SLAYER EXCITERS & TESLA COILS everything you need to know to get started!
by suchb on March 19, 2015

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Intro: SLAYER EXCITERS & TESLA COILS everything you need to know to get started!

Hello Instructables!

I began writing an explanation on tesla coils and slayer circuits and how they operate in a comment on YouTube, and somehow it turned into several hundred lines of deep explanation of the theory behind tesla coils and slayer circuits.

I decided I spent way too much effort writing this to not post somewhere other than a YouTube comment, so here it is.

(Make sure you watch at least the first lightbulb video so you know what I mean when I am referring to "my project")

Keep in mind, this is all theory and less application. Application will be covered in the video I eventually make such as how to wind the coil, which caps to buy, how to do calculations etc...

Also, if you like this, please subscribe to my YouTube channel. It's brand new. I want to get the ball rolling quickly on my subscriber count and popularity so that it will be worth it for me to spend more time making tutorial videos for you guys. Also if you have any questions, I would be happy to answer them, but please post them in the comments on YouTube rather than here on instructables.

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THIS COMMENT EXPLAINS EVERYTHING YOU WILL NEED TO KNOW ABOUT SLAYER CIRCUITS AND TESLA COILS!

written by *suchbuild*

(If you don't care about any tesla coil theory and just want slayer circuit information scroll down past the line. Troubleshooting tips are at the bottom.)

I spent a long time writing this. I wish could have had an instructional like this when I was first learning about Tesla Coils. I hope it saves people time and helps clear things up. Let me know if it does!

In case this comment is copied and posted somewhere else, it was originally written explaining tesla coil and slayer circuit theory for my device in this video, and can be found here:

EXPLAINING RESONANT FREQUENCY:

The reason the Slayer Circuit is so popular, especially with people who are new to electronics, is because of how simple it is. Not only does it require minimal electronic components (only a transistor, resistor, and LED!), but it also doesn't require any "tuning". All other tesla coils need to be "tuned" to their "resonant frequency". I'll explain: the secondary coil (the coil of very thin windings if magnet wire with many many turns usually around a plastic tube) has a natural frequency at which it likes to "oscillate" which is determined by factors such as dimension of the coil, # of turns of wire, and capacitance between both end points of the coil. This is similar to how a pendulum with a certain length and weight will always want to swing back and forth at the same frequency, which is determined by the length and weight. A lighter / shorter pendulum will want to swing back and forth at a faster rate, and a longer and heavier pendulum will swing slower. This is called the pendulums "resonant frequency" and is actually used to keep time in many old clocks because as long as the dimensions and weight of the pendulum are right, it will always swing at precisely at it's resonant frequency. Another way to take advantage of a pendulum's resonant frequency is by applying a force to swing the pendulum at intervals matching the resonant frequency.

When you push someone on a swing, you don't push them at random times throughout the swinging motion. You time your pushes perfectly with the forward stroke of the swing. By doing this, you are applying "constructive" forces, which like waves, add to each other because they are in phase. If you were to apply the force at the wrong time, when the swing is coming back towards you, you would be causing destructive forces and whoever you are swinging is probably going to get pissed. Applying a force matched to a system's resonant frequency is very efficient. The combination of these small, but timed forces can add up to have an enormous effect on a larger system. It would take quite a lot of effort to lift whoever you are swinging above your head. However several small, light pushes of the swing over time makes it easy to have the swing high above your head. We take advantage of this quite a bit in society, whether it be car engines, jack hammers, a tetherball game, or radios. An old radio works by turning an adjustable capacitor connected to a coil of wire. Capacitance, like I stated before, changes the resonant frequency of a coil of wire. You can think of the radio station as being like the person pushing the swing, and the coil as being the swing. Changing the capacitance with the tuning dial could be like changing the weight of the swing (and the frequency it resonates at). When you have the knob set to a certain spot, only 1 radio station will have that perfect frequency with the perfect timing that causes constructive forces on the coil. In this case rather than a physical push, the force is applied through magnetism from quite a distance. But the efficiency of resonance is so good, that even at such a huge distance, it is enough to make the electrons in the coil begin oscillating back and forth as they are "pushed" by the oscillating magnetic field that the radio station is generating miles away. Electrons moving through a coil is electricity, which is then channelled through the end of the coil, through some sort of amplification circuit out to a speaker.

http://oldengine.org/members/cprops/d9.jpg

Here is a picture of an old radio.

From front to back we have the amplifier transformer, two vacuum tube amplifiers (now we use transistors), the coil, and the two things in the back are adjustable capacitors. Changing the amount that the multiple plates overlap changes the capacitance, and thus resonant frequency of the coil. Changing resonant frequency of the coil makes it only receive constructive forces from a certain frequency i.e. Radio channel.

TESLA COIL PRINCIPLES:

Typical schematic: http://upload.wikimedia.org/wikipedia/commons/thum...

Great, so how does this tie in with a tesla coil? A tesla coil is one of the most famous devices for taking advantage of resonant frequency efficiency. There are many different methods to powering them, but the way that the actual coils interact is always the same. Around every secondary coil (the long skinny one with hundreds or thousands of turns) is the primary coil. It is always very few turns of much thicker wire. This is effectively the "radio station" from the previous example. However the observant person might note that the primary is a little closer to the secondary than a radio station is to a radio. (If you noticed that, well done. pats on the back). As stated before, the secondary coil will have a very specific frequency at which it will resonate, determined by the dimensions of the coil windings, and the amount of coil turns, and the capacitance. The only way to change the resonant frequency of the secondary once it has been build is to change the capacitance buy putting a different size or shape metal object on the top of the coil. This is why you generally want to "tune" the frequency of the primary to match the secondary rather than the other way around. More on that in a moment...One thing to note, is that resonating frequencies of coils are very fast. Therefore, high frequency must be generated in the primary to match the resonant frequency of the secondary. Many tesla coils use different methods of doing this. Solid state tesla coils use circuits with non moving parts i.e. variations of high power transistors to rapidly change the direction of the electricity flowing through the primary. (a transistor is essentially a switch that can be turned on and off very fast and precisely without any actual moving parts.) Spark gap tesla coils (see schematic at the top) use capacitors in parallel with an air gap between to electrodes. The change in the capacitor builds up (much like a river filling up a dam with water) until the charge difference between the two electrodes is enough to allow a spark to occur. As soon as the spark occurs the air around the spark turns from oxygen O2 to ozone O3 (which is much more conductive). More Ozone, allows for more spark, which makes more Ozone etc... this happens in a split second however and creates a massive surge of electricity to flow out of the capacitor and from one electrode to another (much like a small hole in a dam getting pushed larger by the water until the whole dam collapses and a massive amount of water surges down the river.) The surge of electricity is forced to go around the primary coil on it's way to the negative terminal. This massive instant surge of electricity through the primary creates a massive...
magnetic field around the secondary and pushes up on the electrons in the secondary coil. The more they rise up the coil, the more they want to go the opposite way much like stretching a spring. This is because with all the electrons being pushed up the coil, the like charges crammed into the topload repel eachother, making them want to shoot back down the coil. Mean while, the surge of electricity flowing through the primary has finished, which collapses the upward pushing magnetic field on the electrons in the secondary. The electrons then shoot back down the coil. Naturally, they will overshoot their equilibrium state much like how if you stretched a spring or pull on a pendulum and let go, it would not stop in the middle, but would overshoot and go to far the other way, and then begin coming back towards you again. The electrons overshoot down the coil, into the ground, making the top of the coil positively charged due to a lack of electrons which then pulls the electrons back up the coil again. But, in the meantime, the capacitor in the primary was charging up, and if we have timed our primary circuit right, the spark, and massive surge through the primary creating the large upward pushing magnetic field should happen just as the electrons are already flowing back up the coil, giving it that extra "boost". This whole process happens over and over again, with the electrons being pushed further out of equilibrium each time, just like how each swing push makes the swing go a little higher. Eventually the system will reach a point where it wont be able to push any further and will stay at that amplitude as long as the push happens with each stroke. Just like how no matter how hard you push, you will only ever be able to get the swing to a certain height. However for most tesla coils, especially larger and more powerful ones, this is enough to send the electrons shooting through the air in massive magnetic fields and bolts of lightning!

It appears as though the lightning output is a constant outward stream, however this is not the case, as I just described. The lightning bolt is only produced when the electrons are on the up stroke and shooting out of the top of the coil. For the other half of the time, they are shooting into the ground connection (which you obviously don't see). The lightning bolts only seem like they are constantly shooting out the top because the cycle is happening far too fast for our eyes to detect (along with persistence of vision. look it up). The reason the bolt generally returns to the shape as last time each time it shoots back up is because the lightning bolts (as with the spark gap) are turning the air into ozone where ever the bolt happens to be. The cycle happens so fast that all the air that has been converted to ozone doesn't have any time to change its position between bolts, kind of like an ozone gas statue in the shape of a lightning bolt. so as the electrons begin shooting out of the top again, they follow along the same conduction ozone path that was shaped by the bolt before it. If you were to disconnect a tesla coil from the ground, and turn it horizontally, and move the primary from the bottom of the secondary to the middle of the secondary, and slow time down enough, you would see the lighting shooting out of both ends of the coil alternatively, back and forth as they oscillate out one end of the coil and the other. This unique design is called a "di-polar" Tesla Coil. I actually happen to have built the worlds smallest Bi-Polar tesla coil which you can see here:

So you see, a tesla coil is really just a big swing set!

TUNING A TESLA COIL:

The most crucial part of a tesla coil is matching the resonant frequency of the primary to the secondary. You can make calculations to estimate what the resonant frequency of the secondary will be based on the factors I mentioned before, and try to match your timing as best you can. But usually, math can only give a rough estimate and you need to "tune" the primary to the secondary to hit that sweet spot. Changing the frequency of your primary coil to match your secondary coil is much easier than trying to change the secondary because there are actually a couple ways to change the primary frequency quite easily. Changing the capacitor value in the primary will change the frequency, however that is not really something you can easily vary and fine tune. Fortunately you can change the distance between the two spark gap electrodes. A larger distance will mean that the capacitor will take longer to charge up enough for a spark to bridge the bigger air gap. This will lower your frequency, and obviously making a smaller gap will increase it. However while small changes are ok, you would begin to loose a lot of efficiency if the gap was too big because eventually the spark will begin to struggle making a quick connection between the two electrodes as that bridge becomes less of an obvious route. You'll end up loosing quite a bit of charge (called carona losses) as some of the ions escape into the air in different directions trying their own paths to the ground, rather than instantly being attracted to the other electrode like before. On the flip side, too small of a gap will not be as efficient because the capacitor wont have the chance to charge up to its full potential before the spark event happens. Not to mention all the ozone from the previous spark will make the air more conductive for the next spark, causing it to fire even earlier. This becomes more of a problem the smaller spark gap you have, but no matter the size it is always best to have a fan or a vacuum moving the ozone away from the electrodes. This is called "quenching" the gap.

And finally, the best and most fine-tuneable way to tune the primary is by changing the amount of turns. This is usually pretty easy and manageable since there aren't that many turns to deal with. Many larger tesla coils (such as mine) feature a flat spiral type coil out of bare copper tubing.

This way you can force the spark event happen each time the electrodes pass by each other, and effectively control the tuning of the coil on the fly by changing the speed of the motor. I personally have never seen the point of these over a stationary gap, as it just adds another level of complexity and potential failure to the system. As long as you get your tuning right, a stationary spark gap can be just as good as a rotary one.

BACK TO SLAYERS...........

BENEFITS OF SLAYER:

So if you bothered reading my above overview of resonance and tuning a tesla coil, you'll see how important (and tricky!) getting the tuning right can be. If you didn't... well that was basically the sparknotes version of it...

I didn't even go into how to calculate all your primary components before hand, so that they will generally already be close to resonant with the secondary and only need minimal tuning. I will definitely be going over that in my tutorial video however, because pre-designing and calculations for the coil is crucial for getting any output out of a coil.

This is why the Slayer Circuit is so popular as a first tesla coil type project, because the circuit tunes and resonates to itself! In short, there is a small parasitic capacitance between the top of the coil and ground which allows oscillation to occur in the circuit, but I'll dive into more detail:

EXPLAINING THE SLAYER CIRCUIT:

Follow along with this circuit as I explain whats going on:

First off, pretend the switch in the diagram is always closed or not there. It obviously serves no purpose to the function of the circuit other than to manually turn it on or off. Also, for those who don't know much about transistors (in this case a 2222A, however any NPN transistor will work in the same way), it essentially acts like a switch...
with no moving parts, that can allow or stop the flow of electricity from the pin at the top to the pin at the bottom. The pin on the left is called the "gate". Imagine it like a hose where the gate is the tap that allows the water to flow through from the positive rail to the -ve. Being an NPN transistor (rather than a PNP) the transistor allows current flow from the top pin to the bottom pin when there is a voltage present on the gate pin, and does not allow any flow when there is not. We start the cycle with the NPN transistor being in an open switch state, that is, not allowing electricity to flow from the positive line at the top through the primary coil (3 turns) and into the ground line at the bottom. With that route closed, and the diode facing the wrong way (diodes only let electricity flow in 1 direction), the positive line's only option is to flow through the high resistance path of the resistor into the gate. As soon as it does this, it enables flow through the transistor, and now the positive line is free to surge through a super low resistance path through the primary coil, through the transistor and into the ground. A magnetic field is generated from the primary, pushing up on the electrons in the secondary sending them up the coil. However, as the electrons get "sucked" up the secondary, they actually pull some of the electrons from the surge that just went through the primary on their way to ground through the LED and up into the secondary coil. This is why the LED will strangely light up even though it has its anode (+) pin connected to the ground. However the electrons are also "sucked" from the gate since it is also connected to the bottom of the secondary, and the positive line has been happier flowing through the primary to ground rather than through the big resistor. Now there is no charge on the gate to hold it closed and the transistor stops flow. This collapses the magnetic field produced by the primary, and the electrons in the secondary race down the coil, overshooting their equilibrium state in the same way when you let go of a swing it shoots right on past the bottom equilibrium spot and up the other side. The electrons now, again, only have the option to flow through the resistor and activate the gate pin again. The charged gate pin allows for flow through the primary and transistor, which creates the magnetic field pushing upward, which sucks the electrons back up the coil, starting the whole process over again. This cycle happens incredibly fast, but will always be in tune with itself since the gate will only become activated with the electrons from the secondary coil are at their lowest point, because of the incredibly small, but real delay between gate activation and the beginning of flow through the transistor, the electrons will already be on their way back up the coil when the surge comes through the primary coil again, timed perfectly with the up stroke of the electrons in the secondary.

So essentially with no guesswork or calculations or tuning, you can get a slayer exciter coil to work efficiently almost instantly with zero adjustments. This is why it is a favourite when it comes people's first Tesla Coil related project. It gives results instantly with little experience needed.

WHY I DIDNT USE A SLAYER CIRCUIT FOR MY DESIGN:
Slayer circuits are fun, but they have draw backs. One being that they are very small and produce little to no sparks. You can try to beef them up by making larger secondary's and primary's and using more power rated parts, however this barely improves performance, and actually makes the design look less impressive when you have such a massive machine putting out so little power. If you look at some of my smaller tesla coils on my page, such as the bipolar one I mentioned previously, you can see that the spark size compared to the machine size is much bigger than any slayer circuit you will ever see, and they are running of measly 12v batteries.

Also, there is no limit to how big and powerful you can make a tesla coil.

But the main reason that I went with a tesla coil design is that the transistor in the typical slayer circuit tends to get very hot and overheat when you try to get more power. I even went with a higher power tip32 with it still over heating at the power I needed. The reason I was pulling more than typical power was because I wanted the light bulb to light up even when my hand was not touching it. If you are holding a florescent tube, you are attracting the electrons through the tube because you are a big ground reservoir that they want to go to. So that is why it is very easy for most small low powered slayer circuits to light up florescent lights that are being held from a decent distance. It is another story when the bulb has nothing conductive around it, such as my design when it is sitting a top the box. I likely could have gotten the bulb bright enough with lower power if I had a larger coil size, but since I was trying to fit everything into the tiny little box, I had to make an incredibly small secondary coil. Due to the smaller than average size of the secondary, I needed to provide slightly more power than normal to get the bulb to light up. However the transistors I was using began overheating as soon as I provided that extra power needed light the bulb sitting on the box. So I decided to make my own, more efficient primary oscillating circuit (basically a sstc). However I couldn't rely on the self tuning properties that make the slayer so popular. So I had to make rough calculations for the resonant frequency of the secondary to guess what timing I needed for the primary. It ended up working beautifully first try. It is less efficient than the slayer circuit would have been, as my frequency calculations might be off by a bit , which would drastically reduce output. However at least with my new circuit I could pull a lot more power without anything overheating, and it was enough to light the florescent light sitting on the box without touching it.

TIPS FOR TROUBLE SHOOTING SLAYER CIRCUITS!
1. MAKE SURE YOU DIDNT PUT THE DIODE ON BACKWARDS! So many people wire it backwards because they assume that the cathode (-) is supposed to connect to the ground like it would in almost any other circuit. This circuit is very unique! I explain why the diode is wired that way and why it lights up even though it is attached to (-) earlier on, however if you don't understand, just make sure that either the long leg of the LED is connected to the (-ve) (bottom) rail. Or make sure the flat side of the plastic dome of the led is opposite to the (-ve) rail. Or if you are using an actual diode, make sure the white line is facing away from the (-ve)

2. MAKE SURE THE PRIMARY COIL AND SECONDARY COIL SPIRAL IN OPPOSITE DIRECTIONS!
Unlike a typical tesla coil, the rotation direction of the coils matter! This is because the secondary is triggering the gate by the direction of it's flow of electrons. If they are flowing the opposite way that they should, it will not activate the transistor on the right stroke direction causing an out of phase destructive force. Tesla coil primaries dont depend on what the secondary is doing, so if the primary coil pushes down on the secondary instead of up (depending on whether the spiral is clockwise or counter-clockwise), it wont matter. It's the same as how it doesn't matter which side you push the swing from. As long as you are pushing in the same direction as the swing is already going, the outcome will be the same.

3. YES YOU CAN USE A PNP TRANSISTOR!!!
Some of you might only have PNP transistors available, because you might have already fried all your NPN transistors. For some reason, every slayer circuit you will find online uses an NPN, however you can use a PNP if you just put it in backwards of how the NPN is supposed to go in.

4. IS YOUR LED NOT LIGHTNING UP?
Are you getting output from your coil but the LED isn't lighting up? This is because your circuit is struggling to tune itself. Yes the slayer circuit can usually tune itself, but if your coils are too far from naturally resonant, it might cross the line where it can no longer be resonant, and your performance will drop considerably. Try putting several more turns on the primary coil and see if that works. If it still doesn't light up, you probably didn't do a great job winding the secondary and have a lot of windings that overlap eachother.

This took a long time to write. Show some love. Subscribe!