

STACCATO QCW DRSSTC: FULL INSTRUCTIONS

You will need the following parts (links included):

- One 12VAC transformer (14VAC is also acceptable): [Mouser](#) / [Digikey](#)
- Two high-power IGBTs (FGA60N65SMD): [Mouser](#) / [Digikey](#)
- Two 2N2222 NPN transistors: [Mouser](#) / [Digikey](#)
- One UCC37322 gate driver IC: [Mouser](#) / [Digikey](#)
- One UCC37321 gate driver IC: [Mouser](#) / [Digikey](#)
- One 74HC14 hex inverter Schmitt trigger: [Mouser](#) / [Digikey](#)
- One 74HCT74N dual flip-flop: [Mouser](#) / [Digikey](#)
- Two 555 timers (NE555): [Mouser](#) / [Digikey](#)
- One 7812 12V linear voltage regulator: [Mouser](#) / [Digikey](#)
- One 7805 5V linear voltage regulator: [Mouser](#) / [Digikey](#)
- Five 1N4148 diodes: [Mouser](#) / [Digikey](#)
- Two bridge rectifiers (over 500V and 15A): [Mouser](#) / [Digikey](#)
- One 220uF electrolytic capacitor (must have 3.5mm lead spacing to fit PCB and should be 25V or greater): [Mouser](#) / [Digikey](#)
- Two 470uF electrolytic capacitors (must have 5mm lead spacing to fit PCB and should be 25V or greater): [Mouser](#) / [Digikey](#)
- Three 100K resistors: [Mouser](#) / [Digikey](#)
- Seven 10K resistors: [Mouser](#) / [Digikey](#)
- Two 5.6 ohm resistors (2W-rated): [Mouser](#) / [Digikey](#)
- One 51K resistor: [Mouser](#) / [Digikey](#)
- One 2K resistor: [Mouser](#) / [Digikey](#)
- Five 1K resistors: [Mouser](#) / [Digikey](#)
- One 20K potentiometer: [Mouser](#) / [Digikey](#)
- One 100K potentiometer: [Mouser](#) / [Digikey](#)
- Four 1uF film or ceramic capacitors: [Mouser](#) / [Digikey](#)
- Five 0.1uF film or ceramic capacitor: [Mouser](#) / [Digikey](#)
- One 0.33uF film or ceramic capacitor: [Mouser](#) / [Digikey](#)
- One 0.01uF film or ceramic capacitor: [Mouser](#) / [Digikey](#)
- One 10uF film or ceramic capacitor: [Mouser](#) / [Digikey](#)

- Two 0.68uF film capacitors (must have lead spacing between 10mm and 20mm, voltage over 450VDC): [Mouser](#) / [Digikey](#)
- One toroidal ferrite for the GDT: [Mouser](#) / [Digikey](#)
- Two TO-247 compatible heatsinks. For my PCB: [Mouser](#) / [Digikey](#)
- Somewhat optional: Two ~400V 1.5kW bidirectional TVS diodes to protect the IGBTs (I used two 1.5KE220CA's in series for each IGBT, but a single 1.5KE400CA or 1.5KE440CA should work equivalently): [Mouser](#) / [Digikey](#)
- Optional: two DIP-14 IC sockets: [Mouser](#) / [Digikey](#)
- Optional: four DIP-8 IC sockets: [Mouser](#) / [Digikey](#)
- Optional: two terminal blocks for easy wire connection: [Mouser](#) / [Digikey](#)

Total cost: \$65 (USD) + shipping

Other materials needed:

- Some 1kV or higher film capacitors to set up the MMC bank (I recommend buying a set of ten 0.01uF capacitors)
- Wire (including magnet wire for the secondary coil), pipe (for secondary coil form), and miscellaneous hardware parts
- Soldering iron and solder
- Either the official PCB (details below) or breadboard
- Optional but recommended: a handheld multimeter, oscilloscope, and Variac

Step 1: Order the materials

WARNING: DO NOT PURCHASE IMPORTANT COMPONENTS LIKE IGBT'S OR DRIVER IC'S FROM GENERAL SHOPPING WEBSITES LIKE AMAZON OR EBAY! MANY PEOPLE HAVE PURCHASED CIRCUIT COMPONENTS FROM SUCH SITES AND FOUND THEY WERE TOTALLY USELESS. DON'T WASTE YOUR MONEY: BUY SEMICONDUCTORS FROM ESTABLISHED SITES LIKE MOUSER OR DIGIKEY!

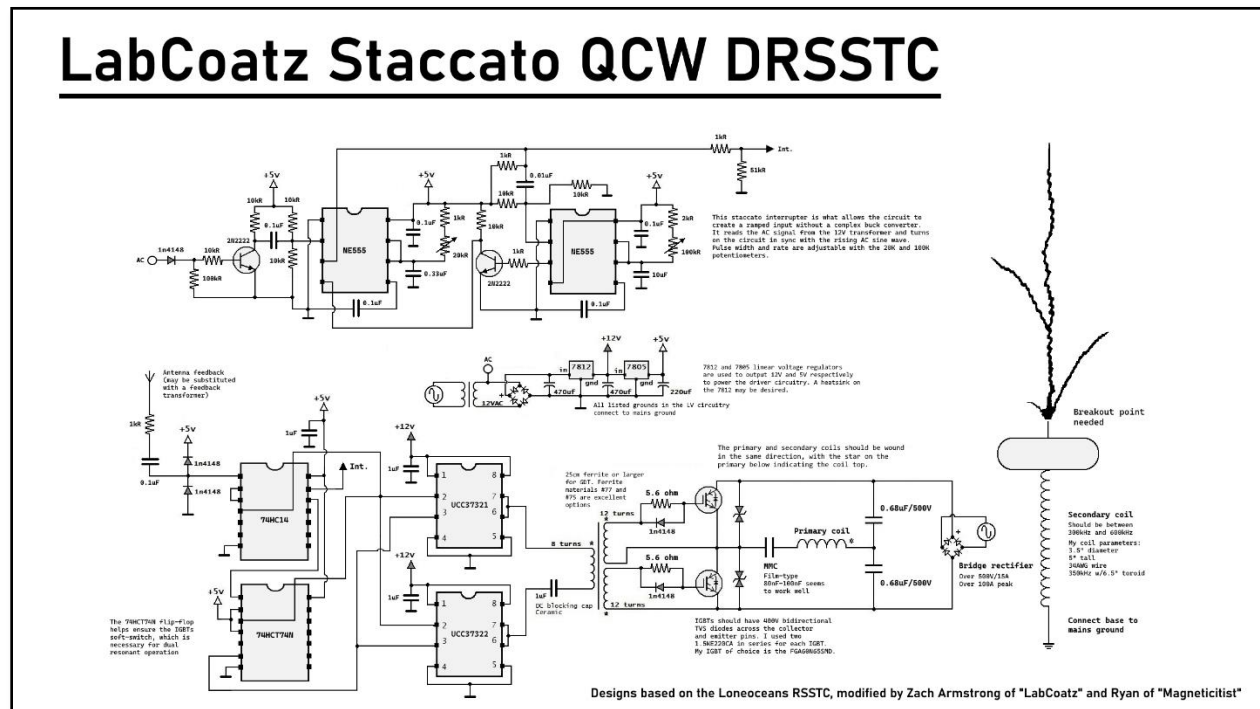
Listed above is every part needed to build a high-performance staccato QCW DRSSTC. Most of the links should take you to a webpage (either on Mouser.com or Digikey.com) with a variety of options for a given component. Feel free to pick whichever parts are available or fit your budget best, since I've narrowed down the options in each link to ones that are suitable for this circuit. Please note, however, that most of these part values are not super critical, and substitutions can be easily made (see below for more details). Additionally, if you possess parts of similar values, feel free to save money and use your parts instead! Owning a 12VAC transformer of your own could save you an extra \$10!

It is also worth noting that having a few extra components on hand isn't a bad idea. The main components to worry about include the IGBTs, 400V TVS diodes, the UCC gate drivers, the 74HC14, and the high voltage supply's bridge rectifier. The IGBTs are the most likely item to break, followed by the bridge rectifier (the rectifier typically dies from the overcurrent caused by IGBT failure). Minor screw-ups can also lead to the IC chips blowing, and they are dirt cheap, so it's smart to buy an extra or two of each.

After you've settled on which parts to order, it's time to start thinking about what you'll mount them on. I personally recommend the official LabCoatz PCB, which I designed specifically for this circuit, but standard breadboard is also an option. The PCB should only cost a few dollars to buy, it is thoroughly labeled, and highly user-friendly. For the remainder of this instructional, I will be primarily talking about constructing the circuit on this PCB.

To order the PCB, simply take the "Staccato QCW PCB" .zip file downloaded with these instructions and submit it to a PCB manufacturing website like JLCPCB.com. This .zip file is technically referred to as a gerber file. If you want, you can change how many PCBs you order and what color they are. The minimum order size with JLCPCB is 5 copies, which costs around \$10 (plus shipping) for this PCB.

Step 2: The Circuit, How it Works, and QCW



This is the circuit we will be building: essentially, it is the Loneoceans RSSTC (SSTC 3) with a few notable modifications. For one, the circuit has been simplified somewhat, so it lacks unnecessary components like the UVLO circuit and a few filtering capacitors. Additionally, the old 0.2uF capacitor in the staccato interrupter has been replaced with a 0.33uF capacitor, which allows the pulse width to be longer (special thanks to Ryan of the YouTube channel *Magneticitist* for this design idea). This results in noticeably quieter and thicker sparks, since the ramp-down period of the mains sinewave is now included. Finally, the pièce de résistance: since this circuit features a flip-flop (the 74HCT74N), it is capable of handling dual-resonant operation! Loneoceans never truly explored this possibility in his writeup, but if you wire a resonant-size capacitor in series with the primary coil, the spark size increases substantially! More about this later...

How it works

The circuit accepts a feedback signal either from antenna feedback or from a feedback winding (“ANT.” and “FEED.” on the PCB, use whichever method you prefer. I recommend antenna feedback for beginners). This signal is then filtered, limited, and cleaned up by a resistor, capacitor, and diode clipping array. After this, the signal passes through a 74HC14 Schmitt trigger, which converts the somewhat sloppy signal into a more functional squarewave that matches the resonant frequency. This squarewave signal is then sent to a pair of UCC gate driver ICs (one UCC37322 and one UCC37321), which amplify the signal. These gate driver chip feature enable pins, which basically act like the on-and-off switch. If we feed the interrupter’s signal to the enable pins, we can control the Tesla coil’s pulse width and frequency (BPS).

The resulting interrupted signal from our gate driver ICs is finally sent to a small device known as a gate drive transformer, or GDT. If properly assembled, the GDT converts the single 12V signal from our driver into two 18 volts signals, which are optimal for switching our transistors. By phasing the GDT correctly, the transistors will switch the DC voltage from our power supply across the primary coil at the resonant frequency.

Dual resonance and the flip-flop

Up until this point, I’ve basically described the construction of a classic SSTC. So, what sets this build apart as a DRSSTC? There are actually a few things: first, the resonant capacitor. The main drawback of solid-state Tesla coils like the LabCoatz SSTC 2.0 is that their current is limited by the primary circuit. The primary coil has a certain inductance, and that inductance causes a kind of resistance specific to AC signals, known as reactance. Fortunately, there is a trick to eliminate this unwanted reactance, and that is to add a capacitor of a specific size in series with the inductor. If the capacitor-inductor combination has a resonant frequency matching the frequency being applied to it, the reactances cancel, leaving only the very small resistance of the wire itself. This is, in fact, the main principle behind dual resonance: the goal is to have the primary circuit tuned so that its reactance is as close to zero as practical, which allows the resonant signal produced by the solid state circuitry to flow with little impedance at very high currents. Higher primary currents result in higher secondary voltages, and therefore longer sparks.

Unfortunately, making a DRSSTC isn't as simple as throwing a resonant-size capacitor into any old SSTC. If you saw the tutorial for the LabCoatz SSTC 2.0, you might remember that I had to avoid primary impedances below 6 ohms to keep the IGBTs alive. So how do DRSSTCs get away with much lower impedance values? As it turns out, the secret is in the switching: for a DRSSTC to function properly without failing, it is necessary to soft-switch the transistors. This is where the flip-flop comes into play: essentially, it prevents the interrupter from shutting off your transistors while current is flowing, which could kill them if you're running in dual resonance.

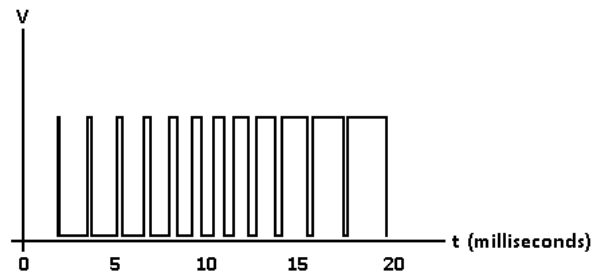
For best results with a flip-flop, primary feedback is recommended over secondary or antenna feedback. If you choose to use primary feedback though, you'll need your primary circuit to be tuned fairly precisely, otherwise your coil will behave rather poorly. When I built this circuit, I chose to stick with antenna feedback, just because I'm used to it and it's easy to set up. Using secondary feedback does make running in dual resonance somewhat more dangerous to the transistors though, since the secondary signal isn't precisely synced with the primary switching, which prevents the flip-flop from doing its job perfectly. If you want to try dual resonance with secondary feedback like I did, I recommend detuning your primary circuit somewhat. This will allow the impedance to be low, but not low enough to cause significant overcurrent issues and harmful voltage spikes.

To further protect the IGBT transistors, I also recommend soldering 400V TVS diodes across the collector and emitter pins. Even with a flip-flop and some detuning, high voltage spikes are almost inevitable in a DRSSTC, so it is best to be prepared! The circuit will run fine without TVS diodes, but the IGBTs may die sooner than desired. Unfortunately, the PCB didn't have enough room to fit connection points for the TVS diodes, so they must be soldered directly to the IGBT pins.

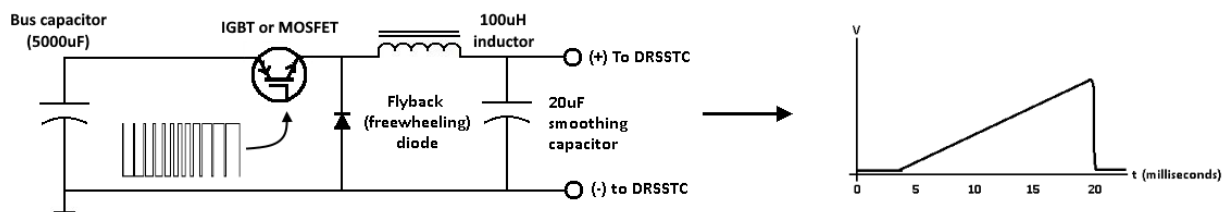
Staccato and QCW: The secret to BIGGG SPARKS!

Let's face it: you didn't download these instructions to build any old SSTC or DRSSTC. You want to learn the secrets of QCW (Quasi-Continuous Waveform) so that you too can transcend the mortal realm of Tesla coiling and produce the longest sparks possible! Well, you've come to the right place! But before I fully divulge how this circuit achieves its ridiculous spark sizes so easily, let's take a moment to look at how traditional QCW coils do it...

The secret to QCW coils is voltage ramping: QCW coils are just ordinary DRSSTCs that have their input voltage ramped up over a period of 10-20 milliseconds. In a "true" QCW coil, this is accomplished with PWM: a programmable circuit such as an Arduino creates a moderate-frequency PWM signal (15-30kHz) that increases its pulse width from zero to 100% over a period of a few tens of milliseconds:



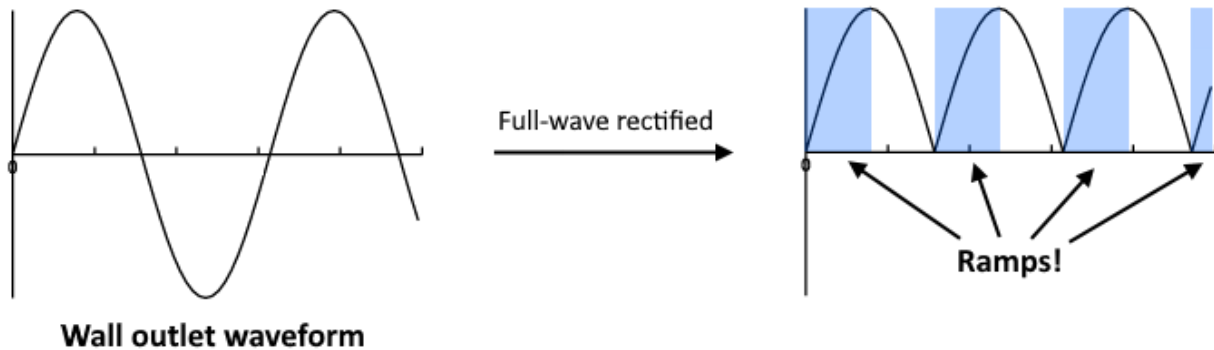
This signal controls an IGBT or MOSFET in series with the power supply (which is usually a very large bus capacitor). The transistor chops up the power supply current and passes it through a large inductor (about 100uH, or slightly more) to smooth out the 30kHz noise. A smoothing capacitor (about 20uF) helps keep the voltage steady, and voila! A nice, clean voltage ramp!



People who have experience with electronics may recognize this topology as nothing more than a fancy buck converter. Of course, to drive the transistor properly, some circuitry is usually used in addition to the programmable PWM generator (check out the [Loneoceans website](#) for some awesome [QCW designs](#) and info). Overall, the complexity and cost of such setups tends to limit QCW to only the more experienced individuals and coilers.

Of course, why waste precious time and money trying to set up a “true” QCW when you can just use the voltage ramps that are already available to you?

QCW was actually developed from an earlier technology used by the vacuum tube coil community: staccato interruption. A staccato interrupter is one that reads the AC signal coming from your wall socket and turns the coil on only when the rectified voltage is ramping up:



Since the electricity from standard wall outlets runs at 50-60Hz, you can easily get 4-5 milliseconds of ramp-up time, which is plenty to produce some wicked sparks! Additionally, each hump of the rectified sine wave also comes with a ramp-down time, which will allow the sparks to be quieter and thicker if utilized.

Step 3: Build Tips and Part Substitution

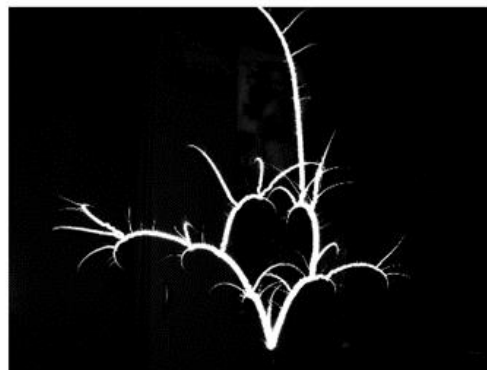
When building a QCW-type Tesla coil, there are a few main thing you can do to get the most from your design. Below is a generalized list of what to do and what not to do:

First, if you are building this circuit without the custom PCB, try to keep the inter-component connections as short as possible to reduce interference. Also, be sure to ground the negative rail of the low voltage circuitry: this is pretty important!

Next, try to make sure the resonant frequency is above 300kHz. Below 300kHz, the sparks tend to become more chaotic and less straight. In order to get the longest sparks possible, we want most of the coil energy directed into a single long spark as opposed to several branches or odd formations. If you like more branched and messy arcs, feel free to experiment below 300kHz, but if you're going for distance, it's best to stay above that range. It's also best to stay below 600kHz. Above this point, the IGBTs will be much more stressed, and the sparks will become more curvy instead of straight. See the pictures below to observe what I mean:



<300kHz



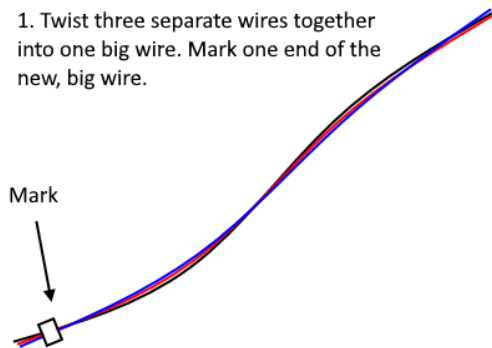
>600kHz

Finally, try to use more primary turns, less capacitance, and tighter coupling. In a traditional DRSSTC, the opposite is usually preferred, but in a QCW coil, these traits are quite desirable. This might have something to do with QCW's close relation to vacuum tube Tesla coils, which historically have followed similar design paths.

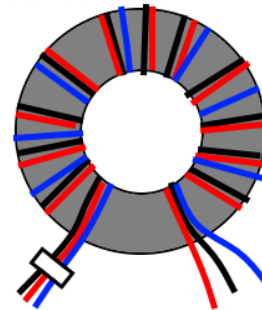
Gate drive transformer (GDT) winding:

For the gate drive transformer, you'll want to wrap two twelve-turn coils and one eight turn coil onto a suitable ferrite core (more details about the core material on page 11). Iron cores are almost non-functional at these high frequencies, so I advise against using them. As you can see in the circuit schematic, the two twelve turn coils are connected to the transistors with "opposing polarity" (they are 180 degrees out-of-phase). This is necessary for the transistors to switch correctly. If you mess up the GDT phasing, the transistors will almost certainly die, so **PAY ATTENTION TO HOW YOU WIND THEM!** My PCB takes care of the phasing for you, and has marks to help indicate phasing. If you have a hard time understanding this, all you have to do is:

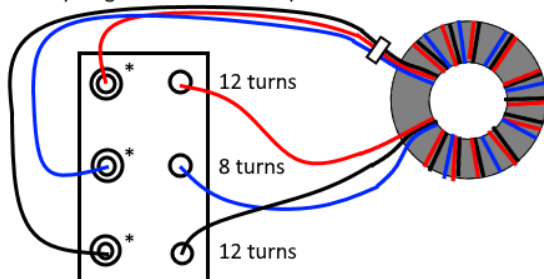
1. Twist three separate wires together into one big wire. Mark one end of the new, big wire.



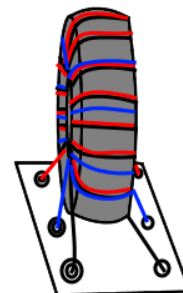
2. Separate one of the wires. Wrap 12 turns with the two wires that are still together and then wrap eight turns over the twelve with the last wire. All wires should be wrapped in the same direction



3. Now, simply connect all the wires! All the wires on the marked side go to the PCB holes with white dots (or the ones without white dots. All that matters is that they all go to the same side).



4. Secure everything and make it look good!



Part substitution and necessary parameters:

Perhaps one of the best parts about this circuit is its ability to handle changes and customization. As mentioned before, a number of its parts don't need to be super exact, and can be swapped with similar parts if need be. This section is your guide to customizing the designs and making them your own.

These are the general requirements for each circuit component. If you follow what I say here, you should be good to go:

555 timer, 74HC14, 74HCT74N, UCC37322, and UCC37321: as far as I can tell, there are no suitable replacements for these parts. If you are more experienced in electronics designs, feel free to look around though! As a sidenote, these parts are usually available under slightly different names (for example, the UCC37322P or the SN74HC14AN).

Linear voltage regulators (7812 and 7805): most 12V and 5V positive linear voltage regulators that can output over 1A will work

1N4148 diodes: most fast-recovery signal diodes will work

Gate drive transformer (this is mostly regarding the ferrite itself):

- Initial permeability (μ): over 2000
- Diameter: around 20-30cm, it all depends on what you're comfortable winding. Larger toroids are typically easier!
- Recommended materials: 77, 75, and N87 are best, but 43 is also usable
- Wire: most thin, insulated wire. **DON'T USE MAGNET WIRE!** Magnet wire will simply arc over, despite the low voltages. I've tried with the "proper" type of enameled magnet wire, and everything sparked and shorted through the core.

Resistors:

- Power rating: most can be 1/4W (maybe less). The 5.6 ohm resistors should be around 2 watts though, since they'll be handling more power.
- Resistance: try to stay within a few kilohms of the recommended values, except for the 5.6 ohm resistors.

Capacitors:

- **Voltage:** should be above 25V for the low voltage areas. For the inverter capacitors in the power section near the transistors, the voltage must be even higher: over 450V is needed, and over 500V is recommended. The resonant capacitor should also be fairly high-voltage (over 1kV recommended).
- **Capacitance:** For the small electrolytic capacitors (used in the low voltage regulator section), any high capacitance (over 200uF) should work. For the small-value film and ceramic capacitors it's best to stay within range of the ratings given. Variation by a few tens of percent is likely acceptable though. For the inverter capacitors, it's best to stay in the range of 0.5 – 2uF. For the resonant capacitor, it really depends on your coil setup (I had good luck with 0.08 – 0.1uF).

Bridge rectifiers:

- **Reverse voltage:** over 50V for the low voltage one (since it's only handling around 25V max from the transformer) and around 1000V for the high voltage one.
- **Current:** 4A or more for the low voltage one and 15A or more for the high voltage one. Peak current rating for the high voltage one should be over 100A.
- **Pro tip:** since bridge rectifiers are pretty cheap, just buy two of the high power ones! That actually what I suggest and linked to in the parts list I provided.

2N2222 transistors: can be swapped with most small NPN transistors

Power transistors:

- **Type:** IGBT is best, but N-channel MOSFETs can also work (although performance might be worse). Should have an internal diode.
- **Power:** over 250W (over 400W if you plan to operate at higher BPS/duty)
- **Voltage:** 500V or more
- **Current:** less important, but I recommend over 20A
- **Peak current:** most important, should be over 60A

Potentiometers: power above 1/5W, keep resistance close to the recommended values

Step 4: Troubleshooting and Operation

While it's totally possible for you to wire this circuit up and get it running well on the first try, you'll more than likely experience some bumps. Fortunately, they are usually quite manageable and can be overcome with minimal effort. Here are a few of my best tips for troubleshooting this circuit:

If there is no output:

- First, check all of your connections. I've been totally lost on several occasions, and the culprit turned out to just be a bad connection
- Try bringing the feedback antenna closer to the coil. I've found my coil works best when the antenna is within a foot (30cm) or so of the secondary coil
- If tons of current is being pulled, it's possible that you wired your GDT wrong and killed your IGBTs. You may have killed them in other ways, but this is the most common scenario. It's also possible that there is a random, accidental short somewhere in the circuit

If the output is very weak:

- Try swapping the primary coil connections. This almost always solves the issue
- The antenna might not be close enough, try moving it closer
- Check the secondary coil's ground connection. If a coil isn't properly grounded, the voltage at the top could be lower with respect to ground, and therefore yield weaker output
- Your coupling could be very low or your primary impedance could be extremely high. Try running some calculations and see if anything jumps out as strange or off

If you have "bad" output (unstable BPS or pulse width, weird noises, etc.)

- For some reason, the primary setup seems to affect this. Try lowering the coupling, increasing the number of primary turns and/or the resonant capacitor size.
- Interference may be the culprit. Make sure your PCB's ground connection is good, or, if you're building it without the PCB, make sure the low voltage negative/neutral is grounded. Also, try shielding the circuit with a layer of grounded metal or metal foil, this really helps!

Unexplainable IGBT failure:

- It's possible that you wired your GDT wrong and killed your IGBTs. Again, this is a common mistake. Be sure to check the phasing (the PCB has dots indicating the proper phase connection points)!
- The GDT might be wound poorly. Jay from Plasma Channel had this issue when he build my last SSTC: <https://youtu.be/wWleUsnqkRk?t=466>. Teslaundmehr has an excellent tutorial on GDT winding and design, if you have trouble: <https://youtu.be/ahb5woa-AW8>
- The primary might have too little inductance. Try adding more turns.
- The primary capacitor might have too little capacitance. Too much is fine (the circuit just behaves like an SSTC), but too little tends to cause problems. It's best to have a capacitor slightly large-than-resonant size.
- Shielding or poor grounding might be an issue. Makes sure the ground connections are secure!
- It's possible that something is simply misconnected. Go over your work and make sure everything is in proper working order.

Crank it up!

Once the design, assembly, and troubleshooting are out of the way, it's time to get your taste of QCW! When built properly, this circuit can easily produce sparks larger than the secondary coil itself, even without a resonant capacitor in series with the primary! Here are some stats from my unit with a 5-inch tall secondary (350kHz with a 6.5" toroidal topload):

- 120V input, no resonant capacitor: 8" sparks
- 240V input, no resonant capacitor: 12" sparks
- 120V input, dual resonant: 12" sparks
- 240V input, dual resonant: 20" sparks
- 240V input, dual resonant, no topload: 17" sparks

With 20" sparks from a 5" coil, this represents a monumental achievement in the Tesla coil world: the sparks are **FOUR TIMES LARGER THAN THE COIL MAKING THEM!** This kind of achievement is almost impossible to reach with most dual resonant, spark gap, or vacuum tube coils! Plus, this circuit also holds a whole host of other benefits:

- The sparks are extremely quiet, making it perfect for indoor operation
- Spark size is adjustable with pulse width (although shorter pulse widths tend to be louder)
- The circuit doesn't use an expensive/bulky bus capacitor or thermistor
- Runs best with small, higher frequency coils, which are easier to make
- Small size, highly portable!

Not getting the spark lengths you hoped for? Here are some pro tips for getting the largest sparks possible from your design:

- Fiddle with the coupling. Intercoil arcing is not as common with this coil type, so feel free to experiment!
- Try using fewer turns on the primary coil. I found that it's best to stay above five turns, however, otherwise the driver begins to act up.
- Play with different topload sizes!
- If you live in a 110-120V region, consider buying a 240V transformer to get the most out of your circuit. I used an 800W unit which can be purchased on Amazon.com for around \$50.