oneTesla

Musical 10" Coil User Manual

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Welcome to the world of high voltage.

Singing lightning, wireless energy, high-frequency resonators, and beautiful sparks fascinate us too. That's why we made oneTesla. We want the fun of musical Tesla coils to be available to all passionate hobbyists, and not just experts in power electronics. We want to remove the barriers between what you dream of and what you can build.

oneTesla is the smallest, most powerful Tesla coil kit you can find. How well it works, though, is contingent upon the quality of your workmanship. You will probably need a few tries to get it right, so be patient, ask for help when you need it, and ensure that you have replacement parts. Solder carefully, crimp well, keep wires neat, maintain a clean workspace, and have a critical attitude. Follow the instructions closely, and you'll likely get yourself some beautiful arcs and sparks!

Read and understand the entire manual before beginning! It's important that you understand how the Tesla coil works in order to build it right and handle it safely. Ensure that you are comfortable working with hazards. You should not construct this kit without supervision if you are under 18.

Table of Contents

Need help?

Ask questions and get help on the online forum at http://onetesla.com/forum.

Need replacement parts?

Get components from our online store at http://onetesla.com or your favorite electronics supplier like Digi-Key at http://digikey.com.

Stay tuned for updates.

Follow the blog at http://onetesla.com/blog.

Note: We try our best to keep all images and instructions consistent with the latest revision of the oneTesla hardware, but the photos in this manual and on our website are not always identical to the components you will receive in your kit. They will, however, maintain the same functionality.

IMPORTANT SAFETY WARNINGS

ELECTRICAL SAFETY WARNING

HIGH VOLTAGE AND HIGH FREQUENCY OUTPUT: The Tesla coil output is over a quarter million volts of high-frequency electricity, at currents of up to tens of milliamperes. NEVER TOUCH THE OUTPUT OF THE TESLA COIL. At best, you will get a nasty burn; at worst, you'll get a potentially life-theatening shock.

PRIMARY VOLTAGE AND CURRENT WARNING: Though lower in voltage, the approximately 270VDC on the primary side of the coil can be even more dangerous than the sparks. The primary carries up to hundreds of amperes of current for short periods of time. For reference, just 10mA across your heart is enough to kill you. NEVER SERVICE THE BOARD WHILE IT IS POWERED ON. ALWAYS WAIT AT LEAST FIVE MINUTES AFTER THE BOARD IS POWERED OFF FOR CAPACITORS TO DISCHARGE BEFORE SERVICING.

To safely work with electrical hazards, observe the following rules:

- Always be in control of the power source. Have the plug within your reach at all times.
- Perform power testing hands-off. This means that the board should be enclosed in the chassis when it is powered, and you should not service it when it is energized.
- Wait 5 minutes after unplugging the board for capacitors to discharge before servicing the board.
- Don't wear jewelry that could accidentally come into contact with circuitry and cause short-circuits.
- Never work on something dangerous when you're alone.
- If you feel tired or uncomfortable at any point, take a break and come back to your work later.
- If you have any hesitation about the nature of the high voltage circuits you are probing, work with one hand in your pocket. This prevents you from inadvertently touching a grounded object with your other hand when probing something that is potentially high voltage, which could cause a short-circuit across your chest.

IMPORTANT SAFETY WARNINGS

Adult Supervision Required

Users under 18 should only use this kit under the supervision of an experienced adult.

Pacemaker Warning

Persons with electronic medical implants such as pacemakers should not be near the Tesla coil during operation. EMI from the coil may interfere with the pacemaker's function.

Ozone Warning

The high temperature of the Tesla coil streamers causes the gases that make up air to form other compounds, including ozone (which can often be smelled when the coil is in operation) and nitrogen oxides. Keep the Tesla coil work area well-ventilated to prevent the buildup of irritating gases such as ozone and nitrogen oxides, which become toxic if concentrated.

Fire Hazard

The arcs from the Tesla coil can set flammable objects on fire. Keep all flammable objects away from the Tesla coil while it is in operation.

Ear Protection Recommended

The Tesla coil output is loud; ear protection is recommended.

Eye Glasses Required

Always wear eye protection while soldering. Power semiconductors may overheat and fail violently, causing a shrapnel hazard. Wear safety glasses when working on the board while it is energized. Only power up the board when it is fully enclosed inside the chassis.

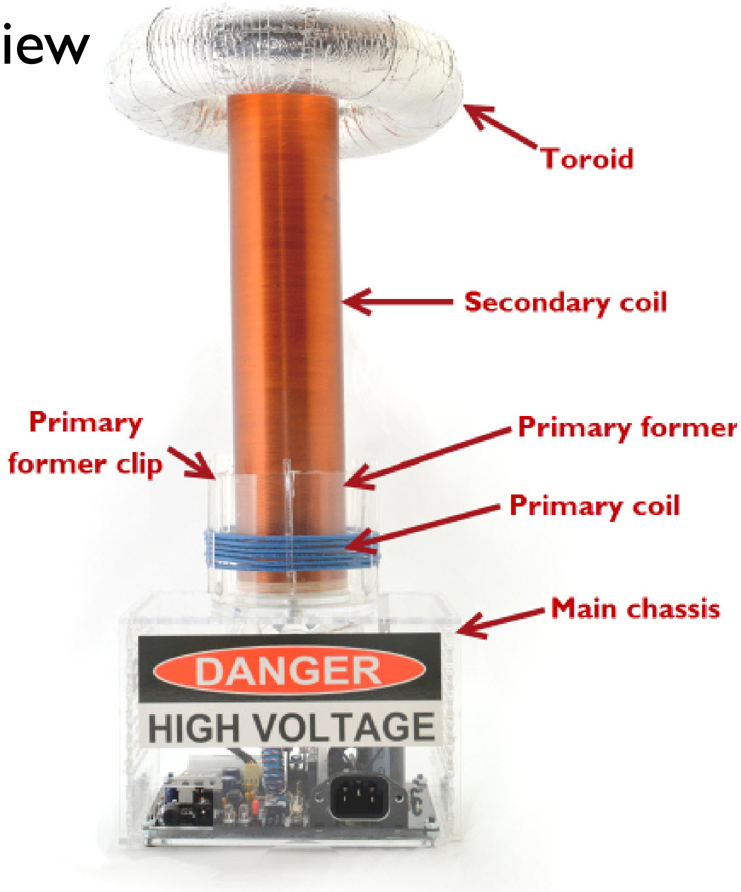
RF Warning

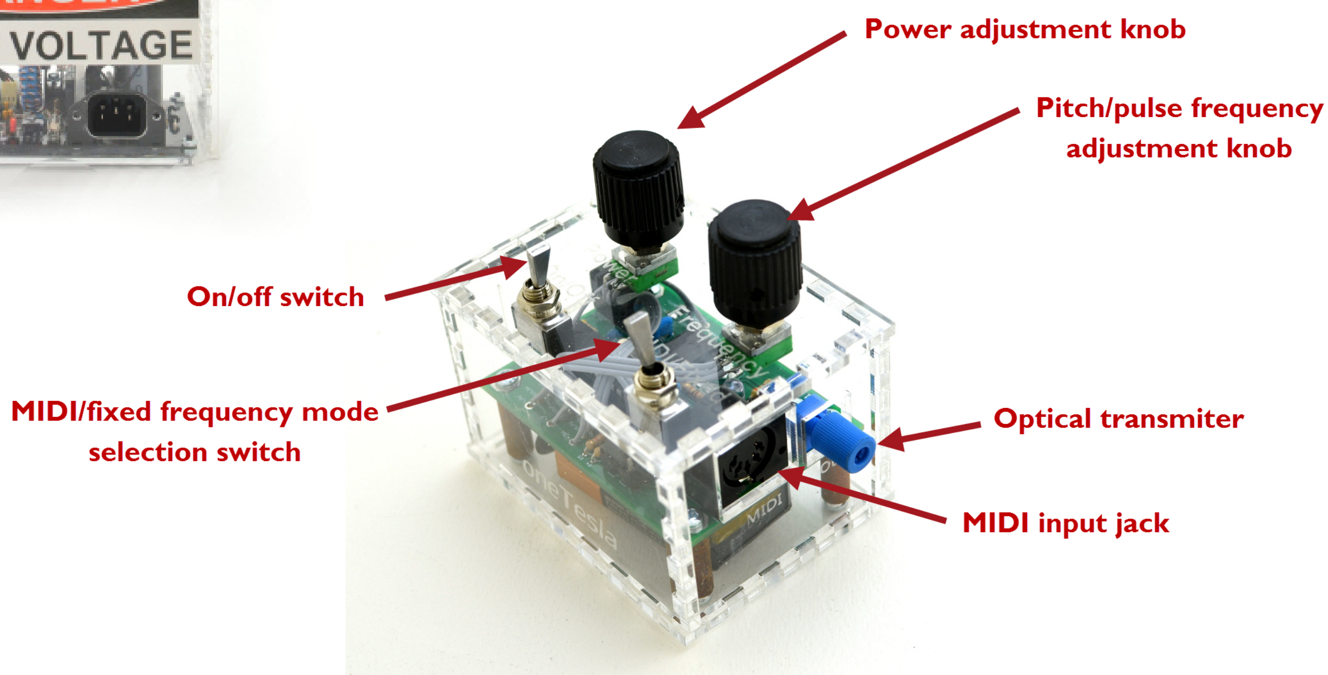
Keep sentitive electronics away from the Tesla coil at all times. Use the entire length of the included fiber optic cable to distance your computer from the Tesla coil.

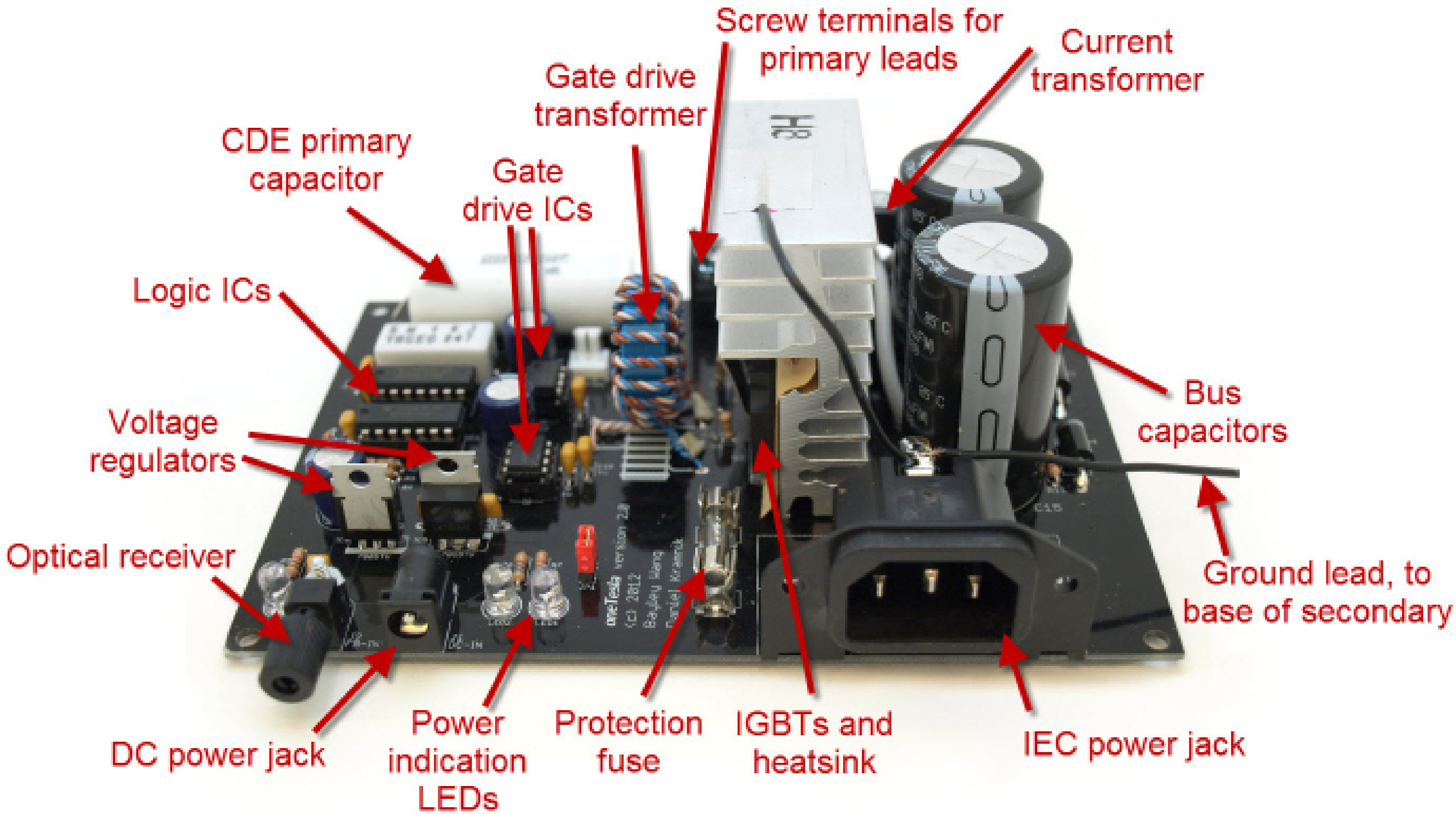
Observe Good Workspace Practices

- Keep your workspace neat and orderly.
- Always obey common sense.
- Do not continue work if at any point you feel uncomfortable with the hazards.
- Always work with a clear mind. Do not work when you are tired.
- Use caution when soldering; lead is hazardous, and the iron is extremely hot.

Overview


Toroid
Secondary coil
Primary former clip
Primary former
Primary coil
Main chassis
DANGER
HIGH VOLTAGE


Power adjustment knob
Pitch/pulse frequency adjustment knob
On/off switch
MIDI/fixed frequency mode selection switch
Optical transmiter
MIDI input jack

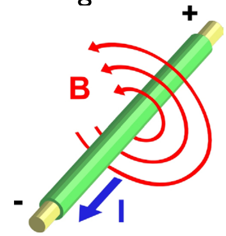

Screw terminals for primary leads
Current transformer
Gate drive transformer
CDE primary capacitor
Gate drive ICs
Logic ICs
Voltage regulators
Bus capacitors
Optical receiver
Ground lead, to base of secondary
DC power jack
Power indication LEDs
Protection fuse
IGBTs and heatsink
IEC power jack

How does the Tesla coil work?

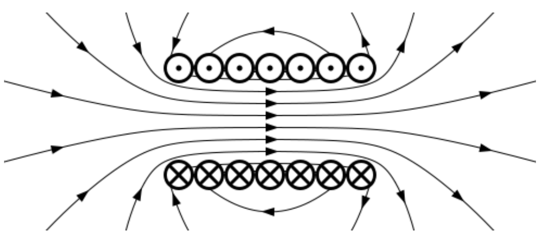
The Tesla coil is well-known for producing extremely high voltages. In this section, we'll explain how the oneTesla 10" coil can reach voltages over a quarter million volts using coupled resonant circuits. We'll build up from the fundamentals, to give you a thorough explanation of what's going on.

Current, Magnetic Fields, and Induction

Let's start with the basics of electromagnetism. One of Maxwell's equations, Ampere's law, tells us that current flowing through a wire creates a magnetic field around it.



If we want to use this magentic field to our adavantage, as we do in an electromagnet, we coil the wire. The magnetic fields from the individual turns add together in the center.



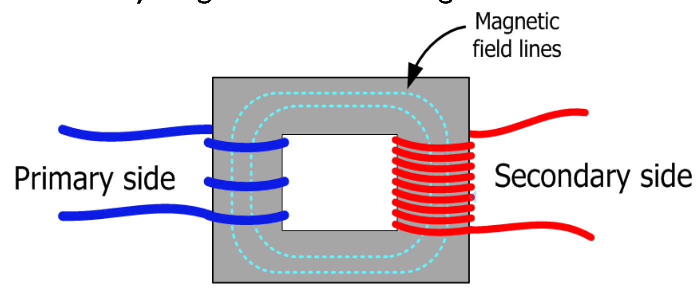
A constant current makes a static magnetic field. What happens with we put a changing current through the wire? Another of Maxwell's equations, Faraday's law of induction, tells us that a magnetic field changing in time induces a voltage across the wire proportional to the rate of change of the magnetic field:

$$V_{induced} = -NA\frac{dB}{dt}$$

If the current is abruptly shut off, Faraday's law tellls us that there will be a sharp spike of voltage. If an oscillating current flows through the coil, it induces an oscillating magnetic field inside it. This, in turn, induces a voltage across the coil which tends to oppose the driving current. Intuitively, the magnetic field is "stubborn," inducing a voltage that opposes any change to the field.

Transformers

A transformer takes advantage of the law of induction to step AC voltages up or down. It consists of two coils of wire around a core. The core is soft iron or ferrite, materials which are easily magnetized and demagnetized.



An oscillating current in the primary winding establishes an oscillating magnetic field in the core. The core concentrates the field, ensuring that most of it passes through the secondary. As the magnetic field oscillates, it induces an oscillating current in the secondary coil. The voltage across each turn of wire is the same, so the total voltage across the coils is proportional to the number of turns:

$$\frac{N_1}{V_1} = \frac{N_2}{V_2}$$

Because energy is conserved, the current on the side of the transformer with the higher voltage is smaller by the same proportion.

The Tesla coil is a very souped-up transformer. Let's briefly consider what would happen if it were a perfect transformer. The primary winding has six turns and the secondary has about 1800 turns. The primary is driven with 340 volts, so the secondary will have 340V x 300 = 102kV across it. That's a lot! But not quite a quarter million. Additionally, becuase the Tesla coil is air-cored and the coils are positioned relatively far apart, only a small fraction of the magnetic field produced by the primary is actually interlinked with the secondary. To understand more of what's going on, we need to introduce resonant circuits.

Resonant Circuits

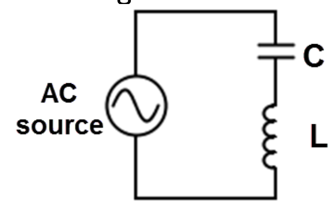
A resonant circuit is like a tuning fork: it has a very strong amplitude response at one particular frequency, called the resonant or natural frequency. In the case of the tuning fork, the tines vibrate strongly when excited at a frequency determined by its dimensions and the material properties. A resonant circuit achieves the highest voltages when driven at its natural frequency, which is determined by the value of its components.

Resonant circuits use capacitors and inductors, and therefore are also known as LC circuits. They are also known as "tank circuits," because of the energy storage elements present.

Capacitors store energy in the form of an electric field between two plates separated by an insulator, known as a dielectric. The size of the capacitor is dependent upon the size of the plates, the distance between them, and the properties of the dielectric. Interestingly, the topload on the Tesla coil acts like a one-plate capacitor, with the ground plane surrounding the coil acting as the opposing plate. The capacitance of the topload is determined by its dimensions and its proximity to other objects.

Inductors store energy in the form of a magnetic field around a wire, or in the middle of a loop of wire. The primary inductor in the oneTesla 10" coil is six turns of AWG14 wire, and the secondary is approximately 1800 turns of AWG36 wire.

An LC circuit can have an inductor and capacitor in series or parallel. Here, we are using series LC circuits like this:



Consider what happens when you don't drive the circuit (assume that the AC source in the above figure is replaced by a wire), but start out with the capacitor charged. The capacitor wants to discharge, so charge flows around the circuit, through the inductor, to the other plate. In the process, a magnetic field builds up inside the inductor. When the charge on each plate of the capacitor is zero, current stops flowing. But at this point, the inductor has energy stored up in a magnetic field - which tends to oppose change. The magnetic field collapses, inducing a continuing current in the same direction, thereby recharging the capacitor and restarting the cycle in the opposite direction.

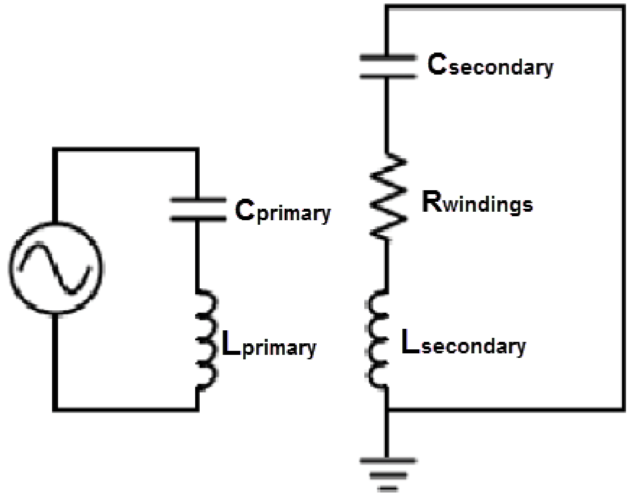
The resonant frequency of an LC circuit, or the frequency at which the energy cycles between the capacitor and inductor as described above, is:

$$f_o = \frac{1}{2\pi\sqrt{LC}}$$

Driving the circuit at its resonant frequency adds energy during each cycle. By providing a succession of well-timed pushes, we can build up to extremely high voltages! In the Tesla coil, a spark breaks out and discharges the circuit once the voltage is high enough.

DRSSTC

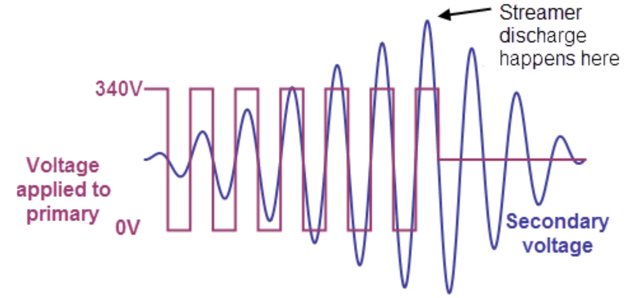
The oneTesla 10" coil employs a double-resonant topology, hence the name double-resonant solid-state Tesla coil, or DRSSTC. In a DRSSTC, the circuit driving the secondary LC circuit is another LC circuit, tuned to the same resonant frequency. In the following diagram, L1 and L2 are the primary and secondary inductors, respectively. They are weakly coupled, linking around one-tenth of their magnetic fields.



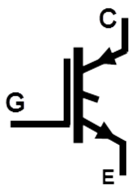
There are several reasons why Tesla coils do not employ a magnetic core. First of all, the voltages in the Tesla coil are so high that the core would quickly saturate, meaning it would no longer be magnetizable past a certain point. Also, most materials pose a resistance and heat up in a magnetic field that switches rapidly, as is the case in the coil. The high voltage the coil produces also has the potential to arc to the core. But most importantly, it's critical that the primary and secondary coils be loosely coupled—so the secondary is not loaded down by the primary.

Half-Bridge

How do we go about exciting the primary? We use a DC voltage source, and apply the voltage in alternating directions across the primary.

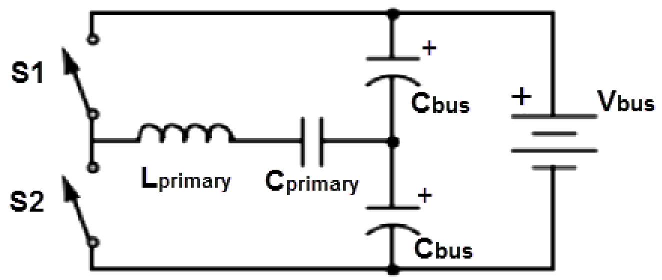


The switches that we use to apply a DC voltage in alternating directions across the primary are IGBTs, short for insulated gate bipolar transistors. An IGBT is a transistor capable of controlling very high voltages and currents. This is its schematic symbol:



Its terminals are labelled collector, gate and emitter as a holdover from vacuum tubes, before the era of transistors. A simplified model of an IGBT is normally open switch that closes when a positive gate voltage (V_{GE}) is applied.

In the following diagram of a half-bridge, S1 and S2 represent the IGBTs. They alternately turn on and off, which switches the polarity of $V_{bus}/2$ across $L_{primary}$ and $C_{primary}$, the primary inductor and capacitor. The oneTesla 10" coil runs off a bus voltage of 340VDC.



On the control board, we get the bus voltage from rectfied and doubled line voltage. We'll go into detail about that portion of the circuitry later.

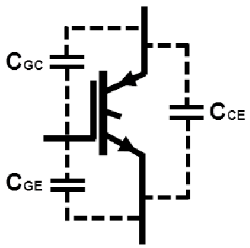
Zero-Current Switching

When the IGBTs are fully on (the switches closed), they are nearly perfect conductors. When they are fully off (the switches fully open), they are nearly perfect insulators. When they are in transition between fully open and fully closed, or vice versa, however, they behave like resistors. Recall that the amount of power dissipated in a circuit is P=VI. If we try to switch the IGBT while the current through the circuit is large, then it will heat up a lot! We have to time the switching of the IGBTs to the natural zero-crossings of the primary LC circuit.

On the oneTesla board, we achieve zero current switching by sensing the primary current and using control logic to ensure the transistors switch at the correct times. We'll describe this logic circuitry in a following section.

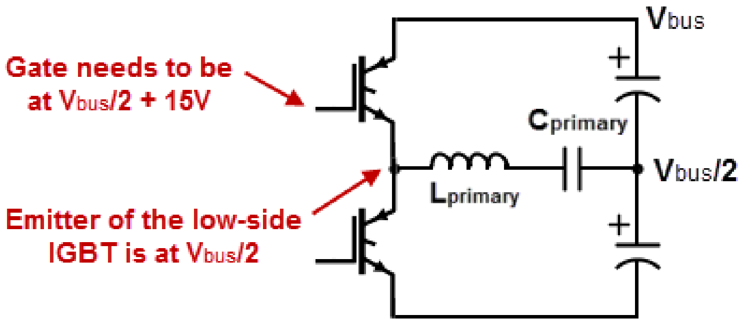
Gate Driving

The IGBTs are far from ideal switches. We want them to switch fast, to minimize the time during which they are resistive and dissipate power. The issue with switching gates fast is that they have significant internal capacitance, and it takes a lot of charge to fill up that capacitance and achieve the turn-on voltage across the gate (the voltage of a capacitor is given by V=Q/C).



To charge C_{GE} in as short a time as possible, we want to use a short, high-current pulse. Gate drive ICs are designed to do exactly this. We use UCC3732x ICs, which can source up to 9A for brief pulses. The logic circuitry preceeding the gate drivers isn't even close to being able to source enough current to turn the gates on fast, so the gate drivers are essential components.

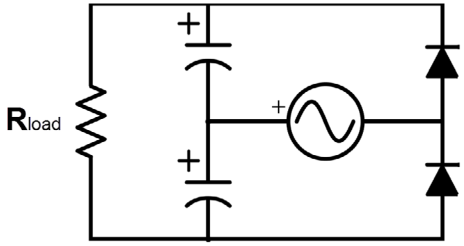
Lastly, we need to isolate the gate drivers from the IGBTs using a gate drive transformers (GDT) Each IGBT needs gate voltage to be applied between its gate and emitter to turn on. This is easy on the low-side (bottom) IGBT - its emitter is always at ground, meaning its gate only needs to be brought up to +15V. Things are not so easy with the high-side (top) IGBT, because its emitter is referenced to the collector of the low-side IBGT, a node which swings between 0 and $V_{bus}/2$ (which, in our case, is 170V). This means we need to bring the gate of the high-side IGBT up to $V_{bus}/2$ + 15V to turn it on.



Fortunately, there is a simple way around this! We can drive the primary of a 1:1:1 transformer with the (bipolar) drive signal derived from a push-pull pair of UCCs.

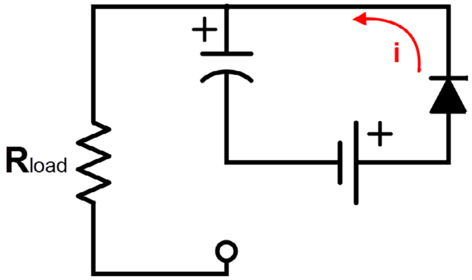
More specifically, we drive the primary of the transformer with the difference of the outputs of an inverting and non-inverting gate driver. This ensures that half the time, this signal is positive, and half the time, this signal is negative. Due to transformer action, the voltage across each secondary of the GDT is guaranteed to replicate the voltage across the primary, no matter where we connect the ends. This means we can simply connect a secondary across the gate and emitter of each IGBT, and guarantee that V_{ge} will always swing between 0 and 15V (regardless of the emitter's potential).

Rectifier & Doubler

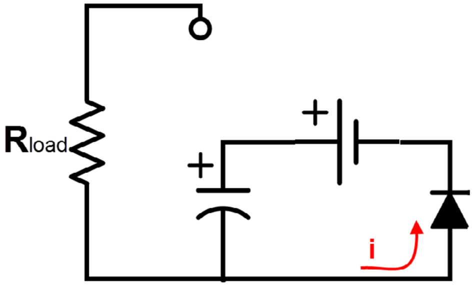


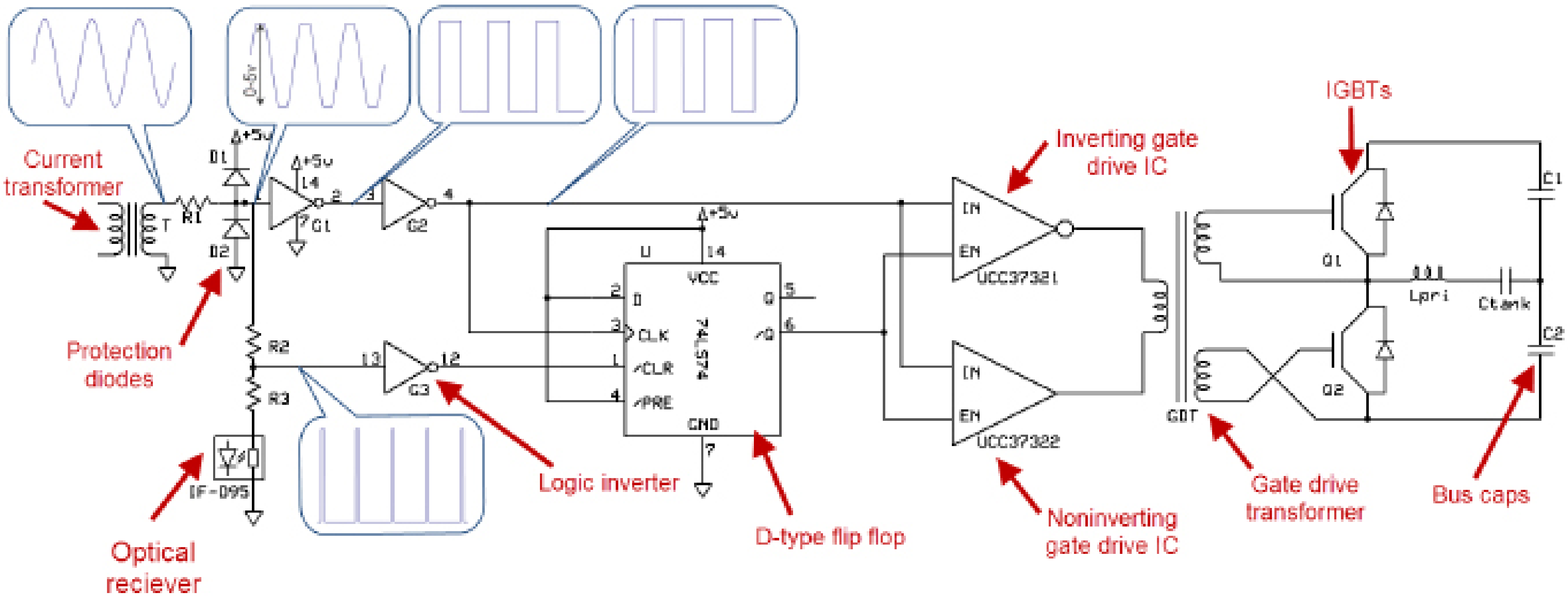
The half-bridge in oneTesla is driven by a doubling rectifier as shown in the diagram above. This rectifier alternately charges each capacitor on alternating half-cycles of the AC input, resulting in twice the source voltage across the load.

On the positive portion of the cycle, the top diode conducts and charges the top capacitor.



On the negative portion of the cycle, the bottom diode conducts and charges the bottom capacitor. The voltage across the load is the sum of the voltages on each capacitor.





Logic

As mentioned previously, control logic is necessary to sense the primary current and prevent turning on and off the IGBTs while there is current through them. Let's step through the above schematic from left to right. (Note that the part numbers in the schematic don't correspond to those on the board, but we use them here just for explanatory purposes. Refer to the Eagle files, available at http://onetesla.com/downloads, for the full schematic.)

The current transformer steps down the primary current to a safe level to use on the logic section of the board. R1 is a 5W resistor that loads down the transformer and limits the current. D1 starts conducting when the signal exceeds 5.7V, which is the rail voltage plus the forward voltage drop of the diode, effectively preventing the signal from exceeding 5.7V. D2 starts conducting when the signal is -0.7V. Together, D1 and D2 are protection diodes that clip the signal and prevent damage to the logic ICs if the signal from the current transformer is too high. Next, G1 and G2 are inverters which square up the signal for subsequent ICs.

The optical receiver outputs 5V or 0V depending on the signal from the interrupter. R1, R2, and R3 form a resistor network that ensure that the coil can be "tickled" into operation by just the interrupter signal on startup, in absence of a feedback waveform. When the coil is just starting up, there is no feedback signal, but the interrupter signal makes it through to the UCCs. When the coil is in operation, the feedback signal dominates the top of the signal pathway.

The inverted interrupter signal and the square wave from the squared primary current signal are then fed into a D-type flip flop, which performs logic that determines when the gate drivers recieve a signal. They are only turned on when there is a zero-crossing as well as a signal from the interrupter. The D flip-flop behaves according to the following truth table:

FUNCTION TABLE

INPUTS				OUTPUTS	
$\overline{PRE}$	$\overline{CLR}$	CLK	D	Q	$\overline{Q}$
L	H	X	X	H	L
H	L	X	X	L	H
L	L	X	X	H†	H†
H	H	↑	H	H	L
H	H	↑	L	L	H
H	H	L	X	Q_0	$\overline{Q}_0$

In our circuit, \PRE and D are pulled high. The inverted interrupter signal, which is fed into \CLR, sets \Q high when the interrupter is ON. When the interrupter turns off, \Q stays high until the next falling edge of CLK (which is synchronized with the zero crossings of the primary current), upon which it switches low.

The inverting gate driver turns on when IN is high and EN is low. The noninverting gate driver turns on when IN is high and EN is high.

Interrupter

The oneTesla interrupter is a microcontroller-based device that converts an incoming stream of MIDI commands into a stream of pulses for the Tesla coil. These pulses turn the entire coil on or off, thereby controlling both power throughput and allowing for music playback.

The MIDI commands are received through the MIDI input jack. As per MIDI specifications, the 4N25 optoisolator provides the isolation necessary to eliminate ground loops. When the microcontroller receives a note-on command, it begins output a stream of pulses at the note's frequency. The lengths of these pulses are specified by a lookup table in the firmware. The interrupter uses separate MIDI channels to play multiple notes at once - in order to play back two channels, the software simply generates pulse trains corresponding to each channel, and then performs the OR logic function on the pulse trains before outputting them. Maximum pulse-width limitation ensures that the resulting stream does not have excessively long pulses.

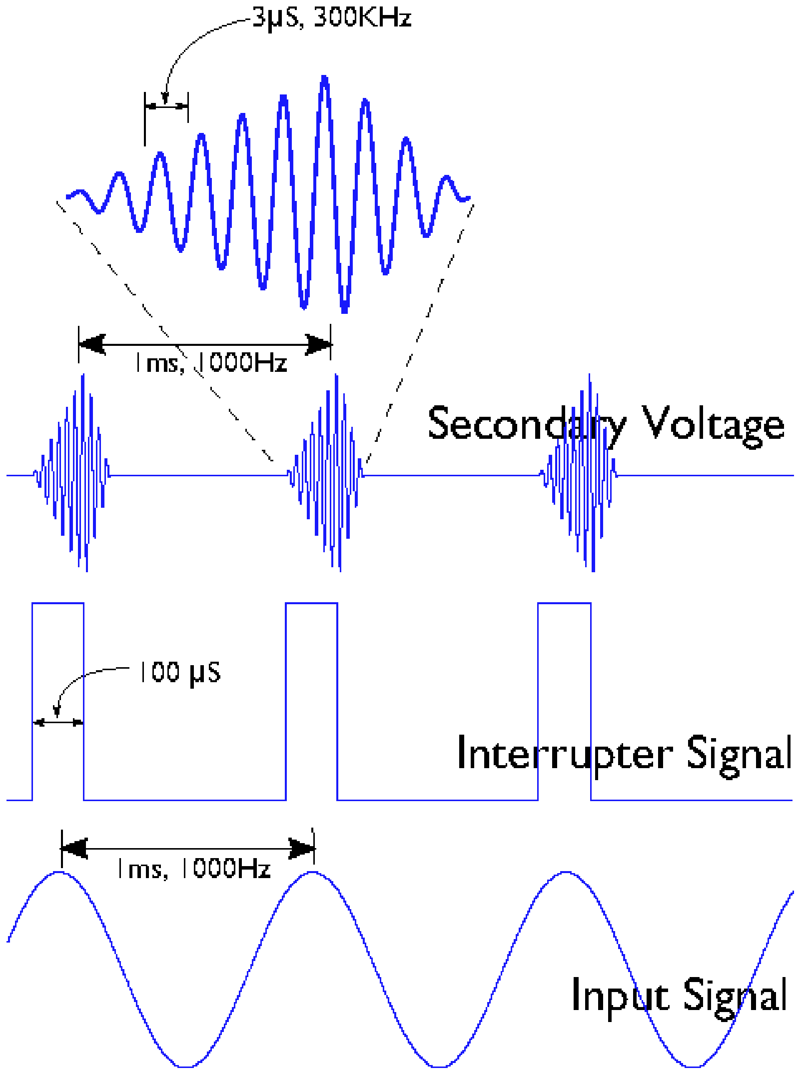
Power control linearly scales the pulse widths based on the position of the potentiometer. While this does not give linear spark length, it has the advantage of predictably scaling the power consumption of the coil, a feature that would be lost if the scaling curves were tweaked for linear spark growth.

So how does it make music?

Sound is a pressure wave. Its pitch is determined by the frequency of the wave. We can make sound in a variety of ways: conventional speakers vibrate a membrane, and Tesla coils use the expansion and contraction of air due to heating from plasma.

The secondary's resonant frequency is about 230kHz, far above the audio range. We can use bursts of sparks that are firing away at 230kHz to create pressure waves at the audio frequency. A burst of sparks fires at every peak of the audio signal. The rapid firing of the sparks is faster than your eye can resolve, so it looks continuous, but in reality the spark is forming and extinguishing at intervals of the audio frequency. This modulation technique is known as pulse-density modulation (PDM) or pulse-repetition modulation (PRM).

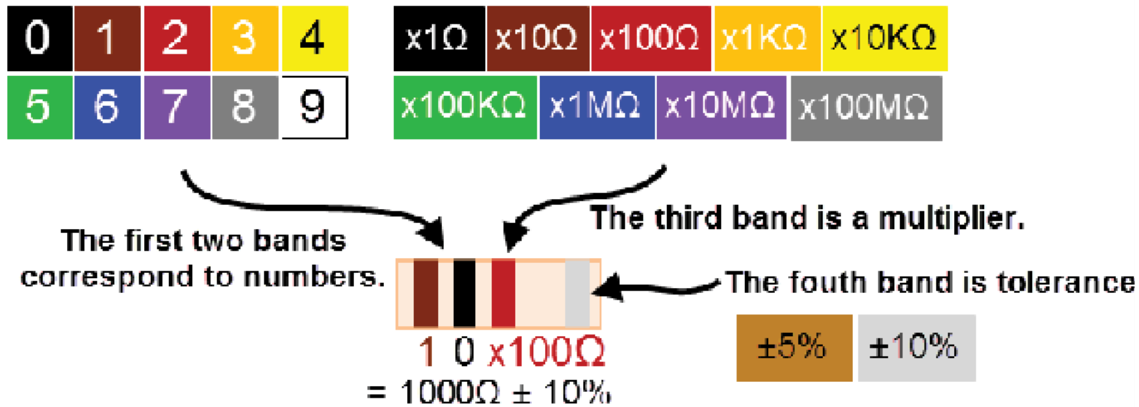
Current in the primary keeps increasing while the bridge is being driven. It's important to make the bursts short enough so that the IGBTs don't overheat. Within a single cycle, the current on the primary can reach up to hundreds of amps for a short time. Due to thermal reasons, the maximum duty cycle of the bridge is approximately 10%. The interrupter's firmware has a lookup table of frequencies and on times, which are determined empirically by varying the pulse width and watching the spark performance.



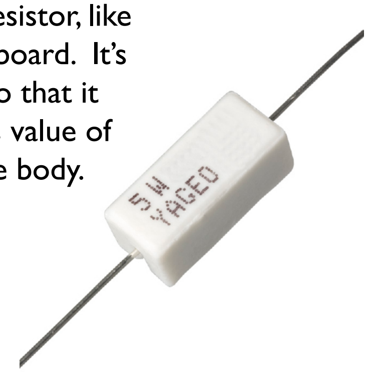
Some Notes about Electronic Components

Resistors

The value of a resistor can be read from its color bands. Or you can measure the resistance with a multimeter and avoid straining your eyes!



Resistors of different power handling capabilities are dramatically different sizes. This one is a 5 Watt resistor, like R1 on the oneTesla control board. It's large and made of ceramic so that it can withstand high heat. Ths value of the resistor is printed on the body.



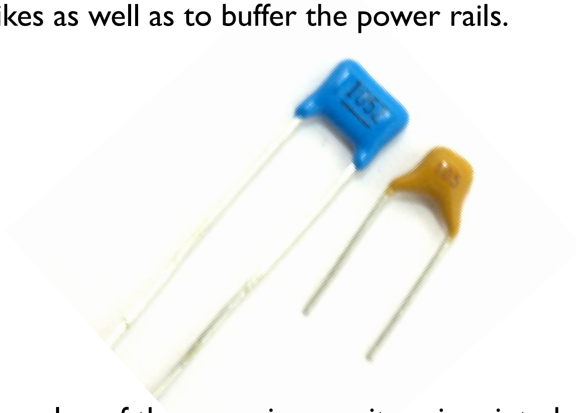
Potentiometers are variable resistors. Turning the knob changes the position of a sliding contact along a resistive path. The resistance between the first and third contacts is always the same, but the resistance between the first and second contacts changes as you rotate the knob. We use a potentiometer to modulate the power of the Tesla coil on the interrupter board.

This is a 1/4 Watt resistor, which is used for most applications.

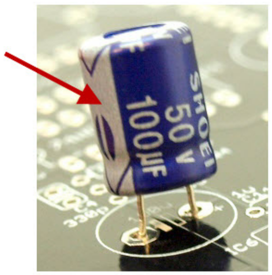
Capacitors

There's a huge variety of capacitor types. We use three different varieties on the oneTesla board: ceramic capacitors, electrolytic capacitors, and a film capacitor.

Ceramic capacitors are the small capacitors we provide you. They are often used as decoupling capacitors across the power pin of an IC to short out high-frequency voltage spikes as well as to buffer the power rails.

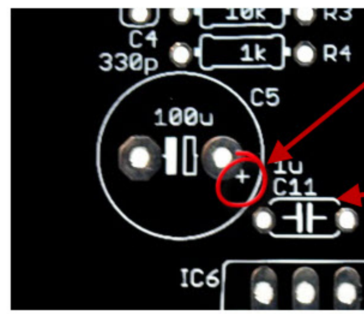


Electrolytic capacitors are polar. You will damage the component if you install it backwards, so be sure to match the positive side of the capacitor to the "+" sign on the board!

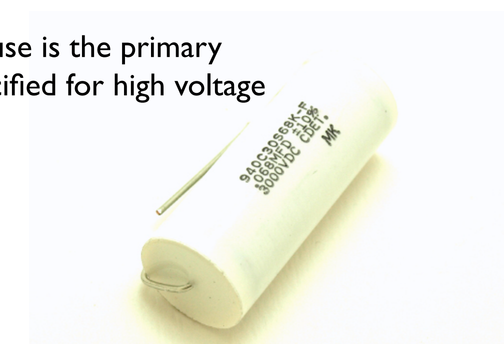


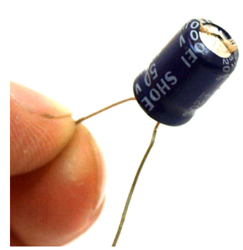
The value of the ceramic capacitors is printed on the casing using two or three numbers. If there are only two numbers, that is the value in picofarads.

If there are three numbers, multiply the first two numbers by 10 raised to the power of the third to get the capacitance in picofarads. So, for example, 154 means 15×10^4 picofarads, or $15 \times 10^4 \times 10^{-12}\text{F} = 15 \times 10^{-8}\text{F} = 150\text{nF}$.



The one film capacitor we use is the primary tank capacitor, which is specified for high voltage use.

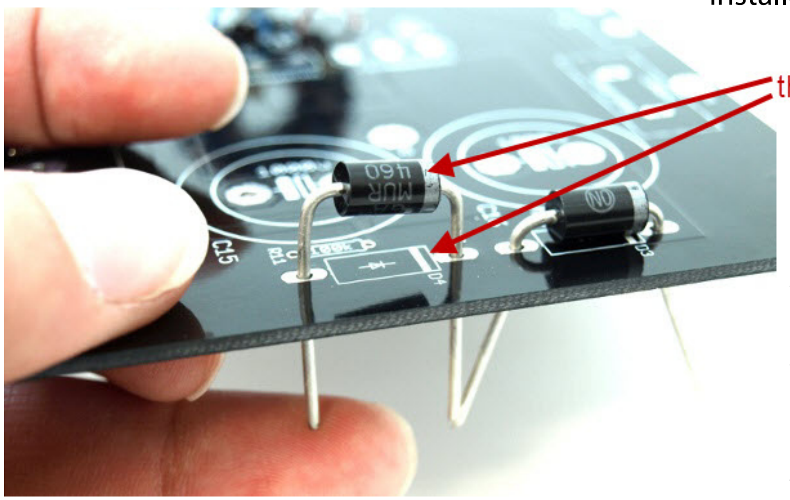




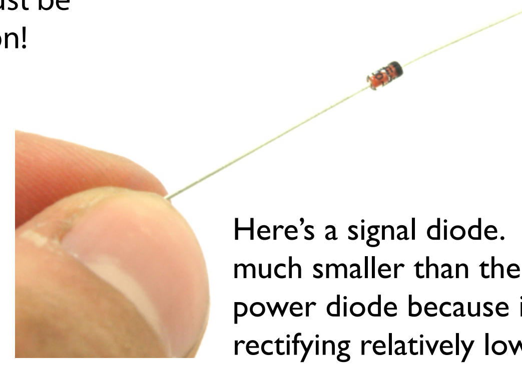
Electrolytic capacitors have a safety vent at the top, which ruptures when the capacitor is connected backwards. Don't re-use blown capacitors!

Diodes

All diodes are directional and must be installed in the correct orientation!



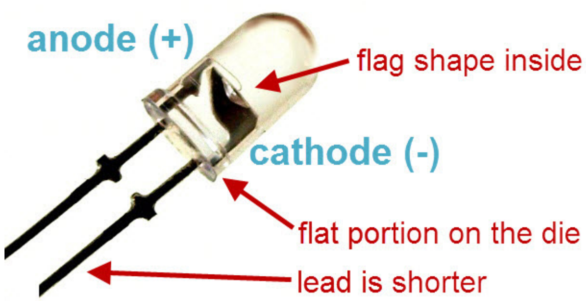
Here are power diodes, which rectify the AC from mains. They're big because they handle a lot of current. Their polarity is marked by a silver band on the diode.

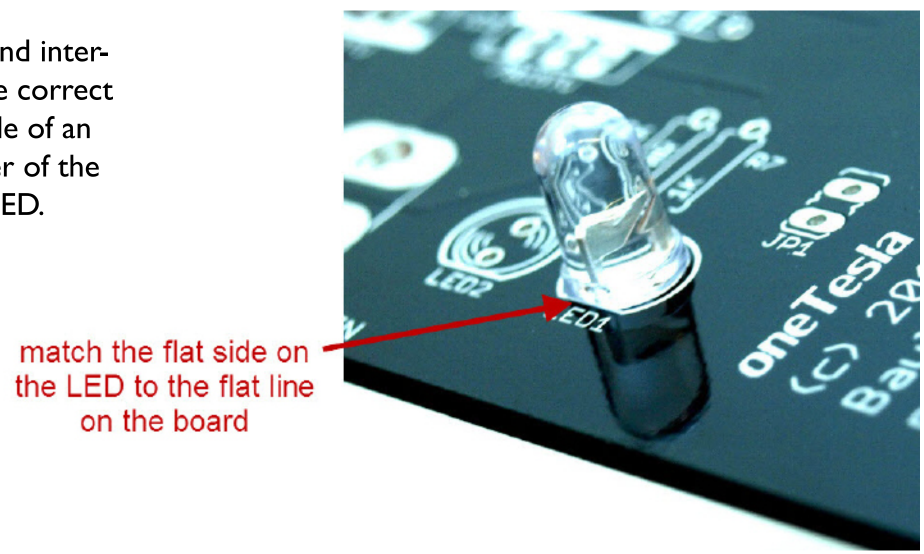


Here's a signal diode. It's much smaller than the power diode because it rectifying relatively low-power signals. This kind of diode has its polarity marked by a black band, which needs to line up with the band on the board.

Light Emitting Diodes (LEDs)

On the oneTesla board, LEDs are used as power indications and interrupter signal indicators. LEDs only work when installed in the correct direction. There are three ways to determine the negative side of an LED: locating the flat portion of the die, identifying the shorter of the two leads, or looking closely at the internal structure of the LED.



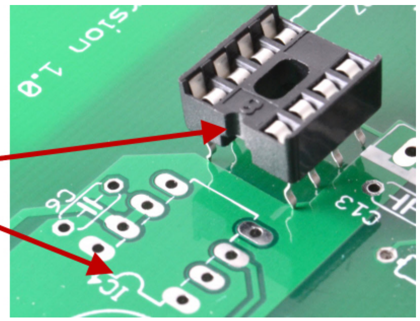


Integrated Circuits (ICs)

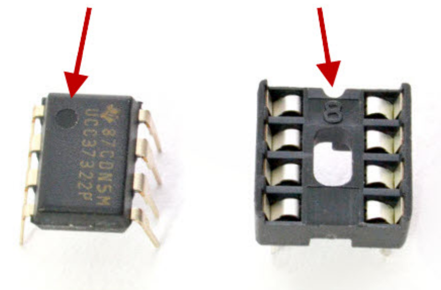
There are a variety of ICs on the oneTesla board. The 74-series chips are logic. The UCC chips are gate drivers. On the interrupter, there's a 6-pin optocoupler and an ATmega microcontroller. The main board also has IGBTs and voltage regulators.

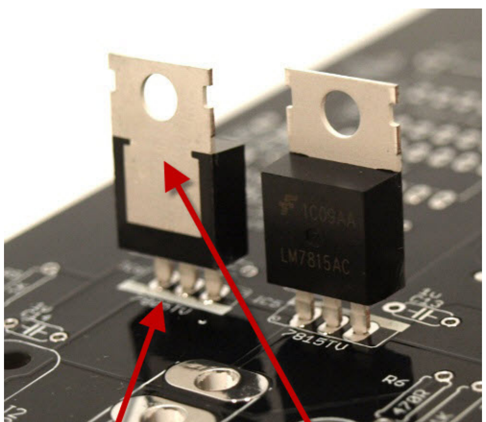
DON'T SOLDER ICs DIRECTLY TO THE BOARDS! Solder on a socket with the correct number of pins, and insert the IC into the socket. Keep the notch on the socket aligned with the socket on the board, and keep the notch on the IC aligned with the notch on the socket. Some chips don't have notches, but rather a single dot on the appropriate side.

Align the notch on the socket to the notch on the board.



Match the notches or markings of the IC and the socket.

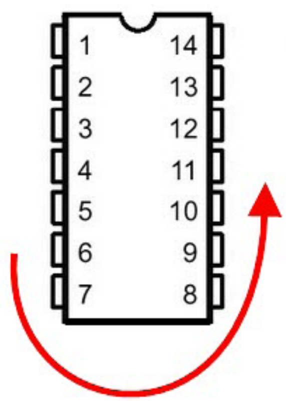




Band on the board

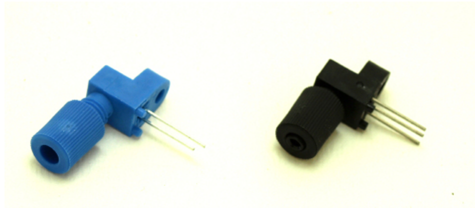
Back of the voltage regulator

The voltage regulators and IGBTs are in three-legged vertical package in order to enhance thermal properties and make heatsinking easy. The voltage regulators and IGBTs should be inserted into the board so that the metal tab of the component aligns with the band on the board.

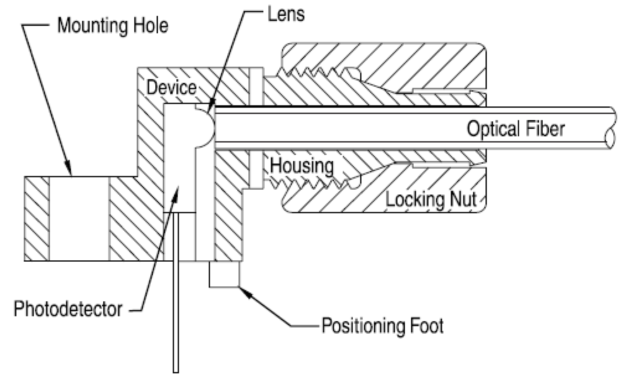


The pins of ICs are numbered sequentially starting from the one to the left of the notch, then circling counterclockwise around the chip.

Optical transmitters and receivers



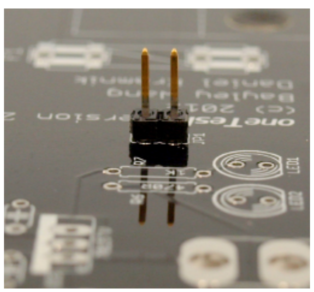
The optical transmitter and receiver are probably the two most delicate electronic components. The transmitter has two terminals (power and ground) and a blue casing. The receiver has a black casing and three terminals (power, ground, and output voltage). Secure them with a 4-40 bolt before soldering them in.

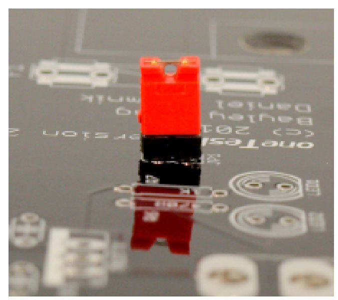


This cross-section is taken from the data sheet of the receiver. Since the fiber sits right against the lens, never push it in too hard. Also, if you need to cut the optical fiber, use a sharp razor blade and keep the cut as close to a neat 90-degree angle as possible.

Headers & Jumpers

Headers should be installed with the long ends sticking up, out of the board. Jumpers slide right over them.





Want to learn more?

If you want to find out more about any component, look for its data sheet online. Data sheets usually have all you need, and more. Here are some links to the data sheets of components that there are most often questions about:

- 74HCT74 D-type flip-flop: http://www.nxp.com/documents/data_sheet/74HC_HCT74.pdf
- UCC3732x gate drivers: http://www.ti.com/lit/ds/symlink/ucc37321.pdf
- LM78xx voltage regulators: http://www.fairchildsemi.com/ds/LM/LM7805.pdf
- FGH60N60 IGBT: http://www.fairchildsemi.com/ds/FG/FGH60N60SMD.pdf
- Optical receiver: http://i-fiberoptics.com/pdf/ifd95.pdf
- Optical transmitter: http://i-fiberoptics.com/pdf/if-e96edatasheet.pdf

Step 0

Preparation

Before you begin, you will need:

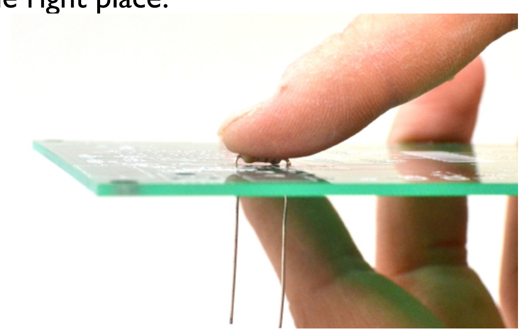
- a temperature-controlled 20W-30\ soldering iron and solder
- safety glasses
- small pliers
- flush cutters
- wire strippers
- crimp tool (or large pliers)
- screwdriver
- electrical tape
- hot glue gun or superglue
- solder wick or solder sucker
- multimeter

A quick review of how to solder

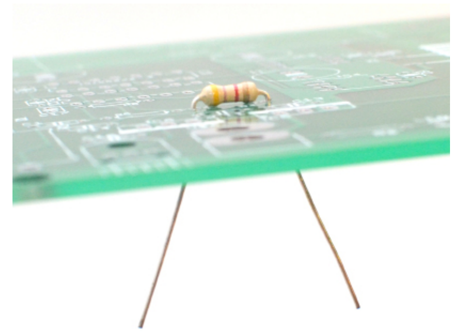
1. Assemble your tools, put on safety goggles, and turn on the iron.

2. Neatly bend the component leads to fit into the holes in the board, either with your fingers or small pliers.

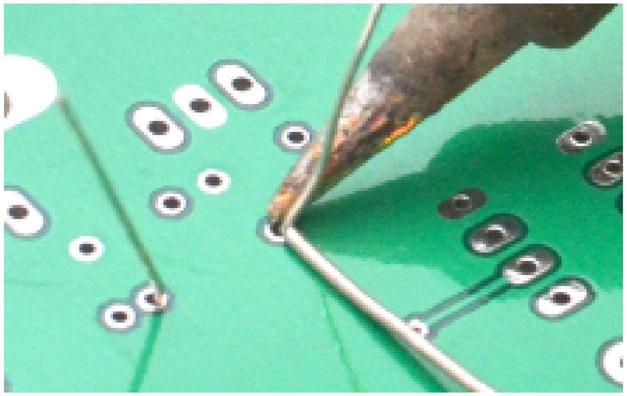
3. Insert the component into the board, and ensure it lies flush. Make sure you have the right component in the right place.



4. Bend the leads of the component slightly so that it stays in place.

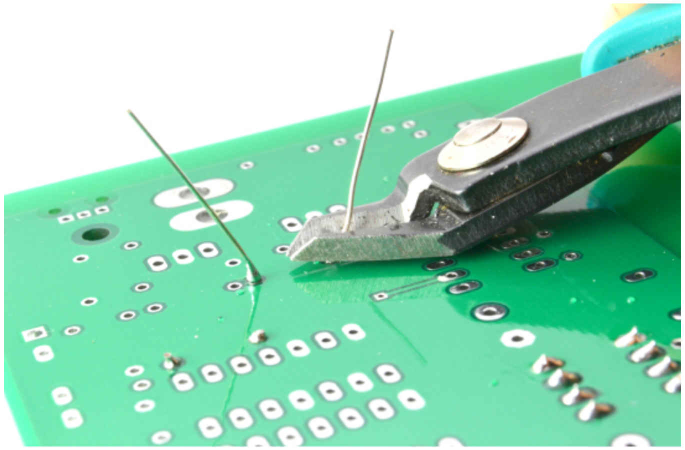


5. Flip over the board. Place the tip of the iron against both the pad and the component lead. The idea is that the iron heats up the surfaces that you want the solder to wet to, and the solder flows onto those surfaces by itself, without touching the iron.

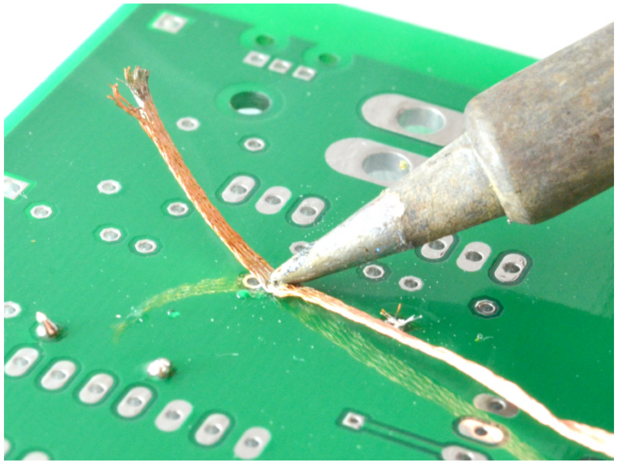


6. Once your solder has wet to both the lead and the pad, remove the iron. Generally, don't apply heat to the pad for too long, because it can become weak and fall off the board. Inspect the joint. Is it sticking well to both surfaces?

7. If the joint is satisfactory, trim the lead with flush cutters.



8. If you make a mistake, remove excess solder using solder wick. The holes in our boards are plated on the inside, which makes removing improperly soldered components rather difficult. Get it right the first time!



Soldering tips:

- The order in which you install the components doesn't matter, but it's generally easier to start with the parts with the shortest leads first.

- A bit of masking tape can hold components to the board while you solder.

- We highly recommend investing in a good iron. Weller irons are probably the best, but comparably good ones can be found for around $40. Invest in a good iron early! It will pay off in saved time and avoided frustration.

- Some of the pads are octagonal. These pads connect to power planes on the board, and as such, are trickier to solder because of the high thermal mass of the planes. A little patience (and maybe gently feeding extra solder at the joint, or increasing iron temperature slightly) goes a long way on these pads.

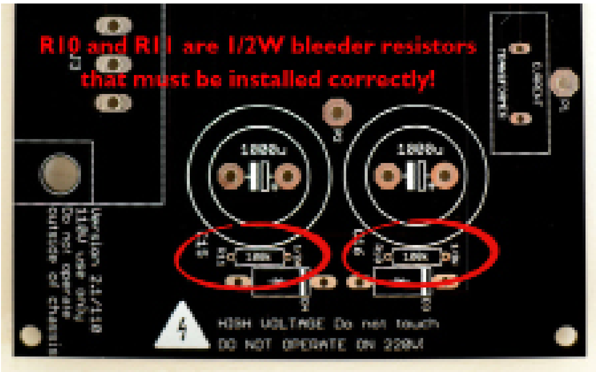
Step 1

Let's start soldering!

We begin by populating the main circuit board. Each component's number and value is printed on the board. You can also use the tables to the right as a reference.

1. Install R1. Note that it is a large, rectangular, ceramic 5W resistor.

2. Install R2 through R11. ENSURE THAT R10 AND R11 ARE INSTALLED PROPERLY. These are 1/2W, 100KΩ bleeder resistors which drain the large capacitors C14 and C15 when the unit is powered off. Failure to install R10 and R11 properly will result in the capacitors storing energy for extended periods of time, and a board that is unsafe to service. The two 1/2W resistors are slightly larger than the one 1/4W 100KΩ resistor in the kit.



3. Install ceramic capacitors C1 and C4.

R1	1KΩ, 5W
R2	100KΩ
R3	10KΩ
R4, R5, R7	1KΩ
R6	560Ω (marked 470Ω on the board, but either value is fine)
R8, R9	6.8Ω
R10, R11	100KΩ, 1/2W

C1	0.1μF
C2, C3	1μF
C4	330pF
C5 - C7	220μF
C8 - C14	1μF
C15, C16	1000μF 250V

IC1	74HCT14
IC2	74HCT74
IC3	UCC37321
IC4	UCC37322
IC5	LM7815
IC6	LM7805
Q1, Q2	FGA60N60SMD IGBTs

4. Install C2, C3, and C5 through C16. Note that C5-C7, C15, and C16 are all electrolytic capacitors, and the polarity matters.

5. Install signal diodes D1 and D2, matching the band on the diode to the band on the board to ensure correct polarity.

6. Install power diodes D3 and D4, matching the band on the diode to the band on the board to ensure correct polarity.

7. Install the three LEDs, matching the flat side of the LED to the flat side of the symbol on the board to ensure correct polarity. The red LED is the 15V indicator, the blue LED is the 5V indicator, and the green LED is the interrupter signal indicator.

8. Install J1, the 2.5x5.5mm DC jack. Note that the holes in the board are large, and you need to fill them in with solder.

9. Install J2, the fiber receiver. CAREFUL! This component is delicate. Use a 4-40 bolt and nut to secure it to the board before soldering the leads.

10. Install X1, the 3-pin fan header.

11. Install J3, the IEC power plug. Use 6-32 bolts and nuts to secure this power plug to the board, to prevent excessive stress when plugging and unplugging the cord.

12. Install J4, a 2-terminal block that you will later attach primary wires to.

13. Install JP1, a two-pin header. If you are using the 19V DC power supply provided by us, slide a jumper over the pins. This is because the power supply is floating. If you are using your own grounded power supply, do not connect the pins together.

D1, D2	1N4148 signal diode
D3, D4	MUR460 power diode
LED1	Red LED
LED2	Blue LED
LED3	Green LED
J1	2.5x5.5mm DC jack
J2	IF-D95 Fiber receiver
J3	IEC power plug
J4	2-terminal output block
JP1	2-pin header
F1	10A fuse
X1	3-pin fan header

Tank capacitor
Current transformer

Step 1 (continued)

14. Install F1, the fuse holder and fuse. The fuse holder is composed of two identical fuse clips. Install these in the board. Note that the ends with the bent tabs should be on the outside to allow the fuse to slide in. It's a good idea to install the clips with a fuse inserted to make sure the spacing and direction is correct.

15. Install 14-pin sockets for IC1 and IC2. Match the notch on the socket to the notch on the board. Don't solder the ICs directly to the board!

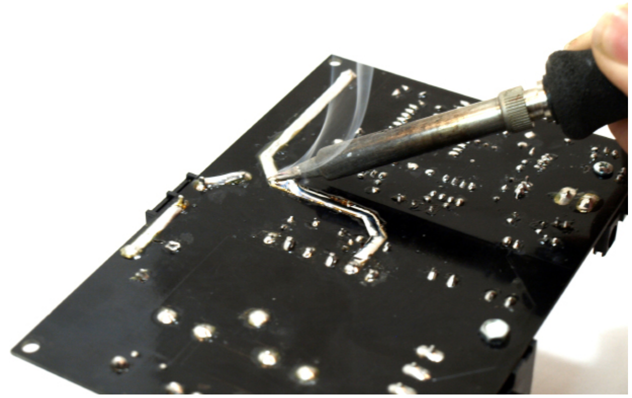
16. Install 8-pin sockets for IC3 and IC4. Match the notch on the socket to the notch on the board. Don't solder the ICs directly to the board!

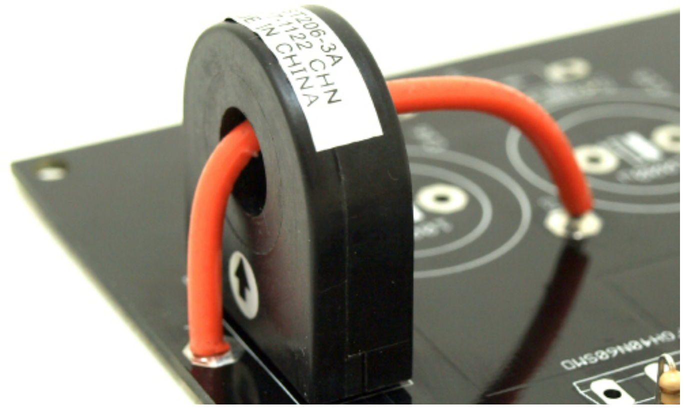
17. Install IC5 and IC6, voltage regulators. Be sure not to confuse the two! IC5, the LM7815, is the 15 volt regulator, and IC6, the LM7805, is the 5 volt regulator. Don't install them backwards! The tab of the voltage regulator need to match the stripe on the board.

18. Install the IC's in their sockets. IC1 is the SN-74HCT14, IC2 is the SN74HCT74. IC3 and IC4 are the UCC3232x gate drivers; for now, you can just install them in either socket, but you may have to swap their positions later.

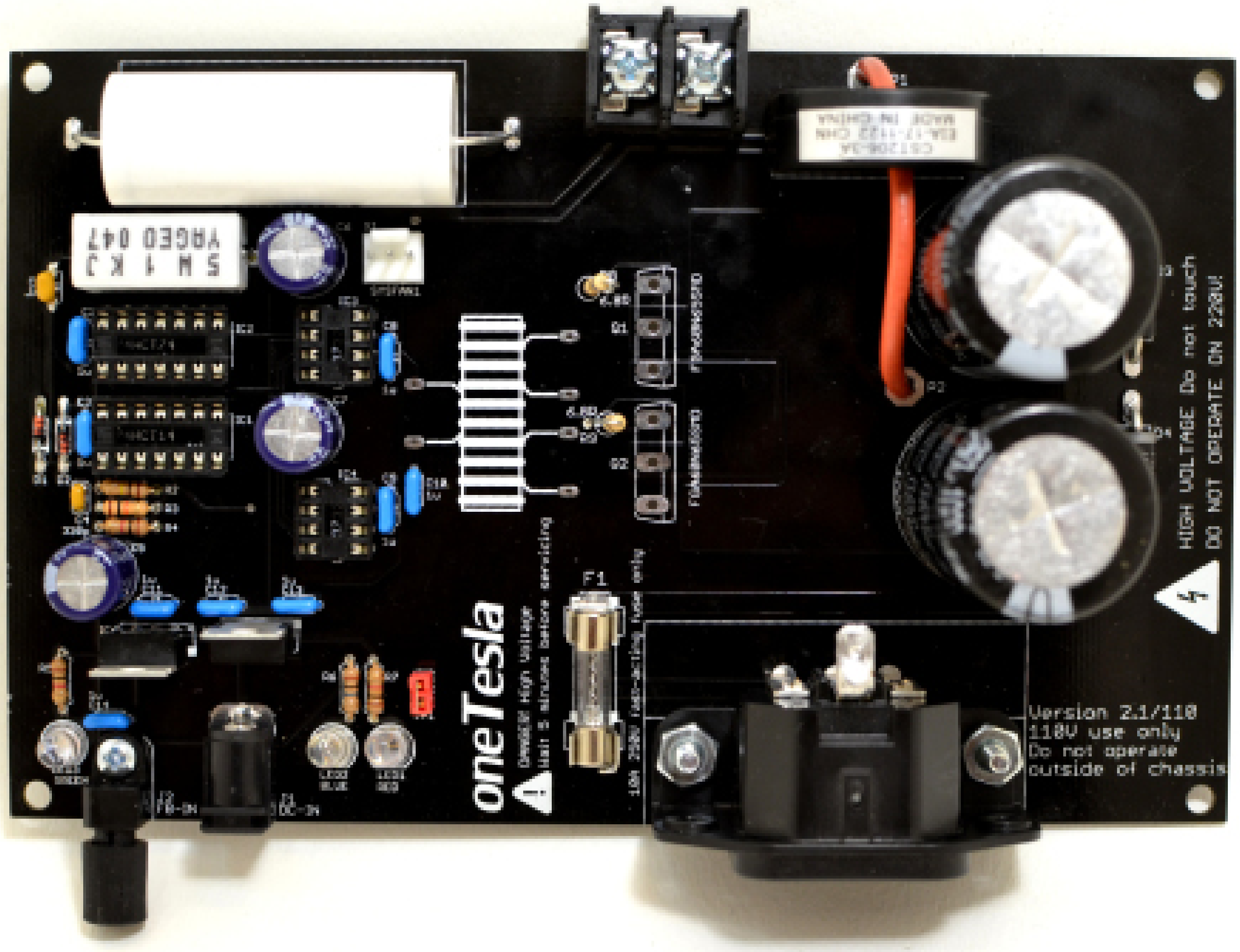
19. Install the current transformer. Cut a few inches of AWG14 wire and strip the ends. Put it through the current transformer and place the ends into solder pads P1 and P2, like the following picture. Solder it in.

20. Install the tank capacitor (the large, white CDE film capacitor).





21. There are three thick power traces that carry a lot of current on the back of the board. Tin them (coat them in a thick layer of solder). but don't cover the holes of components that are not yet installed.



By the end of step 1, your board should look like this, with the addition of ICs inserted into the sockets.

Step 2

Gate drive transformer

The gate drive transformer isolates the IGBTs from the gate drivers. It's important to maximize coupling here, so twist the wires together tightly, and then wind them on the core tightly! It's also VERY IMPORTANT that the wires have the correct phasing; the coil will not work if you don't insert the wires into the board in the right configuration!

1. Twist three strands of thin wire together tightly. You can do it by hand, but it goes much faster if you use a hand drill: clamp the wire in the chuck, hold the other end, and turn the drill.

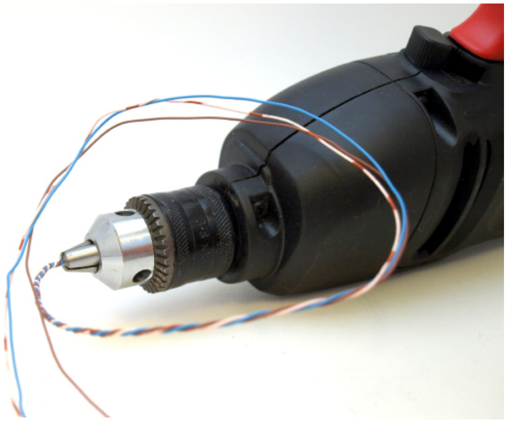
2. Wind up to 12 turns of the twisted wire tightly around the toroidal core. Leave a few inches of extra wire at each end. (Note that the ferrite toroid in your kit is gray and slightly larger than the toroid in the photos here. That's why it needs fewer turns than in the picture.)

3. Mark one end of the twisted bundle with a marker. Then, separate the wires.

4. Twist each color pair together a few turns close to where they come off the toroid. Trim the leads so that the GDT is relatively flush to the board.

5. Install the transformer in the board, making sure that the marked ends are on the inside of the row of four through-holes. The other side doesn't matter.

1



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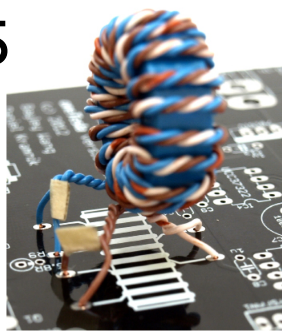
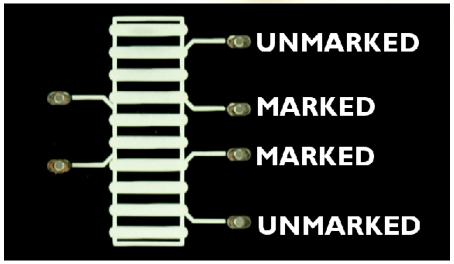




Step 3

Mounting the heat sink

We want good thermal conduction between the IGBT and the heat sink, but no electrical conduction.

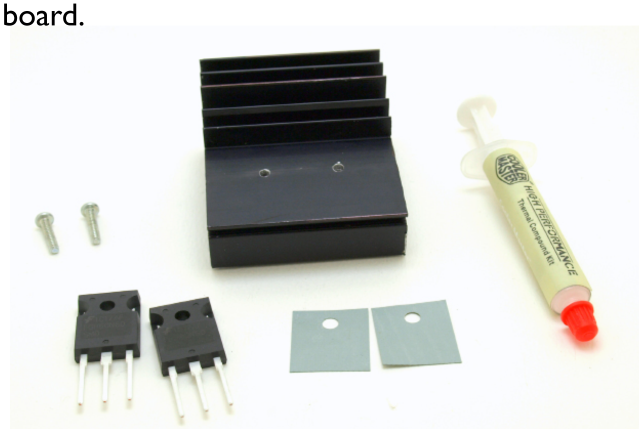
1. Clean the backs of the IGBTS and the heat sink with some rubbing alcohol. You want thermal conduction to be as good as possible, so it's important that the surfaces be clean.

2. If you have thermal compound, place a small amount of thermal compound on the back of the IGBTs and on the heat sink around the holes. The thermal compound fills in the portions where the IGBT is not completely flat. It sometimes helps to spread it out with a flat object like a credit card. It is not strictly necessary in addition to thermal compound.

3. Put a 4-40 bolt through the hole in each IGBT and sil-pad.

4. Screw the IGBTs to the heatsink.

5. Solder the IGBT and heatsink assembly into the board.



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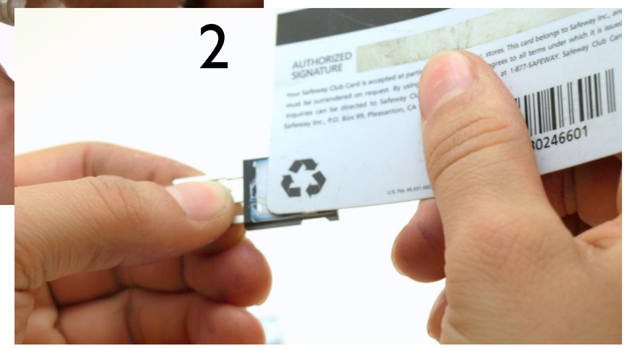

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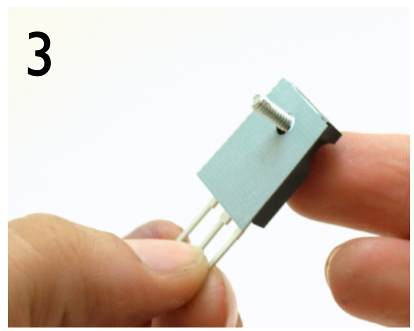

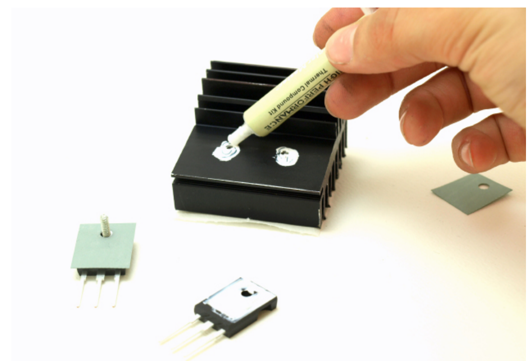

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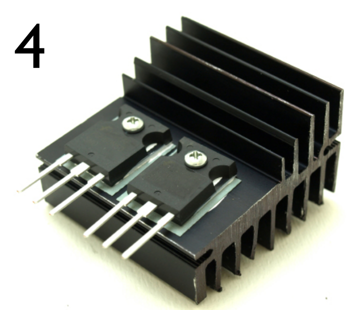


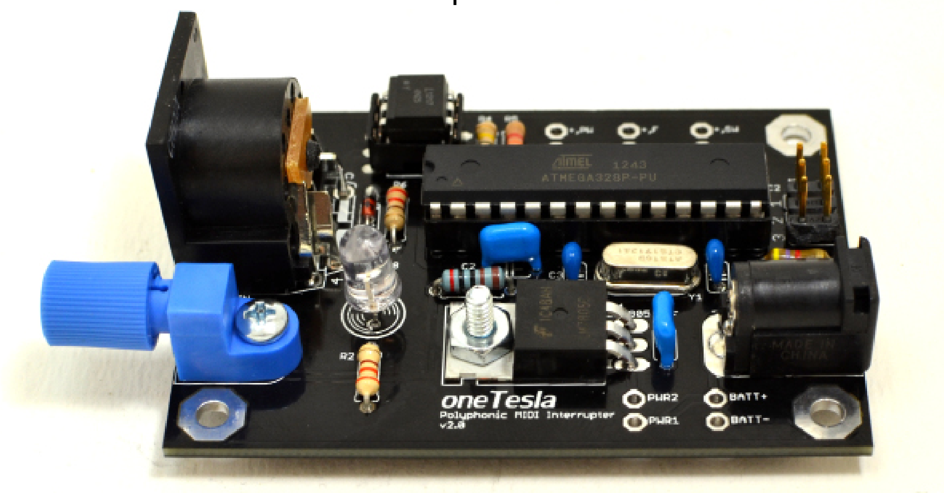
5

Step 4

Interrupter board

Populate the interrupter board with the components in the list to the right. Use the picture as a reference.

1. Install R1 through R6.
2. Install capacitors C1 through C4.
3. Install the 28-pin socket for the ATMEGA328. Match the notch on the socket to the notch on the silkscreen. Don't solder the IC directly to the board!
4. Install the 6-pin socket for the optocoupler. Match the notch on the socket to the notch on the board. Don't solder the IC directly to the board!
5. Install IC3, the 5V voltage regulator. Carefully bend it backwards and use a 4-40 bolt and nut to secure it to the board.
6. Install Y1, the 16MHz crystal.
7. Install JP1, the 2x3 programming header for the ATMEGA. Don't attach anything else to the pins.
8. Install D1, the 1N4148 diode, and LED1, the power indicator LED.
9. Install J1, the power jack, if it is included. It is not necessary if you connect the battery.
10. Install the MIDI-in jack.
11. Install the fiber-out jack. CAREFUL! This component is delicate. Use a 4-40 bolt and nut to secure it to the board immediately after installation to prevent straining it.
12. Insert the ATMEGA328 into the socket, ensuring that the notch on the IC lines up with the notch on the board.
13. Insert the optocoupler into the socket, ensuring that the dot on the IC lines up with the notch on the board.



R1	4.7KΩ
R2	330Ω
R3	100Ω
R4	100KΩ
R5	3.3KΩ
R6	220Ω

C1,C2	1uF
C3,C4	18pF

D1	1N4148
IC1	ATMEGA328P-PU microcontroller
IC2	4N25 optocoupler
IC3	LM7805 voltage regulator
Y1	16MHz crystal
JP1	2x3 programming header
J1	2.5mmx5.5mm power jack
	MIDI-in jack
	Fiber-out jack

Step 5

Interrupter knobs & switches

In addition to the board-mounted components, we will need to install a couple of off-board controls: two 10K potentiometers and two toggle switches.

1. Using flush cutters, separate the ribbon cable into three 3-wire strands and one two-wire strand. Separate about an inch of each strand at the ends. Strip half an inch of insulation off the ends of the ribbon cable.

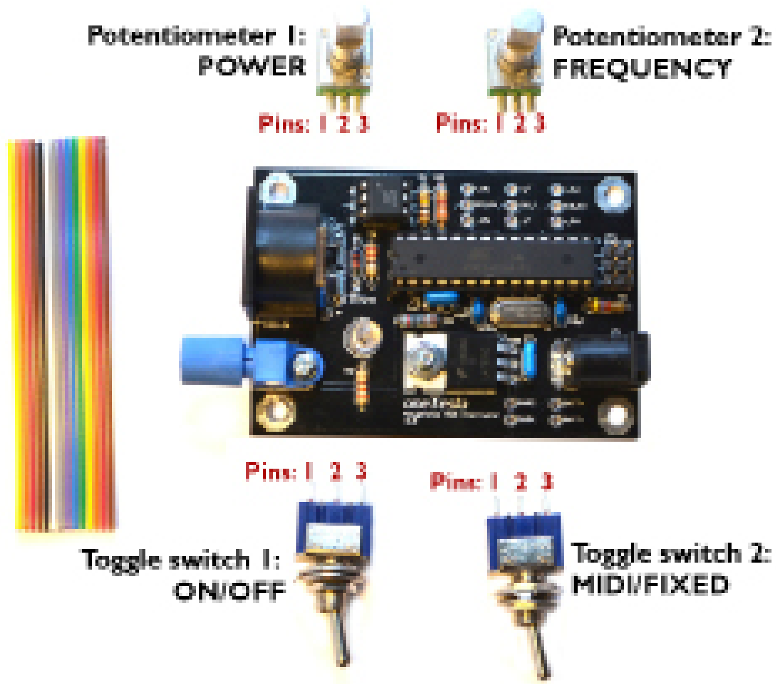
2. Solder one end of each ribbon cable into the board and the other end to a poteniometer or toggle switch.

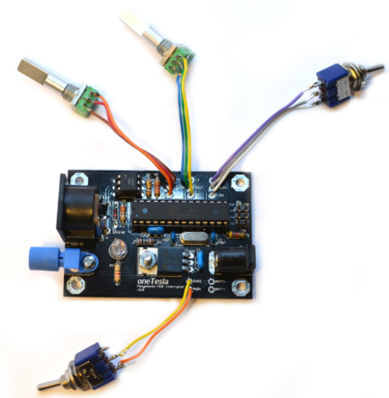
Potentiometer 1: POWER	Pin 1	- PW
	Pin 2	SIG PW
	Pin 3	+ PW
Potentiometer 2: FREQUENCY	Pin 1	+ F
	Pin 2	SIG F
	Pin 3	- F
Toggle Switch 1: ON/OFF	Pin 1	PWR 1
	Pin 2	PWR 2
	Pin 3	No connection
Toggle Switch 2: MIDI/FIXED	Pin 1	+ SW
	Pin 2	SIG SW
	Pin 3	- SW

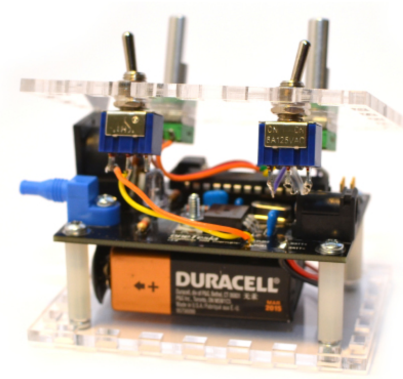
3. Mount the potentiometers and toggle switches to the top plate of the chassis. Match the toggle switches to the labels on the chassis.

4. Solder the battery connector to the underside of the circuit board. The red lead goes into the +BATT pad and the black lead goes into the -BATT pad.

5. Mount the circuit board to the bottom plate of the chassis using four nylon standoffs and 8 M3 screws.





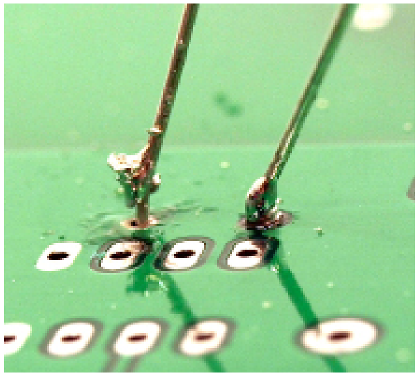


Step 6

Double-check your boards

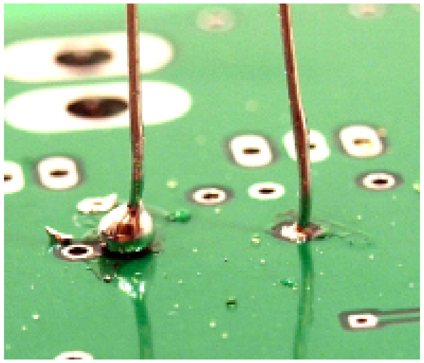
At this point, the electronics should be completely assembled. Scrutinize your boards and look for the following:

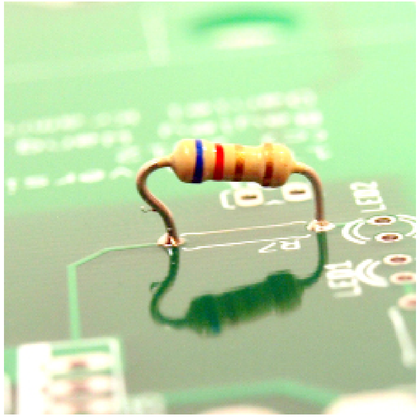
- Check that all components are soldered in properly, and that there are no solder bridges. Look closely! If you're unsure of the quality of the joints, pass over them again with a good soldering iron to reflow them. Poor soldering will invariably lead to difficult-to-trace problems.
- Confirm that diodes D1, D2, D3, and D4 are installed with the correct polarity.
- Confirm all electrolytic capacitors are installed with the correct polarity.
- Confirm the LEDs are installed with the correct polarity.
- Confirm the LM7805 and LM7815 voltage regulators are not installed backwards or switched.
- Confirm that the 74HCT14 AND 74HCT74 are in the correct socket and in the correct direction.
- Confirm that the UCC37321 and UCC37322 and all other ICs are inserted in the sockets in the correct direction.
- Confirm the 100K 1/2W bleeder resistors, R10 and R11 are installed properly.
- Confirm all of the resistor values are correct.



If your soldering looks like this, you have a problem.

Clean up messy joints! Remove blobs of solder using solder wick, and make sure that you're not shorting terminals together.





Component not flush? Fix it.

Step 7

Interrupter chassis

You will need a small amount of hot glue, superglue or epoxy to put the chassis together. Hot glue is preferable because it doesn't damage the acrylic like superglue does, and if you make a mistake or need to fix the circuitry it's relatively easy to pull the chassis apart and scrape off the old glue.

1. First check that the toggle switches are in the right orientation in the chassis and affixed securely. With the battery attached and the second toggle switch in the "Fixed" position, check that the light in the optical transmitter turns on when the power switch is in the "ON" position and turns off when the switch is in the "OFF" position. The light should not turn on at all when the second toggle switch is in the "MIDI" position unless there is a MIDI input.

2. Peel the protective paper off the acrylic parts.

3. Carefully assemble the sides of the chassis without putting any strain on the optical transmitter.

4. Use a small amount of hot glue at the corners of the chassis to hold it together.

Step 8

Interrupter testing

Testing and debugging the driver board relies on a functional interrupter, so we wil debug it first. This is a low power test only! DO NOT PLUG THE TESLA COIL INTO AC POWER IN THIS STEP.

Connect a 9V battery to the interrupter. Put the toggle switches in the "OFF" and "Fixed" positions, respectively. Gently insert the fiber cable into the transmitter on the interrupter and and receiver on the main board. Do not push the fiber in too hard! There is a delicate glass lens inside the transmitter and receiver that will break if you push the fiber in too hard.

Plug the 19V wall adapter into the main driver bord. This is a low power test only, so DO NOT PLUG THE IEC CABLE INTO THE BOARD! Flip the toggle switch on the interrupter to the "On" position. The interrupter should now be emitting pulses. Does the green LED next to the fiber receiver light up?

NO

YES

1. Flip the MIDI/Fixed switch to MIDI, then turn the interrupter off and back on. If the LED lights up, you have the switch wired backwards; to fix this, simply rotate the switch 180 degress in the chassis.

2. Disconnect the fiber from the receiver end and confirm that the fiber emits light. If it does, the interrupter is functioning, and the control board is faulty.

3. If there is no light, disconnect the fiber from the transmitter end and examine whether the LED in the transmitter emits light. If it does, you either have a damaged cable (check for kinks or obstructions in the cable) or a damaged fiber transmitter.

4. If the fiber transmitter does not emit light, check for poor solder connections on the interrupter board. In particular, the crystal is sensitive to bad solder joints. Make sure pin 23 of the ATMega328 is not shorted to ground.

Sweep the power knob from minimum to maximum while playing a note. Does the green LED fade and brighten correspondingly?

YES

NO

1. Check the power knob potentiometer and confirm all solder joints are intact (in particular, excessive strain on the wires connected to this potentiometer may damage the solder connections)
2. Make sure there are no solder bridges between pin 23 of the ATMega328 and the +5V rail.

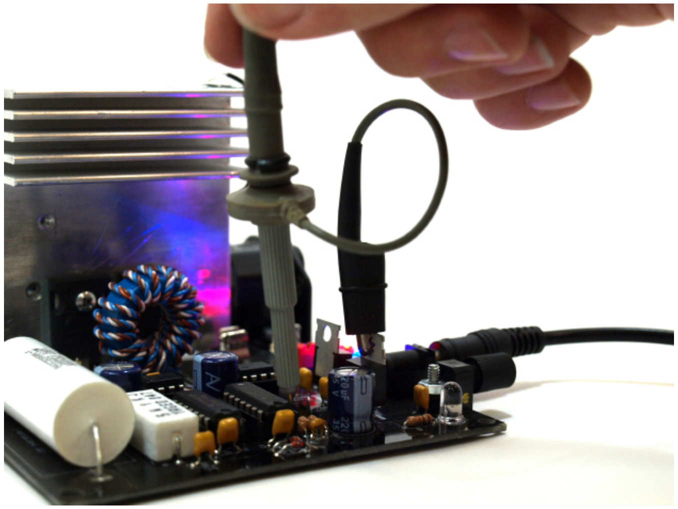
At this point, you are ready to test the control circuitry on the driver board.

Low-power system testing

Step 9

We will now test the main chassis and interrupter together at low power.

When probing anything on the board, clip the ground lead to the back of the voltage regulator like in the picture below.



Plug the 19V adapter into the DC power jack on the driver board. We are only doing low-voltge testing at this stage, so DO NOT PLUG IN THE IEC CORD. Do the LEDs light up?

NO

1. Measure the outputs of the 5V regulator and and 15V regulator with a multimeter. If they are they correct voltage, you have a poorly soldered LED or a damaged LED.

2. Confirm that the 19V power jack is properly soldered.

3. Remove all socketed ICs on the board. Measure the resistance between the rail in question and ground. It should be a high value. If not, check for solder bridges between the rails and ground.

4. With the ICs removed, measure the 5V and 15V rails with a multimeter. If they are now the correct value, you have a damaged or backwards IC. Reinstall the ICs (taking care to note the location of pin 1) and measure the rails after each IC is installed. The IC that causes the rails to vanish is the culprit.

5. If none of the above resolve the problem, replace the voltage regulator(s) in question.

YES

Use a voltmeter to measure pin 14 of the 74HCT14 and 74HCT74. Confirm that the voltage of the pins is 5V. Also confirm that pin 1 of the optical receiver is 5V. Are all the voltages 5V?

NO

1. Check the soldering of pins 7 and 14 on the socket.
2. Make sure the IC is seated properly.

YES

Use a voltmeter to measure pins 1 and 8 of the UCC3732x gate drive ICs. Again the ground lead of your multimeter should be touching the back tab of one of the the voltage regulators. Do they measure 15V?

Step9(continued)

YES NO

1. Check the soldering of pins 1, 4, 7, and 8 on the socket.

2. Make sure the IC is seated properly.

I

Disconnect the 19V adapter. Plug an IEC power cord into the AC jack on the board, and plug it into a wall outlet. Nothing should happen. Do the bus capacitors (C15 and C16) get hot? WARNING: Do not touch the tops!

WARNING! Board is energized. Proceed with extreme caution.

If the capacitors get hot, immediately unplug the IEC power cord. Wait five minutes, and then check the polarity of the bus capcitors.

Does the fuse blow?

1. Unplug the board and wait 5 minutes for the capacitors to discharge. Examine the board (primarily the right-hand side, which contains the power components) for shorts or solder bridges. Also, confirm the capacitors are installed with the correct polarity.
2. Ensure that you properly insulated the backs of the IGBTs form the heat sink using sil-pad, which is thermally conductive but electrically resistive.

After any errors found are fixed, unplug the board and wait five minutes. Prior to further working on the board, measure the bus voltage (you can do this by using a multimeter on the 1000VDC setting to measure across the far ends of D3 and D4) afterwards and confirm that it is ZERO VOLTS.

Step 10a

Test For Startup Pulses (no scope)

Set the mode switch on the interrupter to FIXED mode, power on the interrupter, turn the POWER knob to maximum, and connect the interrupter to the driver board via fiber optic cable. DO NOT ENERGIZE THE BOARD BY PLUGGING IT INTO AN AC POWER SOURCE WITH THE IEC CABLE. This is a low-power test only.

The next steps should be done in a quiet room. Plug the 19V adapter into the driver board. Listen to the gate drive transformer (GDT) and verify that there is a faint buzzing noise.

If you cannot hear the GDT buzz:

1. Ensure that you're in a quiet environment. The buzzing is quite faint.

2. Make sure all ICs are seated properly.

3. Make sure the fiber cable is installed correctly in both the interrupter and the control board.

4. Make sure all solder joints are good; in particular:

- R4 and R5
- Pins 12 and 13 of the 74HCT14 IC
- Pins 1, 2, 3, 4, 5, and 6 of the 74HCT74 IC
- Pins 2, 3, 7, and 8 of the UCC3732x gate drive ICs
- The three pins of the optical receiver

5. Make sure the GDT is properly wound and installed, and none of the GDT leads are shorted to anything.

If no soldering errors are found:

1. Replace the 74HCT14 and 74HCT74 ICs. Retest the board.

2. Replace the UCC3732x gate drive ICs. Retest the board.

3. Replace the optical receiver. Retest the board.

Note: it is exceedingly unlikely that a brand-new component is defective. It is strongly advised to check for other errors first.

Step 10b

Test For Startup Pulses (with scope)

If you don't have an oscilloscope or if the test without a scope has been sucessful so far, you can skip this step. You may want to refer back here to do more in-depth trouble-shooting later.

Power on the interrupter and turn the pulsewidth knob to maximum. Connect the interrupter to a MIDI source (refer to Step 7 for details on how), and connect the interrupter to the driver board via fiber optic cable. Plug the 19V adapter into the driver board.

1. Play a note, and probe pin 7 of the UCC3732x gate drive ICs. Does the waveform there match (A)?

NO YES

1. The startup pulses are present. Proceed to Step 11.

1. Probe pins 2 and 3 of the UCC3732x gate drive ICs. Does the waveform there match (C)?

NO YES

1. Check for shorts from pins 7 and 8 to ground.
2. If there are no shorts, replace the IC.

1. Check the soldering of each socket.
2. Confirm each IC is seated properly.

If there are no visible soldering errors, remove all ICs from

Probe the center pin of the optical receiver. Does the wave-form there match (D)?

YES NO

1. Confirm that the fiber cable is installed correctly at both ends.
2. Check for shorts from this pin to 5V or ground. In particular, this pin is adjacent to the 5V and ground connections for the optical receiver, so this is a likely cause.
3. If there are no shorts, the optical receiver has been damaged. Replace it.

Reinstall the 74HCT14. Inspect the output of the optical receiver; if it has vanished, replace the 74HCT14. Probe pin 13 of the 74HCT14. Does the waveform there match (N)?

YES NO

1. Check soldering of R4 and the IC socket.
2. Make sure the IC is seated properly.
3. Make sure pin 13 of the IC is not bridged to any adjacent pins.
4. As a last resort, replace the IC.

(Proceed to the next page)

Test For Startup Pulses (with scope)

Does pin 12 of the 74HCT14 match waveform (M)?

YES NO

1. Make sure the IC is seated properly
2. Make sure pin 13 of the IC is not bridged to any adjacent pins.
3. As a last resort, replace the IC.

Does pin 1 of the 74HCT14. match waveform (F)?

YES NO

1. Check the soldering of R5 and the socket.
2. Make sure the IC is seated properly.
3. As a last resort, replace the IC.

Do pins 2, 3, and 4 of the 74HCT74 match the waveforms (F), (I), and (J)?

YES NO

1. Check the soldering of the socket around that pin.
2. Make sure the IC is properly seated.
3. As a last resort, replace the IC.

1. Reinstall the 74HCT74 IC.
2. Probe pins 4 and 12 of the 74HCT14. If the waveform has vanished, replace the 74HCT74 IC.

Probe pins 2 and 4 of the 74HCT74. Do they read 5V?

YES NO

1. Make sure the IC is seated properly.
2. Make sure the socket is properly soldered.
3. As a last resort, replace the IC.

Does pin 1 of the 74HCT74 match waveform (M)?

YES NO

1. Make sure the IC is seated properly.
2. Make sure the socket is properly soldered.
3. As a last resort, replace the IC.

Does pin 3 of the 74HCT74 match waveform (E)?

YES NO

1. Make sure the IC is seated properly.
2. Make sure the socket is properly soldered.
3. As a last resort, replace the IC.

Does pin 6 of the 74HCT74 match waveform (O)?

(continued on the next page)

Step10b(continued)

Test For Startup Pulses (with scope)

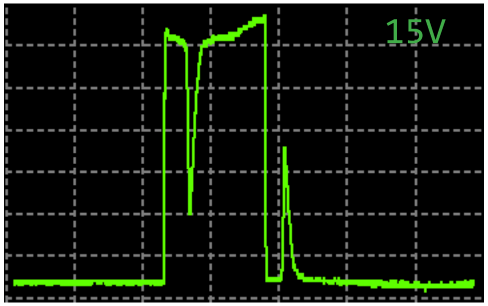
YES NO

1. Make sure the IC is seated properly.
2. Make sure pin 6 is not bridged to any adjacent pins.
3. Replace the 74HCT74

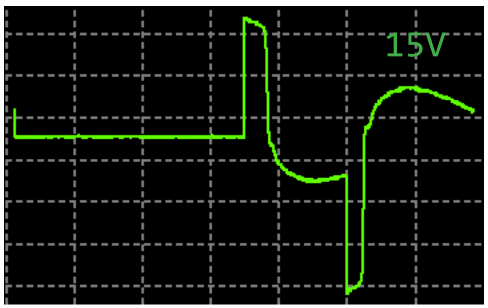
1. Reinstall the UCC37322 IC.
2. Probe pins 2 and 3 of the IC. If there are waveforms there, check the seating of the IC. If the IC is properly seated, replace the IC.
3. There should now be the correct waveforms on pins 7 and 8 of the IC.
4. Repeat the above 3 steps with the UCC37321 IC.

If there is still no output, double check to make sure the above steps have been followed. Make sure no components have been damaged during the troubleshooting process (sometimes, this can happen if your probe strays and shorts components on the board). Make sure all component values are correct. Make sure there are no stray bits of wire stuck between pins.

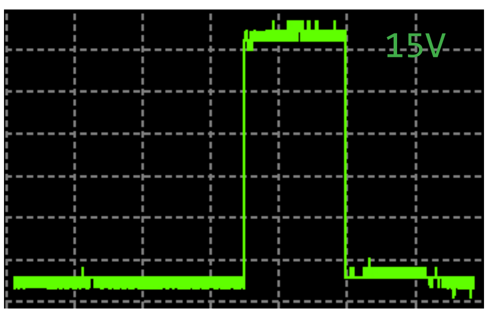
Test For Startup Pulses (with scope)



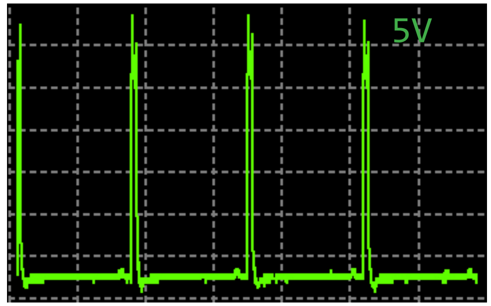
A) UCC37322 output (startup)



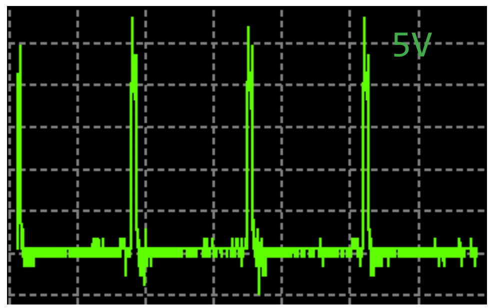
B) IGBT Vge (startup)



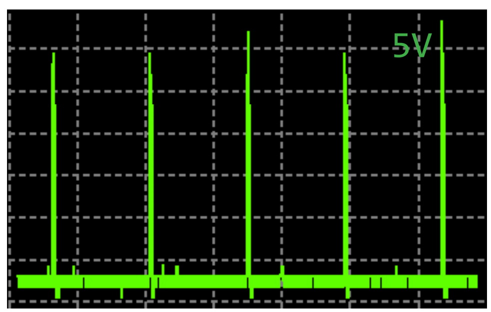
C) UCC37322 Input (startup)



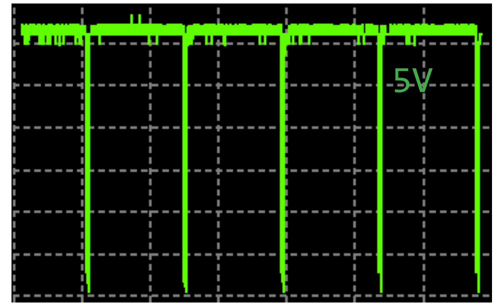
D) Optical receiver output



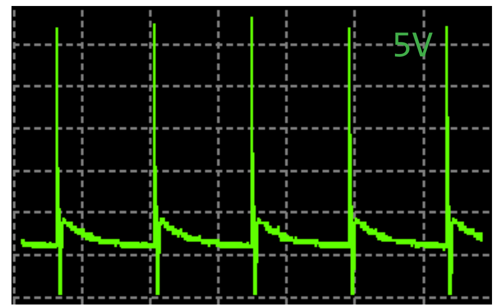
E) 74HCT74 Pin 3



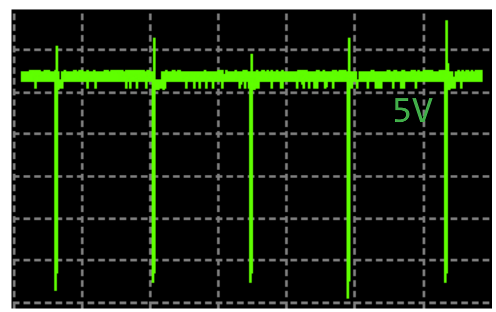
F) 74HCT14 Pin 1 (startup)



G) 74HCT74 pin 2 (startup)



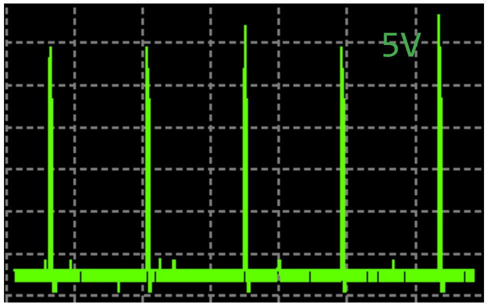
H) 74HCT14 pin 1 (startup)



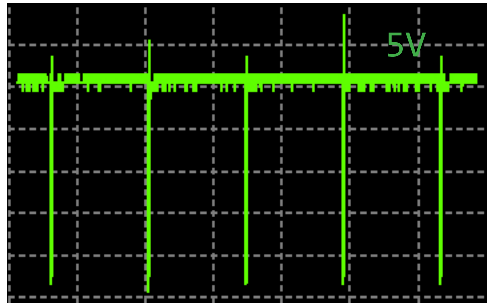
I) 74HCT14 pin 3 (startup)

Step10b(continued)

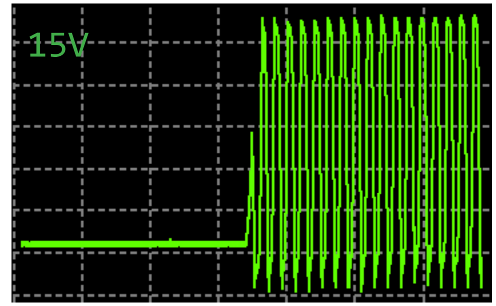
Test For Startup Pulses (with scope)



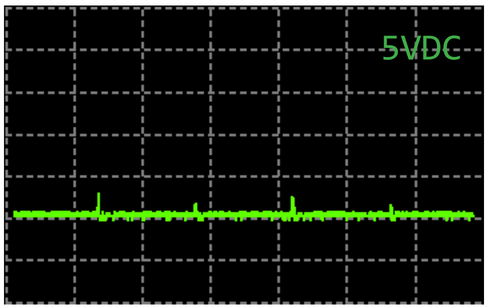
J) 74HCT14 pin 4 (startup)



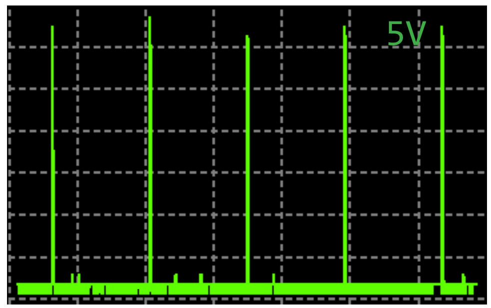
M) 74HCT14 pin 12 (startup)



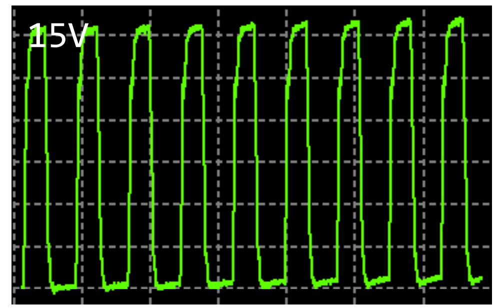
P) UCC37322 output (oscillation)



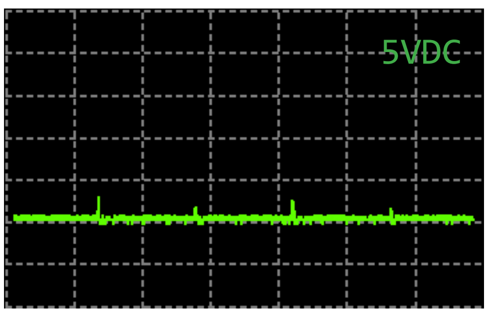
K) 74HCT74 pin 4 (startup)



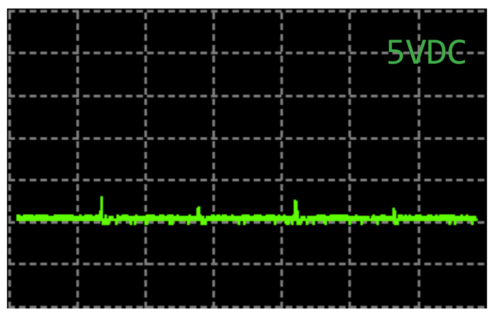
N) 74HCT14 pin 13 (startup)



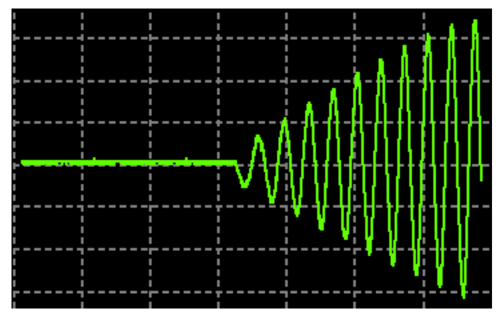
Q) IGBT Vge (oscillation)



L) 74HCT74 pin 2 (startup)



O) 74HCT74 pin 6 (startup)


Primary current (oscillation)

Step 11

Main chassis assembly

As when assembling the interrupter chassis, you will need a small amount of hot glue, epoxy, or superglue. Hot glue is by far the best option because it's sturdy enough to hold the chassis together, but it's still possible to take apart the chassis if you made a mistake or need to go fix the circuitry later.

1. Peel the protective paper off the acrylic parts. The chassis has two sides with vent holes; a front plate with holes for the optocoupler, power jack and IEC jack; a back plate with a fan grille; a bottom plate to which you screw the board; and a top plate. The rest of the laser cut parts are for the primary and secondary assembly, and the interrupter chassis.

2. Place the "DANGER HIGH VOLTAGE" warning sticker on the front plate of the chassis in the marked area. DO NOT OMIT THE WARNING LABEL. It's important that the Tesla coil is marked as a high voltage device.

3. Align the chassis front and back pieces correctly with the IEC jack and primary screw terminal, respectively. Completely assemble the chassis, with the board inside, WITHOUT GLUE. There's only one right way to put the sides together, so make sure that you have them in the correct orientation before applying glue! The warning label and "oneTesla" logos on the side pieces should be on the outside of the box.

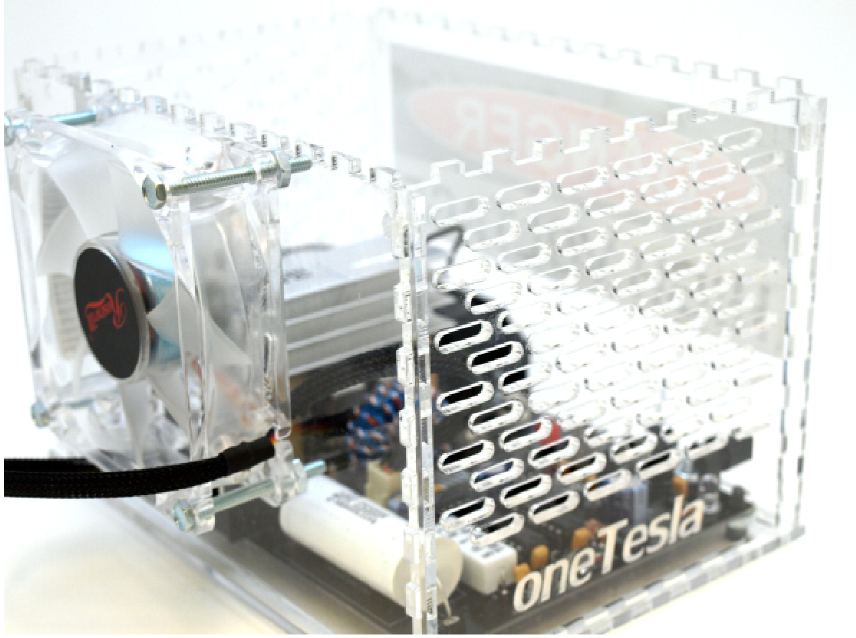
4. Use four 6-32 bolts, 6-32 nuts and 1/4" standoffs to attach the main circuit board to the bottom plate, in the correct orientation.

5. Use small dabs of glue in the corners to assemble the chassis. A little glue goes a long way! DON'T GLUE ON THE TOP.

6. Use long 4-40 bolts to attach the cooling fan to the back. Put its power cable through the hole under the fan, and connect it to the jack on the board.

Don't omit the warning label!


DANGER
HIGH VOLTAGE
Put dabs of glue here


oneTesla

Step 12

Primary Assembly

The challenge in winding the primary is getting the turns tight and even. We designed laser-cut clips to hold the wire to the acrylic former for a nice clean look.

1. Roughly measure enough AWG14 wire for six turns on the former plus about a foot of extra length on each end.

2. Tape the wire to the primary about a foot from the end.

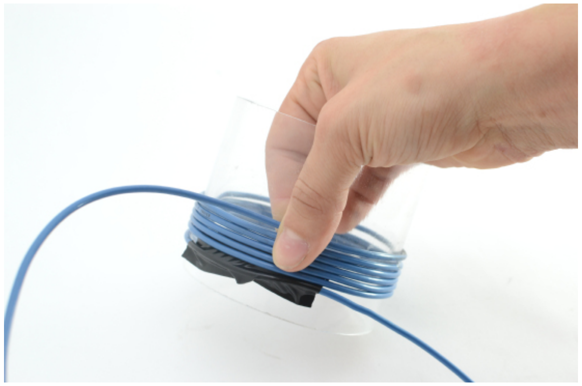
3. Wind six turns around the former as tightly as possible, and keep it tight until you tape down the other end.

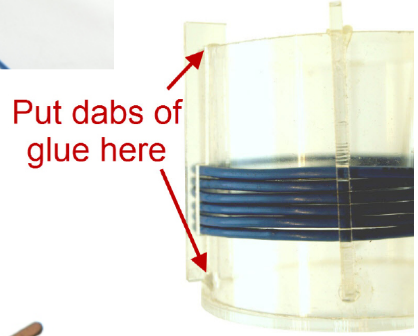
4. Tightly twist together the leads coming off the primary, all the way down their length. Use some heat shrink tubing or electrical tape to secure the leads right where they come off the primary.

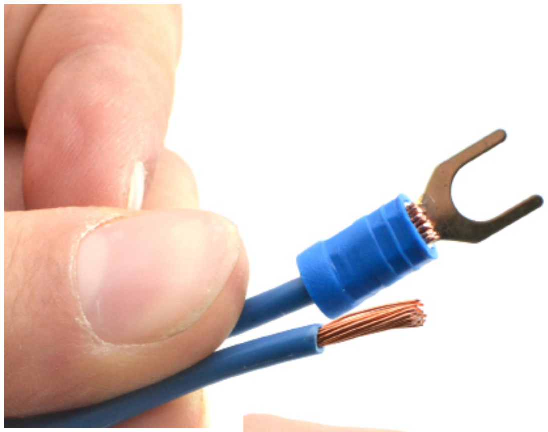
5. When the windings are sufficiently secured with pieces of tape, slide the clips over the windings, like hair pins. Space them evenly around the former. They break easily, so be careful!

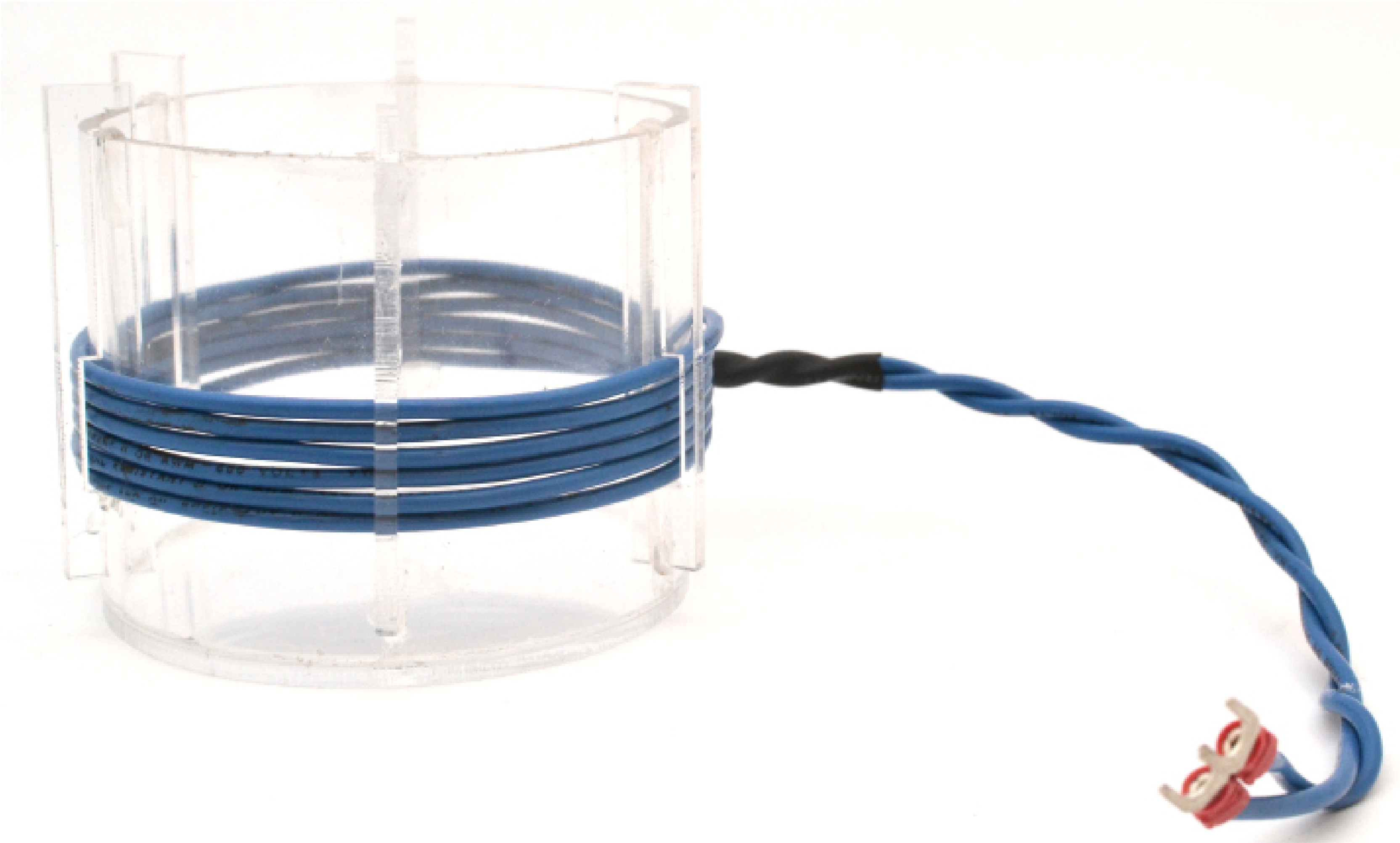
6. Use a dab of hot glue at the top and the bottom of each clip to hold it in place. When all the clips are in place, take off the tape for a clean look. Glue the circular base plate onto the former as well.

7. Strip a quarter inch of insulation off the ends of the wire. Crimp spade terminals to the ends of the wire, using a crimp tool if you have one, or large pliers. You can also solder the terminals on.









Step 13

Secondary Assembly

Thank us: we've saved you hours of tedious work manually winding 2000 turns of 36-gauge wire without a single crossed turn!

1. There are a few inches of loose wire coming off of each end of the secondary. Gently sand off the enamel at the end. If the lead breaks while you are doing this, gently peel off more. You should see exposed copper when you are finished.

2. Solder the end of the lead to a ring terminal.

3. Put the ring terminal over a 1/4-20 bolt. Put the bolt through a secondary end cap, so that the ring is clamped between the bolt and the plastic. Use a small amount of hot glue to attach the bolt to the cap.

4. Use a small amount of hot glue to put on the secondary end cap.

5. Repeat on the other end of the secondary

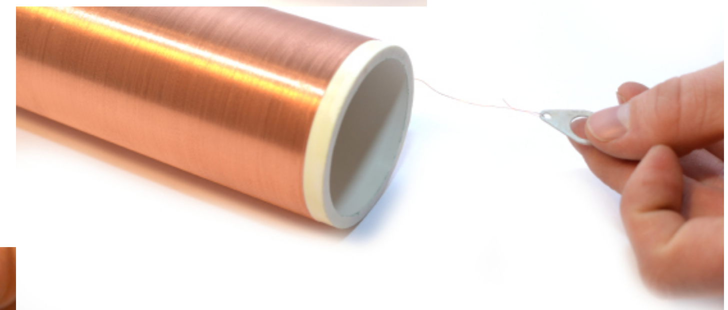
6. Use a multimeter to check the resistance between the two bolts. It should read about 300 ohms. If it reads significantly more, or jumps between values, check your connections.

7. You should do whatever is necessary to attach the secondary wire to the bolt. If it's easier for you to wind the fine wire around the bolt directly, then do that.

1

2

3



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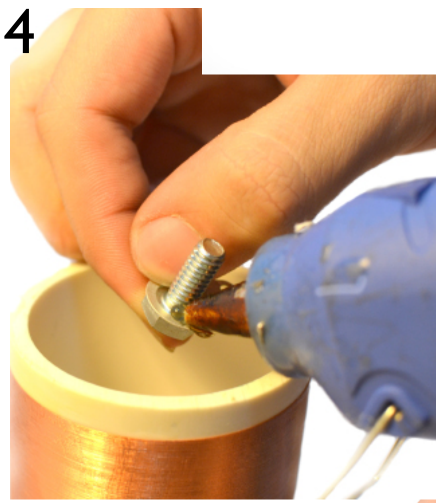


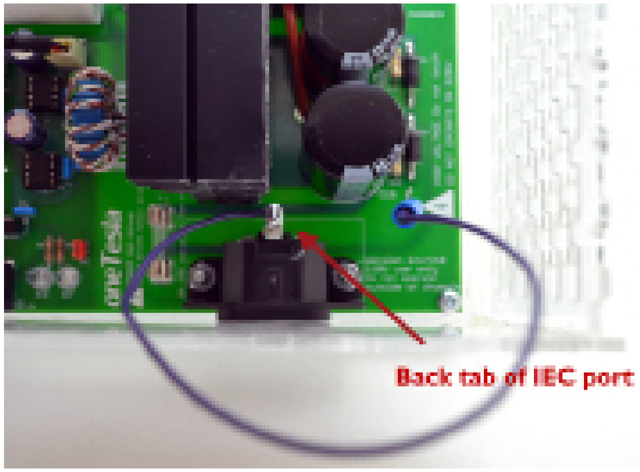
5

Step 14

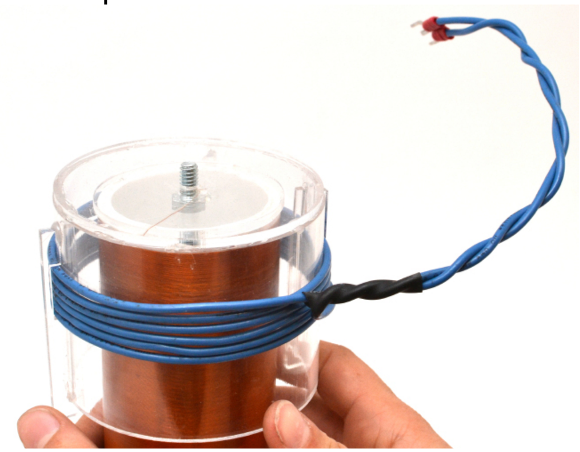
Putting together the primary and secondary

The most important thing to pay attention to when putting together the whole assembly is proper grounding of the secondary.

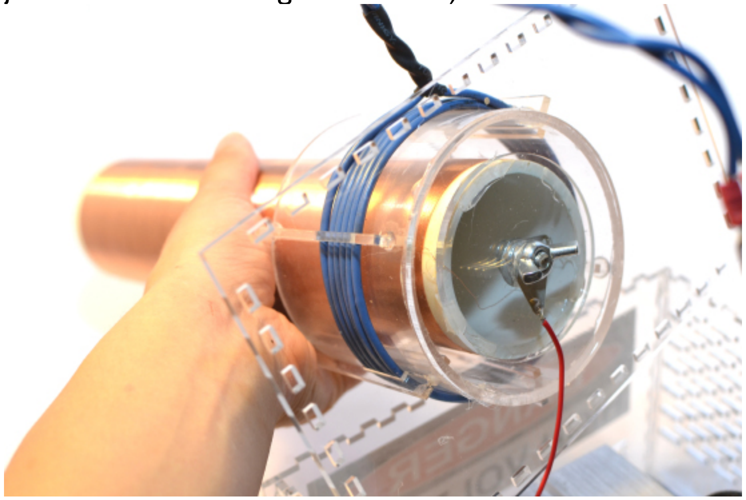
1. First we're going to make a good ground connection on the circuit board. Solder a wire ~5" long to the back tab of the IEC port. Crimp or solder a spade terminal to the other end of the wire.



2. Put the primary assembly over the secondary assembly like in the photo below.



3. Place the top plate of the chassis on the stack as well, with the bolt going through the hole in the middle of the plate. Use a wing nut to clamp down the spade terminal (the photo shows a ring terminal; either is fine, just be sure to make good contact).



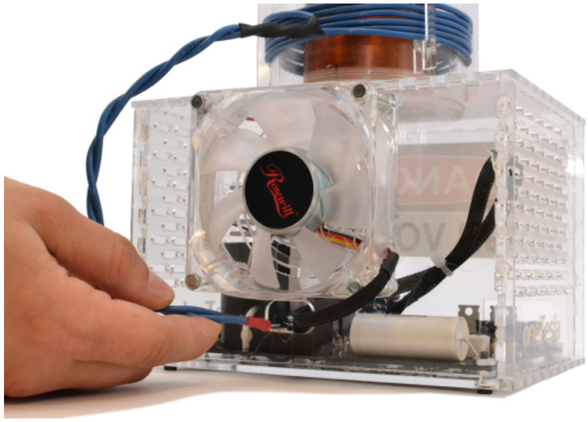
When the assembly is complete, put the top lid on the chassis. Don't glue it down!

4. Place the metal toroid on top of the secondary, with the bolt going through the hole in the toroid. Secure it using a wing nut. Note: if you do not have a metal toroid, you can use a tire inner tube that's close to 8" major diameter (across the whole toroid), 2" minor diameter (a cross-section of the tube), and cover it in aluminum tape. Hold the inner tube in place with a cardboard disc with a hole in it.

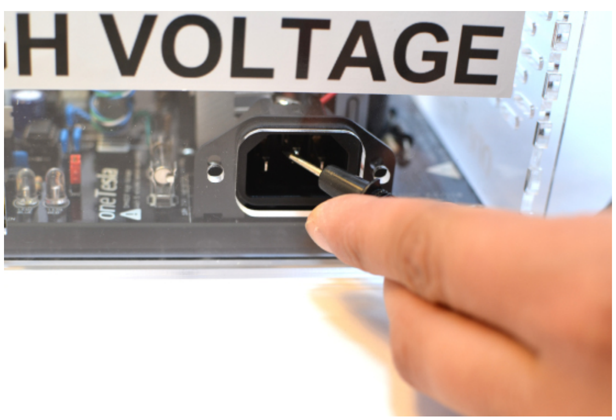
5. Attach the primary wires to the primary screw terminals through the hole in the back of the chassis. You

Step14(continued)

will need to lift up the lid of the chassis to tighten the terminals with a screwdriver.



6. Verify that you have a good ground connection. DO NOT SKIP THIS STEP. ALSO, DO THIS CHECK EVERY TIME YOU MOVE THE SECONDARY OR TOROID. An ungrounded Tesla coil runs poorly and can damage the board. Use a multimeter to probe between the ground prong of the IEC port (the middle prong) and the metal toroid. There should be ~250Ω. More than that means that you have a bad connection whch you need to fix.



Special instructions for external grounding.

If you do not have a grounded outlet, you need to externally ground the coil.

- To externally ground the coil, run a wire from the bottom of the secondary to a ground point close to the coil. A good ground point could be a stake in the ground, a water pipe, or a large metal sheet
- We highly recommend running your coil on a counterpoise: a sheet of aluminum foil, metal window screen, or chicken wire at least 4 feet in diameter that's also externally grounded. This gives the sparks a convenient place to jump to right underneath the coil.
- If you have a GFCI, external grounding may be necessary. If the GFCI on the outlet repeatedly trips, you will need to disconnect the internal ground, and ground to a stake or water pipe as specified above.
- No 2-prong to 3-prong adapters allowed! If you're unsure of whether the wiring in your building was done properly (for instance, if you're in an old building), use a ground tester to confirm that your outlet is grounded.

Step 15

Pre-Operating Warnings

We are now ready to power test the coil! Before we do so, we want to do some final checks. Reference this step before every time you run the coil. Follow this list and the diagram on the following page.

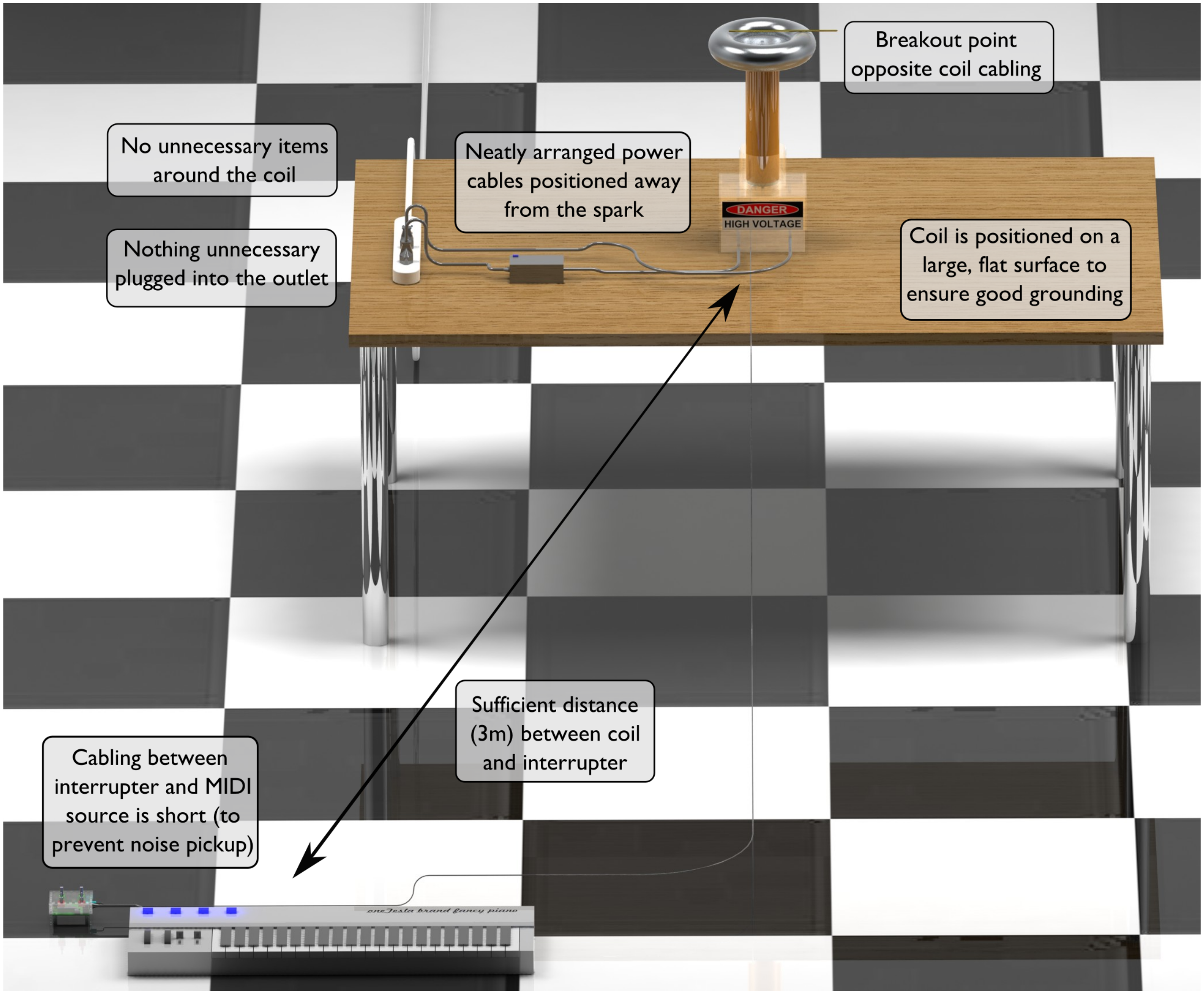
Proper Tesla coil setup:

- Make sure all mechanical components are sturdily mounted.
- MAKE SURE THE TESLA COIL IS PROPERLY GROUNDED. Follow the instructions in step 14 to check whether your outlet is properly grounded. A grounded outlet is preferred, but if one is not available, use an external ground. Use a multimeter to ensure that there is at most 500Ω between the toroid and the ground prong of the power plug. Improper grounding results in damage to the coil. Using a counterpoise is an excellent idea.
- Make sure the secondary is vertical and centered in the primary. DO NOT RUN THE COIL WITHOUT THE SECONDARY IN PLACE! This will overload and destroy the driver immediately, necessitating a replacement of the bridge.
- Make sure the cooling fan is plugged into the fan header on the board and that it runs when you plug in the 19V plug. Never run the Tesla coil without the cooling fan.

Proper environment for operation:

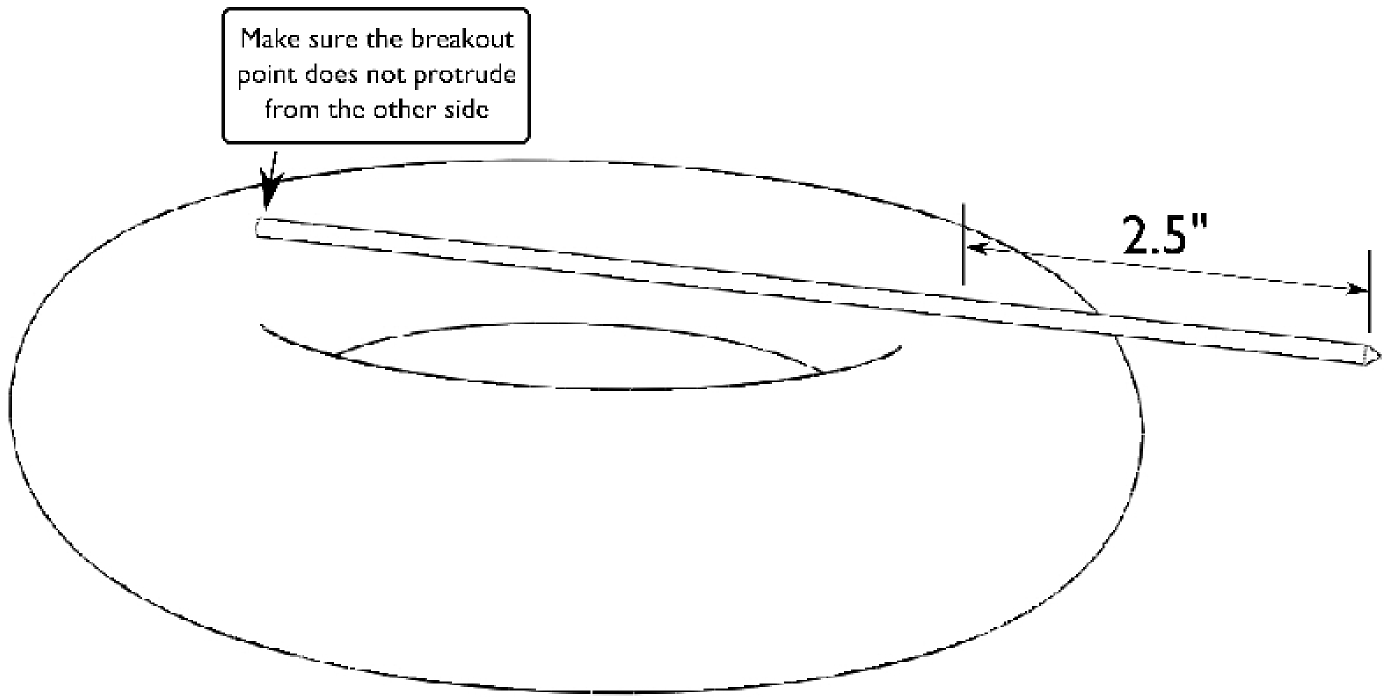
- ENSURE THAT THE TESLA COIL IS POSITIONED IN SUCH A WAY THAT THE SPARKS DO NOT STRIKE ANYTHING. They should discharge into the air. There should be nothing within two feet of the breakout point.
- PEOPLE WITH PACEMAKERS SHOULD NOT BE IN THE VICINITY OF THE COIL.
- BE AWARE THAT THE COIL IS VERY LOUD. If you are indoors, ear protection may be necessary. Always turn up the power of the coil slowly.
- Make sure you, your MIDI source, and the interrupter are at least 10 feet away from the Tesla coil. This is the minimum safe distance for people and equipment.
- If you are using a laptop as a MIDI source, MAKE SURE IT IS NOT PLUGGED IN. The RF returning through mains ground will be injected back into the laptop, often causing problems. If you are using a MIDI keyboard, battery or USB-powered keyboards are preferable.
- ONLY RUN THE TESLA COIL ON A LARGE, FLAT SURFACE. The tuning of the Tesla coil is very sensitive to its surroundings. In its stock configuration, it is tuned to operate properly on a large table or on the floor. If you run the coil on a small surface or an insulating surface, you may suffer from reduced performance or cause coil damage.
- The radiated electric field has a tendency to temporarily cause nearby capacitive touchscreens and laptop touchpads to misbehave. This is normal, and will not permanently damage your electronics. If this happens, just move further away from the coil.
- TURN OFF COMPUTERS in the vicinity of the coil to prevent potential data loss in case they're poorly shielded. This probably won't happen, but don't take risks.

Tesla coil operating rules



Breakout Point Placement

Positioning of the breakout point can significantly affect coil performance and reliability. Follow the diagram on this page as a guide. If performance is low, try moving the breakout point further in. If the secondary flashes over, trying moving the breakout point out a little.



Step 16

Power test in fixed-frequency mode

Power up the Tesla coil by following these steps in the exact order they are written. The purpose of these steps is to ensure that if something is wrong with the Tesla coil's construction, you minimize the risk of being near it when it is energized and malfunctioning. Ensure that you have read and continue to follow all the pre-operating warnings.

1. Put the toggle switch on the interrupter box to "Fixed" mode and turn on the interrupter.
2. Look at the fiber transmitter on the interrupter. Turn the power knob and observe the light changing in brightness. Turn the power knob so that the light is as dim as it gets. You may want to mark the direction of increasing power on the case with a marker.
3. Turn off the interrupter. Connect the main board and the interrupter via the fiber optic cable.
4. With the other end disconnected, plug the IEC cable to the main board. CONNECT THE IEC CABLE TO THE BOARD BEFORE PLUGGING IT INTO AN OUTLET.
5. Ensure that the power cable is on the opposite side of the breakout point, so there's no risk of a spark hitting the power cable. Ensure that your MIDI interrupter is the full distance that the optical fiber allows it to be from the coil.
6. Standing away from the coil, plug the other end of the IEC cable into the power outlet. THE COIL IS NOW ENERGIZED! DO NOT APPROACH IT OR OPEN THE CHASSIS!
7. Slowly turn up the power on the interrupter. Sparks should fly! As you turn the power up, you should get a nice clean tone and steadily increasing spark length.
8. If the coil doesn't work, don't panic! Unplug the IEC cable from the power source, wait 5 minutes before touching the board, and proceed to step 18, troubleshooting.

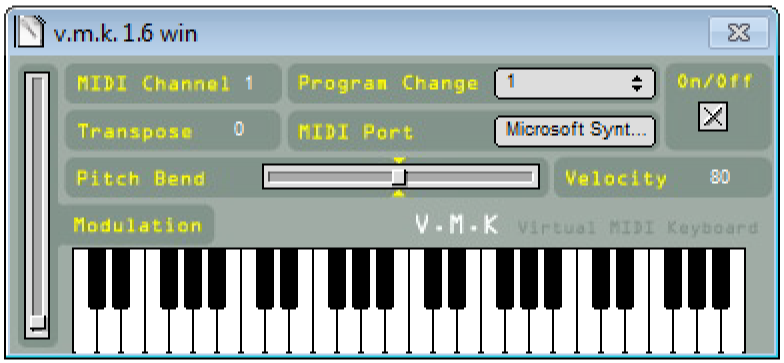
> Due to the self-resonant nature of the driver, there is inherently a 50% chance the Tesla coil will not produce output the first time. In that case, reverse the positions of the UCC37322 IC and the UCC37321 IC, and re-test the Tesla coil. This should be the first step you take if your Tesla coil does not work.

Step 17

Power test with MIDI Input

If the power test in fixed-frequency mode works, then continue to test with a MIDI input. As before, power up the Tesla coil by following these steps in the exact order they are written.

A good tool for debugging is a virtual MIDI keyboard. For Windows computers, download V.M.K. 1.6, available at: http://www.hitsquad.com/smm/programs/VMKXP/



You will also need MIDIEditor, available at http://midieditor.sourceforge.net/. MIDIEditor is an open-source program for playing and editing MIDI files.

1. Plug the USB to MIDI adapter into a free USB port. Due to driver limitations, you should use the same USB port every time; if it doesn't work, try another USB port!
2. Open MIDIEditor.
3. Go to Midi>MIDI settings, and select "USB2.0-MIDI" in the list under "Send Output To..."
4. Plug the OUT cable of the MIDI adapter into the interrupter.
5. Power on the logic on the driver board with the 19V adapter.
6. Turn the interrupter off and set the pulsewidth knob to minimum.
7. With the other end disconnected, plug the IEC cable to the main board. CONNECT THE IEC CABLE TO THE BOARD BEFORE PLUGGING IT INTO AN OUTLET.
8. Ensure that the power cable is on the opposite side of the breakout point, so there's no risk of a spark hitting the power cable. Ensure that your MIDI interrupter is the full distance that the optical fiber allows it to be from the coil.
9.  Standing away from the coil, plug the other end of the IEC cable into the power outlet. THE COIL IS NOW ENERGIZED! DO NOT APPROACH IT OR OPEN THE CHASSIS!
10. Turn the interrupter on.
11. Go to File>Open in MIDIEditor, and open a song of your choice.
12. Click the "Play" button. You should see small sparks coming from the breakout point and faintly hear the music.
13. Slowly turn up the power on the interrupter. Sparks should fly and music should play!
14. If the coil doesn't work, don't panic! Unplug the IEC cable from the power source, wait 5 minutes before touching the board, and proceed to step 18, troubleshooting.

Tesla coil troubleshooting

Problem	Solution
Fuse blows immediately upon insertion of IEC cable	• On a brand-new board: check for solder bridges across the IGBTs and voltage doubler diodes, check the polarity of the bus capacitors, and check the phasing of the GDT. • This often indicates a damaged bridge. Use a multimeter to confirm that both IGBT's and doubler diodes are intact. Then, check that all of the traces in the power section are intact. A bridge failure during operation may excessive currents to flow through the traces on the board, possibly damaging them. • Check that the IGBTs are properly insulated from the heat sink with sil-pad by metering between the heatsink and pin 2 (collector) of each IGBT.
Coil underperforms, and/ or outputs noisy sparks. As you turn up the power, you should get steadily increasing spark length and a clean tone from the coil.	• Stop operating! Turning up the pulsewidth further will not rectify this problem! • Check the coil's grounding. There should be no more than 500Ω between the toroid and the ground prong of the IEC cable if you are using a grounded outlet. Use a ground tester to make sure your outlet is properly grounded. Put the coil on a grounded counterpoise: an aluminum foil/chicken wire/metal window screen circle at least 4 feet in diameter. • Check for poor soldering on the driver board. Try reflowing all solder joints; this kind of error is often caused by a bad solder joint picking up noise. • Your coil might be out of tune. See the corresponding fix listed under problem 5.
Laptop, interrupter, or MIDI keyboard latches up often	• Increase distance between the device and the coil. • Use cables with better shielding. • Use a ground tester to make sure that the outlet you are using to power the coil is properly grounded.
No output in MIDI mode	• Is the "OUT" LED on the MIDI adapter blinking? If not, you have a configuration problem on your computer. Try the usual (restarting the program, unplugging the adapter, etc.) • If the "OUT" LED is blinking, check to make sure that the values of the resistors and direction of the 1N4148 diode on the optoisolator section of the interrupter board are correct. Check your soldering.

Coil appears to work fine, but the IGBTs unexpectedly fail or heat up excessively	• One possibility is a tuning issue. Check the primary and secondary assemblies for any physical damage, then, use the capacitance setting on your multimeter to check the value of the primary capacitor. If it is not close to 0.068uF, you will need a replacement. • Another possibility is a gate drive issue. With a signal generator supplying a 250kHz sine wave at the feedback input of the 74HC14, use an oscilloscope to observe the waveforms between the gate and emitter of each IGBT. You should see a 30 volt peak-to-peak square wave. - If there is ringing, check to make sure your gate resistors are not shorted out and are within +/-5% of 6.8 ohms. If the gate resistors are fine, then your GDT has too much leakage inductance and you should rewind it tighter and with shorter, more tightly twisted leads. - If the edges of the square wave look significantly rounded off, then there is excessive damping resistance on the gate, causing the IGBTs to spend too much time in their linear region during each switching cycle and dissipate more power than they should. Check the soldering of the GDT, IGBTs, and gate resistors for poor joints, and confirm that the values of the gate resistors are 6.8 ohms. - If the peak-to-peak voltage is less than 30V, then there is an issue in the gate drive circuitry. Check the +15V logic rail. If it is correct, then probe the outputs of the UCCs. - It is likely that one of both of the gate driver chips have sustained damage and will need to be replaced.
Coil does not respond at all to interrupter input, but interrupter appears to be working	One possible cause is that the interrupter is low on batteries. Because the microcontroller is capable of running down to 3.3V, there are situations where the interrupter operates, but the transmitter LED is not bright enough to trigger the optical receiver. In these cases, replace the battery.

Step 19

Operating your Tesla coil

1. Watch out for flashover and surface tracking on the secondary

Flashover is the phenomenon where an arc forms between the primary and secondary. Surface tracking on the secondary is where an arc forms between two points on the secondary. Both of these events are extremely harmful. In addition to possibly destroying your secondary or your bridge, they also severely degrade the insulation on the secondary and primary wires.

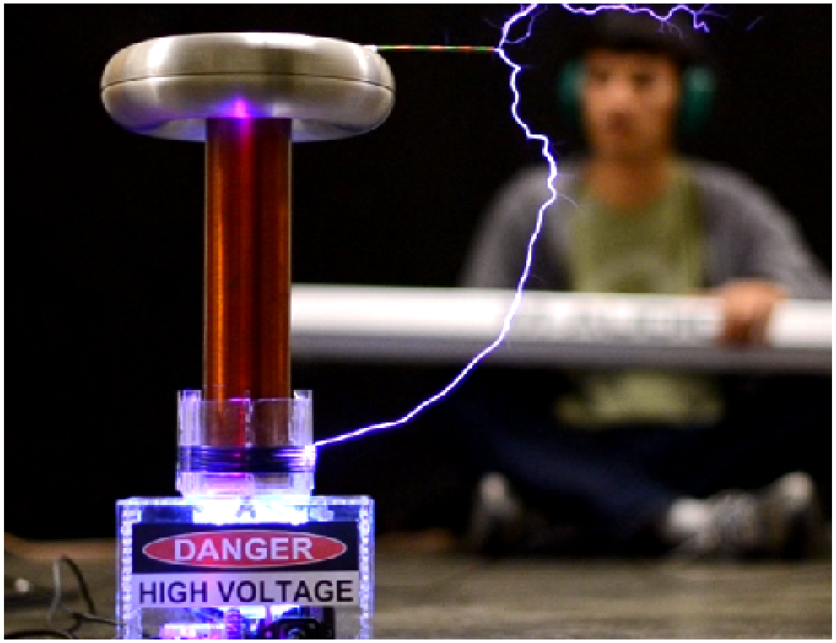
Why do these events occur? Well, oneTesla is optimized for performance on a large, flat ground plane, and performs best on certain notes. An unfortunate side effect is that on nonoptimal conditions, the coil may flash over. Rather than, for example, disable nonoptimal notes, we leave them enabled for flexibility. It is up to you, the user, to ensure that these features are used wisely.

Curing flashover:

- Adjust the breakout point and improve the surroundings so the coil sits on a ground plane. You want the spark discharge to have an easy path between the breakout point and ground. If there's no single easy path for the sparks to take, discharge in undesirable places, such as between the secondary and primary, will happen more often.
- Avoid playing low notes. The coil most often flashes over on low notes because of their long pulse widths.
- Each time your coil flashes over, it degrades the insulation on both the secondary and the primary. If flashover is persistent, it's necessary to re-varnish the secondary with a few coats of polyurethane.
- Watch carefully where flashover takes place. Sometimes the arc will track along the primary former and down a clip. Rounding the edges of the clips or removing them entirely may help.
- Ensure that your secondary is centered in the primary.

Step19(continued)

2. Watch out for arcing to the primary or power cords



Arcing to the primary coil or any power cords should be avoided, particularly the cables of the 19V adapter. If this happens, it's again is a problem of geometry. Move the cords away from the region where the spark might strike them. Move out the breakout point so that the sparks have a longer path to curve back and hit the primary.

3. Watch out for device latchup

Occasionally, noise picked up by poorly shielded MIDI cables or an interrupter too close to the coil will cause the optical transmitter on the interrupter to latch high. This tells the Tesla coil to stay on continuously, which causes the average current draw of the coil to become extremely high in a matter of tens of milliseconds. In this case, the fast-acting fuse will blow to protect the main control board. You will typically hear a high-pitched whine when the coil latches up, followed by a flash of green light from the blowing fuse (as in the picture to the left). If latch-up happens frequently, move your interrupter and MIDI cable further away from the coil. You may want to replace the MIDI cable with a well-shielded one of good quality if it's a recurring problem.

Sometimes the fuse may not blow fast enough to save the bridge, in which case you will need to replace the IGBTs.

4. Avoid excessive ground strikes

- While it may be fun to watch white-hot ground strikes, these arcs also carry significantly more current that regular streamers. This in turn translates into increased inverter current, which generally makes things run hotter on the driver.
- Stop turning up the pulse width.
- Ensure that there's nothing for the sparks to hit.

5. Avoid excessively long runs

- Avoid excessively long runs. In general, oneTesla is tolerant of long runs - the default interrupter settings run the inverter at conservative peak currents, and the bulky heatsink and active cooling help keep the power components cool. However, long runs will result in an overall greater chance of failure. We recommend ~3 minute songs with 3 minutes of time between songs.
- Don't let the secondary get too hot! Because the secondary is wound with fine wire, it has several hundred ohms of resistance, which dissipates quite a lot of power.

6. Be aware of how loud your coil is

- Recognize that a coil suddenly starting to operate can startle people. Always start at low power and gradually turn it up. (This helps you identify problems with the coil and fix them before running at full power too.)
- Don't annoy your neighbors with a blaring Tesla coil at strange hours of the night.

7. Be aware of ozone buildup

- Ozone is an irritating gas with a has a pungent smell, a little bit like the air before a thunderstorm. If you smell ozone, stop operating for a while until it dissipates. Ensure you're in a well-ventilated area.

Step 20

Coil Service & Repair

As carefully as you build your coil and as conservatively as you run it, sometimes you will run into problems. Building and maintaining your Tesla coil is a learning experience! Usually a damaged coil can be repaired with just a handful of components available from any electronic parts supplier or our online store at http://onetesla.com.

Conceptually, the components on the coil fall into two categories:

1. Semiconductor devices, including:
   - FGA60N65SMD IGBTs
   - MUR460 diodes
   - UCC37321/2 Gate Drive ICs
   - 74HCT14 and 74HCT74
   - 1N4148 signal diodes
   - Optical receiver
   - Indicator LEDs
   - LM78xx voltage regulators

   These components are most likely to fail, and are the first suspects in case of a failure.
2. Passive devices (resistors, capacitors, transformers). These components are exceedingly unlikely to fail.

Electronics often fail in unpredictable ways, so we're not going to give you a step-by-step flowchart to follow. Instead, this step will comprise of some handy general tips that will help you fix your coil. Remember that you can always ask for help on the online forum at http://onetesla.com/forum.

- The IGBTs are by far the most failure-prone components. IGBT's often fail short - if you measure across pins 2 and 3 of the IGBT in diode test mode on a multimeter (positive lead on pin 2), it should read open. If not, the IGBT is damaged, and should be replaced. When replacing IGBT's, always replace both at the same time.
- A blown fuse will often be associated with damaged IGBT's or damaged MUR460 diodes. Test the MUR460's with a multimeter to confirm that they are not shorted.
- If the IGBT's and diodes are confirmed working, it is helpful to re-run steps 9 and 10. This will isolate any damaged semiconductors in the control circuitry.
- After replacing a failed bridge, do not immediately power test. Test the remaining systems as you would in a freshly built coil - often, a failed bridge leads to cascading failures in the logic circuitry; these failures could then damage the new bridge, causing an endless cycle of self-propagating failures.
- Passives almost never fail. The exception is the tank capacitor; extended runs have a nonzero chance of overheating it and damaging the internal structures. This often manifests itself as a reduction in capacitance and a subsequent loss of performance - if you see a sudden loss of performance, the tank capacitor might be suspect (however, other components are far more likely to fail first!)
- Very rarely, the low-side IGBT fails open. This will manifest itself as a sudden decrease in performance, often accompanied by an unstable spark. In this case, the fuse will not blow.

Thanks to all those who made oneTesla happen!

On Dec 25, 2012 we launched a Kickstarter campaign. Within a week, we reached 845% of our goal, selling 600 kits. We had so much demand that we had to stop adding more rewards, despite being only a quarter of the way into our campaign!
929 backers helped make oneTesla what it is.

David Gaipa, Peyton, Wendy Rowe, John Arrasjid, Jay Gilligan, Alfred DiBlasi, emele, marc weill, Stephan H. Wissel, jon c mortimer, Nigel Nathan, Mark Pearse, Steve Watson, Attila Králik, Griebenow Andreas, Georg Zmugg, Mick Fielding, CISR, Deakin University, Stefano Pento, Sean Smith, Gavin Maxwell, Sweet Pea, Bronte Roberts, Koori Wong, Allie Paterson, Andrew Relf, HangFire, Kjetil Lio, John Hutchinson, Nicolas Chauvin, Alan R. Parker, Noel Keating, Rémy MAGNAC, Vegard Stenhjem Hagen, Christopher Kay-Chalk, K1, Simon Holmes à Court, Jens Rosenfeld, Jon Russell, Philip Davidson, Riley Lu, Ponsonby Computer Club, Timbo Newbs, Grant Lindsay, Jim Moretti, Romanoff, DavidPapp.com, David Rioux, Jon Newlands, Nobody confuse, Aaron "ODIN" Jensen, Eddy Wilbers, Tesla Toni, Eric VanWyk, Timothy Roach, Jennifer Moores, Marcellino, Juan Quezada, Michael Una, Ed Schnurr, Chris Howard, T.A. Valdes, Erik Cubbage, Michael Dewberry, Kurt Kurasaki, Andrew LeTourneau, Carl Witty, Matthew S Phillips, Ludwig, Bradley Feder, Jeff Howbert, Jeff Coffin, Dave Rivera, Chuck Pint, Craig Allen, Len Shustek, Stephen Jacobs, Christopher Kelly, rudiemcska, Derek Graham, W Szydtowski, Tim Henning, Craig Calkins, Barry Grall, Gerhard Spangenberg, Mark Boenke, j4cbo, Bill Riess, Zane Faught, Emmanuel Hernandez, Corey Runge, Andy Miller, Rich Mills, Chip Crell, Walter Murphy, E. Horikawa, Master Norberto, Christine & JT, Ellert, Dan Stewart, Morgan Sandercock, Jose R Cordero Ladner (Joey), Bruce Odelberg, Samuel Lawrence Foundation, Mark Rowe, Dick Bell, Jason Sanphy, Paul Blackborow, Jeremy Hammer, John McCoy, Parts and Crafts, Sam Schneider, Mr. Borodiansky, Gregory, wooby6, Mitch "Fiddy" Fidler, Julian Ringel, Marcus, Leif, Jason DTB Hunter, Christian, Phil Davies, Noel B, TheOnlyZby, Marcel Smeets, Warry, Arcangelo Argento, Eirik Mikkelsen, Pål Øyvind Reichelt, Scherrer Beat, Vincent v/d Mark aka "Dayokun", John Harrison, Ahaxz, Kristian (Lord Tesla and ruler of middle earth), Ben Attfield, tommy t, Thomas Uddmar, Richard Proctor, Fidi & Dad, Dr Marc Eberhard, James Bailey, Peter Cramp, Donald D. Parker, Tristan Graham, Nicholas J Atkins, Gogar, Marc Gunter, Tom Callaghan, Jose Roberto Lopez, Chuck Fogh, Maarten Lens-FitzGerald, J Lane, Erwin Erkinger, Mark Walton, Tim Shaw, Cooper Chan, Bradley Clay, 2Lt Rhys Alasdair Hexter, Paul Marchant, Geoffrey Ward, Floris, Stéphane Boillon, Jens Wiechers, Admiral Aaron Ravensdale, Martin Decurtins, Andrew, Robert Barnbrook, mafro, Aaron Clauson, Ronald Frahm, elSombrereroLoco, Guenther Friesinger (paraflows), H. Simonis, Stuart Griffiths, Åpen sone for eksperimentell informatikk, Yukihisa Okada, James Heaver, John Tumbach, James Dantow, Cam Farnell, David Tragger - Hypocrite Productions Inc., Parable, WhiteStatic, Philip Chalk, Daniel Carmichael, N4EWT, Michael Casselli, Jon Jackson, Julia Takarada, Chris, Laura, and Quinn Smith, Brian Davis, Rick Rubio, GT & D$, William Griffith, Ken Purcell, Daniel Goldman, Alison Tisza, Brian Glogower, xthulu, T. Alva Edison, Mario P. Alexandre, Joseph Cortese, Randy Main, Rob Winters, Main Light Industries, Jim Tolley, TheXenocide, Gregg, Ken Sweeney, Richard Wolff, Jim Stratigos, Matt Shabet, Jareth Hein, Nathan Taube, Guy Marsden, Tim Moore, Nick Stock, Marcus Eubanks, Ryan Wenner, Douglas B. Fletcher, Wally Kissel, Peter Casper, Will Ernst, Eden Brandeis, Techniplex, The Stein family from Downers Grove, Barry Brian Wheeler, Dr. Richard Boulanger, Justin Capogna, John H Borleis III, Andrew Creighton, Jeremy Alliger, d. andruczyk, Eric R. Schroeder, Clement T Cole & Margaret E Marshall, Nathan Hangen, Andrew J. Welker, Clockwork Feathers, Richard Brull, Gary Ricard, Bhusan Gupta, Lee White, Peter W Piechocniski, Donby Mathieu, Michael Wacht, David Friedlander-Holm, Steven Collier, Alex 'Orion' Kiwerski, Jeremy Faircloth, The Jon Atwood, John Penny, Tox, Charles Alvis, Bradley C Howes, Ron Beck, Ward Shelley, Doug Hill, David Judd Dove, Dan Mozgai, Steve Fish, Matthew Shurboff, James Fulton, Tom Zelickman, Aaron Rosenthal, Raygun Ballet, John Lewis, Tom McKeone, Freeside Atlanta, David R. Tabb, Michael D. Kellner, Tyler Madison, Caleb Cotter, Ben THomas, Steve Goldstein, Marco Alpert, Dave Hall, Paul Camann ("Krellmusician"), Kerry Hammil, WireKAT, Tadei, Christopher Strider Cook, Steve Mueller, Dr. Sam N. Jaxsam, Artemus Jules Rodin, Handy Gelbard, David, panicopticon, David F. Bishop, Peter Dyer, Duane Zobrist, @thebrianmanley, Ali Hassan, Enrico Ros, Rafael, Matt Wasserman, Dimitri Diakopoulos, lint, Dewey Electronics Corp, Rustcycle, Steven R. 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