NextGen Asset Tracking Device (NAT)

Group 1 – NAT

Brianna Thomason	Computer Engineer
Brittney Fry	Computer Engineer, Project Manager
Lucas Dickinson	Electrical Engineer, Computer Engineer
Ralph Baird	Computer Engineer
Wayne Marshall	Electrical Engineer

SPONSORED PROJECT

- YOUNG ENGINEERING SERVICES LLC
  - Professor Young
  - Professor McAlpin
- This project is multilayered
  - This SD project is only starting point
  - CS Team(s) will develop further
    - INS Algorithm
    - Other beneficial software features
      - Website additions
      - Additional Firmware functionality

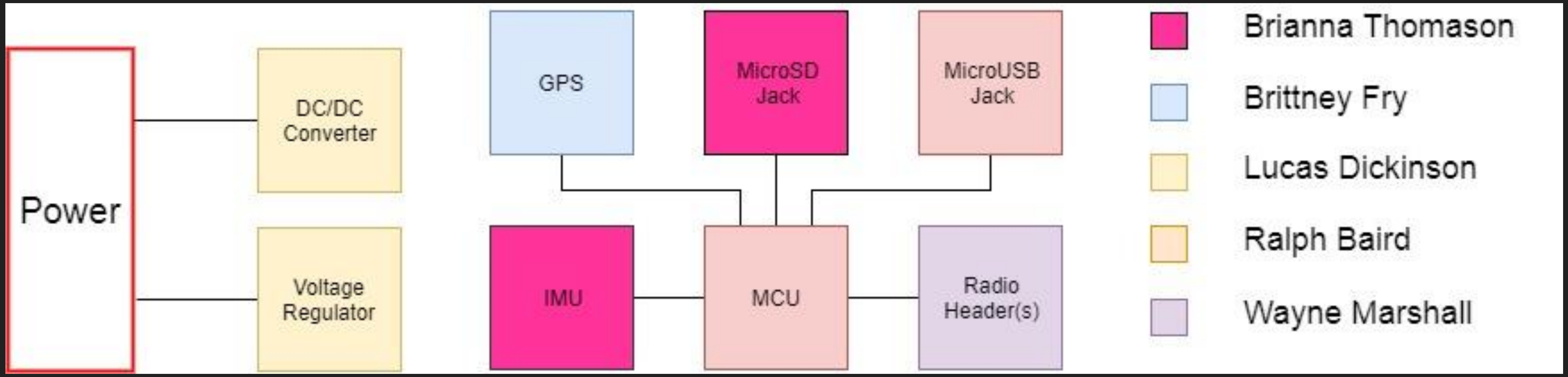
Motivation

- Objects get lost all of the time
  - Both for individuals and companies
- US =~20 to 50 billion dollars in lost or stolen equipment (Incorp, 2017)
- Companies embed software and hardware
  - Find my iPhone (Apple)
  - Find my mobile (Samsung)
  - Car keys tracker dongles
  - OnStar©
- INS Tracking

Goals and Objectives

- Main Goal
  - Produce a low-cost IOT module that can be attached to objects and report back its location
- Other Goals
  - Small device
  - Low power consumption

Overall Block Diagram



- The main processing power = Microcontroller
- Communication = Radio Modules
- Location = GPS
- Backup Location/Motion Data = IMU
- Main information storage = SD
- Power = Battery
- Everything communications with and through Microcontroller

Responsibilities

	Research					
	MCU	Radio	GPS	Power	IMU	MicroSD
Brianna					Primary	Primary
Brittney			Primary			
Lucas		Secondary		Primary		
Ralph	Primary					
Wayne		Primary		Secondary		

Responsibilities

	Schematic	Preliminary Testing HW	PCB	Firmware	Configuration GUI	Client GUI
Brianna				Secondary	Secondary	Primary
Brittney				Secondary	Primary	Secondary
Lucas	Primary	Secondary	Primary			
Ralph				Primary	Secondary	Secondary
Wayne	Secondary	Primary	Secondary			

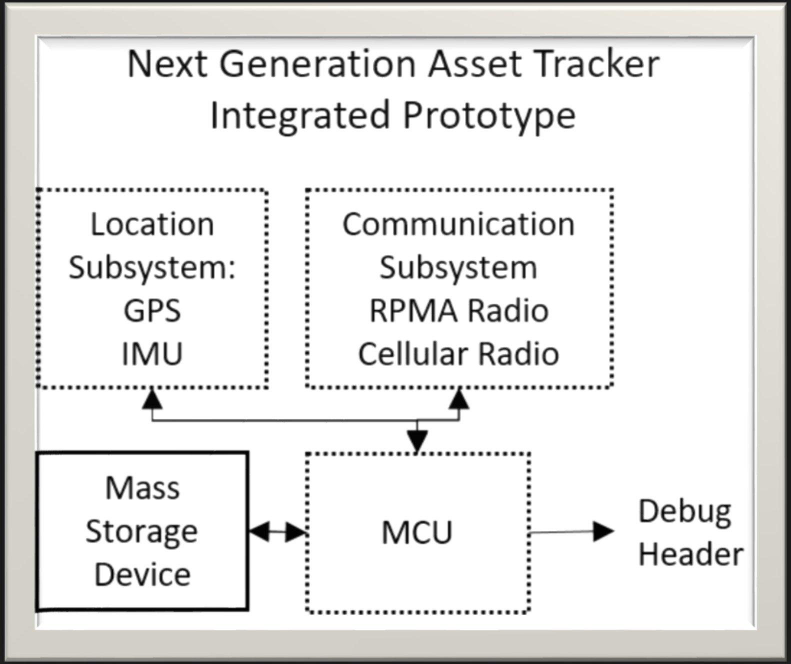
Specifications

General Specifications		
PCB	Size	Approx. size of credit card
Power	Voltage	Operate on 3.7V battery
Location	Accuracy	<3m
Software	Type	Firmware, Configuration GUI, Client GUI
Motion	Accuracy	<10degrees

Specifications

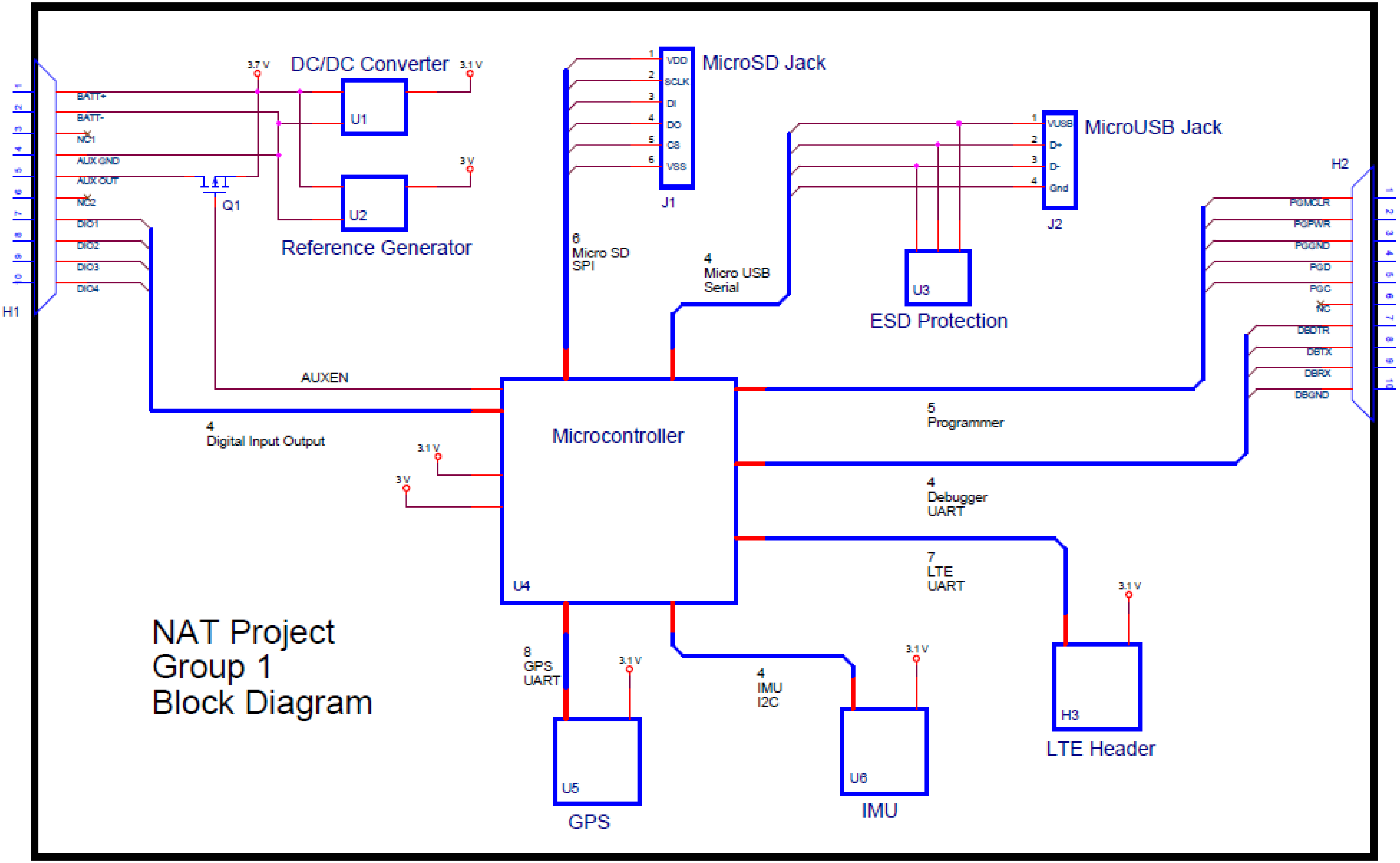
Hardware Specific	Software Specific
Integrate low power 16-bit MCU	Windows based Config GUI
Integrate GPS receiver	Configure Device with MSD/HID
Integrate 9-axis MPU	Communicate with Config GUI over USB
Integrate Radio Module	Web Based Client GUI
Able to record data	Communicate with Client GUI over radio modules
Able to recharge battery	Firmware that interfaces MCU with Radio, MPU, and GPS modules
Able to move between power modes	Firmware that creates data packet(s) to be sent on the network

Hardware Architecture

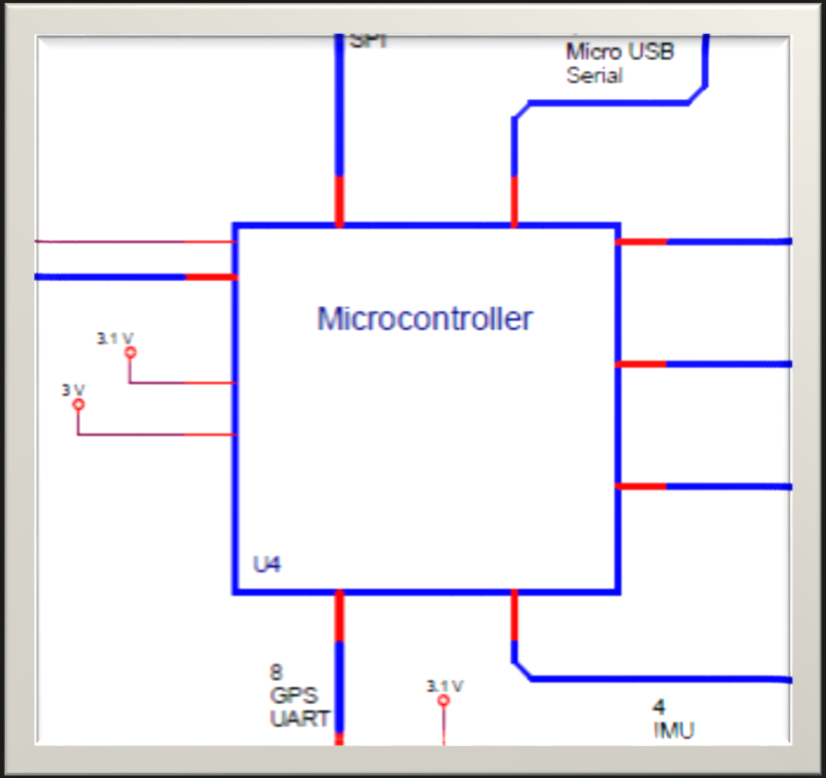


- MCU, IMU, and GPS chips integrated to single board design
- Traces for I^2C and UART from MCU to IMU and GPS respectively
- USB, UART, MSD and programming header on main board
- Off the shelf radio modules attaching to daughterboard interfaces
  - Removable and swappable during development

Electrical Block Diagram



Microcontroller Section



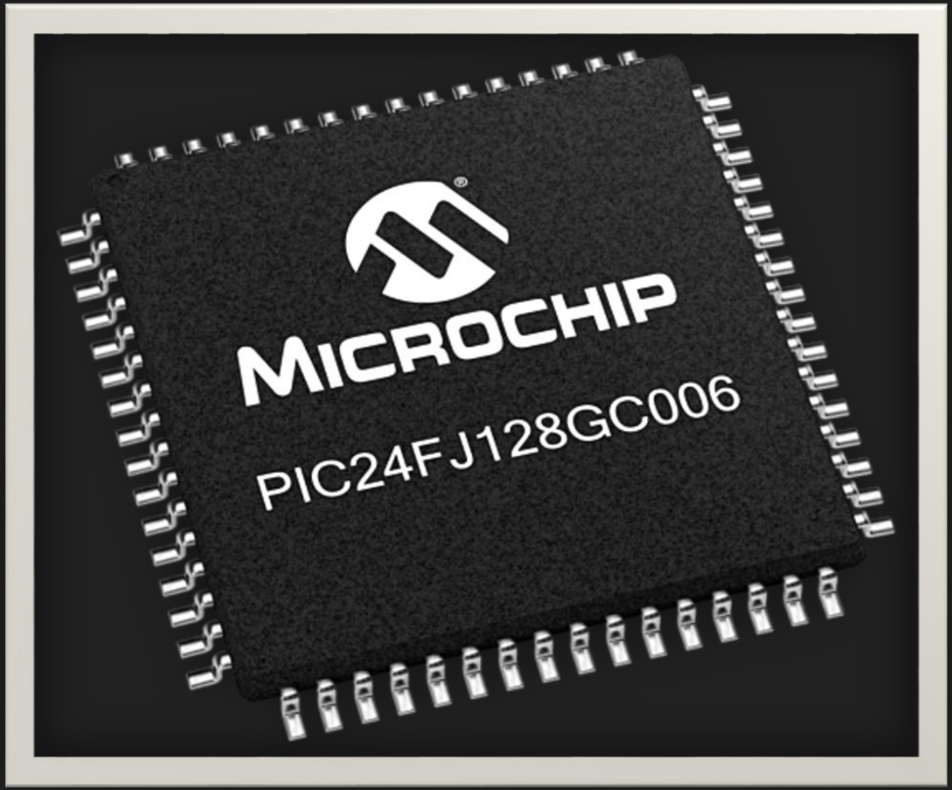
Central digital logic

- Coordinates communication between GPS, IoT communication, IMU, and SD card
- Controls full and low-power states of all of the above

Microcontrollers

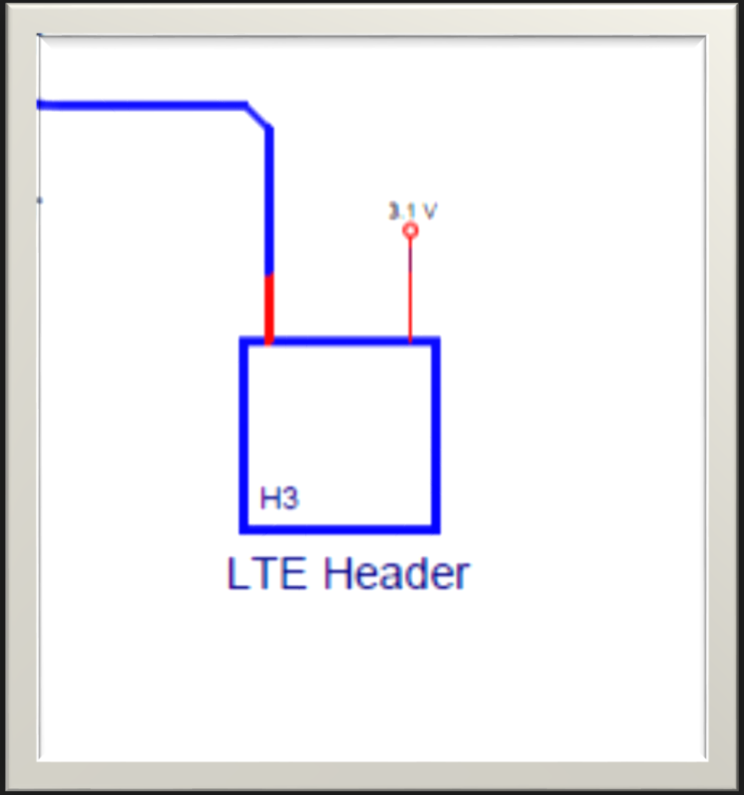
- Most straightforward solution
- Classroom experience in Embedded Systems
- Low power chips meet battery life requirement
- Flash programmability massively simplifies firmware development

PIC24FJ128GC006



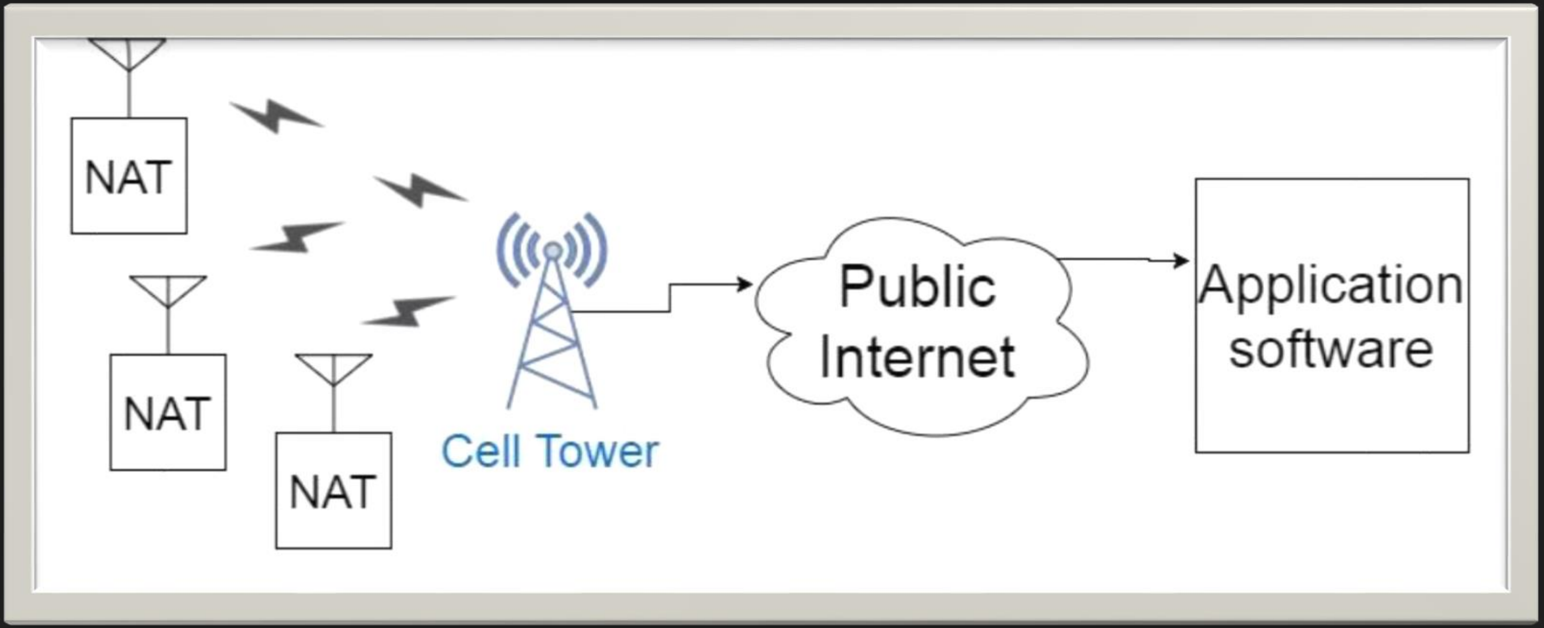
- 16-bit architecture optimized for C programming
- Free (Gratis) development toolchain
- Configuration and diagnostics
  - UART communications ports
    - GPS (NMEA standard)
    - LTE (Hayes command set derivative)
    - Debug interface (TTY terminal emulator)
  - I2C interfaces
    - Inertial measurement unit
  - SPI Interfaces
    - MircoSD
  - USB interfaces

Communications Section



- Purpose
  - Communication between NAT device and GUI application.
  - GPS and IMU data to application software
- LTE CAT 1
  - Similar to 4G LTE on cell phones
  - Designed with IoT and M2M in mind
  - 2G and 3G will be phased out
  - Operates on pre-existing networks

Communication Block Diagrams



Network System Diagram using Cellular Technology

LPWAN

- Designed for M2M communication with embedded devices on the IoT
  - Low power communication protocol
  - Effective over a wide are
- Most effective when used with infrequent, low bit-rate communications

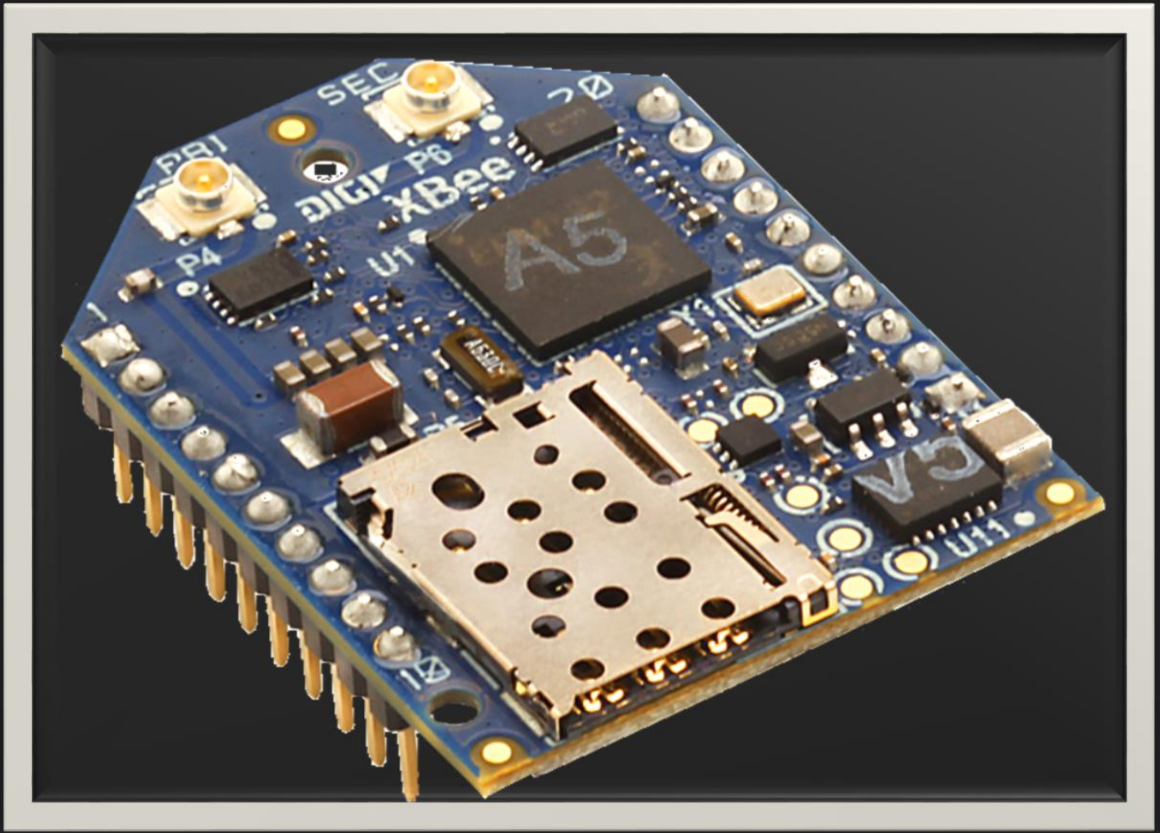
	Sigfox	LoRa	Ingenu	LTE Cat M1
Range	~ 13 km	~ 11 km	~ 15 km	~ 15 km
Data Rate	100 bps	10 kbps	624 kpbs	1 Mbps
Battery Life	> 10 years	> 10 years	> 10 years	> 10 years

LTE CAT1

	CAT 4	CAT 1
Downlink peak rate	150 Mbps	10 Mbps
Uplink peak rate	50 Mbps	5 Mbps
Duplex mode	Full duplex	Full duplex
Maximum Transmit power	23 dBm	23 dBm

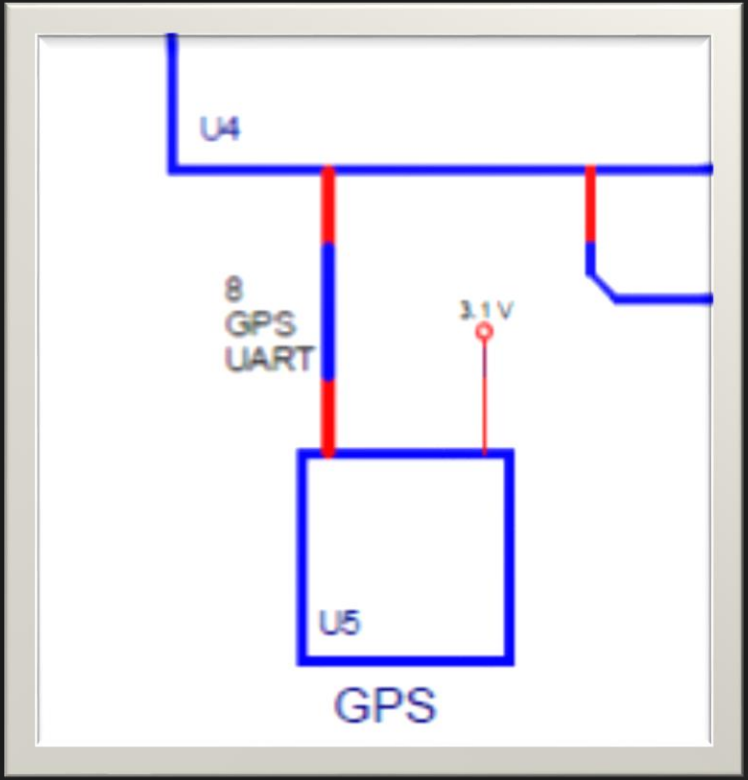
- Low throughput
- Less power hungry than LTE CAT 3 or 4
- Full duplex
- Less complex

Digi XBEE LTE CAT1



- Evaluation board for easy prototyping
- XCTU for easy configuration and testing
- XBee 20-pin form factor
  - Future upgrade
- Free* data for 6 months
- Large online support
  - Forums
  - Customer Support

GPS Section

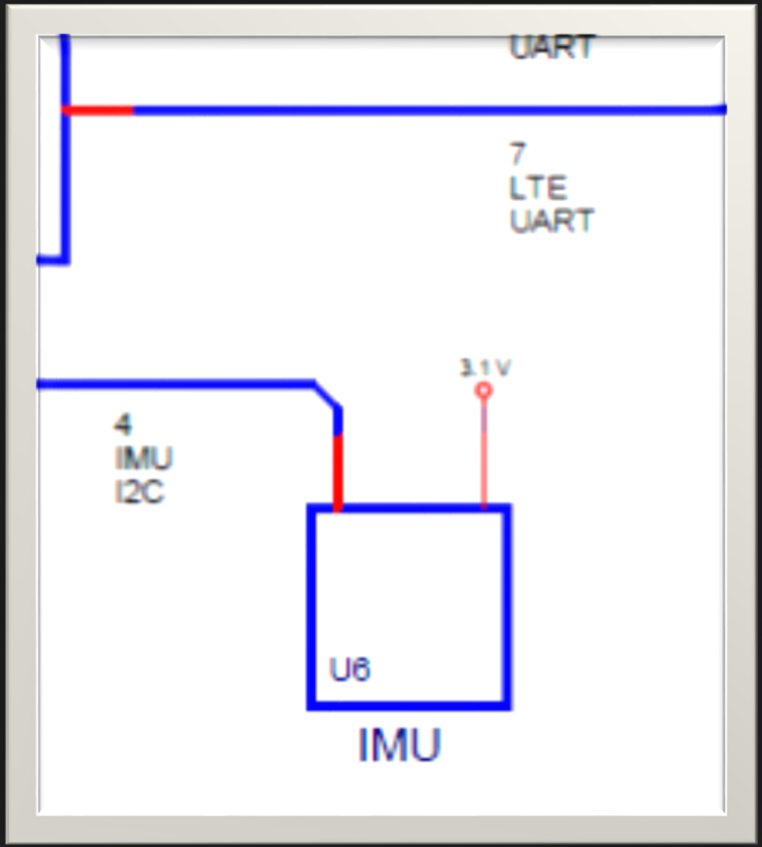


- Tracker device
  - Location hardware necessary
- GPS = Main Location Hardware
- Only communicate with MCU
- Receive the latitude, longitude, and altitude data and report
- Data will be
  - reported directly to users
    - Radio modules and client software
  - Stored on SD card
  - Used in INS software
    - future implementation

OriginGPS NanoHornet

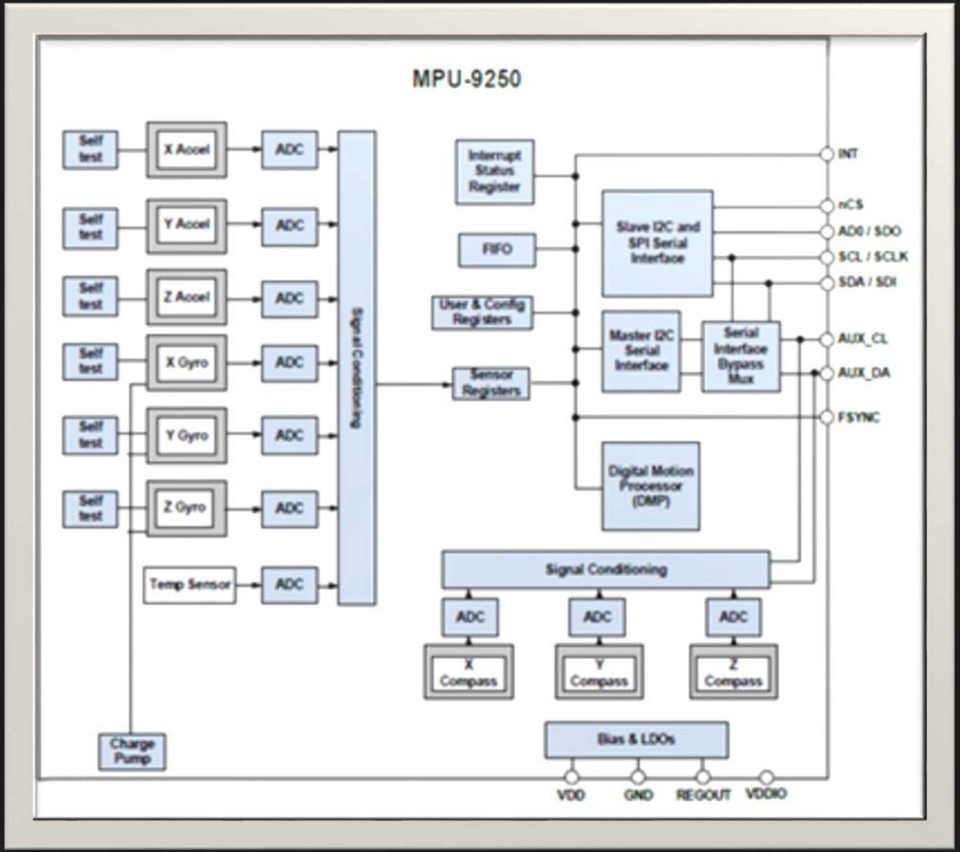
- NanoHornet meets all of the needs of the NAT device
  - Small Size (10mmX10mm)
  - Horizontal accuracy of <2.5m
  - Quick TTFF (<1 second)
  - Supply power within given range
  - Embedded Antenna on the module
    - No extra design necessary
  - Autonomous operation
  - Self Managed Low power modes
  - Selectable interface between UART, SPI, and I^2C
  - Programmable baud rate

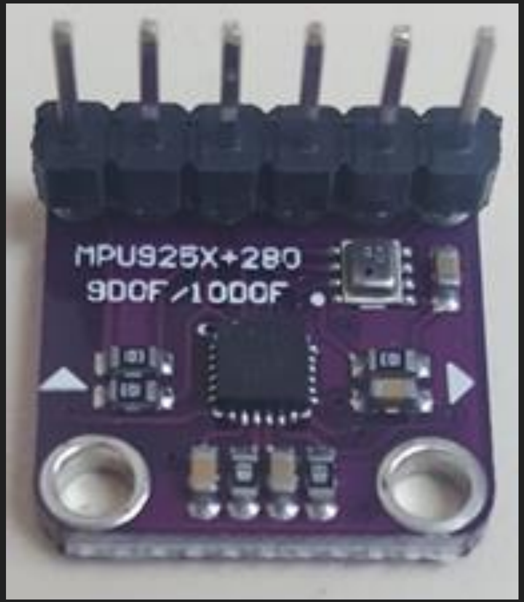
Inertial Measurement Unit (IMU) Section



- IMU and GPS
  - Force, angular rate and magnetic field
  - Sense motion, track position
  - Accelerometers, gyroscopes and magnetometers
  - Inertial Navigation System (INS)

InvenSense MPU 9250





- Small size 3x3x1mm package
- Digital-output x, y, and z-axis angular rate sensors
- Programmed to collect data continuously or when triggered

3-Axis MEMS Gyroscope

- Rotate about x, y and z-axes
  - Maintains a reference direction
  - Vibration sensed
  - Signal amplified, demodulated and filtered
  - Produces voltage proportional to angular rate

3-Axis MEMS Accelerometer

- Rate of change of velocity
- Detects and monitors vibration
- Multi-axes detects
  - Magnitude
  - Direction

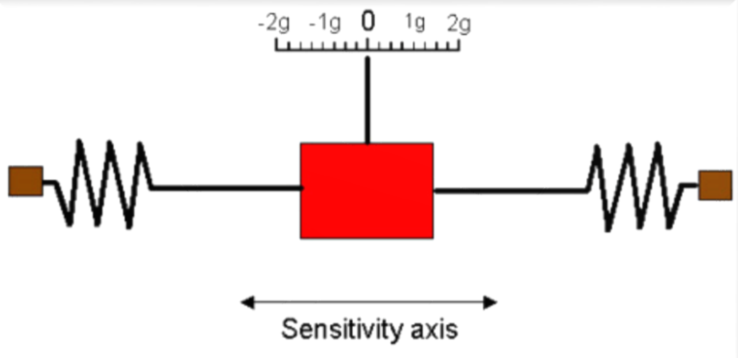


Fig. 1. Schematic structure of an accelerometer

Source: Innoventions, INC

3-Axis MEMS Magnetometer

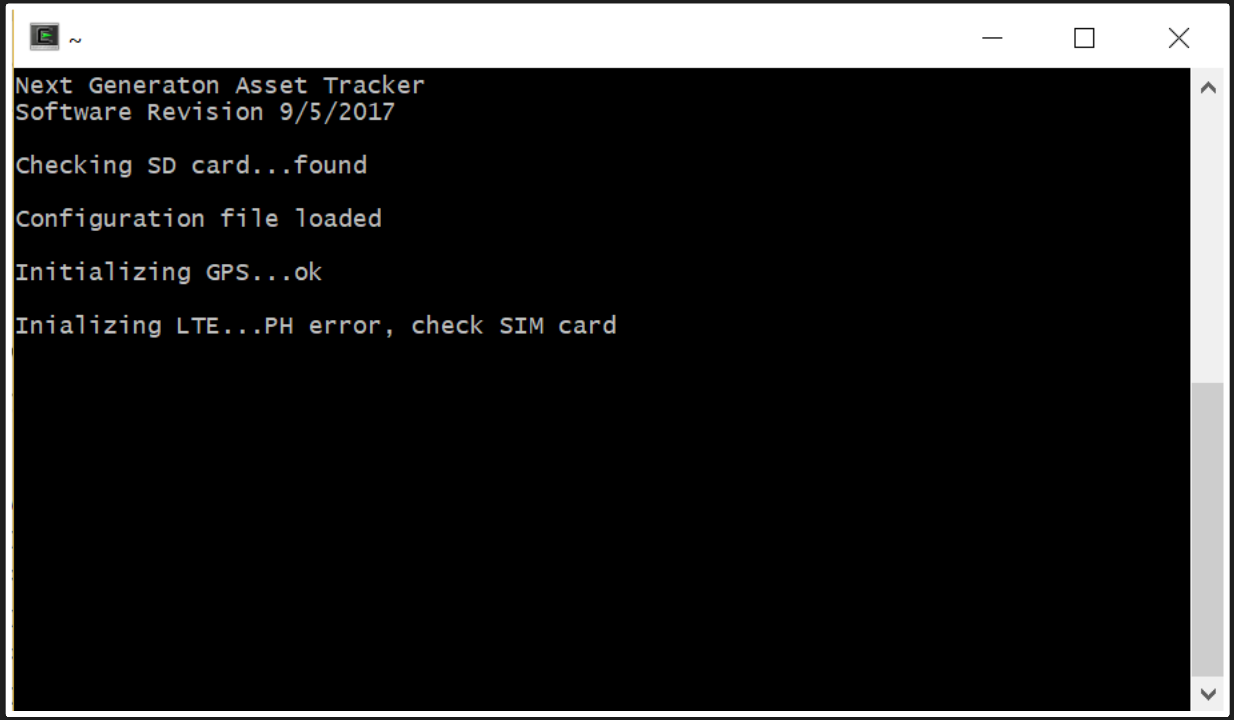
- Measures magnetic field
  - Relative change of a magnetic field at a particular location
- 3-axis measurements
  - Direction and intensity of the magnetic field around the sensor

USB Interface

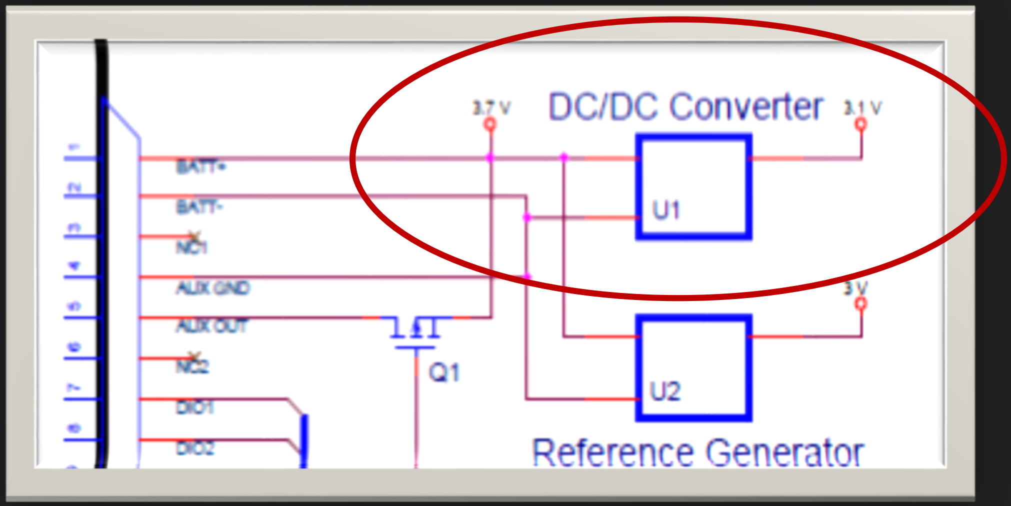
- USB 2.0 standard allows for one USB device to expose multiple interfaces – "composite device"
- HID
  - Streams diagnostic data from each NAT peripheral for display on workstation
- Mass Storage Device (MSD)
  - Exposes SD card for configuration updates and access to the debug and operational logs
- USART
  - Provides UART over USB, adding second option for UART debugging interface

UART Debugging

- Diagnostic log saved to SD card with listings of major operational events and error messages transmitted over the debugging UART
- Development troubleshooting effects seen in real time

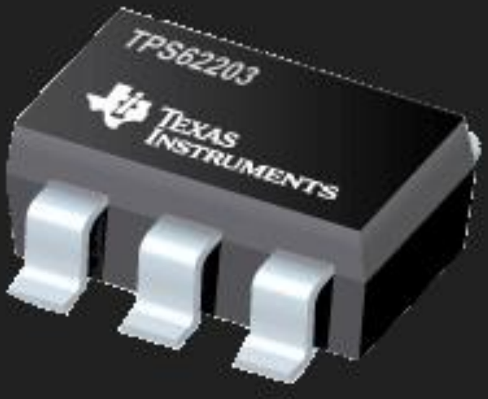


DC/DC Converter Section



- Converts one voltage level to another.
- Step up (boost), step down (buck), inverts.
- Higher efficiency than linear regulator
- Low waste heat

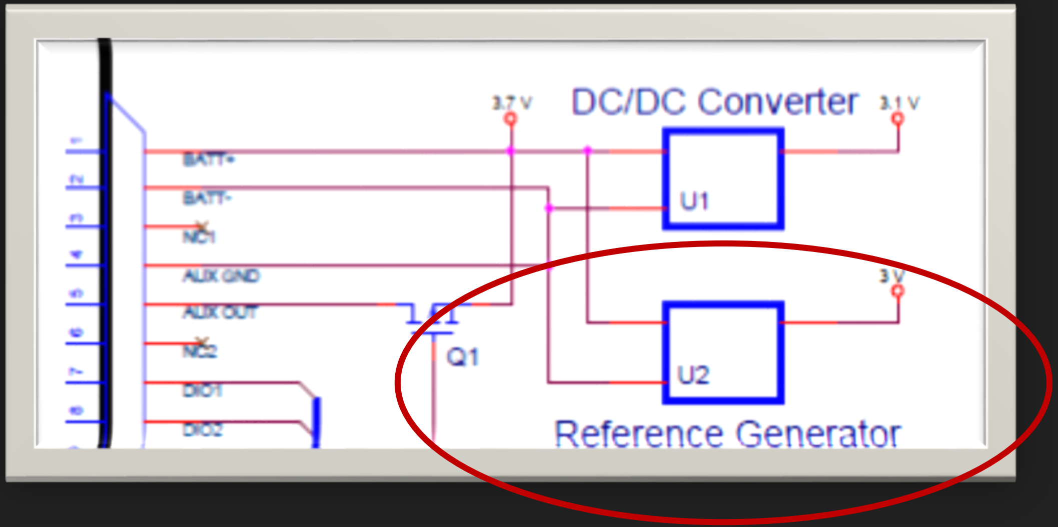
DC/DC Converter Selection



	LDO	Quiescent Current	Low Power	Output Current	Cost [1]
TPS6220	Yes	15 μA – 30 μA	Yes	≤ 300 mA	$0.96
LTC1701	Yes	135 μA	No	≤ 500 mA	$2.12
FAN5307	No	15 μA – 30 μA	Yes	≤ 300 mA	$1.23

- Texas Instruments TPS6220
- high efficiency operation under normal loads
  - 95 % efficiency
- Low Drop Out (LDO) operation
- Low power mode
- Minimal size and part requirements

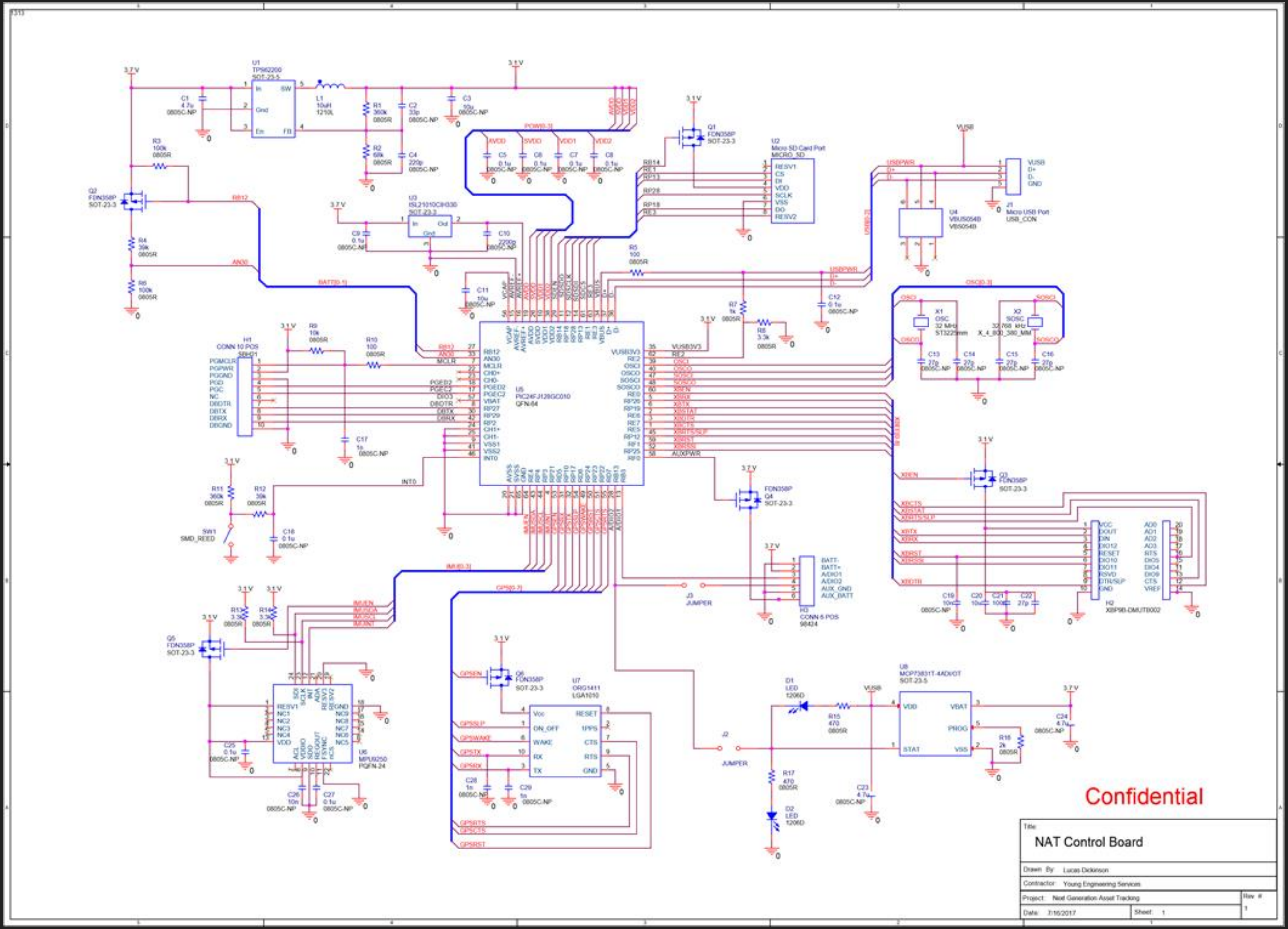
Reference Generator Section



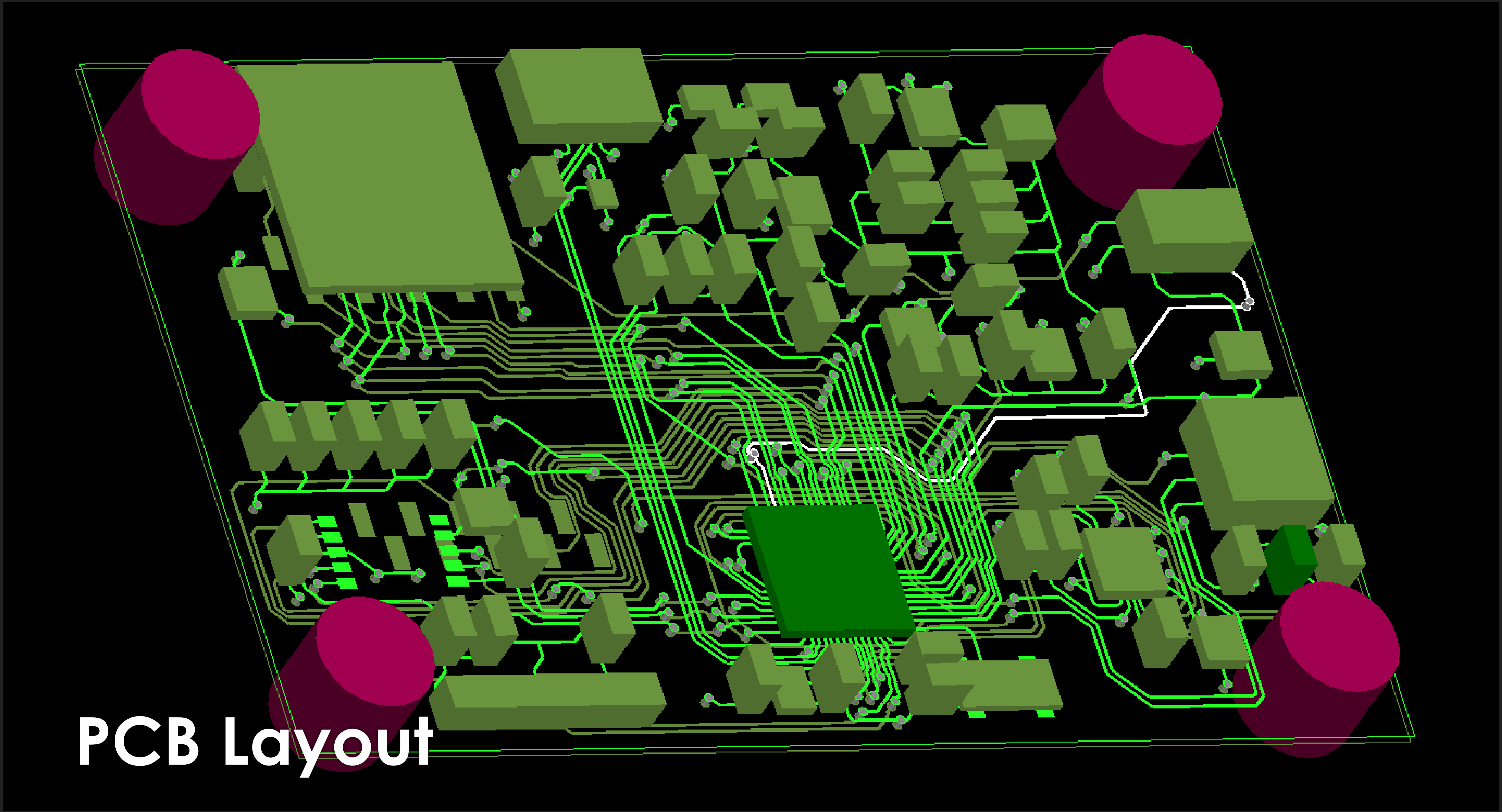
- Similar to voltage regulators
- Tighter output voltage tolerances
- Easy and cheap implementation
  - PN junction diodes
  - Diode connected transistors

Reference Generator

- ISL21080
  - 3.0 volts reference generator
  - Provides Initial accuracy 0.2%
- Used to calibrate 16-bit ADC or DAC
- Maintains high accuracy over long periods


Confidential
Title:
NAT Control Board
Drawn By: Lucas Dickinson
Contractor: Young Engineering Services
Project: Next Generation Asset Tracking
Date: 7/16/2017
Sheet: 1
Rev #
1

PCB Layout



Hardware Progress

60% COMPLETE

- Completed integration of parts needed for development and testing
- Integration of new features in progress
  - USB charging
  - High voltage input
- PCB design and printing
- PCB stuffing
- The next steps in hardware will be decided after testing

Hardware Issues

- Ingenu going through changes
- Flow control not yet implemented; current design requires software delay to prevent overloading IMU chip by polling too often

Software Components

- 3 Major Pieces of Software
  - Firmware
    - Software inside the device itself
  - Windows Configuration GUI
    - Software the distributer will use to configure the device to the specific settings the user wants
  - Web Client GUI
    - What the client will use to find their device

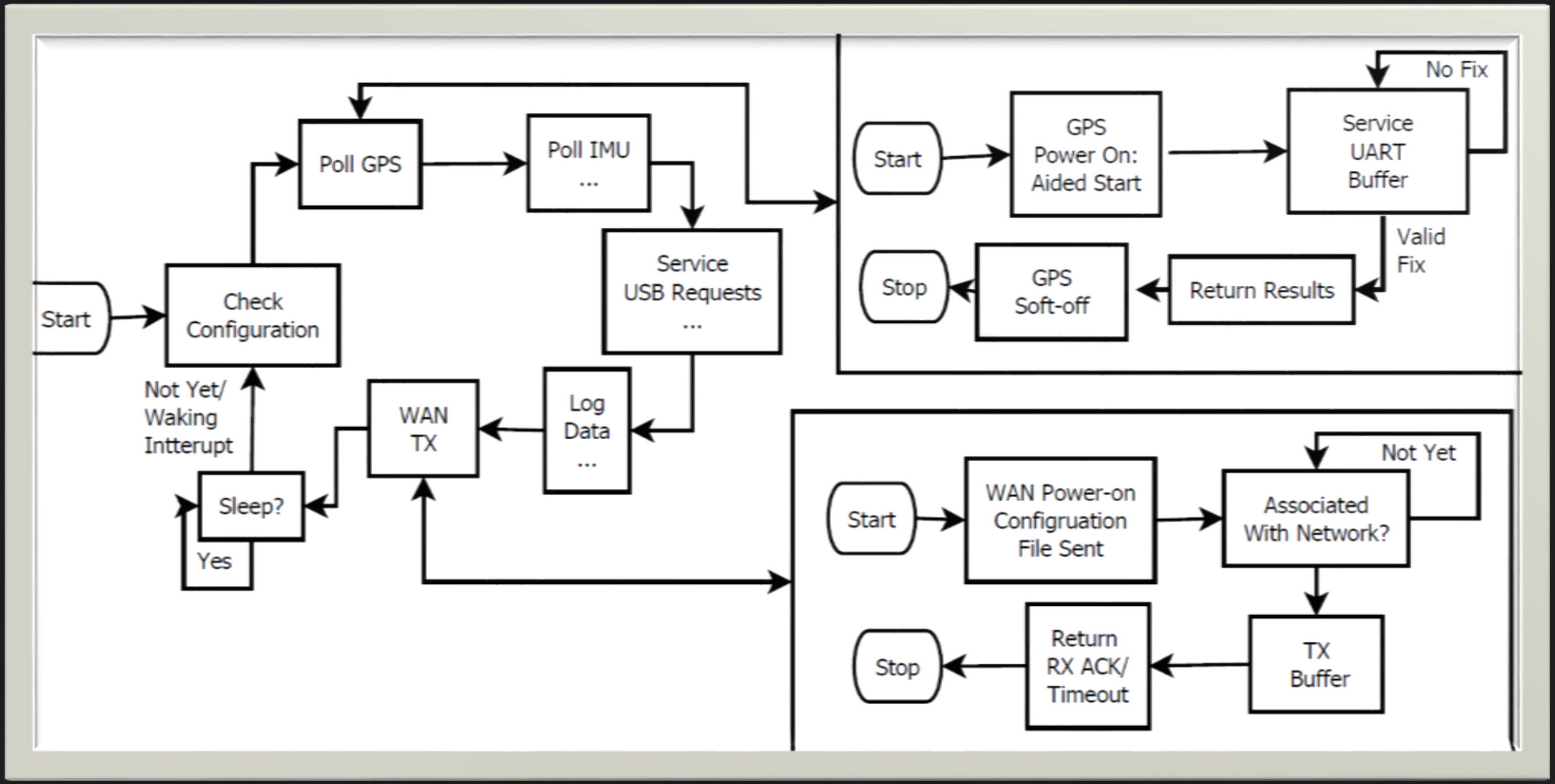
Software Development

- IDE
  - Configuration GUI = Visual Studio
  - Firmware = MPLab X
- Version Control
  - Every software component will use GIT
  - Configuration GUI:
    - GIT through Visual Studio Team Services

Firmware

- PIC24 program executes main loop, polling each peripheral for status and data
  - State machines acting in a cooperative multitasking environment
- After position data is collected
  - Switches to low power mode once IoT transmission buffers are empty or configured timeout interval reached
  - Returns to active processing based on configured timer or inertial measurement interrupts

Firmware Flowcharts



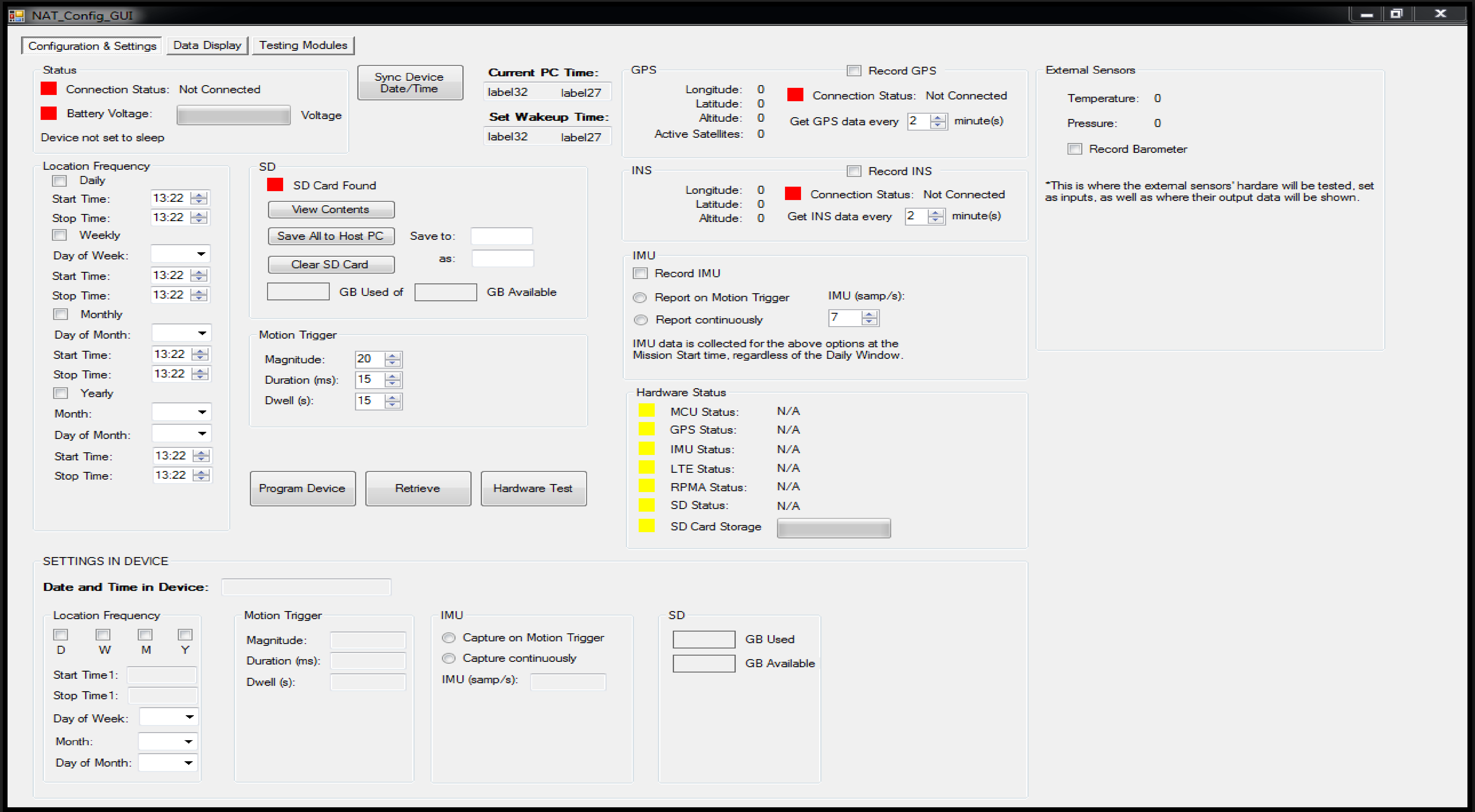
Firmware Current Progress

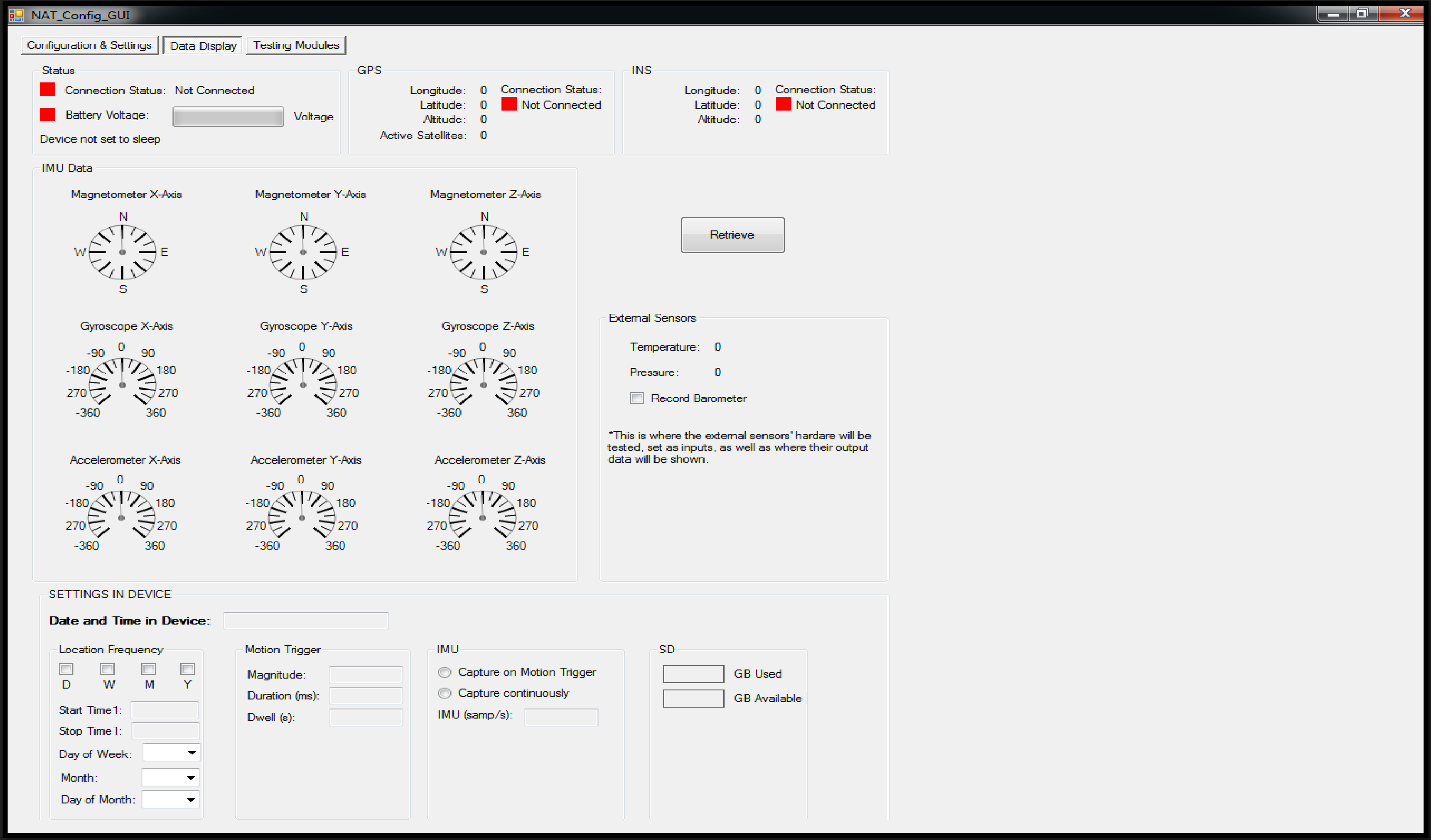
30 % COMPLETE

- Progress
  - Isolated GPS and IMU modules complete
  - LTE, SD, and USB modules currently being developed
- Next steps
  - Add state machines and process yielding to each module
  - Module integration and testing

Configuration GUI

- Software utilized by the manufacturer and distributer
  - Will configure to settings client designated
- Developed as a Windows form
  - 3 Tabs
    - Configuration and Settings
    - Data Display
    - Testing Modules
- Connected to device over USB
- Not accessible to the client
  - Client has their own software
- Senior Design Version not final version (too many functions)


NAT_Config_GUI
Configuration & Settings
Data Display
Testing Modules
Status
Connection Status: Not Connected
Battery Voltage:
Voltage
Device not set to sleep
Sync Device Date/Time
Current PC Time:
label32 label27
Set Wakeup Time:
label32 label27
GPS
Record GPS
Longitude: 0
Latitude: 0
Altitude: 0
Active Satellites: 0
Connection Status: Not Connected
Get GPS data every 2 minute(s)
External Sensors
Temperature: 0
Pressure: 0
Record Barometer
*This is where the external sensors' hardare will be tested, set as inputs, as well as where their output data will be shown.
Location Frequency
Daily
Start Time: 13:22
Stop Time: 13:22
Weekly
Day of Week:
Start Time: 13:22
Stop Time: 13:22
Monthly
Day of Month:
Start Time: 13:22
Stop Time: 13:22
Yearly
Month:
Day of Month:
Start Time: 13:22
Stop Time: 13:22
SD
SD Card Found
View Contents
Save All to Host PC
Save to:
as:
Clear SD Card
GB Used of
GB Available
INS
Record INS
Longitude: 0
Latitude: 0
Altitude: 0
Connection Status: Not Connected
Get INS data every 2 minute(s)
IMU
Record IMU
Report on Motion Trigger
Report continuously
IMU (samp/s):
7
IMU data is collected for the above options at the Mission Start time, regardless of the Daily Window.
Motion Trigger
Magnitude: 20
Duration (ms): 15
Dwell (s): 15
Program Device
Retrieve
Hardware Test
Hardware Status
MCU Status: N/A
GPS Status: N/A
IMU Status: N/A
LTE Status: N/A
RPMA Status: N/A
SD Status: N/A
SD Card Storage
SETTINGS IN DEVICE
Date and Time in Device:
Location Frequency
D W M Y
Start Time1:
Stop Time1:
Day of Week:
Month:
Day of Month:
Motion Trigger
Magnitude:
Duration (ms):
Dwell (s):
IMU
Capture on Motion Trigger
Capture continuously
IMU (samp/s):
SD
GB Used
GB Available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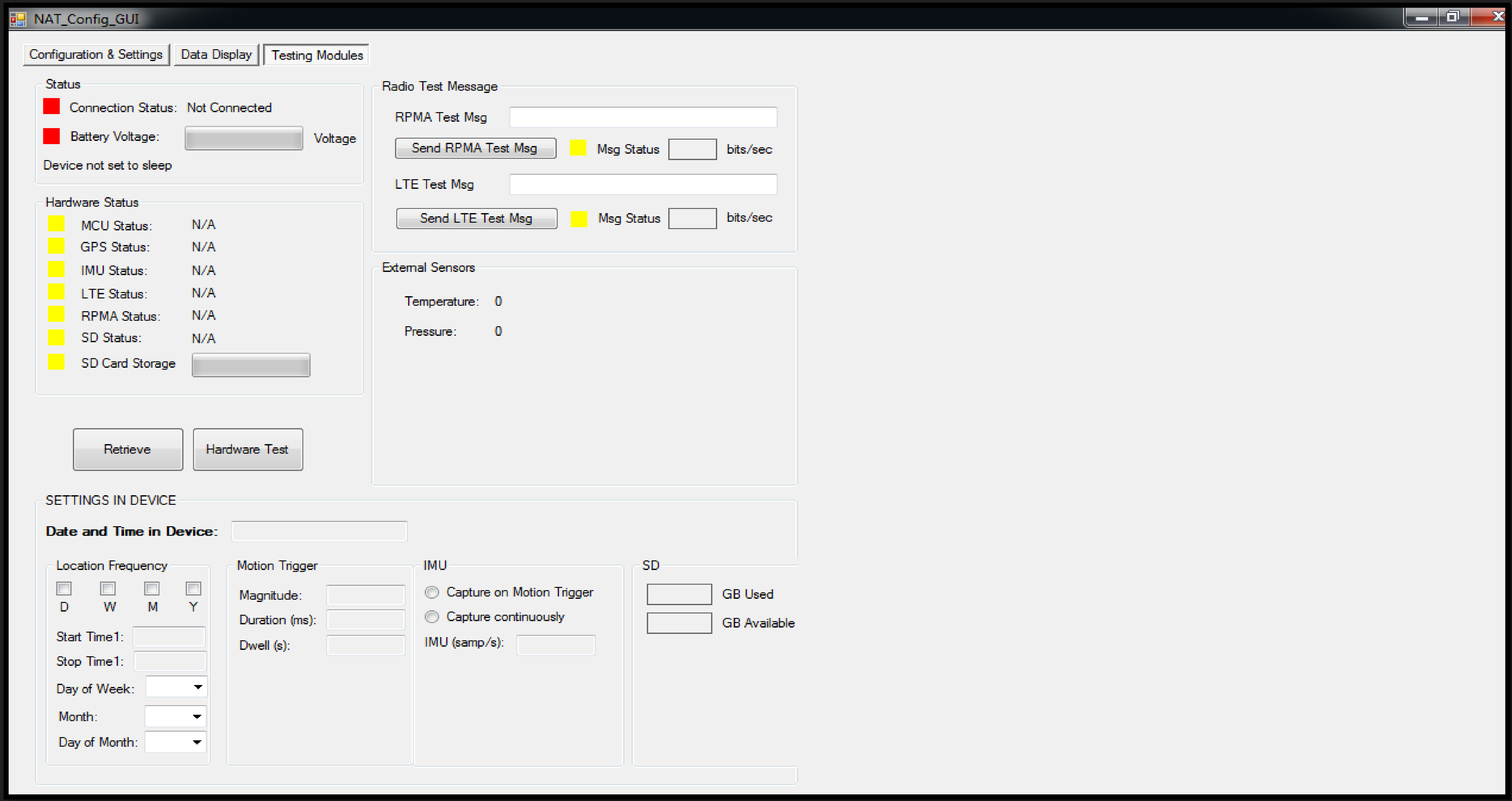
Latitude: 0
Altitude: 0
Active Satellites: 0
Connection Status:
Not Connected
INS
Longitude: 0
Latitude: 0
Altitude: 0
Connection Status:
Not Connected
IMU Data
Magnetometer X-Axis
Magnetometer Y-Axis
Magnetometer Z-Axis
N
W
E
S
Gyroscope X-Axis
Gyroscope Y-Axis
Gyroscope Z-Axis
Accelerometer X-Axis
Accelerometer Y-Axis
Accelerometer Z-Axis
0
-90
90
-180
180
270
-360
360
Retrieve
External Sensors
Temperature: 0
Pressure: 0
Record Barometer
*This is where the external sensors' hardare will be tested, set as inputs, as well as where their output data will be shown.
SETTINGS IN DEVICE
Date and Time in Device:
Location Frequency
D
W
M
Y
Start Time1:
Stop Time1:
Day of Week:
Month:
Day of Month:
Motion Trigger
Magnitude:
Duration (ms):
Dwell (s):
IMU
Capture on Motion Trigger
Capture continuously
IMU (samp/s):
SD
GB Used
GB Available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Device not set to sleep
Hardware Status
MCU Status: N/A
GPS Status: N/A
IMU Status: N/A
LTE Status: N/A
RPMA Status: N/A
SD Status: N/A
SD Card Storage
Retrieve
Hardware Test
Radio Test Message
RPMA Test Msg
Send RPMA Test Msg
Msg Status
bits/sec
LTE Test Msg
Send LTE Test Msg
Msg Status
bits/sec
External Sensors
Temperature: 0
Pressure: 0
SETTINGS IN DEVICE
Date and Time in Device:
Location Frequency
D W M Y
Start Time1:
Stop Time1:
Day of Week:
Month:
Day of Month:
Motion Trigger
Magnitude:
Duration (ms):
Dwell (s):
IMU
Capture on Motion Trigger
Capture continuously
IMU (samp/s):
SD
GB Used
GB Available

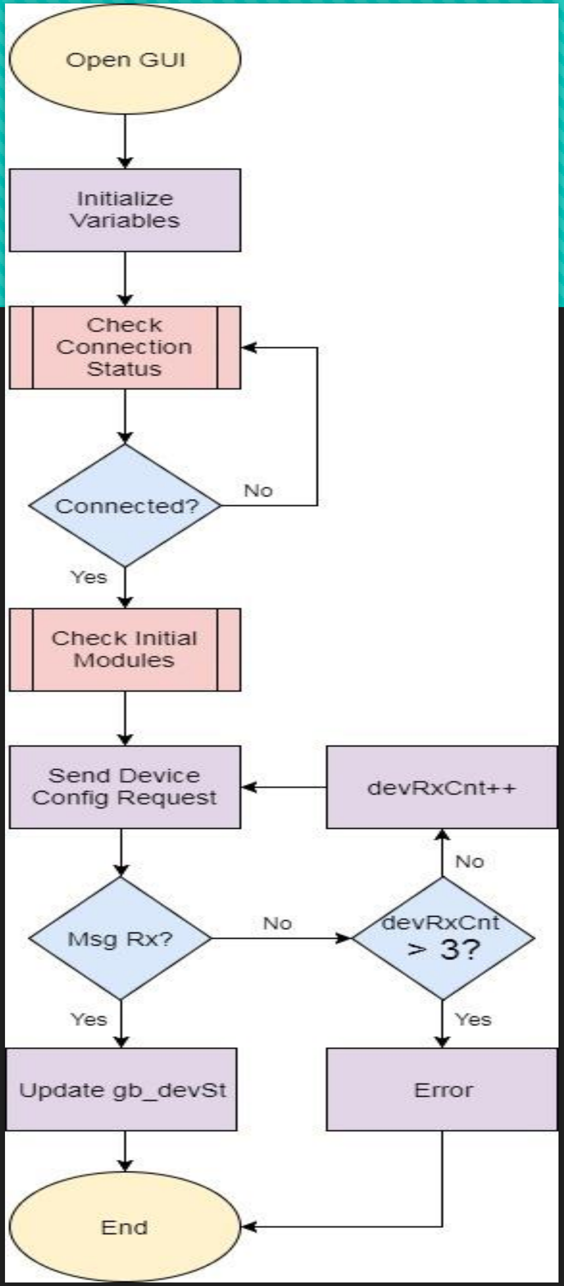
Communication With Firmware

```
[Interrupt]
Wake-Up Interval: true ;true/false
Month: * ;1-12/*
Day: * ;1-28/*
Weekday: UMTWRFS ;UMTWRFS/U/M/T/W/R/F/S/*
Time: 0100 ;0000-2400

[Motion Trigger]
Wake on Motion: true ;true/false
Magnitude: 20 ;0-9999
Duration: 15 ;0-9999 milliseconds
Dwell: 15 ;0-9999 seconds

[GPS]
GPS Record: true ;true/false
GPS Poll: 2 ;2-30 minutes

[IMU]
IMU record: true ;true/false
INS record: true ;true/false
Record: Continuous ;Continuous/MotionTrigger
Sample Rate: 10 ;1-100 samples/second
```

- nat.conf file transmitted between device and GUI
- Will be stored always on the device
  - Storing current communication settings
- Configuration GUI will download the file from the device
  - Update this file directly with any updates from the GUI
  - Send the device the new file
  - The device will update its configuration settings based on changes in the file
  - Overwrite the old file with the new one

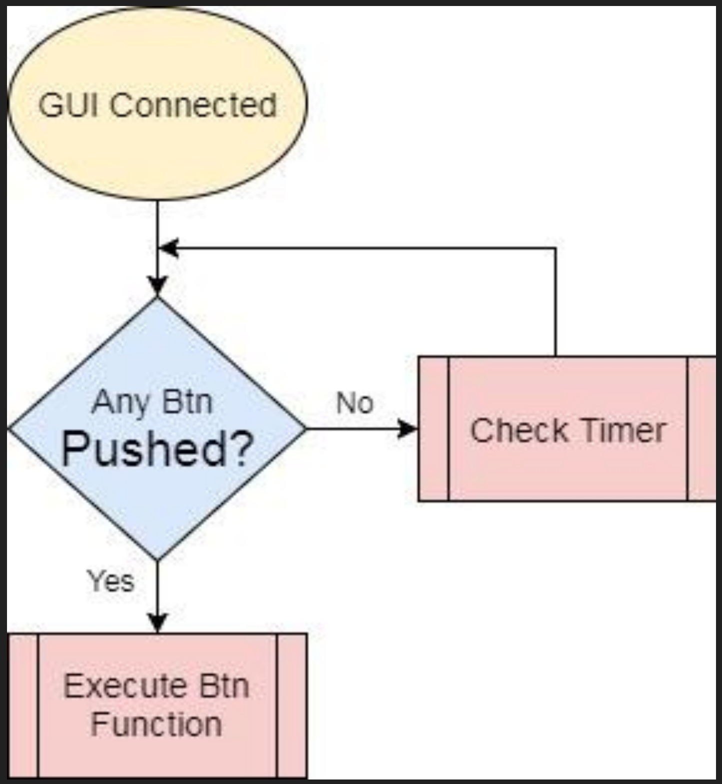
Configuration GUI Flow Charts

- When GUI is opened
  - Initialize all variables in the software
  - Check to see if connected
    - If not connected sit in loop until connected
  - Get devices current nat.conf file
    - If the file does not arrive after certain time request again
    - Only request 3 times before failing and exiting loop
  - Update the group of current device settings



Configuration GUI Flow Charts

- While GUI is running
  - Wait for a button to be pushed
  - Timer to make sure device still connected
    - Check connection every minute or so
  - If a button is pushed run that button’s specific code flow



Configuration GUI Current Progress

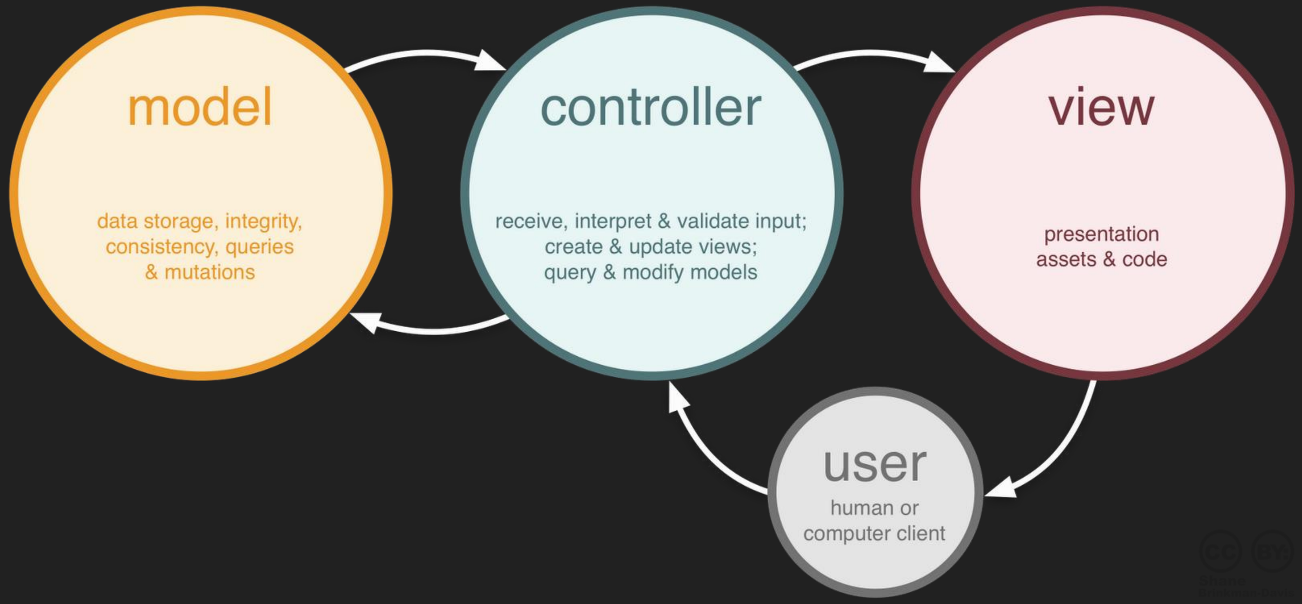
20 % COMPLETE

- The GUI layout has been created
  - Needs to be redesigned for updates in functionality
- The code behind the form has started to be written
- NEXT STEPS:
  - Get the GUI to communicate with the NAT device VIA the nat.conf file

Web GUI

- Web GUI Current Progress
  - To be started October 2017
- MVC (Model-View-Controller)
  - 3 interconnected parts
    - Model
    - Controller
    - View

Model – View - Controller



Overall Software Progress

- Standalone firmware modules are 50% complete and module integration has not yet started
  - Waiting for PCB
- Configuration GUI initial design layout is complete, core logic is waiting on firmware and changes will be incorporated during integration
- Web GUI and backend server software is still in design phase

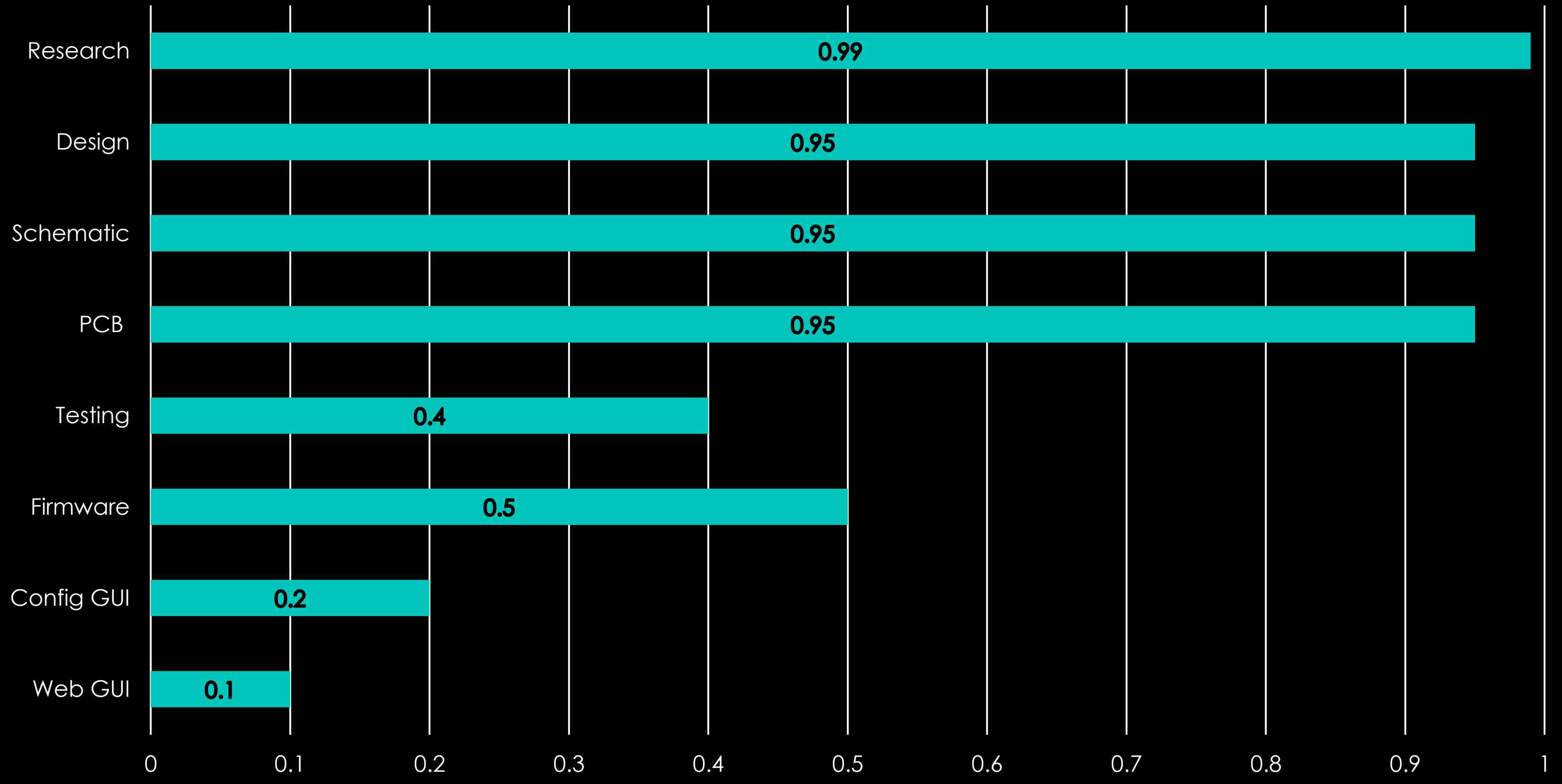
Software Issues

- USB times out after 50 ms for some host polling operations
  - easily exceeded with blocking delay loops in current prototype modules
  - State machine and cooperative multitasking concept needed in firmware
- LTE software module sends commands and data to LTE hardware module too quickly for reliable operation
  - Again, a state machine to provide non-blocking waits for command acknowledgement and valid network connectivity is needed
  - Buffer-based flow control

Administrative Content - Budget

	Qty/Board * 4	Price/Unit	Total
LTE Module	4	$99.00	$396.00
IMU	4	$8.50	$34.00
MCU	4	$5.00	$20.00
GPS Module	4	$20.50	$82.00
DC-DC Converter	4	$1.50	$6.00
Voltage Reference	4	$1.50	$6.00
SD Socket	4	$10.50	$42.00
USB ESD Protection Unit	4	$1.00	$4.00
TOTAL EST BUDGET		$147.50	**$590.00**

Administrative Content - Progress



Administrative Content – Final Steps

- Electrical Engineers (Hardware)
  - Waiting for the arrival of the PCB
  - Developing the Bill of Materials for sponsor
  - Create the Kit of Parts to stuff PCB when it arrives
- Computer Engineers (Software)
  - Development and testing external to hardware awaiting PCB
    - Firmware on development boards
    - Configuration GUI with test text files
    - Web GUI in early stages
    - Training next team(s)

Questions?