Reducing Electric Power Consumption when Transmitting ECG/EMG/EEG using a Bluetooth Low Energy Microcontroller[†]

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Low-power wearable sensors now have sufficiently high sampling rates and bandwidth to support acquisition of electrophysiologic signals (e.g., ECG/EMG/ EEG) [1-3]. But, these higher sampling rates are associated with higher power consumption, greatly reducing battery life [4, 5]. Thus, we examined average power consumption in a commercial Bluetooth low energy microcontroller (TI CC2640R2 BLE Module) while varying transmission power (maximum vs. minimum available), time interval between transmissions (10 ms to 5 s), sampling frequency (1000 to 4000 Hz), and transmit payload size (all samples vs. one "processed" value per interval); since each of these variants can influence power consumption [6, 7]. Neither sampling rate nor payload size noticeably altered power consumption. Increased transmit power, as expected, increased power consumption. Longer transmit intervals reduced power consumption, with most of this advantage occurring by intervals as small as 50–100 ms. Thus, relatively low latency (≤ 100 ms), low power signal acquisition is supported by these commercial modules, without particular regard to payload size or sampling rate.

We developed a prototype wireless electrophysiologic acquisition system, applicable to ECG/EMG/EEG signals, comprised of an analog front end and a Bluetooth low energy microcontroller (TI CC2640R2 BLE Module). The front end (see [8]) consisted of an instrumentation amplifier (AD8422), passive band pass filtering, and DC-shifting of the signal into the range of the on-board, unipolar, 12-bit ADC. A set of average electrical current consumption measurements was made while varying all combinations of Bluetooth transmission power (+5 dBm = maximum power, +0 dBm = minimum power), the time interval/latency between transmissions (10, 20, 50, 100 ms), the sampling frequency (f_{Sample} = 1000, 2000, 4000 Hz) and the processing-transmission mode (transmit raw two-byte signal vs. transmit one byte per interval—representing on-board signal processing, which greatly reduces channel bandwidth). Average current consumption was measured by inserting a small resistance (1.2 Ω) in series with the 3.3 V battery and then averaging voltage across it for 30 s with a hand-held digital multimeter (RSR MAS830, resolution of 0.1 mV). We separately measured current in the analog front end and in the TI CC2640R2 BLE module.

For all conditions, the analog front end average current consumption was 0.8–0.9 mA. Neither sampling rate nor processor-transmission mode substantively altered this consumption (Table 1). These conditions vary the transmit payload, since longer intervals communicate more samples per transmit cycle. Thus, the volume of data transmitted had no practical influence on Bluetooth module power consumption.

Transmit Power = +5 dBm (Maximum)

	Raw Signal			One Byte/Interval		
	f_{Sample} (Hz)			f_{Sample} (Hz)		
Interval	**1000**	**2000**	**4000**	**1000**	**2000**	**4000**
10 ms	3.0	3.0	3.1	3.0	3.0	3.0
20 ms	1.9	1.9	1.9	1.9	1.9	1.9
50 ms	1.2	1.2	NA	1.2	1.2	1.3
100 ms	1.0	NA	NA	1.0	1.1	1.0

Transmit Power = +0 dBm (Minimum)

	Raw Signal			One Byte/Interval		
	f_{Sample} (Hz)			f_{Sample} (Hz)		
Interval	**1000**	**2000**	**4000**	**1000**	**2000**	**4000**
10 ms	2.3	2.4	2.4	2.3	2.4	2.3
20 ms	1.6	1.6	1.6	1.7	1.7	1.8
50 ms	1.0	1.0	NA	1.0	0.9	1.0
100 ms	0.9	NA	NA	0.9	NA	NA

Table 1. Average current consumption (mA), TI BLE Module CC2640R2 (excludes analog front end). "NA" denotes packet size too large or unreliable

However, transmit power and interval had a noticeable influence on average current—larger transmit powers and shorter intervals led to larger currents. We further tested transmit intervals of 500 ms, 1 s, 2 s and 5 s (f_{Sample} = 4000 Hz, Mode = one datum/cycle, lower transmit power). In each case, Bluetooth module average current was 0.8–0.9 mA—essentially its minimum. Thus, Bluetooth module current was maximum at the shortest transmit interval of 10 ms, (2.3 mA) but fell rapidly with increasing interval, quickly approaching its minimum. Overall, power consumption was not substantively influenced by sampling rate or payload size, and transmit intervals above ~50 ms consumed power indistinguishable from minimum power. Transmit power, as expected, directly influenced power consumption. In applications, choice of transmit power level will be influenced by the necessary transmit distance and the ambient environmental electronic noise level [9, 10].

[†] This work supported by US Army Contract W81XWH-17-C-0167. Views, opinions and/or findings are the authors' and should not be construed as official Department of Army position, policy or decision unless so designated by other documentation.

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Abstract

- Low-power wearable sensors now have sufficiently high sampling rates and bandwidth to support acquisition of electrophysiologic signals (e.g., ECG/EMG/ EEG). But, these higher sampling rates are associated with higher power consumption, greatly reducing battery life
- The goal of this project was to design inexpensive wireless ECG/EMG/EEG electrodes by using the latest Bluetooth Low-Energy (BLE) standard. Depending on the application, these electrodes could be operated for 6–24 hours between recharging.

Background

IoT technology is no longer a new term along with the rapid development of technology, but it is quietly changing our lives. Meanwhile wearable and wireless body-area networks are revolutionizing healthcare. Today, wireless communications are rapidly evolving, and the advent of low-power wireless protocols has made high-resolution wireless medical signal acquisition possible. Among them, wireless EEG/EMG/ECG electrode systems are a communication application where multiple slave devices need to talk to one master device, and the Bluetooth Low Energy (BLE) protocol has undoubtedly become an ideal choice. However, high-rate wireless transmission inevitably increases the power consumption of the wireless system. This poster explores the impact of different transmission rates on system power consumption using the BLE 5.0 protocol.

Overall Design

The design is divided into two parts: Analog front end (AFE) design and Wireless node selection/ programming.

- **AFE should satisfied high sample rate (4KHz), high resolution (≥ 12 bits/sample), low noise(< $1\ \mu V_{rms}$)**
- **Wireless MCU should satisfied high throughput (> 1mbps), low latency (< 20ms)**

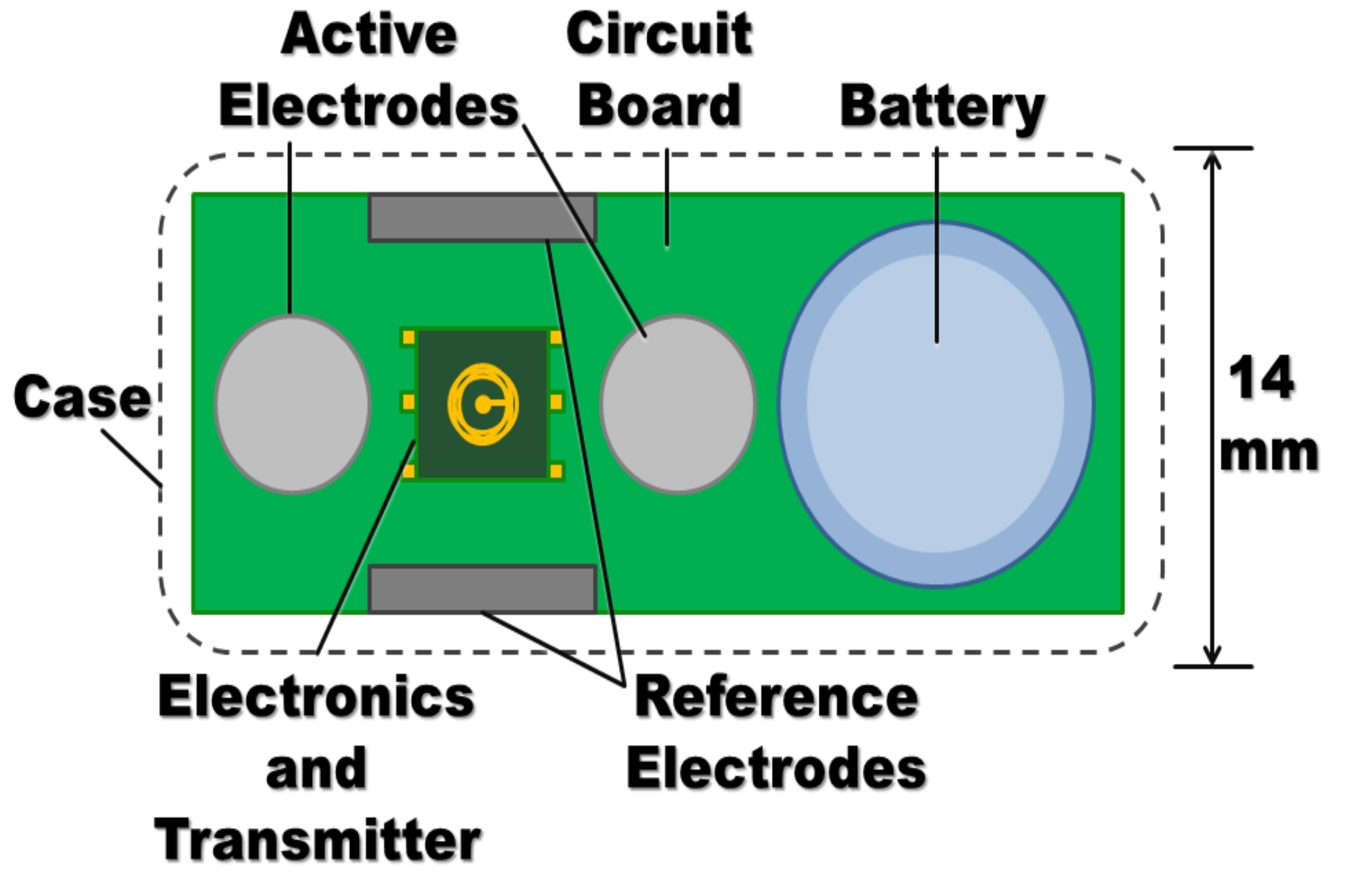
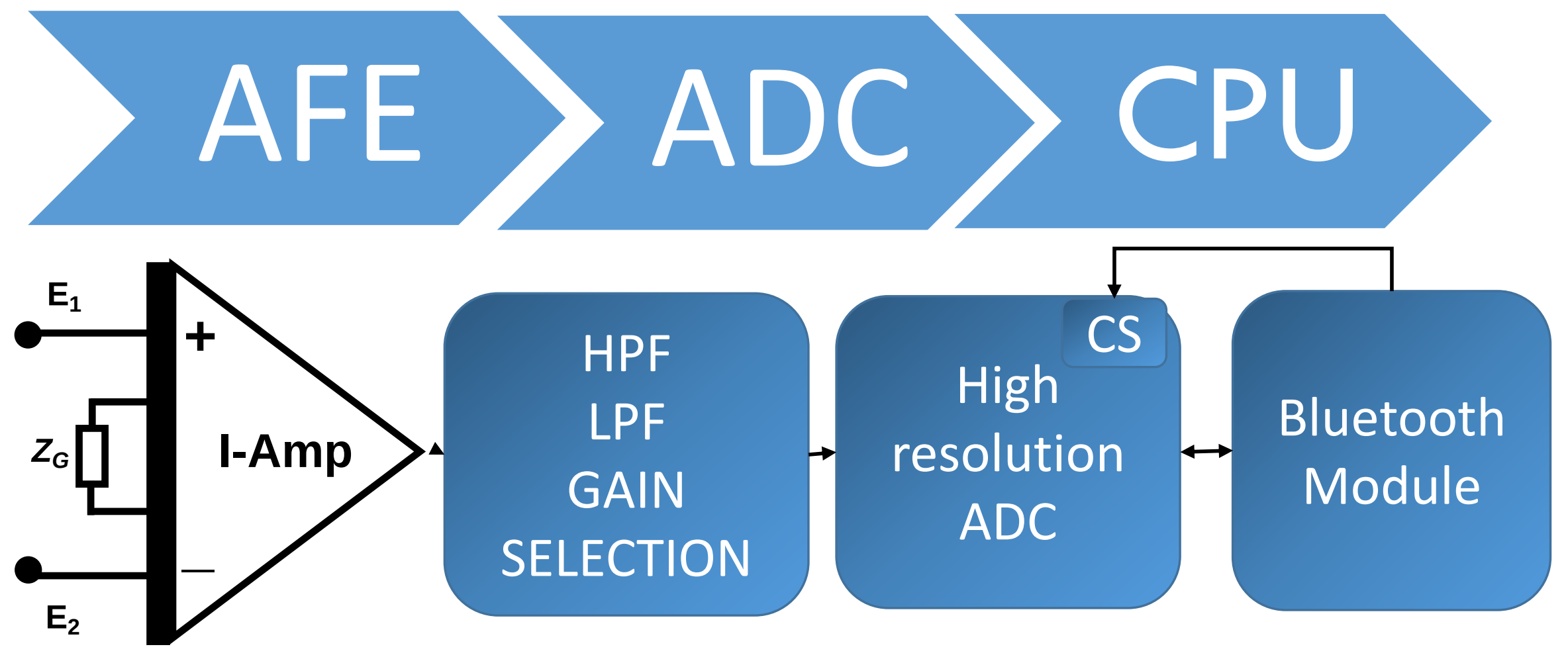


Fig. 1: Proposed layout of wireless electrode

Function Diagram



Instrumentation Amplifier(AD8422)

AFE Hardware Design

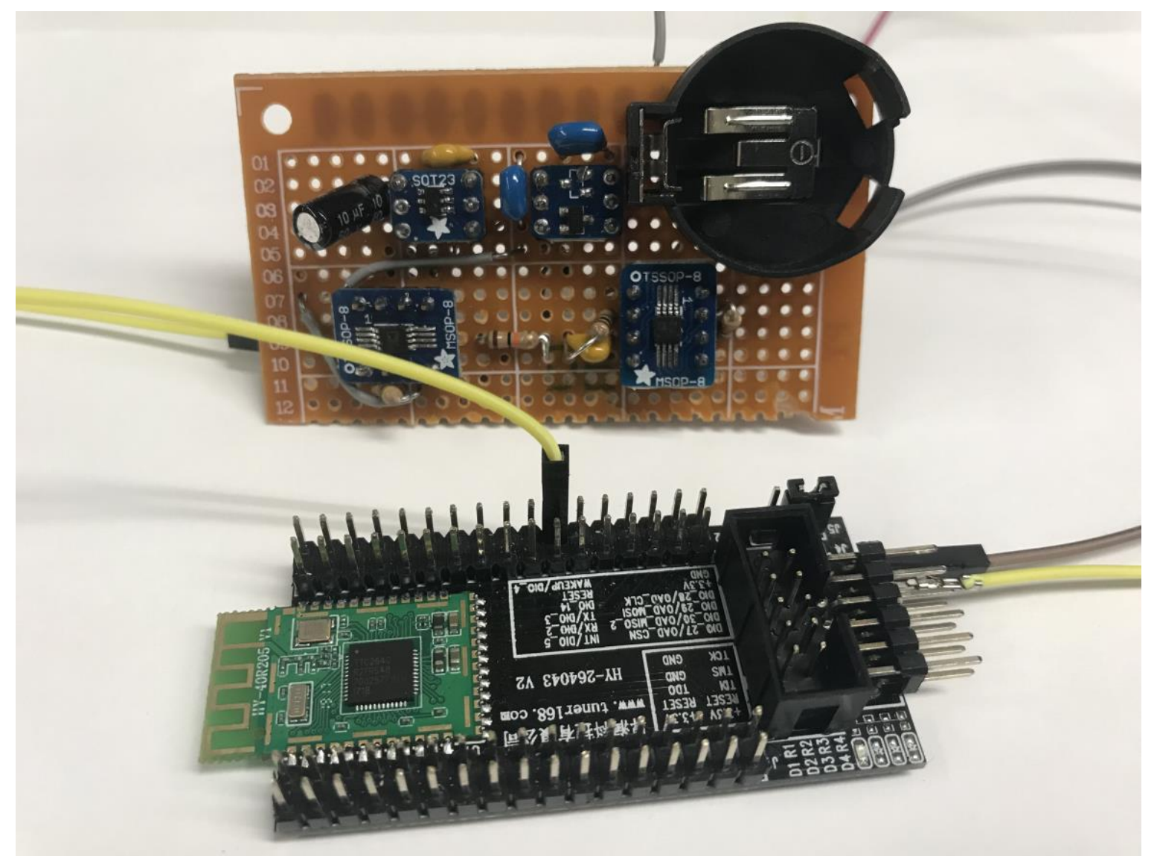


Fig. 2: AFE (top) testing with the selected Bluetooth module (bottom)

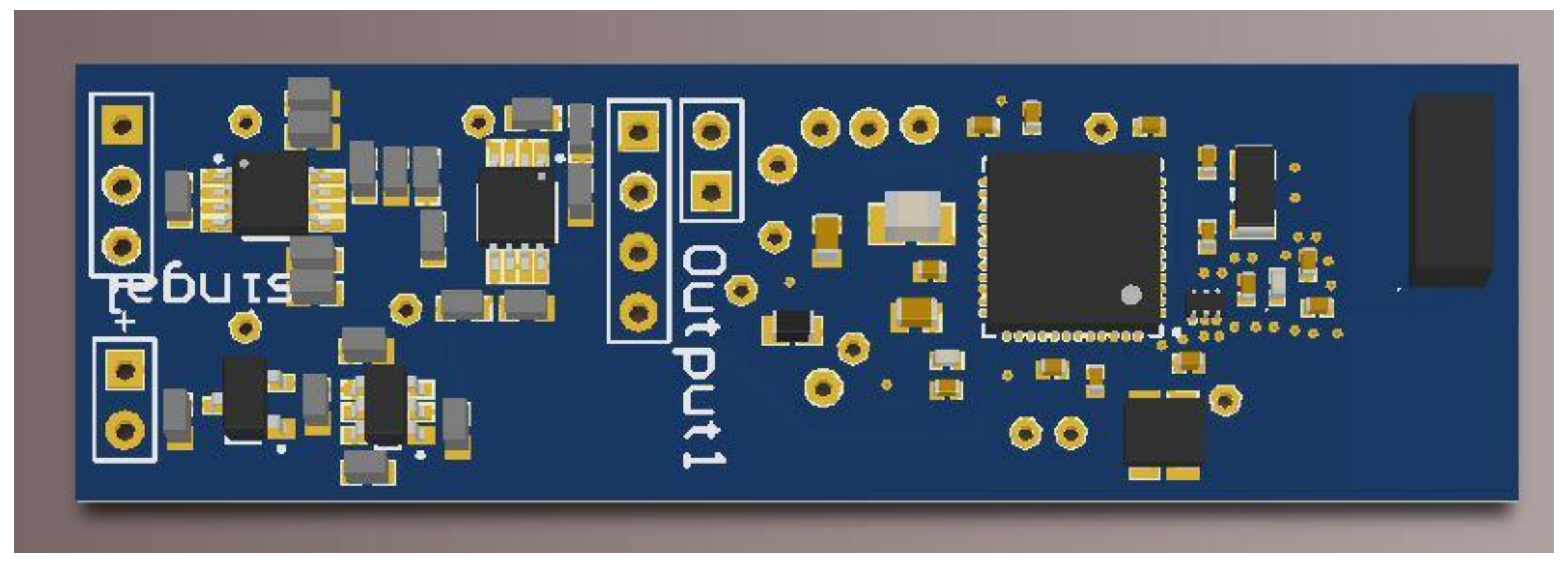


Fig. 3: PCB layout for the whole system

Testing for AFE

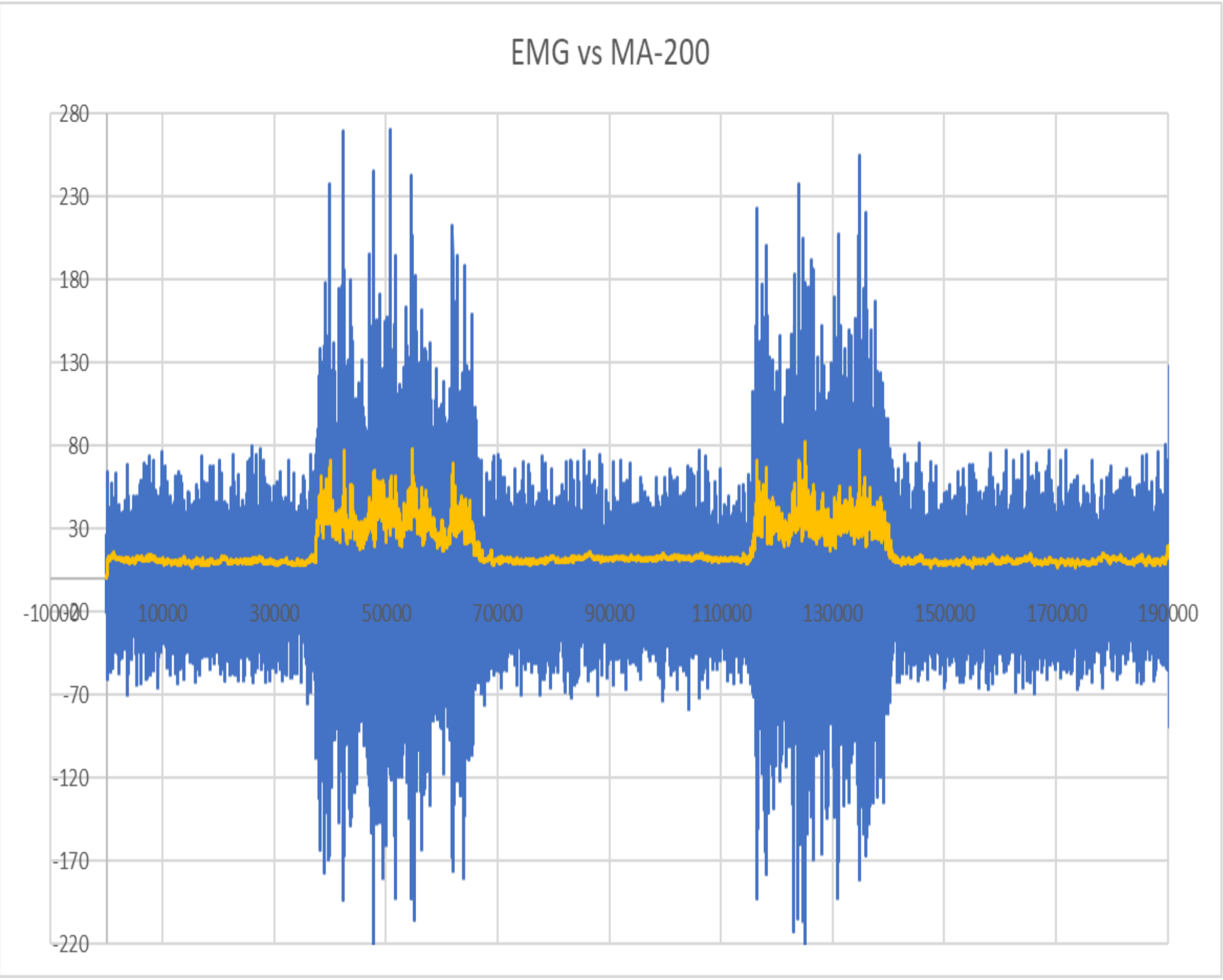


Fig. 4: 4 KHz sample rate,12-bit ADC EMG data . Raw EMG signal (blue) vs. Moving Averaged signal (yellow)

Latency Test

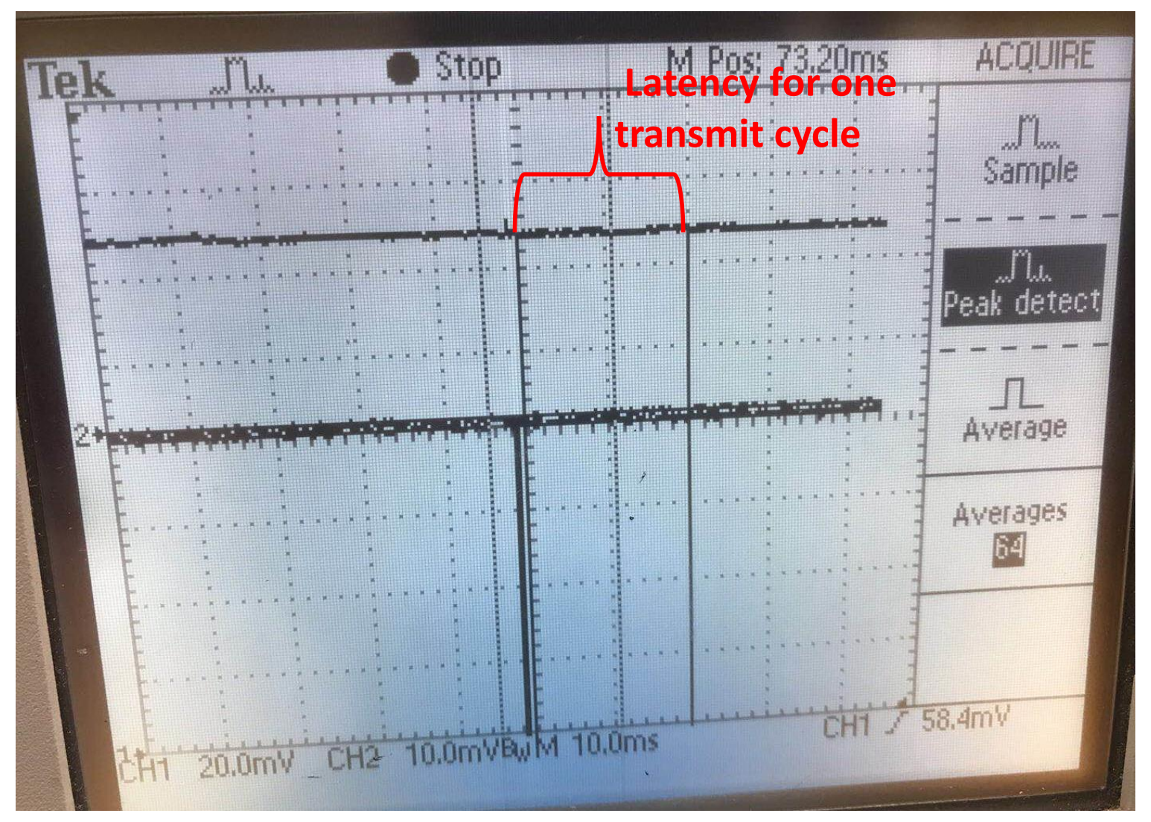


Fig.5: First receiver sends a command to transmitter. Second receiver told PC send commend successfully (data length extend mode). Last Receiver receives the data. Average latency is approximately 10 ms.

Power Consumption Test

A. Measuring Method

Average current consumption was measured by inserting a small resistance (1.2 Ω) in series with the 3.3 V battery and then averaging voltage across it for 30 s with a hand-held digital multimeter (RSR MAS830, resolution of 0.1 mV).

B. FactorsTested:

- **Transmission power**

  (+5dBm = maximum power, +0dBm = minimum power)
- **Time interval/latency between transmissions**

  (10, 20, 50, 100 ms)
- **Sampling frequency**

  (f_{Sample} = 1000, 2000, 4000 Hz)
- **Processing-transmission mode**

  (Transmit raw two-byte signal vs. Transmit one byte per interval—representing on-board signal processing, which greatly reduces channel bandwidth)

C. Results

Transmit Power = +5 dBm (Maximum)

	Raw Signal f_{Sample} (Hz)			One Byte/Interval f_{Sample} (Hz)		
Interval	1000	2000	4000	1000	2000	4000
10 ms	3.0	3.0	3.1	3.0	3.0	3.0
20 ms	1.9	1.9	1.9	1.9	1.9	1.9
50 ms	1.2	1.2	NA	1.2	1.2	1.3
100 ms	1.0	NA	NA	1.0	1.1	1.0

Transmit Power = +0 dBm (Minimum)

	Raw Signal f_{Sample} (Hz)			One Byte/Interval f_{Sample} (Hz)		
Interval	1000	2000	4000	1000	2000	4000
10 ms	2.3	2.4	2.4	2.3	2.4	2.3
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50 ms	1.0	1.0	NA	1.0	0.9	1.0
100 ms	0.9	NA	NA	0.9	NA	NA

Table 1. Average current consumption (mA), TI BLE Module CC2640R2 (excludes analog front end). "NA" denotes packet size too large or unreliable

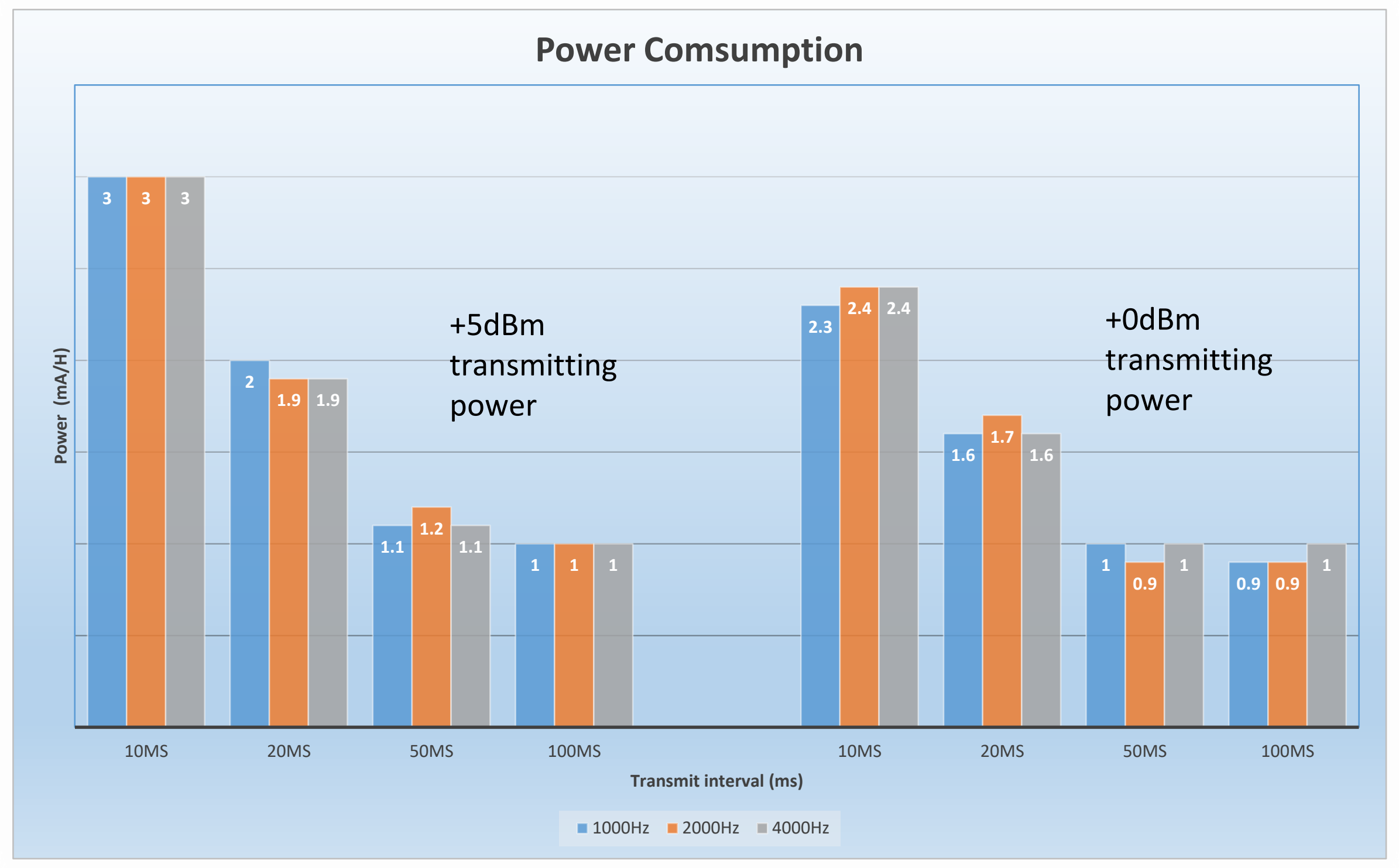

Fig.6: Power consumption between different sample intervals, sample rate and transmit power

D. Discussion

- **Neither sampling rate nor processor-transmission mode substantively altered current consumption (Table 1). These conditions vary the transmit payload, since longer intervals communicate more samples per transmit cycle. Thus, the volume of data transmitted had no practical influence on Bluetooth module power consumption.**
- **Transmit power and interval had a noticeable influence on average current—larger transmit powers and shorter intervals led to larger currents.**
- **Additional transmit intervals of 500ms, 1 s, 2 s and 5 s (f_{Sample} = 4000 Hz, Mode = one datum/cycle, lower transmit power) were tested. In each case, Bluetooth module average current was 0.8–0.9 mA—essentially its minimum.**
- **Bluetooth module current was maximum at the shortest transmit interval of 10 ms, (2.3 mA) but fell rapidly with increasing interval, quickly approaching its minimum.**

Summary

- **From all the testing, the whole system could satisfied the basic requirement. Power consumption is mainly influenced by transmit interval (and transmit power).**
- **Power consumption was not substantively influenced by sampling rate or payload size, and transmit intervals above ~50ms consumed power indistinguishable from minimum power.**
- **Transmit power, as expected, directly influenced power consumption. In applications, choice of transmit power level will be influenced by the transmit distance and the ambient environmental electronic noise level.**

Acknowledgements

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