

Research Article

A Biomedical Design of a Femtotesla Ferromagnetic Detector with Quasi-Super Conductor

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Abstract

This paper presents a flexible femto-tesla detector design using multi-level cascade modules (quantum magnetic chips, semiconductor cooling, graphene superconductors, power supply, and control circuits). The quantum magnetic chip could be any quantum effect-based chip such as tunnel magnetoresistance, superconducting quantum interference devices, spin exchange relaxation-free, optically pumped magnetometers, semiconductor cooling device could be made of bismuth telluride, lead telluride, silicon–germanium, and bismuth antimonide alloys with copper or graphene coated ceramic plate, soft version is preferable to prevent long term cracking issue, the superconductor could be zero resistance based or Meissner effect based, critical temperature high one is preferable, such as graphene, quasi superconduct like Ohno Continuous Casting (CCC) is acceptable as well, power supply and control circuits must be extreme low noise made with the latest chip technology like silicon carbide and silicon nitride. Such design is mainly meant for educational usage. The lower cost is the main design goal. Its magnetic focusing lens combines semiconductors with room-temperature quasi-superconductors. A tapered superconducting disk with a central elliptical hole concentrates magnetic flux by repelling field lines toward the hole, amplifying field strength. Civilian applications include detecting biological magnetism, say, monitoring the student attention level during the study, diagnosing Alzheimer's and depression in humans/pets. The high-end military uses involve long-range detection of stealth submarines, carriers, tanks, and stealth aircraft. The main challenge of designing such a system is to understand the environment magnetic noise fluctuation patterns, as such, we have conducted short and long term measurements to catch the effect of Moon cycle on the background noise, these data and analysis will allow us to design an advanced Karman filter to remove the Moon noise, to see femto-Tesla variation in a more accurate design.

Keywords

Femto-Tesla Ferromagnetic Detector, Quantum Magnetic Chip Module, Study Focusing Level, Elliptical Rectangular Hole Disk, Room-Temperature Superconductor

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1. Introduction

The technical field of magnetic focusing biomagnetic imaging belongs to electromagnetism, precision instrument manufacturing, image analysis, and superconductor technology. Its core principle involves focusing and gathering the diamagnetism generated by superconductors through multi-level lens shapes to form an effect of gradually amplifying the magnetic field intensity. In biomagnetic imaging, a higher magnetic field intensity directly translates to improved resolution and sensitivity [1]. This enhancement makes the resulting spectrum simpler and easier to analyze. Therefore, increasing the magnetic field intensity is a primary objective for advancing the brain attention level detection [2, 3].

Magnetic sensing technology finds extensive applications. In the medical field, analysis was conducted on magnetoencephalography (MEG) data from both depression patients and healthy subjects exposed to emotional picture stimuli. This analysis employed methods including multiscale permutation entropy (MPE), symbolic transfer entropy (STE), and signal decomposition into frequency bands combined with permutation entropy [4]. The results demonstrated that in the MPE complexity analysis, the multiscale permutation entropy values across various channels were significantly higher in healthy individuals compared to depression patients, with this difference being particularly prominent in the frontal region [5, 6]. In the military domain, this technology enables long-range early warning for silent nuclear submarines, aircraft carriers, and stealth aircraft. Based on the magnetic field propagation equation, assuming a magnetic sensor can detect a 1-gram paperclip at a distance of x meters, it can detect a nuclear submarine weighing y^3 grams at a distance of $x*y$ meters.

Current biomagnetic sensing technologies face critical limitations. Superconducting Quantum Interference Devices (SQUIDS), employed in applications like magnetoencephalography (MEG) and magnetocardiography (MCG), exemplify these challenges. They mandate cryogenic operation, typically requiring complex and expensive liquid helium cooling systems. This results in prohibitively high manufacturing and operational costs (e.g., multi-million-dollar systems like IBM Q) and severely restricts portability due to the necessary cryogenic infrastructure [7]. While emerging room-temperature quasi-superconductors offer theoretical alternatives, their practical implementations still necessitate energy-intensive thermoelectric or solid-state refrigeration to stabilize the superconducting state, leading to substantial power consumption and significant thermal management challenges [8]. Furthermore, both conventional SQUIDS and emerging alternatives exhibit insufficient resilience against electromagnetic interference in unshielded environments (e.g., urban settings with $\sim 50 \mu\text{T}$ background noise). This lack of

robustness fundamentally constrains their deployment in cost-sensitive biomedical diagnostics and long-range military detection scenarios where femtotesla-level sensitivity is essential.

Addressing these bottlenecks requires innovative approaches. The theoretical relationship $E = EC^2$ suggests that space and energy can be converted into each other, implying that space may represent a low-dimensional form of energy. This concept potentially underpins novel strategies for manipulating magnetic fields or developing next-generation superconducting materials and cooling mechanisms to achieve the desired high-intensity, focused fields for biomagnetic imaging without the current limitations. Our work aims to leverage such principles to overcome the existing technological barriers for low-cost classroom or homeroom usage.

2. The Detail Design

A design method for a magnetic focusing magnetic map, characterized in that the strong anti-magnetic field generated by a superconductor [9], when the magnetic field is irradiated onto the superconductor, in order to focus the magnetic field, the method we adopt is: when some superconductors are irradiated by the magnetic field, they will not (or rarely) the magnetic lines of force penetrate the (quasi) superconductor and are focused together to form a stronger magnetic field, thereby increasing the magnetic field strength many times. Since the fluctuation of the biomagnetic map is proportional to the magnetic field strength, enhancing the field strength multiple times will correspondingly amplify the fluctuation. This amplification improves sensitivity and simplifies the analysis of the map. When a magnetic field is irradiated onto a superconductor, the superconductor repels magnetic induction lines to prevent them from penetrating, and by using specially designed superconducting structures like disks with elliptical holes, the repelled magnetic flux lines can be concentrated in the central hole to enhance the magnetic field strength, which can amplify the weak signal fluctuations of biological magnetograms such as magnetoencephalography and magnetocardiography to improve the detection sensitivity [10].

Figure 1 depicts a block diagram of the components of the femtotesla magnetic field detector. Within this diagram: 1 and 2 signify magnetic focusing superconductors; 3 denotes the ultraquantum chip; 4 indicates the target under detection; 5 represents the detector itself; 6 signifies the magnetic field lines; 7 stands for the receiving line; 8 represents the amplifier; 9, the oscilloscope; and 10, the refrigeration generator.

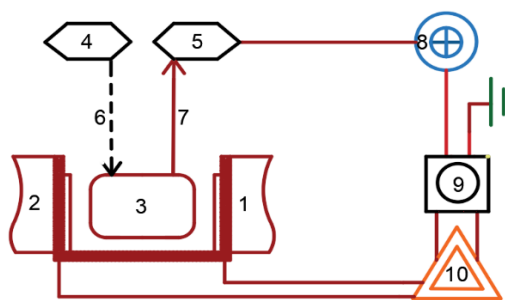


Figure 1. A block diagram of the components of the femtoTesla magnetic field detector

1 and 2 signify magnetic focusing superconductors: Designed based on the diamagnetism of superconductors, it uses an elliptical hole disk structure to focus the magnetic field and enhance the field strength.

3. Ultraquantum chip: In collaboration with a magnetic focusing superconductor, the magnetic field is concentrated into the central hole by leveraging the superconducting material's diamagnetic property to repel magnetic field lines, thereby achieving multi-stage amplification of the magnetic field intensity.

5. Detector: Receives the enhanced magnetic field signals and converts them into electrical signals for subsequent processing.

3. Experimental Procedure and Results

3.1. Room Experimental Methods

To detect magnetic field perturbations, this study sys-

tematically observed ambient magnetic field noise generated by lunar tidal activities. Dual-channel high-sensitivity magnetometers (Base1/Base2) were deployed at a fixed site to synchronously acquire time-domain magnetic field signals (voltage values, unit: mV) alongside corresponding spatiotemporal information. Observations employed three-tiered temporal resolution: long-term daily testing involved continuous recording of noise voltage amplitudes over no fewer than one complete synodic month cycle to capture macroscopic trends correlated with lunar phases (Figure 2 (a1)) [11]; hourly testing comprised uninterrupted 24-hour sampling during key lunar phase days, with time-domain plots precisely annotated at specific temporal nodes (e.g., 14:00 in Figure 4 (c1)) to reveal diurnal periodic characteristics; finally, high-resolution 5-minute testing enabled dense data acquisition during targeted intervals, with synchronized clock signals ensuring temporal precision (Figure 3 (b1)).

All time-domain data underwent Fast Fourier Transform (FFT) processing to generate corresponding spectral plot groups. Spectral analysis focused on frequency component separation and anomaly detection. By comparing amplitude and phase spectra across varying temporal scales, anomalous deviations in frequency components relative to the baseline noise model were identified—including abrupt shifts in amplitude spectral peaks, discontinuous phase jumps, or emergent frequency components. Such anomalies may originate from stealth aircraft-induced modulation of ambient magnetic field noise, thereby providing a basis for subsequent target identification. This dataset will serve as the foundation for training neural network models to enhance the automation and accuracy of anomaly detection.

3.2. Room Experimental Results

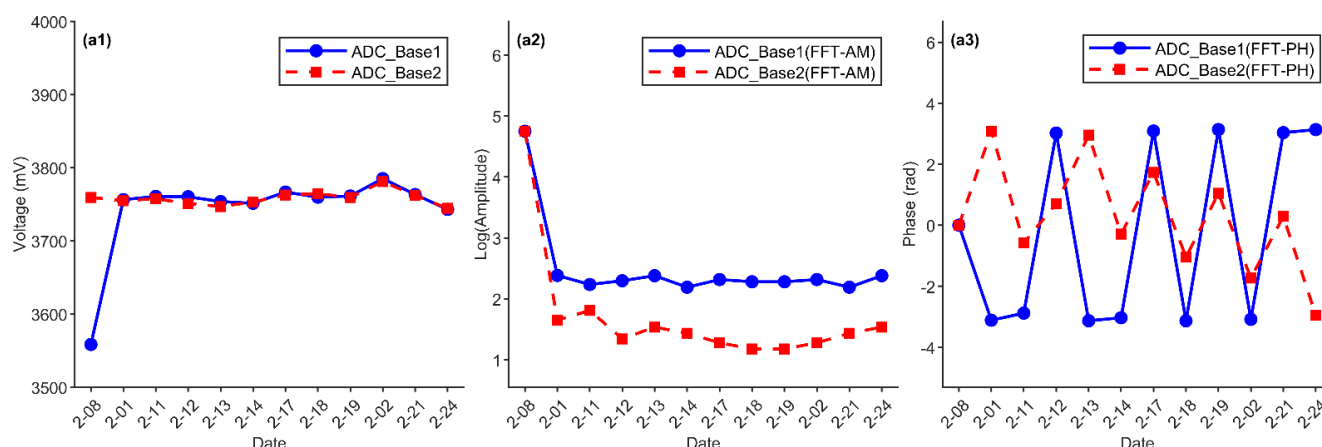


Figure 2. Daily-measured background noise values, along with their frequency domain diagram and phase diagram.

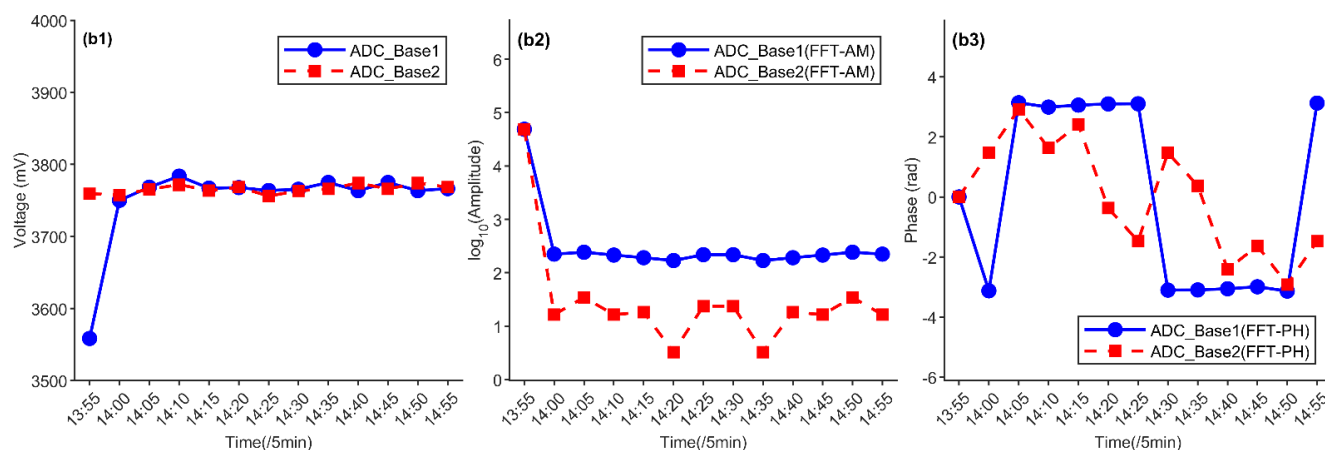


Figure 3. The background noise value, along with its frequency domain diagram and phase diagram, measured at intervals of every 5 minutes.

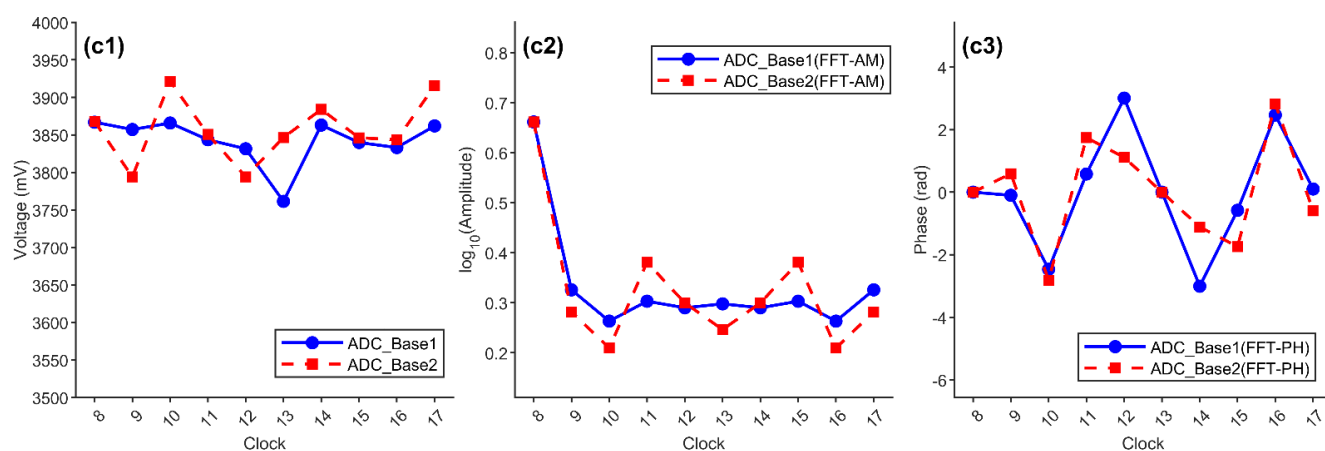


Figure 4. Hourly measured background noise levels, along with their frequency domain plot and phase diagram.

The voltage, amplitude, and phase data in all three sets of charts (a/b/c) have shown periodic fluctuations (especially in the phase charts a3/b3/c3). Their period closely matches the lunar tidal cycle.

Time Scale Transformation:

Voltage Values: Long Scale (Figure 2 (a1)): Base1 shows slightly larger voltage fluctuation amplitudes compared to Base2. **Short Scale (Figure 3 (b1)):** Base1 exhibits a more pronounced initial voltage jump, while Base2 remains relatively stable. **Medium Scale (Figure 4 (c1)):** The peak and trough periods of voltage partially overlap and partially diverge between the two bases. **FFT Amplitude (FFT - AM): Long Scale (Figure 2 (a2)):** Base1 amplitude remains consistently low and stable over the long term, while Base2 exhibits more intense fluctuations. **Short Scale (Figure 3 (b2)):** Base1 amplitude drops sharply and then stabilizes, whereas Base2 amplitude continues to fluctuate. **Medium Scale (Figure 4 (c2)):** Base1 amplitude has shallower troughs and gentler fluctuations compared to Base2. **FFT Phase (FFT - PH): Long Scale (Figure 2 (a3)):** Base1 phase demonstrates clearer periodic cycles, whereas Base2 phase appears disordered/noisy. **Short Scale (Figure 3 (b3)):** Base1 phase transitions are sharper, while Base2 phase changes are relatively

smoother. **Medium Scale (Figure 4 (c3)):** Base1 phase peaks and troughs are more regular, in contrast to the irregular fluctuations of Base2.

4. Conclusion and Future Work

4.1. Conclusion

Minute-scale measurements provide a low-noise regime favorable for weak target detection, while hourly measurements serve as the cornerstone for environmental noise modeling. The integration of both temporal scales enables the separation of local interference from cosmic signals, facilitating the capture of transient anomalies through spectral analysis (such as phase jumps or emergent frequency components) and thereby enhancing target signal identification reliability.

Conventional biomagnetic sensing technologies based on superconducting quantum interference devices (SQUIDs)—essential for applications like magnetoencephalography (MEG) and magnetocardiography (MCG)—are constrained by cryogenic operation (liquid helium cooling),

high costs, poor portability, and susceptibility to electromagnetic interference ($>10 \mu\text{T}$ background noise compromising femtotesla-level sensitivity). While room-temperature alternatives such as atomic magnetometers and tunnel magnetoresistance (TMR) sensors overcome cryogenic limitations and enhance spatial resolution and flexibility, further development is needed. To address these challenges, this work proposes a magnetic focusing technique leveraging superconducting diamagnetism. The approach employs a mathematically optimized ellipsoidal disk with a rectangular aperture and thickness gradient (thick periphery, thin center, and central circular hole). This design harnesses superconducting diamagnetism to compress and repel peripheral magnetic flux, forcing target magnetic fields (e.g., from biomagnetic sources or motor currents) to converge through the central aperture. Consequently, it amplifies field strength, enhances detection sensitivity, and simplifies classroom or clinic spectral analysis [12].

4.2. Future Work

The system integrates a non-contact multimodal biomagnetic sensor array to enable continuous, real-time monitoring of multi-parameter physiological magnetic signals (cardiac, gastric, and cerebral) in both young [13] and elderly populations [14]. This capability supports comprehensive education or health analysis and automated teachers or caregiver alerts, thereby enhancing quality of life while reducing teaching or nursing workload [15].

A fundamental technical limitation of the current system design resides in its reliance on low-temperature/room-temperature quasi-superconductors, necessitating semiconductor refrigeration to maintain operational superconducting states. This requirement consequently induces three critical constraints: elevated power consumption, compromised system stability due to inherent temperature fluctuations, and increased technical implementation costs. To overcome this limitation, we propose structural optimization of the superconductor material through computational topology optimization methodologies, targeting enhanced magnetic field focusing efficiency as a primary performance metric [16].

Abbreviations

SQUID	Superconducting Quantum Interference Device
MEG	Magnetoencephalography
MCG	Magnetocardiography
MPE	Multiscale Permutation Entropy
STE	Symbolic Transfer Entropy
FFT	Fast Fourier Transform
TMR	Tunnel Magnetoresistance
AACBT	Australian Association for Cognitive and Behaviour Therapy
EAST	Experimental Advanced Superconducting Tokamak

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Conflicts of Interest

The authors declare no conflicts of interest.

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