

Wireless Door and Window Sensors With the Sub-1GHz SimpleLink Wireless MCU

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ABSTRACT

This application report discusses the main challenges related to wireless door and window sensor design and how they are addressed by [CC1310](#) and [CC1350](#) wireless MCU. First it gives a short overview of what a wireless door and window sensor is. Then, it discusses wireless technology requirements for door and window sensors and other security system use-cases. The application report validates the Sub-1GHz technology as an excellent fit for door and window sensors and explains the main benefits for systems based on the CC1310 or CC1350 with a focus on RF, wireless communication and low power design. It concludes with a test case describing a potential use case along with its state machine and power consumption analysis.

To get started immediately, visit the following:

- [CC1310](#) product page
- [CC1350](#) product page
- [CC1310 LaunchPad™](#) or [CC1350 LaunchPad](#) evaluation kit
- [Linux®-based Sensor to Cloud](#)
- [RTOS-based Sensor to Cloud](#)
- [CC1310 or CC1350 SDK](#)

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1 Overview

Door and window sensors are key components in most security systems. They monitor the status of an entry point and indicate whether the entry point is open or closed. Door and window sensors are usually constructed out of two separate units. One unit is mounted on a stationary surface like the frame of the door or the window while the other is mounted on the moving part of the door or the window. The stationary unit is typically the one that handles both the sensing and the resulting action based on the detection. The moving unit is simply a magnet used for detection. When the door or window is closed, the magnet is located in close proximity to the detecting unit (about half an inch apart). Once the door or window is opened, the magnet moves away, which is detected by the sensor.

Common door and window detection techniques are Reed switches and Hall effect sensors:

- **Reed Switch** - electrical switch that is controlled by the magnet. There are two metal plates that close an electrical circuit and conduct current when touched together. Whenever the plates are not physically touching each other the circuit is open and no current flows in the circuit. The magnet is used to control the position of one metal plate vs the other. When the magnet is in close proximity, one plate moves towards or against the other plate. When the magnet is far away, the plate moves in the other direction. The flow of current is detected by the sensor
- **Hall Effect** – the presence of a magnetic field creates a voltage difference on two sides of a conducting surface that carries a constant current. The voltage difference is detected by the sensor indicating the presence or absence of the magnet.

Both technologies are well established and deployed. Reed switches have moving parts making the system less immune. It has a built in hysteresis and has less leakage current than the Hall Effect technology.

We can distinguish between two different types of systems that use door and window sensors:

- **Door and window sensors that are part of a complete security system.** In this case, they are installed in every entry point in the house and they are connected to the security panel. In these systems, it is common to find other security sensors or devices such as motion detectors, volume sensors, security cameras, and so forth, along with the door and window sensors to provide full house protection. Using wireless sensors for security systems reduces installation and maintenance costs. There is no need to route wires through the walls and ceiling and there is no concern of wires being damaged giving wireless solutions a great advantage compared to hard wired solutions.
- **Stand-alone Door and window sensors.** These systems typically contain one or more sensors along with a speaker unit and sometimes a panic button to arm / disarm the system. These systems are useful either when a complete security system does not exist or to secure other areas. For example, it is common to use door and window sensors on medicine or liquor cabinets, fire arm cabinets or pool gates. Using wireless technology for those stand-alone systems that do not use pre-installed wires is the practical way when communication is required.

Door and window sensors based on magnets are prone to tampering attempts by intruders. Simply place a strong magnet close enough to the door or window frame where the sensor is expected to be located. Therefore, many implementations contain an anti-tamper mechanism. They use a dual sensor technique. One sensor is the main sensor that detects the desired magnet. A second sensor is placed some distance from the main sensor. It is placed and designed in such a way that the target magnet does not activate the second sensor because of its location or its detection level.

2 Wireless Communication Technology

When considering a wireless technology for door and window sensors and other security sensors, it is important that all of the system requirements are met by the technology selected. Some common system requirements include:

- **Range** – The system may be installed in a large house, office, facility or building. Therefore, the technology must support wide area coverage. In some cases users can place the door and window sensor outdoors such as on pool gates, sheds, back yard gate, and so forth. In those cases, the signal transmitted by the sensor needs to be received inside the house.
- **Low power** – for battery operated sensors, it is critical that the wireless technology supports a low power connection. Most of the door and window sensors are battery operated. Changing batteries in those sensors is a hassle especially in the complete security system case where there are tens of sensors around the house installed in the window and door frame. Achieving long battery lifetime with a coin cell battery is an important requirement for those sensors.
- **Security** – The wireless technology should provide protection against security attacks. Intruders might exploit weakness of the system in order to break in undetected. When the security network is also connected to the internet through the home Wi-Fi network, hackers might use a weakness in the system to attack other connected elements in the house such as the door lock.
- **Robustness** – The connection should be robust against interference, jammers and different RF conditions. Potential jammers may be generated by an innocent device but may also be generated intentionally by an intruder.
- **Scalable** – the wireless technology should be scalable so that more devices can be added to the network. A typical security system monitors all entry points along with other security measures, in addition to, safety sensors such as fire detectors. The number of end nodes in the system can easily reach over 30 in a typical house. In commercial buildings, the number of nodes connected to the network may be much higher.
- **Network type** – One way or two way communication. Many legacy wireless door and window sensors support only one way communication. They transmit their indication to a central unit without receiving an acknowledgment and without any capability to receive any downlink messages. In advanced systems, there are many use-cases that require two way communication where the central unit also transmits messages to the end nodes. Such use-cases include simple commands like enable / disable, firmware upgrade, configuration settings and more.

Sub-1GHz wireless technology answers all of the above requirements and is widely used across security systems in buildings thanks to its excellent RF performance, its low power and its low cost. RF signals in Sub-1 GHz frequency bands propagate well in air, through walls and around corners. Therefore, it is easy to achieve robust wireless signal coverage of an entire house, a large floor 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 external trigger or timer to transmit and receive messages.

The TI SimpleLink™ Sub-1 GHz CC13xx wireless MCU provides long range and excellent RF performance that results in a robust connection. They achieve industry lows in terms of power consumption and enable sensors to operate for many years on batteries. They also answer the security and scalability requirements mentioned above when using the [SimpleLink CC13XX SDK](#). These qualities make this device the perfect fit for door and window sensors.

3 Designing the System With Sub-1 GHz SimpleLink Wireless MCU

The low power wireless MCU (CC1310) functions as the main MCU of the system handling the sensing activities, notifications such as sounds or LEDs, if needed, button functionality if desired to set modes of operation and controls all of the networking communication activities. The Hall effects sensor or the REED switch is connected directly to the MCU GPIO. It functions as an interrupt to the main MCU allowing it to stay in low power mode for the majority of the time and only be activated upon a change of state. By choosing a wireless MCU vs a chipset of MCU and RF transceiver, the system can achieve lower power, integration, size and cost benefits along with a quicker time to market. The accelerated design cycle is achieved by re-use of wireless protocols and examples that are part of the device SDK.

Figure 1 shows a block diagram of a door and window sensor with main and secondary sensors for anti-tamper detection.

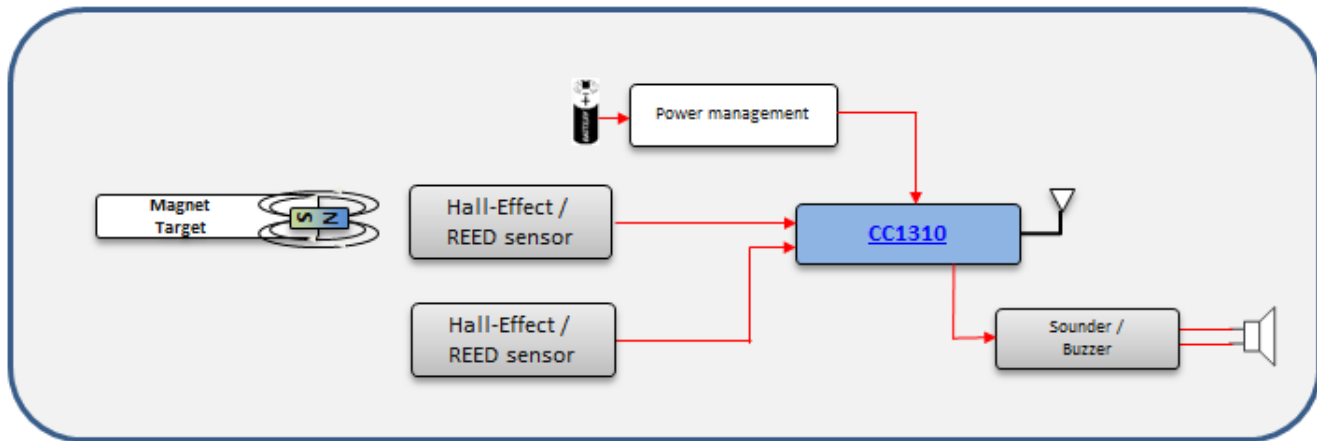


Figure 1. Wireless Door and Window Sensor Block Diagram

4 Sub-1 GHz Network

4.1 Star Network

For systems that contain a panel the typical network topology is a star network with sleepy end nodes. In star networks, there is one singular concentrator to which all other nodes are connected. Sleepy end nodes means that the nodes that are connected to the concentrator are in their low power state most of the time and wakeup to transmit their message periodically or based on event triggers such as the opening or closing of a door or window. The panel functions as the concentrator. Since the panel is powered by hard wires, it can be always on and active in receive mode. The end node sensors may send keep alive messages to the panel indicating their status along with information of battery level and other parameters. When the panel has a message to send to the end nodes, it waits for such keep alive message and it sends its message as a response. The frequency of sending keep alive messages is a function of the desired lifetime of the end node and the desired latency of the entire system responding to messages originated by the panel.

The SimpleLink CC13x0 SDK contains the [15.4 stack](#) that provides a complete solution for a star networks based on the 802.15.4g standard including a frequency hopping mechanism and added 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 it helps the robustness of the network in the case that some of the channels are occupied with other networks. Frequency hopping is also required by FCC regulation in order to utilize higher transmission power. The 15.4 stack supports a 50 kbps data rate mode and a long range mode of 5kbps data rate. The 15.4 standards is based on an advanced CSMA/CA networking algorithm for maximum channel capacity and implements a “listen before talk” mechanism to minimize the amount of collisions. Acknowledgments are part of the standard to confirm successful transmission.

4.2 Other Network Options

Apart from the 15.4 stack star network topology, the CC13x0 SDK supports proprietary network implementations. The SDK contains an easy way to enable proprietary RF implementation called Easylink. The Easylink layer exposes a simple set of APIs for controlling the RF functionality of the device. It comes with several simple examples of transmit and receive. This option gives the designer flexibility to build any network protocol. It is the preferred option if someone wants to use their own protocol for the door and window sensor network.

5 Low Power for Battery-Operated Fire Alarm

In order to achieve 10 years or more of operation out of battery, the system must be very low power. For example, when considering a coin cell battery that has 240 mAh capacity the average current consumption should be slightly above 2 μ A. Under a certain use-case (number of close/open events per day, period of keep alive messages) the energy consumed needs to be evaluated per each of the different activities, modes and phases of the product life cycle.

- Sending event driven message - energy consumed by the system once an event is detected by the sensor. The sensor interrupt wakes the main MCU from standby mode. The MCU generates a message, sends it to the collector, receives an acknowledgment and goes back to standby mode.
- Sending keep alive message - energy consumed by the wireless MCU for sending a single message. Periodic messages are sent to ensure proper operation of the system, report battery status, collect logs and data and poll for incoming messages from the panel. When calculating the energy consumed by sending messages, we need to consider a probability of retransmission due to collisions
- Standby current - energy consumed by the system when idle. The sensors are actively ready for detection and the MCU and sensor controller are in standby mode. RTC timer is actively counting the time in order to send periodic keep alive message at the configured timing.
- System setup - energy consumed during initial system setup – depends on type of setup. Might be negligible.

Sub-1 GHz SimpleLink Wireless MCUs provide industry low power consumption because every component and element described above 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 μ A/0.7 μ A, respectively). In addition, it has low MIPS/MHz (51 μ A/MHz) current consumption, making computation, decision making and housekeeping activities efficient as well. Finally the RX mode (5.4 mA), TX mode (13.4 mA @10dbm) along with optimized and fast transition time between the modes contributes to reduced overall current consumption.

In addition to the power modes and low current consumption of specific activities, the CC1310/CC1350 is equipped with a unique sensor controller engine. This additional small micro controlling unit is extremely low power and is able to operate while the rest of the device is in low power mode. It can monitor sensors, control GPIOs, wait for interrupts, operate ADC and comparators, control SPI and I2C interfaces and conduct basic computations. For example, the sensor controller can monitor the ADC and capture an ADC sample every second at average current consumption of 0.95 μ A.

Figure 2 illustrates the current profile of a panel connected door and window sensor use case. The sensor periodically sends keep alive messages. These messages provide general status to the system reporting battery status and other optional parameters. It also gives the panel the option to send a downlink message such as a command or indication of available software update. Whenever the sensor is triggered, it generates an immediate message reporting the status change.

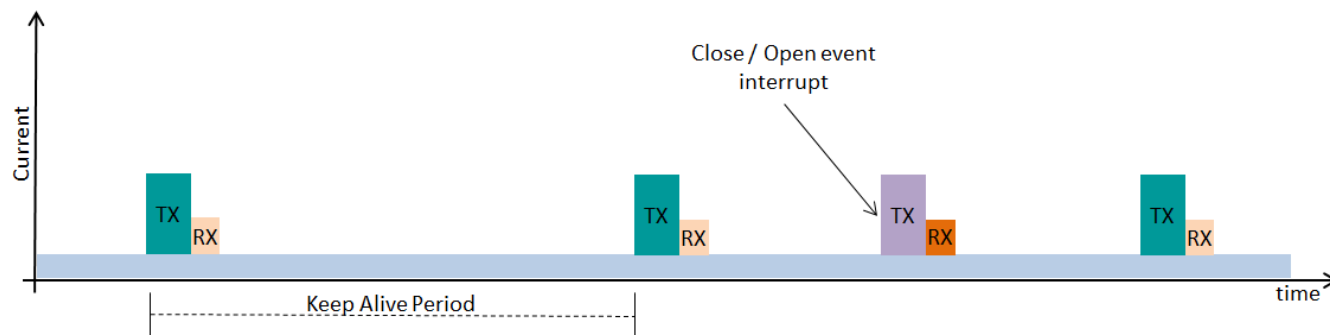


Figure 2. Power Profile for Door and Window Sensor

6 Cloud Connected Fire Alarm System

Security systems benefit from cloud connectivity. It gives them the ability to dispatch the security company when necessary. Cloud connectivity also gives the home owner the ability to monitor and control his system remotely. It enables automatic software updates to the panel and to the end nodes for fixing bugs or adding functionality.

Sub-1 GHz technology requires a gateway in order 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 offers two reference designs called Sensor to Cloud for connecting Sub-1 GHz end nodes to the cloud via gateway. One reference is based on Linux platform that supports both Ethernet and Wi-Fi connectivity and the second one is based on RTOS platform and supports Wi-Fi connectivity. Both reference designs provide end to end solutions for two way communications between the sensor end nodes and the cloud. Sensors report status and measurement results to the cloud and users can send actuation and other commands from the cloud to the sensors.

- [Sub-1 GHz Sensor to Cloud Industrial IoT Gateway Reference Design](#)
- [SimpleLink™ Sub-1 GHz Sensor to Cloud Gateway Reference Design for TI-RTOS Systems](#)

7 Test-Case

This section analyzes the use-cases, state machine and power consumption of wireless door and window sensor.

Consider a Hall effect based door and window sensor similar to the one presented in [Figure 1](#). The sensor is connected to a concentrator that is the main security panel.

In the steady state (after being installed and connected to the network), the sensor end node sends periodic keep alive messages reporting status and in parallel waiting to receive interrupts from the Hall effect sensor indicating a change in the status of the magnet.

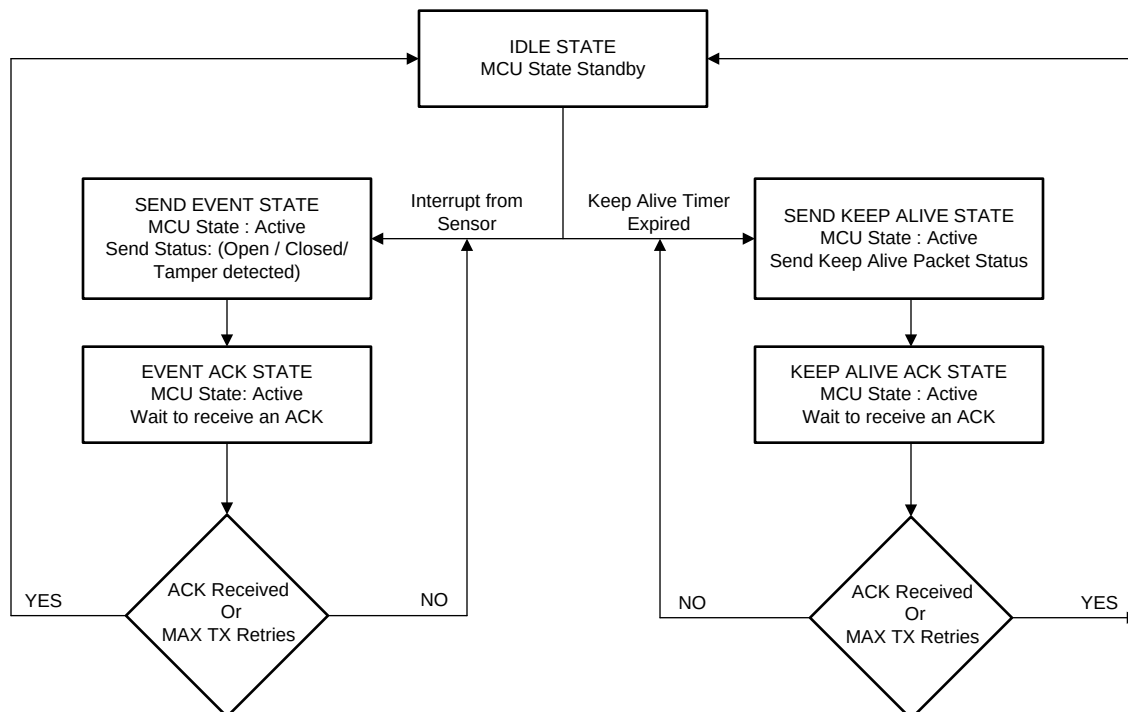


Figure 3. Test-Case State Machine

The following assumptions are taken:

- Keep alive messages are sent every 30 min
- 48 entry events per 24 hours. Two messages per entry.
- Max TX retry is 3 – after three consecutive unsuccessful transmissions the sensor returns to its idle state until the next scheduled keep alive message or event interrupt. Probability for single packet to be unsuccessful is 5%
- System is based on TI 15.4 stack at 50kbps with security and frequency hopping
- Battery – coin cell battery 240 mAh and derating factor of 85%
- Standby power consumption for the entire system is – 2 μ A
- Sending packets of 20B message for both events and keep alive messages (overall message including headers and preamble is 54B). Current is 13.4mA for 10.5ms and 10dBm
- Receiving packet of ACK and command takes 10.5 ms at 5.5 mA

Table 1. Test Case Power Analysis

Factor	Calculation
Number of event driven messages per day	$48 * 2 = 96$
Number of keep alive transmissions per day	$2 * 24 = 48$
Charge consumed during one transmission cycle and the ACK reception	$10.5 \text{ ms} * 13.4 \text{ mA} + 10.5 \text{ ms} * 5.5 \text{ mA} = 198.45 \text{ } \mu\text{C}$
Total charge of transmission cycles per day including 5% retransmission	$(96 + 48) * 198.45 \text{ } \mu\text{C} * 1.05 = 30 \text{ mC}$
Total charge of standby mode per day	$2 \text{ } \mu\text{A} * (24 * 60 * 60) \text{ sec} = 172.8 \text{ mC}$
Total Charge per day	$30 \text{ mC} + 172.8 \text{ mC} = 202.8 \text{ mC/Day}$
Average current	$\frac{202.8 \text{ mC} / \text{Day}}{86400 \text{ sec} / \text{Day}} = 0.0023 \text{ mA} = 2.3 \text{ } \mu\text{A}$
Battery capacity	$240 \text{ mAh} = 864 \text{ C}$
Lifetime	$\frac{864 \text{ C} * 0.85}{202.8 \text{ mC} / \text{Day}} = 3621 \text{ Days} = 9.9 \text{ years}$

8 Summary

This application report discussed the main challenges related to wireless door and window sensor system design. The document explained the benefits of a wireless door and window sensor compared to wired sensors including the benefits from a two way communication system. Sub-1 GHz technology is a good choice for wireless door and window sensor end equipment thanks to its superior RF characteristics as explained above. The SimpleLink Sub-1 GHz Wireless MCU CC1310 and CC1350 devices enable integrated door and window sensor designs with robust RF communication, low power for long battery life and advanced networking options. Low power aspects and challenges were explored including a test case that demonstrated a battery lifetime calculation.

9 References

- [Low-Power Door and Window Sensor With Sub-1GHz and 10-Year Coin Cell Battery Life Reference Design](#)
- [How to build a fully managed and scalable long-range network with low-power nodes](#)
- [Bringing wireless scalability to intelligent sensing applications](#)

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