A Quantum Magnetometer for Electric Vehicle (EV) Battery Characterization

Based on a commercial Yttrium Iron Garnet (YIG) oscillator

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Abstract

Magnetometers are important tools in the automotive industry. One key application is that they can be used to locate defects in EV batteries by detecting changes in local magnetic field due to unexpected current flow.

YIG oscillators are established low-phase-noise devices that resonate at microwave frequencies and are normally used as frequency references. Their resonant frequency linewidth is exceptionally narrow and is dependent on both the amplitude and direction of the DC magnetic field. Due to the high number density of unpaired spins this technology offers potential for solid-state quantum devices with high signal to noise ratio (SNR) [1].

A magnetometer has been created and tested, using a commercial YIG oscillator as the key component, that can detect changes in magnetic field of ≤0.01 Gauss.

Motivation

YIG is a ferrimagnetic insulating oxide [2]. In our application it is manufactured as a crystal sphere of diameter ~ 1 mm (Fig 1a). The resonant frequency, f_r, is directly proportional to the magnetic flux density, B that the YIG sphere is exposed to by $f_r = \gamma \cdot B$ (Fig 1e), where γ = 2.8 MHz/Gauss [3].

Due to the small size of the YIG sphere the device is potentially suitable for fabricating a magnetometer with both high SNR and high spatial resolution.

Methods

Several commercial YIG oscillators were sourced. One was de-capped and reverse engineered to gain an understanding of the mode of operation. The magnetic field measurements described in this poster were carried out using an unmodified Stellex 6755-726F YIG oscillator [4,5].

Low-noise current drivers for the YIG sphere magnetic field biasing coils were simulated in LTSpice and designed using Fusion360 (Fig 1c). Printed circuit board (PCB) manufacture was out-sourced, while component assembly was carried out in-house.

The resonant frequency was measured using a spectrum analyzer (Fig 1c). Data files were saved for analysis using python, as described in the *Measuring the magnetic field* section. It was found experimentally that fine control of the YIG resonant frequency and phase noise could be obtained by simple modulation of the Frequency Modulation (FM) coil.

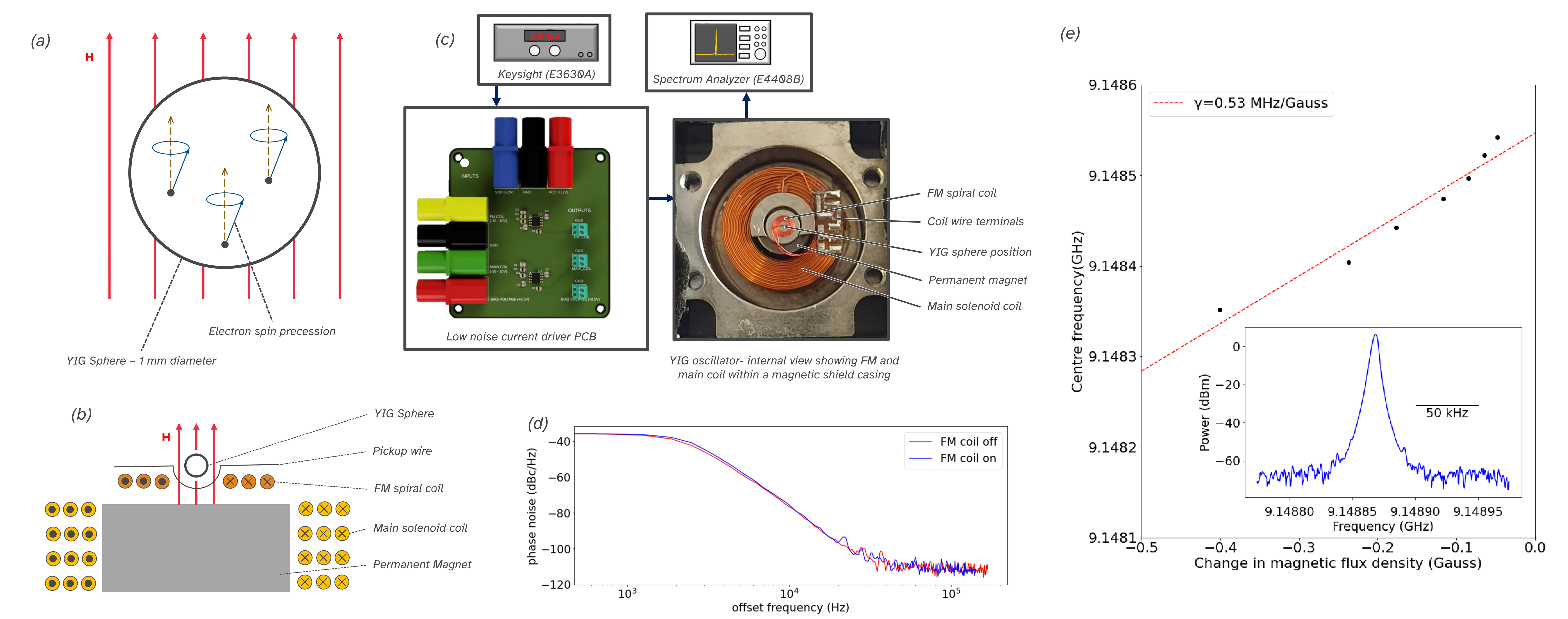

Figure 1: (a) Electron spin precession inside the YIG sphere immersed in a DC magnetic field H. (b) YIG sphere in DC magnetic field H induced by FM coil and permanent magnet, the pickup wire is used to detect the spin precession resonant frequency (c) simplified magnetometer set up, (d) Measured phase noise (e) Resonant frequency vs magnetic flux density.

Phase Noise

One concern was that noise added by the the coil current drivers would distort readings from the YIG oscillator. An initial phase noise measurement was taken with only the bias voltage necessary to operate the YIG oscillator internal circuits and the DC magnetic field H supplied by the permanent magnet only (Fig 1d red line). A second phase noise measurement was then taken with DC magnetic field H supplied by both the permanent magnet and the FM coil (Fig 1d blue line). The data shows that the addition of the FM coil modulation does not make a significant change to the phase noise.

Measuring the magnetic field

After ensuring that the FM coil operation did not adversely impact phase noise, the YIG oscillator resonant frequency was measured as a function of applied external DC magnetic field. Using a commercial fluxgate magnetometer, it was observed that a 1 V change was equivalent to a 0.1 Gauss change in applied external DC magnetic field in proximity to the YIG sphere. In Fig 1e, the YIG oscillator resonant frequency (Fig 1e inset peak value) was recorded for 7 values of external applied DC magnetic field. Forcing a linear fit to the data implies a gradient γ = 0.53 MHz/Gauss, lower than the theoretical value of 2.8 MHz/Gauss. A potential explanation is attenuation of the applied external DC magnetic field by the magnetic shield which forms the casing (Fig 1c) of the YIG oscillator. Future work should focus on replacing this magnetic shield with e.g. an un-shielded 3D printed case.

Conclusion

We have demonstrated that a commercial YIG oscillator can be used to create a magnetometer with potential to measure small magnetic fields with high spatial resolution.

The high spatial resolution (mm scale) offered by a YIG magnetometer differentiates this approach from other magnetometers and is potentially a significant benefit for EV battery diagnostics.

Next steps

There are several improvements and tests still to be carried out before this technology can be used in industry. Listed below are some suggested next steps.

- Change the oscillator's magnetic shield casing to an un-shielded 3D printed case.
- Regulate the temperature of the YIG sphere.
- Investigate methods for reducing phase noise in the data readings.
- Applications testing

References

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Intern bio

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