Magnetically Clean Antenna Design for CubeSat Missions

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1. Abstract:

Steel carpenter's tape has been a common choice for antennas on microsatellites and CubeSats for decades due to its simplicity and reliability. However, the magnetic permeability of spring steel is unsuitable for use on satellites with fluxgate magnetometers. Our magnetically clean design for the ELFIN mission relies on phosphor bronze extension springs to provide the energy needed to deploy two aluminum antenna elements to form a UHF dipole. These elements are secured by conventional nylon lines onto raised platforms on the solar panel to prevent contact with the solar cells during launch. Surface mount burn resistors are used to deploy the antenna elements, which is registered with snap-action switches (identical to our P-POD deployment switches) and photodiode/emitter pairs.

In addition to magnetic cleanliness, the design was heavily driven by the limited internal and external volume and mass available. Solar cells on the exterior of the satellite placed constraints on where the antenna elements and spring could be secured to the panel. Internal torque coils placed limitations on the spring length, necessitating springs with a higher spring constant. The deployment mechanism and RF properties of the system are currently being tested.

2. Design Options:

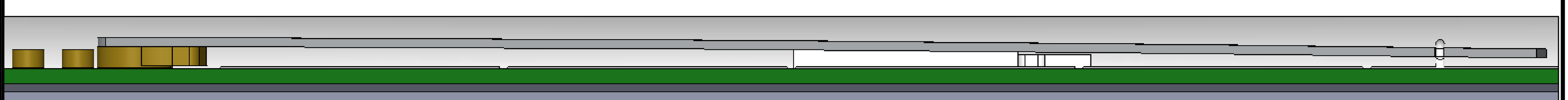
Satellites that contain magnetometers are often restricted to using nonmagnetic materials. This limitation prevents ELFIN from using carpenters tape, which is a spring steel, as antenna elements. One proposed alternative was a tape spring constructed from a nonmagnetic material, such as phosphor bronze or beryllium copper. This is being employed for two out of the four antennas for ELFIN.

One of the UHF dipoles requires a different deployment mechanism to avoid "cutting into" the 3U rails. While a certain amount of recessed rails is permitted in the CubeSat Design Specification, this is undesirable for ELFIN due to structural and internal layout considerations.

3.1 Stowed Configuration:

In the stowed configuration, each antenna element is held in place with a nylon line. Each nylon line passes over two redundant burn resistors that are used for deployment. The aluminum elements rest on Delrin blocks that prevent the antenna elements from contacting the solar cells during launch. The Delrin block also reduces the risk of the nylon line being overly tight when stowed, which can permanently deform the elements.

The aluminum and tape spring antennas are oriented in a manner such that, should antenna deployment accidentally occur within the P-POD, deployment of the CubeSat itself should still be successful, although probably at a reduced velocity.



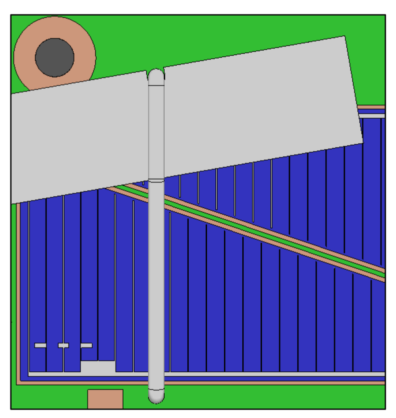
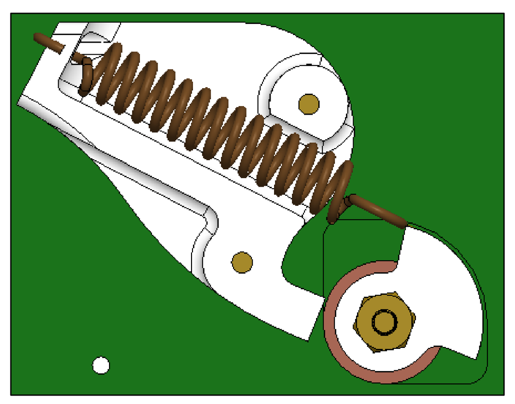
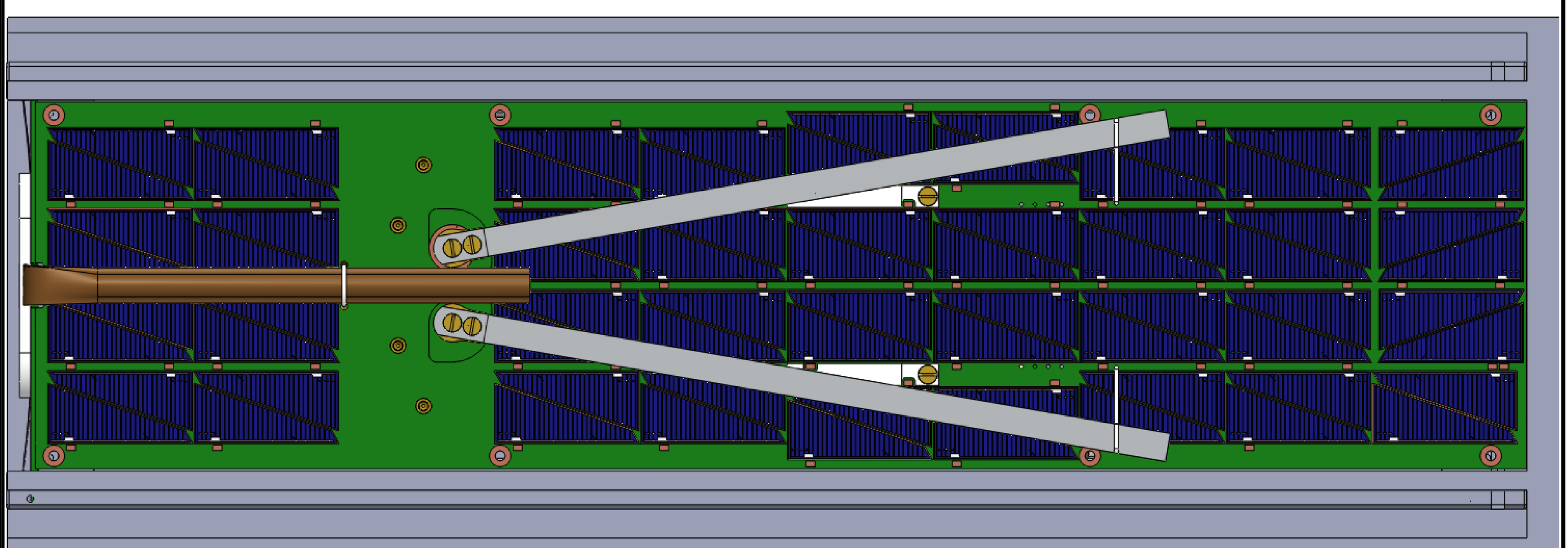


Figure 1 (top): Antenna elements in stowed configuration resting on Delrin blocks. The elements are ~3.5 mm above the board.
Figure 2 (left): Nylon line used to secure antennas in stowed configuration.
Figure 2 (right): Spring in stowed state.
Figure 3 (below): Antennas in stowed configuration inside of the P-POD. The CubeSat is ejected to the left





3.2 Deployment:

The antennas are deployed by burning through the nylon line with burn resistors. Traditionally CubeSats have used through hole resistors, but for ELFIN's layout this would mean less area would be available for solar cells. We have instead opted to use surface mount resistors, one on the outside face of the PCB, and the other on the inside face. Thermistors next to each resistor provide an important telemetry point, and when combined with a pre-timed burn duration, prevent the resistors from burning out. Power is applied to the resistors in ~100 ms pulses, with ~10s of cooldown, until confirmation is received that the antennas deployed.

Once the nylon line has been cut with the burn resistors, a phosphor bronze extension spring provides the energy needed to rotate the antenna elements into the deployed configuration. The phosphor bronze spring is anchored to a piece of Delrin on one end and a line is tied to a cam on the other end, converting the linear motion into the rotational motion needed to deploy the antenna elements. A stop on the cam prevents the antennas from rotating too far. The antennas are secured to a brass piece that passes through the PCB and interfaces with the cam.

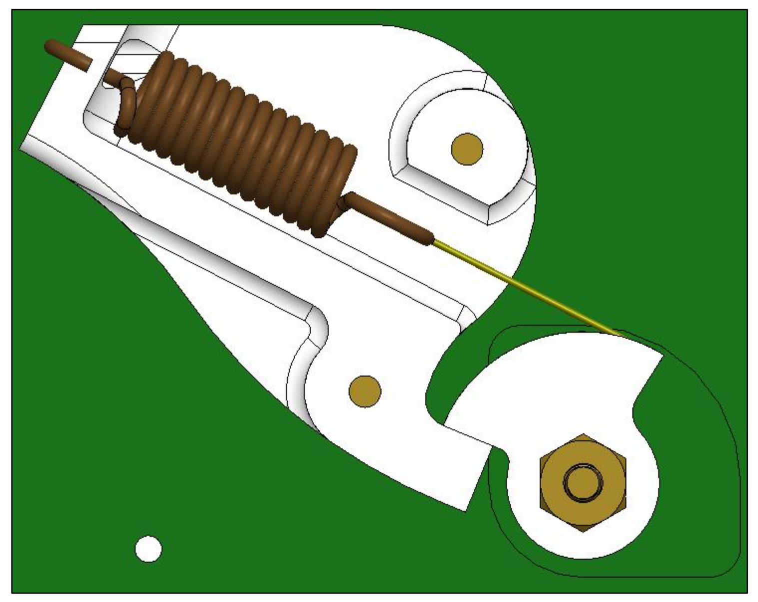
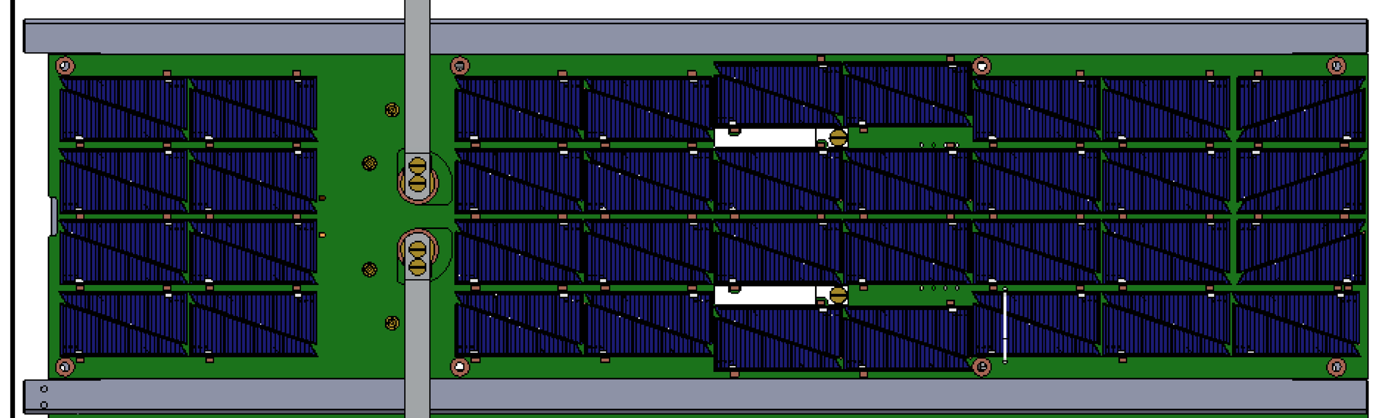


Figure 5 (right): Spring mechanism in deployed configuration.

Figure 6 (below): Antenna elements in the deployed configuration.



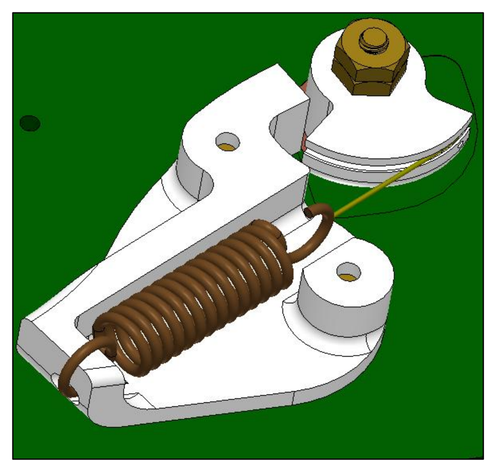


Figure 7 (right): Spring in a partially extended state. A line connects the spring to the cam, which converts the linear motion to rotational motion.

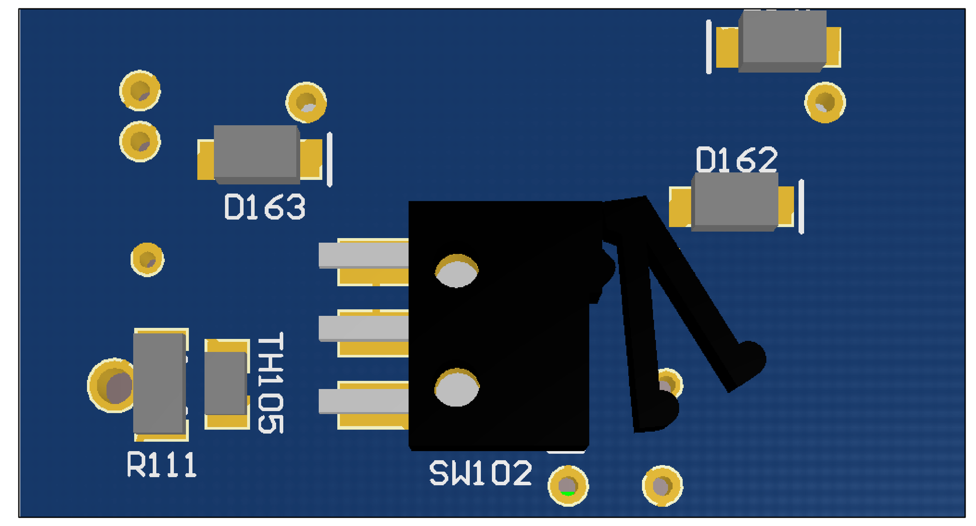
3.3 Spring Choice:

Several different springs and spring materials were examined. In the early stages of the design, torsion springs were considered as they directly convert their energy into rotational motion. However, lightweight nonmagnetic variants of these springs were incapable of providing the energy necessary to deploy the antennas. Other springs, such as balance springs, suffered from similar shortcomings, and extension springs became the logical choice. Phosphor bronze was chosen as the material as it is nonmagnetic, cheap, and relatively stiff. The spring was sized so that it is capable of deploying the antenna while the CubeSat is tumbling. Additionally, the spring is slightly oversized so that it is still 10% extended when the antenna is fully deployed. This ensures that antennas remain in the fully deployed configuration throughout the mission.

3.4 Deployment Detection:

Successful antenna deployment is detected with two different sensors. An ultraminature snap-action switch adjacent to each nylon line detects whether or not the resistors successfully burned through the line. These are the same switches used on our rails to indicate deployment from P-POD, and have heritage from Cal Poly's Polysat program (and likely other teams) and will be used on AMSAT's Fox cubesats. The contact current exceeds the 5ma minimum whetting current to ensure reliable detection, while an upstream MOSFET will inhibit the current after the switches have been used, preventing a permanent power drain.

Figure 8: The ultraminiature snap-action switch, shown in both the depressed and relaxed state, is used to detect nylon line burn through. The switch is placed at the edge of the via that the nylon line passes through to ensure it won't be sent a false signal during the launch environment.



Additionally, a pair of photo diodes, one for each antenna element, detects whether the elements have reached their fully deployed state. The photo diodes are bottom-facing and mounted inside the CubeSat structure to reduce the UV exposure that will brown the photodiode's plastic enclosure. A plated hole in the PCB acts as a simple collimator, and from a layout and schematic perspective this resembles a coarse sun sensor.

LEDs are mounted on the exterior surface, adjacent to the collimators. When the antenna elements are fully deployed, the light from the LED should reflect off of the antenna elements and be detected photo diodes. It is expected that this verification would best work while eclipsed, although a modulated single similar to consumer remote controls could enable verification while illuminated. It is expected that the LED be either in the infrared range (matching the peak response of the photodiode) or be visibly red, which also provides a significant photodiode response while also being a useful visible indicator during debugging, assembly, & test.

3.5 Antenna Elements:

The antenna elements are made of strips of 6061-T6 aluminum. The current design relies on elements that are 6.4 mm wide and 1 mm thick. The elements are secured to a piece of brass that is compressed against a solder pad on the PCB. RF signals are sent from an SMA connector, through a matching network on the panel, and into the antenna elements.

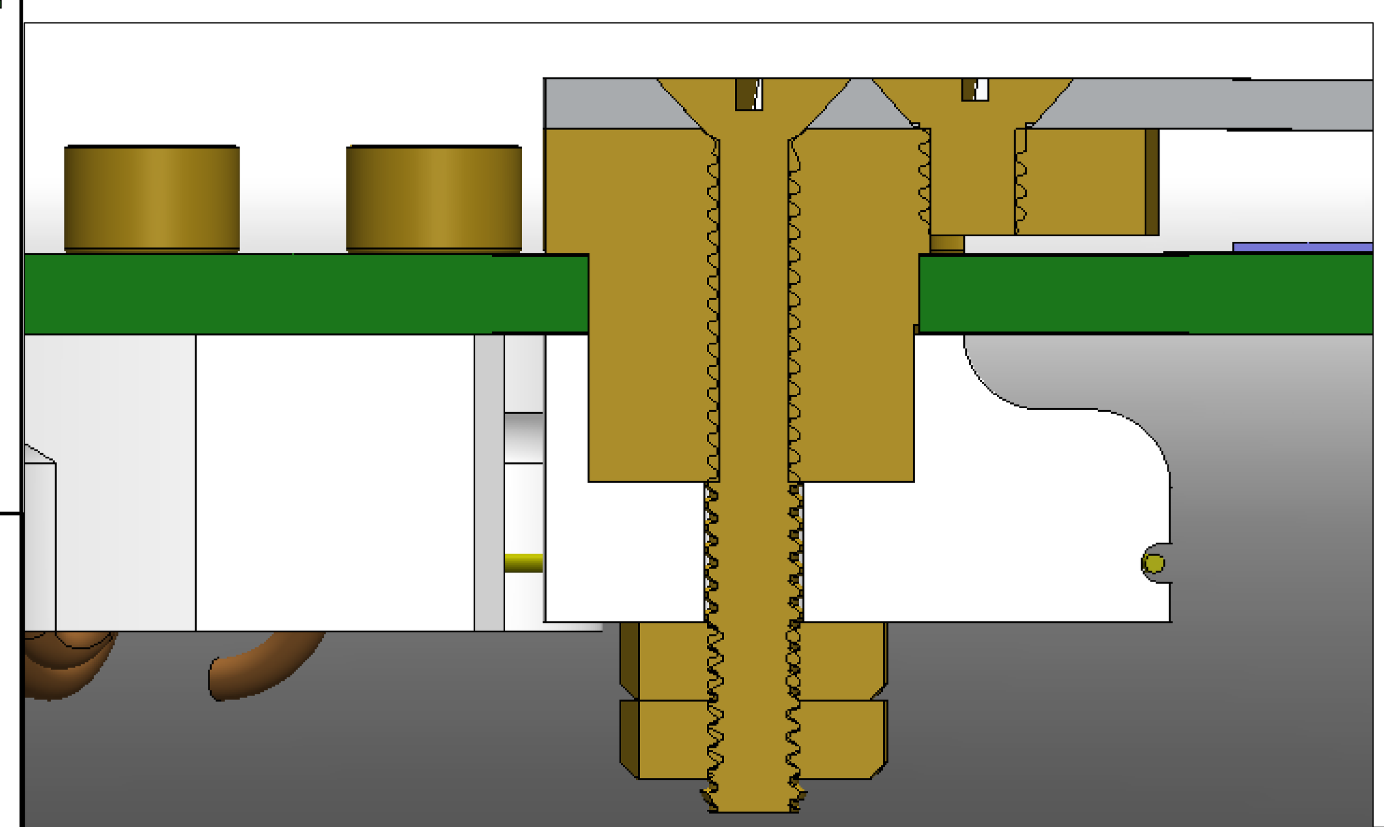


Figure 9: The antenna is secured to the brass piece with two countersunk 2-56 screws. The brass piece has a key feature in it to ensure that it doesn't slip with in the Delrin cam on the underside of the board. The compression between the brass piece and the solder pad is set by torquing the two brass nuts . Two nuts are used to ensure the assembly doesn't slip during launch.

3.6 Testing and Future Work:

A prototype of the antennas has been fabricated and are currently being tested. Initial tests with the burn resistors have been successful and deployment testing will begin shortly. RF testing of the antennas is also in progress. Preliminary test results have demonstrated that this design represents a viable option for use on CubeSats that have strict magnetic cleanliness requirements

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