Optimization of geomagnetic shielding for MKIDs mounted on rotating cryostat

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GroundBIRD is a ground-based CMB experiment which aims to detect the CMB B-modes polarization imprinted by the gravitational waves. We employ Microwave Kinetic Inductance Detectors(MKIDs) as focal plane detectors. We designed magnetic shield for the telescope from experiments and simulations.

・Introduction

MKIDs

Microwave Kinetic Inductance Detectors (MKIDs) are superconducting detectors. Below the critical temperature, a photon with energy hν > 2Δ (Δ : gap energy) breaks Cooper pairs, creates quasiparticles (a), and changes surface impedance (b). It results in lower resonance frequency, broader bandwidth (c) and phase shift (d).

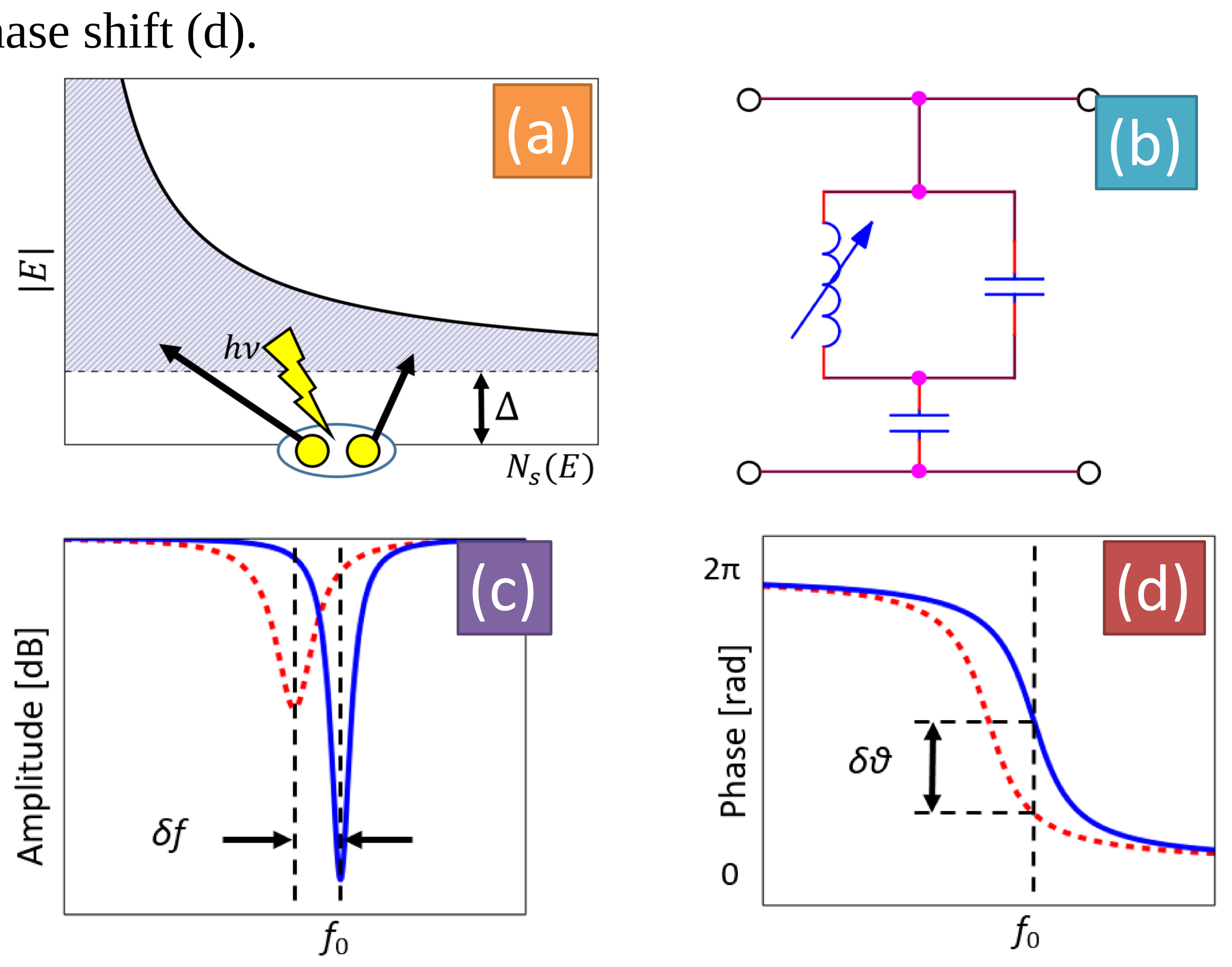


Fig1. Detection principle of MKIDs.

GroundBIRD

One of the key features of the GroundBIRD telescope is the rotational scanning in azimuth direction at 20 rpm to suppress the baseline drift of the detector response caused by 1/f atmospheric fluctuation.

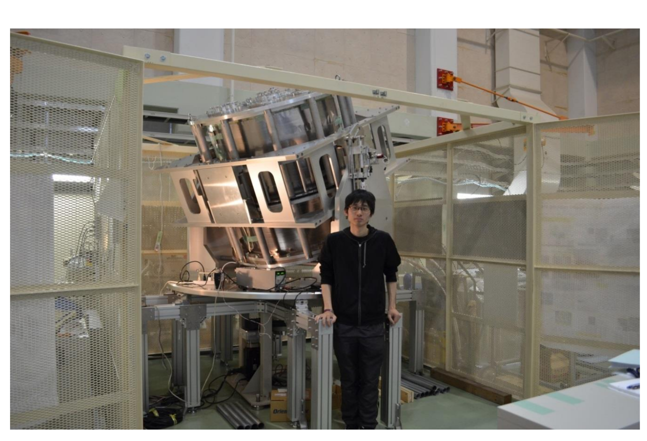


Fig2. GroundBIRD and I.

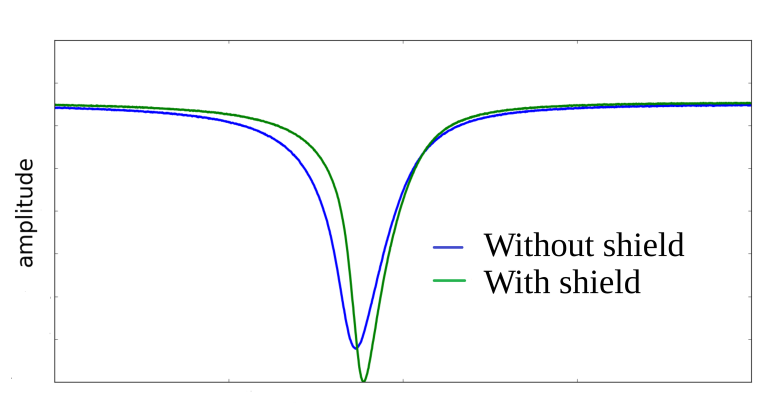


Fig3.Magnetic field effect of MKIDs.

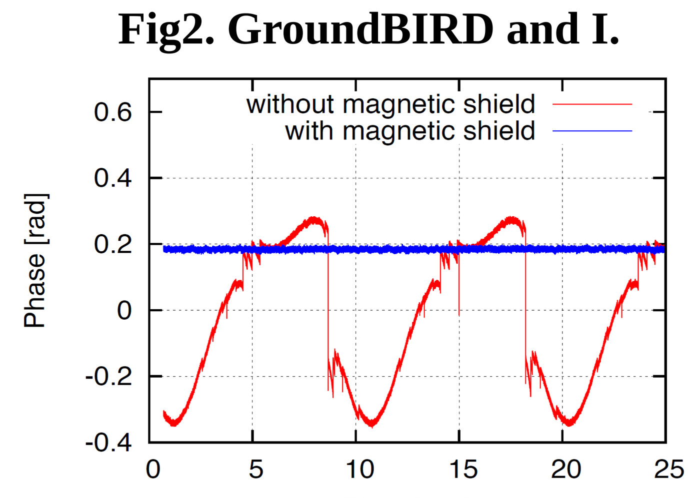
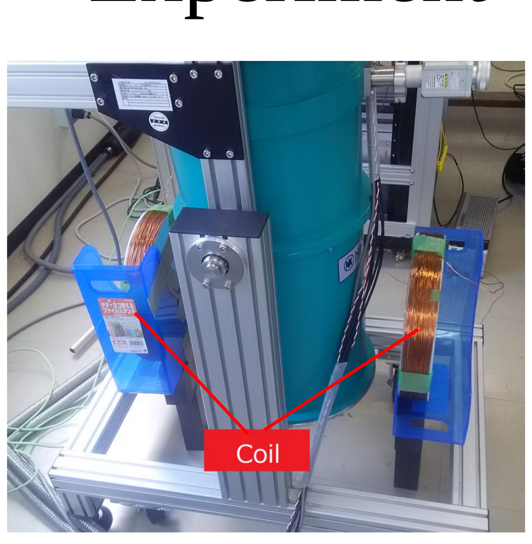
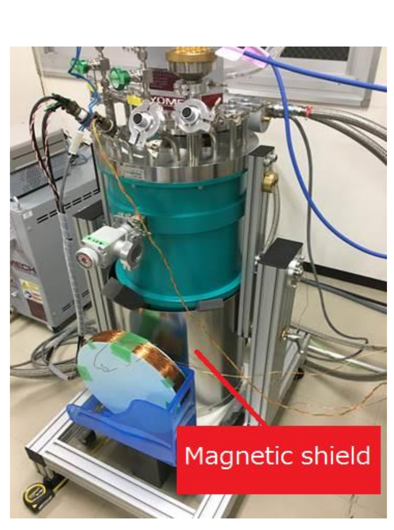


Fig4.Magnetic field effect by rotation.

MKIDs are very sensitive to magnetic fields. For rotating cryostat, change of magnetic field direction causes shift of the center frequency of MKIDs. To solve these problems, we designed a shield to reduce the magnetic field at the focal plane.

・Experiment





We measured the magnetic field response of MKIDs using a cryostat in Research Center for Neutrino Science, Tohoku University. Al MKIDs are installed in the cryostat. A magnetic shield (40 dB) can be set to the cryostat. We applied magnetic field using a pair of coils and measured the response of MKIDs by Vector Network Analyzer (VNA). We performed measurements (1,2) attaching and detaching the magnetic shield as described in the following table.

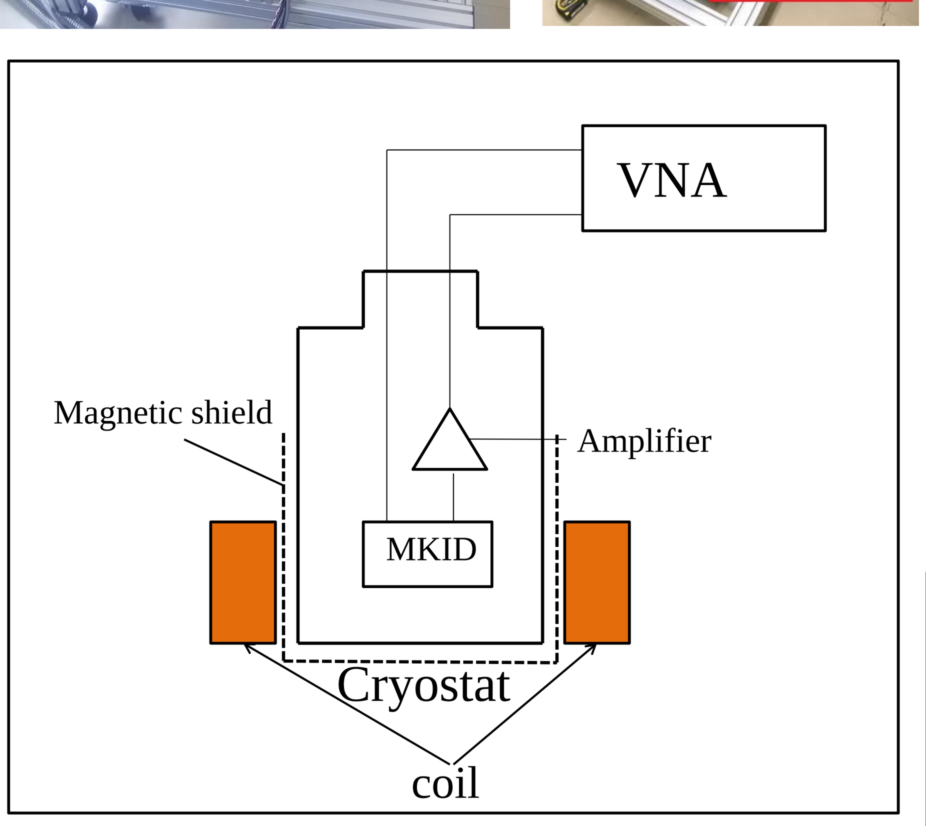


Fig5. Magnetic field Measurement setup.

Table1.Measurement setup

	Case 1	Case 2
During superconducting transition	NO	YES
During measurement	NO	NO
Δfr	30kHz	~1kHz

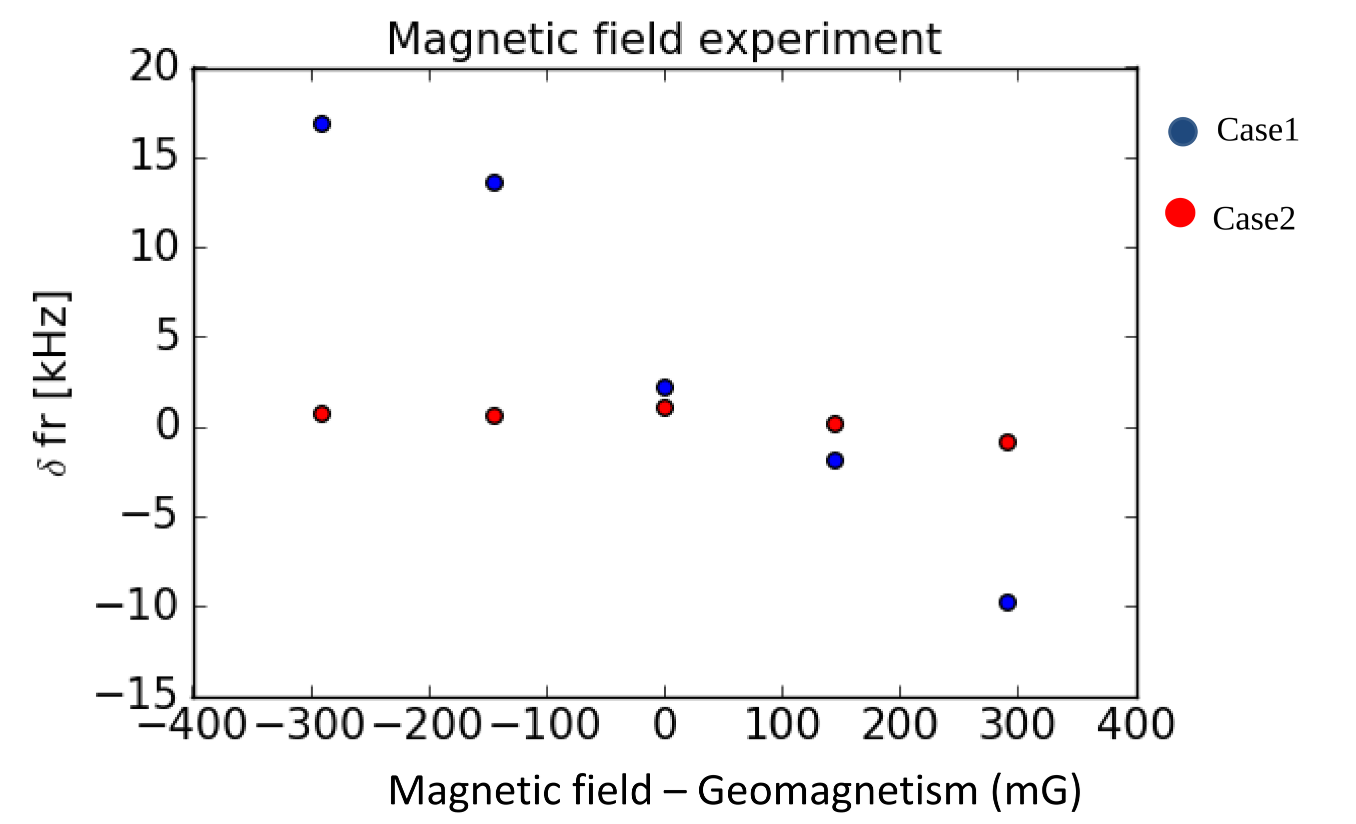


Fig6. The result of magnetic field experiment.

GroundBIRD rotates at 20 rpm, resulting in 1.5-s period variation in the response of MKIDs. Each detector has the frequency range of 125 - 165 GHz. GroundBIRD demands NET ($\sim$300 μK$\sqrt{s}$) which is converted to power ($P_{GB}\sim1.2\times10^{3}$ eV/s) in these conditions. Δfr_1 and Δfr_2 are also converted to powers (P_1,P_2) using the gap energy (0.18×10^{-3} eV), $\mathrm{d}fr/\mathrm{d}N_{qp}$ (~ 0.017Hz) and the time constant τ_{qp} (~ 200 μs). We obtain $P_1=3\times10^{6}$ eV/s, $P_2\sim1\times10^{5}$ eV/s.

If the magnetic shield is set to the cryostat both during the superconducting transition and the experiment (case3), the center frequency shift (Δfr_3) is estimated to be less than 0.01 kHz, from which we acquire the equivalent power $P_3<1\times10^{3}$ eV/s.

From $P_3<P_{GB}$, we conclude that about 40 dB magnetic shield is enough for GroundBIRD.

・Simulation

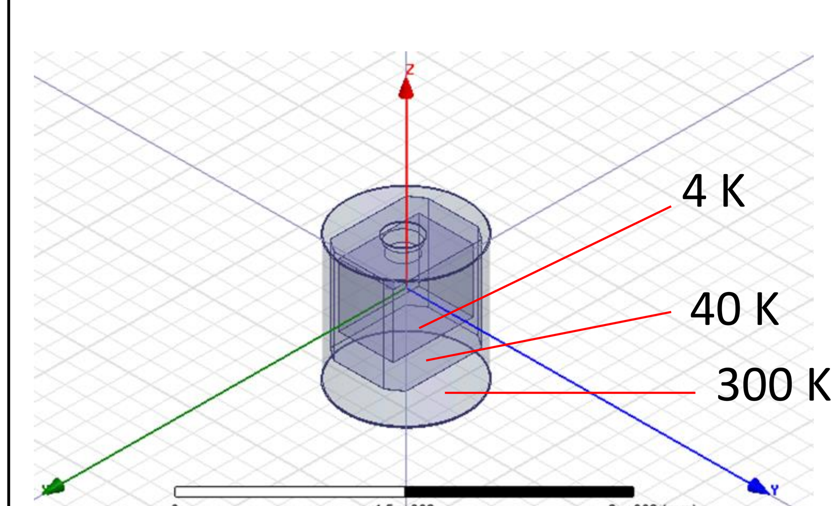


Fig7. Magnetic field simulation.

GroundBIRD has a window to observe sky, and it also allows magnetic flux to enter the cryostat. The window is near detectors on the focal plane and cannot be covered with magnetic shield. The telescope has three cavities (4 K, 40 K, 300 K) on which magnetic shields can be set.

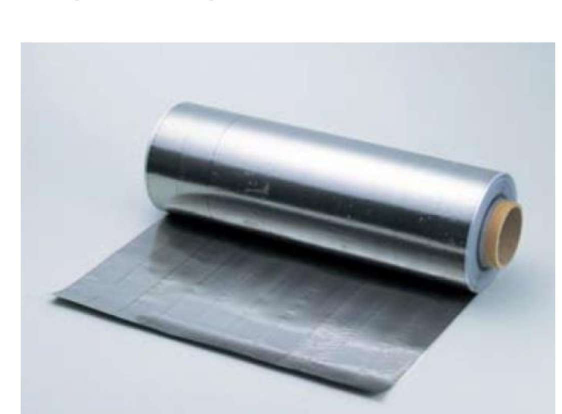


Fig8. Magnetic shield MS-FR.

We used MS-FR made by Hitachi-material as a high permeability magnetic shield. The shield is very thin (~0.12 μm) and has high permeability (μ ~ 70000).

In order to design the magnetic shield, we evaluated the shielding efficiency by ANSYS Maxwell, which employs finite element method to simulate electromagnetic field.

Shield effect decreases about 5 dB when 5 cm gap is formed in each cavity. From measurement and simulation we conclude that the sensitivity of MKIDs is not affected by geomagnetism if 9 sheets of MS-FR are set on each cavity of the cryostat.

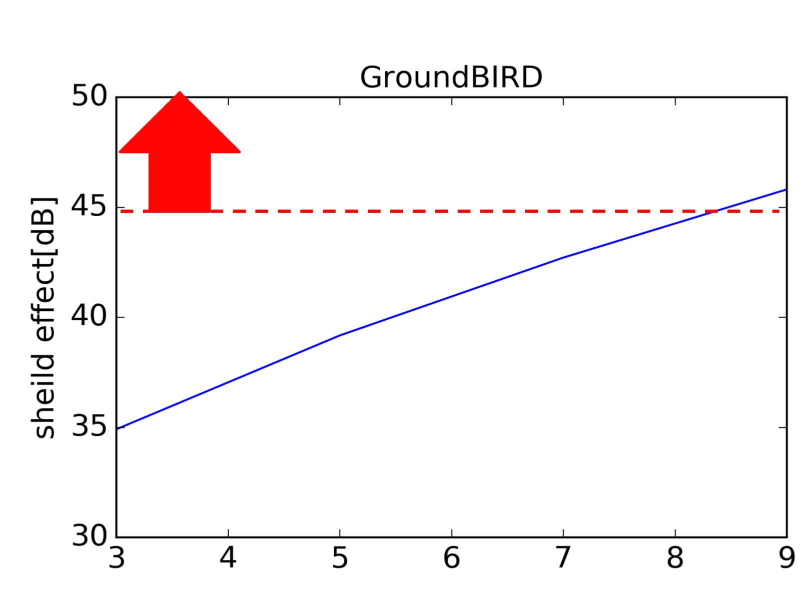


Fig9. Number of magnetic shield vs magnetic shield effect by Maxwell.

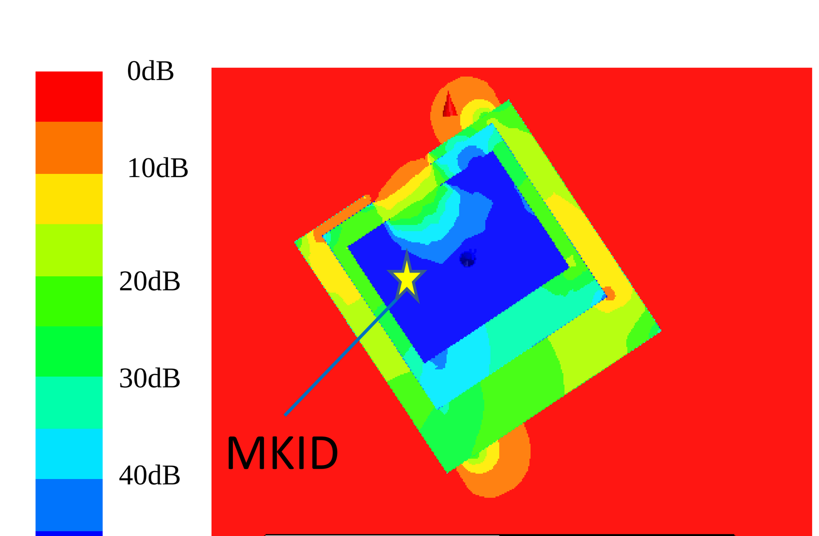


Fig10. Maxwell simulation.
Over 45 dB suppression is achieved near the focal plane.