Another Twist on the Rotating Coil

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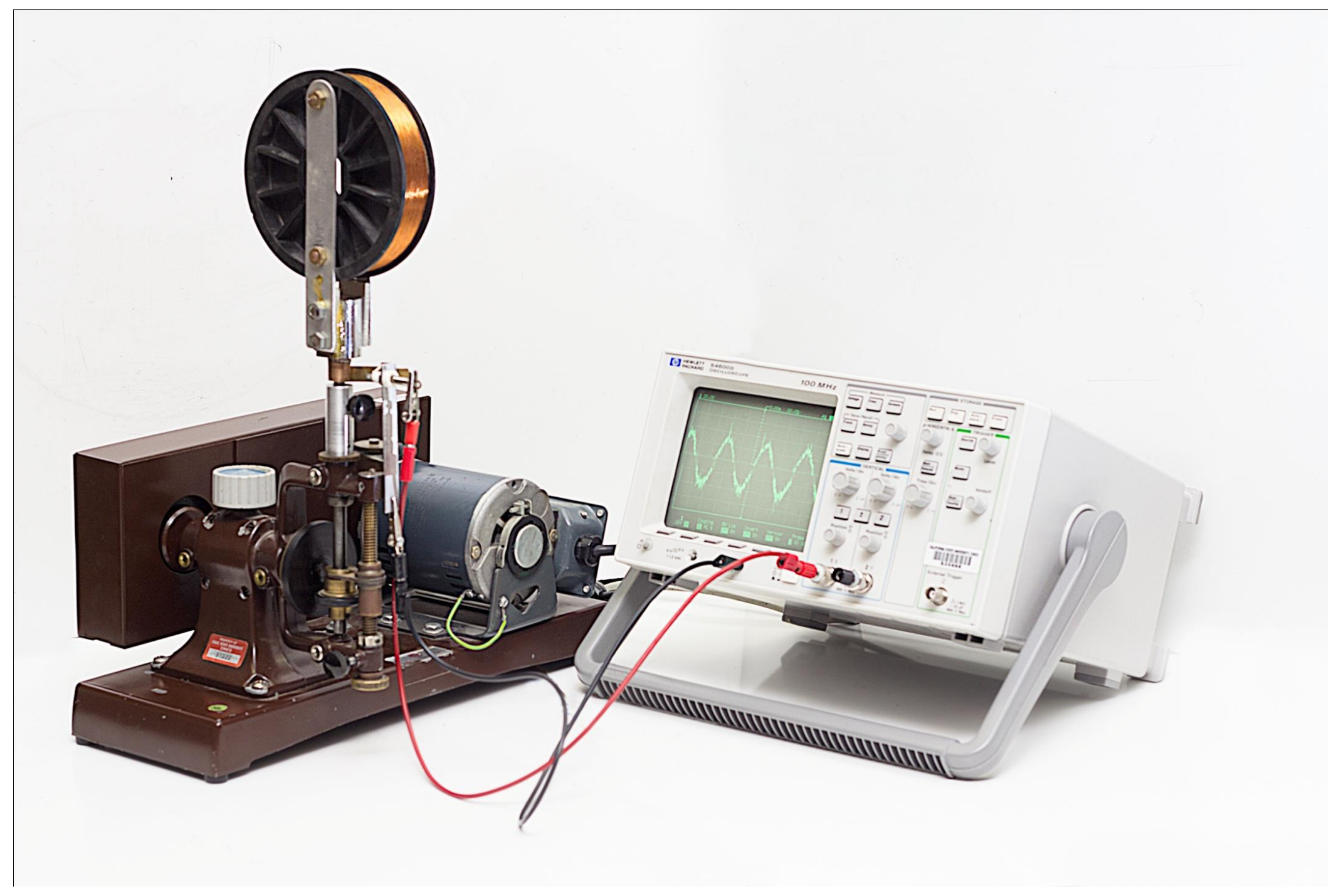
Introduction

Background:

The measurement of the Earth's magnetic field for an introductory physics lab presents several interesting challenges. At Chico State, we have been using an apparatus originally proposed by D. Kagan[1] in 1986, which involved a coil mounted on a rotator (see the picture right below).

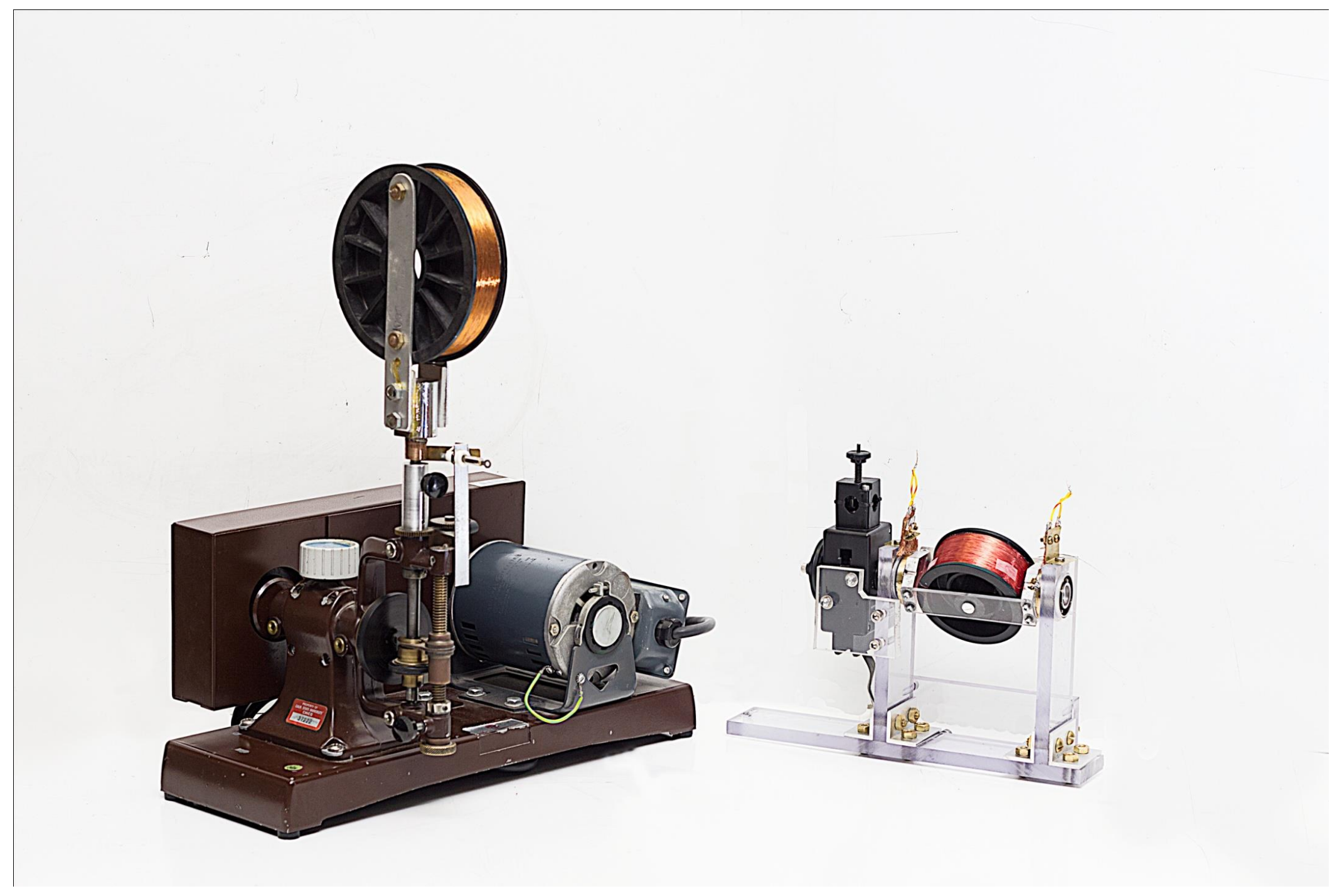
Over nearly three decades of use, we have noted several issues with this apparatus: it is electrically and acoustically noisy and the rapidly rotating coil poses a potential danger as well. The maintenance and replacement of the worn rotator units have also proven to be quite expensive and impractical.



Our Approach:

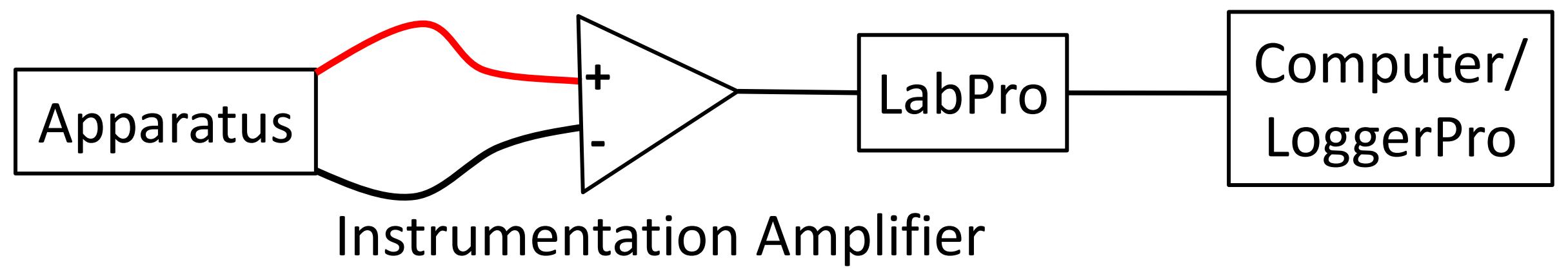
We have developed a smaller, less expensive, greener, and quieter alternative to the electrically driven rotator. It has been replaced with a bearing-mounted coil that can be driven by a falling mass (see the picture below for a comparison between the ready-made rotator and our newly built spinning coil).

This technique is also pedagogically superior as it offers a much richer data analysis experience for students.

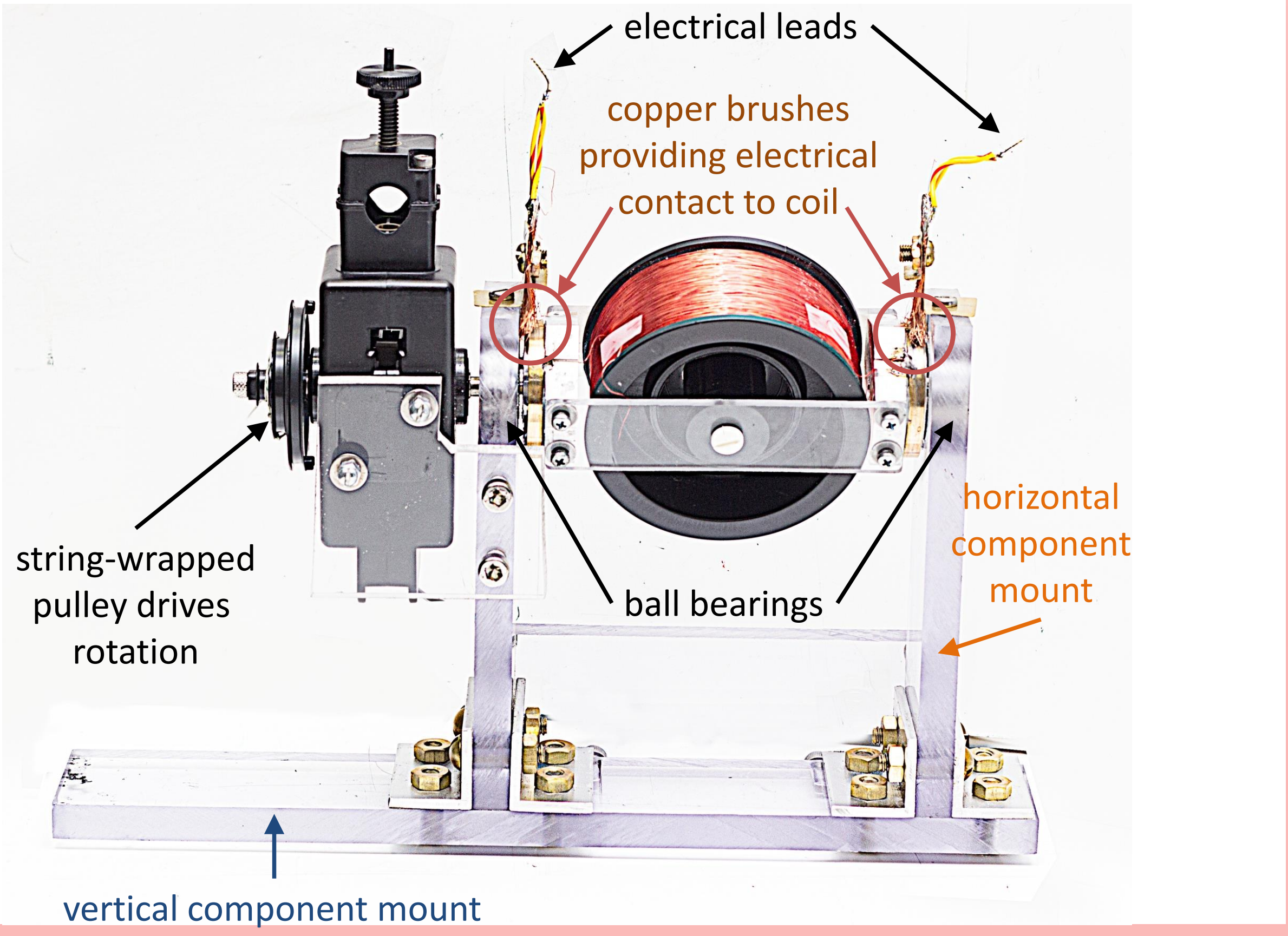


Apparatus Description and Experiment Set-Up

The copper coil is fastened to an axle made of conducting material, and is allowed to rotate via ball-bearings. The axle is attached to a rotary motion sensor's plastic pulley wrapped in string, and rotation is enabled by a falling mass rigged to the other end of the string. In order to minimize friction, the leads from the coil are soldered to brass sleeves mounted on the axle and copper brushes are in electrical contact with the brass sleeves. Connected to a voltage amplifier, LabPro, and computer with the LoggerPro program, the apparatus (see the diagram below) can be fixed to a table top to measure either the vertical or horizontal component of Earth's magnetic field.



Apparatus
+
-
LabPro
Computer/
LoggerPro
Instrumentation Amplifier



Data Analysis

When the hanging mass (300 g – 700 g) is released, the coil angularly accelerates and an emf is induced. LoggerPro can then plot a voltage versus time graph (Graph 1 and Graph 3 below). From these plots, each peak voltage from the accelerating part (boxed by dashed lines on Graphs 1 & 3) and their corresponding half periods can be recorded, and then the peak voltage versus angular speed can be manually plotted on LoggerPro (Graph 2 and Graph 4). (Note that we did not use the rotary motion sensor to measure the angular speed ω due to its low 100/s sampling rate.)

$$
\begin{aligned}
emf &= N\frac{d\phi}{dt}\\
&= N\frac{d}{dt}[B\,A\cos(\omega t)]\\
&= N\,B\,A\omega\sin(\omega t)
\end{aligned}
$$

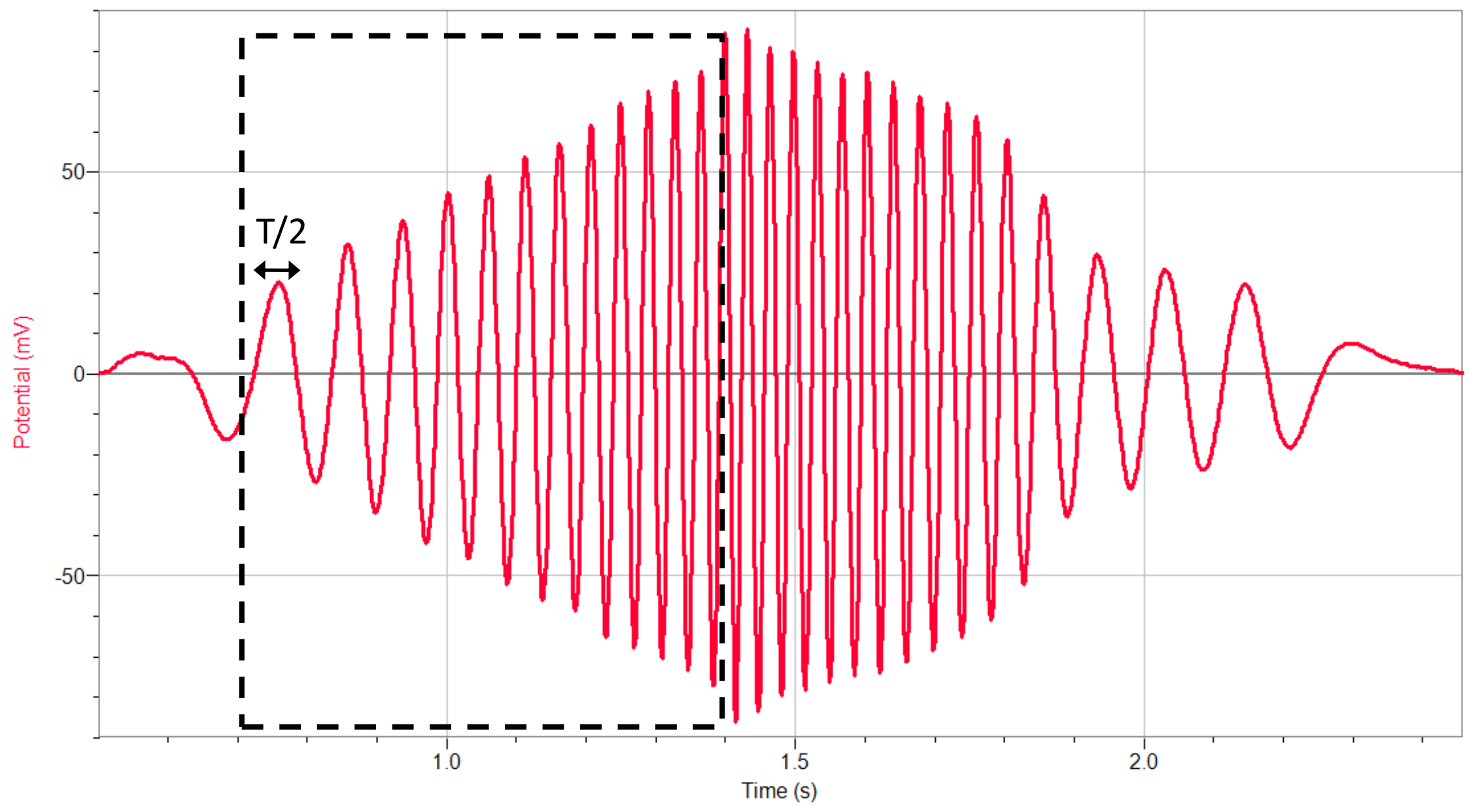
$$emf_{peak} = V_p = (N\,B\,A)\,\omega$$

$$V_p = m\,\omega$$

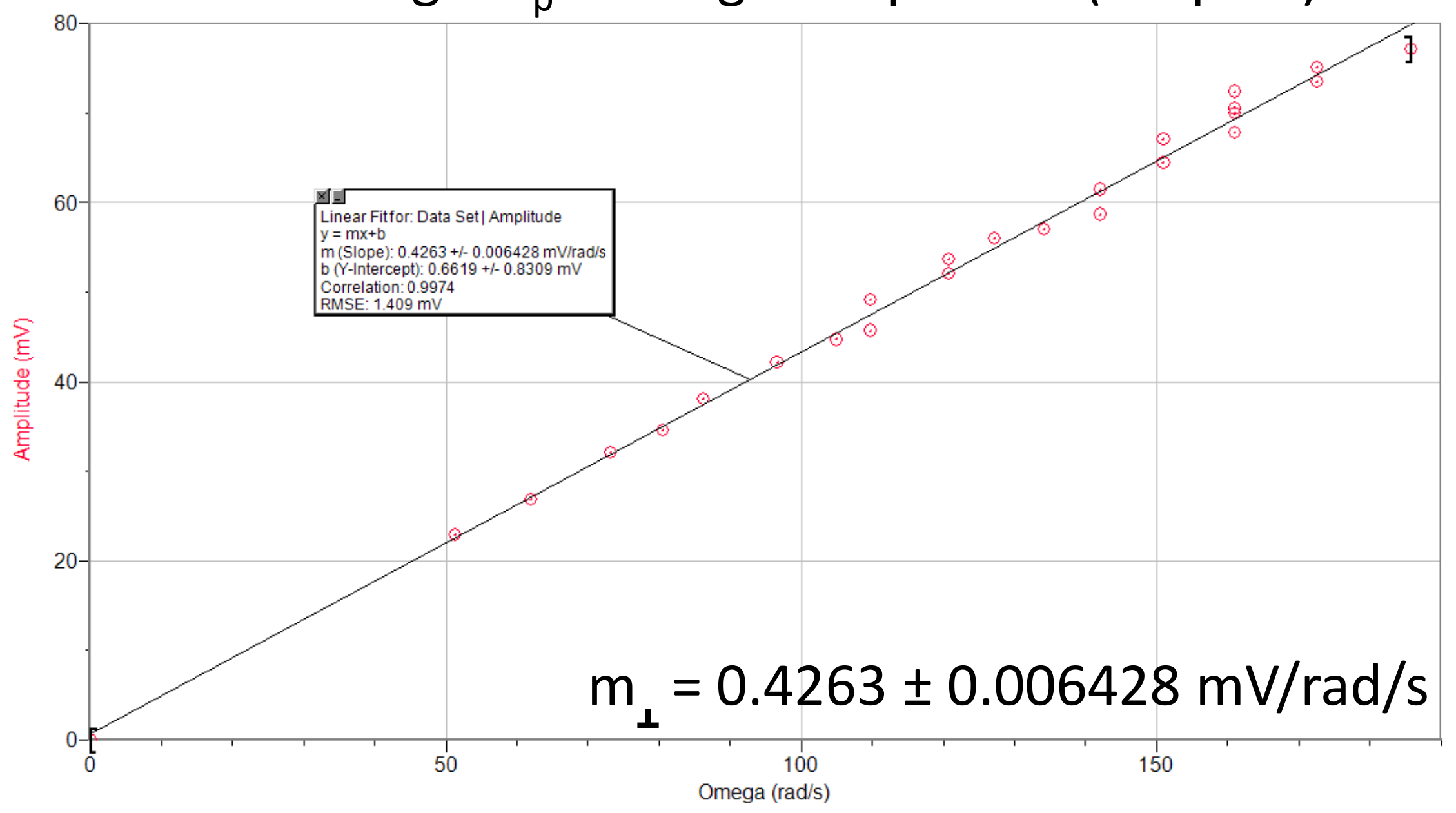
V_p ≡ voltage amplitude
N ≡ number of coil turns
ω ≡ angular speed = 2π/T
T ≡ period
A ≡ cross sectional area of coil
m ≡ experimental slope

Vertical Component

Potential vs. Time (Graph 1)



Peak Voltage V_p vs. Angular Speed ω (Graph 2)

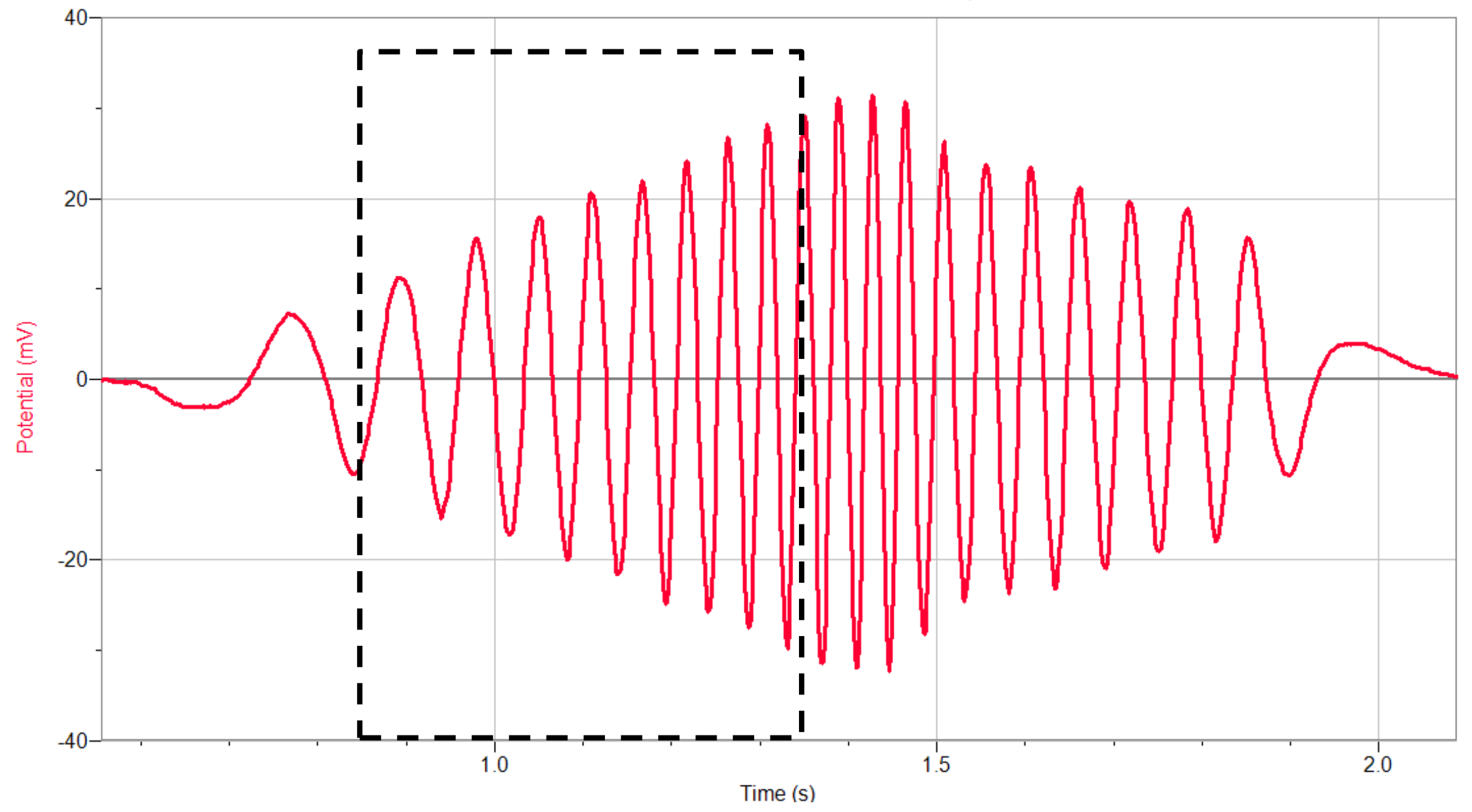


Linear Fit for: Data Set | Amplitude
y = mx+b
m (Slope): 0.4263 +/- 0.006428 mV/rad/s
b (Y-Intercept): 0.6619 +/- 0.8309 mV
Correlation: 0.9974
RMSE: 1.409 mV

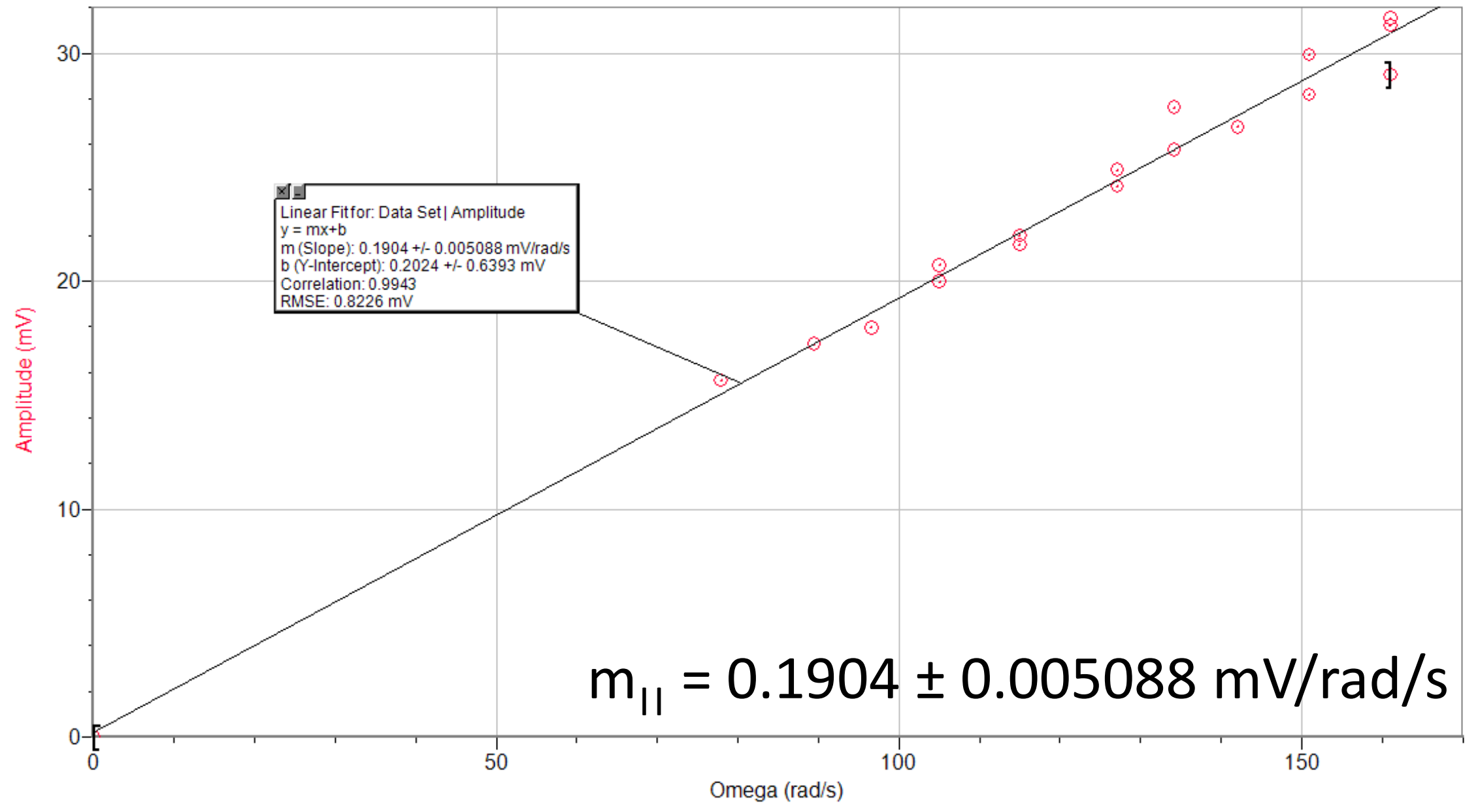
$m_{\perp}$ = 0.4263 ± 0.006428 mV/rad/s

Horizontal Component

Potential vs. Time (Graph 3)



Peak Voltage V_p vs. Angular Speed ω (Graph 4)



Linear Fit for: Data Set | Amplitude
y = mx+b
m (Slope): 0.1904 +/- 0.005088 mV/rad/s
b (Y-Intercept): 0.2024 +/- 0.6393 mV
Correlation: 0.9943
RMSE: 0.8226 mV

$m_{||}$ = 0.1904 ± 0.005088 mV/rad/s

Results and Conclusion

The slope from the linear fits is then used to solve for the component of the magnetic field at the location of the coil:

$$B = \frac{m}{N\,A}$$

We then compare our experimental results to accepted values for Earth's magnetic field (as of June 27, 2013)[2] at our location in Chico, California.

Component	$B_{experimental}$ ± ΔB (μT)	$B_{accepted}$ (μT)
Vertical	44.0 ± 0.7	44.555
Horizontal	19.7 ± 0.5	22.685

Based on our results seen in the table above, we are confident that we will be able to replace the electrical rotator-mounted coils with our new falling-mass-driven coil.

Future Work

We will make six sets of the apparatus and use them with students in our introductory EM lab beginning in Fall 13. Interactions of students with the apparatus will be observed and documented in the future.

References & Acknowledgement

[1] D. Kagan. *Phys. Teach.* 24, 423 (1986)
[2] ngdc.noaa.gov/geomag-web/#igrfwmm

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