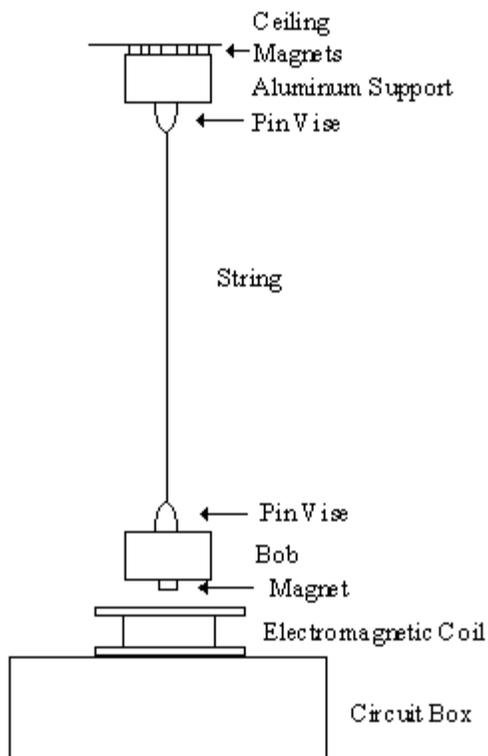


Foucault Pendulum

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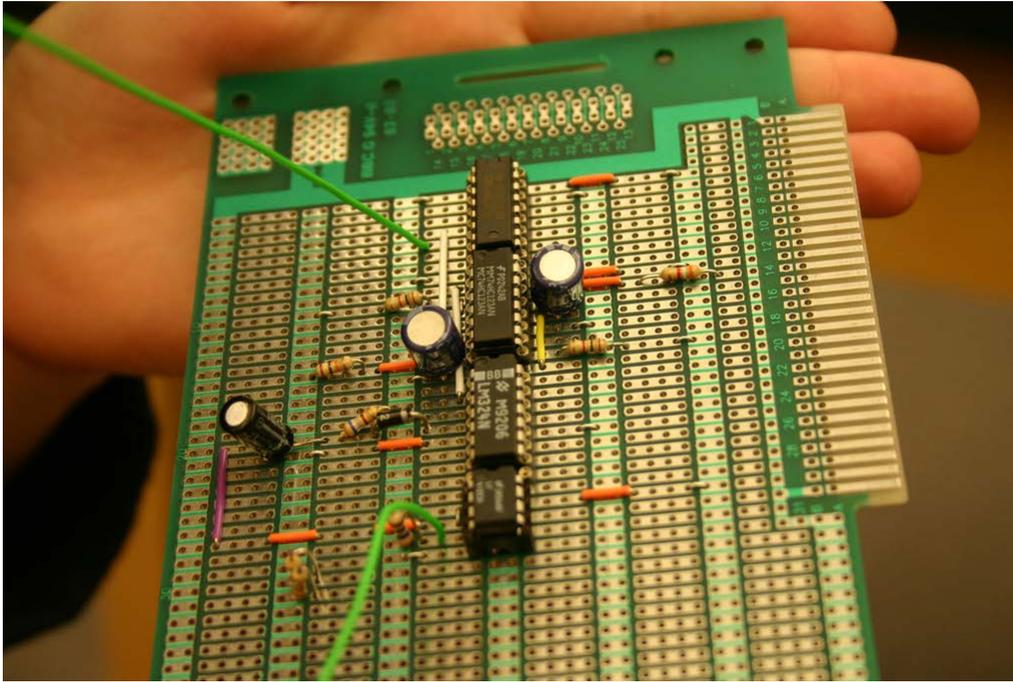
It was proposed several hundred years ago that the earth rotated. Though this fact is widely known today, the proof was not easy to find. The effect on objects is minimal, so it is fairly difficult to show. In 1851, Foucault built a pendulum. This pendulum hung from the Meridian Room of the Pantheon in Paris. The temporary support string was burned, letting the pendulum swing without ellipsing (swinging in an elliptical pattern as opposed to remaining in a plane). Although the pendulum was only swinging in one plane, that plane of rotation rotated. This was the proof needed to show that the earth was rotating.



This is a diagram of the set-up of our Foucault Pendulum

There is more to the Foucault pendulum than just the earth rotating beneath it, though. On the poles, the plane of the pendulum swing would make one rotation each day. On the equator, however, the plane will not rotate at all. This begs the question of why the plane rotates. Due to rotating reference frames and the Coriolis force, the pendulum rotates at a different rate at different latitudes. If your frame of reference were on the earth, then depending on where you stand, the earth will be “moving” at different speeds. Suppose we were standing on the North Pole. In our reference frame, the earth would rotate clockwise making hanging objects appear as though they were rotating counterclockwise. At the North Pole, you are on the axis of spin, and would therefore only see the affects of rotation. If you stand on the equator, keeping the axis of rotation at a constant angle, the earth does not rotate in your reference frame. As you move closer to the pole, the rotation in your reference frame becomes greater and greater. This allows for different amounts of rotation on different latitudes for the Foucault Pendulum. The amount of rotation per day for the pendulum can be found using the following formula. $N=360*\sin(x)$, where x is the latitude in degrees and N is the amount of rotation per day.

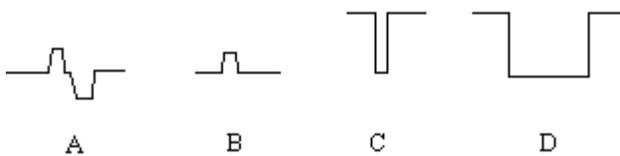
Another way to think about the rotating frame of reference is to think of a child on a merry-go-round. If the child is spinning around and lets go of a ball, anybody watching would see the ball go in a straight line off the merry-go-round. But in the reference frame of the child, it appears that there is some force making the ball curve, as the child must turn his or her head in order to keep seeing the ball. So, just as the child on the merry-go-round thinks there is some force pulling on the ball after it left their hand, we think there is a force pulling things in directions since we are on a spinning ball. This is the Coriolis force that we mentioned earlier.



Our circuit board prior to debugging.

Pendulums in the atmosphere have the problem that air resistance damps the oscillations. Because of this damping, we must provide the pendulum with energy (without biasing the swing) to keep it from stopping. From now on in this paper, this addition of energy will be called “driving” the pendulum. There are different ways to drive a pendulum. One of these ways is to connect the top of the pendulum to a speaker which would decrease the length of the string at the pendulum’s lowest point and increase the length of the string at the highest point in its swing. This would provide the energy needed to drive the pendulum as a child on a swing pumps their legs in order to increase their amplitude.

Another way to drive the pendulum would be to have an electromagnetic coil below the pendulum and have a light sensor at the top of the pendulum to detect when the string passes through. As the string disrupts the light sensor, the coil would turn on, giving the pendulum the extra energy needed for sustaining its swing. Another option that would also use the electromagnetic coil at the bottom would, instead of having a light sensor at the top, have a second coil at the bottom to detect when the pendulum is over the coil. This would then be used to turn the first coil on and off.

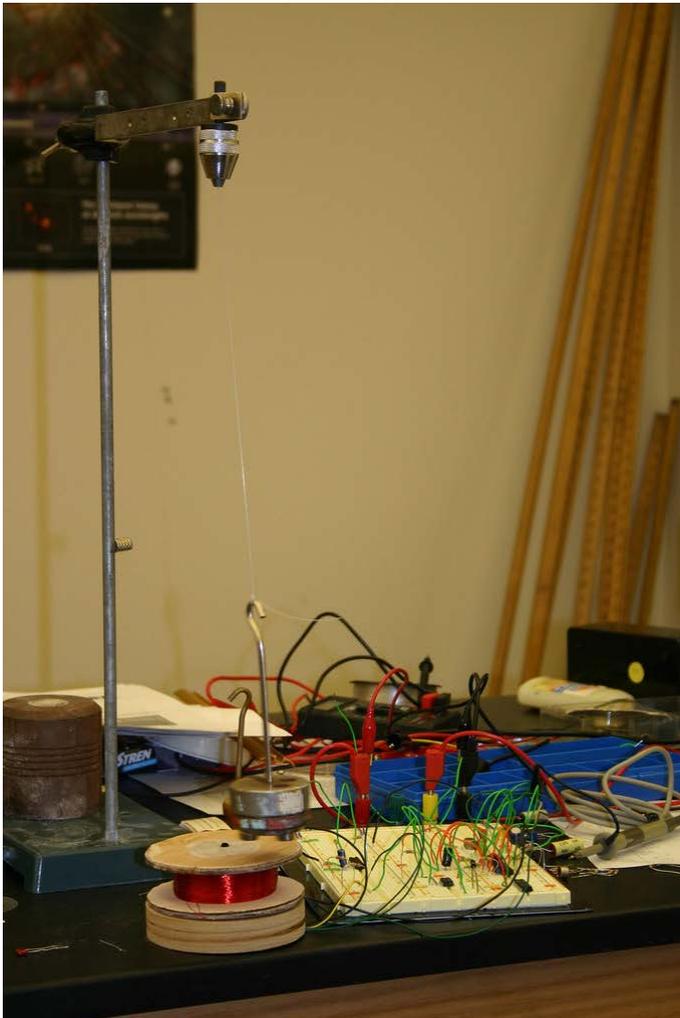


This is the signal at various stages in our circuit. A shows the incoming signal from the photodiode. After passing through a low pass filter and a diode, the negative portion of the signal is removed leaving the positive portion as shown in B. The positive portion is compared to ground in a comparator giving the signal shown in C. A 555

timer uses this signal to generate D which is used to power the coil.

The method we chose to drive our pendulum was similar to the first option. We chose to use an electromagnetic coil to drive our pendulum and an LED and photodiode pair placed under the pendulum to detect when the pendulum is over the coil. Using these two systems along with a custom-built circuit, we are able to impart energy upon the pendulum bob at just the right moment to counteract the air friction forces. Our custom circuit (see attached schematic) detects the signal change from the photodiode when the pendulum moves over the photodiode. When the photodiode detects the signal, a timer circuit will turn off the power to the electromagnet for a set amount of time. Once this amount of time has elapsed, the electromagnet returns to the on state. This means that the pendulum bob will be attracted to the coil when it is away from the coil. As soon as it reaches the lowest point in the swing, it will no longer be attracted and will continue swinging out with more energy.

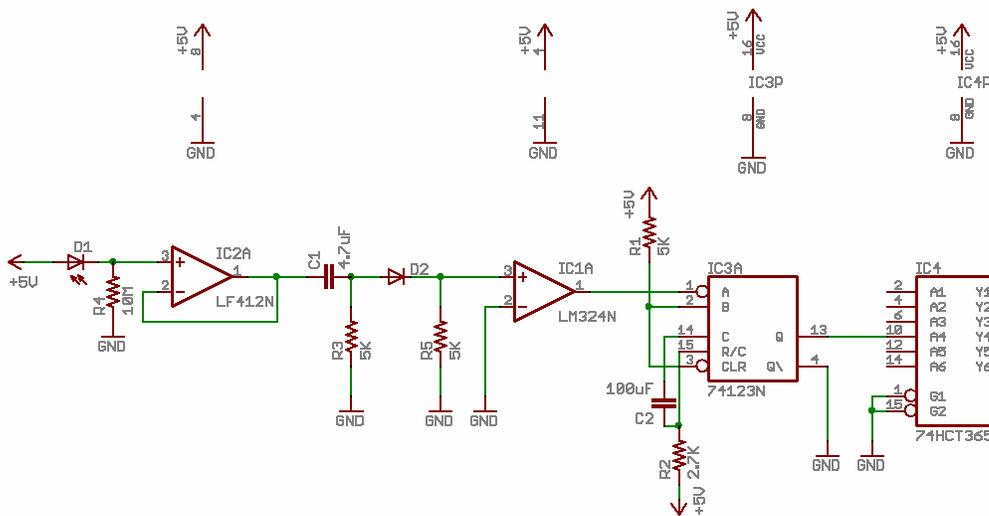
There were many difficulties encountered in the construction of our circuit. In detecting the bob, it was found that a single coil would not be sufficient since there is a large pulse through the electromagnetic coil from interactions between the coil and the bob that leaks through into the rest of the circuit. This causes problems in the circuit that prevent us from reliably energizing the coil. We solved this by using a separate optical circuit to detect the bob which would then energize the driving coil.



A smaller version of our pendulum hanging from a biased stand.

The most abundant capacitors available to us were electrolytic. This caused our circuit to malfunction on our board. After replacing them with ceramic capacitors, the circuit was more reliable. Electrolytic capacitors respond differently at higher frequencies and are unsuitable for frequency processing. On our circuit board, the comparator would only

work when the oscilloscope was touching the chip. The oscilloscope was able to discharge the diode because it has a high resistance to ground. A simple fix of adding a resistor to ground allowed the diode to discharge, thus letting the comparator do its job.



This is the schematic of the circuit used to drive the pendulum.

Our original pendulum, used for testing purposes only, would sway in one particular plane with the swing of the pendulum. This swaying biased the swing of the pendulum preventing it from rotating. We tried to prevent the swaying of the stand by adding another. This was a failed attempt to compensate as both stands would then sway together. In our final pendulum, the sway is not present as the aluminum support is not biased in any particular direction.

Many Foucault Pendulums in place today are suspended using piano wire which must be handled very carefully, lest there be a bias in the wire itself. Our pendulum is not suspended by wire, but by fishing line which claims to have no memory, thus providing us with an unbiased suspension.

Our bob is made out of an aluminum cylinder which was cut to preserve cylindrical symmetry. The mass of the bob could not exceed 17 pounds due to restrictions in our string. Our bob ended up weighing much less, so we did not have to worry about the mass limits of both the string and the magnets on the ceiling. Because aluminum is not magnetic, and would therefore not be affected by our electromagnetic coil, we attached powerful magnets to the bottom of the bob.

One of the major deterrents from keeping the pendulum from working correctly is air currents. The bob on our pendulum is light enough that a mild current may sway the pendulum from its correct path. A wind shield was built using plastic sheets kept in place with metal supports. This shield is placed around the pendulum to protect it from air currents as well as curious people who want to touch. The pendulum itself is suspended from the ceiling using magnets, a pin vise and an aluminum brace. This keeps the top of the pendulum in place as the bob swings below.

Foucault Pendulums are known for their accurate rotations. To keep track of the rotations in our pendulum, a board marking each ten degrees was made. Given our latitude in Mount Vernon, this pendulum should rotate approximately ten degrees per hour. The board will help distinguish the rotation of the pendulum. Because the pendulum rotates so slowly, it is difficult to tell just by watching.



The final Foucault pendulum.

The intent of this project was to make a working Foucault Pendulum to display on the Physics floor in West Science. The finished pendulum is now on display in the Physics lounge.