Distributed Sniffer Nodes for Batteryless Sensor Nodes

(sdmay24-25)

Website

https://sdmay24-25.sd.ece.iastate.edu/

Team Lead/ Software Lead: Thomas Gaul
Hardware Lead: Tori Kittleson
Hardware Member: Matthew Crabb
Software Member: Spencer Sutton
Scribe/Software Member: Ian Hollingworth

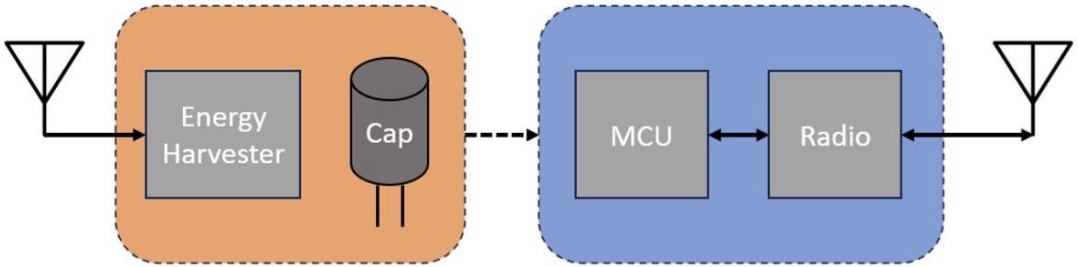
Advisor/Client: Henry Duwe

CPRE/EE 492 Spring 2024

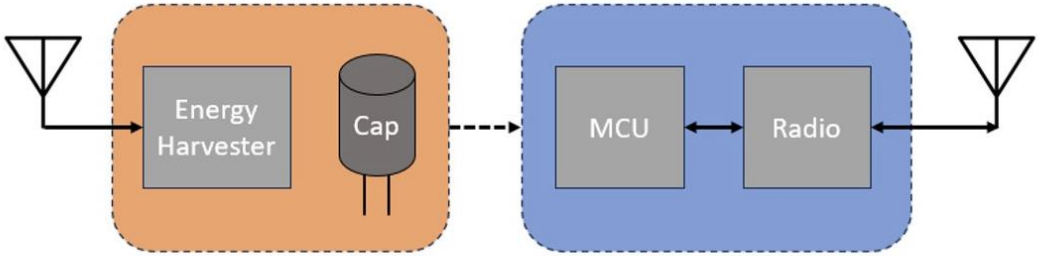
IOWA STATE UNIVERSITY

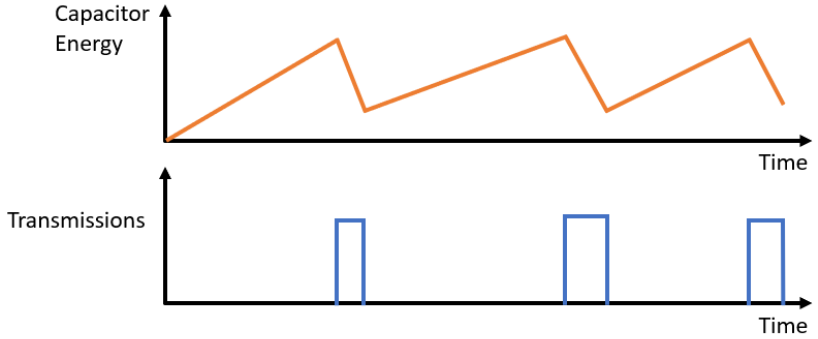
Project Overview

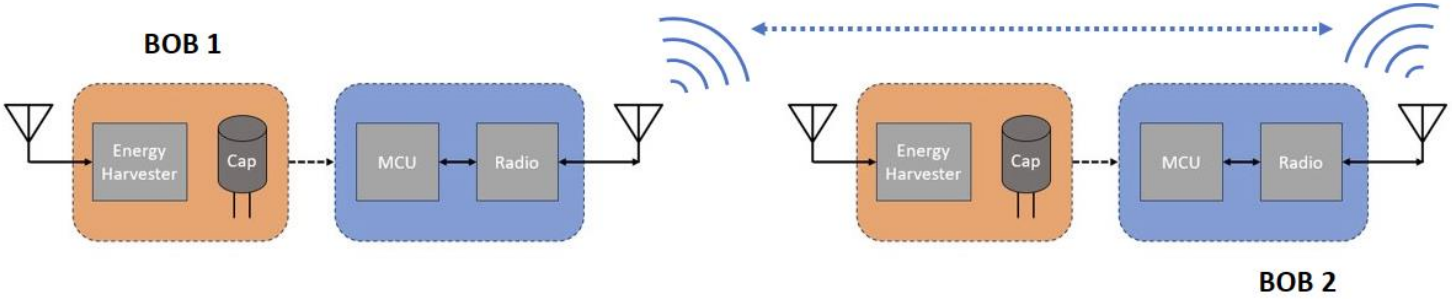
BOB Node - Batteryless sensor designed by client.

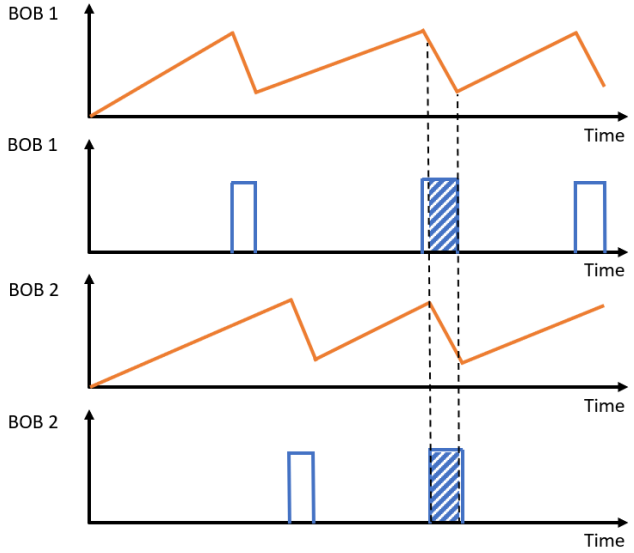


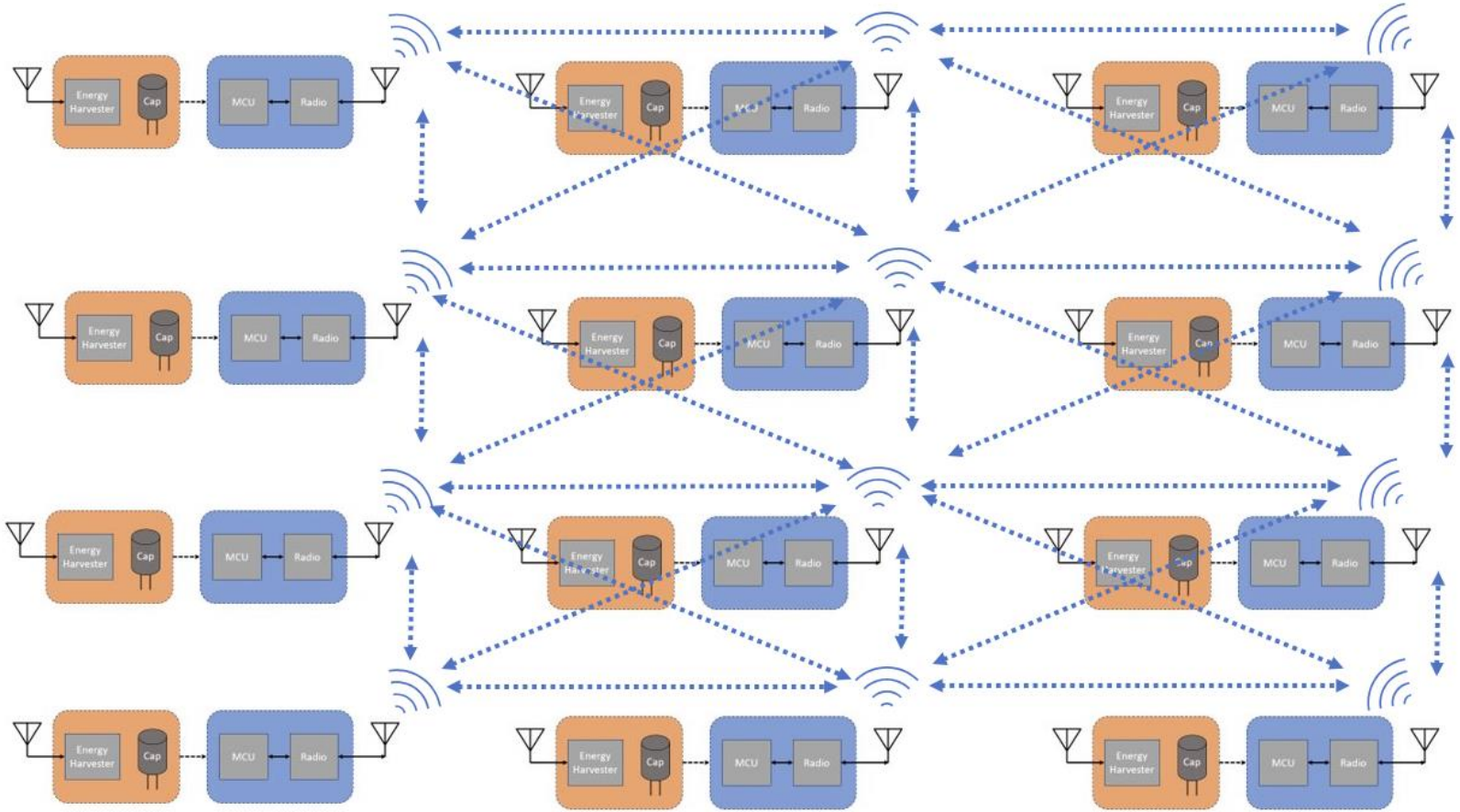
Project Overview



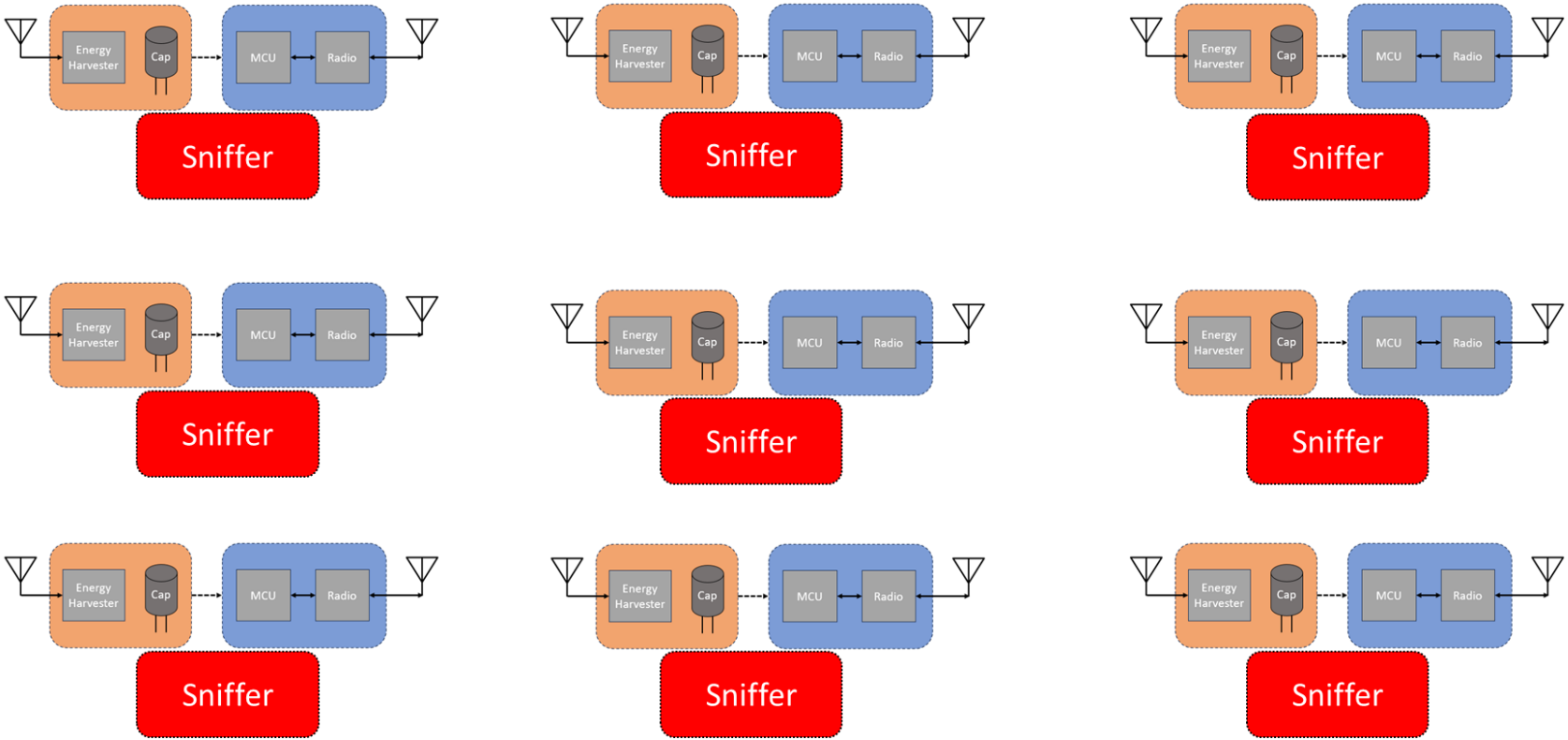



BOB 1
Energy Harvester
Cap
MCU
Radio
Energy Harvester
Cap
MCU
Radio
BOB 2


BOB 1
Time
BOB 1
Time
BOB 2
Time
BOB 2
Time


Energy Harvester
Cap
MCU
Radio

Goal: Create testbed for researchers to use for the batteryless nodes they are developing.



Use Cases

Scenario Node Tests

- Single node tests
- Multi-node and single lab testing (goal of 9)
- Large scale testing (goal of 100 – 1000)

Users

- Dr. Duwe's research group
- Universities, companies, hobbyists through open-source nature

Potential Impact

- Forest fire detection in national parks
- Factory condition monitoring
- Weather monitoring and recording

Requirements

Functional

- 9 BOB/Sniffer pairs
- Sink Sniffer Node with continuous power
- Host system to organize and store Sniffer logs
- Sniffer Nodes powered for one week
- Sniffer Nodes inflict minimal effects on BOB Nodes
- BOB Nodes electrically isolated from one another
- Modular stack of BOB and Sniffer custom boards

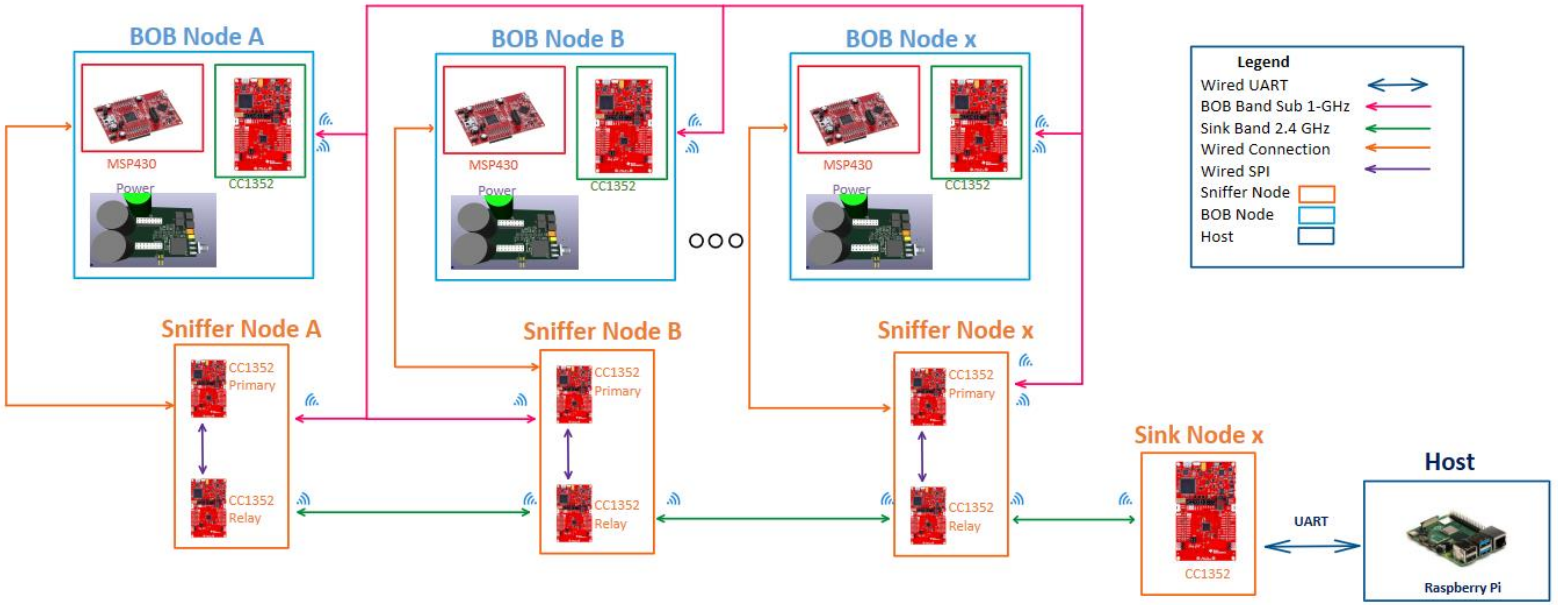
Non-functional

- Scalable for a potential larger (100+ node) design
- Documentation
- Mechanical durability of system

Deliverables

- Breakout Board Hardware
- MSP Simplified Hardware
- Sniffer Node Hardware
- Sniffer Node Software
- Open-Source Documentation
- Mechanically Sound System

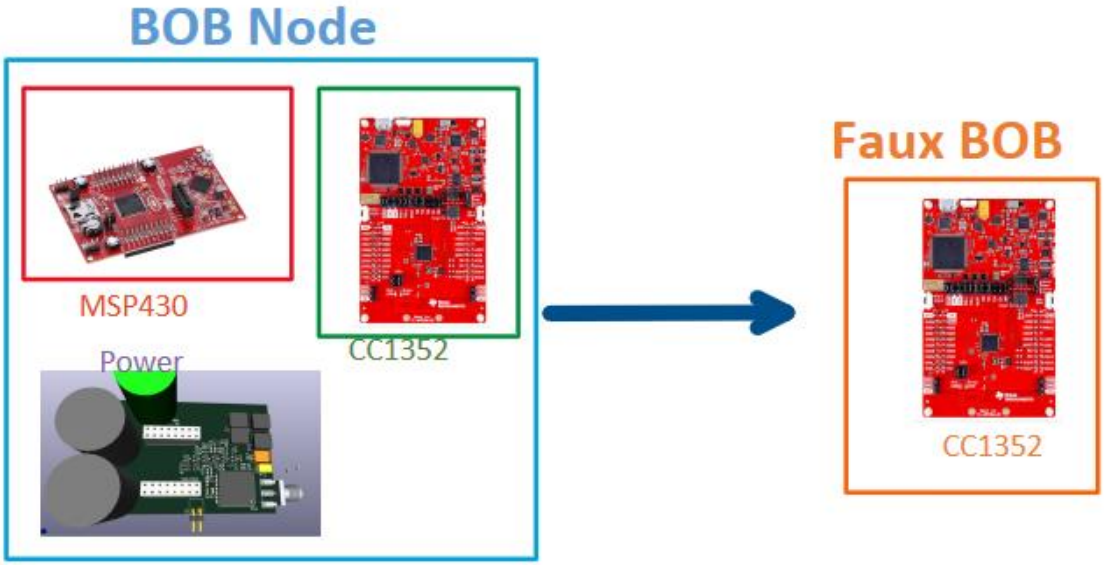
System Design



Work Progress: Faux BOB

Goal

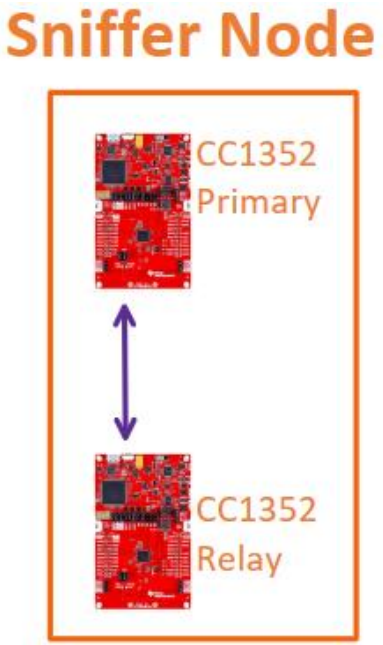
- Create a test tool
- Emulate BOB functionality
- Allows us to have a know test



Work Progress: SPI interface

Goal

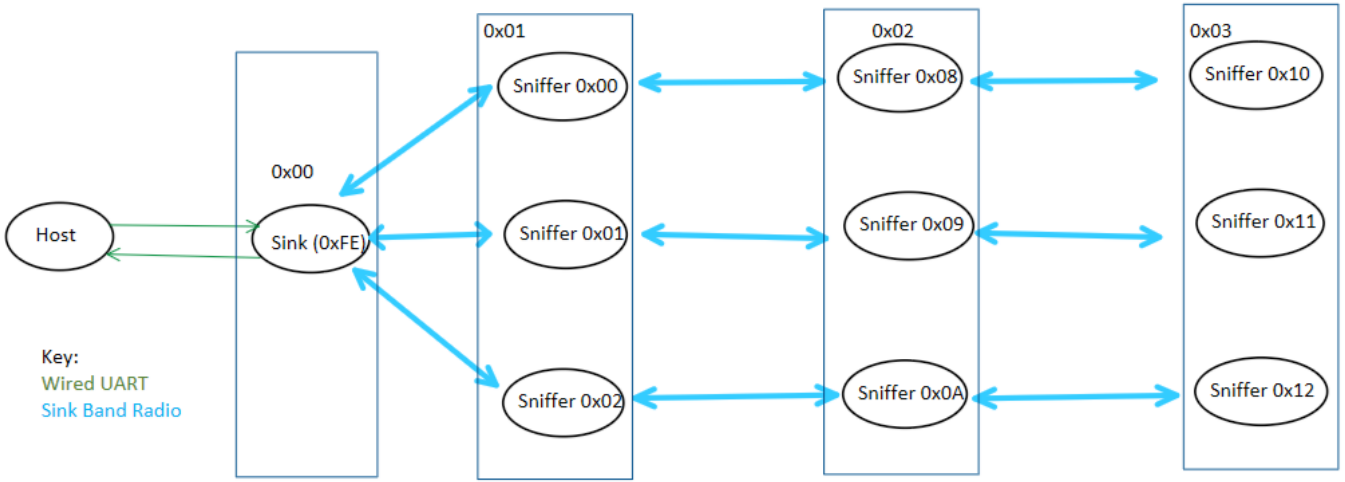
- Create interface for communicating between two CC1352s
- Allows us to take data from Band (2.4 GHz) and send it to Sub-1 GHz and vice versa



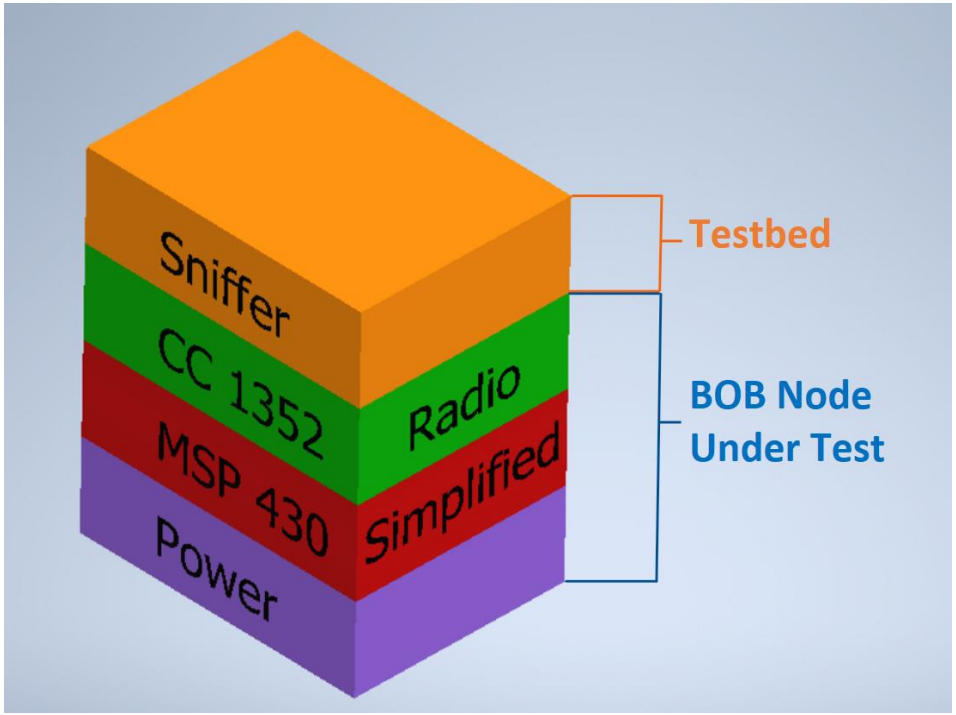
Work Progress: Software Network

Depth Parameter
Depth = ⌊Destination Address/8⌋ + 1
Transmit to all is 0xFF
Transmit to Sink 0xF
From Sink Node knows path by doing
Destination % 8

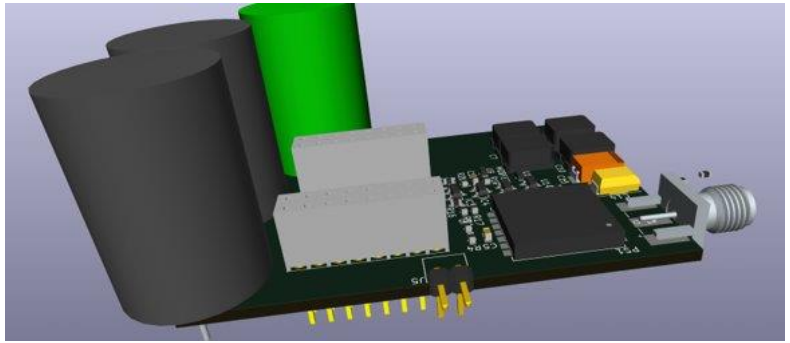
Each destination is 1 byte meaning maximum of 255 destinations in the network(could be increased but due to address filtering in the BOBs this would be unnecessary unless that BOB code changes

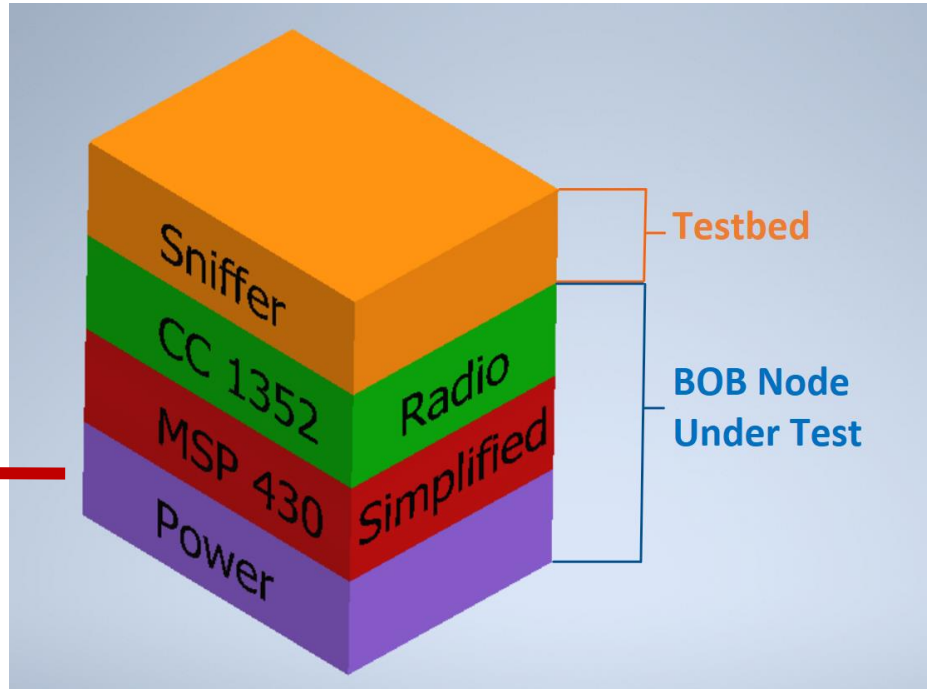


System Physical Design



System Physical Design





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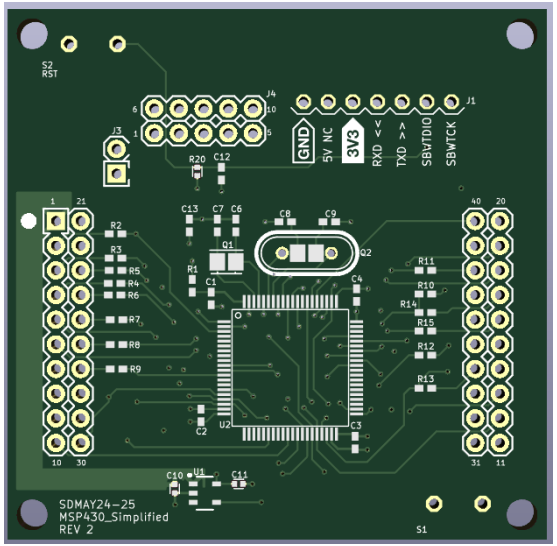
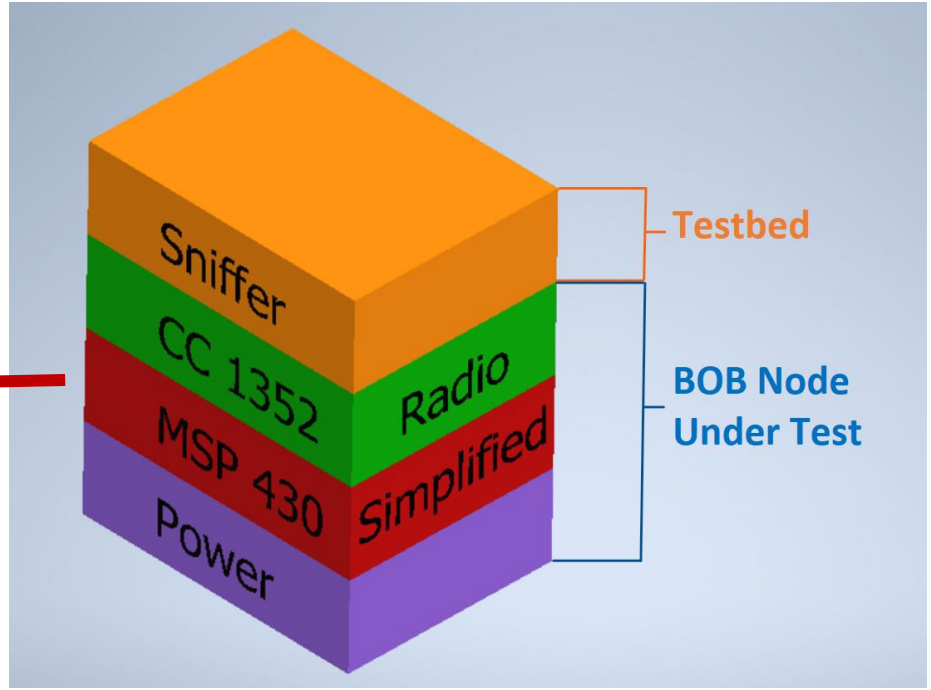
System Physical Design





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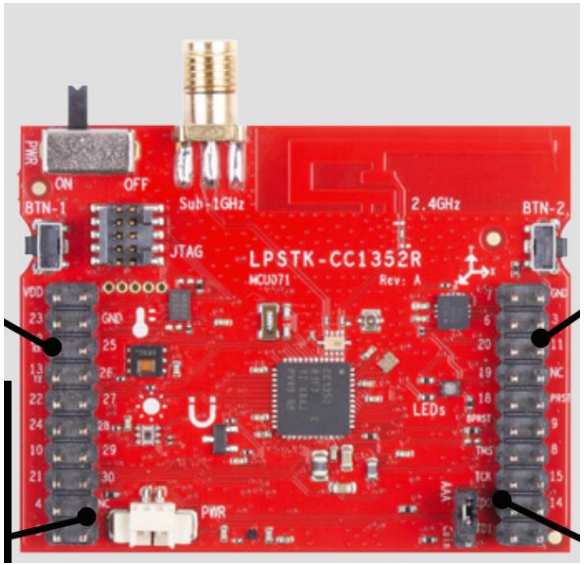
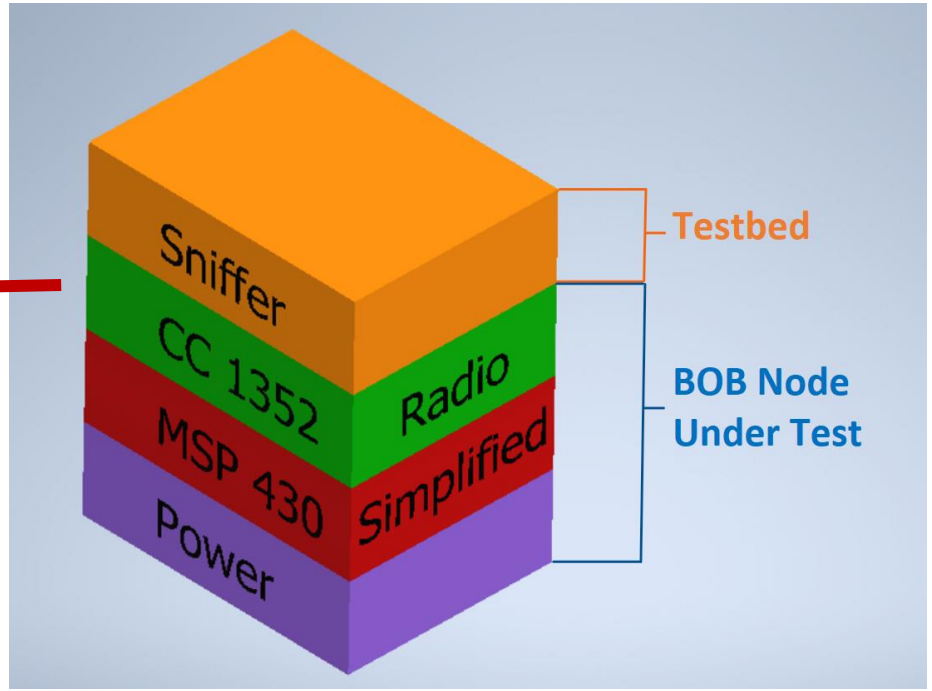
System Physical Design





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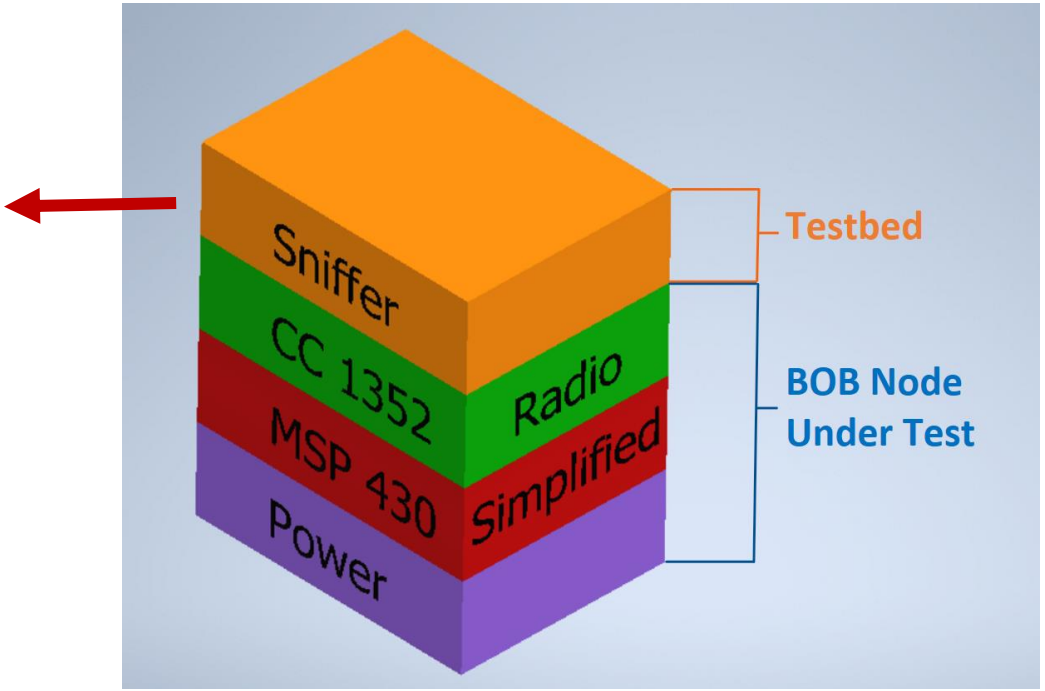
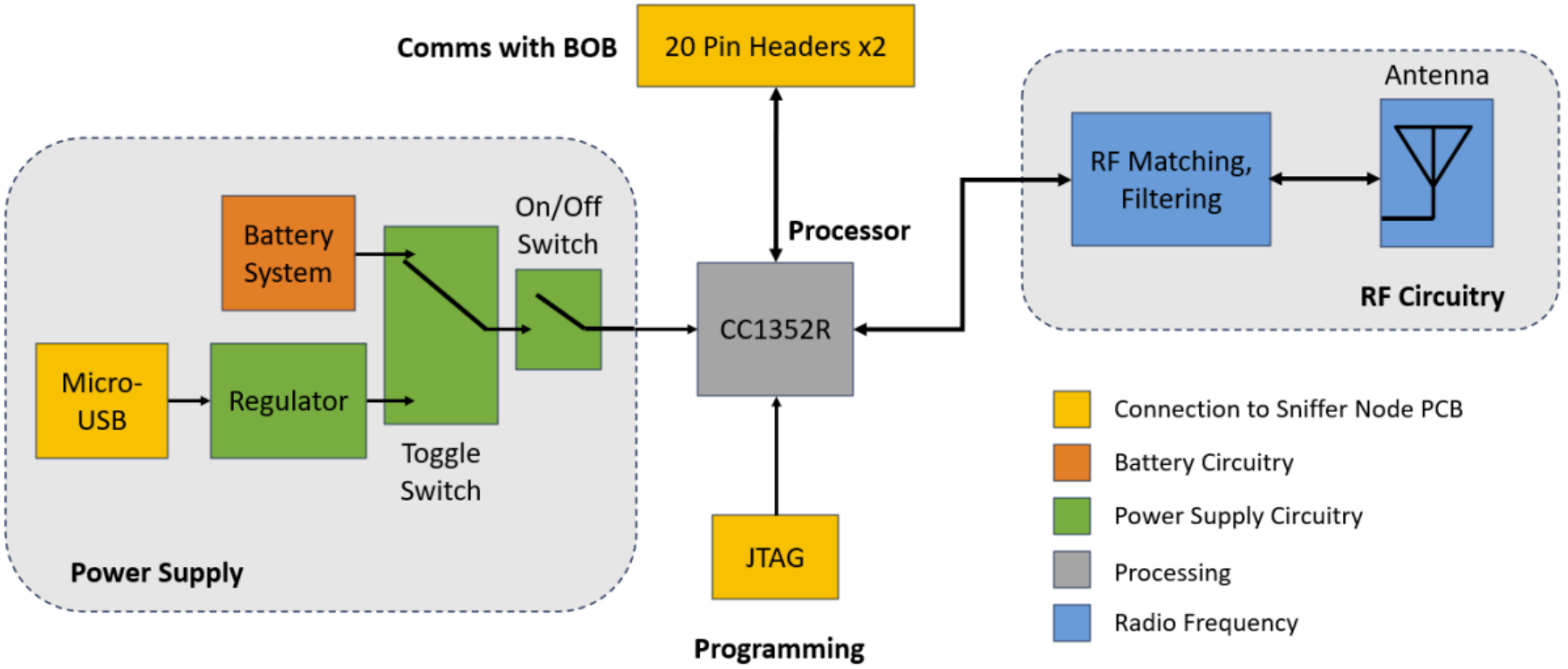
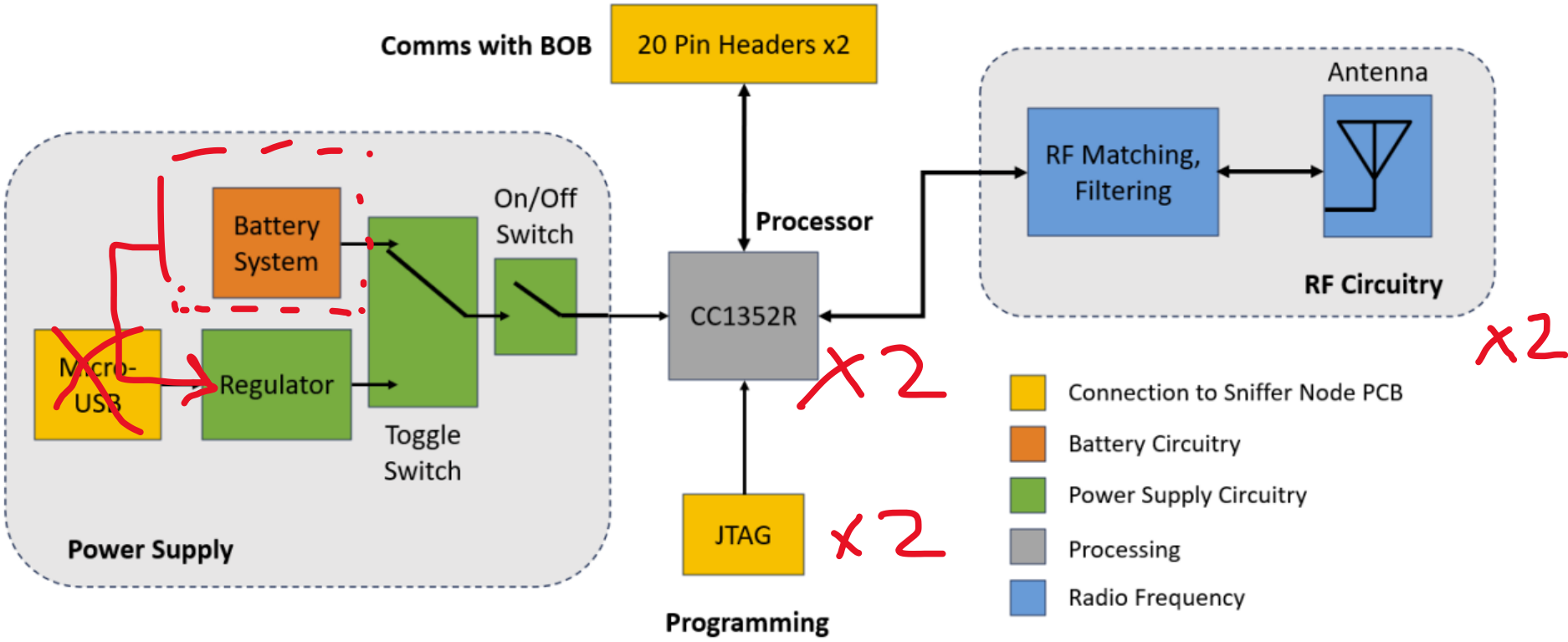
System Physical Design

Our Design




Comms with BOB
20 Pin Headers x2
Antenna
RF Matching, Filtering
Processor
On/Off Switch
Battery System
Micro-USB
Regulator
Toggle Switch
CC1352R
RF Circuitry
Power Supply
JTAG
Programming
Connection to Sniffer Node PCB
Battery Circuitry
Power Supply Circuitry
Processing
Radio Frequency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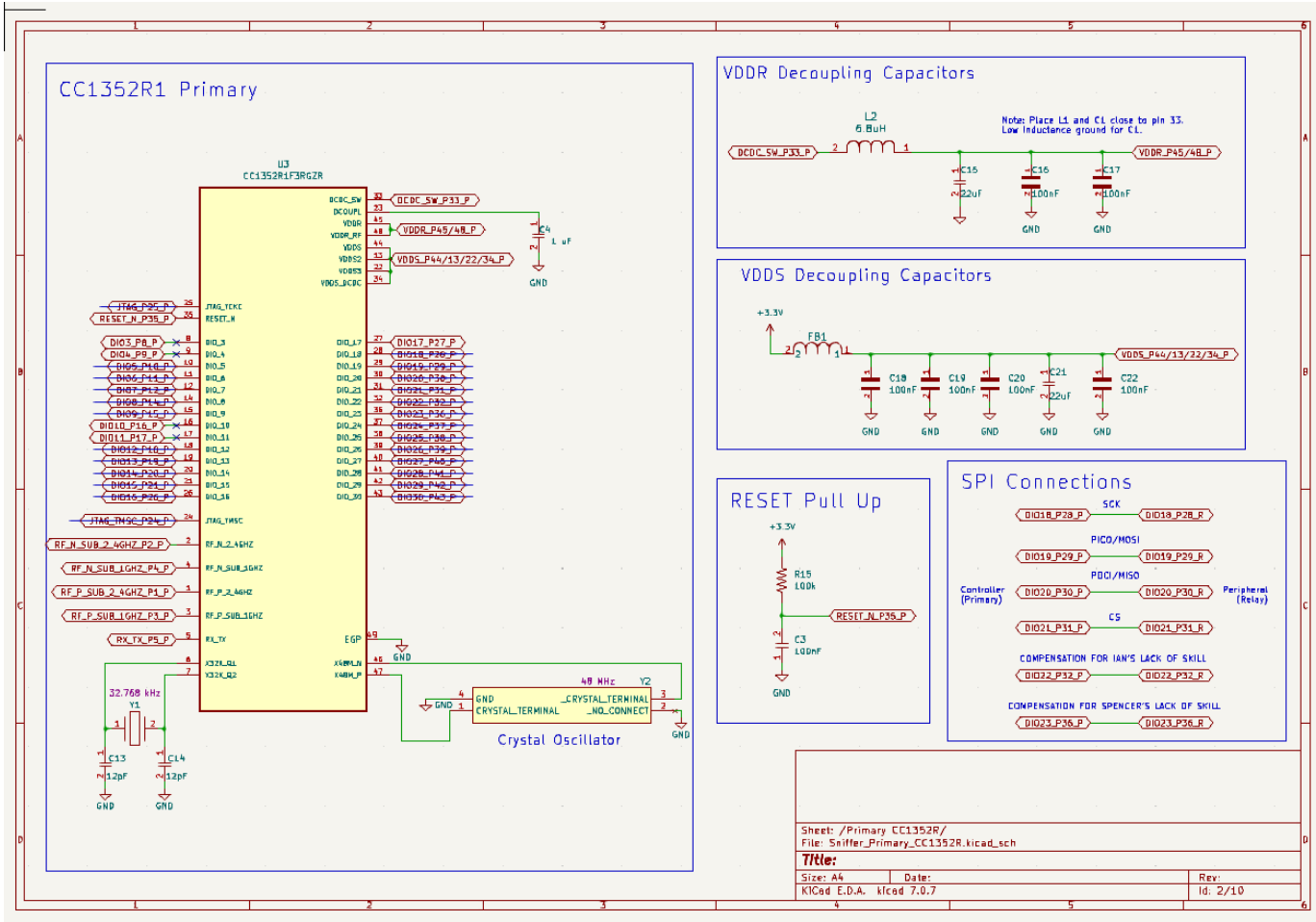
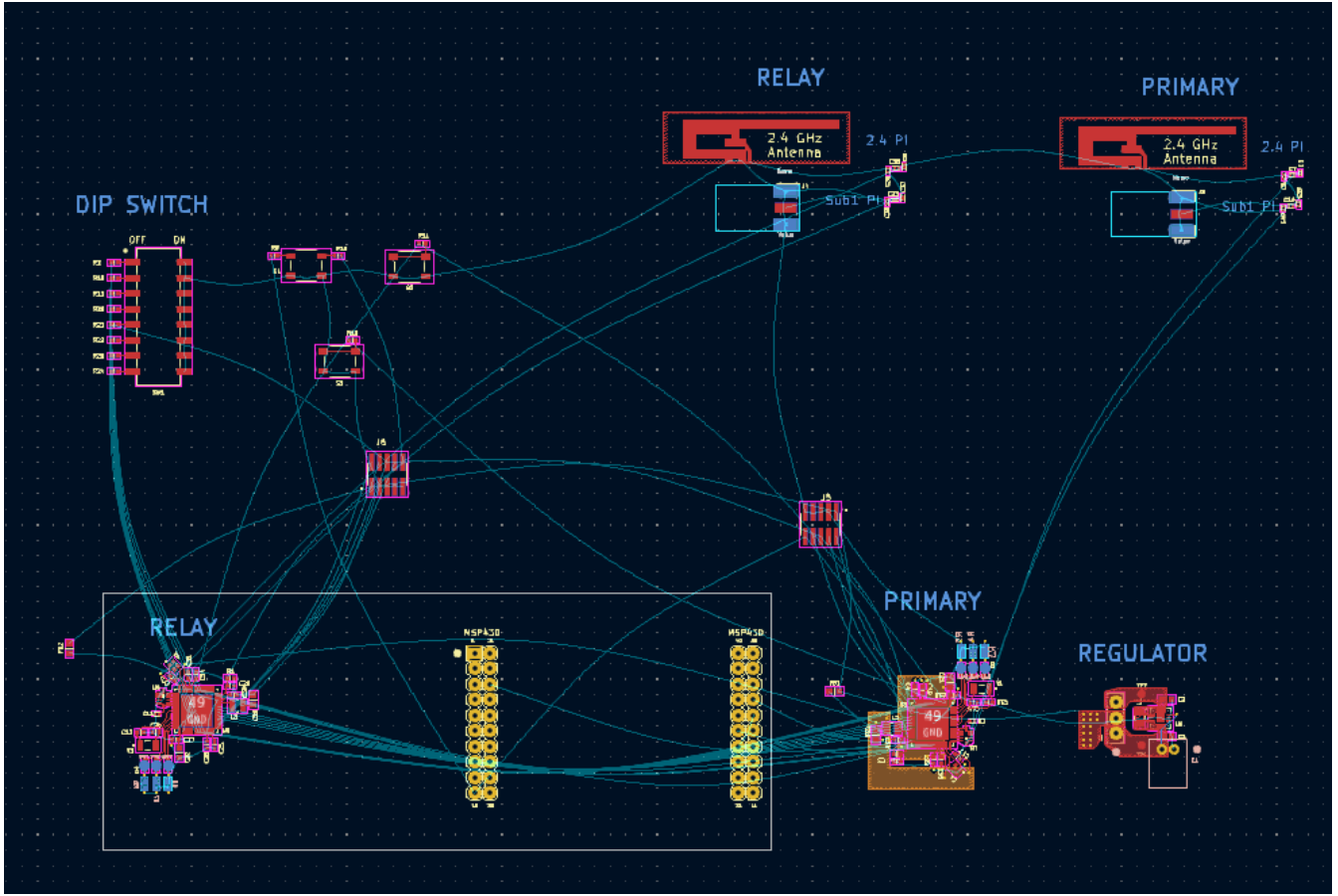
RF Circuitry
x2
Power Supply
JTAG
x2
Programming
Connection to Sniffer Node PCB
Battery Circuitry
Power Supply Circuitry
Processing
Radio Frequency

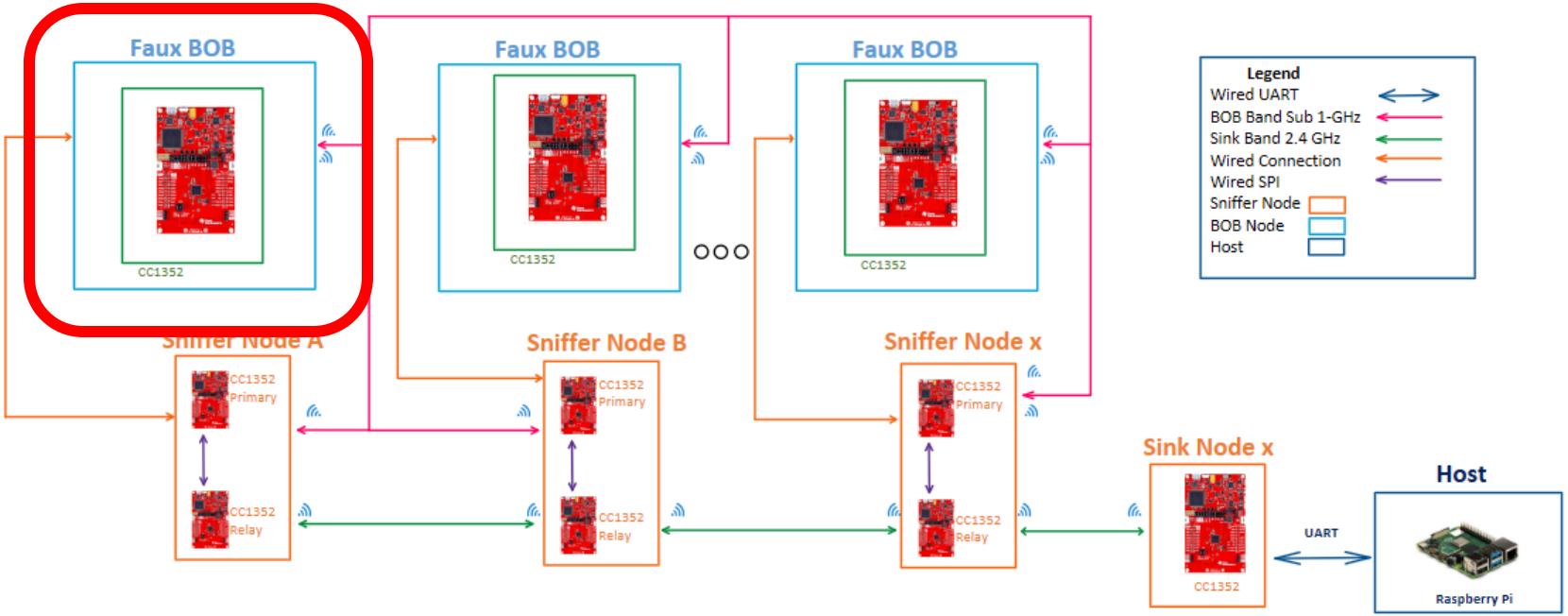
Our Design Phase:

- Schematic reviewed
- Layout In Prog

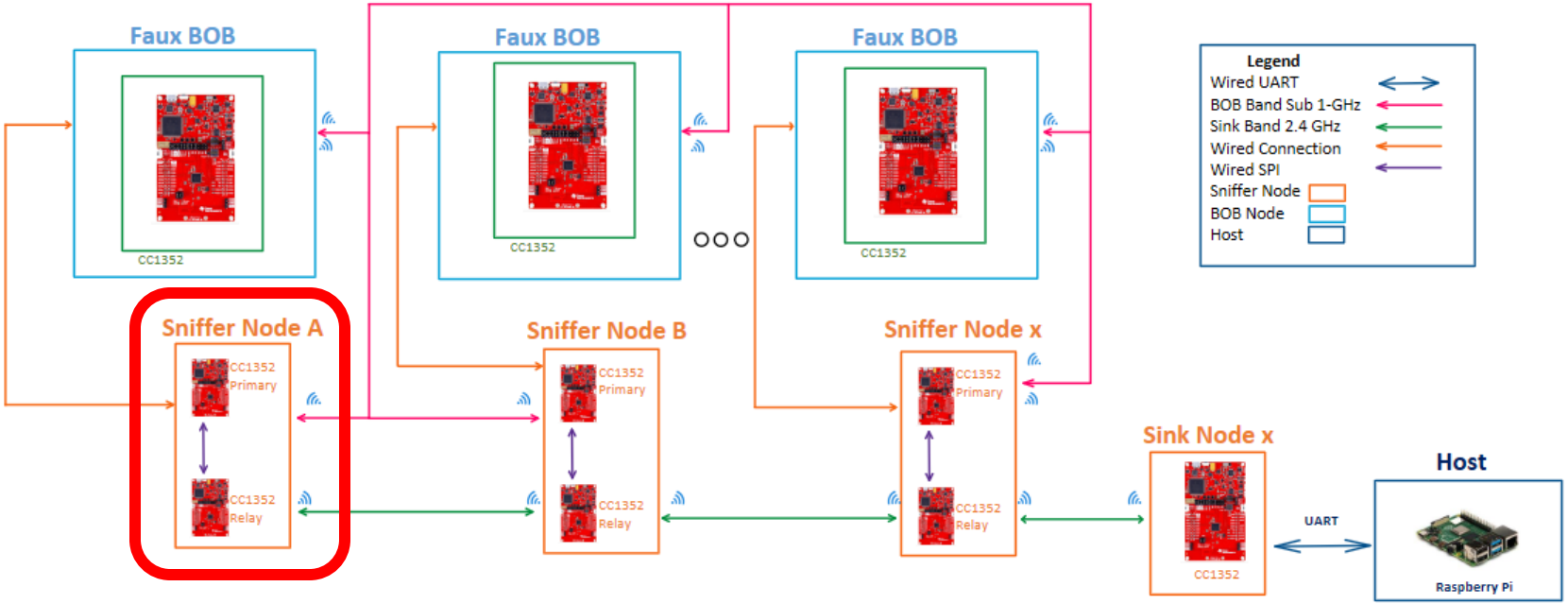



RELAY
PRIMARY
2.4 GHz Antenna
2.4 PI
Sub1 PI
2.4 GHz Antenna
2.4 PI
Sub1 PI
DIP SWITCH
OFF
ON
RELAY
PRIMARY
REGULATOR

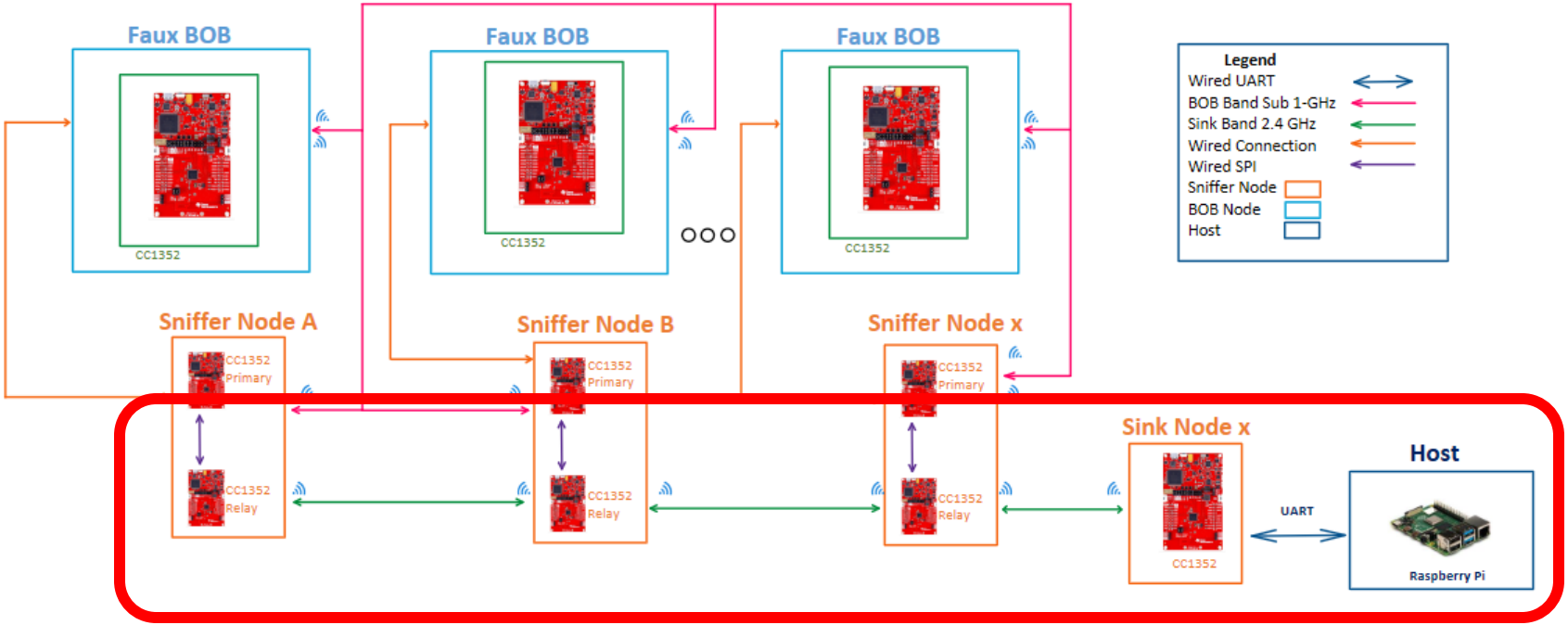
Current Software Walk-through



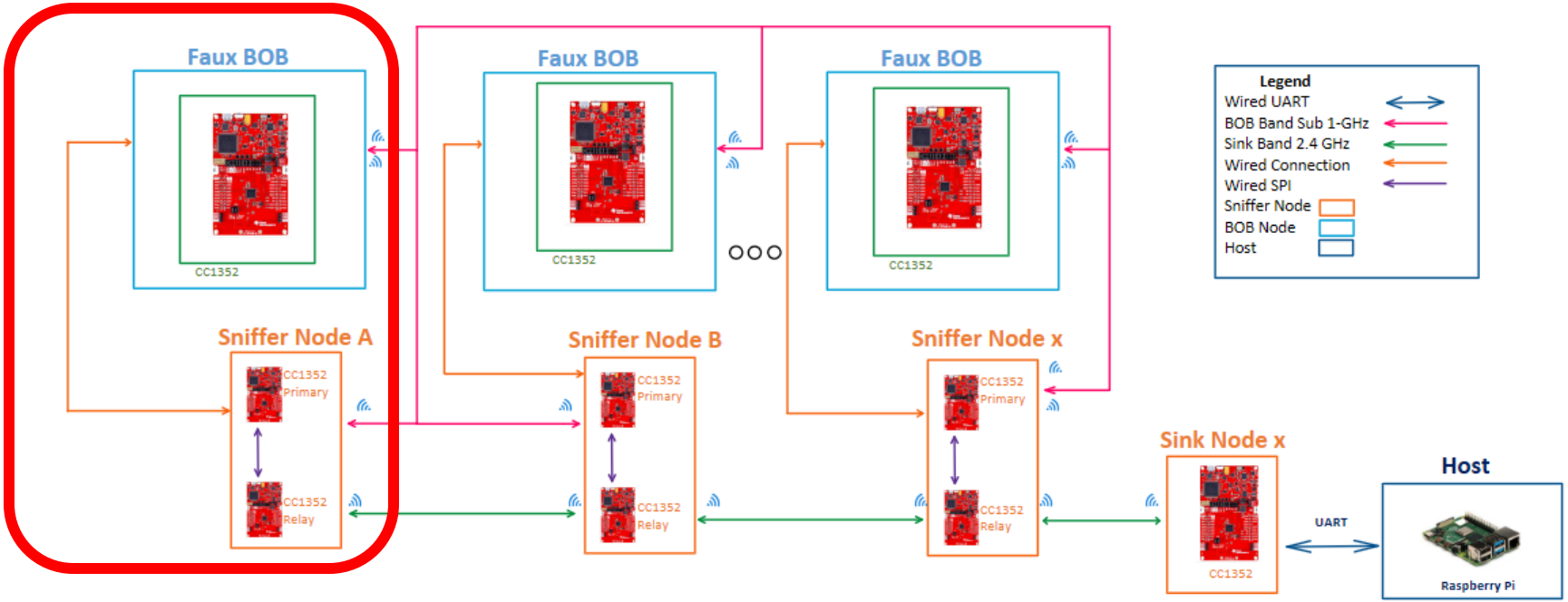
Current Software Walk-through



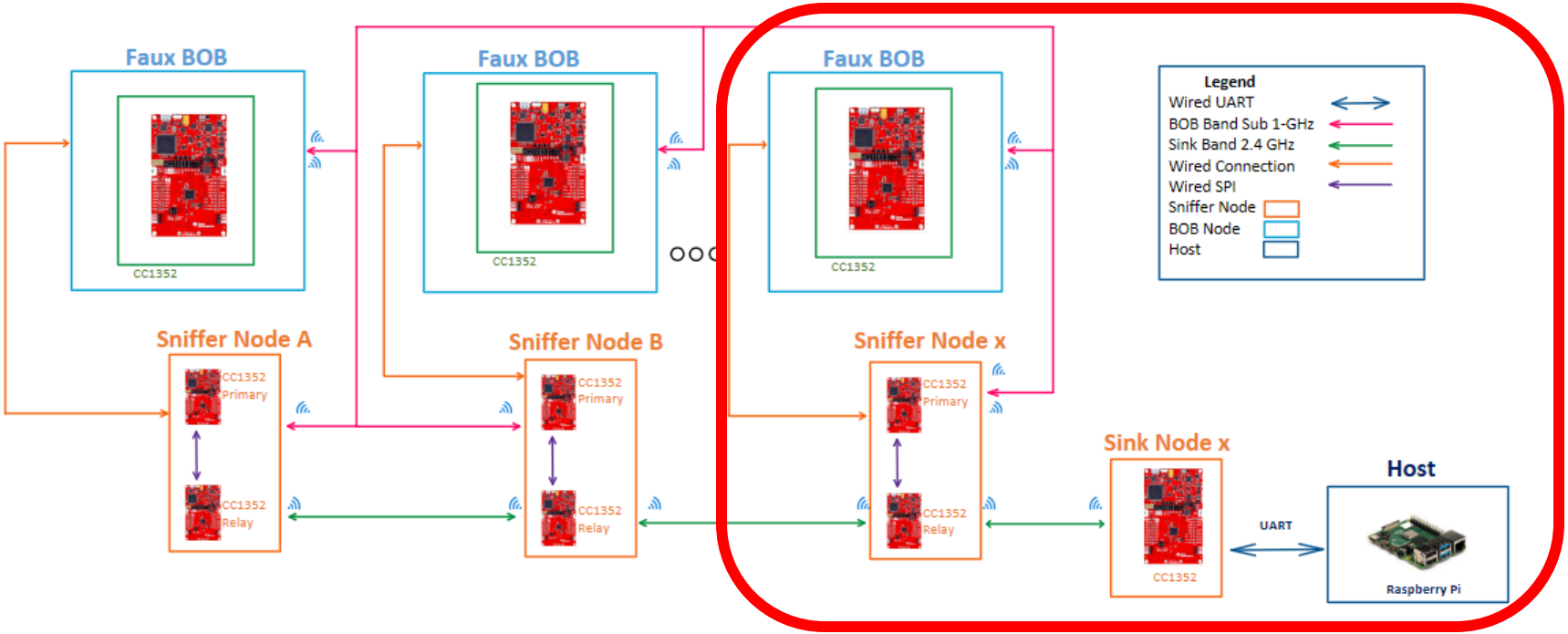
Current Software Walk-through



Next Step Software Walk-through



Next Steps ~90% complete



Hardware Challenges and Solutions

- ➔ **Requirement Modifications**
- ➔ **Second Revision of a PCB (layout mistake)**
- ➔ Worked with client to discuss and fine tune requirements
- ➔ Reworked PCB for a second order
- ➔ Revised the Gantt chart to update for current progress

- ➔ PCB Delays – symbols, footprints, small details

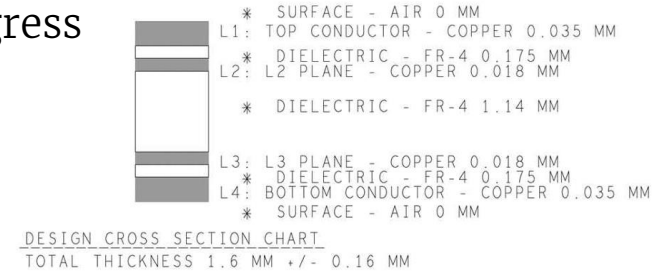
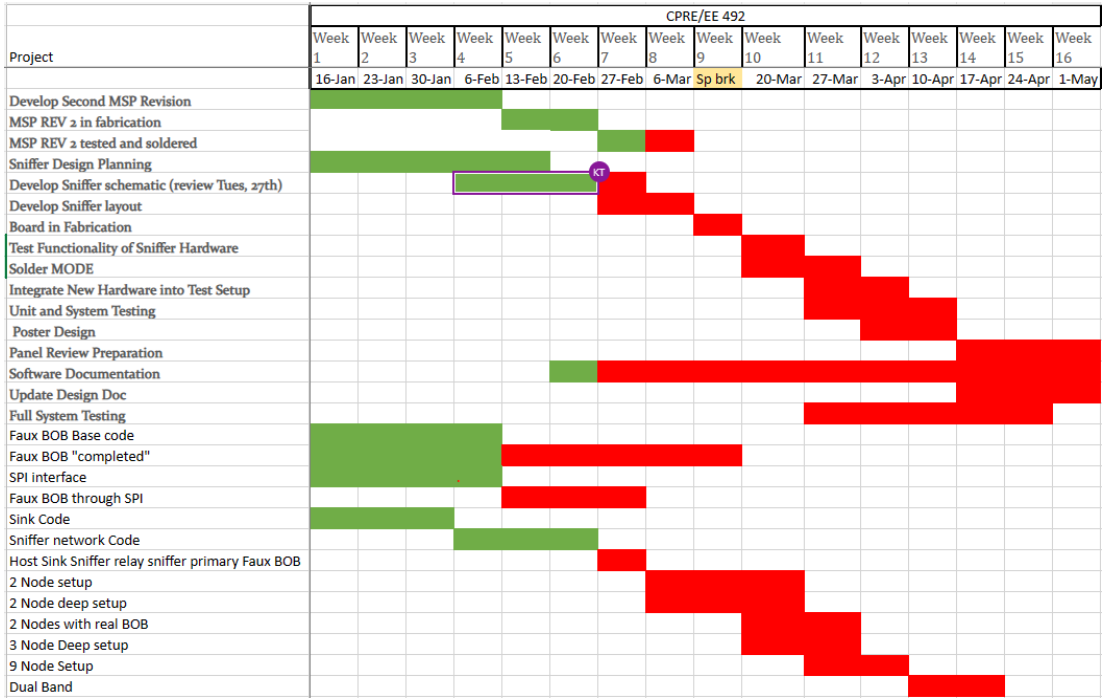


Figure 4-1. CC1312R Board Stack Up

Software Challenges and Solutions

- ➔ **SPI integration**
- ➔ Talked to people who previously implemented it
- ➔ **Poor documentation/Weird Quirks of Software**
- ➔ Got help from experienced individuals
- ➔ Divided up unknowns and shared knowledge

Project Plan – Schedule/Milestones



Thank you!

Hardware Cost Estimates

Cost for Single Board

Item #	Designator	Manufacturer	Mfg Part #	Description / Value	Package	Supplier	Link	Qty	Cost	Total Cost
1	U1	GLF Integrated Power	GLF1111	Power Switch/Driver P-Channel 2A	SOT-23-5L	DigiKey	https://www.d	1	0.33	0.33
2	C1, C2	Samsung Electro-Mechanics	CL05A104KA5NNNC	CAP CER 0.1UF 25V X5R 0402	0402	DigiKey	https://www.d	2	0.01	0.02
3	J1	Samtec Inc.	SSW-110-03-G-D	CONN RCPT 20POS 0.1 GOLD PCB	-	DigiKey	https://www.d	2	3.89	7.78
4	J2	Molex	22122024	TH, Right Angle 2 position 0.100" (2.54mm)	-	DigiKey	https://www.d	1	0.77	0.77
5	R1	Stackpole Electronics	RMCF0805ZT0R00	RES 0 OHM JUMPER 1/8W 0805	0805	DigiKey	https://www.d	1	0.018	0.018
6	-	-	-	Board Fabrication	-	JLCPCB	-	1	3.892	3.892
								Total Cost		12.48

Cost Per Breakout Board

Cost for single board

Item #	Designator	Manufacturer	Mfg Part #	Description / Value	Package	Supplier	Link	Qty	Cost	Total Cost
1	U1	GLF Integrated Power	GLF1111	Power Switch/Driver P-Channel 2A	SOT-23-5L	DigiKey	https://www	1	0.33	0.33
2	C1, C2, C3, C4, C10, C11	TDK Corporation	C1005X5R1A104M050BA	CAP CER 0.1UF 10V X5R 0402	0402	DigiKey	C1005X5R1A	6	0.021	0.126
3	J2	Samtec Inc.	SSW-110-03-G-D	CONN RCPT 20POS 0.1 GOLD PCB		DigiKey	SSW-110-03	2	3.89	7.78
4	J3	Molex	22122024	TH, Right Angle 2 position 0.100" (2.54mm)	-	DigiKey	https://www	1	0.64	0.64
5	C6, C7	TDK Corporation	C1005C0G1H220J050BA	CAP CER 22PF 50V C0G 0402	0402	DigiKey	C1005C0G1H	2	0.047	0.094
6	C12	TDK Corporation	C1005X7R1H102K050BA	CAP CER 1000PF 50V X7R 0402	0402	DigiKey	C1005X7R1H	1	0.051	0.051
7	C13	Murata Electronics	GRM155R61A106ME11D	CAP CER 10UF 10V X5R 0402	0402	DigiKey	GRM155R61A	1	0.091	0.091
8	J1	Sullins Connector Solutic	PRPC007SBAN-M71RC	CONN HEADER R/A 7POS 2.54MM	-	DigiKey	PRPC007SBA	1	0.191	0.191
9	Q1	EPSON	FC-135R 32.7680KA-A0	CRYSTAL 32.7680KHZ 12.5PF SMD	-	DigiKey	FC-135R 32	1	0.7	0.7
10	R1, R2, R3, R4, R5, R6, R	YAGEO	RC0402JR-070RL	RES 0 OHM JUMPER 1/16W 0402	0402	DigiKey	RC0402JR-0	17	0.0045	0.0765
11	R18	YAGEO	RC0402FR-0747KL	RES 47K OHM 1% 1/16W 0402	0402	DigiKey	RC0402FR-0	1	0.015	0.015
12	U2	Texas Instruments	MSP430FR5994IPN	IC MCU 16BIT 256KB FRAM 80LQFP	-	Mouser	MSP430FR59	1	11.27	11.27
13	Q2	DNP								
14	-	Würth Elektronik	60900213421	JUMPER W/TEST PNT 1X2PINS 2.54MM	-	DigiKey	6090021342	1	0.31	0.31
15	S1,S2	E-Switch	TL59NF160Q	SWITCH TACTILE SPST-NO 0.05A 12V	-	DigiKey	TL59NF160(	2	0.284	0.568
16	J2 (trying another comp	Samtec Inc.	SSW-110-23-G-D	CONN RCPT 20POS 0.1 GOLD PCB	-	DigiKey	SSW-110-23	0	5.71	0
17	-	-	-	PCB Fabrication	-	JLCPCB	-	1	4.96	4.96
								Total Cost		27.2025

Cost Per MSP Simplified Single Board Cost

Approximate Cost Per Board	
Breakout Board	~$13
MSP Simplified	~$28

Literature Study

- "Experimental Study of Lifecycle Management Protocols for Batteryless Intermittent Communication"[2]

- "Toward a Shared Sense of Time for a Network of Batteryless, Intermittently-powered Nodes"[3]

- "Reliable Timekeeping for Intermittent Computing"[4]

Stack Pinouts

SD)

Table 1

GPIO	MSP430	CC1352 radio	I/O (as seen from the msp)
Data Received	P5.0	DIO22	I
Transmit Request	P5.1	DIO3	O
Transmit Done	P5.2	DIO24	I
SPI Master Ready	P5.3	DIO19	O
SPI Slave Ready	P5.4	DIO7	I
FRAM Written	P5.5	DIO11	O
Power radio	PJ.4		
SPI MOSI	P6.4	DIO9	
SPI MISO	P6.5	DIO8	
SPI CLK	P6.6	DIO10	
SPI SS	P6.7	DIO20	O

Table 2

GPIO	MSP430	CC1352 radio	CC1352 sniffer		Harvester	I/O
Powered ON	P7.7		DIO25	DIO28		O
Event Gen	P7.4		DIO26	DIO29		I
Testbed Reset	P7.5		DIO27	DIO30		I
Easylink Tx		DIO25	DIO24	DIO21		
Event drop	P7.6		DIO9	DIO8		O
Reset	P7.3				Reset	I

Note currently in our setup we have only one sniffer for two msp430 nodes. I/O are defined with respect to msp430 node
Code needs update

Figure 12: Plan to Create Extra NC Pins on the CC1352R Development Board

Stack Pinouts

MSP Board Pinout							
Pin #	Func	Pin #	Func	Pin #	Func	Pin #	Func
1	3V3 to CC	21	3V3	40	P5.4	20	GND
2	GPIO	22	GND	39	GPIO	19	P5.1
3	GPIO	23	NC	38	P6.7	18	P5.5
4	GPIO	24	GPIO	37	P3.5	17	GPIO/EN
5	P5.0	25	GPIO	36	GPIO	16	NC
6	P5.2	26	GPIO	35	GPIO	15	P6.4
7	P6.6 (SPI)	27	GPIO	34	RST_MSP	14	P6.5
8	P1.0	28	P7.3	33	P1.1	13	P1.6
9	P7.4	29	P7.5	32	P1.7	12	P2.6
10	P7.6	30	P7.7	31	P2.5	11	GPIO

Figure 14: MSP Simplified Pinout

Stack Pinouts

Harvester Board Pinout							
Pin #	Func	Pin #	Func	Pin #	Func	Pin #	Func
1	NC	21	3V3	40	P5.4	20	GND
2		22	GND	39		19	P5.1
3		23	NC	38	P6.7	18	P5.5
4		24		37	P3.5	17	
5	P5.0	25		36		16	NC
6	P5.2	26		35		15	P6.4
7	P6.6	27		34		14	P6.5
8	P1.0	28	P7.3	33	P1.1	13	P1.6
9	P7.4	29	P7.5	32	P1.7	12	P2.6
10	P7.6	30	P7.7	31	P2.5	11	

Figure 15: Power Harvester Pinout

LIPO Cost Estimate (Slightly Outdated)

Item	Cost per Item	Quantity	Total Cost
LIPO	$5.00	10	$50.00
Battery Mount	$3.00	10	$30.00
Protection/Management ICs	$0.50	10	$5.00
Charger ICs and parts	$1.00	10	$10.00
Charger PCB	$15.00	1	$15.00

Cost per board: $11.00

Updated cost per board (no charging board): $9.5

Time Skew Analysis

CC1352 clock was ran with constant time reporting, compared to real-time clock

Skew ended up > .005%, .01% between any given 2 nodes

Two nodes skewing in opposite directions: take 50 seconds to skew by 5 ms

Prototype Implementations - ????

No Transmit	Min	Max	Mean
Power (mW)	4.6707	7.5945	5.9900
Current (mA)	1.4154	2.3014	1.8152

Transmit every 5ms	Min	Max	Mean
Power (mW)	4.6707	7.5945	5.9900
Current (mA)	1.4154	2.3014	1.8152

$$P_{avg} = 0.5(5.99) + 0.5(26.09) = 16.04mW$$

$$E_{wk} = P_{avg}(7)(24)(60)(60) = 9.701kJ$$

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Prototype Implementations - ????

No Transmit	Min	Max	Mean
Power (mW)	4.6707	7.5945	5.9900
Current (mA)	1.4154	2.3014	1.8152

Transmit every 5ms	Min	Max	Mean
Power (mW)	4.6707	7.5945	5.9900
Current (mA)	1.4154	2.3014	1.8152

$$capacity - needed = (0.5(I_{normal}) + 0.5(I_{trans,5ms}))(7)(24)$$

$$capacity - needed = ((0.5)(1.8152) + (0.5)(7.9060))(7)(24) = 816.581 mAh$$

$$capacity - needed = (\frac{P_{avg}}{V_{supplied}})(7)(24) = \frac{2695}{V_{supplied}} mAh$$

+10% buffer

p. 37-38

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