Flux Transformers for Magnetic Calorimeter X-Ray Detector Arrays

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Introduction

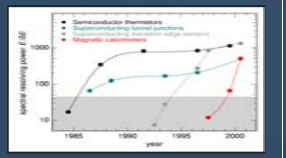
I. The Beyond Einstein Program: answering questions about the origin and fate of the universe by studying black holes

The Great Observatories

Figure 1: Artists' Concepts of Constellation-X (Left) and LISA (Right)

II. Magnetic Calorimeters: an alternative technology to detect X-rays

Figure 2: (Right) A graph showing the improvement of various X-ray detector technologies; magnetic calorimeters show great promise



III. My Project: Continuing the development of Magnetic Calorimeters by testing a key component for array fabrication - Flux transformers

The Science of Magnetic Calorimeters

I. Using Magnetism to detect X-Rays

Incident X-Ray → Change in energy → Change in temp →

Change in magnetism → Change in current → Detection of X-Ray

Figure 3 (Left) shows the fundamental relationships of a magnetic calorimeter. The magnetism of paramagnetic metals depends on temperature.

Curie's Law

$M \propto 1/T$

Magnetism is inversely proportional to temperature

II. Working at super cold temperatures

A. Only at low temperatures do we see a large magnetic response to temperature, as described by Curie's Law: Magnetization is inversely proportional to temperature
B. Low temperatures help eliminate thermal noise as we detect very small changes in energy

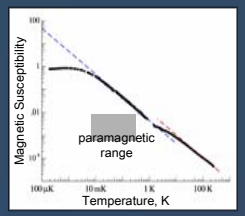


Figure 4 (Left) shows the relationship between magnetism and temperature for Erbium embedded in gold

III. The Components of an X-Ray Detector

A. Mushroom-shaped absorber
B. Thermometer
1. Paramagnetic material
2. Dipole moments try to align with an applied magnetic field
3. Erbium obeys Curie´s Law below 50 mK
C. Weak Thermal Link
D. Read out electronics
1. SQUID (Superconducting Quantum Interference Device)
a. Allows for measurement of energy change due to incident x-ray
b. Amplifies the current created by the applied magnetic field
2. Multiplexer
3. Flux Transformers: connect absorber and SQUID

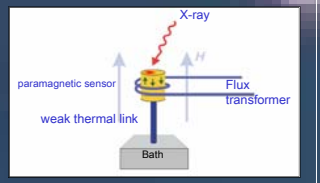


Figure 5: (Right) A schematic of the mushroom-shaped absorber and flux transformer

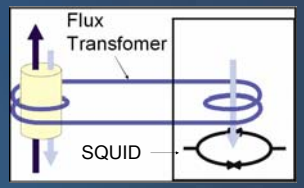


Figure 6: (Left) A schematic showing the flux transformer wrapped around the absorber and SQUID

More on Flux Transformers

I. A niobium wire coil that encircles the absorber on one side and the SQUID on the other

II. Advantage: eases construction of arrays of absorbers

My Contribution

I. Validating magnetic model of prototype flux transformers

A. Select well fabricated devices from first batch
1. Measure resistance and critical current at 4 K
2. Put samples under a vacuum and dunk them into a dewar, or insulated container, holding liquid helium
3. Successful construction signified by zero resistance as the material goes superconducting
B. Measure inductances in adiabatic demagnetization refrigerator
- Consider 9 different coil geometries

Figure 7: (Left and Right) Photographs of repair work on the dunker used to cool chips by lowering them into a dewar; a microscope is used to see the small electronics

II. Work to date

A. Analyzed a set of potential absorber geometries to see how they were affected by cryogenic temperatures
B. Repaired dunker equipment

Figure 8 (Below) shows a schematic of the dewar containing liquid helium used to cool samples down to 4 K.

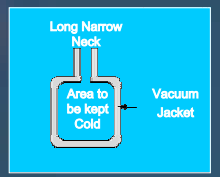
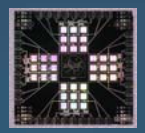
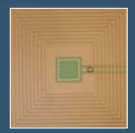


Figure 9 (Above) On the right is the schematic of a ~1/2 inch square chip with 64 absorber chip geometries. (Left) Photographs of individual absorber chips, showing damage after cooling.





III. Future work

A. Continue testing on flux transformers
1. Finish chip selection
2. Use ADR to make inductance measurements
B. Redesign dunker equipment

Figure 10: (Above) On the left is a 12 mm square chip with 36 transformers, each with a different geometry; (Right) One transformer coil with a sample absorber ring inside

Acknowledgements

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