Novel tabletop method to measure small magnetic moments

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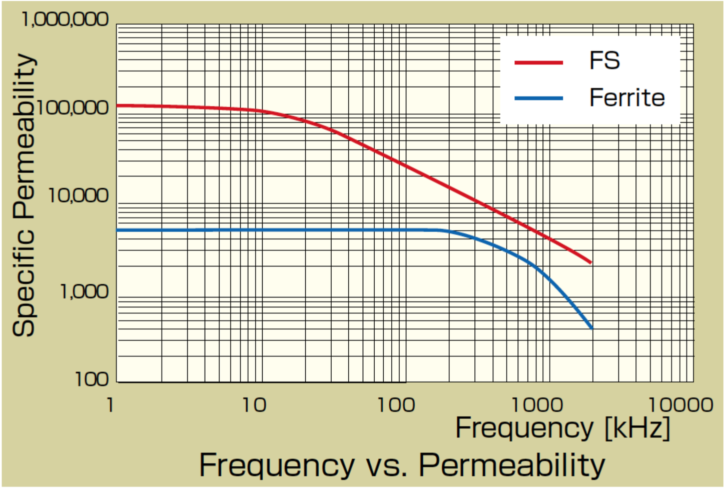
ABSTRACT

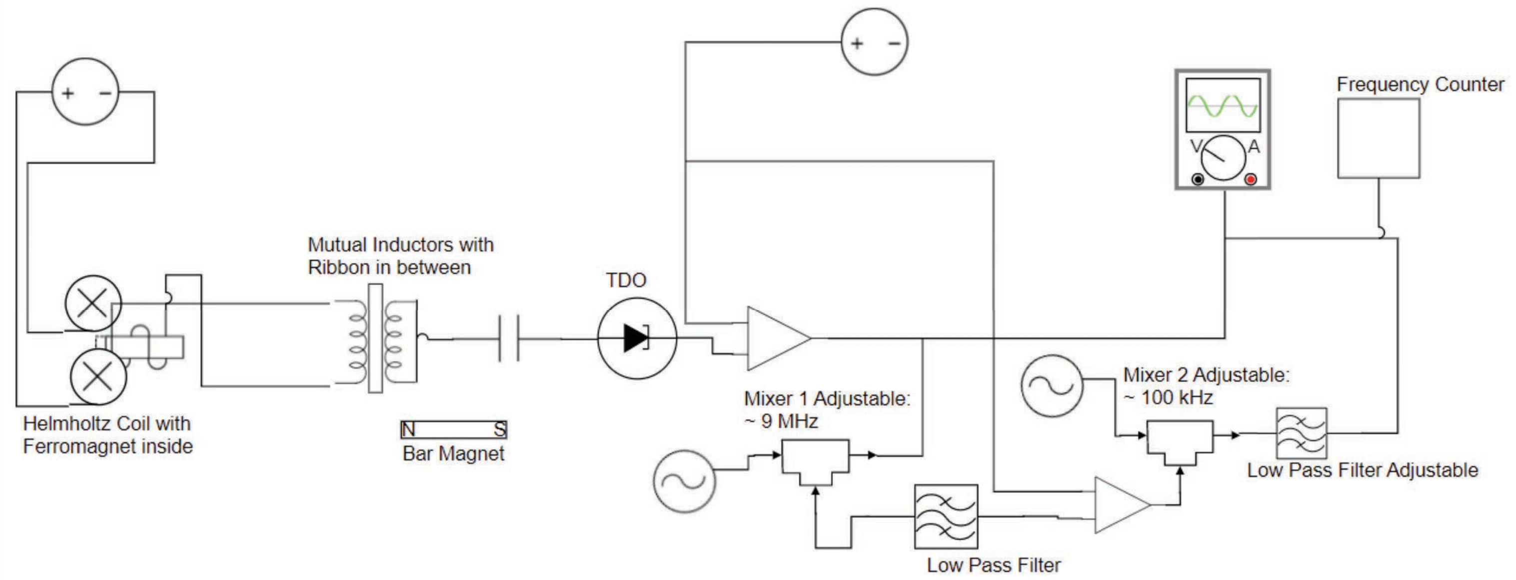
Measuring small magnetic fields, like a 1 ppm of the earth magnetic field has many technological or biological applications. Current devices (magnetometers) capable of such performance are either of large size, or require special conditions, like cryogenic temperatures, ultra-high isolations from earth field, motion of sample, etc. Here we present a novel potential tabletop, static, and room-temperature operated magnetometer, with promising sensitivity, and much more versatility. We present our measurements on standard magnetic samples, discuss the current performances, and compare to commercially available magnetometers.

METHOD

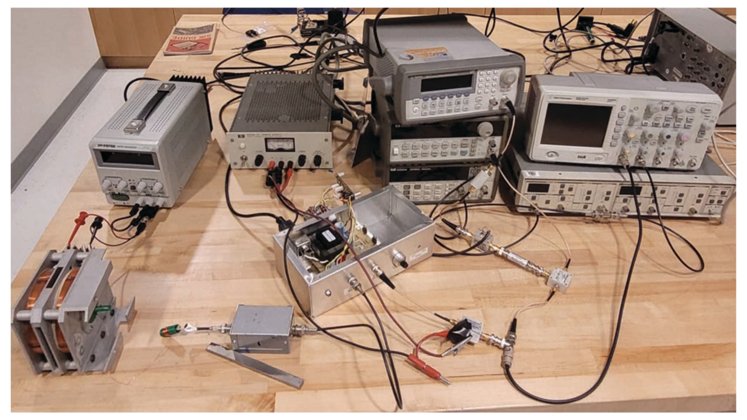
Our goal was to measure the magnetization of a small sample and built our magnetometer using Helmholtz coils, mutual inductors, a tunnel diode oscillator (TDO), amplifiers, low pass filters, and two mixers, as seen in our schematic. We have been using a small ferromagnet as our sample and placed it inside a coil placed in the center of the Helmholtz coil. The coil is connected to our mutually coupled inductors with a ribbon between them. We utilized a Fe-based ferromagnetic amorphous alloy ribbon (FAA) with large magnetic permeability ($\mu_r \approx 10^4$-10^5). We use are using the FAA to amplify the mutual inductance between the inductor of a tunnel diode resonator (TDR) and that of the sensing solenoid. A bar magnet is used to create an external magnetic field that changes the flux in the sensing coil, which in turn changes the magnetization of the FAA ribbon and through mutual inductance it changes the resonant frequency of the TDR circuit. The bar magnet is tested in a variety of orientations and at a variety of distances to find the largest impact on magnetization. This technique combines and relies on the high sensitivity of two probes: a radio-frequency resonator [3] and the permeability of FAA materials [4]. We then are able to tune the two mixers and adjustable low pass filter to find the frequency of our sample.



MAGNETOMETER SCHEMATIC



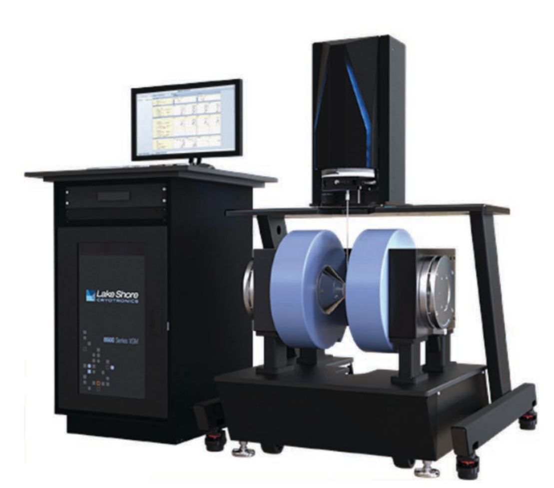
MAGNETOMETER COMPARISON



Novel tabletop magnetometer

Dimensions: 130 x 76 x 33 cm^3

No cooling system or magnetic shielding required



8600 Series Vibrating Sample Magnetometer [2]

Dimensions:
Console: 79 x 77 x 160 cm^3
Electromagnet: 84 x 82 x 140

Requires a cooling system

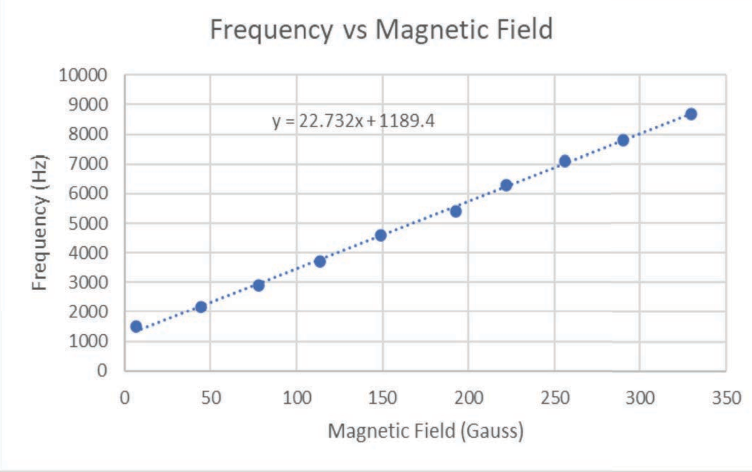
SQUID Magnetometer: Quantum Design MPMS 3 [1]

Dimensions:
Cabinet: 84 x 104 x 199 cm^3
Pump console: 71 x 61 x 61 cm^3

Requires cryogenic temperatures and shielding from external magnetic sources for superconductor operation

DATA

Mixer 1: 9.106 MHz
Mixer 2: 100 kHz
Low Pass Adjustable: 29.5 kHz



Voltage (V)	B Field (Gauss)	Freq (kHz)
0	6.5	4.5
2	44.4	2.15
4	78	2.9
6	114	3.7
8	149	4.6
10	193	5.4
12	222	6.3
14	256	7.1
16	290	7.8
18	330	8.7

CONCLUSIONS

The sensitivity of our setup is currently 22.7 Hz/Gauss but can be improved with optimization of our mutual inductor and placement of the bar magnet. Our setup is significantly miniaturized compared with commercial magnetometers and unlike other magnetometers, we are able to operate our setup at room temperature and without moving parts. With continued optimization in the feeling factor of our mutual inductor and general layout we will be able to further decrease the footprint of our tabletop setup, increase our sensitivity, and maintain room temperature operation with no moving parts.

REFERENCES

[1]Quantum Design North America - Products - SQUID Magnetometer – Quantum Design MPMS®3. (n.d.). Quantum Design North America. Retrieved March 31, 2022, from https://www.qdusa.com/products/mpms3.html#productFeatures
[2]8600 Series VSM. (n.d.). LakeShore Cryogenics. Retrieved March 31, 2022, from https://www.lakeshore.com/products/categories/overview/material-characterization-products/vsm-systems/8600-series-vsm
*[3]*van Degrift, C. T. (1975). Tunnel diode oscillator for 0.001 ppm measurements at low temperatures. *Review of Scientific Instruments*, *46*(5), 599–607. https://doi.org/10.1063/1.1134272
[4]https://www.toshiba-tmat.co.jp/

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