A Low-cost, Miniaturized, Homogeneity-optimized Helmholtz Cage for CubeSat Attitude Control Ground Testing

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Introduction

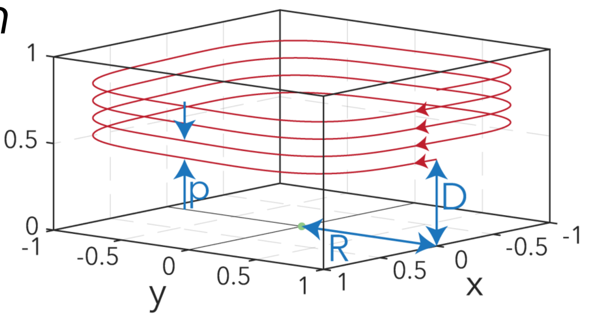
- As CubeSats are subject to a large initial tumble during orbital injection, democratizing low-cost passive or active attitude control systems (PACS/AACS) is key to enabling accessible nanosatellite missions ranging from remote sensing to space debris tracking
- Magnetic stabilization techniques such as hysteresis rods or magnetorquers offer good rotational detumbling performance while being ideal for satellites with low-power budgets
- Rigorously ground-testing these sub-systems in a laboratory setting benefits from simulating the transient magnetic conditions in LEO (ex. overflying the poles)
- However, doing so in a large enough volume for a satellite to tumble in with flightlike high magnetic spatial homogeneity, all while keeping costs down for accessibility to student groups and researchers presents a complex optimization challenge
- We present a miniaturized, homogeneity-optimized 3-axis Helmholtz Cage of a modified *squircle* shape that can reproduce transient LEO magnetic fields for 1U satellites with high homogeneity (<1% **B**-field deviation) and for 2U satellites with modest homogeneity (<3% **B**-field deviation)
- *We believe this to be a first-of-its kind homogeneity and size optimization of a CubeSat Helmholtz cage*

Magnetic homogeneity

Squircle coil shape function

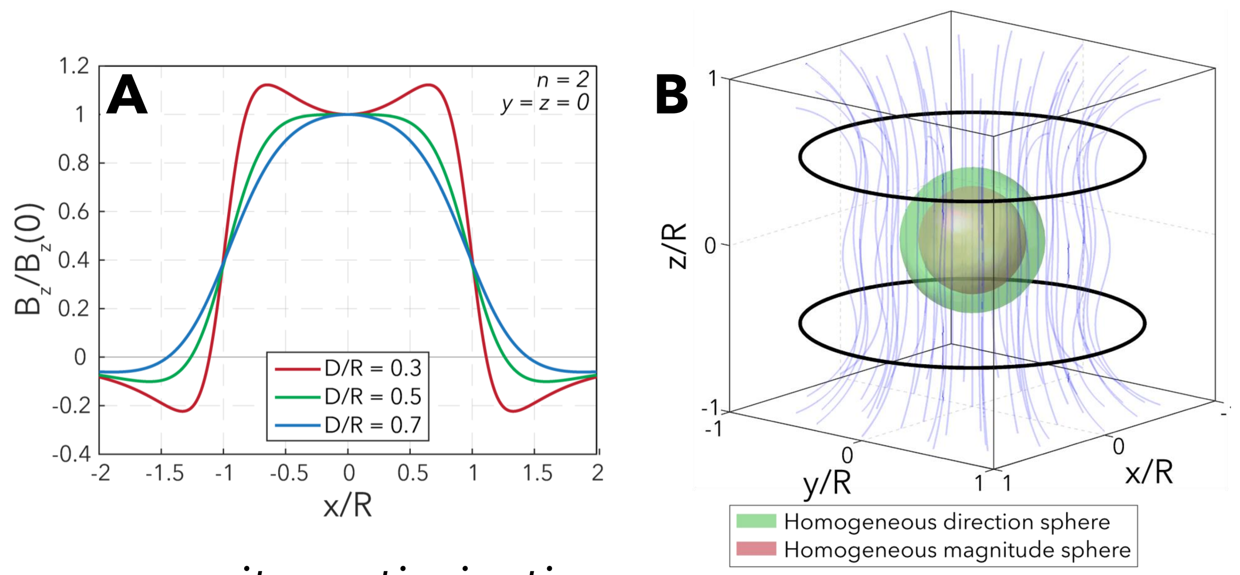
$$x^n + y^n = R^n$$

$$\mathbf{r}(\theta) = \left(r(\theta)\cos\theta, r(\theta)\sin\theta, \frac{p}{2\pi}\theta + D\right)$$

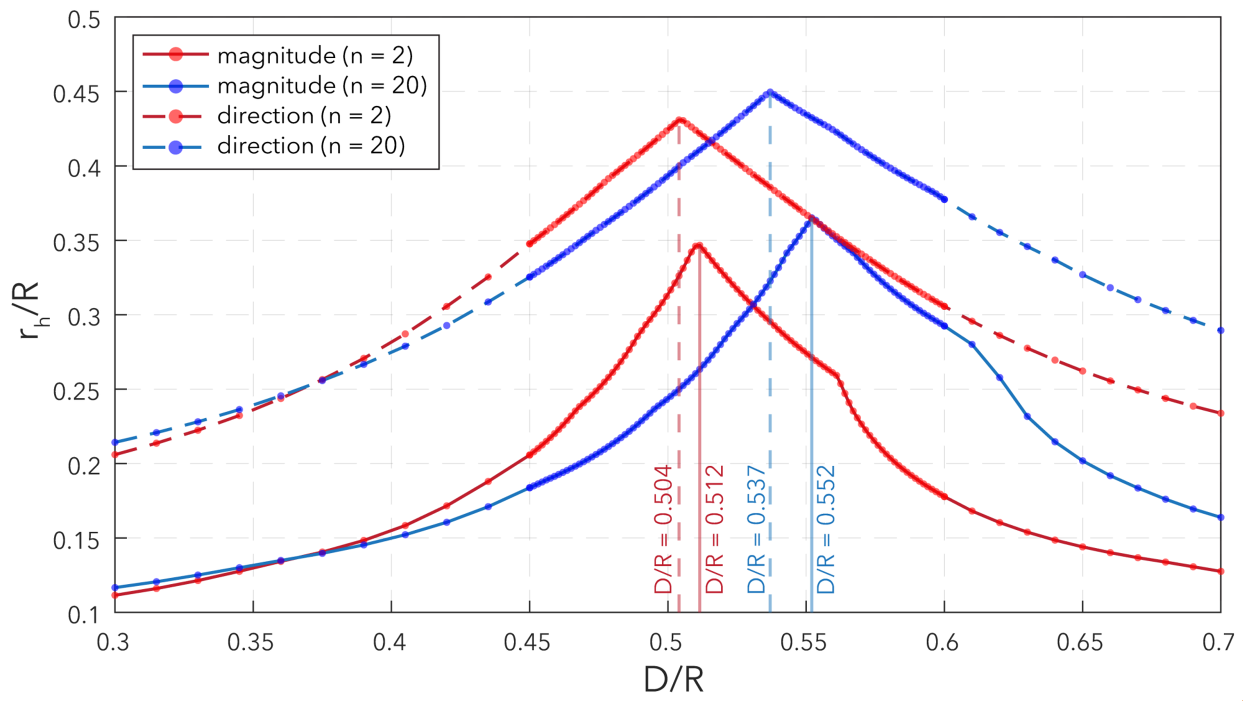


Numerical magnetic field simulation

$$\mathbf{B}(\mathbf{r_s}) = \frac{\mu_0}{4\pi}\sum_{j=1}^{N_{coils}} \oint_{C_j} I_j \left(\frac{\mathbf{dl} \times (\mathbf{r_s} - \mathbf{r_{c,j}})}{|\mathbf{r_s} - \mathbf{r_{c,j}}|^3}\right)$$

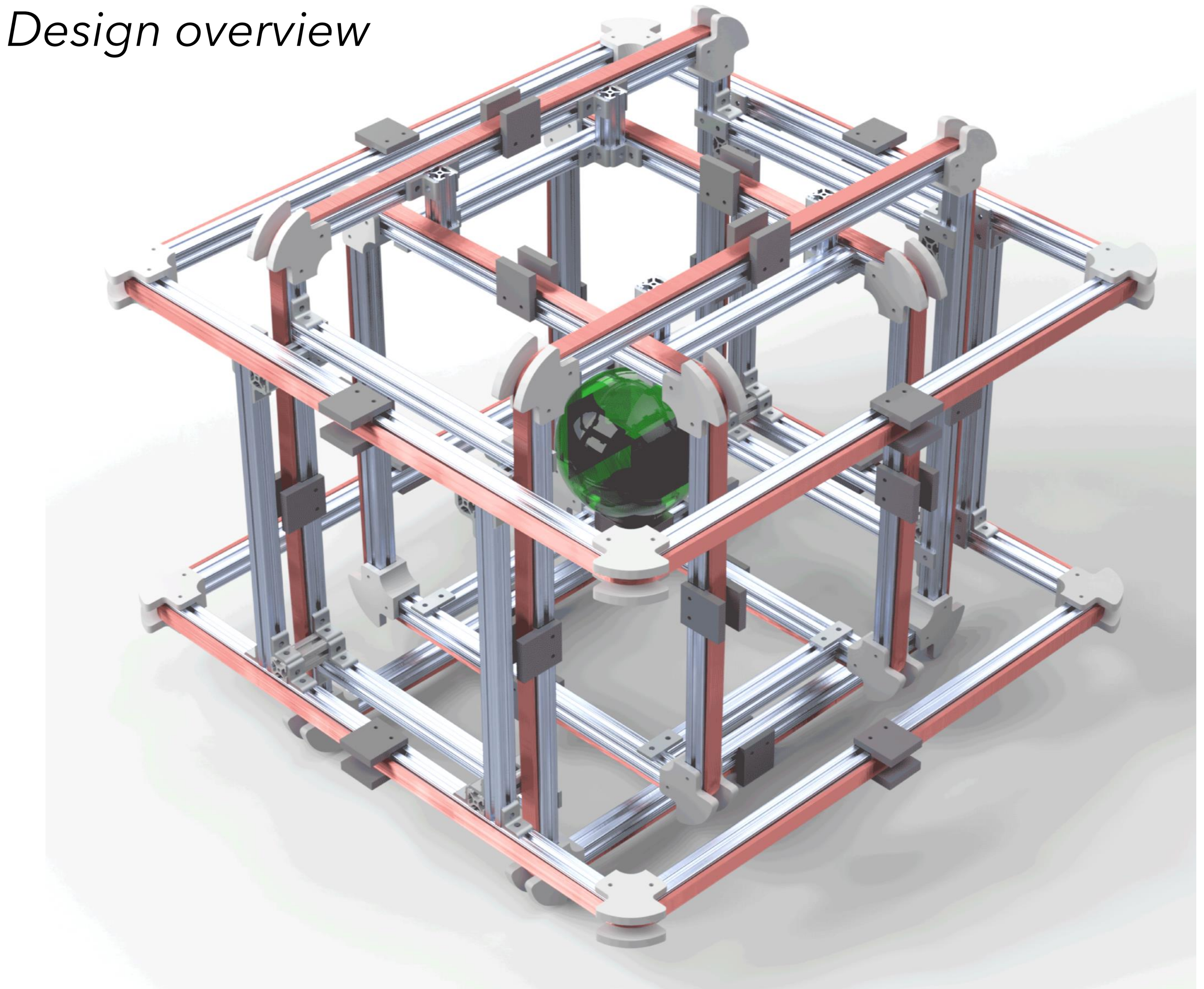


Homogeneity optimization



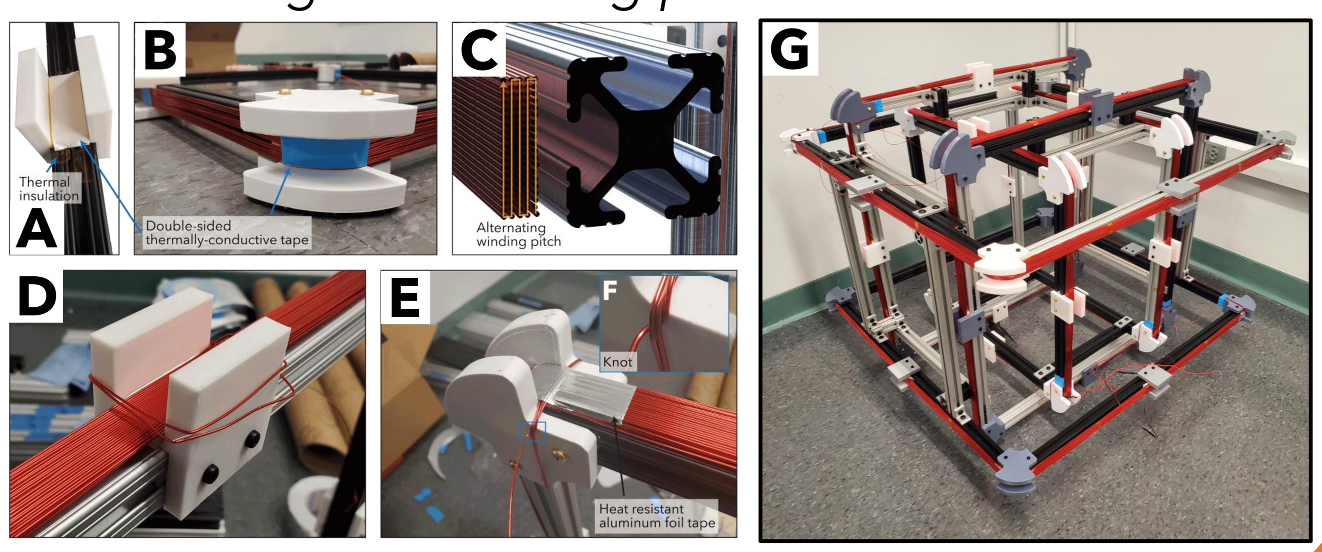
Coil design & manufacturing

Design overview



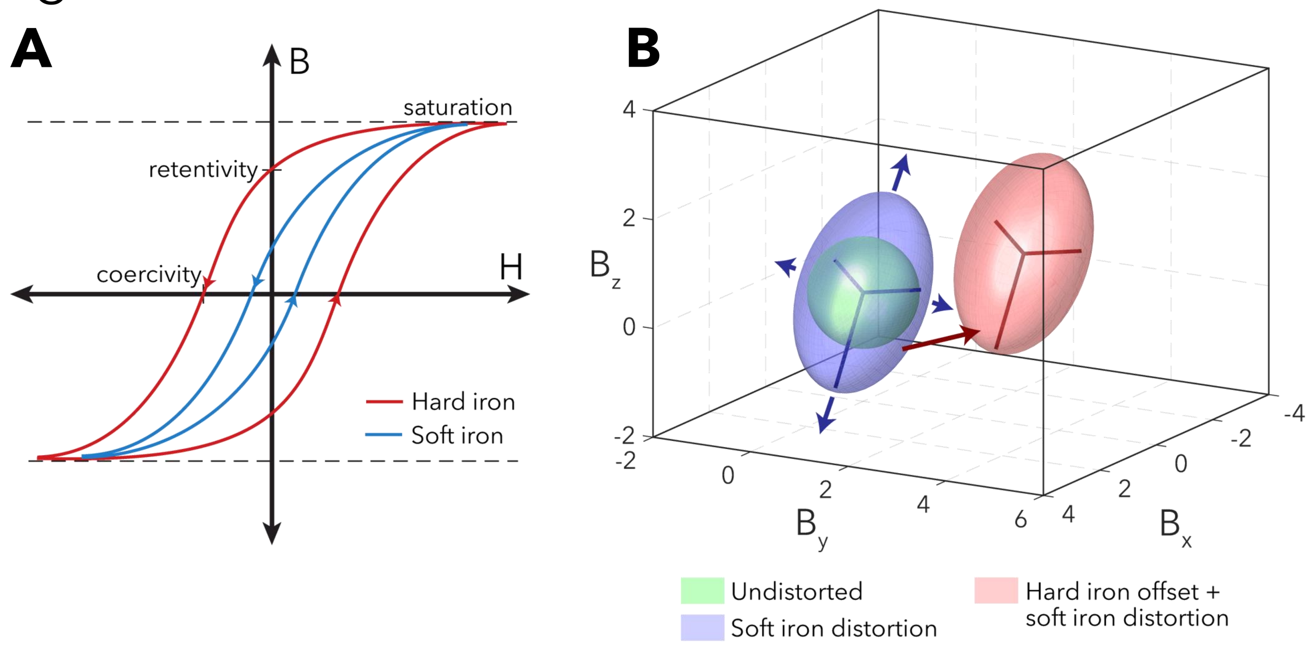
CubeSat size	Radius of sphere required (mm)	Maximum B-field magnitude deviation (%)	Maximum B-field direction deviation (°)
1U	86.6	0.68	0.23
2U	122.5	2.50	0.96

Manufacturing and winding process



Magnetic field diagnostics

Magnetometer calibration



Hard and soft iron correction:

$$\mathbf{B} = \mu_0(\mathbf{H} + \mathbf{M})$$

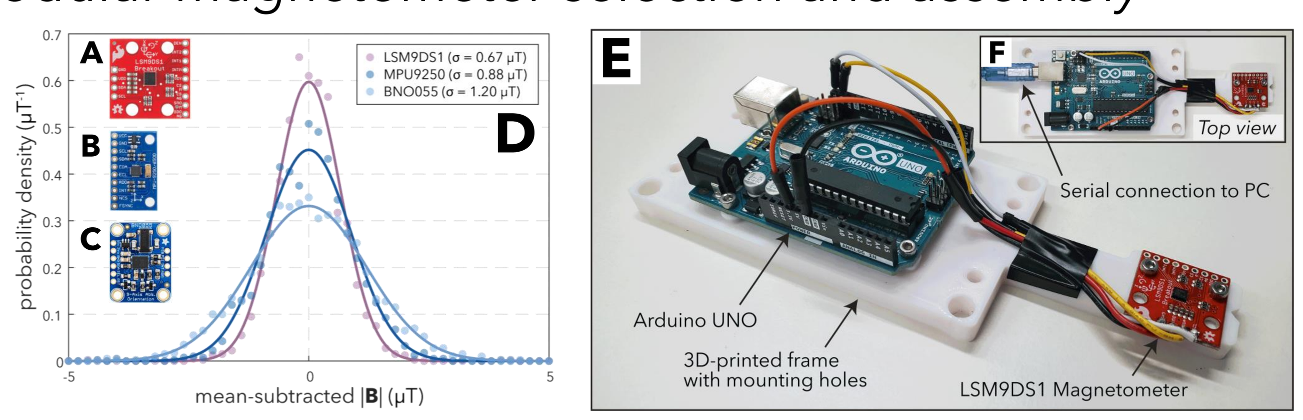
$$\mathbf{B_c} = E_{SI,C}E_{SI}^{-1}(\mathbf{B_m} + \mathbf{e_{HI}})$$

$$E_{SI} = \begin{bmatrix} b_1\vec{e_1} & b_2\vec{e_2} & b_3\vec{e_3} \end{bmatrix}$$

$$E_{SI} = b_c\begin{bmatrix} \vec{e_1} & \vec{e_2} & \vec{e_3} \end{bmatrix}$$

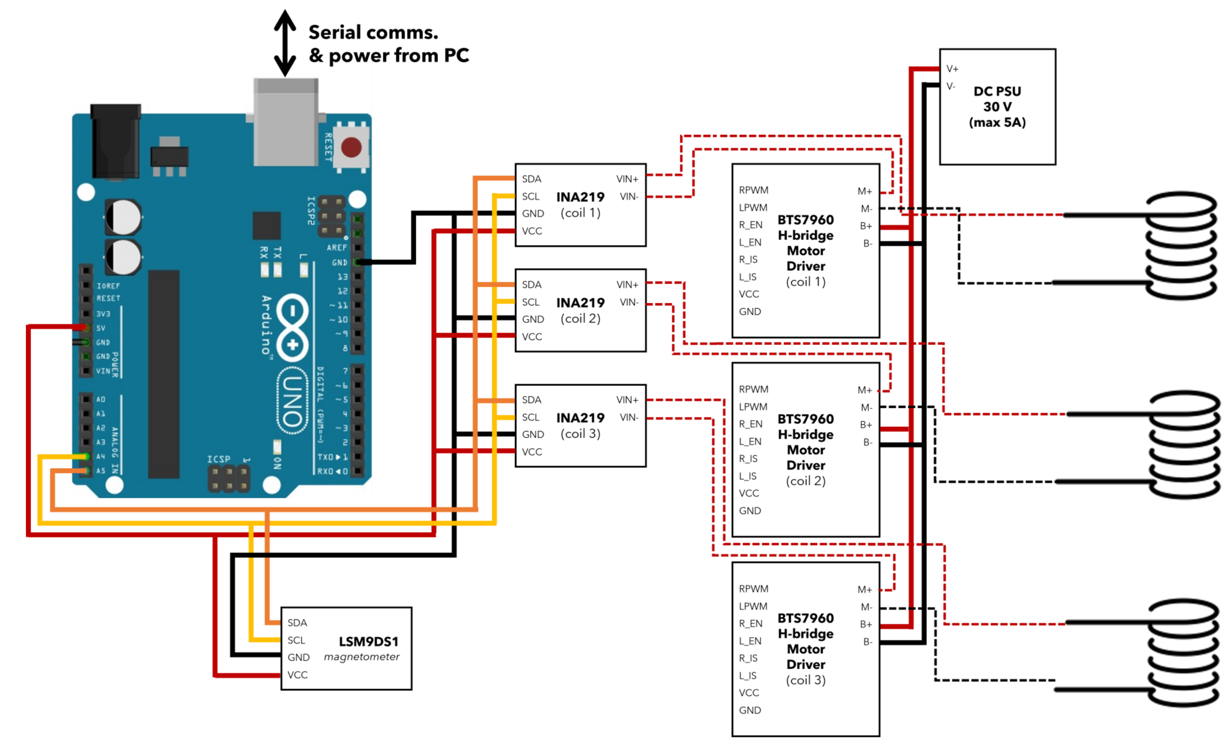
$(b_i, \vec{e_i})$: calibration eigenvector-eigenvalue

Modular magnetometer selection and assembly

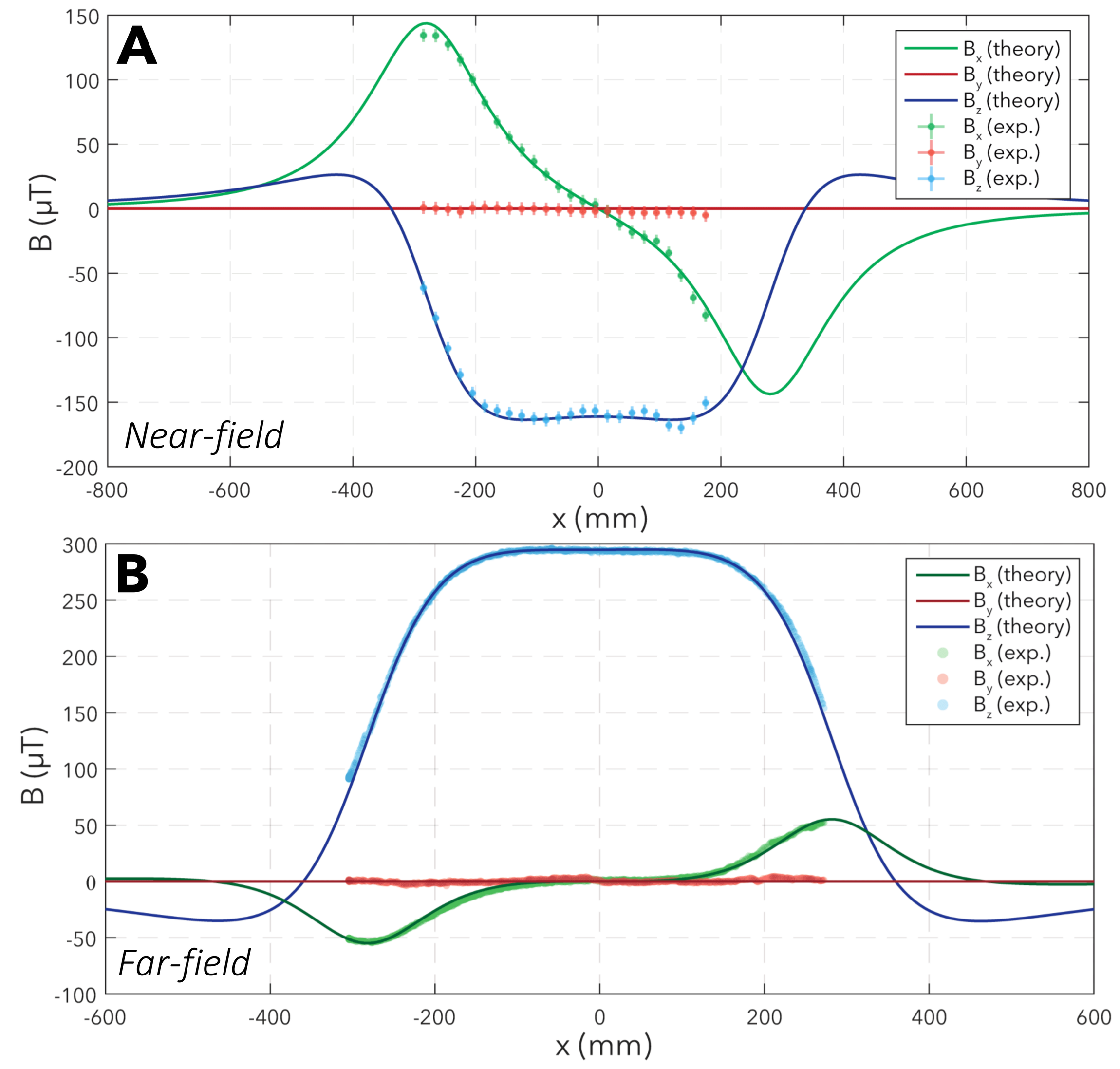


Control electronics & characterization

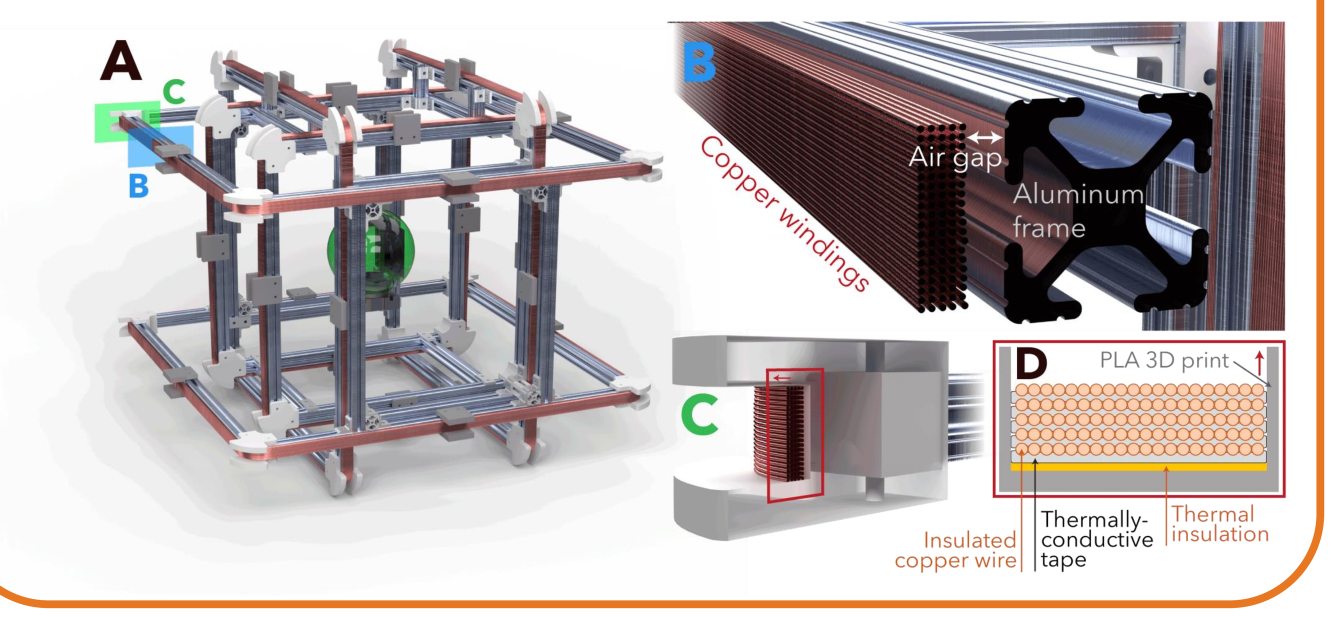
Control circuit



Field verification



Thermal considerations



Key references

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2. Al-Abri, Aaisha Rashid, et al. "Helmholtz cage for attitude testing of cubesat." 2022 Advances in Science and Engineering Technology International Conferences (ASET). IEEE, 2022.
3. Ozyagcilar, Talat. "Calibrating an ecompass in the presence of hard and soft-iron interference". Freescale Semiconductor Ltd, 2012, pp. 1–17.

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