Development status of the cryogenic holder mechanism for LiteBIRD LFT PMU

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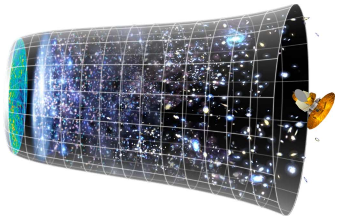
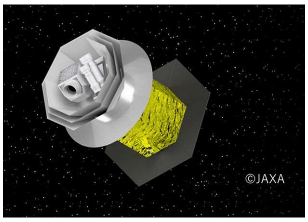
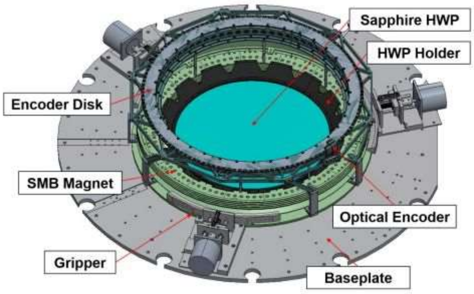
Introduction



Cosmic inflation is a hypothesis of exponential expansion of space at the early universe. The primordial gravitational wave (GW) would be generated with the expansion of space and GW leave a specific polarization signal on the cosmic microwave background radiation (CMB) in the form of B-modes.



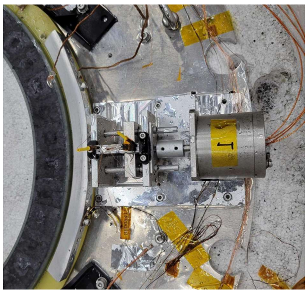
LiteBIRD is a next CMB polarization experiment satellite that targets the measurements of the primordial B-modes to test cosmic inflation. The LiteBIRD Low-Frequency Telescope employs a polarization modulator unit (PMU) to minimize the 1/f noise and the differential systematic effects.



The continuous cryogenic rotation mechanism employs a superconducting magnetic bearing (SMB). At a temperature below its critical temperature about 90K, YBCO bulk superconductors will levitate the SmCo magnet ring as a rotor. The SMB with no mechanical contact realize to avoid the heat dissipation from the physical friction.

Minimizing the heat dissipation is one of the development goals of the PMU rotation mechanism due to the limited cooling power of the satellite system.

Cryogenic holder mechanism : Experiment for optimization



Function of cryogenic holder mechanism are

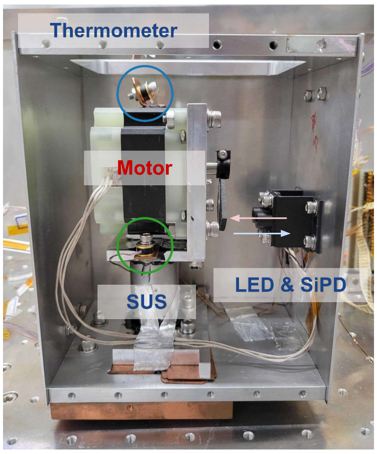
- to hold the rotor until the SMB cools below its critical temperature after launch and,
- to serve a conductive path to the rotor when they are held.

This holder is actuated by a **cryogenic stepping motor.**

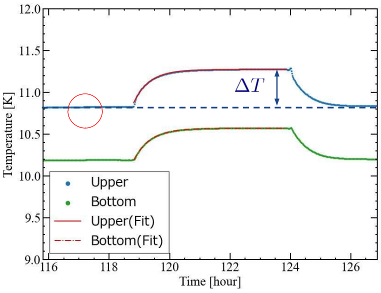
Custom Cryogenic stepping motor design

We aim to minimize the heat dissipation from the stepping motor. A commercial stepping motor dissipate more than 20 mW by only the Joule heating at coils.

We prepared the custom stepping motor that has **coils using high-purity copper wire** to minimize the Joule heat and **GFRP case** instead of aluminum enclosure to reduce the eddy current



We tested its functionality at the temperature below 10 K. We estimated the total heat dissipation from the change of its temperature when the motor operated **without any mechanical load.**



Experimental Result : Characterization of contribution of heat sources

Frequency-independent		Frequency-dependent heat source				
The Joule heat $P_{\mathrm{j}} = I^2 R$	+	Eddy current loss $P_{\mathrm{e}} \propto f^2, B^2$	+	Hysteresis loss $P_{\mathrm{h}} \propto f, B^{1.6}$	+	Friction loss $P_{\mathrm{m}} \propto f$

The electrical resistance of the high-purity copper coils at 11 K is on average 2053 times lower than the resistance at room temperature.

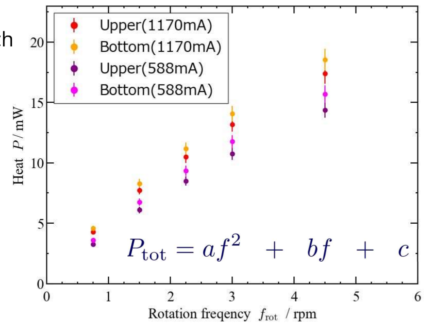
	Coil A Resistance	Coil B Resistance
303 K	3.85 Ω	3.88 Ω
11 K	1.74 mΩ	2.04 mΩ

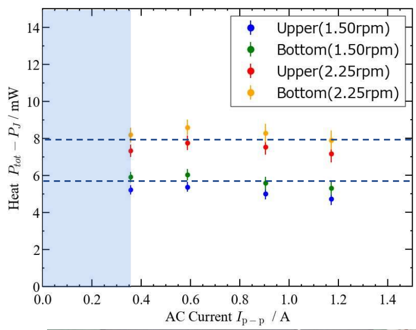
The Joule heat is 3.5 mW even when an AC of 1.2 A in amplitude is applied.

The dominant contribution to the heat dissipation is the source which is proportional to the rotation frequency.

→ **Hysteresis loss or friction loss are dominant.**

This result suggests that there are an heat source which does not depends on the applying AC current. We have expected that this non-zero heat source correspond to **a friction loss**.





Summary and next steps

- **Optimization for the cryogenic stepping motor**
  - To minimize the heat dissipation of the motor, next steps are
    - to optimize an applying current
      - There is a trade off between reducing the current and a torque at the motor shaft.
      - The requirement torque is 0.057 N m with current PMU design.
    - to optimize an rotation frequency of the motor
    - to change the bearing to reduce the friction loss. (e.g. MoS2,ceramic ball)
- **Optimization for the Cryogenic holder mechanism**

  We aim to characterize the stability of the holder assembly at the cryogenic temperature.

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