TI Designs
Multi-Standard CC2650 SensorTag Design Guide

TEXAS INSTRUMENTS

TI Designs

TI Designs provide the foundation that you need including methodology, testing and design files to quickly evaluate and customize the system. TI Designs help *you* accelerate your time to market.

Design Resources

http://www.ti.com/tool/TIDC-CC2650STK-SENSORTAG	Tool Folder Containing Design Files
http://www.ti.com/product/cc2650	Product Folder
http://www.ti.com/product/opt3001	Product Folder
http://www.ti.com/product/tmp007	Product Folder
http://www.ti.com/product/hdc1000	Product Folder
http://www.ti.com/tool/cc2650stk	Tools Folder
http://www.ti.com/tool/ccstudio	Tools Folder

TI E2E™ Community

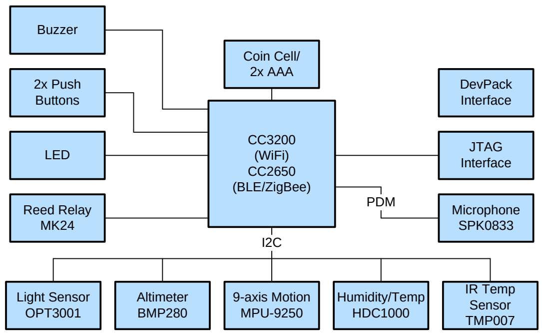
ASK Our E2E Experts
WEBENCH® Calculator Tools

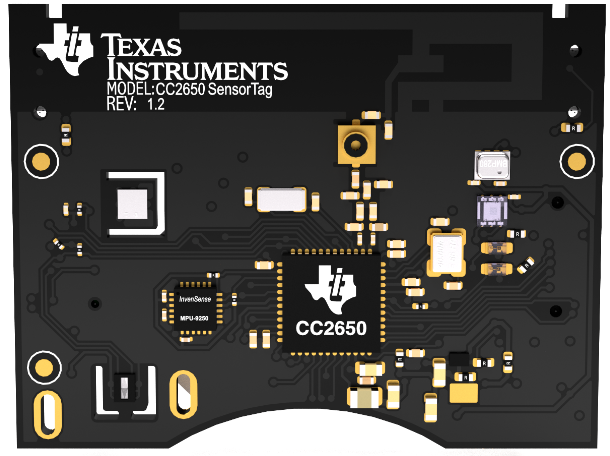
Design Features

- Offers Cloud Connectivity Out of Box
  - Access and Control Your SensorTag From Anywhere and Explore a Seamless Integration With Mobile Applications and Web Pages Through Javascript and MQTT
- Supports Multi-Standard Wireless MCU
  - *Bluetooth*® Smart
  - ZigBee®
  - IPv6 over low-power wireless personal area networks (6LoWPAN)
- Offers Low Power
- Supports 10 Low-Power Sensors
  - Ambient Light
  - Infrared Temperature
  - Ambient Temperature
  - Accelerometer
  - Gyroscope
  - Magnetometer
  - Pressure
  - Humidity
  - Microphone
  - Magnetic Sensor
- Based on the Extremely Low-Power and High-Performance ARM® Cortex®-M3 CC2650 Wireless MCU
- Can Use DevPacks to Expand the Functionality of the SensorTag to Fit Your Design Ideas
  - The Emulator Debug DevPack With a Free Code Composer Studio™ IDE License, Provides a Complete Development System.

Featured Applications

- Handsets for Smart Phones
- Home Automation
- Sensor Nodes
- Smart Watches
- Weather Stations





An IMPORTANT NOTICE at the end of this TI reference design addresses authorized use, intellectual property matters and other important disclaimers and information.

1 System Description

1.1 Multi-Standard CC2650 SensorTag

The SensorTag kit invites you to realize your cloud-connected product idea. The new SensorTag includes 10 low-power MEMS sensors in a small package and is expandable with DevPacks that make adding your own sensors or actuators easy.

Connect to the cloud with *Bluetooth* Smart and get your sensor data online in three minutes. The SensorTag is ready to use right out the box with an iOS™ and Android™ application and require no programming experience to get started.

The SensorTag is based on the low-power and high-performance CC2650 wireless MCU, which offers 75% lower power consumption than previous *Bluetooth* Smart products. This rate of power consumption lets the SensorTag use battery power and offers years of battery life from a single coin cell battery.

The *Bluetooth* Smart SensorTag includes iBeacon™ technology. This technology allows your phone to launch applications and customize content based on SensorTag data and your physical location.

The SensorTag can be enabled with ZigBee / 6LoWPAN technology.

Visit www.ti.com/SensorTag for more information on SensorTag technology.

1.1.1 Block Diagram

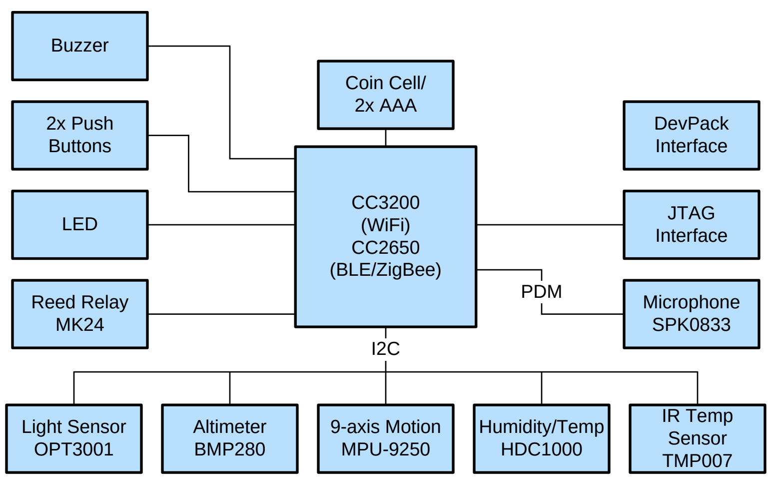


Figure 1. Block Diagram

2 Highlighted Products

The design features the following devices:

- CC2650
- OPT3001
- TMP007
- HDC1000

For more information on these devices, see the product folders at www.TI.com.

2.1 CC2650 – Wireless MCU

The CC2650 device is a wireless MCU targeting *Bluetooth* Smart, ZigBee and 6LoWPAN, and ZigBee RF4CE remote control applications.

The device is a member of the CC26xx family of cost-effective, ultra-low power, 2.4-GHz RF devices. The ability to consume very low active RF and MCU currents and low-power mode currents provides excellent battery life for the device. This ability also lets the device operate on small coin cell batteries and in energy-harvesting applications.

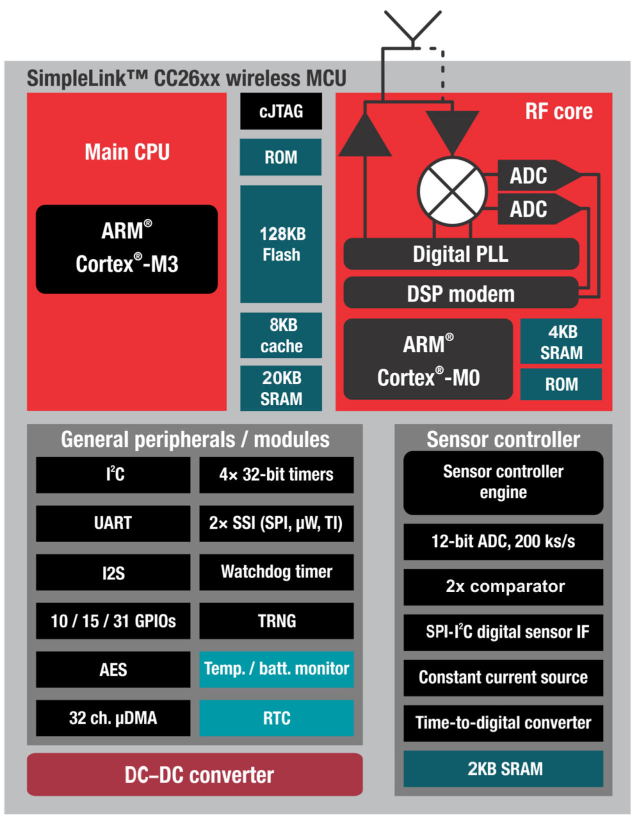


Figure 2. CC2650 Functional Block Diagram

2.2 OPT30001 – Ambient Light Sensor

The OPT3001 sensor measures the intensity of visible light. The spectral response of the sensor closely matches the photopic response of the human eye and includes infrared rejection.

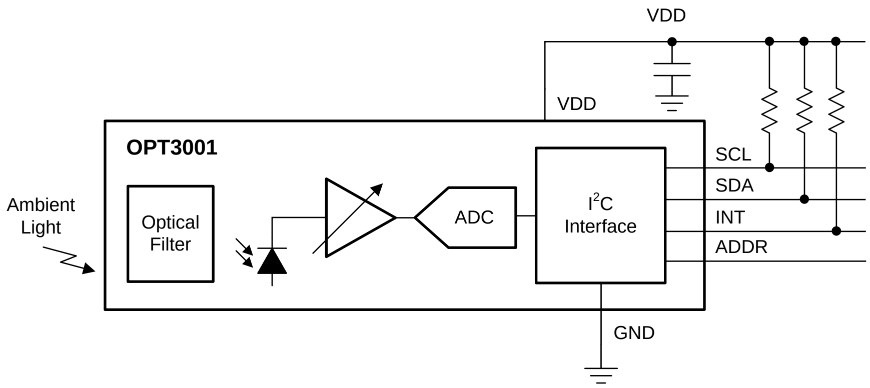


Figure 3. OPT3001 Functional Block Diagram

2.3 TMP007 – Infrared Thermopile Temperature Sensor

The TMP007 sensor is an IR thermopile sensor that measures the temperature of an object without direct contact with it. The integrated thermopile absorbs the infrared energy from the object in the field of view of the sensor. The device digitizes the thermopile voltage and then provides it and the die temperature as inputs to the integrated math engine. The math engine then computes the temperature of the corresponding object.

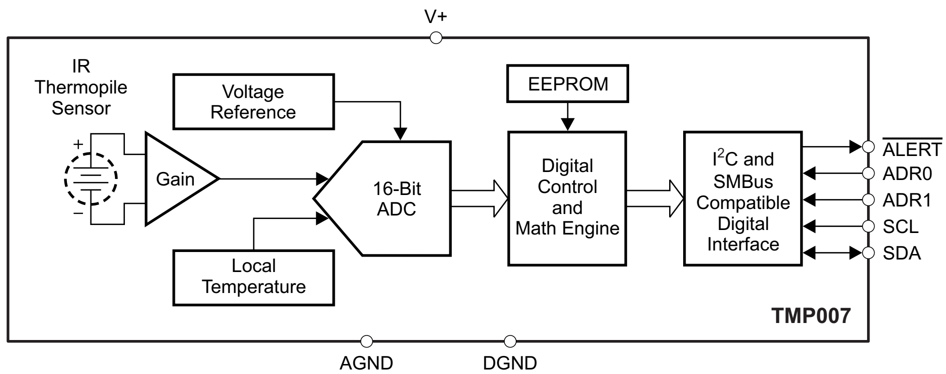


Figure 4. TMP007 Functional Block Diagram

2.4 HDC1000 – Humidity Sensor With Integrated Temperature Sensor

The HDC1000 sensor is a factory-calibrated digital humidity sensor with an integrated temperature sensor that provide accurate measurements at very low power. The HDC1000 sensor measures humidity based on a novel capacitive sensor and functions within thetemperature range of –40°C to 125°C. The innovative WLCSP (wafer-level chip scale package) simplifies board design with an ultra compact package and the sensing element on the bottom of the HDC1000 device protects against dirt, dust, and other contaminants.

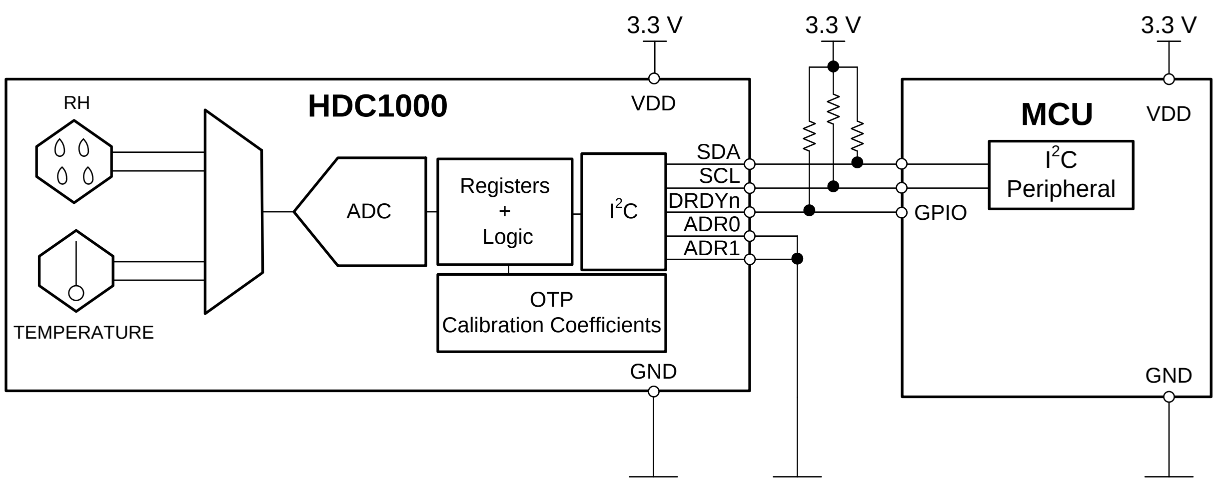


Figure 5. HDC1000 Functional Block Diagram

3 System Design Theory

The SensorTag is a complete development kit that requires no knowledge of embedded software to get started testing with the kit. Connect the SensorTag to your smart phone using *Bluetooth* Smart; then use your phone to connect to the cloud and access your latest workout data online in a matter of minutes. iBeacon lets your phone launch applications and customize content based on SensorTag data and your physical location.

Get started quickly using your applications, the supporting iOS and Android applications, or the SensorTag to develop your own product using the low-power sensors.

3.1 Application and Web Development

Access data from your SensorTag through cloud providers or use JavaScript and jQuery examples to access data directly. Use Android and iOS mobile applications as starting points for your own Internet of Things (IoT) projects or write HTML5 platform-independent code based on the source code from sample web application projects.

3.2 Embedded Software Development

The SensorTag offers open hardware and software reference design for low-power IoT nodes at a low cost. The SensorTag with the Debug DevPack provide the most affordable platform for developing hardware. Port the SensorTag application between radio standards to quickly evaluate which wireless technology is right for your application.

3.3 Hardware Development

Use the SensorTag hardware as the development platform for your IoT project. The open hardware demonstrates how to use 10 low-power sensors. The DevPack interface makes it easy to develop and test your own sensors and actuators on the IoT cloud.

4 Getting Started

4.1 Hardware

The SensorTag kit includes everything needed to get started. Download the free SensorTag application from the Apple App Store™ or Google Play™ and get started with your IoT development.

4.2 Firmware

4.2.1 The *Bluetooth* Low Energy Stack (BLE-STACK-2): includes download links for the SensorTag *Bluetooth* Low Energy firmware.

4.2.2 SensorTag ZigBee Firmware

The ZigBee stack (Z-STACK-HOME) includes download links for the SensorTag ZigBee firmware.

4.2.3 SensorTag 6LowPAN Firmware

The Contiki stack includes download links for the SensorTag 6LowPAN firmware.

5 Test Setup

We measured the antenna radiation pattern in a 3-m long RF shielded room (an anechoic chamber). The device under test (DUT) was set in transmit mode and rotated around to create a 360° antenna radiation pattern. The measurement antenna was placed in the opposite side of the chamber. The DUT transmitted a continuous wave (CW) at 2440 MHz and the antenna measured the wave with 15° steps in azimuth and elevation. Figure 6, Figure 7, and Figure 8 show the test set up.

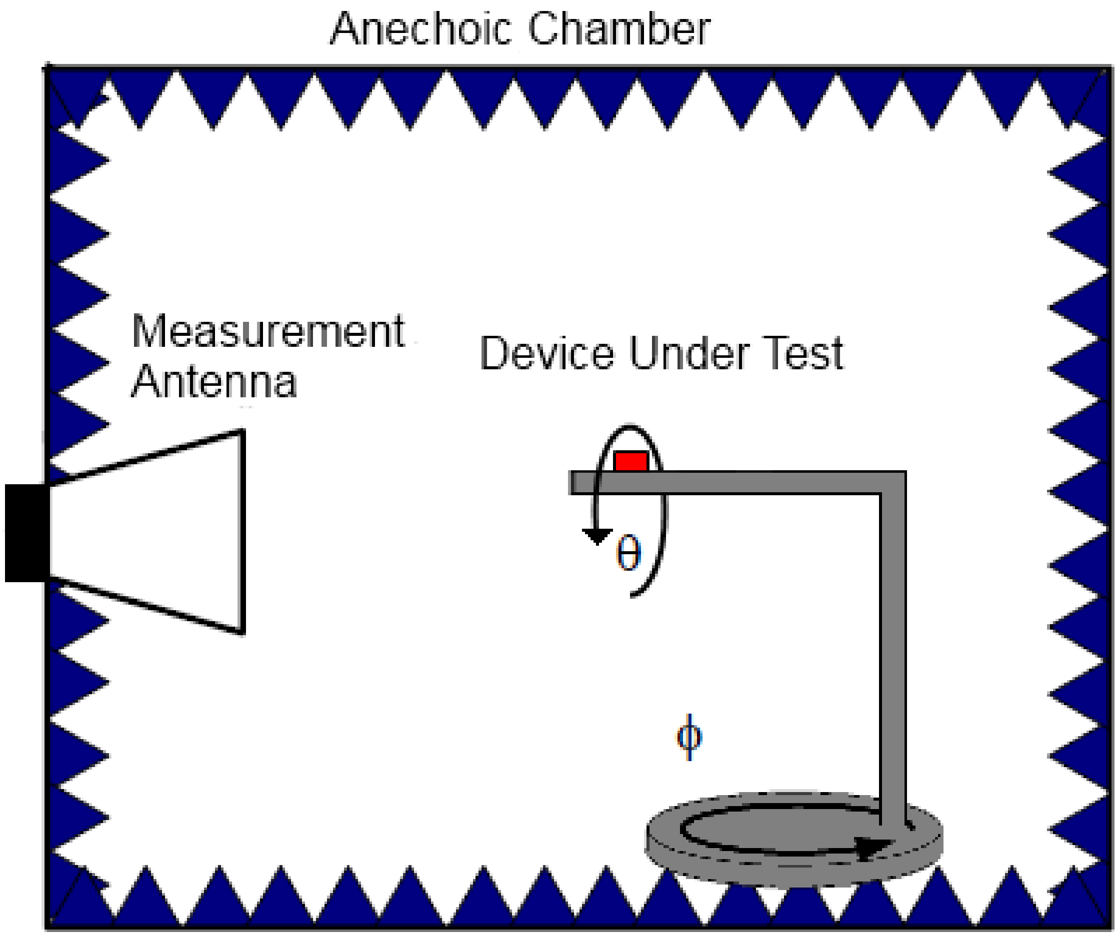


Figure 6. Antenna Radiation Pattern

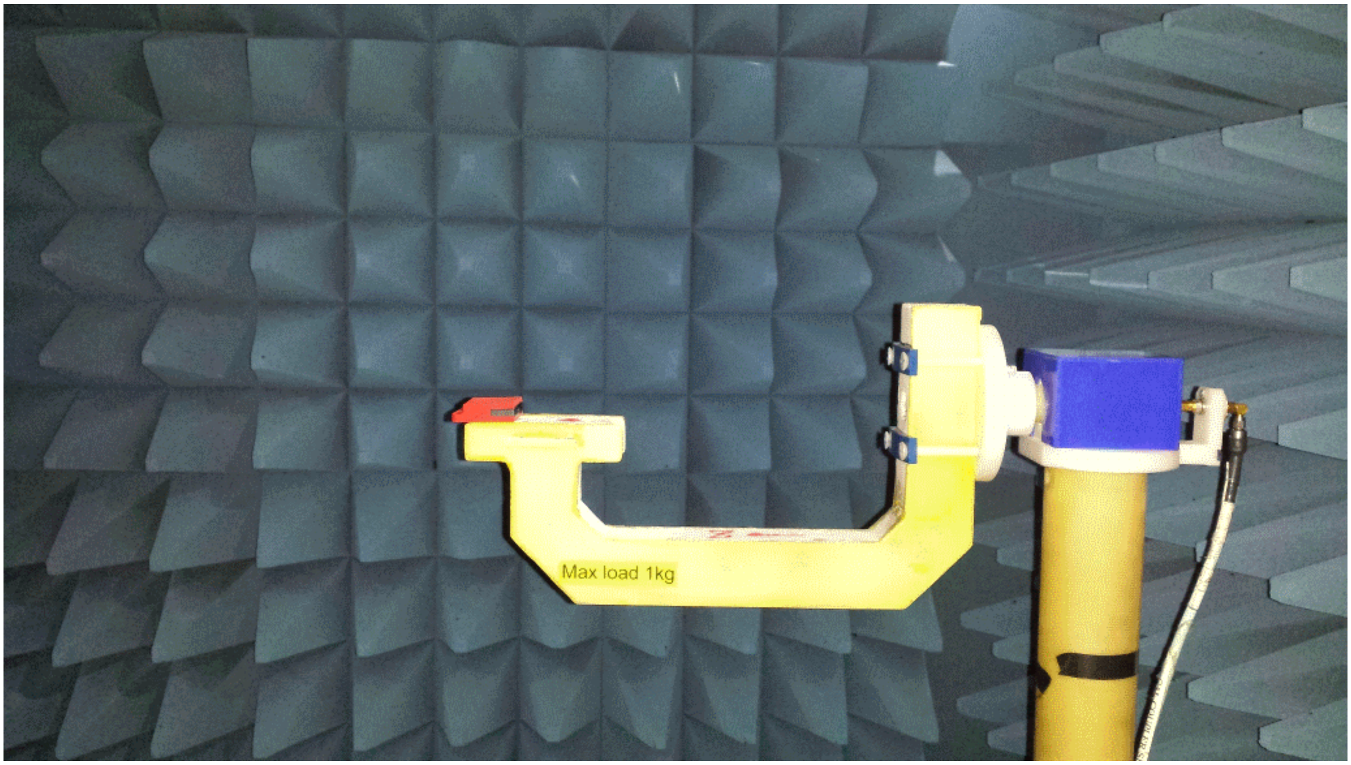


Figure 7. DUT Mounted On Rotating Arm

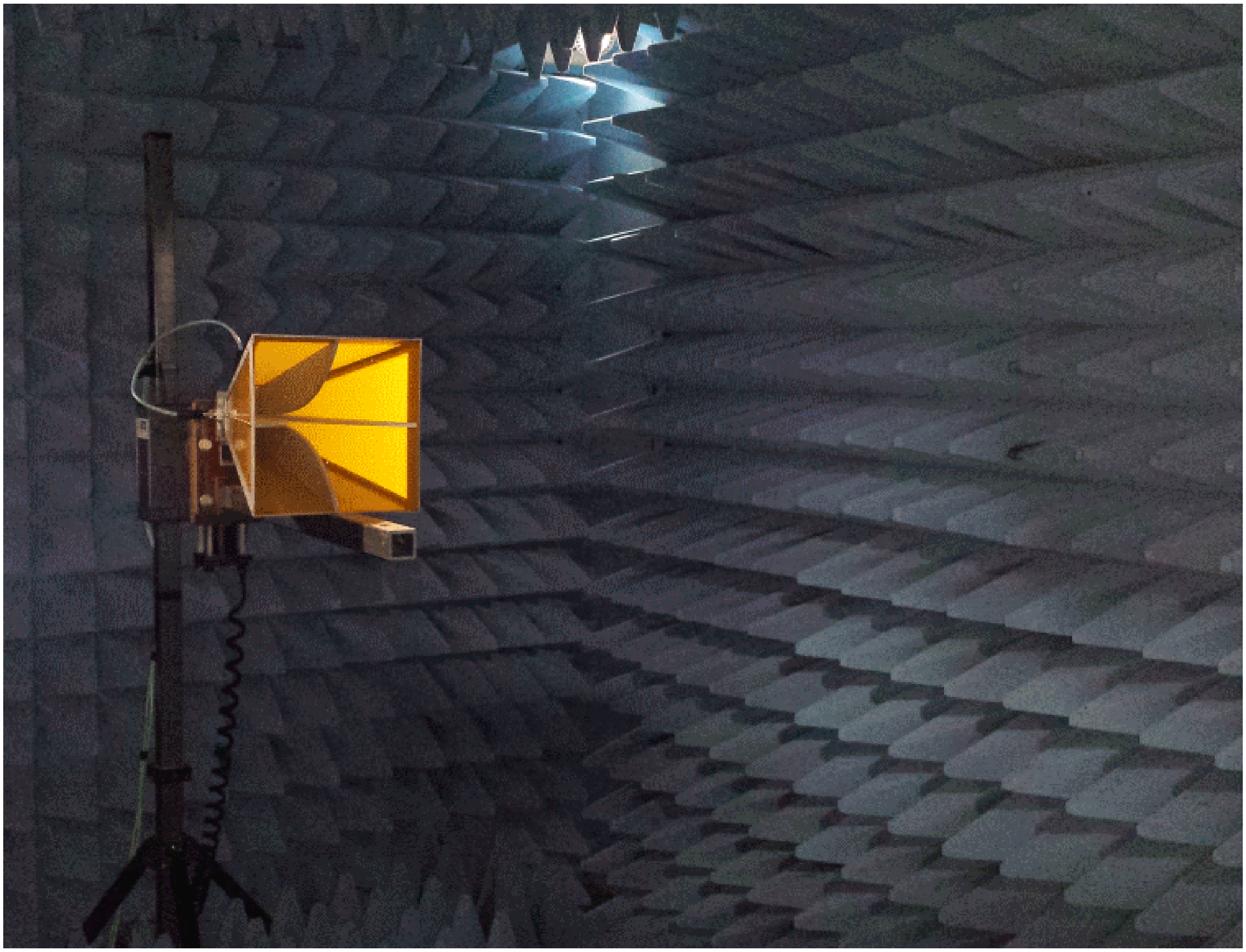


Figure 8. Measurement Antenna

6 Test Data

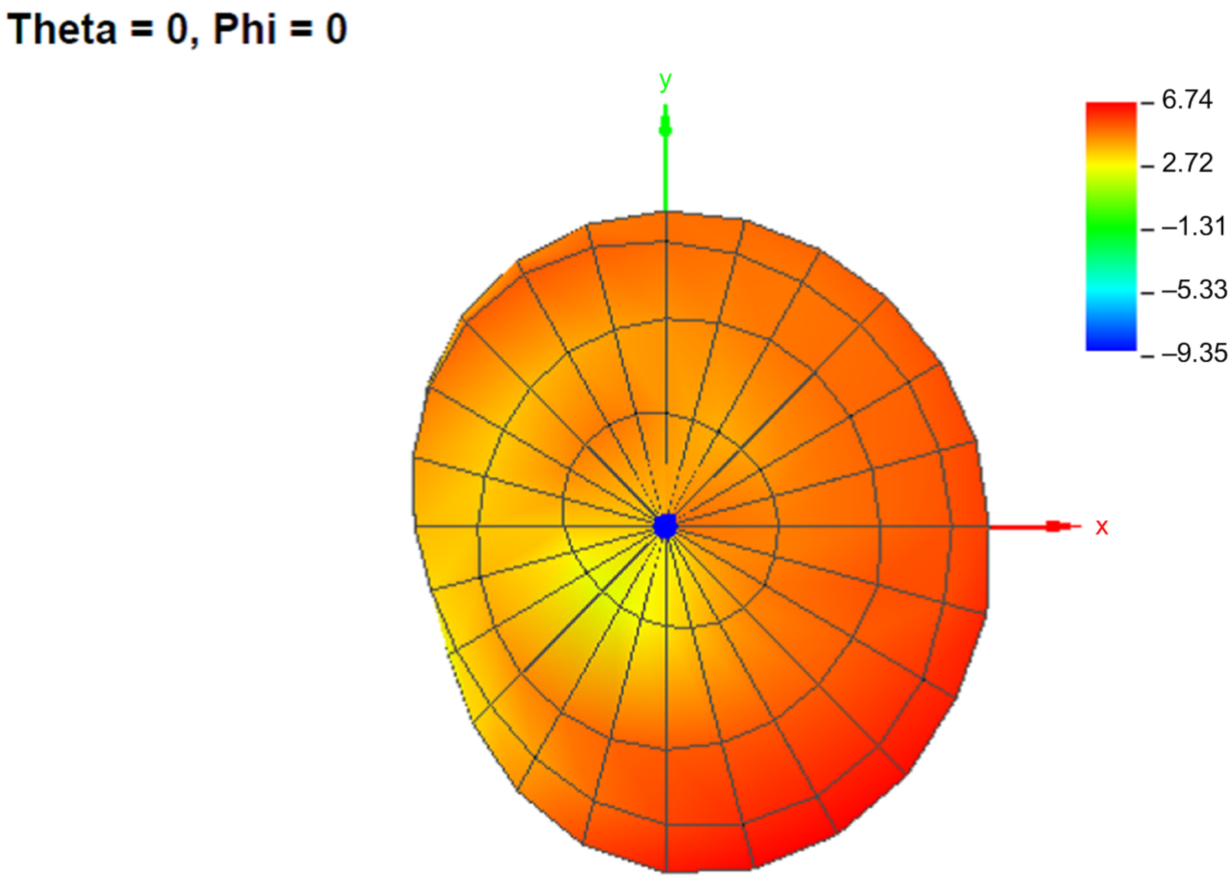


Figure 9. Theta = 0, Phi = 0

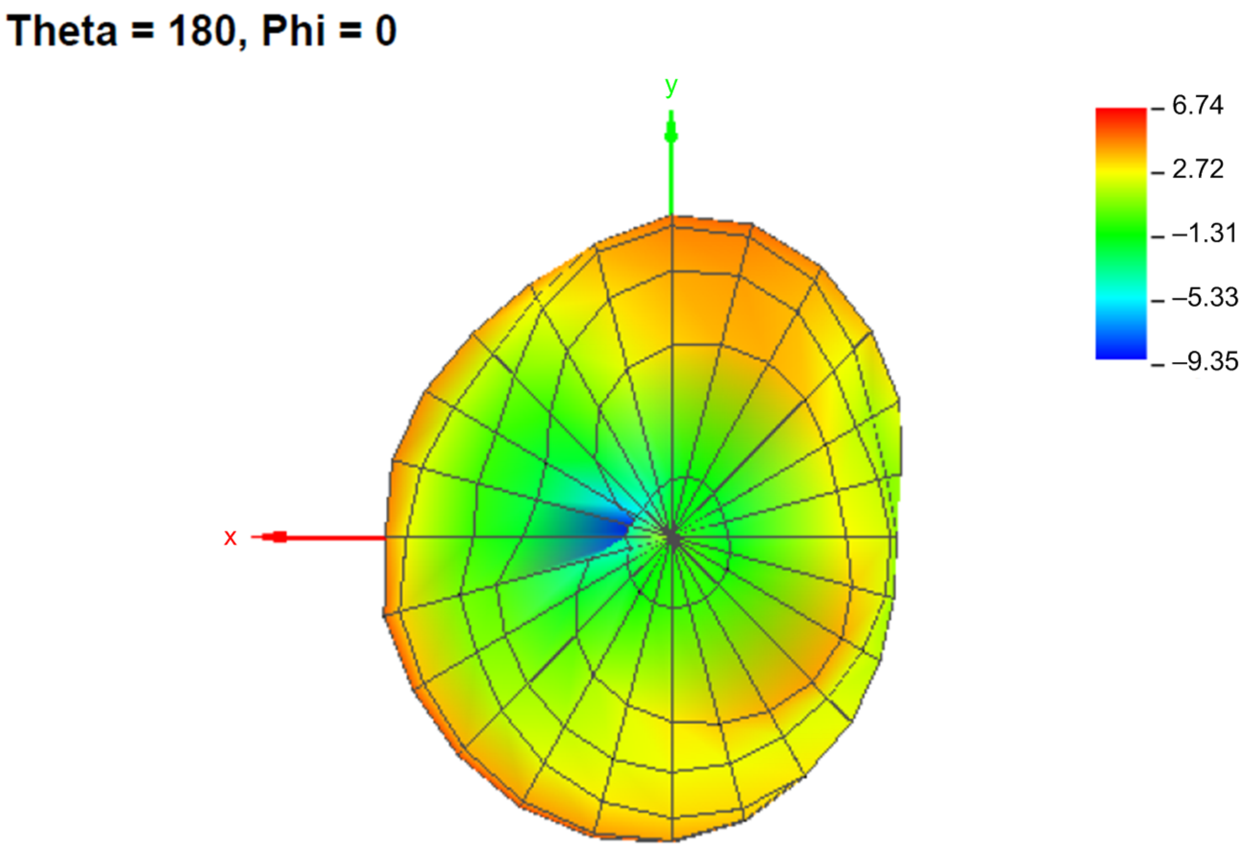


Figure 10. Theta = 180, Phi = 0

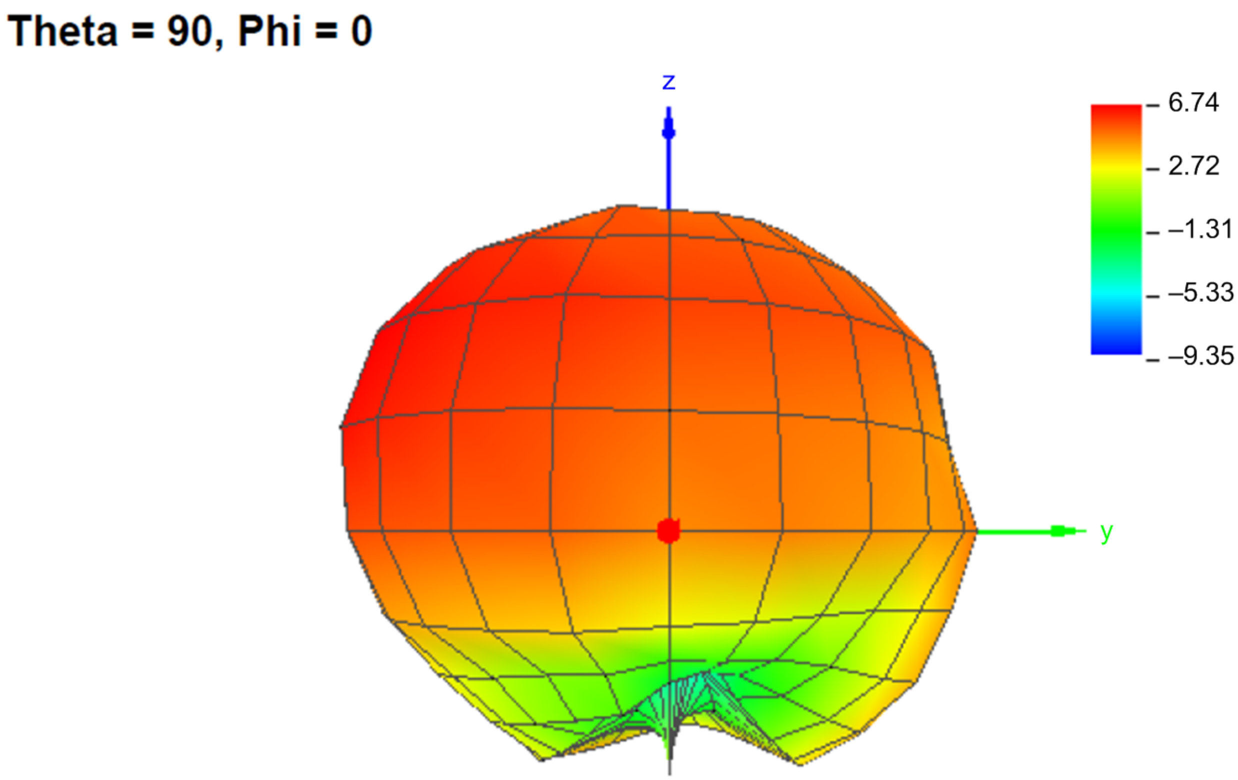


Figure 11. Theta = 90, Phi = 0

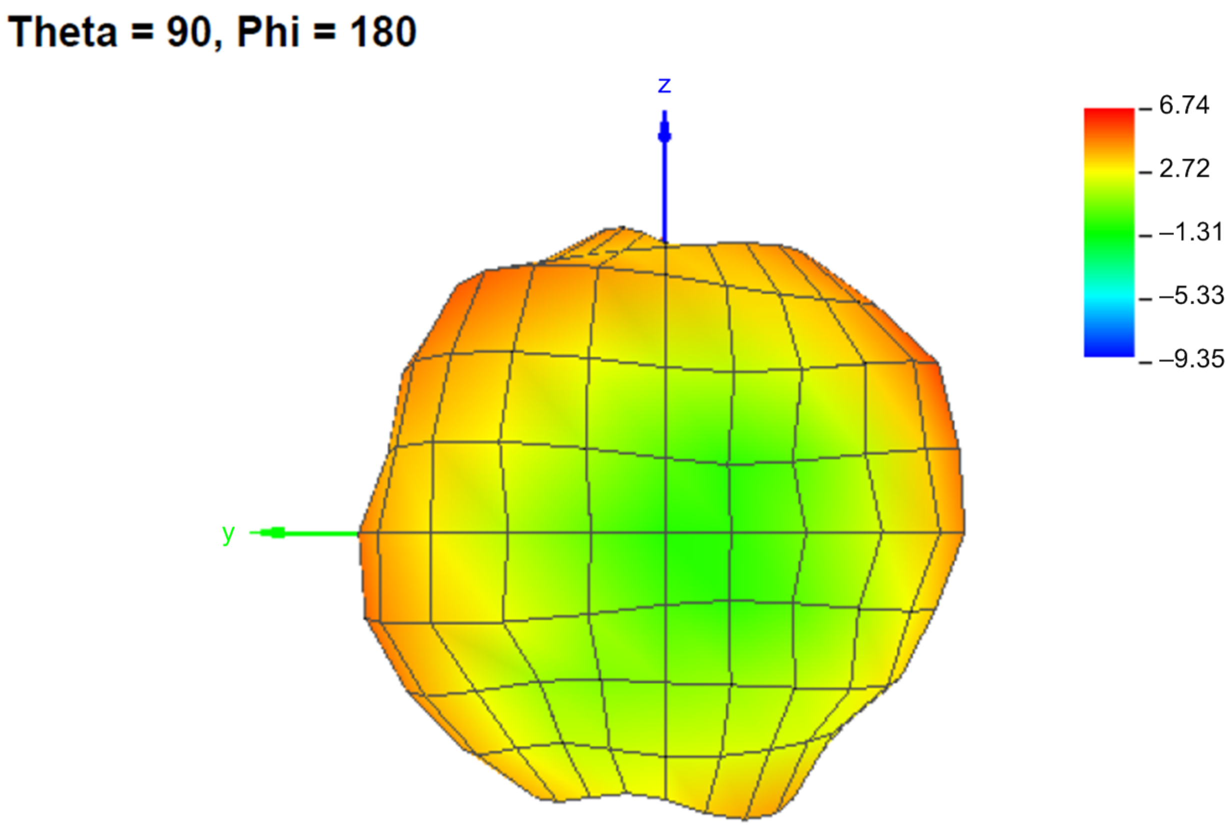


Figure 12. Theta = 90, Phi = 180

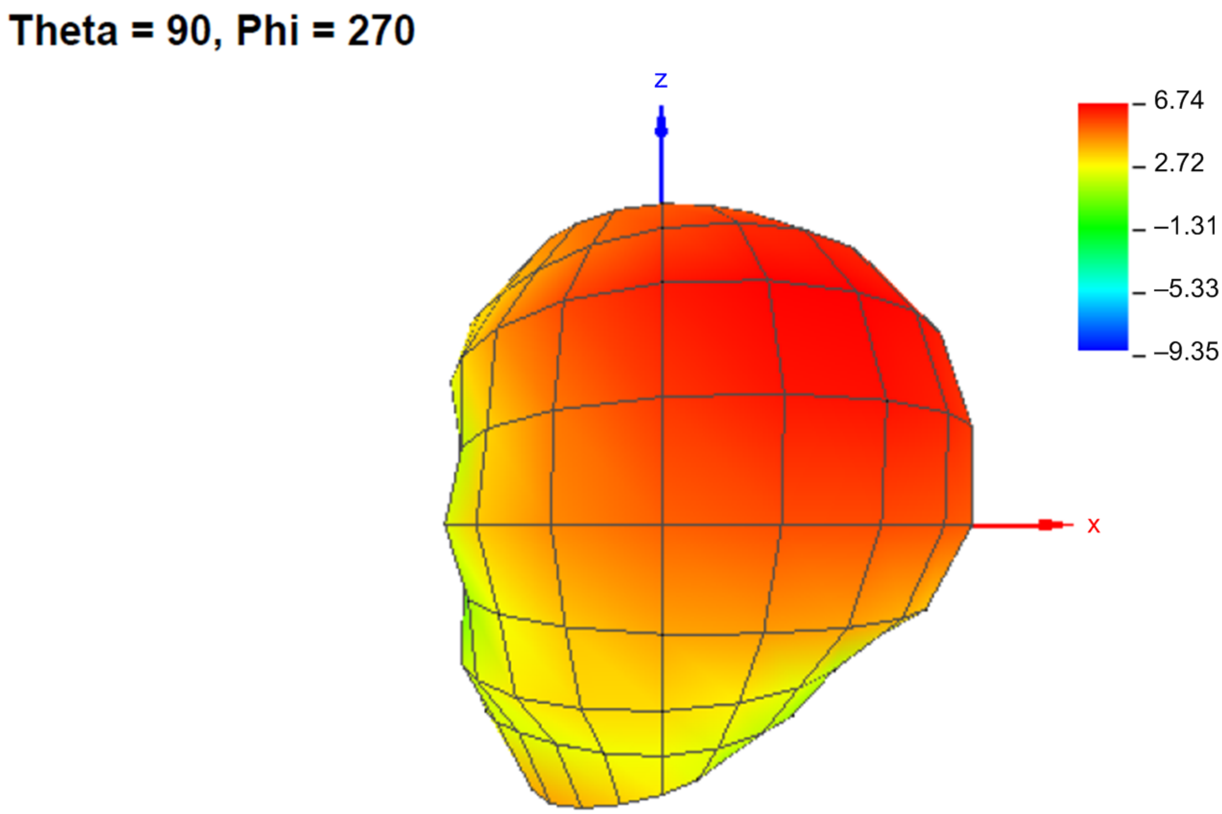


Figure 13. Theta = 90, Phi = 270

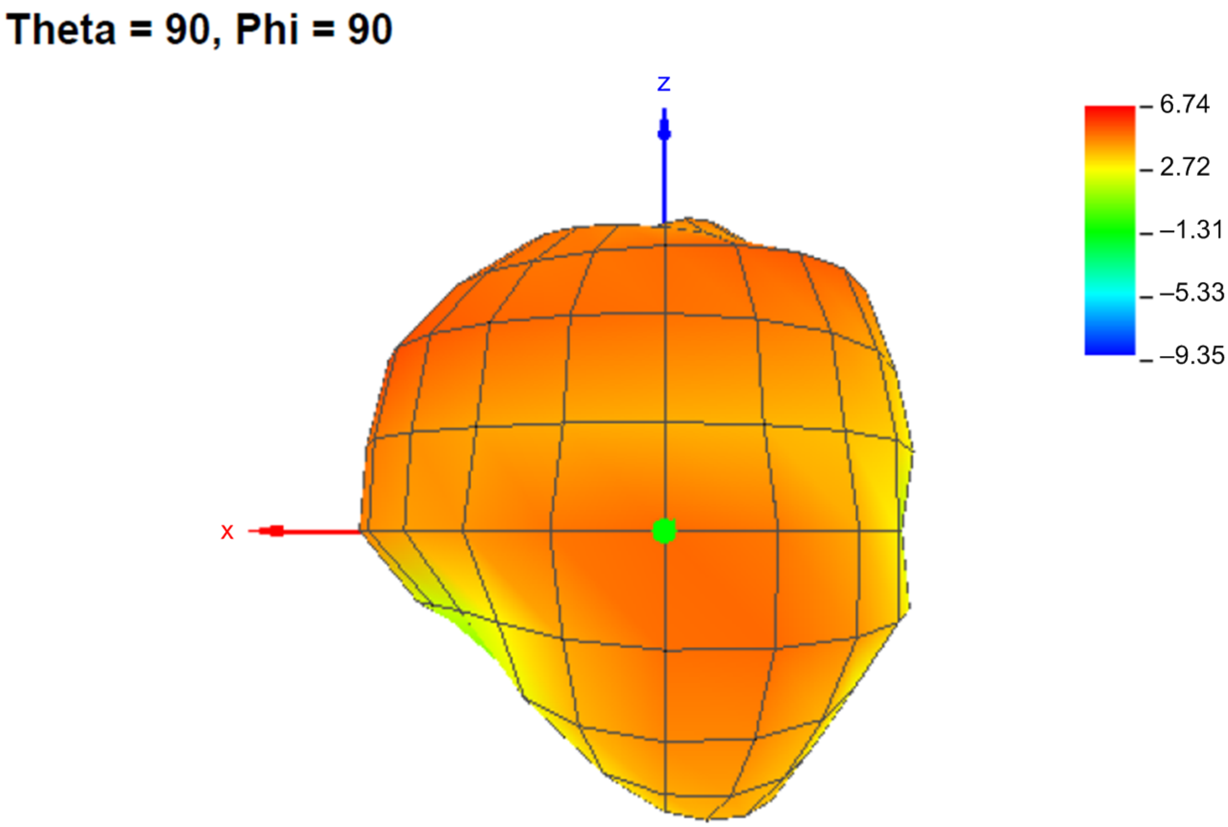


Figure 14. Theta = 90, Phi = 90

7 Design Files

7.1 Schematics

To download the schematics for each board, see the design files at SWRR134.

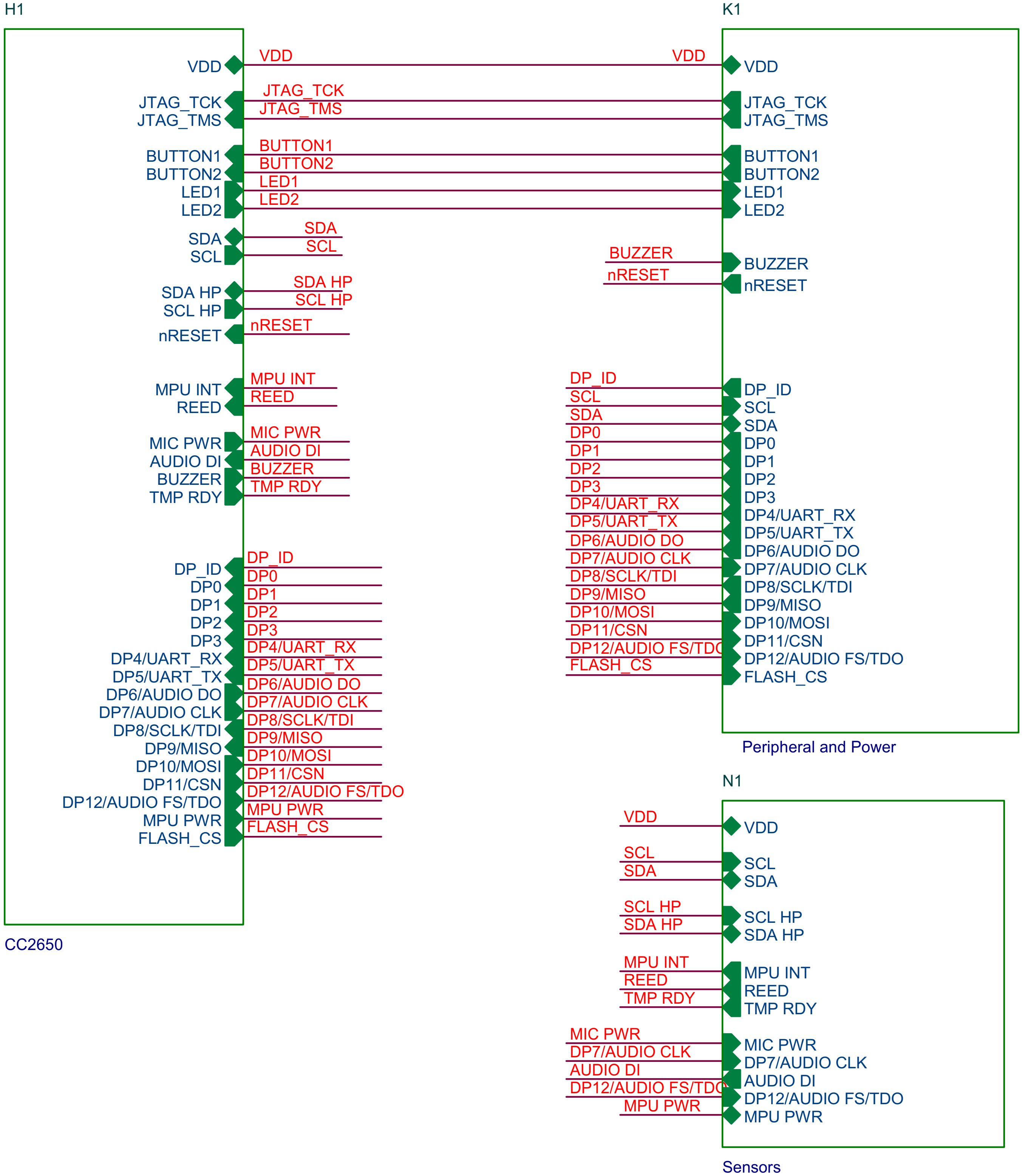


Figure 15. CC2650STK Schematics

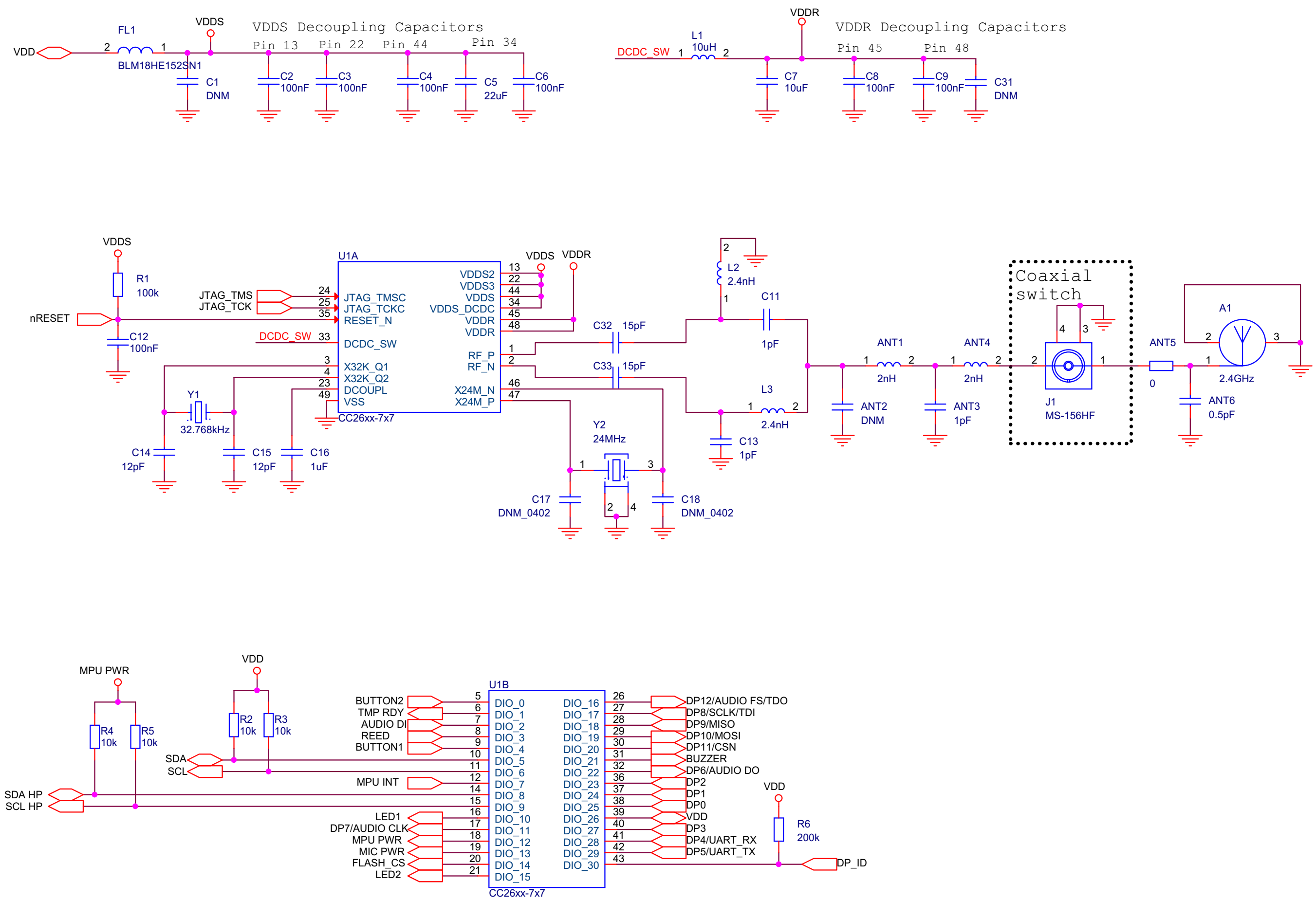


Figure 16. CC2650STK Schematics

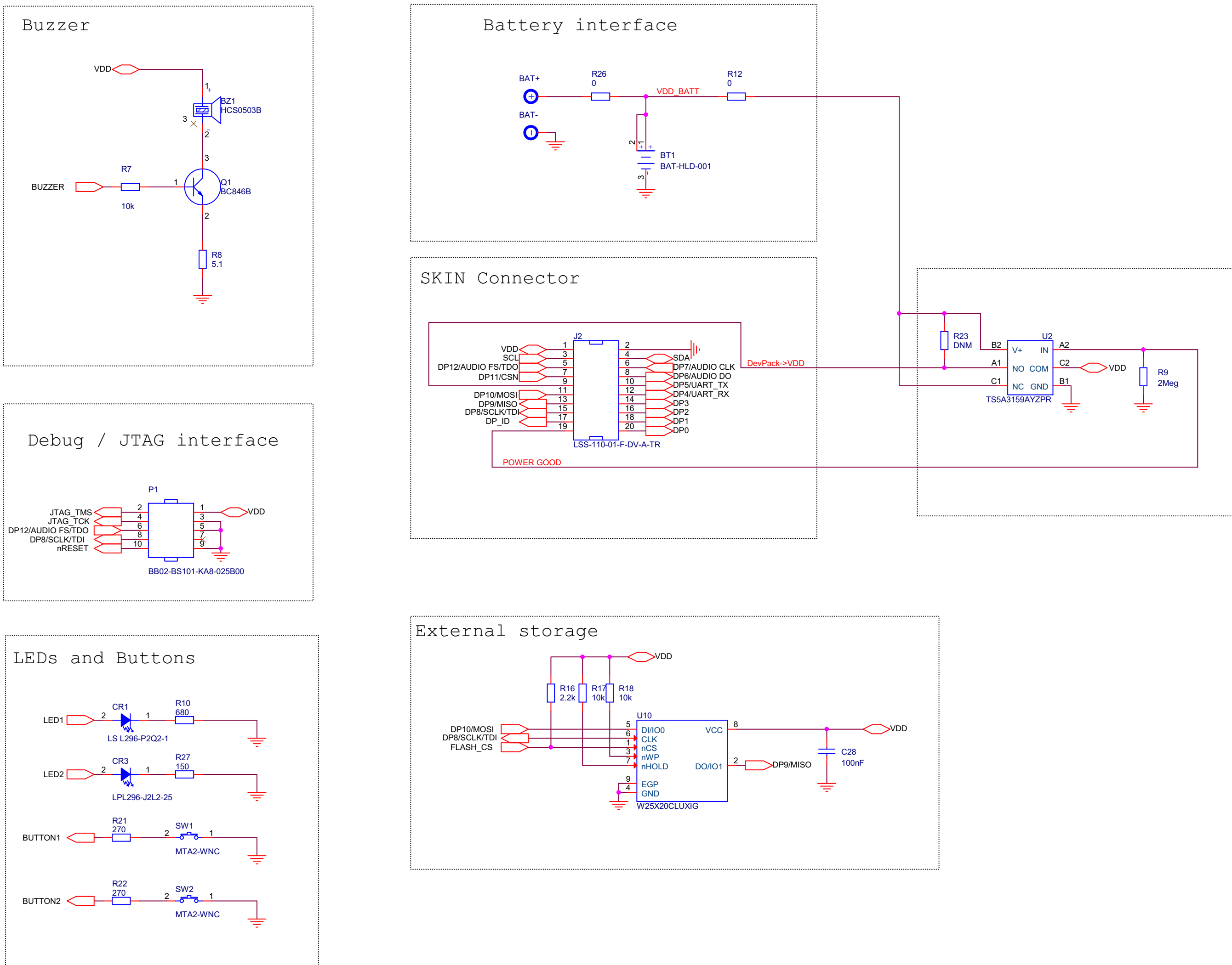


Figure 17. CC2650STK Schematics

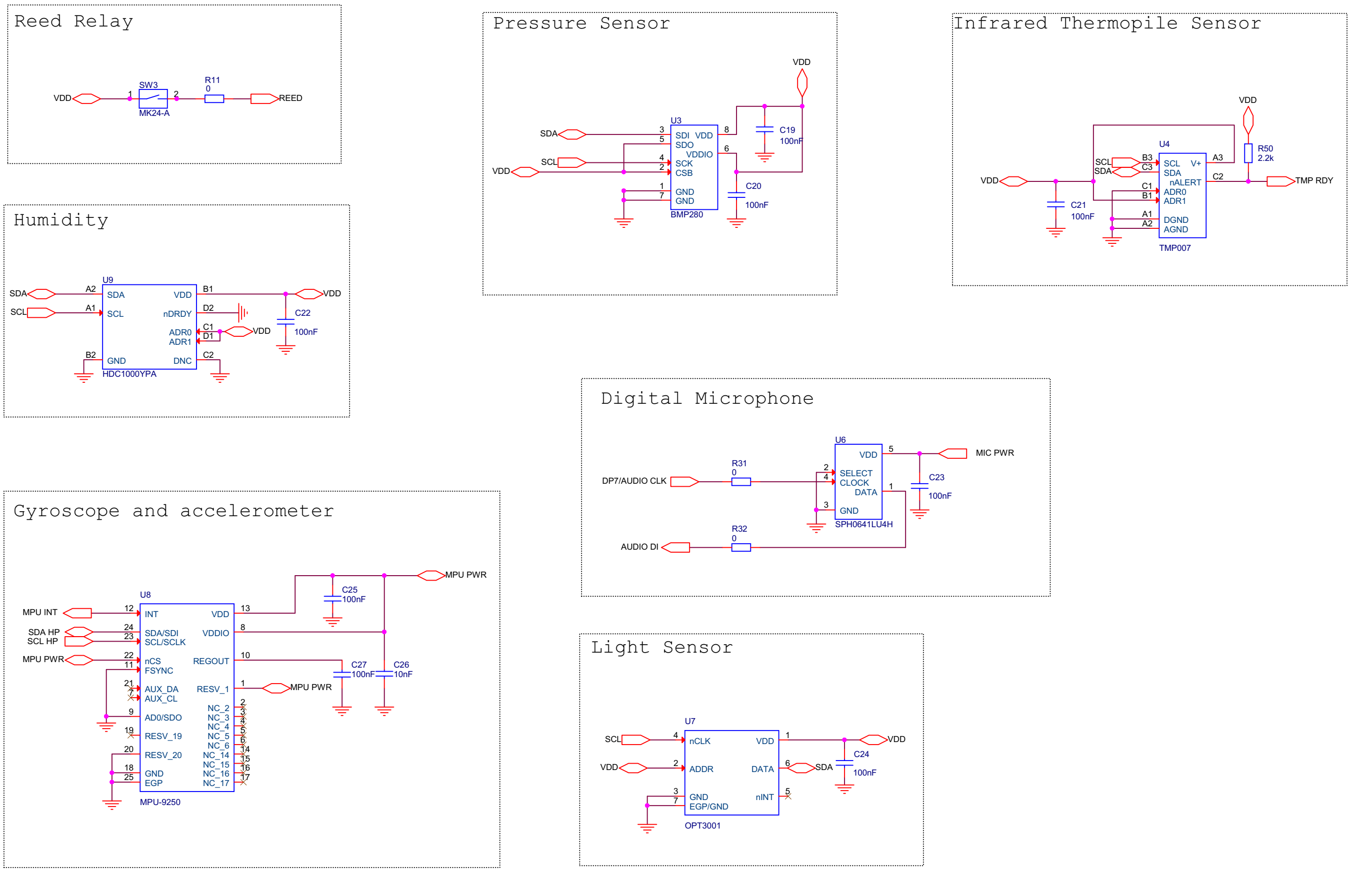


Figure 18. CC2650STK Schematics

7.2 Bill of Materials

To download the bill of materials (BOM), see the design files at SWRR135.

Table 1. BOM

ITEM NUMBER	PART REFERENCE	QUANTITY	VALUE	DESCRIPTION	MPN	MANUFACTURER
1	A1	1	DNM	Mechanic, 2.4-GHz inverted F antenna, SMD	DN007	TI
2	ANT1, ANT4	2	2 nH	Inductor, Chip, 2 nH, –0.3 nH / +0.3 nH, 0.3 A, –55°C / 125°C, 0402, SMD	LQG15HS2N0S02D	Murata
3	ANT2, C17, C18, C31	4	DNM	Capacitor, Ceramic, N/A value, –55°C / 125°C, 0402, SMD	CAPACITOR_0402_DNM_N/A_M	Manufacturer Selection
4	ANT3, C11, C13	3	1 pF	Capacitor, Ceramic C0G / NP0, 1 pF, 50 V, –0.25 pF / 0.25 pF, –55°C / 125 °C, 0402, SMD	GRM1555C1H1R0CA01D	Murata
5	ANT5, R12, R26	3	0	Resistor, Thick Film, 0, – 5% / 5%, 0.063 W, 50 V, –55°C / 155°C, 0402, SMD	RESISTOR_0402_0_ ±5%_50V_0.063W_M_±200PPM	Manufacturer Selection
6	ANT6	1	0.5 pF	Capacitor, Ceramic C0G / NP0, 0.5 pF, 50 V, –0.1 pF / 0.1 pF, –55°C / 125°C, 0402, SMD	GRM1555C1HR50BA01D	Murata
7	BAT+	1	DNM	Noncomponent, Battery + Pad, SMD		
8	BAT–	1	DNM	Noncomponent, Battery – Pad, SMD		
9	BT1	1	BAT-HLD-001	Battery, Holder for CR2032 and CR2025 batteries, SMD	BAT-HLD-001	Linx
10	BZ1	1	HCS0503B	Acoustic, Buzzer, 3 V, –40°C / 85°C, SMD	HCS0503B	Changzhou Tianyin
11	C1	1	DNM	Capacitor, Ceramic X5R, 2.2 µF, 10 V, –20% / 20%, –55°C / 85°C, 0603, SMD	GRM188R61A225ME34D	Murata
12	C2, C3, C4, C6, C8, C9, C12	7	100 nF	Capacitor, Ceramic X7R, 100 nF, 6.3 V, –10% / 10%, –55°C / 125°C, 0402, SMD	GRM155R70J104KA01D	Murata
13	C5	1	22 µF	Capacitor, Ceramic X5R, 22 µF, 4 V, –20% / 20%, –55°C / 85°C, 0603, SMD	GRM188R60G226MEA0D	Murata
14	C7	1	10 µF	Capacitor, Ceramic X5R, 10 µF, 6.3 V, –20% / 20%, –55°C / 85°C, 0603, SMD	GRM188R60J106ME47D	Murata
15	C14, C15	2	12 pF	Capacitor, Ceramic C0G / NP0, 12 pF, 50 V, –5% / +5%, –55 DEGC / +125 DEGC, 0402, SMD	GRM1555C1H120JA01D	Murata
16	C16	1	1 µF	Capacitor, Ceramic X5R, 1 µF, 10 V, –10% / 10%, –55°C / 85°C, 0402, SMD	GRM155R61A105KE15D	Murata
17	C19, C20, C21, C22, C23, C24, C25, C27, C28	9	100 nF	Capacitor, Ceramic X5R, 100 nF, 10 V, –10% / 10%, –55°C / 85°C, 0201, SMD	CAPACITOR_0201_100nF_ X5R_I_±10%_10V	Manufacturer Selection

Table 1. BOM (continued)

ITEM NUMBER	PART REFERENCE	QUANTITY	VALUE	DESCRIPTION	MPN	MANUFACTURER
18	C26	1	10 nF	Capacitor, Ceramic X5R, 10 nF, 10 V, –10% / 10%, –55°C / 125°C, 0201, SMD	GRM033R71A103KA01D	Murata
19	C29	1	DNM			
20	C32, C33	2	15 pF	Capacitor, Ceramic, 15 pF, 50 V, –5% / 5%, –55°C / 125°C, 0201, SMD	GRM0332C1H150JA01D	Murata
21	CR1	1	LS L296-P2Q2-1	Opto, LED, Super Red Color, 630 nm, 1.8 V TO 2.3 V, 0.06 A, 0603, SMD	LS L296-P2Q2-1-Z	Osram
22	CR3	1	LPL296-J2L2-25	Opto, LED, Green Color, 562 nm, 0.02 A, 0.08 W, 0603, SMD	LP L296-J2L2-25	Osram
23	FIDU1, FIDU2, FIDU3, FIDU4, FIDU5, FIDU6	6	DNM	Fiducial Mark, Round 1.27 mm		
24	FL1	1	BLM18HE152SN1	Filter, EMI, 1500 @ 100 MHz, –55°C / 125°C, 0603, SMD	BLM18HE152SN1D	Murata
25	J1	1	MS-156HF	Connector Coax RF, Straight, Female, SMD	MS-156HF	Hirose
26	J2	1	LSS-110-01-F-DV-A-TR	Connector, Header, Hi-speed Socket, Female, Straight, 2 Rows, 20 Pins, Pitch 0.635 mm, SMD	LSS-110-01-F-DV-A-TR	Samtec
27	L1	1	10 µH	Inductor, Chip, 10 µH, –20% / 20%, 0.11 A, –40°C / 85°C, 0805, SMD	CKS2125100M-T	Taiyo Yuden
28	L2, L3	2	2.4 nH	Inductor, Chip, 2.4 nH, –0.3 nH / 0.3 nH, 0.3 A, –55°C / 125°C, 0402, SMD	LQG15HS2N4S02D	Murata
29	P1	1	BB02-BS101-KA8-025B00	Connector, Header, Male, 2 Rows, 10 Pins, Pitch 1.27 mm, SMD	BB02-BS101-KA8-025B00	Gradconn
30	Q1	1	BC846B	Transistor, Bipolar NPN, 65 V, 0.1 A, 0.25 W, SOT –23, SMD	BC846B,215	NXP
31	R1	1	100 k	Resistor, Thick Film, 100 k, –5% / 5%, 0.063 W, 50 V, -55°C / 155°C, 0402, SMD	RESISTOR_0402_100k_ +/-5%_50V_0.063W_M_±200PPM	Manufacturer Selection
32	R2, R3, R4, R5, R7, R17, R18	7	10 k	Resistor, Thick Film, 10 K, –5% / 5%, 0.05 W, 30 V, –55°C / 125°C, 0201, SMD	RESISTOR_0201_10k_ ±5%_30V_0.05W_M_±200ppm	Manufacturer Selection
33	R6	1	200 k	Resistor, Thick Film, 200 K, –1% / 1%, 0.05 W, 30 V, –55°C / 125°C, 0201, SMD	CRCW0201200KFKED	Vishay Dale
34	R8	1	5.1	Resistor, Thick Film, 5R1, –5% / 5%, 0.05 W, 25 V, –55°C / 125°C, 0201, SMD	RMC1/205R1JPA	Kamaya
35	R9	1	2 MΩ	Resistor, Thick Film, 2M, –1% / 1%, 0.063 W, 50 V, –55°C / 155°C, 0402, SMD	RC0402FR-072ML	Yageo
36	R10	1	680	Resistor, Thick Film, 680, –5% / 5%, 0.063 W, 50 V, –55°C / 155°C, 0402, SMD	RESISTOR_0402_680_±5%_50V_ 0.063W_M_±200PPM	Manufacturer Selection
37	R11, R31, R32	3	0	Resistor, Thick Film, 0, –1% / 1%, 0.05 W, 30 V, –55°C / 155°C, 0201, SMD	RESISTOR_0201_0_±1%_30V_ 0.05W_M_±100PPM	Manufacturer Selection

Table 1. BOM (continued)

ITEM NUMBER	PART REFERENCE	QUANTITY	VALUE	DESCRIPTION	MPN	MANUFACTURER
38	R16, R50	2	2.2 k	Resistor, Thick Film, 2K2, –5% / 5%, 0.05 W, 30 V, –55°C / 125°C, 0201, SMD	CRCW02012K20JNED	Vishay
39	R21, R22	2	270	Resistor, Thin Film, 270, –5% / +5%, 0.0625 W, 50 V, –55 DEGC / +125 DEGCC, 0402, SMD	RESISTOR_0402_270_±1%_50V_ 0.063W_M_ ±200PPM	Manufacturer Selection
40	R23	1	DNM	Resistor, Do Not Mount, 0402, SMD	DNM	Do Not Mount
41	R27	1	150	Resistor, Thick Film, 150, –5% / +5%, 0.063 W, 50 V, –55 DEGC / +155 DEGC, 0402, SMD	RESISTOR_0402_150_±5%_50V_ 0.063W_M_±200PPM	Manufacturer Selection
42	SW1, SW2	2	MTA2-WNC	Switch, Tact Switch, Right Angle, 0.05 A @ 12 VDC, SMD	MTA2-WNC-V-T/R	Diptronics
43	SW3	1	MK24-A	Switch, Other, Reed Sensor, SPST-NO, Pull-in: 23 AT to 50 AT, 0.3 A @ 60 V, 0.3 A, 60 V, SMD	MK24-A-3	Meder
44	U1	1	CC26xx-7x7	IC, Digital, TI Custom 26xx, QFN48, SMD	CC26xx_7x7_QFN48	TI
45	U2	1	TS5A3159AYZPR	IC, Analog, SPDT Switch Single-channel 2:1 Multiplexer / Demultiplexer, 4.5 V to 5.5 V, DSBGA6, SMD	TS5A3159AYZPR	TI
46	U3	1	BMP280	IC, Transducer Pressure, 300 hPa to 110 hPa, 1.71 V to 3.6 V, LGA8, SMD	BMP280	Bosch
47	U4	1	TMP007	IC, Transducer, Infrared Thermopile Sensor, 2.5 V to 5.5 V, DSBGA8, SMD	TMP007AIYZFR	TI
48	U6	1	SPH0641LU4H	IC, Digital, Microphone with Multiple Performance Mode, 1.62 V to 3.6 V, SMD	SPH0641LU4H	Knowles
49	U7	1	OPT3001	IC, Analog, OPT3001, SON6, SMD	OPT3001	TI
50	U8	1	MPU-9250	IC, Transducer, 3-AXIS Accelerometer, 3-AXIS Gyroscope, 2.4 V to 3.6 V, QFN24, SMD	MPU-9250	Invensense
51	U9	1	HDC1000YPA	IC, Transducer, Low-power, High-accuracy Digital Humidity Sensor with Integrated Temperature Sensor, 2.7 V TO 5.5 V, DSBGA8, SMD	HDC1000YPAR	TI
52	U10	1	W25X40CLUXIG	IC, Memory, 4 M-bit of Serial Flash Memory, 2.3 V to 3.6 V, USON8, SMD	W25X40CLUXIG	Winbond
53	U11	1	DNM			
54	Y1	1	32.768 kHz	Crystal, Resonator, 32.768 kHz, –20 PPM / 20 PPM, –40°C / 85°C, SMD	FC-135 32.7680KA-AG0	Epson

Table 1. BOM (continued)

ITEM NUMBER	PART REFERENCE	QUANTITY	VALUE	DESCRIPTION	MPN	MANUFACTURER
55	Y2	1	24 MHz	Crystal, Crystal Oscillator, 24 MHz, –15 PPM / °C / 15 PPM / °C, –40°C / 85°C, SMD	TSX-3225 24.0000MF15X-AC3	Epson

7.3 PCB Layout Recommendations

7.3.1 Layout Considerations for CC2650 – Wireless MCU

Ensure the following layout considerations:

- Ensure that the layout of the RF components follows the reference designs.
- Ensure that RF components connected to the ground have multiple ground vias close to their ground pads to minimize ground impedance.
- Ensure that an uninterrupted and solid ground plane exists under all the RF components (from the antenna and to the ground vias in the exposed ground pad).
- Place the balun and/or RF filter as close to the CC2650 device as possible to ensure no traces are under the RF path.
- Place the antenna matching components as close to the antenna as possible.
- Place the decoupling capacitors as close to their VDD pins as possible.
- Ensure that the ground return path from the decoupling capacitors to the EGP is as short and direct as possible.
- Place the DCDC components (L1 and C7) close to the DCDC_SW pin.
- Ensure that the ground connection of the DCDC-capacitor is as short and direct as possible to avoid ground-switching noise.
- Position the humidity and IR temperature sensors away from hot points on the board like the battery, display, or microcontroller because they are dependent on temperature.
- Use the slots around the device to reduce the thermal mass for a quicker response to environmental changes.

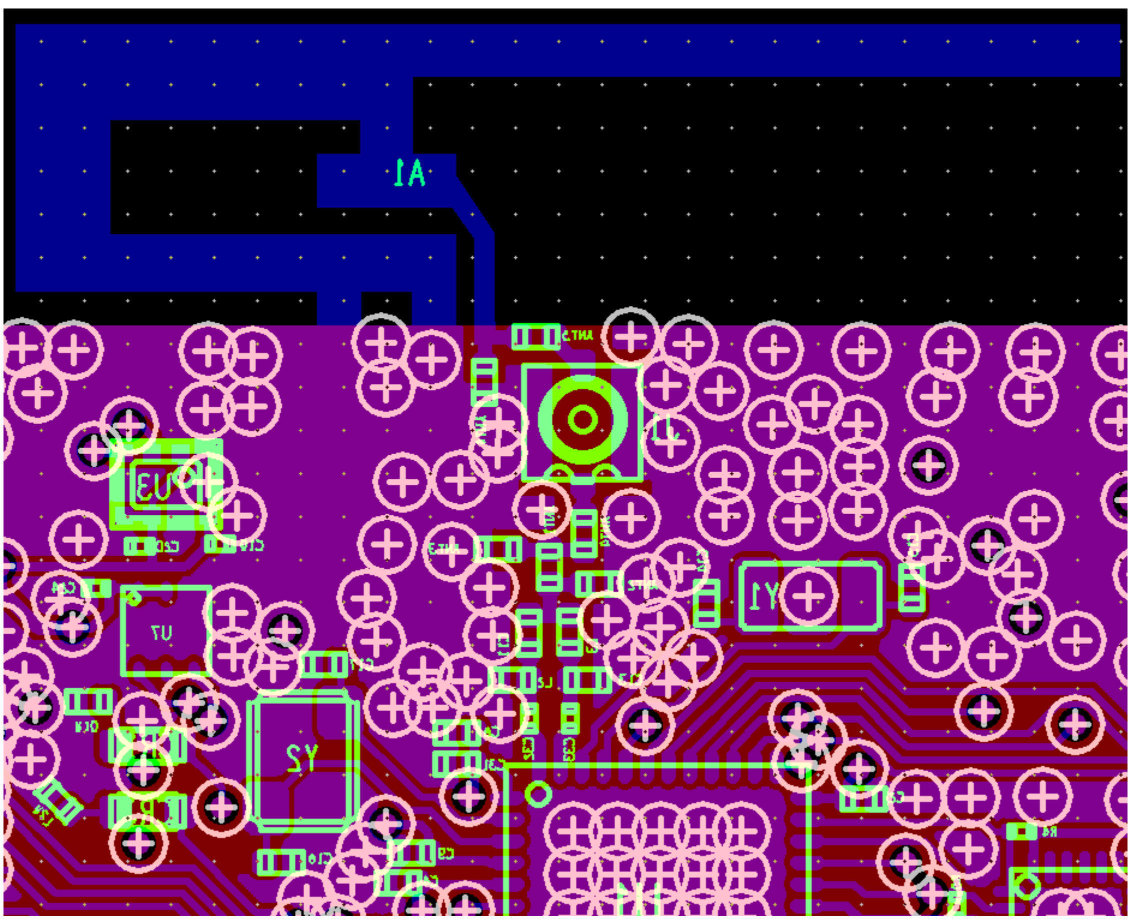


Figure 19. RF Layout Considerations

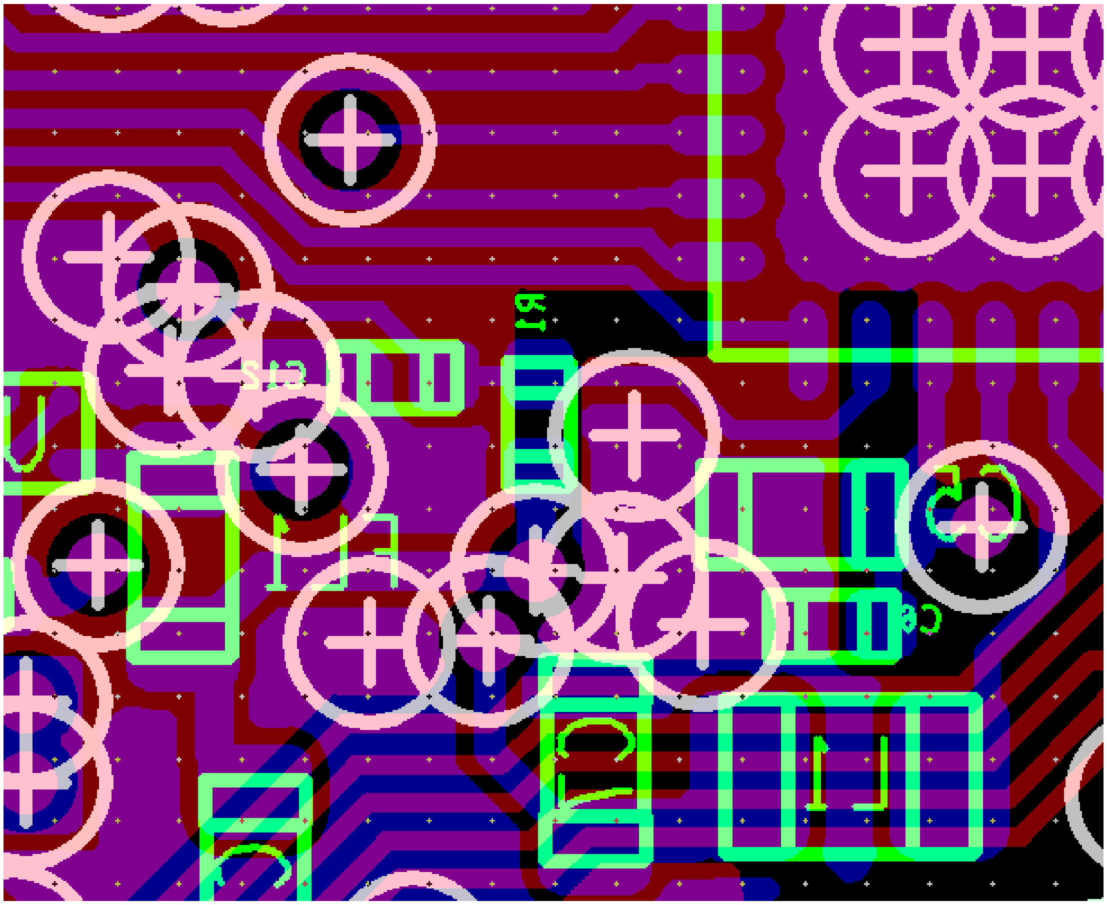


Figure 20. DCDC Layout Considerations

7.3.2 Layout Considerations for Humidity Sensor – HDC1000

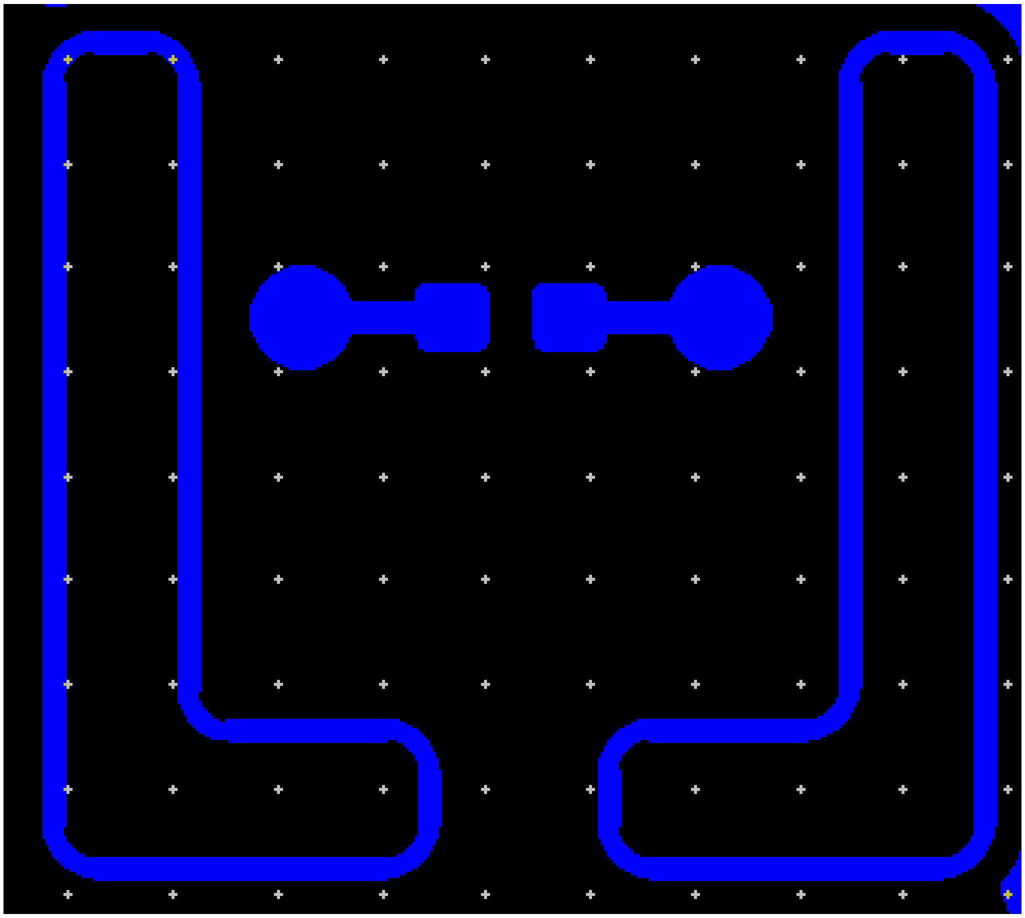


Figure 21. HDC1000

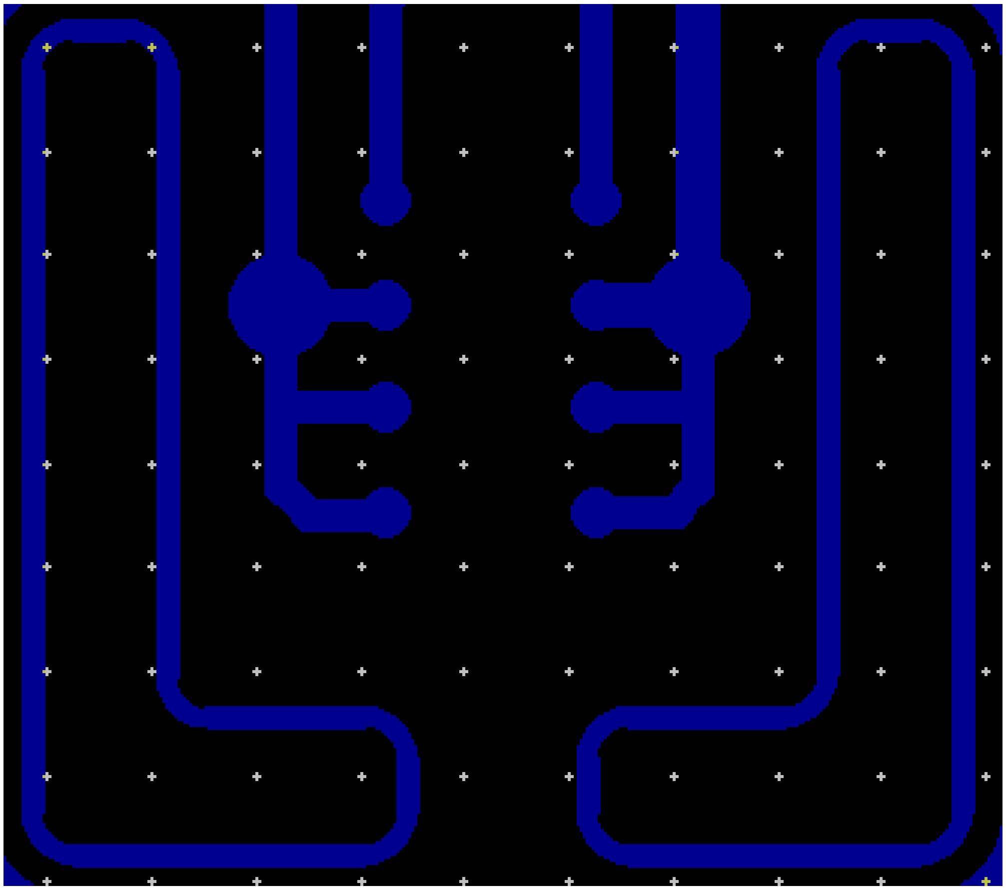


Figure 22. HDC1000

7.3.3 Layout Considerations for the IR Temperature Sensor – TMP007

For layout assembly considerations for the TMP007, see SBOU143.

7.3.4 Layout Prints

To download the layout prints for each board, see the design files at SWRC304

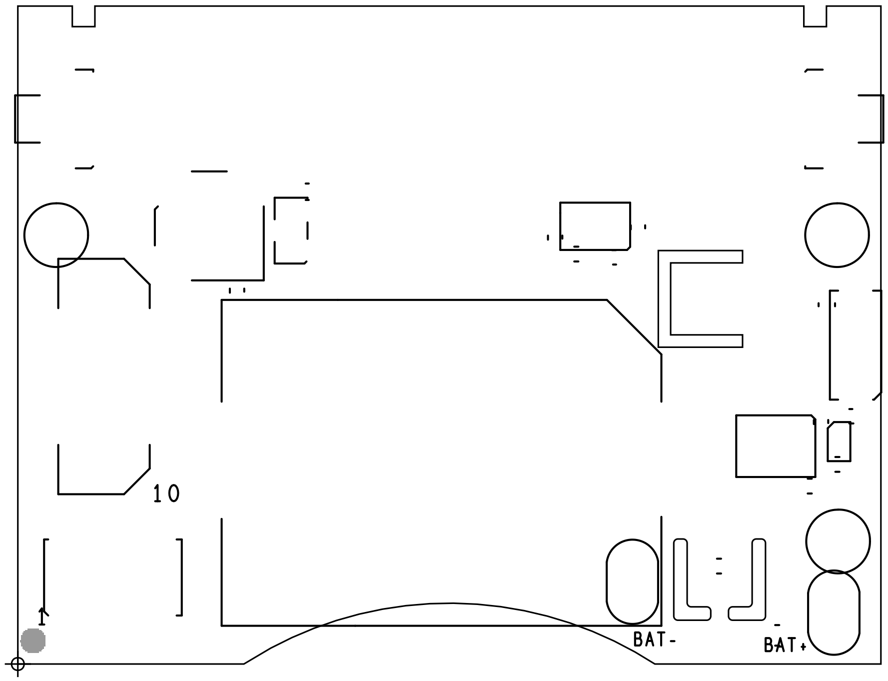


Figure 23. Top Silkscreen

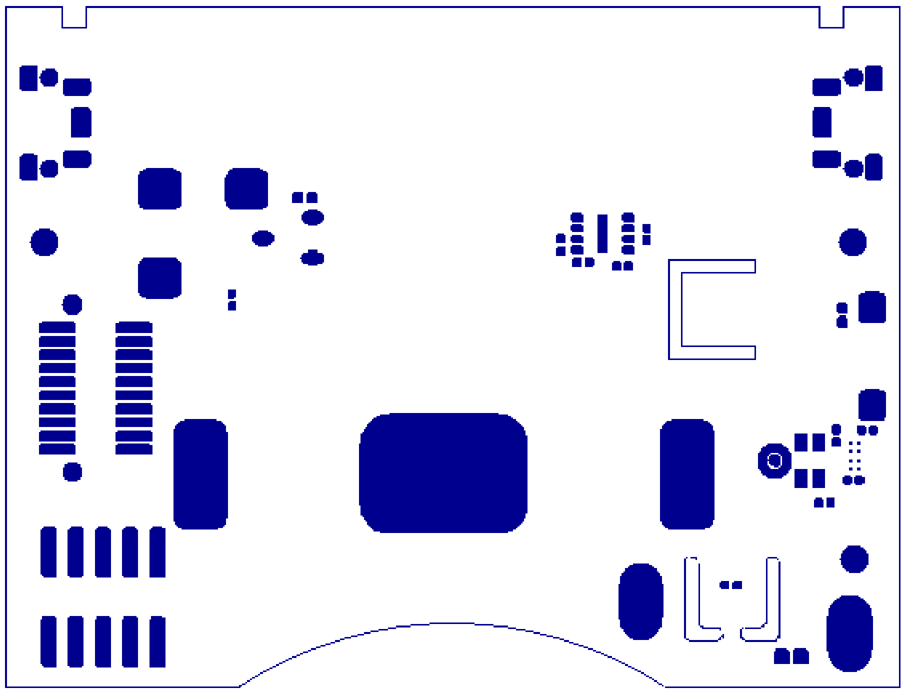


Figure 24. Top Solder Mask

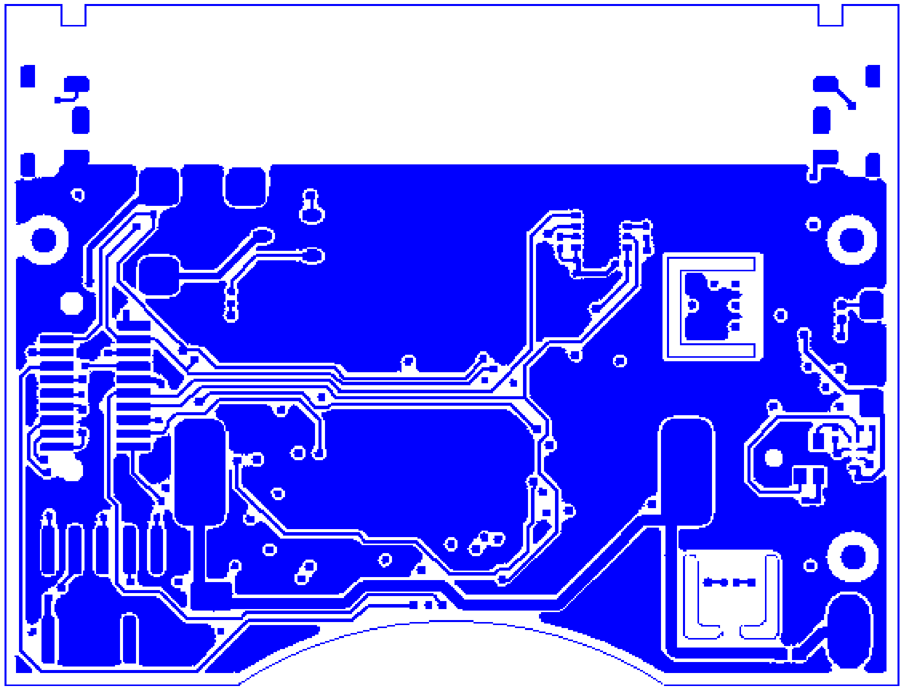


Figure 25. Top Layer

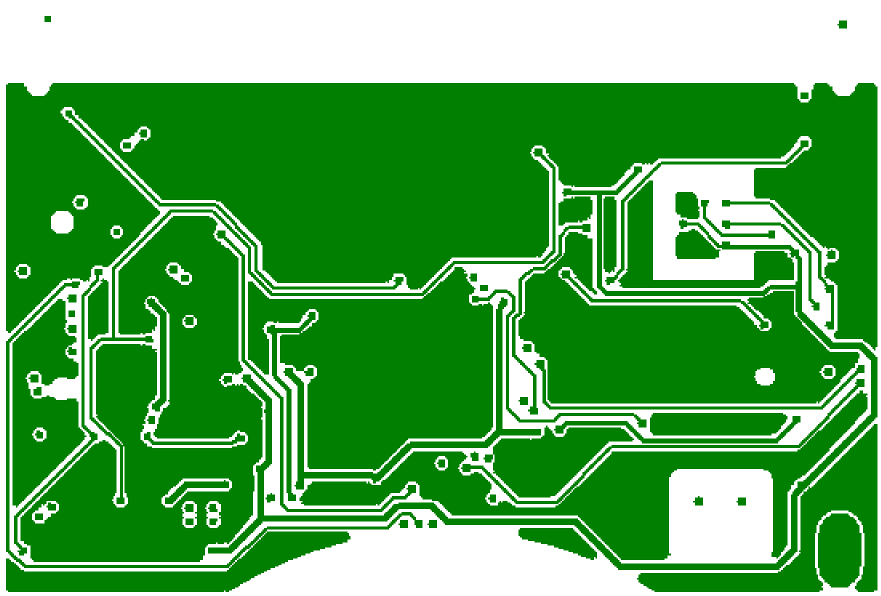


Figure 26. Layer 2

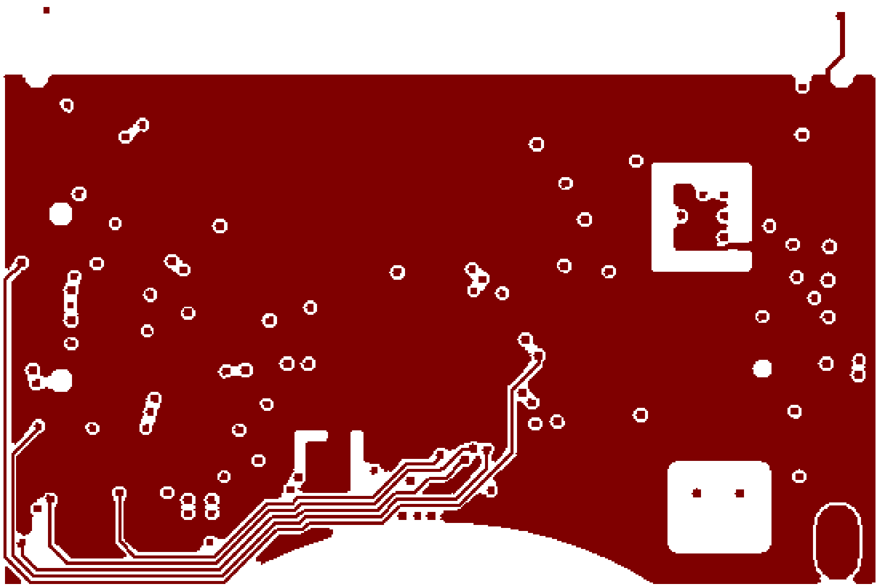


Figure 27. Layer 3

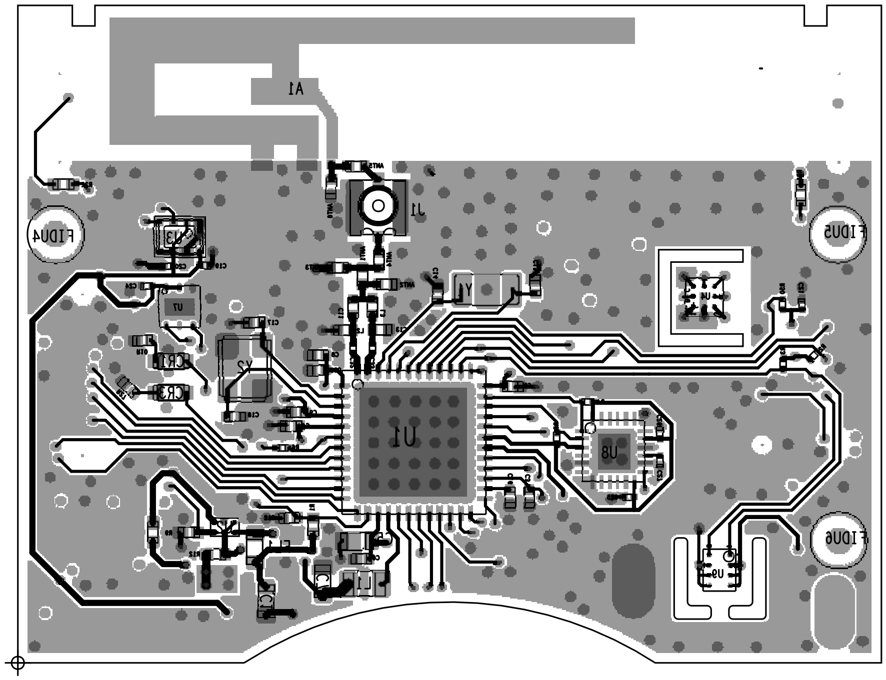


Figure 28. Bottom Layer

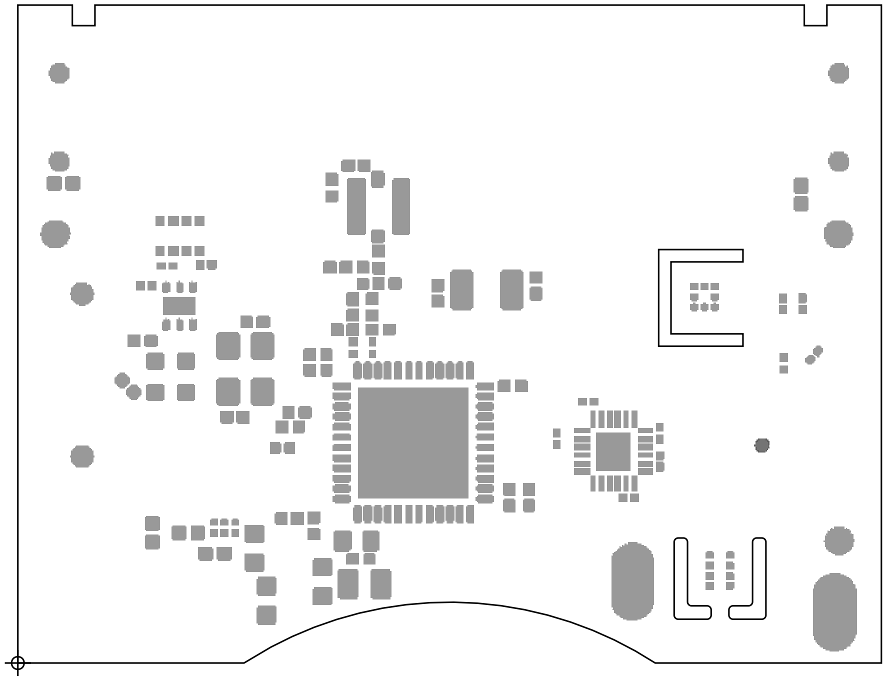


Figure 29. Bottom Solder Mask

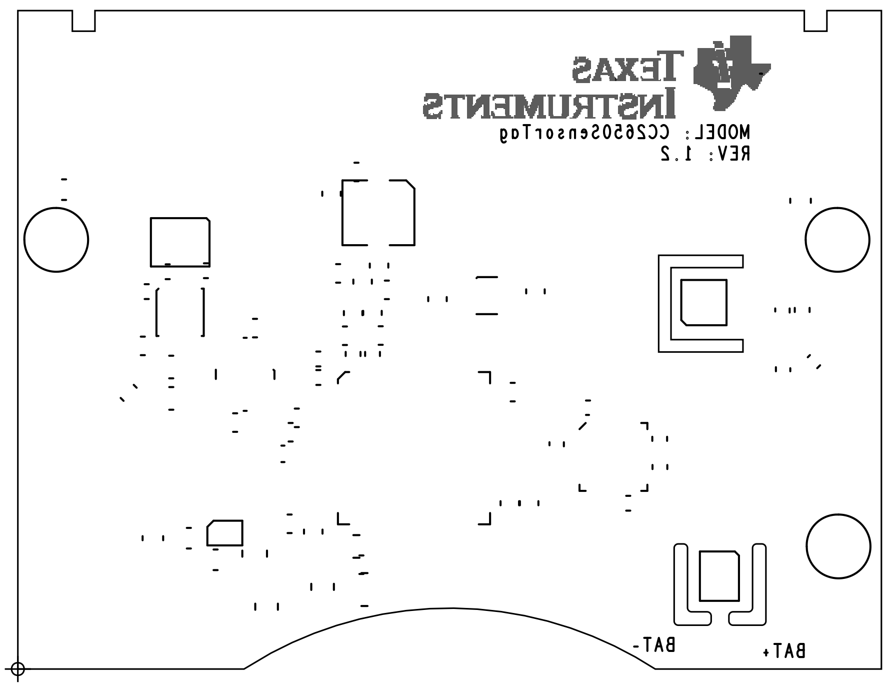


Figure 30. Bottom Silkscreen

Figure 31. Mechanical Dimensions and Drill Holes

7.4 Cadence Allegro Project

Download the Allegro project files for the SensorTag at SWRC304.

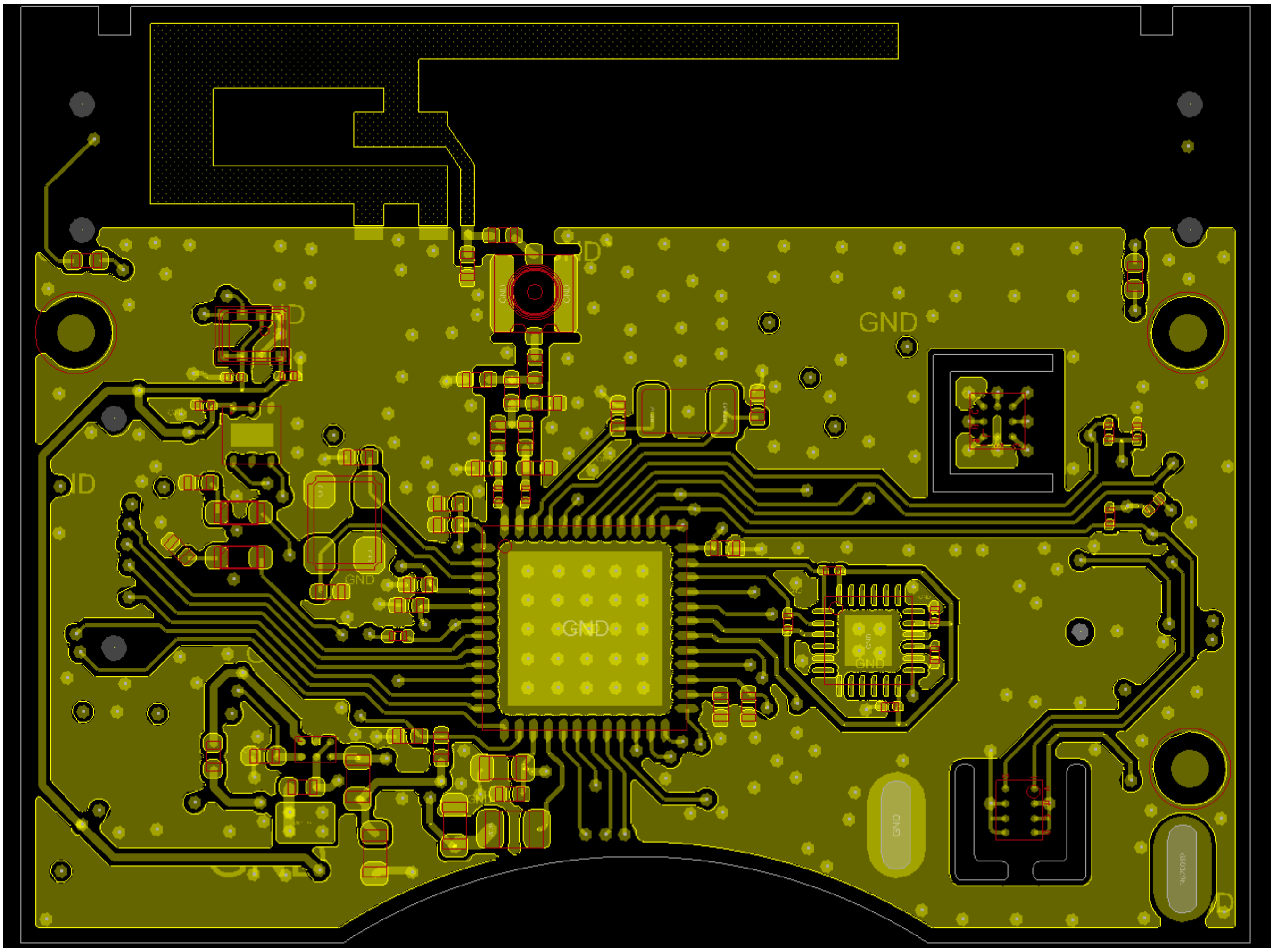


Figure 32. SensorTag Allegro project

7.5 Layout Guidelines

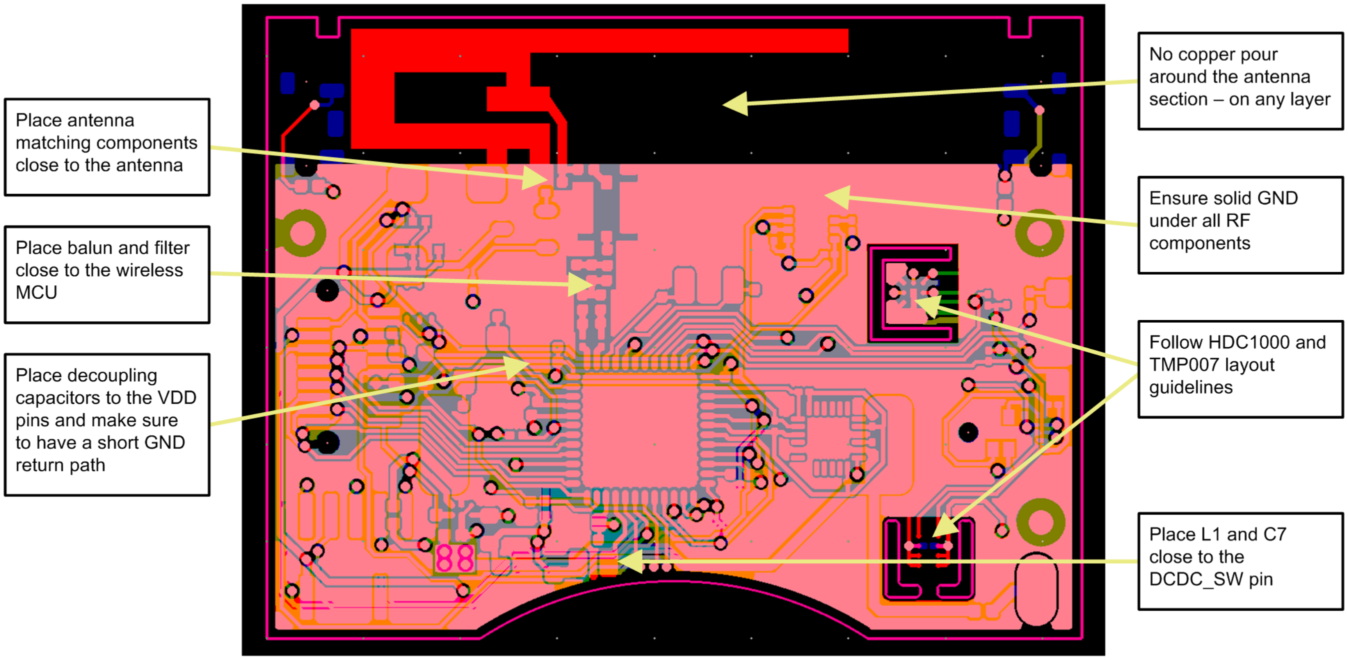
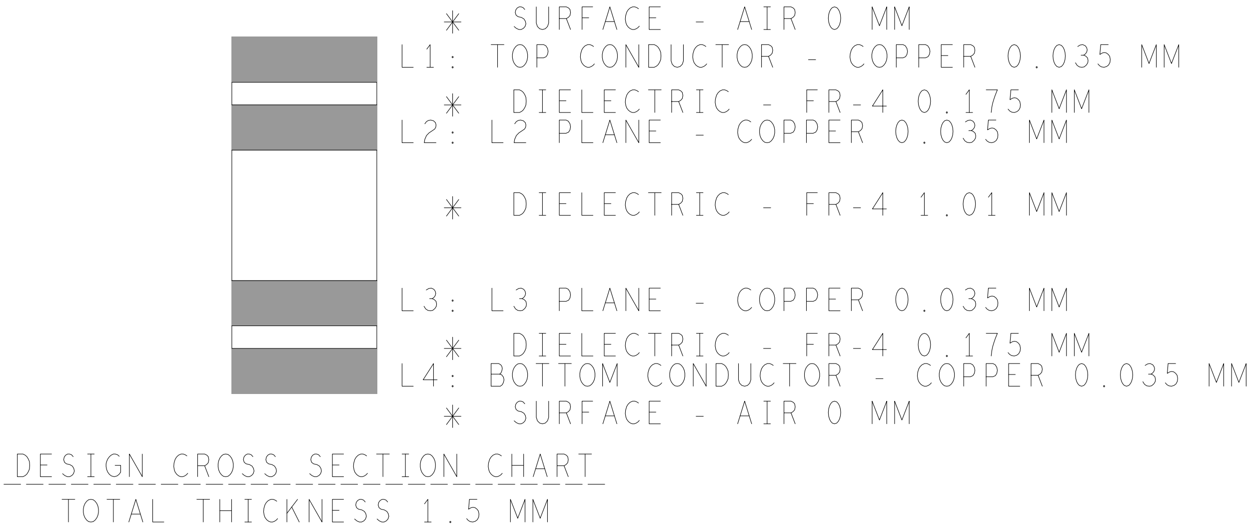
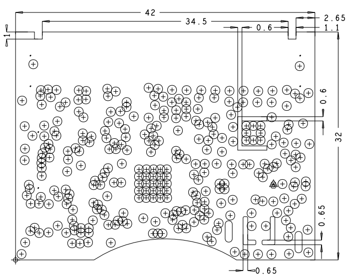


Figure 33. CC2650 SensorTag Layout Guidelines

7.6 Gerber Files

To download the Gerber files, see the design files at SWRC304.





DRILL CHART: TOP to BOTTOM			
ALL UNITS ARE IN MILLIMETERS			
FIGURE	SIZE	PLATED	QTY
⊙	0.2	PLATED	307
·	0.6	NON-PLATED	1
▲	0.6	NON-PLATED	1
·	0.9	NON-PLATED	2
·	0.9	NON-PLATED	4
0	3.0x1.0	PLATED	2

Figure 34. CC2650STK Mechanical Drawing

7.7 Assembly Drawings

To download the assembly drawings for each board, see the design files at SWRC304.

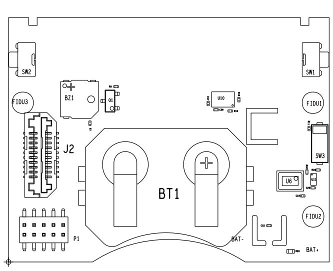


Figure 35. Assembly Drawing (Top)

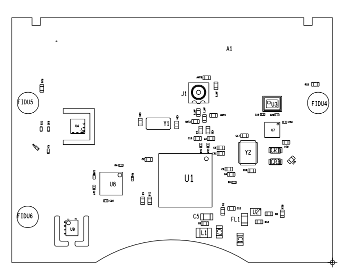


Figure 36. Assembly Drawing 2 (Bottom Side Mirrored)

7.8 Software Files

For information regarding software, see Section 4.2.

8 References

1. TI Technical Reference Manual, *CC26xx SimpleLink™ Wireless MCU*, SWCU117
2. TI Application Note, *SimpleLink™ Bluetooth Low Energy CC2640 Software Developer's Guide*, SWRU393
3. TI Application Note, *OPT3001: Ambient Light Sensor Application Guide*, SBEA002
4. TI Application Note, *TMP007 Layout and Assembly User Guide*, SBOU143
5. TI Application Note, *Humidity Sensor*, SNAA216

9 About the Author

ESPEN SLETTE is a systems application engineer at TI, where he develops reference design solutions for wireless connectivity (that is, Wi-Fi, *Bluetooth* Smart, RF4CE, ZigBee / 6LoWPAN, and sub-1GHz). Espen Slette has experience in application support for wireless products and RF design. Espen Slette earned his Master of Science in Electrical Engineering (MSEE) from NTNU in Trondheim, Norway.

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