Magnetic Levitation Kit

Parts and layout

This kit contains all the components needed to build a working circuit that can control the levitation of a small permanent magnet EXCEPT the electromagnet that you provide. The electromagnet can be made from a large solenoid or relay coil, part of an electromagnetic clutch, or hand wound. This circuit will power up to 3 Amps at 24 Volts, or any powerful electromagnetic coil of 8 Ohms or higher.

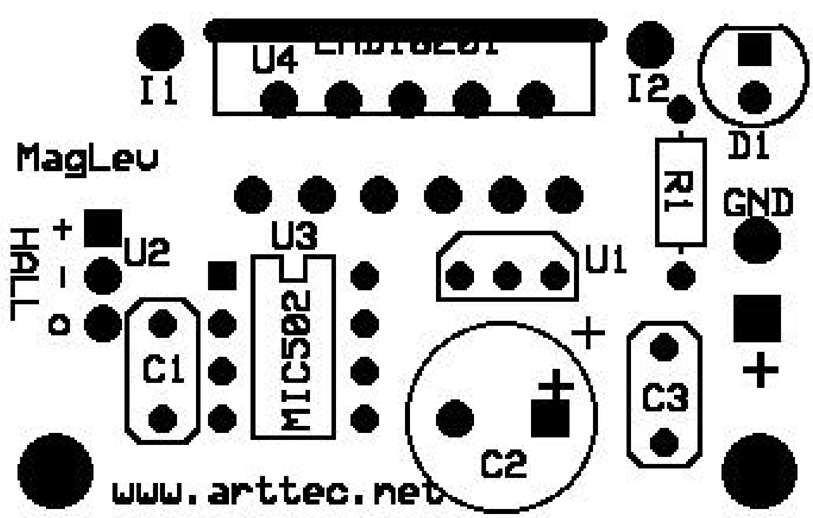
Parts List

C1	0.01uF	monolithic capacitor (beige)
C2	470uF	electrolytic capacitor
C3	0.1uF	monolithic capacitor (blue)
D1	LED	red LED
HS1	Heat Sink	for U4
L1	electromagnet	electromagnet coil
M1-3	magnets	Rare earth magnets 3/8” diameter X 1/8” approx
R1	220 Ohm	1/4 watt resistor
U1	LM78L05	5 Volt regulator
U2	SS495A	Hall effect sensor
U3	MIC502	Fan Management IC
U4	LMD18201	Motor control IC

Circuit board

6” of 3 conductor ribbon wire
short piece of 1/8” heat shrink tubing

COMPONENT PLACEMENT



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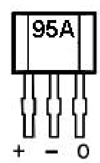
Magnetic Levitation Kit
Assembly Instructions

First things first. Unpack and identify all the components and lay them out neatly on your workbench.
Now go and wash your hands - it will make you feel better and gives you a "fresh start"!
Start by installing the smallest components first in the following order: R1,C1,C2,U3,U1,D1,C2,U4. Insert the components, bend their leads over on the back to hold them in place, double check orientation, then solder each part one at a time. C2 has a square hole for the positive (longer) lead. Install all components EXCEPT U2 which is installed on a length of ribbon wire.

WIRING THE SENSOR
Carefully separate the ends of the length of 3 conductor ribbon wire about 1" back and strip 1/8" of insulation from the ends, then tin the ends to keep the strands together. (Tinning means melting solder into the wire). Now cut the wires on U2 down to about 1/2" and tin the ends with a small amount of solder. Slide short lengths of 1/8" heat shrink tubing onto the ends of the ribbon wire. Hold U2 in a clamp or heatsink and solder the tinned wires to the sensor very carefully. Be sure not to overheat the sensor or damage it. Slide the shrink tubing over the soldered leads and heat the tubing with a heat gun or the end of your soldering iron (without touching). The end should look like this:



Now solder the other ends into the PC board in the same order as the component leads. Note that the part number and beveled faces are facing you as in the picture.

Now using 22 Gauge or thicker wire, install 2 power wires (6" or longer) into the holes marked + and - . Your board should now look like this:

You can bolt the heat sink on at this time if you wish, the fins should face away from the board. All that remains is to solder 2 more wires at least 6" long into the holes on each side of U4. These wires will connect to your coil.

Your Levitation Kit is now assembled and ready for calibration and testing! Let the magic begin!

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Theory of operation

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 it's 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 beams components.

My approach is to use a Hall Effect sensor with an output that is proportional to magnetic flux. Meaning 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 3 leaded device is at 50% of a single 5VDC supply (2.5V) in the absence of a nearby magnet. The output can go rail to rail (0 to 5V) 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 it's width to apply more or less power to the device over time. PWM circuits can be constructed from opamps 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 it's output. I used a LM18201(U4) motor control chip that is well known to robotics hobbyists. It can control up to 3 Amps (6 Amp peak) with the appropriate heat sink.

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% 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.

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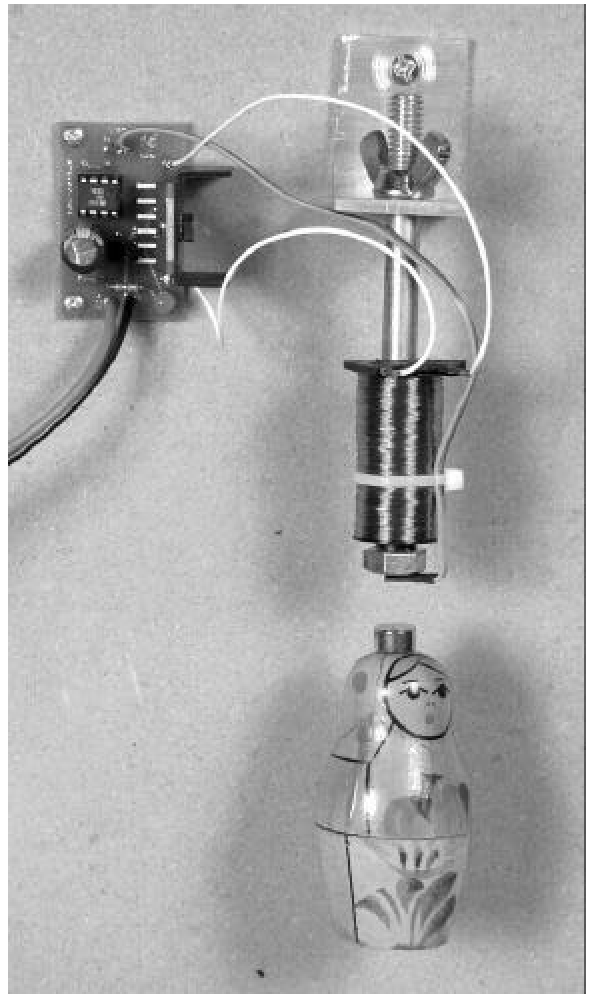
Testing



MAKING THE ELECTROMAGNET

Solenoids with coils of more than 100 Ohms will draws less than half an Amp at 24 Volts so you may not need a heat sink, but your electromagnet may draw more and need it. The LED will light when U4 reaches 145F, then U4 will shut down at 180F to protect itself. A large heatsink than provided may be needed, and for loads much over 1 Amp a fan cooled heat sink would be in order.

The electromagnet can be any substantial solenoid or relay coil. Look for something rated around 12VDC with a lot of pulling force -- at least 12oz pull at 1/4", 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 3 Amps or so. I made my 32 Ohm electromagnet (shown) from a spare solenoid by replacing the plunger with a 5/16" bolt so it's head sticks out of the bottom of the coil. You can glue the shaft into the solenoid (or wrap a turn or 2 of tape around it and force it in). I also have use 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 8" above the base to give you room to work.

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. An adjustable power supply is be ideal for this.

Take a small Neodymium magnet and tape it to the end of a plastic pen for testing. 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. 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" you should begin to feel a slight push or pull. If you have a 'scope you should see a 50% waveform at pin 7 of U3 when no magnet is present. The pulse width and frequency will change as a magnet approaches, 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 it's construction and you will feel the coil switching as a vibration as you move the magnet around near it.

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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 Effect Sensor, and the suspended magnet. If your magnet pulls toward the coil, try reversing the magnet. If the magnet still pulls toward the coil try reversing the coil wires. Eventually you will know which combination works when the pen will feel pushed away when it gets close 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 your power supply it will go up as the pen approaches from over 1/2" 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. The wave form will be a very noisy 40-50% duty cycle

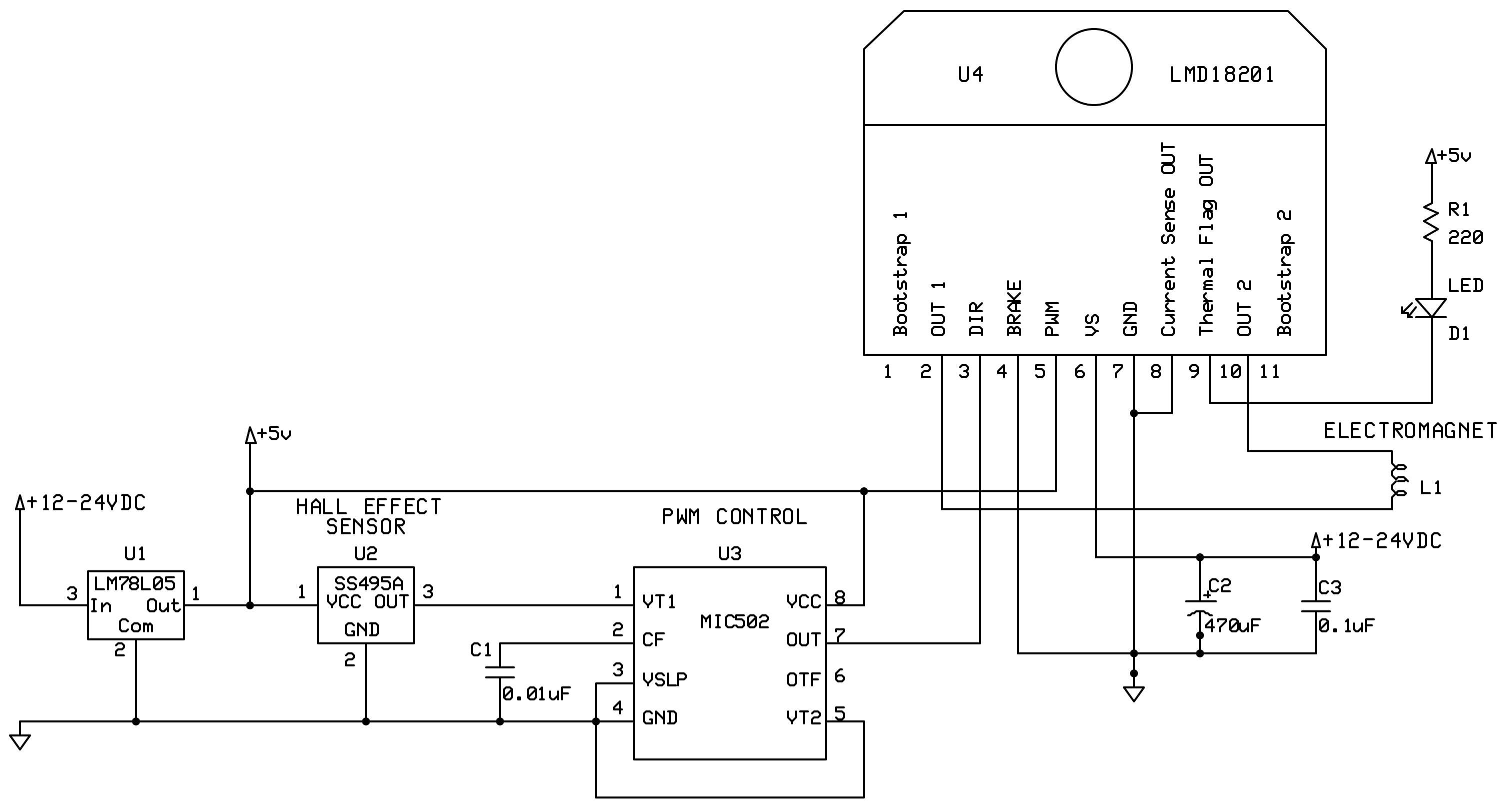
CALIBRATION
Once the polarities are right you will feel the magnet "grab" as it enters the "sweet spot" under the coil.
At this point you should try to let the pen go very gently so you don't bump it up, down, or sideways.
If it pulls up and sticks to the coil, you will need to add more weight, try sticking another magnet to the top. If it falls away, your pen is too heavy, or your electromagnet is not strong enough. If it bobbles up and down, add some ferrous metal to the suspended magnet - like some small washers. This will damp the magnetic reactance of the circuit.

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 for any given combination of electromagnet and permanent magnet, so be prepared to do a lot of testing and changing of weights.

PATIENCE IS REWARDED
My design is very simple and does not use any dynamic damping as some other designs I have seen do, but those design are very complex. You can expect the levitated object to bobble up and down a bit until it stabilizes. If your weight is not right it may eventually lose control and stick to the coil or fall away. 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. Have fun!

SEND ME IMAGES OF YOUR LEVITATED OBJECTS!
I will post good quality images to my web site of your setup. Email them to me at: guy@arttec.net

This kit is designed around the construction article that I wrote for Nuts & Volts Magazine's September 2003 issue.



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Rev 2.0

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