30mm Tesla Coil Project

Written By Flavio Spedalieri November 2020

Abstract – This document details the project undertaken to construct a small Tesla Coil with focus and considerations to many of the design elements and materials to achieve a functional and high-quality instrument.

I. Introduction

The construction of a Tesla coil has been a long-standing desire for many years, however I first came to hear of a Tesla Coil much earlier in 1990, around the same time as my own interests and study in the fields of photonics and LASERS had commenced, where I was shown the circuit diagram of Tesla Coil System. Some 24 years would come to pass before I commenced building components for a larger 100mm (4-Inch) Tesla Coil.

As many things in life, I came against limitations of where to run a coil of this size, storage, acquisition of high-quality materials, design considerations including design and construction of RF earth systems, the project remains on the boil.

In late August 2020, my motivation again had started to peak when I decided to build a *Slayer Exciter* [1] circuit. Around the same time, I also viewed a project by Jay Bowles's [2] *Plasma Channel* [3] on using an arc lighter as a high voltage power source for a small Tesla Coil [4].

The use of a small battery powered high voltage power source was very inspiring and this led me to sit down and begin engineering my own build.

II. The Tesla Coil – Overview

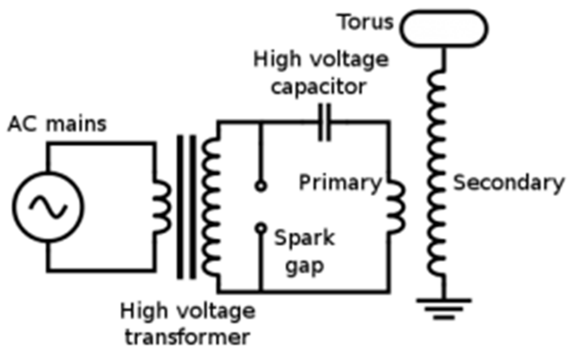


FIG 1 – Tesla Coil Circuit

A Tesla Coil is a *Resonant Transformer* [5], invented by Nikola Tesla [6] where low voltage AC currents are transformed to very high voltages, low current, high-frequency alternating currents. [7]

A Tesla Coil comprises of two L-C (inductor – capacitor) tuned (resonant) circuits [8] that are inductively (loosely) coupled.

The primary L-C circuit comprises of the 'tank' capacitor, primary coil (inductor), and a '*switch*' to complete the circuit.

Switching of the primary circuit can be achieved by several methods; In a 'classic' Tesla Coil, a basic spark gap arrangement is used. Other topologies include; vacuum tube and in modern Dual-Resonant Solid-State Tesla Coils (DRSSTC), solid-state transistors (IGBT) are employed & require complex control electronics.

The secondary L-C circuit comprises of the secondary coil (the large central tower that is iconic to a Tesla Coil), and the 'Top Load' which provides the capacitance.

When power is applied to the primary circuit, the capacitor will begin to charge, eventually the voltage across the capacitor will increase sufficiently to short across the spark gap. The energy of the capacitor will discharge through the spark gap and into the primary coil. The energy will oscillate back and forth between the capacitor and the primary coil at a (high) frequency that is determined by the capacitor value (µF) and the primary coil's inductance (Henry, H).

A Tesla Coils ability to generate very high voltages and long arcs (streamers), is due to a process known as Resonant Voltage Rise occurring in the secondary LC circuit. [9]

In summary; the basic operation of a Tesla Coil may be described is most simple form, as a person pushing a child on a swing;

The energy in the primary circuit, moving back and forth between the capacitor and primary coil (like a mechanical pendulum), transfers (couples) some of the energy to the secondary circuit, at each "push", the voltage in the secondary continues to rise until the electrical field strength exceeds that of the insulating property of air surrounding the large surface areas of the top load and breaks out as an arc.

Tesla coils can be scaled up to produce many millions of volts. Currently the world's largest Tesla coil designed and built is the 'Electrum' designed by Eric Orr and built by Greg Leyh (Lightening on Demand). [10]

III. Design Concept

The initial inspiration and design brief for a tesla coil: To design a small unit, using an arc lighter power supply as the high voltage source.

In part, the motivation of the project was to gain a 'feel' and experience for researching magnetic wire sizes and coil form material to use as the secondary. Much of the research focused on the design parameters of wire sizing, preparation of the coil form and finally applying these theories to winding of the secondary coil.

At hand, I had several main components available;

Capacitor(s): 3000pF (3nF) 20kVAC 'doorknob' ceramic capacitor.

Winding Wire: Available spool: 0.25mm (30AWG) ~ 25gms / 58 meters.

Aluminium Toroid: 107mm (major) x 27mm (minor).

High Voltage Supply: Arc lighter or 6kV / 30mA Neon Transformer.

IV. Software Design

With some of the basic parameters in hand, the design concept(s) were then modelled in *JavaTC* [11] and *TeslaMap* [12] design programs.

V. Inspired Design Elements

One major aspect of the project was starting with components that had on hand and or accessible through local supplies prior to embarking on a larger project.

In the very early stages of the project a 50mm (2 inch) secondary had been designed, however the required lengths of wire, would have required a special order for a large spool.

Revising the available wire from our local electronics store (Jaycar Electronics), they had available a small spool of 0.25mm enamelled copper wire.

Given the available length of wire, and confirmation of readily available diameters of PVC tube, the next several hours was spent in calculating a secondary form that would allow for around a 4:1 aspect ratio.

The final design resolved a coil of 33.5mm diameter with a winding height of 132mm, with the coil wound on a 30mm PVC form.

SECONDARY COIL OUTPUT DATA

Secondary Resonant Frequency	1618.28	kHz
Angle of Secondary	90	deg °
Length of Winding	13.2	cm
Turns Per Unit	37.88	cm
Space Between Turns (e/e)	0.00936	mm
Length of Wire	52.62	m
H/D Aspect Ratio	3.94	:1
DC Resistance	17.6699	Ohms
Reactance at Resonance	18794	Ohms
Weight of Wire	0.024	kg
Effective Series Inductance-**Les**	1.848	mH
Equivalent Energy Inductance-Lee	1.931	mH
Low Frequency Inductance-Ldc	1.879	mH
Effective Shunt Capacitance-**Ces**	5.233	pF
Equivalent Energy Capacitance-Cee	5.009	pF
Low Frequency Capacitance-Cdc	8.014	pF
Topload Effective Capacitance	3.997	pF
Skin Depth	0.0562	mm
AC Resistance	88.3825	Ohms
Secondary Q	213	

FIG 2 – Secondary Coil Data (JavaTC)

With the secondary design completed in JavaTC, construction commenced in Ernest.

VI. Winding of Secondary

Preparation and winding of the secondary commenced on 7th September 2020.

A 160mm length of PVC tube was cut allowing for approximately 10mm clear at each end. The PVC was then sanded, and the surface sealed with two coats of *UltiMeg 2000* electrical varnish. [13]

The winding process commenced, using a hand drill to hold the form and slowly guiding the wire onto the form. The winding process was completed in around two and a half hours.

Photo 1 – Completed Secondary coil

Over the next several days, the secondary was coated and sealed with several coats of clear varnish.

Photo 2 – Measuring Approximate Turns

The approximated (averaged turns); 38 turns / cm ~ 500 turns total.

Photo 3 – Secondary & Toroid.

The ends of the secondary form have been sealed using FR-4 (uncladed PCB).

The construction techniques for the secondary have been adhered to as would with much larger (high performance) coils [14], no part of the winding penetrates the form. The ground end of the winding is terminated using a copper tab construction, while the top of the coil supports a nylon screw that has been epoxied to the top plate prior to sealing of the secondary form.

The ends of the windings have been finished with black electrical tape and the secondary given several more coats of clear varnish.

A coupling method was utilised that would allow the secondary to "plug-in" to the system, this would allow a modular approach and safe storage of the secondary when not in use.

The coupling also serves as the electrical ground connecting point at the base of the secondary.

Photo 4 – Secondary & Support Coupling

The secondary form was completed on 11th September 2020.

Initial baseline characterisation conducted on the secondary coil with an CRO and sig-gen;

DC Resistance:	19.2 Ω
Resonant Frequency:	1708 kHz (with toroid) 2489 kHz (Without)

Photo 5 – Secondary Resonance Freq Tests

VII. Project Direction

Following the completion of the secondary coil, it was clear the project was taking on a more 'serious' build in that this no longer was a "stepping stone" to gain knowledge and experience, but rather a project to build a high-quality (museum grade), instrument where the aesthetical presentation is also a key design element.

The change of goal also moved to using a Neon Sign Transformer (NST) which I had available, rated at 6,000V at 30mA (180W).

Running additional calculations, a resonant capacitor size was calculated at 0.0159uF, with a larger than resonant (LTR) capacitor at 0.24uf. The initially selected 0.003uF (3nf) will continue to be used as will also provide flexibility to increase capacitance if needed.

Using a Neon sign transformer, some additional components needed would be the protection filter ('Terry Filter'), power factor correction capacitor and EMI line filter.

VIII. Primary Coil Design & construction

The next phase of the project involves the design and construction of the primary coil, supports and platforms to mount all the main coil components.

One of the important criteria when working with high-voltages and high-frequency is consideration to clearances (to minimise arcing and insulation breakdown), selection of appropriate materials suitable for electrical work and finally, methods and techniques of fastening the components together.

The design of the primary commenced on 14th September 2020, with the selection of material for supporting the coil components.

The main support material selected is '*SwitchPanel Type X*' [15], a fibre reinforced, impregnated phenolic resin, designed for electrical insulation purposes.

For the coil, three sections were ordered from Vale Plastics, 180mm x 180mm, with one panel cut with a 50mm central hole to allow it to clear the coupling. This would become the support plate for the primary coil.

The design of the primary took considerable analysis of the best approach with considerations to electrical parameters, size, and design (flat spiral, vertical and conical).

Spending several days researching, a discussion topic was found on the design of the primary coil [16].

With additional understanding of the way the primary coil's electromagnet flux is presented to the secondary coil, a conical primary with an angle of 30° degree is selected.

The conical primary coil field distribution is more uniform over the secondary coil's aspect.

At the widest point (outermost turn), the primary width is set approximately the same as the secondary is tall (~ 140mm). A copper capillary tube with a diameter of 2.14mm is selected and an inter-turn (edge-edge) spacing of 5mm (7.14mm centres) is designed, allowing for a total of 10.5 turns for flexibility in range of tuning.

The mounting platform of the primary coil may be adjusted to fine-tune the coupling with respect to the secondary if required.

Construction of the primary coil commenced on 15th September with construction of the 4 support wedges, which have been cut and prepared from hardwood.{1}

Photo 6 – Primary Coil Support Wedges

The next day, work continued with additional measurements, and final design parameters for coupling mounting of secondary form.

The mounting of the support wedges to the SwitchPanel was achieved using Loctite® two-part epoxy resin adhesive.

Loctite® two-part epoxy was selected due to is new formulation & gap filling characteristics.

One of the most important considerations is that no metal screws or nails would be used, with all fixed components, glued or fastened using nylon fixings.

Initial Shaping of the copper capillary commenced on 17th September 2020, with completion of the primary coil on 22nd September 2020.

Photo 7 – Shaping of Primary Coil

Photo 8 – Shaping of Primary Coil - Detail

Photo 9 – Making of Support Caps

The method to affix the primary coil to the supports and structure is with the use of Loctite® two-part epoxy adhesive and a final wood cap also glued into place to increase mechanical support and add to the aesthetical design element.

Photo 10 – Final Assembly & Gluing of Primary coil & caps.

The central coupler is also glued into place. A copper strip, central brass screw, nut and acorn are used to complete the grounding termination for the secondary.

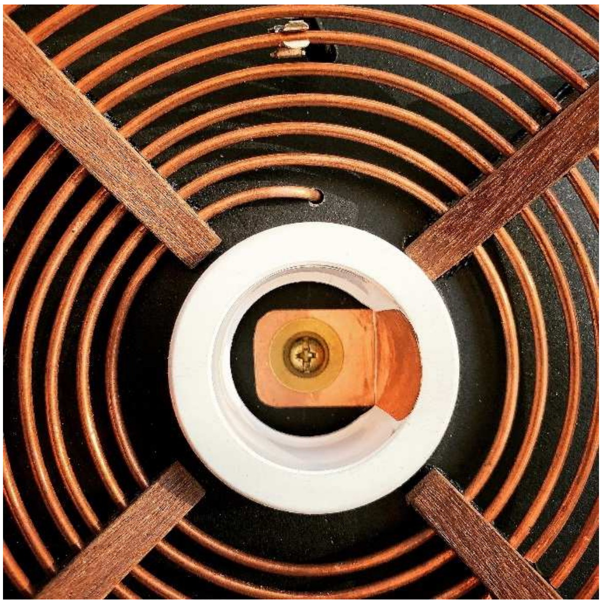


Photo 11 – Secondary Coupler & Grounding

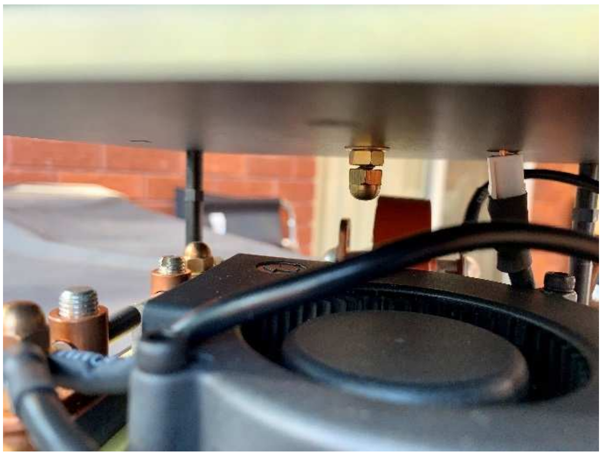


Photo 12 – Secondary Grounding Point

Photo 13 – Completed Primary & Secondary

At this point the major construction of the Primary and secondary components are almost complete.

FIG 3 – JavaTC 3D Rendering.

IX. Terry Filter & Safety Gaps

With the consideration to using a Neon Sign Transformer (NST), the secondary windings are made with very fine wire and typically the insulation is not very good at handling fast, high-voltage transients that are generated in Tesla Coil application each time the spark-gap fires, which can lead to shortening the life of the NST. [17][18]

A method to protect the transformer's secondary windings is the implementation of a low-pass R-C filter network known as a "*Terry Filter*" [19][20].

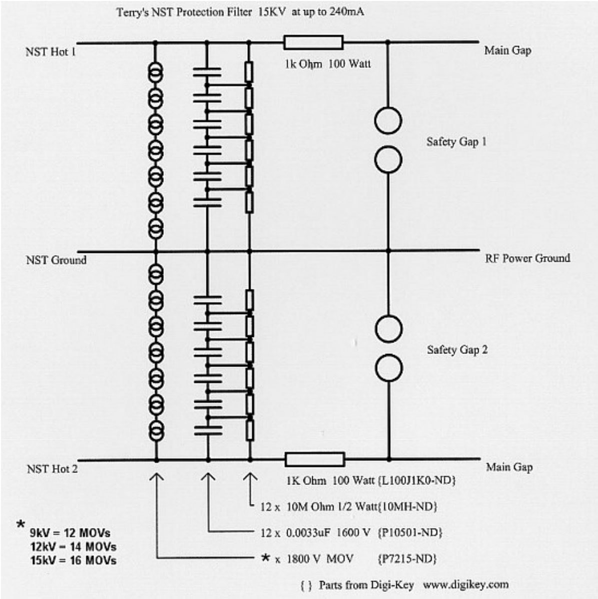


FIG 4 – Terry Filter Circuit (JavaTC)

Construction of the Terry Filter commenced on 28th September 2020, together with additional elements including the main spark gap and safety gaps.

The main capacitors & MOVs are mounted on FR-4 board. The component positioning layout and marking for drilling was completed using a piece of 'Perf board' (prototyping PCB), and the holes drilled by hand using 1mm drill.

Soldering of the components utilised a special soldering technique called "ball soldering" where the joints are made as smooth spherical finish to minimise on corona losses at high voltages.

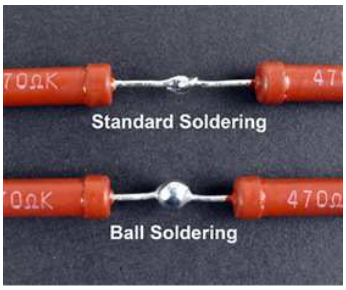


Fig 5 – Ball Soldering

Construction of the safety gaps consisted of 3 brass draw knobs, each ball had to be sanded and with fine wet & dry sandpaper to remove the clear lacquered coating. Each ball was predrilled and tapped with an M4 thread. The three Aluminium blocks have been repurposed as the supports.

The ends of each block were predrilled and tapped with an M4 thread to allow for mounting onto FR-4 substrate and the existing holes redrilled and tapped with an M4 thread. The two left/right balls can be adjusted for correct operation of the safety gap.

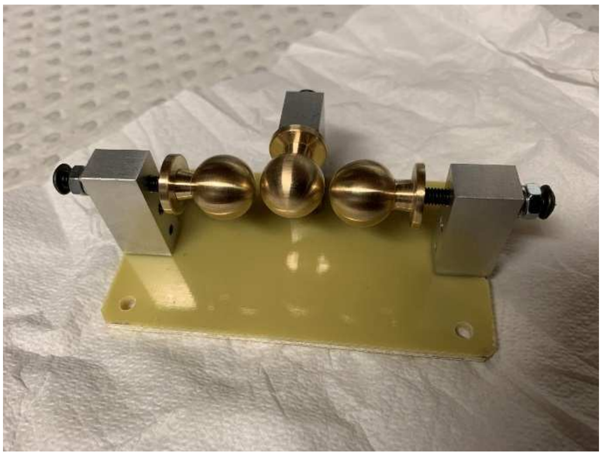


Photo 14 – Safety Gap Construction

Photo 15 – Layout of Terry Filter Design

The high voltage cables that connect the inputs and output to the coil itself have been constructed using 7.5mm^2 OFC stranded power cable, which two layers of PTFE tape are applied, followed by heat shrink tube,

followed by an additional layer of PTFE tape and a final layer of heat shrink tube.

The use of readily available white PTFE (plumbing tape) makes use of PTFE's high dielectric strength of around 60kV to 70kV/mm [21]. Common high-density PTFE plumbing tape has a density of around 0.3g/cm^3 and nominal thickness of 0.1mm [22].

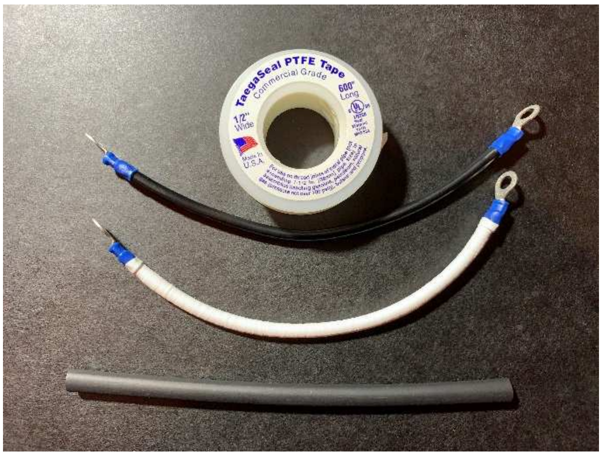


Photo 16 – Building of High Voltage Insulated Interconnecting Cables

The Terry Filter & safety gaps were finally mounted together on a plate of SwitchPanel Type X measuring 150mm x 250mm x 12mm and completed on 6th October 2020.

Photo 17 – Completed Filter Module

The electrical connections to the filter completed with brass hardware and acorn nuts.

Connection to the Tesla Coil is via the two aluminium blocks on the left and right.

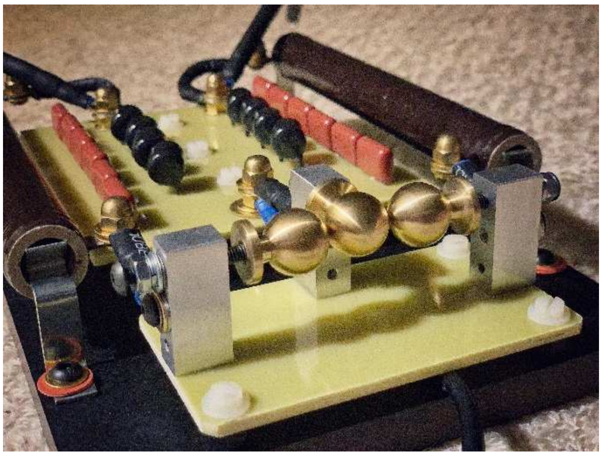


Photo 18 – Completed Filter Module - Detail

Initial testing of the Terry filter was completed, and initial setting of the safety gaps set.

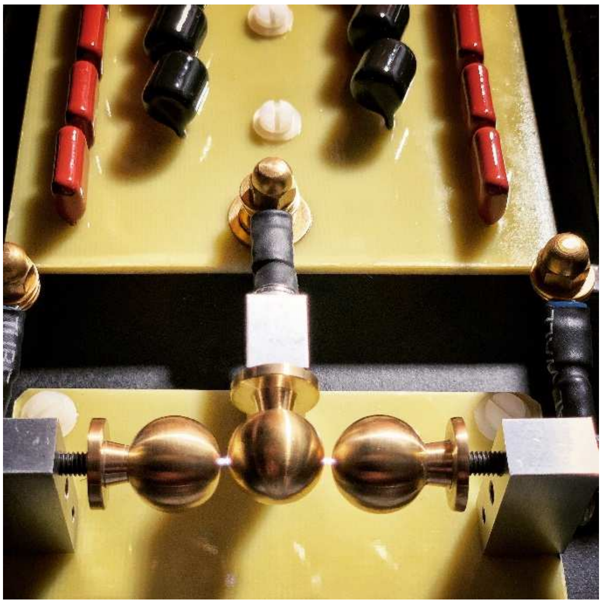


Photo 19 – Testing & Setting of Safety Gaps

X. Main Spark Gap & Tank Circuit

As the Terry filter construction was finalised, work continued with the main spark gap and layout of the tank circuit components.

The performance of a Tesla Coil is determined by the performance of the spark gap, which is a momentary switch that connects the capacitor to the primary coil, and when the gap is closed, the capacitor's energy is discharged into the primary coil.

A spark gap may be a simple device; however, the dynamics of its operation are rather more complex.

The voltage breakdown of the spark gap is set by the width between the electrodes. With a static gap, the width would be set at the power supply line voltage, in this case, 6,000V and would be at the correct setting with the gap firing at the full applied voltage of the transformer.

This project utilises a Static Gap arrangement, however much larger coils employ rotary spark gaps which do offer better control and performance. A coil of the size designed in this project would me a slight over-kill.

The main spark gap consists of the electrode holders, and the actual electrodes themselves. For this project, 6.35mm diameter, parallel faced tungsten rods are employed. Tungsten is a favoured material to make spark gaps due to its high melting point therefore more resistant to burning and pitting.

When the gap closes, the arc will ionise and heat the air within the gap which in turns makes the gap highly conductive, and once a gap conducts, it will continue to conduct even when the capacitor's voltage has dropped below that of the breakdown of the gap. With a conducting gap, this can allow the energy from the secondary to return to the primary, thus energy will be lost within the gap and primary components as heat, sound and light, and overall, the coil's performance is lost.

The ability to extinguish a conducting spark gap is known as "*quenching*" and is significantly important so to maximise the energy that is retained in the secondary.

Quenching is the action of the spark gap going open circuit and ceasing to conduct, and can only occur when the current through a conducting gap falls to a point where the arc may no longer be sustained, and the air within the gap has cooled enough to prevent arc over as the voltage begins to rise again on the next cycle.

Total energy transfer time is the number of half-cycles at the resonant frequency to transfer all the energy from the primary circuit to the secondary (not including energy losses). Ideally, we would like to trap all the energy within the secondary, as any energy that returns to the primary will contribute to energy loss (and less energy available for output arcs).

The only way to trap the maximum energy within the secondary is to stop the gap conducting when the current in the primary circuit first reaches zero.

Known as the '*first (primary) notch*', this period of time is very short and the amount of energy still within the primary is sufficiently high, keeping the gap conducting.

As the gap continues to conduct, the next available opportunity to open the spark gap is at the next point the current returns to zero (next available primary notch) and so on.

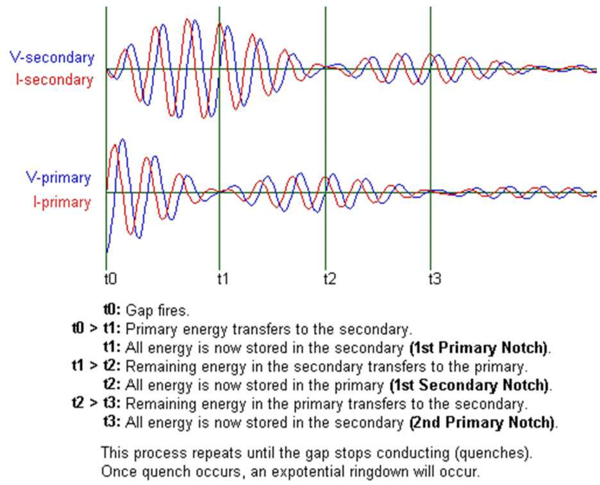


Fig 6 – Primary & Secondary Waveforms (JavaTC)

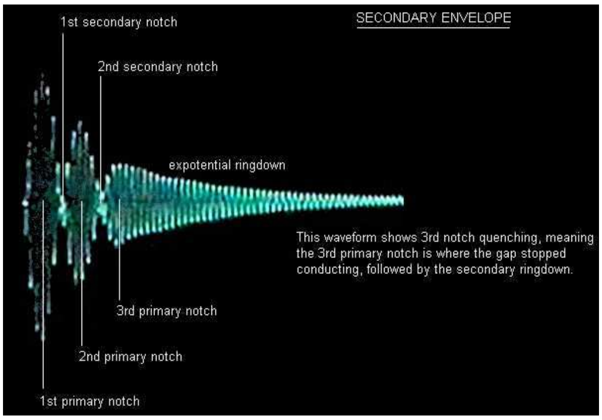


Fig 7 – Secondary Waveform (JavaTC)

Early quenching of the spark gap may be achieved through various methods, including magnetic quenching [23], air-blast [24], vacuum (sucker) [25], forced air (fan) and most commonly with the use of a rotary spark gap arrangement.

The use of forced air (or vacuum) or a rotary gap allows for the cooling of the gap and a method to remove hot ionised air from the gap which reduces the chance of the gap re-igniting.

For this project, a centrifugal blower fan is employed as they have the advantage of generating high pressure air flows compared to an axial fan.

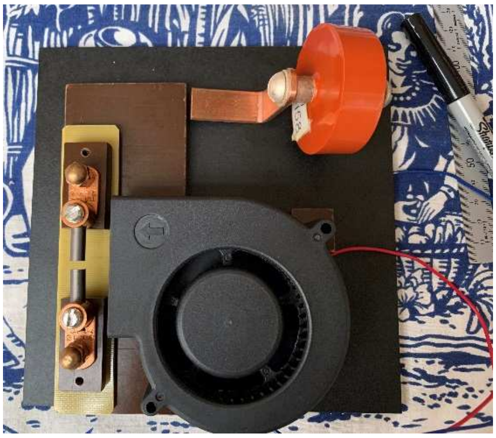


Photo 20 – Gap Quenching Blower Fan

Fan Specifications:

Supply voltage:	12VDC@860mA
Dimensions:	97mm x 94mm x 33mm
Air Volume:	0.74m^3 / 26cfm
Rotational Speed:	3600 RPM

Fan control implementation change:

A PWM fan speed control was going to be implemented to allow for speed adjustment of the fan, however, in testing, the controller offered little control and therefore abandoned. The fan is operated at full speed.

XI. Main Gap Construction

The construction of the main gap commenced with the appropriate mounting methods and materials.

A phenolic resin plinth was cut that serves as the mounting base for both the spark gap assembly and the connections to the capacitor.

The gap itself was formed by mounting the electrode holders onto two phenolic support blocks which then affixed to a strip of FR-4 substrate and then affixing the assembly to the phenolic base.

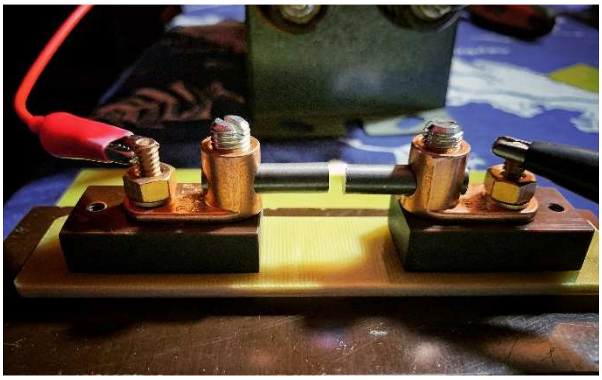


Photo 21 – Main Spark Gap Under Test

A copper buss bar is used to form the support for the capacitor, and a short connection using copper tube to connect to one side of the gap.

Photo 22 – Assembled Tank Circuit & Fan

Photo 23 – Capacitor / Gap Connection

Photo 24 – Safety & Main Gap, Primary coil

Photo 25 – Tesla Coil Overview.

XII. Strike Rail

A last detail for the coil is the addition of a strike rail, this is used to protect the primary coil and primary circuit components from any strikes. The ground rail presents a low impedance path to RF ground.

The rail is constructed using 2.3mm capillary copper tube. It is important this ring does not physically form a closed loop as will present as a shorted turn.

The strike rail supports are constructed from 9mm x 9mm x 46mm wood sections. A 2.5mm hole drilled through each support. A final sand and stain were applied prior to gluing into place with Loctite® epoxy.

The copper tube was then slid into place and heat-shrink used to cover the open section.

Photo 26 – Completed Strike Rail.

Photo 27 – Strike Rail & Grounding Post

A clip was manufactured using a copper saddle and fitted to make a snug fit onto the strike rail.

A grounding post was added to terminate the secondary ground and strike rail. This post will be used to then connect the system to RF ground.

XIII. Primary Tap Point

One of several challenges was the method to construct the primary tap connection.

Early in the project, four clearance holes had been drilled with the idea to bring the tap wire up through the bases, however, this later proved to cause issues with flexibility and once constructed, difficult to disassemble. The tap wire was simply brought up from the side.

The clip was constructed using a M205 fuse clip and reduced to create a firm and snug fit. A length of copper braid was used to strengthen the clip and provide firmer connection.

Photo 28 – Primary Coil Tap Connection

Capacitor Bleed Resistor Notes:

As of 12th October 2020, Much of the Tesla Coil project has been completed, however was still awaiting arrival of the high-voltage bleed resistors (10MΩ / 10kV) for the capacitor.

Due to delays with the 10MΩ resistors, an alternate resistor was needed. Researching Digi-key, a 100MΩ 2.5W Maxi-Mox resistors from Ohmite was found, Digi-Key PN: MOX1FE-100M-ND, (MOX-1-121006FE). This resistor offers a 10kV rating.

Another deciding factor to move to a 100MΩ value was in calculation of the required power rating, at 10MΩ this would have required a 7.2W resistor, however increasing to 100MΩ, this only required a 1W resistor and still maintaining a discharge of the capacitor to a safe 50V level in 1.5 seconds.[26] An order with Digi-Key was placed on 23rd October 2020.

Photo 29 – Almost Completed. Awaiting Bleed Resistors – 2L Bottle for Scale.

The bleed resistors together with a 2A circuit breaker and EMI line filter arrived on 27th October 2020. The bleed resistor was wired directly across the capacitor.

XIV. RF Earth System

One of the more overlooked and important areas with any RF systems is the provisioning of a suitable low impedance earth system.

Tesla coils generate heavy RF currents which must be appropriately distributed to earth.

A good earthing system is key to a good performing coil as it's the earth that forms the return path for the secondary side of the LC circuit.

At the time of writing this document (23rd October 2020), research is still being undertaken to provision a suitable dedicated earth.

Update: 2nd November 2020:

19mm x 2.4-meter earth rod sunk, 1.8 meters. A second "domestic" size rod sunk 1.2 meters. Rods bonded together.

Connection to coil via 25mm^2 welding cable.

XV. Measurements

Initial measurements undertaken on the Tesla Coil to determine tuning parameters and confirm resonant frequencies against the calculated design.

Photo 30 – Secondary Streamer Simulation Test.

Photo 31 – Primary Resonance Waveform Test.

The Resonant waveform measured as approximately 124uS corresponding to the total energy transfer time, first notch approximately 8.2uS.

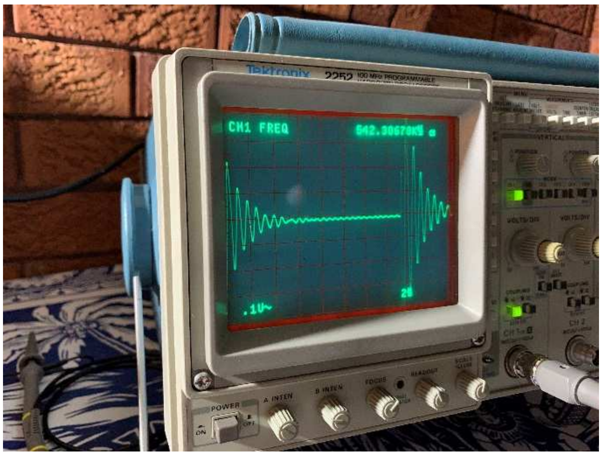


Photo 32 – Primary Resonance Waveform Test, 124uS.

Interesting observation made during the tests of the Tesla coil on the Cathode-Ray Oscilloscope, was an eventual interference from the coil saturating the amplifiers, this causing strange behaviour from the oscilloscope (with believe there was a fault developing), however on other uses, the oscilloscope was stable,

Additional tests conducted with a small Digital Oscilloscope.

XVI. Tesla Coil Specifications

Primary Circuit:

Primary Capacitor:	3nF / 20kVAC
Primary tap Frequency:	1527kHz
Primary tap turn:	T4.25
Inductance @ tap:	2.23uH
Total primary Inductance:	13.5uH

Secondary:

Resonant Freq with toroid:	1708khz
Resonant Freq w/out toroid:	2489kHz
DC resistance:	19.2Ω
Inductance:	1.720mH
Calculated No of Turns:	~500

Toroid:

Major Diameter (d1):	107mm
Minor (Ring) diameter (d2):	27mm
Calculated Capacitance:	4.62pF
Calculated Breakout V:	80.62kV

Neon Transformer Measurements:

Input:	240VAC
Output:	60kV / 30mA (180W)
R-primary:	11Ω
R-secondary:	12.7kΩ (6.3kΩ to CT)
Impedance:	199039.75Ω

No PFC:

0.084A, PF: 33% (open circuit)
0.810A, PF: 21% (drawing arc)

10uf PFC:

0.727A, PF: NA (open circuit)
0.212A, PF: 72% (drawing arc)

XVII. Power Supply Module & Control Box

On 2nd November 2020, building and completion of the high voltage supply module.

The NST mounted to a 12mm base of SwitchPanel, 200 x 300. Two wood stand-offs used to manufacture the mounting point for the Terry Filter module.

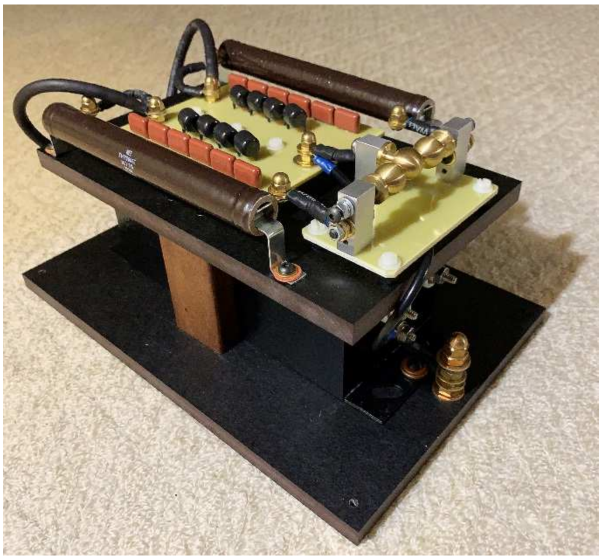


Photo 33 – High Voltage Supply Module (NST & Terry Filter). PFC Capacitor Not Visible.

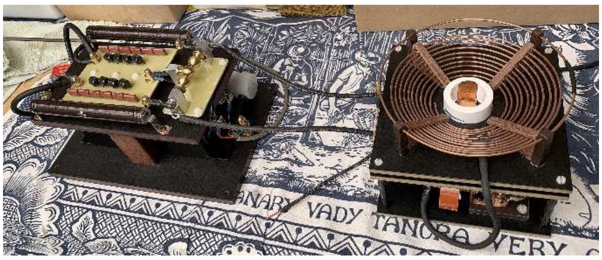


Photo 34 – HV Module & Primary Circuit

The control box consists of a EFI/RFI line filter which has been selected to prevent outgoing generated interference from the equipment.

The TE Connectivity 3A EMC series has been selected for the purpose.

A small SMPS to provide 12V 1.2A for the quenching fan supply.

The box features a main switch to supply power, switch for the fan and the main switch to supply power to the transformer (using a rocket cover).

Indicator lamps also used to confirm active power to the circuits. A 2A thermal magnetic circuit breaker has been installed.

This control box is used together with a variac to provide full adjustable control to the coil.

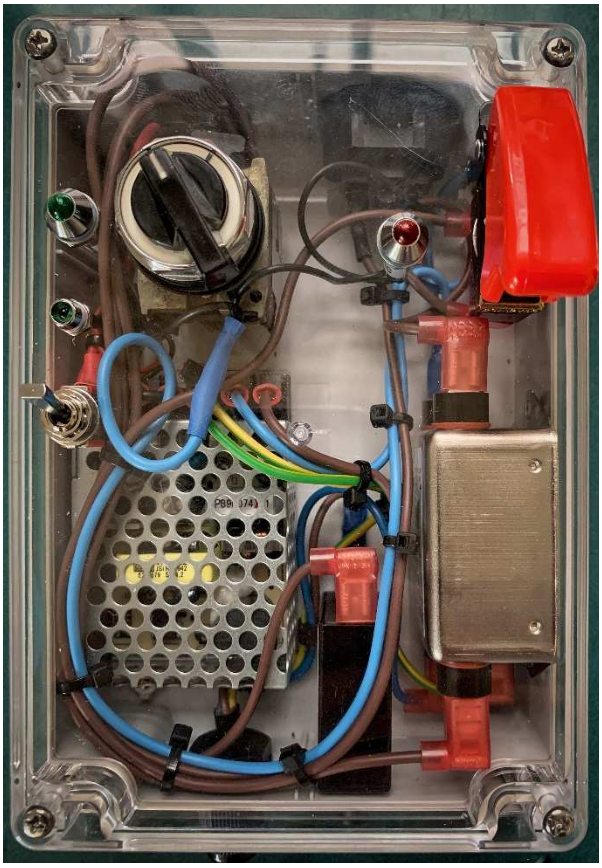


Photo 35 – Control Box

XVIII. First Light Tests

Following on close to three months of development through theoretical design and construction of the coil and its components, an initial momentary test was conducted on 3rd November 2020 using the NST power supply and the variac (prior to construction of the control box).

First Test Results:

Noted a flashover occurred from the end of the primary winding to the strike rail, this flashover occurring several times at the same location causing a tracking burn to occur.

On inspection, found an oversight, the end of the primary was not smoothed off and sealed. The sharp edges contributing to the breakdown and arcing.

Also noted that another overlooked area was not sealing off the supports with varnish such as Ultimeg to increase the insulation.

Completed repair of the area, smoothing off the copper end and applying both an epoxy resin to seal. The tracking burns also cleaned and subsequently sealed.

Additional build-up of epoxy added to all key areas at the primary junction and supports.

In addition, the application of several coats of Ultimeg electrical varnish to the timer supports.

The primary coil assembly was left to cure over the next several days prior to performing additional tests.

Photo 36 – Arc-Over Burn.

{1}: In hindsight;

The pulsed nature of the high-voltage present on the primary coil, wood is not the best material option, A more suitable material would be phenolic resin, however its expensive in small quantity and with dimensions suitable in a timeframe. A consideration would be the use of Switch panel Type-X, however, to create the smaller parts, they would need to be cut from a larger sheet and required a greater deal of time.

XIX. Low Power Test

On 8th November 2020, a second light test was conducted.

An ignition coil circuit powered from 12V was employed as the high-voltage power supply.

The spark gap was 'closed down' to around 3-4 mm for the test.

The low power test was successful, with nice break-out occurring.

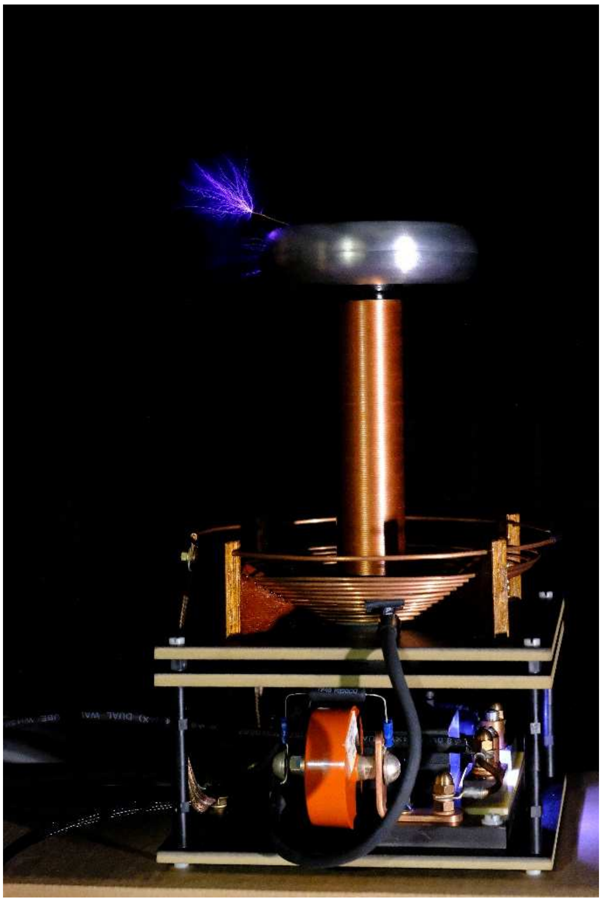


Photo 37 – Low Power Run.

XX. Power Test – NST Supply

Following completion of the control box on 12th November 2020, A test was conducted using the primary Neon Sign Transformer (NST) supply module.

Gap Set to ~ 5mm.

Run was successful, however some flash-over between the final turn of the primary to the strike rail randomly observed.

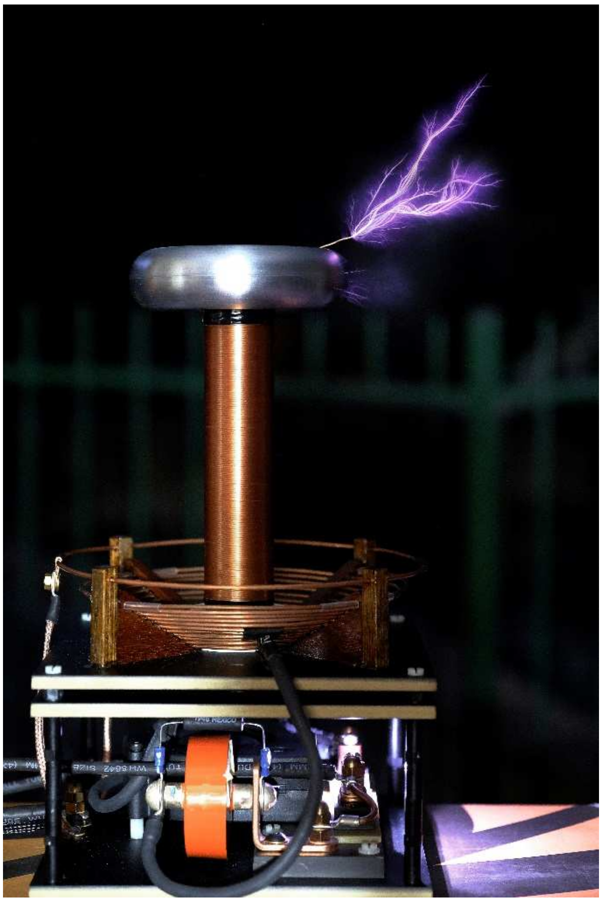


Photo 38 – Powered Run ~ 200V Input (Variac Setting)

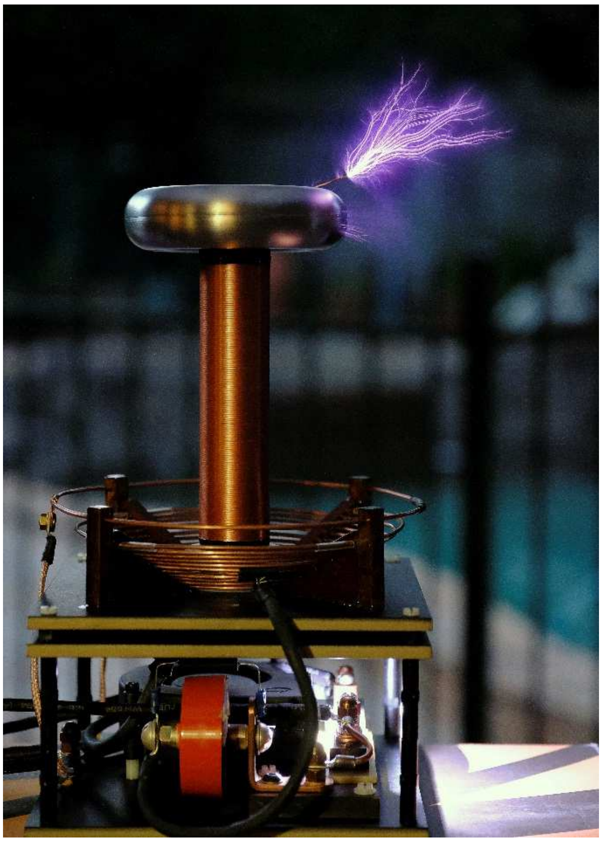


Photo 39 – Powered run

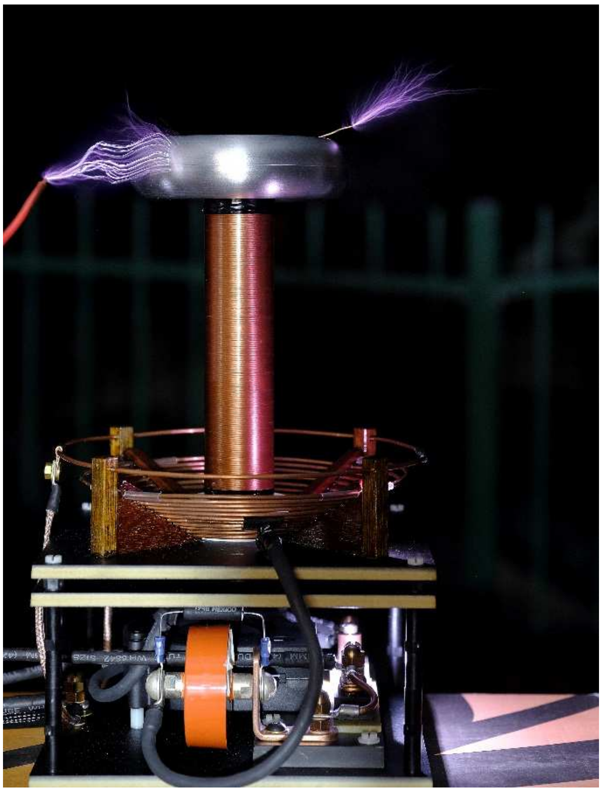


Photo 40 – Grounded Arcs

XXI. Improvements

Following the first successful power run, additional work will focus on building up the insulation between the strike rail and the final turn of the primary coil. On 13th November 2020, commenced application of additional layers of Ultimeg varnish in addition to installation of short lengths of clear vinyl tube (CVT) around key point on the strike rail and final primary turn.

Final coats applied on 18th November 2020. The varnish allowed to cure over the next week.

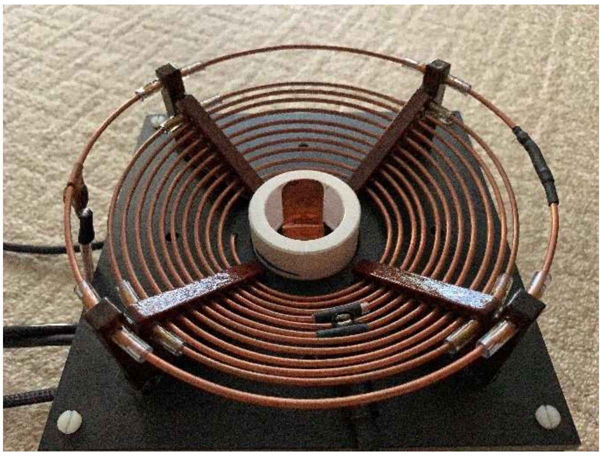


Photo 41 – Updated Primary With Additional Insulation At Key Points & Several Coats of Varnish.

XXII. Full Power Test

Following remediation work on improving the insulation at the junction points of the primary coil and its support points, a full power test was completed on 24th November 2020.

The full 240VAC applied to the Neon transformer via a variac.

Additional work to adjust the parallel alignment of the spark gap electrodes.

The full power test was very successful with no arcing issues at the support points.

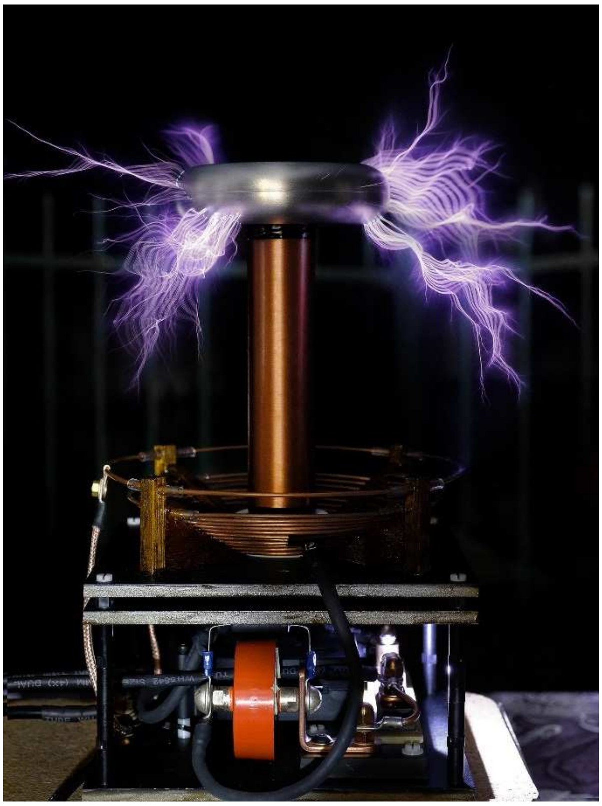


Photo 42 – Full Power Run.

The Tesla Coil Project officially completed on 25th November 2020.

Flavio Spedalieri 25.11.2020

XXIII. Topload Upgrade

In October 2020, a larger toroid was ordered from a US company, taking close to 2 months to arrive, however their customer service left little to be desired and therefore will not make any references within the document other than that the product was received.

The specifications for the larger topload:

Toroid:

Major Diameter (d1):	152mm
Minor (Ring) diameter (d2):	38.64mm
Calculated Capacitance:	6.61pF
Calculated Breakout V:	114.74kV

Photo 43 – Small & Large Toroids.

The additional capacitance of the larger toroid also required the re-tapping of the primary coil to bring the primary into tune with the lower resonant frequency of the secondary.

A further resonant test using an oscilloscope and signal generator was completed on the secondary coil to determine the resonant frequency. The new resonant frequency confirmed at 1,360 kHz.

The primary tap was moved by one turn, which also accounting for a loaded secondary, this placing the system back in resonance.

Full power testing completed:

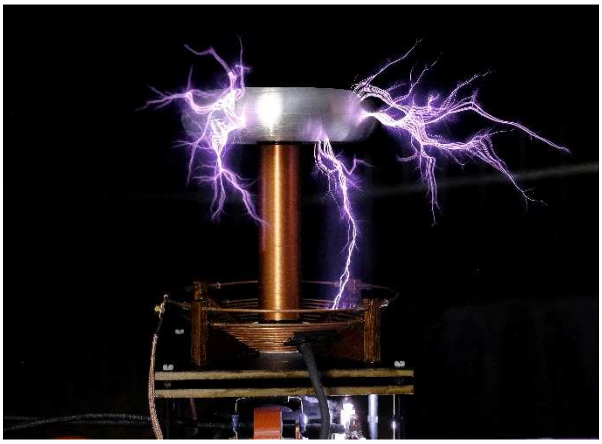


Photo 44 – Large Toroid, Full Power Test.

The performance of the coil now increasing significantly with longer streamers reaching the strike rail and are of equivalent length to that of the secondary coil.

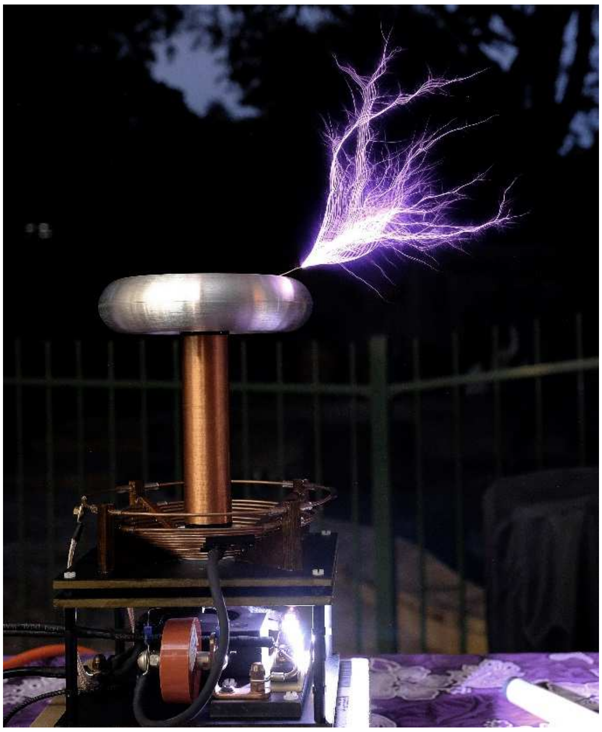


Photo 45 – Performance Test.

An additional experiment conducted with simply placing the two toroids on the coil, re-tuning of the coil was not required, however found that it also aided in the lengths of the streamers.

Photo 46 – Dual Toroids.

On 17th March 2021, I had my three Toroids welded, which I then further cleaned and sanded.

Photo 47 – Welded Toroids.

In May 2021, I was fortunate enough to find an X-Ray Transformer from a local Australian seller.

The transformer is rated for 120V input with a 1:360 turns ratio, or an output of 43.2kV (under oil).

I tested the transformer with my Tesla Coil with good success and only 20v input to the X-Ray transformer.

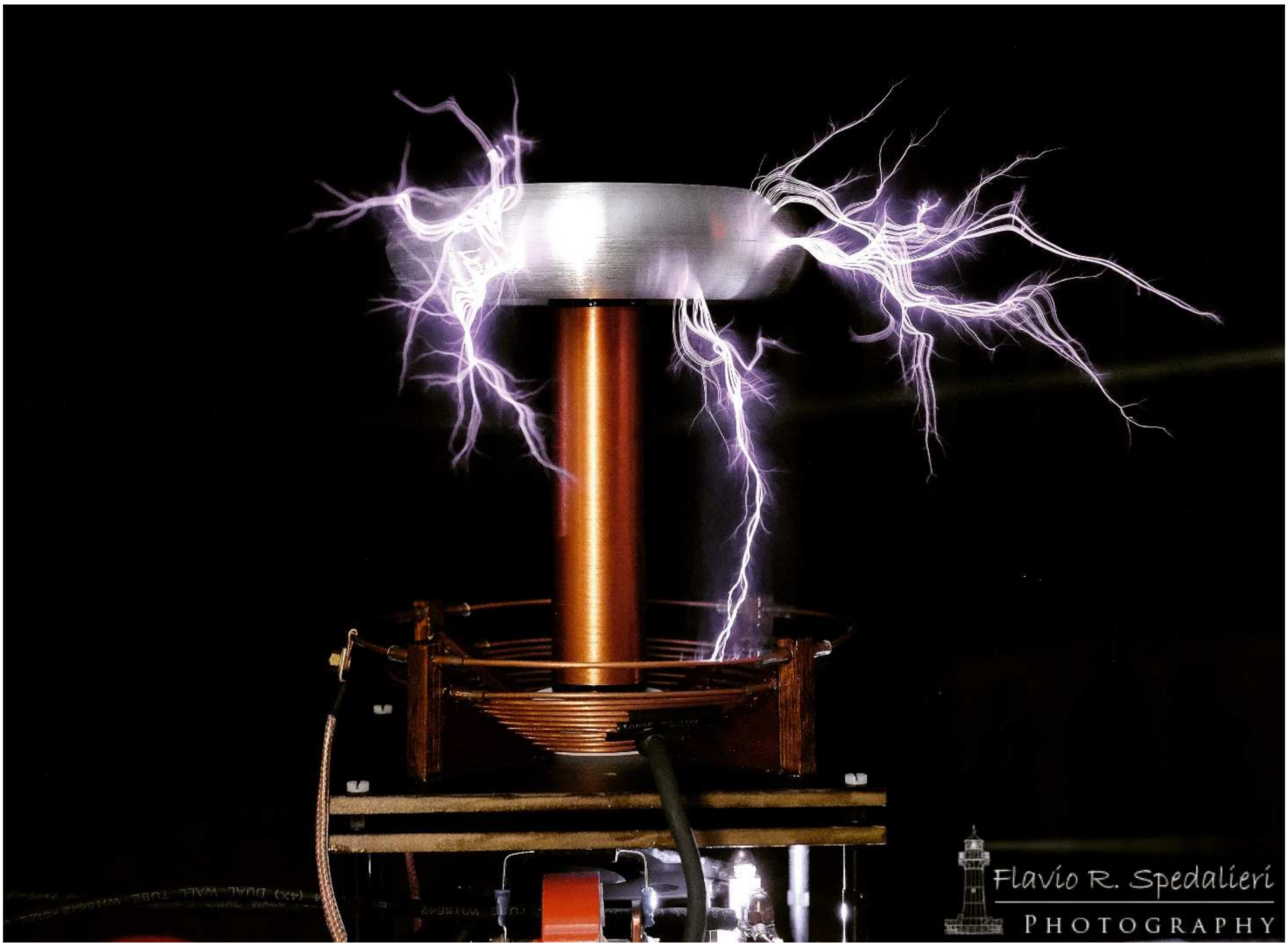
Photo 48 – Driving with X-Ray Transformer.

XXIV. NOTES

Document Version: 3.3 (© Copyright Release)

1st Update: 3rd December 2020 (V3.1)
2nd Update: 28th December 2020 (V3.2)
3rd Update: 12th October 2021 (V3.3

Project Completion: 25th November 2020.
Larger Top Load Tests: 27th December 2020.


Flavio R. Spedalieri
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Addendum

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Appendix

J A V A T C version 13.5 - CONSOLIDATED OUTPUT

21/10/2020, 1:20:23 AM

Units = Centimetres
Ambient Temp = 20ºC

Secondary Coil Inputs:

Current Profile = G.PROFILE_LOADED
1.675 = Radius 1
1.675 = Radius 2
30 = Height 1
43.2 = Height 2
500 = Turns
30 = Wire Awg

Primary Coil Inputs:

Round Primary Conductor
3.2 = Radius 1
6.6 = Radius 2
28.7 = Height 1
30.7 = Height 2
5.35 = Turns
0.214 = Wire Diameter
0 = Ribbon Width
0 = Ribbon Thickness
0.003= Primary Cap (uF)
0 = Total Lead Length
0 = Lead Diameter

Secondary Coil Outputs:

1618.28 [kHz] = Secondary Resonant Frequency
90 [deg °] = Angle of Secondary
13.2 [cm] = Length of Winding
37.88 [cm] = Turns Per Unit
0.00936 [mm] = Space Between Turns (edge to edge)
52.62 [m] = Length of Wire
3.94 [:1] = H/D Aspect Ratio
17.6699 [Ohms] = DC Resistance
18794 [Ohms] = Reactance at Resonance
0.024 [kg] = Weight of Wire
1.848 [mH] = Les-Effective Series Inductance
1.931 [mH] = Lee-Equivalent Energy Inductance
1.882 [mH] = Ldc-Low Frequency Inductance
5.233 [pF] = Ces-Effective Shunt Capacitance
5.009 [pF] = Cee-Equivalent Energy Capacitance
8.014 [pF] = Cdc-Low Frequency Capacitance
0.0562 [mm] = Skin Depth
3.997 [pF] = Topload Effective Capacitance
88.3825 [Ohms] = Effective AC Resistance
213 [Q] = Quality Factor

Primary Coil Outputs:

1619.5 [kHz] = Primary Resonant Frequency
0.08 [% low] = Percent Detuned
30 [deg °] = Angle of Primary
164.71 [cm] = Length of Wire
7.89 [mOhms] = DC Resistance
0.523 [cm] = Average spacing between turns (edge to edge)
1.884 [cm] = Proximity between coils
1.54 [cm] = Recommended minimum proximity between coils
3.219 [µH] = Ldc-Low Frequency Inductance
0.003 [µF] = Cap size needed with Primary L (reference)
0 [µH] = Lead Length Inductance
9.483 [µH] = Lm-Mutual Inductance
0.122 [k] = Coupling Coefficient
0.121 [k] = Recommended Coupling Coefficient
8.2 [half cycles] = Number of half cycles for energy transfer at K
2.51 [µs] = Time for total energy transfer

Top Load Inputs:

Toroid #1: minor=2.7, major=10.7, height=45, topload

Disc #1: inside=0.6, outside=5.2, height=45, topload

Transformer Inputs:

----

240 [volts] = Transformer Rated Input Voltage
6000 [volts] = Transformer Rated Output Voltage
30 [mA] = Transformer Rated Output Current
50 [Hz] = Mains Frequency
240 [volts] = Transformer Applied Voltage
0 [amps] = Transformer Ballast Current

Transformer Outputs:

----

180 [volt*amps] = Rated Transformer VA
200000 [ohms] = Transformer Impedance
6000 [rms volts] = Effective Output Voltage
0.75 [rms amps] = Effective Transformer Primary Current
0.03 [rms amps] = Effective Transformer Secondary Current
180 [volt*amps] = Effective Input VA
0.0159 [ºF] = Resonant Cap Size
0.0239 [ºF] = Static gap LTR Cap Size
0.0415 [ºF] = SRSG LTR Cap Size
10 [ºF] = Power Factor Cap Size
8485 [peak volts] = Voltage Across Cap
21213 [peak volts] = Recommended Cap Voltage Rating
0.11 [joules] = Primary Cap Energy
259 [peak amps] = Primary Instantaneous Current
49.2 [Centimetres] = Spark Length (JF equation using Resonance Research Corp. factors)
10.8 [peak amps] = Sec Base Current

Static Spark Gap Inputs:

----

2 = Number of Electrodes
0.25 [cm] = Electrode Diameter
0.45 [cm] = Total Gap Spacing

Static Spark Gap Outputs:

0.45 [cm] = Gap Spacing Between Each Electrode
8485 [peak volts] = Charging Voltage
8189 [peak volts] = Arc Voltage
36395 [volts] = Voltage Gradient at Electrode
18197 [volts/cm] = Arc Voltage per unit

96.5 [%] = Percent Cp Charged When Gap Fires
0.965 [ms] = Time To Arc Voltage
1036 [BPS] = Breaks Per Second
0.1 [joules] = Effective Cap Energy
200405 [peak volts] = Terminal Voltage
104 [power] = Energy Across Gap
55.9 [Centimetres] = Static Gap Spark Length (using energy equation)

Chapter Index

Photo Index

Figures Index