Home Healthcare Assistant

GROUP 8

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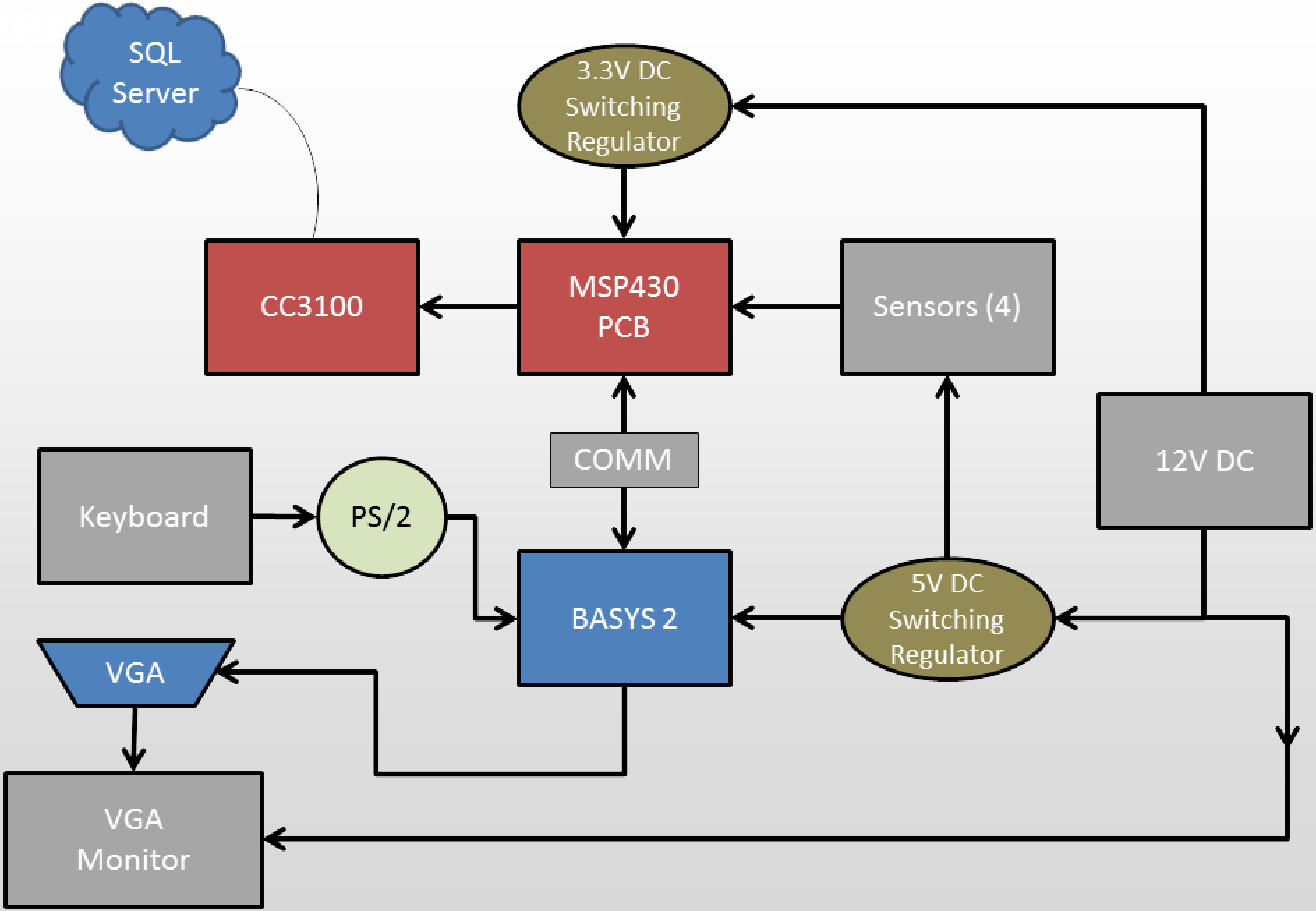
Project Motivation and Goals

- 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

Sphygmomanometer (Blood pressure)

- To accurately read a persons blood pressure to Hypertension Stage 1

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

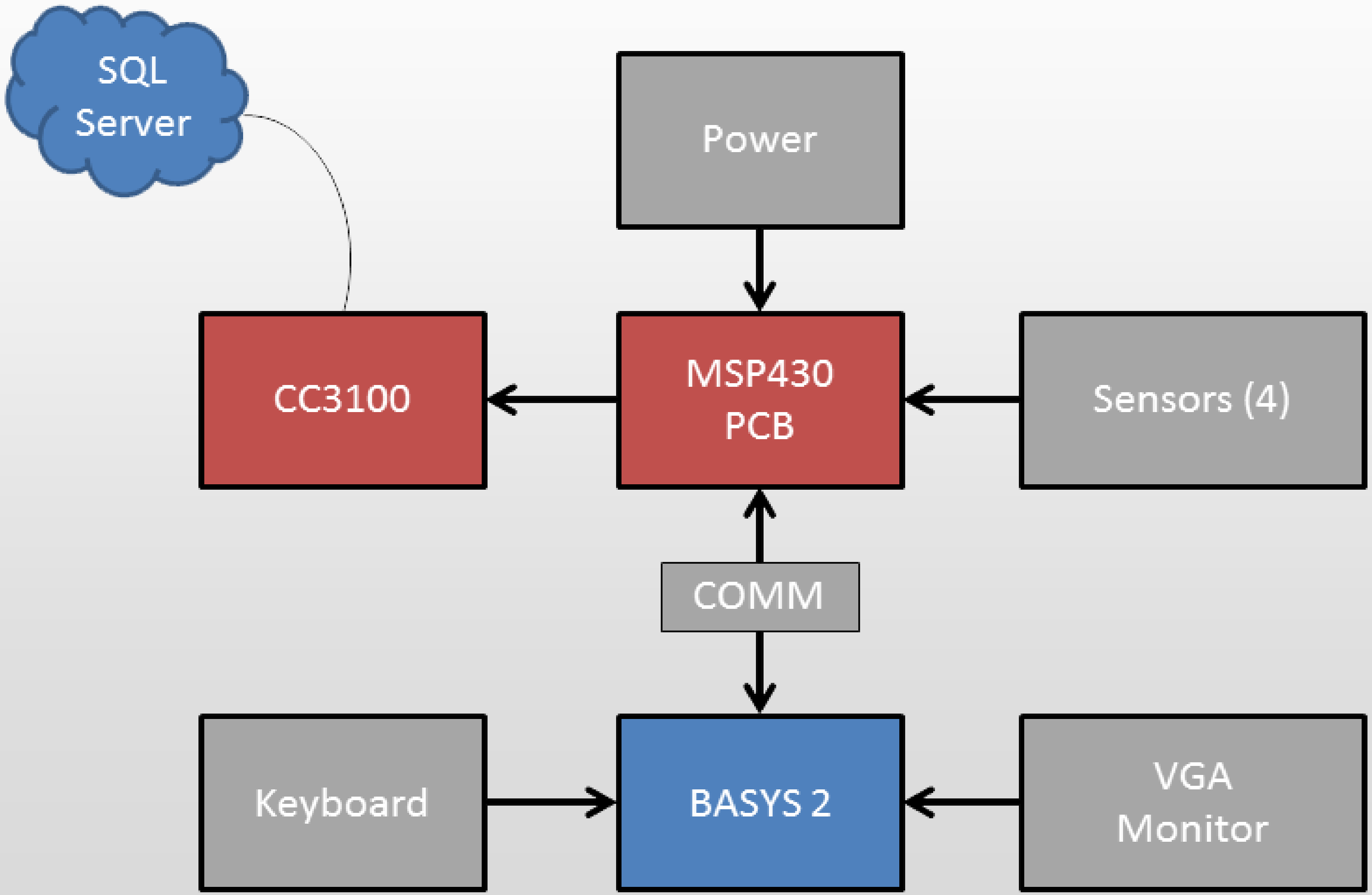
MSP430F5529 MCU

- 63 GPIO pins
- Low power
- Schematics readily available

Raspberry Pi 2

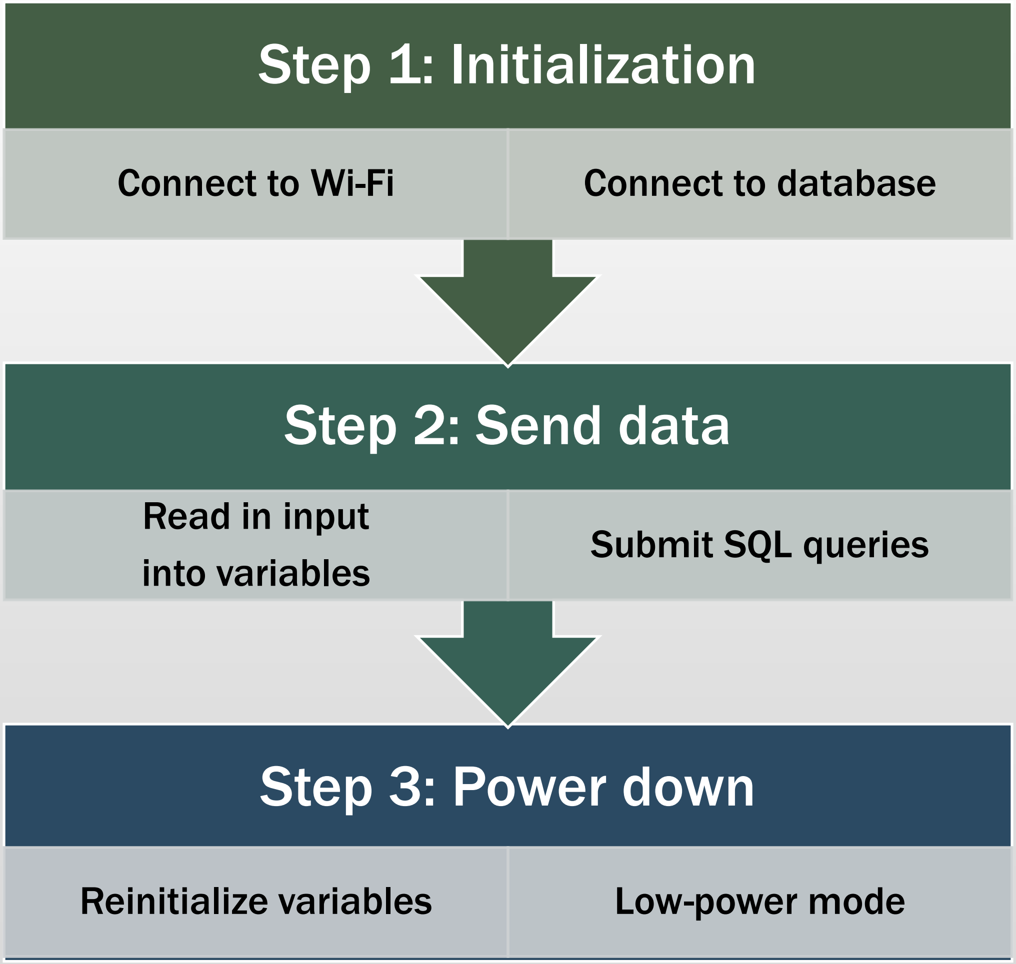
- Built-in Wireless module and USB ports
- Difficult to implement on PCB
- 26 GPIO

MSP430 PCB Connections



Connection to Database

- CC3100 Wi-Fi authenticates with wireless network and SQL server
- MCU sends variables via SQL queries to designated fields

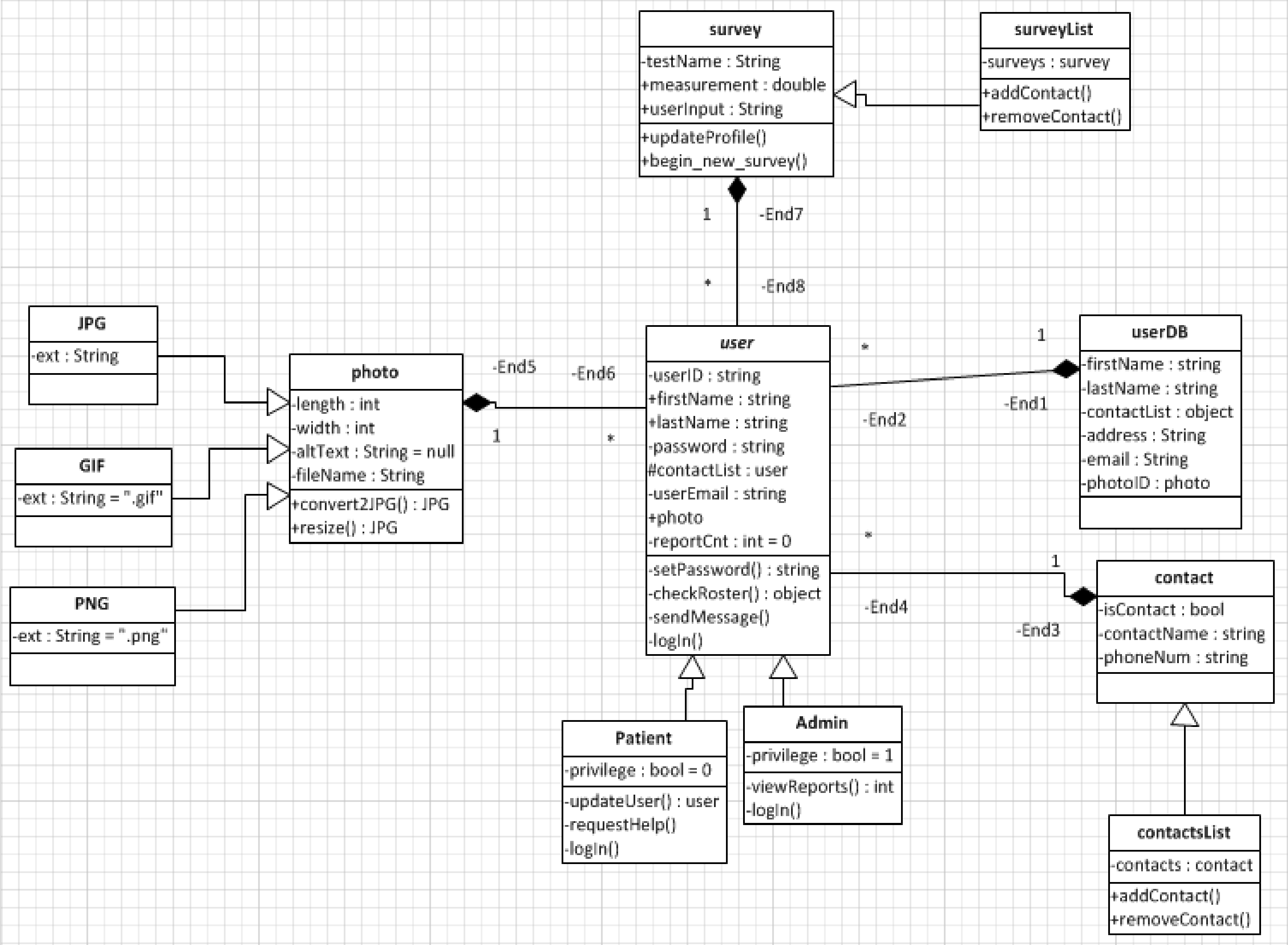


IoT Host – Microsoft Azure

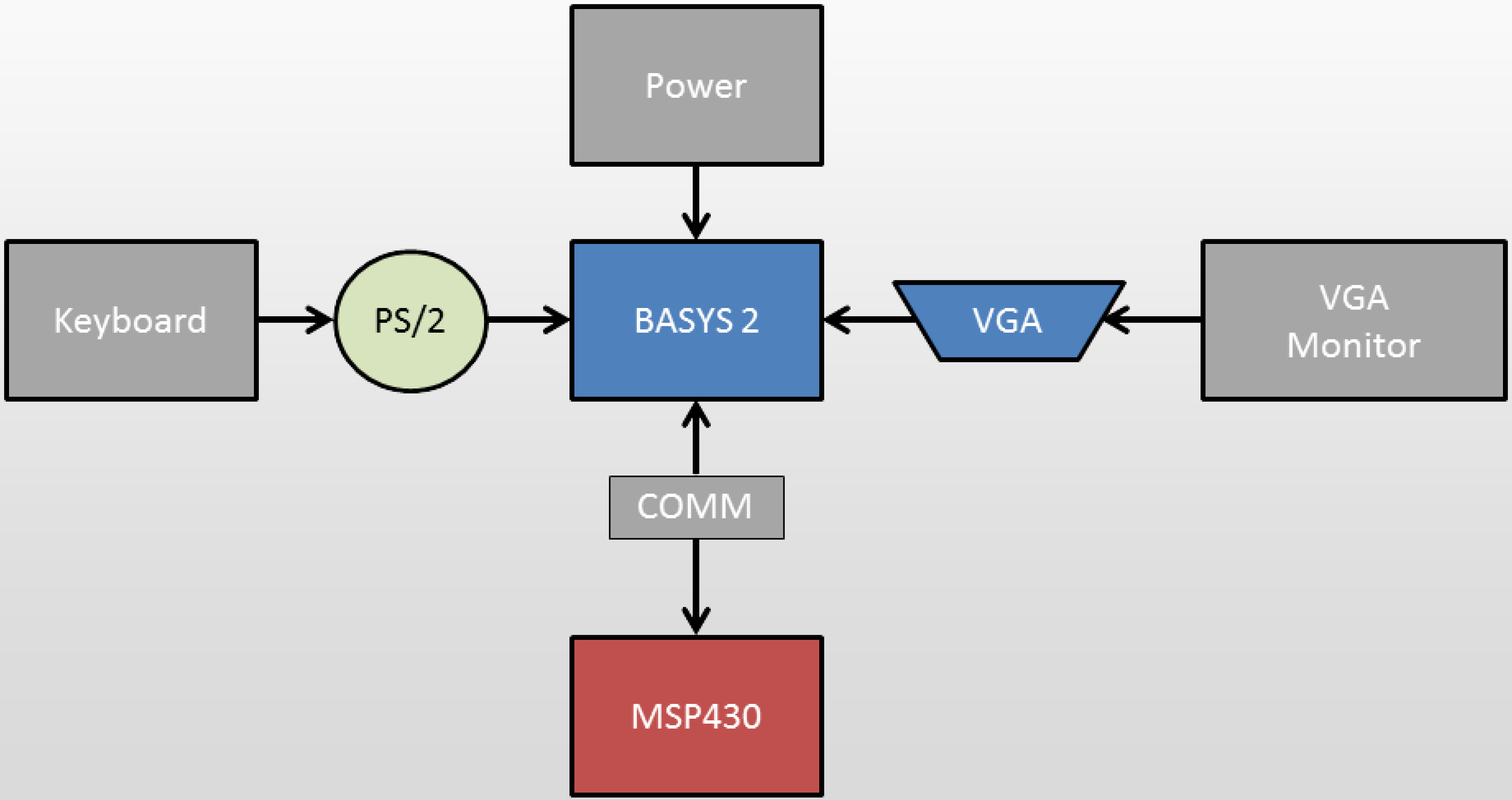
- Cloud based service and development platform
  - Visual Studio integration
- Compliant with **HIPAA**, FIPS 140-2, FERPA, among many others
- Dreamspark: Azure emulator
- $200/1 mo. Trial

Microsoft Azure Logo ©Microsoft 2015

Database Class Diagram



BASYS 2 Connections



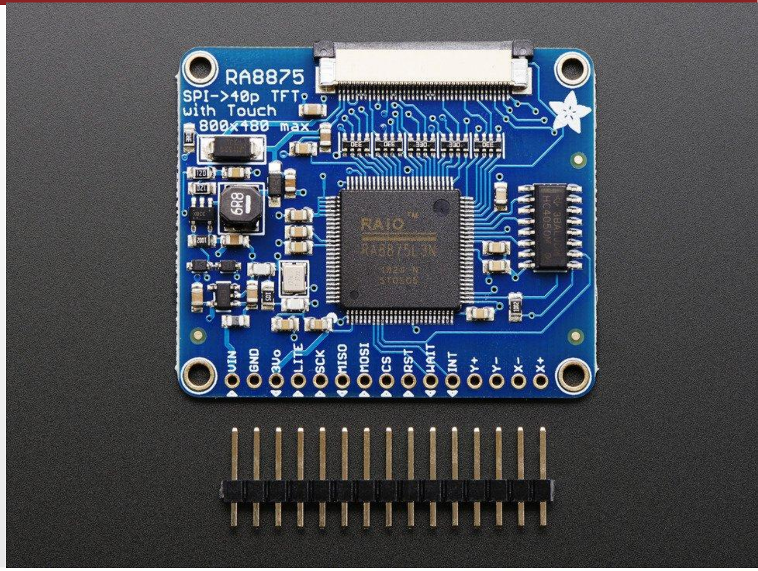
User Interface

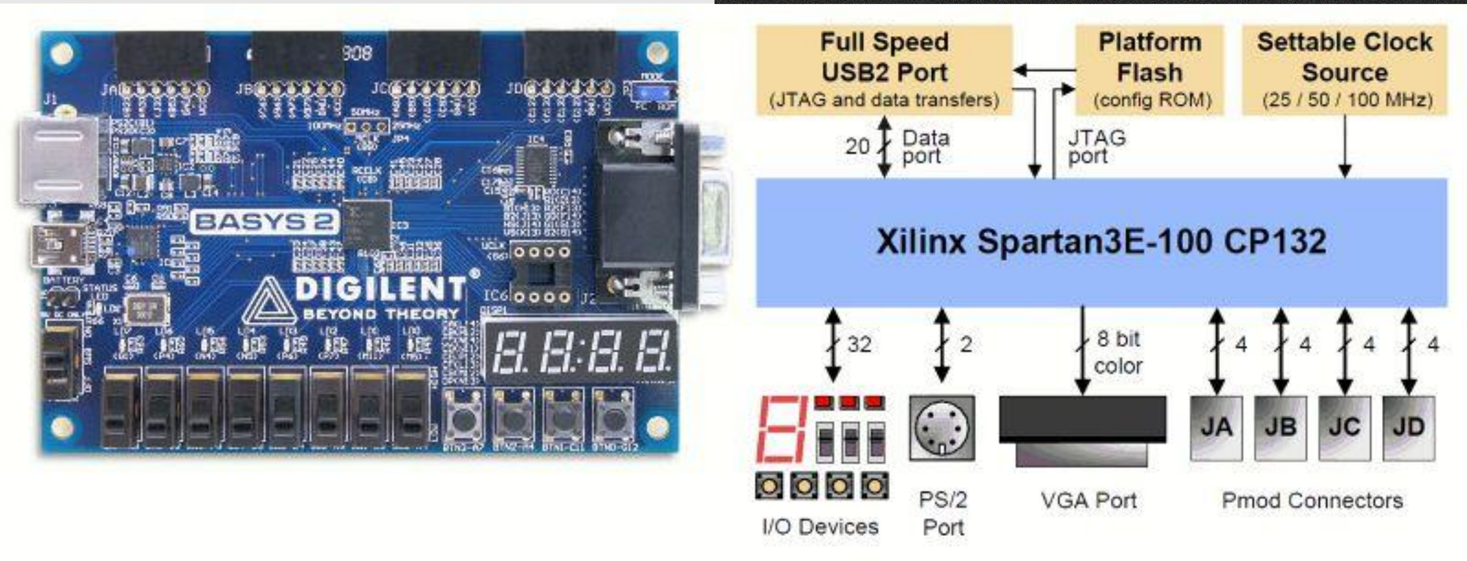
- Requirements: Present questionnaire, provide sensor operation instructions and feedback to the user. Obtain user responses.
- FPGA experience was desired
- Possible alternative approaches:

  - VGA control board with SPI connection to MCU

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

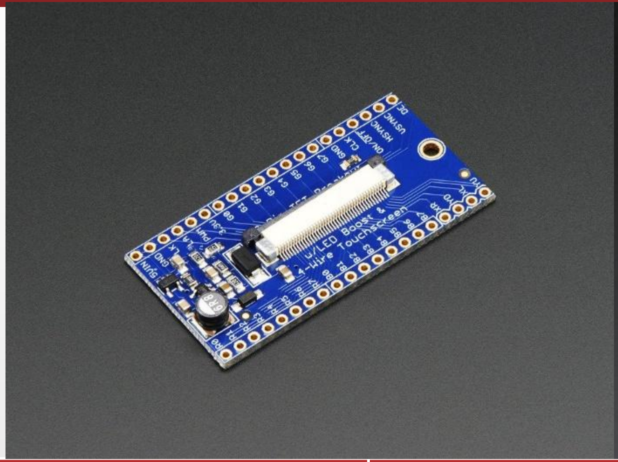
  - PS/2 port - VGA port
- BASYS 2 issue: internal clock jitter
- Solution: External crystal oscillator

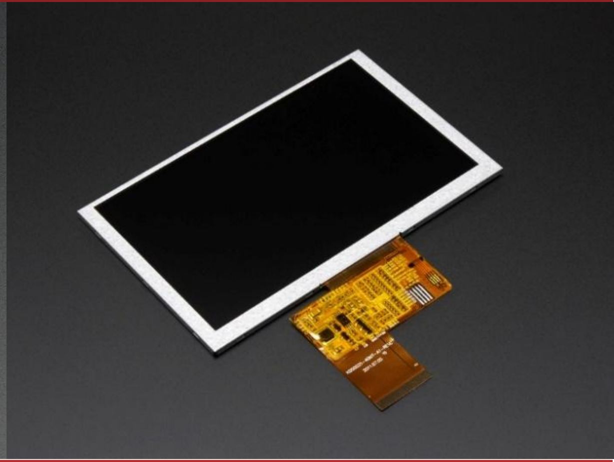




Monitor selection

- 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

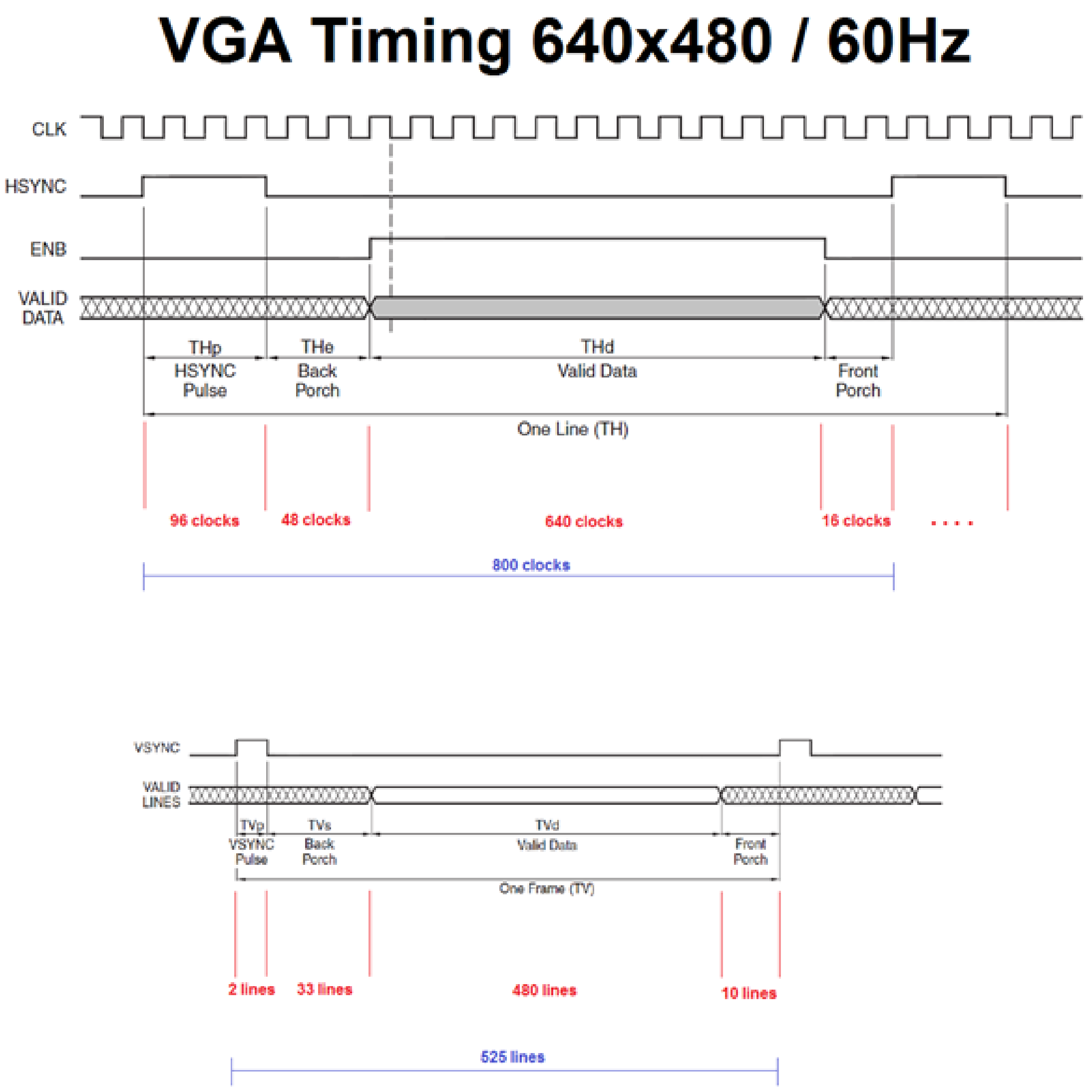
VGA Standard

- 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

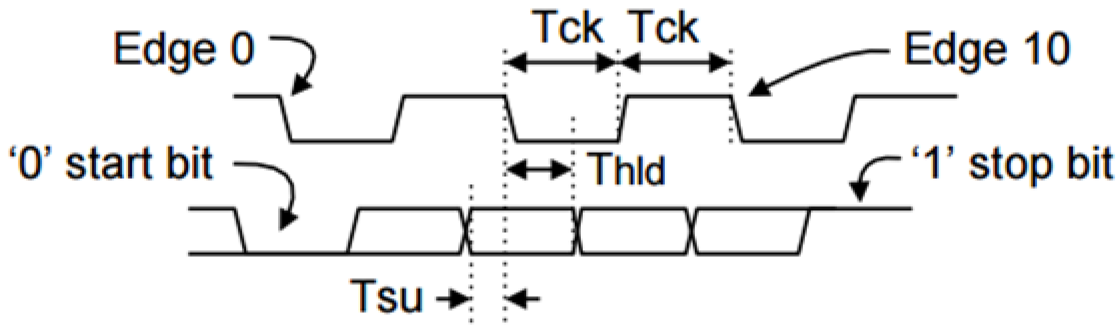
- Preset values in RGB registers used to generate a static background color, refreshed at 60 Hz

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



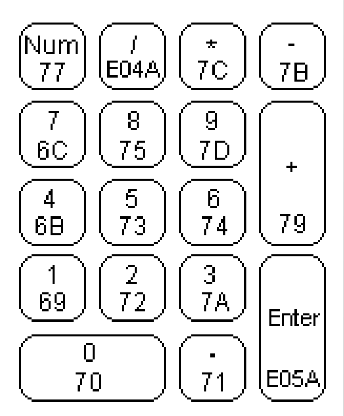
PS/2 Standard and keypad choice

- 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

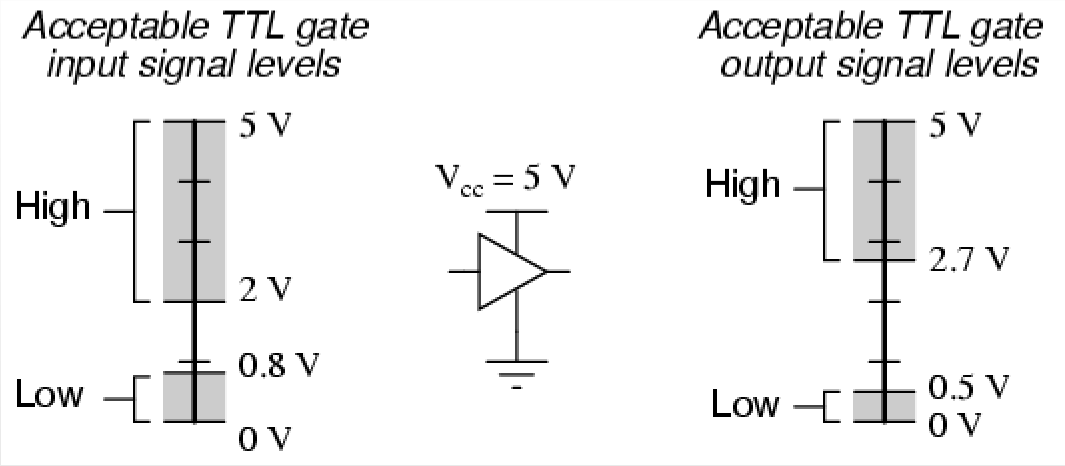
- Data line and an “enable” line

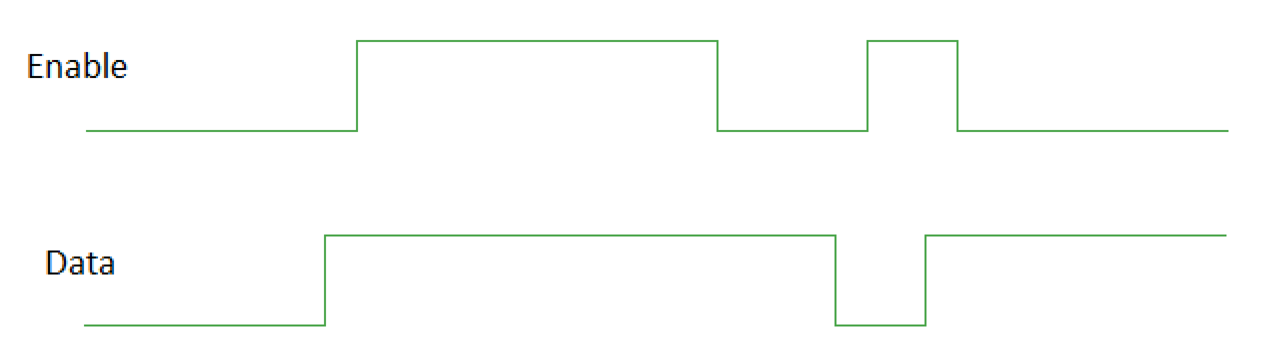
- Receiver polls enable line at its own clock rate and latches on to data value at both the positive and negative edges of the enable line

- 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,
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00001111111100000000111111110000,
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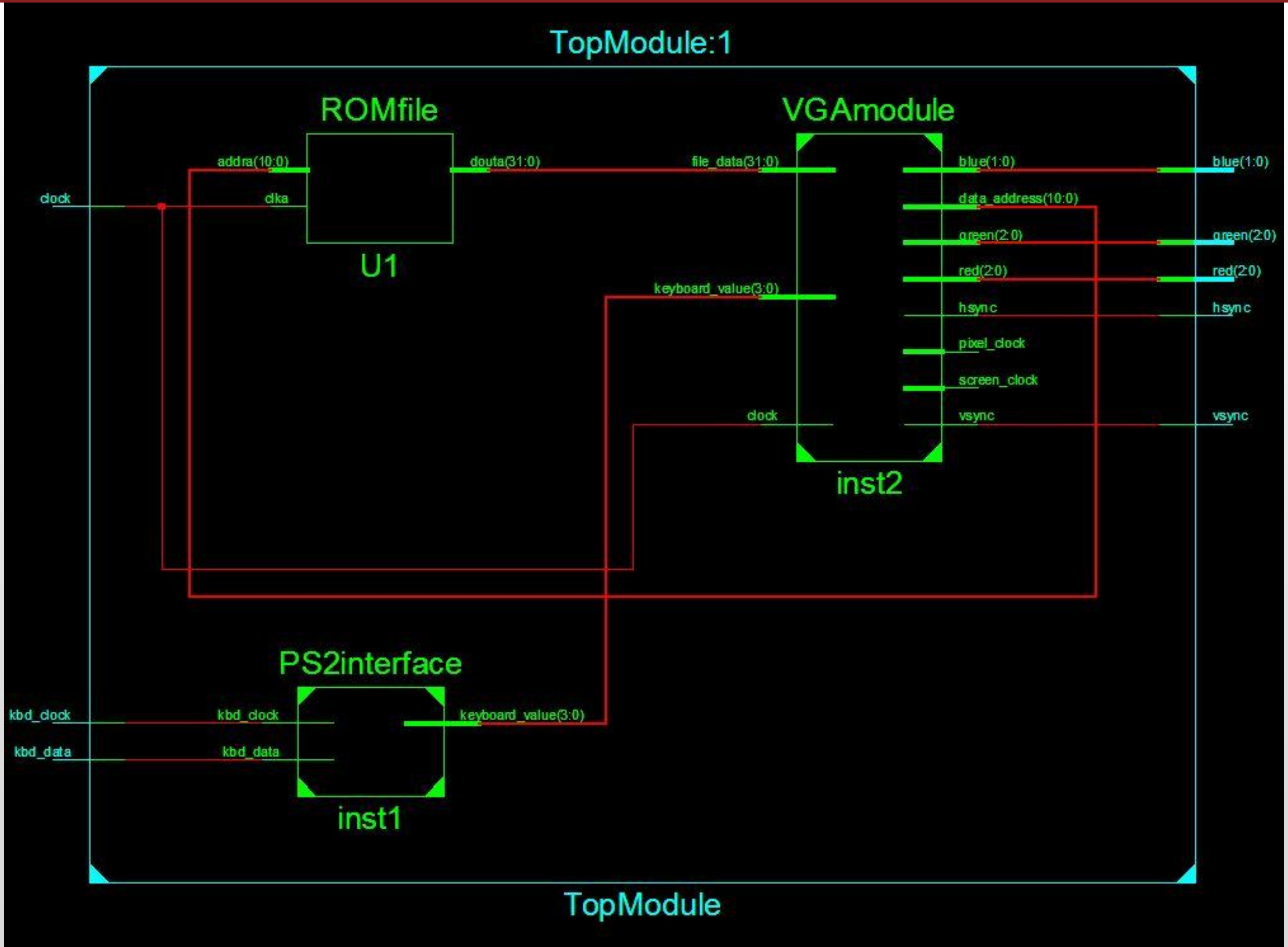
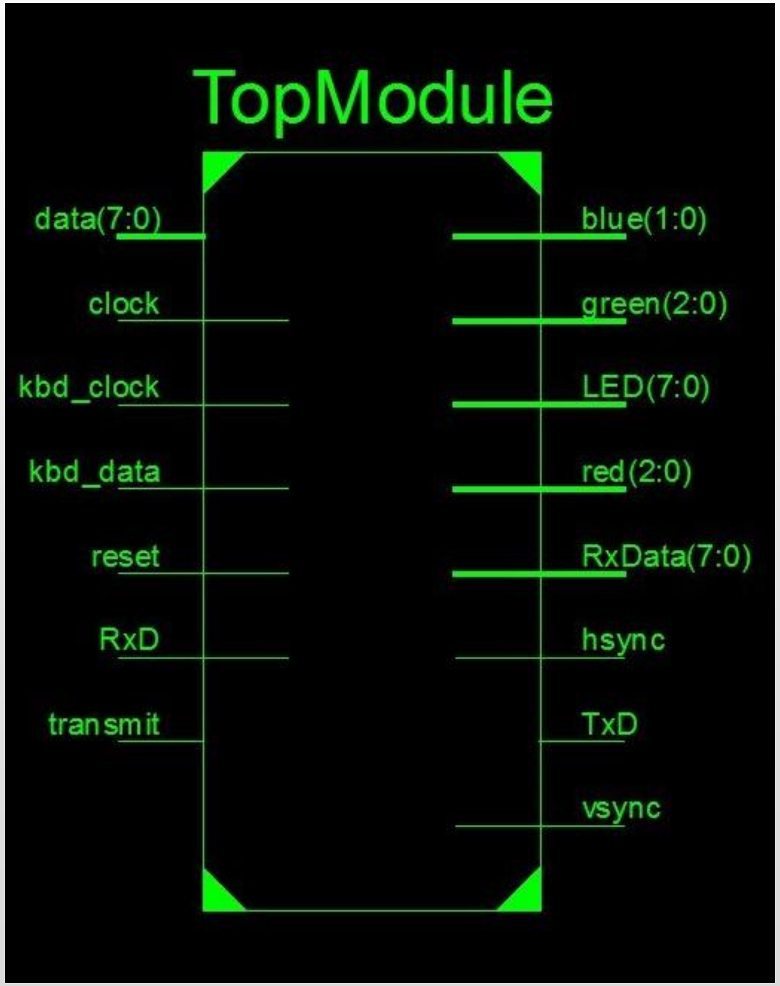
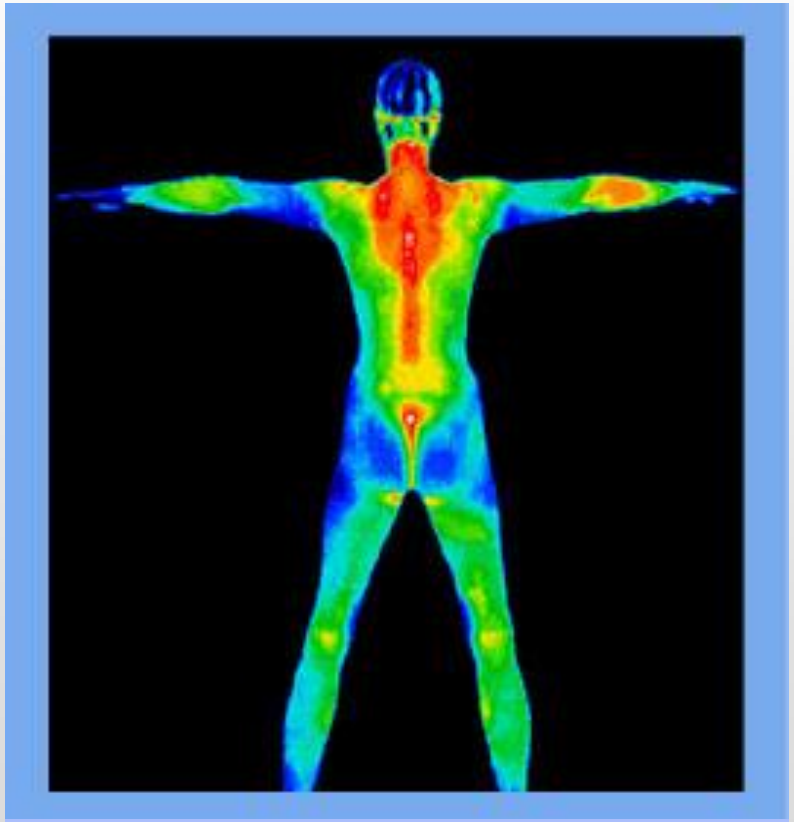
Verilog Register-Transfer Level (RTL) schematics





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

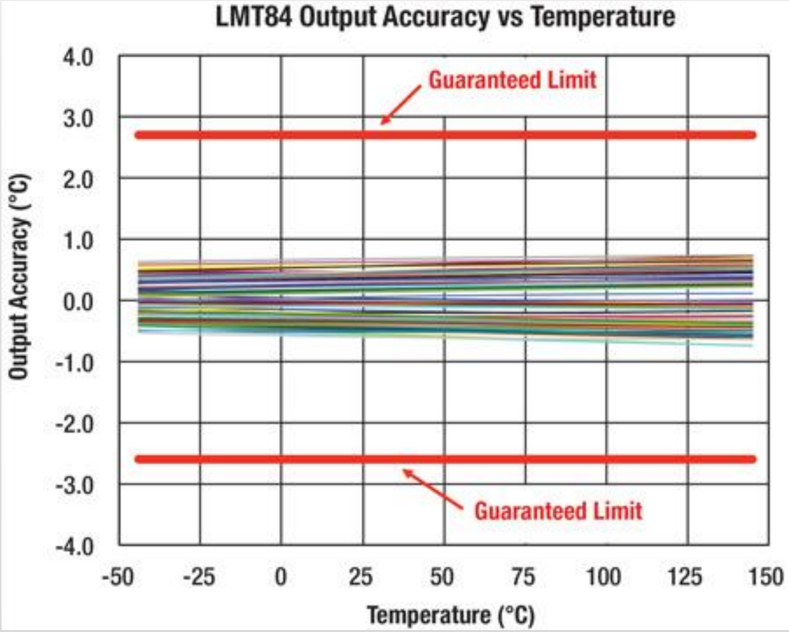
Temperature Sensors

LMT Series

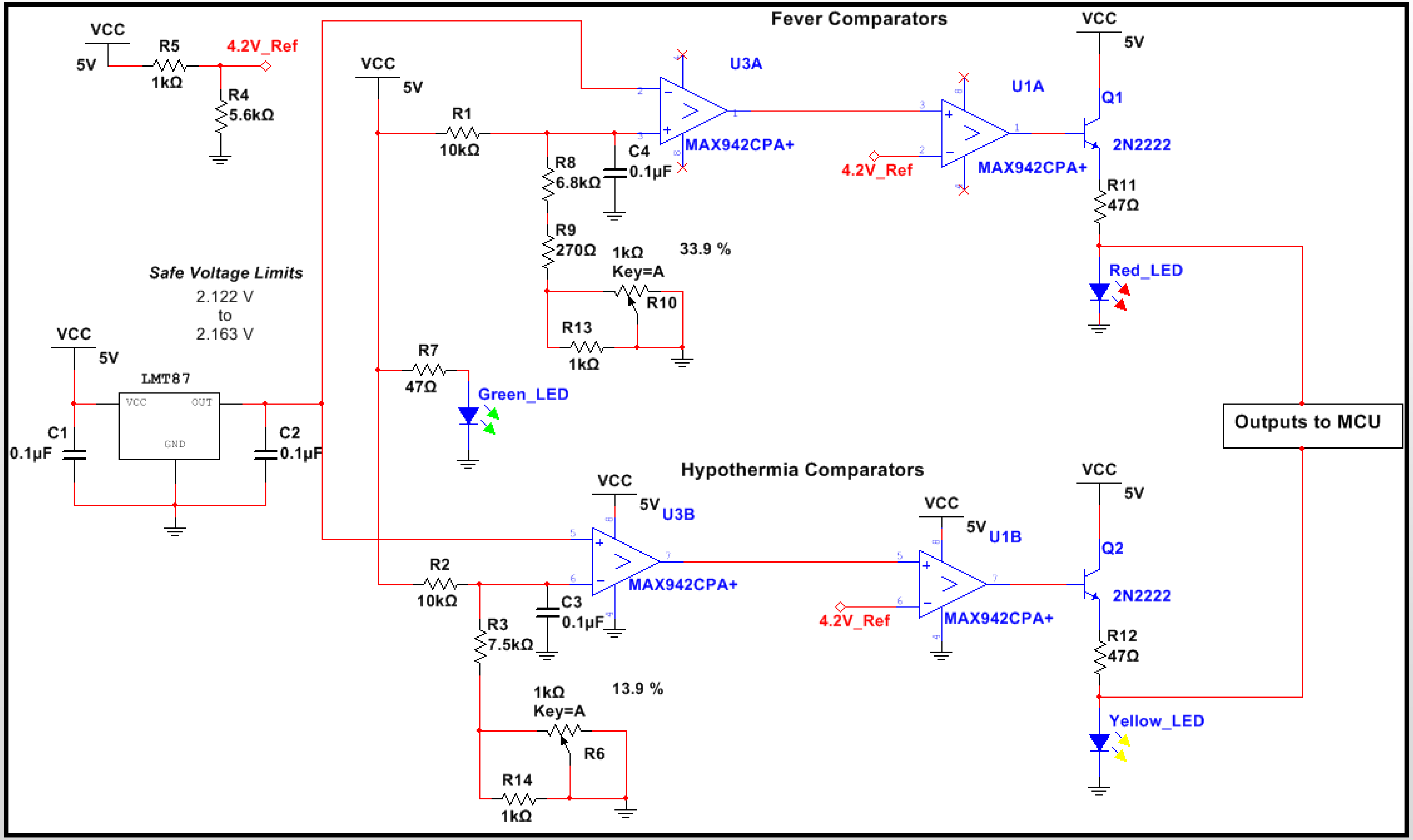
- Typical values are more accurate ~ 0.2°C vs LMs 0.3°C
- Texas Instruments will be coming out this year with a brand-new temperature sensor, the LMT70.
- The LMT70 will have a range of inaccuracy between min and max around 0.3°C and a typical 0.05°C. It will also be recommended for medical applications.
- 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.

Weight Sensor: Strain Gauge Comparisons

TYPE OF LOAD CELL	WEIGHT RANGE	ACCURACY (FS)	APPLICATIONS	ADVANTAGES	DISADVANTAGES
Bending Beam	10-5,000 lb	0.03%	Tanks, platform scales	Low cost, simple construction	Strain gages are exposed, require protection
Shear Beam	10-5,000 lb	0.03%	Tanks, platform scales, off- center loads	High side load rejection, better sealing and protection	
Canister	Up to 500,000 lb	0.05%	Truck, tank, track, and hopper scales	Handles load movements	No horizontal load protection
Ring and Pancake	5- 500,000 lb		Tanks, bins, scales	All stainless steel	No load movement allowed
Button and washer	0-50,000 lb 0-200 lb typ.	1%	Small scales	Small, inexpensive	Loads must be centered, no load movement permitted

Load Sensors

We chose the SEN – 10245

- Bending beam load cell
- Cheap ($9.95)
- 50 Kg payload each
- 3 needed to support up to 350 pounds

Capacity	kg	40-50
Comprehensive Error	mv/v	0.05
Output Sensitivity	mv/v	1.0±0.1
Nonlinearity	%FS	0.03
Repeatability	%FS	0.03
Hysteresis	%FS	0.03
Creep	(3min)%FS	0.03
Zero Drift	(1min)%FS	0.03
Temp. Effect on Zero	%FS/10℃	1
Temp. Effect on Output	%FS/10℃	0.05
Zero Output	mV/V	±0.1
Input Resistance	Ω	1000±20
Output Resistance	Ω	1000±20
Insulation Resistance	MΩ	≥5000
Excitation Voltage	V	≤10
Operation Temp. Range	℃	0--+50
Overload Capacity	%FS	150

Blood Pressure Machine Types

Wrist Blood Pressure Machine

Pros

- Portable
- Light weight

Cons

- Not as accurate
- Only fit one smaller arms
- Costs more
- Not easy to hack

Upper Arm Blood Pressure Machine

Pros

- Cheaper
- More accurate
- Better Possibility to get electrical readings

- Changeable bands to fit different arms

Cons

- Not convenient for a portable system

Pulse Oximeter Overall System

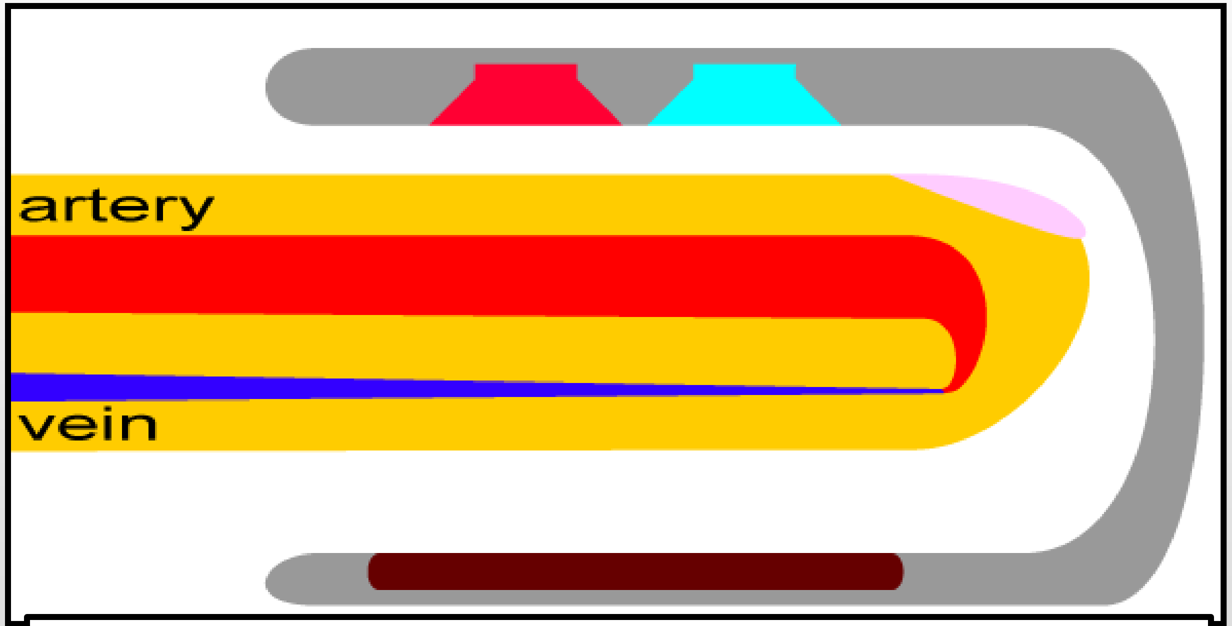


Image by Prassana Tilakaratna

Step 1:
Alternating LED Lights

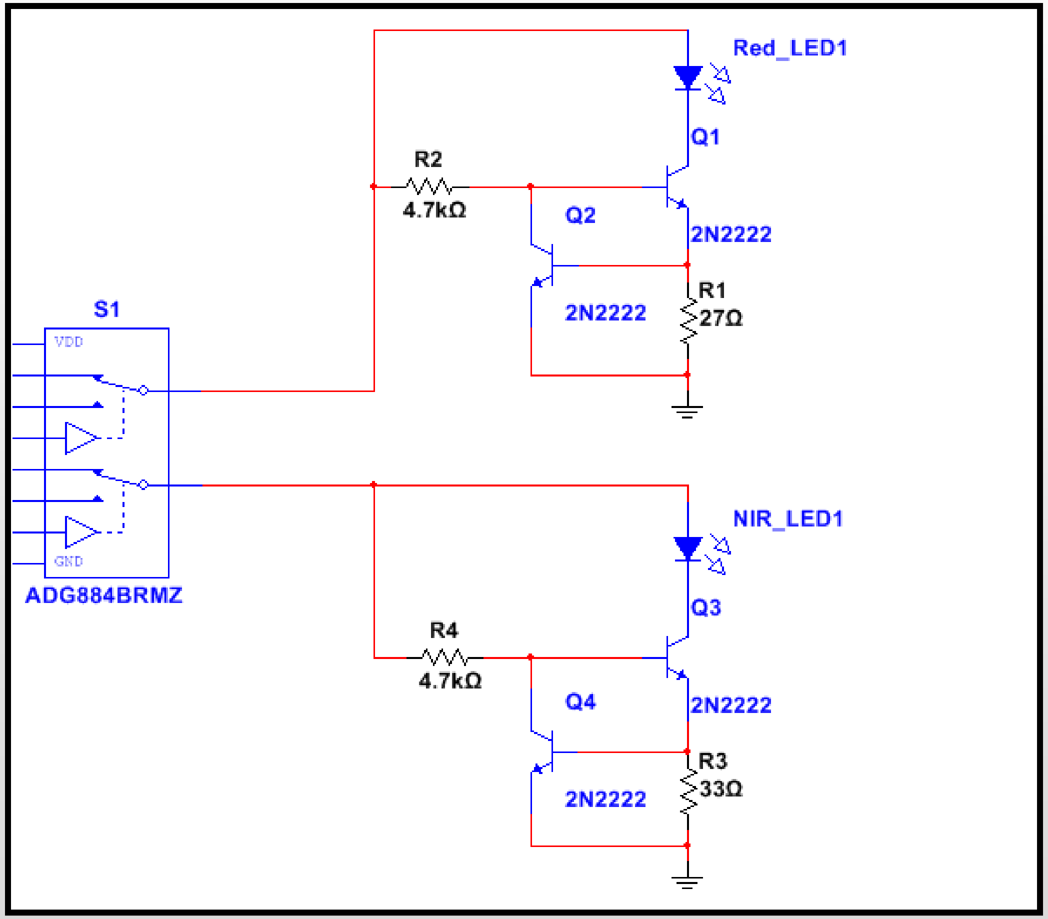
Step 2:
Light is Absorbed Through Finger

Step 3:
Sensor Detects Unabsorbed Light

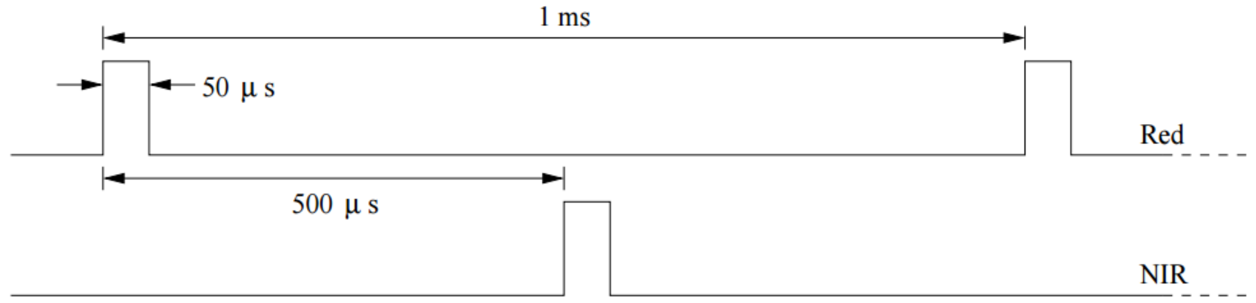
Step 4:
Filter Out Noise

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

Step 1:
Constant-Current Schematic for Alternating LEDs

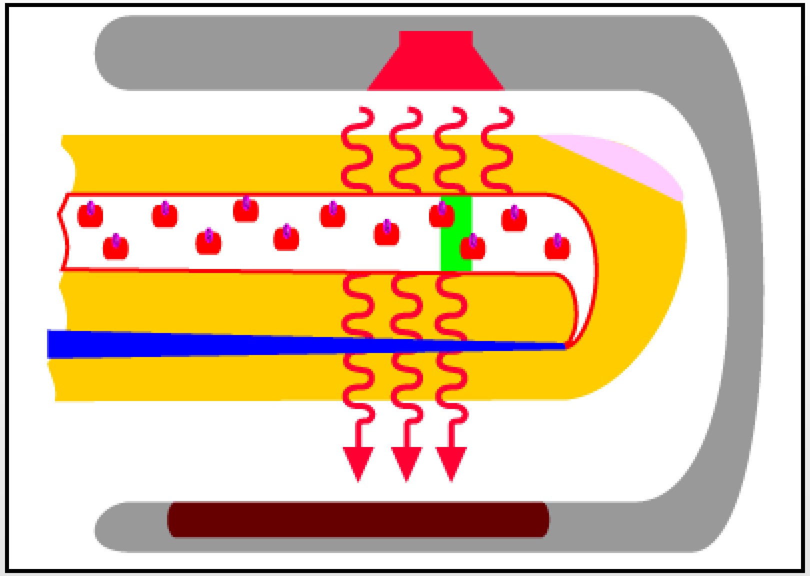


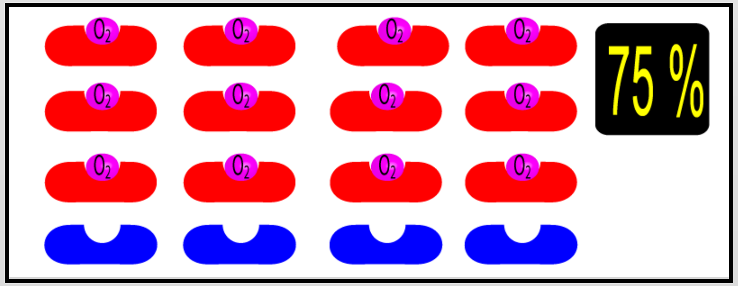
- LEDs must be supplied a constant current in each pulse to avoid calculation errors. The error occurs because different currents in each pulse will create different light intensities.
- The wavelength must be 660nm for the red LED and 940nm for the near-infrared (NIR) LED.
- Cardiac frequency is between 0.5 – 5 Hz therefore pulsing the LEDs at 1kHz is more than enough to obtain good readings.

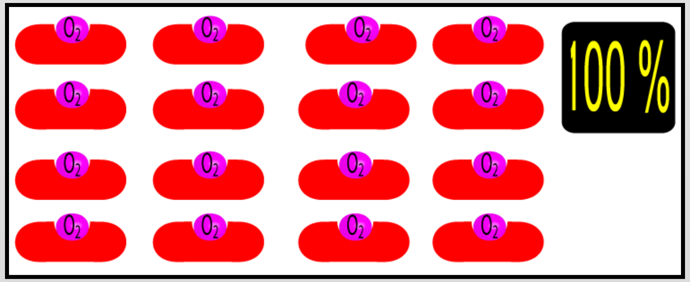


Timing Diagram by Dr.Lionel Tarassenko and Dr.Neil Townsend

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.

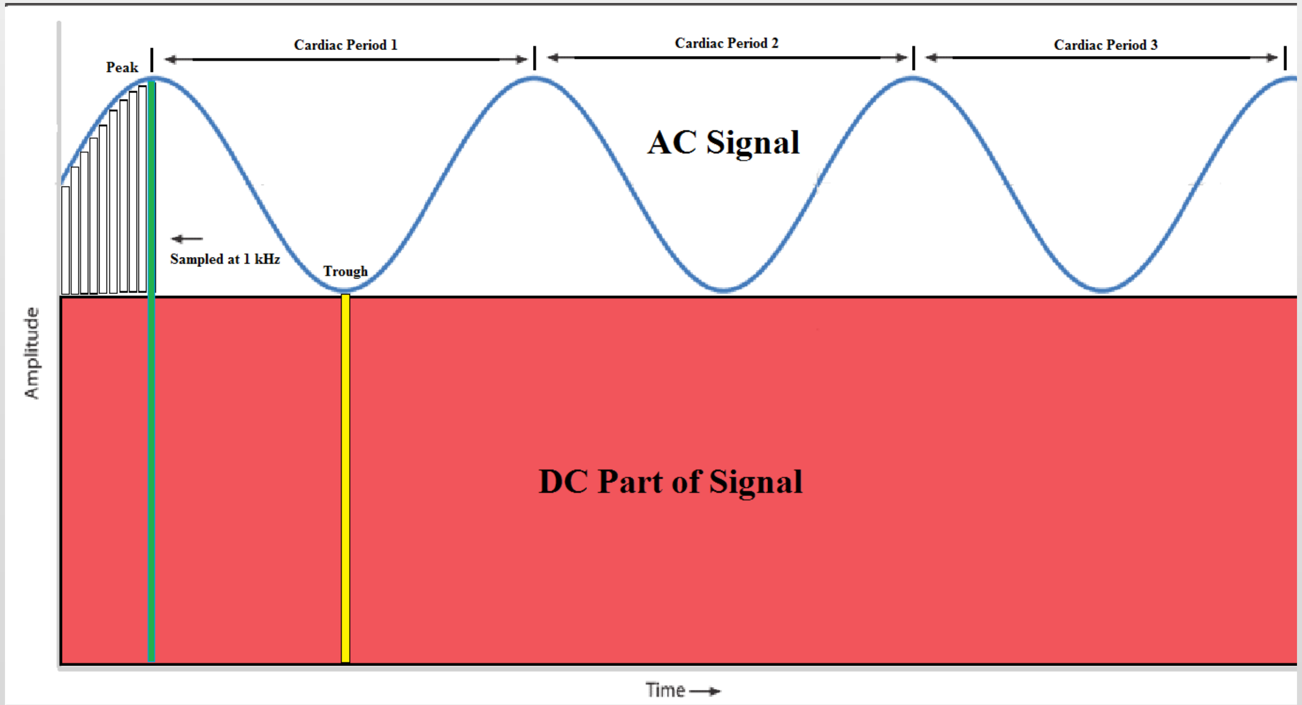
- The reason 660nm and 940nm LEDs are used is because:

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

Step 3:
Sensor Detects Unabsorbed Light

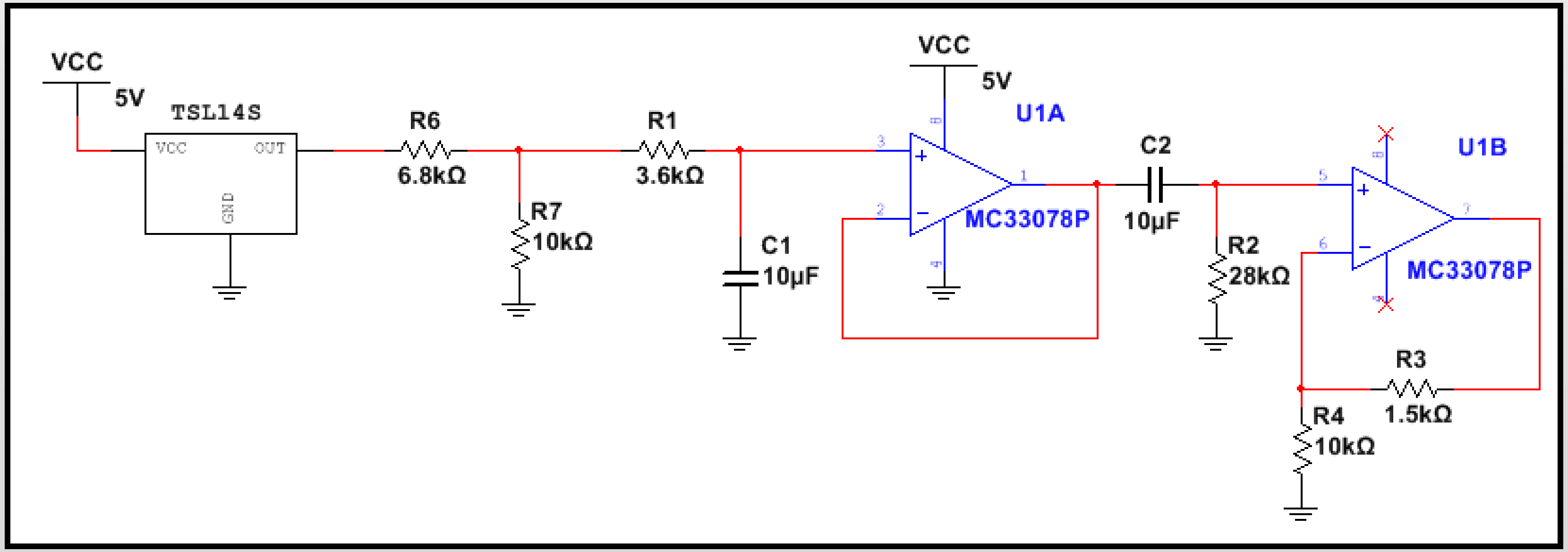
The light sensor chosen is the TSL14S by AMS AG

- 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



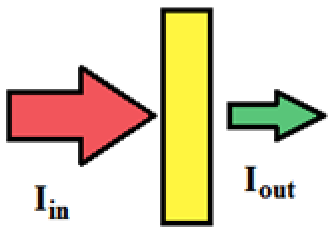
Step 4:
Noise Filter Schematic

- 0.5 – 5 Hz Bandpass Filter
- MC33078 op-amps chosen for its low price, high-speed, low-noise, unity-gain stable and single-supply operation.
- Voltage divider at the output of the sensor to prevent the sensor from outputting a voltage that can cause harm to the MSP430.
- 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.

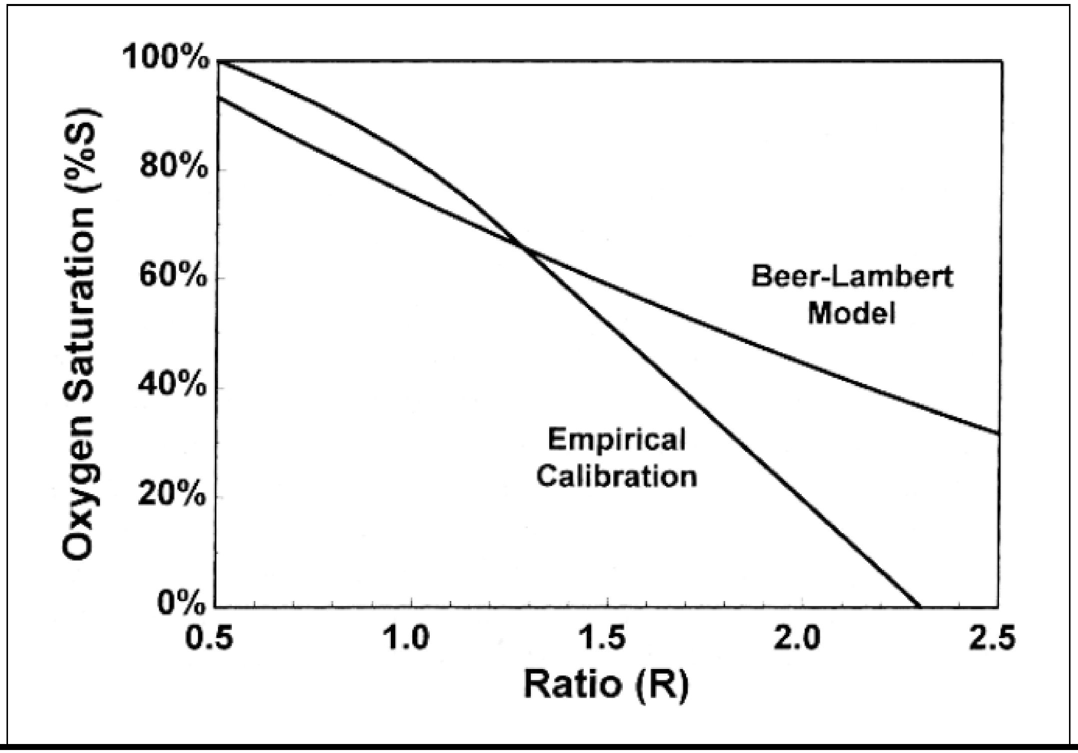
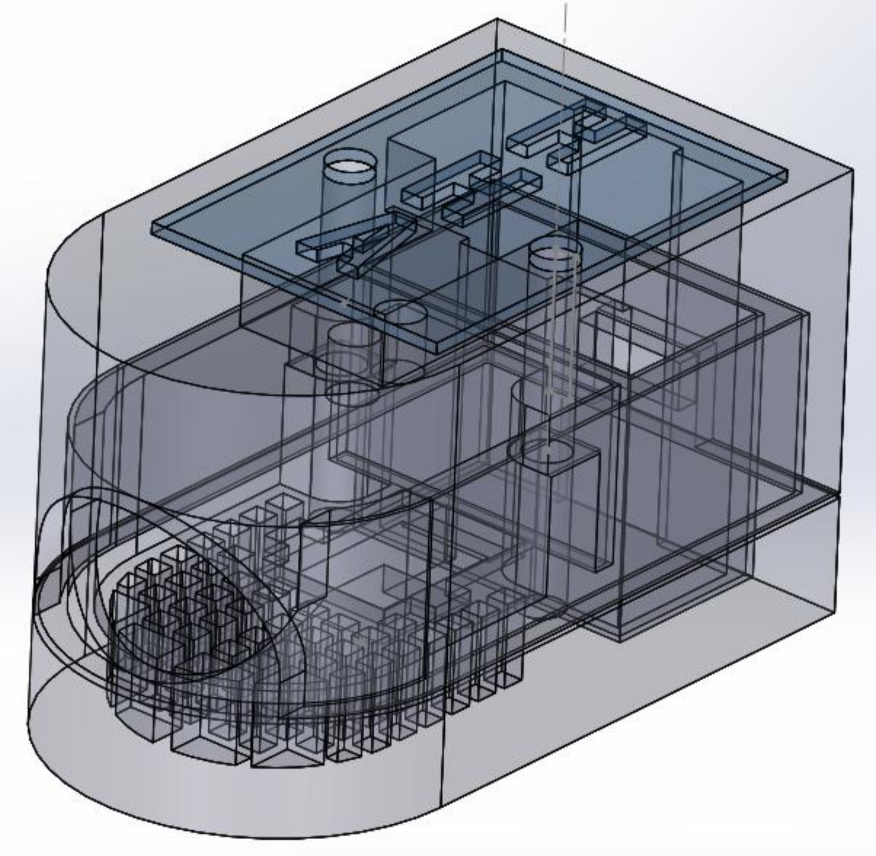
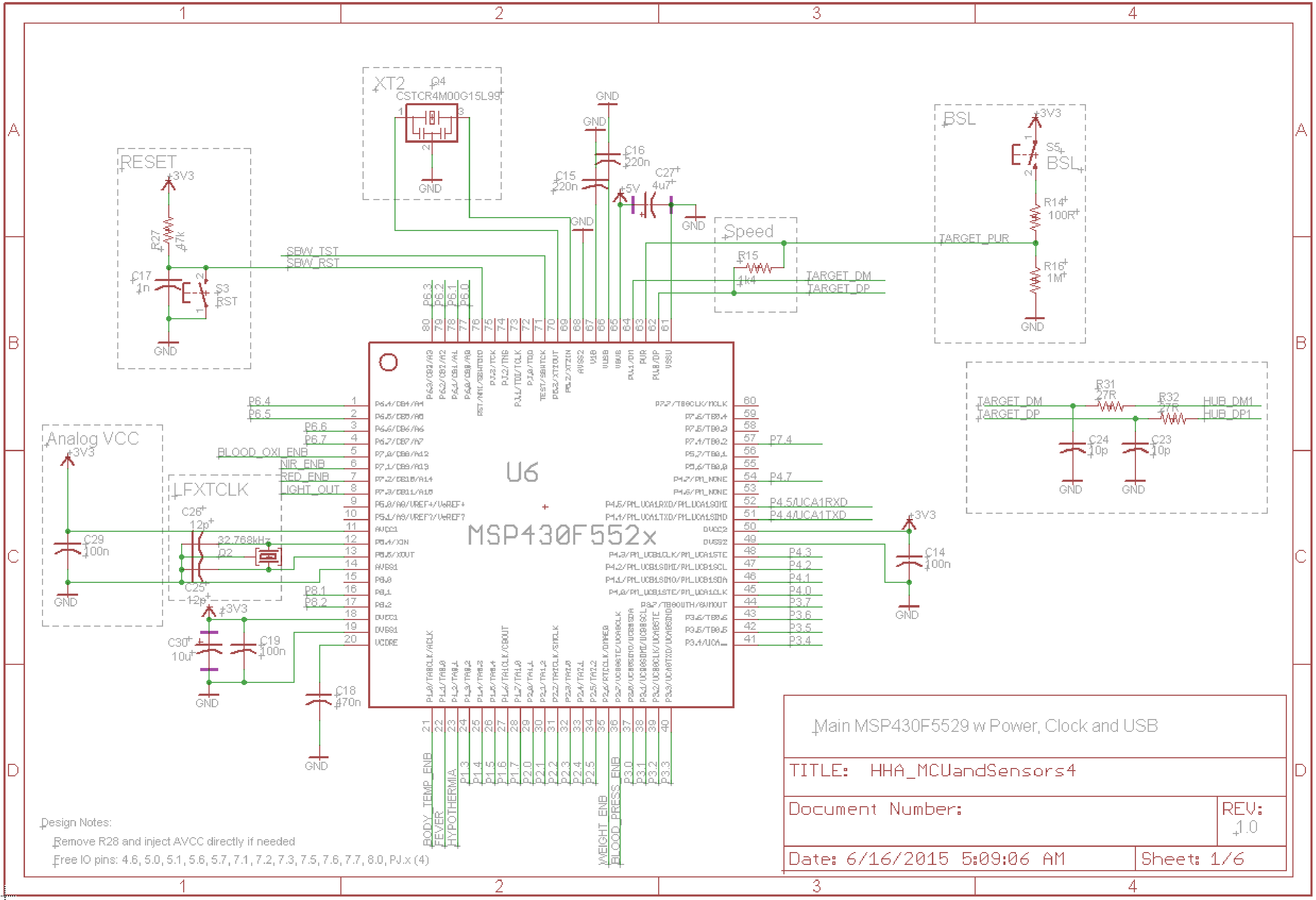


Image by Lionel Tarassenko

HHA Pulse Oximeter: Casing

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XT2
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Speed
BSL
Analog VCC
LFXTCLK
32.768kHz
U6
MSP430F552x
SBW_TST
SBW_RST
TARGET_PUR
TARGET_DM
TARGET_DP
HUB_DM1
HUB_DP1
BLOOD_OXI_ENB
NIR_ENB
RED_ENB
LIGHT_OUT
P4.5/UCA1RXD
P4.4/UCA1TXD
BODY_TEMP_ENB
FEVER
HYPOTHERMIA
WEIGHT_ENB
BLOOD_PRESS_ENB
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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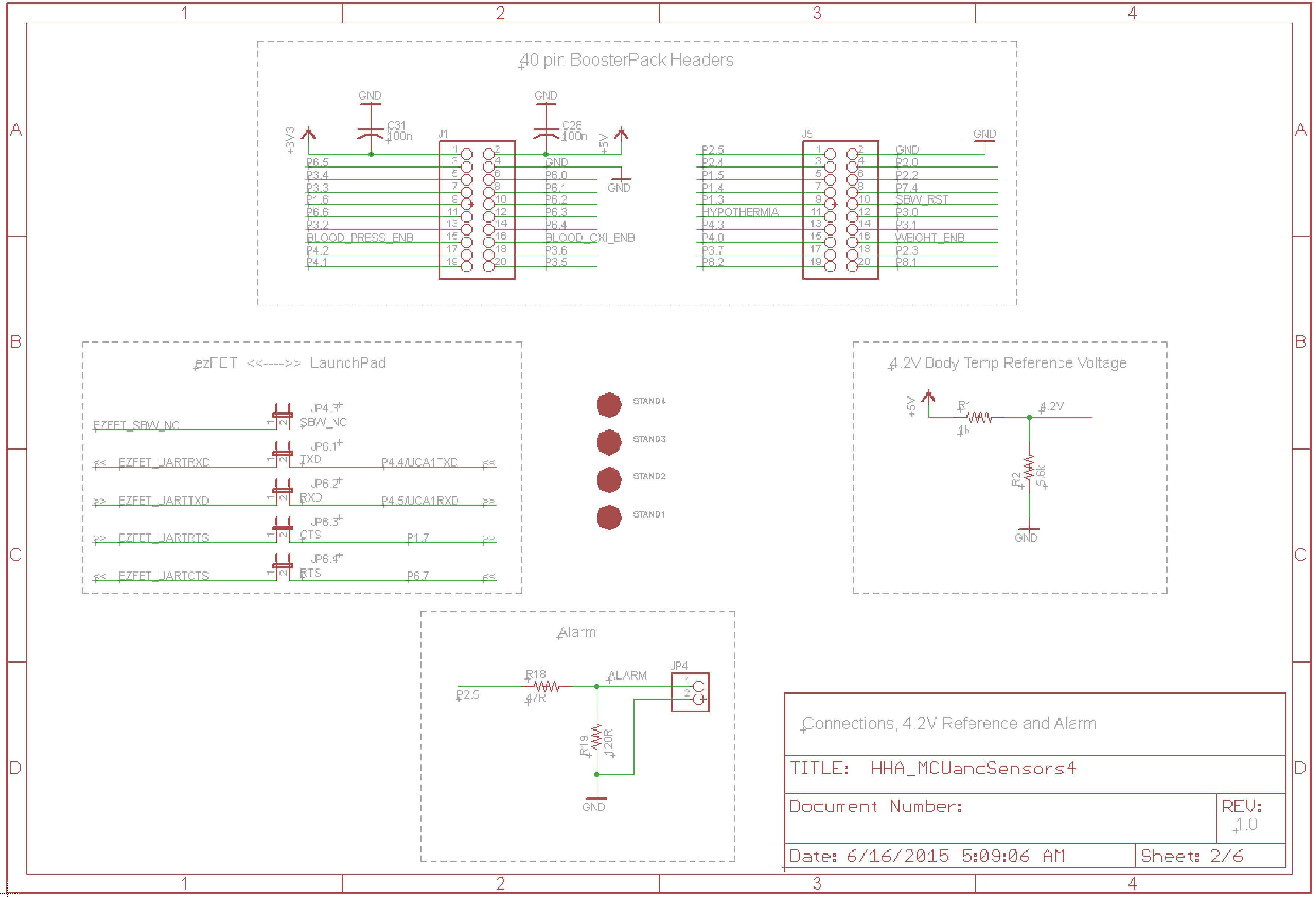
Date: 6/16/2015 5:09:06 AM
Sheet: 1/6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C31
100n
GND
C28
100n
+3V3
+5V
J1
P6.5
P3.4
P3.3
P1.6
P6.6
P3.2
BLOOD_PRESS_ENB
P4.2
P4.1
GND
P6.0
P6.1
P6.2
P6.3
P6.4
BLOOD_OXI_ENB
P3.6
P3.5
J5
P2.5
P2.4
P1.5
P1.4
P1.3
HYPOTHERMIA
P4.3
P4.0
P3.7
P8.2
GND
P2.0
P2.2
P7.4
SBW_RST
P3.0
P3.1
WEIGHT_ENB
P2.3
P8.1
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EZFET_SBW_NC
JP4.3
SBW_NC
EZFET_UARTRXD
JP6.1
TXD
P4.4/UCA1TXD
EZFET_UARTTXD
JP6.2
RXD
P4.5/UCA1RXD
EZFET_UARTRTS
JP6.3
CTS
P1.7
EZFET_UARTCTS
JP6.4
RTS
P6.7
STAND4
STAND3
STAND2
STAND1
4.2V Body Temp Reference Voltage
+5V
R1
1k
4.2V
R2
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P2.5
R18
47R
ALARM
JP4
R19
120R
GND
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Document Number:
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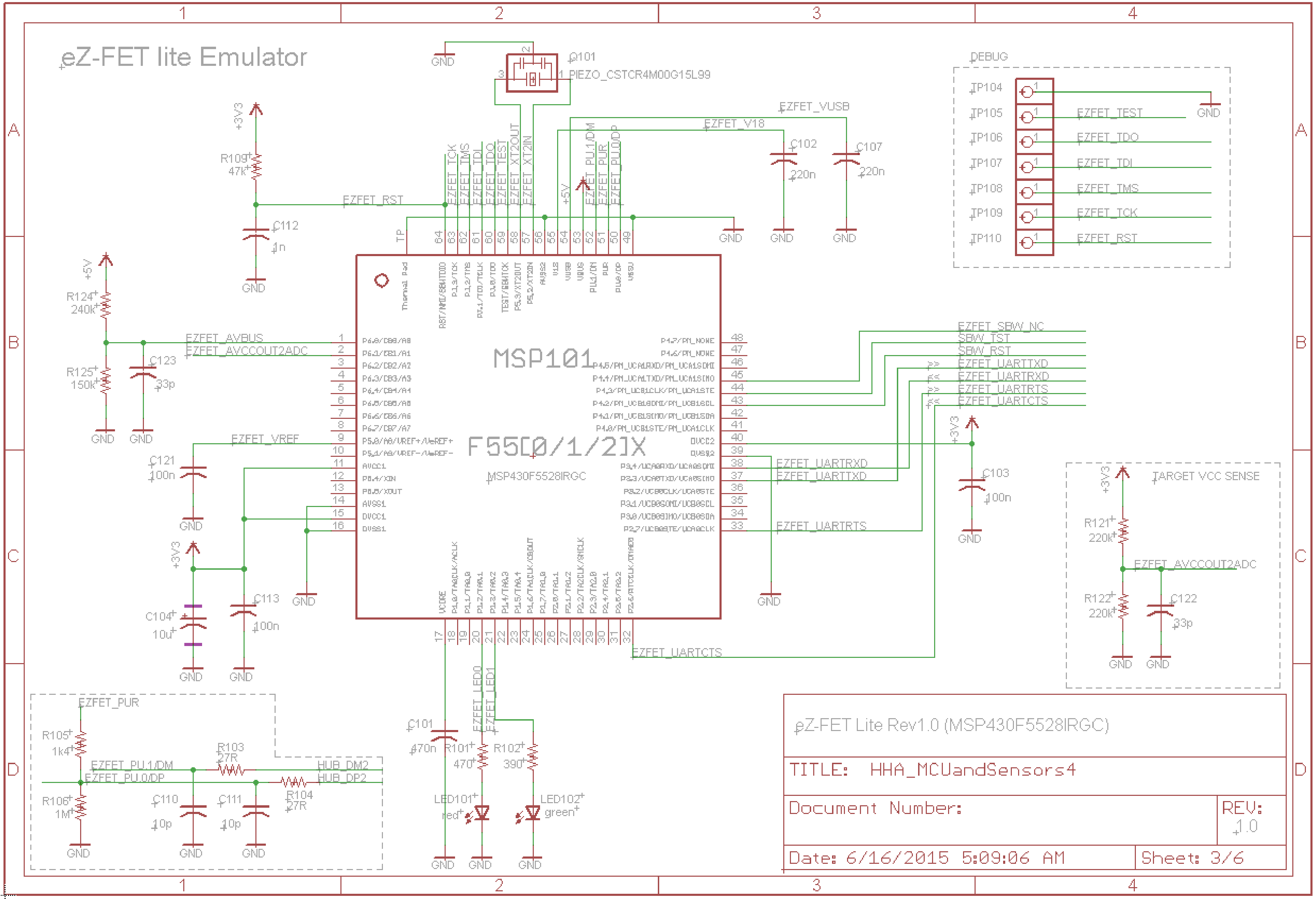
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TP105
TP106
TP107
TP108
TP109
TP110
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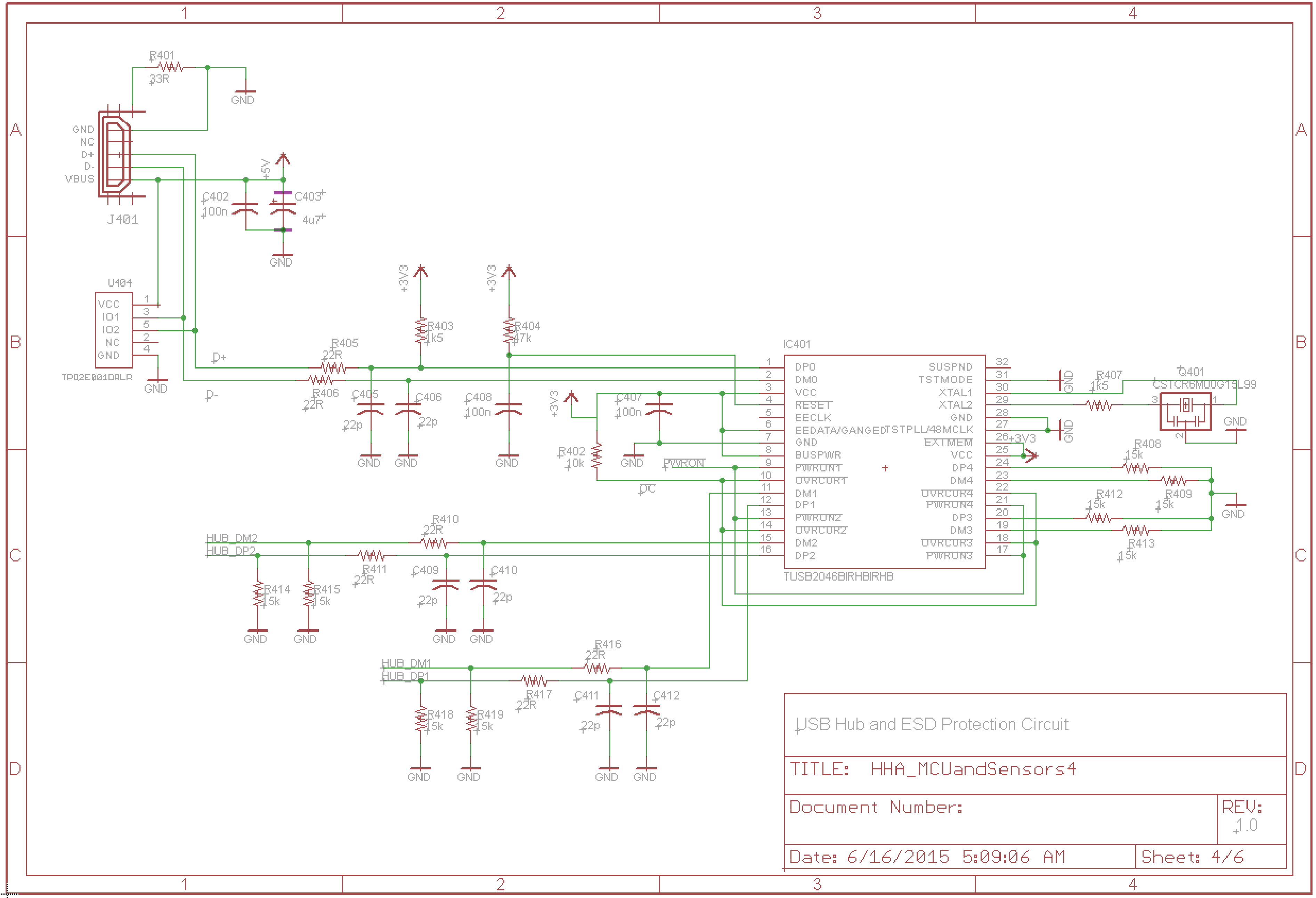
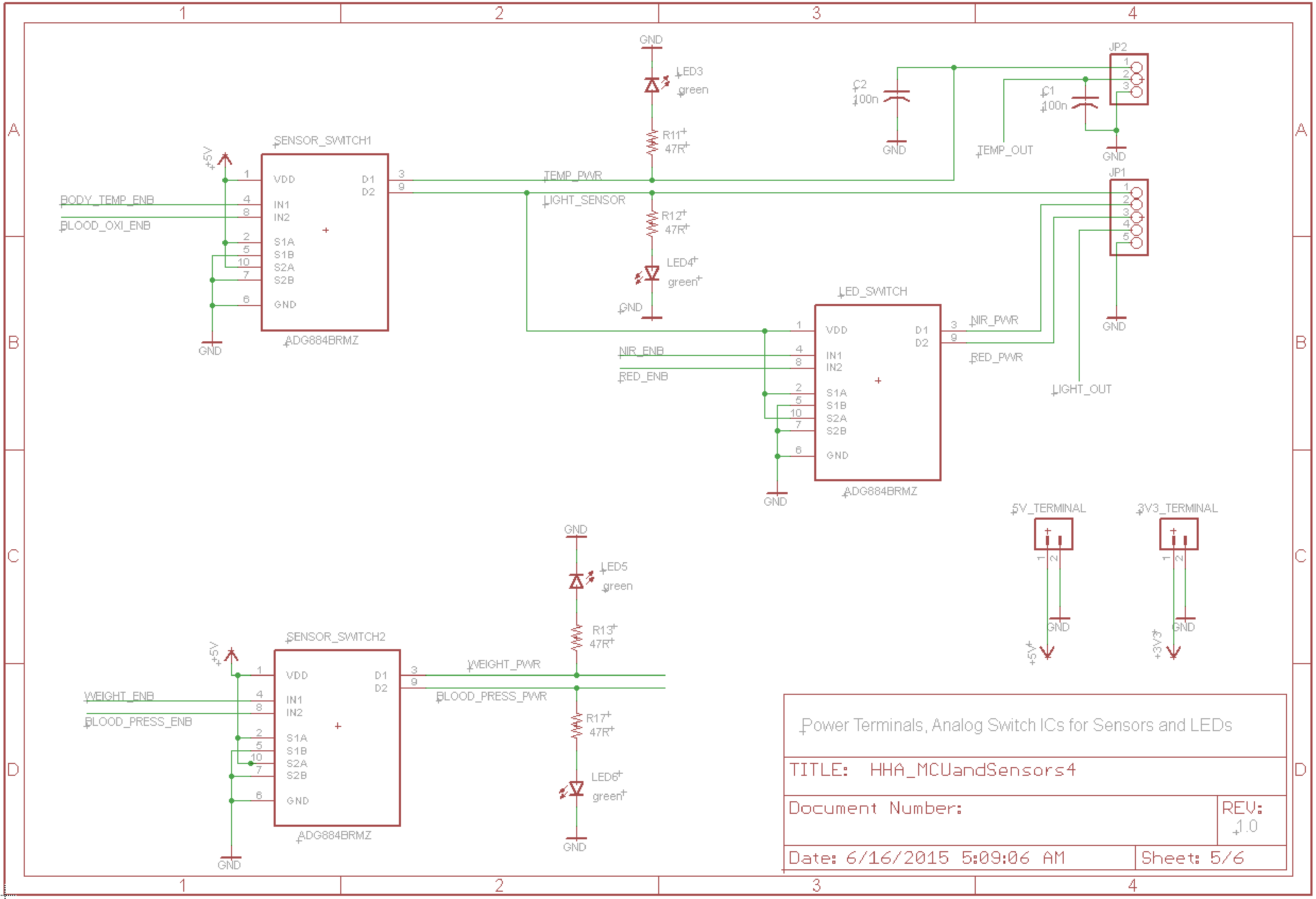
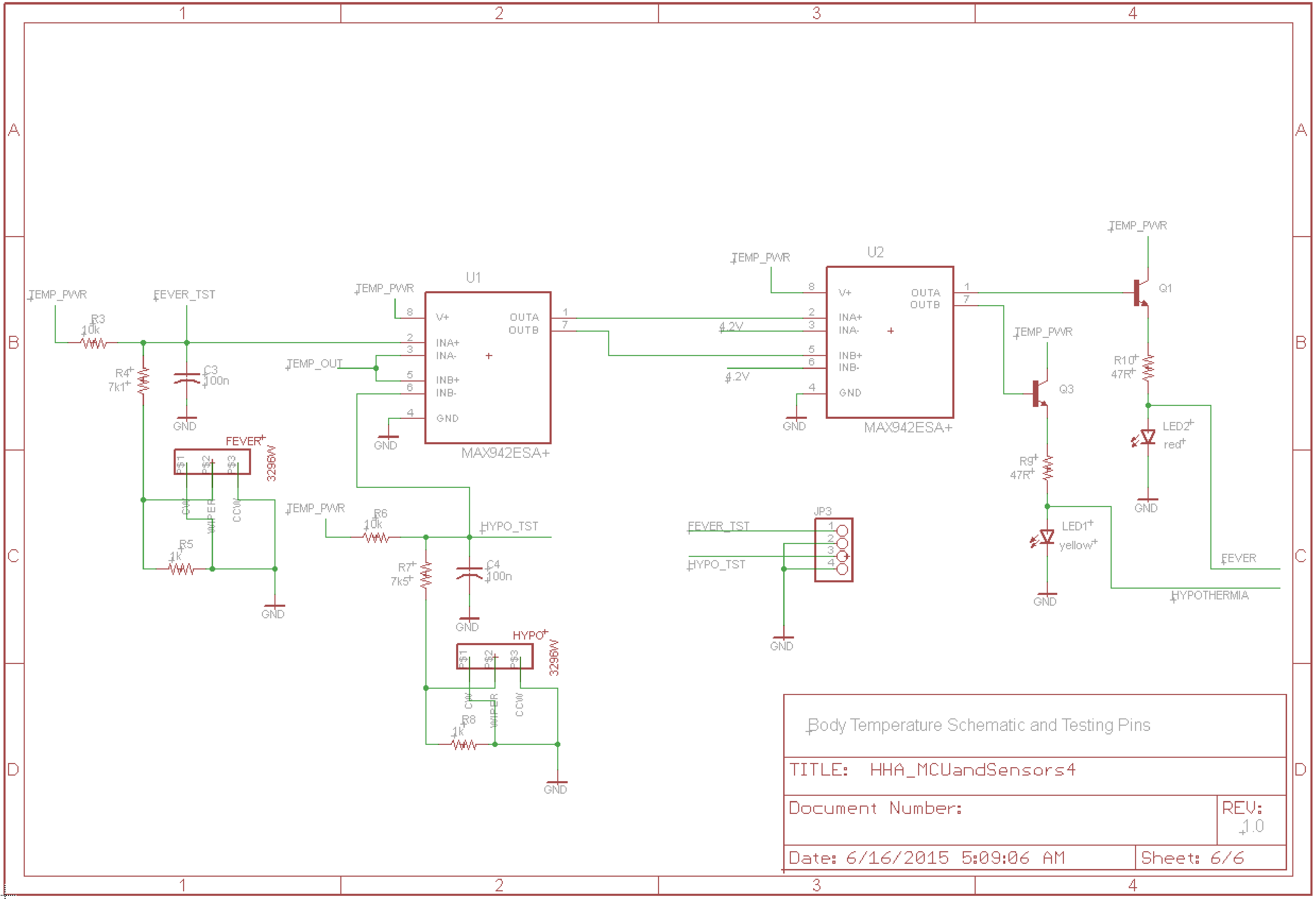
EZFET_TDO
EZFET_TDI
EZFET_TMS
EZFET_TCK
EZFET_RST
EZFET_VUSB
EZFET_V18
C102 220n
C107 220n
R109 47k
C112 1n
R124 240k
R125 150k
C123 33p
EZFET_AVBUS
EZFET_AVCCOUT2ADC
EZFET_VREF
C121 100n
C104 10u
C113 100n
MSP101
F55[0/1/2]X
MSP430F5528IRGC
EZFET_SBW_NC
SBW_TST
SBW_RST
EZFET_UARTTXD
EZFET_UARTRXD
EZFET_UARTRTS
EZFET_UARTCTS
C103 100n
TARGET VCC SENSE
R121 220k
R122 220k
C122 33p
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 470
R102 390
LED101 red
LED102 green
EZFET_LED0
EZFET_LED1
GND
+3V3
+5V
eZ-FET Lite Rev1.0 (MSP430F5528IRGC)
TITLE: HHA_MCUandSensors4
Document Number:
REV: 1.0
Date: 6/16/2015 5:09:06 AM
Sheet: 3/6


R401
33R
GND
J401
GND
NC
D+
D-
VBUS
+5V
C402
100n
C403
4u7
U404
VCC
IO1
IO2
NC
GND
TPD2E001DRLR
D+
D-
+3V3
R403
1k5
R404
47k
R405
22R
R406
22R
C405
22p
C406
22p
C408
100n
C407
100n
R402
10k
PWRON
OC
IC401
DP0
DM0
VCC
RESET
EECLK
EEDATA/GANGED
GND
BUSPWR
PWRON1
OVRCUR1
DM1
DP1
PWRON2
OVRCUR2
DM2
DP2
SUSPND
TSTMODE
XTAL1
XTAL2
GND
TSTPLL/48MCLK
EXTMEM
VCC
DP4
DM4
OVRCUR4
PWRON4
DP3
DM3
OVRCUR3
PWRON3
TUSB2046BIRHBIRHB
R407
1k5
Q401
CSTCR6M00G15L99
R408
15k
R409
15k
R412
15k
R413
15k
HUB_DM2
HUB_DP2
R410
22R
R411
22R
C409
22p
C410
22p
R414
15k
R415
15k
HUB_DM1
HUB_DP1
R416
22R
R417
22R
C411
22p
C412
22p
R418
15k
R419
15k
USB Hub and ESD Protection Circuit
TITLE: HHA_MCUandSensors4
Document Number:
REV: 1.0
Date: 6/16/2015 5:09:06 AM
Sheet: 4/6


SENSOR_SWITCH1
ADG884BRMZ
VDD
IN1
IN2
S1A
S1B
S2A
S2B
GND
D1
D2
+5V
BODY_TEMP_ENB
BLOOD_OXI_ENB
GND
TEMP_PWR
LIGHT_SENSOR
GND
LED3
green
R11
47R
R12
47R
LED4
green
GND
C2
100n
GND
C1
100n
TEMP_OUT
GND
JP2
JP1
GND
LED_SWITCH
ADG884BRMZ
NIR_ENB
RED_ENB
NIR_PWR
RED_PWR
LIGHT_OUT
GND
5V_TERMINAL
3V3_TERMINAL
GND
GND
+5V
+3V3
SENSOR_SWITCH2
ADG884BRMZ
+5V
WEIGHT_ENB
BLOOD_PRESS_ENB
WEIGHT_PWR
BLOOD_PRESS_PWR
GND
GND
LED5
green
R13
47R
R17
47R
LED6
green
GND
Power Terminals, Analog Switch ICs for Sensors and LEDs
TITLE: HHA_MCUandSensors4
Document Number:
REV:
1.0
Date: 6/16/2015 5:09:06 AM
Sheet: 5/6



Body Temperature Schematic and Testing Pins

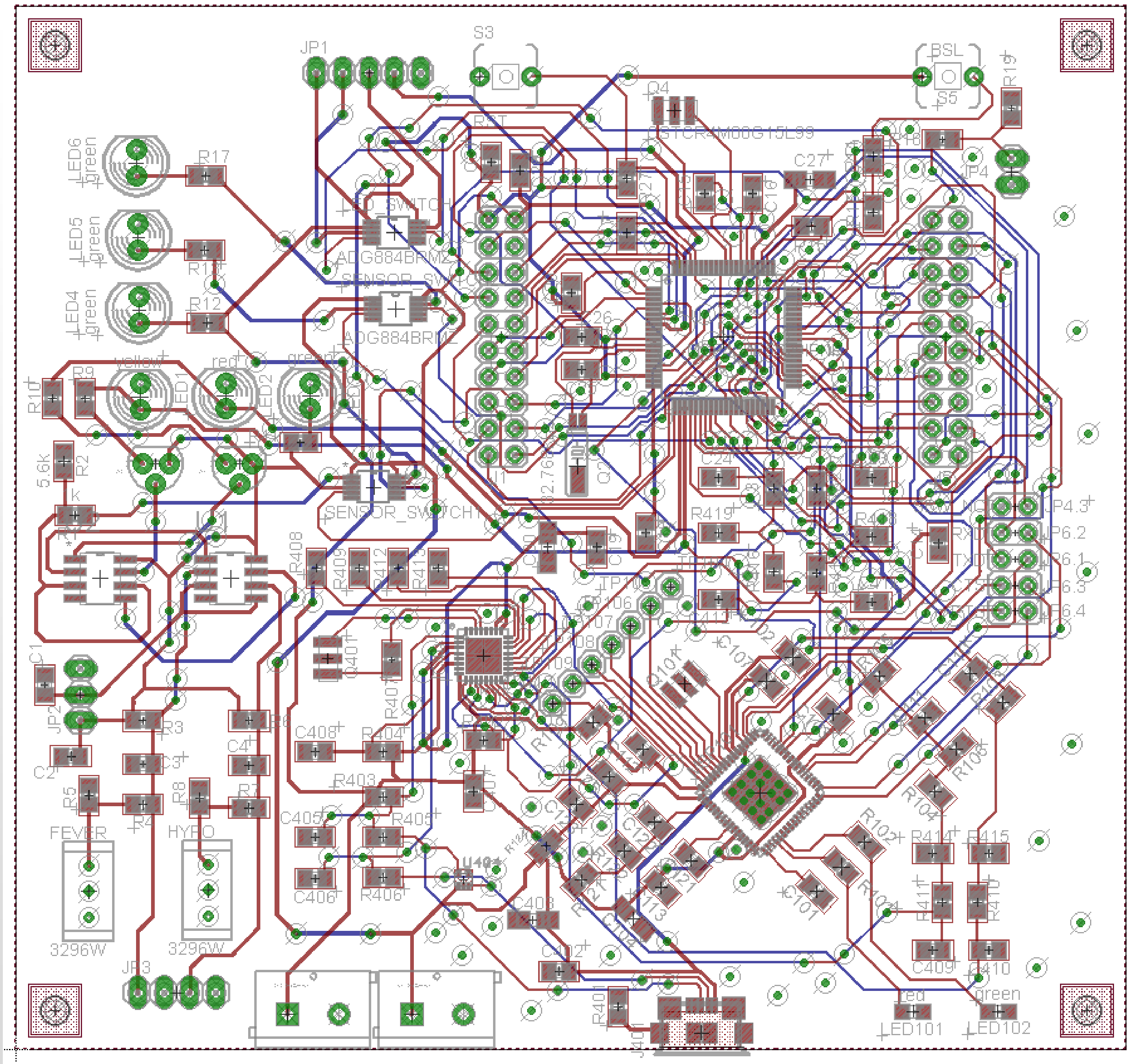
TITLE: HHA_MCUandSensors4

Document Number:

REV: 1.0

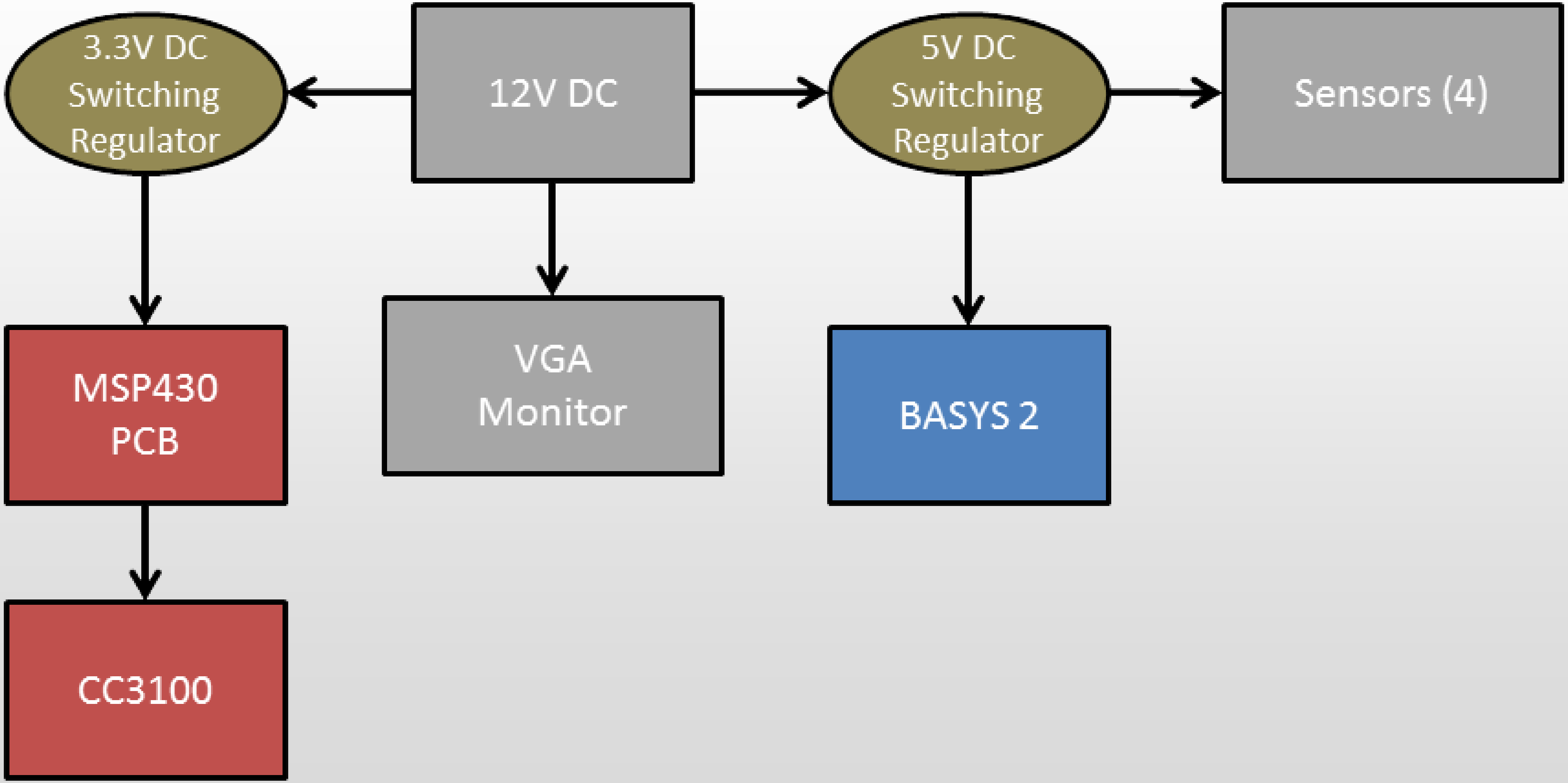
Date: 6/16/2015 5:09:06 AM

Sheet: 6/6



JP1
S3
BSL
S5
R19
Q4
CSTCR4M00G15L99
C27
JP4
R17
green
LED6
LED5
LED4
R12
ADG884BRMZ
SENSOR_SWITCH
yellow
red
green
R9
R10
5.6K
R2
R408
R409
R412
R419
C24
JP4.3
JP6.2
JP6.1
JP6.3
JP6.4
C1
JP2
C2
R3
C3
C4
R5
R4
R8
R7
FEVER
HYPO
3296W
JP3
C408
R404
R403
C405
R405
C406
R406
C403
C402
R401
R414
R415
R410
C409
C410
red
green
LED101
LED102
R102
R104
R105
C101

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

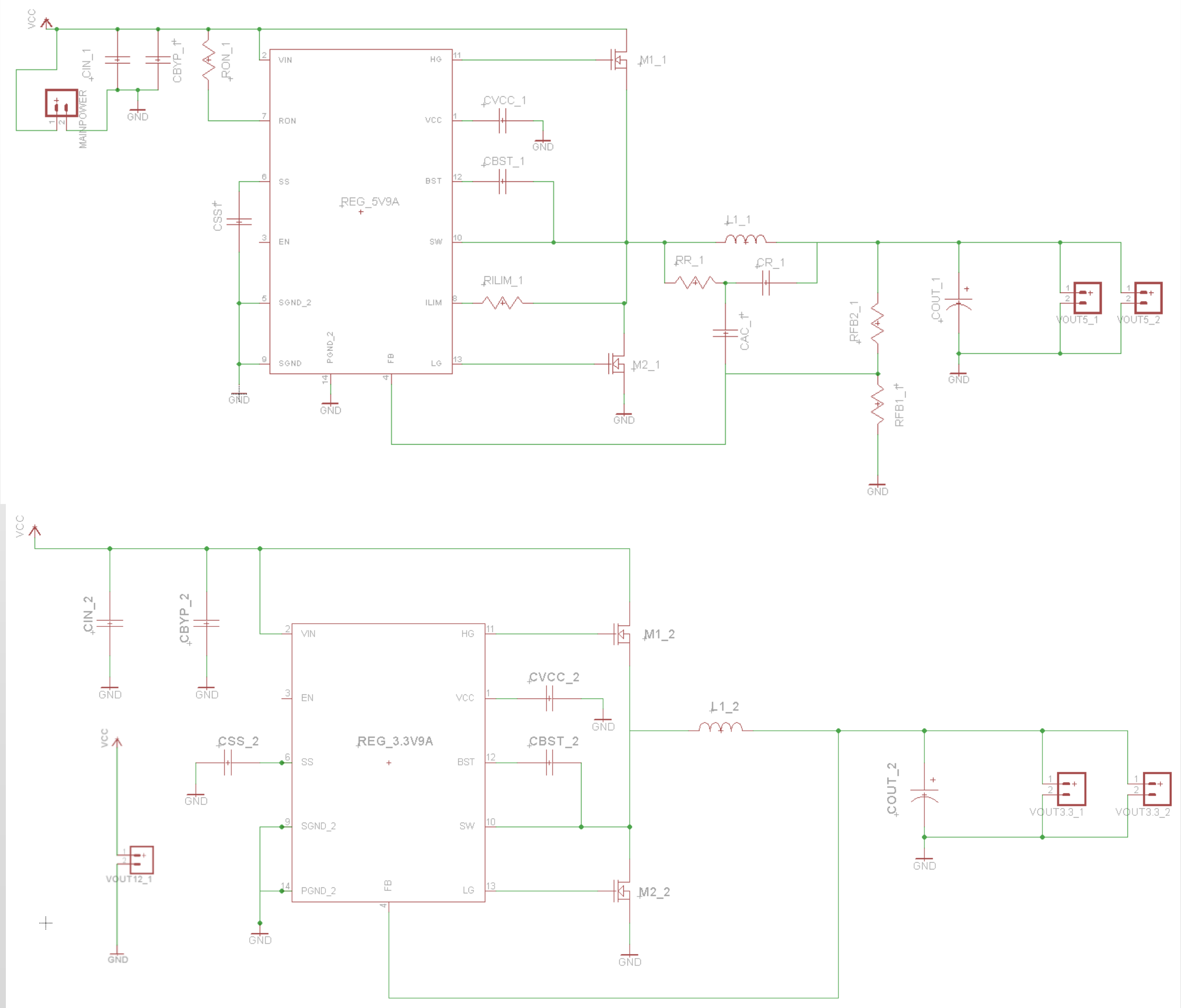
Component	Max I/V requirements
MSP430F5529 and MSP430F5528IRGC	250 mA, 3.3 V
CC3100	450 mA, 3.3 V
Pulse oximeter sensor	160 mA, 5 V
BASYS 2 FPGA	250 mA, 5 V
Body temperature sensor	100 mA, 5 V
7" LCD Monitor	700 mA, 12 V

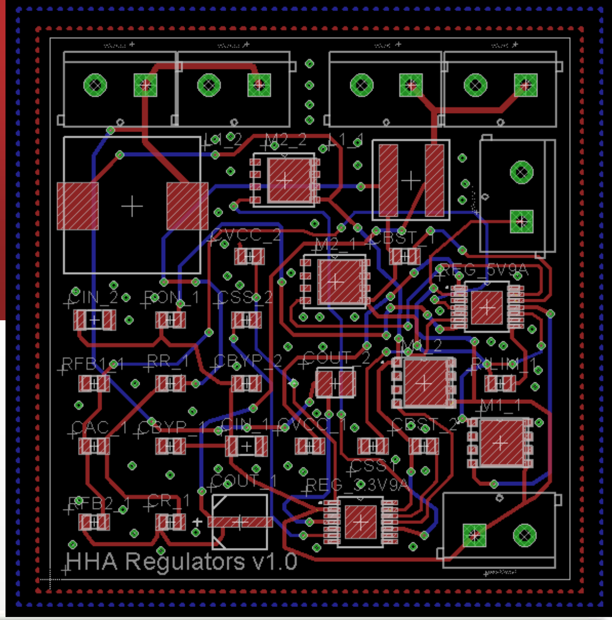
Power regulation PCB (cont.)

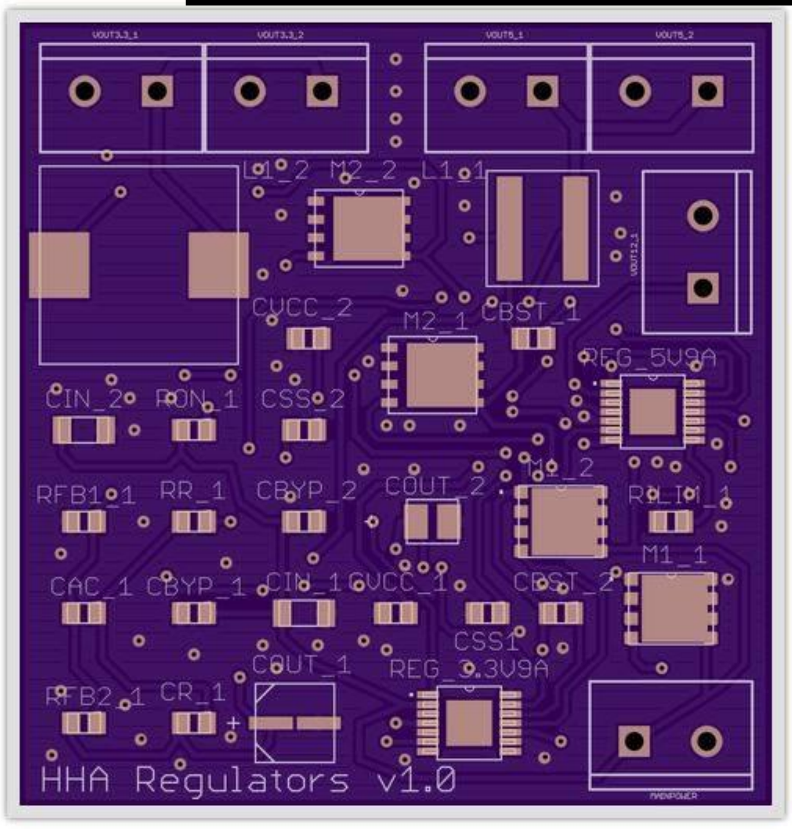
- 120V AC to 12V, 12A DC adapter powers the HHA

- 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	Already 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	Yes
ADG884BRMZ	$ 2.86	$ 2.70	-	3	Yes
MAX942	-	-	$ 2.80	2	No
MC33078P	$ 0.88	$ 0.88	$ 0.77	2	No
2N2222	$ 0.85	$ 1.79	-	4	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		
NIR LED	-	-	$ 0.60	1	Yes
TSL14S-LF	$ 1.48	$ 1.54	-	1	Yes
LMT87LP	$ 1.00	$ 1.00	$ 0.98	1	Yes
All Regulators Combined	-	-	$ 45.00	1	No
MCU PCB Parts	-	-	$ 50.00	1	No
PCBs	-	-	$ 122.00	6	No
Weight Scale	-	-	$ 32.18	1	No
Soldering Station	-	-	$ 30.00	1	Yes
Wrist Blood Pressure Monitor	-	-	$ 26.99	1	No
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

Blood Pressure Machine

- Unable to decide on which device to use
- Fearful that removing the LCD will damage the device

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?