Mechanical detection of magnetic resonance via LC resonant magnetometer

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Abstract

This project investigates magnetic sensing circuits based on an **LC resonant oscillator**.

A nearby magnetic field changes the effective inductance of the coils, which shifts the circuit's **resonant frequency and waveform amplitude**.

Resonant frequency changes with magnet distance; the circuit functions as a **simple magnetic field sensor**.

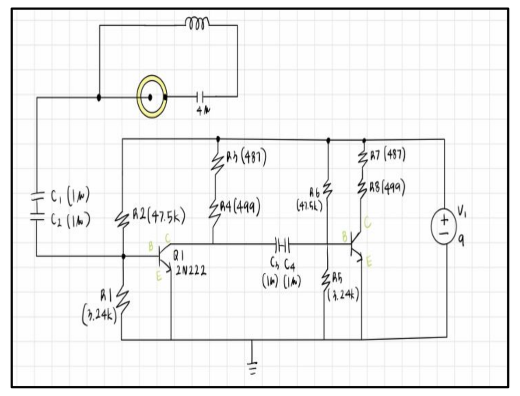
Proper LC tuning and output conditioning can significantly improve magnetic resonance detection performance.

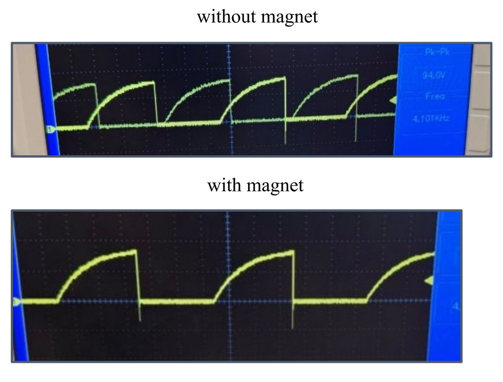
To compare different design ideas, the team built four prototype circuits.

The prototypes were compared through magnet-distance testing by measuring waveform and frequency changes as a magnet was moved near the inductors.

Prototypes 1 & 2

Prototype 1: LC Resonant Coil Magnetometer

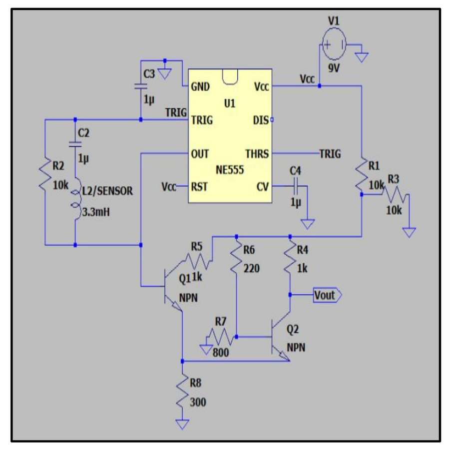


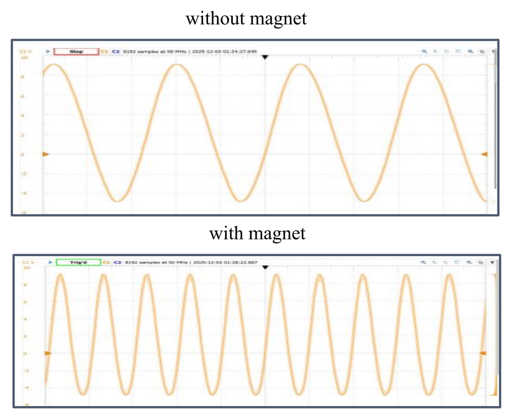


This prototype uses a **hand-wound coil and LC resonant**. The circuit includes a **165 μH inductor**, **4 μF capacitor network**, and a **transistor-based amplifier**.

Frequency changed from about **4.15 kHz** to **4.4 kHz** with a magnet nearby. This produced a **250 Hz shift**, or about **4–5X** higher sensitivity.

Prototype 2: NE555 Magnet-Sensitive Oscillator



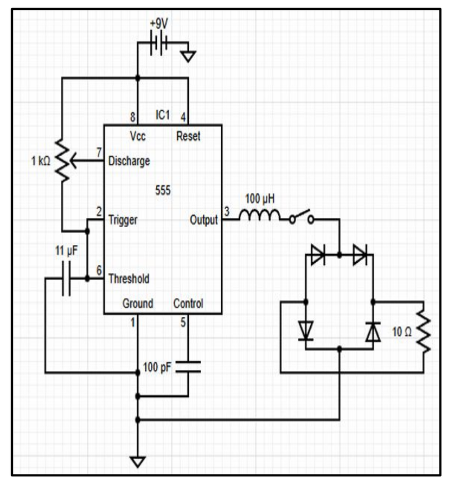


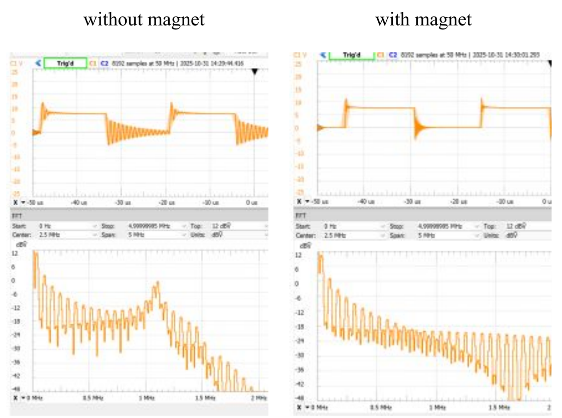
This prototype uses a **NE555 timer** with a **3.3 mH sensing inductor** and **dual-transistor output conditioning**.

Frequency changed from about **36.06 kHz** to **102.06 kHz**, with an improved gain of **730.336 kHz/T**, showing **13.44X improvement**.

Prototypes 3 & 4

Prototype 3: LM555 LC Resonant Oscillator

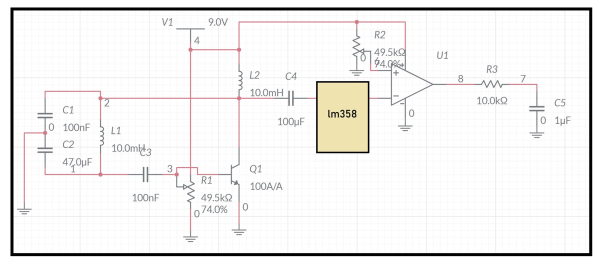




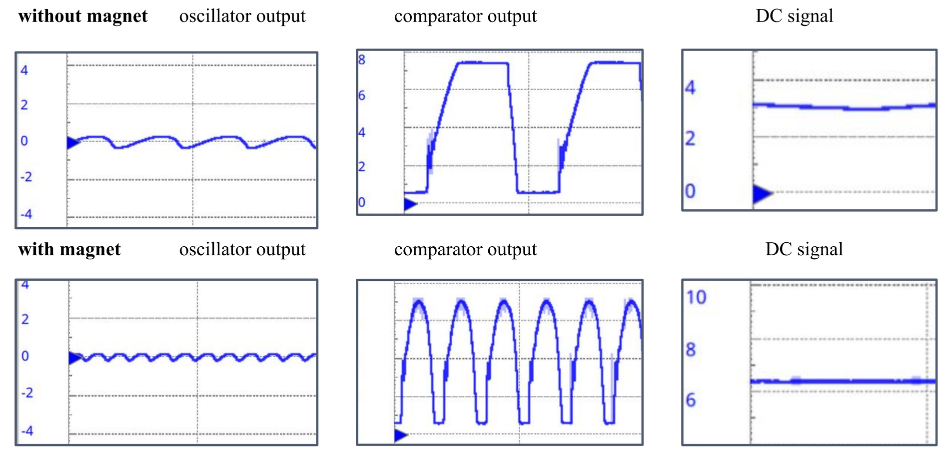
This prototype uses an **LM555 timer-based oscillator** as the main sensing architecture. The circuit includes two inductors at the output. The oscillator generates square-wave pulses, and the LC network produces ringing behavior whose frequency changes with magnetic field strength.

Resonance frequency to about **11.13 MHz** and improved average gain to **0.3103 MHz/mT**, showing 3X improvement.

Prototype 4: DC Output from a Colpitts Oscillator



This prototype uses the **LC tank** of a **Colpitts oscillator** to sense external magnetic fields. When the inductor approaches **saturation** under a strong magnetic field, the oscillation **frequency increases** by up to **3×**. To improve usability, the amplified oscillatory output is converted to a **DC** signal using a **low-slew-rate comparator** followed by a **low-pass filter**.

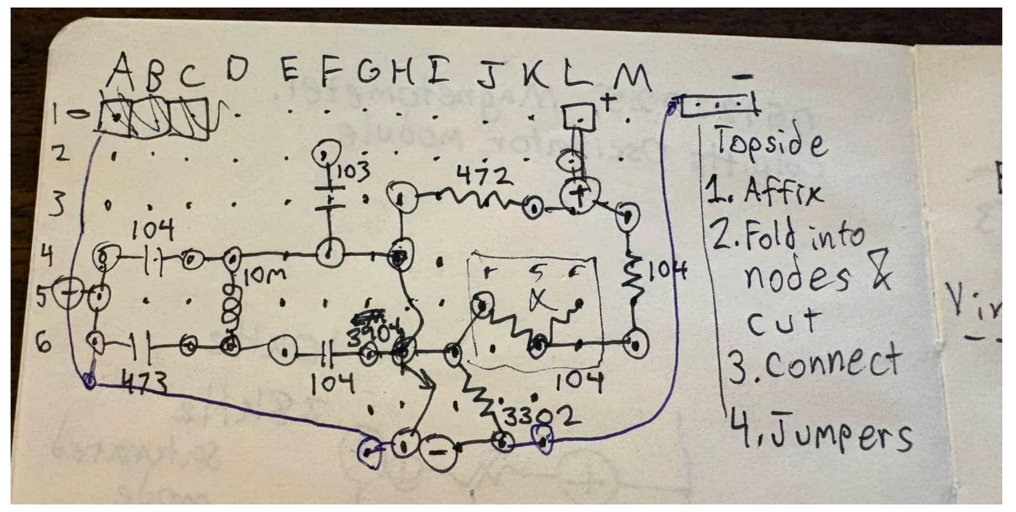


This produces a continuous voltage proportional to field strength. Unlike frequency-based outputs, the **DC** signal enables straightforward **amplification**, **range scaling**, and direct interfacing with **ADCs**, allowing for **higher-resolution** and more accessible **digital measurement**.

Because prototype 4 has a different output type, its improvement must be measured as normalized sensitivity, which can be expressed as **%ΔV / %ΔB** or **%ΔF / %ΔB**, depending on the output. Prototype 4 improved by an average of **10x** under different field strengths.

Final Design Selection

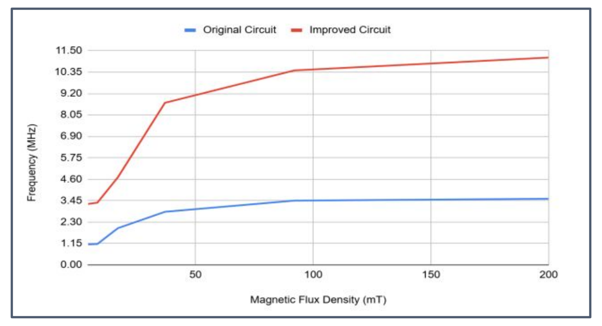
Unlike the other designs, this prototype focuses on improving output usability and versatility rather than maximizing frequency alone. The circuit translates frequency variation into a directly usable measurement domain and eliminates the need for complex signal processing. The resulting voltage is proportional to magnetic field strength, enabling straightforward amplification, range scaling, and direct interfacing with analog-to-digital converters, ultimately improving measurement accessibility and effective resolution. By combining high sensitivity with practical signal conditioning, this design represents the most complete and scalable implementation of the project's magnetic sensing approach.

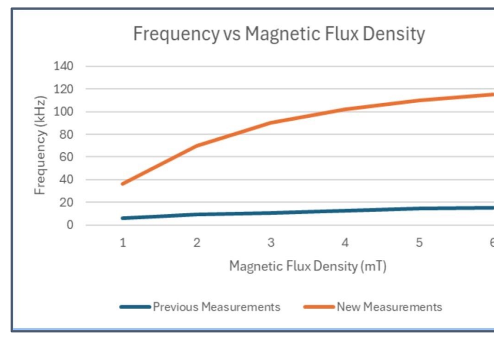


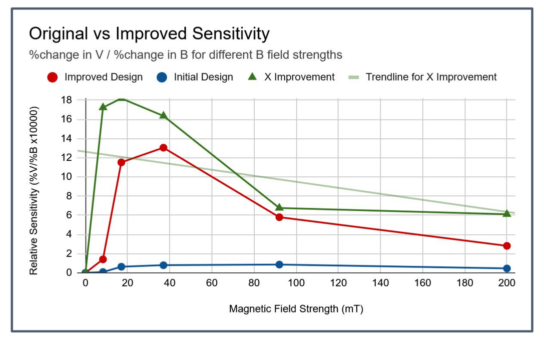
Performance Evaluation

The objective of this project was to design a magnetometer and improve its performance by 10x. Performance was primarily evaluated using frequency sensitivity (Hz/mT).

Prototype 1







Prototype 3 Prototype 4

In addition to quantitative improvements, Prototype 4 introduced a functional advancement by converting the oscillatory signal into a continuous DC output. This enables direct measurement, amplification, and integration with analog-to-digital systems, representing a significant increase in practical usability compared to frequency-only outputs.

Overall, the prototypes met or exceeded the defined performance goals, with some designs demonstrating higher sensitivity and improved signal accessibility. These results validate the effectiveness of prototype circuit comparison for magnetic field sensing applications.

Conclusion

For our project, we built four different oscillator circuits. We demonstrated that each version can detect magnetic fields by measuring changes in frequency and waveform behavior. By designing and testing many prototype circuits, we were able to directly compare different strategies and identify what really impacted performance and sensitivity.

Our results showed that magnetic proximity consistently altered the inductance of the sensing coil, producing detectable frequency changes. From the tested designs, later prototypes achieved significantly higher sensitivity and gain, confirming that careful component selection and circuit optimization strategies can enhance detection capability.

Overall, the project proves the feasibility of low-cost, circuit-based magnetic sensing using LC resonance. The approach of iterative prototyping was essential in our strategy for improving performance and selecting a final design. Our findings give a strong foundation to be further refined on, and have potential applications in future magnetic field sensing and measurement systems.

Recommendations

- Increase coil inductance and optimize winding geometry to improve magnetic field coupling and sensitivity
- Replace parallel capacitor combinations with a single precision capacitor to reduce parasitics and tuning error
- Refine transistor biasing to ensure stable oscillation and maximize signal amplitude
- Minimize loading between the LC tank and amplifier using buffering (e.g., emitter/source follower stage)
- Tune the oscillation frequency to more closely match the LC resonant frequency for peak sensitivity
- Implement a controlled magnetic field source (e.g., Helmholtz coil) for accurate and repeatable calibration
- Standardize testing conditions by fixing coil–magnet distance, alignment, and orientation
- Add shielding to reduce external electromagnetic interference
- Integrate temperature compensation to reduce drift in component values
- Incorporate an ADC + microcontroller for digital readout and signal processing