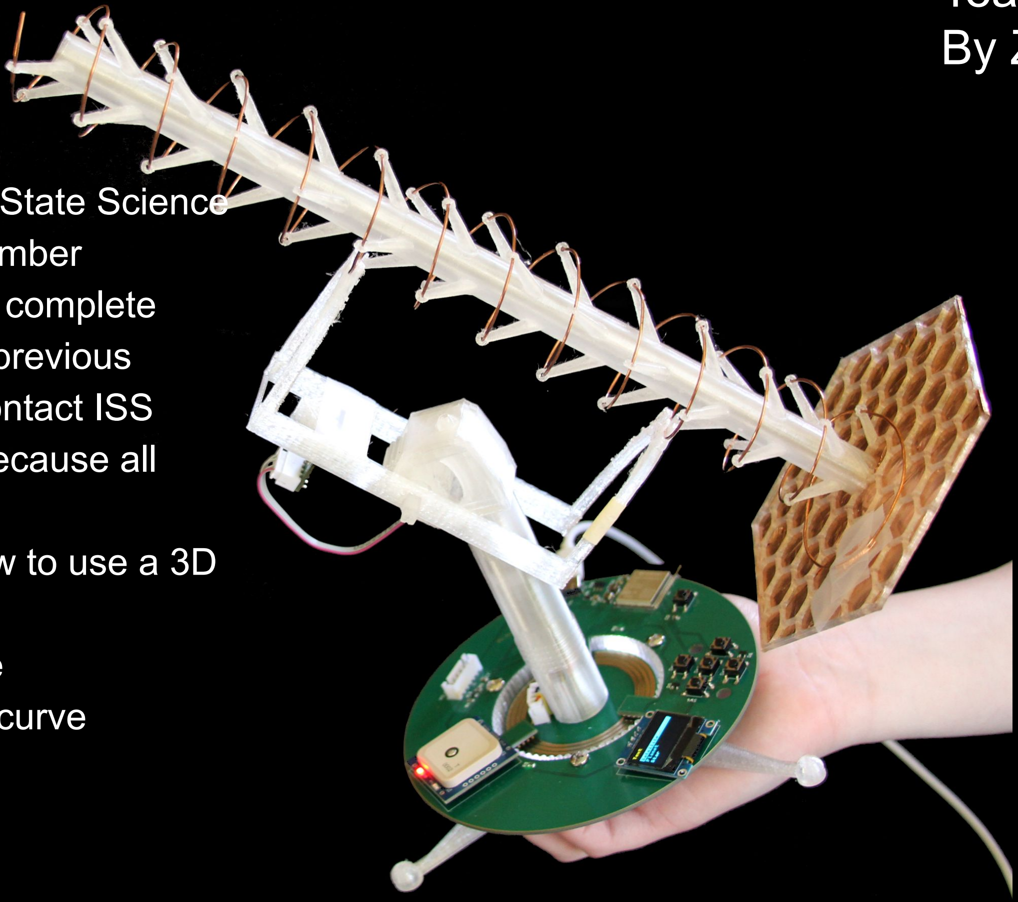
An Affordable Portable Orbital Desktop Satellite Tracker

Teardown 2024
By Zeke, KJ7NLL

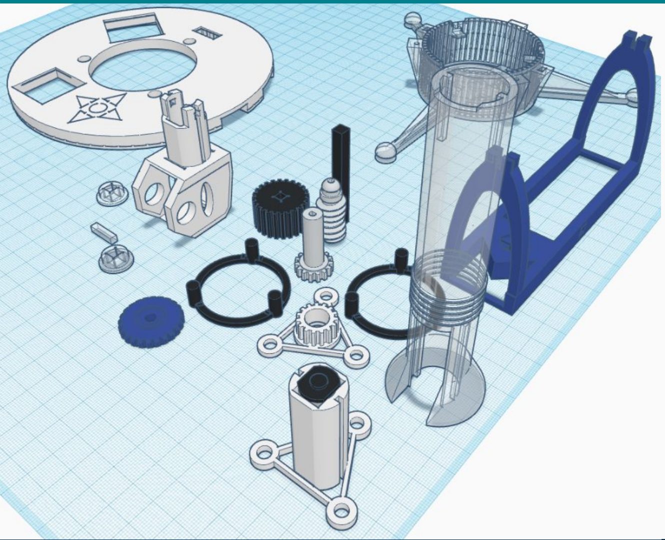
- Heard about Oregon State Science Fair (NWSE) in December
- Only three months to complete
- Sat tracker because previous project's tracker to contact ISS
- Wanted to 3D print because all others were lego
    - Didn't know how to use a 3D printer.
    - Didn't have one
    - Steep learning curve

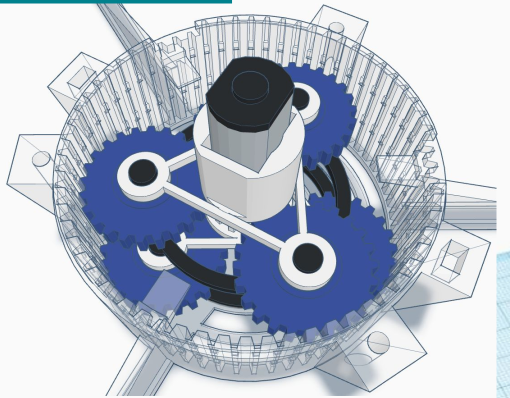


Tinkercad Model

Designed and built in TinkerCAD [1]

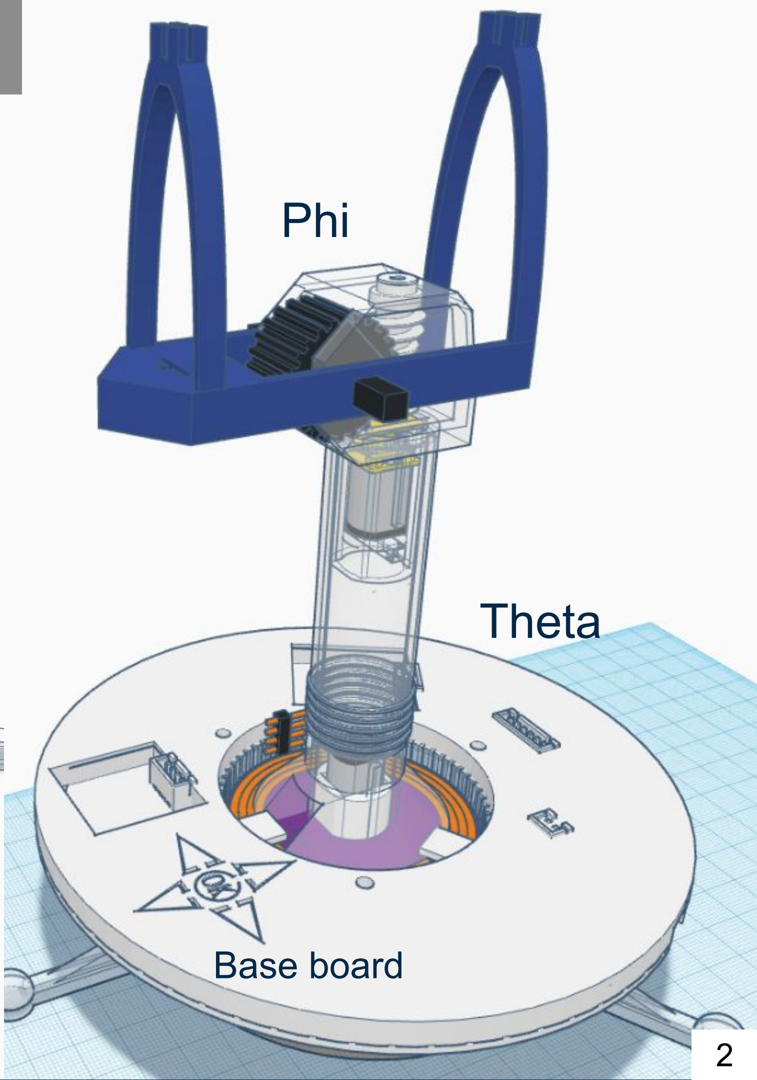
Part Types





Planetary gear system

Assembled

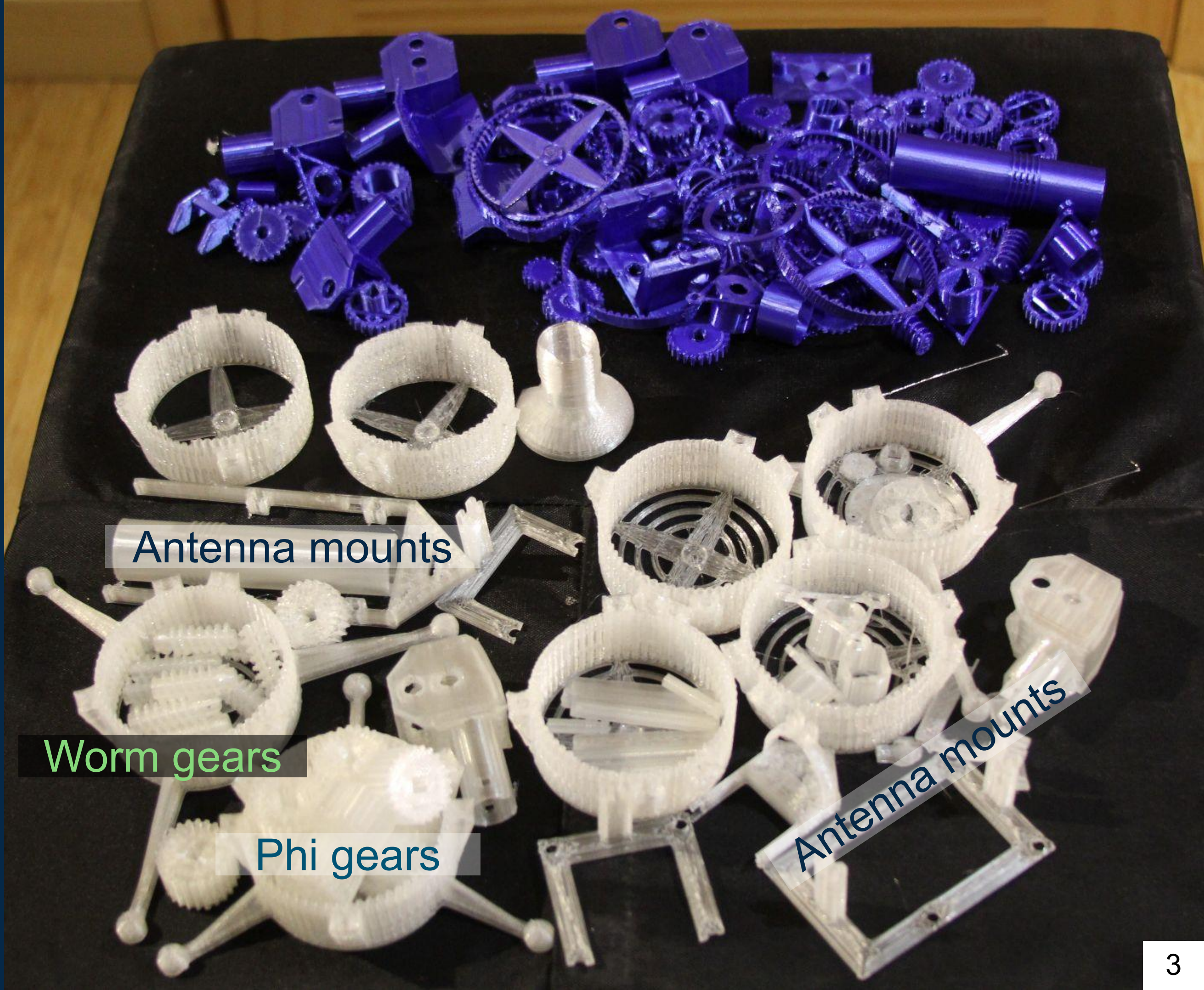


3D Print Attempts

3D prints were designed and tested but needed revision:

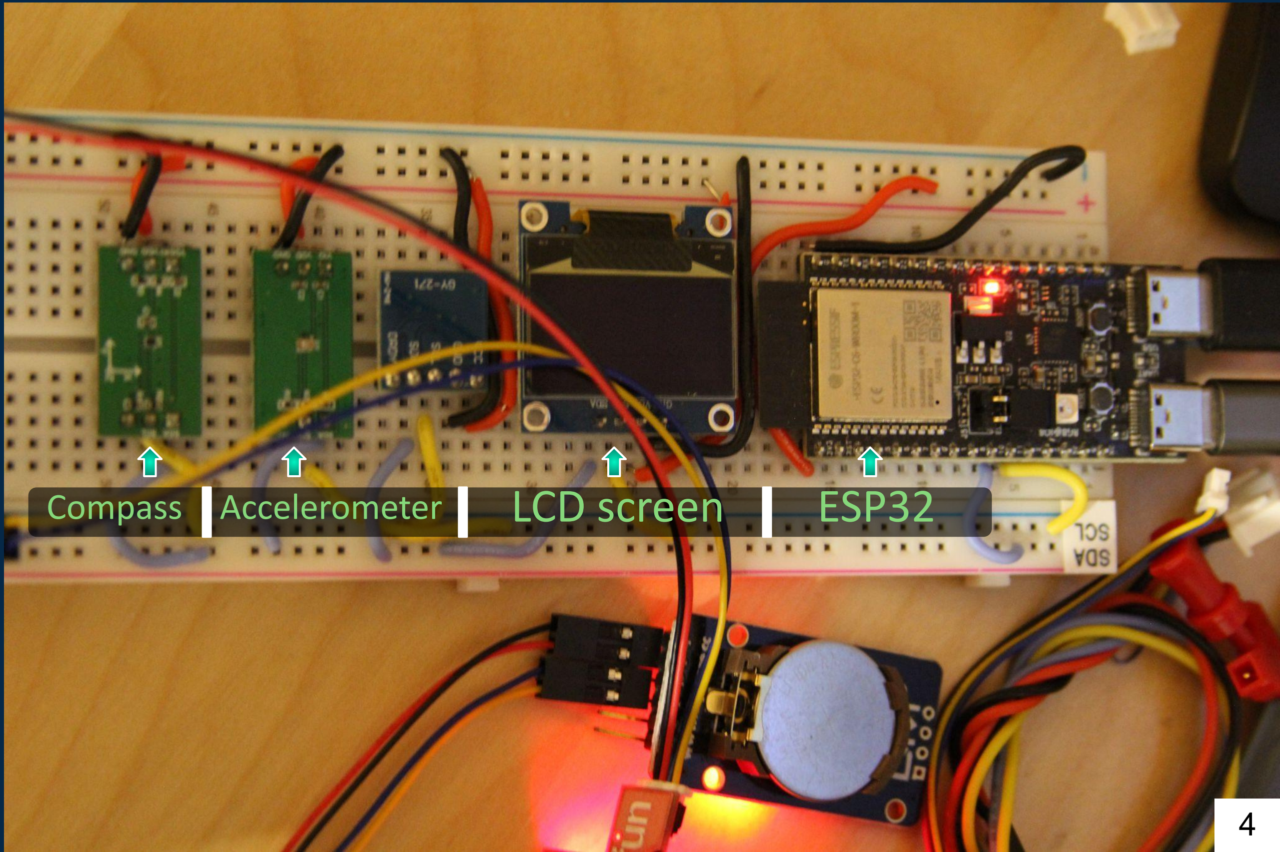
- 20 worm gears
- 15 phi gears
- 12 rings

- Small teeth require high tolerances
- Next time, bigger teeth



Experimental Design: Development Board

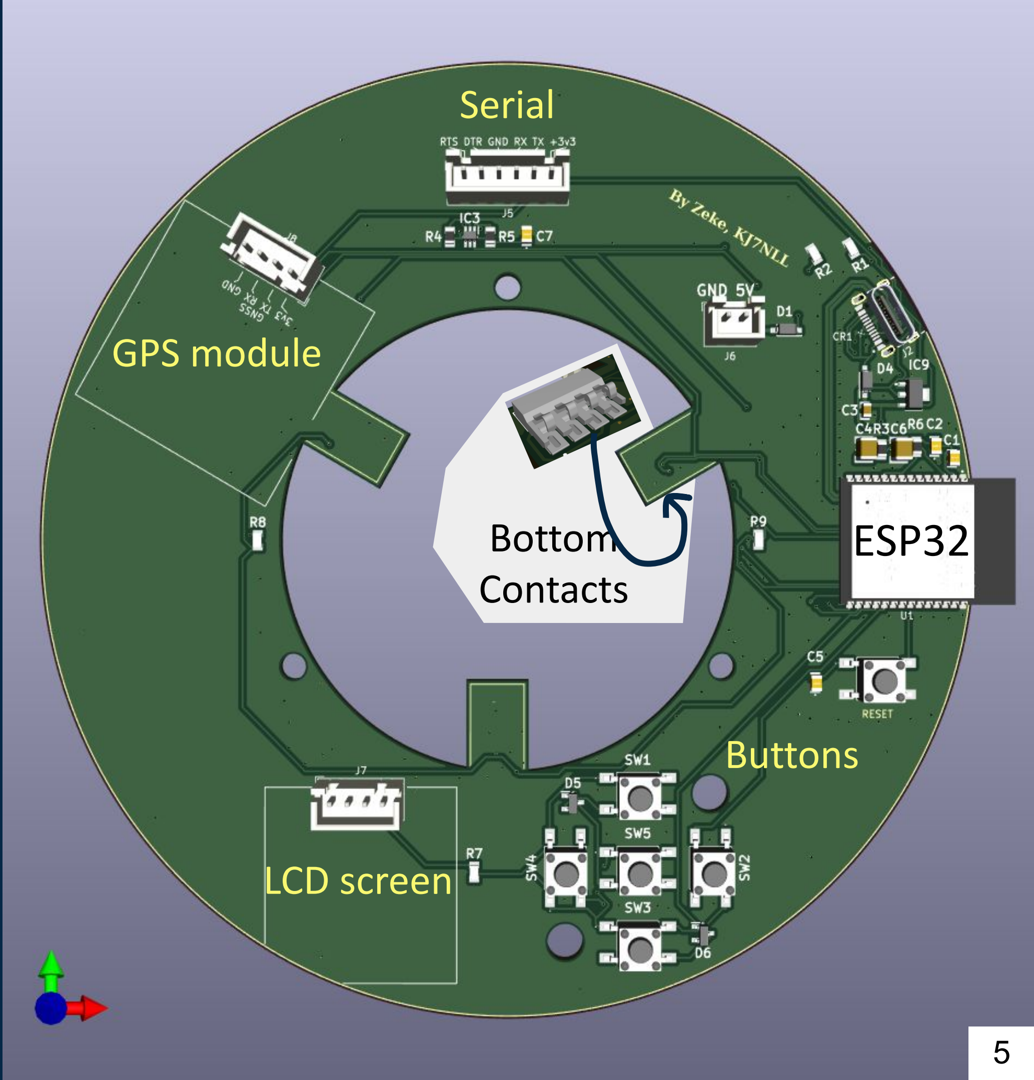
- ESP32 [11]
  - Micro controller chip that controls the tracker
- LCD screen
  - Displays satellite telemetry
- Accelerometer [8]
  - Measures the angle (up/down) to point at the satellite
- Compass (Magnetometer) [7]
  - Measures the angle (left/right) to point at the satellite



Base Board

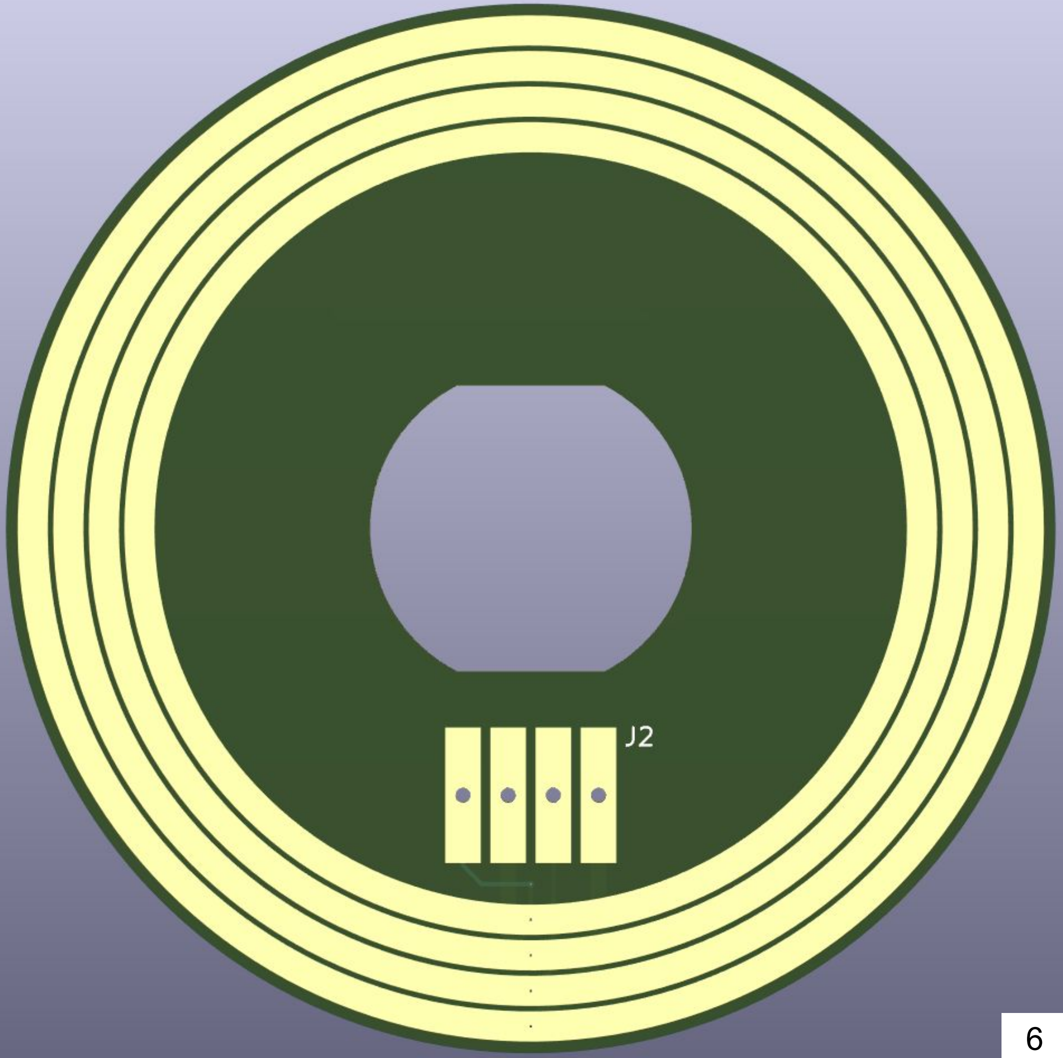
This circuit board is based on the development board and attaches to the actual tracker.

- GPS module [12]
  - Obtains accurate positioning for satellite tracking.
- Serial
  - Allows to talk to it over serial
- Buttons
  - Controls the tracker along with the menu on the LCD screen.



Circle Board

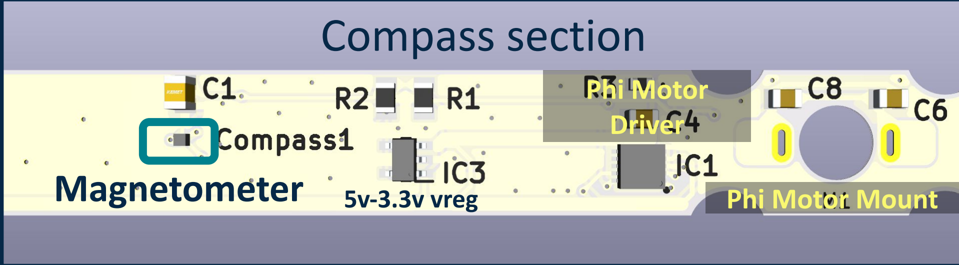
- Contacts press
- I could not use a wire to connect theta and phi because of twist up
- Turn forever
- Flex board connects

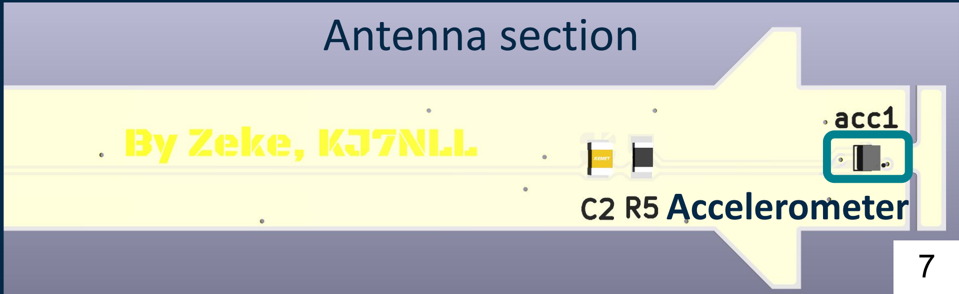


Flex Board

This is a flexible circuit board that folds into the tracker to connect the motors to the sensors.

- Connector
  - Connects to the circle board
- Theta motor driver [13]
  - Controls PWM.
- Phi motor driver [13]
  - Controls the PWM
- 5v-3.3v vreg
  - Lowers the 5-volt supply for the motors to 3.3-volts for the compass and accelerometer.
- Acc1
  - The accelerometer (I2C bus)
- Compass1
  - The compass (I2C bus)



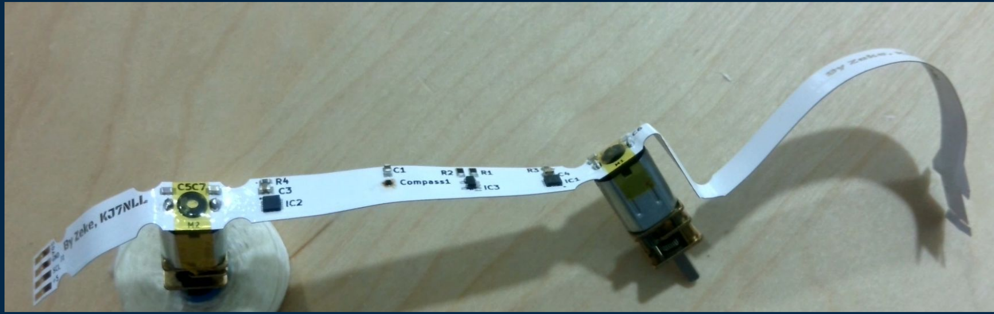


Flex Board

This is a flexible circuit board that folds into the tracker to connect the motors to the sensors.

- Problems I had
  - Pads coming off
  - Burnt pads
  - Font holes
- Solutions
  - Wider copper pours
  - Shrunken coverlay
  - No more than 250°C for SMT
  - No more than 300°C for through hole
  - Stencilled fonts

Flex Board Complete with Motors

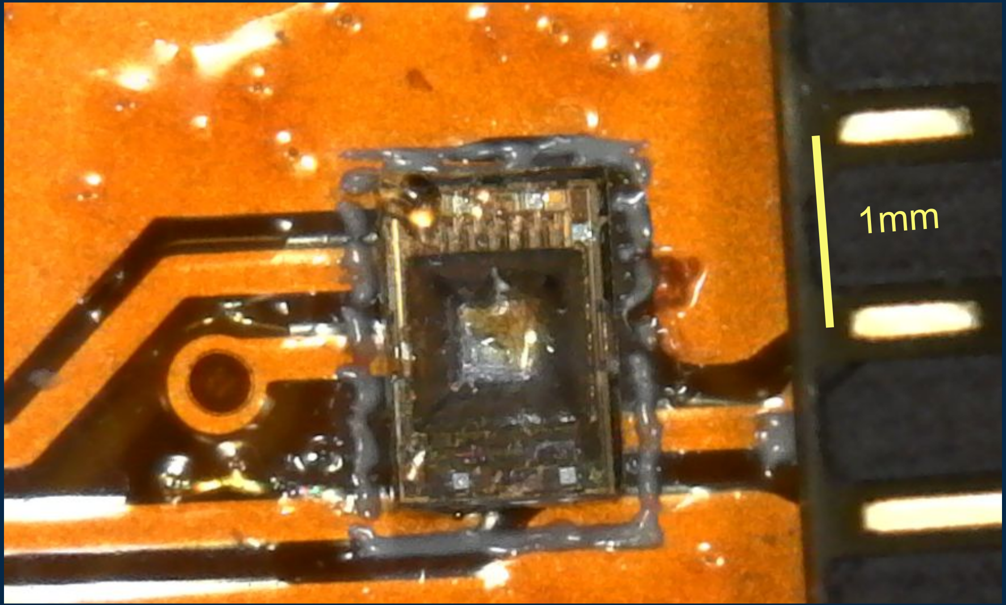


Flex Board Unsoldered with Stencilled Font

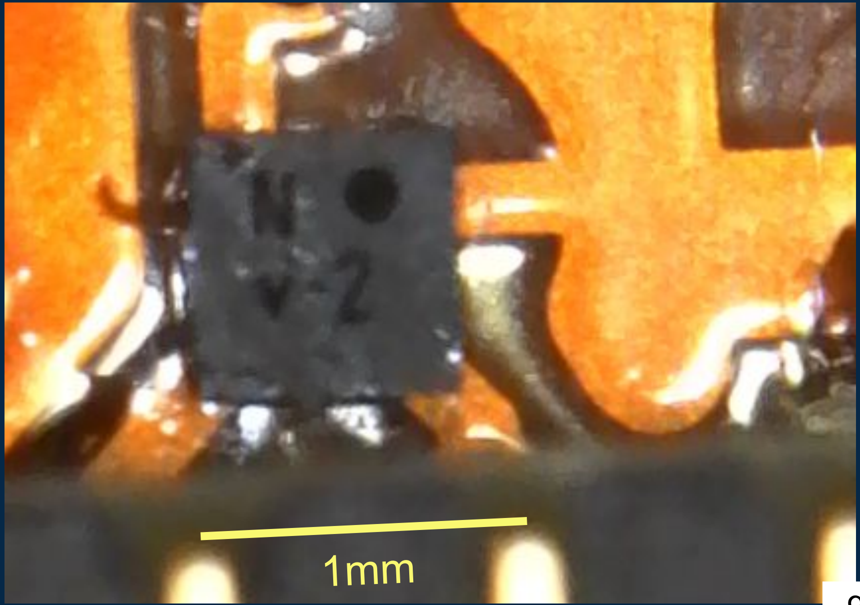
Accelerometer and Magnetometer Soldering

- Balls of solder on pads of the WLCSPs

Accelerometer



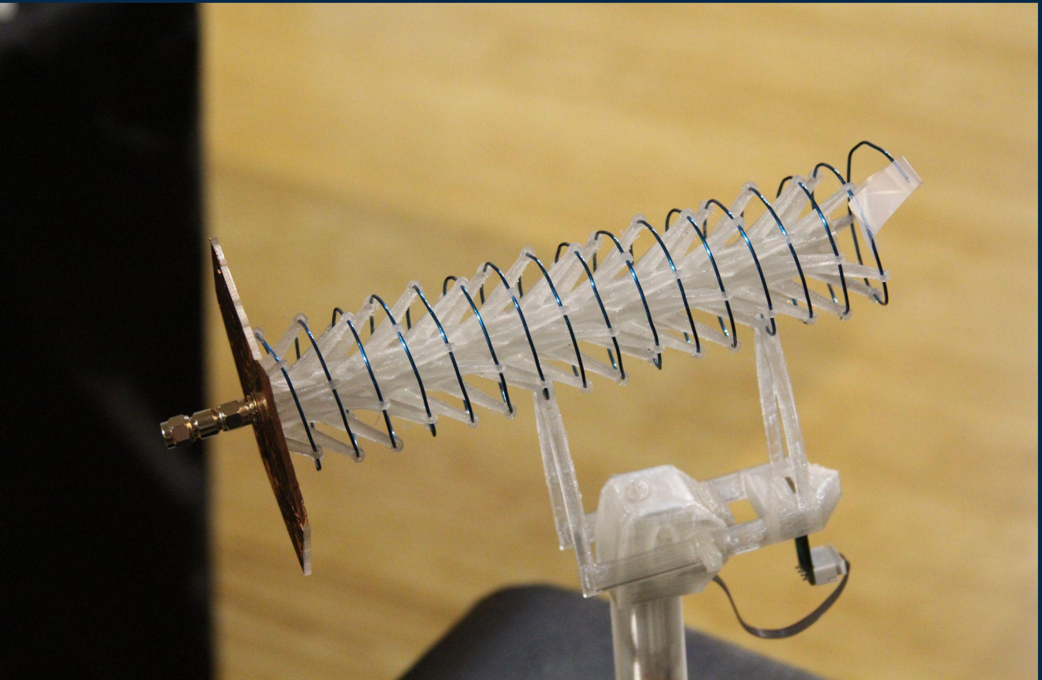
Magnetometer



(Notice the component scale)

Helical Antenna

- Made by Portland State Aerospace Society at Portland State University
- New OreSat 0.5 launch later this year



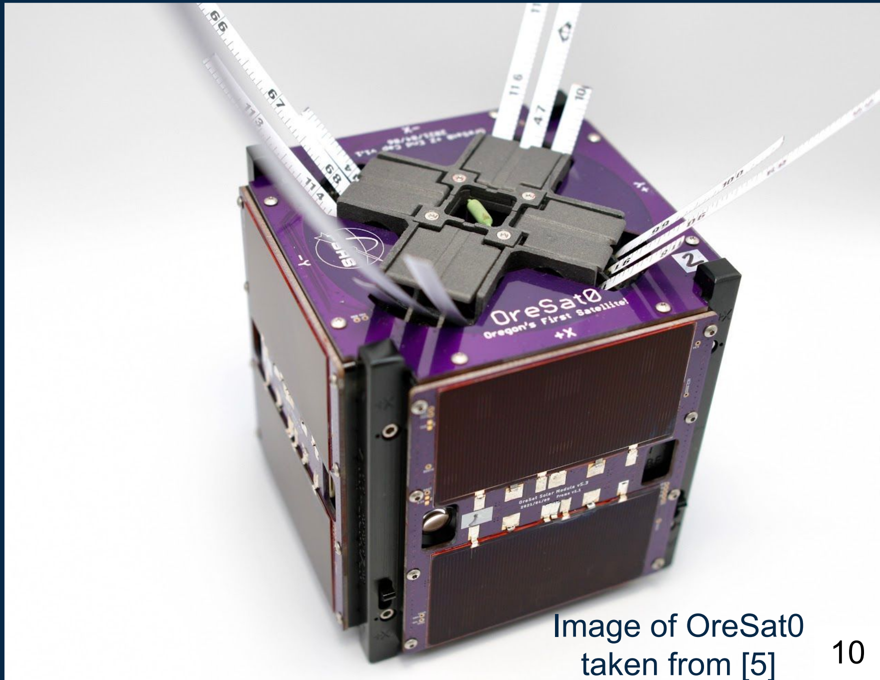
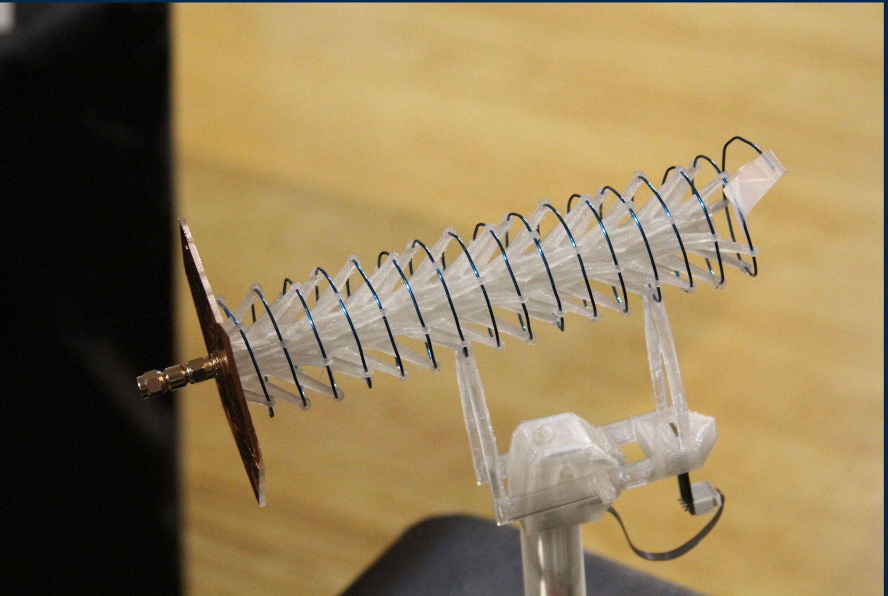


Image of OreSat0 taken from [5]

My Antenna Characteristics

According to [3], the table on the right shows the characteristics of my 13cm (2.422GHz) antenna.

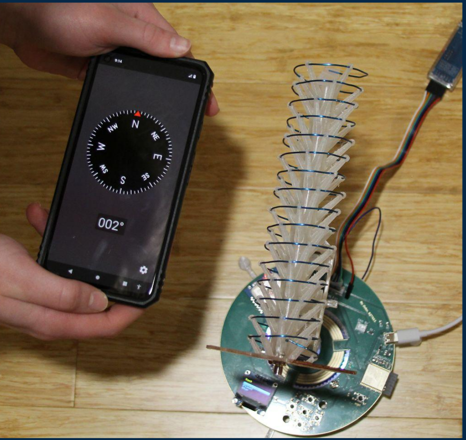


F	user input	2422	MHz	Operating frequency
S_λ	user input	.1	λ	Spacing between turns
n	user input	15		Number of turns
C_λ	user input	1	λ	Helix circumference (normally 1)
λ	= c/F/1000	123.8	mm	Operating wavelength
C	$= \lambda * C_\lambda$	123.8	mm	Helix circumference (real)
D	$= C/\pi$	39.4	mm	Helix diameter
S	$= \lambda * S_\lambda$	12.4	mm	Spacing between turns (real)
B_{hp}	$= 52/(C_\lambda * \sqrt{(n*S)})$	42.5	deg	Half power beam width
B_{fn}	$= 115/(C_\lambda * \sqrt{(n*S)})$	93.9	deg	First null beam width
G	$= 11.8+10\log(C_\lambda{}^2 * n * S)$	15.9	dBi	Estimated gain
Z	$= 140 * C_\lambda$	140	Ω	Estimated impedance
A	= n*S	185.7	mm	Height of helix (axial length)
α	= atan(S/C)	5.7	deg	Pitch angle
L_t	$= \sqrt{(S^2+C^2)}$	124.4	mm	Length of 1 turn
L_h	$= L_t * n$	1866	mm	Total length of helix conductor
d	$= \lambda * 0.02$	2.48	mm	Ideal diameter of helix conductor
R_{min}	$= \lambda * 0.75$	92.9	mm	Min. diameter of reflector
R_{max}	$= \lambda * 1.1$	136.2	mm	Max. diameter of reflector

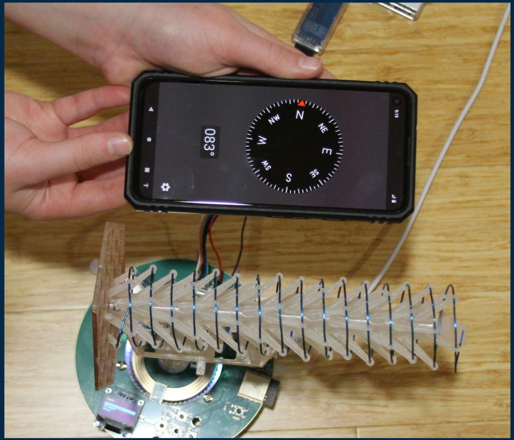
Results: Magnetometer Accuracy

I used a compass [10] to measure the accuracy of the magnetometer:

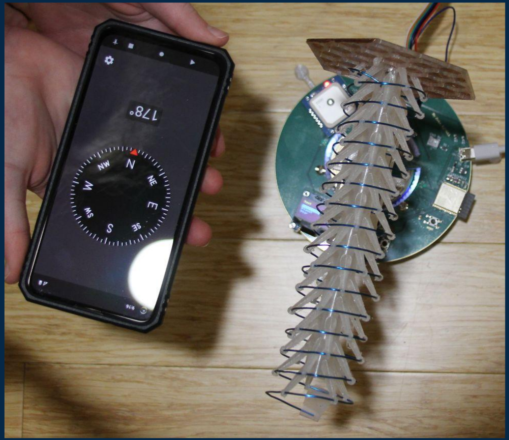
These measurements show that -7 degrees is within the half power beam width of 42.5 degrees. Clearly, this is accurate enough to get a signal from OreSat0.



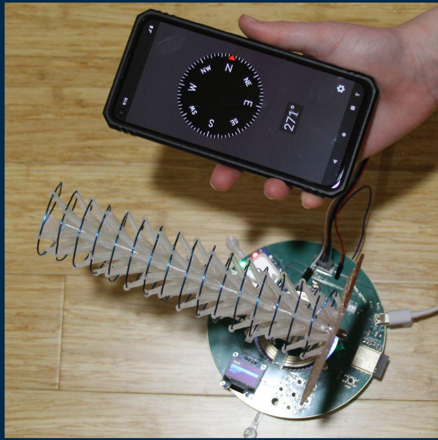
North, +2 degrees off
002 degrees measured



East, -7 degrees off
083 degrees measured



South, -2 degrees off
178 degrees measured

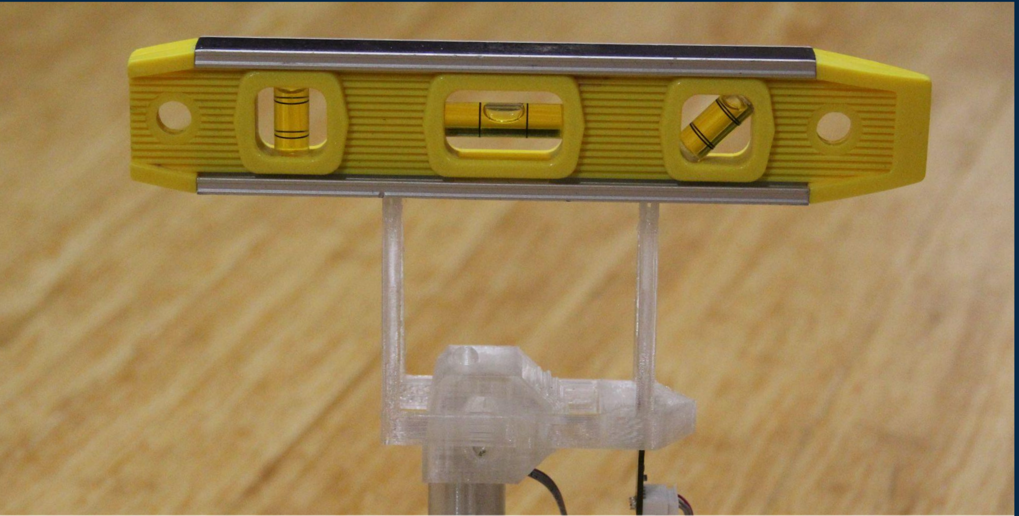


West, +1 degree off
271 degrees measured

Results: Accelerometer Accuracy

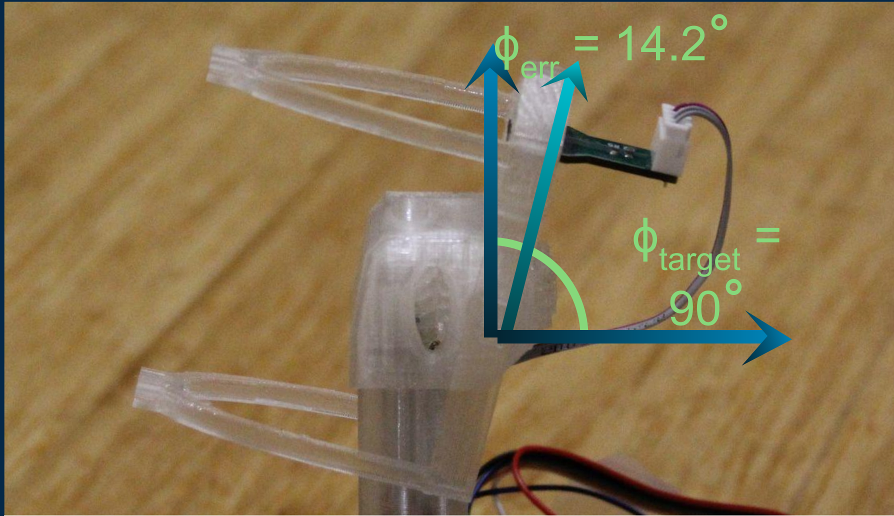
I used a level to measure the accuracy of the accelerometer:

Phi has an error of 14.2 degrees, which is acceptable because it is within the 42.5 degree half-power beam-width.



Step 1

Level the level, $\phi_{target} = 0^{\circ}$

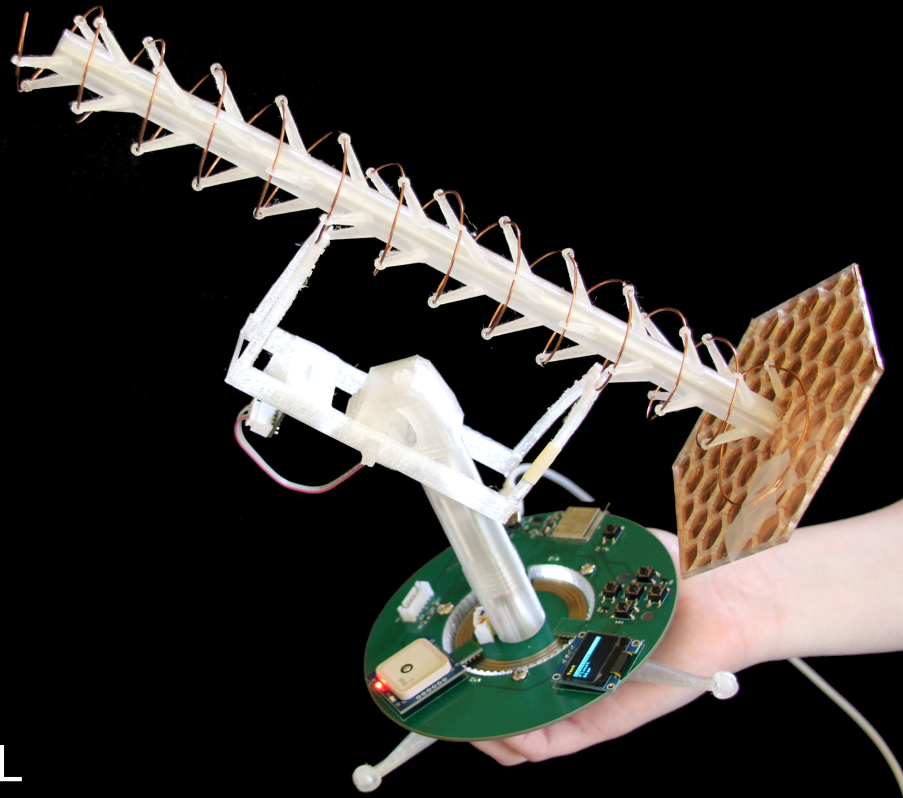


Step 2

Measure ϕ_{err} when $\phi_{target} = 90^{\circ}$

Thank you!

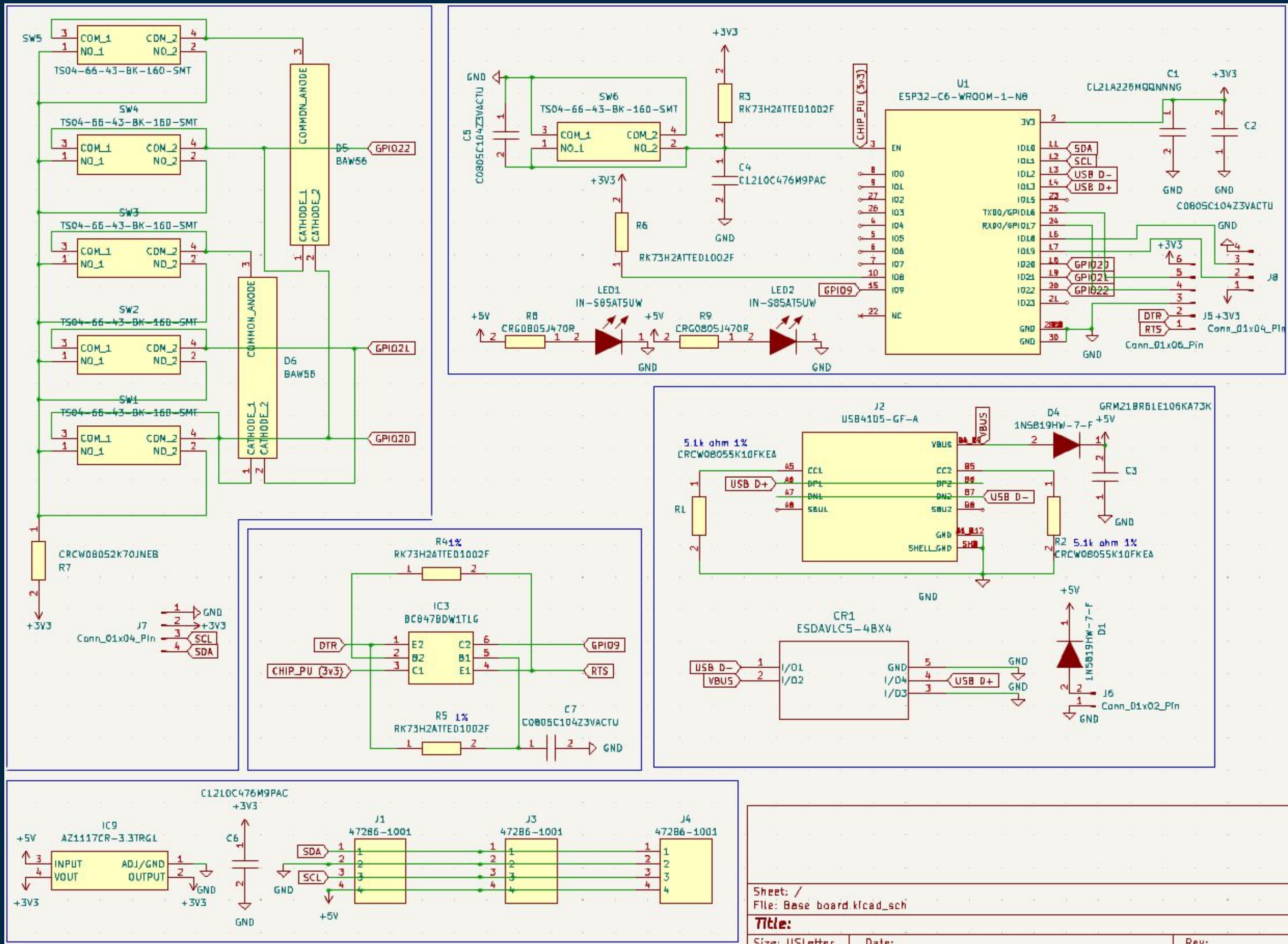
- Cadence
- Crowd Supply
- PCBWay
- PSAS
- Qorvo
- RFMW



youtube.com/@KJ7NLL - github.com/KJ7NLL

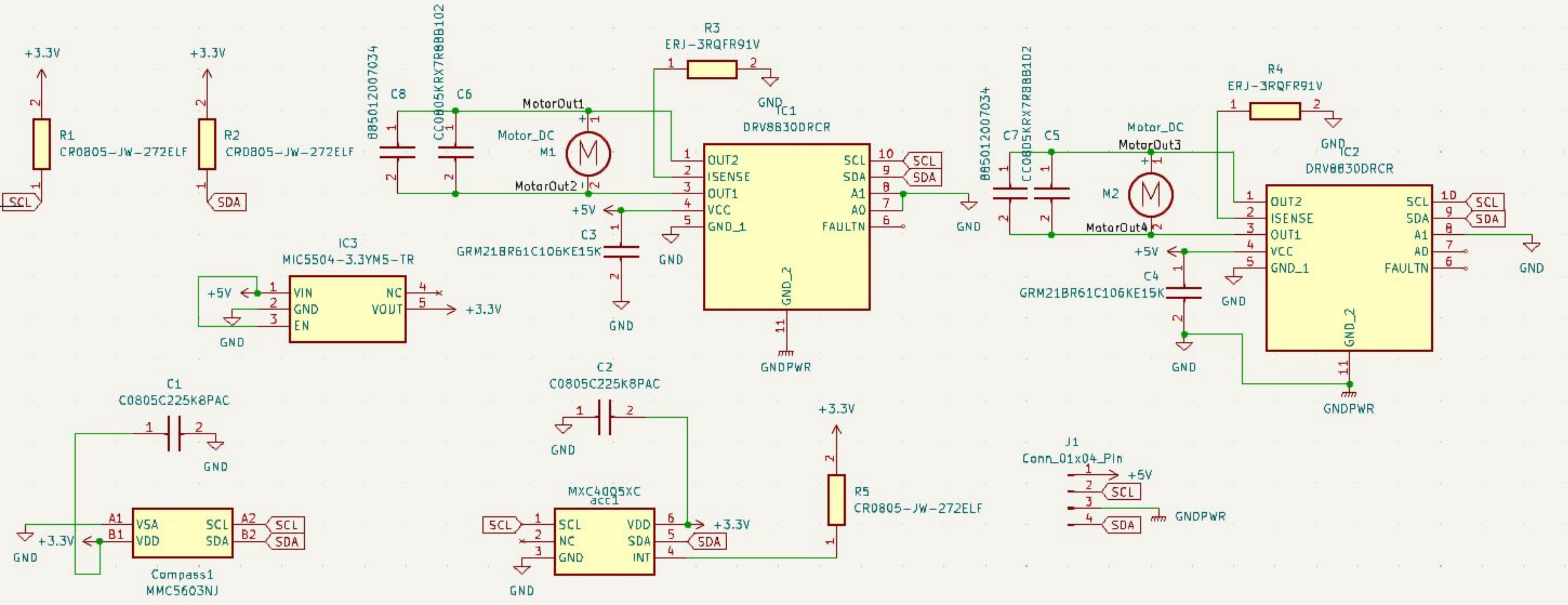
Base Board Schematic

This schematic defines the connectivity of the wires on the circular base board.



Flex Board Schematic

This schematic defines the connectivity of the wires on the flex board.



Revisions of Phi Parts

The revision history of phi's 3D printed parts

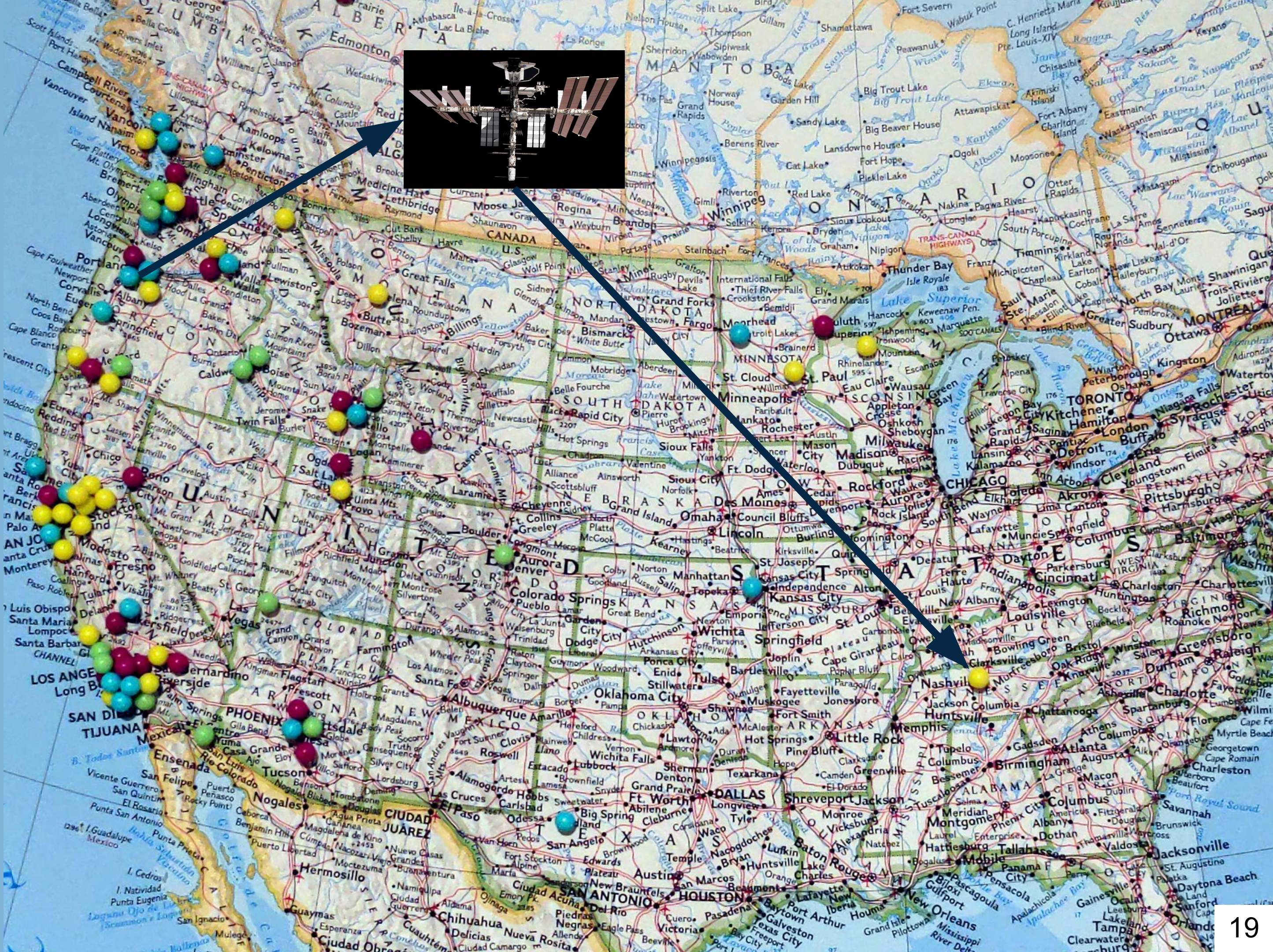
	Phi big gear	Phi assembily	Worm gear	Arrow	Helix antenna
Orig design	complex slip gear	oversized worm/slip gear holder	worm gear	doesn't exist yet	doesn't exist yet
Revision 1	more complex slip gear	scaled down assembily	added torus cutout	doesn't exist yet	doesn't exist yet
Revision 2	now a big gear	added view holes in sides	adjusted torus cutout	doesn't exist yet	doesn't exist yet
Revision 3	added torus cutout	motor mounts on the bottom with pin	adjusted torus cutout	doesn't exist yet	doesn't exist yet
Revision 4	removed torus cutout	nothing changed	adjusted torus cutout	doesn't exist yet	doesn't exist yet
Revision 5	nothing changed	added cutout for flex board	adjusted torus cutout	doesn't exist yet	helix antenna tree
Revision 6	nothing changed	added centering cutouts	Added centering bubble	arrow with holes for posts	DONE!
Revision 7	shrinked height	added bushings, larger view hole	DONE!	changed holes to antenna supports	
Revision 8	DONE!	DONE!		DONE!	

Revisions of Theta Parts

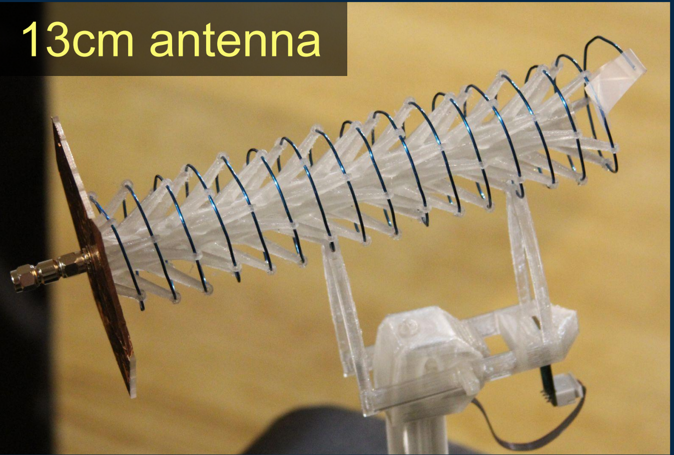
The revision history of theta's 3D printed parts

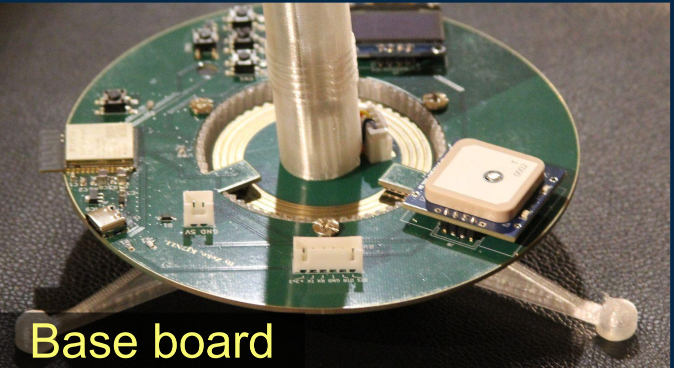
	Ring	Drive gear	Carrier	Planetary gears	Triangle gear	Motor triangle	Tube
Orig design	2 piece circle with gear hole	gear with hole	ring with circles	normal gear	triangle with gear	triangle with motor hole	tube
Revision 1	added bottom crosses	expanded hole to fit motor	added struts for gears to rub agenst	added ring on top of gear	nothing changed	nothing changed	added rings for wires
Revision 2	merged into a single piece	DONE!	turned circles into stubs	DONE!	added rings on edges of circle	added rings on edges of circle	Added cutout for flex boards
Revision 3	added rings to hold gears in		DONE!		DONE!	nothing changed	nothing changed
Revision 4	thickened bottom crosses					nothing changed	nothing changed
Revision 5	added support for base board					nothing changed	increced flex board cutouts
Revision 6	nothing changed					added centering cutouts	added centering supports
Revision 7	added leg supports					DONE!	DONE!
Revision 8	lengthened leg supports						
Revision 9	DONE!						

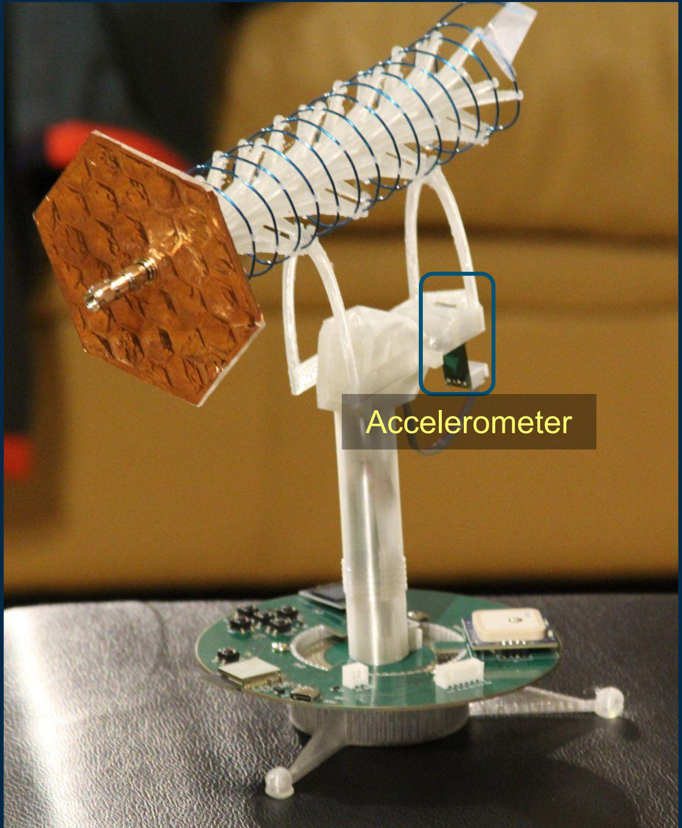
ISS Contacts

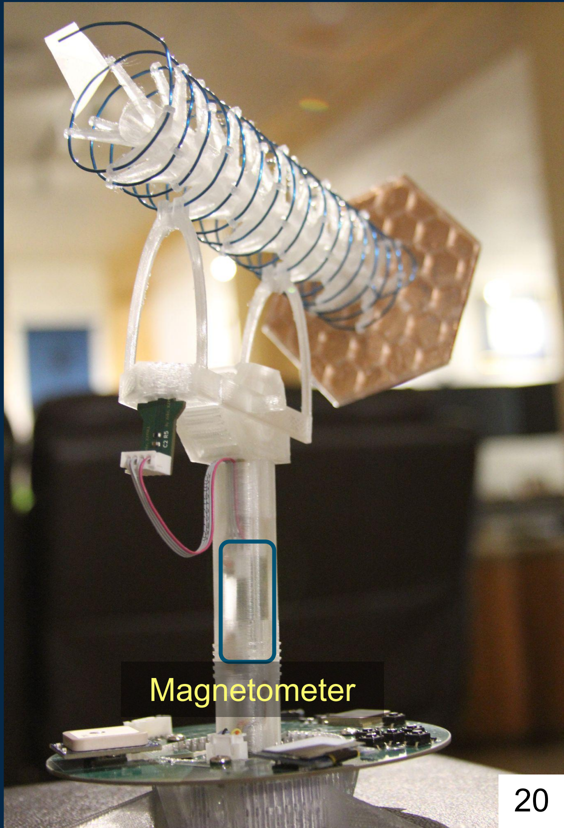


Real Life Model









Accelerometer and Magnetometer - How it Works

$$tan(\theta) = \frac{\bar{z}}{y}$$

$$atan(tan(\theta)) = atan(\frac{\bar{z}}{y})$$

$$\theta = atan(\frac{\bar{z}}{y})$$

$$a^2 + b^2 = c^2$$

$b = a$ when $\theta = 45^{\circ}$, therefore:

$$2a^2 = 1g$$

$$\frac{2a^2}{2} = \frac{1}{2}$$

$$a^2 = \frac{1}{2}$$

$$\sqrt{a^2} = \sqrt{\frac{1}{2}}$$

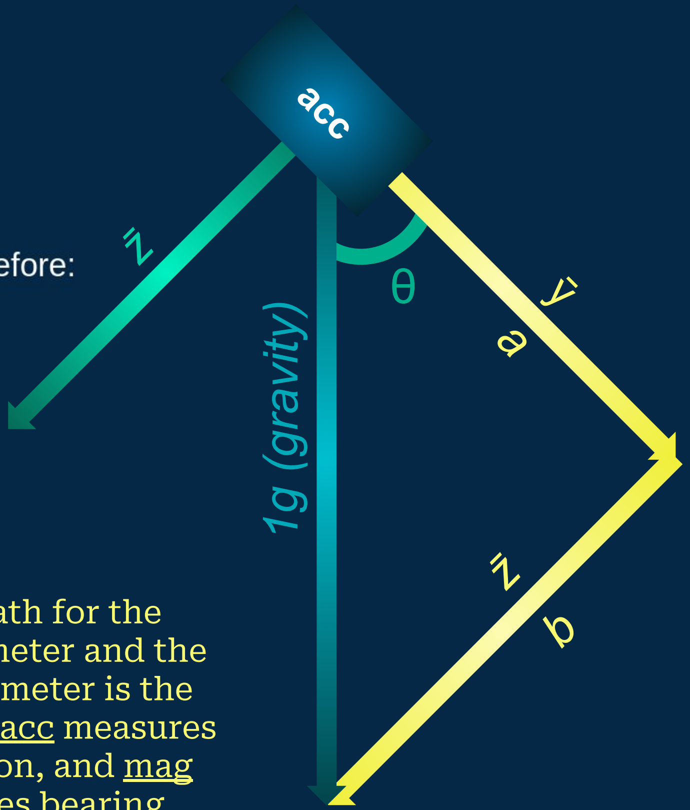
$$a = \sqrt{\frac{1}{2}}$$

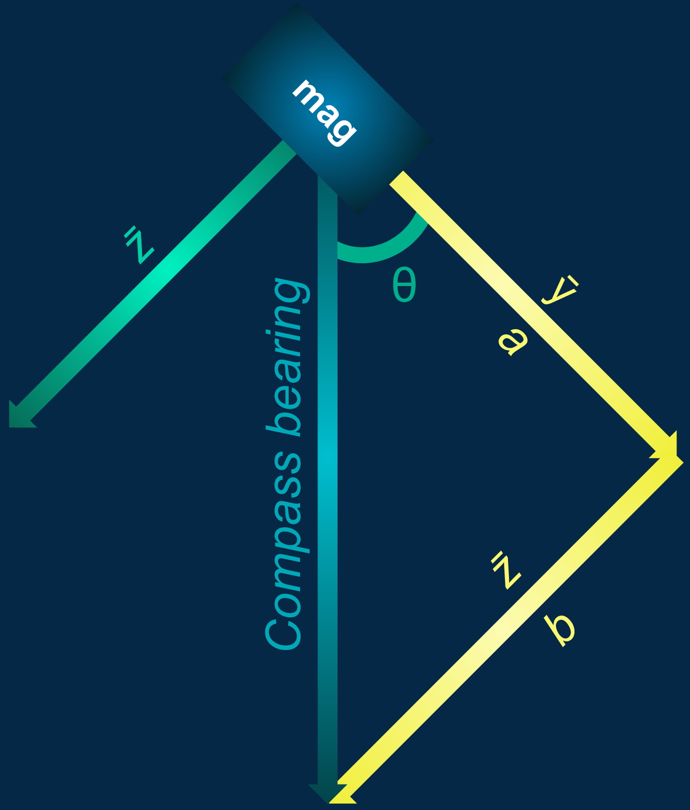
$$a = \frac{\sqrt{1}}{\sqrt{2}}$$

$$a = \frac{\sqrt{1} \cdot \sqrt{2}}{\sqrt{2} \cdot \sqrt{2}}$$

$$a = \frac{1 \cdot \sqrt{2}}{2}$$

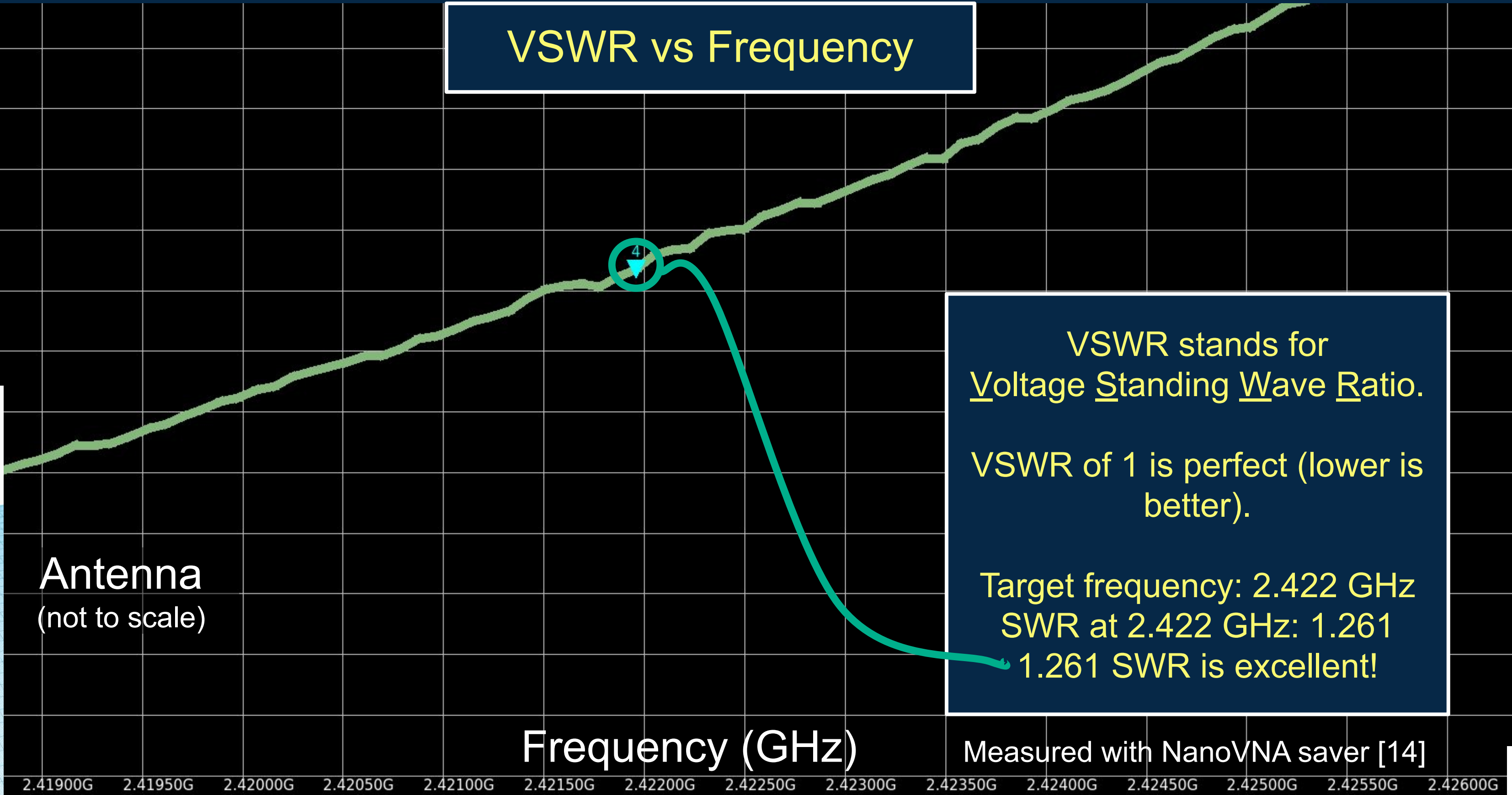
The math for the accelerometer and the magnetometer is the same, but acc measures inclination, and mag measures bearing.

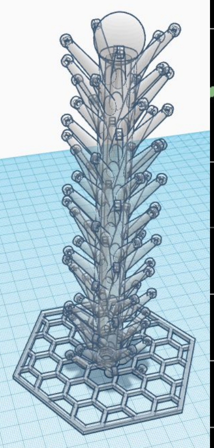




Results: 13cm Antenna VSWR

VSWR vs Frequency





Antenna
(not to scale)

VSWR stands for
Voltage Standing Wave Ratio.

VSWR of 1 is perfect (lower is better).

Target frequency: 2.422 GHz
SWR at 2.422 GHz: 1.261
1.261 SWR is excellent!

Measured with NanoVNA saver [14]

Favorite Moment

My favorite moment in the project was when the circuit boards arrived, because it was the first time that I could actually start working on making the Desktop Satellite Tracker track a satellite.

Later, I felt a real sense of accomplishment when I realized that I had been programming in C all evening without receiving help.

Conclusion: Takeaways and Future Work

In this project I designed, built, programmed, and tested a Desktop Satellite Tracker to move a 13cm antenna to point at satellites, planets, and stars.

Problems:

The magnetometer did not always calibrate fully. This happened because either there was metal nearby which affected the measured position, or there was a bad I2C signal.

The accelerometer has a 14.2 degree error. This may be due to the fact that the chip is not level on the circuit board, or that it needs to be calibrated.

Solutions and Future Work to Expand the Project

To fix the calibration problem for the magnetometer, I can discard any bad samples and I can ignore spikes in the magnetic field.

Regarding the accelerometer, I can add a limit switch to the tube to allow for automatic calibration.

I also want to make a curriculum for teachers to use with the Desktop Satellite Tracker, to teach their students about astronomy and satellite communication.

Problem to Solve

In my previous research [4], I learned that using potentiometers to measure position requires a lot of calibration and they run out of room to rotate when they reach their limits.

In this project, I designed and tested a Desktop Satellite Tracker. I wanted to know if an accelerometer and a magnetometer could replace the potentiometers, automatically calibrate, and rotate without reaching a limit. In addition, I wanted to develop a hands-on tracking tool for teachers in the classroom.

Hypothesis

My hypothesis is that I can use an accelerometer and a magnetometer in a Desktop Satellite Tracker to measure the position of an antenna to track satellites, planets and stars.

Prior Work in the Field

- In [2], the author used stepper motors to measure position and point at satellites.
- In [6], potentiometers were used to measure position.
- In [4], old Tenna Rotors were used with worm gears and their AC motors were replaced with DC Lego motors for use with an az/el rotor system.

Differences in My Project

- I am using DC motors to drive my two-stage planetary gears system.
- In my project I am using an accelerometer and a magnetometer.

SI Units in this Project and How they are Used

- Base Units
  - Time: Satellite position calculations
  - Meters: Antenna wavelength, board dimensions, helical circumference
  - Amps: Motor current to prevent overheating drivers
- Derived Units
  - Acceleration: Accelerometer (m/s^2 measured in G’s)
  - Newtons: Button gram-force
  - Gauss: Magnetometer
  - Volts: Circuit boards use various voltages (3.3V, 5V)
  - Watts: Antenna signal strength (dBm)
  - Farads: Capacitors used for RF, energy storage
  - Henrys: To filter high frequencies on the low noise amplifier board
  - Impedance: To calculate VSWR of antenna
    - Resistance: Resistors on circuit boards for various purposes
  - Hertz: 100 kHz I2C bus, 2422 MHz for 13cm antenna, 160MHz MCU
  - Radians: radians used in accelerometer and magnetometer direction calculation

Affordable Portable Orbital Satellite Tracker for Educators

Ezekiel Wheeler	
In this project, I designed a Desktop Satellite Tracker and used a magnetometer and an accelerometer for measuring position. I modeled my Desktop Satellite Tracker in 3D CAD and designed the circuit boards to control it and to allow it to track satellites. The Desktop Satellite Tracker tracks satellites, planets and stars. I wanted to create the Desktop Satellite Tracker to help science teachers teach STEM because I could not find any small affordable satellite tracker that was commercially available. I got the idea to do this project from my previous research, which used potentiometers to measure position.	

Bibliography

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Lego Rotor