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Active Electromagnetic Deflection: Optimized Satellite Radiation Shielding via Lorentz Force

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Abstract

This project presents an Active Electromagnetic Shielding system designed to protect satellites from space radiation. Using a Gaussian magnetic field model, we simulated how the shield deflects particles like light Helium ions (He^{+2}) and heavy ions like iron (Fe). By using a calculated magnetic flux density of 1.04 T, the system shows a strong ability to keep a safe area around the satellite even against fast moving particles. Our results show that using the Lorentz Force to push particles away is an effective, lightweight alternative to heavy traditional shields.

Introduction / Background

Space is filled with charged particles that pose a serious risk to satellite electronics, often causing permanent damage or system failures. Traditional protection methods use Passive Shielding , like thick layers of aluminum, which make the satellite very heavy and expensive to launch. To solve this, our project explores Active Shielding, which is a method that uses magnetic fields to change the path of charged particles before they hit the satellites. We focus on the most dangerous parts of space radiation which are Light ions like Helium and Heavy, high-speed ions like iron, which are the hardest to deflect.

- Secondary Radiation Risk: Traditional shields often fall against heavy ions because the collisions produce secondary particles that are more damaging to internal components than the original radiation.
- Active Defense Advantage: By using magnetic fields, we deflect particles before they collide with the satellite, ensuring no secondary fragments are created.
- Mission Sustainability: This approach is critical because it minimizes launch mass while maximizing protection.

System Model / Methodology

The simulation was created in MATLAB using a 3D particle tracking system.

- Main Principle: The system works based on the Lorentz Force Equation: **F** = q(**v** x **B**), which deflects particles when they enter the magnetic field.
- Calculation Method: We used the ODE45 solver to calculate the exact paths of ions as they move through the shield.
- Field Shape: The model uses a Gaussian Magnetic Flux shape , which is similar to the field created by real magnetic coils on a satellite.
- Testing: We tested the shield using different particle masses, charges, and speeds to make sure it works in various space weather conditions.

Table 1. Comparison of Shielding Technologies

Feature	Traditional Shielding (Passive)	Electromagnetic Shielding (Active)
Material	Heavy Metals (Lead / Aluminum)	HTS Coils providing magnetic flux density
Mass Impact	Very high (adds launch costs)	Minimal (low-mass HTS coils)
Efficiency	Decreases as particle's energy increases	Optimized for high-energy particles
Protection	Stops particles by collision	Deflects particles via Lorentz Force
Particle Scope	Charged & uncharged particles	Targets both light & heavy ions (charged particles only)

Proposed Solution / Main Idea

We propose an Electromagnetic Shield powered by High-Temperature Superconducting (HTS) Coils.

- How it Works: The system automatically sets the Required Flux Density (B_{req}) based on the speed and mass of incoming particles.
- Saving Weight: By using magnetic fields instead of thick metal walls, this design can reduce the shield's weight by more than 50%.
- Safety Zone: The design Uses a specific setting (σ = 1.8) to ensure that particles turn away long before they reach the satellite, creating a reliable "Safe-Zone".

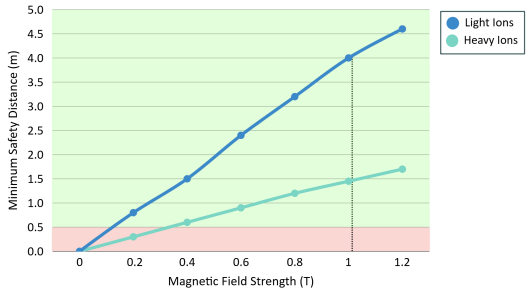


Chart 1. Impact of Field Strength on Minimum Safety Distance for Heavy and Light Ions relative to the Satellite Boundary.

Results / Simulation / Discussion

The simulation confirms a 100% deflection rate when using the calculated magnetic flux density 1.04 T.

- Mass Impact: Heavy ions have higher momentum, resulting in a smaller deflection angle and closer approach distances compared to light ions.
- Field Correlation: Chart 1 shows the relationship between Magnetic Flux Density and the Minimum Safety Distance; higher B values expand the safe-zone.
- Visual Proof: Figure 1 shows particles being deflected by the field, keeping the satellite completely protected.

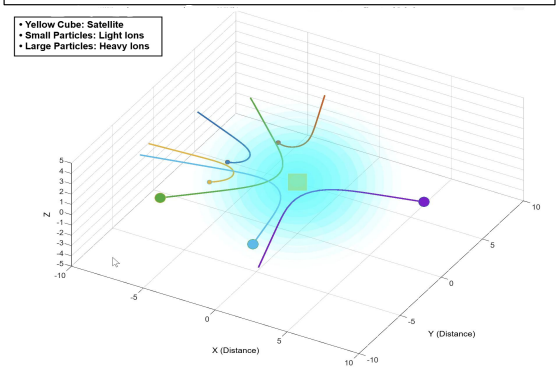


Figure 1. 3D Simulation of Particle Trajectories via Electromagnetic Shielding.

Conclusions

Our project proves that Active Electromagnetic Shielding is an effective way to protect satellites.

- Key Results: A magnetic flux density of 1.04 T successfully deflects both light and heavy space radiation.
- Main Benefit: Using this system with HTS Coils allows for lighter and longer-lasting satellite missions.
- Future Work: We aim to develop a Hybrid Shielding System that combines magnetic deflection with thin passive layers to provide protection against neutral and charged particles.