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LoRa IoT Mulch Sensor

User Guide

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Revision History

Version	Date	Editor	Status	Comments
0.1	July 17, 2020	Lukas Morrison	Draft	Initial draft.
1.0	November 18, 2020	Lukas Morrison	Release	• Updated conversion formula (Section 4.5). • Updated Figure 1-1, Figure 2-2, Figure 4-1.
1.1	August 26, 2021	Mark Oevering	Release	• Update to document revisions in the References Section

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Acronyms and Glossary

ADC .... Analog-To-Digital Converter
AWG.... .... American Wire Gauge
bps....... .... bits per second
DC........ .... Direct Current
FCC....... .... Federal Communications Commissions
FET....... .... Field-Effect Transistor
I/O....... .... Input / Output
IoT .... Internet of Things
IP .... Ingress Protection
LED .... Light Emitting Diode
LoRa .... a patented "long-range" IoT technology acquired by Semtech
LoRaWAN......... .... LoRa Wide Area Network (a network protocol based on LoRa)
LSB....... .... Least Significant Bit
LTC....... .... Lithium Thionyl Chloride (chemistry of LTC batteries)
MCU .... Microcontroller Unit
(Mulch) Sensor. .... any variant of the TEKTELIC LoRa IoT Mulch Sensor
NC........ .... Not Connected
OC........ .... Open Circuit
OTA .... Over the Air
PCB .... Printed Circuit Board
PCBA.... .... PCB Assembly
PTC .... Positive Temperature Coefficient
Rev .... Revision
RF .... Radio Frequency
RFU...... .... Reserved for Future Use
RS .... Recommended Standard (as in RS-232, RS-422, RS-485)
RTU...... .... Remote Terminal Unit (as a Modbus type)
Rx .... Receiver / Receive
SC......... .... Short Circuit
SSR....... .... Solid-State Relay
Tx......... .... Transmitter / Transmit
UV........ .... Ultraviolet
ver. .... version
WSOR .. .. Weld-Slag and Oil-Resistance

1 Product Description

1.1 Overview

The TEKTELIC LoRa IoT Mulch Sensor is a LoRaWAN IoT sensor intended for interfacing automation and control instrumentation to a LoRaWAN network. The Mulch Sensor supports up to three analog and digital inputs allowing for the remote capture of data, and two switched outputs to actuate externally connected devices. The built-in serial relay allows for serial communication over a RS-232 or RS-485/422 bus. Table 1-1 presents the currently available LoRa IoT Mulch Sensor models.

Table 1-1: Mulch Sensor Models

Product Code & Revision	Description	RF Region	Tx Band (MHz)	Rx Band (MHz)
T0006813 Rev C	Mulch Sensor Module – 4 ft, EU/NA	US915	902.3 – 914.9	923.3 – 927.5
		EU868	863 – 870	
T0006814 Rev C	Mulch Sensor Module – 8 ft, EU/NA	US915	902.3 – 914.9	923.3 – 927.5
		EU868	863 – 870	

The main features of the Mulch Sensor are the following:

- **Temperature Transducer:** Reports ambient temperature of the local environment.
- **Digital Input**: Reports open-drain or driven signals.
- **Analog 0 mA – 20 mA Current Input:** Monitors and reports current outputs of remote equipment.
- **Analog Thermistor Input**: Monitors and reports the voltages corresponding to the variable impedance of a remote 10-*k*Ω temperature probe.
- **60 V DC Output (FET Based)**: Non-isolated open-drain output.
- **60 V DC Output (SSR)**: Isolated relay output.

Figure 1-1 illustrates the Mulch Sensor in the enclosure with the temperature probe attached.

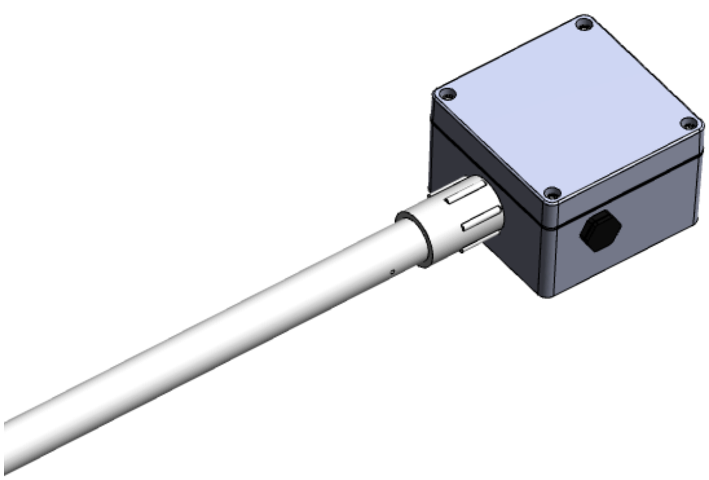

Figure 1-1: LoRa IoT Mulch Sensor

1.2 Physical Interfaces

Figure 1-2 illustrates the terminal block on the PCBA, which provides customer accessible interfaces for the Mulch Sensor.[1] All models share the same layout.

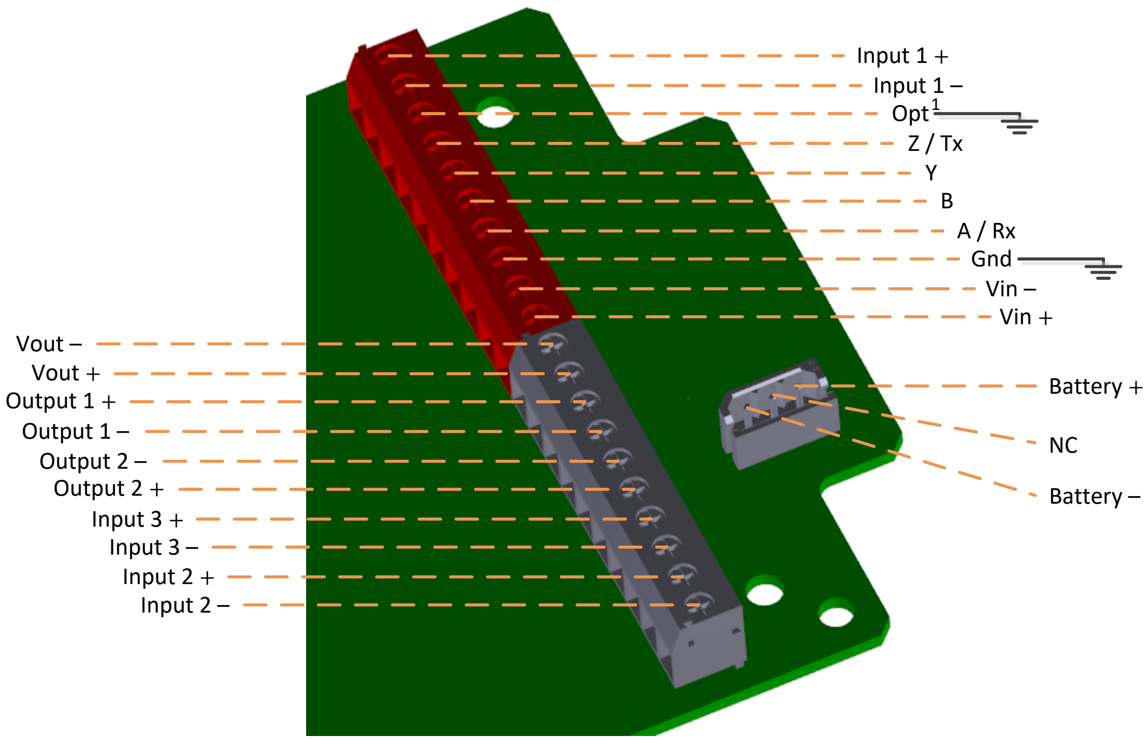

Figure 1-2: Mulch Sensor Interface Layout (Terminal Block and Battery Connector Pinout)

1.3 Specifications

The Mulch Sensor specifications are listed in Table 1-2. Also, Table 1-3 shows the Sensor serial interface operating specifications. Moreover, Table 1-4 indicates the absolute maximum ratings for the Sensor.

Table 1-2: LoRa IoT Mulch Sensor Specifications

Attribute	Specification
Use Environment	Industrial, indoor/outdoor commercial/residential
Environmental Rating	IP67
Enclosure	Hammond Manufacturing 1554E2GY UL 508 approved which includes 720-hour UV testing
Cable Gland	Bud Industries NG-9513 Cable Gland Nylon PG11 Black Cable diameter range 0.20" ~ 0.30" (5.0mm ~ 7.5mm)
Humidity Vent	IP67 rated

[1] Opt terminal block connection is RFU.

Operating Temperature	-40°C – 85°C
Storage Temperature for Optimal Battery Life	-40°C – 75°C
Operating Relative Humidity	10% – 100%, condensing
Storage Relative Humidity	5% – 95%, non-condensing
Size	90 mm x 90 mm x 60.5 mm
Weight	Without battery: 205 g With D-cell LTC battery: 295 g
Power Source	• Battery powered: 1x D-cell LTC with keyed battery connector and reverse polarity protection • Externally powered: 10 V – 26 V DC (typically 12 V – 24 V DC) with reverse polarity protection
Network technology/Frequency band	LoRaWAN in several variants (see Table 1-1): US915, EU868, DN915, CN470
Air Interface	LoRa
Battery Lifetime	25 years[2]
Maximum Tx Power	22 dBm
LEDs (internal)	System LED (Green): Joining the network activity LoRa LED (Red): LoRa Tx or Rx activity
Sensing Functions	Temperature (MCU & ambient), 1x digital input, 2x analog input, 2x digital output
MCU Temperature Measurement Accuracy	$< \pm 5$°C between -40°C and 85°C
Ambient Temperature Measurement Accuracy	± 0.5°C between 15°C and 40°C ± 1°C between 0°C and 60°C [as per the HTS221 datasheet]
Digital Input (Input 1)	Input open drain or driven signals Input Low: SC or 0 V – 1.8 V Input High: OC or 1.8 V – 60 V Asynchronous response
Analog Current (Input 2)	Measurement of input over the range 0mA – 20mA. Use of 12-bit ADC gives a precision of 5.4 μA/LSB (with input range up to 22.3 mA corresponding to the ADC reference voltage of 1.25 V).
Thermistor (Input 3)	Measurement of a 10-kΩ thermistor as a remote temperature probe (e.g. Vishay component Cantherm CWF3AA103G3380).
Serial Interface	Support of Modbus RTU device over RS-232/422/485 (half- or full-duplex mode) with a baud rate support of up to at least 250 kbps.

[2] This is for transmission at maximum power every 15 minutes at room temperature, with an LTC battery having a nominal capacity of 19 Ah and self-discharge rate of 0.7%. Large variations to this estimate can occur depending on the ambient temperature, amount of usage, battery capacity, and battery self-discharge rate. For example, continuously being at -30°C and transmitting at maximum power every 30 seconds, the same battery may not last above a year.

FET Output (Output 1)	Grounded source FET that allows open drain style operation on external lines up to 60 V. Output impedance 10.2 Ω when turned on, > 40 MΩ when turned off.
SSR Output (Output 2)	An isolated, polarity agnostic relay switch for operation on external lines up to ±60 V. Output impedance 35.6 Ω when turned on, > 40 MΩ when turned off.

Table 1-3: Serial Interface Operating Specifications

Parameter	Min	Typical	Max
RS-232 Tx	±5 V	±5.5 V	–
RS-232 Rx	-15 V	–	+15 V
RS-485/422 Tx[3,4]	1.5 V differential	–	3.3 V differential
RS-485/422 Rx Threshold[3,4]	-200 mV differential	-125 mV differential	-50 mV differential

Table 1-4: Sensor Absolute Maximum Ratings

Parameter	Absolute Maximum[5]
Operating Temperature Range	-40°C – 85°C
Battery Vin	3.7 V
External Vin	42 V
Digital Input (Input 1)	60 V
Current Input (Input 2)	46 mA
FET Output (Output 1)	Voltage rating: • 60 V DC operating • 100 V DC no damage Current rating: • 75 mA at -40°C • 50 mA at 23°C • 25 mA at 85°C
SSR Output (Output 2)	Voltage rating: • ±60 V DC operating • ±100 V DC no damage Current rating: • 75 mA at -40°C • 50 mA at 23°C • 25 mA at 85°C
Serial Interface	+/-18 V

[3] RS-485 signals are differential and are measured as such.

[4] The serial transceiver in the design is compliant with both RS-232 and RS-422/485 standards.

[5] Operating outside of these ranges will damage the Sensor or battery.

2 Installation

2.1 Included Product and Installation Material

The following items are shipped with each sensor:

- LoRa IoT Mulch Sensor
- LTC Battery, D-size
- Temperature Probe
- Product Manual

2.2 Safety Precautions

The following safety precautions should be observed:

- Use only LTC cells.
- Do not exceed the maximum specified terminal voltages.
- All installation practices must be in accordance with the local and national electrical codes.
- Sensor inputs and outputs do not provide electrical isolation to system ground, or between each other.

2.3 Unpacking and Inspection

The following should be considered during the unpacking of a new Mulch Sensor:

- Inspect the shipping carton and report any significant damage to TEKTELIC.
- Unpacking should be conducted in a clean and dry location.
- Do not discard the shipping box or inserts as they will be required if a unit is returned for repair or re-configuration.

2.4 Equipment Required for Installation

The following tools are required to install the Mulch Sensor:

- #2 Phillips screwdriver (4 x enclosure screws)
- #0 Phillips screwdriver (internal terminal block connections)
- Wrench to tighten cable gland
- Wire Stripper
- Wire Cutter

2.5 Mulch Sensor Mounting

When the cover is removed, four (4) mounting holes are exposed See Figure 2-1. These mounting holes can be used to screw the enclosure to a solid surface. The recommended mounting screw size is M3 or #6. Mounting screws are not provided with the sensor.

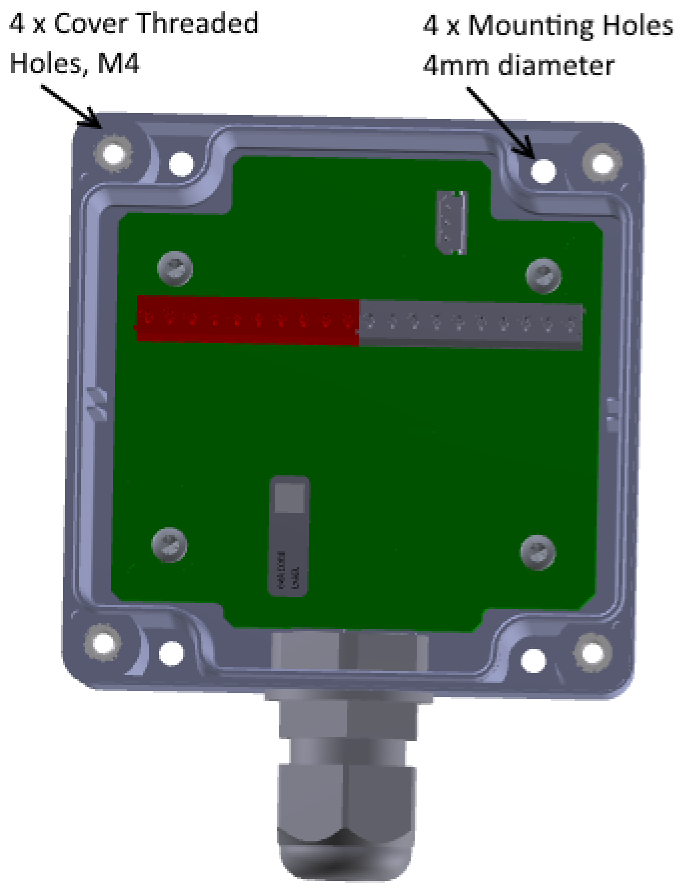

Figure 2-1: Mounting Holes and Threaded Cover Holes

The mounting surface must be capable of holding more than 2 kg (4.5 lbs). Clearance must be provided for the modules cable gland and input cable.

2.6 Cable Installation

The Mulch Sensor enclosure is provided with an IP68 cable gland through which all connections must be routed. The supplied cable gland size is PG-11. This gland supports cables with a straight jacket of diameter of 5.0 mm to 9.9 mm (0.2" to 0.39"). The customer supplied cable must be rated for outdoor use and have **a single, smooth, and straight jacket** to achieve a watertight seal and IP68 rating with the gland. The recommended gland nut torque is 4 Nm (35 in-lbs).

Suggested cable: Molex 155220-0047 (Flamar Sensor Cable, WSOR Jacket, Unshielded, 12 Circuits, 24 AWG, 6.90 mm Diameter).

The I/O terminal block accepts 18 – 26 AWG wires. Select a cable that meets the application requirements and local and national electrical codes.

Figure 2-2 shows the terminal block wiring connections. To install the cable, first make the appropriate connections between the input cable and the terminal block. Next dress the internal wires so that the cable gland seals against the outer cable jacket. Finally, tighten the cable gland.

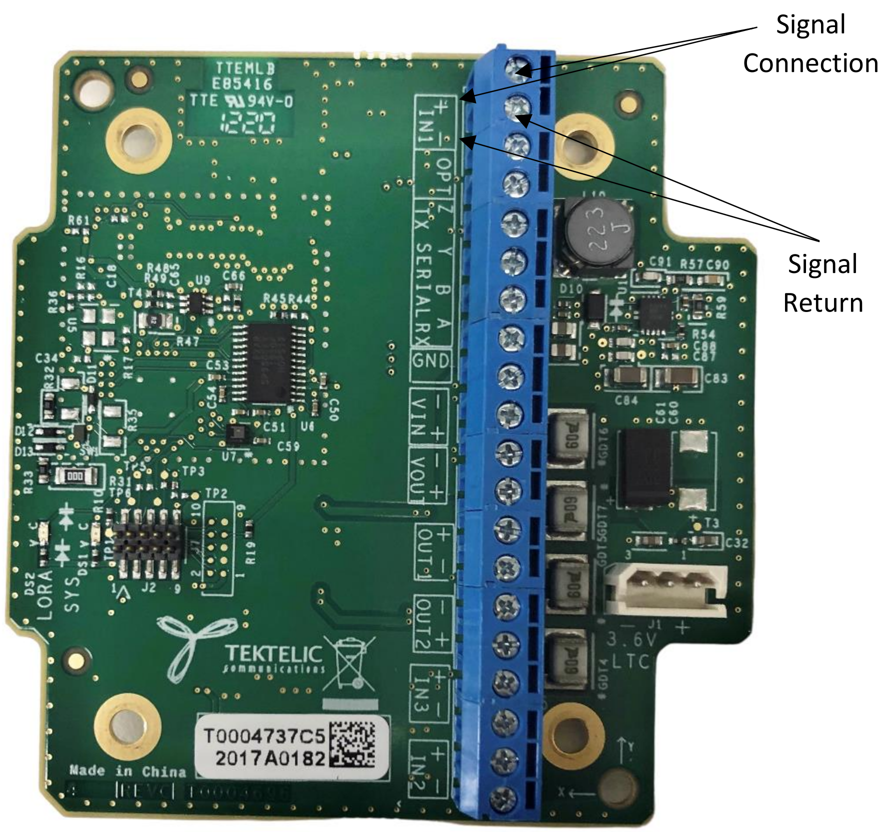

Figure 2-2: Mulch Sensor External Connector Signals

The inputs and outputs are labeled on the PCB. Signal connections should be connected to the positive terminal (labeled '+') of the desired I/O channel as indicated by the silkscreen. Similarly, the return path should be connected to the negative terminal (labeled '-') of the matching I/O channel.

NOTE: Mulch Sensor I/O are referenced to the sensor ground and are not isolated (except for Output 2 that is isolated relay switch).

The Mulch Sensor serial port provides a means to connect the Sensor to devices communicating over RS-232, RS-422, or RS-485 standard channels. No hardware flow control is offered for RS-232 operation. Full and half duplex modes are available in RS-485 operation as required.

The serial port connections on the terminal block have been shown in Table 2-1.

Table 2-1: Serial Port Connections

Terminal	RS-232	RS-422	RS-485 Half Duplex	RS-485 Full Duplex
Z / TX	Tx	Tx-	Data-	Tx-
Y	NC	Tx+	Data+	Tx+
B	NC	Rx-	NC	Rx-
A / RX	Rx	Rx+	NC	Rx+
GND	Ground	(Shield)	(Shield)	(Shield)

The GND labeled terminals provide a signal reference for single ended RS-232 signalling. When differential mode RS-422/485 is used, the GND terminals may be used for cable shield connections.

NOTE: Mulch Sensor serial I/O are referenced to the sensor ground and are not isolated, even in differential mode the I/O present no isolation.

3 Power Up, Commissioning, and Monitoring

3.1 Required Equipment

- A #2 Phillips screwdriver

3.2 Power Up/Down Procedure

- The sensor is shipped with the battery wire unplugged. Remove 4 screws holding the cover, to gain access to the Sensor battery connector. Be careful not to misplace the silicone cover gasket.
- Once the sensor is configured on the Network Server and input cable is installed, plug the battery into the sensor circuit board. See Section 4.3 for the LED behaviour.
- Once the Sensor is powered, replace the cover and gasket. Make sure that the gasket is properly seated in the cover before placing on the Sensor housing. Tighten the 4 cover screws to 2.5 lbf-in (30 N-cm).
- To reset or turn off the device the battery must be unplugged from the circuit board. The unit must remain un-powered for 1 minute to completely reset.

4 Operation, Alarms, and Management

4.1 Configuration

The Mulch Sensor supports a full range of OTA configuration options. Specific technical details are available in the Industrial Sensor Technical Reference Manual. All configuration commands need to be sent OTA during a sensor's downlink windows.

4.2 Default Configuration

The default configuration on the Mulch Sensor is as follows:

- Report Temperature every one (1) hour.
- Report Battery Voltage every one (1) hour.
- Report actuation of the digital input element every one (1) actuation.
- Report Input 1 (Digital), Input 2 (Current) and Input 3 (Thermistor) reading every fifteen (15) minutes.

The default configuration of the Mulch Sensor serial port is as follows:

- Protocol RS232
- Baud rate 115200 bps
- 8 Date Bits, No Parity Bits, 1 Stop Bit

4.3 LED Behavior

See Figure 4-1 for the location and identification of the Mulch Sensor LEDs.

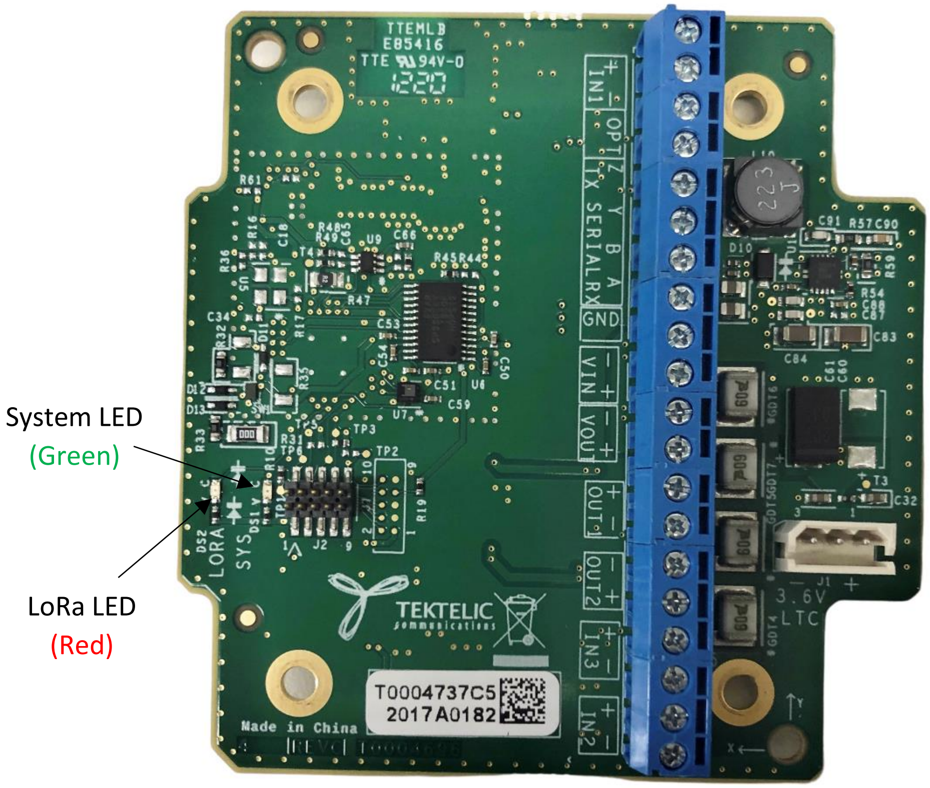

Figure 4-1: Mulch Sensor LEDs

During the boot and join procedure:

- Both LEDs will come on briefly when power is first applied.
- After a small delay (< 1 second) the LEDs will turn off and one of them will blink briefly.
    - If the System LED blinks, then all health checks on the board have passed.
    - If the LoRa LED blinks, then one of the health checks has failed. Consider replacing the battery, or moving the sensor to an environment within the temperature range.
- Immediately after the delay, the join procedure will begin. During the time the System LED will blink continuously until the sensor joins a network.
- The LoRa LED will now blink whenever LoRa activity occurs on the sensor (transmitting or receiving packets)

During normal operation:

- The LoRa LED will blink whenever LoRa activity occurs on the sensor (transmitting or receiving packets)
- The System LED can be controlled via the downlink command interface.

4.4 Inputs and Outputs

Three input channels and two output channels are present on the Mulch Sensor. All channels are connected to external devices (transducers) via the screw down terminal block (see Figure 2-2).

4.4.1 Digital Input (Input 1)

The digital input channel allows an open drain/relay based or driven signal to be monitored. This input is compliant to 60 V. The signal to this input is treated as an interrupt and read asynchronously. Example applications for this input include leak detection and reading a magnetic reed switch.

4.4.2 Current Input (Input 2)

A current input channel on the sensor allows the measurement of the industry standard 4 – 20mA current signal. This is achieved by converting the input current to a voltage through a sensing resistor that is within the ADC measurement range. The 4 – 20mA current loop is a widely use signalling standard in the industrial environment as it offers good noise immunity and is relatively simple.

4.4.3 Thermistor Input (Input 3) [6]

The thermistor input permits measurement of remote temperature through a 10 $k\Omega$ thermistor probe. The sensor reports voltage values corresponding to the variable impedance of the thermistor. The voltage values can then be converted to temperatures using a conversion table or formula.

4.4.4 Open Drain FET (Output 1)

The FET based output channel features a grounded source FET that allows open drain style operation on external lines up to 60 V. The PTC in the circuitry limits the operating current to 75 mA at -40°C, 50 mA at 23°C, and 25 mA at 85°C. As the FET source is connected to the PCB ground, this output switch is not isolated from the system.

4.4.5 Solid State Relay (Output 2)

Unlike the open drain output, the SSR output is isolated from the rest of the system (i.e. the PCB ground and other signals). The connection of the relay is polarity agnostic and is compliant to 60 V. Again, the PTC in the circuitry limits the operating current to 75 mA at -40°C, 50 mA at 23°C, and 25 mA at 85°C.

4.5 Thermistor Input (Input 3) Conversion

This section will describe the process used to convert the voltage data from the thermistor into a temperature value. The voltage reported back is based on the variable impedance of the thermistor. In order to convert this number into temperature two formulas must be used. The constant values include:

- $R = 68100\ \Omega$ (68.1 kΩ)
- $V_{\mathrm{MCU}} = 2.7$ V
- $R_0 = 10000\ \Omega$ (10 kΩ)
- $T_0 = 298.15$ K (25°C)
- $\beta = 3380$ (CWF3AA103G3380)

[6] Board revisions of C1 and earlier have an Analog Input 3. The analog input allows the user to measure a voltage of 0 – 10 V. This is present on T0005322 (EU Module) Rev A.

Firstly, a voltage divider equation is used to find the resistance of the variable resistor. This equation requires the MCU voltage, known resistor value, and the reported voltage value, V_{in}, as shown below. This formula can be rearranged to solve for the unknown value, R_T:

$$V_{in} = V_{\mathrm{MCU}} \frac{R_T}{R_T + R}$$

$$\downarrow$$

$$R_T = \frac{R \cdot V_{in}}{V_{\mathrm{MCU}} - V_{in}}$$

Voltage Divider Equation

Once the three known values are plugged into the formula and R_T is obtained, the second formula, β-parameter equation, is implemented. This equation needs the β-value of the thermistor used, along with R_T, R_0, and $T_0 = 298.15$. The value R_0 represents the resistance of the specific thermistor at T_0 (298.15 *K* or 25°C).

$$R_T = R_0\, e^{\beta\left(\frac{1}{T} - \frac{1}{T_0}\right)}$$

$$\downarrow$$

$$T = \frac{T_0 \cdot \beta}{T_0 \ln(R_T/R_0) + \beta}$$

β-parameter Equation

An overall formula for the conversion can be found below:

$$T = \frac{T_0 \cdot \beta}{T_0\, ln\left(\frac{R \cdot V_{in}}{R_0 \cdot (V_{\mathrm{MCU}} - V_{in})}\right) + \beta}$$

Replacing variables with constant numbers yields:

$$T = \frac{298.15\ K \cdot 3380}{298.15\ ln\left(\frac{68100\ \Omega \cdot V_{in}}{10000\ \Omega \cdot (2.7\ V - V_{in})}\right) + 3380}$$

In Kelvin, for thermistor CWF3AA103G3380. Note that temperature T in this formula is in Kelvin. To convert T into Celsius subtract 273.15.

Another method to get even more accurate conversion formula, at the expense of doing a full calibration of the thermistor, is to rearrange the above formula for *T* as,

$$\boldsymbol{T = \frac{-\beta}{ln\left(\frac{V_{\mathrm{MCU}} \frac{R_0}{R} e^{-\frac{\beta}{T_0}}}{V_{in}} - \frac{R_0}{R} e^{-\frac{\beta}{T_0}}\right)}}$$

or

$$\boldsymbol{T = \frac{-\beta}{ln\left(\frac{a}{V_{in}} - b\right)}}$$

then to find parameters a and b by measuring temperatures using an accurate temperature sensor for different voltages, and doing curve fitting (i.e. basically calibrating a specific thermistor with a given β).[7]

[7] An accuracy of $\pm$ 1.7 °C can be obtained using the given values without curve fitting.

5 Battery Replacement

The LoRa IoT Mulch Sensor can be powered with a D-size, 3.6 V, LTC battery (T0005303). Use only approved LTC cells when replacing the battery. The following are approved replacement batteries:

- Saft LS33600
- Tadiran TL-5930/S
- Xeno XL-205F STD

To access the battery, remove the four screws located on the top of the sensor enclosure (see Figure 5-1). These screws require a #2 Phillips screwdriver.

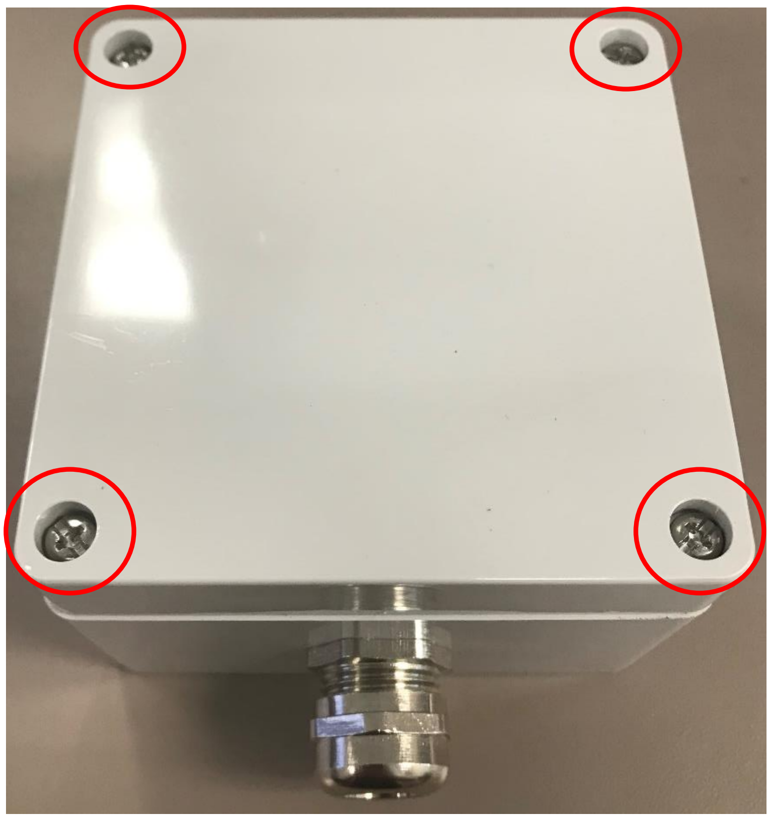

Figure 5-1: Enclosure Screws (x4)

1. Remove the four screws on the top of the sensor enclosure.
2. Unplug the battery connector from the sensor circuit board (see Figure 5-2).

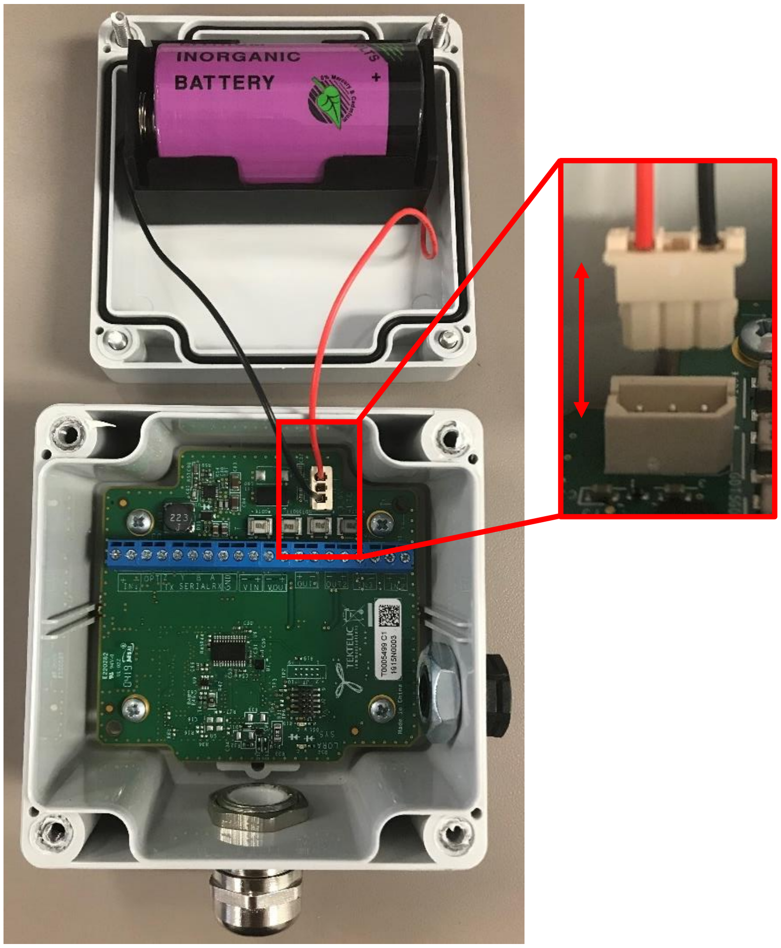

Figure 5-2: Battery Connector Removal

3. Remove the battery from the battery holder.
4. Insert a new battery into the battery holder. The battery and battery holder are both labeled with + symbols, be sure to line these up.
5. Plug the battery connector back into the sensor circuit board (the connector will only plug in the correct direction).
6. Check for LED activity. Blinking LEDs indicate the board is powered on and the battery replacement was successful.
7. Replace the sensor enclosure cover, and re-insert the four screws.

6 Compliance Statements

Federal Communications Commission:

This device complies with Part 15 of the FCC Rules. Operation is subject to the following two conditions:

1. This device may not cause harmful interference, and
2. This device must accept any interference received, including interference that may cause undesired operation.

Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment. This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to Part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one of the following measures:

- Reorient or relocate the receiving antenna.
- Increase the separation between the equipment and receiver.
- Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.
- Consult the dealer or an experienced radio/TV technician for help.

To comply with FCC exposure limits for general population / uncontrolled exposure, this device should be installed at a distance of 20 cm from all persons and must not be co-located or operating in conjunction with any other transmitter.

6.1 Proposition 65

⚠ WARNING: This product can expose you to chemicals including lead, nickel & carbon black, which is known to the State of California to cause cancer, birth defects or other reproductive harm. For more information, go to www.P65Warnings.ca.gov.

References

[1] LoRa Alliance, "LoRaWAN Specification," ver. 1.0.2, 2016.

[2] LoRa Alliance, "LoRaWAN 1.1 Regional Parameters," ver. 1.1, rev. B, Jan 2018.

[3] TEKTELIC Communications Inc., "LoRa IoT Industrial Transceiver Technical Reference Manual," ver 2.0, April 2021.

[4] TEKTELIC Communications Inc., "LoRa IoT Industrial Transceiver User Guide," ver 1.10, November 2020.