Home Healthcare Assistant

GROUP 8

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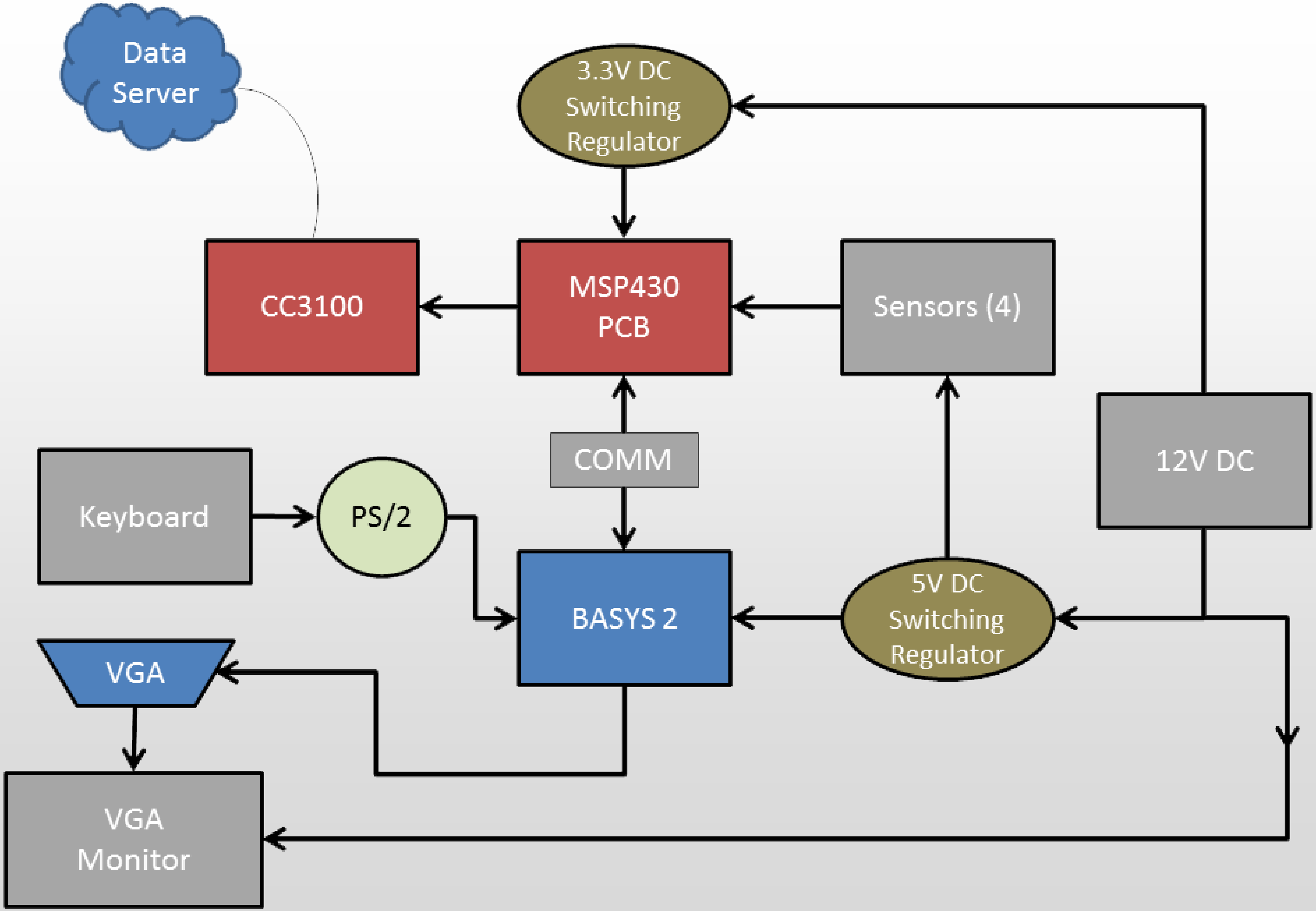
Project Motivation and Goals

- Create an all-inclusive device that will read in multiple types of vitals
- Transmit readings to a central database
- Explore and gain experience in working within our areas of interest for personal and career growth
- Gain experience in integrating different workloads from different engineering disciplines.

HHA Overview



Requirements

MCU:

- 22 GPIO ports
- Wi-Fi ready and enabled

FPGA:

- PS/2 and VGA interface
- Stable clock signal
- External power source

Software:

- 128KB Flash, 8KB RAM on MCU

User Interface:

- Readable at 4’ with 20/20 vision
- “Yes/No” input & numeric data entry

Physical Limitations:

- Must not take up more than half of the available space on a standard nightstand*

I/O:

- 10-button keypad
- 7” monitor
- 4 vitals sensors

*approx 18” x 16” base

Sensor Specifications

Weight Scale

- Accurately display the weight of a person up to 350 pounds

Pulse Oximeter (Blood Oxygen)

- Follow Beer-Lambert's Law
  - With 5% error

Body Temperature

- Read temperatures from 95 to 101°F
  - With 4% error

Main Processing Chip Choices

MSP430G2553 MCU

- 20 GPIO pins
- Low power
- Schematics readily available

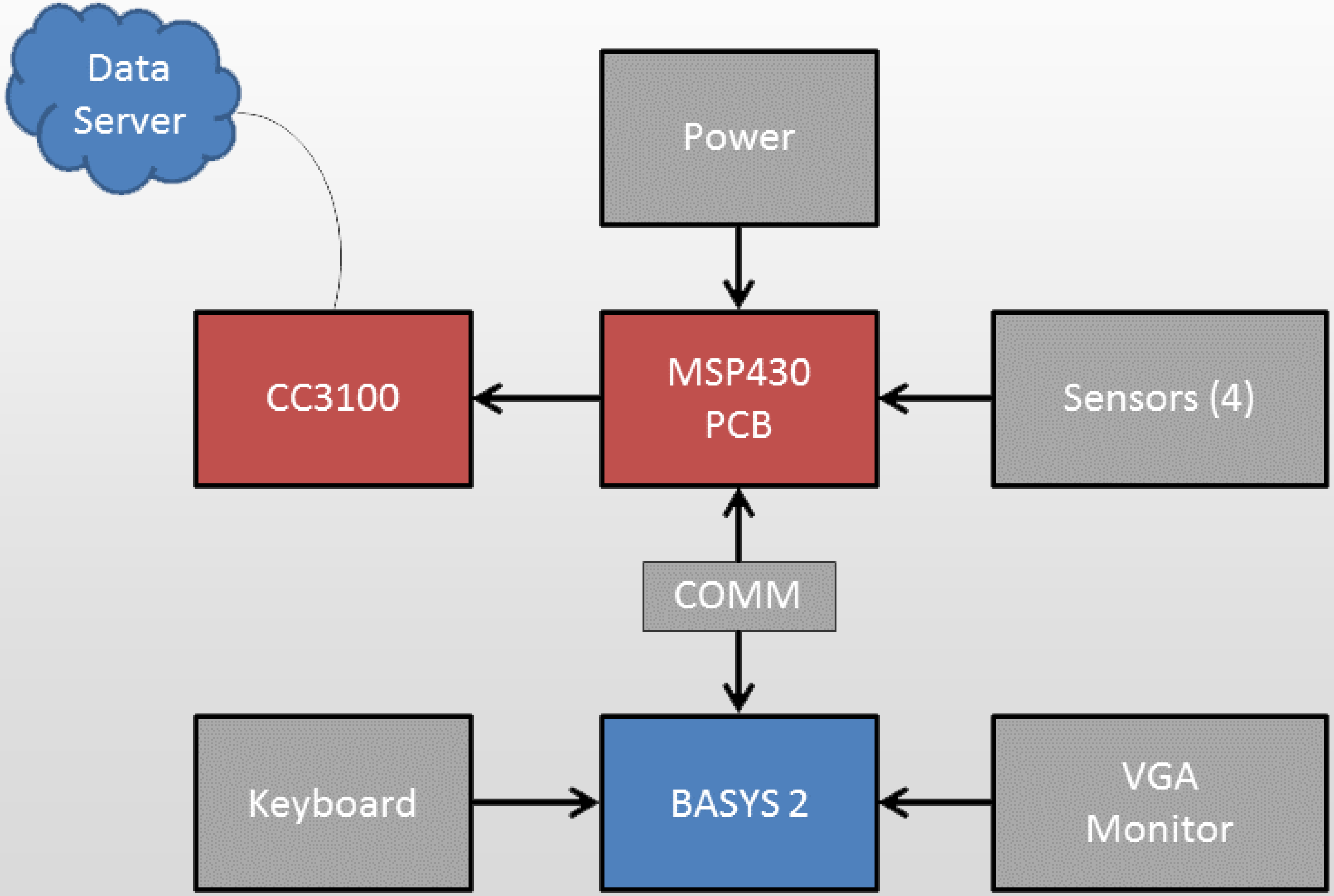
MSP430F5529 MCU

- 63 GPIO pins
- Low power
- Schematics readily available

Raspberry Pi 2

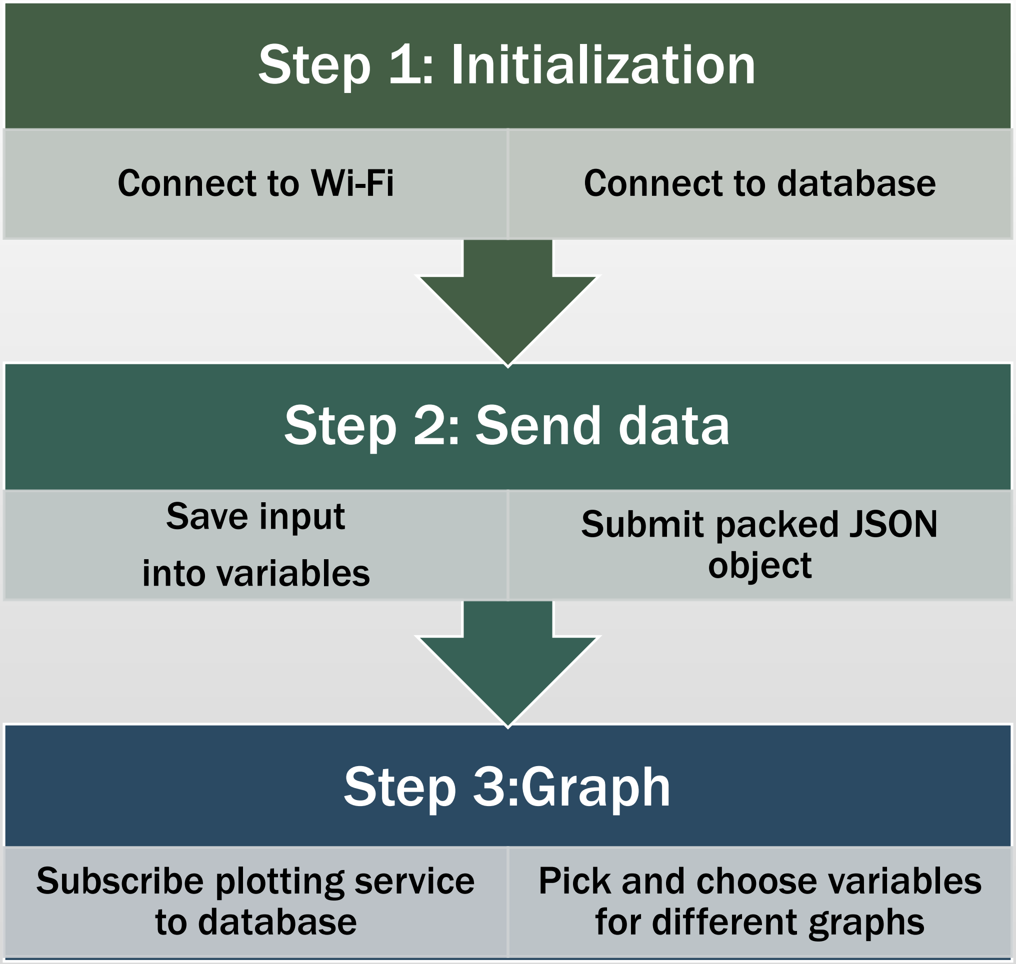
- Built-in Wireless module and USB ports
- Difficult to implement on PCB
- 26 GPIO

MSP430 PCB Connections



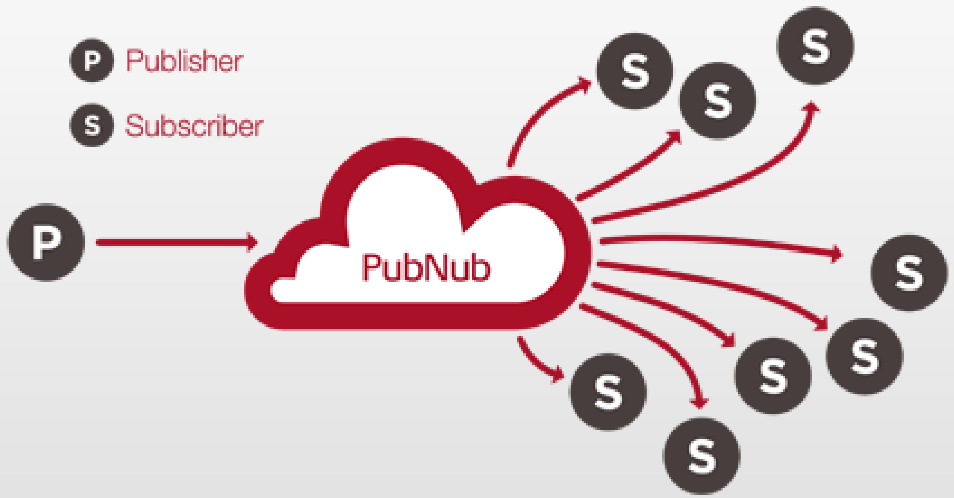
Connection to Database

- CC3100 Wi-Fi authenticates with wireless network and data server
- MCU uploads queries via JSON objects in a predictable fashion



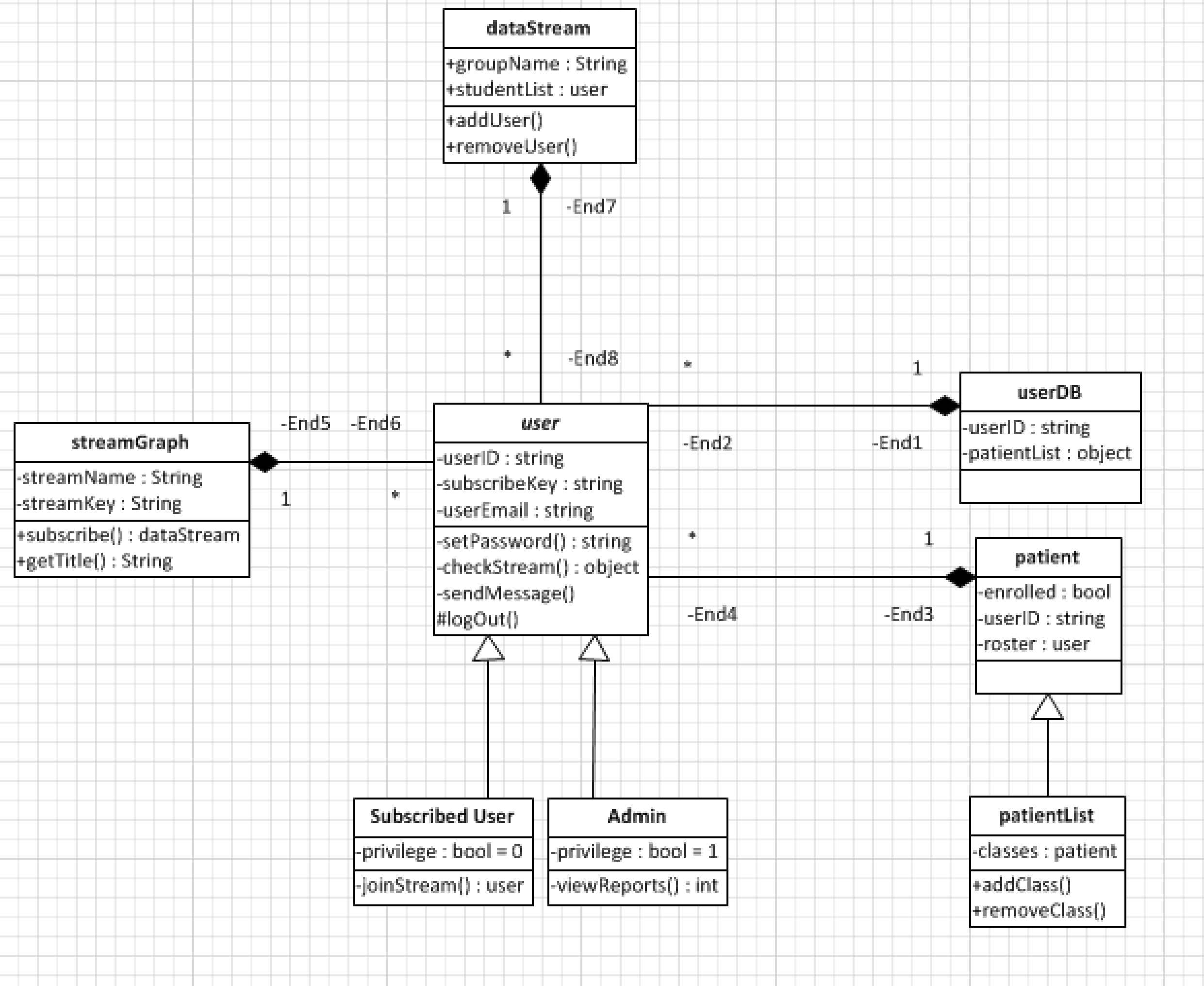
IoT Host – PubNub

- Cloud based storage platform
  - Mobile accessible
- Compliant with **HIPAA**, SOX, Data Protection Directive, and more
- 1 mo. Premium Features Trial
- Published data easily subscribable
  - Public/private visibility

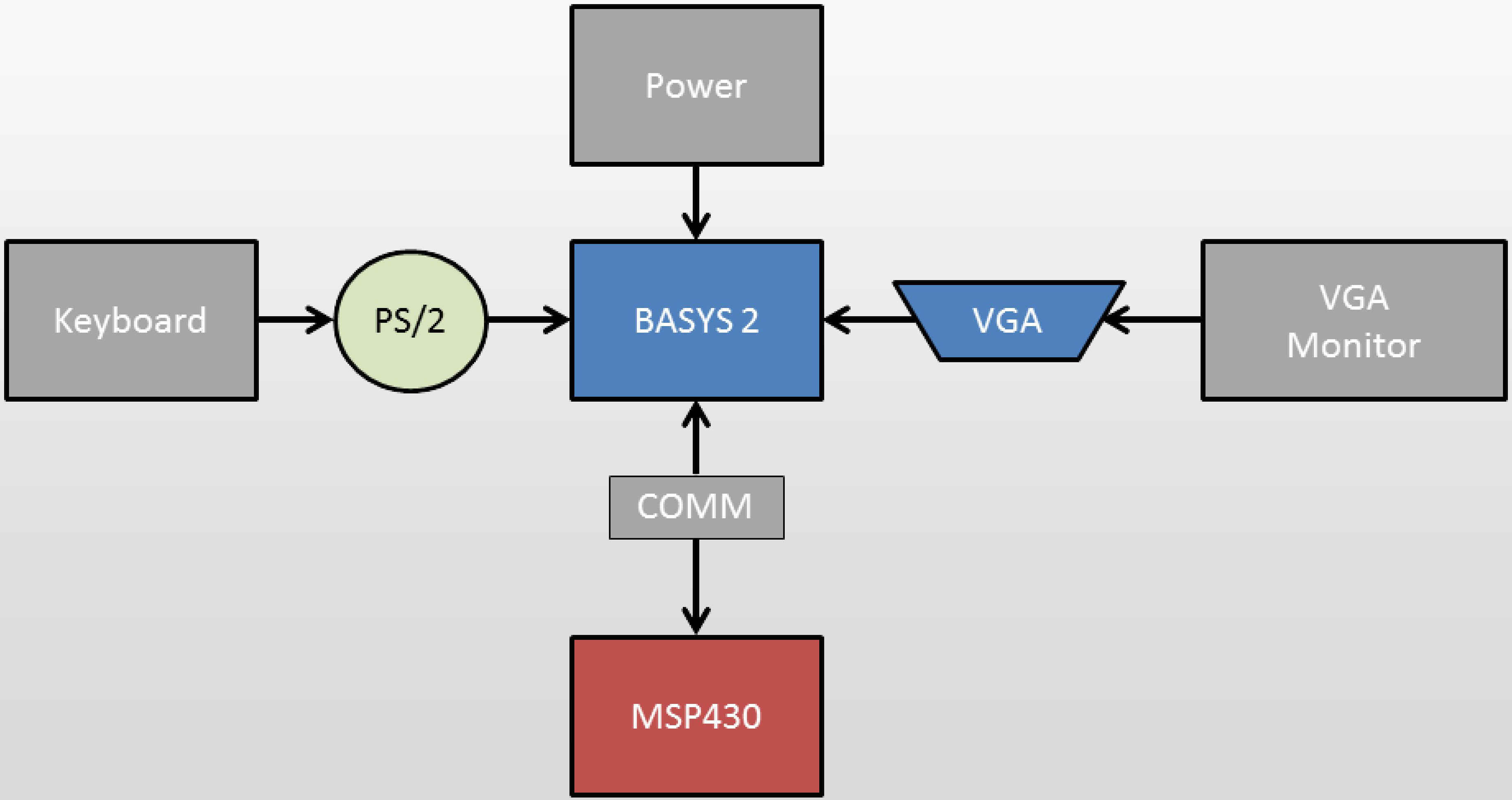


Pubnub IoT Chart by Pubnub (Fair Use)

Database Class Diagram



BASYS 2 Connections



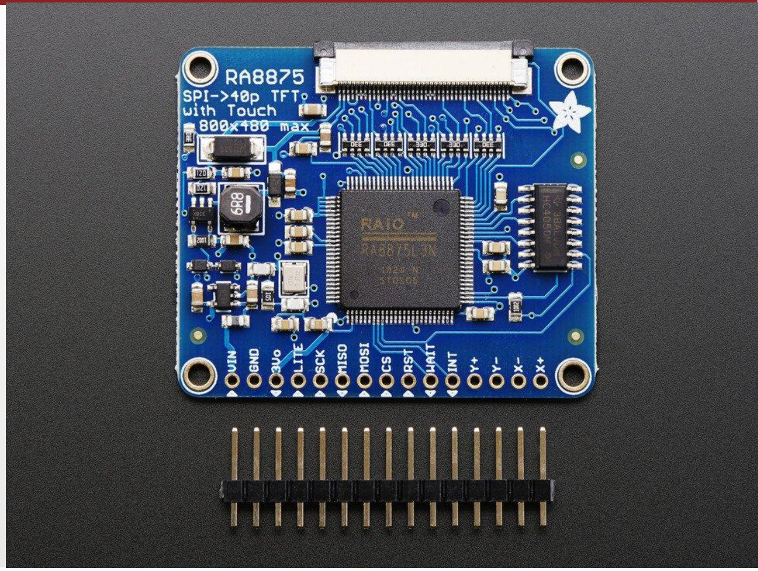
User Interface

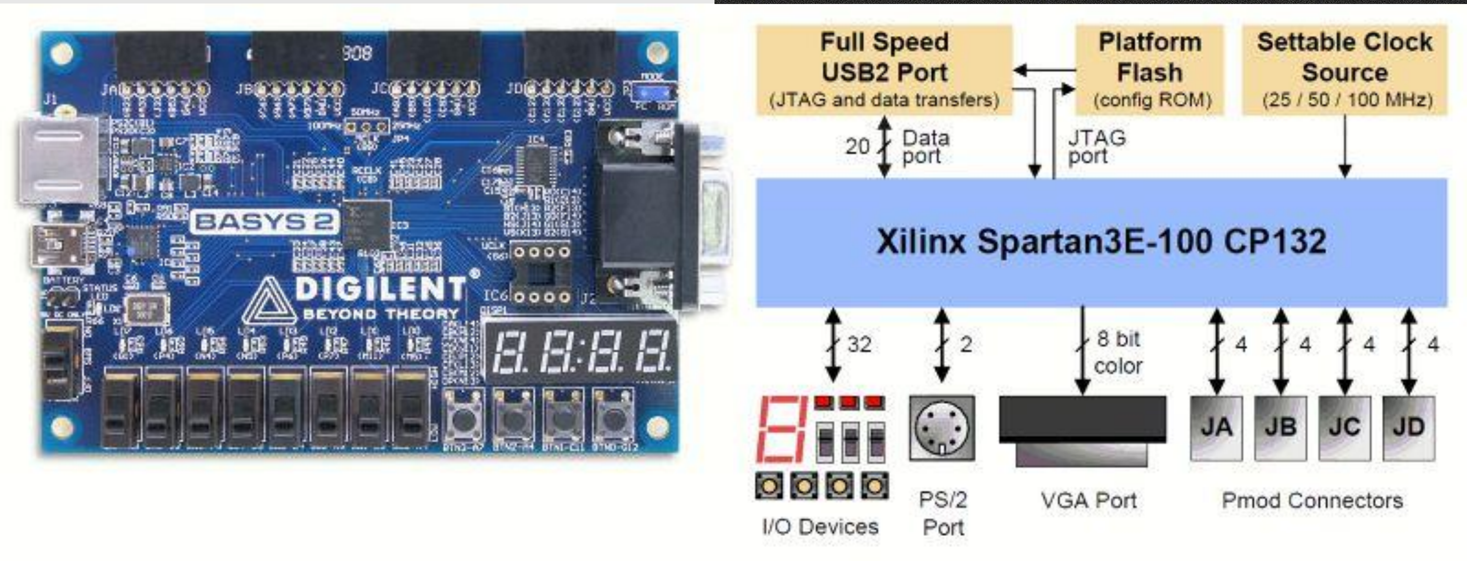
- Requirements: Present questionnaire, provide sensor operation instructions and feedback to the user. Obtain user responses.
- FPGA experience was desired
- Possible alternative approaches:

  - VGA control board with SPI connection to MCU

  - High performance MCU with SRAM chip for frame buffering
- Digilent BASYS 2 already owned

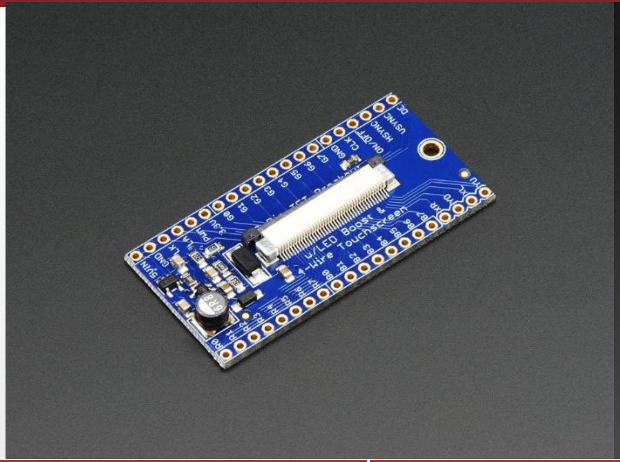
  - PS/2 port - VGA port
- BASYS 2 issue: internal clock jitter
- Solution: External crystal oscillator

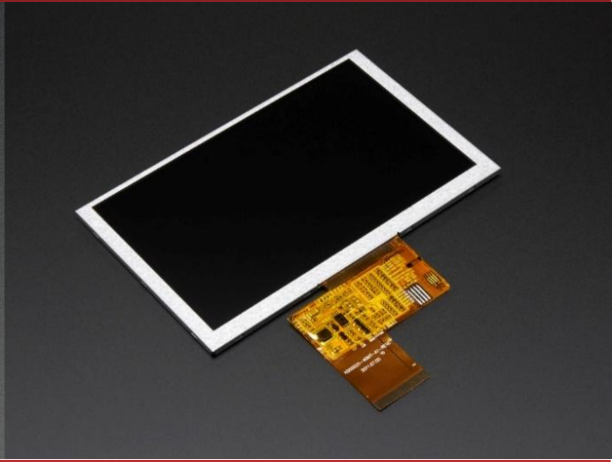




Monitor selection

- Requirements: 7” display for comfortable viewing 4 ft from the screen
- 640x480 resolution VGA signals supported at 60 Hz
- Relatively low power consumption





7” TFT VGA monitor	7” 40-pin TFT LCD screen
+ Standard VGA connector	- Requires breakout board
+ Adjustable monitor stand	- Mounting required/ fixed viewing angle
- ~8W power consumption	+ ~4W consumption
- Bulky	- Requires 2 power supplies
+ Wide input voltage range from 9 – 32V	- Requires power-on sequence coding
$45	$37.50 + $10

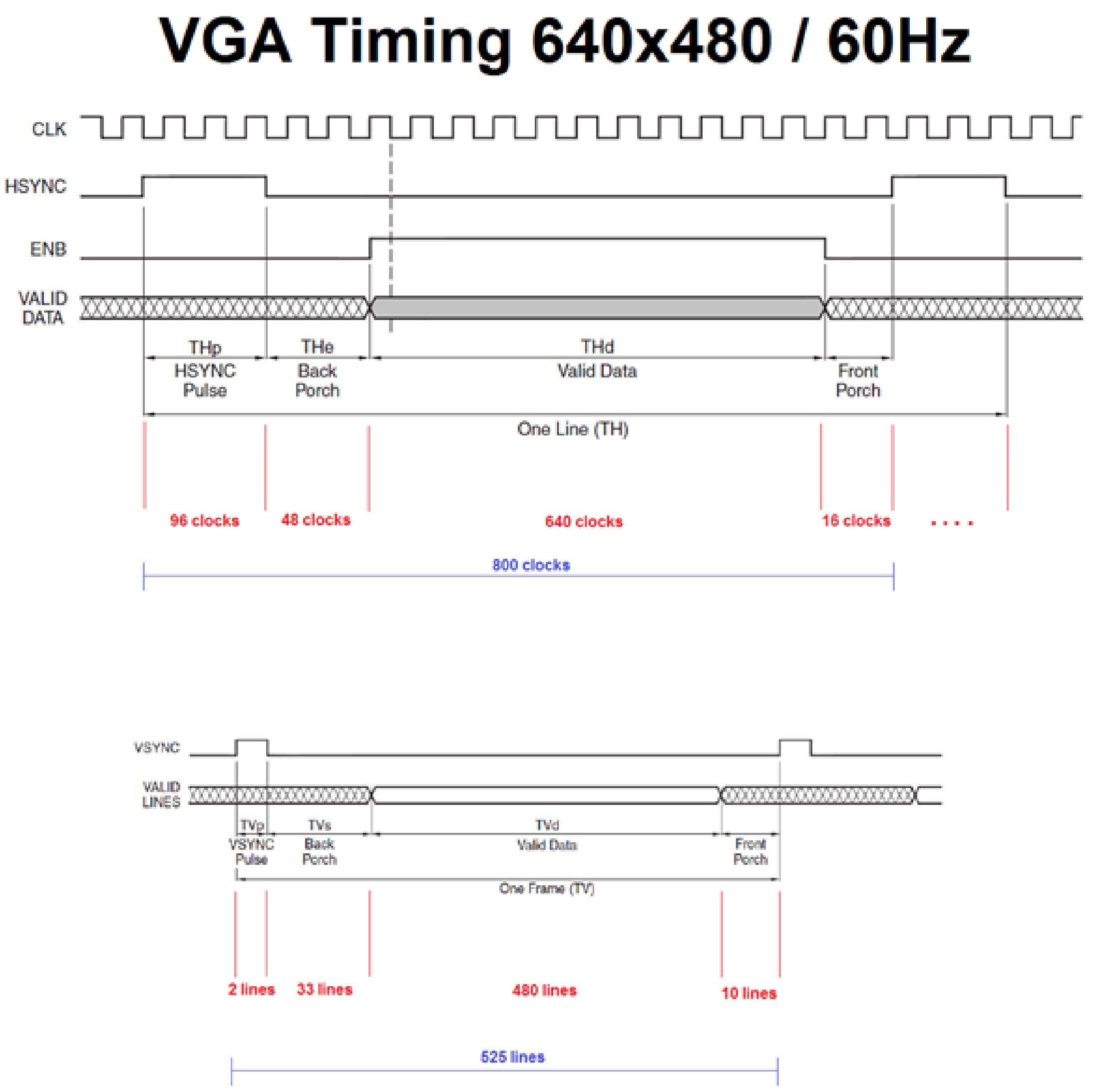
VGA Standard

- Pixel clock rate at 25.175 (~25) MHz generated using a clock divider from the 100 MHz external oscillator

- HSYNC and VSYNC signals used to govern the active region for RGB data transmission

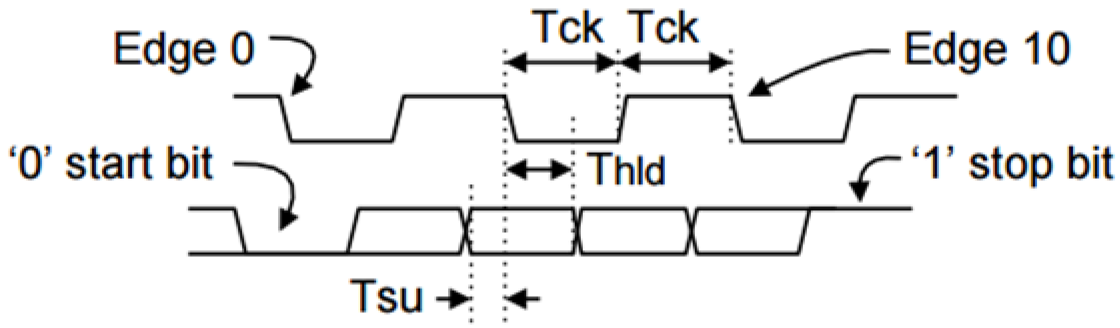
- Preset values in RGB registers used to generate a static background color, refreshed at 60 Hz

- Implemented in Verilog for the 8-bit VGA output of the BASYS 2



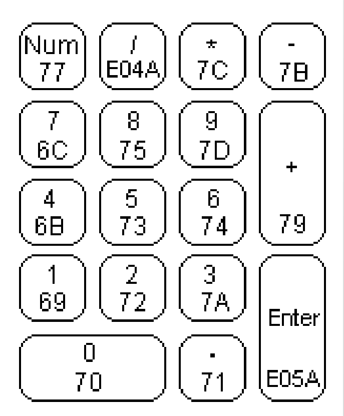
PS/2 Standard and keypad choice

- 2 wire interface – keypad clock & data, sent simultaneously
- Start bit, 8 bits of data, parity bit, stop bit
- Each key has a unique 8-bit scan code
- Non-standard vs standard keypad layout
- Standard layout more robust
- Debouncing circuit implemented
- Both priced at $9



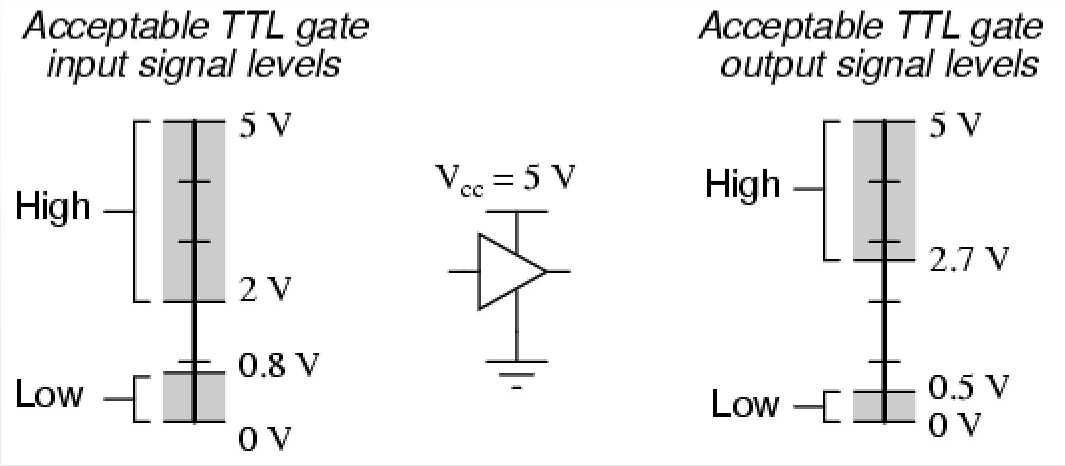
Symbol	Parameter	Min	Max
T_{CK}	Clock time	30us	50us
T_{SU}	Data-to-clock setup time	5us	25us
T_{HLD}	Clock-to-data hold time	5us	25us

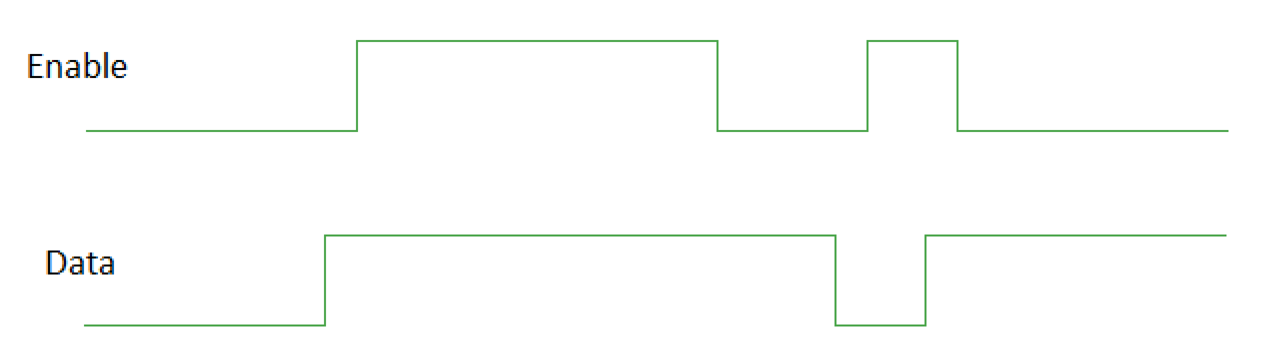
PS/2 signal timing



FPGA/ MCU communication

- No pins preconfigured for UART on FPGA
- Created custom protocol for communication at indeterminate instances in time
- Data line and an “enable” line
- Receiver polls enable line at its own clock rate and latches on to data value at both the positive and negative edges of the enable line
- Example data transfer: 1101
- Method works because enable line will not toggle twice faster than clock rate of either MCU (25 MHz) or FPGA (100 MHz)
- Aiming to implement 4+ parallel data lines





Verilog memory module

- Contains 32x32 pixel bitmaps of all alphanumeric characters and some special characters, all in one column
- 8x8 and 16x16 bitmaps were tested and found to be too small to meet project requirements
- ROM file measures 32x1282 bits
- Given address of the first pixel in a row, the module outputs the 32 pixel values for that row
- RGB signals are all assigned zero or max values based on pixel bitmaps to display white text characters

```
00000000000000000000000000000000,
00000000000000000000000000000000,
00001111111100000000111111110000,
00001111111100000000111111110000,
00001111111100000000111111110000,
00001111111100000000111111110000,
00001111111100001111111100000000,
00001111111100001111111100000000,
00001111111100001111111100000000,
00001111111100001111111100000000,
00001111111111111111000000000000,
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00000000000000000000000000000000,
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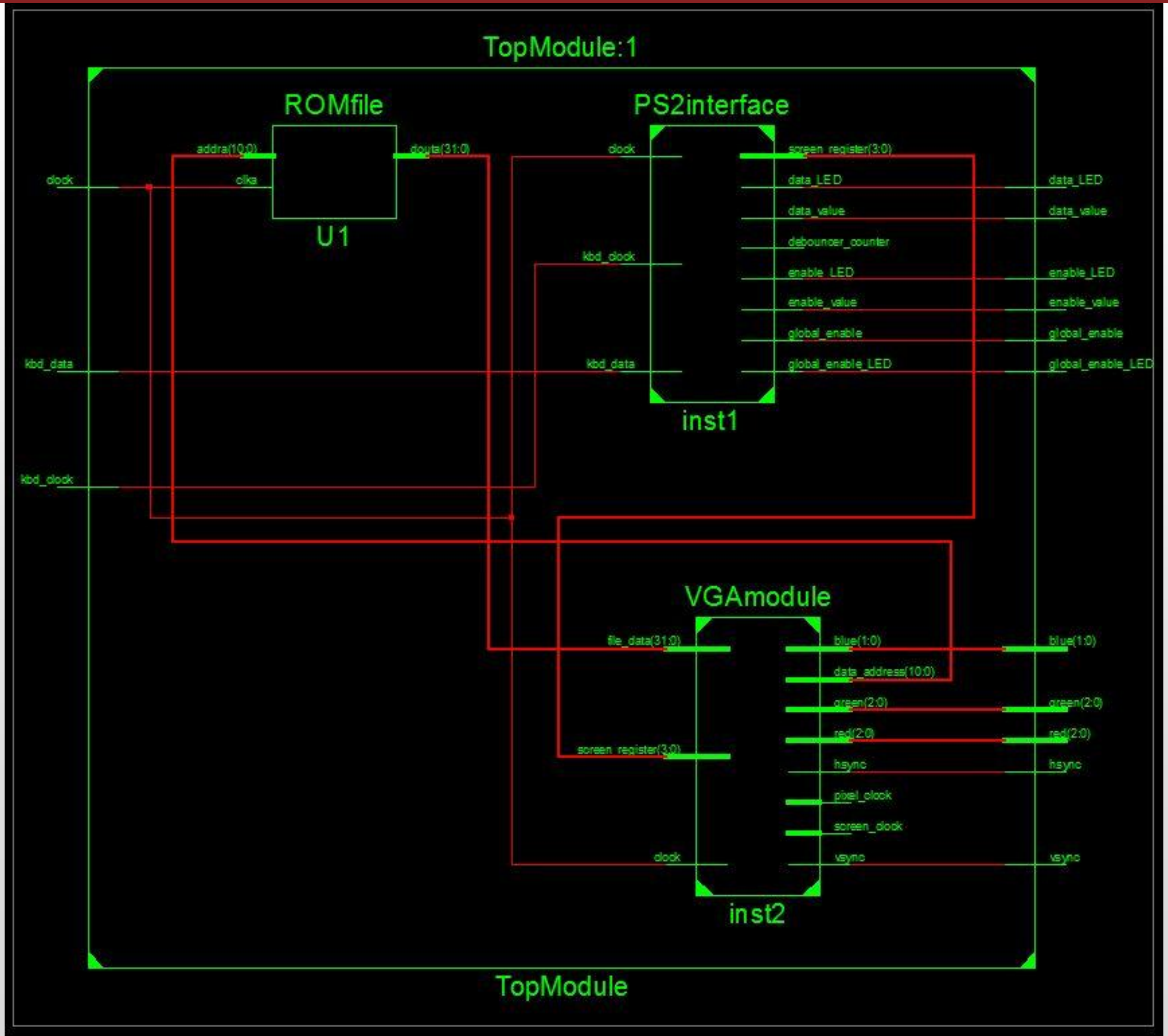
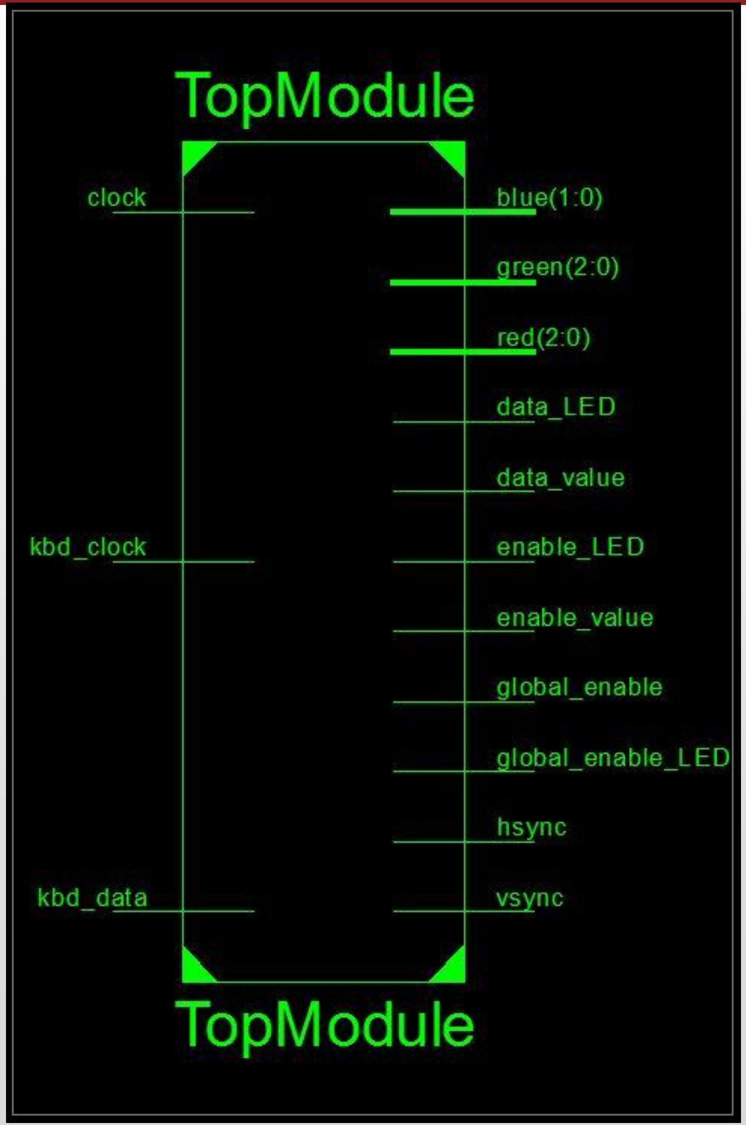
Verilog Register-Transfer Level (RTL) schematics





Distribution of Body Heat

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- Four common locations to measure body temperature are the mouth, ear, armpit, and rectum.
- From the four options, measuring temperature orally is the most convenient for our project.
- Since we are measuring body temp. orally, the material used to house the sensor has to be waterproof, water-resistant, and non-toxic. The material has to be thermally conductive.
- Even though all medical establishments agree that 98.6°F is the average body temperature, they seem to disagree in what temperature a fever and the onset of hypothermia should be.
- HHA safe temperature range:
  - Fever: 38°C = 100.4°F
  - Hypothermia: 35°C = 95°F

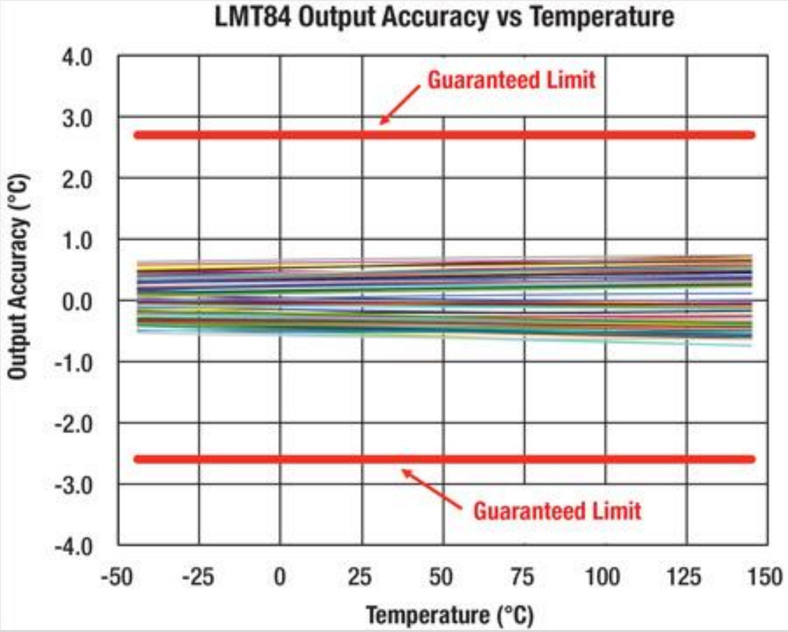
Temperature Sensors

LMT Series

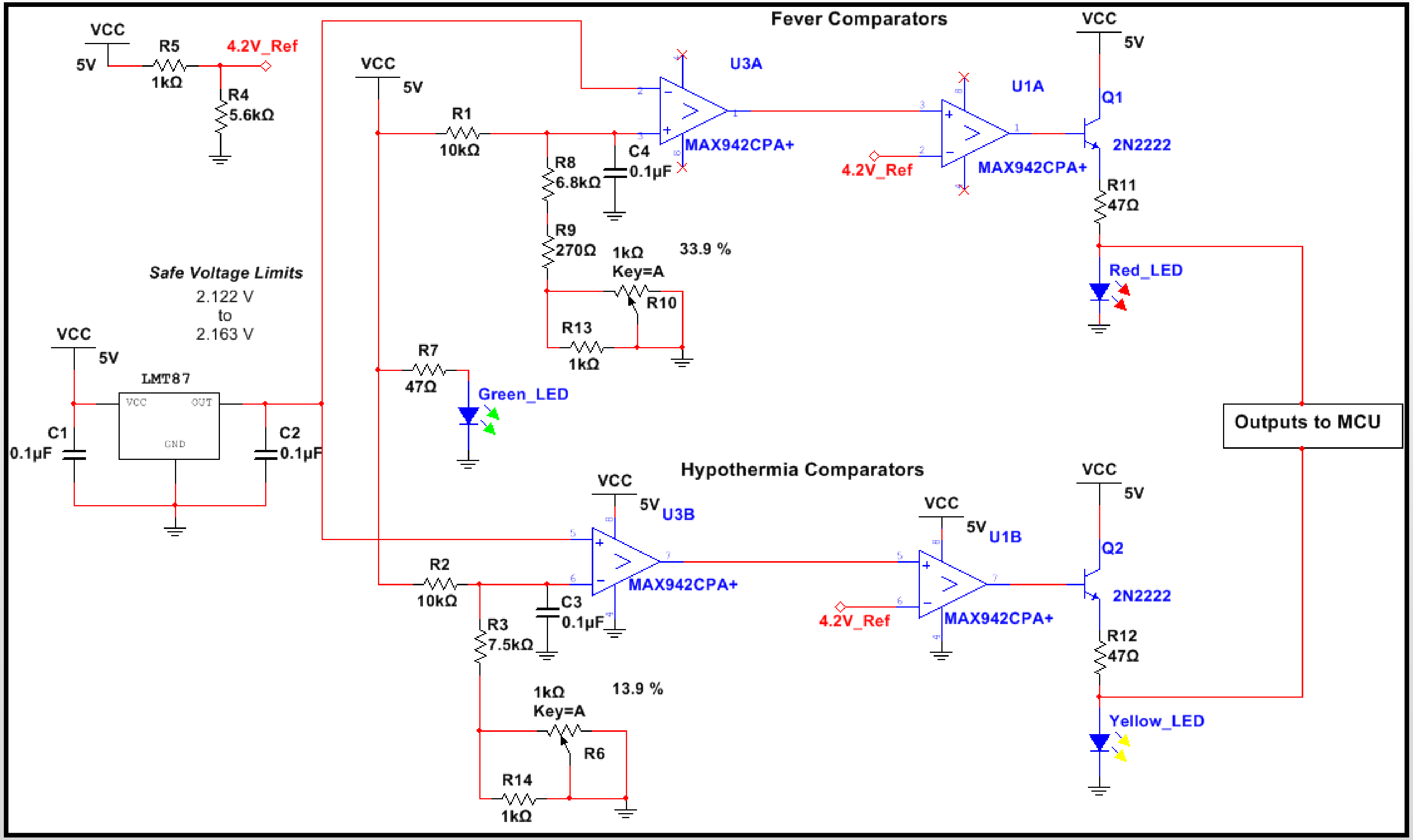
- Typical values are more accurate ~ 0.2°C vs LMs 0.3°C
- Texas Instruments will be coming out this year with a brand-new temperature sensor, the LMT70.
- The LMT70 will have a range of inaccuracy between min and max around 0.3°C and a typical 0.05°C. It will also be recommended for medical applications.
- For now, the HHA will be using the LMT87 because it provides better accuracy for the temperature ranges needed for the HHA thermometer.

LM Series

- Smaller range of inaccuracy between min and max values
~ 1.0°C vs LMTs 1.5°C
- Few cents cheaper



Body Temperature Schematic



MAX942CPA+ Comparator:

- Internal hysterisis (1 – 3 mV) to detect slow moving input signals and have clean output signals
- Low input offset voltage (Vio)
- Other comparators tested:
  TLC3702
  LM393NG

- LED turn-on voltage is greater than $V_{cc\_MSP430}/2$ required for MSP430 to read input "high" and less than V_{cc_MSP430} to avoid damage.
- 2N2222 BJTs work as a current amplifier needed to light the LEDs.

Pulse Oximeter Overall System

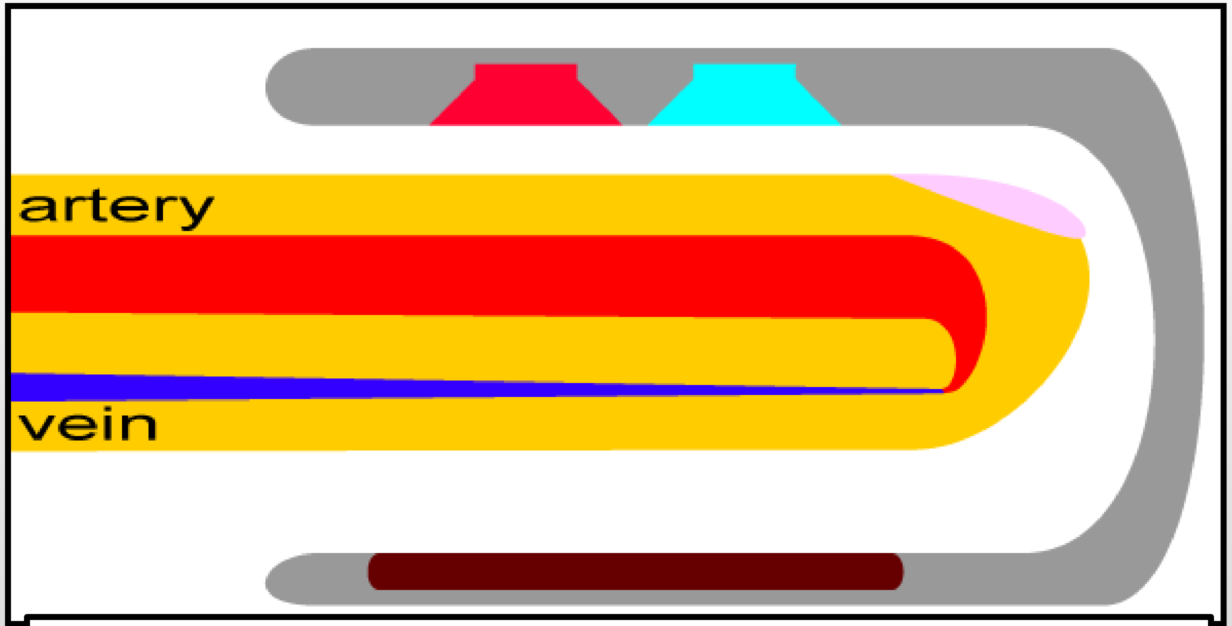


Image by Prassana Tilakaratna

Step 1:
Alternating LED Lights

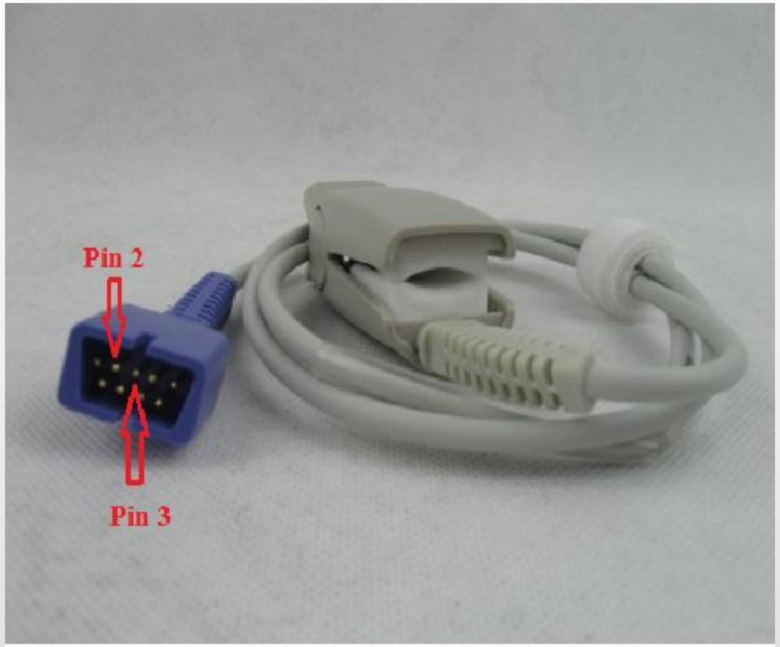
Step 2:
Light is Absorbed Through Finger

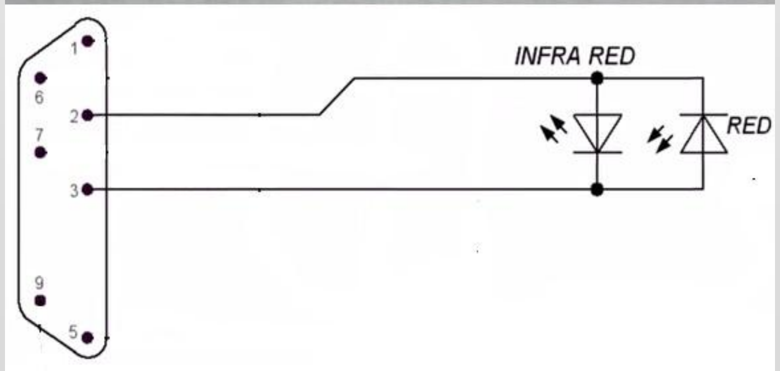
Step 3:
Sensor Detects Unabsorbed Light

Step 4:
Filter Out Noise

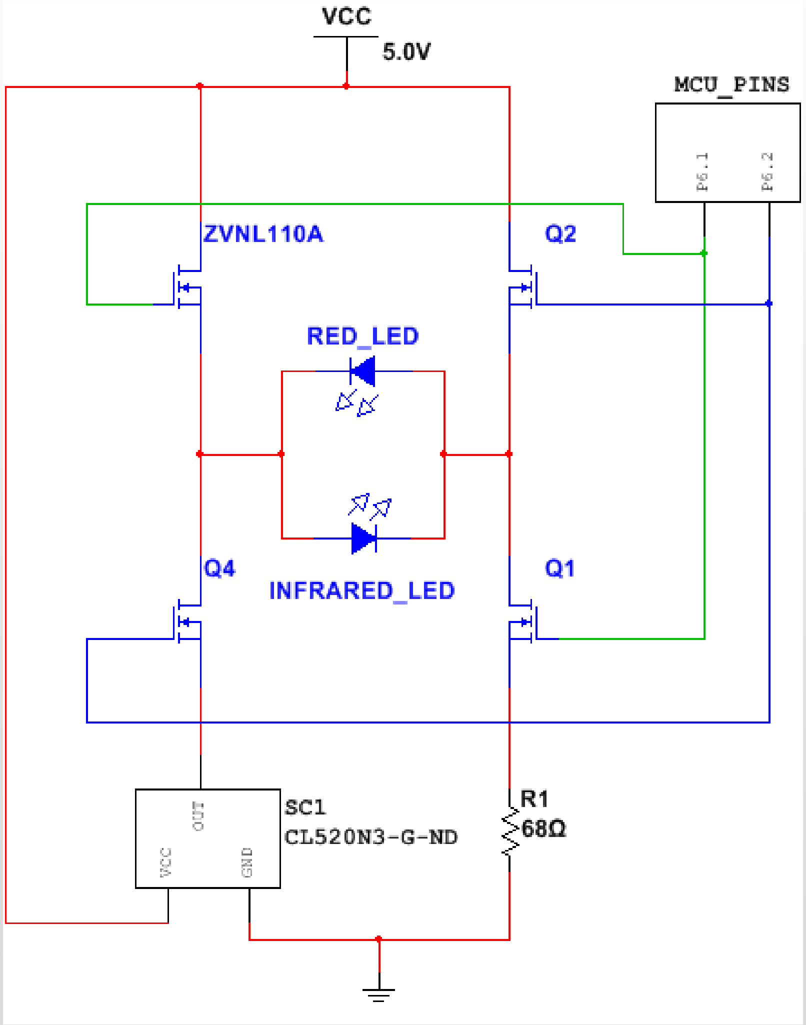
Step 5:
Blood Oxygen (SpO_2) and Heart Rate Calculations

Step 1:
Constant-Current Schematic for Alternating LEDs



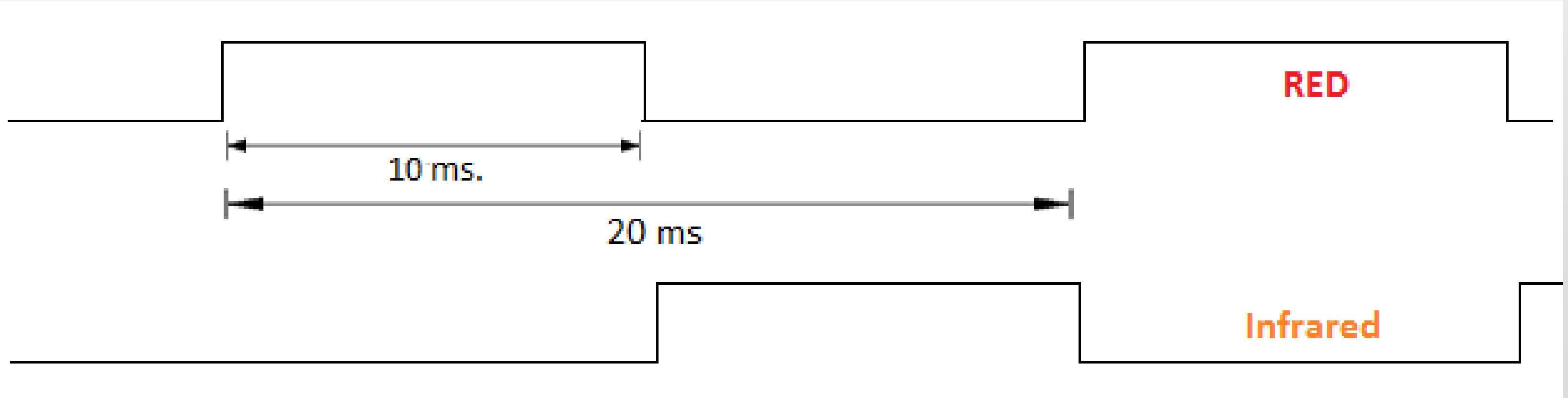


- LEDs must be supplied a constant current in each pulse to avoid calculation errors. The error occurs because different currents in each pulse will create different light intensities.
- The wavelength must be 660nm for the red LED and 940nm for the near-infrared (NIR) LED.
- Cardiac frequency is between 0.5 – 5 Hz therefore pulsing the LEDs at 50Hz is enough to obtain decent readings.
- Red LED runs at 20mA while the Infrared LED runs at 50mA.
- Since the two LEDs share the same pins but are pointing in opposite direction, the current flow has to be reversed.
- An H-Bridge allows the current flow to be reversed whenever the MOSFETs receive



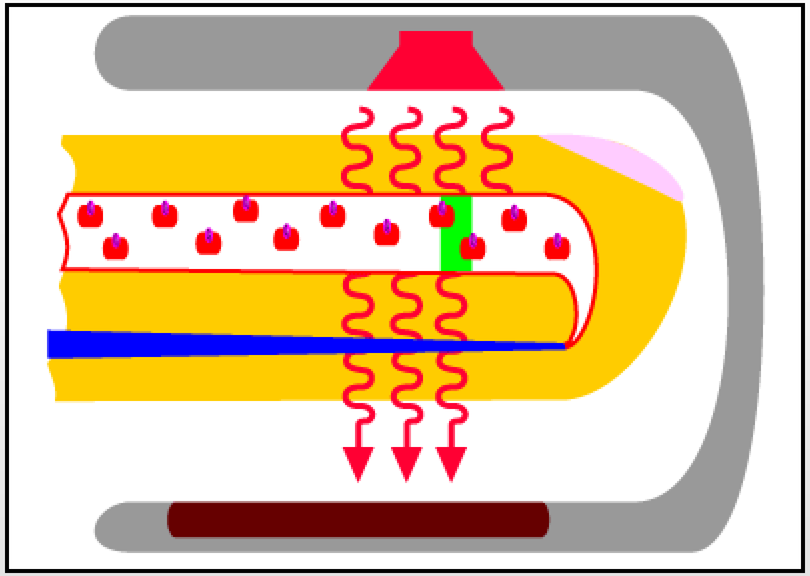
Step 1: (Continued)

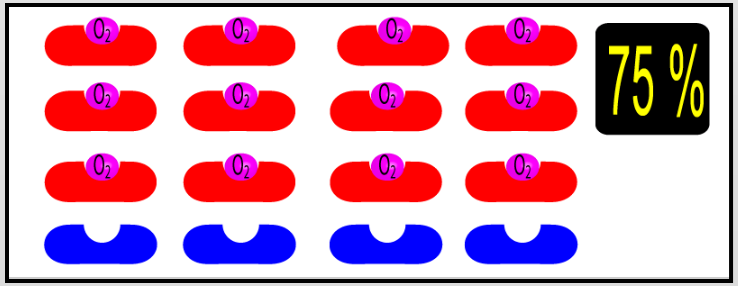
- Cardiac frequency is between 0.5 – 5 Hz therefore pulsing the LEDs at 50Hz is enough to obtain decent readings without overflowing the MCU.
- Readings are taking at the end of each pulse when the current through the LED has stabilized.
- In most cases, the heart rate will be at a frequency between 1 – 2 Hz which means about 50 points will outline each heartbeat.

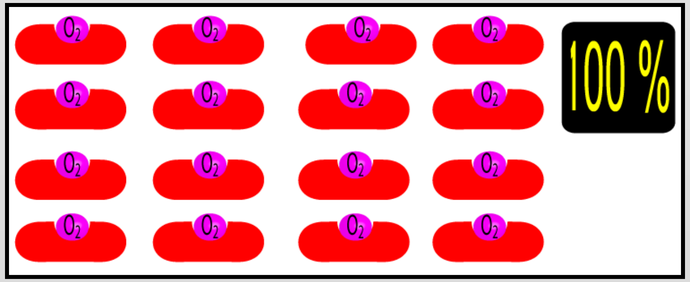


Timing Diagram

Step 2:
Light is Absorbed Through Finger







Images by Prassana Tilakaratna

- Hemoglobin acts as a transport of both oxygenated and deoxygenated blood cells.

- Each time the heart beats, blood flows through the arteries and expands them. When it expands, more hemoglobin flows through which makes it easier to distinguish the artery from other non-pulsating components that make up our finger.

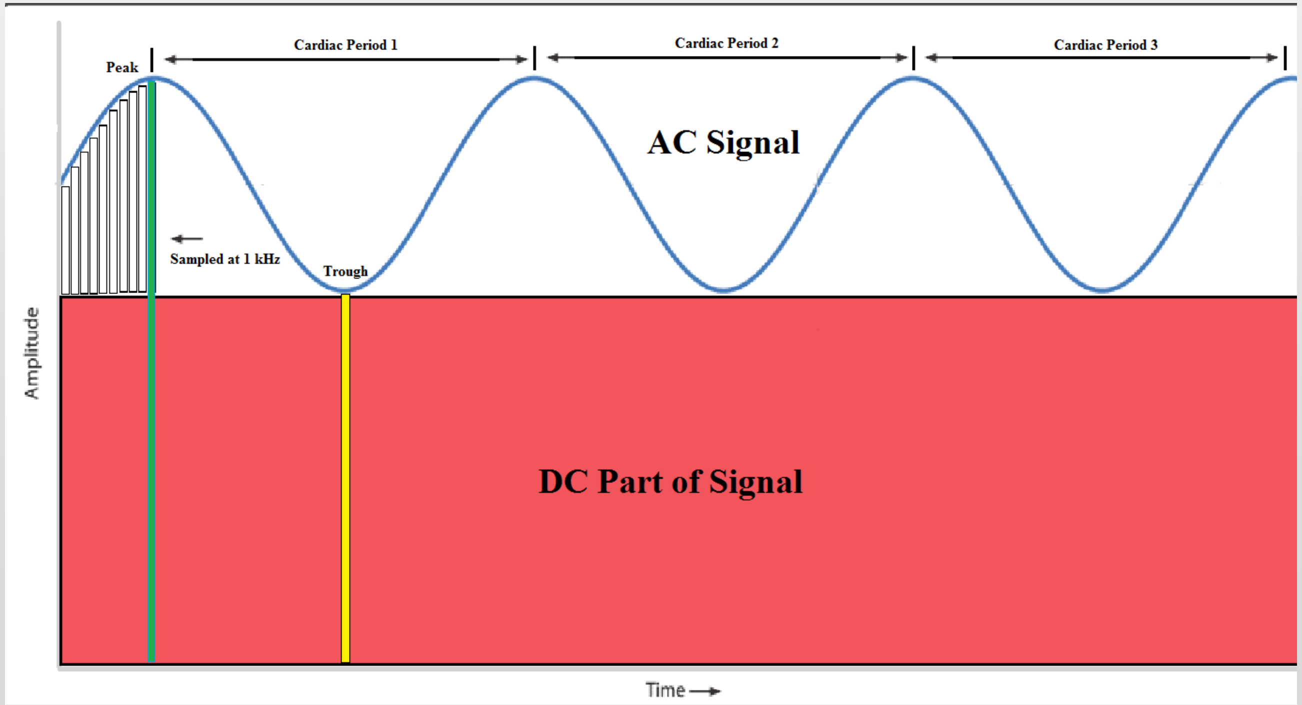
- The reason 660nm and 940nm LEDs are used is because:

➢ 660nm light is easily absorbed by deoxygenated hemoglobin and
➢ 940nm light is easily absorbed by oxygenated hemoglobin

Step 3:
Sensor Detects Unabsorbed Light

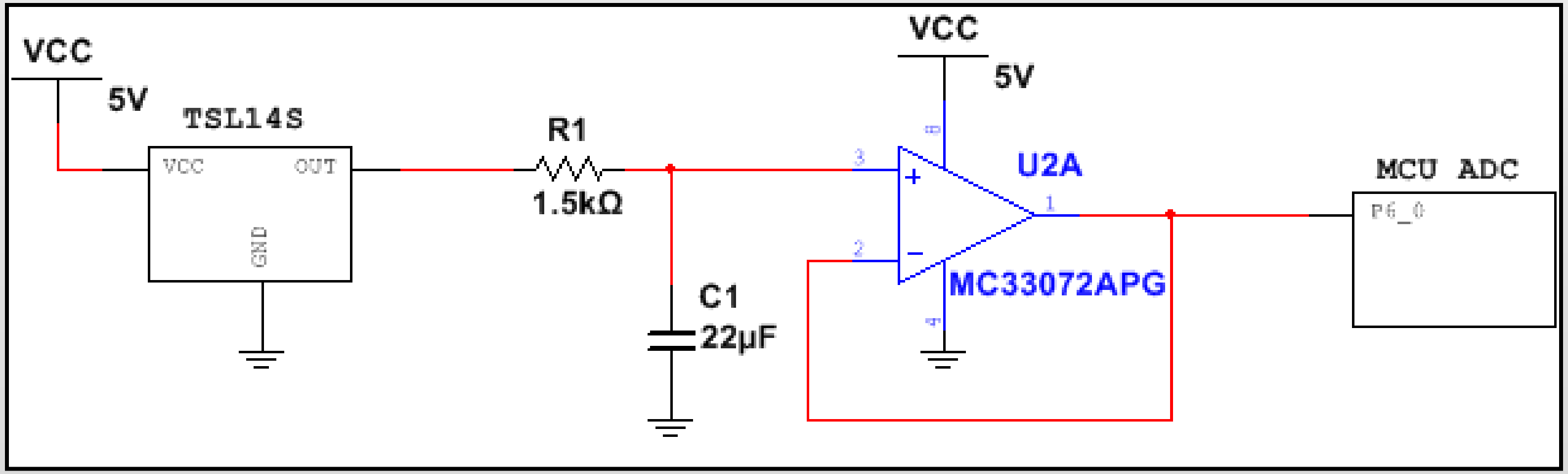
The light sensor chosen is the TSL14S by AMS AG

- Very Fast Response (4µs)
- Large range of wavelength detection (320 nm to 1050 nm)
- Output voltage is linear with light intensity
- Amplifies the signal of an integrated photodiode
- Contains feedback components



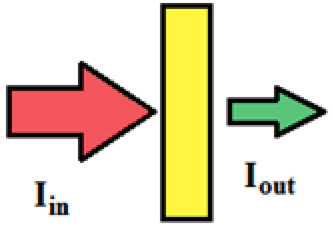
Step 4:
Noise Filter Schematic

- 5 Hz Lowpass Filter
- Prevents flickering and ambient light from corrupting the results
- MC33072APG op-amps chosen for its low price, high-speed, low-noise, unity-gain stable and single-supply operation.
- The output of the last stage is connected to the MSP430’s analog-to-digital converter in order to do the calculations.



Step 5:
Calculating SpO_2 and Pulse

- To calculate the blood oxygen levels (SpO_2), Beer-Lambert's law is applied

Beer-Lambert Law	SpO2	Alternative SpO2
Absorbance $A = \log_{10}(I_{in}/I_{out})$  	$R = \frac{log_{10}(I_{ac}) * \lambda_{660}}{log_{10}(I_{ac}) * \lambda_{940}}$ I = light intensity λ = wavelength	$R = \frac{(AC_{660})/(DC_{660})}{(AC_{940})/(DC_{940})}$

- To calculate pulse, the number of peaks in the light-absorbing signal are equivalent to heartbeats. The heartbeats are then divided by the amount of time allocated for that part of the exam.

Pulse = Heartbeats / Time of the exam

HHA Pulse Oximeter: Problems to Overcome

- Beer-Lambert Law does not take into account light-scattering.
- Ambient light can cause discrepancies in the results.
- Movement of finger will corrupt data.
- Skin and blood problems can affect data.

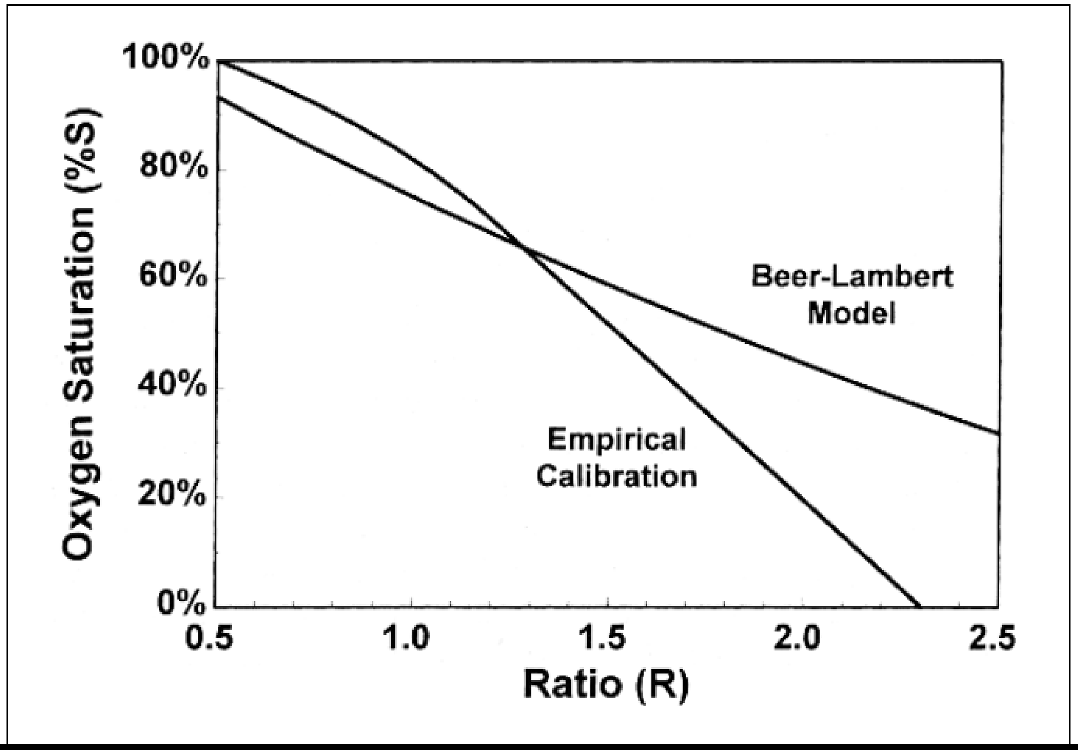
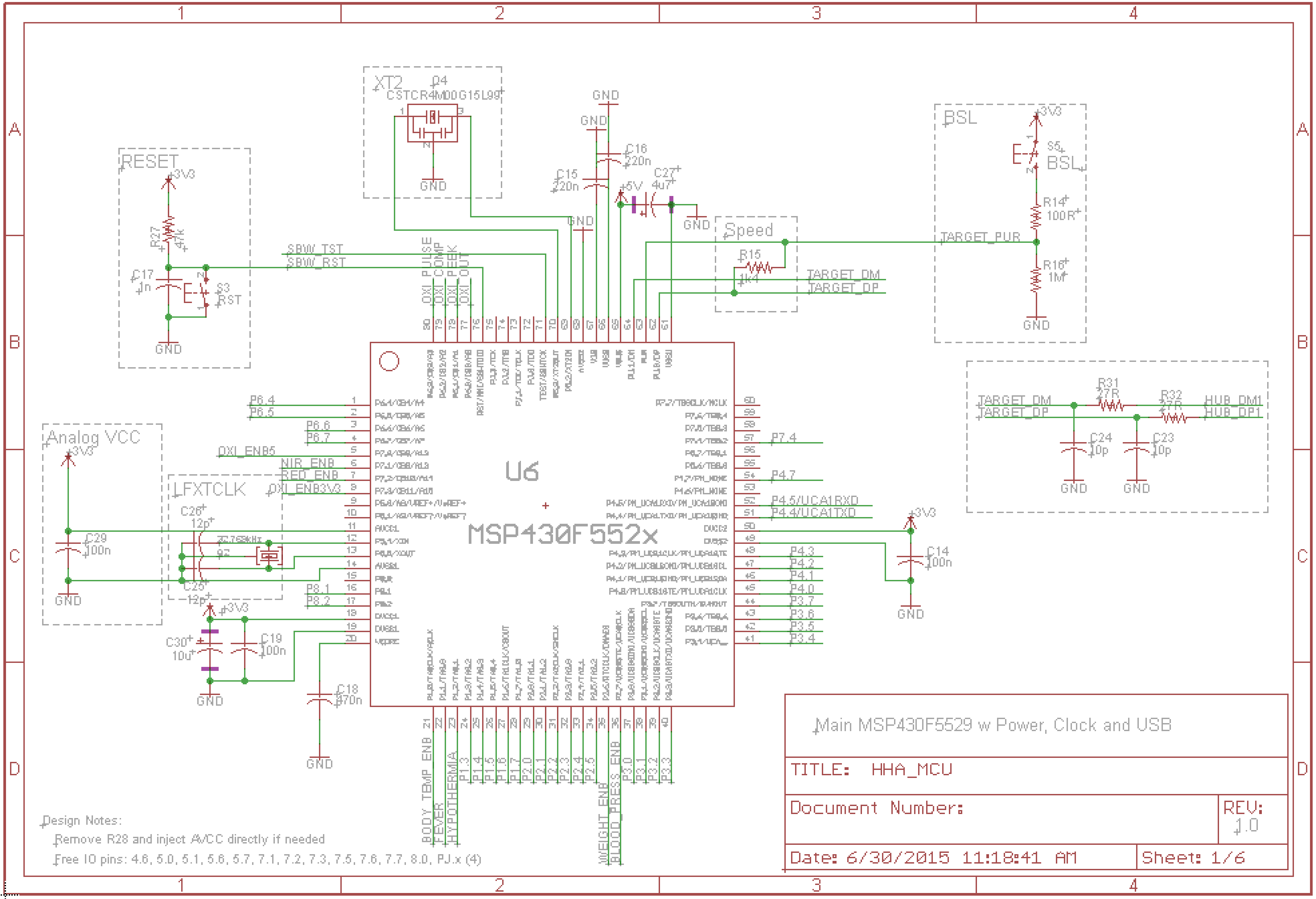


Image by Lionel Tarassenko



RESET
+3V3
R27
47k
C17
1n
S3
RST
GND
XT2
Q4
CSTCR4M00G15L99
C16
220n
C15
220n
C27
4u7
+5V
Speed
R15
1k4
TARGET_DM
TARGET_DP
BSL
S5
BSL
R14
100R
TARGET_PUR
R16
1M
R31
27R
R32
27R
HUB_DM1
HUB_DP1
C24
10p
C23
10p
SBW_TST
SBW_RST
OXI_PULSE
OXI_COMP
OXI_PEEK
OXI_OUT
U6
MSP430F552x
P6.4
P6.5
P6.6
P6.7
OXI_ENB5
NIR_ENB
RED_ENB
OXI_ENB3V3
Analog VCC
C29
100n
LFXTCLK
C26
12p
C25
12p
32.768kHz
P8.1
P8.2
C30
10u
C19
100n
C18
470n
P7.4
P4.7
P4.5/UCA1RXD
P4.4/UCA1TXD
C14
100n
P4.3
P4.2
P4.1
P4.0
P3.7
P3.6
P3.5
P3.4
BODY_TEMP_ENB
FEVER
HYPOTHERMIA
P1.3
P1.4
P1.5
P1.6
P1.7
P2.0
P2.1
P2.2
P2.3
P2.4
P2.5
WEIGHT_ENB
BLOOD_PRESS_ENB
P3.0
P3.1
P3.2
P3.3
Design Notes:
Remove R28 and inject AVCC directly if needed
Free IO pins: 4.6, 5.0, 5.1, 5.6, 5.7, 7.1, 7.2, 7.3, 7.5, 7.6, 7.7, 8.0, PJ.x (4)
Main MSP430F5529 w Power, Clock and USB
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Document Number:
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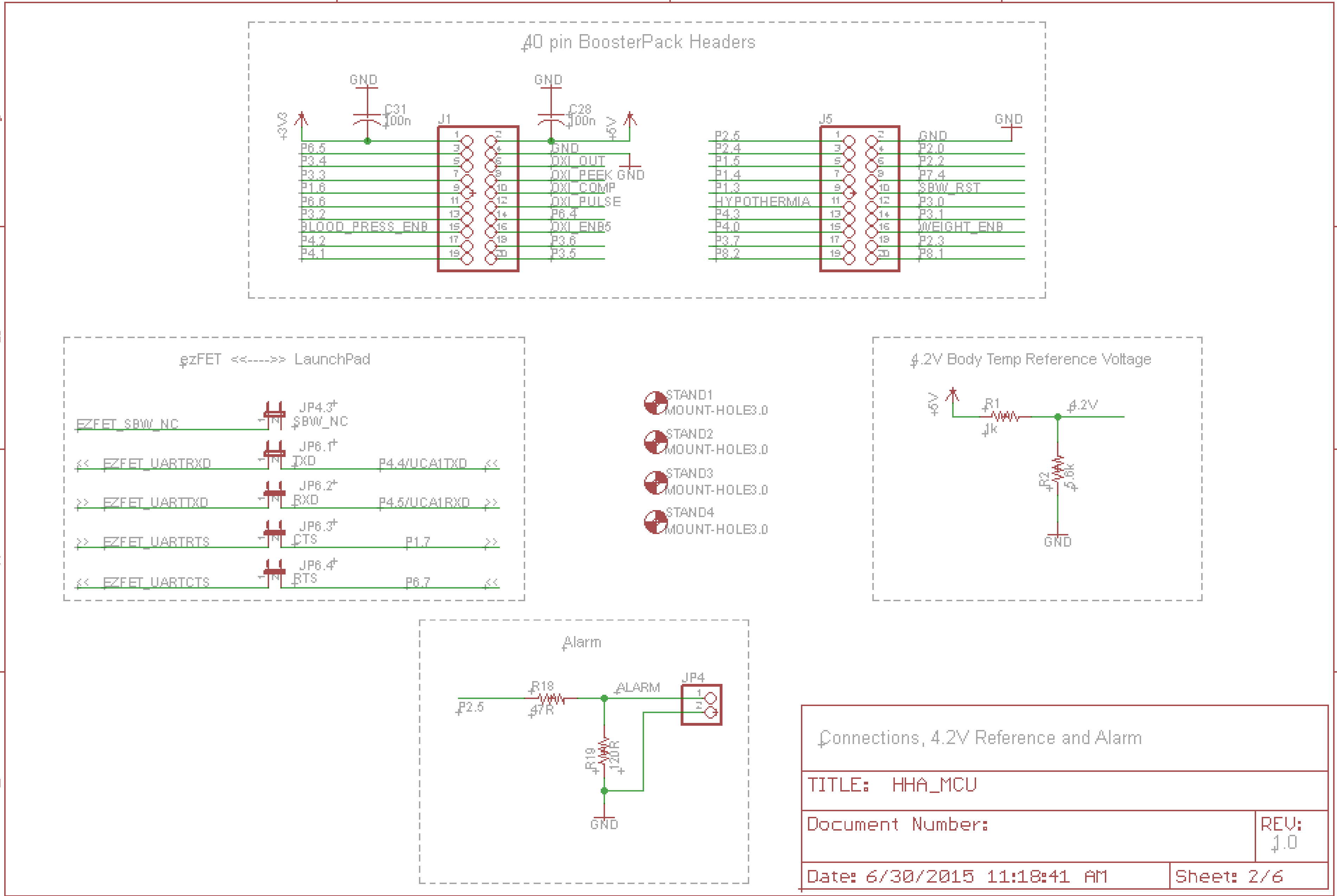
Date: 6/30/2015 11:18:41 AM
Sheet: 1/6



Connections, 4.2V Reference and Alarm

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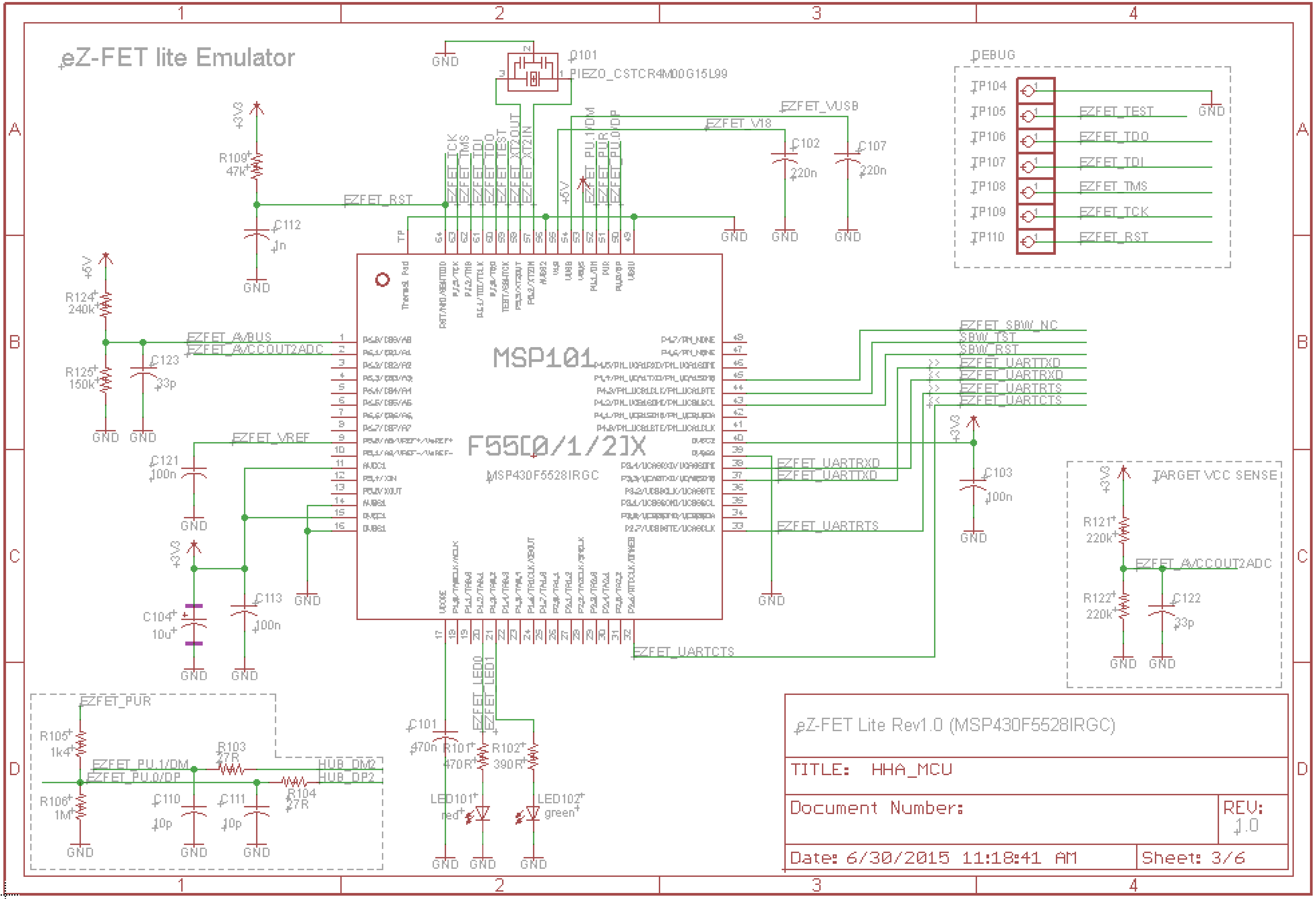
Document Number:	REV: 1.0
Date: 6/30/2015 11:18:41 AM	Sheet: 2/6


eZ-FET lite Emulator
Q101
PIEZO_CSTCR4M00G15L99
EZFET_VUSB
EZFET_V18
C102
220n
C107
220n
R109
47K
EZFET_RST
C112
1n
R124
240k
R125
150k
C123
33p
EZFET_AVBUS
EZFET_AVCCOUT2ADC
EZFET_VREF
C121
100n
C104
10u
C113
100n
MSP101
F55[0/1/2]X
MSP430F5528IRGC
EZFET_SBW_NC
SBW_TST
SBW_RST
EZFET_UARTTXD
EZFET_UARTRXD
EZFET_UARTRTS
EZFET_UARTCTS
C103
100n
DEBUG
TP104
TP105
TP106
TP107
TP108
TP109
TP110
EZFET_TEST
EZFET_TDO
EZFET_TDI
EZFET_TMS
EZFET_TCK
EZFET_RST
TARGET VCC SENSE
R121
220k
R122
220k
C122
33p
EZFET_AVCCOUT2ADC
EZFET_PUR
R105
1k4
R106
1M
R103
27R
R104
27R
EZFET_PU.1/DM
EZFET_PU.0/DP
HUB_DM2
HUB_DP2
C110
10p
C111
10p
C101
470n
R101
470R
R102
390R
LED101
red
LED102
green
EZFET_LED0
EZFET_LED1
GND
+3V3
+5V
eZ-FET Lite Rev1.0 (MSP430F5528IRGC)
TITLE: HHA_MCU
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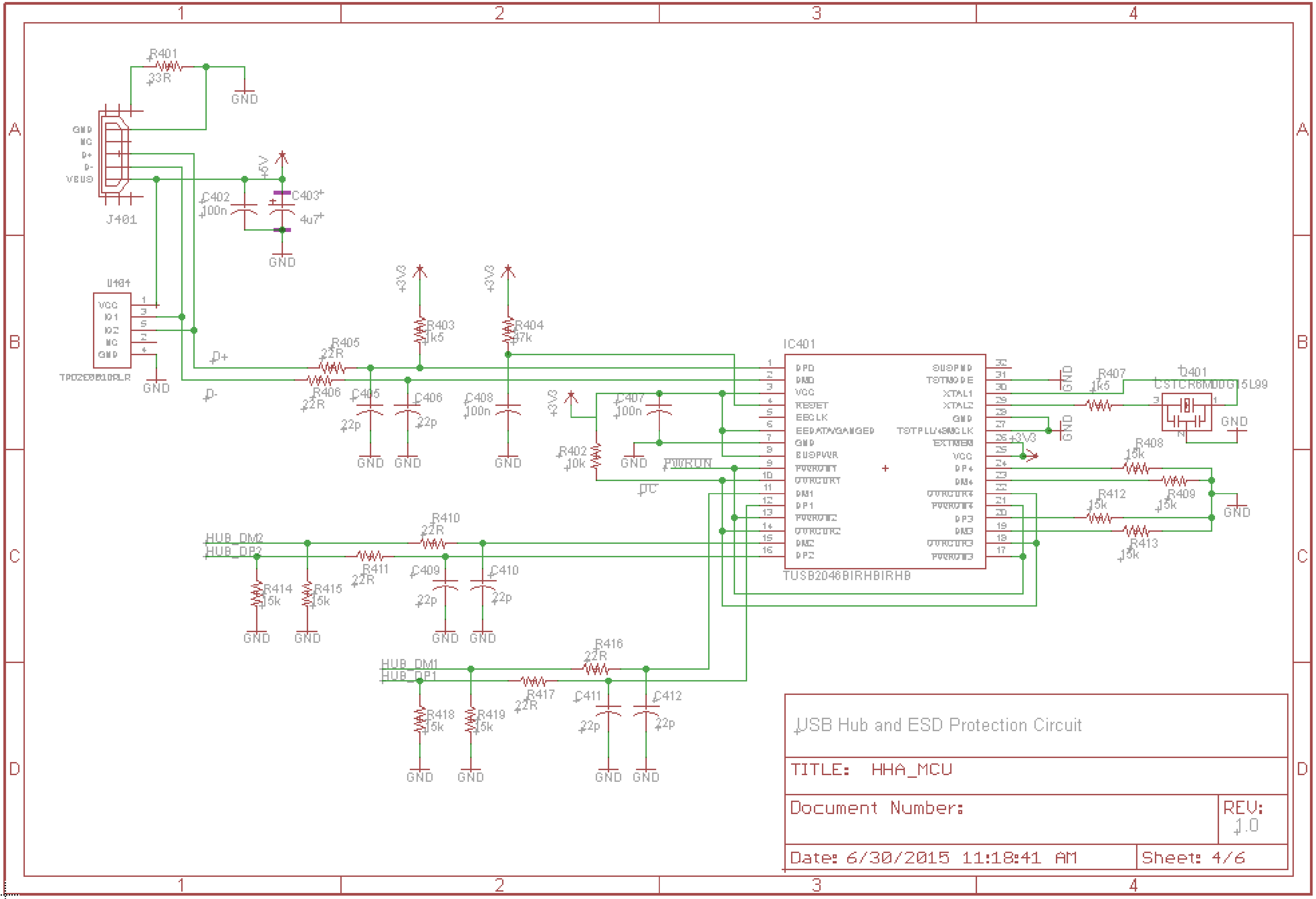
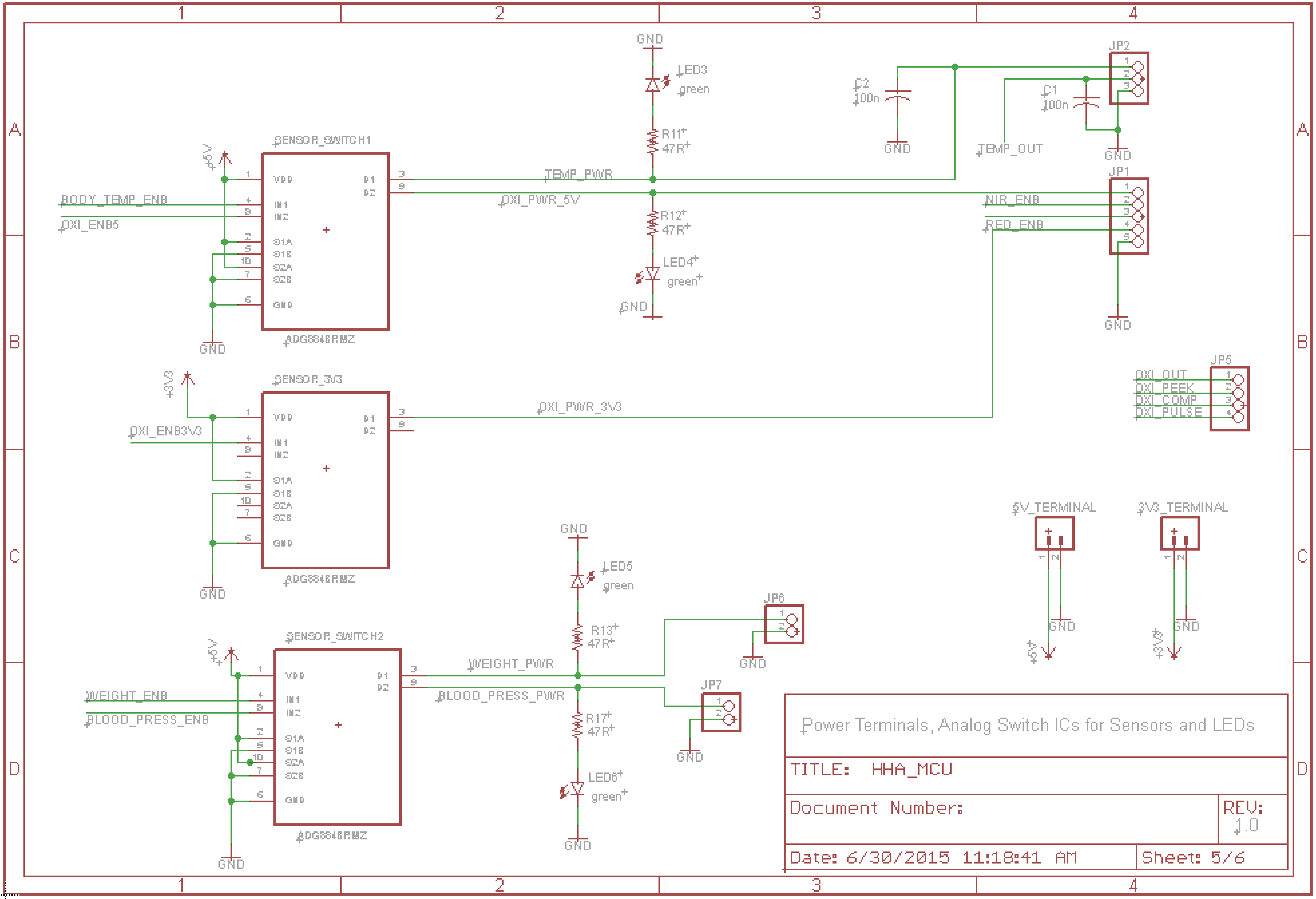
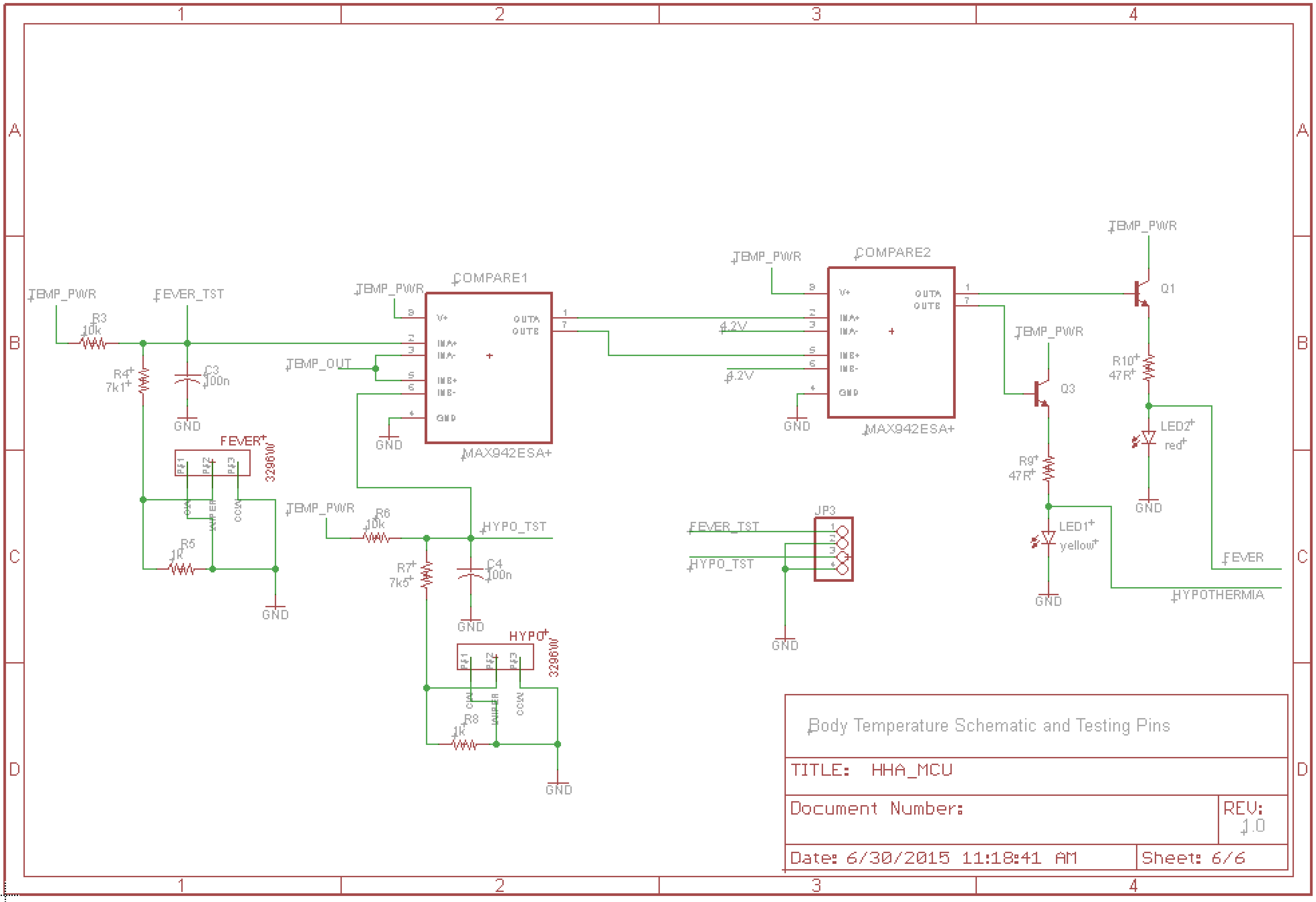
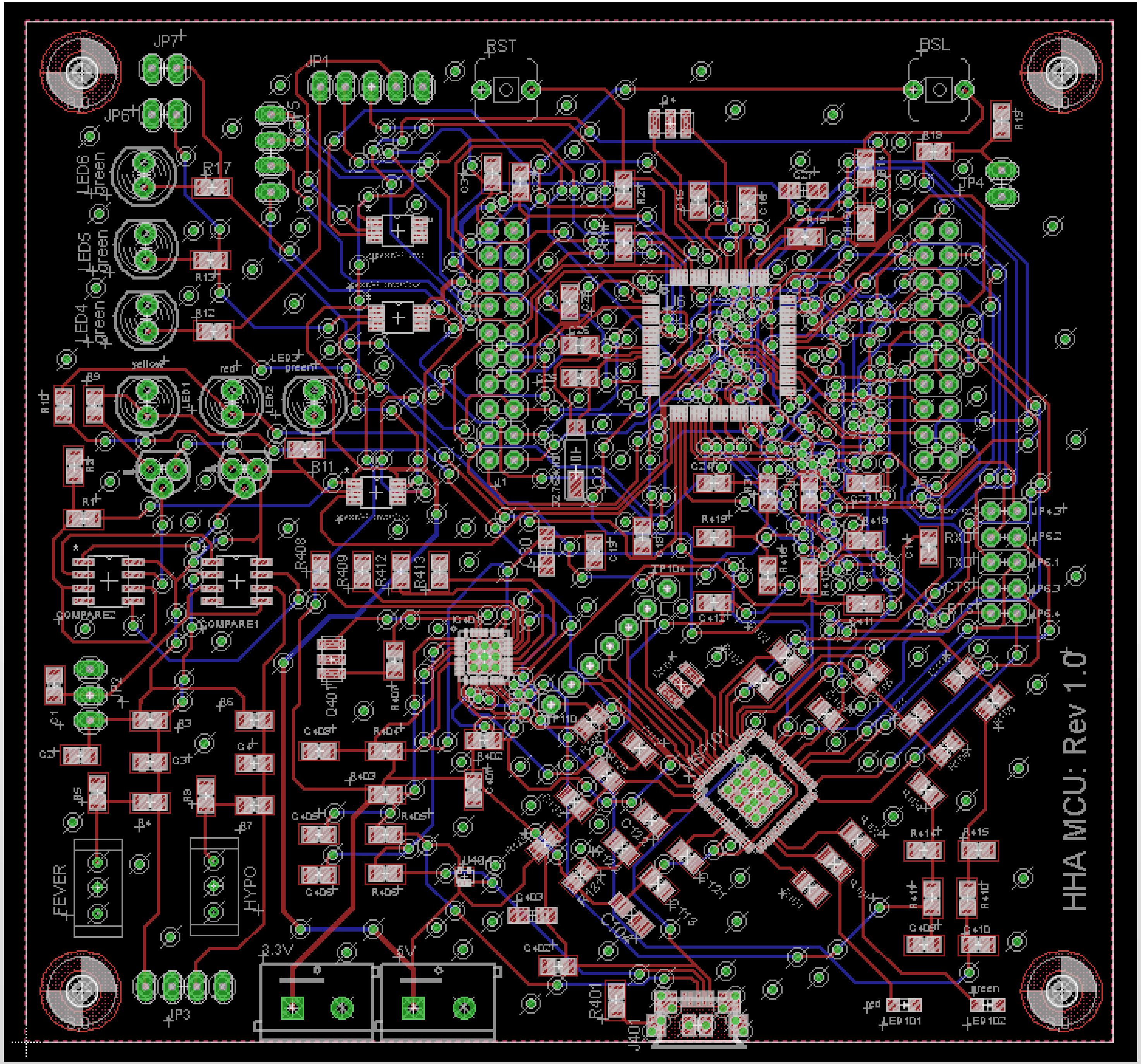

USB Hub and ESD Protection Circuit
TITLE: HHA_MCU
Document Number:
REV: 1.0
Date: 6/30/2015 11:18:41 AM
Sheet: 4/6
J401
R401
33R
GND
C402
100n
C403
4u7
+5V
U404
VCC
GND
R403
1k5
R404
47k
+3V3
R405
22R
R406
22R
D+
D-
C405
C406
22p
C408
100n
C407
100n
R402
10k
PWRON
OC
IC401
TUSB2046BIRHBIRHB
R407
1k5
Q401
CSTCR6M00G15L99
R408
15k
R409
15k
R412
15k
R413
15k
HUB_DM2
HUB_DP2
R410
22R
R411
22R
R414
15k
R415
15k
C409
22p
C410
22p
HUB_DM1
HUB_DP1
R416
22R
R417
22R
R418
15k
R419
15k
C411
22p
C412
22p

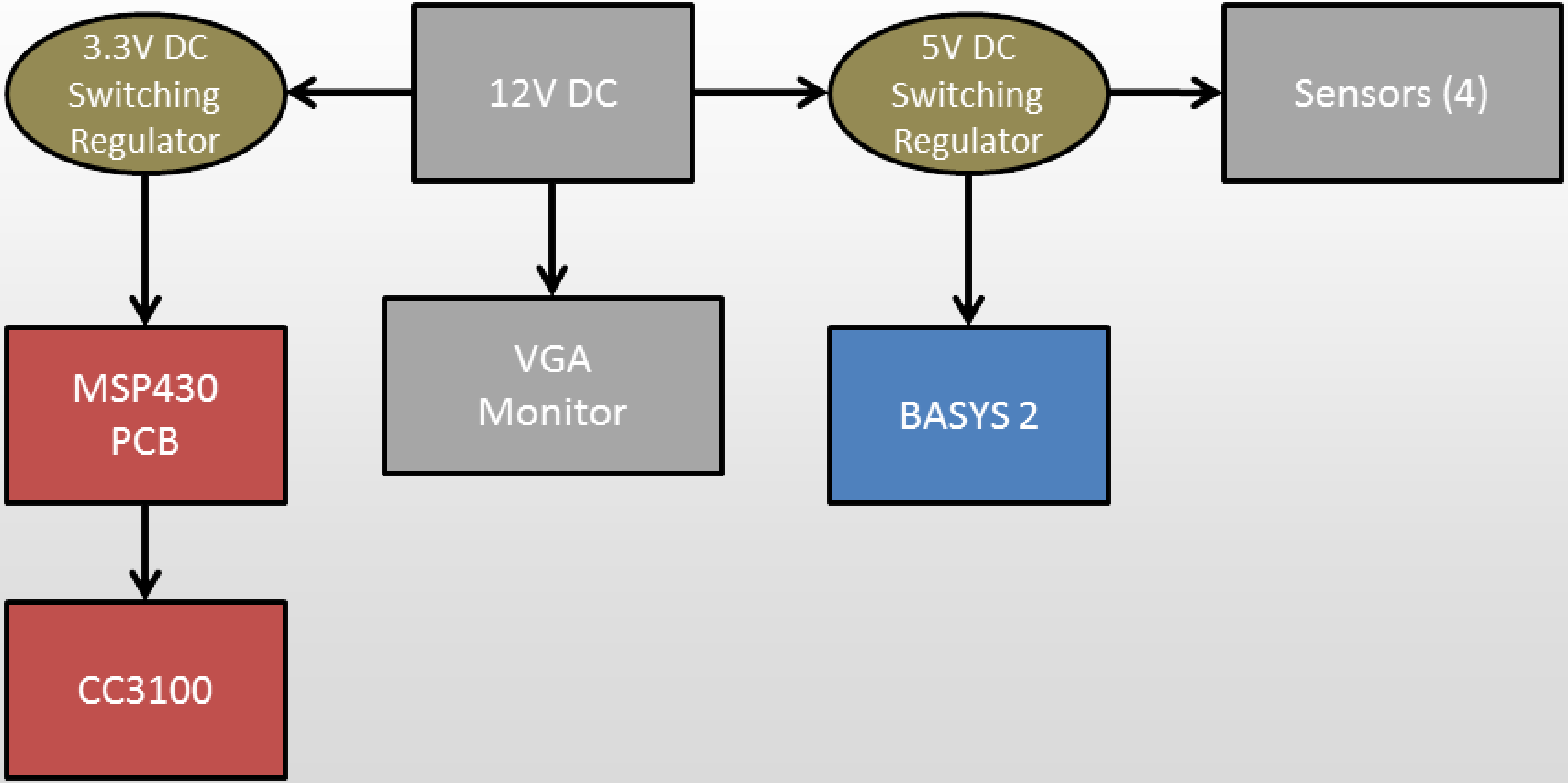


SENSOR_SWITCH1
ADG884BRMZ
BODY_TEMP_ENB
OXI_ENB5
+5V
GND
TEMP_PWR
OXI_PWR_5V
LED3
green
R11
47R
R12
47R
LED4
green
C2
100n
C1
100n
TEMP_OUT
JP2
JP1
NIR_ENB
RED_ENB
SENSOR_3V3
ADG884BRMZ
+3V3
OXI_ENB3V3
OXI_PWR_3V3
JP5
OXI_OUT
OXI_PEEK
OXI_COMP
OXI_PULSE
5V_TERMINAL
3V3_TERMINAL
SENSOR_SWITCH2
ADG884BRMZ
WEIGHT_ENB
BLOOD_PRESS_ENB
WEIGHT_PWR
BLOOD_PRESS_PWR
LED5
green
R13
47R
R17
47R
LED6
green
JP6
JP7
Power Terminals, Analog Switch ICs for Sensors and LEDs
TITLE: HHA_MCU
Document Number:
REV: 1.0
Date: 6/30/2015 11:18:41 AM
Sheet: 5/6


TEMP_PWR
FEVER_TST
R3
10k
R4
7k1
C3
100n
GND
FEVER
3296W
CW
WIPER
CCW
R5
1k
COMPARE1
MAX942ESA+
V+
INA+
INA-
INB+
INB-
GND
OUTA
OUTB
TEMP_OUT
R6
10k
R7
7k5
C4
100n
HYPO_TST
HYPO
R8
1k
COMPARE2
MAX942ESA+
4.2V
Q1
Q3
R10
47R
R9
47R
LED2
red
LED1
yellow
JP3
FEVER
HYPOTHERMIA
Body Temperature Schematic and Testing Pins
TITLE: HHA_MCU
Document Number:
REV: 1.0
Date: 6/30/2015 11:18:41 AM
Sheet: 6/6


HHA MCU: Rev 1.0
RST
BSL
JP7
JP1
JP6
JP4
JP3
LED6
LED5
LED4
green
yellow
red
R17
R11
COMPARE1
COMPARE2
RXD
TXD
CTS
RTS
FEVER
HYPO
3.3V
5V
R401
J401

Power


3.3V DC Switching Regulator
12V DC
5V DC Switching Regulator
Sensors (4)
MSP430 PCB
VGA Monitor
BASYS 2
CC3100

Power regulation PCB

- Current requirements were doubled to err on the safe side, then used to generate 3.3V and 5V switching regulator schematics in Webench

- Calculated trace widths were too wide for certain pins; they were minimally reduced to accommodate clearance constraints.

- Current headroom in calculation allowed final design to supply at least the required currents

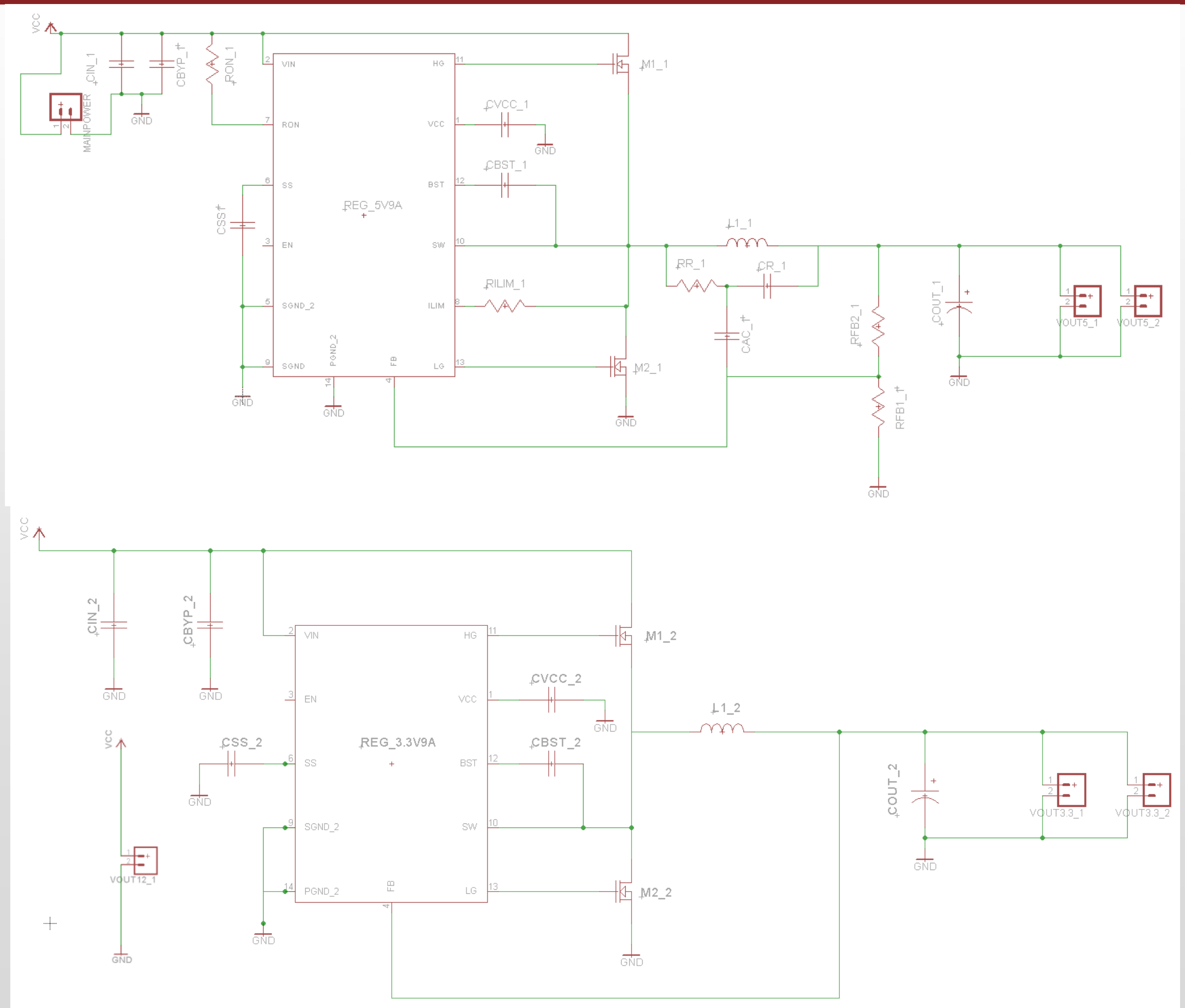
- Switching regulators chosen primarily to minimize thermal energy waste. Too much heat may cause HHA to become uncomfortable to use, or require heat sinks that impose upon HHA's small size requirement

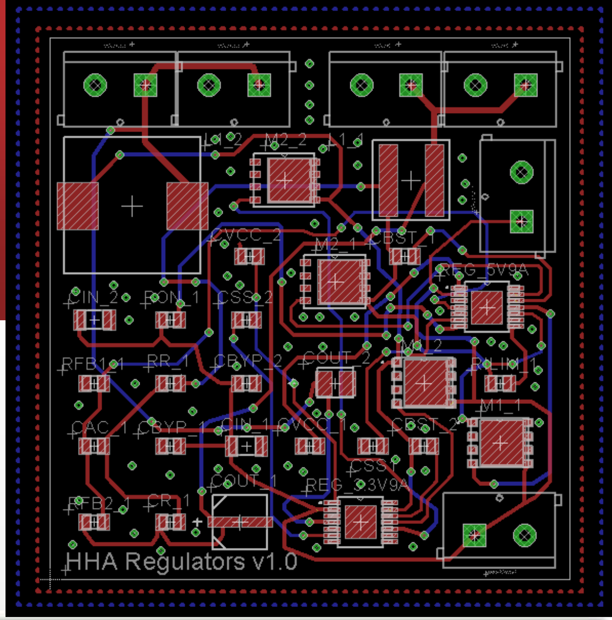
Component	Max I/V requirements
MSP430F5529 and MSP430F5528IRGC	250 mA, 3.3 V
CC3100	450 mA, 3.3 V
Pulse oximeter sensor	160 mA, 5 V
BASYS 2 FPGA	250 mA, 5 V
Body temperature sensor	100 mA, 5 V
7" LCD Monitor	700 mA, 12 V

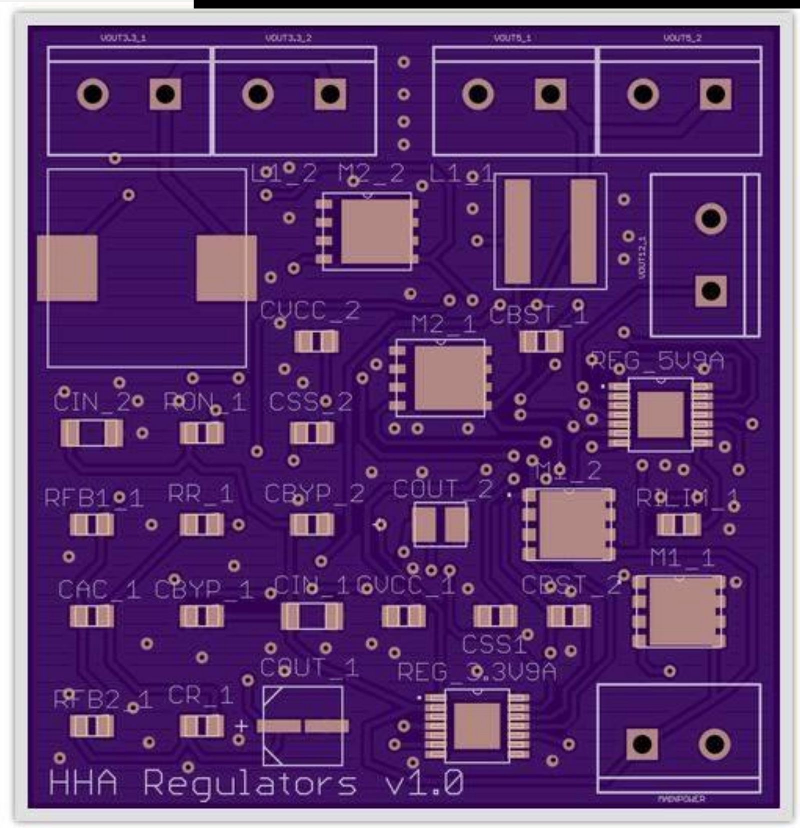
Power regulation PCB (cont.)

- 120V AC to 12V, 12A DC adapter powers the HHA
- Board designed in Eagle CAD, sent to OSH Park for fabrication
- PCB parts ordered from Digikey and CoilCraft

Power regulation PCB schematics and board layout







Administrative Content

Bill of Materials List

Component / Part Number	Supplier / Distributor Price			Quantity	Previously Owned?
	Digikey	Mouser	Other		
CC3100 Booster	$20.39	$20.39	-	1	Yes
MSP430F5529	$ 8.05	$ 8.05	-	1	Yes
BASYS 2 FPGA	-	-	-	1	Yes
100MHz Oscillator	-	-	$ 6.00	1	Yes
PS/2 Keypad	-	-	$ 10.00	1	No
ADG884BRMZ	$ 2.86	$ 2.70	-	3	Yes
MAX942	-	-	$ 2.80	2	No
MC33072APG	$ 1.12	$ 1.12	$ 1.12	1	No
2N2222	$ 0.85	$ 1.79	-	2	No
7" LCD Screen	-	-	$ 46.00	1	No
Power Supply	-	-	$ 39.99	1	No
Buzzer	-	-	-	1	Yes
Red LED	-	-	$ 0.49	2	Yes
Yellow LED	$ 0.10	$ 0.10	$ 0.49	1	No
Green LED	$ 0.19	$ 0.19	$ 0.49	4	No

Bill of Materials List (Cont.)

Component / Part Number	Supplier / Distributor Price			Quantity	Already Owned?
	Digikey	Mouser	Other		
Blue LED	$ 0.19	$ 0.19	$ 0.49	1	Yes
NIR LED	-	-	$ 0.60	1	Yes
TSL14S-LF	$ 1.48	$ 1.54	-	1	Yes
LMT87LP	$ 1.00	$ 1.00	$ 0.98	1	Yes
ZVNL110A-ND	$ 0.78	$ 0.78	-	1	Yes
CL520N3-G-ND	$ 0.54	$ 0.50	-	1	Yes
All Regulators Combined	-	-	$ 45.00	1	No
MCU PCB Parts	-	-	$ 75.00	1	No
PCBs	-	-	$ 122.00	6	No
Weight Scale	-	-	$ 45.00	1	No
Soldering Station	-	-	$ 30.00	1	Yes

Bill of Materials List (Cont.)

Component / Part Number	Supplier / Distributor Price			Quantity	Already Owned?
	Digikey	Mouser	Other		
80mm Fan	-	-	$ 12.89	1	
Nellcor Fingertip Clip	-	-	$ 21.00	1	
Wire Packs	-	-	$ 10.00	1	
Acrylic Panels	-	-	$ 7.70	7	
Extra Case Components	$ 25.00	-	-	1	
Total Price of Parts	$ 412.58				

Workload Distribution

Team Member	Nicholas	Alex	Jonathan	Zishan
FPGA Programming				X
MCU Programming		X	O	
Database Management		X		
Sensor Design	O		X	
Power Distribution			O	X
PCB Design			X	X

Legend
X – Primary O – Secondary

Constraints

- Time
- Capital
- Tabletop area of space
- Health Safety Standards
- Information Security and Privacy

HIPAA Logo ©U.S. HHS 2015

Problems to Overcome

BASYS 2

- Possibly insufficient look-up tables (LUTs) for interfacing with keyboard, monitor, and MCU
- Allow user to erase inputted data

MSP430+CC3100

- Transmitted data unencrypted
- Wi-Fi access point cannot easily be reconfigured
- Possible solution: implement Wi-Fi Protected Setup (WPS)
- Volatile memory

Sensors: Problems to Overcome

Digital Scale

- Currently cannot get the existing scale from Target to give any consistent readings via the multi-meter
- Waiting for strain gauges to come in to start testing on self built scale

Possible solutions

- Use item that come out of the box and manually enter data via number pad
- Buying existing platforms with sensors that exist to communicate with the MSP430

Questions?