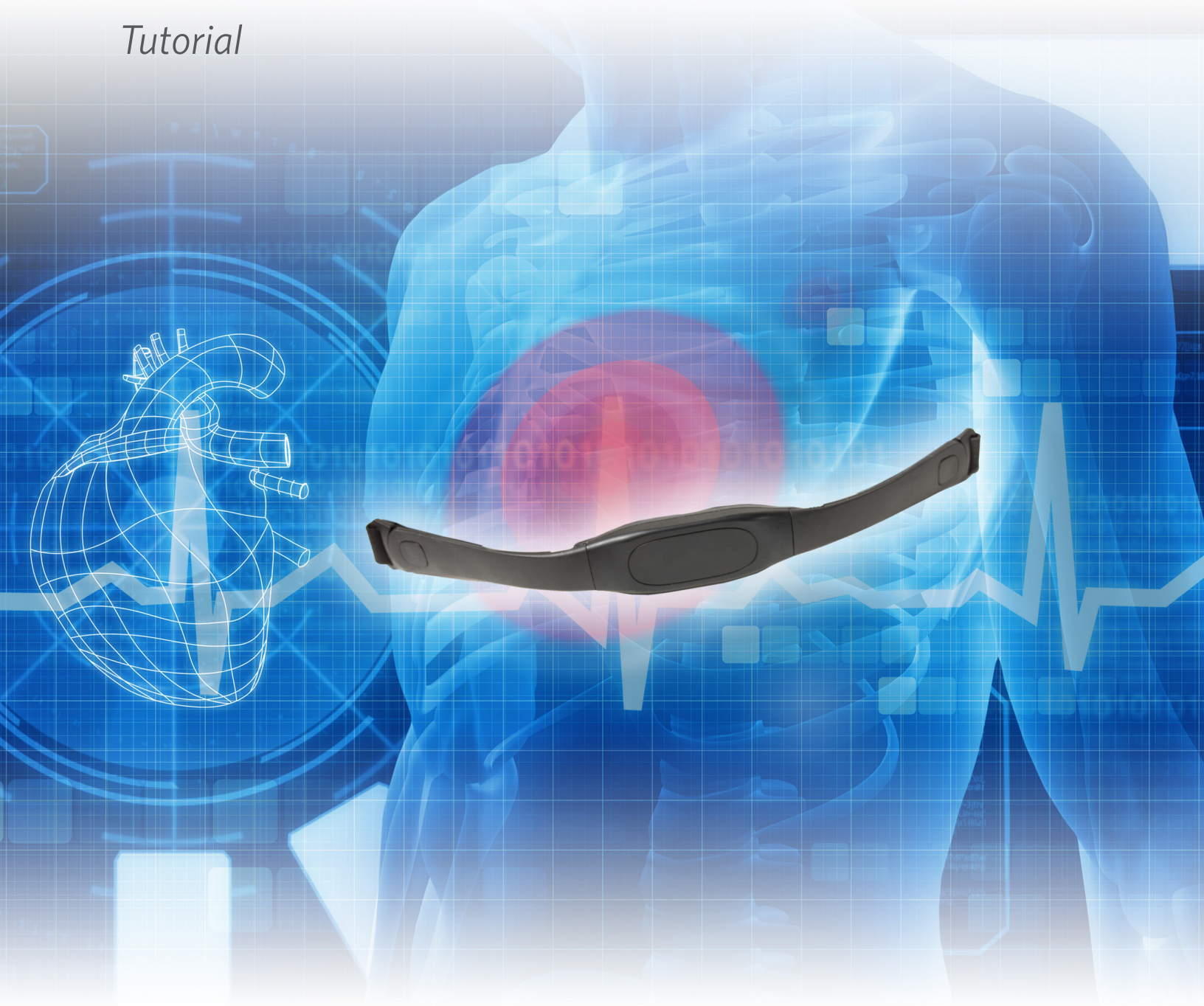


# HOW TO MEASURE BIOPOTENTIAL ECG USING A CHEST STRAP

*Tutorial*



## Introduction to Biopotential ECG Measurement

An electrocardiogram (ECG) is used to provide a wealth of information about a person's heart. It is probably one of the simplest and oldest techniques used to perform cardiac investigations. In its most basic form, it provides an insight into the electrical activity generated within heart muscles that changes over time. By detecting and amplifying these differential biopotential signals, a lot of information can be gathered quickly, including the heart rate. Among professional medical staff, individual signals have names such as "the QRS complex," which is the largest part of an ECG signal and is a collection of Q, R, and S signals, including the P and T waves. In this tutorial, we will investigate the techniques necessary for reliable ECG measurement in wearable chest-strap applications such as fitness heart-rate sensors. We will examine how heart-rate sensors measure the peak-to-peak interval of the R signal and yield heart-rate measurement (see **Figure 1**).

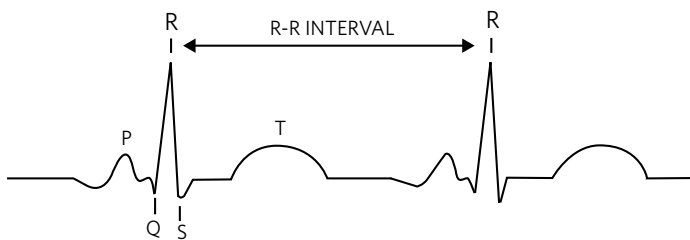


Figure 1. Primary ECG Signals

## ECG Measurement with a Chest Strap

Electrodes that come in contact with the skin—wet or dry types—are used to receive the ECG signals. Typically, for clinical use, they are wet electrodes that use a sticky gel to adhere to the body. With chest-belt or chest-strap applications, the electrodes are dry. Electrodes are typically two pads manufactured into an elasticated and conductive material that connects to a small, sealed, and battery-powered electronics circuit. The electronics provide ECG signal processing and data conversion prior to wirelessly communicating to a host device, typically using Bluetooth®. In order to maintain a light-weight, low-profile device that is comfortable to wear the sensor electronics will often be powered from a single coin-cell battery.

## Design Considerations

When embarking on a heart-rate sensor design based on a chest strap, there are a number of important design considerations.

### Electrodes and Input Circuitry

Any electrode requires a good connection to the body to provide a reliable signal of sufficient amplitude for detection. Electrode size and material characteristics also influence the signal quality and levels detected. While the use of dry electrodes is far more convenient than using wet types (you can just take them on and off), dry electrodes present a very high impedance when initially placed on the body. This means that the ECG signal is likely to be attenuated, resulting in a small signal. This 'dry start' scenario typically lasts for a short duration until the wearer has exercised sufficiently to start sweating, thus lowering the impedance and increasing signal levels. To accommodate dry starts, the input impedance of the ECG channel's analog circuitry should be very high so that attenuation is kept to a minimum.

## Rejection of Motion Artifacts in the Analog Domain

As the body moves during exercise there are a number of factors that can interfere with signal quality. For example, the simple motion of a body running or cycling, the movement of clothes hitting the body and/or the chest strap, and the movement of the electrodes all result in interference to the ECG signal. Removing such interference from these motion artifacts is essential if the ECG signal quality is to be maintained. Typically, such motion artifacts will be present on, or common to, signals from both electrode pads, so the common-mode rejection ratio (CMRR) of the analog front-end needs to be as high as possible. Also, it should be observed that the heavier the sensor electronics, the more likely it is that the unit will bounce around when in use, creating more motion artifacts.

## Power Consumption

As already highlighted, due to the small form factor of such chest straps, the space available to host the electronics and power source will be minimal. Maintaining an extremely low-power consumption profile during operation will permit the use of a single coin-cell battery and prolong its life. Established design techniques should be employed to maximize battery life since users will not favor devices that require regular battery replacement.

## Consider a Fully Integrated Solution

It can be a challenge to balance these key design considerations. Achieving the level of signal quality necessary for accurate readings, while maintaining reliable, low-power operation in a small, durable, lightweight form factor is no easy feat. This is where a fully integrated solution can provide the perfect answer.

The **MAX30003** is a fully integrated biopotential ECG analog front-end IC for use in wearable designs. This single biopotential channel, ultra-low-power device can be used for both clinical and fitness applications. It is capable of providing ECG waveforms and heart-rate detection.

The biopotential channel has ESD protection, EMI filtering, internal lead biasing, DC leads-off detection, ultra-low-power leads-on detection during standby mode, series isolation and polarity switches, and extensive calibration voltages for built-in self-test. Soft power-up sequencing ensures no large transients are injected into the electrodes. The biopotential channel also has a high input impedance, low noise, high CMRR, programmable gain, various digital lowpass and highpass filter options, and a high-resolution analog-to-digital converter. The device is also DC-coupled, handles large electrode voltage offsets, and has a fast recovery mode to quickly recover from overdrive conditions such as defibrillation and electrosurgery. **Figure 2** shows a functional block diagram of the MAX30003.

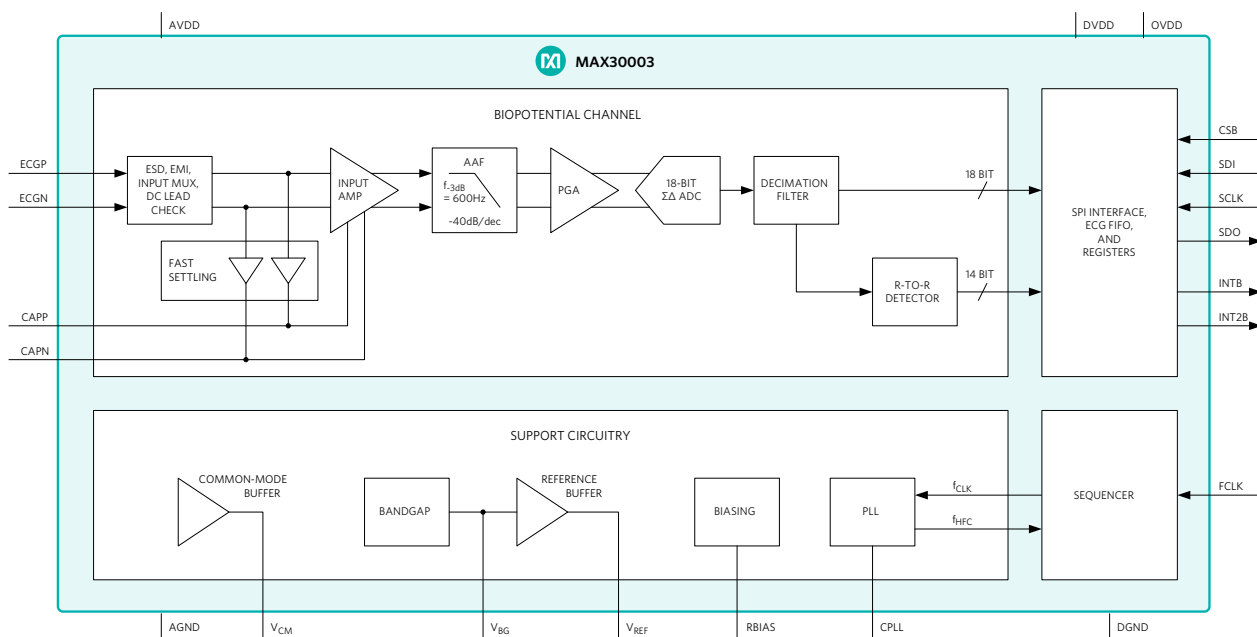


Figure 2. MAX30003 Functional Block Diagram

Together with a microcontroller and suitable power supply, a complete chest-strap ECG/heart-rate wearable solution can be created, as shown in **Figure 3**.

Preserving a high input impedance is essential to ensure good dry-start performance. On the MAX30003, selectable lead bias resistors are used to assist with this in addition

to helping improve the CMRR. The MAX30003 has superior CMRR characteristics, typically up to 115dB. Keeping the electrode PCB traces short and even in length are important factors as well. **Figure 4** illustrates the various sections contained within the input MUX block (top left of Figure 2).

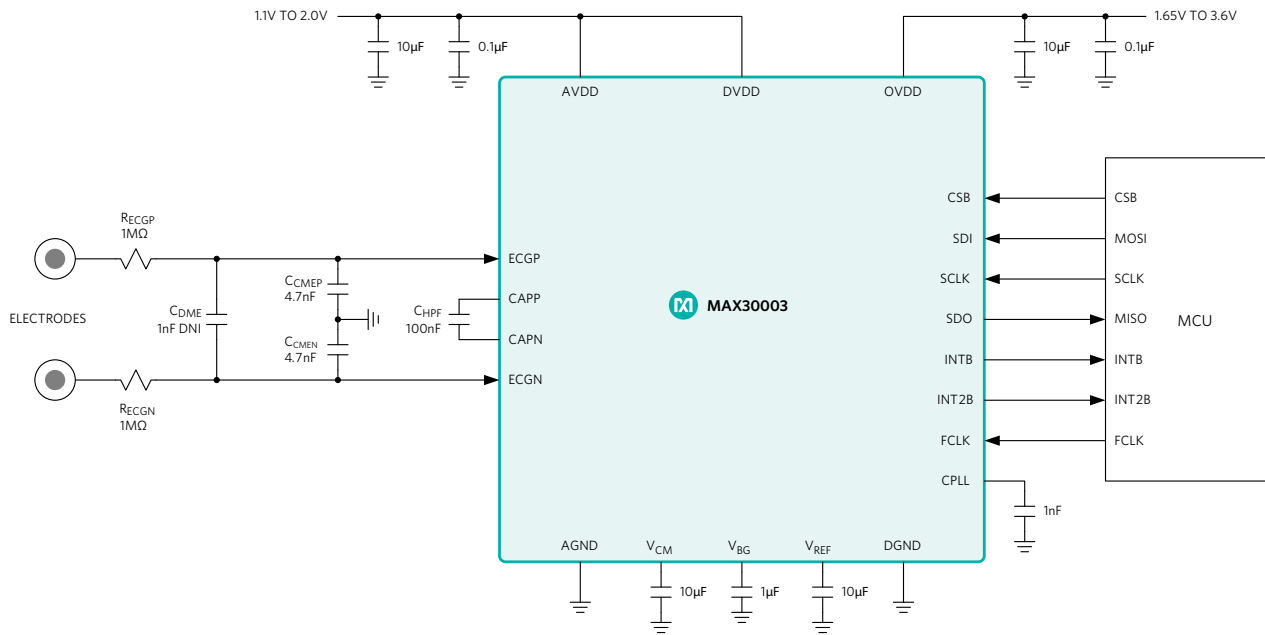


Figure 3. Example Biopotential ECG/Heart-Rate Design Schematic

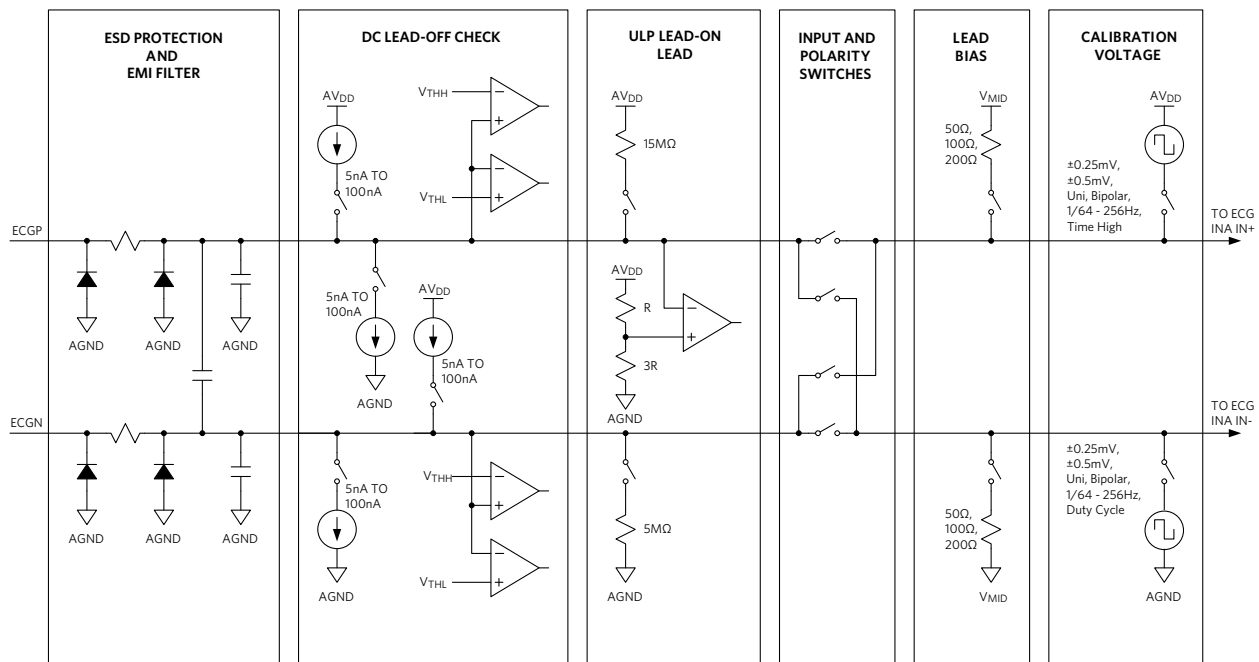


Figure 4. Input MUX Blocks

## Motion Artifact Bandpass Filters

The removal or reduction of motion artifacts is best done in the analog domain prior to the electrode signals being converted into the digital domain. The primary way to do this is by reducing the bandwidth using highpass and lowpass filters. The single-pole highpass corner frequency is set by an external capacitor,  $C_{HPF}$ , connected to the MAX30003 CAPP and CAPN pins shown in Figure 3. The value used should set the highpass corner at 5Hz, especially for high-motion usage such as most sports and fitness applications. For clinical applications, this can be a lot lower, typically down to 0.5Hz or even 0.05Hz. If there is little to no movement, this provides better quality ECG information for diagnosing conditions. **Figure 5** highlights the analog bandpass bode plot for a chest-strap application.

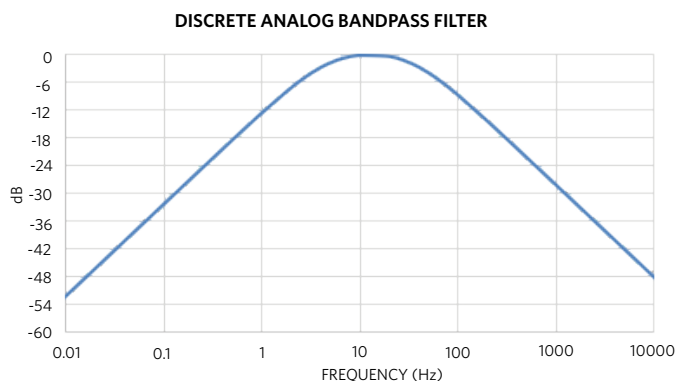


Figure 5. Analog Bandpass Filter Bode Plot for Chest Strap

A value of 100nF for  $C_{HPF}$  (see Figure 3) sets the highpass corner at a minimum of 5Hz but could go as high as 7Hz for high motion requirements. This results in using a 68nF capacitor for  $C_{HPF}$ .

The lowpass filter is set by the components to the left of CAPP and CAPN pins, which are  $R_{ECGP}$ ,  $R_{ECGN}$  (1M $\Omega$ ),  $C_{CMEP}$ , and  $C_{CMEN}$  (4.7nF) in Figure 3. This sets the common-mode lowpass corner at 34Hz, which is found to be best for limiting shirt or clothing noise during dry starts. Limiting the bandwidth on the high end is also important to attenuate noise from static electricity and high-frequency signals. The impedance of the series resistors,  $R_{ECGP}$  and  $R_{ECGN}$ , should be limited such that the root-sum-square (RSS) of the resistor thermal noise and the input noise of the ECG channel should not be much more than the input noise alone. The differential mode capacitor,  $C_{DME}$ , is not used but it is recommended to run an experiment to compare the performance of the common-mode lowpass filter to the differential mode lowpass filter since each design could have its own noise sources.

Follow these layout recommendations when designing the PCB and selecting components:

- Use COG-type ceramic capacitors, if possible, in the signal path to reduce signal distortion; for the ECG path this includes  $C_{HPF}$ ,  $C_{DME}$ ,  $C_{CMEP}$ , and  $C_{CMEN}$
- Place discrete components close to the MAX30003 and keep traces as short as possible
- For the differential signals (ECGP/ECGN) keep the traces of equal length and symmetrical to maintain a high CMRR
- Use a single ground plane under the device; do not split AGND and DGND

Other biopotential channel and input MUX functional blocks include a fast settling function that allows the front-end to automatically recover (typically within 500ms) from excessive electrode inputs that could saturate the amplifier. The anti-aliasing filter (a lowpass filter that prevents aliasing of signals, an artifact of using an ADC) and a programmable gain amplifier (PGA) condition the analog signal while the 18-bit ADC converts the analog signal into the digital domain. Sampling can be selected in the range of 125sps to 512sps.

## Maintaining a Low-Power Consumption Profile

There are a number of MAX30003 features that contribute to lowering the overall system power consumption requirements. One is the use of a 32-word FIFO that can contain up to 32 results of the ECG data conversions so that the host microcontroller does not have to process every single reading. This ensures that the MCU stays asleep longer, reducing its power consumption profile. The MCU wakes up and quickly obtains the collected data before going back to sleep again. The MCU can be programmed to collect data at every reading or every 32<sup>nd</sup> reading, or any other point in between. In addition to the ECG data being transferred, the MAX30003 provides tags to the MCU about the quality of the received data. It highlights data that might be corrupted or out of range. In this way the MCU doesn't have to process data that could potentially be invalid or doesn't bother reading other registers to determine the data quality. This saves further unnecessary system power consumption.

The MAX30003 has a built-in algorithm, based on the [Pan-Tompkins](#) algorithm, for detection of the R-to-R peak intervals. This is hard-coded into the device rather than requiring this to run on the host MCU. This represents a significant power saving, since if it were on the MCU, the MCU would need to run continuously. In this way, the MAX30003 only consumes

approximately 1µA, compared to 50 to 100 times that figure if the MCU hosted the algorithm. It should be noted that the MAX30003 not only provides the R-to-R peak-based heart rate but the complete clinical-quality ECG waveform information, should the application require it.

Other power-saving features of the MAX30003 include the lead-on detect function. Consuming only 70nA, this sets a status bit when it detects that the two electrodes have been attached to the wearer’s body. This ensures that the overall system power consumption is reduced to an absolute minimum until such time that the electrode impedance falls below approximately 20MΩ and the status bit is set. This will wake up the MCU from sleep to commence the heart-rate measurement process.

### Options for Powering a Complete Chest-Strap Solution

There are a number of options to power a complete solution depending on the battery source and how complex it needs to be. The simplest option is to use a linear regulator to create a common 1.8VDC rail from a coin cell that varies from 3.4V down to 2.2V, typically (see **Figure 6**). This approach is not particularly efficient overall, which leads to using a buck regulator to make it more efficient (**Figure 7**). The third and most efficient approach uses an extremely efficient **MAX14750** (**Figure 8**) to provide multiple outputs. This solution can deliver separate outputs for the MCU, analog front-end, and the digital interface.

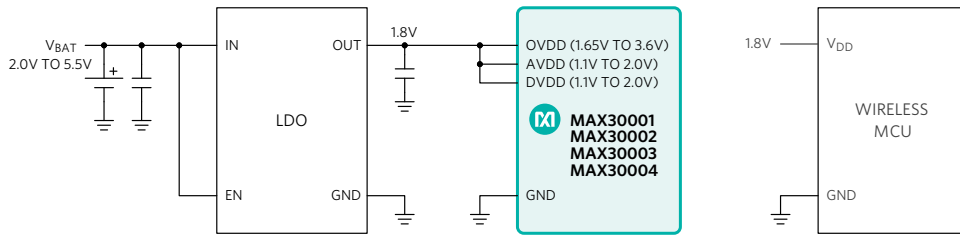


Figure 6. A Simple Linear Dropout Regulator Power Scheme

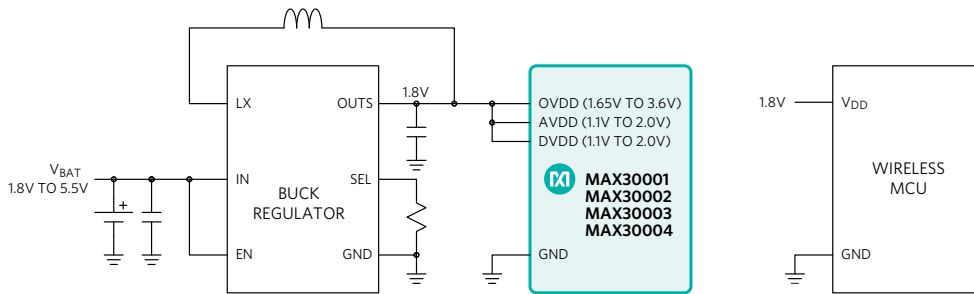


Figure 7. A Buck Regulator Power Scheme

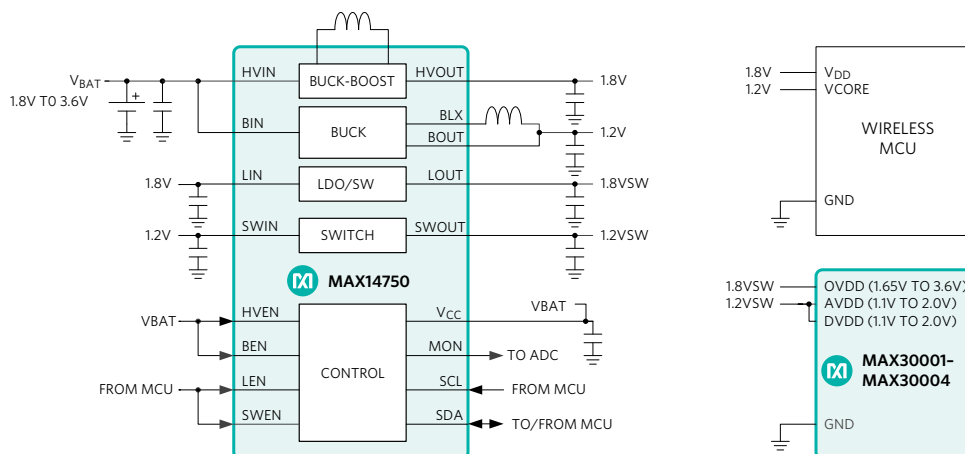


Figure 8. Using the MAX14750 PMIC and a 3VDC Coin Cell

## Design Resources

The recommended evaluation and development platforms for the MAX30003 device are the **MAXREFDES100** and the **MAX-ECG-MONITOR**.

The MAXREFDES100 Health Sensor Platform incorporates one MAX30003 biopotential analog front-end solution with additional temperature sensors, two MEMS inertial sensors, and a barometric sensor for evaluation of high-end fitness solutions.

The MAX-ECG-MONITOR Wearable ECG and Heart Monitor Evaluation and Development Platform analyzes data and accurately tracks heart signals (ECG and heart rate), as well

as user status signals such as temperature and motion, to provide valuable insight for development of clinical and fitness applications.

The **MAX30001EVSYS** may also be used to evaluate the functionality of the MAX30003 by disabling the bioimpedance and pace detection channels in the **MAX30001**.

The MAX30003 is part of a family of ultra-low-power, integrated biopotential (ECG, R-to-R algorithm) and bioimpedance (BioZ) analog front-end devices used in wearable health and fitness sensor applications.

### Biopotential and Bioimpedance Analog Front-End (AFE) Device Features

Description	MAX30001	MAX30002	MAX30003	MAX30004
Functionality	ECG, R-R, BioZ, PACE detection	BioZ only	ECG, R-R	R-R detection only
Applications	Patient monitors, high-end fitness	HR on wrist, respiration, GSR	Chest straps, patient monitors	Chest straps
Power Dissipation	225µW	158µW	84µW	84µW
Built-In R-R Algorithm	Yes	No	Yes	Yes
Packages	28-TQFN 5mm x 5mm, 30-WLP 2.7mm x 2.9mm			
Compatibility	All are pin- and register-compatible			
Samples	Yes	Use <b>MAX30001</b>	Yes	Yes
Production	Yes	Yes	Yes	Yes
EV Kits/Development Platforms	<b>MAX30001EVSYS</b>	Use <b>MAX30001</b>	<b>MAXREFDES100</b> <b>MAX-ECG-MONITOR</b>	Use <b>MAX30003</b>

### Learn More

[Video: Meet the Health Sensor Platform](#)

[Video: Introducing the MAX-ECG-MONITOR Wearable ECG and Heart Monitor](#)

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