HASP Student Payload Application for 2022

Payload Title: CySol	
Institution: Iowa State University	
Payload Class: SMALL	Submit Date: 01/07/2022

Project Abstract:
CySol will measure the 30cm wavelength solar flux for the duration of the HASP mission. The HASP measurements will be compared with measurements taken by a ground station copy of the HASP payload and the two datasets will be compared. CySol will be constructed during spring 2022 by the CySat team at Iowa State University. CySat's main faculty advisor is Matthew Nelson and the spring 2022 student project manager is Kevin Gruhlke. CySol will not have any uplink or discrete command requirements. It is projected to have a power budget of 10.4W and weight about 1.2kg.

Team Name: CySat	Team or Project Website: https://m2i.aere.iastate.edu

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Flight Hazard Certification Checklist

NASA has identified several classes of material as hazardous to personnel and/or flight systems. This checklist identifies these documented risks. Applying flight groups are required to acknowledge if the payload will include any of the hazards included on the list below. Simply place an (x) in the appropriate field for each hazard classification. **Note:** Certain classifications are explicitly banned from HASP (grey filled items on table below) and the remaining hazards will require additional paperwork and certifications. If you intend to include one of the hazards, you must include detailed documentation in section 3.8 of the application as required by the HASP Call for Payloads.

This certification must be signed by both the team faculty advisor and the student team lead and included in your application immediately following the cover sheet form.

Hazardous Materials List

Classification	Included on Payload	Not Included on Payload
RF transmitters		X
High Voltage		X
Lasers (Class 1, 2, and 3R only) Fully Enclosed		X
Intentionally Dropped Components		X
Liquid Chemicals		X
Cryogenic Materials		X
Radioactive Material		X
Pressure Vessels		X
Pyrotechnics		X
Magnets less than 1 Gauss		X
UV Light		X
Biological Samples		X
Batteries		X
High intensity light source		X

Student Team Leader Signature: Kevin Gruhlke

Faculty Advisor Signature: ______________________________

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1. Payload Description

1.1 Payload Scientific / Technical Background

1.1.1 Mission Statement

CySol will measure the 30cm wavelength solar flux for the duration of the HASP balloon flight. It is intended to be a prototype and a proof of concept for CySat-2, the next CubeSat being developed by the CySat team at Iowa State University, which is planned to carry out the same task from orbit for 3-12 months starting during the next solar maximum in summer 2025.

1.1.2 Mission Background and Justification

The 10.7cm solar radio flux (F10.7) is one of the most widely used indices of solar activity. Its applications include use as a simple activity level indicator, as a proxy for other solar emissions or quantities which are more difficult to obtain, and also as a commonly available datum for antenna calibration [1]. However, F30 (30cm solar radio flux) has been gaining recognition as an alternative to F10.7 that provides more information for phenomena such as solar flares and is potentially more useful for scientific pursuits such as thermospheric density modeling [2]. F30 is also easier to process with a less expensive SDR since it has a lower Nyquist frequency, but it is still highly correlated with F10.7 as shown in Figure 1.

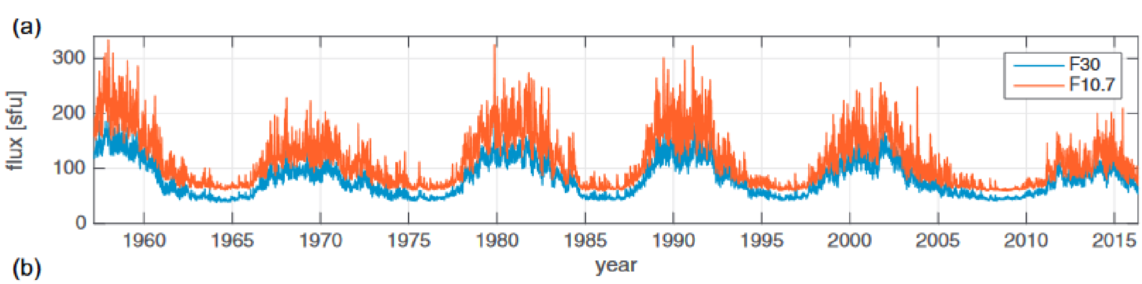

Figure 1: Values of F30 and F10.7 since 1 March 1957 [3].

Therefore, the CySat team will gather the F30 information from the Sun with a Cubesat(CySat-2) to avoid having to measure solar energy that was attenuated after traveling through the upper atmosphere. This will directly assist in the gathering of information about the 30cm solar flux which can be useful for modeling the Sun's thermospheric density. Furthermore, the cold environment of LEO will improve the performance of the antenna measuring the solar flux as well as the radio's low noise amplifiers used to amplify the solar flux signal.

Henceforth, the CySat team will be moving forward with a High-Altitude Student Payload (HASP) mission to test the electronics and antenna that will be used onboard the satellite. This test is a prototype and a technology demonstration of the solar flux measuring payload that will be used in CySat-2.

1.1.3 Mission Objectives

The objective of our payload is to demonstrate the capabilities of compact antennas being used to measure solar flux. This HASP payload is a proof of concept for a future payload that will be integrated into a cubesat. A successful mission will be defined as the payload completing its goal of accurately measuring the 30 cm solar flux (as compared to a ground station simultaneously taking the same measurements during the HASP flight) and storing the data to be analyzed and made public by the end of 2022. Another objective of this mission is to test the viability of our antenna design. The HASP flight will give us useful insight into the performance of the antenna before it is integrated into the team's Cubesat design.

1.2 Payload Systems and Principle of Operation

CySol's payload will consist of a 1GHz antenna to capture the 30cm wavelength solar flux, a front-end consisting of cascaded radio frequency (RF) components like low noise amplifiers and filters, a software-defined radiometer (SDR) to process the measured signal, and an onboard computer (OBC) to process and store the data received from the SDR. The OBC will also be responsible for performing health checks on the payload, sending telemetry, and monitoring the payload temperatures. See Figure 2 below for a system level diagram.

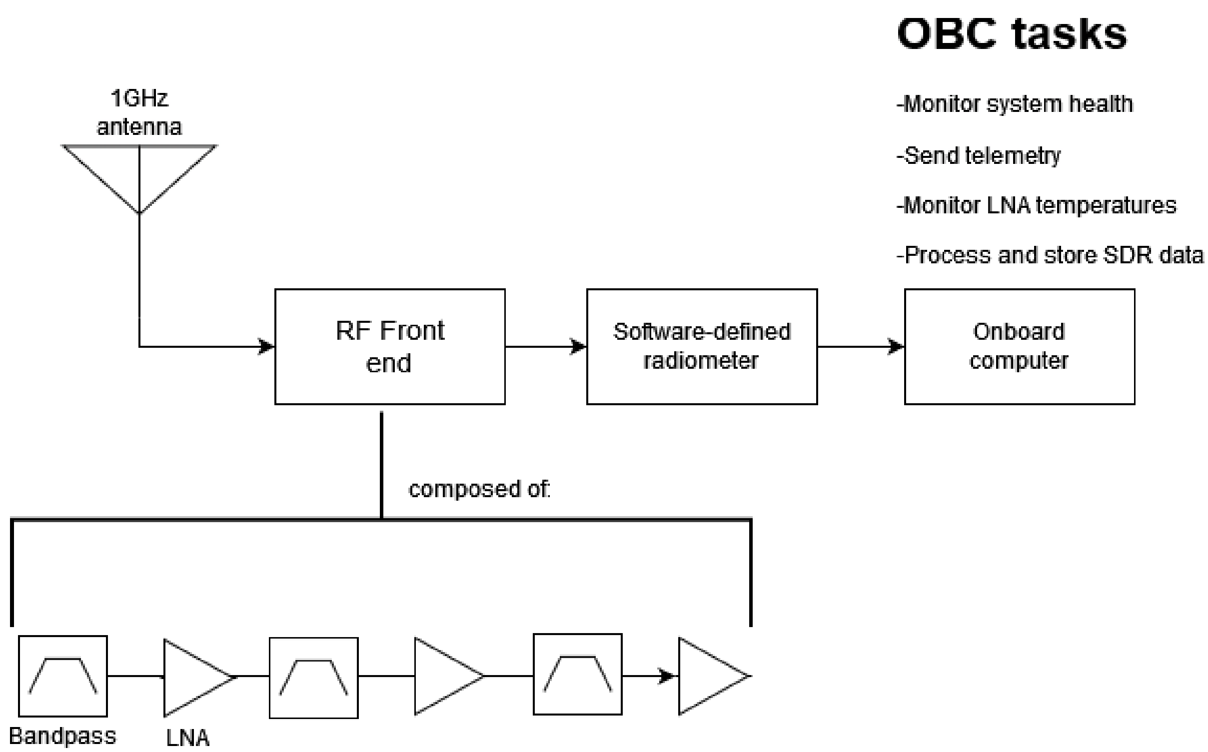

Figure 2: Diagram of CySol's major components

1.3 Major System Components

CySol's major component groups are the antenna, the RF front end, the SDR, and the OBC. The antennae will receive the solar flux signal from the sun and relay it to the RF front end via a coaxial connection. The high and lowpass filters attenuate the signal at all frequencies except those explicitly being measured. The low noise amplifiers (LNAs) will amplify the incoming signal, as the signal measured by the antenna is expected to be weak. There will be three pairs of bandpass filters and LNAs to ensure the signal at the frequency of interest is measurable by the SDR. The software defined radiometer will be a LimeSDR. The platform has a built-in Field Programmable Gate Array (FPGA) and can be programmed using GNU Radio. This component will do most of the data processing required. The OBC will be a Raspberry Pi Compute Module 4 (CM4). The OBC will handle storing the data gathered onto a 512 GB MicroSD card along with the other functions listed in Figure 2.

1.4 Mechanical and Structural Design

The enclosure for the payload will be 3D-printed with ABS plastic. It will be box-shaped with a removable lid (the top face) attached with M3 fasteners The enclosure, expected to be printed in-house, will hold all aforementioned electronic components and will additionally serve as the mounting surface for the antenna. Its footprint will measure 14.8cm x 14.8cm (thus falling within the 15cm x 15cm footprint allotted for small payloads, even assuming a very liberal 0.5mm 3D-printing manufacturing tolerance) and, including the lid, will measure 6 cm.

The antenna will be helical with a circular ground plane. The helix will be manufactured from 2mm copper wire and the ground plane will be a circular, 14.8cm diameter cutout from a 0.5mm copper sheet, or as thin of a sheet as possible to minimize weight and cost while still being structurally sound. Copper was chosen for its high conductance which makes it an ideal antenna material. The electrical characteristics of the antenna design are explored in section 1.5. The antenna will be attached to the top face of the enclosure with M3 fasteners in the ground plane. These fasteners' presence on the ground plane will alter the antenna's gain pattern, so they should be as small and unobtrusive as possible so as to change it only minimally. A coaxial feedline on the bottom side of the ground plane will deliver the signal measured by the antenna to the RFE. The helix will likely be supported by either off-the-shelf PVC tubing attached to the ground plane, as in Figure 3a, or by a (likely 3D-printed in-house with ABS) helix holder as in Figure 3b. The former solution would be ideal as it would make the antenna manufacturing process simpler and cheaper, but if it is not possible (e.g., tubing of an appropriate radius cannot be found) then the team will resort to the latter solution. CySol's primary faculty advisor, Dr. Matt Nelson, has education in electrical engineering and additionally has experience operating amateur radio, so the team will be utilizing his expertise to guide the antenna's design and manufacture.

Figure 3: Two methods of supporting the antenna helix. The team will explore both (a) using off-the-shelf plastic tubing [3] and (b) manufacturing a helix holder [4].

The payload will be attached to the HASP payload plate with four ¼" diameter x ¾" length nut-and-bolt fasteners placed in through holes drilled into the payload and the bottom of the enclosure. See Figure 4 for projected fastener placement on the payload plate.

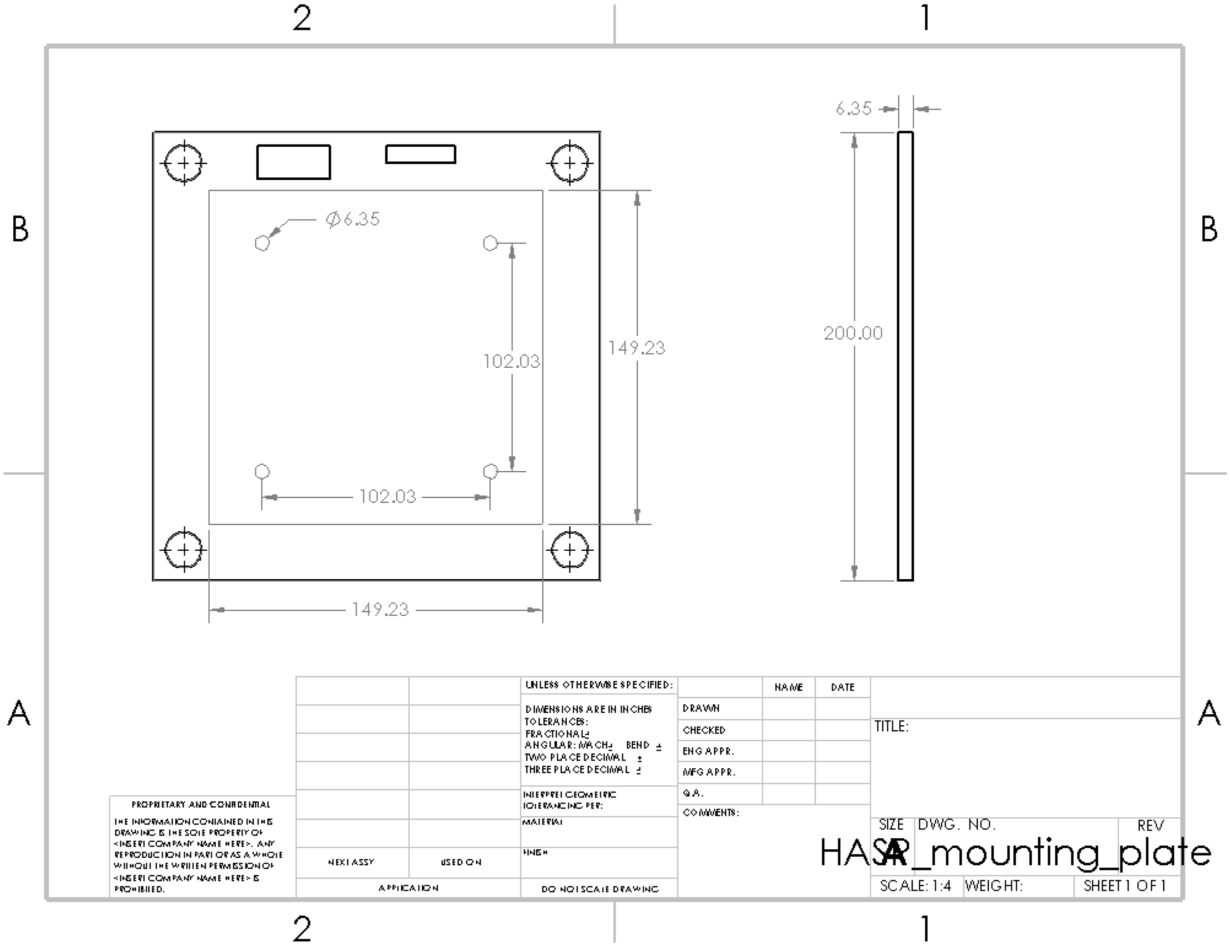

Figure 4: HASP mounting plate with projected through hole placement for mounting the CySol payload. Dimensions in millimeters. Note that the through holes, shown here measuring 6.35mm, will be accommodating ¼” fasteners.

The maximum expected stresses on the payload are expected to occur upon touchdown throughout the enclosure, but especially in the lid. The lid is supporting the antenna which is estimated to weigh 120-150 grams, so if the lid is incapable of handling the impact it will crack and potentially split open, causing the antenna to fall onto the electrical components. When the spring 2022 semester begins, the team will carry out impact analysis on the enclosure using ANSYS Discovery to simulate the 10g vertical and 5g horizontal kick loads to determine if the current enclosure design is viable. If the lid fails under the vertical load (the load most similar to what the payload will experience upon touchdown), the thickness of the lid design will be increased until the design can handle the load stresses with a 1.5x factor of safety. The enclosure base will be shortened to compensate in case the payload’s height comes too close to the 30cm height limit.

1.5 Electrical Design

CySol will have a power regulation board to step down the +30VDC provided by HASP to the voltages required by the payload components. See the power schematic and voltage regulator circuit in Figures 5 and 6, respectively.

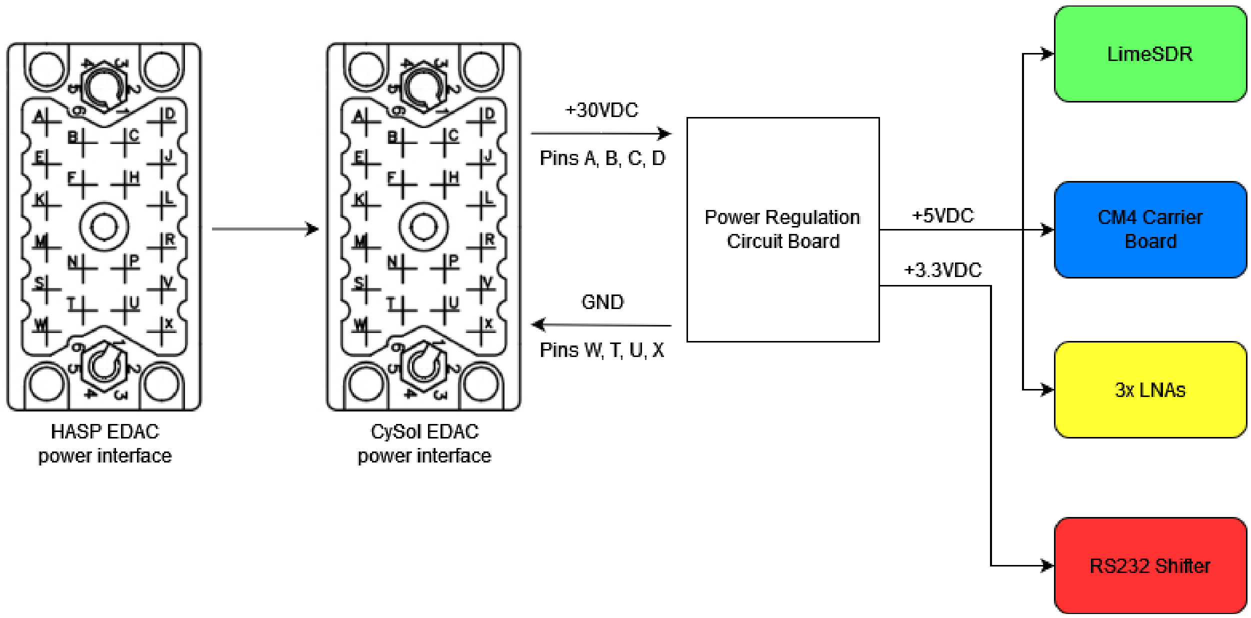

Figure 5: CySol power schematic. The power regulation board carries 3 of the LM2596 circuits shown in Figure 6.

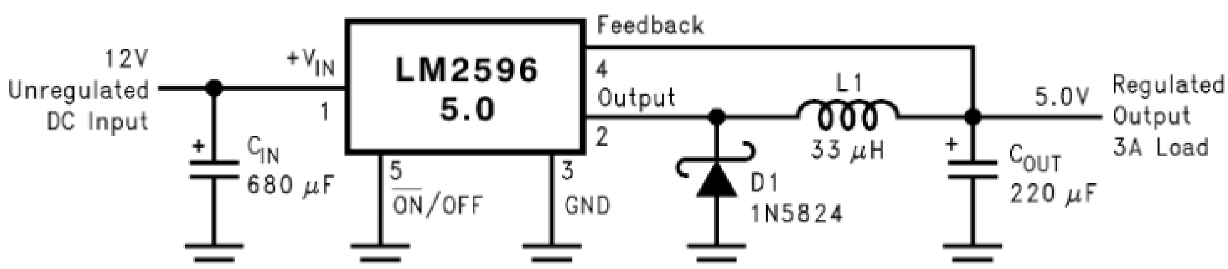

Figure 6: LM2596 voltage regulator circuit. The power regulation board will carry one of these circuits for +3.3VDC, one for +5VDC, and one for +12VDC for a total of 3 voltage regulation circuits.

The CM4 will serve as the payload's controller. It will be mounted to a Seeed Dual Gigabit Ethernet NICs carrier board. The CM4 will process data from the SDR, monitor the health of other systems (primarily the SDR), monitor the temperature of the LNAs, and interface with HASP if/when necessary. LNA temperature will be measured using thermistors adhered to each LNA with the CM4 performing the voltage-to-temperature conversion.

The CM4's operating system, code, and any and all data gathered by the payload will be stored in a 512GB MicroSD card placed in the MicroSD slot on the CM4's carrier board. The data generated by the SDR over the course of a 15 hour flight is anticipated to be 300-400GB, hence the need for a data storage device of this size.

Data collection will be carried out by the antenna, the RFE, and the SDR. The current antenna design (see Figure 7) was analyzed with MATLAB's Antenna Designer. The payload height limit unfortunately constrains the helical antenna to 3 turns (at least 5 turns is standard) and the footprint limit constrains the ground plane diameter to a little under 15cm (¾ wavelength, or 22.5cm for this antenna, is considered ideal). Due to these limitations, the antenna's max gain is just 6.53dBi, the half-power bandwidth (a measure of the antenna's directionality) is quite high at 80°, and there is a large backlobe with over 4dBi of gain which means that the antenna will pick up 1GHz signals transmitted from Earth as well as those originating from the Sun and reflecting off of Earth. It is unclear if this backlobe will be an issue with the enclosure and the other components hopefully attenuating signals coming from below; if testing reveals this to still be an issue, the team will consider placing lightweight material, like metal foil or reflective paint, under the payload or under the antenna to reduce the intensity of Earth-originating radio waves. See Figures 8 and 9 for the antenna patterns.

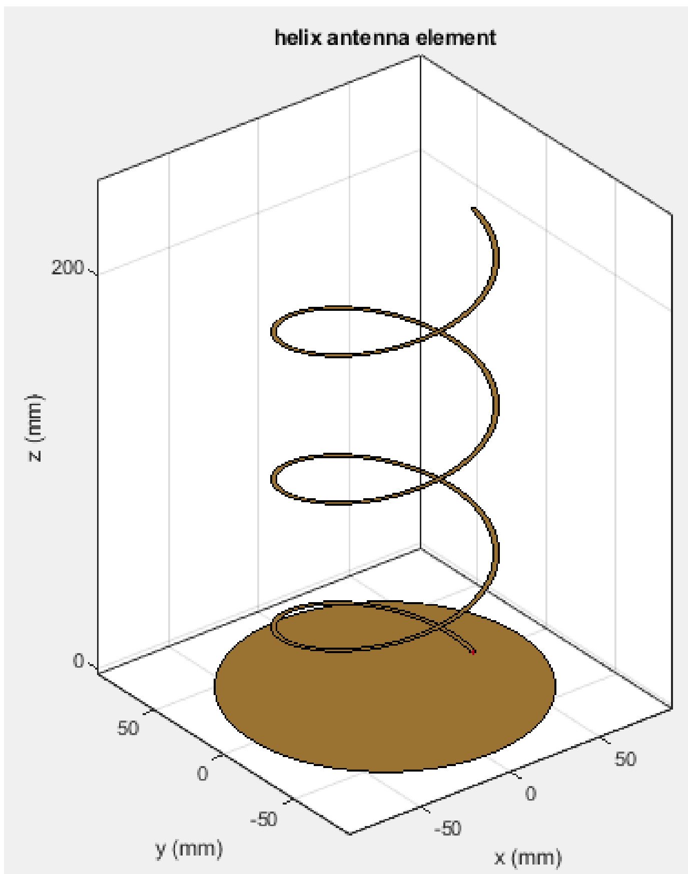

Figure 7: 1GHz copper helical antenna design modeled in MATLAB's Antenna Designer.

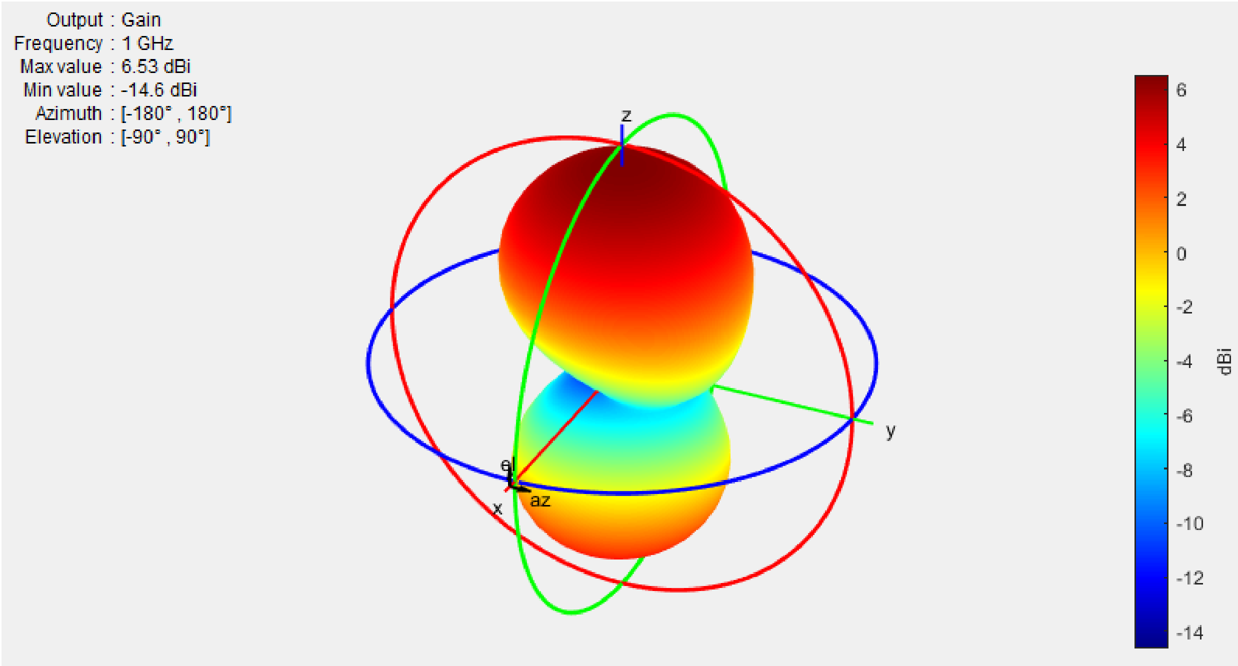

Figure 8: 3D antenna gain pattern of the antenna shown in Figure X.

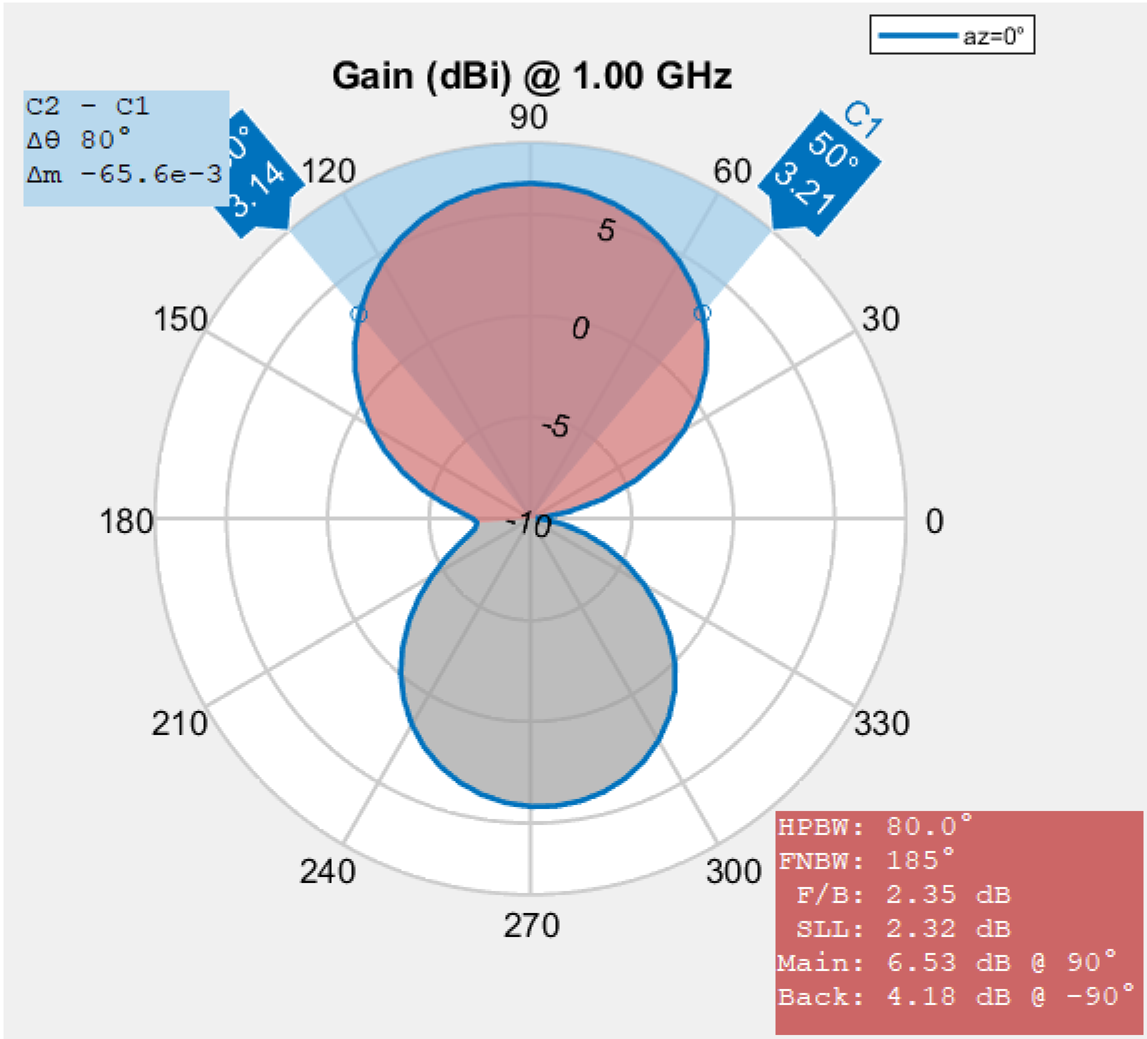

Figure 9: 2D elevation gain pattern of the antenna shown in Figure X.

1.6 Thermal Control Plan

As of writing, the thermal control plan is still fluid. The components most in need of thermal control are the low noise amplifiers (LNAs) which ideally should stay within a 1°C temperature range. The temperature of each LNA will vary its gain, so thermistors will be placed on each LNA and the temperature of each amplifier will be periodically measured and recorded by the OBC so that each LNA's gain throughout the flight will be known for data analysis.

The team expects that the temperature of the payload will tend too low rather than too high, though thermal vacuum tests will be performed to confirm this. Depending on how these tests go, the payload will likely be wrapped in polyimide tape to prevent heat from escaping.

Though there are no thermal vacuum chambers on the Iowa State University campus with which to test the payload, a nearby university does have one. The CySat team will be reaching out to the instrument's operators within the next few weeks to set up testing dates.

2. Team Structure and Management

2.1 Team Organization and Roles

CySat is a part of the College of Engineering's Make to Innovate (M2I) program which is taken as a semesterly for-credit course, so membership often fluctuates from semester to semester. Moreover, recruitment typically takes place in the first week of every semester which at the time of this application's submission has not yet occured. However, all three of CySat's regular members from the fall 2021 semester are slated to return and a few more new members from spring recruitment are expected to come onboard. A current organization chart is shown in Figure 10. Though CySat typically has team leads in addition to the project lead, the teams' compositions are reorganized every semester to suit the project's needs which vary significantly from semester to semester. New teams and team leads will be assigned once the spring roster is finalized.

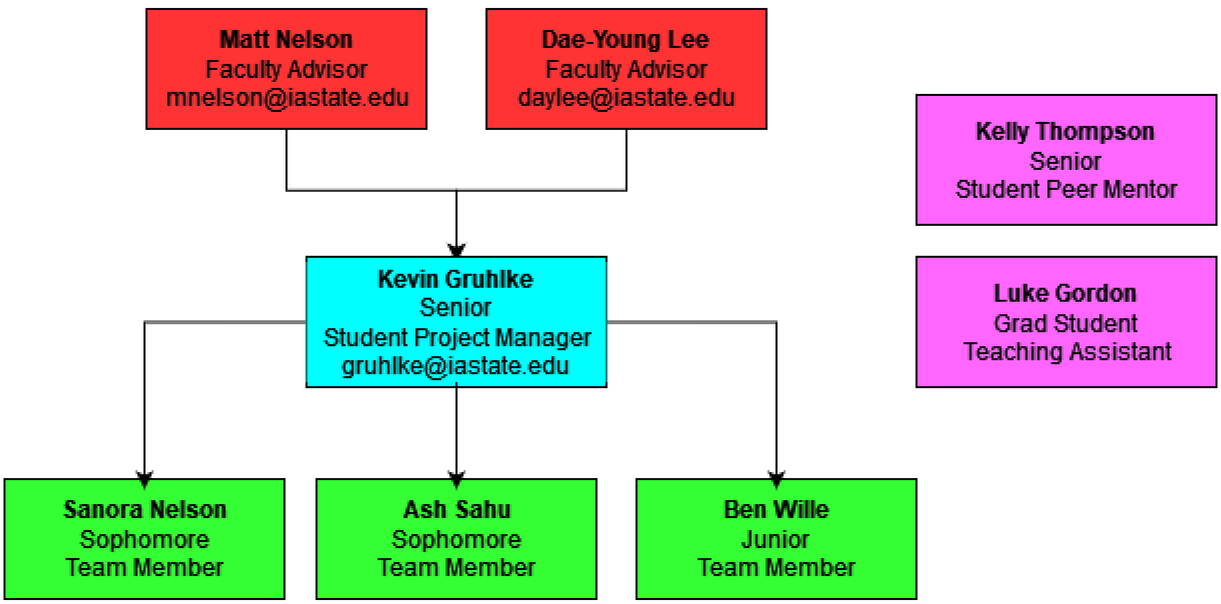

Figure 10: CySat org chart. Note that this does not include any new members gained from spring recruitment.

2.2 Timeline and Milestones

See Figure 11 below for a timeline of CySol's development, including major milestones and development stages.

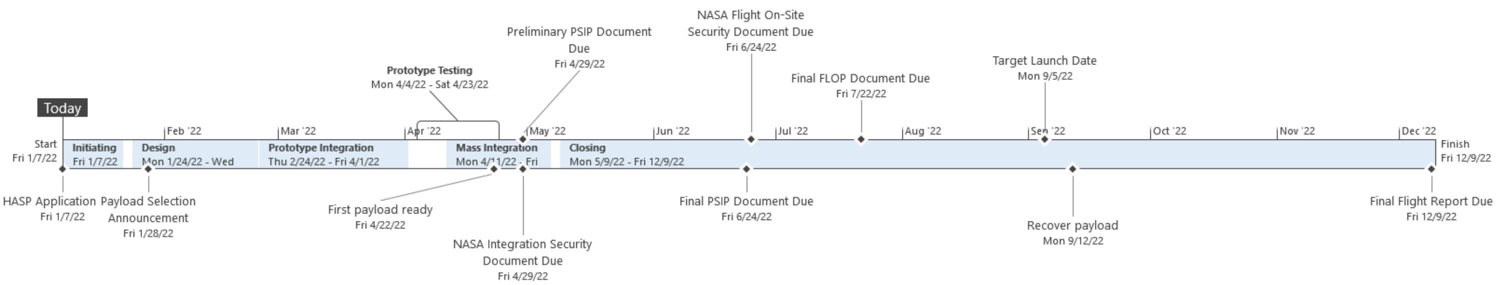

Figure 11: CySol 2022 timeline, including milestones and stages of development.

2.3 Anticipated Participation in Integration and Launch operations

The team plans to send 2 student members, plus both faculty advisors (assuming they are both available), to the payload integration and testing event in late July/early August. If the integration goes well and the team receives a Payload Integration Certification, the payload will not require any further intervention from the team for launch operations and there are currently no plans for any of the CySat members to attend the launch. However, if issues are uncovered during testing, then by necessity we will be sending the same amount of students and advisors to the launch to deliver the payload.

3. Payload Interface Specifications

3.1 Weight Budget

CySol's weight budget is shown below in Table X, along with the source of the weight shown in the comments column. Note that some components' datasheets did not list the weight. In those cases, the weight was estimated.

Item	Mass (g)	Uncertainty (g)	Comments
Helical antenna (including feedline)	135	15	SOLIDWORKS model's mass properties for copper
Enclosure (base and lid)	293	10	SOLIDWORKS model's mass properties for ABS
Compute Module 4	12	0.1	Datasheet
CM4 carrier board	43	0.1	Datasheet
MicroSD card	5	1	Estimated
LimeSDR	80	0.1	Datasheet
RS232 shifter	40	1	Estimated
Low noise amplifiers	23 each, 69 total	0.5 (total)	Datasheet
Bandpass filters	42 each, 126 total	0.5 (total)	Datasheet
LM2596 (voltage regulator)	10 each, 30 total	5 (total)	Estimated
EDAC 516 connector	14	0.1	Datasheet

DB9 DTE connector	20	5	Estimated
Misc. electrical components and wiring	100	25	Estimated
Fasteners	200	50	Estimated
TOTAL	**1167**	**100**	

Table 1: Weight budget

CySol has a total estimated mass of about 1.2kg, far less than the maximum of 3kg allotted to small payloads.

3.2 Power Budget

A small payload on HASP provides up to 15W of power (0.5A at 30V). Based on the power budget shown in Table 2 below, CySol will be capable of carrying out its mission with the provided power source without exceeding 15W.

Item	Voltage (V)	Current (A)	Power (W)	Comments
Compute Module 4 and Carrier Board	+5	1.0±0.4	2 (idle) up to 7 (max), expected 5 (avg)	Current draw determined from CM4 datasheet. Depending on the tasks it will carry out, required power may vary considerably; testing will be carried out to find actual power consumption.
LimeSDR	+12	0.2±0.05	2.5±0.6	Current draw determined from the LimeSDR's constituent components' datasheets. Like the CM4, required power may vary considerably depending on implementation and further testing is required.
Low Noise Amplifiers (x3)	+3	0.056±0.01	0.50±0.10	Current draw determined from ZX60-P33ULN+ datasheet.
BOB-11189	+3.3	0.0006±0.0003	0.002±0.001	Current draw determined from SP3232 datasheet.
Voltage Regulators (3V, 5V, 12V)	+4-+40	-	2.63±1.13	Power losses due to regulator inefficiencies are modeled here as power consumption. This number will be static throughout the flight, but its actual value will depend on the amount

				of current passed through each regulator since the efficiencies are dependent on output voltage. Once again, further testing is required.
TOTAL			**10.6±3.8**	**Steady state: 10.6W** **Transient: 14.4W**

Table 2: Power table showing voltage, current, and power consumption by component.

Note that all of the values shown in Table 2 are estimates from documentation. The team's mission timeline includes power consumption verification for each component listed in the table. It is unlikely that the steady state power consumption will exceed 15W as this would represent a nearly 50% increase over expected values; however, if the transient power consumption exceeds 15W during testing, then the team will consider two options:

1. scaling back the intensity of the computational loads on the SDR and OBC as much as possible (e.g., making more efficient code) without compromising the payload's mission since most of the transient power draw will be from the computational loads on these components; or,
2. placing circuitry including a 0.5A constant current IC and a high-farad capacitor between the power interface and the rest of the electronics which will allow the payload to store excess power when consumption is below 15W and then use the stored power in addition to the HASP's power supply when consumption exceeds 15W.

3.3 Downlink Serial Data

CySol will be downlinking telemetry data. The solar flux measurements will be too large to downlink, so that data will be stored onboard the payload. Downlinking will be reserved for health checks carried out by the OBC on the rest of the system.

3.4 Uplink Serial Commanding

CySol has no planned serial commanding needs.

3.5 Analog Downlink

CySol has no planned analog downlink needs.

3.6 Discrete Commanding

CySol does not intend to utilize the extra discrete commanding capabilities.

3.7 Payload Location and Orientation Request

CySol has no payload seat preference. The data-collecting antenna is directional with the direction of highest gain being roughly straight up and the antenna's gain profile is essentially symmetrical around this axis, so the payload's data-collecting capabilities will be equal in any seat.

3.8 Special Requests

CySol has no special requests and does not intend to submit a request waiver.

4. Preliminary Drawings and Diagrams

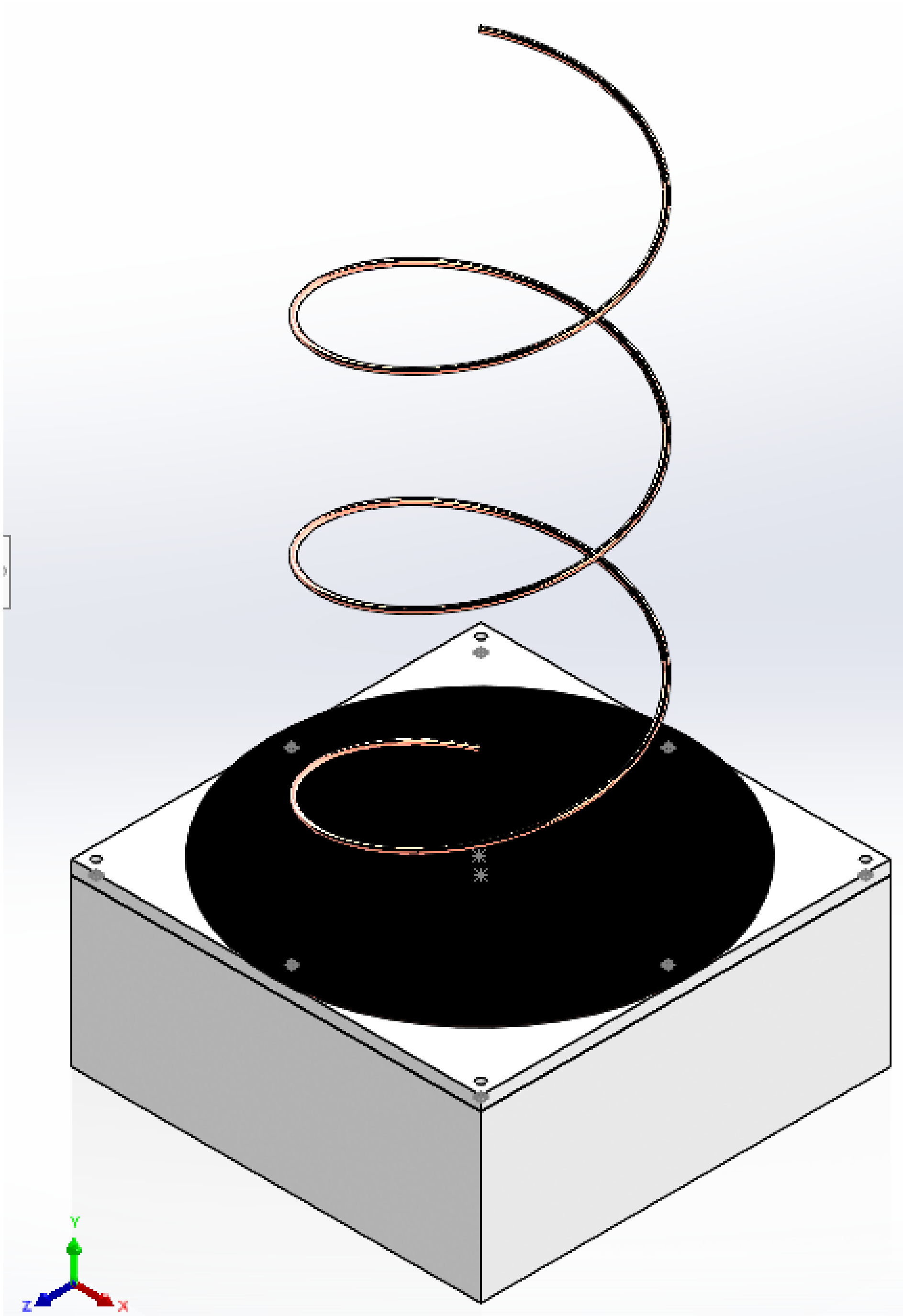

Figure 12: Full model of CySol payload.

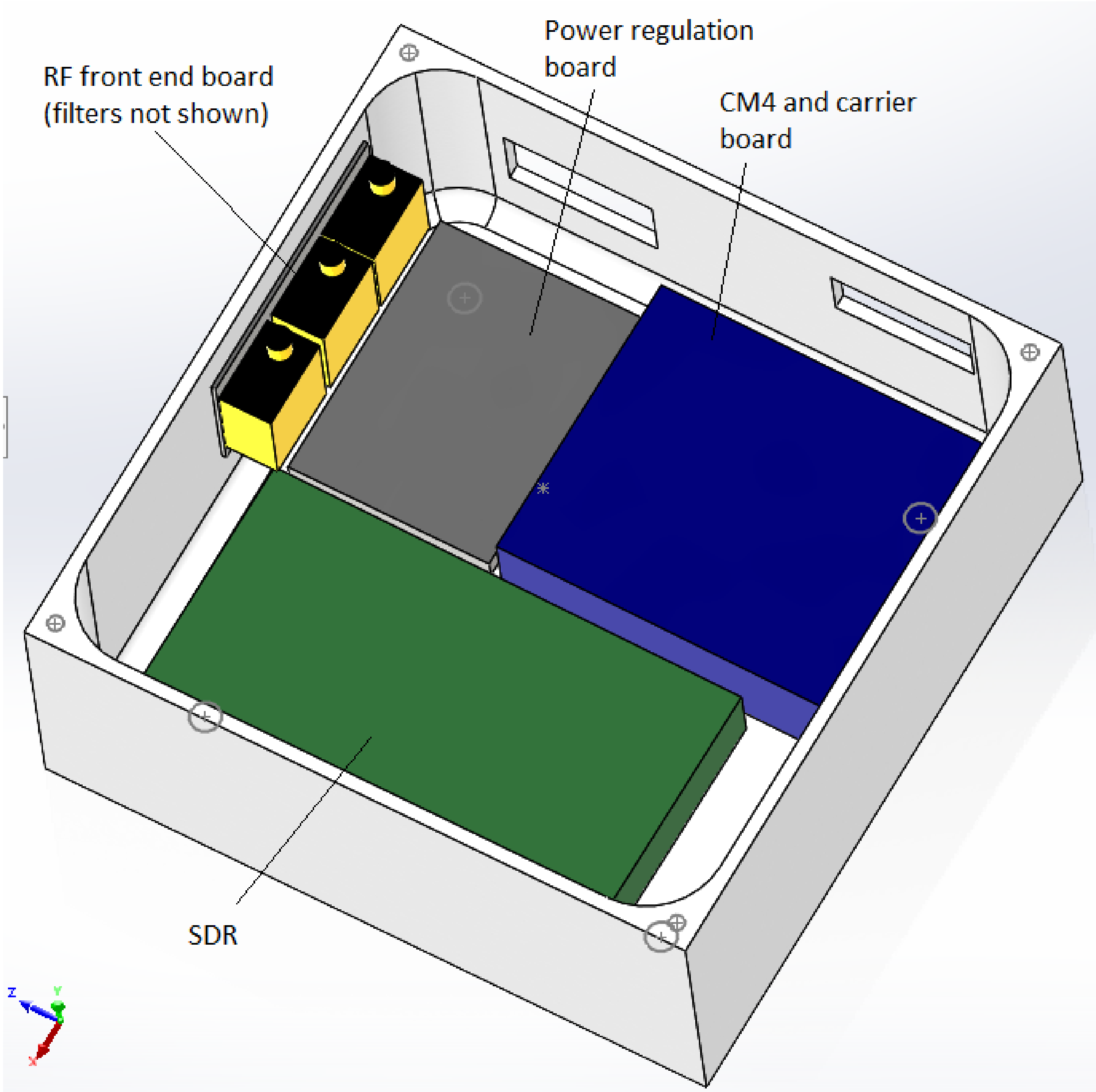

Figure 13: Enclosure base with internal components labeled. The 1GHz bandpass filters are not modeled here because they are cylinders that fit in-line with the coaxial cables connecting the LNAs rather than needing to be mounted on a board. Note, on the far face, the port for the EDAC connector (left) and the port for the DB9 connector (right).

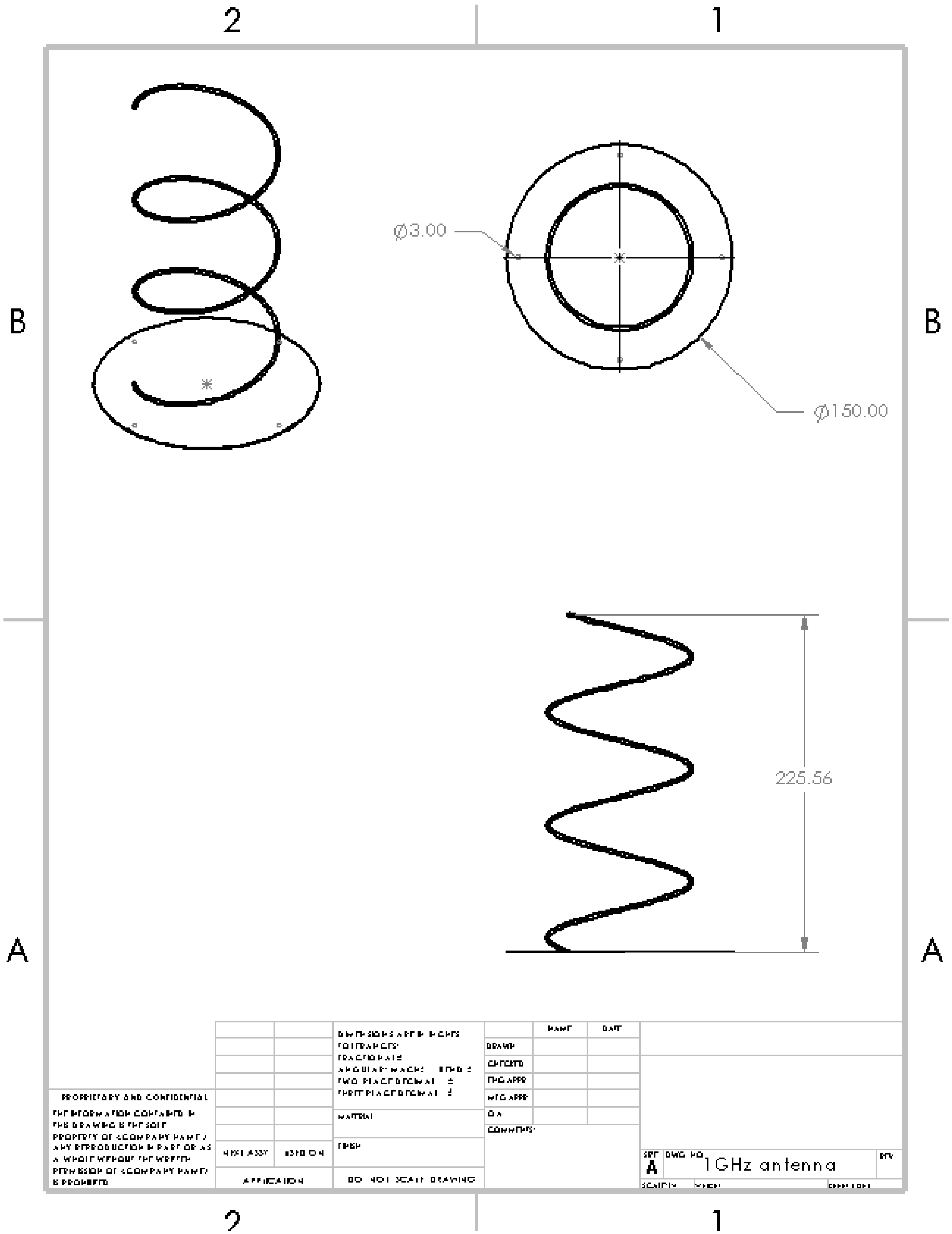

Figure 14: 1GHz antenna drawing. It is a 3 turn helical antenna with 7.5cm spacing between turns. The top right image shows the diameter of the ground plane and the diameter of the through holes that will be used to attach the antenna to the enclosure lid. Units in millimeters.

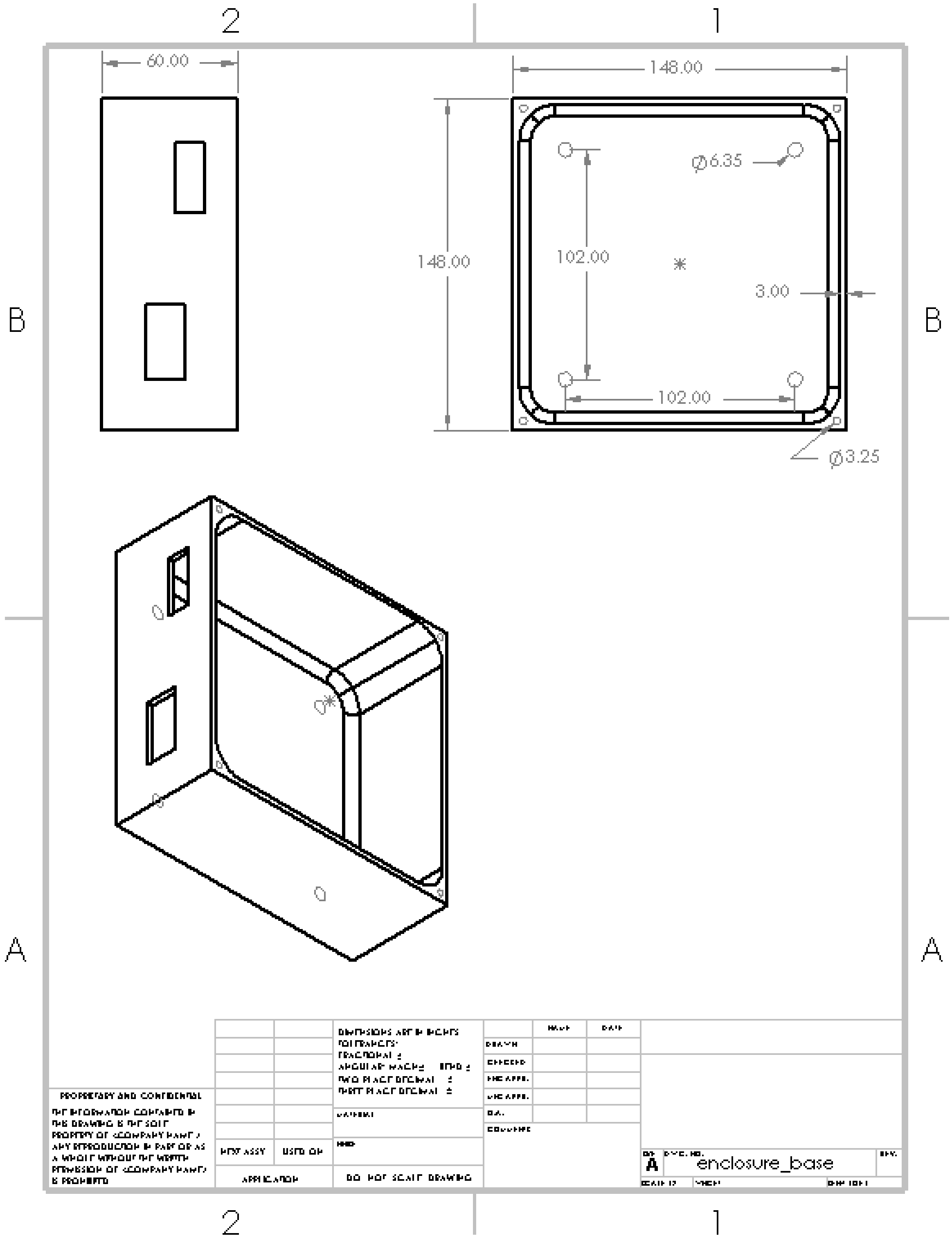

Figure 15: Enclosure base. In the top right image, note the 6.35mm holes used to attach the payload to the mounting plate and the 3.25mm holes used to attach the enclosure lid. Units in millimeters.

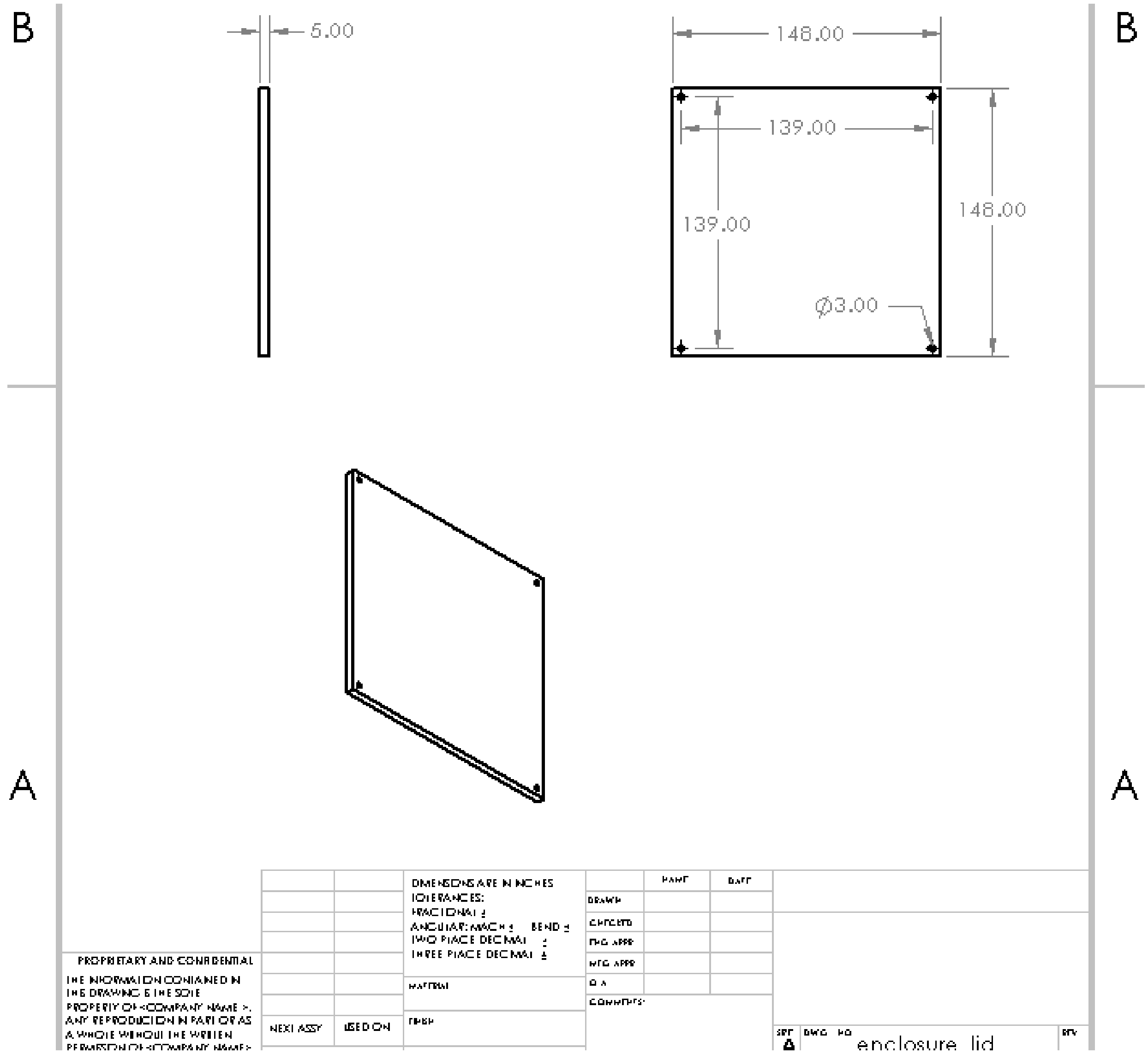

Figure 16: Enclosure lid. Units in millimeters.

The mounting plate, the planned alterations for it, and the method of attachment to the payload are outlined in section 1.4.

5. References

[1] https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/swe.20064

[2] https://www.swsc-journal.org/articles/swsc/pdf/2017/01/swsc160042.pdf

[3] https://www.rcgroups.com/forums/attachment.php?attachmentid=4473756 (helical antenna w/ pvc)

[4]
https://hackaday.com/2020/08/04/a-hybrid-helical-antenna-for-the-eshail-2-geosynchronous-repeater/
(helical antenna w/ wire holder)