



iCE40 Ultra Wearable Development Platform User Guide

EB100 Version 1.0, July 2015

Introduction

The iCE40 Ultra Wearable Development Platform is an easy-to-use platform which demonstrates how the iCE40 Ultra and MachXO2 FPGAs can be utilized in wearable and mobile applications. Along with the evaluation board and accessories, there are reference designs available to demonstrate the functionality of the boards and components.

The iCE40 Ultra Wearable Development Platform consists of two boards: the Main Board and the Sensor Board. The Main Board contains the iCE40 Ultra and MachXO2 FPGAs, which drive various components on the board. The iCE40 Ultra focuses on interfacing with peripheral components such as LEDs, sensors and BLE connectivity. The MachXO2 focuses on driving the MIPI DSI Display from a Quad SPI flash functioning as a frame buffer and storage device. The Sensor Board contains several sensors that are typically found in mobile and wearable devices. By separating the two boards, the interconnect headers can be used to directly interface with peripherals for testing (see the [Headers](#) section).

The contents of this user guide include a description of the board features, header connection descriptions and pinouts, instructions on loading demonstration bitstreams, a complete set of schematics, and the bill of materials.

Features

The iCE40 Ultra Wearable Development Platform includes:

- iCE40 Ultra Wearable Development Platform Main Board:
 - iCE40 Ultra (iCE5LP-4K-SWG36) device in a 36-ball WLCSP package
 - MachXO2 (LCMXO2-2000ZE-1UWG49) device in a 49-ball WLCSP package
 - High-current IR, White, and RGB LEDs
 - Stereo Microphones
 - Connector and driver circuitry for MIPI DSI Display
 - Headers for I2C, SPI, and UART
 - Mini-USB programming connection
 - Battery charger
 - RoHS-compliant packaging and process
- iCE40 Ultra Wearable Development Platform Sensor Board:
 - Bluetooth Low-Energy Module
 - Heart-rate/SpO2 Sensor and Analog Front End
 - Skin temperature sensor
 - Pressure sensor
 - Accelerometer/Gyroscope
 - Pads for soldering on battery (charger accepts Li-Ion and Li-Po)
- Syma 652030 Battery – 3.7 V, 250 mAh Lithium-Polymer Battery provides power while the USB cable is disconnected
- LG LH154Q01 Display – 240x240 Single Lane MIPI DSI Display. Must be attached prior to power-up
- USB Connector Cable – A mini-USB port provides power and a programming interface for the board
- Watch Strap – A watch strap comes pre-attached to the Sensor Board

Note: Static electricity can severely shorten the lifespan of electrical components. Use care while handling the iCE40 Ultra Wearable Development Platform to avoid ESD damage.

Figure 1 through Figure 4 show the top and bottom sides of the Main and Sensor boards, with key features highlighted.

Figure 1. Main Board (Top Side)

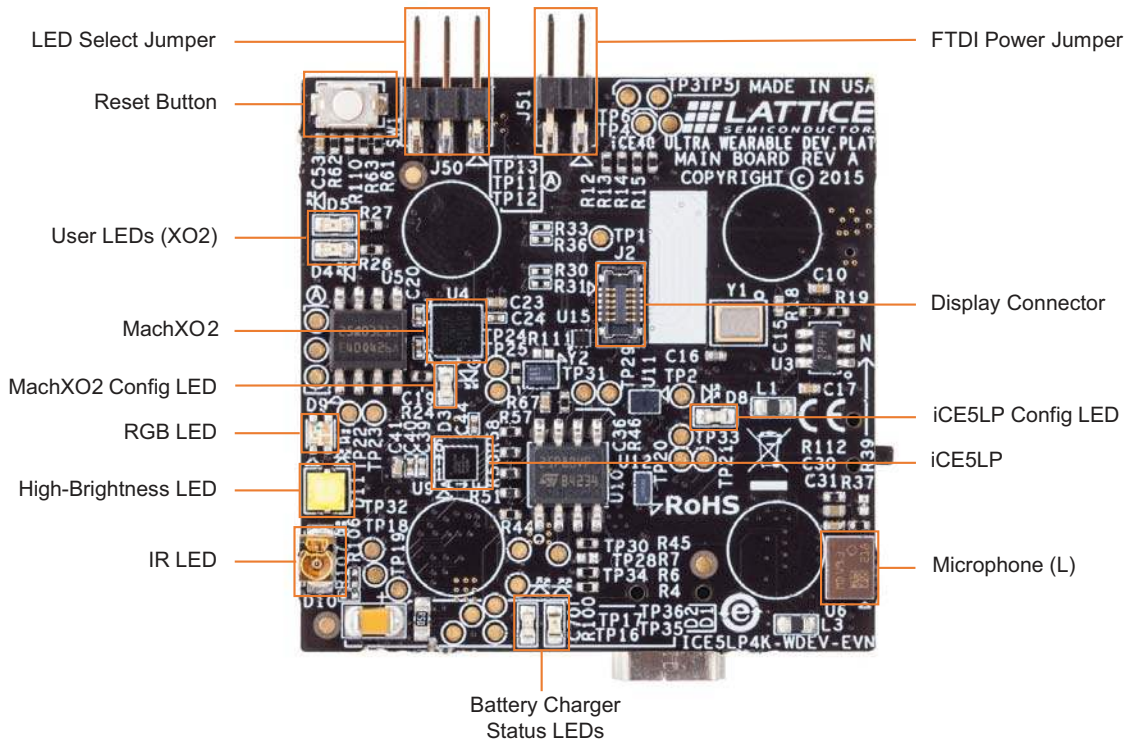


Figure 2. Main Board (Bottom Side)

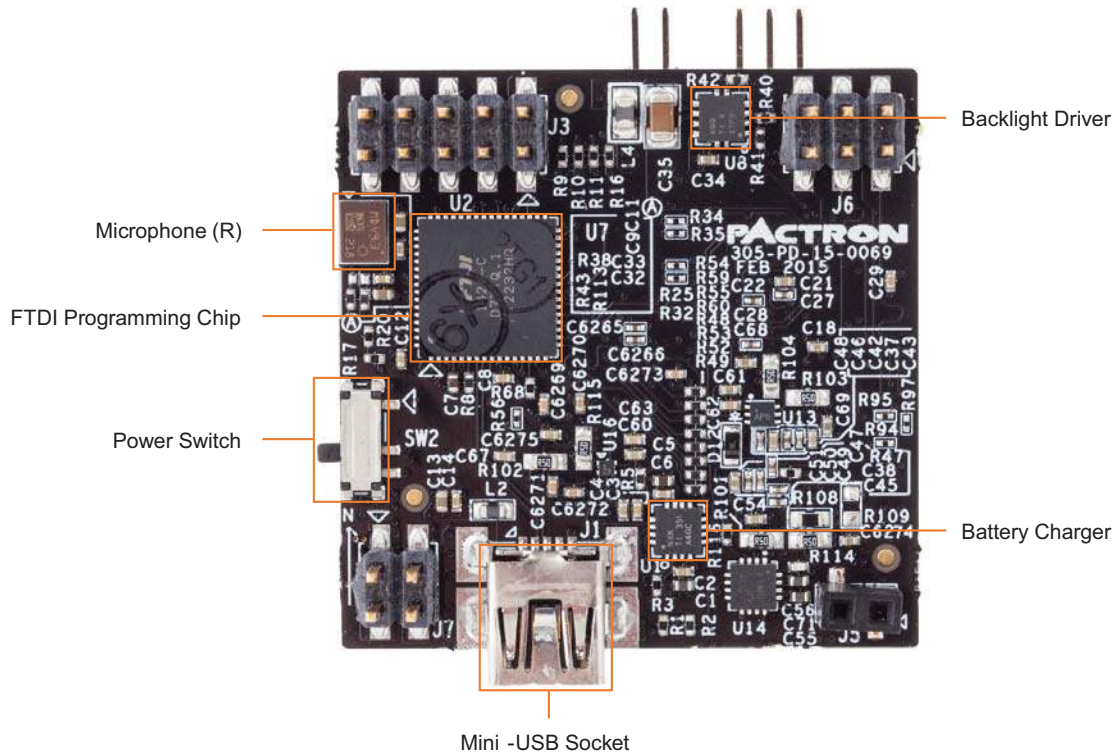


Figure 3. Sensor Board (Top Side)

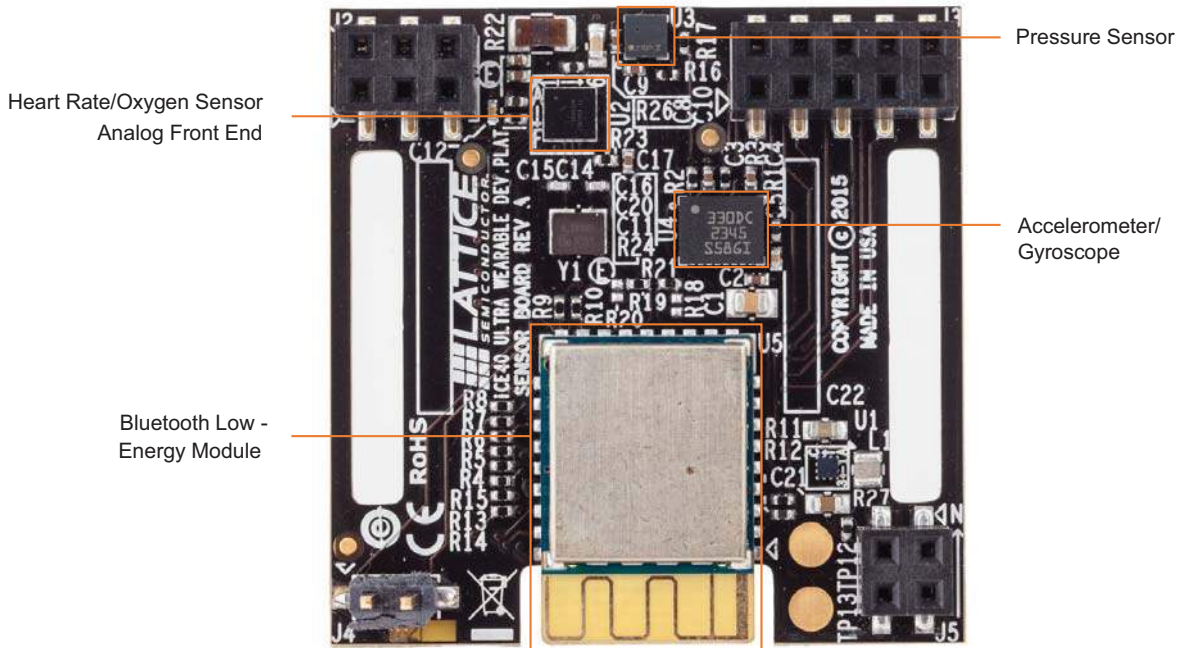
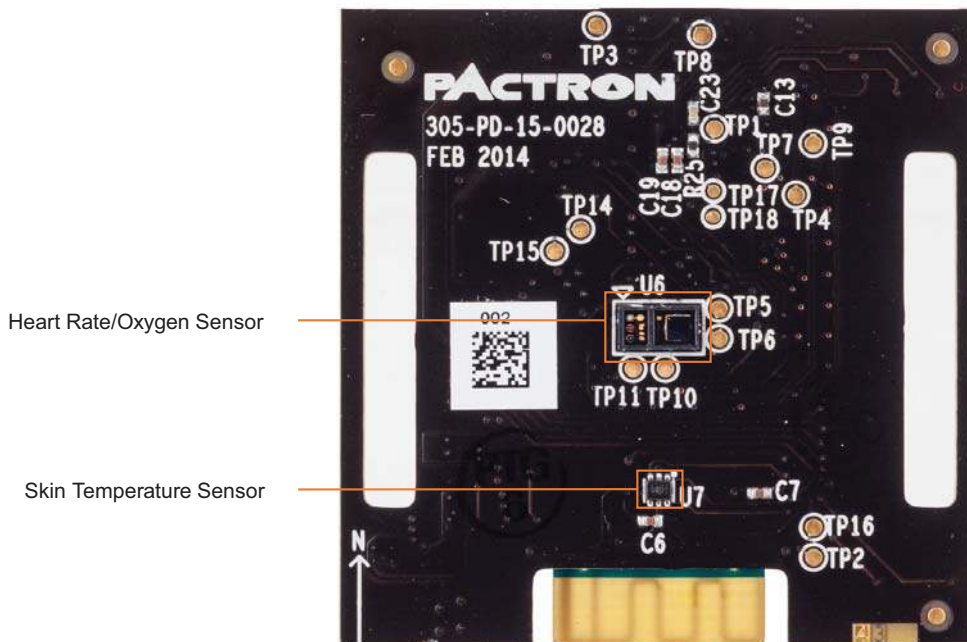


Figure 4. Sensor Board (Bottom Side)



Lattice Semiconductor Devices

The Main Board features an iCE5LP4K and a MachXO2-2000ZE FPGA.

The iCE5LP4K has a 1.2 V core supply and is packaged in a 36-ball WLCSP package. For a complete description of this device, see DS1048, [iCE40 Ultra Family Data Sheet](#).

The MachXO2-2000ZE has a 1.2 V core supply and is packaged in a 49-ball WLCSP package. For a complete description of this device, see DS1035, [MachXO2 Family Data Sheet](#).

Software Requirements

The following software must be installed before designs can be developed for this board:

- iCEcube2 2014-12 (or higher)
- Diamond® 3.4 (or higher)
- Diamond Programmer 3.4 (or higher)

This software is available at the Lattice website [Design Software & IP](#) page.

Board Power

The iCE40 Ultra Wearable Development Platform uses the USB connection as its primary source of power. It is also equipped with a battery and charger for use without a wired connection. A power switch (SW2) allows for the regulators to be disabled while allowing the battery to continue charging. Two status LEDs allow the battery charger to be monitored (see Table 12).

The battery charger and regulators are located on the Main Board. The battery attaches to the Sensor Board. Power is transferred between the two boards using the Power Connector header. See Table 2 for connections.

The VREG_ADJ I/O supply net for the iCE5LP is adjustable, but is an internal, reserved feature. Changing this net from 3.3 V (default) to 1.8 V will cause voltage-level mismatches that can permanently damage the iCE5LP.

To allow current measurements to be made for specific supplies, resistors with test points have been inserted into the circuit. Refer to Table 1 to see which test points correspond to which supplies.

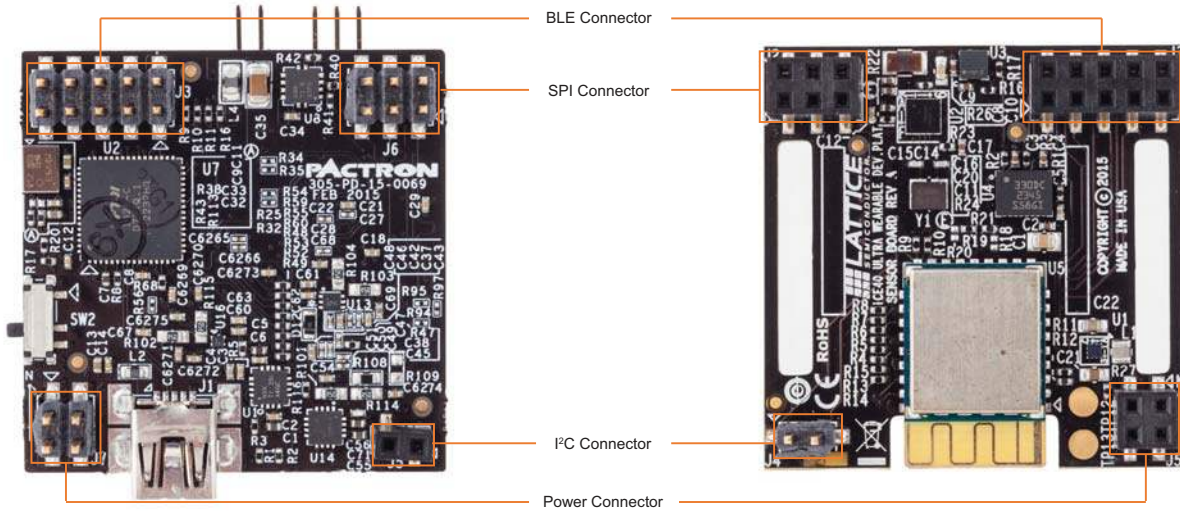
Table 1. Supply Current Test Points

| Supply | TP+ | TP- | Resistance |
|-----------------|------|------|------------|
| MachXO2 1.2 V | TP20 | TP21 | 0.5 Ohms |
| MachXO2 3.3 V | TP18 | TP19 | 0.5 Ohms |
| iCE5LP 1.2 V | TP20 | TP33 | 0.5 Ohms |
| iCE5LP 3.3 V | TP18 | TP32 | 0.5 Ohms |
| 3.3 V Regulator | TP16 | TP17 | 0.5 Ohms |
| Display 3 V | TP25 | TP24 | 0.5 Ohms |
| Display 1.8 V | TP22 | TP23 | 0.5 Ohms |

Headers

Four headers are used to connect the Main Board and the Sensor Board. The signals and connections are shown in the tables below:

Figure 5. Headers



Power Connector (Main Board J7, Sensor Board J5): Power connection between the two boards

Table 2. Power Connector

| Pin Number | Signal | Description |
|------------|----------|--|
| 1 | 3V3 | Regulated 3.3 V supply |
| 2 | BT_3V7 | Unregulated ~3.7 V battery voltage |
| 3 | VREG_ADJ | Adjustable I/O Voltage (3.3 V default) |
| 4 | GND | Ground |

I2C Connector (Main Board J5, Sensor Board): Interface for pressure sensor, temperature sensor, and accelerometer/gyroscope

Table 3. I2C Connector

| Pin Number | Signal | iCE5LP Ball # |
|------------|------------|---------------|
| 1 | Sensor SCL | C1 |
| 2 | Sensor SDA | E2 |

SPI Connector (Main Board J6, Sensor Board): Interface for the Analog Front-End of the Heart Beat/SpO2 sensor

Table 4. SPI Connector

| Pin Number | Signal | iCE5LP Ball # |
|------------|-----------|---------------|
| 1 | AFE SCLK | D6 |
| 2 | AFE MISO | F6 |
| 3 | AFE Ready | B5 |
| 4 | AFE SS | D5 |
| 5 | AFE MOSI | E6 |
| 6 | GND | — |

BLE Connector (Main Board J3, Sensor Board): Contains a UART connection to iCE5LP and a configuration SPI connection for the iCE5LP

Table 5. BLE Connector

| Pin Number | Signal | Ball # |
|------------|---------------|------------|
| 1 | BLE Prog | MachXO2 G2 |
| 2 | BLE SS | Config |
| 3 | BLE MISO | Config |
| 4 | BLE MOSI | Config |
| 5 | BLE SCLK | Config |
| 6 | CRSTb | — |
| 7 | CDONE | MachXO2 E3 |
| 8 | UART Rx (out) | iCE5LP F5 |
| 9 | UART Tx (in) | iCE5LP E5 |
| 10 | GND | — |

Jumpers

The following jumpers can be used for adjusting board functionality:

- High-current LED select (J50): Controls whether the IR LED (1+2) or High-current White LED (2+3) is driven by the iCE5LP device
- FTDI Power (J51): To minimize power consumption and increase battery life, the FTDI programming chip can have its power supply cut-off by removing the jumper from J51. J51 must be in place prior to powering up in order to program the devices on this board.

Test Points

Several test points have been included into the design to ease debug. Descriptions of these test points can be found below:

Table 6. Main Board Test Points

| Test Point | Signal/Function |
|------------|--|
| 1 | Configuration Signal: CResetn_FTDI |
| 2 | Configuration Signal: iCE_CDONE |
| 3 | Configuration Signal: FTDI_TCK (XO2) |
| 4 | Configuration Signal: FTDI_TDI (XO2) |
| 5 | Configuration Signal: FTDI_TDO (XO2) |
| 6 | Configuration Signal: FTDI_TMS (XO2) |
| 11 | Configuration Signal: JTAGEN (XO2) |
| 12 | Configuration Signal: PROGRAMN (XO2) |
| 13 | Configuration Signal: INITN (XO2) |
| 16 | Current Measurement (See Table 1) |
| 17 | Current Measurement (See Table 1) |
| 18 | Current Measurement (See Table 1) |
| 19 | Current Measurement (See Table 1) |
| 20 | Current Measurement (See Table 1) |
| 21 | Current Measurement (See Table 1) |
| 22 | Current Measurement (See Table 1) |
| 23 | Current Measurement (See Table 1) |
| 24 | Current Measurement (See Table 1) |
| 25 | Current Measurement (See Table 1) |
| 28 | Configuration Signal: FLASH_MISO (iCE) |
| 29 | Configuration Signal: FLASH_MOSI (iCE) |
| 30 | Configuration Signal: FLASH_CSB (iCE) |
| 31 | Configuration Signal: FLASH_SCLK (iCE) |
| 32 | Current Measurement (See Table 1) |
| 33 | Current Measurement (See Table 1) |
| 34 | 3.3 V Regulator Output Control (See TPS7A7200) |
| 35 | 3.3 V Regulator Output Control (See TPS7A7200) |
| 36 | 3.3 V Regulator Output Control (See TPS7A7200) |

Table 7. Sensor Board Testpoints

| Test Point | Signal/Function |
|------------|--------------------------------------|
| 1 | AFE4403: CLKOUT |
| 2 | BLE Config: SWCLK |
| 3 | LPS25H: INT1 |
| 4 | AFE4403: TX3 |
| 5 | AFE4403: INN |
| 6 | AFE4403: INP |
| 7 | AFE4403: ADC_RDY |
| 8 | AFE4403: LED_DRV_SUP |
| 9 | AFE4403: VCM |
| 10 | AFE4403: TXP |
| 11 | AFE4403: TXN |
| 12 | Battery Connector (+) |
| 13 | Battery Connector (-) |
| 14 | LSM330DLC: INT1_G |
| 15 | LSM330DLC: INT2_G |
| 16 | BLE Config: SWDIO |
| 17 | AFE4403: Manual Reset, short to TP18 |
| 18 | AFE4403: Manual Reset, short to TP17 |

Device Interconnects

Six general purpose connections have been made between Lattice MachXO2 and iCE5LP devices for communication between FPGAs. Level translators have been implemented on these lines, which limit their operation frequency. Table 8 lists connection ports and maximum operation frequencies:

Table 8. MachXO2 and iCE5LP Interconnections

| Net Number | MachXO2 Ball | iCE5LP Ball | Max Frequency |
|------------|--------------|-------------|---------------|
| 1 | E6 | C2 | 20 MHz |
| 2 | E5 | B1 | 20 MHz |
| 3 | D5 | D2 | 100 MHz |
| 4 | D4 | B2 | 100 MHz |
| 5 | G4 | B4 | 100 MHz |
| 6 | F4 | F4 | 100 MHz |

Display

The iCE40 Ultra Wearable Development Platform includes an LG LH154Q01 Display and necessary driving circuitry. MIPI DSI clock and data signals are driven by the Lattice MachXO2 device, through a resistor network for achieving proper voltage levels. This display also provides a frame-sync signal, B_Sync, which is routed to a MachXO2 pin. Display supplies and the backlight driver are controlled by outputs from the MachXO2.

Table 9. Display Signals

| Signal | MachXO2 Ball | I/O Type |
|---------------|--------------|---------------|
| Clock HS+ | C4 | LVDS25 |
| Clock HS- | D3 (Auto) | LVDS25 (Auto) |
| Clock LP+ | C7 | LVC MOS12 |
| Clock LP- | C6 | LVC MOS12 |
| Data HS+ | C1 | LVDS25 |
| Data HS- | D2 (Auto) | LVDS25 (Auto) |
| Data LP+ | A7 | LVC MOS12 |
| Data LP- | B6 | LVC MOS12 |
| Reset | B2 | LVC MOS33 |
| B_Sync | A3 | LVC MOS33 |
| Backlight PWM | C3 | LVC MOS33 |
| 3 V Enable | C2 | LVC MOS33 |
| 1.8 V Enable | E2 | LVC MOS33 |

Note: For the high-speed differential signals (Clock HS, Data HS) only the positive channel must be assigned, the negative channel will be automatically placed.

Clock Sources

The Main Board has a single 27 MHz clock source that connects to the Lattice MachXO2 device. To use this external clock with the iCE5LP device, the 27 MHz clock can be routed from the MachXO2 via one of the six general purpose interconnects. These connections can be found in Table 8.

Table 10. Clock Sources

| Source | Frequency | XO2 Ball | iCE Ball |
|------------|-----------|----------|----------|
| Oscillator | 27 MHz | E4 | — |

Reset Button

A button (SW1) is included for performing resets of systems on board the iCE40 Ultra Wearable Development Platform. By default, this button will perform a configuration reset of the iCE5LP, MachXO2, and the Bluetooth module.

Table 11. Reset Resistors and Pins

| Device | Resistor | FPGA Ball |
|----------|----------|-----------|
| MachXO2 | R110 | B3 |
| iCE5LP | R62 | — |
| Seed BLE | R63 | — |

Note: If VREG_ADJ (see the [Board Power](#) section) is changed, these resistors must be removed to prevent voltage level mismatches.

LEDs

The Main Board has four system status LEDs, two user LEDs, an RGB LED, an IR LED, and a High-current White LED.

The iCE40 Ultra has I/O ports specially built for sinking current from high-power LEDs. The RGB LED ports (A6, B6, and C6) are able to sink 24 mA each, while the high-current LED port (A2) is able to sink up to 500 mA.

Please note that the IR LED is only rated for 100 mA and can be damaged by incorrectly configuring the port in custom designs. This is not a problem for the RGB LED and High-current White LED, since they are rated for more current than the ports can sink.

The LED functions and FPGA connections are detailed below:

Table 12. Main Board LEDs

| LED Number | MachXO2 Ball | iCE40 Ball | Function |
|------------|--------------|------------|--|
| D1 | — | — | Power Source Connected |
| D2 | — | — | Battery Charging |
| D3 | Config | — | MachXO2 CDONE |
| D4 | E7 | — | User LED |
| D5 | F7 | — | User LED |
| D8 | — | Config | iCE40 CDONE |
| D9 (R) | — | C6 | RGB LED (Red) |
| D9 (G) | — | B6 | RGB LED (Green) |
| D9 (B) | — | A6 | RGB LED (Blue) |
| D10 | — | A2* | IR LED (see the Jumpers section) |
| D11 | — | A2* | High-current White LED (see the Jumpers section) |

Sensors and Peripherals

The iCE40 Ultra Wearable Development Platform utilizes several third-party devices. Links for more information can be found below:

Table 13. Main Board Sensors and Peripherals

| Name | Reference Number | Interface | FPGA Connections | Part Number | Link |
|------------|------------------|-----------|-------------------------------|-------------|---|
| Microphone | U6, U7 | I2S | iCE5LP: Clock (F3), Data (E3) | MP34DB01 | http://www.st.com/web/en/catalog/sense_power/FM125/SC1564/PF250941 |

Table 14. Sensor Board Sensors and Peripherals

| Name | Reference Number | Interface | FPGA Connections | Part Number | Link |
|-------------------------------|------------------|-----------|------------------|--------------------|---|
| Temperature Sensor | U7 | I2C | See Table 3 | TMP112 | http://www.ti.com/product/tmp112 |
| Pressure Sensor | U3 | I2C | See Table 3 | LPS25H | http://www.st.com/web/catalog/sense_power/FM89/SC1316/PF255230 |
| Accelerometer/ Gyroscope | U4 | I2C | See Table 3 | LSM330DLC | http://www.st.com/web/en/catalog/sense_power/FM89/SC1448/PF252427 |
| Heart Rate & Oxygen Sensor | U6 | — | — | SFH7050 | http://www.osram-os.com/osram_os/en/products/product-promotions/infrared-products/sensor-family/biomon-sensor-sfh-7050/index.jsp |
| Analog Front End | U2 | SPI | See Table 4 | AFE4403 | http://www.ti.com/product/afe4403 |
| BLE Module | U5 | UART | See Table 5 | Seeed 113050012 | http://www.seeedstudio.com/wiki/BLE_Micro |

Flash Memory Devices

The Lattice MachXO2 and iCE5LP are each equipped with an external SPI Flash memory device.

Table 15. Flash Devices

| Master Device | Reference Number | Part Number |
|---------------|------------------|-------------------------|
| MachXO2 | U5 | Micron N25Q032A13ESC40G |
| iCE5LP | U10 | Micron M25P80-VMN6TP |

The iCE5LP external Flash memory is intended for holding configuration data, while the MachXO2 external Flash memory is intended for storing data, such as images for the included display. Because of the target application, the Flash device connected to the MachXO2 is capable of using the higher-bandwidth Quad-SPI protocol.

Table 16. Flash Connections

| Master Device | Reference Number | Signal | FPGA Ball |
|---------------|------------------|--------|-----------|
| MachXO2 | U5 | DQ0 | G1 |
| | | DQ1 | F5 |
| | | DQ2 | F3 |
| | | DQ3 | G3 |
| | | SCLK | F6 |
| | | CS | G7 |
| iCE5LP | U10 | MISO | F2 |
| | | MOSI | D1 |
| | | SCLK | E1 |
| | | CS | F1 |

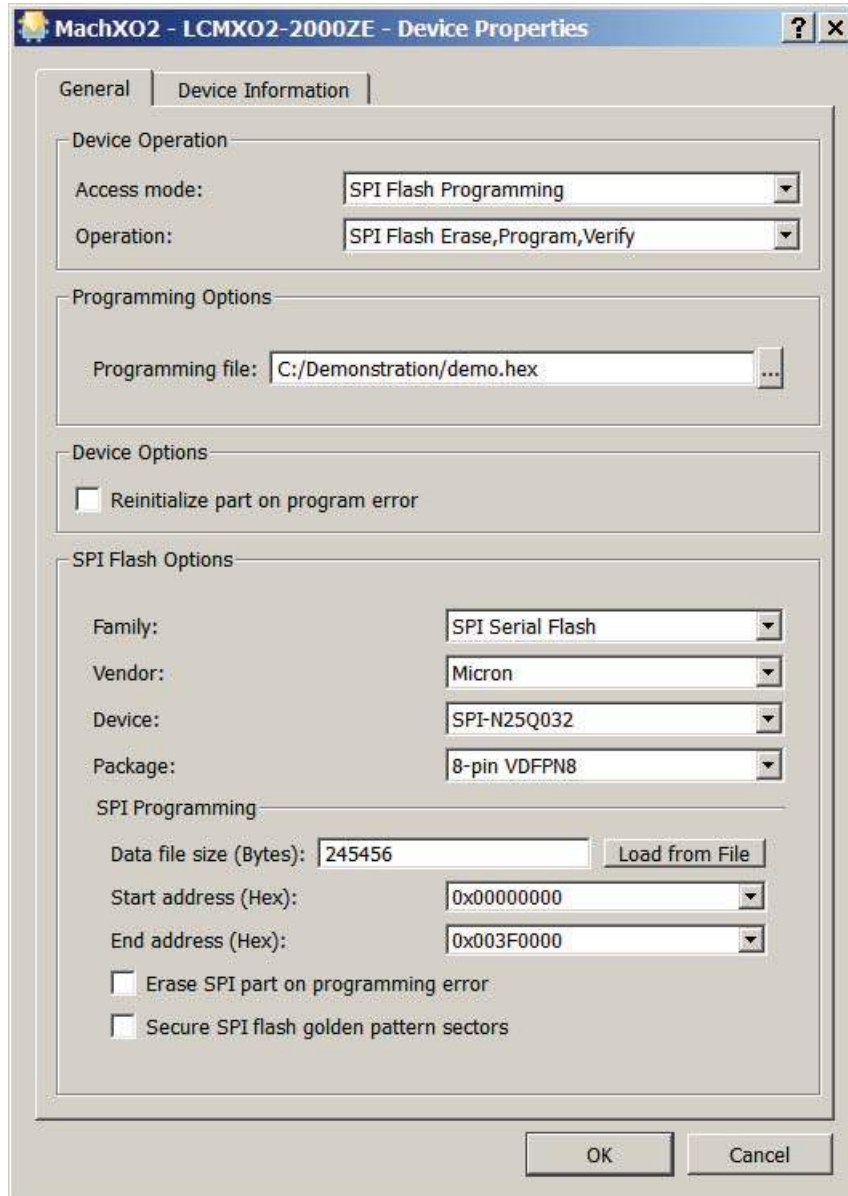
Board Configuration and Programming

Lattice MachXO2

The Lattice MachXO2 features internal configuration Flash. This allows configuration data to be stored internally while the external Flash memory device is used for auxiliary functions.

1. Ensure that header J51 is shunted and the power switch (SW2) is in the *on* position.
2. Plug in the mini-USB cable (J1).
3. Launch Diamond Programmer.
4. Select **Create a new project from a scan** and click **Detect Cable**.
5. Select the FTUSB-1 Port.
6. Select **MachXO2** and **LCMXO2-2000ZE** in the Device Family and Device columns.
7. Double click on the Operation column and select the appropriate operation.
 - a. Internal Flash: Flash Programming Mode: SPI Flash Erase, Program, Verify
 - b. External Flash: SPI Flash Programming: SPI Flash Erase, Program, Verify
8. If targeting the External Flash memory, copy the SPI Flash Options from Figure 6.
9. Select the programming bitstream in the “File Name” column.
10. Click the Program Icon or select Program from the Design dropdown menu.

Figure 6. MachXO2 External Flash



Lattice iCE5LP

The Lattice iCE5LP can be directly programmed, however, unless single-time programmable NVCM is used, the configuration data will be lost when the device is powered down.

1. Ensure that header J51 is shunted and the power switch (SW2) is in the *on* position.
2. Plug in the mini-USB cable (J1).
3. Launch Diamond Programmer.
4. Select **Create a new project from a scan** and click **Detect Cable**.
5. Select the FTUSB-0 Port.
6. Select **iCE5LP** and **iCE5LP4K** in the Device Family and Device columns.

7. Double click on the Operation column and select the appropriate operation
 - a. Direct Program: CRAM Programming: Fast Program (Volatile)
 - b. NVCM (Single-use): NVCM Programming Mode: NVCM Program, Verify, Secure
 - c. External Flash: SPI Flash Programming: SPI Flash Erase, Program, Verify
8. If targeting the External Flash memory, copy the SPI Flash Options from Figure 7.
9. Select the programming bitstream in the File Name column
10. Click the Program Icon or select Program from the Design dropdown menu

Figure 7. iCE5LP External Flash

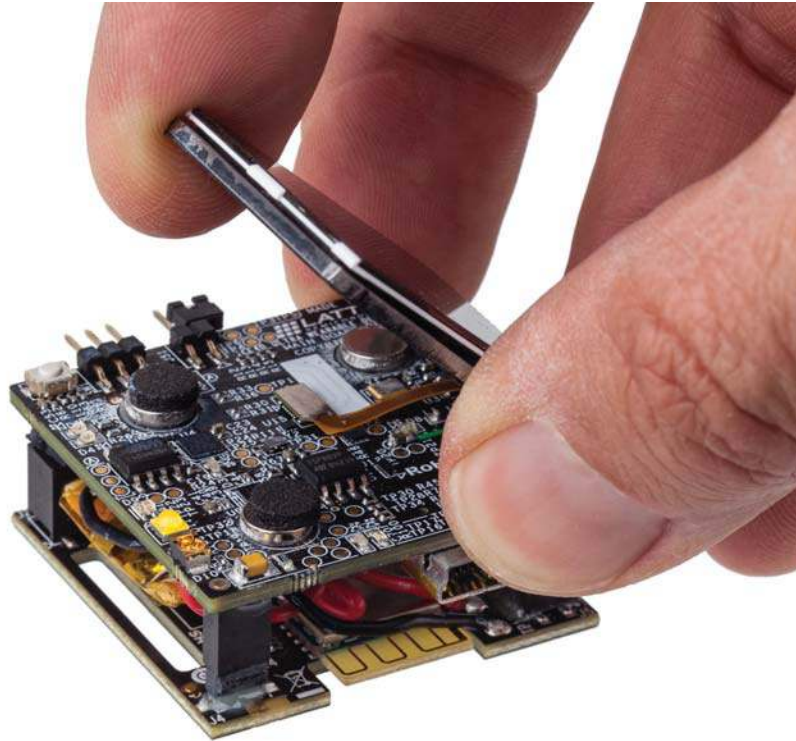
The screenshot shows the "iCE5LP - iCE5LP4K - Device Properties" dialog box with the "Device Information" tab selected. The "Device Operation" section has "Access mode" set to "SPI Flash Programming" and "Operation" set to "SPI Flash Erase, Program, Verify". The "Programming Options" section has "Programming file" set to "C:/Demonstration/demo.hex". The "Device Options" section has "Reinitialize part on program error" unchecked. The "SPI Flash Options" section has "Family" set to "SPI Serial Flash", "Vendor" set to "Micron", "Device" set to "SPI-M25P80", and "Package" set to "8-pin SOIC". The "SPI Programming" section has "Data file size (Bytes)" set to "245456" with a "Load from File" button, "Start address (Hex)" set to "0x00000000", and "End address (Hex)" set to "0x00030000". There are also two unchecked checkboxes: "Erase SPI part on programming error" and "Secure SPI flash golden pattern sectors". "OK" and "Cancel" buttons are at the bottom right.

Pre-Loaded Demonstration Design

The iCE40 Ultra Wearable Development Platform comes pre-loaded with the Parallel-to-MIPI DSI demo. In order to run the demo, follow these steps:

1. Ensure that the display is attached in the proper orientation, with the connector ribbon extending toward the right edge of the device (see Figure 8).

Figure 8. Display Connector



2. Plug a mini-USB cable into the mini-USB port (J1) to supply power to the device.
3. Switch power switch to the *on* position.
4. The screen should alternate between two images, with the User LEDs (D4, D5) indicating the demo mode.


For more detailed operation instructions, please refer to the Quick Start User Guide included with the demo design.

This demo design can be reprogrammed onto the board by downloading the project (see the [Additional Demonstration Designs](#) section) and following the documented instructions. Please note that in this demo, the MachXO2 uses its internal Flash to store configuration data and the external Flash to store image data, so two programming procedures must be performed.

Additional Demonstration Designs

Several additional demonstration designs have been developed for the iCE40 Ultra Wearable Development Platform. These designs can be found under the Design File Tab of the Documentation section of the board web page here: <http://www.latticesemi.com/ultrawearable>.

Ordering Information

| Description | Ordering Part Number | China RoHS Environment-Friendly Use Period (EFUP) |
|---|----------------------|---|
| iCE40 Ultra Wearable Development Platform | ICE5LP4K-WDEV-EVN |  |

Technical Support Assistance

Submit a technical support case through www.latticesemi.com/techsupport.

Revision History

| Date | Version | Change Summary |
|-----------|---------|------------------|
| July 2015 | 1.0 | Initial release. |

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Appendix A. Main Board Schematic Diagrams

Figure 9. Block Diagram

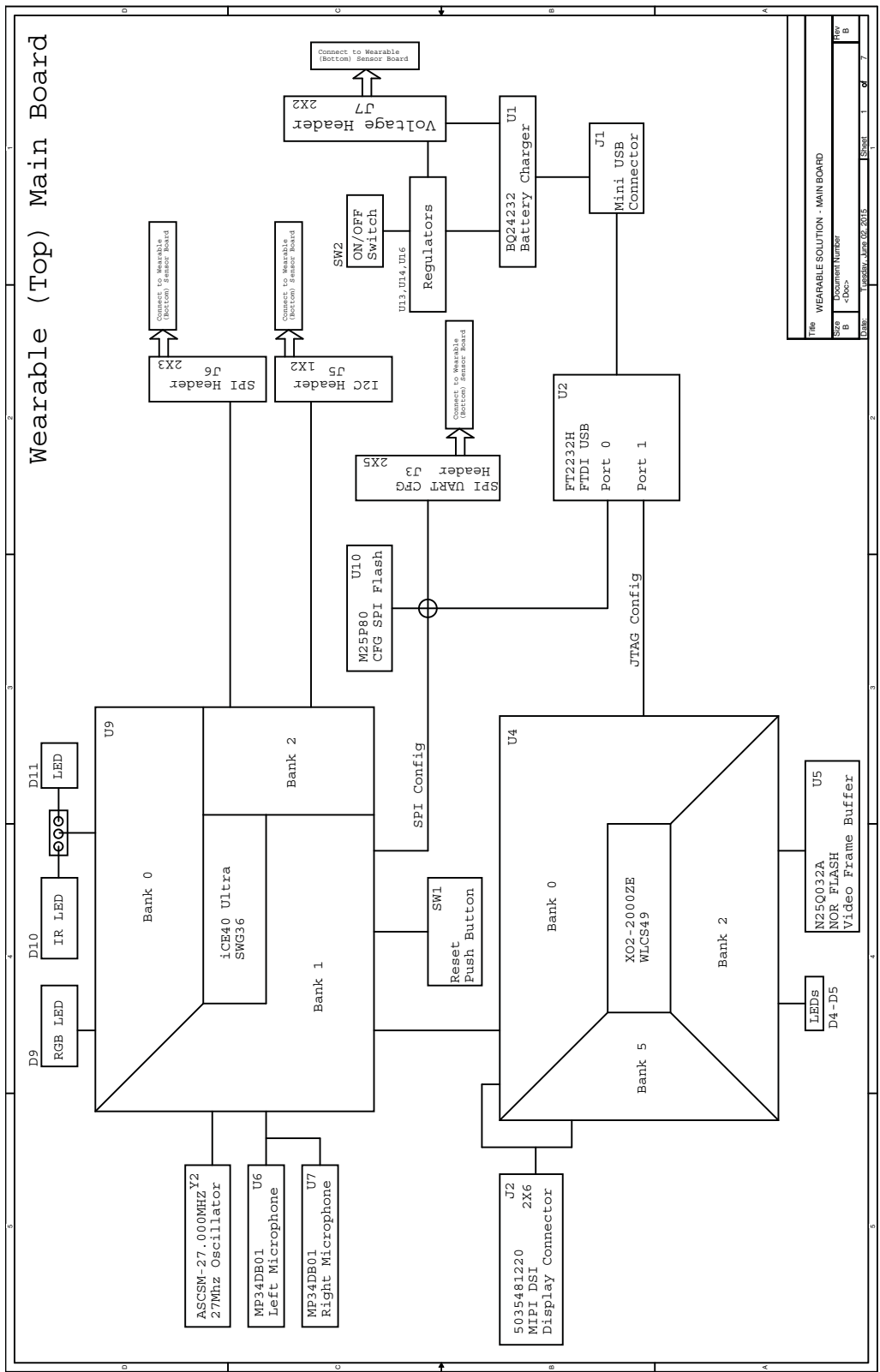


Figure 10. Mechanical Design

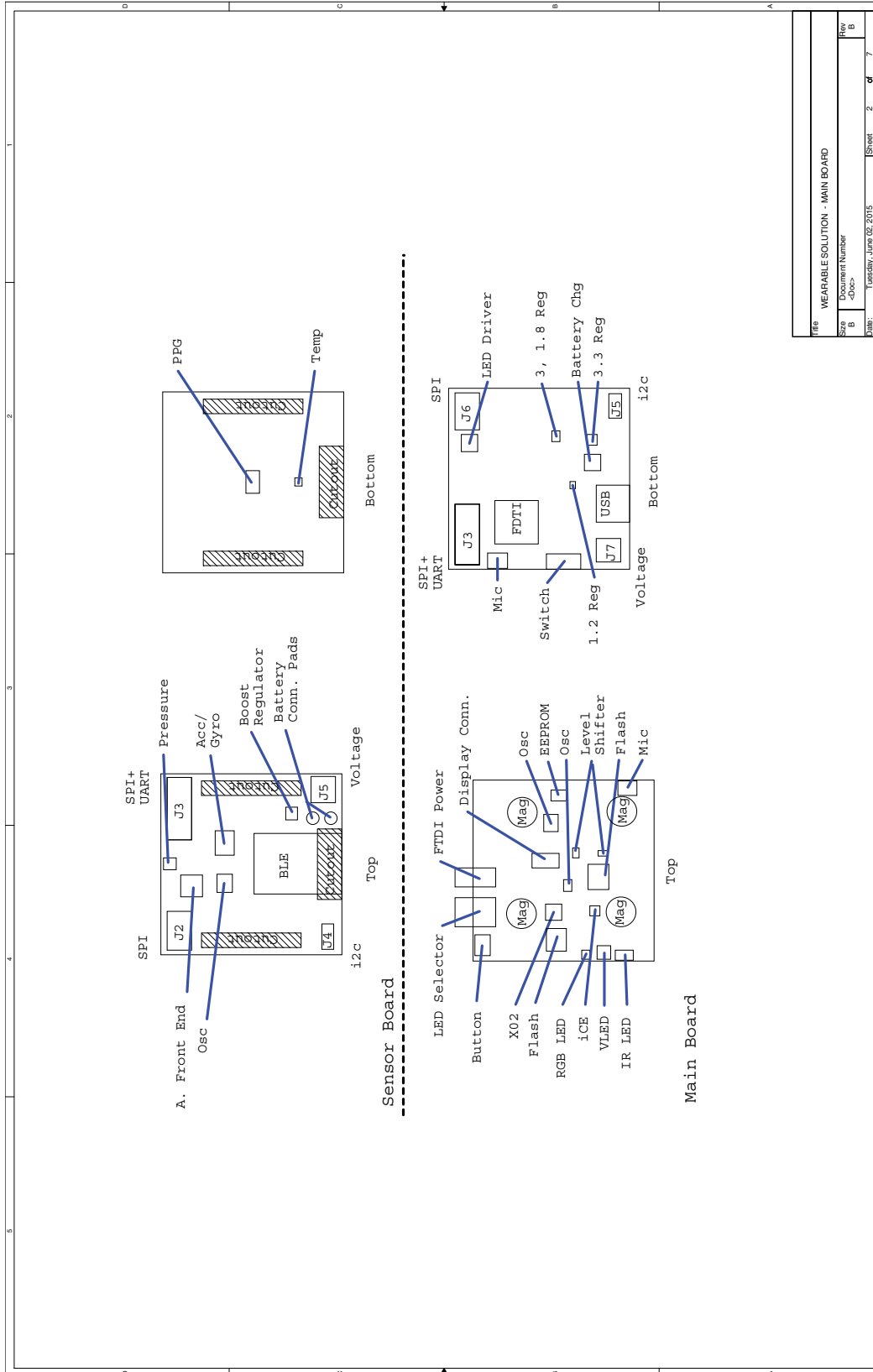
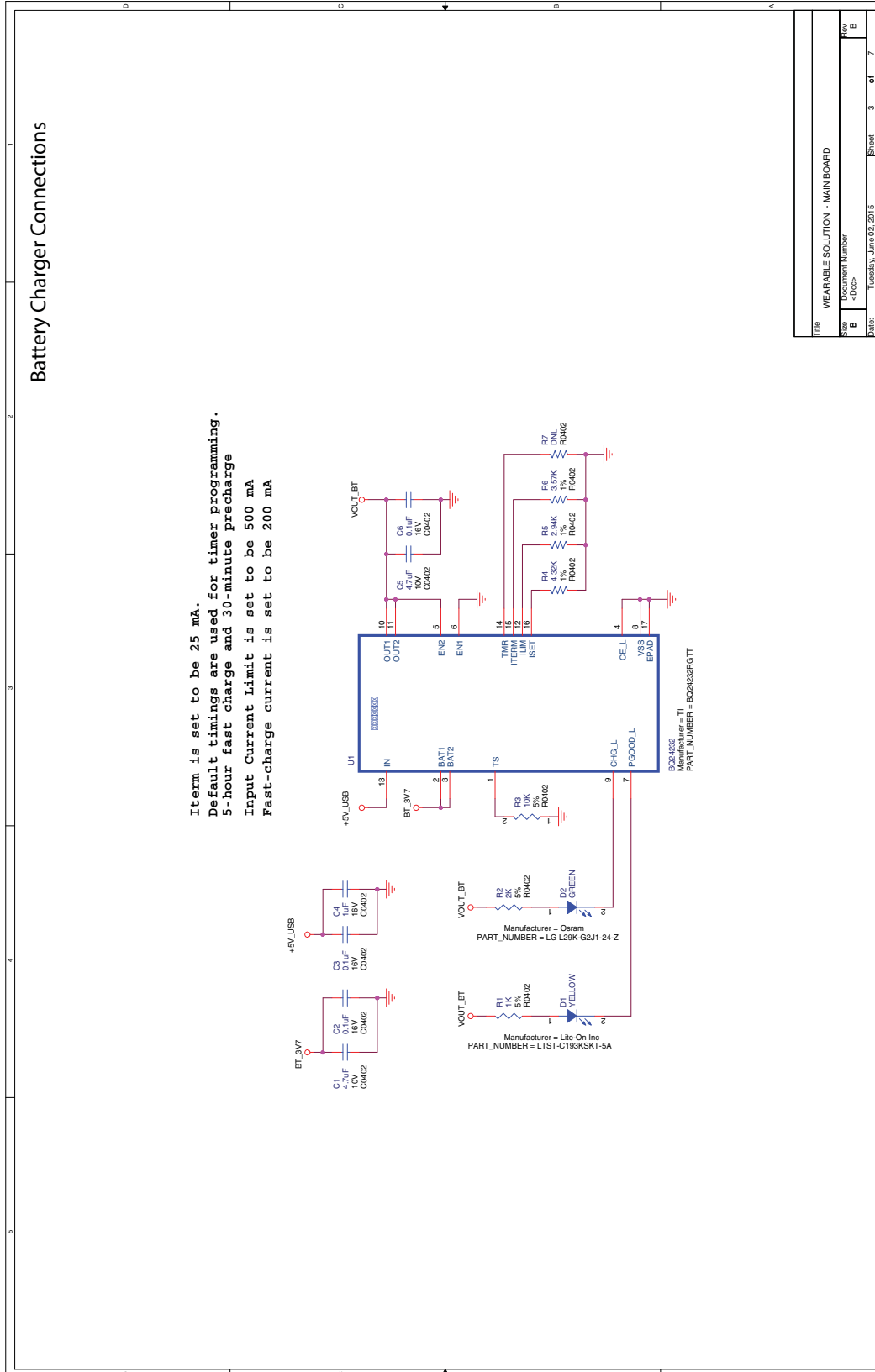
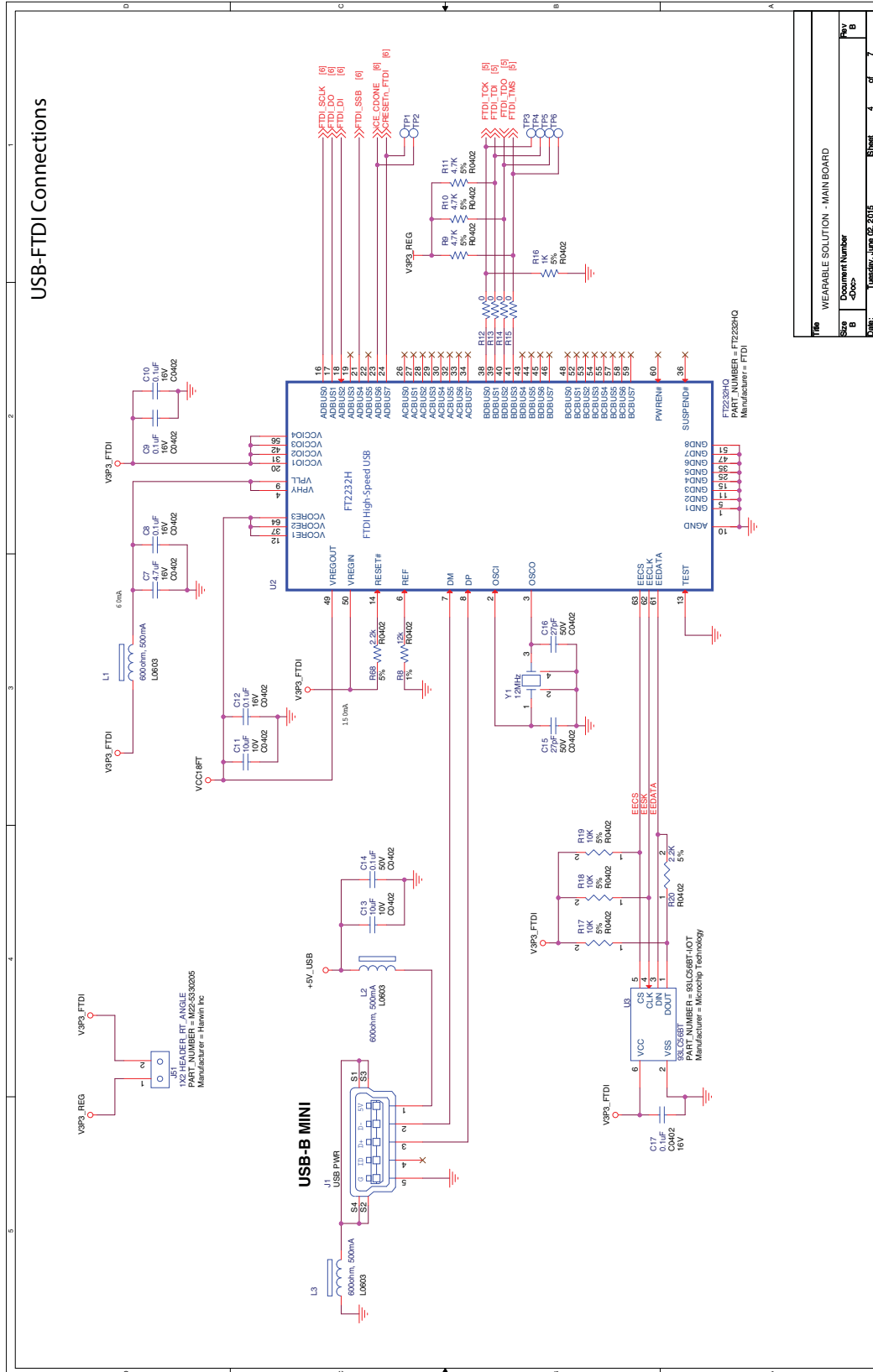


Figure 11. Battery Charger Connections



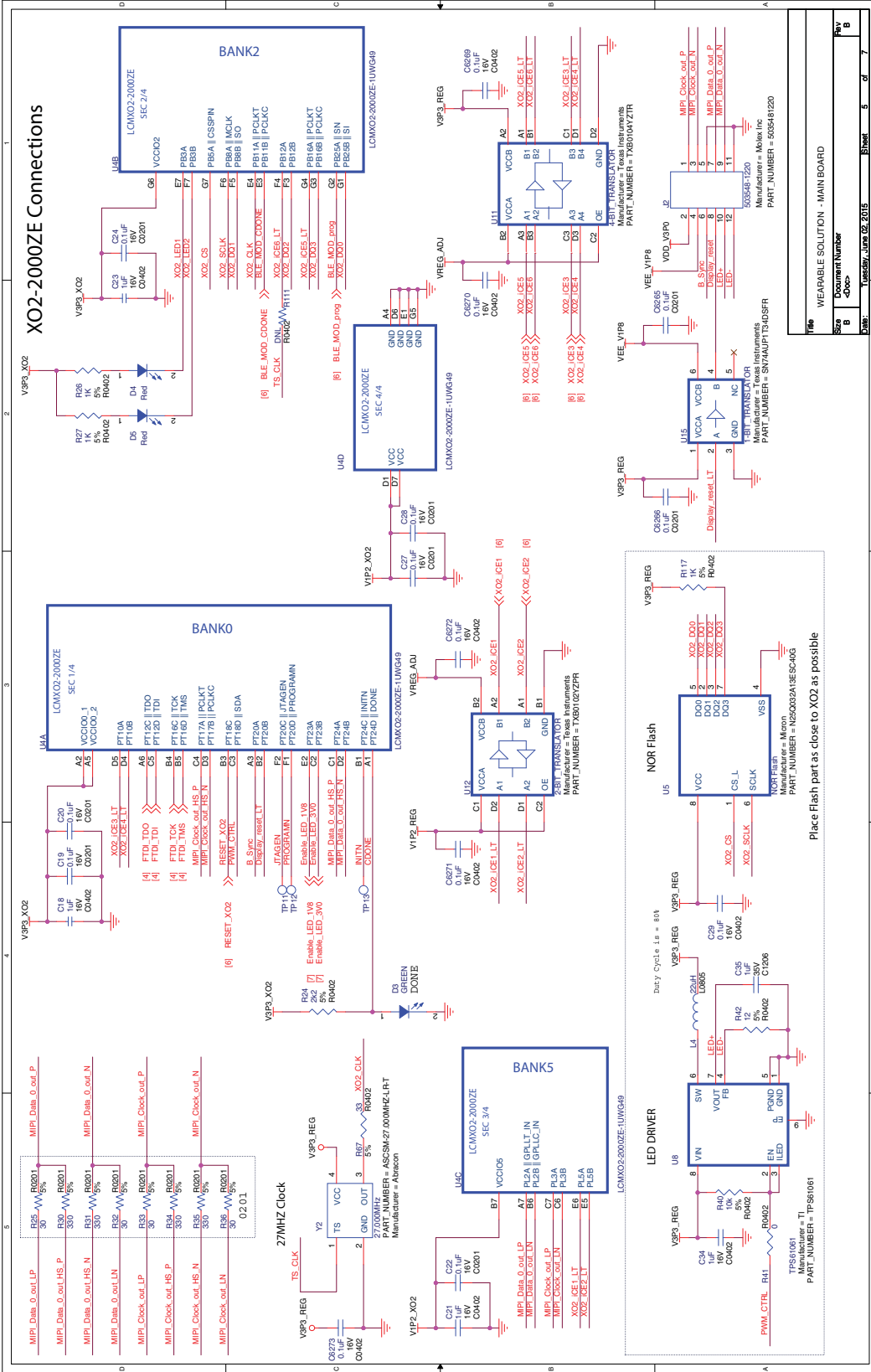
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| Document Number | <Doc> | | | | | |
| Rev | B | | | | | |
| Sheet | 3 | of | 7 | | | |
| DATE | 10/25/2015 | | | | | |

Figure 12. USB-FTDI Connections



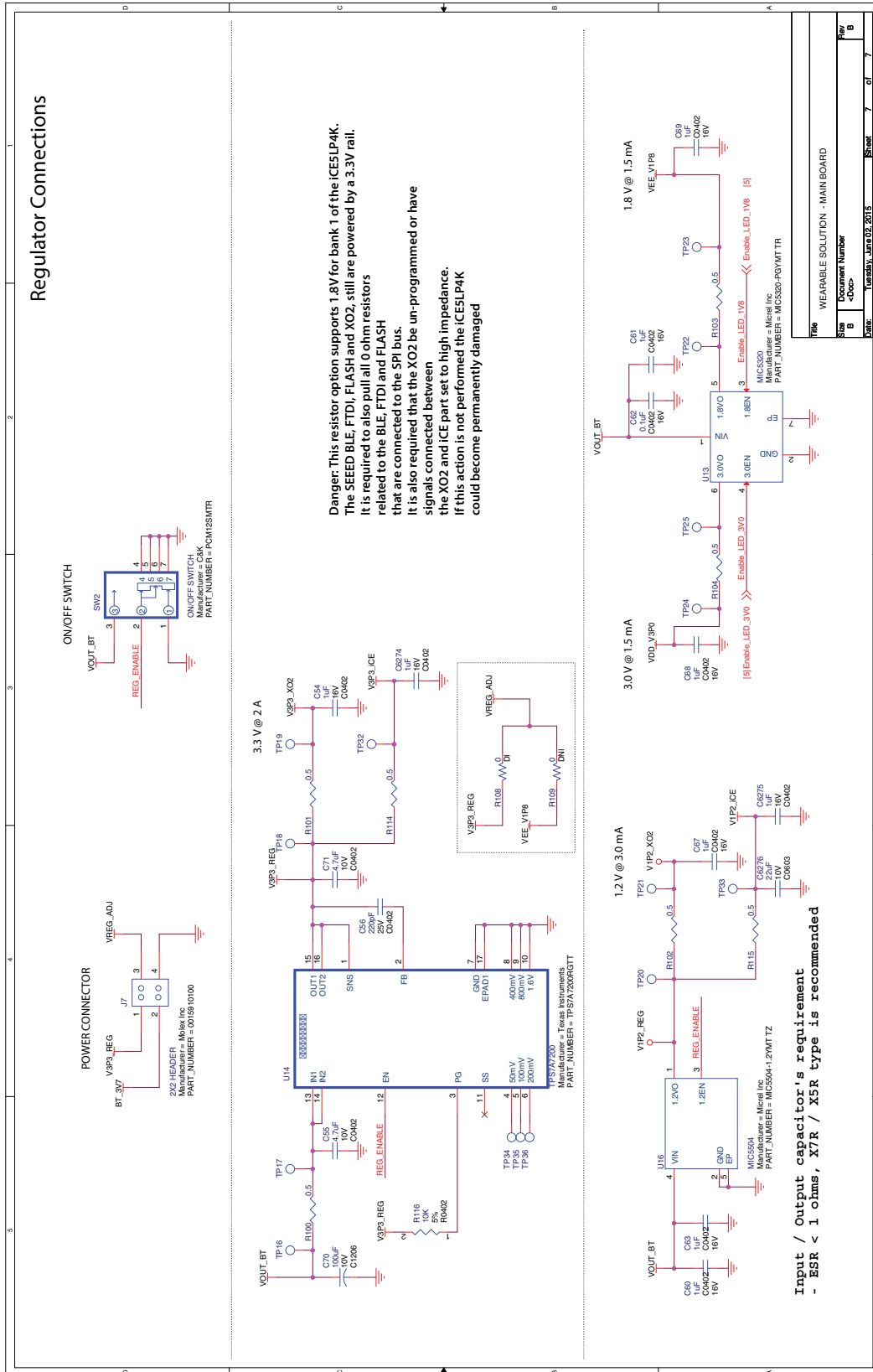
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| Size | B | | | | | | |
| Doc# | 4-0000 | | | | | | |
| Rev. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

Figure 13. MachXO2-2000ZE Connections



| | | | | |
|--------------------------------------|------------|-------|-------|-----|
| Title WEARABLE SOLUTION - MAIN BOARD | | | | |
| Doc# 0000 | | | | |
| Rev | Doc Number | Sheet | Total | Rev |
| B | 0000 | 5 | 6 | B |
| Date: Tuesday, June 02, 2015 | | | | |

Figure 15. Regulator Connections



Appendix B. Sensor Board Schematic Diagrams

Figure 16. Block Diagram

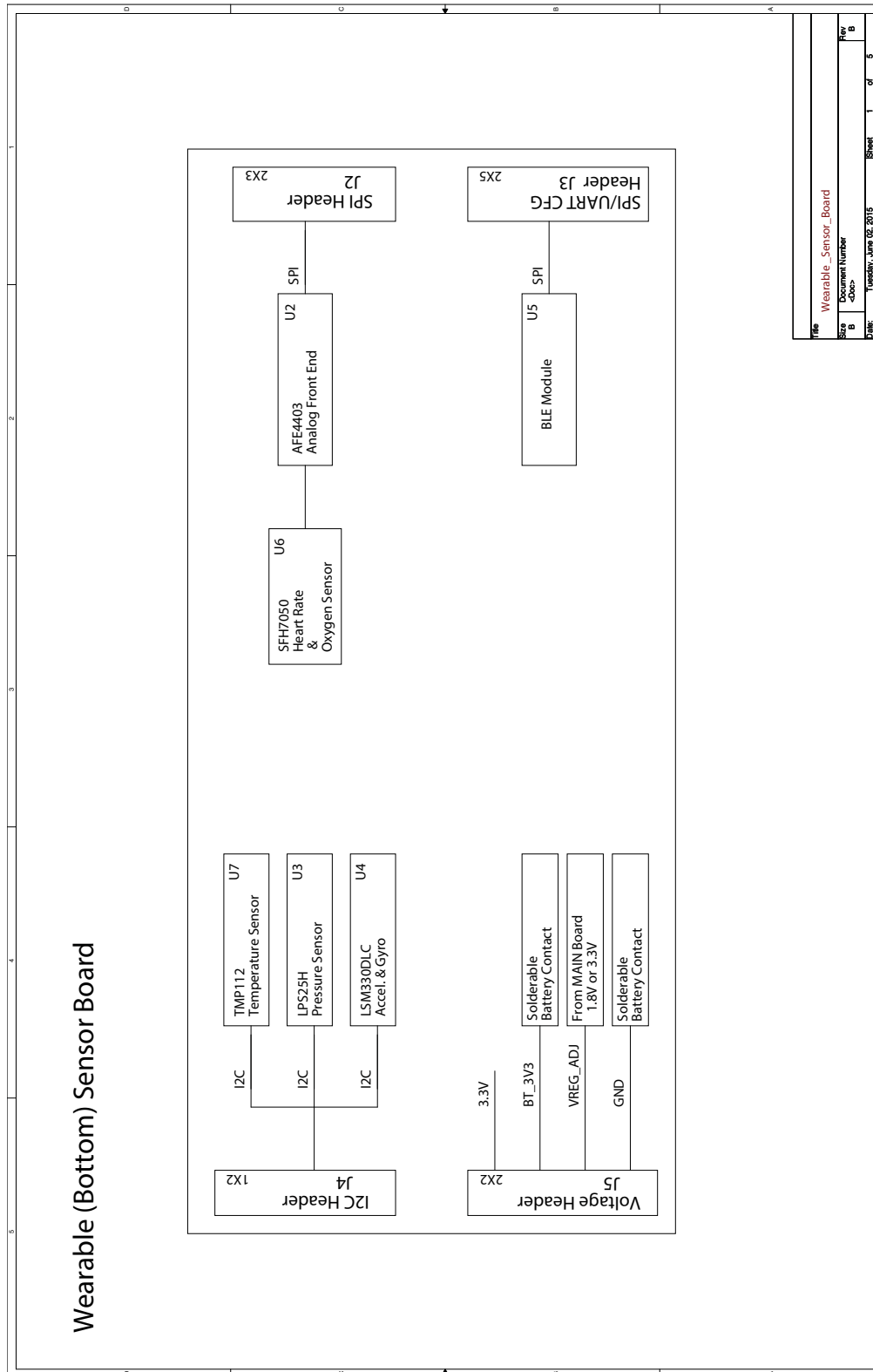


Figure 17. Mechanical Design

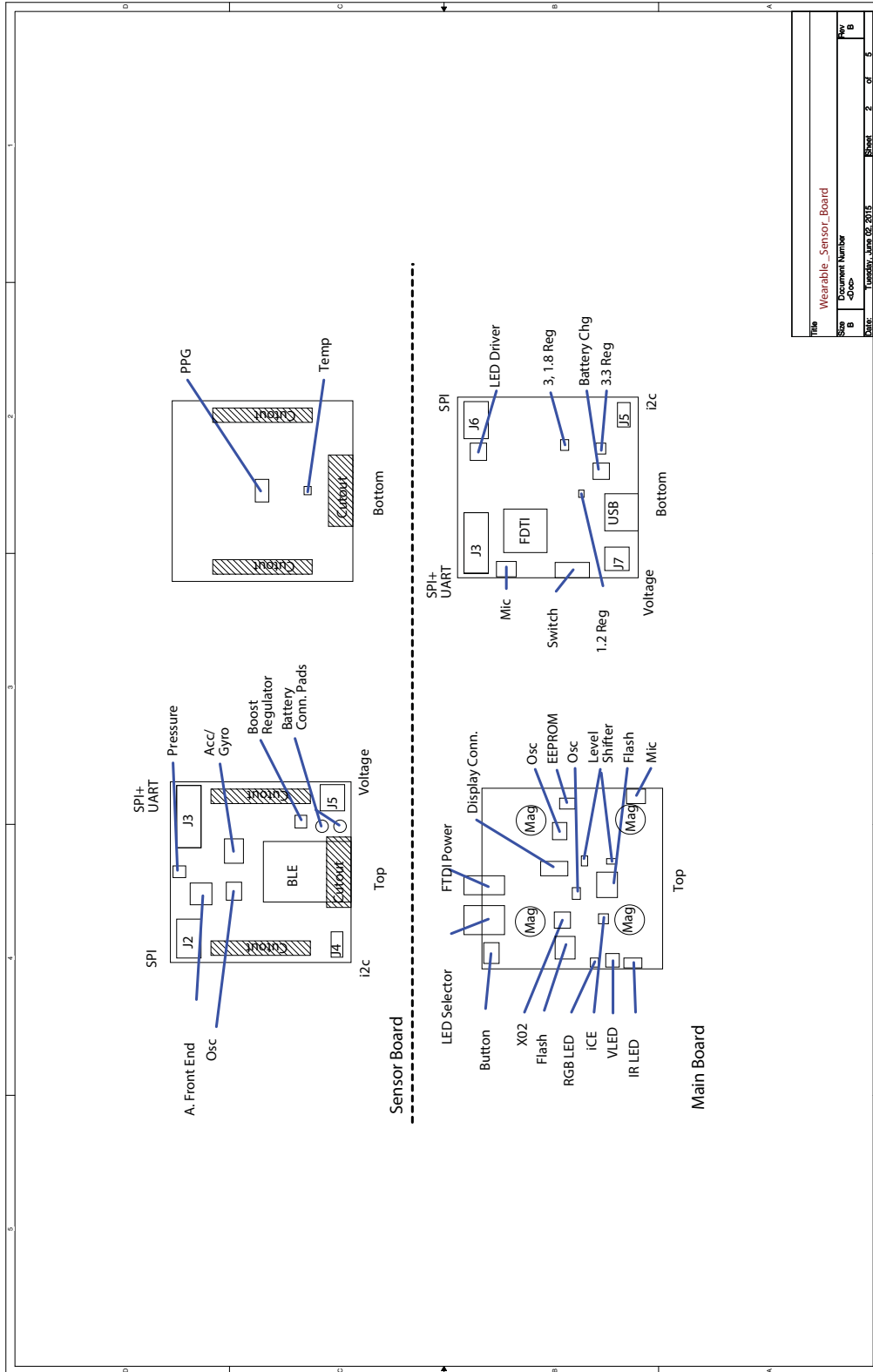


Figure 19. Sensor Connections - 2

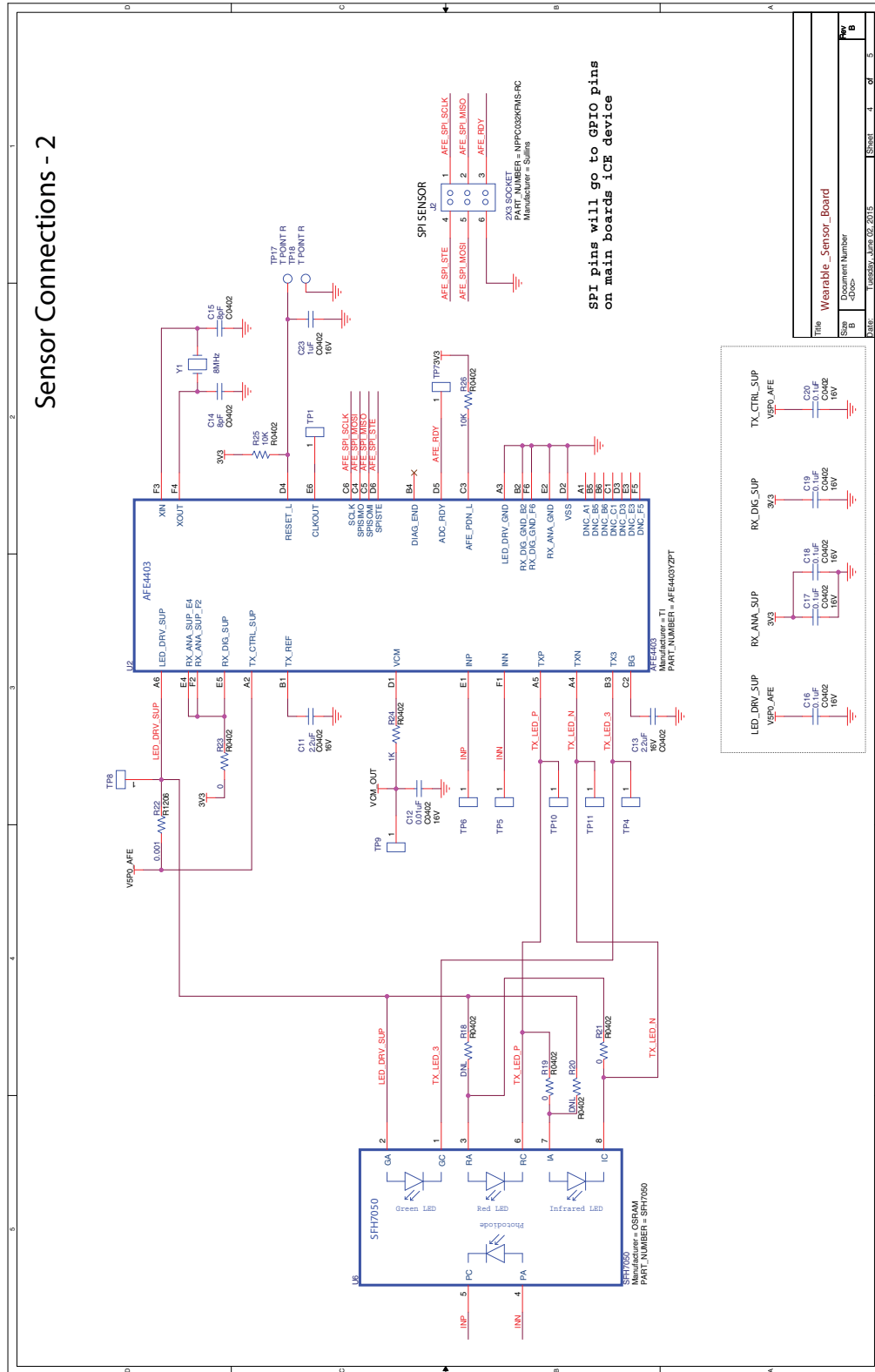
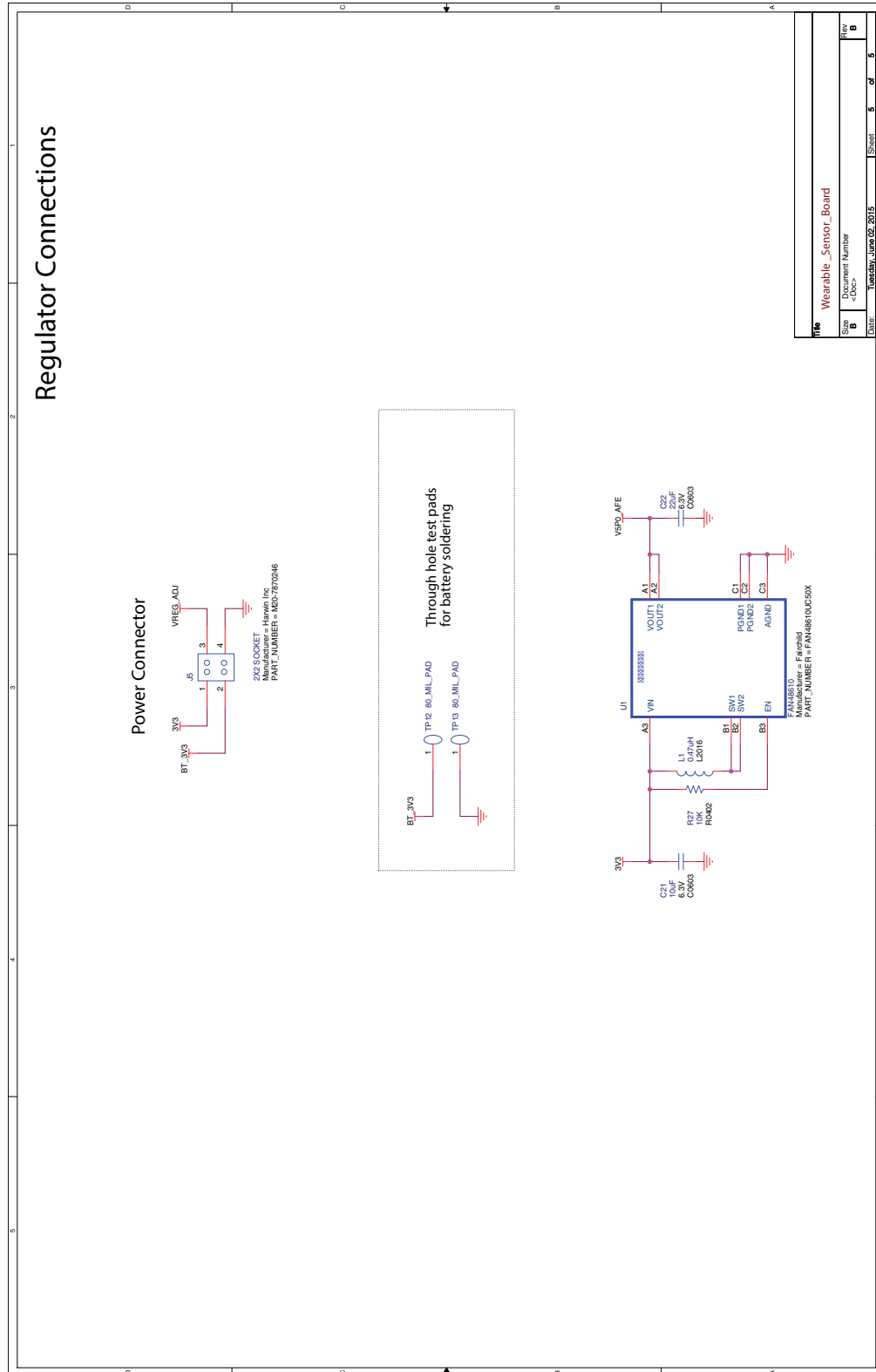


Figure 20. Boost Regulator



Appendix C. Main Board Bill of Materials

Figure 21. Main Board Bill of Materials

| Item | Reference | Qty | Part | PCB Footprint | Comments | Part Number | Manufacturer | Description |
|------|---|-----|---------------------|---------------------------|----------------|--------------------------|-----------------|------------------------------------|
| 1 | C1,C5,C55,C71 | 4 | 4.7uF | C0402 | — | C1005X5R1A475K050BC | TDK | CAP CER 4.7 µF 10 V 10% X5R 0402 |
| 2 | C2,C3,C6,C6269,C6270,C6271,C6272 | 7 | 0.1uF | C0402 | — | C1005X5R1C104K050BA | TDK | CAP CER 0.1 µF 16 V 10% X5R 0402 |
| 3 | C4 | 1 | 1uF | C0402 | — | GRM155R61C105KE01D | Murata | CAP CER 1 µF 16 V 10% X5R 0402 |
| 4 | C7 | 1 | 4.7uF | C0402 | — | C1005X5R1A475K050BC | TDK | CAP CER 4.7 µF 10 V 10% X5R 0402 |
| 5 | C8,C9,C10,C12,C14,C17,C29,C31,C33,C36,C53,C62,C6273 | 13 | 0.1uF | C0402 | — | C1005X5R1C104K050BA | TDK | CAP CER 0.1 µF 16 V 10% X5R 0402 |
| 6 | C11,C13,C30,C32 | 4 | 10uF | C0402 | — | CL05A106MP5NUNC | Samsung | CAP CER 10 µF 10 V 20% X5R 0402 |
| 7 | C15,C16 | 2 | 27pF | C0402 | — | CL05C270JB5NUNC | Samsung | CAP CER 27 pF 50 V 5% NP0 0402 |
| 8 | C18,C21,C23,C34,C41,C43,C46,C51,C54,C60,C61,C63,C67,C68,C69,C6274,C6275 | 17 | 1uF | C0402 | — | GRM155R61C105KE01D | Murata | CAP CER 1 µF 16 V 10% X5R 0402 |
| 9 | C19,C20,C22,C24,C27,C28,C40,C42,C44,C45,C47,C50 | 12 | 0.1uF | C0201 | — | C0603X5R1C104K030BC | TDK | CAP CER 0.1 µF 16 V 10% X5R 0201 |
| 10 | C35 | 1 | 1uF | C1206 | — | GMK316BJ105KLHT | Taiyo Yuden | CAP CER 1 µF 35 V 10% X5R 1206 |
| 11 | C37,C38,C39,C48,C49 | 5 | 10nF | C0201 | — | GRM033R61C103KA12D | Murata | CAP CER 10000 pF 16 V 10% X5R 0201 |
| 12 | C56 | 1 | 220pF | C0402 | — | GRM1555C1E221JA01D | Murata | CAP CER 220 pF 25 V 5% NP0 0402 |
| 13 | C70 | 1 | 100uF | C1206 | — | F951A107KAAQ2 | AVX | CAP TANT 100 µF 10 V 10% 1206 |
| 14 | C6265,C6266 | 2 | 0.1uF | C0201 | — | C0603X5R1E104M030BB | TDK Corporation | CAP CER 0.1 µF 25 V 20% X5R 0201 |
| 15 | C6276 | 1 | 22uF | C0603 | — | C1608X5R1A226M080A C | TDK | CAP CER 22 µF 10 V 20% X5R 0603 |
| 16 | D1 | 1 | YELLOW | LED0603 | — | LTST-C193KSKT-5A | Lite-On Inc | LED YELLOW RECT CLEAR 0603 |
| 17 | D2 | 1 | GREEN | LED0603 | — | LG L29K-G2J1-24-Z | Osram | LED SMARTLED GREEN 570NM 0603 |
| 18 | D3,D8 | 2 | GREEN | LED0603 | — | LG L29K-G2J1-24-Z | Osram | LED SMARTLED GREEN 570NM 0603 |
| 19 | D4,D5 | 2 | Red | LED0603 | — | LTST-C190KRKT | LITE-On INC | LED SUPER RED CLEAR 0603 SMD |
| 20 | D9 | 1 | TRICOLOUR_LED | APTF1616SE_RGB | — | APTF1616SEEZQBDC | Kingbright | LED RED/GREEN/BLUE WTR CLEAR SMD |
| 21 | D10 | 1 | IR_LED | SFH4645_2SMD | — | SFH 4645 | OSRAM | EMITTER 950NM MIDLED SIDELK SMD |
| 22 | D11 | 1 | LED | XBDAWT_2SMD | — | XBDAWT-00-0000-00000LCE3 | Cree Inc | LED HIGH BRIGHTNESS |
| 23 | D12 | 1 | CDBU0520 | DIODE_SOD523F | — | CDBU0520 | Comchip | DIODE SCHOTTKY 20 V 500 mA 0603 |
| 24 | J1 | 1 | USB PWR | CONN_S5P1RMINIUS_BB_MOLEX | — | 67503-1020 | Molex | CONN RECEPT MINI-USB R/A 5POS SMD |
| 25 | J2 | 1 | 503548-1220 | 2X6HDR_5035481220 | — | 5035481220 | Molex Inc | CONN RCPT BTB 12POS DL VERT SMD |
| 26 | J3 | 1 | 2x5 HEADER | 2X5_HDR_SMD | BREAKAWAY PART | 15910100 | Molex Inc | CONN HEADER 10POS .100" STR 15AU |
| 27 | J5 | 1 | 1X2 SOCKET | 1X2_SOCKET_SMD | — | NPPC021KFXC-RC | Sullins | CONN FEMALE 2POS .1" SMD GOLD |
| 28 | J6 | 1 | 2X3 HEADER | 2X3_HDR_SMD | BREAKAWAY PART | 15910100 | Molex Inc | CONN HEADER 10POS .100" STR 15AU |
| 29 | J7 | 1 | 2X2 HEADER | 2X2_HDR_SMD | BREAKAWAY PART | 15910100 | Molex Inc | CONN HEADER 10POS .100" STR 15AU |
| 30 | J50 | 1 | 1X3 R/A HEADER | 1X3_HDRRAM22_SMD | — | M22-5330305 | Harwin Inc | 3 WAY SIL HORIZ SMT PIN HDR |
| 31 | J51 | 1 | 1X2 HEADER_RT_ANGLE | 1X2_HDRM22_SMD | — | M22-5330205 | Harwin Inc | 2POS SIL HORIZ SMT PIN HEADER |

| Item | Reference | Qty | Part | PCB Footprint | Comments | Part Number | Manufacturer | Description |
|------|---|-----|---------------|-----------------------|----------|--------------------|---------------------|-----------------------------------|
| 32 | L1,L2,L3 | 3 | 600ohm, 500mA | L0603 | — | MMZ1608R601A | TDK Corp | FERRITE CHIP 600 Ohm 500 mA 0603 |
| 33 | L4 | 1 | 22uH | L0805 | — | AIML-0805HC-220M-T | Abracon Corporation | HIGH CURRENT CHIP IND 22.0UH 20% |
| 34 | R1 | 1 | 1K | R0402 | — | ERJ-2GEJ102X | Panasonic | RES SMD 1K Ohm 5% 1/10W 0402 |
| 35 | R2 | 1 | 2K | R0402 | — | ERJ-2GEJ202X | Panasonic | RES SMD 2K Ohm 5% 1/10W 0402 |
| 36 | R3,R116 | 2 | 10K | R0402 | — | ERJ-2GEJ103X | Panasonic | RES SMD 10K Ohm 5% 1/10W 0402 |
| 37 | R4 | 1 | 4.32K | R0402 | — | ERJ-2RKF4321X | Panasonic | RES SMD 4.32K Ohm 1% 1/10W 0402 |
| 38 | R5 | 1 | 2.94K | R0402 | — | ERJ-2RKF2941X | Panasonic | RES SMD 2.94K Ohm 1% 1/10W 0402 |
| 39 | R6 | 1 | 3.57K | R0402 | — | ERJ-2RKF3571X | Panasonic | RES SMD 3.57K Ohm 1% 1/10W 0402 |
| 40 | R7 | 1 | DNL | R0402 | DNL | — | — | — |
| 41 | R8 | 1 | 12k | R0402 | — | ERJ-2RKF1202X | Panasonic | RES SMD 12K Ohm 1% 1/10W 0402 |
| 42 | R9,R10,R11 | 3 | 4.7K | R0402 | — | ERJ-2GEJ472X | Panasonic | RES SMD 4.7K Ohm 5% 1/10W 0402 |
| 43 | R12,R13,R14,R15,R37,R43,R48,R49,R50,R51,R52,R53,R54,R55,R57,R58,R59,R60,R62,R63,R112,R113 | 22 | 0 | R0402 | — | ERJ-2GE0R00X | Panasonic | RES SMD 0.0 Ohm JUMPER 1/10W 0402 |
| 44 | R16,R26,R27,R44 | 4 | 1K | R0402 | — | ERJ-2GEJ102X | Panasonic | RES SMD 1K Ohm 5% 1/10W 0402 |
| 45 | R17,R18,R19,R40,R45,R46,R61 | 7 | 10k | R0402 | — | ERJ-2GEJ103X | Panasonic | RES SMD 10K Ohm 5% 1/10W 0402 |
| 46 | R20,R68 | 2 | 2.2k | R0402 | — | ERJ-2GEJ222X | Panasonic | RES SMD 2.2K Ohm 5% 1/10W 0402 |
| 47 | R24 | 1 | 2k2 | R0402 | — | ERJ-2GEJ222X | Panasonic | RES SMD 2.2K Ohm 5% 1/10W 0402 |
| 48 | R25,R32,R33,R36 | 4 | 30 | R0201 | — | ERJ-1GEJ300C | Panasonic | RES 30 Ohm 1/20W 5% 0201 SMD |
| 49 | R30,R31,R34,R35 | 4 | 330 | R0201 | — | CRCW0201330RJNED | Vishay | RES 330 Ohm 1/20W 5% 0201 SMD |
| 50 | R38,R39 | 2 | DNL | R0402 | DNL | — | — | — |
| 51 | R41 | 1 | 0 | R0402 | — | ERJ-2GE0R00X | Panasonic | RES SMD 0.0 Ohm JUMPER 1/10W 0402 |
| 52 | R42 | 1 | 12 | R0402 | — | ERJ-2GEJ120X | Panasonic | RES SMD 12 Ohm 5% 1/10W 0402 |
| 53 | R47 | 1 | 0 | R0402 | — | ERJ-2GE0R00X | Panasonic | RES SMD 0.0 Ohm JUMPER 1/10W 0402 |
| 54 | R56 | 1 | 1K | R0201 | — | ERJ-1GEJ102C | Panasonic | RES SMD 1K Ohm 5% 1/20W 0201 |
| 55 | R67 | 1 | 33 | R0402 | — | ERJ-2GEJ330X | Panasonic | RES SMD 33 Ohm 5% 1/10W 0402 |
| 56 | R94,R95,R97 | 3 | 0 | R0201 | — | ERJ-1GN0R00C | Panasonic | RES SMD 0.0 Ohm JUMPER 1/20W 0201 |
| 57 | R100,R101,R102,R103,R104,R114,R115 | 7 | 0.5 | Current_Sens_Res_0603 | — | RL0603FR-070R5L | Yageo | RES SMD 0.5 Ohm 1% 1/10W 0603 |
| 58 | R106,R107 | 2 | 10k | R0201 | — | ERJ-1GEJ103C | Panasonic | RES SMD 10K Ohm 5% 1/20W 0201 |
| 59 | R108 | 1 | 0 | R0603 | — | ERJ-3GEY0R00V | Panasonic | RES SMD 0.0 Ohm JUMPER 1/10W 0603 |
| 60 | R109 | 1 | 0 | R0603 | DNL | ERJ-3GEY0R00V | Panasonic | RES SMD 0.0 Ohm JUMPER 1/10W 0603 |
| 61 | R110 | 1 | 0 | R0402 | — | ERJ-2GE0R00X | Panasonic | RES SMD 0.0 Ohm JUMPER 1/10W 0402 |
| 62 | R111 | 1 | DNL | R0402 | DNL | — | — | — |
| 63 | R117 | 1 | 1K | R0402 | — | ERJ-2GEJ102X | Panasonic | RES SMD 1K Ohm 5% 1/10W 0402 |
| 64 | SW1 | 1 | PB | 2psmd_eswitch | — | TL1015AF160QG | E-Switch | SWITCH TACTILE SPST-NO 0.05A 12 V |
| 65 | SW2 | 1 | ON/OFF SWITCH | PCM12SMTR | — | PCM12SMTR | C&K | SWITCH SLIDE SPDT 300 mA 6 V |

| Item | Reference | Qty | Part | PCB Footprint | Comments | Part Number | Manufacturer | Description |
|------|---|-----|--|-----------------------|-------------------|--|----------------------|--|
| 66 | TP1,TP2,TP3,TP4,TP5,TP6,TP11,TP12,TP13,TP16,TP17,TP18,TP19,TP20,TP21,TP22,TP23,TP24,TP25,TP32,TP33,TP34,TP35,TP36 | 24 | T POINT R | TEST_POINT | DNL | — | — | — |
| 67 | TP28,TP29,TP30,TP31 | 4 | T POINT R | TEST_POINT | DNL | — | — | — |
| 68 | U1 | 1 | BQ24232 | BQ24232_16VQFN | — | BQ24232RGTT | TI | IC LI+ CHARGER PWR MGMT 16QFN |
| 69 | U2 | 1 | FT2232HQ | FT2232HQ_64QFN | — | FT2232HQ | FTDI | IC USB HS DUAL UART/FIFO 64-QFN |
| 70 | U3 | 1 | 93LC56BT | 93LC56BT_6SOT23 | — | 93LC56BT-I/OT | Microchip Technology | IC EEPROM 2KBIT 2MHZ SOT23-6 |
| 71 | U4 | 1 | LCMXO2-2000ZE-1UWG49 | XO2_2000ZE_49CSP | CUSTOMER SUPPLIED | LCMXO2-2000ZE-1UWG49 | Lattice | LCMXO2-2000ZE-1UWG49 |
| 72 | U5 | 1 | NOR Flash | N25Q032A_8SOIC | — | N25Q032A13ESC40G | Micron | IC FLASH 32MBIT 108MHZ 8SO |
| 73 | U6 | 1 | MIC_LEFT | MP34DB01_RHLGA | — | MP34DB01TR | STMicroelectronics | MIC MEMS DIGITAL PDM OMNI -26DB |
| 74 | U7 | 1 | MIC_RIGHT | MP34DB01_RHLGA | — | MP34DB01TR | STMicroelectronics | MIC MEMS DIGITAL PDM OMNI -26DB |
| 75 | U8 | 1 | TPS61061 | TPS61061_8QFN | — | TPS61061DRBR | TI | IC LED DRIVER WHITE BCKLGT 8SON |
| 76 | U9 | 1 | iCE5LP4K | iCE5LP4K_SWG36 | CUSTOMER SUPPLIED | iCE5LP-4K-SWG36 | Lattice | iCE40 Ultra family is an ultra-low power FPGA and sensor manager |
| 77 | U10 | 1 | NOR-FLASH | M25P80_SO8N | — | M25P80-VMN6TP | Micron | IC FLASH 8MBIT 75MHZ 8SO |
| 78 | U11 | 1 | 4-BIT_TRANSLATOR | 12DSBGA_TXB0104 | — | TXB0104YZTR | Texas Instruments | IC XLATR VOLT-LVL 4B ESD 12DSBGA |
| 79 | U12 | 1 | 2-BIT_TRANSLATOR | 8DSBGA_TXB0102 | — | TXB0102YZPR | Texas Instruments | IC 2BIT V-TRANS-LATR W/ESD 8DSBGA |
| 80 | U13 | 1 | MIC5320 | MIC5320_6MLF | — | MIC5320-PGYMT TR | Micrel Inc | IC REG LDO 3 V/1.8 V 0.15A 6TMLF |
| 81 | U14 | 1 | TPS7A7200 | TPS7A7200_16QFN | — | TPS7A7200RGTT | Texas Instruments | IC REG LDO FIX/ADJ 2A 16QFN |
| 82 | U15 | 1 | 1-BIT_TRANSLATOR | 6SON_SN74AUP1T34 | — | SN74AUP1T34DSFR | Texas Instruments | IC V-LEVEL XLATR UNIDIR 6SON |
| 83 | U16 | 1 | MIC5504 | MIC5504_4TDFN | — | MIC5504-1.2YMT TZ | Micrel Inc | IC REG LDO 1.2 V 0.3A 4TDFN |
| 84 | Y1 | 1 | 12MHz | 403C35D12M00000_4 SMD | — | 403C35D12M00000 | Abracon Corp | CRYSTAL 12MHZ 18 pF SMD |
| 85 | Y2 | 1 | 27.000MHz | OSC_ASCSM | — | ASCSCM-27.000MHZ-LR-T | Abracon | OSC XO 27.000MHZ CMOS SMD |
| 86 | WEARABLE SOLUTION MAIN BOARD PCB | 1 | — | — | — | 305-PD-15-0069 | PACTRON | — |
| 87 | LCD Display | 1 | www.vcdisplay.com - David Fontano / david@vcdisplay.com | LH154Q01-TD01 | LG | http://vcdisplay.com | | |
| 88 | Battery | 1 | http://www.ebay.com | S107-19 or 652030 | Syma | 3.7 V 240mAh Li-Po Battery for SYMA S026 RC Remote Quadcopter - bag & tag item | | |
| 89 | Magnet | 8 | http://www.amazon.com | ??? | MyMagnetMan | MyMagnetMan® 1/4" x 1/16" (6.35 x 1.58mm) 3M-467 Adhesive Rare Earth Neodymium Disc Magnets for Crafts | | |

Appendix D. Sensor Board Bill of Materials

Figure 22. Sensor Board Bill of Materials

| Item | Reference | Qty | Part | PCB Footprint | Comments | Part Number | Manufacturer | Description |
|------|--|-----|------------|-----------------|---|-------------------------|--------------------|--|
| 1 | C1 | 1 | 10uF | C0805 | — | C2012X5R1C106K085AC | TDK | CAP CER 10 μ F 16 V 10% X5R 0805 |
| 2 | C2,C3,C4,C6,C7,C9,C10,C16,C17,C18,C19,C20 | 12 | 0.1uF | C0402 | — | C1005X5R1C104K050BA | TDK | CAP CER 0.1 μ F 16 V 10% X5R 0402 |
| 3 | C5,C12 | 2 | 0.01uF | C0402 | — | GRM155R61C103KA01D | Murata | CAP CER 10000 pF 16 V 10% X5R 0402 |
| 4 | C8 | 1 | 4.7uF | C0603 | — | EMK107ABJ475KA-T | Taiyo Yuden | CAP CER 4.7 μ F 16 V 10% X5R 0603 |
| 5 | C11,C13 | 2 | 2.2uF | C0402 | — | C1005X5R1C225K050BC | TDK | CAP CER 2.2 μ F 16 V 10% X5R 0402 |
| 6 | C14,C15 | 2 | 8pF | C0402 | — | GRM1555C1E8R0CA01D | Murata | CAP CER 8 pF 25 V NP0 0402 |
| 7 | C21 | 1 | 10uF | C0603 | — | C1608X5R0J106K080AB | TDK | CAP CER 10 μ F 6.3 V 10% X5R 0603 |
| 8 | C22 | 1 | 22uF | C0603 | — | C1608X5R0J226M080AC | TDK | CAP CER 22 μ F 6.3 V 20% X5R 0603 |
| 9 | C23 | 1 | 1uF | C0402 | — | C1005X5R1C105K050BC | TDK | CAP CER 1 μ F 16 V 10% X5R 0402 |
| 10 | J2 | 1 | 2X3 SOCKET | 2X3_SOCKET_SMD | — | NPPC032KFMS-RC | Sullins | CONN FEMALE 6POS DL .1" GOLD SMD |
| 11 | J3 | 1 | 2X5 SOCKET | 2X5_SOCKET_SMD | — | NPPC052KFMS-RC | Sullins | CONN FEMALE 10POS DL .1" GOLD SMD |
| 12 | J4 | 1 | 1X2 Header | 1X2_HDR_SMD | BREAKAWAY PART | 15910100 | Molex Inc | CONN HEADER 10POS .100" STR 15AU |
| 13 | J5 | 1 | 2X2 SOCKET | 2X2_SOCKET_SMD | — | M20-7870246 | Harwin Inc | 02+02 DIL SMT SKT |
| 14 | L1 | 1 | 0.47uH | L2016 | — | 1286AS-H-R47M | Toko | Inductor 0.47uH DFE201612C series |
| 15 | R1,R12,R15,R25,R26,R27 | 6 | 10K | R0402 | — | ERJ-2RKF1002X | Panasonic | RES 10K Ohm 1/10W 1% 0402 SMD |
| 16 | R2,R3,R4,R5,R6,R7,R8,R9,R10,R11,R13,R14,R16,R17,R19,R21,R23 | 17 | 0 | R0402 | — | ERJ-2GE0R00X | Panasonic | RES 0.0 Ohm 1/10W 0402 SMD |
| 17 | R18,R20 | 2 | DNL | R0402 | DNL | — | — | — |
| 18 | R22 | 1 | 0.001 | R1206 | — | CSNL1206FT1L00 | Stackpole | RES SMD 0.001 Ohm 1% 1W 1206 |
| 19 | R24 | 1 | 1K | R0402 | — | ERJ-2RKF1001X | Panasonic | RES 1K Ohm 1/10W 1% 0402 SMD |
| 20 | TP1,TP2,TP3,TP4,TP5,TP6,TP7,TP8,TP9,TP10,TP11,TP14,TP15,TP16 | 14 | TEST POINT | TEST_POINT | DNL | — | — | — |
| 21 | TP12,TP13 | 2 | 80_MIL_PAD | TP_80MIL | DNL | — | — | — |
| 22 | TP17,TP18 | 2 | T POINT R | 30_mil_pad | DNL | — | — | — |
| 23 | U1 | 1 | FAN48610 | FAN48610 | — | FAN48610UC50X | Fairchild | IC REG BOOST SYNC 5 V 1A 9WLCSP |
| 24 | U2 | 1 | AFE4403 | AFE4403_36DSBGA | — | AFE4403YZPT | TI | IC AFE FRONT END 36DSBGA |
| 25 | U3 | 1 | LPS25H | LPS25H_10HCLGA | — | LPS25HTR | STMicroelectronics | IC MEMS PRESSURE SENSOR 10HCLGA |
| 26 | U4 | 1 | LSM330DLC | LSM330DLC_28LGA | — | LSM330DLCTR | STMicroelectronics | ACCELEROMETER/ GYROSCOPE 28LGA |
| 27 | U5 | 1 | SeeedBLE | SeeedBLE | http://www.seeedstudio.com | 113050012 | Seeed | Low cost ARM cortex-m0 based module for Bluetooth module |
| 28 | U6 | 1 | SFH7050 | SFH7050 | — | SFH7050 | OSRAM | Biomonitoring Sensor for heart rate monitoring, Pulse oximetry and proximity |
| 29 | U7 | 1 | TMP112 | TMP112_SOT563 | — | TMP112AIDRLT | TI | IC TEMP SENSOR DGT 5 V SOT563 |
| 30 | Y1 | 1 | 8MHz | NX3225GD_8MHZ | — | NX3225GD-8MHZ-STD-CRA-3 | NDK | CRYSTAL 8MHZ 8 pF SMD |
| 31 | WEARABLE SOLUTION SENSOR BOARD PCB | 1 | — | — | — | 305-PD-15-0028 | FACTRON | — |