CHALLENGES OF LOW-POWER HALL THRUSTER MINIATURIZATION

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ABSTRACT

Hall thrusters are currently one of the most advanced as well as efficient types of electrostatic propulsion for spacecraft with an efficiency of about 50%.

Low-power Hall-effect thrusters (HET) produce about 100W of power, in comparison high-power ones can produce up to 100kW and beyond. Miniaturizing and creating low-power HET presents us with a significant number of issues that need to be addressed.

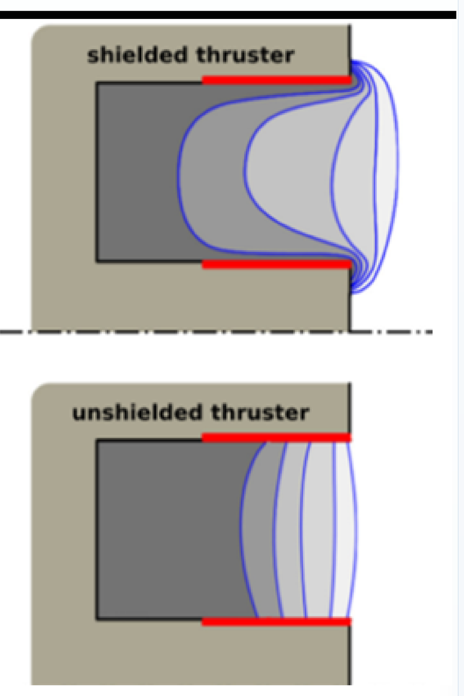
Low-power Hall thrusters exhibit a large surface-to-volume ratio, which translates into large power losses - the acceleration region has to be scaled down along with the channel width. The design of the magnetic field must be carefully adjusted to accommodate the reduced dimensions.

There is a large channel wall erosion rate problem to the point where the magnetic coils become exposed to the plasma flow and is the main source of failure in Hall thrusters. Miniaturized Hall thrusters have a smaller thermal mass, making them more susceptible to overheating. Effective thermal management is critical to ensure the components remain within operational temperature limits, and suitable materials must be chosen to withstand the heat generated.

Details of the channel structure, materials, design and magnetic field shape determine the performance, efficiency, and life of the HET. Hall thruster must be optimized in terms of gas injection system, geometry and magnetic field topology, in order to achieve higher thrust and efficiently use fuel.

Magnets and their topology

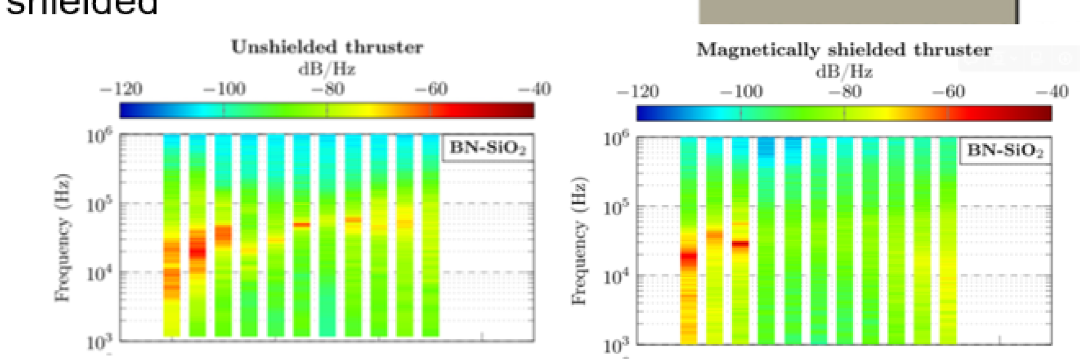
Magnetic Field Design: Creating a stable and efficient magnetic field in a smaller thruster can be challenging.



The magnetic field is generated by way of small cylindrical Samarium–cobalt (SmCo) magnets brought together inside rings located on either side of the channel walls. Magnets are attractive in terms of power, volume and mass saving. But, contrary to magnetizing coils, instant adjustment of magnetic field magnitude and topology cannot be achieved.

Differences between magnetically shielded and unshielded configurations:

- Discharge stability
- Erosion
- Thrust
- Doubly charged ions

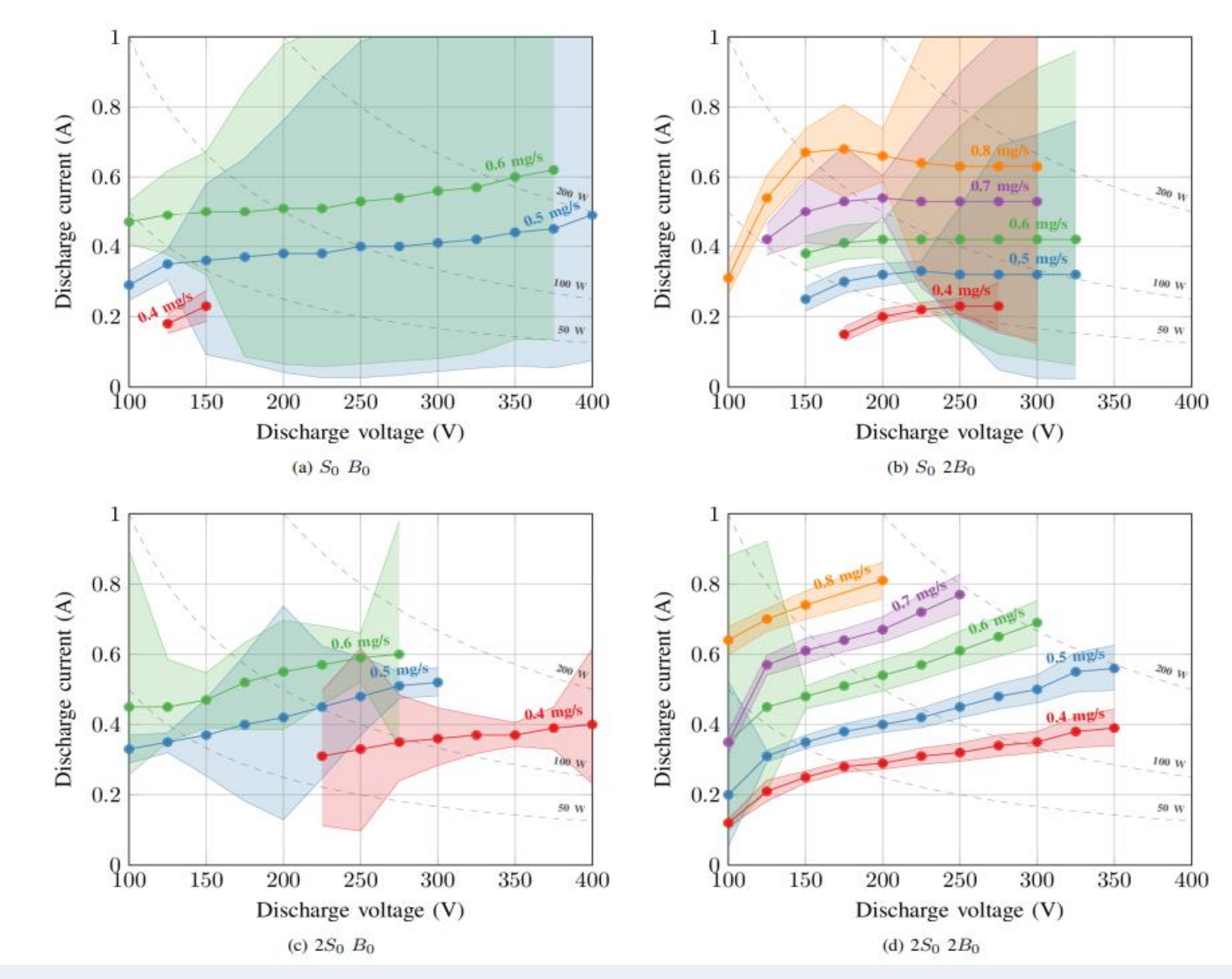


Channel's symmetry and scaling

Miniaturization requires a higher level of precision in manufacturing and assembly processes. Even minor errors in component fabrication or alignment can significantly impact the thruster's performance.

SCALING

- Acceleration region must be scaled down along with the channel width and the magnetic field strength must be increased in proportion to 1/h.
- The channel length l is selected to maintain neutral density in the order of the critical density which ensures a high ionization degree.
- The channel has also to be long enough to allow the ionization region to fully expand.
- The channel width h can easily be modified while keeping the mean diameter d unchanged by means of various sets of ceramic rings.
- Works on scaling laws and HT design have shown that a large h leads to higher propellant utilization, thrust and anode efficiency.



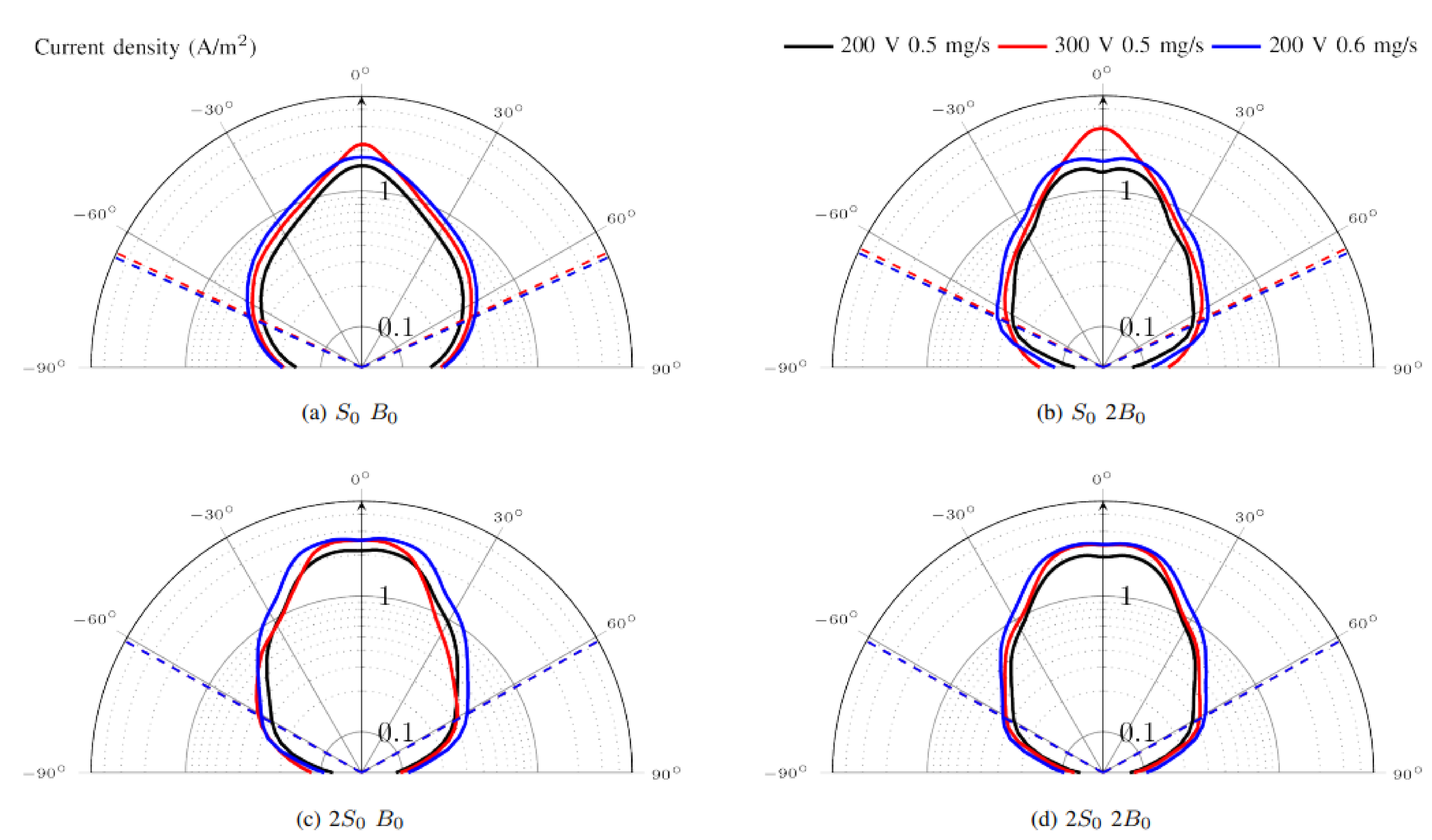
(a) S_0 B_0 (b) S_0 $2B_0$ (c) $2S_0$ B_0 (d) $2S_0$ $2B_0$

Plume divergence and characteristics

Achieving ionization and acceleration of the propellant in a miniaturized Hall thruster can be more challenging due to the smaller size and magnetic field considerations. Precise control of plasma physics is necessary to optimize thrust and efficiency.

From this table it is apparent that the main parameter that influences the divergence angle is the channel width.

- The S0 configurations all have higher divergence than the 2S0 ones
- The magnetic field intensity does not greatly influence the plume divergence angle.
- The propellant utilization does not have any clear behavior tied to the magnetic field intensity.
- The ion beam current fraction shows an increase particularly significant at the highest voltage.

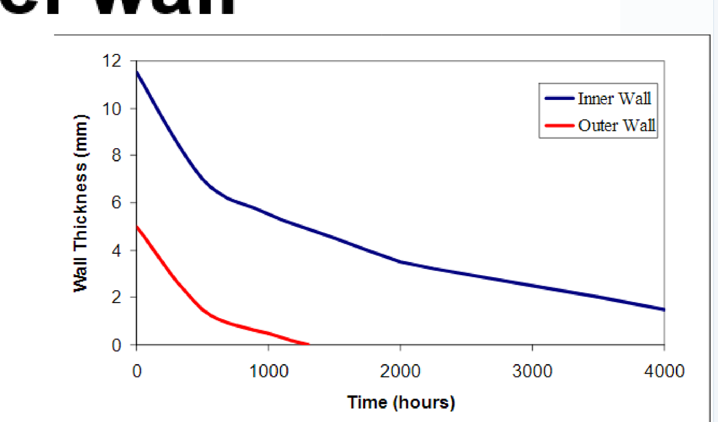


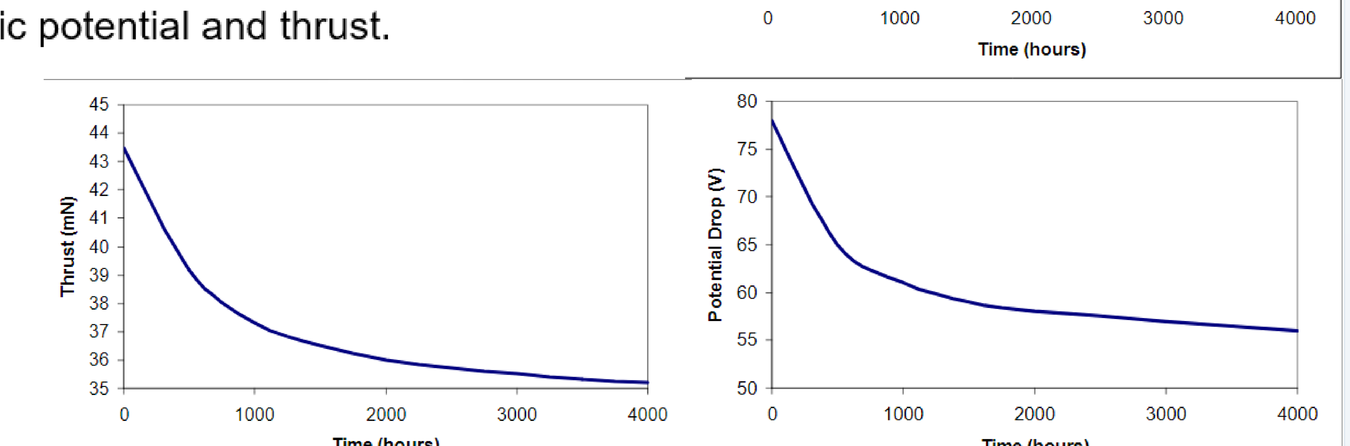
(a) S_0 B_0 (b) S_0 $2B_0$ (c) $2S_0$ B_0 (d) $2S_0$ $2B_0$

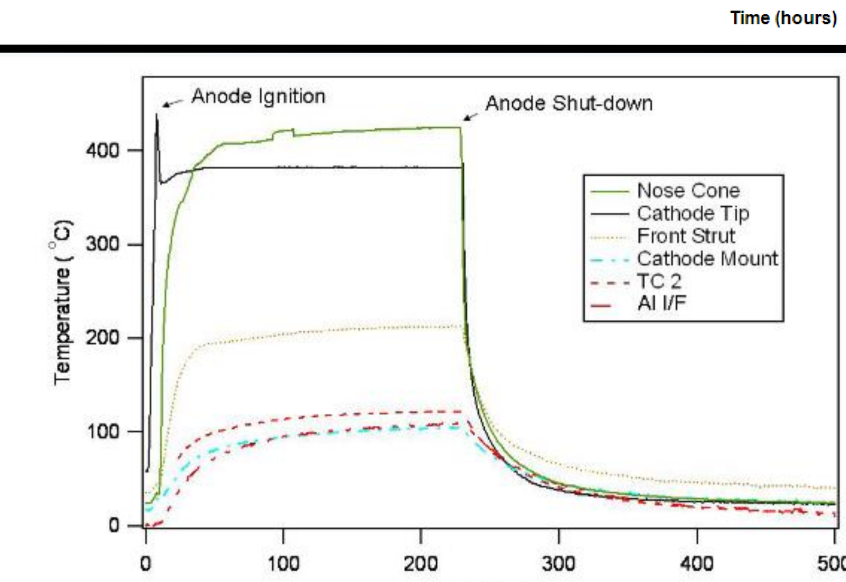
Interaction with the channel wall

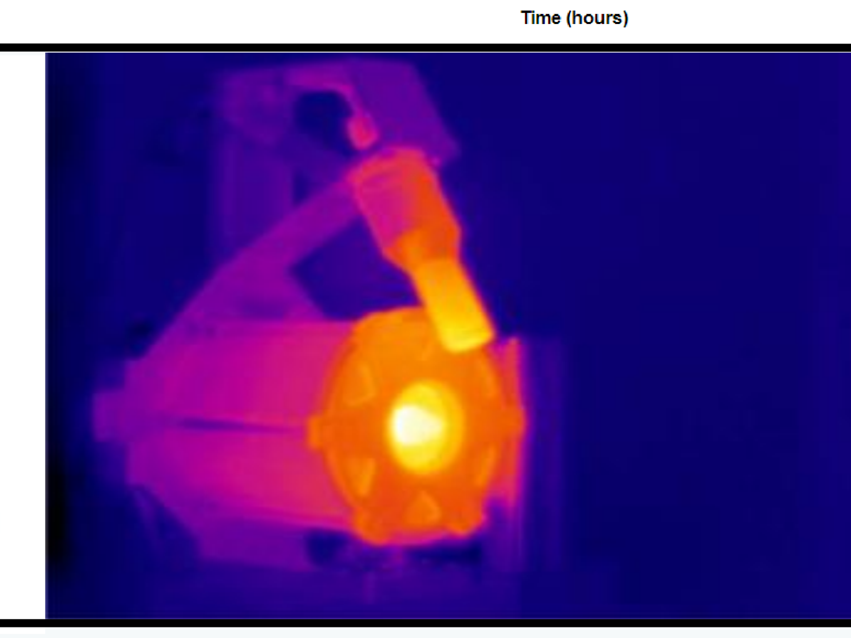
Erosion of the anode channel wall, to the point where the magnetic coils become exposed to the plasma flow is the main source of failure in Hall thrusters.

- As the high-energy ions collide with the channel wall, the channel wall ejects atoms.
- The erosion of the anode also leads to decrease in electric potential and thrust.









REFERENCES

[1] G. Xu PhD, K. Lemmer PhD, in Space Micropropulsion for Nanosatellites, 2022.
[2] K. Dannenmayer , S. Mazouffre, Elementary scaling laws for sizing up and down Hall effect thrusters, 2009.
[3] S. Mazouffre, Lou Grimaud. Characteristics and Performances of a 100-W Hall Thruster for Microspacecraft, 2018.
[4] S. Mazouffre, L. Grimaud. Conducting wall Hall thrusters in magnetic shielding and standard configurations, 2017.
[5] Alex M. Bohnert, Thermal Characterization of a Hall Effect, 2008.

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