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APPLICATION NOTE 7051

TRACK YOUR HEART RATE WHILE YOU LISTEN TO YOUR FAVORITE TRACK

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Abstract: In this design solution, we consider some of the challenges and constraints when developing a custom photoplethysmography (PPG) solution using an optical sensor IC in hearable or in-ear fitness and health wearable devices such as earbuds.

Introduction

After another busy day designing circuits, you head for the woods, park your car, jump out and stretch your legs. You stick your earbuds in your ears and start to feel your stress levels reduce as your favorite album begins to stream wirelessly from your phone, drowning out the din of the world outside. All you need to do now is to make sure your fitness wearable is securely fastened so it can accurately track your heart rate activity while you run when- DOH! – you realize you've left it charging at work. Sound familiar?

Health and fitness wearables are great but wouldn't it be even better if there was some other way to capture this vital sign without the constraints of having to "wear" a dedicated device on your wrist or chest? You've got earbuds (**Figure 1**) in your ears – surely there's no way they could hold the sensors and analog front-end (AFE) required to perform that function in such a confined space? Or could they? As you head off on your run, without your realizing it, your imagination has you once again wearing that engineer's "hat" you thought you'd left at the office.

Figure 1. Wireless earbuds.

In this design solution, we review some of the challenges associated with accurately measuring heart rate and blood oxygen saturation (SpO_2) before introducing a fully integrated modular solution that now makes it possible to perform these measurements using a “hearable” (in-ear health and fitness wearable).

Heart-Rate Detection

Heart-rate (or pulse) detection is an almost ubiquitous feature of wearable health and fitness monitors. This reading is useful because heart rate is a vital sign that provides a good indication of heart-rate variability (HRV). HRV can be used to assess stress levels, overall well-being, and sleep quality among others. This measurement is based on a technique called photoplethysmography or PPG. A PPG signal is obtained by illuminating skin using a light-emitting diode (usually green) and detecting changes in the intensity of the reflected light (**Figure 2**) using a photo diode which generates a current proportional to the amount of received light.

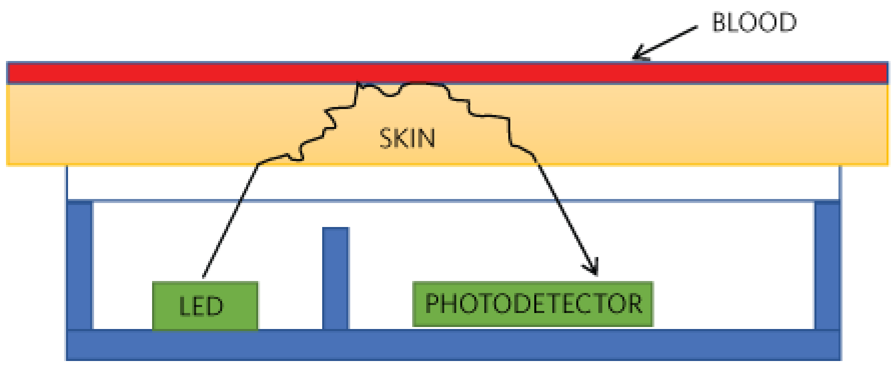

Figure 2. PPG using LED and photodiode.

As the heart pumps blood the amount of light returned to the photodiode from the skin registers a small change in amplitude (AC signal). This small change is superimposed on a large static amplitude (DC signal) which represents the ambient (background) lighting conditions in which the measurement is being made. The current signal is digitized and sent to a microprocessor within the device, which then uses an algorithm to calculate the heart rate. There are several major challenges in making accurate heart-rate measurements using hearable devices.

Lighting

The first challenge is the variation in lighting conditions the user encounters either during exercise or in normal living conditions. Rapidly varying lighting conditions can introduce "artifacts" into the measurement process. Artifacts are large changes in the received signal, which effectively mask the small AC signal, causing problems for the microprocessor to correctly calculate the pulse rate. Wearable devices must be able to compensate for large variations in ambient lighting to prevent spurious readings. While ambient light compensation is a feature of many modern health and fitness devices, the magnitude (ambient range) and quality (ambient rejection) varies widely. Currently available solutions have an ambient range only up to 25µA and an ambient rejection of up 55dB (at 120Hz).

Motion

The second challenge is the motion of the user, particularly during periods of high-intensity training, which can also cause artifacts. Currently available solutions use digital filtering techniques to attempt to compensate for motion artifacts, but these are not always successful.

Power

Apart from the challenges associated with artifacts, wearable devices need to consume as little power as possible, to prolong battery life. The power budget must provide for three LEDs (red, green and infrared) and a photodiode whose output signal must then be conditioned by appropriate AFE circuitry.

Form Factor

Incorporating the light LEDs, photodetector, and low-noise electronics into an earbud represents a significant optomechanical design challenge, not only due to space limitations, but also because poor design can negatively impact measurement accuracy. For example, the light transmitted by the LEDs is not fully absorbed by the skin, leading to unwanted reflections from the enclosure window on the photodiode. This undesirable phenomenon is called “crosstalk” and minimizing it requires a detailed understanding of the physics of the materials used in the manufacture of the optical enclosure. It includes other factors such as air gap and crosstalk reduction techniques (inking).

Modular Approach

In the face of the considerable design effort required to successfully overcome these challenges, a more convenient way to incorporate PPG measurement into an earbud enclosure might be to use an integrated modular solution which has the advantage of already incorporating the optical and AFE elements into a single package. **Figure 3** shows a simplified block diagram of this type of solution. Apart from helping to minimize component count and board area, this solution has several advantages over other designs requiring several parts (separate optical and AFE).

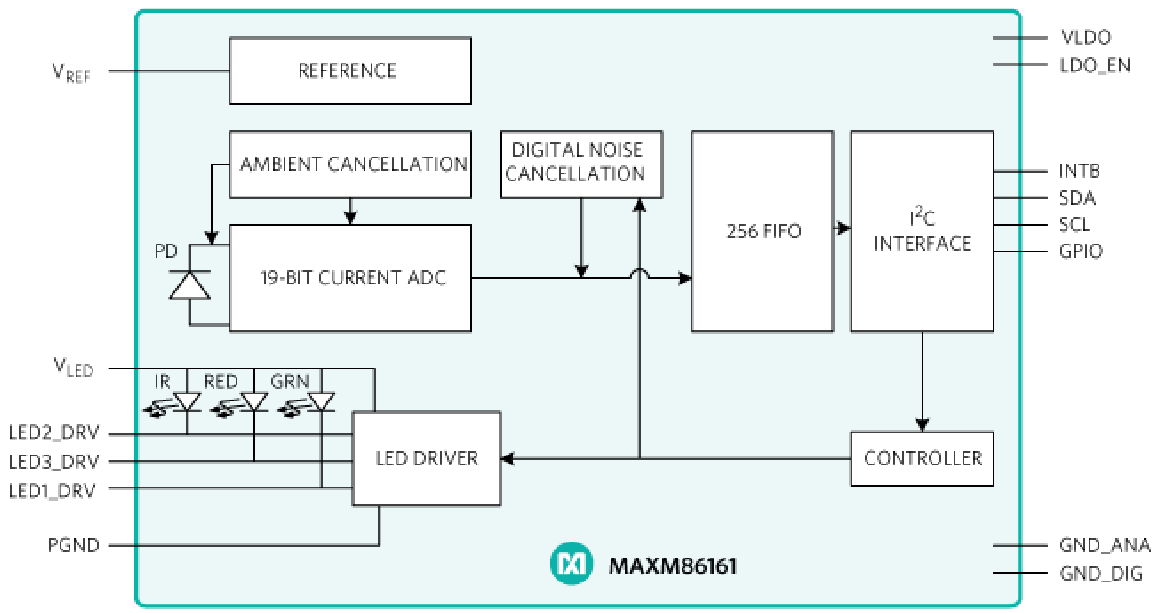

Figure 3. Simplified block diagram of MAXM86161 integrated optical module.

Apart from the ambient range (> 100µA) and ambient rejection (> 70dB) at 120Hz, both of which far exceed those of other optical parts, it also has the advantage of employing a proprietary “picket-fence” algorithm to mitigate the effects of rapidly varying lighting conditions (fast ambient transients). Consuming less than 300µW of power, the module is available in a miniature 14-pin OLGA package measuring only 2.9mm × 4.3mm × 1.4mm as shown in **Figure 4**, powered from a single supply.

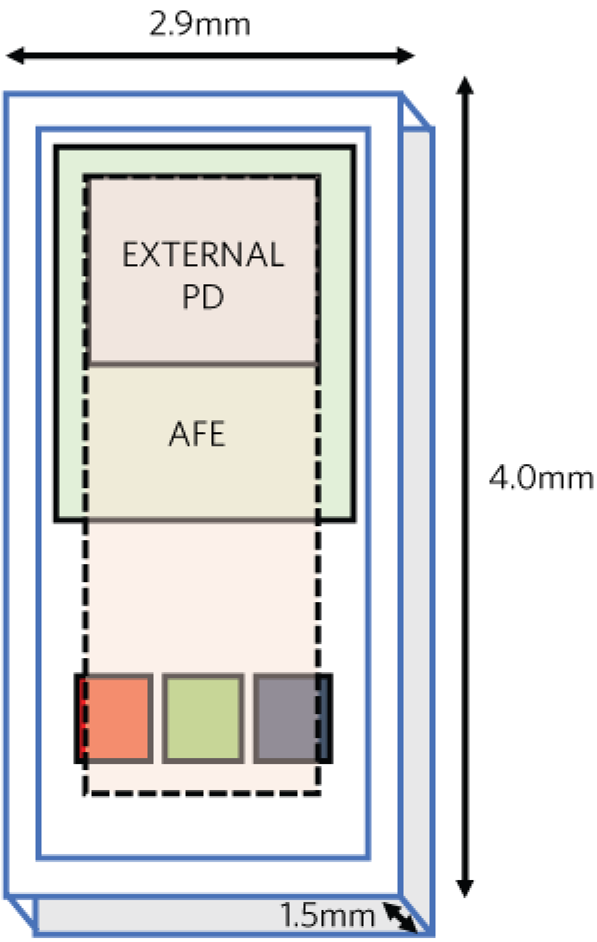

Figure 4. MAXM86161 module dimensions.

Figure 5 shows a cross-section of how this module may look within an earbud enclosure.

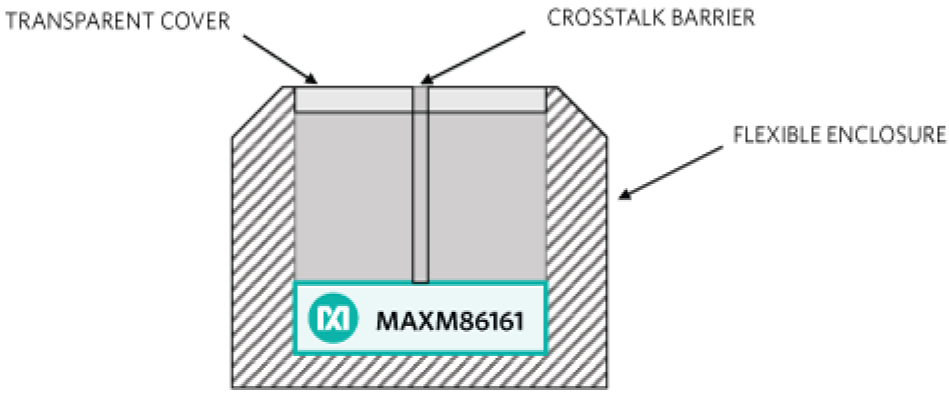

Figure 5. Cross-section of an earbud showing the MAXM86161 module.

Summary

In this design solution, we have considered some of the challenges and constraints when developing a custom PPG solution for hearable devices. We can conclude that using a single module that integrates all the optical sensing elements and the AFE into a single package confers several advantages over a custom design, including reduced power and area while improving optical performance in a shorter design cycle.

Related Parts		
MAXM86161	Single-Supply Integrated Optical Module for HR and SpO_2 Measurement	Samples

More Information
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