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Wearable Bio-Sensing Series

Application

Optical Heart Rate Monitoring (OHRM) uses the principle of photoplethysmography (PPG) to determine the heart rate. For a healthy individual, the heart pumps blood to all parts of the body in each cardiac cycle. This causes the volume of the blood in the arteries to have a pulsating component that has the periodicity of the heart rate. By illuminating the skin using a light-emitting diode (LED) and measuring the amount of light either transmitted or reflected to a photodiode (PD), the pulsating waveform can be converted to a signal current. As shown in [Figure 1](#), an analog front-end (AFE) converts the signal current waveform from the PD to a digitized waveform which can then be processed by a signal processing algorithm in the MCU to extract the heart rate (HR).

In a device like a smartwatch, the LED and PD both face the wrist. The light from the LED is incident on the skin, and the reflection of the light from the artery results in a pulsating component. Typically, green LEDs are used, and the signal from multiple spatially-separated PDs are combined to mitigate effects such as motion.

The clinical range of the HR frequency is 0.5 Hz to 4 Hz. The PPG waveform is sampled at a rate (for example, 25 Hz), that is referred to as the pulse repetition frequency (PRF).

To save power, the LED is pulsed at the PRF rate, turning on for a short window in each PRF cycle. Each turning on of the LED results in one sample in the digital data stream.

AFE4432

The AFE4432 is a high-performance, low-power AFE from Texas Instruments that is designed for OHRM on wearables and hearables.

- **Interface:** SPI™, I²C interfaces: Selectable by pin
- **Package:** 1.9-mm × 1.8-mm DSBGA, 0.35-mm pitch
- **Supplies:** RX: 1.7 V–1.9 V, TX: 3.0 V–5.5 V
- **Features:**
 - First in, first out (FIFO) with 160-sample depth
 - Internal oscillator, external clock options

Differentiation

- Signal chain has wide adaptability (LED current, transimpedance amplifier (TIA) gain, offset digital-to-analog converter (DAC) range) for a variety of use cases including low perfusion index, high ambient, and motion
- Noise reduction filter limits optical noise bandwidth and provides high signal-to-noise ratio (SNR) even at low LED currents
- Input offset cancellation DAC cancels DC from both ambient and LED, and allows a high TIA gain setting for the best noise performance

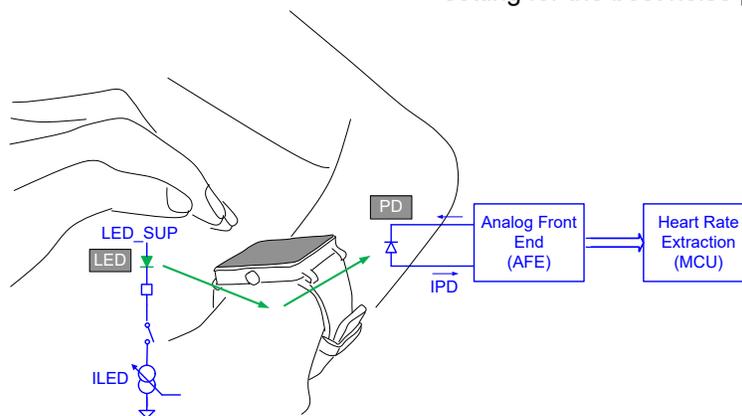


Figure 1. Heart Rate Monitoring on a Wearable Device

Figure 2 shows the reference schematic for an OHRM application using the AFE4432 and Table 1 shows the specifications of an OHRM system.

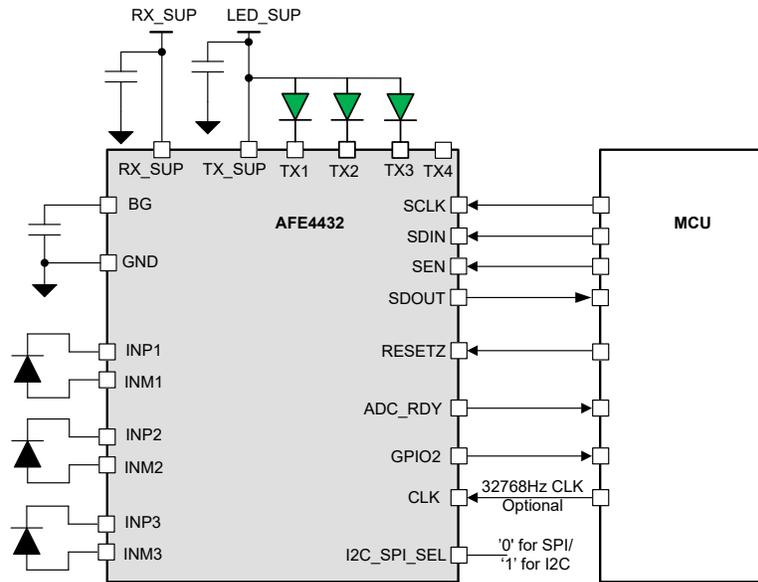


Figure 2. Reference Schematic for OHRM Using AFE4432

Table 1. Specifications for OHRM on Wearables

System Specifications	AFE4432	Comments
Multi-sensor support	4 LEDs, 3 PDs	Combining signals from multiple PDs and LEDs helps mitigate motion artifacts
Sampling rate	1 Hz–1 kHz	A sampling rate of 25 Hz to 100 Hz is typically used for continuous HRM
Current consumption	12 μ A	For the receiver at 25 Hz PRF
Peak SNR	115 dB over 10-Hz bandwidth	Important consideration to achieve good accuracy in low perfusion cases.
Ambient rejection	> 70 dB up to 160 Hz	Good ambient rejection helps remove the spurious tones caused by ambient light from sources such as indoor lighting

Figure 3 shows the PPG signal chain in AFE4432.

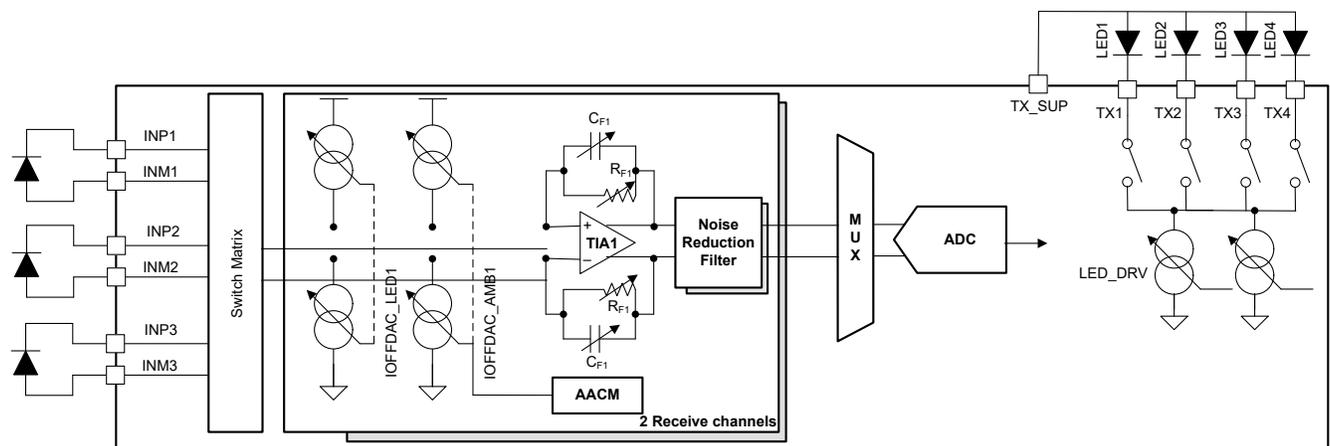


Figure 3. PPG Signal Chain in AFE4432

The LED driver drives up to 4 LEDs with programmable current. Each receiver can interface to up to 3 PDs and comprises a TIA, input DC offset cancellation DACs (for ambient, LED light), and noise reduction filters with programmable bandwidth. Both receivers share a common analog-to-digital converter (ADC). The PPG signal chain for optical heart rate monitoring on wearables is supported on many other AFEs from Texas Instruments such as the AFE4950, AFE4960P, and AFE4500 devices.

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