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APPLICATION NOTE 7035

CHOOSE THE PROPER PMIC TO BOOST YOUR OPTICAL SENSOR SNR

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Abstract: Boost converters are typically used to step up the battery voltage in portable and wearable devices. However, they exhibit behavior that can negatively impact the signal-to-noise ratio (SNR) in optical sensing applications. In this design solution, we explain why this happens and then present a new type of power management using a PMIC that features a boost converter specifically designed to maximize SNR in optical sensing applications.

Introduction

In your relentless pursuit of that holy grail of wearable devices, i.e., longer battery life, have you ever considered the possibility that the power-saving techniques you are employing might actually be negatively impinging on the very function that the device was designed for? Ironic, yes, but it is only as wearable devices (**Figure 1**) have proliferated that we've begun to better understand when and how they expend battery power. This understanding is leading to new techniques that can improve on universally accepted approaches to power-saving. In this design solution, we review the way in which battery voltage is currently managed in optical sensing applications and the caveats of this approach. We then consider the advantages of using a new PMIC that overcomes these limitations, improving sensor performance while also lowering power consumption.

Figure 1. Wearable health and fitness monitor.

Optical Sensing

Optical sensors are commonly used to measure health indicators like heart rate and blood oxygenation (SpO_2). These measurements are based on a technique called photoplethysmography (PPG). A PPG signal is obtained by illuminating skin using a light-emitting diode and detecting changes in the intensity of the reflected light (**Figure 2**) using a photodiode which generates a current proportional to the amount of received light.

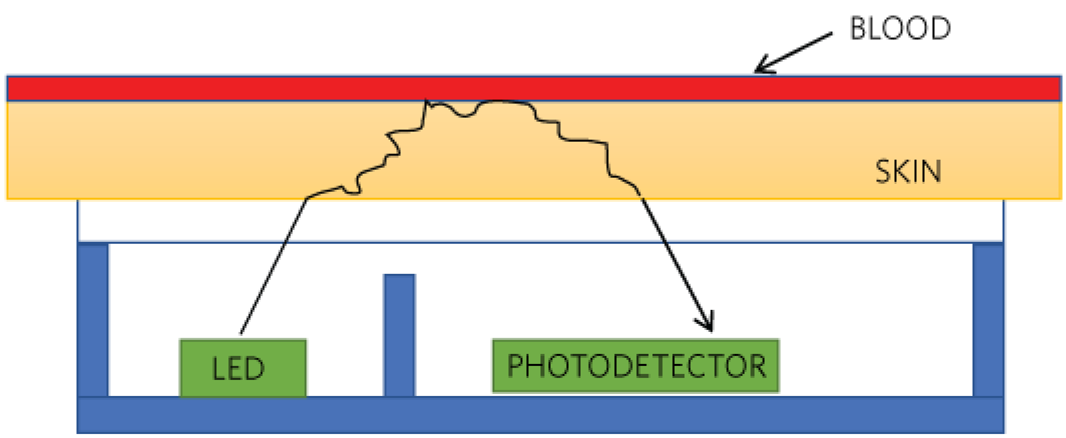

Figure 2. PPG signal using an LED and a photodiode.

The number and intensity of pulses of light required to make accurate measurements will depend on the use case at a particular time. For example, the measurement is more challenging when the wearer is engaged in vigorous physical activity than during sleep. Ambient conditions and skin pigmentation of the wearer also affect LED current.

Battery Management

Since some class of lithium battery (which can range from 3.2V to 4.35V) is used as a power source, a boost (or buck-boost) DC-DC converter is used to increase the battery voltage to whatever nominal output voltage (V_{OUT_NOM}) is required by the optical sensors during heavy load operation (typically 5V). Since battery life is critical, it is important that the converter have low quiescent current consumption (I_Q). In order to save power during light load conditions, these converters operate in what is commonly referred to as a “burst mode.” For heavier loads, the converter transitions into a “continuous current” mode of operation. Both modes of operation are shown in **Figure 3**.

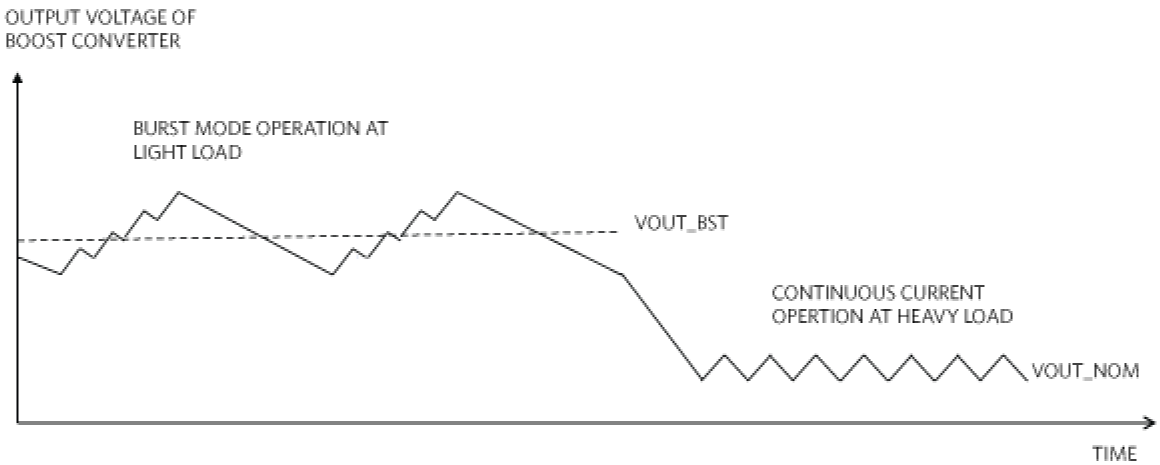

Figure 3. Light and heavy load conditions of a boost converter.

Burst mode is a commonly used power supply architecture to save energy in light load conditions. However, it can cause problems when used for optical sensing applications, as explained in the following sections.

Burst Mode Ripple

The ripple on the output voltage (V_{OUT_BST}) is both low frequency and high amplitude. High amplitude ripple causes inconsistent LED light pulses, leading to inconsistent measurements, while the low ripple frequency is close enough to the sampling frequency of the optical sensor to effectively become a source of “in-band” noise which cannot be adequately rejected by the sensor. Burst mode ripple (120mV, 1.6kHz) for a boost converter with a load current of 10mA is illustrated in **Figure 4**.

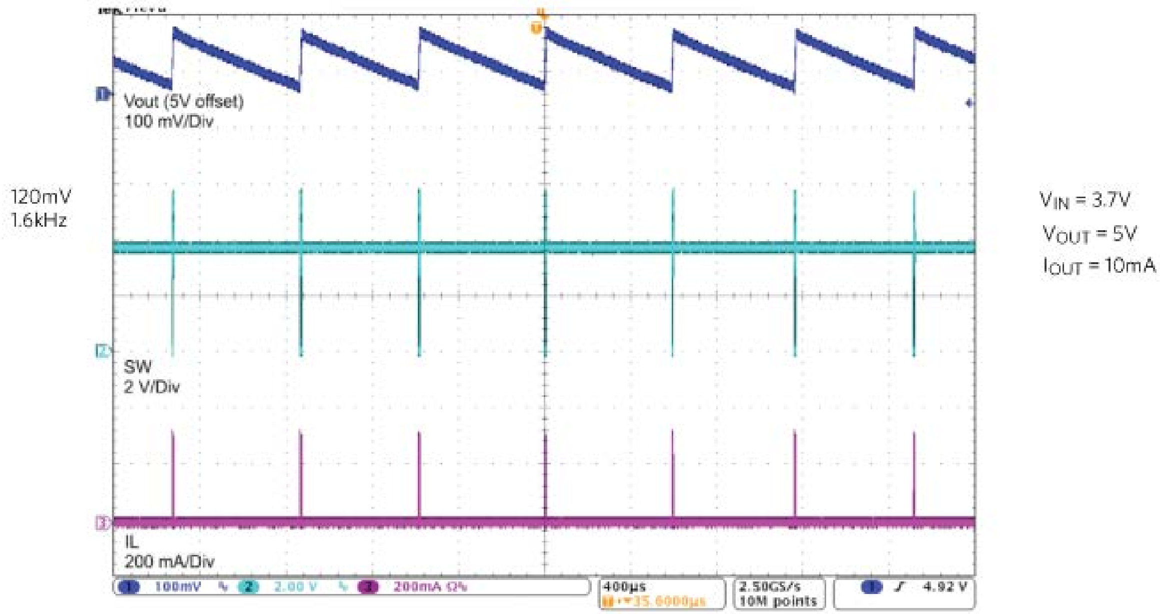

Figure 4. Burst mode voltage ripple of a boost converter with 10mA load current.

Unpredictable Noise Between Transitions

Occasionally, as the converter transitions from light to heavy load operation during an LED pulse, unpredictable noise can appear on the output voltage, as shown in **Figure 5**. Once again this causes a variable LED current, potentially causing unreliable measurements.

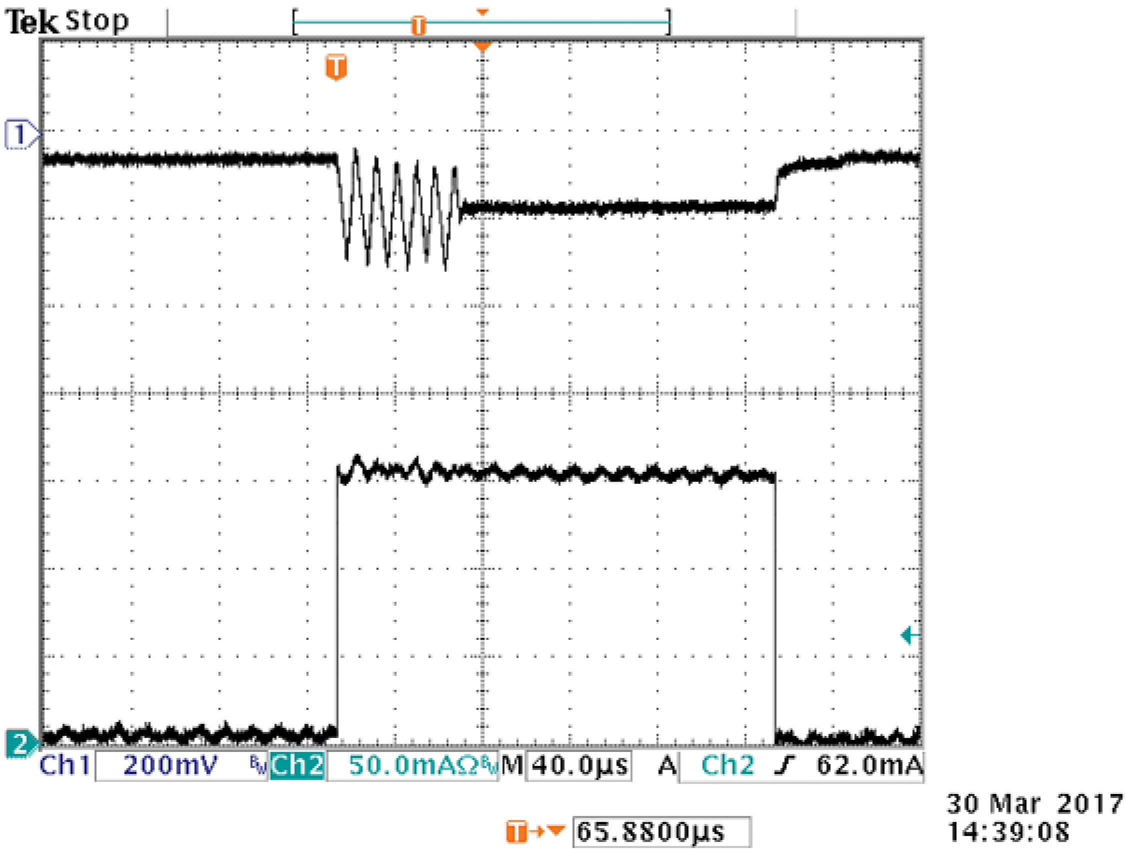

Figure 5. Noise during transition between modes.

Slow Response to Load Transients

The typical duration of LED light pulses is of the order of hundred of microseconds. Therefore, for consistent LED pulse current, the settling time when responding to load transients must be as short as possible (<< 117µs). **Figure 6** shows that the transient response time for a typical boost converter can be as high as 50µs, which is a significant portion of the LED light pulse duration.

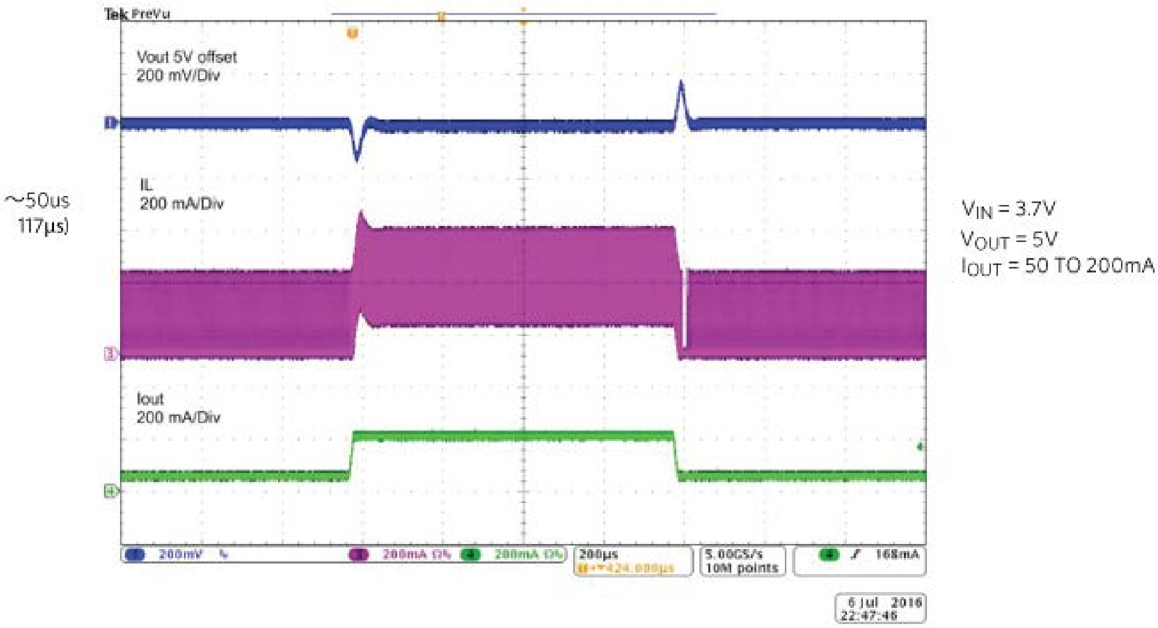

Figure 6. Response time to mode transitions.

The problem caused by a slow transient response is clearly shown in **Figure 7**, where the transient has barely died out by the end of a single-pulse duration.

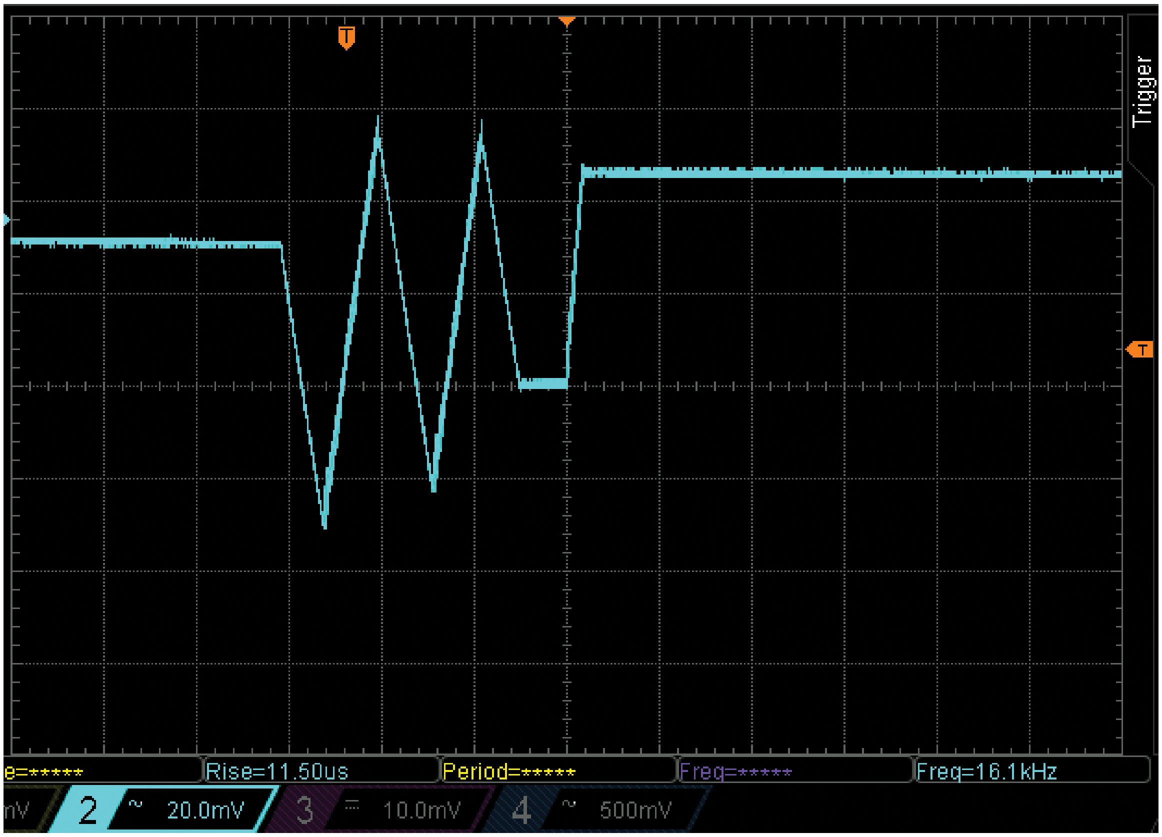

Figure 7. Slow response to load transients of a single-pulse duration.

Boost Converter for Optical Sensors

Clearly, some boost converters exhibit burst-mode behavior that causes problems for optical sensing applications. The PMIC shown in **Figure 8** includes a buck-boost converter, which has been designed to overcome these problems.

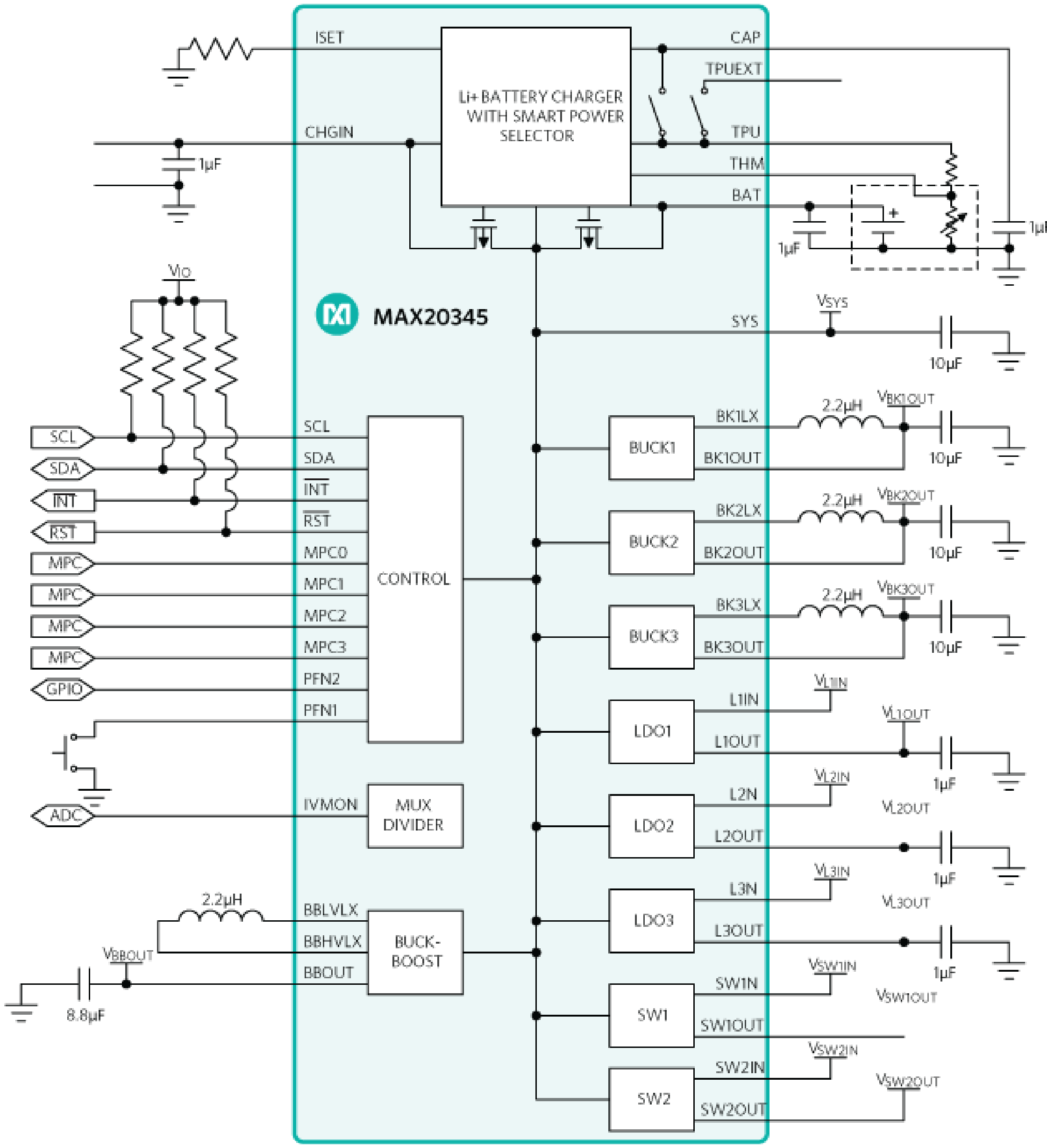

Figure 8. MAX20345 PMIC with a buck-boost converter.

As seen from **Figure 9**, the light-load ripple for the buck-boost converter on this part is much lower in amplitude (≤ 20mV), ensuring more consistent light-load LED current than other converters. It also operates with higher frequency at a given load. For instance, with loads as low as 5mA, the switching frequency is over 100kHz. The higher operating frequency helps to keep switching noise from interfering with the measured signal.

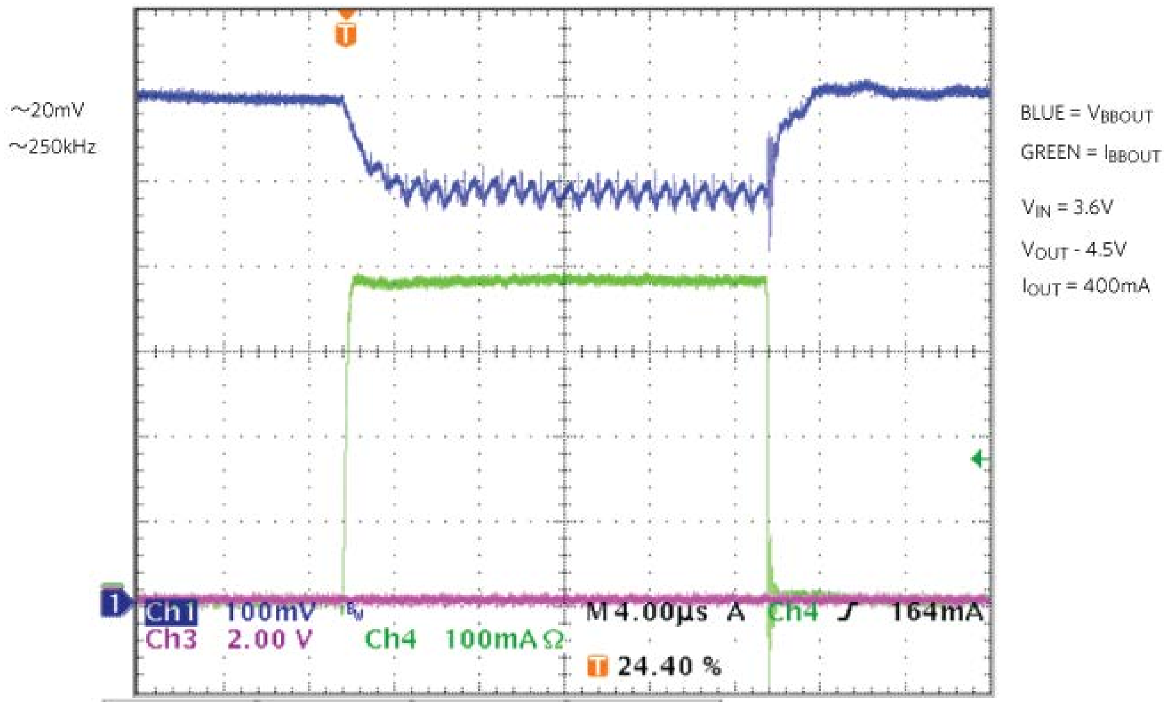

Figure 9. Burst mode ripple of a buck-boost converter with lower amplitude (MAX20345).

Secondly, the response time to load transients (< 3µs) is significantly lower than the LED pulse duration (117µs) and is an order of magnitude improvement on the converter previously shown. This faster response means that the load-transient response time of the buck-boost does not limit the overall setup time of the optical system's measurement. Importantly for this converter, both the load-transient response time, and the characteristics of the ripple, are consistent and repeatable from pulse to pulse.

As shown in **Table** 1, when a traditional burst mode converter is used to power the MAX86140 optical pulse oximeter and heart-rate sensor, the sensor's SNR performance is degraded by up to 7dB when compared to that measured in ideal laboratory conditions (89dB). Remarkably, when powered by the new buck-boost converter on this PMIC, the sensor's SNR performance approaches that of ideal laboratory conditions.

Table 1. Unfiltered SNR Performance (dB) of MAX86140

Photodiode Current (µA)	MAX20345 SNR (dB)	Competitor SNR (dB)
1.5	80.74	77.96
15	88.20	81.55
32	88.78	81.20

Together with the buck-boost regulator, this PMIC also features three buck regulators, and three low-dropout (LDO) linear regulators, which provide up to seven regulated voltages, each with an ultra-low quiescent current. This allows the PMIC to power multiple peripherals and sensors (including the MAX86140 optical AFE) including a microcontroller in a typical wearable device design, as shown in **Figure 10**. The PMIC is available in a 56-bump, 0.4mm pitch, 3.37mm x 3.05mm wafer-level package (WLP).

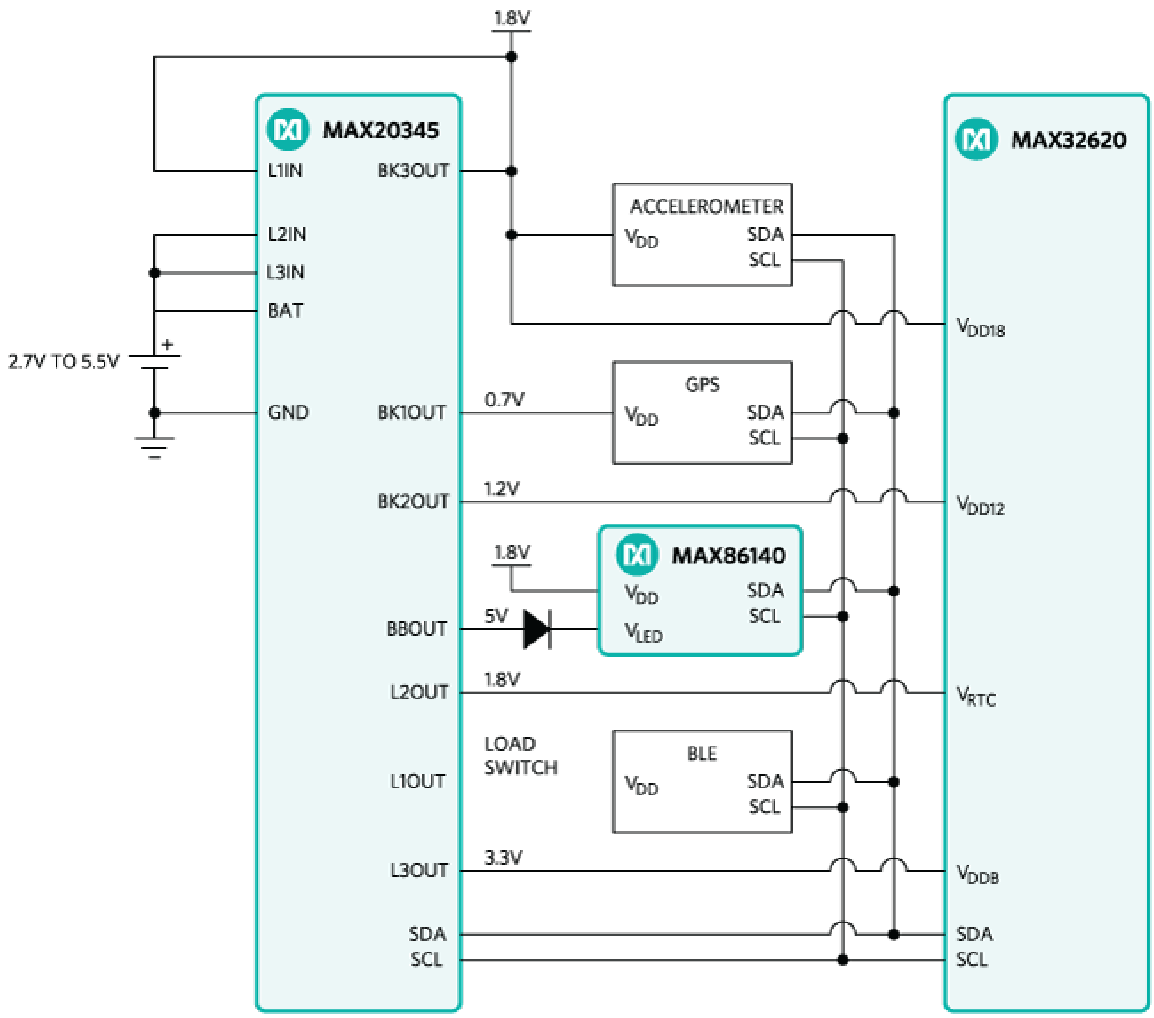

Figure 10. PMIC with buck-boost regulator powers multiple peripherals, sensors, and a microcontroller.

Summary

In this design solution, we reviewed how optical sensors in wearable devices measure health indicators such as heart rate and blood oxygenation. These sensors need a higher voltage than one provided by a lithium-ion battery, requiring a boost converter. However, a typical "burst-mode" boost converter can exhibit behavior that negatively impacts the SNR performance of these sensors. We then presented a new type of power management solution using a PMIC with a buck-boost converter specifically designed for optical sensing applications. The use of buck-boost converters greatly improves the SNR performance of wearables and other IoT applications.

Glossary

PPG: Photoplethysmography is the volumetric measurement of an organ
IC: Integrated Circuit
PMIC: Power Management Integrated Circuit. Used to regulate and control power.
LDO: Low Dropout. A linear voltage regulator that will operate even when the input voltage barely exceeds the desired output voltage.
LED: Light-Emitting Diode. A semiconductor device that emits light (usually visible or infrared) when forward-biased.
Photodiode: A semiconductor device that converts light into an electrical current
SNR: Signal-to-Noise Ratio. Ratio of the amplitude of the desired signal to the amplitude of noise signals at a given point in time. The larger the number, the better. Usually expressed in dB.

Related Parts		
MAX20345	PMIC with Ultra-Low I_Q Voltage Regulators, Buck-Boost for Optical Sensing and Charger for Small Lithium Ion Systems	Samples
MAX86140	Best-in-Class Optical Pulse Oximeter and Heart-Rate Sensor for Wearable Health	Samples

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