Designing a Wireless Heart Rate Monitor with Remote Data Logging

By Archana Yarlagadda, Applications Engineer, Cypress Semiconductor Corp.

Extending the Human-to-Machine Interface (HMI) using wireless communications is a fast developing field. Important improvements in HMI functionality have been made possible by continuing advancements in Machine-to-Machine interfaces in terms of increased baud rate, low power consumption and reach (distance) of communication. HMI also benefits from advances in System-On-Chip technology which enable greater integration, greater power efficient, and higher accuracy. This article focuses on showing how these technologies drive forward HMI capabilities and considers the heart rate monitor with wireless transmission as a case study.

Heart Rate Monitors (HRM) have been an inherent part and important step of diagnosis in medical field for ages. The current generation of portable heart rate sensors has extended the usability of these devices out to the average person for use during day to day activities such as exercise and sports. These devices are typically either mechanically based (converting vessel ripples using piezoelectric signals) or utilize pulse rate electrical signal detection methods, which require placement of two or more electrodes on the skin for electric impulse reception.

Most devices on the current market often have a real-time display without large data storage capacities. There are some devices, like Holter monitors, with long-term recording capabilities which use a dedicated transmitter - receiver pair for individual usage. One disadvantage of these devices when they are used in sports training or medical monitoring systems where there is need for group monitoring/supervision is that they do not facilitate real-time centralized data logging and supervision.

The system suggested in this article uses one receiver as a Hub that aggregates data from several different transmitters. This allows supervision and data logging when several monitors are collocated for applications like sports, hospitals, and/or research by coaches, medical caregivers, or supervisors. This new method will be helpful both in facilitating fitness training for athletes as well as remote monitoring of patients. It also allows the resources on the receiver to be shared, thus decreasing overall system cost.

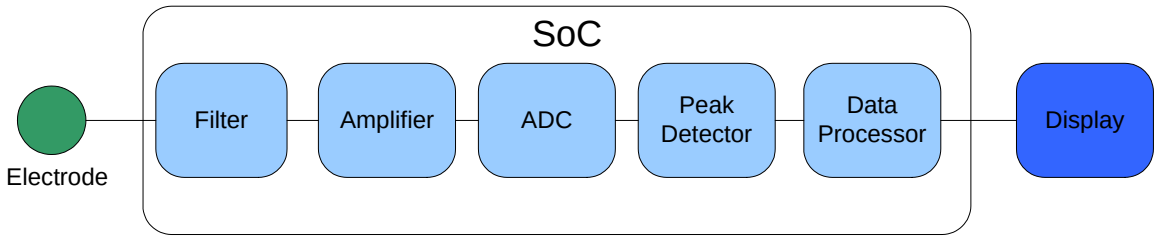

Figure 1: Block diagram of traditional HRM system

Heart rate can be monitored using various methods. The most common way is to show the result in the digital format (not waveform) on a display console. For the scope of this article, an Electrocardiogram (ECG) type of monitoring is considered. The block diagram for a traditional ECG-based HRM system [1] is shown in Figure 1. Electrodes should be in direct contact with the skin of the patient and are held in place using self-adhesives or flexible straps. To make pulse rate monitoring more comfortable during training, many commercial products place the electrodes on a flexible waistband.

The SoC chip where the heart rate is captured, processed, and displayed can be connected to a wireless transmitter over with which the data will be transmitted through an I^2C communication [2]. In traditional systems, the data is displayed directly on the display and/or transmitted to a specific wireless receiver. This system cannot be used to monitor a group of athletes during their training season or group of patients in a hospital because multiple transmitters will interfere with each other. In order to avoid interference, developers can instead “bind” a single receiver to many transmitters by assigning a unique identifier to each transmitter in the area of coverage. This will form a complete remote data logging system as shown in Figure2.

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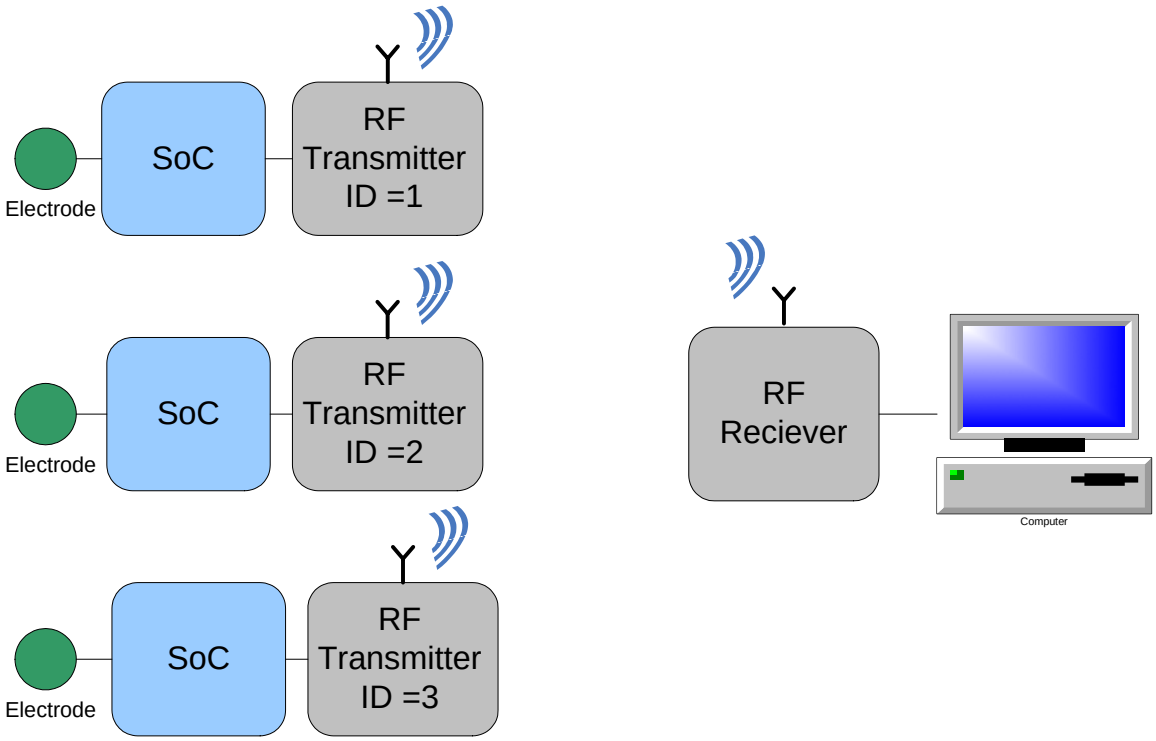

Figure 2: Block Diagram of Wireless HRL with Remote Data Logging

In order to implement Remote Data Logging (RDL) in this fashion, developers must reconsider some of the important blocks in the HRM system, namely the sensor electrodes, SoC implementation, and transmitter/receiver pairs.

Sensor Electrodes

The sensors measure the electric impulse on the skin and convert it into and electrocardiogram. The ECG obtained from the sensor electrodes will inevitably contain noise due to interfering signals from surrounding electrical devices and also other electrical signals in human body including muscular activity. The placement of the electrodes plays an important role in the accuracy of the signal obtained. Sensor electrodes that are placed around the chest obtain most accuracy. When using any other type of placement, such as wristbands, developers trade-off user comfort for accuracy.

The ideal signal obtained from the ECG, with no noise, is shown in Figure 3. The peak signal should be identified from other smaller noise peaks. These noise peaks in the signal are filtered out and the R-R interval is averaged out over a period of time. The reciprocal of the R-R interval then gives the heart rate in terms of Beats-Per-Minute (BPM).

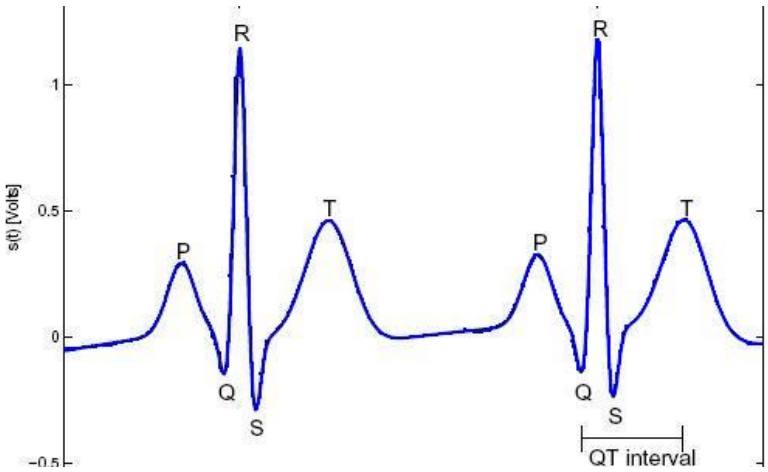

Figure 3: ECG output of an ideal pulse rate

SoC Implementation

The most important block required in the proposed system shown in Figure 1 is the SoC. The ECG signal obtained from the electrodes is passed through a differential amplifier with a high common mode rejection ratio. This reduces common mode environmental noise and amplifies only the desired signal. Though the filter is shown as one part in the block diagram, the noise filtering is a distinct different block of the system, both in the analog and digital domains. The Analog-to-Digital Convertor (ADC) block is used to convert the analog sensor signal into the digital domain. The pulse detector uses a threshold comparator to detect the R peaks. These peaks are collected for a certain number of clock cycles. The final value of heartbeat in terms of BPM is processed in the firmware and this value, in the traditional system, is displayed onto a dedicated console. In case of remote supervision and data logging, this value is transmitted through the RF transmitter with a unique ID. The SoC used for implementation of this project was CY8C27x43 [1]. This system can be implemented with any SoC that has the ability to implement the blocks mentioned.

RF Transmitter and Receiver

In the application of heart rate monitors for supervision, the idea is to supervise and record the data of all the athletes/patients in the field or in a building using a wireless link. Figure 5 shows data being collected from multiple sources. This data was collected by a receiver implemented using the Cypress CyFi wireless kit (CY3271) evaluation kit which employs a low-power consumption, short-range 2.4 GHz wireless link with a range of 200 to 400 meters. The data is passed to the RF transmitter through a digital communication interface on the SoC. The RF transmitter then transmits this data. After receiving the data, the RF receiver passes on the information over USB to the PC.

The wireless transceiver is implemented using a Star Network Protocol (SNP). The receiver that is connected to the data-logging system forms the “Hub” for the network and each of the heart rate monitors connected to the athletes form the “Nodes” in the network. The Hub that is used in the CyFi kit can connect up to 250 nodes, setting this as the upper limit for the number of athletes that can be monitored at a single time with this system.

The unique ID with which the Node/Athlete is identified can be either be assigned “On-the-Fly”, assigned by the Hub, or be predefined. Using an On-the-Fly ID method simplifies monitoring of large number of nodes at the same time by eliminating the need to worry whether a particular predefined ID is being used by multiple nodes. The connection between the hub and a specific node is done during the configuration communication (bind mode) and the hub receives the information during the application communication (data mode).

When the hub is set in the bind mode sequence, it assumes the network parameters and “listens” to any bind requests from the receiver. When the bind is activated on the node side, it sends out a Hub Bind Request packet and waits for the acknowledgment from the Hub. Both the node and the Hub perform this sequence on different channels until their channels overlap. The timing of the channel hopping is made such that the hub and the node will have multiple channel overlap and thus sufficient binding opportunities. Once the node receives the acknowledgement from the hub, it stores the parameter data that the hub decides into Flash and then uses this in the data packets that it sends henceforth. The state diagram for the Hub and the Node for the protocol is given in Figure 4.

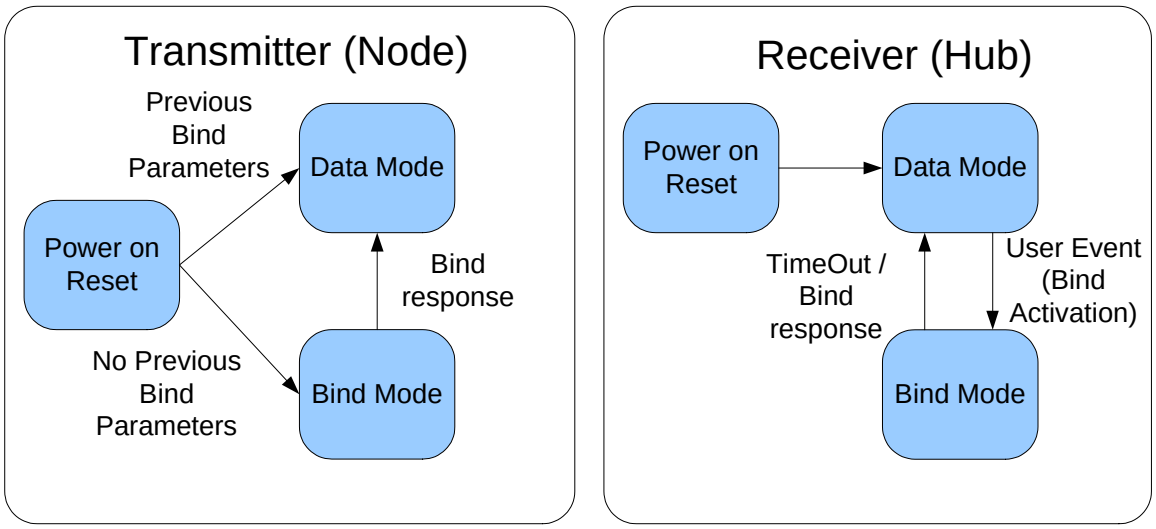

Figure 4: State diagram of Transmitter and Receiver in Wireless HRM

Computer GUI Interface

The coach/supervisor can then process the data obtained on the USB port using the required form of analysis. The graphs shown in Figure 5 show remotely logged data after it has been plotted by the "Sense and Control Dashboard" software GUI available with the CyFi kit. Each plot shows the data collected from a specific transmitter. The Y-axis shows the heart rate in terms of BPM and the X-axis is the Time. Based on the graphs, a doctor can monitor multiple patients simultaneously or a coach can decide the cardio-vascular regime for individual athletes. The same graphs can be used in different fields to make different decisions based on the heart rate of the subjects under study.

Figure 5: Graphical user interface showing remote data logging and supervision

The efficiency, range, and cost-effectiveness of heart monitoring and other sensor systems can be improved through the use of wireless and SoC technology. By leveraging a hub-based topology, developers can reduce the cost and complexity of managing and remotely logging data from multiple monitors. In this way, developers can design systems that meet the cost and reliability of a variety of applications, from high-impact sports monitoring to critical patient heart monitoring in hospitals.

Cypress Semiconductor
198 Champion Court
San Jose, CA 95134-1709
Phone: 408-943-2600
Fax: 408-943-4730
http://www.cypress.com