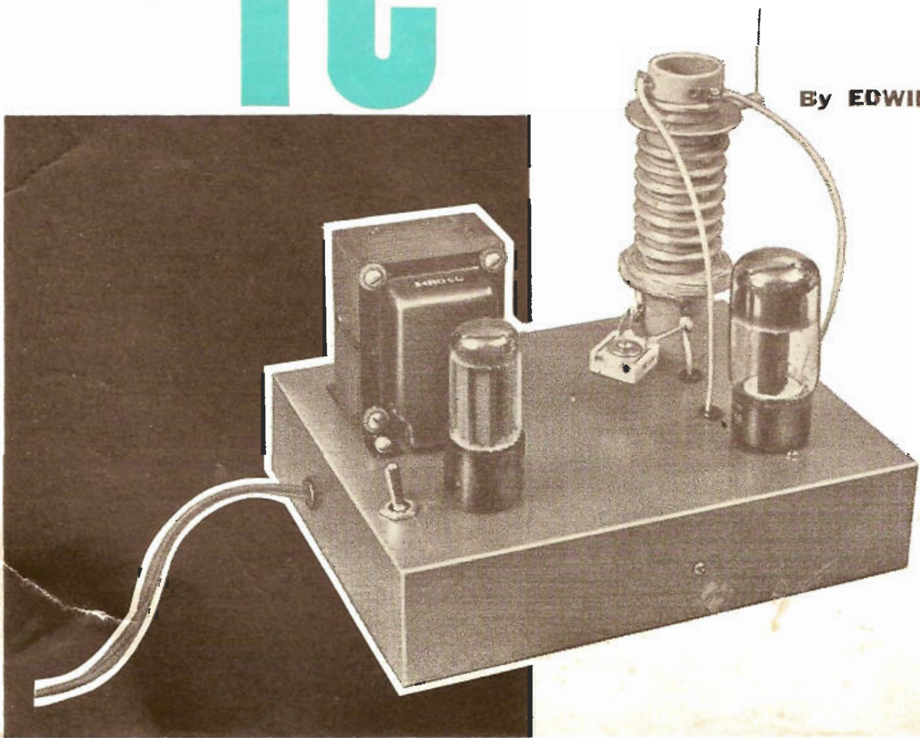
A potent "little brother" to "Big TC," this Tesla coil version is inexpensive, easy to build, and it can put out 30,000 volts!

Li'l TC

IF you have read the preceding article on "Big TC," you will have learned that a Tesla coil is simply a radio-frequency step-up transformer carried to extreme limits. While a coil that can generate 150,000-200,000 volts is exciting and very dramatic, many of the same visual effects can be demonstrated on a smaller scale with "Li'l TC." In fact, "Li'l TC" is much safer, easier to build, and less expensive—your junk box probably contains many of the necessary parts.

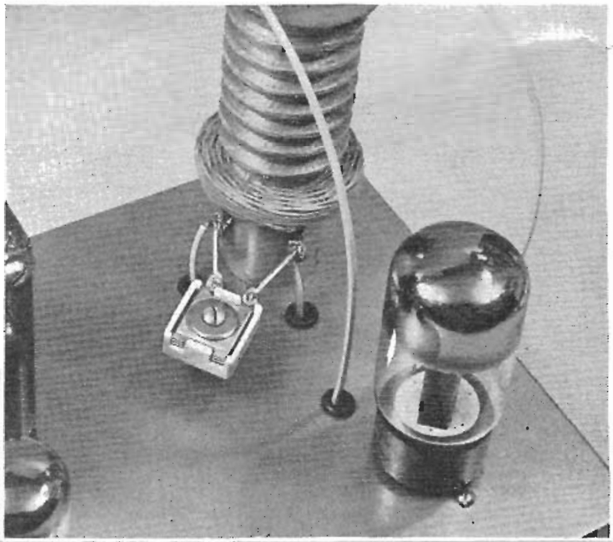
The only item many experimenters will have to buy in order to build "Li'l TC" is the r.f. coil. This coil is manufactured by the J. W. Miller Co. for use in generating the high voltages required in large-screen TV receivers. It is an item that is not stocked by many parts stores, although most of them can obtain it for you within 48 hours. If you have trouble finding the coil, it can be ordered from Allied Radio Corp., 100 N. Western Ave., Chicago 80, Ill., as their stock number 61G102 at a price of $8.82 plus postage. An experienced project builder may not find it necessary to buy one of these coils, but may be able to

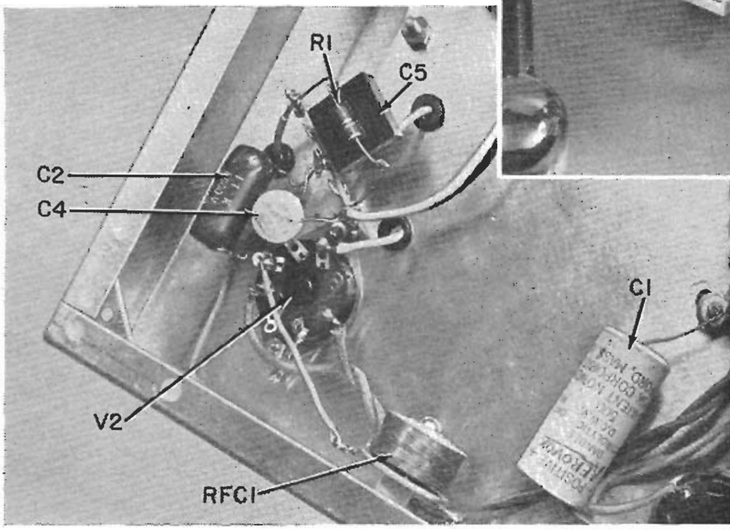
By EDWIN N. KAUFMAN



Li'l TC

Tuning capacitor C3 is attached to the h.v. coil with two bus-bar leads so that it will be suspended in mid-air away from the coil and metal chassis. Use an insulated alignment tool to rotate the setscrew adjustment.





Most of the parts are grouped around the base of tube V2. Leads to the h.v. coil pass through grommeted holes to the terminal connections on the Miller coil form.

construct "Li'l TC" using a high-voltage transformer from a large-screen old-style TV receiver.

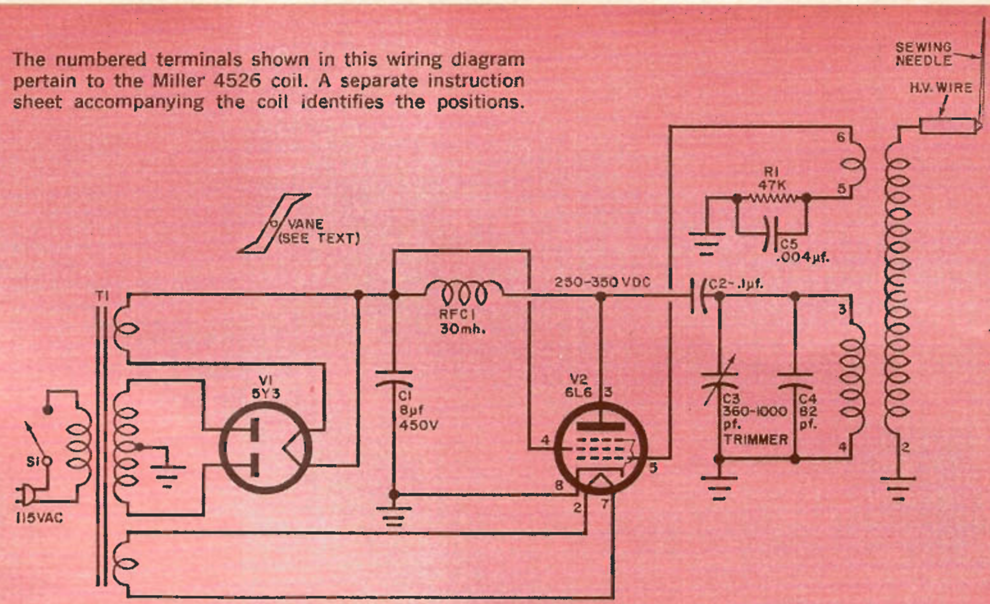
Construction. The mechanical layout is not critical, and the design shown in the photographs need not be followed exactly. It is convenient to place the r.f. coil off in one corner of the chassis and to drop the connecting leads to *V2* through grommeted holes in the chassis deck. The high-voltage output lead of the coil is shortened and a sewing needle soldered to the end to show "point discharge" effects.

The power supply is of conventional design and the B-plus applied to the plate of *V2* can range from 250 to 500 volts. However, 250 - 350 volts is more than ample for an output of between 12,000 and 15,000 volts. The output will also vary according to the type of tube used at *V2*. When you open the coil box, you will see that a 6Y6 is recommended by the manufacturer. However, noticeably improved effects were obtained by the author by substituting a 6L6. A 6V6 or another equivalent power pentode would do in a pinch.

Capacitor *C3* is used to tune the primary of the h.v. coil. For convenience, two bus-bar leads about 1" in length were soldered to the capacitor and used to support it in mid-air. The remaining components are scattered around below the chassis deck.

Firing Up Li'l TC. When used in a TV receiver, the high voltage generated by this coil/oscillator arrangement is rectified and filtered. It is then considerably more dangerous than the unfiltered r.f. generated by Li'l TC. Nevertheless, Li'l TC should be treated with respect, for the voltage can puncture the skin of a finger, although high-frequency voltages usually tend to flow relatively harmlessly along the skin's surface.

The numbered terminals shown in this wiring diagram pertain to the Miller 4526 coil. A separate instruction sheet accompanying the coil identifies the positions.



PARTS LIST

C1—8.0-µf., 450-volt electrolytic capacitor
C2—0.1-µf., 600-volt molded capacitor
C3—360-1000 pf. trimmer capacitor
C4—82-pf., 1.6-kv. ceramic capacitor—see text
C5—0.004-uf., 600-volt mica capacitor
R1—47,000-ohm, ½-watt resistor
RFC1—30-mh., 100-ma. r.f. choke (I. W. Miller 692 or equivalent)
S1—S.p.s.t. toggle switch
T1—Power transformer: primary, 117 volts a.c.; secondaries, 500 volts, CT, 5 volts at 2 amperes, and 6.3 volts at 2.5 amperes (Thordarson 24R09U or equivalent)
V1—5Y3 tube
V2—6L6 tube—see text
1—High-voltage coil (I. W. Miller 4526—see text)
1—Metal chassis (Premier ACH-404 or equivalent)
Misc.—Tube sockets, wire, solder, etc.

After double-checking your wiring, **turn on** the a.c. power and permit the two tubes to warm up. Take an insulated screwdriver—something like a long alignment tool—and adjust *C3* for a brush discharge from the needle point. If you do not have enough range in *C3* to tune through the maximum discharge, change the value of *C4*—add more capacitance at *C4* if the plates of *C3* are tightly meshed; use less if *C3*'s are too loose. You can set *C3* for maximum discharge by listening to the sound of the brush effect—tune for a clean high-pitched hiss and not a sputtering sound.

The brush discharge from Li'l TC will be about 1″ in height and can be seen best in a dimly lighted room. Actually, a brush corona will appear at any sharp edge on the output lead, so be careful to round out the soldered connections between the eye of the needle and the shortened h.v. lead.

Ionic Propulsion Vane. Probably the most impressive demonstration of a Tesla coil is the ionic propulsion vane. You can make one for Li'l TC by cutting out the general pattern shown in the diagram above.

Make the over-all length of the vane about 1″ to 1½″. Cut the vane from aluminum foil and puncture the center so that the vane is balanced. Use one of your wife's extra beads as a bearing by slipping it on the upright needle. Then drop the vane over the needle so that it rests on the bead and can rotate freely. Put a piece of cork or rubber on the tip of the needle to stop the vane from picking up so much speed that it spins right off the needle.

The photograph on the first page of this article is a two-second time exposure (slightly enlarged) showing what the brush corona discharge and rotating vane should look like. —30—

BIG TC

A quarter of a million volts? All it takes is a transformer, a capacitor, a spark gap, and Tesla's famous coil

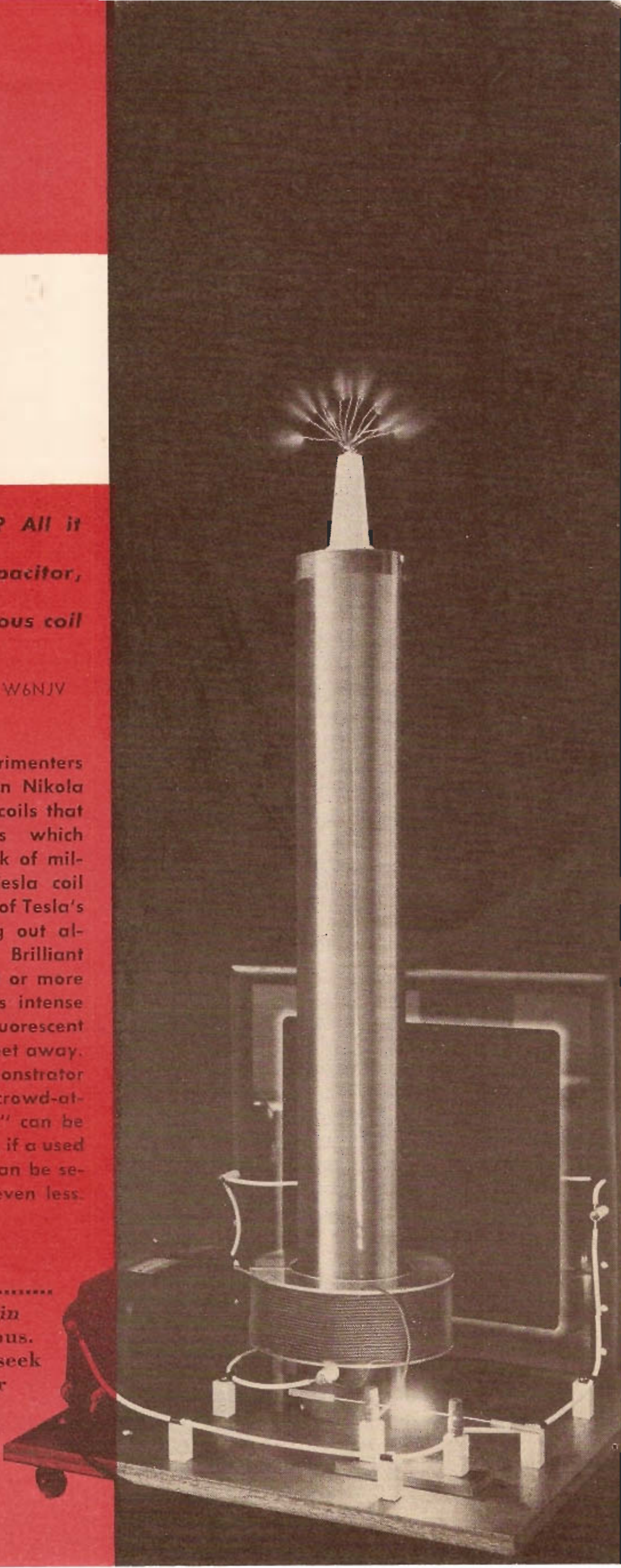
By **CHARLES CARINGELLA,** W6NJV

TESLA COILS have fascinated experimenters ever since the early 1900's when Nikola Tesla first experimented with giant coils that produced lightning-like discharges which would span his laboratory—the work of millions of volts of electricity. The Tesla coil described here is smaller than some of Tesla's designs, but it's capable of putting out almost *a quarter of a million volts!* Brilliant corona discharges as long as a foot or more provide a spectacular display of its intense electrical field, and neon and fluorescent lamps can be excited as far as five feet away.

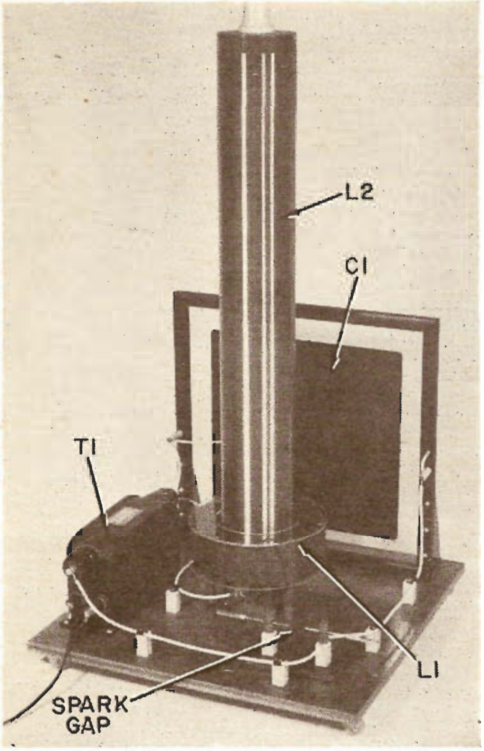
Intended both as a dynamic demonstrator of electrical principles and as a crowd-attracting science fair project, "Big TC" can be put together for about $30. However, if a used transformer from a neon sign shop can be secured reasonably, the cost will be even less.

WARNING: The voltages used in this project are highly dangerous. Inexperienced persons should seek aid from an instructor or other expert before building it.

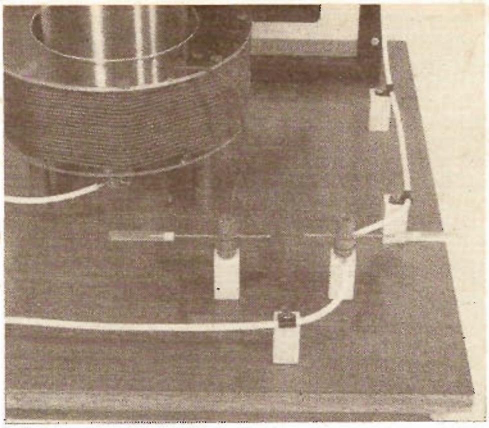
COVER STORY

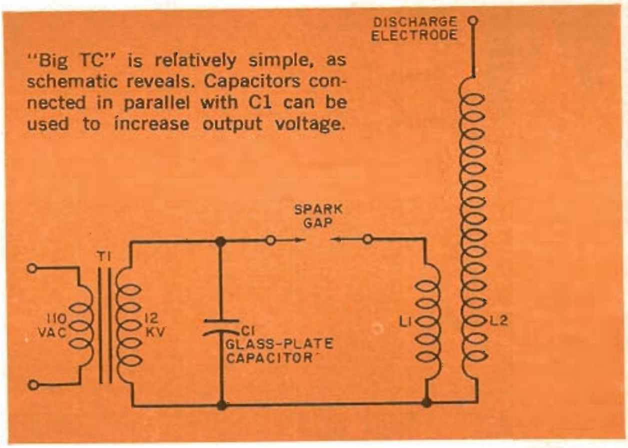


BIG TC



Mount L1-L2 in center of base, T1 and C1 at edges. A bigger base and greater component spacing will permit greater voltage output with less arcing.


Spark gap generates r.f. energy to excite coil. It consists of two copper rods mounted on standoffs.



"Big TC" is relatively simple, as schematic reveals. Capacitors connected in parallel with C1 can be used to increase output voltage.

As shown in the schematic diagram above, *T1* steps the household line voltage up to 12,000 volts. The transformer is the type commonly used to operate neon signs. A high-voltage glass-plate capacitor, *C1*, is connected directly across the high-voltage secondary winding of *T1*. The capacitor serves as an energy storage device, charging up to *T1*'s secondary voltage and then discharging in response to the 60-cycle a.c. voltage.

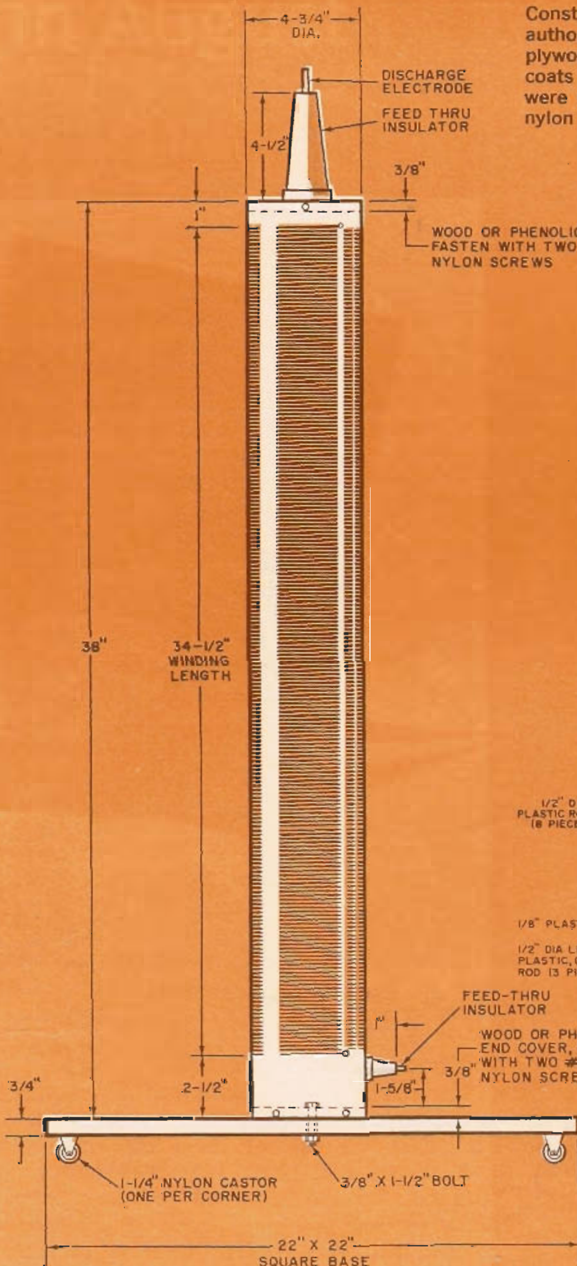
Discharging of *C1* is through the spark gap into coil *L1*. Each time the spark gap "fires," a high current flows through *L1*. The larger capacitor *C1* is made, the larger will be the current through *L1*. Discharges across the spark gap produce extremely jagged pulses of power which are very rich in r.f. harmonics. The energy—due to the values of the components used—is greatest in roughly the 100-kc. region.

Windings *L1* and *L2* form a air-core step-up transformer, with *L1* the primary and *L2* the high-voltage secondary. The voltage at *L2* will be 75,000 to 250,000 volts depending on the size of *C1*.

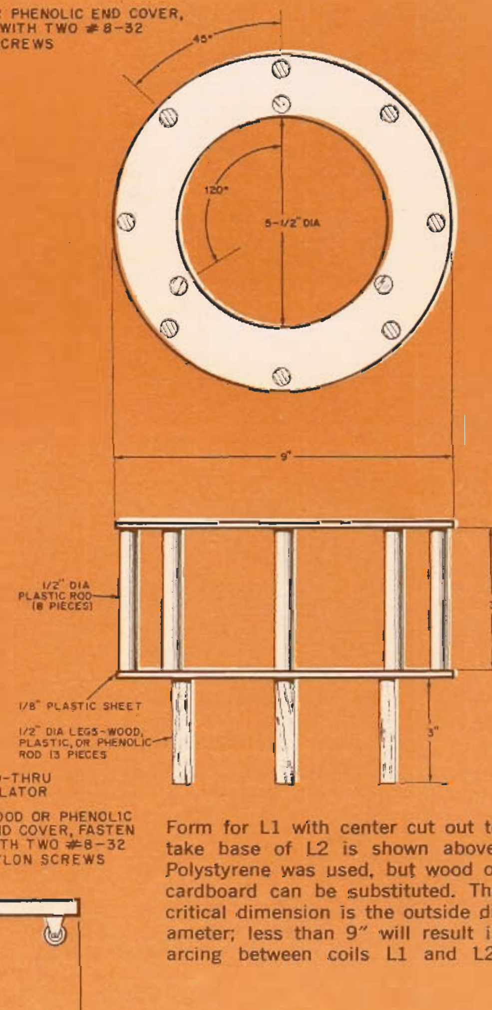
Design and Layout. The prototype of "Big TC" was built on a plywood base measuring ¾" x 22" x 22", although a larger base would be desirable for high-voltage units to prevent arcing between *L2* and *T1* and *C1*. Mount *L2* in the center of the base and *T1* and *C1* as close to the edges as possible; if you plan to operate the unit at voltages exceeding 100,000 volts, make the base 3' x 3' for even greater separation between components.

Power transformer *T1* is the only

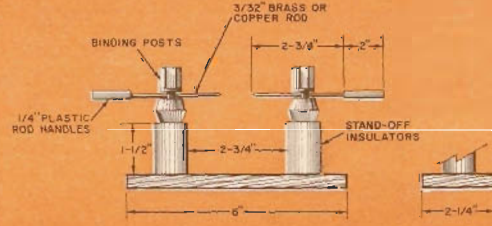
Constructed for classroom demonstration, the author's unit was mounted on mahogany veneer plywood which was sanded and covered with five coats of plastic varnish. Other finishing touches were wood tape veneer around the edges, and nylon casters to make the unit easy to move.



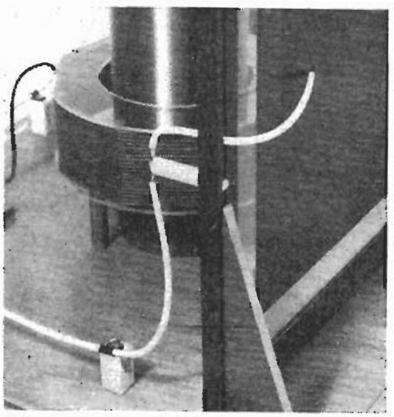
The various dimensions of the prototype coil are indicated in the drawing; none is particularly critical. Note that space has been left at each end of coil, and that stand-off insulators are used to bring out the ends. Nylon screws or glue must be used to fasten top end cover to avoid arcing. After winding coil, cover with many coats of acrylic plastic spray. Spray form first if cardboard is used. Details on spark gap are shown at right.



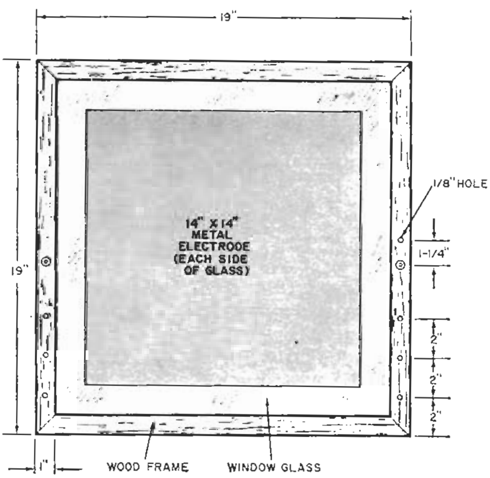
Form for L1 with center cut out to take base of L2 is shown above. Polystyrene was used, but wood or cardboard can be substituted. The critical dimension is the outside diameter; less than 9" will result in arcing between coils L1 and L2.

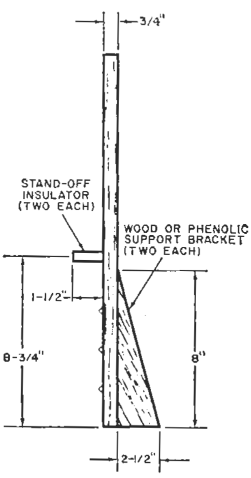


BIG TC



Leads are soldered directly to capacitor plates. Note use of stand-off insulators.





Glue metal plates to glass, leaving a generous margin of glass on all sides (see text). Epoxy glue, contact cement, or any other glue which will form a tight bond can be used. The wood frame protects the glass and makes mounting it possible.

high-cost component. A neon-sign unit rated at 12,000 volts a.c. at 30 ma., it sells for about $40 new, but used transformers are constantly being salvaged by sign shops, and can be picked up for $10 to $20. It is also possible to find neon signs in junk yards, in which case you can probably buy the transformer for practically nothing. The author used a GE unit, No. 51G473, known technically as a "luminous tube transformer." Measuring 9½" x 6" x 4", it has 2" feedthrough insulators at either end connecting to the high-voltage winding.

Primary coil *L1* and all connecting leads must be made with high-voltage wire, preferably supported away from the base on 1" ceramic standoff insulators. Test prod wire such as Belden Type 8898 is ideal—it has flexible rubber insulation with a puncture voltage rating of 29,000 volts.

Winding the Coil. For the big coil (*L2*) a phenolic coil form* measuring 4¾" in outside diameter and 38" in length was used. Alternately, cardboard, wood or other insulating materials can be substituted. You can improve these latter types of coil forms by spraying on at least six coats of acrylic plastic spray before winding the wire on them.

The winding itself is done with No. 26 Formvar-insulated wire—two 1-lb. spools (splice them together and keep the solder joint as small as possible) will give you a 2000-turn, tightly spaced coil covering 34½" of the coil form. There should be extra space between the ends of the winding and the ends of the form—see the drawing on page 31.

The lower end of the coil is terminated at a 1" feedthrough insulator installed in the side of the form, the top end of the coil at a 4½" feedthrough mounted to the top end of the form. Make the end covers of wood or phenolic discs cut to the inside diameter of the coil form, and mount them in place with

(*Continued on page* 76)

*Tubing can be found in metropolitan areas at surplus houses and establishments which sell plastics (sheets, rods, etc.). Clear acrylic tubing (48" long, 4½" O.D.) can be ordered from Industrial Plastics Supply Co., 324 Canal St., New York, N. Y. 10013, for $13.85 including shipping charges and postage; address your order to the attention of Mr. Charles Roth.

Big TC

(*Continued from page* 32)

nylon screws (metal screws at the top end would produce corona discharges which could burn the coil form). Alternatively, the top coil cover can be cemented in place with epoxy cement if a sturdy coil form is used. The coil is attached to the base with a 3/8" bolt.

Winding the coil is not nearly as difficult as it appears—the author completed the task in about two hours. Spray the entire winding with acrylic plastic for added insulation, moisture protection, and to keep the windings in place. You can't overdo this step—the author used the contents of an entire aerosol spray can on the prototype, applying one thin layer at a time and letting it dry before adding another.

Building the Primary. As shown on page 31, the form for *L1* was made with polystyrene rods and sheeting. While the plastic has excellent insulating qualities and looks attractive, wood or even cardboard can be substituted. If plastic is used, it can be strongly "welded" together with acetone. Regardless of the material used, the form should have an outside diameter of at least 9" to avoid arc-over between *L1* and *L2*. The coil itself (*L1*) consists of 20 turns of heavy test prod wire.

Spark Gap. The spark gap is simply two ordinary binding posts mounted on stand-off insulators. In turn, these are mounted on a phenolic base measuring 3/8" x 2¼" x 6". The electrodes are brass and copper rods with a gap on the order of 1" between them. This distance will vary slightly, depending on the size of capacitor *C1*.

Fabricating the Capacitor. The capacitor consists of two 14" x 14" sheets of tin cemented to a 18½"-square piece of window glass. Although aluminum foil can be used for the capacitor plates, tin was obtained from a sheet metal shop for this purpose so that connecting leads could be soldered directly to it. If you use aluminum foil, a fairly good connection can be had by making leads of ½"-wide aluminum foil strips and taping them down to the electrodes.

Glass is an excellent dielectric material for this application since it has an extremely high puncture voltage and a high dielectric constant. As you will note in the drawing on page 32, a border of glass is left around the capacitor plates—this should be at least 1½" wide. The calculated capacity of *C1* is approximately 0.0027 μf.

Testing and Operation. Caution! Adjustments to the Tesla coil, and specifically to the spark gap, should be made *only* when the unit is *off*. Although the output voltage of the Tesla coil may be on the order of 150,000 volts, the current capacity is only hundreds of microamps. This current can inflict a nasty shock and r.f. burns, however.

Use EXTREME CAUTION around the neon sign transformer. It delivers 12,000 volts at 30 ma., and this voltage could be lethal under certain conditions. Again, be sure the plug is out when you make adjustments.

To adjust the spark gap, first open it to about 1½"; it will not fire at this point. Gradually move the electrodes together—unplugging the unit each time you adjust the gap—until the point is reached where the gap "fires."

The author's version of "Big TC" produced an output voltage of 100,000 volts with the 0.0027-μf. capacitor described. To increase the output voltage, simply construct one or two more capacitors and parallel them across *C1*. With two capacitors in parallel, the prototype Tesla coil produced 150,000 volts; with three capacitors, 200,000 volts. However, it began to break down between coil *L2* and capacitor *C1* above the 200,000-volt region. As mentioned earlier, greater output voltage can be obtained by making the base larger and increasing the spacing between components to eliminate arcing.

The output of your Tesla coil can be estimated by drawing an arc to a metallic object attached to a long wooden handle. Slowly increase the distance between the object and the discharge terminal until the arcing stops: a 6" arc represents 100,000 volts, a 14" arc about 200,000 volts, and a 21" arc some 300,000 volts. More amazing than figures, however, are the brilliant, spectacular phenomena exhibited by high-voltage, high-frequency electricity. –30–

Simple Tesla coil

I'M SURE THAT MANY READERS FOUND the article on the recreation of Tesla's original experiments by Robert Golka (see **Radio-Electronics,** February 1981 issue) very interesting. I know that I did, especially since I built a small version of a Tesla coil not too long ago (although I'm only age 14). I'd like to share the details with you.

There is one important thing to keep in mind before we even begin: The Tesla coil described here can generate 25,000 volts so, even though the output current is low, **be very careful!**

The main component of the Tesla-coil circuit is a flyback transformer. You can get one from a discarded TV.

The first thing you must do is to get rid of any excess wire or other debris that's on the transformer's core, as shown in Fig. 1. Leave the high-voltage winding alone; but if there is a capacitor at the end, it should be removed.

After that, you can start winding a new primary coil. Begin by winding 5 turns of No. 18 wire on the core. Then

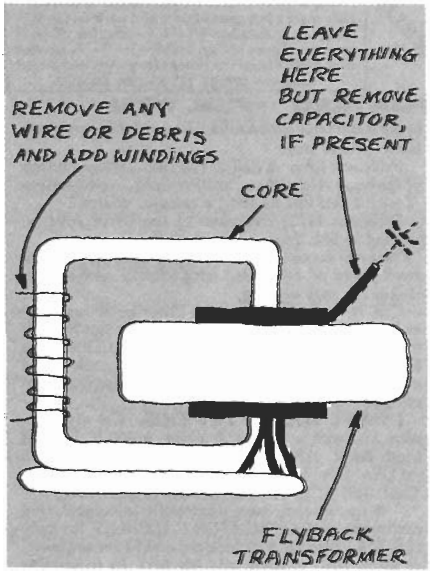


FIG. 1

twist a loop in the wire and finish by winding five more turns. Wrap with electrical tape, but leave the loop exposed.

A four-turn winding has to be wound over the ten-turn winding that you've just finished. That is done the same way. First wind two turns of No. 18 wire, then make a loop, and finish up by winding two more turns. Again, wrap the new winding with electrical tape, leaving the loop exposed.

When the windings are finished, the two loops shouldn't be more than ¼-inch apart (but take care that they do not touch). Connect a 240-ohm resistor between the two loops. The modified transformer now should look like the one shown in Fig. 2.

Connect the transformer as shown in Fig. 3. The 27-ohm resistor and the two transistors should be mounted on a heat sink and *must be insulated from it.*

The output of the high-voltage wind-

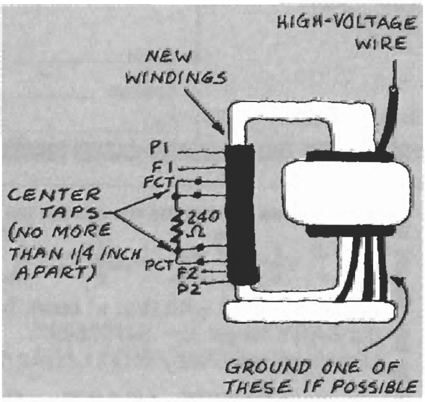


FIG. 2

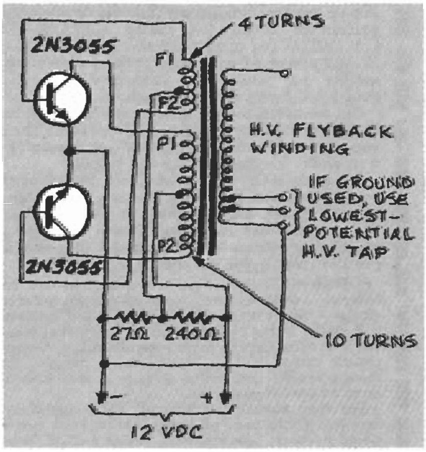


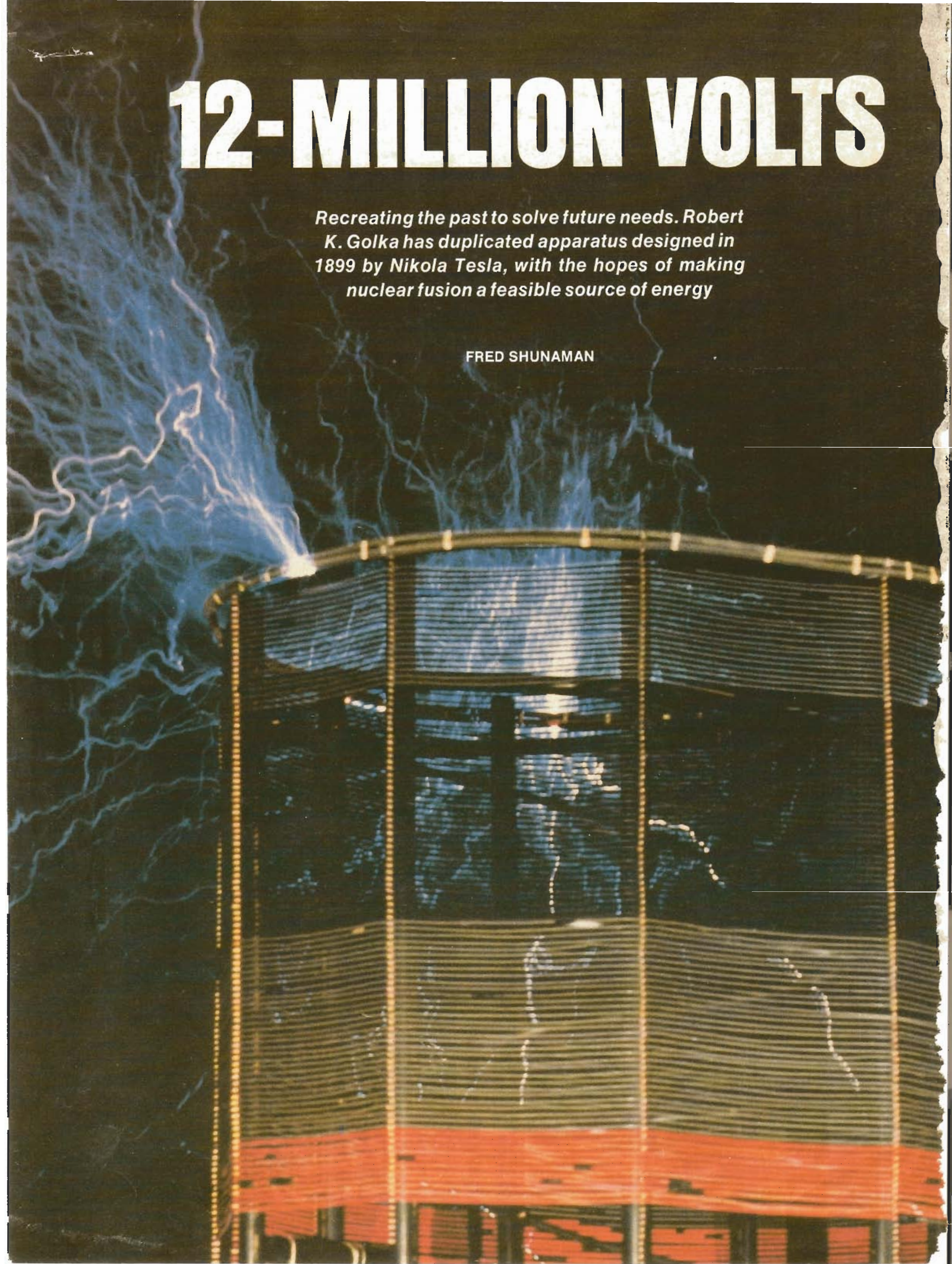
FIG. 3

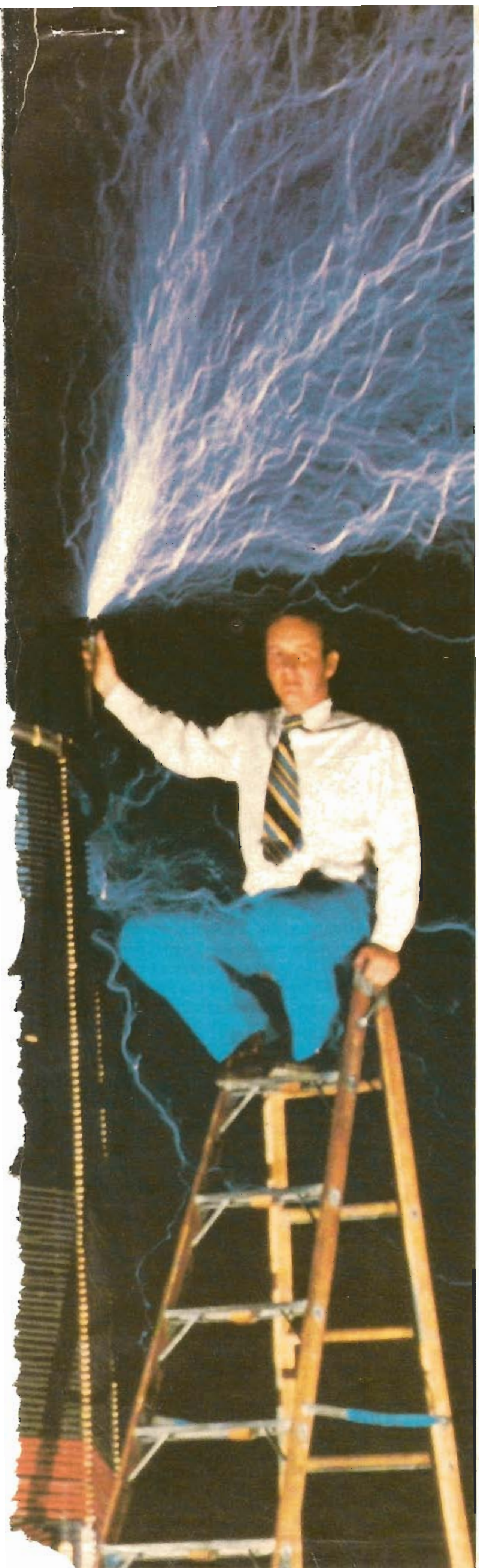
ing should begin to oscillate as soon as the circuit is connected to a 12-volt DC power supply. If it does not, reverse the connections to the base leads of the transistors. In normal operation, you should be able to draw 1-inch sparks from the high-voltage lead using an **insulated** screwdriver.—*Eric Wold*

12-MILLION VOLTS

Recreating the past to solve future needs. Robert K. Golka has duplicated apparatus designed in 1899 by Nikola Tesla, with the hopes of making nuclear fusion a feasible source of energy

FRED SHUNAMAN





IN THE SUMMER OF 1899, NIKOLA TESLA, POSSIBLY THE world's greatest engineer, set up an experimental laboratory or station near Colorado Springs with the intention (he told curious reporters and residents) of "sending a telegram from Pike's Peak to Paris." It is highly possible that long-distance wireless communication was the main objective of his work there, but he was probably also interested in wireless power transmission.

Tesla used a radio-frequency transformer (Tesla coil) of unheard-of dimensions and power—at least 12-million volts were generated. He was not too communicative about his experiments—either their purposes or results—and visitors were not encouraged. (This may have been partly because of the dangerous nature of the work.) So exact details are lacking.

Today—nearly 80 years later—in an Air Force hangar at Wendover, Utah, that 12-million volt record has for the first time been equalled and possibly exceeded. The second man to generate 12-million volts is Robert K. Golka, of Golka Associates, Brockton, Massachusetts. And he is doing it with equipment designed to duplicate Tesla's as closely as possible. Mr. Golka has instituted what is now called Project Tesla to study one of the results of Tesla's experiments that the great scientist almost brushed off as an interesting but unimportant phenomenon.

The exact equipment Tesla used cannot be determined. Probably he made numerous changes, so conflicting reports may be correct for the situation at the time reported. All agree that the primary of the Tesla coil was of heavy copper wire (1½-inch thick) placed at the bottom of the secondary, which was 51 feet in diameter. The type of conductor used for the secondary and the number of turns is not quite clear, but all reports (and the photographs) agree that there was an addition to the secondary—a coil of 100 turns, 8-feet 3-inches in diameter, placed in the center of the larger coil. The main secondary appears to have had a natural resonance of about 50 kHz; the additional coil resonated at the second harmonic, 100 kHz.

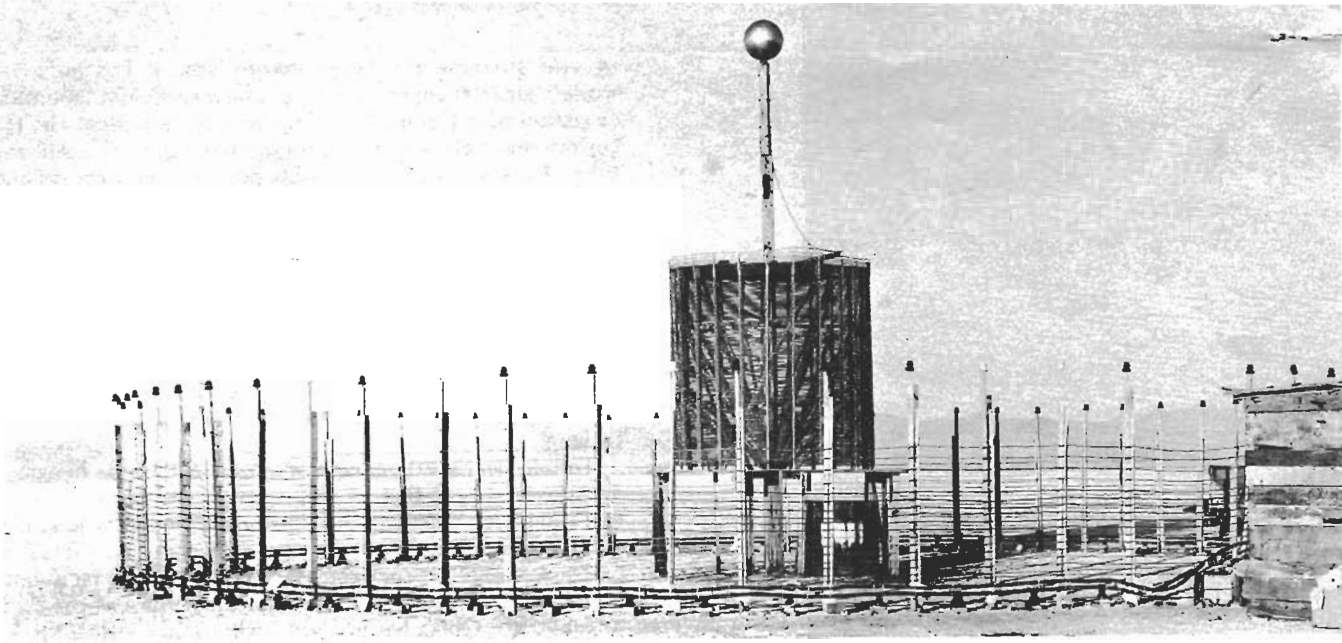
The input power was thought to be up to 50 kW, but when the coil was first energized, it blew out the generator of the Colorado Springs lighting and power system. (Tesla supervised the rebuilding). The blowout may of course have been due to a radio-frequency surge or kickback rather than to the amount of power drawn. (Of little consequence to the Colorado Springs lighting and power system.)

Two important by-products

Tesla made two important discoveries not connected with his original objective. He was an interested student of natural electricity, which the many thunderstorms of the region produced in vast abundance. He made special recording equipment to record their intensity and characteristics. These recordings gave him no room to doubt that he was observing standing waves in the earth. "Impossible as it seemed," he reported, "this planet, despite its vast extent, behaves like a conductor of limited dimensions. The tremendous significance of this fact in the transmission of energy in my system had already become quite clear to me. Not only was it possiblt to send telegraphic messages to any distance without wires, as I recognized long ago, but also to impress on the entire globe the faint modulation of the human voice. Far more significant is the ability to transmit power in unlimited amounts to almost any terrestrial distance and almost without loss."

To illustrate his point, Tesla lit a bank of 200 carbon-filament lamps—consuming about 10 kW—26 miles from the station, a feat that has not since been equalled. This experiment was duly witnessed and recorded by his assistant, Fritz Lowenstein, later to become a prominent electronic inventor in his own right.

(It is doubtful indeed, says Mr. Golka, that power could be sent completely around the world from one



THIS TESLA COIL created the highest voltage ever produced by mankind—12,500,000. Estimated peak current: 1,100 amps.

source, as Tesla envisioned. The resistance losses would far outweigh the power actually used. Some rocky soil has a resistance as high as 1,000 ohms per meter.)

Ball lightning

The second discovery was recorded almost as an aside by Tesla in his description of the electrical displays of the region: "Lightning discharges are, accordingly, very frequent and sometimes of inconceivable violence. . . . Many of them resembled gigantic trunks of trees with the trunks up or down. I never saw fire balls, but as a compensation for my disappointment I succeeded later in determining their mode of formation and in producing them artificially."

Fire balls, or ball lightning, have long been a puzzle to scientists. Many of the scientists have simply denied their existence (as a simple solution to a problem that appeared to have no reasonable answers). They are glowing balls apparently of electrical plasma, a foot or less in diameter, floating a few feet off the ground. Their exact composition and mode of formation is not known. They appear in the wake of thunderstorms and move slowly, bouncing when they strike the earth or a solid object.

Despite earlier doubts, the existence of ball lightning was pretty well established by Niels Bohr, who saw a fireball and reported it. (Possibly lesser scientists have also seen ball lightning but have remained discreetly silent about it, like the sea captain who remained below eating his dinner when the deck crew reported a sea serpent. "I don't want to be called a liar all the rest of my life," he said.)

A few prominent physicists have speculated and formed tentative theories about ball lightning. (Tesla was the first to try to develop a theoretical explanation.) But it was considered a special subject well away from the mainstream of scientific investigation.

All this changed with the coming of the nuclear age. Scientists have been struggling to contain and control the plasma of ionized and superheated gases resulting from the fission or fusion of nuclear materials. A constricting magnetic field in the shape of a large doughnut has been labored with for some years. Its latest name is the Tokamack, given by the Russians, meaning toroidal-confinement. In the earlier days it was known by other names! The Perhapsatron was an interesting name for an early magnetic confinement device. The Theta-Pinch and the Beta device were all variations of this idea.

Since every plasma behaves thermodynamically like a liquid, why not use surface tension to partly help in holding the plasma together? Of course other parameters will have to be exactly right for the effect to take place, but surface tension plays a predominant part, just as in the production of soap bubbles using a soapy liquid.

The various theories about ball lightning agree that it must be a plasma—a ball of ionized air or other gases. Yet it is self-contained and does show evidence of surface tension—bouncing off objects it strikes and regaining its spherical form. True, it is far from permanent, lasting about five seconds on the average—though observers have reported fire balls with a life of minutes.

Ball lightning then, might serve as a model for controlled fusion or at the very least a study of it might produce new knowledge that would be helpful in obtaining controlled fusion. But the problem of observing natural ball lightning is insurmountable. It is much more common in some areas (notably parts of Sweden and Australia) than others, but nowhere does it occur often enough (or long enough) for study.

The lightning maker

Robert K. Golka became interested in the subject when he read—in O'Neill's *Prodigal Genius*—that Tesla, though he had never seen natural ball lightning, had produced it artificially during his Colorado Springs experiments. Contacting Leland Anderson, long-time Tesla student and historian, he was told that little information was available, but there might be more in Tesla's notebooks in the Tesla Museum in Beograd, Yugoslavia.

After playing with the idea for a year, Golka went to Yugoslavia and was able to get permission to read the Colorado Springs diary. (Fortunately, Tesla wrote his notebooks in English, but Golka reports that the handwriting was such that reading the notebook was almost like translating from a foreign language.) A little experimenting with Tesla coils convinced Golka that he was on the right track, but that a much bigger coil than anything he could construct would be required. What was necessary, Golka believed, is the following.

1. A generator of moderately low frequency and with enough power to be able to excite certain areas of land with standing waves.
2. Land area where electrical reflections can be set up (due to ground faults or other causes) to support standing wave phenomena.
3. High-intensity electrical discharges in which the plasma "ball" can be formed in-channel and disassociated from the discharge

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path by changing the primary coil frequency abruptly.

4. Reinforcement of the energy contained in the "ball."

Taking his conclusions and plans to Washington, D.C.–where more than one agency was interested in any research that might lead toward solving the problem of confining a dense highly heated plasma for thermonuclear applications–Golka succeeded in securing backing for the present Bonneville Flats installation.

The work is still in the early stages, but results are already promising. Golka has achieved voltage discharges up to 15 million (the highest yet made by man) for a period of 8 minutes, and "sparks" (or lightning bolts) rivalling the 20 to 30-footers attributed to Tesla. Already small discharges resembling ball lightning–with a life of about 0.1 second–have been observed.

This is a far cry from controlled nuclear fusion, yet there is more than a chance that–like Faraday's "new-born infant"–it may be the first step toward techniques that could have as great an effect on our future civilization as Tesla's development of alternating-current electricity has had on our present one. **R-E**