SpaceNet
Spring Final Review

Spring 2021

Team: Ryan Burdick, Sam Firth, Noah Francis, Jordan Gage, Forest Owen,Tyler Pirner, Keith Poletti, Ryan Prince, Israel Quezada, Colin Ruark, Benji Smith

Customer: Martin Wilson

Advisor: Francisco Lopez Jimenez

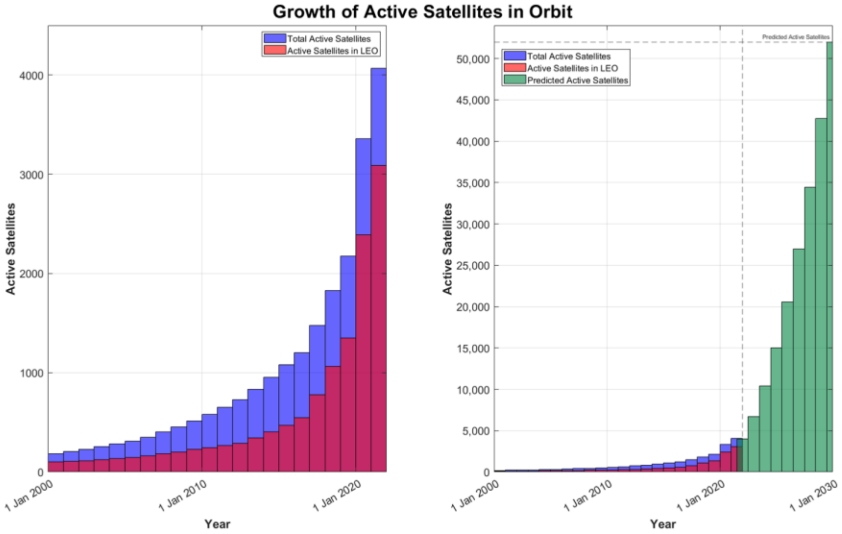
Raytheon Technologies + University of Colorado Boulder

Project Purpose and Objectives

What is SpaceNet?

A **Low-Cost** network of **Software Defined Radio(SDR)** equipt ground stations for monitoring LEO space domain to relieve existing high fidelity sensors

The system would produce two-line element sets(TLE) that could be compared to expected orbits to determine if something is out of place



This Project

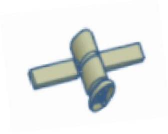
Four unit proof of concept proving hardware and software

This project will produce four functional ground units that can record UHF/L-Band satellite Quadrature signal (IQ) data

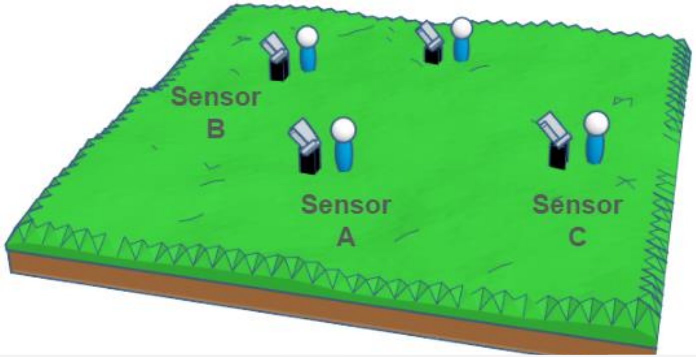
The recorded data will be used to produce both a position estimation and orbit estimate

SpaceNet
Concept of Operations (CONOPS)

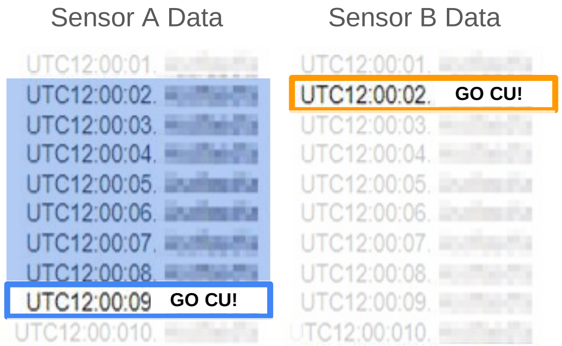
1. Sensors are temporarily deployed
2. Sensors synchronize to UTC time



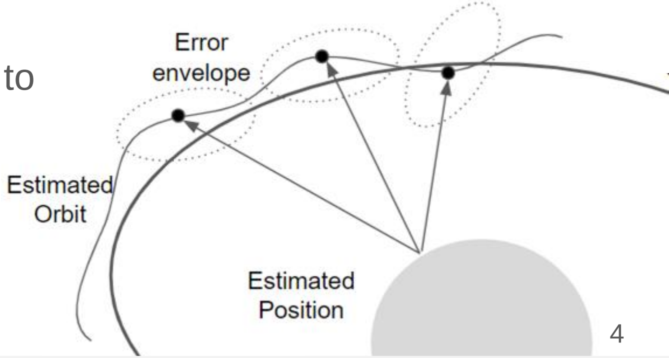
3. Satellite transmits during flyby
4. Transmissions are received by sensors



5. Transmissions are identified post test
6. Time delay of signal arrival is calculated from UTC time



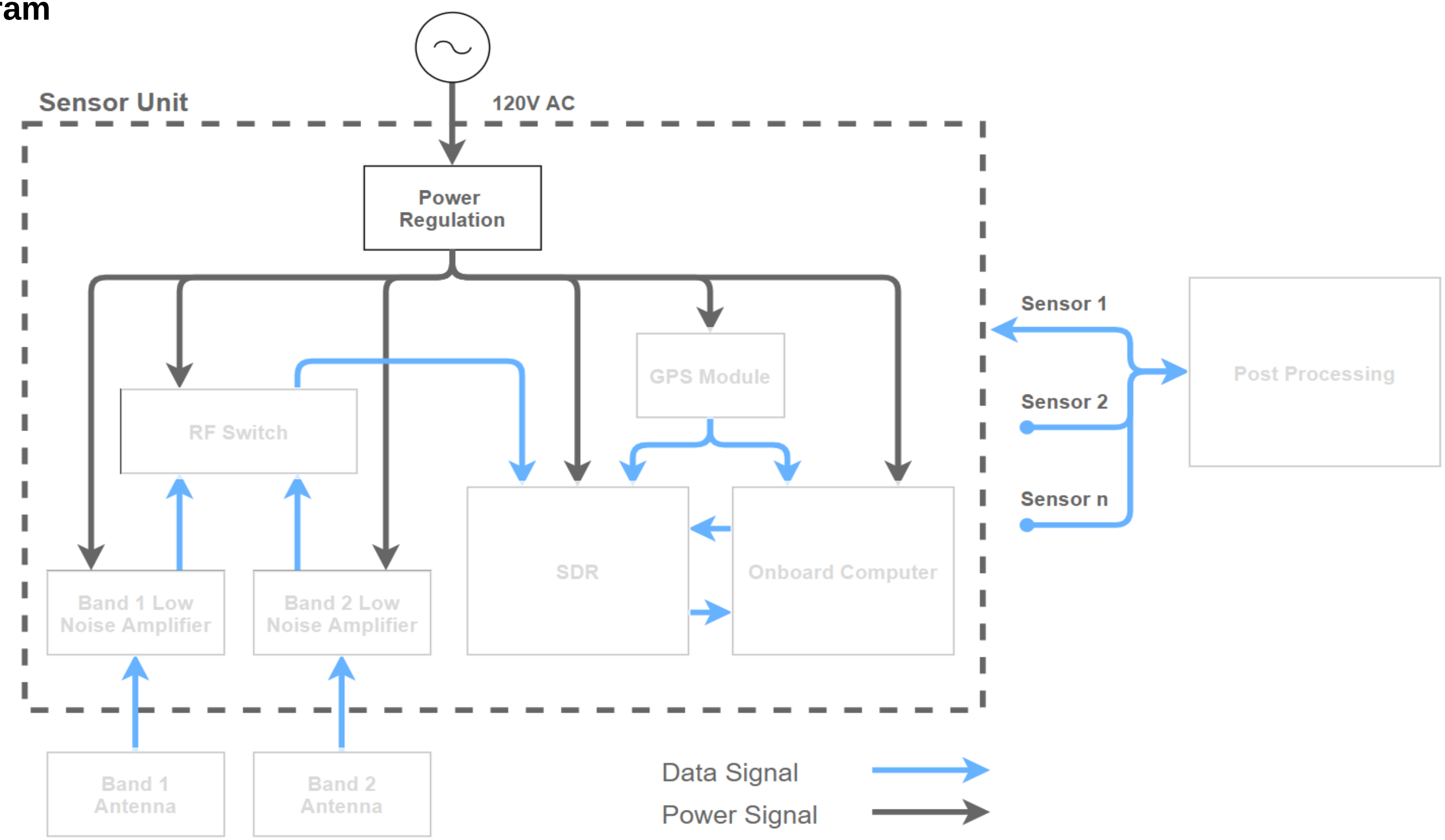
7. Time delay is used to estimate satellite position
8. Position used to estimate orbit



Levels of Success	Key Objectives
1	• TDOA from artificial data • Orbital Prediction from artificial data • 4 units built • Sensor Units shall receive on single band • Sensor units shall be able to synchronize to UTC time via GPS
2	• TDOA prediction from 2 units data • Sensor Units shall receive on dual bands • Sensor Units shall be able to recover in result of a power outage • Sensor Units data shall be synchronized to within 420 ns
3	• Four Units are deployed and operational • Manufacturing Documentation (schematics, procedure, manufacturing analysis, suggested improvements, and ways to drive down cost) • TDOA prediction from 4 units data • Orbital prediction from data

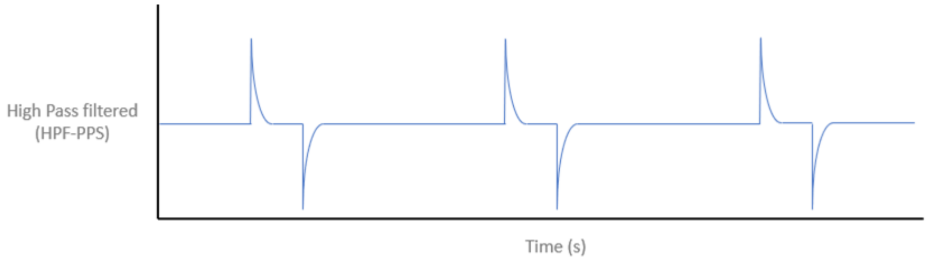
Design Description

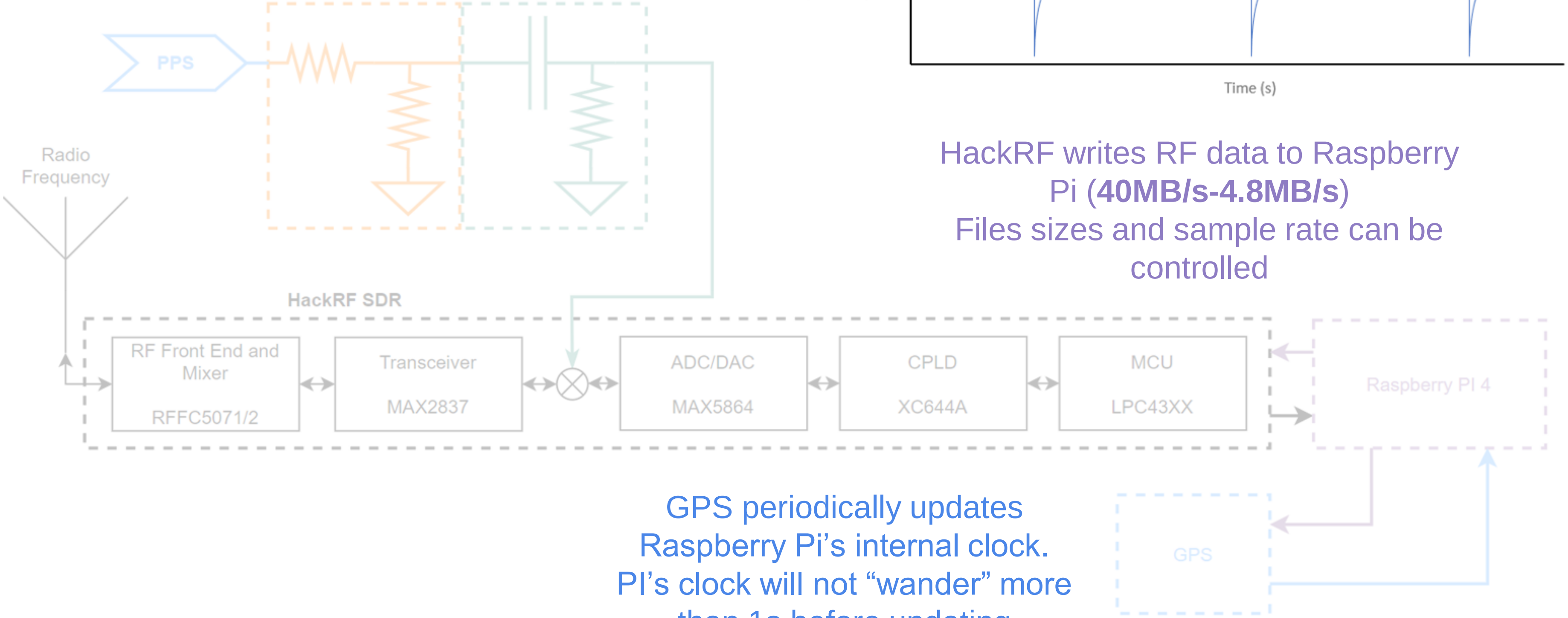
SpaceNet Functional Block Diagram



SpaceNet Electronics and Data handling

Pulse per second(PPS)



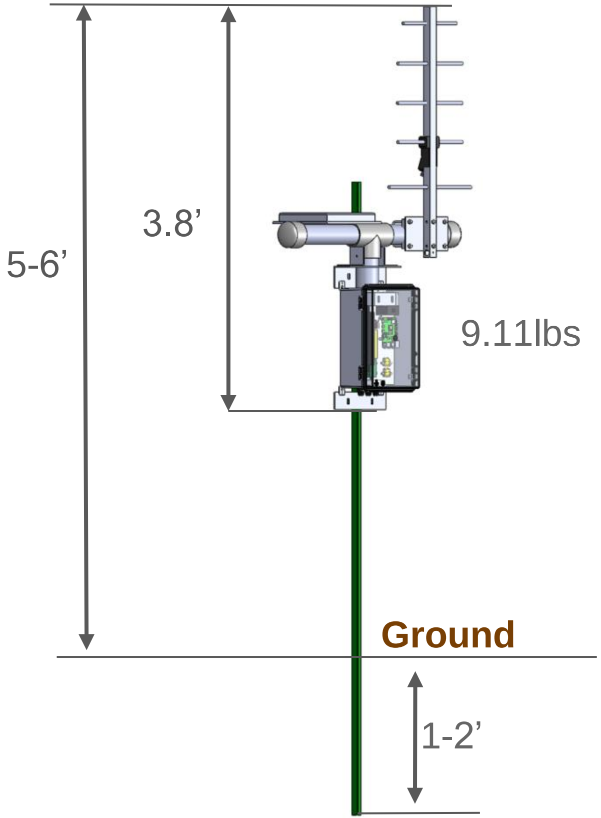


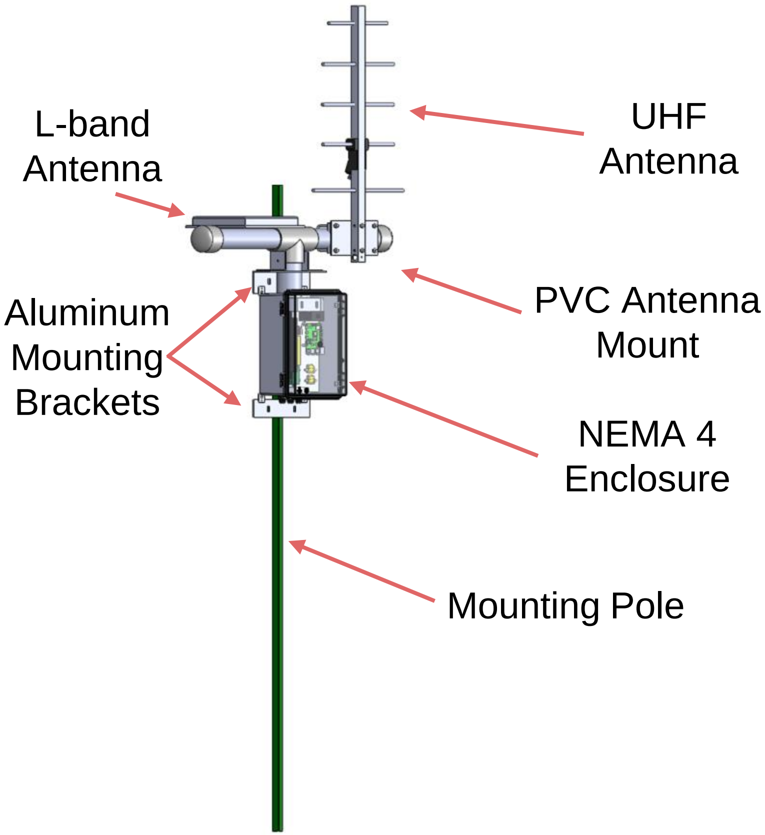
HackRF writes RF data to Raspberry Pi (**40MB/s-4.8MB/s**)
Files sizes and sample rate can be controlled

GPS periodically updates Raspberry Pi’s internal clock.
PI’s clock will not “wander” more than 1s before updating

Baseline Hardware Design

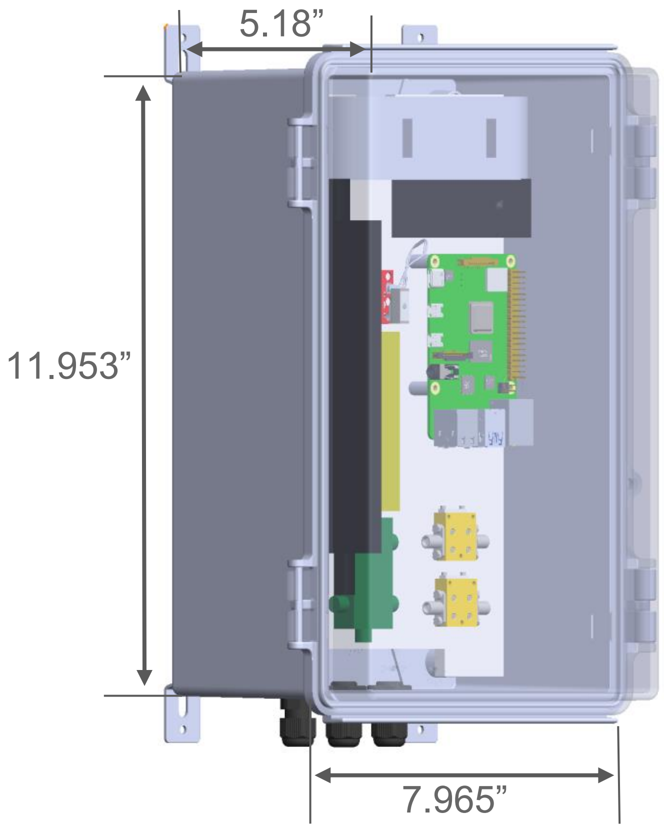
External

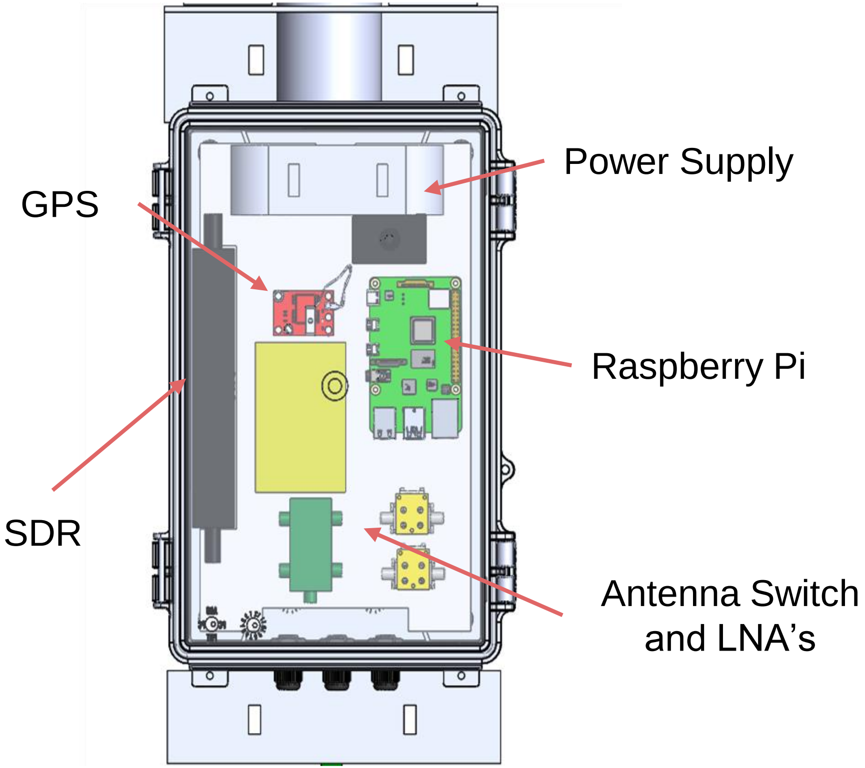




Baseline Hardware Design

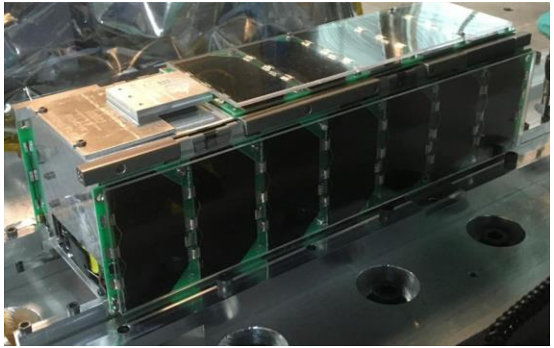
Internal





Satellite Targets

UHF Target: CSIM
The main target we will be using for this Frequency band is the CSIM Satellite operated locally here at CU Boulder



Operational characteristics:

- Fc = 437.25 MHz (Carrier)
- P = 5 W (Transmitted power)
- BW = 30 kHz (Beamwidth)
- DR = 9.6 kbps
- Demod = GMSK

L-Band Target: Iridium Next
Our primary target for this band is the Iridium NEXT Constellation.

Operation characteristics:

- Fc = 1616-1626.5 MHz (Carrier)
- P = 5 W (Transmitted power)
- BW = 30 kHz (Beamwidth)
- Possible data rates
  - Voice = 2.4kBps
  - Short Burst = 64 kBps

Critical Project Element	Why is This Critical?
Environmental Readiness	Testing time will be dictated by satellite’s orbital passes. The sensor unit must be ready to operate in rain, snow and the temperatures expected during spring semester in Boulder
RF Front End	The RF front enables UHF and L-band signal reception. The reception must be good enough to discern the transmission from the noise floor
Timing Synchronization	The received data must be alignable such that time delay can be measured with extreme precision. Error here has a large impact on positional predictions
Position Vector Estimate using TDoA	Time Delay of Arrival(TDoA) ranging is used to produce the positional information required for orbital prediction
Orbital determination	Two methods: Gibbs and Particle Filter. Both produce orbital predictions that are the final product of the project

Test Overview

Component Level Testing

Box Weatherproof	Test that the box and cable pass throughs are weather resistant and leak proof
GPS	Ensure the GPS Pulse Per second meets the device specifications
HackRF & Timing scheme	Ensure the SDR meets the device specifications for sample rate and that timing scheme operates as expected
UHF LNA	Ensure the UHF LNA performs per spec sheet
L-Band LNA	Ensure the L-band LNA performs per spec sheet
RF Switch	Measure the noise level with switch and without switch
RF_Control.py	Ensure the Raspi can command the switch to change between the two RF Inputs
GPS_timer.py	Ensure the Raspi can use GPS time to determine when to start data collection
Data_handler.py	Ensure recorded data can be slimmed and moved to proper location for off loading
Correlation Testing (TDOA)	Ensure that the correlation scheme works and does not add delay above required max
Orbit determination	Ensure orbit prediction works based on simulated data.

SubSystem Level Testing

Temperature	Ensure that the internal temperature of the box will remain within operating conditions as modelled
Onboard OS	Ensure that the subscripts run on start-up and operate as expected.
Raspi HackRF Compatibility	Ensure the HackRF performs the same when connected to the Raspi
Circuit Board	Test the power and signal distribution board behaves as expected
UHF Frontend	Ensure that the UHF front end meets the design Signal to noise ratio and other parameters
L-band Frontend	Ensure that the L-band front end meets the design Signal to noise ratio and other parameters
Post Processing software	Ensure the orbit determination meets requirements given TDOA output
Single Unit	Build an unit and repeat all subsystem to unit to see if the results match.

Full System Level Testing

Signal Correlation	Ensure that the signals from boxes can be aligned and maintain the timing accuracy calculated
Full suite test	Ensure that the predicted orbited from test data is within the expected error

Will be in Presentation

Completed

Incomplete

Component Level Testing

Box Weatherproof	Done Complete	
GPS	Done Completed 2/27	
HackRF & Timing scheme	Done Completed 2/10	
UHF LNA	Done Completed 3/8	Will be tested as part of frontend testing
L-Band LNA	Done Completed 3/8	Will be tested as part of frontend testing
RF Switch	Done Completed 3/19	Will be tested as part of Onboard OS testing
RF_Control.py	Done Late 4/10	Revised due to bugs
GPS_timer.py	Done Late 4/10	Revised due to bugs
Data_handler.py	Done Late 4/10	Revised due to bugs
Correlation Testing (TDOA)	Done Completed. 3/12	Completed with Simulated Data
Orbit determination	Done Completed 2/01	

SubSystem Level Testing

Temperature	Done Late 4/14	
Onboard OS	Done Late 4/10	
Raspi HackRF Compatibility	Done Completed 2/24	
Circuit Board	Done Completed 2/28	Waiting on hardware
UHF Frontend	Done Completed 3/8	
L-band Frontend	Failed	IQ data is inconsistent between units.
Post Processing software	In Progress Revised 4/24	Waiting on Data
Single Unit	Done Late 4/14	Waiting on other subsystems

Full System Level Testing

Signal Correlation	Incomplete Est. 4/30	Likely not to happen
Full suite test	Incomplete Est.4/30	Likely not to happen

Done
In Progress
Incomplete

Completed	Date Finished
Estimated	Planned Deadline
Revised	Behind Schedule. New Deadline
Late	Completed but late

Test Results

Box Weatherproof Test:

Overall Test Goal(s): Test that the box and cable pass throughs are weather resistant and not susceptible to ingress of water.

Requirements: DR1.1

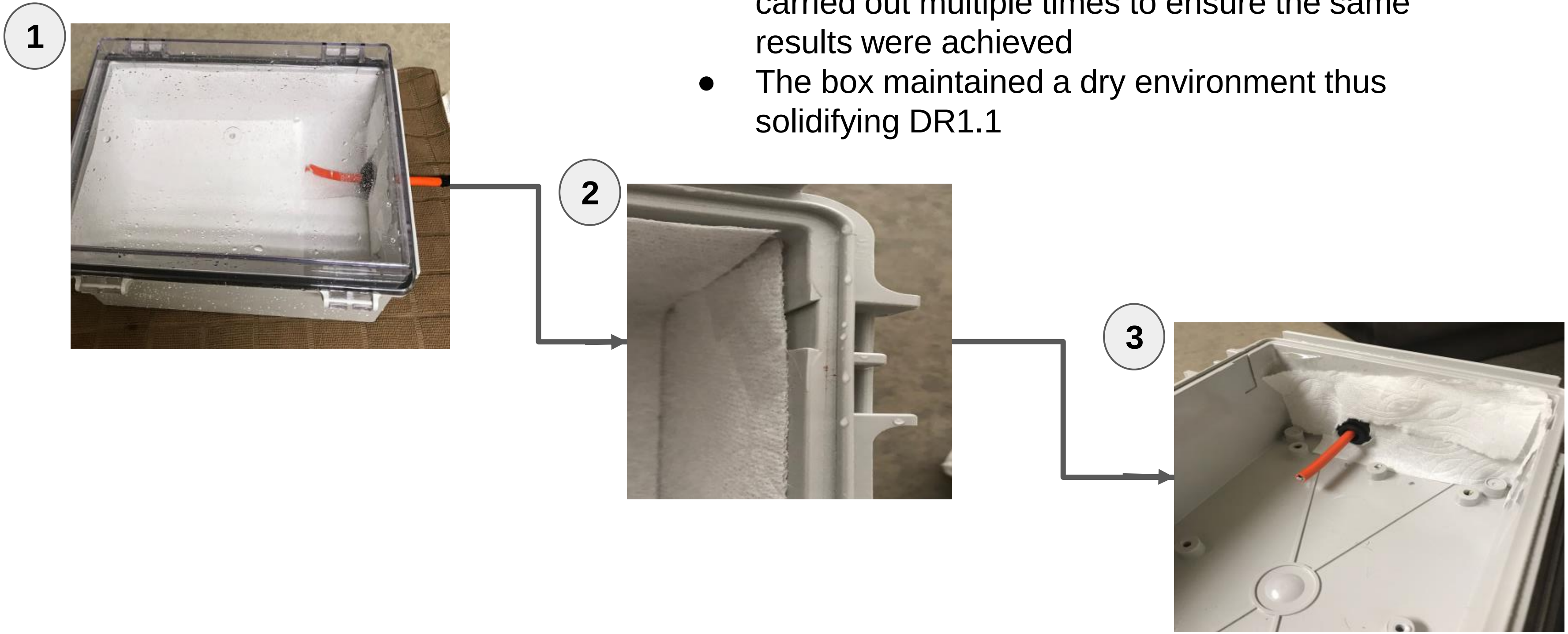
Risk Mitigated: Hardware not fully operational/could be damaged during satellite pass over.

Test Progression:

Weatherproof Results (**Pass**):

Verification Steps:

- Each test consisted of the following steps, and were carried out multiple times to ensure the same results were achieved
- The box maintained a dry environment thus solidifying DR1.1



Circuit Board Test:

Overall Test Goal(s): Verify that the power distribution, PPS Filter, GPS clock interface and reset button are all working as expected. Verify that the PPS is visible over the noise floor on target frequencies.
Requirements: FR2, DR2.4, DR2.5, DR5.1

Risk Mitigated: Reduces chance of failure in the field due to a faulty board. Ensures the PPS is usable and doesn't change the RF data in unexpected ways

Modelled Results:

Power Distribution	5v, 2.3A
PPS	200mv pk-pkv, rise time<50ns
PPS + hackRF	PPS is visible at target frequencies and has no adverse effect on the RF data making it unusable
GPS interface	Give Raspi access to GPS accurate UTC clock
Reset Button/ LED	Causes Unit to reset on press and lights on Raspi command

Circuit Board Test Results:

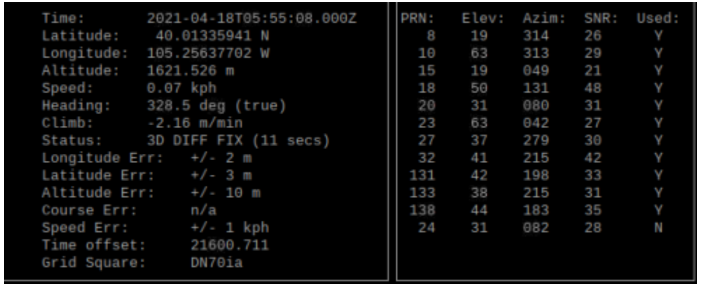
Power Distribution(**Pass**):

Per power budget 5V, 2.3A should be sufficient to support the RF switch and both LNAs.

Shorting 5v-GND measured ~2.3A

GPS interface(**Pass**):

Both status LEDS illuminate when the GPS is communicating with the Raspi. The Raspi also reports proper communication with the GPS

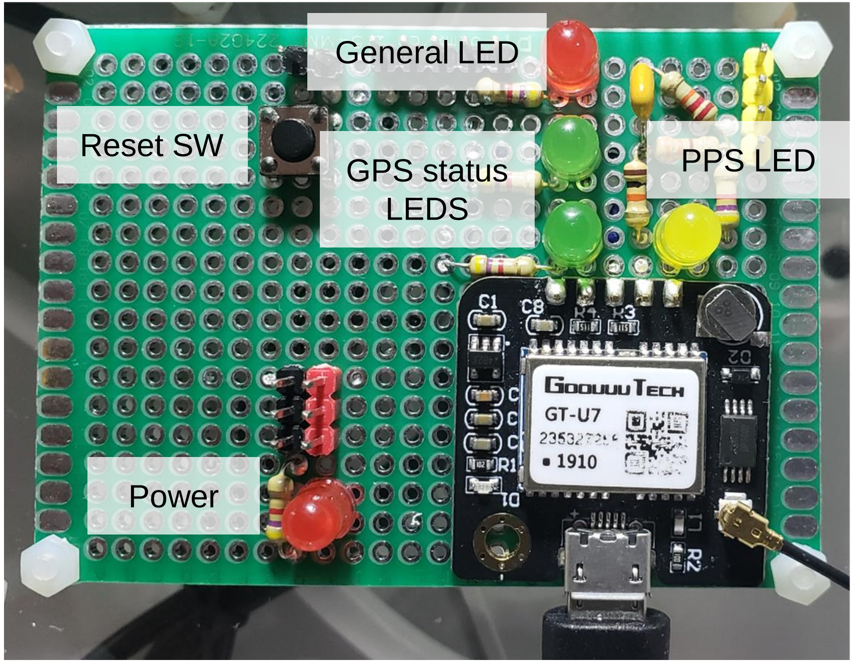


Time:	2021-04-18T05:55:08.000Z
Latitude:	40.01335941 N
Longitude:	105.25637702 W
Altitude:	1621.526 m
Speed:	0.07 kph
Heading:	328.5 deg (true)
Climb:	-2.16 m/min
Status:	3D DIFF FIX (11 secs)
Longitude Err:	+/- 2 m
Latitude Err:	+/- 3 m
Altitude Err:	+/- 10 m
Course Err:	n/a
Speed Err:	+/- 1 kph
Time offset:	21600.711
Grid Square:	DN70ia

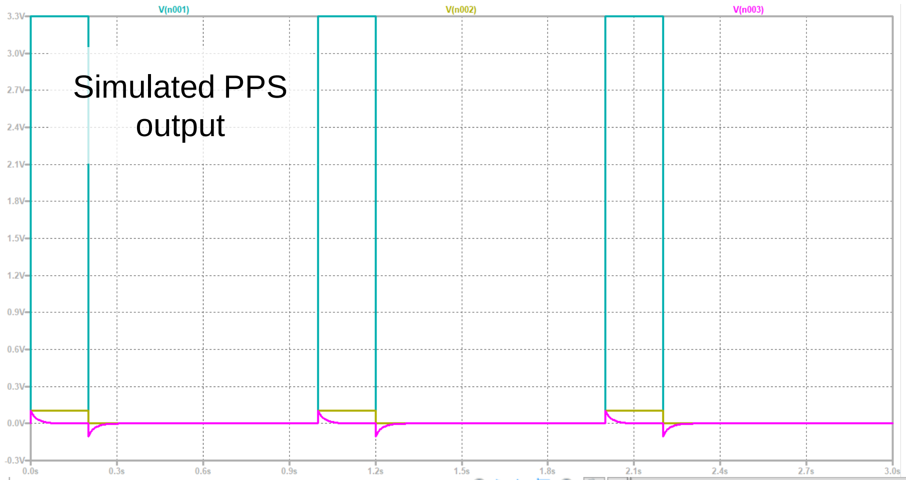
PRN:	Elev:	Azim:	SNR:	Used:
8	19	314	26	Y
10	63	313	29	Y
15	19	049	21	Y
18	50	131	48	Y
20	31	080	31	Y
23	63	042	27	Y
27	37	279	30	Y
32	41	215	42	Y
131	42	198	33	Y
133	38	215	31	Y
138	44	183	35	Y
24	31	082	28	N

Rest Button/LED(**Pass**):

When pressed the Raspi reboots as expected. The Raspi also has full control of the general LED



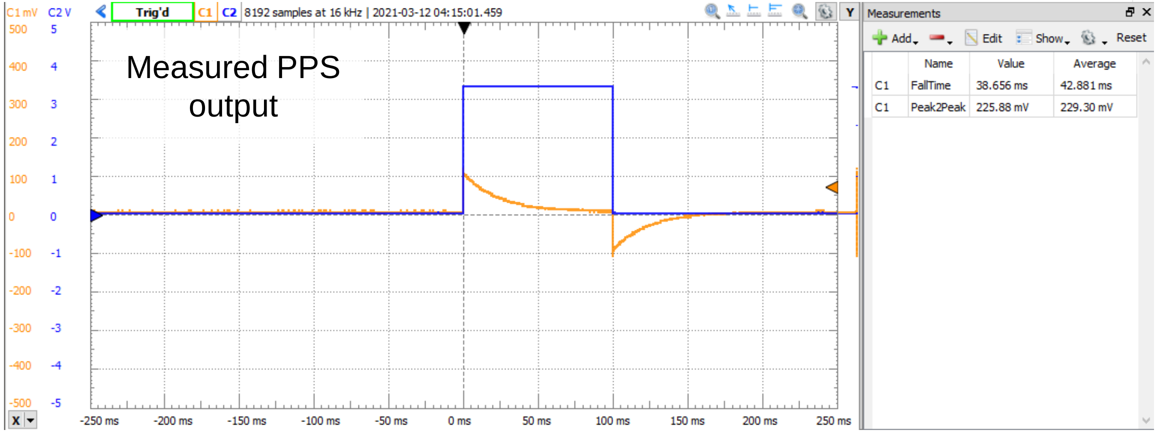
Circuit Board Test Results:



PPS (**Pass**):

The PPS output was measured using an oscope and compared to a LTspice simulation. Comparing the two side by side the filtered PPS performs nearly identical to the simulation with a pk-pk ~200mv and a rise time <50ns.

The PPS shape is key as without it we are unable to measure time delay and make orbital predictions.



Circuit Board Test Results:

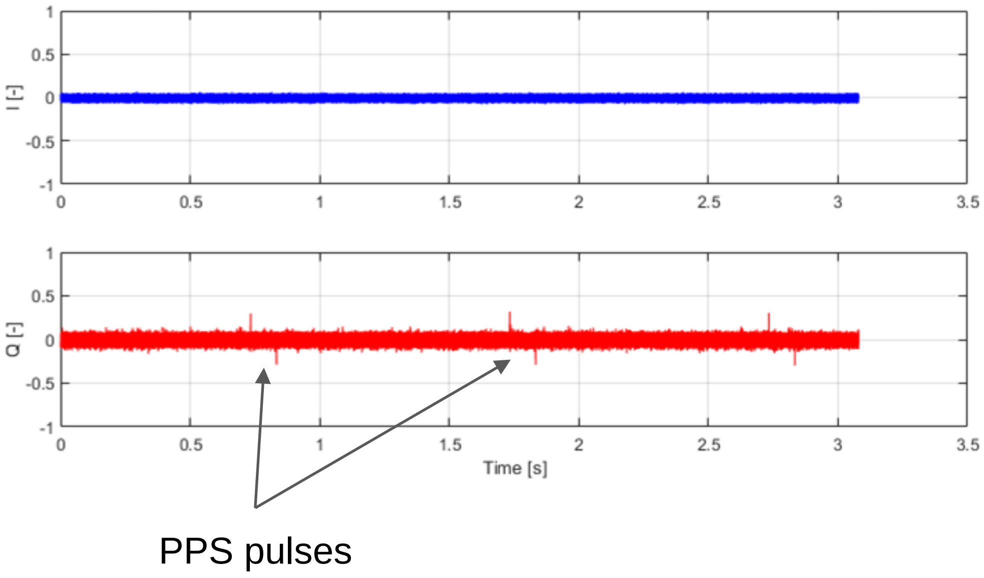
PPS + hackRF(**Pass**):

The final test is making sure the PPS can be seen when superimposed on the hackRF at the target frequencies.

The expected result is that the PPS will be visible over the noise floor and leave the RF stream mostly untouched.

Injecting the PPS onto the hackRF we clearly see the PPS at both target bands. The PPS seems to mildly increase the noise floor this could be due to coupling between the differential amp in the DAC or improper common ground. Either way the RF data is usable and the PPS appears as expected.

Example of PPS in IQ streams at 437.25 MHz



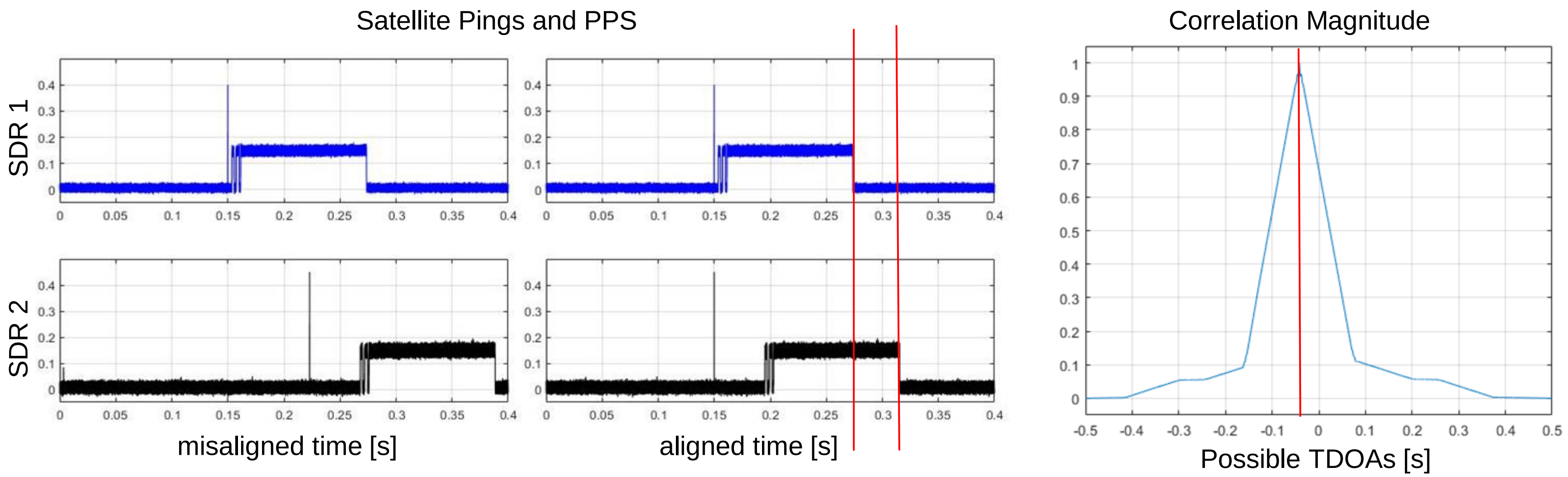
Time Synchronization Test(**Pass**):

Overall Test Goal(s): Test the data collection is synchronized and has the PPS signal.

Requirements: 5.1 &5.2

Risk Mitigated: Bottleneck of entire project

Modelled Results: Data collection starts within 1 second. Synchronized to UTC. Physical TDOA found.



Raspberry Pi and HackRF Interfacing Test:

Overall Test Goal(s): Ensure the HackRF is operable when connected to the Raspi

Requirements: FR2 DR2.4

Risk Mitigated: Not compatible with the onboard OS and Raspi. Failure to collect necessary amount of samples per second.

Modelled Results: Seeing anywhere between 10Ms/s - 20Ms/s based on settings

Acquired Sample Rate	**Conditional Pass**	Verify that the correct amount of samples is being recorded from the SDR each second

Raspberry Pi and HackRF Interfacing Analysis:

After this initial testing, there were several issues that we ran into:

1. The sampling rate for the HackRF was inconsistent at high values, as seen in the test results
2. The HackRF could not record data for long periods of time without posting an error

To solve these problems:

- Implemented a data recording scheme where the HackRF only records for 15 seconds at a time
- We performed further testing with sample rates of 10 Ms/s and 5 Ms/s to test sample rate stability
    - The mean and standard deviations of the sample rates from these tests were:
        - 10 Ms/s sample rate: 7.7449 ± 3.0789 Ms/s
        - 5 Ms/s sample rate: Mean: 4.7094 ± 1.2163 Ms/s

RF Front End Test:

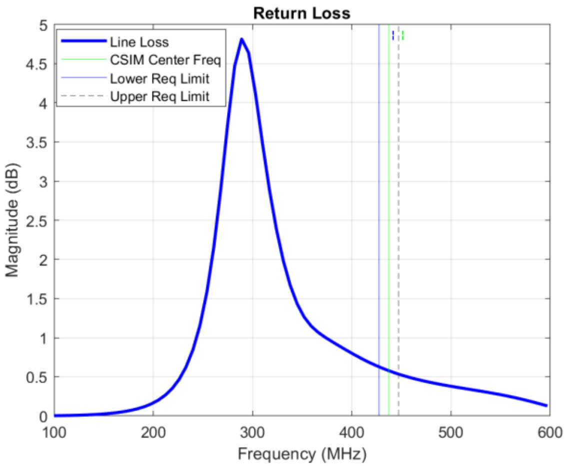
Overall Test Goal(s): Ensuring that the products our team purchased work as advertised and more importantly these devices will ensure our received signals stand out sufficiently above the noise floor.

Requirements: DR3.1, DR3.3

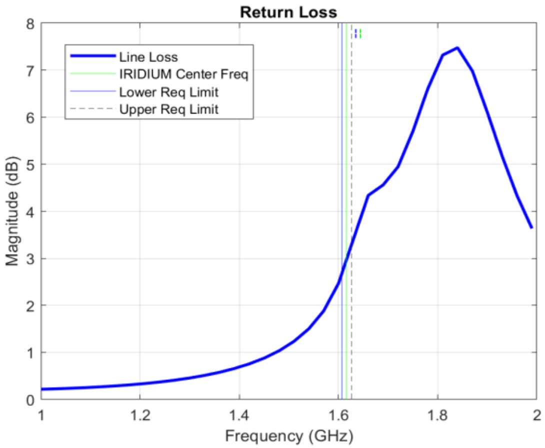
Risk Mitigated: Eliminating the potential for unexpected RF blind spots when trying to receive satellite signals. As well as ensuring our ability to properly calculate TDOA's from distinct and unique recorded signals

Modelled Results: We can see our desired signals clearly Eb/No=12.1dB and 4.4dB for UHF and L-Band respectively.

RF Front End Results:



Band	UHF
Satellite	CSIM
Center Freq	437.25 MHz
Data Rate	9.6kbps
Link Margin	12.1 dB (**Pass**)



Band	L-Band
Satellite	Iridium
Center Freq	1616 MHz
Data Rate	96kbps
Link Margin	4.4 dB (Conditional Pass)

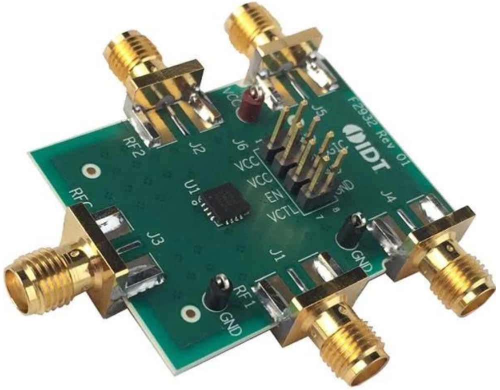
Dual-Band Capability Test:

Overall Test Goal(s): Prove that our system can switch between received frequency bands rapidly and on demand

Requirements: FR 3.6, 4.1, 4.2

Risk Mitigated: Having a computer controlled switch makes switching between signals a trivial issue

Results: Working two band system



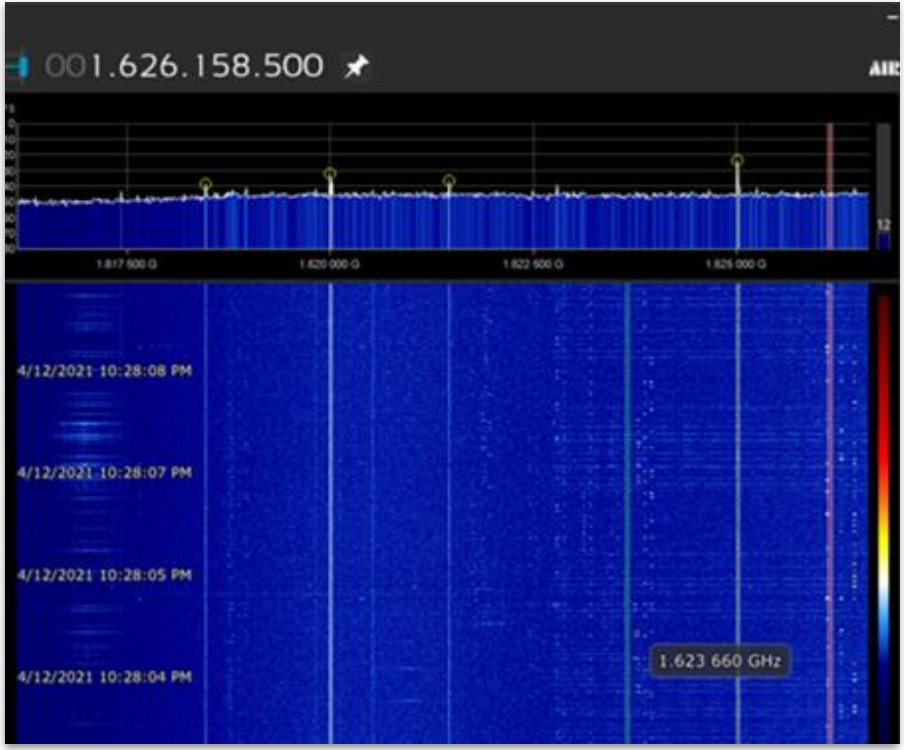
Dual-Band Capability Test Results:

UHF signal response:

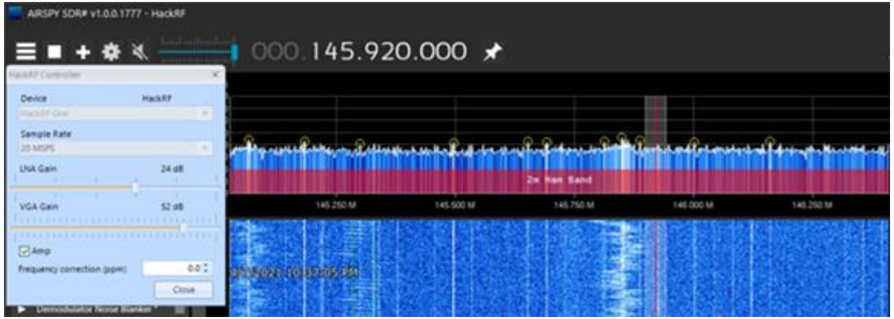
- Csim produces a stronger and larger individual pulse which is easily identifiable in the IQ Data
- (**Pass**)

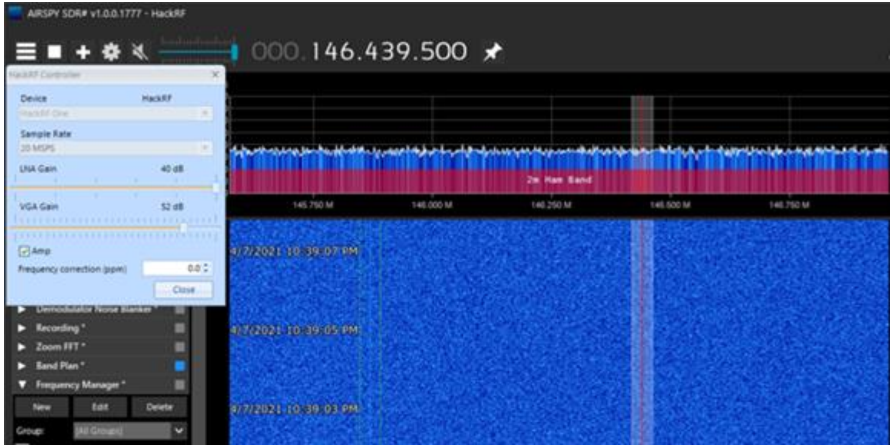
L-Band signal response:

- Visually distinct on a waterfall plot
- Phased Satellite array
- Multiple Sats overhead at once
  - Iridium 111, Iridium 146, Iridum 149, and Iridum 162
- (**Conditional Pass**)



Extended Test Results:





VHF Testing results: (Backup band)

- During early stages of modeling it appeared to viable candidate
- Even with a healthy amount of signal conditioning the yagi antenna is just totally blind to most of the VHF spectrum
- (**Fail**)

Onboard OS Test:

Overall Test Goal(s): Ensure that the Onboard OS can run autonomously without unexpected failures. Ensure that the OS is capable of coping with power outages and failures.

Requirements: FR2, DR2.4 and DR2.5

Risk Mitigated: Ensures that data is collected on time and in the expected format (removes the human error)

Modelled Results: These tests summarize the onboard OS's nominal operation

On start	Unit automatically updates scripts, get flyby list for the current day, enter standby waiting for orbital pass
New Day	Unit will automatically get flyby list for the new day, enter standby waiting for orbital pass
Missing GPS	Unit will give visual indication, delay till GPS lock is acquired
Power Outage	Unit will follow "on start" procedure
Various errors	Unit will give visual indication, log error, exit to a safety loop

Onboard OS Test Results:

Running the software and performing fringe case testing the OS software performs as expected.

On start	**pass**	Unit performed as expected only requiring a reset
New Day	**pass**	Unit will automatically get flyby list for the new day, enter standby waiting for orbital pass
Missing GPS	**pass**	Unit will give visual indication, delay till GPS lock is acquired
Power Outage	**pass**	Unit will follow “on start” procedure
Various errors	**pass**	Unit will give visual indication, log error, exit to a safety loop

Only “failure” was a hardware level failure.
If power is lost while interfacing with the USB there is a possibility that the USB becomes corrupted and “bricked”. The software minimizes the time spent interacting with the usb but this doesn't solve the problem. A solution would be to add a secondary power source that would enable the system to shut down safely when a loss of power is detected.

Single Unit Test:

Overall Test Goal(s): Run a unit for 24 hours. Ensure at least 4 flybys are collected.

Requirements: 1, 3, 5.5

Risks Mitigated: Long exposure and autonomy. Confirms on-board OS can run for extended periods

Modelled Results: These results are the goals of the 24 hour single unit test

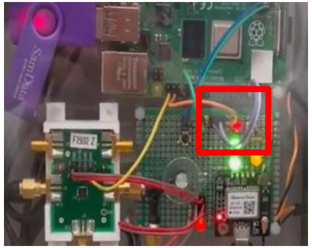
Flybys	Unit will Records all flybys scheduled. At minimum records 4 flybys.
New Day	Unit will automatically get flyby list for the new day, enter standby waiting for orbital pass
Various errors	Unit will give visual indication, log error, exit to a safety loop
Temperature	Unit will remain in the operating requirements. 0℃ to 50℃

Single Unit Test Results:

7am 8am 9am 10am 11am 12pm 1pm 2pm 3pm 4pm 5pm 6pm 7pm 8pm 9pm 10pm 11pm 12am 1am 2am 3am 4am 5am 6am 7am 8am

7:30am:
Unit is turned on.
Startup LED Blinks successfully

11:09am:
First flyby.
Indicator LED turns on.
11:32 am LED turns off.



12:46pm:
Second Flyby.

6:00pm:
Unit cycles to UTC next day. Error LED remains off.

6:04pm:
Third Flyby.

9:58pm:
Fourth Flyby.
Verifies DR 5.5

11:32pm:
Fifth Flyby.

5:11am:
Sixth Flyby

6:52am:
Seventh Flyby.
T =1.1℃

7:30am:
Single Unit Test Complete (**Pass**)

Full Suite Testing:

Overall Test Goal(s): Ensure that full system suite is capable of autonomously handling data collection.
Requirements: FR 5, FR 6

Risk Mitigated: Verification of simulated models and allocated tolerances.

Modelled Results: Compliance with FR 5 and FR 6.

Zero TDoA	**Incomplete**	Verify unit and data collection process by practicing data collection of a CSIM flyby with all units stationed in Boulder.

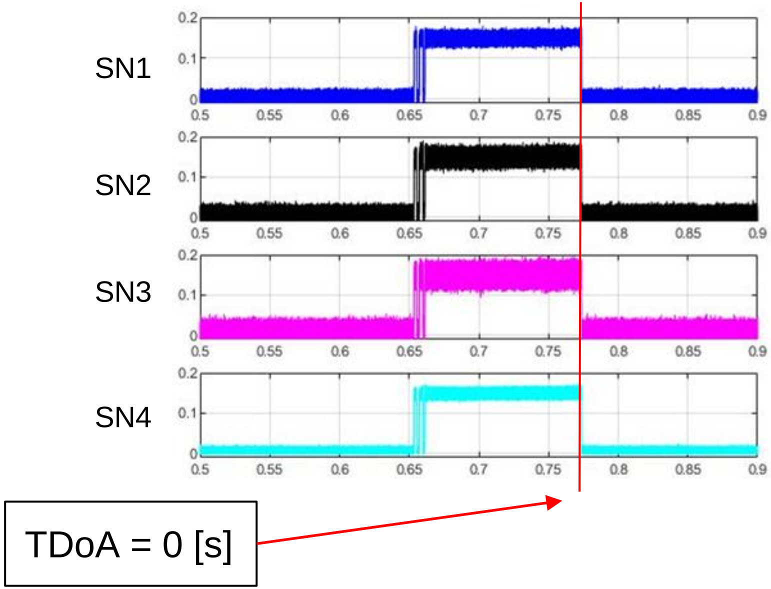
Zero TDoA Test Overview:

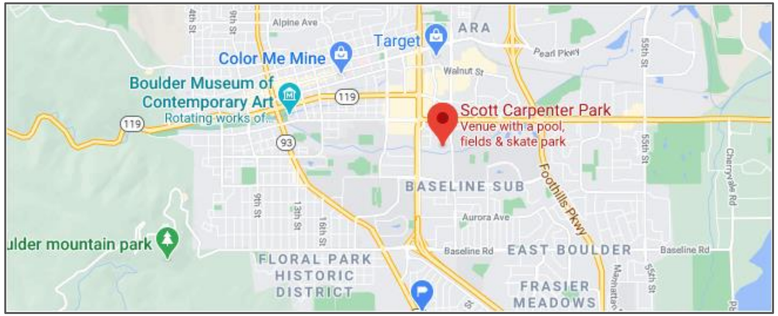
Procedure:

1. Collect and store data with SN1-SN4 at the same location for a single flyby
2. Stored data is off-loaded for post processing.
3. TDoA output is zero for all sensors.
    - Baseline verification (cannot find orbit here).
    - Verification of hardwares ability to perform desired system operations

Results:(**Incomplete**)

- Final test results will be reported in the final paper
- Will conclude this project at about ~80% of initial intended scope.

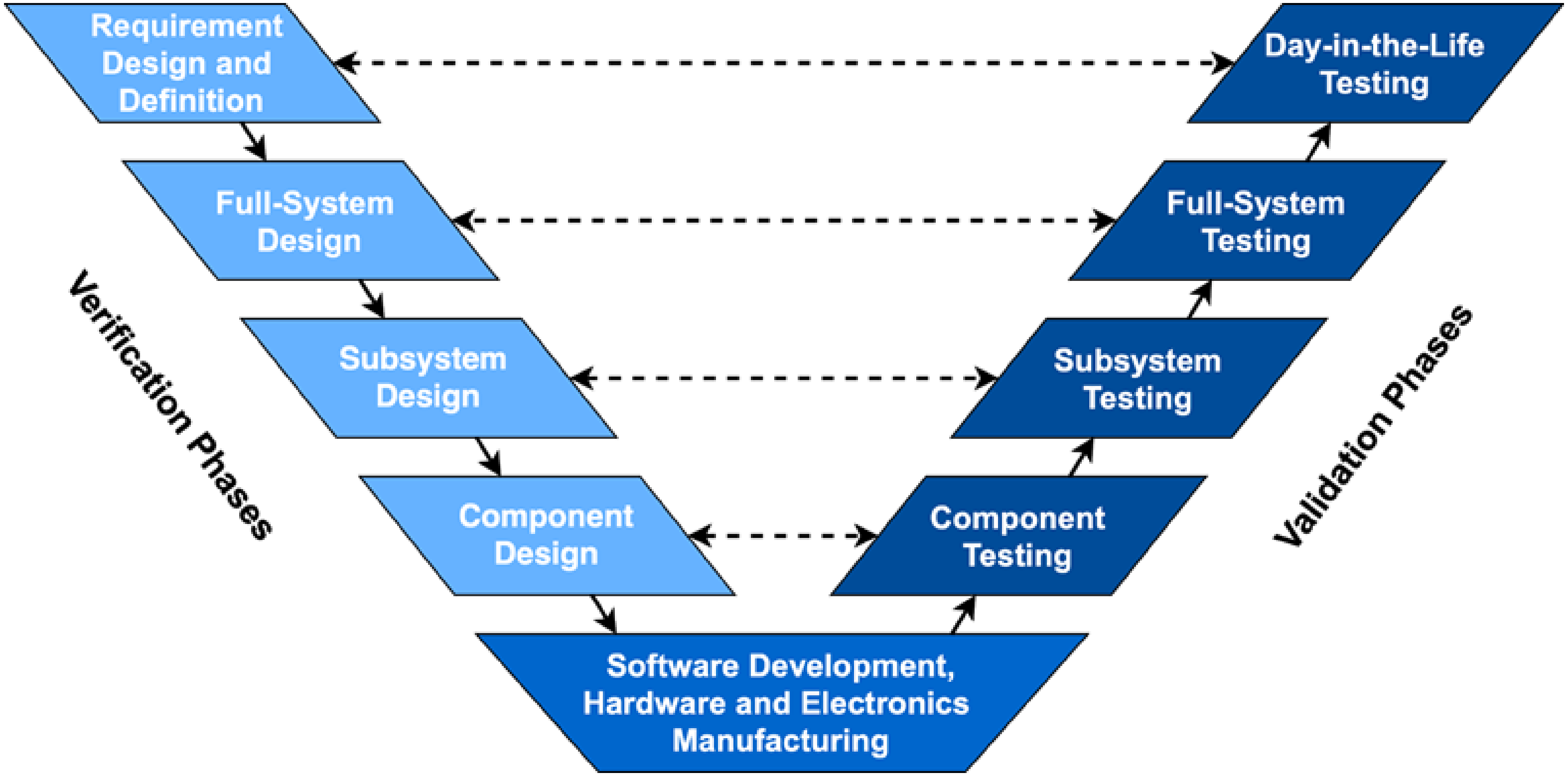




Levels of Success	Key Objectives	● {Completed} ● {Blocked}
1	● {TDOA from artificial data} ● {Orbital Prediction from artificial data} ● {4 units built} ● {Sensor Units shall receive on single band} ● {Sensor units shall be able to synchronize to UTC time via GPS}	
2	● {TDOA prediction from 2 units data} ● {Sensor Units shall receive on dual bands} ● {Sensor Units shall be able to recover in result of a power outage} ● {Sensor Units data shall be synchronized to within 420 ns}	
3	● {Four Units are deployed and operational} ● {Manufacturing Documentation (schematics, procedure, manufacturing analysis, suggested improvements, and ways to drive down cost)} ● {TDOA prediction from 4 units data} ● {Orbital prediction from data}	

Systems Engineering

Test Methodology



Trade Studies

Study	Outcome	Reasoning
Satellite Candidate	CSIM (UHF), Iridium (L-Band)	Locally Operated, Well known Orbits
On-Board Computer	Raspberry Pi 4	Cost, Functionality
SDR	HackRF	Cost
GPS	NEO-6M	Cost, Positioning accuracy
Sensor Unit Housing	NEMA Electrical Enclosure	Durability

Development of Requirements

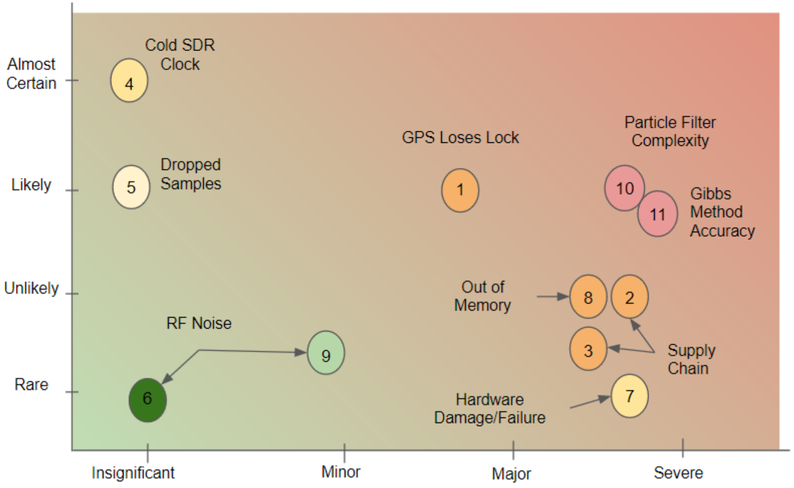
Customer wanted a cost effective Low-Earth Orbit Satellite tracking system

- The sensor unit shall be weather resistant and capable of nominal operation outdoors for 24 continuous hours. **(FR 1)**
- The sensor unit shall be transportable and deployable by a single individual. **(FR 2)**
- Each sensor unit will be capable of receiving RF signals from both UHF and L band ranges. **(FR 3)**
- The RF system will be capable of obtaining RF lock such that lock is achieved by at least 4 units at a time. (**FR 4)**
- Recorded data can be used to produce a orbital position within a 3σconfidence of 100 km of a known satellite candidate. (**FR 5)**
- Recorded data can be used to produce a TLE prediction of a known satellite candidate that is able to predict a future pass-over after 1 day within ±45 minute time accuracy, ±30 deg azimuth accuracy at the start of the pass-over and ±15 deg elevation at the midpoint (**FR 6)**
- The sensor unit shall be easily accessible and easy to manufacture. **(FR 7)**

Risk Assessment

Risks were assessed and characterize the specific project risks, and were used for each design and implementation risk prior to CDR

Major Risks	
1	GPS loses lock for more than a minute
2	SDR is out of stock/lead time is too long/dead on arrival
3	Raspberry Pi is out of stock
4	SDR clock is cold
5	SDR drops samples
6	PPS lost to noise
7	Electrical short, water damage, antenna mount fails
8	Raspberry Pi runs out of memory
9	System noise greater than expected
10	Particle filter is not complete
11	Three out of plane position estimates for Gibb's.



Systems Engineering Challenges

Unpredicted: Lots of bugs and unexpected failure mechanisms led to drawn out development time for the Onboard OS

Predicted: Large file sizes made getting data to those who needed it for testing slow and time consuming

Major Risks	
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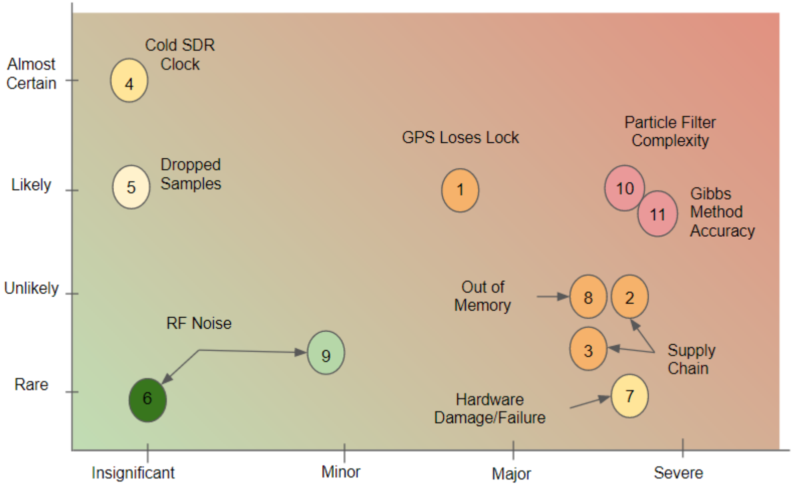


Lessons Learned

Documentation and organization are crucial.

- Better documentation in early phases of design would have facilitated organization and communication between team members.
  - Differences in software run times utilizing different SD card sizes

- All-team meetings were less important as time went on; emphasis should

have been placed on subsystem meetings.

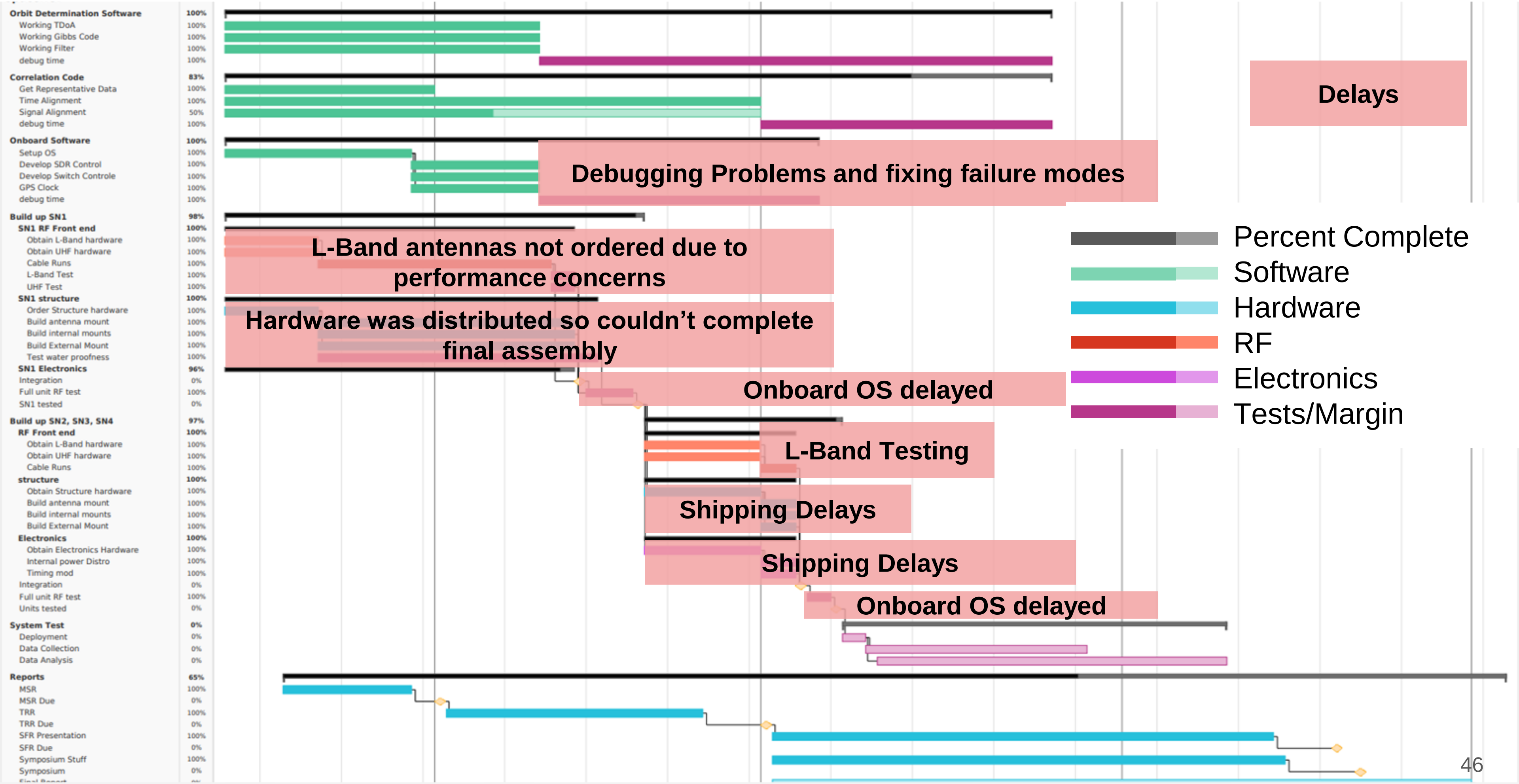
Subsystems can be difficult to separate and manage individually.

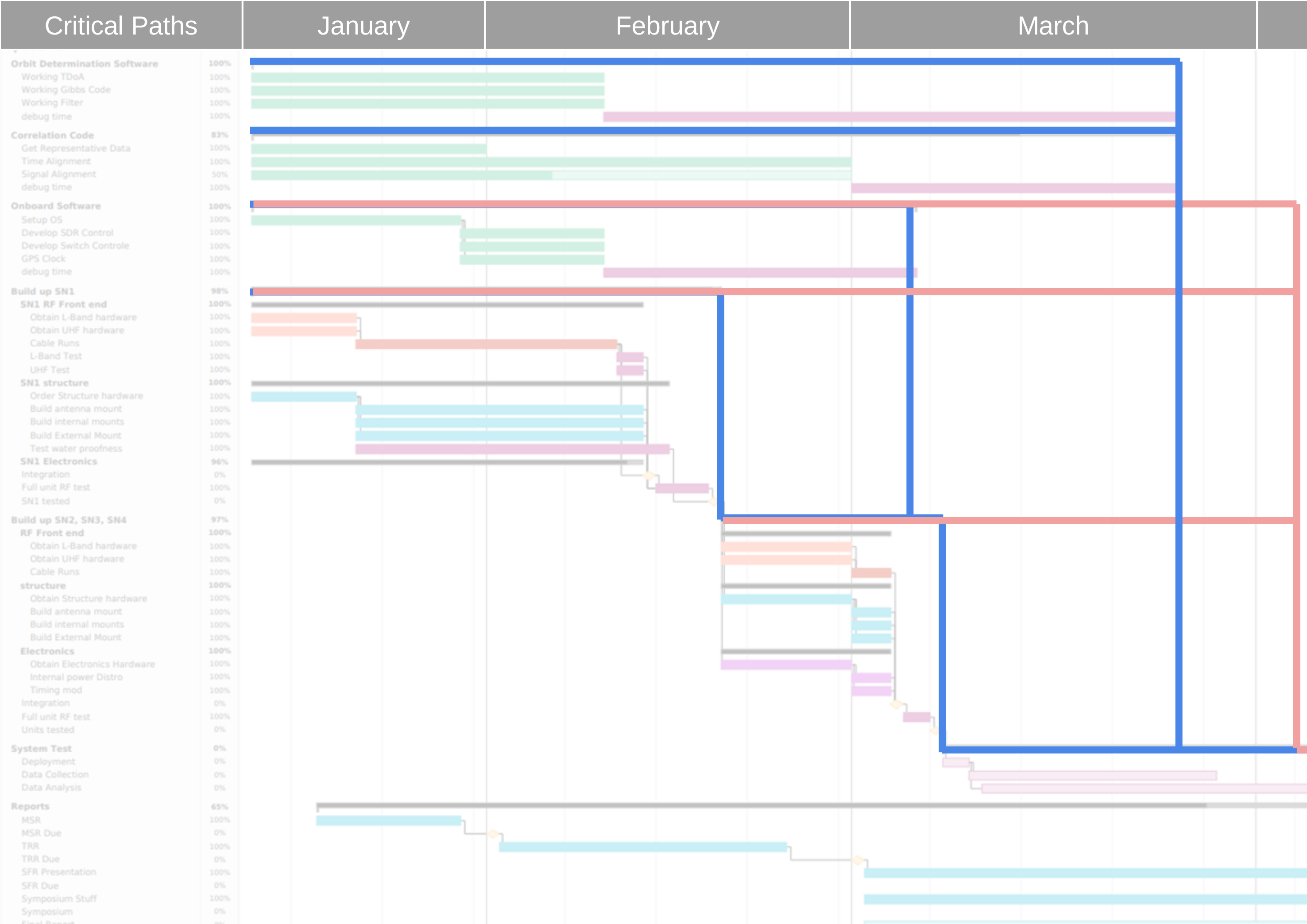
- This project had a plethora of subsystems, with team members spread across several subteams

Led to miscommunication among team members, as team member roles were unclear.

Project Management

Schedule


January
February
March
April
May
Orbit Determination Software 100%
Working TDoA 100%
Working Gibbs Code 100%
Working Filter 100%
debug time 100%
Correlation Code 83%
Get Representative Data 100%
Time Alignment 100%
Signal Alignment 50%
debug time 100%
Onboard Software 100%
Setup OS 100%
Develop SDR Control 100%
Develop Switch Controle 100%
GPS Clock 100%
debug time 100%
Build up SN1 98%
SN1 RF Front end 100%
Obtain L-Band hardware 100%
Obtain UHF hardware 100%
Cable Runs 100%
L-Band Test 100%
UHF Test 100%
SN1 structure 100%
Order Structure hardware 100%
Build antenna mount 100%
Build internal mounts 100%
Build External Mount 100%
Test water proofness 100%
SN1 Electronics 96%
Integration 0%
Full unit RF test 100%
SN1 tested 0%
Build up SN2, SN3, SN4 97%
RF Front end 100%
Obtain L-Band hardware 100%
Obtain UHF hardware 100%
Cable Runs 100%
structure 100%
Obtain Structure hardware 100%
Build antenna mount 100%
Build internal mounts 100%
Build External Mount 100%
Electronics 100%
Obtain Electronics Hardware 100%
Internal power Distro 100%
Timing mod 100%
Integration 0%
Full unit RF test 100%
Units tested 0%
System Test 0%
Deployment 0%
Data Collection 0%
Data Analysis 0%
Reports 65%
MSR 100%
MSR Due 0%
TRR 100%
TRR Due 0%
SFR Presentation 100%
SFR Due 0%
Symposium Stuff 100%
Symposium 0%
Delays
Debugging Problems and fixing failure modes
L-Band antennas not ordered due to performance concerns
Hardware was distributed so couldn't complete final assembly
Onboard OS delayed
L-Band Testing
Shipping Delays
Shipping Delays
Onboard OS delayed
Percent Complete
Software
Hardware
RF
Electronics
Tests/Margin



At TRR we forecasted that we would be slightly behind schedule due to lack of hardware

However, compounding problems ultimately used up the conservative amount of testing time

Original Path

Actual Path

What went wrong…

Attempted Agile management style:
Team lacked experience in multiple areas and underestimated topics complexity

Mix of information from self educating made it difficult to split up tasks due to conflicting understandings

Idea to build a single unit first was good in theory. COVID made it hard for teams to get their hands on hardware. If one team fell behind and couldn't hand off the hardware it had a cascading effect.

Overall struggled to communicate virtually

Other Problems:

Bugs and unexpected failure mechanisms in OS. Led to drawn out development time

Large files sizes made testing slow and time consuming

What went right…

Project Breakdown:
The chosen subteams worked well

Teams were able to work mostly independently from other teams. Teams could avoid having to rely on other teams progress till integration

Starting the project with a simple prediction method and a more complex one for safety worked well.

Lessons Learned

Properly dividing work helps individuals from becoming overwhelmed and falling behind

Trying to keep subteams independent from one another is key

Industry Cost of Project

Labor Cost

Total Hours Worked
1,962 Hours

Estimated Entry Level Salary
$65,000 for 2,080 hours

Assumed Overhead
200%

Total Labor Cost
$122,625

Material Cost

Projected Material Cost
$3392.92

Actual Material Cost
$3951.02

The discrepancy between the projected and the actual is due to extra hardware being ordered early on to aid in early development.

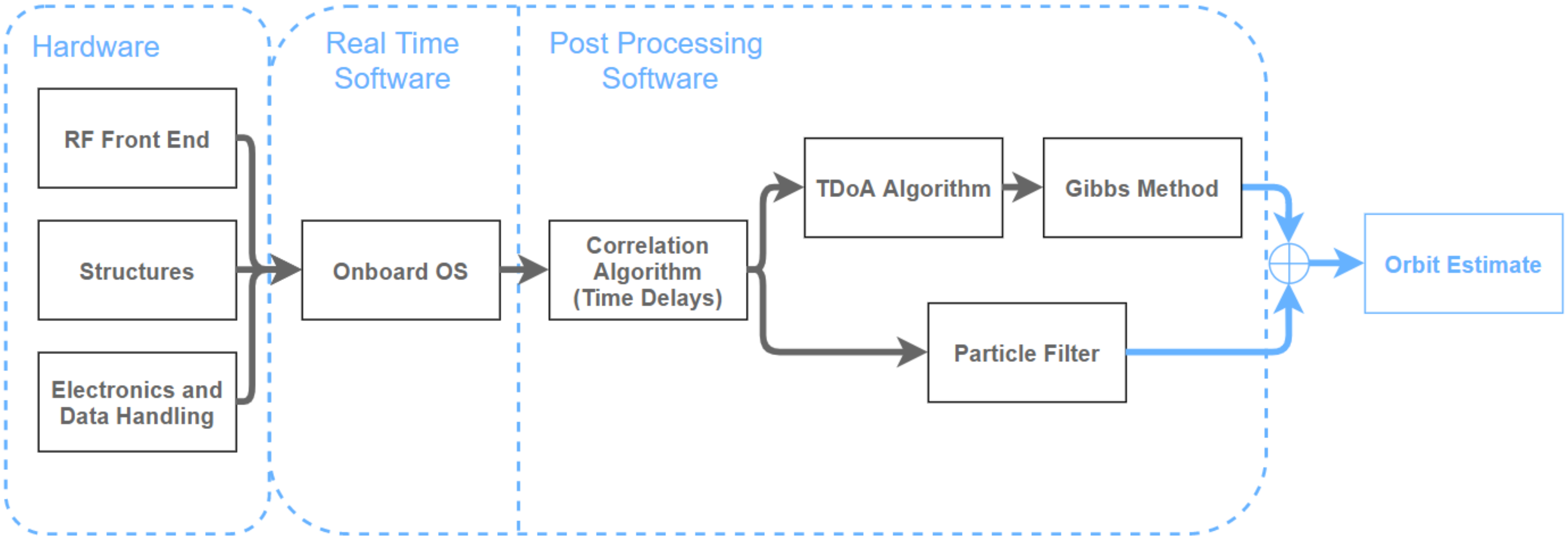
Total Project Cost
$126,576.02

Acknowledgements

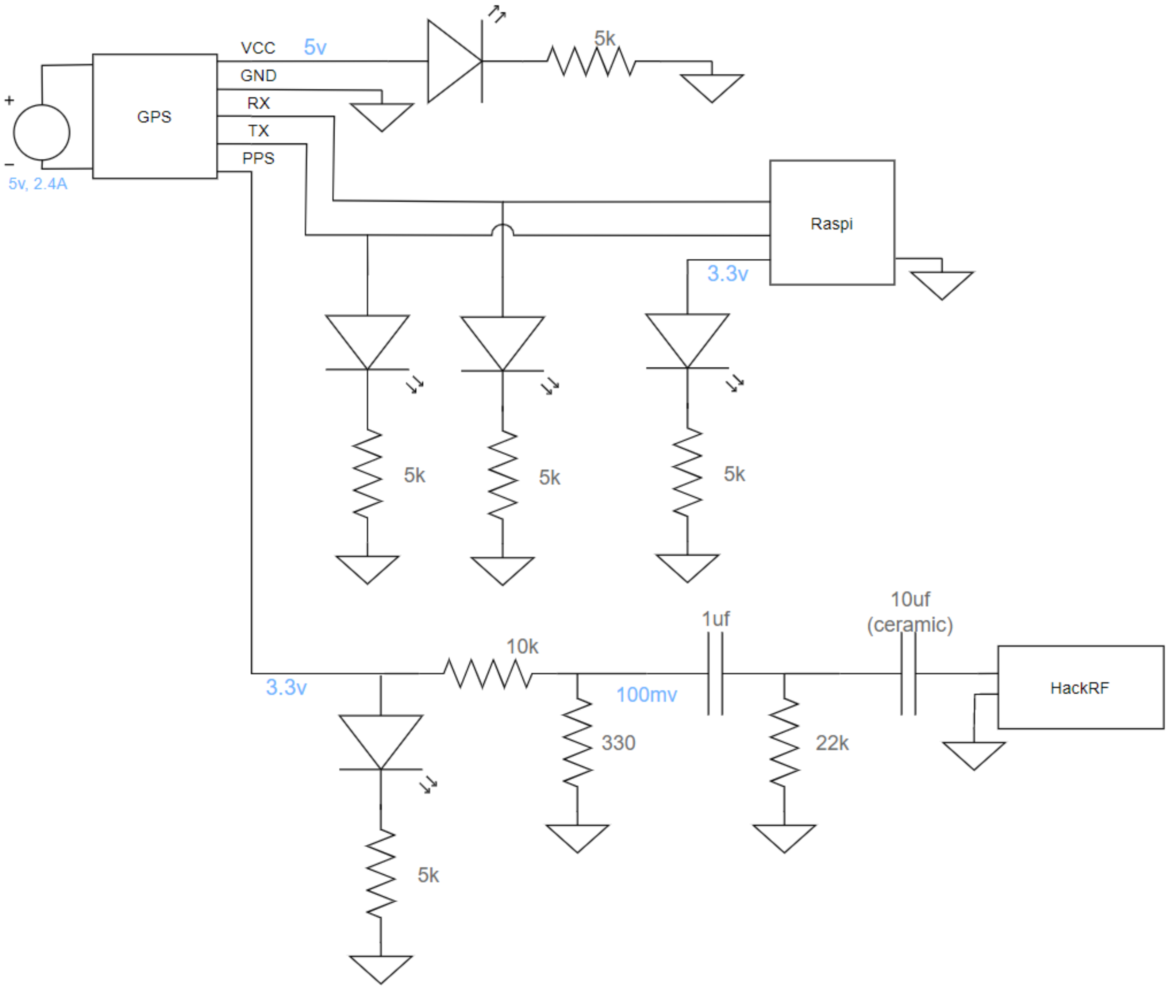
- Dr. Francisco López Jiménez
- Martin Wilson (Raytheon)
- Mike Walker (Raytheon)
- Sheldon Clark (Raytheon)
- Mark Werremeyer (Raytheon)
- Dr. Zachary Sunberg
- KatieRae Williamson
- Dr. Rainville

Backups

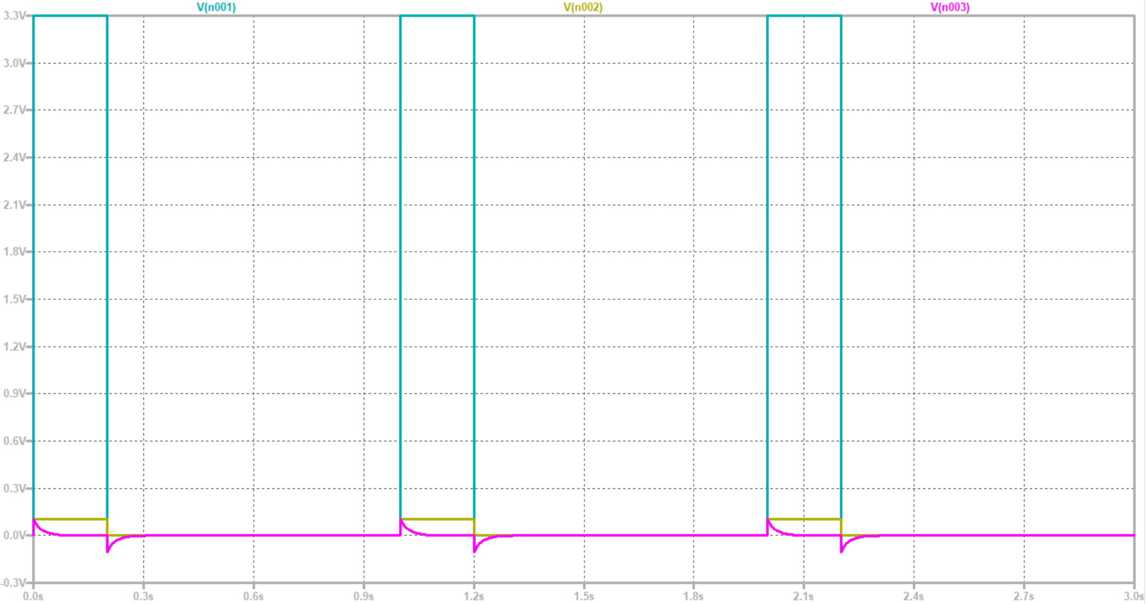
Conceptual Block Diagram

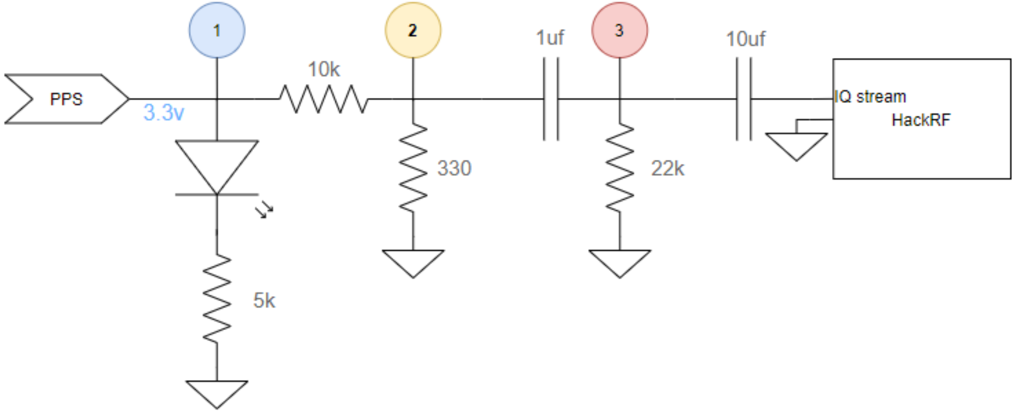


Full Electronics Schematic



PPS breakdown





Correlation Testing (TDOA) Test

Overall Test Goal(s): Ensure that the correlation scheme works and does not add delay above the required max.

Requirements: FR 5, FR 6

Risk Mitigated: SDRs cannot be aligned according to GPST.

Modelled Results: Simulated TDoAs.

Test(s)	Status	Test Goal
Zero TDoA	In Progress	Cross correlate 2 signals and pull out a TDoA = 0 to heuristically evaluate SDR noise
B-A TDoA	Incomplete	Cross correlate 2 signals between (B)oulder and (A)urora

Zero TDoA Test Overview

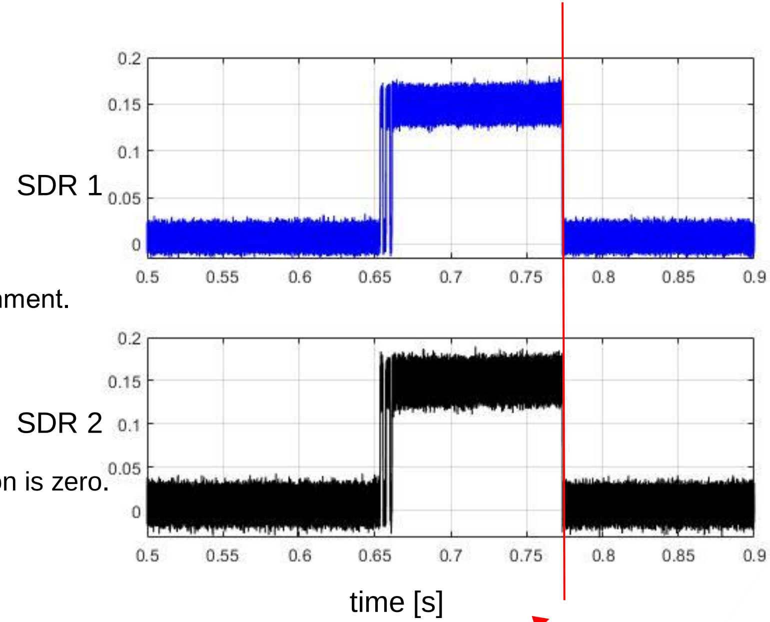
Procedure:

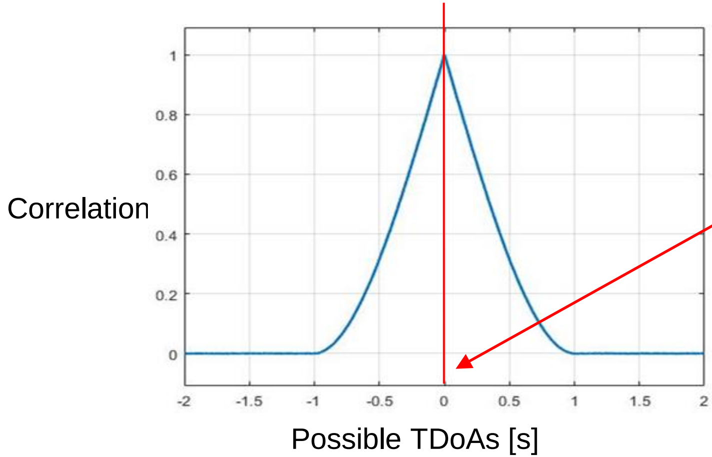
- Collect Data with SDRs at the same location.
- Press ‘collect’ within one second of each other for gps alignment.

Equipment/Facilities needed:

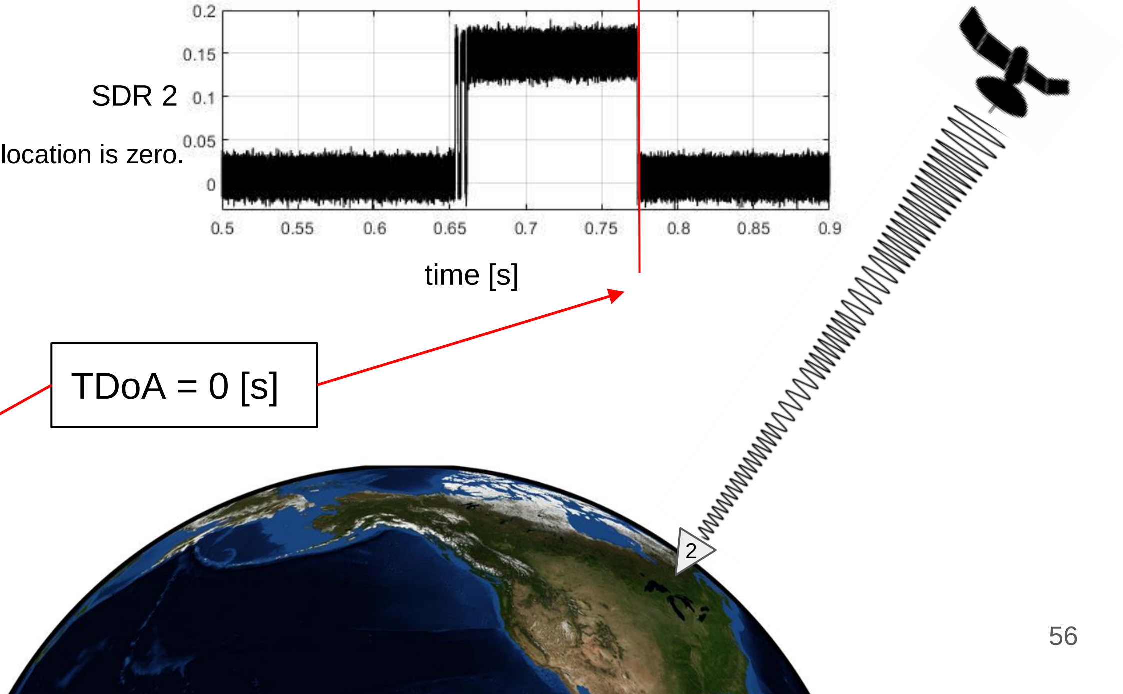
- Two SDRs.

Test goal - Verify that TDoA between two SDRs at the same location is zero.

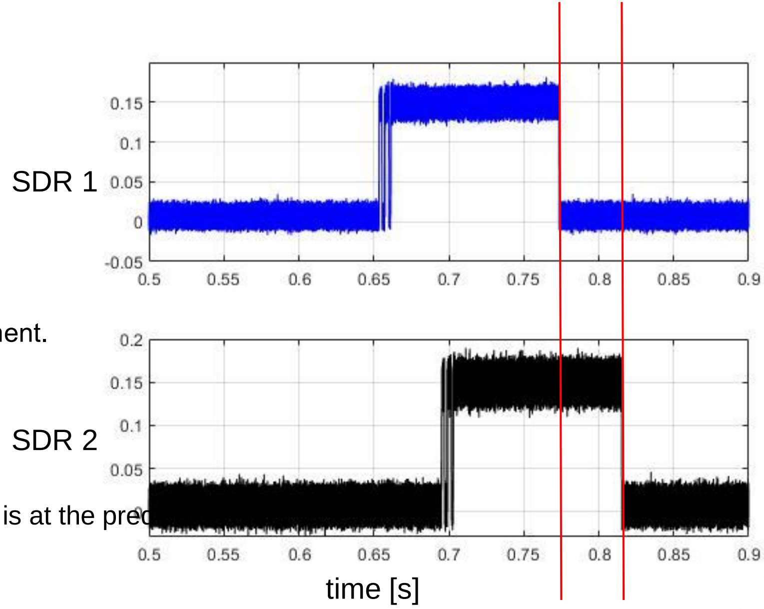




TDoA = 0 [s]



B-A TDoA Test Overview



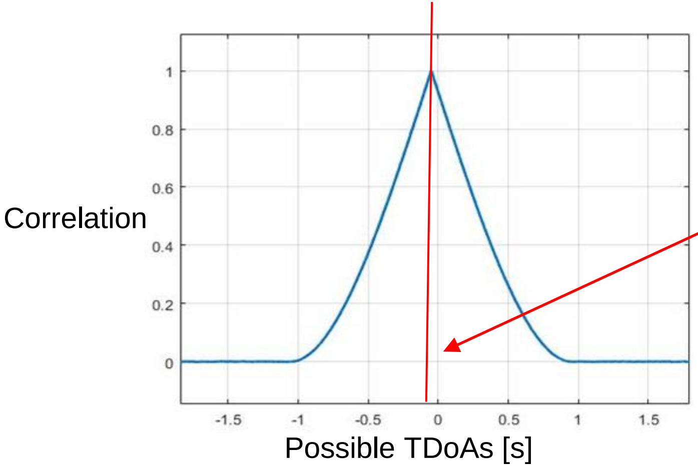
Procedure:

- Collect Data with SDRs in Aurora, CO and Boulder, CO.
- Press ‘collect’ within one second of each other for gps alignment.

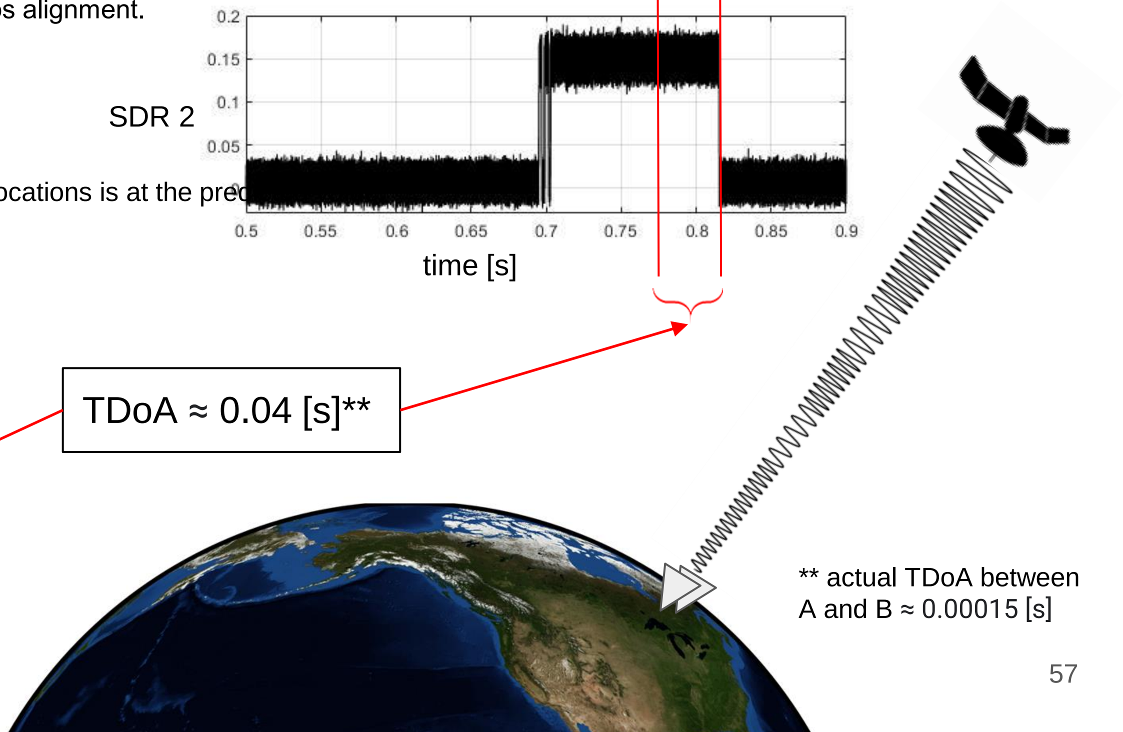
Equipment/Facilities needed:

- Two SDRs.

Test goal - Verify that TDoA between two SDRs at different locations is at the pre



TDoA ≈ 0.04 [s]**



** actual TDoA between A and B ≈ 0.00015 [s]

Orbit Determination Test

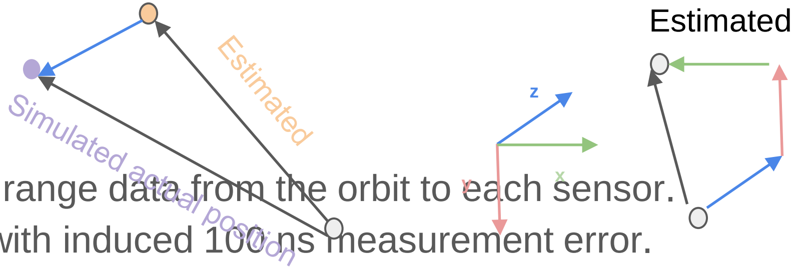
Overall Test Goal(s): Prove Determination software predicts Orbits within margins.
Requirements: FR 5, FR 6

Risk Mitigated: Verified that post processing is free of systematic errors.

Modelled Result: Post processing steps completed successfully.

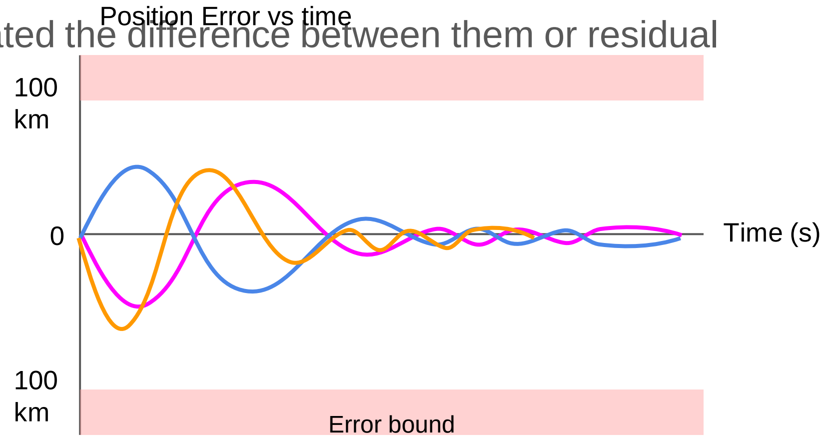
Test(s)	Status	Test Goal
Verify PF	Done	Verify Particle Filters ability to successfully generate the state time series
Verify TLE	Done	Verify that the state time series can be successfully used to generate a TLE
Verify SGP4	Done	Verify SGP4 propagators ability to generate accurate satellite passover list

Orbit Determination Test Overview



Test Procedure Overview:

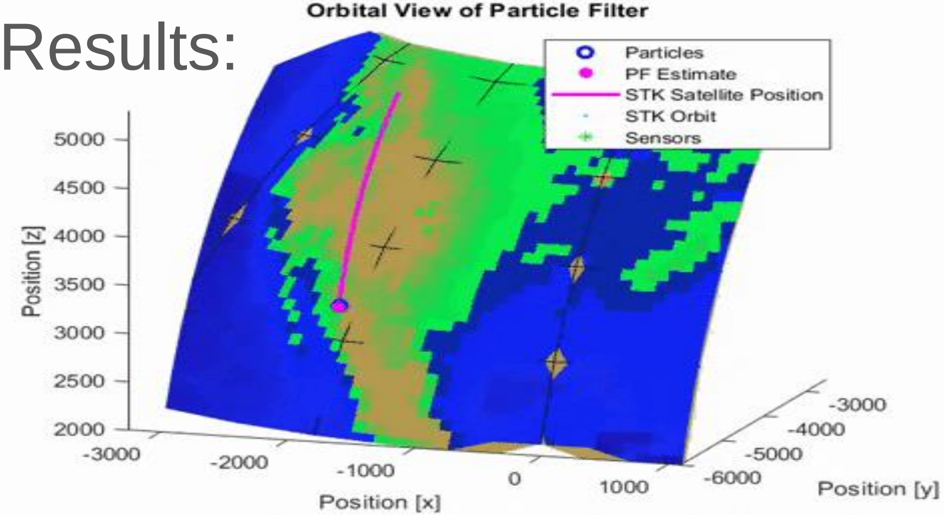
- STK produced multiple sample satellite orbits and range data from the orbit to each sensor.
- Calculated sample TDoA values from the ranges with induced 100 ns measurement error.
- TDoA values initialized the orbital determination method.
- Update estimate with remaining TDoA values.
- Compared output estimates to STK data. Calculated the difference between them or residual vectors.

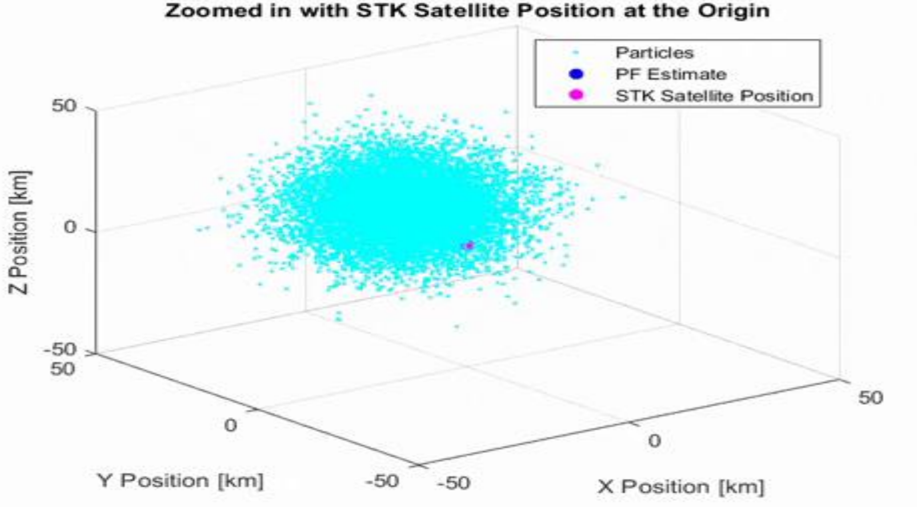


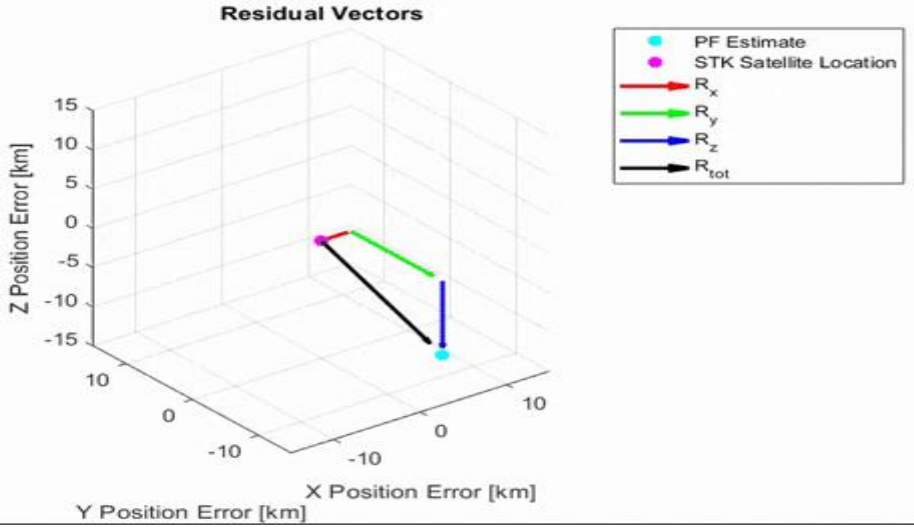
Equipment/Facilities needed:

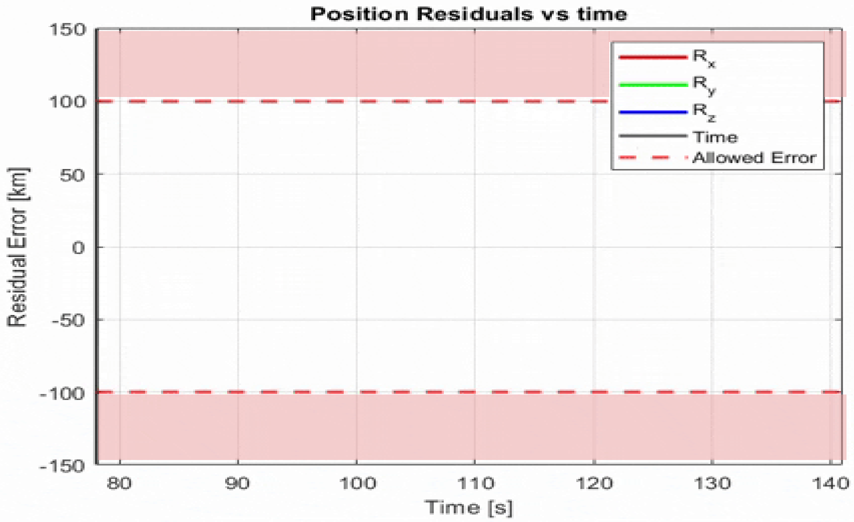
STK and Matlab

Results:


Orbital View of Particle Filter
Particles
PF Estimate
STK Satellite Position
STK Orbit
Sensors
Position [z]
Position [x]
Position [y]
5000
4500
4000
3500
3000
2500
2000
-3000
-2000
-1000
0
1000
-3000
-4000
-5000
-6000


Zoomed in with STK Satellite Position at the Origin
Particles
PF Estimate
STK Satellite Position
Z Position [km]
Y Position [km]
X Position [km]
50
0
-50
50
0
-50
-50
0
50


Residual Vectors
PF Estimate
STK Satellite Location
R_x
R_y
R_z
R_{tot}
Z Position Error [km]
X Position Error [km]
Y Position Error [km]
15
10
5
0
-5
-10
-15
10
0
-10
-10
0
10

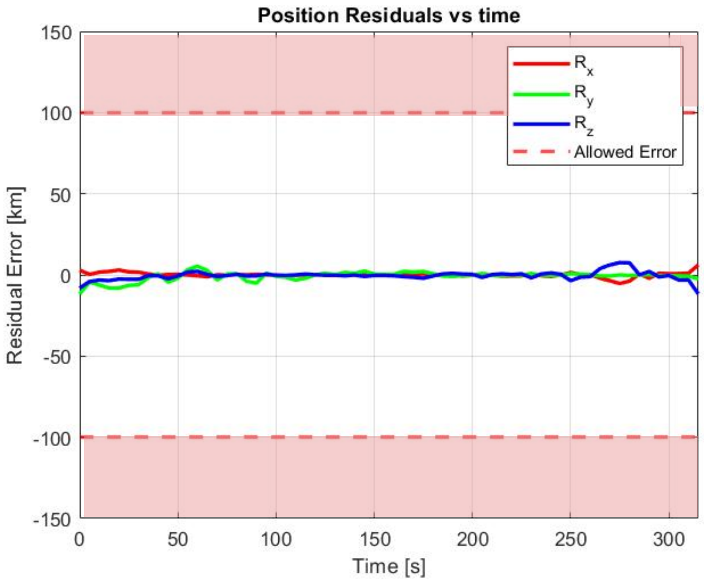

Position Residuals vs time
R_x
R_y
R_z
Time
Allowed Error
Residual Error [km]
Time [s]
150
100
50
0
-50
-100
-150
80
90
100
110
120
130
140

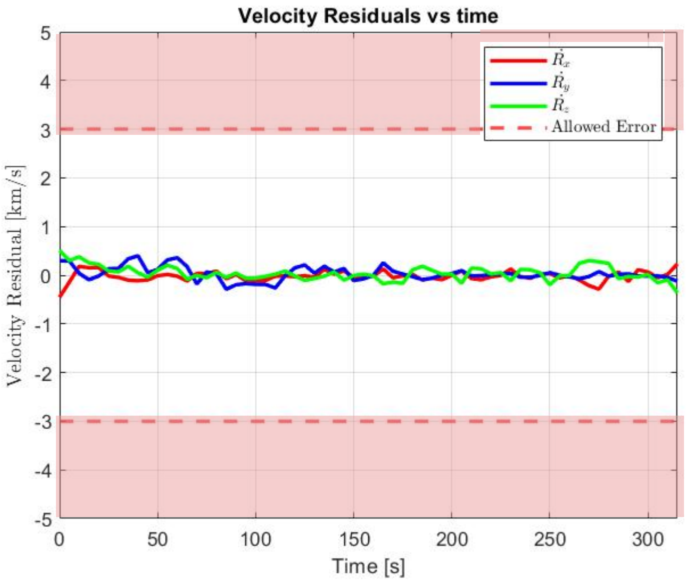
Orbit Prediction Results:

- Verifies FR5: position estimate with 100 km of the true position.
- Consistently within 0.5 km error and 0.050 km/s error.
    - Satellites position has the greatest effect on error.

Average Position Error: 0.409 km

Average Velocity Error: 0.015 km/s





Onboard OS Test

Overall Test Goal(s): Ensure that the subscripts run on start-up and operate as expected.

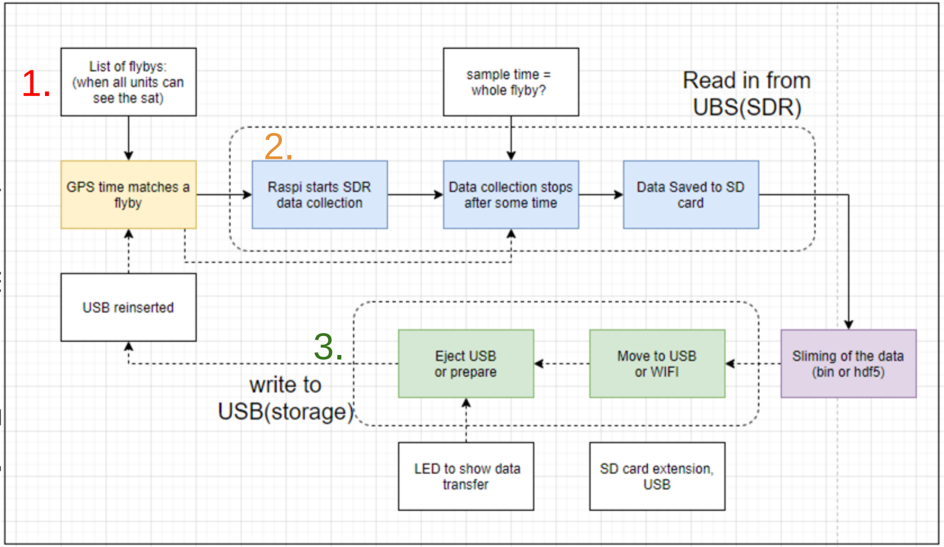
Requirements: FR2 DR2.4 and DR2.5

Risk Mitigated: Possible malfunction while testing the required individual components in each unit

Results: We have found that the Raspbian OS is compatible with the required devices to receive and store RF data

Test(s)	Status	Test Goal
Fly-by test	In Progress	To have the pi autonomously run all implemented software and subscripts to receive and collect simulated fly by data and to visually verify the test follows the state machine model.

State Machine Model:



Test Procedure Overview:

1. Store a set amount of specific times on the Pi tha

2. Pi will autonomously run all implemented scripts a stored fly bys.

3. After last fly by orbit has finished, USB will be eje naming convention, correct slimmed file size, and ex

It is important to note that there is no need for special equipment or facilities for these tests outside the hardware and software itself.

Raspberry Pi and HackRF Compatibility Test

Overall Test Goal(s): Ensure the HackRF is operable when connected to the Raspberry Pi

Requirements: FR2 DR2.4

Risk Mitigated: Not compatible with the onboard OS and Raspberry pi. Failure to collect necessary amount of samples per second.

Modelled Results: Seeing anywhere between 10Ms/s - 20Ms/s based on settings

Test(s)	Status	Test Goal
Acquired Sample Rate	Done	Verify that the correct amount of samples is being recorded from the SDR each second

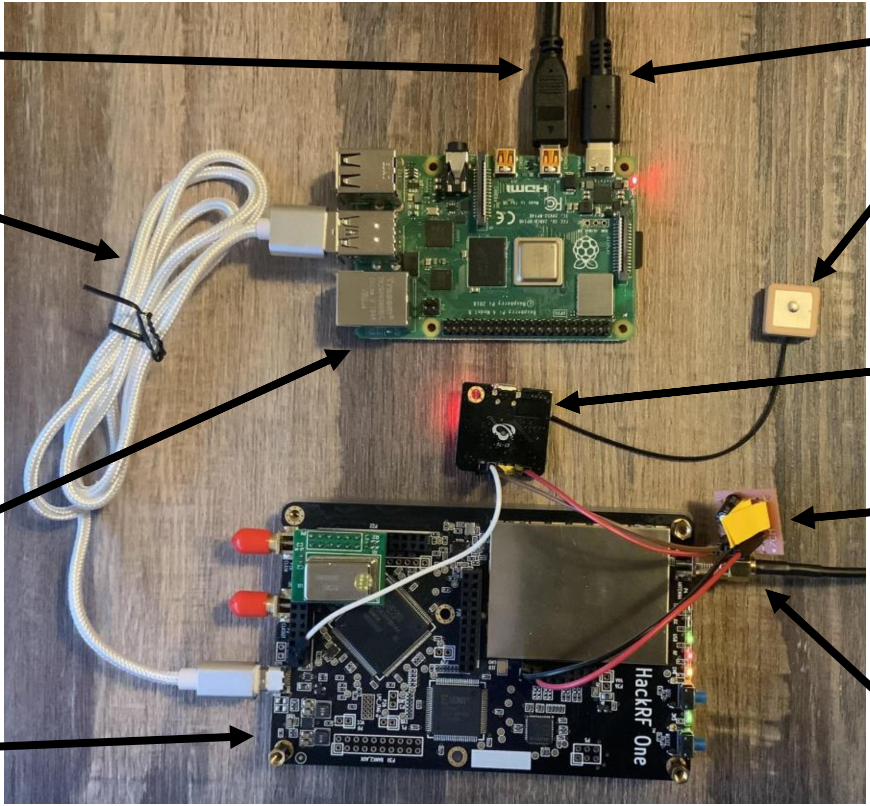
Raspberry Pi and HackRF Compatibility Test Setup

Micro HDMI Connection

USB Type-A to Micro USB connection between Raspberry Pi and HackRF

Raspberry Pi 4

HackRF One SDR



Raspberry Pi Power (5V)

GPS Antenna

GPS Module

High Pass Filter

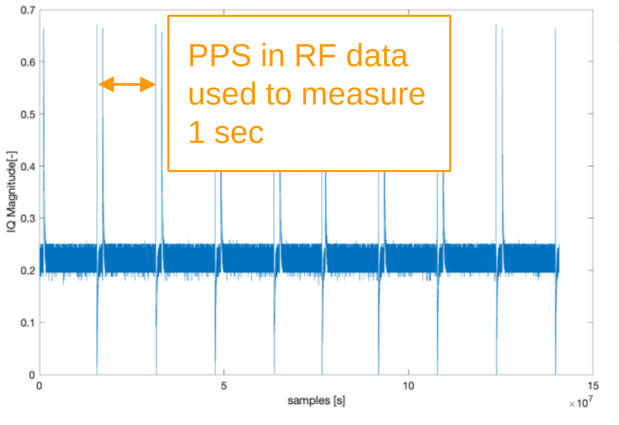
SMA connection between HackRF and antenna

Raspberry Pi and HackRF Compatibility Test Procedure Overview

1. The HackRF is hooked up to the Pi.
2. Using GNU Radio Companion and a GUI slider, the HackRF is then changed to different sample s/s.

erent sample rates and verified with Matlab that the proper data was

T ent or facilities for these tests outside the hardware itself.



Example IQ data from test with sample rate at 16 Ms/s

Set Test Sample Rate Ms/s	Average Sample Deviation from Set Rate	Timing Error Due to Deviation
10	1 Samples	100 ns
13	2 Samples	153.84 ns
16	2 Samples	125 ns
20	375626 Samples	18781300 ns

RF Front End Testing Overview

- Due to the symmetry of this system between the UHF/VHF and the L-Band systems, namely their constituent components, they will have almost identical tests.
- The only difference will be the frequencies used
  - VHF: 30 MHz to 300MHz
  - UHF: 300 MHz to 3 GHz
  - L-Band (IEEE*): 1-2GHz
- System Components for both:
  - Antenna
  - LNA
  - Switch
  - Cables

* IEEE stands for the Institute of Electrical and Electronics Engineers designation

Full Suite Test

Overall Test Goal(s): Ensure that the predicted orbit is within the expected error.
Requirements: FR 5, FR 6

Risk Mitigated: Verification of simulated models and allocated tolerances.

Modelled Results: Compliance with FR 5 and FR 6.

Test(s)	Status	Test Goal
Practice Run	Incomplete	Verify unit and data collection process by practicing data collection of a CSIM or IRIDIUM flyby with all units stationed in Boulder.
Iridium Flyby	Incomplete	Run data collection process on Iridium satellite candidate flyby with sensor units stationed across CO to verify FR 5 & FR 6 compliance for L-Band.
CSIM Flyby	Incomplete	Run data collection process on CSIM satellite candidate flyby with sensor units stationed across CO to verify FR 5 & FR 6 compliance for UHF-Band.

Practice Run Test Overview

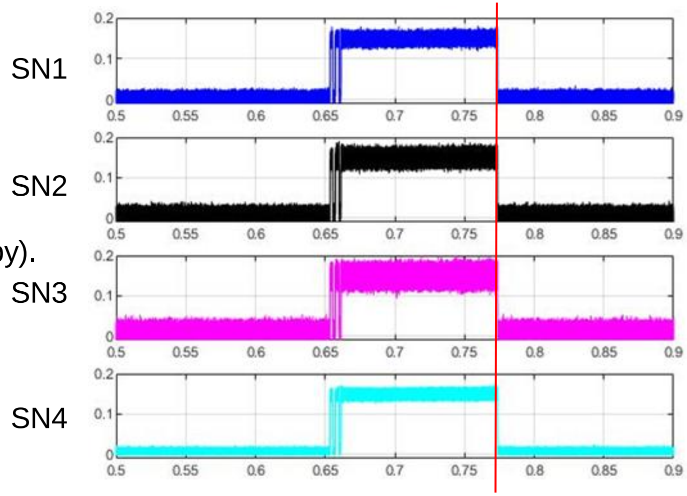
Procedure:

1. Collect and store data with SN1-SN4 at the same location (single flyby).
2. Stored data is off-loaded for post processing.
3. Verify that TDoA output is zero for all sensors.
    - Baseline verification (cannot find orbit here).

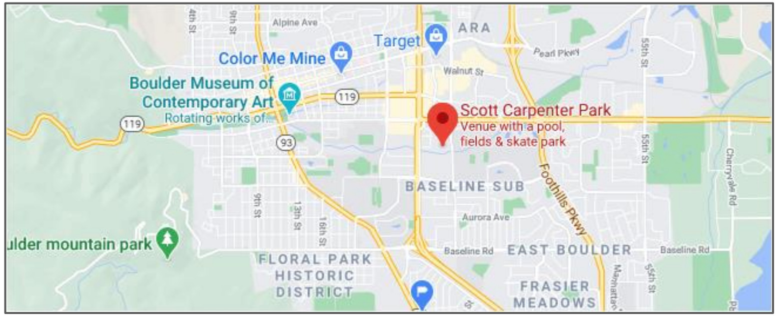
Equipment/Facilities needed:

- Four assembled units (SN1, SN2, SN3, SN4)
- Two to three team-members
- Laptop
- Park

Test goal - Final validation of hardware and software before full-scale test.



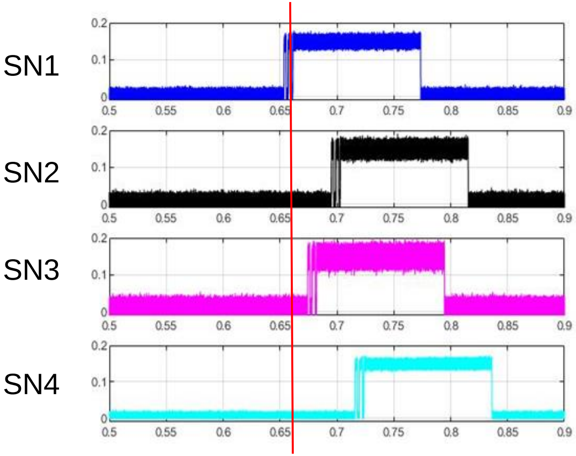
TDoA = 0 [s]



Iridium/CSIM Flyby Test Overview

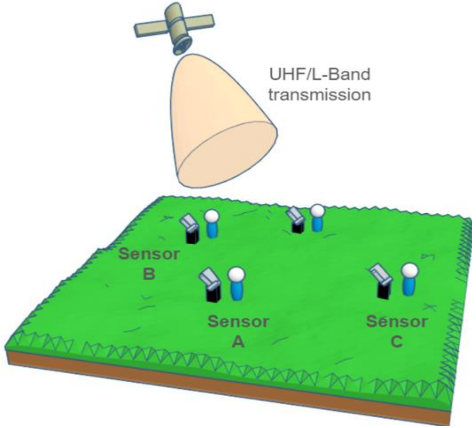
Procedure:

1. Collect and store data with SN1-SN4 around Colorado (multiple flybys).
2. Stored data is off-loaded for post processing.
3. Cross Correlation → TDoA→ Satellite State Vector
   - Verify State Vectors consistent with FR 5.
4. Satellite State Vectors → TLE
   - Verify TLE consistent with FR 6.



Equipment/Facilities needed:

- Four Assembled units (SN1, SN2, SN3, SN4)
- Four team-members/volunteers
- Laptops
- Units deployed to Pueblo, Boulder, Kremmling, and Virginia Dale

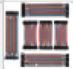
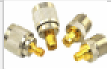
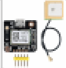


Test goal - Satellite position accuracy and TLE prediction characteristics consistent with FR 5 and FR 6

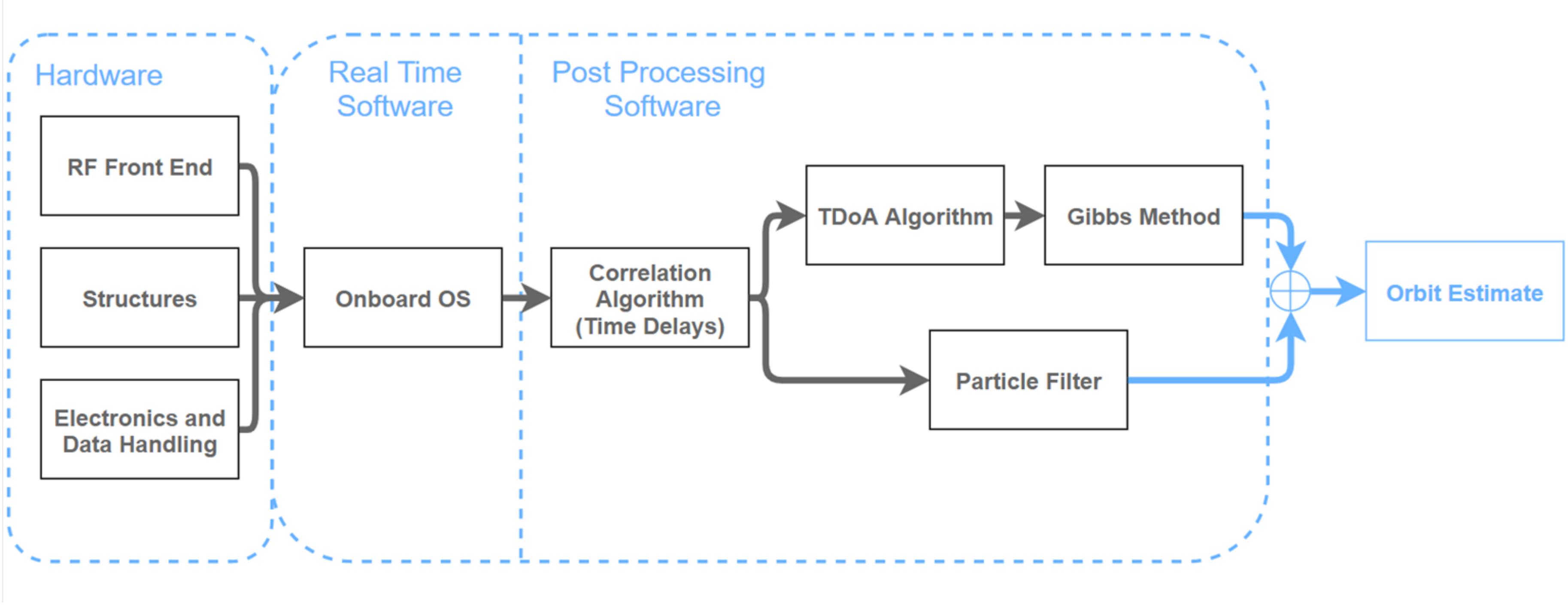
PRODUCT NAME	SpaceNet Ground Station	CONTACT INFO
APPROVED BY		
DATE OF APPROVAL		
PART COUNT	58	
TOTAL COST	$ 1,045.93	This is not accurate!!! look below

	Complete
	Ordered
	Ready to Order
	Ignore for now

PART NUMBER	PART NAME	DESCRIPTION	Purchase Link	QUANTITY	UNITS	PART IMAGE	UNIT COST	UNITS SERVICED	AMOUNT per UNIT	Inventory	Required Total
	Raspberry Pi 4 Model B (4 GB)	On board computer	https://www.sparkfun.com/products/15447	1	ea		$ 55.00	1	$ 55.00	1	4
	SD card	On board storage	https://www.amazon.com/SAMSUNG-Select-microSDXC-Adapter-MB-	1	ea		$ 18.99	1	$ 18.99	1	4
	SPF5189Z RF Amplifier	UHF LNA	https://www.amazon.com/Zerone-Amplifier-4000MHz-SPF5189Z-	1	ea		$ 15.00	1	$ 15.00	1	4
	ZX60-242GLN-S+	L Band LNA	https://www.mouser.com/ProductDetail/Mini-Circuits/ZX60-	1	ea		$ 74.82	1	$ 74.82	1	4
	Power Strip	handles all internal power distribution	https://www.amazon.com/dp/B083XR.IX5D/ref=emc_b_5_i	1	ea		$ 14.00	1	$ 14.00	1	4
	Raspberry Pi 4 Official Power Supply	AC to DC supply for raspberry pi	https://vilros.com/collections/official-raspberry-pi-accessories/products/official-	1	ea		$ 8.00	1	$ 8.00	1	4
	ProtoBoard 32 pack	Used to handle power distribution to the LNAs, GPS Module, and Switcher Device	https://www.amazon.com/ELEGOO-Prototype-Soldering-	1	pack of 32		$ 10.00	4	$ 2.50	1	1
	Great Scott Gadgets HackRf One-Software Defined Radio	Software Defined Radio that will handle demodulatin the RF Signal	https://www.adafruit.com/product/3583 2 gclid=Cj0KCQiAvb	1	ea		$ 339.95	1	$ 339.95	1	4
972-F2932EVBI	F2932EVBI Evaluation Board	RF logic computer controlled switch	https://www.mouser.com/ProductDetail/Renesas-IDT/F2932EVBI?	1	ea		$ 248.75	1	$ 248.75	2	4
	Mopower Micro USB Cable, 10 Pcs 3FT High Speed USB 2.0 A	Used to channel power from power strip USB ports to protoboard to power the LNAs, GPS Module, and Switcher Device	https://www.amazon.com/gp/product/B07J9WTJFQ/ref=ct_ewc_title_dp_1?	1	pack of 10		$ 13.99	4	$ 3.50	0	1
	WH-16 Hinged Nema Enclosure	Nema rated enclosure to house electronics. Includes clear top to enable GPS lock	https://www.polycase.com/wh-16?msclkid=4864cdd62fdc12c2de4792b	1	ea		$ 50.75	1	$ 50.75	1	4
	50ft outdoor extension chord	used to produce an outdoor rated cable leading from the box to the wall outlet	https://www.homedepot.com/p/HDX-50-ft-16-3-Landscape-Extension-Cord-	1	ea		$ 13.29	1	$ 13.29	1	4
94639A713	Nylon Unthreaded spacer, for number 2 bolt (1/2")	Used for offesting electronics from the hardware rack	https://www.mcmaster.com/panel-standoffs/nylon-unthreaded-	1	pack of 100		$ 10.60	4	$ 2.65	1	1
94639A536	Off-White Nylon Unthreaded Spacer, 1/2" OD, 1" Long, for Number 8 Screw Size	Used for offesting electronics from the hardware rack	https://www.mcmaster.com/panel-standoffs/nylon-unthreaded-	1	pack of 100		$ 13.04	4	$ 3.26	1	1
94613A086	Nylon Bolt	threaded nylon bolt	https://www.mcmaster.com/bolts/length~1-1-2/length~1/plastic-	1	pack of 100		$ 6.69	4	$ 1.67	1	1
94812A100	Nyoln Nut	threaded nylon nit	https://www.mcmaster.com/nuts/material~plastic/nut-type~hex/height~	2	pack of 100		$ 7.14	4	$ 3.57	1	2
8982K124	4 ft long, 2 ½ ", Angled Aluminum"	For anetenna Mounting	https://www.mcmaster.com/angles/multipurpose-6061-aluminum-90-	1	ea		$ 26.92	4	$ 6.73	1	1
89015K232	4ft long, Aluminum flat stock	For anetenna Mounting	https://www.mcmaster.com/aluminum-stock/multipurpose-6061-aluminum-	1	ea		$ 19.68	4	$ 4.92	1	1
	Rivets	For anetenna Mounting	https://www.homedepot.com/p/Arrow-1-8-in-Aluminum-Short-Rivets-100-Pack-	1	pack of 50		$ 5.98	4	$ 1.50	1	1
69915K54	Nema Cord Grips	For power	https://www.mcmaster.com/cord-grips/compact-plastic-	1	ea		$ 3.34	1	$ 3.34	3	4
69915k52	Nema Cord Grips	For Coax	https://www.mcmaster.com/69915K52/	2	ea		$ 3.30	1	$ 6.60	0	8
	Coaxial cable	Outdoor Rated Coaxial Cable to antennas	https://www.amazon.com/CIMPLE-CO-Connectors-Internet-	1	ea		$ 8.97	4	$ 2.24	1	1
	Coaxial cable	LNA to Swtich/Swtich to SDR Coaxial Cable:	https://www.amazon.com/Monoprice-Shield-Coaxial-Cable-	1	ea		$ 4.99	4	$ 1.25	1	1
	SMA Connectors male	Internal connectors	https://www.amazon.com/dp/B089CJY1GX/ref=sspa_dk_detail_3?	1	pack of 10		$ 8.89	1	$ 8.89	1	4
	SMA Connectors female	external connector to antenna	https://www.amazon.com/dp/B089NHW2X9/ref=sspa_dk_detail_3?	1	pack of 10		$ 8.89	4	$ 2.22	0	1
8560K214	Acrylic	Plastic Sheet for Mounting Plate:	https://www.mcmaster.com/8560K214//	1	ea		$ 32.75	4	$ 8.19	1	1
5415K38	Steel Screw, 1/2" Band Width, 4-1/8" to 7" Clamp ID	For mounting box to something	https://www.mcmaster.com/5415K38/	1	pack of 10		$ 15.05	4	$ 3.76	0	1
	T-post	to mount box to	https://www.homedepot.com/p/Everbilt-1-3-4-in-x-3-1-2-in-x-6-ft-Green-Steel-	1	ea		$ 4.70	1	$ 4.70	1	4
	PVC pipe	Antenna mount, 10ft, 2inch, Schedule 40	https://www.homedepot.com/p/2-in-x-10-ft-280-PSI-Schedule-40-PVC-DWV-	2	ea		$ 8.84	4	$ 4.42	2	2
	PVC cap	Antenna mount	https://www.homedepot.com/p/Charlotte-Pipe-2-in-PVC-Schedule-40-	2	ea		$ 1.86	1	$ 3.72	2	8
	PVC Tee fitting		https://www.homedepot.com/p/NIBCO-2-in-PVC-DWV-All-Hub-Sanitary-Tee-	1	ea		$ 3.53	1	$ 3.53	1	4
91257A634	Bolts	Bolts for antenna	https://www.mcmaster.com/bolts/hex-head-screws/high-strength-grade-8-	1	pack of 25		$ 12.76	4	$ 3.19	1	1
95462A031	Nuts	Nuts for antenna	https://www.mcmaster.com/nuts/hex-nuts/medium-strength-steel-hex-	1	pack of 100		$ 8.79	4	$ 2.20	1	1
92620A726	bolts	PVC to Aluminum	https://www.mcmaster.com/92620A726/	1	ea		$ 1.37	1	$ 1.37	0	4
92620A726	M5 x 0.8 mm Thread, 35 mm Long	Internal mount	https://www.mcmaster.com/92005A334/	1	pack of 100		$ 10.20	4	$ 2.55	0	1

91831A137	18-8 Stainless Steel Nylon-Insert Locknut	PVC to Aluminum	https://www.mcmaster.com/91831A137/	1	pack of 10		$ 4.70	4	$ 1.18	0	1	
	PVC Glue	For pvc end caps etc	https://www.homedepot.com/p/Weld-On-Weld-On-700-PVC-Solvent-Cement-	1	ea		$ 2.98	4	$ 0.75	0	1	
	10uf cap	for pps filter	https://www.sparkfun.com/products/523	5	ea		$ 0.45	4	$ 0.56	0	5	
	Resistor Kit - 1/4W (500 total)	1k, 4.7k, 10k	https://www.sparkfun.com/products/10969	1	ea		$ 7.95	4	$ 1.99	0	1	
	Jumper Wires	To get power/pps/data to everything	https://www.amazon.com/IZOKEE-Solderless-Breadboard-	1	ea		$ 8.99	4	$ 2.25	0	1	
	male Header	Found in a trash pin (prince has them). note normally you only ever want **nonpowerd** pins to be sticking up where someone could touch them but this is cheap and the whole thing should be a		1	ea		$ -	4	$ 0.00	1	1	
	velcro	Velcro to secure: power strip, Hackrf, GPS antenna	https://www.amazon.com/Strenco-Inch-Self-Adhesive-Hook/dp/B00FQ93	1	15 ft of both sides		$ 7.92	4	$ 1.98	0	1	
	Proxicast Pro-Grade Extra Strong 30mil Weatherproof Self-Fusing Silicone Rubber Sealing Tape	Used for water proofing under electrical tape(no UV resistance)	https://www.amazon.com/Proxicast-Pro-Grade-Weatherproof-Self-	2	15' 1" roll		$ 17.95	4	$ 8.98	0	2	
22508	Permatex Dielectric 22508	used inside the connector to keep water and moisture out	https://www.amazon.com/Permatex-22058-Dielectric-Tune-Up-	1	3oz		$ 6.99	4	$ 1.75	0	1	
Super 88	3M Scotch Vinyl Electrical Tape Super 88, Premium Grade All-Weather, 3/4 in x 44 ft, 8.5-mil thick, Black, 1 roll	Used for uv protection	https://www.amazon.com/3M-88-Super-3-4x44FT-Vinyl-Electrical/dp/B000	1	3/4 in x 44 ft		$ 7.20	4	$ 1.80	0	1	
	UHF Antenna	400 to 470MHz 9 dbi antenna	https://www.amazon.com/HYS-Antenna-Elements-Motorola-	1	ea		$ 50.00	1	$ 50.00	1	4	
	pl259 to SMA adapter	adapt UHF antenna to SMA	https://www.amazon.com/SMA-UHF-Connectors-Nickel-Plated-	1	ea		$ 7.68	1	$ 7.68	1	4	
RE1208P-SM	LBand Antenna	1.616 GHz	https://www.mouser.com/ProductDetail/Taoglas/IAA01121111/8	1	ea		$ 25.11	1	$ 25.11	1	4	
	GPS Module	GPS Module GPS NEO-6M(Ar duino GPS, Drone Microcontroller GPS Receiver) Compatible with 51 Microcontroller STM32 Ar duino UNO R3 with IPEX Antenna High Sensitivity for Navigation	https://www.amazon.com/Microcontroller-Compatible-Sensitivity-	1	ea		$ 10.90	1	$ 10.90	4	4	
			TOTAL PARTS	58			TOTAL	$ 1,045.93	Total Per 4 Units	$ 4,183.70	Total Spent on units	$ 1,300.97

Conceptual Block Diagram



GPS Test

Overall Test Goal(s): Ensure the GPS Pulse Per second meets the device specifications

Requirements: DR5.1

Risk Mitigated: Debugging the timing hardware during the full system test.

Modelled Results : Per GPS data sheet the PPS is expected to be a pulse wave with a on duty cycle of 10%. PPS should start with in a indistinguishable amount of time from one another.

Test(s)	Status	Test Goal
Compare GPS(s) PPS	Done	To ensure that the rising edge of the GPS timepulse(s) are within 10ns of each other.

Test Procedure Overview:

Equipment: AD2 Oscope

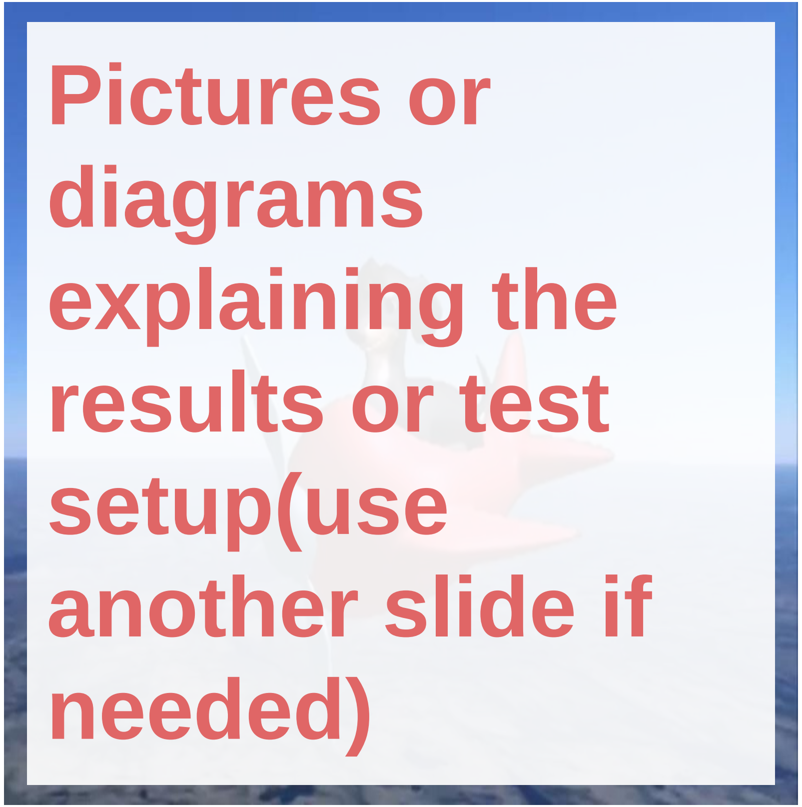
Two GPS modules were connected to a Digilent analog discovery 2 Oscope.

PPS from each GPS were placed on different channels.

Test Results:

Rising edge of both GPS PPS started within less than ≤ 10ns of each other.

Note. The Rise time, duty cycle and accuracy to UTC do not matter. As long as error related to the Rising edge is consistent across all units.



Test Procedure Overview:

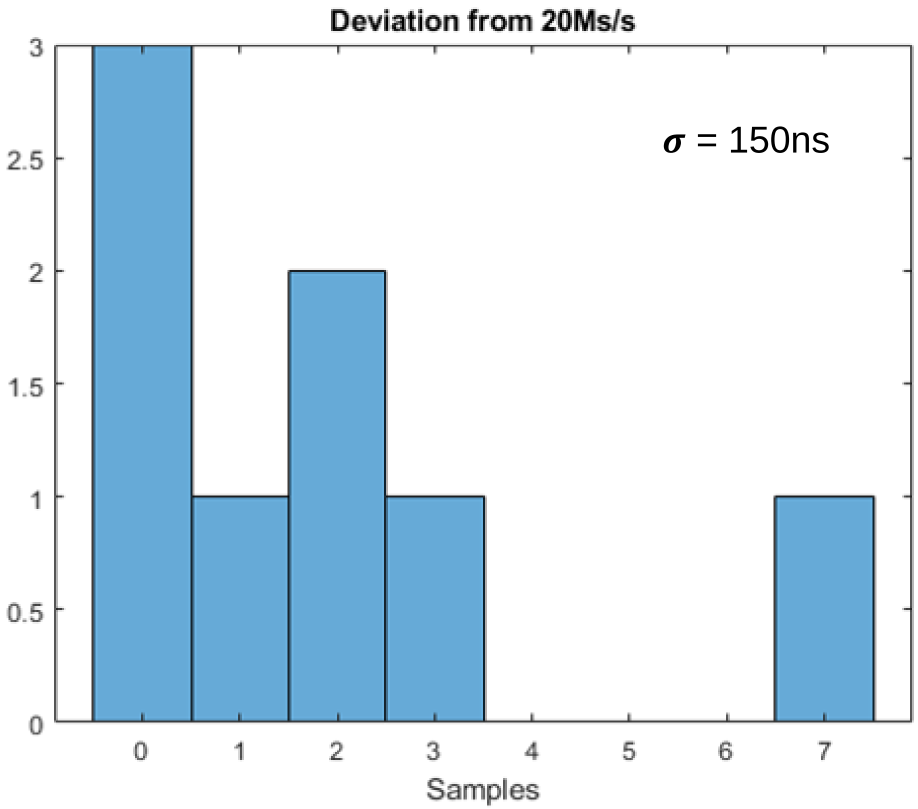
Equipment: HackRF, GPS, Matlab, SDRsharp, SDRConsole

The hackRF was equipped with the GPS timing modification. SDRsharp/SDRConsole were used to set/record data from the SDR. The PPS was used to identify 1s intervals in the recorded data.

Test Results:

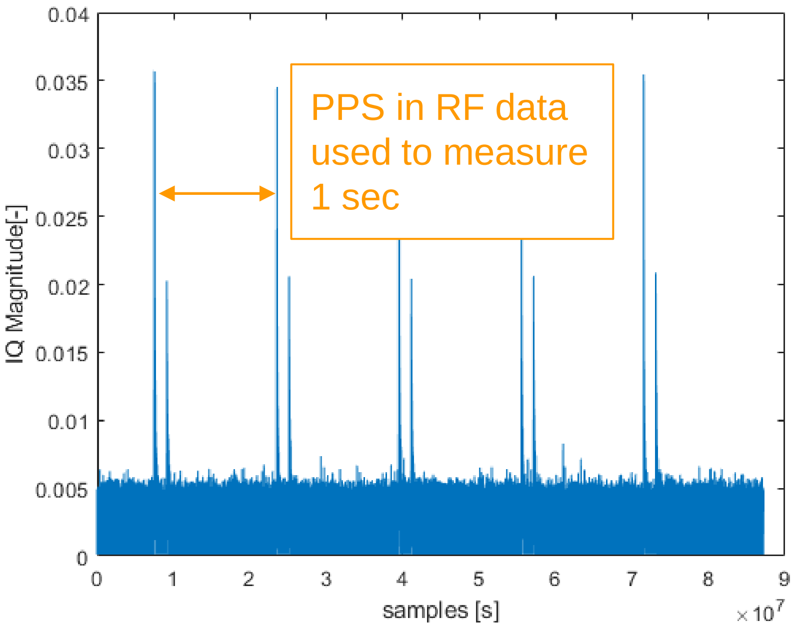
Depending on the software used the SDR was able to achieve 20Ms/s (+/-) 3. This error decreased at lower sample rates.

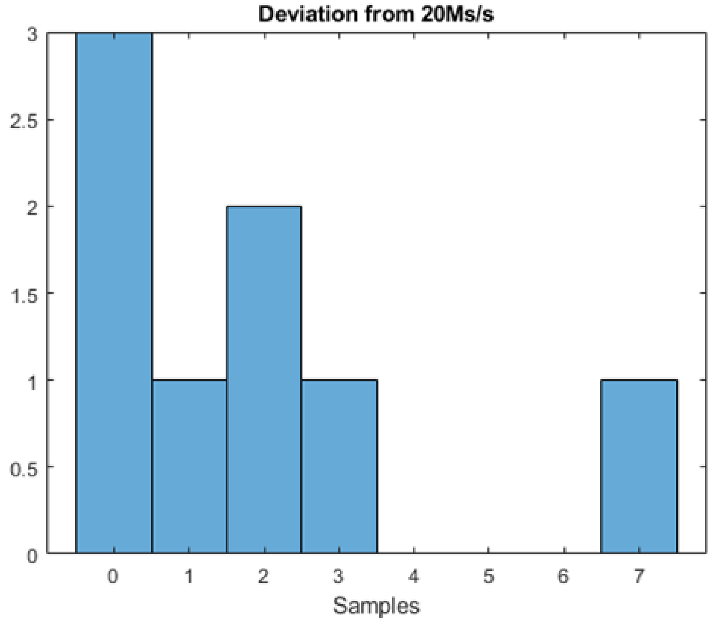
Unknown if the sample variation is due to the GPS, SDR or PPS detection method. The sample variation is acceptable for this application.

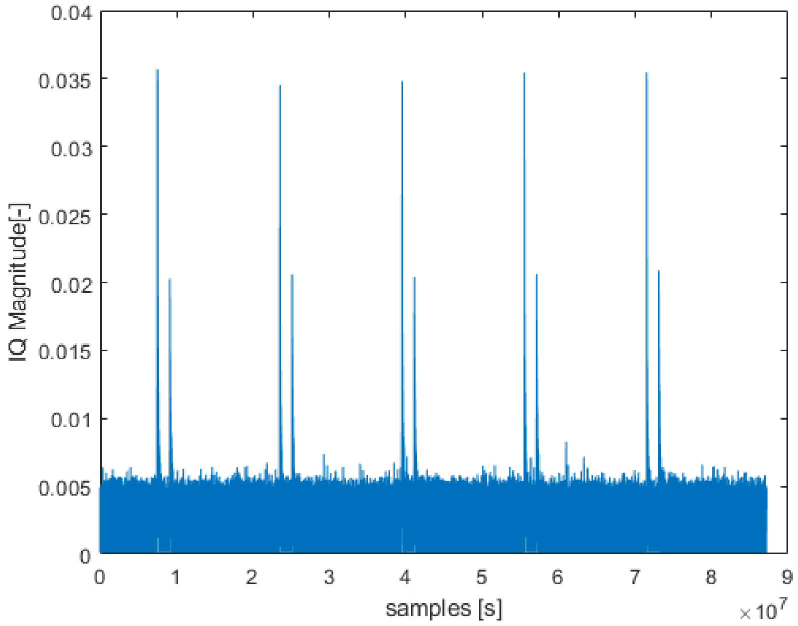


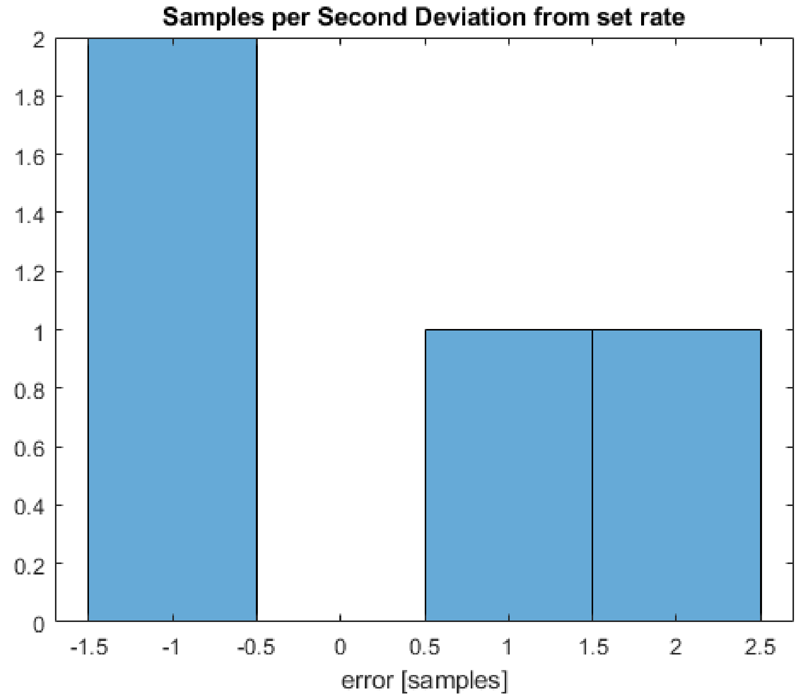
May add another slide to help explain this if we have time/room

Sample Rate MS/s	Avg. Samples per second MS/s	σ (Samples)
10	10	1
12.5	12.5	3
16	16	4
20	17	3e6






0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
IQ Magnitude[-]
0
1
2
3
4
5
6
7
8
9
samples [s]
× 10^7


Samples per Second Deviation from set rate
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
error [samples]

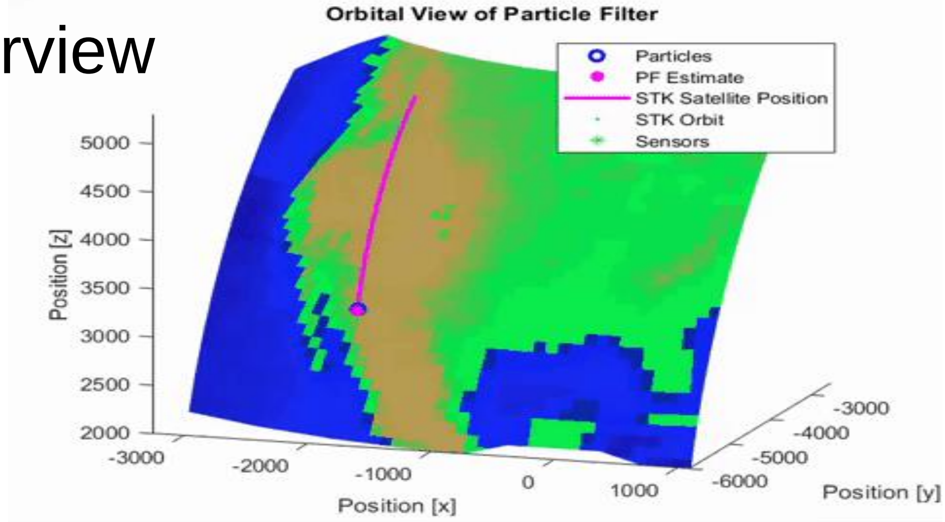
Orbit Determination Test Overview

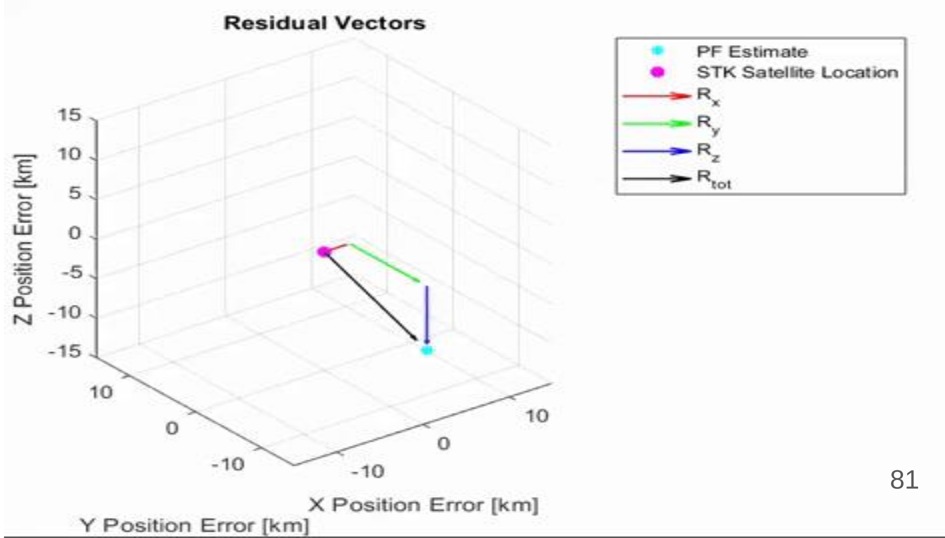
Test Procedure Overview:

- STK produced multiple sample satellite orbits and range data from the orbit to each sensor.
- Calculated sample TDoA values from the ranges with induced 100 ns measurement error.
- TDoA values initialized the orbital determination method.
- Update estimate with remaining TDoA values.
- Compared outputs to STK data. Calculated the difference between them or residual vectors.

Equipment/Facilities needed:

STK and Matlab





Temperature Test

Overall Test Goal(s): Ensure that the internal temperature of the box will remain within operating conditions as modelled

Requirements: DR 1.2

Risk Mitigated: Component failure due to being outside of operating conditions, which would result it incorrect or no pass over data being captured.

Modelled Results:

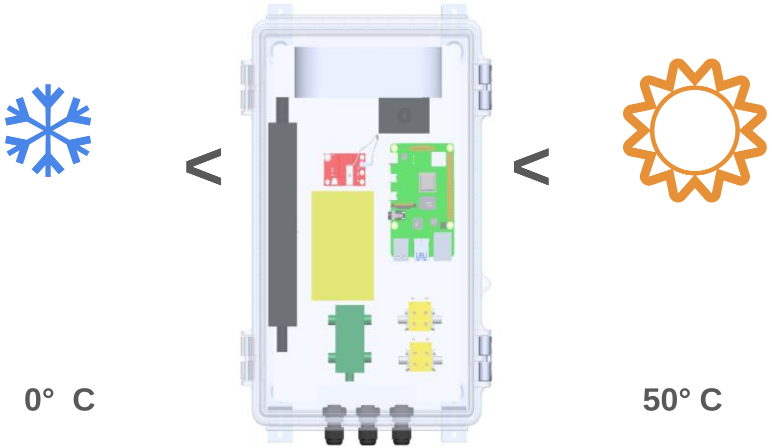
Test(s)	Status	Test Goal
Indoor Operation	Incomplete	Determine actual $\dot{Q}$ in order to more accurately determine current operating conditions of the unit.
Heater Freezer Test	Incomplete	If heater is determined necessary, test that desired operating conditions can be met when placed in a cold environment.
Outdoor Operation	Incomplete	Ensure that sensor unit hardware remains operational over a 24 hour period.

Test Procedure Overview:

- Run thermal test such that the box is operating for an extending duration of time (Approx: 1-3 hours).
- Use raspberry pi to measure the temperature inside the box in each scenario and use this data to more accurately model the $\dot{Q}$ to determine whether heater is necessary and if so the required size.

Equipment/Facilities Needed:

- Fully integrated unit with operational hardware
- Clock/Timer
- External Temperature Sensor/Thermometer



Onboard OS Sub-System Test

Overall Test Goal(s): Ensure that the subscripts run on start-up and operate as expected.

Requirements: FR2 DR2.4 and DR2.5

Risk Mitigated: Possible malfunction while testing the required individual components in each unit

Results: We have found that the Raspbian OS is compatible with the required devices to test

Test(s)	Status	Test Goal
RF Control	In Progress	Esure the Raspberry Pi can command the switch to change between the two RF inputs.
GPS Control	In Progress	Esure the Raspberry Pi can use GPS time to determine when to start data collection.
Data Handling	In Progress	Ensure record data can be slimmed and moved to the proper location for off loading.

Test Procedure Overview:

RF Control:

- Attach the raspberry pi to the switch and program the pi to switch between 2 different radio station. This will be verified using a GUI on GNU Radio Companion.

GPS Timer:

- Give the Raspberry Pi a set of times. Attach the GPS to the Raspberry pi. Connect a LED to the Pi and verify that the LED lights up when the times programmed times line up with the GPS time.

Test Procedure Overview:

Data Handling:

- Collected RF Data for a specific amount of time and store the data onto a flash drive.
- Program the Pi to slim the data and collect data for the same amount of time as the sampled collection.
- Compare the slimmed data file size is significantly smaller than the original collected data.
- Ensure that the data is stored with the proper naming convention in relation to the fly by time and respective sensor unit.

It is important to note that there is no need for special equipment or facilities for these tests outside the hardware itself.

RF Front End Test #2: Bandwidth / Received signal roll-off

Overall Test Goal(s): Verify that the RF front end must is able to cover ±10MHz of the target UHF frequency.

Requirements:, DR3.3

Risk Mitigated: Limits signal contamination of our desired signals by using a relatively small bandwidth. As well as proving that our antennas are capable of receiving satellite signals

Results:

Models: None(?)

Test(s)	Status	Test Goal
UHF	Done	±10MHz of the target (437.25 MHz)
VHF	Done	±10MHz of the target (145.3 MHz)
L-Band	Done	±10MHz of the target (1616 MHz)

Test Procedure Overview:

RF Control:

- Attach the raspberry pi to the switch and program the pi to switch between 2 different radio station. This will be verified using a GUI on GNU Radio Companion.

GPS Timer:

- Give the Raspberry Pi a set of times. Attach the GPS to the Raspberry pi. Connect a LED to the Pi and verify that the LED lights up when the times programmed times line up with the GPS time.

Test Procedure Overview:

Data Handling:

- Collected RF Data for a specific amount of time and store the data onto a flash drive.
- Program the Pi to slim the data and collect data for the same amount of time as the sampled collection.
- Compare the slimmed data file size is significantly smaller than the original collected data.
- Ensure that the data is stored with the proper naming convention in relation to the fly by time and respective sensor unit.

It is important to note that there is no need for special equipment or facilities for these tests outside the hardware itself.

Signal Correlation Test

Overall Test Goal(s): Ensure that the signals from boxes can be aligned and maintain the timing accuracy calculated.

Requirements: FR 5, FR 6

Risk Mitigated: Sensor Units can't be aligned according to GPST

Modelled Results: Simulated TDoAs

Test(s)	Status	Test Goal
Practice Run	Incomplete	Verify zero TDoA values at a single location.
Iridium Flyby	Incomplete	Verify expected TDoA with sensor units stationed across CO.
CSIM Flyby	Incomplete	Verify expected TDoA with sensor units stationed across CO.

Practice Run Test Overview

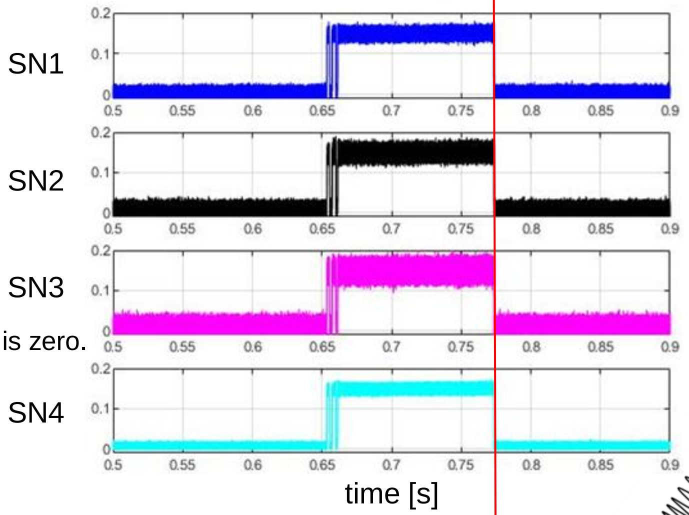
Procedure:

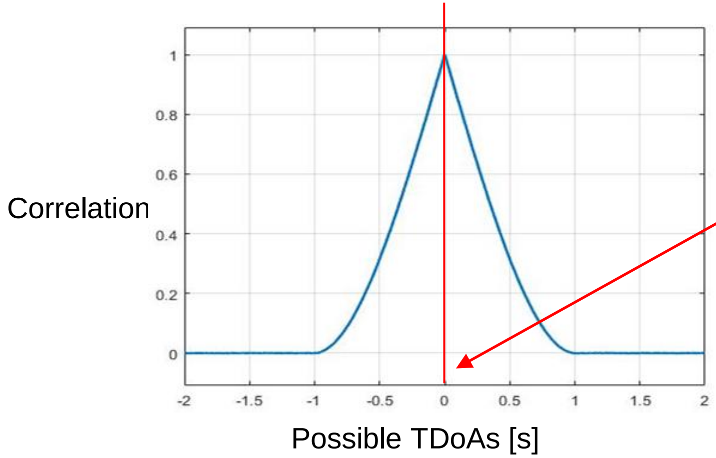
- Collect Data with Sensor Units at the same location.
- Press ‘collect’ within one second of each other for gps alignment.

Equipment/Facilities needed:

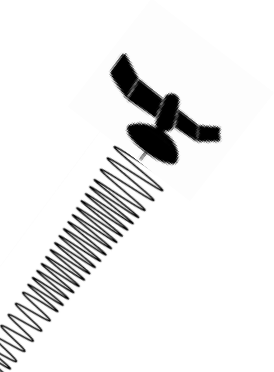
- 4 Sensor Units.

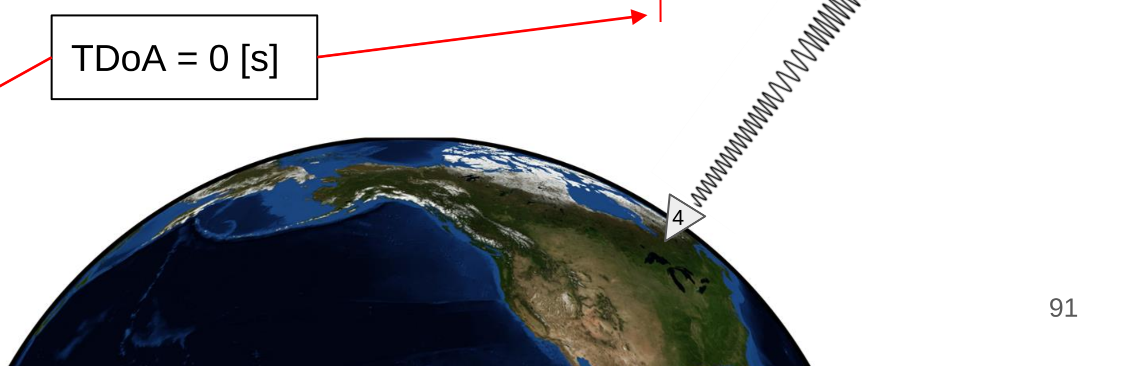
Test goal - Verify that TDoA between all Sensor Units at the same location is zero.





TDoA = 0 [s]





Iridium/CSIM Flyby Test Overview

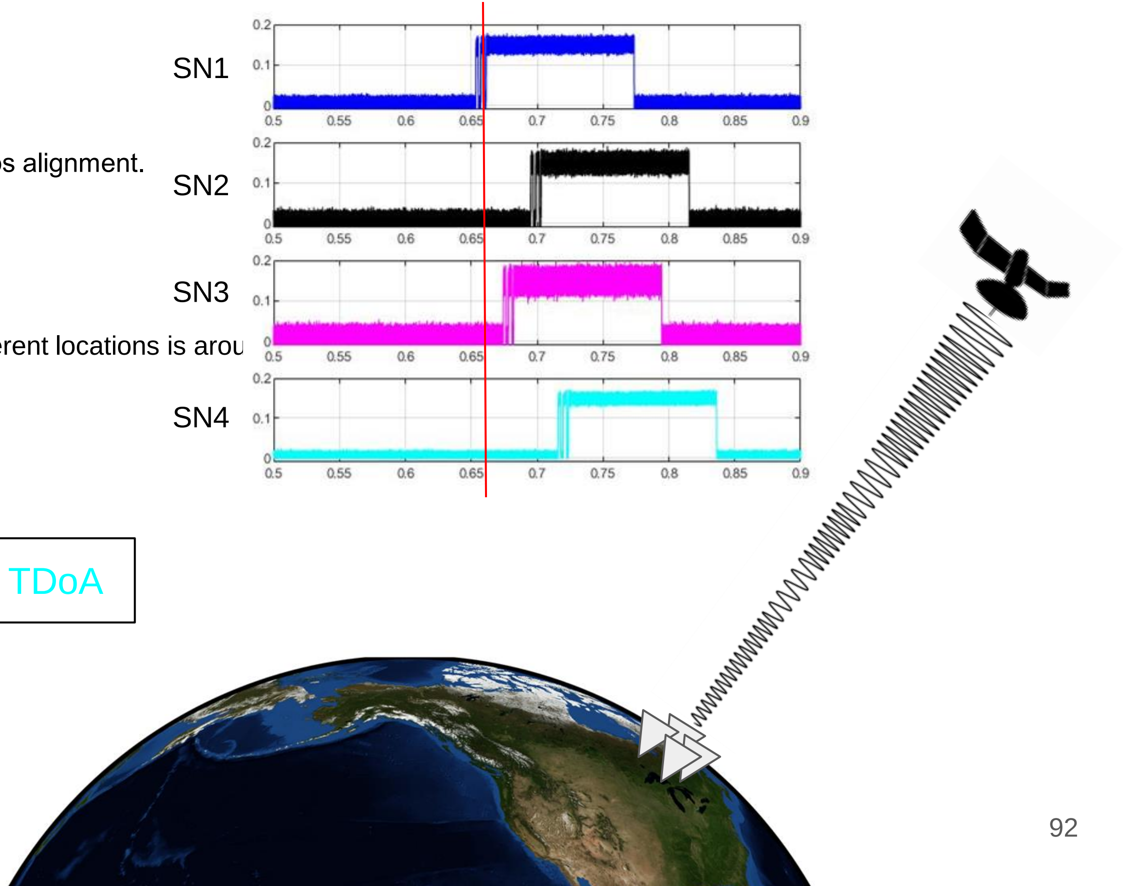
Procedure:

- Collect Data with Sensor Units around Colorado.
- Press ‘collect’ within one second of each other for gps alignment.

Equipment/Facilities needed:

- 4 Sensor Units.

Test goal - Verify that TDoA between all Sensor Units at different locations is arou



TDoA = 0 < TDoA < TDoA < TDoA

Test Procedure Overview:

- Measure water flow from water source being used in order to
- Inlay the box with paper towels on all edges of the box for co at after test.

Equipment/Facilities:

- Volume container with measurements indicated on the side.
- Access to water source
- Paper Towels
- Stop Watch

Single Unit Test Results:

7:30 am:
Unit is turned on. Startup LED Blinks successfully

11:09 am:
First flyby detected. Indicator LED turns on.
11:32 am
LED turns off.

12:46 pm:
Second Flyby.

6:00 pm: Unit cycles to UTC next day. Error LED remains off.

6:04 p
Third Flyby.

9:58 pm:
Fourth Flyby Successfully collected. Verifies DR 5.5

11:32 pm:
Fifth Flyby.

5:11 am:
Sixth Flyby

6:52 am:
Seventh Flyby.
T = 34°F

7:30 am:
Single Unit Test Complete

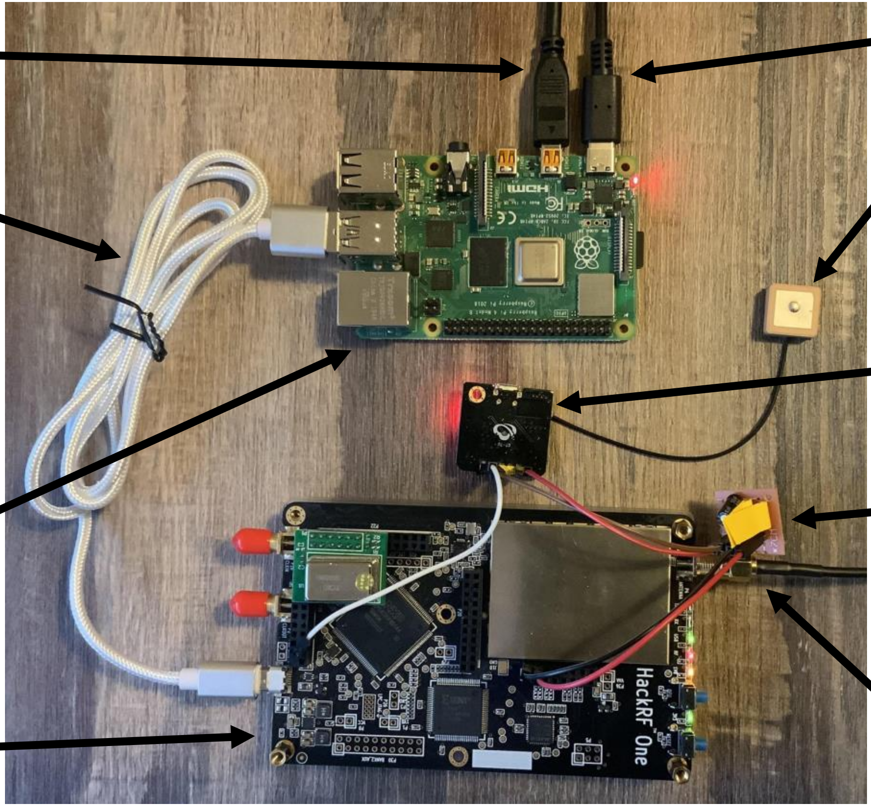
Raspberry Pi and HackRF Interfacing Test Setup

Micro HDMI Connection

USB Type-A to Micro USB connection between Raspberry Pi and HackRF

Raspberry Pi 4

HackRF One SDR



Raspberry Pi Power (5V)

GPS Antenna

GPS Module

High Pass Filter

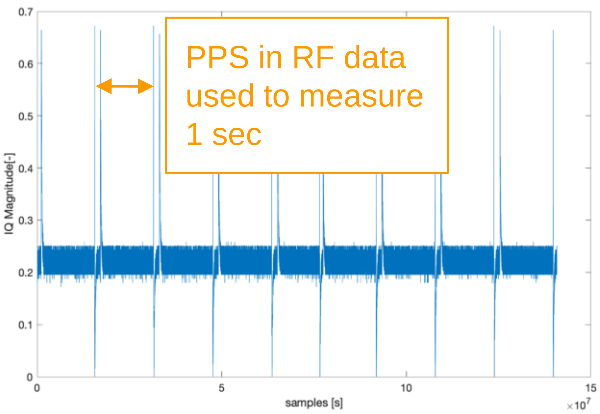
SMA connection between HackRF and antenna

Raspberry Pi and HackRF Interfacing Test Procedure

1. The HackRF is hooked up to the Raspi.
2. Using command line, the HackRF is changed to different sample rates ranging from 1Ms/s to 20 Ms/s.
3. The data is then recorded at different sample rates and verified with Matlab that the proper data was received by the Raspi.

There was no need for special equipment or facilities for these tests outside the hardware itself.

Raspberry Pi and HackRF Interfacing Test Results



Example IQ data from test with sample rate at 16 Ms/s

Set Test Sample Rate Ms/s	Average Sample Deviation from Set Rate	Timing Error Due to Deviation
10	1 Samples	100 ns
13	2 Samples	153.84 ns
16	2 Samples	125 ns
20	375626 Samples	18781300 ns

Box Weatherproof Test

Overall Test Goal(s): Test that the box and cable pass throughs are weather resistant and not susceptible to ingress of water.

Requirements: DR1.1

Risk Mitigated: Hardware not fully operational/could be damaged during satellite pass over.

Results: Box unit from manufacture is weather resistant and not susceptible to ingress of water. With cable pass throughs in place, no water leakage was observed.

Test Progression: