Purdue Embedded Systems Laboratory

QUBE FACTSHEET

Rev.1

esl
10-20-2013

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QUBE

Design goal

The design goal for QUBE is to create a general purpose self-powered ultra-low energy system with sensing and wireless capabilities and with a small form-factor. A stackable architecture, as shown in Figure 1 is preferred for making QUBE general purpose where the system designer can decide the functionality of each layer in the stack. All the stacks are re-orderable except for the base-MCU stack. QUBE defines a Bus design which makes the design general purpose and gives the system engineer flexibility and control in hardware and software alike.

Power Supply

Power supply for QUBE is through any energy harvesting source. This single source powers the entire stack. The MCU gates the power to each of the layers as required by the state of the program. The MCU is always ON whenever QUBE has enough power.

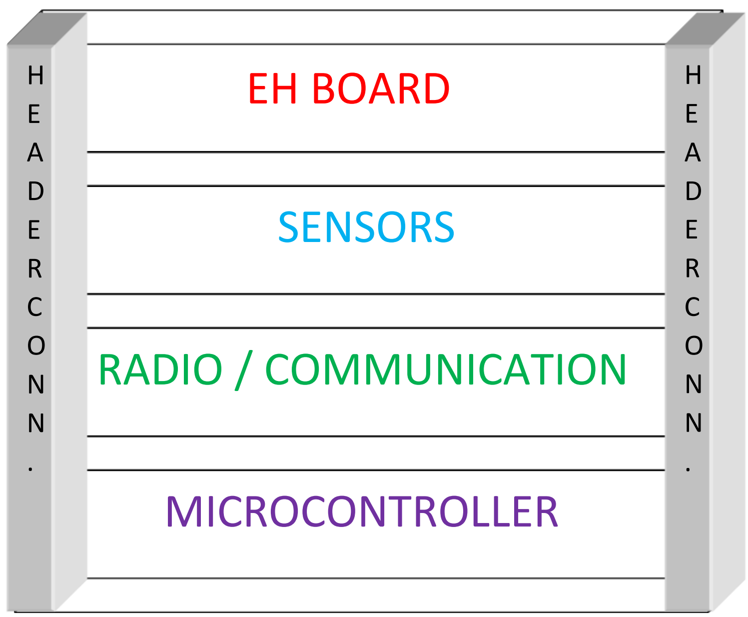


Figure 1: Example of stacked architecture in QUBE

Bus Design

QUBE uses a 40-bit bus which includes SPI, I2C, and UART interfaces along with multiple configurable GPIOs. The detailed configuration of the bus is given in Table 1. The bus is realized as 2 headers on the PCB which provides sufficient mechanical stability to the entire stack.

Communication Interfaces

SPI Interface

The bus supports a maximum of 4 slaves. SPI slave selects are to be tied together using 0-Ohm resistors so as to enable flexibility in system design. This is shown in Figure 2. The SPI Interface is provided by the MCU Board.

Bit	Function	Bit	Function
H101	EH_VDD	H201	GND
H102	GND	H202	SPI_CSx1
H103	Power ENx1	H203	SPI_CSx2
H104	Power ENx2	H204	SPI_CSx3
H105	Power ENx3	H205	SPI_CSx4
H106	Power ENx4	H206	SPI CLK
H107	GPIOx1	H207	SPI MISO
H108	GPIOx2	H208	SPI MOSI
H109	UART RX	H209	I2C SDA
H110	UART TX	H210	I2C SCL
H111	UART CT	H211	GPIOx3
H112	UART RT	H212	GPIOx4
H113	Analog I	H213	Analog III
H114	Analog II	H214	Analog IV
H115	INT I	H215	INT IV
H116	INT II	H216	INT III
H117	Expansion	H217	Expansion
H118	Expansion	H218	Expansion
H119	Expansion	H219	Expansion
H120	Expansion	H220	Expansion

Table 1: QUBE Bus Bit Definition

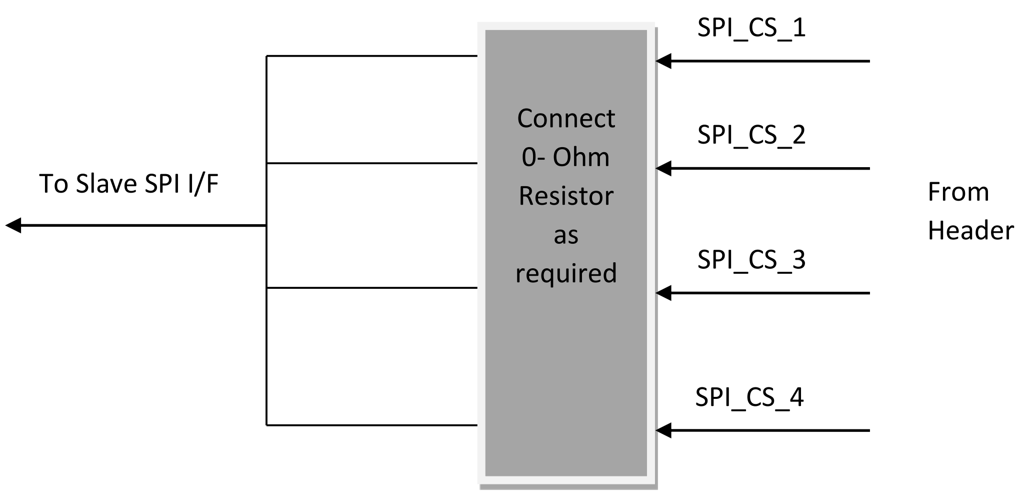


Figure 2: SPI Slave Side Bus I/F.

I2C Interface

A standard I2C interface is provided by the MCU board and 2 bits are dedicated in the bus for the SDA and SCL respectively.

UART Interface

The bus allots 4-bits for UART communication for RX, TX, RT and CT lines. The system designer can use the interface as 2-wire or 4-wire as per design requirements. In the event, it is used as 2-wire, the other 2 pins may be used as GPIOs as long as other layer interactions are taken care of.

Misc. GPIO Functions

Analog Channels

The bus design forces the system designer to allot 4 GPIOs from the MCU exclusively for Analog. This concurs with the general purpose them for QUBE.

Interrupts

The bus design enforces 4 GPIOS with Interrupt capabilities with to be routed from the MCU. The Interrupt priority, if possible, is such that INT 1 > 2 > 3 > 4.

Multiple GPIOs

In addition to the above, the bus brings out the rest of MCU GPIOs. The unused pins, at the end of the headers, are left for the system designer to use as needed and for expansion in future revisions.

Power Signals

Domains and routing

Bits H101 through H106 and H201 are reserved for Power routing and control. Bit H101 supplies power from the Energy Harvester Board to all the layers. The bus supports 4 different power domains in addition to the MCU & Voltage monitoring power-domains. These 4 power domains are gated by bits H103 through H106. 4 GPIOs of the MCU are dedicated as power domain controllers and the power management is done through software.

On each of the stack layers, the power enables are connected as shown in Figure 3. This allows the system designer freedom to choose the power domain at deployment time.

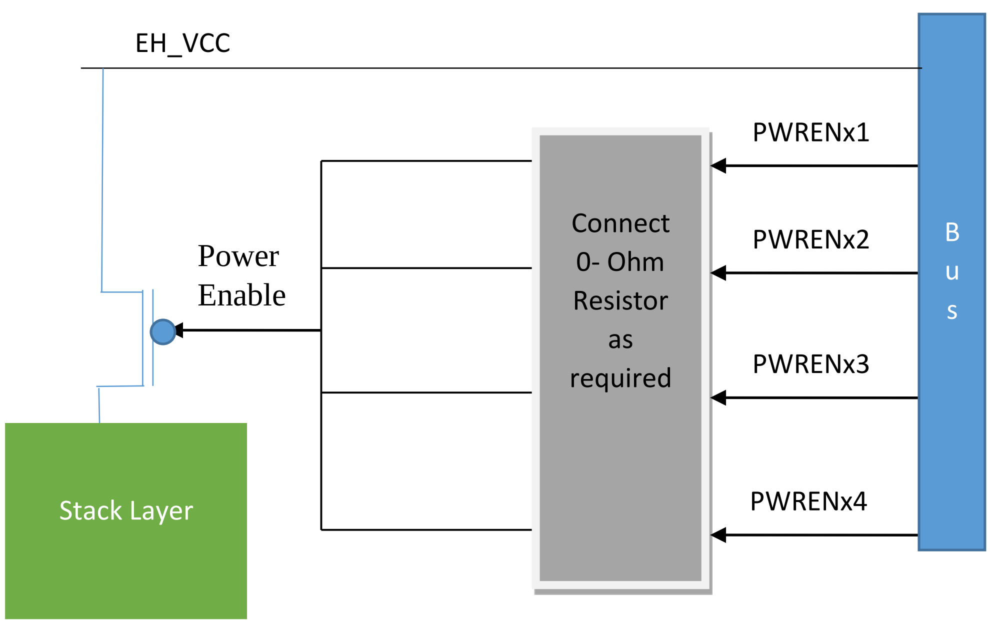


Figure 3: Power Gating Stack Layers

Bus Isolation

To avoid unnecessary interactions of bit-lines with powered-off layers, each bit connected to the layer goes through a switch. The switch is enabled by the same power controller and thus isolates the board from the bus when it is powered off.

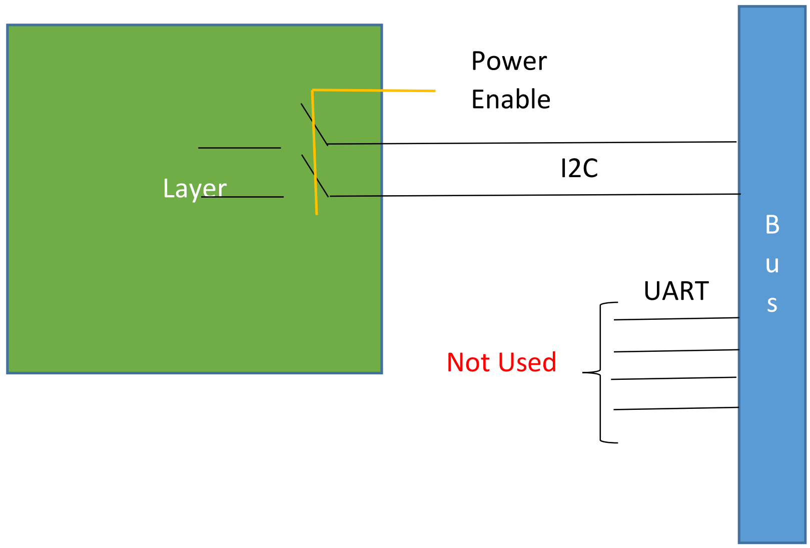


Figure 4: Example of Bus Isolation in a Layer

QUBE System

In this Section, an example QUBE implementation is considered. The system consists of an MCU Board, Radio Board and Sensor Board. The MCU Board becomes the base of the stack. The radio and sensor board could be interchanged and reordered. The block diagram of the entire system is given in Figure 4.

Choice of Components

Microcontroller

The MCU Board consists of a Texas Instruments microcontroller, MSP430FR5739, and a voltage monitoring unit to enable QUICKRECALL. This is the heart of the design which maximizes the utilization of resources for computations.

The MCU uses FRAM as the memory as compared to Flash. The MCU GPIOs are routed to the QUBE Bus as given in Table 2. In particular, the expansion port H217 is used as GPIOx5. Our implementation allows us to demonstrate QUICKRECALL, which is a light-weight checkpointing scheme targeted at transiently powered computers. Table 3 consists of the GPIO connections made specific to this QUBE implementation. The MCU board consists of 2 different footprints for the crystal oscillator which the system designer can choose and solder before deployment.

Voltage Monitoring (Optional)

Voltage monitoring lies at the heart of QUICKRECALL. QUBE uses a 1.8V Voltage reference chip and a comparator which compares the voltage with the supply voltage.

QUICKRECALL Checkpointing V_{Trig} (Optional)

The trigger voltage for check-pointing can be set using resistors R3 through R7 on the MCU board.

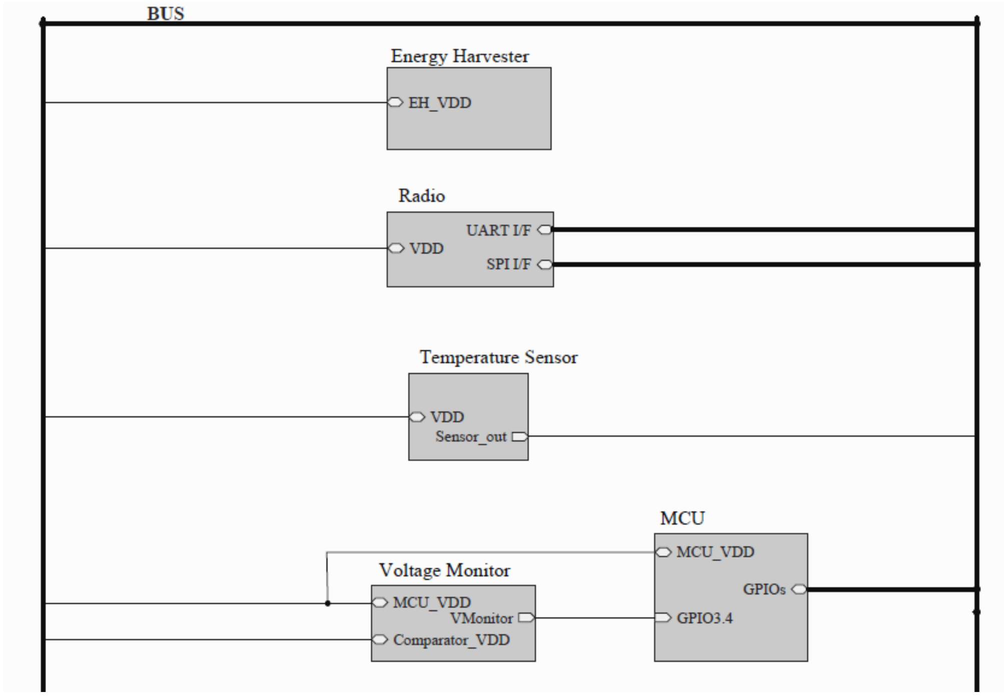


Figure 4: QUBE System

Radio

The radio chosen is a Bluegiga [BLE113](), which is a Bluetooth Low Energy Radio Module. QUBE grants freedom to the system designer in choosing any radio technology. We chose Bluetooth Low Energy due to its low energy and high applicability in embedded systems

Sensor

Finally, the sensor board houses an analog temperature sensor.

GPIO to Header Map			
P10	INT I	P30	SPI CS 2
P11	Analog I	P31	SPI CS 1
P12	Analog II	P32	GPIOx1
P13	Analog III	P33	UART CT
P14	Analog IV	P34	GPIOx2
P15	INT II	P35	INT IV
P16	I2C SDA	P36	INT III
P17	I2C SCL	P37	GPIOx3
P20	UART TX	P40	PWRENx1
P21	UART RX	P41	PWRENx2
P22	UART RT	P42	PWRENx3
P23	SPI CS 4	P43	PWRENx4
P24	SPI CLK	P44	GPIOx4
P25	SPI MOSI	P45	GPIOx5
P26	SPI MISO	P46	Clock

Table 2: MCU GPIO Functions on the Bus

GPIOx	Function
P2.6	SPI SOMI to Radio
P2.5	SPI SIMO to Radio
P2.3	SPI STE to Radio
P2.4	SPI CLK to Radio
P3.2	Radio Software Reset
P2.0	UART Tx to Radio
P2.1	UART Rx to Radio
P2.2	UART RT
P3.3	UART CT
P1.3	Analog In from Temp. Sensor
P3.4	QUICKRECALL Comparator In

Table 3: Interface between components in QUBE

Power Considerations

The QUBE power consumption could be broken down into 2 parts. First, the MCU board, power gating circuitry, and bus isolation logic across layers are always ON. These make up the minimum constant power required for QUBE to function. The rest are the individual power requirements for the Radio & Sensor boards when they are required to function. The following table captures the power break-down in terms of current.

#	Power Domains	Worst case Current Consumption
0	Always ON Components	820uA
1	Radio	270uA , Tx @ 0dbm 18mA
2	Sensor	6uA
	Total Current Consumed (all ON)	~1.2mA

Table 4: Break-down of current consumption in different power domains

Programming

The programming is done through JTAG interface which resides on the bottom side of the MCU board. The current JTAG Interface uses a 4-wire JTAG interface. It is possible to power the entire stack via the JTAG Interface via a Jumper on the JTAG header.

Power Measurement

This version of QUBE includes current measurement resistors. The voltages of individual power domains are brought out as shown in the below Table.

Bus Bit	Power Domain
H117	Sensor
H118	Comparator
H119	MSP430
H120	Radio

Table 5: Power measurement pins

Mechanical Specifications

Each Board is of size 25.0mm x 25.0mm. This is chosen so as to allow expansions in future revisions without increasing the form-factor. The base board has provision for double sided tape to be attached. The inter board spacing is ~3.5mm and thus, the total height of the stack is around 20mm.

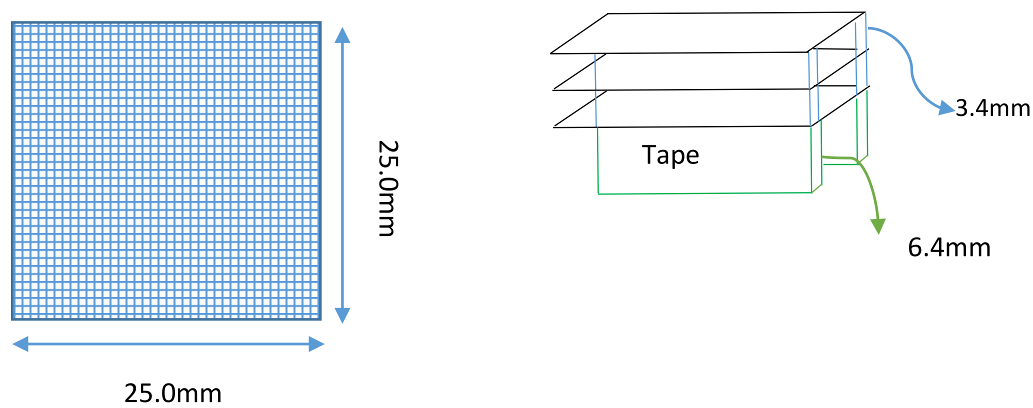
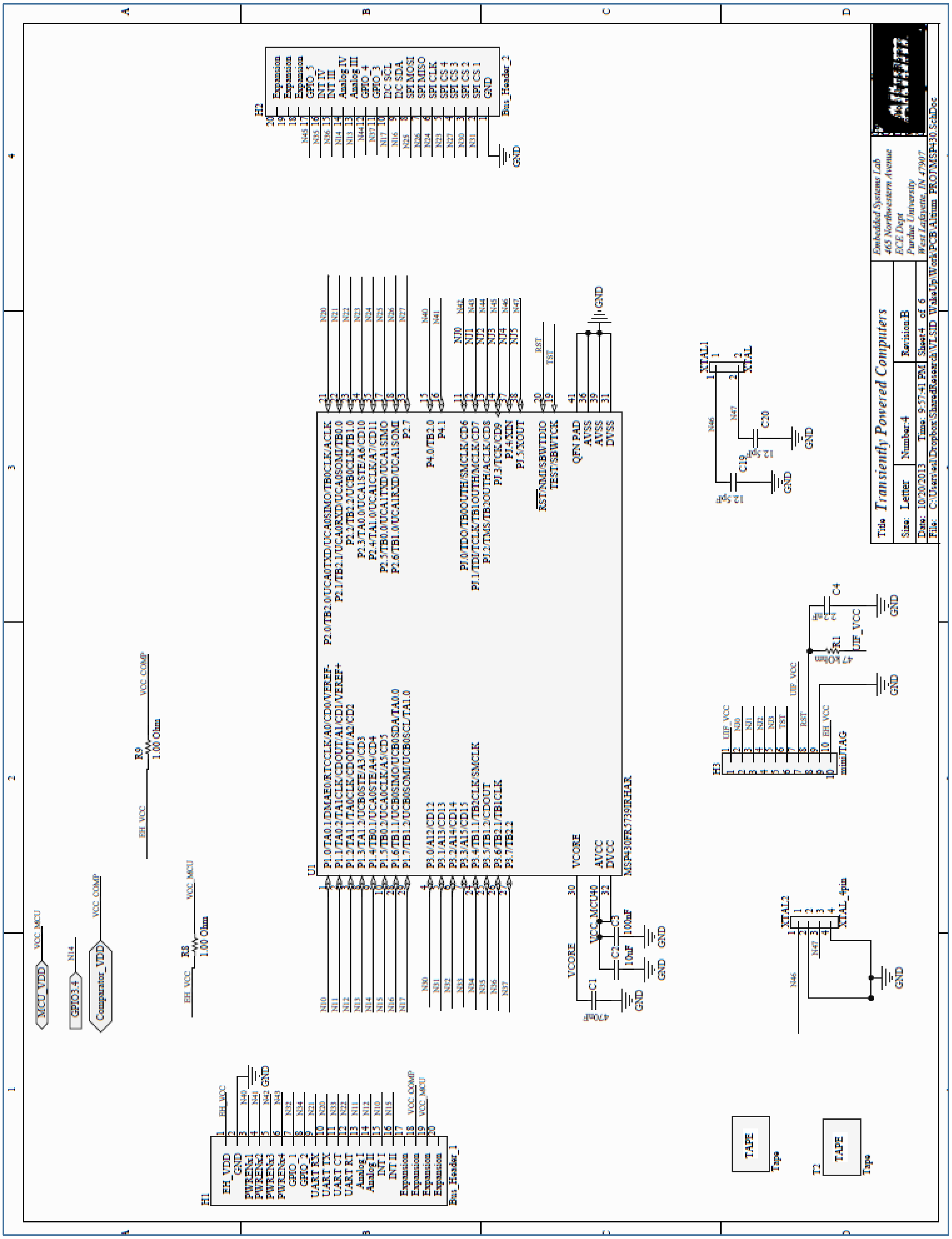


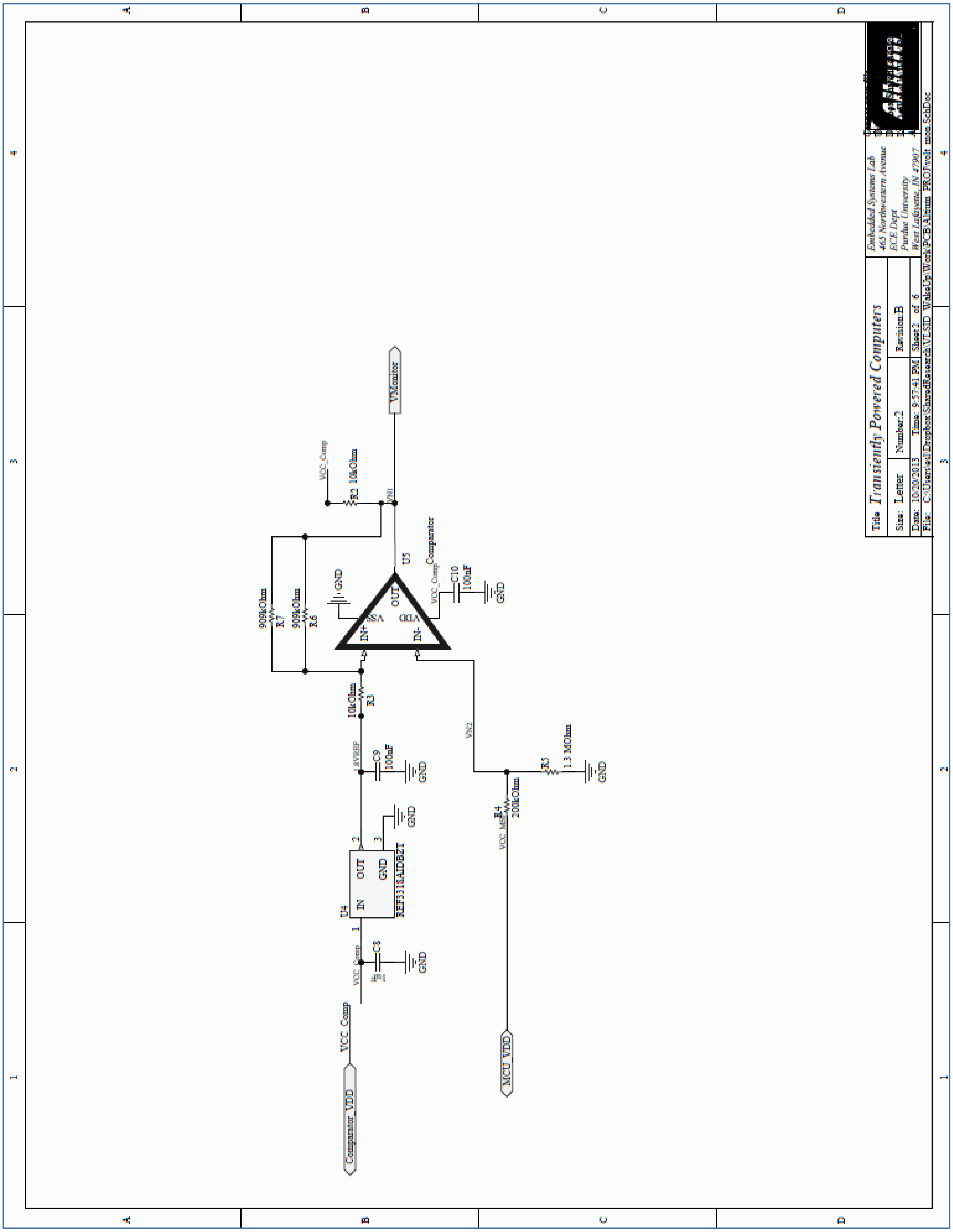
Figure 5: QUBE Stack dimensions

Schematics

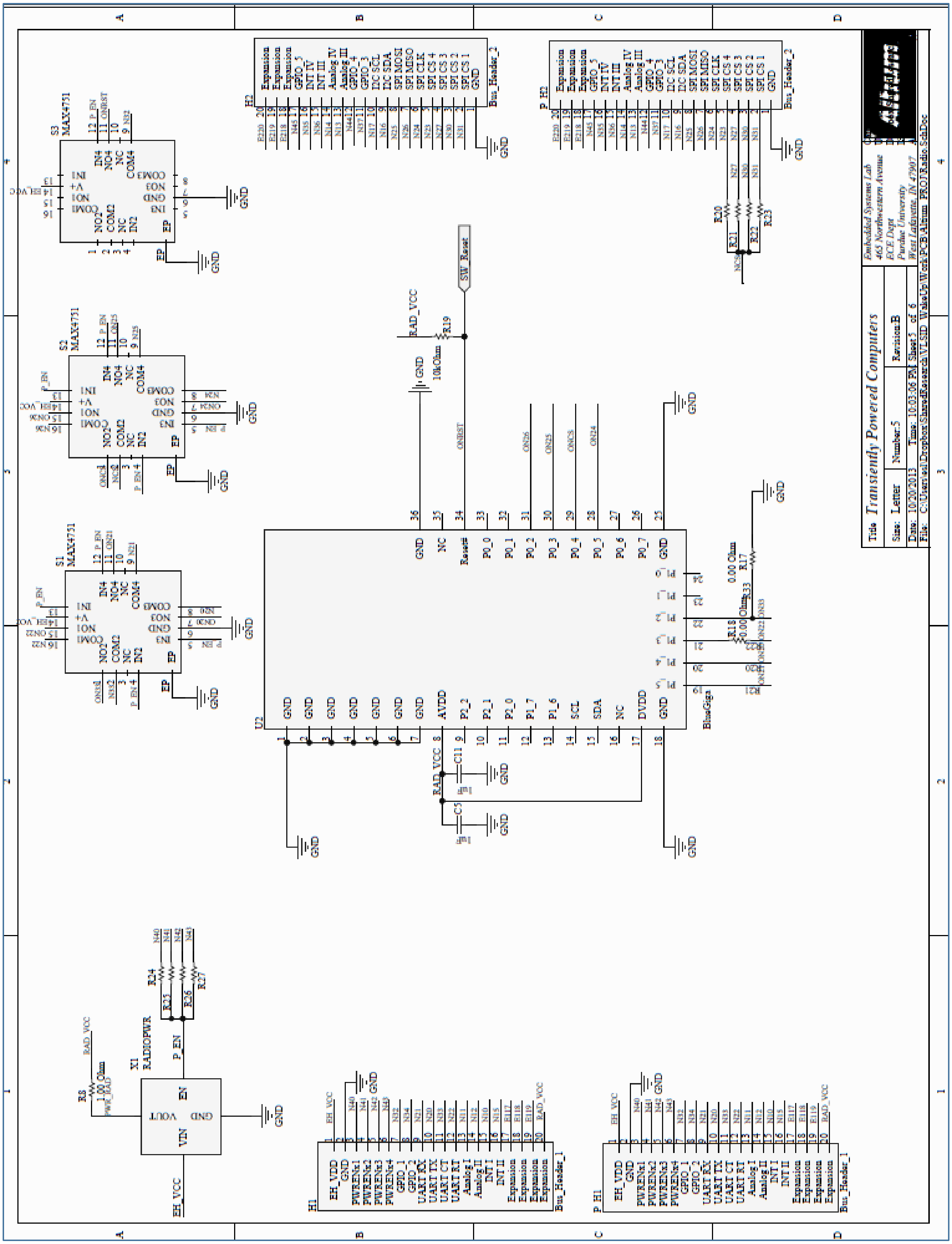
Microcontroller



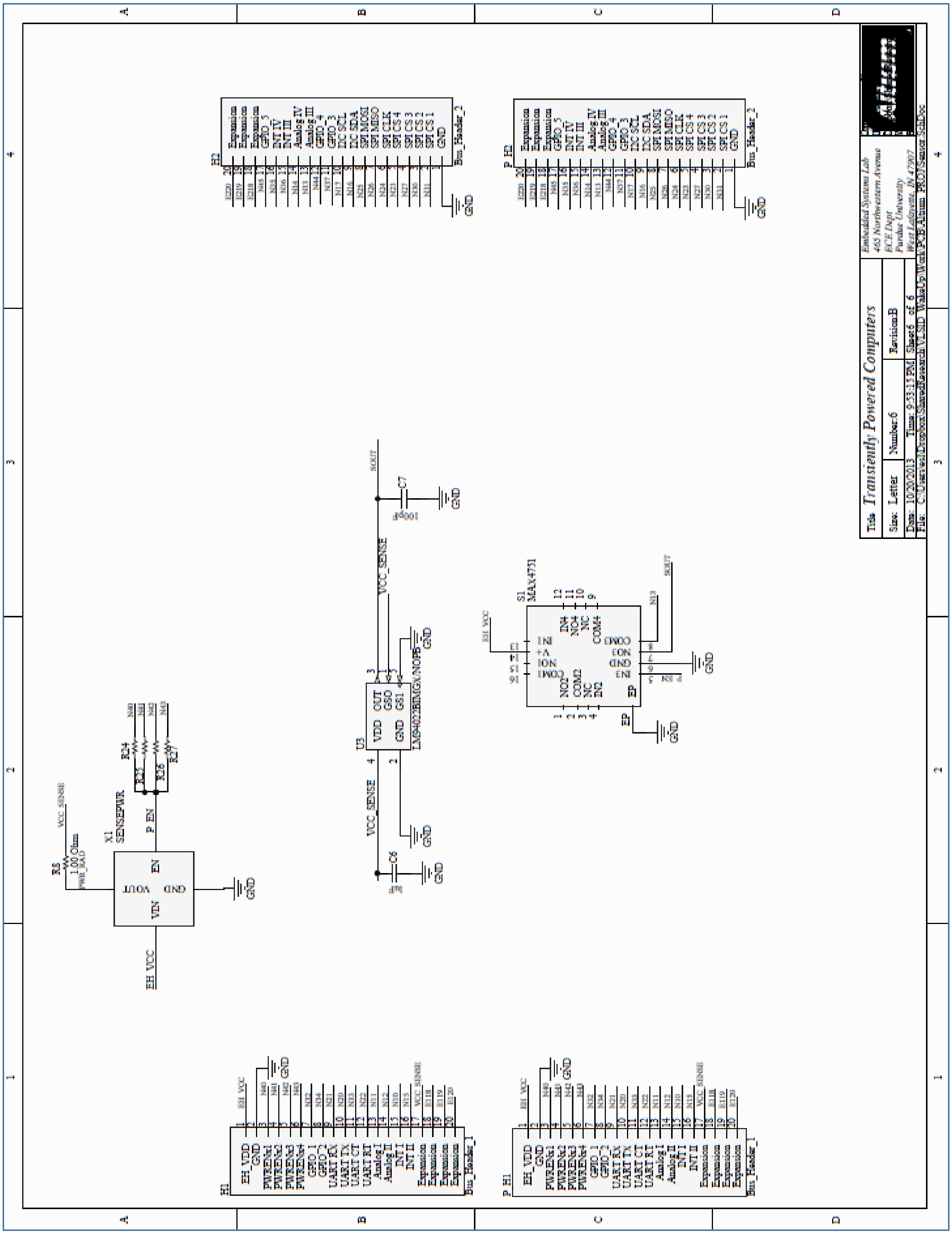
Voltage Monitor



Radio

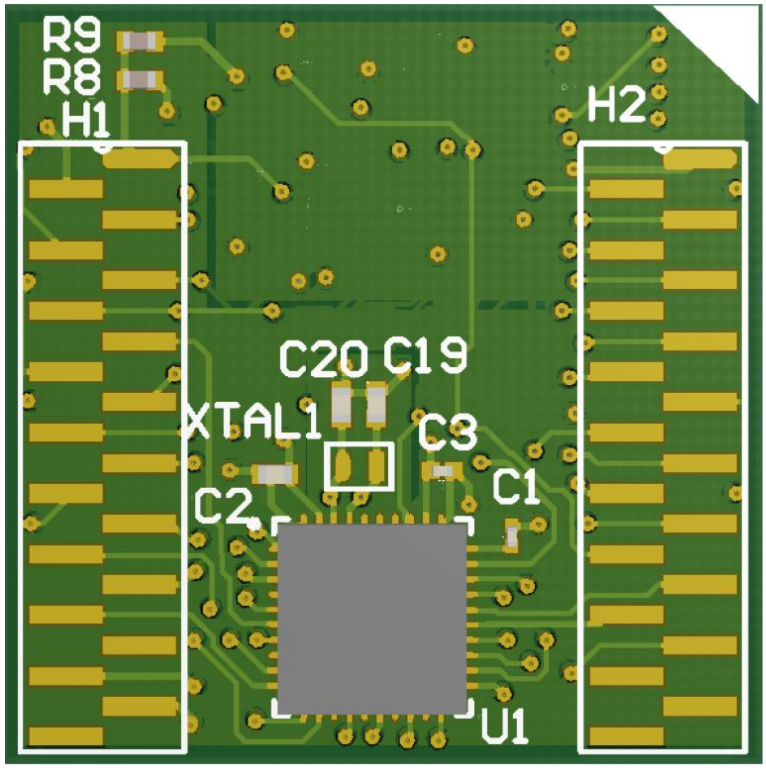


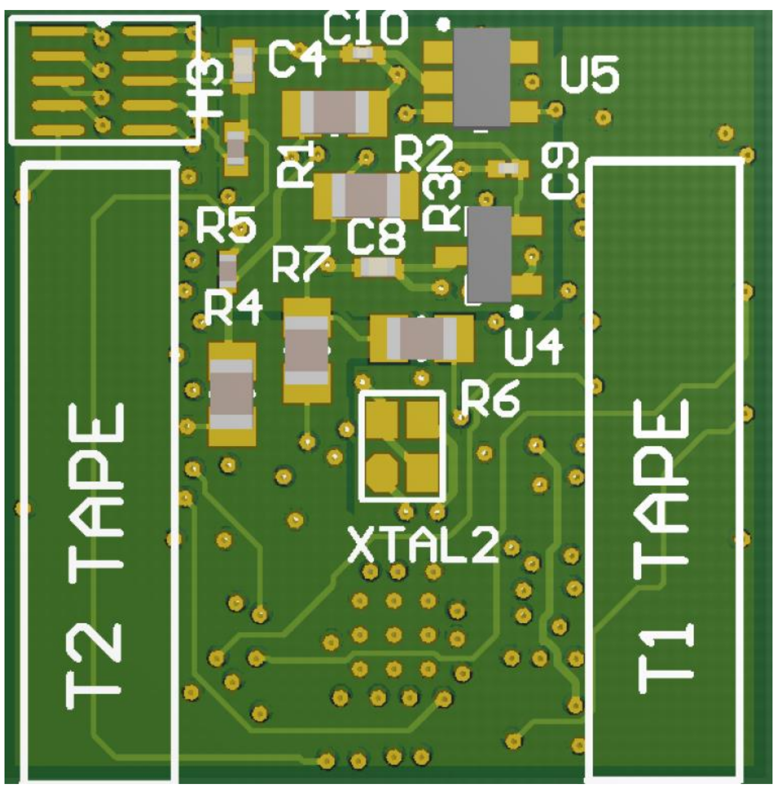
Sensor



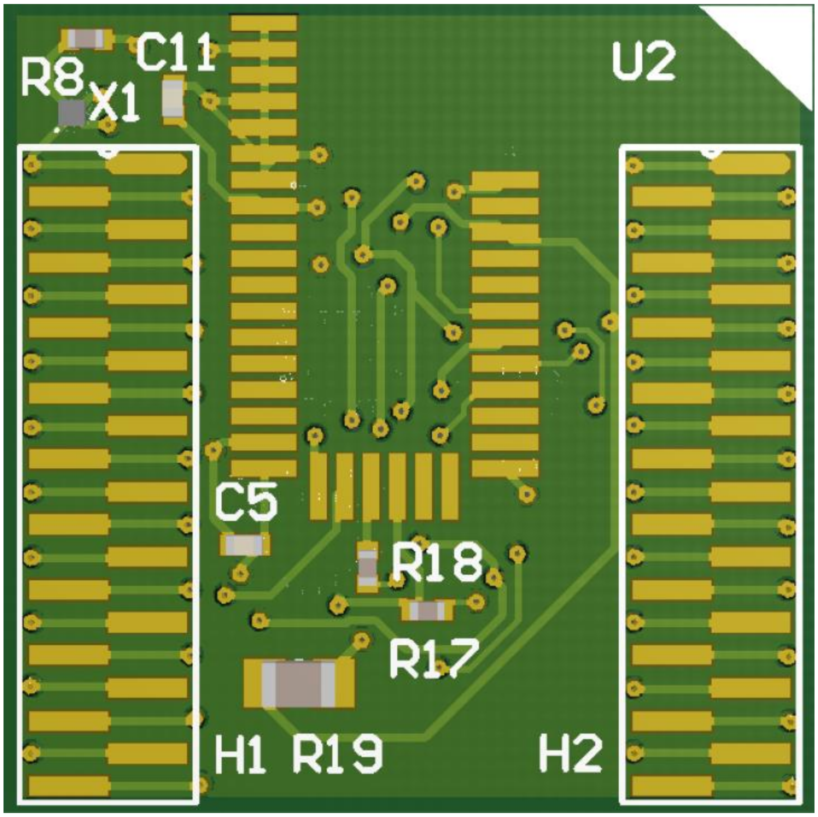
PCBs

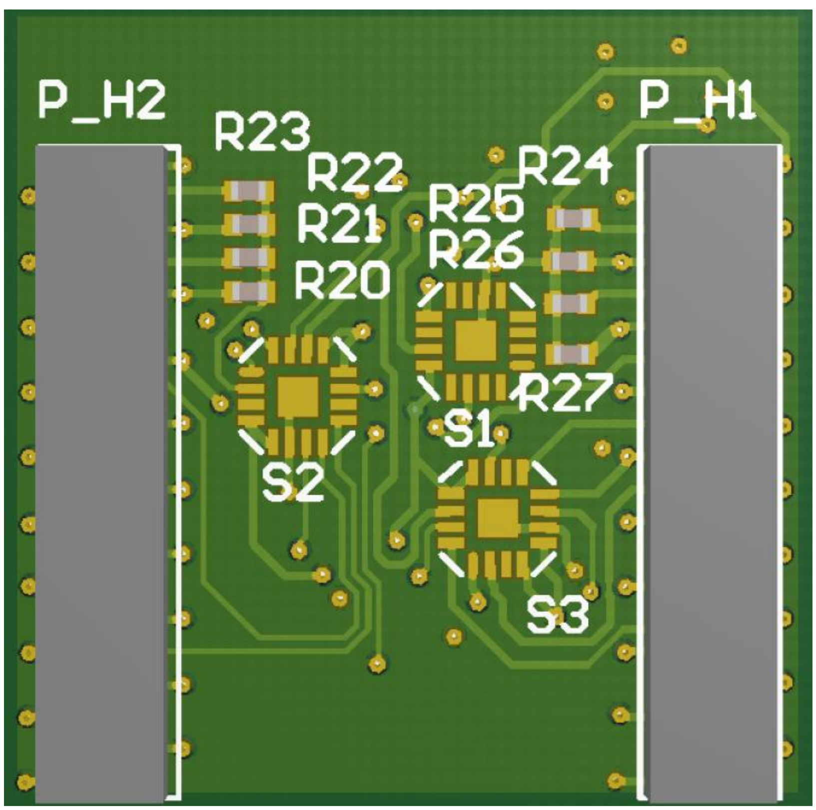
Microcontroller PCB





Radio PCB


R8
C11
X1
U2
C5
R18
R17
H1
R19
H2


P_H2
P_H1
R23
R22
R24
R21
R25
R26
R20
R27
S1
S2
S3

Sensor PCB