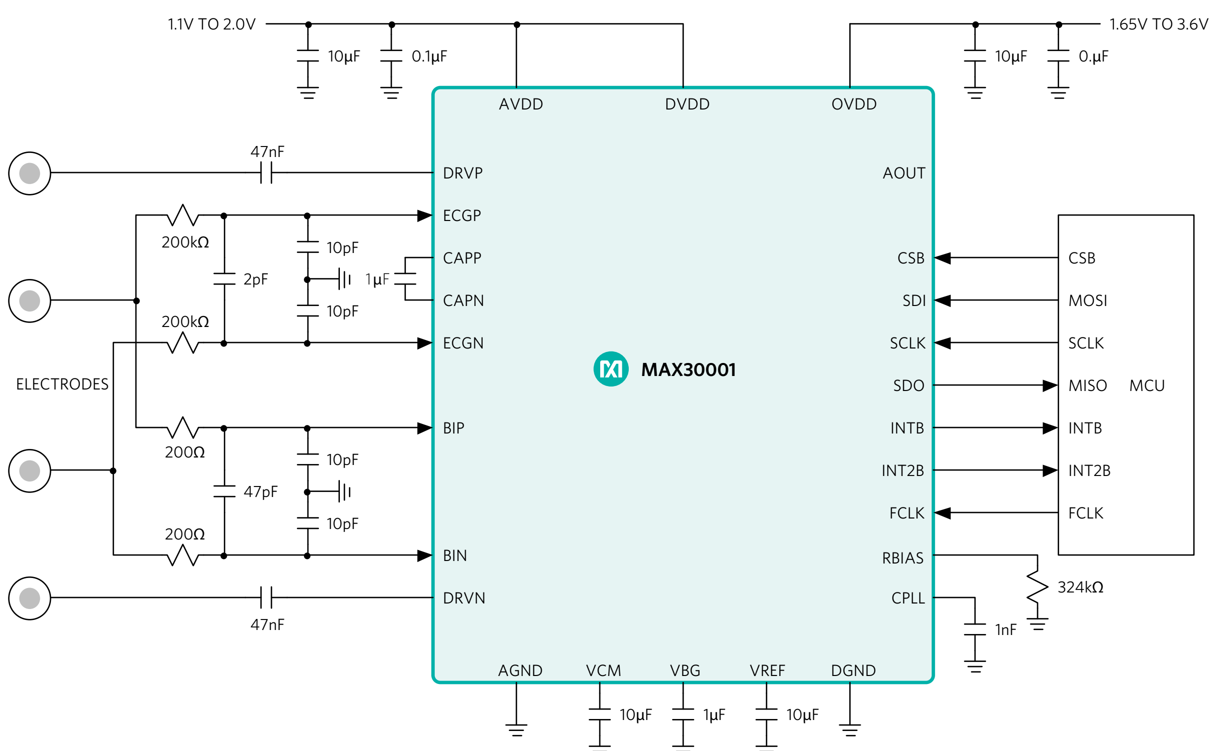

Figure 3. Four-Electrode ECG and Respiration Monitor Typical Application Circuit

Conclusion

In this design solution, we have reviewed the concepts of biopotential and bioimpedance and how they are used in portable clinical equipment for ECG, R-R, PACE and BioZ measurements. We touched on the conflicting requirements for developing a wearable medical device—the need to provide as much functionality as possible with the lowest possible power consumption within the smallest possible footprint while still meeting the required regulatory standards. The MAX30001 biopotential and bioimpedance AFE addresses these challenges by providing more functionality, with less power consumption than was previously possible within a single integrated package. It is well-suited for applications including single-lead event monitors for arrhythmia detection, single-lead wireless patches for inpatient/outpatient monitoring, chest-band heart-rate monitors for fitness applications, bioauthentication and ECG-on-demand applications, respiration and hydration monitors, and impedance-based heart-rate detection.

Glossary

ESD: Electrostatic discharge. Release of stored static electricity. Most commonly includes the potentially damaging discharge of many thousands of volts that occurs when an electronic device is touched by a charged body.

AFE: Analog front-end. The analog portion of a circuit which precedes analog-to-digital conversion.

WLP: Wafer-level package (WLP). WLPs allow an IC to be attached to a printed-circuit board (PCB) face down, with the chip's pads connected to the PCB pads through individual solder balls.

ECG: Electrocardiography (ECG or EKG) is the process of recording the electrical activity of the heart over a time interval using electrodes placed on the skin.

IEC60601-2-47: Requirements for the safety and essential performance of ambulatory electrocardiographic systems.

IEC61000-4-2: Test standard for electrostatic discharge (ESD) immunity.

Learn more:

MAX30001 Ultra-Low-Power, Single-Channel Integrated Biopotential (ECG, R-to-R, and PACE Detection) and Bioimpedance (BioZ) AFE

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