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Final Design Report Draft
For
Wireless Charger Project

A design project to fulfill the requirements of Senior Design in the Department of Electrical Engineering at The University of Texas at Tyler

The individuals whose names and signatures appear below certify that the narrative, diagrams, figures, tables, calculations, and analyses contained within this document are their original work except as otherwise cited.

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ACKNOWLEDGMENTS

We as a team wish to thank Indus Instruments and Dr. Sridhar Madala for being the benefactors and sponsors of our Project. Indus Instruments develops and creates electronic devices and software to meet the needs of various industries; for instance, they provide Baylor College of Medicine critical equipment for medical research. Dr. Sridhar Madala has been generous with our time and was critical in the initial planning phase of the project. Dr. Madala's familiarity with FCC and international wireless transmission regulations gave clear constraints and direction to this project. Thus, we especially thank Dr. Sridhar Madala for agreeing to be HEC-2's technical advisor.

EXECUTIVE SUMMARY

The team has designed and is prototyping a managed, 30 watt wireless resonant charger for use with lithium-ion battery packs. It shall be a versatile solution to the problem of powering autonomous mobile devices fitted with moderately sized battery packs of approximately four to six 18650 cells configured for 7.4 to 14.7 volts nominal output. With an estimated cost around $300, it fills a gap between inexpensive inductive chargers in the 5 watt range and custom 90 watt robotic power systems that have an entry level price of $2000.

Our charging system is made with two essential components: a transmitter and receiver. The transmitter is supplied by standard line voltage and will be responsible for safely delivering up to 30 watts of resonant power to the receiver when in range and appropriately positioned. It shall communicate status with the receiver over a Bluetooth link and shall enable or disable power transmission when requested.

The receiver shall communicate with the transmitter and to a user GUI over Bluetooth links, and optionally with the user's own application (i.e. a robot microcontroller) over a serial link. It will be capable of delivering requested power transmission and charging status information and beginning or ending the charging process. It shall cease charging on receipt of an error status from the charging circuit and will notify the user to take corrective action. Under normal conditions it will deliver power to the charging control IC, which shall charge the attached battery pack.

The charger may be configured to charge 7.4 to 14.7 nominal Li-Ion battery cells, which must have internal protection circuitry in accordance with UL1642 and IEC61960. Optimal configurations would include a 7.4V pack rated for 3.2A charging, a 11.1V pack rated for 2.2A charging, or a 14.8V pack rated for 1.7A charging.

To best demonstrate the full potential of our project, the team is pursuing optional deliverables that should be completed if time permits once the core project is completed. These stretch goals include a mobile robot capable of charging itself for continuous wireless operation and integration with a smart Li-ion battery for detailed fuel gauge and battery health status.

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I. PROJECT DESCRIPTION

Our team noted a need for users to charge medium power devices via wireless charging. After further investigation we also determined that there is a shortage of cost effective medium power wireless chargers on the market.

Our project is a 30 watts nominal resonant wireless charger prototype for use with 4 to 6 cell lithium ion battery packs. It is managed by a microcontroller. It may be monitored and controlled by a user GUI or directly by the target application. Unlike existing customized and proprietary robotic charging systems, our product will charge a standard battery type and be suitable for both stand-alone operations and integration into the user's own design.

The team has been unable to discover any equivalent products to our own for retail. The most comparable product is Wibotic's Standard High Power System[1], a 90 watt magnetic resonance device that is marketed to businesses designing commercial drones and robotic systems. On the lower end, nearly all unbranded, low-cost wireless chargers that are available from mass online retailers supply no more than 5W via inductive charging. For a single industrial unit, we have received a price quote for approximately $2000 USD. Individuals and small R&D teams that search for suitable devices through online retailers will find that these low-end transmitters are not modular and are limited to one specific purpose such as charging cell phones or key-fobs.

Our charging system employs magnetic resonance coupling to charge a lithium ion battery pack, delivering between 15 and 30 watts of power. The power transmitter and receiver communicates as a unified system that can provide battery management, protect against overcharging, and provide both diagnostic and telemetric information to the user and to an optional serial connection with the powered application's control circuitry. The charging system may be monitored and controlled by the user either through an attached LCD interface or a GUI from either a Bluetooth connected PC or smartphone.

This wireless charging alternative's intended market consists of hobbyists and prototype designers considering a self-docking direct electrical connection solution. This is the charging method used by the Roomba[2], which engages with a custom dock and charges using metal contacts. While this is a cost-effective solution for a mass-produced product, wireless charging is a superior choice for autonomous mobile devices that might have a wide variety of sizes and shapes. The benefits offered by our product's wireless charging include flexible placement of the charger, a compact charging area, greater tolerance for misalignment between the charger and the target device, and the absence of exposed electrical connections. Additionally, this product would solve the same need for OEM producers who are interested in a "turn-key" wireless charging solution.

To best demonstrate the full potential of our project, the team has specified optional deliverables that include a mobile robot capable of charging itself for continuous wireless operation, fully integrated with a smart Li-ion battery for detailed fuel gauge and battery health status.

The team holds that a moderate power, low cost wireless charger with accessible telemetry is useful to a small but important market of robotics hobbyists and developers, who at present, are not being served by either costly, proprietary business-to-business solutions or the low power and poorly documented inductive chargers available on the hobby market.

Below in Figure 1, the general flow of power from the AC to DC Wall Converter to the end user's device and information from the user is shown.

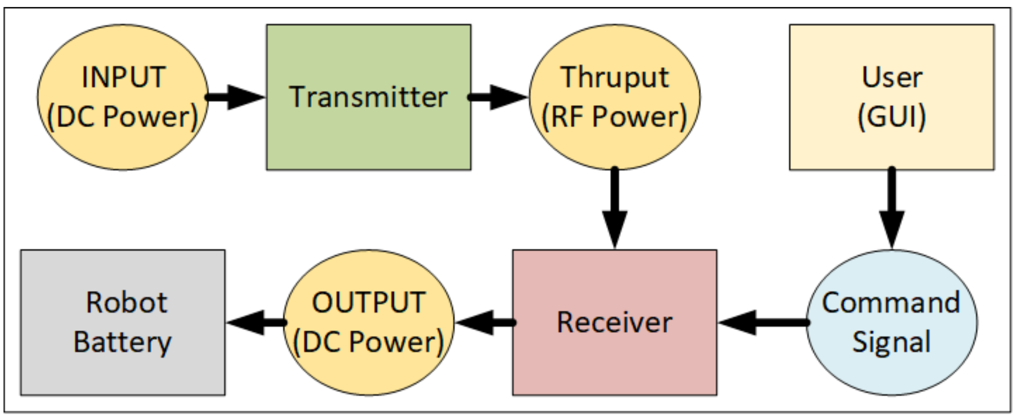


Figure 1: Operation Story Block Diagram

II. FINAL DESIGN SPECIFICATIONS

Table 1 below shows the specs of the receiver subsystem in the wireless power charging system.

Table 1: Receiver Specifications

Charge time (Per 4Ah Battery Packs)	5 Hours Max
Battery pack voltage	14.2 V
Coupling Efficiency Transmitter to Receiver	90%
AC-DC Conversion Efficiency	80%
Charging Controller DC-DC converter	85%
Overall Receiver Conversion Efficiency	61.2%
Maximum Battery Charging Current	1.25 A (14.7 V battery pack)
Charger Subsystem Charge Protocol	Constant Current Constant Voltage (Li-ION Battery)
Battery Type	Lithium-Ion (4 x18650 in Series or 2P4S Configuration)
Power Negotiation	Bluetooth 5 LE
Transmitter Locator Method	RF Localization [Bluetooth]
Deliverable Demo	Self-Moving Device (Robot)
Telemetry	Report State to GUI Device
LCD display	Diagnostic Character String Display

Table 2 below shows the specs of the transmitter subsystem in the wireless power charging system.

Table 2: Transmitter Specifications

Operating frequency	13.56 MHz
RF power output	30 W
Max operating range	5 cm
DC Power supply	48 V 1.25 A max.
Conversion Efficiency DC-AC	80%
Telemetry	Report State to GUI Device

Table 3 below shows the communication specifications.

Table 3: Communication Link Specifications

Communication Medium	Bluetooth 5 LE
Protocol	L2CAP (RFCOMM)

Table 4 below shows the GUI software specifications.

Table 4: GUI Specifications

GUI OS	WinOS, IOS, Linux, & Android
License	LGPL 3.0
Software Architecture	Model-Controller-View (MCV) Architecture
Delivery Model	Open Source (Free App Download)

A. Feasibility Study

The design consists of two subsystems: the transmitter and the receiver. This product is expected to be used by hobbyists and prototype designers for different applications that require contactless charging. There is no similar device available in the price range from $200 to $400. The expected cost of the charger system is $300. There are some commercial chargers available right now and the cost of that system is $2000. The price of $300 per system will make wireless charging affordable for hobbyists and freelance hardware developers.

The design tools such as Altium designer and Multisim simulator are available free of charge to all group members using the provided UT Tyler license. Also, parts manufacturers are providing free simulation and evaluation tools for development. In addition to the software evaluation kits may be required for testing certain parts of the system such as the microcontroller, Bluetooth module, and the battery charger controller. Most of those evaluation modules are already purchased and they are available to team members. Evaluation kits are purchased by Indus Instruments.

The system is designed such that it uses standard components that are available at any electronic components store and they can be purchased without restrictions. PCB fabrication will be given to a company located in China that is offering quick turnaround PCB fabrication and fast shipping. Components purchasing and printed circuit board assembly will be done at Indus Instruments. Indus Instruments have all the necessary equipment that can handle surface mount components.

All test equipment required for development and testing will be available. Indus Instruments will provide space and necessary test equipment for the wireless charging system prototype evaluation and testing.

The final product cost is estimated at around $300 (for small quantities). Most likely for larger quantities, it is possible to decrease the cost even more.

B. *Microcontroller*

There are four aspects to analyze: economics, technical, legal, and scheduling. A single MSP430FR5994 part costs about $3 to $4, while the MSP-EXP430FR5994 LaunchPad kit costs $16.99. Considering the team only needs two of these microcontrollers (one for the transmitter and one for the receiver), this is an economic and reasonable cost. [3] [4]. On the technical side, this microcontroller's memory, voltage supply limitations, UART and I2Cmode specifications, and overall low power consumption makes it the ideal model for our project needs [3]. Some of the most important standards TI's MSP430FR5994 complies with include ANSI, JEDEC, and ESDA [3]. Lastly, the team already has in hands the LaunchPad kit for the microcontroller. The individual microcontrollers are also ready-to-purchase items with delivery times of less than 7 days. More testing will be done once the team has the first PCB design in hands.

C. *Transmitter Coil*

The circular planar coil was the most inexpensive approach, the copper tubing to make the coils has an approximate value of $15.99. The design properties also significantly contributed to reducing the complexity of acquiring the main coil parameters. It was important to take this factor into account because of the time constraint of two months. In order to reduce the complexity in our project, the spiral planar design was the best option.

The calculation of the inductance formula in the planar spiral design was easier to acquire than the other two proposed solutions. This was crucial because it significantly gave the project a higher chance of matching the predestined inductance of the circuit requirement of .909 μH.

The economical and ethical considerations did not affect our decision making as much, due to the fact that there were not many differences. Furthermore, this design was appropriate for our project and the team does have the budget, resources and time to successfully to implement this design.

The planar spiral coil design allows the project to more reduces the complexity of the formulas implemented in the calculations.

D. *Transmitter*

The transmitter class-E amplifier circuit was simulated at an efficiency of 98%. The actual transmitter efficiency would be around 90%. In the simulation, it was determined that the current required to power the class-E amplifier is 0.9 A at 30 V. The power for the transmitter will be supplied by using an external 48 V AC to DC converter followed by a step-down converter in the transmitter subsystem.

The main concern in this subsystem is the immunity of the supporting circuits to the RF electromagnetic field generated by the transmitter coil. The transmitter coil placement must be done such that the electromagnetic field has minimal effects on the electronic circuits in the transmitter. The transmitter sensitive electronic parts may require EMI shields.

During the simulation, the high voltage across the coil was observed. The highest voltage observed was 320 Vpp. That voltage poses a serious electric shock hazard. Therefore, the transmitter coil insulation must be capable of withstanding voltages that are in the 500V to 1kV range to provide a safety margin for the design. One way of achieving this is to make a plastic box that would contain the transmitter coil and have insulation that is capable of withstanding voltages in the 500 V to 1000 V range.

Heat dissipation in the Class E amplifier circuit is expected to be around 3W (based on the efficiency of 90%). That dissipation will occur in inductors, capacitors (due to ESR), and the amplifier transistor. The transistor will have a proper heatsink to prevent overheating. Since the dissipation in the transistor is very small (on-resistance is 50 mΩ) the proper thermal management will be achieved on the printed circuit board. Coils used in the transmitter will be designed such that the col resistance is minimized which also will decrease the heat dissipation in the transmitter circuit.

E. Receiver

There is a possibility that the receiver RF to DC stage performs with higher losses than the losses that were determined in the simulation. According to the simulation data, the RF to DC conversion will be 81% efficient. In the system specification, the conversion efficiency is set to 80%. It is important to keep efficiency above 80% to prevent excessive heat generation. If received power is 25W and efficiency is 80% then power dissipation is 5 W.

The excessive heat may have adverse effects on battery life and the speed of charging [5]. A higher temperature environment requires lower charging currents to prevent further temperature rise and damage to the battery cells. Also, excessive heat generation must be minimized to avoid the use of fans and large heat-sinks. Heat-sinks and fans would increase the cost and the size of our product. If during the prototype test phase efficiency drops below 80% the circuit must be redesigned to achieve the target specification efficiency.

One problem that is likely to occur is the interference in the battery charging and communication link circuits caused by a strong electromagnetic field generated by the transmitter coil. Even though all good practices will be followed for the circuit board design the electromagnetic interference still may not be prevented. Charging circuit disruption can cause battery failure due to overcharging or overheating. If this problem occurs the additional EMI shielding will be required. The shielding includes placing metal boxes over sensitive electronic subcircuits and placing additional filters in series with DC power supplies for sensitive parts such as a microcontroller, Bluetooth module, and charger controller.

F. Thermal Considerations for 3.3V and 5V Voltage Regulators

According to the simulation data both parts have small power dissipation. The largest power dissipation is 0.18 W (5.0V regulator).

The graph below provides thermal resistance junction to ambient as a function of the printed circuit board. The equation below can be used to find the required thermal resistance junction to ambient (Θ_{JA}). The estimated ambient temperature in the transmitter is 45°C.

$$\Theta_{JA} = \frac{125°C - T_{A(max)}}{P_{D(max)}} \left[\frac{°C}{W}\right] \tag{1}$$

$\Theta_{JA} = \frac{125-45}{0.18} = 444.44 \left[\frac{°C}{W}\right]$
The estimated transmitter PCB area will be around 100cm2. Given the board size and thermal resistance vs. board size, those regulators will have a proper heatsink.

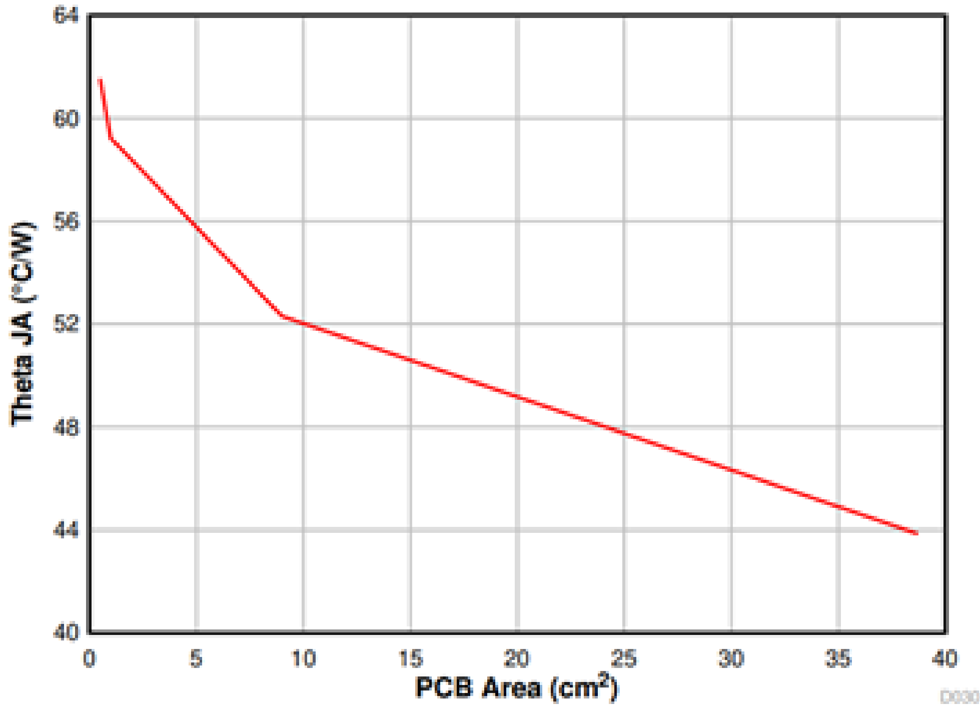


Figure 35. θ_{JA} versus PCB Area

Figure 2: Thermal Resistance vs. PCB Area [5]

Thermal considerations(for class E amplifier voltage regulator (30V, 1.0A buck converter)

$$T_{A(max)} = T_{J(max)} - R_{TH} \cdot P_{TOT} \tag{2}$$

· P_{TOT} is the total device power dissipation in [W]
· T_A is the ambient temperature in [°C]
· T_J is the junction temperature in [°C]
· R_{TH} is the thermal resistance of the package $\left[\frac{°C}{W}\right]$
· $T_{A(max)}$ is the maximum ambient temperature in [°C]
· $T_{J(max)}$ is the maximum junction temperature in [°C]

The expected ambient temperature is 40°C (that is temperature inside the transmitter enclosure).
Thermal resistance for a standard board (Θ_{JA}) is 62.5$\left[\frac{°C}{W}\right]$ [6].
From the simulation the total power dissipation is 1 W.
From the recommended operating conditions the maximum junction temperature is 150°C [6].
Based on the data from the simulation and the datasheet the maximum ambient temperature can be determined
$T_{A(MAX)} = T_{J(MAX)}$ - R_{TH}*P_{TOT}
$T_{A(MAX)}$ = 150 – 62.5*1 = 87.5°C

The expected ambient temperature is lower than the maximum temperature calculated based on simulation data. Therefore, this part will operate within specified recommended conditions in the datasheet.

G. Charging Subsystem

The LTC4162-L is designed to manage a power path between an external input power source Vin, an output power V_{out}, and an installed battery pack. When external input power greater than the battery voltage is available at V_{in}, the LTC4162 will route V_{in} to V_{out} and charge the connected battery. If external power is interrupted or falls below V_{bat}, battery power will be automatically routed to V_{out}. As long as the battery has charge or a power source exists at V_{in}, V_{out} will be supplied with power, but the voltage will range from V_{bat} to V_{in}. In order to provide consistent voltage to the target device output power should be drawn directly from the battery. Leaving V_{out} unused allows the maximum power point tracking feature to operate with optimal efficiency.

The LTC4162 draws power directly from Vout and has its own internal LDO linear regulators. All other components of the wireless receiver PCB must be powered by an appropriate DC-DC stage at V_{out} that can convert any potential input voltage (i.e. 7.4-35 V) to the required operating voltages of 5 V and 3.3 V. In the event that the battery is severely depleted and cannot power the microprocessor and Bluetooth interface, it will be necessary for the transmitter to be capable of initiating charging independently.

Since the LTC4162 has only an internal buck voltage regulator, the wireless power receiver subsystem must provide power to Vin that is higher than the voltage of the battery but below the maximum input voltage of 35V.

The LTC4162 approaches 95% efficiency at recommended switching frequency when the input voltage is no more than approximately 5V above battery charging voltage, and surpasses 90% in less ideal configurations. Heat losses will be in the range of three watts or less. It has a Θ_{JC} of 3.4 $\left[\frac{°C}{W}\right]$ and will be soldered to a four-layer PCB. The team does not anticipate any thermal management issues with this circuit.

H. Battery Considerations

Li-Ion batteries offer superb performance and high energy density, but require special attention to safety. Under normal circumstances the LTC4162-L will monitor battery voltage and avoid overcharging. A NTC thermistor will allow the LTC4162 to monitor local charging temperatures and limit current in accordance with JEIDA recommendations.

For safety reasons, the team requires stricter battery specifications than originally planned. While our charger's thermistor can limit charging current in response to ambient temperature extremes, it cannot monitor individual cells–particularly if the battery pack is intended to be modular. While it can recognize and respond to abnormal battery voltages or short conditions, it cannot automatically determine maximum safe charging current. Any battery pack used must have a maximum charge current greater than the maximum current delivery of the charger. Battery packs must also meet UL1642 and IEC61960 standards and contain internal protection circuitry to limit charge and discharge currents and protect against thermal runaway.

The LTC4162 can deliver a maximum of 3.2 amps and has an efficiency of up to 95%. Assuming optimal efficiency and 26 W output from the wireless receiver, the charging voltage must be at least $\frac{25W}{3.2A} = 7.8$ V in order to fully utilize the available power. Since the voltage of a typical Li-Ion cell is 3.7 V and the charging voltage is 4.2 V, the target battery pack should consist of two or more cells in series. The LTC4162 supports 1 to 8 cell series arrangements provided the input voltage is adequate. Optimal arrangements would include a 7.4V pack rated for 3.2 A charging, a 11.1 V pack rated for 2.2 A charging, or a 14.8 V pack rated for 1.7 A charging. The number of cells is set by selection pins and may be configured by a DIP switch or jumpers. It is not necessary to specify a specific number of cells for suitable battery packs, provided that they meet UL1642 and IEC61960 standards. The optimal balance of safe charging rates and performance will likely be found with packs utilizing six to eight 18650 cells or the equivalent. The power delivery estimates above are optimistic and actual power delivery from the charger may not reach these levels. As prototyping progresses, it will be possible to refine battery recommendations and expected charging times.

Ideally, up to 25 W will be delivered to the battery pack, making the battery the largest potential source of heat in our system. Since the battery pack is intended to be a modular, removable component with flexible specifications, it will not necessary for it to be enclosed with the wireless receiver PCB and receiving coil. It will be connected by an appropriate low-loss cable and connector, and exact placement will be determined by the user application. For this reason, the team has specified that only battery packs with internal temperature monitoring and protection circuitry should be used with this charger.

Our original specifications suggested that the charging subsystem would be capable of detailed monitoring of battery health and charge state. The team has learned that this type of information must be obtained at the individual cell level by a specialized controller which is usually integrated into the battery pack itself. Our charge subsystem can only recognize an approaching low-battery condition by a drop in voltage, and cannot estimate battery capacity except by calculation using charging voltage, charge times and currents, and such data would be of limited use considering battery aging and user-replaceability. It will be possible to notify the user and target device of a drop in battery voltage, but more detailed fuel gauge and battery health information will require an SMBus enabled smart battery. An I2C line on the MSP430FR5994 will be reserved for communication with an optional SMBus capable smart battery pack. If feasible, optional battery pack telemetry may be polled by firmware and reported to the user along with the data already available from the LTC4162.

All the parts and design resources needed to complete the charging and power subsystem are readily available. Constructing this subsystem within the projected time-frame is feasible.

Table 5: Final Design's Charging Subsystem Specifications

DC-DC stage from wireless receiver to V_{in}	May not be necessary, pending further determination of wireless receiver output voltage
DC-DC stage from V_{out}	5V at 100mA; 3.3V at 100 mA
Battery Requirements	UL1642 and IEC61960 compliant Li-Ion packs with 7.4-15 V_{DC} nominal output voltage
Maximum Charging Current	3.2A (7.4V); 2.2A (11.1V); 1.7A (14.8V)
Provision for optional smart battery health and fuel gauge monitoring	Reserved I2C line from MSP430FR5994 with buffering

I. Microcontroller Considerations

The MSP430FR5994 has a body size that ranges from 6mm by 6mm to 12mm by 12mm depending on the package the group purchases, 8KB RAM, 68 GPIO pins, 4 I^2C, 4 UART, up to four serial communication ports, and 20 ADC channels. The MSP430 series include limitations that range from safety to performance [3].

Relevant limitations to the project include:

1. ESD (Electrostatic discharge) ratings. For a human-body model, safe discharge ratings are around 500 V to 1000 V, while for a charged-device model, safe discharge ratings are around 250 V. These regulations are taken from JEDEC JS-001 and JESD22-C101 respectively [3].

2. Absolute maximum ratings: voltage applied to any pin must be within -0.3 V to 4.1 V, voltage difference between DVCC and AVCC pins must stay within -0.3 V to 0.3 V (if not, writing errors could occur to RAM and FRAM), and current at any device pin must have a maximum of -2 to 2 mA [3].

3. Supply voltage applied should be within 1.8 V to 3.6 V, maximum ACLK frequency should be 50 kHz, and maximum SMCLK frequency should be 16 MHz [3].

4. For the eUSCI I^2C, eUSCI (enhanced universal serial communication interface) input clock frequency should not exceed 16 MHz, SCL clock frequency should not exceed 400 kHz [3].

J. Firmware Requirements: Transmitter

The Wireless Power Transmission Stage (Transmitter) will be controlled by an MSP430FR5994 running custom firmware. The firmware must meet the following requirements:

1.) Activate or deactivate wireless transmitter.

2.) Respond to commands received from a Bluetooth link with the Wireless Power Receiver Stage (Receiver), which may include requests for power delivery measurements or instructions to initiate or cease charging.

3.) Continuously monitor wireless power transmitter current and voltage and calculate delivered power.

4.) Automatically cease power transmission when the Receiver requests a shutdown or if severe interference is detected.

5.) Communicate operating status to the Receiver via Bluetooth, and directly to the user via fault LED's or an installed LCD.

K. Firmware Requirements: Receiver

The Wireless Power Receiver Stage (Receiver) will be controlled by an MSP430FR5994 running custom firmware. The firmware must meet the following requirements:

1.) Link to the Transmitter over Bluetooth.

2.) Link to user GUI device over Bluetooth.

3.) Link to an optional UART connection with the target device.

4.) Respond to queries or instructions from the Bluetooth connection to the user GUI or from the optional UART connection.

5.) Monitor charging state and battery status though I2C connection with LTC4162 and optional SMBus link with smart battery.

6.) Recognize low voltage state or optional low capacity battery warning and notify the user and target device.

7.) Signal the Transmitter via Bluetooth to initiate charging when instructed by the user or target device.

8.) Continuously monitor wireless power receiver current and voltage and calculate delivered power.

9.) Monitor reported power transmission from the Transmitter, compare it with received power, and recognize excessive power losses that could indicate unsafe interference conditions

10.) In the event of excessive transmission losses, instruct the Transmitter to cease power transmission. Notify the user and target device of the error condition.

The Transmitter and Receiver firmware will be developed with Texas Instruments Code Composer Studio. The team has suitable Launchpad development boards and access to all necessary documentation and libraries are available. The team is composed of multiple experienced programmers in our group. The firmware requirements are limited and well-defined and completing it within our scheduled time-frame is feasible.

L. Software Requirements: GUI

The GUI will be operated on multiple platforms and rely upon QT5 to operate. The software must fulfill the following requirements:

1.) Provide connection to transmitter and receiver for the product's user that grants sufficient control over the product's hardware

2.) Serve as a platform for custom messages to and from the user's device connected to the receiver.

3.) Provide alert system via push notifications and continuous monitoring of the transmitter and receiver.

M. Coil Considerations

Table 6: Final Design's Coil Tubing Specifications

Material	122 Copper
Tube Size	1/8 [in]
Outter Diameter (OD)	1/4 [in]
Wall Thickness	0.049 [in]
Inner Diameter (ID)	0.152 [in]
Fabrication	Seamless
Bending Method	By hand
Temper Rating	Soft
Compatible Tube Fittings	Compression, Solder Connect
Specifications met	ASTM B75 RoHS 3(2015/863/EU) Compliant
Resistivity	1.68 x 10^{-8} [Ω/m]
Conductivity	5.96 x 10^{7} [S/m]

This tubing has good corrosion resistance and excellent heat transfer qualities. All tubing meets international standards for copper tubing. Important to note: Tube size is an accepted industry designation, not an actual size [7].

Table 7: Final Design's Receiver Coil Specifications

Outside Diameter of Coils (Do)	90 mm
Number of Turns	4
Length	729.6 mm
Spacing	4.81 mm
Width of Tubing	3.175 mm
Inner Diameter (Di)	26.12 mm
Winding Radius	29.03 mm
Radial Depth	31.94 mm
Inductance	909.66 nH.
Capacitance	150.55 pF
Frequency	13.6 MHz
Resistance (Dc)	1.5462 mΩ
Total Resistance	69.46 mΩ
Quality Factor	1119.09

N. Specification Summary

Table 8: Final Design's Receiver Specifications

Charge time(4Ah Battery Pack)	5 Hours Max
Battery pack voltage	User Selectable: 7.4V-14.2 V
Coupling Efficiency Transmitter to Receiver	90%
AC-DC Conversion Efficiency	80%
Charging Controller DC-DC Converter	85%
Overall Receiver Conversion Efficiency	61.2%
Battery Requirements:	UL1642 and IEC61960 compliant Li-ion packs.
Maximum Battery Charging Current	3.2A (7.4V); 2.2A (11.1V); 1.7A (14.8V)
Charger Subsystem Charge Protocol	Constant Current Constant Voltage (Li-Ion Battery)
Battery Type	UL1642 and IEC61960 compliant Li-Ion packs; 7.4-15 VDC nominal output voltage.
Power Negotiation	Using Bluetooth 5 LE
Deliverables	Wireless resonant charger with approximately 30W power transmission capability. Stretch Goal: a mobile device to demonstrate autonomous charging.
Telemetry	Report State to GUI Device
LCD display	Diagnostic Data Character String Display

Table 9: Final Design's Transmitter Specifications

Operating Frequency	13.56 MHz
RF Power Output	30 W
Max. Charging Distance	30 cm
DC Power supply	48V 1.25A min.
Conversion Efficiency DC-AC	80%
Telemetry	Report State to Receiver

Table 10: Final Design's Communication Link Specifications

Communication Medium	Bluetooth 5 LE
Protocols	GUI: Host Controller Interface (HCI) Receiver- transmitter: Synchronous Connection-Oriented (SCO) link

Table 11: Final Design's GUI Specifications

OS	WinOS, IOS, Linux, & Android
License	LGPL 3.0
Software Architecture	Model-Controller-View (MCV) Architecture
Delivery Model	Open Source Free App Download

O. Ethical and Professional Considerations

1.) Public Health: Life preserving medical equipment requires concern in the transmission of powerful RF charging signals that may interfere with the medical equipment. We will adhere to FCC standards for intentional radiators and ensure that the charger transmitter does not exceed FDA guidelines for RF emission. Our design will be informed by the guidelines of the National Council on Radiation Protection and Measurements (NCRP) and the Institute of Electrical and Electronics Engineers (IEEE).

2.) Safety and Welfare: Our design may contribute to public safety and welfare by easing the development of robotic systems intended to handle hazardous materials, work in narrow spaces, high temperature environments, or in vacuum. We will follow industry best practices for safe charging, such as current limiting and temperature monitoring, to minimize the risk of battery failure.

3.) Global Factors: The pressures of governing bodies are to be taken into consideration in any choice this project takes; however, we are primarily concerned with the US governing bodies and then the EU bodies in order to streamline our development process to hit the largest market base possible. Additionally, Canadian and Mexican regulations would be considered as immediate market options.
In an alternate vein, there are sourcing questions that must be investigated before production in order to conform with internation laws and prevent being banned from specific global markets whether at home or abroad.

4.) Societal factors The source code will be educational as well as providing value to the device itself. The design's modular intention will permit versatile implementations at work or at home. The product should serve influenceable groups such as teenagers, helping them enter STEM related fields.
The product as a whole should be considered in a way that would encourage further education in the classroom in physics. Likewise, the production of the product should foster a community between the product's programmers and engineers.

5.) Environmental factors: This concern requires continual attention for any anomalies concerning the battery cells. The device cannot account for all of these concerns, but should maintain labeling that makes the customer aware of such concerns that may be caused by their device. The project must provide a means of emergency shut off by some interrupt port that is always active. The operating robot, the user via a GUI, and the receiver itself must have this ability to turn off the charging feature of the receiver.

6.) Economic factors: The device could fulfill legal requirements for a client, and, in that case, a custom suite would be developed in the software at a premium to satisfy a client's needs. Additionally, creating a lightweight, low-cost production process is critical in maximizing profits. The open-source market also provides extensive free advertising momentum when capitalized successfully. Additionally, the product would assist in producing other products, especially in research and development.

Table 12: Ethical and Professional Considerations

Public Health	· Medical Equipment RF Exposure · Electrical Shock · Chemical Exposure
Safety and Wellness	· RF Bandwidth Jamming · Electrical Shock · Chemical Exposure
Global Factors	· International Governing Bodies · Sourcing Restrictions · Inter-Market Penetrability
Societal Factors	· Open-Source Capitalization · STEM Educational Resources · Professional Organizations · Customer Privacy & Security
Environmental Factors	· Chemical Pollution · User Environmental Awareness · Emergency Shut Off Cases
Economic Factors	· Open-Source Capitalization · Specialty Clientele · Rapid Agile-Deployment · Light-Weight Production

III. DESIGN SOLUTION

A. Product Architecture

The wireless charger system consists of two main subsystems, the receiver and the transmitter. The transmitter is powered by an external AC/DC 48 V power supply. The transmitter subsystem converts DC power into RF power to drive the transmitter coil. The transmitter has a microcontroller that communicates with the receiver and controls its wireless power transfer. The receiver has a receiving coil and capacitor that completes a 13.56 MHz parallel LC resonant circuit. The magnetic field generated by the transmitter induces an electric current in the receiving coil. The received power is rectified and transferred to the battery charger circuit. Also, the receiver has a microcontroller that communicates with the transmitter and indirectly controls transmitter circuits such as the wireless power transfer circuit. The receiver also communicates with remote devices such as tablets,tw phones, or computers to provide telemetry data.

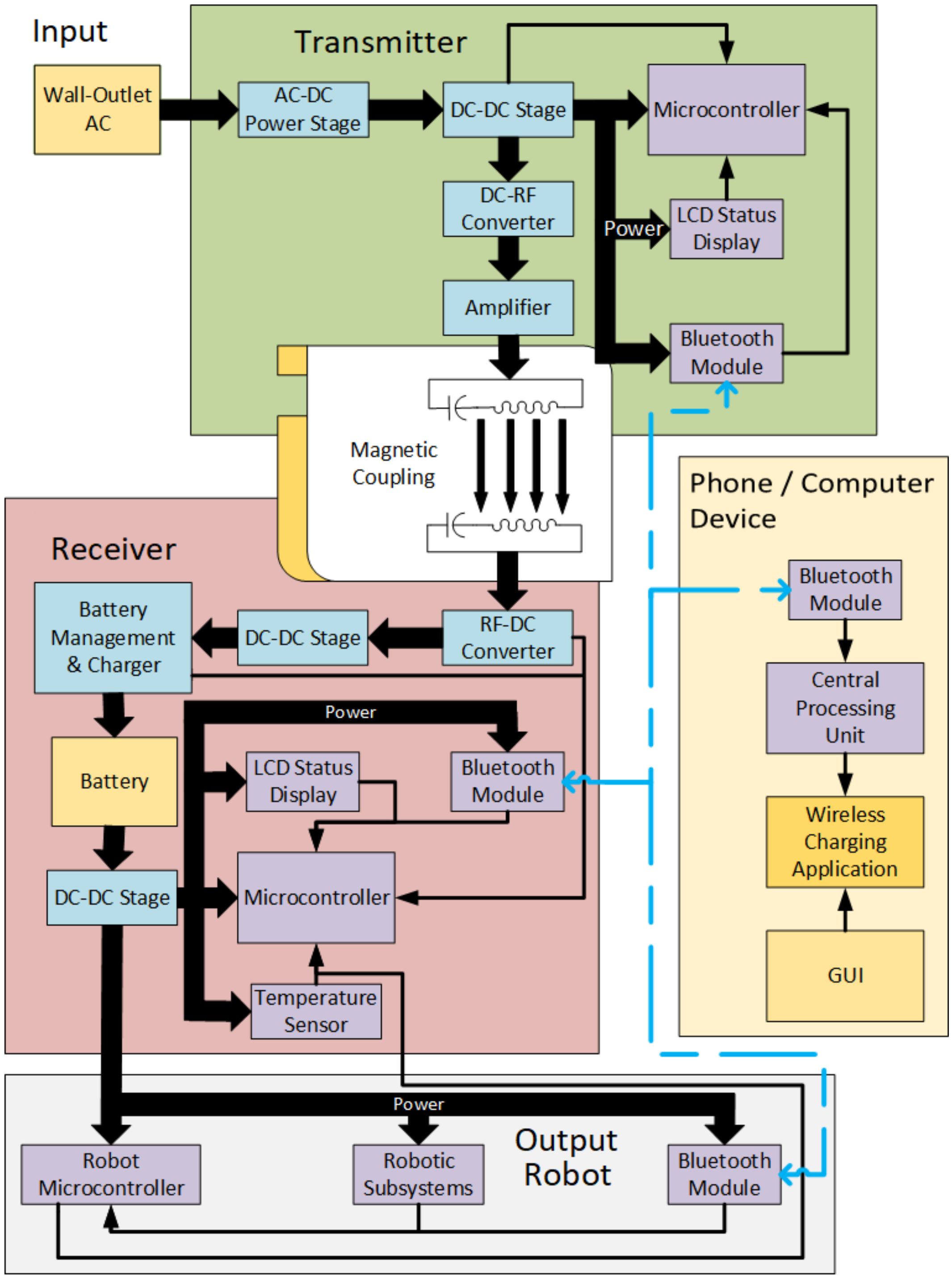


Figure 3: System Level Block Diagram

The graphical user interface (GUI) displays information with lists, data feeds, and visual aids that keep track of the battery's charge and any information passed along by the receiver to the user's remote device. The GUI's information on each device's connection and charging information allows real-time troubleshooting of each device.

The GUI Wireframe image below provides an example of how the GUI is structured. The selection widget shall be used to select between receiver devices to connect to. The top panel is reserved for battery monitoring. The Info panel utilizes wifi symbols to indicate connection status between devices while the lightning bolts reflect their on-going charging status. The bottom text panel is reserved for general warnings and information.

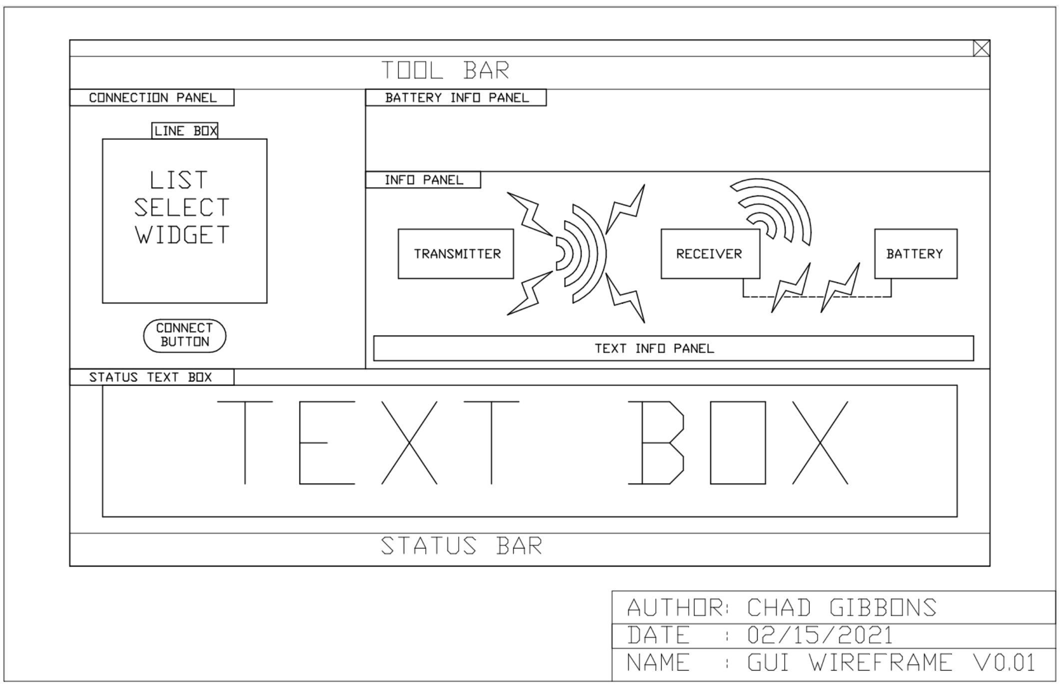


Figure 4: GUI Wireframe Diagram

B. Hardware Subsystems

1.) Transmitter Subsystem The transmitter circuit requires a 48 V power supply that will be down-regulated to 30V, 5V, and 3.3V. 30V is used by a coil driver (class E amplifier). 5 V supply will be used for the LCD and class E amplifier buffer. 3.3V is used by digital circuits such as microcontroller and Bluetooth.

The block diagram below shows internal voltage regulator connections.

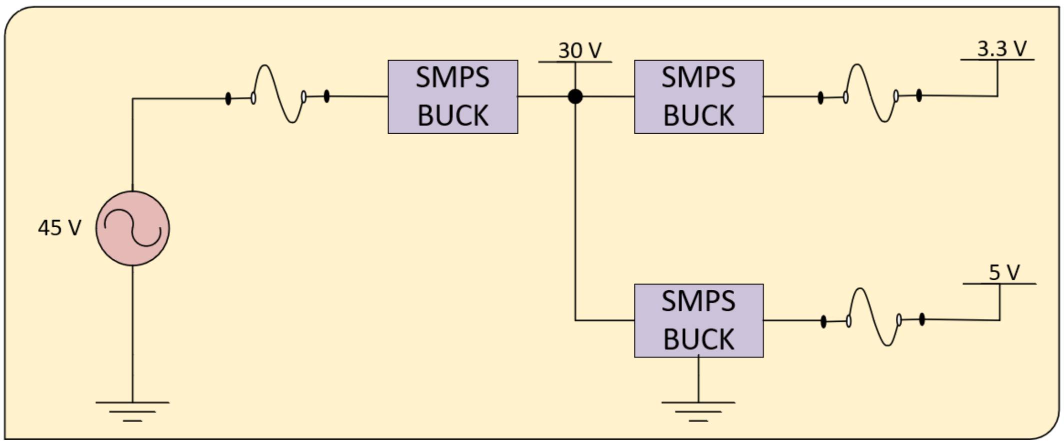


Figure 5: Transmitter Subsystem Voltage Regulator

The transmitter subsystem block diagram below illustrates how transmitter subcircuits interact with each other. The microcontroller is used to control most of the circuits in the transmitter subsystem. The Bluetooth module is connected to the microcontroller using the UART interface with flow control (RTS and CTS lines). The Bluetooth module is connected to the circuit that controls display contrast. The display parallel I/O interface is connected to the microcontroller through a level shifter. Also, the transmitter has four multipurpose user buttons that can be used to set the different modes of operations.

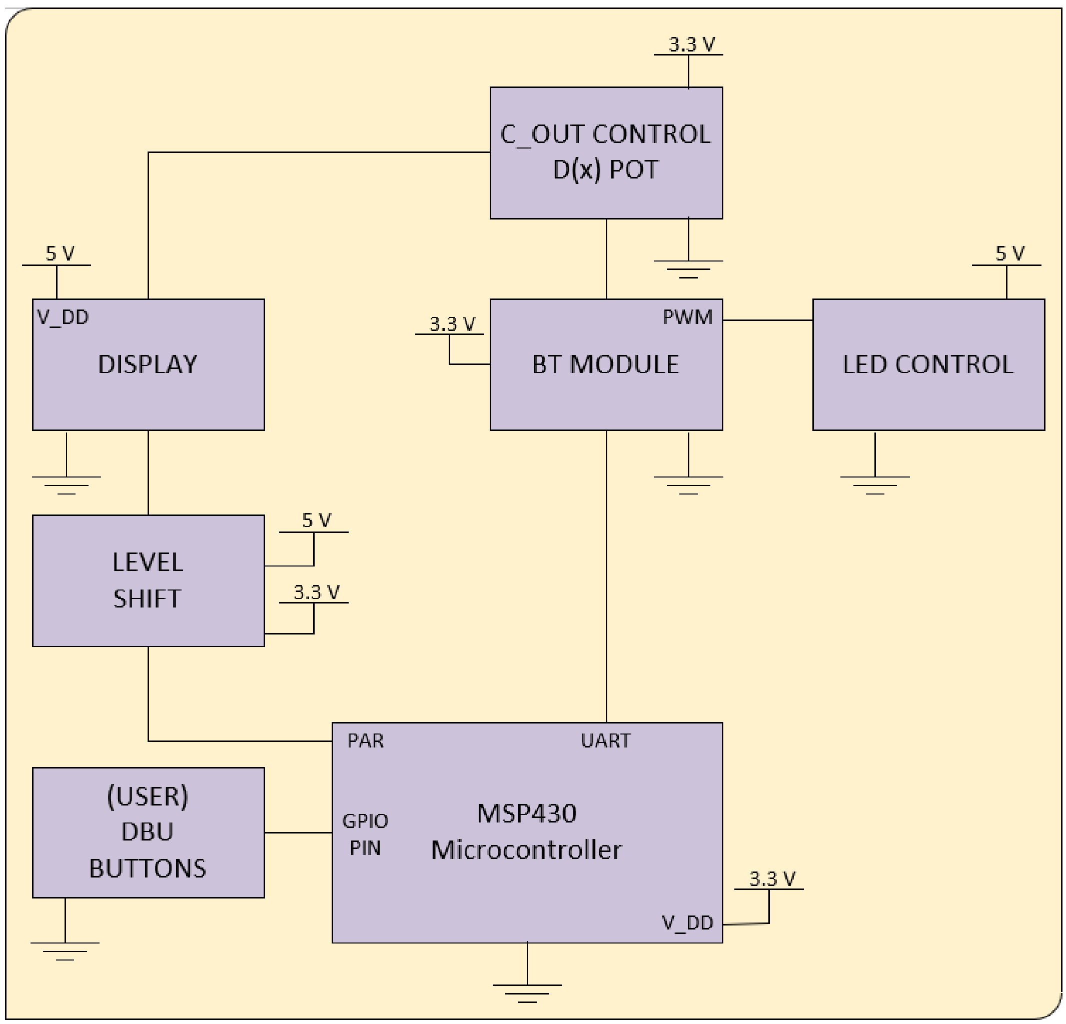


Figure 6: Transmitter Subsystem Block Diagram

The block diagram below illustrates the power transmission or DC to RF converter subcircuit. The subcircuit has an oscillator, buffer, and a coil driver. The 13.56 MHz signal is generated by a temperature-compensated crystal oscillator. The output of the oscillator is buffered using the GaN FET driver. A tuned switching power amplifier, also known as a Class E amplifier, is used to drive the transmitter coil where a GaN FET is used as a single-pole switching element. The transmitter coil and capacitors in series create the resonant LC circuit.

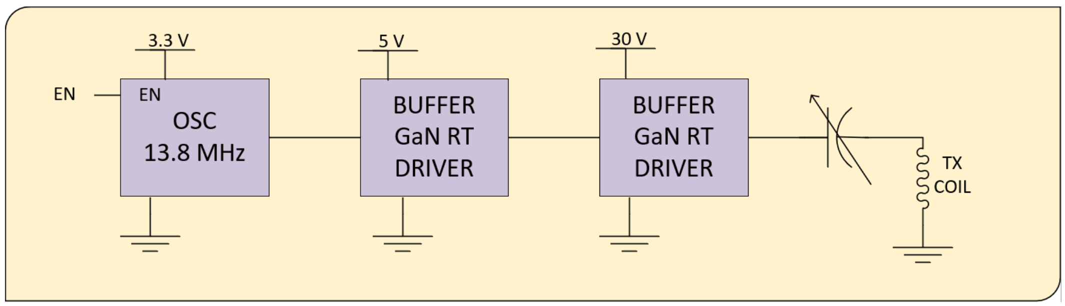


Figure 7: Coil Driver Subcircuit

The schematic diagram for the microcontroller (U2: MSP430FR5994), Bluetooth module (MD1 RN4870) display connector P3, the display illumination control (U5: MCP6001T-I/OT, U6: NUD3112LT1G), and LCD contrast control (U7: MCP4531-103E/MS) can be found in appendix NN.

The input power is supplied by an external AC/DC SMPS (Switched Mode Power Supply) converter. The power output of the buck SMPS is protected by a PPTC resettable fuse as short circuit protection. The fuse rating is 2.5A. A 48V power is converted to 30V which is used by the class E amplifier's 5V buck converter and 3.3V buck converter. Each SMPS module output has overcurrent protection using resettable PPTC fuses. Both fuses are 0.5A rated. Both low voltage regulators (5V and 3.3V) have additional filtering at their outputs using ferrite beads and 0.1 μF capacitors.

Voltage regulators are shown below

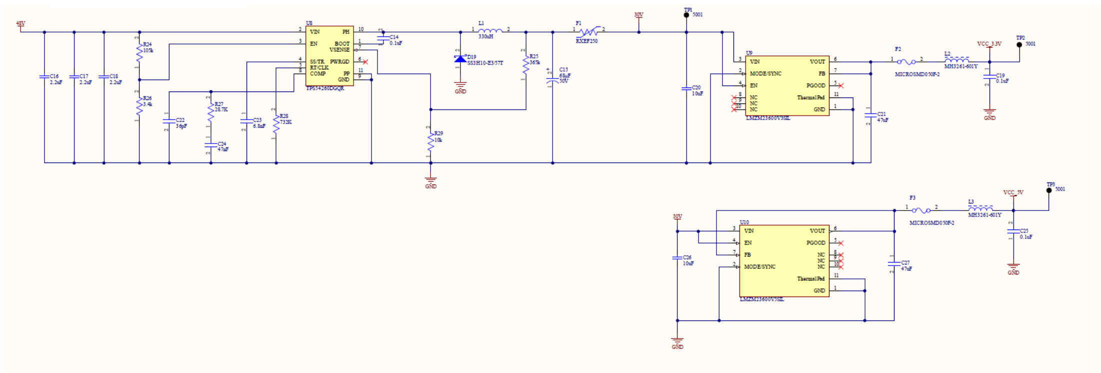


Figure 8: SMPS Subcircuit

The output of the temperature-compensated crystal oscillator (Y2) is connected to the GaN FET driver (U11: LM5112) which is connected to a GaN FET (Q1: EPC2019). the output of the class E amplifier is connected to the transmitter coil. The amplifier circuit has a peak detector (R30, R35, D20, C36 and R36) to detect the peak voltages of its output. The voltage on the peak detector will be sampled using the microcontroller's ADC in order to validate the receiver's presence via loading effects on the coil.

The coil driver circuit is shown below

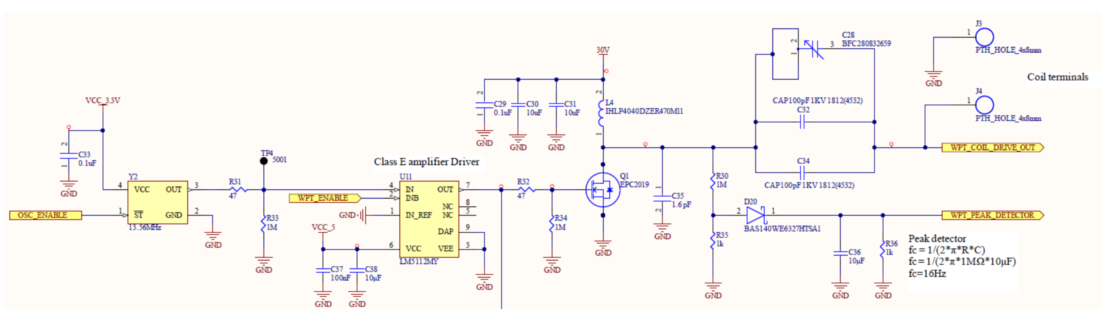


Figure 9: Transmitter Subcircuit

The transmitter subsystem function control and communication circuits schematic diagram shows the microcontroller (U2: MSP430FR5994), Bluetooth module (MD1 RN4870) display connector P5, the display illumination control (U5: MCP6001T-I/OT, U6: NUD3112LT1G), and LCD contrast control (U7: MCP4531-103E/MS). The schematic diagram can be found in appendix NN.

2.) Receiver Subsystem The main components in the receiver microcontroller subcircuit are identical to the transmitter microcontroller subcircuit.

The diagram below shows connections between receiver subcircuits.

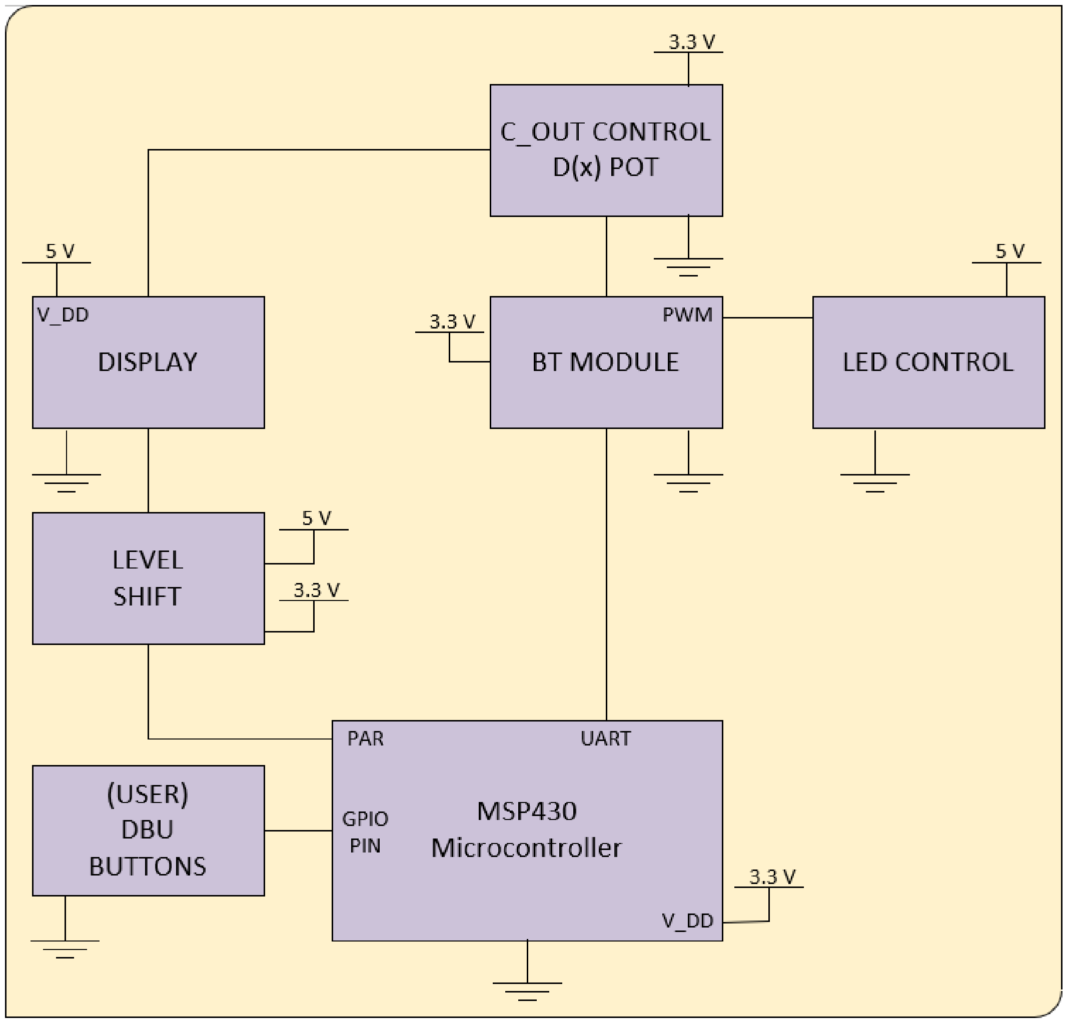


Figure 10: Receiver Subsystem Block Diagram

The receiver coil and parallel capacitor are acting as resonant tank circuit at a frequency of 13.56 MHz. The received power is rectified using a full wave rectifier bridge and then supplies to the battery charger circuit. The rectifier output voltage and current are constantly sampled by the microcontroller to determine instantaneous received power. The battery pack is connected to the charger for charging and the battery pack SMbus interface is connected to the microcontroller.

The diagram below shows the receiver's charging subcircuits.

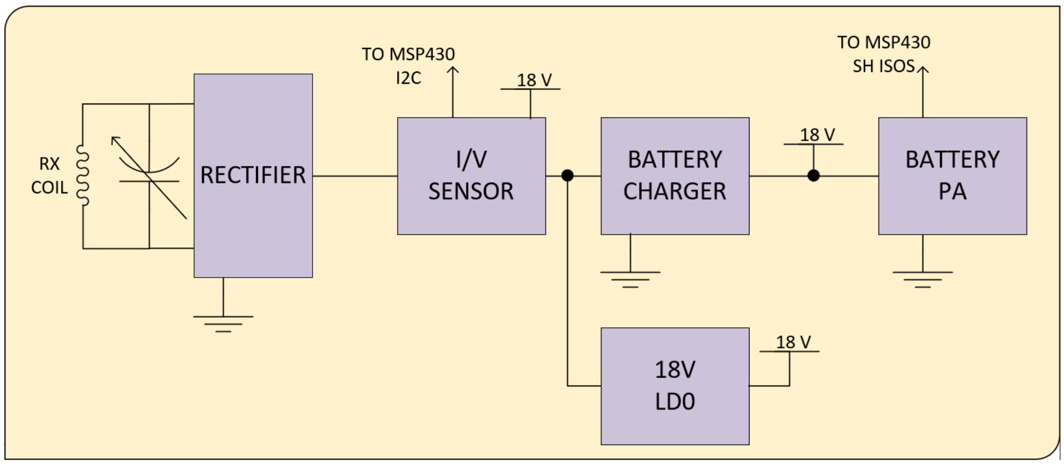


Figure 11: Receiver Coil Subsystem Block Diagram

The diagram below shows the voltage regulators utilized in powering the receiver's digital circuits and draws power from the battery pack directly.

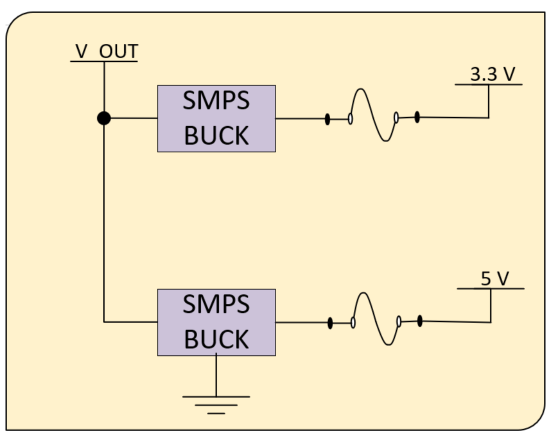


Figure 12: Receiver Voltage Regulator

On the receiver, battery management and power delivery functions are performed by the LTC4162-L monolithic charging controller. It handles many important battery testing and safety procedures automatically. Batteries are tested before charging, and should abnormal charging currents or voltages be detected the LTC4162-L will cease charging without firmware intervention. If conditions fall outside the preset limits a microcontroller interrupt may be triggered via the SMBALERT line for further error handling. The microcontroller firmware may read and change the LTC4162 status over an SMBus interface at any time.

A RRC smart battery will handle cell monitoring, balancing, and charging capacity measurement. It will automatically limit charge and discharge current to ensure safe functioning. Any one of a family of smart batteries may be connected to a keyed cable connector that ensures correct polarity and an SMBus connection. The SMBus interface will communicate with the microcontroller firmware to provide battery charge capacity and health information to the user.

Charger subcircuit is realized using LTC4162EUFD-SAD integrated circuit and may be found in Appendix A.2.

The power receiver subcircuit consists of the receiver coil, rectifier bridge, voltage sensor, and current sensor on the DC side of the circuit and feeds into the battery charging subcircuit. The rectifier bridge is designed using silicon carbide Schottky diodes.

DC Voltage detector and current sensor will be used to determine received power levels which can be used as an indication of transmitter-receiver inductive coupling. DC Voltage levels and current are sampled using the MSP430FR5994 AD converter.

The RF receiver rectifier and power sensor are shown below and can be found in larger print in Appendix A.3.

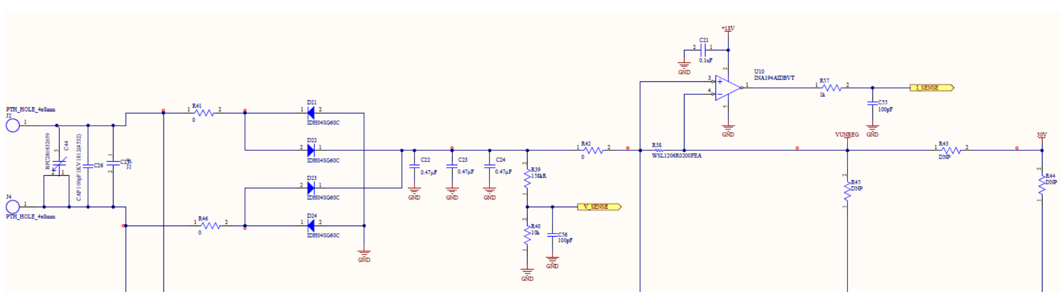


Figure 13: Rectifier and Power Sensor Subcircuit

3.) Planar Coil Inductor The transmitter and receiver utilize identical planar coils in the wireless power transfer process with an inductance of 0.909 μH. The coils utilize copper tubing to reduce weight and costs.

The dimensions of the coil are shown below.

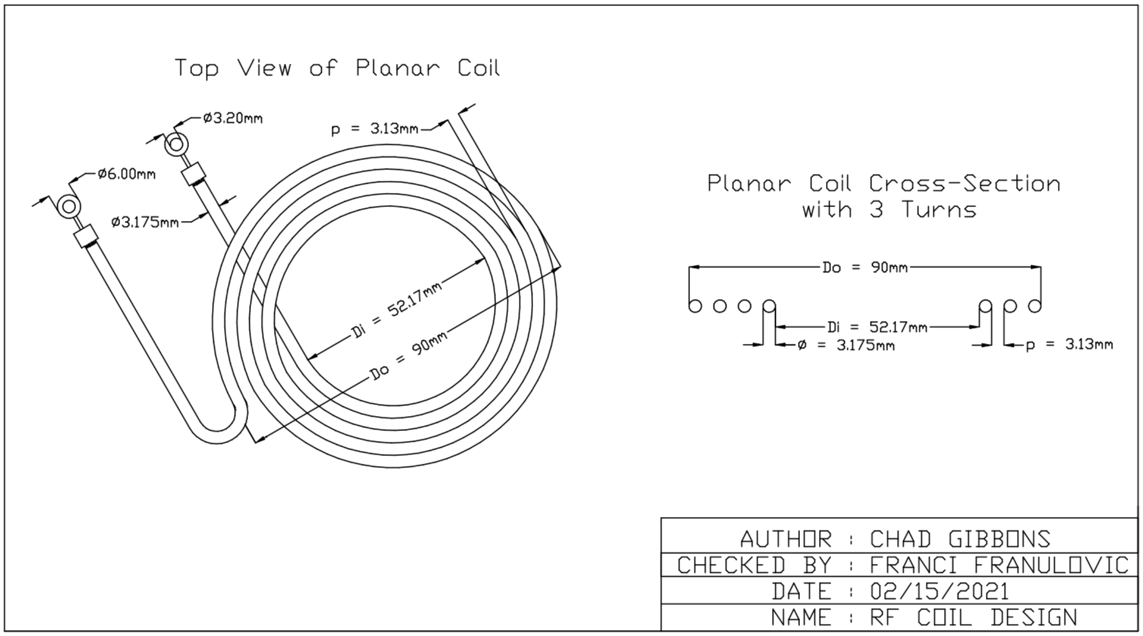


Figure 14: Planar Coil CAD Drawing

C. Software Architecture

1.) Firmware Architecture The microcontrollers' firmware architecture is split into two general categories: core functionality that is required for the microcontroller to operate and utilities that handle specific tasks that the microcontrollers need to complete. The core functions primarily stem from interrupt calls and setup sequences. The util functions will communicate through the bluetooth, display information, and handle or monitor power transmission.

Below is an example of the firmware architecture.

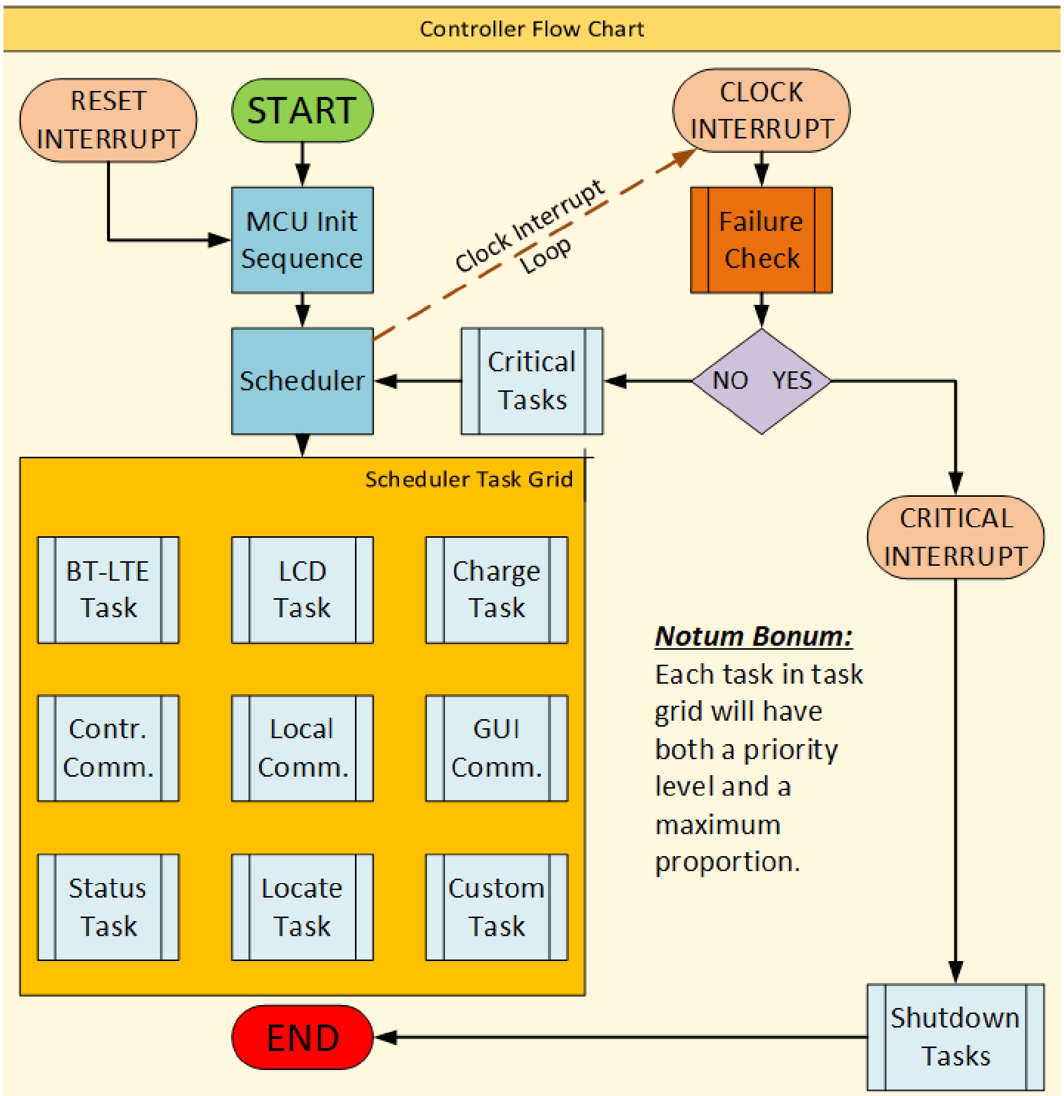


Figure 15: Controller Flow Chart

2.) GUI Software Architecture The GUI Software architecture is split into three general categories: Model, Controller, and View (MCV) components. Each general category is then subdivided into layers of functionality to maintain modularity. The Model is critical for handling data classes and storing data into files. The Controller is responsible for operating the visual components and model objects. The view category is utilized strictly for showing the graphical displays and are passive elements in the design's architecture.

The figure below shows the application of the Model-Controller-View (MCV) GUI Architecture

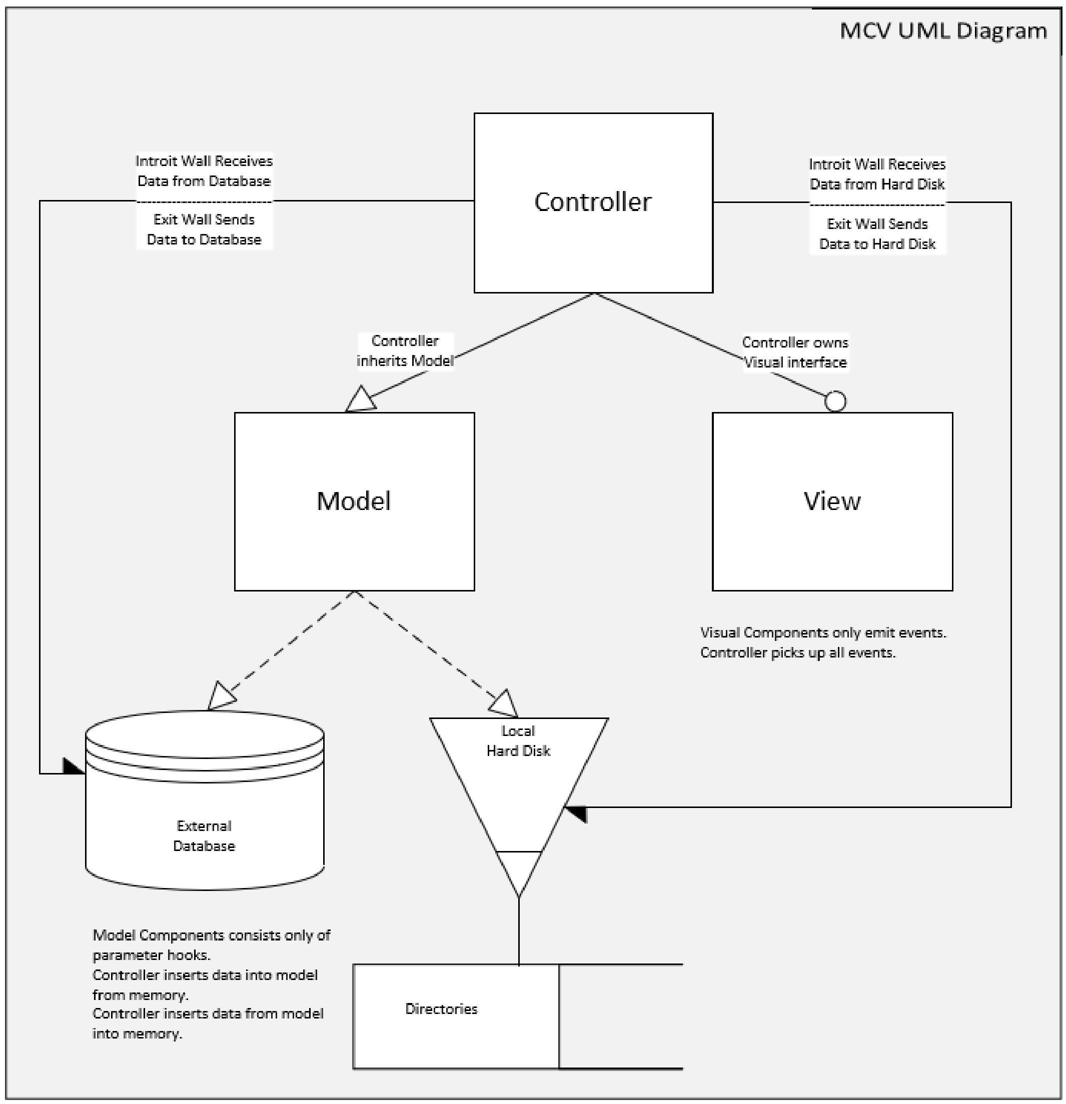


Figure 16: High Level GUI Software Architecture Example

D. Software Modules

1.) Firmware Modules Programmed on TI's Code Composer software and tested on TI's MSP430FR5994 Launchpad Kit

* = confer to both header and C files.

Microcontroller Setup
Location: Firmware\MSP430FR5994_MCU\core\mcu_setup.*
Function: Activates port settings and instantiates utility functions that operate the program.

Microcontroller Reset
Location: Firmware\MSP430FR5994_MCU\core\mcu_reset.*
Function: Resets microcontroller to initial setup configuration.

Task Queue Scheduler
Location: Firmware\MSP430FR5994_MCU\util\Scheduler\scheduler.*
Function: Creates and operates the scheduler method class that selects the next task to be run in the main loop based on task priorities.

Clock Interrupt
Location: Firmware\MSP430FR5994_MCU\core\Interrupts\clock_interrupt.*
Function: The code uses Timer A and SMCLK (1 MHz) to test clock interrupt. Once the program starts running, the timer counts up to 4 ticks to emit the clock interrupt signal every 250 ms period. Additionally, it instantiates utility functions considered critical to repeat frequently.

Button Interrupt
Location: Firmware\MSP430FR5994_MCU\core\Interrupts\button_interrupt.*
Function: Four buttons are set up within a port. The code sets up an interrupt service routine to run when a button is pushed, so that their respective function is called.

Pin Input Voltage Reader
Location: Firmware\MSP430FR5994_MCU\core\Interrupts\pins.*
Function: The function reads the analog 12 bit ADC input voltage at a port's pin.

Communication Transmission
Location: Firmware\MSP430FR5994_MCU\util\Bluetooth\bluetooth_trans.*
Function: The code permits the transmitter to communicate directly with the receiver. Alternatively, it permits the receiver to communicate with both the transmitter and a mobile device.

Communication Received
Location: Firmware\MSP430FR5994_MCU\util\Bluetooth\bluetooth_recv.*
Function: The code facilitates the reception and reaction to bluetooth messages received.

2.) GUI Software Modules

††† = architecture layer (Abstract - Base - Panel - Page - Window - App)
* = confer to both header and C++ files

Controllers
Location: Software\controller\†††_controller.*
Function: The doer or agent component of the program. Controllers allocate functions to particular events in the UI or manipulations to data models.

Widget Constructor
Location: Software\controller\widget_setter.*
Function: The factory class that is dedicated to building widgets in a panel with the proper hierarchy of inheritance in order to give the controller mediate control of all widgets.

Bluetooth Low Energy
Location: Software\core\Bluetooth\Protocols\bt_le.*
Function: The concrete method class handling Qt5 Bluetooth classes.

App Initialization
Location: Software\core\app_init.*
Function: Configure all initial settings and ensure that the program is properly installed.

Models
Location: Software\model\†††_model.*
Function: Data classes that can be pickled into compressed and encrypted binary data files. These models provide the stable memory of the application.

Canvas
Location: Software\ui\CanvasTools\†††_canvas.*
Function: Concrete instances of Qt5's QCanvas class for graphical displays of information.

Canvas Shapes
Location: Software\ui\CanvasTools\†††_canvas_shape.*
Function: Individual images used as graphical displays of information and placed on their respective canvases.

Panels
Location: Software\ui\Panels\+++_panel.*
Function: Concrete instances of movable panels used to hold widgets or canvases in GUI.

Toolbar Tools
Location: Software\ui\ToolbarTools\win_bar_tools.*
Function: Flushes out available toolbar icons and functions. Can also expand or limit drop down menu options at top of window.

Widgets
Location: Software\ui\Widgets
Function: Too many individual modules to account for in this document. See GitHub repository `https://github.com/gibbs212521/HEC_2_senior_design` for further detail. These modules are Abstract-Concrete constructor classes that build their respective widgets with additional custom methods or attributes.

Windows
Location: Software\ui\Windows\+++_window.*
Function: Abstract-Concrete constructor classes that permit the appearance of various types of windows in the application (restricted in tablet/cellphone device compilation).

Power Monitor
Location: Software\util\power_monitor.*
Function: Method class that ascertains whether the transmitter is sending power currently or not. Collects additional ancillary charging data.

Ticker Class
Location: Software\ui\Ticker\+++_ticker.*
Function: Collects or alters LCD ticker read out on the microcontroller.

App Configurations
Location: Software\config.h
Function: Global variable module. Ideally this file remains blank.

Application's Hidden Settings
Location: Software\.settings
Function: This file shall operate as a flat file to write or read current or most recent states in the application.

Main Program
Location: Software\app.cpp
Function: The proverbial main.cpp that handles all dependencies of the application's program.

E. Hardware Off The Shelf Items

The table below provides links and information on hardware incorporated in the post-production of the PCB. Further information can be found in the BOM Appendices in Appendix NN through Appendix NN.

Table 13: Off The Shelf Items Utilized in Prototype

Description [Name]	Part Number	Link
Line Power Adapter: 65W 48V DC	DT62PW480D	https://product.tdk.com/en/search/power/switching-power/ac-dc-converter/info?part_no=DT62PW480D
74.52 Wh Li-Ion Battery	RRC RRC2040-2	https://www.rrc-ps.com/en/battery-packs/standard-battery-packs/products/rrc2040-2/
LCD Display	NHD-0420DZ-FSW-FBW	https://www.newhavendisplay.com/specs/NHD-0420DZ-FSW-FBW.pdf

F. Software Off The Shelf Items

The table below includes all software used to develop hardware and the software for the wireless charger project.

Table 14: Off The Shelf Software Items

Name and Version	License Type	Restrictions	Link
National Instruments Multisim 14.1	Commercial	None	https://www.ni.com/en-us/shop/software/products/multisim.html
Altium 21.0.9	Commercial	None	https://www.altium.com/
Altium 365	Commercial	None	https://www.altium.com/altium-365
Gerbv 2.6A	GPL 2.0	None	http://gerbv.geda-project.org/
Saturn PCB Design Inc. – PCB Toolkit ver.7.13	Commercial Freeware	None	https://saturnpcb.com/pcb_toolkit/
TI Code Composer	Commercial Freeware	None	https://www.ti.com/tool/CCSTUDIO
Qt5	LGPL 3	Code must be Open Source and Free to Download	https://doc.qt.io/qt-5/licensing.html
MS Visio	Personal License	No Corporate Use	https://www.microsoft.com/en-us/microsoft-365/visio/flowchart-software
NanoCAD	Personal License	No Corporate Use	https://nanocad.com/products/nanoCAD/
GCC	GPL 2.0	None	https://nanocad.com/products/nanoCAD/

IV. REFERENCES

SOFTWARE REFERENCES

Block diagrams were rendered in Windows Visio Standard 2019.
Multisim circuits simulated in NI Multisim V.14.2 2019.

DESIGN REFERENCES

[1] "Standard High Power System". In: *WIBOTIC Products* (2021). URL: https://www.wibotic.com/products/high-power-dev-kit/.

[2] "Anatomy of a Create 2". In: *iRobot Education: Create 2: Create | Advanced* (2021).

[3] "MSP430FR599x, MSP430FR596x Mixed-Signal Microcontrollers". In: *Texas Instruments Inc. SLASE54C - MARCH 2016 - REVISED AUGUST 2018* (2018), pp. 1–172. URL: https://www.ti.com/lit/ds/symlink/msp430fr5994.pdf?ts=1604041478538\&ref_url=https\%253A\%252F\%252Fwww.ti.com\%252Fproduct\%252FMSP430FR5994.

[4] *Texas Instruments MSP430FR5994 Tool Description*. URL: https://www.ti.com/tool/MSP-EXP430FR5994.

[5] "TPSM265R1 65-V Input, 100-mA Power Module with Ultra-Low IQ". In: *Texas Instruments Inc. SNVSBF6A - OCTOBER 2019 - REVISED DECEMBER 2019* (2019), pp. 1–32. URL: https://www.ti.com/lit/ds/symlink/tpsm265r1.pdf?ts=1606735419804&ref_url=https\%253A\%252F\%252Fduckduckgo.com\%252F.

[6] "TPS54160 1.5-A, 60-V, Step-Down DC/DC Converter with Eco-mode". In: *Texas Instruments Inc. SLVSB56C - MAY 2012 - REVISED FEBRUARY 2014* (2014), pp. 1–58. URL: https://www.ti.com/lit/ds/symlink/tps54160.pdf.

[7] *Conductor Bulk Resistivity & Skin Depths*. RF Cafe. URL: https://www.rfcafe.com/references/electrical/cond-high-freq.htm.

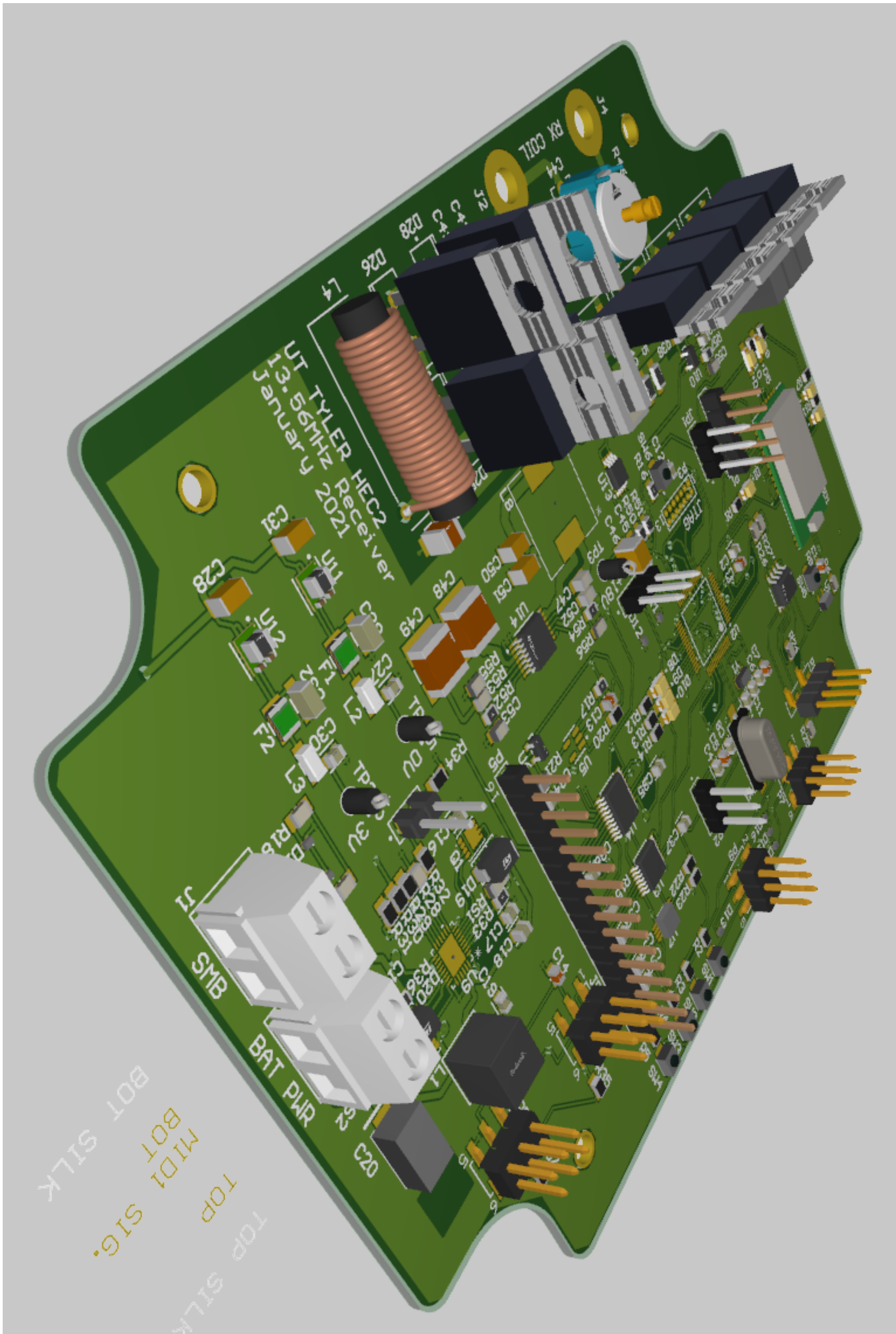
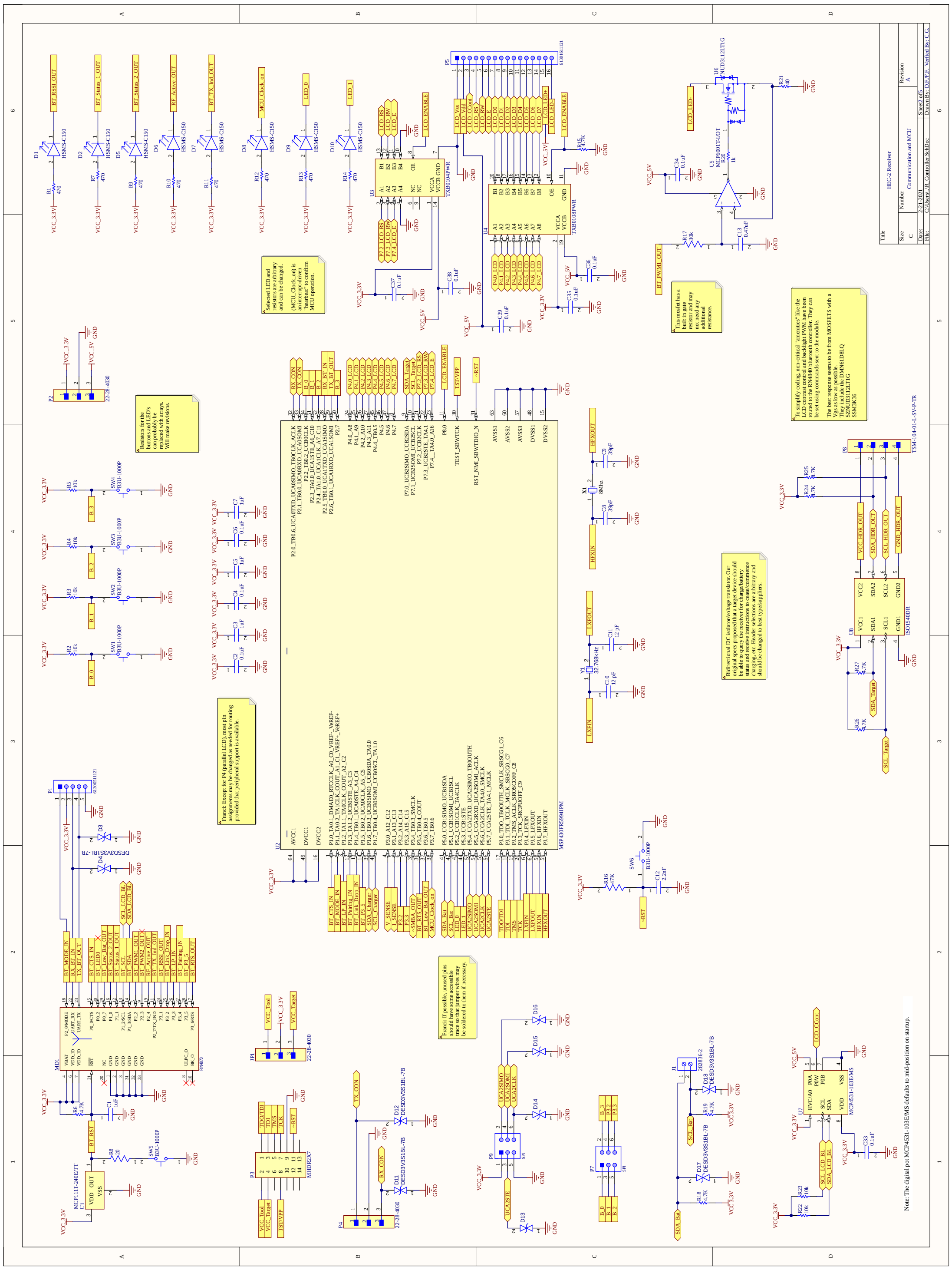
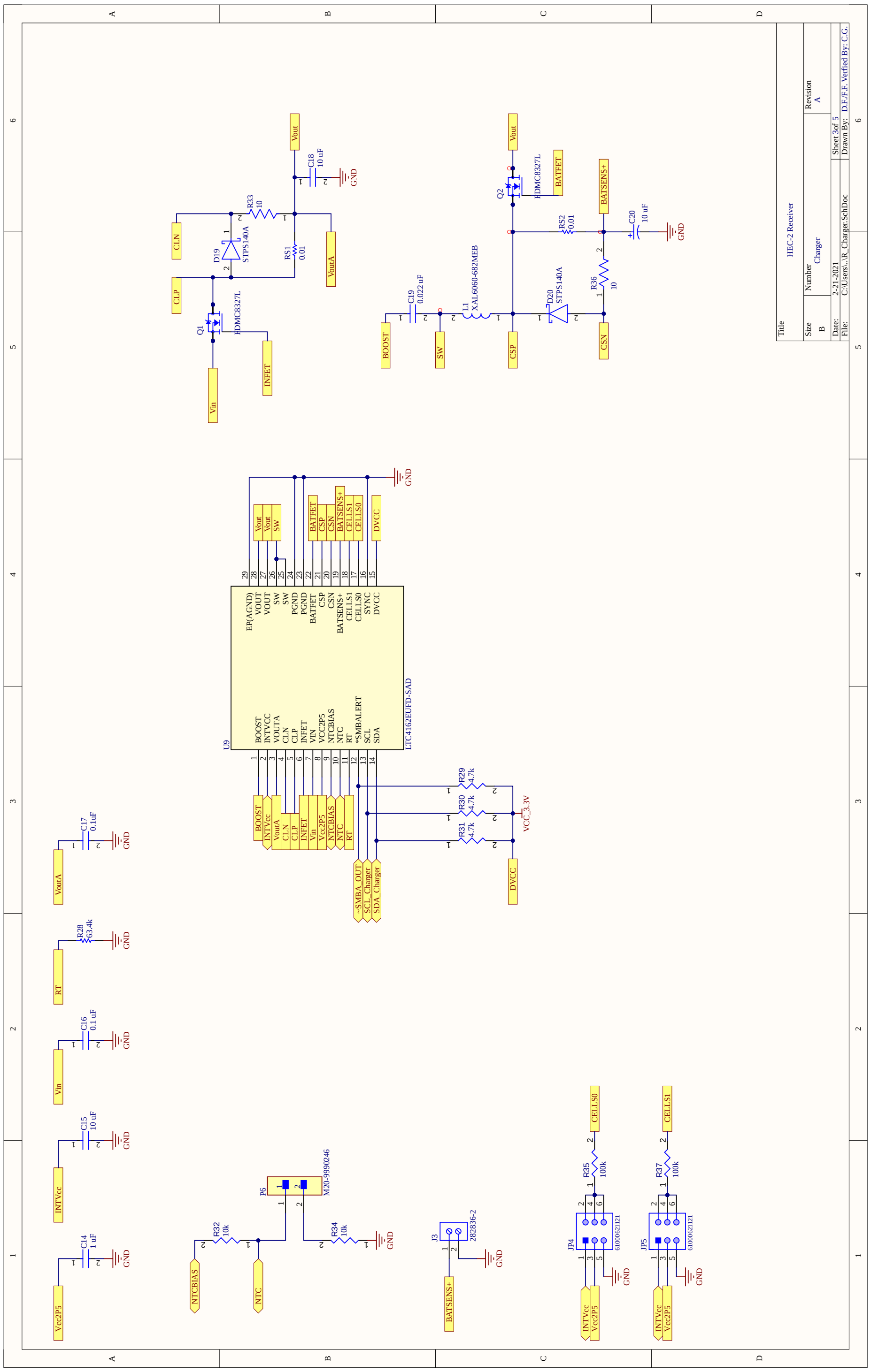


Figure 17: Isometric Image of Receiver PCB

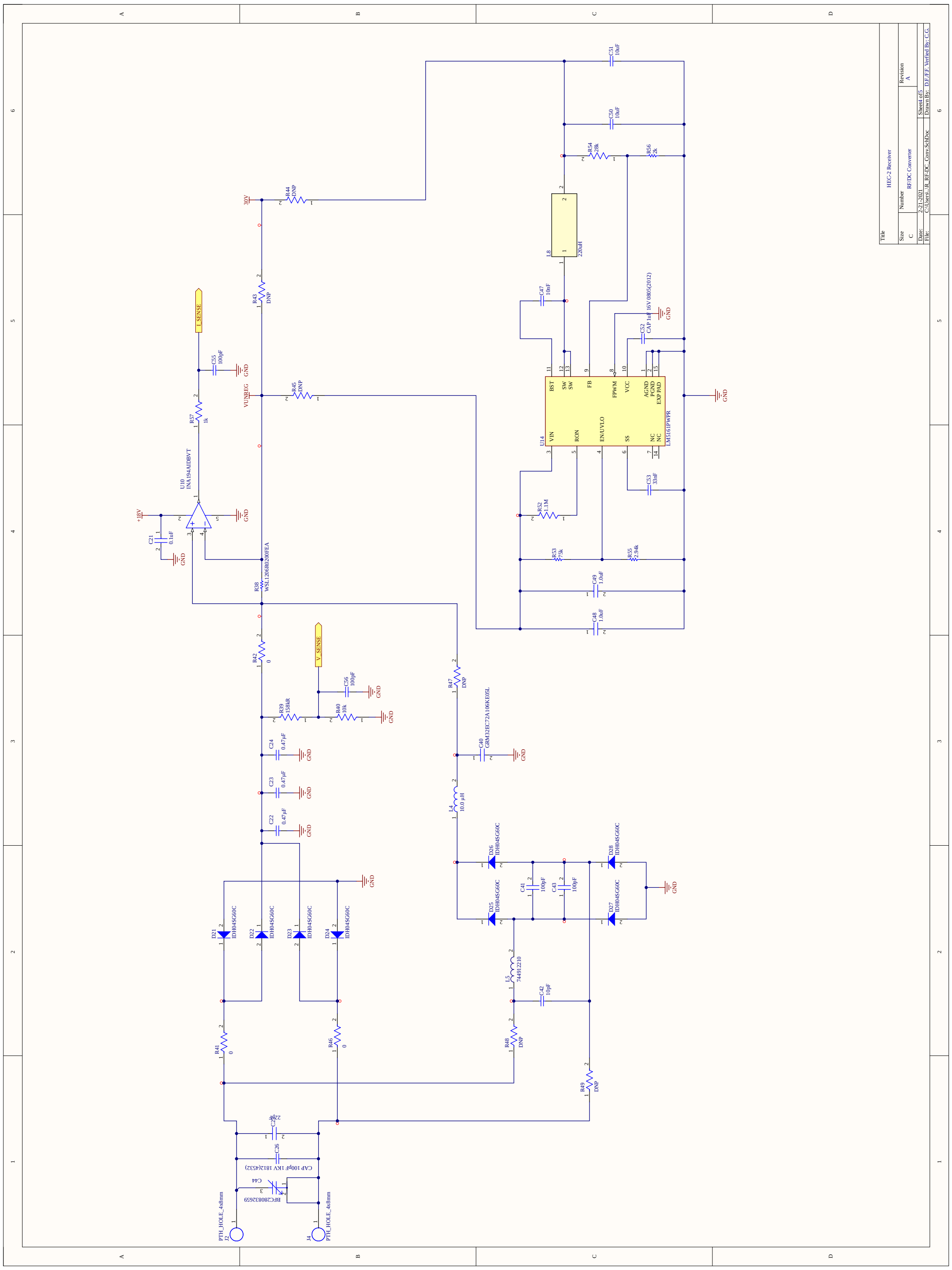
1. Receiver Controller



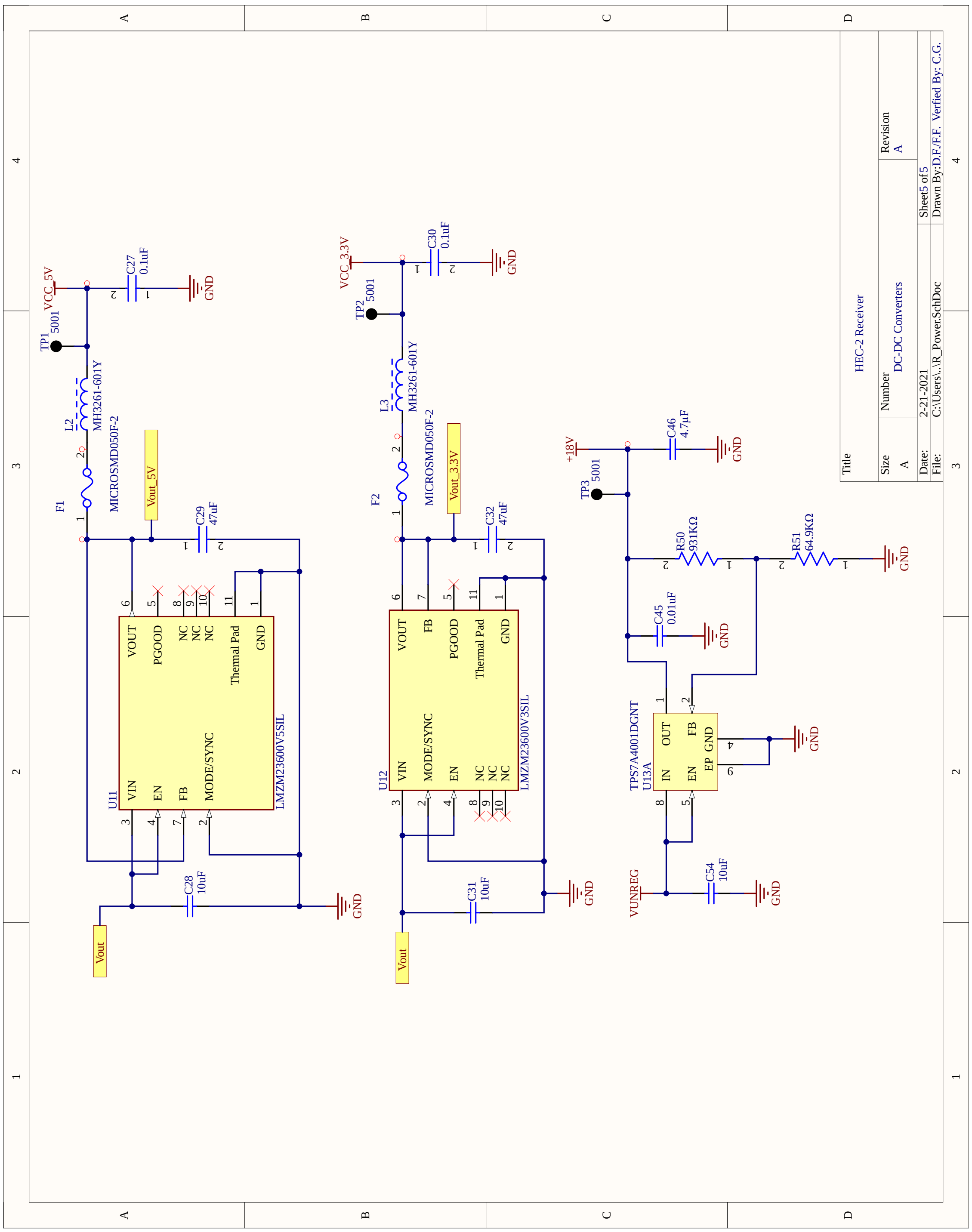
2. Receiver Battery Charger



3. *RF/DC Converter*



4. DC/DC Converter



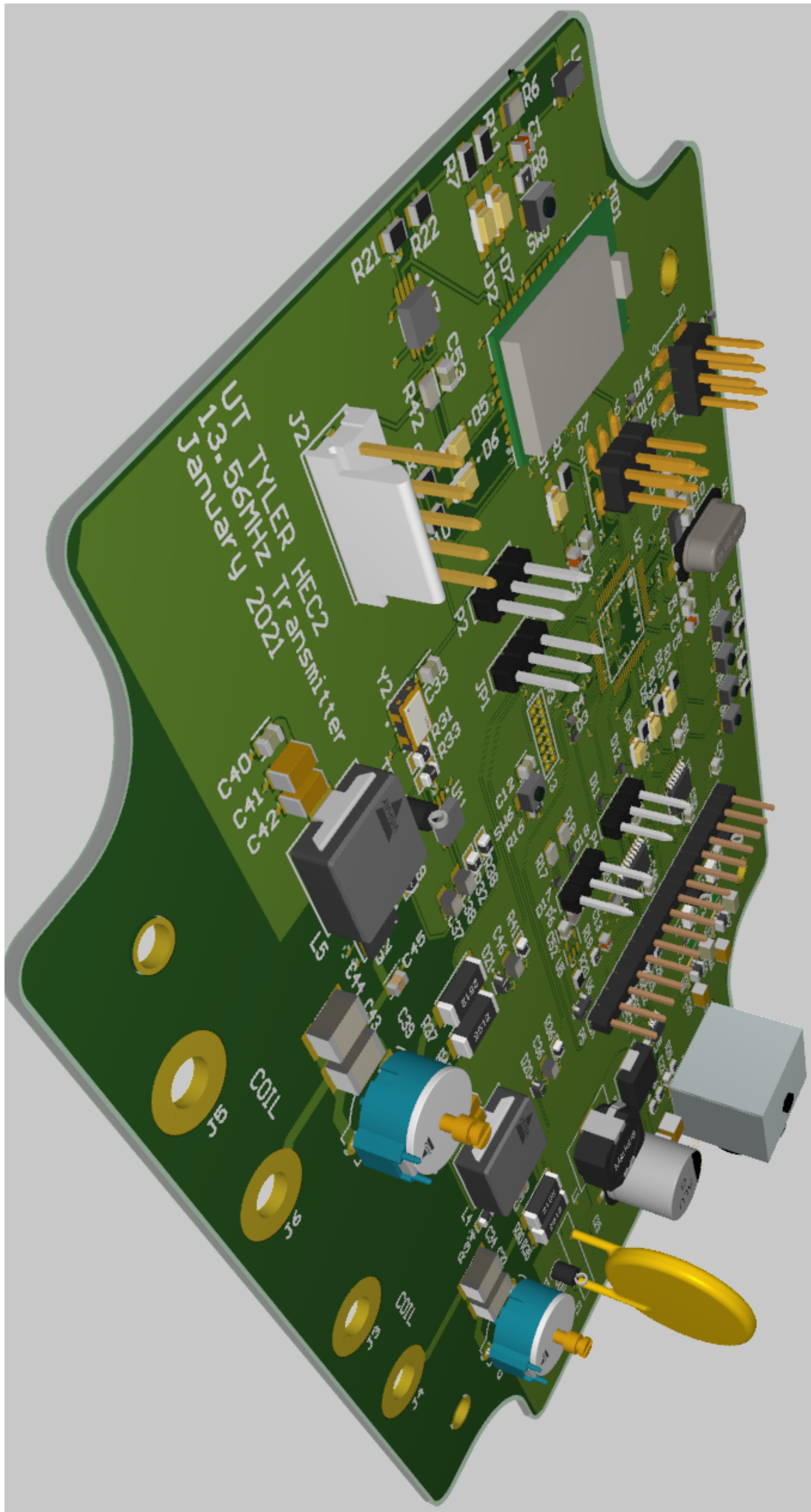
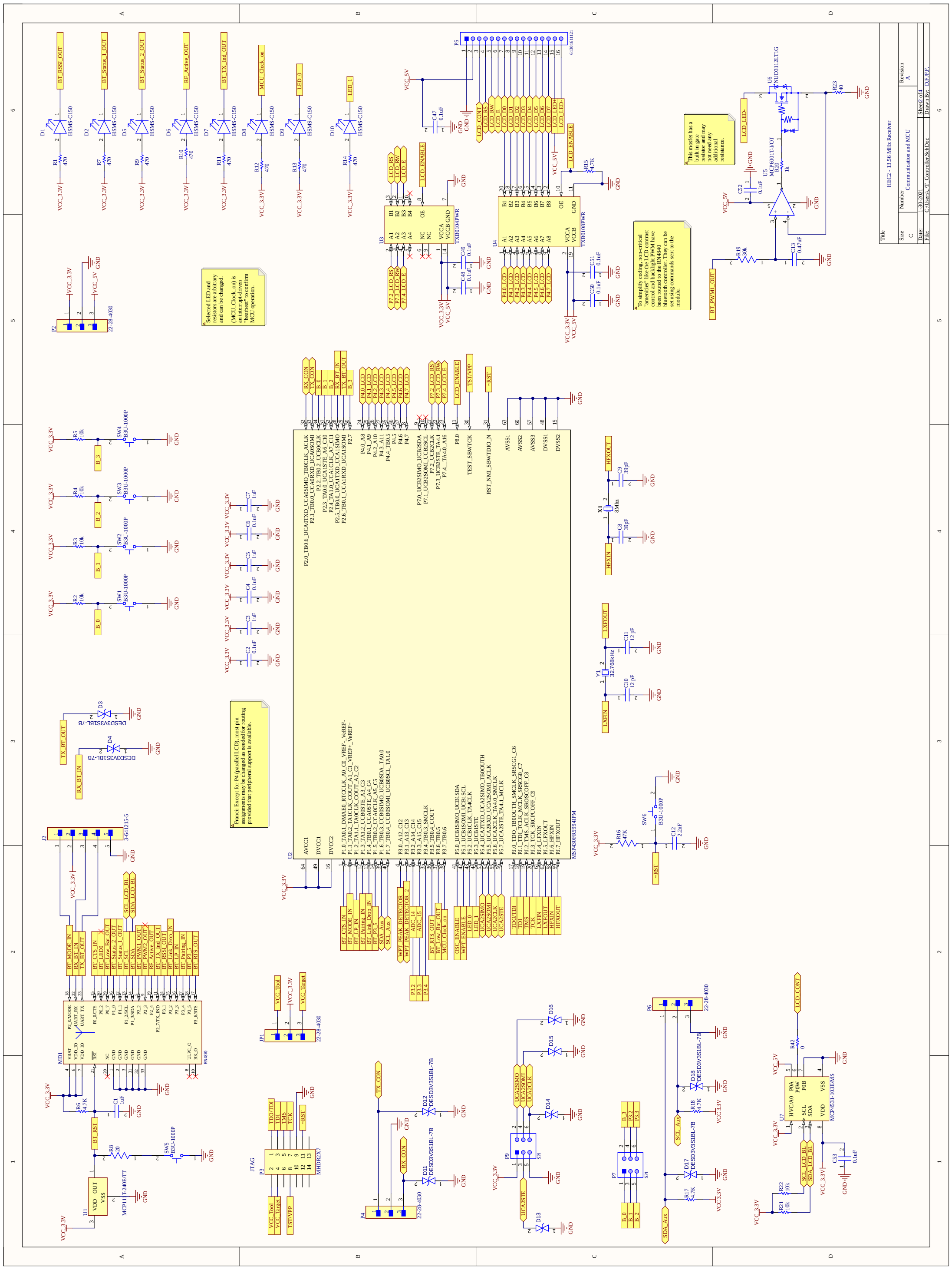
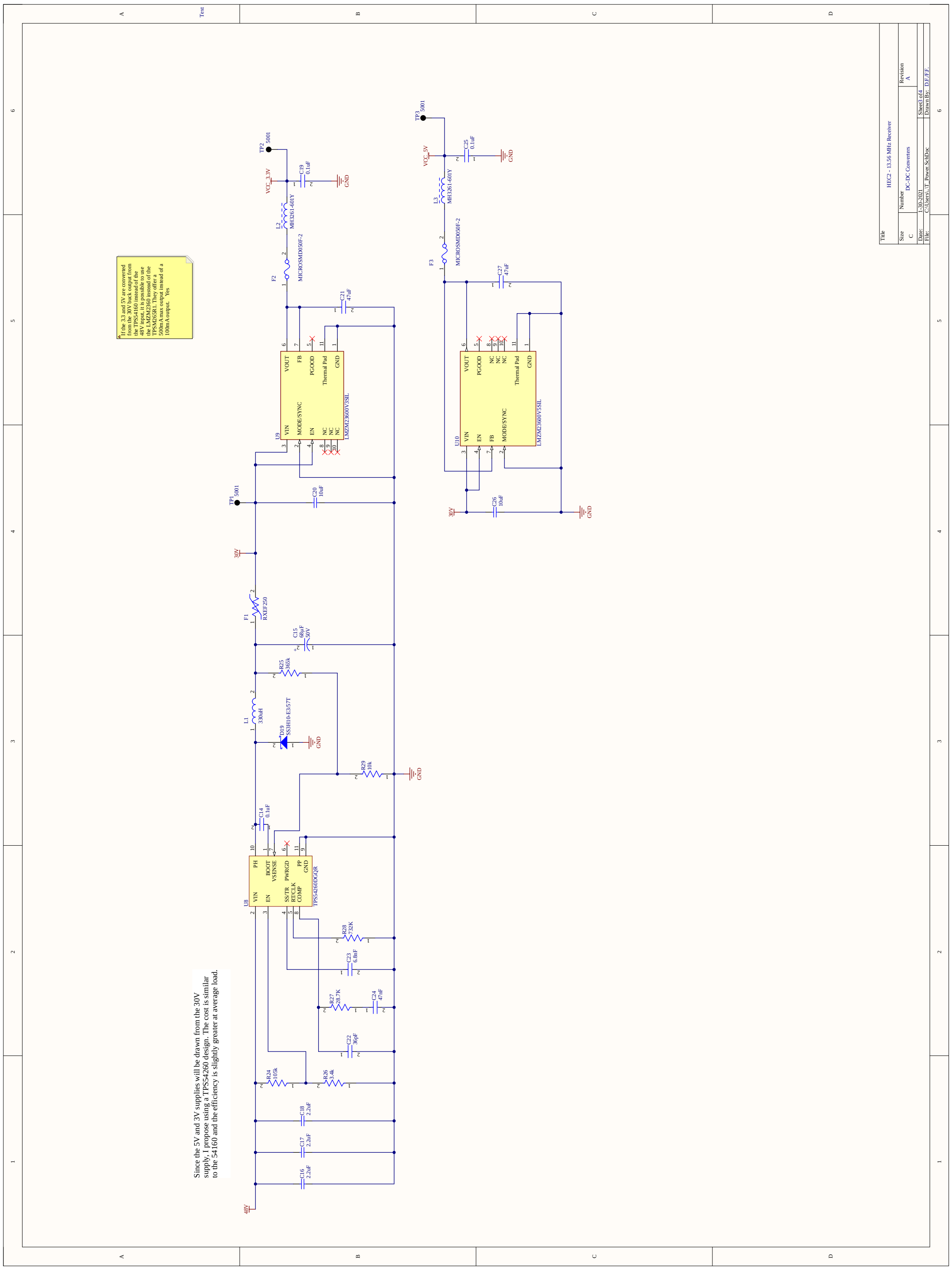


Figure 18: Isometric Image of Transmitter PCB

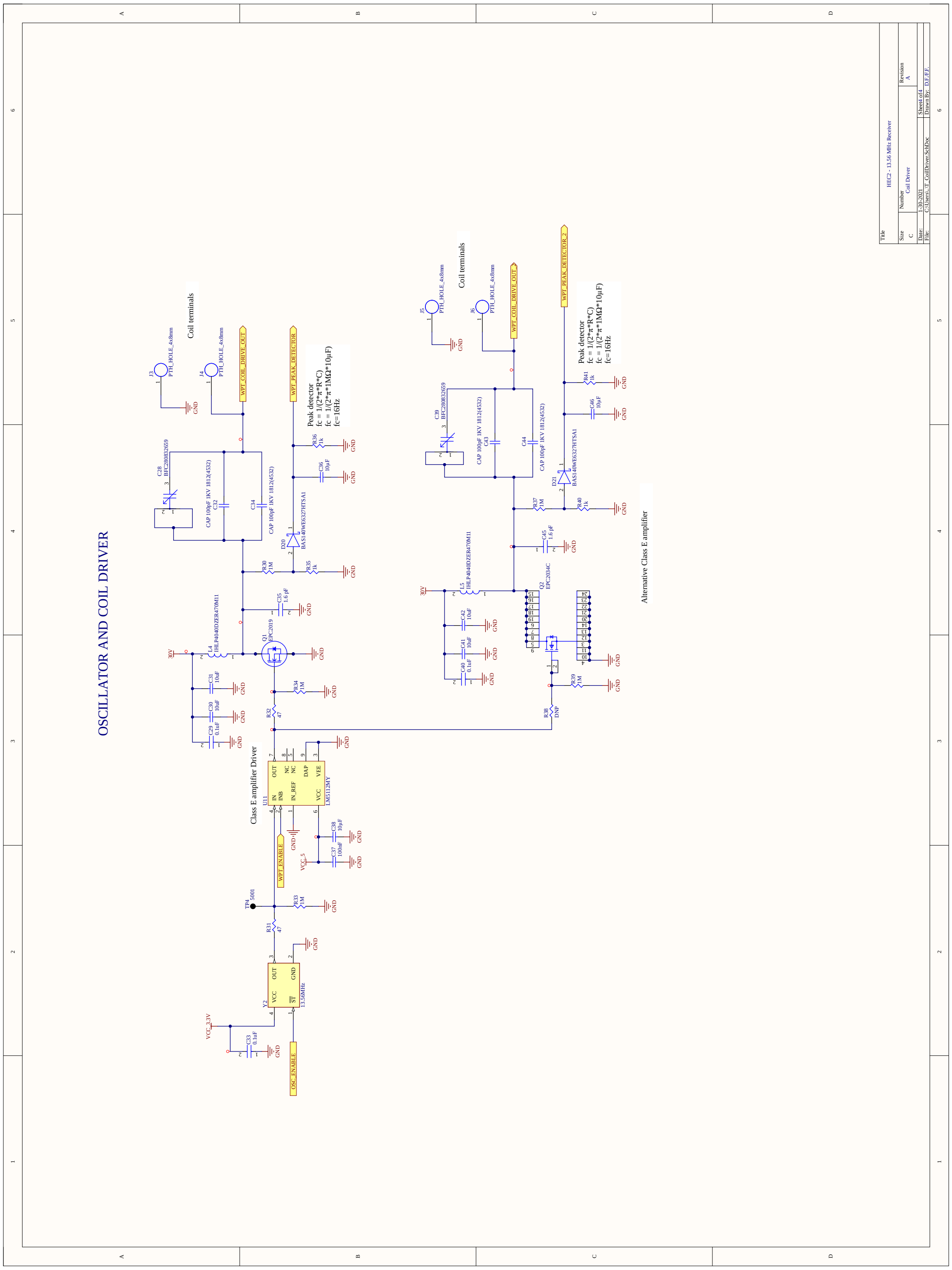
1. *Transmitter Controller*



2. *DC/DC Converter*



3. *Coil Driver*



APPENDIX C: RECEIVER BOM

ASSEMBLY NO:		DATE:	03-02-21
ASSEMBLY NAME:	HEC2 Receiver	PREPARED BY:	David Flory
REVISION:	A	VERIFIED BY:	Franci Franulovic
SOLDER TYPE:	Lead-Free		

ITEM	QTY	REFERENCE	DESCRIPTION	MFG	MFG P/N	VENDOR	VENDOR P/N	Datasheet URL	NOTES	Unit Price
1	4	C1, C3, C5, C7	Multilayer Ceramic Capacitors MLCC - SMD/SMT Multilayer Ceramic Capacitors MLCC - SMD/SMT 1.0uF 10V X7R 10%	Yageo	CC0805KKX7R6BB105	Mouser	603-CC805KKX7R6BB105	https://www.mouser.com/datasheet/2/447/UPY-GPHC_X7R_6.3V-to-50V_18-1154002.pdf		$0.25
2	14	C2, C4, C6, C17, C21, C27, C30, C33, C34, C35, C36, C37, C38, C39	Multilayer Ceramic Capacitors MLCC - SMD/SMT Multilayer Ceramic Capacitors MLCC - SMD/SMT 50V 0.1uF X7R 0805 10%	KEMET	C0805C104K5RACTU	Mouser	80-C0805C104K5R	https://www.mouser.com/datasheet/2/212/KEM_C1002_X7R_SMD-1102033.pdf		$0.13
3	2	C8, C9	Multilayer Ceramic Capacitors MLCC - SMD/SMT Multilayer Ceramic Capacitors MLCC - SMD/SMT 50V 39pF C0G 0805 5%	KEMET	C0805C390J5GACTU	Mouser	80-C0805C390J5G	https://www.mouser.com/datasheet/2/212/KEM_C1003_C0G_SMD-1101588.pdf		$0.24
4	2	C10, C11	Multilayer Ceramic Capacitors MLCC - SMD/SMT Multilayer Ceramic Capacitors MLCC - SMD/SMT 50V 12pF C0G 0805 5%	KEMET	C0805C120J5GACTU	Mouser	80-C0805C120J5G	https://www.mouser.com/datasheet/2/212/KEM_C1003_C0G_SMD-1101588.pdf		$0.11
5	1	C12	Multilayer Ceramic Capacitors MLCC - SMD/SMT Multilayer Ceramic Capacitors MLCC - SMD/SMT 50V 2200pF X8R 0805 5%	KEMET	C0805C222J5HACTU	Mouser	80-C0805C222J5H	https://www.mouser.com/datasheet/2/212/KEM_C1007_X8R_ULTRA_150C_SMD-1102703.pdf		$0.69
6	1	C13	Multilayer Ceramic Capacitors MLCC - SMD/SMT Multilayer Ceramic Capacitors MLCC - SMD/SMT 470nF 16V X7R 10%	Yageo	CC0805KKX7R7BB474	Mouser	603-CC805KKX7R7BB474	https://www.mouser.com/datasheet/2/447/UPY-GPHC_X7R_6.3V-to-50V_18-1154002.pdf		$0.23
7	1	C14	Multilayer Ceramic Capacitors MLCC - SMD/SMT Multilayer Ceramic Capacitors MLCC - SMD/SMT 1.0uF 10V X7R 10%	Yageo	CC0805KKX7R6BB105	Mouser	603-CC805KKX7R6BB105	https://www.mouser.com/datasheet/2/447/UPY-GPHC_X7R_6.3V-to-50V_18-1154002.pdf		$0.25
8	2	C15, C18	Multilayer Ceramic Capacitors MLCC - SMD/SMT Multilayer Ceramic Capacitors MLCC - SMD/SMT 10volts 10uF X5R 10%	KEMET	C0805C106K8PACTU	Mouser	80-C0805C106K8P	https://www.mouser.com/datasheet/2/212/KEM_C1006_X5R_SMD-1103249.pdf		$0.14
9	1	C16	Multilayer Ceramic Capacitors MLCC - SMD/SMT Multilayer Ceramic Capacitors MLCC - SMD/SMT 50V 0.1uF X7R 0805 10%	KEMET	C0805C104K5RACTU	Mouser	80-C0805C104K5R	https://www.mouser.com/datasheet/2/212/KEM_C1002_X7R_SMD-1102033.pdf		$0.24
10	1	C19	Multilayer Ceramic Capacitors MLCC - SMD/SMT Multilayer Ceramic Capacitors MLCC - SMD/SMT 50V 0.022uF C0G 0805 5%	KEMET	C0805C223J5GACTU	Mouser	80-C0805C223J5G	https://www.mouser.com/datasheet/2/212/KEM_C1003_C0G_SMD-1101588.pdf		$0.76
11	1	C20	Tantalum Capacitors - Solid SMD Tantalum Capacitors - Solid SMD 50V 10uf 2917 10% ESR=800mOhms	KEMET	T491D106K050AT	Mouser	80-T491D106K050	https://www.mouser.com/datasheet/2/212/1/KEM_T2005_T491-1093550.pdf		$1.83
12	1	C25	Multilayer Ceramic Capacitors MLCC - SMD/SMT Multilayer Ceramic Capacitors MLCC - SMD/SMT 22pF 1KVolts 5%	Murata	GRM31A7U3A220JW31D	Mouser	81-GRM31A7U3A220JW1D	https://www.mouser.com/datasheet/2/281/1/GRM31A7U3A220JW31_01-1987629.pdf		$0.43
13	1	C26	Multilayer Ceramic Capacitors MLCC - SMD/SMT Multilayer Ceramic Capacitors MLCC - SMD/SMT 100pF 1KV C0G 5%	Vishay	VJ1812A101JXGAT	Mouser	77-VJ1812A101JXGAT	https://www.mouser.com/datasheet/2/427/vjcommercialseries-1764145.pdf		$0.76
14	4	C28, C31, C50, C51	Multilayer Ceramic Capacitors MLCC - SMD/SMT Multilayer Ceramic Capacitors MLCC - SMD/SMT 1206 50V 10uF X5R 10% T: 1.6mm	TDK	C3216X5R1H106K160AB	Mouser	810-C3216X5R1H106K	https://product.tdk.com/info/en/catalog/datasheets/mlcc_commercial_general_en.pdf?ref_disty=mouser		$0.85
15	2	C29, C32	Multilayer Ceramic Capacitors MLCC - SMD/SMT Multilayer Ceramic Capacitors MLCC - SMD/SMT 1206 25VDC 47uF 20% X5R 1.6mm	TDK	C3216X5R1E476M160AC	Mouser	810-C3216X5R1E476M	https://product.tdk.com/info/en/catalog/datasheets/mlcc_commercial_general_en.pdf?ref_disty=mouser		$1.05
16	1	C40	Multilayer Ceramic Capacitors MLCC - SMD/SMT Multilayer Ceramic Capacitors MLCC - SMD/SMT 100Vdc 10uF 10% 1210/2502	Murata	GRM32EC72A106KE05L	Mouser	81-GRM32EC72A106KE05	https://www.mouser.com/datasheet/2/281/1/GRM32EC72A106KE05_01A-1988109.pdf		$1.38
17	1	C42	Multilayer Ceramic Capacitors MLCC - SMD/SMT Multilayer Ceramic Capacitors MLCC - SMD/SMT 0805 10pF 1KV C0G 5%	Vishay	VJ0805A100JXGAT5Z	Mouser	77-VJ0805A100JXGAT5Z	https://www.mouser.com/datasheet/2/427/vjhvarcguard-1763127.pdf		$0.68
18	1	C44	Trimmer / Variable Capacitors Trimmer / Variable Capacitors TRIMMER CAPACITOR	Vishay	BFC280832659	Mouser	594-2222-808-32659	https://www.vishay.com/doc?28528		$7.21
19	1	C46	Multilayer Ceramic Capacitors MLCC - SMD/SMT Multilayer Ceramic Capacitors MLCC - SMD/SMT 50V 4.7uF X7R 1210 10%	KEMET	C1210X475K5RACTU	Mouser	80-C1210X475K5R	https://www.mouser.com/datasheet/2/212/1/KEM_C1013_X7R_FT_CAP_SMD-1103280.pdf		$1.81
20	1	C47	Multilayer Ceramic Capacitors MLCC - SMD/SMT Multilayer Ceramic Capacitors MLCC - SMD/SMT 16V .01uF C0G 0805 5%	AVX	0805YA103JAT2A	Mouser	581-0805YA103J	https://www.mouser.com/datasheet/2/40/C0GNP0_Dielectric-951274.pdf		$0.96

21	2	C48, C49	Multilayer Ceramic Capacitors MLCC - SMD/SMT Multilayer Ceramic Capacitors MLCC - SMD/SMT 2220 1uF 250volts X7R 10%	Murata	GRM55DR72E105KW01L	Mouser	81-GRM55RR72E105K	https://www.mouser.com/datasheet/2/281/1/GRM55DR72E105KW01_01-1988382.pdf		$1.48
22	1	C52	Multilayer Ceramic Capacitors MLCC - SMD/SMT Multilayer Ceramic Capacitors MLCC - SMD/SMT 16V 1uF X7R 0805 10%	KEMET	C0805C105K4RACTU	Mouser	80-C0805C105K4R	https://www.mouser.com/datasheet/2/212/KEM_C1002_X7R_SMD-1102033.pdf		$0.13
23	1	C54	Multilayer Ceramic Capacitors MLCC - SMD/SMT Multilayer Ceramic Capacitors MLCC - SMD/SMT 100V 10uF X7R 2220 20% Tol HIGH CV	AVX	22201C106MAT2A	Mouser	581-22201C106MAT2A	https://www.mouser.com/datasheet/2/40/X7RDielectric-777024.pdf		$1.83
24	8	D1, D2, D5, D6, D7, D8, D9, D10	Standard LEDs - SMD Standard LEDs - SMD Red Diffused 626nm 10mcd	Broadcom Limited	HSMS-C150	Mouser	630-HSMS-C150	https://www.mouser.com/datasheet/2/678/av02-0551en-ds-hsmx-cxxx-05mar2012-1827675.pdf		$0.41
25	5	D3, D11, D12, D17, D18	ESD Suppressors / TVS Diodes ESD Suppressors / TVS Diodes Low Cap Bi TVS 10pF 3.3V 3.8Vbr 25kV	Diodes Incorporated	DESD3V3S1BL-7B	Mouser	621-DESD3V3S1BL-7B	https://www.mouser.com/datasheet/2/115/DESD3V3S1BL-321080.pdf		$0.29
26	5	D4, D13, D14, D15, D16	ESD Suppressors / TVS Diodes ESD Suppressors / TVS Diodes Low Cap Bi TVS 10pF 3.3V 3.8Vbr 25kV	Diodes Incorporated	DESD3V3S1BL-7B	Mouser	621-DESD3V3S1BL-7B	https://www.mouser.com/datasheet/2/115/DESD3V3S1BL-321080.pdf		$0.29
27	2	D19, D20	Schottky Diodes & Rectifiers Schottky Diodes & Rectifiers 1.0 Amp 40 Volt	STMicroelectronics	STPS140A	Mouser	511-STPS140A	https://www.mouser.com/datasheet/2/389/stps140-1851573.pdf		$0.44
28	8	D21, D22, D23, D24, D25, D26, D27, D28	Schottky Diodes & Rectifiers Schottky Diodes & Rectifiers SIC DIODES	Infineon	IDH04SG60CXKSA2	Mouser	726-IDH04SG60CXKSA2	https://www.infineon.com/dgdl/Infineon-ApplicationNote_PFCCCMBoostConverterDesignGuide-AN-v02_00-EN.pdf?fileId=5546d4624a56eed8014a62c75a923b05		$2.64
29	2	F1, F2	Resettable Fuses - PPTC Resettable Fuses - PPTC .5A 13.2V 40A Imax	Littelfuse	MICROSMD050F-2	Mouser	650-MICROSMD050F-2	https://www.mouser.com/datasheet/2/240/Littelfuse_PTC_MICROSMD_Catalog_Datasheet.pdf-1021745.pdf		$0.47
30	2	J1, J3	Fixed Terminal Blocks Fixed Terminal Blocks 5.0MM PCB MOUNT 2P	TE Connectivity	282836-2	Mouser	571-2828362	http://www.te.com/commerce/DocumentDelivery/DDEController?Action=srchrtrv&DocNm=114-20079&DocType=Specification+Or+Standard&DocLang=English&PartCntxt=282836-2		$0.80
31	2	J2, J4				Mouser				
32	3	JP1, P2, P4	Headers & Wire Housings Headers & Wire Housings 3P VERT HEADER Sn	Molex	22-28-4030	Mouser	538-22-28-4030	https://www.mouser.com/datasheet/2/276/0022284030_PCB_HEADERS-228162.pdf		$0.16
33	2	JP4, JP5	Headers & Wire Housings Headers & Wire Housings WR-PHD 2.54mm SMT 6P Hdr Dual Strt	Wurth Elektronik	61000621121	Mouser	710-61000621121	https://www.mouser.com/datasheet/2/445/61000621121-1717892.pdf		$0.93
34	1	L1	Fixed Inductors Fixed Inductors 6.8uH Shld 20% 9A 20.8mOhms AECQ2	Coilcraft	XAL6060-682MEB	Mouser	994-XAL6060-682MEB	https://www.mouser.com/datasheet/2/597/xal60xx-270658.pdf		$2.58
35	2	L2, L3	Ferrite Beads Ferrite Beads 600 ohms 25% HIGH CURRENT	Bourns	MH3261-601Y	Mouser	652-MH3261-601Y	https://www.mouser.com/datasheet/2/54/mh-777565.pdf		$0.10
36	1	L4	Fixed Inductors Fixed Inductors WE-SD Rod Core 10uH 5A 15.1mOhm	Wurth Elektronik	744711005	Mouser	710-744711005	https://www.mouser.com/datasheet/2/445/744711005-1722097.pdf		$1.83
37	1	L5	Fixed Inductors Fixed Inductors WE-CAIR Air Coil 100nH 1.7A 150MHz	Wurth Elektronik	744912210	Mouser	710-744912210	https://www.mouser.com/datasheet/2/445/744912210-1723335.pdf		$1.16
38	1	L8	Fixed Inductors Fixed Inductors 220uH Shld 10% 2.1A 245mOhms AECQ2	Coilcraft	MSS1210-224KEB	Mouser	994-MSS1210-224KEB	https://www.mouser.com/datasheet/2/597/mss1210-270677.pdf		$2.26
39	1	MD1	Bluetooth Modules (802.15.1) Bluetooth Modules (802.15.1) Bluetooth Low Energy BLE Module, Shielded, Antenna, ASCII Interface, 12x22mm	Microchip	RN4870-I/RM140	Mouser	579-RN4870-I/RM140	https://www.mouser.com/datasheet/2/268/RN4870-71-Bluetooth-Low-Energy-Module-Data-Sheet-D-1658564.pdf		$7.38
40	1	P1	Headers & Wire Housings Headers & Wire Housings WR-PHD 2.54mm Hdr 5P Single Str Gold	Wurth Elektronik	61300511121	Mouser	710-61300511121	https://www.mouser.com/datasheet/2/445/61300511121-1717845.pdf		$0.25
41	1	P3	Headers & Wire Housings Headers & Wire Housings WR-PHD1.27mm Hdr 14P Dual Str Gold	Wurth Elektronik	62201421121	Mouser	710-62201421121	https://www.mouser.com/datasheet/2/445/62201421121-1718302.pdf		$1.48
42	1	P5	Headers & Wire Housings Headers & Wire Housings WR-PHD 2.54mm Hdr 16P Single Str Gold	Wurth Elektronik	61301611121	Mouser	710-61301611121	https://www.mouser.com/datasheet/2/445/61301611121-1717958.pdf		$0.90
43	1	P6	Headers & Wire Housings Headers & Wire Housings 02 SIL VERTICAL PIN HEADER TIN	Harwin	M20-9990246	Mouser	855-M20-9990246	https://www.mouser.com/datasheet/2/181/M20-999-1218971.pdf		$0.11
44	2	P7, P9	Headers & Wire Housings Headers & Wire Housings WR-PHD 2.54mm SMT 6P Hdr Dual Strt	Wurth Elektronik	61000621121	Mouser	710-61000621121	https://www.mouser.com/datasheet/2/445/61000621121-1717892.pdf		$0.93
45	1	P8	Headers & Wire Housings Headers & Wire Housings .100" Surface Mount Terminal Strip	Samtec	TSM-104-01-L-SV-P-TR	Mouser	200-TSM10401LSVPTR	https://www.mouser.com/datasheet/2/527/tsm-1344849.pdf		$1.27
46	2	Q1, Q2	MOSFET MOSFET PT8 40V/20V LL NCh PowerTrench MOSFET	ON Semiconductor	FDMC8327L	Mouser	512-FDMC8327L	https://www.mouser.com/datasheet/2/308/FDMC8327L-D-1807402.pdf		$0.86
47	8	R1, R7, R9, R10, R11, R12, R13, R14	Thick Film Resistors - SMD Thick Film Resistors - SMD 470 OHM 1%	Yageo	RC0805FR-07470RL	Mouser	603-RC0805FR-07470RL	https://www.mouser.com/datasheet/2/447/PYu_RC_Group_51_RoHS_L_10-1664068.pdf		$0.13

48	6	R2, R3, R4, R5, R22, R23	Thick Film Resistors - SMD Thick Film Resistors - SMD 10K OHM 1%	Yageo	RC0805FR-0710KL	Mouser	603-RC0805FR-0710KL	https://www.mouser.com/datasheet/2/447/PYu_RC_Group_51_RoHS_L_10-1664068.pdf		$0.13
49	8	R6, R15, R18, R19, R24, R25, R26, R27	Thick Film Resistors - SMD Thick Film Resistors - SMD 1/8watt 4.7Kohms 5% 200ppm	Vishay	CRCW08054K70JNTA	Mouser	71-CRCW0805J-4.7K	https://www.mouser.com/datasheet/2/427/dcrcw-1762150.pdf		$0.12
50	1	R8	Thick Film Resistors - SMD Thick Film Resistors - SMD 1/8watt 20ohms 1% 100ppm	Vishay	CRCW080520R0FKEA	Mouser	71-CRCW0805-20-E3	https://www.mouser.com/datasheet/2/427/dcrcwe3-1762152.pdf		$0.10
51	1	R17	Thick Film Resistors - SMD Thick Film Resistors - SMD 1/8watt 30Kohms 1% 100ppm	Vishay	CRCW080530K0FKEA	Mouser	71-CRCW0805-30K-E3	https://www.mouser.com/datasheet/2/427/dcrcwe3-1762152.pdf		$0.10
52	1	R20, R57	Thick Film Resistors - SMD Thick Film Resistors - SMD 1K OHM 1%	Yageo	RC0805FR-071KL	Mouser	603-RC0805FR-071KL	https://www.mouser.com/datasheet/2/447/PYu_RC_Group_51_RoHS_L_10-1664068.pdf		$0.13
53	1	R21	Thick Film Resistors - SMD Thick Film Resistors - SMD 1/8watt 40.2ohms 1% 100ppm	Vishay	CRCW080540R2FKTA	Mouser	71-CRCW0805-40.2	https://www.mouser.com/datasheet/2/427/dcrcw-1762150.pdf		$0.16
54	1	R28	Thick Film Resistors - SMD Thick Film Resistors - SMD 1/8watt 63.4Kohms 1% 100ppm	Vishay	CRCW080563K4FKEA	Mouser	71-CRCW0805-63.4K-E3	https://www.mouser.com/datasheet/2/427/dcrcwe3-1762152.pdf		$0.10
55	3	R29, R30, R31	Thick Film Resistors - SMD Thick Film Resistors - SMD 1/8watt 4.7Kohms 1%	Vishay	CRCW08054K70FKEA	Mouser	71-CRCW0805-4.7K-E3	https://www.mouser.com/datasheet/2/427/dcrcwe3-1762152.pdf		$0.10
56	2	R32, R34	Thick Film Resistors - SMD Thick Film Resistors - SMD 10K OHM 1%	Yageo	RC0805FR-0710KL	Mouser	603-RC0805FR-0710KL	https://www.mouser.com/datasheet/2/447/PYu_RC_Group_51_RoHS_L_10-1664068.pdf		$0.13
57	2	R33, R36	Thick Film Resistors - SMD Thick Film Resistors - SMD 1/8watt 10ohms 5% 200ppm	Vishay	CRCW080510R0JNEA	Mouser	71-CRCW080510R0JNEA	https://www.mouser.com/datasheet/2/427/dcrcwe3-1762152.pdf		$0.10
58	2	R35, R37	Thick Film Resistors - SMD Thick Film Resistors - SMD 100K OHM 1%	Yageo	RC0805FR-07100KL	Mouser	603-RC0805FR-07100KL	https://www.mouser.com/datasheet/2/447/PYu_RC_Group_51_RoHS_L_10-1664068.pdf		$0.13
59	1	R38	Current Sense Resistors - SMD Current Sense Resistors - SMD 1/4watt .02ohms 1%	Vishay	WSL1206R0200FEA	Mouser	71-WSL1206R0200FEA	http://www.vishay.com/doc?30373		$0.89
60	1	R39	Thick Film Resistors - SMD Thick Film Resistors - SMD 1/4watt 158Kohms 1%	Vishay	CRCW1206158KFKEA	Mouser	71-CRCW1206-158K-E3	https://www.mouser.com/datasheet/2/427/dcrcwe3-1762152.pdf		$0.10
61	1	R40	Thin Film Resistors - SMD Thin Film Resistors - SMD 0.1W 10Kohms 0.1% 1206 25ppm Auto	Vishay	MCA12060D1002BP500	Mouser	594-MCA12060D1002BP5	https://www.mouser.com/datasheet/2/427/mcx0x0xpre-1762843.pdf		$0.51
62	3	R41, R42, R46	Thick Film Resistors - SMD Thick Film Resistors - SMD 0ohm Jumper	Bourns	CR1206-J/-000ELF	Mouser	652-CR1206-J/-000ELF	https://www.mouser.com/datasheet/2/54/crxxxxx-1858361.pdf		$0.10
63	6	R43, R44, R45, R47, R48, R49	Thick Film Resistors - SMD Thick Film Resistors - SMD 0ohm Jumper	Bourns	CR1206-J/-000ELF	Mouser	652-CR1206-J/-000ELF	https://www.mouser.com/datasheet/2/54/crxxxxx-1858361.pdf		$0.10
64	1	R50	Thin Film Resistors - SMD Thin Film Resistors - SMD 1/8W 931K ohm .1% 25ppm	Yageo	RT0805BRD07931KL	Mouser	603-RT0805BRD07931KL	https://www.mouser.com/datasheet/2/447/PYu_RT_1_to_0_01_RoHS_L_11-1669912.pdf		$0.43
65	1	R51	Thin Film Resistors - SMD Thin Film Resistors - SMD 1/8W 64.9K ohm .1% 25ppm	Yageo	RT0805BRD0764K9L	Mouser	603-RT0805BRD0764K9L	https://www.mouser.com/datasheet/2/447/PYu_RT_1_to_0_01_RoHS_L_11-1669912.pdf		$0.43
66	1	R52	Thick Film Resistors - SMD Thick Film Resistors - SMD 1/8watt 1.1Mohms 1%	Vishay	CRCW08051M10FKEA	Mouser	71-CRCW08051M10FKEA	https://www.mouser.com/datasheet/2/427/dcrcwe3-1762152.pdf		$0.10
67	1	R53	Thick Film Resistors - SMD Thick Film Resistors - SMD 1/8watt 75Kohms 1% 100ppm	Vishay	CRCW080575K0FKEA	Mouser	71-CRCW0805-75K-E3	https://www.mouser.com/datasheet/2/427/dcrcwe3-1762152.pdf		$0.10
68	1	R54	Thick Film Resistors - SMD Thick Film Resistors - SMD 1/8watt 28Kohms 1% 100ppm	Vishay	CRCW080528K0FKEA	Mouser	71-CRCW0805-28K-E3	https://www.mouser.com/datasheet/2/427/dcrcwe3-1762152.pdf		$0.10
69	1	R55	Thick Film Resistors - SMD Thick Film Resistors - SMD 0805 2.94Kohms 1% AEC-Q200	Panasonic	ERJ-6ENF2941V	Mouser	667-ERJ-6ENF2941V	https://www.mouser.com/datasheet/2/315/AOA0000C304-1149620.pdf		$0.10
70	1	R56	Thin Film Resistors - SMD Thin Film Resistors - SMD 1/10W 2Kohm 0.5% 25ppm	Susumu	RR1220P-202-D	Mouser	754-RR1220P-202D	https://www.mouser.com/datasheet/2/392/susumu_RR_Data_Sheet-1206438.pdf		$0.10
71	2	RS1, RS2	Current Sense Resistors - SMD Current Sense Resistors - SMD 1206 0.010ohm 1% Curr Sense AEC-Q200	Panasonic	ERJ-8BWFR010V	Mouser	667-ERJ-8BWFR010V	https://www.mouser.com/datasheet/2/315/AOA0000C313-1141758.pdf		$0.74
72	6	SW1, SW2, SW3, SW4, SW5, SW6	Tactile Switches Tactile Switches Top Actuated w/o boss w/o ground	Omron	B3U-1000P	Mouser	653-B3U-1000P	https://www.mouser.com/datasheet/2/307/en-b3u-3615.pdf		$0.92
73	3	TP1, TP2, TP3	Circuit Board Hardware - PCB Circuit Board Hardware - PCB TEST POINT BLACK	Keystone Electronics	5001	Mouser	534-5001	https://www.mouser.com/datasheet/2/215/000-5004-741181.pdf		$0.35
74	1	U1	Supervisory Circuits Supervisory Circuits Open Drain	Microchip	MCP111T-240E/TT	Mouser	579-MCP111T-240E/TT	https://www.mouser.com/datasheet/2/268/21889b-64653.pdf		$0.47
75	1	U2	16-bit Microcontrollers - MCU 16-bit Microcontrollers - MCU	Texas Instruments	MSP430FR5994IPM	Mouser	595-MSP430FR5994IPM	https://www.ti.com/lit/pdf/slaa722		$8.11
76	1	U3	Translation - Voltage Levels Translation - Voltage Levels 4-Bit Bi-directional V-Level Translator	Texas Instruments	TXB0104PWR	Mouser	595-TXB0104PWR	https://www.ti.com/lit/pdf/scea064		$0.93
77	1	U4	Translation - Voltage Levels Translation - Voltage Levels 8-Bit Bi-directional V-Level Translator	Texas Instruments	TXB0108PWR	Mouser	595-TXB0108PWR	http://www.ti.com/general/docs/suppproductinfo.tsp?distId=26&gotoUrl=http%3A%2F%2Fwww.ti.com%2Flit%2Fgpn%2Ftxb0108		$1.29

78	1	U5	Operational Amplifiers - Op Amps Operational Amplifiers - Op Amps Single 1.8V 1MHz	Microchip	MCP6001T-I/OT	Mouser	579-MCP6001T-I/OT	https://www.mouser.com/datasheet/2/268/21733j-740845.pdf		$0.24
79	1	U6	Gate Drivers Gate Drivers 12V Industrial Relay Inductive Load	ON Semiconductor	NUD3112LT1G	Mouser	863-NUD3112LT1G	http://www.onsemi.com/pub/Collateral/AND8116-D.PDF		$0.44
80	1	U7	Digital Potentiometer ICs Digital Potentiometer ICs Sngl 7B V I2C POT	Microchip	MCP4531-103E/MS	Mouser	579-MCP4531-103E/MS	https://www.mouser.com/datasheet/2/268/DS-22096a-36447.pdf		$0.70
81	1	U8	Digital Isolators Digital Isolators Low-Power,Bidirec I2C Iso	Texas Instruments	ISO1540DR	Mouser	595-ISO1540DR	https://www.ti.com/lit/pdf/slyt403a		$4.51
82	1	U9	Battery Management Battery Management 35V/3.2A Multi-Cell Lithium-Ion Step-Down Battery Charger with PowerPath and I2C Telemetry	Analog Devices Inc.	LTC4162EUFD-SAD#PBF	Mouser	584-4162EUFDSADPB	https://www.mouser.com/datasheet/2/609/LTC4162_S-1398197.pdf		$7.33
83	1	U10	Current & Power Monitors & Regulators Current & Power Monitors & Regulators Vltg Out Hi-Sd Msmnt Current Shunt Mntr	Texas Instruments	INA194AIDBVT	Mouser	595-INA194AIDBVT	https://www.ti.com/lit/pdf/sloa228		$2.89
84	1	U11	Non-Isolated DC/DC Converters Non-Isolated DC/DC Converters	Texas Instruments	LMZM23601V5SILT	Mouser	595-LMZM23601V5SILT	https://www.ti.com/lit/pdf/snva834		$6.17
85	1	U12	Non-Isolated DC/DC Converters Non-Isolated DC/DC Converters	Texas Instruments	LMZM23601V3SILT	Mouser	595-LMZM23601V3SILT	https://www.ti.com/lit/pdf/slpa015		$6.17
86	1	U13	LDO Voltage Regulators LDO Voltage Regulators 50mA,100Vin,Sgl Out put LDO Linear Reg	Texas Instruments	TPS7A4001DGNT	Mouser	595-TPS7A4001DGNT	http://www.ti.com/general/docs/suppproductinfo.tsp?distId=26&gotoUrl=http%3A%2F%2Fwww.ti.com%2Flit%2Fgpn%2Ftps7a4001		$2.81
87	1	U14	Switching Voltage Regulators Switching Voltage Regulators	Texas Instruments	LM5161PWPR	Mouser	595-LM5161PWPR	https://www.ti.com/lit/pdf/snaa137a		$4.21
88	3	C22, C23, C24	Film Capacitors Film Capacitors 100V .47uF 10% 1E=4.5x9.5x7.2 PCM 5	WIMA	MKS2D034701E00KSSD	Mouser	505-MKS2.47/100/10	https://www.mouser.com/datasheet/2/440/e_WIMA_MKS_2-1139871.pdf		$0.48
89	1	R16	Thick Film Resistors - SMD Thick Film Resistors - SMD 1/8watt 47Kohms 1% 100ppm	Vishay	CRCW080547K0FKEA	Mouser	71-CRCW0805-47K-E3	https://www.mouser.com/datasheet/2/427/dcrcwe3-1762152.pdf		$0.10
90	1	X1	Crystals Crystals 8MHz 20pF	Fox	FOXSDLF/080-20	Mouser	559-FOXSD080-20-LF	https://www.mouser.com/datasheet/2/160/C4SD-1131563.pdf		$0.27
91	2	C41, C43	Multilayer Ceramic Capacitors MLCC - SMD/SMT Multilayer Ceramic Capacitors MLCC - SMD/SMT 1206 100pF 1000volt C0G +/-5%	Murata	GRM31A5C3A101JW01D	Mouser	81-GRM31A5C3A101J01D	https://www.mouser.com/datasheet/2/281/1/GRM31A5C3A101JW01_01-1987513.pdf		$0.52
92	1	C45	Multilayer Ceramic Capacitors MLCC - SMD/SMT Multilayer Ceramic Capacitors MLCC - SMD/SMT 50V 0.01uF X7R 0805 10%	KEMET	C0805X103K5RAC7210	Mouser	80-C0805X103K5R7210	https://www.mouser.com/datasheet/2/212/1/KEM_C1013_X7R_FT_CAP_SMD-1103280.pdf		$0.35
93	1	C53	Multilayer Ceramic Capacitors MLCC - SMD/SMT Multilayer Ceramic Capacitors MLCC - SMD/SMT 50V 0.033uF X7R 0805 10%	KEMET	C0805S333K5RACTU	Mouser	80-C0805S333K5R	https://www.mouser.com/datasheet/2/212/1/KEM_C1014_X7R_FE_CAP_SMD-1102761.pdf		$0.41
94	2	C55, C56	Multilayer Ceramic Capacitors MLCC - SMD/SMT Multilayer Ceramic Capacitors MLCC - SMD/SMT 50V 100pF C0G 0805 5%	KEMET	C0805C101J5GACTU	Mouser	80-C0805C101J5G	https://www.mouser.com/datasheet/2/212/KEM_C1003_C0G_SMD-1101588.pdf		$0.16
95	0	Y1	Crystals Crystals 32.768KHZ 10PPM 7PF -40C +85C	ABRACON	ABS07-166-32.768KHZ-T	Mouser	815-ABS0716632.768KT			$0.66
96	1	Alternate Y1	Crystals 32.768kHz 6pF -40C +85C	ECS	ECS-.327-6-34G-TR	Mouser	520-.327-6-34GT	https://www.mouser.com/datasheet/2/122/ECX-34G-1064121.pdf		$0.74

APPENDIX D: TRANSMITTER BOM

ASSEMBLY NO:		DATE:	03-02-21
ASSEMBLY	Transmitter	PREPARED BY:	David Flory
REVISION:	A	VERIFIED BY:	Franci Franulovic
SOLDER TYPE:	Lead-Free		

ITEM	QTY	REFERENCE	DESCRIPTION	MFG	MFG P/N	VENDOR	VENDOR P/N	Datasheet URL	NOTES	Unit Price
1	1	R42	Thick Film Resistors - SMD Thick Film Resistors - SMD 1/8watt ZEROohm Jumper	Vishay	CRCW08050000Z0EA	Mouser	71-CRCW0805-0-E3	https://www.mouser.com/datasheet/2/427/dcrcwe3-1762152.pdf		$0.10
2	1	R8	Thick Film Resistors - SMD Thick Film Resistors - SMD 1/8watt 20ohms 1% 100ppm	Vishay	CRCW080520R0FKEA	Mouser	71-CRCW0805-20-E3	https://www.mouser.com/datasheet/2/427/dcrcwe3-1762152.pdf		$0.10
3	1	R23	Thick Film Resistors - SMD Thick Film Resistors - SMD 1/8watt 40.2ohms 1% 100ppm	Vishay	CRCW080540R2FKTA	Mouser	71-CRCW0805-40.2	https://www.mouser.com/datasheet/2/427/dcrcw-1762150.pdf		$0.16
4	2	R31, R32	Thick Film Resistors - SMD Thick Film Resistors - SMD 0805 47.0ohms 1% Tol AEC-Q200	Panasonic	ERJ-6ENF47R0V	Mouser	667-ERJ-6ENF47R0V	https://www.mouser.com/datasheet/2/315/AOA0000C304-1149620.pdf		$0.10
5	8	R1, R7, R9, R10, R11, R12, R13, R14	Thick Film Resistors - SMD Thick Film Resistors - SMD 470 OHM 1%	Yageo	RC0805FR-07470RL	Mouser	603-RC0805FR-07470RL	https://www.mouser.com/datasheet/2/447/PYu_RC_Group_51_RoHS_L_10-1664068.pdf		$0.13
6	4	TP1, TP2, TP3, TP4	Circuit Board Hardware - PCB Circuit Board Hardware - PCB TEST POINT BLACK	Keystone Electronics	5001	Mouser	534-5001	https://www.mouser.com/datasheet/2/215/000-5004-741181.pdf		$0.35
7	1	P5	Headers & Wire Housings Headers & Wire Housings WR-PHD 2.54mm Hdr 16P Single Str Gold	Wurth Elektronik	61301611121	Mouser	710-61301611121	https://www.mouser.com/datasheet/2/445/61301611121-1717958.pdf		$0.90
8	4	D13, D14, D15, D16	ESD Suppressors / TVS Diodes ESD Suppressors / TVS Diodes Low Cap Bi TVS 10pF 3.3V 3.8Vbr 25kV	Diodes Incorporated	DESD3V3S1BL-7B	Mouser	621-DESD3V3S1BL-7B	https://www.mouser.com/datasheet/2/115/DESD3V3S1BL-321080.pdf		$0.29
9	16	C2, C4, C6, C14, C19, C25, C29, C33, C37, C40, C47, C48, C49, C50, C51, C52, C53	Multilayer Ceramic Capacitors MLCC - SMD/SMT Multilayer Ceramic Capacitors MLCC - SMD/SMT 50V 0.1uF X7R 0805 10%	KEMET	C0805C104K5RACTU	Mouser	80-C0805C104K5R	https://www.mouser.com/datasheet/2/212/KEM_C1002_X7R_SMD-1102033.pdf		$0.13
10	1	C13	Multilayer Ceramic Capacitors MLCC - SMD/SMT Multilayer Ceramic Capacitors MLCC - SMD/SMT 470nF 16V X7R 10%	Yageo	CC0805KKX7R7BB474	Mouser	603-CC805KKX7R7BB474	https://www.mouser.com/datasheet/2/447/UPY-GPHC_X7R_6.3V-to-50V_18-1154002.pdf		$0.23
11	2	C35, C45	Multilayer Ceramic Capacitors MLCC - SMD/SMT 0805 1.6pF 250volts C0G 0.1pF	Murata	GQM2195C2E1R6BB12D	Mouser	81-GQM2195C2E1R6BB2D	https://www.mouser.com/datasheet/2/281/GQM2195C2E1R6BB12_01-1976051.pdf		
12	3	C36, C38, C46	Multilayer Ceramic Capacitors MLCC - SMD/SMT 10volts 10uF X5R 10%	KEMET	C0805C106K8PACTU	Mouser	80-C0805C106K8P	https://www.mouser.com/datasheet/2/212/KEM_C1006_X5R_SMD-1103249.pdf		$0.14
13	1	R24	Thin Film Resistors - SMD Thin Film Resistors - SMD 1/8W 105K ohm .1% 25ppm	Yageo	RT0805BRD07105KL	Mouser	603-RT0805BRD07105KL	https://www.mouser.com/datasheet/2/447/PYu_RT_1_to_0_01_RoHS_L_11-1669912.pdf		$0.43
14	6	R2, R3, R4, R5, R21, R22	Thick Film Resistors - SMD Thick Film Resistors - SMD 10K OHM 1%	Yageo	RC0805FR-0710KL	Mouser	603-RC0805FR-0710KL	https://www.mouser.com/datasheet/2/447/PYu_RC_Group_51_RoHS_L_10-1664068.pdf		$0.13
15	1	R29	Thick Film Resistors - SMD Thick Film Resistors - SMD 10K 5%	Bourns	CR0805-JW-103ELF	Mouser	652-CR0805-JW-103ELF	https://www.mouser.com/datasheet/2/54/crxxxxx-1858361.pdf		$0.10
16	6	C20, C26, C30, C31, C41, C42	Multilayer Ceramic Capacitors MLCC - SMD/SMT Multilayer Ceramic Capacitors MLCC - SMD/SMT 1206 50V 10uF X5R 10% T: 1.6mm	TDK	C3216X5R1H106K160AB	Mouser	810-C3216X5R1H106K	https://product.tdk.com/info/en/catalog/datasheets/mlcc_commercial_general_en.pdf?ref_disty=mouser		$0.85
17	2	C10, C11	Multilayer Ceramic Capacitors MLCC - SMD/SMT Multilayer Ceramic Capacitors MLCC - SMD/SMT 50V 12pF C0G 0805 5%	KEMET	C0805C120J5GACTU	Mouser	80-C0805C120J5G	https://www.mouser.com/datasheet/2/212/KEM_C1003_C0G_SMD-1101588.pdf		$0.11
18	1	Y2	Standard Clock Oscillators Standard Clock Oscillators 13.56MHz 50ppm -40C +85C	Epson	SG5032CAN 13.560000M-TJGA3	Mouser	732-5032CAN13.5TJGA3	https://www.mouser.com/datasheet/2/137/SG5032CAN_en-961596.pdf		$1.17
19	1	R20	Thick Film Resistors - SMD Thick Film Resistors - SMD 1K OHM 1%	Yageo	RC0805FR-071KL	Mouser	603-RC0805FR-071KL	https://www.mouser.com/datasheet/2/447/PYu_RC_Group_51_RoHS_L_10-1664068.pdf		$0.13
20	2	R35, R40	Thick Film Resistors - SMD Thick Film Resistors - SMD 2512 1Kohms 1% Tol AEC-Q200	Panasonic	ERJ-1TNF1001U	Mouser	667-ERJ-1TNF1001U	https://www.mouser.com/datasheet/2/315/AOA0000C304-1149620.pdf		$0.63
21	2	R36, R41	Thick Film Resistors - SMD Thick Film Resistors - SMD 0805 1Kohms 5% AEC-Q200	Panasonic	ERJ-6GEYJ102V	Mouser	667-ERJ-6GEYJ102V	https://www.mouser.com/datasheet/2/315/AOA0000C301-1488782.pdf		$0.10

22	2	R30, R37	Thick Film Resistors - SMD Thick Film Resistors - SMD 2512 1Mohms 1% Tol AEC-Q200	Panasonic	ERJ-1TYF105U	Mouser	667-ERJ-1TYF105U	https://www.mouser.com/datasheet/2/315/AOA0000C301-1488782.pdf		$0.46
23	3	R33, R34, R39	Thick Film Resistors - SMD 0805 1.0Mohms 0.5W 1% Tol AEC-Q200	Panasonic	ERJ-P06F1004V	Mouser	667-ERJ-P06F1004V	https://www.mouser.com/datasheet/2/315/AOA0000C331-1141874.pdf		$0.18
24	4	C1, C3, C5, C7	Multilayer Ceramic Capacitors MLCC - SMD/SMT Multilayer Ceramic Capacitors MLCC - SMD/SMT 1.0uF 10V X7R 10%	Yageo	CC0805KKX7R6BB105	Mouser	603-CC805KKX7R6BB105	https://www.mouser.com/datasheet/2/447/UPY-GPHC_X7R_6.3V-to-50V_18-1154002.pdf		$0.25
25	1	C12	Multilayer Ceramic Capacitors MLCC - SMD/SMT Multilayer Ceramic Capacitors MLCC - SMD/SMT 50V 2200pF X8R 0805 5%	KEMET	C0805C222J5HACTU	Mouser	80-C0805C222J5H	https://www.mouser.com/datasheet/2/212/KEM_C1007_X8R_ULTRA_150C_SMD-1102703.pdf		$0.69
26	3	C16, C17, C18	Multilayer Ceramic Capacitors MLCC - SMD/SMT Multilayer Ceramic Capacitors MLCC - SMD/SMT 1210 100V 2.2uF X7R 10% T: 2.3mm	TDK	C3225X7R2A225K230AB	Mouser	810-C3225X7R2A225K	https://product.tdk.com/info/en/catalog/datasheets/mlcc_commercial_midvoltage_en.pdf?ref_disty=mouser		$0.70
27	4	JP1, P2, P4, P6	Headers & Wire Housings Headers & Wire Housings 3P VERT HEADER Sn	Molex	22-28-4030	Mouser	538-22-28-4030	https://www.mouser.com/datasheet/2/276/0022284030_PCB_HEADERS-228162.pdf		$0.16
28	1	R27	Thin Film Resistors - SMD Thin Film Resistors - SMD 1/8W 28.7K ohm 1% 50ppm	Yageo	RT0805FRE0728K7L	Mouser	603-RT0805FRE0728K7L	https://www.mouser.com/datasheet/2/447/PYu_RT_1_to_0_01_RoHS_L_11-1669912.pdf		$0.12
29	1	R26	Thin Film Resistors - SMD Thin Film Resistors - SMD 1/8W 3.4K ohm .1% 25ppm	Yageo	RT0805BRD073K4L	Mouser	603-RT0805BRD073K4L	https://www.mouser.com/datasheet/2/447/PYu_RT_1_to_0_01_RoHS_L_11-1669912.pdf		$0.43
30	1	R19	Thick Film Resistors - SMD Thick Film Resistors - SMD 1/8watt 30Kohms 1% 100ppm	Vishay	CRCW080530K0FKEA	Mouser	71-CRCW0805-30K-E3	https://www.mouser.com/datasheet/2/427/dcrcwe3-1762152.pdf		$0.10
31	0	Y1	Crystals Crystals 32.768KHZ 10PPM 7PF -40C +85C	ABRACON	ABS07-166-32.768KHZ-T	Mouser	815-ABS0716632.768KT			$0.66
32	1	Alternate Y1	Crystals 32.768kHz 6pF -40C +85C	ECS	ECS-.327-6-34G-TR	Mouser	520-.327-6-34GT	https://www.mouser.com/datasheet/2/122/ECX-34G-1064121.pdf		$0.74
33	1	L1	Fixed Inductors Fixed Inductors WE-PD 330uH 710mA DCR=750mOhms AECQ200	Wurth Elektronik	7447714331	Mouser	710-7447714331	https://www.mouser.com/datasheet/2/445/7447714331-1722496.pdf		$2.17
34	1	J2	Headers & Wire Housings Headers & Wire Housings FRICTION LCK HDR 5P Straight Post gold	TE Connectivity	3-641215-5	Mouser	571-3-641215-5	https://www.te.com/commerce/DocumentDelivery/DDEController?Action=srchrtrv&DocNm=641215&DocType=Customer+Drawing&DocLang=English&PartCntxt=3-641215-5&DocFormat=pdf		$1.45
35	1	R25	Thin Film Resistors - SMD 365Kohms .1% 25ppm	Vishay	TNPW0805365KBEEN	Mouser	71-TNPW0805365KBEEN	https://www.vishay.com/doc?28771		
36	1	C22	Multilayer Ceramic Capacitors MLCC - SMD/SMT Multilayer Ceramic Capacitors MLCC - SMD/SMT 50V 36pF C0G 0805 5%	KEMET	C0805C360J5GACTU	Mouser	80-C0805C360J5G	https://www.mouser.com/datasheet/2/212/KEM_C1003_C0G_SMD-1101588.pdf		$0.29
37	2	C8, C9	Multilayer Ceramic Capacitors MLCC - SMD/SMT Multilayer Ceramic Capacitors MLCC - SMD/SMT 50V 39pF C0G 0805 5%	KEMET	C0805C390J5GACTU	Mouser	80-C0805C390J5G	https://www.mouser.com/datasheet/2/212/KEM_C1003_C0G_SMD-1101588.pdf		$0.24
38	4	R6, R15, R17, R18	Thick Film Resistors - SMD Thick Film Resistors - SMD 1/8watt 4.7Kohms 5% 200ppm	Vishay	CRCW08054K70JNTA	Mouser	71-CRCW0805J-4.7K	https://www.mouser.com/datasheet/2/427/dcrcw-1762150.pdf		$0.12
39	1	R16	Thick Film Resistors - SMD Thick Film Resistors - SMD 1/8watt 47Kohms 1% 100ppm	Vishay	CRCW080547K0FKEA	Mouser	71-CRCW0805-47K-E3	https://www.mouser.com/datasheet/2/427/dcrcwe3-1762152.pdf		$0.10
40	1	C24	Multilayer Ceramic Capacitors MLCC - SMD/SMT Multilayer Ceramic Capacitors MLCC - SMD/SMT 25V 0.047uF C0G 0805 5%	KEMET	C0805C473J3GACTU	Mouser	80-C0805C473J3G	https://www.mouser.com/datasheet/2/212/KEM_C1003_C0G_SMD-1101588.pdf		$0.72
41	2	C21, C27	Multilayer Ceramic Capacitors MLCC - SMD/SMT Multilayer Ceramic Capacitors MLCC - SMD/SMT 1206 25VDC 47uF 20% X5R 1.6mm	TDK	C3216X5R1E476M160AC	Mouser	810-C3216X5R1E476M	https://product.tdk.com/info/en/catalog/datasheets/mlcc_commercial_general_en.pdf?ref_disty=mouser		$1.05
42	1	C23	Multilayer Ceramic Capacitors MLCC - SMD/SMT 0.0068uF 50Volts C0G 1%	Murata	GRM2195C1H682FA01D	Mouser	81-GRM2195C1H682FA1D	https://www.mouser.com/datasheet/2/281/murata_03052018_GRM_Series_1-1310166.pdf		
43	1	R28	Thin Film Resistors - SMD 0805 732Kohm 0.1% 25ppm	Panasonic	ERA-6AEB7323V	Mouser	667-ERA-6AEB7323V	https://www.mouser.com/datasheet/2/315/AOA0000C307-1149632.pdf		
44	1	X1	Crystals Crystals 8MHz 20pF	Fox	FOXSDLF/080-20	Mouser	559-FOXSD080-20-LF	https://www.mouser.com/datasheet/2/160/C4SD-1131563.pdf		$0.27

45	6	SW1, SW2, SW3, SW4, SW5, SW6	Tactile Switches Tactile Switches Top Actuated w/o boss w/o ground	Omron	B3U-1000P	Mouser	653-B3U-1000P	https://www.mouser.com/datasheet/2/307/en-b3u-3615.pdf		$0.92
46	2	D20, D21	Schottky Diodes & Rectifiers Schottky Diodes & Rectifiers Silicon Schottky Didode	Infineon	BAS140WE6327HTSA1	Mouser	726-BAS140WE6327HTSA	https://www.mouser.com/datasheet/2/196/Infineon-BAS40_BAS140SERIES-DS-v01_01-en-767893.pdf		$0.48
47	2	C28, C39	Trimmer / Variable Capacitors Trimmer / Variable Capacitors TRIMMER CAPACITOR	Vishay	BFC280832659	Mouser	594-2222-808-32659	https://www.vishay.com/doc?28528		$7.21
48	4	C32, C34, C43, C44	Multilayer Ceramic Capacitors MLCC - SMD/SMT Multilayer Ceramic Capacitors MLCC - SMD/SMT 100pF 1KV C0G 5%	Vishay	VJ1812A101JXGAT	Mouser	77-VJ1812A101JXGAT	https://www.mouser.com/datasheet/2/427/vjcommercialseries-1764145.pdf		$0.76
49	1	C15	Aluminum Organic Polymer Capacitors Aluminum Organic Polymer Capacitors 50volts 68uF ESR 20mohm	Panasonic	50SVPF68M	Mouser	667-50SVPF68M	https://www.mouser.com/datasheet/2/315/AAB8000C177-947360.pdf		$2.65
50	6	D3, D4, D11, D12, D17, D18	ESD Suppressors / TVS Diodes ESD Suppressors / TVS Diodes Low Cap Bi TVS 10pF 3.3V 3.8Vbr 25kV	Diodes Incorporated	DESD3V3S1BL-7B	Mouser	621-DESD3V3S1BL-7B	https://www.mouser.com/datasheet/2/115/DESD3V3S1BL-321080.pdf		$0.29
51	1	R38	Thick Film Resistors - SMD Thick Film Resistors - SMD 0805 47.0ohms 1% Tol AEC-Q200	Panasonic	ERJ-6ENF47R0V	Mouser	667-ERJ-6ENF47R0V	https://www.mouser.com/datasheet/2/315/AOA0000C304-1149620.pdf		$0.10
52	1	Q1	N-Channel 200V 8.5A (Ta) Surface Mount Die	EPC	EPC2019	Digikey	917-1087-2-ND	https://epc-co.com/epc/Portals/0/epc/documents/datasheets/EPC2019_datasheet.pdf		3.54
53	1	Q2	N-Channel 200V 48A (Ta) Surface Mount Die	EPC	EPC2034C	Digikey	917-1214-2-ND	https://epc-co.com/epc/Portals/0/epc/documents/datasheets/EPC2034C_datasheet.pdf		7.32
54	2	L4, L5	Fixed Inductors Fixed Inductors 47uH 20%	Vishay	IHLP4040DZER470M11	Mouser	71-IHLP4040DZER470M1	http://www.vishay.com/doc?34251		$2.58
55	1	J1	DC Power Connectors DC Power Connectors 4P JACK SKT SHIELDED SNAP AND LOCK	Kycon	KPJX-4S-S	Mouser	806-KPJX-4S-S	https://www.snapeda.com/parts/KPJX-4S-S/Kycon/view-part/?ref=mouser		$2.23
56	1	U11	Gate Drivers Gate Drivers Tiny 7A MOSFET Gate Dvr	Texas Instruments	LM5112MY/NOPB	Mouser	926-LM5112MY/NOPB	https://www.ti.com/lit/pdf/snva606		$1.31
57	1	U9	Non-Isolated DC/DC Converters Non-Isolated DC/DC Converters	Texas Instruments	LMZM23600V3SILR	Mouser	595-LMZM23600V3SILR	https://www.ti.com/lit/pdf/snva807a		$4.52
58	1	U10	Non-Isolated DC/DC Converters Non-Isolated DC/DC Converters	Texas Instruments	LMZM23600V5SILR	Mouser	595-LMZM23600V5SILR	https://www.ti.com/lit/pdf/snva807a		$4.52
59	1	U1	Supervisory Circuits Supervisory Circuits Open Drain	Microchip	MCP111T-240E/TT	Mouser	579-MCP111T-240E/TT	https://www.mouser.com/datasheet/2/268/21889b-64653.pdf		$0.47
60	1	U7	Digital Potentiometer ICs Digital Potentiometer ICs Sngl 7B V I2C POT	Microchip	MCP4531-103E/MS	Mouser	579-MCP4531-103E/MS	https://www.mouser.com/datasheet/2/268/DS-22096a-36447.pdf		$0.70
61	1	U5	Operational Amplifiers - Op Amps Operational Amplifiers - Op Amps Single 1.8V 1MHz	Microchip	MCP6001T-I/OT	Mouser	579-MCP6001T-I/OT	https://www.mouser.com/datasheet/2/268/21733j-740845.pdf		$0.24
62	2	L2, L3	Ferrite Beads Ferrite Beads 600 ohms 25% HIGH CURRENT	Bourns	MH3261-601Y	Mouser	652-MH3261-601Y	https://www.mouser.com/datasheet/2/54/mh-777565.pdf		$0.10
63	2	F2, F3	Resettable Fuses - PPTC Resettable Fuses - PPTC .5A 13.2V 40A Imax	Littelfuse	MICROSMD050F-2	Mouser	650-MICROSMD050F-2	https://www.mouser.com/datasheet/2/240/Littelfuse_PTC_MICROSMD_Catalog_Datasheet.pdf-1021745.pdf		$0.47
64	1	U2	16-bit Microcontrollers - MCU 16-bit Microcontrollers - MCU	Texas Instruments	MSP430FR5994IPM	Mouser	595-MSP430FR5994IPM	https://www.ti.com/lit/pdf/slaa722		$8.11
65	1	U6	Gate Drivers Gate Drivers 12V Industrial Relay Inductive Load	ON Semiconductor	NUD3112LT1G	Mouser	863-NUD3112LT1G	http://www.onsemi.com/pub/Collateral/AND8116-D.PDF		$0.44
66	1	F1	Resettable Fuses - PPTC Resettable Fuses - PPTC Radial Lead 2.5A 72V 40A Imax	Littelfuse	RXEF250	Mouser	650-RXEF250	https://www.mouser.com/datasheet/2/240/Littelfuse_PTC_Rline_Catalog_Datasheet.pdf-1021735.pdf		$0.63
67	2	P7, P9	Headers & Wire Housings Headers & Wire Housings WR-PHD 2.54mm SMT 6P Hdr Dual Strt	Wurth Elektronik	61000621121	Mouser	710-61000621121	https://www.mouser.com/datasheet/2/445/61000621121-1717892.pdf		$0.93
68	1	D19	Schottky Diodes & Rectifiers Schottky Diodes & Rectifiers 3.0 Amp 100 Volt	Vishay	SS3H10-E3/57T	Mouser	625-SS3H10-E3	https://www.mouser.com/datasheet/2/427/ss3h9-1768234.pdf		$0.60
69	1	U8	Switching Voltage Regulators Switching Voltage Regulators 3.5-60V 2.5A 2.5MHz Step Down Converter	Texas Instruments	TPS54260DGQR	Mouser	595-TPS54260DGQR	https://www.ti.com/lit/pdf/slva464e		$3.50
70	1	U3	Translation - Voltage Levels Translation - Voltage Levels 4-Bit Bi-directional V-Level Translator	Texas Instruments	TXB0104PWR	Mouser	595-TXB0104PWR	https://www.ti.com/lit/pdf/scea064		$0.93
71	1	U4	Translation - Voltage Levels Translation - Voltage Levels 8-Bit Bi-directional V-Level Translator	Texas Instruments	TXB0108PWR	Mouser	595-TXB0108PWR	http://www.ti.com/general/docs/suppproductinfo.tsp?distId=26&gotoUrl=http%3A%2F%2Fwww.ti.com%2Flit%2Fgpn%2Ftxb0108		$1.29

72	1	L1A	Fixed Inductors Fixed Inductors 330uH Shld 10% 1.7A 360mOhms AECQ2	Coilcraft	MSS1210-334KED	Mouser	994-MSS1210-334KED	https://www.mouser.com/datasheet/2/597/mss1210-270677.pdf		$2.26
73	1	L1B	Fixed Inductors Fixed Inductors WE-PD 330uH 1.5A DCR=430mOhms AECQ200	Wurth Elektronik	7447709331	Mouser	710-7447709331	https://www.mouser.com/datasheet/2/445/7447709331-1722838.pdf		$2.41
74	1	L1C	Fixed Inductors Fixed Inductors PA4320 12x12mm 330uH 1.7A 340mOhms	Pulse	PA4320.334NLT	Mouser	673-PA4320.334NLT	https://www.mouser.com/datasheet/2/336/P787-1526943.pdf		$2.57
75	8	D1, D2, D5, D6, D7, D8, D9, D10	Standard LEDs - SMD Standard LEDs - SMD Red Diffused 626nm 10mcd	Broadcom Limited	HSMS-C150	Mouser	630-HSMS-C150	https://www.mouser.com/datasheet/2/678/av02-0551en-ds-hsmx-cxxx-05mar2012-1827675.pdf		$0.41
76	1	MD1	Bluetooth Modules (802.15.1) Bluetooth Modules (802.15.1) Bluetooth Low Energy BLE Module, Shielded, Antenna, ASCII Interface, 12x22mm	Microchip	RN4870-I/RM140	Mouser	579-RN4870-I/RM140	https://www.mouser.com/datasheet/2/268/RN4870-71-Bluetooth-Low-Energy-Module-Data-Sheet-D-1658564.pdf		$7.38
77	1	P3	Headers & Wire Housings Headers & Wire Housings WR-PHD1.27mm Hdr 14P Dual Str Gold	Wurth Elektronik	62201421121	Mouser	710-62201421121	https://www.mouser.com/datasheet/2/445/62201421121-1718302.pdf		$1.48

APPENDIX E: WIRELESS POWER TRANSFER MODULE BOM

		ASSEMBLY NO:			DATE:	03-02-21				
		ASSEMBLY NAME:	Wireless Charger System		PREPARED BY:	Franci Franulovic				
		REVISION:	A		VERIFIED BY:	David Flory				
		SOLDER TYPE:	Lead-Free							
ITEM	QTY	REFERENCE	DESCRIPTION	MFG	MFG P/N	VENDOR	VENDOR P/N	Datasheet URL	NOTES	Unit Price
1	1	RECEIVER	Desktop AC Adapters 65W 48Vout 1.36A	TDK-Lambda	DT62PW480D	Mouser	967-DT62PW480D	https://www.mouser.com/datasheet/2/400/dt62-80-d_e-1825770.pdf		$53.00
2	1	RECEIVER / TRANSMITTER	Electrical Enclosures IP68/NEMA 6P Plastic Enclosure 5.88" x 4.38" x 2.19" Opaque	Bud Industries	PU-16537	Mouser	967-DT62PW480D	https://www.mouser.com/catalog/specsheets/Bud_PU%20Series_NEMA_6PIP68_PC_Enclosure.pdf		$25.30
3	1	RECEIVER	Printed Circuit Board	JLC PCB		JLC PCB			Custom made	$6.68
4	1	TRANSMITTER	Printed Circuit Board	JLC PCB		JLC PCB			Custom made	$6.69
5	0.1	COIL RECEIVER	Hook-up Wire 14AWG 19/27 PTFE Spool 304.8 m	Alpha Wire	5859 RD005	Mouser	602-5859-100-03	https://www.mouser.com/datasheet/2/14/AW_Product_Specification-1837536.pdf		$1.98
6	0.1	COIL TRANSMITTER	Hook-up Wire 14AWG 19/27 PTFE Spool 304.8 m	Alpha Wire	5859 RD005	Mouser	602-5859-100-03	https://www.mouser.com/datasheet/2/14/AW_Product_Specification-1837536.pdf		$1.98
7	4	COIL RECEIVER / TRANSMITTER	Terminals SOLIS DIN 0.5-1.0	TE Connectivity	165291	Mouser	571-165291	https://www.te.com/commerce/DocumentDelivery/DDEController?Action=srchrtrv&DocNm=165291&DocType=Customer+Drawing&DocLang=English&PartCntxt=165291&DocFormat=pdf		$0.45
8	0.67	COIL RECEIVER	Super-Conductive 101 Copper TubesCopper Tubing 1/8" 3ft spool	Mcmaster-Carr	8965K22	Mcmaster-Carr	8965K22	https://www.mcmaster.com/tubing/od~1-8/material~copper/		$6.94
9	0.67	COIL TRANSMITTER	Super-Conductive 101 Copper TubesCopper Tubing 1/8" 3ft spool	Mcmaster-Carr	8965K22	Mcmaster-Carr	8965K22	https://www.mcmaster.com/tubing/od~1-8/material~copper/		$6.94
10	1	Receiver	RRC-SMBus Cable	RRC	RRC-SMBus Cable	Mouser	328-RRCSMBUSCABLE	https://www.mouser.com/datasheet/2/836/DS_SMBus_Battery_Cable_B-1360935.pdf		$22.35
11	2	COIL RECEIVER / TRANSMITTER	Enclosures, Boxes, & Cases SENSOR CUBE WHITE	New Age Enclosures	789-S1A-404012	Mouser	789-S1A-404012	https://www.mouser.com/datasheet/2/290/NewAgeEnclosures_12092019_404012_cube_r1_0-1673104.pdf	Coil enclosure	$5.70