The Infinite Beast
A Driven Chaotic Pendulum

http://www.github.com/YalePhysicsLabs/Infinite_Beast

Designed by Stephen Irons at Yale University for the 2019 AAPT Summer Meeting

Introduction

The pendulum is one of the most iconic of harmonic systems that students encounter. It provides a rich array of phenomena that can be investigated at many levels of complexity. And yet it is remarkably simple in its design: A weight suspended at the end of a string, set to oscillating in a gravitational field. In this configuration, the weight will oscillate back and forth in a plane (ignoring for now, the Coriolis effect), eventually coming to a stop due to the effects of friction.

If, however, we provide a source of energy to counteract the frictional effects, we can create a pendulum that will oscillate indefinitely (at least until the energy source is depleted). This is perhaps interesting, but may become boring after a while. What if we could introduce a little randomness into the system too?

This kit, The Infinite Beast, contains everything you need to build a driven, chaotic pendulum out of prefabricated printed circuit boards (PCBs), a few basic electric components and some magnets. The circuit that drives the pendulum works by providing a pulse of current to a coil of wire (located under the platform) when the pendulum bob, a magnet itself, is moving nearby. This short pulse of current produces a force between the bob and the coil that adds a little energy to the system, keeping it oscillating. The circuit is also designed to pulse randomly in the absence of a moving magnetic bob, which makes the system self-starting. In other words, the pendulum will start oscillating even if the bob is initially at rest.

To create the chaotic motion, three permanent magnets are glued to the underside of the platform in a roughly triangular arrangement. As the pendulum swings back and forth, the bob interacts with the magnets in a random way, causing it to oscillate unpredictably.

The Infinite Beast kit contains the following components:

- 1 – Snake shaped PCB - green
- 1 – Circular shaped PCB - black
- 2 – 100k Ohm resistors (brown)
- 1 – 330 Ohm resistor (blue)
- 2 – 1000 μF capacitors
- 1 – 100 pF capacitor
- 1 – 2N3904 NPN transistor
- 1 – 2N3906 PNP transistor (yellow cap)
- 1 – 1N4007 diode
- 1 – LED 5mm (red)
- 1 – SPDT switch
- 1 – AAA battery holder
- 1 – metal nut
- 1 piece of string
- 1 – copper wire coil
- 2 – nylon screws with nuts
- 3 – ½ inch diameter disk magnets
- 3 – 5/16 inch disk magnets

Not Included: AAA Battery, Solder and soldering iron, side snip wire cutters, glue.

Assembly instructions – (READ THEM ALL THE WAY THROUGH BEFORE STARTING)

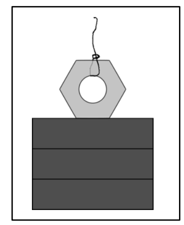
To assemble this kit, you will need some experience with soldering. There are also a couple of places where it is important to install the components in a specific way (noted below). There is no required order in which you must install the components, but some approaches may be easier than others. Refer to the circuit diagram below and assembly video that can be found on the Project Github listed on the first page.

Solder the components onto the PCB as indicated. Please note the following **CAUTIONS**:

- The LED should fit into the LED shaped hole (the eye) with some room to spare. Make sure the longer of the LED legs (the positive leg) is on the side with the "+" sign. Solder the legs to the patches of silver next to the hole, then trim the wires.
- When soldering in the two 1000 μF capacitors (They are electrolytic, watch the polarity!), **DO NOT** snug them up against the board. It will make it impossible to solder in both. Note that C2 (unlike all the other components) must be installed on the bottom side of the PCB. These capacitors should stick out between 1.5 – 2 cm from the board. This is so they can be bent to your liking to act as ears. See the photograph on the first page for clarification.
- Solder in the transistors so they stick out enough to be bent down into the "mouth" so they look like teeth. Pay attention to orientation. When installed on the front of the board, the rounded sides are initially facing upward.
- Make sure you install the battery holder with the positive terminal at the top. Also, the solder points are quite small which will make them a little difficult to solder – an unfortunate design flaw. My apologies.
- The diode (1N4001), like all diodes should be installed in the correct orientation. In this case, the white stripe facing away from the mouth.

- To connect the two PCBs, slide the two slots together, so they are fully seated, and the Lorentz Attractor drawing is facing the head of the beast. Solder them together by creating a solder bead across the patches of silver on all four sides. See the photograph at right.
- Glue the wire coil to the center of the underside of the platform, making sure the wires are long enough to reach the exposed pads. Solder one end of the coil to one of the pads on the underside of the circular PCB platform. Solder the other end to the other pad.
- Insert the nylon screws in from the top of the circular base and screw on a nut from the underside to create the two additional feet making up the tripod that supports the base.
- Install the battery and turn on the power. If it's working, you should observe the LED flashing about once per second.

Attaching the pendulum



- Tie one end of the string to the metal nut (see right).
- Magnetically attach the three larger disk magnets to the metal nut (as shown right)
- Choose one of the holes (at the chin) to hang the pendulum from so it hangs over the small circle on the platform. Tie it off so that the bottom of the bob is suspended no more than 1mm above the platform when at rest. If the pendulum is too long, tie one overhand knot in the string to shorten it by about 1.5 mm.

Attaching the magnets

The three smaller disk magnets are glued to the bottom to create the chaos in the pendulum oscillation. They can be placed however you like though the suggested placement is a triangular arrangement as described below. Before you glue (hot glue works well and is forgiving) them in place, you should first experiment using removable tape.

- It is important that they are all placed with the same polarity upward so that each one will oppose the downward polarity (your choice) of the pendulum bob and create a repulsive force between them.
- One of the magnets should be placed up against the where the two PCBs are slotted together. This will prevent the pendulum from hitting the support structure.
- The other two magnets should be placed about 120 degrees away to either side, at about the same radial distance as the first magnet. This is approximately near where the two nylon foot screws are located.

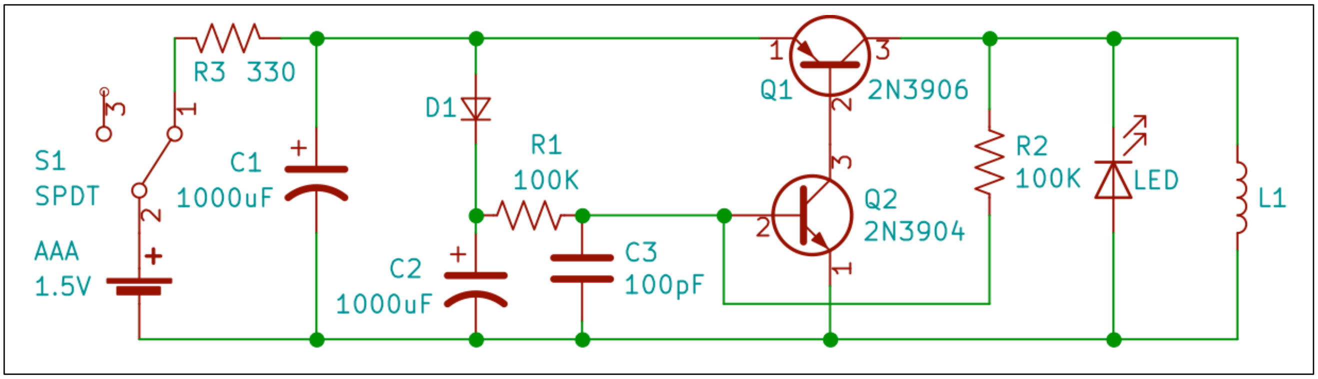
Operation

Device operation is quite simple. Install the battery and turn it on. The circuit will begin pulsing the solenoid and flashing the LED. This will start the pendulum oscillating back and forth, slowly gaining amplitude. The bob will eventually start interacting with the permanent magnets on the underside of the platform and begin bouncing around randomly. Each time the bob passes near or over the solenoid, the eye will flash and the pendulum will get a little kick. Sometimes the pendulum bob will "escape" into a stable oscillation and just swing in a plane. Adjusting the location of the underside magnets can prevent this although it's interesting to see how quickly it can find this stable part of phases space.

Troubleshooting

- If the pendulum bob gets pulled toward and trapped by one of the underside magnets, just turn the pendulum bob over so that the force between the magnetic bob and the underside magnets is now repulsive.
- If the device won't self-start anymore, the battery is probably run down. Below around 1.4 Volts, it can't start the bob from rest, though may be able to keep it going.
- If the bob at rest is more than 2 mm above the base, the magnetic interaction might be too weak to give the bob a strong enough pulse to keep it going.

CIRCUIT DIAGRAM FOR INFINITE BEAST



Created with KiCAD by S. Irons

How does the circuit drive the pendulum?

The circuit driving the Infinite Beast is a modified version of one built by TinselKoala (2014) shown on YouTube. A version of it was first published in ***Nuts and Volts*** (August 2012) by David Williams.

The general operation in the absence of a moving magnet interacting with the solenoid is as follows:

- C1, which is kept charged by the voltage supply, is discharged through Q1 into the solenoid (L1) providing the magnetic pulse.
- Q1 is triggered by a rise in the base current into Q2, which is held just below turn on by D1 and C2.
- In the absence of a magnet moving over the coil (L1), the increase in base current into Q2 is controlled by the time constant formed by R3, C1 and C2.
- When Q2 turns on, the voltage at the base of Q1 drops and permits charge from C1 to flow through Q1 into the solenoid.
- As the current falls due to the depletion of C1, the coil's inductance creates a voltage at Q1's collector that is below 0V, causing the LED to flash.
- Through R2, the low voltage at the Q1 collector, cuts off Q2 which subsequently cuts off Q1.
- C1 begins charging up again and the process repeats. Components are chosen so the LED flashes a little less than once per second.

- How C3 (added by this author to create reliable behavior) operates exactly is a little mysterious, but investigations suggest that it acts as a low-pass filter that suppresses unwanted high frequency feedback which prevents proper operation.

When a magnetic pendulum bob moves in proximity to the coil (L1) the circuit responds as follows:

- The moving magnetic field from the pendulum bob induces an EMF in the coil that creates a brief positive voltage at Q1's collector.
- Through R2, this voltage triggers a current spike into the base of Q2 which subsequently opens Q1 and allows a current pulse into the solenoid that interacts with the pendulum bob to give it a push or a pull.
- Once the pendulum bob moves away from the coil, the current through it eventually shuts off for the same reason described above.
- The discharge of C1 is greater in this case than in the natural oscillation, and hence the circuit stays off longer, and generally stays off until the magnet comes close to the coil again. This means that the circuit only pulses when the pendulum bob moves over the coil, thus creating a perfectly timed pulse.
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While this circuit uses a 1.5 V battery, it was originally designed to run off of a 2V solar panel and could be modified to do so.