

Why Build a Tesla Coil? A Journey Through Curiosity, Passion, Physics, and High Voltage

Why would an engineer, student, or hobbyist build a Slayer Exciter in 2025? The answer is not just nostalgia or visual spectacle, it's rooted in deep curiosity, a desire to explore electromagnetic phenomena with one's own hands, and the satisfaction of building something both fascinating and educational.

The Slayer Exciter is a simplified version of the classic Tesla coil, with one key difference: it doesn't use a "spark gap" or "rotary interrupter" to excite the secondary coil. Instead, it relies on a solid-state transistor (BJT, MOSFET, IGBT) to drive the coil into resonance, hence the name solid-state Tesla coil.

The circuit is really minimalistic: a resistor, a led, a power transistor, a primary coil, and a feedback mechanism (either inductive or capacitive) are enough to build it.

Building a Slayer Exciter allows you to work directly with one of the most important concepts in electromagnetics: LC resonance. The oscillatory behavior of inductive-capacitive systems is at the heart of communication systems, switching power supplies, and RF devices.

Seeing a resonant system create thousands of volts from a simple low-voltage supply is both eye-opening and memorable.

How It Works

The Slayer Exciter is a solid-state Tesla coil (SSTC) that operates on the principle of resonant inductive coupling. It uses a single transistor as an active switching element, driven by positive feedback from the secondary coil.

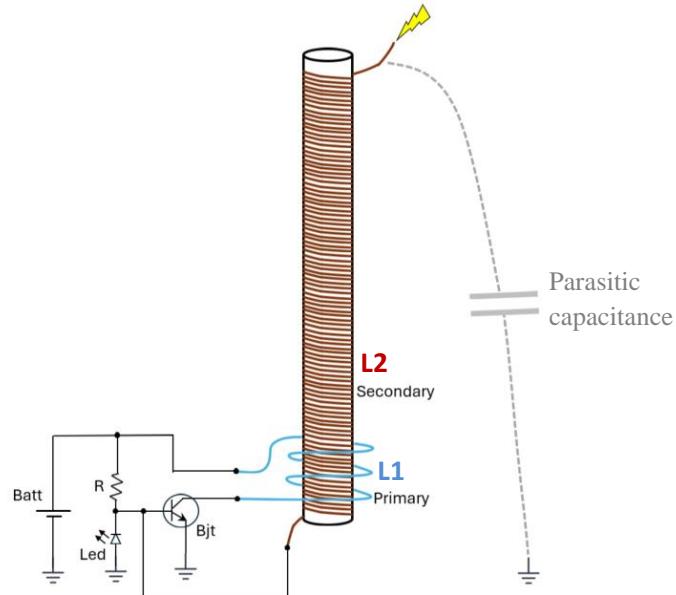


Figure 1: SSTC with Slyer oscillator driver

The main components of the circuit are described below.

- Primary Coil (L1): A few turns of thick wire, typically air-cored, located at the base of the secondary and connected in series with the collector (or drain) of the transistor. (blue coil in Figure 1)
- Secondary Coil (L2): A high number of turns of thin enameled wire, wound on a non-conductive tube. It resonates with its parasitic capacitance to form an LC circuit. (red coil in Figure 1)
- Transistor (NPN BJT or N-channel MOSFET): Acts as an oscillator driver.
- Power Supply: Low voltage (5V to 24V DC) powering the primary side through the transistor.
- Base Resistor and Protection Diode: Controls current to the base/gate and protects the transistor from back EMF.

The working principle is described below:

1. Initial Power-Up: When the DC power supply is turned on, a small current flows through the base of the NPN transistor via a resistor. This switches the transistor on, allowing current to flow from the collector to the emitter (or drain to source in a MOSFET), which energizes the primary coil.
2. Magnetic Coupling: As current flows through the primary coil, a changing magnetic field is generated. This field induces a voltage in the secondary coil (L2) due to transformer action.
3. Feedback and Self-Oscillation: A portion of the induced voltage in the secondary is fed back to the base (or gate) of the transistor. If the phase is correct, this feedback enhances the conduction of the transistor, driving it further into saturation. However, as the magnetic field collapses, the polarity reverses, and the transistor is driven out of conduction, stopping current flow. This creates a self-sustaining oscillation based on feedback and the natural resonant frequency of the coil. The result is a continuous pulsing of the primary coil current, synchronized with the resonant frequency of the secondary coil (and parasitic capacitance)
4. Resonance in the Secondary: The secondary coil acts as a resonant LC tank, where the inductance of the coil and the parasitic capacitance (mainly from the top of the coil to ground) create a

resonant circuit. This leads to voltage magnification at the top terminal of the secondary. The energy stored in the magnetic field of the coil and the electric field of the top terminal oscillates, producing high-voltage, high-frequency AC. This voltage can be enough to generate small sparks and light up fluorescent tubes wirelessly.

5. Capacitive Coupling to Ground: The secondary's top terminal acts as a capacitive plate with respect to the environment (earth ground). The distributed capacitance of the coil contributes to the tuning of the resonance. The combination of inductance (L) and parasitic capacitance (C) determines the resonant frequency as described below.

The resonant frequency of the secondary coil can be estimated with the standard LC formula:

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

Where:

- f_0 : Resonant frequency in Hz
- L: Inductance of the secondary coil in Henries
- C: Total capacitance to ground in Farads

You can estimate the inductance of a long, thin solenoid with:

$$L = \mu_0 N^2 \frac{A}{l}$$

Where:

- N = Number of turns
- A = Cross-sectional area of the coil (in m^2)
- l = Length of the coil (in m)
- $\mu_0 = 4\pi \cdot 10^{-7} \text{ H/m}$

In my prototype, the secondary coil is a single layer winding with $N=2200$, $A=0.000314 \text{ m}^2$ (secondary coil diameter = 20 mm), $l=0.3\text{m}$, so $L \approx 6 \text{ mH}$



Figure 2: Inductance measurement of secondary coil

The parasitic capacitance C value mainly depends on:

- The geometry of the secondary coil
- Proximity to ground or metallic surfaces
- Presence of a top load (like a toroid or sphere)

If no top load is used, typical values for stray capacitance range from 5 pF to 20 pF, depending on coil size and surroundings.

For example, the prototype I built has an oscillation frequency of about 1 MHz, so the parasitic capacitance is about:

$$C = \frac{1}{4\pi^2 L f_0^2} = 13 \text{ pF}$$

The primary coil, physically connected to the driver, is made using a three-turn single layer winding.



Figure 3: Primary coil



WARNING: Make sure the primary and secondary coils are spiral wound in opposite directions!

Unlike a conventional Tesla coil, the winding direction of the coils in a Slayer Exciter matters significantly. This is because the secondary coil is actively involved in triggering the transistor's base by inducing a feedback signal, and that signal depends on the direction of electron flow. If the coil is wound in the wrong direction, the feedback will be out of phase, preventing the transistor from turning on at the correct point in the cycle.

Estimate Power Dissipation

The Slayer Exciter operates in a linear and switching hybrid mode, so there's significant switching loss and conduction loss. Let's assume that the average current I_{avg} through the BJT is 3A.

For simplicity, we will also assume that: $P_{diss} = V_{CEsat} \cdot I_{avg} + P_{switching}$

Where $V_{CEsat} \approx 1.5$ V for a BJT and we “roughly” consider switching loss equal to conduction loss, so:

$$P_{diss} \approx 2 * (V_{CEsat} \cdot I_{avg}) = 2 * (1.5 \text{ V} \cdot 3 \text{ A}) = 9 \text{ W}$$

Usually is safe to keep the transistor junction below 150 °C. To do so, the required total thermal resistance from chip junction to ambient is:

$$R_{\theta total} = (T_{j_max} - T_{amb}) / P_{diss} = (150 - 30) / 9 \approx 13 \text{ °C/W}$$

On the other hand:

$$R_{\theta total} = R_{\theta sa} + R_{\theta jc} + R_{\theta cs} \text{ where:}$$

- $R_{\theta jc}$ Thermal resistance junction-to-case $\sim 2 \text{ °C/W}$
- $R_{\theta cs}$ Thermal resistance case-to-heatsink $\sim 0.5 \text{ °C/W}$
- $R_{\theta sa}$ Thermal resistance from heat sink to Ambient

So, the maximum allowable heatsink thermal resistance is:

$$R_{\theta sa} = R_{\theta total} - R_{\theta jc} - R_{\theta cs} \approx 13 - 2 - 0.5 \approx 11 \text{ °C/W}$$

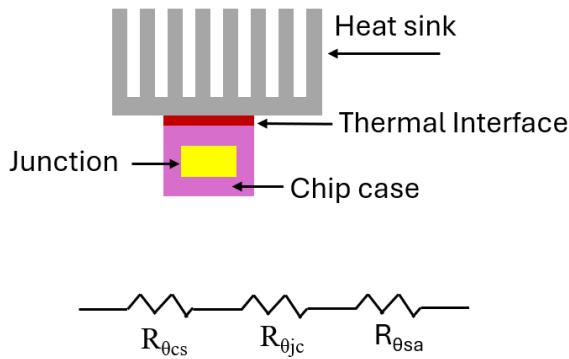


Figure 4: Heat sink thermal circuit

Keep in mind that heat sinks are rated in terms of °C/W. A lower value indicates better cooling, so, for a 9W dissipation, we might choose a passive heat sink with $R_{\theta sa} \ll 11 \text{ °C/W}$.

Sparks length

The relationship between the applied voltage and the resulting spark length is approximately proportional under standard atmospheric conditions. Essentially, the greater the voltage potential across the two electrodes, the longer the distance the electrical arc is capable of bridging through the air. This is since a higher electric field is required to ionize the air molecules and initiate breakdown over a longer path.

A widely accepted rule of thumb used by engineers and hobbyists alike is that it takes about 10,000 volts (10 kV) to bridge a gap of one centimeter in dry air at sea level.

This rule is not “exact” but serves as a practical approximation for estimating required voltages in typical conditions. Factors such as humidity, air pressure, temperature, and electrode shape can all affect the actual breakdown voltage, making real-world results vary slightly from this guideline. Nonetheless, it provides a useful baseline.

In the prototype I built, the generated sparks are about 1 cm long (24V, 4 Amps power supply), so the high voltage generated is about 10000 V.

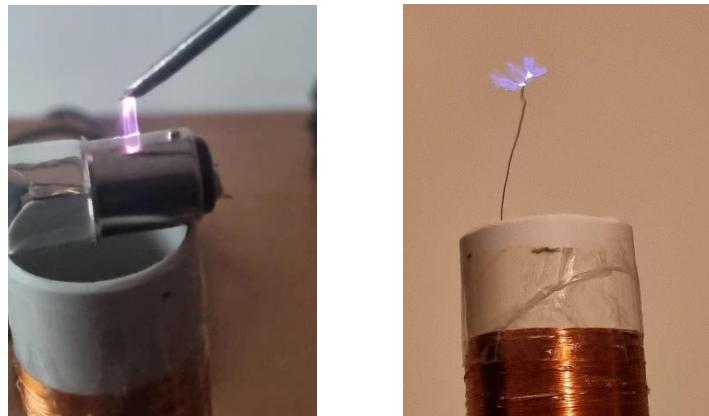


Figure 5: Sparks of the prototype

Simulate before you build

In the past, building high-voltage circuits meant long hours of trial and error, lots of soldering, and a fair amount of smoke. Today, with free tools like LTspice, you can simulate the entire circuit, visualize waveforms, identify unstable operating points, and estimate transistor heating, all without lifting a soldering iron.

In this case, using LTspice, you can:

- Check for sustained oscillation
- Plot voltages and currents
- Tune components values
- Test power dissipation and transistor safety margins
- Simulate feedback effects and parasitic inductances

This dramatically shortens development time and increases your chances of success on the first try.

The image below shows the LTSpice simulation of the proposed circuit.

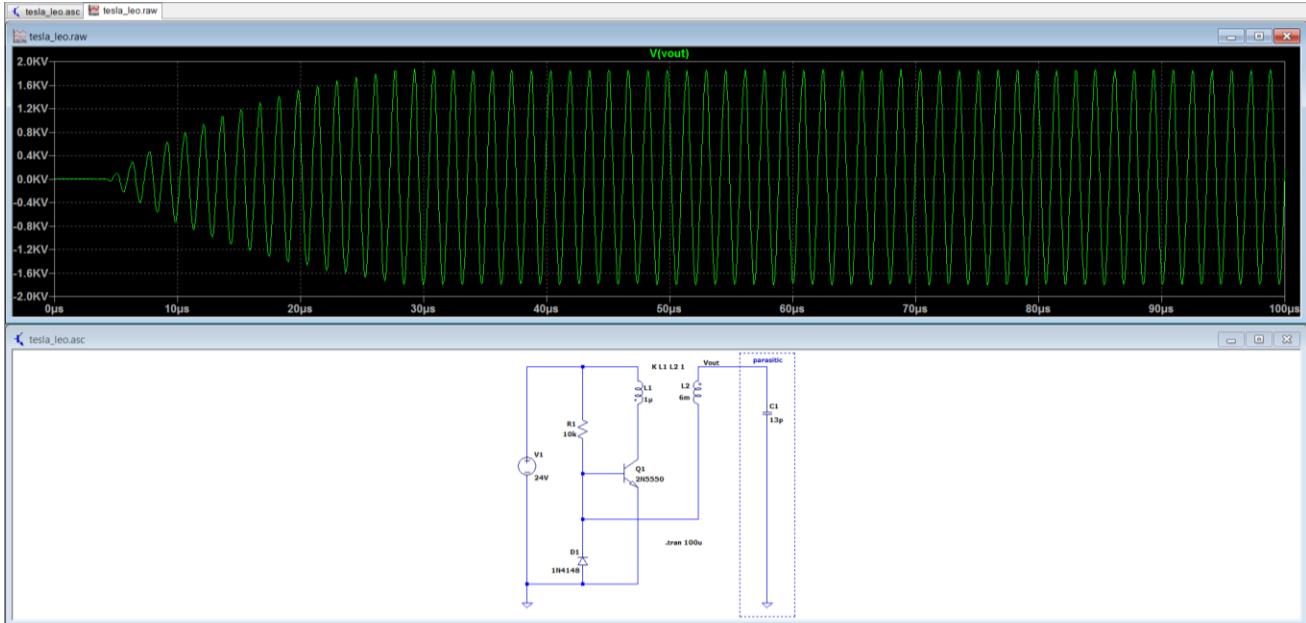


Figure 6: Simulation with LTSpice

Limitations, Notes, Tips.

While the Slayer Exciter represents a good, fascinating, and accessible starting point for solid state Tesla coil design, it's important to understand its inherent limitations. Because of its simplicity, the circuit sacrifices efficiency and control for ease of construction, which can lead to performance issues or unpredictable behavior under certain conditions. The following notes highlight the key constraints and considerations to keep in mind when building or experimenting with this type of coil.

- No tuning: Slayer doesn't tune the drive frequency, so it relies on self-resonance.
- Transistor stress: The transistor gets very hot within seconds, so a heat sink is needed, and I recommend only using for a few minutes.
- Low/no control: It works like a brute-force resonator.

Ever wanted to build your own Tesla coil with a Slayer Exciter?

You're in for a fascinating hands-on experience in high-voltage electronics! The Slayer Exciter is one of the simplest solid-state Tesla coil circuits, making it perfect for beginners and hobbyists alike.

You'll find plenty of step-by-step tutorials, circuit diagrams, and videos online to guide you through the process. Just remember to follow safety precautions: you're dealing with thousands of volts!



Important Safety issues

Slayer Tesla coils produce high-voltage, high-frequency electrical arcs that can be dangerous. While they are generally considered less hazardous than larger Tesla coils due to their lower power output and higher frequency, they still require caution. It's crucial to avoid contact with any part of the circuit, especially the electrodes and output terminals, as they can cause burns or electric shock. Additionally, the high-frequency output can interfere with nearby electronics.

If you are inexperienced with high-voltage circuits, seek guidance from a knowledgeable person before operating a Slayer Exciter.

Be aware of potential fire hazards and ensure the coil is operated in a safe environment away from flammable materials.

Have fun with the Tesla coil!

Have you ever wondered how a Tesla coil works using just one transistor?

In this deep-dive article, I explore the Slayer Exciter, a minimalist yet fascinating simple solid-state Tesla coil.

Inside the article, I break down:

- How the Slayer circuit generates high-frequency oscillations
- The role of resonance and parasitic capacitance to ground
- A practical approach to heatsink thermal calculations
- Safety issues

Whether you are an enthusiast, a hobbyist, a student, or an engineer curious about Tesla coil technology, this guide combines theory and practice in a hands-on way.

Read the full article and join the conversation!

#TeslaCoil #SlayerExciter #HighVoltage #ThermalManagement #Electronics #NikolaTesla