HOW THE LEVITRON WORKS

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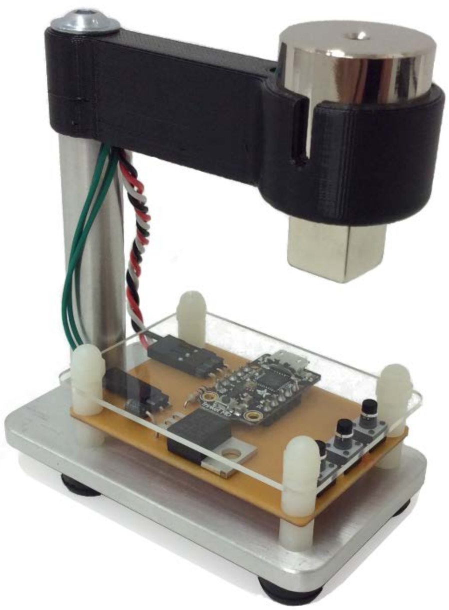
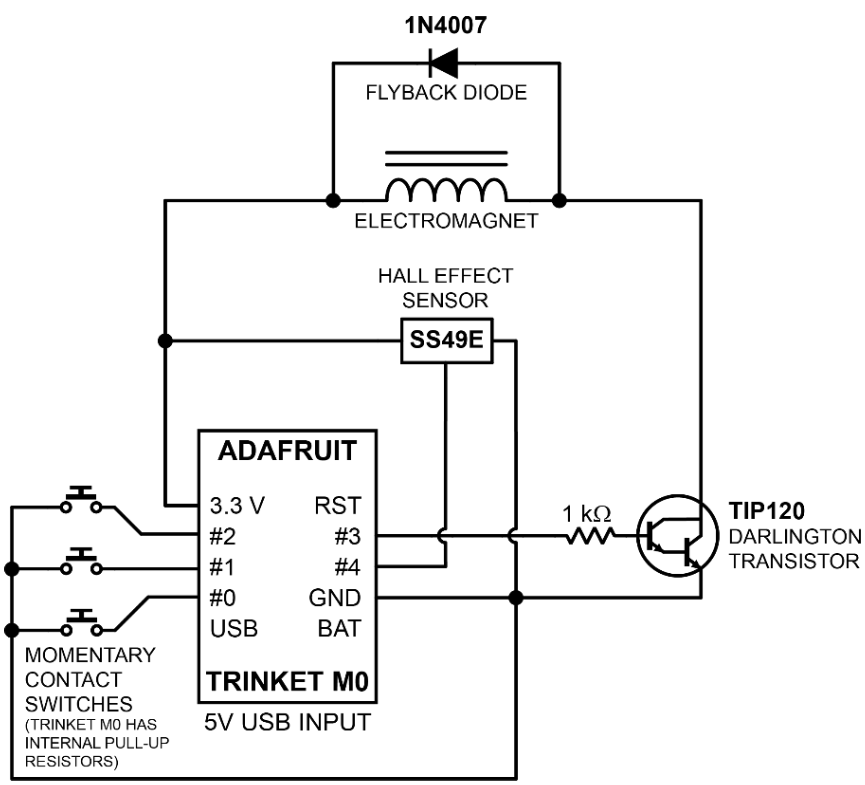


The Levitron uses simple digital control to rapidly switch an electromagnet on and off to levitate a small, but very strong neodymium cube magnet. The programmable control board reads the output of a hall effect sensor located on axis between the electromagnet and cube magnet to maintain the cube at a predefined set point where the magnetic force and the gravitational force are in balance. The following circuit diagram shows the array of electronic components used in the design.

A flyback diode is connected in parallel with the electromagnet to prevent high-voltage spikes from damaging the circuit when the electromagnet is suddenly switched off. This is an essential component for circuits with high-inductance devices like solenoids or motors. The high gain Darlington transistor serves as a switch for the electromagnet and can be controlled with a digital output. The 1 kΩ resistor limits the base current to less than 3 mA, which is well below the 7 mA maximum allowable current for the digital output of the Adafruit Trinket M0 control board.



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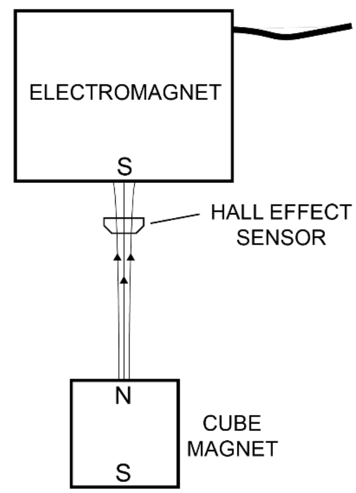
A USB cable or wall adapter connected to the Trinket M0 board is the only power source required for the Levitron. The USB connection also serves as the data link for programming the board. Power is supplied to the hall effect sensor and electromagnet through the 500 mA onboard 3.3 V regulator. Although, the electromagnet is rated for 5 V operation, it provides sufficient magnetic field strength to maintain levitation control even when powered at 3.3 V. Most of the magnetic force required to levitate the cube magnet comes from the cube magnet's attraction to the iron core of the electromagnet. The weaker magnetic field of the electromagnet is used to maintain position by adjusting the magnetic force rapidly based on input from the hall effect sensor.

The cube magnet is oriented such that its north pole faces upward and the electromagnet, when energized, has its south pole facing downward. This arrangement creates a stronger force of attraction between the magnets when the electromagnet is switched on and a weaker force when switched off. The electromagnet is switched on if the cube magnet falls too far down from the electromagnet and off if the magnet rises up too close. The magnetic field formed between the two magnets also creates lateral stability that keeps the cube magnet centered under the electromagnet.



The hall effect sensor output is linearly related to the magnetic flux density passing through the sensor. The nominal output voltage of the sensor with no magnetic flux present is one half of the 3.3 V supply voltage, which is approximately 1.65 V. If a positive magnetic flux passes through the sensor, the voltage increases to a maximum of approximately 1 V less than the supply voltage. Similarly, if a negative flux is present, the output voltage decreases down to a minimum of near 1 V. Based on the orientation of the hall effect sensor in the Levitron, both the cube magnet and the energized electromagnet produce a negative output from the sensor. Therefore, the output voltage decreases if the cube magnet moves closer to the sensor (i.e. upward) and increases back toward the midpoint (1.65 V) if the magnet moves far away (i.e. downward).

Similarly, the sensor output decreases when the electromagnet is energized, creating a problem for stable control. If the reading is taken with the electromagnet on versus off, even with the cube magnet in exactly the same position, a different value will be recorded. To maintain levitation at a specific set point, the reading must be consistent for any position of the cube magnet to determine if it is too close or far from the magnet and take the appropriate control action. One way to solve this problem is to create a sensor offset value that accounts for the contribution of the electromagnet in the reading of the sensor. By accounting for this offset when the electromagnet is on, a consistent reading is possible.

Three momentary contact tactile switches are included in the design of the Levitron circuit to allow for additional functions. Some possible uses of button control are: a park feature that makes the cube magnet stick to the electromagnet before unplugging the device, a fine tuner that allows the set point to be adjusted on the fly, or a means to change the color and/or intensity of the RGB DotStar LED that is built into the Trinket M0 board.

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The Trinket M0 board can easily be programmed in the Arduino IDE or with Adafruit's CircuitPython language. CircuitPython is particularly easy because it comes preinstalled on the controller and allows virtually any text editor to be used to write, edit and store code on the board. Below is a basic, functional CircuitPython program to control the Levitron with comments that explain each line of code.

```
import board #library to interface with Adafruit Trinket M0 board
from digitalio import DigitalInOut, Direction #library for digital i/o to control
electromagnet
from analogio import AnalogIn #library for analog i/o to read hall effect sensor

ElectroMagnet = DigitalInOut(board.D3) #create instance of DigitalInOut class using pin #3
ElectroMagnet.direction = Direction.OUTPUT #set pin #3 as output
ElectroMagnet.value = 0 #intialize output value of pin #3 to 0 (turns electromagnet off)

HallEffectSensor = AnalogIn(board.A4) #create instance of AnalogIn class using pin #4

#Define a variable for the control set point--the hall effect sensor reading that the/
#control algorithm will attempt to maintain.  The sensor reading varies with vertical/
#position of the cube magnet.  The higher the magnet, the lower the value of the sensor./
#The sensor reading is a 16-bit integer value analog-to-digital conversion from the 3.3 V/
#logic of the Trinket M0.  The nominal reading with no magnetic field present is
#approximately 32768 which corresponds to 1.65 V.
SetPoint = 25600

#When the electromagnet is turned on it influences the hall effect sensor reading, making/
#stable control difficult.  The variable defined here is a sensor offset that accounts/
#for the amount the reading is reduced when the electromagnet is fully on and the cube/
#magnet is near its set point position.
SensorOffset = 1600

#The control strategy is quite simple.  The electromagnet and cube magnet are oriented/
#to attract each other with opposite poles.  The sensor reading is checked in a continuous/
#while loop.  If the cube magnet is too close to the electromagnet (i.e. the sensor/
#reading is smaller than the set point, the electromagnet is turned off.  If it gets too/
#far away (i.e. reading larger than set point), the electromagnet is turned back on.
while True:
    reading = HallEffectSensor.value #read the current value of the hall effect sensor
    if (ElectroMagnet.value == 1) and (reading+SensorOffset < SetPoint):
        ElectroMagnet.value = 0 #turn off electromagnet
    elif (ElectroMagnet.value == 0) and (reading > SetPoint):
        ElectroMagnet.value = 1 #turn on electromagnet
```