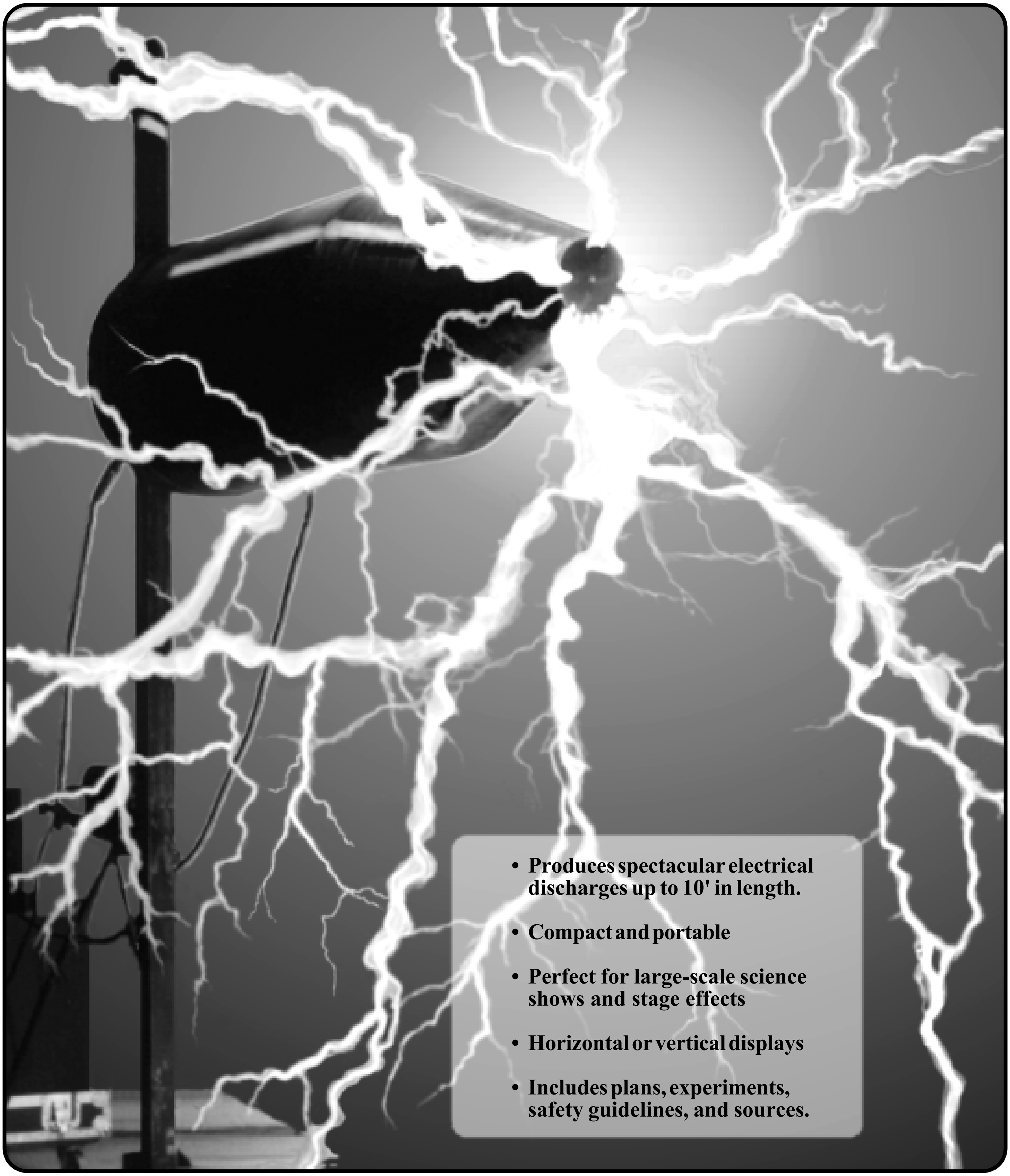
How to Build a
GIANT TESLA COIL

by Lloyd F. Ritchey WWW.LloydRitchey.com



CAUTION

THE APPARATUS DESCRIBED IN THIS MANUAL HAS COMPONENTS THAT CAN CAUSE SERIOUS INJURY, DELIVER LETHAL ELECTRICAL SHOCK, CREATE RADIO INTERFERENCE, AND DAMAGE SENSITIVE ELECTRONIC EQUIPMENT. FOLLOW DIRECTIONS FOR SAFE CONSTRUCTION AND USE. READ MANUAL BEFORE CONSTRUCTION AND NOTE ALL SAFETY MEASURES AND PRECAUTIONS.

THE READER SHOULD HAVE A GOOD UNDERSTANDING OF ELECTRICAL PRINCIPLES AND TERMINOLOGY BEFORE UNDERTAKING CONSTRUCTION. THE READER IS FURTHER ADVISED TO GAIN EXPERIENCE BY WORKING WITH SMALLER TESLA COILS BEFORE ATTEMPTING TO BUILD LARGE APPARATUS.

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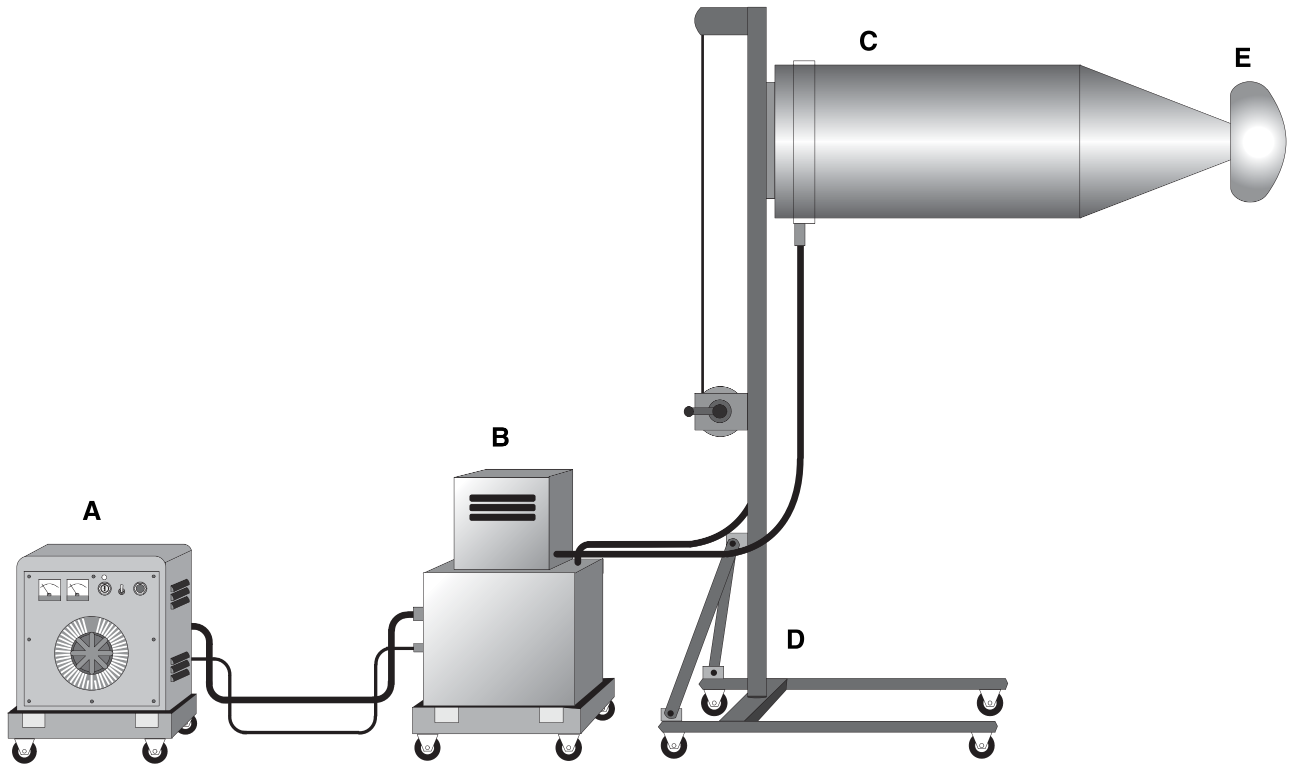


Fig. 1 - Complete Road Show Tesla Coil system. (A) Power Supply (B) Oscillator (C) Tesla Coil (D) Vermette Stand (E) optional Discharge Electrode.

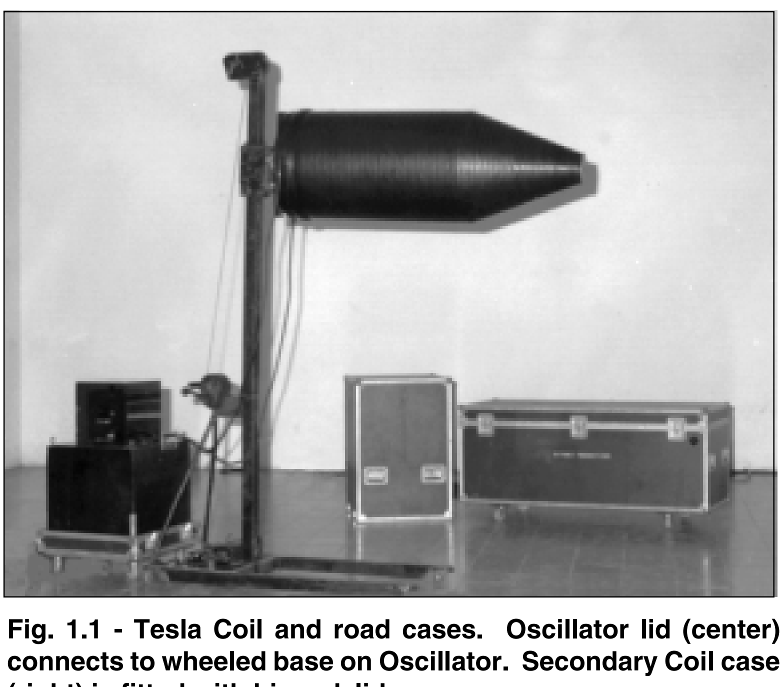


Fig. 1.1 - Tesla Coil and road cases. Oscillator lid (center) connects to wheeled base on Oscillator. Secondary Coil case (right) is fitted with hinged lid.

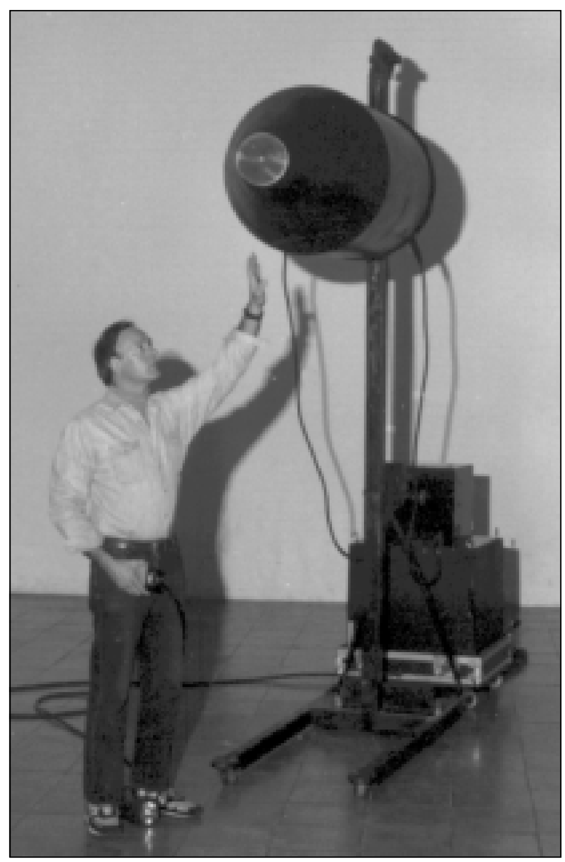


Fig. 1.2 - Tesla Coil cranked to eight foot elevation on Vermette stand.

Fig. 1.3 - Performer draws a crackling discharge from the ROAD SHOW TESLA COIL during a stage performance at the SCIENCE PLACE museum, Dallas.

INTRODUCTION

The **ROAD SHOW TESLA COIL** described in this manual delivers spectacular displays of electrical energy for large-scale science shows, special effects, and stage productions.

The Coil is an excellent project for universities, colleges, science museums, special effects engineers, researchers, and experimenters who want a rugged, portable, powerful instrument.

Two of the ROAD SHOW coils constructed by the author have toured across the country with rock n' roll groups and promotional shows. One of the coils has been in use almost daily since 1988 at the Southwest Museum of Science and Industry (THE SCIENCE PLACE) in Dallas.

The Coil is capable of producing electrical discharges up to 10 feet long in free air and can be used in many audience-pleasing demonstrations. The variety of special effects that can be produced is limited only by the ingenuity of the builder.

Although Tesla Coil design hasn't really changed much since Nikola Tesla's originals, modern materials allow the construction of more compact and efficient instruments. The ROAD SHOW TESLA COIL uses "state of the art" components and practical design to achieve high performance in a relatively small package.

Experimenters not familiar with Tesla Coils or high voltage circuits are strongly advised to gain experience with a smaller Tesla Coil (such as the Tesla Coil described in the manual, ***TABLE TOP LIGHTNING***) before undertaking the construction of the Road Show Tesla Coil.

SPACE REQUIREMENTS

When operated at medium power levels, the Road Show Tesla Coil will require a ceiling height of at least 16' and a floor space 16' wide and 20' deep. If the Coil is to be used at maximum power, it will need a ceiling height of 20' and a floor space 20' x 20' (Fig. 2).

Keep in mind that the Coil will induce currents in wiring not protected by a grounded shield or conduit. The discharges can pass through sheet rock, plywood, plastic, and other non-conducting materials (see section on Safety).

SPECIFICATIONS

The Coil disassembles into four units: The Secondary Coil, Oscillator, Stand, and Control Box.

Power requirements: 30 A @ 240 V AC or 60 A @ 120 V AC. A separate earth ground is required.

Circuit: "classic" AC Tesla Coil circuit using an asynchronous rotary spark gap

Operating Frequency: approximately 170-200 kHz

Approximate Weight:

Oscillator	200-250 lbs.
Secondary	80-90 lbs.
Control Box	80 lbs.
Stand	75 lbs.

Peak output voltage is estimated at 2-3 million. Average output current is estimated to be several milliamps. Peak output current may be several amperes.

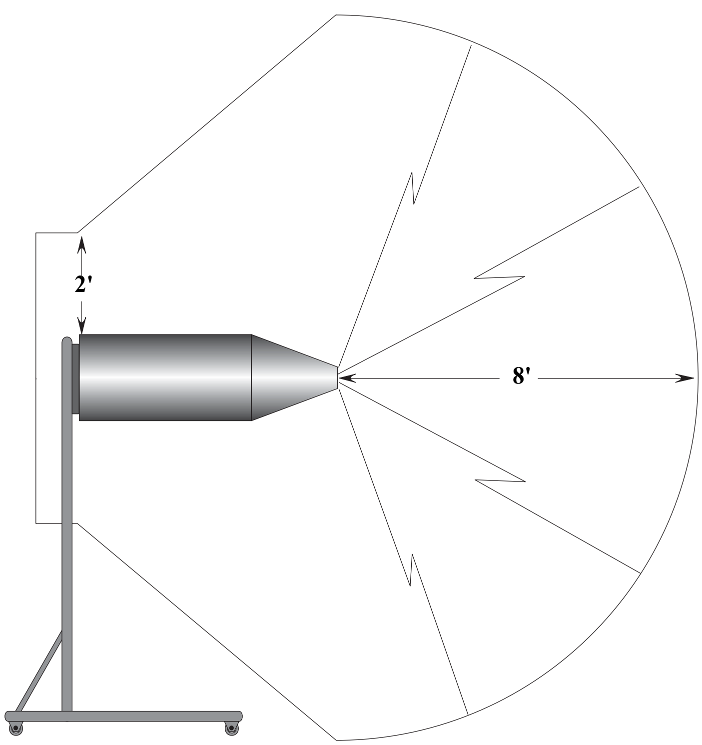


Fig. 2 - The Tesla Coil's "Strike Zone" is a 360° pattern within which any conducting object may be hit by a discharge streamer. If the Coil is operating at maximum power, the zone should be extended to ten feet.

HISTORY

Nikola Tesla employed large Tesla Coils for research into wireless transmission of power. His efforts were to have culminated in the Wardenclyffe Transmitting Station, New York, which he nearly completed in 1901. With this station, Tesla believed that he could transmit power, without loss, to any point on the planet. Indeed, while Marconi was struggling to send the first wireless signal across the Atlantic with a relatively crude apparatus, Tesla was planning to transmit *power* across the Atlantic to light the Paris World's Fair! Tesla's technology was years ahead of Marconi's.

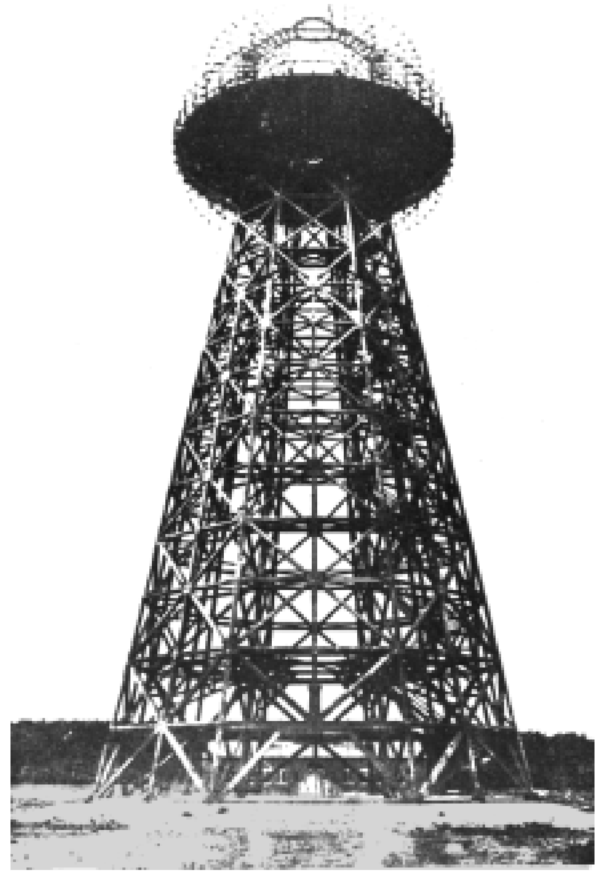


Fig. 3 - Wardenclyffe Tower, part of Tesla's system designed to transmit power across the Atlantic.

Tragically, financing for the Wardenclyff Station was removed by Tesla's backer, J.P. Morgan, before the station was ready, and the project died. Tesla took many of the station's secrets with him to the grave.

During the period from around 1890 to 1904, Tesla refined his designs and invented a number of variations. He devised sophisticated rotary spark gaps (he called them "circuit controllers" or "interrupters") that used mercury, held against the inside of a cylinder by centrifugal force, and high speed rotating electrodes.

Some of his rotary gaps employed insulating gas at high pressure. Some were synchronous, and others employed more than one set of rotating electrodes.

The spark gap used for the Road Show Tesla Coil is based on one of several designs Tesla used successfully during his Colorado Springs Experiments.

Tesla designed many primary/secondary coil configurations, including double-ended, flat spiral, conical, and "extra coil" combinations.

He experimented with the influence of antenna height and capacitance on transmission distance, and designed a number of sophisticated circuits to receive signals and power.

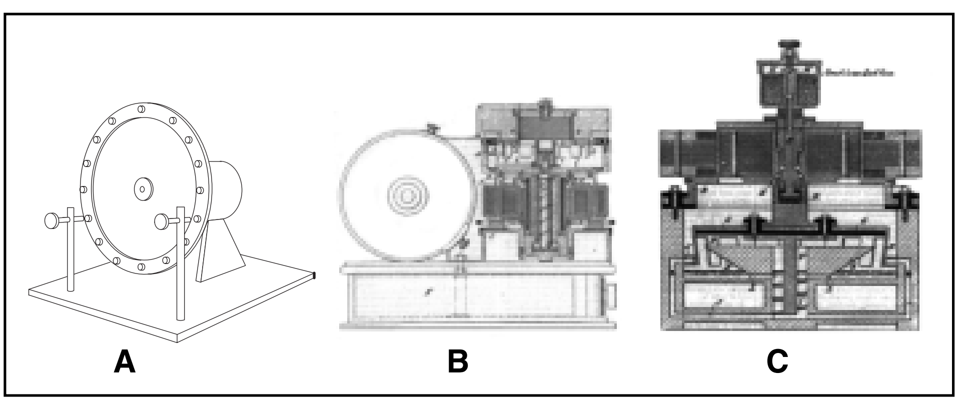


Fig. 4 - Rotary Spark Gaps. (A) Typical early design employing multiple points (B) Portable Tesla Mercury Interrupter attached to a Tesla Coil (C) Cross section of "industrial size" Tesla Interrupter.

THEORY

The Tesla Coil is a resonant air-core transformer. A Secondary Coil comprising many turns of wire is in close inductive relationship with a Primary Coil having few turns (Fig. 5).

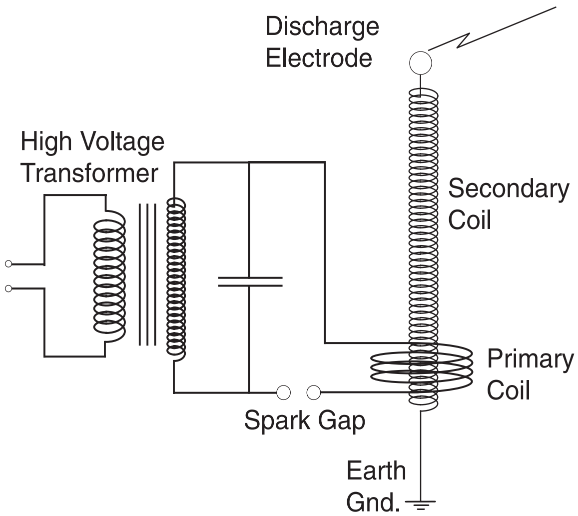


Fig. 5 - "Classic" spark-gap Tesla Coil circuit with Secondary Coil grounded at one end and primary circuit tuned to 1/4 the frequency of the Secondary Coil.

The Secondary Coil has a natural resonant frequency that is determined primarily by its length, inductance, and lumped capacitance.

The Primary Coil is part of a tuned circuit designed to oscillate at a frequency one-fourth as high as the Secondary resonant frequency.

Energy is coupled into the Secondary Coil from the Primary Coil. Because of the 1/4 wavelength tuning, voltage induced in the Secondary reaches a peak at the top of the coil, the bottom being held at ground potential.

Secondary voltage is determined largely by the "Q" factors of the respective circuits and, to an extent, by the turns ratio between the primary and secondary coils.

The coil in this manual uses a step-up transformer that provides 16,000 volts for the primary circuit. This output is applied across the terminals of a Capacitor.

The Capacitor charges during one half of the AC cycle and then discharges across the Rotary Spark Gap into the Primary Coil. When the Spark Gap fires, the conducting spark provides a low resistance path for oscillations to occur between the Primary Coil and the Capacitor.

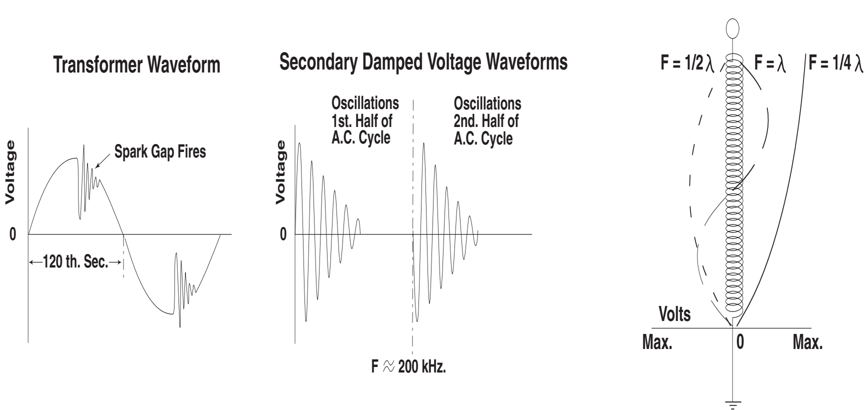


Fig. 6 - Waveforms and Secondary voltage gradients for different wavelengths.

The size of the Primary Coil and Capacitor determines the frequency of the primary circuit. If the Primary is properly tuned to the Secondary, a series of damped oscillations at the Secondary resonant frequency occurs during each half cycle of AC current (Fig. 6).

The theoretical maximum voltage the system would develop under perfect conditions is the product of the system's "Q" times the impressed voltage (approximately 16 kV). There is some debate regarding the degree to which turns ratio influences voltage developed by a Tesla Coil.

Frequency affects striking distance, so the "rule of thumb" of 3 feet per million volts doesn't necessarily hold. The voltage developed by the Road Show Tesla Coil is estimated to be from two to three million.

Because considerable energy is stored in the inductive field of the Tesla Coil's secondary, a discharge spark can briefly release peak currents of many amperes. Tesla calculated that his Colorado Springs coil discharged peak currents of more than 2,000 amperes. His coil developed around 20 million volts. Assuming that the current and voltage were in phase, the instrument would have had a peak instantaneous output of a whopping 400 million watts. This was from an average input power of around 40 kilowatts.

CONSTRUCTION

Secondary Coil

The Road Show Tesla Coil's rocket-shaped Secondary allows the discharge to be concentrated and "directed" from a small surface area instead of from a large toroid or sphere, a compromise which I believe results in maximum discharge length. (A simpler, totally cylindrical design is presented on Page 54). The horizontal configuration places the Coil closer to eye level and allows the audience to view the entire discharge.

The discharge electrode consists of a 7" diameter aluminum disk. Discharge spheres or toroids can be used, but adding surface area lowers the resonant frequency, and the Coil must be re-tuned if the size of the discharge electrode is changed.

The Secondary Coil consists of approximately 450 turns of No. 12 THHN stranded wire wound in a single, closely-spaced layer over the coil form.

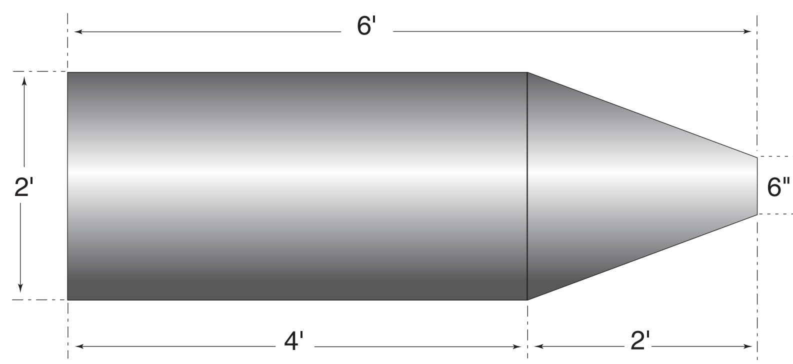
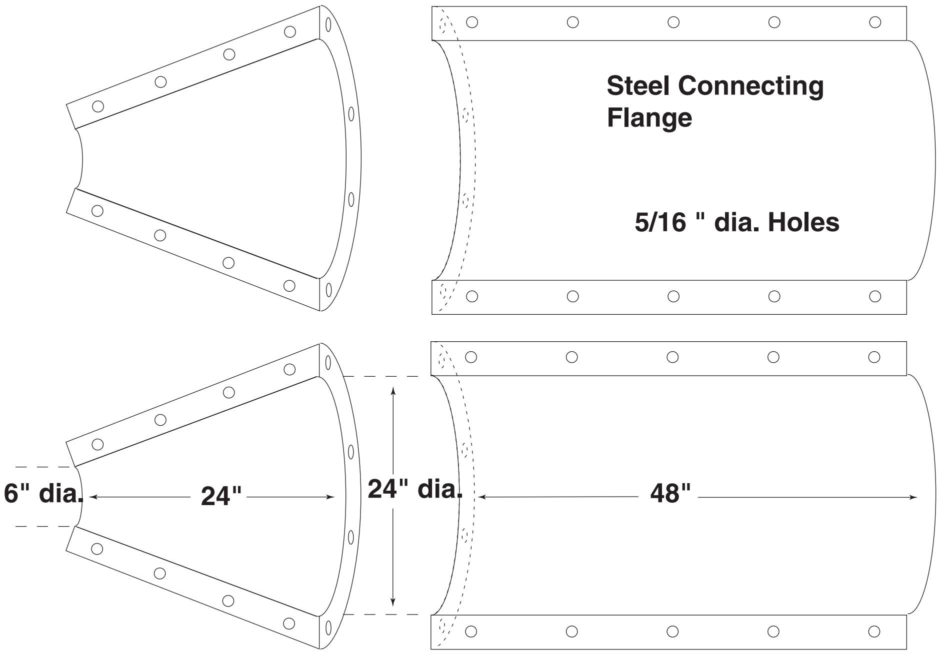


Fig. 7 - Secondary Coil

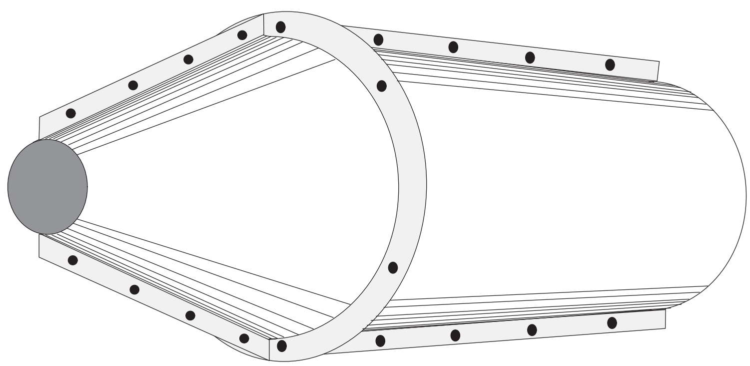
Building the Secondary Coil Form

The Secondary Coil Form for the Road Show Tesla Coil is made of fiberglass hand-laid in a female mold. Because of its strength, light weight, and good electrical characteristics, fiberglass is the preferred material.

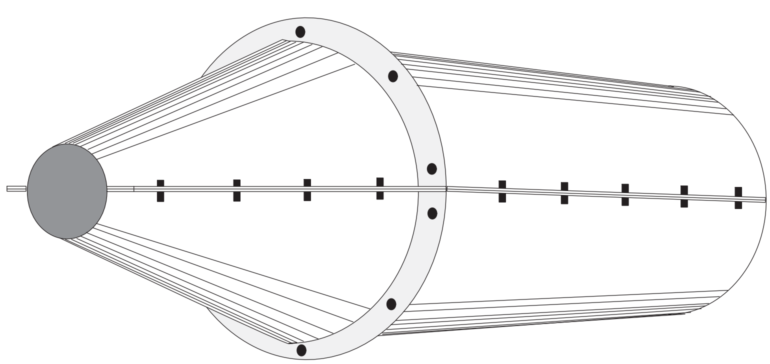
If you have no experience working with fiberglass (and don't care about learning!) you might find a local fiberglass shop that can do the job for you.



A. MOLD SECTIONS



B. Assembled Mold Form With Connecting
Flanges in Vertical Position



C. Assembled Mold Form With Connecting
Flanges in Horizontal Position

Fig. 8 - SHEET METAL MOLD FORM

Warning: Fiberglass resin should only be used in a well-ventilated area. The fumes from polyester resin and solvents like acetone are dangerous to inhale. MEK peroxide, the chemical used as a catalyst for polyester resin, is a powerful oxidizing agent and will burn the skin. Acetone should be used sparingly to clean the hands, as it is absorbed through the skin. Acetone is highly flammable, and polyester resin will also burn. Ask your dealer about a new, non-toxic, non-flammable solvent that can be used like soap to clean resin from the hands.

Molds

The easiest mold to use is one made of sheet metal (Fig. 8). A metal mold is strong, easy to prepare, and easy to align. The finished fiberglass parts are also quite easy to remove from such a mold. A sheet metal shop can make a complete mold for you, but check around, prices can vary widely.

A relatively inexpensive mold can be made from a two-foot diameter paper foundation pier form. If you use the pier form, you'll need to ensure that the form's interior surface is smooth. This can be easily accomplished by covering the inside with mylar, a plastic sheeting material impervious to polyester resin. Mylar comes in different widths and is usually sold by the yard.

Spray the interior of the pier form with contact cement, then lay in the mylar. The adhesive will hold the mylar in place while the fiberglass is being laid in. Overlapping edges of the mylar can be held in place with cellophane tape.

Formica can also be used as a mold material. Keep in mind that the mold must be strong and must have a smooth interior surface. The nose cone must also be accurately aligned with the cylindrical part of the Secondary Coil Form when the two parts are fiberglassed together.

Applying The Fiberglass

Once the molds are constructed, three layers of fiberglass are laid in (only two layers if the coil is to be mounted vertically). Fiberglass is sold by the yard and by its "ounce" rating. The first layer to go into the mold is of 6 oz. cloth, which is followed by two layers of 1 1/2 oz. fiberglass mat. Four fiberglass reinforcing stringers will be added longitudinally to the cylinder.

The cylinder and nose cones are constructed, or "laid up," separately in their respective molds. They are then fiberglassed together to make a single unit.

Place the molds at a comfortable, level working height. The seams inside the sheet metal molds should be filled with silicone sealer and smoothed with a finger or squeegee to make the inside as smooth as possible. After the silicone sealer has hardened, apply three coats of mold release wax to the interior surface of the molds, following the wax manufacturer's directions. If you are using mylar, you theoretically don't need to apply mold release wax to the mylar surface, but it's a good idea to do it anyway.

Cut a piece of 6 oz. fiberglass cloth large enough to cover the bottom half of the mold's interior. Lay the cloth inside the mold so that it covers the bottom half. If you must use more than one piece of fiberglass, overlap the edges several inches.

Catalyze about a quart of laminating resin (follow manufacturer's directions as to quantity of catalyst to add) and pour a narrow "trail" down the center of the mold, wetting the cloth. Use a 3" natural bristle brush (use the cheapest you can find) to spread the resin evenly over the cloth. Apply more resin to the cloth, just as you would coats of paint.

As the cloth is saturated, rotate the mold form slightly and pour/brush more resin until the cloth is completely wetted out. (Use no more resin than is necessary to saturate the cloth...you don't want excess resin running and pooling inside the mold.) Using a brush or a special fiberglass roller, press out all bubbles and make sure that the cloth is as smooth as possible, including the edges. If you run out of resin before the cloth is totally wetted out, mix and apply more resin immediately, before the first batch starts to gel.

Rotate the mold about 180 degrees after the resin has hardened (about an hour) so you can apply cloth to the second half. Cut the second piece of cloth large enough to overlap the edges of the first piece by 2 or 3 inches. Catalyze more resin and repeat the application procedure until the entire interior of the mold is covered with a smooth layer of cloth.

Excess fiberglass that protrudes from the edges of the molds can be easily trimmed flush with a sharp knife before the resin fully cures. After the resin hardens, it will be necessary to trim any remaining excess with a disk sander and heavy grit sandpaper.

Let the resin harden about an hour, then apply a layer of fiberglass mat using the same procedure you used with the cloth. The mat will be much "thirstier" than the cloth and will probably take twice as much resin. Plan ahead; mat is more time consuming to work with and you don't want the resin to gel before you have time to work out the trapped air bubbles and smooth down the mat.

Once you have a smooth layer of mat applied to the interior, let it harden and then apply a second mat layer (a second mat layer is not needed if the coil is to mounted vertically). When this layer has hardened, fiberglass a plywood ring into one end of the cylinder (Fig. 9-A&B). Cover the entire ring with two layers of mat. Use strips of mat about 6" wide as the attachment pieces.

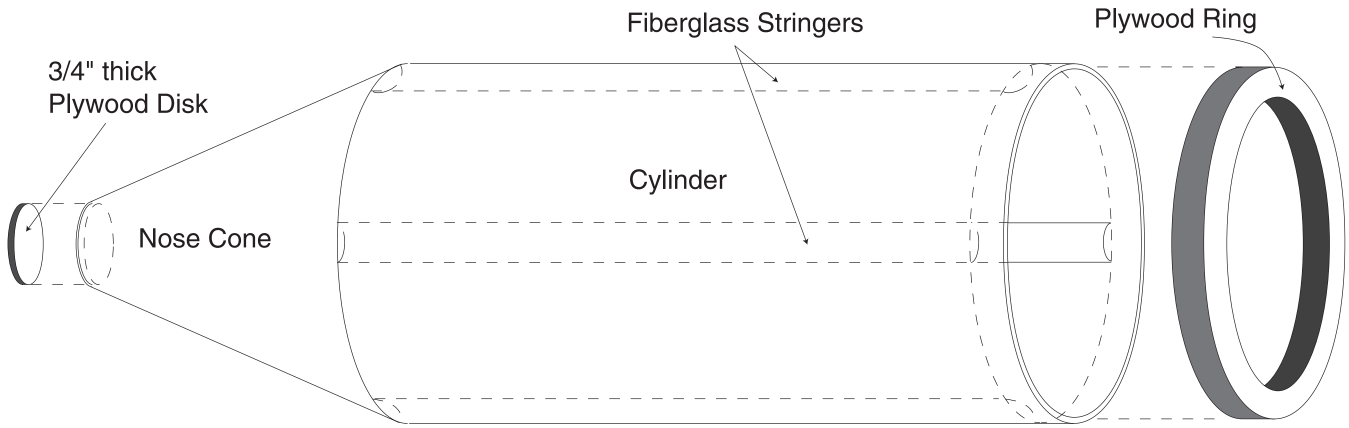
Four half-round fiberglass "stringers" will now be fiberglassed into the cylinder to add strength. The conical nose will not need stringers (Fig. 9-A&B).

The stringers are made as follows: Cut a 3" or 4" dia. x 45" long PVC pipe or cardboard cylinder in half lengthwise. The half-round sections will serve as molds for the stringers. Apply three coats of mold release wax to the PVC section's interior. If you use cardboard, you'll need to cut mylar to fit inside the cardboard to provide a surface the resin won't permanently bond to.

Cut pieces of fiberglass mat to fit inside the half-round sections and apply the resin, pressing out trapped air bubbles. Use two layers of mat. When the resin has gelled, trim the excess flush with the mold edges.

Remove the stringers after the resin has cured. The stringers are then fiberglassed into the cylinder with strips of mat. One layer of mat will be enough.

Cut a 3/4" thick hardwood or plywood disk to fit flush inside the front of the cone and fiberglass it



A. Detail of Secondary Coil Form

B. Completed Form Prior to Winding

Figure 9 - Fiberglass Secondary Coil Form

securely in place (Fig. 9-A&B). The disk can be held in place with epoxy and then fiberglassed from inside the cone. Keep in mind that if you add a toroid or sphere to the end of the coil, the disk will need to be strong enough to support the weight.

After the resin has hardened overnight, finish trimming the excess fiberglass flush with the mold edges. If you used the sheet metal mold shown in Fig. 8, you can bolt the conical mold to the cylindrical mold to make a single, aligned piece. Fiberglass the cone to the cylinder with strips of fiberglass cloth or mat about 6" x 6." Lay the fiberglass along the entire seam between the cone and the cylinder. One layer should suffice.

Removing The Coil Form From The Mold

Let the resin cure overnight. Now the mold sections can be unbolted and easily separated from the fiberglass with a little prying. If the parts are difficult to remove, banging the mold sides with a rubber hammer should help.

If you used a paper pier form as a mold, simply cut through it with a knife, being careful not to deeply gouge the coil form.

If a sheet metal mold was not used, and no provision was made to accurately bolt the nose cone mold section to the cylindrical mold section, the nose cone and cylinder will have to be aligned and fiberglassed together after they have been removed from their respective molds. Here's one way to do it: Set the cylinder upright and align the cone accurately on top of it. Catalyze some epoxy. (Use a thick epoxy, such as "Marine Tex," and make certain that you do not use a brand containing metallic powder.) Using a putty knife, force the epoxy into the seam where the cone and the cylinder meet. After the epoxy has hardened, place the assembly in a horizontal position and fiberglass the two pieces together on the inside, using fiberglass mat or cloth strips about 6" x 6." One layer of fiberglass should suffice.

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Laminating resin normally has a slightly tacky surface after it has cured, except for the surface that was in contact with the mold....In other words, the inside of the cylinder will be slightly tacky, and the outside will not. Although the tackiness will not affect the coil's performance, you can make the surface tack-free if you want to. You can buy "sanding" or "finishing" resin for the last coat of resin. Sanding resin has a special additive (commonly called "wax solution") to make the surface hard and tack-free. If you can't find sanding resin, you may be able to purchase the wax solution and add it to the final coat of laminating resin. Sanding resin or wax solution should *not* be used between layers of fiberglass, as it will cause the layers to separate.

Imperfections in the cylinder and cone surfaces, such as pits caused by air bubbles, can be filled with BONDO and sanded smooth. BONDO is a common automotive body filler and is sold in many automotive and hardware stores.

Painting the finished Secondary Coil form is not recommended, as some paints contain carbon or other materials that can short circuit high voltage currents.

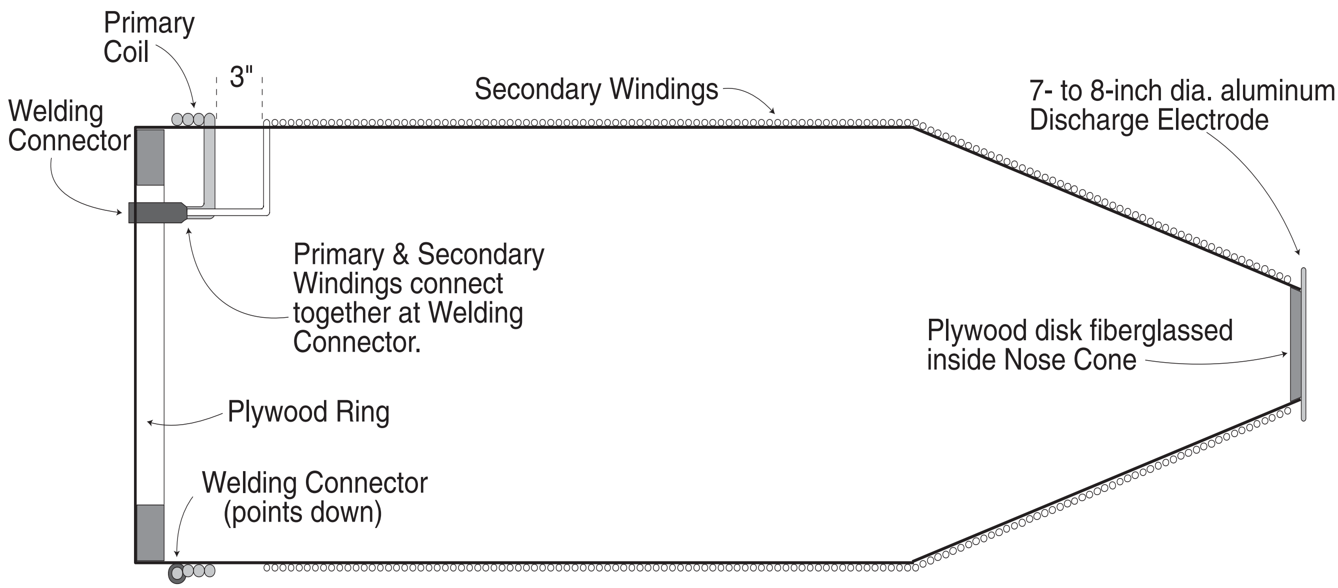


Fig. 10 - Cross-Section of Secondary

WINDING THE SECONDARY COIL

The Secondary is wound with a single layer of #12 stranded THHN copper wire closely spaced. This wire gives approximately 7 turns per inch for a total of about 450 turns. The total length will be about 2,400 feet.

The Primary Coil is wound just a few inches below the Secondary. Refer to Fig. 10 for correct placement.

Winding may be easier if the Secondary Coil Form is placed in a vertical position on a turntable (Fig. 11). An inexpensive turntable, such as those used in chairs and bar stools, can be purchased from a hardware store.

Vertical placement facilitates winding the nose cone because the weight of the wire tends to keep each winding close together, instead of allowing it to slip along the conical surface. Slippage can be further minimized by applying strips of double-sided tape to the nose cone (Fig. 11).

Mark a line around the circumference of the Secondary Coil Form 8" from the bottom of the form. This line will serve as a guide to keep the first winding even. Drill a hole through the form at the 8" mark large enough for the #12 wire to pass through.

Insert about 18" of the #12 wire through this hole; have an assistant rotate the coil form for you and begin winding, following the line you marked around the circumference.

If you're right-handed, winding will probably be easier if the Secondary Coil Form is rotated clockwise.

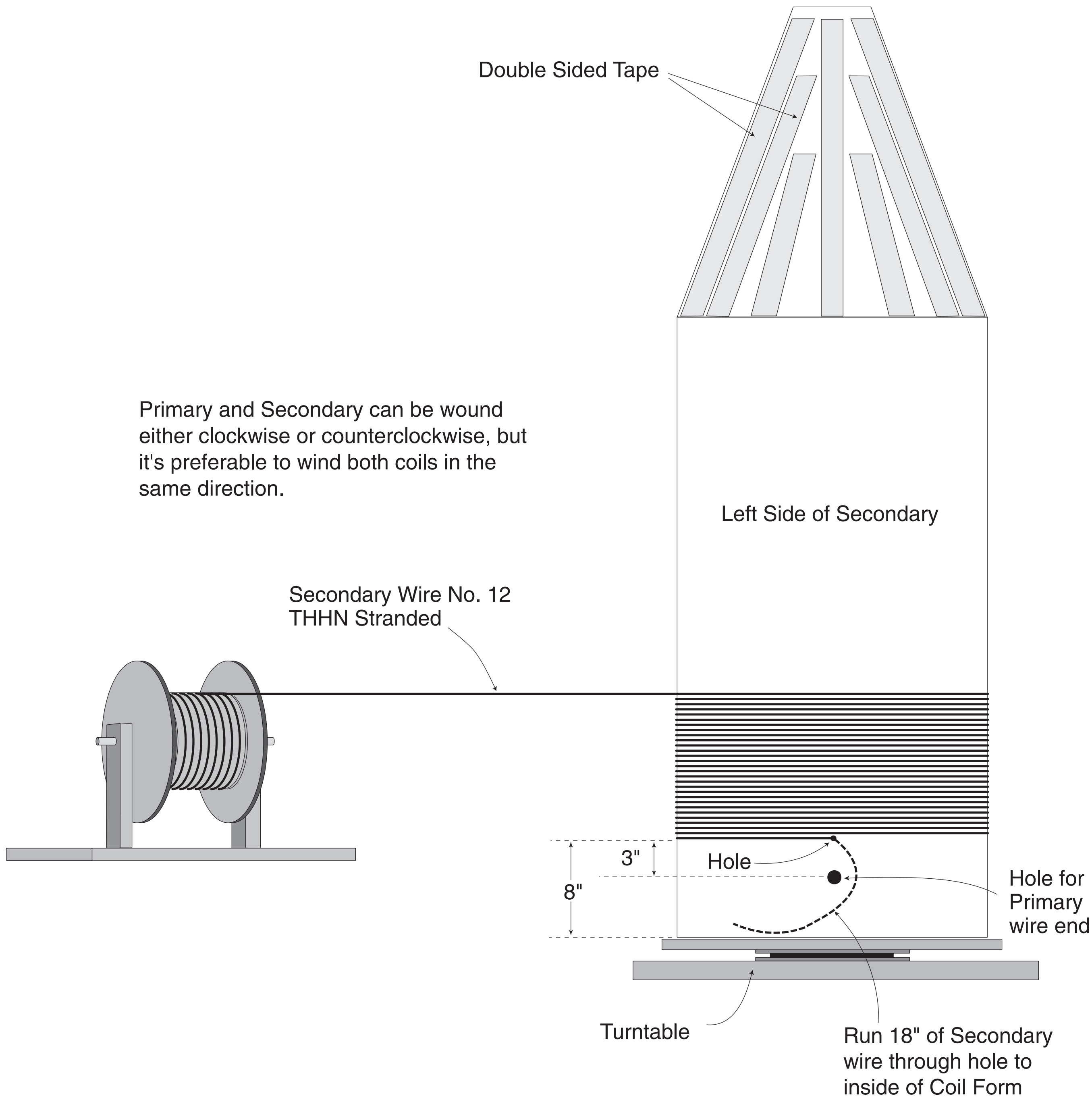


Fig. 11 - Winding the Secondary Coil

After the first turn has been applied, tape it securely in place. Continue winding, keeping the turns as tight and close together as possible. Tape the turns every six inches or so to keep the windings from accidentally coming loose.

If you have to splice the wire, make the splices compact. Solder them well and then wrap with electrical tape.

You'll need to wind the conical section slowly, working the wire carefully to keep the turns as close as possible. Stop winding about 1/2" from the end of the cone and tape the wire securely in place. Solder a copper strip about 1/2" wide x 5" long on the end of the wire (Fig.12). The copper strip will be sandwiched between the discharge electrode and the wooden disk fiberglassed into the end of the cone.

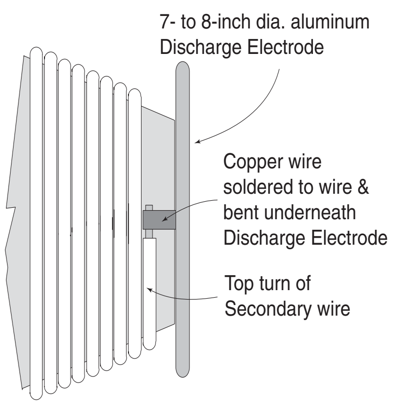


Fig. 12 - Secondary Winding Termination

Apply several beads of clear epoxy (like "five minute" epoxy) to the cone windings to hold them permanently in place. Smooth the epoxy down so that the surface of the windings remains even. Varnish, which will be brushed on the windings, tends to dissolve the adhesive on the double-sided tape, and the epoxy will be needed to prevent the wire from slipping.

After the epoxy has hardened, apply several coats of clear polyurethane varnish to the windings of the entire coil. Remove the tape from the windings as the varnish is applied.

If the coil windings are to be left exposed to view (not covered with tape, as described below), you will need to apply many coats of varnish until you are satisfied with the final appearance. Make sure that you allow the varnish to dry sufficiently between coats.

Another alternative to varnish is clear epoxy. Some electrical suppliers sell an epoxy that has good characteristics at radio frequencies. This material is fairly expensive, but should give a strong, attractive finish. The author has no experience with this epoxy, so if you decide to use it, experiment with some first.

If the Tesla Coil is to endure a lot of travel and rough handling, and if it's not important that the windings be visible, the entire Secondary Coil can be wrapped with 2" wide electrical tape. Several grades or thicknesses of this tape are available, the heaviest being almost 1/16" thick. A coil so-wrapped is virtually "gorilla-proof." If you have trouble finding the correct tape, contact 3M Company for your nearest dealer.

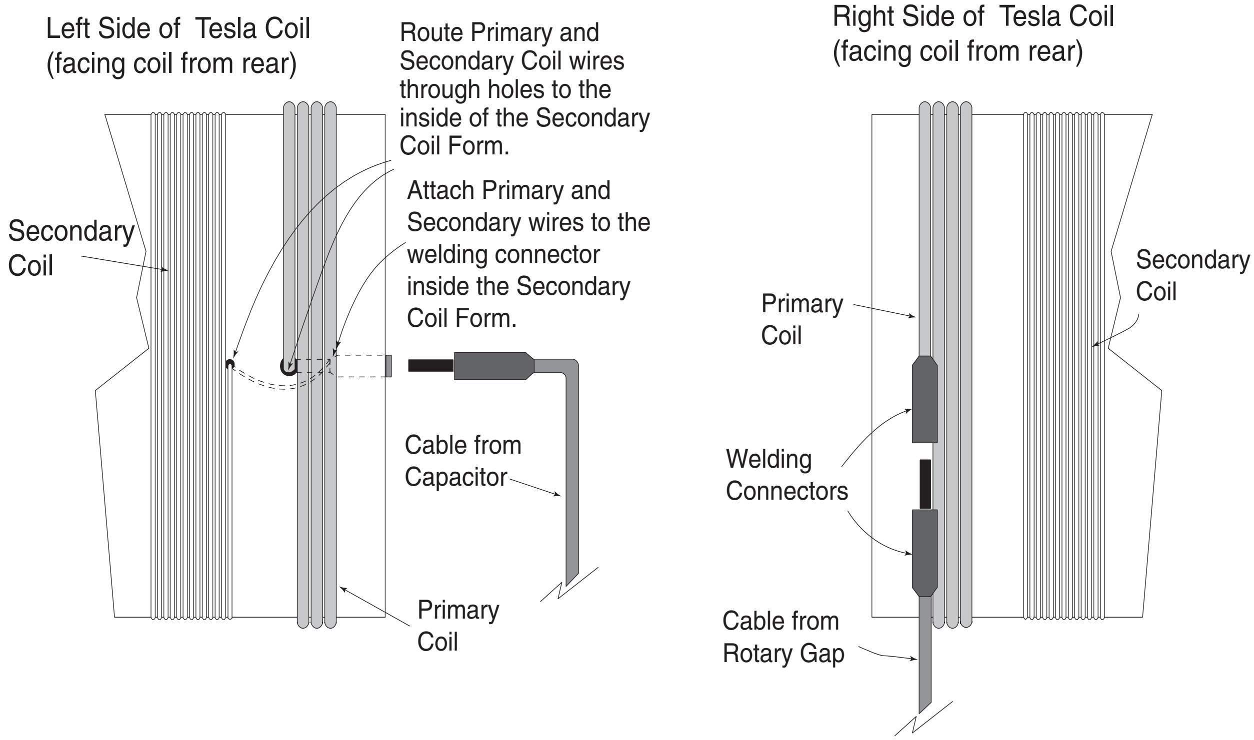


Fig. 13 - Primary & Secondary Connections

WINDING THE PRIMARY COIL

The Primary Coil consists of approximately 3 1/2 turns of #2 welding cable wound 3" below the Secondary Coil.

Drill a hole 3" from the bottom of the Secondary Winding on the left side of the Coil Form, in line with the hole for the Secondary Winding, and insert a length of #2 welding cable from the outside. Attach a welding cable connector to the free end inside the Secondary Coil Form, and position the connector so that it just extends outside the bottom of the Form (Fig. 13). Attach the free end of the bottom turn of the Secondary Winding to the same welding cable connector.

Wind about five turns of cable clockwise toward the bottom of the Coil Form and tape it temporarily into position. Because the exact number of Primary turns will be determined experimentally (the procedure is covered later under “TUNING”), the Primary Coil should not be permanently attached until the Secondary Coil is mounted and the rest of the Tesla Coil system is completed.

Attach a welding cable connector to the remaining cable end.

Later, once the exact number of turns is determined, the welding cable can be held in place with nylon wire stays or twine passed through holes drilled through the Coil Form at several locations on either side of the cable.

A more attractive technique is to use Plexiglas clamps and nylon bolts (Fig. 14). If the coil is to be handled frequently, wrapping the turns with 2" wide electrical tape will help keep the cable from shifting.

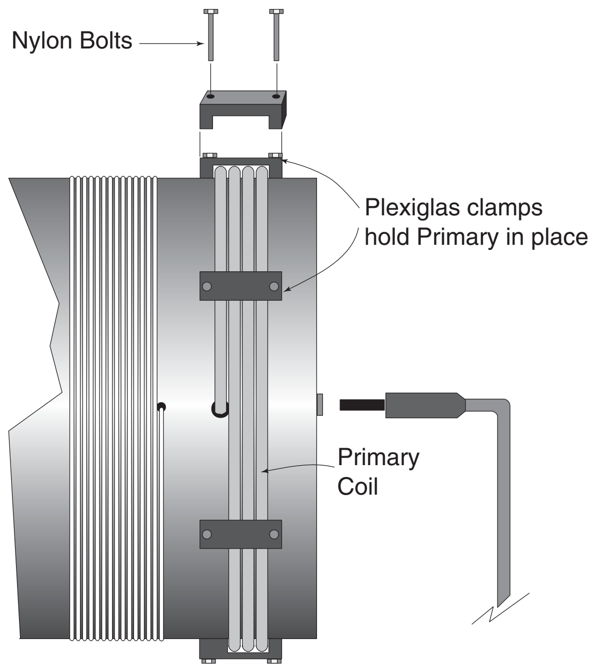


Fig. 14 - Securing Primary Coil

OSCILLATOR

The Road Show Tesla Coil's Oscillator is comprised of a Capacitor, Transformer, and Rotary Spark Gap. These components are housed in a two-foot cubical cabinet, with the Rotary Spark Gap attached to the top (Figs. 15 & 16).

The Coil was designed not only to travel, but to be "flown" (hoisted into the air) for various special effects. The cabinet frame is therefore made of welded aluminum and is strong enough for steel cables to be attached at the corners to lift the unit high above stage. If no such demands are to be made of the system, the Oscillator Cabinet can be made of other materials, such as plywood, plastic, or steel.

The Oscillator is bolted inside a wheeled road case. When erecting the Tesla Coil, the Road Case top is lifted off and the power and control cables are plugged in. If the system is to remain at one location, the road case can be eliminated and the wheels can be located on the Oscillator Cabinet.

The top of the Oscillator Cabinet is made of 1/4" or 1/2" Plexiglas; sides are lightweight aluminum panels.

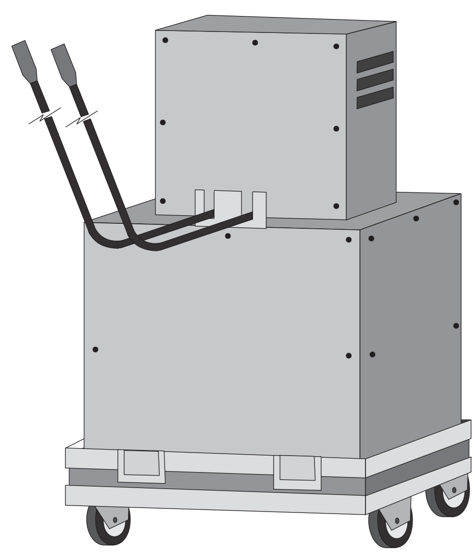


Fig. 15 - Oscillator

Oscillator Wiring

High voltage wiring is routed away from all other conductors and metal parts; high frequency currents can easily puncture insulation and can jump an inch or more to other wiring or to the metal enclosure.

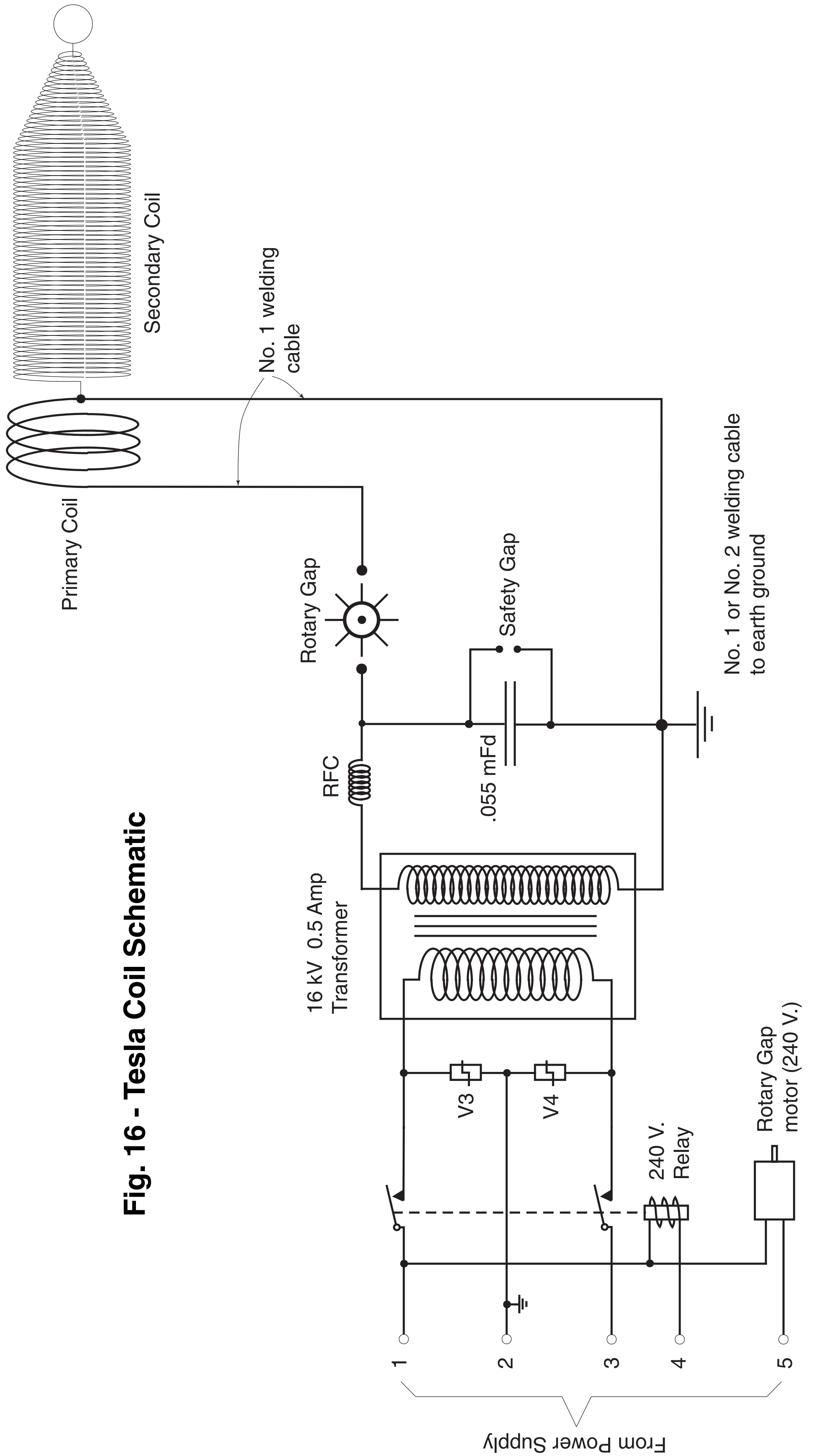
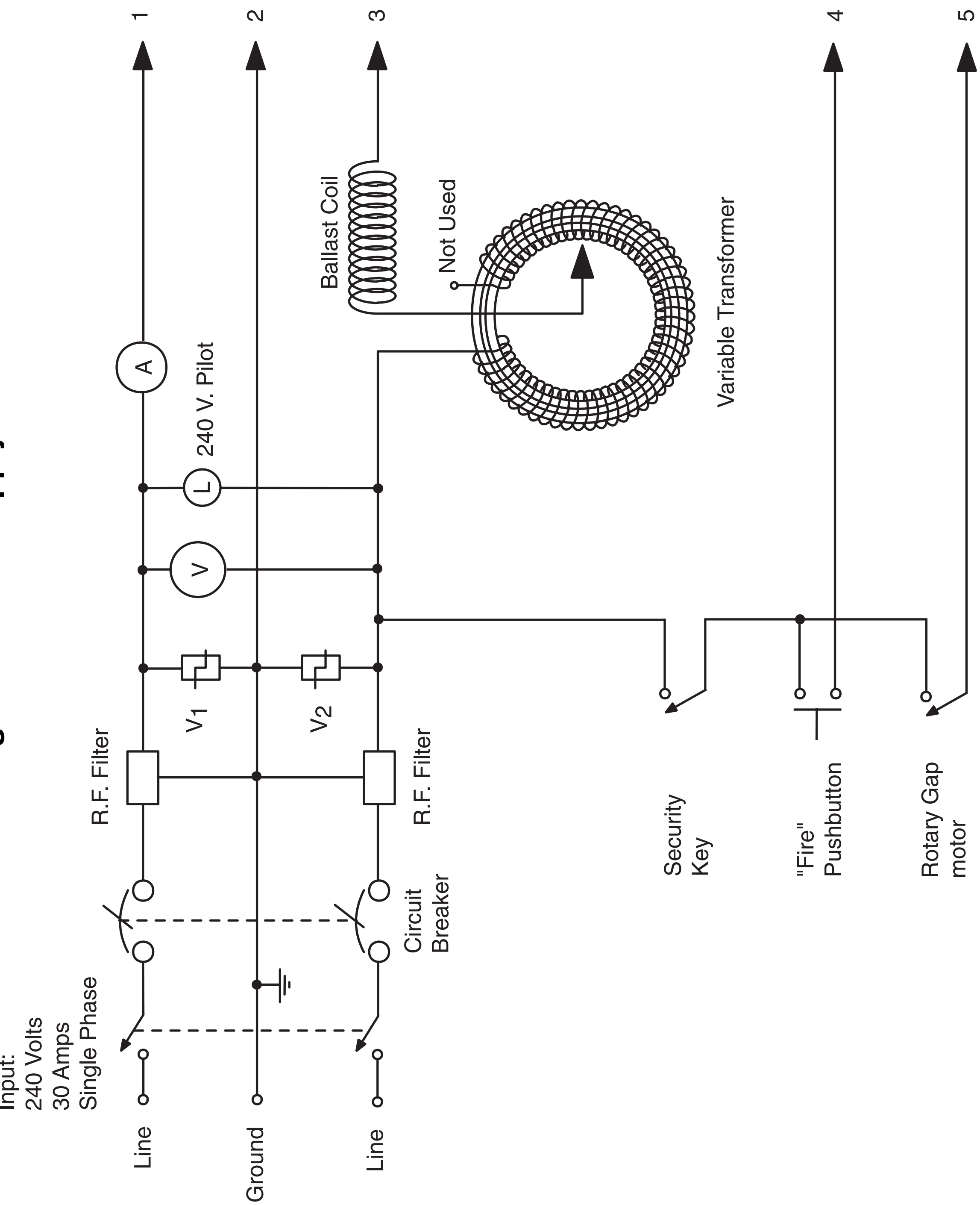
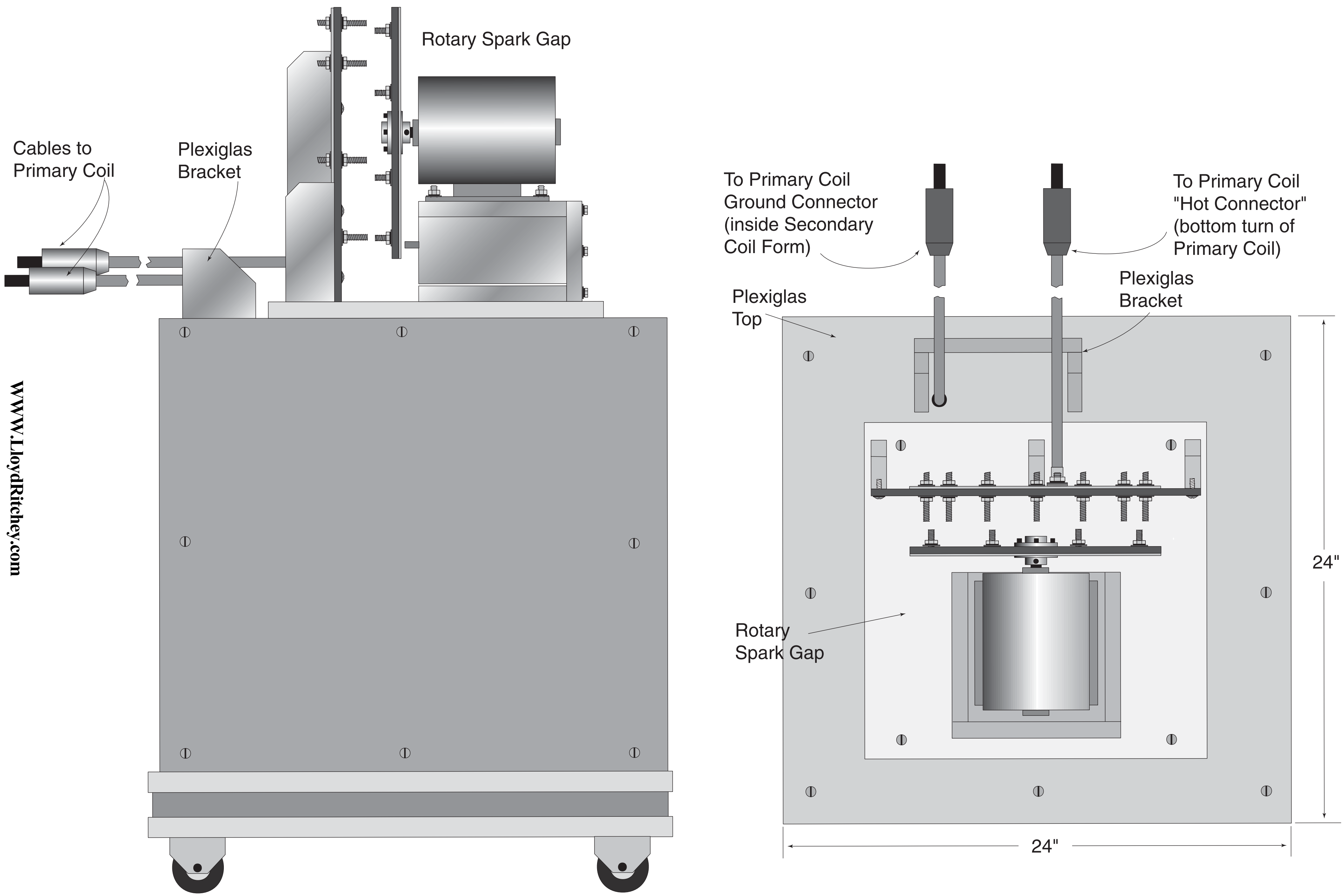


Fig. 16 - Tesla Coil Schematic

Fig. 17 - Power Supply Schematic





A. Side View of Oscillator

B. Top View of Oscillator

Figure 18

240 Volts from the Control Box enters the Oscillator via a three-conductor cable of No. 10 stranded wire. If the motor or relay require 120 volts, the control cable can be three conductor #18 to #12. A neutral return is included in the control cable for added safety and to allow the Relay and Rotary Gap motor to be tested while the power cable to the Oscillator is unplugged.

Note: Heavy RF currents flow in the Tesla Coil ground cable. If for any reason an impedance appears in this cable (bad connections, coming loose from the ground connection, etc.), the voltage will climb above ground potential and can reach many thousands of volts. It is therefore important that the cable be routed to ground the shortest distance possible and not coiled or folded back on itself.

One leg of the high voltage Transformer's secondary is grounded, thereby raising the transformer's second leg to the full secondary voltage above ground. These voltages can easily puncture insulation and can sometimes jump more than an inch to grounded wiring or chassis (or body!) parts. Keep this in mind when placing components and routing wiring.

Output from the "hot" leg of the Transformer is applied to one side of the Capacitor. A choke placed in series with this leg helps keep RF out of the Transformer. The choke should be mounted several inches from other wiring and chassis parts. Wire from transformer to Capacitor should be rated 15,000 volts or more and should not touch other components or wiring. If high voltage wire is difficult to find, ordinary No. 12 stranded wire can be used if it is sheathed in neoprene or rubber tubing.

Wiring between the Capacitor and Rotary Spark Gap should be kept as short as possible. The Capacitor and Transformer are protected from high voltage transients by means of a simple ball gap placed across the Capacitor (see "Interference & Transients," p. 50).

Although the Tesla Coil will only draw around 1/2 ampere from the Transformer, peak RF currents in the Coil's tank circuit (Capacitor, Primary Coil, and Rotary Spark Gap) will be very high. For this reason, No. 1 welding cable (same cable as used for the Primary Coil) is used to wire the tank circuit.

Welding cable also runs from the ground leg of the Transformer to the Capacitor and to the earth ground terminal on the Oscillator chassis. This cable should be treated as if it were carrying high voltage, because if it were to lose ground connection, its potential will rise to many thousands of volts.

Wiring for the motor and relay should be routed away from all high voltage wiring and should be secured with nylon wire stays.

Use crimp-on terminals to attach the welding cable to components. After crimping the terminals on the cable, solder the terminals to improve conductivity. A propane torch with a soldering attachment works well for this purpose.

The welding cable connecting the Secondary Coil and Oscillator should not exceed eight feet in length or else performance will suffer. If the Secondary needs to be elevated beyond ten feet from the floor, the Oscillator will also need to be raised. The shorter the cables, the better.

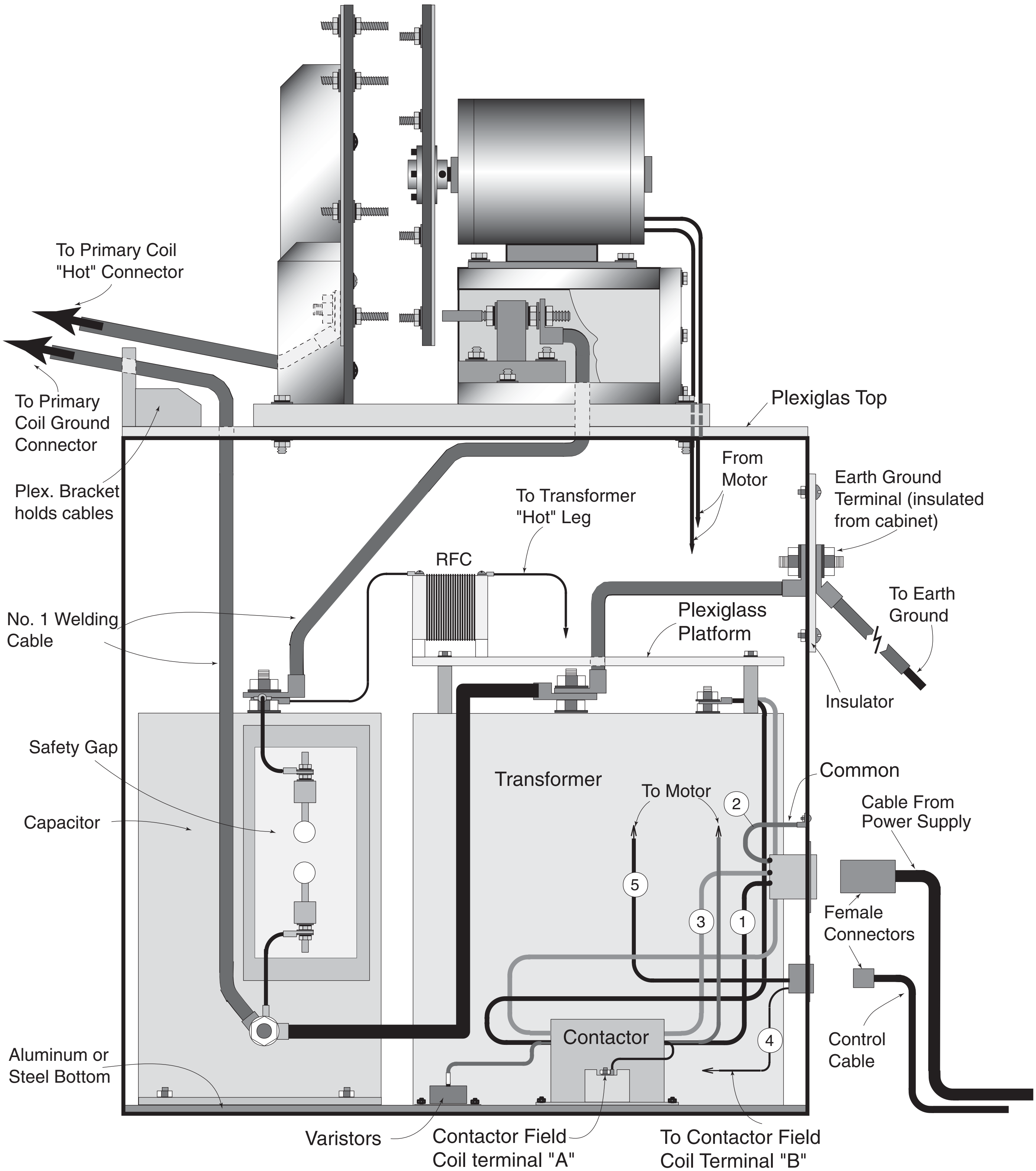


Fig. 19 - Side View of Oscillator

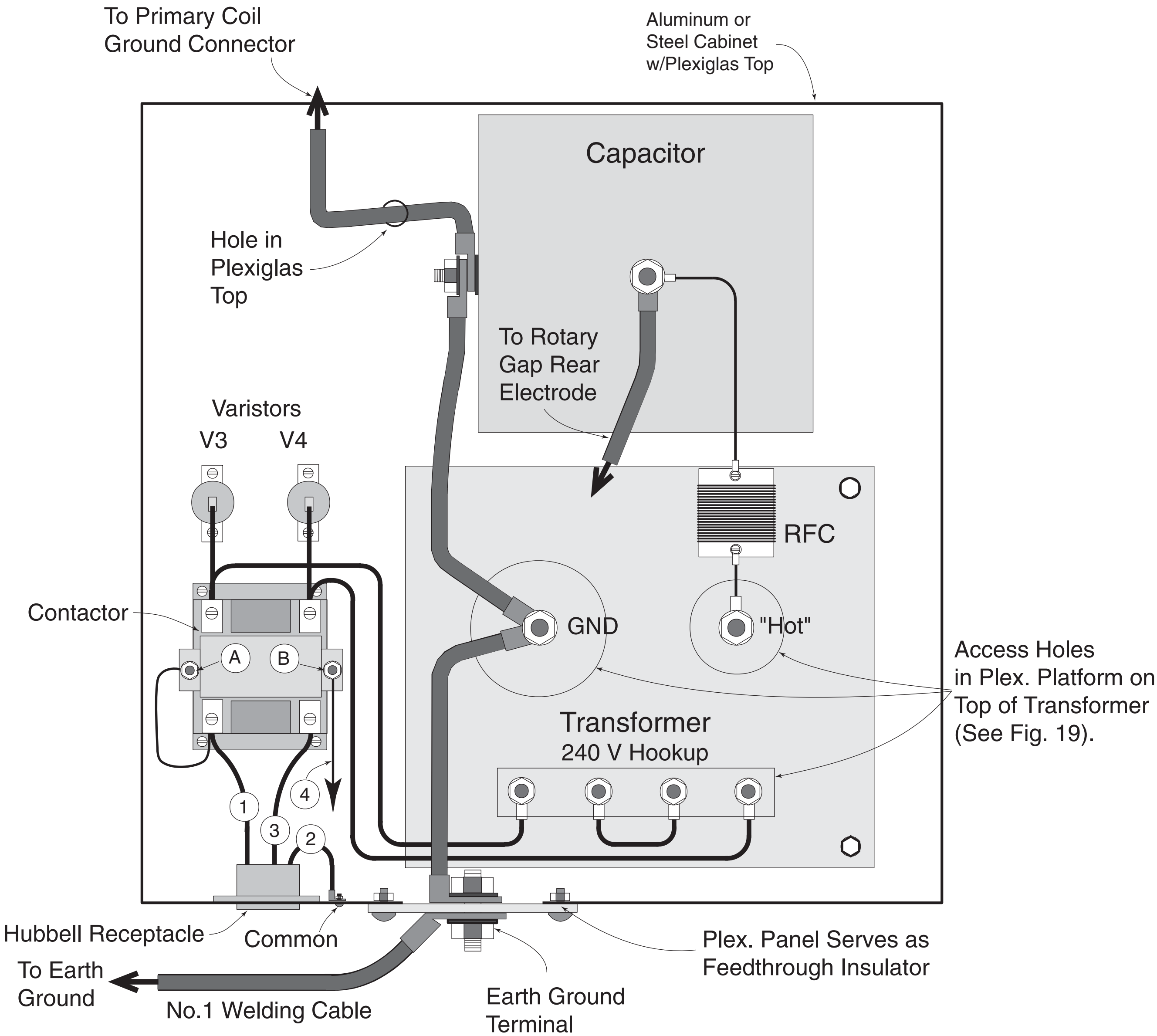
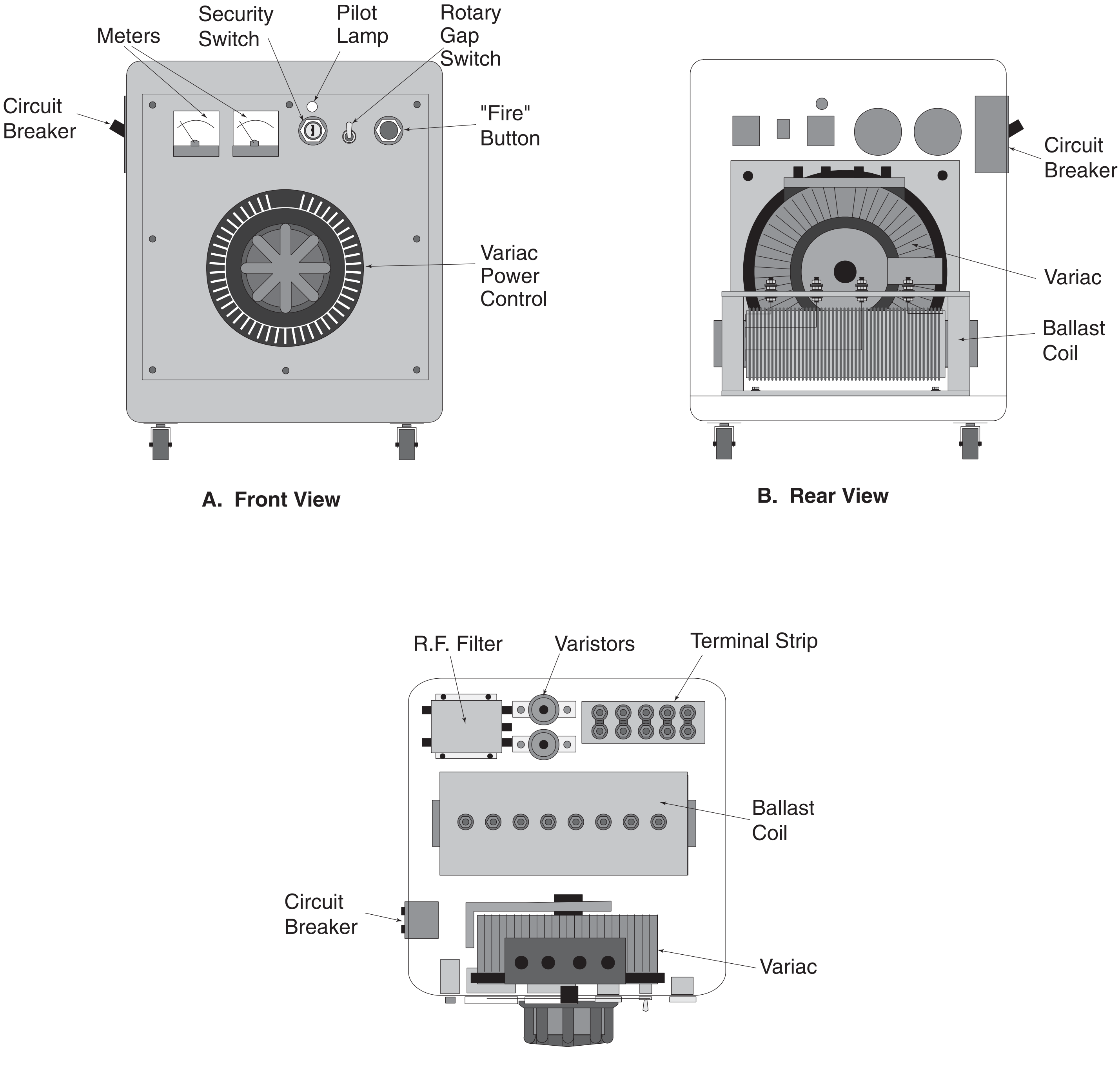


Fig. 20 - Oscillator Top View

CONTROL BOX

The Control Box is comprised of a variable transformer, a ballast, control switches, and filters. These components are built into a commercially available steel cabinet that can be positioned five, ten, or twenty feet from the Oscillator (Fig. 21). Recessed Hubble connectors are mounted on the cabinet side for power and control cables.

Like the Oscillator described above, the Control Box can be fitted with a set of wheels or, if it is to travel, mounted inside a road case. For additional flexibility, a hand-held remote switch box with Rotary Gap and "Fire" controls can be plugged in via a connector located on the cabinet.

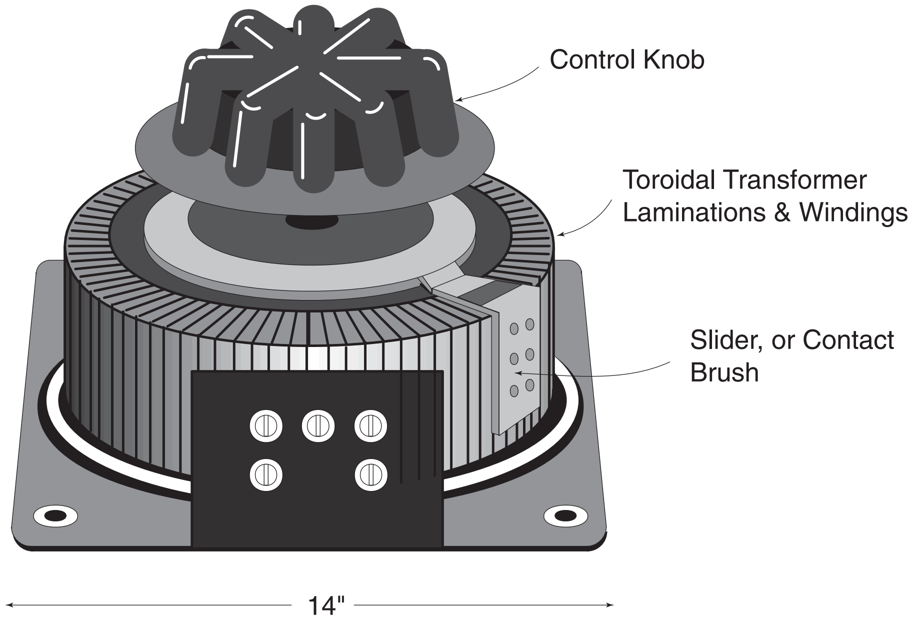


A. Front View

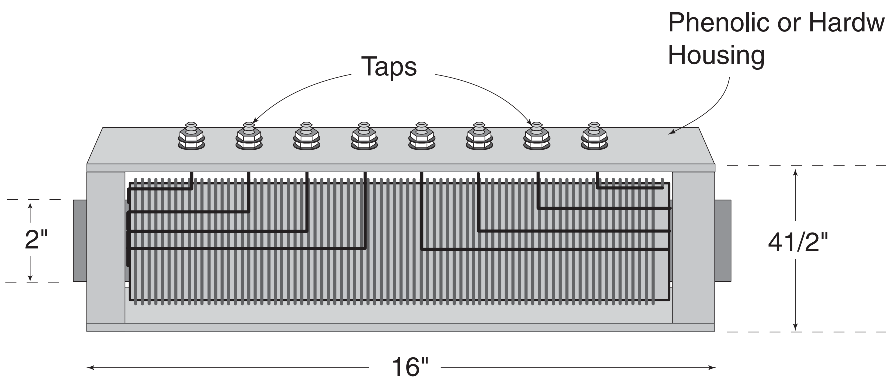
B. Rear View

C. Top View

Fig. 21 - Control Box Layout



A. Typical variable transformer. Some units allow control knob to attach to either side, permitting flush mounting on a vertical or horizontal surface.



B. Ballast: Approx. 300 turns of #10 wire on a 2" dia. PVC pipe. Tap every 50 turns. If the system is to be operated on 120 Volts, use #8 wire.

Fig. 22 - Variac and Ballast

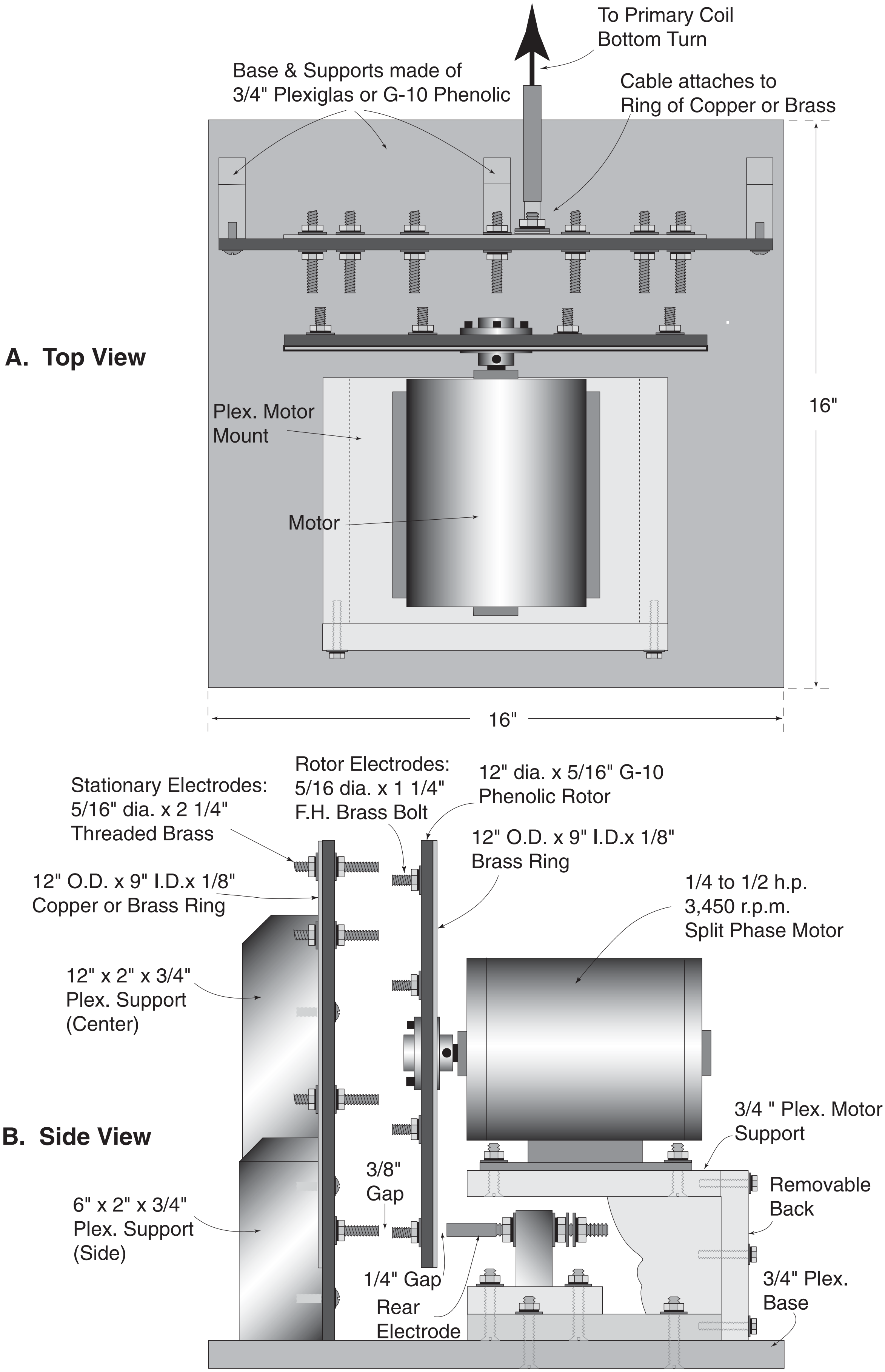


Fig. 23 - Rotary Spark Gap

ROTARY SPARK GAP

The Rotary Spark Gap is a variation of a design Nikola Tesla used (aren't they all!) and seemed to like. Kenneth Strickfaden used a similar design with some of his Tesla Coils that appeared in various movies.

The Rotary Gap has eight electrodes on the rotor and seven on the front electrode array (Fig. 23). No two electrode groups fire at the same time; the spark "chases" as one pair of electrodes after another is brought close together.

The motor is 1/6 to 1/2 h.p. 3,450 r.p.m. split phase. The rotary gap shown in this manual was designed for a motor having a NEMA frame 48 or 56. If your motor is of a different size or has a different mounting plate, you may need to adjust the motor mount and Rear Electrode dimensions.

Be particularly careful that the conducting portions of the Rear Electrode are at least 1 3/4" away from the motor frame and motor mounting bolts, or else arcing might occur. If clearance is too tight, the Rear Electrode can be raised and mounted to either side of the motor platform.

The Rotary Spark Gap is assembled on a base of G-10 phenolic (see Appendix for sources) or Plexiglas measuring approximately 16" x 16" and from 1/2" to 3/4" thick. Wood is not recommended for base material.

ROTOR: The rotor is a 12" diameter disk made from 5/16" or 3/8" G-10 phenolic. The G-10 is extremely durable, has excellent electrical characteristics, and usually requires little machining to correct warpage. Do *not* use Plexiglas, it doesn't have enough strength.

The eight electrodes for the Rotor are made of 5/16" x 1 1/4" flat head brass bolts. Fancier, and much costlier, electrodes can be machined from brass stock, but will produce no visible improvement in performance.

A machine shop should check the G-10 for warpage, cut the disk out, drill the electrode holes, drill the center shaft hole, and make the steel hub that connects to the motor shaft. If the machinist doesn't think the G-10 is flat enough, you'll have to search for better stock or buy a thicker piece and have him turn it to a uniform thickness.

The machinst should also cut, drill, and countersink the 1/8" thick brass ring that fits on the back of the rotor. Make sure the machinist knows that the flat head bolts comprising the electrodes must fit flush with the brass ring so that he countersinks the G-10 and the brass ring while they're mounted together.

It's a good idea to bring the motor and rotor electrodes with you so the machinist can make sure the parts will fit.

Use brass washers and nuts, and steel split-ring lock washers to attach the bolts to the rotor. Use Loctite on the steel hub set-screws, but don't use it on bolts carrying electric current.

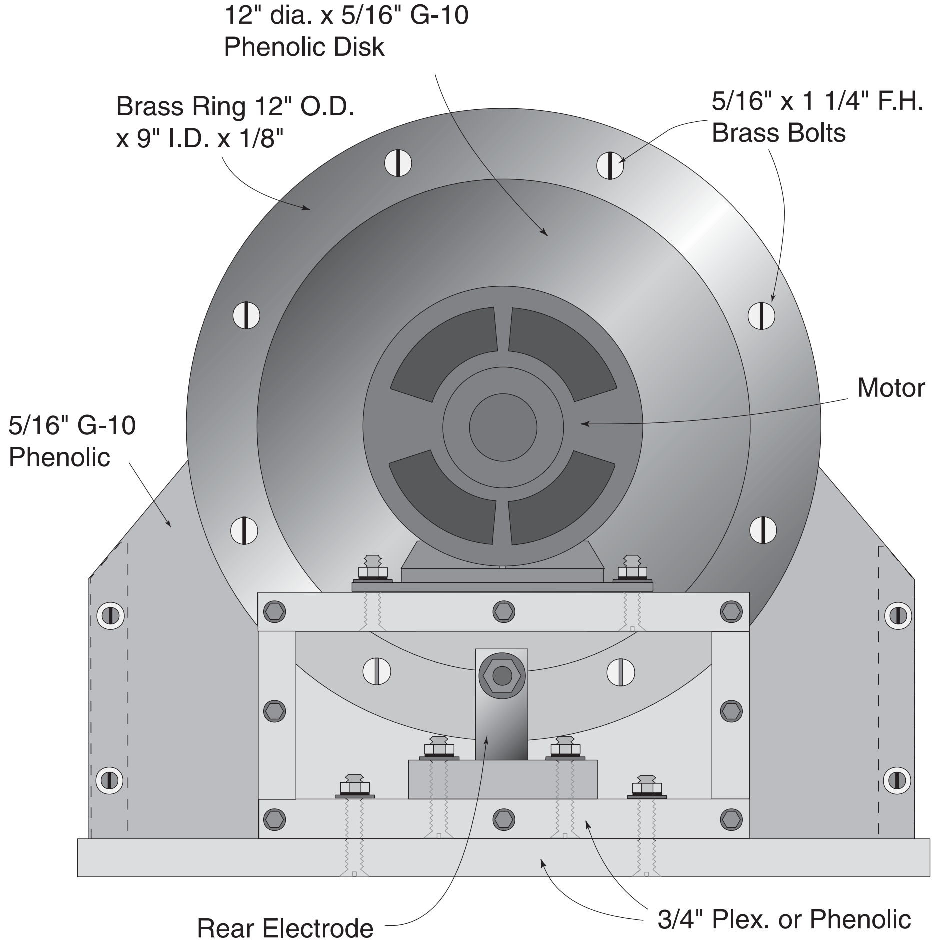


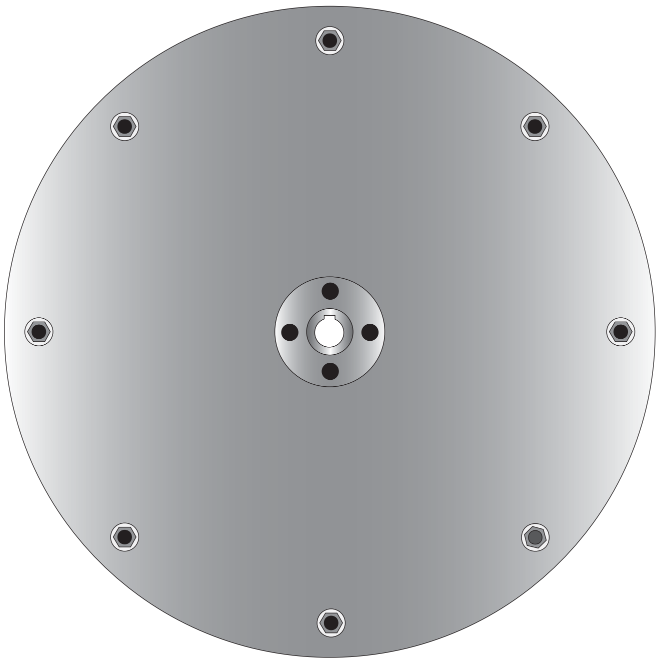
Fig. 24 - Rear View of Rotary Spark Gap

The motor is mounted on a box made of 3/4" Plexiglas or phenolic. The front of the box is open, and the back unscrews to allow access to the rear electrode.

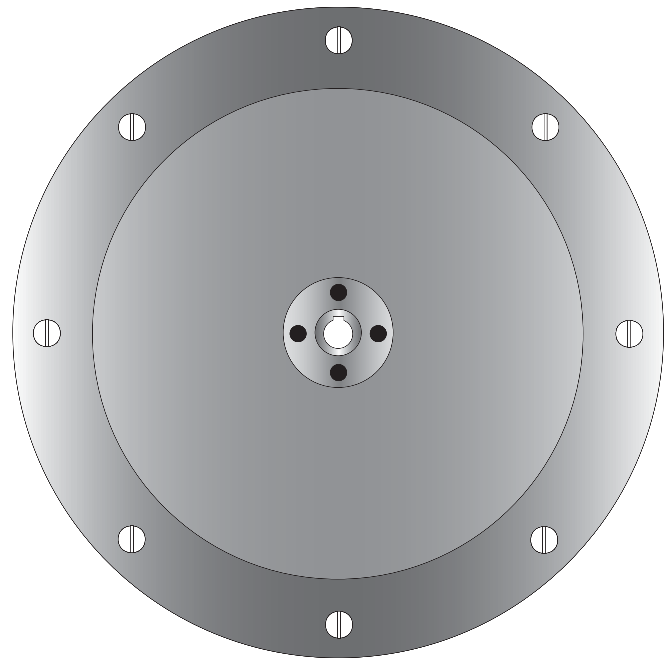
FRONT & REAR ELECTRODES: The rear electrode is mounted directly underneath the motor and consists of a 3/8" diameter brass bolt or threaded brass stock mounted in a brass post. Maintain approximately a 1/8" to 1/4" gap between this electrode and the brass ring on the rotor.

As previously stated, the motor frame is assumed to be a NEMA type 48 or 56. If your motor size and frame type differ, make sure that at least 1 3/4" of clearance is maintained between the rear electrode and any motor mounting bolts. If clearance is a problem, mount the electrode to the side of the motor instead of underneath. If the electrode is mounted to the side, it will have to be raised several inches and must be mounted securely enough that it will not vibrate out of adjustment.

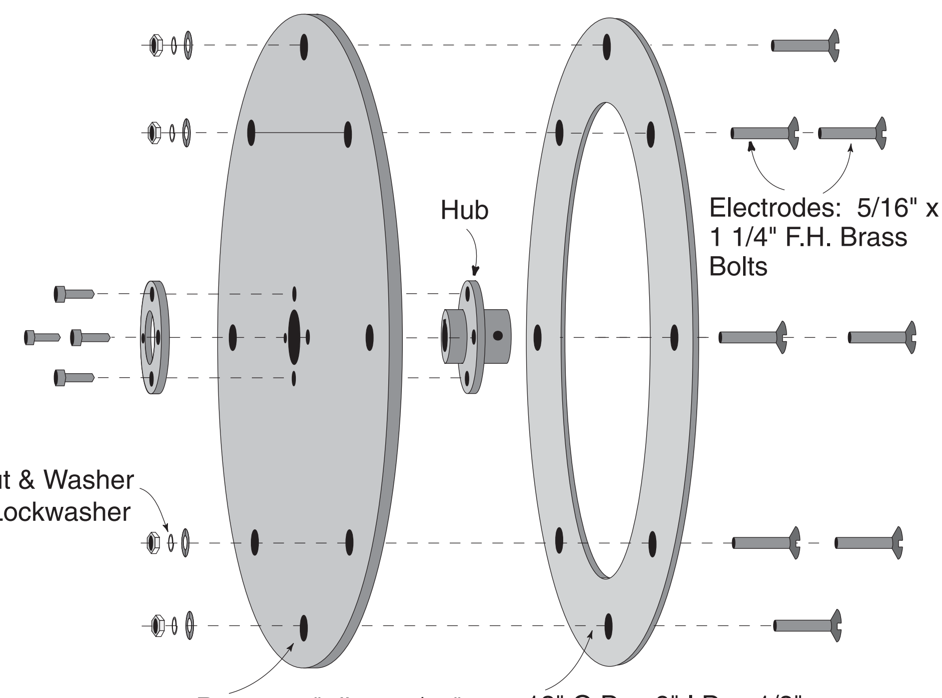
The front electrodes are made from 5/16" threaded brass stock or brass bolts. The mount and supports for the 1/8" thick copper ring and electrodes are made of Plexiglas or phenolic. The vertical supports should be 3/4" thick; the vertical panel on which the copper ring is mounted can be 1/4" to 3/8" thick.



A. Front View



B. Rear View



C. Rotor Assembly

Fig. 25 - Detail of Spark Gap Rotor

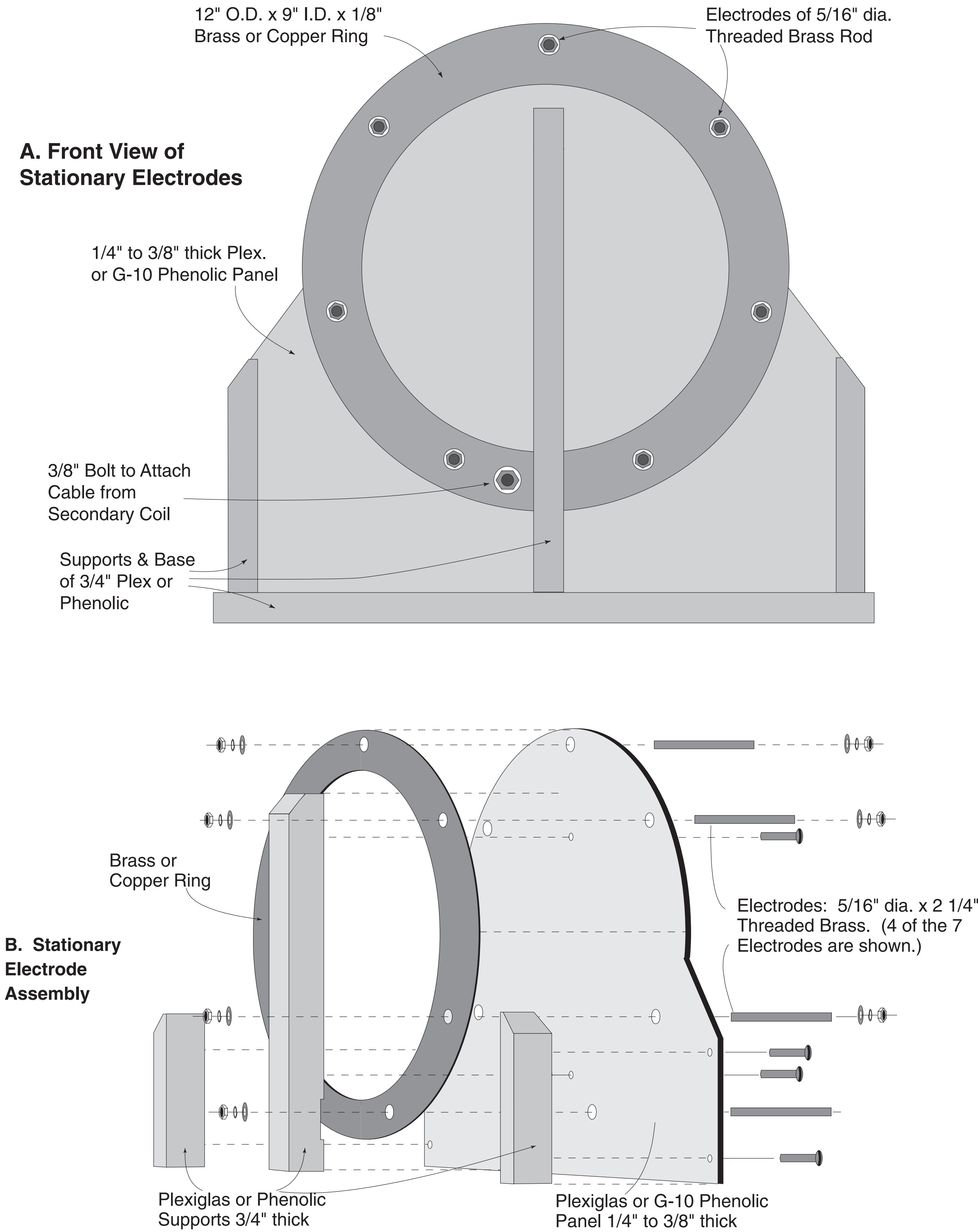


Fig. 26 - Front Electrodes

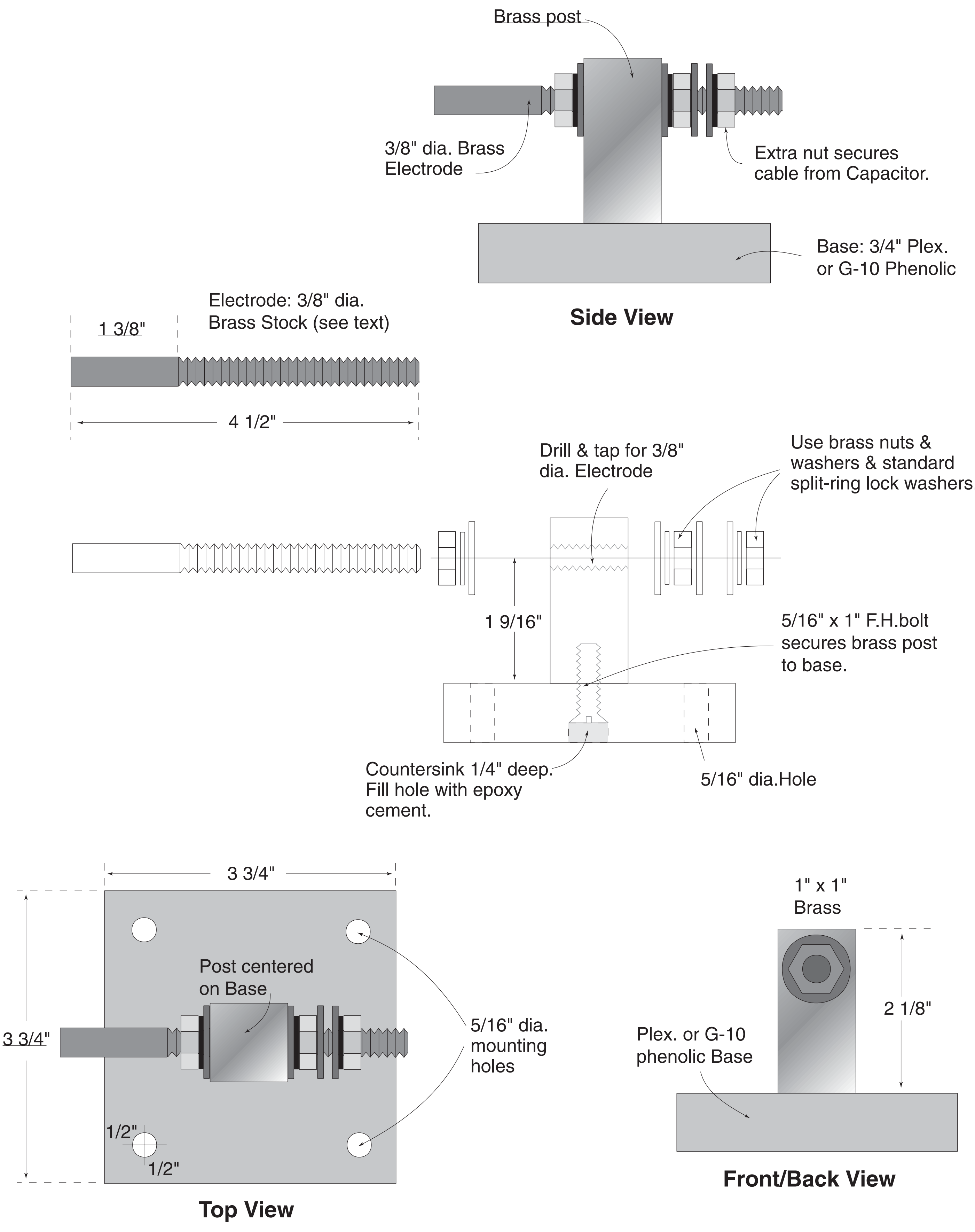


Fig. 27 - Rear Electrode

Adjust the front electrodes to a 3/8" gap, as shown in Fig. 23.
The cable from the Capacitor is brought to the Rear Electrode through a hole just behind the Electrode.

The Rotary Gap should run with a minimum of vibration and virtually no movement of the fixed electrodes. Double-check tightness of all electrodes and mounting bolts.

Build a cover for the Rotary Spark Gap out of 1/4" or 3/8" Plexiglas or phenolic. Smoked Plex. is ideal; clear Plex. will allow too much light to escape and interfere with viewing of the Tesla Coil discharge. Drill vent holes in the box sides to allow corrosive gases to escape when the spark gap fires.

TRANSFORMER

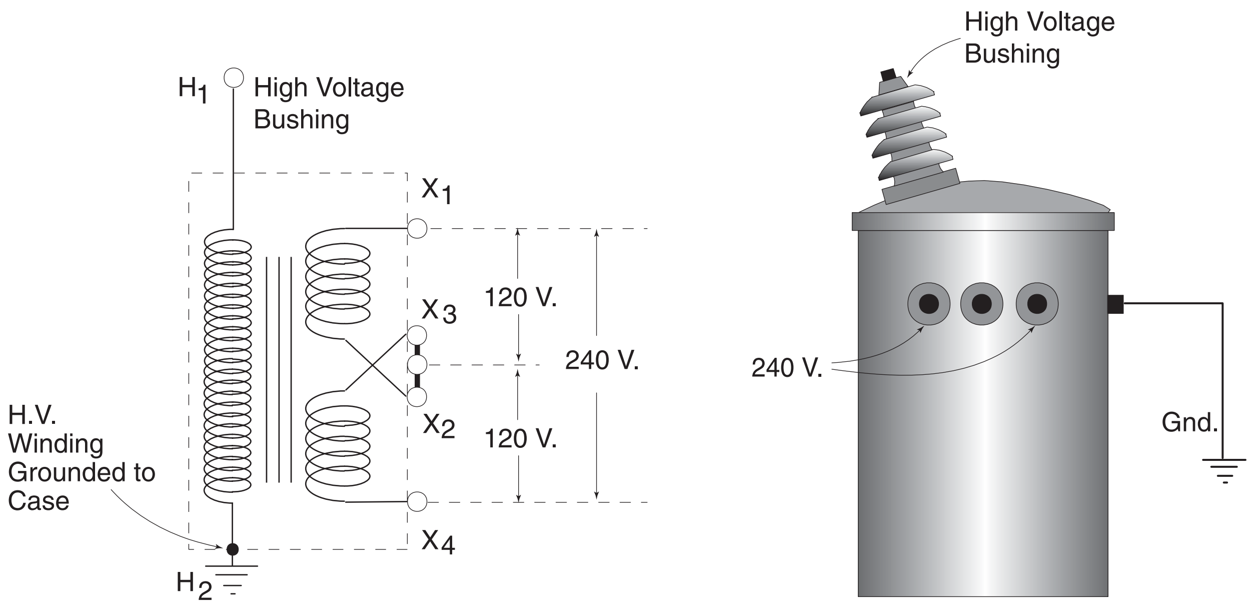


Fig. 28 - Typical Distribution Transformer. These transformers vary in configuration and construction. Make certain that the transformer has adequate ratings and that the connections are correct.

The transformer used in the Road Show Tesla Coil was custom made and is one of three identical units the author used in equipment appearing in shows across the United States.

The compact transformer is oil-filled, rated 16 kilovolts RMS @ .50 A. The input is either 240 or 120 Volts, 60Hz. Typical power demand on the transformer is 7.2 kVA. Weight of the transformer is around 120 lbs.

The leakage reactance of this transformer is fairly low, and input power is regulated by a combination of variable reactance and fixed resistance. One output leg is grounded.

The transformer is mounted inside a welded aluminum "tank" measuring only 13" deep, 13" wide, and 14" high. The top, to which the primary and secondary terminals are attached, is made of G-10 phenolic, which is sealed around the edges with silicone sealer.

The transformer was made by Geotronics, Dallas. Geotronics and several additional custom manufacturers are listed in the Appendix.

Common "pole" or distribution transformers can also be used and can usually be purchased from the local power cooperative or utility company. Although rugged, a pole transformer will take up more space because of its large porcelain feedthrough insulator.

A 5 kVA - 10 kVA pole transformer will handle power requirements for the Tesla Coil. Primary voltages for these transformers can vary, but they're usually rated to provide 120 and 240 volts. A fairly common primary rating is 14.4 kV, which is adequate. The lower voltage, however, will result in slightly lower Tesla Coil performance.

In order to use a pole transformer, connect the low voltage input to the bushings located on the side of the transformer (Fig. 28). To operate the transformer from 120 volts, use either of the outside bushings and the center bushing. To operate the transformer from 240 volts, use the two outside bushings.

The tall bushing on top will be used as the “hot” leg, and the smaller bushing will be connected to ground. Some distribution transformers have only one high voltage bushing and ground one leg to the case. Check that you make the right connections and have the right ratings.

Do *not* attempt to use neon sign transformers! They won’t work, even if a number of them are wired in parallel. The insulation will fail and the transformers will burn out.

CAPACITOR

The capacitor for the Road Show Tesla Coil was custom made by Plastic Capacitors, Chicago. The dielectric is polypropylene. Ratings are: .055 µF, 16 kV AC rms. This capacitor is lightweight and measures only 10" long, 8" wide, and 14" high.

Custom capacitors are expensive, but necessary for a truly professional Tesla Coil. We’ve had excellent results with products made by Plastic Capacitors, but should you want to shop around, several additional manufacturers are listed in the Appendix.

Homemade capacitors using glass sheets, popular in the early days of radio, are not recommended. Glass will work, but the relatively poor performance, enormous size, and “off-the-scale” weight makes them almost totally unacceptable. Capacitors employing a paper or ceramic dielectric will degrade very quickly, and are also not recommended.

Should you find some surplus pulse capacitors that can be combined for the correct rating, you might try them. Mica transmitting capacitors would work very well, but they're hard to find.

If you search the surplus market, remember that a DC-voltage rated capacitor must, as a general rule, have three times the voltage rating when used in an AC circuit.

Try to find a capacitor within 15% of the .055 µF rating. A .01 µF capacitor, for instance, would nearly double the Tesla Coil's input power. Whereas this would provide longer, brighter sparks, the gain would not be in proportion to the increase in power without redesigning the Secondary Coil. In addition, the Transformer, Rotary Gap, Control Box, Primary Coil, and other elements would need to be changed. A Tesla Coil must be designed as a complete system; altering one component sometimes requires adjustment of virtually all the remaining components.

VARIABLE TRANSFORMER

The input power to the Road Show Tesla Coil is regulated by a variable transformer used as a series adjustable reactance, and by a separate ballast.

Staco Co. manufactures variable transformers (trade name "Variac") for 120 or 240 Volt operation. Using 240 Volts for the Tesla Coil's input power is preferable, as the power cables can be smaller and lighter.

For 120 Volt operation, use a 60 amp. 8.4 kVA unit (Staco model 6010).
For 240 Volt operation, use a 35 amp. 9.8 kVA unit (Staco model 6020).

Pay attention when making connections to the Variac to ensure that turning the control knob clockwise results in a *decrease* in inductance, which will cause an *increase* in power.

BALLAST

Spark gap quenching can sometimes be improved by adding a Ballast in series with the variable transformer. A ballast isn't always needed, but low leakage reactance transformers often need one.

The Ballast for the Road Show Tesla Coil consists of approximately three hundred turns of No. 10 (No. 8 if using 120 V. input) stranded wire wound over a 2" dia. PVC pipe. (Fig. 22). The final number of turns used will be determined experimentally (see "Tuning").

Provide a tap every 50 turns. These taps will be used during the tuning process to help regulate the Coil's input power.

Don't mount the Ballast permanently inside the control box until the Tesla Coil has been tuned, as more turns may need to be added.

DISCHARGE ELECTRODE

Various sizes and shapes of discharge electrodes can be used, but all that is really needed is a simple 7" aluminum disk attached flush with the end of the Secondary Coil's "nose cone."

The larger the discharge electrode, the lower the Coil's resonant frequency. The Tesla Coil should always be tuned with the discharge electrode in place, and re-tuned if the electrode is changed.

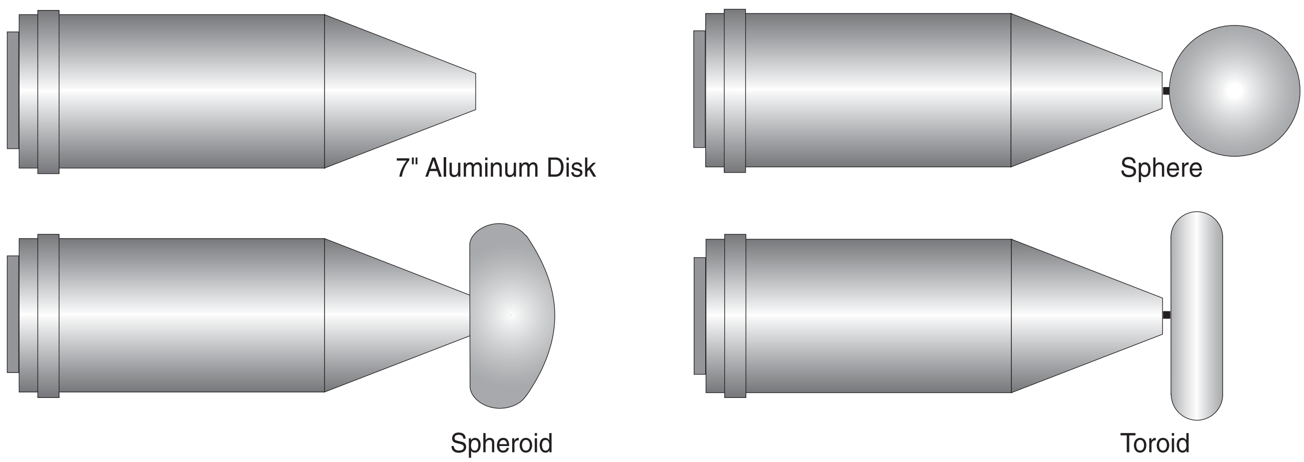


Figure 29 - Discharge Electrode Styles

MOUNTING STAND

A "Vermette" type stand is an absolute necessity if the Tesla Coil is to be frequently moved and is to be mounted in a horizontal position (Fig. 30A).

These stands are normally used to raise and lower materials at construction sites. They can be easily modified to allow attachment of the Tesla Coil Secondary.

Vermette stands break down into several sections for shipping. They assemble quickly and can easily raise and lower the Tesla Coil Secondary by means of a rear-mounted hand crank.

If the Tesla Coil will remain in a horizontal position for long periods, a cheaper fixed stand can be constructed of 3" diameter steel pipe (Fig. 30B). Mounting the Secondary to such a stand, however, will require at least two (probably three!) strong men and a couple of ladders.

Ferrous metals should be kept away from the Secondary Coil, so an aluminum mounting bracket is attached to the rear of the Coil to provide several inches of separation from the steel mounting stand (Fig. 30C). If you use an aluminum stand, the bracket can be eliminated and the Secondary Coil can be attached directly to the stand. Use brass bolts to attach the mounting bracket to the Secondary Coil.

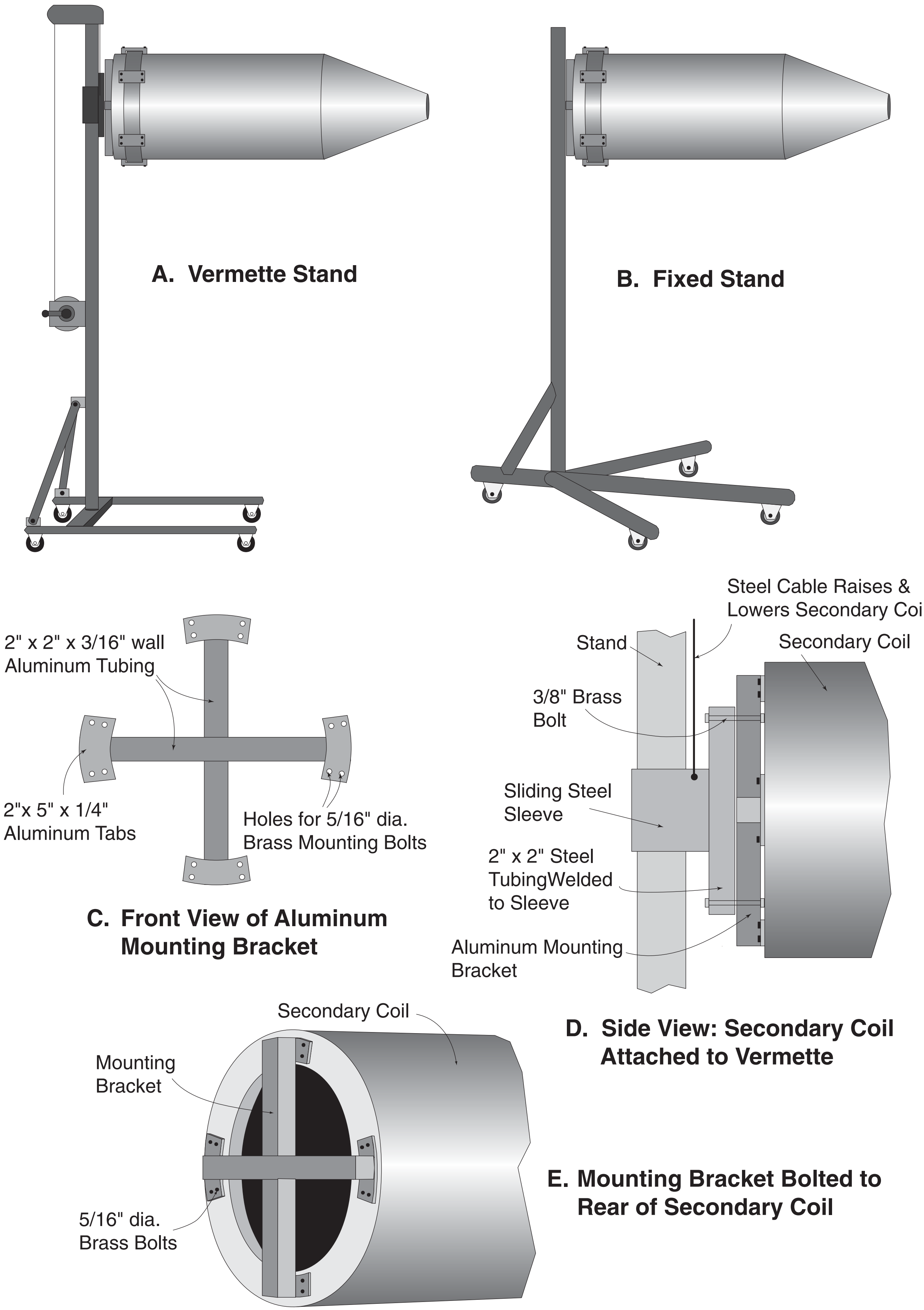


Fig. 30 - Horizontal Mounting

VERTICAL MOUNTING

If the Tesla Coil is to be mounted vertically, construct a larger Oscillator Cabinet and mount the Rotary Spark Gap inside, in front of the Capacitor (Fig. 31). In order to keep out corrosive gases produced by the Rotary Gap, install a partition between it and the other components. The top of the Oscillator Cabinet should be made of wood, phenolic, or a similar material strong enough to carry the coil's weight.

Cables from the Primary Coil can be connected to terminals or feedthrough insulators in the top of the Oscillator Cabinet. If wood is used for the top of the cabinet, do not allow conductors carrying high voltage to touch the cabinet. (A flat spiral Primary can used instead, if desired.)

The wires to the Primary Coil can remain entirely on the outside of the Secondary Coil Form. The grounded end of the Secondary Coil can be brought through a hole in the Secondary Coil Form and attached to the top turn of the Primary Coil, or it can be inserted through a hole in the top of the Oscillator and attached to the grounded side of the Capacitor.

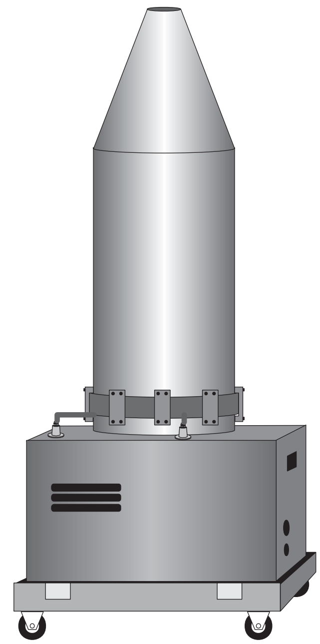


Fig. 31 - Vertically Mounted Tesla Coil

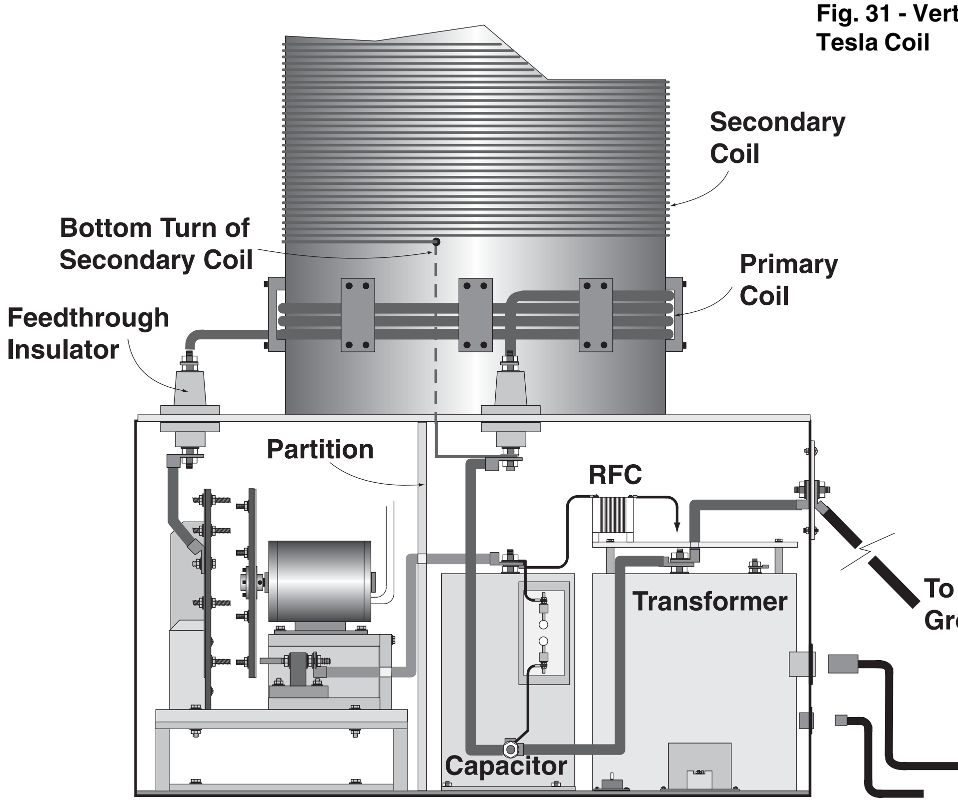


Fig. 32 - Parts Layout for Vertically Mounted Tesla Coil

CABLES & CONNECTORS

The Tesla Coil will draw approximately 30 amperes if designed for 240 volt input, and about 60 amperes if designed for 120 volt operation. For power cables 30' or shorter, use #10 stranded wire with 240 volts; use #6 for 120 volts. Consult the electrical code book for long power cable runs, and check with a qualified electrician if the installation is to be permanent

We have used Hubbell connectors with all the systems we've constructed and recommend them highly. These connectors were designed with touring equipment in mind. They're extremely durable and require very little maintenance. Many electrical supply stores sell Hubbell products.

Twist-lock welding cable connectors work very well on the high voltage leads from the Oscillator to the Tesla Coil. They're rugged, connect/disconnect quickly, and are designed to carry heavy currents.
Welding supply stores sell connectors, cable, ground clamps, and lugs.

TUNING

Tuning can begin after the Tesla Coil system is completed and the Secondary Coil is mounted in its operating position (horizontal or vertical).

The Tesla Coil should be set up in a dark location (the darker, the better) and away from conducting objects (Refer to Fig. 2).

If the Secondary Coil is horizontally mounted, the bottom edge of the Discharge Electrode should be eight or nine feet from the floor and at least eight feet from the ceiling. If the ceiling and floor are made of non-flammable materials, such as concrete, the Discharge Electrode can be as close as seven feet. Operating at full power, the Tesla Coil will strike walls, ceilings, or floors that are seven feet or closer.

Remember that changing Discharge Electrode sizes will alter the frequency, necessitating tuning adjustment.

You can eliminate some guesswork by using a function generator to determine the resonant frequency of the Coil. The generator should have an input power of at least 8 watts. Connect the function generator as shown in Figure 33. Switch the generator to "square wave" mode and turn the output up to maximum.

Tape one lead of a small neon lamp to the Discharge Electrode and tune the generator through a range of frequencies. The neon lamp should glow when the resonant frequency is reached (around 170-200 kHz). The lamp may also glow when the generator is tuned to several harmonics of the fundamental, but it will glow conspicuously brighter when the true resonant frequency is reached.

Once the resonant frequency is determined, use the standard formulas (see Appendix) to calculate the inductance needed and number of turns required for the Primary Coil. The final number of turns needed for maximum coil output will probably vary slightly from the calculated number, so it's still necessary to go

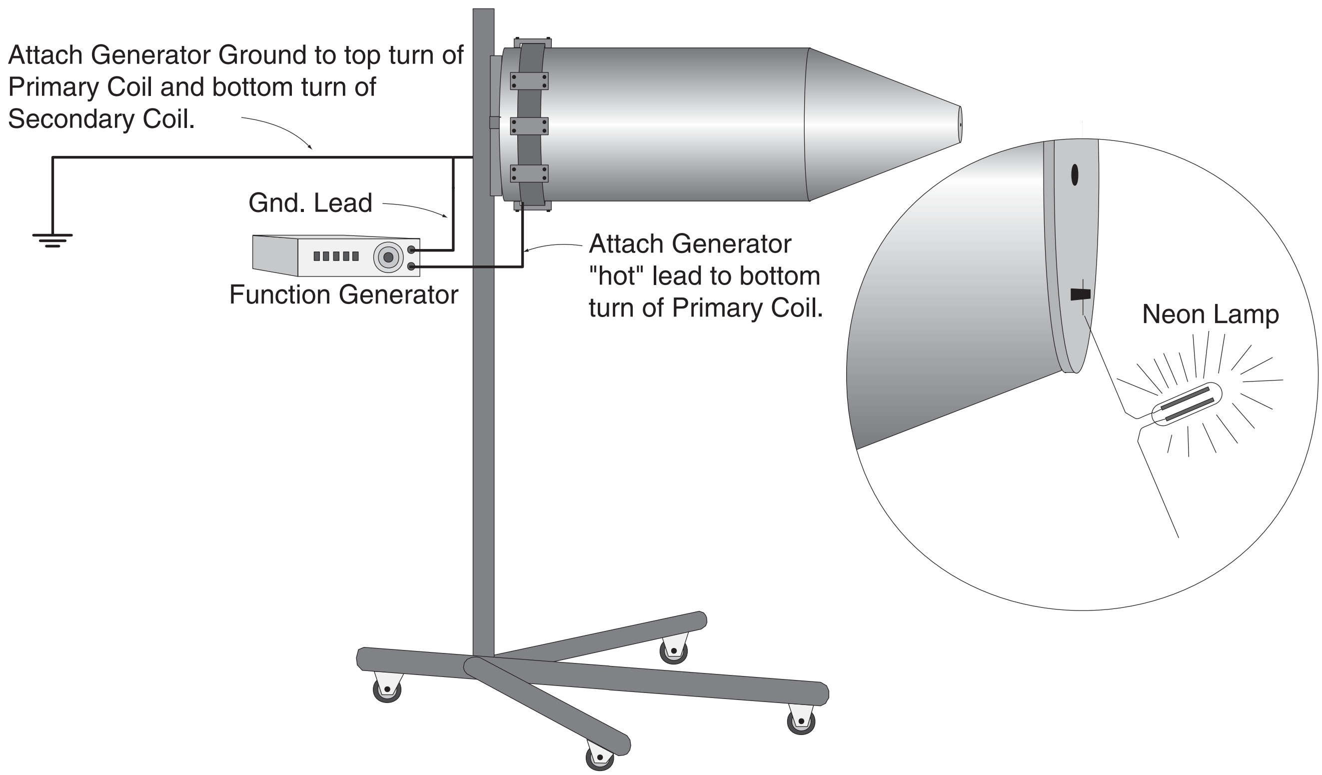


Fig. 33 - Determining Resonant Frequency with a Function Generator

through the tuning process below.

Attach a No. 1 or No. 2 welding cable to the ground lug on the Oscillator cabinet and attach the other end to a good earth ground. Smaller ground cable sizes will work, but if the coil is to be moved to different locations, the use of a large cable will ensure better performance. Do not use a ground wire smaller than #6, even if the distance to ground is less than 50'. The cables running from the Oscillator to the Secondary Coil should be as short as possible.

Cold water pipes, steel building frames, and properly grounded conduit are usually adequate as electrical grounds. Some buildings have "floating grounds," which means that the conduit may not provide an adequate ground connection.

If you are uncertain about a ground, check it by connecting a 100 watt light bulb between the ground and a 120 volt "hot" wire. If the bulb glows at less than full brilliancy, find a better ground.

Connect all power and control cables. Set the Variac to about 60%. Make certain that people and other conducting objects are outside the "Strike Zone." Arm the system by turning the circuit breaker and security key switch to the "on" position. Turn on the Rotary Spark Gap (which should have been tested by now for vibration and stability). An observer will be helpful during the tuning process, as he can help watch for problems, such as arcing inside the Oscillator Cabinet and sparking between the Primary and Secondary Coils.

Push the "Fire" button for one second. A spark several feet long should dart from the Discharge Electrode. The Rotary Gap should fire with a steady, crisp, buzzing sound reminiscent of a buzz saw. The Rotary Gap spark should be blue-white in color and should be relatively short in length, confined to the distance between the electrodes.

Most importantly, no sparks should dart between the Primary and Secondary Coil or between windings on the Secondary.

If no sparks occur between the Primary and Secondary Coils or between the Secondary Coil Windings, and if the sparks from the Discharge Electrode are at least three or four feet long, increase the Variac power to about 70% and fire the Coil again for about one second.

The discharge should grow in length to about six feet and the Rotary Gap should fire with a steadier appearance and sound.

If, on the other hand, sparks occur between the Primary and Secondary, or along the Secondary Coil, the system is off resonance. Alter the Oscillator frequency by uncoiling one turn from the bottom of the Primary coil. The excess length can be temporarily draped across something insulating, like PVC pipe or Plexiglas. Keep the excess length fairly straight. If it is allowed to coil up, it will add inductance to the system and make tuning inaccurate.

Fire the Coil again and see if performance improves. If the sparking between the Primary and Secondary continues or worsens, try adding wire instead of removing it.

Add or subtract turns until maximum discharge length is obtained. Fine tune the Coil by adjusting the Primary in 1/4-turn increments. There should be absolutely no sparking between Primary and Secondary Coils or along the Secondary Coil.

If a .055 mFd Capacitor is used in the circuit, as specified, resonance should be achieved with from two to five turns on the Primary. Typically, three and one half turns will be needed.

For horizontal mounting, it is necessary that the Primary Coil's leads plug in on opposite sides of the Coil. If, for example, three primary turns are required for best tuning, this will place both leads on the same side of the coil. If this happens, give the Primary Coil three and one half turns in order to place the lead on the opposite side of the Coil. However, to keep from adding too much inductance, space the extra one-half turn as far away from the other turns as possible. If necessary, the remaining turns may also have to be spaced slightly farther apart to compensate for the added inductance.

Once the number of Primary turns has been established, the input power can be fine tuned by adjusting the Variac and the Ballast Coil.

Operate the Coil using various settings of the Ballast and Variac. At some point, the Spark Gap should fire with the "cleanest," steadiest note and the Tesla Coil discharge length should be at its absolute maximum length. This point might occur with the Variac at about 80% and using the third or fourth tap on the Ballast.

Opening the Rotary Gap electrodes beyond 3/8" will tend to increase the coil's discharge length. Keep in mind, however, that widening the gap places more stress on the Capacitor.

If the Spark Gap fires intermittently, try increasing the Variac power. If the gap fires with heavy, sputtering, yellowish sparks that stretch for several inches beyond the electrode gaps, decrease the Variac power output. Fine tune the spark with the Ballast Coil.

If the entire Ballast Coil is used and the Rotary Gap continues to fire with a sputtering, yellowish spark, it will be necessary to add turns to the Ballast. Try adding as many as two hundred turns, bringing out taps every 50 turns.

JUDGING PERFORMANCE

The maximum free-air discharge length of the Road Show Tesla Coil, using a 16 kV rms input voltage with a .055 µFd capacitor, is approximately ten feet. The instrument will deliver heavy, nearly constant discharges to a ground rod held at six feet. As the rod is moved farther and farther away, the discharges will strike it less often. A point will be reached where the discharge “ignores” the rod and crackles about freely in the air. The longest discharges will occur in free air, not to a grounded electrode.

Discharges are measured in a straight line starting at their point of origin at the Discharge Electrode to their “end,” where they meet a conducting object or where the discharge can no longer be seen in total darkness.

TROUBLESHOOTING

Spark Gap Doesn't Fire: Output from a fully-energized 14 to 16 kV transformer can bridge a gap about one inch wide. When connected in parallel with the Capacitor, the distance can extend beyond one inch. The Rotary Gap should have a total gap distance of less than one inch. Check that the Rear Electrode is only around 1/4" from the Rotor conducting ring and that the other electrodes are spaced 3/8" apart at their closest point.

Check the amount of current the system pulls when the "Fire" button is depressed. With the Rotary Gap out of the circuit, approximately 22 amperes will be drawn with the transformer connected for 240 volts input, and 44 amperes if connected for 120 volts. If the readings are much higher, suspect a short circuit. If the readings are much lower, the Transformer may not be producing its full potential, the input voltage is too low (some buildings are wired for 208 volts instead of 240), or the Capacitor is defective.

If very little or no current is drawn when the Transformer is activated, suspect an open circuit. The Transformer can be tested by disconnecting the high voltage leads from the circuit and arranging them where they can be briefly brought close together to check arcing distance.

If such a test is desired, make absolutely certain that the high voltage output cannot jump to the rest of the circuit. One way to make the test is to prepare an adjustable spark gap (such as the Safety Gap) and attach the Transformer secondary leads across it. The gap should fire at approximately 3/4 to 1 inch separation and should produce a heavy, yellowish, flaming arc. The amount of current drawn will be limited primarily by the Variac and Ballast.

If the spark is weak, even with increased power, the Transformer may be defective.

If the Transformer is OK, check the Capacitor for a short or open circuit.

If the Transformer and Capacitor are OK, search for short or open circuits elsewhere. With high power levels, short circuits usually manifest themselves quickly!

Spark Gap Fires Intermittently: All the above checks and remedies apply. A weak Transformer or partial short-circuit in the Capacitor will reduce voltage across the Rotary Gap and can cause a "stuttering" spark.

If the Tesla Coil produces a good discharge, but the Rotary Gap "stutters" or seems to misfire, try adjusting the Ballast.

Rotary Gap "Flames Out": A yellowish, flaming spark across the gap can be caused by a narrow gap, by an open circuit in the Capacitor, or by too much power.

Sparking Between Primary and Secondary: Absence of an earth ground connection to the bottom wire of the Secondary will cause sparking between Primary and Secondary.

Check that the Primary Coil is wired correctly. The top of the winding must be connected to the grounded side of the Capacitor and to the bottom turn of the Secondary Coil, and the bottom of the winding must be connected to the Rotary Spark Gap (see schematic and pictorial diagrams).

Poor tuning or a Primary Coil too close to the Secondary Winding can also cause sparking. Make sure that the Primary Winding is no closer than two inches from the Secondary Coil.

The sparking between Primary and Secondary should disappear as the tuning is improved. Using power levels above 8 kW can also cause sparking and could necessitate moving the Primary Coil farther away from the Secondary.

Under normal conditions, it should not be necessary to keep the Primary Coil more than three inches from the Secondary.

System Draws too Much Current: Apart from the obvious, such as a short circuit, the system will draw more current when off-resonance than when properly tuned. If the Tesla Coil is operating well but tripping the circuit breaker, simply reduce the power input using the Variac and Ballast.

Note: Ammeters will sometimes indicate that more current is being drawn than is actually the case. This is because there is always a "kickback" current that flows from the Tesla Coil circuit back through the Transformer and into the AC line. The phase relationship between the kickback current and the line current can cause the Ammeter to give an inaccurate reading.

Sparking Along the Length of the Secondary Coil: Poor tuning can cause the Secondary Coil to spark along its own length. All the above remedies related to tuning and proper Primary/Secondary/Ground connections apply.

Sparking along the length can also be caused by a conductor touching or shorting Secondary Coil turns. An example would be a length of wire carelessly left inside the Secondary Coil.

Discharges must be drawn only from the Discharge Electrode. If discharges are accidentally drawn from the Secondary Coil, sparking along the length of the coil and damage to the windings can result.

Note: Many of the Tesla Coil's components are placed under considerable stress when the Coil is operated. Although the instrument has been designed to be rugged and dependable, leaving it on for long periods will reduce the life of the components.

The Capacitor is the most likely component to fail, as it usually experiences the fastest heat buildup.

The Author has never had a Road Show Tesla Coil component failure despite years of almost daily use. Here is the duty cycle recommended: If the Coil will be demonstrated for minutes or hours at a time, allow three seconds "on" and 10-15 seconds "off." If the Coil is to be demonstrated briefly, as it would be during a science show, it can be switched "on" for 6-10 seconds several times in close succession if it is allowed several minutes "off."

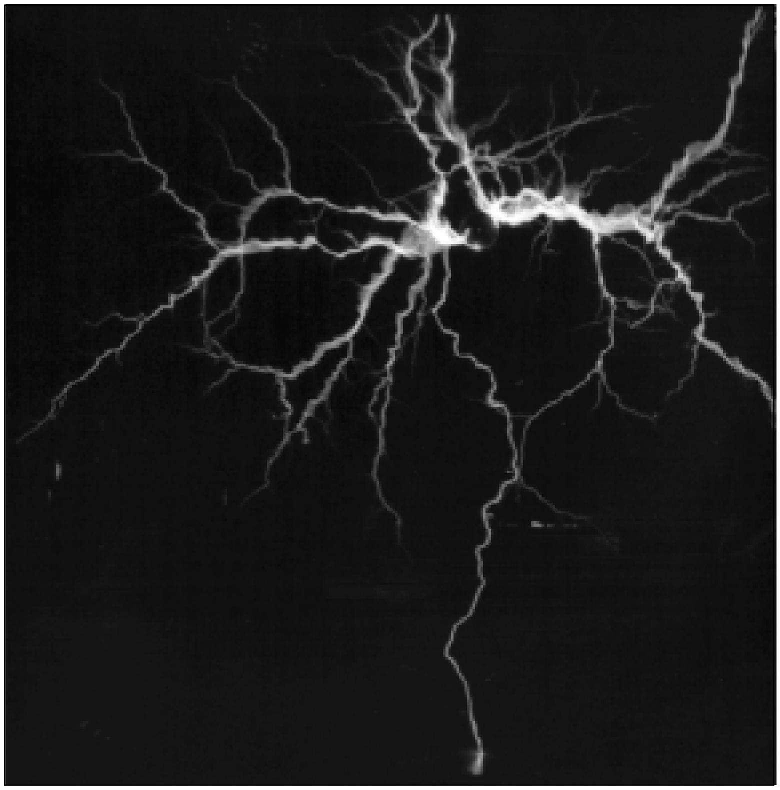


Fig. 34 - A discharge streamer approx. eight feet long strikes the stage during a performance at THE SCIENCE PLACE, Dallas.

EXPERIMENTS

FREE-AIR DISCHARGE: The basic free-air discharge is probably the most spectacular of the various Tesla Coil Phenomena (Figs. 34-36). The high voltage appearing at the Discharge Electrode ionizes the air molecules and forms lightning-like channels through which the current passes.

Theoretically, a spark is formed every time the spark gap fires, giving approximately 120 individual sparks per second. These individual sparks form larger "channels" and can be clearly seen in photographs having an exposure of 1/30th of a second or longer (Fig. 35.).

The horizontally mounted Road Show Tesla Coil takes full visual advantage of the free-air discharge, as the entire hemispherical pattern can be seen.

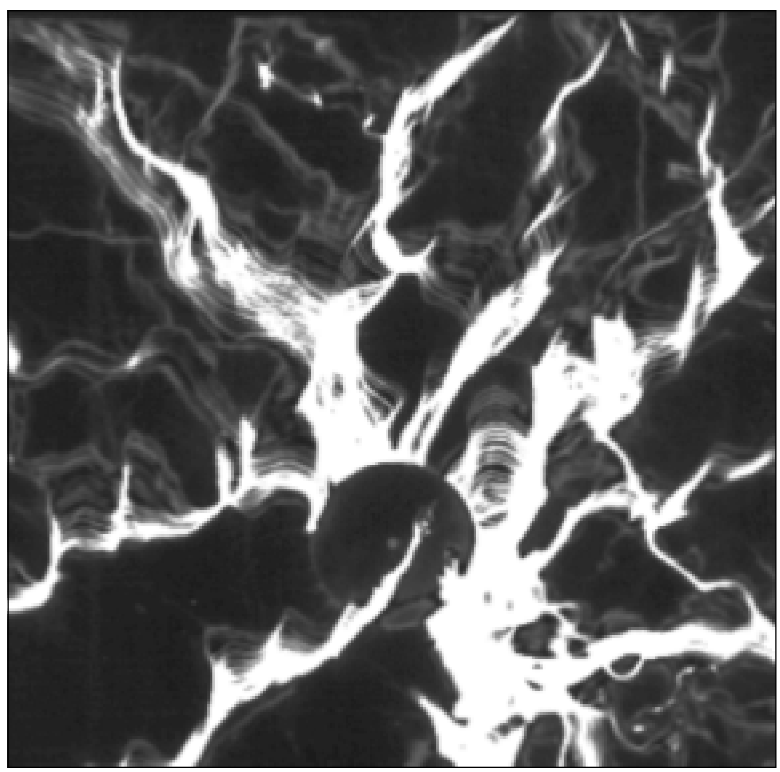


Fig. 35 - Close up of discharge shows individual parallel sparks that comprise the larger channels. The author has no explanation of why the channels tend to form spiral paths.

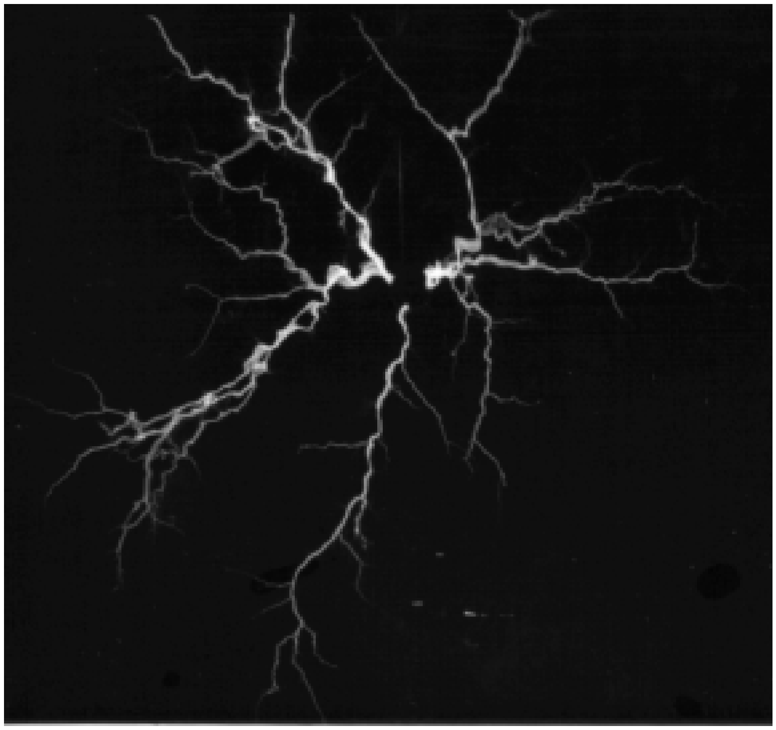


Fig. 36 - Discharge streamers eight feet long crackle from the Road Show Tesla Coil. Film exposure was around 1/3 second. A longer exposure would show more sparks, but this photo closely shows what the eye sees.

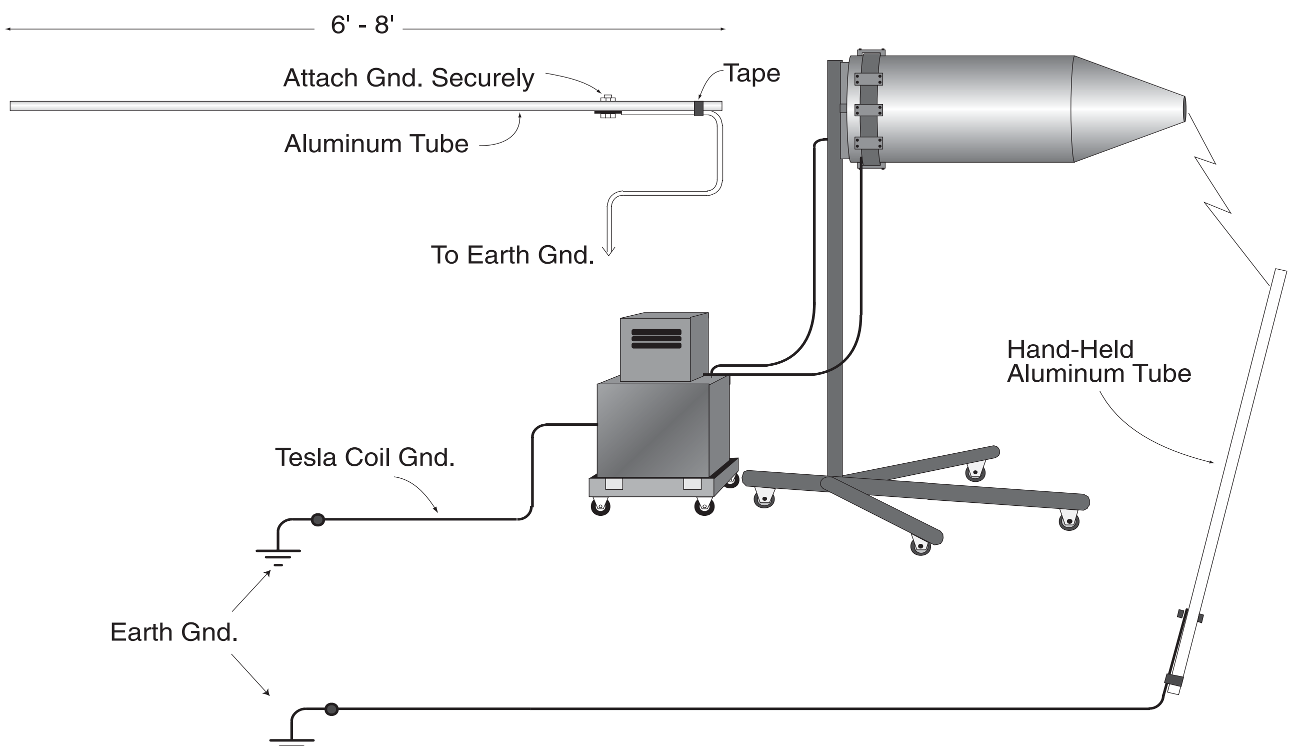


Fig. 37 - Hand-held Discharge Arrangement

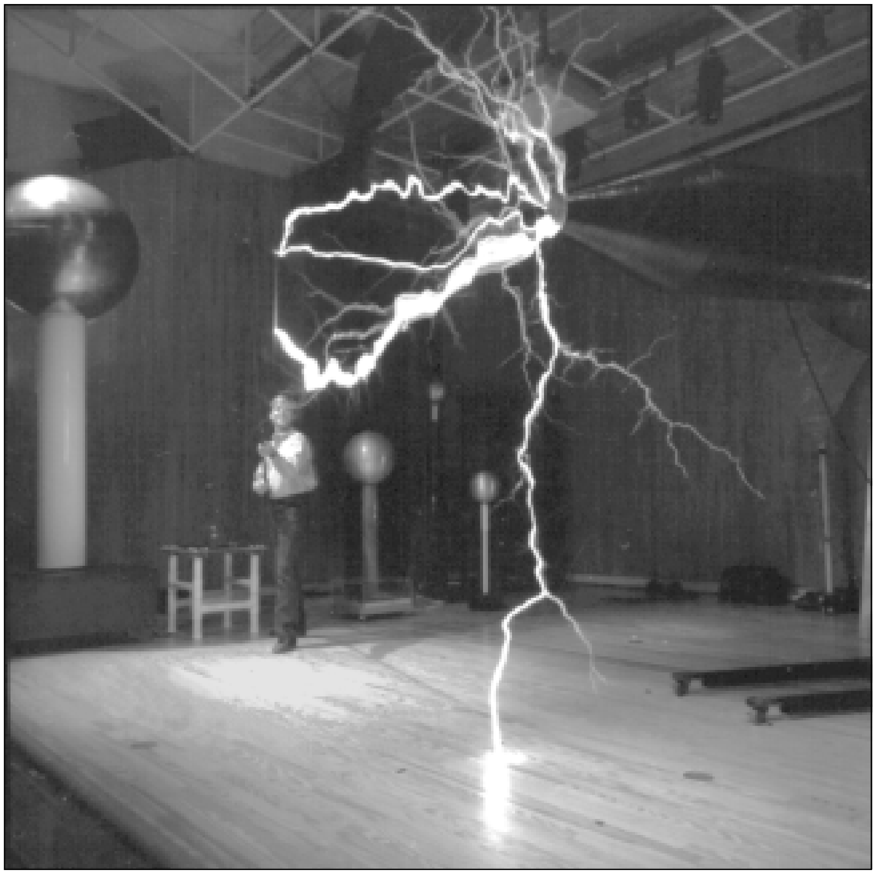


Fig. 38 - Performer draws a discharge to a grounded, hand-held aluminum rod. A constant, heavy discharge can be drawn up to about six feet. At greater distances, the discharge will wander.

DISCHARGE TO A HAND-HELD ELECTRODE: During this "death defying" stunt, a heavy, waving discharge is drawn to a conducting rod held in the bare hand. ***Use an aluminum tube or rod about eight feet long and attach a ground lead of #12 or larger wire to one end of the rod. It's OK to use the same earth ground point that the Tesla Coil uses, but the ground wire from the rod should be run separately. Do not attach it to the ground connection on the Oscillator (Fig.37).***

Hold the rod at the end where the ground wire is attached and maintain at least 15 feet between your body and the Tesla Coil's discharge electrode. ***Never stand close enough for the discharge to strike you!*** The Coil's discharge will deliver a painful, potentially dangerous shock (see section on Safety).

Have an assistant turn the coil "on" and bring the rod close to the Discharge Electrode. No sensation will be felt as deadly-appearing streamers crackle to the rod. Use a rod that is not painted or insulated. The hands must be in contact with bare metal. If an insulating medium is interposed between the hand and the metal rod, sparks will jump between them, causing a mild but uncomfortable shock. This is because the body receives a charge conducted through the air. This charge seeks ground through the rod. If the hand is making close contact with the rod, the charge passes with no sensation.

Note: Never allow discharges to be drawn directly from the windings. This will burn the insulation and eventually damage the coil.

ZEPPELIN BLASTER: Toss a large, tightly-inflated balloon (dressed-up as a Zeppelin) at the Discharge Electrode. A streamer striking the balloon will pop it. Place some wadded-up bits of aluminum foil inside the balloon to encourage the discharge streamers. For added entertainment, attach a dozen or so balloons to a piece of plywood and place beneath the Tesla Coil. As streamers rake the plywood, they will pop a number of balloons.

KINDLING PAPER: Attach a wad of paper to the end of the hand-held aluminum electrode and draw a discharge from the Tesla Coil. Discharges passing through the paper will set it ablaze in a matter of seconds. Aside from the obvious fire hazard, ash from the paper conducts electricity; don't let it collect on the Secondary Coil.

Attach a spike to the aluminum rod on which a cigar can be skewered lengthwise. With a little practice, the cigar can be ignited.

COOK A HOT DOG/MARSMALLOW: A hot dog or marshmallow attached to the end of the hand-held electrode will be cooked as discharge streamers pass through them. Although a hot dog cooked in this manner probably isn't poisonous, I don't recommend eating it...the ozone imparts a really bad taste!

HOT SPARKS: Attach a tuft of fine steel wool to the end of the hand-held ground electrode and bring the rod close to the Discharge Electrode. The steel wool fibers will immediately burst into a shower of hot sparks as the streamers strike them. Exercise the same caution as you would with burning paper.

RING DISCHARGE: Heavy, crackling streamers create fascinating, random patterns as they jump from the Discharge Electrode to a grounded, vertically mounted ring 10' to 12' in diameter. Metal shops equipped with large tubing-benders can make an appropriate ring. Either square or round tubing can be used. Have the ring constructed in four sections that can be bolted together to form a circle. Mounting tabs can be welded on opposite sides of the ring to allow attachment to adjustable tripod stands.

WIRELESS LIGHTS: Hold neon and fluorescent lamps 15 to 30 feet from the Tesla Coil. The lamps will be illuminated from the Tesla Coil's electrostatic field and from conduction through the atmosphere. You can experiment with tuning devices and receiving antennas to enhance the range and intensity.

Fig. 39 - Ring Discharge

Neon and other gas discharge lamps are excellent conductors of high voltage electricity, so maintain a safe distance from the Coil.

FARADAY CAGE: A Faraday Cage is an excellent addition to science shows featuring large Tesla Coils (Fig. 40). A man steps into the cage, the door is shut behind him, and the cage is "zapped" with heavy discharges from the Tesla Coil. The man, of course, is unharmed. The high frequency currents are shunted by the cage to ground. Even if a ground wire is not attached, the man will be safe. However, without a ground, the discharge will strike the cage and then seek the nearest path to ground by jumping to any conductor within range.

ADDITIONAL EXPERIMENTS: Directing the Tesla Coil's output against various insulating mediums, such as glass and Formica, can yield dramatic results. The discharge can be made to pass through barriers made of paper, foam board, wood, and plastic. Always be aware of the fire hazard.

During the early 20th century, experimenters dazzled their audiences by standing atop a Tesla Coil discharge terminal and throwing streamers from their fingertips. This stunt is performed by various experimenters today as well, and the techniques for performing "human electrode" demonstrations may be the subject of a later manual. Currently, however, this author questions the long-term physiological effects of powerful high frequency currents through the body and hesitates to suggest that the techniques are safe.

SAFETY

LETHAL currents are present in the Primary Coil, Capacitor, Spark Gap, and Transformer. Output from the Secondary Coil is also extremely dangerous. Despite the high frequency, a strike to the body from the Tesla Coil's Secondary will cause a powerful shock. The discharge can also cause burns: a brief, direct "hit" can raise a red welt the size of a quarter on exposed skin.

Refer to the "Strike Zone" diagram (Fig. 2) before operating the Tesla Coil. Keeping body parts and other conducting objects outside this zone will greatly reduce the chance of accidental shock. Always be certain that the hand-held electrode draws discharges from the Discharge Electrode only. Don't draw sparks from the Secondary Coil windings, and never bring the hand-held electrode, your body, or any other conductor close to the Primary Coil or Primary wires.

A good earth ground must always be attached to the hand-held electrode when drawing sparks from the Discharge Electrode. Failure to attach a ground wire could result in strong electric shock. Do not attach the Hand-Held Electrode ground to the Tesla Coil ground terminal at the rear of the Oscillator; run the Hand Held Electrode wire separately to earth ground.

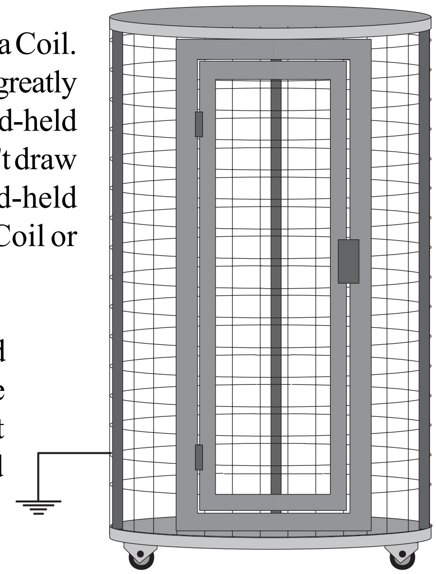


Fig. 40 - Faraday Cage

Heart Pacemakers may be affected, but the author is unaware of any conclusive tests that would suggest a safe distance. A 200' distance would probably be adequate, but the author makes no claim regarding the accuracy of this figure.

The Rotary Spark Gap should always be operated with the protective enclosure in place. Aside from the obvious potential hazards, such as the rotor flying off, or exposed high voltage, the Rotary Gap produces ultraviolet light that can burn the eyes. Observe the spark gap only while wearing dark, UV-blocking sunglasses or welding goggles.

The Tesla Coil was not designed for continuous operation. To preserve the life of the components, it's a good idea to operate the Coil conservatively. Approximate duty cycles are as follows:

10 seconds "on" with 15 seconds "off" for no more than 10 repetitions.
Let the Coil "rest" for several minutes before repeating the cycle.

3 seconds "on" with 10 seconds "off" for no more than 30 repetitions.
Let the Coil rest for 10 minutes before repeating the cycle.

If the Coil is to be used for long periods of time, it's a good idea to check the components for heat buildup. Be certain that the power is turned off and the Capacitor is shorted before working inside the Oscillator.

The Road Show Tesla Coil will produce a considerable amount of ozone. Ozone is a lung irritant and can be dangerous in large quantities, so operate the Coil in a well-ventilated area.

Always disconnect input power when working on the Tesla Coil, and short circuit the Capacitor before touching high voltage components. The Capacitor is normally shorted through the Transformer secondary winding, but should an open circuit occur, a dangerous charge could be stored.

INTERFERENCE & TRANSIENTS

Tesla Coils produce a broad spectrum of electrical "noise" that can interfere with AM radio and television. The effective range of the interference is mostly determined by the propagation characteristics of the area in which the coil is used, by the fundamental frequency, input power, and radiating efficiency of the Coil.

Used in the open, the Road Show Tesla Coil might be expected to radiate detectable rf noise several miles. However, a coil demonstrated inside, say, a museum constructed of masonry, may not radiate interference outside the building.

If the Coil is to be used for permanent demonstrations, it's a good idea to check the interference range with a portable AM radio. FM reception is usually not affected.

The FCC is "complaint-driven," typically responding if someone calls them about recurring interference. Keep operation of the Coil short and be aware of times of the day when interference will be most objectionable.

The interference produced by Tesla Coils is normally propagated through space and through the AC wiring. High voltage spikes and radio frequency interference conducted along the AC line can sometimes be strong enough to damage sensitive components in computers and other electronic apparatus.

Line filters and spike protectors in the Tesla Coil AC line will greatly reduce the RF noise and high voltage transients, but it is advisable to have additional protection on the AC line feeding the sensitive electronic equipment.

For permanent installations, it may be necessary to test the AC power with an oscilloscope or spectrum analyzer. A digital storage oscilloscope will provide a very useful measurement of the interference voltage levels at various locations.

In extreme cases, where the Tesla Coil must be used in the same environment as computers and similar equipment, the Coil can be mounted inside a large Faraday Cage (Fig. 41). The cage will prevent damaging RF from being radiated, and AC line filters and spike protectors will effectively keep interference from the AC power.

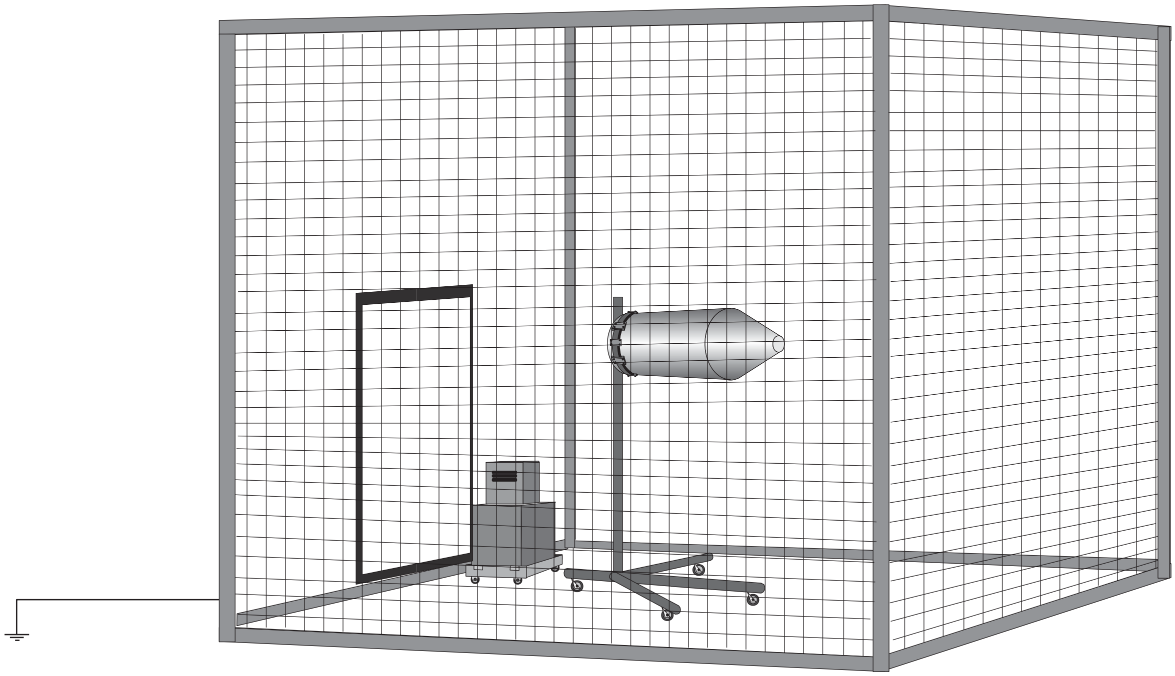


Fig. 41 - Tesla Coil inside Faraday Cage

If a Faraday Cage is not used, nearby unshielded AC wiring can receive a great deal of radiated energy from the Tesla Coil, so much in some cases that, without spike protection, flashover between the "hot" wires and ground or neutral can occur.

Metal oxide varistors offer one of the best means of reducing high voltage transients in the AC line. Varistors are rated according to operating voltage and level of protection (Fig. 42). Physical size and shape vary considerably. General Electric manufactures a complete line of quality varistors, and we have had good success with the GE-MOV model V150PA20C placed between each 240 Volt leg and neutral, as shown in the schematic.

If additional protection is required, consult GE for recommendations. They also offer a catalog of varistors and a transient technical manual (see Appendix).

High voltage transients can also appear across the terminals of the Transformer and Capacitor. To provide protection, a simple ball gap is placed across the Capacitor and adjusted to approximately 1 1/2" separation (Fig. 43). A spark should bridge the

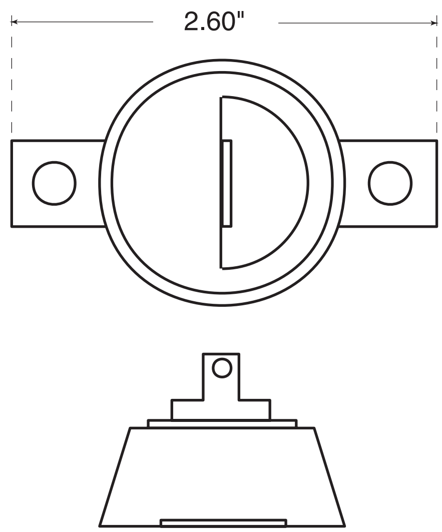


Fig. 42 - GE Metal Oxide Varistor type V150PA20C. This model can dissipate up to 70 Joules for a millisecond. Larger models are available.

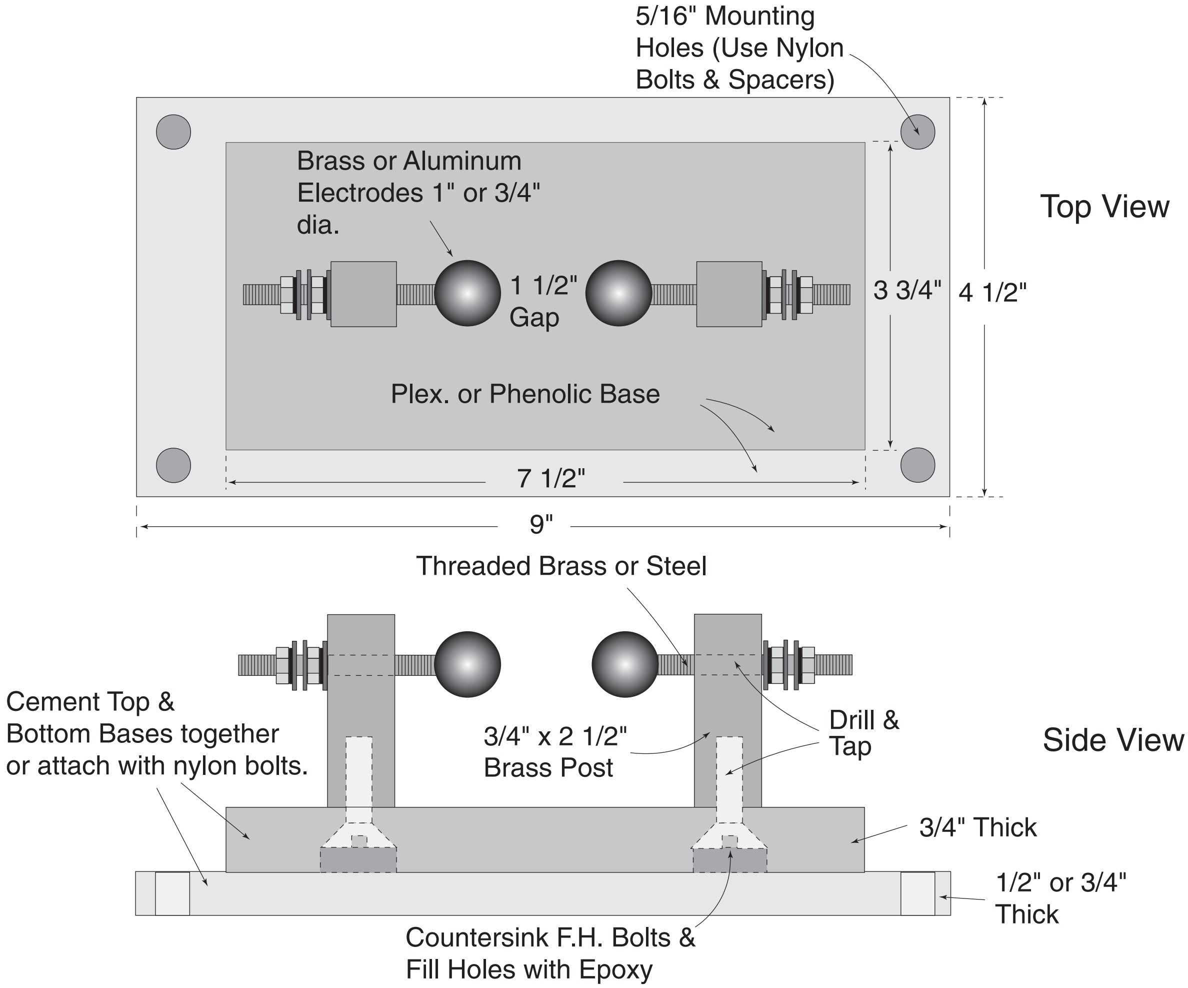


Fig. 43 - Safety Gap protects Capacitor and Transformer against potentially damaging transient voltages generated in the Oscillator circuit.

ball gap only occasionally when the Tesla Coil is operated. If the gap fires too often, open the gap to about 2" separation. If the gap continues to fire often, make sure that the Rotary Gap electrodes are spaced correctly.

The gap should be mounted as close to the Capacitor as possible. The gap's mounting base can be epoxied to the Capacitor or bolted to the bottom of the Oscillator Cabinet next to the Capacitor. Use nylon bolts and 1/2" nylon spacers when attaching the Gap to a metal surface. Maintain at least 2" separation between the gap's electrodes and other components.

A simple choke is placed in series between the "hot" side of the Transformer secondary and the Capacitor in order to reduce RF kickback from the tank circuit. The choke should be no larger than the design in Fig. 44, or the choke itself can become the source of unwanted high voltage.

"Off the shelf" AC line filters are available through electronics supply companies (see Appendix). When buying a filter, make sure that it can handle the required current and that correct connections are made between line and neutral or ground.

Filters will not totally eliminate interference. As previously mentioned, the Tesla Coil radiates a great deal of energy, which will find its way into the line.

Individuals wearing heart pacemakers should be warned to stay away from the Tesla Coil. An educated guess is that 100 or 200 feet would be an adequate distance, but no claim is made regarding the accuracy of these distances.

A Case History:

We installed a Road Show Tesla Coil on stage in the 220 seat auditorium of the SCIENCE PLACE MUSEUM in Dallas in 1988. The Coil has been virtually in daily use since that time.

A Colortran computerized lighting system controls stage lights. Dimmers just off stage connect with the Colortran console in the control room at the rear of the auditorium. The control cable between the dimmers and the Colortran console communicates via a 5 mHz, 5 Volt digital signal fed through shielded control cable.

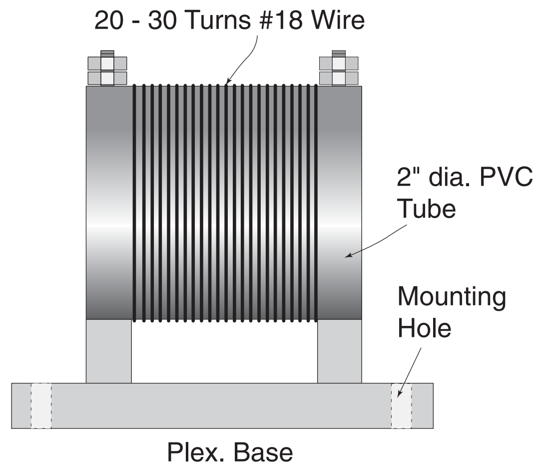


Fig. 44 - Radio Frequency Choke reduces RF kickback from Tank Circuit

The Tesla Coil caused the dimmers to receive false signals, turning lights on and off at random. We analyzed the problem with a digital oscilloscope and found that the signals were being picked up by the dimmer control cable. We also found that the control cable shielding was being held above ground potential, presumably because of the circuit configuration of the Colortran system. If the system were designed to carry the shield at true ground potential, we feel the problem would be reduced.

In addition to causing false signals in the control cable, the Tesla Coil's radiated energy was actually powerful enough to damage some of the console's circuits. The greatest levels of interference are experienced when the Tesla Coil discharge strikes directly to a grounded electrode.

Instead of trying to re-engineer the lighting system, we opted to employ a more direct method to alleviate interference...we installed a pushbutton-activated relay to turn the Colortran system off and disconnect the Colortran control cable when the Tesla Coil is used.

Just outside the auditorium, several computers are employed to operate various exhibits. Although some interference with one particular computer has been suspected from time to time, the museum has had virtually no other Tesla Coil-related trouble with any of its many computers and control microprocessors.

After more than 5,000 performances involving the Road Show Tesla Coil, the author is not aware of any problems with heart pacemakers (a warning is given before each performance) or of complaints about radio interference outside the auditorium.

ALTERNATIVE
SECONDARY COIL DESIGN

A practical alternative to the rocket-shaped Secondary Coil featured in this manual is a straight solenoid such as that shown in Figure 45. This cylindrical version is somewhat easier to build and wind, but it will require a discharge electrode made of a large toroid or aluminum plate. The cylindrical secondary will also need about 400' more wire (total of about 2,800').

Performance of the cylindrical version will be approximately the same as the "rocket," even though the inductance of the straight solenoid is higher. This disparity is probably due to the fact that the conical section does a better job concentrating the discharge. (Tesla wrote in his Colorado Springs Diary, 1899, that the greatest spark length would be achieved with a discharge terminal of small capacity.)

Construction and tuning methods for the two designs are virtually identical. Both can be mounted horizontally or vertically. If the cylindrical coil is to be mounted horizontally, keep in mind that, because of the additional fiberglass, wire, and large discharge electrode, weight at the coil's nose will be increased by 30 pounds or more.

Although not recommended, a cardboard pier form (Sonotube) can sometimes be substituted for fiberglass as a Secondary Coil Form if it is very dry and heavily varnished. If you opt for a cardboard form, wrap multiple layers of mylar around the outside of the form for additional insulation. Keep in mind that, if the Secondary Winding sparks briefly between turns or along the coil's length, the sparks will easily burn conducting carbon tracks in the Sonotube, which can quickly ruin it. The Sonotube will not have the requisite strength for horizontal mounting.

Expect the frequency to drop from around 180 kHz to approximately 160 kHz, as the cylindrical form will require more wire. An additional turn or two on the Primary Coil will also be needed. If a large toroid is employed, the frequency will drop several more kHz.

The Primary Coil for either Secondary design can be cylindrical or flat spiral. The cylindrical design is more compact and easier to wind, but a spiral made of bare copper tubing is easier to tap for tuning purposes.

If a spiral primary is used, make certain that the inside turn is connected to the grounded side of the Capacitor.

Although an aluminum disk about three feet in diameter will work as a discharge electrode, a toroid is preferable. Attach a short metal spike to the toroid or aluminum plate in order to concentrate the discharge for maximum spark length.

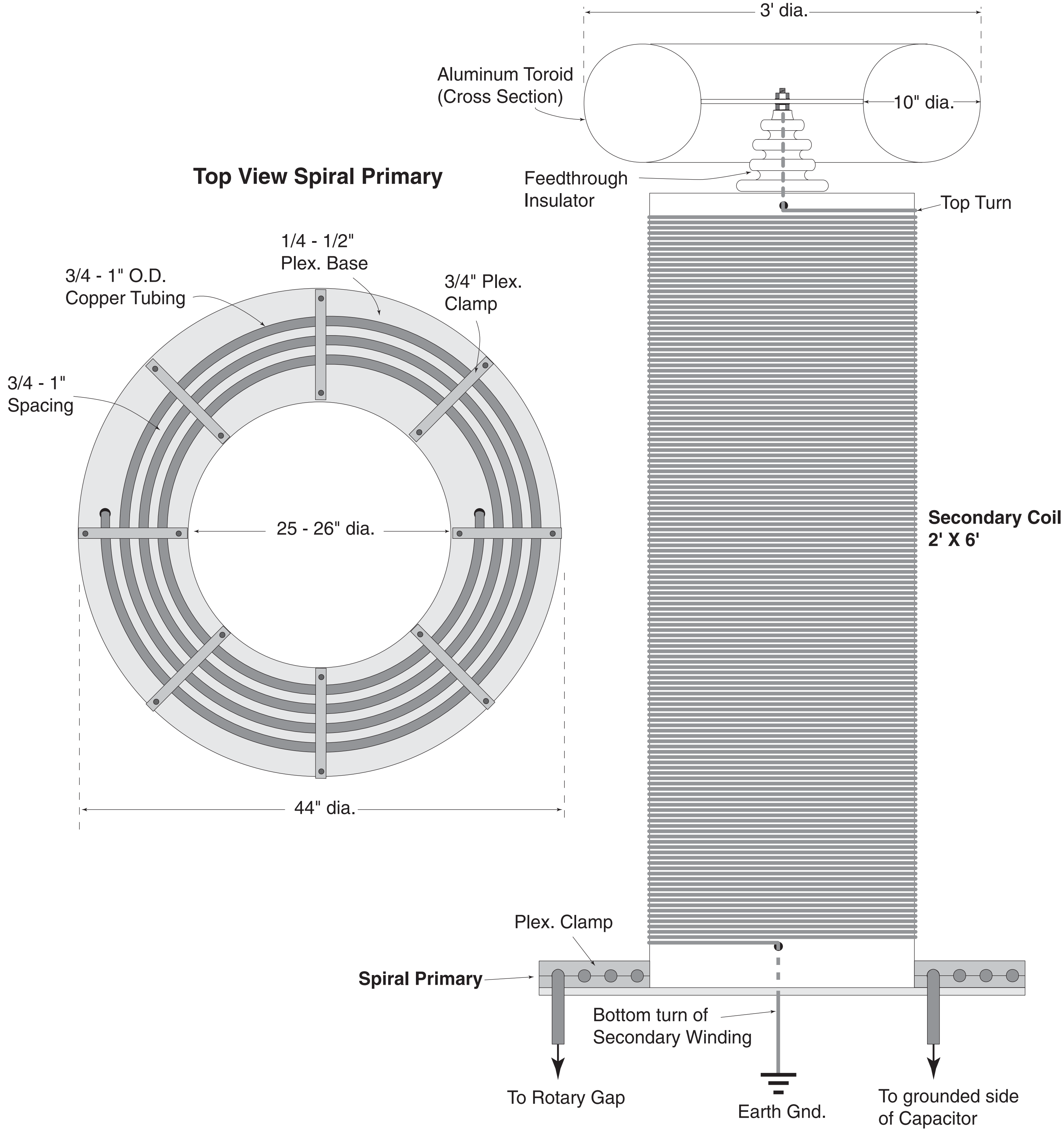


Fig. 45 - Straight Solenoid Secondary Coil and Flat Spiral Primary

PARTS & MATERIALS

Fiberglass Secondary Coil Form

1. Mold Forms (see text)
2. Approx. 40 sq. ft. of 6 oz. fiberglass cloth (about 3 1/2 yds. of 48" or 52" wide cloth)
3. Approx. 80 sq. ft. of 1 1/2 oz. fiberglass mat (about 7 yds. of 48" or 52" wide mat)
4. Approx 5 gal. polyester laminating resin
5. One gallon finishing or sanding resin (optional) to make inside of form tack-free
6. Enough MEK Peroxide catalyst for five or six gallons of resin (follow Manufacturer's recommendations)
7. One gallon acetone
8. Non-toxic fiberglass solvent hand cleaner
9. Approx. eight inexpensive, natural bristle, 3" brushes
10. Fiberglass roller (optional) to help smooth bubbles out of fiberglass
11. Mold release wax
12. Sandpaper: 30, 80, and 100 grit
13. Disk sander and sanding disks (heavy grit)
14. Respirator and dust mask
15. 3/4" plywood for reinforcing rings to fit in rear of coil form and for disk to fit in nose cone
16. Bondo or similar fiberglass repair material to fill voids in coil form surface
17. Mylar if using a cardboard pier form as a mold
18. Silicone sealer to fill seams in mold forms
19. PVC or cardboard tubing about 4" in diameter to make reinforcing stringers
20. Spray adhesive to adhere mylar to inside surface of cardboard pier form

Secondary Coil

1. Approx. 2,400 feet # 12 THHN stranded wire for Secondary Coil. It's a good idea to get a sample of the wire you're going to use and check the number of turns per inch it yields. Accurately measure the outside diameter of the Secondary Coil Form, then calculate the length of wire needed. The cylindrical Secondary described on P. 54 will require about 2,800' of wire if the Primary Coil is wound on the Secondary Coil Form, and 2,900' if a flat spiral Primary Coil is used (the flat spiral allows more wire to be wound on the Secondary Coil Form).
2. Approx. 30' of #1 welding cable for the Primary Coil (if Primary Coil is to be wound on the Secondary Coil Form). If a flat spiral Primary Coil is to be used, about 34' of 3/4" or 1" copper tubing will be needed.
3. Two pairs of welding cable connectors for the Primary Coil (if mounting the Tesla Coil horizontally)
4. Copper strip for connecting end of Secondary Coil winding to Discharge Electrode.
5. Discharge Electrode (see text)
6. Double-sided tape to help in winding conical portion of Secondary
7. Bar-stool turntable to place underneath Seconday Coil Form while winding
8. Polyurethane varnish or electrical-grade epoxy to coat windings
9. 2" wide electrical tape to wrap windings (optional)
10. Plexiglas or phenolic "clamps" and nylon bolts to hold Primary Coil windings in place

Rotary Spark Gap

1. Rotor: Disk 12" dia. x 5/16" or 3/8" made of G-10 phenolic.
2. Plexiglas or phenolic stock 1/4" to 3/8" thick from which to cut mounting panel for front electrodes.
3. Plexiglas or phenolic stock 3/4" thick for 16" x 16" base of Rotary Spark Gap (1/2" thickness will work, but 3/4" is preferred).
4. Plexiglas or phenolic 3/4" thick from which to make motor base, Rear Electrode base, and vertical supports for Front Electrodes.
5. Solid brass stock approx. 1" x 1" x 2 1/8" for Rear Electrode
6. 3/8" dia. 4 1/2" solid or threaded brass rod for Rear Electrode
7. 5/16" x 1" F.H. bolt for attaching Rear Electrode brass stock to base
8. 3/8" brass nuts & washers for Rear Electrode
9. Seven 5/16" x 2 1/4" threaded brass rod for Front Electrodes
10. Fourteen 5/16" brass nuts and washers for Front Electrodes, plus 14 lockwashers
11. Brass or copper ring 1/8" thick x 12" O.D. for Front Electrodes
12. 12" O.D. x 9" I.D. x 1/8" brass ring for Rotor (see PP. 26-30)
13. Eight 5/16" x 1 1/4" F.H. brass bolts for Rotor electrodes
14. Eight 5/16" brass nuts and washers, plus lock washers, for Rotor electrodes
15. Hub for Rotor (see PP. 26-30)
16. Twelve 5/16" FH bolts, nuts, washers, & lockwashers for attaching Rear Electrode and motor to motor support, and motor support to Rotary Spark Gap base.
17. Eight 5/16" (or 1/4", depending upon thickness of plastic used) bolts to attach removable back to motor support.
18. Six 5/16" or 1/4" RH bolts, washers, and lockwashers to attach supports to Front Electrodes panel.
19. Six 5/16" x 1 3/4" FH bolts to attach plastic supports to Rotary Gap base Note: 2" x 2" angle brackets can be used instead.
20. 3/8" hex or RH brass bolt, two 3/8" brass washers, and two 3/8" lockwashers to attach Primary Coil cable to copper ring on Front Electrode panel.
21. 1/4 to 1/2 h.p. 3,450 r.p.m. split phase motor (1/2 h.p. preferred).

Oscillator

1. Transformer: 5 to 7 kVA @ 14 to 16 kV rms, oil filled (see P. 32). *No* center tap should be on high voltage winding, as one leg will be grounded.
2. Capacitor: .055 to .06 mFd., 16 kV rms, 60 Hz. (see P. 33)
3. 2PST Contactor rated for 30 A. if running the coil from 240 volts, or 60 A if using 120 V.
4. Radio Frequency Choke (see P. 53)
5. Varistors: four GE type Vi50PA20C
6. Hubbell 30 amp. 2 pole, 3 wire flanged inlet for power input from Power Supply
   Hubbell nylon 15 amp. 2 pole, 3 wire flanged inlet for control cable from Power Supply
7. Plexiglas plate or disk approx. 6" dia. x 1/4" for Oscillator Ground Terminal
8. 3/8" brass bolt w/nuts & washers to attach ground cable at rear of Oscillator Cabinet
9. Plexiglas platform 1/4" thick for top of Transformer (assuming the same transformer design is used as depicted in Fig. 19)
10. Cabinet measuring 2' x 2' x 2' (if mounting the Tesla Coil horizontally)

11. Plexiglas or phenolic approx. 2' x 2' x 1/4" to serve as top of Oscillator Cabinet
12. Four swiveling, locking castors for Oscillator Cabinet (if a road case is to be used, the Cabinet will be bolted inside the case and will not need wheels).
13. 1/4" or 1/2" Plex. or phenolic to fabricate bracket to hold cables going to Primary Coil
14. Safety Gap (see plans on P. 52):
    Two pcs. brass stock approx 3/4" x 3/4" x 2 1/2" to fabricate posts
    Two pcs. threaded brass rod 5/16" x 1 3/4" for electrodes
    Two brass balls (optional) to attach to electrodes
    Two 1/4" x 3/4" long F.H. bolts
    Plex. or G-10 3/4" thick & approx. 7 1/2" x 3 3/4" for base
    Plex. or G-10 1/2" or 3/4" thick & approx. 9" x 4 1/2" for base

Power Supply

1. Variable Transformer:
    For 240 Volt operation, use a 35 amp. 9.8 kVA unit (Staco model 6020 or equivalent).
    For 120 Volt operation, use a 60 amp. 8.4 kVA unit (Staco model 6010 or equivalent)
2. Ballast:
    PVC pipe 2" O.D. x 18" long as coil form
    Approx. 320 ft. #10 THHN stranded wire
    Plexiglas or phenolic to build mounting bracket for Ballast Coil
    Eight 5/16" brass bolts w/nuts & washers for Ballast Coil terminals
3. Panel-mounted circuit breakers:
    35 amp. for 240 Volt operation
    70 amp. for 120 Volt operation
4. Ammeter & Voltmeter: Suggest 0-100 amp. & 0-500 volt
5. Switches as follows:
    (Suggest using GE or Cutler-Hammer 22 or 30 mm "heavy duty oiltight." These switches are quality, industrial grade.)
    SPST security key switch
    SPST pushbutton to activate the relay and "fire" the Tesla Coil
    SPST lever or toggle switch to activate Rotary Spark Gap Motor
6. Pilot lamp: Suggest large "jewel" neon lamp
7. Double row, five or six terminal, flat mount terminal block to connect power and control cables. You may want to use two different terminal blocks for power and control.
8. RF filter: CORCOM type 30 VB6, or larger for 240 V.
9. Hubbell 2 pole, 3 wire, twist lock connectors as follows (for 240 volt operation):
    30 amp. flanged inlet and flanged outlet for power supply input and output
    Two 30 amp. connectors and one plug for power input and output cables
    Nylon 15 amp. flanged outlet plus cable connector and plug for control output
10. Varistors: Two GE type V150PA20C (see P. 51)
11. Cabinet: Bud manufactures economical, quality cabinet racks of various sizes. Their "CR-1727" cabinet rack, for instance, measures approx. 21" wide x 12" deep x 22" high. Allied Electronics and Newark sell these racks.
12. Casters can be bolted to the bottom of the cabinet rack or, if a road case is to be used, the rack can be bolted inside the case.

Miscellaneous

1. Wire & Cable:
   About 50' of #1 welding cable will be needed to wind the Primary Coil, provide leads between the Primary Coil and the Oscillator, and wire part of the inside of the Oscillator. The farther away the earth ground connection is located, the heavier the ground cable must be. As a "rule of thumb," use #6 stranded wire if the ground connection is only 20'-40' away, and #1 cable if it is farther.
2. Three-conductor cable of #10 stranded wire will be adequate for 240 volt power cable if the run is only 20-30 feet. For longer runs, it's a good idea to use #8 wire. If the Coil is to operate from 120 volts, #8 is the minimum wire size for runs of 20' or less. For runs up to 50', #6 is recommended.
3. Control cable can be three-conductor cable of #14-16 stranded wire.
4. Use #12 stranded hookup wire for the motor and relay field coil.
5. Use 15 kV neon sign wire between the high voltage "hot" leg of the Transformer and the rf choke, and between the choke and the Capacitor.
6. Use nylon wire stays and cable clamps to secure all wiring, being especially mindful of wiring close to high voltage circuits.
7. Use solderless terminals on all connections. Crimp and solder connections carrying rf curents.
8. A small amount of epoxy cement will be needed for the Safety Gap and Rear Electrode.
9. Plexiglas cement will be needed for constructing the Plexiglas cover for the Rotary Gap and for the Plex. cable brackets attached to the front of the Oscillator.

Mounting Stand

1. The modified "vermette" hoist that serves as a stand for mounting the Tesla Coil horizontally is one of several similar designs available commercially. Check the Yellow Pages under "hoists" or "lifts." The hoist's forks or lifting tines can be cut off and replaced with a vertical piece of steel tubing, as shown in Fig. 36.
2. The aluminum bracket that attaches to the hoist and Tesla Coil is fabricated from square tubing, as shown in Fig.36.
3. Eight 5/16" x 3" brass bolts attach the aluminum bracket to the rear of the Tesla Coil.

APPENDIX

SOURCES:

Capacitors

Plastic Capacitors. Inc., 2623 N. Pulaski Road, Chicago, IL Phone: (312) 489-2229 FAX: (312) 489-0496. Capacitor is rated .055 μFd., 16 kV A.C. rms. Ask for Tom Brown. Tell him the capacitor is for a Tesla Coil. The author has constructed many Tesla Coils using capacitors produced by Plastic Capacitors. They make an excellent capacitor that withstands the rigors of spark gap circuits.

You can also try Cornell Dubilier, P.O. Box 128, Pickens, SC 29671. Phone: (803) 843-2277 FAX (803) 843-3800. Ask for Joe Moxley.

Another option is Maxwell Laboratories, Inc., 8888 Balboa Ave., San Diego, CA 92123 Phone: (619) 576-7545 Fax: (619) 279-1554. The author has no experience using capacitors manufactured by Maxwell Labs, but they appear to build a very high quality unit.

Transformers

16 kV, 5 to 7 kVA. Contact Geotronics, 115 W. Greenbriar Lane, Dallas, TX 75208 Phone: (214) 946-7573. Geotronics made three of these custom, oil-filled transformers for us. The transformer is relatively expensive, but it's very compact (13" x 13" x 14") and of high quality.

Nova Magnetics has constructed several custom transformers for us for smaller Tesla Coils, and they can make virtually any size you need. Their costs are reasonable and quality is good. Address: 1101 E. Walnut 75040 Phone: (214) 272-8287.

Another transformer source is your local power company. See if a 14.4 kV distribution transformer can be purchased. If the company is reluctant to sell one, try Greenville Transformer Co., PO Box 845, Greenville, TX 75403. Phone: (903) 455-1610.

Brass Stock

All sizes and shapes can be ordered from McMurray Metals, 3000 Elm Street, Dallas, TX 75226 Phone: (214) 742-5654.

Motors & Contactors

W.W. Grainger Co. has locations throughout the U.S. In addition to motors and heavy duty electrical equipment, the company sells a very wide range of tools and electronic test equipment. In Dallas: 1520 Round Table Drive, 75247-3576 Phone: (214) 637-2380.

Plexiglas

Cadillac Plastics has locations throughout the U.S. Corporate headquarters is 143 Indusco Court, P.O. 7035, Troy, Michigan 48007-7035 Phone: (800) 488-1200.

A-1 Plastics also carries a large inventory plastics, resin, and fiberglass (see below).

Fiberglass

Most large cities will have an outlet that sells fiberglass mat, cloth, and resin. If you can't find one near you, contact A-1 Plastics, 6787 Oakbrook Blvd., Dallas, TX Phone: (800) 272-2344. This company sells all types of plastics in addtion to fiberglass materials.

Toroids & Spheres	Check your Yellow Pages directory for "metal spinners." If there's one in your area, you may be able to get them to spin a special size and shape for you. Metal spinnings can be very expensive. If the metal spinner already has a mold for spinning an acceptable size sphere or toroid, the price may be fairly reasonable. However, if the spinner has to build the mold to your specifications, costs can be astronomical. Prices can vary greatly (from $65 to $250 for a 12" aluminum sphere), so shop around. Texas Metal Spinning, Inc., has molds for spinning various sizes of spheres and toroids. You can probably get a reasonable deal with them. Their address: 2403 Ludelle Street, Fort Worth, TX 76105 (may have changed) Phone: (817) 847-0086 FAX: (817) 536-8827 (may have changed). Another possibility is Precision Metal Spinning, 1120 Fenway Circle, Fenton, Michigan 48430 (may have changed) Phone: (810) 629-5430 FAX: (313) 629-2393 (may have changed). American Welding and Fabricating, (800) 579-8663 has just been added to our list of reasonably-priced metal spinners. Contact Bill Ottan. You'll want to send the metal spinner an accurate drawing of the part you need so there's no confusion. Another source you may wish to use for spheres are manufacturers of flag pole balls. A flag pole "ball," as they're called in the trade, is actually a sphere, and they're available up to 24" in diameter. A 12" spun aluminum ball costs around $65, but a 24" diameter ball costs around $1,000! We've ordered aluminum spheres in a number of different sizes from the W.F. Norman Corp., 214-32 N. Cedar Street, Nevada, Missouri 64772-0323 Phone: (800) 641-4038 FAX: (417) 667-2708. (I've heard that Norman no longer sells them, but try them anyway)
Variacs Switches Meters Cabinets	Allied Electronics, with many outlets throughout the U.S., supplies a wide range of electronic parts. For a catalog or information call: 1-800-433-5700. Another good source for general electronic items is Newark Electronics. For a catalog or information, call: (312) 784-5100.
Wire	All sizes and lengths are available from Fay Electric Wire Corp., 130 Summit-Suite 9, Plano, TX 75074 Phone: (214) 422-2797 Toll Free: (800) 441-9473 FAX: (214) 422-0329.
Varistors	Contact GE PESD Dept., Electronics Park, Bldg. 7, Syracuse, NY 13221.

FORMULAE

Below are several common formulas for calculating frequency, inductance, and capacitance. If, for instance, a function generator is used to determine the resonant frequency of the Secondary Coil, the formulas can be used to give a close approximation of the number of Primary turns required.

Frequency of the Primary Circuit is given by:

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

Where:
F = Frequency in Hertz
L = Primary Coil Inductance in Henrys
C = Capacitance of Capacitor in Farads

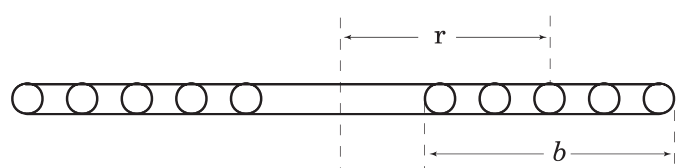
Primary Coil inductance:

$$L = \frac{(rn)^2}{9r + 10S}$$

Where:
L = Inductance in Henrys
r = Radius of Primary Coil in inches
n = Number of turns
S = Length of coil in inches

Inductance of a flat spiral coil:

$$L = \frac{(rn)^2}{9r + 11b}$$



Where:
L = Inductance in Henrys
r = Radius (center of coil to middle of winding) of Primary Coil in inches
n = Number of turns
b = Width of coil

If the resonant frequency of the Secondary Coil is known, and the value of the Capacitor or Primary Coil is known, then:

$$LC = \frac{25{,}330}{F^2}$$

Where:
L = Inductance of Primary Coil in Microhenrys
C = Capacitance of Capacitor in Picofarads
F = Resonant Frequency of Secondary Coil in Megahertz