

The Hard Drive: An Experiment for Faraday's Law

Brad Hinaus and Mick Veum, Department of Physics and Astronomy, University of Wisconsin–Stevens Point, Stevens Point, WI 54481-3879; bhinaus@uwsp.edu

Physics experiments relating Faraday's law to everyday life can sometimes be difficult to develop. Although there are common devices such as transformers and generators that work because of Faraday's law, it is not obvious to students that they use them on a daily basis. We have developed an experiment using a simplified, scaled-up model of the computer hard drive to study Faraday's law along with magnetic data storage and access. The difficulty of the lab can be adjusted, so it may be used from the high school through college level.

Computers store and access information with the use of binary numbers, strings of ones and zeros. Therefore, all the letters, numbers, and symbols the computer stores have to be converted into binary numbers. The binary numbers are permanently saved onto the hard drive as strings of magnets, referred to as magnetic bits.

The hard drive is a highly advanced computer component, and its operation can be very complex.¹ The important components for the purpose of this lab are the platter and the read/write head. The platter is a disk coated with a magnetic material, which can be magnetized to store the binary numbers. The read/write head writes each binary number as a microscopic magnet onto the platter so its magnetization is in the plane of the platter.^{2,3} It also reads the polarity of each bit as the platter spins below it. The "write" part of the head is an inductive coil,¹ while the "read" portion of the head can be an inductive coil, a magnetoresistive (MR) sensor, or a giant magnetoresistive⁴ (GMR) sensor.

In the laboratory, students "write" a word of their choosing onto a scaled-up model of the platter with the use of permanent magnets, and read it using a solenoid (read head) as shown in



Fig. 1. Scaled-up model of the hard drive's platter (disk) and inductive "read" head (solenoid). Permanent magnets at edge of platter store the information. When the disk is spun, an emf is induced in the solenoid and recorded by the computer.

Fig. 1. We use an 8-in circular piece of wood mounted on a variable-speed motor⁵ as the platter. To save a word, letters are first converted to binary with the aid of Fig. 2, and then binary is converted to a specific magnetization.⁶ To simplify the lab, the magnetization is oriented so it is perpendicular to the plane of the platter. A binary 1 is a magnet with its north pole vertically above the south pole, with the opposite for a binary 0. Using these conversions, a word is then "written" to the disk by taping permanent mag-

a	00001	j	01010	s	10011
b	00010	k	01011	t	10100
c	00011	l	01100	u	10101
d	00100	m	01101	v	10110
e	00101	n	01110	w	10111
f	00110	o	01111	x	11000
g	00111	p	10000	y	11001
h	01000	q	10001	z	11011
i	01001	r	10010		

Fig. 2. Conversion table used to translate between letters and their binary equivalents.

nets to the perimeter of the platter.

The read head, a small solenoid with an iron core,⁷ is mounted above the spinning disk. The solenoid is attached to a voltage probe⁸ and interfaced^{9,10} with a computer. As each magnet moves under the solenoid, the magnetic flux (number of field lines through the coil) changes as a function of time, and an emf is induced (in each turn of the coil) according to Faraday's law,¹¹

$$\epsilon = - \frac{d\Phi}{dt}, \quad (1)$$

where ϵ is the induced emf, and Φ is the magnetic flux through the loop. The computer program produces an emf-versus-time graph.

Interpreting the graph is best performed by considering the emf produced by a single bit representing a binary 1. The magnetic field strength versus the distance from a binary 1 magnet has roughly a Gaussian profile. This causes the flux through the solenoid as a function of time to have the Gaussian profile as shown in Fig. 3a. The emf versus time can be deduced from Faraday's law (Eq. 1) by plotting the "negative" slope of the flux-versus-time curve. The shape is shown in Fig. 3b, a negative pulse followed by a positive pulse. A binary 0 has an inverted shape. Figure 3c shows an experimental measurement of the binary number 10. After learning how to read their own word, lab

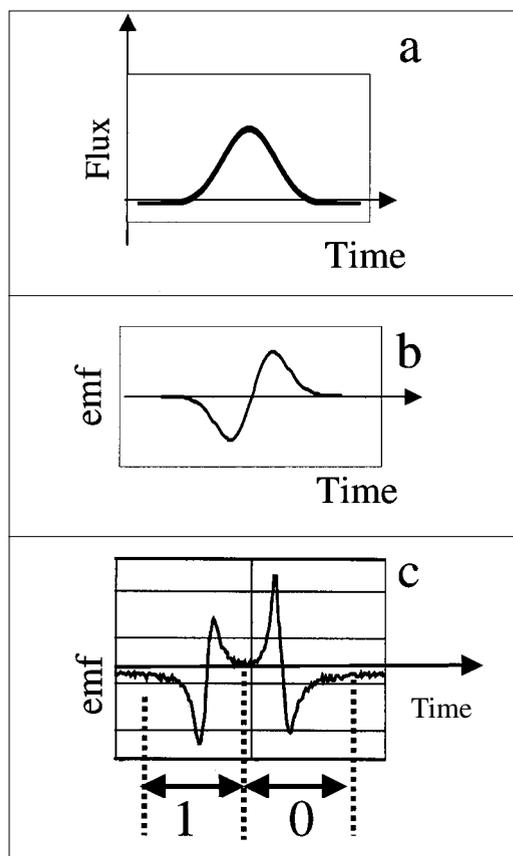


Fig. 3. (a) Magnetic flux vs time as a north pole (binary 1) moves under a solenoid. (b) Induced emf in the coil vs time as the binary 1 moves under it, which is the negative of the slope of the flux vs time. (c) Experimental recording of the binary number 10 where the bits are spaced closely.

groups trade disks and read an unknown word.

Modifications can be made to simplify the lab. Use a ruler as the platter and tape the magnets to it to save a word. Attach the solenoid to a galvanometer. Have students place the solenoid over each magnetic bit and pull it away. The needle on the meter will deflect in opposite directions for binary ones and zeros. This version also illustrates Faraday's law and the general physical concepts used in the hard drive.

In conclusion, an effective and exciting lab has been created to teach Faraday's law and illustrate how physics permeates everyday life.

References

1. See <http://www.pcguide.com/ref/hdd/index.htm>.
2. D. Macaulay, *The Way Things Work* (Houghton Mifflin, New York, 1988), p. 340.
3. See <http://www.pcguide.com/ref/hdd/geom/data.htm>.
4. See <http://www.research.ibm.com/research/gmr/basics.html>.
5. *Sargent-Welch Featuring Cenco Physics 2001–2002 Catalog* (Sargent-Welch, 2001), p. 670; <http://www.sargentwelch.com/>.
6. Of course one could use more standard seven-bit ASCII representations of letters as an alternative to the table shown in Fig. 2.
7. Ref. 5, p. 846.
8. We use Vernier Voltage Probes available at <http://www.vernier.com>.
9. Logger Pro software is used and is available from Vernier at <http://www.vernier.com>. Other computer lab systems may be substituted. The signal can also be seen on an oscilloscope, although triggering may be challenging.
10. A free PC oscilloscope can be downloaded from <http://polly.phys.msu.su/~zeld/oscill.html>.
11. R.A. Serway, *Physics for Scientists and Engineers*, 4th ed. (Saunders, New York, 1996), p. 908.