Experimenter's Corner

By Forrest M. Mims

HIGH-VOLTAGE DC/DC CONVERTERS

IN THIS day of low-voltage semiconductor circuits that are often battery-powered, electronics experimenters rarely use more than 10 or 15 volts for their projects. But, although vacuum-tube projects are becomingly increasingly rare, there are still many requirements for high voltages in modern circuits. For example, neon lamps require 60 to 70 volts, semiconductor laser pulse power supplies require up to several hundred volts, and xenon flash tubes require several hundred discharge volts and several kilovolts of trigger potential. Other high voltage components include photomultiplier tubes, helium-neon laser tubes, and image converters.

Some of the more exotic components that require a high operating potential are far too expensive for the average hobbyist, but many HV components are readily available. Advertisers in this magazine regularly offer such goodies as neon glow lamps, laser tubes, laser diodes, Panaplex™ displays, and assorted HV capacitors, SCR's, triacs, and rectifiers.

Several different circuits can be used to generate the high voltages required by these and other components. The most common up-converters are powered by household line current. This, of course, poses a safety problem in addition to the HV output and limits portability to the length of the power cord. For this reason miniature solid-state dc-to-dc voltage converters that operate from low-voltage batteries are very popular with both engineers and experimenters who require a high-voltage power supply.

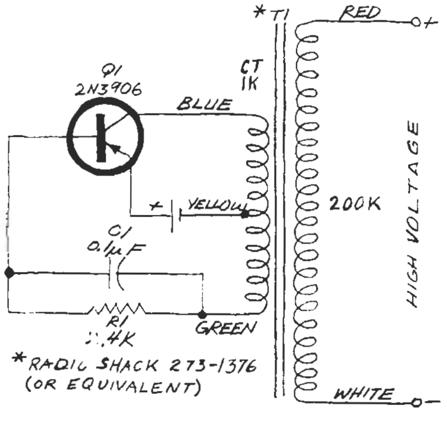


Fig. 1. Simple dc/dc converter.

Dc-to-dc Converters. Let's examine two very simple dc-to-dc converters that can be used in low-current, high-voltage applications. The first circuit, shown in Fig. 1, is ultra-simple and illustrates the miniaturization potential of a solid-state high-voltage power supply.

The circuit is a modified Hartley oscillator that uses an ordinary audio input transformer for the inductor. The low-impedance, center-tapped secondary supplies the feedback required to start and maintain oscillation. The pulses generated by the oscillator pass through the secondary winding, where they are inductively coupled into the primary. The transformer steps up the input from a few volts of steady dc to several hundred volts of rapidly pulsating current.

To give some idea of the performance of this potent circuit, here's a table of the outputs I measured for a range of input voltages:

Input (volts)	**Output** (volts)
0.5	1
1.0	200
2.0	440
3.0	625
4.0	800
5.0	900
6.0	1000

These potentials were measured under open-circuit conditions. When the converter is connected to an output device, the subsequent load will reduce the output voltage. Nevertheless, the performance of the circuit is quite impressive. Incidentally, with the component values specified, the oscillator frequency ranged from 344 to 574 Hz over the range of input voltages. The pulse width was a relatively constant 150 µs.

The current output of this circuit is minuscule, but it can easity ionize a neon lamp or power a semiconductor laser power supply. It can also operate the simple neon-lamp relaxation oscillator shown in Fig. 2. This circuit will flash about once a second with the component values shown. In operation, *C1* charges through *R1* until the breakdown voltage of *I1* is reached. When *I1* fires, *C1* discharges through *I1*, and the cycle repeats. Diode *D1* keeps *C1* from discharging back through the transformer winding.

A single 1.5-volt cell will provide enough power when using the dc-to-dc converter to operate neon lamps. Since a neon lamp requires 60 to 70 volts for operation, this provides an impressive demonstration of the circuit's high-voltage capability.

The current drain of the Fig. 1 circuit connected to the neon flasher in Fig. 2 is fairly low. The circuit draws 12.3 mA from a fresh D cell at 1.5 volts, 8.3 mA from a fully charged 1.2-volt nickel-cadmium cell, and only 6.8 mA from a 1-volt source.

The simple circuit in Fig. 1 is typical of most dc-to-dc converters in that the transformer plays an active role in both the oscillator and HV sections of the circuit. Dc-to-dc converters can also be designed so that the transformer functions strictly as a voltage converter. One possibility is shown in Fig. 3, where a unijunction transistor oscillator is connected to a high-turns-ratio input transformer like the one used in Fig. 1. The oscillator produces a series of fast risetime pulses each time *C1* discharges through the emitter-to-B1 junction of *Q1*. The pulses are passed through the low-impedance winding of the transformer

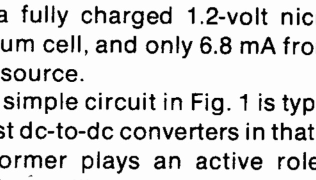


Fig. 2. Neon relaxation oscillator.

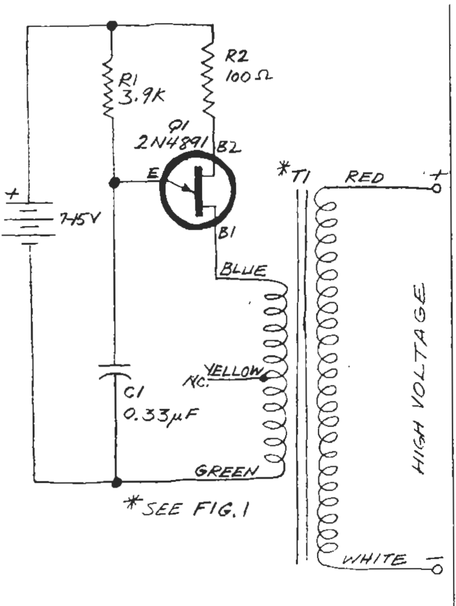


Fig. 3. UJT dc/dc converter.

and induced into the high-impedance winding as high voltage pulses.

Due to the presence of the unijunction transistor, the circuit in Fig. 3 requires a higher operating voltage (7 to 15 volts) than the circuit in Fig. 1. But at 10 volts the circuit will operate the neon flasher in Fig. 2 with a current drain of only 0.5 mA. This corresponds to a total power consumption of about 5 mW versus about 18 mW for the previous circuit.

Conclusion. The two simple dc-to-dc converters described in this column are adequate for powering neon lamps, diode-laser pulse generators, and other low-current devices. If you have access to an oscilloscope, you can watch the output voltages while tinkering with the values of *R1* and *C1* in both circuits to optimize the operating conditions. More powerful converters are required for many HV applications, and a subsequent column will continue this interesting subject with a couple of additional dc-to-dc converters.

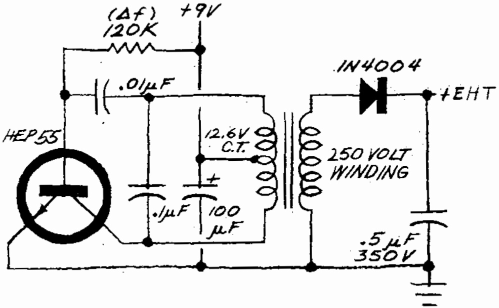
Meanwhile, try experimenting with the circuits described here to get experience. Finally, always use care when experimenting with *any* high-voltage circuit. Small size and low battery voltage mean little when high voltage is present! A low-current shock may not harm you, but the resulting reflex jerk may injure a hand, arm, or elbow and knock items from your workbench. A high-current shock, such as from a charged capacitor, can be fatal. ◆

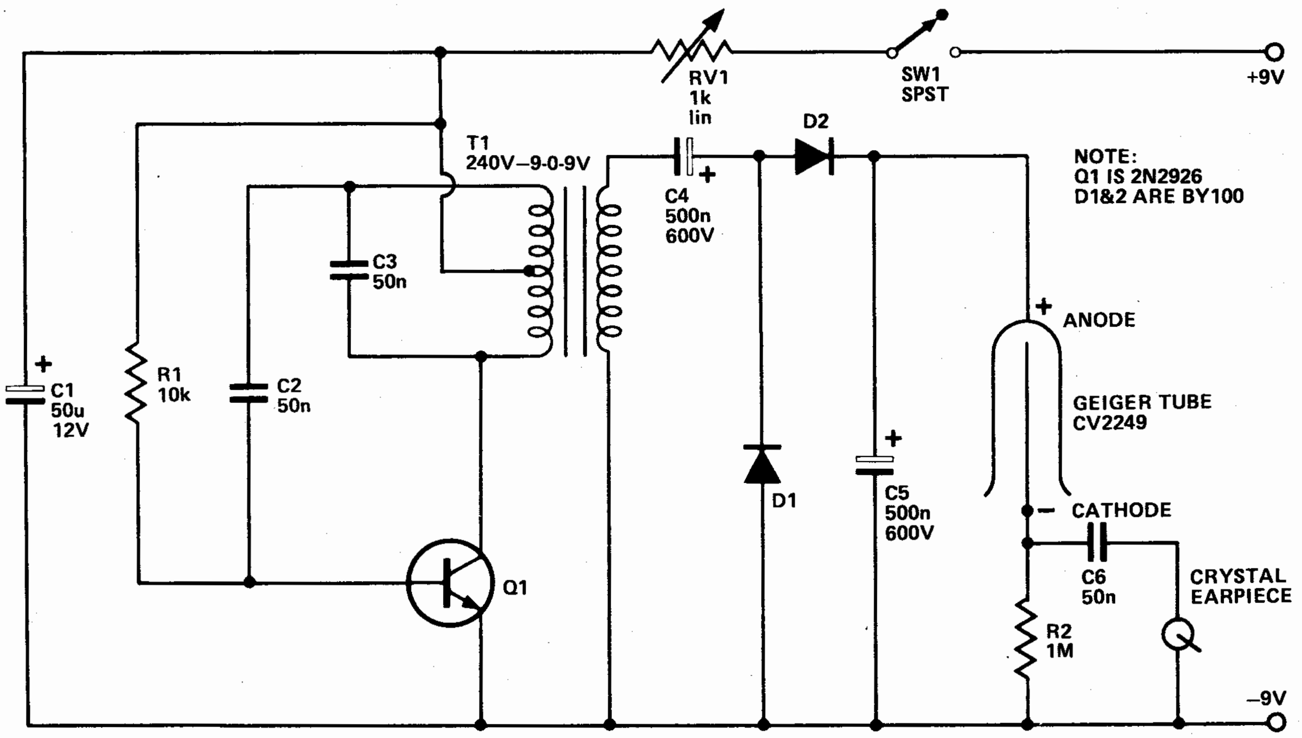
Hobby Scene

High-Voltage Geiger Supply

Q. *I am experimenting with an old Geiger counter. Unfortunately, I can no longer buy the high-voltage batteries that the unit requires. Is there a simple 300-volt converter that could be powered from the internal battery?*

A. The circuit shown at the right will generate about 300 volts dc—at a very low current, but enough for your Geiger tube.





Geiger Counter

A. Wheatley

Although the circuit is imexpensive and simple it is just as sensitive as many commercial devices. The important part is the geiger tube and this will probably cost about £1.90. It needs a high voltage supply which, in this case consists of Q1 and its associated components. The transformer is a low current 250V 9-0-9 and is connected in reverse. The secondary is connected into a Hartley oscillator, the base bias being provided by R1. RV1 is connected to control the voltage to the Geiger tube. A device to double the voltage is included because otherwise the voltage would still be insufficient to drive the tube. This comprises D1, D2, C4 and C5. This also rectifies it and smooths it. It is very important that C4 and especially C5 are of good quality and have low leakage. RV1 should be set so that each click heard is a nice clean one because over a certain voltage all that will be heard is a continuous buzz. The high voltage section is perfectly safe although if touched it will give a slight shock. This is unpleasant but quite harmless.

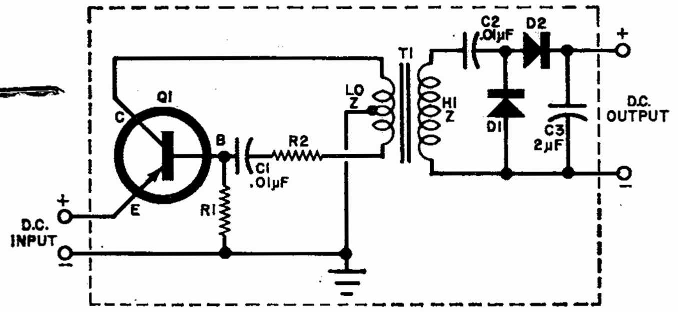


Fig. 1. A d.c./d.c. converter can be modified to provide a variety of output voltages for various low-current and high-voltage supply applications.

Reader's Circuit. Sometimes called a d.c. transformer, the d.c./d.c. converter circuit illustrated in Fig. 1 was developed using "junk-box" parts, according to its contributor, David Sharp, WA9RRJ (14715 Magnolia Blvd., Apt. #4, Sherman Oaks, California 91403). With minor modifications to meet individual requirements, the basic design can be used as a low-current, high-voltage power supply in small oscilloscopes, neon lamp displays, electric fences, Geiger counters, and similar projects.

Referring to the schematic diagram, *Q1* is used as a power oscillator in a modified Hartley circuit, with *T1*'s tapped primary providing the feedback needed to start and maintain oscillation. Voltage divider *R1-R2* determines the optimum feedback signal level, while *C1* serves as a simple d.c. blocking capacitor. Resistor *R1* also establishes *Q1*'s base bias.

The a.c. voltage developed by the oscillator is stepped up by *T1*'s transformer action and changed to d.c. by a conventional voltage-doubler network made up of series capacitor *C2*, rectifier diodes *D1* and *D2*, and filter capacitor *C3*.

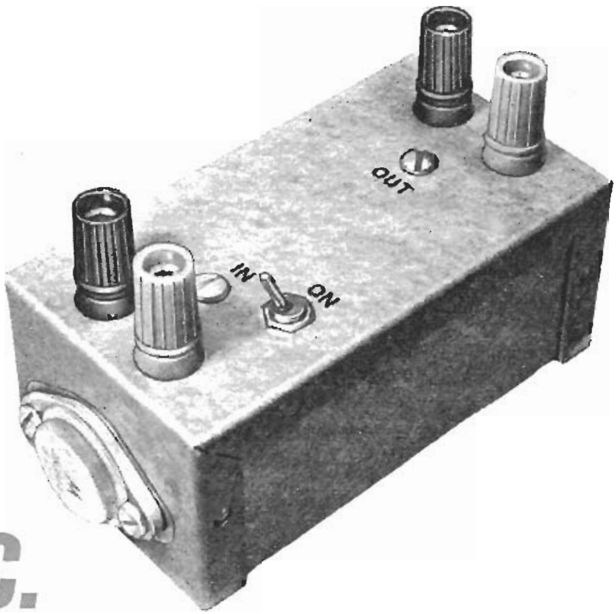
Having used surplus "junk-box" parts in assembling his model, Dave did not specify component type numbers on the project. Instead he suggests that the individual builder use available components, adjusting circuit values experimentally as needed to obtain optimum performance. Transistor *Q1* is a general-purpose, medium-power *pnp* type. Transformer *T1* has a small iron core with both high impedance and tapped low-impedance windings. Typically, a small power transformer or "universal" tube-type audio output transformer could be used here. Rectifiers *D1* and *D2* are high-voltage diodes.

With relatively high voltages developed in the output circuit, *D1, D2, C2* and *C3* should have appropriate ratings. The diodes should have a PIV rating at least twice *T1*'s output voltage while *C2* and *C3* can be 3000-volt units, although the minimum ratings needed will depend on the d.c. supply voltage and *T1*'s step-up ratio.

The resistor values (*R1* and *R2*) are determined experimentally. Breadboard the circuit and use 500k rheostats for *R1* and *R2*, preset for maximum resistance. A light resistive load of from 4.7 to 10 megohms (1 watt) should be connected across the circuit's d.c. output terminals for stability. With a suitable d.c. source connected (from 1.5 to 18 volts, depending on the supply to be used in the final model), adjust the rheostats to *lower* values until the circuit oscillates. In some cases, oscillation can be detected by a "whine" or hum from the transformer, but a scope, signal tracer, or similar test instrument may be used to check operation. Afterwards, disconnect the power source and measure the rheostat values, substituting appropriate fixed half-watt resistors for these units. After a second check for operation, the circuit can be reassembled in its final form.

Neither final layout nor lead dress are critical and, therefore, any construction technique may be used. The power transistor should be heat-sinked if it became warm during breadboard tests; and, of course adequate insulation and component spacing should be used in the high-voltage output circuit to avoid arcing.

BY JON COLT



BUILD A D.C. TRANSFORMER

HIGH VOLTAGE FOR THE NON-SEMICONDUCTORS

WHILE IT IS TRUE that many 1970 electronic devices involve low-voltage circuits, there are still quite a few high-voltage circuits and components around. If you don't believe it, try to fire a neon lamp or a flashtube with a 9-volt battery. You might as well use a match—at least you will make the lamp or tube warm.

The next time you want to power a neon-lamp multivibrator or even rediscover vacuum tubes (they are fascinating, by the way), the d.c. "transformer" might be just what you need. It is called a transformer because it accepts a wide range of input voltages (3-15 volts d.c.) and delivers anywhere from 80 to 425 volts d.c. output with an efficiency of approximately 70% with higher loads. Best of all, the d.c. transformer uses standard, low-cost components—no expensive, hard-to-locate inverter transformer.

The d.c. transformer is so simple in design (see circuit in Fig. 1) that it can be assembled, checked out, and put to work in about four hours.

Construction. The prototype d.c. transformer in Fig. 2 is built in a 4″ × 2″ × 2″ metal utilities box. All components are mounted on the top half of the box except for *R1*, *R2*, *C1*, and *RECT1*. Capacitor *C1* is supported by output binding posts *BP3* and *BP4*, while resistors *R1* and *R2*, because of their size, are made self-supporting via their connection points.

Integrated bridge rectifier assembly *RECT1* is mounted as follows: First press two layers of insulating vinyl tape onto

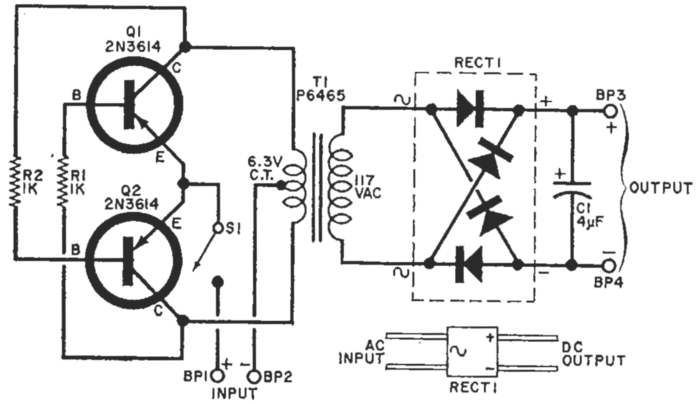


Fig. 1. Multivibrator circuit employs common filament transformer as saturable device. Output is rectified by RECT1, filtered by capacitor.

PARTS LIST

BP1-BP4—Five-way binding post
C1—4-µF, 500-volt electrolytic capacitor
Q1,Q2—2N3614 or Motorola HEP-232 transistor
R1,R2—1000-ohm, ½-watt resistor
RECT1—Integrated bridge rectifier (Motorola No. MDA 920-7, or similar)
S1—S.p.s.t. miniature toggle switch
T1—117-volt primary, 6.3-volt center-tapped secondary at 0.6 ampere filament transformer (Stancor No. P6465)
1—4" x 2" x 2" metal utility box
2 sets—TO-3 transistor insulating and mounting hardware
Misc.—6-32 hardware for transformer mounting; #6 solder lugs (2); vinyl tape; epoxy cement; solder; etc.

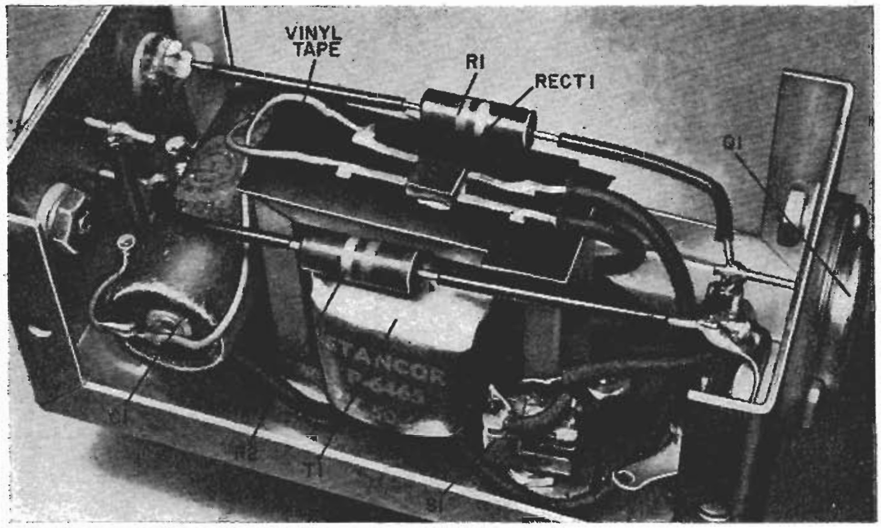


Fig. 2. Transistors are mounted on opposite ends of small utility box. Note that RECT1 is mounted on and insulated from transformer frame with daub of epoxy cement and vinyl tape.

the top of the transformer's frame. Then use epoxy to cement *RECT1* directly to this tape. Also, for insulation purposes, cut out Fig. 3 (or make a copy) and tape this to the inside of the bottom half of the utility box to prevent the rectifier assembly from shorting out against the case. Besides providing insulation, the chart gives you a handy reference for the d.c. transformer's transfer characteristics.

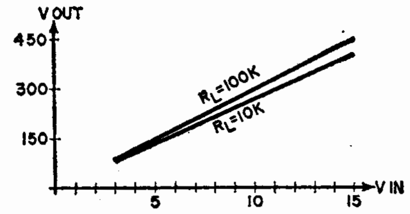


Fig. 3. Graph shows typical transfer characteristics for d.c. transformer when load resistance is 100,000 ohms and 10,000 ohms.

Transistors *Q1* and *Q2* are then mounted at the ends of the case with insulating shoulder washers and TO-3 mica insulators. Put a solder lug on one of the hold-down screws on each transistor to provide collector connection points. Remember to provide adequate clearance when drilling the holes for the base and emitter pins, and heat-sink these pins when soldering to them.

How To Use. As can be seen from Fig. 4, the output of the d.c. transformer starts to drop at any voltage with a

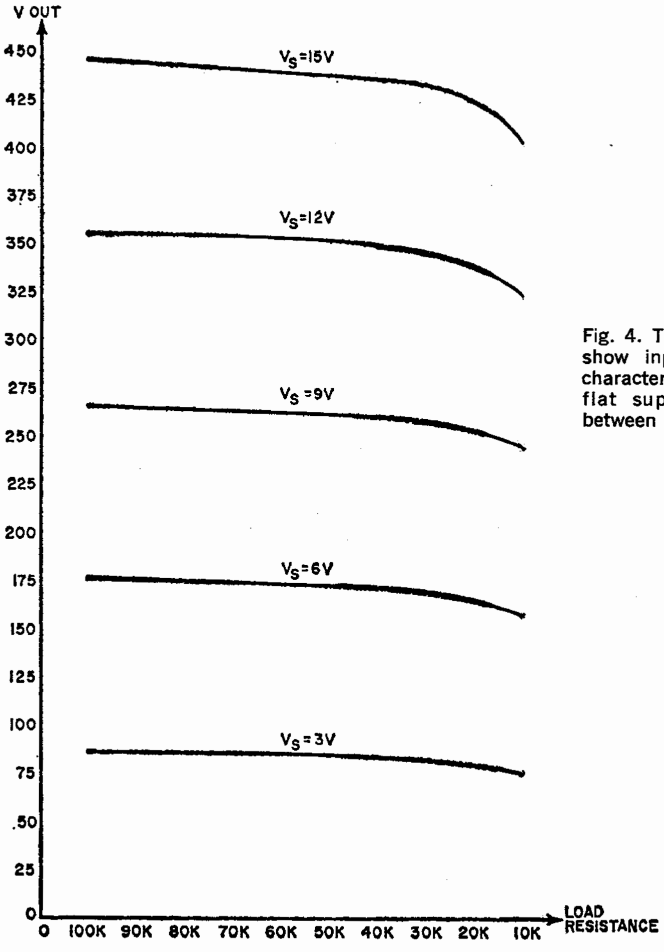


Fig. 4. These operating curves show input voltage vs. load characteristics. Note the fairly flat supply voltage curves between the load extremes.

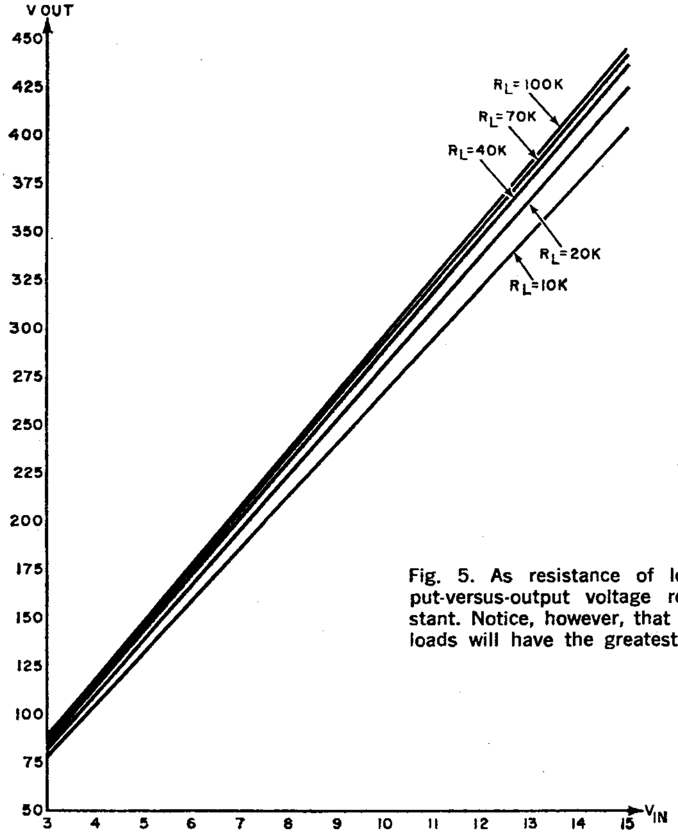
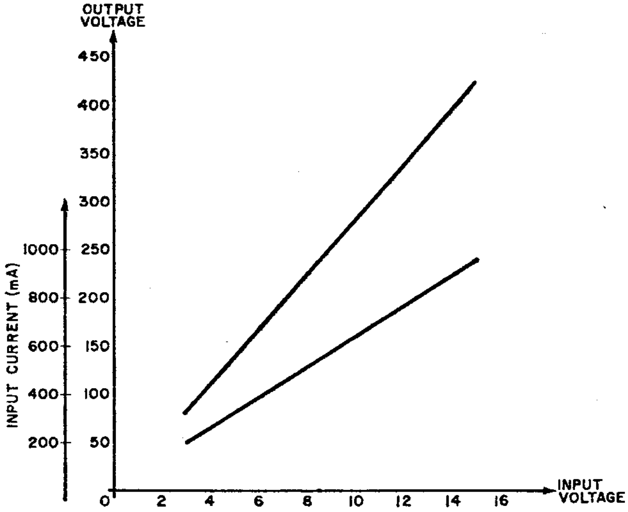
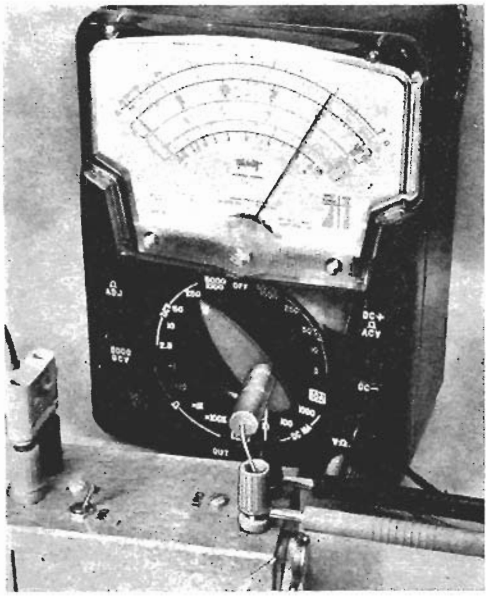


Fig. 5. As resistance of load decreases, input-versus-output voltage remains fairly constant. Notice, however, that very low resistance loads will have the greatest inefficiency effect.

Fig. 6. Graph shows relationships between input voltage and output voltage/current for 20k load on the d.c. transformer.





Proper output voltage is obtained by measuring potential across equivalent output load resistor.

10,000-ohm load. The converter, in fact, will not start at all when a 5000-ohm load is connected to the output. A good rule to follow is: do not try to drive loads which are equivalent to less than 10,000 ohms. For example, from Fig. 5, you can see that the output will be about 135 volts for a 5-volt input to *BP1* and *BP2*.

According to the rule, you cannot draw more than 13.5 mA (135 volts/10,000 ohms, by Ohm's Law) from the supply. But don't be misled into thinking that the supply is not powerful. With 15 volts input and a 10,000-ohm load, output current is greater than 40 mA, representing a power output of 16.25 watts.

Because the converter's current drain, like its output voltage, varies linearly with respect to supply voltage (see Fig. 6), operation from a supply made up of ten D cells is not out of the question for short periods of time. A 6-volt d.c. input results in an output of 165 volts to a 20,000-ohm load, representing an 8.25-mA drain, while the converter draws about 380 mA from the supply.

The input voltage range was not chosen arbitrarily. For inputs lower than about 3 volts, the converter will not start. And for inputs higher than 15 volts, the voltage ratings of *RECT1* and *C1* become the limiting factors. Even if you decide to experiment with higher output voltages by replacing *RECT1* and *C1* with appropriately rated devices, the breakdown voltage of *Q1* and *Q2* will limit the maximum voltage applied to *BP1* and *BP2* to about 20-25 volts.

One more thing: don't let the converter's small package fool you. High voltage *does* come in small packages; and under the proper conditions can be just as dangerous. Treat high voltage with respect.

—30—

HOW IT WORKS

The d.c. "transformer" is built around a magnetically coupled astable multivibrator circuit (stages *Q1* and *Q2* in Fig. 1). What is different about this circuit is the use of a common filament transformer, rather than a special inverter transformer, as the saturating device.

Transformer *T1* is connected so that the low-voltage supply is across the 6.3-volt, center-tapped winding with high-voltage a.c. pulses across the 117-volt winding. The high-voltage pulses are then rectified by bridge rectifier *RECT1* and filtered by capacitor *C1*. Because the output of an inverter is essentially a square wave, much less filtering is needed than would be required for a rectified sine wave.

Inputs between 3 and 15 volts d.c. are applied between *BP1* and *BP2*, triggering the multivibrator circuit. Once rectified and filtered, the output d.c. voltage (with slight a.c. ripple superimposed on it), is available at *BP2* and *BP3*.

PROJECT OF THE MONTH

BY FORREST M. MIMS

MINIATURE DC-DC CONVERTER

The LM3909 was originally designed as an LED flasher, but has many other applications. One that I've enjoyed experimenting with is a miniature power supply that allows a tiny watch battery to power a neon lamp or even a powerful semiconductor-laser pulser. Both these applications require 70 to 150 volts at relatively low current.

Figure A shows the circuit of the LM3909 dc-dc converter. In operation, the LM3909 rapidly switches *Q1* on and off at a rate determined by *C1*. The transistor can be considered a switch in series with choke *L1* and resistor *R2*. Each time *Q1* switches off, the magnetic field set up by the current flowing through *L1* collapses and induces a high voltage across the inductor. This voltage is rectified and stored in *C2*.

The LED is a bonus feature of the circuit. It glows to indicate when the circuit is operating. The neon lamp and 15,000-ohm series resistor shown in Figure A are optional. They provide a visual indication that the circuit is producing 70 or more volts. When powered by a 1.2-volt nickel-cadmium or 1.35-volt mercury "button" cell, the circuit produces enough voltage to flash the lamp when it is connected across capacitor *C2*.

If you don't like the orange glow of a neon lamp, try a *green* neon lamp (Radio Shack 272-1106 or equivalent). This lamp has a phosphor coating on its inside surface that glows green when illuminated by the radiation produced inside the lamp. In any case, be sure to use a quality lamp because some of the surplus neon lamps I've tried do not work well.

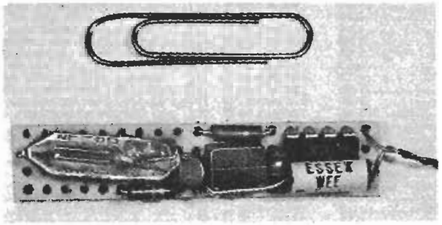


Fig. C. Photo of prototype version of the dc-dc converter.

The key components of the circuit are *L1* and *R2*. In the prototype circuit, I used a miniature Essex choke with an inductance of 1000-µH for *L1*. This choke is about the size of a ¼-watt carbon composition resistor. If this choke is used, the resistance of *R2* should be between 75 and 85 ohms.

If you can't find this choke, experiment with others until you find one that produces enough voltage to light a neon lamp. You'll find that many different chokes will produce a useful output. One version of the circuit that I built uses a miniature 33-mH choke (Aladdin) with excellent results. The 1979 Allied catalog (401 E. 8th St., Fort Worth, TX 76102) lists a number of subminiature r-f inductors on page 145 that should work fine.

If you don't use the 1000-µH choke specified, you'll need to experiment with the value of *R2*. As the inductance is increased, *R2*'s value can be decreased. Actually, *R2* is not even necessary beyond a few millihenries.

Assembly of this circuit should present no problems once you've selected a choke and determined the resistance of *R2* (if it is necessary). I used a piece of perforated board with copper solder pads at each hole. Figure B is a pictorial view of the assembled circuit.

Begin by inserting the components into the top side of the board and interconnecting their leads with wrapping wire. Then solder all the connections to their respective solder pads. Figure C is a photograph of the complete prototype. This circuit includes a neon lamp and series resistor to illustrate its operation as a dc-dc converter. Don't forget that the circuit has many other possibilities.

For example, most semiconductor lasers require current pulses of many amperes for proper operation. The circuit in Figure A can power a four-layer-diode laser pulser with ease, especially if *L1* has an inductance of 10 to 35 mH. Recently, I built a midget laser transmitter using the circuit in Fig. A as a power supply (*L1* = 33 mH, no *R2*). The circuit is completely self-contained and includes lens, mercury "button" cell and switch in a 0.5" × 3" (1.3 cm × 7.6 cm) brass tube. If there is sufficient interest, I'll describe its construction as a future Project of the Month.

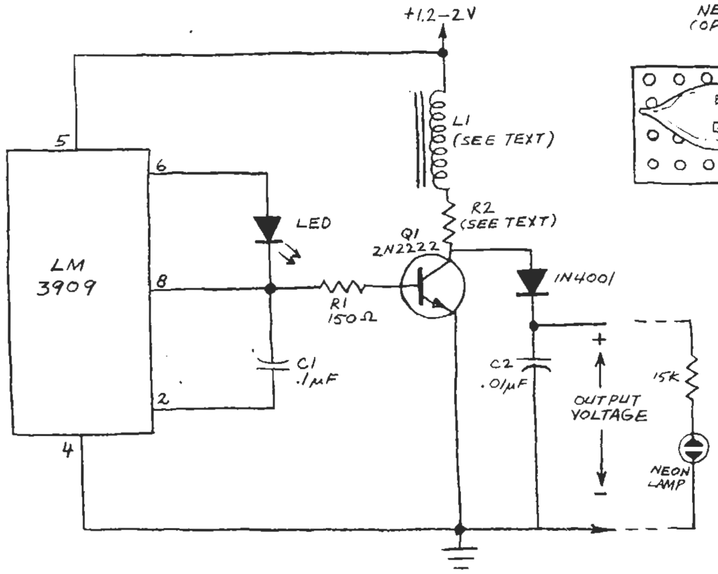


Fig. A. Miniature dc-dc converter circuit diagram.

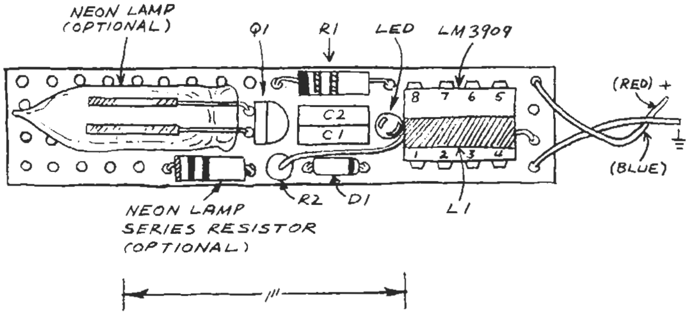


Fig. B. Arrangement of components on the board for the converter.