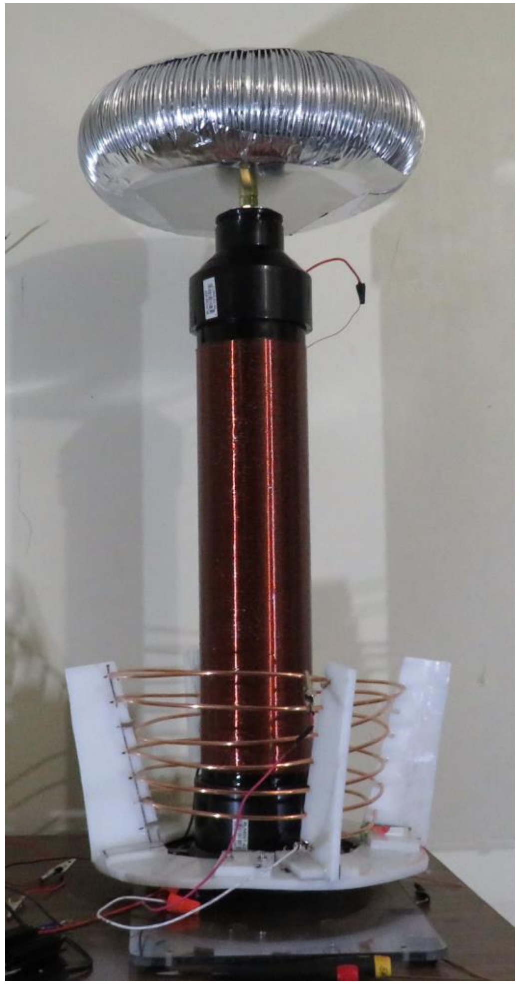
Basics of Tesla Coil



Make Your Own Tesla Coil

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Sequence

Brief Theory
Principles of Operation

↓

Design and Construction

↓

Tests and Measurements

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Theory: What you need

1. Knowledge of Basic LRC Circuit : Transient and AC Response

2. Circuit Analysis Software:

LTSpice

Download and use it for free

https://www.analog.com/en/design-center/design-tools-and-calculators/ltspice-simulator.html

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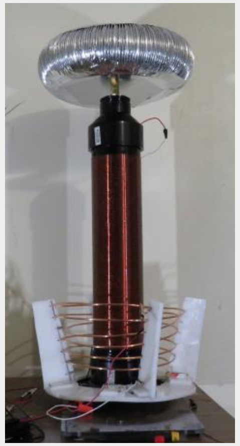
Tesla Coil: Not an Ordinary Transformer

Though it looks like a transformer, however not an ordinary one. Energy is transferred from the primary to the secondary by carefully adjusting the ***coupling*** and the secondary is tuned at ***resonance*** to achieve maximum voltage

Low voltage AC → Tesla Coil → Very High voltage AC

Tesla Coil



Uses two effects: Resonance and Coupling

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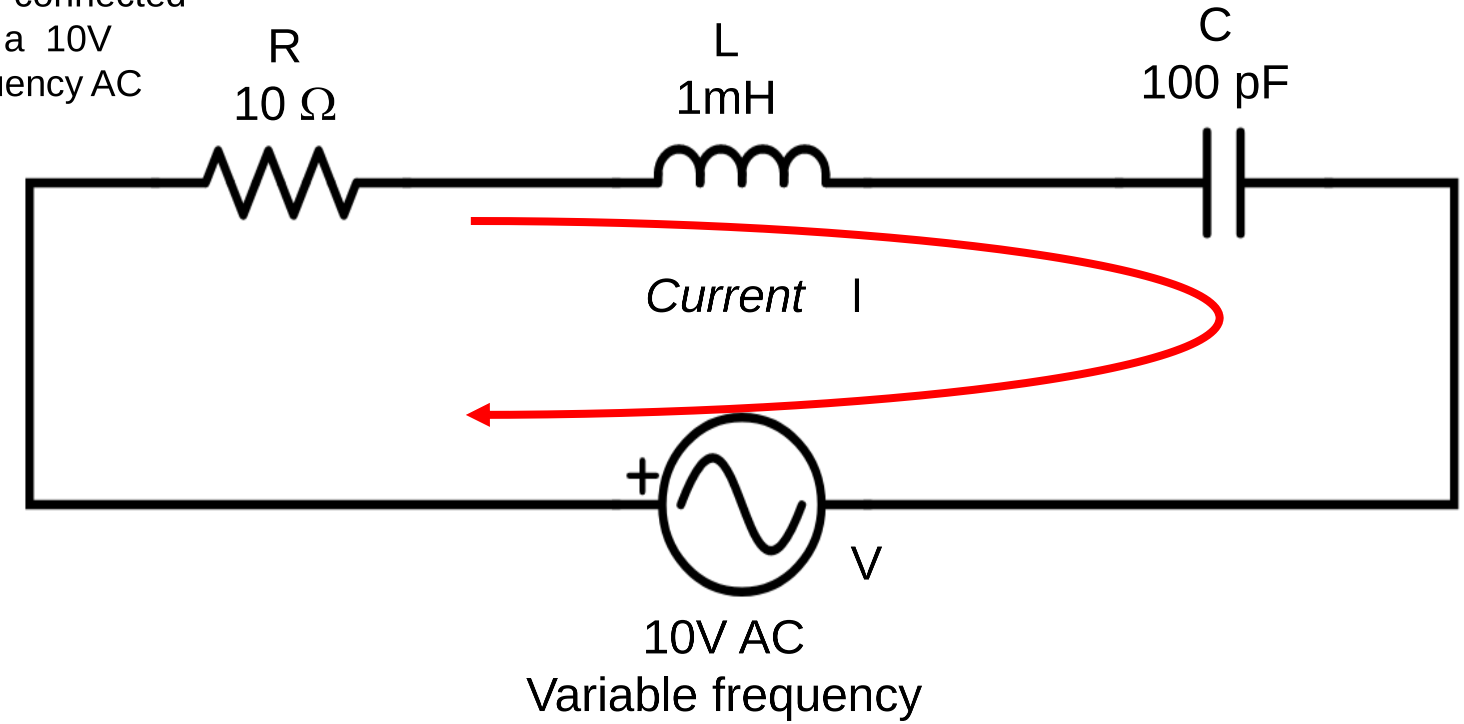
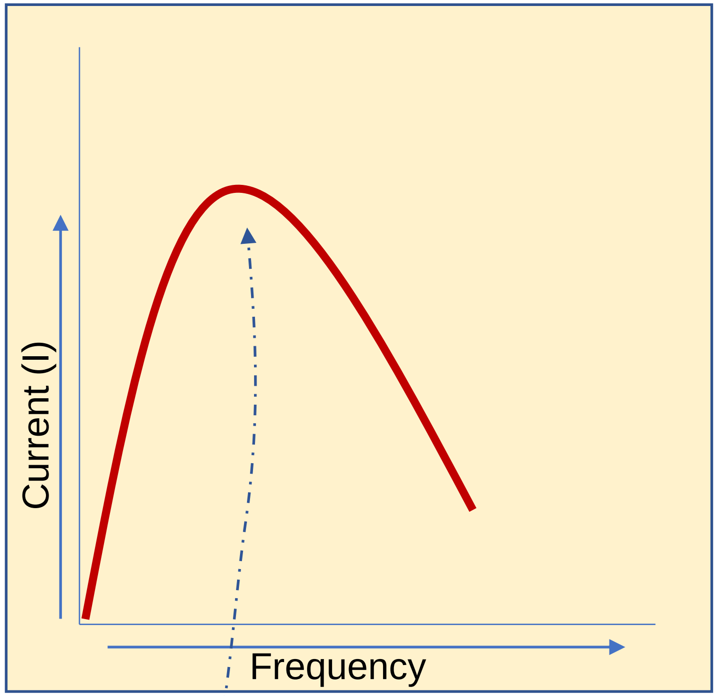
A Simple LRC Series Circuit and Resonance

An inductor, a capacitor and a resistor connected in series with a 10V variable frequency AC source





Impedance (z) of series LRC:

$$z = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$$

$$I = \frac{V}{Z}$$

At resonance:

$$\omega L - \frac{1}{\omega C} = 0$$

$$I = \frac{V}{R}$$

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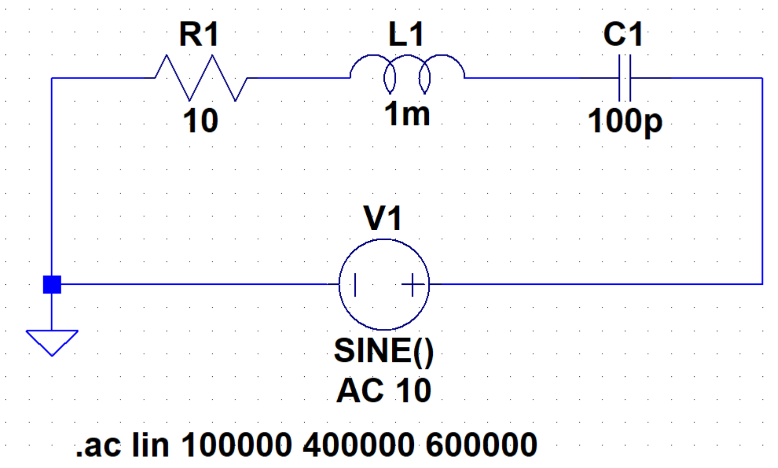
Analysing The LRC Circuit with LTSpice

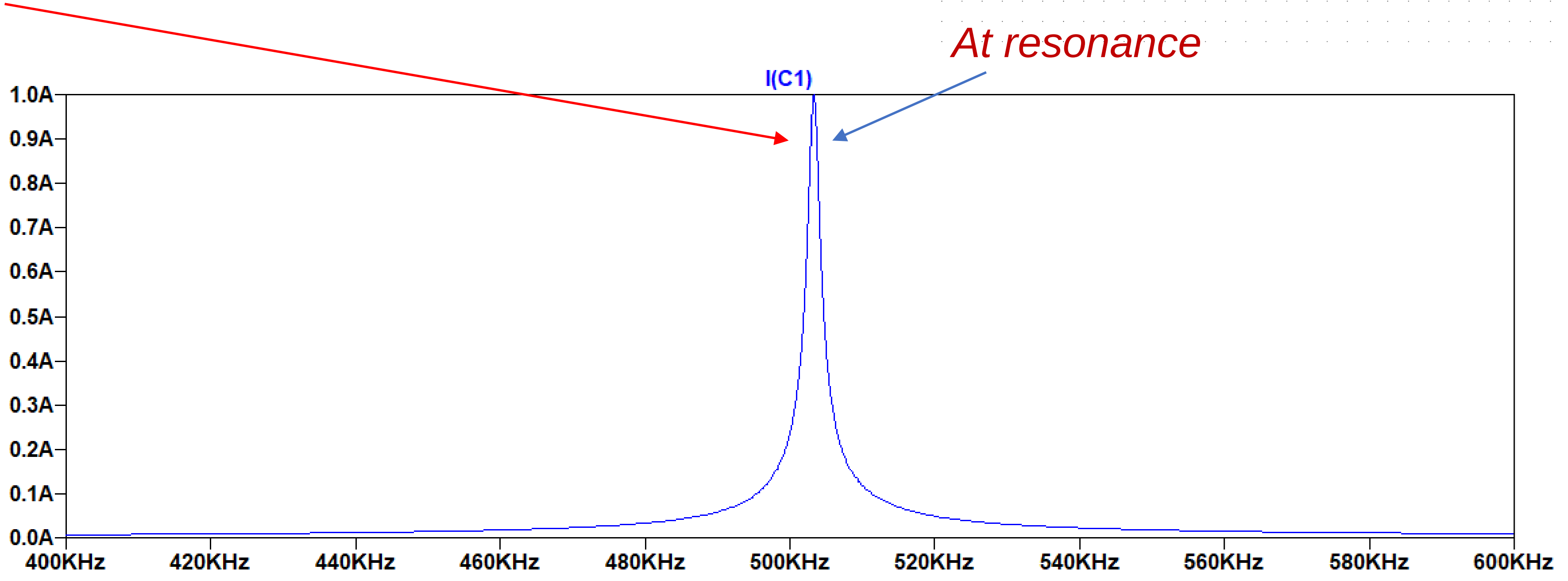
At resonance

$$z = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$$

$\omega L = 1/\omega C$

$I = V/R$





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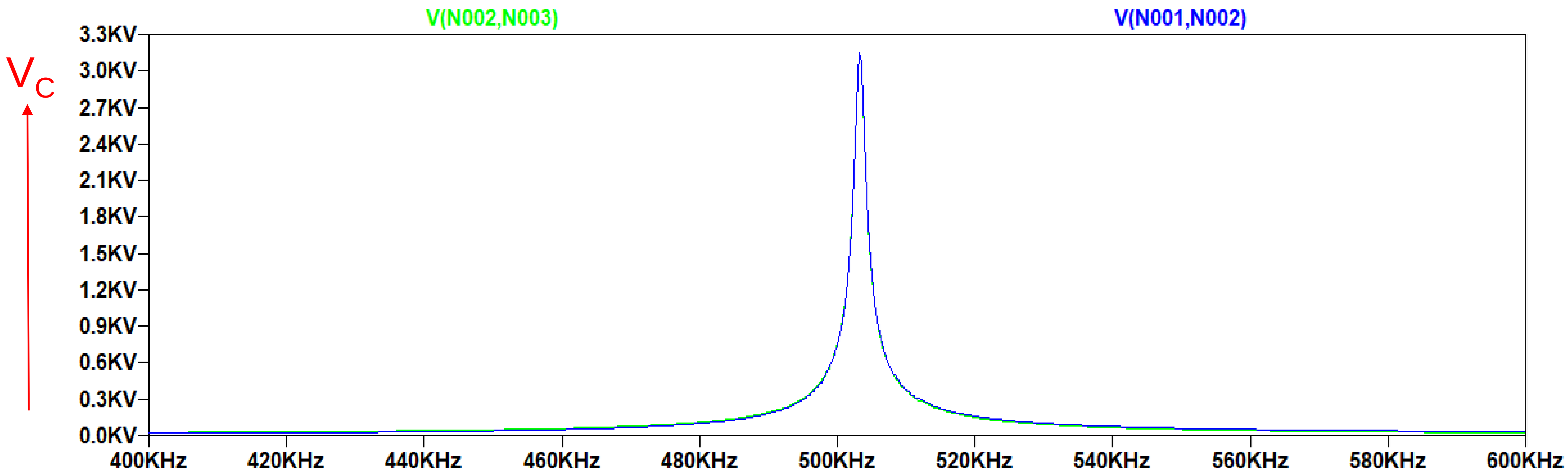
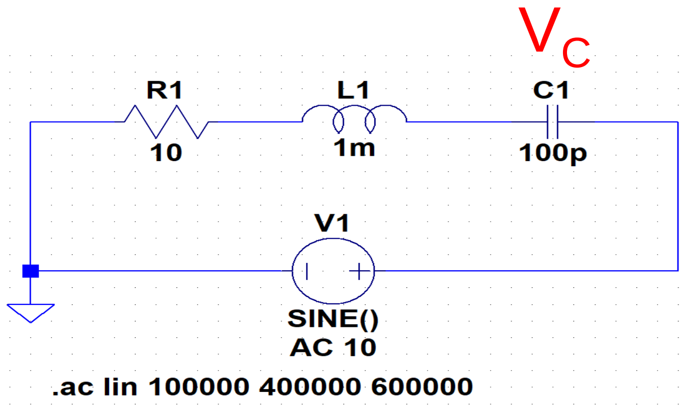
Voltage Across Capacitor



Lower the value of **C**

Higher the voltage **Vc**

Vc = I/ωC



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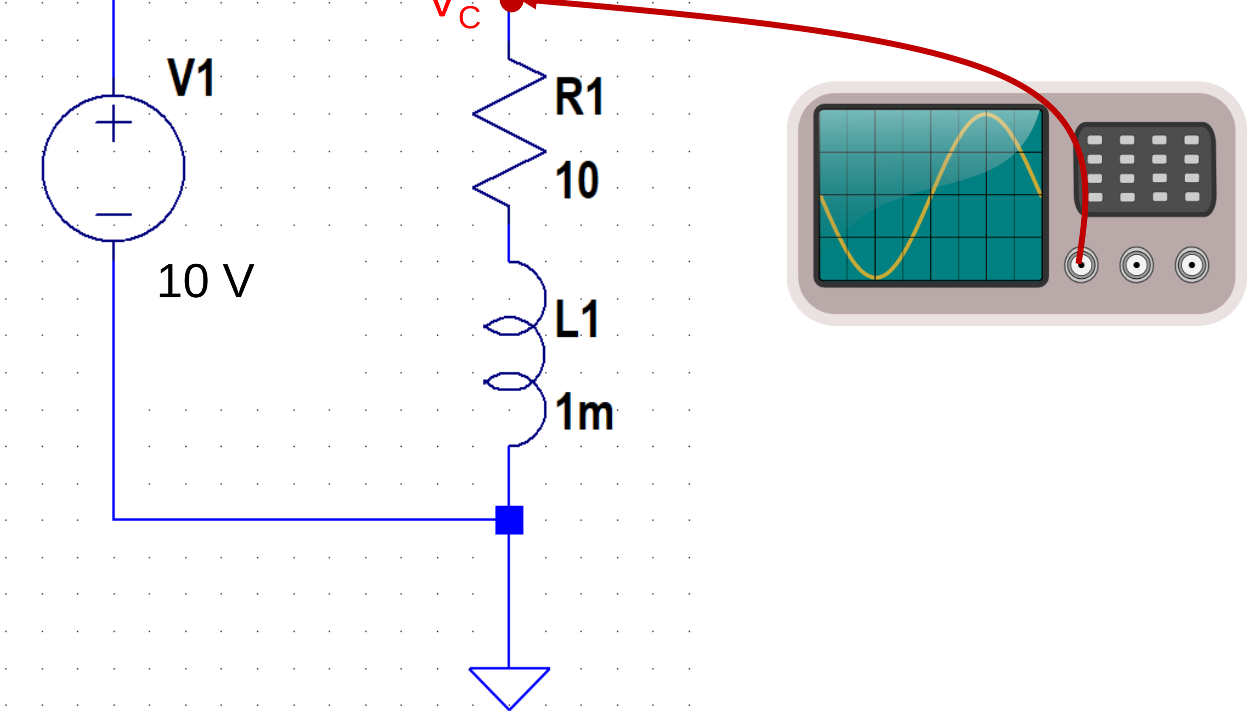
Voltage Gain

Simulation shows, voltage at the point

$V_C = 3kV$

Supply voltage: 10 V

Gain: 3000/10 = 300



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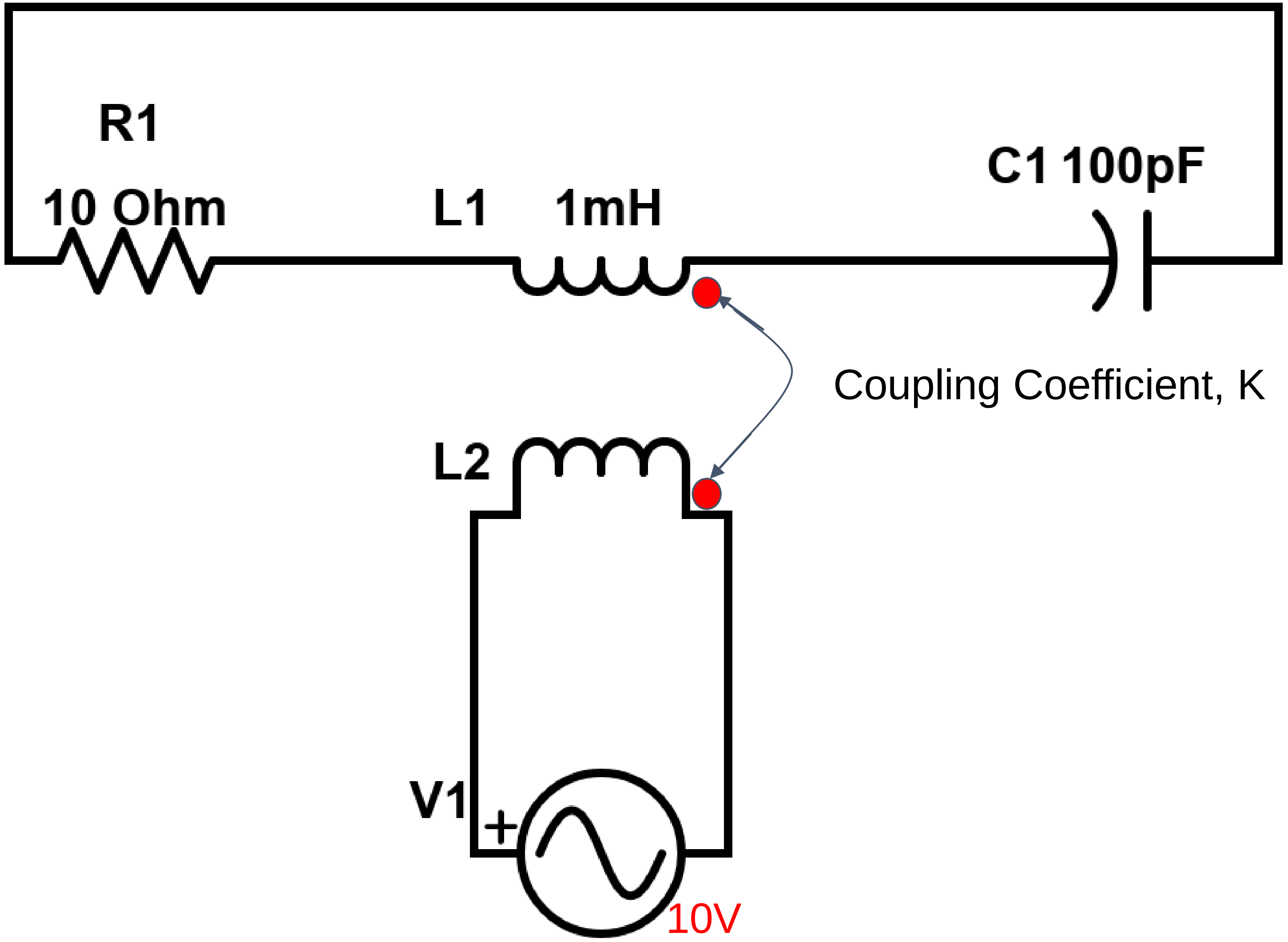
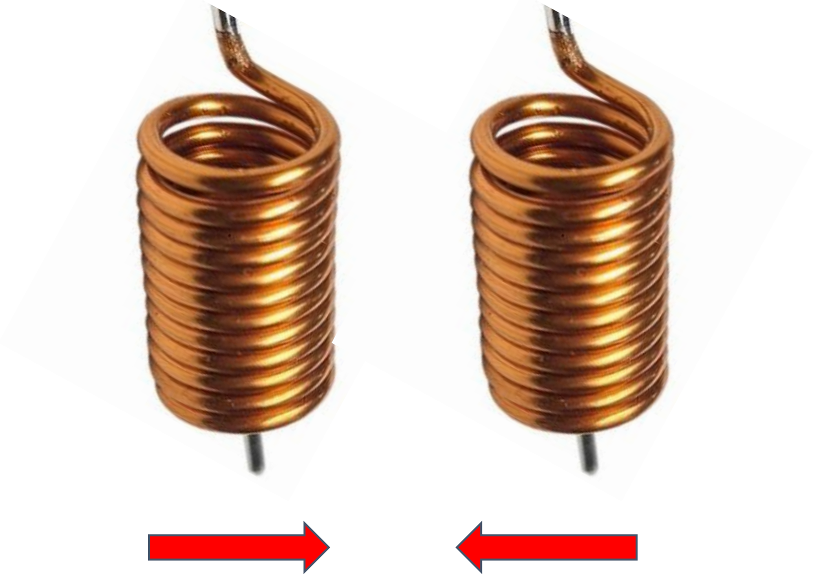
AC Source Replaced by Transformer Coupling





Closer: Tighter coupling, K
Maximum K = 1

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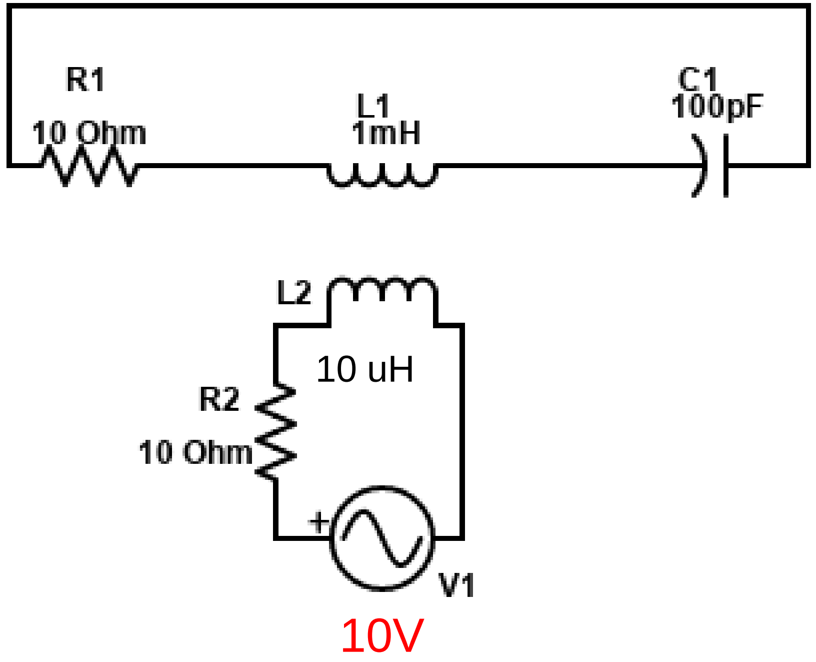
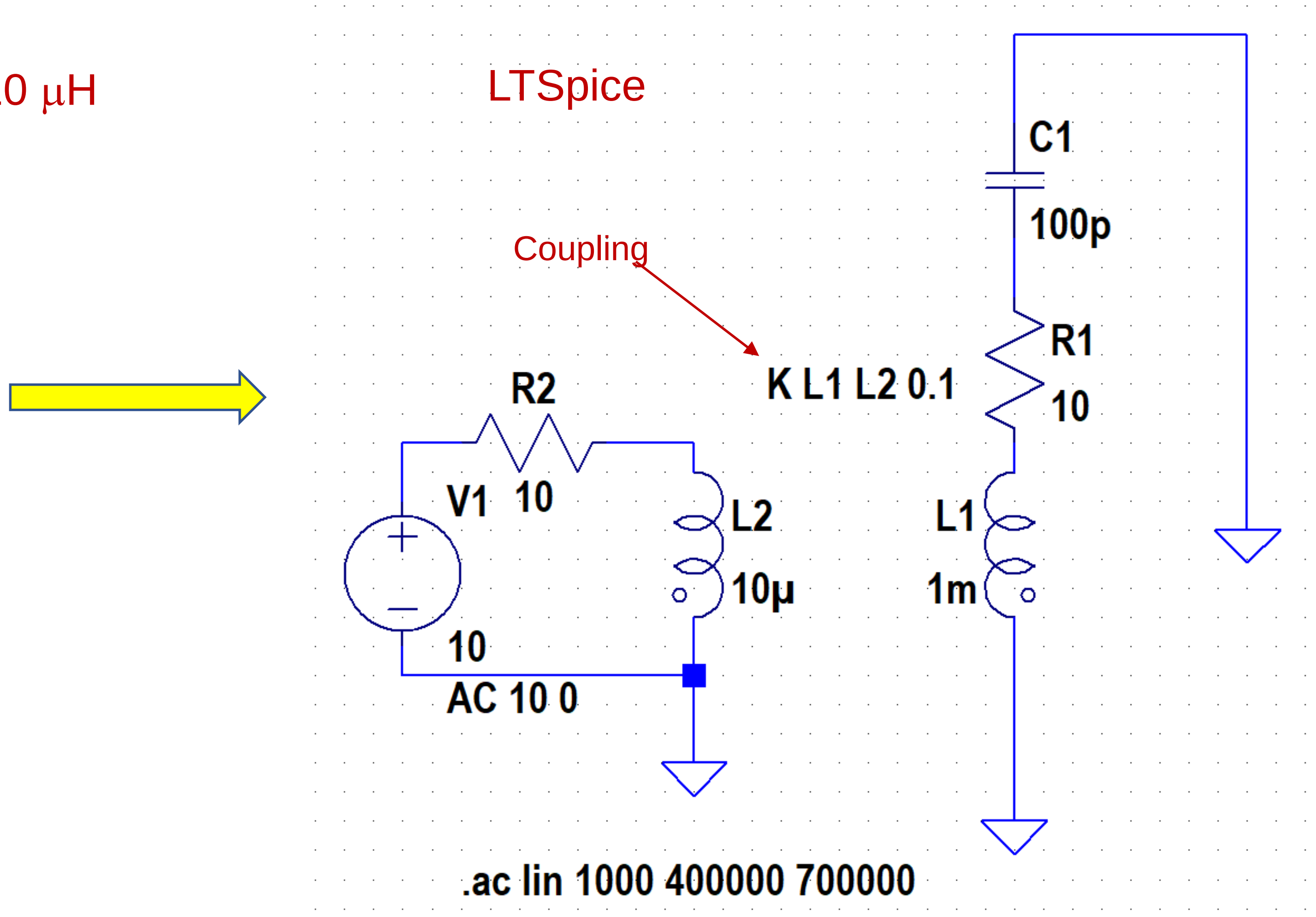
Simulation of a Coupled Circuit

Considering Primary-coil (L2) Inductance = 10 μH





10 Ω is added to limit the current to 1 A

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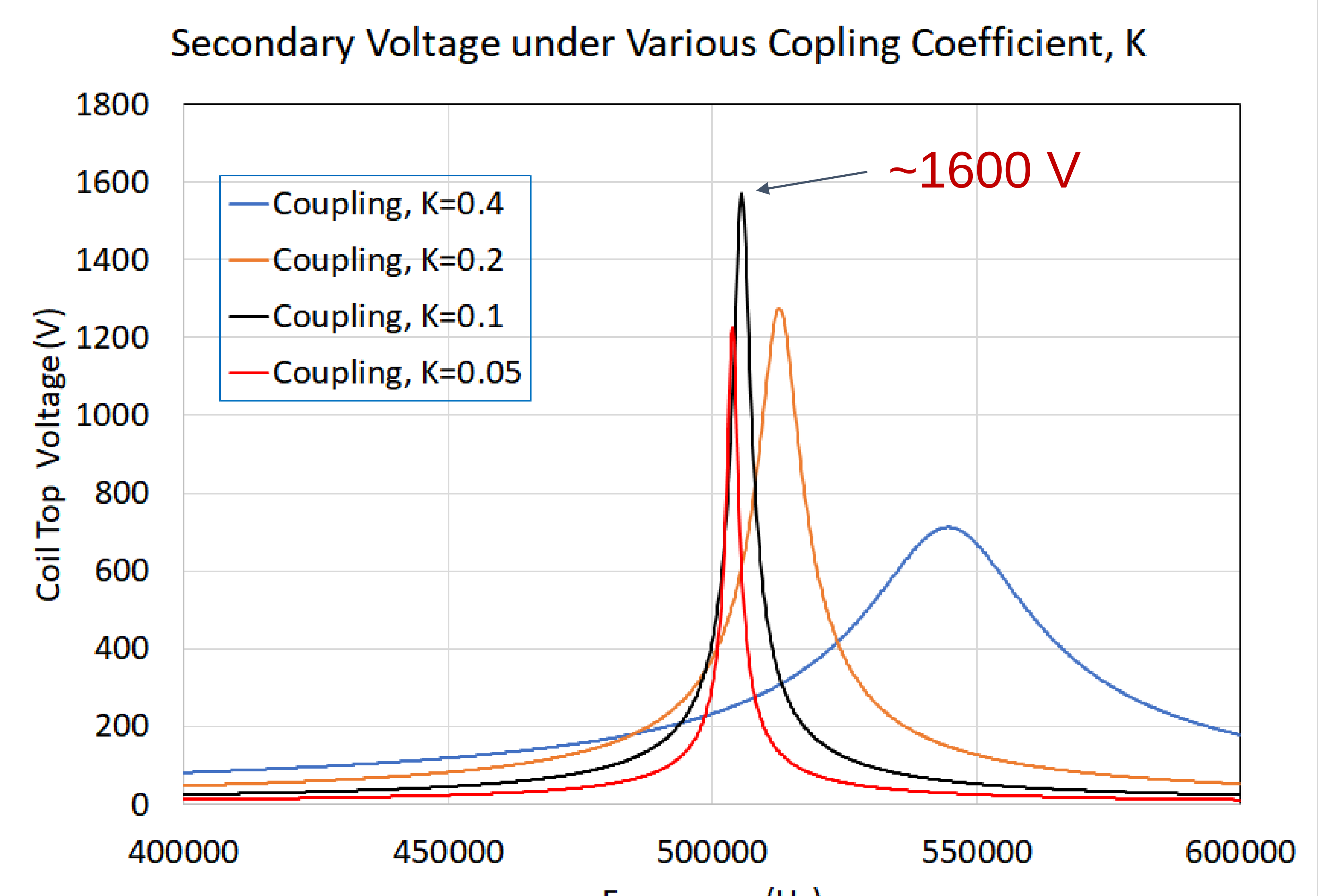
Instead of Source, Energy Supplied by Transformer Coupling

Our goal is to get maximum voltage at the secondary

Coupling, K~0.1
Gives best result

For tighter coupling (K=1): Energy is transferred to Secondary and part of that comes back

For a loose Coupling: Very little energy is transferred to the secondary



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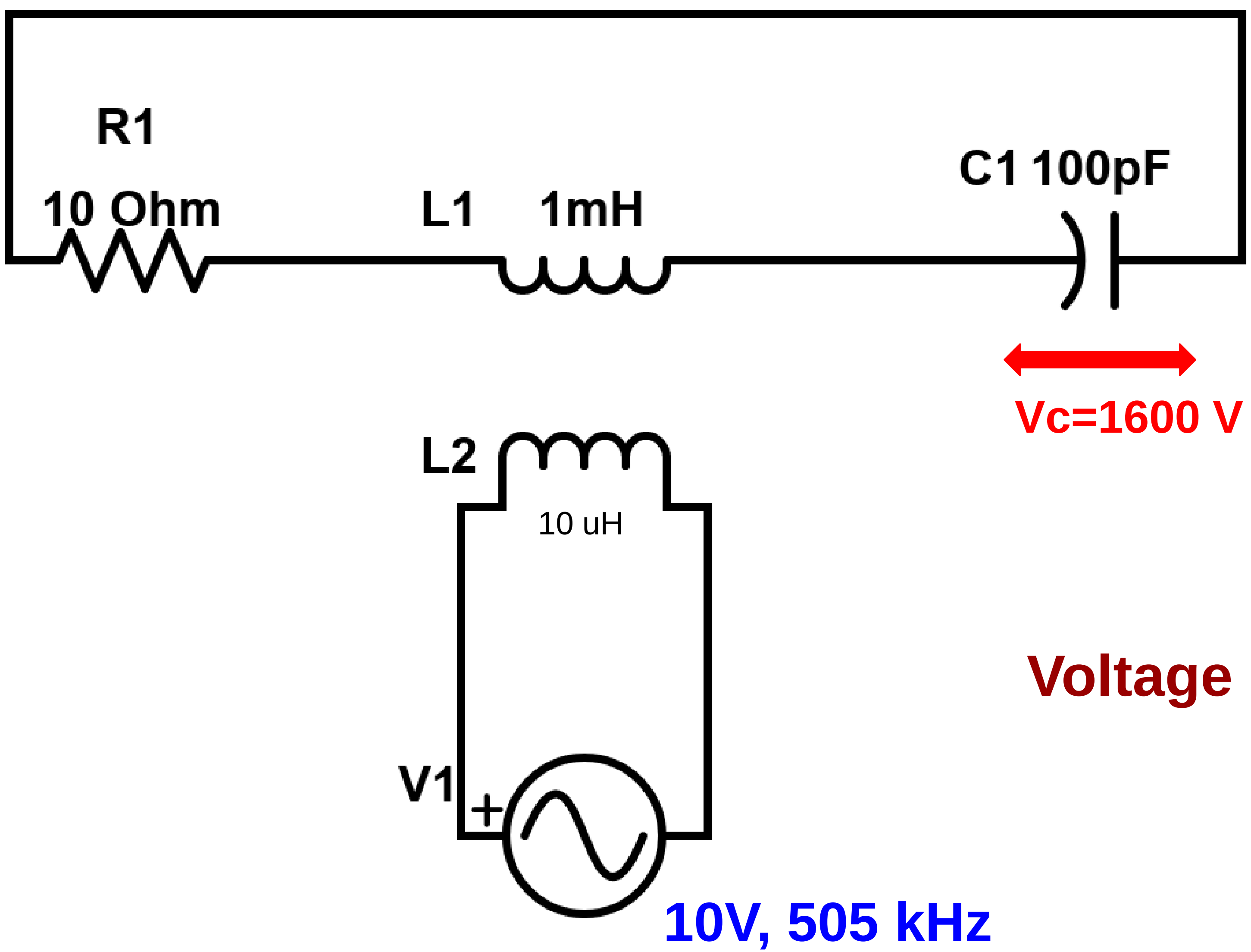
Important Points to Note



At resonant frequency (~505 kHz), voltage across Capacitor reaches ~1600 V. However, the source is only 10 V

Voltage gain = 1600V/10V = 160

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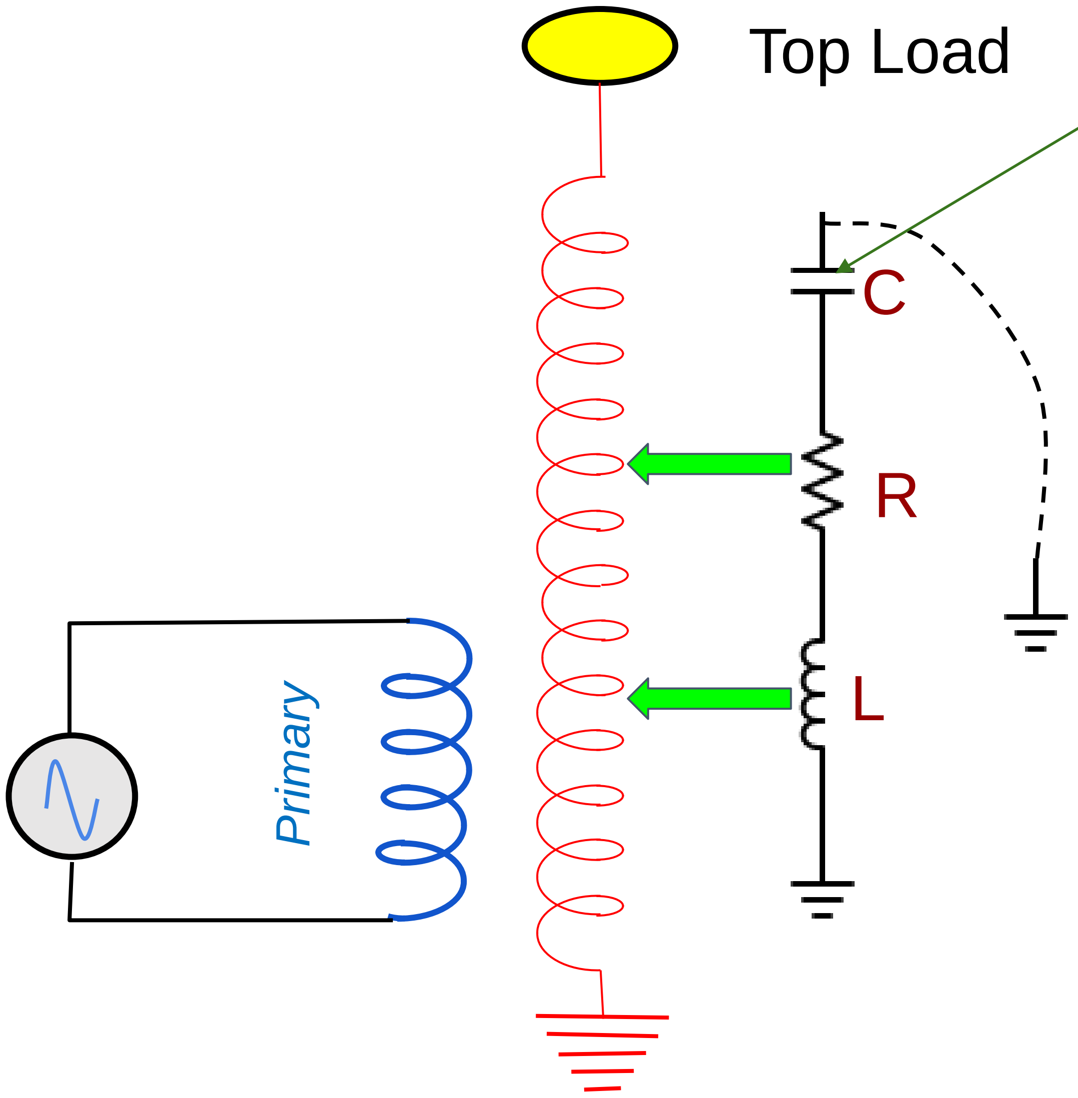
Tesla Coil as a Tuned LCR Circuit



Capacitance is introduced by the top load and distributed capacitance of the coil to ground

Equivalent circuit of the secondary coil. R and L are the resistance and inductance of the coil.

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To Build a Successful Tesla Coil

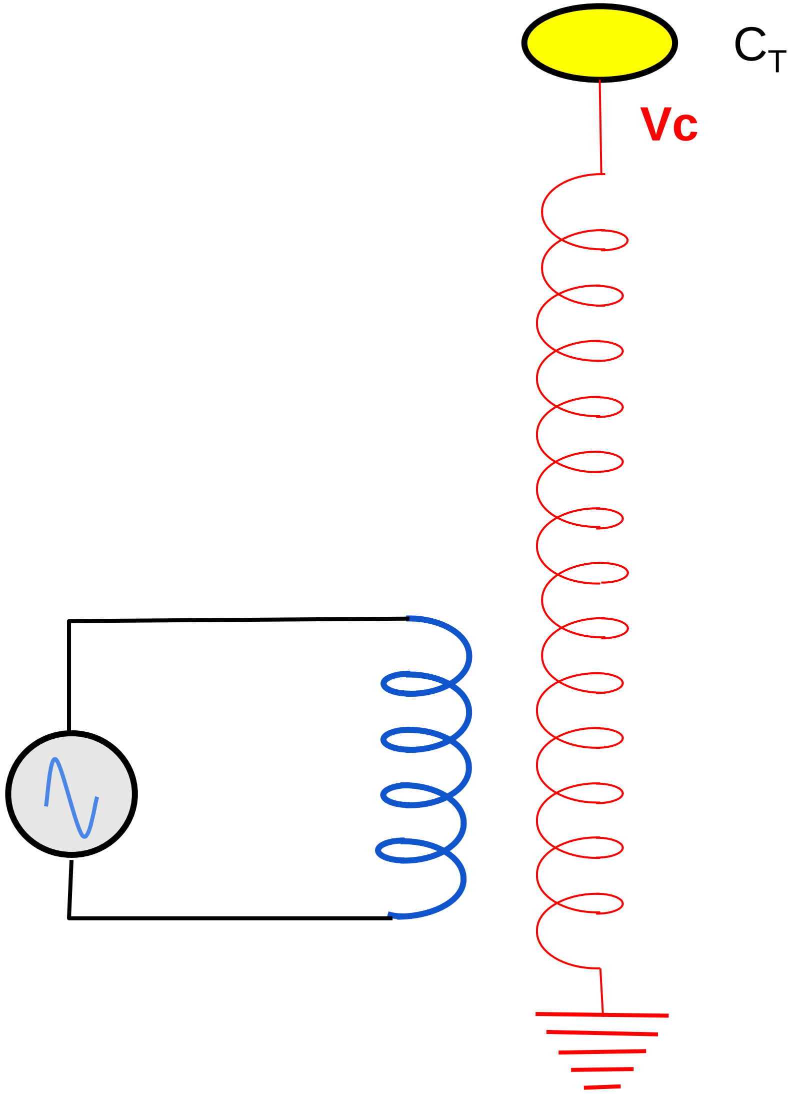
1. Proper tuning to resonant frequency
2. Optimum Coupling (in our case , K = 0.1)
3. Low capacitance

$V_c = I/\omega C$

Higher the voltage

Lower the capacitance

4. If Top load is removed, capacitance will be lower. However, resonant frequency will go high. Component choice and tuning is more difficult. Power loss at the switching device will go higher.



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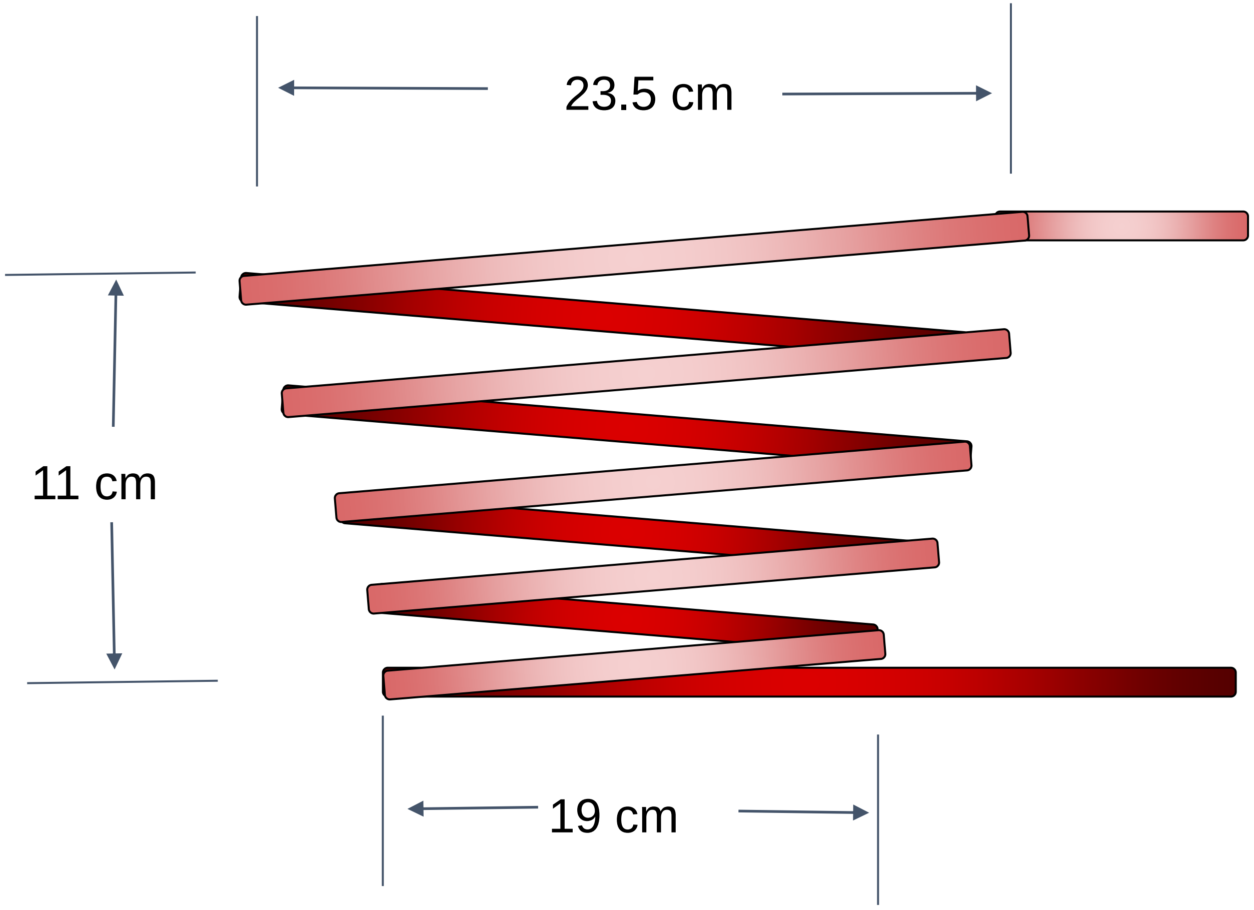
Primary Coil Construction

Primary Coil: Conical
Number of Turns, N=6
Wire Gauge: AWG #8
Larger diameter: 23.5 cm
Smaller diameter: 19 cm
Width: 11 cm
Calculated inductance: ~ 8.1 uH

https://coil32.net/online-calculators/conical-tesla-coil.html



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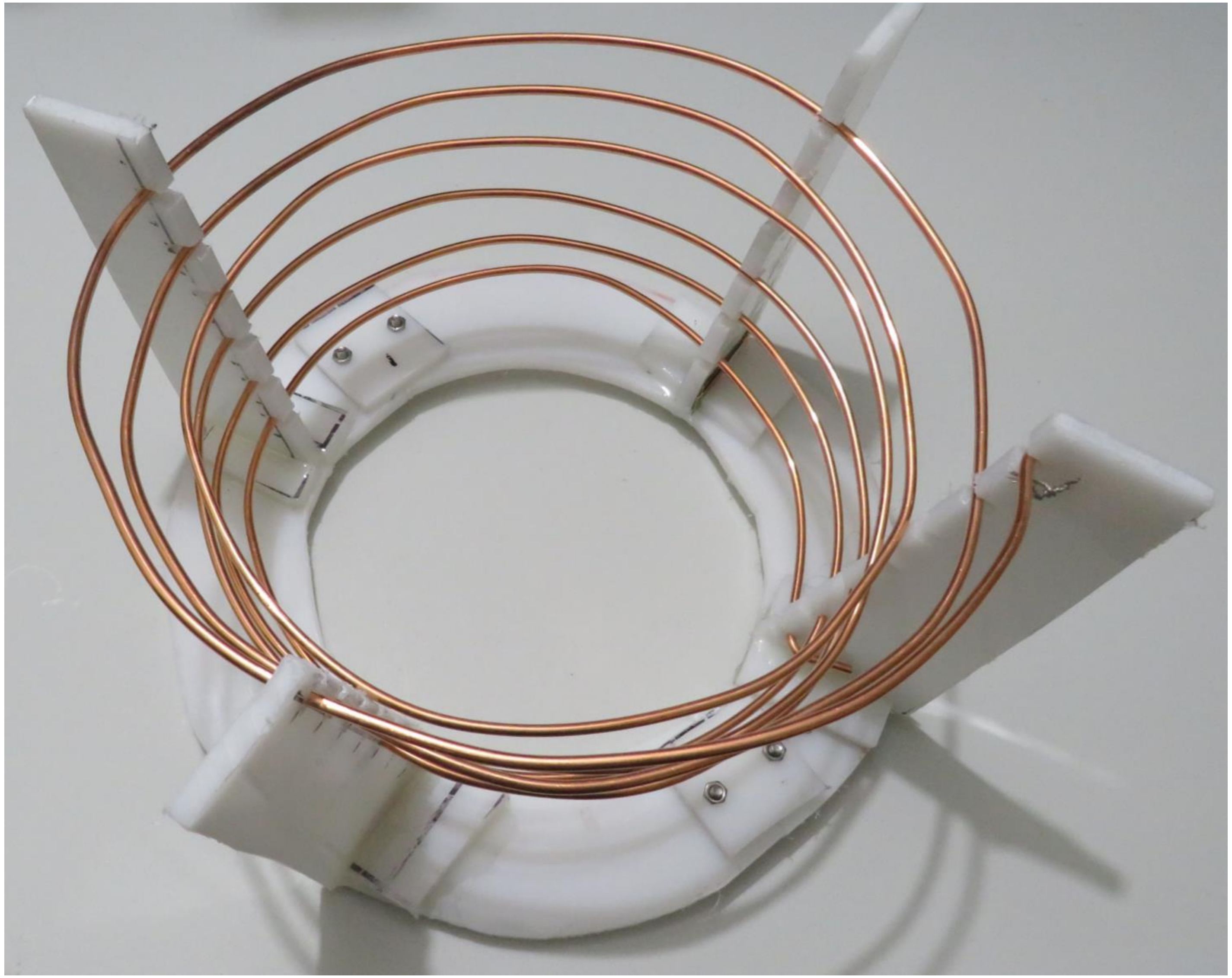
Primary Coil Construction



White acrylic sheet was used to make the coil format.

A jigsaw was used to cut the shapes and two-part epoxy was used to join the parts.

Parts Used for Secondary Coil

These parts are bought from local hardware store (Homedepot)

3” x 2” ABS Reducing Coupling

1.5” x 0.75” Bushing Adapter

4”X3” Adjustable Closet Flange Hub

As a coil Base

ABS PIPE 3 inches x 3 ft CELL CORE

Copper wire is wound on this pipe

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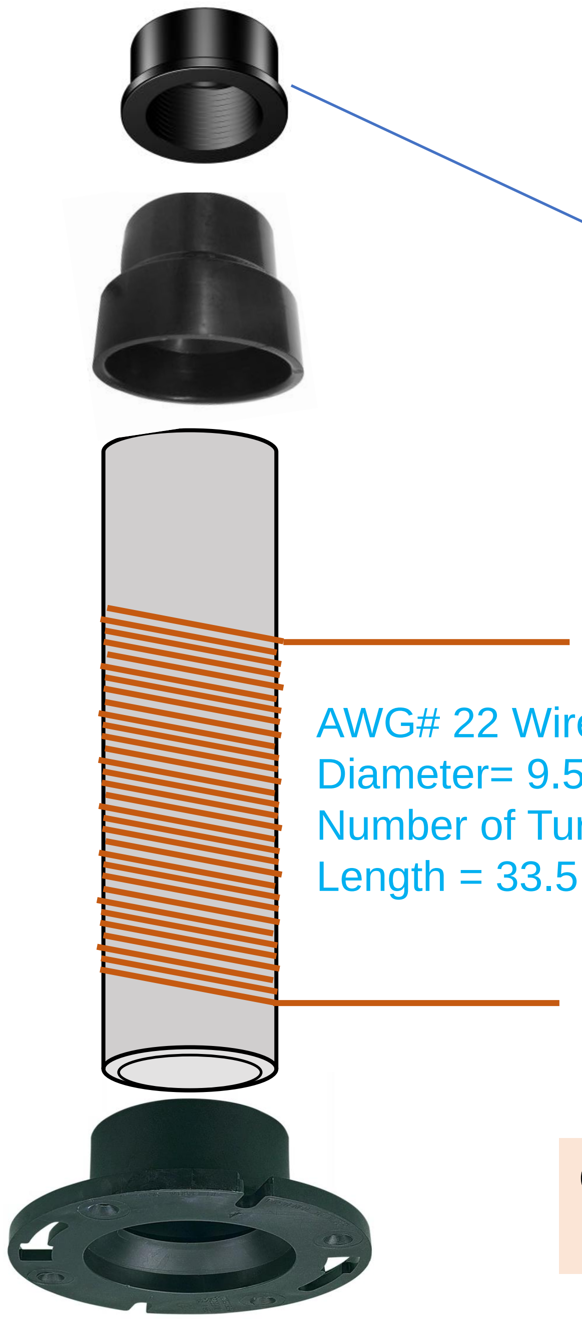
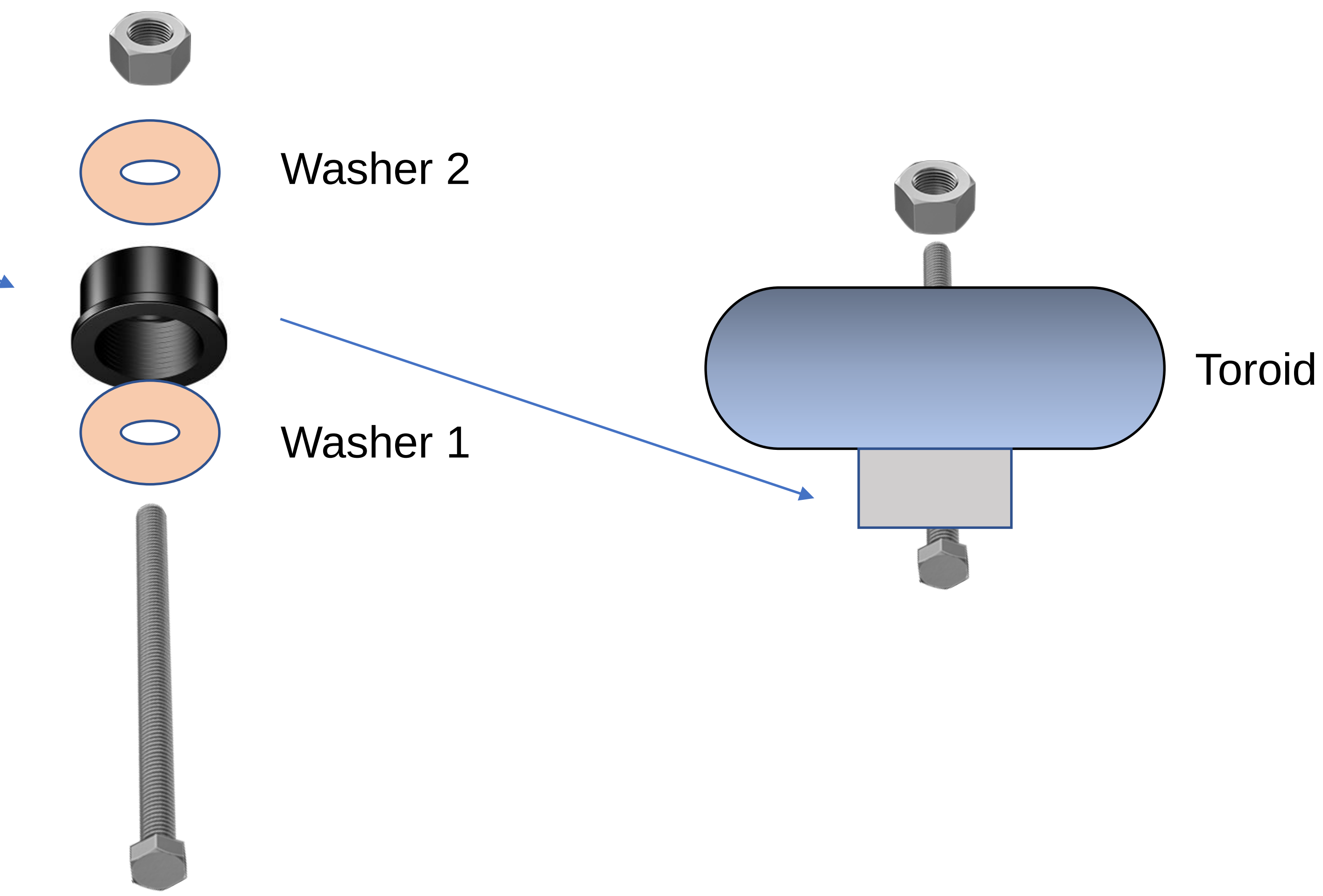
Secondary Coil Construction



AWG# 22 Wire wound on pipe
Diameter= 9.5 cm
Number of Turns, N_2= 515
Length = 33.5 cm



Calculated Inductance, L_2~ 6.4 mH
Measured: 6.7 mH

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Primary and Secondary Coil-Data at a Glance

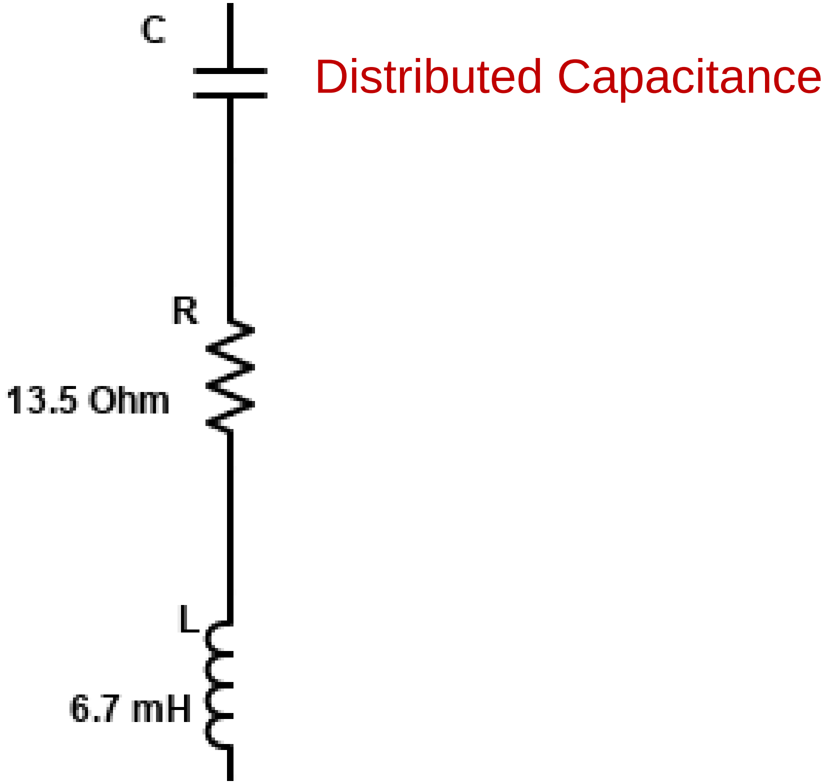
Secondary Coil:
New Tesla coil Data:
Coil Dimension: Diameter: 8.95 cm (3.5 inches), Length: 33.5 cm (13.2 inches)
Wire Gauge: AWG# 22, Number of Turns, N = 515

R= 13.5 Ohm
L=6.7 mH
Considering the top capacitance, resonant frequency: 460kHz
Capacitance:~ 18pF

Primary Coil: Conical
Number of Turns, N=6
Larger diameter: 23.5 cm
Smaller diameter: 19 cm
Width: 11 cm
Calculated inductance: 8.1 uH

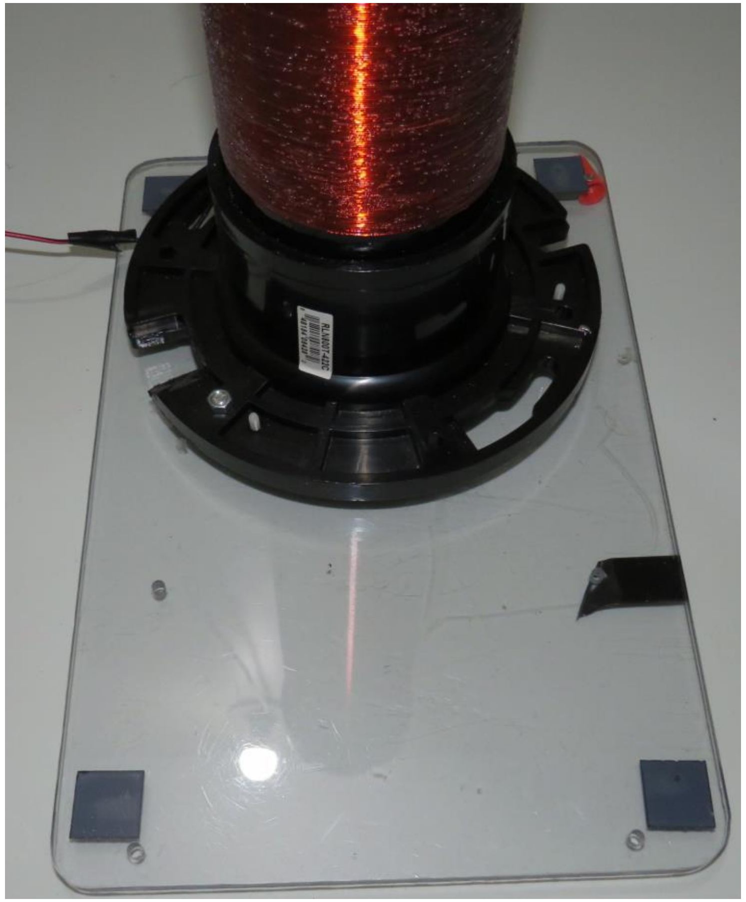
Secondary Coil and Tesla Coil Base

Equivalent Circuit



Calculated Inductance, $L_2 \sim 6.4$ mH
Measured: 6.7 mH

Tesla Secondary Coil : Photo



Coil-base on a plexiglass plate

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Top Load Construction

Flexible Aluminum Duct: 3 inch x8 foot *(Expanded)*

Bent to for toroid
Aluminum sheet-disc
And foil tape is used

Calculating the capacitance of a toroid:

D1: the major diameter of the
D2: is the minor diameter of the ring of the toroid.

D1 =9.5”
D2= 3”

This formula is using inches for measurements. Result is in pF.

$$C = 2.8 \cdot \left(1.2781 - \frac{D2}{D1}\right) \cdot \sqrt{\frac{2 \cdot \pi^2 \cdot (D1 - D2) \cdot \left(\frac{D2}{2}\right)}{4 \cdot \pi}}$$

C ~ 10.5 pF

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Tesla Coil with Top Load

Calculated top load capacitance:
C_T= 10.5 pF

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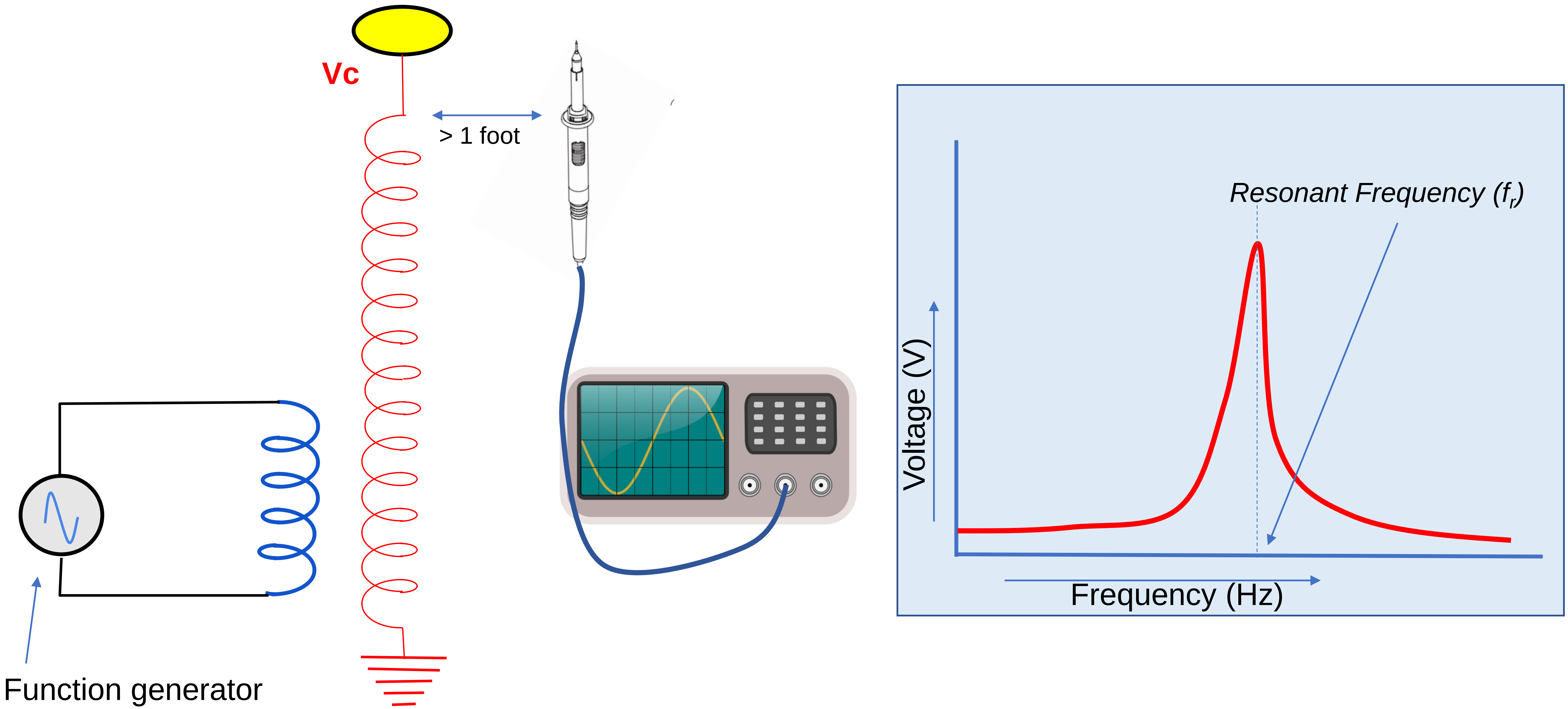
Experimental Determination of Resonant Frequency



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Experimental Setup to Determine the Resonance-Frequency

Resonant frequency found: 460 kHz

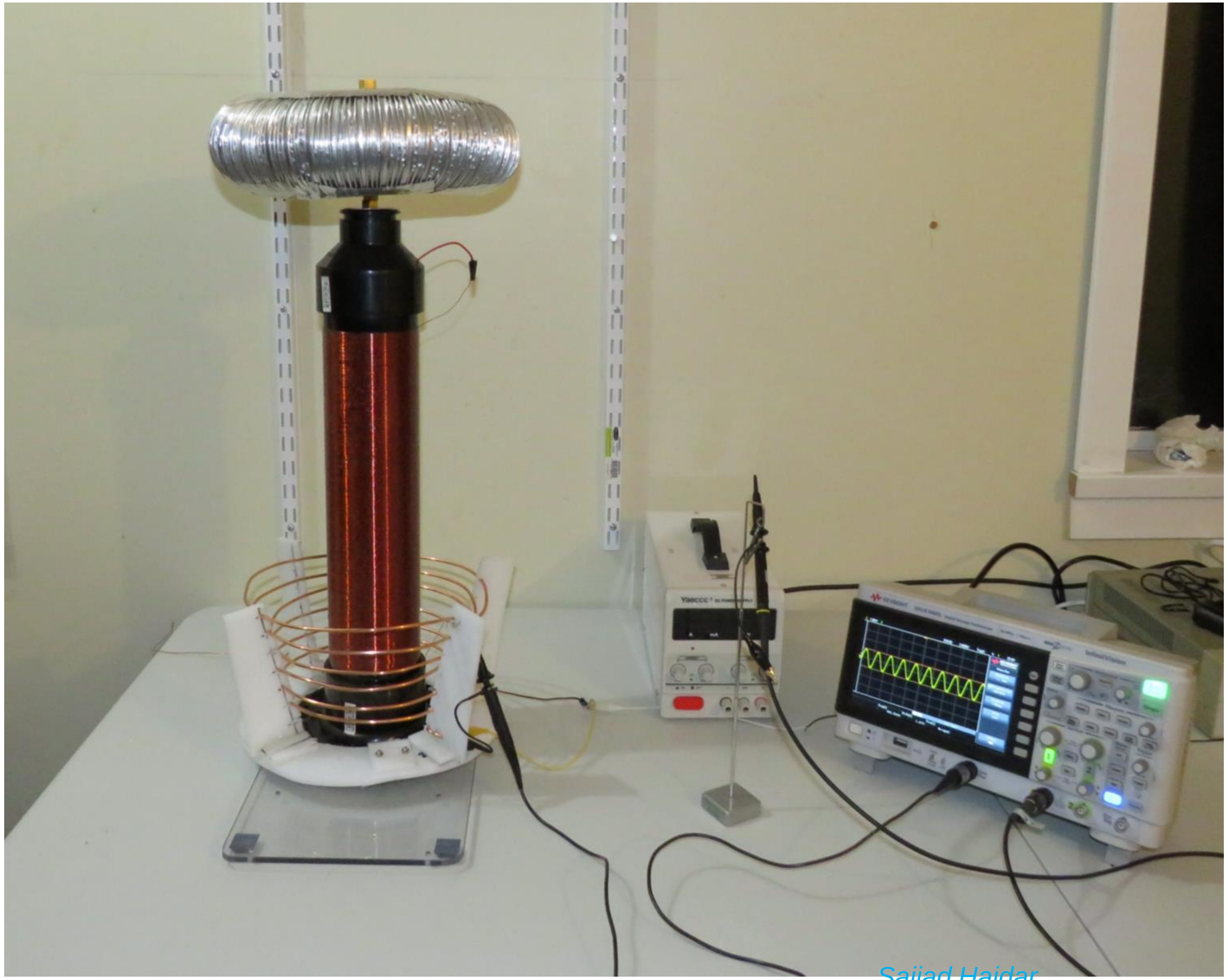
Inductance of the secondary coil: 6.7 mH

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

Which gives, C ~ 18 pF

Distributed capacitance of the coil:

$$C_D = C - C_T = 18 - 10.5 = 7.5\ pF$$



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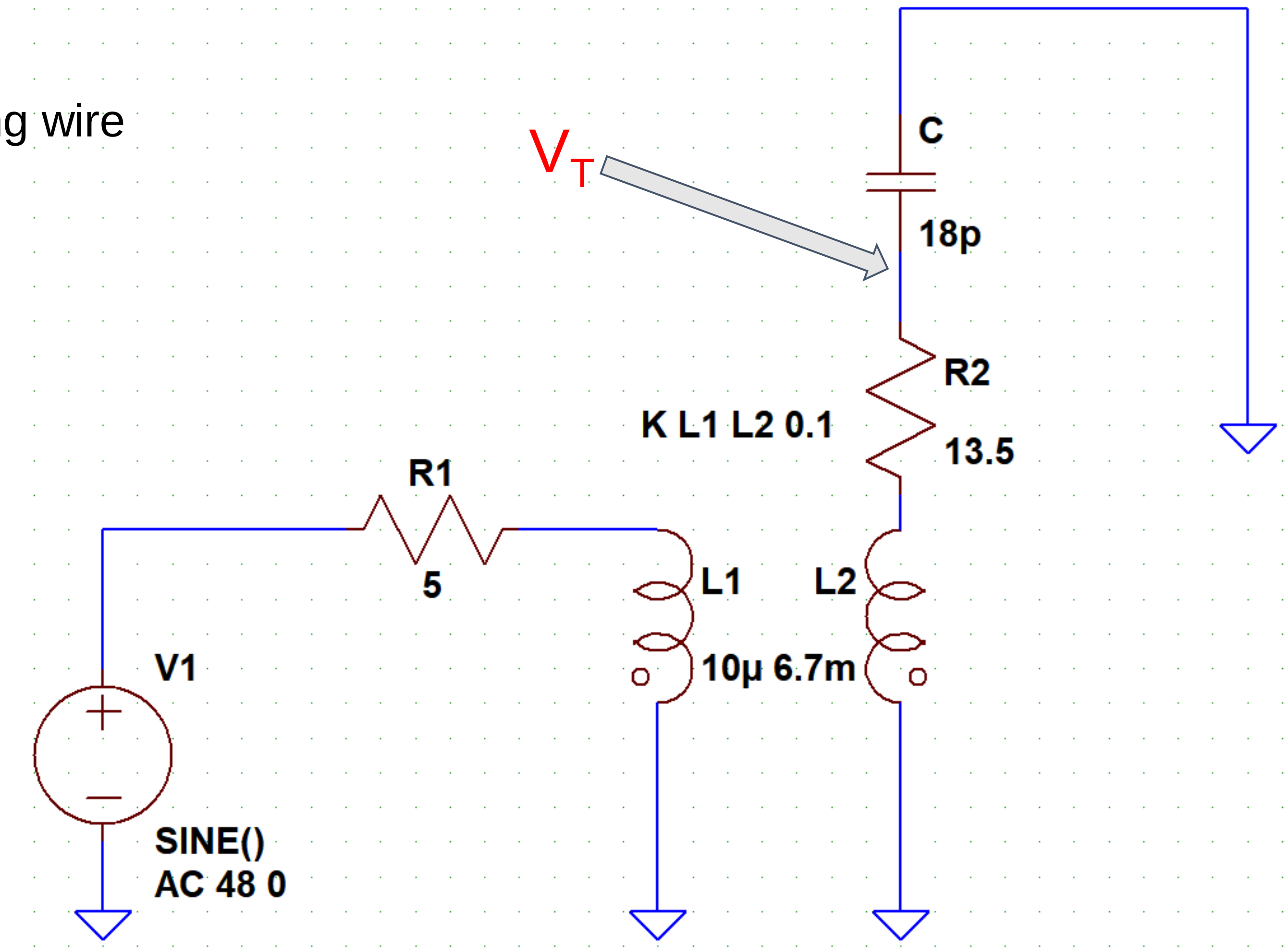
Equivalent Circuit Simulation in LTSpice

Primary inductance, L1 = 8 uH + connecting wire inductance ~2 uH, L1 ~10 uH

To protect the main switching circuit (MOSFET) a series resistance (~5 Ohm) is used. R1 ~ 5

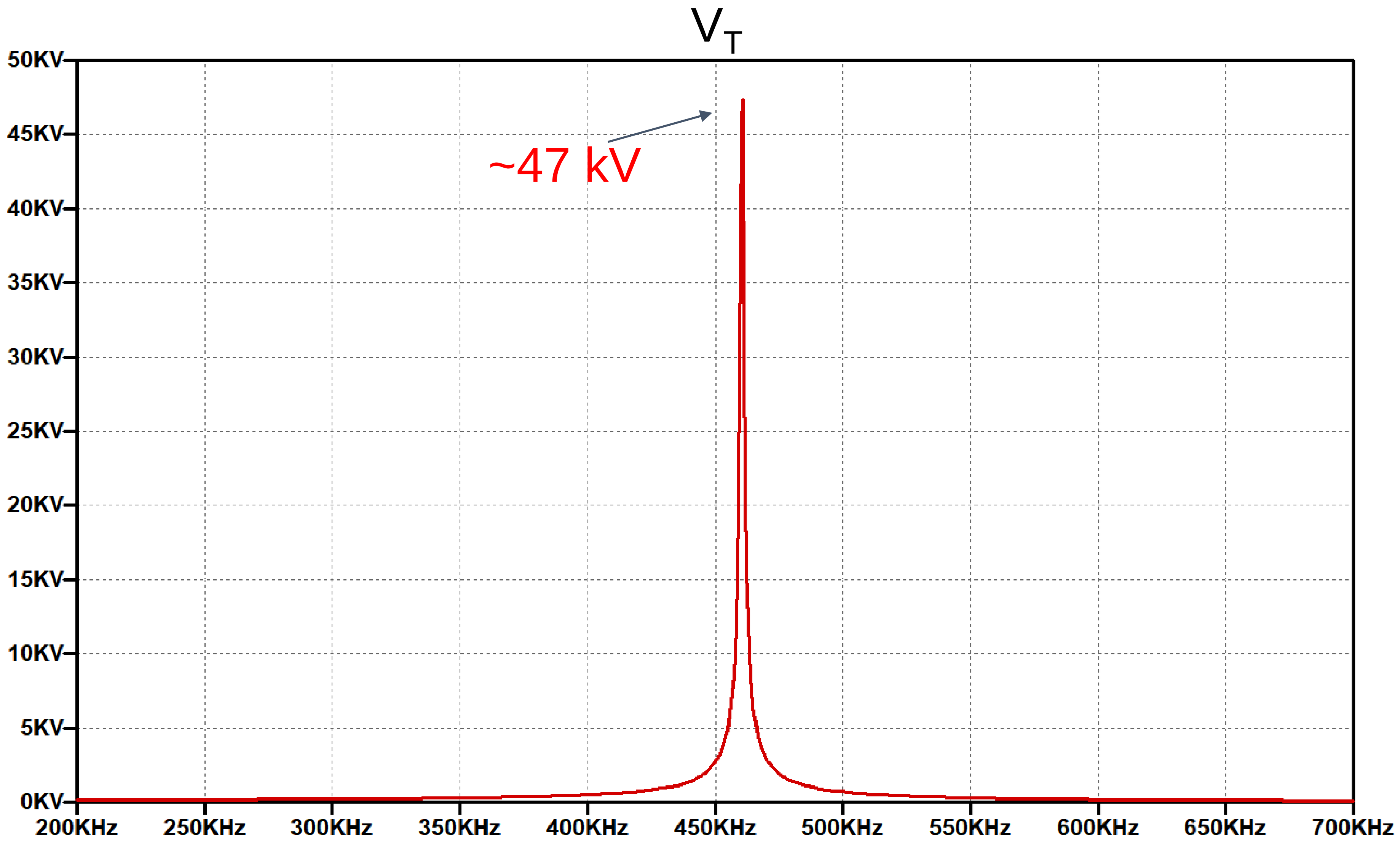


Simulation Result

Voltage gain

$$\frac{47\ kV}{48\ V}$$

~1000



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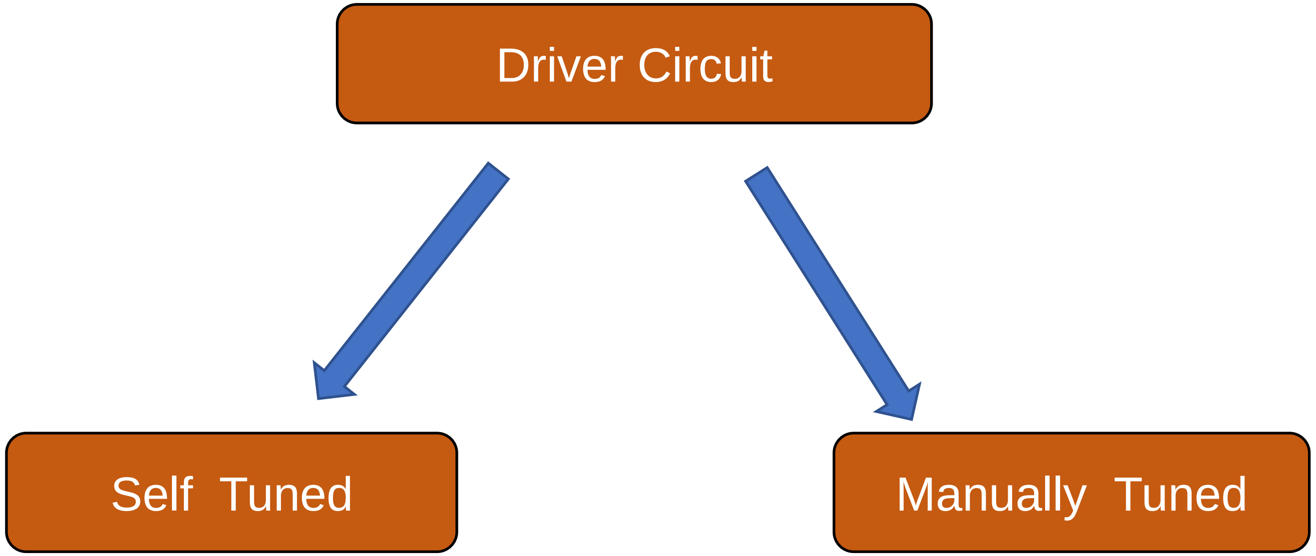
Practical Tesla Coil Driver Circuits



Part of secondary coil signal is fed back to the driver circuit to maintain oscillation at the resonant frequency

Tuned by itself

Tuneable oscillator drives a half or full bridge, the output of the bridge drives the primary

Difficult to tune, as resonance changes for various reasons

Tried both

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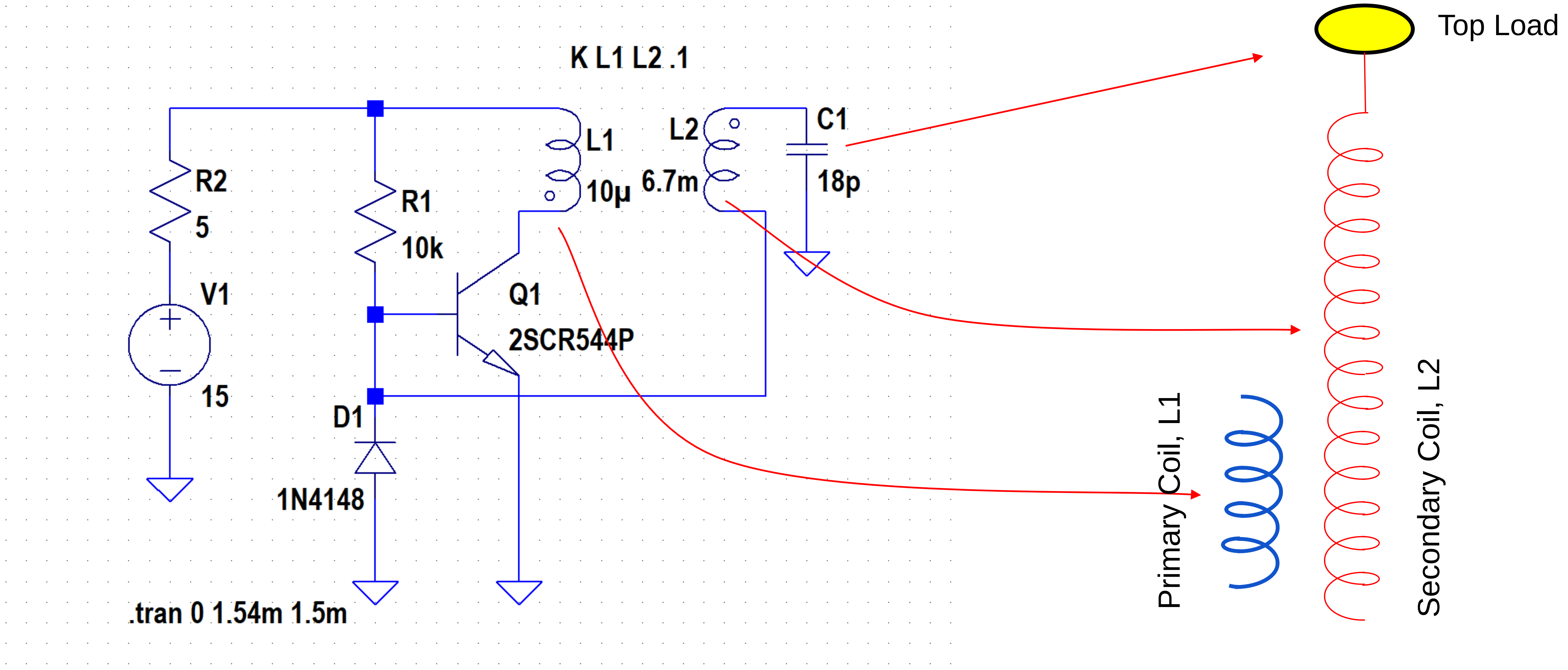
Simulation: Simple Slayer Exciter Circuit to Test the Tesla Coil



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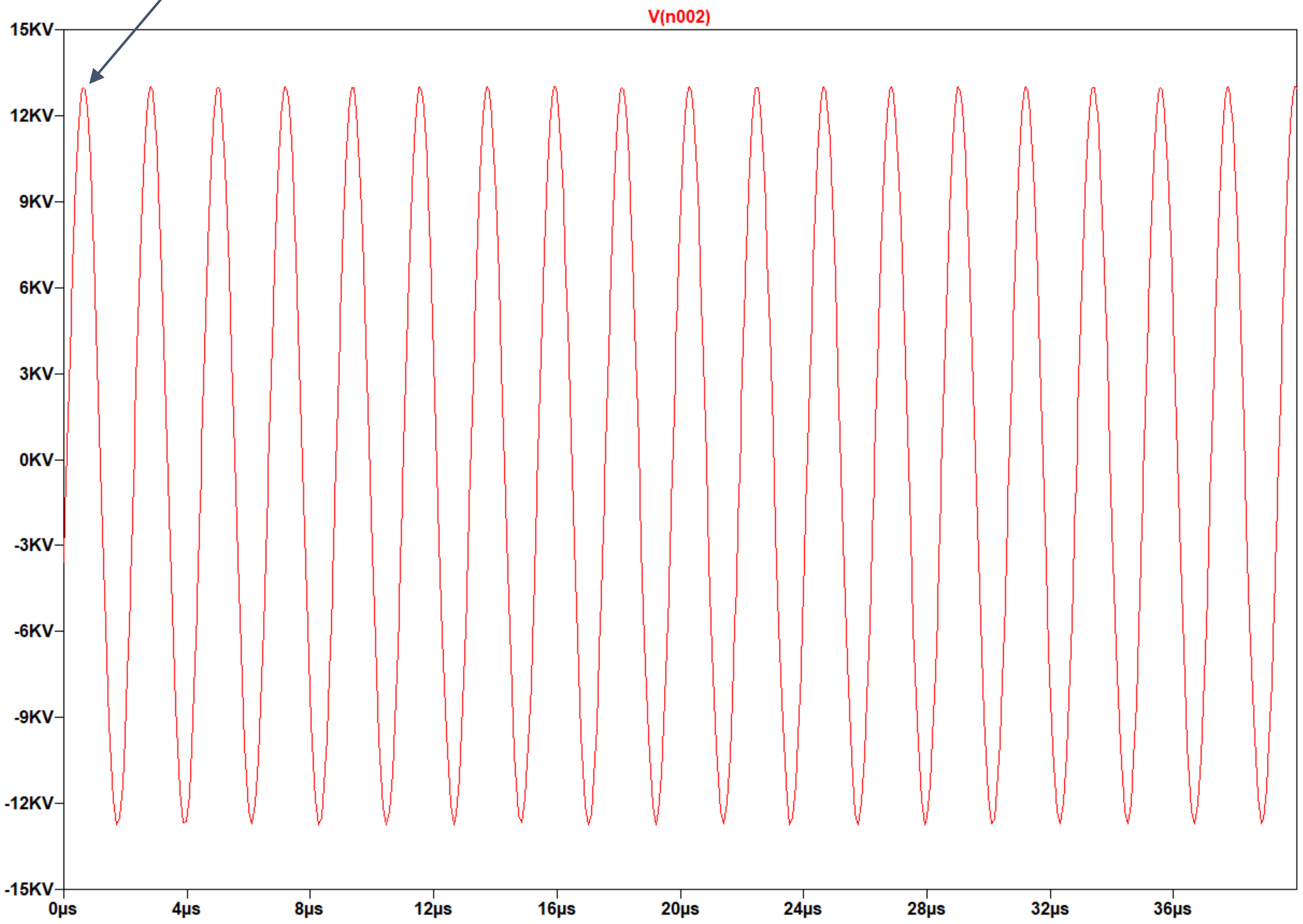
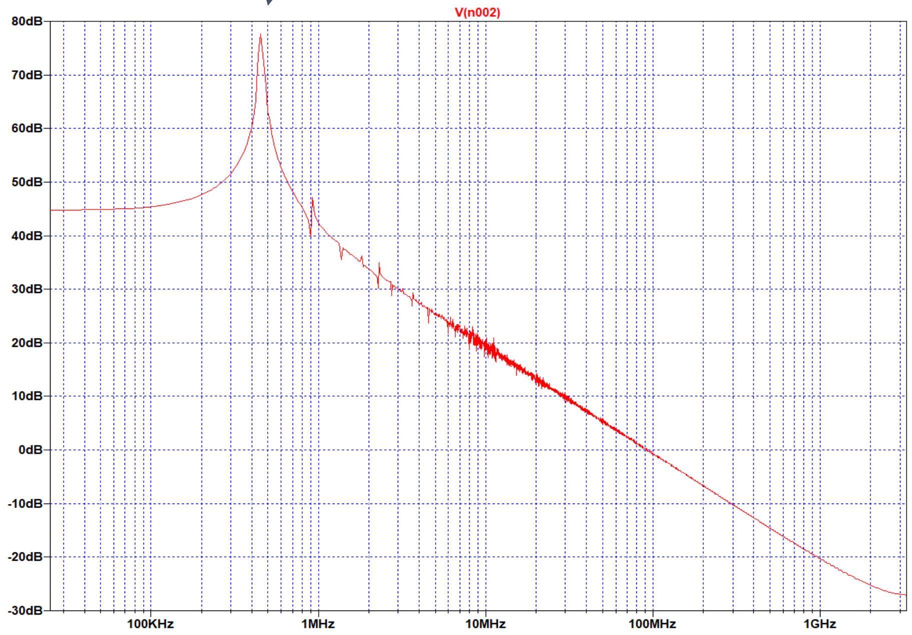
Simple Slayer Exciter Circuit to Test the Tesla Coil
Simulation Result

13 kV



Oscillation Frequency
455 kHz



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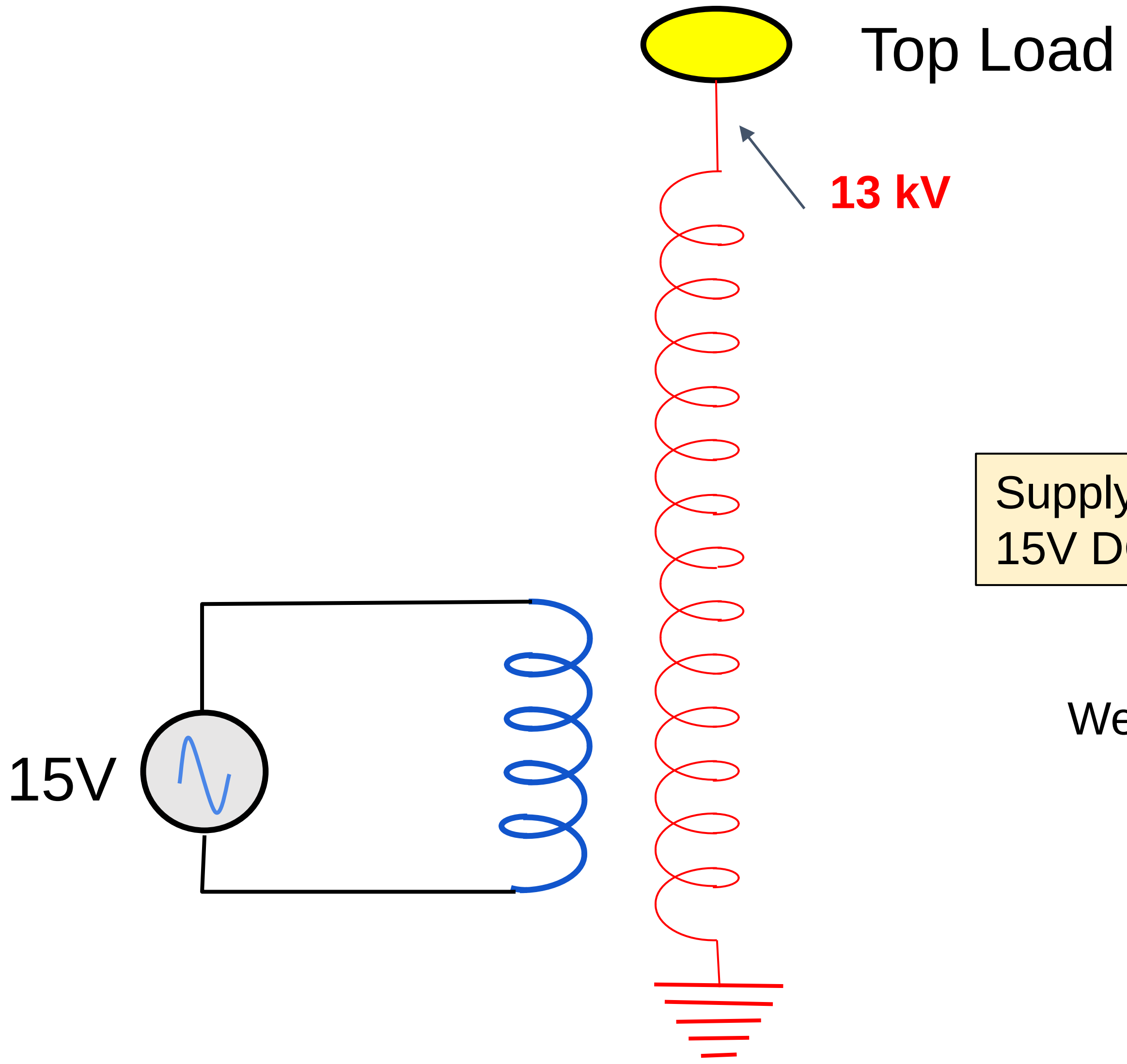
Simulated Tesla Coil Voltage



Supply voltage
15V DC

Top load Voltage
13 kV AC

We are getting ***13 kV*** *(!)* with this simple circuit

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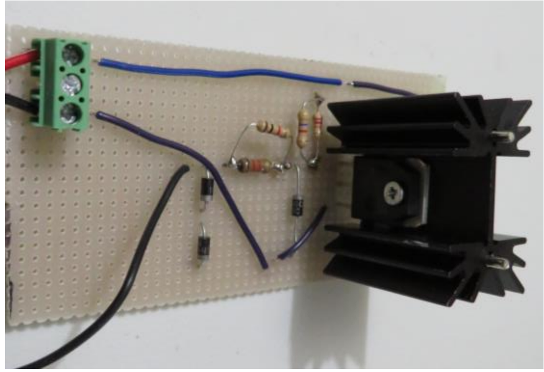
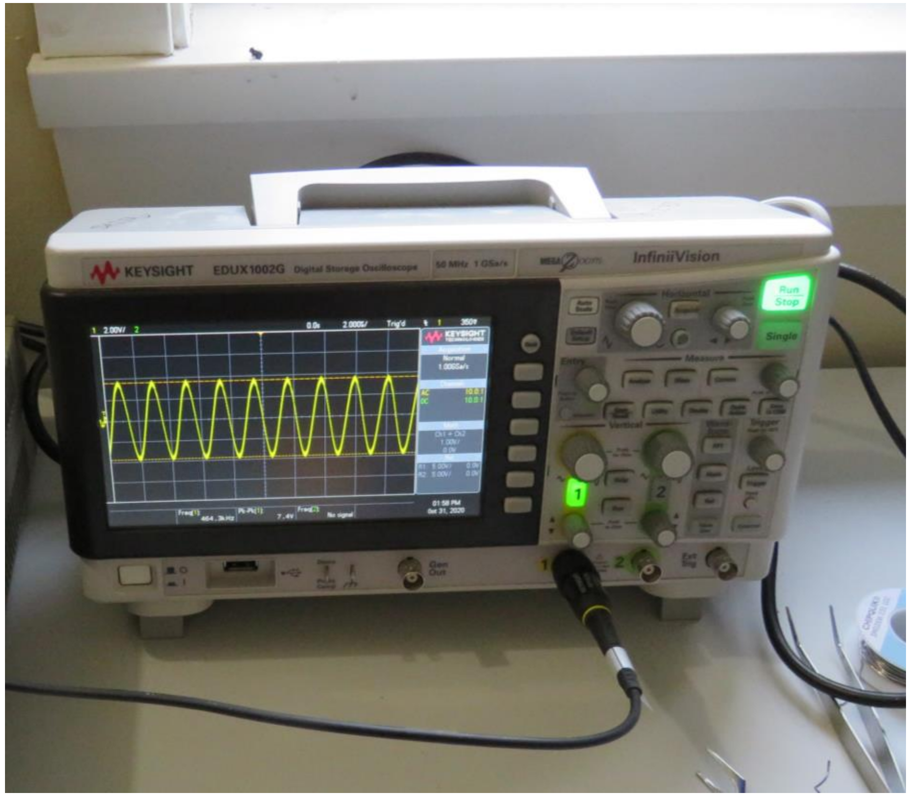
Test of the Simple Slayer Exciter Circuit





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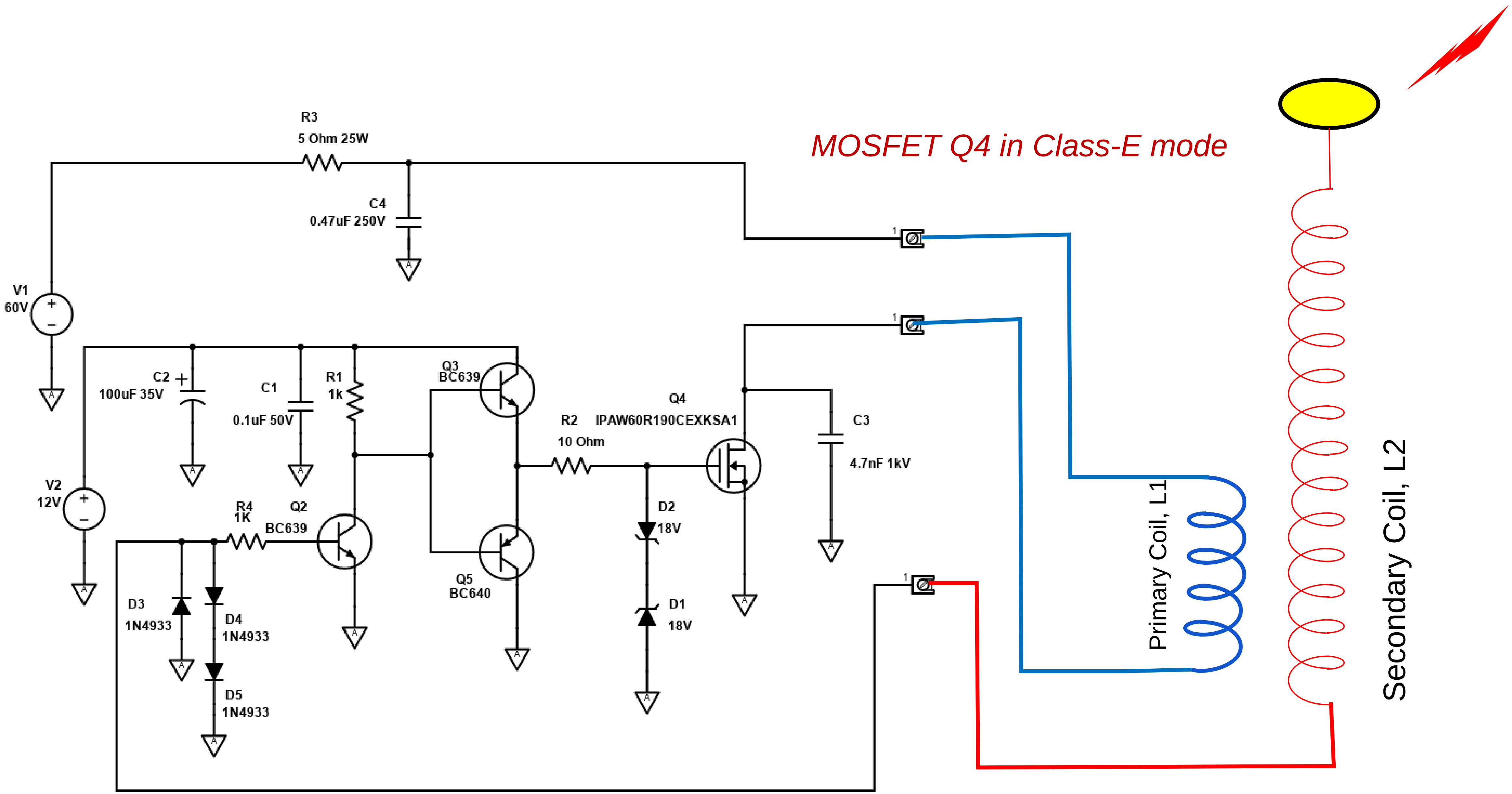
To Achieve Higher Voltage (Bigger Arc)   Modified Circuit is Used



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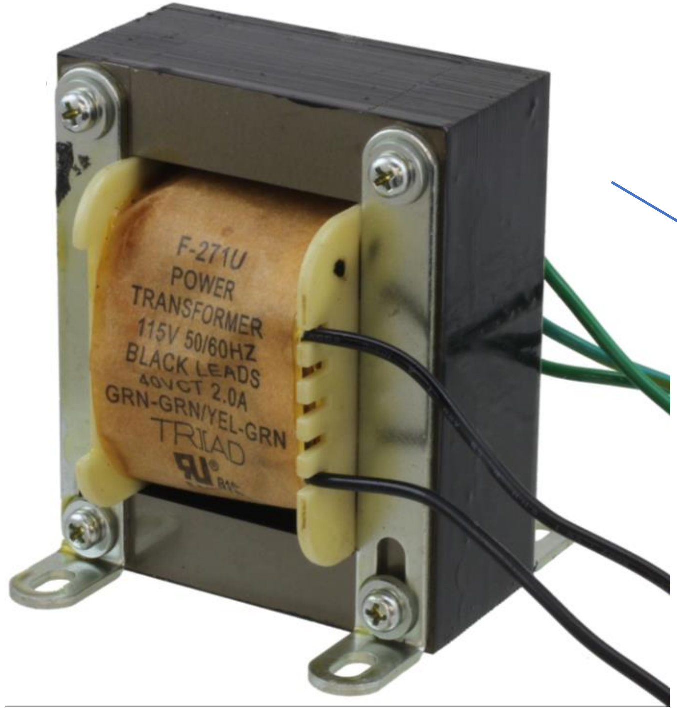
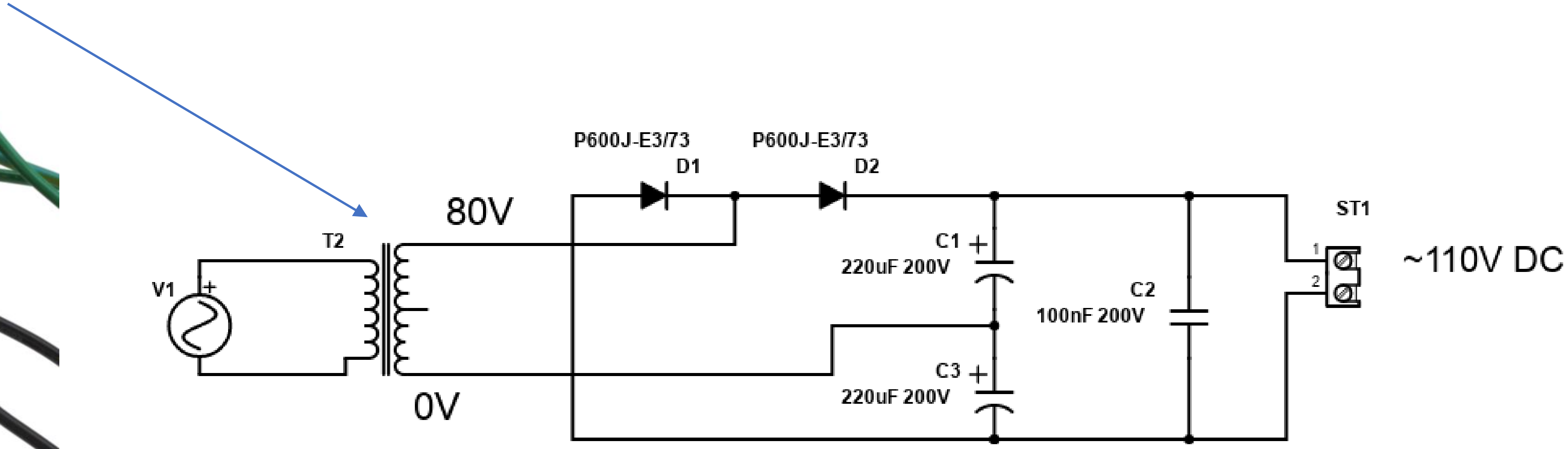
110V DC Power Supply for Tesla Coil





F-271U
Primary: 115V Ac
Secondary: CT, 40V, 2A
Power 80 VA

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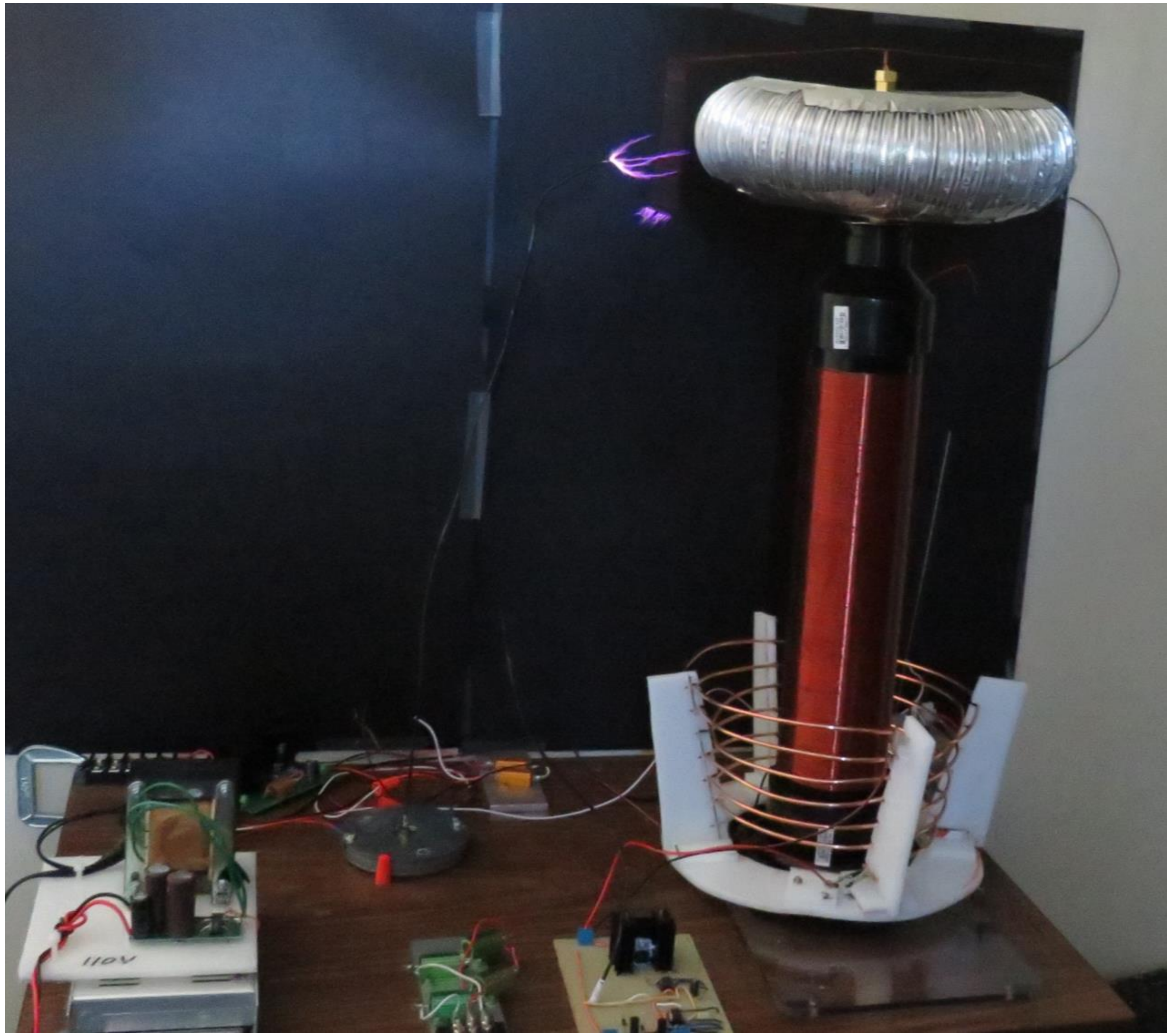
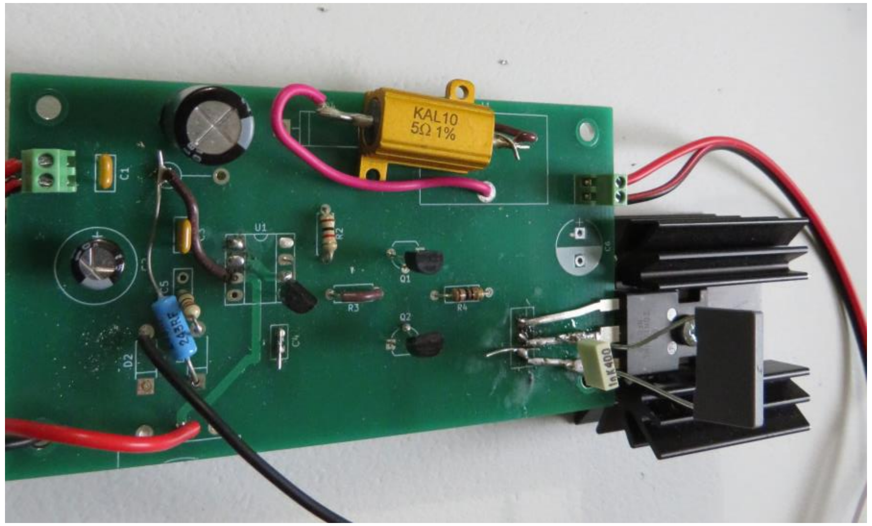
Class-E MOSFET Slayer Exciter Circuit, Driving Voltage: 110V DC





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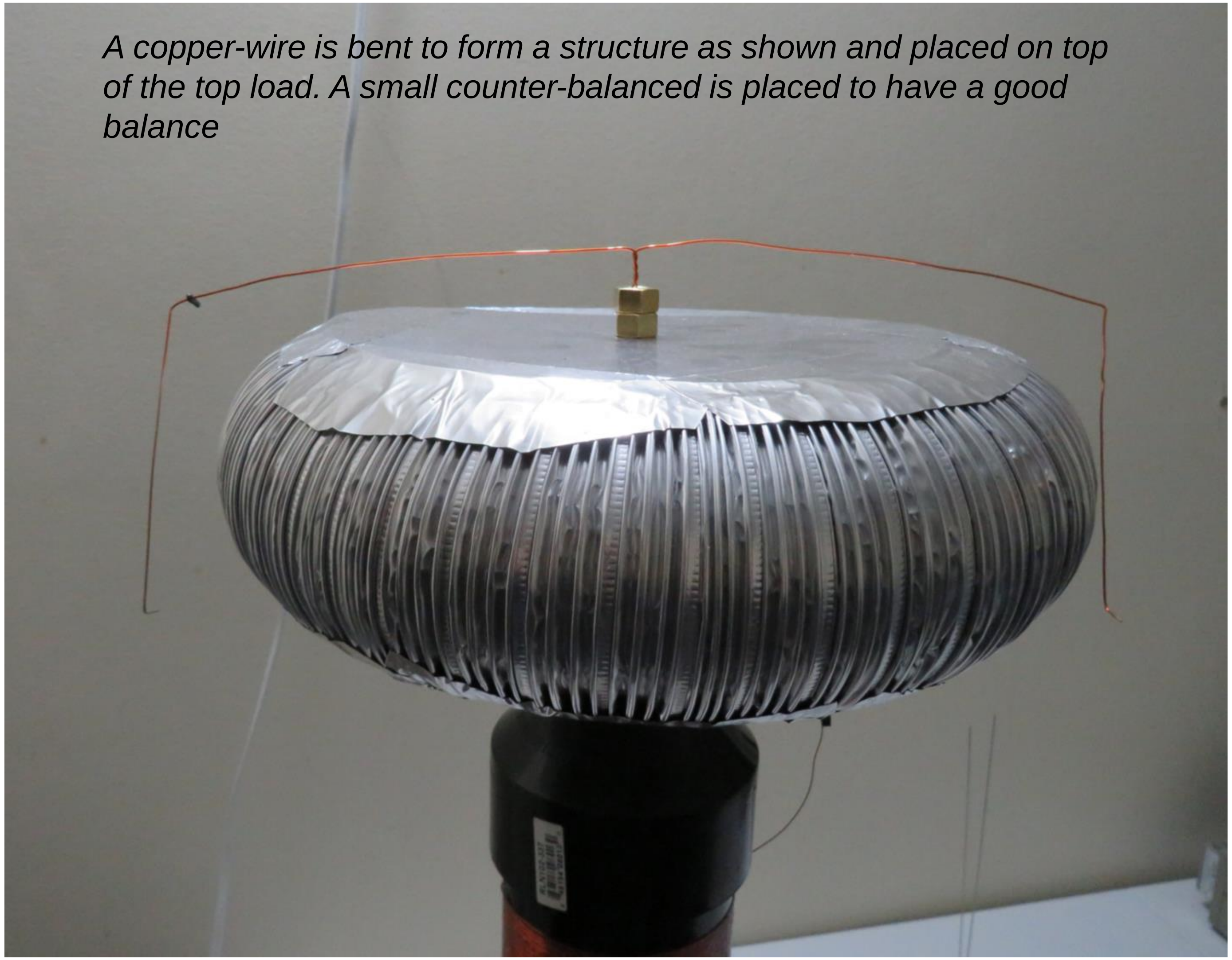
Rotating Ionic Propulsion with Tesla Coil

A copper-wire is bent to form a structure as shown and placed on top of the top load. A small counter-balanced is placed to have a good balance



https://www.youtube.com/watch?v=U2QSbAbUgPc&feature=youtu.be

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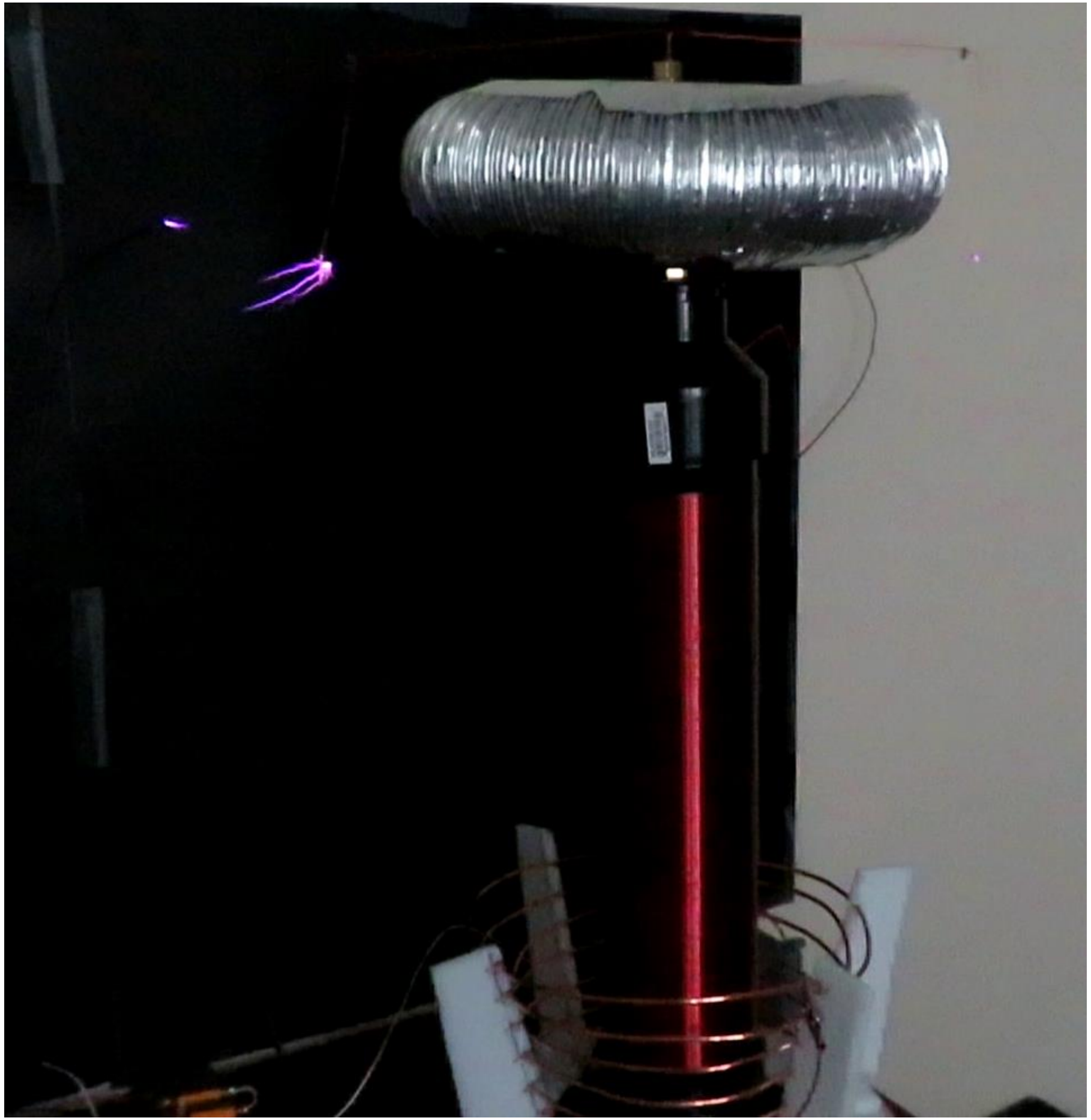

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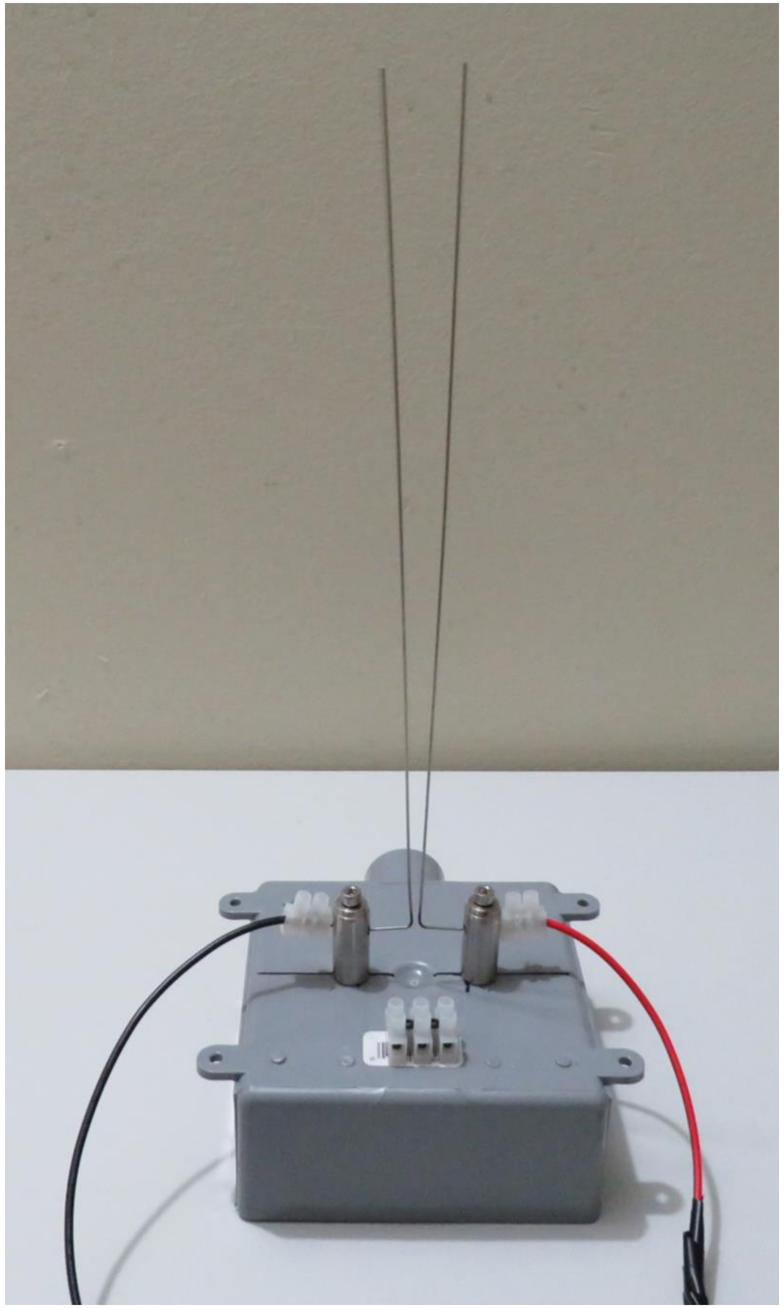

Tesla Coil with Jacob's Ladder

A pair of steel-wire is bent as shown to form a Jacob's ladder. One terminal is connected to the ground and the other to the top load. Arcing starts from the bottom and reaches the top. Cycle begins

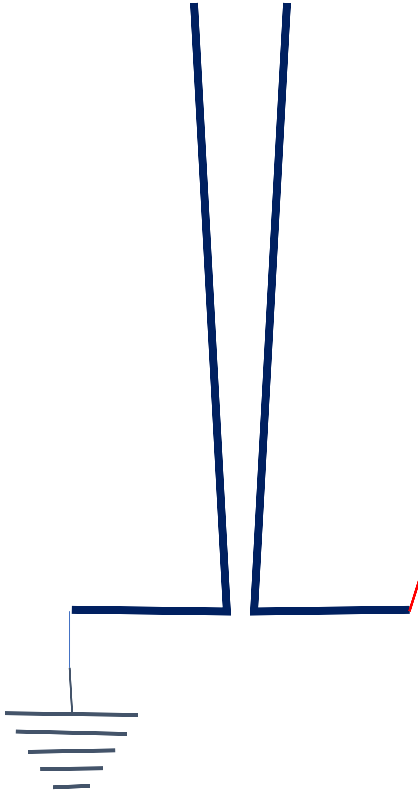

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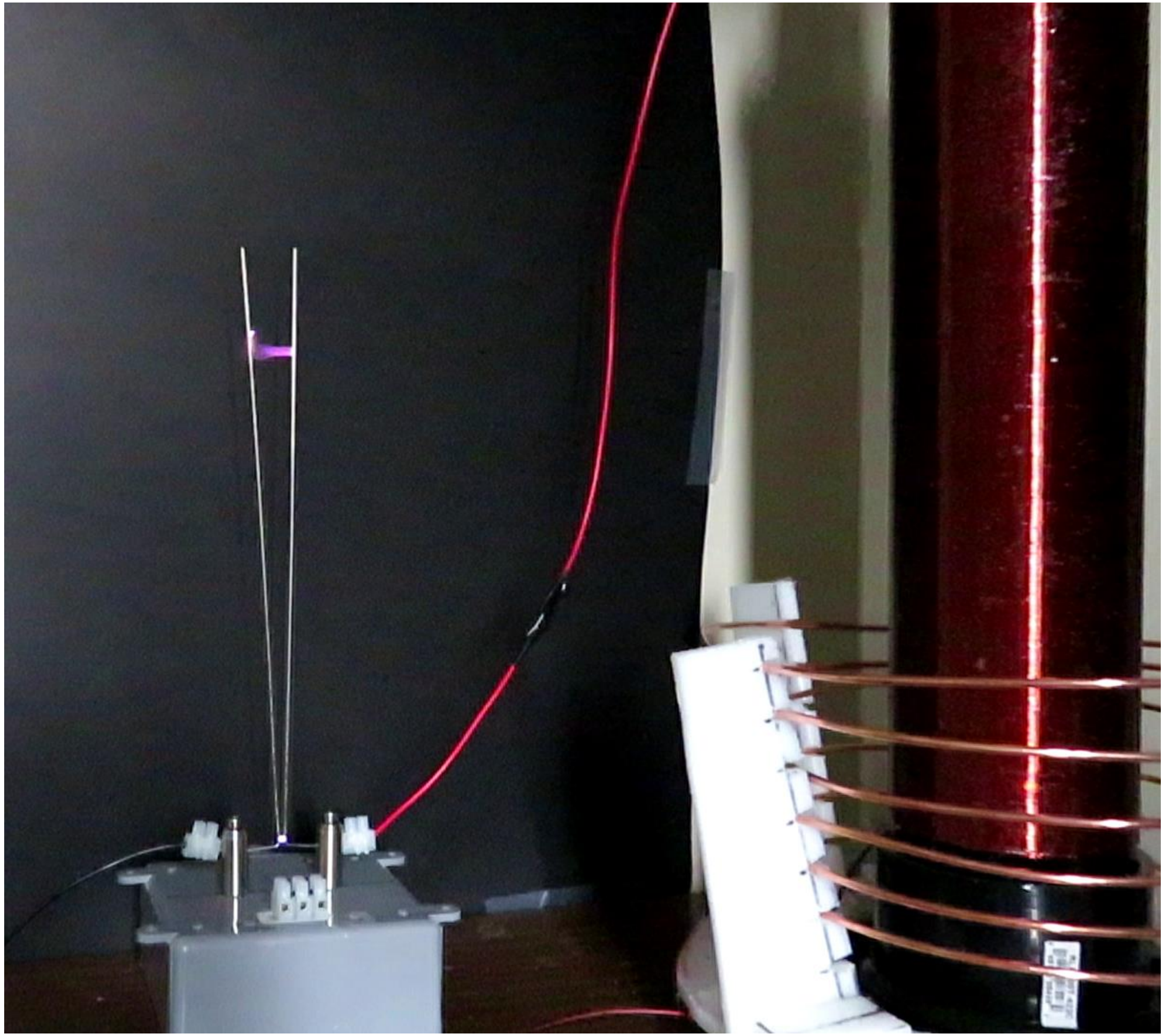
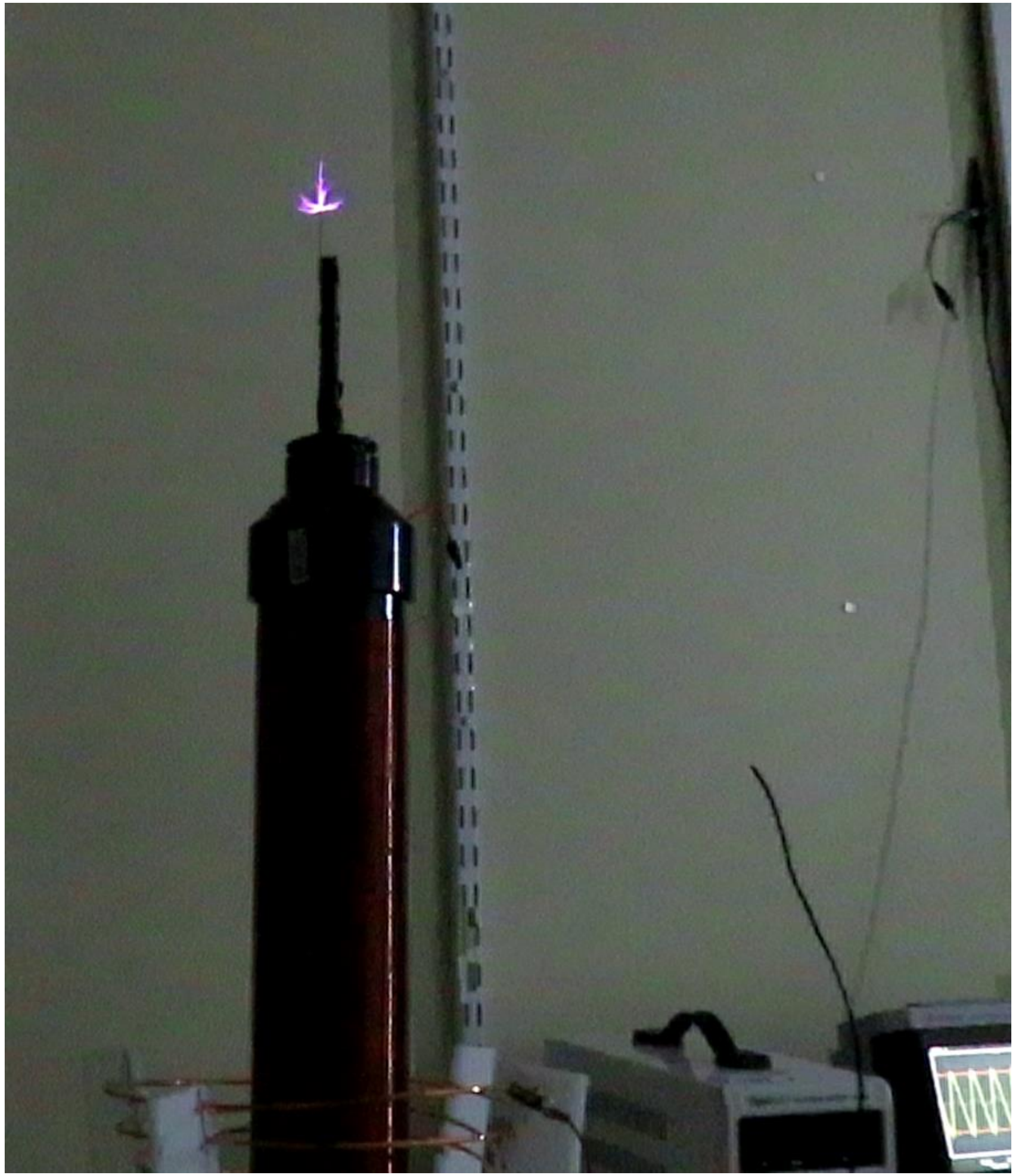
Photo and Video-link of the Tesla coil Connected to the Jacob's Ladder



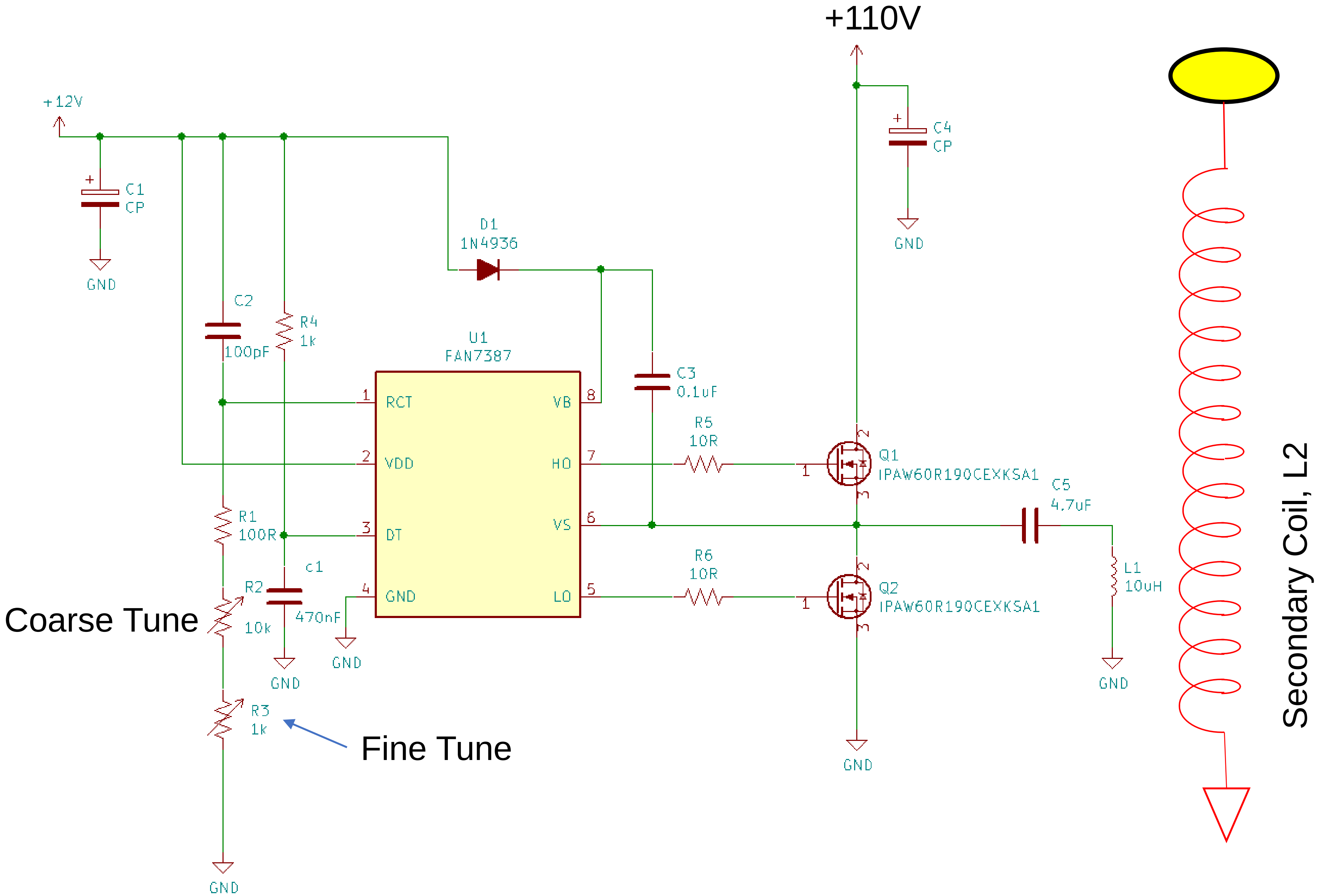
https://www.youtube.com/watch?v=ZHksr7DKXZ4&feature=youtu.be

Tesla coil without the Top Load



https://www.youtube.com/watch?v=nxPptbAT3AE&feature=youtu.be

Manually Tuned Tesla Coil Driver



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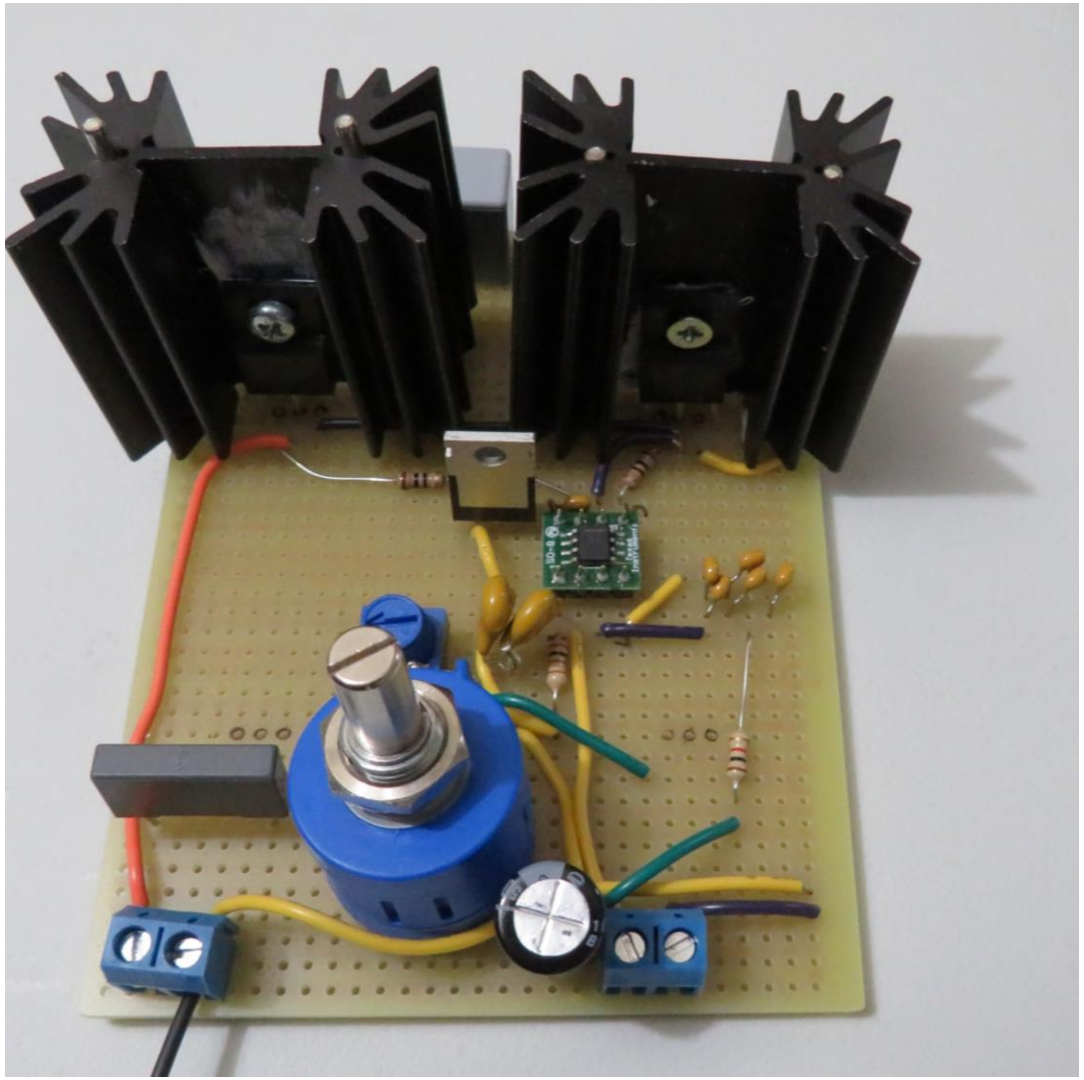
Practical Half-Bridge Driver

Using this half-bridge driver circuit shows similar kind of effect as that of the class-E Slayer exciter circuit. However, difficult to tune. Tuning is achieved by two knobs: coarse and finetuning



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Reference

Best: lot of workable practical examples

https://www.stevehv.4hv.org/SSTCindex.htm