Guitars: Pickup Coils and Noise Reduction

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Objective: In this project, we would like to explore the functionality of pickup coils in electric guitars via Faraday's Law. We would also like to explore "hum" noise cancellation via the use of multiple pickup coils.

Equipment: Small circular magnets (2x), Thin ferromagnetic wire, Thin copper wire, Copper Wire, Oscilloscope, Extra Equipment: Signal Generator, Vibrator

Experiment A Summary: Construct either Setup A or Setup B below and verify/modify our model based on experimental results.
Procedure:

1. Construct Setup B Below
2. Pluck the string or use the vibrator to oscillate the spring at frequency ω
3. Record voltage across coil over time via Oscilloscope

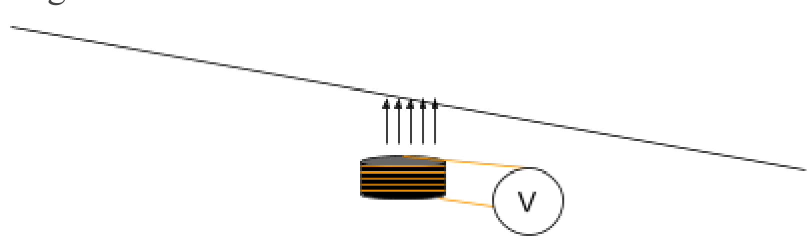
Experiment B Summary: Use two pickup coils with opposite sides. Empirically check how noise is reduced compared to one individual pickup coil.

1. Construct Setup B Below with 2 pickup coils
2. Pluck the string or use the vibrator to oscillate the spring at frequency ω
3. Record voltage across coil over time via Oscilloscope
4. Repeat 2-3 in the presence of fluorescent light or other hum generator

Theory (Pretty Much All But Images Ignorable for Now)

We ignore edge effects of the solenoid, and idealize the magnetic field so that it is uniform. Our overall model consists of several smaller models building off of previous experiments we have performed.

Setup A: Ferromagnetic Wire



Consider an oscillating ferromagnetic wire in the presence of a uniform magnetic field. The mechanism by which the guitar works is that the oscillating wire causes an oscillating magnetic field within the coil, which induces an EMF in the coil by Faraday's law. In this experiment, we can consider the simple case where the wire is only oscillating in one direction, and approximate the magnetic field induced within the coil simplistically by a damped harmonic oscillation and velocity-dependent damping:

$$\vec{B}(t) = B_0 e^{-\beta t} \cos(\omega t + \phi)\, \hat{z}$$

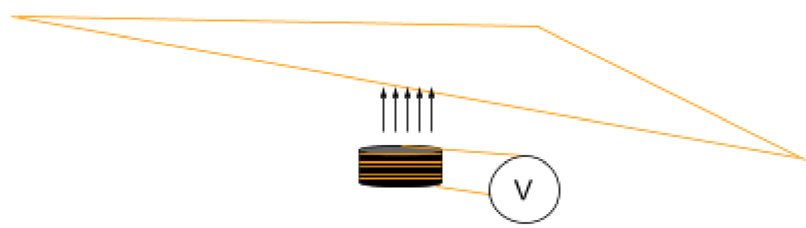
Then we have:

$$\epsilon = -\frac{\partial\Phi}{\partial t} = -A\frac{\partial B}{\partial t} = A(B_0\beta e^{-\beta t}\cos(\omega t + \phi) - B_0\omega e^{-\beta t}\sin(\omega t + \phi))$$

$$= AB_0 e^{-\beta t}(\beta\cos(\omega t + \phi) - \omega\sin(\omega t + \phi))$$

as our model for the induced EMF in the pickup coil. This is rather simplistic, since it doesn't account for permeability and the interaction between the coupled wire and magnet in the pickup coil.

Setup B: Copper Wire with Ends Connected Electrically



For the purpose of our experiment, in the event that thin iron or nickel wires are not available, it may be possible to use copper wire with the ends connected electrically. Consider a copper wire strung and vibrating according to a damped harmonic oscillation and velocity-dependent damping:

$$y(t) = y_0 e^{-\beta t}\cos(\omega t + \phi)$$

Then the induced current through the wire is proportional to y', or

$$I = -ky_0\beta e^{-\beta t}\cos(\omega t + \phi) + y_0\omega e^{-\beta t}\cos(\omega t + \phi)$$

Thus the magnitude of the magnetic field due to the wire is

$$B = \frac{\mu_0 I}{2\pi h} = \frac{\mu_0}{2\pi h}(\omega - k\beta)y_0 e^{-\beta t}\cos(\omega t + \phi)$$

which in turn creates an EMF in the coil via Faraday's law:

$$\epsilon = -\frac{\partial\phi}{\partial t} = -A\frac{\partial B}{\partial t} = \frac{\mu_0}{2\pi h}(\omega - k\beta)y_0 A(\beta - \omega)e^{-\beta t}\cos(\omega t + \phi)$$

$$= \frac{\mu_0}{2\pi}(\omega - k\beta)A(\beta - \omega)e^{-\beta t}\cos(\omega t + \phi)$$

since $y_0 = h$.