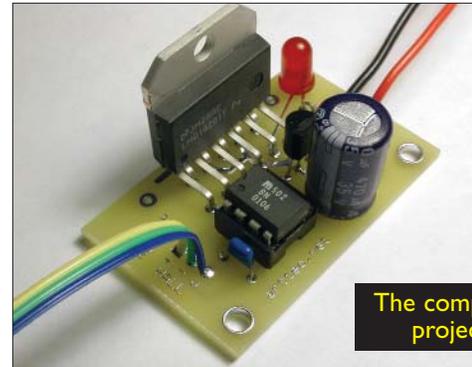
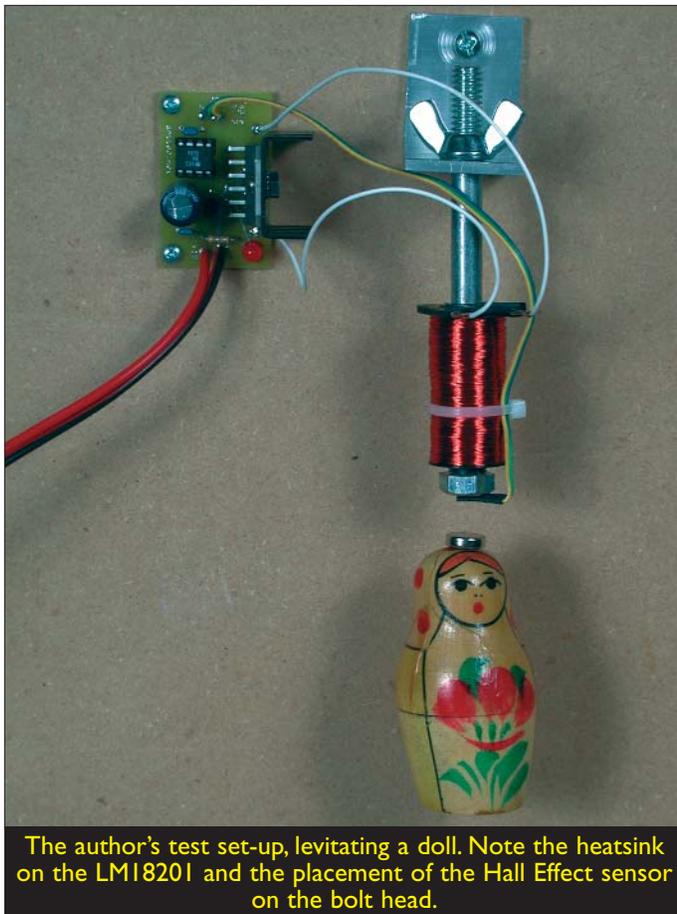


Levitation!

Float objects in a servo-controlled magnetic field.

Levitation! The word inspires images of stage magicians and lovely ladies. For me, it became a challenge to create a simple workable design to make an object hover in space. The trick obviously is to use magnets. The design problem has to do with overcoming Earnshaw's Theorem that explicitly states that it is impossible to achieve stable magnetic levitation using exclusively permanent magnets in a gravity system.

Implied in that theorem is the need for some kind of electromagnetic servo that can respond to the position of a permanent magnet and stabilize it in position. My design places a variable strength electromagnet above a suspended permanent magnet — the electromagnet is



servo-controlled to hold the permanent magnet in place beneath it.

POSITION SENSOR

A servo system requires feedback from some kind of positional sensor. A simple way to sense the position of a magnet that is suspended below an electromagnet uses a light beam with LEDs on one side and a photo cell on the other. As the object moves, a shadow from its upper or lower edge partially blocks the light, and changes the corresponding resistance of a photocell so that a proportional signal is generated. The drawback to me is the visual "give away" of the light beam's components. We're going for magic here — right?

My approach is to use a Hall Effect sensor with an output that is proportional to magnetic flux. This means that the closer to a magnet it gets, the greater the signal that it produces. My sensor of choice is a Honeywell SS490 high performance miniature ratiometric linear sensor (U2). The output of this simple three-leaded device is at 50 percent of a single 5VDC supply in the absence of a nearby magnet. The output can go rail to rail depending on the polarity of the nearby magnet. A magnet with a north pole facing the sensor will drive the output in one direction while a south pole will drive it the other way. This provides an ideal servo proportional control signal.

PWM CONTROL

To make use of this signal, I wanted to drive an electromagnet with a PWM (Pulse Width Modulated) signal. This is a scheme most often used to control the brightness of DC lamps and the speed of DC motors. A repeating pulse changes its width to apply more or less power to the device over time. PWM circuits can be constructed from op-amps or timer circuits, but I wanted to keep my design very simple with a really low parts count.

In my research, I came across a chip that is used to modulate the speed of CPU cooler fans based on the resistance of a thermistor. The chip provides only as much fan speed as is needed to cool the computer, with the side benefit of a quieter running fan. I realized that the

thermistor could be replaced with any proportional signal, such as that provided by the Hall sensor. The chip is made by Micrel — part number MIC502 (U3). The pulse frequency can be set by a capacitor. A 0.1uF cap will give approximately a 100Hz signal and a 0.01uF cap will yield about 10kHz. I opted for the higher frequency as it provides a more rapid response dynamic.

ELECTROMAGNETIC DRIVER

Since an electromagnet (or solenoid coil) has a ferrous core, the suspended permanent magnet will be attracted to it. My theory for the control is that if the suspended magnet gets too close to the electromagnet above it, the electromagnet should push it away. Conversely, if it falls too low the electromagnet should work at pulling it back up, eventually reaching a balance of push-and-pull. This theory requires that the electromagnet can change polarity from attraction to repulsion in a proportional manner. I decided to use a motor driver chip that has a built-in H-bridge switch that can reverse the polarity of its output. I used a LM18201 (U4) motor control chip that is well known to robotics hobbyists. It can control up to three amps (six amp peak) with the appropriate heatsink.

By wiring the PWM signal to the U4's DIR (pin 3) input and connecting the PWM input (pin 5), to 5V the electromagnet can be proportionately controlled from full reverse to full forward current. If the input signal is at 50 percent, then the net effect is equal attraction and repulsion of the suspended permanent magnet. As the permanent magnet moves further away from the Hall sensor, the duty cycle changes to a higher ratio that attracts the magnet, and the reverse.

CONSTRUCTION

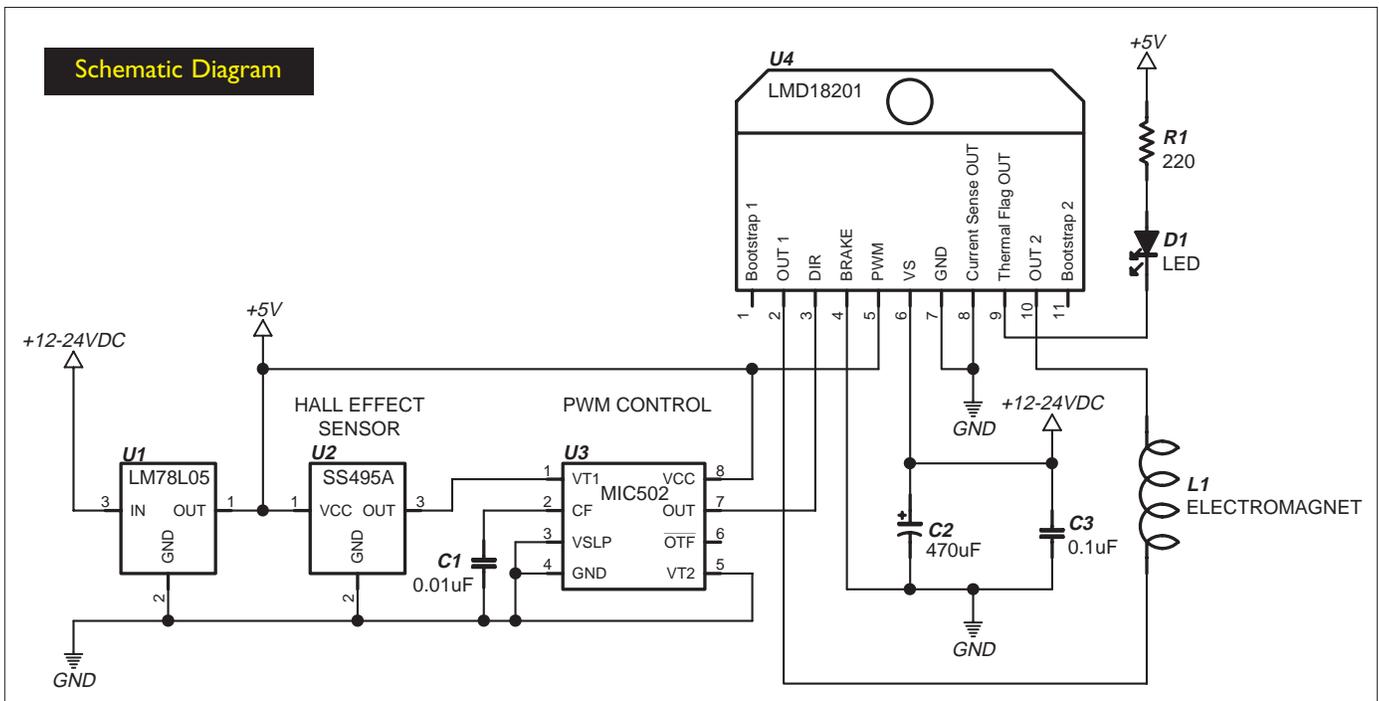
Construction is fairly simple — there are no significant part placement issues. The only annoyance is the lead spacing of the LMD18201 which won't fit into 0.1-inch perf-board without a lot of bending. Be very careful to observe the pin numbering that goes left to right (long leads are odd numbered) and keep the leads apart. C2 and C3 should be as close as possible to U4 for good filtering of the motor switching spikes. I designed a small circuit board to simplify construction (see parts list).

An optional LED and 220-ohm resistor can be connected to pin 9 of U4. This will give you early warning that the chip is overheating. I used a solenoid that draws less than half an amp, so I didn't bother with a heatsink. However, your electromagnet may draw more and need it. For that reason, be sure to place U4 with its tab at the edge of your board to make it easier to attach it to a large heatsink.

The Hall sensor (U2) should be connected with three wires — I used ribbon cable. Make sure to carefully insulate the leads at the chip with shrink tubing or tape. It's almost certain that those wires will get smashed between the magnet and solenoid as you fool around with the set-up. A bit of tape or heat shrink tubing around the body of the sensor will also help protect it from physical shock. Leave two wires with stripped ends connected to pins 2 and 10 of U4 (or use screw terminals) so that you can readily reverse the wires or swap out different coils for testing.

MAKING THE ELECTROMAGNET

The electromagnet can be any substantial solenoid.





Suggested Hall Effect sensor wiring to prevent shorted leads during testing.

Look for something rated around 12VDC with a lot of pulling force — at least 12 oz. pull at 1/4 inch, preferably much more than that. You can wind your own from magnet wire, but be sure to calculate your current consumption before hooking it to the circuit so you don't exceed three amps or so. Anything below about eight ohms will cook U4! I made my (32 ohm) electromagnet from a spare solenoid by hacking off the end of the plunger so it sits flush with the end of the coil. Glue the shaft into the solenoid (or wrap a turn or two of tape around it and force it in). I also have used a small DC clutch as a magnet with a steel shaft inside it. An actual commercial lifting type electromagnet will work fine, too.

BUILDING A SUPPORT

It is very important that the axis of the electromagnet be perfectly vertical for this design to work. So give some thought to mounting so that it can be adjusted and leveled. The sensor should be securely taped or glued to the center of the bottom of the coil, right on the shaft. Mount your solenoid at least eight inches above the base to give you room to work. I used particle board (MDF) and angle brackets (image), and my solenoid is about 18 inches

above the base, which puts the magnet above eye level when I'm sitting at my workbench.

TESTING

The circuit requires at least 12VDC from a regulated power supply — this is the minimum voltage requirement for U4. It will not work at all below about 11 volts. U4 can handle up to 60 volts, but the circuit is limited by the 78L05's max of 30 volts and the voltage tolerance of C2 and C3. This gives you the opportunity to "overdrive" 12V solenoids up to 24 volts or so to enhance the performance.

Take a small Neodymium magnet and tape it to the end of a plastic pen for testing. The magnets I used are 3/8 inch in diameter and 1/8 inch to 1/4 inch thick. They are available from many of the surplus stores advertising in *Nuts & Volts*. Don't glue it, as you may need to flip it over to get all the polarities correct. Connect your solenoid and connect power to the circuit. Power consumption should be very low — under 50mA for a 30-ohm coil like I used.

Now hold the pen in your hand and slowly move it up towards the electromagnet, keeping it directly in line below the center of the coil. As it approaches the coil within about 1/2 inch, you should begin to feel a slight push or pull. If you have a 'scope, you should see a 50 percent duty-cycle waveform at pin 7 of U3 when no magnet is present. The pulse width and frequency will change as a magnet approaches, and you will also see a lot of "hash" on the waveform as the circuit engages and switches the coil. You may also hear a squeal from your coil, depending on its construction, and you will feel the coil switching as a vibration as you move the magnet around near it.

POLARITIES

Three things need to be in the correct magnetic polarity relative to each other in order for it to work: the coil, the Hall sensor, and the suspended magnet. If your magnet pulls toward the coil, try reversing the coil wires. If the magnet still pulls toward the coil, try reversing the orientation of the magnet. Eventually, you will know which combination works when you feel the pen pushed away as it gets close to the coil.

Of course, if your magnet gets too close, it will be attracted to the core of the electromagnet and smack into it, potentially crushing the Hall Effect sensor, so take care. If you have a current meter on

PARTS LIST

U1	LM78L05	5-volt regulator	DIGI-KEY NJM78L05A-ND
U2	SS495A	Honeywell Hall Effect sensor	NEWARK 52F1662
U3	MIC502	Micrel Fan Management IC	NEWARK 05C4623
U4	LMD18201	Motor control IC	DIGI-KEY LMD18201T-ND
C1	0.01uF 50V	monolithic capacitor	DIGI-KEY P4963-ND
C2	470uF 35V	electrolytic capacitor	DIGI-KEY P5168-ND
C3	0.1uF 50V	monolithic capacitor	DIGI-KEY P4923-ND
D1	LED	LED	
R1	470 ohm	1/4 watt resistor	
L1	electromagnet	solenoid or hand wound coil (8 ohm min. 16+ ohm good)	

Kit of parts available from the author for \$40.00 includes circuit board, electronic parts, and two magnets. You will need to supply your own electromagnet. Suggested sources for electromagnets and kits are on the author's web site:

www.arttec.net/Levitation/Kit.html

your power supply, it will go up as the pen approaches from over 1/2 inch away, then go down as you hit the ideal levitation position, then go up again as you move it closer to the coil. Once you have the design tweaked, the power consumption will stay relatively low during stable levitation.

CALIBRATION

Once the polarities are right, you will feel the magnet "grab" as it enters the "sweet spot" under the coil. At this point, you should try to let the pen go very gently so you don't bump it up, down, or sideways.

If it pulls up and sticks to the coil, you will need to add more weight — try sticking another magnet to the top. If it falls away, your pen is too heavy, or your electromagnet is not strong enough. It will take some time to find the right weight that your combination of electromagnet and permanent magnet will lift. The range of viable weights is fairly small, so be prepared to do a lot of testing and changing of weights. Small plastic models like Harry Potter toys will be sure to delight the kids!

PATIENCE IS REWARDED

My design is very simple and does not use any dynam-

ABOUT THE AUTHOR

Guy Marsden designs custom prototypes for inventors and controls for kinetic artworks. He also makes electronic and wood sculptures and furniture. See his extensive web site at www.arttec.net or email him at guy@arttec.net.

ic damping as some other designs I have seen do, but those designs are very complex. You can expect the levitated object to bobble up and down a bit until it stabilizes. Adding a small amount of ferrous metal to the suspended magnet will dampen the vertical oscillations and stabilize the levitation — try small washers or nuts.

It takes some patience to learn how to carefully get the magnet into position and release it so it stays stable. It is a very spooky feeling when it all works right and the magnet pulls into place. If you start a levitated object spinning it will continue for a long time — it's a frictionless bearing!

This is the type of simple magic that evokes my favorite quote from science fiction writer Arthur C. Clarke: "Any sufficiently advanced technology is indistinguishable from magic." People young and old will marvel at your mastery of the "magic" of electronics! **NV**

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