SwiftMote

The IoT Customizable Sensor Platform

User Guide

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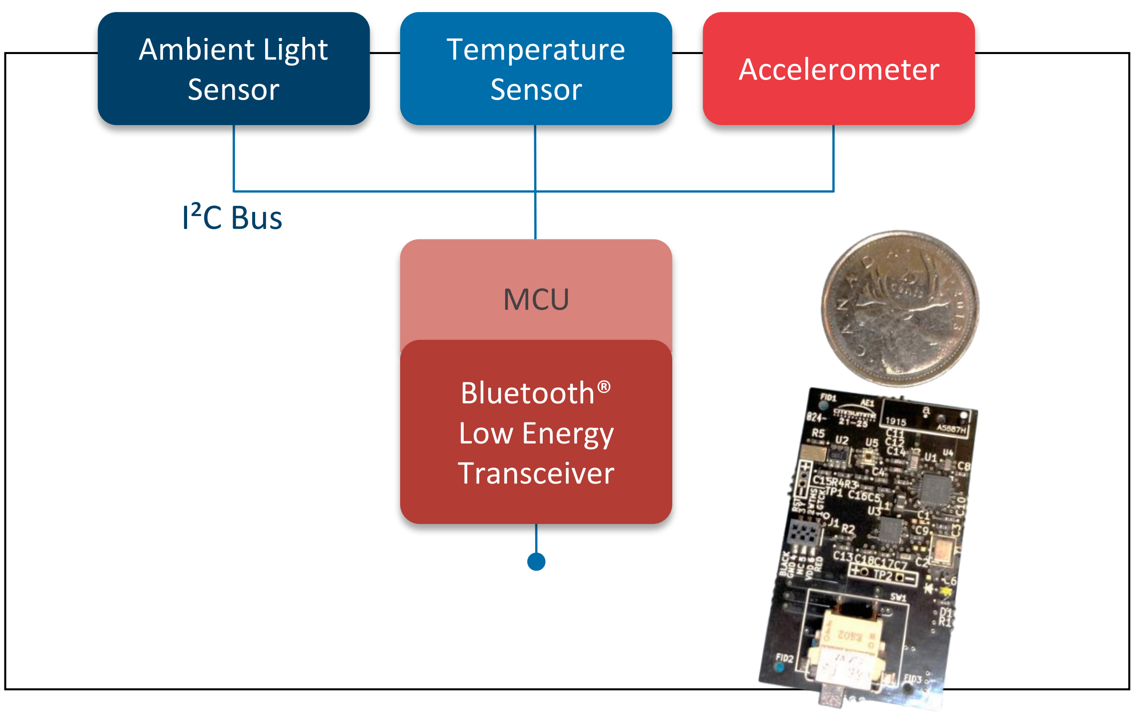

The SwiftMote Platform

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Acronyms

Acronym	Description
ADC	Analog to Digital Converter
BLE	Bluetooth Low Energy (protocol)
CPU	Central Processing Unit
GPIO	General Purpose Input/Output
I2C	Inter-Integrated Circuit
JTAG	Joint Test Action Group
MCU	Microcontroller Unit
RAM	Random Access Memory
SMBus	System Management Bus
QFN	Quad-Flat No-leads (package)
RTC	Real Time Clock
SPI	Serial Peripheral Interface

1. Overview

This document provides a description of the customizable IoT Sensor Platform, SwiftMote, showcasing a multi-component and ultra-low power Bluetooth Low Energy System (BLE). SwiftMote is based on the silicon interposer IoT sensor node first released in 2018. The sensor node is equipped with an ambient light sensor, a temperature sensor, an accelerometer, and on/off switch.

The features of the SwiftMote sensor node include:

- Bluetooth Low Energy (BLE) wireless connectivity
- Real-time sensors array
- Direct smartphone / tablet connectivity
- Coin cell battery
- Small form factor with integrated antenna
- JTAG access to customize the firmware

The microcontroller unit (MCU) firmware is user-configurable allowing you to realize a variety of applications. This document describes the sensor node components, and how their features can be used to implement a low-power sensor node for multiple applications, including:

- Real time sensing of ambient light and temperature for environmental monitoring and control
- HVAC systems and building automation
- Shock, vibration, and temperature monitoring of industrial equipment
- Theft and temperature monitoring of storage / shipping containers

A photograph of the sensor node is shown in Figure 1 to demonstrate the compact size of the design.

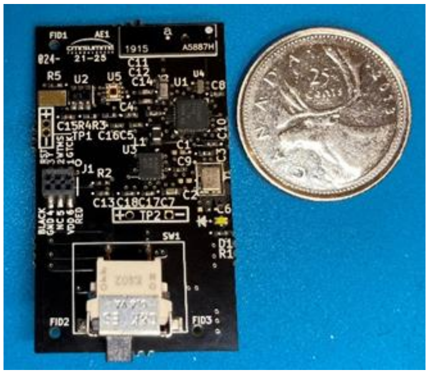

Figure 1: SwiftMote Sensor Node

2. System Description

2.1. The Sensor Node

The SwiftMote sensor node is based on the low-power and high-performance CC2640 wireless MCU with Bluetooth Low Energy (BLE) capabilities from Texas Instruments (TI). This MCU is used to communicate with a low power temperature sensor, ambient light sensor, and accelerometer, and to transmit the measurements to a BLE-enabled device. The block diagram of the system is shown in Figure 2.

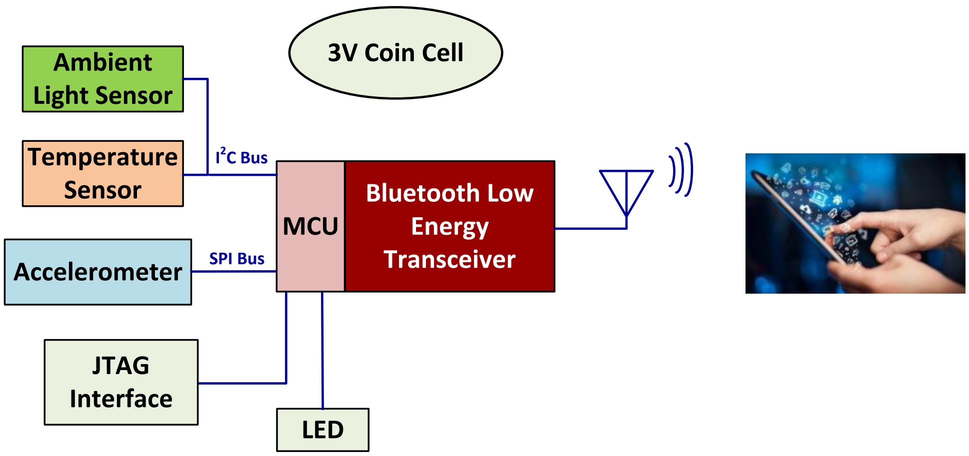

Figure 2: Block Diagram of the Sensor Node

The system is powered by a compact 12.5 mm 3 V coin cell, and an LED is included for visual debugging purposes. The LED can also be used in the final application, but will reduce the lifetime of the sensor node.

2.2. Sensor Node Components

The sensor node features the following low-power components:

- CC2640 Wireless MCU from Texas Instruments
- OPT3002 Ambient Light Sensor from Texas Instruments
- TMP100 Digital Temperature Sensor from Texas Instruments
- ADXL362 3-Axis Accelerometer from Analog Devices

2.2.1. CC2640 Wireless MCU

The CC2640 is a wireless MCU from Texas Instruments that communicates via BLE. It is targeted towards low-power devices and offers low-active and standby currents to extend battery lifetime.

The MCU offers a variety of power saving modes down to 100 nA when shutdown to wake up on external events to 1 uA when an RTC is running with RAM/CPU retention. Refer to the

CC2640 datasheet as well as Texas Instruments application note SWRA478D for more information on current consumption.

The MCU is also equipped with common digital peripherals, including an I^2C and SPI interface. You can configure various internal timers and 2-wire JTAG debugging is supported.

The specific variant of the CC2640 used in this reference design is packaged in a 4 mm x 4 mm QFN package, which offers 10 general purpose IOs (GPIOs) in a compact footprint.

2.2.2. OPT3002 Ambient Light Sensor

The OPT3002 sensor is a low power ambient light sensor from Texas Instruments. The spectral response of the sensor is wide and ranges from approximately 300 to 800+ nm.

The sensor provides a fully digital output using an I^2C interface and has a compact 2 mm x 2 mm footprint. Its typical operating current is 1.8 uA, depending on ambient light conditions, and its standby current can be as low as 0.4 uA.

A measurement can be initiated upon request by the MCU. Upon completion of the measurement, the sensor returns to standby mode to conserve power. Alternatively, the sensor can be configured to automatically measure ambient light conditions. In this scenario, the OPT3002 can send an interrupt to the MCU to alert it (or wake it up) if a user-configurable lighting event is detected.

2.2.3. TMP100 Digital Temperature Sensor

The TMP100 is a digital temperature sensor from Texas Instruments. The sensor offers a typical accuracy of ±1°C without requiring calibration or external component signal conditioning over the range of -55°C to 125°C. The on-chip ADC offers 9-12 bits user-selectable resolutions. It is capable of reading temperatures with a resolution of 0.0625°C when the ADC is set to 12-bit.

The TMP100 sensor provides SMBus, two-wire, and I^2C compatible interface. It allows up to eight devices on one bus. This reference design uses the I^2C interface. The shutdown mode of the TMP100 sensor maximises power saving by shutting down all device circuitry, which reduces current consumption to less than 1 µA.

2.2.4. ADXL362 3-Axis Accelerometer

The ADXL362 is a low power 3-Axis accelerometer from Analog Devices. It has three ranges of operation (±2 g, ±4 g, and ±8 g) to optimize performance based on the application, and offers multiple measurement modes to trade-off power with accuracy. The sensor provides a fully digital output using an SPI interface, and has a compact 3.25 mm x 3 mm footprint. During measurement mode, the measurement data rate can be configured between 12.5 Hz and 400 Hz. The typical current consumption over this entire range is typically less than 3 µA.

The sensor can also be placed in wake-up mode to serve as a motion detector. During this mode, measurements are made at a rate of ~6 Hz with an average current consumption of 270 nA for a

2.0 V power supply. Once an event surpasses a user-defined threshold, the sensor sends an interrupt to the MCU to alert it (or wake it up).

2.3. Usage Examples

The combination of low power sensors chosen for this reference design enables a variety of application modes. For example, the sensor node can be placed into a low-power sleep state until motion is detected, at which point it will wake up and start transmitting sensor data. The same concept can be used for the ambient light and temperature sensors. The SwiftMote can be targeted to machine-health monitoring applications as well as physiology experiments.

3. System Development

The SwiftMote sensor node is designed to serve as a reference for hardware, firmware, and software development.

3.1. Hardware Development

The physical layout can be used as a reference when designing an IoT sensor platform, and the key layout guidelines can be extended to other wireless devices as well. The key layout considerations are summarized in Section 4.3.

3.2. Firmware Development

An initial version of the reference firmware is released in CMC's IoT platform GitHub repository: https://github.com/cmcmicrosystems/iot_platform. Development work continues to implement the power saving features offered by the components used in this design to extend battery lifetime. The IoT platform repository will be updated from time to time to offer the most optimized firmware or new feature implementations.

The Bluetooth Low Energy Stack for the CC2640 MCU (BLE-STACK-2) can be found here. The software and technical reference manual for the CC2640 MCU can be found here.

3.3. Software Development

The reference software is under development and will provide the ability to record and share measurements, as well as modify various configurable parameters that are built into the reference firmware.

Reference code for apps on both Android and iOS operating systems from Texas Instruments can be found here. These are based on a different sensor mote tag and will need to be modified accordingly to work with this design.

4. Design Files

4.1. Schematic

The schematic of the sensor node is shown in Figure 3.

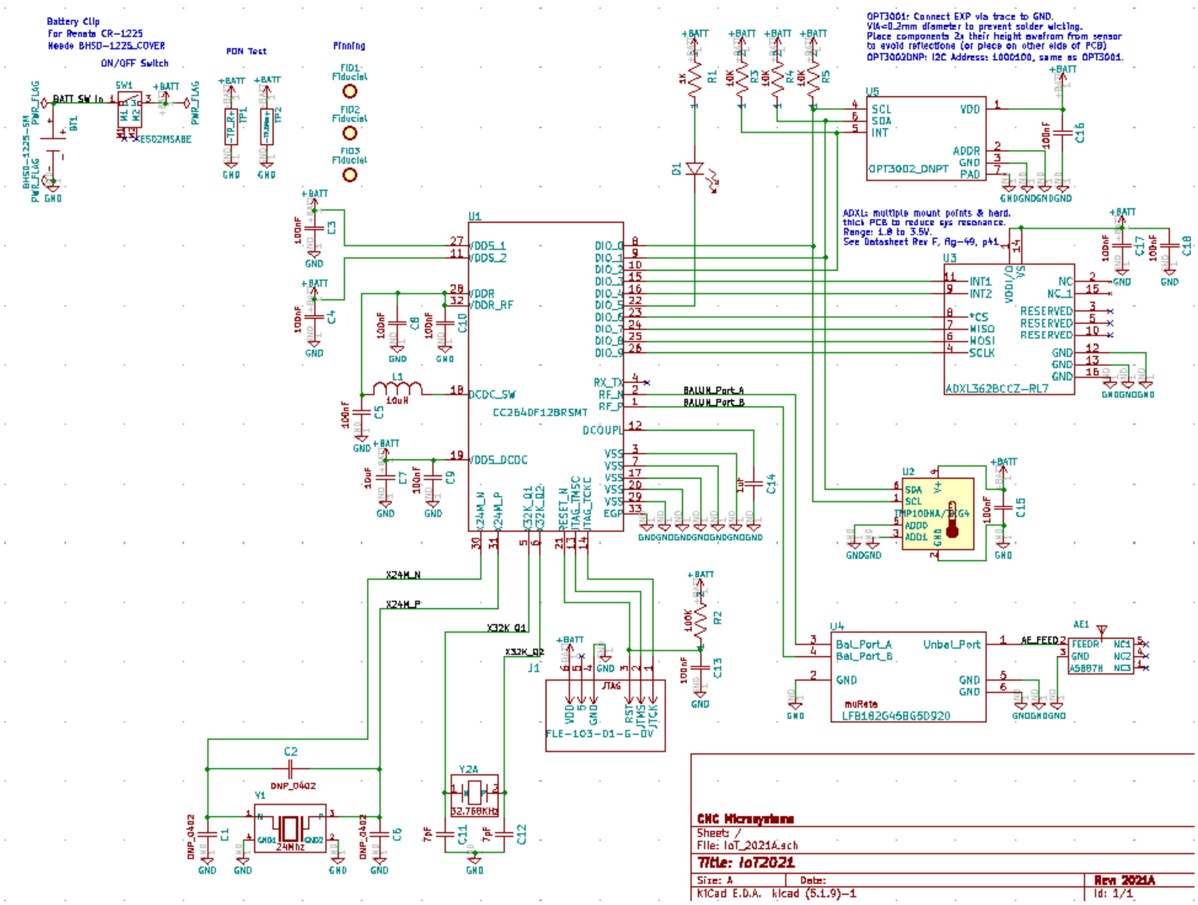

Figure 3: Schematic of SwiftMote

4.2. Bill of Materials

The bill of materials for the sensor node is shown in Figure 4, with manufacturer part numbers and the distributor used at that time. Other distributers also carry these components, and CMC Microsystems does not endorse one over the other.

Reference	Manufacturer Part Number	MANUFACTURER	VENDOR
U4	LFB182G45BG5D920	muRata	Mouser
U3	ADXL362BCCZ-RL7	Analog Devices	Digikey
U5	OPT3002_DNPT	Texas Instruments	Digikey
Y2	SC20S-7PF20PPM	Seiko Instruments Inc.	Digikey
Y1	NX3225SA-24.000M-STD-CSR-1	NDK America Inc.	Digikey
TP1	TP_R	plated through hole only	N/A
TP2	TP_200m	plated through hole only	N/A
AE1	A5887H	Antenova	Digikey
C17	GRM155R70J104KA01D	muRata	Mouser
C18	GRM155R70J104KA01D	muRata	Mouser
C16	GRM155R70J104KA01D	muRata	Mouser
C15	GRM155R70J104KA01D	muRata	Mouser
R5	ERJ-2GEJ103X	Panasonic	Mouser
R4	ERJ-2GEJ103X	Panasonic	Mouser
R3	ERJ-2GEJ103X	Panasonic	Mouser
R1	ERJ-2RKF1001X	Panasonic	Digikey
J1	FLE-103-01-G-DV	Samtec Inc.	Digikey
C14	CL05A105KO5NNNC	Samsung Electro-Mechanics	Digikey
U1	CC2640F128RSMT	Texas Instruments	Digikey
C13	GRM155R70J104KA01D	Murata	Mouser
R2	ERJ-2GEJ104X	Panasonic	Digikey
C11	GRM1555C1H7R0BA01D	muRata	Digikey
C12	GRM1555C1H7R0BA01D	muRata	Digikey
C1	GRM155R70J104KA01D_DNP	**muRata -DO NOT PLACE**	Mouser
C6	GRM155R70J104KA01D_DNP	**muRata -DO NOT PLACE**	Mouser
C2	GRM155R70J104KA01D_DNP	**muRata -DO NOT PLACE**	Mouser
C9	GRM155R70J104KA01D	muRata	Mouser
C7	GRM188R60J106ME47D	muRata	Mouser
C10	GRM155R70J104KA01D	muRata	Mouser
C5	GRM155R70J104KA01D	muRata	Mouser
L1	CKS2125100M-T	Taiyo Yuden	Digikey
C8	GRM155R70J104KA01D	muRata	Mouser
C4	GRM155R70J104KA01D	muRata	Mouser
C3	GRM155R70J104KA01D	muRata	Mouser
BT1	BHSD-1225-SM	MPD	Digikey
D1	SMLE12WBC7W1	ROHM Semiconductor	Mouser
U2	TMP100NA/3KG4	Texas Instruments	Digikey
SW1	ES02MSABE	CK Switches	Digikey
FID1	Fiducial	Non-plated thru-hole only	N/A
FID2	Fiducial	Non-plated thru-hole only	N/A
FID3	Fiducial	Non-plated thru-hole only	N/A

Figure 4: Bill of Materials

4.3. Layout Considerations

Figure 5 shows the overall layout with all signal layers shown. The size of the sensor mote realized on PCB is 1 inch x 1.7 inch, and if the switch is removed and battery moved up, the design can easily be on a 1 x 1-inch PCB.

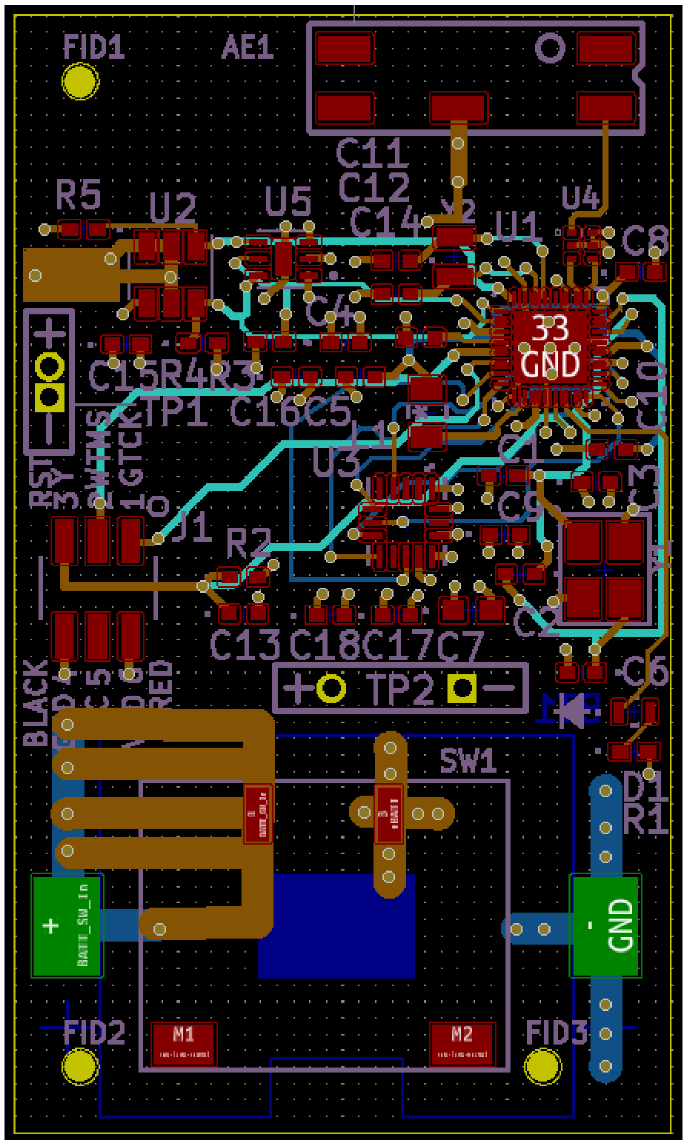

Figure 5: Overall Layout of the SwiftMote Sensor Node

Figure 6 shows the layout with the routing layers visible and the labeled components. This view helps to visualize concerns that must be considered in a system with sensors. Note that the temperature sensor is placed on the left side and the MCU on the right side to minimize heat from the processor and to not impact the temperature readings. The temperature sensor has its own ground plane on the top layer to couple the ambient heat into the sensor.

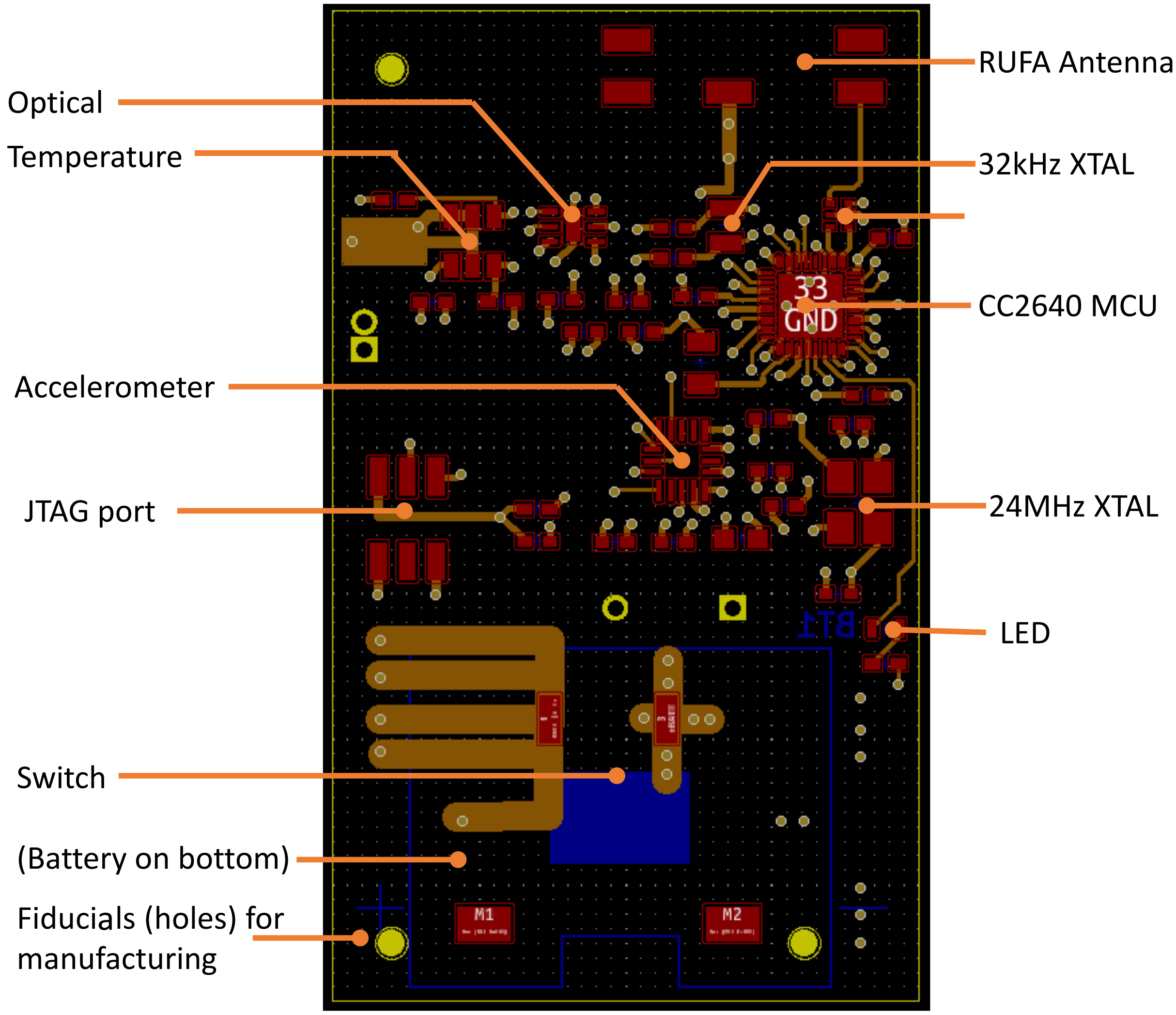

Figure 6: Top Metal Layer of SwiftMote with the Key Components Labeled

Place the ambient light sensor in a region that does not contain components which can block the light reaching it. This includes any components that are significantly thicker than the light sensor and will block light that is incident at a 45° angle.

The accelerometer must be placed flat, and if the interposer is to be mounted on a fixture, place the accelerometer as close to the mounting point as possible to avoid errors due to the vibration of the substrate.

Place the RUFA Antenna, (MPN# A5887H) at the corner edge of the right side of the board. Alternatively, if placing on the corner edge of the left side of the board, antenna A5839H can be substituted. The antenna requires a clearance of at least 2 mm from ground planes and components to function properly. Discrete components can be used to match the antenna with the processor output, however, muRata and Johanson Technology provide conjugate match baluns for TI processors so an integrated solution can be used. For this version, the muRATA LFB182G45BG5D920 was used, but the Johanson 2450BM14G0011T-AEC was used previously. If more power is required in the signal, TI provides an amplifier with the CC2590/2.

Oscillator selection is simplified by using TI's application report *Crystal Oscillator and Crystal Selection for the CC26xx and CC13xx Family of Wireless MCUs* on TI's website. The tables within the guide list tested parts for 24 and 48 MHz as well as 32 kHz crystals. Suggestions for layout are provided, including keeping traces from crystals to the processor as short as possible as well as making use of reference planes for signal integrity.

Placement of the antenna is shown in Figure 6. The RF trace leading to the antenna is 8.5 mils wide to provide an impedance of ~50 Ω when referenced to the wider ground trace below. Note that this is a ceramic chip antenna, and there should be no metal underneath the antenna itself.

The board stackup used is shown in Table 1:

Table 1: Stackup

IoT2021A - Stackup					
	Project Name:		IoT2021A		
	Final Thickness:		0.035	inches	
	Panel Size:		12x18	inches	
	Material:		370HR		
	Average Dk:		4.04		
	Layer Sequence	**Name**	**Function**	**Copper**	**thickness (inches)**
	Layer 1	F.Cu	SIG	0.5 Oz	0.0007
			Prepreg		**0.005**
	Layer 2	F.GND	GND	1 Oz	0.0014
			Core		**0.004**
	Layer 3	F.BATT	PWR	1 Oz	0.0014
			Prepreg		**0.0106**
	Layer 4	In3.Cu	SIG	1 Oz	0.0014
			Core		**0.004**
	Layer 5	B.GND	GND	1 Oz	0.0014
			Prepreg		**0.005**
	Layer 6	B.Cu	SIG	0.5 Oz	0.0007
				total=	0.0356

Note: Overall thickness may be up to 40 mils.

Layers 2 and 3 represent the power/ground plane pair and they are spaced at only 4 mils to provide the maximum capacitance manufacturable within the PCB to handle components with potentially fast rise-times. Discrete capacitors on the board provide the remaining capacitance. To design the trace from the balun to the antenna feed, you can use Keysight ADS linecalc to obtain a ballpark figure, however, the dimensions and materials need to be checked versus the factory's capabilities.

For this design, the factory could best achieve a 50 Ohm trace with the following:

- Top layer: 0.5 oz Copper
- Second metal layer: a height of 5 mils using:
  - Isola 370HR PCB with an average Dk of 4.04, and

– the trace drawn with a width of 8.5 mm

Further details regarding factory constraints are provided in the **FabNotes_IoT_RevXXXX** text file on GitHub located here: iot_platform/PCB_Version_KiCAD_5_1_9/Manufacturing_BoM/.

5. Acknowledging CMC

If your research benefits from products and services provided by CMC Microsystems, please acknowledge this support in any publications about your work. Publications may include journal articles, conference papers, scientific posters, presentations, thesis, and other documents that feature your research. For more information, please visit https://www.cmc.ca/be-sure-to-acknowledge-cmc/.

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