ASEN 4018 Senior Projects Fall 2018

Preliminary Design Review

ARGUS

Auto-Tracking RF Ground Unit for S-Band

Team: Trevor Barth, Anahid Blaisdell, Adam Dodge, Geraldine Fuentes, Thomas Fulton, Adam Hess, Janell Lopez, Diana Mata, Tyler Murphy, Stuart Penkowsky, Michael Tzimourakas

Advisor: Professor Dennis Akos

Customer: Raytheon

Project Motivation

The motive for a portable ground station is such that a military personnel in combat may deploy the ground station to communicate with the "SeeMe" constellation. The SeeMe satellites will take an image of a specified location on Earth and downlink the image directly to the soldier. This allows the user to image unknown locations real-time is a short, simple manner.

Project Overview → Baseline Design → Antenna → Tracking → Signal Processing → Conclusion

Project Definition

Mission Statement: The ARGUS ground station is designed to be able to track a LEO satellite and receive a telemetry downlink using a platform that is both portable and more affordable than current S-Band ground stations for implementation in remote locations.

- Low Cost < $5000.00
- Commercial Off The Shelf (COTS) where possible
- Portable – two person carry

Functional Requirements

1.0 The ground station shall be capable of receiving signals from a LEO satellite between 2.2 to 2.3 GHz, in QPSK modulation with a BER of 10e-5, and a G/T of 3 dB/K.

2.0 The ground station shall mechanically steer an antenna/system to follow a LEO satellite between altitude of 200 km to 600 km between 10° elevation and 170° elevation.

3.0 The ground station shall be reconfigurable to be used for different RF bands.

4.0 Two people shall be capable of carrying and assembling the ground station.

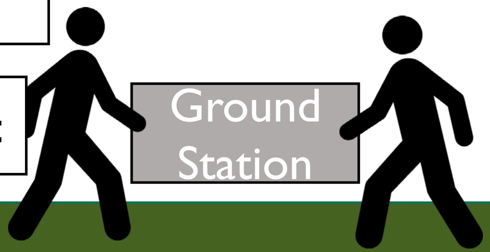
5.0 The ground station onboard computer shall interface with a laptop using a Cat-5 ethernet cable.

CONOPS

Legend

Red arrow	Overall
Green arrow	Ground Station

1 **Transport**



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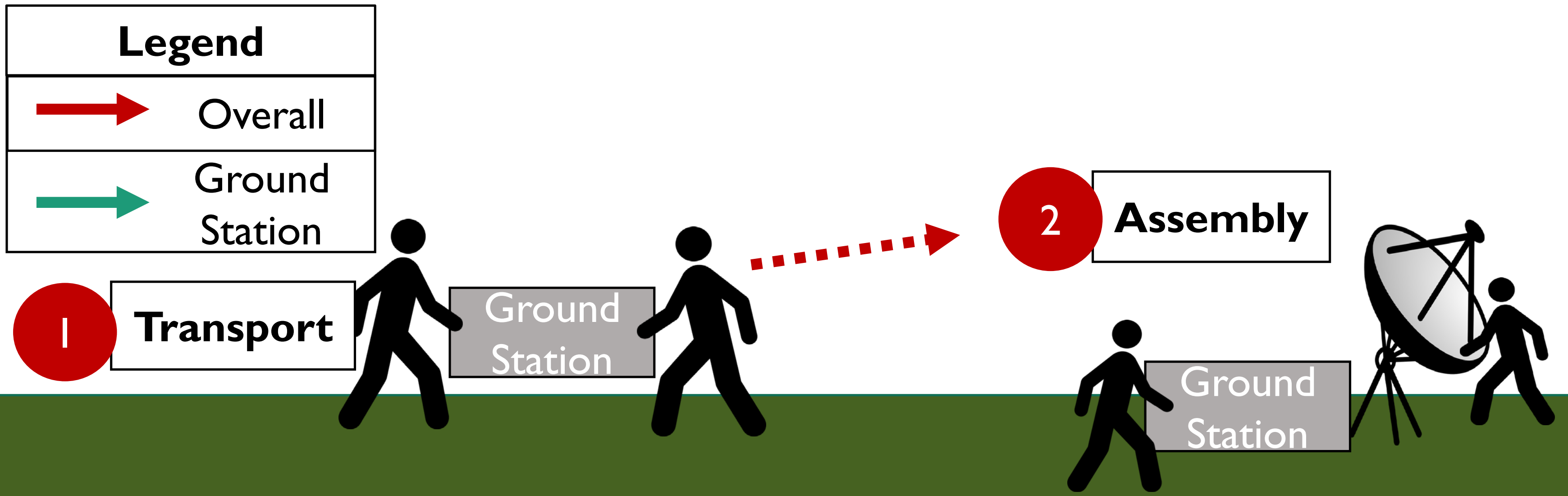
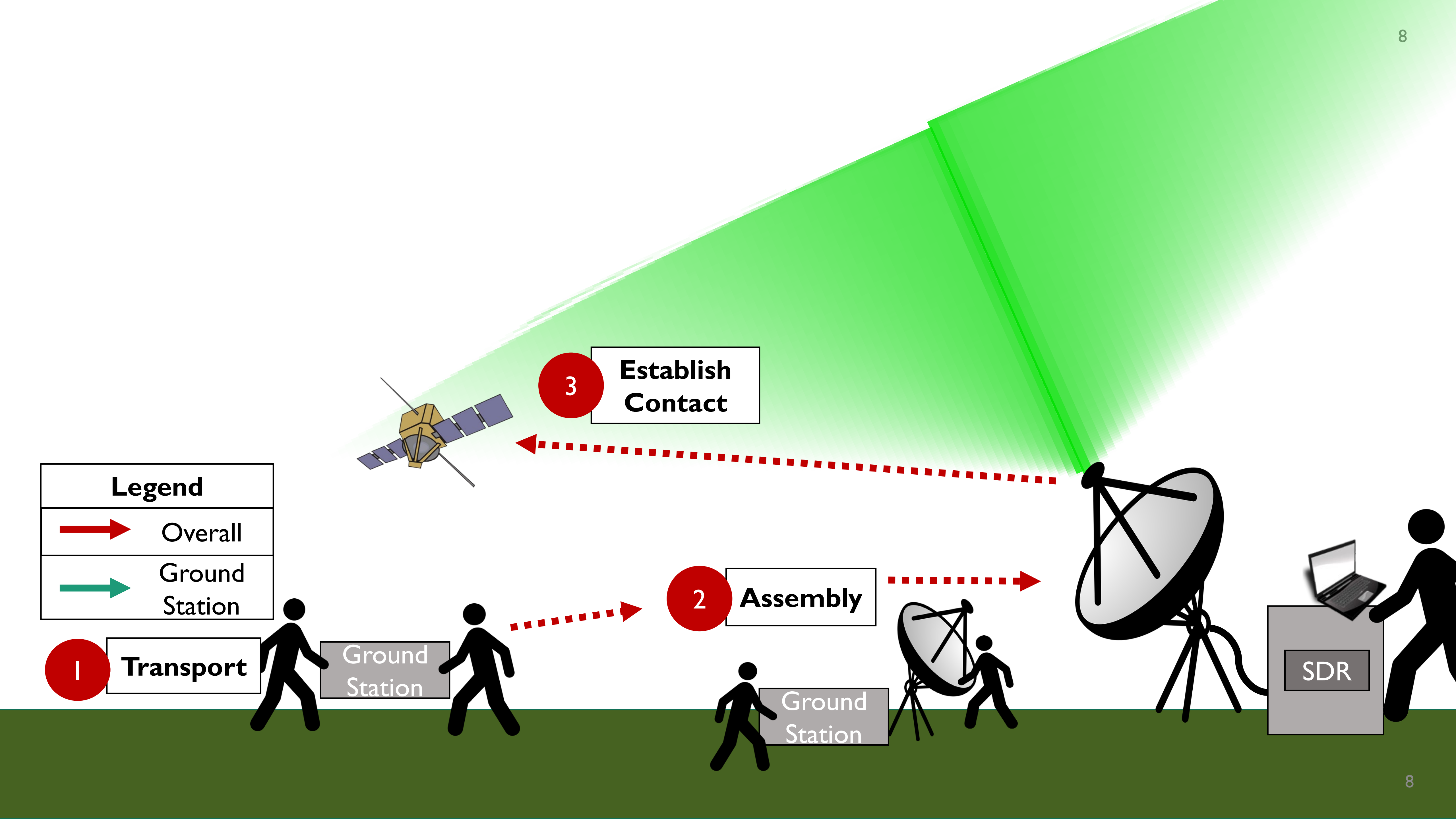
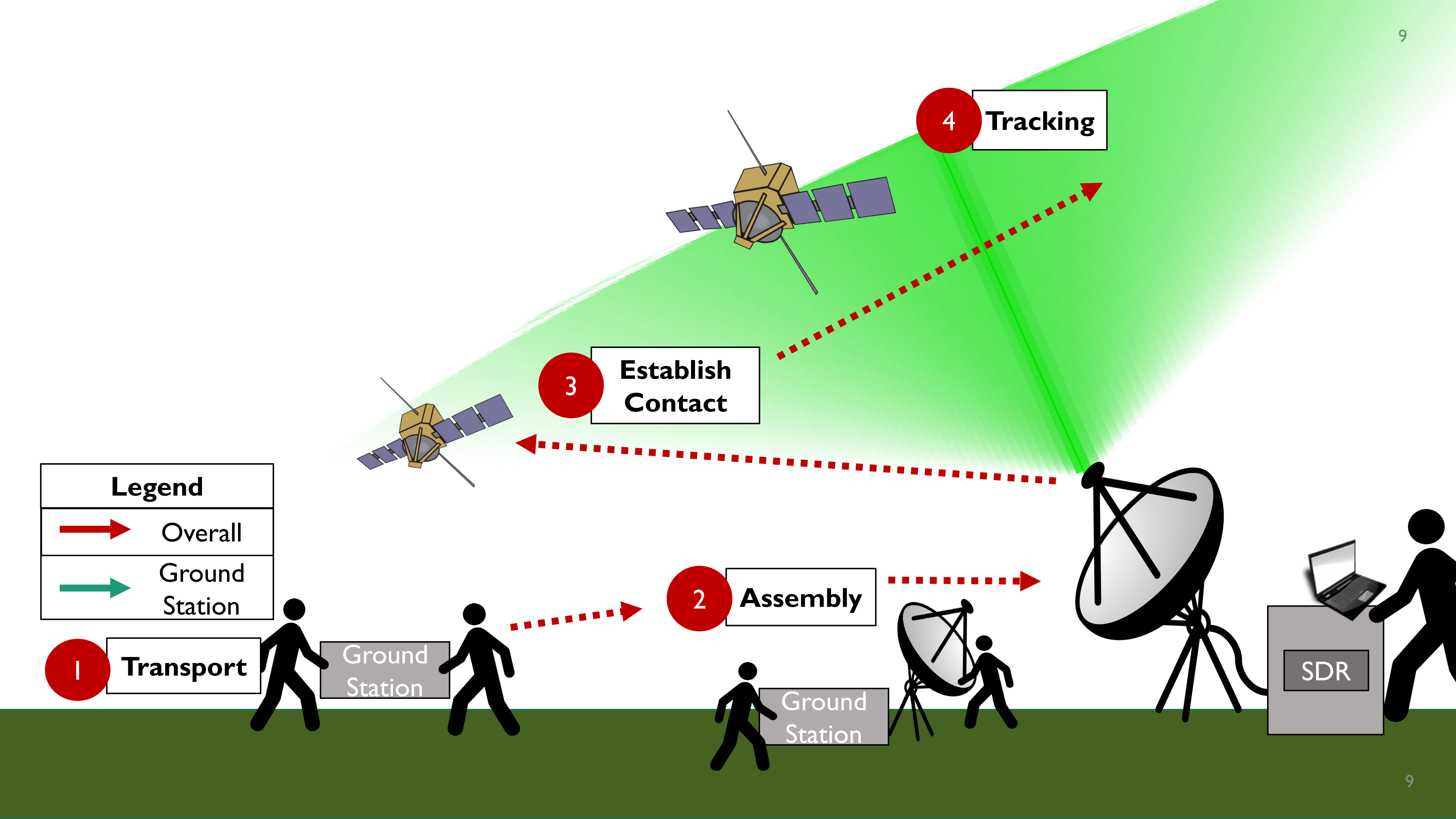
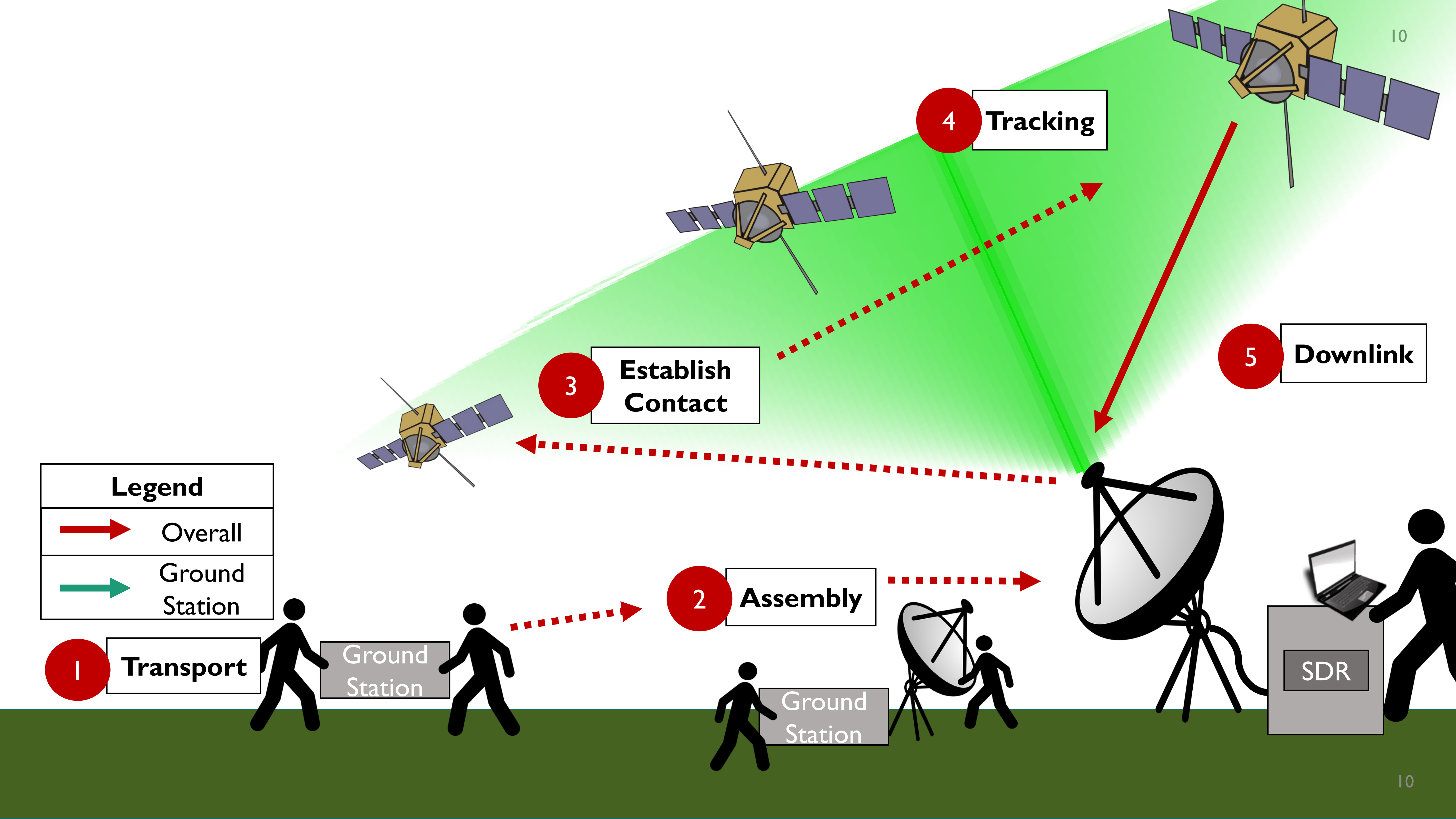
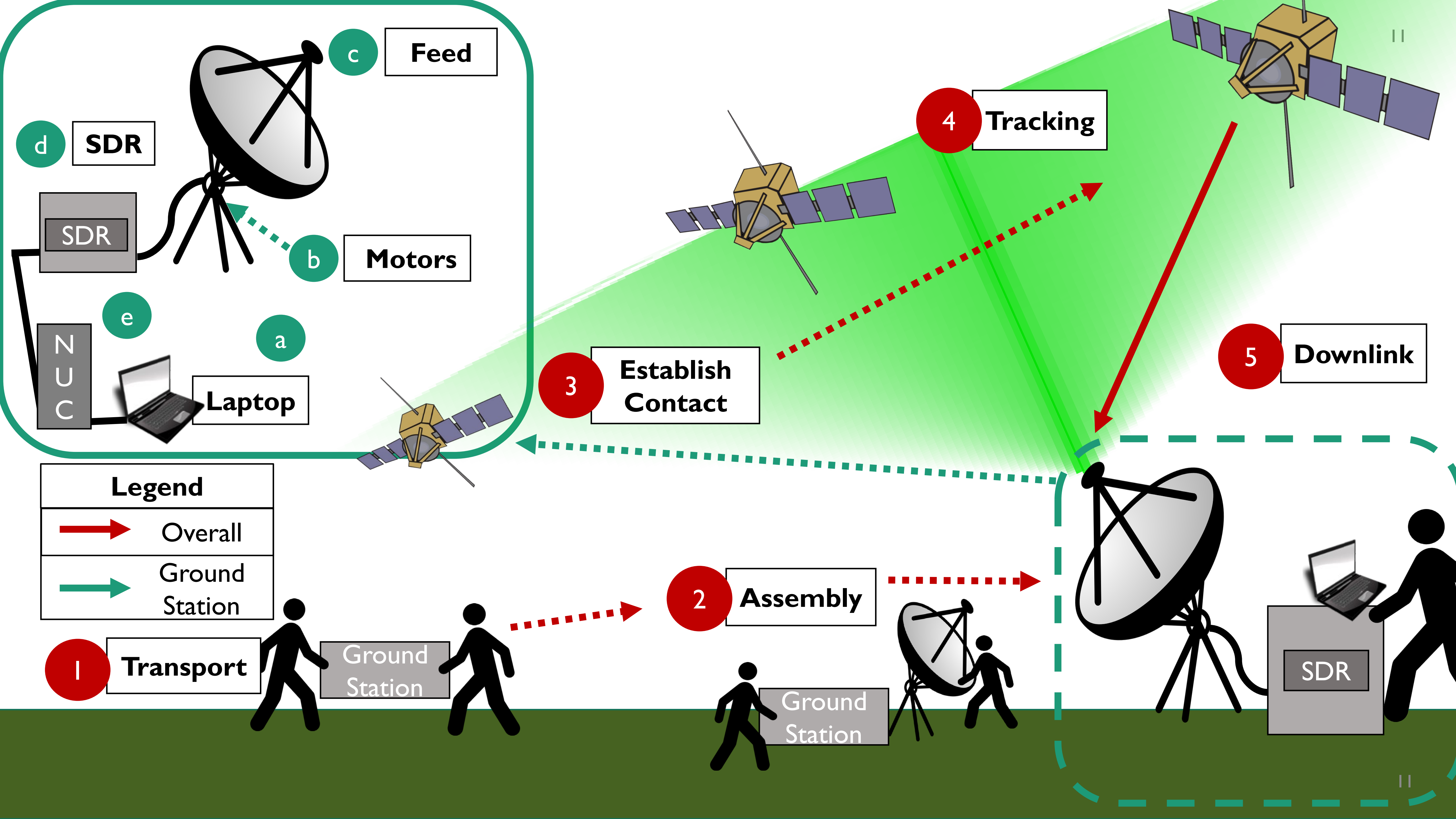

Legend
Overall
Ground Station
1
Transport
Ground Station
2
Assembly
Ground Station

7


3
Establish Contact
Legend
Overall
Ground Station
2
Assembly
1
Transport
Ground Station
Ground Station
SDR


4
Tracking
3
Establish Contact
Legend
Overall
Ground Station
2
Assembly
1
Transport
Ground Station
Ground Station
SDR


4
Tracking
3
Establish Contact
5
Downlink
Legend
Overall
Ground Station
2
Assembly
1
Transport
Ground Station
Ground Station
SDR



c
Feed
d
SDR
SDR
b
Motors
e
a
NUC
Laptop
4
Tracking
3
Establish Contact
5
Downlink
Legend
Overall
Ground Station
1
Transport
Ground Station
2
Assembly
Ground Station
SDR

Critical Project Elements

Antenna

Tracking Hardware

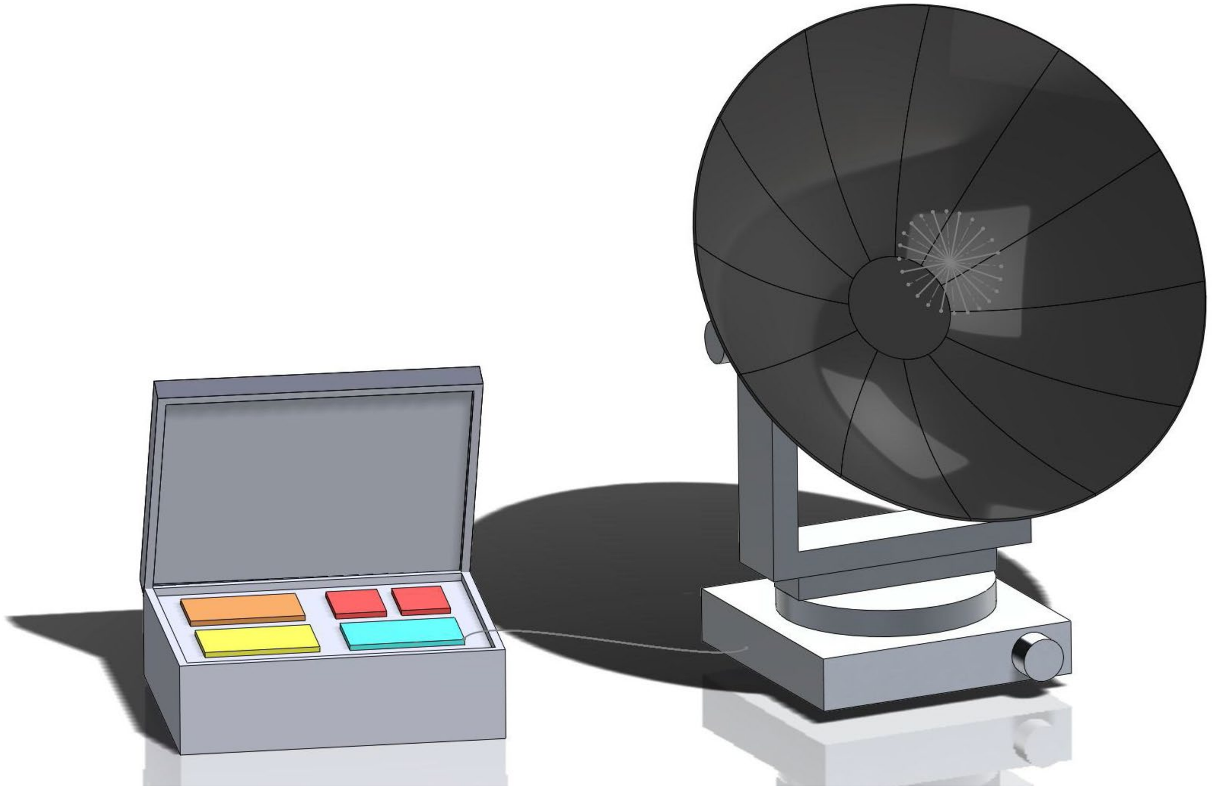
Tracking Software

Signal Processing

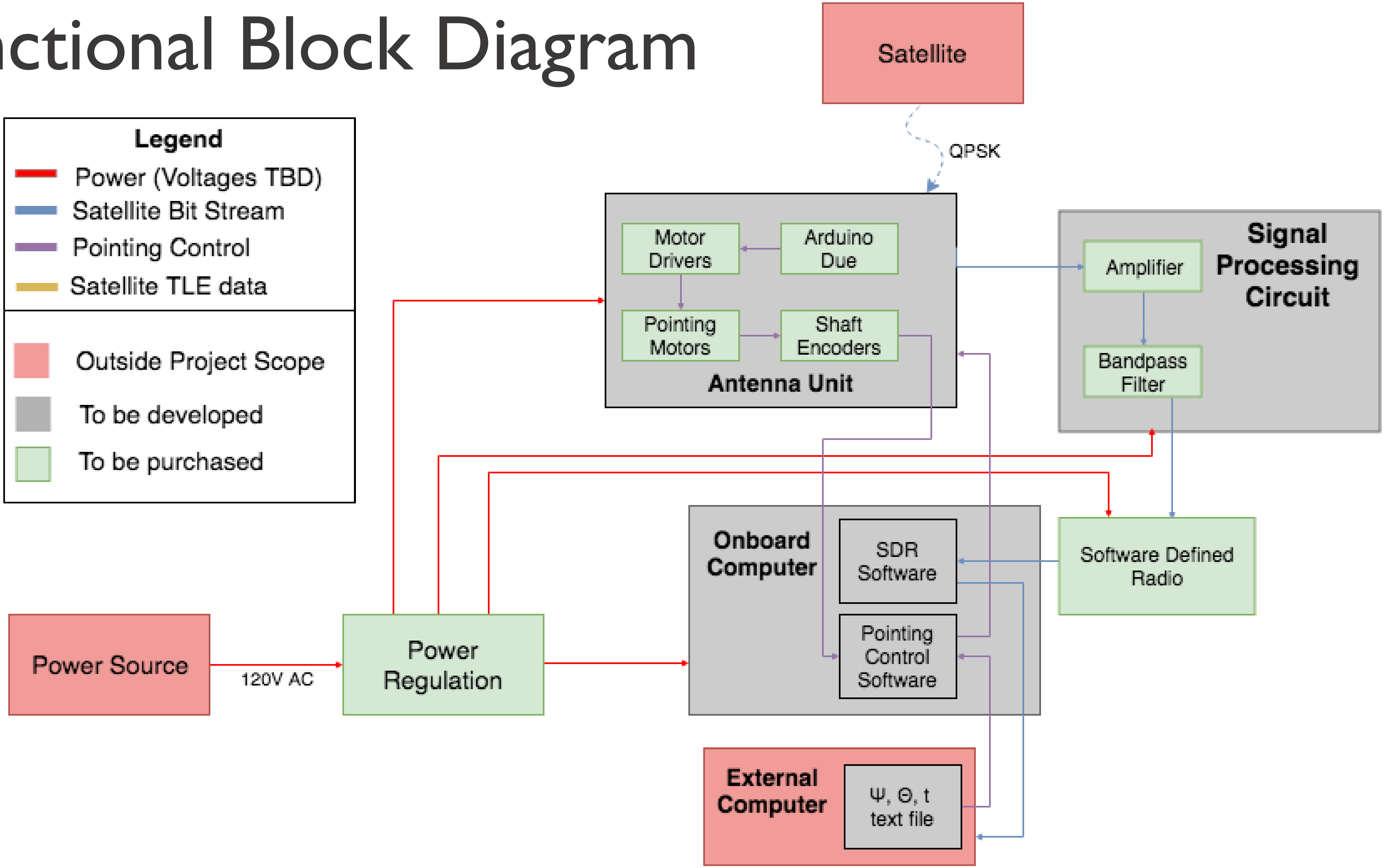
Mobility

Baseline Design

- This is a rough preliminary design of the ground station
- Displayed are:
  - Antenna parabolic dish
  - Two-axis motorized gimbal mount
  - Case with the SDR, Signal Processing Circuit, NUC, motor controller, and motor drivers



Functional Block Diagram



Antenna Baseline Design

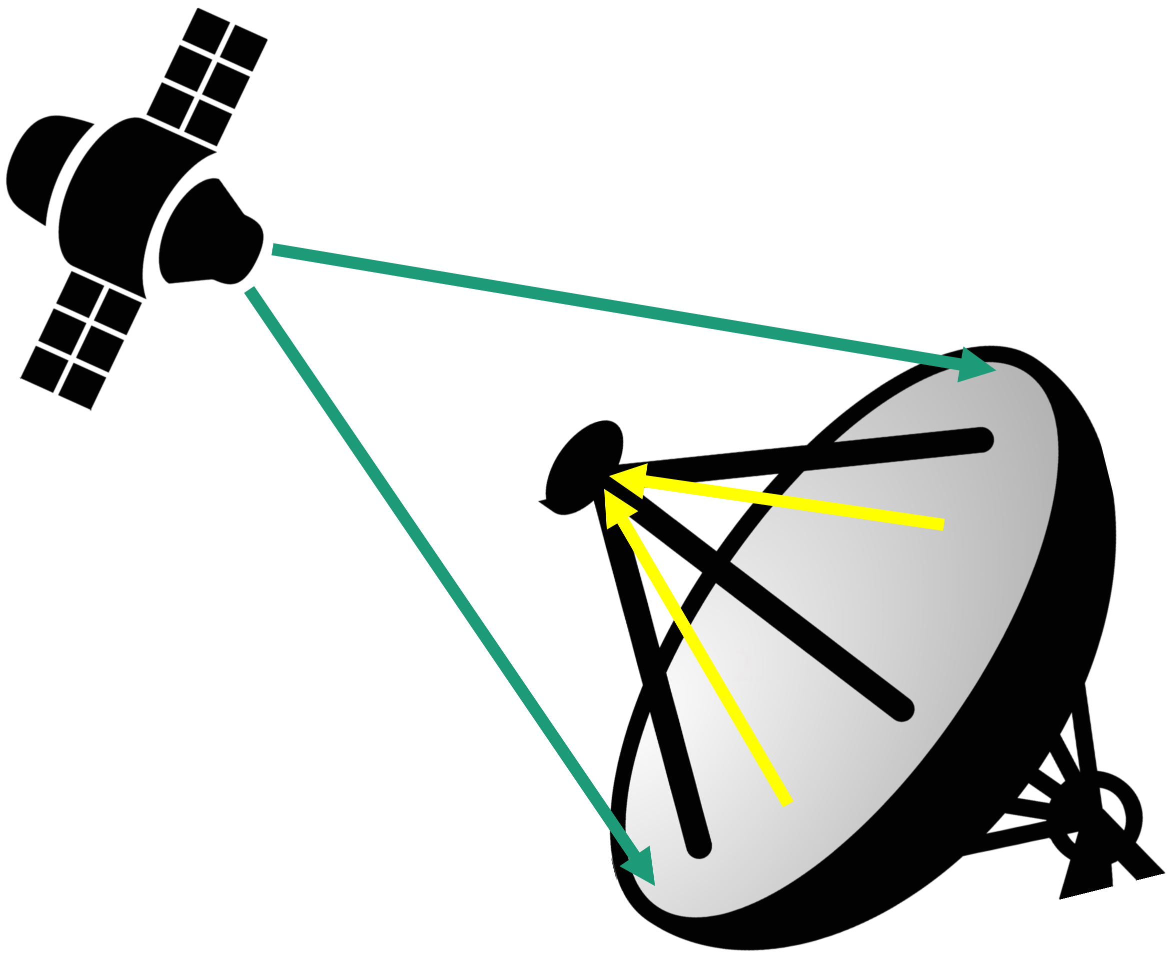
- Customer Requirements:

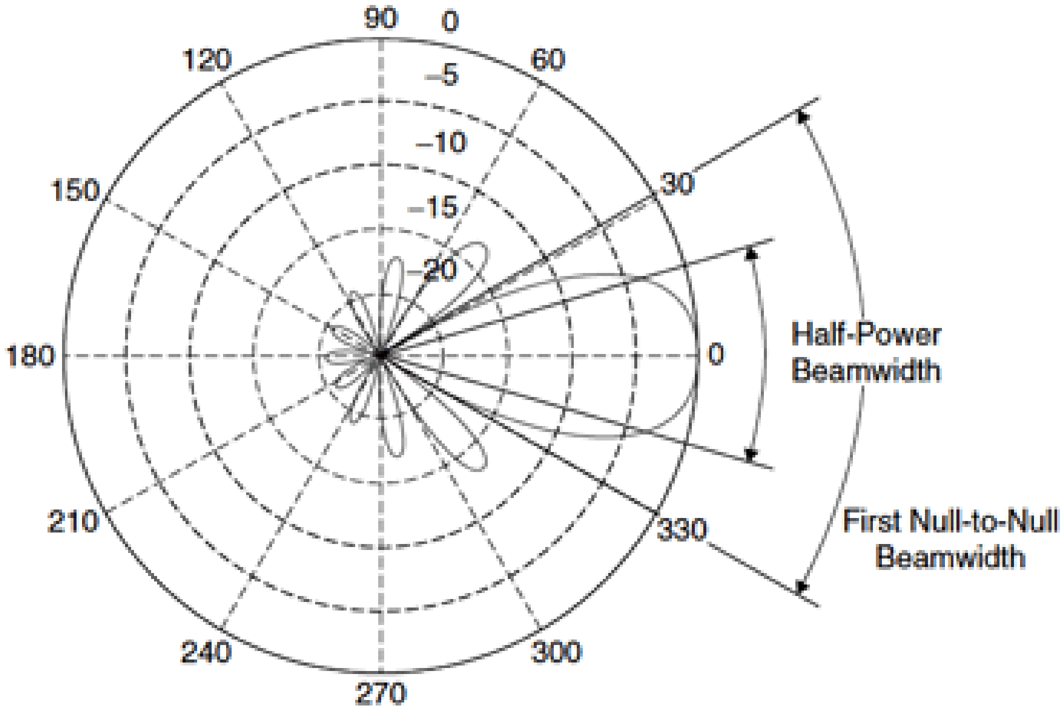
Frequency Range	2.2-2.3 GHz
Polarization	Right Hand Circular Polarized
Gain/Temperature Ratio	3 dB/K

- Used these parameters to calculate design variables of antenna:

Diameter	1.5 m
Half Power Beamwidth	9°
Gain	27.3 dBi

Antenna Baseline Design





Tracking Software Baseline Design

Obtain azimuth, elevation, and a predicted orbit from downloaded TLE using orbit propagator and coordinate transformation

→

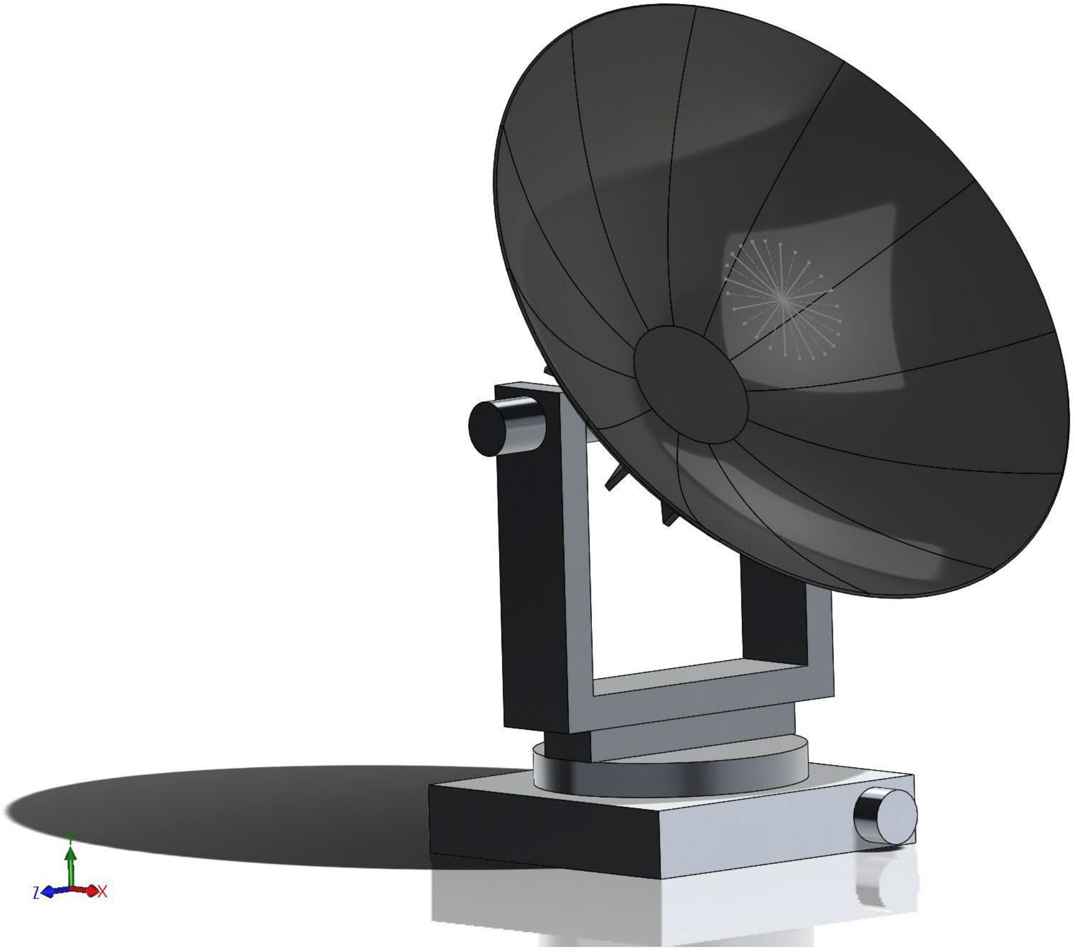
Calibrate pointing and verify signal

→

Maintain link with satellite during pass

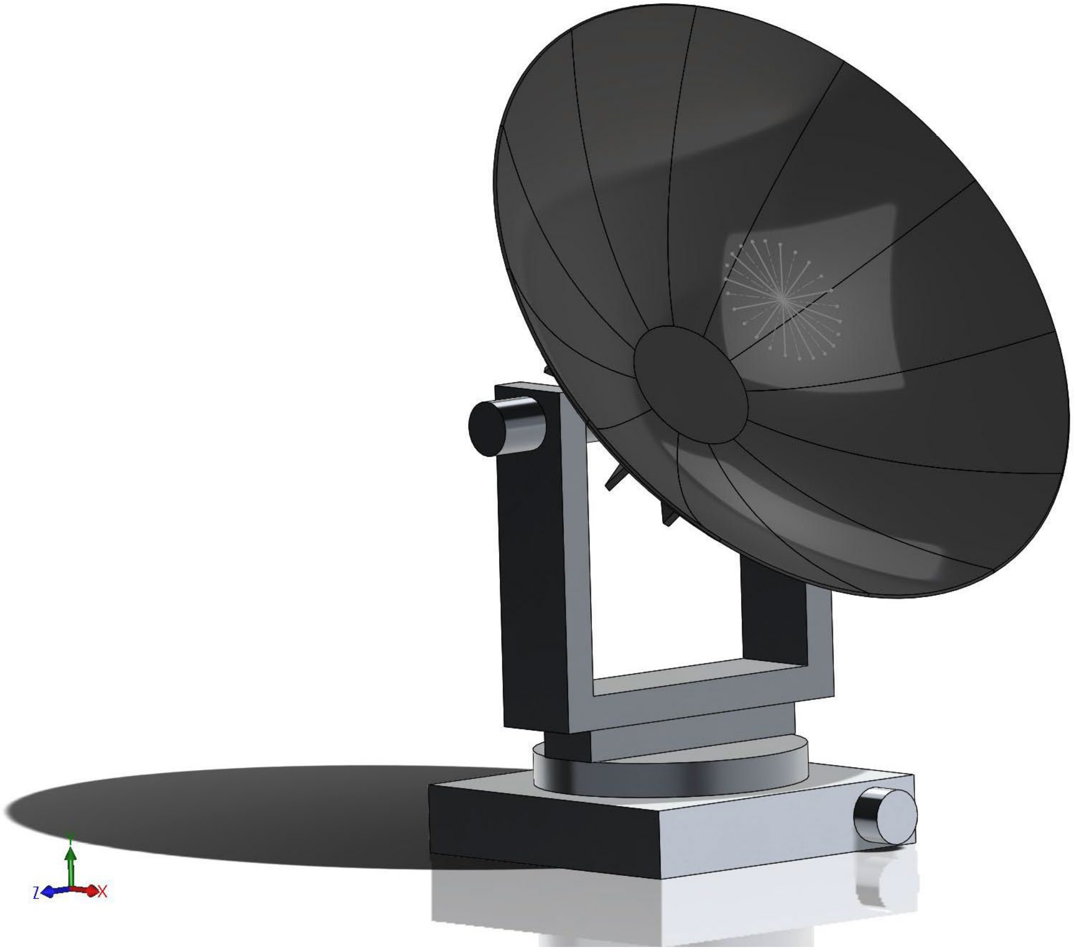
Tracking Hardware Baseline Design

- Custom parabolic dish
- Two-Axis Gimbal
- Driven by two direct drive motors
- Rotational data provided by absolute rotary encoders



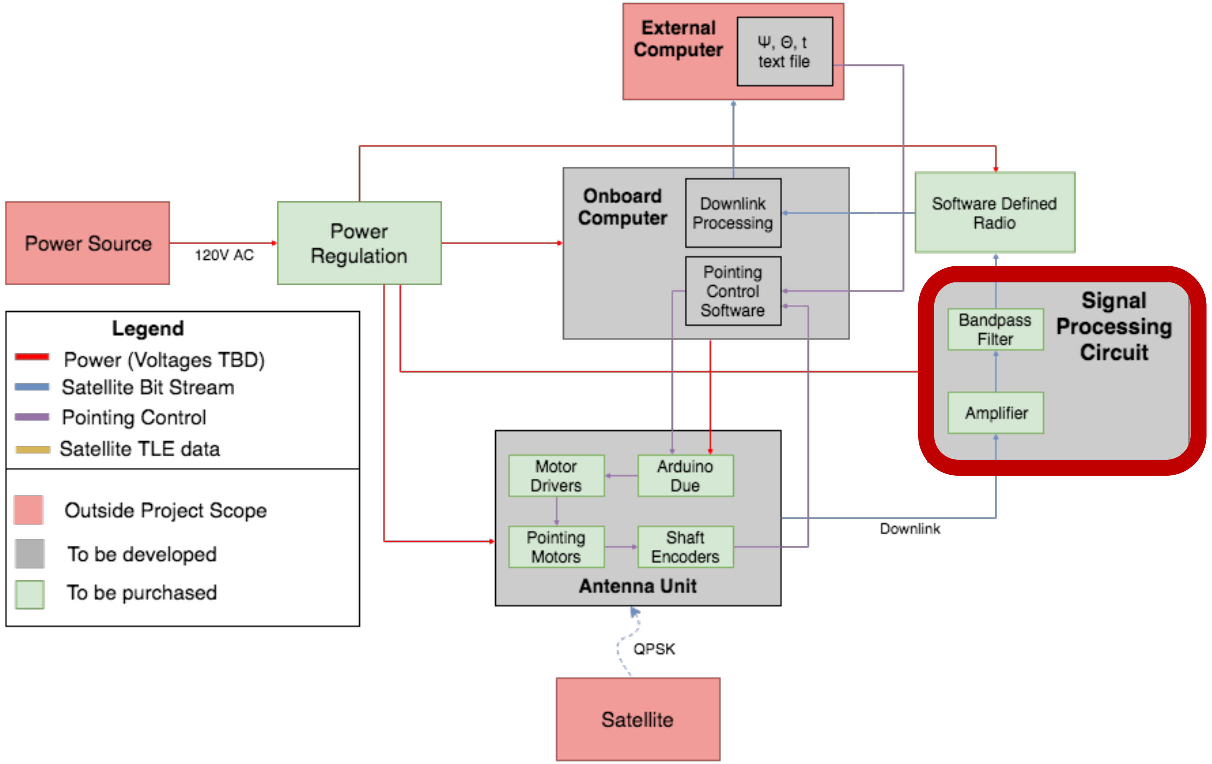
Tracking Hardware Baseline Design

- Components:
  - Elevation and azimuthal motor(s)
  - Two-axis Gimbal mount
  - Rotary Encoder, Hall Effect Sensor, etc.
  - Motor controller
  - Motor Driver
- Requirements:
  - Must be capable of driving antenna at max slew rate of 2.26° per second
  - Mount must be capable of withstanding driving torques
  - Shall be able to point to an accuracy of ±4°



Signal Conditioning Baseline Design

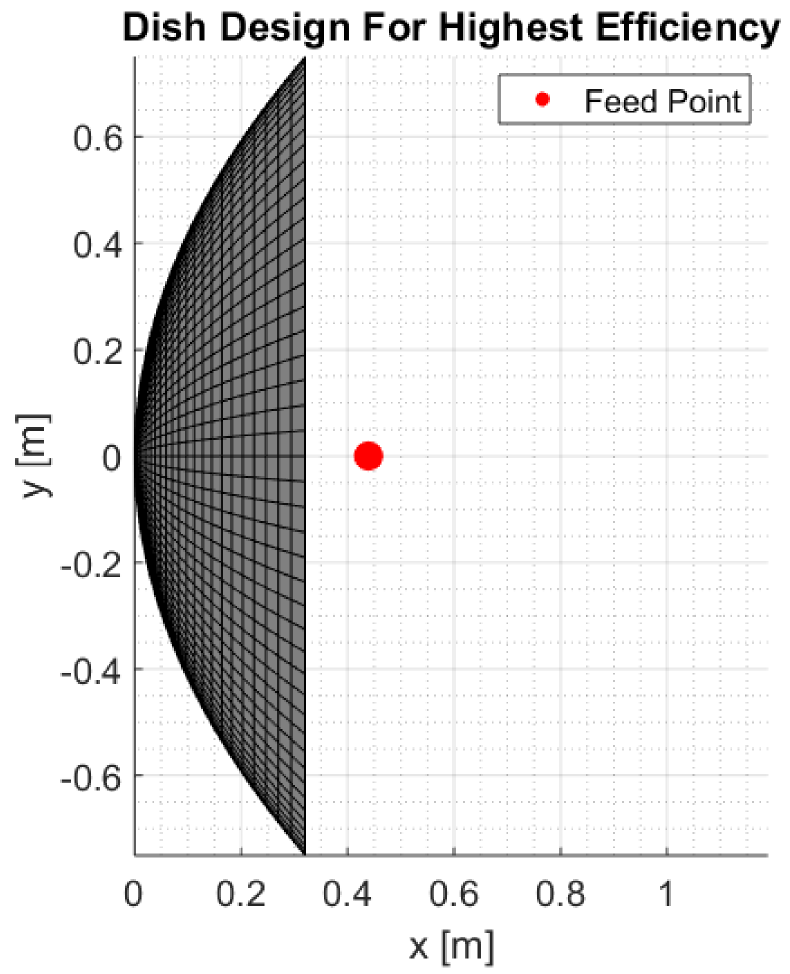
- Components
  - Low-noise amplifier (LNA)
    - Gain: 15-25 dB
  - Bandpass filter
    - Passband: 2 to 2.5 GHz
- Interfaces
  - Antenna feed – SMA or N-type connector (input)
  - Software defined radio – SMA connector (output)
  - LNA to filter – SMA connectors (internal)
- Purpose
  - Amplify target signal above noise floor for accurate sampling
  - Isolate signal from other powerful sources to reduce error from interference

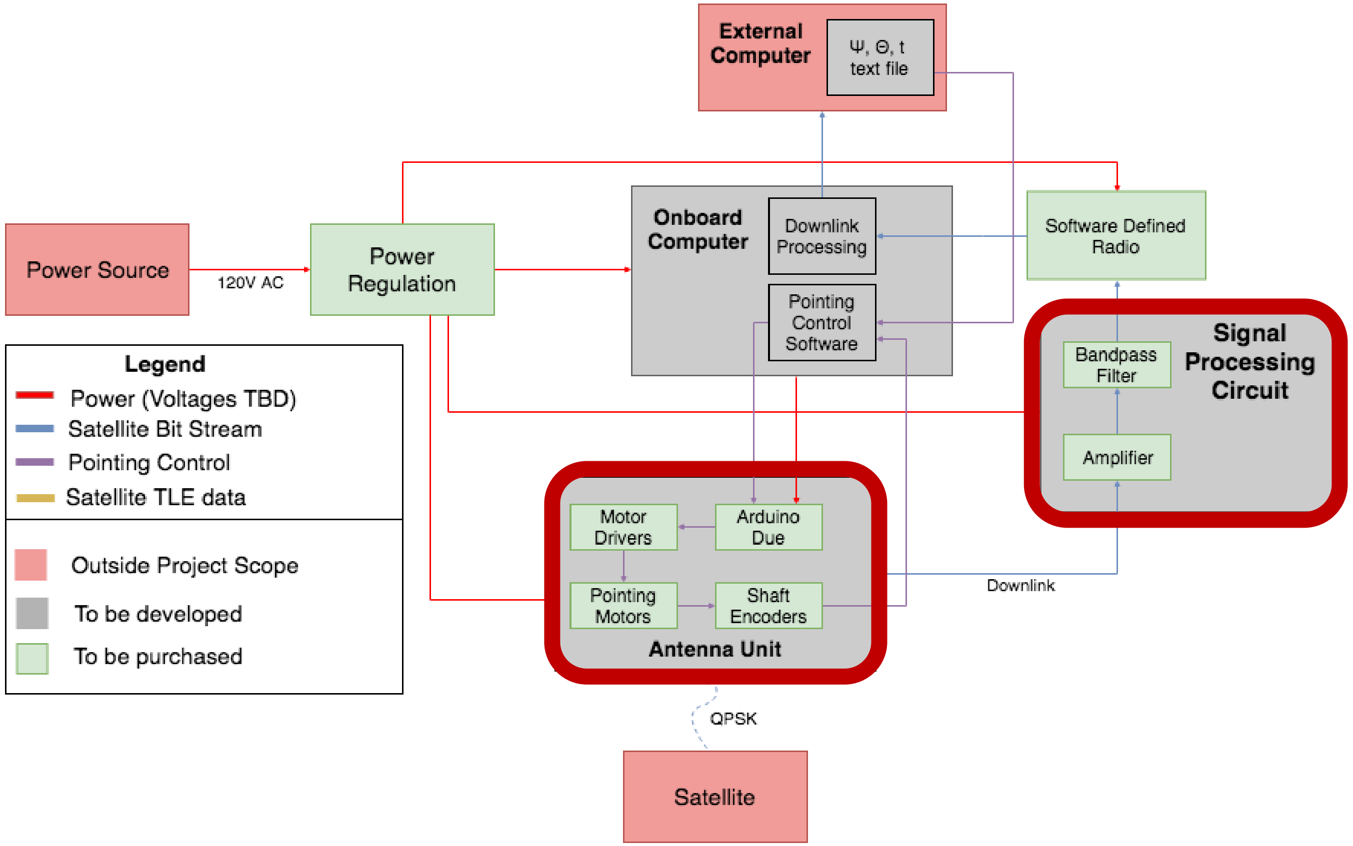


Antenna

Antenna Parameters

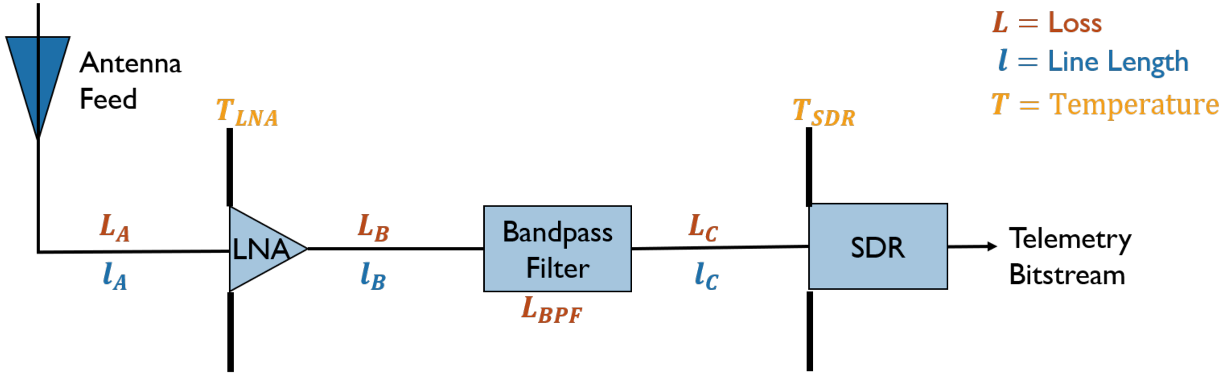
Frequency Range	2.2-2.3 GHz
Polarization	Right Hand Circular Polarized
Gain/Temperature Ratio	3 dB/K





Gain Estimation

Requirement: $\frac{G}{T_S} = 3\,\frac{dB}{K}$



- Losses are dependent on purchased components
- Estimate component losses to determine required gain:

$T_s \approx 171\ K$ → $G_{min} \approx 27.3\ dBi$ → D = 1.5 m

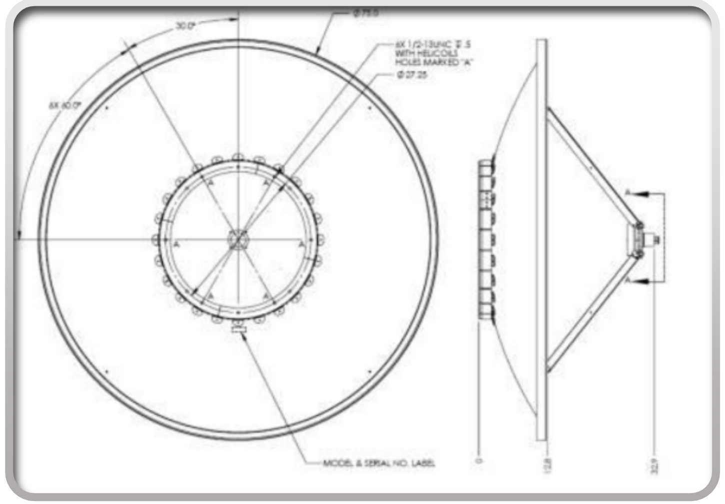
$$T_S = aT_a + (1-a)T_0 + T_{LNA} + \frac{T_{SDR}}{G_{LNA}/L_C}$$

$$a = 10^{-L_{tl}/10}$$

$$L_{tl} = \frac{loss}{m}(l_A + l_B) + L_{BPF} + (\text{\# of connectors})L_{connector}$$

Option 1: Commercial Antenna

- Off the shelf possibilities that meet frequency, polarization, gain, and beamwidth requirements
- Weight range: 17-60 lbs
- Less mobile
- Verified by manufacturer
- $4000

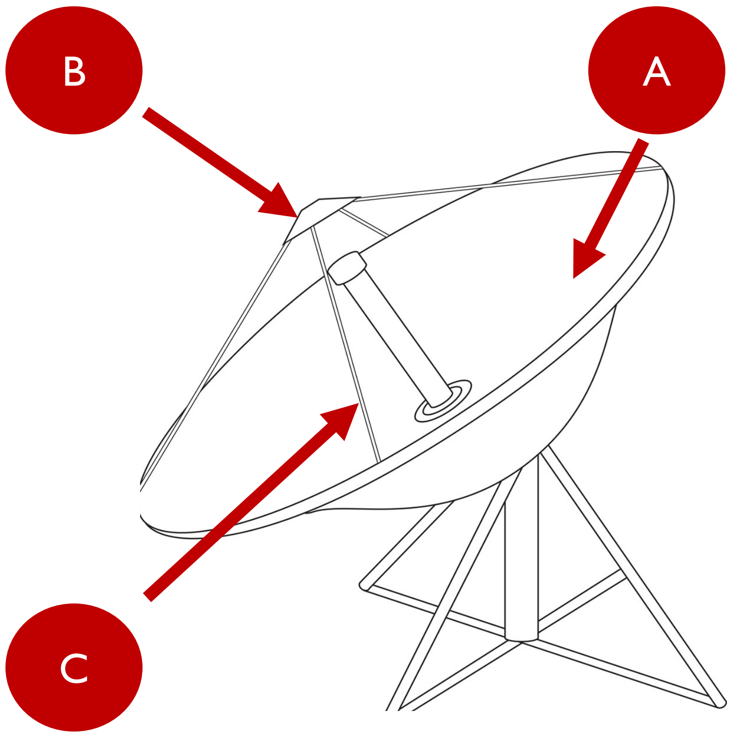


mWAVE RPDC-6-22-N-R1
6 ft
Aluminum

mWAVE RPCD-4-23-S
4 ft
Aluminum

Option 2: Building Reflector, Buying Feed

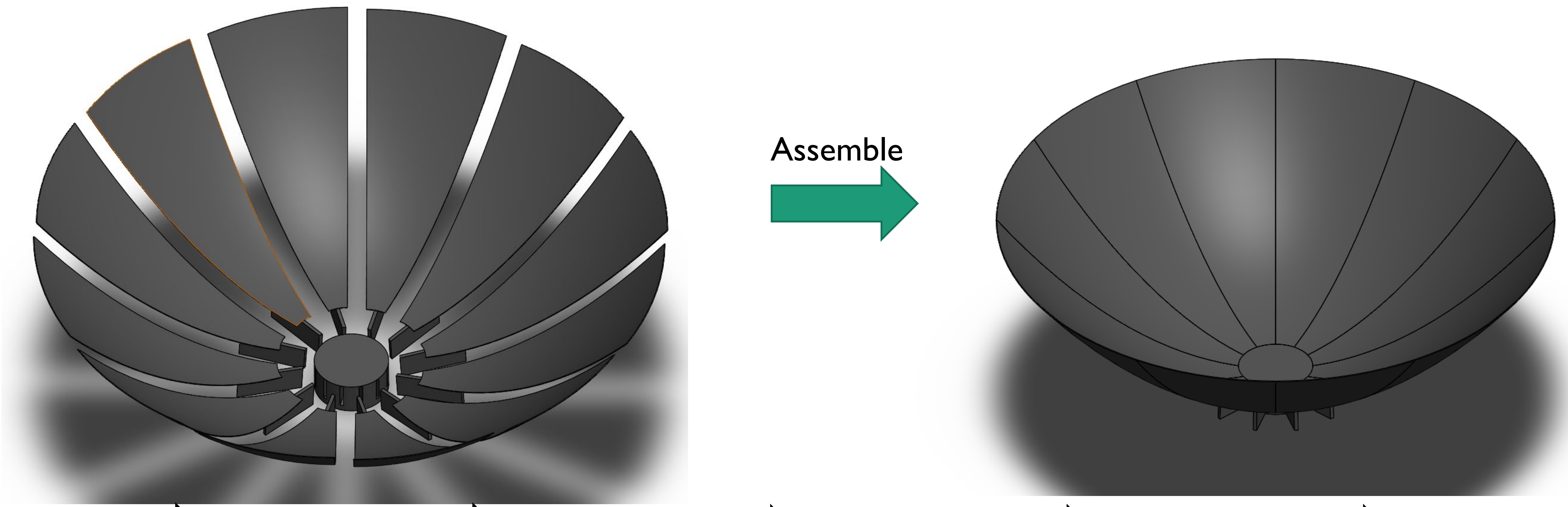
- A: Parabolic Dish Reflector
- B: Commercial Feed
- C: Struts and Feed Mounting System



Option 2A: Parabolic Reflector Design

Based on θ = 118°
Diameter = 1.5 m

Depth = 0.212 m
Focus = 0.663 m



Option 2A: Parabolic Reflector Design

- λ = 13.252 cm
- Manufacturing Accuracy/Minimum Gap size = $\lambda/10$ = 1.32 cm
- Numerous Design Options
  - ❖Mold Injected w/ Mylar Skin
  - ❖Carbon Fiber
  - ❖Metallic Mesh

  Viable to be assembled in house, if in split panel configuration

FEASIBLE

Option 2B: Commercially Available Feeds

Southwest Antennas Helical #1005-007
1.7-2.7 GHz
LHCP
H Beamwidth: 360°
V Beamwidth: 118°

Alaris Antennas SPRL-A0010
1.0-2.5 GHz
LHCP
Beamwidth: 120°

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Option 2C: Feed Mount

- 4 supports to hold in feed center
- Aluminum: lightweight
- Thin: 1/8" diameter to reduce blockage loss

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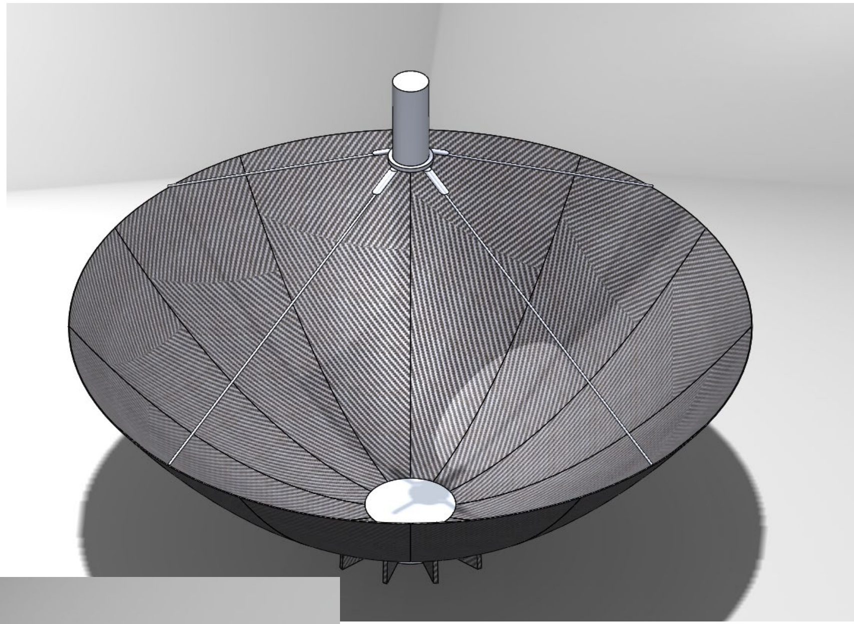

Antenna Verification

Variable	**Verification**
Dish parameters: frequency, gain, and HPBW	Anechoic chamber
Dish dimensions: weight and size, surface accuracy	SolidWorks Simulation
Feed parameters: beamwidth, polarization	Manufacturer's spec sheet
Feed dimensions: weight and size	Manufacturer's spec sheet

Tracking

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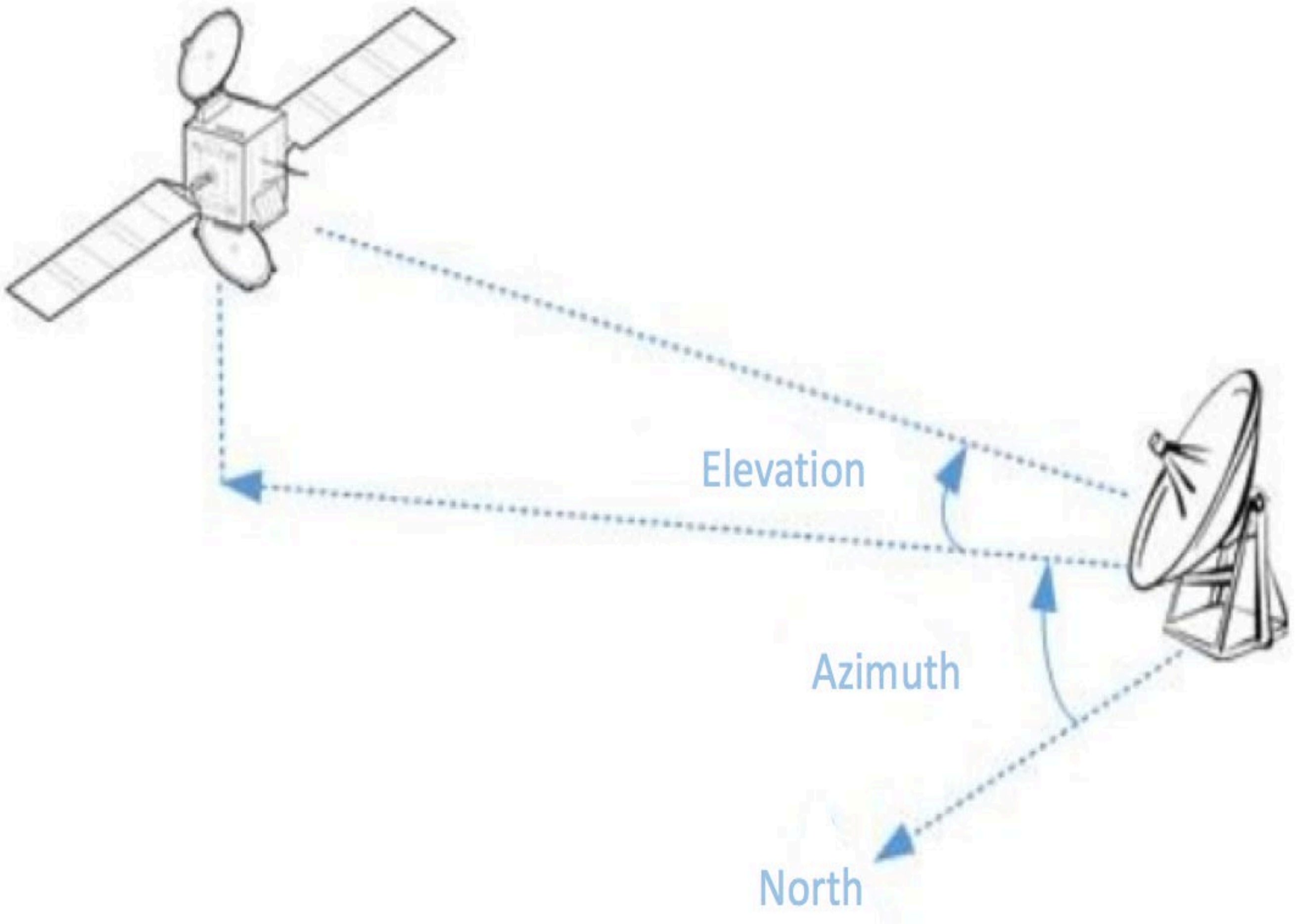
Two Line Element Set

```
0 MTI
1 26102U 00014A   18287.55642534  .00005617  00000-0  97971-4 0  9992
2 26102  97.5765 128.0378 0007825 323.3119  91.8875 15.51134943 29527
0 YAOGAN 6
1 34839U 09021A   18287.71605027  .00000664  00000-0  27907-4 0  9998
2 34839  97.0819 319.8707 0029555  42.2947 318.0564 15.26319735526486
```

- TLE text file, downloaded from Space-Track.org
- Contains Keplerian elements such as e, i, ω, Ω, M_e, n
  - From these Azimuth, Elevation can be derived
- Also contains important identifiers

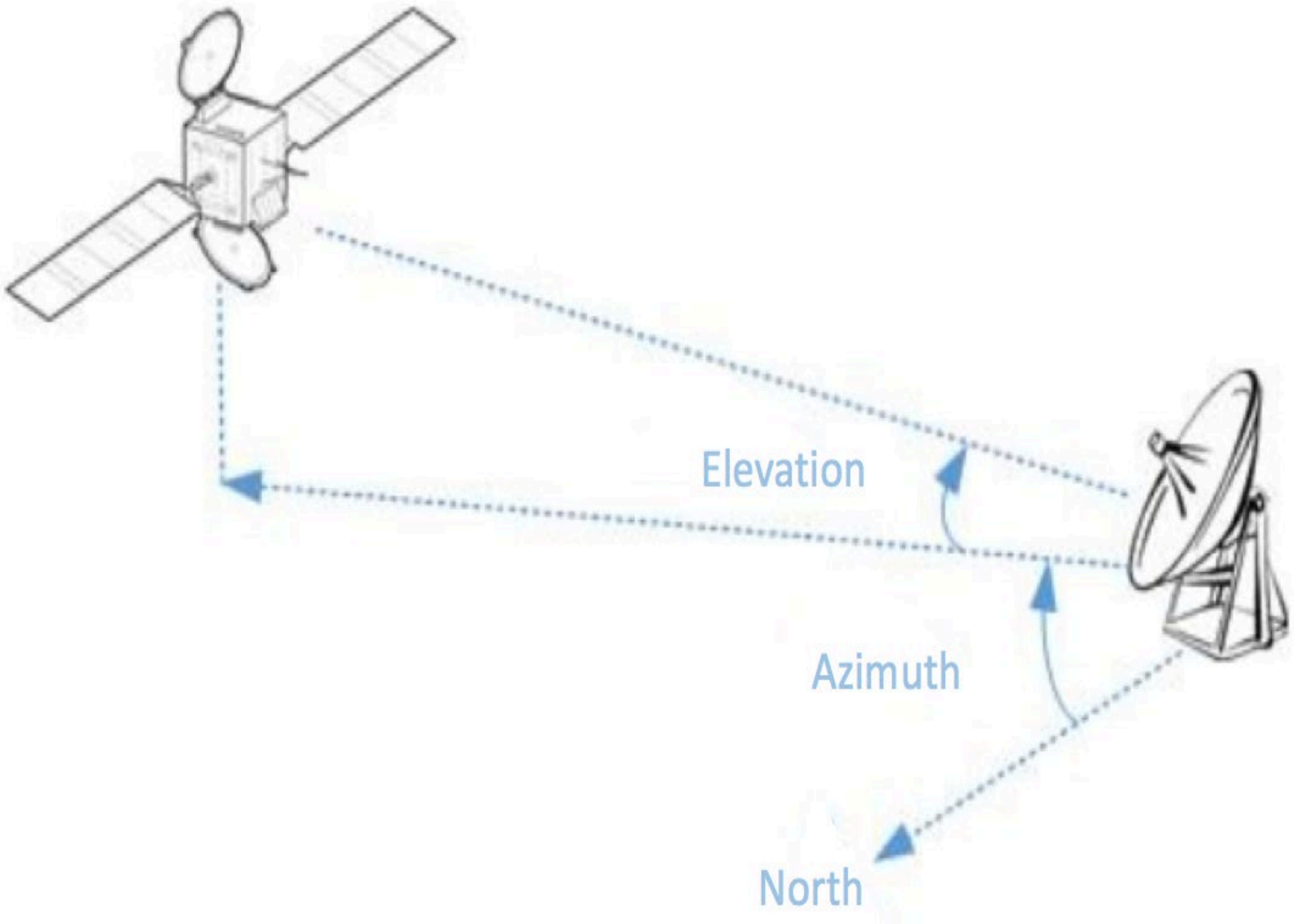
Tracking Software – Program Track

- Gpredict/Predict
  - Has database containing TLE sets for satellites
  - Outputs Azimuth and Elevation dependent of time
- Create our own orbit-prediction software
  - Have a TLE reader
  - Theory from ASEN 3200 for calculating remaining orbital elements, position, and velocity
  - Coordinate Transformations to calculate Azimuth and Elevation



Tracking Software – Auto-Track

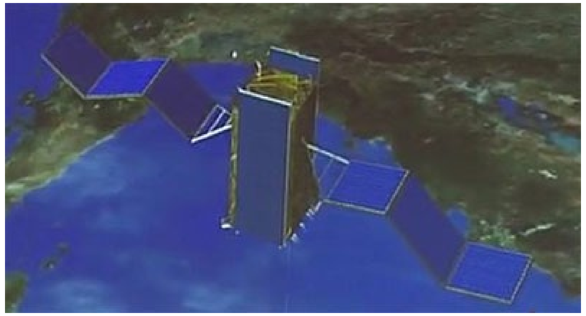
- Point in predicted Azimuth and Elevation from TLE data
- Obtain Signal
- Perform signal to noise (SNR) calculation on signal
- Follow direction of strongest SNR
  - Could be slightly different than TLE prediction due to TLE error



Tracking Software – Confirming Frequency Range

Altitude Requirement	200-600 km
Frequency Range	2.2-2.3 GHz

- In order to confirm the frequency range, two S-band LEO satellites will be tested for reception :
  - MTI: operating at 2.21 GHz
  - Yaogan 6: operating at 2.296 GHz



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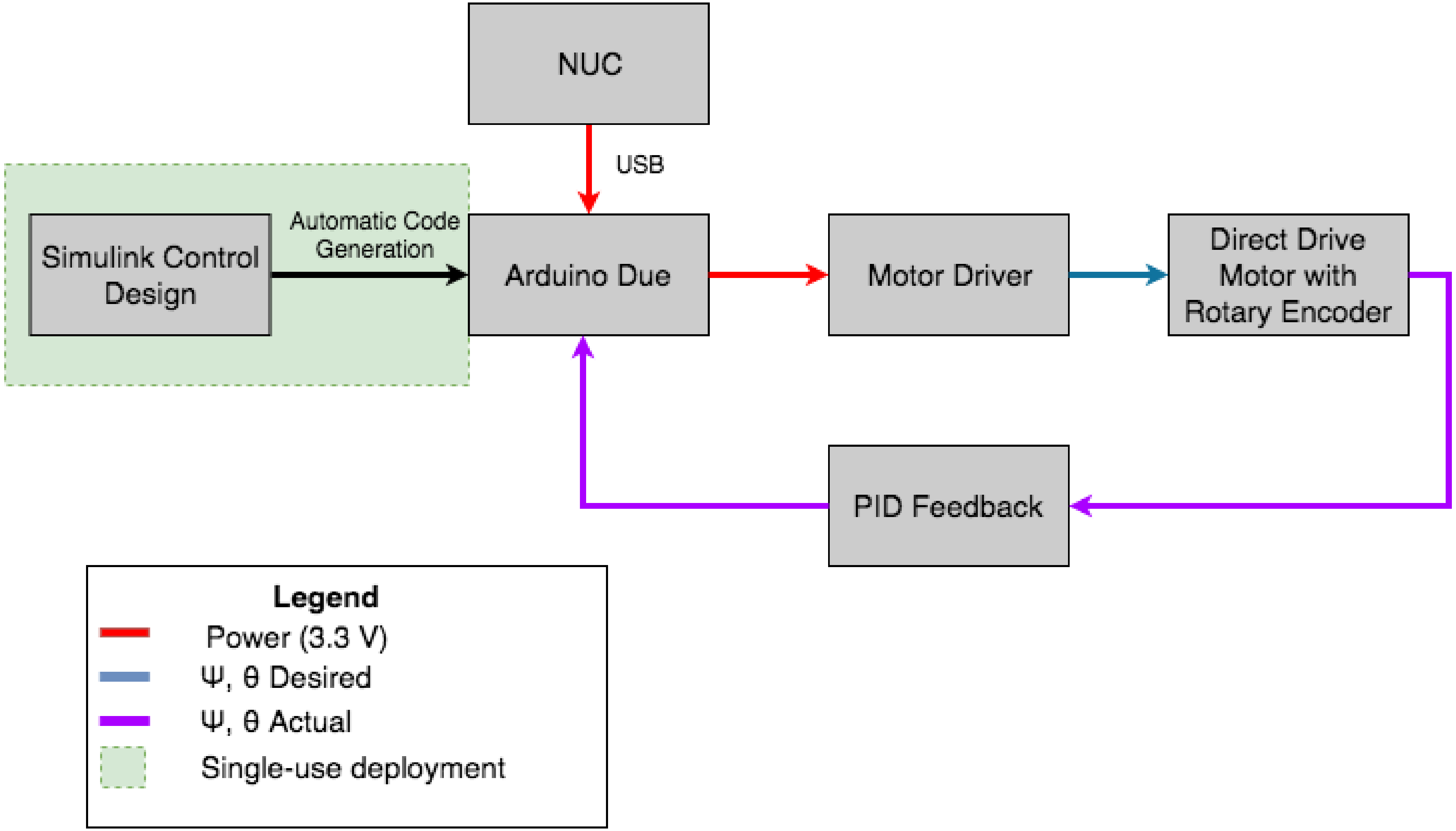
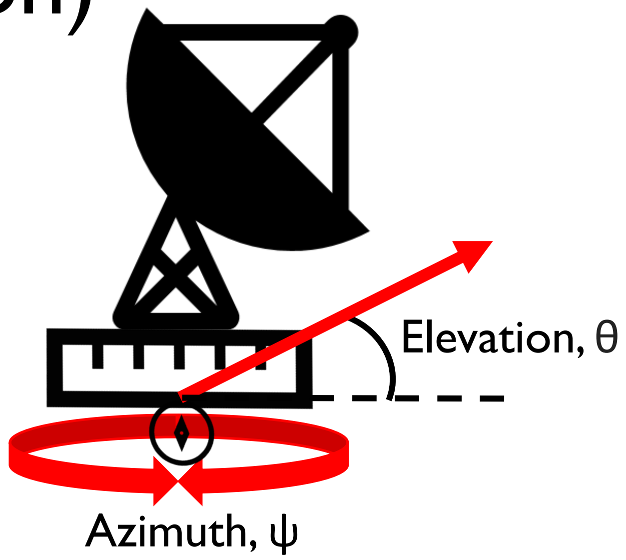
Tracking Hardware Control Interface



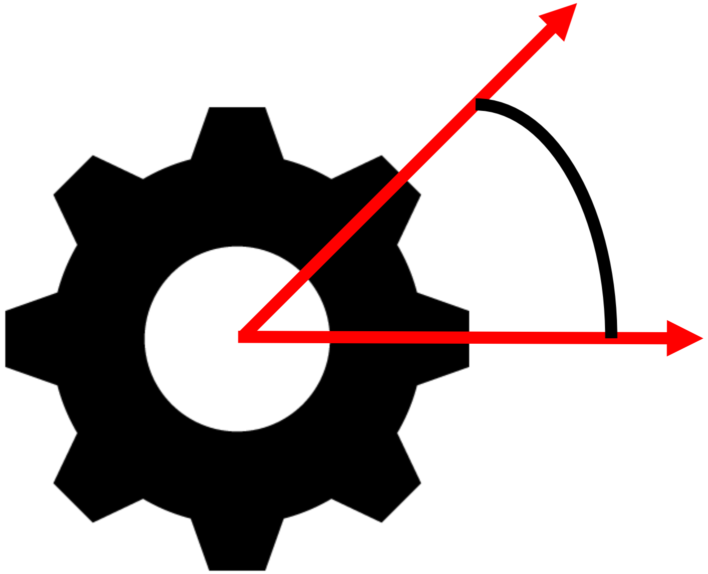
Azimuth and Elevation Calibration

- Azimuth: Point at sun, zero with tracking software to achieve 0° (true North)
- Elevation: Level tool to achieve 0° (horizon)
- Software tuning
  - Power on sequence
  - TLE load and track to starting points



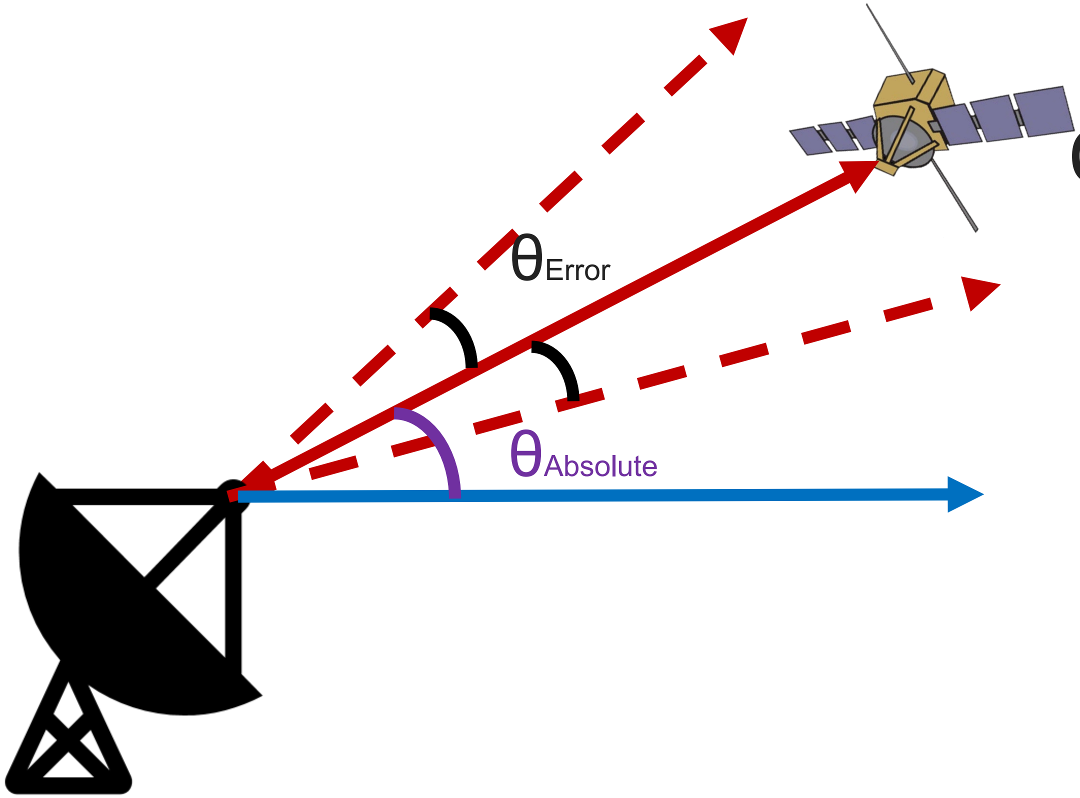
Ψ, θ to Motor Commands

- Determine number of motor steps for given angle
- Requires sufficient resolution…



Motor Resolution

- Minimum shaft movement required to be on-target



$\Theta_{Error} = \Theta_{TLE, Error} + \Theta_{Motor, Error} < \mathbf{4.5°}$

- Requires minimum of 80 steps/revolution
- Easily acquired COTS

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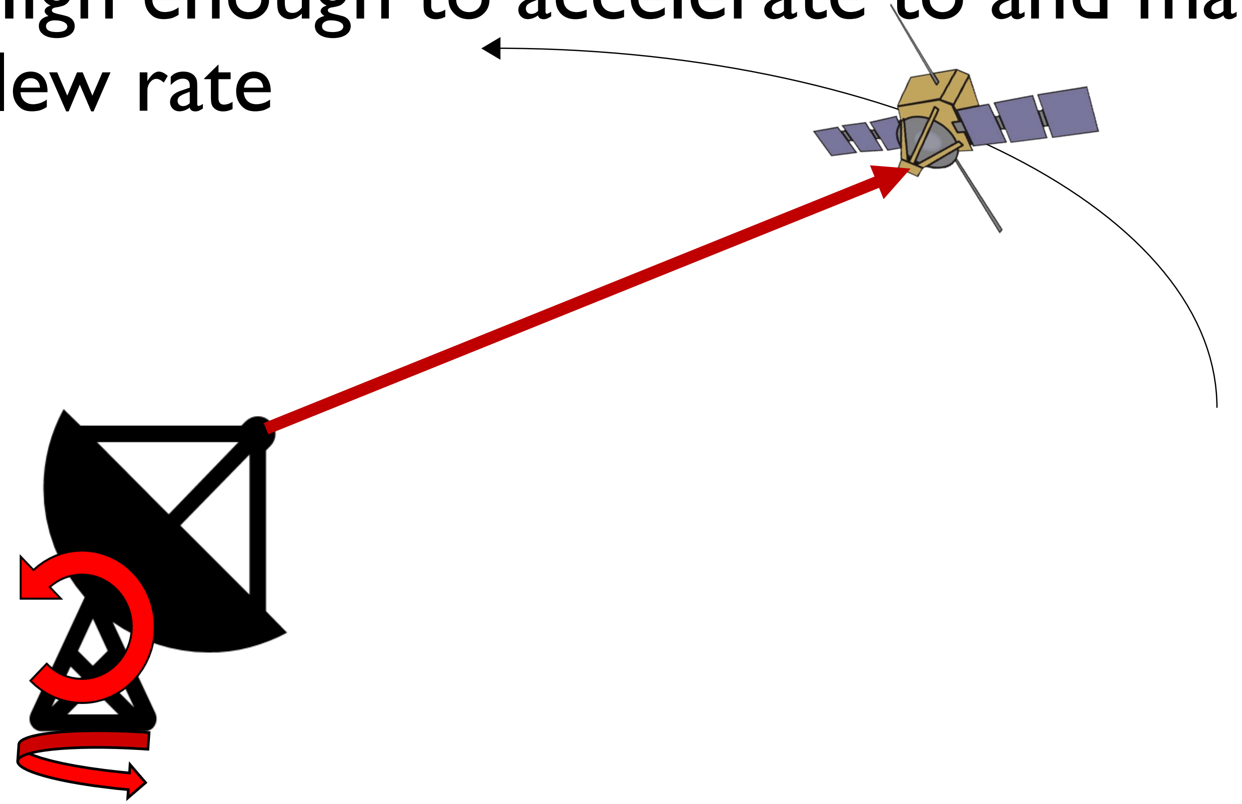
Motor Torque

- Torque needed to drive antenna
- High enough to accelerate to and maintain the maximum slew rate



Must be rated for at least 4.57 N-m of torque

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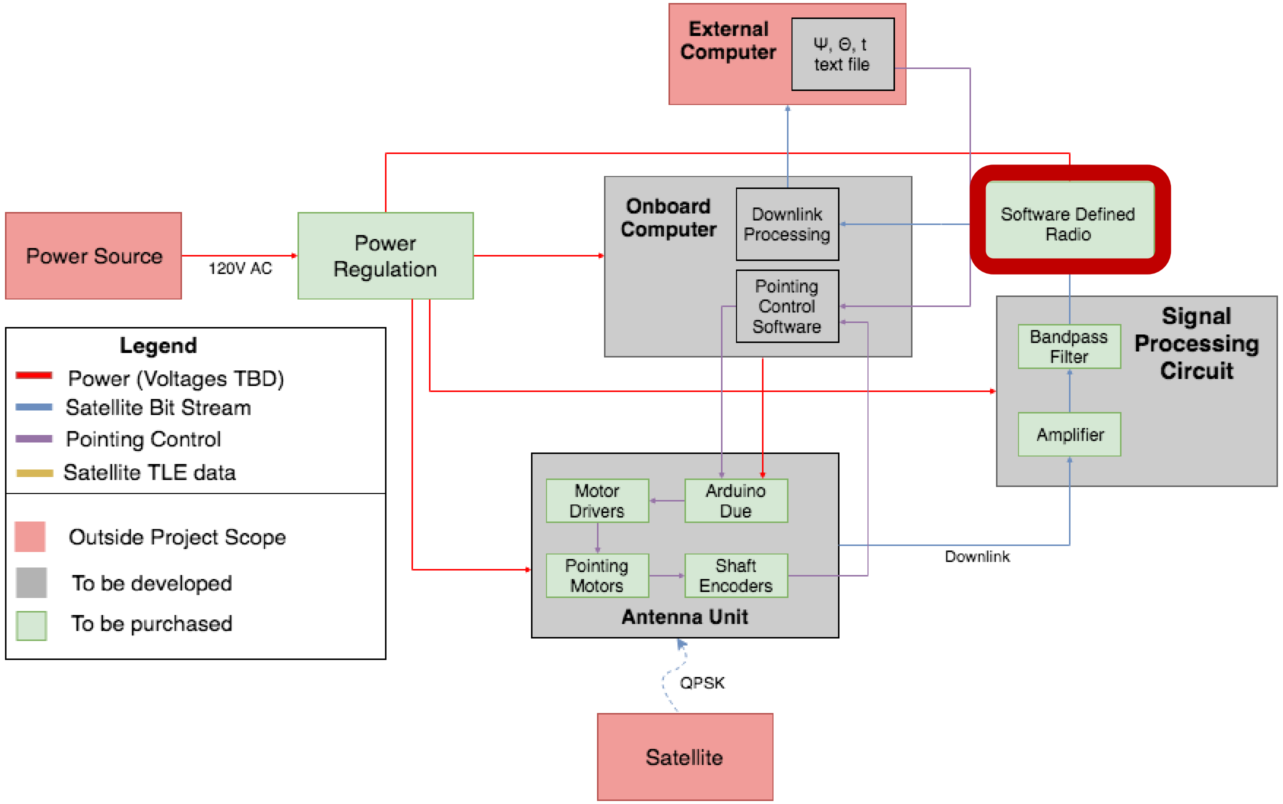
Tracking Verification

Variable	**Verification**
Track between 10-170 degrees	Demonstrate range of motion
Minimum motor resolution	Datasheet
Minimum motor torque	Datasheet
Tracking Software	STK
Frequency Range	Two satellites, one at each limit of frequency range

Signal Conditioning & Processing

Software Defined Radio (SDR) – Processing

- The ground station will have an SDR to process the received signal
  - Mixing
  - Amplification and Filtering
  - Analog to Digital Conversion
- SDR output will be received and processed using software created using open source GNURadio software packages
  - Demodulation



SDR Options

Requirements:

- 2.1: Max Frequency >= 2.5GHz
- 2.10.1: Sample Rate >= 5MHz

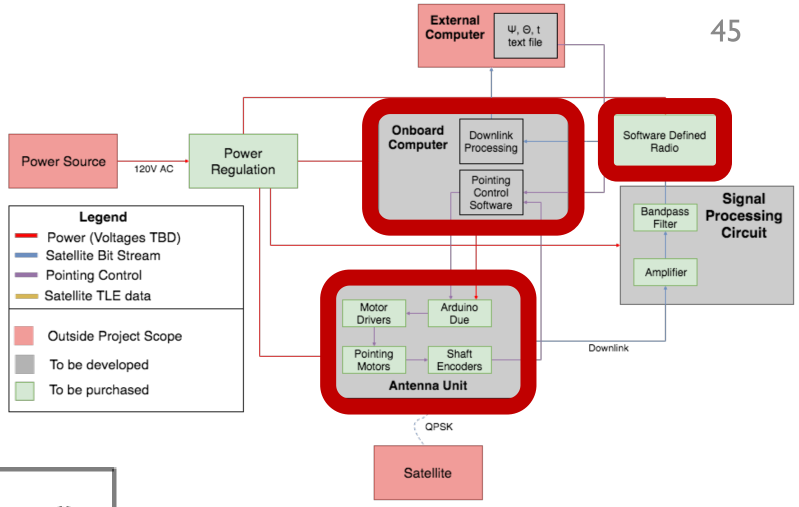
Desires:

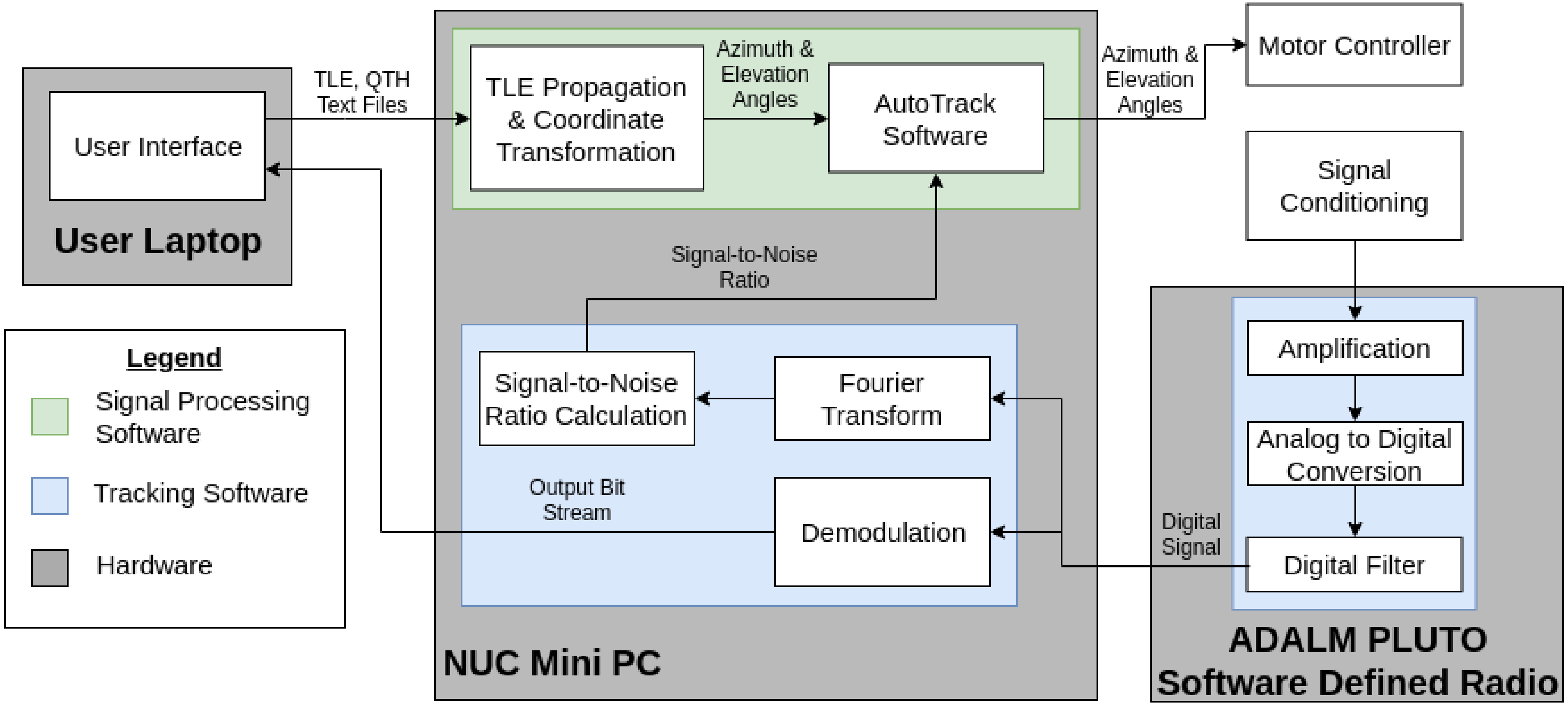
- Low Cost
- Accurate ADC

	HackRF One	ADALM-PLUTO	LimeSDR
Cost	$300	$100	$300
Max Frequency	6 GHz	3.8 GHz	3.5 GHz
ADC Bits	8 bits	12 bits	12 bits
Sampling Rate	20 MHz	61.44 MHz	61.44 MHz
Description	Hess has Experience Well Documented Coding Examples Online	Meant for Education Decent Documentation Fairly New Product	Not Well Documented Crowdfunded Hard to Find Specs

FEASIBLE

Software Block Diagram



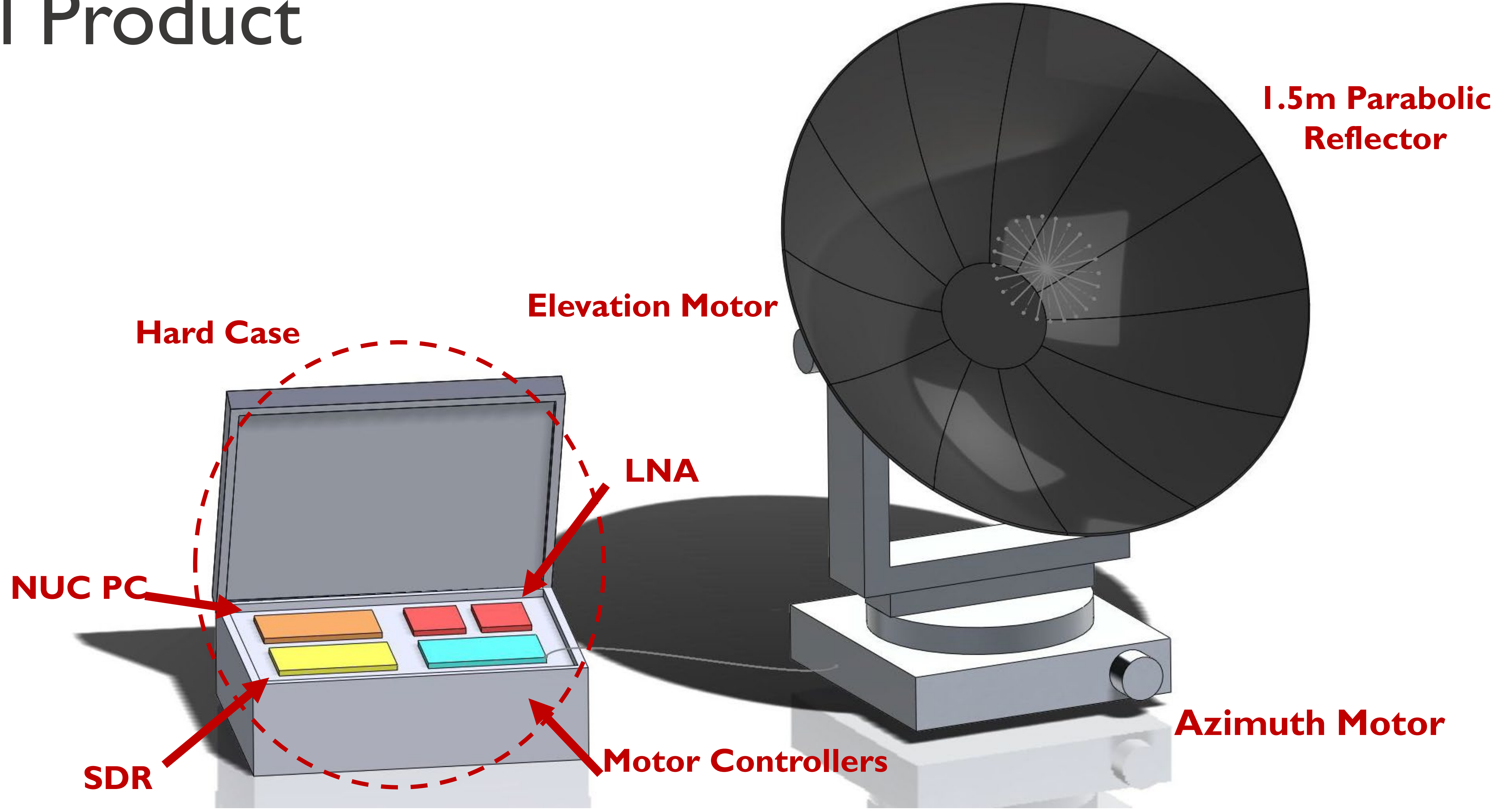


Signal Processing Verification

Variable	Verification
Signal Conditioning (LNA & BPF)	Attenuated Generated Signal
Bit Error Rate (SDR)	Generated Signal Comparison
Maximum Frequency (SDR)	Product purchase specification
Bandwidth (SDR)	Product purchase specification

Conclusion

Final Product

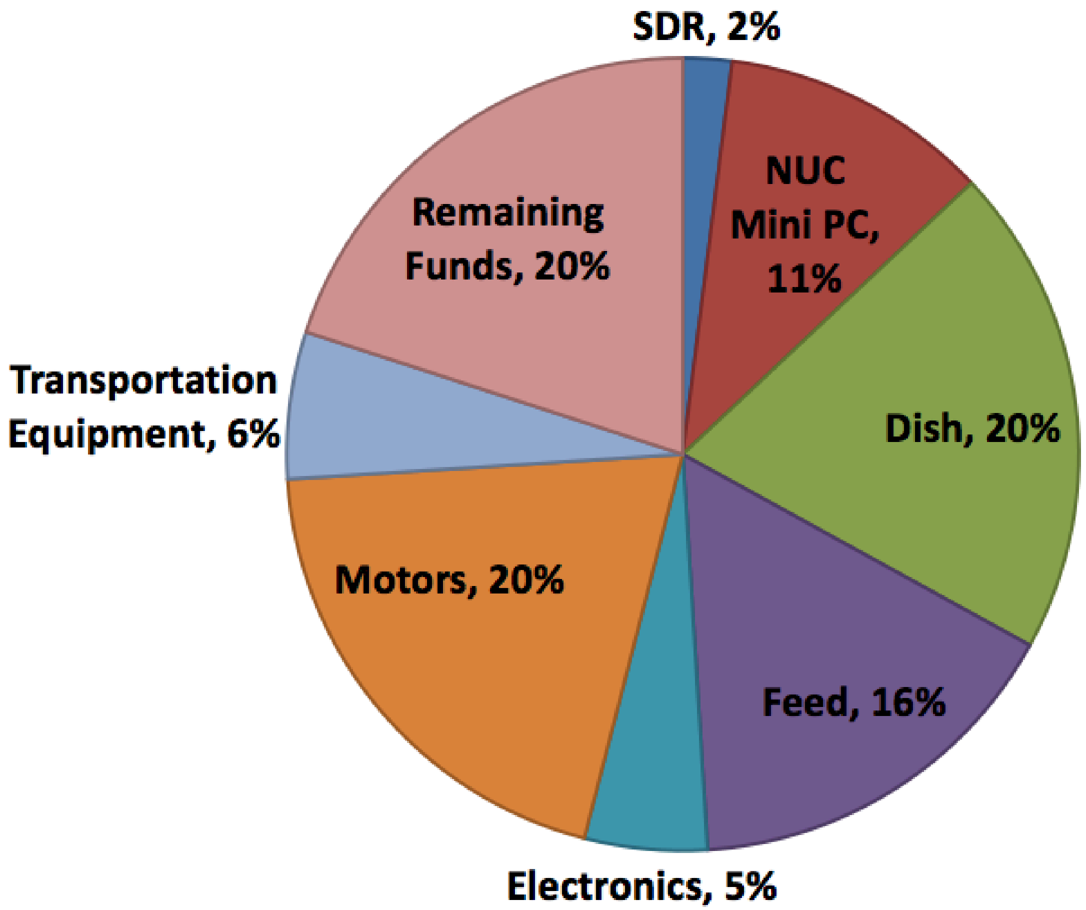


Conclusions

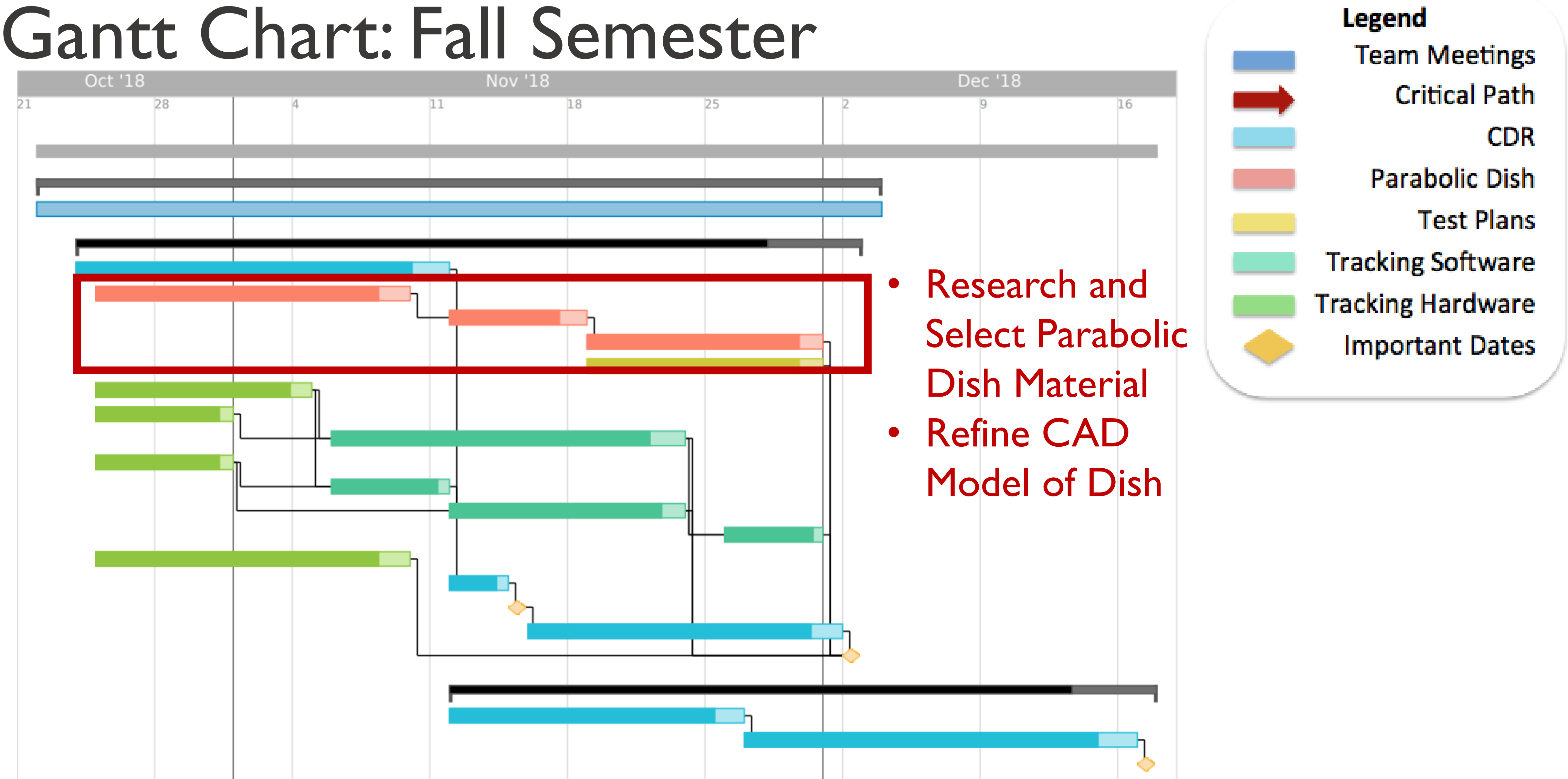
Objective	Requirement	Verified?
Communication	Antenna dish requirements	✓
	Antenna feed requirements	✓
Signal Processing	Software Defined Radio	✓
Tracking Software	Program Track	✓
	Auto-Track	✓
Tracking Hardware	Motor Torque	✓
	Motor Resolution	✓

Budget

Summary	
Item	**Cost ($)**
SDR	100.00
NUC Mini PC	550.00
Dish	1000.00
Feed	800.00
Electronics	250.00
Motors	1000.00
Transportation Equipment	300.00
Remaining Funds	**1000.00**
Total	**5000.00**

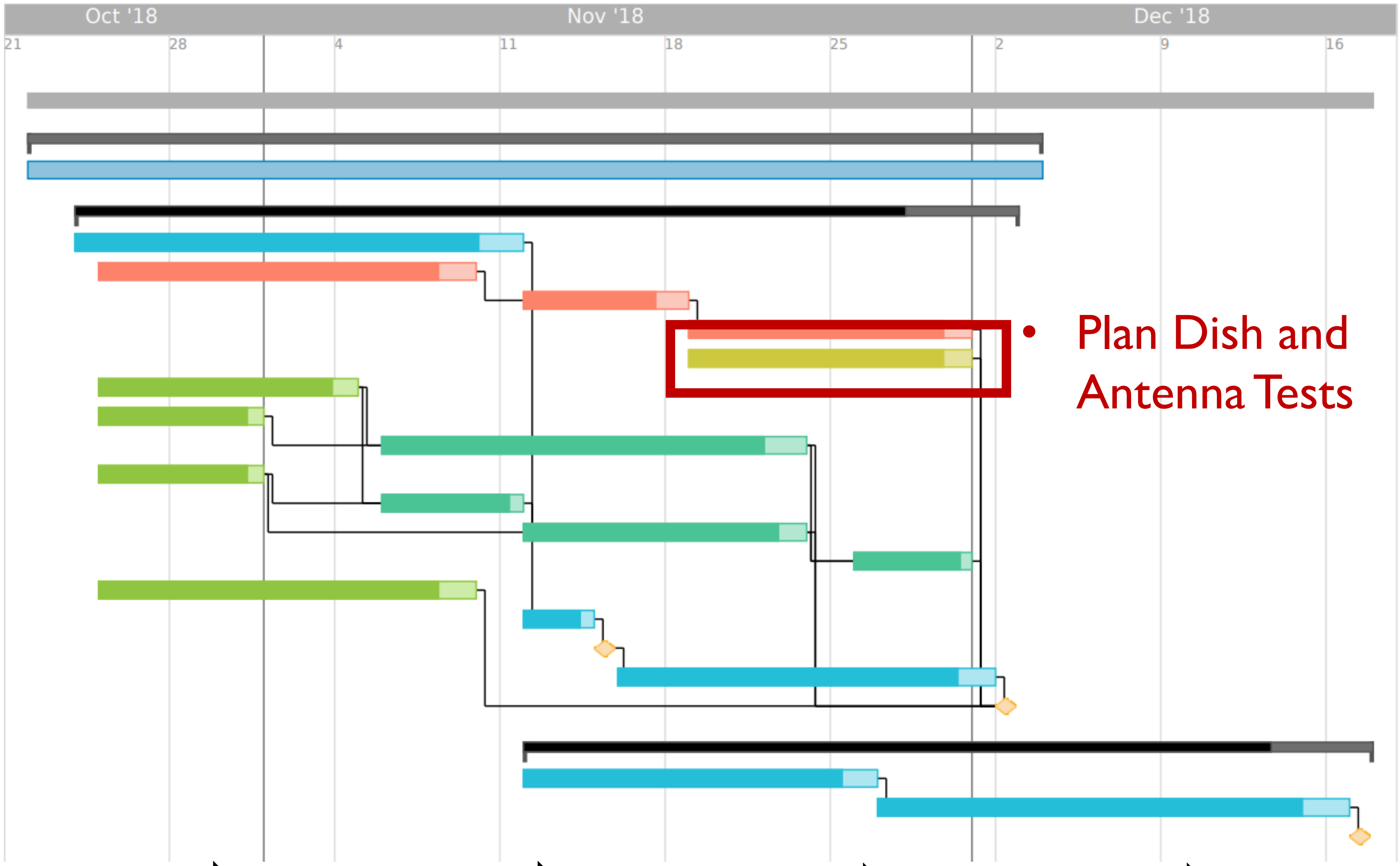


Gantt Chart: Fall Semester



- Research and Select Parabolic Dish Material
- Refine CAD Model of Dish

Gantt Chart: Fall Semester

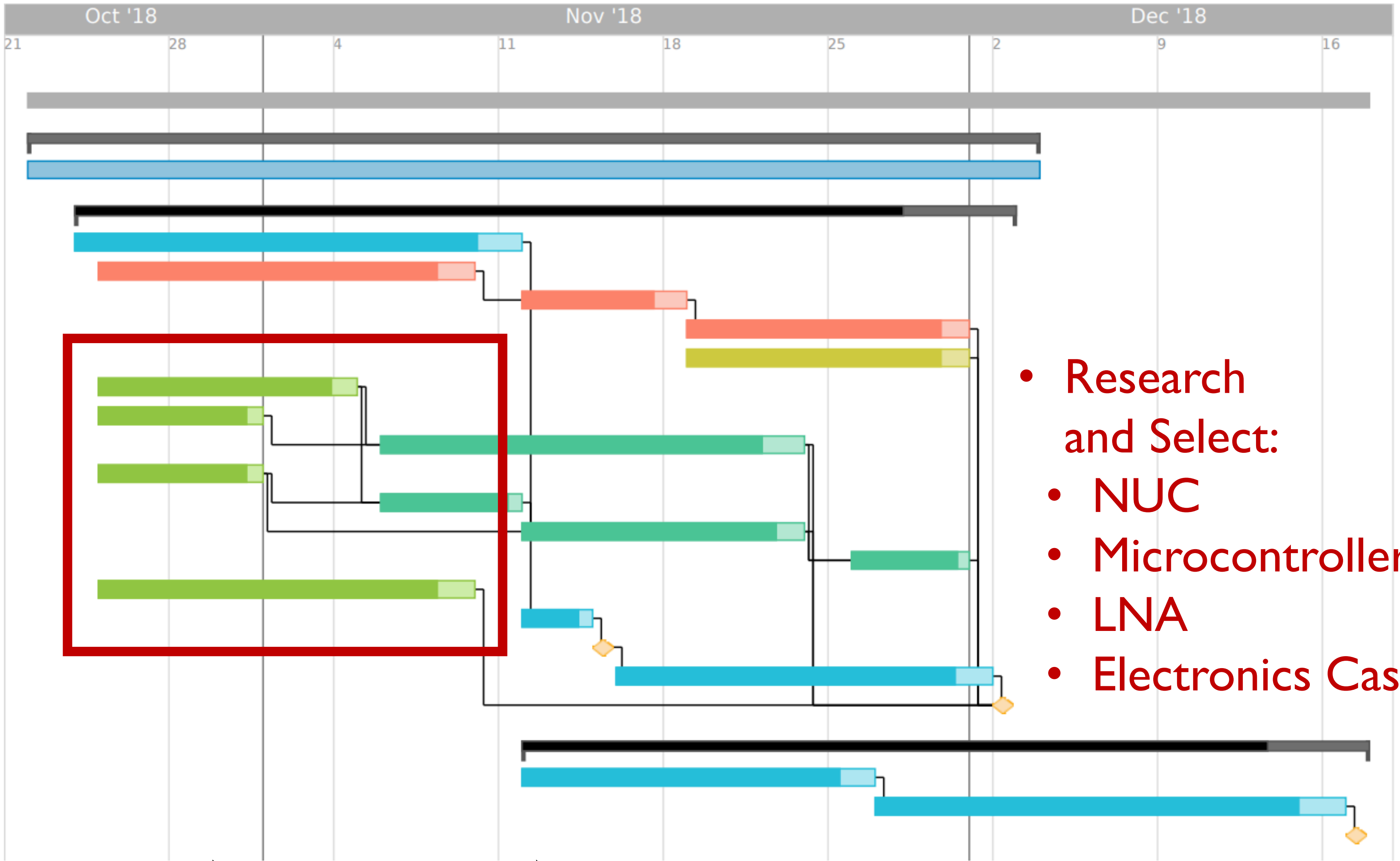


- Plan Dish and Antenna Tests

Legend

- Team Meetings
- Critical Path
- CDR
- Parabolic Dish
- Test Plans
- Tracking Software
- Tracking Hardware
- Important Dates

Gantt Chart: Fall Semester



- Research and Select:
  - NUC
  - Microcontroller
  - LNA
  - Electronics Case

Legend

- Team Meetings
- Critical Path
- CDR
- Parabolic Dish
- Test Plans
- Tracking Software
- Tracking Hardware
- Important Dates

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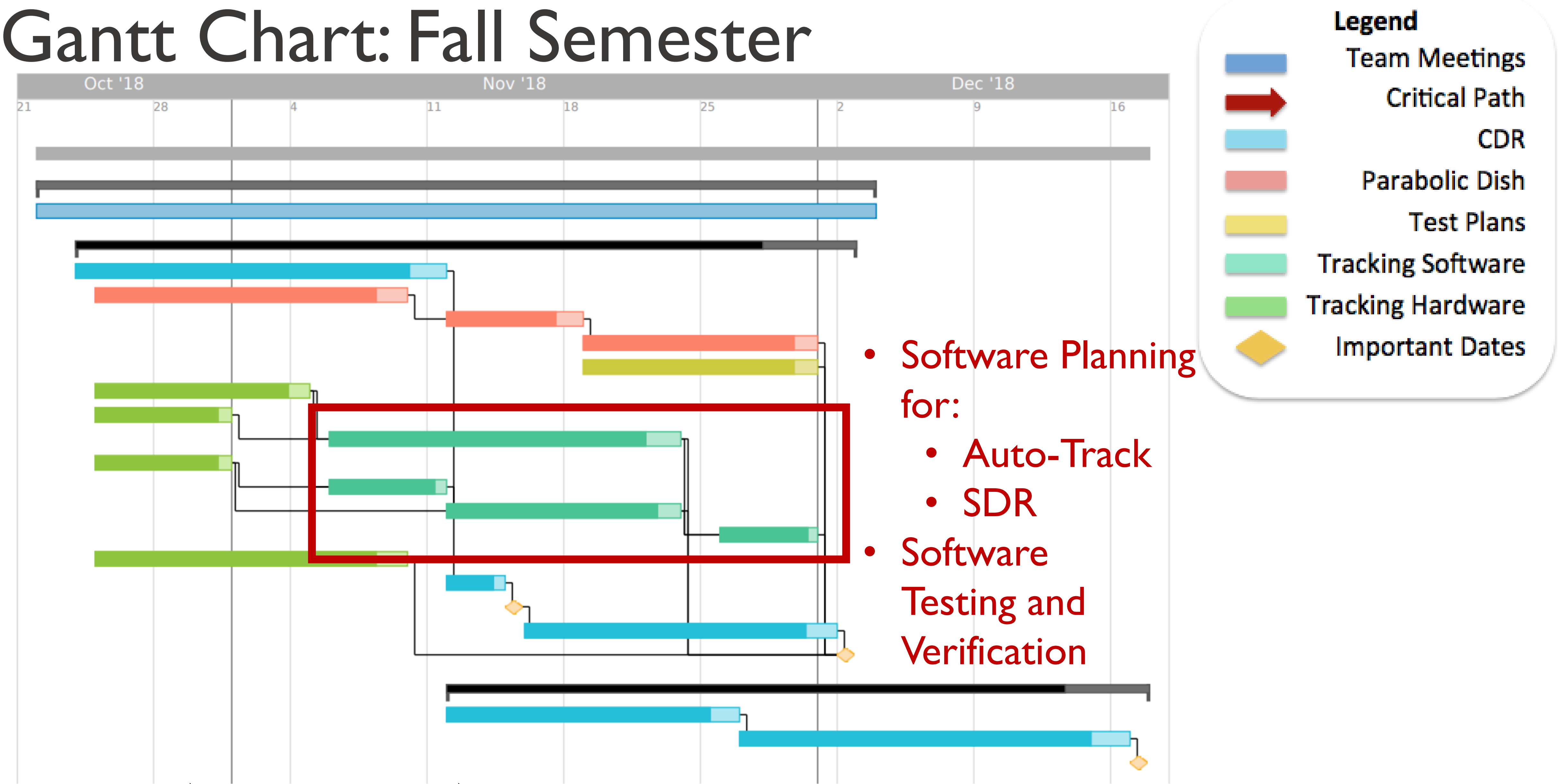
Gantt Chart: Fall Semester



- Software Planning for:
  - Auto-Track
  - SDR
- Software Testing and Verification

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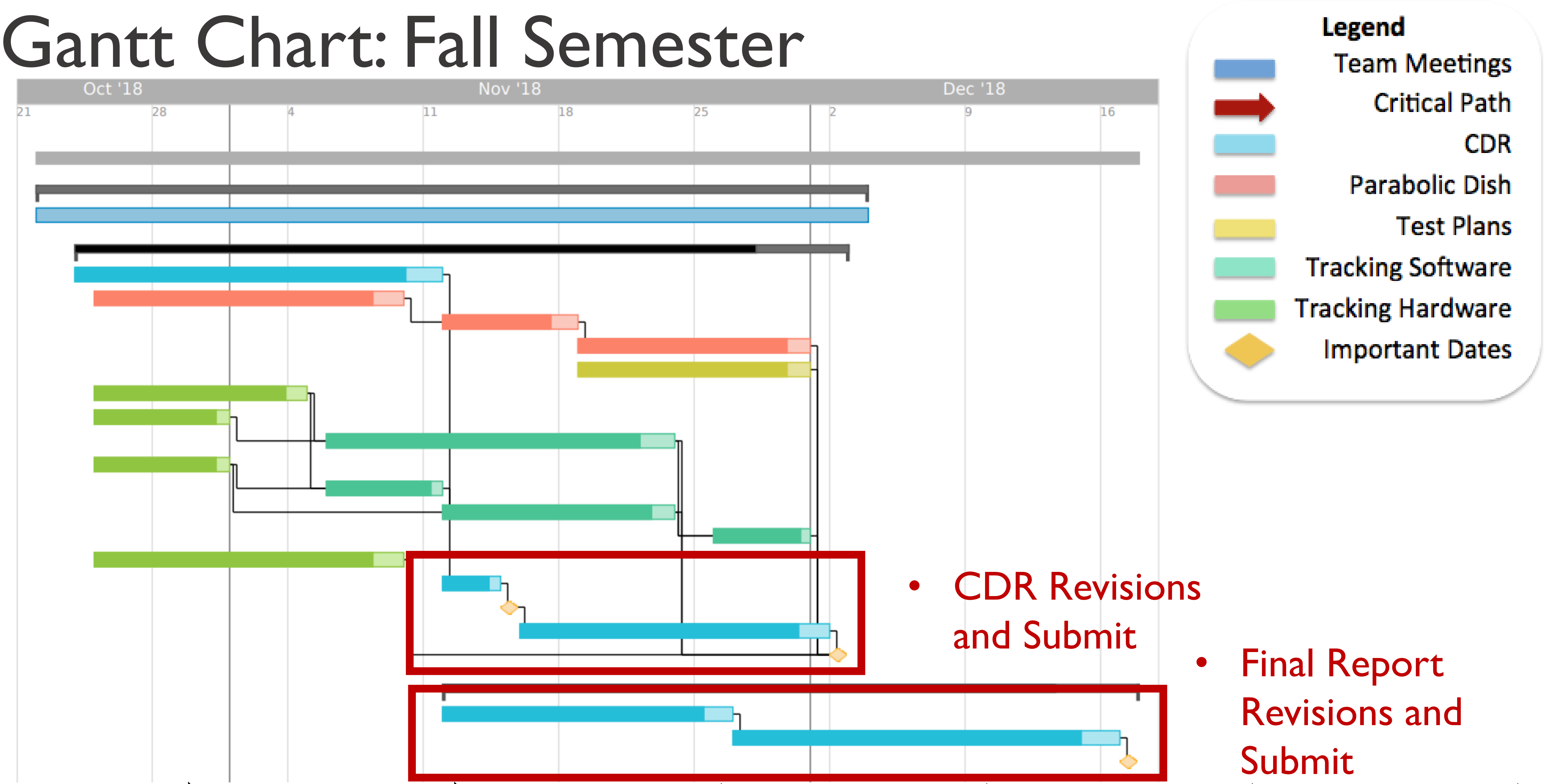
Gantt Chart: Fall Semester



- CDR Revisions and Submit
- Final Report Revisions and Submit

Project Overview | Baseline Design | Antenna | Tracking | Signal Processing | Conclusion

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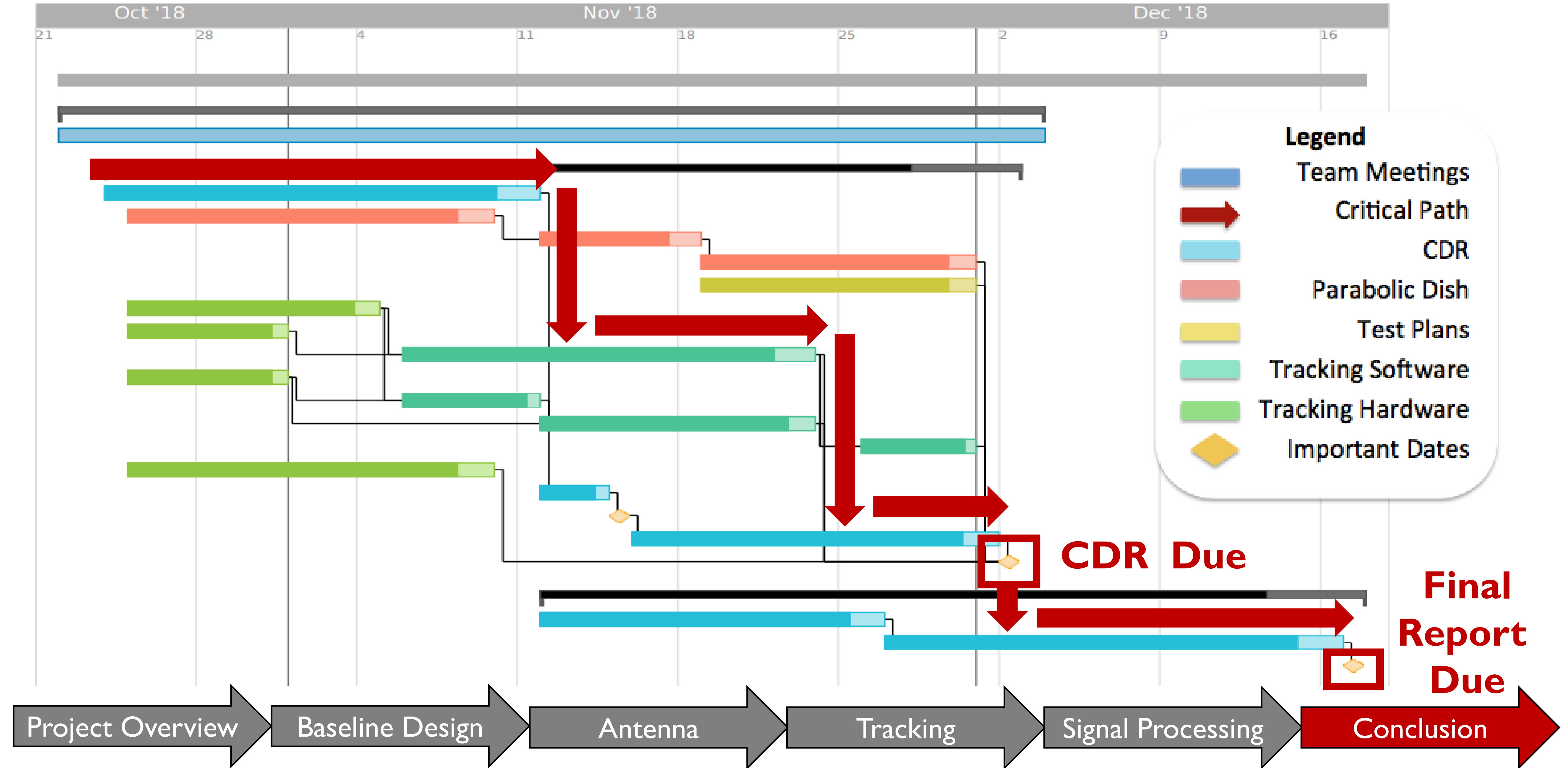
Gantt Chart: Fall Semester



References

[1] Andersen, Dwight E. "Computing NORAD Mean Orbital Elements From a State Vector." *Thesis.* Air Force Institute of Technology. 1991. http://www.dtic.mil/dtic/tr/fulltext/u2/a289281.pdf.

[2] "Definition of Azimuth, Elevation and It's Calculation." *Broadcast Idea*, 13 Nov. 2016, broadcastidea.com/index.php/2016/02/16/azimuth-and-elevation-calculation/.

[3] Donges, Niklas. "Gradient Descent in a Nutshell – Towards Data Science." *Towards Data Science*, Towards Data Science, 7 Mar. 2018, towardsdatascience.com/gradient-descent-in-a-nutshell-eaf8c18212f0.

[4] "Dual Port Circular Polarized Antenna." *Alaris Antennas*, www.alarisantennas.com/products/dual-port-circular-polarised-antenna/.

[5] Electronics Notes. "Parabolic Reflector Antenna Gain." *Electronics Notes*, www.electronics-notes.com/articles/antennas-propagation/parabolic-reflector-antenna/antenna-gain-directivity.php.

[6] "High Performance Conical Helical Antenna, RHCP, 1.7 - 2.7 GHz, 4 DBiC." *High Performance RF and Microwave Antennas & Custom Antenna Manufacturing*, www.southwestantennas.com/omni-antennas/conical-helical/high-performance-conical-helical-antenna-rhcp-17-27-ghz-4-dbic-1005.

[7] "MPPT Algorithm." *MATLAB & Simulink*, www.mathworks.com/discovery/mppt-algorithm.html .

[8] "Technical Details for Satellite YAOGAN 6." *N2YO.Com - Real Time Satellite Tracking and Predictions*, www.n2yo.com/satellite/?s=34839.

[9] Wade, Mark. *Encyclopedia Astronautica Index*, 2016, http://www.astronautix.com/index.html.

[10] "Definition of Azimuth, Elevation and It's Calculation." *Broadcast Idea*, 13 Nov. 2016, broadcastidea.com/index.php/2016/02/16/azimuth-and-elevation-calculation/.

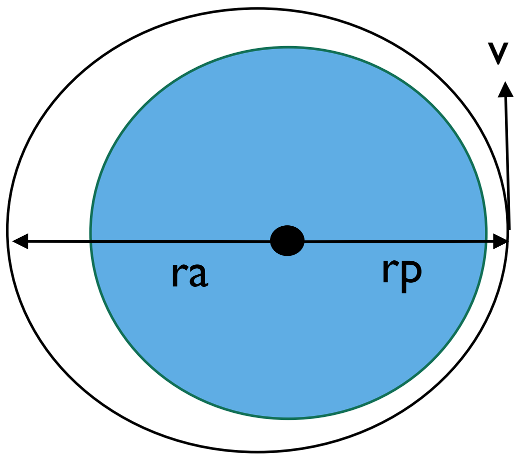
Questions?

Backup Slides

Slew Rate Calculations

<u>Knowns:</u>

$$\mu = 38600 \, \frac{km^3}{s^2}$$
$$r_p = 6578 \, km$$
$$r_a = 6978 \, km$$
$$a = 6778 \, km$$



<u>Assume</u>: Elliptic orbit at perigee directly above user in retrograde orbit. 2 body problem

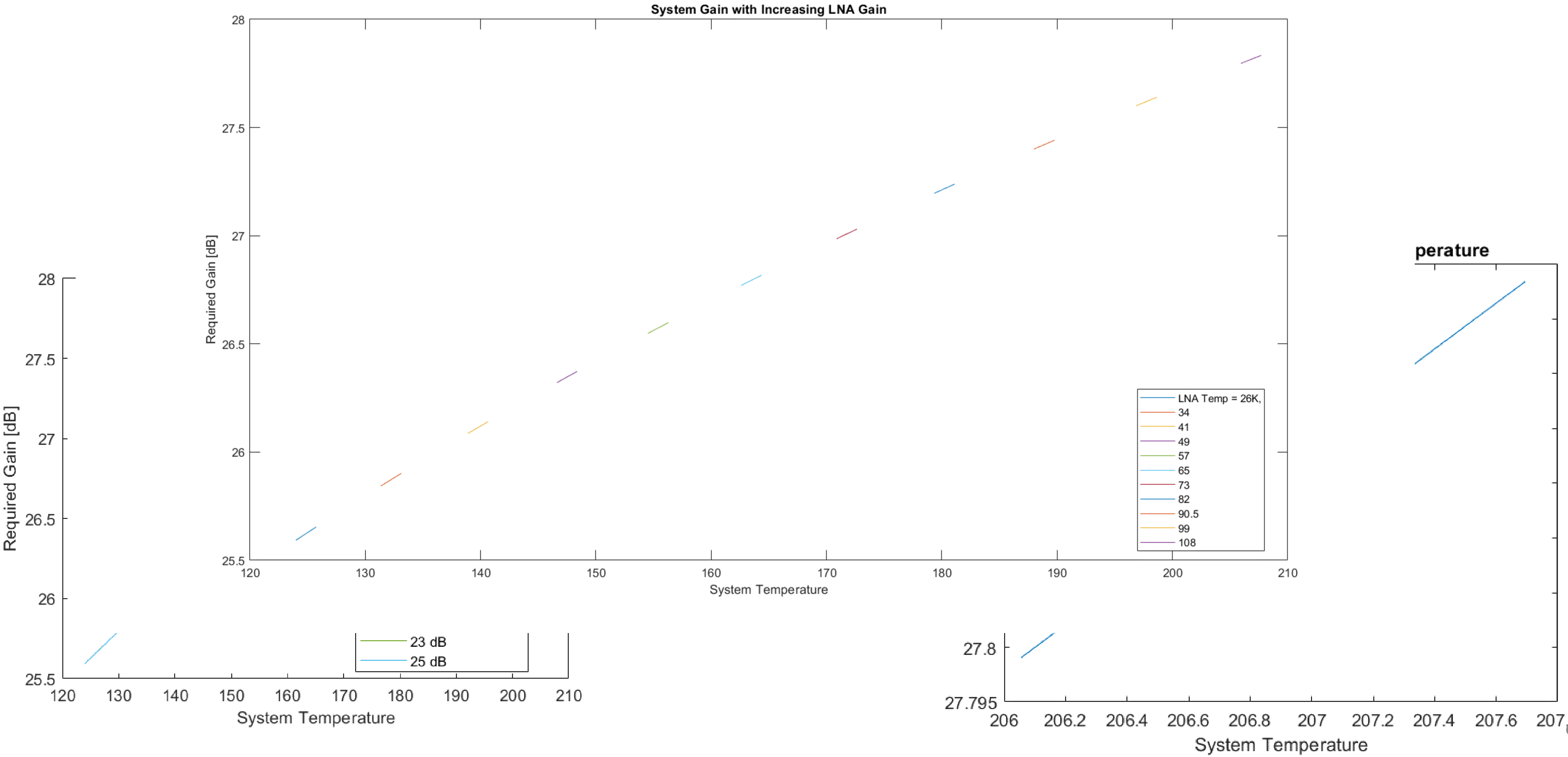
<u>Equations:</u>

$$v = \sqrt{\frac{2\mu}{r} - \frac{\mu}{a}}$$
$$\dot{\theta} = \frac{v}{r}$$

<u>Work:</u>

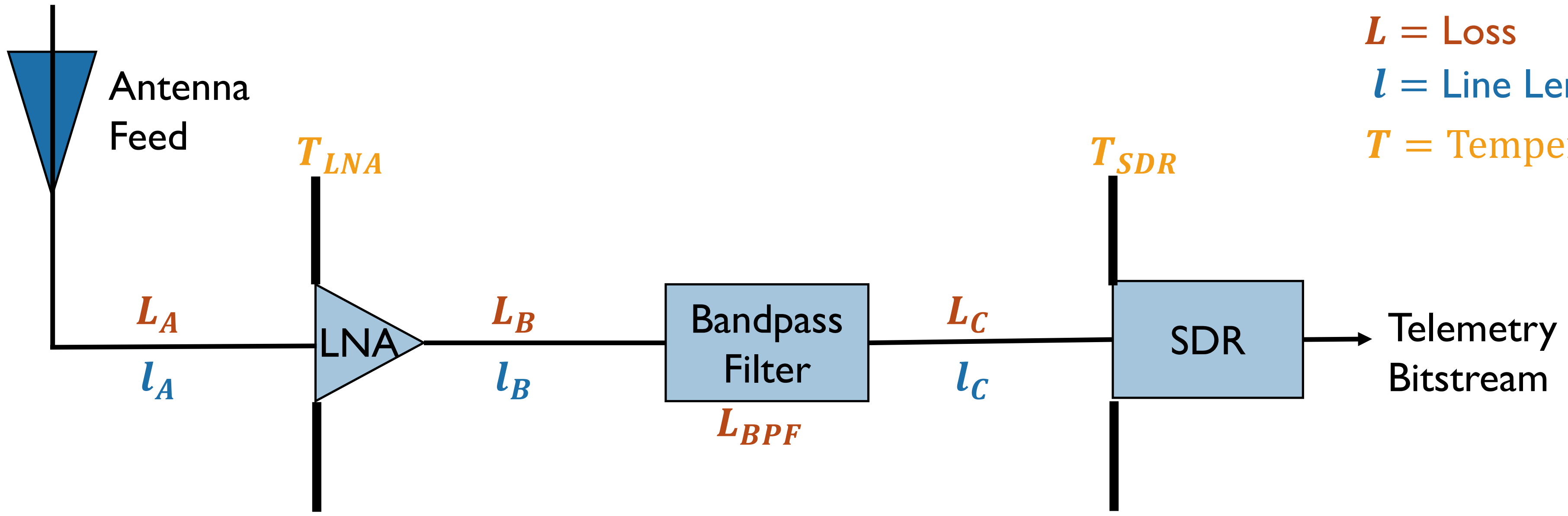
$$v = \sqrt{\frac{2\mu}{r} - \frac{\mu}{a}} = 7.898 \, km/s$$
$$\dot{\theta} = \frac{v}{r} = 0.0395 \, rad/s = 2.2627 \, °/s$$

Antenna Gain Assumptions



Gain Estimation

Requirement: $\frac{G}{T_S} = 3\,\frac{dB}{K}$



$\boldsymbol{L}$ = Loss

$\boldsymbol{l}$ = Line Length

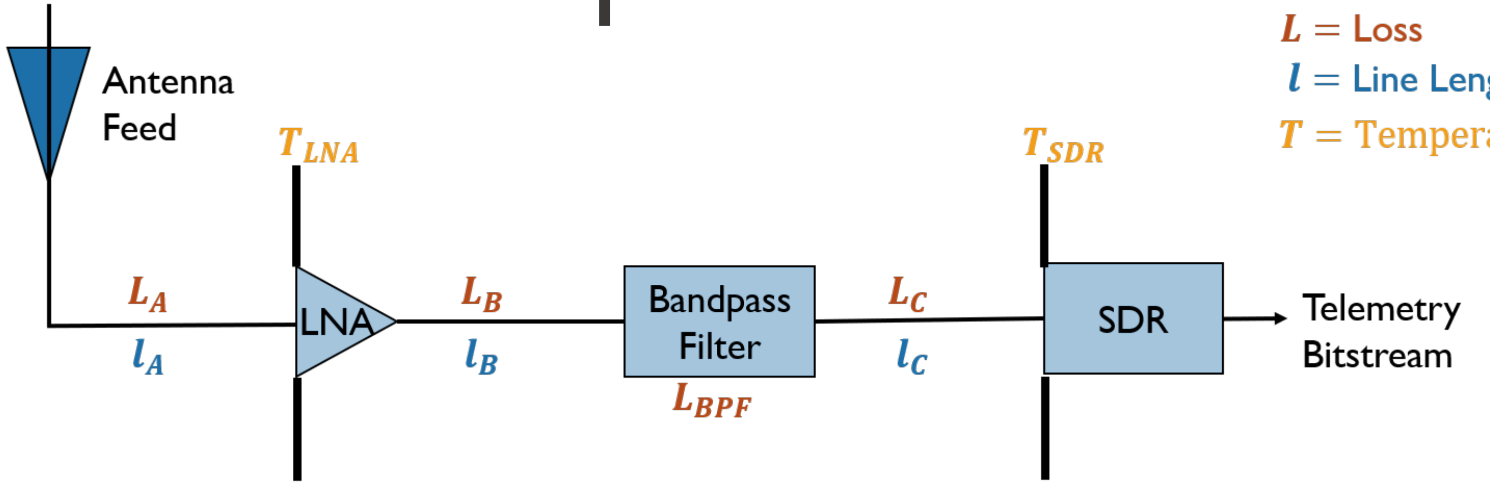
$\boldsymbol{T}$ = Temperature

$$T_S = aT_a + (1-a)T_0 + T_{LNA} + \frac{T_{SDR}}{G_{LNA}/L_C}$$

$$a = 10^{-L_{tl}/10}$$

$$L_{tl} = \frac{loss}{m}(l_A + l_B) + L_{BPF} + (\#\text{ of connectors})L_{connector}$$

Antenna Gain Assumptions



L = Loss
l = Line Length
T = Temperature

$$T_S = aT_a + (1-a)T_0 + T_{LNA} + \frac{T_{SDR}}{G_{LNA}/L_C}$$

$$a = 10^{-L_{tl}/10}$$

$$L_{tl} = \frac{loss}{m}(l_A + l_B) + L_{BPF} + (\text{\# of connectors})L_{connector}$$

$l_A = l_B = 0.05\ m$

$l_C = 2\ m$

$\frac{loss}{m} = -0.092\ dB/m$

(Belden 9913 cable)

3 connectors

$L_{connector} = -0.05\ dB$

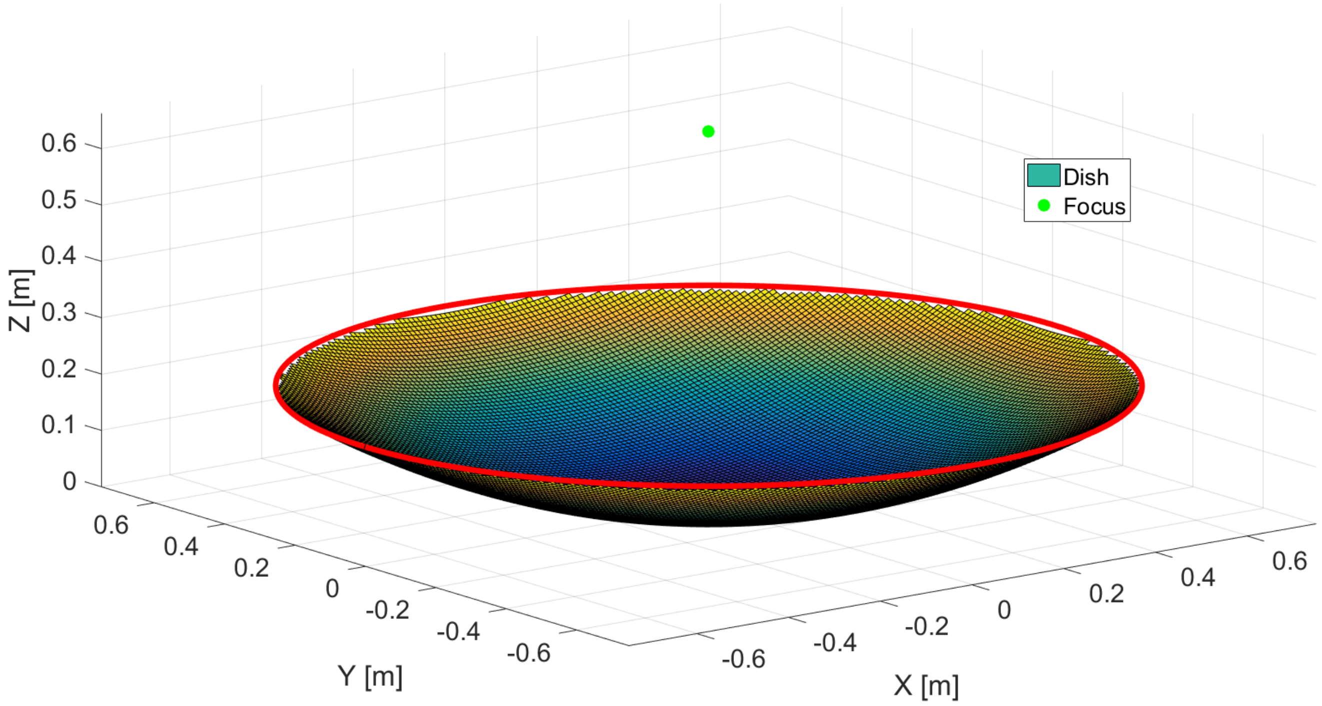
$L_{BPF} = -1.5\ dB$

$T_{LNA} = 60\ K$

$G_{LNA} = 18\ dB$

$T_{SDR} = 1000\ K$

Antenna Baseline Design



Beam Width Equation $$\frac{f}{D} = \frac{1}{4tan(\theta/4)}$$

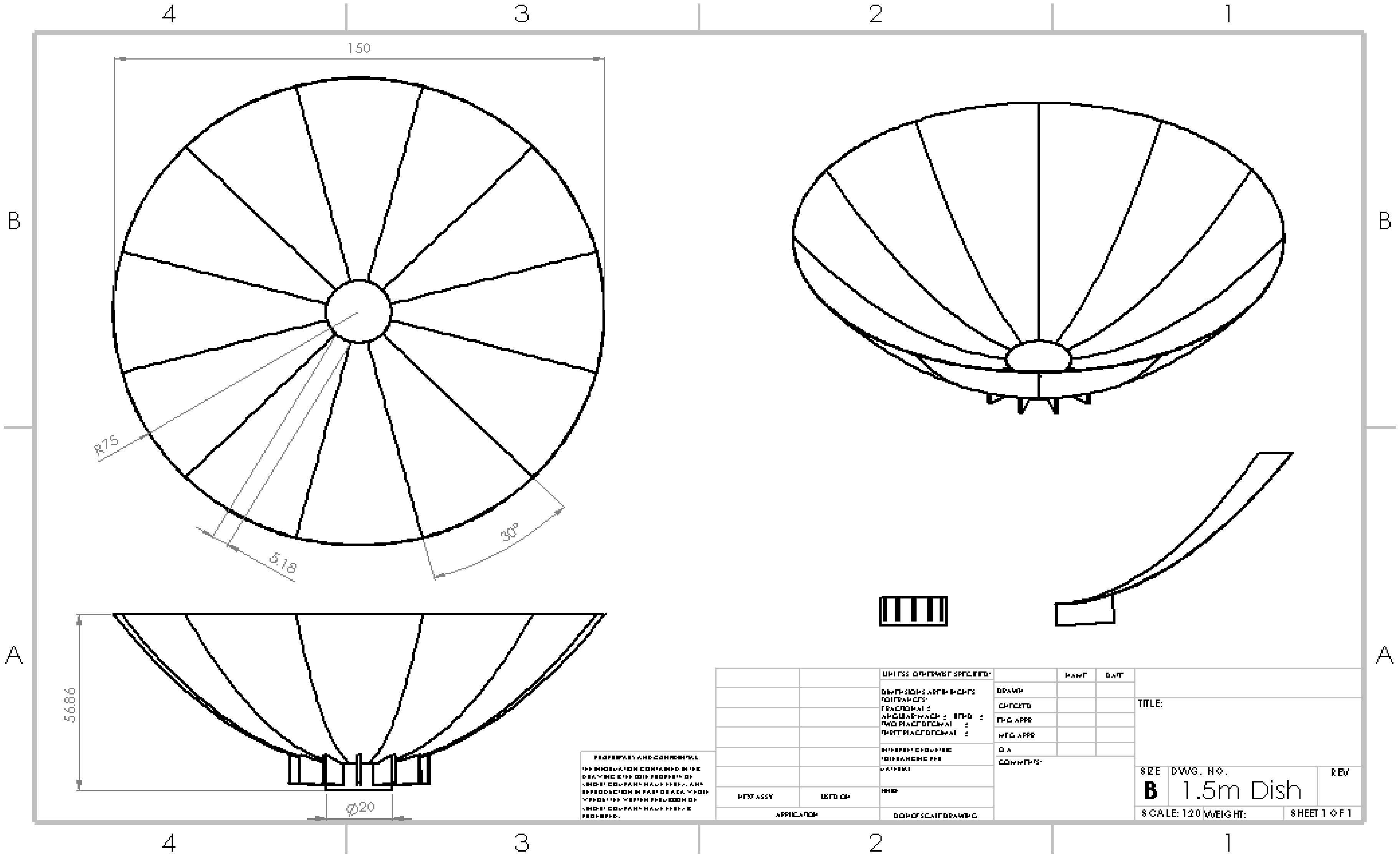
Focus Length $$f = \frac{D^2}{16d}$$

Wave length $$\lambda = \frac{c}{F}$$

Paraboloid Equation $$\frac{x^2}{a^2} + \frac{y^2}{b^2} = \frac{z}{c}$$

Solution $$z = 2.6(\frac{x^2}{(4f)^2} + \frac{y^2}{(4f)^2})$$

Parabolic Reflector Dimensions



Parabolic Reflector Properties

Mass properties of Dish_Ass
Configuration: Default
Coordinate system: -- default --

Mass = 14.40 kilograms

Volume = 0.01 cubic meters

Surface area = 5.59 square meters

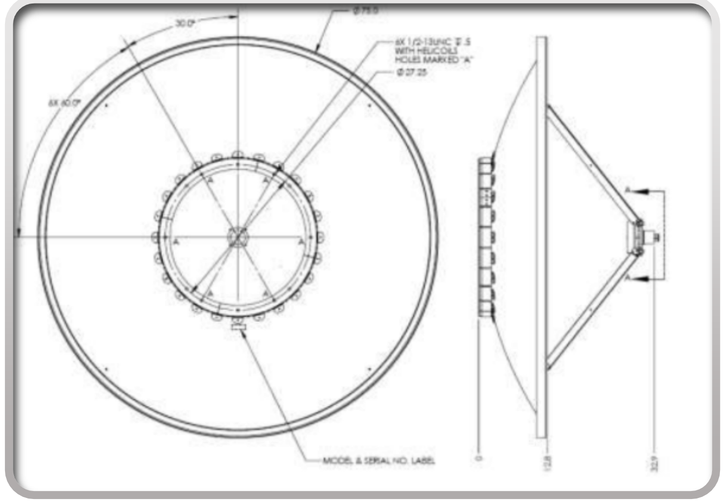
Center of mass: (meters)
X = 0.07
Y = 0.30
Z = 0.17

Principal axes of inertia and principal moments of inertia: (kilograms * square meters)
Taken at the center of mass.
Ix = (0.00, 0.00, 1.00) Px = 1.82
Iy = (1.00, 0.00, 0.00) Py = 1.82
Iz = (0.00, 1.00, 0.00) Pz = 2.70

Moments of inertia: (kilograms * square meters)
Taken at the center of mass and aligned with the output coordinate system.
Lxx = 1.82 Lxy = 0.00 Lxz = 0.00
Lyx = 0.00 Lyy = 2.70 Lyz = 0.00
Lzx = 0.00 Lzy = 0.00 Lzz = 1.82

Moments of inertia: (kilograms * square meters)
Taken at the output coordinate system.
Ixx = 3.58 Ixy = 0.32 Ixz = 0.18
Iyx = 0.32 Iyy = 3.20 Iyz = 0.75
Izx = 0.18 Izy = 0.75 Izz = 3.23

Commercial Dish Details



Mwave RPDC-6-22-N-R1
6 ft
Aluminum
Feed supported by 4 aluminum bars
Dual polarized: RHCP and LHCP
Type N RF inputs behind feed

RHCP System Sense

Frequency (GHz)	Gain (dBic)	HPBW (deg.)	On-Axis Axial Ratio (dB)	F/B (dB)	Return Loss (dB)
2.00	28.6	5.3	0.7	>40	28.3
2.25	29.0	5.2	1.1	>40	22.0
2.50	29.7	4.9	1.0	>40	34.9

Mwave RPCD-4-23-S
6 ft
Aluminum
Feed supported by 4 aluminum bars
Dual polarized: RHCP and LHCP
Type SMA female inputs behind feed
Comes with optional pipe mount

RHCP-System Port

Frequency (GHz)	Gain (dBic)	HPBW (deg.)	On-Axis Axial Ratio (dB)	F/B (dB)	Return Loss (dB)
2.15	25.5	8.0	0.3	>40	18.6
2.25	25.7	7.7	0.3	>40	27.9
2.35	25.9	7.5	0.6	>40	27.0

Commercial Feed Details

Southwest Antennas Helical #1005-007

1.7-2.7 GHz
LHCP
H Beamwidth: 360°
V Beamwidth: 118°
Bandwidth: 1 GHz

Gain: 4dBi
Input Power: 50 W
SMA Female RF connector
7" long, 5.5" diameter
17 oz

Alaris Antennas SPRL-A0010

1.0-2.5 GHz
LHCP
Beamwidth: 120°
Gain: 7 dBi
Input Power: 50 W

N Female RF connector
17" long, 6" diameter
5.5 lbs

Tracking Software Design – Confirming Strongest Signal

- Two methods for confirming signal:
  - Perturb and observe method applied to SNR
    - Small alterations to predicted direction during pass
    - If SNR improves, change to new reference direction
      - SNR calculated by performing FFT of small sample of data at dithered location, compare target peak to average noise floor dB, reference this to previous undithered direction SNR figure
    - Continue to dither about new, better reference point in search of better SNR
    - Dither angle determined pending antenna beam width
  - MPPT Algorithm – gradient descent method through Simulink
    - Determine slope of signal strength in all directions and trend toward highest slope of increasing SNR figure

Power Regulation

Components

- AC-DC converter
  - Readily available COTS
  - <$100

- DC-DC converter
  - Tunable
  - <$20
  - 3-40V to 1.5-35V
  - Up to 3A

AC-DC Converter

DC-DC Converter

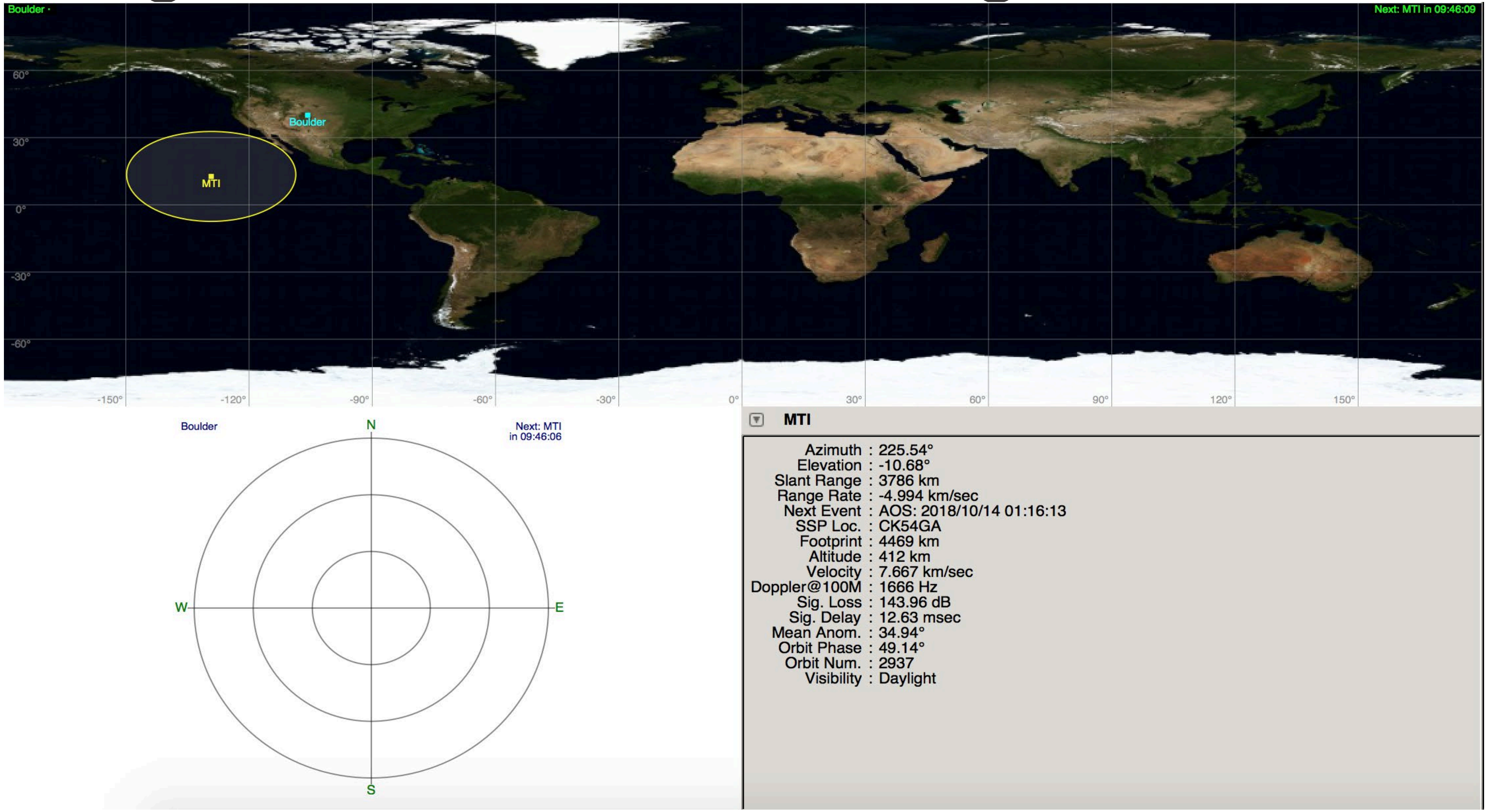
Budget

Subsystem	**Cost ($)**
Antenna	
SDR	
Laptop	
Tracking Hardware	500 (direct drive motor x2, motor driver x1, rotary encoder x2, Arduino Due x1, micro USB cable x1)
Mobility	
Total	

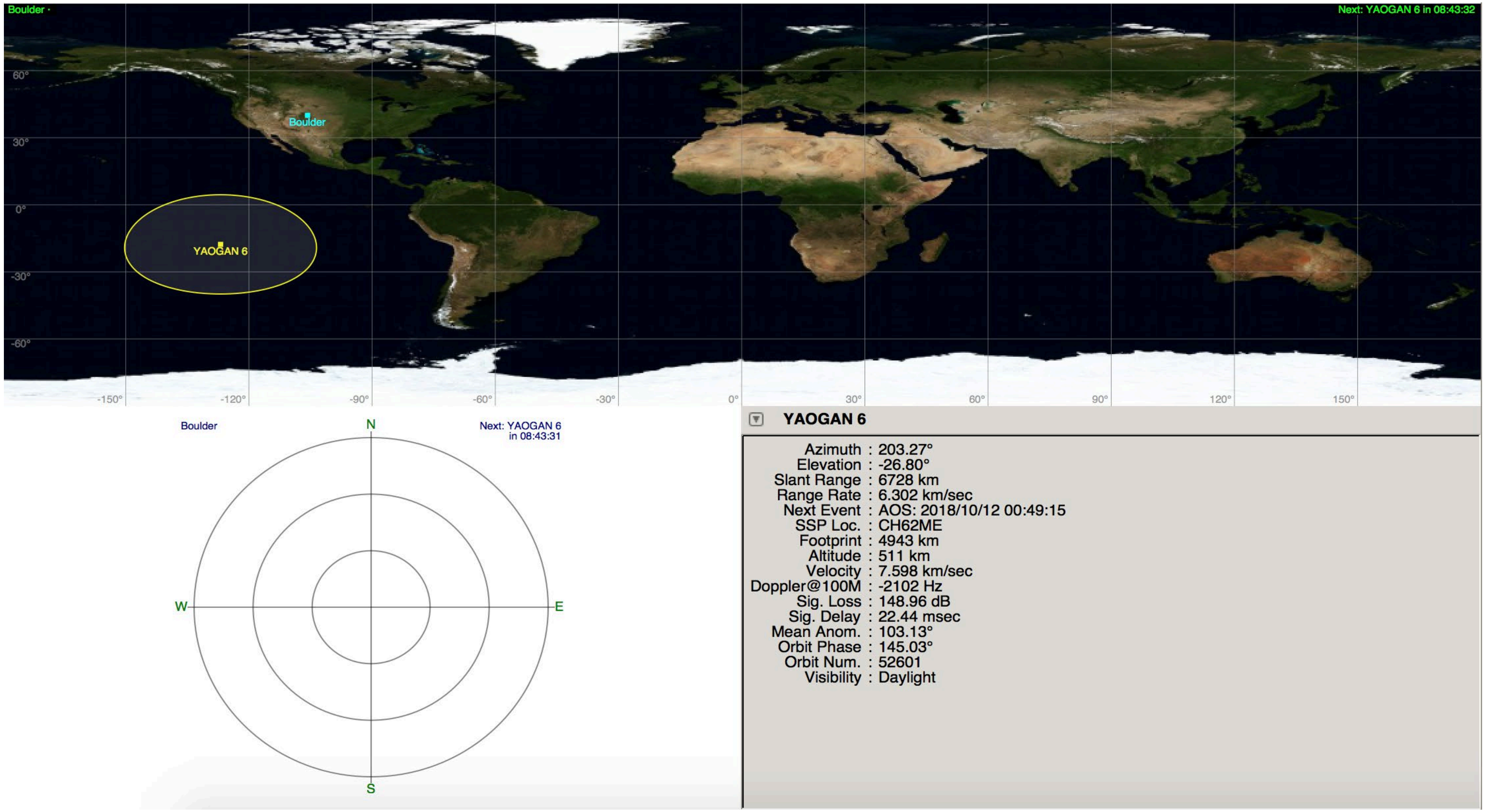
Tracking

Item	Quantity	Cost Each ($)
Direct Drive Motor	2	500.00
Motor Driver	1	7.00
Rotary Encoder	2	500.00
Arduino Due	1	38.50
Micro USB Cable	1	3.00
Total		

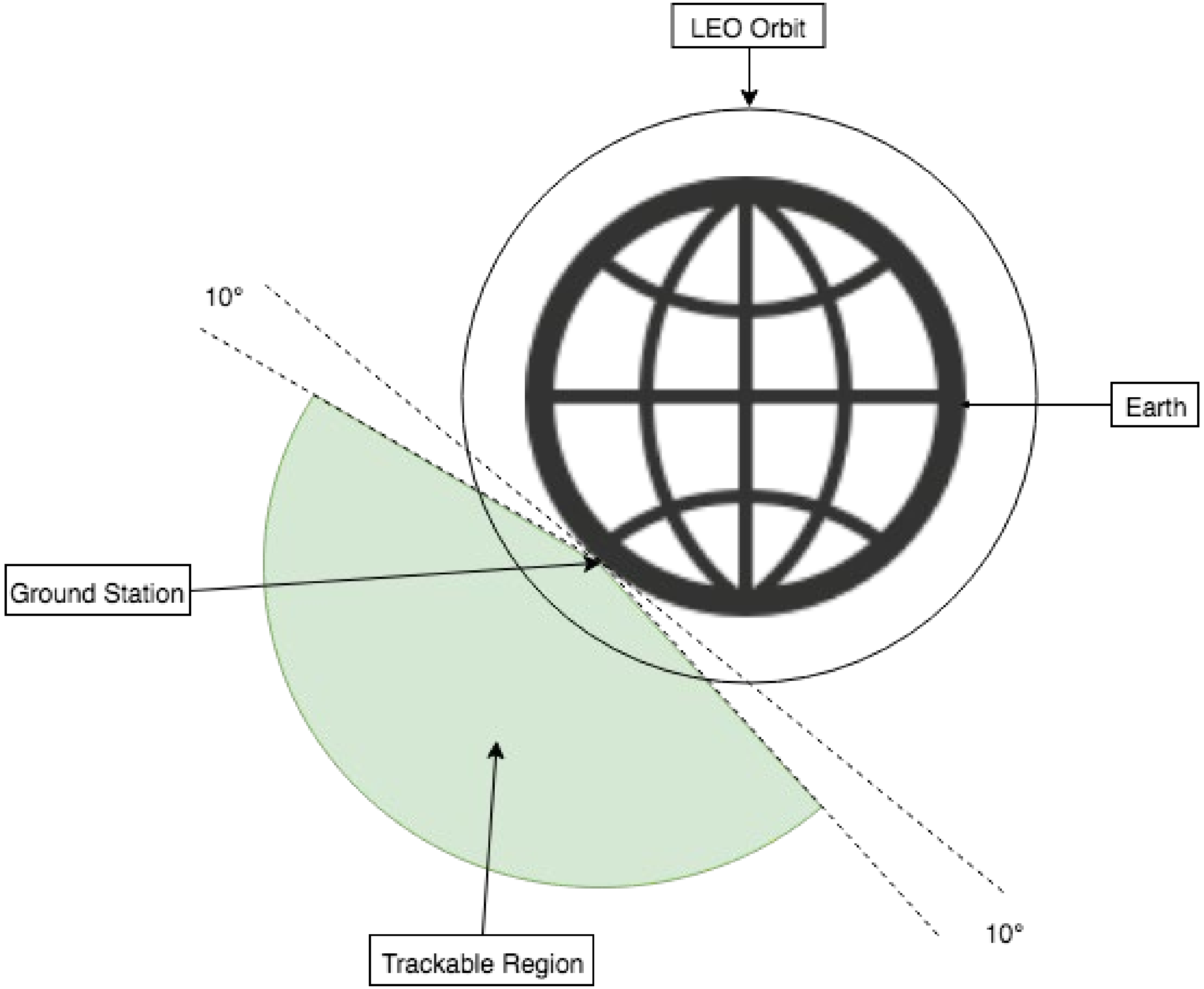
Tracking Software Baseline Design – TLE Prediction



Tracking Software Baseline Design – TLE Prediction



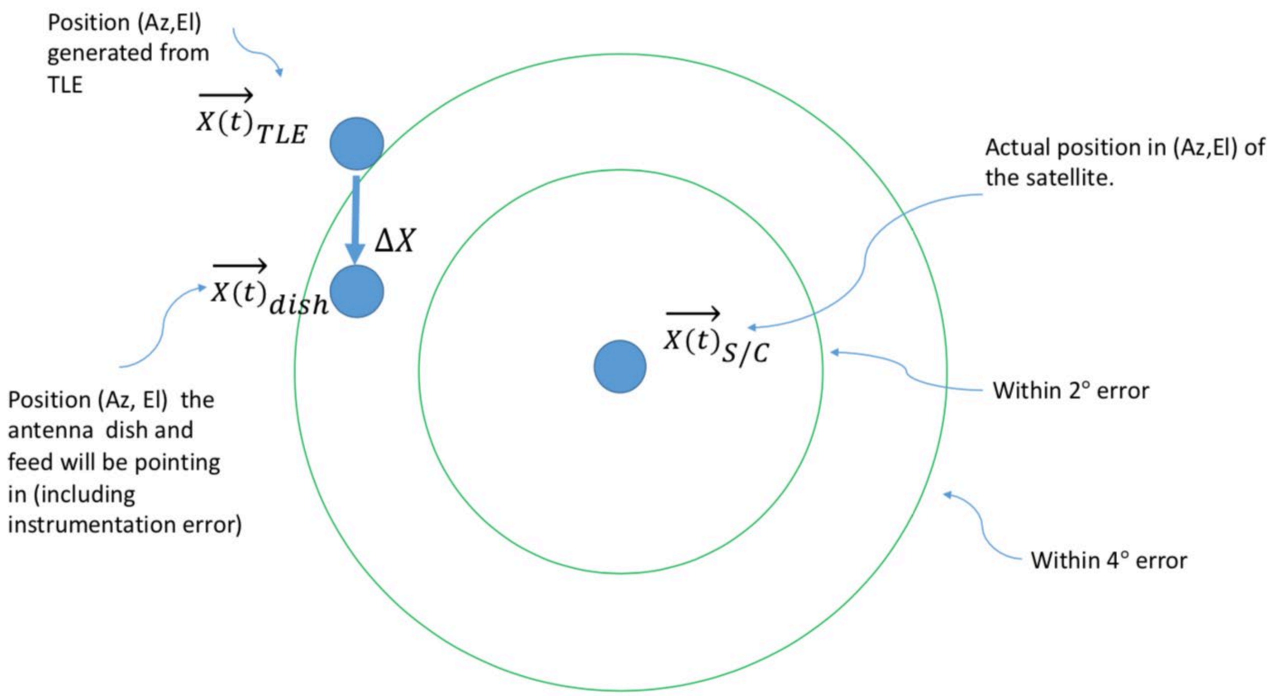
Trackable Field of View



Field of view is rotated orthogonally from the surface location of the ground station to ensure that any satellite pass that comes above 10° from the surface horizon can be tracked in any direction

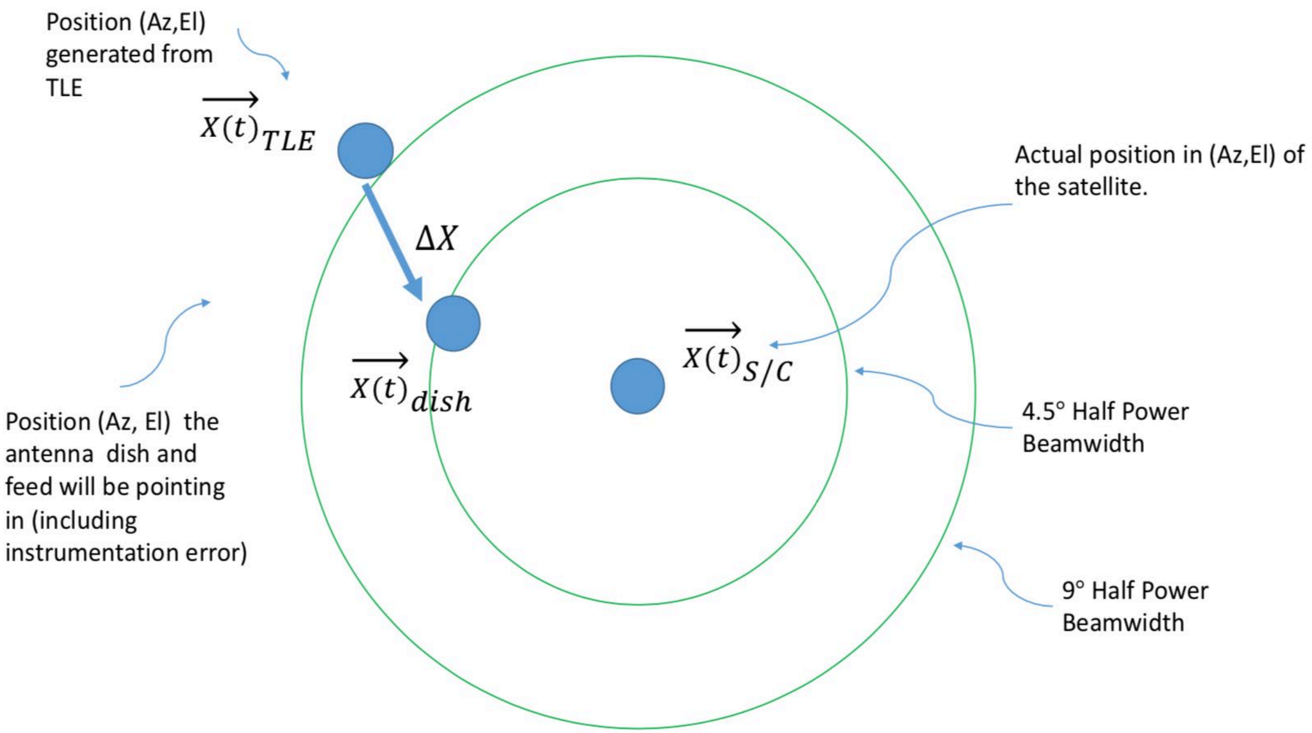
Tracking Software – Confirming Auto-Track Function

- TLE text file has some error
- Accuracy of TLE depends on:
  - Sensors
  - Amount of data collected
  - Type of orbit
- These vary for each TLE which causes accuracies of TLEs to vary

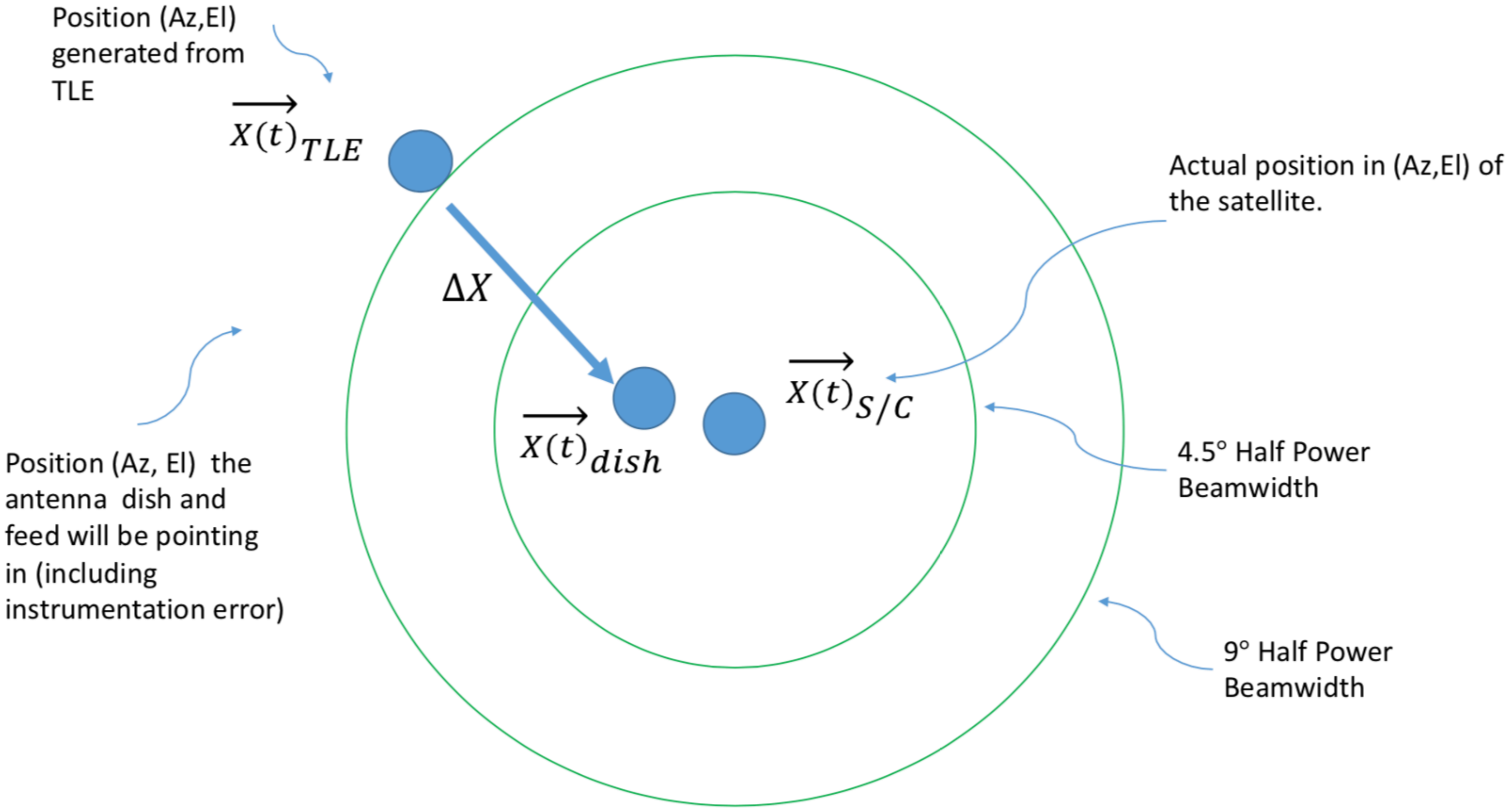


Tracking Software Baseline Design

- Instrumentation used will contain some inherent system error
- Assuming these errors, the station must dither towards the direction with greatest increase in SNR
  - Gradient descent method
- Algorithm used: MPPT with Simulink



Final Position



Tracking Software – TLE prediction

Upcoming passes for MTI
Observer: Boulder,
LAT:40.02 LON:-105.72

AOS	TCA	LOS	Duration	Max El	AOS Az	LOS Az
2018/10/14 01:16:13	2018/10/14 01:20:17	2018/10/14 01:24:21	00:08:08	9.25	39.59	143.81
2018/10/14 02:47:24	2018/10/14 02:52:28	2018/10/14 02:57:31	00:10:06	36.66	3.25	209.76
2018/10/14 13:12:38	2018/10/14 13:17:42	2018/10/14 13:22:45	00:10:06	42.51	153.24	355.20
2018/10/14 14:46:06	2018/10/14 14:49:55	2018/10/14 14:53:44	00:07:37	7.65	220.74	317.50
2018/10/15 02:01:19	2018/10/15 02:06:25	2018/10/15 02:11:31	00:10:11	39.09	19.64	178.37
2018/10/15 03:34:00	2018/10/15 03:38:01	2018/10/15 03:42:03	00:08:03	9.55	345.61	242.90
2018/10/15 12:27:47	2018/10/15 12:31:54	2018/10/15 12:36:01	00:08:13	10.53	119.76	12.87
2018/10/15 13:58:32	2018/10/15 14:03:33	2018/10/15 14:08:35	00:10:02	33.87	184.41	338.87
2018/10/16 01:16:02	2018/10/16 01:20:04	2018/10/16 01:24:06	00:08:04	9.01	40.02	143.13
2018/10/16 02:47:11	2018/10/16 02:52:15	2018/10/16 02:57:18	00:10:07	37.60	3.52	209.25

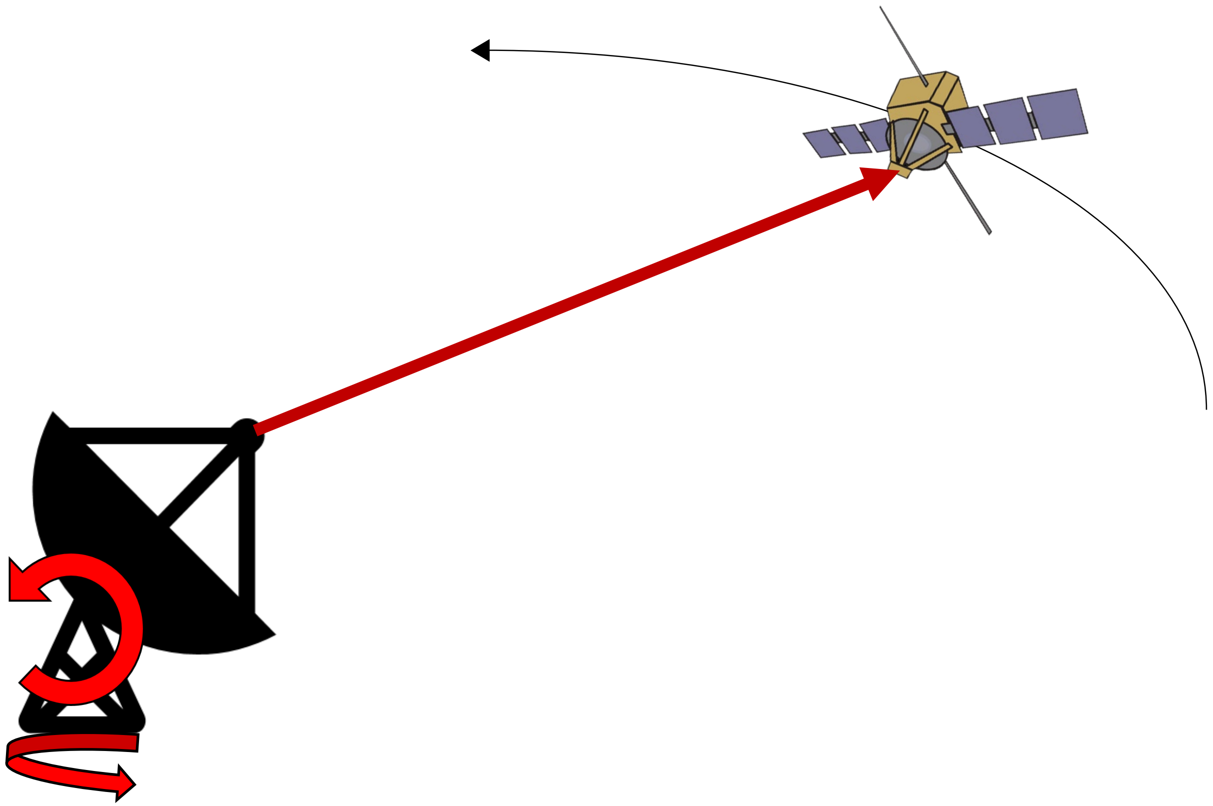
Orbit 2943

Time	Az	El	Range	Footp
2018/10/14 01:16:13	39.59	-0.00	2369	4544
2018/10/14 01:16:38	42.75	1.20	2239	4543
2018/10/14 01:17:02	46.28	2.41	2114	4541
2018/10/14 01:17:26	50.24	3.62	1998	4540
2018/10/14 01:17:51	54.67	4.81	1890	4538
2018/10/14 01:18:15	59.61	5.95	1794	4536
2018/10/14 01:18:40	65.08	7.00	1711	4535
2018/10/14 01:19:04	71.07	7.91	1643	4533
2018/10/14 01:19:28	77.54	8.63	1592	4532
2018/10/14 01:19:53	84.37	9.09	1560	4530
2018/10/14 01:20:17	91.40	9.25	1548	4528
2018/10/14 01:20:42	98.45	9.11	1556	4527
2018/10/14 01:21:06	105.33	8.67	1585	4525
2018/10/14 01:21:30	111.86	7.97	1633	4524
2018/10/14 01:21:55	117.94	7.07	1699	4522
2018/10/14 01:22:19	123.49	6.02	1780	4521
2018/10/14 01:22:44	128.51	4.87	1874	4520
2018/10/14 01:23:08	133.01	3.67	1980	4518
2018/10/14 01:23:32	137.03	2.44	2096	4517
2018/10/14 01:23:57	140.61	1.21	2220	4516
2018/10/14 01:24:21	143.81	-0.00	2350	4515

Orbit 2944

Time	Az	El	Range	Footp
2018/10/14 02:47:24	3.25	0.00	2370	4550
2018/10/14 02:47:55	1.93	2.02	2156	4549
2018/10/14 02:48:25	0.29	4.24	1944	4547

Tracking Hardware – Minimum Torque Est.



If the maximum slew rate is: 2.26°/s

Then the motors should be powerful enough to accelerate the dish to this rate w/o breaking the 4° pointing accuracy.

Therefore, the motors must supply a minimum torque of:

$$\Delta\theta_{max} = \omega_{max} \cdot t \implies \Delta t = \frac{\Delta\theta_{max}}{\omega_{max}} = 1.77\ sec$$

$$\alpha_{req} = \frac{\omega_{des}}{\Delta t} = \frac{2.26°/s}{1.77s} = 1.277°/s^2$$

$$\tau_{min} = I \cdot \alpha_{req} = (3.58kg \cdot m^2) \cdot \left(1.28° \frac{deg}{s^2}\right) = \boxed{4.572N \cdot m}$$

Antenna

Item	**Cost ($)**
Dish: Commercial	$4000
Dish: Build	
Feed	$300-$800

Parabolic Dish Design

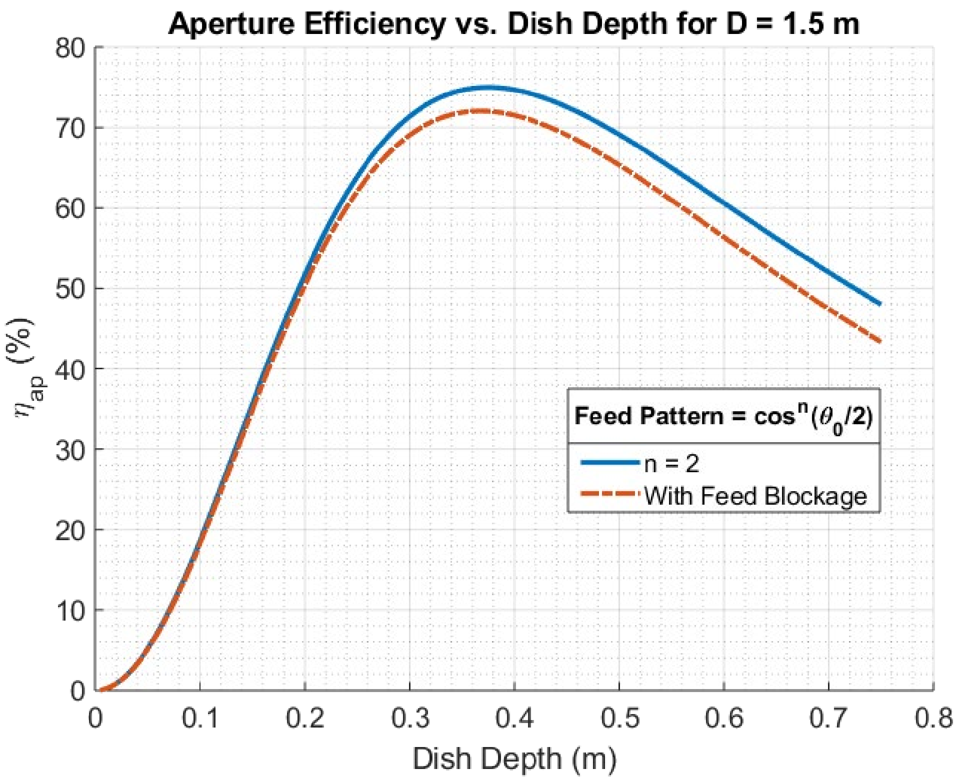
Requirement: $\frac{G}{T_S} = 3\ \frac{dB}{K}$

$$G_{parabolic} = \eta \left(\frac{\pi D}{\lambda}\right)^2$$

$$\eta = \eta_{ill}\eta_{sp}\eta_{bl}\eta_{pol}\eta_{\phi}$$

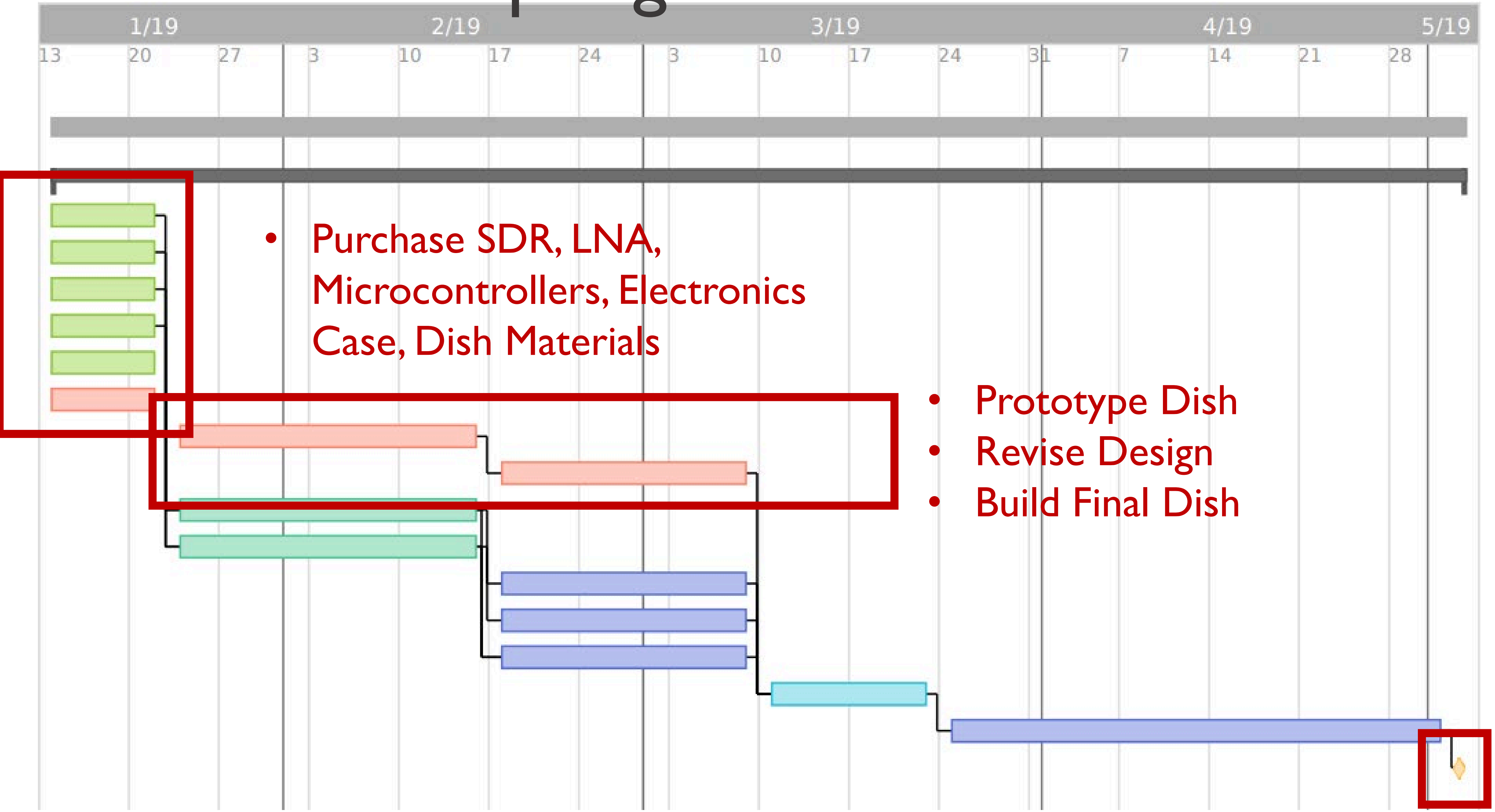
$\eta_{ill}, \eta_{sp}, \eta_{bl}$ → Can be estimated with precise knowledge of feed pattern

η_{pol}, η_{ϕ} → Difficult to quantify



→ Assuming efficiency of 50%, D=1.5 m → Use to design optimal dish depth

Gantt Chart: Spring Semester

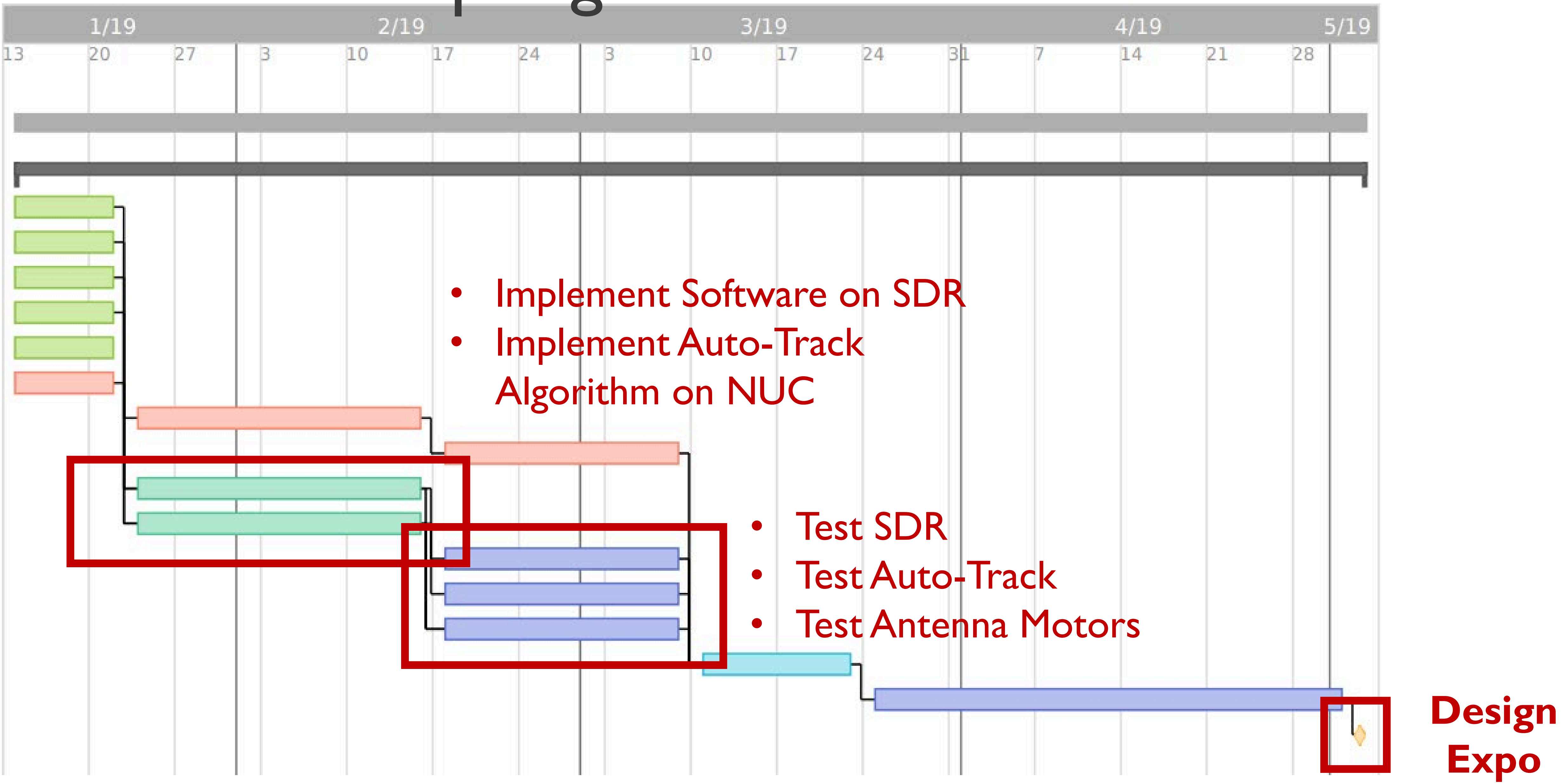


- Purchase SDR, LNA, Microcontrollers, Electronics Case, Dish Materials

- Prototype Dish
- Revise Design
- Build Final Dish

Design Expo

Gantt Chart: Spring Semester



Gantt Chart: Spring Semester