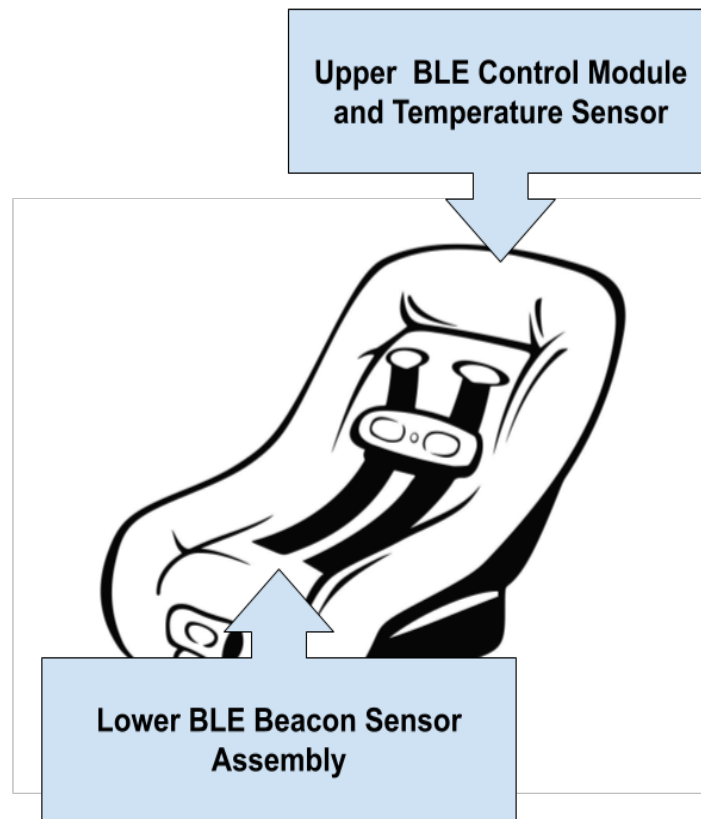


# ENT 498 Final Report:

## Child Safety Seat Occupant Detection and Alert System



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## **Statement of Purpose**

This report covers the necessity, design, and progress achieved in creating a Child Safety Seat Occupant Detection and Alert System (CS-SODAS) during the fall 2019 and spring 2020 semesters. The timeline, budget, scope, design parameters, implementation, and state of the completed project are discussed. The intent of this report is to illustrate the usefulness of an Internet-of-Things (IoT) device to provide protection for children, and peace of mind to parents. The following pages document the work required to design and create the CS-SODAS, and the outcome of such work.

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## **Glossary of Terms and Acronyms**

**App** - Shortened form of Application

**BLE** - Acronym of Bluetooth Low Energy

**CS-SODAS** - Acronym of Child Safety Seat Occupant Detection and Alert System

**GATT** - General Attributes Profile

**Hysteresis** - The state of a given system being determined by the past states of that system

**IDE** - Acronym of Integrated Development Environment

**IoT** - Acronym of Internet-of-Things

**mAh** - Mili-Amp Hour, a measure of battery capacity

**NIH** - National Institutes of Health

**RSSI** - Received Signal Strength Indicator

**Rx/Tx** - Abbreviation of receive/transmit, also used individually as Rx and Tx

**SODA** - Shortened form of CS-SODAS

**TI** - Texas Instruments

**UART** – Acronym of Universal Asynchronous Receive and Transmit

**UI** - Acronym of User Interface

**UUID** - Universally Unique ID (Identification number)

**WBS** - Acronym of Work Breakdown Structure



# Chapter 1 Scope and Methodology

## Objective

To prevent unintentional injuries to children left in heated vehicles through the use of a low-cost child seat accessory that communicates the presence of an occupant via common wireless communication protocols. This device will also educate parents by providing temperature data which will ideally lead them to making better choices.

## Justification and Applicability

According to a recent study made by “Safe Kids Worldwide”, in the United States alone 14% of parents admit that they have left their infant, toddlers or young children alone inside parked vehicle despite the risk of heatstroke [1]. An additional 11% of parents admitted to outright forgetting their child in a car. A further 6% are comfortable letting their young children stay in a parked, locked vehicle for longer than 15 minutes.

These data demonstrate an urgent need. Each year hundreds of parents leave their child unattended in a hot vehicle, which can result in devastating health problems or tragic consequences for children six years or under. If an internal car temperature reaches 104 °F, major organs may begin to shut down and death can occur in a short time frame. Parents may be unaware that the temperature inside of a car can rise 20 °F in a matter of minutes. Many believe that leaving windows down helps the environment inside the car, but this is not enough to bring the car’s interior into thermal equilibrium with the outside temperature. Many are also unaware that a child is at greater risk than an adult in a hot car due to their inherently smaller mass.

For a parent it can be stressful to pick a car seat that fits the needs of your child. Most currently available car seats do not offer any systems that provide alerts when occupants are unintentionally left in a parked car. These concerns will be addressed by creating a device that fits into any currently available car seat. This will both lower production costs and allow parents to retrofit their favorite car seat with enhanced life-saving features. The design must focus on creating an always-on, battery efficient system that automatically interfaces with existing smartphone devices. Furthermore, the device will be able to log and transmit temperature data to further educate users of the risks associated with leaving occupants in a vehicle for even a short period of time.

The combination of features, low-costs, and ease-of-use will allow our end-product to solve the aforementioned problems. By educating parents about a vehicle’s internal thermal levels coupled with a smart occupant detection and alert system we address both parents who choose to leave their children in cars and those that do so by accident. Life is precious; by providing parents with low-cost tools and meaningful data this project hopes to increase awareness to any overstressed parent regarding their child’s safety.

## Research and Methods

In today’s world everyone’s favorite research method is the internet. While the internet is guilty at times of providing highly inaccurate information, it is also the single greatest wealth of information in all of human history. The beauty is in the speed and ease with which information can be added. While this can cause issues with the reliability of internet information, it allows for

multiple, independent verification of source information. As, the CS-SODAS project is based upon relatively new technologies, the internet was instrumental in all research performed. The aim is to avoid the mistake of relying too heavily upon one source of information. This project contains many interacting fields of study. For example, Bluetooth waves travel differently through moving bodies than stationary ones [2]. This information comes from a health journal, not a technological journal.

The design and testing methods employed are iterative. If the goal is met, then the next challenge is addressed. If the goal was not met, repeat the procedure until the goal can be met. This iterative approach will allow for fine tuning at each step. The following steps illustrate the procedure.

1. Design/Redesign (Change to produce new results)
2. Implement
3. Test
4. Observe results and repeat test if necessary.

### **Scope and Methodology Conclusion**

While there are similar products in the market, they are either bulky, expensive, inaccurate, or have lackluster reviews. By engineering a low-cost user installable alternative that allows any existing car seat to be converted into a smart seat, the group is accepting additional design challenges beyond human detection and control unit connectivity. The ability of this product to be retrofitted into many different car seat designs presents a challenge that will require non-standard solutions. Typically, load sensing cells would be utilized to measure weight and thus the presence of a person. Typical train gauges internal to load cells are sensitive to installation and not suited for installation by customers. The design will need to consider which alternatives can best fit the use-case.

In addition to the end-user installation requirements, environmental conditions provide natural constraints to the design. The assumption is that this device will be stored and used in an environment that exceeds 60 degrees centigrade. This limits which batteries can be used as power sources and the level to which sensors will need to be calibrated. Given that the device will be positioned under and around a young child, SODA must also ensure conformity to child safety best practices [3]. The strong likelihood of exposure to unwanted bodily fluids also dictates that these systems be waterproof.

From a user interface perspective, this device must be easy to interact with. We plan to enable seamless integration with existing smart devices such as phones and wearables through the Bluetooth Low Energy (BLE) communication protocol. Given that the major goal of our project is to help users remember their children, we do not want to add a layer of additional distractions by requiring the device be activated upon each use. The newer Bluetooth 5.0 (BLE) standards allows for a workaround by automating the device pairing process at the hardware level. A further subset of the new Bluetooth standard, Bluetooth Beacons, allows for ultra-low power consumption through transmission-only hardware configurations. This project desires to utilize these emerging technologies in our final design.

As a society, we are becoming more comfortable with sensor-enabled embedded smart systems. These consumer products are becoming ubiquitous in the home automation sector; we feel now is the time to push this technology into the service of solving a persistent problem. The

intentions of this project are to provide an affordable, robust, easily usable device that addresses the above problems in ways that benefit consumers.

# Chapter 2 Design and Planning

## Design Constraints

- Accurately detects human presence with minimal false positives
- Measures and logs temperature at predetermined intervals
- Communicates data and warnings to broad range of existing devices
- Operates in environments ranging from -20C to 80C
- Childproof and child friendly
- Water Resistant (minimum IPX 4 standards)
- Battery Life > 6 months, preferably > 1 year
- User installable and serviceable
- Cost to manufacture < \$20

## Work Breakdown Structure (WBS)

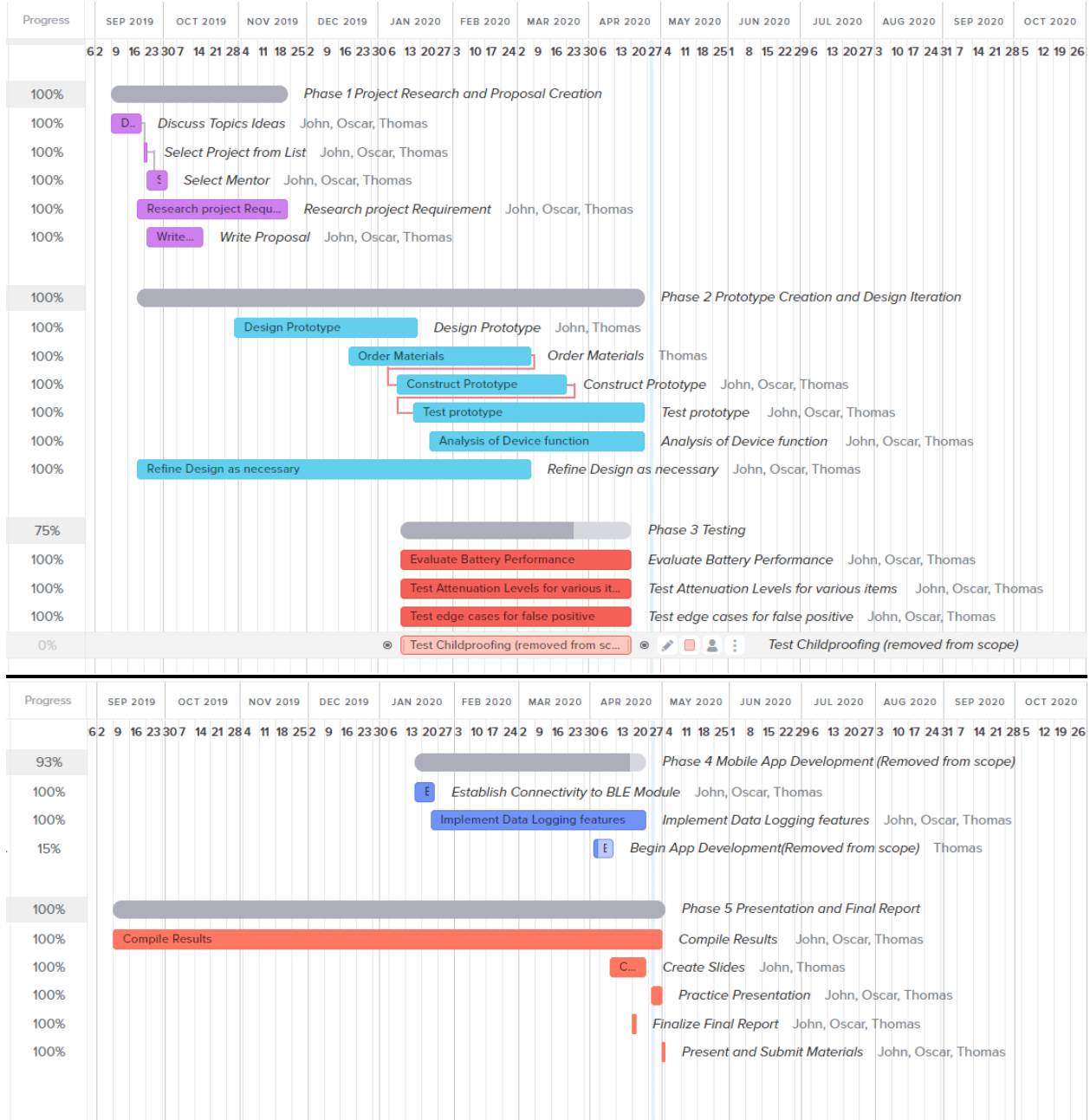
- Discuss project ideas.
  - Narrow down ideas to certain areas.
  - Select an idea for proposal
- Research
  - Study current car seat monitoring systems.
  - Research Bluetooth beacon technology.
- Design sensor network which will limit false positives, eliminate false negatives.
  - Create proper conditional circuit parameters to limit false results.
  - Create proper coding conditions to limit false results.
- Build prototype.
  - Purchase components based upon design specifications.
    - Purchase currently available comparable IoT car seat systems.
  - Fabricate sensor network.
  - Test operation then tune system to reflect desired operation.
  - Use coding to test for proper conditions.
  - Compare prototype to “off the shelf” units.
  - Repeat the above steps with each prototype iteration.
- Documentation (This process will occur simultaneously with all others).
  - Keep track of all expenditures as they occur.
  - Document all testing procedures and results.
- Testing
  - After working prototype is attained, perform test:
    - Battery performance test
    - Signal attenuation levels with bodies are present
    - False positive avoidance
- Finalize design.
  - After device works as expected, fine tune the user interface.
- Begin Mobile App Development (Time Permitting)
  - Signal capture from BLE Master Device
  - Data logging and rudimentary processing from sensors

- Push notification system to user's devices
- Create simple UI to present data
- Final report and presentation.
  - Combine documentation and summarize the findings in formal report format.
  - Practice our presentation often and be prepared to answer questions.

**Proposed Budget**

<b><u>Item</u></b>	<b><u>Quantity</u></b>	<b><u>Price/Unit</u></b>	<b><u>Total</u></b>
<b><i>Design</i></b>			
Arduino Board	3	\$ 10.00	\$ 30.00
Bluetooth Transmission Module	12	\$ 10.00	\$ 120.00
Sensor Kits	3	\$ 40.00	\$ 120.00
Batteries for testing	1	\$ 50.00	\$ 50.00
IC Components	1	\$ 100.00	\$ 100.00
Carseat	1	\$ 100.00	\$ 100.00
PCB Creation	1	\$ 50.00	\$ 50.00
<b><i>Research</i></b>			
3D Manufacturing/Rapid Prototyping	1	\$ 100.00	\$ 100.00
Elepho eClip Baby Reminder For Your Car	1	\$ 49.99	\$ 49.99
Automobile Car Safety Belt Pressure Sensor	1	\$ 12.99	\$ 12.99
Baby hot car Reminder, Alarm	1	\$ 29.99	\$ 29.99
SoftClip II TwinPak Safety Seat Monitor	1	\$ 69.90	\$ 69.90
	Estimated Total		\$ 832.87
	Margin of Error (20%)		\$ 166.57
	<b>Total Requested</b>		<b>\$ 999.44</b>

# Timeline



## **Initial Testing Data and Design Parameters**

The initial design was rather rudimentary, consisting of only an HM-19 BLE module in beacon mode. This was a proof of concept iteration. In this phase, a smart phone was used to observe attenuation levels and record early results.

The design of the CS-SODAS uses the attenuation properties of the human body interacting with Bluetooth signals as the “sensor”. This interaction is well documented. Bluetooth is essentially low energy radio waves. As anyone of a certain age can attest, a human moving through a room could interfere with TV, AM, FM and other radio wave signals. This is true of lower energy waves also.

In preliminary testing, clear attenuation was achieved when a human hand was placed between the Beacon device and the control module analog (smart phone). This signal showed noticeable, reliable attenuation in every test with the hand (Test Figure #1).

Another parameter was also inadvertently met through the original testing setup which involved a water bladder (Test Figure #2). A water bladder was chosen given the human body is composed primarily of water. The weight of the bladder also matched theoretical test conditions for human infants, as it is roughly the same mass and shape of infants. When being tested negligible attenuation was noted. This level of discrimination between human and non-human objects will help eliminate false positives being placed in a car seat.

The preliminary tests illustrated the validity of the attenuation theory. Based upon the NIH research paper and the well documented effect of human bodies interfering with radio signals, further testing was performed without attention to calculated statistical significance. The tests were performed in order to design the proper filtering method and to observe the overall noise level in the RSSI signal strength. This initial test also established the need to use test objects with flesh and bones, of both comparable size and weight to human infants.

Test Two was performed using a bone-in, ten-pound ham as an analog to the human body. This bone-in ham, and later frozen whole poultry carcasses, was the most widely available feasible human proxy. The non-human objects consisted of a full computer bag and a full backpack. The control condition was an empty car seat, measured shortly after removing each test object to eliminate any chance of environmental variances. This setup is demonstrated in Test Figure #3.

From these test data, a pattern could be observed. The RSSI levels exhibited high variability, but the human analog had significantly greater attenuation. To overcome these spikes in signal, a simple moving average filter was used in later builds to smooth input signal. This technique is commonly known as low pass filtering, a process where any high frequency changes are attenuated and lower signals are unaffected. This was found to eliminate rapid condition switching by passing a conditioned signal to be processed as opposed to a raw input

The average difference between a present condition and the nearest condition in Test Two was a difference of 8.2 dBm. The equation below shows that -8.2 dBm is equivalent to 15% the strength of the highest level with a non-present condition.

$$\text{Test Two Equation \#1 } -\frac{8.2}{10} = -.82 \quad 10^{-.82} \approx .15$$

Test Two was performed using a smartphone as the receiving module. The TI CC2640, running in a low power iBeacon mode, was used as the transmission module.

# Test Figure #1



Screen shots showing a clear attenuation increase. Left figure captured when no hand was present. Right figure was recorded with a human hand present.

# Test Figure #2



Water bladder test subject



## Test Figure #3



Experimental setup testing attenuation levels more accurately. In this photo the test subject is a ten-pound bone-in ham.

# Test Figure #4

Condition		
No item in car seat	Attenuation dBm TI	Additional Information
	-57	
	-59	
	-56	
	-55	
	-60	
	-61	
	-57	
	-49	Closer, devices placed on sides
	-52	Closer, devices placed on sides
	-57	Closer, devices placed on sides
Average	-56.3	
Ham Test	Attenuation dBm TI	Additional Information
	-72	
	-71	
	-71	
	-75	
	-74	
	-65	
	-67	Moving, car seat being rocked
	-72	Moving, car seat being rocked
	-60	Moving, car seat being rocked
	-60	Moving, car seat being rocked
Average	-68.7	
Other Items	Attenuation dBm TI	Additional Information
Computer bag	-64	All stationary
Computer bag	-57	
Computer bag	-60	
Computer bag	-59	
Computer bag	-61	
Backpack	-63	
Backpack	-59	
Backpack	-61	
Backpack	-60	
Backpack	-61	
Average	-60.5	

Test data demonstrating diferent attenuation level based upon conditions.

# Chapter 3 Build Phase

## Iterative process

As with many design-build projects, iterations help to create a final product when a group has a clearly defined outcome, but not a direct path to that goal. Iterations aid in exposing weakness in a design before crafting a final design. This iterative method was chosen for its flexibility. This process also allowed the scope of the project to be adjusted as the year progressed. The original scope for the project included design elements that needed to be scaled back. Even with these adjustments, the final prototype contains every major element proposed in the original work breakdown structure (WBS).

These smaller step-based designs were key to the success of the SODA project. This build process uncovered several clear design bottlenecks in the programming arena which required the build to pivot away from certain hardware and software. Initially, there were plans to use a TI CC2640 chip-based solution. Texas Instrument's professional IDE, Code Composer Studio, was used in this phase of this plan. A developmental kit was purchased from TI, their BLE libraries were downloaded for study, and basic code was written using the C programming language. Problems arose when trying to port TI's code and libraries over to other CC2640-based boards outside of their supplied development kits. In order to program these chips directly, expensive hardware is required. Additionally, the CC2640 chips could only be sourced in bare form, or already pre-built into consumer level Bluetooth modules. Buying surface mount microchips, custom designing a printed circuit board (PCB), and populating it with requisite control hardware seemed well beyond the scope of this project. Even in a production environment, increasing the skilled human labor needed for assembly instead of working with preassembled modules could be sub-optimal from a business perspective.

While the foundational idea of using relative Bluetooth signal strength between two modules remained sound, the project would either need to be subjugated to cumbersome development boards or methods needed to be devised in order to interact with low-cost consumer level products. Additional research turned up a similar product offered by Nordic Semiconductor, based around the nRF52840, which was fully programmable using a modified Arduino IDE. While not strictly Arduinos, they are targeted at the hobbyists. To program these boards, custom firmware needed to be loaded which removed the abstractions of dealing with the lowest level chip functionality [7]. This allowed for the use of common C-based libraries and modern coding practices.

This solution was adopted, and coding commenced in earnest. Given that the Nordic Board's included ancillary features appeal to broader audiences, the costs of this board were higher than desired. Lower-cost alternatives utilizing the same nRF52840 system were identified and tested. Products from Raytac, DSD-TECH, GeekPi, and various non-branded boards were evaluated. Unfortunately, none of these products were found to provide full chip-level programmability, even with reasonable modifications including burning custom firmware. One additional path, which was partially explored, centered around using Nordic's software development kit. Like TI's Code Composer Studio, Nordic offers a professional level full-featured IDE based around Segger Studio. Time did not permit an extensive pursuit of this possibility, though Segger Studio was able to program inexpensive nRF52840 modules without any additional intermediate hardware, a feature not found within Code Composer Studio.

The final prototype demonstrates that the design constraints initially established were feasible. The cost constraints for large scale manufacture of the device may have been estimated a bit low, but in an economies of scale operation these calculations seemed reasonable. If this product were to be sent to market, either custom boards could be produced in bulk at lower costs, or professional software developers could be hired to migrate the code to a lower-level language suitable for existing low-cost hardware.

## **Powering the Modules**

The designed application of SODA requires it to function while being left in the enclosed cabin of an automobile. To meet this specification, the unit's power source needs to be able to withstand the high temperatures of a parked, sealed automobile. Axiomatically, the electronics would need to be able to withstand these temperatures.

Temperatures of greater than 60 °C routinely occur in parked cars exposed to direct sunlight. Frigid winter temperatures can also present problems for batteries as their self-discharge rate accelerates as temperatures approach extremes. For this reason, non-rechargeable lithium CR123a cells were chosen to power the modules. They are nominally 3V with real world operating ranges from 3.3V fully charged to under 2V in a fully discharged state. They offer 4.5W of average usable power (3V x 1500mAh stated capacity) and have a temperature operating range from -20 to 85 °C. They are widely available and have been employed for decades in many mission-critical roles by both the U.S. armed forces and NASA.

While earlier designs featured a smaller capacity coin cell battery offering 0.63W of average usable power (3V x 210mAh) for the secondary module, this design proved to be dangerous for children. The initial designs were miniaturized to the point where they could become a choking hazard had the module become detached and ingested by the child. Furthermore, coin cells are the size and width of common candy items; in the unlikely event of a failure of the protective housing, this battery would appeal to the child. Lithium coin cells have been identified as both a choking and chemical burn hazards for young children. In light of these concerns, the need to miniaturize was abandoned and the larger CR123a lithium cells were used.

## **Hardware and Software**

The completed design uses the HM-19 as the secondary module and the SparkFun Pro nRF52840 Mini Development Board as the primary module. The coding for the primary module was performed in Arduino IDE and loaded onto the board through a custom firmware update. This code has been organized into functional areas and commented below.

As the secondary module neither makes connections nor collects data, programming it was a trivial matter. The HM-19 from DSD-Tech, a BLE 5.0 capable module built around the CC2640 from Texas Instruments was selected for the secondary module. This module is prepopulated with the requisite components to handle power management and serial communications. The HM-19 offers connector pins for power and data transmission, which were wired to a serial programmer. Using UART, serial commands were passed from a computer via USB connected to the module. A limited set of commands enabled the selection of power levels, UUID, address, and various parameters. The module was set to a -6 dBm power transmission level (command: AT+POWE1), configured to run in iBeacon mode (command: AT+IBEA1) and assigned a UUID (AT+UIDFFE0).

The primary module was much more challenging, both in design and implementation. Upon powering on, the module begins broadcasting its name, UUID, and available services using the Bluetooth LE protocol. Three BLE characteristics are defined, one each for the person flag, RSSI level, and temperature data. These functions are largely handled by boilerplate library functions, though parameters had to be adjusted to meet the targets of this project. After initializing, the module persistently runs in scanning mode looking for a device with a UUID known to be broadcasted by the secondary module. Filtering by UUID prevents interference from other Bluetooth devices, which would normally be detected by the module. Once the secondary module is discovered, the primary module captures the RSSI level between the two devices and passes this data to a moving average filter. The window of this filter is selectable; testing was performed to arrive at a window that did not introduce an unaccepted level of hysteresis into the sensor while also reducing any spikes in the RSSI level.

After filtering, the RSSI level average is recorded and made available as a global variable. This value is passed to a BLE service function which calls another update function to ultimately broadcast the values to any listening BLE application.

Whenever the module detects that is a connection (a processes handled by a connected callback function,) it begins making it services (person flag, temperature, RSSI reading) available to the connected device. This is where a smart app would have access to this data and could make decisions using changes in the data. Another important function is called from the device connected callback function: an auto-calibrate feature. The module monitors a long-run average of the no-person present state while performing the moving average calculations. In real-world cases, a connection would occur when users are approaching the vehicle. At this point, the module sets the long run average to be the minimum threshold level – a value to mark what RSSI signal indicates an infant is not in the seat. This allows the two modules to adjust sensitivity levels based on variances in physical installations between end-users, a factor that cannot be controlled for outside laboratory conditions.

While these functions are running, updates to the RSSI are being passed to an algorithm in the form of an if-else statement to determine whether to set the person-present flag. A differential has been preset to 7 RSSI; once the received signal averages to greater than 7 RSSI below the minimum threshold arrived at by the calibration feature, the application sets the person-present flag to “1”. In testing, this number could have been set to as high as 10, but to avoid false negatives (indicating the child is not present while it is), a conservative differential of 7 was chosen. This value would likely need further testing in later stages of production, or additional data to confirm the assumptions being made.

In the same fashion, once the RSSI drops back below the minimum threshold the person-present flag resets to “0”. All the while these data are being broadcast to the connected BLE application, which results in near real-time updates. One notable advantage of utilizing callback functions over a constant while-loop is that the module performs less extraneous operations, resulting in power savings.

The module was also able to monitor and pass temperature reading to the phone app via a GATT service [8]. A 50k thermistor was employed which was configured as a voltage divider using a 50k resistor (see Build Figure #2). The voltage difference was passed to an analog read pin on the Bluetooth module. This voltage was converted to a temperature scale using commonly known temperature characteristics of thermistors. The temperature value was then rounded to a whole number integer and passed to the mobile application at a rate of

approximately once every 10 seconds using a counter embedded into the moving average filter function.

## Primary Module Code

The code is commented for ease of understanding. Every comment line (//) describes the functionality of the following line or lines of code. Syntax coloring have been preserved to aid in readability.

```
#include <bluefruit.h>

//Moving average filter variables
#define WINDOW_SIZE 8
int INDEX = 0;
int value = 0;
int sum = 0;
int readings[WINDOW_SIZE];
int averaged = 0;
int sample_counter = 0;
int longRunAverage = 0;

//Declaring lower threshold used for automatic calibrations
int LOWER_THRESHOLD = 0;

// UUID chosen for LOWER MODULE
const uint8_t LOWER_MODULE = 0xFFE0;

//Global Person Flag, indicates if a body is detected in the seat
int PERSON_FLAG = 0;

//Differential between occupant and no occupant
int DIFFERENTIAL = 7;

//Service ID chooses to house the sensor input values
//BLE Services are broadcasts and appear in dector applications
BLEService detector = BLEService(0x111D);

//Declare Characteristic for person detection flag
//0x111E is the ID chosen for the 'person flag' feature
BLECharacteristic person_flag = BLECharacteristic(0x111E);

//Declare Characteristic for RSSI readout
//0x111F is the ID chosen for 'RSSI' feature
BLECharacteristic rssi_readout = BLECharacteristic(0x111F);

//Declare Characteristic for temperature reading
//0x1120 is the ID choose for the temperature feature
BLECharacteristic temperature_update = BLECharacteristic(0x1120);

BLEDis bledis; // DIS (Device Information Service) helper class instance
```

```

BLEBas blebas;      // BAS (Battery Service) helper class instance

void setup()
{
  Serial.begin(115200);

  // Initialize the upper module
  Bluefruit.begin();

  // Set the advertised device name (keep it short!)
  Bluefruit.setName("CS SODAS Upper");

  // Set the connect/disconnect callback handlers
  Bluefruit.Periph.setConnectCallback(connect_callback);
  Bluefruit.Periph.setDisconnectCallback(disconnect_callback);

  // Configure and Start the Device Information Service
  Serial.println("Configuring the Device Information Service");
  bledis.setManufacturer("sparkFun - Sr. Design Project");
  bledis.setModel("Childseat Upper Module - Beta");
  bledis.begin();

  // Start the BLE Battery Service and set it to 100%
  blebas.begin();
  blebas.write(100);

  // Setup the Detector service using BLEService and BLECharacteristic
  classes
  setupDetector ();

  // Setup the advertising packet(s)
  startAdv();

  /* Start Central Scanning
   - Enable auto scan if disconnected
   - Filter out packet with a min rssi
   - Interval = 100 ms, window = 50 ms
   - Use active scan (used to retrieve the optional scan response adv
packet)
   - Start(0) = will scan forever since no timeout is given
*/

  Bluefruit.Scanner.setRxCallback(scan_callback);
  Bluefruit.Scanner.restartOnDisconnect(true);
  Bluefruit.Scanner.filterRssi(-100);
  // only invoke callback if Lower Module is found
  Bluefruit.Scanner.filterUuid(0xFFE0);
  // in units of 0.625 ms
  Bluefruit.Scanner.setInterval(640, 320);
  // Request scan response data
  Bluefruit.Scanner.useActiveScan(true);
  // 0 = Don't stop scanning after n seconds
  Bluefruit.Scanner.start(0);

  //For testing
  //Serial.println("Looking for UUID ");

```

```

}

void scan_callback(ble_gap_evt_adv_report_t* report){
//Function to pull the raw RSSI value from the BLE data
//generated by the generic report as part of the library

    PRINT_LOCATION();
    uint8_t len = 0;
    uint8_t buffer[32];
    memset(buffer, 0, sizeof(buffer));

    /* RSSI value */
    // Serial.printf("%14s %d dBm\n", "RSSI", report->rssi);
    int signal_strength = report->rssi;

    //Send RSSI to moving average filter for processing
    moving_average_filter(signal_strength);

    //call to check RSSI against person algorithm
    RSSI_comparison(averaged);

    /*
    // For testing only
    Serial.print("Person flag = ");
    Serial.print(PERSON_FLAG);
    Serial.println();
    */

    //Call Scanner resume() to continue scanning
    Bluefruit.Scanner.resume();
}

void startAdv(void){
    // Advertising packet
    Bluefruit.Advertising.addFlags(BLE_GAP_ADV_FLAGS_LE_ONLY_GENERAL_DISC_MODE)
;
    Bluefruit.Advertising.addTxPower();
    // Include Detector Service UUID
    Bluefruit.Advertising.addService(detector);
    // Include Name
    Bluefruit.Advertising.addName();

    /* Start Advertising
        - Enable auto advertising if disconnected
        - Interval: fast mode = 20 ms, slow mode = 152.5 ms
        - Timeout for fast mode is 30 seconds
        - Start(timeout) with timeout = 0 will advertise forever (until
        connected)

        For recommended advertising interval
        https://developer.apple.com/library/content/qa/qa1931/ INDEX.html
    */
    Bluefruit.Advertising.restartOnDisconnect(true);
    Bluefruit.Advertising.setInterval(32, 244); // in unit of 0.625 ms
    Bluefruit.Advertising.setFastTimeout(20); // number of seconds in fast
mode

```



```

    Bluefruit.Advertising.start(0);           // 0 = Don't stop
    advertising after n seconds
}

void setupDetector (void){
    detector.begin();
    // Note: You must call .begin() on the BLEService before calling .begin()
    on
    // any characteristic(s) within that service definition.. Calling .begin()
    on
    // a BLECharacteristic will cause it to be added to the last BLEService
    that
    // was 'begin()'ed!

    //Begin person flag characteristic, used to pass 0 or 1 if person is
    present/absent
    person_flag.setProperties(CHR_PROPS_NOTIFY);
    person_flag.setPermission(SECMODE_OPEN, SECMODE_NO_ACCESS);
    person_flag.setFixedLen(1);
    person_flag.begin();
    uint8_t flag[1] = {0b00000111}; // Set the characteristic to use 8-bit
    values, with the sensor connected and detected
    person_flag.write(flag, 1);

    //Begin RSSI characteristic, used to pass RSSI values
    rssi_readout.setProperties(CHR_PROPS_NOTIFY);
    rssi_readout.setPermission(SECMODE_OPEN, SECMODE_NO_ACCESS);
    rssi_readout.setFixedLen(1);
    rssi_readout.begin();

    //Begin temperature update characteristic, used to pass Temperature values
    temperature_update.setProperties(CHR_PROPS_NOTIFY);
    temperature_update.setPermission(SECMODE_OPEN, SECMODE_NO_ACCESS);
    temperature_update.setFixedLen(2);
    temperature_update.begin();
}

void connect_callback(uint16_t conn_handle){
    // Get the reference to current connection
    BLEConnection* connection =Bluefruit.Connection(conn_handle);

    char central_name[32] = { 0 };
    connection->getPeerName(central_name, sizeof(central_name));

    //Set the lower threshold whenever a device connects
    //This will occur whenever a user approaches the device
    //and before any occupants are placed inside
    LOWER_THRESHOLD = averaged;

    //For testing
    /*
    Serial.print("Connected to ");
    Serial.println(central_name);
    */
}

```

```

void disconnect_callback(uint16_t conn_handle, uint8_t reason){
/*
    Callback invoked when a connection is dropped
    @param conn_handle connection where this event happens
    @param reason is a BLE_HCI_STATUS_CODE which can be found in ble_hci.h
*/
    (void) conn_handle;
    (void) reason;
    Serial.print("Disconnected, reason = 0x"); Serial.println(reason, HEX);
    Serial.println("Advertising!");
}

void cccd_callback(uint16_t conn_hdl, BLECharacteristic* chr, uint16_t
cccd_value){
    // Display the raw request packet
    Serial.print("CCCD Updated: ");
    //Serial.printBuffer(request->data, request->len);
    Serial.print(cccd_value);
    Serial.println("");
}

void RSSI_comparison(int input_signal){
    //Bring global variable into local scope
    //prevents errors if global update occurs while this
    //function is running
    int rssi = input_signal;

    //Expected level without a person in seat
    int max_level = LOWER_THRESHOLD;
    //Expected level with perosn in seat
    int min_level = LOWER_THRESHOLD - DIFFERENTIAL;

    //Person detection algorithm
    if (rssi >= max_level) {
        PERSON_FLAG = 0;
        //Call function to update mobile application
        update_person_flag();
    }
    else if (rssi <= min_level) {
        PERSON_FLAG = 1;
        //Call function to update mobile application
        update_person_flag();
    }
    else {
        //no other state to consider
    }
}

void update_person_flag(){
    //Function to push notifications to mobile application
    //whenever there is an update to the 'person flag
    if (Bluefruit.connected()) {
        uint8_t flag[1] = {PERSON_FLAG};
    }
}

```

```

    person_flag.notify(flag, sizeof(flag));
}
}

void update_RSSI(int signal_strength){
//Function to push notifications to mobile application
//whenever there is an update to the RSSI signal strength
    int rssi = signal_strength;
    if (Bluefruit.connected()) {
        int flag[4] = {rssi};
        rssi_readout.notify(flag, sizeof(flag));
    }
}

void update_temperature(int temperature){
    Serial.println(temperature);
//Function to push notifications to mobile application
//whenever there is an update to the thermistor reading
    if (Bluefruit.connected()) {
        int flag[4] = {temperature};
        temperature_update.notify(flag, sizeof(flag));
    }
}

void moving_average_filter(int RSSI_value){
    // Remove the oldest entry from the sum
    sum = sum - readings[INDEX];
    // Read the next RSSI value
    value = RSSI_value;
    // Add the newest reading to the window
    readings[INDEX] = value;
    // Add the newest reading to the sum
    sum = sum + value;
    // Increment the INDEX, and wrap to 0 if it exceeds the window size
    INDEX = (INDEX+1) % WINDOW_SIZE;
    // Divide the sum of the window by the window size for the result
    averaged = sum / WINDOW_SIZE;
    //Increment sample counter
    sample_counter = (sample_counter+1);

    //Code used to verify functionality - serial output
    Serial.print(value);
    Serial.print(",");
    Serial.print(averaged);
    Serial.println(LOWER_THRESHOLD);

    //Rudimental counter to read temp out every ~10 seconds
    if (sample_counter == 10){
        //Call read temperature function
        read_temp();
        //Reset sample_counter
        sample_counter = 0;
    }

    //Call the function to pass new RSSI value to phone
    update_RSSI(averaged);
}

```

```

void read_temp(){

//Set analog input pin on board
int ThermistorPin = 3;
//Variable to hold voltage reading from thermistor
int Vo;
//Set resistor level, 50k
float R1 = 50000;
//Declare variables needed for voltage to temp conversion (float needed for
float arithmetic)
float logR2, R2, Temp;
//Constants used for conversion
float c1 = 1.009249522e-03, c2 = 2.378405444e-04, c3 = 2.019202697e-07;

//Perform voltage reading
Vo = analogRead(ThermistorPin);
R2 = R1 * (1023.0 / (float)Vo - 1.0);
logR2 = log(R2);
//Temperature in Kelvin
Temp = (1.0 / (c1 + c2*logR2 + c3*logR2*logR2*logR2));
//Temperature in centigrade
Temp = Temp - 273.15;
//Final temperature in Fahrenheit
Temp = (Temp * 9.0) / 5.0 + 32.0;

//Round to whole number
int rounded_temp = round(Temp);

//Code used to verify functionality - serial output
Serial.print("Temperature: ");
Serial.print(rounded_temp);
Serial.println(" F");

//Call to function to update temperature reading on mobile application
//Pass temperature reading in F
update_temperature(Temp);
}

void loop(){
//Nothing here, functionality handled in callbacks
//By avoiding using a persistent loop, power is saved.
//Callbacks only occur when devices are connected.
}

```

## **Module Packaging**

AutoCAD was used to design two independent enclosures intended to house the primary and secondary modules. These prototypes (see Build Figures #1a,b,c) were created using additive manufacturing techniques at Miami Hamilton's Engineering Technology lab with the assistance of Frank Tonner. These enclosures served as early housing prototypes and suffered from sizing issues. Due to the fraught nature of 3-D printing using PET, tolerances needed to be increased. After the closure of Miami's Campuses, further design iterations were shelved due to the lack of access to production equipment. This led to the abandonment of custom enclosures and the adoption of a previous solution – prefabricated plastic boxes, as shown in Build Figures 3 and 4. These enclosures were oversized, but provided a secure seal for all of the necessary components. Attenuation caused by these cases was negligible and the devices operated as predicted when enclosed. The attenuation levels scaled linearly, and no unpredictable interference was observed in testing.

Both Bluetooth modules were attached to the car seat with commercially available adhesive strips (see Build Figures #5-7). An instructional brochure was designed to explain the attachment procedure and to serve as marketing material for interested parties (see appendix).

Through testing, it was observed that the most efficient method to attach the devices was by placing them on the exterior sides of the car seat. This shifted the nomenclature of upper and lower module to become primary and secondary modules. The primary module runs the more advanced custom firmware and is designed to connect to a mobile application while the secondary module runs in a low power broadcast mode. For end-users installing the two modules, there is no requirement to differentiate between primary and secondary modules.

## **Build Phase Conclusion**

By knowing the RSSI (received signal strength indicator) value between two signal sources when a space is void, it is possible to analyze changes in signal level and correlate the differential to changes in said void. Following this method, the RSSI was measured in the car seat when no items were present. Whenever items were placed in the seat, the RSSI level was noted. Whenever the difference of these two readings was greater than a few units, it was reasonable to assume a human-like object had been placed between the modules.

The SODA device was tested using a variety of items designed to either mimic the body composition of a small human body, or to serve as a false-positive test case. Animal carcasses were chosen for the former, and common grocery items the latter. These items included a 14-pound frozen turkey, a 7-pound frozen chicken, a 7-pound fresh chicken, a 10-pound sack of potatoes, an 8-pound sack of dry beans, and 12 aluminum cans of seltzer water. For an in-depth analysis, see Build Figure #9.

These test data offered numerous findings. Chiefly, the design goal of avoiding false positives from storing non-intended items in the car seat was achieved. The minimum, present condition average differential observed with the fresh 7-pound chicken was -9.55 dB. This correlates to an average of 11% change in relative signal strength between the present and non-present states. The differential with non-human analogs was far less, varying only one to two decibels. Of note, while testing the case of seltzer water the item-present state demonstrated a

higher RSSI than in the item-absent state. This indicates that the signal was boosted by the aluminum and water.

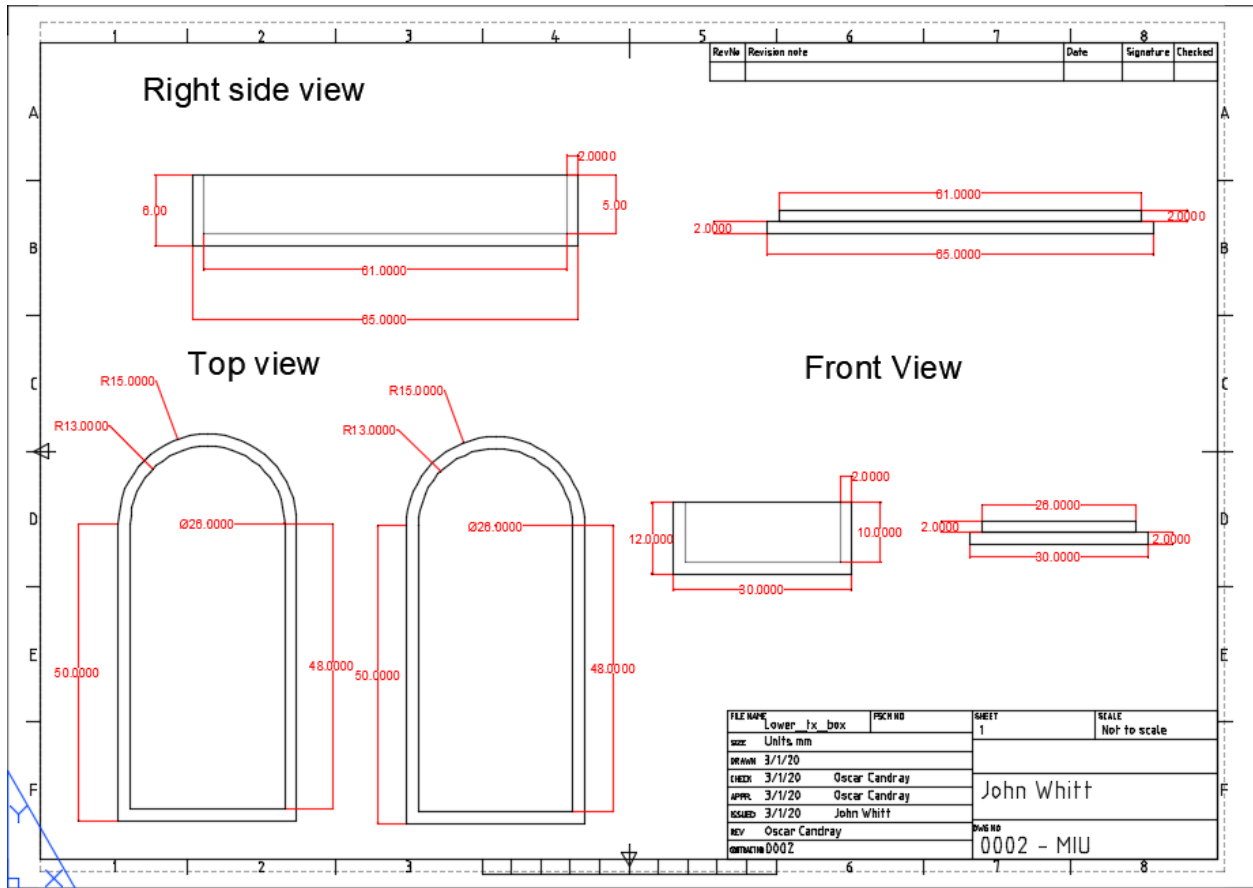
While the signal strength does exhibit some variability, this differential method allows for the device to observe the signal before the human analog is present, which eliminates false positives. The code limits the false negatives by determining the switching condition based upon an automatic calibrating feature. The modules program records a predefined number of samples and determines the lowest average signal strength. This number is then set as the seat-empty condition whenever the primary module detects it has been connected to. In a real-world scenario, this would occur after installation and whenever users would approach the car. In this fashion, the unit adjusts for variability in installation location and environmental conditions inside an automobile.

To register the presence of an occupant, the module's programming requires the signal strength to drop below the lowest value minus a constant decibel level. Once that condition is set the signal strength must rise to the minimum initial condition before switching back, thus eliminating rapid switching. This functionality resembles the operation of the ubiquitous Schmitt trigger. The code introduces hysteresis into the system.

Hysteresis occurs when the output of a system varies based upon the previous state of the system. For example, Schmitt triggers change state at a different level based upon the "direction" of the input signal. If the voltage is rising it will trigger at a certain value, while if the voltage is dropping it will trigger at a different lower point. Hysteresis can be thought of as the system having memory.

The SODA reliably detects human analogs by setting the present condition flag, a binary trigger which is flipped back to "0" when the item is removed (see Build Figures #8a,b). These values are passed to the nRF Connect software on a smart device, which can then make decisions based on the flag value of 0 or 1. The data sent is in hexadecimal encoding, and it illustrates the condition and the signal levels expressed in dBm. The RSSI value is represented in hexadecimal 2's complement form which is converted in Build Figure #9. Temperature data, recorded via a thermistor, is passed in hexadecimal format as well.





Print of slim profile Tx box with lid

## Build Figures #8

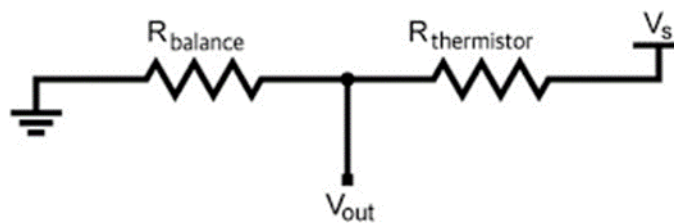


Illustration of voltage divider circuit used with the thermistor. The balancing resistor is selected to match the resistance of the thermistor and voltage is read between the two components.

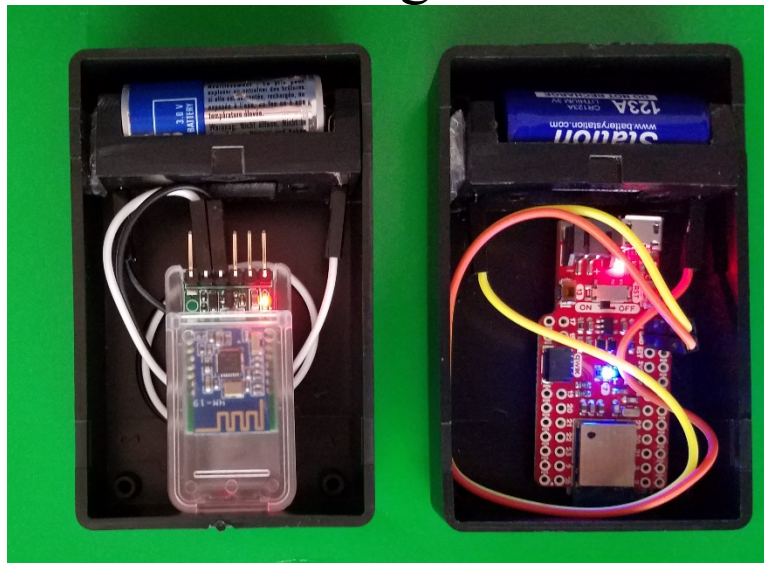


## Build Figure #3



Assembling the SparkFun primary module. Resistors and thermistor have been soldered to the underside of the board.

## Build Figure #4



Boxes containing the HM-19 secondary module (left) and the SparkFun primary module (right). These units both are powered by cr123a cells and rely on BLE technology to transmit and receive data packets.

# Build Figure #5



Location of primary module on the car seat

# Build Figure #6



Location of secondary module on the car seat

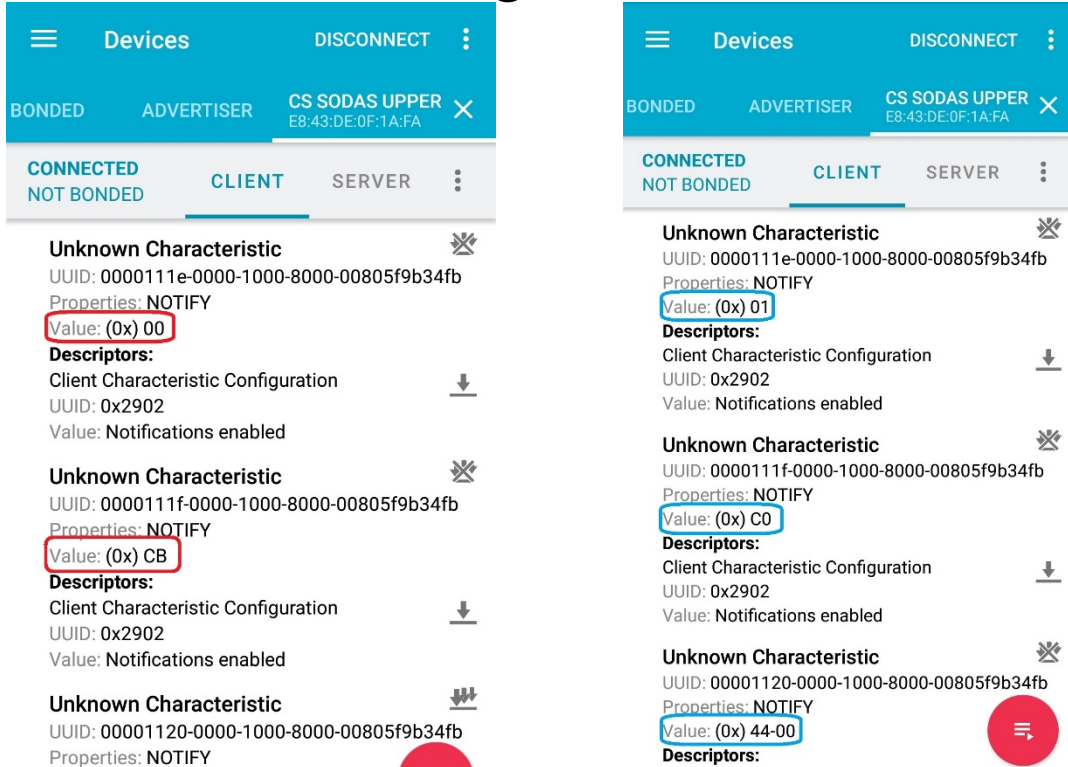


## Build Figure #7



Path between the modules optimized for attenuation (arrow illustrates optimal signal path)

# Build Figures #8a, b



Screen shots of chicken not present (left) and chicken present (right)

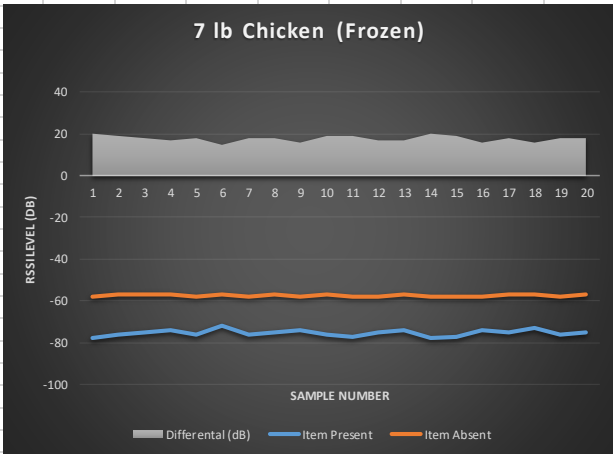
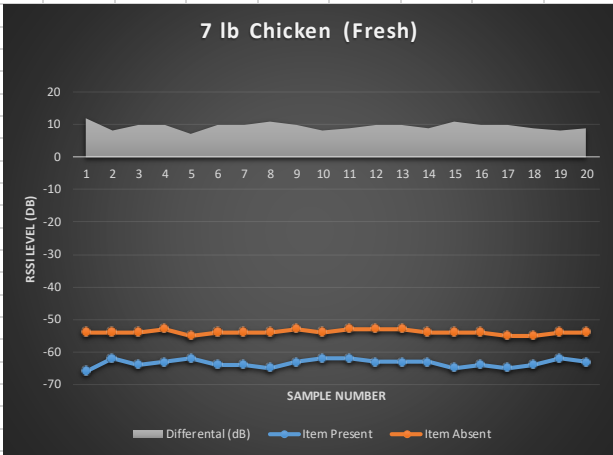
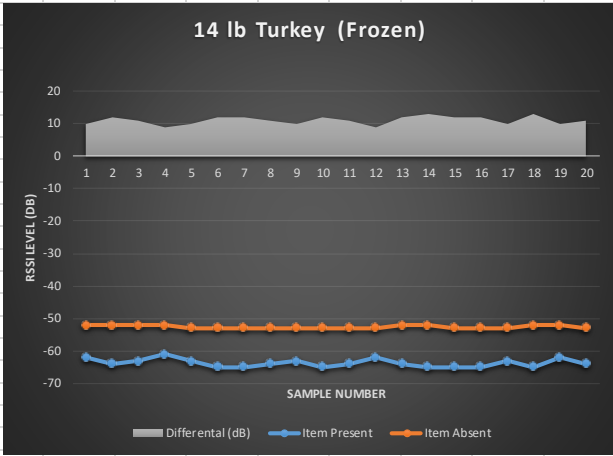
In the first red box, the person flag is showing hex value 00, indicating a body was not detected. In the second red box, the raw RSSI value is displayed in 2's complement form. In this instance, 0xCB corresponds to a -53 dB level reading

After the chicken was placed in the car seat, the first blue box reflects the transition to hex value 01, the person-present state. To verify, the second blue box shows the RSSI signal level dropping to 0xC0, or -64 dB. This is a reduction in signal strength of 11 decibels, which is beyond the trigger point of a 7 dB differential.

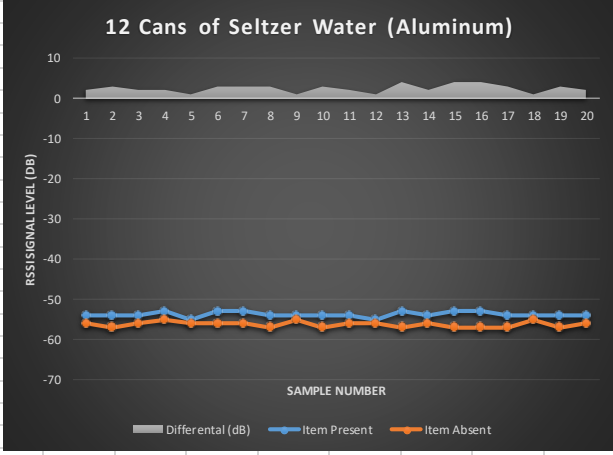
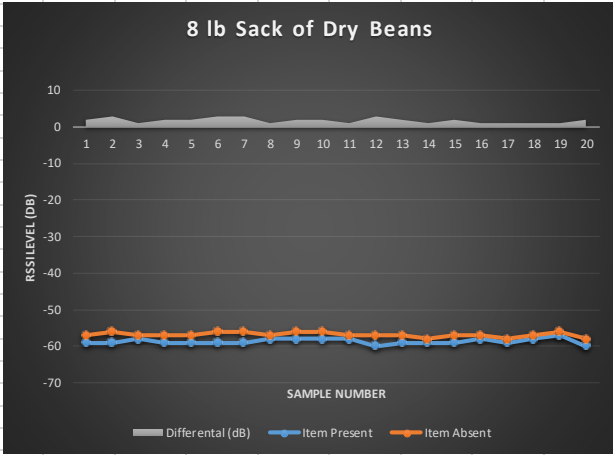
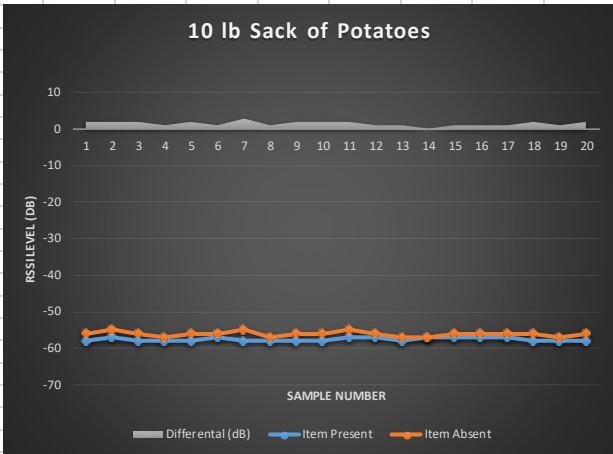
Also, the third blue box shows that the temperature sensor has passed a value of 0x44, which is in standard hexadecimal format and corresponds to decimal 68 which is the temperature in °F.

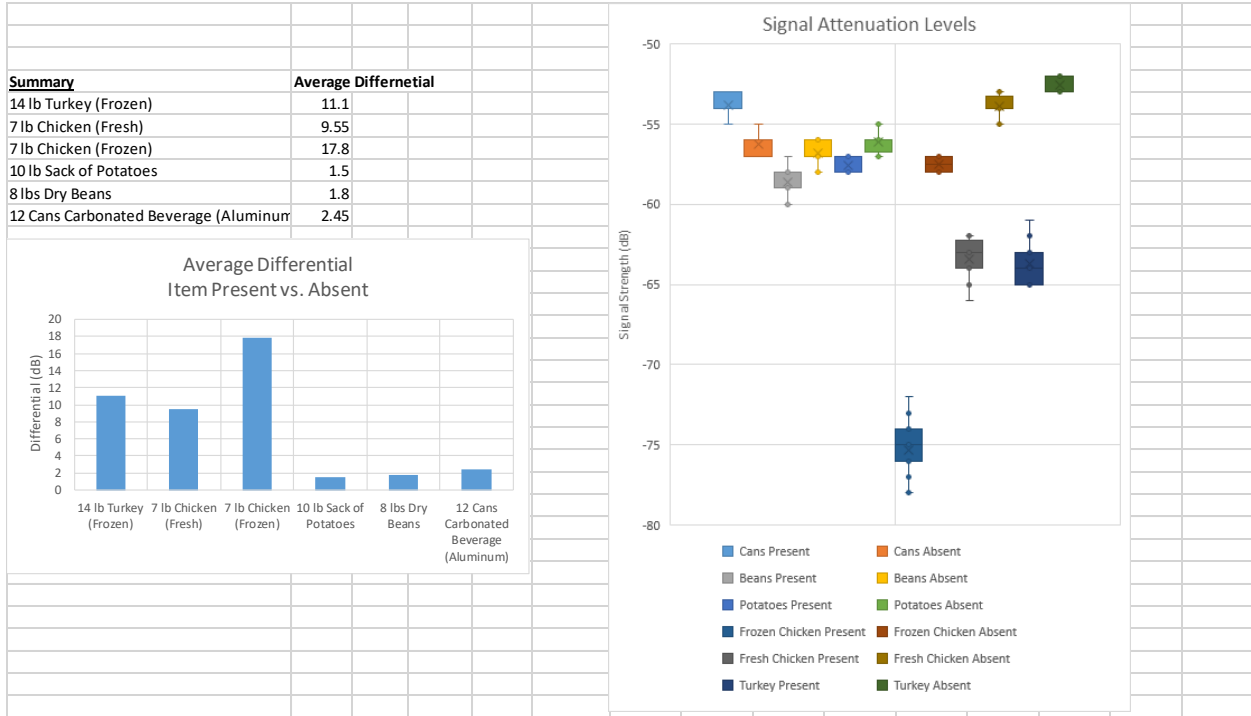
# Build Figure #9

Sample	Item Present (hex)	Item Absent (hex)	Item Present (dB)	Item Absent (dB)	Differential (dB)
<b>14 lb Turkey (Frozen)</b>					
1	C2	CC	-62	-52	10
2	C0	CC	-64	-52	12
3	C1	CC	-63	-52	11
4	C3	CC	-61	-52	9
5	C1	CB	-63	-53	10
6	BF	CB	-65	-53	12
7	BF	CB	-65	-53	12
8	C0	CB	-64	-53	11
9	C1	CB	-63	-53	10
10	BF	CB	-65	-53	12
11	C0	CB	-64	-53	11
12	C2	CB	-62	-53	9
13	C0	CC	-64	-52	12
14	BF	CC	-65	-52	13
15	BF	CB	-65	-53	12
16	BF	CB	-65	-53	12
17	C1	CB	-63	-53	10
18	BF	CC	-65	-52	13
19	C2	CC	-62	-52	10
20	C0	CB	-64	-53	11
<b>Average</b>			<b>-63.7</b>	<b>-52.6</b>	<b>11.1</b>
<b>7lb Chicken (Fresh)</b>					
1	BE	CA	-66	-54	12
2	C2	CA	-62	-54	8
3	C0	CA	-64	-54	10
4	C1	CB	-63	-53	10
5	C2	C9	-62	-55	7
6	C0	CA	-64	-54	10
7	C0	CA	-64	-54	10
8	BF	CA	-65	-54	11
9	C1	CB	-63	-53	10
10	C2	CA	-62	-54	8
11	C2	CB	-62	-53	9
12	C1	CB	-63	-53	10
13	C1	CB	-63	-53	10
14	C1	CA	-63	-54	9
15	BF	CA	-65	-54	11
16	C0	CA	-64	-54	10
17	BF	C9	-65	-55	10
18	C0	C9	-64	-55	9
19	C2	CA	-62	-54	8
20	C1	CA	-63	-54	9
<b>Average</b>			<b>-63.45</b>	<b>-53.9</b>	<b>9.55</b>
<b>7lb Chicken (Frozen)</b>					
1	B2	C6	-78	-58	20
2	B4	C7	-76	-57	19
3	B5	C7	-75	-57	18
4	B6	C7	-74	-57	17
5	B4	C6	-76	-58	18
6	B8	C7	-72	-57	15
7	B4	C6	-76	-58	18
8	B5	C7	-75	-57	18
9	B6	C6	-74	-58	16
10	B4	C7	-76	-57	19
11	B3	C6	-77	-58	19
12	B5	C6	-75	-58	17
13	B6	C7	-74	-57	17
14	B2	C6	-78	-58	20
15	B3	C6	-77	-58	19
16	B6	C6	-74	-58	16
17	B5	C7	-75	-57	18
18	B7	C7	-73	-57	16
19	B4	C6	-76	-58	18
20	B5	C7	-75	-57	18
<b>Average</b>			<b>-75.3</b>	<b>-57.5</b>	<b>17.8</b>



10 lb Sack of Potatoes					
1	C6	C8	-58	-56	2
2	C7	C9	-57	-55	2
3	C6	C8	-58	-56	2
4	C6	C7	-58	-57	1
5	C6	C8	-58	-56	2
6	C7	C8	-57	-56	1
7	C6	C9	-58	-55	3
8	C6	C7	-58	-57	1
9	C6	C8	-58	-56	2
10	C6	C8	-58	-56	2
11	C7	C9	-57	-55	2
12	C7	C8	-57	-56	1
13	C6	C7	-58	-57	1
14	C7	C7	-57	-57	0
15	C7	C8	-57	-56	1
16	C7	C8	-57	-56	1
17	C7	C8	-57	-56	1
18	C6	C8	-58	-56	2
19	C6	C7	-58	-57	1
20	C6	C8	-58	-56	2
<b>Average</b>			<b>-57.6</b>	<b>-56.1</b>	<b>1.5</b>
8 lb Dry Beans					
1	C5	C7	-59	-57	2
2	C5	C8	-59	-56	3
3	C6	C7	-58	-57	1
4	C5	C7	-59	-57	2
5	C5	C7	-59	-57	2
6	C5	C8	-59	-56	3
7	C5	C8	-59	-56	3
8	C6	C7	-58	-57	1
9	C6	C8	-58	-56	2
10	C6	C8	-58	-56	2
11	C6	C7	-58	-57	1
12	C4	C7	-60	-57	3
13	C5	C7	-59	-57	2
14	C5	C6	-59	-58	1
15	C5	C7	-59	-57	2
16	C6	C7	-58	-57	1
17	C5	C6	-59	-58	1
18	C6	C7	-58	-57	1
19	C7	C8	-57	-56	1
20	C4	C6	-60	-58	2
<b>Average</b>			<b>-58.65</b>	<b>-56.85</b>	<b>1.8</b>
12 Cans Seltzer Water (Aluminum)					
1	CA	C8	-54	-56	2
2	CA	C7	-54	-57	3
3	CA	C8	-54	-56	2
4	CB	C9	-53	-55	2
5	C9	C8	-55	-56	1
6	CB	C8	-53	-56	3
7	CB	C8	-53	-56	3
8	CA	C7	-54	-57	3
9	CA	C9	-54	-55	1
10	CA	C7	-54	-57	3
11	CA	C8	-54	-56	2
12	C9	C8	-55	-56	1
13	CB	C7	-53	-57	4
14	CA	C8	-54	-56	2
15	CB	C7	-53	-57	4
16	CB	C7	-53	-57	4
17	CA	C7	-54	-57	3
18	CA	C9	-54	-55	1
19	CA	C7	-54	-57	3
20	CA	C8	-54	-56	2
<b>Average</b>			<b>-53.8</b>	<b>-56.25</b>	<b>2.45</b>





Results of functional SODA devices exposed to varying test objects.

# Chapter 4 Conclusion

## Report Conclusion

The CS-SODAS project was a design intensive project requiring extensive research and development. The ability to remain flexible was pertinent to the success of SODA. Software design often uses the Agile approach to project management. As there was no end customer to contend with, the group had to make several decisions about how to proceed based upon the original design constraints. This led to a finished prototype that meets every goal desired.

CS-SODAS demonstrates the validity of signal attenuation as a “sensor.” By observing the signal strength through time, SODA is able to accurately determine whether or not a human proxy is in the car seat. It does not indicate that the proxy is present even when other items (dry groceries, computer bag, backpacks, etc.) are placed in the car seat. This ability was a main design goal of the project.

The program running on the primary module updates a conditional variable based upon this presence before passing this condition to a smart device. Additionally, the module can measure and pass accurate temperature data to the mobile application. False positives have been eliminated through testing, tuning, and implementing signal conditioning. Based on the performance in testing, the scope of the original project was met.

The pandemic caused by the SARS-CoV2 virus also illustrated the advantages of iterative development. By building the devices in iterative steps, the group was able to quickly access and respond to the rapidly changing regulations imposed by institutions and governing bodies. The SODA project had met the majority of its goals prior to campuses and businesses closing, and modifications to the project were minimal. The largest change revolved around maintaining communications without physical meetings. To overcome this barrier, team members met remotely, utilizing conference calls and Google Hangouts to share progress.

The original intent of this project was to design a device comparable to devices on the market, in that respect the project proves that goal was attainable. The current functionality of the device is comparable to other devices. Some goals of the project simply required more time and testing of the device. With the bulk of the project’s testing phase being interrupted, the higher goals were forgone, and additional time was spent developing marketing material and refining the software. These were both able to be accomplished by group members working in isolation of each other and their shared material.

Despite paying retail prices, the prototype was constructed using less than 50 dollars’ worth of components. These components are significantly more expensive and capable than the end design would require. It seems that the design constraint of approximately 20 dollars to manufacture would be attainable as we have lowered the assembly time and reduced the hardware bill of materials.

Considering the low power requirement of BLE devices and the ability to change power setting and broadcast intervals, the device could be incredibly energy efficient. Further real-world testing needs to be performed to arrive at the optimal signal transmission level, but the devices currently draw very little power. Testing was performed on raising the transmission power level of the secondary module, but the RSSI signal differential remained constant. The RSSI levels increased as more power was sensed by the primary module, but this did not lead to a larger difference between the absent and present conditions of items being tested. The second



to lowest transmission level was settled on, and both units have been operating for over three months without showing signs of a voltage drop from CR123a cells.

The estimated cost of this project was greater than required, which left some unused funds in the budget. Had the campus shutdowns not occurred and restrictions on receiving university purchase orders at home been in place, some additional testing of exiting products may have taken place. There was an interest in comparing this design to existing products, which would occur if this product were to be marketed. Originally the project received funding through the Fleck Scholarship Fund in the amount of \$832.87. The total spent through the Fleck scholarship was \$599.08, as is shown in Conclusion Figures #1-4. Other expenses not included in the budget included the ham, turkey and chicken used for testing. Additionally, small items drawn in from personal supplies included CR123a batteries and the Command™ strips.

### **Recommendation for Future Development**

In its current state, the CS-SODAS project is a fully functioning device. The hardware currently passes all required signal information to a third-party mobile application (nRF Connect). While there are portions of a custom mobile application written, not all desired features are present. Currently, the mobile application can detect the module, read BLE Characteristics, and pair with the primary module, but it cannot parse the incoming data transmissions nor make decision based on their data. Further time and training would be required to refine application functionality and ensure a positive user experience. To ensure maximum compatibility, a separate iOS application should also be coded for Apple devices.

Beyond application development, the SODA encasement would need to undergo strenuous real-world testing to ensure water resistance up to IPX6 standards. While it would be trivial to seal the housing units with silicon, this would limit the ability of end-users from doing battery replacements. After completing these tasks, the SODA would be a full-feature viable commercial device. If this project were to be monetized, formal marketing data would need to be collected, a task far beyond the scope of this project.

While the Arduino-based IDE and the SparkFun development module worked well for this project, commercial needs would be better addressed by a professional development IDE and custom-built boards. These could then be mass produced in smaller form and higher volume resulting in a lower overall costs than the current prototype.

### **Further Research Topics**

This project has demonstrated a relatively novel use of an existing technology and would be well-suited to other common applications. Because of the remarkable energy efficiency of BLE devices (working lifespans measured in years from 210mAh coin cell power sources), these units could serve as a low overhead surveillance system. As noted in an Information Engineering Express journal article, BLE modules have been deployed to measure whenever test subject approach a pill cabinet [9].

In a retail setting, there was initially strong interest in using BLE-based broadcaster units. Apple and Google have developed standards (iBeacon and Eddystone, respectively), with the intent to push micro targeted advertisements to smart devices via custom retail applications. These devices also functioned on location-based principles, with power level being tunable to adjust for radius of interaction.

In a similar fashion, power levels could be raised on the secondary module to create a wider monitoring area. Additional BLE devices, arranged in an ad-hoc network, could monitor and report the path of an individual based on spikes in attenuation between each other and a central node. This would all occur without subjects having to either have an application downloaded to their device, have Bluetooth enabled, or having location services enabled (all current requirements to track subjects using existing iBeacon and Eddystone frameworks).

Unlike security cameras, these small BLE modules do not require hardwiring, large batteries, lighting, or to be directly exposed to unknowing subjects. Existing security systems may see benefits from a hybrid design where BLE devices act a trigger for high-power sensors and cameras. There may be further niche use-cases involving signal attenuation as a proximity sensor which expand upon the groundwork laid by this project.

# Conclusion Figures #1-4

## PARTS & SUPPLIES PURCHASE ORDER FORM

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How is purchase being paid for, Fleck Scholarship Account, ENT, Personal?: Fleck Scholarship

### Purchaser Information

**Project Name:** Child Safety Seat Occupant Detection and Alert System

**Your Name (Print):** Thomas Tully

**Date:** 12/18/19 **Phone #:** REDACTED **E-mail:** tullytv@miamioh.edu

**Signature:**  **Advisor's Signature:** [Click here to enter text.](#)

### Vendor Information:

**Company Name:** Texas Instruments

**Address:** 12500 TI Boulevard Dallas, Texas 75243 USA

**Contact information & name:** N/A

**Internet link to company and order:** [www.ti.com](http://www.ti.com)

**Date Needed:** 12/31/2019

Qty.	Part # & Description	Unit Cost	Amount
3	SimpleLink™ Bluetooth® Low Energy CC2640R2F wireless MCU LaunchPad™ development kit <a href="https://www.ti.com/store/ti/en/p/product/?p=LAUNCHXL-CC2640R2">https://www.ti.com/store/ti/en/p/product/?p=LAUNCHXL-CC2640R2</a>	29.00	87.00
1	SimpleLink™ multi band CC1352R wireless MCU Launchpad™ SensorTag kit <a href="https://www.ti.com/store/ti/en/p/product/?p=LPSTK-CC1352R">https://www.ti.com/store/ti/en/p/product/?p=LPSTK-CC1352R</a>	30.00	30.00
1	<b>Shipping Cost</b>	6.99	6.99
	<b>Exact or Estimated Total</b>		123.99

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**Project Name:** Child Safety Seat Occupant Detection and Alert System

**Your Name (Print):** Thomas Tully

**Date:** 12/18/19 **Phone #:** REDACTED **E-mail:** tullytv@miamioh.edu

**Signature:**  **Advisor's Signature:** [Click here to enter text.](#)

### Vendor Information:

**Company Name:** Various/Amazon

**Address:** N/A

**Contact information & name:** N/A

**Internet link to company and order:** [www.amazon.com](http://www.amazon.com)

**Date Needed:** 12/31/2019

Qty.	Part # & Description	Unit Cost	Amount
1	GeekPi nRF52840 Micro Dev Kit USB Dongle <a href="https://www.amazon.com/gp/product/B07MJ12XLG">https://www.amazon.com/gp/product/B07MJ12XLG</a>	16.99	16.99
1	DSD TECH SH-U09C2 USB to TTL Adapter Built-in FTDI FT232RL IC for Debugging and Programming <a href="https://www.amazon.com/gp/product/B07TXVRQ7V">https://www.amazon.com/gp/product/B07TXVRQ7V</a>	9.99	9.99
1	ELEGOO UNO R3 Project Most Complete Starter Kit w/Tutorial Compatible with Arduino IDE (63 Items) <a href="https://www.amazon.com/gp/product/B01CZTLHGE">https://www.amazon.com/gp/product/B01CZTLHGE</a>	53.99	53.99
1	Graco SnugRide SnugLock Extend2Fit 35 Infant Car Seat   Ride Rear Facing Longer with Extend2Fit, Haven <a href="https://www.amazon.com/gp/offer-listing/B07D7DGMGN/ref=dp_olp_used?ie=UTF8&amp;condition=used">https://www.amazon.com/gp/offer-listing/B07D7DGMGN/ref=dp_olp_used?ie=UTF8&amp;condition=used</a>	112.60	112.60
1	ELEGOO for Arduino Nano V3.0, Nano Board CH340/ATmega328P Without USB Cable, Compatible with Arduino Nano V3.0 (Nano x 3 Without Cable) <a href="https://www.amazon.com/ELEGOO-Arduino-ATmega328P-Without-Compatible/dp/B0713XK923">https://www.amazon.com/ELEGOO-Arduino-ATmega328P-Without-Compatible/dp/B0713XK923</a>	12.86	12.86

1	No Clean Lead Free Low Temperature Solder Paste 15 Grams <a href="https://www.amazon.com/gp/product/B017RSGPI8">https://www.amazon.com/gp/product/B017RSGPI8</a>	10.99	10.99
1	Kaisi lead-free solder wire, Sn 99.3% Cu 0.7%, 1.7oz(50g) (0.3mm) <a href="https://www.amazon.com/gp/product/B07MX9G4HY">https://www.amazon.com/gp/product/B07MX9G4HY</a>	5.98	5.98
1	<b><u>Shipping Cost</u></b>	0	0
	<b><u>Exact or Estimated Total</u></b>		223.40

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**Your Name (Print):** Thomas Tully

**Date:** 2/12/20 **Phone #:** REDACTED **E-mail:** tullytv@miamioh.edu

**Signature:**  **Advisor’s Signature:** [Click here to enter text.](#)

**Vendor Information:**

**Company Name:** Various/Amazon

**Address:** N/A

**Contact information & name:** N/A

**Internet link to company and order:** www.amazon.com

**Date Needed:** 2/19/2020

Qty.	Part # & Description	Unit Cost	Amount
1	8pcs ON and Off Switch 2X 3V CR2032 Cell Button Battery Holder for LED <a href="https://www.amazon.com/gp/product/B07PH1BX98">https://www.amazon.com/gp/product/B07PH1BX98</a>	3.99	3.99
1	SRA Soldering Products PEN_RMA SRA #99-20 Rosin Rma Soldering Flux Pen – Refillable <a href="https://www.amazon.com/gp/product/B008OC3VMU/">https://www.amazon.com/gp/product/B008OC3VMU/</a>	8.99	8.99
1	10 Pcs CR123A CR123 Lithium Battery Holder Box Clip Case w PCB Solder Mounting Lead by Uptell <a href="https://www.amazon.com/gp/product/B07BKQSCPD">https://www.amazon.com/gp/product/B07BKQSCPD</a>	7.13	7.13
1	CR2032 Coin Button Cell Holder, SDTC Tech 6V 2xCR2032 Battery Case with ON/Off Switch, Cover and Lead Wire - 5 Pack <a href="https://www.amazon.com/gp/product/B07QW1HMQJ">https://www.amazon.com/gp/product/B07QW1HMQJ</a>	7.49	7.49
1	PortaPow Dual USB Power Monitor with Data Blocker <a href="https://www.amazon.com/gp/product/B01CVMK2M">https://www.amazon.com/gp/product/B01CVMK2M</a>	14.99	14.99
1	SparkFun Pro nRF52840 Mini - Bluetooth Development Board Includes LiPo battery charger Qwiic connector On/off switch	34.95	34.95

	Reset switch User LED/button Pre-programmed with a USB bootloader Small footprint <a href="https://www.amazon.com/gp/product/B07MWGN5KV">https://www.amazon.com/gp/product/B07MWGN5KV</a>		
1	Adafruit Feather nRF52 Bluefruit LE - nRF52832 <a href="https://www.amazon.com/gp/product/B06XXSVYLC">https://www.amazon.com/gp/product/B06XXSVYLC</a>	22.99	22.99
1	DSD TECH HM-17 Bluetooth 4.2 Module with CC2640 Chip Compatible with iOS Devices <a href="https://www.amazon.com/gp/product/B07GP2WZ2J">https://www.amazon.com/gp/product/B07GP2WZ2J</a>	4.99	4.99
1	DSD TECH HM-19 Bluetooth 5.0 BLE Module with CC2640R2F Chip for Arduino and DIY <a href="https://www.amazon.com/gp/product/B07MBLVHH8">https://www.amazon.com/gp/product/B07MBLVHH8</a>	9.99	9.99
1	Raytac MDBT50Q-RX Nordic nRF52840 Bluetooth Zigbee Thread Combo Dongle Parts BT5.1 & BT5.0 FCC IC CE Pre-Certified (No Bootloader Pre-Loaded) <a href="https://www.amazon.com/gp/product/B081GXC2L6">https://www.amazon.com/gp/product/B081GXC2L6</a>	12.59	12.59
1	Helping Hands with Fans Soldering Third Hand with Magnifying Glass and Mini Flashlight Fans Soldering Tool Perfect for Electronics PCB Repair Holder <a href="https://www.amazon.com/gp/product/B0814865N7">https://www.amazon.com/gp/product/B0814865N7</a>	34.99	34.99
1	<b>Shipping Cost</b>	0	0
	<b>Exact or Estimated Total</b>		163.09

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**Purchaser Information**

**Project Name:** Child Safety Seat Occupant Detection and Alert System

**Your Name (Print):** Thomas Tully

**Date:** 2/12/20 **Phone #:** REDACTED **E-mail:** tullytv@miamioh.edu

**Signature:**  **Advisor’s Signature:** [Click here to enter text.](#)

**Vendor Information:**

**Company Name:** MakerFabs

**Address:** Shenzhen,China

**Contact information & name:** <https://www.makerfabs.com/contact.html>

**Internet link to company and order:** <https://www.makerfabs.com/>

Product Name	Model	Unit Price	Quantity	Total
<a href="#">Vibration Motor</a>	MAM1027VM	\$0.90	2	\$1.80
<a href="#">Bluetooth Low Energy Module- CC2541</a>	MCB2541CC	\$2.10	1	\$2.10
<a href="#">Battery Holder with Switch - 2 x AA</a>	MPC0002AA	\$0.55	2	\$1.10
<a href="#">Wired NTC Thermistor- 10K 1M</a>	MSE010NTC	\$0.60	2	\$1.20
<a href="#">Battery Holder-2AAA</a>	MPC002AAA	\$0.15	4	\$0.60
<a href="#">ProtoBoard 7x5cm- 2.54mm</a>	CP07005BR	\$0.30	8	\$2.40
<a href="#">ProtoBoard 15x9cm- 2.54mm</a>	CP15009BR	\$1.30	1	\$1.30
<a href="#">DS18B20 Temperature Sensor TO-92</a>	MSM018B20	\$1.10	1	\$1.10
<a href="#">CC2541 Bluetooth Module Airsync iBeacon</a>	MCB2541BT	\$3.00	1	\$3.00
<a href="#">CC2640 iBeacon Module</a>	MCB2640CC	\$6.50	6	\$39.00
<a href="#">nRF52832 BLE4.2 Module</a>	MCB52832N	\$6.00	1	\$6.00
	<b>Product Total</b>			59.60
*** Use DHL (3-6 Business Days)	<b>Shipping Cost</b>			29.00***
	<b>Exact or Estimated Total</b>			88.60

**Date Needed:** 2/29/2020

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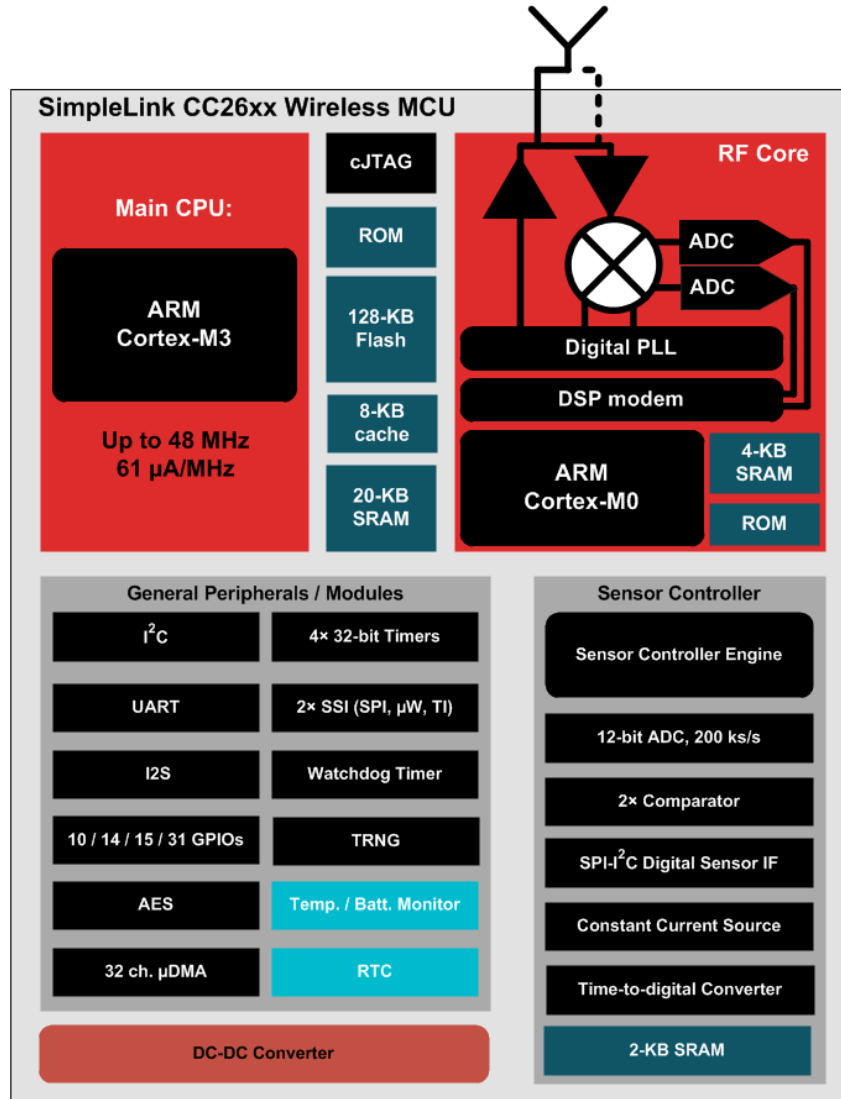


## References

- [1] No author listed, “New Study: 14% of Parents Say They Have Left a Child Alone Inside Parked Vehicle Despite the Risks of Heatstroke,” safekids.org, Apr 29, 2014. [Online]. Available: <https://www.safekids.org/press-release/new-study-14-parents-say-they-have-left-child-alone-inside-parked-vehicle-despite>. [Accessed Sept. 5, 2019].
- [2] M. Vallejo, J. Recas, P. Garcia del Valle, and J. Ayala, “Accurate Human Tissue Characterization for Energy-Efficient Wireless On-Body Communications,” ncbi.gov, Jun 10, 2013. [Online]. Available: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3715232/>. [Accessed Dec. 11, 2019].
- [3] No author listed, “Ingress Protection (IP) and what it Means,” dsmt.com, no date. [Online]. Available: <http://www.dsmt.com/resources/ip-rating-chart/>. [Accessed Sept. 12, 2019].
- [4] No author listed, “CC2640R2F SimpleLink Bluetooth® Low Energy Wireless MCU,” ti.com, no date. [Online]. Available: <https://www.ti.com/product/CC2640R2F>. [Accessed Sept. 12, 2019].
- [5] No author listed, “DSD TECH HM-19 Bluetooth 5.0 BLE Module with CC2640R2F Chip Compatible with iOS Devices,” dsdtech-global.com, no date. [Online]. Available: <http://www.dsdtech-global.com/2018/06/dsdtech-hm-19.html>. [Accessed Sept. 19, 2019].
- [6] C. Escudero, T. Fernández-Caramés, P. Fraga-Lamas, and D. Hernandez, “Design and Practical Evaluation of a Family of Lightweight Protocols for Heterogeneous Sensing through BLE Beacons in IoT Telemetry Applications,” researchgate.net, Dec 2017. [Online]. Available: [https://www.researchgate.net/publication/322092785\\_Design\\_and\\_Practical\\_Evaluation\\_of\\_a\\_Family\\_of\\_Lightweight\\_Protocols\\_for\\_Heterogeneous\\_Sensing\\_through\\_BLE\\_Beacons\\_in\\_IoT\\_Telemetry\\_Applications](https://www.researchgate.net/publication/322092785_Design_and_Practical_Evaluation_of_a_Family_of_Lightweight_Protocols_for_Heterogeneous_Sensing_through_BLE_Beacons_in_IoT_Telemetry_Applications). [Accessed Sept. 19, 2019].
- [7] Kevin Townsend, “Bluefruit nRF52 Feather Learning Guide,” mouser.com, Aug 26, 2018. [Online]. Available: <https://www.mouser.com/pdfdocs/bluefruit-nrf52-feather-learning-guide.pdf>. [Accessed Feb. 19, 2020].
- [8] Mohammad Afaneh, “Bluetooth GATT: How to Design Custom Services & Characteristics [MIDI device use case],” novelbits.io, Jun 27, 2017. [Online]. Available: <https://www.novelbits.io/bluetooth-gatt-services-characteristics/>. [Accessed Feb. 21, 2020].
- [9] K. Sugino, Y. Niwa, S. Siramatsu, T. Ozono, T. Shintani, “Developing a Human Motion Detector using Bluetooth Beacons and its Applications,” *Information Engineering Express*, Vol. 1, No. 4, pp 95-105, 2015.

Appendices

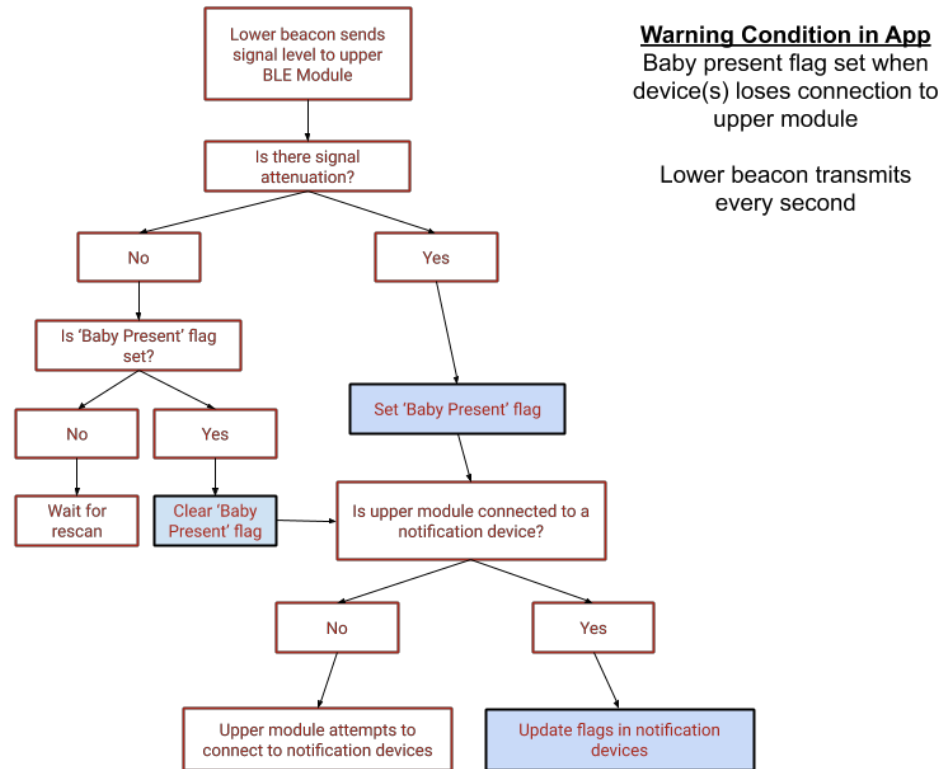
Figure #1 Specifications Diagram of CC2640RF2



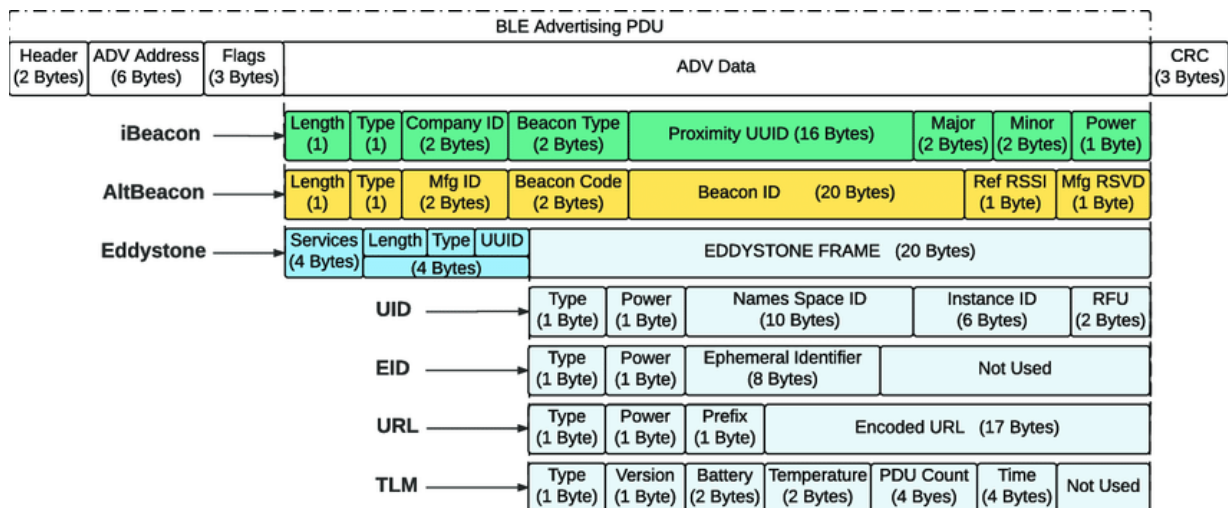
Copyright © 2016, Texas Instruments Incorporated

Above: Functional diagram showing the capabilities and features of the chosen Bluetooth IC, CC2640RF2, from Texas Instruments [4].

## Figure #2 Project Operation Algorithm

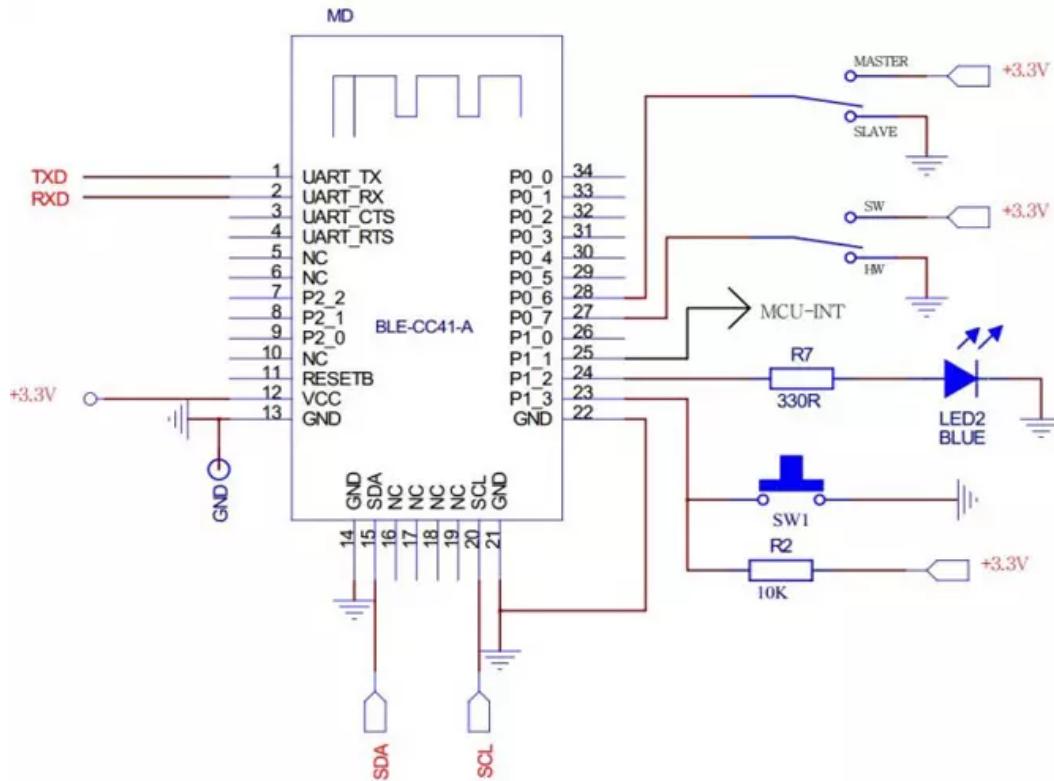


## Figure #3 Bluetooth Beacon Type and Protocols



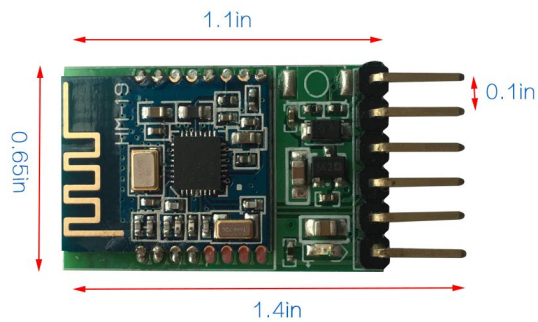
Above: BLE Beacon protocol that will be used for data transmission [6].

Figure #4 HM-19 Circuit



Above: Circuit diagram showing the breakout board utilized in the HM-19 breakout board [5].

Figure #5 HM-19 Module



Above: HM-19 Module with dimensions notated [5].

Figure #6 Pamphlet (Prototype design)



Front of tri-fold brochure with right side being the front

## SAFETY GUIDE



Try to keep your child rear facing until at least 2 years old, or as long the features of the car seat allow. The CS-SODAS is designed for use on rear facing car seats.

### • BOX DEVICE SETUP



Remove one of the small boxes from the package, the device is already installed and ready to be set up.

## ADDING THE DEVICE TO THE CAR SEAT

Once the device is set up use a command strip to the small box to the side of the car seat as follows



### • DEVICE PLACEMENT RECOMMENDATION



The secondary and the primary modules can be placed on opposing sides



The secondary module can be placed under the car seat with and the primary module on the top

Beware that many car seats will have clearance issues with this method

**“ Children are the world’s most valuable resource and its best hope for the future”**

– John F. Kennedy –

The inside of tri-fold brochure



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Datasheet

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Data transmission module provider

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WebSite: <http://www.jnhuamao.cn>

WebSite: <http://www.huamaosoft.com>

Mail: [webmaster@jnhuamao.cn](mailto:webmaster@jnhuamao.cn)



**The most complete, most convenient, the most stable of  
Bluetooth data transmission, Remote control and PIO input  
status acquisition module**

*---- Master and slave role in one*

*---- Remote control PIO with AT Commands*

*---- Remote acquisition of PIO input status with AT Commands*

**1. Product Parameters**

BT Version: Bluetooth Specification V4.0 BLE

Working frequency: 2.4GHz ISM band

Modulation method: GFSK(Gaussian Frequency Shift Keying)

RF Power: -23dbm, -6dbm, 0dbm, 6dbm

Speed: Asynchronous: 2-6K Bytes

Synchronous: 2-6K Bytes

Security: Authentication and encryption

Service: 0xFFE0 (Modifiable use AT+UUID command)

Characteristic: 0xFFE1 (Modifiable use AT+UUID command)

Characteristic: Notify and Write (Modifiable use AT+UUID command)

Power: +2.5V~3.3VDC 50mA

Power: Active state 8.5mA; Sleep state 50~200uA

Working temperature: -20 ~ +95 Centigrade

Size: HM-10 27mm x 13mm x 2.2 mm

Size: HM-11 18mm x 13mm x 2.2mm

Size: HM-15 65mm x 32mm x 16mm

## 2. Product overview

First of all, Thank you for choose our Bluetooth products.

If you want to know more about us, [www.inhuamao.cn](http://www.inhuamao.cn) could help you (Videos, New version datasheet, Module work flow, project Codes, etc.)

HM Bluetooth modules use CSR or TI CC254x or cypress chips, Master and slave roles in one, data transmission version and remote control version and PIO status acquisition version in one, Support the AT commands modify module parameters, Convenient and flexible.

### **Data Transmission version:**

Before connect:

You can configure module parameters with AT Commands through UART

After connect:

- 1) Send and receive Bluetooth data through UART.

### **Remote Control version:**

Before connect:

You can configure module parameters with AT Commands through UART

After connect:

- 1) Send and receive Bluetooth data through UART.
- 2) Remote device could configure module parameters with AT Commands
- 3) Remote device could control PIO2~PIO11 output low or high

### **PIO acquisition version:**

Before connect

You can configure module parameters with AT Commands

After connect

- 1) Send and receive Bluetooth data through UART.
- 2) Remote device could configure module parameters with AT Commands
- 3) Remote device could control PIO2, 3 output low or high with AT Commands

HM-11 has no this function

- 4) Remote device could get PIO4 ~ 11 input status with AT Commands

HM-11 only has PIO2 and PIO3.

**Module version:**

HM-01 to HM-09 is Bluetooth V2.1 version.

HM-10, HM-11 is Bluetooth V4.0 BLE version.

HM-12, HM-13 is Bluetooth Dual mode support EDR 4.0 and BLE 4.0

HM-16, HM-17 is Bluetooth V4.1 BLE version.

HM-18, HM-19 is Bluetooth V4.2 BLE version.

HM-01, HM-02, HM-09, HM-10, HM-16 and HM-18 is Pins to Pins.

HM-05, HM-06, HM-07, HM-11, HM-17 and HM-19 is Pins to Pins.


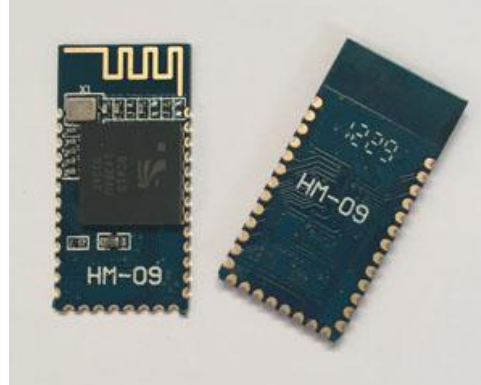
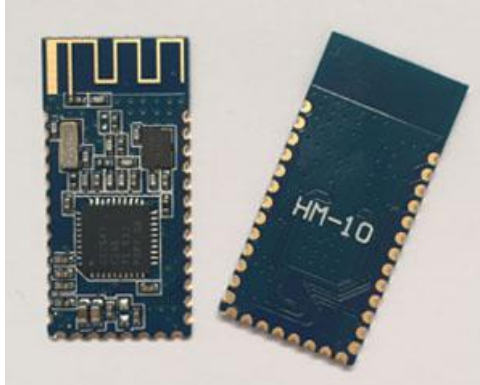

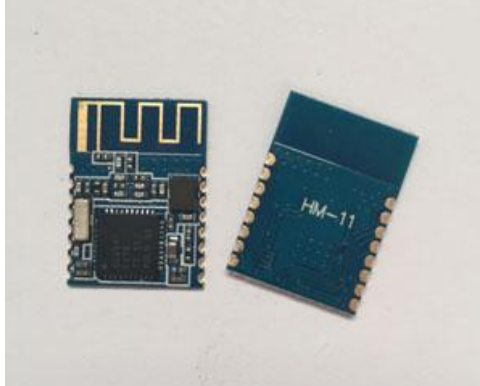
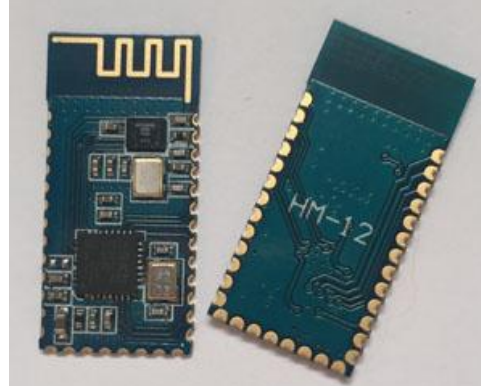
### 3. Product model

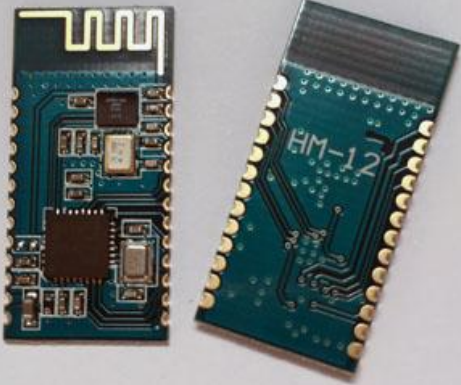


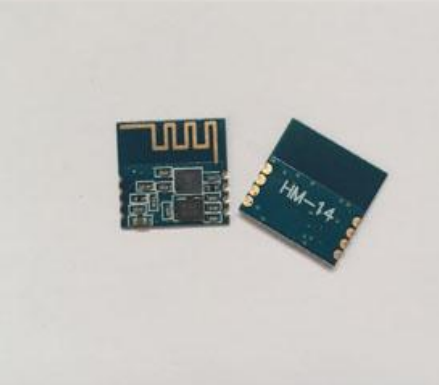

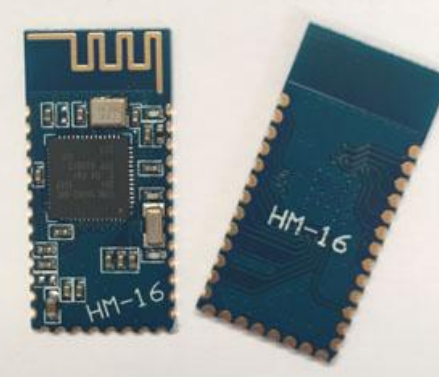
Modules	VDD	Size(mm)	Flash	Chip	BT Version
HM-01	2.5-3.7V	27 * 13 * 2.2	8M	BC417143	V2.1+EDR
HM-02A	2.5-3.7V	27 * 13 * 2.2	6M	BC31A223	V2.1
HM-02B	2.5-3.7V	27 * 13 * 2.2	6M	BC41C671	V2.1+EDR
HM-03A	2.5-3.7V	27 * 12.5 * 4.3	6M	BC31A223	V2.1
HM-03B	2.5-3.7V	27 * 12.5 * 4.3	6M	BC41C671	V2.1+EDR
HM-04A	2.5-3.7V	Not for sale			
HM-04B	2.5-3.7V	Not for sale			
HM-05/06A	2.5-3.7V	18 * 13 * 2.2	6M	BC31A223	V2.1
HM-05/06B	2.5-3.7V	18 * 13 * 2.2	6M	BC41C671	V2.1+EDR
HM-07	2.5-3.7V	18 * 13 * 2.2	8M		V2.1+EDR
HM-08	2.5-3.7V	27 * 13 * 2.5	8M	Class 1	V2.1+EDR
HM-09	2.5-3.7V	27 * 13 * 2.2	8M		V2.1+EDR
HM-10	2.2-3.7V	27 * 13 * 2.2	256Kb	CC2540/1	V4.0 BLE
HM-11	2.2-3.7V	18 * 13 * 2.2	256Kb	CC2540/1	V4.0 BLE
HM-12	2.5-3.9V	27 * 13 * 2.2	64KB	Dual mode	EDR 40 + BLE 40
HM-13	2.5-3.9V	18 * 13 * 2.2	64KB	Dual mode	EDR 40 + BLE 40
HM-14	2.2-4.0V	13 * 12 * 2.0		Dual mode	EDR40 + BLE 40
HM-15	5V	65 * 32 * 16	256Kb	CC2540	BLE V4.0
HM-16	2.1-5.5V	27 * 13 * 2.2	128KB		BLE V4.1
HM-17	2.1-5.5V	18 * 13 * 2.2	128KB		BLE V4.1
HM-18	2.1-5.5V	27 * 13 * 2.2	256KB		BLE V4.2
HM-19	2.1-5.5V	18 * 13 * 2.2	256KB		BLE V4.2

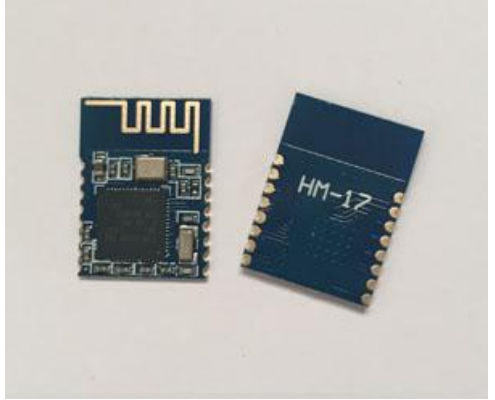
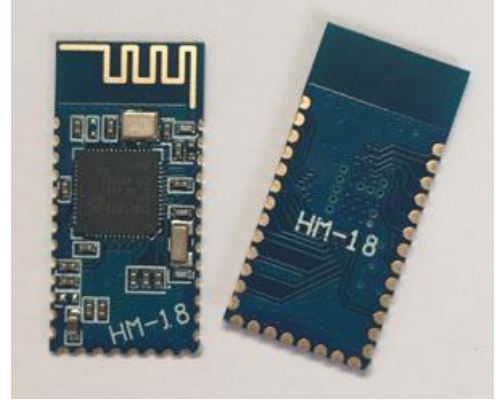
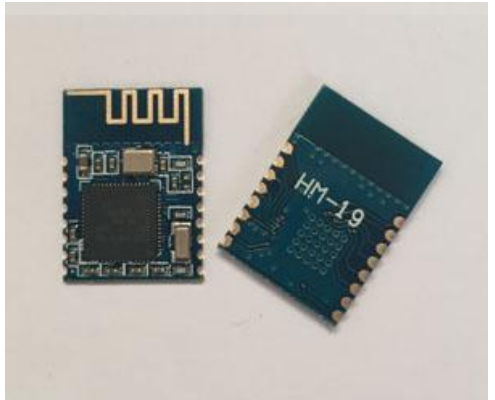

### 4. Product certificate

Products have FCC-ID, CE, RoHS. You can download certification from [www.jnhuamao.cn](http://www.jnhuamao.cn) or [www.huamaosoft.com](http://www.huamaosoft.com)

### 5. Product pictures

	
<p><b>HM-06 EDR 2.1</b> <b>HMSoft</b></p>	<p><b>HM-09 EDR 2.1</b> <b>HMSoft</b></p>
	
<p><b>HM-10S BLE 4.0</b> <b>HMSoft</b></p>	<p><b>HM-10C BLE 4.0</b> <b>HMSoft</b></p>
	
<p><b>HM-11 BLE 4.0</b> <b>HMSoft</b></p>	<p><b>HM-12S Dual (EDR 4.0 &amp; BLE 4.0)</b> <b>HMSoft</b></p>

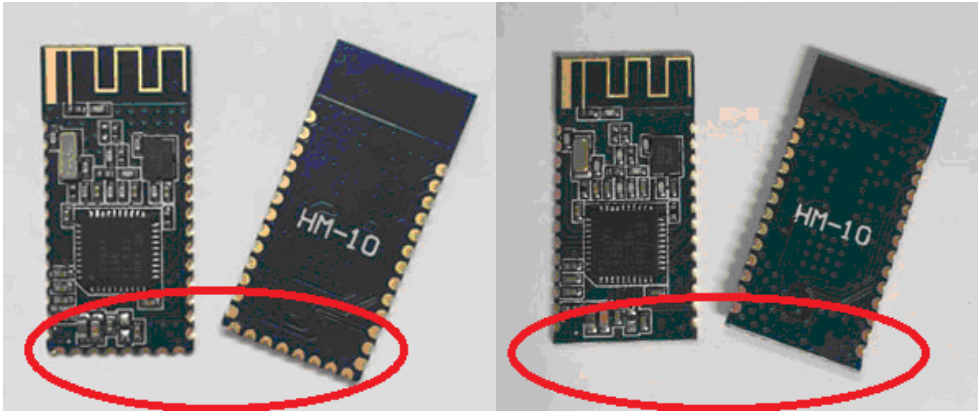
	
<p><b>HM-12C Dual (EDR 4.0 &amp; BLE 4.0)</b> HMSoft</p>	<p><b>HM-12T Dual (EDR 4.0 &amp; BLE 4.0)</b> HMSoft</p>
	
<p><b>HM-13 Dual (EDR 4.0 &amp; BLE 4.0)</b> HMSoft</p>	<p><b>HM-14 Dual (EDR 4.0 &amp; BLE 4.0)</b> HMSoft</p>
	
<p><b>HM-15 BLE 4.0 USB Dongle</b> HMSoft</p>	<p><b>HM-16 BLE 4.1</b> HMSoft</p>

	
<p align="center"><b>HM-17 BLE 4.1</b> <b>HMSoft</b></p>	<p align="center"><b>HM-18 BLE 4.2</b> <b>HMSoft</b></p>
	
<p align="center"><b>HM-19 BLE 4.2</b> <b>HMSoft</b></p>	<p align="center"><b>HM Beacon BLE 4.0</b> <b>HMBeacon</b></p>
<p align="center"><b>WIFI</b> <b>Testing</b> <b>Coming soon</b></p>	<p align="center"><b>WIFI+BLE</b> <b>Testing</b> <b>Coming soon</b></p>
<p align="center"><b>HM-20</b></p>	<p align="center"><b>HM-21</b></p>

## 6. Product technical specifications

This document only include Bluetooth BLE 4.0 document, If you want to know more about other modules, [www.inhuamao.cn](http://www.inhuamao.cn) or [www.huamaosoft.com](http://www.huamaosoft.com) could help you.

### What's different between HM-10S and HM-10C?

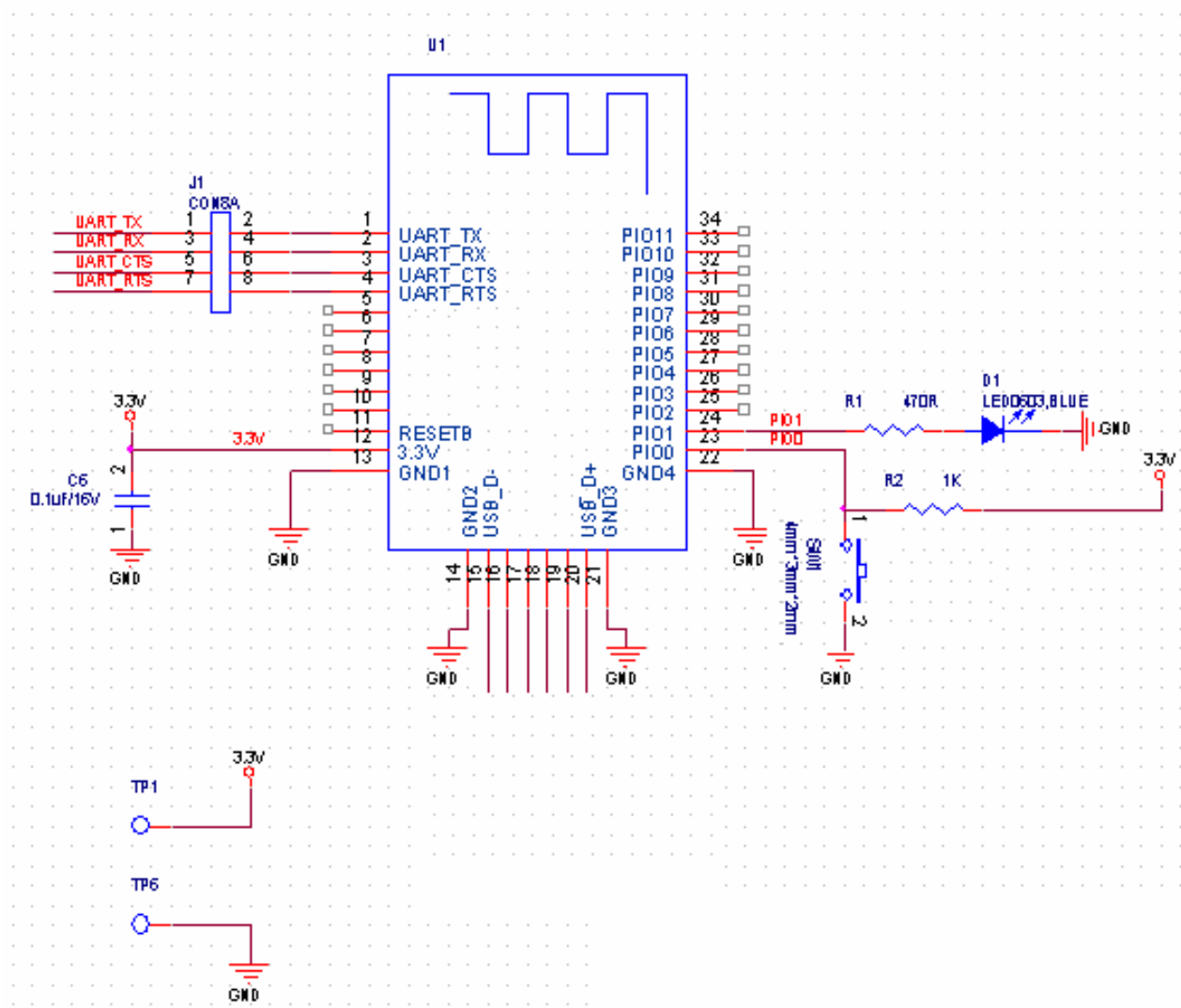


Left is HM-10S, It have 34 Pads. Right is HM-10C and it only have 26 Pads

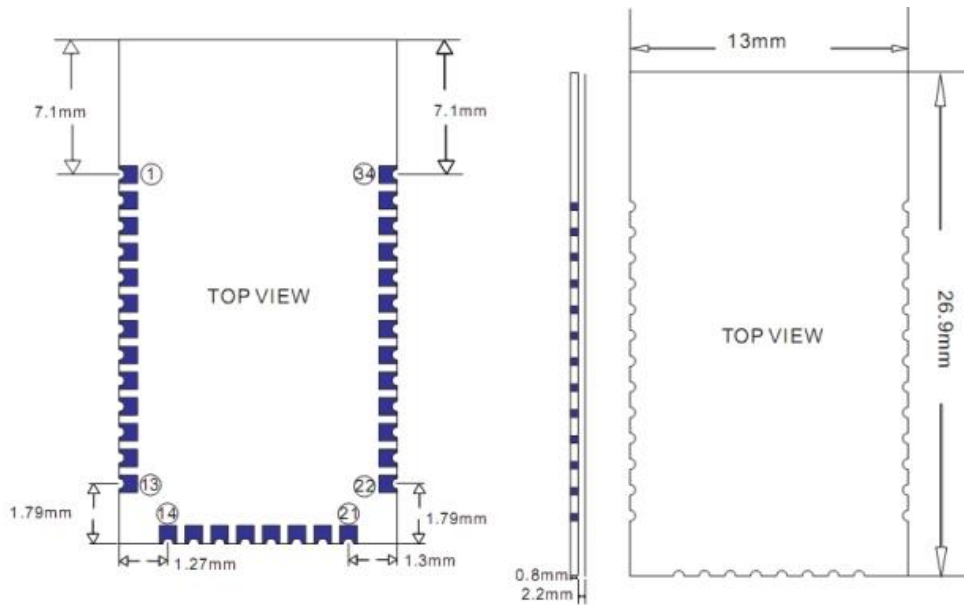
HM-10C is equal HM-10S removed bottom Pads.

### 6.1 HM-10 Schematic

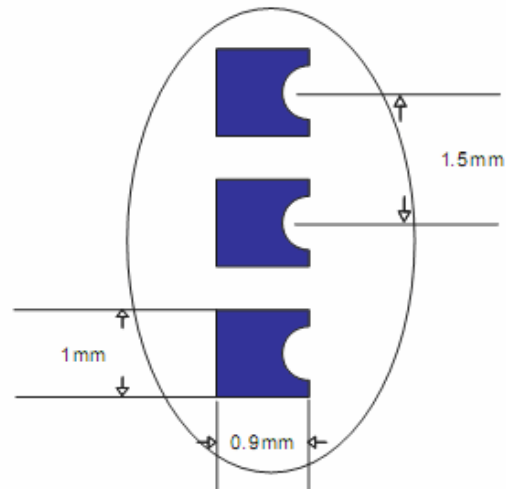




## 6.2 HM-10 Size



### 6.3 HM-10 package information



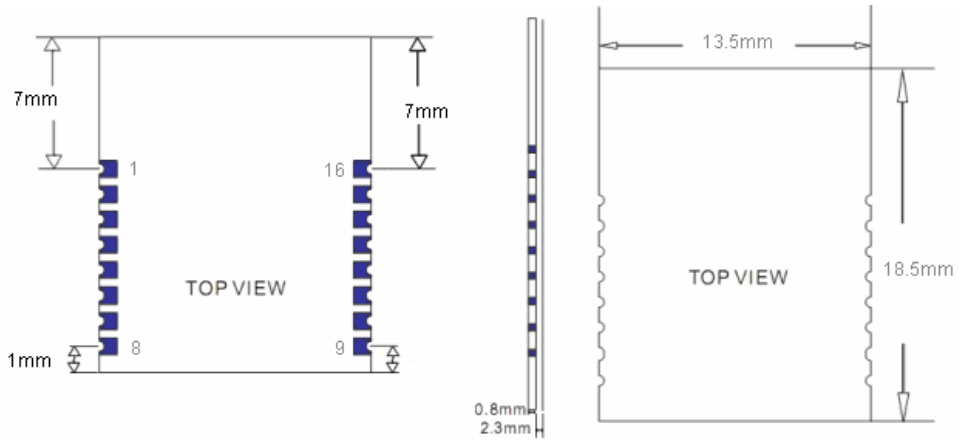
### 6.4 HM-10 Device Terminal Functions

HM-10S	HM-10C	Name	Description	CC254X
1	1	UART_TX	UART interface	P1_6
2	2	UART_RX	UART interface	P1_7
3	3	UART_CTS	UART interface	P1_4

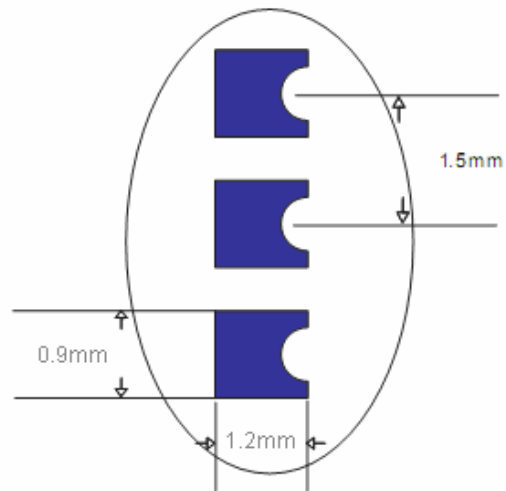
4	4	UART_RTS	UART interface	P1_5
5	5	NC	NC	
6	6	NC	NC	
7	7	NC	NC	P2_2
8	8	NC	NC	P2_1
9	9	NC	NC	P2_0
10	10	NC	NC	
11	11	RESETB	Reset if low >100ms.	RESET
12	12	VCC	3.3V	
13	13	GND	Ground	
14	X	GND	Ground HM-10C doesn't have this pin	
15	X	USB_D-	USB interface HM-10C doesn't have this pin	PIN3
16	X	NC	NC HM-10C doesn't have this pin	
17	X	NC	NC HM-10C doesn't have this pin	
18	X	NC	NC HM-10C doesn't have this pin	
19	X	NC	NC HM-10C doesn't have this pin	
20	X	UB_D+	USB interface HM-10C doesn't have this pin	PIN2
21	X	GND	Ground HM-10C doesn't have this pin	GND
22	22	GND	Ground	GND
23	23	PIO0	System Key	P1_3
24	24	PIO1	System LED	P1_2

25	25	PIO2	input/output pin. PWM output	P1_1
26	26	PIO3	input/output pin/ADC	P1_0
27	27	PIO4	input/output pin/ADC	P0_7
28	28	PIO5	input/output pin/ADC	P0_6
29	29	PIO6	input/output pin/ADC	P0_5
30	30	PIO7	input/output pin/ADC	P0_4
31	31	PIO8	input/output pin/ADC	P0_3
32	32	PIO9	input/output pin/ADC	P0_2
33	33	PIO10	input/output pin/ADC	P0_1
34	34	PIO11	input/output pin/ ADC/DS18B20/DHT11	P0_0

### 6.5 HM-11 Size



### 6.6 HM-11 Package information



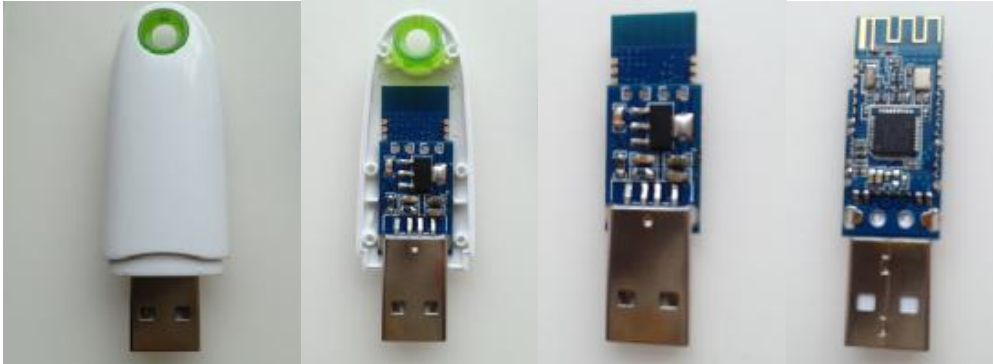
### 6.7 HM-11 Device Terminal Functions

No	Name	Description	CC254X
1	UART_RTS	UART interface	P1_5
2	UART_TX	UART interface	P1_6
3	UART_CTS	UART interface	P1_4
4	UART_RX	UART interface	P1_7
5	NC	NC	P2_1
6	NC	NC	P2_2
7	NC	NC	PIN2
8	NC	NC	PIN3
9	VCC	V3.3	VCC
10	NC	NC or VCC	
11	RESETB	Reset if low <100ms	RESET_N
12	GND	Ground	GND
13	PIO3	input/output pin	P1_1
14	PIO2	input/output pin/PWM	P1_0

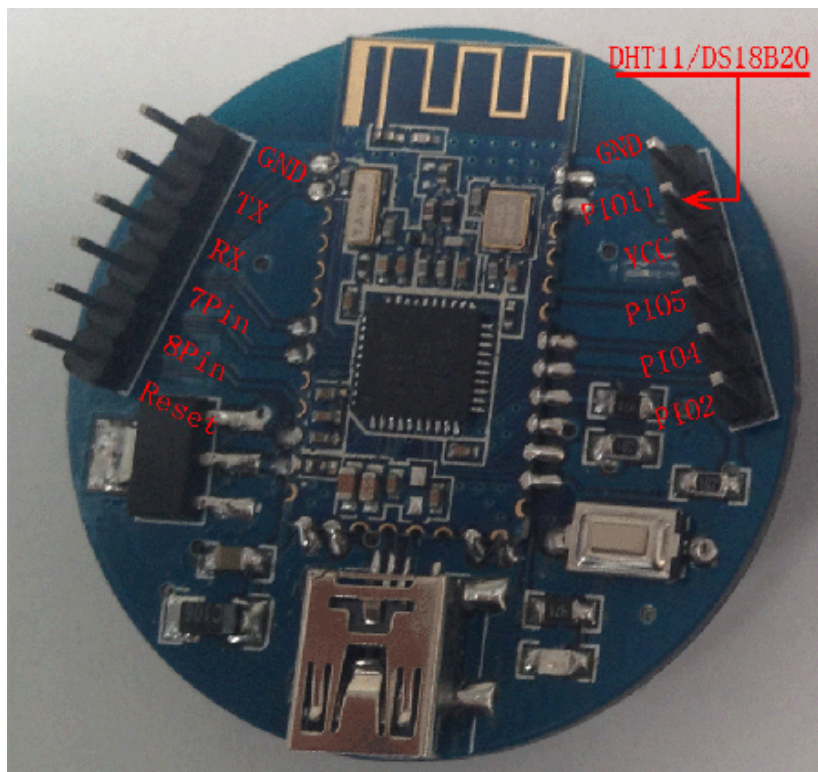
15	PIO1	System LED	P0_7
16	PIO0	System KEY	P0_6

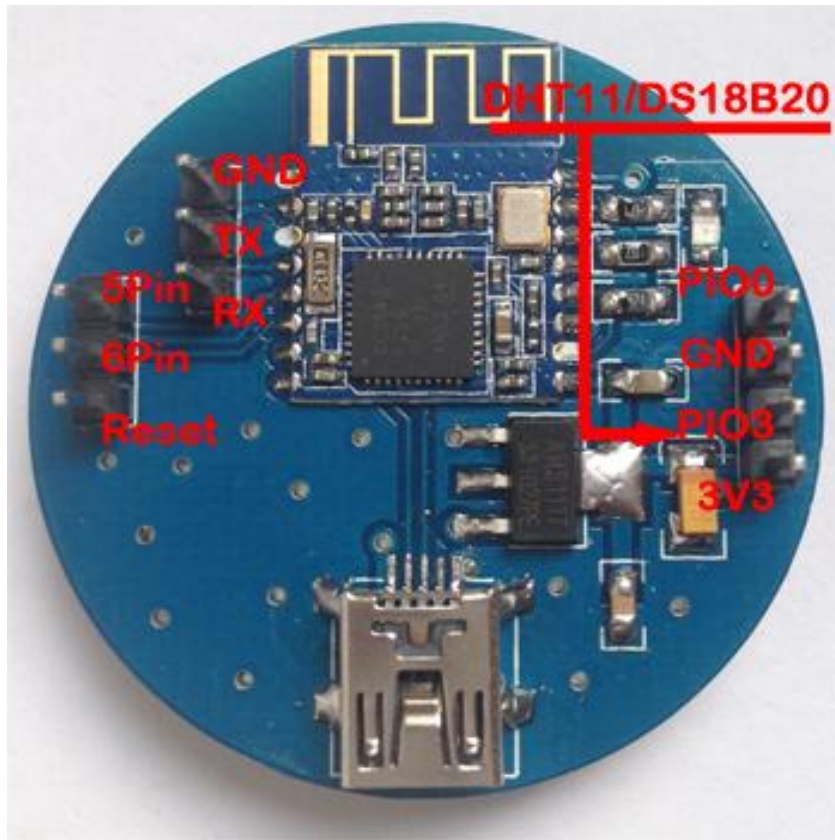
### 6.8 HM-15

HM-15 is based HM-10, a real USB interface.

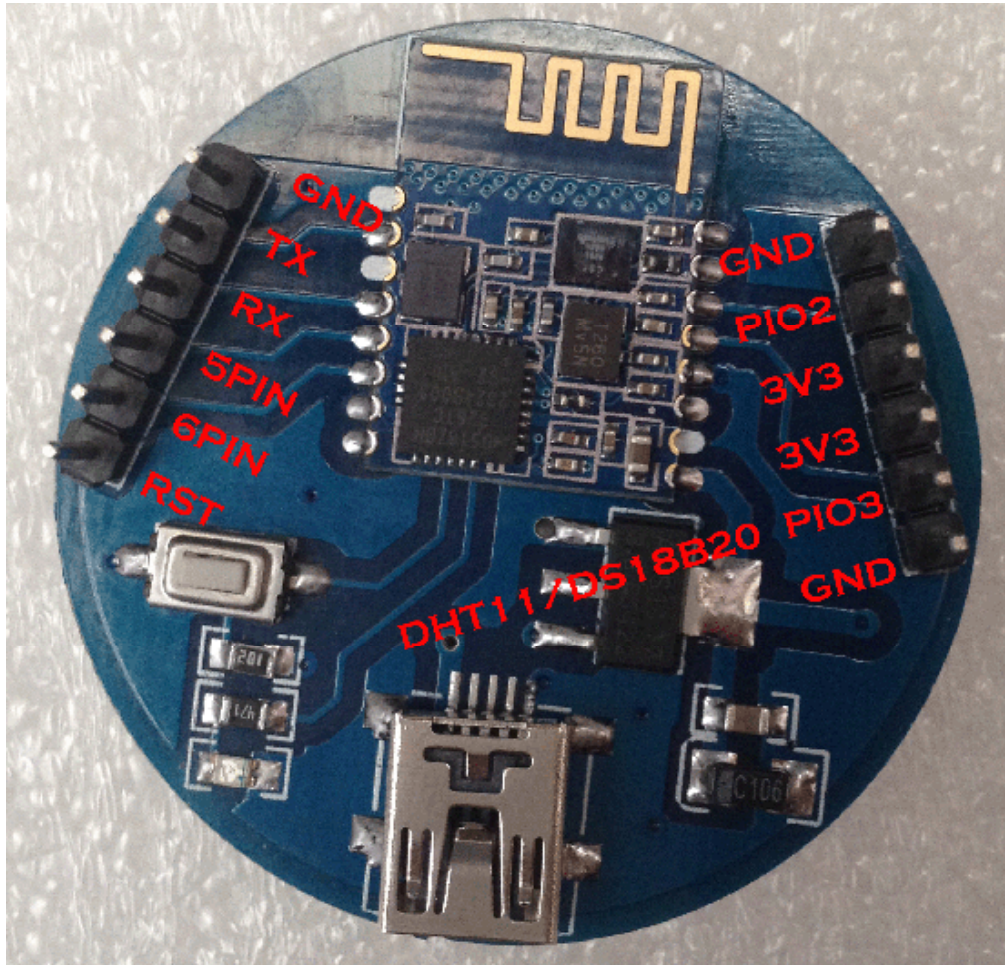


### 6.9 HM-Sensor









## 7. System function

### How to wake up module from sleep mode?

There are two ways to wake up module from sleep mode, if module was in sleep mode..

7.1 Send "I am iron man, I am iron man, I am iron man I am iron....." string.

Yes, that's a joke, in sleep mode, you can send a long string (Length > 80 or more), that string can made module wake up, and you will receive "OK+WAKE" string from UART. Note: That wake up string is better not include any AT commands.

7.2 Long press system KEY  $\geq 1000$  ms.

After wake up module, you can send and receive AT commands.

### How to let module into sleep mode?

1. Send "AT+SLEEP" string through UART, if all is okay, module will return



“OK+SLEEP” string and into sleep mode.

2. Execute “AT+PWRM1” command, Module will auto into sleep mode when power on or disconnect from remote device.

### System advert packet

In iOS system you can't get model MAC address directly. So we put MAC address information into advert packet.

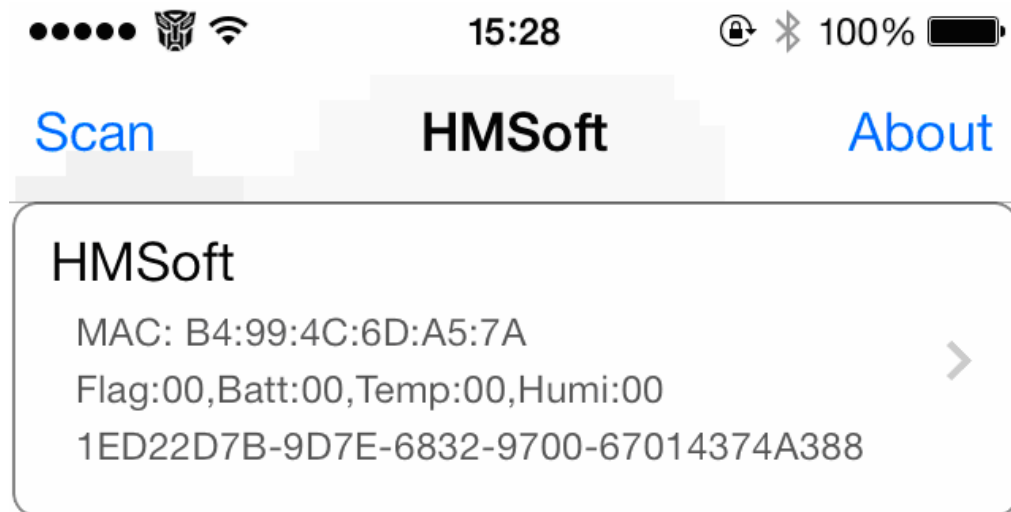
You can use CBAvertisementDataManufactureDataKey property to get it, MAC address information string format like follow:

Total length is 8 Bytes, First of two bytes is identify string, it always is 0x48 and 0x4D, the rest 6 bytes is MAC address string

For example: 0x48, 0x4D, 0xB4, 0x99, 0x4C, 0xXX, 0xXX, 0xXX

0x48 and 0x4D is “HM” string.

0xB4: 0x99: 0x4C: 0xXX: 0xXX: 0xXX is BLE MAC Address.



### System KEY function (PIO0)

Press if Low > 1000ms:

#### 7.3.1 If Module is in sleep mode

Module will wake up immediately, if AT+NOTI value is “1”, module will send “OK+WAKE” string through UART.

#### 7.3.2 If Module has already connected to remote device

Module will disconnect from remote device.

### 7.3.3 If Module is standby mode

Module will reset to default configuration. Then restart.

#### **System LED function (PIO1)**

In sleep mode, LED has turned off.

If AT+PIO10 is setup

Unconnected status: Output High 500 ms, Low 500 ms

Connected status: Output High

If AT+PIO11 is setup

Unconnected status: Output Low.

Connected status: Output High.

#### **System work Mode**

##### A) Mode 0(Transmission mode):

Before connect, you can configure module parameters with AT Commands

After connect, you can send and receive Bluetooth data through UART.

##### B) Mode 1(PIO acquisition mode):

Before connect, you can configure module parameters with AT Commands

After connect

1) Send and receive Bluetooth data through UART.

2) Remote device could configure module parameters with AT Commands

3) Remote device could control PIO2 and PIO3 output low or high with AT

Commands

HM-11 has no this function

4) Remote device could get PIO4 ~ 11 input status with AT Commands

HM-11 only has PIO2 and PIO3.

##### C) Mode 2 (Remote control mode):

Before connect, you can configure module parameters with AT Commands

After connect:

1) Send and receive Bluetooth data through UART.

2) Remote device could configure module parameters with AT Commands

3) Remote device could control PIO2~11 output low or high

HM-11 only has PIO2 and PIO3.

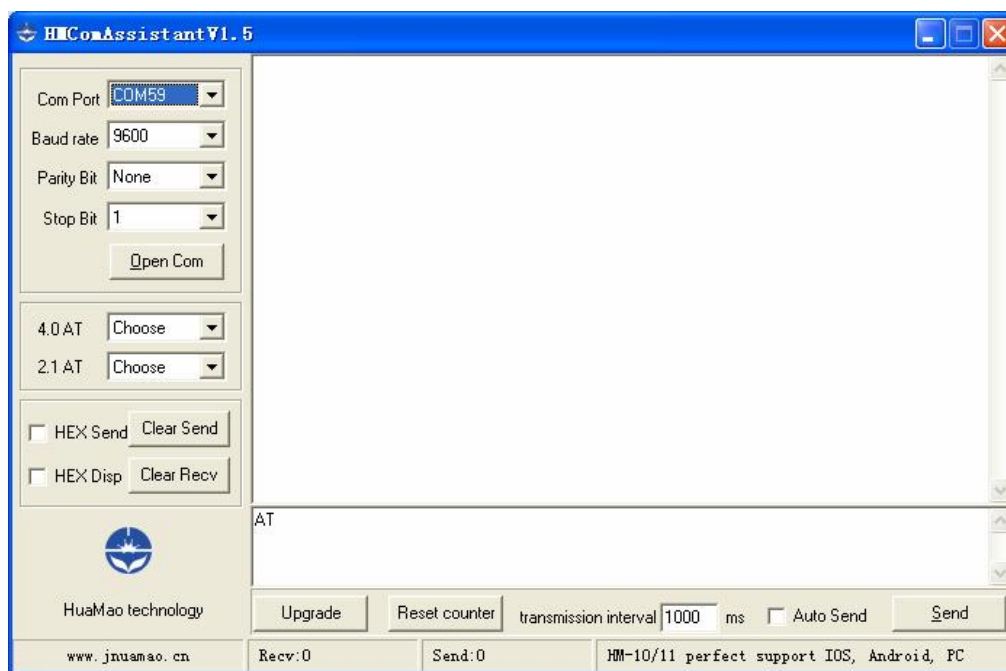
## 8 AT Commands

Factory default setting:

Name: HMSoft; Baud: 9600, N, 8, 1; Pin code: 000000; Peripheral Role; transmit mode.

AT Command format:

Uppercase AT command format. string format, without any other symbol. (e.g. \r or \n).



On Transmit version: Only accept AT Command from UART interface when Bluetooth device is not connected with remote device.

On Remote version: Can accept AT Command from UART interface when Bluetooth Device is not connected with remote device, Also can accept AT Command from remote Bluetooth device when connected that.

On PIO collection version: Only accept AT Command from UART interface when Bluetooth device is not connected with remote device.

### 1. Test Command or Disconnect Command

Send	Receive	Parameter
AT	OK OK+LOST	None

If Module is not connected to remote device will receive: "OK"

If Module has connected, module will disconnected from remote device, if "AT + NOTI" is setup to 1, will receive: "OK+LOST"

2. Query module address

Send	Receive	Parameter
AT+ADC[P1]?	OK+GET:0.00	P1: 3,4,5,6,7,8,9,A,B map to PIO3~PIOB

HM-11 has no this function.

Add since V526.

3. Query module address

Send	Receive	Parameter
AT+ADDR?	OK+ADDR:MAC Address	None

3. Query/Set Advertising interval

Send	Receive	Parameter
AT+ADVI?	OK+ Get:[P1]	None
AT+ADVI[P1]	OK+ Set:[P1]	P1: 0 ~ F 0: 100ms 1: 152.5 ms 2: 211.25 ms 3: 318.75 ms 4: 417.5 ms 5: 546.25 ms 6: 760 ms 7: 852.5 ms 8: 1022.5 ms 9: 1285 ms

		A: 2000ms B: 3000ms C: 4000ms D: 5000ms E: 6000ms F: 7000ms Default: 9 HMSoft Default: 0 HMSensor Default: 9
--	--	--

The maximum 1285ms recommendations form the IOS system. That is to say, 1285ms is apple allowed, but in response to scan and connected all the time will be long.

This command is added since V517 version.

V522 allow max value F.

#### 4. Query/Set Advertising Type

Send	Receive	Parameter
AT+ADTY?	OK+ Get:[P1]	None
AT+ADTY[P1]	OK+ Set:[P1]	P1: 0~3 0: Advertising ScanResponse, Connectable 1: Only allow last device connect in 1.28 seconds 2: Only allow Advertising and ScanResponse. 3: Only allow Advertising Default: 0

Added since V519

#### 5. Query/Set apple ANCS switch

Send	Receive	Parameter
------	---------	-----------

AT+ANCS?	OK+ Get:[P1]	None
AT+ANCS[P1]	OK+ Set:[P1]	P1: 0 ~ 1 0: Off 1: On Default: 0

Note1: This command added in V524.

Note2: Please send AT+RESET to restart module if you set value 1.

Note3: Must execute AT+TYPE3 first.

#### 6. Query/Set white list switch

Send	Receive	Parameter
AT+ALLO?	OK+ Get:[P1]	None
AT+ALLO[P1]	OK+ Set:[P1]	P1: 0 ~ 1 0: Off 1: On Default: 0

Note1: This command added in V523.

Note2: White List allows three MAC address link to module. Please use AT+AD command set white list MAC address.

#### 7. Query/Set white list MAC address

Send	Receive	Parameter
AT+AD[P1]??	OK+ Get:[P2]	None
AT+ALLO[P1][P2]	OK+ Set:[P2]	P1: 1, 2, 3 P2: MAC address P1 default: 0

Note1: This command added in V523.

E.g.

Send AT+ID1001122334455

Recv OK+Set:001122334455

#### 8. Query/Set Module pin output state, After power supplied

Send	Receive	Parameter
AT+BEFC?	OK+ Get:[P1]	None
AT+BEFC[P1]	OK+ Set:[P1]	P1: 000~ 3FF Default: 000

This command added in V527.

3FF == 001111111111, left to right side is map to PIO0~PIOB, PIO0 and Plo1 is used by system. Only Pio2~PIOB pins is available.

e.g. Set PIO2~PIOB all output high after power supplied.

Send: AT+BEFC3FF

Recv:OK+Set:3FF

When next time power on, module PIO2~PIOB will output high.

Note: Query PIO pins current state please use AT+PIO?? Command.

Note: Please don't use this command when "AT+MODE1" is setup.

9. Query/Set Module pin output state, After connection is established

Send	Receive	Parameter
AT+AFTC?	OK+ Get:[P1]	None
AT+AFTC[P1]	OK+ Set:[P1]	P1: 000~ 3FF Default: 000

This command added in V527.

3FF == 001111111111, Left to right side is map to PIO0~PIOB, PIO0 and Plo1 is used by system. Only Pio2~PIOB pins is available.

e.g. Set PIO2~PIOB all output high when connection is established.

Send: AT+AFTC3FF

Recv: OK+Set:3FF

When Bluetooth connection is established, module PIO2~PIOB will output high.

Note: Query PIO pins current state please use "AT+PIO??" command.

Note: Please don't use this command when "AT+MODE1" is setup.

10. Query/Set battery monitor switch

Send	Receive	Parameter
------	---------	-----------

AT+BATC?	OK+ Get:[P1]	None
AT+BATC[P1]	OK+ Set:[P1]	P1: 0 ~ 1 0: Off 1: On Default: 0

This command added in V520

### 11. Query battery information

Send	Receive	Parameter
AT+BATT?	OK+BATT:[P1]	P1: 000~100

There has three ways to get battery information:

- a. Before establishing a connection, Send “AT+BATT?” through UART.
- b. After established a connection, In Mode 1 or 2, remote side send “AT+BATT?”

Battery information has included in scan response data package, one hour update once. You can use Android or IOS discovery module, when module has been discovered, you can get it from scan result array.

Data format is 0x02, 0x16, 0x00, 0xB0, [FLAG], [temperature], [ humidity], [battery].

Android:

Included in OnLeScan function result array, you can see it direct.

```
private BluetoothAdapter.LeScanCallback mLeScanCallback = new BluetoothAdapter.LeScanCallback() {
```

```
    @Override
```

```
    public void onLeScan(final BluetoothDevice device, int rssi,
```

```
        byte[] scanRecord) {
```

```
        .....<Other code>.....
```

```
        String sBatt = ""; //Battery
```

```
        String sTemp = ""; //Temperature
```

```
        String sHumi = ""; //Humidity
```

```
        for(int i = 0; i < scanRecord.length; i++)
```

```
        {
```

```
            if(i + 7 < scanRecord.length)
```

```
            {
```



```

//Since V522

if(scanRecord[i] == 0x07 && scanRecord[i + 1] == 0x16

    && scanRecord[i + 2] == 0x00 && scanRecord[i + 3] == 0xB0)

{

    if(scanRecord[i + 7] > 0)

        sBatt = String.valueOf(scanRecord[i + 7]);

    if(scanRecord[i + 5] > 0)

        sTemp = String.valueOf(scanRecord[i + 5]);

    if(scanRecord[i + 6] > 0)

        sHumi = String.valueOf(scanRecord[i + 6]);

}

}

}

.....<Other code>.....

}

};

```

iOS:

- c. Included in LeScan function result NSDictionary struct, service id is 0xB000.

### 12. Set battery information byte in advertising data

Send	Receive	Parameter
AT+BATT[P1]	OK+Set:[P1]	P1: 0x00~0xFF Not include '?'

This command is used to set battery information byte in advertising data when you doesn't want to use battery function buy want to use as AT+FLAG command.

### 13. Query/Set Bit format

Send	Receive	Parameter
AT+BIT7?	OK+Get:[P1]	P1: bit7 switch.

AT+BIT7[P1]	OK+Set:[P1]	0----Not compatible 1----Compatible Default: 0
-------------	-------------	--

This command is used only for compatible uses 7 data bits, 2 stop bit device.

14. Query/Set baud rate

Send	Receive	Parameter
AT+BAUD?	OK+Get:[P1]	P1: Baud rate No.
AT+BAUD[P1]	OK+Set:[P1]	0-----9600 1-----19200 2-----38400 3-----57600 4-----115200 5-----4800 6-----2400 7-----1200 8-----230400 Default: 0(9600)

e.g.

Query baud:

Send: AT+BAUD?

Receive: OK+Get:0

Setup baud:

Send: AT+BAUD1

Receive: OK+Set:1

Note: If setup to Value 7, After next power on, module will not support any AT Commands, until PIO0 is pressed, Module will change Baud to 9600.

15. Query/Set Minimum Link Layer connection interval

Send	Receive	Parameter
AT+COMI?	OK+Get:[P1]	P1: 0 ~ 9

AT+COMI[P1]	OK+Set:[P1]	Default: 3(20ms)
-------------	-------------	------------------

P1 Value: 0: 7.5ms; 1: 10ms; 2: 15ms; 3: 20ms; 4: 25ms; 5: 30ms; 6: 35ms; 7: 40ms;  
8: 45ms; 9: 4000ms

Note: This command is added since V538

16. Query/Set Maximum Link Layer connection interval

Send	Receive	Parameter
AT+COMA?	OK+Get:[P1]	P1: 0 ~ 9
AT+COMA[P1]	OK+Set:[P1]	Default: 7(40ms)

P1 Value: 0: 7.5ms; 1: 10ms; 2: 15ms; 3: 20ms; 4: 25ms; 5: 30ms; 6: 35ms; 7: 40ms;  
8: 45ms; 9: 4000ms

Note: This command is added since V538

17. Query/Set Link Layer connection slave latency

Send	Receive	Parameter
AT+COLA?	OK+Get:[P1]	P1: 0 ~ 4
AT+COLA[P1]	OK+Set:[P1]	Default: 0

Note: This command is added since V538

18. Query/Set connection supervision timeout

Send	Receive	Parameter
AT+COSU?	OK+Get:[P1]	P1: 0 ~ 6
AT+COSU[P1]	OK+Set:[P1]	Default: 6(6000ms)

P1 Value: 0: 100ms; 1: 1000ms; 2: 2000ms; 3: 3000ms; 4: 4000ms; 5: 5000ms; 6:  
6000ms;

Note: This command is added since V538

19. Query/Set The Switch of update connection Parameter

Send	Receive	Parameter
AT+COUP?	OK+Get:[P1]	P1: 0 ~ 1
AT+COUP[P1]	OK+Set:[P1]	0: Don't update 1: Update Default: 1(update)

This command is only use when module is in slave role.

Note: This command is added since V538

20. Query/Set Characteristic

Send	Receive	Parameter
AT+CHAR?	OK+Get:[P1]	P1: 0x0001~0xFFFFE
AT+CHAR[P1]	OK+Set:[P1]	Default: 0xFFE1

e.g. change characteristic value to 0xAAA0

Send: AT+CHAR0xAAA0

Recv: OK+Set:0xAAA0

21. Clear Last Connected device address

Send	Receive	Parameter
AT+CLEAR	OK+CLEAR	None

Notice: Only Central role is used.

22. Try connect to last succeeded device

Send	Receive	Parameter
AT+CONNL	OK+CONN[P1]	P1: L, E, F, N L: Connecting E: Connect error F: Connect Fail N: No Address

Notice: Only Central role is used. Must set up AT+IMME1 and AT+ROLE1 first.

If remote device has already connected to other device or shut down, "OK+CONNF" will received after about 10 seconds.

23. Try connect an address

Send	Receive	Parameter
AT+CO[P0][P1]	OK+CO[P0][P0][P2]	P0: N, 0, 1, 2 N: Normal Address 0: Static MAC 1: Static random MAC

		2: Random MAC P1: Address Like: 0017EA090909 P2: A, E, F A: Connecting E: Connect error F: Connect Fail
--	--	---

Notice: Only central role is used. Must set up AT+IMME1 and AT+ROLE1 first.

If remote device has already connected to other device or shut down, "OK+CONN" will received after about 10 Seconds.

e.g.

Try to connect an device which MAC address is 00:17:EA:09:09:09

Send: AT+CON0017EA090909

May receive a reply:

OK+CONNA ===== Accept request, connecting  
 OK+CONNE ===== Connect error  
 OK+CONN ===== Connected, if AT+NOTI1 is setup  
 OK+CONN F ===== Connect Failed, After 10 seconds

Note: 0 is not zero

#### 24. Connect to an Discovered device

Send	Receive	Parameter
AT+CONN[P1]	OK+CONN[P2]	P1: 0~5 P2: E, F, 0~5 E: Link error F: Link failed 0~5: Try to connect

This command is use after execute AT+DISC?

When AT+DISC? Command return first device use P1 as 0, then second device use P1 as 1, third device use P1 as 2.

This command will clear all discovery data.

25. Query PIO04~PIO11 input(output) state

Send	Receive	Parameter
AT+COL??	OK+ Col:[P1]	P1: 0x00~0xFF

P1 is a byte, has 8 bits, bit 7 ~ bit 0 is map to the PIO4 ~ PIO11.

This command is added since V515 version.

26. Query/Set PIO collection rate

Send	Receive	Parameter
AT+CYC??	OK+ Get:[P1]	P1: 00~99
AT+CYC[P1]	OK+ Set:[P1]	Unit: seconds Default: 10

In mode 1, when PIO state is change, module will send OK+Col:[xx] to UART or remote side. This command is set send interval.

This command is added since V515 version.

27. Query/Set The switch of study function

Send	Receive	Parameter
AT+COMP?	OK+ Get:[P1]	P1: 0, 1, ?
AT+COMP[P1]	OK+ Set:[P1]	?: Query; 0: Off; 1: On Default: 0

Please reference <How\_To\_Use\_HM-1x\_Study\_function.pdf>

This command is added since V542 version.

28. Start a device discovery scan

Send	Receive	Parameter
AT+DISC?	OK+DIS[P0][P1]	P0: C,0, 1, 2 C: Common string 0~2: Address type P1: S, E, [MAC String] S: Start discovery E: End discovery

		MAC String : Device MAC string
--	--	-----------------------------------

Please set AT+ROLE1 and AT+IMME1 first.

e.g.

Send: AT+DISC?

Recv: OK+DISCS

Recv: OK+DIS[P0]:123456789012 (discovered device address information)

If AT+SHOW1 is setup, you will receive then Name information as follow

Recv: OK+NAME: xxx

After send Name value, will send two extra “\r\n” value ASCII byte

If AT+SHOW2 is setup, you will receive then RSSI information as follow

Recv: OK+RSSI: xxx\r\n

If AT+SHOW3 is setup, you will receive then RSSI information and Name information

Recv: OK+DIS[P0]:234567890123

Recv: OK+NAME: xxx

After send Name value, will send two extra “\r\n” value ASCII byte

.....(Before V535 max results is 6, Since V535 not limit)

Recv: OK+DISCE

**Connect use array index:**

Connect to a discovered device: AT+CONN0, AT+CONN1.....AT+CONN5

**Connect use MAC string:** AT+CON[MAC String]

29. Start a iBeacon device discovery scan

Send	Receive	Parameter
AT+DISI?	OK+DISC[P0:P1:P2:P3:P4]	P0: Factory ID P1: iBeacon UUID P2: Major Value Minor Value Measured Power P3: MAC

		P4: RSSI
--	--	----------

Please set AT+ROLE1 and AT+IMME1 first.

e.g.

Send: AT+DISI?

Recv: OK+DISCS (Scan start)

Recv: OK+DIS[P0:P1:P2:P3:P4] (if have one device)

Recv: OK+DIS[P0:P1:P2:P3] (if have two devices)

.....

Recv: OK+DISCE (Scan end)

P0 length is 8; P1 length is 32; P2 length is 10; P3 length is 12, P4 length is 4

P2 include Major Value (length 4);

Minor Value (length 4);

Measured Power (length 2)

If the device not enable iBeacon function, P0, P1, P2 will use '0' fill.

Note: Added since V539

### 30. Start a full information device discovery scan

Send	Receive	Parameter
AT+DISA?	OK+DISAS -> Start scan OK+DISC[P0:P1:P2:P3:P4] OK+DISAE -> Scan finished	P0: Device MAC (6Byte) P1: Device Type(1Byte) P2: Device RSSI(1Byte) P3: Rest Data Length (1Byte) P4: Rest Data

Please set AT+IMME1 and AT+ROLE1 first.

Note: All data is in Hex format.

Added in V547

### 31. Query/Set iBeacon deploy mode

Send	Receive	Parameter
AT+DELO[P1]	OK+DELO[P1]	P1: 1, 2



		1: Allowed to broadcast and scanning 2: Only allow broadcast
--	--	---

After receive OK+DELO[P1], module will reset after 500ms.

This command will let module into non-connectable status until next power on.

### 32. Remove bond information

Send	Receive	Parameter
AT+ERASE	OK+ERASE	

Note: Added in V524 version.

### 33. Set module use one Characteristic or two Characteristic UUID

Send	Receive	Parameter
AT+FFE2[P1]	OK+ Set:[P1]	P1: ?, 0, 1, 2 ?: Query 0: Only use one Characteristic 2: Use two Characteristic Second Char value = first Char value + 1 3: Use two Characteristic Second Char value = first Char value - 1

Note: This command added since V550.

### 34. Set advertising data FLAG byte

Send	Receive	Parameter
AT+FLAG[P1]	OK+ Set:[P1]	P1: 0~FF (one byte)

Note: This command added in V530. Please ref to AT+BATT? Command.

### 35. Query/Set UART flow control switch

Send	Receive	Parameter
AT+FIOW?	OK+ Get:[P1]	P1: 0, 1
AT+FIOW[P1]	OK+ Set:[P1]	0: Off 1: On Default: 0

36. Query/Set module RX gain

Send	Receive	Parameter
AT+GAIN?	OK+ Get:[P1]	P1: 0, 1
AT+GAIN[P1]	OK+ Set:[P1]	0: No RX gain 1: Open RX gain Default: 0

Note: This command is added since V535

37. System Help Information

Send	Receive	Parameter
AT+HELP?	Help Information	None

38. Set Humi information byte in advertising data

Send	Receive	Parameter
AT+HUMI[P1]	OK+Set:[P1]	P1: 0x00~0xFF

This command is used to set humi information byte in advertising data when you doesn't want to use humi function buy want to use as AT+FLAG command.

Added in V544

39. Query/Set Module work type

Send	Receive	Parameter
AT+IMME?	OK+ Get:[P1]	P1: 0, 1
AT+IMME[P1]	OK+ Set:[P1]	1: When module is powered on, only respond the AT Command, don't do anything. Until AT + START, AT+CON, AT+CONNL commands is received. 0: When power on, module will start work immediately Default: 0

This command is only used for Central role.

40. Query/Set Module iBeacon switch

Send	Receive	Parameter
AT+IBEA?	OK+Get:[P1]	P1: 0, 1
AT+IBEA[P1]	OK+Set:[P1]	0: Turn off iBeacon 1: Turn on iBeacon Default: 0

iBeacon UUID is: 74278BDA-B644-4520-8F0C-720EAF059935.

This command is added since V517 version.

#### 41. Query/Set iBeacon UUID

Send	Receive	Parameter
AT+IBE0?	OK+Get:[P1]	P1: 00000001~
AT+IBE0[P1]	OK+Set:[P1]	FFFFFFFE Default: 74278BDA

iBeacon UUID is: **74278BDA**-B644-4520-8F0C-720EAF059935.

This command can change red color string in iBeacon UUID.

This command is added since V520 version.

e.g.: Send: AT+IBE012345678 change iBeacon UUID red color string to "12345678"

#### 42. Query/Set iBeacon UUID

Send	Receive	Parameter
AT+IBE1?	OK+Get:[P1]	P1: 00000001~
AT+IBE1[P1]	OK+Set:[P1]	FFFFFFFE Default: B6444520

iBeacon UUID is: 74278BDA-**B644-4520**-8F0C-720EAF059935.

This command can change red color string in iBeacon UUID.

This command is added since V520 version.

e.g.: Send: AT+IBE112345678 change iBeacon UUID red color string to "12345678"

#### 43. Query/Set iBeacon UUID

Send	Receive	Parameter
------	---------	-----------

AT+IBE2?	OK+Get:[P1]	P1: 00000001~ FFFFFFFFE Default: 8F0C720E
AT+IBE2[P1]	OK+Set:[P1]	

iBeacon UUID is: 74278BDA-B644-4520-8F0C-720EAF059935.

This command can change red color string in iBeacon UUID.

This command is added since V520 version.

e.g.: Send: AT+IBE112345678 change iBeacon UUID red color string to "12345678"

#### 44. Query/Set iBeacon UUID

Send	Receive	Parameter
AT+IBE3?	OK+Get:[P1]	P1: 00000001~ FFFFFFFFE Default: AF059935
AT+IBE3[P1]	OK+Set:[P1]	

iBeacon UUID is: 74278BDA-B644-4520-8F0C-720EAF059935.

This command can change red color string in iBeacon UUID.

This command is added since V520 version.

e.g.: Send: AT+IBE112345678 change iBeacon UUID red color string to "12345678"

#### 45. Query/Set Module iBeacon Marjor version

Send	Receive	Parameter
AT+MARJ?	OK+Get:[P1]	P1: 0x0001, 0xFFFE Default: 0xFFE0
AT+MARJ[P1]	OK+Set:[P1]	

E.g. Change marjor version to 0x0102

Send: AT+MARJ0x0102, if all is okay, module will send back OK+Set: 0x0102

This command is added since V517 version.

#### 46. Query/Set Module iBeacon minor

Send	Receive	Parameter
AT+MINO?	OK+Get:[P1]	P1: 0x0001, 0xFFFE Default: 0xFFE1
AT+MINO[P1]	OK+Set:[P1]	

This command is added since V517 version.

47. Query/Set Module iBeacon Measured power

Send	Receive	Parameter
AT+MEAS?	OK+Get:[P1]	P1: 0x01~ 0xFF
AT+MEAS[P1]	OK+Set:[P1]	Default: 0xC5

This command is added since V519 version.

48. Query/Set Module Work Mode

Send	Receive	Parameter
AT+MODE?	OK+Get:[P1]	P1: 0, 1, 2
AT+MODE[P1]	OK+Set:[P1]	0: Transmission Mode 1: PIO collection Mode + Mode 0 2: Remote Control Mode + Mode 0 Default: 0

Mode 0:

Before establishing a connection, you can use the AT command configuration module through UART.

After established a connection, you can send data to remote side from each other.

Mode 1:

Before establishing a connection, you can use the AT command configuration module through UART.

After established a connection, you can send data to remote side. Remote side can do fellows:

Send AT command configuration module.

Collect PIO04 to the PIO11 pins input state of HM-10.

Collect PIO03 pins input state of HM-11.

Remote control PIO2, PIO3 pins output state of HM-10.

Remote control PIO2 pin output state of HM-11.

Send data to module UART port (not include any AT command and per package must less than 20 bytes).

Mode 2:

Before establishing a connection, you can use the AT command configuration module through UART.

After established a connection, you can send data to remote side. Remote side can do fellows:

Send AT command configuration module.

Remote control PIO2 to PIO11 pins output state of HM-10.

Remote control PIO2, PIO3 pins output state of HM-11.

Send data to module UART port (not include any AT command and per package must less than 20 bytes).

49. Query/Set Notify information

Send	Receive	Parameter
AT+NOTI?	OK+Get:[P1]	P1: 0, 1
AT+NOTI[P1]	OK+Set:[P1]	0: Don't Notify 1: Notify Default: 0

If this value is set to 1, when link ESTABLISHED or LOSTED module will send OK+CONN or OK+LOST string through UART.

50. Query/Set notify mode

Send	Receive	Parameter
Q: AT+NOTP?	OK+ Get[P1]	P1: 0, 1; default: 0
Q: AT+NOTP[P1]	OK+ Set[P1]	0: without address 1: with address

This command must work with "AT+NOTI1", if this switch is open, when the module connect to disconnect, the prompt string will include the remote address.

OK+CONN:001122334455 String "001122334455" is the MAC address string

Added since V534

51. Query/Set Module name

Send	Receive	Parameter
AT+NAME?	OK+NAME[P1]	P1: module name, Max length is 12. Default: HMSoft
AT+NAME[P1]	OK+Set[P1]	

e.g.

change module name to bill\_gates

Send: AT+NAMEbill\_gates

Receive: OK+SetName:bill\_gates

52. Query/Set output driver power

Send	Receive	Parameter
Query: AT+PCTL?	OK+Get:[P1]	None
Set: AT+PCTL[P1]	OK+Set:[P1]	P1: 0,1 0:Normal power output 1:Max power output Default: 1

Noted: Added in V527

53. Query/Set Parity bit

Send	Receive	Parameter
Query: AT+PARI?	OK+Get:[P1]	None
Set: AT+PARI[P1]	OK+Set:[P1]	P1: 0,1,2 0:None 1:EVEN 2:ODD Default: 0 (None)

54. Query/Set PIO1 output status (System LED)

Send	Receive	Parameter
AT+PIO1?	OK+Get:[P1]	P1: 0, 1

AT+ PIO1 [P1]	OK+Set:[P1]	0: Unconnected Output 500ms High 500ms Low, Connected output High. 1: Unconnected output Low, Connected output High. Default: 0
---------------	-------------	--

55. Query/Set PIO pins output high or low (Only this time, when module next power on, this value is not be used)

Send	Receive	Parameter
AT+PIO[P1]?	OK+PIO:[P1][P2]	P1: 2~B, ?
AT+PIO[P1][P2]	OK+PIO:[P1][P2]	P2: 0, 1, ? HM-11 only has 4 pins. P1 is which PIO pin you want to Query/Set Value: 2,3,4,5,6,7,8,9,A,B. P2 is Query or setup value. "0" is low and "1" is high and "?" is query

e.g.

Query PIO2

Send: AT+PIO2?

Setup PIO2 output high

Send: AT+PIO21

Receive: OK+PIO21

HM-10 HMSensor version: P1 value is 2~A

HM-10 HMSoft version: P1 value is 2~B

HM-11 HMSensor version: P1 value is 2

HM-11 HMSoft version: P1 value is 2, 3

V525 added PIO2 PWM function, P2 value is 0~9



- 0: output low
- 1: output high
- 2: output 100ms PWM
- 3: output 200ms PWM
- .....
- 9: output 800ms PWM

V527 added AT+PIO?? Format query all pins output state.

56. Query/Set Pin Code

Send	Receive	Parameter
AT+PASS?	OK+Get:[P1]	P1 is Pin Code,
AT+PIN[P1]	OK+Set:[P1]	000000~999999 Default: 000000

e.g.

Query Pin Code

Send: AT+PIN?

Receive: OK+PIN:000000

Setup Pin Code 008888

Send: AT+PIN008888

Receive: OK+Set:008888

57. Query/Set Module Power

Send	Receive	Parameter
AT+POWE?	OK+Get:[P1]	None
AT+ POWE [P1]	OK+Set:[P1]	P1: 0 ~ 3 0: -23dbm 1: -6dbm 2: 0dbm 3: 6dbm Default: 2

58. Query/Set Module sleep type

Send	Receive	Parameter
AT+PWRM?	OK+Get:[P1]	None
AT+PWRM[P1]	OK+Set:[P1]	P1: 0~1 0:Auto sleep 1:don't auto sleep Default: 1

Only support peripheral role.

#### 59. Query/Set reliable advertising mode

Send	Receive	Parameter
AT+RELI?	OK+ Get:[P1]	P1: 0, 1 0: Normal advertising 1: Reliable advertising Default: 0
AT+RELI[P1]	OK+ Set:[P1]	

Note: This command is added since V530

#### 60. Restore all setup value to factory setup

Send	Receive	Parameter
AT+RENEW	OK+RENEW	None

#### 61. Restart module

Send	Receive	Parameter
AT+RESET	OK+RESET	None

#### 62. Query/Set Master and Slaver Role

Send	Receive	Parameter
AT+ROLE?	OK+Get:[P1]	P1: 0, 1 0: Peripheral 1: Central Default: 0
AT+ROLE[P1]	OK+Set:[P1]	

#### 63. Query RSSI Value

Send	Receive	Parameter
AT+RSSI?	OK+RSSI:[P1]	None

Require: AT+MODE value > 0

This command only used by Remote device query after connected.

64. Query Last Connected Device Address

Send	Receive	Parameter
AT+RADD?	OK+RADD:MAC Address	None

65. Query/Set Module Sensor work interval

Send	Receive	Parameter
AT+RAT??	OK+Get:[P1]	P1: 00~99
AT+RAT[P1]	OK+Set:[P1]	0:Save when connected 1:Don't Save Default: 0 Unit: minute

Note: This command is only use for HMSensor

66. Query/Set Stop bit

Send	Receive	Parameter
AT+STOP?	OK+Get:[P1]	None
AT+STOP[P1]	OK+Set:[P1]	P1:0, 1 0: One stop bit 1: Two stop bit Default: 0 (One stop bit)

67. Work immediately (Switch to auto work state)

Send	Receive	Parameter
AT+START	OK+START	None

This command is only used when AT+IMME1 is setup.

68. Query Module into sleep mode

Send	Receive	Parameter
AT+SLEEP	OK+SLEEP	None

Only support Peripheral role.

69. Query/Set Module save connected address information

Send	Receive	Parameter
AT+SAVE?	OK+Get:[P1]	None
AT+SAVE[P1]	OK+Set:[P1]	P1: 0~1 0:Save when connected 1:Don't Save Default: 0

Note: After power on, if module checked this information, module will try to connect it until AT+TCON command setting timeout or AT+CLEAR command to clear this information, then module will into discovery mode.

70. Query/Set Module discovery time when module in master role

Send	Receive	Parameter
AT+SCAN?	OK+Get:[P1]	None
AT+SCAN[P1]	OK+Set:[P1]	P1: 1 ~ 9 Unit: Second Default: 3 Seconds

Note: Add in V543

71. Query/Set sensor type on module PIO11(HM-11 is PIO3)

Send	Receive	Parameter
AT+SENS?	OK+Get:[P1]	P1: 0, 1, 2
AT+SENS[P1]	OK+Set:[P1]	0: None 1: DHT11 2: DS18B20 Default: 0

Note: This command is use for HMSensor.

72. Query/Set if show device information when discovery

Send	Receive	Parameter
AT+SHOW?	OK+Get:[P1]	None
AT+SHOW[P1]	OK+Set:[P1]	P1: 0, 1, 2 0:Don't show information

		1: Show name 2: Show RSSI 3: Show RSSI and Name Default: 0
--	--	---

If AT+SHOW1 is setup, AT+DISC? Command will add the device name information into scan result package.

If AT+SHOW2 is setup, AT+DISC? Command will add device rssi information into scan result package.

If AT+SHOW3 is setup, AT+DISC? Command will add device name and rssi information into scan result package.

73. Query/Set Module Sensor Temperature and humidity(if has a sensor)

Send	Receive	Parameter
AT+TEHU?	OK+Get:[P1][P2]	P1: 000~120 P2: 000~100

Note: This command is only use for HMSensor version.

This value is added into scan response data package.

Data format is 0x02, 0x16, 0x00, 0xB0, [reserved], [temperature], [ humidity], [battery].

Android:

Included in OnLeScan function result array, you can see it direct.

iOS:

Included in LeScan function result NSDictionary struct, service id is 0xB000.

74. Query DS18B20 Sensor or IC temperature

Send	Receive	Parameter
AT+TEMP?	OK+Get:[P1]	P1: 000.000~255.000

Note1: if not setup AT+SENS value, will get IC temperature.

Note2: Added in V523 version, Modified at V544.

75. Set temperature information byte in advertising data

Send	Receive	Parameter
AT+TEMP[P1]	OK+Set:[P1]	P1: 0x00~0xFF Not include '?'

This command is used to set temperature information byte in advertising data when you doesn't want to use temperature function buy want to use as AT+FLAG command.

Added in V544

76. Query/Set module connect remote device timeout value

Send	Receive	Parameter
AT+TCON?	OK+Get:[P1]	None
AT+TCON[P1]	OK+Set:[P1]	P1 is timeout value. When time is up, module will not connect this address anymore, then enter search mode.  P1 allowed value: 000000~999999  Unit is ms.  Default: 000000 Connect forever

This value is only used for Central Role, when module has Last Connected address.

77. Query/Set Module Bond Mode

Send	Receive	Parameter
AT+TYPE?	OK+Get:[P1]	None
AT+TYPE[P1]	OK+Set:[P1]	P1: 0~2 0:Not need PIN Code 1:Auth not need PIN 2:Auth with PIN

		3:Auth and bond Default: 0
--	--	-------------------------------

**Important: If your module version is less than V515, please don't use this command.**

**Under android 4.3 AT+TYPE1 is same to AT+TYPE2.**

**Note: Value 3 is added in V524.**

78. Query/Set service UUID

Send	Receive	Parameter
AT+UUID?	OK+Get:[P1]	P1: 0x0001~0xFFFE
AT+UUID[P1]	OK+Set:[P1]	Default: 0xFFE0

e.g. Change UUID value to 0xAAA0

Send: AT+UUID0xAAA0

Recv: OK+Set:0xAAA0

79. Query/Set UART sleep type

Send	Receive	Parameter
AT+UART?	OK+Get:[P1]	P1: 0~1
AT+UART[P1]	OK+Set:[P1]	0: When module into sleep mode, you can wake up module through UART. 1: When module into sleep mode, also shutdown UART. Default: 0xFFE0

Note: This command is only use for HMSensor version.

80. Query Software Version

Send	Receive	Parameter
AT+VERR? AT+VERS?	Version Information	None

Resource:

Bluetooth Module 2.1 datasheet:

[http://www.jnhuamao.cn/Bluetooth\\_en.zip](http://www.jnhuamao.cn/Bluetooth_en.zip)

Bluetooth Module 4.0 datasheet:

[http://www.jnhuamao.cn/Bluetooth40\\_en.zip](http://www.jnhuamao.cn/Bluetooth40_en.zip)

Bluetooth Module 4.0 USB Dongle

[http://www.jnhuamao.cn/HMDongle40\\_en.zip](http://www.jnhuamao.cn/HMDongle40_en.zip)

Bluetooth 2.1 Com Assistant for android:

<http://www.jnhuamao.cn/HMComAssistant.rar>

Bluetooth 4.0 Com Assistant for android 4.3:

<http://www.jnhuamao.cn/HMBLEComAssistant.rar>

Bluetooth 4.0 IOS Code:

[http://www.jnhuamao.cn/HMSoft\\_iso7.zip](http://www.jnhuamao.cn/HMSoft_iso7.zip)

[http://www.jnhuamao.cn/HMSoft\\_iso7.zip](http://www.jnhuamao.cn/HMSoft_iso7.zip)



# CC2640R2F SimpleLink™ Bluetooth® low energy Wireless MCU

## 1 Device Overview

### 1.1 Features

- Microcontroller
  - Powerful ARM® Cortex®-M3
  - EEMBC CoreMark® Score: 142
  - Up to 48-MHz Clock Speed
  - 275KB of Nonvolatile Memory Including 128KB of In-System Programmable Flash
  - Up to 28KB of System SRAM, of Which 20KB is Ultra-Low Leakage SRAM
  - 8KB of SRAM for Cache or System RAM Use
  - 2-Pin cJTAG and JTAG Debugging
  - Supports Over-The-Air Upgrade (OTA)
- Ultra-Low Power Sensor Controller
  - Can Run Autonomous From the Rest of the System
  - 16-Bit Architecture
  - 2KB of Ultra-Low Leakage SRAM for Code and Data
- Efficient Code Size Architecture, Placing Drivers, TI-RTOS, and Bluetooth® Software in ROM to Make More Flash Available for the Application
- RoHS-Compliant Packages
  - 2.7-mm × 2.7-mm YFV DSBGA34 (14 GPIOs)
  - 4-mm × 4-mm RSM VQFN32 (10 GPIOs)
  - 5-mm × 5-mm RHB VQFN32 (15 GPIOs)
  - 7-mm × 7-mm RGZ VQFN48 (31 GPIOs)
- Peripherals
  - All Digital Peripheral Pins Can Be Routed to Any GPIO
  - Four General-Purpose Timer Modules (Eight 16-Bit or Four 32-Bit Timers, PWM Each)
  - 12-Bit ADC, 200-ksamples/s, 8-Channel Analog MUX
  - Continuous Time Comparator
  - Ultra-Low-Power Analog Comparator
  - Programmable Current Source
  - UART
  - 2× SSI (SPI, MICROWIRE, TI)
  - I2C
  - I2S
  - Real-Time Clock (RTC)
  - AES-128 Security Module
  - True Random Number Generator (TRNG)
  - 10, 14, 15, or 31 GPIOs, Depending on Package Option
  - Support for Eight Capacitive-Sensing Buttons
  - Integrated Temperature Sensor
- External System
  - On-Chip internal DC-DC Converter
  - Very Few External Components
  - Seamless Integration With the SimpleLink™ CC2590 and CC2592 Range Extenders
  - Pin Compatible With the SimpleLink CC13xx in 4-mm × 4-mm and 5-mm × 5-mm VQFN Packages
- Low Power
  - Wide Supply Voltage Range
    - Normal Operation: 1.8 to 3.8 V
    - External Regulator Mode: 1.7 to 1.95 V
  - Active-Mode RX: 5.9 mA
  - Active-Mode TX at 0 dBm: 6.1 mA
  - Active-Mode TX at +5 dBm: 9.1 mA
  - Active-Mode MCU: 61 µA/MHz
  - Active-Mode MCU: 48.5 CoreMark/mA
  - Active-Mode Sensor Controller: 0.4mA + 8.2 µA/MHz
  - Standby: 1.1 µA (RTC Running and RAM/CPU Retention)
  - Shutdown: 100 nA (Wake Up on External Events)
- RF Section
  - 2.4-GHz RF Transceiver Compatible With Bluetooth low energy (BLE) 4.2 and 5 Specifications
  - Excellent Receiver Sensitivity (–97 dBm for BLE), Selectivity, and Blocking Performance
  - Link Budget of 102 dB for BLE
  - Programmable Output Power up to +5 dBm
  - Single-Ended or Differential RF Interface
  - Suitable for Systems Targeting Compliance With Worldwide Radio Frequency Regulations
    - ETSI EN 300 328 (Europe)
    - EN 300 440 Class 2 (Europe)
    - FCC CFR47 Part 15 (US)
    - ARIB STD-T66 (Japan)
- Tools and Development Environment
  - Full-Feature Development Kits
  - Multiple Reference Designs
  - SmartRF™ Tools Portfolio
  - Sensor Controller Studio
  - IAR Embedded Workbench® for ARM
  - Code Composer Studio™
  - CCS Cloud



## 1.2 Applications

- Home and Building Automation
  - Connected Appliances
  - Lighting
  - Locks
  - Gateways
  - Security Systems
- Industrial
  - Logistics
  - Production and Manufacturing Automation
  - Asset Tracking and Management
  - HMI and Remote Display
  - Access Control
- Retail
  - Beacons
  - Advertising
  - ESL and Price Tags
  - Point of Sales and Payment Systems
- Health and Medical
  - Thermometers
  - SpO2
  - Blood Glucose and Pressure Meters
  - Weight Scales
  - Hearing Aids
- Sports and Fitness
  - Activity Monitors and Fitness Trackers
  - Heart Rate Monitors
  - Running and Biking Sensors
  - Sports Watches
  - Gym Equipment
  - Team Sports Equipment
- HID
  - Voice Remote Controls
  - Gaming
  - Keyboards and Mice

## 1.3 Description

The CC2640R2F device is a wireless microcontroller (MCU) targeting Bluetooth® 4.2 and Bluetooth 5 low-energy applications.

The device is a member of the SimpleLink™ ultra-low power CC26xx family of cost-effective, 2.4-GHz RF devices. Very low active RF and MCU current and low-power mode current consumption provide excellent battery lifetime and allow for operation on small coin cell batteries and in energy-harvesting applications.

The SimpleLink Bluetooth low energy CC2640R2F device contains a 32-bit ARM® Cortex®-M3 core that runs at 48 MHz as the main processor and a rich peripheral feature set that includes a unique ultra-low power sensor controller. This sensor controller is ideal for interfacing external sensors and for collecting analog and digital data autonomously while the rest of the system is in sleep mode. Thus, the CC2640R2F device is great for a wide range of applications where long battery lifetime, small form factor, and ease of use is important.

The power and clock management and radio systems of the CC2640R2F wireless MCU require specific configuration and handling by software to operate correctly, which has been implemented in the TI-RTOS. TI recommends using this software framework for all application development on the device. The complete TI-RTOS and device drivers are offered in source code free of charge from [www.ti.com](http://www.ti.com).

Bluetooth low energy controller and host libraries are embedded in ROM and run partly on an ARM® Cortex®-M0 processor. This architecture improves overall system performance and power consumption and frees up significant amounts of flash memory for the application.

The Bluetooth stack is available free of charge from [www.ti.com](http://www.ti.com).

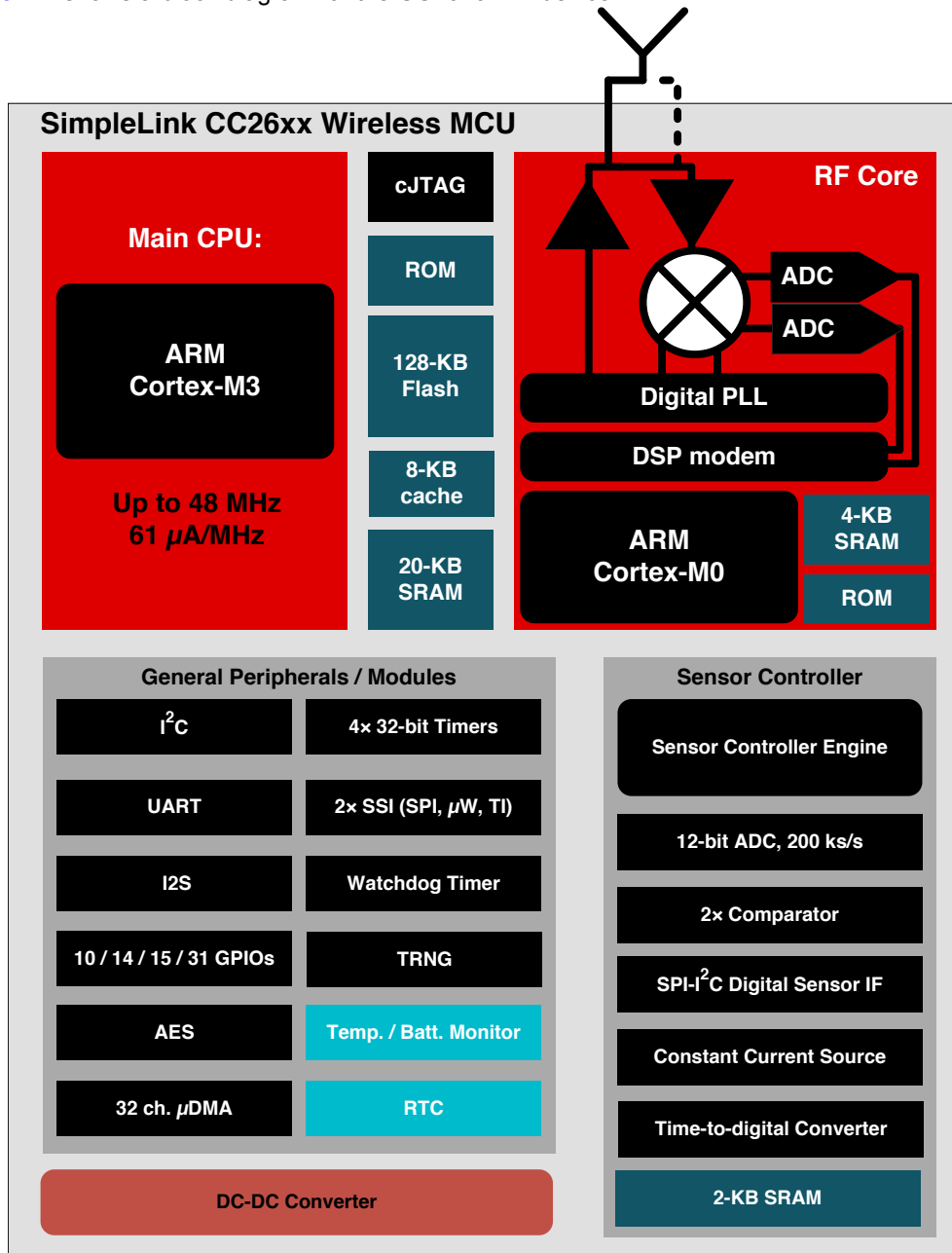
**Device Information<sup>(1)</sup>**

PART NUMBER	PACKAGE	BODY SIZE (NOM)
CC2640R2FRGZ	VQFN (48)	7.00 mm × 7.00 mm
CC2640R2FRHB	VQFN (32)	5.00 mm × 5.00 mm
CC2640R2FRSM	VQFN (32)	4.00 mm × 4.00 mm
CC2640R2FYFV	DSBGA (34)	2.70 mm × 2.70 mm

(1) For more information, see [Section 9](#).

### 1.4 Functional Block Diagram

Figure 1-1 shows a block diagram for the CC2640R2F device.



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Figure 1-1. Block Diagram

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## 2 Revision History

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

Changes from December 6, 2016 to January 13, 2017	Page
• Changed <a href="#">Section 5.2</a>	<a href="#">15</a>

### 3 Device Comparison

**Table 3-1. Device Family Overview**

Device	PHY Support	Flash (KB)	RAM (KB)	GPIO	Package <sup>(1)</sup>
CC2640R2Fxxx <sup>(2)</sup>	Bluetooth low energy (Normal, High Speed, Long Range)	128	20	31, 15, 14, 10	RGZ, RHB, YFV, RSM
CC2640F128xxx	Bluetooth low energy (Normal)	128	20	31, 15, 10	RGZ, RHB, RSM
CC2650F128xxx	Multi-Protocol <sup>(3)</sup>	128	20	31, 15, 10	RGZ, RHB, RSM
CC2630F128xxx	IEEE 802.15.4 (/6LoWPAN)	128	20	31, 15, 10	RGZ, RHB, RSM
CC2620F128xxx	IEEE 802.15.4 (RF4CE)	128	20	31, 10	RGZ, RSM

- (1) Package designator replaces the xxx in device name to form a complete device name, RGZ is 7-mm × 7-mm VQFN48, RHB is 5-mm × 5-mm VQFN32, RSM is 4-mm × 4-mm VQFN32, and YFV is 2.7-mm × 2.7-mm DSBGA.
- (2) CC2640R2Fxxx devices contain Bluetooth 4.2 low energy Host & Controller libraries in ROM, leaving more of the 128KB flash available for the customer application when used with supported BLE-Stack software protocol stack releases. Actual use of ROM and flash by the protocol stack may vary depending on device software configuration. See [www.ti.com](http://www.ti.com) and [Table 3-2](#) for more details.
- (3) The CC2650 device supports all PHYs and can be reflashed to run all the supported standards.

**Table 3-2. Typical<sup>(1)</sup> Flash Memory Available for Customer Applications**

Device	Simple BLE Peripheral (BT 4.0) <sup>(2)</sup>	Simple BLE Peripheral (BT 4.2) <sup>(2) (3)</sup>
CC2640R2Fxxx <sup>(4)</sup>	83 KB	80 KB
CC2640F128xxx, CC2650F128xxx	41 KB	31 KB

- (1) Actual use of ROM and flash by the protocol stack will vary depending on device software configuration. The values in this table are provided as guidance only.
- (2) Application example with two services (GAP and Simple Profile). Compiled using IAR.
- (3) BT4.2 configuration including Secure Pairing, Privacy 1.2, and Data Length Extension
- (4) BLE applications running on the CC2640R2F device make use of up to 115 KB of system ROM and up to 32 KB of RF Core ROM in order to minimize the flash usage. The maximum amount of nonvolatile memory available for BLE applications on CC2640R2F is thus 275 KB (128-KB flash + 147-KB ROM).

#### 3.1 Related Products

##### TI's Wireless Connectivity

The wireless connectivity portfolio offers a wide selection of low-power RF solutions suitable for a broad range of applications. The offerings range from fully customized solutions to turn key offerings with pre-certified hardware and software (protocol).

##### TI's SimpleLink™ Sub-1 GHz Wireless MCUs

Long-range, low-power wireless connectivity solutions are offered in a wide range of Sub-1 GHz ISM bands.

##### Companion Products

Review products that are frequently purchased or used in conjunction with this product.

##### SimpleLink™ CC2640R2 Wireless MCU LaunchPad™ Development Kit

The CC2640R2 LaunchPad™ development kit brings easy Bluetooth® low energy (BLE) connection to the LaunchPad ecosystem with the SimpleLink ultra-low power CC26xx family of devices. Compared to the CC2650 LaunchPad, the CC2640R2 LaunchPad provides the following:

- More free flash memory for the user application in the CC2640R2 wireless MCU
- Out-of-the-box support for Bluetooth 4.2 specification
- 4× faster Over-the-Air download speed compared to Bluetooth 4.1

##### SimpleLink™ Bluetooth low energy/Multi-standard SensorTag

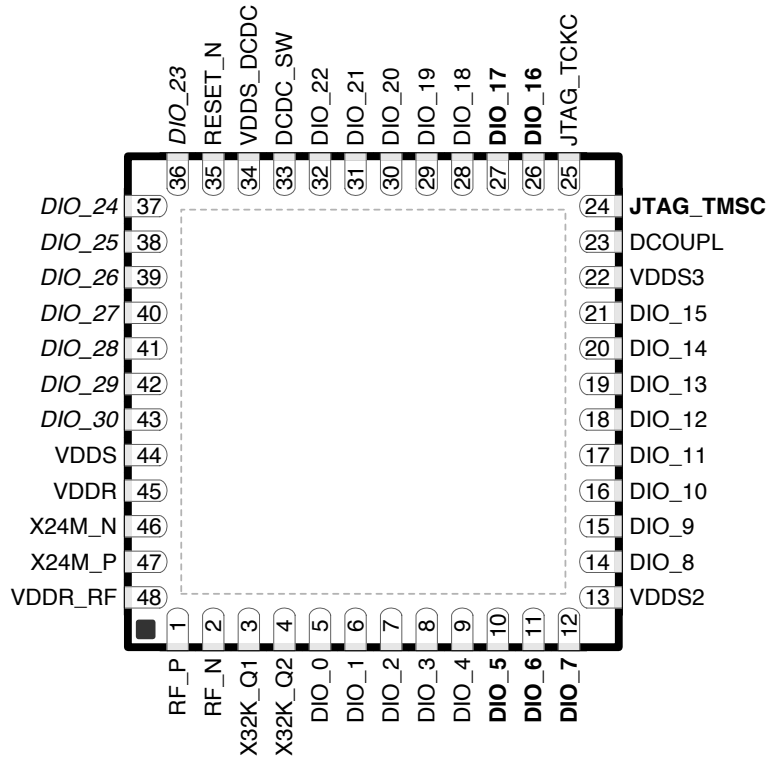
The new SensorTag IoT kit invites you to realize your cloud-connected product idea. The new SensorTag now includes 10 low-power MEMS sensors in a tiny red package. And it is expandable with DevPacks to make it easy to add your own sensors or actuators.

##### Reference Designs for CC2640

TI Designs Reference Design Library is a robust reference design library spanning analog, embedded processor and connectivity. Created by TI experts to help you jump-start your system design, all TI Designs include schematic or block diagrams, BOMs, and design files to speed your time to market. Search and download designs at [ti.com/tidesigns](http://ti.com/tidesigns).

## 4 Terminal Configuration and Functions

### 4.1 Pin Diagram – RGZ Package



**Figure 4-1. RGZ Package  
48-Pin VQFN  
(7-mm × 7-mm) Pinout, 0.5-mm Pitch**

I/O pins marked in [Figure 4-1](#) in **bold** have high-drive capabilities; they are the following:

- Pin 10, **DIO\_5**
- Pin 11, **DIO\_6**
- Pin 12, **DIO\_7**
- Pin 24, **JTAG\_TMS**
- Pin 26, **DIO\_16**
- Pin 27, **DIO\_17**

I/O pins marked in [Figure 4-1](#) in *italics* have analog capabilities; they are the following:

- Pin 36, *DIO\_23*
- Pin 37, *DIO\_24*
- Pin 38, *DIO\_25*
- Pin 39, *DIO\_26*
- Pin 40, *DIO\_27*
- Pin 41, *DIO\_28*
- Pin 42, *DIO\_29*
- Pin 43, *DIO\_30*

## 4.2 Signal Descriptions – RGZ Package

**Table 4-1. Signal Descriptions – RGZ Package**

NAME	NO.	TYPE	DESCRIPTION
DCDC_SW	33	Power	Output from internal DC-DC <sup>(1)</sup>
DCOUPPL	23	Power	1.27-V regulated digital-supply decoupling capacitor <sup>(2)</sup>
DIO_0	5	Digital I/O	GPIO, Sensor Controller
DIO_1	6	Digital I/O	GPIO, Sensor Controller
DIO_2	7	Digital I/O	GPIO, Sensor Controller
DIO_3	8	Digital I/O	GPIO, Sensor Controller
DIO_4	9	Digital I/O	GPIO, Sensor Controller
DIO_5	10	Digital I/O	GPIO, Sensor Controller, high-drive capability
DIO_6	11	Digital I/O	GPIO, Sensor Controller, high-drive capability
DIO_7	12	Digital I/O	GPIO, Sensor Controller, high-drive capability
DIO_8	14	Digital I/O	GPIO
DIO_9	15	Digital I/O	GPIO
DIO_10	16	Digital I/O	GPIO
DIO_11	17	Digital I/O	GPIO
DIO_12	18	Digital I/O	GPIO
DIO_13	19	Digital I/O	GPIO
DIO_14	20	Digital I/O	GPIO
DIO_15	21	Digital I/O	GPIO
DIO_16	26	Digital I/O	GPIO, JTAG_TDO, high-drive capability
DIO_17	27	Digital I/O	GPIO, JTAG_TDI, high-drive capability
DIO_18	28	Digital I/O	GPIO
DIO_19	29	Digital I/O	GPIO
DIO_20	30	Digital I/O	GPIO
DIO_21	31	Digital I/O	GPIO
DIO_22	32	Digital I/O	GPIO
DIO_23	36	Digital/Analog I/O	GPIO, Sensor Controller, Analog
DIO_24	37	Digital/Analog I/O	GPIO, Sensor Controller, Analog
DIO_25	38	Digital/Analog I/O	GPIO, Sensor Controller, Analog
DIO_26	39	Digital/Analog I/O	GPIO, Sensor Controller, Analog
DIO_27	40	Digital/Analog I/O	GPIO, Sensor Controller, Analog
DIO_28	41	Digital/Analog I/O	GPIO, Sensor Controller, Analog
DIO_29	42	Digital/Analog I/O	GPIO, Sensor Controller, Analog
DIO_30	43	Digital/Analog I/O	GPIO, Sensor Controller, Analog
JTAG_TMSC	24	Digital I/O	JTAG TMSC, high-drive capability
JTAG_TCKC	25	Digital I/O	JTAG TCKC
RESET_N	35	Digital input	Reset, active-low. No internal pullup.
RF_P	1	RF I/O	Positive RF input signal to LNA during RX Positive RF output signal to PA during TX
RF_N	2	RF I/O	Negative RF input signal to LNA during RX Negative RF output signal to PA during TX
VDDR	45	Power	1.7-V to 1.95-V supply, typically connect to output of internal DC-DC <sup>(2)(3)</sup>
VDDR_RF	48	Power	1.7-V to 1.95-V supply, typically connect to output of internal DC-DC <sup>(2)(4)</sup>
VDDS	44	Power	1.8-V to 3.8-V main chip supply <sup>(1)</sup>

(1) For more details, see the technical reference manual (listed in [Section 8.3](#)).

(2) Do not supply external circuitry from this pin.

(3) If internal DC-DC is not used, this pin is supplied internally from the main LDO.

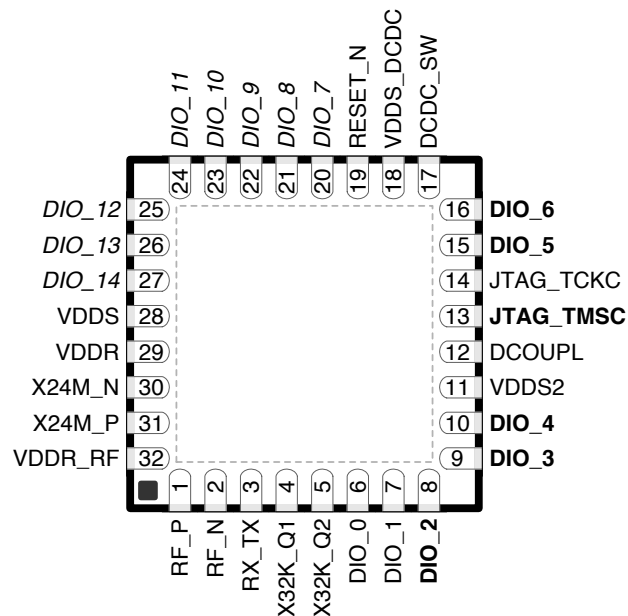
(4) If internal DC-DC is not used, this pin must be connected to VDDR for supply from the main LDO.

**Table 4-1. Signal Descriptions – RGZ Package (continued)**

NAME	NO.	TYPE	DESCRIPTION
VDDS2	13	Power	1.8-V to 3.8-V DIO supply <sup>(1)</sup>
VDDS3	22	Power	1.8-V to 3.8-V DIO supply <sup>(1)</sup>
VDDS_DCDC	34	Power	1.8-V to 3.8-V DC-DC supply
X32K_Q1	3	Analog I/O	32-kHz crystal oscillator pin 1
X32K_Q2	4	Analog I/O	32-kHz crystal oscillator pin 2
X24M_N	46	Analog I/O	24-MHz crystal oscillator pin 1
X24M_P	47	Analog I/O	24-MHz crystal oscillator pin 2
EGP		Power	Ground – Exposed Ground Pad



### 4.3 Pin Diagram – RHB Package



**Figure 4-2. RHB Package  
32-Pin VQFN  
(5-mm × 5-mm) Pinout, 0.5-mm Pitch**

I/O pins marked in [Figure 4-2](#) in **bold** have high-drive capabilities; they are the following:

- Pin 8, **DIO\_2**
- Pin 9, **DIO\_3**
- Pin 10, **DIO\_4**
- Pin 13, **JTAG\_TMSC**
- Pin 15, **DIO\_5**
- Pin 16, **DIO\_6**

I/O pins marked in [Figure 4-2](#) in *italics* have analog capabilities; they are the following:

- Pin 20, *DIO\_7*
- Pin 21, *DIO\_8*
- Pin 22, *DIO\_9*
- Pin 23, *DIO\_10*
- Pin 24, *DIO\_11*
- Pin 25, *DIO\_12*
- Pin 26, *DIO\_13*
- Pin 27, *DIO\_14*

## 4.4 Signal Descriptions – RHB Package

**Table 4-2. Signal Descriptions – RHB Package**

NAME	NO.	TYPE	DESCRIPTION
DCDC_SW	17	Power	Output from internal DC-DC <sup>(1)</sup>
DCOUPPL	12	Power	1.27-V regulated digital-supply decoupling <sup>(2)</sup>
DIO_0	6	Digital I/O	GPIO, Sensor Controller
DIO_1	7	Digital I/O	GPIO, Sensor Controller
DIO_2	8	Digital I/O	GPIO, Sensor Controller, high-drive capability
DIO_3	9	Digital I/O	GPIO, Sensor Controller, high-drive capability
DIO_4	10	Digital I/O	GPIO, Sensor Controller, high-drive capability
DIO_5	15	Digital I/O	GPIO, High drive capability, JTAG_TDO
DIO_6	16	Digital I/O	GPIO, High drive capability, JTAG_TDI
DIO_7	20	Digital/Analog I/O	GPIO, Sensor Controller, Analog
DIO_8	21	Digital/Analog I/O	GPIO, Sensor Controller, Analog
DIO_9	22	Digital/Analog I/O	GPIO, Sensor Controller, Analog
DIO_10	23	Digital/Analog I/O	GPIO, Sensor Controller, Analog
DIO_11	24	Digital/Analog I/O	GPIO, Sensor Controller, Analog
DIO_12	25	Digital/Analog I/O	GPIO, Sensor Controller, Analog
DIO_13	26	Digital/Analog I/O	GPIO, Sensor Controller, Analog
DIO_14	27	Digital/Analog I/O	GPIO, Sensor Controller, Analog
JTAG_TMSC	13	Digital I/O	JTAG TMSC, high-drive capability
JTAG_TCKC	14	Digital I/O	JTAG TCKC
RESET_N	19	Digital input	Reset, active-low. No internal pullup.
RF_N	2	RF I/O	Negative RF input signal to LNA during RX Negative RF output signal to PA during TX
RF_P	1	RF I/O	Positive RF input signal to LNA during RX Positive RF output signal to PA during TX
RX_TX	3	RF I/O	Optional bias pin for the RF LNA
VDDR	29	Power	1.7-V to 1.95-V supply, typically connect to output of internal DC-DC <sup>(3)(2)</sup>
VDDR_RF	32	Power	1.7-V to 1.95-V supply, typically connect to output of internal DC-DC <sup>(2)(4)</sup>
VDDS	28	Power	1.8-V to 3.8-V main chip supply <sup>(1)</sup>
VDDS2	11	Power	1.8-V to 3.8-V GPIO supply <sup>(1)</sup>
VDDS_DCDC	18	Power	1.8-V to 3.8-V DC-DC supply
X32K_Q1	4	Analog I/O	32-kHz crystal oscillator pin 1
X32K_Q2	5	Analog I/O	32-kHz crystal oscillator pin 2
X24M_N	30	Analog I/O	24-MHz crystal oscillator pin 1
X24M_P	31	Analog I/O	24-MHz crystal oscillator pin 2
EGP		Power	Ground – Exposed Ground Pad

(1) See technical reference manual (listed in [Section 8.3](#)) for more details.

(2) Do not supply external circuitry from this pin.

(3) If internal DC-DC is not used, this pin is supplied internally from the main LDO.

(4) If internal DC-DC is not used, this pin must be connected to VDDR for supply from the main LDO.

#### 4.5 Pin Diagram – YFV (Chip Scale, DSBGA) Package

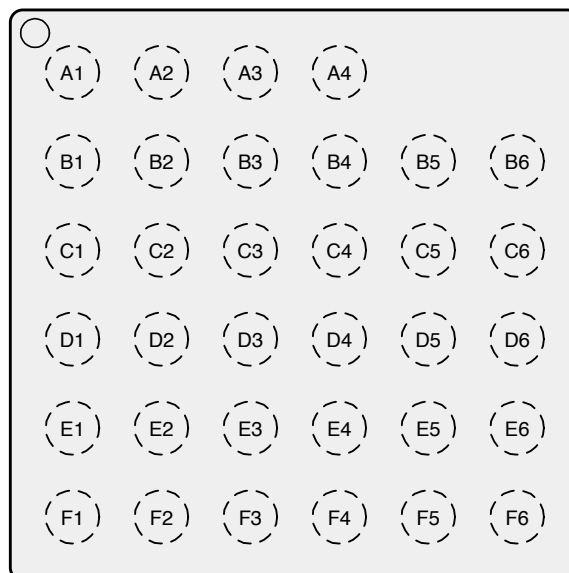


Figure 4-3. YFV (2.7-mm × 2.7-mm) Pinout, Top View

#### 4.6 Signal Descriptions – YFV (Chip Scale, DSBGA) Package

Table 4-3. Signal Descriptions – YFV Package

NAME	NO.	TYPE	DESCRIPTION
DCDC_SW	D1	Power	Output from internal DC-DC <sup>(1)</sup>
DCOUPPL	F3	Power	1.27-V regulated digital-supply decoupling <sup>(2)</sup>
DIO_0	C5	Digital I/O	GPIO, Sensor Controller
DIO_1	F6	Digital I/O	GPIO, Sensor Controller
DIO_2	D5	Digital I/O	GPIO, Sensor Controller, high-drive capability
DIO_3	E5	Digital I/O	GPIO, Sensor Controller, high-drive capability
DIO_4	F5	Digital I/O	GPIO, Sensor Controller, high-drive capability
DIO_5	E3	Digital I/O	GPIO, High-drive capability, JTAG_TDO
DIO_6	F1	Digital I/O	GPIO, High-drive capability, JTAG_TDI
DIO_7	D2	Digital/Analog I/O	GPIO, Sensor Controller, Analog
DIO_8	D3	Digital/Analog I/O	GPIO, Sensor Controller, Analog
DIO_9	A1	Digital/Analog I/O	GPIO, Sensor Controller, Analog
DIO_10	C2	Digital/Analog I/O	GPIO, Sensor Controller, Analog
DIO_11	B2	Digital/Analog I/O	GPIO, Sensor Controller, Analog
DIO_12	D4	Digital/Analog I/O	GPIO, Sensor Controller, Analog
DIO_13	B3	Digital/Analog I/O	GPIO, Sensor Controller, Analog
JTAG_TMSC	E4	Digital I/O	JTAG TMSC, high-drive capability
JTAG_TCKC	F2	Digital I/O	JTAG TCKC
RESET_N	E2	Digital input	Reset, active-low. No internal pullup.
RF_N	B6	RF I/O	Negative RF input signal to LNA during RX Negative RF output signal to PA during TX
RF_P	B5	RF I/O	Positive RF input signal to LNA during RX Positive RF output signal to PA during TX

(1) For more details, see the technical reference manual (listed in [Section 8.3](#)).

(2) Do not supply external circuitry from this pin.

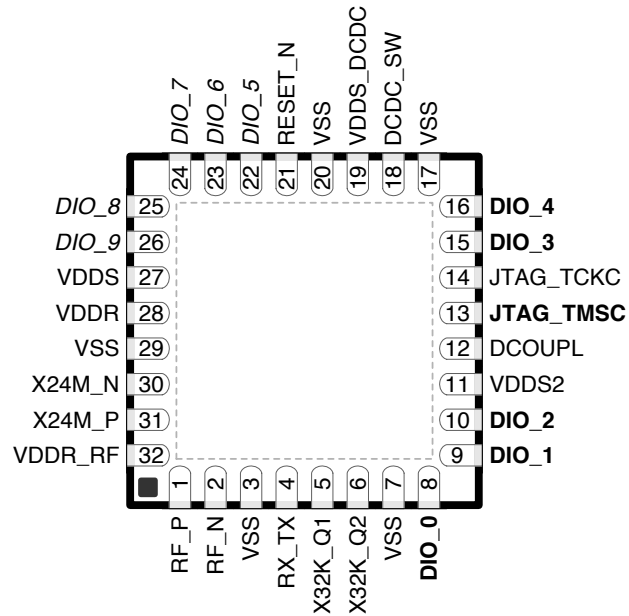
**Table 4-3. Signal Descriptions – YFV Package (continued)**

NAME	NO.	TYPE	DESCRIPTION
VDDR	A3	Power	1.7-V to 1.95-V supply, typically connect to output of internal DC-DC <sup>(3)(2)</sup>
VDDR_RF	B4	Power	1.7-V to 1.95-V supply, typically connect to output of internal DC-DC <sup>(4)(2)</sup>
VDDS	A2	Power	1.8-V to 3.8-V main chip supply <sup>(1)</sup>
VDDS2	F4	Power	1.8-V to 3.8-V GPIO supply <sup>(1)</sup>
VDDS_DCDC	C1	Power	1.8-V to 3.8-V DC-DC supply
X32K_Q1	D6	Analog I/O	32-kHz crystal oscillator pin 1
X32K_Q2	E6	Analog I/O	32-kHz crystal oscillator pin 2
X24M_N	C3	Analog I/O	24-MHz crystal oscillator pin 1
X24M_P	C4	Analog I/O	24-MHz crystal oscillator pin 2
GND	A4, B1, C6, E1	Power	Ground

(3) If internal DC-DC is not used, this pin is supplied internally from the main LDO.

(4) If internal DC-DC is not used, this pin must be connected to VDDR for supply from the main LDO.

#### 4.7 Pin Diagram – RSM Package



**Figure 4-4. RSM Package  
32-Pin VQFN  
(4-mm × 4-mm) Pinout, 0.4-mm Pitch**

I/O pins marked in [Figure 4-4](#) in **bold** have high-drive capabilities; they are as follows:

- Pin 8, DIO\_0
- Pin 9, DIO\_1
- Pin 10, DIO\_2
- Pin 13, JTAG\_TMSC
- Pin 15, DIO\_3
- Pin 16, DIO\_4

I/O pins marked in [Figure 4-4](#) in *italics* have analog capabilities; they are as follows:

- Pin 22, DIO\_5
- Pin 23, DIO\_6
- Pin 24, DIO\_7
- Pin 25, DIO\_8
- Pin 26, DIO\_9

## 4.8 Signal Descriptions – RSM Package

**Table 4-4. Signal Descriptions – RSM Package**

NAME	NO.	TYPE	DESCRIPTION
DCDC_SW	18	Power	Output from internal DC-DC. <sup>(1)</sup> Tie to ground for external regulator mode (1.7-V to 1.95-V operation)
DCOUPPL	12	Power	1.27-V regulated digital-supply decoupling capacitor <sup>(2)</sup>
DIO_0	8	Digital I/O	GPIO, Sensor Controller, high-drive capability
DIO_1	9	Digital I/O	GPIO, Sensor Controller, high-drive capability
DIO_2	10	Digital I/O	GPIO, Sensor Controller, high-drive capability
DIO_3	15	Digital I/O	GPIO, High-drive capability, JTAG_TDO
DIO_4	16	Digital I/O	GPIO, High-drive capability, JTAG_TDI
DIO_5	22	Digital/Analog I/O	GPIO, Sensor Controller, Analog
DIO_6	23	Digital/Analog I/O	GPIO, Sensor Controller, Analog
DIO_7	24	Digital/Analog I/O	GPIO, Sensor Controller, Analog
DIO_8	25	Digital/Analog I/O	GPIO, Sensor Controller, Analog
DIO_9	26	Digital/Analog I/O	GPIO, Sensor Controller, Analog
JTAG_TMSC	13	Digital I/O	JTAG TMSC
JTAG_TCKC	14	Digital I/O	JTAG TCKC
RESET_N	21	Digital Input	Reset, active-low. No internal pullup.
RF_N	2	RF I/O	Negative RF input signal to LNA during RX Negative RF output signal to PA during TX
RF_P	1	RF I/O	Positive RF input signal to LNA during RX Positive RF output signal to PA during TX
RX_TX	4	RF I/O	Optional bias pin for the RF LNA
VDDR	28	Power	1.7-V to 1.95-V supply, typically connect to output of internal DC-DC. <sup>(2)(3)</sup>
VDDR_RF	32	Power	1.7-V to 1.95-V supply, typically connect to output of internal DC-DC. <sup>(2)(4)</sup>
VDDS	27	Power	1.8-V to 3.8-V main chip supply <sup>(1)</sup>
VDDS2	11	Power	1.8-V to 3.8-V GPIO supply <sup>(1)</sup>
VDDS_DCDC	19	Power	1.8-V to 3.8-V DC-DC supply. Tie to ground for external regulator mode (1.7-V to 1.95-V operation).
VSS	3, 7, 17, 20, 29	Power	Ground
X32K_Q1	5	Analog I/O	32-kHz crystal oscillator pin 1
X32K_Q2	6	Analog I/O	32-kHz crystal oscillator pin 2
X24M_N	30	Analog I/O	24-MHz crystal oscillator pin 1
X24M_P	31	Analog I/O	24-MHz crystal oscillator pin 2
EGP		Power	Ground – Exposed Ground Pad

(1) See technical reference manual (listed in [Section 8.3](#)) for more details.

(2) Do not supply external circuitry from this pin.

(3) If internal DC-DC is not used, this pin is supplied internally from the main LDO.

(4) If internal DC-DC is not used, this pin must be connected to VDDR for supply from the main LDO.

## 5 Specifications

### 5.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)<sup>(1)(2)</sup>

		MIN	MAX	UNIT
Supply voltage (VDDS, VDDS2, and VDDS3)	VDDR supplied by internal DC-DC regulator or internal GLDO. VDDS_DCDC connected to VDDS on PCB.	-0.3	4.1	V
Supply voltage (VDDS <sup>(3)</sup> and VDDR)	External regulator mode (VDDS and VDDR pins connected on PCB)	-0.3	2.25	V
Voltage on any digital pin <sup>(4)(5)</sup>		-0.3	VDDSx + 0.3, max 4.1	V
Voltage on crystal oscillator pins, X32K_Q1, X32K_Q2, X24M_N and X24M_P		-0.3	VDDR + 0.3, max 2.25	V
Voltage on ADC input (V <sub>in</sub> )	Voltage scaling enabled	-0.3	VDDS	V
	Voltage scaling disabled, internal reference	-0.3	1.49	
	Voltage scaling disabled, VDDS as reference	-0.3	VDDS / 2.9	
Input RF level			5	dBm
T <sub>stg</sub>	Storage temperature	-40	150	°C

(1) All voltage values are with respect to ground, unless otherwise noted.

(2) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions* is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

(3) In external regulator mode, VDDS2 and VDDS3 must be at the same potential as VDDS.

(4) Including analog-capable DIO.

(5) Each pin is referenced to a specific VDDSx (VDDS, VDDS2 or VDDS3). For a pin-to-VDDS mapping table, see [Table 6-3](#).

### 5.2 ESD Ratings

				VALUE	UNIT
V <sub>ESD</sub>	Electrostatic discharge RSM, RHB, and RGZ packages	Human body model (HBM), per ANSI/ESDA/JEDEC JS001 <sup>(1)</sup>	All pins	±2500	V
		Charged device model (CDM), per JESD22-C101 <sup>(2)</sup>	RF pins	±750	
			Non-RF pins	±750	
V <sub>ESD</sub>	Electrostatic discharge YFV package	Human body model (HBM), per ANSI/ESDA/JEDEC JS001 <sup>(1)</sup>	All pins	±1500	V
		Charged device model (CDM), per JESD22-C101 <sup>(2)</sup>	RF pins	±500	
			Non-RF pins	±500	

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.

(2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

### 5.3 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)

		MIN	MAX	UNIT	
Ambient temperature		-40	85	°C	
Operating supply voltage (VDDS and VDDR), external regulator mode	For operation in 1.8-V systems (VDDS and VDDR pins connected on PCB, internal DC-DC cannot be used)	1.7	1.95	V	
Operating supply voltage VDDS		1.8	3.8	V	
Operating supply voltages VDDS2 and VDDS3	For operation in battery-powered and 3.3-V systems (internal DC-DC can be used to minimize power consumption)	VDDS < 2.7 V	1.8	3.8	V
Operating supply voltages VDDS2 and VDDS3		VDDS ≥ 2.7 V	1.9	3.8	V

### 5.4 Power Consumption Summary

Measured on the TI CC2650EM-5XD reference design with  $T_c = 25^\circ\text{C}$ ,  $V_{\text{DD5}} = 3.0\text{ V}$  with internal DC-DC converter, unless otherwise noted.

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT	
$I_{\text{core}}$	Core current consumption	Reset. RESET_N pin asserted or VDD5 below Power-on-Reset threshold		100		nA	
		Shutdown. No clocks running, no retention		150			
		Standby. With RTC, CPU, RAM and (partial) register retention. RCOSC_LF			1.1		$\mu\text{A}$
		Standby. With RTC, CPU, RAM and (partial) register retention. XOSC_LF			1.3		
		Standby. With Cache, RTC, CPU, RAM and (partial) register retention. RCOSC_LF			2.8		
		Standby. With Cache, RTC, CPU, RAM and (partial) register retention. XOSC_LF			3.0		
		Idle. Supply Systems and RAM powered.			550		
		Active. Core running CoreMark			1.45 mA + 31 $\mu\text{A}/\text{MHz}$		
		Radio RX <sup>(1)</sup>			5.9		mA
		Radio RX <sup>(2)</sup>			6.1		
		Radio TX, 0-dBm output power <sup>(1)</sup>			6.1		
Radio TX, 5-dBm output power <sup>(2)</sup>			9.1				
<b>Peripheral Current Consumption (Adds to core current <math>I_{\text{core}}</math> for each peripheral unit activated) <sup>(3)</sup></b>							
$I_{\text{peri}}$	Peripheral power domain	Delta current with domain enabled		20		$\mu\text{A}$	
	Serial power domain	Delta current with domain enabled		13		$\mu\text{A}$	
	RF Core	Delta current with power domain enabled, clock enabled, RF core idle		237		$\mu\text{A}$	
	$\mu\text{DMA}$	Delta current with clock enabled, module idle		130		$\mu\text{A}$	
	Timers	Delta current with clock enabled, module idle		113		$\mu\text{A}$	
	I <sup>2</sup> C	Delta current with clock enabled, module idle		12		$\mu\text{A}$	
	I2S	Delta current with clock enabled, module idle		36		$\mu\text{A}$	
	SSI	Delta current with clock enabled, module idle		93		$\mu\text{A}$	
	UART	Delta current with clock enabled, module idle		164		$\mu\text{A}$	

- (1) Single-ended RF mode is optimized for size and power consumption. Measured on CC2650EM-4XS.
- (2) Differential RF mode is optimized for RF performance. Measured on CC2650EM-5XD.
- (3)  $I_{\text{peri}}$  is not supported in Standby or Shutdown.

### 5.5 General Characteristics

$T_c = 25^\circ\text{C}$ ,  $V_{\text{DD5}} = 3.0\text{ V}$ , unless otherwise noted.

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
<b>FLASH MEMORY</b>					
Supported flash erase cycles before failure		100			k Cycles
Maximum number of write operations per row before erase <sup>(1)</sup>				83	write operations
Flash retention	105°C	11.4			Years at 105°C
Flash page/sector erase current	Average delta current		12.6		mA
Flash page/sector size			4		KB
Flash write current	Average delta current, 4 bytes at a time		8.15		mA
Flash page/sector erase time <sup>(2)</sup>			8		ms
Flash write time <sup>(2)</sup>	4 bytes at a time		8		$\mu\text{s}$

- (1) Each row is 2048 bits (or 256 Bytes) wide.
- (2) This number is dependent on Flash aging and will increase over time and erase cycles.



## 5.6 125-kbps Coded (Bluetooth 5) – RX

Measured on the TI CC2650EM-5XD reference design with  $T_c = 25^\circ\text{C}$ ,  $V_{\text{DD5}} = 3.0\text{ V}$ ,  $f_{\text{RF}} = 2440\text{ MHz}$ , unless otherwise noted.

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Receiver sensitivity	Differential mode. Measured at the CC2650EM-5XD SMA connector, BER = $10^{-3}$		-103		dBm
Receiver saturation	Differential mode. Measured at the CC2650EM-5XD SMA connector, BER = $10^{-3}$		>5		dBm
Frequency error tolerance	Difference between the incoming carrier frequency and the internally generated carrier frequency	-260		310	kHz
Data rate error tolerance	Difference between incoming data rate and the internally generated data rate (37-byte packets)	-260		260	ppm
Data rate error tolerance	Difference between incoming data rate and the internally generated data rate (255-byte packets)	-140		150	ppm
Co-channel rejection <sup>(1)</sup>	Wanted signal at -79 dBm, modulated interferer in channel, BER = $10^{-3}$		-3		dB
Selectivity, $\pm 1\text{ MHz}$ <sup>(1)</sup>	Wanted signal at -79 dBm, modulated interferer at $\pm 1\text{ MHz}$ , BER = $10^{-3}$		9 / 5 <sup>(2)</sup>		dB
Selectivity, $\pm 2\text{ MHz}$ <sup>(1)</sup>	Wanted signal at -79 dBm, modulated interferer at $\pm 2\text{ MHz}$ , Image frequency is at -2 MHz, BER = $10^{-3}$		43 / 32 <sup>(2)</sup>		dB
Selectivity, $\pm 3\text{ MHz}$ <sup>(1)</sup>	Wanted signal at -79 dBm, modulated interferer at $\pm 3\text{ MHz}$ , BER = $10^{-3}$		47 / 42 <sup>(2)</sup>		dB
Selectivity, $\pm 4\text{ MHz}$ <sup>(1)</sup>	Wanted signal at -79 dBm, modulated interferer at $\pm 4\text{ MHz}$ , BER = $10^{-3}$		46 / 47 <sup>(2)</sup>		dB
Selectivity, $\pm 6\text{ MHz}$ <sup>(1)</sup>	Wanted signal at -79 dBm, modulated interferer at $\pm 6\text{ MHz}$ , BER = $10^{-3}$		49 / 46 <sup>(2)</sup>		dB
Alternate channel rejection, $\pm 7\text{ MHz}$ <sup>(1)</sup>	Wanted signal at -79 dBm, modulated interferer at $\geq \pm 7\text{ MHz}$ , BER = $10^{-3}$		50 / 47 <sup>(2)</sup>		dB
Selectivity, image frequency <sup>(1)</sup>	Wanted signal at -79 dBm, modulated interferer at image frequency, BER = $10^{-3}$		32		dB
Selectivity, image frequency $\pm 1\text{ MHz}$ <sup>(1)</sup>	Note that Image frequency + 1 MHz is the Co-channel -1 MHz. Wanted signal at -79 dBm, modulated interferer at $\pm 1\text{ MHz}$ from image frequency, BER = $10^{-3}$		5 / 32 <sup>(2)</sup>		dB
Blocker rejection, $\pm 8\text{ MHz}$ and above <sup>(1)</sup>	Wanted signal at -79 dBm, modulated interferer at $\pm 8\text{ MHz}$ and above, BER = $10^{-3}$		>46		dB
Out-of-band blocking <sup>(3)</sup>	30 MHz to 2000 MHz		-40		dBm
Out-of-band blocking	2003 MHz to 2399 MHz		-19		dBm
Out-of-band blocking	2484 MHz to 2997 MHz		-22		dBm
Intermodulation	Wanted signal at 2402 MHz, -76 dBm. Two interferers at 2405 and 2408 MHz respectively, at the given power level		-42		dBm

(1) Numbers given as I/C dB.

(2) X / Y, where X is +N MHz and Y is -N MHz.

(3) Excluding one exception at  $F_{\text{wanted}} / 2$ , per Bluetooth Specification.

## 5.7 125-kbps Coded (Bluetooth 5) – TX

Measured on the TI CC2650EM-5XD reference design with  $T_c = 25^\circ\text{C}$ ,  $V_{\text{DDS}} = 3.0\text{ V}$ ,  $f_{\text{RF}} = 2440\text{ MHz}$ , unless otherwise noted.

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Output power, highest setting	Differential mode, delivered to a single-ended 50- $\Omega$ load through a balun		5		dBm
Output power, highest setting	Measured on CC2650EM-4XS, delivered to a single-ended 50- $\Omega$ load		2		dBm
Output power, lowest setting	Delivered to a single-ended 50- $\Omega$ load through a balun		-21		dBm
Spurious emission conducted measurement <sup>(1)</sup>	$f < 1\text{ GHz}$ , outside restricted bands		-43		dBm
	$f < 1\text{ GHz}$ , restricted bands ETSI		-65		dBm
	$f < 1\text{ GHz}$ , restricted bands FCC		-76		dBm
	$f > 1\text{ GHz}$ , including harmonics		-46		dBm

(1) Suitable for systems targeting compliance with worldwide radio-frequency regulations ETSI EN 300 328 and EN 300 440 Class 2 (Europe), FCC CFR47 Part 15 (US), and ARIB STD-T66 (Japan).

## 5.8 500-kbps Coded (Bluetooth 5) – RX

Measured on the TI CC2650EM-5XD reference design with  $T_c = 25^\circ\text{C}$ ,  $V_{\text{DDS}} = 3.0\text{ V}$ ,  $f_{\text{RF}} = 2440\text{ MHz}$ , unless otherwise noted.

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Receiver sensitivity	Differential mode. Measured at the CC2650EM-5XD SMA connector, BER = $10^{-3}$		-101		dBm
Receiver saturation	Differential mode. Measured at the CC2650EM-5XD SMA connector, BER = $10^{-3}$		>5		dBm
Frequency error tolerance	Difference between the incoming carrier frequency and the internally generated carrier frequency	-240		240	kHz
Data rate error tolerance	Difference between incoming data rate and the internally generated data rate (37-byte packets)	-500		500	ppm
Data rate error tolerance	Difference between incoming data rate and the internally generated data rate (255-byte packets)	-310		330	ppm
Co-channel rejection <sup>(1)</sup>	Wanted signal at -72 dBm, modulated interferer in channel, BER = $10^{-3}$		-5		dB
Selectivity, $\pm 1\text{ MHz}$ <sup>(1)</sup>	Wanted signal at -72 dBm, modulated interferer at $\pm 1\text{ MHz}$ , BER = $10^{-3}$		9 / 5 <sup>(2)</sup>		dB
Selectivity, $\pm 2\text{ MHz}$ <sup>(1)</sup>	Wanted signal at -72 dBm, modulated interferer at $\pm 2\text{ MHz}$ , Image frequency is at -2 MHz, BER = $10^{-3}$		41 / 31 <sup>(2)</sup>		dB
Selectivity, $\pm 3\text{ MHz}$ <sup>(1)</sup>	Wanted signal at -72 dBm, modulated interferer at $\pm 3\text{ MHz}$ , BER = $10^{-3}$		44 / 41 <sup>(2)</sup>		dB
Selectivity, $\pm 4\text{ MHz}$ <sup>(1)</sup>	Wanted signal at -72 dBm, modulated interferer at $\pm 4\text{ MHz}$ , BER = $10^{-3}$		44 / 44 <sup>(2)</sup>		dB
Selectivity, $\pm 6\text{ MHz}$ <sup>(1)</sup>	Wanted signal at -72 dBm, modulated interferer at $\pm 6\text{ MHz}$ , BER = $10^{-3}$		44 / 44 <sup>(2)</sup>		dB
Alternate channel rejection, $\pm 7\text{ MHz}$ <sup>(1)</sup>	Wanted signal at -72 dBm, modulated interferer at $\geq \pm 7\text{ MHz}$ , BER = $10^{-3}$		44 / 44 <sup>(2)</sup>		dB
Selectivity, image frequency <sup>(1)</sup>	Wanted signal at -72 dBm, modulated interferer at image frequency, BER = $10^{-3}$		31		dB
Selectivity, image frequency $\pm 1\text{ MHz}$ <sup>(1)</sup>	Note that Image frequency + 1 MHz is the Co-channel -1 MHz. Wanted signal at -72 dBm, modulated interferer at $\pm 1\text{ MHz}$ from image frequency, BER = $10^{-3}$		5 / 41 <sup>(2)</sup>		dB
Blocker rejection, $\pm 8\text{ MHz}$ and above <sup>(1)</sup>	Wanted signal at -72 dBm, modulated interferer at $\pm 8\text{ MHz}$ and above, BER = $10^{-3}$		44		dB
Out-of-band blocking <sup>(3)</sup>	30 MHz to 2000 MHz		-35		dBm
Out-of-band blocking	2003 MHz to 2399 MHz		-19		dBm
Out-of-band blocking	2484 MHz to 2997 MHz		-19		dBm

(1) Numbers given as I/C dB.

(2) X / Y, where X is +N MHz and Y is -N MHz.

(3) Excluding one exception at  $F_{\text{wanted}} / 2$ , per Bluetooth Specification.

### 500-kbps Coded (Bluetooth 5) – RX (continued)

Measured on the TI CC2650EM-5XD reference design with  $T_c = 25^\circ\text{C}$ ,  $V_{\text{DD5}} = 3.0\text{ V}$ ,  $f_{\text{RF}} = 2440\text{ MHz}$ , unless otherwise noted.

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Intermodulation	Wanted signal at 2402 MHz, –69 dBm. Two interferers at 2405 and 2408 MHz respectively, at the given power level		–37		dBm

### 5.9 500-kbps Coded (Bluetooth 5) – TX

Measured on the TI CC2650EM-5XD reference design with  $T_c = 25^\circ\text{C}$ ,  $V_{\text{DD5}} = 3.0\text{ V}$ ,  $f_{\text{RF}} = 2440\text{ MHz}$ , unless otherwise noted.

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Output power, highest setting	Differential mode, delivered to a single-ended 50- $\Omega$ load through a balun		5		dBm
Output power, highest setting	Measured on CC2650EM-4XS, delivered to a single-ended 50- $\Omega$ load		2		dBm
Output power, lowest setting	Delivered to a single-ended 50- $\Omega$ load through a balun		–21		dBm
Spurious emission conducted measurement <sup>(1)</sup>	$f < 1\text{ GHz}$ , outside restricted bands		–43		dBm
	$f < 1\text{ GHz}$ , restricted bands ETSI		–65		dBm
	$f < 1\text{ GHz}$ , restricted bands FCC		–76		dBm
	$f > 1\text{ GHz}$ , including harmonics		–46		dBm

(1) Suitable for systems targeting compliance with worldwide radio-frequency regulations ETSI EN 300 328 and EN 300 440 Class 2 (Europe), FCC CFR47 Part 15 (US), and ARIB STD-T66 (Japan).

### 5.10 1-Mbps GFSK (Bluetooth low energy) – RX

Measured on the TI CC2650EM-5XD reference design with  $T_c = 25^\circ\text{C}$ ,  $V_{\text{DD5}} = 3.0\text{ V}$ ,  $f_{\text{RF}} = 2440\text{ MHz}$ , unless otherwise noted.

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Receiver sensitivity	Differential mode. Measured at the CC2650EM-5XD SMA connector, BER = $10^{-3}$		–97		dBm
Receiver sensitivity	Single-ended mode. Measured on CC2650EM-4XS, at the SMA connector, BER = $10^{-3}$		–96		dBm
Receiver saturation	Differential mode. Measured at the CC2650EM-5XD SMA connector, BER = $10^{-3}$		4		dBm
Receiver saturation	Single-ended mode. Measured on CC2650EM-4XS, at the SMA connector, BER = $10^{-3}$		0		dBm
Frequency error tolerance	Difference between the incoming carrier frequency and the internally generated carrier frequency	–350		350	kHz
Data rate error tolerance	Difference between incoming data rate and the internally generated data rate	–750		750	ppm
Co-channel rejection <sup>(1)</sup>	Wanted signal at –67 dBm, modulated interferer in channel, BER = $10^{-3}$		–6		dB
Selectivity, $\pm 1\text{ MHz}$ <sup>(1)</sup>	Wanted signal at –67 dBm, modulated interferer at $\pm 1\text{ MHz}$ , BER = $10^{-3}$		7 / 3 <sup>(2)</sup>		dB
Selectivity, $\pm 2\text{ MHz}$ <sup>(1)</sup>	Wanted signal at –67 dBm, modulated interferer at $\pm 2\text{ MHz}$ , BER = $10^{-3}$		34 / 25 <sup>(2)</sup>		dB
Selectivity, $\pm 3\text{ MHz}$ <sup>(1)</sup>	Wanted signal at –67 dBm, modulated interferer at $\pm 3\text{ MHz}$ , BER = $10^{-3}$		38 / 26 <sup>(2)</sup>		dB
Selectivity, $\pm 4\text{ MHz}$ <sup>(1)</sup>	Wanted signal at –67 dBm, modulated interferer at $\pm 4\text{ MHz}$ , BER = $10^{-3}$		42 / 29 <sup>(2)</sup>		dB
Selectivity, $\pm 5\text{ MHz}$ or more <sup>(1)</sup>	Wanted signal at –67 dBm, modulated interferer at $\geq \pm 5\text{ MHz}$ , BER = $10^{-3}$		32		dB
Selectivity, image frequency <sup>(1)</sup>	Wanted signal at –67 dBm, modulated interferer at image frequency, BER = $10^{-3}$		25		dB
Selectivity, image frequency $\pm 1\text{ MHz}$ <sup>(1)</sup>	Wanted signal at –67 dBm, modulated interferer at $\pm 1\text{ MHz}$ from image frequency, BER = $10^{-3}$		3 / 26 <sup>(2)</sup>		dB

(1) Numbers given as I/C dB.

(2) X / Y, where X is +N MHz and Y is –N MHz.

## 1-Mbps GFSK (Bluetooth low energy) – RX (continued)

Measured on the TI CC2650EM-5XD reference design with  $T_c = 25^\circ\text{C}$ ,  $V_{\text{DD5}} = 3.0\text{ V}$ ,  $f_{\text{RF}} = 2440\text{ MHz}$ , unless otherwise noted.

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Out-of-band blocking <sup>(3)</sup>	30 MHz to 2000 MHz		-20		dBm
Out-of-band blocking	2003 MHz to 2399 MHz		-5		dBm
Out-of-band blocking	2484 MHz to 2997 MHz		-8		dBm
Out-of-band blocking	3000 MHz to 12.75 GHz		-8		dBm
Intermodulation	Wanted signal at 2402 MHz, -64 dBm. Two interferers at 2405 and 2408 MHz respectively, at the given power level		-34		dBm
Spurious emissions, 30 to 1000 MHz	Conducted measurement in a 50- $\Omega$ single-ended load. Suitable for systems targeting compliance with EN 300 328, EN 300 440 class 2, FCC CFR47, Part 15 and ARIB STD-T-66		-71		dBm
Spurious emissions, 1 to 12.75 GHz	Conducted measurement in a 50- $\Omega$ single-ended load. Suitable for systems targeting compliance with EN 300 328, EN 300 440 class 2, FCC CFR47, Part 15 and ARIB STD-T-66		-62		dBm
RSSI dynamic range			70		dB
RSSI accuracy			$\pm 4$		dB

(3) Excluding one exception at  $F_{\text{wanted}} / 2$ , per Bluetooth Specification.

## 5.11 1-Mbps GFSK (Bluetooth low energy) – TX

Measured on the TI CC2650EM-5XD reference design with  $T_c = 25^\circ\text{C}$ ,  $V_{\text{DD5}} = 3.0\text{ V}$ ,  $f_{\text{RF}} = 2440\text{ MHz}$ , unless otherwise noted.

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Output power, highest setting	Differential mode, delivered to a single-ended 50- $\Omega$ load through a balun		5		dBm
Output power, highest setting	Measured on CC2650EM-4XS, delivered to a single-ended 50- $\Omega$ load		2		dBm
Output power, lowest setting	Delivered to a single-ended 50- $\Omega$ load through a balun		-21		dBm
Spurious emission conducted measurement <sup>(1)</sup>	$f < 1\text{ GHz}$ , outside restricted bands		-43		dBm
	$f < 1\text{ GHz}$ , restricted bands ETSI		-65		dBm
	$f < 1\text{ GHz}$ , restricted bands FCC		-76		dBm
	$f > 1\text{ GHz}$ , including harmonics		-46		dBm

(1) Suitable for systems targeting compliance with worldwide radio-frequency regulations ETSI EN 300 328 and EN 300 440 Class 2 (Europe), FCC CFR47 Part 15 (US), and ARIB STD-T66 (Japan).

## 5.12 2-Mbps GFSK (Bluetooth 5) – RX

Measured on the TI CC2650EM-5XD reference design with  $T_c = 25^\circ\text{C}$ ,  $V_{\text{DD5}} = 3.0\text{ V}$ ,  $f_{\text{RF}} = 2440\text{ MHz}$ , unless otherwise noted.

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Receiver sensitivity	Differential mode. Measured at the CC2650EM-5XD SMA connector, BER = $10^{-3}$		-92		dBm
Receiver saturation	Differential mode. Measured at the CC2650EM-5XD SMA connector, BER = $10^{-3}$		4		dBm
Frequency error tolerance	Difference between the incoming carrier frequency and the internally generated carrier frequency	-300		500	kHz
Data rate error tolerance	Difference between incoming data rate and the internally generated data rate	-1000		1000	ppm
Co-channel rejection <sup>(1)</sup>	Wanted signal at -67 dBm, modulated interferer in channel, BER = $10^{-3}$		-7		dB
Selectivity, $\pm 2\text{ MHz}$ <sup>(1)</sup>	Wanted signal at -67 dBm, modulated interferer at $\pm 2\text{ MHz}$ , Image frequency is at -2 MHz BER = $10^{-3}$		8 / 4 <sup>(2)</sup>		dB

(1) Numbers given as I/C dB.

(2) X / Y, where X is +N MHz and Y is -N MHz.

## 2-Mbps GFSK (Bluetooth 5) – RX (continued)

Measured on the TI CC2650EM-5XD reference design with  $T_c = 25^\circ\text{C}$ ,  $V_{\text{DDS}} = 3.0\text{ V}$ ,  $f_{\text{RF}} = 2440\text{ MHz}$ , unless otherwise noted.

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Selectivity, $\pm 4\text{ MHz}^{(1)}$	Wanted signal at $-67\text{ dBm}$ , modulated interferer at $\pm 4\text{ MHz}$ , $\text{BER} = 10^{-3}$		31 / 26 <sup>(2)</sup>		dB
Selectivity, $\pm 6\text{ MHz}^{(1)}$	Wanted signal at $-67\text{ dBm}$ , modulated interferer at $\pm 6\text{ MHz}$ , $\text{BER} = 10^{-3}$		37 / 38 <sup>(2)</sup>		dB
Alternate channel rejection, $\pm 7\text{ MHz}^{(1)}$	Wanted signal at $-67\text{ dBm}$ , modulated interferer at $\geq \pm 7\text{ MHz}$ , $\text{BER} = 10^{-3}$		37 / 36 <sup>(2)</sup>		dB
Selectivity, image frequency <sup>(1)</sup>	Wanted signal at $-67\text{ dBm}$ , modulated interferer at image frequency, $\text{BER} = 10^{-3}$		4		dB
Selectivity, image frequency $\pm 2\text{ MHz}^{(1)}$	Note that Image frequency + 2 MHz is the Co-channel. Wanted signal at $-67\text{ dBm}$ , modulated interferer at $\pm 2\text{ MHz}$ from image frequency, $\text{BER} = 10^{-3}$		-7 / 26 <sup>(2)</sup>		dB
Out-of-band blocking <sup>(3)</sup>	30 MHz to 2000 MHz		-33		dBm
Out-of-band blocking	2003 MHz to 2399 MHz		-15		dBm
Out-of-band blocking	2484 MHz to 2997 MHz		-12		dBm
Out-of-band blocking	3000 MHz to 12.75 GHz		-10		dBm
Intermodulation	Wanted signal at 2402 MHz, $-64\text{ dBm}$ . Two interferers at 2405 and 2408 MHz respectively, at the given power level		-45		dBm

(3) Excluding one exception at  $F_{\text{wanted}} / 2$ , per Bluetooth Specification.

## 5.13 2-Mbps GFSK (Bluetooth 5) – TX

Measured on the TI CC2650EM-5XD reference design with  $T_c = 25^\circ\text{C}$ ,  $V_{\text{DDS}} = 3.0\text{ V}$ ,  $f_{\text{RF}} = 2440\text{ MHz}$ , unless otherwise noted.

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Output power, highest setting	Differential mode, delivered to a single-ended 50- $\Omega$ load through a balun		5		dBm
Output power, highest setting	Measured on CC2650EM-4XS, delivered to a single-ended 50- $\Omega$ load		2		dBm
Output power, lowest setting	Delivered to a single-ended 50- $\Omega$ load through a balun		-21		dBm
Spurious emission conducted measurement <sup>(1)</sup>	$f < 1\text{ GHz}$ , outside restricted bands		-43		dBm
	$f < 1\text{ GHz}$ , restricted bands ETSI		-65		dBm
	$f < 1\text{ GHz}$ , restricted bands FCC		-76		dBm
	$f > 1\text{ GHz}$ , including harmonics		-46		dBm

(1) Suitable for systems targeting compliance with worldwide radio-frequency regulations ETSI EN 300 328 and EN 300 440 Class 2 (Europe), FCC CFR47 Part 15 (US), and ARIB STD-T66 (Japan).

## 5.14 24-MHz Crystal Oscillator (XOSC\_HF)

$T_c = 25^\circ\text{C}$ ,  $V_{\text{DDS}} = 3.0\text{ V}$ , unless otherwise noted.<sup>(1)</sup>

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
ESR Equivalent series resistance <sup>(2)</sup>	$6\text{ pF} < C_L \leq 9\text{ pF}$		20	60	$\Omega$
ESR Equivalent series resistance <sup>(2)</sup>	$5\text{ pF} < C_L \leq 6\text{ pF}$			80	$\Omega$
$L_M$ Motional inductance <sup>(2)</sup>	Relates to load capacitance ( $C_L$ in Farads)		$< 1.6 \times 10^{-24} / C_L^2$		H
$C_L$ Crystal load capacitance <sup>(2)</sup>		5		9	pF
Crystal frequency <sup>(2)(3)</sup>			24		MHz
Crystal frequency tolerance <sup>(2)(4)</sup>		-40		40	ppm
Start-up time <sup>(3)(5)</sup>			150		$\mu\text{s}$

(1) Probing or otherwise stopping the XTAL while the DC-DC converter is enabled may cause permanent damage to the device.

(2) The crystal manufacturer's specification must satisfy this requirement

(3) Measured on the TI CC2650EM-5XD reference design with  $T_c = 25^\circ\text{C}$ ,  $V_{\text{DDS}} = 3.0\text{ V}$

(4) Includes initial tolerance of the crystal, drift over temperature, ageing and frequency pulling due to incorrect load capacitance. As per specification.

(5) Kick-started based on a temperature and aging compensated RCOSC\_HF using precharge injection.

### 5.15 32.768-kHz Crystal Oscillator (XOSC\_LF)

 $T_c = 25^\circ\text{C}$ ,  $V_{\text{DDS}} = 3.0\text{ V}$ , unless otherwise noted.

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Crystal frequency <sup>(1)</sup>			32.768		kHz
Crystal frequency tolerance, Bluetooth low-energy applications <sup>(1)(2)</sup>		-500		500	ppm
ESR Equivalent series resistance <sup>(1)</sup>			30	100	k $\Omega$
$C_L$ Crystal load capacitance <sup>(1)</sup>		6		12	pF

(1) The crystal manufacturer's specification must satisfy this requirement

(2) Includes initial tolerance of the crystal, drift over temperature, ageing and frequency pulling due to incorrect load capacitance. As per Bluetooth specification.

### 5.16 48-MHz RC Oscillator (RCOSC\_HF)

 Measured on the TI CC2650EM-5XD reference design with  $T_c = 25^\circ\text{C}$ ,  $V_{\text{DDS}} = 3.0\text{ V}$ , unless otherwise noted.

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Frequency			48		MHz
Uncalibrated frequency accuracy			$\pm 1\%$		
Calibrated frequency accuracy <sup>(1)</sup>			$\pm 0.25\%$		
Start-up time			5		$\mu\text{s}$

(1) Accuracy relative to the calibration source (XOSC\_HF).

### 5.17 32-kHz RC Oscillator (RCOSC\_LF)

 Measured on the TI CC2650EM-5XD reference design with  $T_c = 25^\circ\text{C}$ ,  $V_{\text{DDS}} = 3.0\text{ V}$ , unless otherwise noted.

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Calibrated frequency <sup>(1)</sup>			32.8		kHz
Temperature coefficient			50		ppm/ $^\circ\text{C}$

(1) The frequency accuracy of the Real Time Clock (RTC) is not directly dependent on the frequency accuracy of the 32-kHz RC Oscillator. The RTC can be calibrated to an accuracy within  $\pm 500$  ppm of 32.768 kHz by measuring the frequency error of RCOSC\_LF relative to XOSC\_HF and compensating the RTC tick speed. The procedure is explained in [Running Bluetooth® Low Energy on CC2640 Without 32 kHz Crystal](#).

### 5.18 ADC Characteristics

 $T_c = 25^\circ\text{C}$ ,  $V_{\text{DDS}} = 3.0\text{ V}$  and voltage scaling enabled, unless otherwise noted.<sup>(1)</sup>

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Input voltage range		0		V <sub>DDS</sub>	V
Resolution			12		Bits
Sample rate				200	ksps
Offset	Internal 4.3-V equivalent reference <sup>(2)</sup>		2		LSB
Gain error	Internal 4.3-V equivalent reference <sup>(2)</sup>		2.4		LSB
DNL <sup>(3)</sup> Differential nonlinearity			$> -1$		LSB
INL <sup>(4)</sup> Integral nonlinearity			$\pm 3$		LSB
ENOB Effective number of bits	Internal 4.3-V equivalent reference <sup>(2)</sup> , 200 ksps, 9.6-kHz input tone		9.8		Bits
	V <sub>DDS</sub> as reference, 200 ksps, 9.6-kHz input tone		10		
	Internal 1.44-V reference, voltage scaling disabled, 32 samples average, 200 ksps, 300-Hz input tone		11.1		

(1) Using IEEE Std 1241™-2010 for terminology and test methods.

(2) Input signal scaled down internally before conversion, as if voltage range was 0 to 4.3 V.

(3) No missing codes. Positive DNL typically varies from +0.3 to +3.5, depending on device (see [Figure 5-21](#)).

(4) For a typical example, see [Figure 5-22](#).

## ADC Characteristics (continued)

$T_c = 25^\circ\text{C}$ ,  $V_{\text{DD5}} = 3.0\text{ V}$  and voltage scaling enabled, unless otherwise noted.<sup>(1)</sup>

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
THD	Total harmonic distortion	Internal 4.3-V equivalent reference <sup>(2)</sup> , 200 ksps, 9.6-kHz input tone		-65		dB
		VDDS as reference, 200 ksps, 9.6-kHz input tone		-69		
		Internal 1.44-V reference, voltage scaling disabled, 32 samples average, 200 ksps, 300-Hz input tone		-71		
SINAD, SNDR	Signal-to-noise and Distortion ratio	Internal 4.3-V equivalent reference <sup>(2)</sup> , 200 ksps, 9.6-kHz input tone		60		dB
		VDDS as reference, 200 ksps, 9.6-kHz input tone		63		
		Internal 1.44-V reference, voltage scaling disabled, 32 samples average, 200 ksps, 300-Hz input tone		69		
SFDR	Spurious-free dynamic range	Internal 4.3-V equivalent reference <sup>(2)</sup> , 200 ksps, 9.6-kHz input tone		67		dB
		VDDS as reference, 200 ksps, 9.6-kHz input tone		72		
		Internal 1.44-V reference, voltage scaling disabled, 32 samples average, 200 ksps, 300-Hz input tone		73		
Conversion time		Serial conversion, time-to-output, 24-MHz clock		50		clock-cycles
Current consumption		Internal 4.3-V equivalent reference <sup>(2)</sup>		0.66		mA
Current consumption		VDDS as reference		0.75		mA
Reference voltage		Equivalent fixed internal reference (input voltage scaling enabled). For best accuracy, the ADC conversion should be initiated through the TIRTOS API in order to include the gain/offset compensation factors stored in FCFG1.		4.3 <sup>(2)(5)</sup>		V
Reference voltage		Fixed internal reference (input voltage scaling disabled). For best accuracy, the ADC conversion should be initiated through the TIRTOS API in order to include the gain/offset compensation factors stored in FCFG1. This value is derived from the scaled value (4.3 V) as follows: $V_{\text{ref}} = 4.3\text{ V} \times 1408 / 4095$		1.48		V
Reference voltage		VDDS as reference (Also known as <i>RELATIVE</i> ) (input voltage scaling enabled)		VDDS		V
Reference voltage		VDDS as reference (Also known as <i>RELATIVE</i> ) (input voltage scaling disabled)		VDDS / 2.82 <sup>(5)</sup>		V
Input impedance		200 ksps, voltage scaling enabled. Capacitive input, Input impedance depends on sampling frequency and sampling time		>1		MΩ

(5) Applied voltage must be within absolute maximum ratings (Section 5.1) at all times.

## 5.19 Temperature Sensor

Measured on the TI CC2650EM-5XD reference design with  $T_c = 25^\circ\text{C}$ ,  $V_{\text{DD5}} = 3.0\text{ V}$ , unless otherwise noted.

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Resolution			4		°C
Range		-40		85	°C
Accuracy			±5		°C
Supply voltage coefficient <sup>(1)</sup>			3.2		°C/V

(1) Automatically compensated when using supplied driver libraries.



### 5.20 Battery Monitor

Measured on the TI CC2650EM-5XD reference design with  $T_c = 25^\circ\text{C}$ ,  $V_{\text{DDS}} = 3.0\text{ V}$ , unless otherwise noted.

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Resolution			50		mV
Range		1.8		3.8	V
Accuracy			13		mV

### 5.21 Continuous Time Comparator

$T_c = 25^\circ\text{C}$ ,  $V_{\text{DDS}} = 3.0\text{ V}$ , unless otherwise noted.

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Input voltage range		0		V <sub>DDS</sub>	V
External reference voltage		0		V <sub>DDS</sub>	V
Internal reference voltage	DCOUP <sub>L</sub> as reference		1.27		V
Offset			3		mV
Hysteresis			<2		mV
Decision time	Step from -10 mV to 10 mV		0.72		μs
Current consumption when enabled <sup>(1)</sup>			8.6		μA

(1) Additionally, the bias module must be enabled when running in standby mode.

### 5.22 Low-Power Clocked Comparator

$T_c = 25^\circ\text{C}$ ,  $V_{\text{DDS}} = 3.0\text{ V}$ , unless otherwise noted.

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Input voltage range		0		V <sub>DDS</sub>	V
Clock frequency			32		kHz
Internal reference voltage, V <sub>DDS</sub> / 2			1.49–1.51		V
Internal reference voltage, V <sub>DDS</sub> / 3			1.01–1.03		V
Internal reference voltage, V <sub>DDS</sub> / 4			0.78–0.79		V
Internal reference voltage, DCOUP <sub>L</sub> / 1			1.25–1.28		V
Internal reference voltage, DCOUP <sub>L</sub> / 2			0.63–0.65		V
Internal reference voltage, DCOUP <sub>L</sub> / 3			0.42–0.44		V
Internal reference voltage, DCOUP <sub>L</sub> / 4			0.33–0.34		V
Offset			<2		mV
Hysteresis			<5		mV
Decision time	Step from -50 mV to 50 mV		<1		clock-cycle
Current consumption when enabled			362		nA

### 5.23 Programmable Current Source

$T_c = 25^\circ\text{C}$ ,  $V_{\text{DDS}} = 3.0\text{ V}$ , unless otherwise noted.

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Current source programmable output range			0.25–20		μA
Resolution			0.25		μA
Current consumption <sup>(1)</sup>	Including current source at maximum programmable output		23		μA

(1) Additionally, the bias module must be enabled when running in standby mode.



## 5.24 Synchronous Serial Interface (SSI)

$T_c = 25^\circ\text{C}$ ,  $V_{DD5} = 3.0\text{ V}$ , unless otherwise noted.

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
S1 <sup>(1)</sup> $t_{\text{clk\_per}}$ (SSIClk period)	Device operating as SLAVE	12		65024	system clocks
S2 <sup>(1)</sup> $t_{\text{clk\_high}}$ (SSIClk high time)	Device operating as SLAVE		0.5		$t_{\text{clk\_per}}$
S3 <sup>(1)</sup> $t_{\text{clk\_low}}$ (SSIClk low time)	Device operating as SLAVE		0.5		$t_{\text{clk\_per}}$
S1 (TX only) <sup>(1)</sup> $t_{\text{clk\_per}}$ (SSIClk period)	One-way communication to SLAVE - Device operating as MASTER	4		65024	system clocks
S1 (TX and RX) <sup>(1)</sup> $t_{\text{clk\_per}}$ (SSIClk period)	Normal duplex operation - Device operating as MASTER	8		65024	system clocks
S2 <sup>(1)</sup> $t_{\text{clk\_high}}$ (SSIClk high time)	Device operating as MASTER		0.5		$t_{\text{clk\_per}}$
S3 <sup>(1)</sup> $t_{\text{clk\_low}}$ (SSIClk low time)	Device operating as MASTER		0.5		$t_{\text{clk\_per}}$

(1) Refer to SSI timing diagrams [Figure 5-1](#), [Figure 5-2](#), and [Figure 5-3](#).

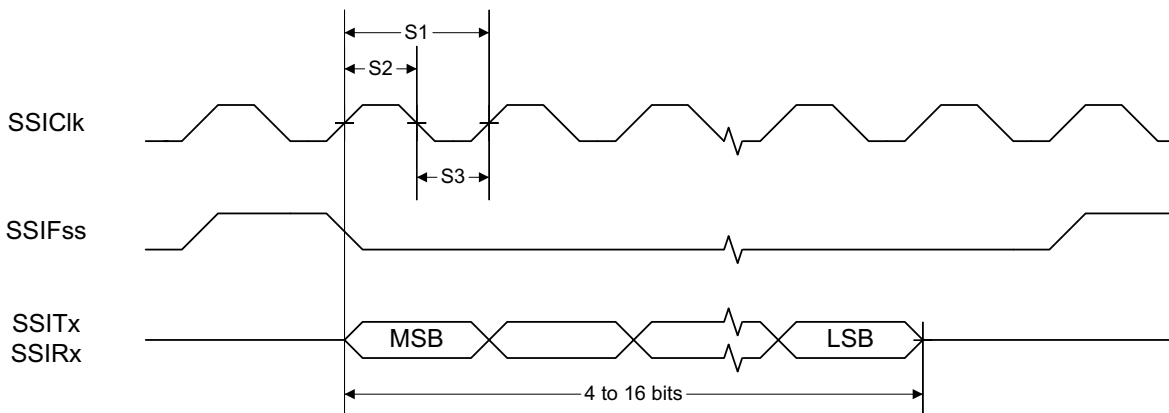


Figure 5-1. SSI Timing for TI Frame Format (FRF = 01), Single Transfer Timing Measurement

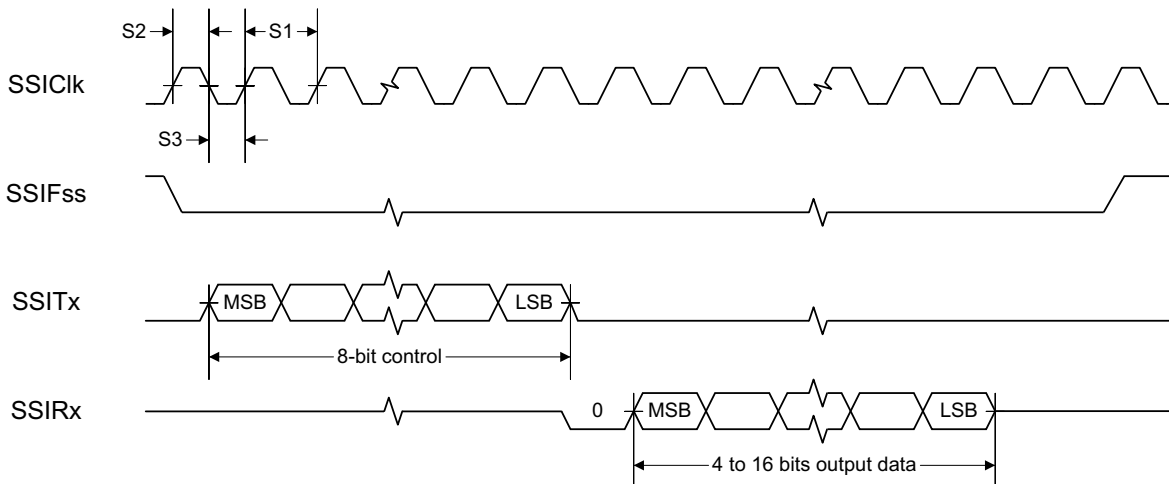


Figure 5-2. SSI Timing for MICROWIRE Frame Format (FRF = 10), Single Transfer

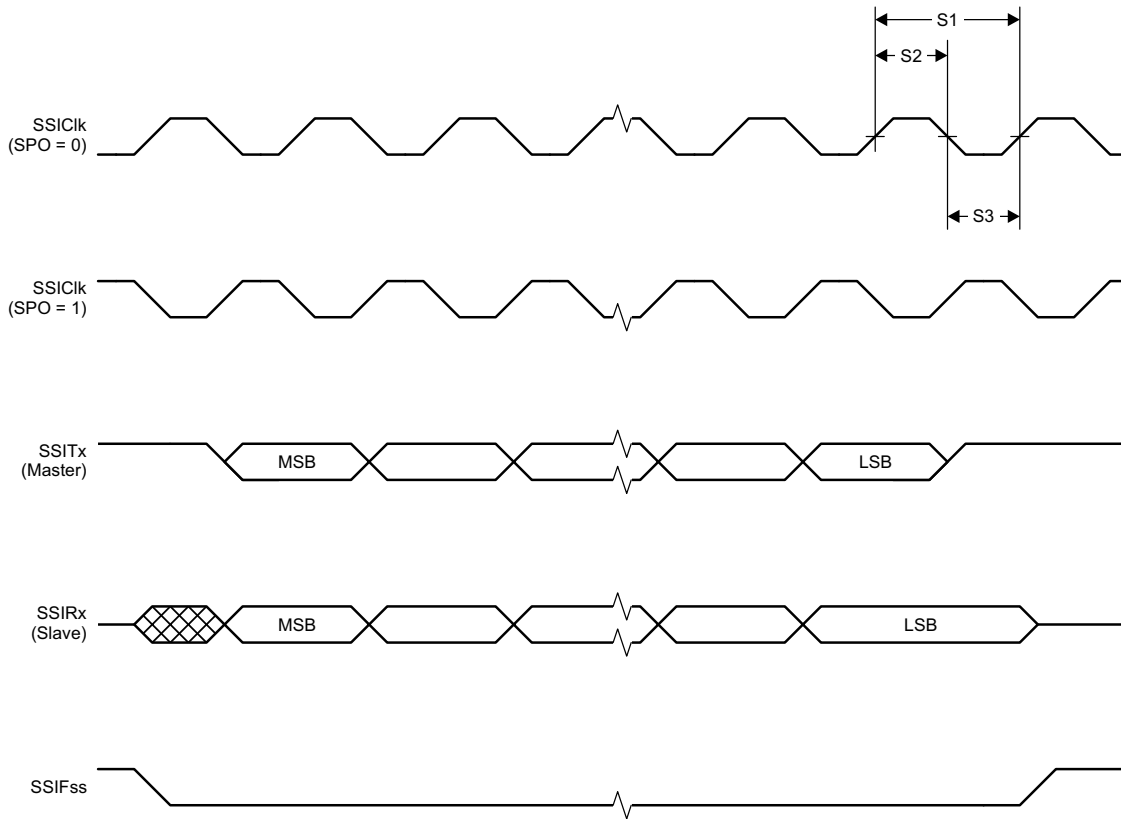


Figure 5-3. SSI Timing for SPI Frame Format (FRF = 00), With SPH = 1

5.25 DC Characteristics

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
<b>T<sub>A</sub> = 25°C, V<sub>DDs</sub> = 1.8 V</b>					
GPIO VOH at 8-mA load	IOCURR = 2, high-drive GPIOs only	1.32	1.54		V
GPIO VOL at 8-mA load	IOCURR = 2, high-drive GPIOs only		0.26	0.32	V
GPIO VOH at 4-mA load	IOCURR = 1	1.32	1.58		V
GPIO VOL at 4-mA load	IOCURR = 1		0.21	0.32	V
GPIO pullup current	Input mode, pullup enabled, Vpad = 0 V		71.7		µA
GPIO pulldown current	Input mode, pulldown enabled, Vpad = VDDs		21.1		µA
GPIO high/low input transition, no hysteresis	IH = 0, transition between reading 0 and reading 1		0.88		V
GPIO low-to-high input transition, with hysteresis	IH = 1, transition voltage for input read as 0 → 1		1.07		V
GPIO high-to-low input transition, with hysteresis	IH = 1, transition voltage for input read as 1 → 0		0.74		V
GPIO input hysteresis	IH = 1, difference between 0 → 1 and 1 → 0 points		0.33		V
<b>T<sub>A</sub> = 25°C, V<sub>DDs</sub> = 3.0 V</b>					
GPIO VOH at 8-mA load	IOCURR = 2, high-drive GPIOs only		2.68		V
GPIO VOL at 8-mA load	IOCURR = 2, high-drive GPIOs only		0.33		V
GPIO VOH at 4-mA load	IOCURR = 1		2.72		V
GPIO VOL at 4-mA load	IOCURR = 1		0.28		V
<b>T<sub>A</sub> = 25°C, V<sub>DDs</sub> = 3.8 V</b>					
GPIO pullup current	Input mode, pullup enabled, Vpad = 0 V		277		µA

**DC Characteristics (continued)**

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
GPIO pulldown current	Input mode, pulldown enabled, V <sub>pad</sub> = V <sub>DD5</sub>		113		μA
GPIO high/low input transition, no hysteresis	IH = 0, transition between reading 0 and reading 1		1.67		V
GPIO low-to-high input transition, with hysteresis	IH = 1, transition voltage for input read as 0 → 1		1.94		V
GPIO high-to-low input transition, with hysteresis	IH = 1, transition voltage for input read as 1 → 0		1.54		V
GPIO input hysteresis	IH = 1, difference between 0 → 1 and 1 → 0 points		0.4		V
<b>T<sub>A</sub> = 25°C</b>					
V <sub>IH</sub>	Lowest GPIO input voltage reliably interpreted as a «High»			0.8	V <sub>DD5</sub> <sup>(1)</sup>
V <sub>IL</sub>	Highest GPIO input voltage reliably interpreted as a «Low»	0.2			V <sub>DD5</sub> <sup>(1)</sup>

(1) Each GPIO is referenced to a specific V<sub>DD5</sub> pin. See the technical reference manual listed in [Section 8.3](#) for more details.

**5.26 Thermal Resistance Characteristics**

NAME	DESCRIPTION	RSM (°C/W) <sup>(1) (2)</sup>	RHB (°C/W) <sup>(1) (2)</sup>	RGZ (°C/W) <sup>(1) (2)</sup>	YFV (°C/W) <sup>(1) (2)</sup>
R <sub>θJA</sub>	Junction-to-ambient thermal resistance	36.9	32.8	29.6	76.2
R <sub>θJC(top)</sub>	Junction-to-case (top) thermal resistance	30.3	24.0	15.7	0.3
R <sub>θJB</sub>	Junction-to-board thermal resistance	7.6	6.8	6.2	16.3
Ψ <sub>SiJT</sub>	Junction-to-top characterization parameter	0.4	0.3	0.3	1.8
Ψ <sub>SiJB</sub>	Junction-to-board characterization parameter	7.4	6.8	6.2	16.3
R <sub>θJC(bot)</sub>	Junction-to-case (bottom) thermal resistance	2.1	1.9	1.9	N/A

(1) °C/W = degrees Celsius per watt.

(2) These values are based on a JEDEC-defined 2S2P system (with the exception of the Theta<sub>JC</sub> [R<sub>θJC</sub>] value, which is based on a JEDEC-defined 1S0P system) and will change based on environment as well as application. For more information, see these EIA/JEDEC standards:

- JESD51-2, *Integrated Circuits Thermal Test Method Environmental Conditions - Natural Convection (Still Air)*.
- JESD51-3, *Low Effective Thermal Conductivity Test Board for Leaded Surface Mount Packages*.
- JESD51-7, *High Effective Thermal Conductivity Test Board for Leaded Surface Mount Packages*.
- JESD51-9, *Test Boards for Area Array Surface Mount Package Thermal Measurements*.

For RSM, RHB, and RGZ, power dissipation of 2 W and an ambient temperature of 70°C is assumed. For YFV, power dissipation of 1.3 W and ambient temperature of 25°C is assumed.

## 5.27 Timing Requirements

	MIN	NOM	MAX	UNIT
Rising supply-voltage slew rate	0		100	mV/ $\mu$ s
Falling supply-voltage slew rate	0		20	mV/ $\mu$ s
Falling supply-voltage slew rate, with low-power flash settings <sup>(1)</sup>			3	mV/ $\mu$ s
Positive temperature gradient in standby <sup>(2)</sup>	No limitation for negative temperature gradient, or outside standby mode			5 °C/s
<b>CONTROL INPUT AC CHARACTERISTICS<sup>(3)</sup></b>				
RESET_N low duration	1			$\mu$ s

- (1) For smaller coin cell batteries, with high worst-case end-of-life equivalent source resistance, a 22- $\mu$ F V<sub>DD5</sub> input capacitor (see [Figure 7-1](#)) must be used to ensure compliance with this slew rate.
- (2) Applications using RCOSC\_LF as sleep timer must also consider the drift in frequency caused by a change in temperature (see [Section 5.17](#)).
- (3) T<sub>A</sub> = -40°C to +85°C, V<sub>DD5</sub> = 1.7 V to 3.8 V, unless otherwise noted.

## 5.28 Switching Characteristics

Measured on the TI CC2650EM-5XD reference design with T<sub>c</sub> = 25°C, V<sub>DD5</sub> = 3.0 V, unless otherwise noted.

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
<b>WAKEUP AND TIMING</b>					
Idle → Active			14		$\mu$ s
Standby → Active			151		$\mu$ s
Shutdown → Active			1015		$\mu$ s

### 5.29 Typical Characteristics

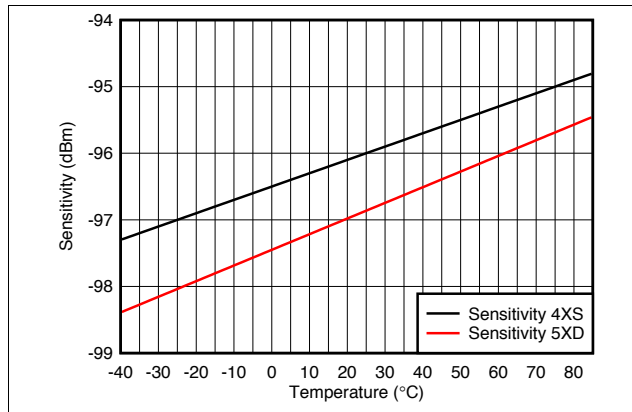


Figure 5-4. BLE Sensitivity vs Temperature

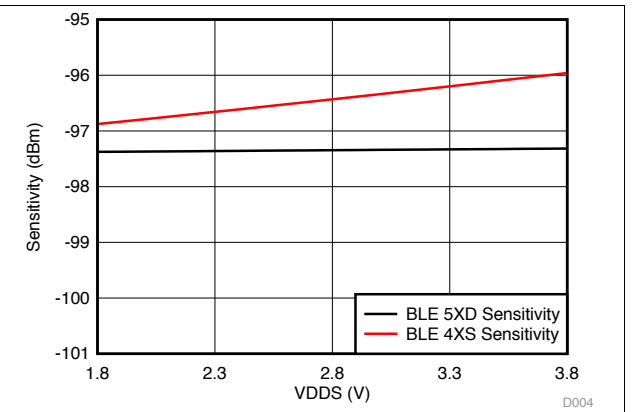


Figure 5-5. BLE Sensitivity vs Supply Voltage (VDD5)

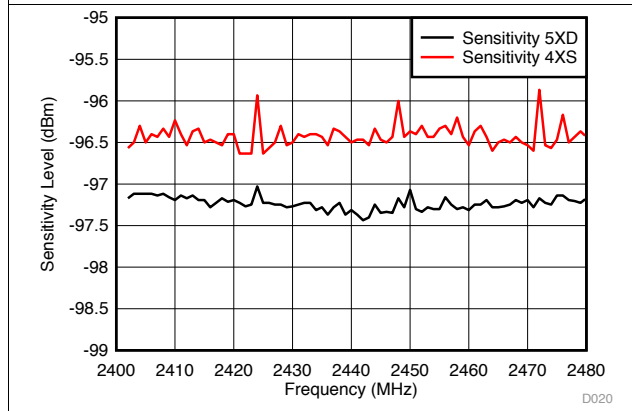


Figure 5-6. BLE Sensitivity vs Channel Frequency

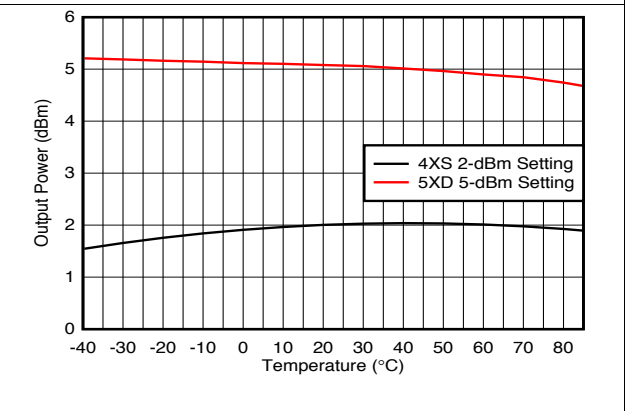


Figure 5-7. TX Output Power vs Temperature

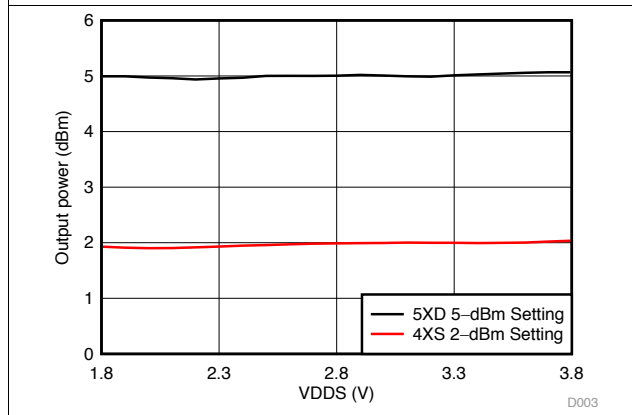


Figure 5-8. TX Output Power vs Supply Voltage (VDD5)

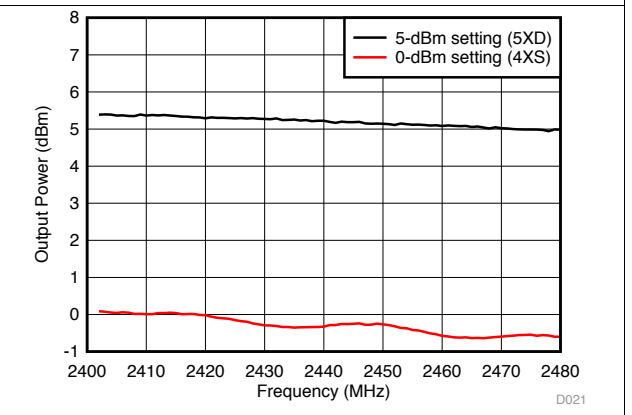
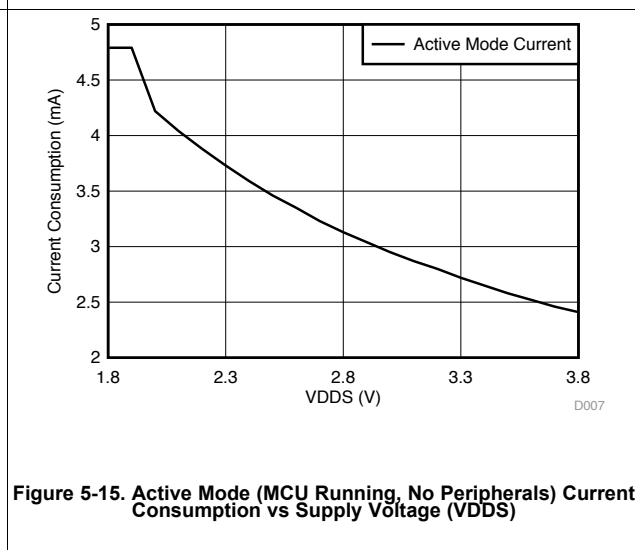
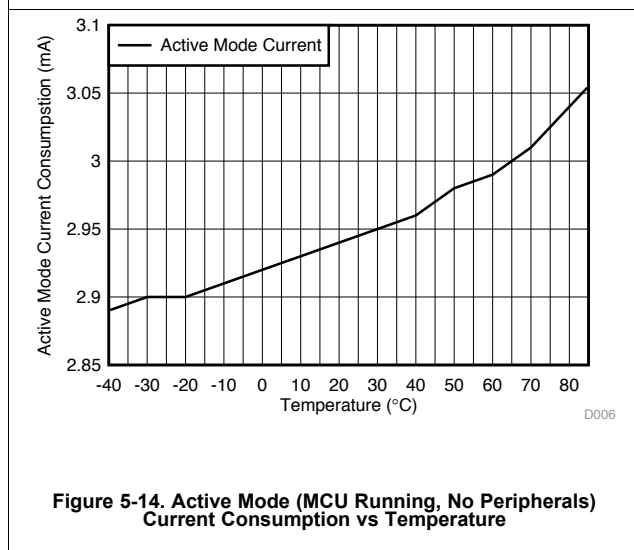
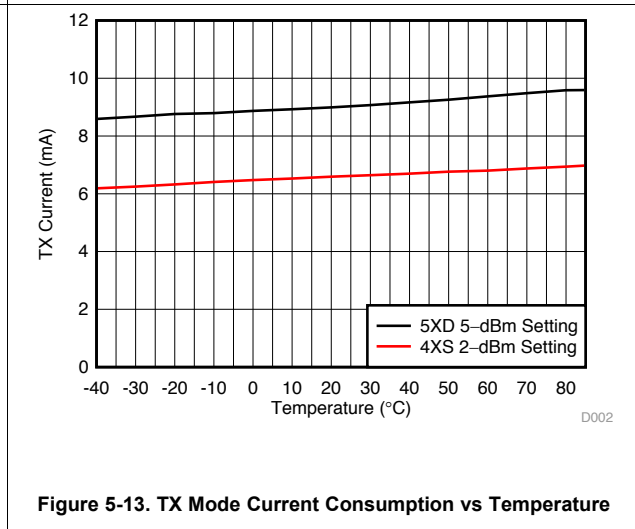
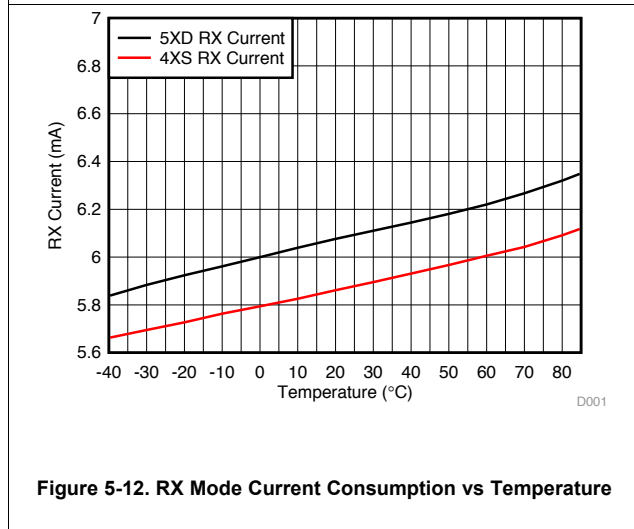
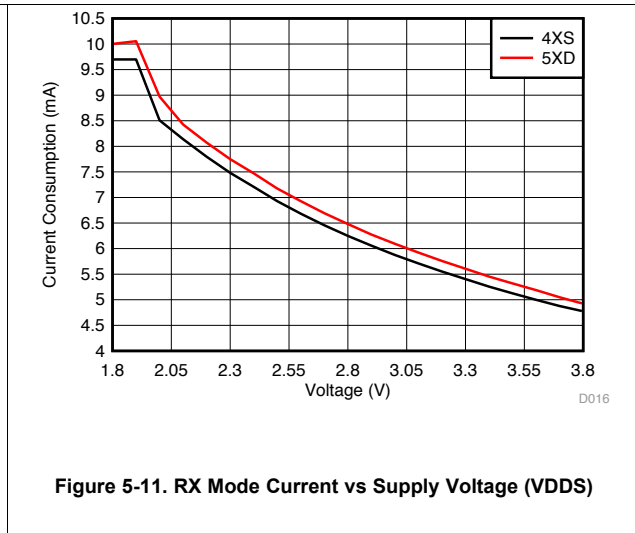
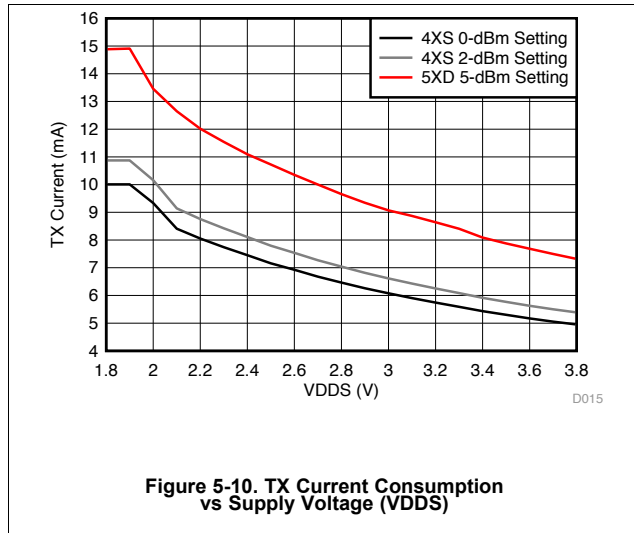


Figure 5-9. TX Output Power vs Channel Frequency

Typical Characteristics (continued)



Typical Characteristics (continued)

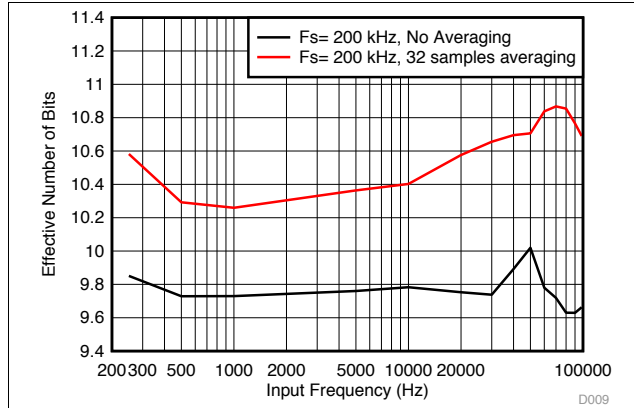


Figure 5-16. SoC ADC Effective Number of Bits vs Input Frequency (Internal Reference, Scaling enabled)

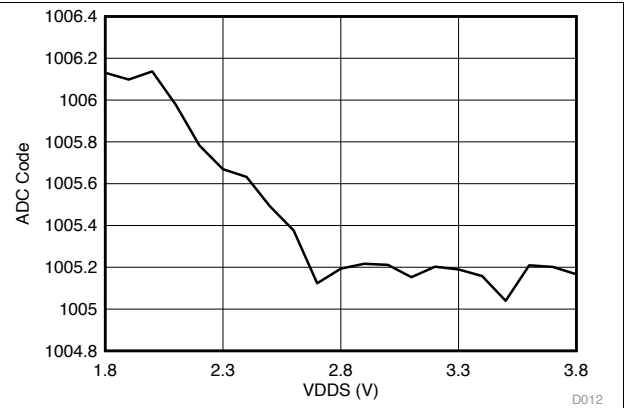


Figure 5-17. SoC ADC Output vs Supply Voltage (Fixed Input, Internal Reference)

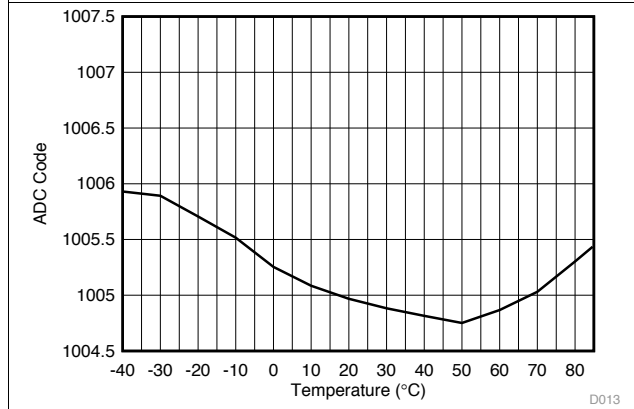


Figure 5-18. SoC ADC Output vs Temperature (Fixed Input, Internal Reference)

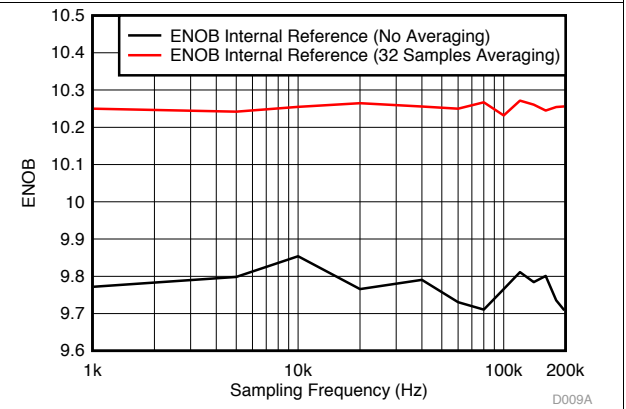


Figure 5-19. SoC ADC ENOB vs Sampling Frequency (Scaling enabled, input frequency = FS / 10)

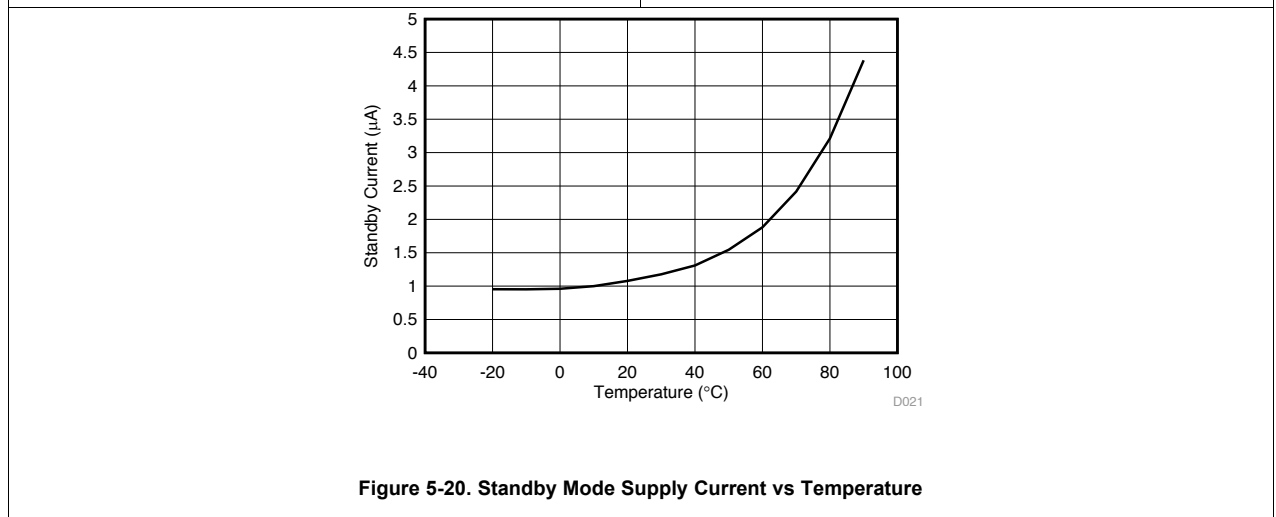
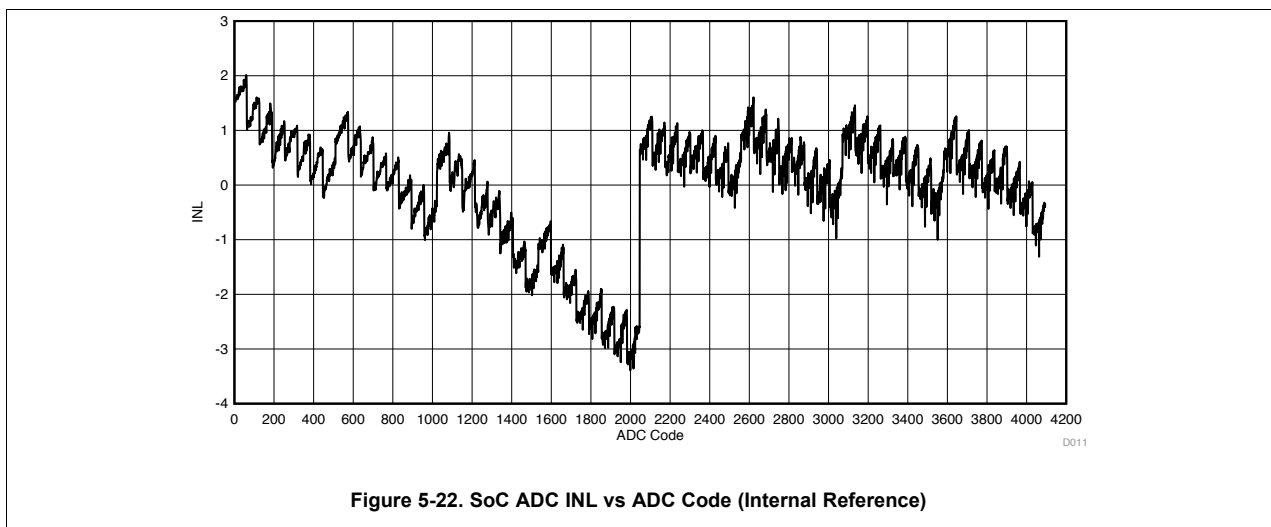
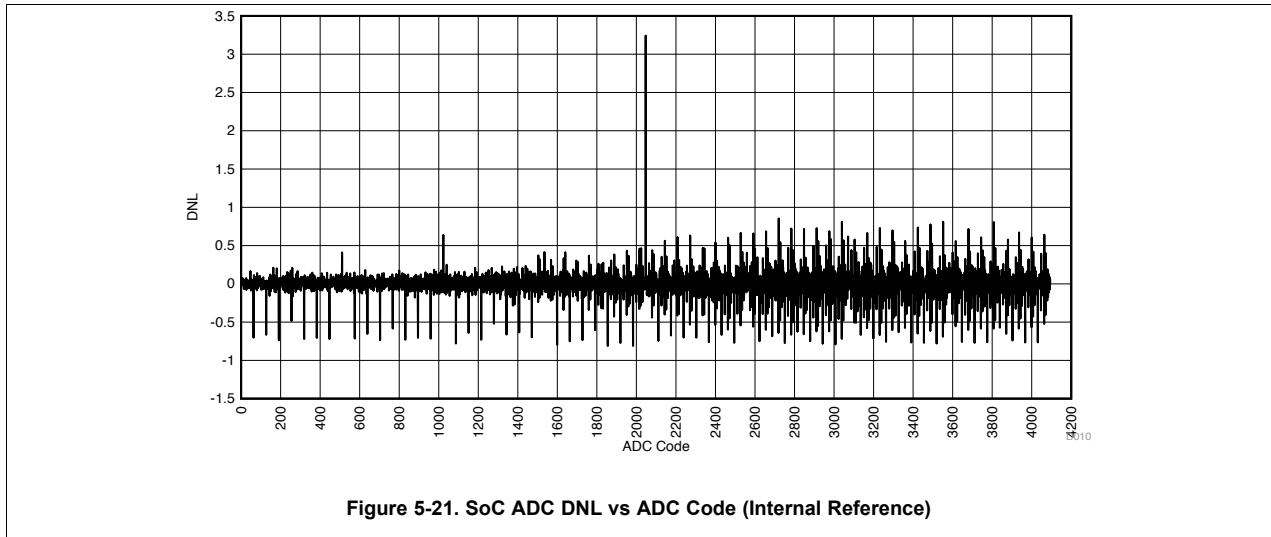


Figure 5-20. Standby Mode Supply Current vs Temperature

Typical Characteristics (continued)



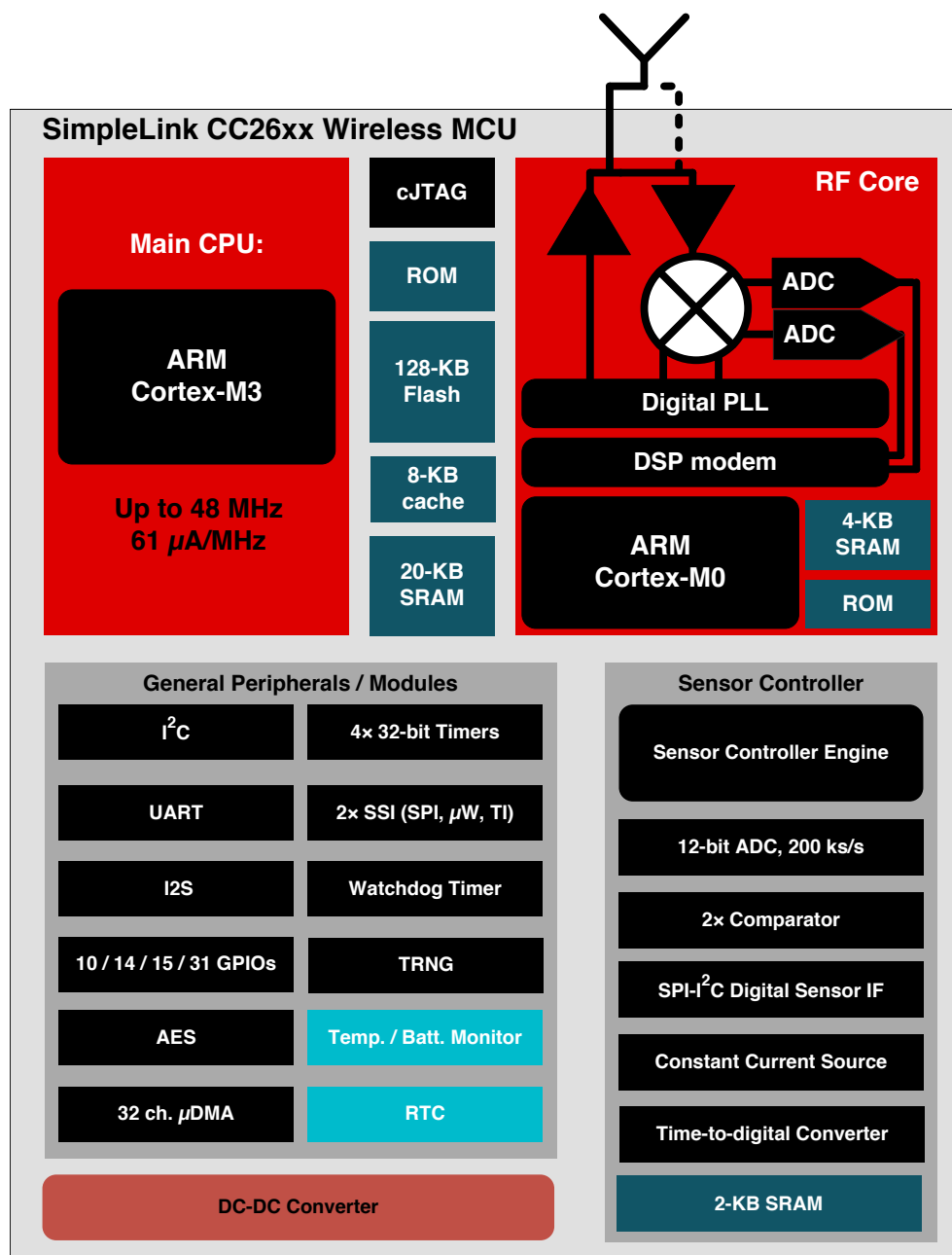


## 6 Detailed Description

### 6.1 Overview

The core modules of the CC26xx product family are shown in [Section 6.2](#).

### 6.2 Functional Block Diagram



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### 6.3 Main CPU

The SimpleLink CC2640R2F Wireless MCU contains an ARM Cortex-M3 (CM3) 32-bit CPU, which runs the application and the higher layers of the protocol stack.

The CM3 processor provides a high-performance, low-cost platform that meets the system requirements of minimal memory implementation, and low-power consumption, while delivering outstanding computational performance and exceptional system response to interrupts.

CM3 features include the following:

- 32-bit ARM Cortex-M3 architecture optimized for small-footprint embedded applications
- Outstanding processing performance combined with fast interrupt handling
- ARM Thumb<sup>®</sup>-2 mixed 16- and 32-bit instruction set delivers the high performance expected of a 32-bit ARM core in a compact memory size usually associated with 8- and 16-bit devices, typically in the range of a few kilobytes of memory for microcontroller-class applications:
  - Single-cycle multiply instruction and hardware divide
  - Atomic bit manipulation (bit-banding), delivering maximum memory use and streamlined peripheral control
  - Unaligned data access, enabling data to be efficiently packed into memory
- Fast code execution permits slower processor clock or increases sleep mode time
- Harvard architecture characterized by separate buses for instruction and data
- Efficient processor core, system, and memories
- Hardware division and fast digital-signal-processing oriented multiply accumulate
- Saturating arithmetic for signal processing
- Deterministic, high-performance interrupt handling for time-critical applications
- Enhanced system debug with extensive breakpoint and trace capabilities
- Serial wire trace reduces the number of pins required for debugging and tracing
- Migration from the ARM7<sup>™</sup> processor family for better performance and power efficiency
- Optimized for single-cycle flash memory use
- Ultralow-power consumption with integrated sleep modes
- 1.25 DMIPS per MHz

### 6.4 RF Core

The RF Core contains an ARM Cortex-M0 processor that interfaces the analog RF and base-band circuitries, handles data to and from the system side, and assembles the information bits in a given packet structure. The RF core offers a high level, command-based API to the main CPU.

The RF core is capable of autonomously handling the time-critical aspects of the radio protocols (Bluetooth low energy) thus offloading the main CPU and leaving more resources for the user application.

The RF core has a dedicated 4-KB SRAM block and runs initially from separate ROM memory. The ARM Cortex-M0 processor is not programmable by customers.

## 6.5 Sensor Controller

The Sensor Controller contains circuitry that can be selectively enabled in standby mode. The peripherals in this domain may be controlled by the Sensor Controller Engine, which is a proprietary power-optimized CPU. This CPU can read and monitor sensors or perform other tasks autonomously, thereby significantly reducing power consumption and offloading the main CM3 CPU. The GPIOs that can be connected to the Sensor Controller are listed in [Table 6-1](#).

The Sensor Controller is set up using a PC-based configuration tool, called Sensor Controller Studio, and potential use cases may be (but are not limited to):

- Analog sensors using integrated ADC
- Digital sensors using GPIOs, bit-banged I<sup>2</sup>C, and SPI
- UART communication for sensor reading or debugging
- Capacitive sensing
- Waveform generation
- Pulse counting
- Keyboard scan
- Quadrature decoder for polling rotation sensors
- Oscillator calibration

---

### NOTE

Texas Instruments provides application examples for some of these use cases, but not for all of them.

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The peripherals in the Sensor Controller include the following:

- The low-power clocked comparator can be used to wake the device from any state in which the comparator is active. A configurable internal reference can be used in conjunction with the comparator. The output of the comparator can also be used to trigger an interrupt or the ADC.
- Capacitive sensing functionality is implemented through the use of a constant current source, a time-to-digital converter, and a comparator. The continuous time comparator in this block can also be used as a higher-accuracy alternative to the low-power clocked comparator. The Sensor Controller will take care of baseline tracking, hysteresis, filtering and other related functions.
- The ADC is a 12-bit, 200-ksamples/s ADC with eight inputs and a built-in voltage reference. The ADC can be triggered by many different sources, including timers, I/O pins, software, the analog comparator, and the RTC.
- The Sensor Controller also includes a SPI–I<sup>2</sup>C digital interface.
- The analog modules can be connected to up to eight different GPIOs.

The peripherals in the Sensor Controller can also be controlled from the main application processor.

**Table 6-1. GPIOs Connected to the Sensor Controller<sup>(1)</sup>**

ANALOG CAPABLE	7 × 7 RGZ DIO NUMBER	5 × 5 RHB DIO NUMBER	2.7 × 2.7 YFV DIO NUMBER	4 × 4 RSM DIO NUMBER
Y	30	14		
Y	29	13	13	
Y	28	12	12	
Y	27	11	11	9
Y	26	9	9	8
Y	25	10	10	7
Y	24	8	8	6
Y	23	7	7	5
N	7	4	4	2
N	6	3	3	1
N	5	2	2	0
N	4	1	1	
N	3	0	0	
N	2			
N	1			
N	0			

(1) Depending on the package size, up to 16 pins can be connected to the Sensor Controller. Up to 8 of these pins can be connected to analog modules.

## 6.6 Memory

The flash memory provides nonvolatile storage for code and data. The flash memory is in-system programmable.

The SRAM (static RAM) can be used for both storage of data and execution of code and is split into two 4-KB blocks and two 6-KB blocks. Retention of the RAM contents in standby mode can be enabled or disabled individually for each block to minimize power consumption. In addition, if flash cache is disabled, the 8-KB cache can be used as a general-purpose RAM.

The ROM provides preprogrammed embedded TI RTOS kernel, Driverlib and lower layer protocol stack software (Bluetooth low energy Controller). It also contains a bootloader that can be used to reprogram the device using SPI or UART. For CC2640R2Fxxx devices, the ROM contains Bluetooth 4.2 low energy host- and controller software libraries, leaving more of the flash memory available for the customer application.

## 6.7 Debug

The on-chip debug support is done through a dedicated cJTAG (IEEE 1149.7) or JTAG (IEEE 1149.1) interface.

## 6.8 Power Management

To minimize power consumption, the CC2640R2F device supports a number of power modes and power management features (see [Table 6-2](#)).

**Table 6-2. Power Modes**

MODE	SOFTWARE CONFIGURABLE POWER MODES				RESET PIN HELD
	ACTIVE	IDLE	STANDBY	SHUTDOWN	
CPU	Active	Off	Off	Off	Off
Flash	On	Available	Off	Off	Off
SRAM	On	On	On	Off	Off
Radio	Available	Available	Off	Off	Off
Supply System	On	On	Duty Cycled	Off	Off
Current	1.45 mA + 31 µA/MHz	550 µA	1 µA	0.15 µA	0.1 µA
Wake-up Time to CPU Active <sup>(1)</sup>	–	14 µs	151 µs	1015 µs	1015 µs
Register Retention	Full	Full	Partial	No	No
SRAM Retention	Full	Full	Full	No	No
High-Speed Clock	XOSC_HF or RCOSC_HF	XOSC_HF or RCOSC_HF	Off	Off	Off
Low-Speed Clock	XOSC_LF or RCOSC_LF	XOSC_LF or RCOSC_LF	XOSC_LF or RCOSC_LF	Off	Off
Peripherals	Available	Available	Off	Off	Off
Sensor Controller	Available	Available	Available	Off	Off
Wake up on RTC	Available	Available	Available	Off	Off
Wake up on Pin Edge	Available	Available	Available	Available	Off
Wake up on Reset Pin	Available	Available	Available	Available	Available
Brown Out Detector (BOD)	Active	Active	Duty Cycled	Off	N/A
Power On Reset (POR)	Active	Active	Active	Active	N/A

(1) Not including RTOS overhead

In active mode, the application CM3 CPU is actively executing code. Active mode provides normal operation of the processor and all of the peripherals that are currently enabled. The system clock can be any available clock source (see [Table 6-2](#)).

In idle mode, all active peripherals can be clocked, but the Application CPU core and memory are not clocked and no code is executed. Any interrupt event will bring the processor back into active mode.

In standby mode, only the always-on domain (AON) is active. An external wake-up event, RTC event, or sensor-controller event is required to bring the device back to active mode. MCU peripherals with retention do not need to be reconfigured when waking up again, and the CPU continues execution from where it went into standby mode. All GPIOs are latched in standby mode.

In shutdown mode, the device is turned off entirely, including the AON domain and the Sensor Controller. The I/Os are latched with the value they had before entering shutdown mode. A change of state on any I/O pin defined as a *wake-up from Shutdown pin* wakes up the device and functions as a reset trigger. The CPU can differentiate between a reset in this way, a reset-by-reset pin, or a power-on-reset by reading the reset status register. The only state retained in this mode is the latched I/O state and the Flash memory contents.

The Sensor Controller is an autonomous processor that can control the peripherals in the Sensor Controller independently of the main CPU, which means that the main CPU does not have to wake up, for example, to execute an ADC sample or poll a digital sensor over SPI. The main CPU saves both current and wake-up time that would otherwise be wasted. The Sensor Controller Studio enables the user to configure the sensor controller and choose which peripherals are controlled and which conditions wake up the main CPU.

## 6.9 Clock Systems

The CC2640R2F supports two external and two internal clock sources.

A 24-MHz crystal is required as the frequency reference for the radio. This signal is doubled internally to create a 48-MHz clock.

The 32-kHz crystal is optional. *Bluetooth* low energy requires a slow-speed clock with better than  $\pm 500$  ppm accuracy if the device is to enter any sleep mode while maintaining a connection. The internal 32-kHz RC oscillator can in some use cases be compensated to meet the requirements. The low-speed crystal oscillator is designed for use with a 32-kHz watch-type crystal.

The internal high-speed oscillator (48-MHz) can be used as a clock source for the CPU subsystem.

The internal low-speed oscillator (32.768-kHz) can be used as a reference if the low-power crystal oscillator is not used.

The 32-kHz clock source can be used as external clocking reference through GPIO.

## 6.10 General Peripherals and Modules

The I/O controller controls the digital I/O pins and contains multiplexer circuitry to allow a set of peripherals to be assigned to I/O pins in a flexible manner. All digital I/Os are interrupt and wake-up capable, have a programmable pullup and pulldown function and can generate an interrupt on a negative or positive edge (configurable). When configured as an output, pins can function as either push-pull or open-drain. Five GPIOs have high drive capabilities (marked in **bold** in [Section 4](#)).

The SSIs are synchronous serial interfaces that are compatible with SPI, MICROWIRE, and Texas Instruments synchronous serial interfaces. The SSIs support both SPI master and slave up to 4 MHz.

The UART implements a universal asynchronous receiver/transmitter function. It supports flexible baud-rate generation up to a maximum of 3 Mbps .

Timer 0 is a general-purpose timer module (GPTM), which provides two 16-bit timers. The GPTM can be configured to operate as a single 32-bit timer, dual 16-bit timers or as a PWM module.

Timer 1, Timer 2, and Timer 3 are also GPTMs. Each of these timers is functionally equivalent to Timer 0.

In addition to these four timers, the RF core has its own timer to handle timing for RF protocols; the RF timer can be synchronized to the RTC.

The I<sup>2</sup>C interface is used to communicate with devices compatible with the I<sup>2</sup>C standard. The I<sup>2</sup>C interface is capable of 100-kHz and 400-kHz operation, and can serve as both I<sup>2</sup>C master and I<sup>2</sup>C slave.

The TRNG module provides a true, nondeterministic noise source for the purpose of generating keys, initialization vectors (IVs), and other random number requirements. The TRNG is built on 24 ring oscillators that create unpredictable output to feed a complex nonlinear combinatorial circuit.

The watchdog timer is used to regain control if the system fails due to a software error after an external device fails to respond as expected. The watchdog timer can generate an interrupt or a reset when a predefined time-out value is reached.

The device includes a direct memory access ( $\mu$ DMA) controller. The  $\mu$ DMA controller provides a way to offload data transfer tasks from the CM3 CPU, allowing for more efficient use of the processor and the available bus bandwidth. The  $\mu$ DMA controller can perform transfer between memory and peripherals. The  $\mu$ DMA controller has dedicated channels for each supported on-chip module and can be programmed to automatically perform transfers between peripherals and memory as the peripheral is ready to transfer more data. Some features of the  $\mu$ DMA controller include the following (this is not an exhaustive list):

- Highly flexible and configurable channel operation of up to 32 channels
- Transfer modes:
  - Memory-to-memory
  - Memory-to-peripheral
  - Peripheral-to-memory
  - Peripheral-to-peripheral
- Data sizes of 8, 16, and 32 bits

The AON domain contains circuitry that is always enabled, except for in Shutdown (where the digital supply is off). This circuitry includes the following:

- The RTC can be used to wake the device from any state where it is active. The RTC contains three compare and one capture registers. With software support, the RTC can be used for clock and calendar operation. The RTC is clocked from the 32-kHz RC oscillator or crystal. The RTC can also be compensated to tick at the correct frequency even when the internal 32-kHz RC oscillator is used instead of a crystal.
- The battery monitor and temperature sensor are accessible by software and give a battery status indication as well as a coarse temperature measure.

## 6.11 Voltage Supply Domains

The CC2640R2F device can interface to two or three different voltage domains depending on the package type. On-chip level converters ensure correct operation as long as the signal voltage on each input/output pin is set with respect to the corresponding supply pin (VDDS, VDDS2 or VDDS3). [Table 6-3](#) lists the pin-to-VDDS mapping.

**Table 6-3. Pin Function to VDDS Mapping Table**

	Package			
	VQFN 7 × 7 (RGZ)	VQFN 5 × 5 (RHB)	VQFN 4 × 4 (RSM)	DSBGA (YFV)
VDDS <sup>(1)</sup>	DIO 23–30 Reset_N	DIO 7–14 Reset_N	DIO 5–9 Reset_N	DIO 7–13 Reset_N
VDDS2	DIO 0–11	DIO 0–6 JTAG	DIO 0–4 JTAG	DIO 0–6 JTAG
VDDS3	DIO 12–22 JTAG	N/A	N/A	N/A

(1) VDDS\_DCDC must be connected to VDDS on the PCB.

## 6.12 System Architecture

Depending on the product configuration, CC26xx can function either as a Wireless Network Processor (WNP—an IC running the wireless protocol stack, with the application running on a separate MCU), or as a System-on-Chip (SoC), with the application and protocol stack running on the ARM CM3 core inside the device.

In the first case, the external host MCU communicates with the device using SPI or UART. In the second case, the application must be written according to the application framework supplied with the wireless protocol stack.

## 7 Application, Implementation, and Layout

### NOTE

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

### 7.1 Application Information

Very few external components are required for the operation of the CC2640R2F device. This section provides some general information about the various configuration options when using the CC2640R2F in an application, and then shows two examples of application circuits with schematics and layout. This is only a small selection of the many application circuit examples available as complete reference designs from the product folder on [www.ti.com](http://www.ti.com).

Figure 7-1 shows the various RF front-end configuration options. The RF front end can be used in differential- or single-ended configurations with the options of having internal or external biasing. These options allow for various trade-offs between cost, board space, and RF performance. Differential operation with external bias gives the best performance while single-ended operation with internal bias gives the least amount of external components and the lowest power consumption. Reference designs exist for each of these options.

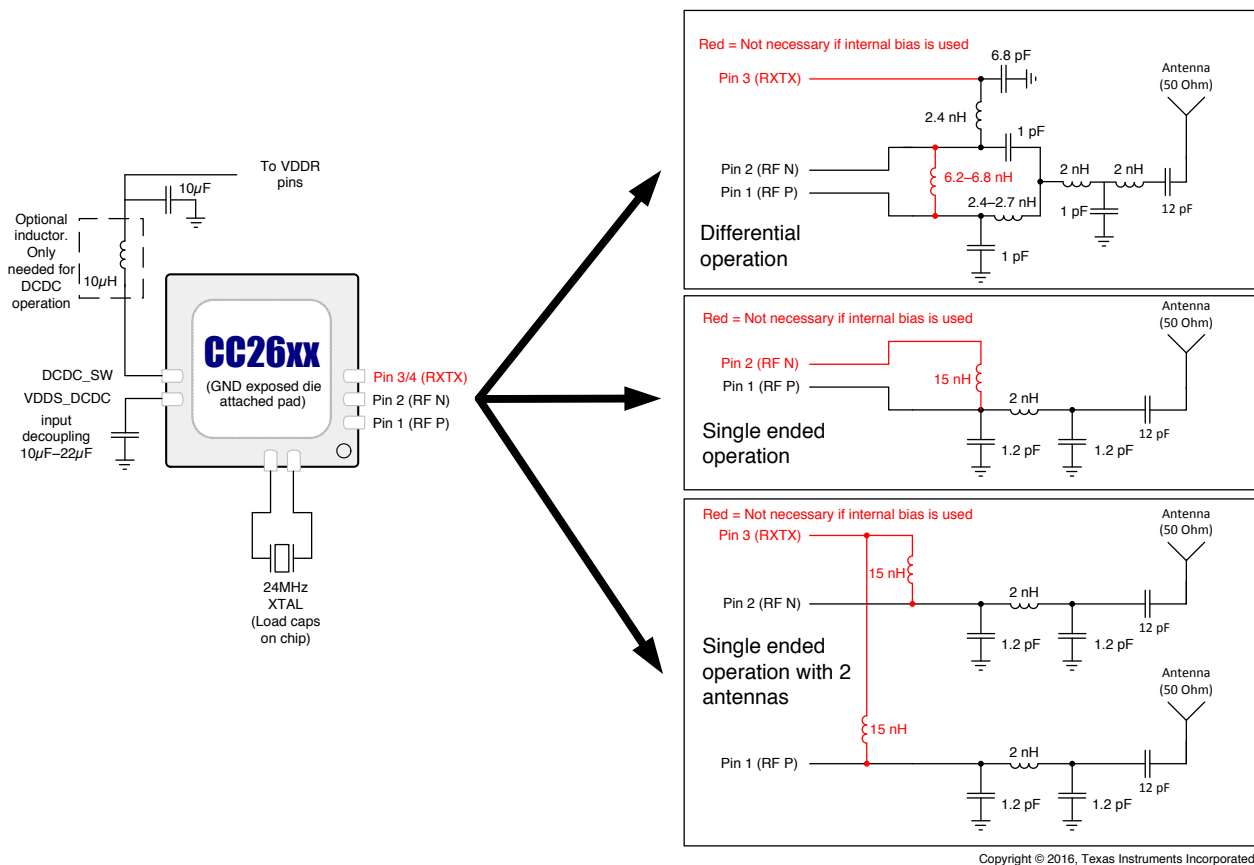


Figure 7-1. CC2640R2F Application Circuit



Figure 7-2 shows the various supply voltage configuration options. Not all power supply decoupling capacitors or digital I/Os are shown. Exact pin positions will vary between the different package options. For a detailed overview of power supply decoupling and wiring, see the TI reference designs and the CC26xx technical reference manual (Section 8.3).

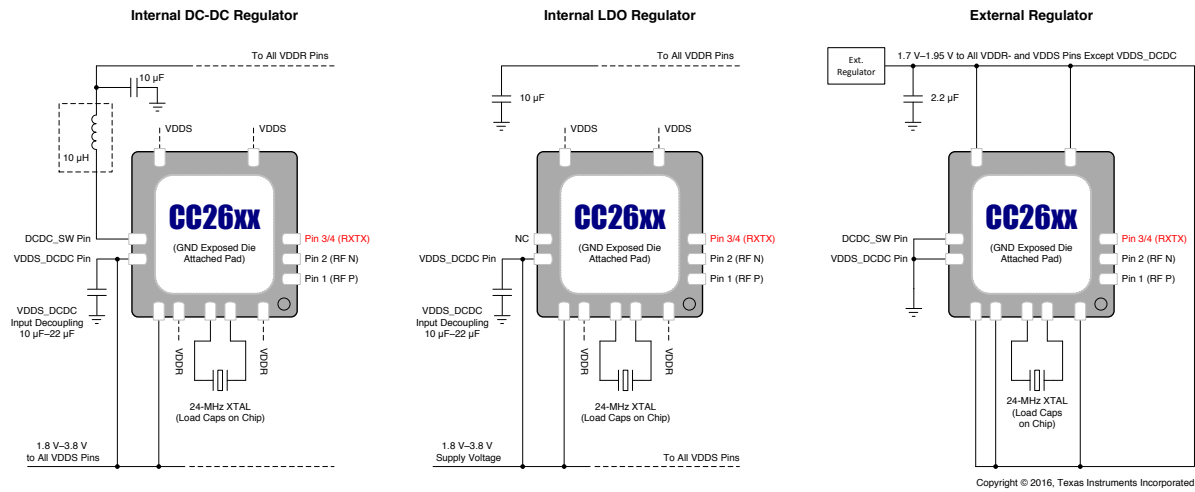


Figure 7-2. Supply Voltage Configurations



### 7.2.1 Layout

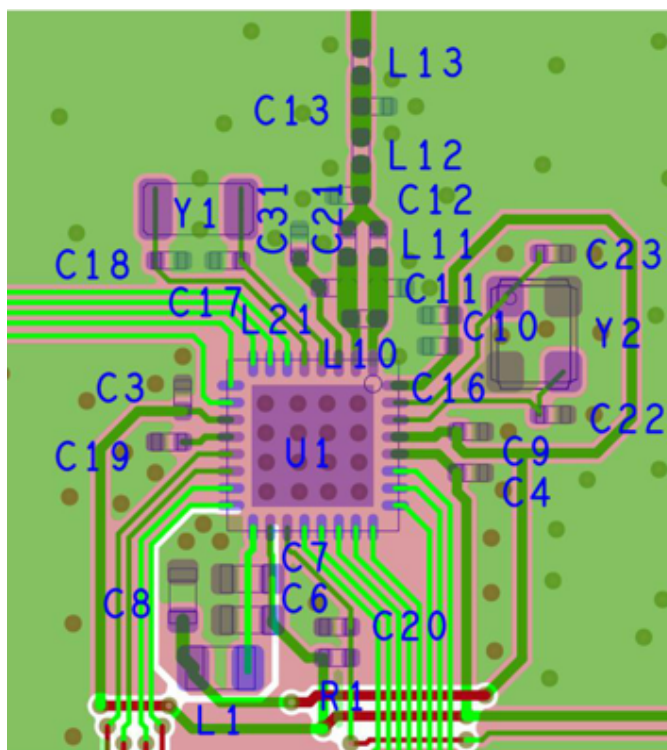


Figure 7-4. 5 × 5 External Differential (5XD) Layout

### 7.3 4 x 4 External Single-ended (4XS) Application Circuit

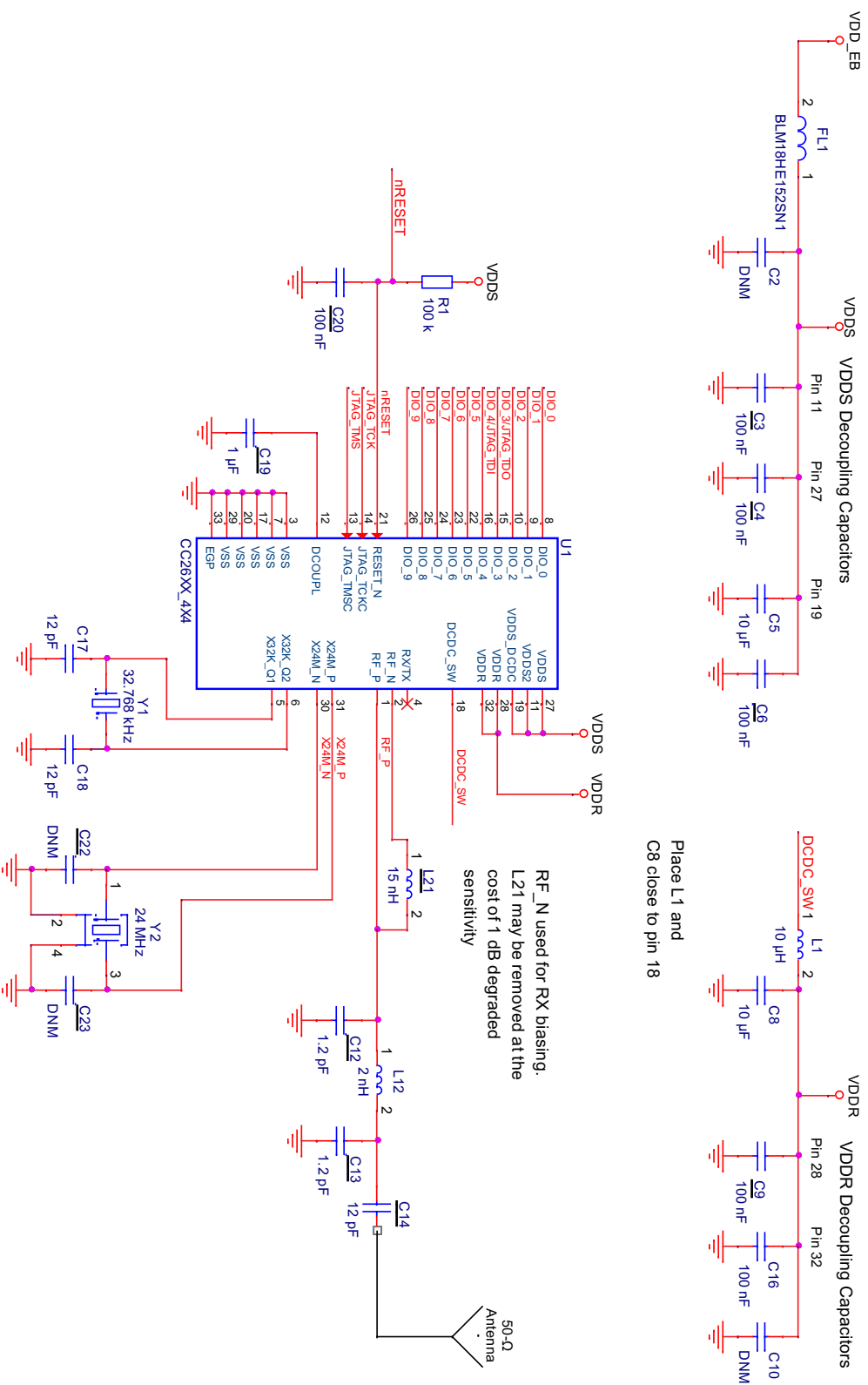


Figure 7-5. 4 x 4 External Single-ended (4XS) Application Circuit

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### 7.3.1 Layout

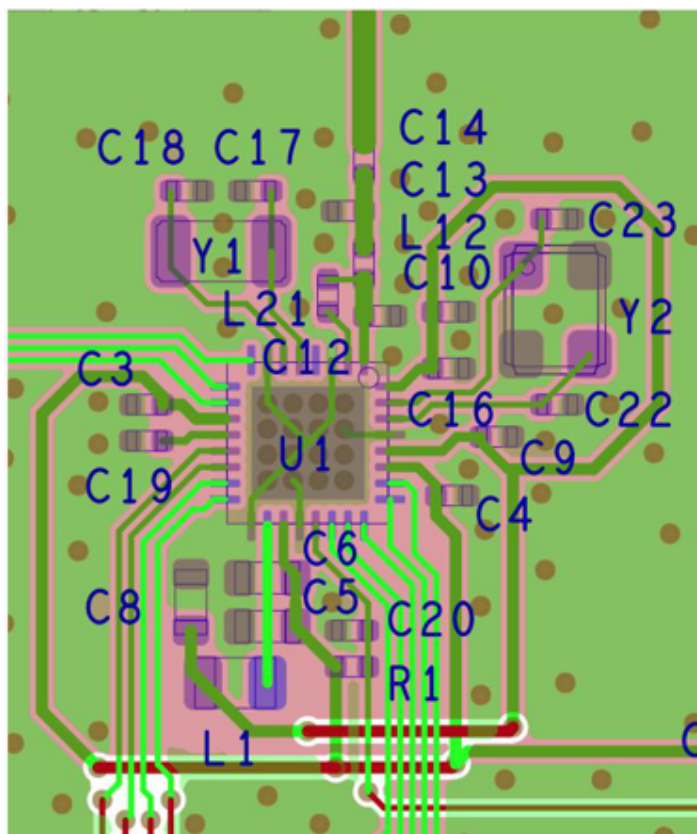


Figure 7-6. 4 × 4 External Single-ended (4XS) Layout

## 8 Device and Documentation Support

### 8.1 Device Nomenclature

To designate the stages in the product development cycle, TI assigns prefixes to all pre-production part numbers or date-code markings. Each device has one of three prefixes/identifications: X, P, or null (no prefix) (for example, CC2640R2F is in production; therefore, no prefix/identification is assigned).

Device development evolutionary flow:

- X** Experimental device that is not necessarily representative of the final device's electrical specifications and may not use production assembly flow.
- P** Prototype device that is not necessarily the final silicon die and may not necessarily meet final electrical specifications.
- null** Production version of the silicon die that is fully qualified.

Production devices have been characterized fully, and the quality and reliability of the device have been demonstrated fully. TI's standard warranty applies.

Predictions show that prototype devices (X or P) have a greater failure rate than the standard production devices. Texas Instruments recommends that these devices not be used in any production system because their expected end-use failure rate still is undefined. Only qualified production devices are to be used.

TI device nomenclature also includes a suffix with the device family name. This suffix indicates the package type (for example, ).

For orderable part numbers of the CC2640R2F device RSM, RHB, RGZ, or YFV package types, see the Package Option Addendum of this document, the TI website ([www.ti.com](http://www.ti.com)), or contact your TI sales representative.

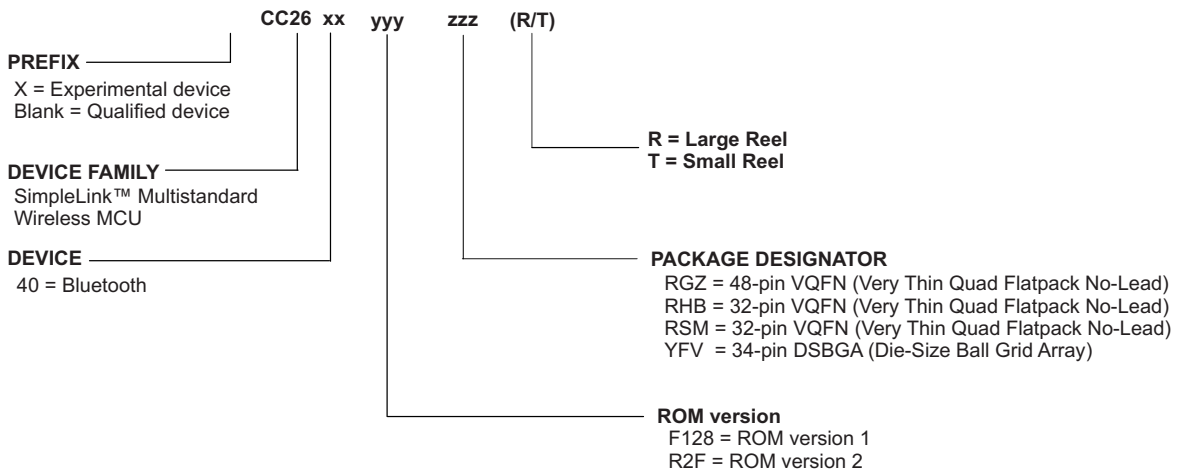


Figure 8-1. Device Nomenclature

## 8.2 Tools and Software

TI offers an extensive line of development tools, including tools to evaluate the performance of the processors, generate code, develop algorithm implementations, and fully integrate and debug software and hardware modules.

The following products support development of the CC2640R2F device applications:

### Software Tools:

**SmartRF Studio 7** is a PC application that helps designers of radio systems to easily evaluate the RF-IC at an early stage in the design process.

- Test functions for sending and receiving radio packets, continuous wave transmit and receive
- Evaluate RF performance on custom boards by wiring it to a supported evaluation board or debugger
- Can also be used without any hardware, but then only to generate, edit and export radio configuration settings
- Can be used in combination with several development kits for Texas Instruments' CCxxxx RF-ICs

**Sensor Controller Studio** provides a development environment for the CC26xx Sensor Controller. The Sensor Controller is a proprietary, power-optimized CPU in the CC26xx, which can perform simple background tasks autonomously and independent of the System CPU state.

- Allows for Sensor Controller task algorithms to be implemented using a C-like programming language
- Outputs a Sensor Controller Interface driver, which incorporates the generated Sensor Controller machine code and associated definitions
- Allows for rapid development by using the integrated Sensor Controller task testing and debugging functionality. This allows for live visualization of sensor data and algorithm verification.

### IDEs and Compilers:

Code Composer Studio:

- Integrated development environment with project management tools and editor
- Code Composer Studio (CCS) 7.0 and later has built-in support for the CC26xx device family
- Best support for XDS debuggers; XDS100v3, XDS110 and XDS200
- High integration with TI-RTOS with support for TI-RTOS Object View

IAR Embedded Workbench for ARM

- Integrated development environment with project management tools and editor
- IAR EWARM 7.80.1 and later has built-in support for the CC26xx device family
- Broad debugger support, supporting XDS100v3, XDS200, IAR I-Jet and Segger J-Link
- Integrated development environment with project management tools and editor
- RTOS plugin available for [TI-RTOS](#)

For a complete listing of development-support tools for the CC2640R2F platform, visit the Texas Instruments website at [www.ti.com](http://www.ti.com). For information on pricing and availability, contact the nearest TI field sales office or authorized distributor.

### 8.3 Documentation Support

To receive notification of documentation updates, navigate to the device product folder on [ti.com](http://ti.com) ([CC2640R2F](#)). In the upper right corner, click on Alert me to register and receive a weekly digest of any product information that has changed. For change details, review the revision history included in any revised document.

The current documentation that describes the CC2640R2F devices, related peripherals, and other technical collateral is listed in the following.

#### Technical Reference Manual

[CC13xx, CC26xx SimpleLink™ Wireless MCU Technical Reference Manual](#)

### 8.4 Texas Instruments Low-Power RF Website

Texas Instruments' Low-Power RF website has all the latest products, application and design notes, FAQ section, news and events updates. Go to [www.ti.com/lprf](http://www.ti.com/lprf).

### 8.5 Low-Power RF eNewsletter

The Low-Power RF eNewsletter is up-to-date on new products, news releases, developers' news, and other news and events associated with low-power RF products from TI. The Low-Power RF eNewsletter articles include links to get more online information.

Sign up at: [www.ti.com/lprfnewsletter](http://www.ti.com/lprfnewsletter)

### 8.6 Community Resources

The following links connect to TI community resources. Linked contents are provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's [Terms of Use](#).

**TI E2E™ Online Community** The TI engineer-to-engineer (E2E) community was created to foster collaboration among engineers. At [e2e.ti.com](http://e2e.ti.com), you can ask questions, share knowledge, explore ideas and help solve problems with fellow engineers.

**TI Embedded Processors Wiki** *Texas Instruments Embedded Processors Wiki*. Established to help developers get started with Embedded Processors from Texas Instruments and to foster innovation and growth of general knowledge about the hardware and software surrounding these devices.

**Low-Power RF Online Community** Wireless Connectivity Section of the TI E2E Support Community

- Forums, videos, and blogs
- RF design help
- E2E interaction

Join [here](#).

**Low-Power RF Developer Network** Texas Instruments has launched an extensive network of low-power RF development partners to help customers speed up their application development. The network consists of recommended companies, RF consultants, and independent design houses that provide a series of hardware module products and design services, including:

- RF circuit, low-power RF, and ZigBee design services
- Low-power RF and ZigBee module solutions and development tools
- RF certification services and RF circuit manufacturing

For help with modules, engineering services or development tools:

Search the [Low-Power RF Developer Network](#) to find a suitable partner.  
[www.ti.com/lprfnetwork](http://www.ti.com/lprfnetwork)



## 8.7 Additional Information

Texas Instruments offers a wide selection of cost-effective, low-power RF solutions for proprietary and standard-based wireless applications for use in automotive, industrial and consumer applications. The selection includes RF transceivers, RF transmitters, RF front ends, and Systems-on-Chips as well as various software solutions for the Sub-1 GHz and 2.4-GHz frequency bands.

In addition, Texas Instruments provides a large selection of support collateral such as development tools, technical documentation, reference designs, application expertise, customer support, third-party and university programs.

The Low-Power RF E2E Online Community provides technical support forums, videos and blogs, and the chance to interact with engineers from all over the world.

With a broad selection of product solutions, end-application possibilities, and a range of technical support, Texas Instruments offers the broadest low-power RF portfolio.

## 8.8 Trademarks

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ARM, Cortex, ARM Thumb are registered trademarks of ARM Limited (or its subsidiaries).

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## 8.9 Electrostatic Discharge Caution



This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

## 8.10 Export Control Notice

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## 8.11 Glossary

[TI Glossary](#) This glossary lists and explains terms, acronyms, and definitions.

# 9 Mechanical, Packaging, and Orderable Information

## 9.1 Packaging Information

The following pages include mechanical packaging and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

**PACKAGING INFORMATION**

Orderable Device	Status <sup>(1)</sup>	Package Type	Package Drawing	Pins	Package Qty	Eco Plan <sup>(2)</sup>	Lead/Ball Finish <sup>(6)</sup>	MSL Peak Temp <sup>(3)</sup>	Op Temp (°C)	Device Marking <sup>(4/5)</sup>	Samples
CC2640R2FFRGZR	ACTIVE	VQFN	RGZ	48	2500	Green (RoHS & no Sb/Br)	CU NIPDAU I CU NIPDAUAG	Level-3-260C-168 HR	-40 to 85	CC2640 R2F	Samples
CC2640R2FFRGZT	ACTIVE	VQFN	RGZ	48	250	Green (RoHS & no Sb/Br)	CU NIPDAU I CU NIPDAUAG	Level-3-260C-168 HR	-40 to 85	CC2640 R2F	Samples
CC2640R2FFRHBR	ACTIVE	VQFN	RHB	32	2500	Green (RoHS & no Sb/Br)	CU NIPDAU I CU NIPDAUAG	Level-3-260C-168 HR	-40 to 85	CC2640 R2F	Samples
CC2640R2FFRHBT	ACTIVE	VQFN	RHB	32	250	Green (RoHS & no Sb/Br)	CU NIPDAU I CU NIPDAUAG	Level-3-260C-168 HR	-40 to 85	CC2640 R2F	Samples
CC2640R2FFRSMR	ACTIVE	VQFN	RSM	32	3000	Green (RoHS & no Sb/Br)	CU NIPDAU I CU NIPDAUAG	Level-3-260C-168 HR	-40 to 85	CC2640 R2F	Samples
CC2640R2FFRSMT	ACTIVE	VQFN	RSM	32	250	Green (RoHS & no Sb/Br)	CU NIPDAU I CU NIPDAUAG	Level-3-260C-168 HR	-40 to 85	CC2640 R2F	Samples
CC2640R2FVFVR	ACTIVE	DSBGA	YFV	34	2500	Green (RoHS & no Sb/Br)	SNAAGCU	Level-1-260C-UNLIM	-40 to 85	CC2640	Samples
CC2640R2FVFVT	ACTIVE	DSBGA	YFV	34	250	Green (RoHS & no Sb/Br)	SNAAGCU	Level-1-260C-UNLIM	-40 to 85	CC2640	Samples

<sup>(1)</sup> The marketing status values are defined as follows:

**ACTIVE:** Product device recommended for new designs.

**LIFEBUY:** TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.

**NRND:** Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

**PREVIEW:** Device has been announced but is not in production. Samples may or may not be available.

**OBSOLETE:** TI has discontinued the production of the device.

<sup>(2)</sup> **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".

**RoHS Exempt:** TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.

**Green:** TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet US709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

<sup>(3)</sup> **MSL, Peak Temp.** - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

<sup>(4)</sup> There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(9) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "-" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

(6) Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

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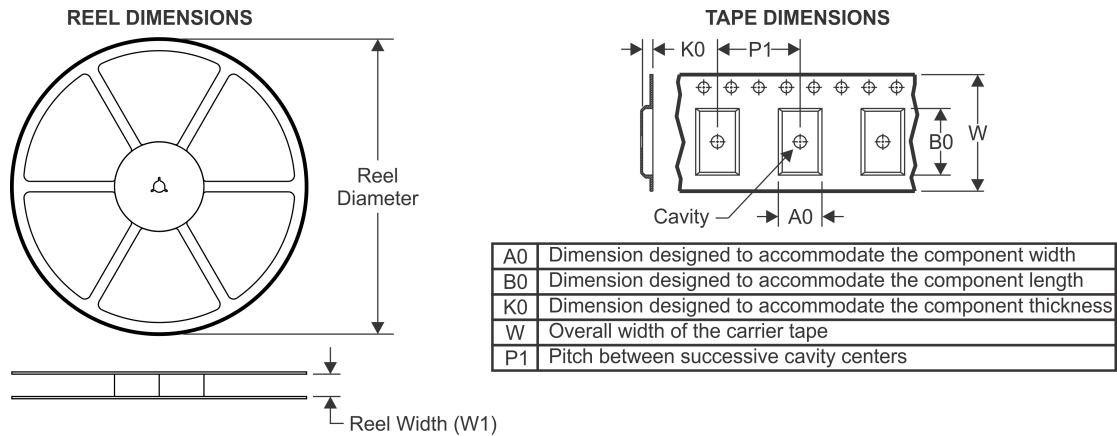
**OTHER QUALIFIED VERSIONS OF CC2640R2F :**

- Automotive : [CC2640R2F-Q1](#)

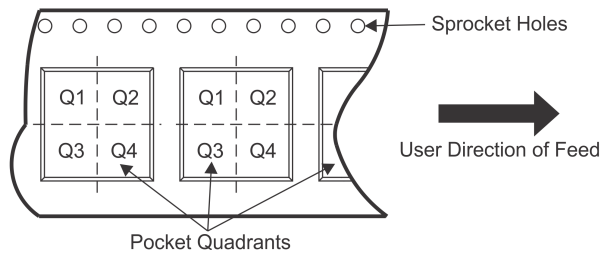
NOTE: Qualified Version Definitions:

- Automotive - Q100 devices qualified for high-reliability automotive applications targeting zero defects

**TAPE AND REEL INFORMATION**

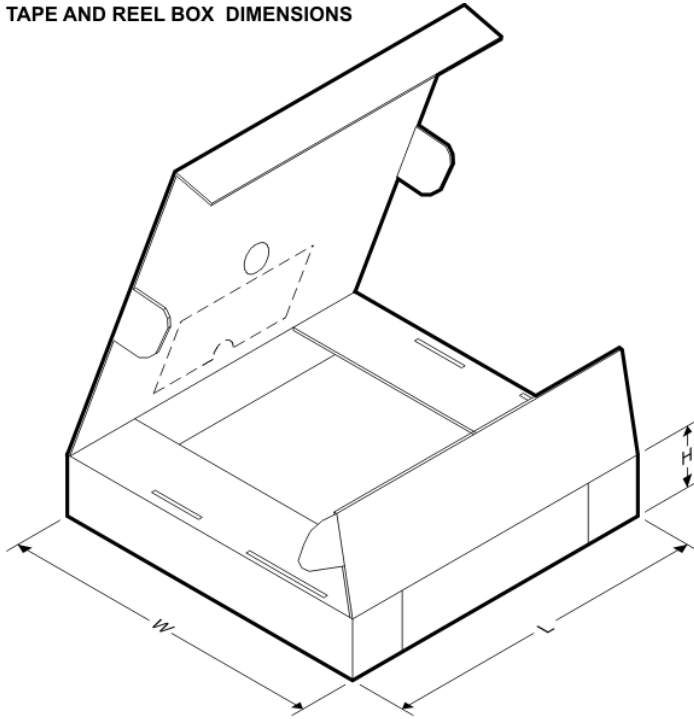


**QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE**



\*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
CC2640R2FRGZR	VQFN	RGZ	48	2500	330.0	16.4	7.3	7.3	1.1	12.0	16.0	Q2
CC2640R2FRGZR	VQFN	RGZ	48	2500	330.0	16.4	7.3	7.3	1.1	12.0	16.0	Q2
CC2640R2FRGZT	VQFN	RGZ	48	250	180.0	16.4	7.3	7.3	1.1	12.0	16.0	Q2
CC2640R2FRGZT	VQFN	RGZ	48	250	180.0	16.4	7.3	7.3	1.1	12.0	16.0	Q2
CC2640R2FRSMR	VQFN	RSM	32	3000	330.0	12.4	4.25	4.25	1.15	8.0	12.0	Q2
CC2640R2FRSMT	VQFN	RSM	32	250	180.0	12.4	4.25	4.25	1.15	8.0	12.0	Q2
CC2640R2FYFVR	DSBGA	YFV	34	2500	180.0	8.4	2.75	2.75	0.81	4.0	8.0	Q1
CC2640R2FYFVT	DSBGA	YFV	34	250	180.0	8.4	2.75	2.75	0.81	4.0	8.0	Q1

**TAPE AND REEL BOX DIMENSIONS**


\*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
CC2640R2FRGZR	VQFN	RGZ	48	2500	336.6	336.6	31.8
CC2640R2FRGZR	VQFN	RGZ	48	2500	367.0	367.0	35.0
CC2640R2FRGZT	VQFN	RGZ	48	250	210.0	185.0	35.0
CC2640R2FRGZT	VQFN	RGZ	48	250	210.0	185.0	35.0
CC2640R2FRSMR	VQFN	RSM	32	3000	336.6	336.6	31.8
CC2640R2FRSMT	VQFN	RSM	32	250	210.0	185.0	35.0
CC2640R2FYFVR	DSBGA	YFV	34	2500	182.0	182.0	20.0
CC2640R2FYFVT	DSBGA	YFV	34	250	182.0	182.0	20.0

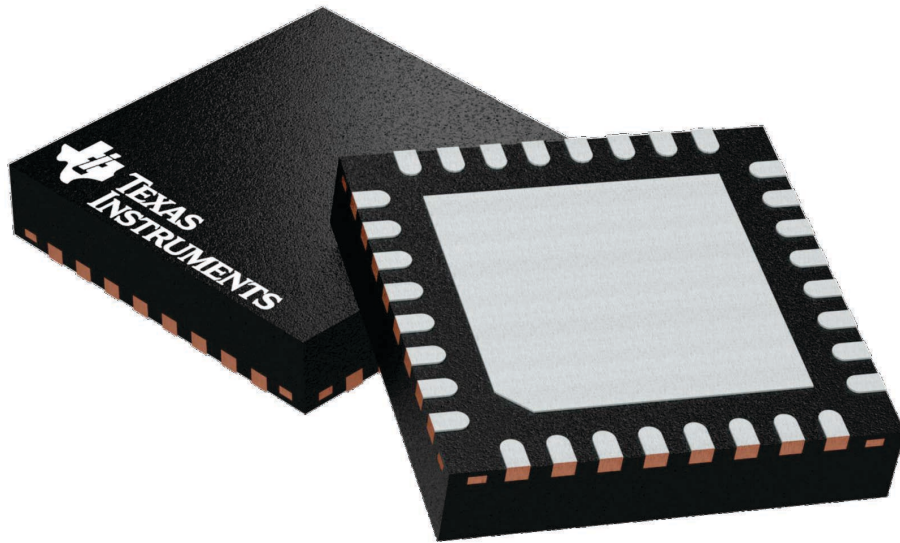
## GENERIC PACKAGE VIEW

**RHB 32**

**VQFN - 1 mm max height**

5 x 5, 0.5 mm pitch

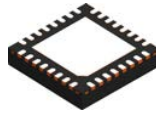
PLASTIC QUAD FLATPACK - NO LEAD



Images above are just a representation of the package family, actual package may vary.  
Refer to the product data sheet for package details.

4224745/A

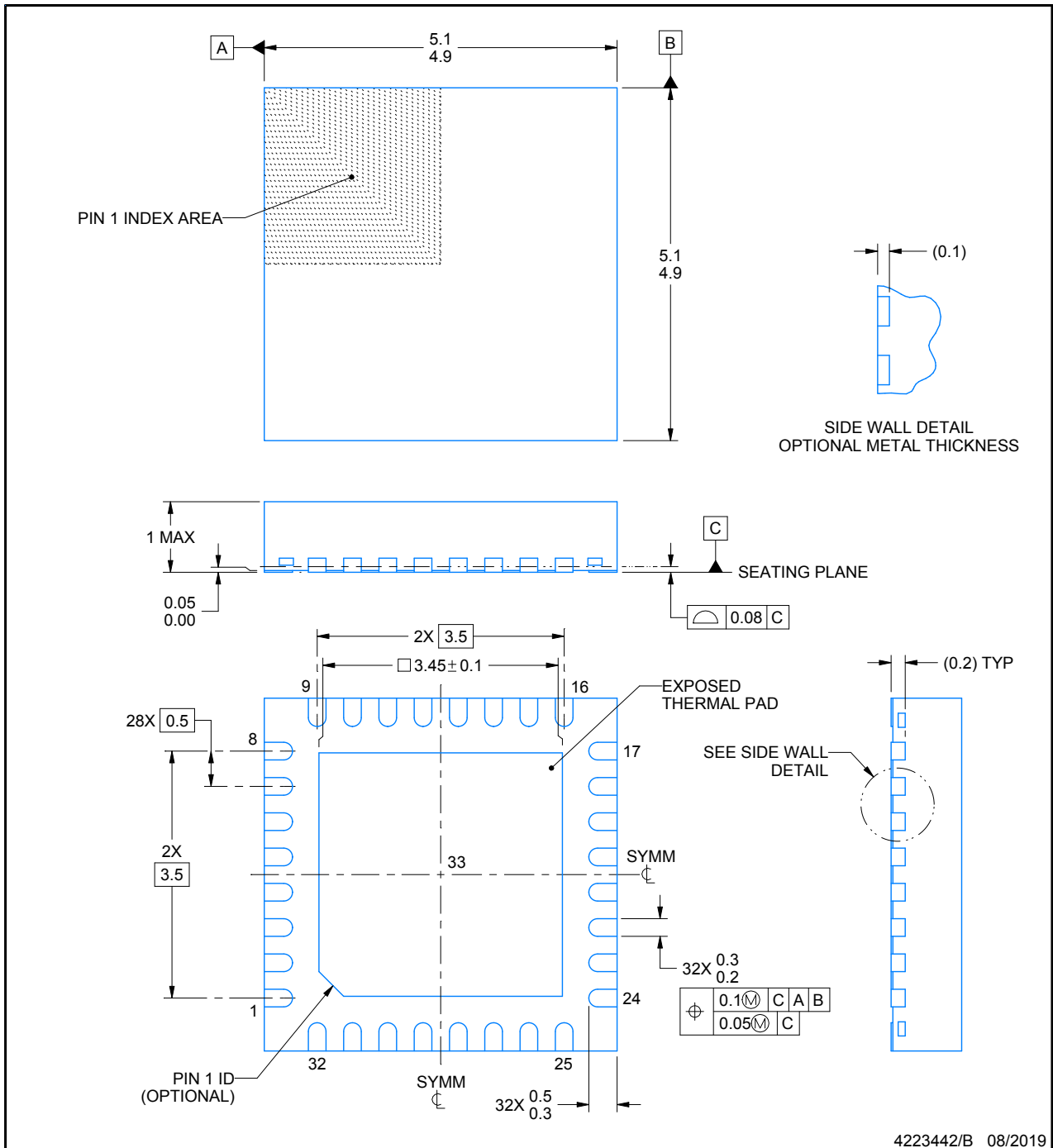
RHB0032E



PACKAGE OUTLINE

VQFN - 1 mm max height

PLASTIC QUAD FLATPACK - NO LEAD



NOTES:

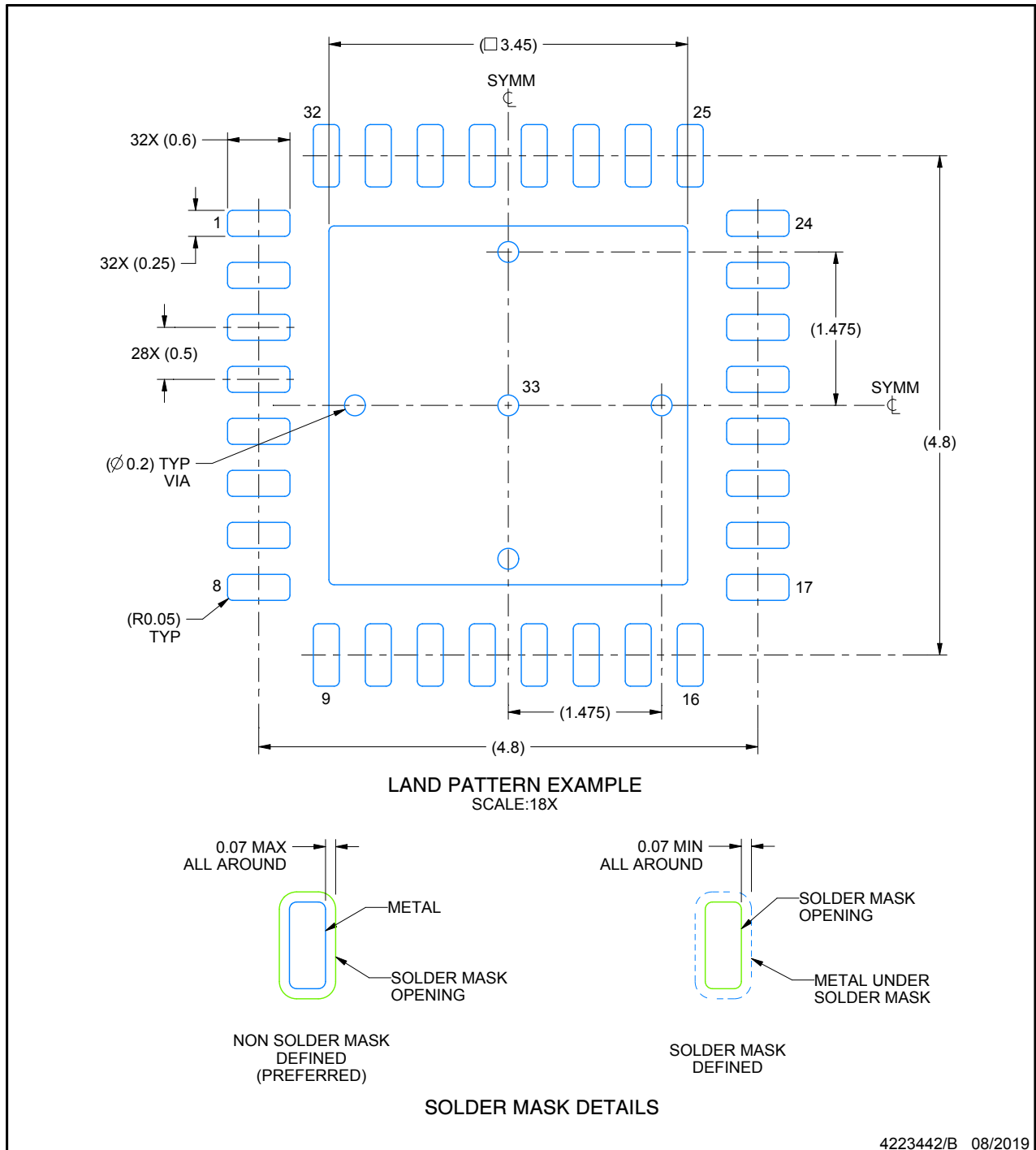
1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. The package thermal pad must be soldered to the printed circuit board for thermal and mechanical performance.

# EXAMPLE BOARD LAYOUT

RHB0032E

VQFN - 1 mm max height

PLASTIC QUAD FLATPACK - NO LEAD



NOTES: (continued)

- This package is designed to be soldered to a thermal pad on the board. For more information, see Texas Instruments literature number SLUA271 ([www.ti.com/lit/slua271](http://www.ti.com/lit/slua271)).
- Vias are optional depending on application, refer to device data sheet. If any vias are implemented, refer to their locations shown on this view. It is recommended that vias under paste be filled, plugged or tented.

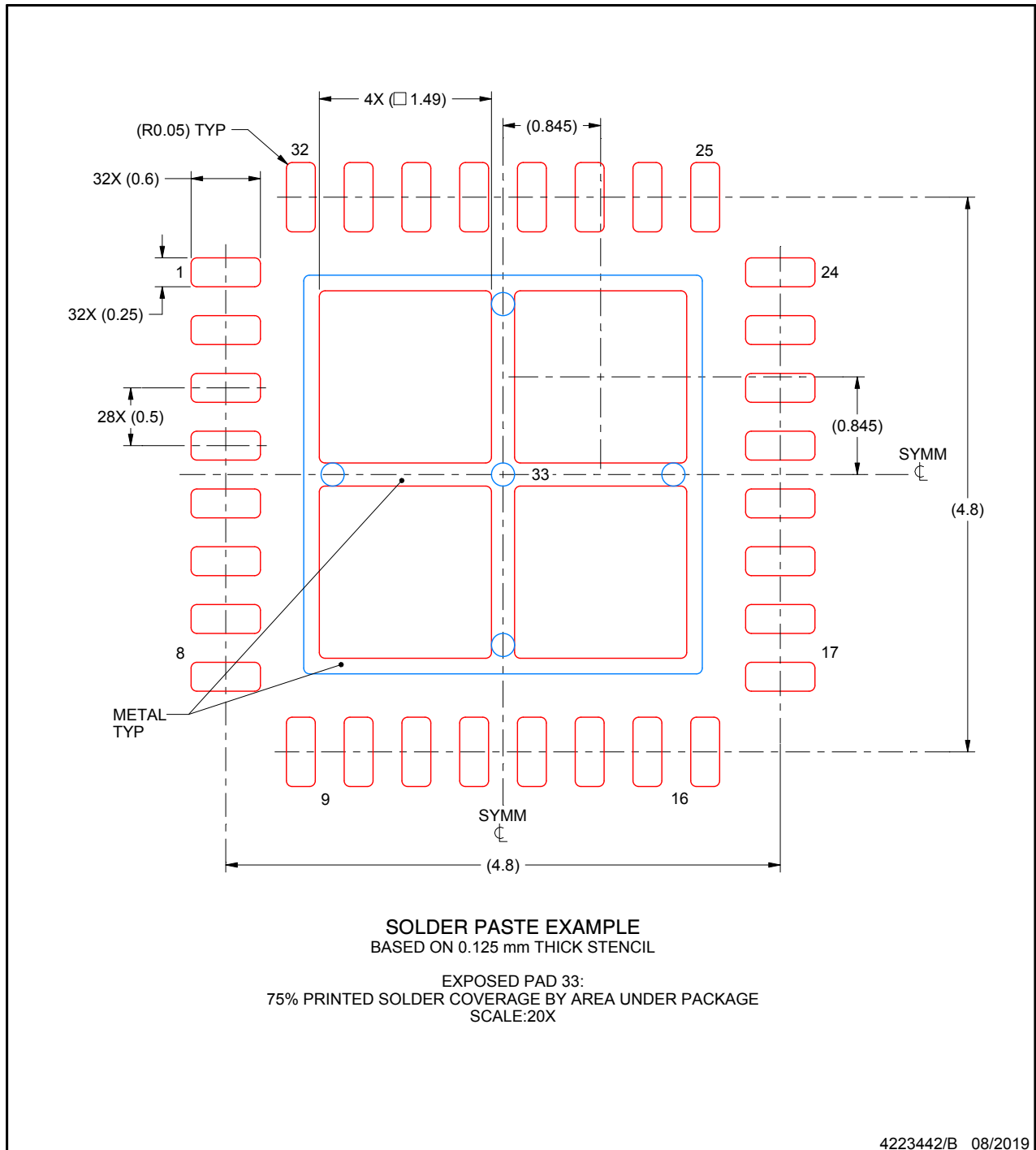


# EXAMPLE STENCIL DESIGN

RHB0032E

VQFN - 1 mm max height

PLASTIC QUAD FLATPACK - NO LEAD



NOTES: (continued)

6. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.

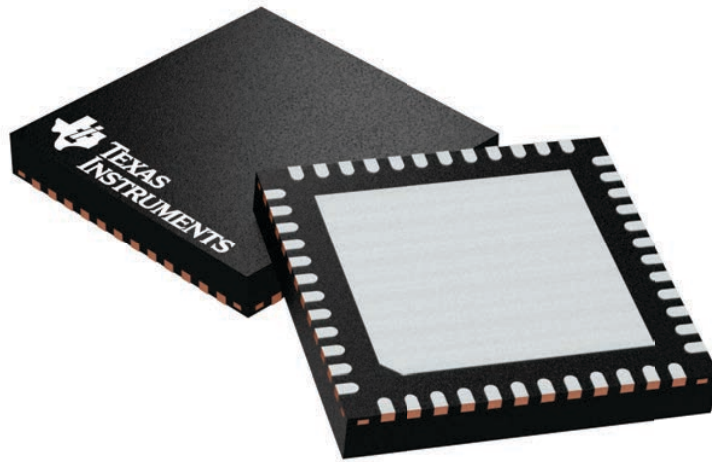
## GENERIC PACKAGE VIEW

**RGZ 48**

**VQFN - 1 mm max height**

7 x 7, 0.5 mm pitch

PLASTIC QUADFLAT PACK- NO LEAD



Images above are just a representation of the package family, actual package may vary.  
Refer to the product data sheet for package details.

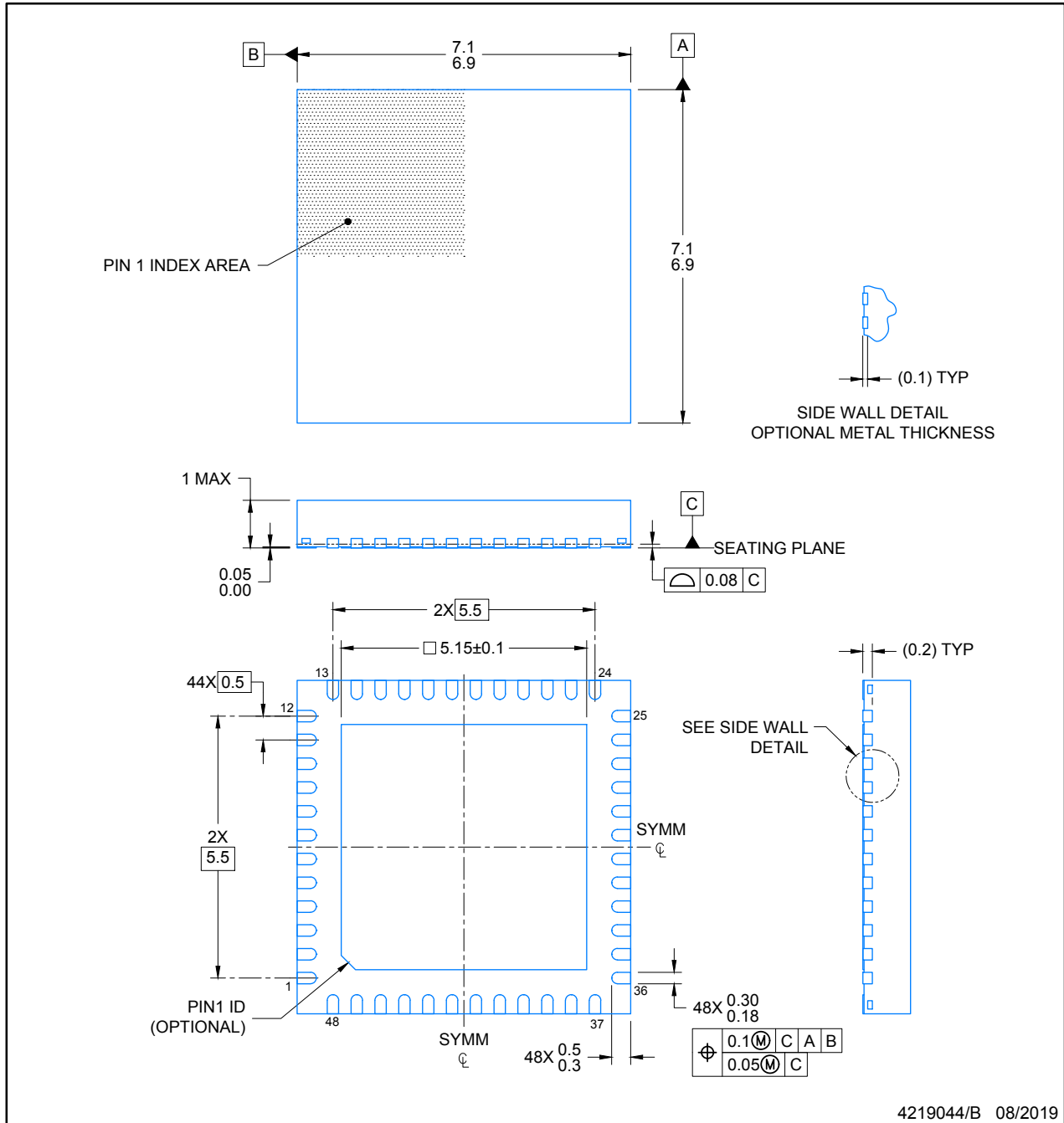
4224671/A

# RGZ0048A

# PACKAGE OUTLINE

## VQFN - 1 mm max height

PLASTIC QUADFLAT PACK- NO LEAD



NOTES:

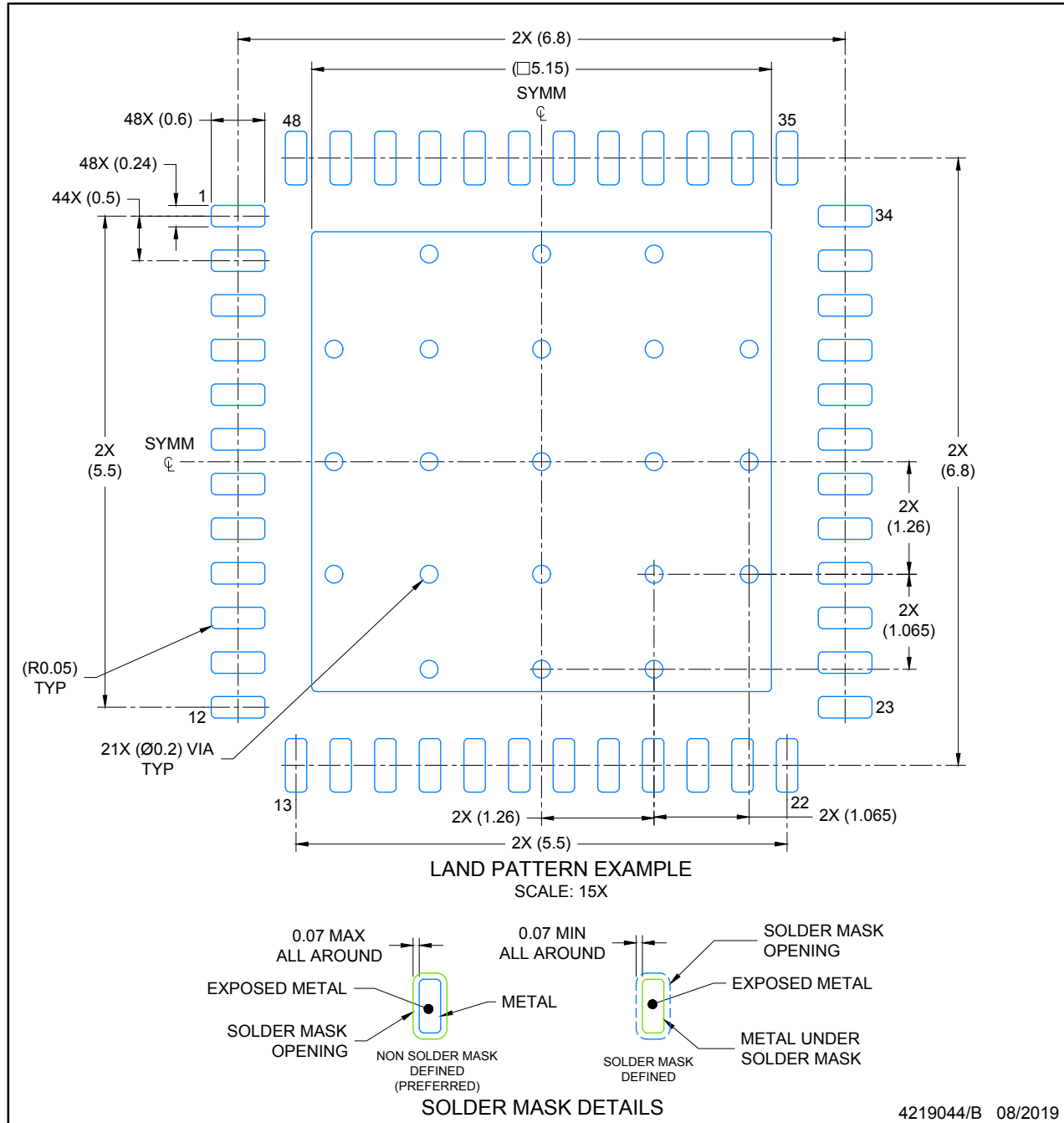
1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. The package thermal pad must be soldered to the printed circuit board for optimal thermal and mechanical performance.

# EXAMPLE BOARD LAYOUT

**RGZ0048A**

**VQFN - 1 mm max height**

PLASTIC QUADFLAT PACK- NO LEAD



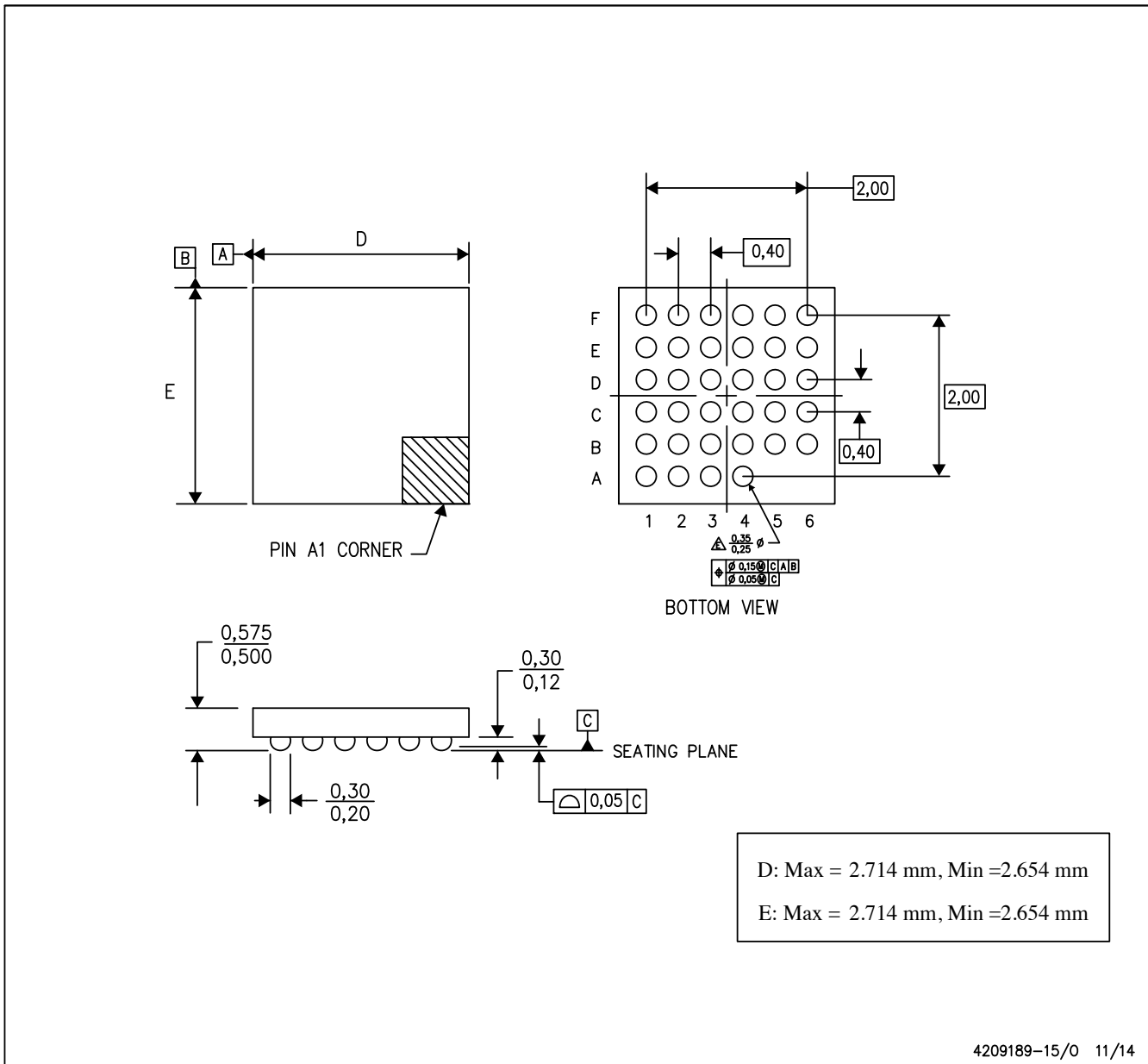
NOTES: (continued)

4. This package is designed to be soldered to a thermal pad on the board. For more information, see Texas Instruments literature number SLUA271 ([www.ti.com/lit/slue271](http://www.ti.com/lit/slue271)).
5. Vias are optional depending on application, refer to device data sheet. If any vias are implemented, refer to their locations shown on this view. It is recommended that vias under paste be filled, plugged or tented.



YFV (R-XBGA-N34)

DIE-SIZE BALL GRID ARRAY (WCSP)



- NOTES:
- A. All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5M-1994.
  - B. This drawing is subject to change without notice.
  - C. NanoFree™ package configuration.
  - D. This package contains Pb-free balls.

NanoFree is a trademark of Texas Instruments.

## GENERIC PACKAGE VIEW

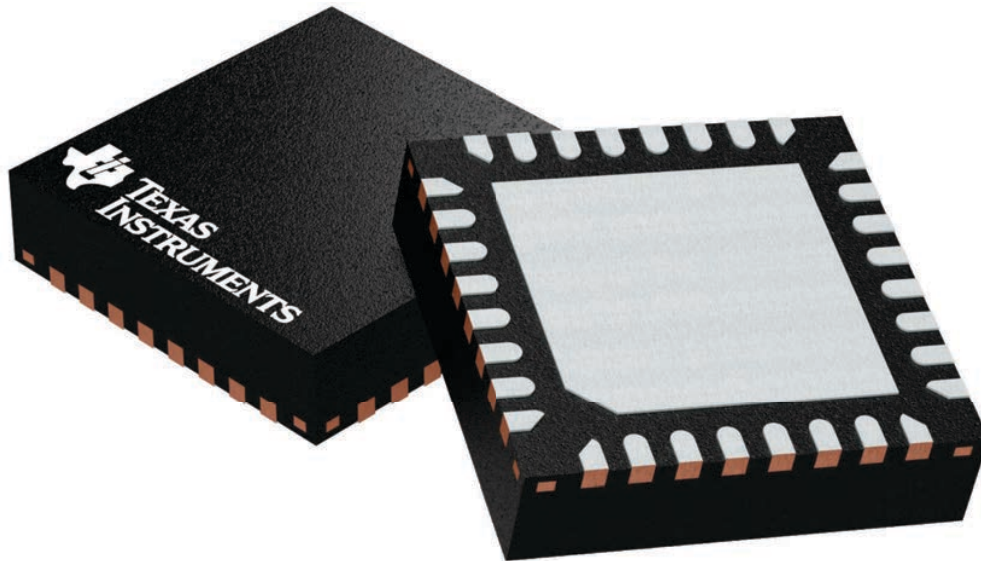
**RSM 32**

**VQFN - 1 mm max height**

4 x 4, 0.4 mm pitch

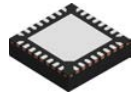
PLASTIC QUAD FLATPACK - NO LEAD

This image is a representation of the package family, actual package may vary.  
Refer to the product data sheet for package details.



4224982/A

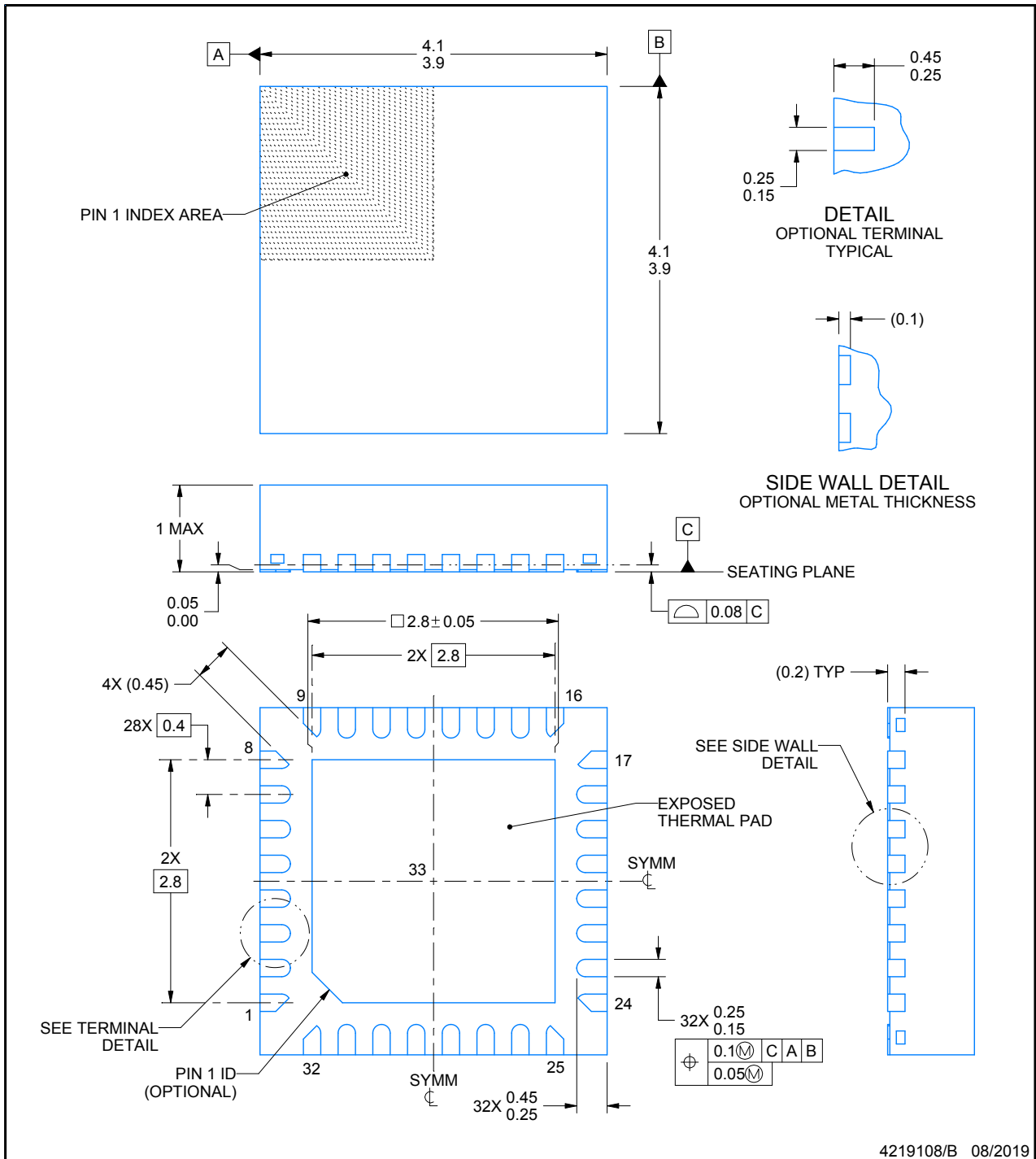
# RSM0032B



# PACKAGE OUTLINE

## VQFN - 1 mm max height

PLASTIC QUAD FLATPACK - NO LEAD



**NOTES:**

1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. The package thermal pad must be soldered to the printed circuit board for thermal and mechanical performance.

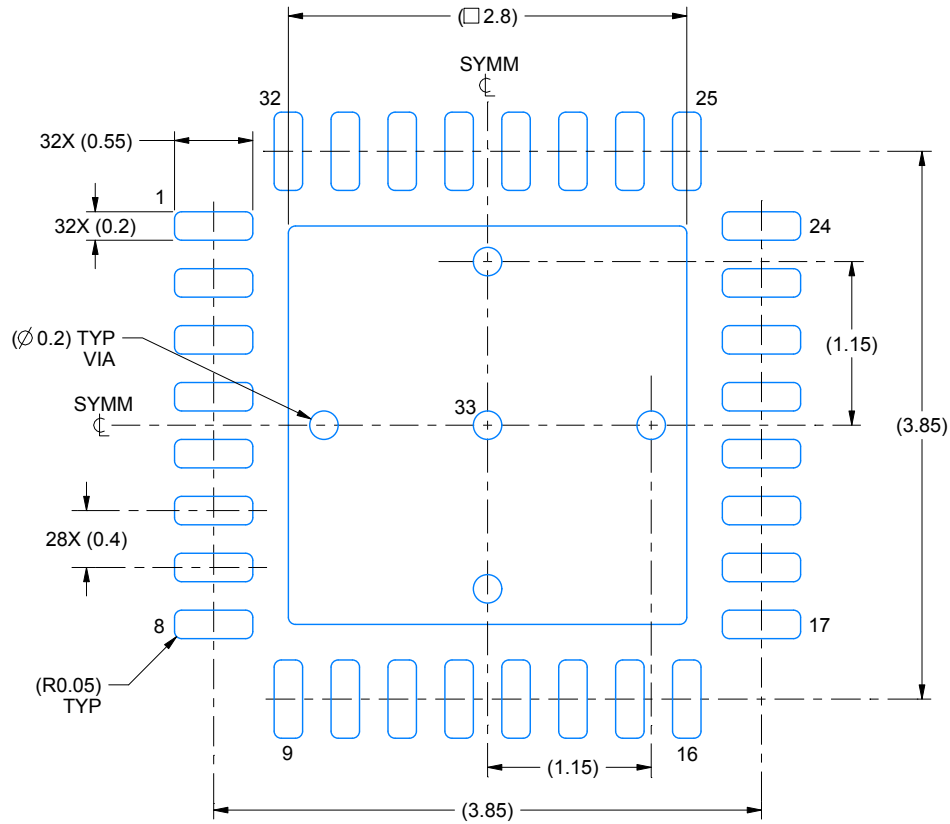


# EXAMPLE BOARD LAYOUT

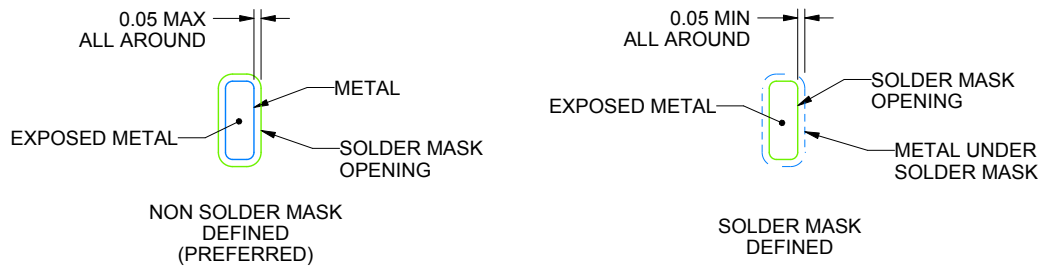
RSM0032B

VQFN - 1 mm max height

PLASTIC QUAD FLATPACK - NO LEAD



LAND PATTERN EXAMPLE  
EXPOSED METAL SHOWN  
SCALE:20X



SOLDER MASK DETAILS

4219108/B 08/2019

NOTES: (continued)

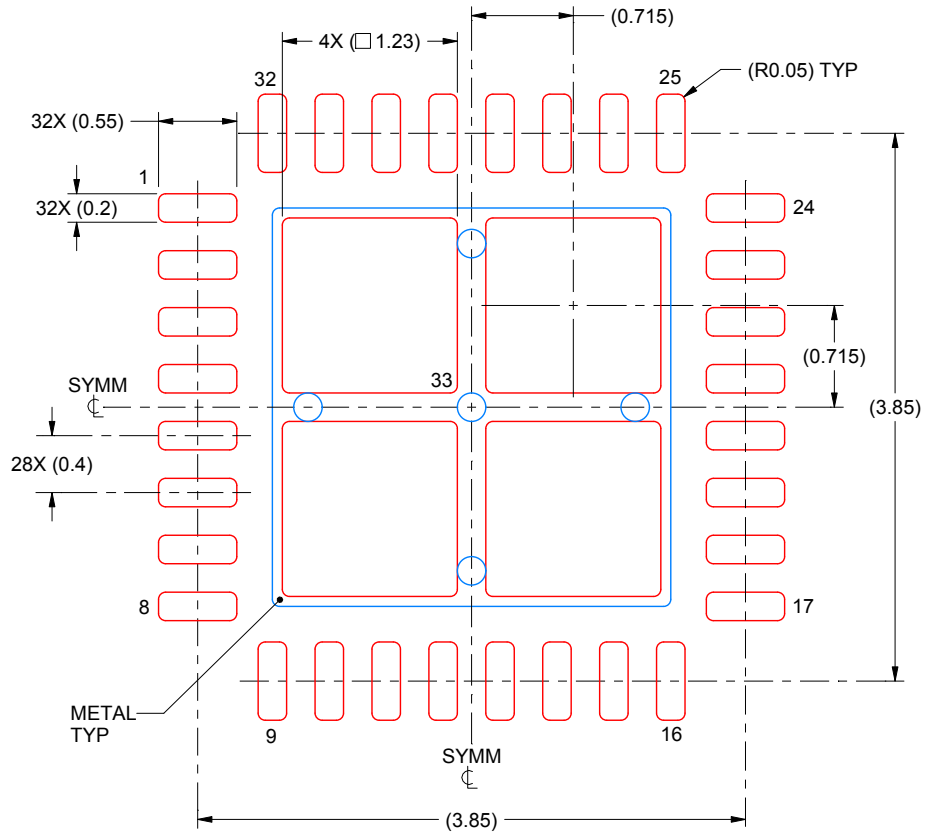
4. This package is designed to be soldered to a thermal pad on the board. For more information, see Texas Instruments literature number SLUA271 ([www.ti.com/lit/sluea271](http://www.ti.com/lit/sluea271)).
5. Vias are optional depending on application, refer to device data sheet. If any vias are implemented, refer to their locations shown on this view. It is recommended that vias under paste be filled, plugged or tented.

# EXAMPLE STENCIL DESIGN

RSM0032B

VQFN - 1 mm max height

PLASTIC QUAD FLATPACK - NO LEAD



**SOLDER PASTE EXAMPLE**  
BASED ON 0.1 mm THICK STENCIL

EXPOSED PAD 33:  
77% PRINTED SOLDER COVERAGE BY AREA UNDER PACKAGE  
SCALE:20X

4219108/B 08/2019

NOTES: (continued)

6. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.

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# Approval Sheet

## (產品承認書)

產品名稱 (Product): BT 5.0 Module (nRF52840)

產品型號 (Model No.): MDBT50Q – 1M (Chip Antenna)

MDBT50Q – P1M (PCB Antenna)

*Working distance of MDBT50Q-1M & MDBT50Q-P1M:*

- **1Mbps:**  
MDBT50Q: over 300 meters in open space.  
MDBT50Q-P: up to 250 meters in open space.
- **2Mbps:**  
MDBT50Q: over 150 meters in open space.  
MDBT50Q-P: up to 120 meters in open space.

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# 1. Overall Introduction

Raytac's MDBT50Q & MDBT50Q-P is a BT 5.0 stack (Bluetooth low energy or BLE) module designed based on **Nordic nRF52840 SoC solution**, which incorporates: **GPIO, SPI, UART, I2C, I2S, PMD, PWM, ADC, NFC** and **USB** interfaces for connecting peripherals and sensors.

Features of the module:

1. Embedded 2.4GHz transceiver supports Bluetooth 5, IEEE 802.15.4 & 2.4Ghz RF & ANT upon customer's preference.
2. Compact size with **(L) 15.5 x (W) 10.5 x (H) 2.2 or 2.0 mm**.
3. Low power requirements, ultra-low peak, average and idle mode power consumption.
4. Be compatible with a large installed base of mobile phones, tablets and computers.
5. Fully coverage of BLE software stack.
6. BLE & RF transmission switching helps products fit all operation system and most hardware.

## 1.1. Application

- IoT Networks
  - Smart home (such as door locks, lighting) sensors and controllers
  - Smart city sensor networks
  - Industrial IoT sensors and controllers
  - Connected white goods
- Personal Area Networks
  - Health / fitness sensor and monitor device
  - Medical device
- Interactive entertainment devices
  - Advanced remote controls
  - Gaming controller
- Advanced wearables
  - Connected watches
  - Advanced personal fitness devices
  - Wearables with wireless secure payment
  - Connected Health
  - Virtual/Augmented Reality applications
- High performance HID Controllers

## 1.2. Features

- Bluetooth 5, IEEE 802.15.4, 2.4 GHz transceiver
  - -95dBm sensitivity in 1Mbps Bluetooth low energy (BLE) mode
  - -103dBm sensitivity in 125Kbps BLE mode (long range)
  - +8 dBm TX power (down to -20 dBm in 4 dB steps)
  - On-air compatible with nRF52, nRF51, nRF24L and nRF24AP Series
  - Programmable output power from +8dBm to -20dB
  - RSSI (1dB resolution)
  - Supported data rates:
    - Bluetooth 5: 2 Mbps, 1 Mbps, 500 kbps, 125 kbps
    - IEEE 802.15.4-2006: 250 kbps
    - Proprietary 2.4 GHz: 2 Mbps, 1 Mbps
- ARM Cortex –M4 32-bit processor with FPU, 64 MHz
- Memory: 1MB flash / 256KB RAM
- HW accelerated security
  - ARM TrustZone Cryptocell 310 cryptographic accelerator
  - 128 bit AES / ECB / CCM / AAR co-processor (on-the-fly packet encryption)
- Advanced on-chip interfaces
  - USB 2.0 full speed (12Mbps) controller
  - QSPI 32MHz interface
  - High speed 32MHz SPI
  - Type 2 near field communication (NFC-A) tag with wake-on field
  - Programmable peripheral interconnect (PPI)
  - 48 general purpose I/O pins
  - EasyDMA automated data transfer without CPU processing on peripherals
- 12 bit, 200ksps ADC – 8 configurable channels with programmable gain
- 4 x 4 channel pulse width modulator (PWM)units with EasyDMA
- Audio peripherals : I2S, digital microphone interface (PDM)
- 5 X 32-bit timers with counter mode
- Up to 4 x SPI masters / 3 x SPI slaves with EasyDMA
- Up to 2 x I2C compatible 2-wire masters / slaves
- 2 x UART(CTS/RTS) with EasyDMA
- Quadrature decoder (QDEC)
- 3 x 24-bit real-time counters (RTC)

- Flexible power management
  - Supply voltage range 1.7V to 5.5V
  - On-chip DC/DC and LDO regulators with automated low current modes
  - Regulated supply for external components from 1.8V to 3.3V
  - Automated peripheral power management
  - Fast wake-up using 64MHz internal oscillator
  - 0.4uA at 3V in OFF mode, no RAM retention
  - 1.5uA at 3V in ON mode, no RAM retention, wake on RTC
- Nordic SoftDevice ready and with support for concurrent multi-protocol



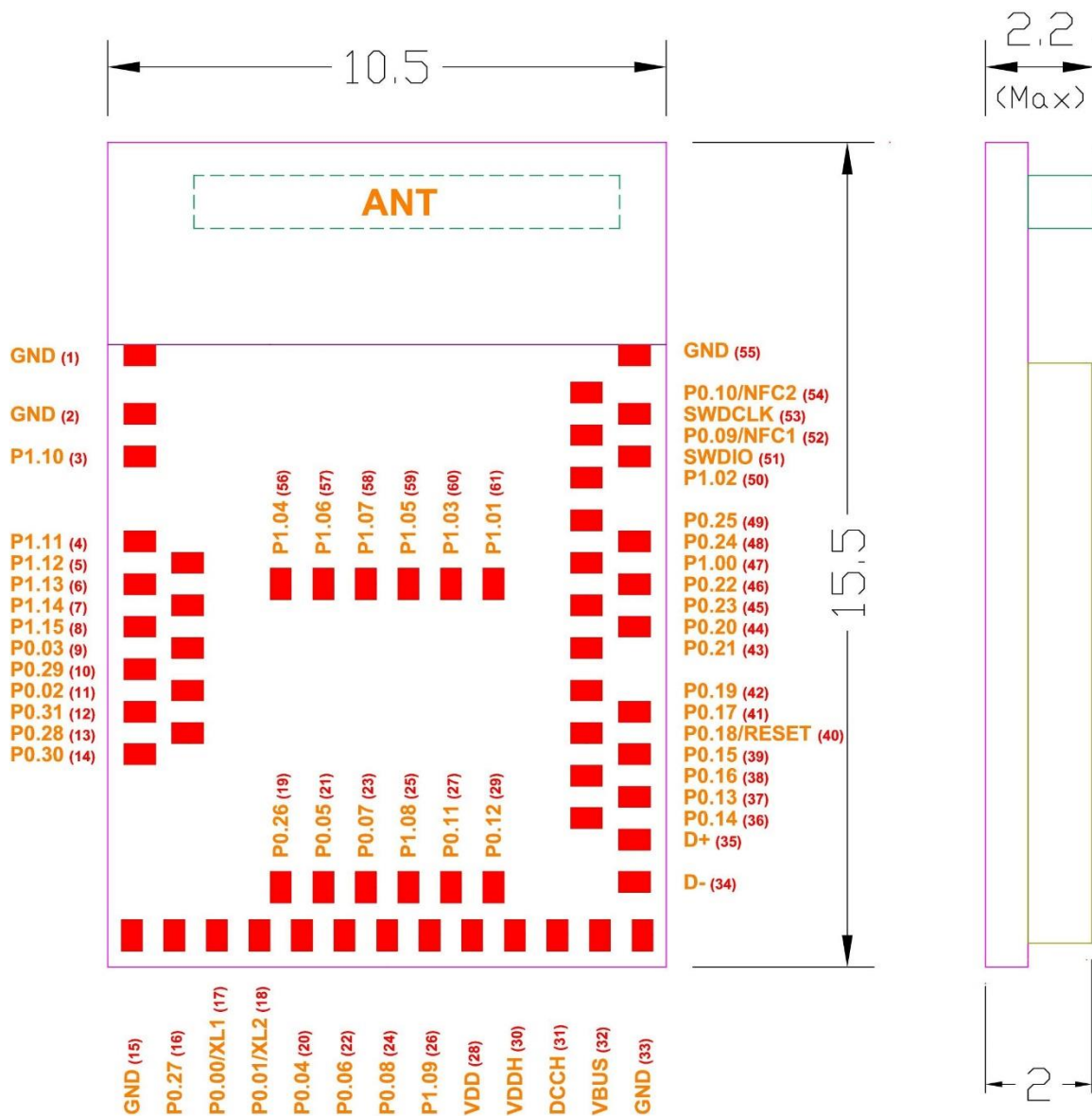


## 2. Product Dimension

### 2.1. PCB Dimensions & Pin Indication

- **MDBT50Q**

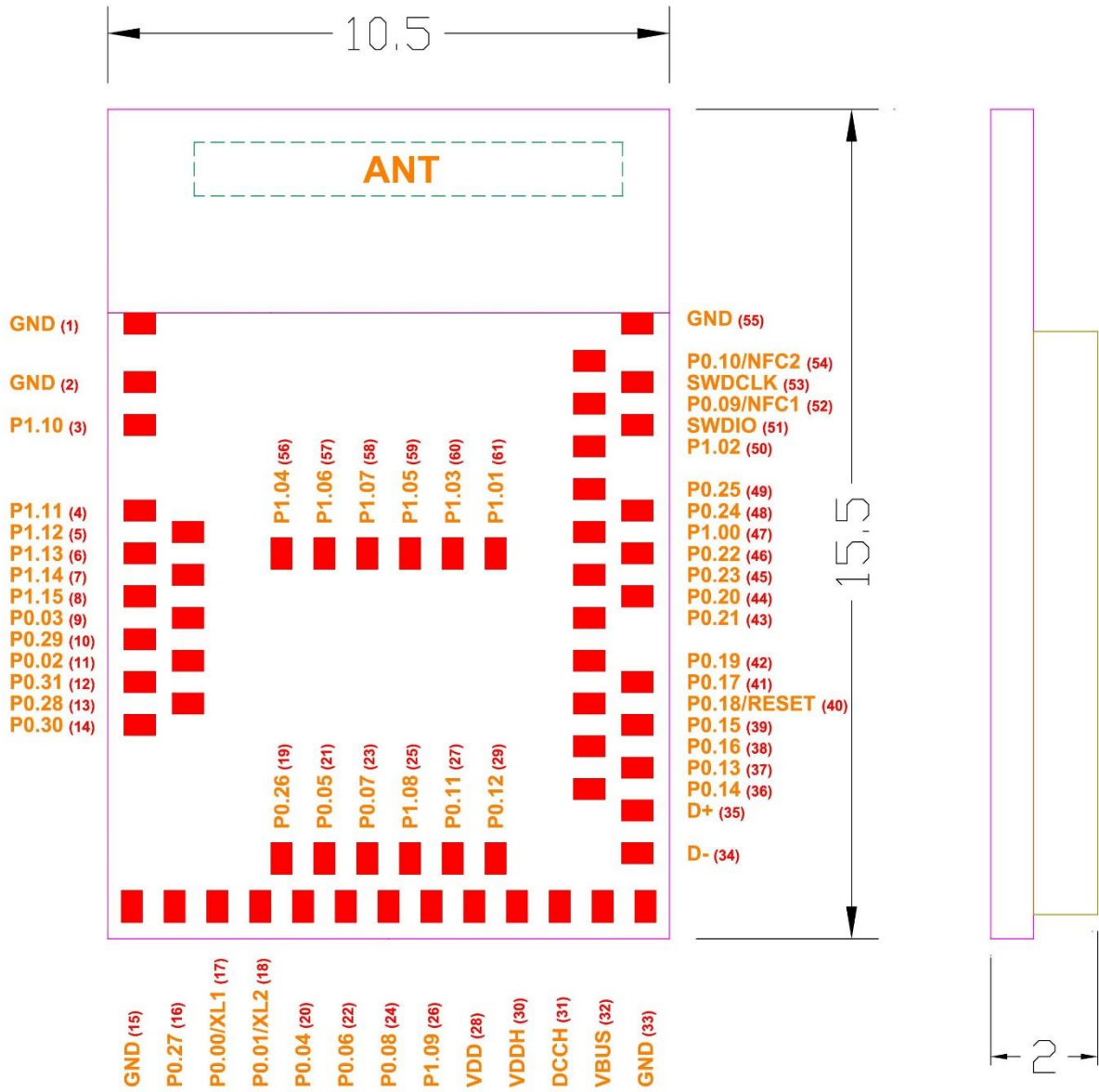
**PCB SIZE: (L) 15.5 x (W) 10.5x (H) 2.2 mm**



Top 單位:(mm)

• **MDBT50Q-P**

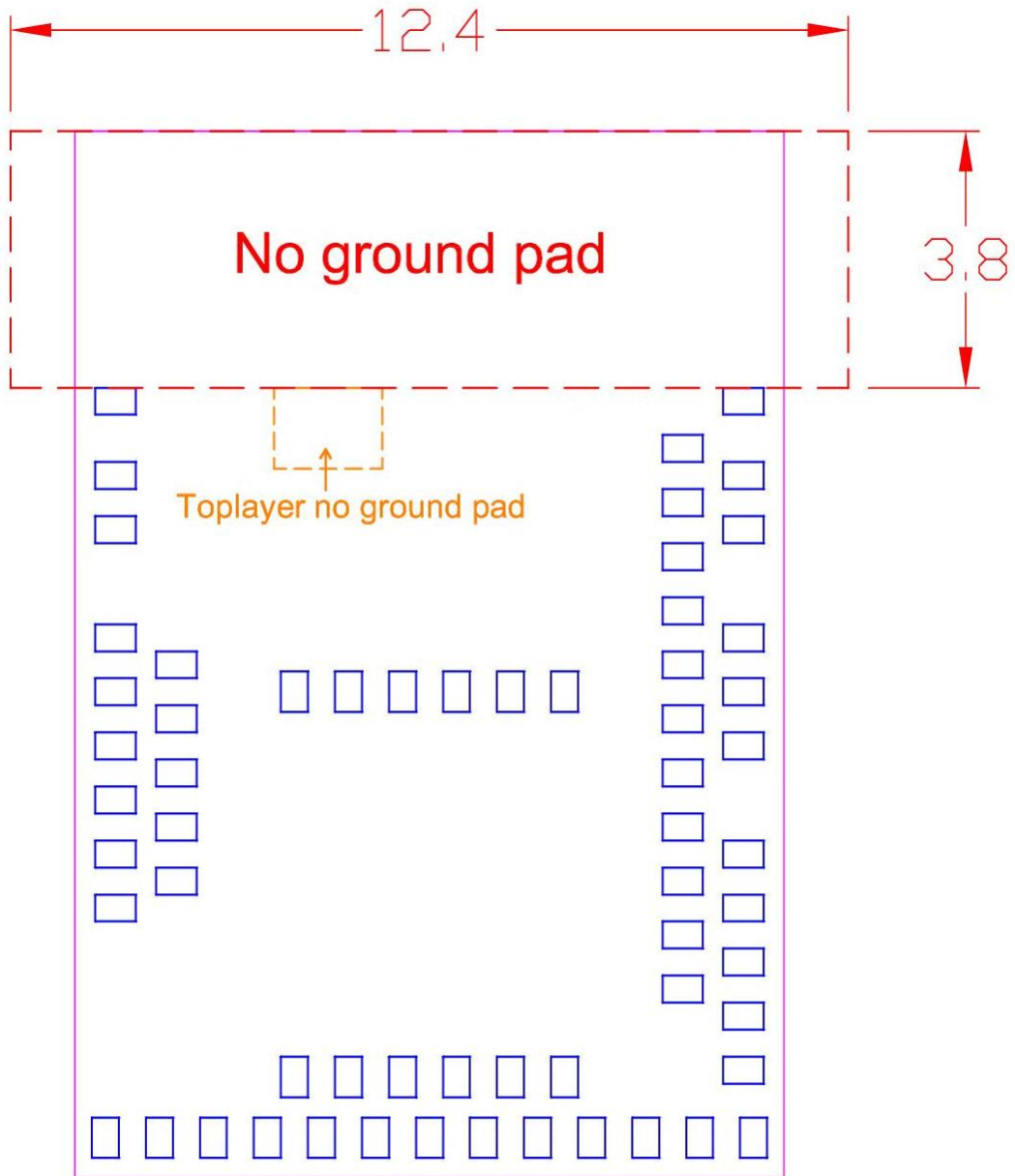
**PCB SIZE: (L) 15.5 x (W) 10.5 x (H) 2.0 mm**



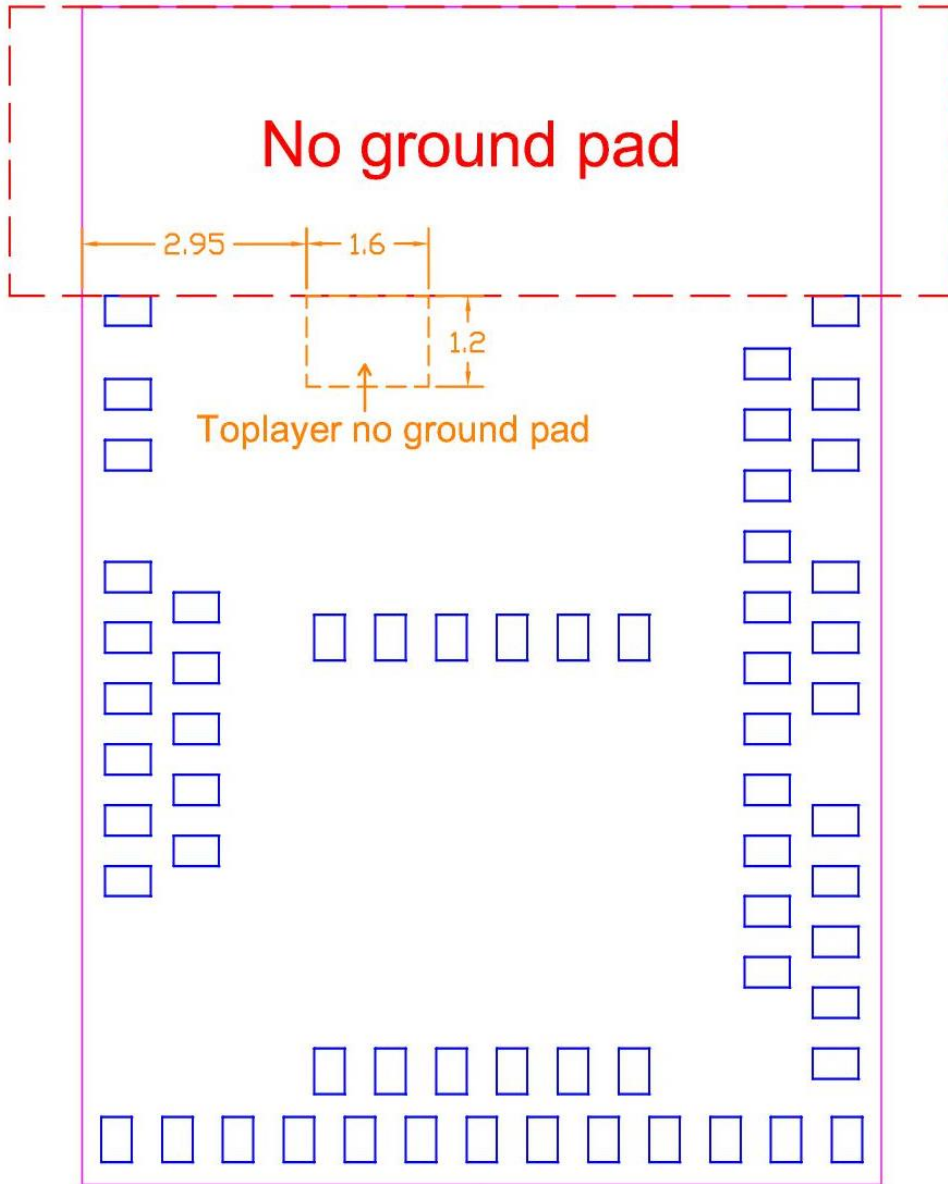
Top 單位:(mm)

## 2.2. Recommended Layout of Solder Pad

*Graphs are all in Top View, Unit in mm.*



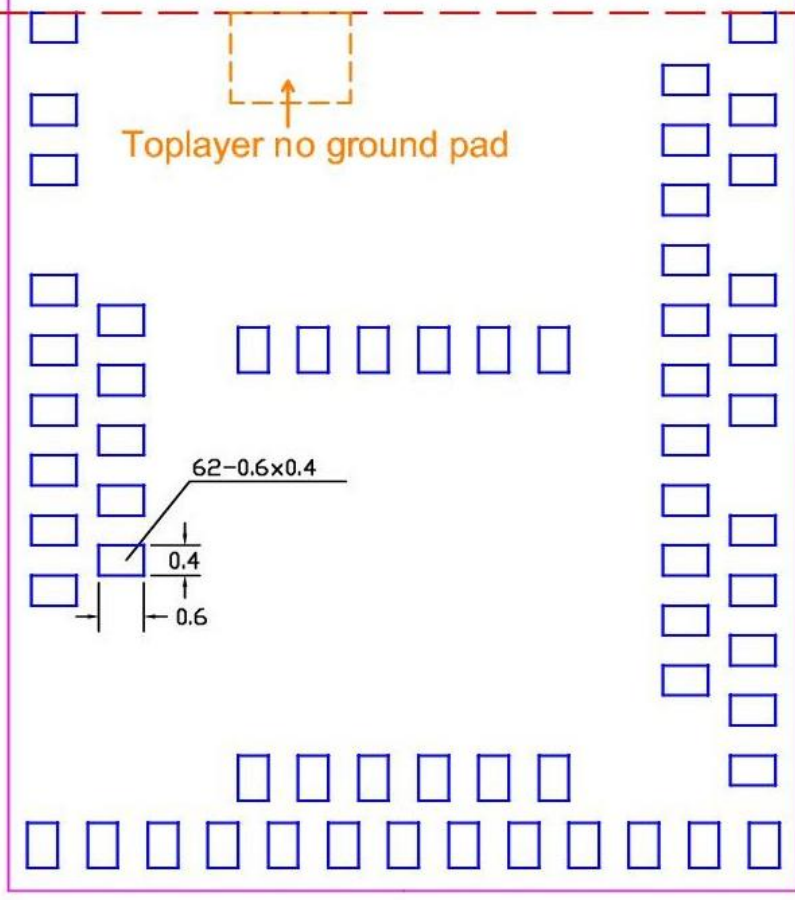
No ground pad

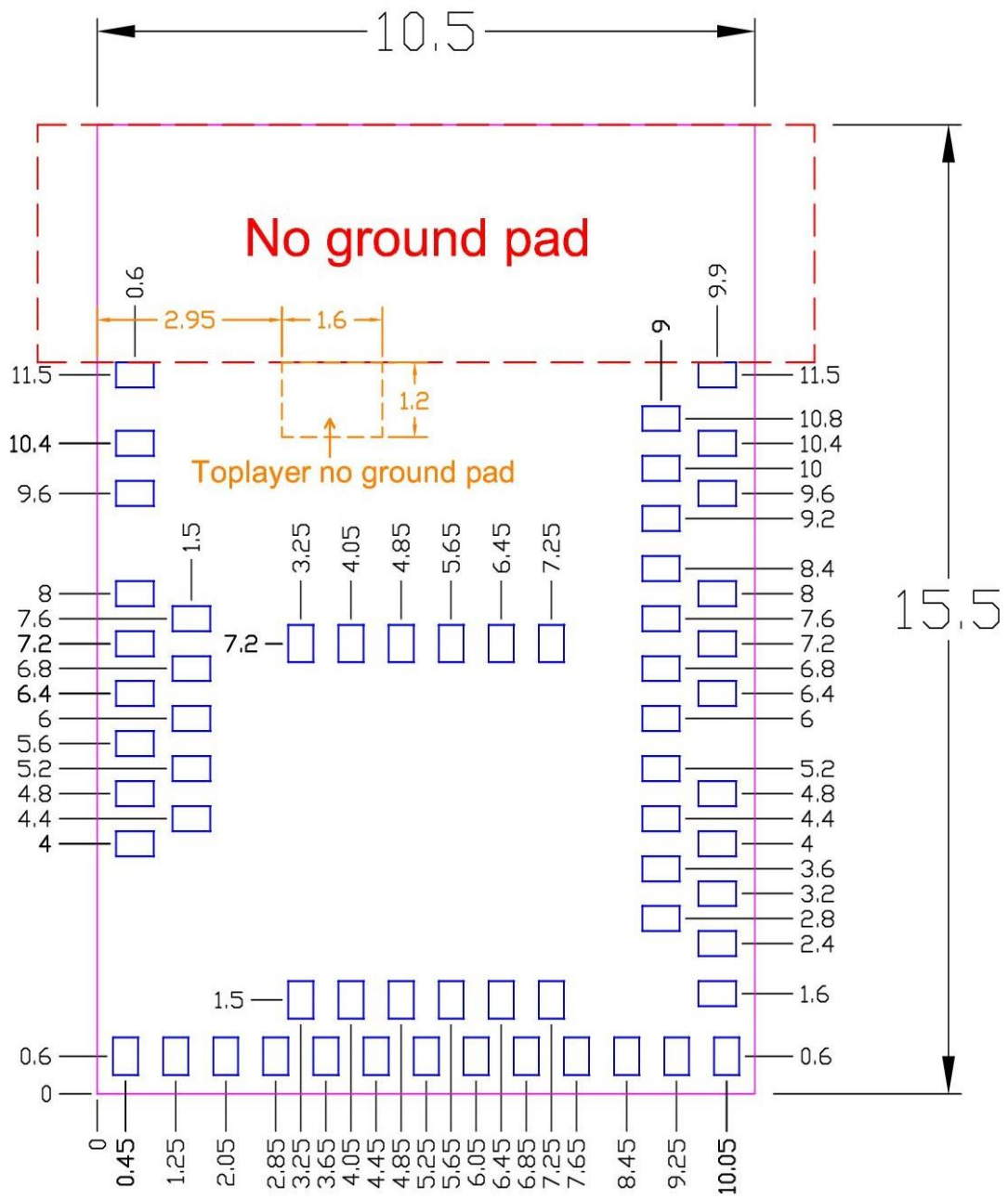


Toplayer no ground pad

# No ground pad

Toplayer no ground pad

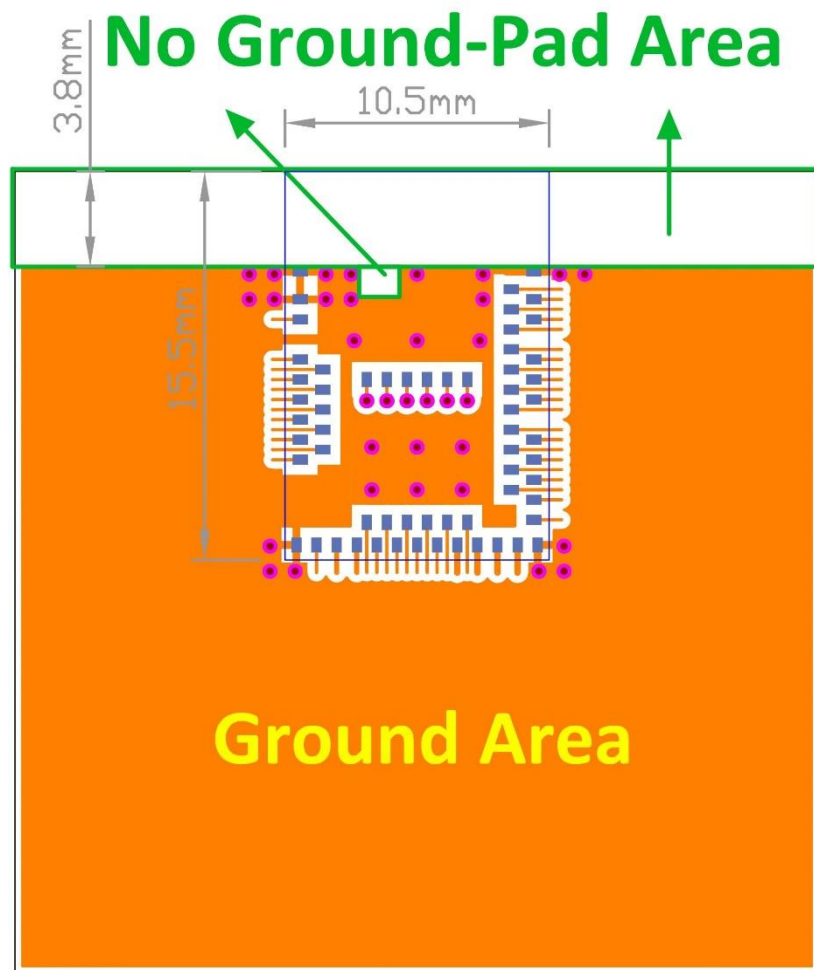




### 2.3. RF Layout Suggestion (aka Keep-Out Area)

Please follow below instruction to have better wireless performance. Make sure to keep the “No-Ground-Pad” as wider as you can when there is no enough space in your design.

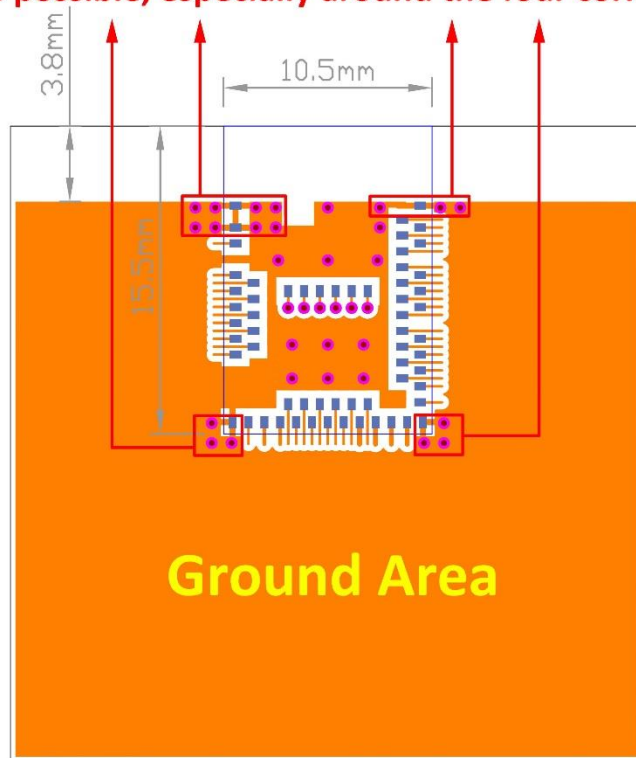
Welcome to send us your layout in PDF for review at [service@raytac.com](mailto:service@raytac.com) with title “Layout reviewing – MDBT50Q/MDBT50Q-P – YOUR company’s name”.



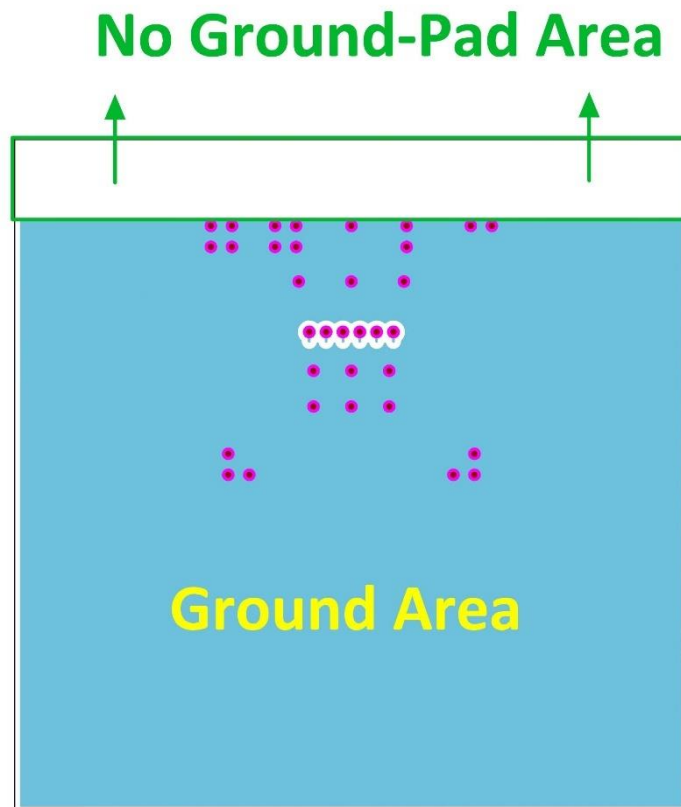
**Top layer**



Please add via holes in GROUND area as many as possible, especially around the four corners.



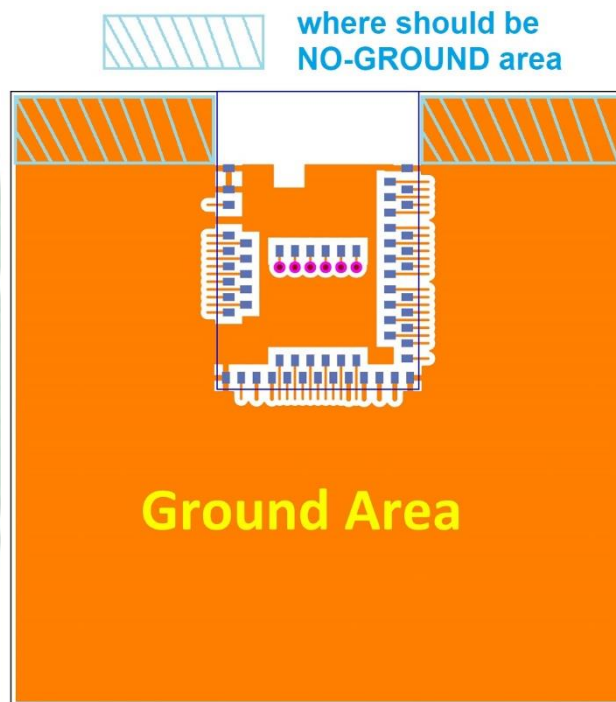
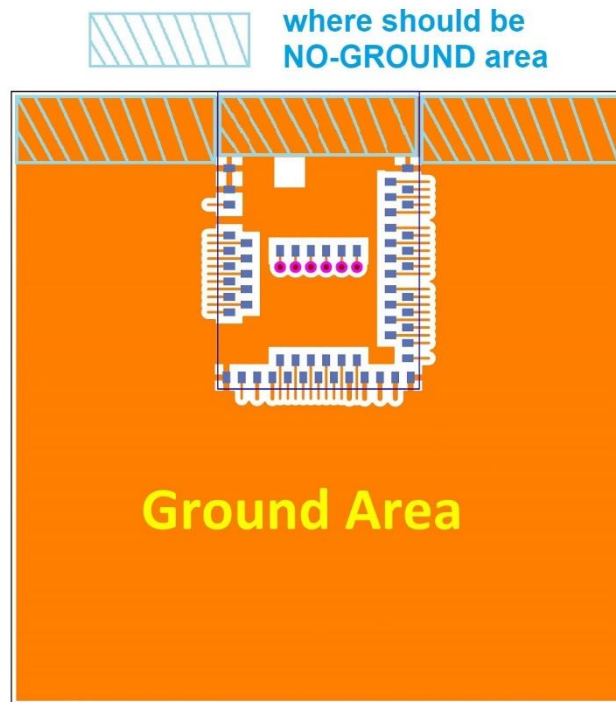
Top layer



Bottom layer



Examples of “**NOT RECOMMENDED**” layout



## 2.4. Pin Assignment

Pin No.	Name	Pin Function	Description
(1)	<b>GND</b>	Power	Ground
(2)	<b>GND</b>	Power	Ground
(3)	<b>P1.10</b>	Digital I/O	General-purpose I/O (standard drive, low frequency I/O only)
(4)	<b>P1.11</b>	Digital I/O	General-purpose I/O (standard drive, low frequency I/O only)
(5)	<b>P1.12</b>	Digital I/O	General-purpose I/O (standard drive, low frequency I/O only)
(6)	<b>P1.13</b>	Digital I/O	General-purpose I/O (standard drive, low frequency I/O only)
(7)	<b>P1.14</b>	Digital I/O	General-purpose I/O (standard drive, low frequency I/O only)
(8)	<b>P1.15</b>	Digital I/O	General-purpose I/O (standard drive, low frequency I/O only)
(9)	<b>P0.03</b>	Digital I/O	General-purpose I/O (standard drive, low frequency I/O only)
	<b>AIN1</b>	Analog input	Analog input
(10)	<b>P0.29</b>	Digital I/O	General-purpose I/O (standard drive, low frequency I/O only)
	<b>AIN5</b>	Analog input	Analog input
(11)	<b>P0.02</b>	Digital I/O	General-purpose I/O (standard drive, low frequency I/O only)
	<b>AIN0</b>	Analog input	Analog input
(12)	<b>P0.31</b>	Digital I/O	General-purpose I/O (standard drive, low frequency I/O only)
	<b>AIN7</b>	Analog input	Analog input
(13)	<b>P0.28</b>	Digital I/O	General-purpose I/O (standard drive, low frequency I/O only)
	<b>AIN4</b>	Analog input	Analog input

Pin No.	Name	Pin Function	Description
(14)	P0.30	Digital I/O	General-purpose I/O (standard drive, low frequency I/O only)
	AIN6	Analog input	Analog input
(15)	GND	Power	Ground
(16)	P0.27	Digital I/O	General-purpose I/O
(17)	P0.00	Digital I/O	General-purpose I/O
	XL1	Analog input	Connection for 32.768 kHz crystal
(18)	P0.01	Digital I/O	General-purpose I/O
	XL2	Analog input	Connection for 32.768 kHz crystal
(19)	P0.26	Digital I/O	General-purpose I/O
(20)	P0.04	Digital I/O	General-purpose I/O
	AIN2	Analog input	Analog input
(21)	P0.05	Digital I/O	General-purpose I/O
	AIN3	Analog input	Analog input
(22)	P0.06	Digital I/O	General-purpose I/O
(23)	P0.07	Digital I/O	General-purpose I/O
	TRACECLK	Trace clock	Trace buffer clock
(24)	P0.08	Digital I/O	General-purpose I/O
(25)	P1.08	Digital I/O	General-purpose I/O
(26)	P1.09	Digital I/O	General-purpose I/O
	TRACEDATA3	Trace data	Trace buffer TRACEDATA [3].
(27)	P0.11	Digital I/O	General-purpose I/O
	TRACEDATA2	Trace data	Trace buffer TRACEDATA[2].
(28)	VDD	Power	Power supply
(29)	P0.12	Digital I/O	General-purpose I/O
	TRACEDATA1	Trace data	Trace buffer TRACEDATA [1].
(30)	VDDH	Power	High voltage power supply
(31)	DCCH	Power	DC/DC converter output
(32)	VBUS	Power	5V input for USB 3.3V regulator

Pin No.	Name	Pin Function	Description
(33)	GND	Power	Ground
(34)	D-	Digital I/O	USB D-
(35)	D+	Digital I/O	USB D+
(36)	P0.14	Digital I/O	General-purpose digital I/O
(37)	P0.13	Digital I/O	General-purpose digital I/O
(38)	P0.16	Digital I/O	General-purpose digital I/O
(39)	P0.15	Digital I/O	General-purpose digital I/O
(40)	P0.18	Digital I/O	General-purpose digital I/O (recommended usage: QSPI / CSN)
	nRESET		Configurable as system RESET
(41)	P0.17	Digital I/O	General-purpose digital I/O
(42)	P0.19	Digital I/O	General-purpose digital I/O (recommended usage: (QSPI / SCK)
(43)	P0.21	Digital I/O	General-purpose digital I/O (recommended usage: QSPI)
(44)	P0.20	Digital I/O	General-purpose digital I/O
(45)	P0.23	Digital I/O	General-purpose digital I/O (recommended usage: QSPI)
(46)	P0.22	Digital I/O	General-purpose digital I/O (recommended usage: QSPI)
(47)	P1.00	Digital I/O	General-purpose digital I/O (recommended usage: QSPI)
	TRACEDATA0	Trace data	Trace buffer TRACEDATA [0].
(48)	P0.24	Digital I/O	General-purpose digital I/O
(49)	P0.25	Digital I/O	General-purpose digital I/O
(50)	P1.02	Digital I/O	General-purpose I/O (standard drive, low frequency I/O only)
(51)	SWDIO	Debug	Debug serial data
(52)	P0.09	Digital I/O	General-purpose I/O (standard drive, low frequency I/O only)
	NFC1	NFC input	NFC antenna connection
(53)	SWDCLK	Debug	Serial wire debug clock input for debug and programming

Pin No.	Name	Pin function	Description
(54)	P0.10	Digital I/O	General-purpose I/O (standard drive, low frequency I/O only)
	NFC2	NFC input	NFC antenna connection
(55)	GND	Power	Ground
(56)	P1.04	Digital I/O	General-purpose I/O (standard drive, low frequency I/O only)
(57)	P1.06	Digital I/O	General-purpose I/O (standard drive, low frequency I/O only)
(58)	P1.07	Digital I/O	General-purpose I/O (standard drive, low frequency I/O only)
(59)	P1.05	Digital I/O	General-purpose I/O (standard drive, low frequency I/O only)
(60)	P1.03	Digital I/O	General-purpose I/O (standard drive, low frequency I/O only)
(61)	P1.01	Digital I/O	General-purpose I/O (standard drive, low frequency I/O only)

## 2.5. GPIO Located Near the Radio



Please refer to [2.4 Pin Assignment](#) on page 16 to 18 where identifies some GPIO that have recommended usage. To maximize RF performance, these GPIO are only available to use under standard drive, low frequency I/O only, wrong usage may lead to undesirable performance.

## 3. Main Chip Solution

RF IC	Crystal Frequency
Nordic NRF52840	32MHZ

*32MHz crystal and RF (VDD) DC/DC inductor are already inside the module.*

## 4. Shipment Packaging Information

Antenna	Model
Chip/Ceramic Antenna	MDBT50Q-1M
	
PCB/Printed Antenna	MDBT50Q-P1M
	

- Unit Weight of Module:

MDBT50Q-1M: 0.68g / pc ( $\pm 0.02g$ ) ; MDBT50Q-P1M: 0.64g / pc ( $\pm 0.02g$ )

- Packaging Type: Tray only

- Minimum Package Quantity (MPQ): 88 pcs per Tray

- Carton Contents: 1760 pcs per carton (20 Full Tray + 1 Empty Tray)

- Dimension of Carton: (L) 37 x (W) 21 x (H) 13 cm

- Gross Weight: approx. 2.80 kgs per full carton (contains 1760pcs)

# 5. Specification

Any technical spec shall refer to Nordic's official documents as final reference.

## 5.1. Absolute Maximum Ratings

	Note	Min.	Max.	Unit
<b>Supply voltages</b>				
VDD		-0.3	+3.9	V
VDDH		-0.3	+5.8	V
VBUS		-0.3	+5.8	V
VSS			0	V
<b>I/O pin voltage</b>				
$V_{I/O}$ , VDD $\leq$ 3.6 V		-0.3	VDD + 0.3 V	V
$V_{I/O}$ , VDD $>$ 3.6 V		-0.3	3.9 V	V
<b>NFC antenna pin current</b>				
$I_{NFC1/2}$			80	mA
<b>Radio</b>				
RF input level			10	dBm
<b>Environmental (aQFN™ package)</b>				
Storage temperature		-40	+125	°C
MSL	Moisture Sensitivity Level		2	
ESD HBM	Human Body Model		2	kV
ESD CDM <sub>QF</sub>	Charged Device Model (aQFN™ 73, 7x7 mm package)		750	V
<b>Flash memory</b>				
Endurance		10 000		Write/erase cycles
Retention		10 years at 40°C		

## 5.2. Operating Conditions

Symbol	Parameter	Min.	Nom.	Max.	Units
VDD	VDD supply voltage, independent of DCDC enable	1.7	3.0	3.6	V
VDD <sub>POR</sub>	VDD supply voltage needed during power-on reset	1.75			V
VDDH	VDDH supply voltage, independent of DCDC enable	2.5	3.7	5.5	V
VBUS	VBUS USB supply voltage	4.35	5	5.5	V
$t_{R\_VDD}$	Supply rise time (0 V to 1.7 V)			60	ms
$t_{R\_VDDH}$	Supply rise time (0 V to 3.7 V)			100	ms
TA	Operating temperature	-40	25	85	°C

\*\*\* The on-chip power-on reset circuitry may not function properly for rise times longer than the specified maximum.

## 5.3. Electrical Specifications

### 5.3.1. General Radio Characteristics

Symbol	Description	Min.	Typ.	Max.	Units
$f_{OP}$	Operating frequencies	2360		2500	MHz
$f_{PLL,CH,SP}$	PLL channel spacing		1		MHz
$f_{DELTA,1M}$	Frequency deviation @ 1 Mbps		$\pm 170$		kHz
$f_{DELTA,BLE,1M}$	Frequency deviation @ BLE 1 Mbps		$\pm 250$		kHz
$f_{DELTA,2M}$	Frequency deviation @ 2 Mbps		$\pm 320$		kHz
$f_{DELTA,BLE,2M}$	Frequency deviation @ BLE 2 Mbps		$\pm 500$		kHz
$f_{skBPS}$	On the air data rate	125		2000	kbps
$f_{chip, IEEE 802.15.4}$	Chip rate in IEEE 802.15.4 mode		2000		kchips

### 5.3.2. Radio Current Consumption (Transmitter)

Symbol	Description	Min.	Typ.	Max.	Units
$I_{TX,PLUS8dBm,DCDC}$	TX only run current (DC/DC, 3 V) $P_{RF} = +8$ dBm	..	14.8	..	mA
$I_{TX,PLUS8dBm}$	TX only run current $P_{RF} = +8$ dBm	..	32.7	..	mA
$I_{TX,PLUS4dBm,DCDC}$	TX only run current (DC/DC, 3 V) $P_{RF} = +4$ dBm	..	9.6	..	mA
$I_{TX,PLUS4dBm}$	TX only run current $P_{RF} = +4$ dBm	..	21.4	..	mA
$I_{TX,0dBm,DCDC,5V,REG0HIGH}$	TX only run current (DC/DC, 5 V, REG0 out = 3.3 V) $P_{RF} = 0$ dBm		3.0		mA
$I_{TX,0dBm,DCDC,5V,REG0L}$	TX only run current (DC/DC, 5 V, REG0 out = 1.8 V) $P_{RF} = 0$ dBm		3.0		mA
$I_{TX,0dBm,DCDC}$	TX only run current (DC/DC, 3 V) $P_{RF} = 0$ dBm	..	4.8	8.7	mA
$I_{TX,0dBm}$	TX only run current $P_{RF} = 0$ dBm	..	10.6	..	mA
$I_{TX,MINUS4dBm,DCDC}$	TX only run current DC/DC, 3 V $P_{RF} = -4$ dBm	..	3.1	..	mA
$I_{TX,MINUS4dBm}$	TX only run current $P_{RF} = -4$ dBm	..	8.1	..	mA
$I_{TX,MINUS8dBm,DCDC}$	TX only run current DC/DC, 3 V $P_{RF} = -8$ dBm		3.3		mA
$I_{TX,MINUS8dBm}$	TX only run current $P_{RF} = -8$ dBm	..	7.2	7.9	mA
$I_{TX,MINUS12dBm,DCDC}$	TX only run current DC/DC, 3 V $P_{RF} = -12$ dBm		3.0		mA
$I_{TX,MINUS12dBm}$	TX only run current $P_{RF} = -12$ dBm	..	6.4	..	mA
$I_{TX,MINUS16dBm,DCDC}$	TX only run current DC/DC, 3 V $P_{RF} = -16$ dBm		2.8		mA
$I_{TX,MINUS16dBm}$	TX only run current $P_{RF} = -16$ dBm	..	6.0	..	mA
$I_{TX,MINUS20dBm,DCDC}$	TX only run current DC/DC, 3 V $P_{RF} = -20$ dBm		2.7		mA
$I_{TX,MINUS20dBm}$	TX only run current $P_{RF} = -20$ dBm	..	5.6	..	mA



Symbol	Description	Min.	Typ.	Max.	Units
$I_{TX,MINUS40dBm,DCDC}$	TX only run current DC/DC, 3 V $P_{RF} = -40$ dBm		2.3		mA
$I_{TX,MINUS40dBm}$	TX only run current $P_{RF} = -40$ dBm	..	4.6	..	mA
$I_{START,TX,DCDC}$	TX start-up current DC/DC, 3 V, $P_{RF} = 4$ dBm		5.2		mA
$I_{START,TX}$	TX start-up current, $P_{RF} = 4$ dBm		11.0		mA

### 5.3.3. Radio Current Consumption (Receiver)

Symbol	Description	Min.	Typ.	Max.	Units
$I_{RX,1M,DCDC}$	RX only run current (DC/DC, 3 V) 1 Mbps / 1 Mbps BLE	..	4.6	..	mA
$I_{RX,1M}$	RX only run current (LDO, 3 V) 1 Mbps / 1 Mbps BLE	..	9.9	..	mA
$I_{RX,2M,DCDC}$	RX only run current (DC/DC, 3 V) 2 Mbps / 2 Mbps BLE	..	5.2	..	mA
$I_{RX,2M}$	RX only run current (LDO, 3 V) 2 Mbps / 2 Mbps BLE	..	11.1	..	mA
$I_{START,RX,1M,DCDC}$	RX start-up current (DC/DC, 3 V) 1 Mbps / 1 Mbps BLE		3.7		mA
$I_{START,RX,1M}$	RX start-up current 1 Mbps / 1 Mbps BLE		6.7		mA

### 5.3.4. Transmitter Specification

Symbol	Description	Min.	Typ.	Max.	Units
$P_{RF}$	Maximum output power	..	8.0	..	dBm
$P_{RFC}$	RF power control range		28.0		dB
$P_{RFCR}$	RF power accuracy			$\pm 4$	dB
$P_{RF1,1}$	1st Adjacent Channel Transmit Power 1 MHz (1 Mbps)	..	-24.8	..	dBc
$P_{RF2,1}$	2nd Adjacent Channel Transmit Power 2 MHz (1 Mbps)	..	-54.0	..	dBc
$P_{RF1,2}$	1st Adjacent Channel Transmit Power 2 MHz (2 Mbps)	..	-25	..	dBc
$P_{RF2,2}$	2nd Adjacent Channel Transmit Power 4 MHz (2 Mbps)	..	-54.0	..	dBc
$E_{vm}$	Error vector magnitude IEEE 802.15.4	..	8	..	%rms
$P_{harm2nd, IEEE 802.15.4}$	2nd harmonics in IEEE 802.15.4 mode	..	-51.0	..	dBm
$P_{harm3rd, IEEE 802.15.4}$	3rd harmonics in IEEE 802.15.4		-48.0	..	dBm

## 5.3.5. Receiver Operation

Symbol	Description	Min.	Typ.	Max.	Units
P <sub>RX,MAX</sub>	Maximum received signal strength at < 0.1% PER		0		dBm
P <sub>SENS,IT,1M</sub>	Sensitivity, 1 Mbps nRF mode <sup>1</sup>		-93		dBm
P <sub>SENS,IT,SP,1M,BLE</sub>	Sensitivity, 1 Mbps BLE ideal transmitter, <=37 bytes BER=1E-3 <sup>2</sup>		-95		dBm
P <sub>SENS,IT,LP,1M,BLE</sub>	Sensitivity, 1 Mbps BLE ideal transmitter >=128 bytes BER=1E-4 <sup>3</sup>		-94.0		dBm
P <sub>SENS,IT,2M</sub>	Sensitivity, 2 Mbps nRF mode <sup>4</sup>				dBm
P <sub>SENS,IT,SP,2M,BLE</sub>	Sensitivity, 2 Mbps BLE ideal transmitter, Packet length <=37 bytes		-92		dBm
P <sub>SENS,IT,BLE LE125k</sub>	Sensitivity, 125 kbps BLE mode		-103.0		dBm
P <sub>SENS,IT,BLE LE500k</sub>	Sensitivity, 500 kbps BLE mode		-99		dBm
P <sub>sense, IEEE 802.15.4</sub>	Sensitivity in IEEE 802.15.4 mode		-100		dBm

1. Typical sensitivity applies when ADDR0 is used for receiver address correlation. When ADDR [1...7] are used for receiver address correlation, the typical sensitivity for this mode is degraded by 3dB.
2. As defined in the Bluetooth Core Specification v4.0 Volume 6: Core System Package (Low Energy Controller Volume).
3. Equivalent BER limit < 10E-04.
4. Same as remark 1.

## 5.3.6. RX Selectivity

Symbol	Description	Min.	Typ.	Max.	Units
C/I <sub>1M,co-channel</sub>	1Mbps mode, Co-Channel interference		9		dB
C/I <sub>1M,-1MHz</sub>	1 Mbps mode, Adjacent (-1 MHz) interference		-2		dB
C/I <sub>1M,+1MHz</sub>	1 Mbps mode, Adjacent (+1 MHz) interference		-10		dB
C/I <sub>1M,-2MHz</sub>	1 Mbps mode, Adjacent (-2 MHz) interference		-19		dB
C/I <sub>1M,+2MHz</sub>	1 Mbps mode, Adjacent (+2 MHz) interference		-42		dB
C/I <sub>1M,-3MHz</sub>	1 Mbps mode, Adjacent (-3 MHz) interference		-38		dB
C/I <sub>1M,+3MHz</sub>	1 Mbps mode, Adjacent (+3 MHz) interference		-48		dB
C/I <sub>1M,±6MHz</sub>	1 Mbps mode, Adjacent (≥6 MHz) interference		-50		dB
C/I <sub>1MBLE,co-channel</sub>	1 Mbps BLE mode, Co-Channel interference		6		dB
C/I <sub>1MBLE,-1MHz</sub>	1 Mbps BLE mode, Adjacent (-1 MHz) interference		-2		dB
C/I <sub>1MBLE,+1MHz</sub>	1 Mbps BLE mode, Adjacent (+1 MHz) interference		-9		dB
C/I <sub>1MBLE,-2MHz</sub>	1 Mbps BLE mode, Adjacent (-2 MHz) interference		-22		dB
C/I <sub>1MBLE,+2MHz</sub>	1 Mbps BLE mode, Adjacent (+2 MHz) interference		-46		dB
C/I <sub>1MBLE,&gt;3MHz</sub>	1 Mbps BLE mode, Adjacent (≥3 MHz) interference		-50		dB
C/I <sub>1MBLE,image</sub>	Image frequency interference		-22		dB
C/I <sub>1MBLE,image,1MHz</sub>	Adjacent (1 MHz) interference to in-band image frequency		-35		dB
C/I <sub>2M,co-channel</sub>	2 Mbps mode, Co-Channel interference		10		dB

Symbol	Description	Min.	Typ.	Max.	Units
C/I <sub>2M,-2MHz</sub>	2 Mbps mode, Adjacent (-2 MHz) interference		6		dB
C/I <sub>2M,+2MHz</sub>	2 Mbps mode, Adjacent (+2 MHz) interference		-19		dB
C/I <sub>2M,-4MHz</sub>	2 Mbps mode, Adjacent (-4 MHz) interference		-20		dB
C/I <sub>2M,+4MHz</sub>	2 Mbps mode, Adjacent (+4 MHz) interference		-44		dB
C/I <sub>2M,-6MHz</sub>	2 Mbps mode, Adjacent (-6 MHz) interference		-42		dB
C/I <sub>2M,+6MHz</sub>	2 Mbps mode, Adjacent (+6 MHz) interference		-42		dB
C/I <sub>2M,≥12MHz</sub>	2 Mbps mode, Adjacent (≥12 MHz) interference		-52		dB
C/I <sub>2MBLE,co-channel</sub>	2 Mbps BLE mode, Co-Channel interference		6.8		dB
C/I <sub>2MBLE,±2MHz</sub>	2 Mbps BLE mode, Adjacent (±2 MHz) interference		-10		dB
C/I <sub>2MBLE,±4MHz</sub>	2 Mbps BLE mode, Adjacent (±4 MHz) interference		-45		dB
C/I <sub>2MBLE,≥6MHz</sub>	2 Mbps BLE mode, Adjacent (≥6 MHz) interference		-48		dB
C/I <sub>2MBLE,image</sub>	Image frequency interference		-24		dB
C/I <sub>2MBLE,image, 2MHz</sub>	Adjacent (2 MHz) interference to in-band image frequency		-35		dB
C/I <sub>125k BLE LR, co-channel</sub>	125 kbps BLE LR mode, Co-Channel interference		4.4		dB
C/I <sub>125k BLE LR,-1MHz</sub>	125 kbps BLE LR mode, Adjacent (-1 MHz) interference		-4.0		dB
C/I <sub>125k BLE LR,+1MHz</sub>	125 kbps BLE LR mode, Adjacent (+1 MHz) interference		-12		dB
C/I <sub>125k BLE LR,-2MHz</sub>	125 kbps BLE LR mode, Adjacent (-2 MHz) interference		-28		dB
C/I <sub>125k BLE LR,+2MHz</sub>	125 kbps BLE LR mode, Adjacent (+2 MHz) interference		-50		dB
C/I <sub>125k BLE LR,&gt;3MHz</sub>	125 kbps BLE LR mode, Adjacent (≥3 MHz) interference		-55		dB
C/I <sub>125k BLE LR,image</sub>	Image frequency interference		-29		dB

Remark: Wanted signal level at PIN = -67 dBm. One interferer is used, having equal modulation as the wanted signal. The input power of the interferer where the sensitivity equals BER = 0.1% is presented.

### 5.3.7. RX Intermodulation

Symbol	Description	Min.	Typ.	Max.	Units
P <sub>IMD,5TH,1M</sub>	IMD performance, 1 Msps, 5th offset channel, Packet length ≤ 37 bytes		-33		dBm
P <sub>IMD,5TH,1M,BLE</sub>	IMD performance, BLE 1 Msps, 5th offset channel, Packet length ≤ 37 bytes		-30		dBm
P <sub>IMD,5TH,2M</sub>	IMD performance, 2 Msps, 5th offset channel, Packet length ≤ 37 bytes		-33		dBm
P <sub>IMD,5TH,2M,BLE</sub>	IMD performance, BLE 2 Msps, 5th offset channel, Packet length ≤ 37 bytes		-31		dBm

Remark: Wanted signal level at PIN = -64dBm. Two interferers with equal input power are used. The interferer closest in frequency is not modulated, the other interferer is modulated equal with the wanted signal. The input power of the interferers where the sensitivity equals BER = 0.1% is presented.

## 5.3.8. Radio Timing Parameters

Symbol	Description	Min.	Typ.	Max.	Units
$t_{TXEN}$	Time between TXEN task and READY event after channel FREQUENCY configured		140		$\mu s$
$t_{TXEN,FAST}$	Time between TXEN task and READY event after channel FREQUENCY configured (fast Mode)		40		$\mu s$
$t_{TXDISABLE}$	Time between DISABLE task and DISABLED event when the radio was in TX and mode is set to 1Mbps		6		$\mu s$
$t_{TXDISABLE,2M}$	Time between DISABLE task and DISABLED event when the radio was in TX and mode is set to 2Mbps		4		$\mu s$
$t_{RXEN}$	Time between the RXEN task and READY event after channel FREQUENCY configured in default mode		140		$\mu s$
$t_{RXEN,FAST}$	Time between the RXEN task and READY event after channel FREQUENCY configured in fast mode		40		$\mu s$
$t_{RXDISABLE}$	Time between DISABLE task and DISABLED event when the radio was in RX		0		$\mu s$
$t_{RX-to-TX \text{ turnaround}}$	Maximum TX-to-RX or RX-to-TX turnaround time in IEEE 802.15.4 mode	..	..	..	$\mu s$

## 5.3.9. RSSI Specifications

Symbol	Description	Min.	Typ.	Max.	Units
$RSSI_{ACC}$	RSSI accuracy valid range -90 to -20 dBm		+2		dB
$RSSI_{RESOLUTION}$	RSSI resolution		1		dB
$RSSI_{PERIOD}$	Sample period		15.0		$\mu s$

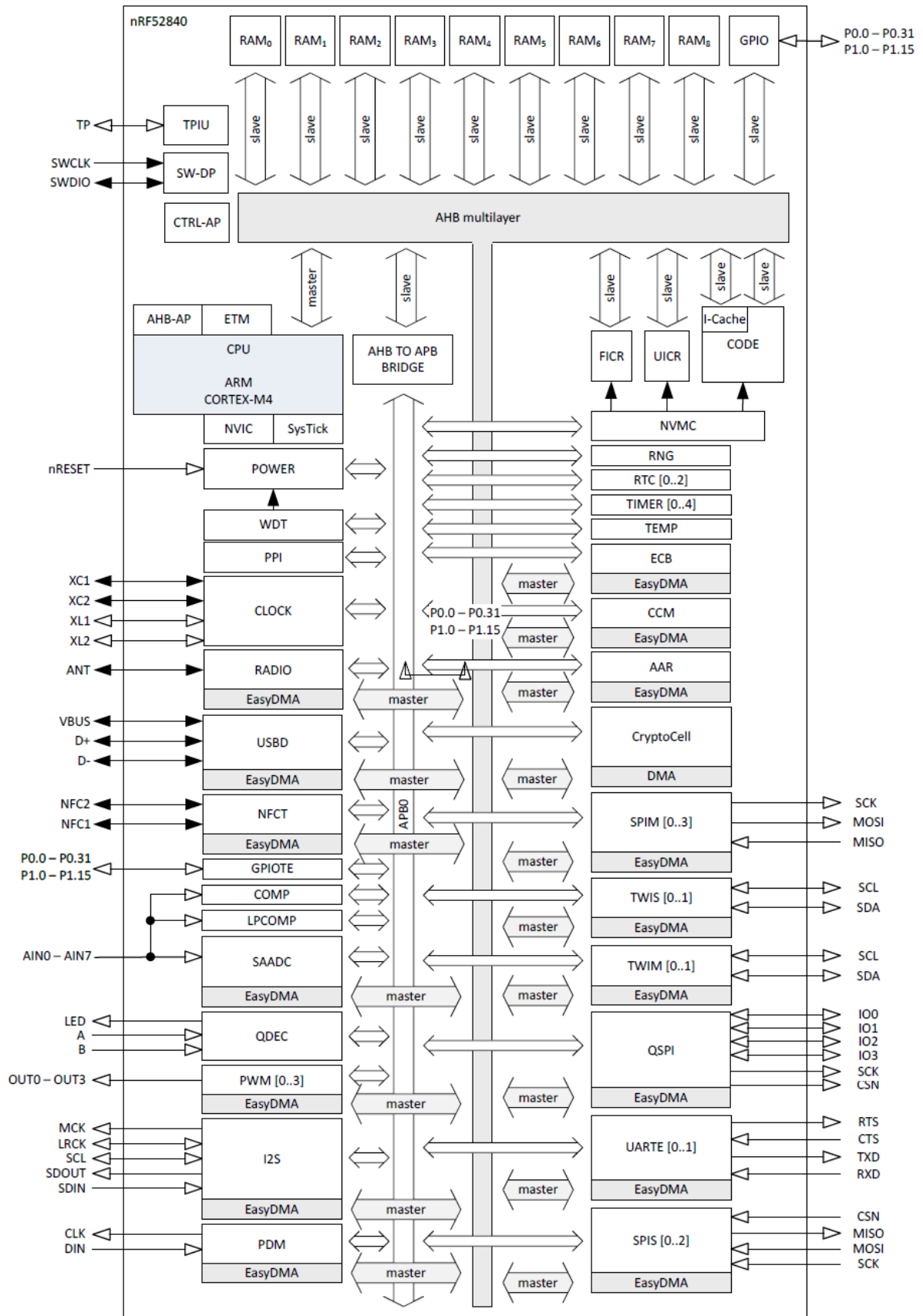
## 5.3.10. CPU

Symbol	Description	Min.	Typ.	Max.	Units
$W_{FLASH}$	CPU wait states, running CoreMark from flash, cache disabled			2	
$W_{FLASHCACHE}$	CPU wait states, running CoreMark from flash, cache enabled			3	
$W_{RAM}$	CPU wait states, running CoreMark from RAM			0	
$CM_{FLASH}$	CoreMark, running CoreMark from flash, cache enabled		212		Coref
$CM_{FLASH/MHz}$	CoreMark per MHz, running CoreMark from flash, cache enabled		3.3		CoreMark/ MHz
$CM_{FLASH/mA}$	CoreMark per mA, running CoreMark from flash, cache enabled, DCDC 3V		59		Coref mA

## 5.3.11. Power Management

Symbol	Description	Min.	Typ.	Max.	Units
I <sub>ON_RAMOFF_EVENT</sub>	System ON, no RAM retention, wake on any event		0.97		μA
I <sub>ON_RAMON_EVENT</sub>	System ON, full 256 kB RAM retention, wake on any event		2.35		μA
I <sub>ON_RAMON_POF</sub>	System ON, full 256 kB RAM retention, wake on any event, power-fail comparator enabled		2.35		μA
I <sub>ON_RAMON_GPIOTE</sub>	System ON, full 256 kB RAM retention, wake on GPIOTE input (event mode)		17.37		μA
I <sub>ON_RAMON_GPIOTEPORT</sub>	System ON, full 256 kB RAM retention, wake on GPIOTE PORT event		2.36		μA
I <sub>ON_RAMOFF_RTC</sub>	System ON, no RAM retention, wake on RTC (running from LFRC clock)		1.5		μA
I <sub>ON_RAMON_RTC</sub>	System ON, full 256 kB RAM retention, wake on RTC (running from LFRC clock)		3.16		μA
I <sub>OFF_RAMOFF_RESET</sub>	System OFF, no RAM retention, wake on reset		0.40		μA
I <sub>OFF_RAMOFF_LPCOMP</sub>	System OFF, no RAM retention, wake on LPCOMP		0.86		μA
I <sub>OFF_RAMON_RESET</sub>	System OFF, full 256 kB RAM retention, wake on reset		1.86		μA
I <sub>ON_RAMOFF_EVENT_5V</sub>	System ON, no RAM retention, wake on any event, 5 V supply on VDDH, REG0 output = 3.3 V		1.29		μA
I <sub>OFF_RAMOFF_RESET_5V</sub>	System OFF, no RAM retention, wake on reset, 5 V supply on VDDH, REG0 output = 3.3 V		0.95		μA

# 6. Block Diagram

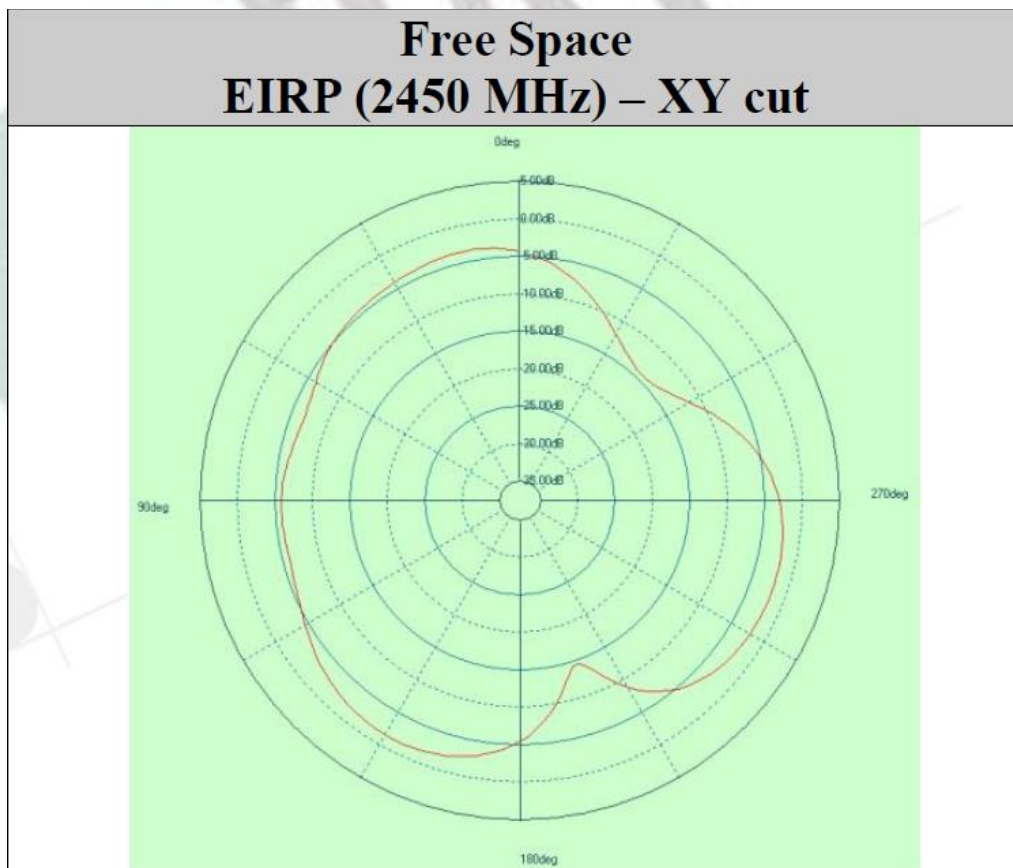


# 7. Antenna

## 7.1. MDBT50Q Series

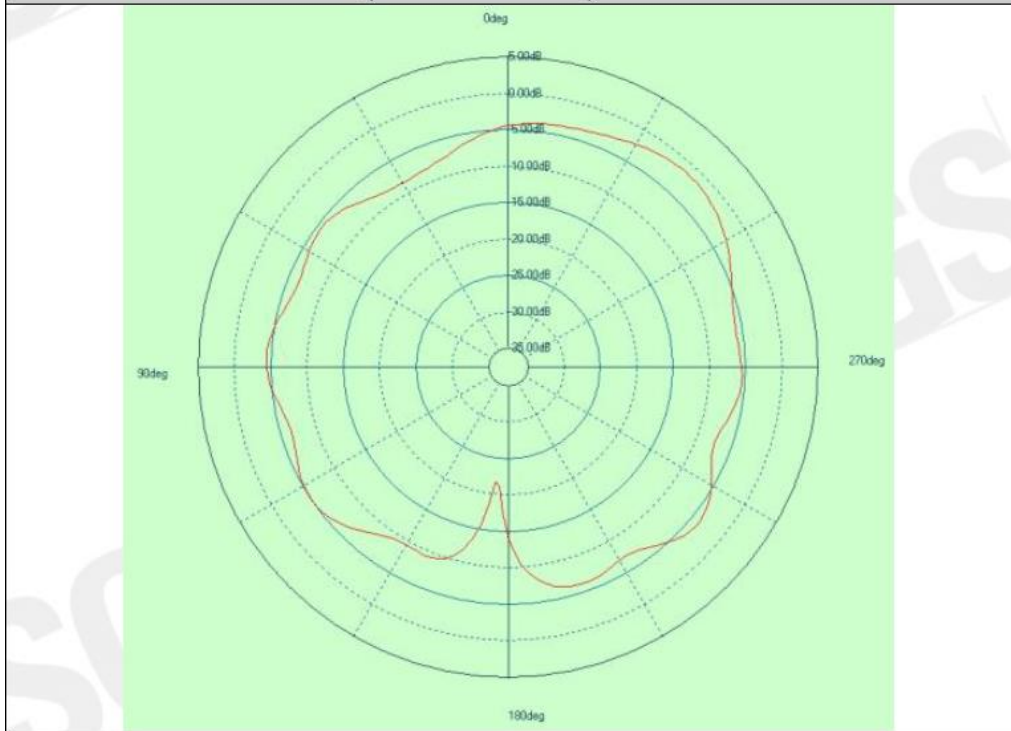
### Antenna Gain and Efficiency

MDBT50Q (CHIP antenna)			
Freq(MHz)	Peak. dBi	Efficiency	Average . dBi
2400.00	-1.47	25.18%	-5.99
2410.00	-1.27	26.07%	-5.84
2420.00	-1.32	27.15%	-5.66
2430.00	-1.12	28.51%	-5.45
2440.00	-0.80	29.41%	-5.32
2450.00	-0.65	29.59%	-5.29
2460.00	-0.82	28.98%	-5.38
2470.00	-0.94	29.31%	-5.33
2480.00	-0.88	29.12%	-5.36
2490.00	-0.98	27.60%	-5.59
2500.00	-1.49	24.96%	-6.03

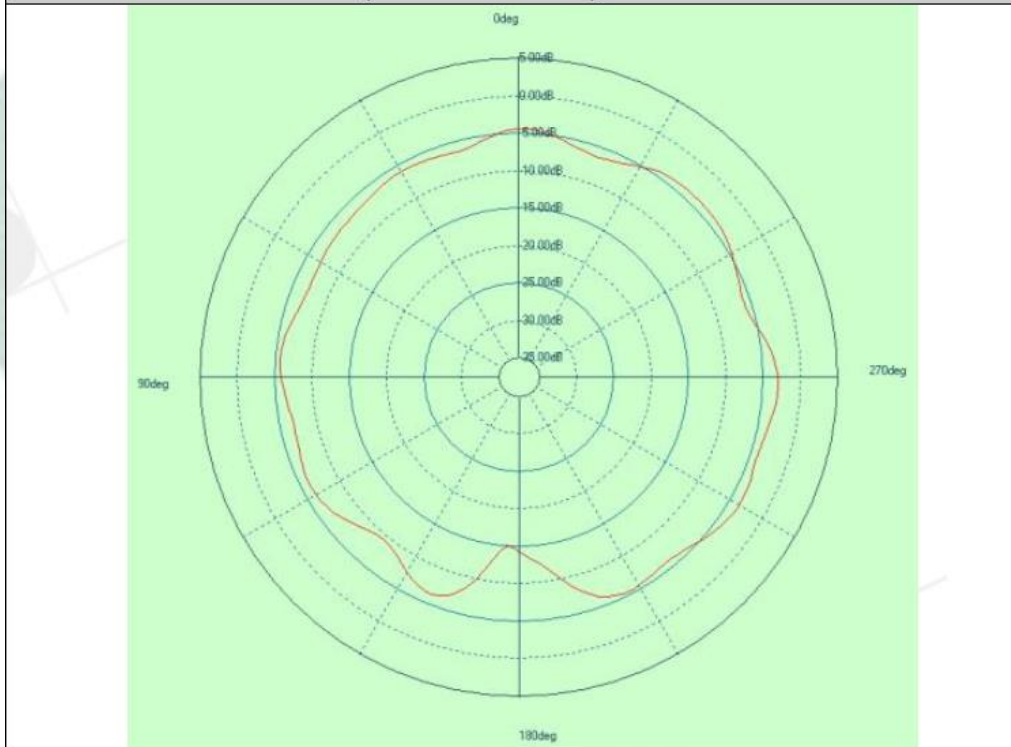




## Free Space EIRP (2450 MHz) – XZ cut



## Free Space EIRP (2450 MHz) – YZ cut



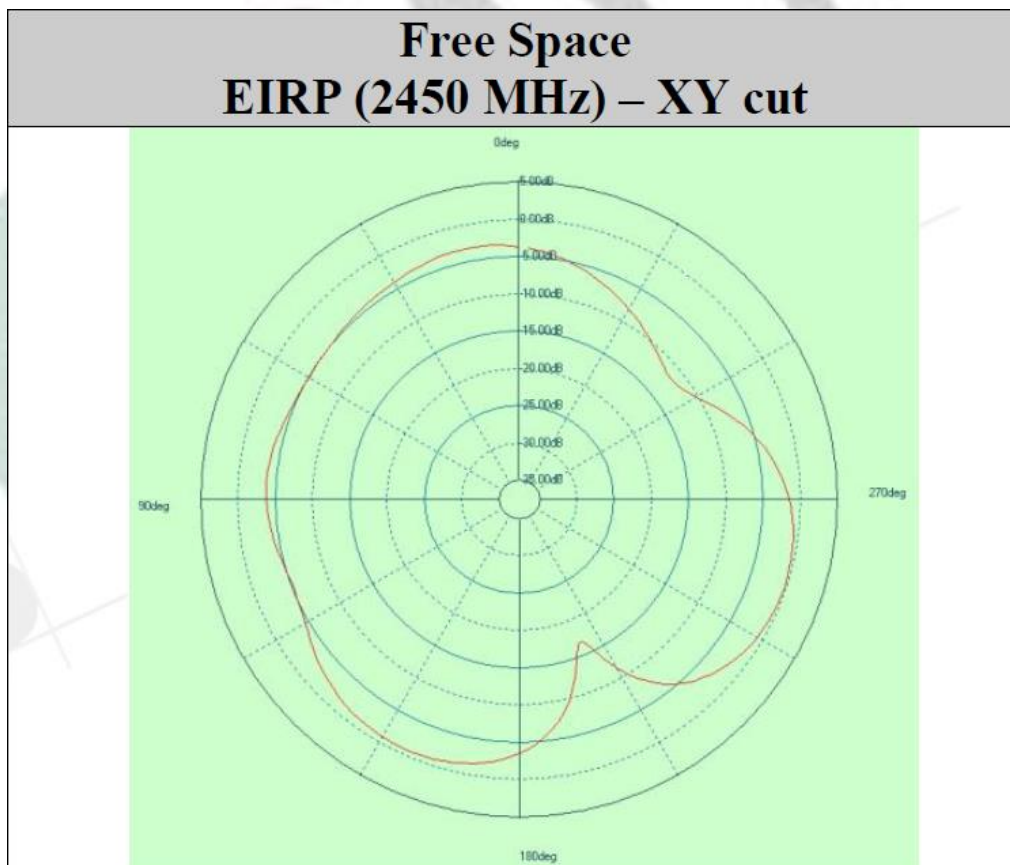


## 7.2. MDBT50Q-P Series

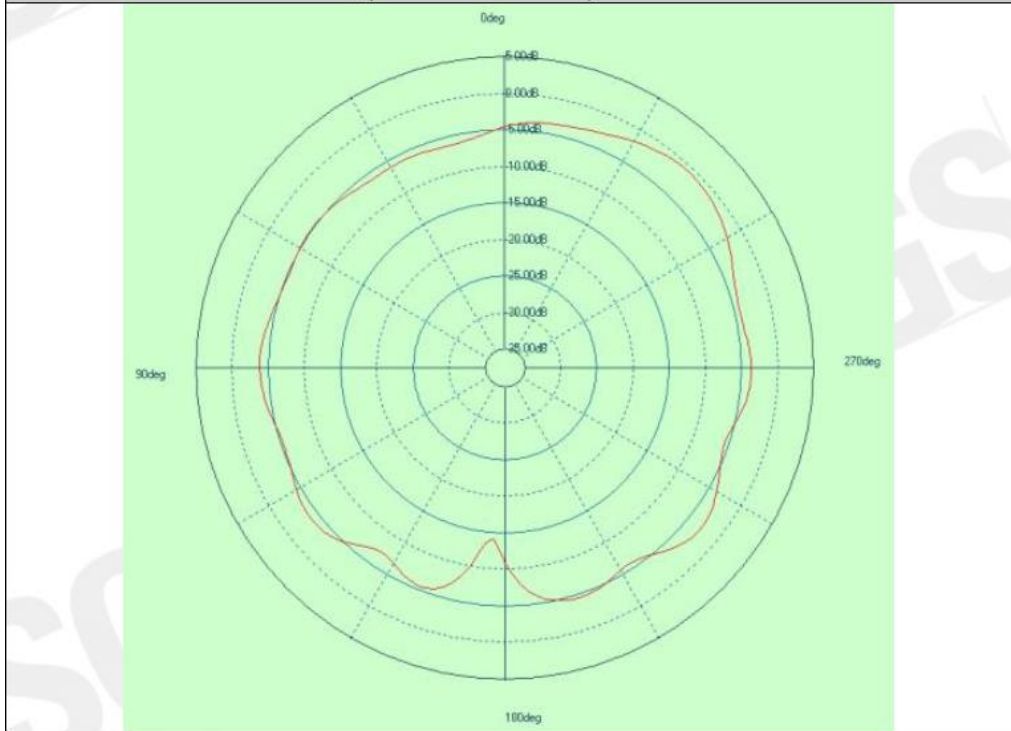
### Antenna Gain and Efficiency

MDBT50Q (PCB antenna)			
Freq(MHz)	Peak. dBi	Efficiency	Average . dBi
2400.00	-0.72	29.40%	-5.32
2410.00	-0.62	31.02%	-5.08
2420.00	-0.44	32.89%	-4.83
2430.00	-0.44	35.00%	-4.56
2440.00	0.08	36.98%	-4.32
2450.00	0.05	37.76%	-4.23
2460.00	0.24	37.40%	-4.27
2470.00	0.26	37.43%	-4.27
2480.00	0.41	36.96%	-4.32
2490.00	0.37	35.03%	-4.56
2500.00	-0.15	31.71%	-4.99

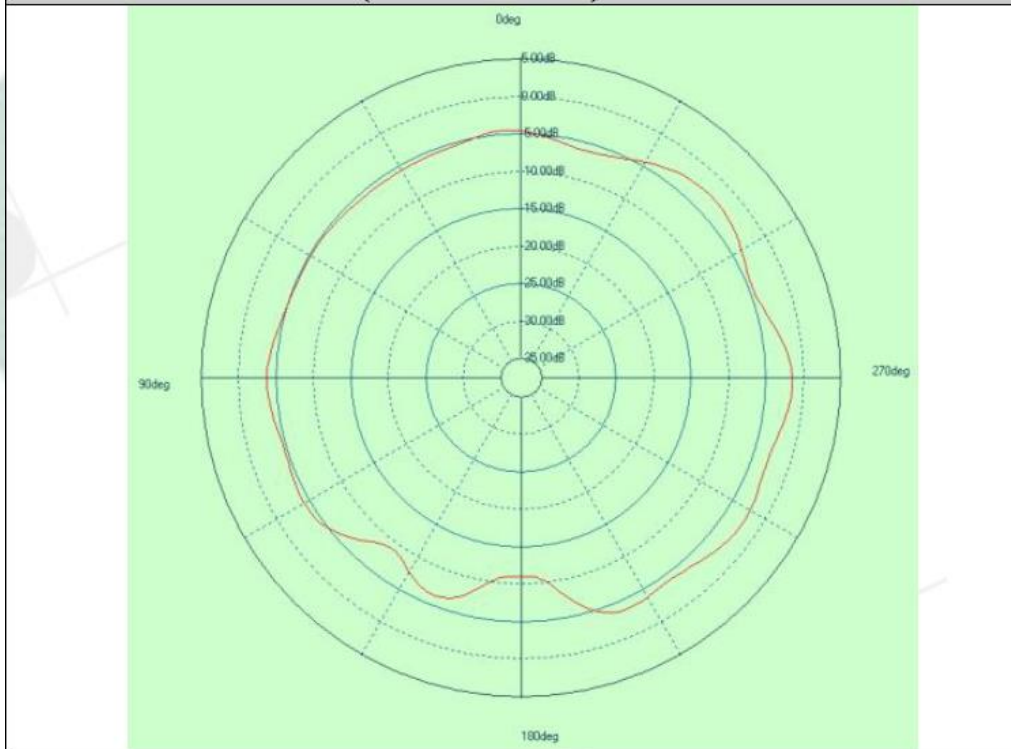
### Free Space EIRP (2450 MHz) – XY cut



## Free Space EIRP (2450 MHz) – XZ cut



## Free Space EIRP (2450 MHz) – YZ cut



# 8. Reference Circuit

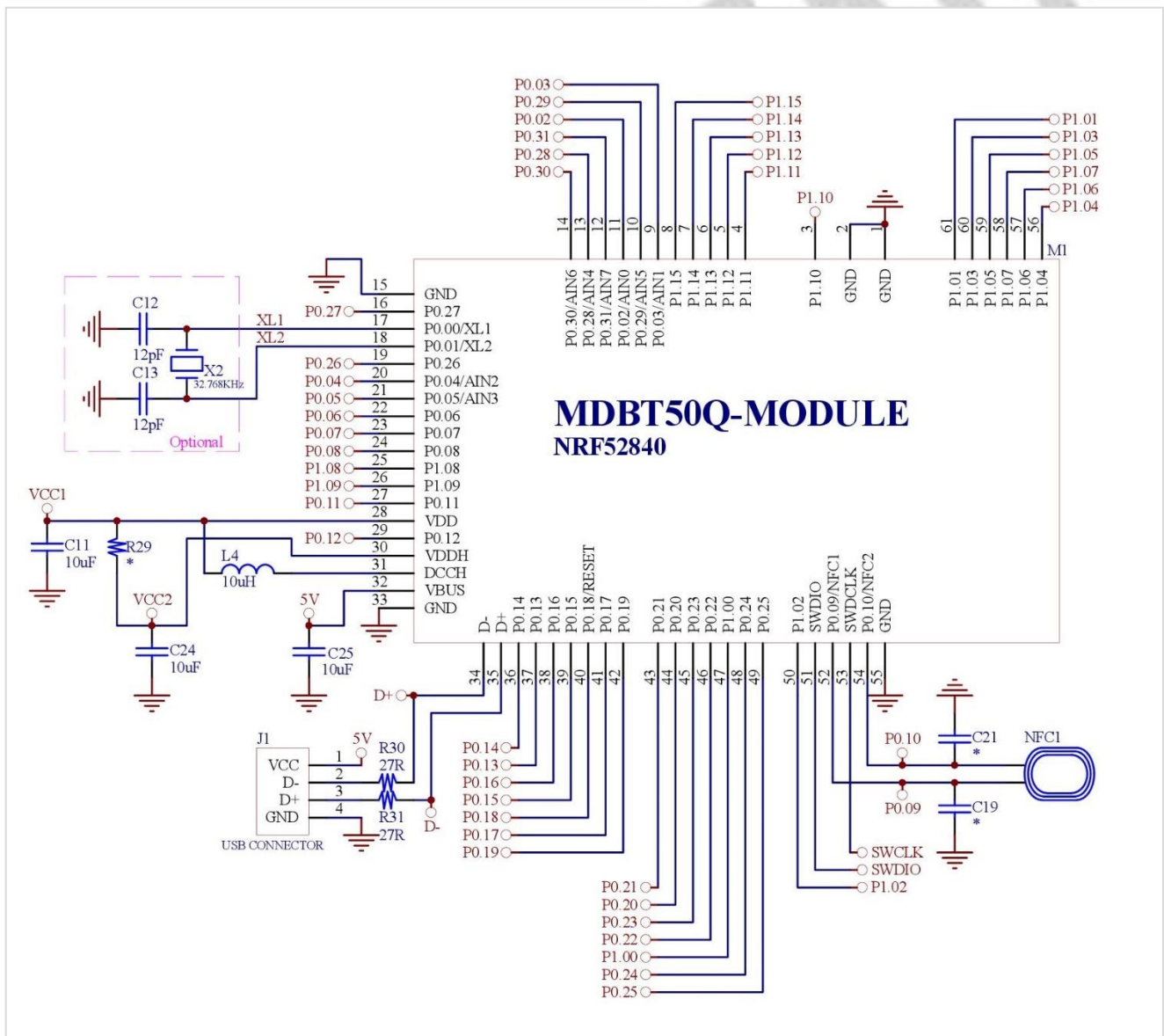
Module's default is using "DC-DC mode", and must connect it to external 32.768khz to work.

**REMARK:**

**\*\* When NOT using DC-DC (VDDH) mode, please remove L4. \*\***  
 (L4 spec: 10μH, 0603 Chip Inductor, IDC, min = 80mA, ±20%)

**\*\* When NOT using NFC, please remove NFC1 / C19 / C21. \*\***

**\*\* When using internal 32.768khz RC oscillator, please remove X2 / C12 / C13. \*\***



## 9. Certification

All certifications are pending. It is estimated to be available in July of 2018.

## 10. Notes and Cautions

Module is not designed to be used and lasting a lifetime. Like general products, it is expected to be worn out after continuous usage through the years. To assure that product will perform better and last longer, please

- Follow the guidelines of this document while designing circuit/end-product. Any discrepancy of core Bluetooth technology and technical specification of IC should refer to definition of Bluetooth Organization and Nordic Semiconductor as final reference.
- Do not supply voltage that is not within range of specification.
- Eliminate static electricity at any methods when working with the module as it may cause damage. It is highly recommended adding anti-ESD components to circuit design to prevent damage from real-life ESD events. Anti-ESD methods can be also applied in mechanical design.
- Do not expose modules under direct sunlight for long duration. Modules should be kept away from humid and salty air conditions, and any corrosive gasses or substances. Store it within  $-40^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$  before and after installation.
- Avoid any physical shock, intense stress to the module or its surface.

The module is not suitable for life support device or system and not allowed to be used in destructive device or system in any direct, or indirect ways. The customer is agreeing to indemnify Raytac for any losses when applying modules under such application as described above.

# 11. Basic Facts for nRF52 Chip

Below is the comparison chart between nRF52840, nRF52832 and nRF52810. Any discrepancy shall refer to Nordic's technical document as final reference.

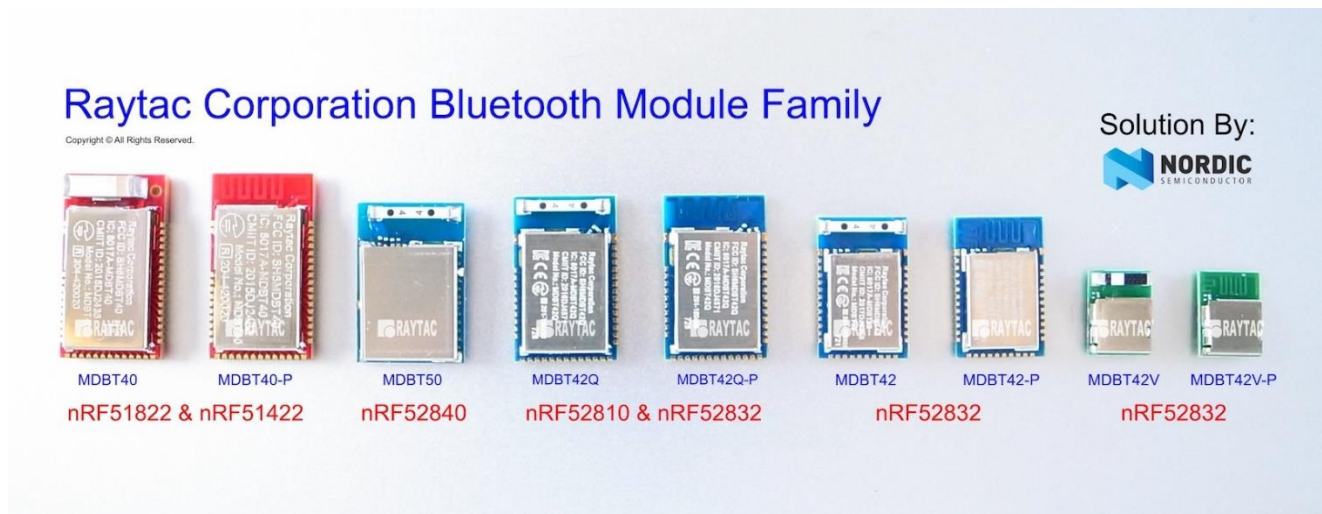
	nRF52840	nRF52832	nRF52810
<b>RAYTAC Model No.:</b>	Click to see " <a href="#">Full List of Raytac's BLE Modules</a> "		
<b>Bluetooth 5 Long Range (x4)</b>	V		
<b>Bluetooth 5 High Speed</b>	V	V	V
<b>Bluetooth 5 Advertisement Extension (x8)</b>	V	V	V
<b>Flash (kBytes)</b>	1024	512	192
<b>RAM (kBytes)</b>	256	64	24
<b>ANT</b>	V	V	V
<b>IEEE 802.15.4</b>	V		
<b>ARM® TrustZone® Cryptocell</b>	V		
<b>USB</b>	V		
<b>QSPI</b>	V		
<b>NFC</b>	V	V	
<b>I2S</b>	V	V	
<b>SPI, TWI, UART, PWM</b>	V	V	V
<b>PDM</b>	V	V	V
<b>ADC, Comparators</b>	V	V	V
<b>Supply Range (V)</b>	1.7 to 5.5	1.7 to 3.6	1.7 to 3.6

## 12. Useful Links

- **Nordic Infocenter:** <https://infocenter.nordicsemi.com/index.jsp>  
All the necessary technical files and software development kits of Nordic's chip are on this website.
- **Nordic Developer Zone:** <https://devzone.nordicsemi.com/questions/>  
A highly recommended website for firmware developer. Interact with other developers and Nordic's employees will help with your questions. The site also includes tutorials in detail to help you get started.
- **Official Page of nRF52840 :** <https://www.nordicsemi.com/eng/Products/nRF52840>  
A brief introduction to nRF52840 and download links for Nordic's developing software and SoftDevices.



# Full List of Raytac's BLE Modules



## MDBT40 & MDBT40-P Series

Series	Nordic Solution	Raytac No.	IC Version	Antenna	RAM	Flash Memory
MDBT40	nRF51822	MDBT40-256V3	3	Chip Antenna	16 kb	256 K
		MDBT40-256RV3			32 kb	256 K
MDBT40-P	nRF51822	MDBT40-P256V3	3	PCB Antenna	16 kb	256 K
		MDBT40-P256RV3			32 kb	256 K
MDBT40 - ANT	nRF51422	MDBT40-ANT-256V3	3	Chip Antenna	16 kb	256 K
		MDBT40-ANT-256RV3			32 kb	
MDBT40 - ANT-P	nRF51422	MDBT40-ANT-P256V3	3	PCB Antenna	16 kb	256 K
		MDBT40-ANT-P256RV3			32 kb	
MDBT40 Nano	nRF51822	MDBT40-n256V3	3	N/A	16 kb	256 K
MDBT40 - ANT-Nano	nRF51422	MDBT40-ANT-n256V3	3	N/A	16 kb	256 K

### MDBT42Q Series (QFN Package IC)

Series	Nordic Solution	Raytac No.	IC Version	Antenna	RAM	Flash Memory
MDBT42Q	nRF52832	MDBT42Q-512KV2	2	Chip Antenna	64 kb	512 K
	nRF52810	MDBT42Q-192K	1		24 kb	192 K

MDBT42Q-P	nRF52832	MDBT42Q-P512KV2	2	PCB Antenna	64 kb	512 K
	nRF52810	MDBT42Q-P192K	1		24 kb	192 K

### MDBT42 Series (WLCSP Package IC)

Series	Nordic Solution	Raytac No.	IC Version	Antenna	RAM	Flash Memory
MDBT42	nRF52832	MDBT42-512KV2	2	Chip Antenna	64 kb	512 K
MDBT42-P		MDBT42-P512KV2		PCB Antenna		

Series	Nordic Solution	Raytac No.	IC Version	Antenna	RAM	Flash Memory
MDBT42V	nRF52832	MDBT42V-512KV2	2	Chip Antenna	64 kb	512 K
MDBT42V-P		MDBT42V-P512KV2		PCB Antenna		

### MDBT50Q Series (aQFN Package IC)

Series	Nordic Solution	Raytac No.	IC Version	Antenna	RAM	Flash Memory
MDBT50Q	nRF52840	MDBT50Q-1M	1	Chip Antenna	256 kb	1MB
MDBT50Q-P		MDBT50Q-P1M		PCB Antenna		
MDBT50Q-U		MDBT50Q-U1M		u.FL Connector		



# Release Note

- 2017/10/30 Pre-release
- 2018/01/19 Model no. officially changed to MDBT50Q-1M & MDBT50Q-P1M.
- 2018/04/10 Version A (1<sup>st</sup> release)
- 2018/06/12 Version B

(1) Added Chapter 4: Shipment Packaging Info and Chapter 7: Antenna.





MIAMI  
UNIVERSITY

OXFORD, OH • EST. 1809

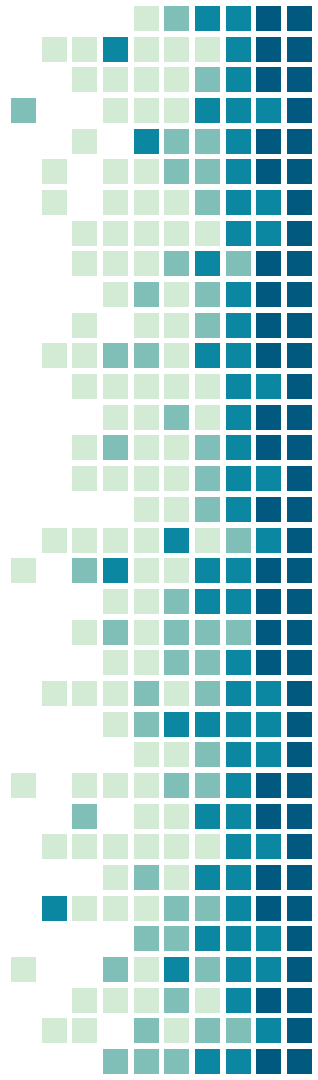
# SENIOR DESIGN

**John Whitt**

**Thomas Tully**

**Oscar Candray**

Miami University Hamilton

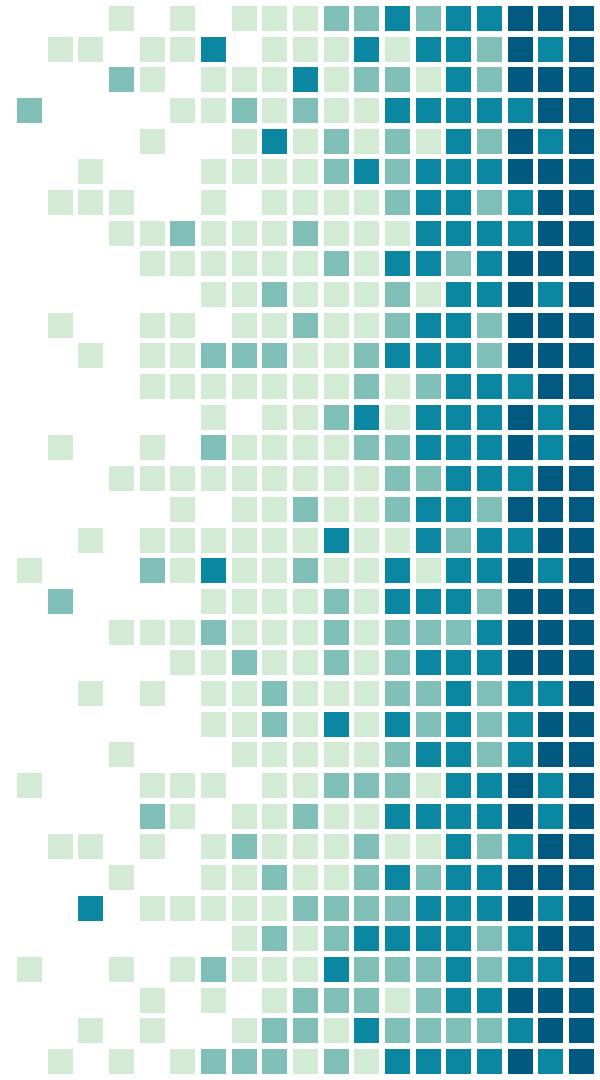


CHILD SAFETY SEAT  
OCCUPANT  
DETECTION  
AND ALERT SYSTEM  
CS-SODAS



1.

# DEFINING THE PROBLEM



14% of parents

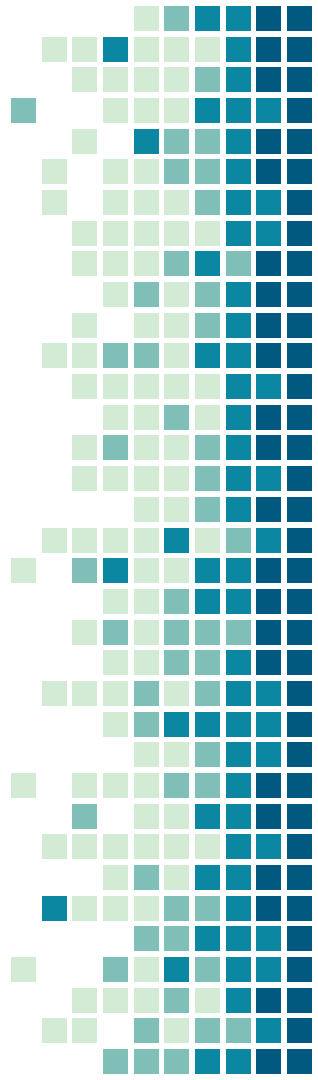
Leave their infants in a car intentionally

11% admit to forgetting

Their young children in a vehicle

6% are comfortable

Leaving an infant longer than 15 minutes



2.

# RESEARCH & DESIGN

How to approach a solution





# IF YOU CAN'T REMEMBER YOUR CHILD

You're not going to remember to:

- Turn on another device
- Pair it with your smartphone
- Charge or change another battery

# DESIGN CONSIDERATIONS

- User installable and serviceable
  - Most consumers already have a favorite car seat
  - Our device should be viewed as an accessory to improve current seats
- Waterproof
  - Will be exposed to bodily fluids on a regular basis
- Baby friendly, Babyproof
  - No loose parts
  - Comfortable to interact with





# DESIGN CONSIDERATIONS

- Energy efficient
  - Battery life > 6 months
- Functional in real-world car temperatures
  - -20C to 80C
- Low-cost
  - Production costs < \$20
  - Want to eliminate acquisition barriers for consumers
- Seamless integration with current devices
  - Must auto-connect to phones and wearables



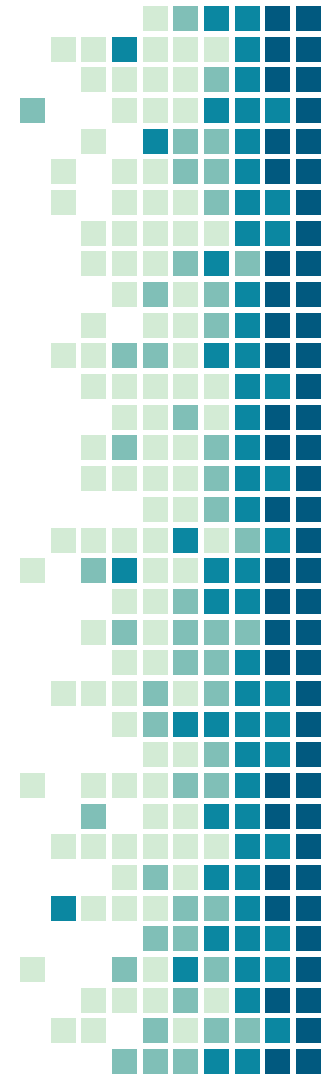
# REQUIREMENTS

## CONNECT TO SMART DEVICES

- Automatic on and off
- Easy to install/retrofittable
- Affordable

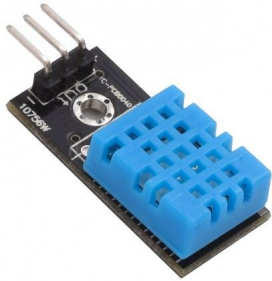
## DETECT PRESENCE OF CHILD

- Minimize false positives
- Eliminate false negatives
- Reliable and power efficient

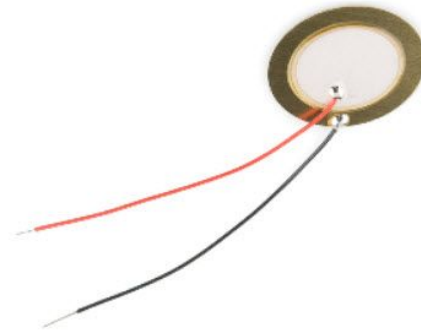


# IDEAS WHICH DID NOT SUCCEED

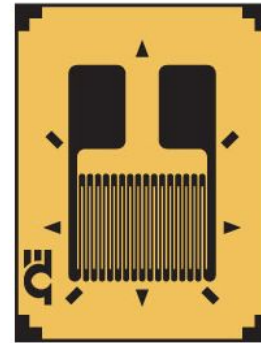
Temperature Sensors



Piezoelectric Sensors



Strain Gauges



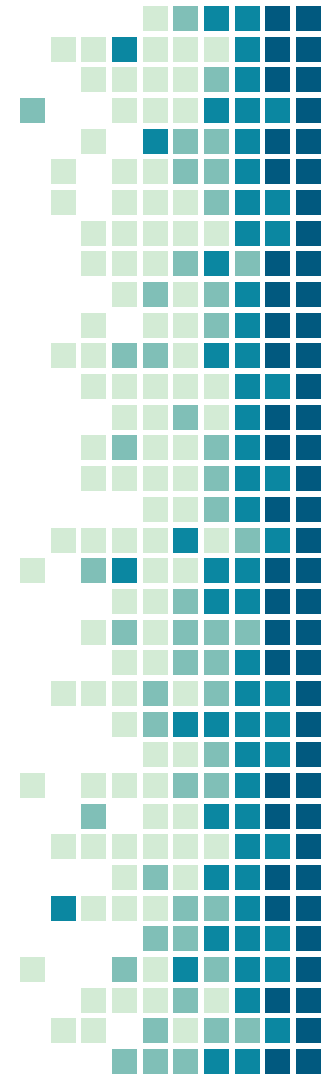
# TEMPERATURE SENSOR

## ADVANTAGES

- Incredibly cheap and reliable
- Easy to place
- Easy to implement in circuitry

## SHORTCOMINGS

- No reliable way to detect a child
- No way to differentiate between child and inanimate objects



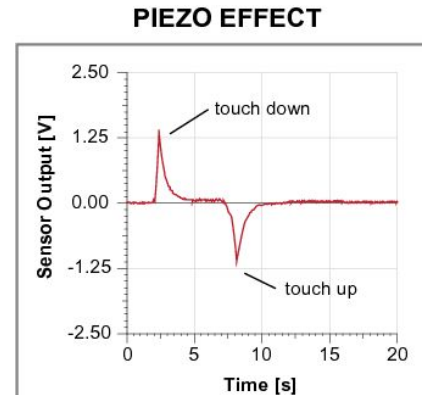
# PIEZOELECTRIC SENSOR

## ADVANTAGES

- Completely passive
- Low cost (~\$0.50)
- Simple to wire
- Easy to acquire data from
- Form factor suited to our application

## SHORTCOMINGS

- Data does not consider all use cases



# STRAIN GAUGE

## ADVANTAGES

- Completely passive
- Low cost (~\$0.80)
- Simple to wire
- Easy to acquire data from

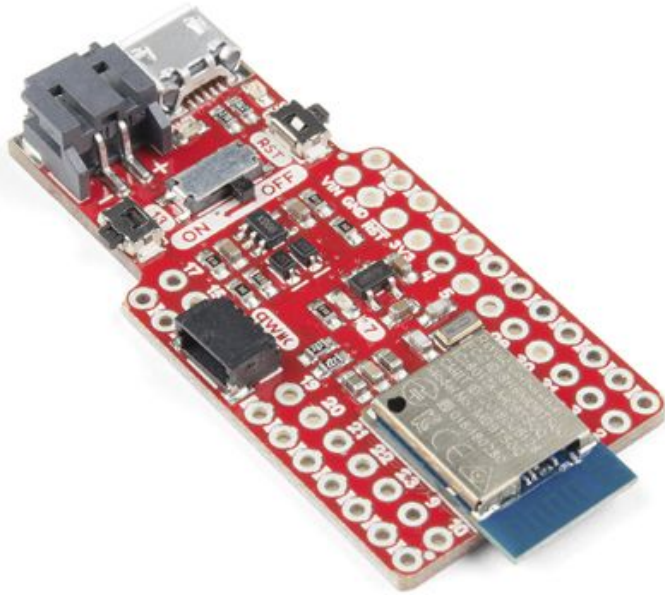


## SHORTCOMINGS

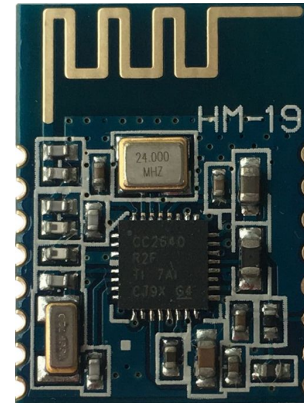
- Requires complex calibrations
- Not suited for user installation
- Load cell apparatus not comfortable for babies
- Sensitive to temperature

# THE SOLUTION

Use Bluetooth radio waves as a wireless person detection system

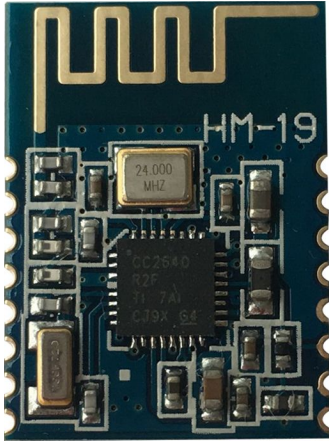


SparkFun BLE Development Board



HM-19 BLE Module

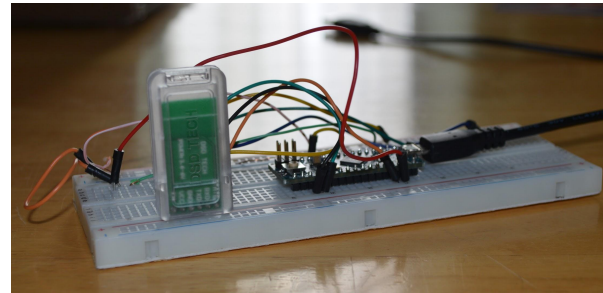
# THE SOLUTION



- TI CC2640 microchip comes prepackaged as the HM-19 BT module
- SparkFun Pro nRF52840 mini which uses Nordic Semiconductor nRF52840 BT module
- Avoids soldering SMT packages

HM-19 is available as a breakout board

- Uses UART protocol for communications
- Programmable via AT commands





# RESEARCH

- Bluetooth signals attenuate when passing through human beings
- Bone, water content, and other physiological factors increase signal attenuation
- Attenuation of the signal increases with movement
- Relative placement of child effects attenuation



# EXPERIMENTAL SETUP



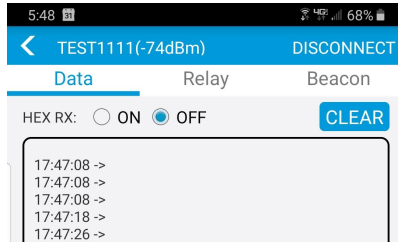
- Baby body composition: 78% water
- BT Test rig placed under the water bladder
- Water bladder inconclusive, substituted with 10 lb bone-in ham
- Smartphone records dB level of the Bluetooth waves



# INITIAL TEST RESULTS

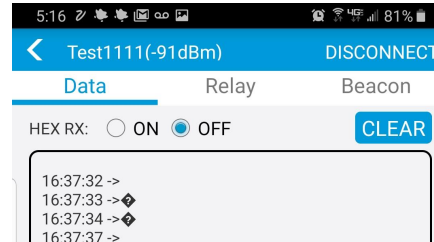
## Test Condition #1

- No human form
- Attenuation relatively consistent, based upon distance
- Great initial conditions



## Test Condition #2

- Human hand(>1 lbs)
- Attenuation increases but is varied
- Based upon many variables
  - Movement
  - Substance
  - Position



# SIGNAL ATTENUATION

- Test shows attenuation and time.
  - Attenuation is in dBm or decibels expressed in miliWatts
- Attenuation being used to “sense” the child’s presence
- Sensor can be configured to relay different data

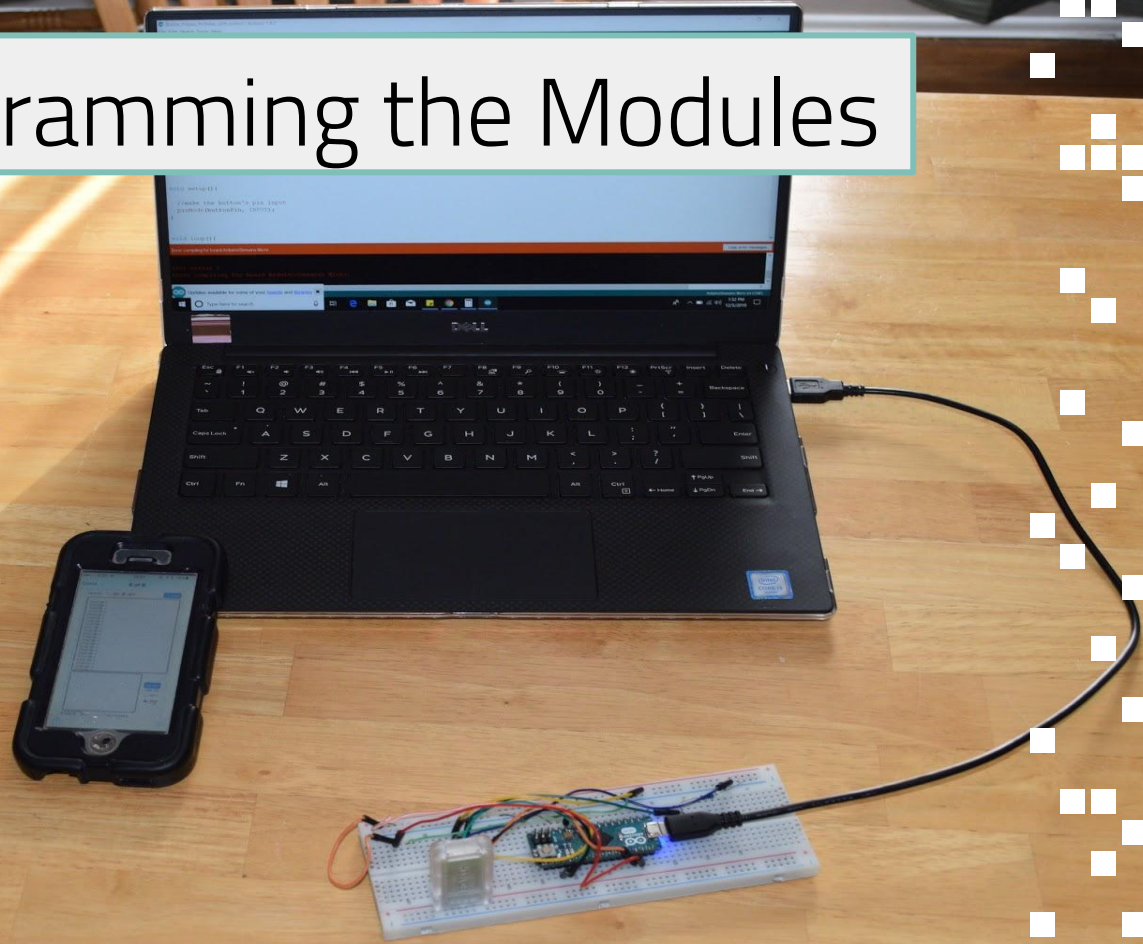


# 3. COMPLETING THE PROJECT

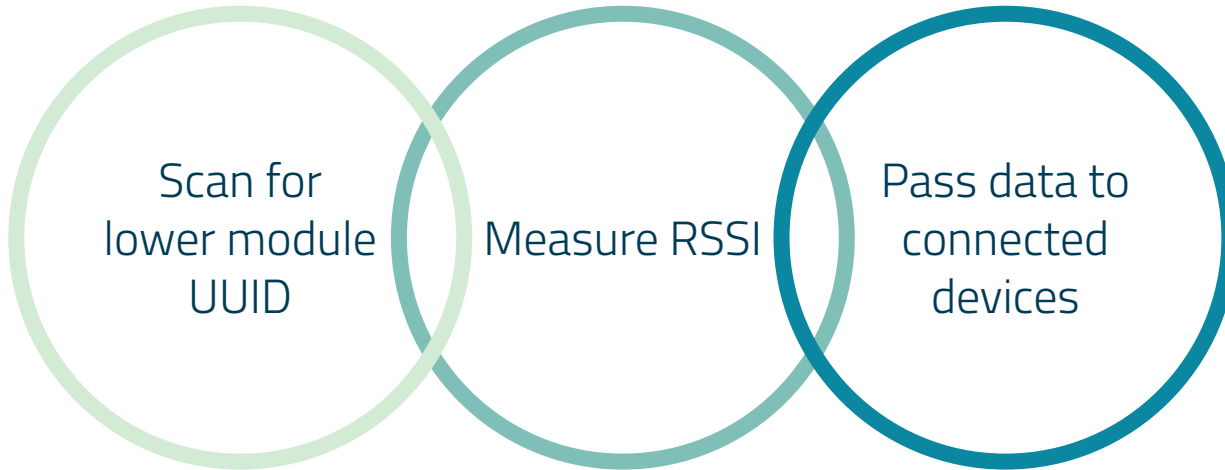
Writing software; wiring hardware



# Programming the Modules



# PRIMARY MODULE GOALS



# UPON LAUNCH

## BLE Library

- Handles low-level functionality
- Sets name, TX interval, UUID

## Filter by UUID

- Function only accepts data from lower module's UUID
- Eliminates interference
- Allows full-functionality without connecting

## Parse RSSI values

- Pulled from large BLE report
- Passed to moving average filter

## Signal Smoothing

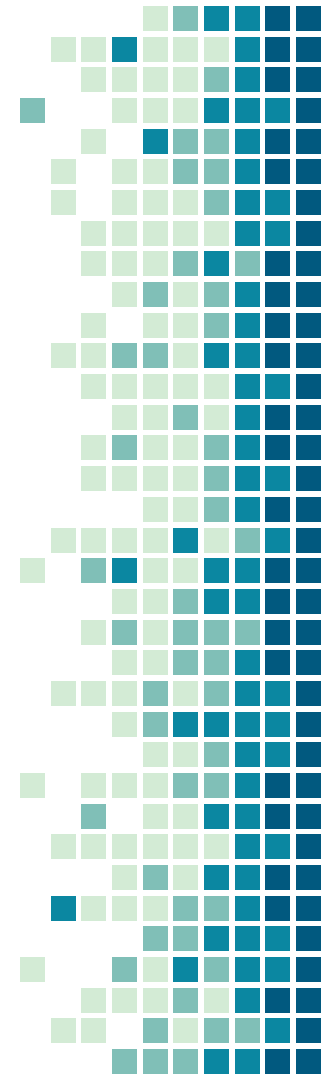
- Previous value removed from array
- Current value appended
- Mean recalculated

## Detection Algorithm

- Average RSSI passed to if-else statements checking for changes
- Threshold set through auto-calibration

## Pass Values to Devices

- Any change to the "person flag" triggers "update\_phone()" function
- Temperature and raw RSSI data also passed





# PRIMARY MODULE CODE

```
//Moving average filter variables
#define WINDOW_SIZE 8
int INDEX = 0;
int value = 0;
int sum = 0;
int readings[WINDOW_SIZE];
int averaged = 0;
int sample_counter = 0;
int longRunAverage = 0;

//Declaring lower threshold used for automatic calibrations
int LOWER_THRESHOLD = 0;

// UUID chosen for LOWER MODULE
const uint8_t LOWER_MODULE = 0xFFE0;

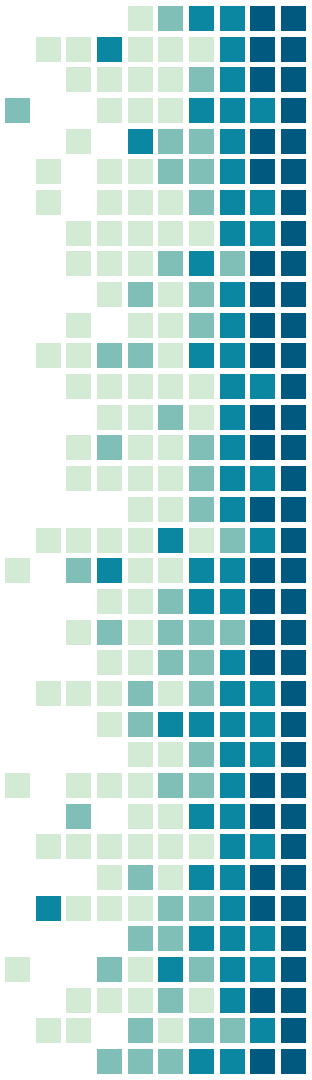
//Global Person Flag, indicates if a body is detected in the seat
int PERSON_FLAG = 0;

//Differential between occupant and no occupant
int DIFFERENTIAL = 7;
```

## Global Variables

```
//Person detection algorithm
if (rssi >= max_level) {
    PERSON_FLAG = 0;
    //Call function to update mobile application
    update_person_flag();
}
else if (rssi <= min_level) {
    PERSON_FLAG = 1;
    //Call function to update mobile application
    update_person_flag();
}
else {
    //no other state to consider
}
```

## Presence Detection Block



# PRIMARY MODULE CODE

```
void moving_average_filter(int RSSI_value){
// Remove the oldest entry from the sum
sum = sum - readings[INDEX];
// Read the next RSSI value
value = RSSI_value;
// Add the newest reading to the window
readings[INDEX] = value;
// Add the newest reading to the sum
sum = sum + value;
// Increment the INDEX, and wrap to 0 if it exceeds the window size
INDEX = (INDEX+1) % WINDOW_SIZE;
// Divide the sum of the window by the window size for the result
averaged = sum / WINDOW_SIZE;
//Increment sample counter
sample_counter = (sample_counter+1);

//Code used to verify functionality - serial output
Serial.print(value);
Serial.print(",");
Serial.print(averaged);
Serial.println(LOWER_THRESHOLD);

//Rudimental counter to read temp out every ~10 seconds
if (sample_counter == 10){
//Call read temperature function
read_temp();
//Reset sample counter
sample_counter = 0;
}
}
```

Moving Average Filter Function Block

```
void read_temp(){
//Set analog input pin on board
int ThermistorPin = 3;
//Variable to hold voltage reading from thermistor
int V0;
//Set resistor level, 50k
float R1 = 50000;
//Declare variables needed for voltage to temp conversion (float needed for
float arithmetic)
float logR2, R2, Temp;
//Constants used for conversion
float c1 = 1.009249522e-03, c2 = 2.378405444e-04, c3 = 2.019202697e-07;

//Perform voltage reading
V0 = analogRead(ThermistorPin);
R2 = R1 * (1023.0 / (float)V0 - 1.0);
logR2 = log(R2);
//Temperature in Kelvin
Temp = (1.0 / (c1 + c2*logR2 + c3*logR2*logR2*logR2));
//Temperature in centigrade
Temp = Temp - 273.15;
//Final temperature in Fahrenheit
Temp = (Temp * 9.0) / 5.0 + 32.0;

//Round to whole number
int rounded_temp = round(Temp);

//Code used to verify functionality - serial output
Serial.print("Temperature: ");
Serial.print(rounded_temp);
Serial.println(" F");

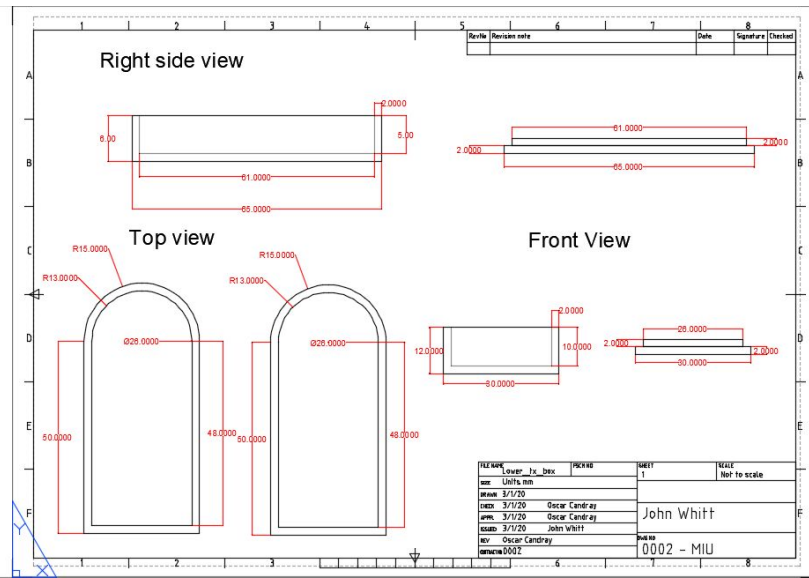
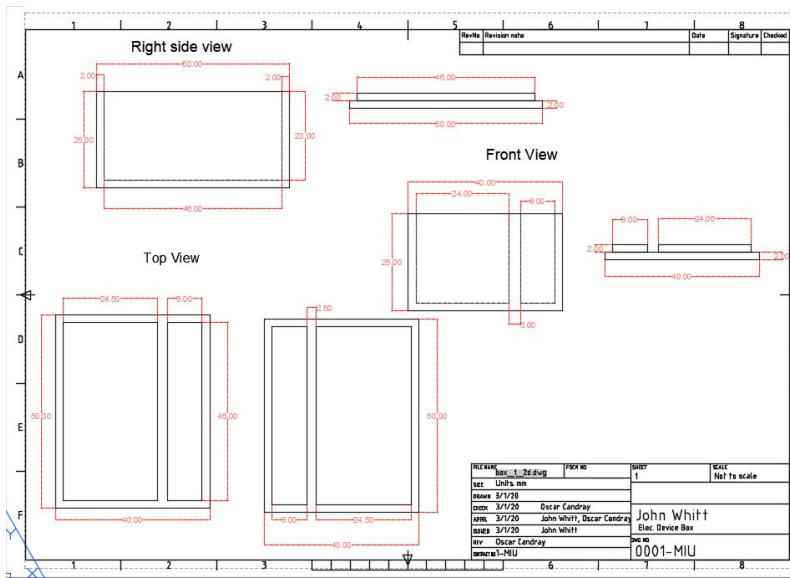
//Call to function to update temperature reading on mobile application
//Pass temperature reading in F
update_temperature(Temp);
}
```

Temperature Function Block

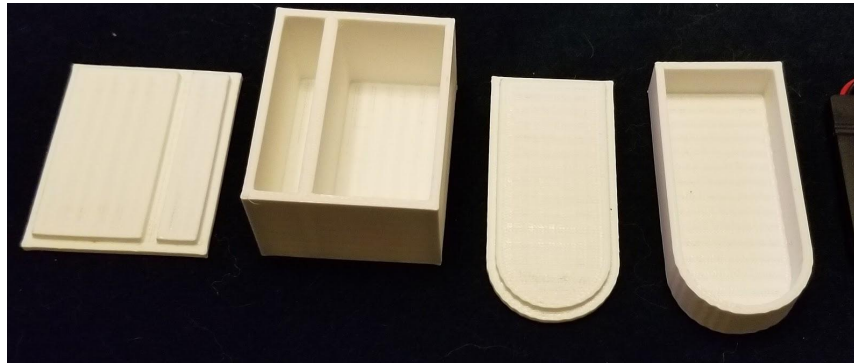


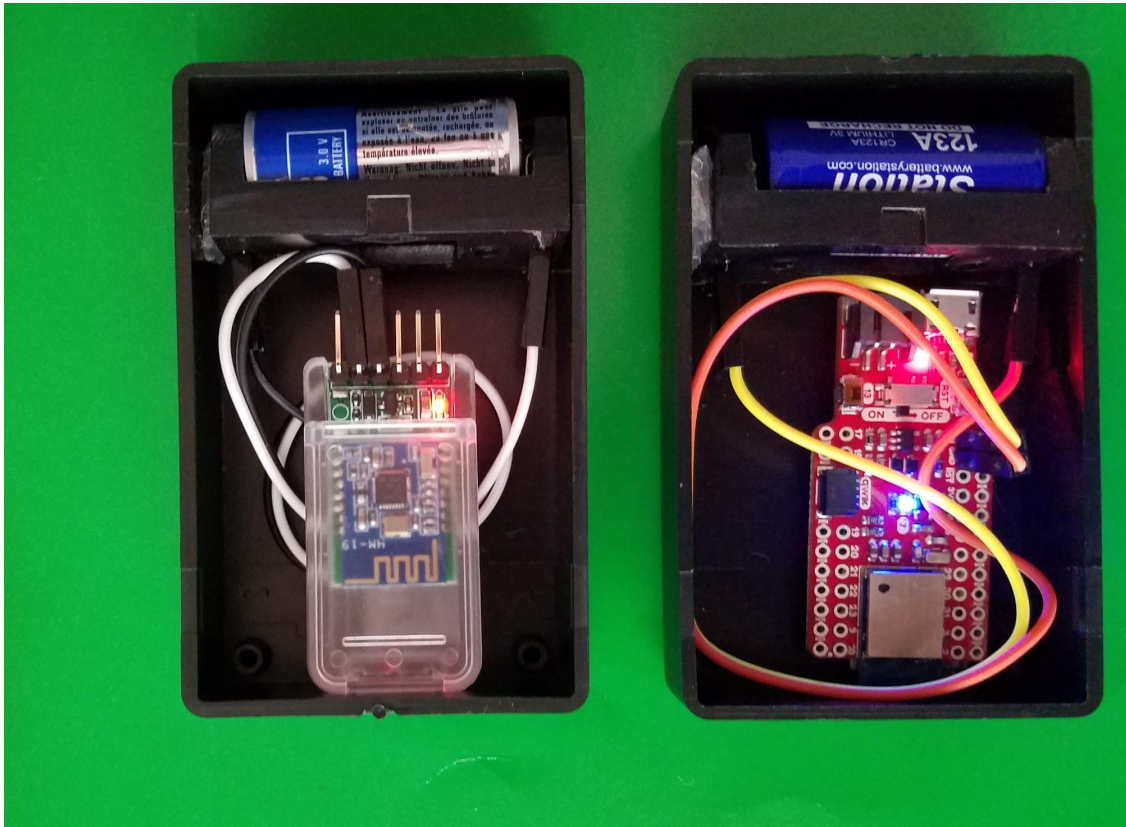
## *Other Features*

- *Temperature Logging*
  - *Utilizes thermistor*
- *Auto-calibrate*
  - *Lower threshold set whenever a user's device connects to primary module*
- *Power saving through functional programming*
  - *No unnecessary 'watchdog' style loops*

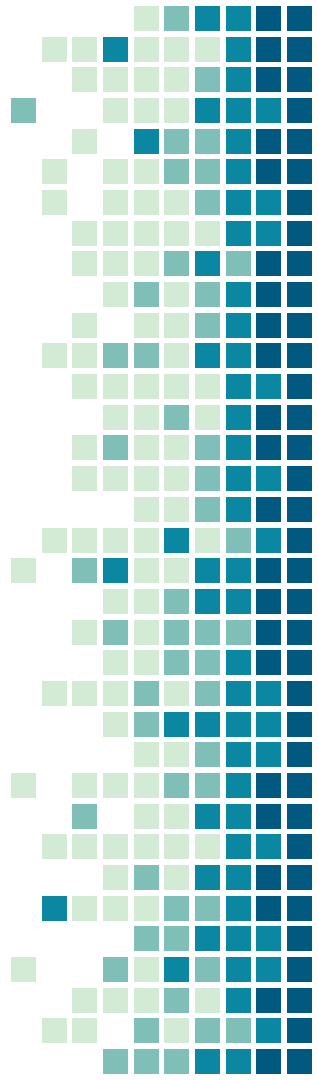


Custom enclosures designed in AutoCad and printed with additive manufacturing





Secondary (Tx) and Primary (Rx) modules



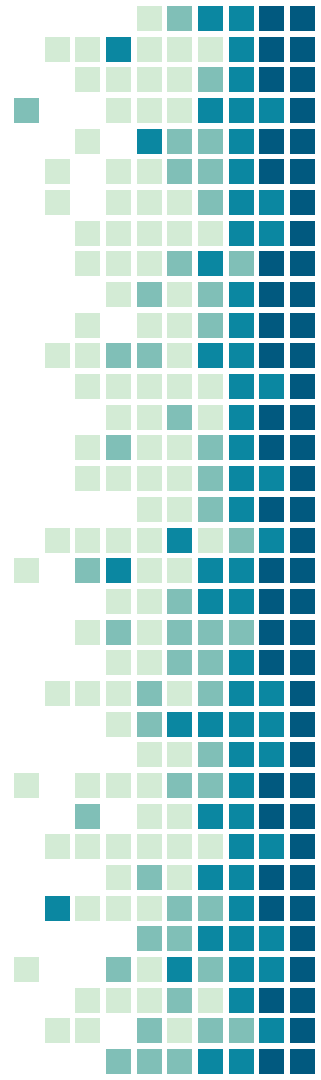




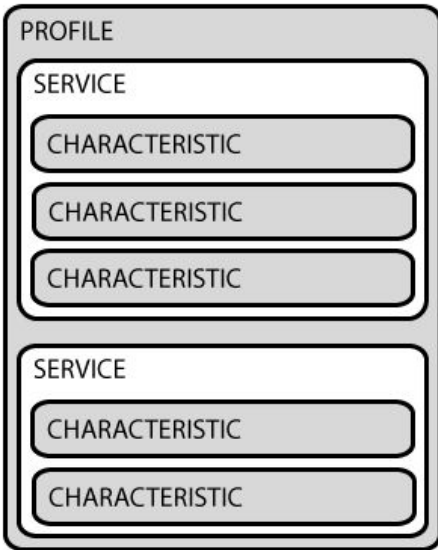
Location of Primary (Rx) module on car seat



Optimal Path of BLE signal



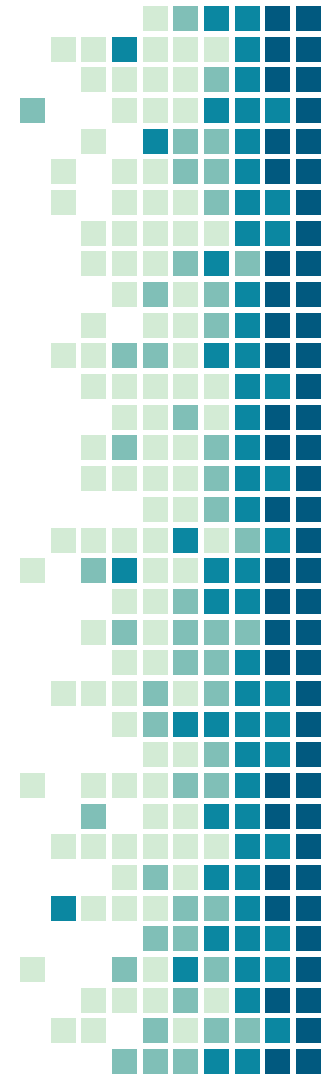
# BLE COMMUNICATION STANDARDS



GATT - Generic attribute profile  
framework for BLE  
communication

BLE Services

BLE Characteristics



# TESTING WITH nRF CONNECT

The screenshot shows the nRF Connect interface for a device named 'CS SODAS UPPER' with MAC address 'E8:43:DE:0F:1A:FA'. The device is bonded and connected. The 'CLIENT' tab is selected. Three 'Unknown Characteristic' entries are listed, each with a 'NOTIFY' property and a 'Value' field circled in red. The values are (0x) 00, (0x) CB, and (0x) 44-00. Each entry also shows a 'Descriptors' section with 'Client Characteristic Configuration' and 'Value: Notifications enabled'. A red semi-circle is visible at the bottom right of the interface.

Devices DISCONNECT

BONDED ADVERTISER CS SODAS UPPER  
E8:43:DE:0F:1A:FA

CONNECTED NOT BONDED CLIENT SERVER

**Unknown Characteristic**  
UUID: 0000111e-0000-1000-8000-00805f9b34fb  
Properties: NOTIFY  
Value: (0x) 00  
Descriptors:  
Client Characteristic Configuration  
UUID: 0x2902  
Value: Notifications enabled

**Unknown Characteristic**  
UUID: 0000111f-0000-1000-8000-00805f9b34fb  
Properties: NOTIFY  
Value: (0x) CB  
Descriptors:  
Client Characteristic Configuration  
UUID: 0x2902  
Value: Notifications enabled

**Unknown Characteristic**  
UUID: 00001120-0000-1000-8000-00805f9b34fb  
Properties: NOTIFY

Screenshot: not present condition

The screenshot shows the nRF Connect interface for the same device 'CS SODAS UPPER'. The device is bonded and connected. The 'CLIENT' tab is selected. Three 'Unknown Characteristic' entries are listed, each with a 'NOTIFY' property and a 'Value' field circled in blue. The values are (0x) 01, (0x) C0, and (0x) 44-00. Each entry also shows a 'Descriptors' section with 'Client Characteristic Configuration' and 'Value: Notifications enabled'. A red circle with a white arrow is visible at the bottom right of the interface.

Devices DISCONNECT

BONDED ADVERTISER CS SODAS UPPER  
E8:43:DE:0F:1A:FA

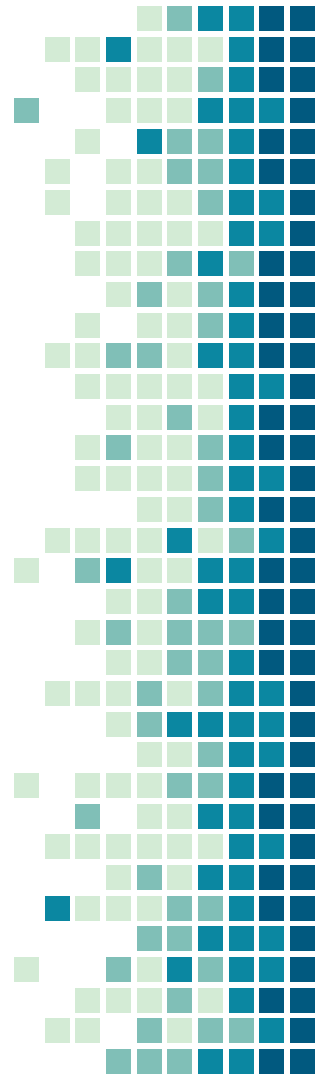
CONNECTED NOT BONDED CLIENT SERVER

**Unknown Characteristic**  
UUID: 0000111e-0000-1000-8000-00805f9b34fb  
Properties: NOTIFY  
Value: (0x) 01  
Descriptors:  
Client Characteristic Configuration  
UUID: 0x2902  
Value: Notifications enabled

**Unknown Characteristic**  
UUID: 0000111f-0000-1000-8000-00805f9b34fb  
Properties: NOTIFY  
Value: (0x) C0  
Descriptors:  
Client Characteristic Configuration  
UUID: 0x2902  
Value: Notifications enabled

**Unknown Characteristic**  
UUID: 00001120-0000-1000-8000-00805f9b34fb  
Properties: NOTIFY  
Value: (0x) 44-00  
Descriptors:

Screenshot: present condition



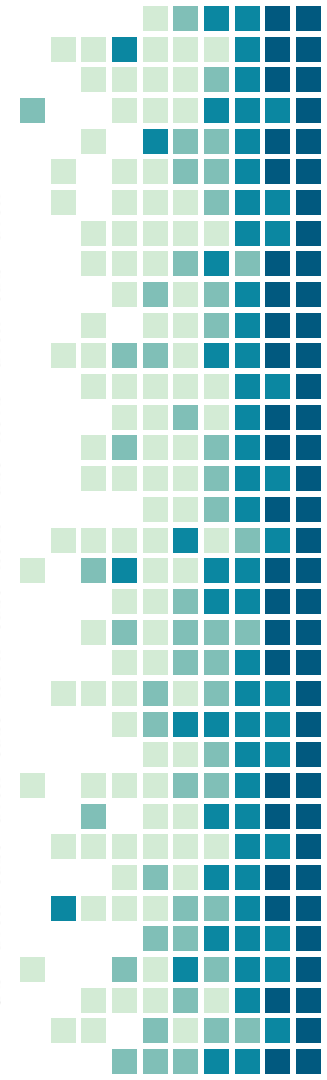
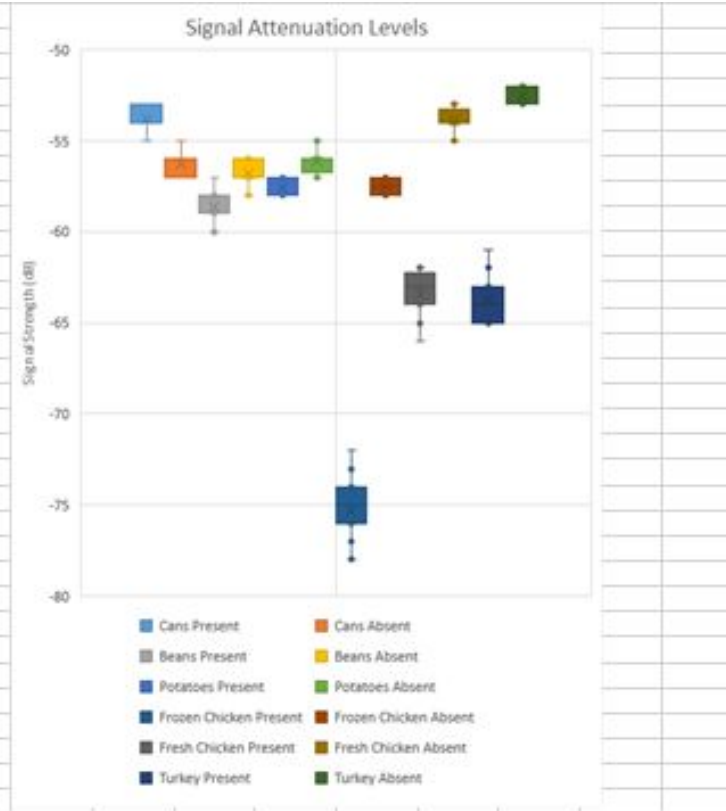


# ATTENUATION TEST CASES

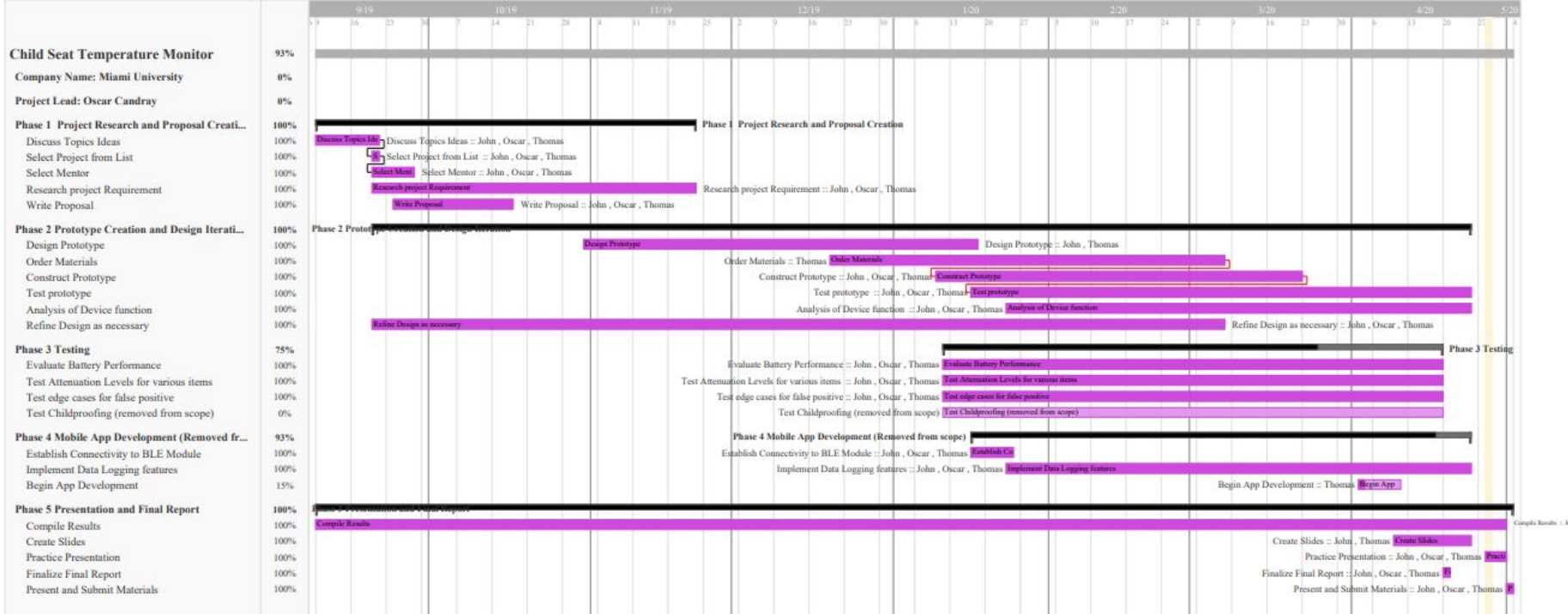
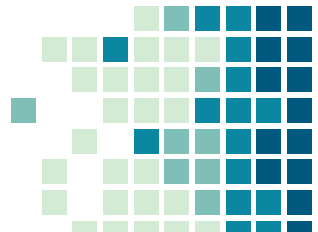
Summary	Average Differential
14 lb Turkey (Frozen)	11.1
7 lb Chicken (Fresh)	9.55
7 lb Chicken (Frozen)	17.8
10 lb Sack of Potatoes	1.5
8 lbs Dry Beans	1.8
12 Cans Carbonated Beverage (Aluminum)	2.45

Item	Differential (dB)
14 lb Turkey (Frozen)	11.1
7 lb Chicken (Fresh)	9.55
7 lb Chicken (Frozen)	17.8
10 lb Sack of Potatoes	1.5
8 lbs Dry Beans	1.8
12 Cans Carbonated Beverage (Aluminum)	2.45



# TIMELINE



# BUDGET

<u>Item</u>	<u>Quantity</u>	<u>Price/Unit</u>	<u>Total</u>
<i>Design</i>			
Arduino Board	3	\$ 10.00	\$ 30.00
Bluetooth Transmission Module	12	\$ 10.00	\$ 120.00
Sensor Kits	3	\$ 40.00	\$ 120.00
Batteries for testing	1	\$ 50.00	\$ 50.00
IC Components	1	\$ 100.00	\$ 100.00
Carseat	1	\$ 100.00	\$ 100.00
PCB Creation	1	\$ 50.00	\$ 50.00
<i>Research</i>			
3D Manufacturing/Rapid Prototyping	1	\$ 100.00	\$ 100.00
Elepho eClip Baby Reminder For Your Car	1	\$ 49.99	\$ 49.99
Automobile Car Safety Belt Pressure Sensor	1	\$ 12.99	\$ 12.99
Baby hot car Reminder, Alarm	1	\$ 29.99	\$ 29.99
SoftClip II TwinPak Safety Seat Monitor	1	\$ 69.90	\$ 69.90
	Estimated Total		\$ 832.87
	Margin of Error (20%)		\$ 166.57
	<b>Total Requested</b>		<b>\$ 999.44</b>

- Final Fleck total spent was \$599.08
- Items highlighted not purchased (\$162.87)
- Amended estimate total \$670.00
- After purchasing "test subjects" \$599.08 + \$85.07 = \$684.15

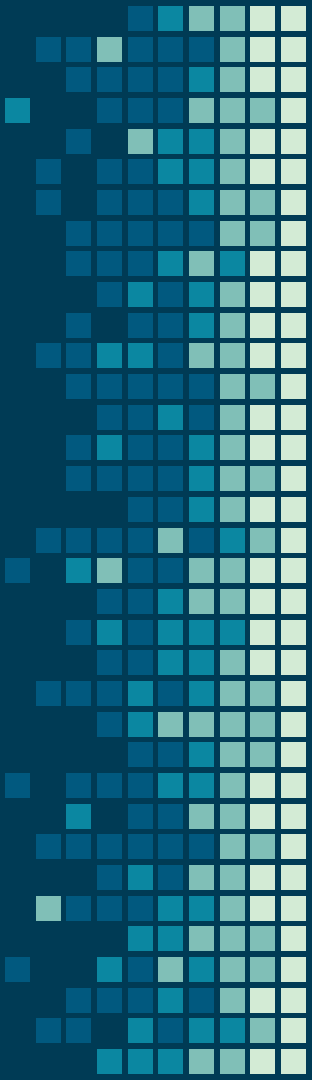


# Questions?

Special thanks to the

Fleck Scholarship Fund

For supporting our research





**MIAMI  
UNIVERSITY**

**Meeting Journal**  
**Department of Engineering Technology**  
**ENT 497 - Senior Design Project**  
**Project Title: Undecided**

	Present
<b>Advisor: Gary Drigel</b>	[ ]
<b>Student: John Whitt</b>	[ x ]
<b>Student: Oscar Candray</b>	[ x ]
<b>Student: Thomas Tully</b>	[ x ]
<b>Student:</b>	[ ]

<b>Meeting Date:</b>	<b>8/29/19</b>
<b>Meeting Location:</b>	<b>Phelps</b>

**Topics Discussed**

- 1- When and where to meet.
- 2- When do our class schedules converge?
- 3- Personal assement of our strengths and weaknesses.
- 4- Choose a mentor.
- 5- Discuss and narrow ideas.

**Responsibilities/ Actions Taken**

- 1- Meet at class, then after class every week.
- 2- Our schedules converge tons. Thomas shares 3 courses with John and Oscar who share 5
- 3- John is a strong writer, but a procratinator.  
Thomas is a strong programmer, but a procrastinator.  
Oscar is a strong worker, stays busy, but is a perfectionist.
- 4- Our mentor is Dr. Hiren Gami.
- 5- Goal for the week is to think of ideas that apply to our ECET skills.

**Next Meeting Date: 9/5/19**

**Location: Phelps**



**MIAMI  
UNIVERSITY**

**Meeting Journal**  
**Department of Engineering Technology**  
**ENT 497 - Senior Design Project**  
**Project Title: IoT Car Seat Sensor**

	Present
<b>Advisor: Gary Drigel</b>	[ ]
<b>Student: John Whitt</b>	[ x ]
<b>Student: Oscar Candray</b>	[ x ]
<b>Student: Thomas Tully</b>	[ x ]
<b>Student:</b>	[ ]

<b>Meeting Date:</b>	<b>9/5/19</b>
<b>Meeting Location:</b>	<b>Phelps</b>

#### **Topics Discussed**

- 1- Work on flushing out ideas for project.
- 2- Work on outlining the project.
- 3- Define roles.
- 4- Talk about Thomas's car seat idea

#### **Responsibilities/ Actions Taken**

- 1- Thomas's Idea about IoT car seat is chosen. Does it require intellectual property protection?
- 2- The sensor and related programming will be the easy part. The App will require the bulk of the work. Perhaps the scope is expanded to include a suite of baby related IoT tech. Use bluetooth range as a limit switch for the functionality of the device. Make this as affordable as possible.
- 3- Thomas work with programming as lead.  
John work with reports as lead and as floater.  
Oscar project lead.

**Next Meeting Date: 9/12/19**

**Location: Phelps**



**MIAMI  
UNIVERSITY**

**Meeting Journal**  
**Department of Engineering Technology**  
**ENT 497 - Senior Design Project**  
**Project Title: IoT Car Seat Sensor**

	Present
<b>Advisor: Gary Drigel</b>	[ ]
<b>Student: John Whitt</b>	[ x ]
<b>Student: Oscar Candray</b>	[ x ]
<b>Student: Thomas Tully</b>	[ x ]
<b>Student:</b>	[ ]

<b>Meeting Date:</b>	9/12/19
<b>Meeting Location:</b>	Phelps

**Topics Discussed**

- 1- Review progress.
- 2- Discuss other designs, Where do we differ?
- 3- Discuss appropriate sensing circuit.
- 4- Discuss Battery ratings.

**Responsibilities/ Actions Taken**

- 1- Proposal is mostly finished, as is the Gantt chart.
- 2- Plan to be affordable to gain greater market penetration than current offerings.  
Other designs may be too complex, not capable of bluetooth inconnectivity, we want privacy.  
No upload to cloud.
- 3- Sensor circuit will require the exacty right parameter to not send false positives.  
This requires much more discussion.
- 4- Batteries already exist which can handle high operating temps in a car, cost may become an issue.

**Next Meeting Date: 9/19/19**

**Location: Phelps**



MIAMI  
UNIVERSITY

**Meeting Journal**  
**Department of Engineering Technology**  
**ENT 497: Senior Design Project**  
**Project Title: Baby Safety Sensors**

Role		Present
Advisor	Gary Drigel	
Student	John Whitt	x
Student	Oscar Candray	x
Student	Thomas Tully	x

<b>Meeting Date</b>	9/19/19
<b>Meeting Location</b>	Phelps

#### Topics Discussed

1. Went over state of Gantt Chart.
2. Cost estimated.
3. Looked at current state of proposal.
4. Looked at sensors and b/t modules.

#### Responsibilities/Actions Taken

1. Gantt chart needs more detail.
2. Proposal is in good shape, just needs tasks, final comments, cost, and Gantt sections finished.
3. John and Thomas focus on finishing up proposal.

**Next Meeting Date** 9/26/19

**Location** Phelps





**Meeting Journal**  
**Department of Engineering Technology**  
**ENT 497: Senior Design Project**  
**Project Title: Baby Safety Sensors**

Role		Present
Advisor	Gary Drigel	
Student	John Whitt	
Student	Oscar Candray	x
Student	Thomas Tully	x

<b>Meeting Date</b>	9/26/19
<b>Meeting Location</b>	Hamilton Campus

**Topics Discussed**

**Moving budget into final proposal**  
**Should we ask Roger S. about validity of project? Any suggestions for improvement**  
**Looked into BLE (Bluetooth low energy) beacon technology**  
**Could we run wiring through existing harnesses for simplicity of design?**  
**Location of pad - bottom or back?**  
**BLE libraries for Cocoa using Swift - make this talk to the phone**

**Responsibilities/Actions Taken**

**Thomas will finish "Final Comments" section by next week.**

**Thomas is sending out a research paper on BLE as monitoring devices**

<b>Next Meeting Date: 10/3/19</b>	<b>Location: Hamilton Campus</b>
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**Meeting Journal**  
**Department of Engineering Technology**  
**ENT 497: Senior Design Project**  
**Project Title: Baby Safety Sensors**

<b>Role</b>		<b>Present</b>
Advisor	Gary Drigel	x
Student	John Whitt	x
Student	Oscar Candray	x
Student	Thomas Tully	x

<b>Meeting Date</b>	10/03/19
<b>Meeting Location</b>	Hamilton Campus

**Topics Discussed**

**Do we need to use MS Project for Gantt?**

**Getting Gary to look over our preliminary proposal - are we ready enough?**

**Need to look study previous proposals in more detail**

**Responsibilities/Actions Taken**

**John will add citations to the project proposal.**

**John will add additional levels of granularity to the Gantt Chart.**

**Thomas will create a WBS, and add to step by step.**

**Thomas will add block diagrams to the project.**

**We will all go over previous proposal examples.**

<b>Next Meeting Date: 10/10/19</b>	<b>Location: Hamilton Campus</b>
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**MIAMI  
UNIVERSITY**

**Meeting Journal**  
**Department of Engineering Technology**  
**ENT 497: Senior Design Project**  
**Project Title: Baby Safety Sensors**

Role		Present
Advisor	Gary Drigel	
Student	John Whitt	x
Student	Oscar Candray	x
Student	Thomas Tully	x

<b>Meeting Date</b>	10/17/19
<b>Meeting Location</b>	Rentschler 300

**Topics Discussed**

Finalize our proposal, anything to add?

**Responsibilities/Actions Taken**

Thomas finished Gantt, John finally did his work!  
 Proposal will be submitted tonight.

<b>Next Meeting</b> Date 10/24/19	<b>Location</b> Rentschler 300
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**Meeting Journal**  
**Department of Engineering Technology**  
**ENT 497: Senior Design Project**  
**Project Title: Baby Safety Sensors**

Role		Present
Advisor	Gary Drigel	
Student	John Whitt	x
Student	Oscar Candray	x
Student	Thomas Tully	x

<b>Meeting Date</b>	10/24/19
<b>Meeting Location</b>	Rentschler 300

**Topics Discussed**

Proposal was accepted.  
Time to begin the design phase?  
How to free adequate time for design. As a group/individually?

**Responsibilities/Actions Taken**

Begin to move forward with design, and testing.  
Get approved for weekend access to labs on campus.  
Clear schedules on to spend time working together in labs.  
Time spent working together is more efficient than alone, eliminates time wasted by repetition in communication.

<b>Next Meeting</b> Date 10/31/19	<b>Location</b> Rentschler 300
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**MIAMI  
UNIVERSITY**

**Meeting Journal**  
**Department of Engineering Technology**  
**ENT 497: Senior Design Project**  
**Project Title: Baby Safety Sensors**

<b>Role</b>		<b>Present</b>
Advisor	Gary Drigel	
Student	John Whitt	X
Student	Oscar Candray	X
Student	Thomas Tully	X

<b>Meeting Date</b>	10/31/19
<b>Meeting Location</b>	Hamilton 300

**Topics Discussed**

**Fleck funding - what do we need for the budget**  
**Where to go next - continue with the prototype, need to develop the master control unit**  
**Where will we meet over winter break?**  
**Checking with Gary over access to labs - what emails to send**

**Responsibilities/Actions Taken**

**Thomas will order another BLE module for the prototype**  
**John and Oscar will check on requirements for Fleck funding**

<b>Next Meeting Date 11/7/2019</b>	<b>Location Phelps 300 (Hamilton)</b>
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**MIAMI  
UNIVERSITY**

**Meeting Journal**  
**Department of Engineering Technology**  
**ENT 497: Senior Design Project**  
**Project Title: Baby Safety Sensors**

Role		Present
Advisor	Gary Drigel	
Student	John Whitt	X
Student	Oscar Candray	X
Student	Thomas Tully	X

<b>Meeting Date</b>	11/7/19
<b>Meeting Location</b>	Hamilton 300

**Topics Discussed**

**What changes need to be made to the Fleck funding application?**  
**How will we fund if we are not approved via Fleck?**  
**Which ethics cases should we analyze?**  
**What sort of experiments do we need conduct to test our design?**  
**Preliminary presentation ideas.**  
**Timing of project - end of semester quickly approaching, need to devote more time.**  
**Schedule - can we meet Thanksgiving week?**

**Responsibilities/Actions Taken**

**John will submit final Fleck funding application by midnight tonight.**  
**Each team member will look through ethics cases, will pick one by next week.**

<b>Next Meeting Date 11/14/19</b>	<b>Location Hamilton 300</b>
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**MIAMI  
UNIVERSITY**

**Meeting Journal**  
**Department of Engineering Technology**  
**ENT 497: Senior Design Project**  
**Project Title: Baby Safety Sensors**

<b>Role</b>		<b>Present</b>
Advisor	Gary Drigel	
Student	John Whitt	X
Student	Oscar Candray	X
Student	Thomas Tully	X

<b>Meeting Date</b>	11/14/19
<b>Meeting Location</b>	Hamilton 300

#### **Topics Discussed**

**Ethics presentation and report**  
**Fleck funding - will know in a few weeks at the latest (Thanksgiving)**  
**Presentation requirements**  
**Presentation locations and time (VOA)**  
**Report format and grading criteria**

#### **Responsibilities/Actions Taken**

**John will begin creating slides for the presentation**  
**Oscar will proofread the Ethics Presentation and Report**  
**Thomas will submit Ethics report for group by midnight**  
**Thomas will order more parts for the project (another BLE module needed)**

**Next Meeting Date 11/21/2019**

**Location Hamilton 300**



**MIAMI  
UNIVERSITY**

**Meeting Journal**  
**Department of Engineering Technology**  
**ENT 497: Senior Design Project**  
**Project Title: Baby Safety Sensors**

<b>Role</b>		<b>Present</b>
Advisor	Gary Drigel	
Student	John Whitt	X
Student	Oscar Candray	X
Student	Thomas Tully	X

<b>Meeting Date</b>	11/21/19
<b>Meeting Location</b>	Virtual

**Topics Discussed**

**Fleck funding approved**  
**No physical meeting**  
**Focus on the final presentation**

**Responsibilities/Actions Taken**

**Thomas will start final presentation**  
**John will assist and work on final report**  
**Oscar assist and prepare for presentation**

**Next Meeting Date 12/5/2019**

**Location VOA campus**





**MIAMI  
UNIVERSITY**

**Meeting Journal**  
**Department of Engineering Technology**  
**ENT 497: Senior Design Project**  
**Project Title: Baby Safety Sensors**

<b>Role</b>		<b>Present</b>
Advisor	Gary Drigel	X
Student	John Whitt	X
Student	Oscar Candray	X
Student	Thomas Tully	X

<b>Meeting Date</b>	12/5/19
<b>Meeting Location</b>	VOA Campus

**Topics Discussed**

**Presentation practice, went well, needs timeline and budget slides**  
**Order parts**  
**TI makes a development kit that will be useful**

**Responsibilities/Actions Taken**

**John will finish final report**  
**John will finish adding slides**  
**John will finish journals**  
**Thomas will assist**  
**Oscar will assist**  
**Get a part list together for next week**

<b>Next Meeting Date 12/122019</b>	<b>Location VOA campus</b>
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UNIVERSITY**

**Meeting Journal**  
**Department of Engineering Technology**  
**ENT 497: Senior Design Project**  
**Project Title: Baby Safety Sensors**

<b>Role</b>		<b>Present</b>
Advisor	Gary Drigel	X
Student	John Whitt	X
Student	Oscar Candray	X
Student	Thomas Tully	X

<b>Meeting Date</b>	12/12/19
<b>Meeting Location</b>	VOA Campus

**Topics Discussed**

**Parts are going to be ordered this week**  
**Final Presentation given, went well**  
**Meeting dates this winter break, sporadic but more regular after the new year**  
**Meet in the Lab at Hamilton for testing**

**Responsibilities/Actions Taken**

**Thomas will order parts**  
**All will finish reflections**  
**Thomas will finalize and submit**  
**Oscar will schedule meeting times**

<b>Next Meeting Date 12/19/2019</b>	<b>Virtual</b>
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**MIAMI  
UNIVERSITY**

**Meeting Journal**  
**Department of Engineering Technology**  
**ENT 498: Senior Design Project**  
**Project Title: CS-SODAS**

<b>Role</b>		<b>Present</b>
Advisor	Gary Drigel	
Student	John Whitt	X
Student	Oscar Candray	X
Student	Thomas Tully	X

<b>Meeting Date</b>	2/4/20
<b>Meeting Location</b>	John's House

**Topics Discussed**

**TI is very troublesome.**  
**Arduino nano 33 BLE.**  
**Order form going out,with supplies arduino, sensors, etc.**  
**Contingencies developed.**  
**Testing of signal attenuation complete.**  
**Deadlines established for contingencies.**

**Responsibilities/Actions Taken**

**Oscar has measurements for lower 3D design of module enclosure.**  
**Thomas continue with TI.**  
**John focus on Arduino.**  
**Parts ordered.**  
**Pictures and blurb sent in for assignment this week.**

<b>Next Meeting Date 2/6/20</b>	<b>Phelps</b>
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**MIAMI  
UNIVERSITY**

**Meeting Journal**  
**Department of Engineering Technology**  
**ENT 498: Senior Design Project**  
**Project Title: CS-SODAS**

<b>Role</b>		<b>Present</b>
Advisor	Gary Drigel	X
Student	John Whitt	X
Student	Oscar Candray	X
Student	Thomas Tully	X

<b>Meeting Date</b>	2/6/20
<b>Meeting Location</b>	Phelps

**Topics Discussed**

**Arduino IDE is working well.**  
**Arduino 33 BLE is back up plan.**  
**Adafruit libraries.**  
**3d printing of lower module.**  
**Coin cell housings.**  
**TI is still highly difficult.**  
**Modules are communicating.**  
**App in early stages.**  
**See if connection between modules will save power or be necessary.**

**Responsibilities/Actions Taken**

**Oscar has measurements for lower 3D design of module enclosure.**  
**Thomas and John work on code and and connecting upper module to smartphones.**  
**Thomas will submit purchase order.**

<b>Next Meeting Date 2/11/20</b>	<b>Phelps</b>
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**MIAMI  
UNIVERSITY**

**Meeting Journal**  
**Department of Engineering Technology**  
**ENT 498: Senior Design Project**  
**Project Title: CS-SODAS**

<b>Role</b>		<b>Present</b>
Advisor	Gary Drigel	
Student	John Whitt	X
Student	Oscar Candray	X
Student	Thomas Tully	X

<b>Meeting Date</b>	2/11/20
<b>Meeting Location</b>	Phone

**Topics Discussed**

Potential device enclosures, ordered or 3D printed?  
 Issues stem from cutting edge of BLE standards.  
 Errors in code libraries require troubleshooting.  
 UUID Universally Unique Identifier helps solve Bluetooth filtering issues.  
 Firmware solution, where MAC is hardware.  
 GATT Generic Attributes Profile.  
 Android App is coming along.  
 Weekend breakthroughs in communication and functionality.  
 Custom android app.  
 Schedule and timeline.

**Responsibilities/Actions Taken**

Oscar and John take detailed measurements for lower, upper, and side mount 3D design of module enclosure.  
 Oscar will begin the 3D design process.  
 Thomas will continue with coding.  
 John will begin updating the report, slides.

**Next Meeting Date 2/13/20**

**Phelps**



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**Meeting Journal**  
**Department of Engineering Technology**  
**ENT 498: Senior Design Project**  
**Project Title: CS-SODAS**

<b>Role</b>		<b>Present</b>
Advisor	Gary Drigel	X
Student	John Whitt	X
Student	Oscar Candray	X
Student	Thomas Tully	X

<b>Meeting Date</b>	2/13/20
<b>Meeting Location</b>	Phelps

**Topics Discussed**

Potential device enclosures, ordered or 3D printed?  
 How to connect to the car seat.  
 Demoad the current state of operations.  
 Seem ahead of schedule, functioning nicely but be wary and keep pedal to metal.  
 Bigger device eliminates swallowing risk.  
 Divide remaining responsibilities.  
 Openscad.

**Responsibilities/Actions Taken**

Oscar and John take detailed measurements for lower, upper, and side mount 3D design of module enclosure.  
 Oscar will begin the 3D design process.  
 Thomas will continue with coding.  
 John will begin updating the report, slides.  
 These responsibilities are going to continue.

<b>Next Meeting Date 2/18/20</b>	<b>Phelps, Phone, or Virtual</b>
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**MIAMI  
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**Meeting Journal**  
**Department of Engineering Technology**  
**ENT 498: Senior Design Project**  
**Project Title: CS-SODAS**

<b>Role</b>		<b>Present</b>
Advisor	Gary Drigel	
Student	John Whitt	X
Student	Oscar Candray	
Student	Thomas Tully	X

<b>Meeting Date</b>	2/27/20
<b>Meeting Location</b>	Phelps

### **Topics Discussed**

**3d design 1st iterations finished.**

**Need to talk to frank about printing, techniques and needs.**

**Test fit the designs and perhaps another design iteration.**

**Meetings scaled back to once a week, more as needed especially down the stretch.**

**On course ahead of schedule, time to begin to update the report and powerpoint.**

### **Responsibilities/Actions Taken**

**Thomas will continue on app development.**

**John will begin on the report and reach out to Mr Tonner.**

**Next Meeting Date 3/5/20**

**Phelps**



**MIAMI  
UNIVERSITY**

**Meeting Journal**  
**Department of Engineering Technology**  
**ENT 498: Senior Design Project**  
**Project Title: CS-SODAS**

<b>Role</b>		<b>Present</b>
Advisor	Gary Drigel	
Student	John Whitt	X
Student	Oscar Candray	X
Student	Thomas Tully	X

<b>Meeting Date</b>	3/5/20
<b>Meeting Location</b>	Phelps

**Topics Discussed**

**3d design 2nd iterations beginning.**  
**Group discussion on 3d design moving forward.**  
**Makerfab order is here yay!**  
**Finalize design for presentation.**

**Responsibilities/Actions Taken**

**Thomas will continue on app development and measure.**  
**John will begin 2nd iteration.**  
**Oscar will design some product literature for device placement and download project.**  
**John will bring in his computer for Oscar.**

<b>Next Meeting Date 3/12/20</b>	<b>Phelps</b>
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**MIAMI  
UNIVERSITY**

**Meeting Journal**  
**Department of Engineering Technology**  
**ENT 498: Senior Design Project**  
**Project Title: CS-SODAS**

<b>Role</b>		<b>Present</b>
Advisor	Gary Drigel	
Student	John Whitt	Virtual
Student	Oscar Candray	Virtual
Student	Thomas Tully	Virtual

<b>Meeting Date</b>	3/12/20
<b>Meeting Location</b>	Phone

**Topics Discussed**

3d design 2nd iterations beginning.  
 How to work around school closure.  
 Meet twice next week pre spring break.  
 Adapt to changing situations, and be prepared for senior design presentation format to change.  
 John And Oscar meet Tuesday and Thursday, Thomas meet Thursday.

**Responsibilities/Actions Taken**

Thomas will finish communication for next week's deadline. Continue on app development and measure.  
 John will begin 2nd iteration and find out how to get it printed with closure.  
 Oscar will design some product literature for device placement and change Gannt over to MS project.  
 Someone buy a Ham for testing.

<b>Next Meeting Date 3/19/20</b>	<b>Virtual</b>
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**MIAMI  
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**Meeting Journal**  
**Department of Engineering Technology**  
**ENT 498: Senior Design Project**  
**Project Title: CS-SODAS**

<b>Role</b>		<b>Present</b>
Advisor	Gary Drigel	
Student	John Whitt	Virtual
Student	Oscar Candray	Virtual
Student	Thomas Tully	Virtual

<b>Meeting Date</b>	3/19/20
<b>Meeting Location</b>	Phone

**Topics Discussed**

**All meetings in person adjourned.**  
**Finish project as is, and begin report.**  
**School closed for year.**

**Responsibilities/Actions Taken**

**Spring break, enjoy it ha!**  
**John will work on report.**  
**Thomas comment out code.**  
**Oscar brochure and updated Gannt.**

<b>Next Meeting Date 4/2/20</b>	<b>Virtual</b>
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**MIAMI  
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**Meeting Journal**  
**Department of Engineering Technology**  
**ENT 498: Senior Design Project**  
**Project Title: CS-SODAS**

<b>Role</b>		<b>Present</b>
Advisor	Gary Drigel	
Student	John Whitt	Virtual
Student	Oscar Candray	Virtual
Student	Thomas Tully	Virtual

<b>Meeting Date</b>	4/2/20
<b>Meeting Location</b>	Phone

**Topics Discussed**

**Thomas has commented code.**  
**Oscar completed brochure and Gantt.**  
**John is working on the report.**  
**Make a video is next step, and finish the powerpoint.**  
**Meet and do google hangouts.**  
**Need to stay in touch, everyone is adjusting well after the initial shock.**

**Responsibilities/Actions Taken**

**John will work on report.**  
**Thomas make a video.**  
**Oscar stay in touch and prepare for our video and presentation.**

<b>Next Meeting Date 4/9/20</b>	<b>Virtual</b>
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**MIAMI  
UNIVERSITY**

**Meeting Journal**  
**Department of Engineering Technology**  
**ENT 497: Senior Design Project**  
**Project Title: CS-SODAS**

<b>Role</b>		<b>Present</b>
Advisor	Gary Drigel	
Student	John Whitt	Virtual
Student	Oscar Candray	Virtual
Student	Thomas Tully	Virtual

<b>Meeting Date</b>	4/9/20
<b>Meeting Location</b>	Phone

**Topics Discussed**

**John is working on the report.**  
**Thomas and Oscar are going to be organizing a script for the presentation.**  
**Group is working to finish the powerpoint.**  
**Meet and do google hangouts.**  
**Need to stay in touch and finish strong.**

**Responsibilities/Actions Taken**

**Responsibilities discussed above.**

<b>Next Meeting Date 4/16/20</b>	<b>Virtual</b>
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**MIAMI  
UNIVERSITY**

**Meeting Journal**  
**Department of Engineering Technology**  
**ENT 497: Senior Design Project**  
**Project Title: CS-SODAS**

<b>Role</b>		<b>Present</b>
Advisor	Gary Drigel	
Student	John Whitt	Virtual
Student	Oscar Candray	Virtual
Student	Thomas Tully	Virtual

<b>Meeting Date</b>	4/16/20
<b>Meeting Location</b>	Phone

**Topics Discussed**

Thomas has worked with video/YT before and is testing equipment to get best results.  
 Photos of the car seat with project in car.  
 Video of real world testing.  
 Update presentation slides.  
 Continue to write final report.  
 Meeting times.

**Responsibilities/Actions Taken**

John and Oscar meet on Monday @ 2pm.  
 Report draft complete by Tuesday night.  
 Slides complete by Wednesday night.  
 Thursday begin recording process, with two separate groups virtually together.

<b>Next Meeting Date 4/23/20</b>	<b>Virtual</b>
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**MIAMI  
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**Meeting Journal**  
**Department of Engineering Technology**  
**ENT 498: Senior Design Project**  
**Project Title: CS-SODAS**

<b>Role</b>		<b>Present</b>
Advisor	Gary Drigel	
Student	John Whitt	Virtual
Student	Oscar Candray	Virtual
Student	Thomas Tully	Virtual

<b>Meeting Date</b>	4/23/20
<b>Meeting Location</b>	Phone

**Topics Discussed**

Continue as planned.  
 Report is 75% complete.  
 Need to make the video, and finish the slides. These can be begun right now.  
 Draft was complete but slides need to be finished.  
 Goals and deadlines placed.

**Responsibilities/Actions Taken**

John and Oscar meet and record our section together.  
 Report finished by Saturday night.  
 Slides complete by Sunday night.  
 Monday at latest, begin the recording process, with two separate groups virtually together.

<b>Next Meeting Date 4/30/20</b>	<b>Virtual</b>
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**MIAMI  
UNIVERSITY**

**Meeting Journal**  
**Department of Engineering Technology**  
**ENT 498: Senior Design Project**  
**Project Title: CS-SODAS**

<b>Role</b>		<b>Present</b>
Advisor	Gary Drigel	
Student	John Whitt	V/person
Student	Oscar Candray	V/person
Student	Thomas Tully	Virtual

<b>Meeting Date</b>	4/30/20
<b>Meeting Location</b>	Person & Phone

**Topics Discussed**

**Report is finished.**  
**Video is finished.**  
**Device operates well.**

**Responsibilities/Actions Taken**

**Enjoy the summer.**

**Next Meeting Date NONE**

**Project Completed**

# ENT 497 Final Reflection

John Whitt  
12 December 2019

Group projects are the bane of most college student's existence. I personally despise them. They do not accurately represent the real world. In the workplace, you have many external factors which motivate group members. In college you have only one external motivation, grade. Many students simply do not care about their grades enough to put forth the effort required to perform a quality project, and this penalizes good students.

Most classes have not allowed me to pick a group, you are assigned one. The best thing I did this entire semester was pick the members of this group. Thomas and Oscar have been amazing group members. They care and are devoted to this success of this project. That is an amazing thing to find in a group project, and it made this semester far easier than I anticipated.

Every member of this group has carried their weight. Often times, a member has carried more than their weight for a certain time span. The amazing part of this group has been our ability to pivot/shift the responsibility load. This semester has been very trying for all group members. We have all had high workload with our senior level ECET (Electrical and Computer Engineering Tech) courses. Sadly, these loads were all occurring at the same time. Oscar and I shared all 5 courses taken this semester and Thomas was in 3 of the same courses. This factor meant a true solidarity among our group, as we each understood the stress each member was under.



Oscar did huge amounts of work in the beginning, which laid out our path. He created large portions of the proposal, Gantt chart, and was instrumental in keeping us on target. He is NOT a procrastinator, which truly helped Thomas and me.

Thomas was the absolute, undisputed MVGM (Most Valuable Group Member). His creativity, intelligence, and fanatic devotion to work quality standards have really driven this project. His idea was the genesis of our project, and he deduced that Bluetooth beacons were suitable to be at the heart of our design.

Finally, it is time to analyze my own performance. I really struggled to get going in the beginning of this semester. I am a procrastinator. ENT 497 & 498 do not reward procrastination. While Oscar and Thomas were carrying the project, I was buried in my other studies. I am disappointed in my own performance through the beginning weeks of the project. Around week 6 I began to take on more responsibilities, and I feel much better about my performance down the stretch. Ever the procrastinator, start slow and finish strong.

Moving forward I hope to keep this momentum, but I understand that I have struggled to do that in the past. Next semester is a lighter course load, I hope. The group also plans to meet over winter break. I am looking forward to working on this project during winter break. That is one sentence I never thought I would write.

This group is amazing. I am actually enjoying being involved in a group project for the second time since becoming a Miami student (already had a project with Thomas). While each member has their own flaws and talents, we complement each other very well. The goal of every group is to become much more than the sum of individual parts. I believe that this group is far

more than simply John + Thomas + Oscar. I am incredibly proud of the work that has been done thus far. I am proud of this group and I am excited to be involved with this amazing project.

Thomas Tully

ENT 497

12/12/2019

## Senior Design Reflections

Or:

### How I Learned to Stop Worrying and Love BLE

I have ran the gamut of emotions over this project, at times believing it too trivial of a topic and too obvious of an answer. This had led me to further question the validity of the proposed solution. Seeing the vast numbers of similar products with lack luster reviews has also forced me to question the worthwhile nature of pursuing this endeavour. Surely those design teams thought through their designs before creating and releasing their solutions. Reading further into these products and their vitriol-filled reviews, it was clear the devices were not functioning as intended; perhaps this was a project worthy of a senior capstone.

Once I began iterating through the solutions and design ideas, I began to think we were being too ambitious with our goals. Consumer electronic projects of this scale require teams of engineers each with their own specializations. There needs to be someone specializing in power management, another embedded software developer, someone who will do signal analysis, another person doing PCB design, and at least one team member specializing in digital logic. This is to say nothing of the project managers and the user interface designers.

Working with my team has lightened the mental burden and helped me realize that we are capable of meeting our original goals. We have stated our intent to create a product capable of helping society, and I am confident we will be able to deliver. While we do not bring years of industry experience to this project, we are proficient enough to develop our idea and learn additional skills throughout the process. I still have my concerns, but thus far we have been able to arrive at satisfactory solutions as problems arise.

The greatest example of this iterative learning process occurred when I stumbled upon a Bluetooth academic paper while doing a literature search on embedded bluetooth signal attenuation. At the time, another team member had raised the question of how we would communicate sensor data back to the user's phone. "Bluetooth", I hastily retorted, knowing nothing about the technology and little about wireless communications in general. Seeking out any relevant information through keyword searches on Miami University Library's website, I happened upon a 2013 paper focused on small, low-power Bluetooth sensors. In the experiment, researchers were using signal strength of stock bluetooth low energy (BLE) devices to record whether senior citizens were approaching a medicine dispenser. Through measuring the signal attenuation it was possible to derive if the test subjects were in between the transmitting and receiving modules, which were placed around a medicine cabinet.

I presented this idea to my group members and they were skeptical at best. This demonstrated a healthy group dynamic, and that we were unknowingly applying engineering skills. After showing them the research and discussing how we could

implement a similar system, we decided that a wireless presence detector seemed reasonable. Being honest, it was all we had left at that point after discovering our other sensor-based ideas were lacking in performance.

Parts were ordered, prototypes built, and the first test distinctly showed our proof-of-concept was valid. This was great news, but this success also provided our group with additional problems. Instead of building a sensor network like we had originally envisioned and that we knew we could achieve, we were left with a solution that we did not fully understand. This led to us further diving into microchip the HM-19 BLE module was built around, the TI CC2640.

We quickly realized the full capacities provided by the TI CC2640 could be an elegant answer to two or three of our outstanding design questions. I was low-energy, could be powered by a 3.3V source, had on-board power management, contained temperature sensors, and had a full ARM M4 Cortex processor. This revelation meant our complex design could be reduced to run on this single microchip. We had turned a complex hardware problem into a software problem. This opens up many additional questions we will need to address as we move into next semester.

As this project moves from concept to fruition, I am reminded of the now infamous 2002 press briefing where then Secretary of State Donald Rumsfeld responded to reporters questioning the US's decision to invade Iraq by stating:

there are known knowns; there are things we know we know. We also know there are known unknowns; that is to say we know there are some things we do not know. But there are also unknown unknowns—the ones we don't know we don't know.

We know we want to help fix what is a serious problem for young infants. We know that the combination of alerts plus temperature information is the most logical approach to solve the problem. We also can define our unknowns, the greatest being will our product appeal to parents. As we push closer to our final design it continues to be the unknown unknowns that have both ground our progress to a halt, and provided the most opportunities for growth

Oscar A Candray  
Final Reflection  
ENT 497 Senior Design  
December 12, 2019

“Senior Semester”, its hasn’t been easy at all, as a college student the workload has tripled but that is not an excuse to be a procrastinator. my motivation are my children, they are everything to me and for them I must put forth and effort required to accomplish this Senior Project.

Senior Design Project started well because my team was already made before the class even started. Once my group was formed, we decided to share the work evenly. I was chosen to be the Project Manager to make sure everything goes according to the plan. The first thing we did was to get ideas for the project. Everyone had their own idea until Thomas showed us his and as a group, we decided to go with Baby car seat monitor.

We thought it was a great idea from the beginning, so we did individual research. We discussed the pros and cons about the whole project. As soon as we could start working on the project, I started working on the project, I created the Timeline with the three different phases of the project. I created like John would say the Backbone of the project. The Timeline and Template of the Report.

My group is amazing, I am so glad to work with such amazing people. John, all I can say are good things about him, he is smart, sometimes procrastinate but one thing I am sure of is that in the end he gets things done. He steps it up in the middle of the road, his performance was absolutely brilliant. There were many occasions that he said I didn’t have to worry about anything because I have already done a lot of the work, which is great to hear. I know I can count on him to get this project done.

Thomas is brilliant, All I can he is amazing, his determination to get this done is fascinating. His idea of the Bluetooth module was great for our project. I never had someone like him in a group, I know I can count on him and I am glad to have him in my group. There is no other word that could describe him but “AMAZING”.

My performance down the stretch hasn't been the greatest, compared to the beginning of the semester. My group has carried me, the amount of work that this semester has laid on my shoulder is a lot and I don't feel like I am contributing to the standards I am used to. For the future I need to perform to the highest level and not think about the amount of work just focus on get things done regardless of the situation.

I have learned so much from my group, we have a common goal that we need to accomplish, and I am sure we will. This is a fantastic group that I am glad to be part of. Moving forward I can't wait to see what the future holds for my group. I understand that not everything will be great because in our own ways we procrastinate at some point, but if one of us do that, I am sure the other two members will carry the load. This group can and will accomplish great things.



# ENT 498 Final Reflection

John Whitt  
30 April 2020

I would love to sit here and write a flowery story about how well this semester went; I simply will not do that. This semester was a disaster, a nightmare, a debacle, and I am not proud of myself for my poor response.

Yes, COVID was a huge factor in this semester's struggles, but I allowed myself to be cowed by societies' ridiculous response to a virus. The fear that was rampant, the closures, I hated every second of this. Ok, that is enough wallowing in misery.

I wish my group communicated better. I wish that I were a more reliable, consistent, and calm group member. I wish we met more, MUCH more. I wish we were not forced to respond to unstable, ever-shifting educational conditions. I wish we all (humanity) responded better.

With all of the negatives you might believe that I have nothing positive to say. That is incorrect. Our group weathered many storms and yet our project is, in my humble opinion, absolutely amazing. Our final report is conclusive and well documented.

We all work with what we are given, and this group has some amazing talents. We may not have been able to meet in person, but we stayed in consistent contact. This time period was heartbreaking for all of us Seniors, and we became a group of individuals who bonded in shared struggle.

I have it on good authority that groups often rely heavily on one member, or small faction of the group. Thomas was that member. He was the driving creative force from the idea for our

project, to the solution for how to make it happen. His technical skills were amazing and pulled this group. Thank you, Thomas.

Oscar is an example of how to juggle the entire world. Two jobs, children, full-time+ student. He was the early go-getter who was the heartbeat of our early project. Thank you, Oscar.

This leaves me, and if I am being honest, I do not really know how to praise myself. I have poured hours of my life into this project, yet no where near as many as Thomas. I tried to be a unifying force, but I am so high-strung that at times I failed desperately. I hope that I made the project easier for everyone, and did not add undue stress.

I am so proud of how the project came together. The work is wonderful, and the device functions as planned. Here are my complaints. Perhaps projects outside the academic world will function exactly as this group project. I highly doubt that. I am still not a fan of forced group projects. We are students who also have so many other responsibilities, and while this project is a huge success it was a terrible hardship.

I learned more about patience and kindness through this project than I ever thought possible. I learned how to sacrifice my wants and needs for those of the group. I learned that given the right people and the right pressures amazing results can occur. I learned that the right people and the right pressures can force others to collapse. I learned that I fall under both of those categories.

I wish that I were sitting next to these two gentlemen at graduation in a couple of weeks. That will not occur, and I am crushed by the weight of that loss. We fought so hard to get through this year together. While things were not always perfect, our project is amazing, and I am proud of our results.

Oscar A Candray C.  
Senior Design Reflective Essay  
ETN 498  
April 30, 2020

My Senior Design experience has been the most challenging experience I ever had. Because I must apply all the knowledge and skills I have acquired while studying at Miami University. Throughout the years I have been put to a test in so many ways that have helped me to get to the place I am at this moment. When I started this journey I never thought that I could accomplish so much to become a better person, every experience I had in each and every classroom, somehow in one way or another I have put in practice in the Senior Design.

The start of this project had me as a Project Manager. One of the competencies that I can reflect is in being able to think critically about the ways we needed to take to approach the problem of our Design. Recognizing, differentiating facts and the ability to revise the information on what parts of the project development were working for us, and what part we needed to deplete. I realized that project management is not an easy task, there are many barriers on the way, and in one way or another must overcome those obstacles to get the project running in the right direction. When applying critical thinking I also must be able to communicate effectively with others. I know I have to work on this, but this project taught me the way that I have to approach each individual to get the information that I required to continue to manage and focus on the different phases of the project. From ordering material, budgeting, and trying to find a common ground when and where to meet, COVID-19 which I hate so much.

At the beginning of the project we all thought it was something very simple and approachable, probably because we didn't realize that most of the design it is programming this area I don't feel very comfortable and I know I need to improve in such a way that I don't need to depend on someone else to get things done. I realized that my capstone material is very useful, labs, schematic designs, AutoCAD, every minor detail I learned was utilized in this project. But not everything was great, we all got frustrated at times, whether the project was not going in the direction we planned, the material was taking too long, or because of the programming in the device was not doing what we were expecting.

In our project, we gather many different ideas about how we wanted to approach the project development. We have a few failures trying to use temperatures sensor and gauge sensors. We realized that we need to be more precise trying to develop a device that was going to monitor a human being, or the coding of the device was more complicated than what our group could handle to mention a few. As you can see there were many variables that lead us to choose the Sparkfun Rx BLE Module and HM-19 Beacon technology. They both are low battery consumption and it is exactly what we needed to develop our device. We needed the devices to monitor the present of an object and the attenuation let us know that an object was present, also we needed to make sure there were no false positives when communicating with a phone application. This result leads Thomas to develop the entire coding because the initial idea was based on small electronics that would have better communication capability. Thomas and his technical skills are something that I envy. I really wished I could do programming as he does.

Knowing how much battery consumption was very important for our project, we needed something that was able to support high and low temperatures, this reason lead us to choose the

lithium CR123 non-rechargeable. We used a 3V operating in the range of -20 and 85 °C. We can order them already wire up and it was easy to add to the other devices.

But enough of technical stuff, I am so proud of how our project came all together in the end, it works just like we thought it would. Probably if we pursue having a finished product, we can accomplish a finished marketable product that can be utilized in the future.

One of the abilities I wished I would have, is the ability that John evolves when he is presenting a project, everything comes naturally. I do not have that, for me as a speaker I have to write and practice and practice. Sometimes I felt like I didn't put enough effort into our project but it is not because I didn't want to, it is because it is hard to balance two jobs, family and be a full-time student. One thing I am sure now that I can depend on John and Thomas to get things done. The sacrifices we all did, it has paid off and our Senior Project shows that. I really want to Thank John and Thomas for carrying me at times. With us being in quarantine made everything so difficult, but we fought as a group and now we can see the finished product and it is worth it. I am so proud of our project. WELL DONE GUYS YOU ROCK! THANK YOU!!

ENT 498

Thomas Tully

05/01/2020

### A Final Reflection

This project was born out of a desire to apply the knowledge, skills, and technical abilities acquired over the course of my educational career towards solving a real-world problem. At the beginning of the fall semester, I was inspired by a news story involving a loving, careful, highly educated parent who, against all their instincts and better desires, forgot their young child in a hot car. The only positive to come from the incident was their commitment to educating others on car seat safety. Aside from education, they were pushing for legislation requiring sensors either in cars or car seats, similar to existing weight-based seatbelt detectors. Even as the story was being told, I was working through possible ways such an alert system might function. The week prior I discovered my wife was expecting our first child; this topic hit very close to home.

After trying and failing at several designs, in early winter we accidentally found that Bluetooth could be used as a rudimentary sensor. We were focusing on using it to pass data to connected devices and were working out ways to ensure the primary module would have enough power to reach end-user's phones. We were able to turn a design problem into an answer. This idea was further boosted by reading academic literature highlighting a similar use-case in a senior living facility.

Prototypes were built, then more refined models. By early spring, we were confident we would succeed and had moved into completing secondary goals. Then the pandemic began closing business and schools across Ohio. Thankfully, our last parts order had arrived one week prior.

Following this, there were lost weeks; entire days of zero productivity. The added emotions from the pandemic and subsequent stay at home orders only added to the mounting uncertainty. Adaptation was required, both mentally and physically. Our group was able to communicate via text

and video calls, but we were never able to find the energy we had prior. I know I could have accomplished more in this phase, and know I am capable of better. This became an occasion where producing any product takes priority in producing a perfect product. I had to overcome my deep-rooted perfectionism – we were no longer living in a tidy world where such luxuries can be afforded – and push through. While much of the project was completed in March, the code was lacking features and rough.

I began reproaching the project after essentially shelving it for a month. To my surprise, the modules were still running and I was able to work through my code. I began refactoring the code to make it more readable, efficient, and modular. After talking with my group members, we decided the best approach would be to revert to older designs and fit the components together as best as possible. Pieces that didn't fit were filed and sanded, and I had a chance to work on my soldering skills.

There is a balance of surprise and elation when watching an idea transform into reality. I still feel those emotions when watching code compile, waiting in earnest for any errors and hoping the syntax is appropriate. Those same feelings apply to this project, with its many changes over the past eight months. While the project is finished in the eyes of the university, I intend to push myself and create the custom application. I feel it only appropriate, and it will aid in my overall productivity.

This sudden air of uncertainty engulfing normal activities brings back dark memories from the 2008-2009 economic crash. I was a senior education major then, in the middle of what was a senior capstone (student teaching). As I am now, I was looking forward to leaving college and finding a worthwhile job in a field I'd devoted many years to learning. I don't know how this will end for me, but I am thankful to have had something to work on these past few weeks. Control over one's life is a core psychological need for humans; the hours sunk into refining the various codes, reports, videos, and miscellaneous deliverables attached to the Senior Design experience has aided in reestablishing my internal locus of control.