DAEmod-915: Open-Source Open-Hardware 915MHz Transceiver

Bradley University Senior Capstone Project

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***Abstract*—Within the market, we found a lack of available 915MHz open-source and open-hardware modules for implementing Digital radio modes. To help remedy this deficiency we are creating one such board and module. The board will be an example use case for our digital radio communication and showcase potential use cases for the project.**

***Index Terms*—open source, open hardware, radio, communication, rf, digital, transceiver**

I. Introduction

A. Project Overview

We believe there is a market for a readily available 915MHz open-source and open-hardware system to enable extensible and easy communication that is easily tailored to specific use cases. This proposal outlines the preliminary research, initial specifications, and the steps we are taking to carry out this project. To complete a practical implementation of the 915MHz module within the limited senior project timeline, it will make use of low cost and easy to get hardware to lower the barrier for future contributors. Also, cheap and ubiquitous hardware will allow the final product to be relatively inexpensive.

In the US, the 915MHz band is one of the Industrial, Scientific, and Medical bands that covers a frequency range of 902–928 MHz. Besides outdated systems and LoRa, this band isn't as widely used as 433MHz or 2.4GHz. As a result, the 915MHz band is a mostly underpopulated service for most devices today. This frequency range strikes a good balance between range, power, and available spectrum for our intended application.

B. Main Competition

As mentioned, the main competitor in this space is LoRa, a proprietary standard for mesh networks. This also means there are a variety of popular 915MHz ISM boards available. The standout difference is our protocol implementation that will allow for a high duty cycle. In Table I below, we highlight the main differences between LoRa and our project.

Spec	***LoRa***	***Our Project***
Frequency	902-928 MHz	902-928 MHz
Data Rate	300 bit/s - 27 kbit/s	512 bit/s - 400 kbit/s
Duty Cycle	Very Low	Up to 100%
Hand-Shake	Required Handshake	Optional Handshake
Broadcasting	Does not Support	Support
Licensing	$6000 Yearly	GPLv3

TABLE I: LoRa vs. Our Project

Overall, our board would be a good alternative for the use cases where a consistent data rate is wanted, if one direction broadcast qualities are required, or using amateur radio privileges.

C. Potential Applications

Potential applications of an open 915MHz transceiver include large data transmissions, one-way transmissions, and amateur radio communication. A large data transmission example is that of a remote trail cam. However, the product is not too applicable where strong infrastructure exists. Therefore, this is best applied when a outside the range of WiFi and free from the cost of cellular. One example of one-way transmission could be a modernized pager system where large and complex messages can be broadcast. This could be the other way around for sensors that do not need to receive commands and instead just regularly transmit information to a central system. We are expecting this to be used within the amateur radio community as a highly configurable and higher power 33cm digital transceiver. With a successful open source project comes a community around to offer additional support and ideas to further the potential applications.

II. Preliminary Specifications

A. Preliminary Specifications of Transceiver module

After selecting 915MHz as the target frequency, we looked at some various different transceiver ICs that were modern, available, and feature rich. We ended up choosing the Silicon Labs EFR32FG23 transceiver for it's low cost and ample documentation. Table II list various specifications and limitations that this transceiver includes.

Transceiver	SiLabs EFR32FG23
Modulation	FSK, ASK, GFSK, AFSK, GMSK, OOK, OQPSK-DSSS
Antenna	SMA male 50 Ω
Expected Power	10 dBm - 10mW
Frequencies	915 ISM Band (902-928 MHz)

TABLE II: Transceiver Module

Theoretical Range

$$\frac{P_r}{P_t} = D_t D_r \left(\frac{\lambda}{4\pi d} \right)^2 \tag{1}$$

- 2dbi Antenna theoretical range is 2.9km (1.80 Miles)
- 5dbi Antenna theoretical range is 15km (9.3 Miles)

Baseline Current draw at 3.3V

- Sleep draw is 1.5nA
- Full TX draw is 120mA
- RX draw is 20mA

B. Preliminary Specifications of Control module

While looking at various microcontrollers, we finally selected the ESP32 microcontroller due to the ubiquity of the hardware and cost.

Baseline Current draw 3.3V

- Sleep draw is .8mA

Microcontroller	ESP 32
Communication I/O Protocols	SPI, I2C, WiFi, BT UART
Power Supply	DC Input 6v - 35V and/or BMS 6V LiFePO4
Supported Modules	Camera, Display, GPS, Battery, and Environment Sensor

TABLE III: Control Module

- RF Tx off draw is 40mA
- RF Tx on draw is 160mA
- RF Tx off, Wifi/BT on draw 240mA

External power budget 6V

- 1A peak draw to peripheral devices

III. System Modularity

A. Block Diagram

The prototype of this project is designed to allow developers and enthusiasts to attach various modules with additional functionality. As shown in Appendix A, our design is exposing or making use of SPI, I^2C, UART, Wi-Fi, Bluetooth, and GPIO. This design allows for multiple different accessories to be compatible at a time. In Table IV, a summary of the interfaces and planned purposes are outlined.

BMS	Handle DC - DC conversion, LiFePO4 charging, and supply of the main 5V
SPI	Transceiver, Camera
I^2C	Environment Sensors, Status Display and control
UART	External Sensors, GPS, Debug Message Output
GPIO	Indicators, Buttons, Control lines

TABLE IV: Inputs and Outputs

B. Potential Modular Accessories

Using various Communication I/O Protocols, there is the potential for many kinds of modules that can extend the usability of the basic transceiver. We are planning to roll out our initial proof-of-concept with Camera, Display, GPS, Battery, and Environment Sensors. The Display allows users to see system status and information at a glance and the Battery will allow for portable use. Module support will not stop there, as the ability to continue development with future devices is likely with the massive catalog of common products that use UART, SPI, I^2C. As an example, We can imagine advanced sensors like Doppler Radar or Thermal Imaging sensors being useful to examine the state of real world objects without infrastructure.

IV. Bill of Materials

Attached in Appendix B is the Full Bill of Materials for the items that we requested from the Bradley University Department of Electrical and Computer Engineering. Future materials and subsequent funds will be needed for a complete prototype system with multiple boards. Considerations and parts selections are currently being made

V. Testing

Our function testing outline to validate the proof-of-concept system.

- Component level testing
  - Software stability
  - Proper hardware installation
- Transceiver Module
  - Successful Tx/Rx modulation
  - Compliance with regulations
- Module Testing
  - Operates as intended
  - Communication between systems

A. Quantitative Testing

Quantitative testing will be done with the Battery, ESP, Display, RGB LED, and Transceiver. Equipment used to do the following tests will include calibrated DMMs, Spectrum Analyzers, and Oscilloscopes.

- Max Range Testing for 2dbi Antenna
- Max Range Testing for 5dbi Antenna
- Power Draw on Maximum RF Tx Power
- Power Draw on Minimum RF Tx Power
- Power Draw for different RF Protocols
- Spurious emissions
- Power envelop of signal
- Signal to Noise Ratio

VI. Project Timeline

A. Fall 2021

The first phase of the project involved brainstorming and defining the scope of the project. The next phase is creating the presentation and proposal documents that outline our goals, plans, and specifications. Currently, we are at this stage of the project, having recently given our project presentation to students and faculty. See the attached graphical timeline for more details in Appendix C.

B. Spring 2022

Starting in 2022, the parts will arrive, proof-of-concept building and programming begins, and the prototype PCB gets designed. In phase four, the finalized PCB will arrive, the system is tested against our requirements, and major programming is completed. The final phase of the project sets up its future as we finish documentation and report on the project outcome. See the attached graphical timeline for more details in Appendix D.

C. Division of Work

Tasks listed above are grouped into 4 different topics and dispersed as follows:

- Software
- Hardware Design
- Communication Protocols
- Documentation

Shown in Figure 1 the work of the various tasks are equal in size and each team member has basic knowledge on those topics.

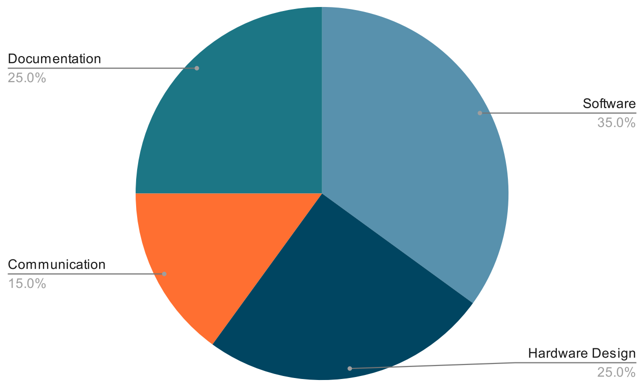

Fig. 1: Shows type of tasks and percentage of the project

VII. End-Use Requirements

Public Health, Safety, and Welfare:
RF Exposure (minimal radiated power in non-ionizing radiation) and a proper part Part 15 and Part 97 Exposure will be conducted. Service-life of the entire board with be tested and documented.

Global:
Open Source and Open Hardware licensing allow anyone to contribute. As well implement the board in their projects.

Environmental:
Open Hardware allows for ease of modification for the user to reuse hardware after the end of service life.

Business:
Open Source and Open Hardware allow free production and modification with a license to be determined in case we need a passive developmental fund for continued improvement and upkeep of active project maintainers.

Economic Factors:
Low Cost and ubiquitous hardware to facilitate inexpensive modules.

Testing:
Testing will guaranty the module works in a minimum viable product to be implemented.

VIII. Additional Considerations

A. Rounds of Funding

Currently, the project has received limited funds by the Bradley University Department of Electrical Engineering for limited proof-of-concept.

Additional funding sought from ARDC would be used to further development with initial prototypes.

A third round of funding will be sought from the Amateur Radio Digital Communications Foundation (ARDC),to produce a production run of board to create development kits that will be seeds to the community and encourage growth of the product.

B. Software and Tools

The software we choose was due to our individual familiarity with the software.

PCB Designer / CAD

- Keysight ADS
  RF simulation of the transceiver module during the design stage.
- KiCAD
  Circuit board design and generating Gerber Files for manufacturing.

Embedded Systems Development

- VS Code + ESP-IDF ESP32
  Programming software for the ESP32.
- Github
  Maintaining the project files and allowing for collaboration.

Tools

- Network Analyzer
- Spectrum Analyzer
- Oscilloscope
- Logic Analyzer
- Digital Multi-meter

IX. Conclusion

Our microcontroller powered RF transceiver board for digital radio modes will operate in the 915 MHz ISM band. This project will be entirely Open-Source and Open-Hardware to make a positive impact in open initiatives and receive contributions from others. To differentiate we will use a higher duty cycle and be designed with extensibility in mind compared to the popular and proprietary alternative LoRa. To be economical, we will use ubiquitous and inexpensive hardware to build the board and interface with a variety of external modules. We will enable tailoring to more specific use cases, like a one-way pager.

References

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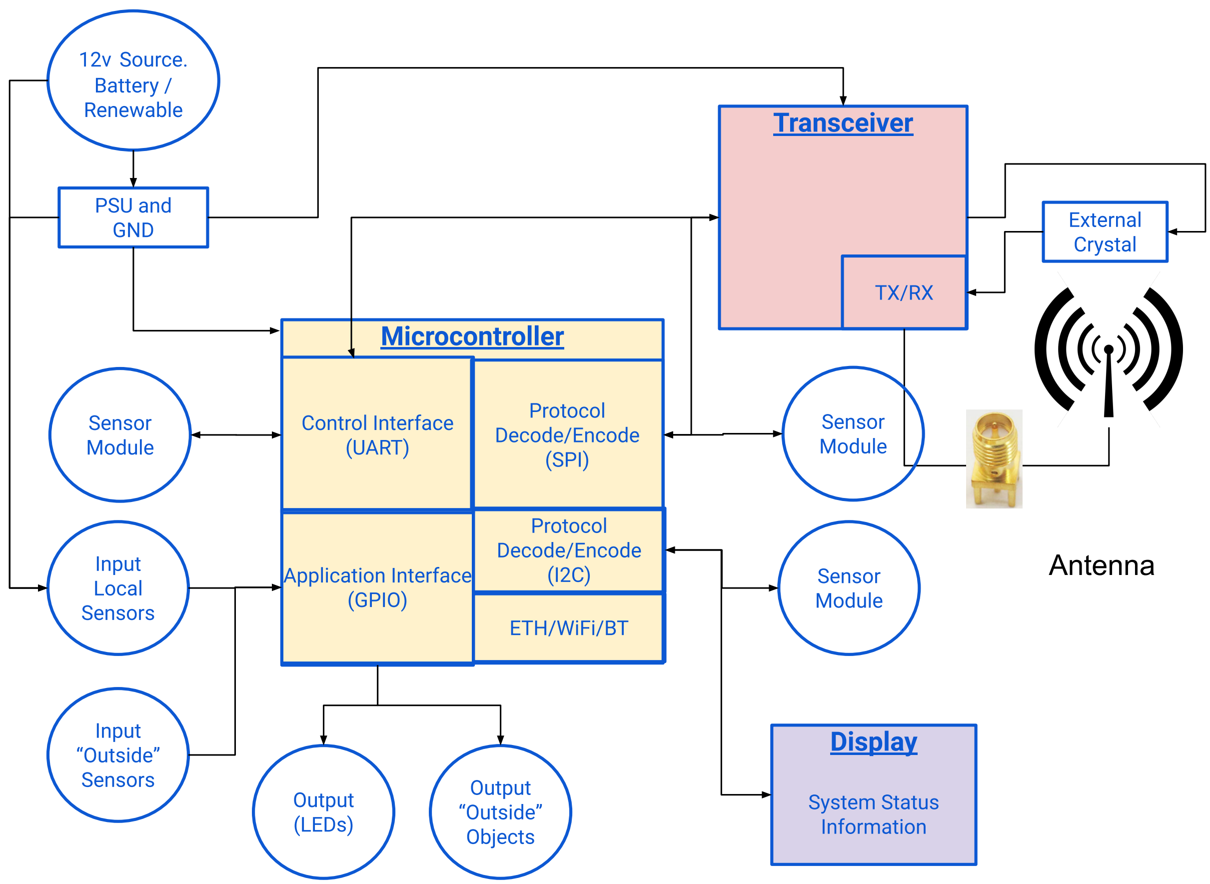
[2] “FG23-DK600A efr32fg23 868-915 mhz +14 dbm Dev Kit - Silicon Labs,” FG23-DK600A EFR32FG23 868-915 MHz +14 dBm Dev Kit - Silicon Labs, 18-Oct-2021. [Online]. Available: https://www.silabs.com/development-tools/wireless/proprietary/efr32fg23-868-915-mhz-14-dbm-dev-kitmanuals. [Accessed: 14-Feb-2022].
[3] “esp32_datasheet_en” espressif. [Online]. Available: https://www.espressif.com/sites/default/files/documentation/esp32_datasheet_en.pdf

Appendix

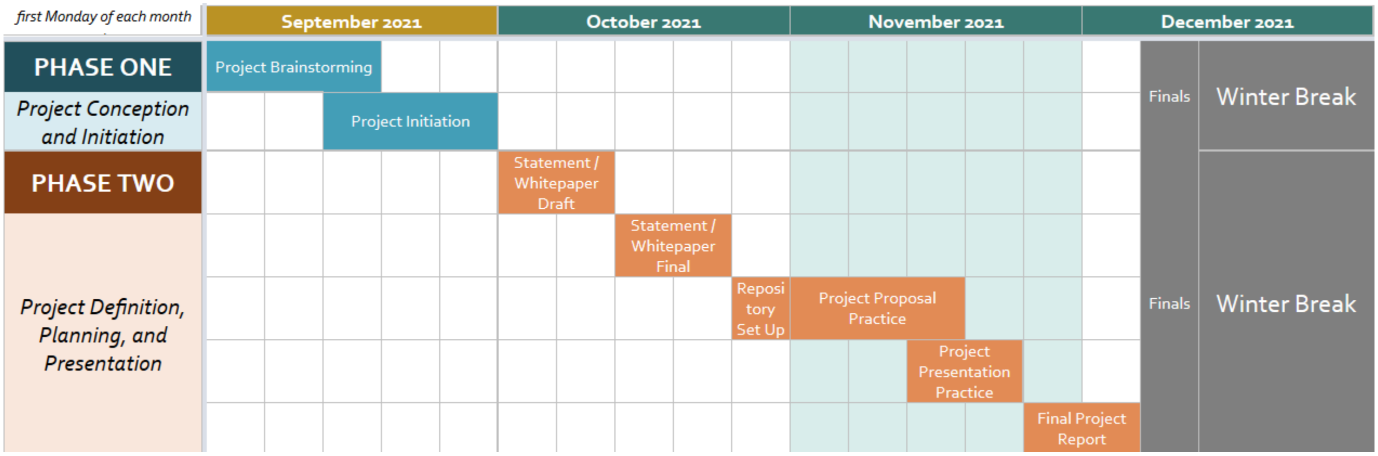
Appendix A: Block Diagram



Appendix B: Bill of Materials approved by ECE Department

QTY	Vendor	Vendor Part	ITEM DESCRIPTION	UNIT PRICE	TOTAL
1	Digikey	MAX7037-EVKIT-915#-ND	Eval Board Max7037	$254.99	$254.99
10	Digikey	MAX7037-EGL+-ND	MAX7037 Chips	$5.96	$59.62
2	Digikey	343-ANT-916-CW-RCL-SMA-ND	900Mhz Hi Gain Antenna	$8.68	$17.36
2	Digikey	2151-RST-W1B6-10808-22M-FY-001-ND	900Mhz Low Gain Antenna	$4.64	$9.28
2	Digikey	1597-104020250-ND	OLED Display 128x128	$12.50	$25.00
1	Digikey	1597-103020272-ND	I2C HUB (6 PORT)	$1.70	$1.70
1	Digikey	1597-1092-ND	4PIN MALE JUMPERS 5PACK	$3.20	$3.20
1	Digikey	1597-109020022-ND	GPS module	$13.10	$13.10
2	Digikey	1597-1674-ND	Switch 5WAY	$4.90	$9.80
2	Digikey	1597-104020169-ND	RGB LED	$4.40	$8.80
2	Digikey	1597-111020103-ND	Switch Dual Button	$2.40	$4.80
1	Digikey	223-1785-ND	MS8607 SENSOR	$16.09	$16.09
2	Digikey	1597-1687-ND	ESP32-CAM 2MP	$10.00	$20.00
2	Digikey	1965-ESP32-DEVKITC-32E-ND	ESP32-WROOM-32E	$10.00	$20.00
1	Amazon		SMA Female Jack 10-Count	$7.89	$7.89
1	Amazon		UART Cable	$10.99	$10.99
				Items Shipping Total	$482.62 $12.00 $494.62

APPENDIX C: PROJECT TIMELINE FALL 2021



APPENDIX D: PROJECT TIMELINE SPRING 2022