BUILD THE POOR-MAN'S PLASMA GLOBE

This plasma globe uses an ordinary, decorative light bulb—and the power supply is great for other high-voltage experiments!

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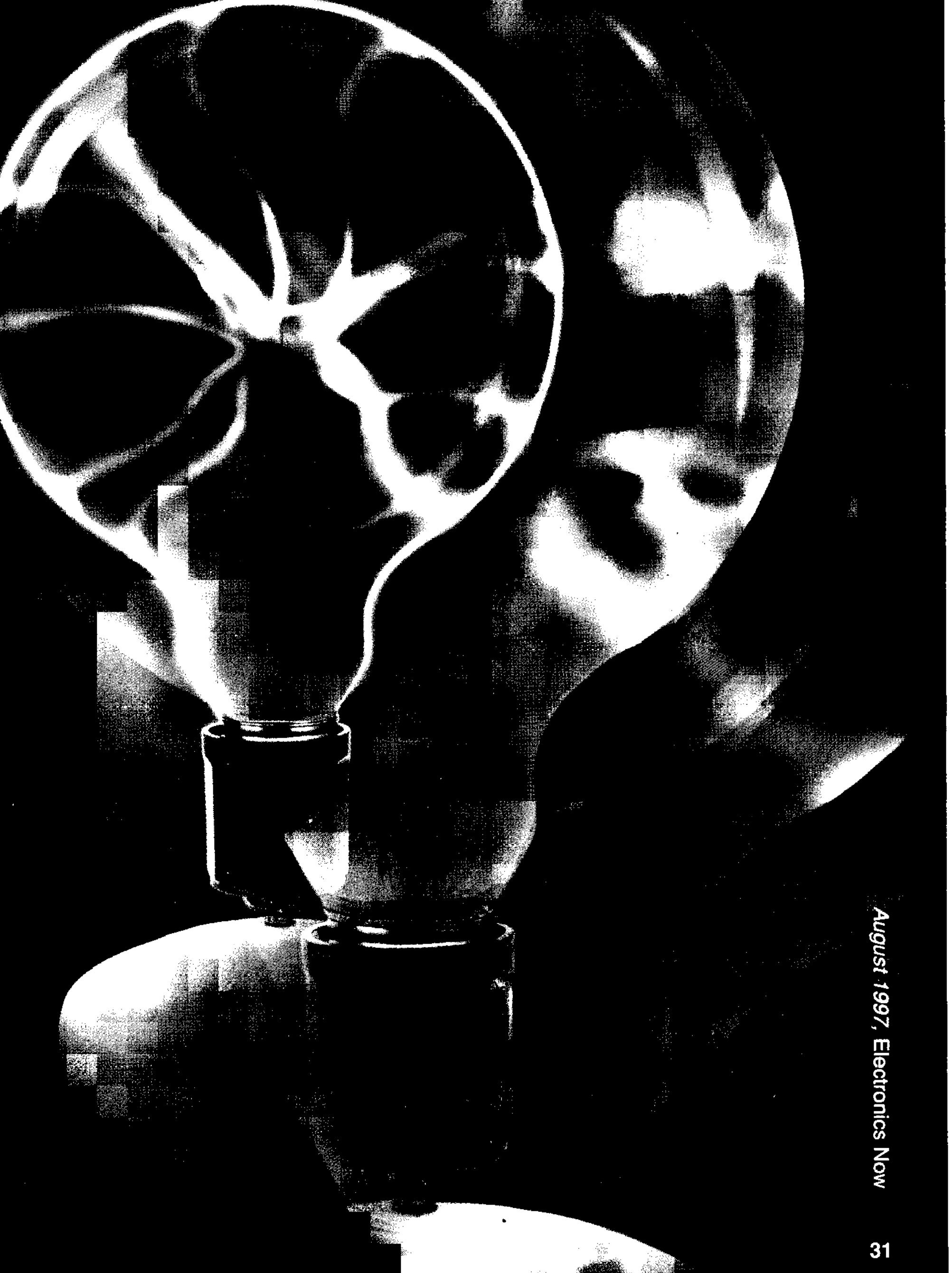
Man has been fascinated by high-voltage electricity ever since our distant ancestors became smart enough to realize that lightning was dangerous. However, it was thousands of years until man discovered that lightning was electrical in nature, and later was able to produce the effect on his own. Today, experimenting with high voltage is one of the most popular activities among electronics hobbyists. It's fascinating to create your own miniature lighting, plasma globe storms, and other high-voltage effects.

The plasma-globe display described here is based on a solid-state power supply that produces a low-power, high-voltage, high-frequency electrical discharge. The main step-up transformer is simply a TV-flyback transformer with a new primary winding. To prevent overheating, the reworked transformer is submerged in mineral oil. The plasma globe itself is an ordinary 100-watt clear-globe light bulb.

Many other high-voltage experiments with bizarre effects can be conducted using the power supply. It is powered from a 12-volt DC supply, so you don't need to get involved with AC-line current. This is one of those projects that will make you feel just a bit like a mad scientist.



The Circuit. Figure 1 is a schematic of the high-voltage power supply. It is simply a step-up transformer driven by an AC signal. Input power is supplied to the circuit through 10-amp fuse F1 and switch S1. The circuit requires an input of 12- to 14-volts DC at 5 to 7 amperes. Since the power input is DC instead of AC, the transformer's input signal is generated by IC1, a Silicon General SG3525A pulse-width-modulator circuit. That component has two outputs that are 180° out of phase. The amount of time that both outputs are off (the "dead" time) is set by R1.

The output frequency of IC1 is made variable by potentiometer R3, with R2 setting the upper limit. That way, the operating frequency can be tuned to the frequency needed by T1 and any particular load connected to it. If you are thinking of connecting a voltage multiplier to the output as an experiment, varying the frequency will run the circuit out of resonance. That will give you a variable high-voltage DC supply.

The outputs from IC1 are amplified by Q1 and Q2, a pair of MOS-FET transistors in a push-pull configuration. Since the transistors are driving a highly inductive load (the step-up transformer), L1 and Cl decouple the transistors from IC1, keeping the RF energy generated by the transistors away from the IC. Any parasitic oscillation that appears at the gates of Q1 and Q2 is eliminated by R4 and R5.

The step-up transformer, T1, is a standard TV flyback transformer to which a new primary winding is added during construction. The secondary winding is part of the original transformer. A snubber network consisting of R6 and C3 controls any energy caused by the transformer's leakage inductance. Otherwise, high-voltage spikes would quickly break down the transistors. The center tap of T1 's primary is RF-grounded by C4 and C5, bypassing any high frequencies that appear at that point. The high-voltage output of the power supply is the result of T1's secondary coil resonating at around 50 to 70 kHz.

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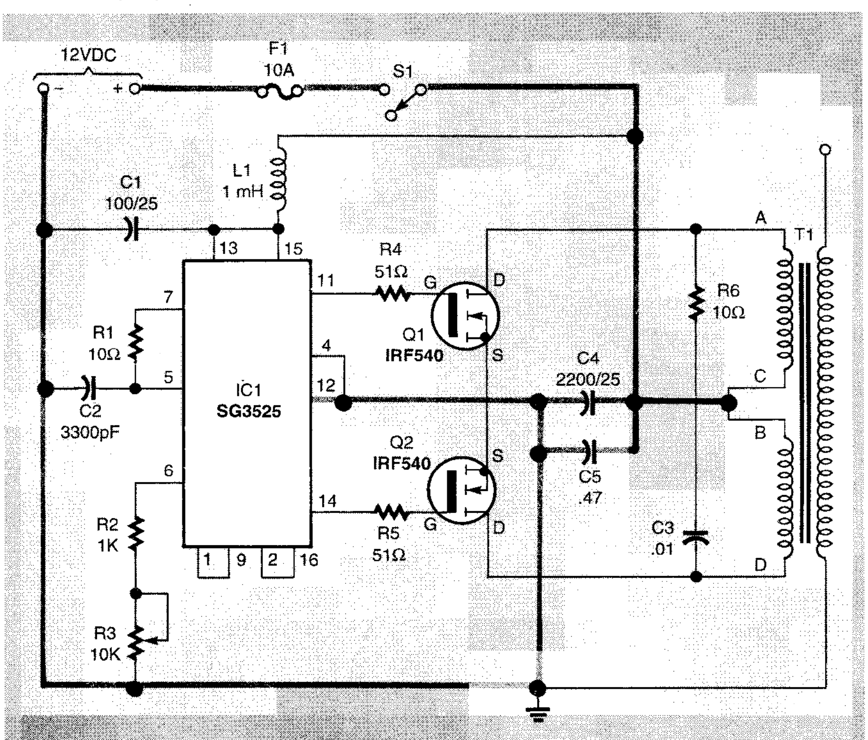

Fig. I. The Poor Man's Plasma Globe is built around a high-voltage power supply. Transformer T1 is a modified television flyback transformer. Colored connections must carry a current up to 7 amps.

Construction. The Plasma Globe is one of those projects in which the vast majority of your time will be spent more in mechanical construction than in actual electronic assembly. If you do not have access to the necessary tools to make the base, individual components and a kit of all parts is available from the source given in the Parts List. While the parts themselves are not exotic, you might find yourself spending a lot of time and effort shopping at many different stores for the various items needed. Some of the more unusual items required include a TV flyback transformer, PVC drain-pipe parts for the tank, and mineral oil to fill it.

There is no PC board for the Plasma Globe because many of the traces wouldn't be able to handle the current. Instead, a 2-inch square piece of perforated construction board and point-to-point wiring is used. The parts-placement diagram in Fig. 2 is just one suggested layout design that you can follow if you choose. Parts placement is not exactly critical, except for Q1 and Q2 if you either buy a pre-drilled base from the source given in the Parts List or make one from the plans in this article. Holes in the base are used to mount the transistors. That way, the base can be used as a heatsink for the transistors. Bolting the transistors to the base is also a simple way to mount the circuit board to the unit. If you're not using an aluminum base, or choose another method of mounting the circuit board to the base, you'll need to come up with some sort of heatsink arrangement for the transistors. If you are using one of those bases, make sure that the holes on the transistor tabs line up with the holes drilled on the base before you solder anything to the transistor leads.

Wire-wrap connections can be used for the connections that are not drawn in color-those connections must be made with 20-gauge wire. However, instead of using wire wrap, it might be easier to simply bend the component leads over and solder them to one another wherever they are supposed to interconnect. Be sure to insulate any connections that cross.

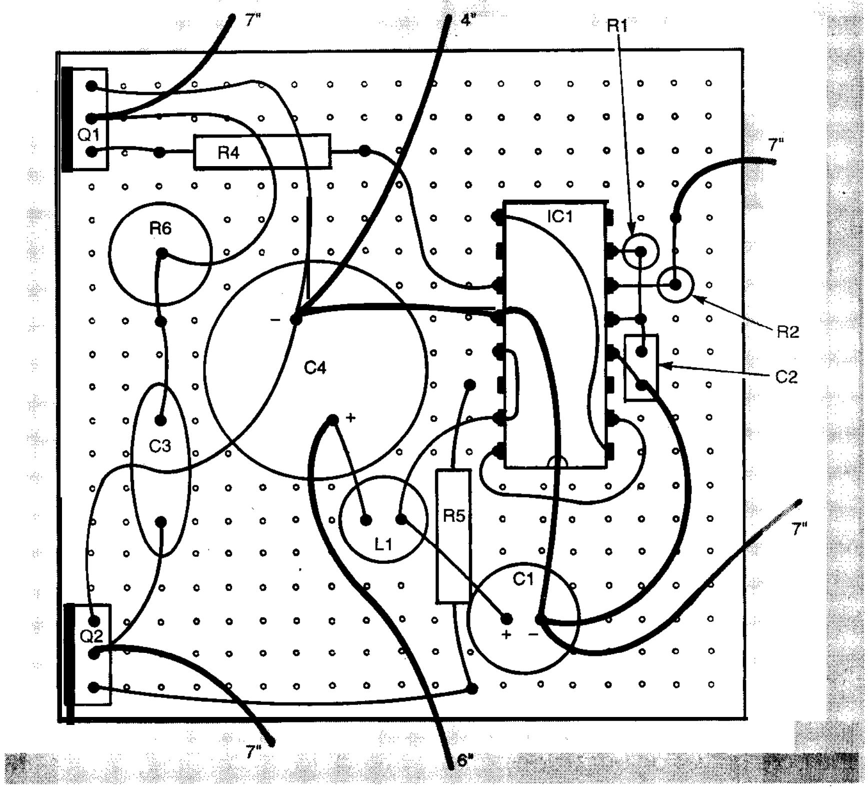

Fig. 2. The circuit is built on a 2-inch square piece of perforated construction board. The colored wires are 20 gauge in order to carry the heavy currents involved.

Six 20-gauge wire leads must be soldered to the finished board. Figure 2 indicates their positions and lengths. You'll trim them down to fit when it comes time for the final wiring.

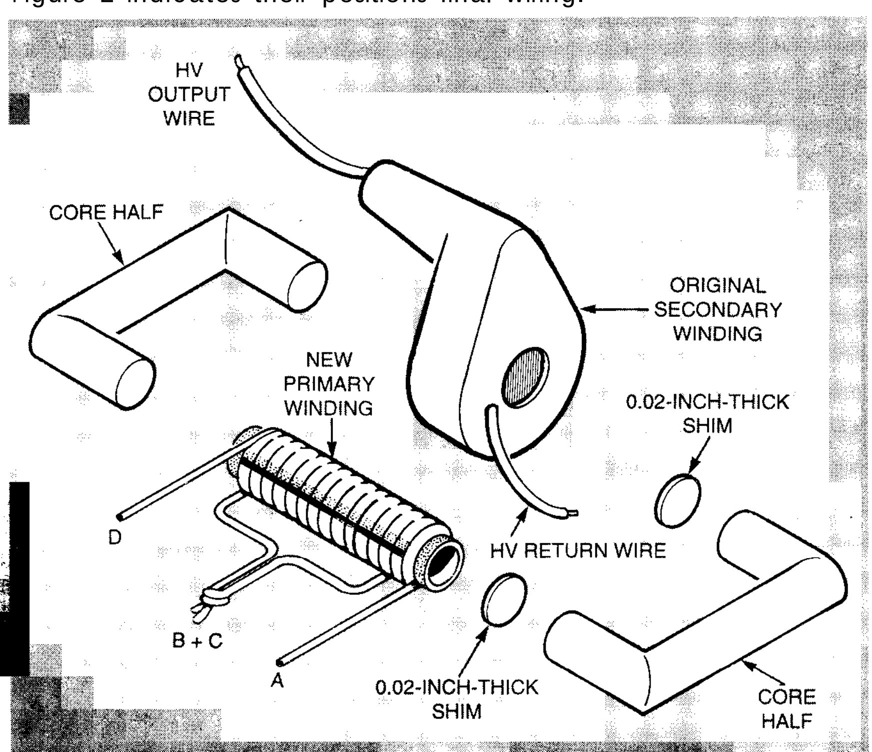

Fig. 3. It's easy to modify the flyback transformer. Parallel-wind 15 turns of 18-gauge magnet wire onto a $1^{1}/_{6}$-inch-long bobbin and wrap the winding with electrical tape. Don't forget the 0.02-inch thick shims between the core halves when reassembling. Use a nylon wire tie to hold the modified transformer together.

Flyback Transformer. Any black-and-white flyback transformer will do for the Plasma Globe. The easiest and cheapest way to get a transformer is to find one surplus. A specific part number is not important-black-and-white flyback transformers are somewhat generic in design. A suitable flyback is available from the source given in the Parts List if you have difficulty finding one or are not interested in buying a complete kit.

The modifications to the flyback transformer are detailed in Fig. 3. There is usually some sort of circuit board that has several pins in it. Those pins are connected to the transformer's primary windings. The primary windings are usually made from enameled magnet wire. There will also be a heavier, insulated wire. That wire is the ground connection of the high-voltage secondary winding. Since a new primary will be wound onto the flyback, any connections to the original primary can be discarded. However, the ground connection for the secondary winding is needed, so it is important to identify that wire first.

Unscrew the two nuts that hold the circuit board in place and remove the base. Clip off the wires from the circuit board. Verify which wire is the secondary return wire by measuring the resistance to the secondary high-voltage wire that sticks out of the top of the transformer. There will be a low resistance between the two wires. Clip off the wires from the old primary as close to the body of the transformer as possible.

The metal bracket that holds the transformer core together is now removed. The core halves are brittle, so be careful when doing the following steps. One end of the bracket passes through the body of the transformer and the other is more or less free-a bit of glue holds it in place. Bend the glued side of the bracket away from the core halves so that you can twist it back and forth. Wiggle it until it slides out of the transistor body; you might even have to "unscrew" it. Once the bracket is freed up enough, the bottom core half should slide out of the core. The

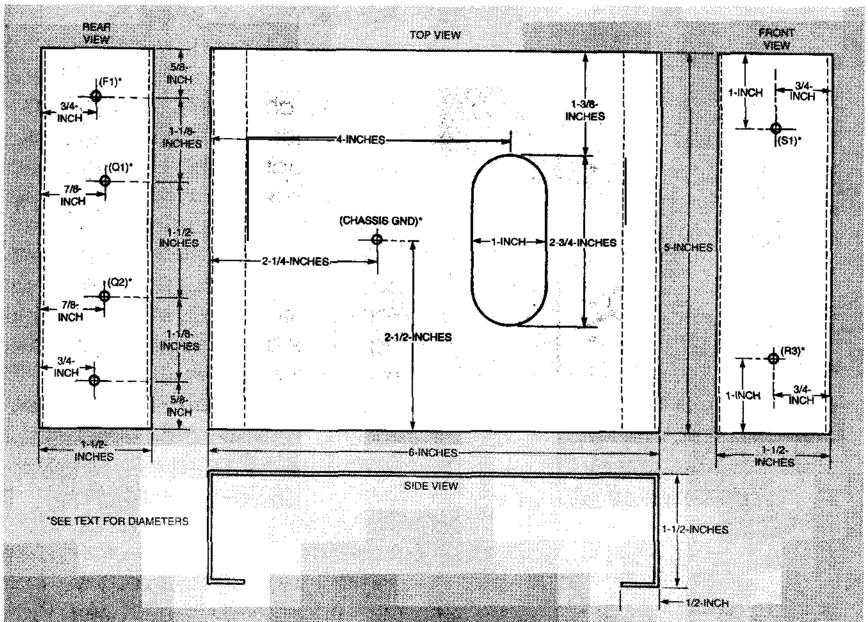

Fig. 4. You can make your own aluminum chassis by following this plan.

metal bracket and any spacers that might be located between the core halves are no longer needed, so they may be discarded. Set the transformer winding and the core halves aside for the moment in a safe place.

The new primary will be wound onto a bobbin. The bobbin can be a piece of rolled-up cardboard or plastic, plastic tubing, or any similar arrangement. The bobbin should be about $1^1/_4$ inches in length with an outside diameter of $^5/_8$ inch and an inside diameter of $^1/_2$ inch. Take two lengths of 18-gauge magnet wire and mark the ends of one wire 'A" and 'C." Mark the ends of the other wire 'B" and "D."

Holding the 'A" side of the first wire and the 'B" side of the second wire together, parallel wind 15 turns onto the bobbin. That type of winding is called a *bifilar* winding-the first wire (winding A-C in Fig. 1) will be loops 1, 3, 5, etc. and the second wire (winding B-D) will be loops 2, 4, 6. etc. There will be 30 loops of wire on the bobbin-15 for each winding. Wrap the bobbin with electrical tape to hold the windings in place. Leave about 5 inches of wire for the leads. Scrape the enamel coating from the ends of the wires and tin the ends. Connect wires "B" and 'C" together.

New shims for the core halves are made from a non-conductive material that is 0.02-inches thick. A business card is usually about 0.012-inches thick, so two layers of business-card stock placed between the core halves on each side of the transformer should do the trick. Check the shim thickness with a caliper if you can, as the thickness is somewhat critical. An alternative is to purchase some sheet plastic of the proper thickness from a hobby shop or craft store.

The transformer core halves, shims, primary winding, and secondary winding are reassembled as shown in Fig. 3. A nylon wire tie can be used to hold the modified transformer together. Do not use the original metal bracket as it only helps to overheat the transformer in its modified form. You can extend the ground return and output leads later on if necessary.

Mounting Base. If you bought the complete kit, then you already have a ready-to-use chassis, If you want to make your own, you can follow the dimensions given in Fig. 4 and make one out of sheet aluminum. The cutout on top of the base can be made by punching 1-inch holes spaced $1^3/_4$-inches center-to-center. Cut and file the remaining material.

The following holes should be drilled to match the size of the hardware you're using. Drill a hole for the chassis ground in the position indicated. That hole should be a clearance diameter for a 6-32 machine screw. Drill holes for poten-

PARTS LIST FOR THE POOR MAN'S PLASMA GLOBE

RESISTORS
(All resistors are $^1/_4$-watt, 5% units unless otherwise indicated.)
R1—10-ohms
R2—1000-ohms
R3—10,000-ohms, potentiometer, panel-mount
R4, R5—51-ohms
R6—10-ohms, 3-watt, non-inductive (not wire-wound)

CAPACITORS
C1—100-µF, 25-WVDC, electrolytic
C2—3300-pF, 50-WVDC, polyester
C3—0.01-µF, ceramic-disc
C4—2200-µF, 25-WVDC, electrolytic
C5—0.47-µF, 250-WVDC, polyester

SEMICONDUCTORS
IC1—SG3525A pulse-width modulator, integrated circuit (Silicon General)
Q1, Q2—IRF540 MOSFET transistor

ADDITIONAL PARTS AND MATERIALS
S1—SPST 7-amp switch
T1—Television flyback transformer (see text)
L1—1-mH choke coil
F1—10-amp fuse
Fuse holder, 6-32 X $^3/_8$ nylon screws and nuts, 6-32 X $^1/_2$ inch screws and nuts, #6 solder lugs, mica insulators for Q1 and Q2, wire strain relief, perforated construction board, 20-gauge wire, 18-gauge wire, 6 feet of 18-gauge magnet wire, metal chassis, 3-inch flat PVC end cap, 3-inch PVC top cap (3-inch curved PVC or soft plastic), 6-inch length of 3-inch diameter PVC tube, mineral oil, hardware, etc.

Note: The following items are available from Information Unlimited, PO Box 716, Amherst, NH 03031, Tel: 800-221-1705, 603-673-4730, Fax: 603-672-5406, web: http://www.amazing1.com: Complete kit of all parts including flyback, PVC parts, hardware, and pre-formed, pre-drilled aluminum base (TCL5-K), \$49.50; Flyback transformer (TCL/SUPPLY), \$14.50; Modified flyback (TCLFLY10), \$24.50; 12-volt, T-amp DC power supply, \$39.50; Complete kit plus power supply (COMBOTCL), \$79.50. Please add \$5 shipping and handling on orders up to \$25, \$7.50 on orders up to \$50, and \$10 on orders up to \$100. NH residents must add appropriate sales tax.

tiometer R3 and switch S1 on the front side and holes for the fuse holder and power-wire bushing on the rear side. Holes for the mounting tabs of Q1 and Q2 are drilled to the same center-to-center spacing as the transistors, They should be centered side-to-side within the rear panel and 1 inch from the top. If you followed the parts layout in Fig. 2, the holes will be $1\frac{1}{2}$ inches apart. The holes for Q1 and Q2 must be de-burred to prevent the transistors from shorting through the mica insulators.

Mount a 3-inch flat-bottom PVC cap onto the top of the base. The cap should be centered on the chassis-ground hole and the elongated slot in the top of the base. Glue or double-sided tape can hold it in place for now. Using the chassis-ground hole in the base as a guide, drill the same size hole through the PVC cap. Using detail 'C" in Fig, 5 as a guide, place a 6-32 screw with a solder lug on each side through the ground hole and PVC cap and tighten in place with a nut. Drill three additional holes in the PVC cap for the transformer-wire lugs. Those holes should be equally spaced within the elongated slot in the base. Each hole receives a screw and pair of lugs in the same way the chassis-mounting screw was installed. Bend the lugs on each side of all four screws up at a right angle and seal the holes over the screw heads and nuts on both sides with epoxy or hot-melt glue. Do not get glue on the parts of the lugs where you will apply solder.

Main Assembly. Mount the circuit board to the underside of the chassis as shown in Fig. 6. The mounting screws for Q1 and Q2 hold the board in place. Be sure to use nylon screws, and put mica insulators between the transistor tabs and the chassis before mounting. Place some double-sided tape under the board to prevent any accidental shorts to the chassis. Use Fig. 6 as a guide when making the final wire

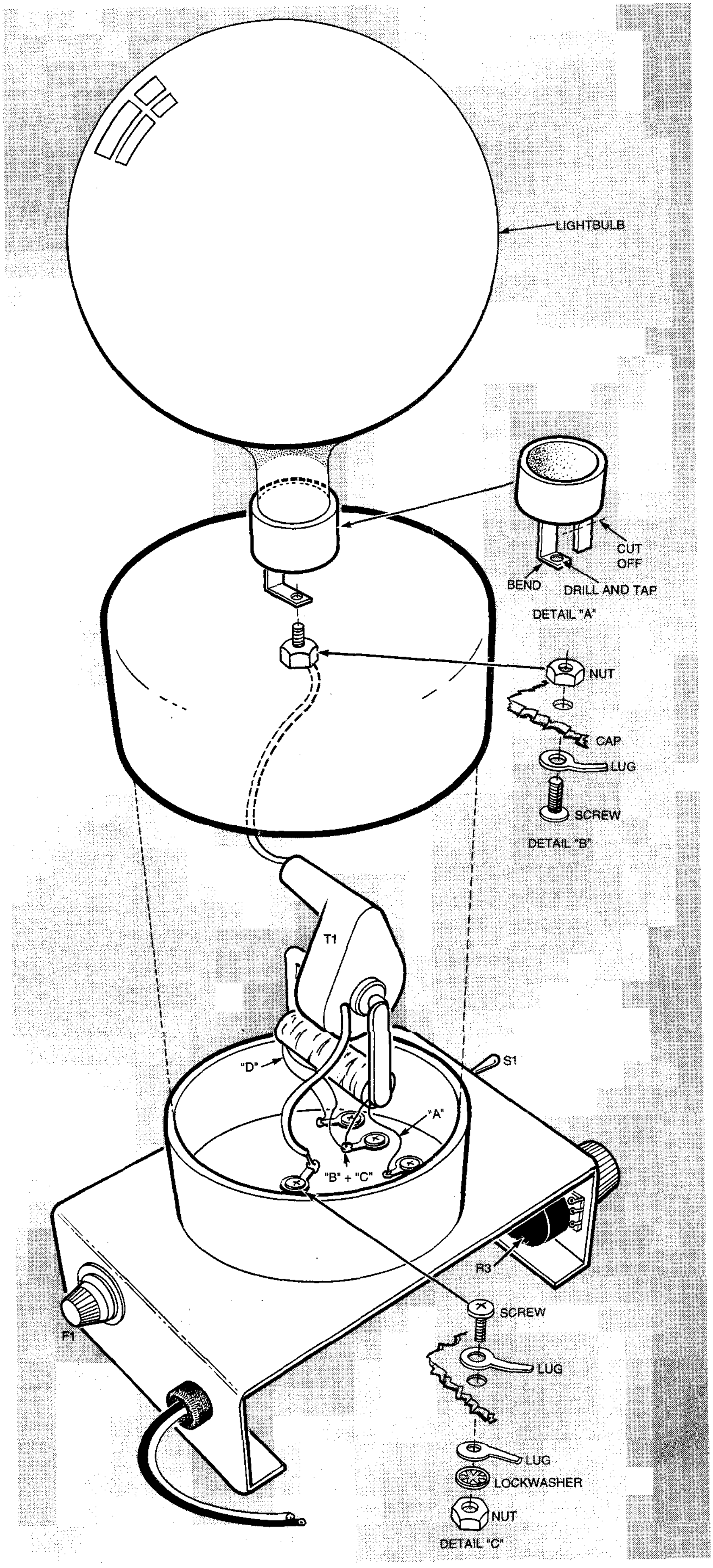

Fig. 5. Solder the transformer primary leads and ground lead to the top lugs as shown. The transformer ground lead can be lengthened if necessary. The light bulb is attached to the output by modifying a plug-in socket as shown in detail "A." The center prong is bent 90 degrees and has a hole drilled through it.

connections on the underside of the chassis. Use 18-gauge wire for the power-input leads. Those wires are indicated in color.

Turn the assembly upright and solder the transformer primary leads to the top lugs as shown in Fig. 5. The transformer ground lead is connected to the chassis-ground lug. It can be lengthened with l&gauge wire if necessary. Insulate the splice with heat-shrink tubing. Re-check all soldering and wiring, and check the transistor tabs with an ohmmeter to make sure that they are not shorted to the chassis. Do not cement the PVC pipe to the PVC cap just yet, because once you do so, the transformer can't be accessed without a hacksaw if testing shows that there is a problem.

If you want to run it for more than just a few seconds at a time, the transformer must be submerged in mineral oil both for its cooling and insulating effects,

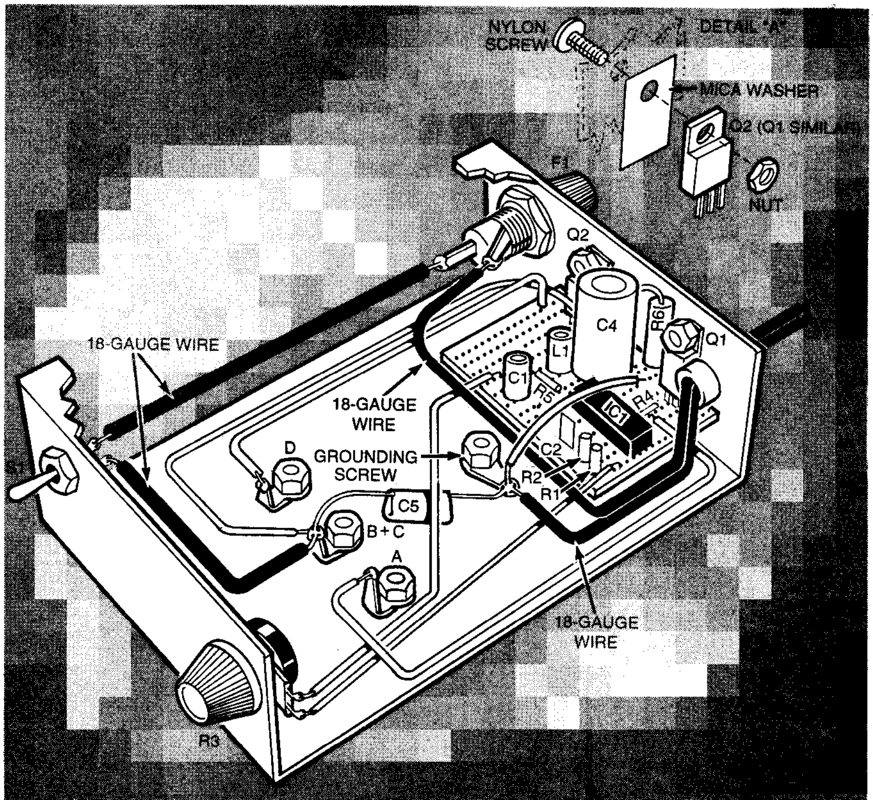

Fig. 6. The circuit board mounts to the underside of the chassis with nylon screws. Use mica insulators between the transistor tabs and the chassis. Put double-sided tape under the board to prevent shorting to the chassis. Use 18-gauge wire where indicated to carry the heavy currents.

Testing and Final Assembly. Since the circuit draws 5 to 7 amps when tuned to the resonant frequency of T1, a 12- to 14-volt DC power supply with a current capacity of at least 7 amps is needed for the Plasma Globe. That's quite a bit of current, so an ordinary power supply just won't do. A car battery will work, but that's hardly convenient. You can build a power supply, but you'll need a very large transformer, an exotic high-current regulator, and some beefy capacitors-an expensive proposition and a full-blown project by itself. It's much cheaper and easier to buy a ready-made power supply. A fixed 12-volt, 7-amp bench-top supply is available from the source given in the Parts List. Such a power supply can be useful on a test bench for years to come, which might make such a purchase a wise investment. Another alternative is a 10-amp car-battery charger, which is also useful off the test bench.

Turn potentiometer R3 fully counterclockwise and make sure that switch S1 is in the off position. Connect one end of a test lead to the chassis ground and place the other end about an inch from the bare-output wire of T1. It is very important to keep your body away from the output. Any discharge sparks can hurt, maim, or even kill. Connect the 12-volt power supply with an ammeter in series and turn on switch S1. The standby current should be about 1 amp. Slowly turn R3 clockwise and note that the current rises to about 2 amps with some corona visible at the output. At that current level, the circuit can be used continuously without risk of overheating the transformer. Continue turning R3 clockwise and note a sharp jump in current to around 7 amps. The output terminal's high-voltage discharge will come to life. Do not run it for more than a few seconds at that level or the transformer will likely overheat.

If everything is working, you're ready to seal the PVC enclosure tube. Slide the tube down over the transformer into the base cap to make sure everything fits properly. If the output lead is too short to reach the top of the tube, lengthen it with l&gauge wire and insulate the splice with heat-shrink tubing. Remove the PVC tube, apply PCV plumbing cement to the bottom of the tube, and slide it back into the base cap. In a few seconds, a liquid-tight seal that will never come apart will form. The tube can then be filled with mineral oil to the top of the transformer.

Drill a small hole in the center of the top cap. Install a screw, solder lug, and nut as shown in detail 'B" in Fig. 5. The arrangement is similar to the connections at the bottom to the tube. The high-voltage wire from T1 is soldered to the lug. The top cap does not have to be cemented onto the tube as long as the Plasma Globe is always kept in an upright position.

At The Top. The plasma globe itself is simply a decorative 100-watt clear-globe light bulb attached to the output. Those types of bulbs are usually found in specialty lighting stores. Detail "A" in Fig. 5 shows one way to connect a light-bulb socket to the output. Use a socket that plugs right into an AC outlet. Bend the prong that goes to the center contact of the bulb. The other prong is cut off flush with the bottom of the socket. The center prong is

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TABLE I-COMPARISON OF LINEAR AND SWITCHING POWER SUPPLIES

Parameter	Switching Supply	Linear Supplty
Efficiency	**60 to 80%**	**30** to **50%**
RF Noise	Can be a problem unless shielded	Usually negligible
Transformers	Smaller, lighter, high-frequency magnetics	Requires bulky 60-Hz magnetics
Ripple	10 to 40 mV pk-pk	1 to 5 mV pk-pk
Regulation	**0.3** to **1%** (V_{FL})	0.05 to **0.1%** (V_{FL})
Power/Weight Ratio	30 Watts/lb. (avg.)	15 Watts/lb. (avg.)
Temperature Rise	**20** to 40 deg. C above ambient	50 to 100 deg. C above ambient
Reliability	Cooler operation improves the reliability	Runs much hotter and can degrade reliability

ponent in the PWM circuit with a component of a different value can effect the switching frequency, which, in turn, may render any RF suppression techniques (which have been optimized for the original frequency) ineffective. Also, use only the same type of parts. If a tantalum capacitor must be replaced, it should be replaced with a tantalum capacitor of the same value. The same is true for all other components.

- Leave calibration adjustments alone. Some versions of switching supplies may contain one or more adjustments to alter such things as current output, voltage reference, or some aspect of the switching circuit. Unless the tools and instruments are available to perform a proper service alignment, it is usually best to leave those adjustments alone. Otherwise, an improper adjustment can degrade the supply just as much as the use of an improper component.

Conclusion. The switching power supply, like all other power supplies, must convert an AC line voltage into some value of DC voltage and current that is used to power an electrical load. A switching supply accomplishes that by chopping a high-voltage, unregulated DC signal at very high frequencies (radio frequencies), transforming the chopped DC into a lower-voltage AC signal, then re-rectifying and re-filtering the AC signal into the desired DC voltage.

The primary advantage of the switching technique is efficiency. Much less power is wasted in a switching supply than in a linear supply, so more output power can usually be developed for the same amount of input power. Another advantage is compactness. Even though more components are needed to make a switching supply, they can be much smaller. That results in a smaller overall assembly

There are some disadvantages encountered in switching supplies. RF noise is the most serious of those. The high-frequency signals generated by the switching network can cause serious interference in other circuits. A variety of noise-suppression techniques are used to keep the RF under control. Regulation and ripple are not as good as in a comparable linear supply, but a switching supply will still work well in many applications.

As switching frequencies rise and RF suppression techniques become more effective, switching power supplies will become the preferred supply for high-power applications where efficiency and size are critical. Ω

PLASMA GLOBE

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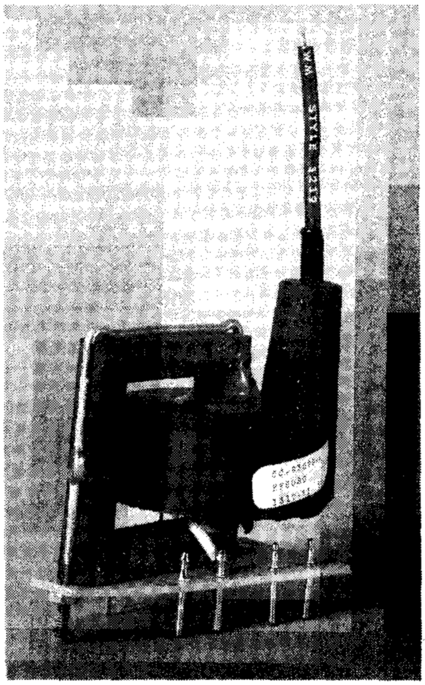
bent 90 degrees. Drill and tap a hole through the bent prong so that it can be attached to the small screw in the top cap. Whenever possible, use clear burned-out light bulbs-they work just as well as good ones.



Here is a standard television-flyback transformer. Modifying it by adding a new primary winding is the heart of the Poor Man's Plasma Globe.

Many interesting experiments can be carried out with the Poor Man's Plasma Globe. You can test different incandescent light bulbs for various effects, try lighting up fluorescent tubes, or even connect a mini-Jacob's Ladder to the output. If you try the Jacob's Ladder, don't expect much in the way of dramatics. You need a lot more than 7 amps to climb a big ladder,

The one important thing to remember with any high-voltage experiment is safety! Nikola Tesla would routinely adjust his high-voltage equipment with one hand in his pocket in order to prevent any accidental shock from zapping his heart. His death at the ripe old age of 86 is testimony to the fact that one can never be too cautious around electricity-high-voltage or otherwise. Ω