ELECOMP CAPSTONE
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THE UNIVERSITY OF RHODE ISLAND

THINK BIG WE DO™

BLE-TSTAT

Two-Wire Bluetooth Thermostat Adapter

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A Taco Group Company

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PROJECT MOTIVATION

Hydronic heating systems are controlled by thermostats located throughout the home, wired directly to an electronic controller at the heating unit. Older thermostats operate similar to a mechanical switch; when the system calls for heat, a connection is made between two wires, and the unit is powered on. With emerging technology, programmable "smart" thermostats have become increasingly more popular in the marketplace. These thermostats require a third (common) wire for power supply and proper operation. Most of the time when a homeowner is looking to upgrade to a smart thermostat, it is necessary to run new thermostat cable from the unit to each zone, increasing costs and challenges in installation. This is undesirable for the homeowner and the installer. The motivation for this project is to allow for convenient installations of smart thermostats to existing two-wire thermostat configurations, with minimal installation effort and no need for routing new wires.

KEY ACCOMPLISHMENTS

Design Concept: The design involved implementing a device able to detect a thermostat heat call signal and transmit it via Bluetooth to the heating unit, using power from the existing thermostat wires. The overall design concept is described by the block diagram in **Fig. 1**.

Component Selection:

Microcontroller: nRF52805 by Nordic Semiconductor was chosen due to its price, BLE capabilities and Taco's relationship with Nordic.

Power Management: A 4-diode bridge rectifier followed by a low-dropout voltage regulator (LDO) was designed for AC-DC conversion. The MCP1792 was selected based on cost and the $55V_{in}$ to $3.3V_{out}$ design specifications. The SOT-223 package with heat sink was chosen for temperature control. To ensure stability, 10uF/50V and 2.2uF/10V ceramic capacitors were selected for the input and output respectively.

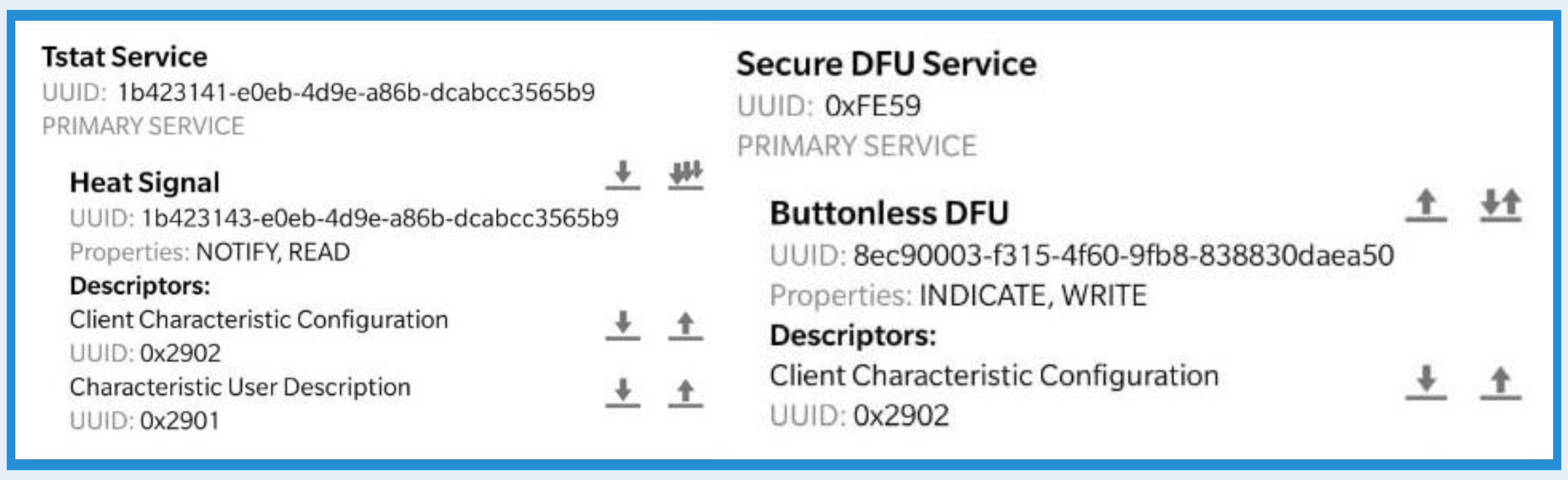
Heat Signal: A FOD817 optocoupler was selected to isolate the AC heat call signal from the DC MCU input. A diode and a 100kΩ current limiting resistor for the input and a 100kΩ pull-up resistor on the collector of the optocoupler were selected. Both resistors are sized for 1/4W power consumption.

Prototype Simulation & Design: A breadboard prototype was created using mostly through-hole components. The 24VAC input was produced via an isolation transformer connected to a Variac transformer for safely isolating earth ground. A resistor was used to simulate the MCU current load during BLE communication. Oscilloscope readings of ±20% nominal voltage were tested in the lab to ensure LDO stability.

PCB Design: Altium Circuit Maker was used for the schematic, **Fig. 2**, and PCB layout. Board specifications and design rules were based on OSH Park 2-layer board guidelines. Circuitry for proper MCU operation was determined via the nRF52805's data sheet. The antenna was based on a template for an AN043 Inverted F Antenna (IFA) designed by Audun Andersen from Texas Instruments to have an impedance of 50Ω at 2.45 GHz.

Firmware Development: Firmware for BLE communication was developed using Segger Embedded Studio and nRF5_SDK examples provided by Nordic Semiconductor. The main service transmits a bluetooth signal to the central unit to indicate when the thermostat heat state changes. A bootloader was created for initiating a buttonless Device Firmware Update (DFU) service for wireless update capabilities. The firmware was designed and tested on the nRF52_SDK and confirmed via Nordic's phone application nRF Connect, shown in **Fig. 4**. It was then adapted and developed for nRF52805 by adjusting certain aspects to accept the S112 SoftDevice. Adjustments included changing the preprocessor definitions, memory segments and section placement macros associated with the correct flash and RAM sizes. New files needed to be patched into the SDK to support the nRF52805 as well as adjusting the post build command associated with generating the settings for the main service.

Alpha Testing: The fabricated PCB, **Fig. 3**, was tested with the transformer power supply setup previously described for the breadboard prototype. The firmware was uploaded to the PCB via the nRF52_SDK using a plug-of-nails connector. More capacitance was needed on the DC side of the board for stability when uploading the firmware. The service failed to show on the nRF connect app, indicating that there are some issues with either the antenna or firmware that need to be solved.



Tstat Service
UUID: 1b423141-e0eb-4d9e-a86b-dcabcc3565b9
PRIMARY SERVICE

Heat Signal
UUID: 1b423143-e0eb-4d9e-a86b-dcabcc3565b9
Properties: NOTIFY, READ
Descriptors:
Client Characteristic Configuration
UUID: 0x2902
Characteristic User Description
UUID: 0x2901

Secure DFU Service
UUID: 0xFE59
PRIMARY SERVICE

Buttonless DFU
UUID: 8ec90003-f315-4f60-9fb8-838830daea50
Properties: INDICATE, WRITE
Descriptors:
Client Characteristic Configuration
UUID: 0x2902

Fig. 4: nRF connect application showing the Tstat heat signal and Device Firmware Update services being transmitted using the nRF52 development kit.

ANTICIPATED BEST OUTCOME

The anticipated best outcome of this design is to develop the hardware to bring power via two existing thermostat wires from an electronic zone controller to a programmable thermostat, pass the heating call signal from a smart thermostat to a microcontroller, and develop firmware to transmit a Bluetooth Low-Energy (BLE) signal from the microcontroller to a hydronic heating unit when the thermostat call state changes. Once all design specifications are met, fabricate a prototype PCB that is functional and ready for lab testing and possible field testing. The device should be cost effective to maximize production and sized efficiently to simplify the installation process.

PROJECT OUTCOME

The hardware and firmware were completed and demonstrated to be working on a breadboard prototype and the nRF52 software development kit. The PCB prototype needed hardware modifications and had issues with showing services on the nRF Connect application. Although the design concept is complete, further firmware debugging needs to be done.

FIGURES

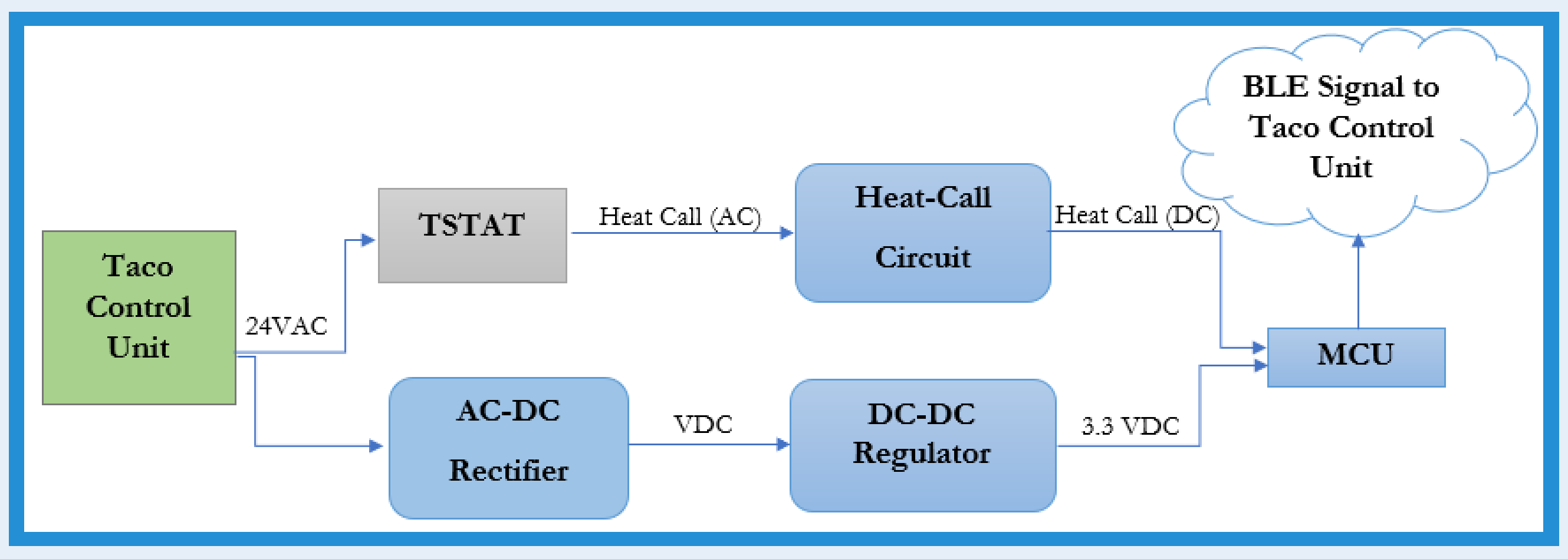


Fig. 1: Block diagram of the overall design.

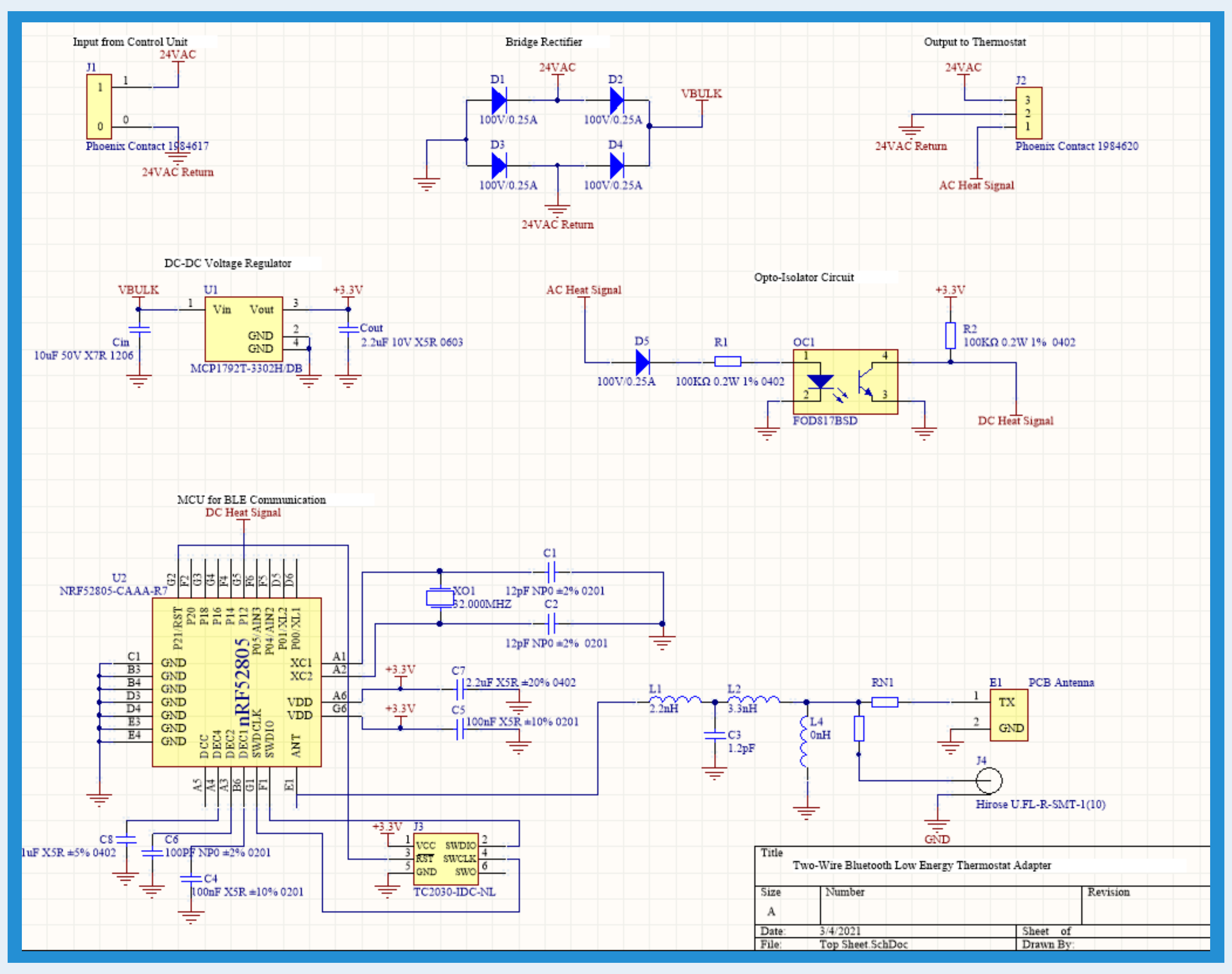


Fig. 2: Schematic showing the components and circuits for the design.

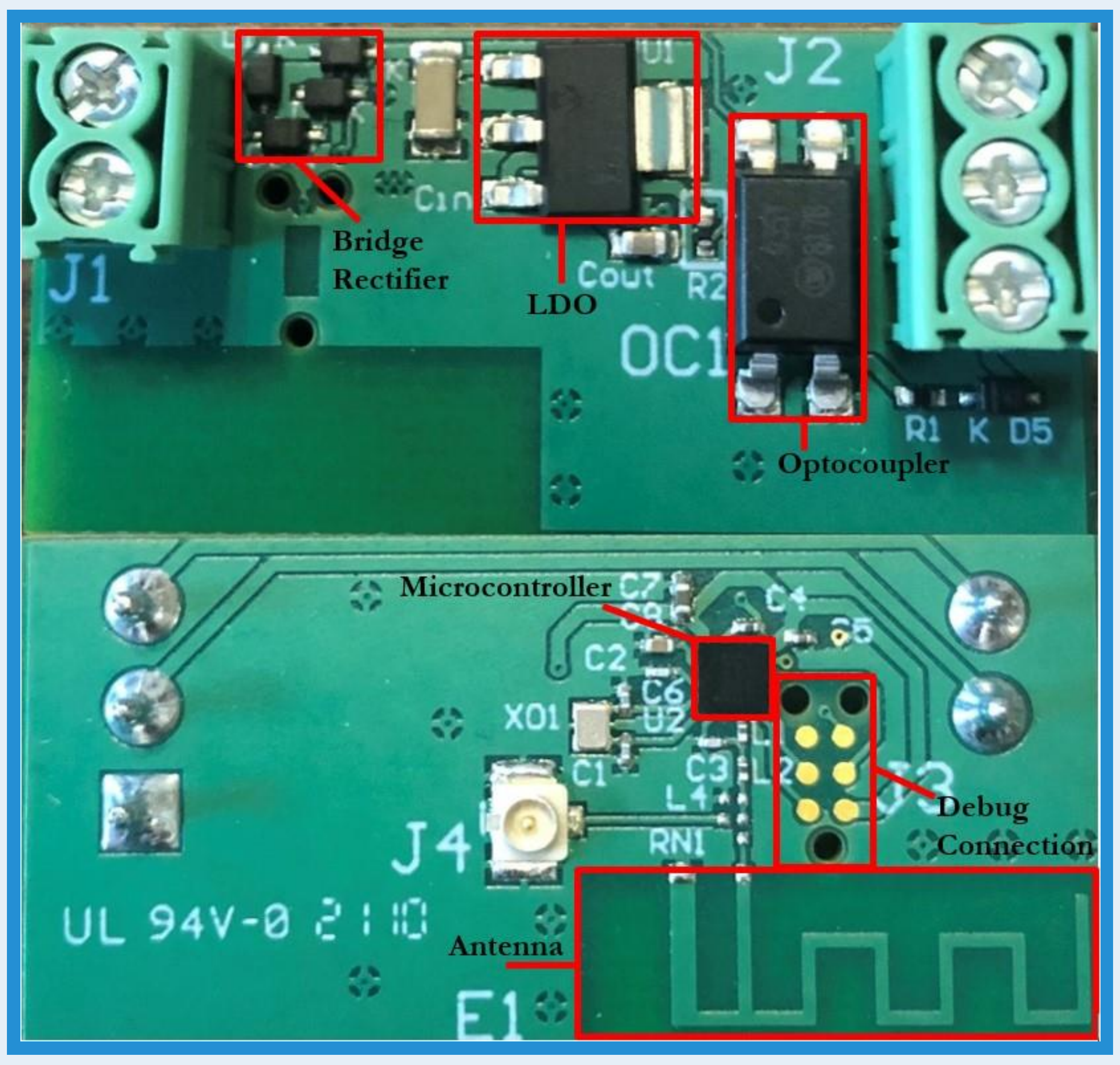


Fig. 3: PCB prototype. Top layer: connectors, power management, and optocoupler circuits. Bottom layer: MCU, antenna, and debug connector.

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