High-Voltage Projects
For Fun and Science

Book 1

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A GERNSBACK PUBLICATION

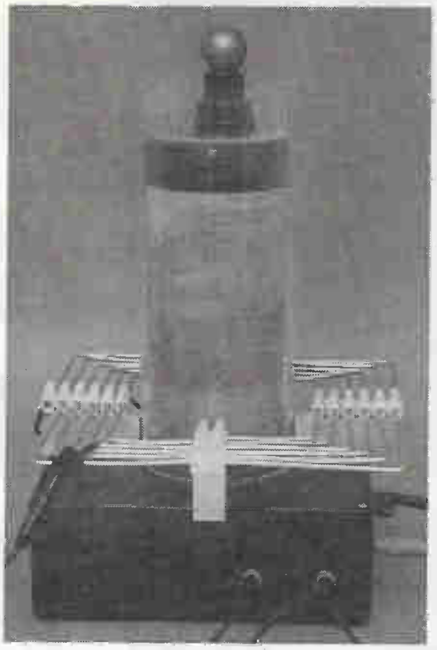
As time passes, the availability of parts and sundries decreases or price changes occur. Contact the suppliers and distributors listed herein for up-to-date information before you proceed with building or assembling the projects.

By the Editors of Electronics Now and Popular Electronics

BY VINCENT VOLLONO

THE SQUARE

SQUARE



SQUARE

SQUARE TESLA COIL

Build this unusual version of Nikola Tesla's most famous experiment!

Nikola Tesla, considered by some to be the greatest inventor of the electrical age, is today best remembered for his fascinating power-transmission experiments, using his famous Tesla Coil. In his original experiment, he was able to transmit electrical energy without wires to light incandescent lamps located over 25 miles way.

Today, most similar circuits—like the *Tesla Coil* described in this article—are used for educational and experimental purposes. Unlike many of the modern versions, our circuit feeds AC to a power transformer capable of outputting about 3-kV AC at 20 milliamps. The output of the transformer is sent to a primary coil, and is magnetically coupled to a secondary coil with a top capacitance. And if the primary coil is properly tuned, a spectacular high-frequency, high-voltage output is produced at the secondary coil.

Circuit Description. Figure 1 shows the schematic diagram of the Tesla Coil circuit. The circuit consists of little more than a few coils, a step-up power transformer, and a capacitor. Power from an AC wall socket is fed to transformer T1 (a small neon-sign transformer) which steps the voltage up to about 3000-volts AC.

The stepped-up output of T1 is fed through L1 and L2 across C1, causing it to charge until enough power is stored in the unit to produce an arc across the spark gap. The spark gap—which momentarily connects C1 and L3 in parallel—determines the amount of current transferred between C1 and L3.

The arcing across the spark gap sends a series of high voltage pulses through L3, giving a sort of oscillating effect. The energy fed through L3 is transferred to L4 via the magnetic coupling between the two coils. (Because of the turns ratio that exists between L3 and L4, an even higher voltage is produced across L4.) Coil L4 steps up the voltage, which collects on the top-capacitance sphere where it causes an avalanche breakdown of the surrounding air, giving off a luminous discharge.

In order to get maximum output from the Tesla Coil, certain conditions must be met. First of all, the primary and secondary resonant frequencies must be made equal by tuning the primary coil, L3. That's accomplished by tapping L3 at points along the coil with a clip lead.

In addition, the setting of the spark gap greatly effects the output of the Tesla Coil. Our Tesla Coil is designed to use either a stationary spark gap or an optional rotary spark gap; both of which must be adjusted for maximum output. (We'll discuss the rotary spark gap a little later.)

If L3 and L4 are coupled too close, coil efficiency is reduced; over-coupling prevents the circuit from resonating at maximum efficiency. That also causes a breakdown between L3 and L4, which can produce arcing between the two coils. By increasing the coupling between L3 and L4, the amount of energy increases in L4 until a "critical coupling" is reached.

In addition, the Q of the coils is very important (the Q of a coil is equal to its inductive reactance divided by its resistance). The lower the Q, the higher the efficiency of the coil. The primary coil was made from a few turns of aluminum grounding wire (so its resistance is very low). The secondary has many more turns of fine magnet wire, which by its very nature exhibits a higher resistance than does the wire used in the primary coil (L3).

Rotary Spark Gap. The rotary spark

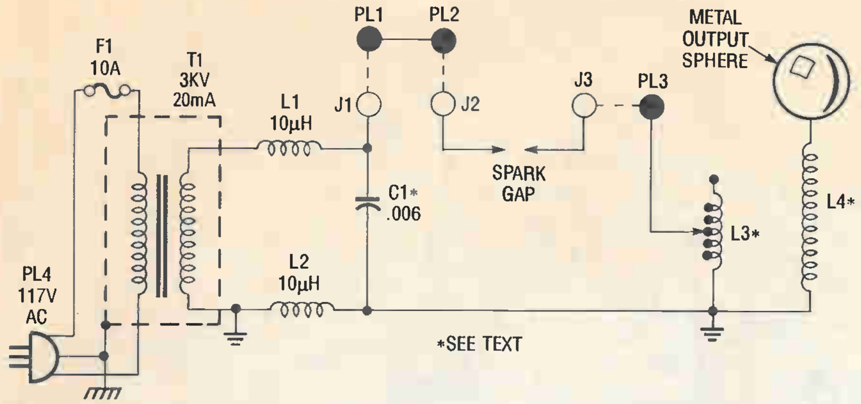


Fig. 1. The Tesla Coil circuit consists of little more than a few coils, a step-up power transformer, and a capacitor.

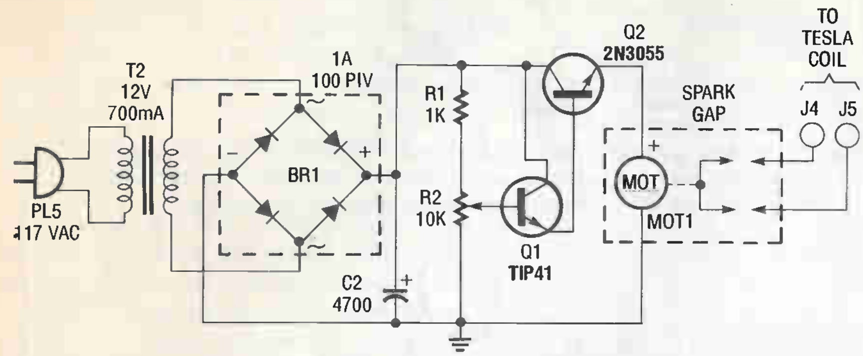


Fig. 2. Here's the schematic diagram for the optional rotary spark gap. The circuit is made up of a 12-volt power transformer, a bridge rectifier, a 4700-μF capacitor, and a 12-volt DC motor.

gap is a simple add-on circuit for the Tesla Coil, consisting of a variable DC power supply and a small, 5000 rpm, DC motor. The circuit allows you to vary the output of the Tesla Coil by adjusting the rotating speed of the motor. A rotary gap is far more efficient than the stationary gap because the stationary gap could cut out, requiring that the gap be readjusted.

Figure 2 shows the schematic diagram of the rotary spark gap, which is assembled as a separate unit. The circuit is made up of a 12-volt power transformer, a bridge rectifier, a 4700-μF capacitor, and a 12-volt DC motor. Power is delivered to the circuit via a 117-volt AC line cord, and fed to transformer T2 (a 12-volt, 700-mA unit), which provides a 12-volt AC output. The output of the transformer is fed to BR1 (a 1-amp, 100-PIV, full-wave bridge rectifier), which converts the AC input to provide 12-volts DC for the operation of the motor.

The output of the rectifier is fed to the base of transistor Q1, which along with Q2 forms a Darlington pair. The output of Q1, which controls the bias presented to the base of Q2, is controlled by potentiometer R2. Potentiometer R2 is used to adjust the base bias on Q1, thereby varying the current through Q2, which in turn varies the rotating speed of the motor.

The rotary spark gap has a stationary post (two screws) mounted on a small square of perfboard, which face a rotor (another perfboard square on which four screws are mounted and electrically connected together with bus wire). The stationary posts and the rotor posts are positioned as close as possible. The movement of the rotor makes and breaks the gap giving maximum impulse power, and will not cut out if the stationary and rotor posts are set properly.

The rotary spark gap is connected to the Tesla Coil through separate wires and banana jacks (J4 and J5). When the circuit is powered up, the current that normally travels through the stationary spark gap on the Tesla Coil is rerouted through the rotary gap via J4 and returned to the Tesla Coil via J5. To make the connections plug PL1 into J1, PL2 into J4, and PL3—which in Fig. 1 is used to connect the output of the stationary spark gap to L3—into J5.

Construction. The author's prototype of the Tesla Coil was built into a large plastic enclosure; because of the high voltages involved, it is imperative that you avoid metal enclosures. Because the circuit consists of very few parts, its components can easily be hard-wired together within the housing, using Fig 1 as a guide. There is nothing particularly critical about the layout of the circuit. Just be sure to maintain adequate spacing between the individual com-

PARTS LIST FOR THE TESLA COIL

L1, L2—10-μH, AC-line filter choke
L3—6 turns, #10 aluminum grounding wire, see text
L4—348 turns, #24 magnet wire, see text
T1—3-kV, 20-mA, neon-sign transformer
C1—.006-μF, 5000-WVDC ceramic capacitor (see text)
F1—10-amp fuse
J1–J3—Banana jack
PL1–PL3—Banana plug
PL4—3-conductor AC power plug with line cord
Metal output sphere, plastic or wooden enclosure, "L" brackets wire, solder, wood, hardware, etc.

PARTS LIST FOR THE ROTARY SPARK GAP

Q1—TIP41 NPN silicon power transistor
Q2—2N3055 NPN silicon power transistor
BR1—1-amp, 100-PIV, full-wave bridge rectifier
MOT1—12-volt, 5000-rpm, DC motor
T2—12-volt, 700-mA, step-down power transformer
R1—1000-ohm, ¼-watt, 5% resistor
R2—10,000-ohm potentiometer
J4, J5—Banana jack
PL5—2-conductor AC power plug with line cord
Perfboard materials, plastic or wooden enclosure, wood, wire, solder, hardware, etc.

Note: A 3-kV, 20-mA, neon-sign transformer (T1) is available as part number 720-391 from N. Glantz & Son, 218 57th St., Brooklyn NY 11220, Tel. 800-522-5120. The 12-volt DC motor for the optional rotary spark gap (MOT1) is available from H&R Corp., 401 E. Erie Ave, Philadelphia, PA 19134, Tel. 800-848-8001. Contact those companies directly for pricing, shipping and handling charges, etc.

Plans for making your own high-voltage capacitors, such as the one required for C1, are available for $3.50 postpaid from Alegro Electronic Systems, 3 Mine Mountain Road, Cornwall Bridge, CT 06754; ask for item number UHVC400.

ponents and wires.

Start by drilling holes in the enclosure to pass wires through and for the panel-mounted components. In the author's prototype, three sides of the enclosure were outfitted with appropriate sized holes. A ⅛-inch hole was drill in one side of the enclosure, through which a ground wire connects to L3.

On another side of the enclosure, holes were drilled to accommodate a dowel rod (which is part of the stationary spark gap), a fuse holder, and the power cord. On the third side, three holes were drilled for banana jacks. It will also be necessary to drill holes in the bottom of the enclosure suitable for T1's mounting hardware.

Begin assembly by mounting the power transformer on the bottom of the enclosure. Next connect a 10-μH AC filter choke in series with each of T1's secondary leads, and then connect the free ends of each coil across C1 (see Fig. 1).

Note: In the author's prototype, C1 is really two .012-μF, 2500-volt AC capacitors that were wired in series to create C1 (giving the capacitor an effective rating of .006 μF at 5-kV AC). If you use the same scheme, keep the connecting leads between the capacitors as short as possible. After connecting the capacitors together, cover the gap between the two units with non-conductive tape, and connect the jerry-rigged unit in the circuit as shown.

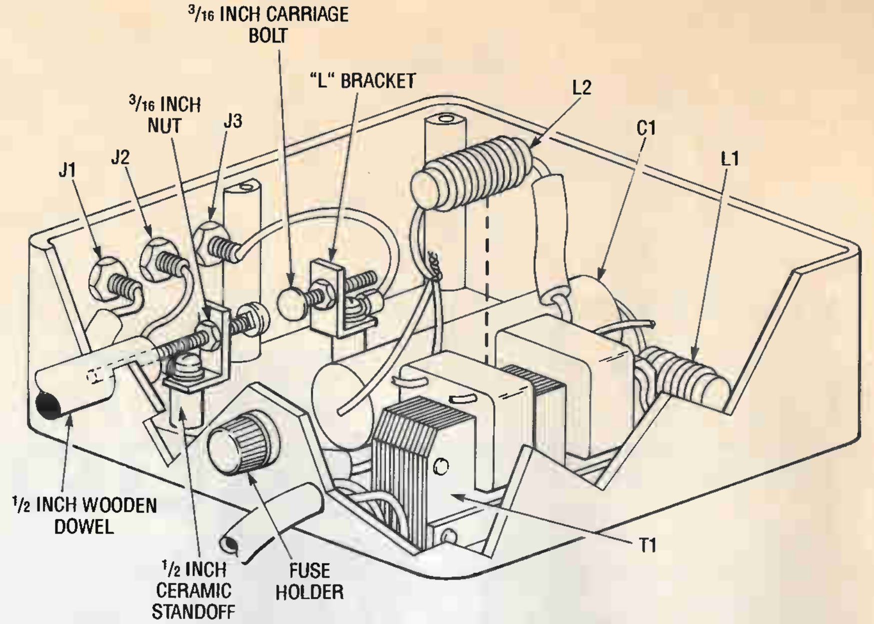


Fig. 3. The stationary spark gap is made from two 3⁄16-inch carriage bolts supported by "L" brackets mounted to spacers so that they face each other. One bolt is made stationary, while the other is made adjustable so as to vary the spark gap.

Stationary Spark Gap. The stationary gap can be made from two 3⁄16-inch carriage bolts (see Fig. 3). One bolt is stationary and the other one is adjustable so that it can be used to vary the spark gap. A ½-inch wooden dowel is attached to the bolt that is to be adjustable, allowing adjustments to the gap to be made from outside the project's enclosure.

The wooden dowel is very important; one does not want to adjust the gap by touching metal (or any other conductive device), since the gap is adjusted with the Tesla Coil in operation.

The bolts that form the spark gap are supported by two "L" brackets mounted to spacers so that they face each other (see Fig. 3). The stationary post of the spark gap is connected to J3, and the movable bolt is connected to J2.

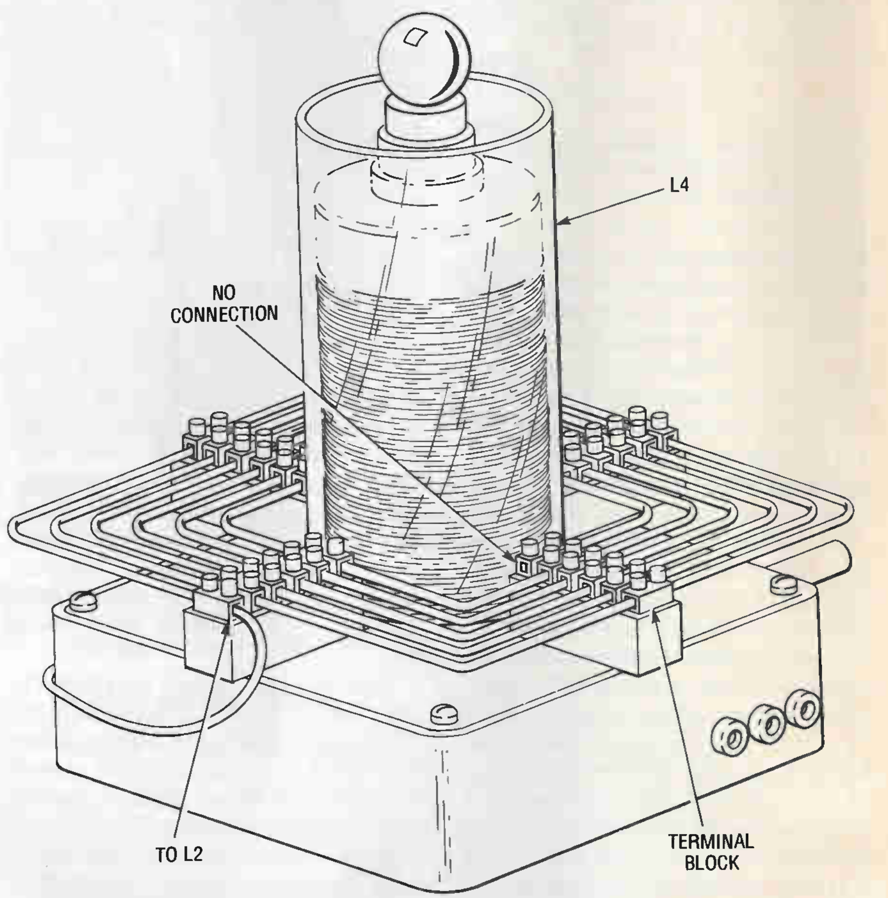


Fig. 4. The inner winding of L3 should have an area of about 6-inches square. When making the coil be careful that you do not form wire loops, instead of the continuous coil illustrated here.

Primary Coil. The original primary coil (L3) was made from 6 turns of #16 aluminum grounding wire in a pancake style winding. However, to give the unit a somewhat unusual look, the original (more-or-less round) primary coil was replaced with a square version made from heavier #10 aluminum grounding wire. The Coil was formed on four 6-position, twin-turnscrew type barrier blocks, which were mounted on four blocks of wood.

The wood blocks (with barrier blocks attached) were mounted to the top of the enclosure near the edges, and bus wire was then connected to the barrier blocks to form the coil. Note: The wires do not have to be fed through the barrier strips because of the twin-turnscrew arrangement. The wire can be cut to the proper size and screwed into the terminal strip to form the primary coil.

The inner dimensions of L3 should be about 6-inches square. When making the coil be careful that you do not form wire loops, instead of the continuous coil illustrated in Fig. 4. When you are finished with the coil, there should be one unoccupied screw terminal at the center and another at the outer rim of the coil. The unoccupied terminal at the outer rim of L3 is connected to ground via a wire that's brought out through a hole in the enclosure. The unoccupied terminal at the center of the coil is left floating.

The Secondary Coil. To fabricate the secondary coil (L4), the author wound about 348 turns of #24 magnet wire onto an 8½-inch length of 3½-inch diameter PVC tubing. That works out to be about 48 turns per inch, covering 7¼ inches on the PVC tubing.

The coil was wound by hand using a simple jig—which consists of little more than a stand for the wire and another for the coil form. When winding the secondary coil, try to keep the winding as even as possible without overlapping any turns.

After the coil has been wound, apply clear varnish or polystyrene (Q-DOPE) to hold the coil windings in place, and to help insulate the coil. Next drill a small hole in the center of the Tesla Coil enclosure lid, and thread the lower lead of L4 through the hole and connect it to the ground end of L3 (as shown in Fig. 1) and mount L4 in the center of L3 (see Fig. 4). The secondary coil is then secured in place with glue.

As an added measure of protection, you can also place clear plexiglass 4-inch OD (outside diameter) tubing over the secondary coil as a second layer of insulation. You might also seal the insulating tube and place mineral oil in it, thereby further increasing the tubing's insulating properties, but that's not necessary for this type of Tesla Coil.

The Output Sphere. The output sphere—a 1¼-inch steel ball on top of a plastic spacer—also serves as the top capacitance. An important point here is that the surface area represents the capacitance not the inner area of the

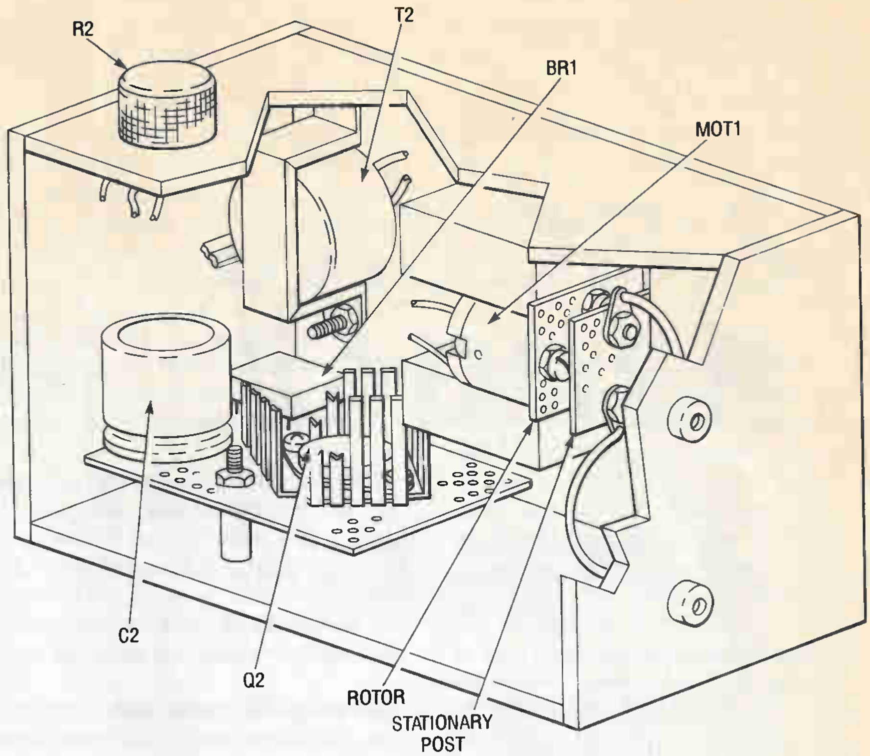


Fig. 5. The rotor of the rotary spark gap is made from a small perfboard square containing four #6 screws that are connected through bare bus wire. The stationary post consists of another perfboard square (of equal size), containing two #6 screws that are not tied together elecrically.

ball. It matters not if you use a solid ball or a hollow ball; they will both work equally well as long as their surface areas are equal.

The size of the sphere effects the secondary's resonant frequency, so if you use a larger sphere, it will be necessary to retune the primary coil for maximum output. A bigger sphere collects more energy, causing it to give off a higher output. So experimenting with the top capacitance is highly recommended.

The Rotary Gap. The rotary spark gap is not necessary to the operation of the Tesla Coil. So, if you do not wish to build the optional rotary gap, skip this section.

The rotor of the rotary spark gap is made from a small perfboard square on which four #6 screws are mounted and electrically connected through bare bus wire. The stationary post consist of another perfboard square (of equal size), containing two #6 screws that are not tied together electrically. The screws of the stationary post are instead taken out to J4 and J5. Perfboard is specified because the holes in perfboard make it easy to align the screws on the rotor with those on the stationary post.

The first step in building the rotary gap is to build and mount the electric motor support. In the author's prototype (see Fig. 5), the motor mount was made from small blocks of wood assembled in a "U" shape. A wooden mount is also used to secure the stationary wood post in place.

The distance between the rotor screws and the stationary post screws must be as small as possible without touching in order for the unit to function properly. After mounting the motor mount in the enclosure, place the motor in the mount and secure it in position with epoxy.

Next assemble the motor controller circuitry on a piece of perfboard, using Fig. 2 as a guide. Note that T2, R2, J4, and J5 aren't mounted to the perfboard, but instead are mounted to the rotary-gap enclosure. Once the controller board is assembled check your work for wiring errors. If all checks out, solder wires to the appropriate points on the board for connection to the off-board components. Set the board to the side for now; it will be installed in a moment.

Mount the off-board components on some convenient spot on the enclosure. Mount R2 so that you'll have easy access to its wiper. Jacks J4 and J5 can be mounted in any desirable loca-

SQUARE TESLA COIL

tion. Before mounting T2, make sure that the transformer leads are long enough to connect to the perfboard assembly.

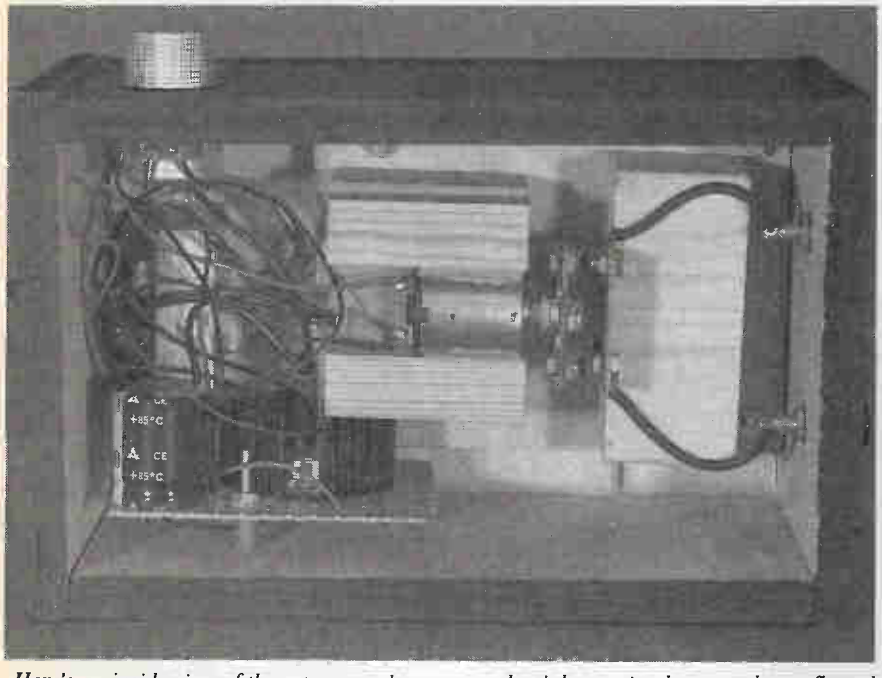
After mounting T2 in the enclosure, mount the perfboard assembly on the enclosure using standoffs, and then complete the wiring between the perfboard assembly and the off-board components. With that done, plug in the line cord and rotate the wiper of R2, making sure that as you do the motor speed increases and decreases. If the circuit does not operate as described, it will be necessary to recheck your work, correct any errors found, and try it again. If everything checks out, the rotary gap is complete.

Caution!!! The most important part of using the Tesla Coil is safety. Never tune (adjust the tap on L3) the Tesla Coil when power is applied to the circuit. grounded. You must use a 3-conductor AC power cord that is grounded (earth grounded) in the Tesla Coil itself. **Do not** touch the Tesla Coil while it's in operation. However if you want to show-off your creation, a fluorescent lamp may be placed near L4 to demonstrate the ionizing power of the Tesla Coil.

Only use properly rated components. Do not use an overrated power transformer. A 3-kV transformer with a 2-kV AC capacitor is out of the question. An overrated capacitor (for instance, a 6-kV AC unit) is fine in the circuit. Remember the capacitors are AC rated not DC rated.

The rotary gap will work well with this unit, but it may not work well with a larger unit. A larger unit will require that the rotary gap be redesigned. You must also protect your eyes: Do not stare at the stationary or rotary spark gaps; doing so can cause eye damage.

Operating the Tesla Coil. With the unit completely assembled, make sure



Here's an inside view of the rotary spark gap; note the tight spacing between the perfboard rotor and the stationary post. The wires coming from the stationary post are connected to J4 and J5, through which the rotary spark gap is connected to the Tesla Coil circuit.

Use a phenolic plastic box or a wooden box to house the Tesla Coil and the rotary gap—avoid metal enclosures like the plague. In addition, it is recommended that you use one hand *only* while working with high voltage, and wear rubber soled shoes to reduce the potential of shock hazard.

The power transformer, capacitor C1, and coils L3 and L4 must be properly

that all the components are properly installed and oriented. If you are using the stationary gap, start with a gap distance of about ¼-inch and tune L3 at any point on the third turn from ground. At that point turn the power on; you should get an output at the sphere. Adjust the spark gap for maximum output.

Tune L3 for maximum output, by changing the position of the alligator clip with the power off. Tuning L3 and adjusting the spark gap greatly effects the output of the Tesla Coil. If you place a grounded wire near the output sphere, you should get 3- to 4-inch sparks.

If you are using a rotary gap, make sure that the screws on the rotor and the screws on the stationary post are as close as possible. Remember, the speed of the motor effects the output, so adjust the motor speed with the variable power supply.

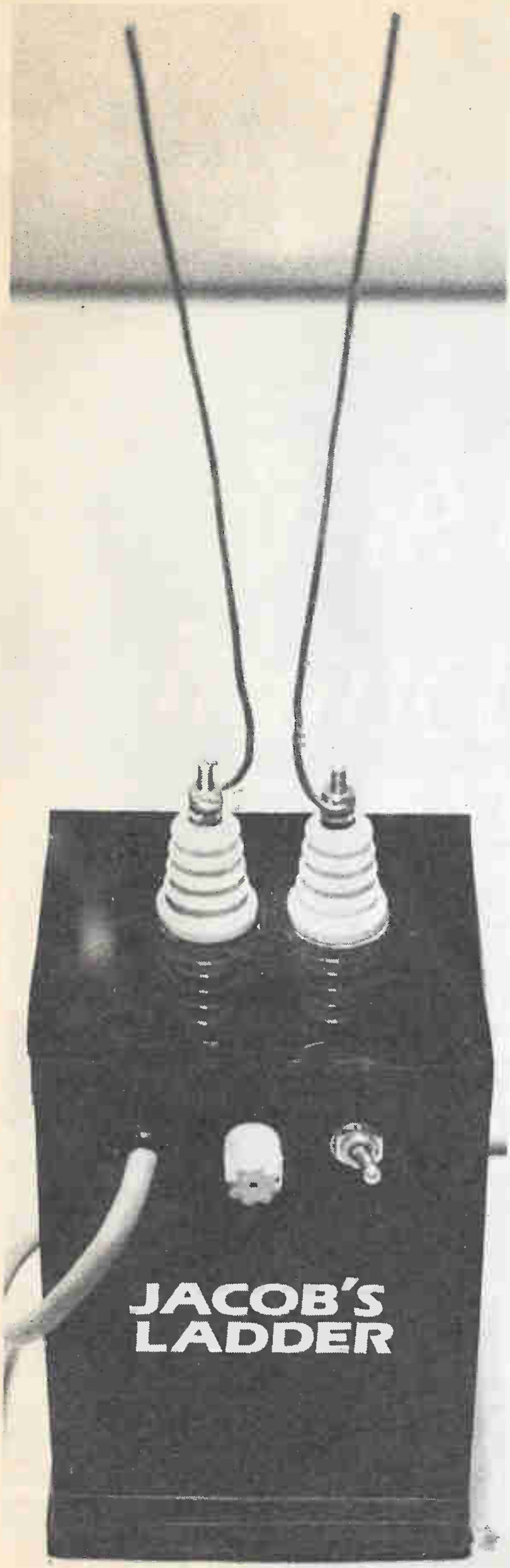
There should be no arcing anywhere. All arcing must be corrected or you'll burn out the turns in the secondary. If L3 is too close to L4, arcing can occur. You may place a 4-inch OD plexiglass tubing over the secondary coil to help prevent arcing between L3 and L4.

Be aware that corona discharge (a bluish-purple ionization, of the air around the Tesla Coil) can cause breakdown along the secondary coil, and loss of power at the output of the sphere. Proper insulation of L4 will limit corona discharge. You may also notice an output at the top of the secondary coil coming out of the sides. That will take away from the output at the sphere, you could place several layers of tape (Turn off the power first!) around the upper-portion of L4, until the output from the sides of the Tesla Coil is reduced.

In operation, the Tesla Coil emits ozone gas, which in large quantities can be dangerous. So use the Tesla Coil in a well ventilated room, and do not operate it for periods of more than 3 to 5 minutes at a time.

In addition, the Tesla Coil emits a fair amount of *R*adio-*F*requency *I*nterference (RFI). Coils L1 and L2 help to limit the amount of high-voltage kickback introduced to the AC power line, and help to prevent the high voltage kickback form damaging the power transformer. Even with such precautions, RFI will still be generated at the spark gap and the output of the Tesla Coil. RFI will effect both AM radio and television reception. That's why you should not operate your Tesla Coil for more than a few minutes.

The Tesla Coil is an excellent introduction to high-voltage, high-frequency, and tuned circuits. And after building this one, you may wish to build a larger unit. The author does not recommend building a larger unit until you've learned enough about such circuits, and the safety precautions that must be followed when using them. ■



JACOB'S LADDER

A climbing electric arc has held the imagination of science-fiction fans as the symbol for an eerie laboratory!

JAMES, NICOLE, and DWIGHT PATRICK, Jr.

IN MANY SCI-FI AND HORROR FLICKS, ESPECIALLY THE STOCK "FRANKENSTEIN" variety, along with weird sound effects and the like, movie producers always feature the fantastic visual effects produced by Tesla coils, van de Graaff generators, and Jacob's Ladders. Of those three devices, the Jacob's Ladder is the easiest to build. With a low-current neon-sign transformer, a converted flyback transformer, converted auto spark coil, or other similar transformer, you can whip together your own Jacob's Ladder in less than an hour. Because the ladder is so simple, there's no need for a detailed parts list or a schematic. We tell you how to build one as we reveal the theory of operation.

Getting started

As we can see in Fig. 1, a Jacob's Ladder provides a fantastic visual effect. A beautiful electric arc hisses its way up two diverging wires, providing a fascinating and downright scary effect. The arc starts at the smallest distance between the vee electrodes (Fig. 1-*a*), and "walks" up the widening gap toward the top of the electrodes (Fig. 1-*b*).

Why does the arc walk up the vee electrodes? You would expect that when the arc starts to jump across the narrow gap at the bottom of the electrodes, that it would stay there where the electrical resistance between the electrodes is lowest. What actually happens is that the arc heats the air it passes through, causing it to rise. Because the heated air is ionized by the high-voltage arc, it provides a very low-resistance path, so the current path (the arc) rises with the warm air.

Eventually the arc reaches the top of the ladder (the electrodes) and bows upward creating an electrical path that gets longer and longer. At the point where the resistance at the bottom of the electrodes is less than that of the arc-path, the upper arc stops, and a new arc begins at the bottom of the ladder. Thus, what is seen is a continuous climbing arc that disappears at the top of the ladder and reappears at the bottom. It's all a lot of fun to watch, providing that you don't poke your finger between the electrodes or get your nose too close.

To build a Jacob's Ladder, you need a high-voltage source that

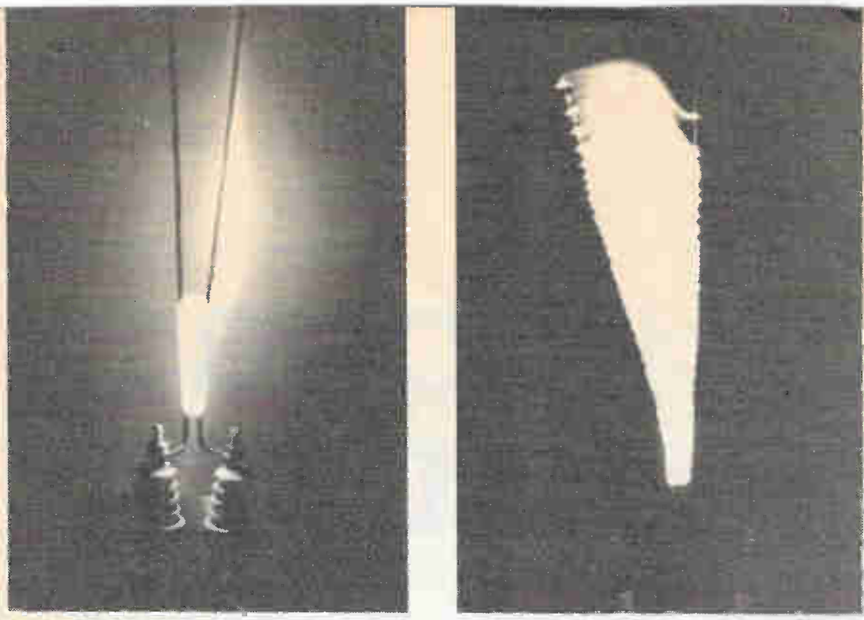


FIG. 1—HERE IS A TIME-EXPOSED PHOTOGRAPH showing the development of an arc at the bottom of the ladder as it climbs to the top. Display Jacob's Ladder in a darkened room for best viewing.

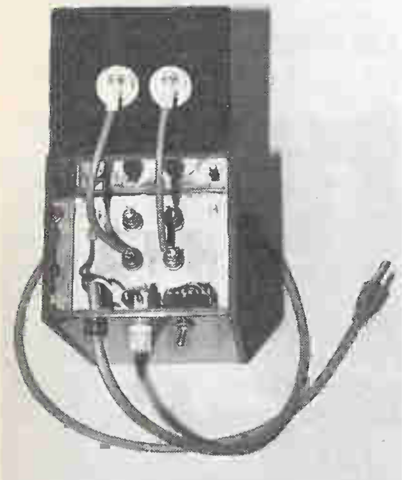


FIG. 2—NOTICE HOW NEAT THE WIRING IS. RTV cement is used around the high-voltage connection points. The line cord's third lead is used to ground the case.

can deliver around 10 kilovolts at 30 milliamperes or more—such as a neon-sign transformer or high-voltage power-supply transformer. The lower the current output, the less chance there is for building a fatal shock hazard. The higher the voltage, the larger the separation you'll be able to make at the top of the ladder's electrodes.

The high-voltage source should be placed in a well-insulated case or cabinet. If the case is metal, it should be adequately grounded. In the photograph in the opening of this article, a 7-kilovolt transformer was placed in a ¼-inch Plexiglas case with the primary winding connected via fuse and switch to the 117-volt AC input. The output of the transformer was connected via high-voltage TV anode hook-up wire to two pieces of no. 12 copper wire used for the vee-shaped electrodes that protrude from porcelain insulators. When removing the insulation, be sure not to nick the wire. The connections between the transformer's secondary and the bottom of the insulators must be kept as short as possible and void of sharp bends (see Fig. 2). Exposed high-voltage points were given a coat of RTV silicon rubber to prevent any arcing inside the enclosure.

Adjustment and operation

The last step in getting your Jacob's Ladder to work is the adjustment of the vee electrodes. DO NOT MAKE ANY ADJUSTMENTS WHEN THE UNIT IS TURNED ON. The unit should be turned off and unplugged when making adjustments, to prevent accidental electrical shocks.

The electrodes must be close enough at the bottom to establish the spark or arc-over, with the wires gently angling away from one another to form the "V." The initial distance at the base to start the spark will vary with the voltage applied, humidity, altitude, etc.; so, it's pretty much done by trial and error. Start with the wires at the base about an inch apart when using 10 kilovolts or more, and move them closer in small increments until an arc is established. But remember to kill the power before each adjustment.

When the distance is correct, the arc should start. On the other hand, if the ladder arcs at the initial setting, move the wires apart until an arc is just sustained. Placing the wires too close together will ruin the transformer over time. When you have established the arc, if it does not move up between the two diverging wires, they must be adjusted in or out.

Better safe than sorry

Once your Jacob's Ladder is up and running, a clear Plexiglas or acrylic cylinder around the entire unit will prevent the unthinkable from happening (see Fig. 3). The clear plastic housing should have vent holes at the top and bottom to allow heated gasses to escape, but not so large that the smallest child in the family can get his or her mitts or anything else inside. Generally, such cylinders can be purchased from most plastic-supply houses rather cheaply, and are well worth the added protection.

You do have to keep in mind that such high voltages are extremely dangerous, and you certainly don't want to come in contact with them. ■

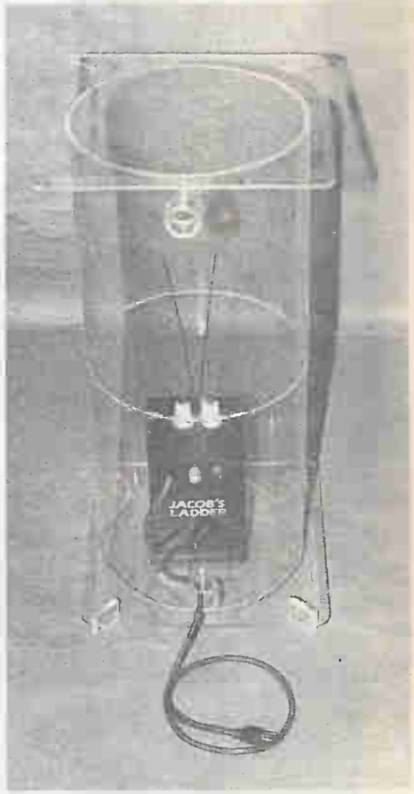
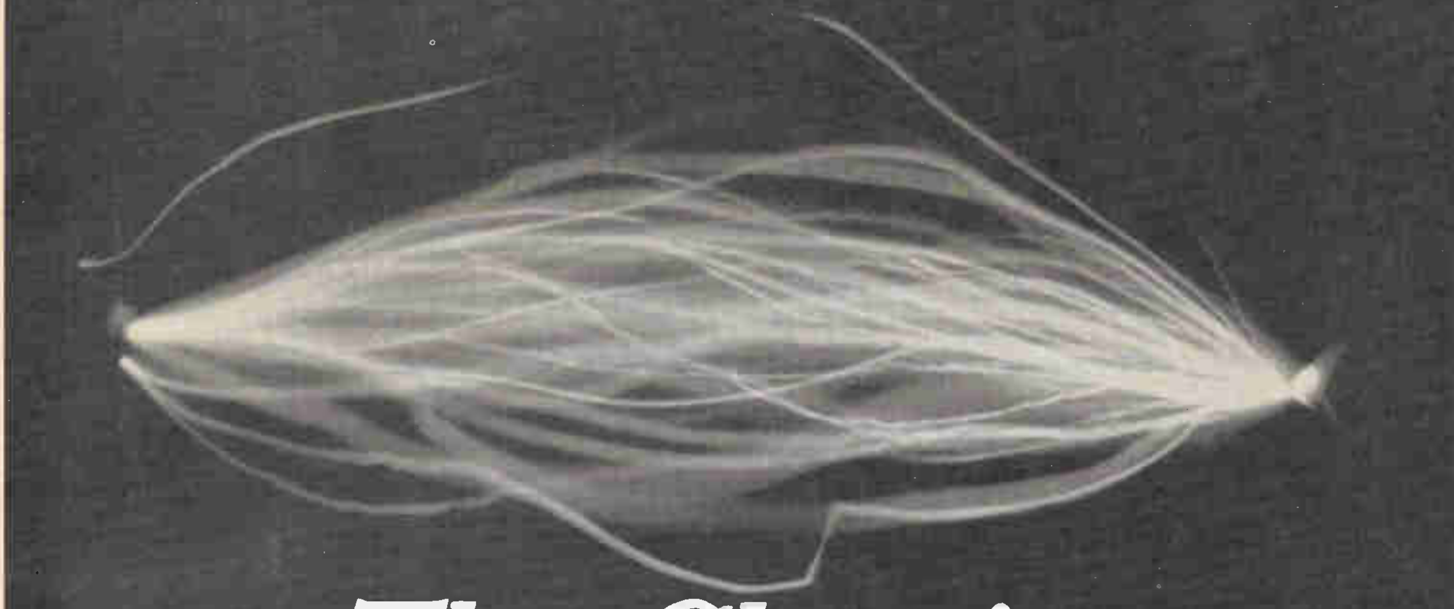


FIG. 3—A PLASTIC SHIELD SHOULD BE USED to prevent inquisitive people from accidentally touching the arc or the electrodes. Be sure to include a vent hole at the top and bottom of the shield so that gasses produced by the arc are allowed to escape.



The Classic Induction Coil

Learn the history behind the induction coil and the men that all invented it at once, and then have a little high voltage fun yourself.

BY STANLEY A. CZARNIK

The final quarter of the 19th century marked a period of extraordinary scientific activity. Excitement was everywhere. Creative intellects flourished as the theory of evolution matured, the camera innovated the study of the stars, and Freud contemplated the meaning of his dreams.

During that same period, important contributions in the area of experimental physics were made. For example, in the late 1800's, Heinrich Hertz produced the first radio waves, which provided a concrete illustration of Maxwell's theory of the identity of electromagnetism and light. In 1895, Wilhelm Roentgen stumbled upon the strange penetrating power of the X-ray. In 1896, Guglielmo Marconi filed a patent application for one of the first wireless-communication systems. And in 1897, Joseph John Thomson announced the discovery of the first subatomic particle: the electron.

WARNING!!
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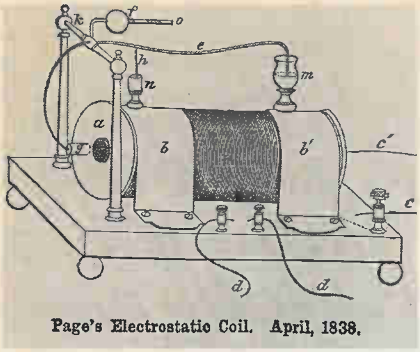
Of course, this list of discoveries in physics is selective and presented here to make a point. Every single innovation in the sequence would have been difficult, if not nearly impossible, were it not for a single piece of laboratory equipment: the high-voltage induction transformer.

Just how, when, and where the induction coil was invented are not easy questions to answer. In fact, the entire matter is submerged in a good measure of ambiguity and confusion. Let's try to disentangle some of the main historical threads.

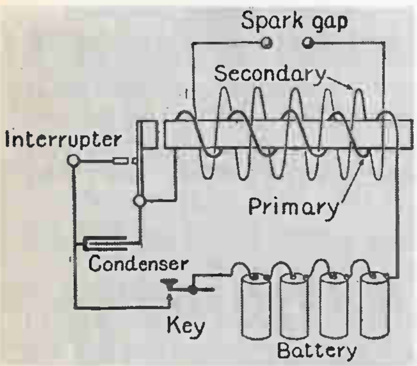
Callan's Magnet. In December, 1836, Nicholas J. Callan published a brief description of a "new Galvanic battery" in *The London and Edinburgh Philosophical Magazine.* At the



Charles Grafton Page was probably the first to construct a high-voltage induction transformer. Page followed his prototype with a long series of improvements. This "Electrostatic Coil" is one of them. The magnetic field around the core attracts the metal button at G. The motion is transmitted by the curved wire at E. The mercury cup contact point is at M.

time, Callan was a clergyman and physics teacher at Maynooth College, in County Kildare, near Dublin, Ireland. The battery consisted of 20 zinc plates, each about two feet square, and a similar number of large copper canisters to hold the acid. The system was activated by lowering the plates into the acid by means of a windlass. Callan's cells required about 30 gallons of acid. The battery was quite powerful and capable of melting thin pieces of platinum wire.

The generation of higher and higher levels of electrical energy seemed very important to Callan, and he proceeded to discuss an alternative way of doing it. He took a bar of soft iron, about 2 feet long, and wrapped it around with two lengths of copper wire, each about 200 feet long. For reasons left unmentioned, Callan connected the beginning of the first coil to the beginning of the second. Finally, he connected a battery, much smaller than the enormous contrivance just described, to the beginning and end of winding one. He found that when the battery contact was broken, a shock could be felt between the first terminal of the first coil and the second terminal of the second coil.



Most standard induction coils equipped with automatic Neef-type vibrator mechanisms operate in a similar way: When the interrupter contact points are closed, the battery current flows through the primary winding. That creates a magnetic field around the core which attracts the vibrator hammer thereby breaking the circuit. When the primary current is cut off, the points spring back and the circuit is re-established.

Further experimentation showed how the coil device could bring the shock from a small battery up to the strength level of a big battery. So, Callan tried making a bigger coil. With a battery of only 14 seven inch plates, the latter device produced power enough for an electric shock "so strong that a person who took it felt the effects of it for several days."

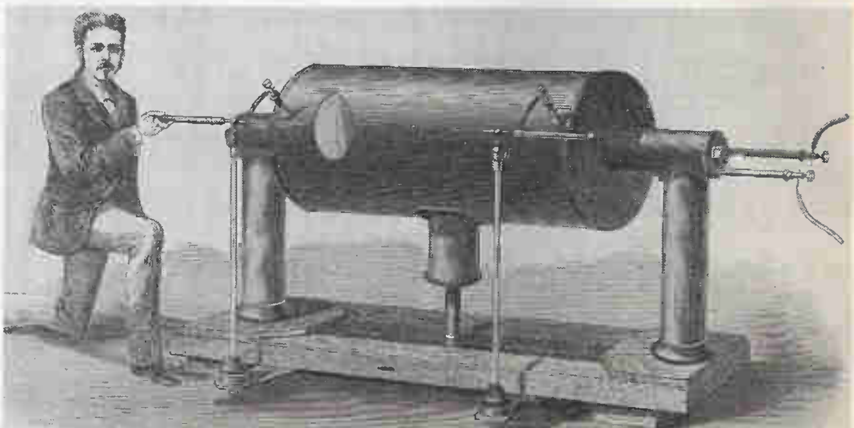
Callan thought of his creation as a kind of electromagnet; but, what he actually made was a primitive induction transformer.

The American Version. Callan was not the only one working with ways of increasing battery power by electromagnetic means. A few months earlier, a similar system had been built in Salem, Massachusetts by a young medical student with a tireless interest in electrical experimentation, Charles Grafton Page.

In a communication to *Silliman's Journal* dated May 12, 1836, Charles Page announced the construction of a device for "increasing shocks" in a new way. That new way involved taking the shocks from a secondary winding longer than the battery circuit. Recall that Callan's original coil was made with two windings of equal length. So, not only was Page's coil made public before Callan's apparatus, it was different. In *The History of Induction* (1867), the one book he wrote, Page described the novelty of his creation as follows: "the use of a longer coil for the secondary current than that used to transmit the battery current" and the production of "shocks from a purely secondary coil exterior to the primary coil."

Page's first inductive device was unlike most of his later models. The prototype was a 220-foot long spiral of copper ribbon mounted inside a wooden box. The coil was tapped in six different places with short copper strips connected to open mercury cups on top of the box. That allowed Page to experiment with "sub-spirals" of various lengths. But note: it's still one continuous winding of ribbon, not two. Page's retrospective claim to have used a "purely" secondary coil "exterior" to the primary is somewhat misleading. Strictly speaking, that's just not the case. Fact is, Page used a single winding with multiple taps; he had built, in effect, an autotransformer.

Simultaneous Invention. In August, 1836, using a coil a bit larger than the one just discussed, Page succeeded in producing not only an electric



This is one of the largest induction transformers ever made. The "Great Coil" of Spottiswoode (named after its creator William Spottiswoode) had a secondary circuit consisting of no less than 230 miles of cable and could generate power enough to throw a spark some 42 inches long.

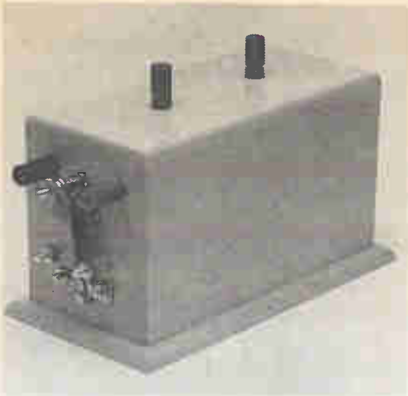
shock, but a very small electric spark between the terminals of a secondary winding. It seems clear that if just one person must be given credit for the invention of the *high voltage* induction coil, it should be Charles Page. Nonetheless, Nicholas Callan still deserves a measure of recognition; after all, he was working along similar lines with similar equipment in the same year.

In his personal history, Page himself notes that he was the first one, but not the only one, to generate an induced high voltage discharge in 1836. A spark, he mentioned, was also obtained by two Italian scientists, Antinori and Linari, and published in the December 13, 1836 issue of *L'Indicatore Sanese*. I have not been able to locate the original Italian reference. Yet, it is possible, even probable, that crude high voltage induction apparatus was being developed independently in not one, not two, but three different places—America, Ireland, and Italy—at almost exactly the same time.

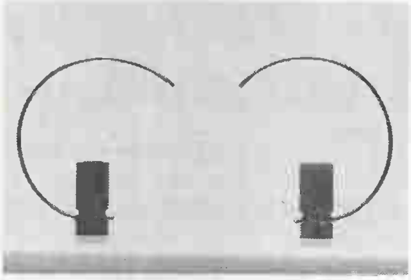
The Lightning Wheel. Page had been in touch with William Sturgeon, a well-known English experimenter and inventor, in 1825, of the first electromagnet. Sturgeon was also responsible for a science journal, *The Annals of Electricity*, and, published a reprint of Page's original article on increasing shocks in 1837. After that, interest in the new spark-producing machinery grew rapidly, and improvements were announced one after another.

One special problem presented itself immediately. The high-voltage impulse in the secondary winding appeared only when the primary circuit was opened or closed. So how to make and break the circuit in the most efficient way possible became a point of major concern. As it turned out, there were a lot of ideas on how to do it.

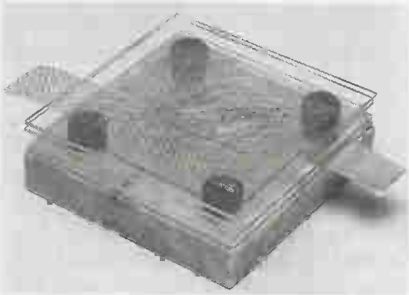
One very early suggestion came from Neef and Wagner of Frankfurt-am-Main, Germany. It was a copper disc, about 6 inches in diameter, equipped with 36 strips of wood inlaid with strips of metal attached to the disc. A flexible conductor made contact with the interleaved wooden and metal surfaces. When the brush hit metal, the circuit was closed; when it hit the wood, the circuit was broken.



The coil from Fisher is sealed in a rectangular wooden case and comes complete with an adjustable Neef-type hammer interrupter.



To test your coil, fashion a spark gap from two pieces of copper wire connected to the high-voltage output terminals on top of the case.



A miniature gaseous tube illuminator can be made with a piece of thin sheet metal, some wire gauze, and a few pieces of plain glass.

Neef, a physician, used the system for the creation of a rapid succession of presumably therapeutic electric shocks. He called his device the "lightning wheel."

The Hammer and the Wasp. The lightning wheel, as well as other similar devices, had to be operated by hand. Such manual contrivances were bothersome. What was necessary was some kind of automatic device.

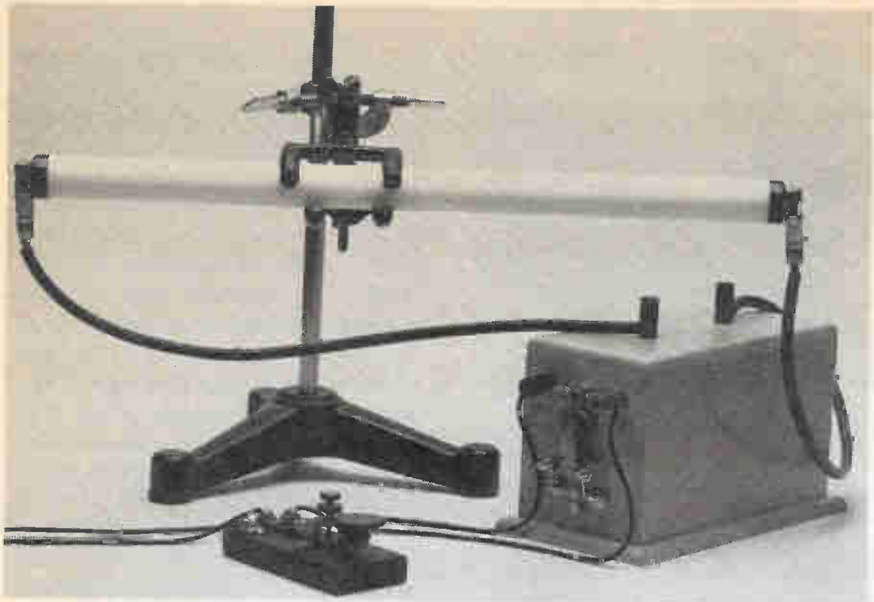
In September, 1837, McGauley, of Dublin, exhibited the first self-acting circuit breaker. McGauley attached a soft iron ball to one end of pivoted wire mounted over the induction apparatus. The ball was situated so as to be within the electromagnetic field produced by the core of the coil. The opposite end of the wire touched the surface of some mercury placed in a small cup. When the system was activated, the magnetic field near the core of the coil attracted the iron ball. That broke the contact at the surface of the mercury, shut down the magnetic field, and released the ball. When the wire at the other end fell back into the mercury, the cycle would begin again.

A very simple mechanism, but it worked quite well and suggested itself elsewhere. Charles Page, without knowledge of McGauley's experiments, came up with almost the exact same thing at just about the same time—yet another instance of simultaneous invention and parallel channels of thought. Page made the automatic circuit-breaker part of his famous "Electrostatic Coil" of 1838. According to A.F. Collins, writing in 1908, the so-called electrostatic machine was the most powerful coil in existence at the time.

The next important development came, once again, from Neef and Wagner in 1839. In short, the men replaced the mercury/cup arrangement with a vibrating metal strip and contact point and placed the entire sub-system at one end of the coil. The great advantage of the device is obvious: it eliminated the mercury.

It did not take long for Neef's simple system, or something very similar to it, to become one favorite method of making and breaking the primary circuit. Now, what to call it? One popular term was "rheotome" (current-slicer). Page liked "electrotome." Callan liked "repeater." Some preferred to honor the inventor with "Neef's hammer." There were regional variations too. In France, according to Becquerel, it was known as a "trembler" (*trembleur*). And of course, among English-speaking experimenters, "interrupter" and "vibrator" were destined to become standard references.

Credit for the most imaginative expression must certainly go to a certain English clergyman and amateur physicist, Reverend Lockey. Lockey noticed that the operation of a typ-



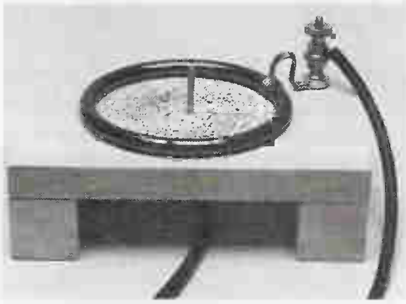
A high-voltage flasher can be easily made by connecting an ordinary 15-inch fluorescent tube to the output of the induction coil, and a telegraph key between your power supply and the input. The circuit makes a unique code-practice device or signaling system.

ical Neef-type device was accompanied by a kind of buzzing, "a constant bee-like hum," as he put it. Apparently, he thought that the name of the mechanism should recall the insect-like sound it made when it worked and suggested the term "galvanic wasp."

The Prize. There is one final chapter in the story of the mid-19th century induction coil. In 1802, following a long visit by Alessandro Volta, Napoleon Bonaparte announced the establishment of a 60,000-franc prize to be given to the creator of the most useful application of the voltaic battery. The Volta Prize was awarded to Humphrey Davy in 1806. It was not awarded again for over fifty years. Following a revival of the competition by Napoleon III, the prize was given to Heinrich D. Ruhmkorff in 1864 for the invention of the induction coil.

Yes, the invention of the induction coil. Heinrich Ruhmkorff did not invent the induction coil; there is no doubt about that. So why, then, was he given the prize? Why not Charles Page? The reasons are very complex and, to this day, not entirely clear.

In 1853, Armand Fizeau, a French physicist, discovered a way of greatly improving the performance of induction coils: the connection of a capacitor parallel to the breaker points of the vibrator. That simple addition had the effect of reducing unwanted discharge at the vibrator points and increasing the intensity of the secondary spark. Ruhmkorff, who had been building induction apparatus at his Parisian workshop since 1851, incorporated Fizeau's modification immediately. It was a good move at a good time. As Page himself said in 1867, Fizeau's contribution to the Ruhmkorff coil "at once gave it a celebrity which, perhaps, it might otherwise not have attained."



This simple device creates a rotating circle of sparks between the central electrode and the inside edge of the metal ring. Note that the input cables are kept at least 3 or 4 inches apart.

A Case of Indifference. There is a wider issue implicated here, an issue involving the sociology of scientific activity. Recall for a moment the period: the middle of the 19th century, almost 150 years ago. At the time, almost none of the major discoveries in the physics of electricity were being made in America; and, perhaps more important, none were really expected. Now, think of the situation on the opposite side of the Atlantic. It could not have been more different. From Galvani to Volta, to Davy, to Oersted, to Ohm, Ampere, Faraday and beyond—everything, but everything, was coming from Europe. So, it must have been only natural to believe that the trend would continue, and in many ways, it did.

Charles Page (much, in fact, like Joseph Henry) was the victim of a notorious indifference to American science by 19th century European philosophers. When Ruhmkorff was recognized and rewarded for the invention of the induction coil, it is likely that the French officials involved had never even heard of the experimenter from Massachusetts. As Salem Howe Wales of *Scientific American* phrased it, the episode was yet another "oversight of American achievements by European savants already too common." The real inventor of the induction coil was not ignored; he was unknown.

A Spark Coil For Your Home Lab. A good electromechanical induction coil is still one of the most versatile and

Further Reading

The History of Induction, Charles Page, Intelligencer Printing, Washington, 1867.

"Description of a Large Induction Coil," William Spottiswoode, *The Philosophical Magazine*, Volume 3 (January 1877), pp. 30–34.

Induction Coils, H.S. Norrie, Spon & Chamberlain, New York, 1901

Experimental Science, George Hopkins, Munn, New York, 1902

Design and Construction of Induction Coils, A. Frederick Collins, Munn, New York, 1908

"The Induction Coil," George Shiers, *Scientific American*, Volume 224 (May 1971): pp. 80-87

Physics, Patents, and Politics: A Biography of Charles Page, Robert C. Post, Science History, New York, 1976.

Note: The books by Norrie, Hopkins, and Collins are currently available in paperback editions from Lindsay Publications (P.O. Box 12, Bradley, Illinois 60915-0012; Tel. 1-815-468-3668). Call them for price and shipping information.

enjoyable high-voltage devices you can possess. An excellent example designed along classical lines is currently available from Fisher Scientific, a laboratory supply company in Chicago (see the Parts and Materials List for more information).

The coil is sealed in a rectangular wooden case (about 8 × 5 × 4 inches) and comes complete with an adjustable Neef-type hammer interrupter. The unit is made to operate with a DC input of about 6 to 10 volts at between 0.5 and 3.5 amps depending on input voltage and adjustment of the breaker points on the hammer. The input terminals are next to the vibrator and the high-voltage output posts are on top—just as they were on the classical induction transformers of the 19th century. The unit delivers a strong spark at least 1 inch long and power enough for most of the standard high-voltage projects and demonstrations.

You will, of course also need a power supply. Anything that can supply the required voltage and current will work, but one with a continuously variable output between 6 and 12 volts is recommended.

Assuming that you have gathered some of the things listed in the Parts and Materials List, let's discuss some experiments you can perform. Keep in mind that these demonstrations, generate a certain amount of ozone; so you'll want to perform all of your experiments in a well-ventilated room.

Testing and Operation. The most obvious thing to do with a spark coil is make a spark. For that, obtain two pieces of bare copper wire each about 3 inches long. Do not use covered wire; the insulation may get hot and melt. Bend each of the pieces into a semi-circle and connect them to the high-voltage terminals. The idea is to keep the two wires as far away from each other except where they form the spark gap somewhere above and between the binding posts. To begin with, make the spark gap about 1 inch across. Make sure the wires are fastened down tight.

Now, look at the vibrator mechanism. You will see a large knurled nut; that is the breaker-point adjustment control. Screw the nut in or out until the points are just barely touching. Finally, note polarity as indicated (by color) at the input terminals of the coil and hook up your low voltage DC power supply.

If necessary, set the supply between 6 and 12-volts. Turning on the supply should cause the coil to produce a strong 1 inch spark. If it doesn't, turn the power off and loosen or tighten the control nut slightly. Make your adjustments conservative, a quarter turn, perhaps; the operational range is not very large. **Do not attempt to touch the vibrator or adjust the points when the unit is in operation.**

Once you get a spark, turn off the coil and make the spark gap about 1/4 inch larger. Then turn on the power and check for a spark. If you have an adjustable supply, raise the input voltage a bit if necessary, but don't overdo it. You can also try readjusting the vibrator. Repeat the procedure until the gap is too wide for a spark to pass. That is one simple way to determine the maximum output of your coil.

When everything is just right, the system will deliver a thin, intermittent, lightning-like spark close to 2 inches long. These long sparks are best observed in a dark room.

Gaseous Tube Illuminator. There are many, many things you can do with your induction coil. With some scrap metal and a few pieces of glass you can make a miniature gaseous-tube illuminator.

Obtain four plates of clear glass about 4 inches square. Such glass plates are standard science items and can be ordered from a supplier mentioned in the Parts and Materials List. You'll also need some clean wire screen and a piece of very thin sheet metal (like brass or aluminum). The metal sheets you select should be thin enough to permit easy shaping with scissors.

Cut the metal sheet to form a rectangle about 2½ inches wide and 4½ inches long. Then, fashion a tab at one narrow end of the rectangle. Now, cut a piece of wire screen to match the size and shape of the metal sheet. The metal sheet and wire screen will be used as electrodes.

You're now ready to build the illuminator. Place the metal-sheet electrode between two of the glass plates. Place the wire-screen electrode between the other two. Rest the sheet-metal sandwich on some sort of insulating material, like a 4 × 4 inch block of wood. Now place a few small neon bulbs on the glass surface over the metal sheet. Then, add four rubber spacers, one at each corner of the glass. Finish by placing the wire mesh arrangement carefully over the

MATERIALS LIST FOR EXPERIMENTS

NOTE: Prices listed may have changed.

6–12-volt, 0.5–3.5-amp DC power supply
Copper wire
15-inch fluorescent tube
Four 4 × 4 inch glass plates
Induction coil
Iron filings
Large binding post or Fahnestock clip
Miniature mercury-vapor bulbs
NE-2 neon bulbs
Salt shaker
Sheet aluminum or brass, 4½ × 2½ inches
Spark-plug wire (or equivalent)
Steel ring
Telegraph key
Threaded rod (or long narrow screw)
Wire screen 4½ × 2½ inches
1 piece of wood, 7½ × 5¾ × ¾ inches
2 pieces of wood, 5½ × 1½ × 1½ inches

Note: The high-voltage induction coil is available from Fisher Scientific EMD (4901 W. LeMoyne, Chicago, IL 60651; Tel. 1-800-621-4769 or 1-312-378-7770) as part number S-43525 for $121.10. Shipping rates vary from place to place so call them for an estimate. Illinois residents will need to add the appropriate sales tax.

The following items are available from American Science and Surplus (601 Linden Place, Evanston, IL 60202; Tel. 1-708-475-8440): 4¾ inches O.D. steel rings, part number 20247 at $2.50 for a package of two; green mercury vapor glow lamps part number 3628 at $2.25 for a package of three. The company requires a $12.50 minimum order and a flat $4.00 fee for shipping and handling. Illinois residents will need to add the appropriate sales tax. Their catalog is 50 cents.

Clean 4 × 4 inch glass plates are available from Hagenow Laboratories (1302 Washington St., Manitowoc, WI 54220) as part number 67C for 49 cents each. The company requires a $15.00 minimum order. Their catalog is $1.50. WI residents must add sales tax.

bulbs; the lower glass plate should rest on the spacers. The tabs on the metal sheet and the wire screen should be pointing away from one another.

Connect one high-voltage output terminal on the induction coil to the sheet-metal tab, and the remaining terminal to the screen's tab. Spark-plug wire is probably the best kind of wire to use; but any sort of heavy, well-insulated hook-up cable will work. Finally, darken the room and turn on the power. A high voltage electric field is created in the space between the plates that causes the neon tubes to flicker and glow like so many little lightning bugs.

You may observe a few stray sparks passing over and around the edges of the glass plates. A very careful re-arrangement of the electrodes (with the power off, of course) will probably solve the problem. If it does not, try using smaller electrodes, larger pieces of glass, or a lower power-supply setting.

For an unusual multicolor effect, try replacing a few of the neons with small mercury-vapor lamps. The type I used were also used in the Electronic Novelty Light featured in the December 1990 issue of this magazine. See the Parts and Materials List for more information.

Fluorescent Flasher. If you enjoy working with gaseous conductors, here's something else you can try. Obtain a good quality telegraph key (or some other kind of momentary-contact switch) and hook it up in series between one output terminal of your power supply and one input terminal of the induction coil. Now, locate an ordinary 15-inch fluorescent tube and connect it directly to the high-voltage output with some spark-plug wire and a couple of alligator clips. To keep the whole contrivance steady and safe, the fluorescent tube should be elevated up and away from the rest of the equipment with a stand of some sort. For such temporary projects, standard laboratory hardware comes in very handy.

With the power supply on, each press of the key will activate the coil and flash the lamp. The circuit makes a unique code practice device or signaling system. For a still better effect, try using a green fluorescent tube in place of the conventional white variety. Such tubes are often sold as replacement parts for photocopying machines.

The Spark Ring. Here's a device which will enable you to create an infinite variety of randomly rotating sparks. The visual effect resembles a wagon wheel spinning under a strobe light. Frozen with a photographic time-exposure, it resembles some sort of weird electric snowflake.

The simplicity of the spark ring allows for a number of equally suitable construction methods; but, here's one easy way of doing it: To begin, you'll need some wood—one piece about 7½ × 5½ × ¾ inches and two pieces 5½ × 1½ inches square. Locate the exact center of the larger piece and drill a hole just big enough to accommodate a long screw or length of threaded rod. The screw should extend at least ½ inch beyond the upper surface of the wood and no more than 1 inch below the lower surface. Drill another hole (somewhere near the upper right hand corner is a good place) for a large binding post or Fahnestock clip. Set the piece aside for now.

Now for the key component: a perfectly circular ring of metal about 4 or 5 inches in diameter. You may very well have something like that in your collection of building materials. If not, just make a loop from some thick wire, metal tubing, or a long metal strip by wrapping it around a large round bottle. Or, you can get something ready made. What I did was obtain a big steel ring from American Science and Surplus (see Parts and Materials List). It's the perfect size and shape. Also, it's heavy enough to stay in one place without the need for additional hardware.

Once you have your metal ring, you'll need to furnish it with a piece of flexible conductor for attachment to the binding post. I used some braided copper grounding cable, but a short length of stranded wire will do just as well. If possible, solder the wire to the metal ring. Do not use too much wire to make the connection, otherwise the metal ring may not lie flat on the wood. Then set the whole construction on the two remaining pieces of wood.

Cut two 15- or 20-inch pieces of spark-plug cable and furnish one of them with a large alligator clip. Connect the clip to the threaded-rod electrode beneath the lower surface of the wood. Connect the other wire to the binding post. Then connect the apparatus to the high-voltage output of the induction coil.

Finally, obtain some powdered iron and place about a tablespoon of it in an old salt shaker. Now, very carefully, sprinkle some of the metal onto the surface of the wood inside the perimeter of the metal ring. Try to distribute the iron as evenly as possible, but do not use too much of it.

When everything is ready, darken the room and turn on the coil. The entire area inside the ring will light up with hundreds of tiny sparks created by the gaps between the particles of iron. If you are not satisfied with the effect at first, just turn the apparatus off, remove the iron particles with a magnet, and try again. Every application of iron will create a slightly different pattern of tiny sparks. The designs bear an interesting resemblance to the Lichtenberg figures discussed in an early article (March 1990).

Do not feel limited to the use of powdered iron. Any low resistance material reduced to the appropriate size will also work; but the effect will be different. You can try tiny bits of stranded copper wire, metal foil, or even a small handful of miniature nuts and bolts. However, do not, under any circumstances, use an easily combustible metallic substance, like powdered magnesium, powdered aluminum, or zinc dust. They are very, very dangerous.

Also, keep in mind that the apparatus does create some heat in the central electrode and metal ring. So, do not run the equipment for extended periods of time and watch carefully for anything suspicious or unusual, like over-active sparks or scorched wood.

Learning More. For more on the history of induction apparatus, see George Shiers' May 1971 article in *Scientific American* and Robert Post's biography of Charles Page. For more experimental ideas, see Volume II, Chapter 2 of George Hopkins' *Experimental Science* and Chapter 5 of H.S. Norrie's *Induction Coils*. For additional information, consult the section entitled "Further Reading." ■

ELECTRONIC DAZER

Never walk in fear with this one-evening project. It won't kill, but it's an effective way to say "Leave me alone!"

By Rick Duker

□THE *ELECTRONIC DAZER* IS A MODERN, PORTABLE, PERSONAL-protection appliance. It generates high potential energy to ward off vicious animals or other attackers. It is an aid to help escape from a potentially dangerous situation. The device develops about 2,000 volts. Higher voltages may be attained by adding additional multiplier stages, but it should be noted that those stages will also increase the overall size of the unit.

The Dazer is very compact, being built into a small plastic case. It is powered a single nine-volt battery, either NiCad or alkaline. The high voltage is applied to two electrodes which require only light contact to be effective. When touched with the Dazer, the victim will receive a stunning, but non-lethal jolt of electricity that will usually discourage any further encounters.

The Electronic Dazer is a power supply which consists of a micro-size regenerative amplifier/oscillator coupled to an energy multiplier section. It should not be confused with cheap induction-type cattle prods. The Dazer is more versatile than other high-voltage stun devices currently being sold. Those devices are basically high-voltage, AC generators which jam the nervous system. However, the Dazer may be used for heating and burning applications, or anywhere a high voltage DC supply is required.

WARNING

THIS DEVICE IS NOT A TOY. We present it for educational and experimental purposes only. The circuit develops about 2000 volts at a respectable amperage. It can cause you pain and even damage if you become careless and touch its output terminals. The unit can also damage property as well so use it wisely.

You should never use the device on another person! It may not be against the law to possess such a device in your area, but if you use it on someone you may be deemed liable in a civil and/or criminal action suit. Don't just follow the golden rule after constructing the project, instead just don't do unto anyone.

Included in the article are a number of instructions on how to build, test, and operate the Dazer; all of them must be followed to the letter. Do not deviate from the procedure.

How It Works

Referring to the schematic diagram in Fig. 1, the two power transistors Q1 and Q2, form a regenerative amplifier operating as a power oscillator. When Q1 turns on, Q2 turns on and that shorts the power supply across the primary of T1. That current pulse induces a high voltage in the secondary of T1. As C1 charges, Q1 turns on again and the cycle repeats itself. Therefore, a rapid series of DC pulses are generated and stepped up by T1 to approximately 300 volts at full battery charge. That voltage is rectified and increased by the voltage multiplier section which consists of C2 and C9, and D1 to D8. The final output is approximately 2000 volts. The neon bulb NE1 is used as a charge indicator and indicates that the unit is charged and operating properly.

Construction

As with all projects start out by laying out and identifying. If you do not wish to make a printed-circuit board, then you

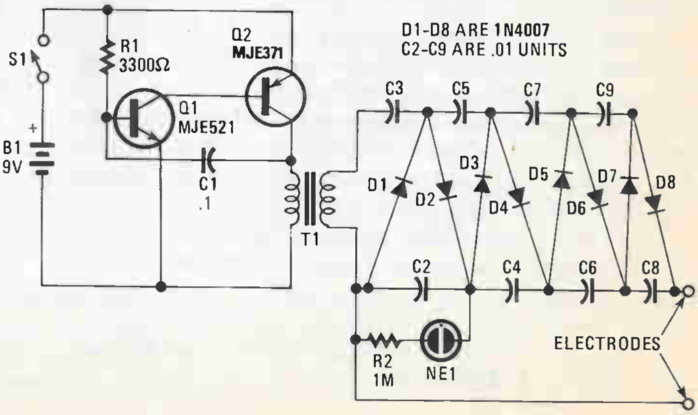


Fig. 1—As you can see, although the Dazer is not complex, it contains enough doubler circuitry to pack quite a punch. The oscillator does nothing more than send sharp current pulses through T1. The back EMF across the secondary winding is then pumped through the multiplier stage to produce the very-high output voltage across the electrodes.

may use a perf board as long as you remember to keep the leads of all high-voltage components isolated. That is to prevent sparks from arcing across your board. A 4 x 7.5 cm perfboard is suitable for that purpose.

The first components you should mount are the two transistors Q1, Q2, transformer T1, resistor R1, and neon bulb NE1. Solder them in place (for PC construction) being sure that the transformer and transistors are hooked up correctly. Apply a small amount of adhesive to the base of NE1 to hold it securely in place.

Mount D1 to D8 and C2 to C9 on the board and make all solder connections. Note proper polarity of the diodes. The off-board components come next. Solder in leads for S1, and the output electrodes. Also solder in the battery clip for B1.

Build the enclosure from some nonconductive material such as plastic. Drill holes for S1, NE1, and output electrodes. Be sure that the output electrodes are about a cm or greater apart. Connect the output wires to the electrodes and insert them through holes from inside of case. Thread on the retaining nuts and tighten them securely. Set the circuit board in the case and mount S1, securing it with a nut. That completes the construction.

PARTS LIST FOR THE ELECTRONIC DAZER

C1—0.1-µF monocapacitor
C2–C9—0.01-µF 400 volt polyester capacitors
D1–D8—1N4007 1-kVolt diode
NE1—Type NE-2 neon bulb
Q1—MJE521 NPN power transistor
Q2—MJE371 PNP power transistor
R1—3,300-ohm ¼-watt resistor
R2—1,000,000-ohm ¼-watt resistor
S1—SPST monetary-contact, pushbutton switch T1—1200 to 8-ohm audio power transformer

ADDITIONAL PARTS AND MATERIALS

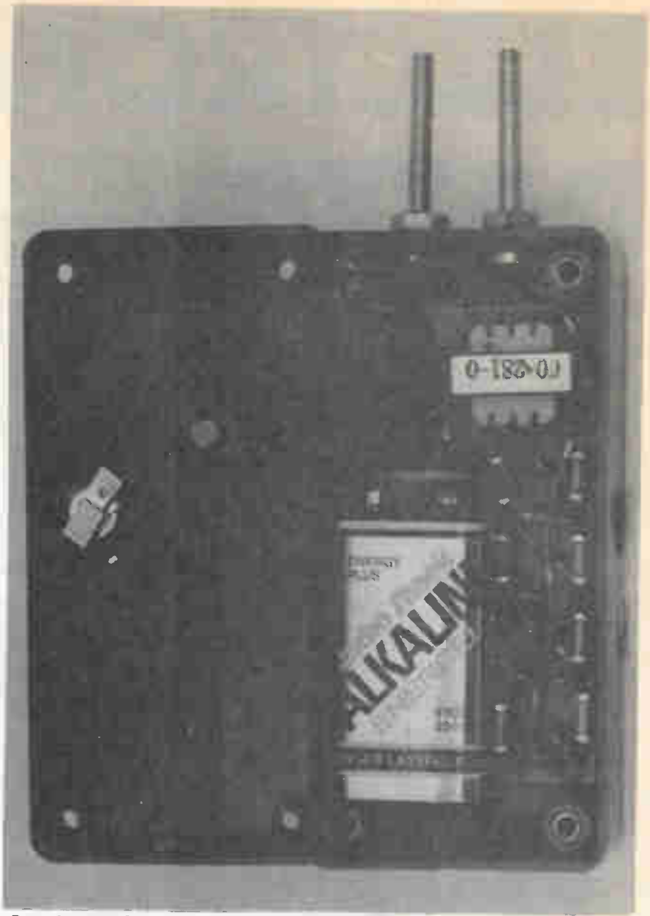
9-volt battery clip, 10 × 5 × 2.5-cm plastic case, 7.5 × 4-cm perfboard or PC board, two 8⁄32 × 1-¼ bolts and nuts for electrodes, adhesive for mounting NE1, circuit board standoffs (optional), hookup wire, solder, etc.

The following are available from Quantum Research, 17919-77th Avenue, Edmonton, Alberta, Canada T5T 2S1:
QV100K1—Complete kit without PCB (includes all above parts except those following the electrodes in the above list)—write for price.
QV100K2—Complete kit with PCB (includes all above parts except those following the electrodes in the above list)—write for price.

Testing

Before inserting the battery and closing the case, a few test measurements should be made to ensure correct operation. With the ground clip connected to the battery, connect a VOM between the positive clip and the positive terminal of the battery. Set the meter for current reading, and press S1. You should measure a current of approximately 300 to 500 mA. NE1 should be glowing.

With a high voltage VOM, you should measure about 2000 volts on the output terminals. Those measurements indicate proper circuit operation. Let the unit run for about one minute. Transistors Q1 and Q2 should be warm, but not hot to the touch. Insert the battery in the holder and close the case. That wraps up the Electronic Dazer.



Good parts layout is the secret to any miniature project. If your layout causes the battery to come too close to the high-voltage components we suggest you insulate it with tape.

Operation and Use

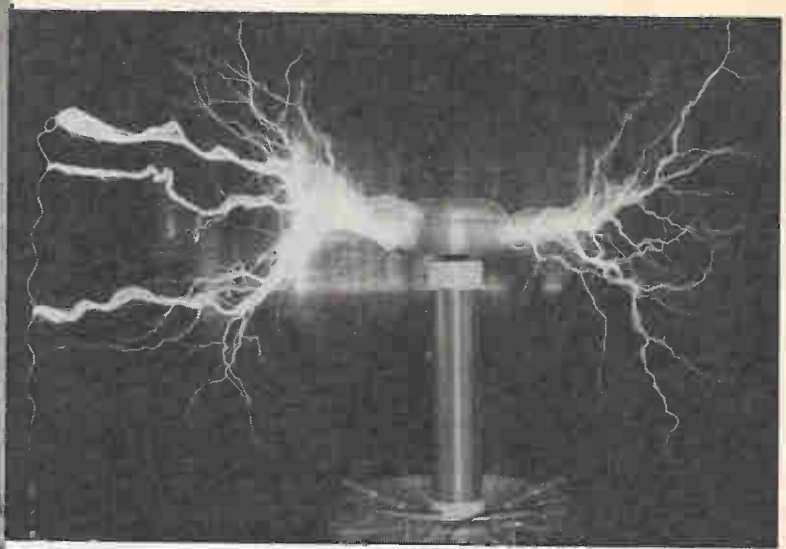
Activate the unit by pressing S1. NE1 will light indicating the dazer is fully charged and ready to use. Notice also that only one pole of NE1 will glow indicating DC voltage present. It is important to remember that the device holds a charge even after S1 is off. To discharge, touch the electrodes to a metal object and note the healthy spark discharge.

The Electronic Dazer was designed as a self-defense weapon for use against vicious dogs or other attacking animals. The device is most effective when the electrodes contact an area of low resistance such as skin or flesh. Those include the snout or mouth since the resistance of those areas are much lower than areas of hair or fur. The electrodes could be pointed to penetrate these areas better. The dazer generates great stopping power. One contact will give a powerful jolt and should discourage any further attacks.

The device can burn and heat materials with low resistance. Those include flesh, moistened paper or wood, etc. That makes the unit potentially hazardous to humans. Remember, the dazer is not a toy but a quality electrical appliance and therefore must be treated accordingly. Use the utmost discretion with this device.

Another use for this device is as a high-voltage DC power supply. It may be constructed as a variable power supply if output taps are taken from various stages of the voltage multiplier section. Remember, always disconnect the battery and fully discharge the capacitors before working with the circuitry. ■

Build capacitors that really pack a punch for high voltage fun!



BY ANTHONY CHARLTON

MAKE YOUR OWN HIGH-VOLTAGE CAPACITORS

As one who supplies parts to those who experiment with high voltage, I get a lot of letters and phone calls from frustrated builders that go like: "Can you supply an inexpensive XXX microfarad capacitor at a working voltage of YYY? My only source wants $249 for one." Sometimes, a high price is justified; other times, a seller has the only capacitors of a special value available, and will soak you for the maximum dollar.

It is feasible to build your own capacitors of any voltage and energy storage size for either AC or DC use. The process involves a step-by-step logical approach that we'll present here. We'll explain how to plan and construct a capacitor, where to get materials, safety considerations, tips and hints, and include a few simple projects.

A Capacitor's Description. A capacitor consists of two or more plates of a conductive material separated by an insulating substance called a dielectric. A dielectric may be solid, gel, liquid, or gas. A capacitor's ability to store energy is measured in either microfarads (μF), nanofarads (nF), or picofarads (pF). Micro means one millionth, nano stands for one billionth, and pico for one trillionth (farads are also used, but in high voltage work they are impractically large units). Several factors affect capacitance. The formula for determining capacitance is:

$$C = (0.224KA/d)(n-1)$$

where C is the capacitance in picofarads, K is a constant that depends on the insulator (or dielectric) between the plates (called the dielectric constant), A is the area of one conductive plate in square inches, d is the separation between adjacent plates in inches, and n is the number of plates. As you may know, different insulators have different dielectric constants. Table 1 shows the values of K for some common materials and the peak voltage they can withstand per $\frac{1}{1000_{th}}$ inch (called a mil) of thickness. This rating is called the puncture or breakdown voltage.

WARNING!! This article deals with and involves subject matter and the use of materials and substances that may be hazardous to health and life. Do not attempt to implement or use the information contained herein unless you are experienced and skilled with respect to such subject matter, materials, and substances. Neither the publisher nor the author make any representations as for the completeness or the accuracy of the information contained herein and disclaim any liability for damages or injuries, whether caused by or arising from the lack of completeness, inaccuracies of the information, misinterpretations of the directions, misapplication of the information or otherwise.

Dielectrics. The better the insulating property of the dielectric, the higher its resistance, and the less dielectric leakage loss present. In low current, high voltage power supplies, minimizing all sources of loss is important to prevent undue power-supply loading. For that reason, plastics are by far the best materials for large capacitors. A serious project should involve one of the plastics.

Lexan, Polystyrene, and Plexiglas in particular are easy to glue, and can be cut with a table saw using a plastics blade, or a carborundum impregnated all-purpose cutting blade like *Zippity-Do* (which is cheaper). A sabre saw with a really coarse wood blade will also work (other blade types clog or chip). Such plastics may be drilled with high quality steel drill bits or special plastic bits. They must be drilled at 300 RPM or slower to prevent chipping and melting, and be sure to leave the protective film or paper on the plastic when working with it.

Mylar, Polyethylene, Nylon, and especially Teflon are difficult to work with as they are very slippery. The best way to attach plates to any of those materials is to use a glue specifically designed for the material. Polyvinyl chloride (or just PVC) is moderately slippery. It can be glued with a PVC cement, or foil plates can be attached using silicone RTV.

Glass is, in principle, an even better dielectric. It also has the advantage of being easy to glue to with Silicone RTV or *Krazy Glue*, and it is readily available and cheap. However, it is fragile, and may contain impurities that allow conductive paths for destructive arcs. Contradictorily, for your first capacitor or two, we suggest that you try a type made with glass to gain experience, since they go together easily and are cheap.

Many industrial capacitors are oil filled. Oil has an extremely high resistance, so it does not measurably increase leakage. Silicone transformer oil is the best liquid insulator, but is rather hard to obtain. Mineral oil, on the other hand, is readily available from most pharmacies. Although it has a low dielectric constant, it can be used in a variety of simple ways to make very good high voltage capacitors.

For example, a dandy variable DC capacitor can be made by immersing a junked AM-radio tuning capacitor of the movable-plate type in mineral oil so its shaft and connection leads come out of the container's top. If you wish to try this idea, make absolutely certain the "cold" plates of the capacitor (the moving plates) are at ground potential. Use a good, large, non-metal knob for adjustment. A 100- to 365-pF variable capacitor with a 1-kVDC breakdown voltage (*i.e.*, a plate spacing of 1 mm) becomes a 270- to 985-pF unit with 7500-VDC breakdown rating. Try pricing a 7500-volt variable capacitor sometime, and you'll see the advantage to this approach!

You can use mineral oil in designs of your own, too. Immersion of a homemade capacitor in mineral oil will greatly improve its voltage rating and lifetime.

Paper is an excellent dielectric when saturated with mineral oil. Try 20-lb. bond computer paper which has a 4 mil thickness. Prepare this inexpensive capacitor by interleaving layers of dry paper with aluminum foil, and then immerse the capacitor in oil until the paper gets saturated.

One disadvantage to using oil in home-made capacitors is that the tape or glue used to bond the assembly must be oil-resistant. Silicone RTV is the best glue for these purposes.

Design Considerations. There are

TABLE 1—DIELECTRIC CONSTANTS AND BREAKDOWN VOLTAGES

Insulator	Dielectric Constant	Puncture Voltage per 0.001 Inch	Notes
Air	1.0	30	1
Window glass	7.8	200	
Polyethylene	2.3	450	
Paper (bond)	3.0	200	
Polycarbonate (Lexan)	2.96	400	
Teflon	2.1	1000	
Polystyrene	2.6	500	
Epoxy circuit board	5.2	700	2, 3
Pyrex	4.8	335	
Plexiglas	2.8	450	
PVC (rigid type)	2.95	725	
Silicone RTV	3.6	550	
Polyethylene terphthalate (Mylar)	3.0	7500	
Nylon	3.2	407	4
Mineral Oil, Squibb	2.7	200	2, 5
Shellac	3.3	200	

NOTES: All measurements at 1 MHz unless otherwise noted.
[1]Tested with dry air.
[2]Tested at 300 HZ using a Healthkit IM-2320 Multimeter and homemade capacitor.
[3]Estimate, based no experiences.
[4]Lowest value of 3 types.
[5]Estimate. Probably higher. A 0.040" gap withstood over 10,000 volts DC before breakdown in one test.

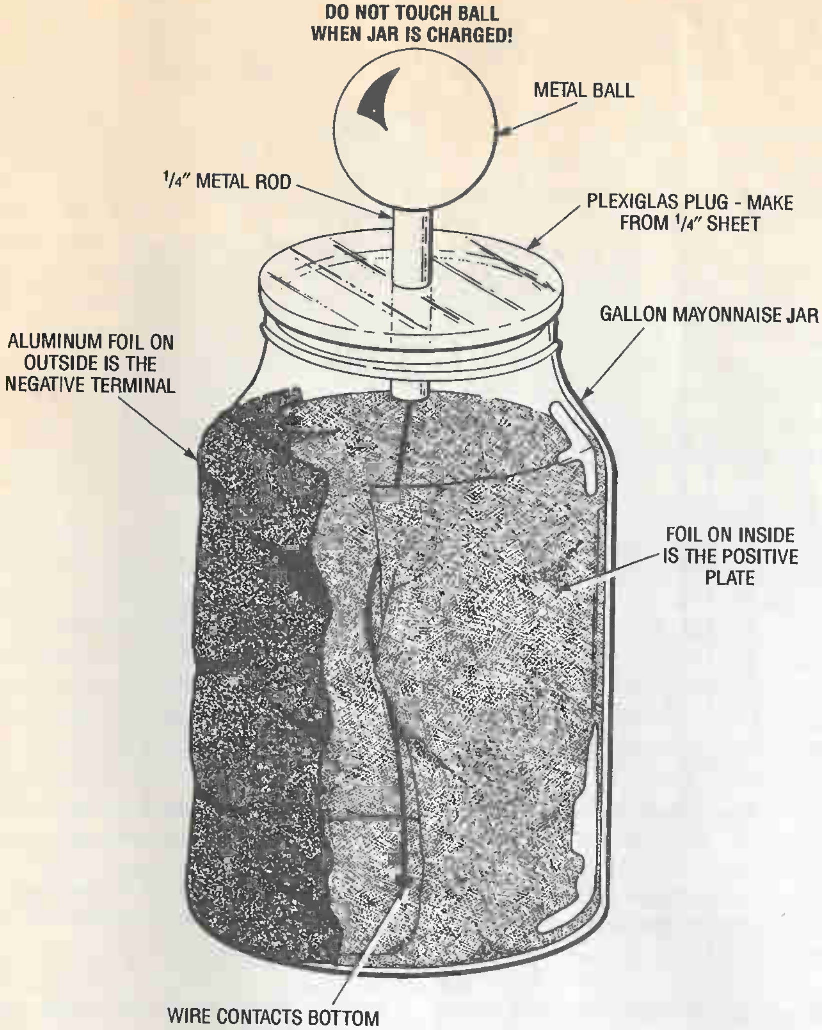


Fig. 1. The classic Leyden jar is the oldest storage capacitor we know of. They are easy to make and the materials only cost around $2.

High Voltage Safety.

High voltage is considered any value over 500 volts AC or DC. When you attach a capacitor to high voltage, you are multiplying its hazard manyfold. Therefore, experimenters must take extra precautions to avoid painful shocks and possible electrocution. Here are a few guidelines to follow when working with high voltage:

- Label your project in several locations with: "Danger, High Voltage" where appropriate. Such a warning label is provided here for you to copy (see Fig. A). Keep children, pets, and curiosity seekers away from the apparatus. Cover all bare leads, wires, connection terminals, and possible points of contact with high voltage putty or a cover fabricated from thick clear plastic.
- Work in a dry location. Working in a damp basement or workshop courts disaster. Wear rubber-soled boots or sneakers. Stand on a thick rubber mat.

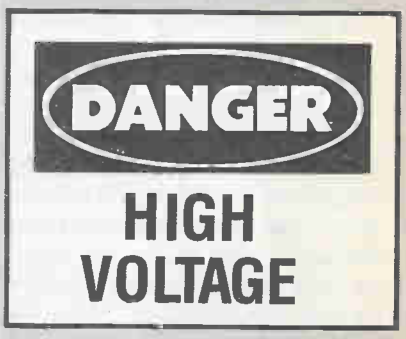


Fig. A. Curiosity can hurt more than just felines, so use this warning label on all your high voltage projects to protect the unwary from harm.

- Never put your body in a position to become a conductor. Locate your apparatus away from appliances, metal doors and windows frames, heating ducts, vents, radiators, sinks, or water pipes. All these items can become a deadly ground if your body comes between them and high voltage.
- Always pull the plug when working on a high voltage circuit unless you must test it. When testing a live circuit, use utmost caution. Keep one hand in your pocket. Use clip-on test leads that are rated twice the voltage of the live circuit. Use a high voltage probe whenever possible—its insulating handle will help protect you.
- Use NE-2 neon lamps to indicate live or stored high voltage. Bleed off the charge on capacitors with a power resistor before performing adjustments.
- Adequate ventilation must be provided for circuits that produce large amounts of ozone such as Jacob's ladders or Tesla coils.

several things to consider when designing and constructing your own capacitor. Let's point out each one before moving to the construction details. The first and most important thing to concern yourself with is safety. Despite the romance of high voltage, it is foolish to needlessly risk your life. Since you will probably be working with lethal voltages, observance of all safety practices for high voltage (or HV) is **absolutely essential**. For some guidelines, see the boxed text entitled "High Voltage Safety."

The next aspect to consider is capacity. If you have a specific capacitance in mind, you can design a capacitor using the information provided elsewhere in this article. Try one of the designs described later. Or perhaps you prefer experimenting instead. Either way, when building for the first time, we suggest making small designs first to get used to techniques and quirks before you invest lots of time and money.

You must also take into consideration the voltage that will be applied to the capacitor. That will affect your choice of a dielectric and thus its required thickness. Should you use an inadequate dielectric or thickness, sparks or arcs can result. A spark is a temporary breakdown that a lot of capacitors will survive, but an arc is serious: it is a path burned into the dielectric or other component. Arcs carbonize materials, producing a highly conductive channel that often renders an apparatus useless and very likely dangerous. Except in special cases where the insulator is a "self-healing" type (like air, oil, and some plastics), a single arc will ruin the capacitor.

To compensate for the impurities that often appear in materials that are not highly refined for capacitor use, we must add a safety margin to the thickness of the dielectric. In the case of DC, a good rule of thumb is a 50% margin. For example, say you need a 500-volt DC capacitor using polystyrene. Consulting Table 1, note polystyrene's breakdown is 500 volts per mil, thus 1 mil is required. Adding 50% gives you 1.5 mils, which is adequate for pure DC. You can always use a thicker dielectric if it's expedient, providing that you adjust the number of plates or their size to accommodate the wider plate separation. It should be mentioned that when making a paper capacitor, you should use a healthy safety margin since paper is not always uniform in thickness.

In comparison to AC, DC puts relatively little stress on a capacitor. By contrast, AC reverses the dielectrics' polarity every cycle. So the dielectric in an AC capacitor must have twice the thickness required in an equivalent DC capacitor. Further, when considering dielectrics in AC applications, you must deal with the *peak voltage*—not rms (*R*oot *M*ean *S*quare) voltage—that they will be exposed to. If you wish to convert an rms voltage to its equivalent peak sinewave value, multiply it by 1.414.

So, to roughly calculate the proper voltage rating needed for an AC capacitor, you first double its required rms voltage rating then multiply by 1.414. To further simplify this calculation, all one needs to do is multiply the AC (rms) voltage in question by 2.828. Now divide the voltage by the puncture-voltage rating to get a preliminary thickness value. Finally, you must add a safety margin of 50% to 100%. The actual percentage depends on the characteristics of the applied AC voltage. For a pure sinewave AC, we suggest a 50% safety margin whereas high frequency, non-sinusoidal applications such as Tesla coils require a full 100% extra thickness.

If one is available, equip an oscilloscope with a high voltage probe to visually observe exactly what the circuit is doing so you can determine the proper safety margin. An oscilloscope will also enable you to detect destructive voltage spikes and superimposed AC (also called AC ripple) so you can design a capacitor to handle those harmful excursions.

Of course physical size, weight, and fragility are also important characteristics of capacitor design. If you have size limitations, Mylar is the best

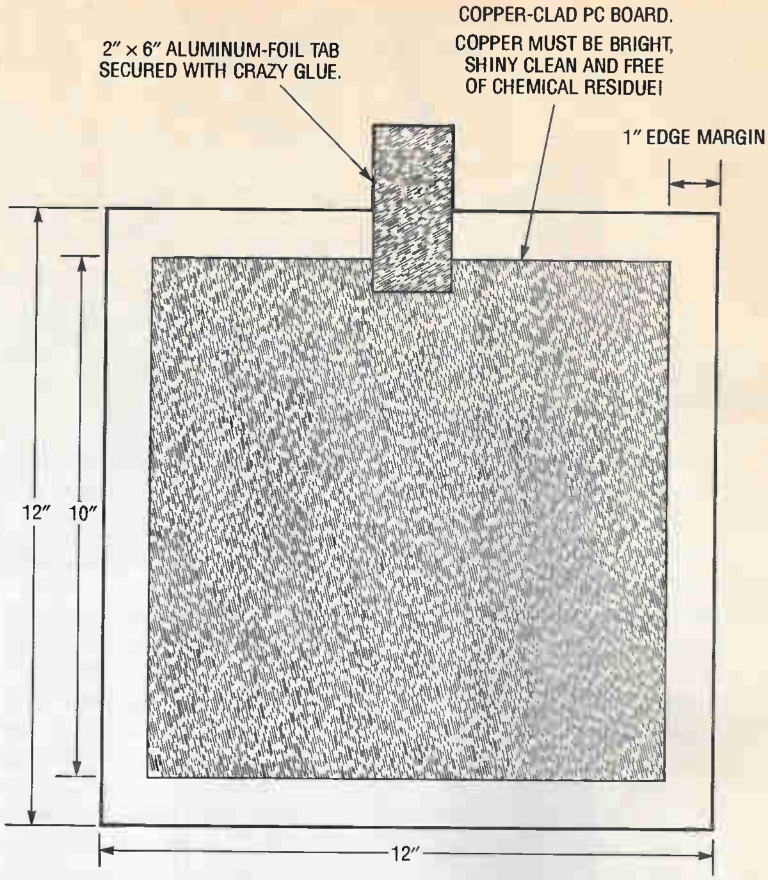


Fig. 2. For a single-section capacitor, use one double-sided PC board. For multiple sections, use several single-sided boards clamped together or bolted together with nylon screws.

dielectric material to use since it has a very high puncture voltage per mil, and thus makes a very compact capacitor. Plastics are light, so most capacitors will weigh less than ten pounds. The toughest plastic is Lexan, which is difficult to crack even with a hammer and is often used for vandal-proof windows. Glass is the worst material for a lightweight, durable capacitor, and can even crack under its own weight when lifted. Take all this into account when selecting your materials.

Of course, the overall cost in labor and materials should also be considered before constructing a capacitor. Calculate beforehand the cost of your materials. Paper and polyethylene are the cheapest. Glass is the next higher price. Labor time is about the same with Plexiglas, Lexan, and glass sheet capacitors. Exotic plastics such as Teflon are not needed unless your application demands extreme chemical and thermal deterioration resistance. Polyethelene has excellent chemical resistance, but breaks down gradually upon exposure to ozone gas (always present around high voltage) becoming brittle and less resistant to arc puncture.

That brings us to another important consideration: the capacitor's useful life. To enhance a capacitor's life keep the working voltage at or below the rated specification in both DC and AC applications. We discovered that charging at no more than 70% of a capacitor's working voltage resulted in an amazing 10-fold increase in lifetime for one type of commercial capacitor. Also, for DC capacitors, watch out for voltage reversals. If your system has a lot of inductance, reverse voltage swings are always produced. Increase the safety margin if a lot of inductance is in the circuit. Furthermore, the temperature should be kept below 120°F. As mentioned earlier, watch out for superimposed AC, voltage spikes, and ringing. These types of AC waves can drastically shorten lifetime. Tesla coils have notorious ringing. To repeat: if feasible, use an oscilloscope to visually analyze your circuit. Often a power resistor inserted in the current path to the capacitor quenches ringing. With this criteria under our belts, let's look at some problems your design and construction methods should prevent.

Signs of Trouble. Your assembly techniques should seek to minimize the likelihood of a few possible problems. Luckily, all of them can be prevented at least in part by using ample amounts of insulating material such as No-arc or Corona Dope and/or high voltage putty on all exposed areas. A plastic case to enclose the apparatus is also recommended (more on that later).

Still and all, you should know what problems the insulation is preventing. The first problem insulation relieves is the possibility of electrical shock.

Insulation also minimizes the production of ozone—a gas created when high voltage causes three oxygen atoms to join together. Ozone has a tart, sweet "electrical" smell, and is 100 times as poisonous as carbon monoxide. Beware: it quickly causes headache, nausea, vomiting, and respiritory irritation. In addition to insulating all the exposed HV areas, you should also operate your equipment with good ventilation if it produces any ozone.

Closely linked to ozone generation is corona leakage. It is produced by a charge being leeched off a highly charged object by the air. That typically produces ozone. However, sometimes a device (such as a Van deGraff generator) is constructed specifically to display corona discharge, and insulating it would defeat that purpose. In such cases, good ventilation is the only practical means of hazard prevention.

Ozone can also be created by arcing, which can occur anywhere. However, ozone production is not the greatest hazard arcing presents. At 50 kV, a spark can arc between an uninsulated contact and your body if you come within 2 inches of the contact. Arcing commonly takes two forms: directly through a capacitor's dielectric (as mentioned earlier), or across the edges of a capacitor's plates to an adjacent plate. A snapping sound indicates the presence of arcing, so keep your ears open.

Arcing from the edges of a capacitor plate, or anywhere the shape of a conductor changes abruptly (such as the tip of a nail) is called point discharge. It can be readily observed in a dark room at very high voltages. Small, bright blue pinpoint(s) are seen leaking electrons into the air, accompanied by a hissing sound and copious ozone production.

Once again, insulation and proper ventilation are the proper solutions to all these problems, and there are some specialized techniques to insulate your capacitors and otherwise improve the safety of your high voltage projects. Let's get to those now.

Construction Requirements. A key ingredient in a good assembly is a proper case. Your capacitor's housing must protect it against moisture, dirt, and accidental discharge. Plastic cases for dry capacitors are easy to make with acrylic sheets glued at all corners with Silicone RTV. Oil-proof cases can be made for immersed models, but you will need to rough-up the plastic at the sealing edges with sandpaper and use both a bonding and second fillet glue coating for a liquid-proof seal. Metal cases can be made from PC boards cut on a shear or large paper cutter and soldered at the edges. Copper roof flashing (available at hardware stores) works well too. However when using metal, always beware of contamination by solder rosin, solder bits, and other crud, which can short out plates or otherwise reduce efficiency.

Whether a capacitor is enclosed or exposed, discharge paths must be wide enough to avoid arcs to the case, adjacent plates, terminals, connections, or components. That is especially important in situations where conductors must be left uninsulated. Note that the space from each plate to the edge of the dielectric must be wide enough to stop any spark from "crawling" over the edge of one plate to another.

Power leads must be capable of withstanding the full voltage of the charge plus at least a 50% safety margin. TV anode wire, which comes rated up to 40-kVDC, makes great leads. Vinyl tubing or aquarium air hose may be slipped over leads to increase their voltage rating.

Make sure the plates are securely mounted or they will tend to shift, or make a noisy rattle when used with AC. Glue or compress the assembly to hold it secure. With regard to mounting, keep in mind that glues that dry by evaporation of a volatile chemical might not set properly if "buried" inside an assembly away from air, and could thus become a fire hazard.

Rolled-up capacitors may be held securely by wrapping the interleaving layers of foil and insulator tight around an insulating mandrel and then taping with a clear PVC tape. Where necessary, coat the ends with Silicone RTV. That will eliminate end-arcing flashover and corona loss. Alternatively, although it is somewhat brittle, paraffin (with a puncture voltage of 250 volts/

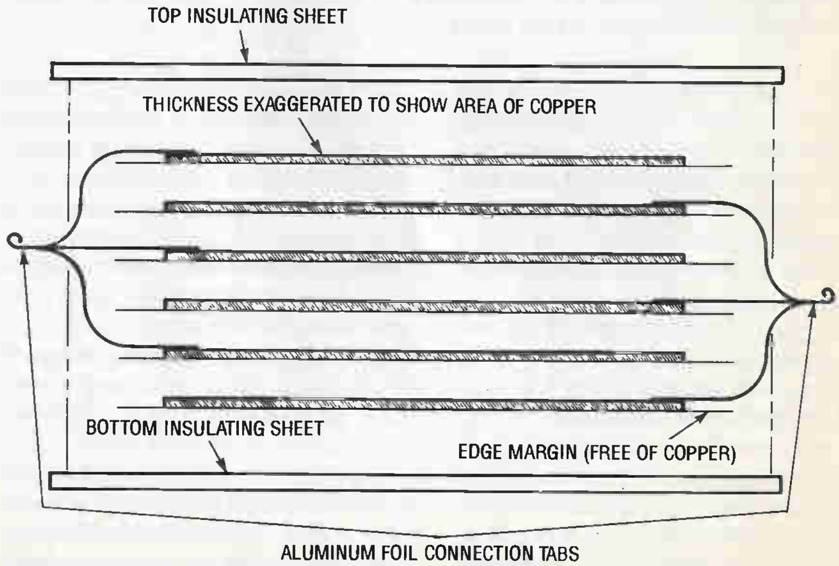


Fig. 3. With this design, you may stack as many plates as you wish, provided there are an equal number of plates attached to each lead.

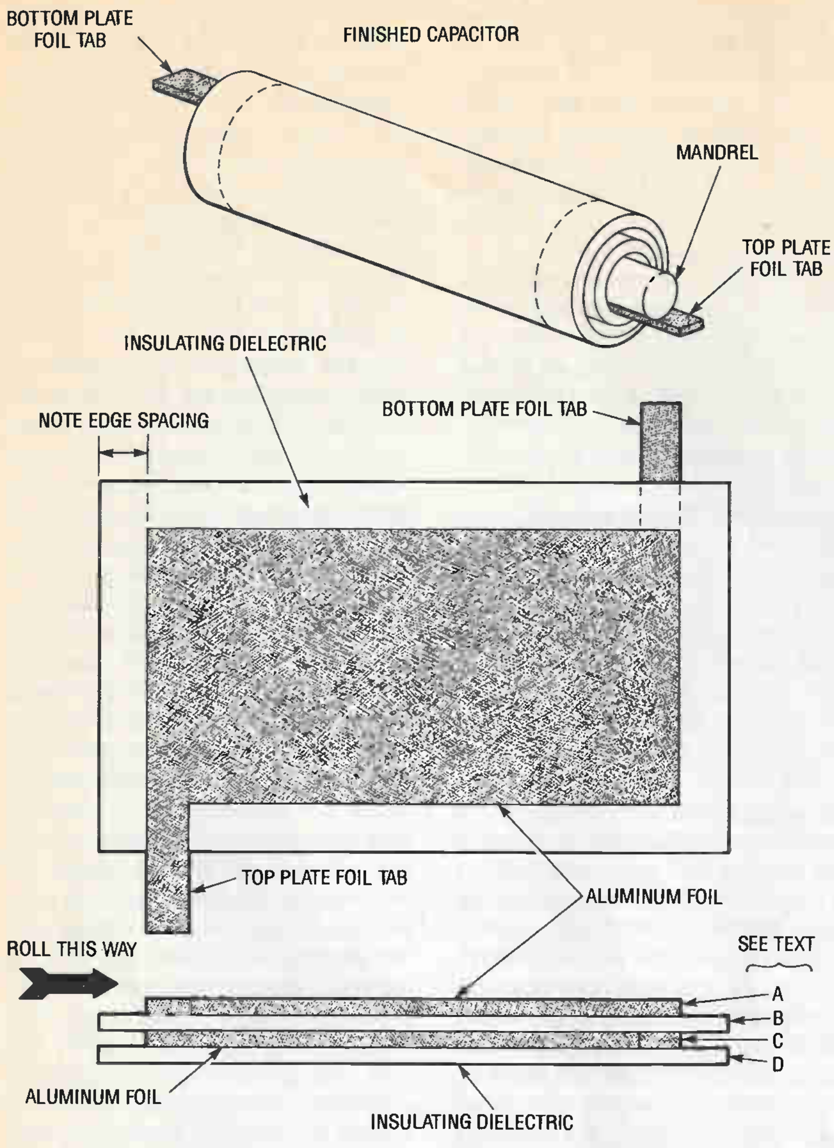


Fig. 4. A rolled-up capacitor, like that shown here, can provide the greatest capacitance in the smallest space. Note that the dimensions in the side view have been greatly exaggerated for the sake of clarity.

mil) is an excellent insulator for the ends of rolled-up capacitors and the edges of flat-plate type capacitors. If you want to use melted paraffin wax, heat the wax only in a double-boiler pan, since if it gets too hot it can catch fire. Be sure to apply several coats, allowing the wax to harden between each coat. Liquid electrical tape also makes a great end seal, however it is somewhat hard to find. Try mail-order distributors for that product.

High voltage terminals for your projects can be made from plastic rods drilled through to accept connection wires. You may add a nut and bolt on top for convenience. However, beyond about 3,000 VDC this method suffers from point discharge. Metal balls make good terminals. Clean them up with a wire brush or steel wool to eliminate rough spots. The author uses fishing floats covered with either aluminum foil or nickel print paint for up to 10 kVDC. Split the bobbin first with a razor blade, remove the line holder and spring, and glue it together again with epoxy.

Furthermore, as you work, keep all materials as clean as possible. Not only will your work have a better appearance, but arcs and burn-throughs due to contaminants will be prevented. High voltage easily tracks along dust, surface contamination, and even finger oil (which contains salt). Also, we shall refer to a "section" as consisting of two conductive plates with an insulating dielectric between them.

By now, we hope you have a good understanding of the principles and techniques involved in making your own capacitors. Without forgetting safety, let's talk about how to build some simple capacitors, any of which can be modified for your application.

A Leyden Jar Capacitor. Leyden Jars are one of the first types of capacitors made, having been invented nearly two and a half centuries ago. Their development was first recorded in 1745 by Ewald von Kliest. In 1746, Peter van Musschenbroeck of Leyden, Holland experimented further with the invention. We can build our own modernized units with a gallon-size wide-mouthed mayonnaise jar. The project only costs about $2, and is good to at least 10 kVDC at 2.5 nF. Units we've tested at 15 kVDC did not fail; at that voltage, the capacitors stored just under ⅓ joule each.

First select a jar without bubbles, cracks, or blemishes and that has a mouth large enough to comfortably slip your hand through. Next, carefully clean it out. You'll use aluminum foil inside and out as the conductive plates (see Fig. 1). Cut a foil disk 1-inch bigger than the bottom of the jar. Now coat the dull side of the foil and inside jar bottom with a thin, even layer of rubber cement. Let both dry for 10 minutes, and press together. Smooth with firm hand pressure. Avoid excess wrinkles. Do the rest of the inside except the top inch of the bottle using three or four pieces of foil. (It is easiest to do the plate in pieces instead of all at once, since rubber cement "grabs" and it is difficult to reposition the foil once contact has been made.) Now do the outside foil plate in pieces, leaving the top inch bare. Check the foils with a continuity tester to determine if the pieces are in good electrical contact. Areas of foil not in contact can be bridged with strips of foil or nickel-print paint.

For the top cover, cut two disks of clear plastic, one slightly smaller than the rim, the other ¼-inch larger than the rim. Glue the two pieces together to form a plug. Drill a ¼-inch hole through the plug's center. Cut and insert a length of ¼-inch (outer diameter) metal rod or tubing through this hole. Attach a ball to its top, and solder a wire or small-link chain to its bottom. The wire must make good electrical contact with the foil. Let the assembly dry for a day with the cover off, to allow vapors from the rubber cement to dissipate, then cement the cover on with silicone or *Krazy Glue*.

PC-Board Capacitor. Some nifty low inductance capacitors can be made from pieces of copper-clad epoxy circuit board (see Fig. 2). For a simple two-plate capacitor, you can use one double-sided sheet. For multiple sections, use single-sided board.

To prepare each board, start by etching away a 1-inch strip from around all its edges. That process can be simplified by first masking off the strip, spraying the bare copper with an etch-resistant paint, removing the masking tape, and then etching.

Clean the board after etching, and rinse with de-ionized or distilled water. Thoroughly air-dry the sections, or use a blow dryer. Attach strips of aluminum foil to each plate.

If you are building a multiple-section capacitor, connect the aluminum foil strips together as shown in Fig. 3 and secure them using glue or nylon bolts at each corner. Spray the finished assembly with several coats of an insulating product, or paraffin.

If you use the dimensions shown in Fig. 2 and a 0.060-inch gap between plates, you can achieve a capacitance of 1.94 nF (1940 pF) per section. When deciding on the gap width to use, keep in mind that the greater the space between successive plates the lower the chance of arcing. For example, a 1-inch spacing gives you a 30% larger gap than a 20-kV spark can jump. Insulation will further improve that margin.

The Stacked Sheet Design. This type is virtually identical to our PC board capacitor, but it can be designed to handle considerably more voltage. You simply substitute sheet plastic or glass dielectrics, and glue aluminum foil in place of the copper for each section (refer to the PC board capacitor drawing in Fig. 3 as needed). All in all, it's an easier design to build, as it does not involve the effort of etching copper, and you can continue to add sections to your original prototype to increase its capacity as future demands require.

Sources

All types of plastics: United States Plastics Corporation, 1390 Neubrecht Lane, Lima, OH, 45801; Tel. 800-537-9724. Company changes for catalog and requires a minimum-amount order. Write or call for details.

High voltage rectifiers and meters: MCM Electronics, 858 E. Congress Park Dr., Centerville, OH 45459-4072; Tel. 513-434-0031. Free catalog.

Sheet and formed metals, plastics, and precision tools: Small Parts, Inc., PO Box 381966, Miami, FL 33238-9980; Tel. 305-751-0856. Free catalog.

Information, technical assistance, high voltage parts, and kits: Allegro Electronic Systems, 3 Mine Mountain Road, Cornwall Bridge, CT 06754; Tel. 203-672-0123 (9 AM–12 noon EST weekdays). Free catalog.

When building a large capacitor of this type, we suggest that you use nylon bolts at the corners to hold it all together. The bolt holes should be pre-drilled before assembly, and all chips cleared away. Make sure the plate-to-edge spacing is adequate for the voltage you will subject the capacitor to. Add extra spacing if you intend to use bolts at the edges.

Glue foil carefully to the top of the first plate using a small amount of spray adhesive, *Krazy Glue* or RTV silicone. Press it smooth and let it dry. A photographic finishing roller is handy for flattening foil. Repeat the procedure for the second sheet, orienting the foil connection tab in the opposite direction. Keep the plates and dielectrics aligned as assembly proceeds. Repeat this procedure for as many sections as you want. Always keep the final number of plus and minus plates equal.

Put an insulating sheet above and below the last plate and secure the assembly with nylon bolts. Do not over tighten or the center of the assembly will "bow." Finally, clean the ends with a very small amount of isopropyl (rubbing) alcohol and wipe dry. Smear a coating of silicone RTV over all the edges.

Roll-Up Design. The kind of capacitor depicted in Fig. 4 can provide large capacitance in a small size. They are a little trickier to make than stacked-section type capacitors, so you might want to try a few small prototypes first. The design uses a layered approach (as shown), and we suggest using only one section as it is difficult to align and wrap multiple sections. By contrast, a single section several feet long is not too unwieldy.

Aluminum foil works great in these capacitors. You'll find the oven/broiler type, which is heavy-duty foil, far easier to work with than the plain variety. Polyethylene and Mylar are the most common dielectrics, but you can experiment with other materials.

Looking at the figure, note the orientation and shape of the foil plates (A) and (C). They can be easily secured to the dielectric (B) using double-sided Scotch tape. Note also the edge spacing. An outer covering of dielectric (D) will prevent the finished capacitor from having a "hot" case, which might be a hazard. With those points in mind, lay the foil out on a smooth sheet of paper, which in turn should be laid out on a smooth, hard surface to prevent wrinkling. Carefully assemble the four layers as shown in the drawing. Strive to make them flat and smooth.

Wrap the capacitor "sandwich" around a non-conductive mandrel or spool—ideally made of plastic or glass rod (be careful not to break a glass rod). Try to make the roll straight and free of lumps and wrinkles. When it's all rolled up, secure it with plenty of tape. The author uses clear package-sealing tape for this. Now secure the positive foil tab (assuming it's going to be for DC) to the mandrel using tape. Finally, coat the exposed ends with an insulating product like silicone RTV.

The remaining foil connection tab may be reinforced by rolling it around a small metal dowel. A nail, or a cut-off piece of ⅛-inch uncoated brazing rod is suggested. Apply glue to hold the assembly together.

Foil tabs can be strengthened by adding "ribs" of adhesive from a hot glue gun. Similarly, the tabs can be made tear-resistant by applying hot glue where they enter the capacitor.

Note most problems with this design come from particle contaminants that stretch a dielectric thin in spots where they are trapped by the tightly rolled dielectric. Another trouble is inadequate edge spacing, causing arcing across the ends. Careful planning and assembly will eliminate both headaches. ■

If you've ever wanted a high-voltage generator to create neat lightning effects, perform Kirlian photography experiments or play with neon lights, then this one's for you!

A HIGH-VOLTAGE PULSE GENERATOR

By Dale Hileman

We will describe a laboratory pulse generator using an auto-ignition coil and capable of delivering a train of pulses having a peak potential up to 30,000 volts. With a couple of minor circuit and construction variations, the project is suitable for use as an electric-fence charger, operating at a lower voltage, but capable of much higher output current.

Applications for a high-voltage spike are numerous: electromagnetic and radio-frequency interference studies, electrostatic-discharge simulation; investigation of insulation breakdown; flammability experiments; strobe effects; etc. A DC power supply or battery is required, and pulse potential may be varied simply by changing the supply voltage. With a 12.6-volt input, the ignition-coil model delivers its maximum pulse, but a unique multivibrator-driver circuit makes operation possible down to a supply voltage as low as 1.5 volts, yielding an output pulse of only a few hundred volts. Its pulse frequency is set by a front-panel control, with a range from about 0.3 Hz to 20 Hz.

An ignition coil, however, is not well adapted to the fence-charger application since its output resistance is so high: typically 10,000 ohms. Thus its output pulse is strongly dependent on loading. With a short fence, long sparks might be struck at risk of igniting brush; while on the other hand, with a long fence, shunting by weeds or by dirt and moisture may reduce its output voltage below an effective value. Hence for the fence-charger version the RATE prf control must be omitted for reasons of safety.

No-load output of the fence-charger option is typically 4 Kv pk (kilovolts peak), or about half that value when connected to a 1-mile fence. A car battery powers the fence-charger model for about four months before recharging is needed (at recommended pulsing rate of 20 pulses/min.)

Two lamps mounted on the circuit board and visible through the see-through front panel are important indicators of the unit's performance.

Precautions

While a single jolt from an ignition coil is itself rarely traumatic, the resulting-reflex muscle contraction could have unfortunate consequences. If a continuous train of pulses causes you to involuntarily grasp the high-voltage conductor, for instance, you might not be able to let go. On the other hand, if a proper return circuit is not provided, an equally distressing shock could be had by contact with the primary circuit. Because the ignition coil is an autotransformer, the return circuit for the high-voltage pulse includes the power leads. Therefore, one side of the power supply should, if possible, be Earth grounded. That precaution, besides preventing shock by contact with the power leads, also precludes arcing within the power supply itself as the high-voltage pulse seeks the shortest return path.

Applying that reasoning to the fence-charger option, we can see why a fixed pulse rate is specified, as there is a strong likelihood of accidental human contact with the fence wire; a rate of 60 pulses per minute or less being considered safe. Also, since there is a good chance of personal contact with the power or battery leads, a good ground connection is essential, as with any electric-fence system.

For maximum safety, we recommend a battery supply for the fence-charger system.

If you should happen to reverse the power-supply leads to either project, the current-limitation lamp, a large automotive bulb easily seen in the photos, lights brightly to warn you. However, the equipment must not be allowed to remain in this condition for more than a few seconds. Even if you never expect to make this mistake, the lamp should be included because it limits excessive surge currents that could otherwise occur under some operating conditions and which could blow the power transistor.

About the Circuit

As shown in Fig. 1, free-running variable multivibrator Q1 and Q2 drive Darlington power amplifier Q3, which makes and breaks the primary current to coil T1 as in an auto ignition system. Duty, or "dwell" is a few miliseconds, and the high-voltage pulse is generated at the end of the period when the circuit is broken and the field of T1 rapidly collapses through the winding.

An unconventional multivibrator circuit was developed to provide high saturation currents over a wide range of supply voltages. In this design both transistors Q1 and Q2 conduct at the same time and both cut off at the same time. Another unique feature: For safety in the fence-charger application, the circuit is designed to automatically shut down if driver Q2 should fail to conduct for any reason (fluctuation

of supply voltage, intermittent connection, etc.)

Starting with both transistors cut off; C3 is discharging, its negative plate rising toward ground at a rate determined by various series resistances; while its positive plate is held near zero volts by a relatively low-resistance path through R6 and R7 and a resistor internal to Q3 across its emitter-base junction.

The series combination of C5 and C6 (discussed later) has negligible effect on the charging rate, which is therefore determined mainly by C3 with the series combination of RATE control R9 and resistor R2 (or R2 alone, in the fixed-frequency version).

Capacitor C3 discharges fully, and then begins charging in the opposite direction as its negative plate rises above zero volts. When Q1 begins conducting, and its collector voltage has dropped far enough to start Q2 conducting also, then a positive-feedback action is initiated, forcing both transistors into saturation. At the same time, power transistor Q3 is turned on by the current supplied through R7.

Dwell is determined by the time constant R6 × C3. When the charging current of C3 diminishes below the value which will sustain conduction of Q1, then a regenerative action is again established, this time cutting off all three transistors. It is at that moment the high-voltage pulse is generated.

Further Details

Capacitors C5 and C6 form a voltage divider which ensures rapid cutoff of Q1; while C6 acts as a bypass to prevent Q1 from being retriggered by pickup of the high-voltage pulse.

Dwell must be long enough to permit the field around

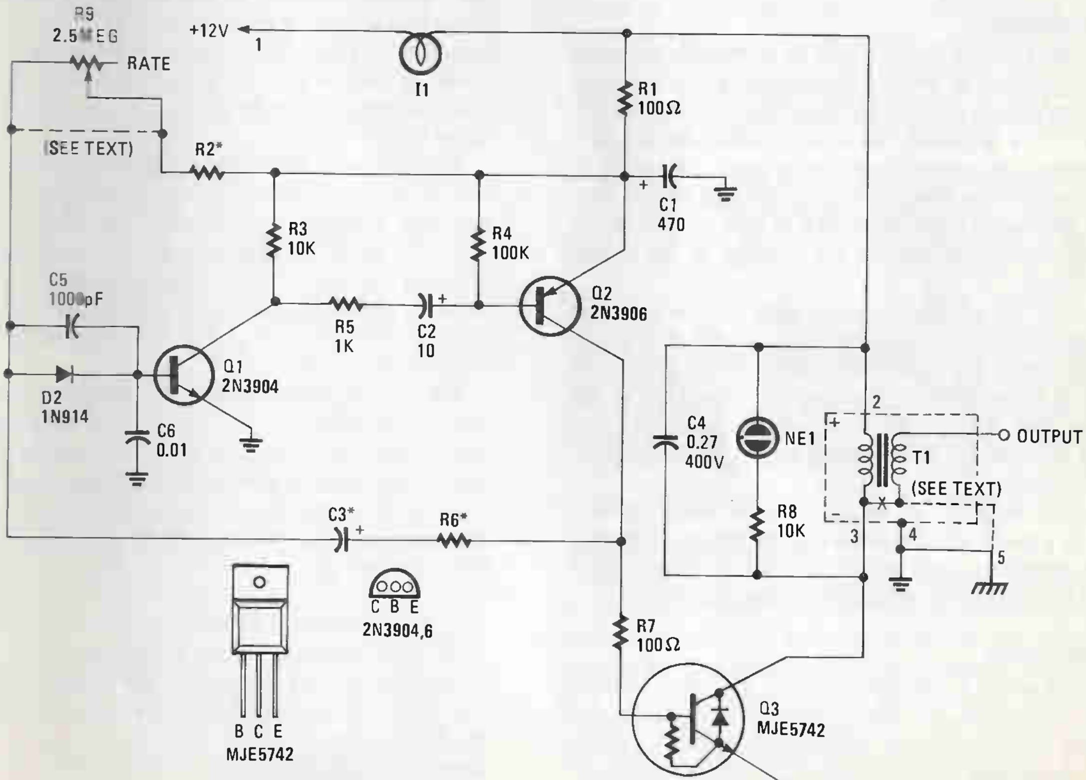
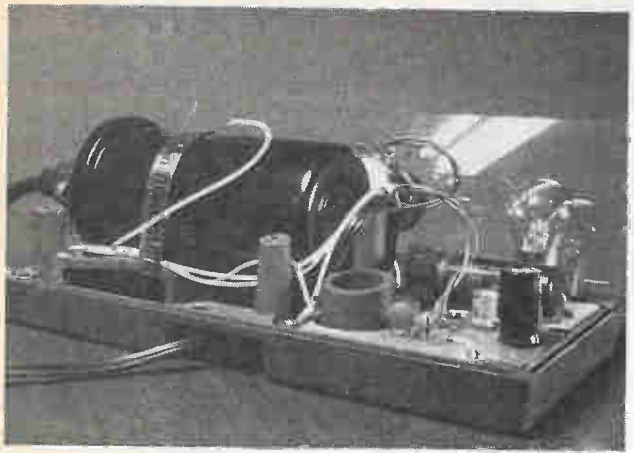


Fig. 1—The pulse-generator version has a variable rate control and requires different values for C3 and R6 than does the fence charger version. The fence charger version has a fixed rate and uses a conventional transformer instead of an auto coil (see dashed lines).

T1 to be fully developed to its steady-state condition under all anticipated conditions of loading. Although the period is not critical, it may be set for optimum results with a particular coil or transformer, as described later.

A higher capacitor value at C3 is specified with the fixed-frequency, or fence-charger version, for reasons of safety. It allows the use of a lower resistance value for R2, reducing the shunting effect of dirt or moisture which might otherwise cause a significant increase in the repetition rate. That is the reason we specify an axial type for C3, so that its pads are more widely spaced than they would be with a radial.



The frequency control is mounted on the see-through front panel behind the ignition coil here. The auto lamp on the circuit board limits current, and lights if the power leads are connected backward. The chimney protruding through the hole in the corner of the circuit board accommodates the 1/2-in. pipe used in the fence-charger version.

Power Amplifier

Because the field of T1, as might be supposed, collapses through the primary as well as the secondary, the inductive "kick" comprises a positive pulse on the collector of Q3. Capacitor C4 is required, as in the conventional auto-ignition system, to prevent excessively rapid voltage build up. Nevertheless, that reactive voltage reaches several hundred volts, and we take advantage of it to light neon indicator NE1. Thus, each flash verifies the integrity of the power-amplifier circuit.

If no arc is drawn, the positive pulse on the collector of Q3 is followed by a negative-going excursion. Transistor Q3, designed for inductive loads, contains a shunt diode which prevents that "backswing" from being applied to the base through the base-collector junction. That diode also protects Q3 if the power-supply leads are accidentally reversed.

Automotive lamp I1, as we said, limits surge currents occurring as a result of various normal operating conditions, as well as accidents, such as the reversal of power-supply polarity. Also, it absorbs the energy of the backswing.

The Transformer

Practically any 12-volt ignition coil having a primary resistance of around 1.5 ohms will work as T1 for the high-voltage pulse generator, but there's a minor consideration in the choice of a transformer for the fence-charger project. A common 12-volt 1-amp transformer with 115-volt primary can be used here—hooked up backward of course, so that the 115-volt winding serves as secondary. The rapid collapse of its field when Q3 cuts off, as compared to the relatively slow 60-Hz sinewave for which it is designed, explains how several thousand volts can be developed across the 115-volt winding ($E = L\, di/dt$). That winding will typically be found to measure 30 to 120 ohms DC, while the 12-volt winding will have a resistance of around 1 ohm. The author has tried many such transformers for T1, including the Stancor P-8392 and P-8393. (The latter provides a somewhat bigger jolt although it costs more than the former.) The problem, however, lies in the breakdown rating of the 115-volt winding.

In most transformers of the species, the winding is rated for breakdown at 1500-volts RMS (corresponding to 2100-volts pk), with a safety margin that may vary depending on the manufacturer; the Stancor rating proving remarkably conservative. The author subjected the winding of a P-8393 to 40 million pulses of 4-Kilovolt amplitude without breakdown. However, he does not guarantee equally good luck in your application.

One way to preclude breakdown with such a transformer is to always operate the fence charger with an appropriate load. If your fence isn't long enough to load T1 to 2-3 Kv pk, you could reduce the supply voltage: Say, use a 6-volt battery instead of 12 volt. Or you could substitute for bulb I1 a type having a lower current rating, and therefore a higher resistance. Either of those approaches, naturally, will somewhat reduce the effectiveness of the unit.

Otherwise, the author offers a transformer specially wound for the fence-charger option and rated at 5 Kv pk (see note at end of parts list).

Other parts

A type MJE5742 transistor is specified for Q3, rated at 400-volts under heavy inductive load. However, you can at some risk substitute the cheaper MJE5741 (350-volt rating) or MJE5740 (300-volt rating), depending on T1. In any case, breaking the circuit to an inductive load is tricky and so if you plan extensive experimentation you should obtain a few spare Q3's.

Potentiometer R9 for the variable pulse generator project can be any 2.5-megohm unit from the junk box. If you use one with a linear taper, though, you will find the control very touchy at the high end of the frequency range. The simplest resolution of that minor inconvenience is to use an ordinary audio-taper potentiometer connected backward; that is, with the high end of the frequency range at the *CCW* (counter clockwise) end.

For reasons already mentioned, the time constant $C3 \times R6$ determines dwell, or "on" time. As we have said, dwell is not critical; but if the capacitor you use for C3 is a low-quality part with an excessively high equivalent series resistance (ESR), then dwell may turn out to be greater than necessary to serve the needs of T1. If in doubt, use a tantalum type for C3.

The Incandescent Lamp

We have emphasized the importance of I1, the current-limiting lamp, and have specified a type 1156 auto bulb. The merit of an incandescent bulb as a protective device lies in the dependence of its resistance upon the value and duration of applied current. With a cold resistance of only about 1/2-ohm, the Type 1156 degrades performance only slightly; but in the case of a current surge or accidental short circuit, its resistance quickly rises to a "hot" value of around 6 ohms, sparing power amplifier Q3 from the devastating requirement of breaking an excessive current into an inductive load. Nevertheless, there is some leeway in the selection of I1.

For instance, in the lab-generator version where the load has a DC resistance of 1.5 ohms, a lower-resistance bulb will give a slightly better spark at high frequencies. The author has used a Type 1157 bulb here, connecting its two filaments in parallel, with satisfactory results. On the other hand, as we have indicated above, to prolong the life of T1 in the fence charger, you may elect a lower-current or higher-resistance bulb. Try the smaller of the two 1157 filaments, alone before experimenting further. After the unit is built feel free to try others.

PARTS LIST FOR THE FENCE CHARGER

SEMICONDUCTORS
D1—No D1 in project; please ignore
D2—1N914 silicon diode or similar
Q1—2N3904 NPN silicon transistor or similar
Q2—2N3906 PNP silicon transistor or similar
Q3—MJE5742 8 amp, 400-volt, NPN Darlington power transistor (see text)

CAPACITORS
C1—470-µF, 16-WVDC electrolytic
C2—10-µF, 16-WVDC electrolytic
C3—For lab model: 2-µF; for fence charger: 10-µF, both 16-WVDC electrolytic, axial (see text)
C4—0.27-µF, 400-WVDC film
C5—1000-pF disc
C6—0.01-µF disc

RESISTORS
(All fixed resistors are ¼-watt, 5%.)
R1, R7—100-ohm
R2—Selected (see text)
R3, R8—10,000-ohm
R4—100,000-ohm
R6—For lab model: 470-ohms; For fence charger: 150-ohm
R9—2.5-megohm pot (see text)

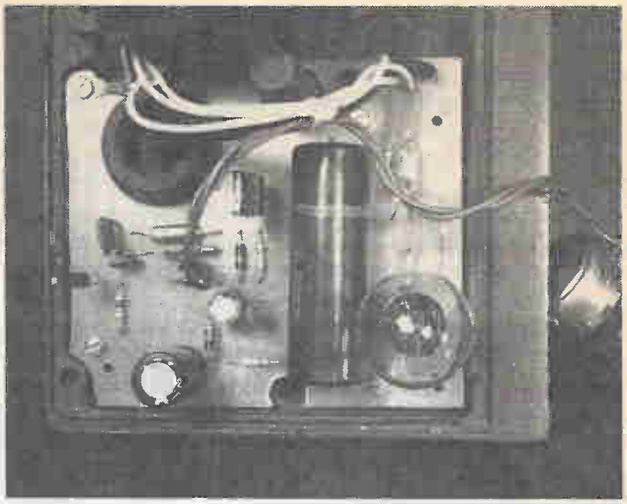
ADDITIONAL PARTS AND MATERIALS
T1—For lab model: Wells C1819 or similar ignition coil; 1.6-ohm primary, 10,000-ohm secondary; For fence charger: 12-volt, 1-amp transformer (see text)
NE1—Neon glow lamp; Type NE-23 or equivalent
I1—12-volt, 2-amp automotive bulb, Type 1156 or equivalent

Cabinet or case; circuit board; solder lugs of various gauge, with internal teeth; cable to power supply, #14 to #18-gauge zip cord or whatever suits, spacers, screws, nuts, lockwashers, hookup wire, cable ties, solder, etc.

Additional parts for the lab model only: 1-in. to 2-3/4-in. radiator-hose clamp to mount ignition coil; 7-mm spark-plug wire, coil clip, coil nipple, alligator clip, alligator insulator; knob for R9; two banana plugs or other suitable terminations for cord to power supply.

Additional parts for the fence charger only: two battery clips, Mueller #46C or the like; 1/2-in. pipe, 1 1/2-in. large nipple, coupling, etc., for grounding system.

All parts except water pipe, caulk, hookup wire, and solder are available individually or in kit form from Maps and Zaps, 1132 Roseta Dr., Topanga, CA 90290. Please write for price list, sending self-addressed envelope with 45¢ postage.



This is a top view of the circuit board. Note the ample space provided between components. That is to prevent arcing between the leads of high-voltage components.

Circuit Construction

All parts for either version of the project are available, including the 2-piece plastic cabinet having provisions for mounting at the end of an ordinary 1/2-in. water pipe or upon a standard camera tripod. You may choose to build either version of the project in whatever kind of cabinet suits your needs. If you decide to use wire-wrap construction however, the ground bus and all connections in the power-amplifier circuit should be made with wire no smaller than #24 gauge. In the author's prototypes, power transistor Q3 stands off the circuit board; but if space limitations permit, a slight margin of safety is affordable by bolting it down flat so that the circuit board provides a measure of heat dissipation.

Omit R2 from circuit board and don't connect the supply conductor to the plus end of T1 until ready to fire up. Also, leave the secondary leads unconnected for the fence charger.

In planning chassis layout, keep high-voltage output conductors well away from the circuit board, especially in the version using an ignition coil as output transformer. A metallic or otherwise conductive cabinet must be connected to the circuit common. Since a 30-kv pulse is capable of jumping a 1-in. gap, however, you may have some difficulty finding a feedthrough insulator big enough to handle the high-voltage conductor. One way to meet that requirement is to use a spark-plug wire, which may be passed through the cabinet wall using only a grommet to prevent chafing. Or the neck of the coil itself may be used as a feedthrough device, as in the author's mode of construction.

Lab Cabinet Loading

If you are using the author's recommended cabinet, situate the circuit board in the left end of its bottom. The board itself can be used as a template for drilling the four mounting holes in the bottom of the cabinet. Mount the board assembly on four 7/16-in. metal spacers. The conductive coating in the cabinet bottom may be grounded with a solder lug placed under one of the screws securing the board to a spacer.

For variable-frequency or lab model, situate the RATE control R9 in the clear-plastic front panel. Bring the power cable into the cabinet through the hole in the bottom rear, using a suitable grommet.

The coil mounts on a platform toward the other end and is secured with a hose clamp. Using the coil called out in the parts list, some filing of the platform is required. The coil case must be grounded or internal arcing may occur. Do not depend on casual contact between the coil case and the conductive coating. A grounding connection can be made by inserting an internal-tooth solder lug between the clamp and coil case. At its base, the coil is stopped by its neck passing through a hole drilled in the end of the cabinet top. Hence, it's not likely to come loose with normal handling.

At the free end of spark-plug wire install an alligator clip or other suitable connector. At the other end, first slide the coil nipple onto the wire, and then install the coil clip. Important: To preclude arcing, solder the end of the wire to the clip. Push it into the coil neck and slip the nipple into place. When the top is installed later, the nipple provides a tight seal.

Fence Charger Version

Construction of the fence-charger version is somewhat simplified by less-stringent needs for insulation and by the more conventional mounting means for T1. Whatever chassis layout scheme you employ, however, the Earth grounding requirements described above also apply to this model: If you use a conductive cabinet, it must be connected to the circuit Earth, and so must the case of T1. Don't forget that a means must be provided to connect that common to an *external* ground.

In the author's model of the fence charger, T1 is mounted in the cabinet bottom. To ensure a good connection to the transformer case, first scrape any varnish or wax from the mounting flanges. Then mount with 1/2-in. metal standoffs and 8-32 hardware. Use two or three solder lugs as required for various grounding connections.

Mount a ceramic feedthrough insulator in middle of the platform for fence connection. The underside of the platform comprises a recess which, in an outdoor installation, keeps the output end of the insulator clean and dry.

The chimney referred to earlier provides the means for connection to an external ground. A pipe nipple and coupling are required. First solder a length of hookup wire to the inside of the nipple. A hot iron (say 200 watts) is required for good wetting. Loosely engage the coupling to the nipple; and passing the wire up through the chimney, screw the nipple into the opening by turning the coupling. The nipple may engage the coupling as it engages the chimney. Although the chimney hole is not threaded, the nipple will nevertheless seat securely. Turn the coupling until it is tight up against the bottom of the cabinet. If desired, apply super glue sparingly around top edge of the nipple, bonding it permanently to the chimney. Now, if you later need to remove the coupling for any reason, the nipple will remain in place. Solder other end of the wire to common at the circuit board or at one end of the lugs on the transformer flanges.

High-Voltage Attenuator

Before proceeding with test and adjustment, you may wish to provide yourself with some means for measuring voltage pulses beyond the range of your oscilloscope. To that end, you can build a 90-megohm attenuator, as shown in Fig. 2. When used with a standard 10-megohm probe, the device extends the vertical range of your scope by a factor of ten.

The attenuator consists of nine 10-megohm resistors connected in series. A length of spark-plug wire provides support for the resistor array and also serves to introduce distributed capacitance for AC equalization. To preclude arcing, each end should extend an inch or two beyond the terminal.

Once you have commissioned your pulse generator or fence charger, you can fine tune the attenuator by adjusting the bus-wire gimmicks at either end of the spark-plug wire. That is most easily done by generating a high-voltage pulse within the range of your oscilloscope (say 1600 volts peak), measuring with only the 10-megohm probe; then, trimming the length of the gimmicks to give the same defection with the probe connected to the 90-meg attenuator (setting the sensitivity 10 times higher, of course).

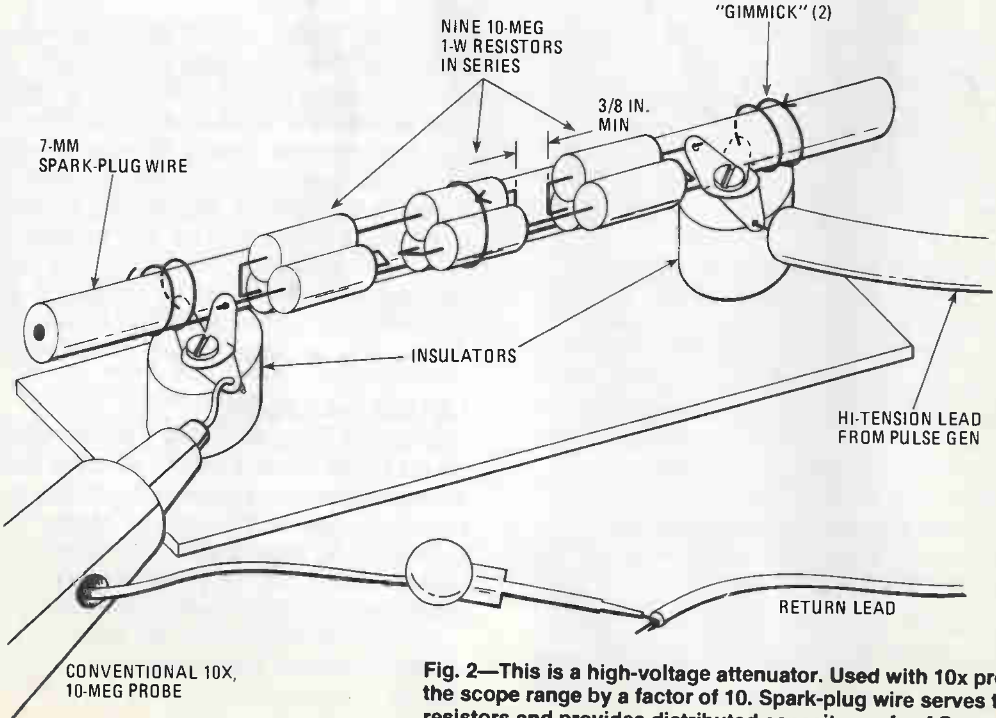


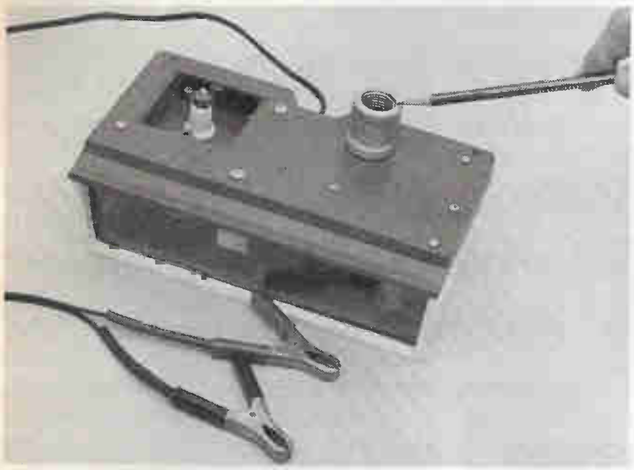
Fig. 2—This is a high-voltage attenuator. Used with 10x probe, it extends the scope range by a factor of 10. Spark-plug wire serves to support resistors and provides distributed capacitance for AC compensation.

Selecting R2

We had advised you during construction to omit one connection to the primary of T1 so that you can now select R2 without energizing the power amplifier. Using clip leads, first connect typical value shown in parts list. Then connect your 'scope to the junction of R6 and R7, and apply power.

For the lab pulse-generator version, now set the RATE control to maximum frequency and select a value for R2 which gives a repetition rate of about 20 Hz. For the fence-charger model. select a value which gives the desired rate, but no higher than 60 times per minute. Remember that the slower the rate, the longer between recharging.

Now turn the supply off and add the missing wire to the power-amplifier circuit. In the author's lab-generator chassis layout, it is necessary to first loosen the coil in order to free the circuit board. If you plan to test the unit with the circuit board loose, be sure to temporarily replace the lugs grounding the coil case and cabinet. Place a cardboard sheet under the circuit board to insulate it from accidental contact with the cabinet coating, etc. The unit is now ready for a performance test.



The fence charger model has a nipple for mounting on a length of water pipe. It effectively grounds the system.

Testing

Connect the high-voltage output to the 90-meg probe or whatever instrument you wish to use to observe the high-voltage pulse. Turn the power supply on and gradually increase the voltage (adjusting the lab-generator rate as desired), synchronizing the 'scope to display the largest excursion. (When you don't know exactly what to expect, it's easy to be fooled into syncing on the backswing or some other minor lobe.)

The unit should start working at a supply voltage of 1.5 to 3 volts, but it will shut itself down down if you vary the voltage too abruptly. If that happens, just turn the power off and then back on.

At a 12-volt input you should get a pulse of about 20 to 30 Kv pk from the lab generator or 3.5 to 5 Kv pk from the fence charger. In the latter version, proceed as follows to decide which secondary lead should be grounded:

1. Turn power off and disconnect scope from both ends. Turn power back on, and using an insulated tool (to avoid getting zapped), bring each end in turn to the transformer case, leaving the opposite end free. One will probably draw a small arc and the other won't.

2. Turn power off and ground the one which drew the smaller arc. Connect the other to the output feedthrough.

3. Reconnect scope, apply power, observe polarity of output pulse. If you get a positive pulse, reverse the primary connections. A negative pulse jumps a longer gap from a small object (the fence wire) to a larger one (the victim) than does a positive pulse (believe it or not).

If you wish to view the current pulse, temporarily hook 0.1 to 0.2-ohm resistor in series with negative power-supply lead, and connect a 'scope across it (being careful to avoid ground loops, as can arise though test connections or via the power-line safety ground). With fence-charger option, if possible, stimulate 1-mile wire by connecting 0.015-μF, 2000-WVDC capacitor across its output. A rising waveform characteristic of *inductor charging* should be obtained—the abrupt drop at its trailing edge of course representing the cutoff of Q3 and the generation of the high-voltage pulse.

With the lab-generator version, dwell is not critical thanks to the relatively low inductance of the typical ignition-coil primary. In the fence-charger option, however, primary inductance will probably be much higher and will vary considerably depending upon your choice of a transformer. Fig. 3 shows the current waveform typical of such a primary. If it ends too soon, that is before the field has reached its steady-state value (A), then maximum output capability cannot be attained. If it ends too late (B), then average current consumption is higher than necessary. To get optimum results (C), adjust the width by changing R6 as needed.

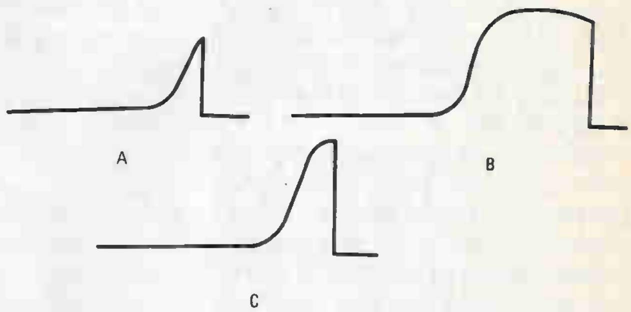


Fig. 3—For the fence-charger option, this is a current pulse seen across the small resistor in series with the supply: In A the pulse width is too short; In (B) The pulse width is too long; and in (C) the pulse width is correct.

If you know the exact value of the small resistor, given the peak voltage appearing across it you can now calculate peak current (I = E/R). A typical value is 4 to 6 amps.

Buttoning Up

Reinstall the circuit board, remembering to replace the lugs which ground the cabinet, pipe coupling, T1, case, etc., and to secure the coil. Test the unit once more, then assemble the cabinet.

If you're using the author's recommended cabinet with the pulse-generator option, leave the high-voltage cable and nipple connected to the coil, passing the other end through the hole in the cabinet top as you bring the top into place. Slide the front panel up into the cabinet top. Now, close the cabinet by swinging the left side down. Moderate force is required to push the coil nipple into the hole. Make sure tongues in the cabinet top engage the mating slots in the bottom, and hold it together with one hand while installing

(Continued on page 32)

Air is the most important ingredient to our survival. Think about it; you may survive a few days without water, a little longer without food, but, deprived of air, your survival time can be measured in minutes.

The quality of the air surrounding many cities has become so poor that many local news stations provide an air-quality report along with the weather forecast. Air pollution is so commonplace now that words have been created to describe it. The word "smog" for example, a contraction of the words "smoke" and "fog." As if smog wasn't enough, today there are new pollution concerns, not the least of which are the increasing CO_2 level, the green-house effect, the depletion in the ozone layer, and acid rain.

Research. Long before there was any talk or concern about air pollution and such, some scientists and experimenters noticed that the ionization of even clean air can improve its quality. Clean air (principally composed of 78% nitrogen and 21% oxygen) is typically full of positive and negative ions in approximately a 5-to-4 ratio. What researchers found was that when this ratio changes one way or the other it has an effect on biological systems.

This idea was popularized by Fred Soyka who, in the 1970's, wrote a book titled "The Ion Effect." Mr. Soyka studied natural occurrences of negative and positive ionized air. His findings and inquiries demonstrated that negatively ionized air had substantial health benefits.

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BY JOHN IOVINE

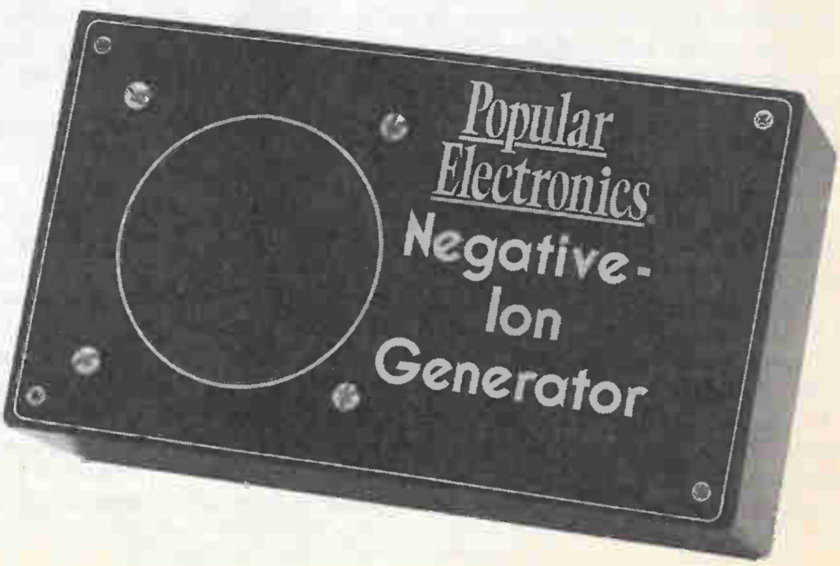
Negative-Ion Generator

Make the very air you breathe healthier with an easy-to-build high voltage project.

To summarize a few points from his book, negative ions help elevate mood, enhance physical performance and training, and sterilize harmful airborne bacteria. An abundance of positive ions on the other hand can be held responsible for a number of low grade medical problems, such as fatigue, headaches, and anxiety.

There are detractors to this point of view. So before I started to design a negative-ion generator, I did some research to find out if it would be worthwhile. I surveyed approximately 100 world-wide scientific reports on the effects of negative ions from 1973 through the present. I can report that out of my survey approximately 80% of the citing's note the beneficial effects of negative ions. Greater than 19% of the reports described no effect, and a few (less than 1%) detailed some detrimental effect. Since the preponderance of the evidence supports the beneficial effects of negative ions, I felt that building an ion generator was a worthwhile project. A summary of some of the beneficial effects reported by some researchers are listed in the boxed text entitled "The Positive Effects of Negative Ions." It is by no means an exhaustive list, it's just a sampling of the scientific benefits noted. But if this is the case it would be to our benefit to improve the quality of air that we breathe with a negative ion generator.

Despite the numerous scientific reports supporting the health benefits of



The Positive Effects of Negative Ions

- Learning enhancement in normal and learning-disabled children. The task used to test the children was a dichotic listening test.
- Negative Ions can be used to decrease amounts of radon in a building atmosphere.
- In one animal study 1279 calves were broken into two groups, one of 649 head and the other of 630 head, negative air ionization was used to test for a prophylactic effectiveness against respiratory diseases. The results were remarkable: In the treated group (649 head) 45 calves became sick and 3 died. In the control group (630 head) 621 became sick and 33 died.
- A 40–50% reduction of microbial air pollution in dental clinics.
- A test using college students showed improved performance on a visual vigilance task.
- In 1983 it was reported that chickens raised in a negatively ionized atmosphere showed improved anabolic processes. The chickens raised in negatively ionized air had an overall greater weight than a control group fed the same quality and quantity of feed. The meat of the treated group had higher protein and essential amino-acid content. In addition, higher concentrations of vitamins E and A were found in their livers.

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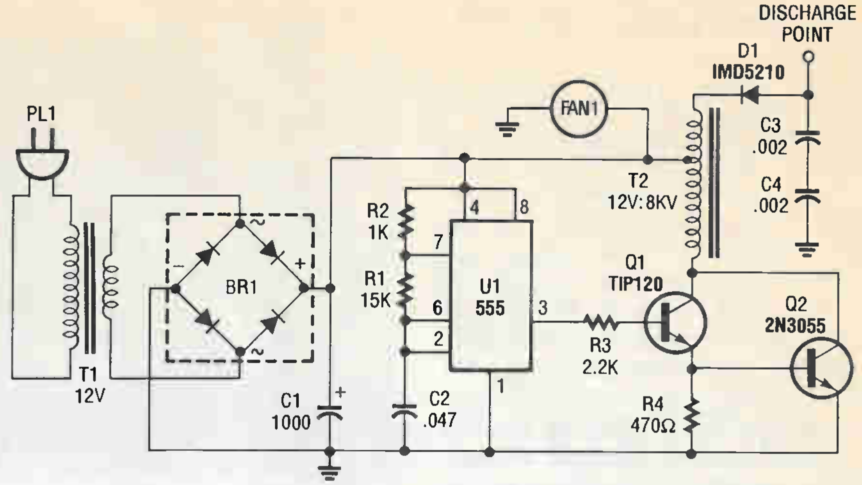


Fig. 1. This is the simple schematic for the Negative-Ion Generator. Note that it is basically a timer that induces a high voltage in the windings of T2.

ionized air, no manufacturer of negative-ion generators can make any health-benefit claims without running afoul of the FDA. For that reason I also will make no such claims. Instead, the research papers supporting this article are listed in the text entitled "Bibliography" so you can do the research on your own and make your own decision.

PARTS LIST FOR THE NEGATIVE-ION GENERATOR

SEMICONDUCTORS
U1—555 timer, integrated circuit
Q1—TIP120 NPN Darlington transistor
Q2—2N3055 power transistor
D1—10,000-volt, 10-mA silicon rectifier diode (see text)
BR1—4-amp, 50-PIV bridge rectifier

RESISTORS
(All resistors are ¼-watt 5% units.)
R1—15,000-ohm
R2—1000-ohm
R3—2200-ohm
R4—470-ohm

CAPACITORS
C1—1000-µF, 15-WVDC electrolytic
C2—0.047-µF, polyester-film
C3, C4—.002-µF, 6,000-WVDC, ceramic-disc

ADDITIONAL PARTS AND MATERIALS
T1—12-volt, 1.2-amp power transformer
T2—12 volt to 8 kilovolt autotransformer
FAN1—12-volt DC fan
Enclosure, line cord, switch, TO-3 socket and heat sink, perfboard, wire, solder, etc.

The following are available from Images Company (P.O. Box 140742 Staten Island, NY 10314-0024; Tel. 718/698-8305): D1 ($1.50), C3 and C4 ($1.50 ea.), and T2 ($17.95). Include an additional $2.50 for shipping and handling. NY residents must add appropiate sales tax.

NOTE: The above prices are subject to change.

The Ion Generator. The design of the Negative-Ion Generator is fairly straightforward (see Fig. 1). The circuit is a high voltage generator. It contains a standard 555 timer that's used to generate square-wave pulses. The pulses are applied to the base of the TIP120 NPN Darlington transistor. The Darlington provides sufficient current to the base of the 2N3055 power transistor to turn it on. Each time that happens, current flows through the high voltage autotransformer, T2. The high voltage lead of the transformer is connected to a 10 kilovolt high voltage diode. Notice the polarity of the diode. It is biased to place a negative charge on C3 and C4, leaving the discharge point negatively charged. The voltage at the discharge point negatively charges the air forced past it by the fan.

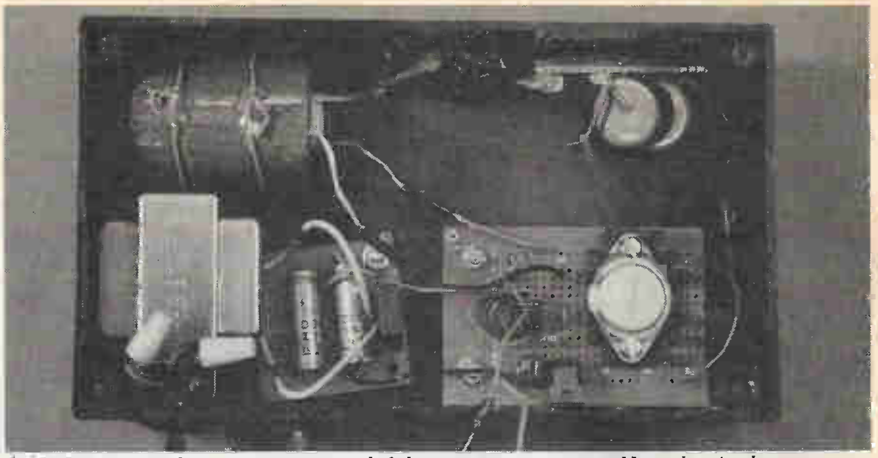
The author's prototype was built on sections of perfboard using point-to-point wiring. It is a suitable method that you can use in your own ion generator provided you follow some precautions: Make sure you place C3, C4, D1, and the discharge point (which we'll describe momentarily) on a piece of perfboard all their own. The junctions between those components should be at least a centimeter apart. Both this little high voltage board and the autotransformer should also be kept at least 1 centimeter away from the perfboard containing the other components, the fan, and the power transformer.

In passing, if you chose not to buy D1

from the supplier mentioned in the Parts List an exact replacement may be difficult to locate. However, even though it has a lower current rating, an ECG-518 should work fine, although this substitution has not been tried.

The discharge point should be "pointy" to enhance the ionization of the air. You can use a sewing needle, for example. An alternate discharge point can be fashioned from a small piece of No. 22 stranded wire. Strip off about ½ inch from one end of the wire and separate the fine copper strands so that they are more or less evenly dispersed. When the wire is connected to the high negative voltage, the end of each strand will behave as a discharge point.

You can use any enclosure large enough to hold all the components. I'd recommend using a plastic enclosure if one is available. You should place a few air holes in the side or bottom of your enclosure for the fan to draw air in. The fan should be situated in the enclosure to pull air in past the discharge point(s) and out through an opening hole at the top of the enclosure.



As you can see, there is some space left between components. Note that in the prototype two capcitors have been used to emulate C1.

Any screen or covering on the fan-outlet hole should be non-metallic or plastic in nature. Using a metal screen would severely cut the efficiency of the generator because the negative ions that come into contact with the metal screen would be neutralized.

When testing the circuit, if you see any arcing or discharge from the high voltage transformer or high voltage capacitors, cut the power immediately. Let the project sit for awhile to let the capacitors discharge, and, without touching the project if possible, coat the faulty area with a little "No Arc" spray (available from Radio Shack). Allow the material to dry before testing the unit again. ■

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the cabinet hardware with the other. Turn the five bottom screws snug, but not tight.

Cabinet assembly of the fence-charger version is easier cause you don't have to cope with the coil neck or connections to the front-panel potentiometer. For outdoor use, however, you will have to caulk seams against the weather. Silicone rubber is good for that purpose because it can later be peeled off if servicing becomes necessary. Acrylic rubber makes a better seal, but because it sticks more tenaciously, it makes later disassembly more difficult.

Carefully apply a very thin bead first along the inside edges of the opening in the top front, and install the front panel. Then, again very carefully and sparingly, apply a bead along the slot in the cabinet bottom; and finally, assemble the top and bottom. Depending on your skill in the application, there may be some squishing around the seams. Surplus material around the outside can be peeled off later, after the sealant has set.

Installation and Operation

For maximum safety, you should, if feasible, connect one side of the lab-generator power supply to Earth ground. If not, then be sure to provide a return path for the spark to one of the power-supply leads. Set the RATE control to get the desired rate, and the power-supply voltage to get the desired output potential. If the output is not excessively loaded, the small in-circuit neon lamp flashes with each pulse. The auto lamp may glow dimly when the rate is set near its upper limit, but otherwise it should never light during normal operation. It does light brightly to warn you when the power leads are reversed or if there is an internal short.

If you need one pulse at a time, or bursts of pulses, connect a pushbutton or momentary switch in series with one of the power-supply leads.

If you have trouble getting lower output voltages, but not higher, the spark-plug cable may have pulled loose. When that happens, high voltage settings give what appears to be normal performance because the spark path is completed by jumping within the neck of the coil; while at the lowest voltage settings it appears not to be working at all. If that difficulty is encountered, pull the cable out, inspect the solder joints, then simply push it back into the coil.

Using the author's cabinet and construction techniques, the fence-charger ground connection is made through the pipe fittings sticking out of the bottom end of the chimney. An Earth-ground means is provided by an ordinary ½-in. water pipe. The length should be chosen to permit the pipe to be driven at least 3 ft deep, but the deeper the better, depending on estimated conductivity of the soil; with enough pipe rising above ground to place the unit at a comfortable viewing level. Thus a pipe of at least 7 ft is required. A more effective ground can be had by adding salt to the soil.

Temporarily screw a pipe cap onto top end so as to protect the threads during hammering operation. Pound it into the ground, remove the cap, and screw the fence-charger assembly onto the end. Connect the fence and battery to the unit.

The neon lamp flashes with each pulse to assure you that everything is working okay, except in absolute darkness, since a few photons of light are necessary to *prime* the neon. That apparent drawback, however, has the definite earmarks of an advantage because when it's pitch black the unit cannot call itself to the attention of an interloper. ■