Application Report

Wireless Motion Detector With Sub-1 GHz SimpleLink™ Wireless MCU

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ABSTRACT

This application report discusses the main challenges related to wireless motion detector design and how they are addressed by the SimpleLink™ Sub-1 GHz CC1310/CC1312 and SimpleLink dual-band CC1350/CC1352R/CC1352P wireless microcontrollers (MCUs). First, the application note gives a short overview of a wireless motion detector. Then the application report discusses the wireless technology requirements which must be met to support motion detector use cases and explains why Sub-1 GHz technology is an excellent fit. This application note explains how to build the system based on the SimpleLink Sub-1 GHz CC131x wireless MCU or the SimpleLink dual-band CC135x wireless MCU, with focus on low power, networking, and cloud connectivity, as well as Sub-1 GHz and Bluetooth® low energy use cases. The document concludes by describing a potential use case, including its state machine and power consumption analysis.

To get started immediately, visit the following:

- CC1310 product page
- CC1312 product page
- CC1350 product page
- CC1352P product page
- CC1310 LaunchPad™ development kit, CC1350 LaunchPad kit, CC1312 LaunchPad kit, and CC1352 LaunchPad evaluation kit
- Sensor to Cloud
- CC1310 and CC1350 Software Development Kit (SDK)
- CC1312 and CC1352 Software Development Kit (SDK)

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1 Overview

Motion detectors are end devices that monitor the presence of a person in the vicinity and then issue some type of notification. The notification can be a sound, light, or transmission of a message to another unit such as a control panel, alarm system, or cloud application. Such motion detectors are widely deployed in households, commercial buildings, and other facilities. The detectors can be installed indoors or outdoors and are used mainly as intrusion-detection systems. In recent years, motion detectors have been deployed in other applications such as automatic doors, automatic lights, airflow control of heating and cooling systems and various other functions. Wireless motion detectors use the wireless medium and transmit their detection status to other units so that further action can be taken. For example, they can transmit their status to a control panel to activate an alarm if the security system is armed.

Common-motion sensing technologies are passive infrared (PIR), ultrasonic emitters, and microwave emitters, described as follows.

- PIR – Senses changes in IR radiation within the field of view determined by the Fresnel lens. PIR is sensitive to anything which generates heat or changes in temperature.
- Ultrasonic emitters – Output signal is a measure of the Doppler Effect produced by the transmitted signal being reflected and received from a moving target (Doppler radar).
- Microwave emitters – Operation is similar to the ultrasonic sensor except for the carrier frequency (40 kHz to 100 kHz for ultrasonic versus 10 GHz or 24 GHz for microwave).

Each motion-sensing technology has advantages and disadvantages in terms of miss detection versus false alarm trade-off, due to different sensitivity levels in various environments. Some solutions use more than one method for better reliability.

In the future, smarter motion detectors will detect not only motion but also the type of the motion (see TIDA-01069 as a reference for such a solution). These smart solutions are designed to distinguish between the movements of either an adult person, child, pet, and flames in a fireplace, or even a person falling. The detectors analyze the different signature that each type of movement creates.

The smarter the motion detector is, the more it requires connectivity and cloud connectivity. If the detector can detect different situations, then it can react and provide the correct action needed, which can require different communication methods. For example, when a senior citizen's fall is detected, the system must communicate with emergency services through the cloud. When an adult's movement is detected, the detector communicates to the security company and to a siren device. When a small child is detected unexpectedly, the system must initiate a message on the phone of the owner.

Whether it is PIR, ultrasonic, or microwave emitter technology, a traditional motion detector or a smarter one, the challenges are similar when it comes to the communication architecture of the system as well as the MCU and low-power requirements.

In many cases, wireless motion detector systems are part of a wider security system in which they function as data points for intrusion detection, along with door and window sensors or glass-break detectors that monitor the status of entry points. In such systems, the motion detectors are usually connected to the main security panel. In other cases, motion detector systems are smaller systems that contain one or more sensing units, an alarm unit, and in many cases a panic button that arms the system. These systems are targeted for DIY users and provide complementary solutions to other security measures. In both cases, wireless systems are the preferred and desired solution, because they avoid the problems presented by wires and reduce installation and maintenance costs.

2 Wireless Communication Technology

When considering which wireless technology to choose for motion detectors and security systems, all of the system requirements must be met by the technology selected. Some common system requirements follow:

- Range – the system can be installed in a large house, office, facility, or a building. Outdoor coverage may also be needed. Therefore, the technology must support wide-area coverage.
- Low power – for battery-operated sensors, it is critical that the wireless technology supports a low-power connection.
- Security – the wireless technology must provide protection against security attacks.
- Robustness – the connection must be robust against interference, jammers, and different RF conditions.
- Scalability – the wireless technology must be scalable so that more devices can easily be added to the network if needed.

Sub-1 GHz wireless technology meets all of the above requirements and is already widely used in motion detector systems and other security sensing systems, thanks to its excellent RF performance, low power, and low cost. RF signals in Sub-1 GHz frequency bands propagate well in the air, through walls, and around corners. Therefore, it is easy to achieve robust wireless-signal coverage of an entire house, large floor of a structure, or a building. In addition, the technology enables low power and supports sleepy end nodes – battery-operated end devices that are in their lowest power state most of the time and wakeup based on an external trigger or timer to transmit their message.

The Sub-1 GHz SimpleLink CC13xx MCUs from TI provide long range and excellent RF performance that results in a robust connection. The MCUs provide an industry lows in terms of power consumption and enable sensors to operate for many years on a small battery such as a coin cell. The MCUs also meet the security and scalability requirements previously mentioned when using the 15.4 Stack SDK. These qualities make this device perfect for building a motion detector system.

3 Motion Detector Design With the SimpleLink Sub-1 GHz Wireless MCU

The low-power wireless MCUs (CC13xx) function as the main MCU of the system, handling the sensing activities, LEDs, and button control and all the networking communication activities (see Figure 3-1). The sensor can either be connected directly to the MCU after filtering and amplifying the signal level leveraging the 12-bit analog-to-digital converter (ADC), or the sensor can be connected to a comparator and trigger the MCU using an interrupt. The CC13xx devices have a large number of GPIOs, I^2C, UART, SPI, and other interfaces that are required by the system. By choosing a wireless MCU versus an MCU and a separate RF transceiver, the system can achieve integration, size, and cost benefits along with a quicker time to market. All these features are supported through an accelerated design cycle with the reuse of wireless protocol and examples that are part of the device SDK.

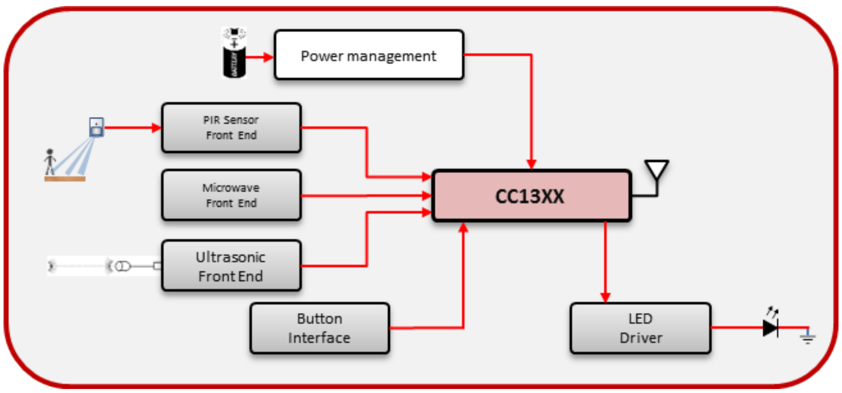

Figure 3-1. Motion Detection System Block Diagram

3.1 Low Power

To achieve 10 years or more of operation from a battery, the system must be very low power. For example, when considering a coin-cell battery that has 240 mhA capacity the average current consumption should be approximately 2.5 µA. Under a certain use case (for example, 10 reported motion events per hour) the energy consumed must be evaluated as a result of the different activities, modes, and phases of the product life cycle, as follows:

- Energy consumed by the sensor while the MCU is in low-power mode – a constant current consumption if the sensor is always on. If the sensor is only operated during certain periods of time (for example, only 14 hours per day during the night), then this information must be considered.
- Energy consumed by the wireless MCU when receiving a trigger from the sensor to wake up and transmit – under the assumption of x number of events per hour or day.
- Energy consumed by transmission and reception of acknowledgement, including assumption of probability of a failure due to collisions or other reasons and retransmission – under assumption of events per hour. Consider keep-alive messages to confirm the sensor status and battery level when there are no detections.
- Energy consumed during initial system setup – depends on the type of setup, may be negligible.
- Energy consumed by the unit before installation, while in the warehouse and duration – if the battery is assembled or connected before system setup.
- Energy consumed by other activities that system supports (for example, software updates, reporting status, log to manufacture, and so on).

Sub-1 GHz SimpleLink wireless MCUs provide industry-low power consumption because every component and element previously described is optimized. Both the time of the activity and the current consumption during the activity are optimized. The MCU shutdown and standby currents are extremely low (0.185 µA and 0.7 µA, respectively). In addition, the MCU has low MIPS/MHz (51 µA/MHz) current consumption making computation, decision-making, and housekeeping activities efficient as well. Lastly, the RX mode (5.4 mA) and TX mode (13.4 mA at 10 dbm) along with optimized and fast transition time between the modes contributes to reduced overall current consumption (see Figure 3-2).

In addition to the power modes and low current consumption of specific activities, the CC13xx devices are equipped with a unique sensor controller engine. This additional small microcontrolling unit is extremely low power and is able to operate while the rest of the device is in low-power mode. The sensor controller unit can be used for on going activities like controlling the sensors, waiting for the interrupt, or even simple computations and decision making. For example, the sensor controller can monitor the ADC and capture an ADC sample every second at an average current consumption of 0.95 µA.

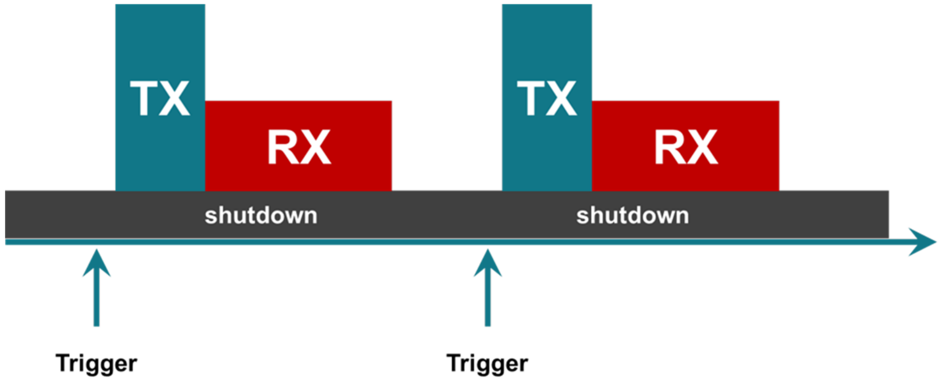

Figure 3-2. Power Profile

3.2 Sub-1 GHz Network

The type of network that works best for a motion detector system or any other typical security system is usually a star-based network with sleepy end nodes. In a star network there is a single concentrator to which all the other nodes are connected. There are several options for such a concentrator, as follows:

- In a simple network the concentrator can be one of the nodes. For example, in a motion detector system that contains one motion detector, one siren unit, and one panic button, the concentrator is probably the siren unit.
- In a more complex security system with multiple sensors, the concentrator is most likely the control panel of the system.
- When the system must also have an internet connection, there is a need for a gateway. In this case, the gateway is also functioning as the concentrator.

TI 15.4 Stack is a networking solution for CC13xx devices, which provides a complete solution for the star network based on the 802.15.4g standard including a frequency-hopping mechanism and security features. The security features encrypt the packets and mandate credentials for joining the network. This prevents attacks and eavesdropping to the system. The frequency-hopping features also help to protect the system against attacks such as denial of service or RF jammers. In addition, frequency hopping helps the robustness of the network if some of the channels are occupied with other networks. Frequency hopping is also required by FCC regulation in order to transmit at high output power. The 15.4 Stack supports a 50-kbps data-rate mode and a long-range, 5-kbps data-rate mode. The 15.4 standards implements a *listen before talk* mechanism to minimize the amount of collisions and to allow maximum bandwidth capacity. Acknowledgments are also sent to confirm successful transmission.

In the motion detector star network, the nodes are in low-power mode most of the time. They wake up to send periodic keep-alive messages or whenever a movement is detected, to send a notification to the concentrator. If the concentrator has a message to the end nodes, it saves this message and sends it as a response to communication initiated by the end node. Example messages can be a command to turn off detections or change settings, or to notify the system of available software updates.

Apart from the 15.4 stack, the SDK contains an easy solution for proprietary RF implementation called Easylink. The Easylink layer exposes a simple set of APIs for controlling the RF. Easylink comes with several simple examples of transmit and receive. This option gives the designer flexibility to build any network protocol. Easylink is the preferred option if someone wants to use their own protocol for the motion detector network system or they are developing a motion detector that must connect to an existing system.

3.3 Cloud Connected Motion Detector

Security systems benefit from cloud connectivity. Cloud connectivity gives security systems the ability to dispatch the security company or fire department when necessary. Cloud connectivity also gives the homeowner the ability to monitor and control their system remotely. Whenever the motion detector is a part of a larger security system, it will likely need to access the Internet.

Sub-1 GHz technology requires a gateway to connect to the Internet. The gateway buffers and translates the messages in the Sub-1 GHz network into Ethernet packets and communicates with the internet over Ethernet or Wi-Fi® interfaces. TI provides two sensor to cloud solutions for connecting Sub-1 GHz network to the cloud:

- Sub-1 GHz Sensor to Cloud Industrial IoT Gateway Reference Design for Linux Systems (http://www.ti.com/tool/tidep0084). This solution is based on Sitara AM335x processor from TI as gateway based on Linux.
- SimpleLink™ Sub-1 GHz Sensor to Cloud Gateway Reference Design for TI-RTOS Systems (http://www.ti.com/tool/tidc-01002) This solution is based on SimpleLink CC3220 (Wi-Fi wireless MCU) and is based on RTOS.

Both solutions provide 2-way communication: sensors report to the cloud, and the cloud sends commands and controls to the sensors. End users can receive notifications of motion detector alerts as well as enable or disable the motion detector from the cloud.

3.4 Sub-1 GHz and Bluetooth low energy Dual-Mode Systems

The CC1350 and CC1352 devices support both Sub-1 GHz and Bluetooth low energy technologies as part of the wireless MCU platform. The addition of Bluetooth low energy sets the foundation to build a more capable motion detector or motion detector system. Bluetooth low energy technology adds a native user interface to the motion detector system at minimal cost. It is currently the easiest wireless technology for connecting a device to a phone. Imagine a simple phone app that can control any function of the motion detector with a touch. Settings like sensitivity levels or regulatory constraints no longer need to be programmed using jumpers in the back of the device. The following sections describe some of the more advanced use cases that can be implemented with the addition of Bluetooth low energy technology to the typical end node in a security system.

3.4.1 System Setup

Using a smartphone and mobile application, the system can be easily configured and receive status updates. During the system setup, the phone connects to the motion detector and transmits network properties and security credentials for the Sub-1 GHz network over Bluetooth low energy. When the network configuration is complete the motion detector switches to Sub-1 GHz mode and connects to the Sub-1GHz network.

Users can use the phone interface and phone to configure many other aspects of the motion detector sensor. Many end users of motion detectors struggle to set the system up so that they get the coverage they need without false alarms. With Bluetooth low energy and a smart phone interface, users can enable more configuration options such as detection modes, sensitivity, night or day or weekend modes, and more. This is becoming more important when considering smarter motion detectors as described previously. If the motion detector is expected to detect a specific event, this requires more system testing and setup issues, as well as more configurations and calibrations to ensure successful operation of more complex systems. A Bluetooth low energy connection and smartphone interface can keep the motion detector design small and cost competitive while still allowing simple operation (see Figure 3-3).

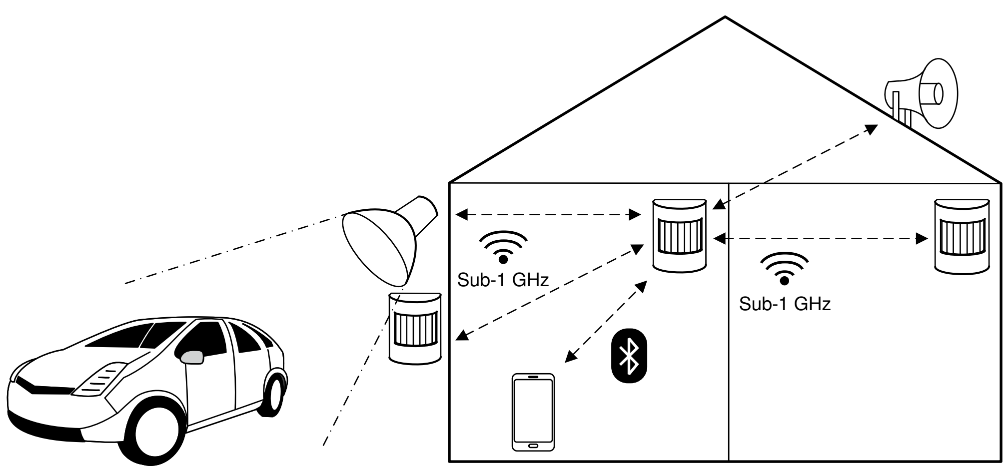

Figure 3-3. Motion Detector System With Bluetooth low energy Connection

3.4.2 Software Updates

A Bluetooth low energy connection to a mobile application makes pushing software updates to any part of the system easy. The user will enjoy a system that is up-to-date and free of bugs. Just release an update, push it to the mobile app users, and they will receive a notification to upgrade their system.

3.4.3 Status Monitoring

Another great feature that Bluetooth low energy provides is connectionless advertisement or beaconing. This feature allows any Bluetooth low energy device to transmit broadcast messages that are received by a nearby phone without the need to initiate a connection. With this feature users can receive real-time status updates on their battery, network issues, or others.

4 Test Case

This section analyzes the use cases, state machine, and power consumption of wireless motion detector systems (it follows some of the calculations and design done in TIDA-00489).

Consider a motion detector system with a PIR sensor, amplifier, filter, and comparator that triggers interrupts to the wireless MCU whenever a movement is detected. The motion detector sends a notification to the concentrator upon receiving an interrupt or sends a keep alive notification periodically. After each transmission The motion detector waits for acknowledgement and retransmits if it is not received. In addition, after motion interrupt, the motion detector waits in standby state for more interrupts for certain time period. If the area is busy and multiple interrupts arrive frequently, it is considered as a single event and not multiple events (see Figure 4-1).

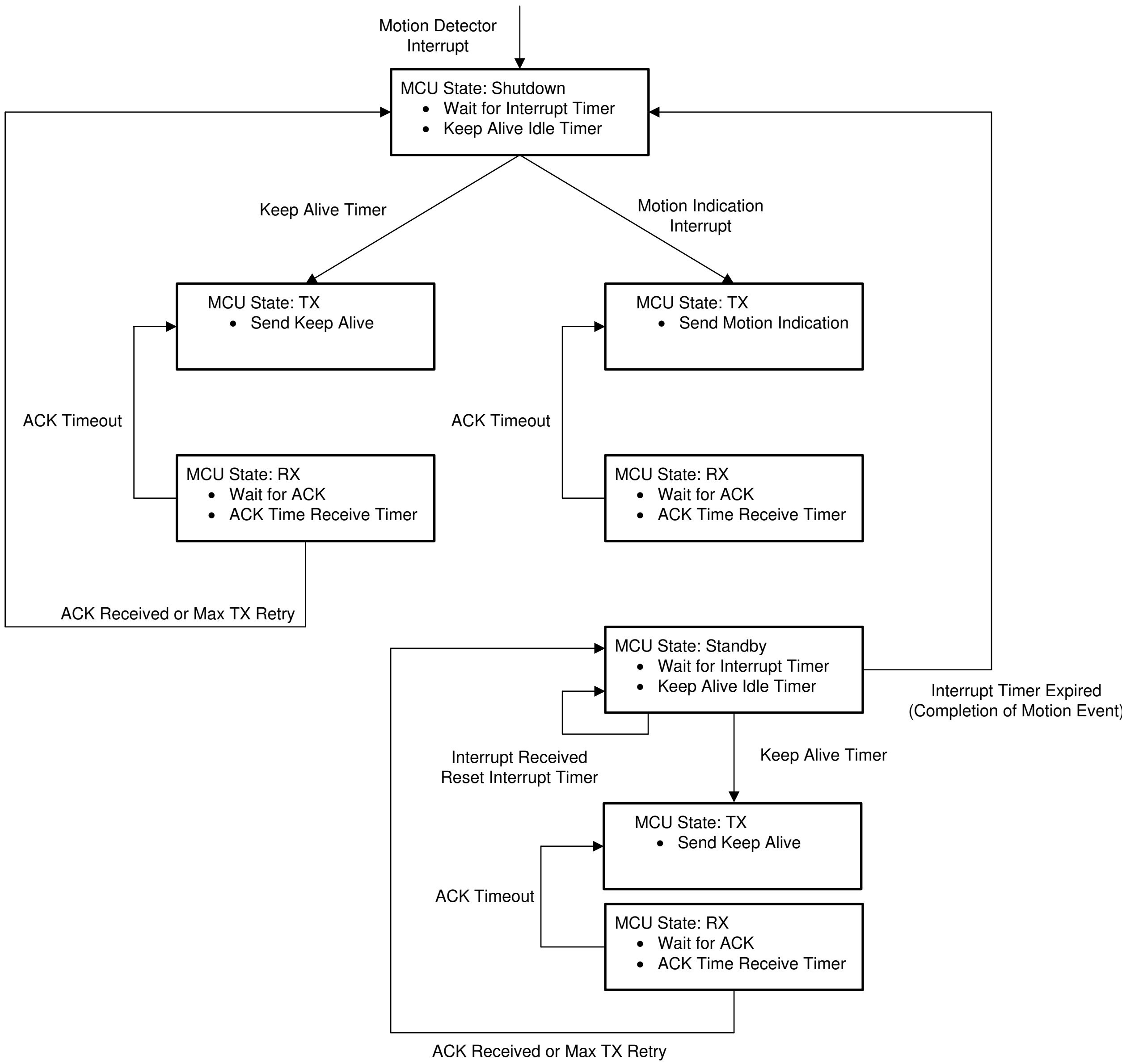

Figure 4-1. Test-Case State Machine

The following parameters were set:

- Motion detector is active an average of 12 hours each day, during the remaining time, no movements are expected.

- Keep-alive period is 30 minutes – concentrator acknowledges the keep alive messages. It can signal the motion detector of any pending downlink message from the cloud or concentrator that must be sent to the motion detector as a part of the acknowledge message. From the power budget perspective, the contribution of downlink messages is negligible assuming they are very infrequent.
- Maximum TX retry is 3 – after three unsuccessful, consecutive transmissions the motion detector indicates (by LED) that it has lost network. The detector keeps trying in the next keep-alive interval or motion event.
- Wait for interrupt timer is 60 seconds – after the interrupt from the motion sensor, if there is another trigger within the next 60 seconds then the motion detector does not send another message and it is considered as the same event. As long as the interrupts are more frequent than 60 seconds, no message is sent after the first one. A keep-alive message is sent indicating that multiple interrupts are being detected.
- During 12 hours of operation there are 10 events per hour. Five events produce a single interrupt and five events are 3 minutes long on average.
- Retransmission probability is 5%.
- System is based on TI 15.4 stack at 50 kbps with security and frequency hopping.
- Battery – coin cell battery with 240 mAh and derating factor of 85%

Based on TIDA-00489, the measured shutdown current is 1.65 µA and the delta current in standby mode is 0.65 µA.

- TX – 20B message (overall message including headers and preamble is 54B). Current is 13.4 mA for 10.5 ms and 10 dBm.
- RX – ACK packets 9.5 ms at 5.5 mA

Table 4-1 lists the detailed power consumption calculations according to the activity and assumptions previously described. The result is 10.8 years of battery lifetime on a coin cell battery.

Table 4-1. Test Case Power Consumption and Battery Life Calculation

Factor	Calculation
Number of mins per hour in standby mode	5 + 3 × 5 = 20
Number of mins per day in standby mode	12 × 20 = 240 mins
Number of keep-alive events per day	24 / 0.5 = 48
Number of motion-detection messages per day	12 × 10 = 120
Number of transmissions, including retransmissions, per day	(120 + 48) × 1.05 = 176
Time in TX mode per day	176 × 10.5 ms = 1848 ms
Time in RX mode per day	176 × 9.5 ms = 1672 ms
Base shutdown current average	1.65 µA
Average current added by standby time	(240 min × 0.65 µA) / 1440 min = 0.108 µA
Average current added by TX	(1848 ms × 13.4 mA) / 86400 secs = 0.286 µA
Average current added by RX	(1672 ms × 5.5 mA) / 86400 secs = 0.106 µA
Total average current	1.65 µA + 0.108 µA + 0.286 µA + 0.106 µA = 2.15 µA
Lifetime	(240 mAh × 0.85) / 2.15 µA = 94883 hours = 10.8 years

5 Summary

This application note discussed the main challenges related to wireless motion detector design. The application note explained the benefits of wireless motion detectors over wired motion defectors and why Sub-1 GHz technology is a good choice for motion detector end equipment as well as the benefits of using the SimpleLink Sub-1 GHz Wireles MCU. The specific challenges of networking, cloud connectivity, and power consumption were also discussed in detail. The application note described advanced use cases and trends in motion detectors, such as detection of the type of motion and activity, as well as how to interact with a smartphone over Bluetooth low energy. Lastly, the application note presented and analyzed a test case, including battery lifetime analysis.

6 References

- Texas Instruments, TI Design TIDA-00489, *Low Power Wireless PIR Motion Detector Reference Design Enabling 10 Year Coin Cell Battery Life*

- Texas Instruments, TI Design TIDA-01069, *Advanced Motion Detector Using PIR Sensors Reference Design For False Trigger Avoidance*
- Texas Instruments, TI Design TIDEP0084, *Sub-1 GHz Sensor to Cloud Industrial IoT Gateway Reference Design*
- Texas Instruments, TI Design TIDA-00759, *Low-Power PIR Motion Detector With Bluetooth Smart & 10-Year Coin Cell Battery Life Reference Design*
- Texas Instruments, TI Design TIDA-01398, *Ultra Low-Power Wireless PIR Motion Detector for Cost-Optimized Systems Reference Design*
- Texas Instruments, E2E Blog, *How to Build a Fully Managed and Scalable Long-Range Network With Low-Power Nodes*
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- Texas Instruments, Advanced Motion Detection With False Trigger Avoidance Video
- ECN Magazine, Advanced Enable Machine Learning with an Advanced Motion Detector using PIR Sensors
- Sensors online, Changing The Way Sensors Communicate Via Dual-Band Wireless Connectivity
- Texas Instruments, TI Design TIDA-01476, *Low Power Wireless PIR Motion Detector Reference Design Enabling Sensor-to-Cloud Networks*

7 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision B (March 2018) to Revision C (May 2021)	Page
• Updated the numbering format for tables, figures and cross-references throughout the document	2

Changes from Revision A (February 2018) to Revision B (March 2018)	Page
• Update was made to the Abstract	1

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