

Contact Free Bicycle Safety Light

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Abstract - This paper presents the design and implementation of a battery-free bicycle safety light. Faraday's law of Induction is the major electromagnetic concept behind this simplistic design. The circuit requires only two magnets, magnetic wiring, and light emitting diodes as hardware.

I. Introduction

The Italian physicist Alessandro Volta was the first to invent a device that produced continuous electrical current for a sustained period of time. Volta accomplished this by chemically reacting vinegar, copper, and zinc.¹ Today, we use Volta's invention of the battery as an energy source to power an eclectic array of devices, ranging anywhere from automobiles to flashlights. Although we have discovered ingenious ways over the past 150 years to manufacture batteries, they are still a relatively expensive energy source. For instance, a package of eight AA batteries from Best Buy retail stores costs \$6.99; making a single 1.5 volt battery cost over \$0.87.² If we were to run from these batteries a common one kilowatt toaster that draws 10 amps of current for one hour, we would spend over \$58.25 in the process, which is a considerable difference from the \$0.0964 Excel Energy would charge to operate that same toaster.³ When taking into account the cost of using batteries to power devices, it would be beneficial if we could utilize some other source of power to operate something as simple as a bicycle light. The thought of creating a bicycle light without a battery seems like a "red herring," but the principle of Faraday's law of Induction makes this task more realistic than first thought. Faraday's law of Induction states that "a time changing magnetic field induces a potential difference" across any resistance in a closed conducting loop.⁴ The bicycling industry already widely uses this principle of electromagnetism when manufacturing speedometers. Nearly all digital speedometers calculate the cyclist's speed by placing a small magnet on a spoke, which then passes a coil affixed to the front fork of the bicycle. As the bicycle wheel rotates, the changing magnetic field induces a current pulse through the coil sensor. This pulse allows

for one to calculate not only the cyclist's speed but direction.

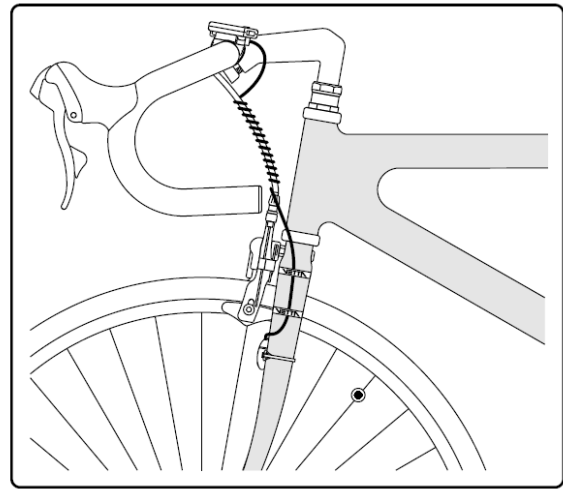


Figure 1: Typical setup of a digital bicycle speedometer

If we connect a light emitting diode (LED) instead of a speedometer computer to the coil, the current impulse will make the LED blink every time the magnet makes one revolution. Thus, we could create a very useful safety light for a bicycle that would be operative whenever the cyclist is in motion and without the use of a battery source.

II. The Design Process

As a direct result of Faraday's law of Induction, the efficiency of the safety light depends not only on the magnetic field strength but also on how quickly it fluctuates. Therefore we would like to maximize field strength, while still allowing the field to change quickly. We can achieve this goal via several methods, but the simplest route involves using only a single magnet and a coil. By attaching the magnet to the spoke of one wheel and the coil to an area of the bike that is near the magnet, there exists a changing magnetic field as the wheel rotates. However, the magnetic field is rather weak by the time it

reaches the coil because of proximity constraints imposed by the bicycle itself. Therefore, this setup would require an unwieldy number of windings to produce a reasonable potential difference.

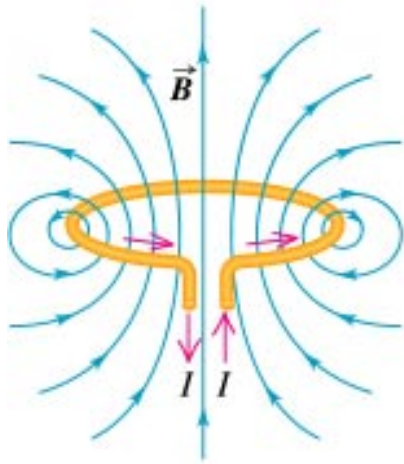


Figure 2: Magnetic Flux Density through a single conducting loop, inducing limited current flow.⁵

A second method involves using two magnets. The reason for the additional magnet comes from efforts to maximize the magnetic field strength inside the solenoid. The easiest way to maximize the field results from moving the magnet closer to the solenoid, even to within its windings. With the field maximized, we can concentrate on allowing that field to fluctuate. Notice that if we bring a second magnet to within close proximity of the first, the two magnets will attract each other. This attraction causes the first magnet, which is physically enclosed inside the solenoid, to tumble. This tumbling action generates a dramatic fluctuation in the magnetic field passing through the solenoid. Although this second method uses two magnets, we need fewer windings because we maximized both the magnetic field inside the solenoid and its fluctuation.

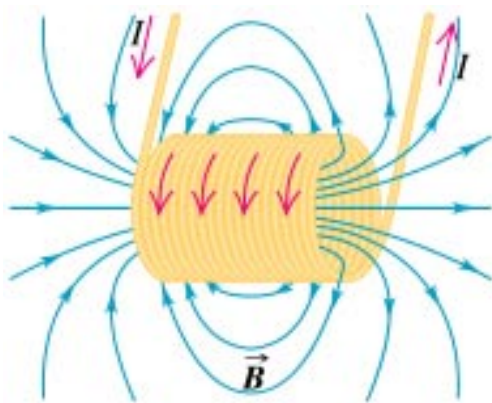


Figure 3: Magnetic Flux Density through a solenoid with N windings, inducing greater current flow.⁶

III. Fabrication

The fabrication of the bicycle light is rather simple because it has a reduced number of components. For example, the light does not require any battery connectors, switches, microcontrollers, etc. which could drastically increase the difficulty of the design and its cost. We owe the simplicity of the design to Faraday's law of Induction because it allows us to power an LED with only a changing magnetic field and a conducting loop. Throughout the entire fabrication of the safety light, we used only two cylindrical rare earth magnets, a prescription pill box, polyvinyl chloride (PVC) pipe, magnetic wiring, 8 LED's, one project enclosure, jumper wire, and connectors. To start the fabrication, loosely fasten one of the two magnets to a spoke on the rear wheel of the bicycle. A mounting system similar to those of digital speedometers, found at nearly any bicycle store, works particularly well. Create the conducting magnetic loop by winding magnetic bell wire around a 20 mm (0.75 inch) diameter PVC pipe. A total of 1100 windings across the 34 mm long PVC pipe are required to generate the necessary potential difference. Unfortunately not all 1100 windings will be able to circumscribe the length of the PVC pipe. Nearly 100 windings will wrap nicely before reaching the edge of the pipe, so at least 11 layers of windings are necessary to light the LED's.



Figure 4: The finished solenoid with cylindrically symmetric magnet and prescription pill container.

Cut another section of PVC pipe that is a smaller diameter and half the length of the first pipe. Position this pipe inside the solenoid such that one edge is at the solenoid's midpoint. Use hot glue to attach the inner PVC pipe to the solenoid. Cut out a piece of plastic (film canister lid works well) that is the same size in diameter as the inner core.

Use hot glue to secure this piece of plastic as well. With the help of a utility knife, make a small opening at the top of the pill box and slide the solenoid leads through. Place the solenoid inside the prescription pill box and pull the leads taut. Now place the second cylindrical magnet within the windings of the solenoid. Fasten the lid of the pill box to an area at the posterior of the bicycle frame, which is also close to the wheel. After attaching the lid to the bicycle frame, secure the pill box onto its lid. Allow the rear tire to rotate freely and test to see if the magnet inside the pill box tumbles. If the magnet does not tumble, adjust the magnet affixed to the spoke and try again. Otherwise, this completes the assembly of the power generating part of the device. A picture of the finished product is shown below for ease in future fabrications.



Figure 5: Completed version of the generating part of the device.

Arrange the 8 LED's into any desirable pattern inside the project enclosure. Solder these together so that the positive leads of four LED's are joined at a single node with the negative leads of the other four. Solder the remaining 8 leads together at another node.

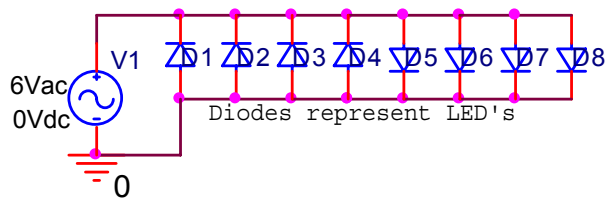


Figure 6: Schematic for LED configuration

Position the project enclosure containing the LED's onto an effective location of the bicycle (typically immediately behind the seat). Trace jumper wire along the bicycle frame from the LED's location to the solenoid. Connect the jumper wire leads to those of the LED's and the

solenoid by using a standard mox connector. Allow the rear wheel to rotate freely once again and see if the LED's light. If the LED's light, this completes the entire fabrication for the safety light. Otherwise, test the connectivity of the circuit by lighting the LED's with a direct voltage source, and by measuring the potential difference generated when the magnet tumbles (Should exceed 2V).

IV. Powering the Light

Whenever the magnet tumbles, it generates nearly a 6 V potential difference across the leads of the solenoid within a 7 ms time interval. This measurement allows us to calculate the magnetic field inside the solenoid by using Faraday's law of Induction.

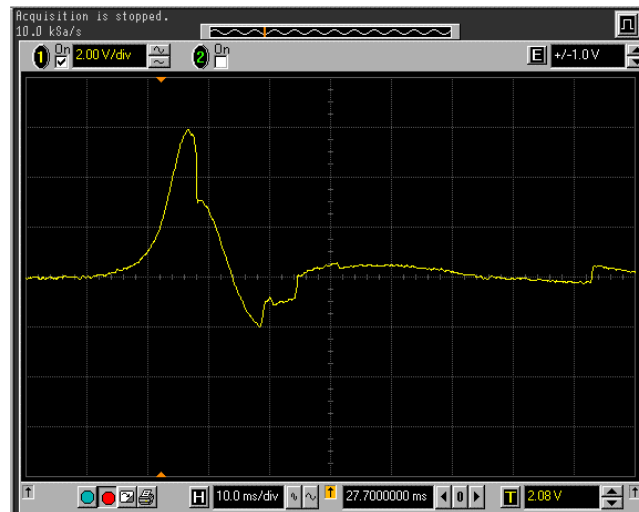


Figure 7: Output of oscilloscope when leads are connected across the solenoid.

In a generalized form, Faraday's law of Induction is:

$$e = \frac{-d\Phi}{dt} = \frac{-d}{dt} \int B dS$$

where S is surface which B passes through.⁷ By rearranging the terms, and solving for B , we can derive the following expression:

$$e = B \cdot \frac{\Delta A}{\Delta t} \cdot N$$

$$B = e \cdot \frac{\Delta t}{\Delta A \cdot N}$$

This expression allows us to estimate the magnetic flux density through the solenoid to be: (Assuming an effective

radius of 11 mm and a voltage peak of 6V within a 7 ms time interval)

$$B = 6 \cdot v \cdot \frac{7 \cdot 10^{-3} \cdot s}{\pi \cdot \left(\frac{22 \cdot 10^{-3}}{2} \right)^2} \cdot 1100$$

$$B = 100 \cdot 10^{-3} \cdot T$$

Therefore, the magnetic flux density through the solenoid is nearly one tenth of a Tesla.

V. Discussions

As the famous philosopher, Publius Syrus once wrote: "It is a bad plan that admits of no modification," there are several opportunities for improvement with the outlined design. For example, by calculating the magnetic flux density within the solenoid, we can derive the number of windings necessary to light a standard LED. Since most LED's require nearly 2 V to light efficiently, we notice that we need nearly:

$$N = e \cdot \frac{\Delta t}{\Delta A \cdot B}$$

$$N = 2V \cdot \frac{7 \cdot 10^{-3} \cdot s}{\pi \cdot \left(\frac{22 \cdot 10^{-3} \cdot m}{2} \right)^2} \cdot 100 \cdot 10^{-3} \cdot T$$

$$N = 368$$

368 windings to effectively light the LED array. Thus, 368 is much smaller than the 1100 windings previously used. Secondly, we can make two simple adjustments inside the solenoid to allow for the magnetic field to fluctuate easier. By not including the smaller PVC pipe in the fabrication, we can save a great deal of time, money, and effort. The smaller pipe only elevates the magnet so that it would tumble at the midpoint of the solenoid. We want the magnet to be near the solenoid's midpoint because it maximizes the potential difference generated. Although, we can still elevate the magnet by drilling two holes at the midpoint of the solenoid, securely attaching the cylindrical magnet to a sturdy metal dole, and inserting this dole into the pre-drilled holes. The dole will act much like an axle, and the magnet will behave very similarly to a generator. By fabricating the solenoid in this manner, the magnet will rotate more freely, thereby allowing the magnetic field to fluctuate more efficiently and predictably.

RECOGNITION:

The idea of a magnetically powered light is not a unique. In fact, after Faraday's law of Induction was published, the knowledge of electromagnetism was sufficient to build such a light. While performing research on the design, we have noticed that several others have had very similar designs to ours. Therefore, this device is not as much of an invention as an improvement on previous work.

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