Build a High-Voltage Power Supply at Low Cost

Looking for HV supply parts? A few dead microwave ovens may supply all the parts you need.

By Randy Henderson, WI5W

Hot from the kitchen, here's a full-course supply for power-hungry vacuum-tube amplifiers. Have you had thoughts of building a high-power amplifier or resurrecting a used "bargain" amp? I've thought about such a project for a long time. Initially, it seemed like a good idea when compared to the price of a new amplifier. After researching the cost of power-supply parts, however, I began to have second thoughts.

I needed the components and materials to make a unit capable of supplying 2700 V at 500 mA or more. I also needed a well regulated 500 V output for the screen grid. I have met several hams who have built such supplies with surplus parts and achieved good results.

10809 NE 17th St
Oklahoma City, OK 73141

When searching surplus and used parts, I never seemed to find just what I wanted. I was also discouraged by the thought of finding replacements for expensive, scarce parts—such as transformers—should future repairs become necessary.

Microwave Ovens

As a source of high-power, high-voltage parts, large (defunct) vacuum-tube color televisions and military-surplus gear are no longer as plentiful as in the past. The ubiquitous microwave oven is in some instances, a good replacement source. The new ones have become so inexpensive that repair is often impractical, so nonworking units can often be obtained at little or no cost.

To better exploit the innards of these appliances, it helps to have some knowledge of how they work, or at least how they are wired.

A single electron tube (a magnetron) generates microwave energy that travels to the cooking cavity by way of a short wave guide. The magnetron uses strong permanent magnets to make electrons swirl past resonant cavities inside the tube. The interaction of electric and magnetic fields sustains oscillation in the cavities.

The circuit powering the magnetron in almost all microwave ovens is similar to Fig 1.[1] There are slight circuit differences between brands and models. Some may not have the bleeder resistor across the capacitor. A few

[1]Notes appear on page 51.

models use separate transformers for the filament windings.

Here's a surprising fact: The various models of microwave ovens have so many similarities that you can mix and match their components. You can build a very reliable power supply by using these components correctly.

The transformer high-voltage winding typically puts out 2100 V RMS under a light load. The capacitor and rectifier are electrically similar in most units. The greatest variation in the components of Fig 1 will be mechanical details such as shape and mounting configurations.

The circuit in Fig 1 is a voltage doubler. The magnetron serves double duty as rectifier and load. There is no second capacitor to smooth the current pulses flowing through the magnetron. Apparently, this modulates the frequency of the magnetron output to help prevent standing-wave patterns that might cause uneven heating in the cooking cavity.

The capacitors in these circuits are usually oil filled, 1 µF or smaller and rated at 2200 V (ac). Generally, you can use them as filter capacitors for dc voltages up to 3200 V.

The rectifiers come in a variety of shapes. They are tough, reliable and much more convenient than strings of smaller diodes.

There are other useful parts, too. Look for fuses, fuse holders, relays, switches, low voltage electrolytic capacitors, resistors, connectors, high-voltage wire, hardware and other goodies for the power supply. I even used part of the cabinet for this project.

While on the subject of salvage parts, I recently saw an interesting source of parts that could be used in the screen supply.[2] Some disposable flash cameras have electrolytic capacitors with ratings of 160 µF at 330 V (dc). Perhaps you can ask a local film processor for some of the used camera bodies destined for the trash bin or recycling center.

Souped-Up Transformers

The high-voltage transformers in typical microwave ovens have features that must be considered when using them in Amateur Radio power supplies. One obvious characteristic is that they have no case; the windings are exposed. *Be careful* not to nick or damage the windings as you work with these heavy, awkward components. This is especially important with the secondary (high-voltage) winding.

The primary and secondary windings are normally wound separately instead of one over the other (see Fig 2). The filament winding, however, is usually wound over the high-voltage (secondary) winding. One side of the high-voltage winding is often grounded to the frame. This is the "cold" or low voltage end of the winding. Even transformers with ungrounded leads do not have sufficient insulation to safely withstand the full secondary voltage at the end of the winding that is normally grounded. For this reason, the transformers must be used in pairs in a full-wave supply.

One feature of the transformer must be modified: A small block of laminations is wedged into the core. These magnetic shunts allow some of the magnetic field to bypass the secondary winding. The effect is similar to putting an inductance in series with the primary. In a microwave oven, this practice helps protect the magnetron from overloads. In a power supply, it will cause poor voltage regulation.

Fortunately, the shunts are pressed in place and can be driven out with a hammer and punch. When doing this, support the transformer core so that the windings are safe from force exerted on the shunt and core. One method is to place wooden 2×4s under each side of the core so that the windings are clear of the work surface. Another method is to bolt the core securely to a frame, such as the one used to construct the power supply.

Some of the shunts are pressed in very tightly, and they may be held together with a rivet. For best results, use a two-pound hammer. The punch

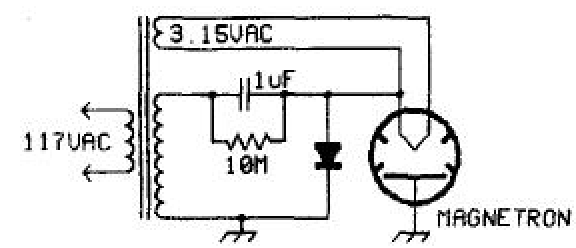

Fig1—This is the power-supply circuit for a typical microwave oven. The 117 V ac enters through a control circuit. Although some use a mechanical timer, others use a sophisticated electronic controller with numerous salvageable parts.

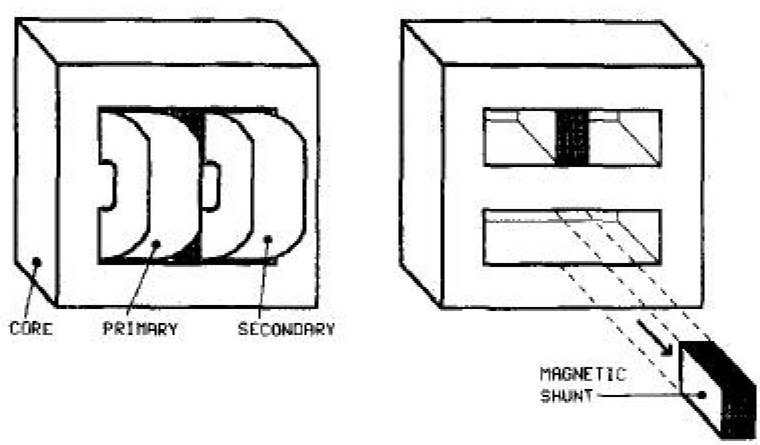

Fig 2—Transformers for microwave ovens are usually constructed with separate winding areas. Some builders find them useful for rewinding because the high-voltage secondary can be cut away with a sharp wood chisel. This leaves plenty of room to install a low-voltage secondary for filament supplies or other low-voltage applications.

should have a flat end and a cross section almost as large as that of the shunt.

Plate and Screen Supply

Fig 3 shows how I used four transformers and a number of other microwave oven components to build a plate and screen supply for a vacuum-tube amplifier. The output of this supply is arranged somewhat unconventionally because the amplifier uses a grounded screen with the cathode floating at −500 V.

It is easy to modify this design for more conventional grounded-cathode applications. Simply disconnect the meter (M) and ground the terminal labeled CATHODE, where all the transformer secondaries tie together. If your amplifier needs a conventional, positive-output screen supply, reverse C2, C3, D1 and D2, then connect the screen grid to the free end of M. If you have a grounded-grid amplifier that needs no screen supply, remove those components along with R5, Z1 and F3.

I was fortunate enough to find transformers where the cold side of the winding was not internally connected to the transformer core. If your transformers have internally grounded secondaries, you can use them in this (unmodified) design, but you must insulate the core from the chassis. I did so in my supply—just in case I need to use internally grounded replacement transformers some day. The insulation between the primary and core will be more than adequate for 500 V dc.

C4 is actually a bank of parallel connected capacitors that can store a large amount of energy. Attempts to charge C4 by suddenly applying full power results in large currents, which could damage the rectifiers and other components. Therefore, power is first applied through R2 and R4 when S1A and S1B are closed. C1 charges through D3 and R3 until the voltage across it is high enough to close the contacts of relay K, which applies full power to the power supply.

When S1 is thrown to the OFF position, the coil of K is shorted by R1, which causes the relay contacts to open. This scheme eliminates the additional high-current relay or switch needed in other stepped-turn-on methods.

The screen supply can be modified to provide a lower screen voltage if needed: If you need a screen voltage of 330 V dc (assuming 117 V ac on each

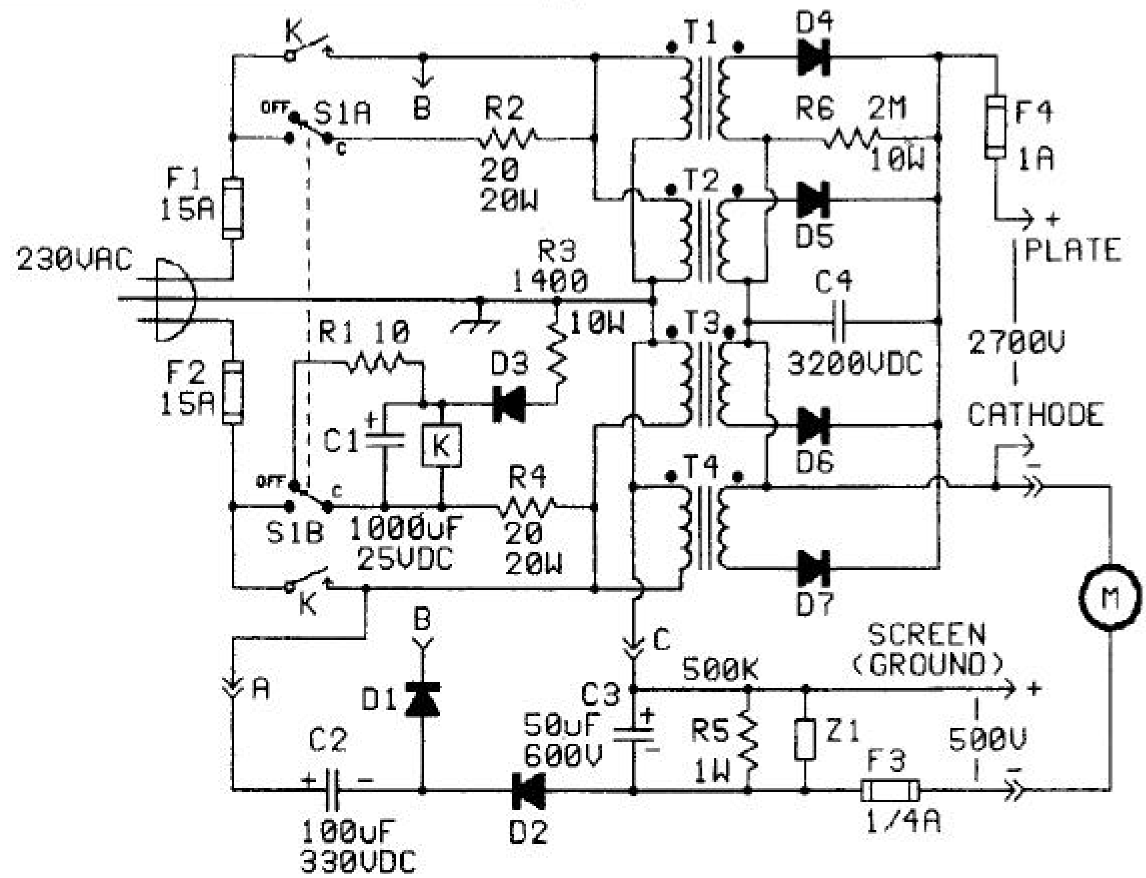

Fig 3—This is how my supply is wired for a tetrode amplifier that has its screen grid tied to dc ground. For use with a more conventional grounded-cathode amplifier circuit, see text. C3 came from my junk box. You will probably need to use two lower-voltage capacitors in series. Install a 100 kΩ, 2 W equalizing resistor across each one. C4 is a bank of 17 salvaged capacitors connected in parallel with a total capacitance of 15 µF. Diodes D1, D2 and D3 are 1N4007s. D4 through D7 are salvaged from various microwave ovens. F1 and F2 are slow-blow 15-A fuses. F4 is made of 5 inches of #40 copper wire supported by terminals on the interior Plexiglas panel. Relay K can be a single DPST relay or two SPST relays. I used two salvaged SPST relays with their +12 V, 160-Ω coils wired in series. They are similar to the Omron LY1-DC12 (from Digi-Key). R6 consists of five 10 MΩ, 2 W carbon-composition resistors in parallel. They were already installed across five of the capacitors comprising C4. Other types of resistors, such as carbon-film, may not withstand the voltage. Z1 is three Radio Shack #276-568 metal-oxide varistors in series.

side of neutral), connect the cathode end of D1 to the neutral wire. (I *don't* recommend this circuit if you plan to use a 117 V outlet. It is too easy to end up in a situation where the polarity is reversed making the amplifier chassis "hot" and potentially lethal.) The circuit is safe with 230 V outlets because they can't be easily reversed.

Capacitive voltage multipliers have a reputation among some experimenters for poor voltage regulation. This can happen if the reactance of the capacitors is too high (capacitance is too low). Using large value capacitors at C2 and C3 results in good voltage regulation. The voltage at F3 drops less than 5% with a screen current of 50 mA.

Transient suppressor Z1 is included in this circuit because I became tired of replacing D2 when an overload of the high-voltage line occurred. This happens because a low resistance path (short) on the plate line causes the negative high-voltage line to "overpower" the screen supply. This increases the voltage across D2, destroying it and sometimes D1, as well. This doesn't happen with a "conventional" setup, where the screen floats above ground. (See Ian White's article for more consideration of screen supply issues.[3]) If an overload occurs now, I need only open the fuse holder and pop in a new F3. (The overload is dissipated in Z1 until F3 blows.) For a conventional screen-grid arrangement, place Z1 on the output side of F3 to help protect the screen grid.

Construction

Each microwave-oven transformer weighs more than 10 pounds. I built a 12×12-inch frame of steel angle stock (1½×1½×⅛-inch) to support the transformers. It rests on an insulated platform inside the enclosure shown in Fig 4. Fiberglass makes a sturdy material for the platform. I used painted wood 2×4s and ¾-inch plywood.

The lower half of the enclosure in the foreground is a light-blue, enamel-coated-steel crisper drawer from a refrigerator. The upper half is a similar white drawer folded back on hinges (in the background). On top of the steel frame is a U-shaped frame made from a microwave-oven cabinet.

Time-delay and screen-supply components are mounted on a perforated phenolic board at the left. On the far side of the U-shaped frame, I bolted a Plexiglas panel that holds the high-voltage rectifiers and output connectors.

Resting atop the U-shaped frame is an assortment of parallel-connected, oil-filled capacitors that make up C4. Some of these capacitors have built-in rectifiers and/or bleeder resistors. Take care to connect those with a rectifier so that the rectifier is reverse biased—a forward-biased rectifier would short circuit the high voltage. (A simple multimeter check may not identify the diode polarity. Use a 9 to 12 V dc source with a 1 kΩ series resistor.)

Swing the top cover closed as shown in Fig 5, and everything is swallowed, as if inside a giant clam. Even the output connectors are inside. This allows me to use binding posts on the Plexiglas panel, instead of expensive high-volt-

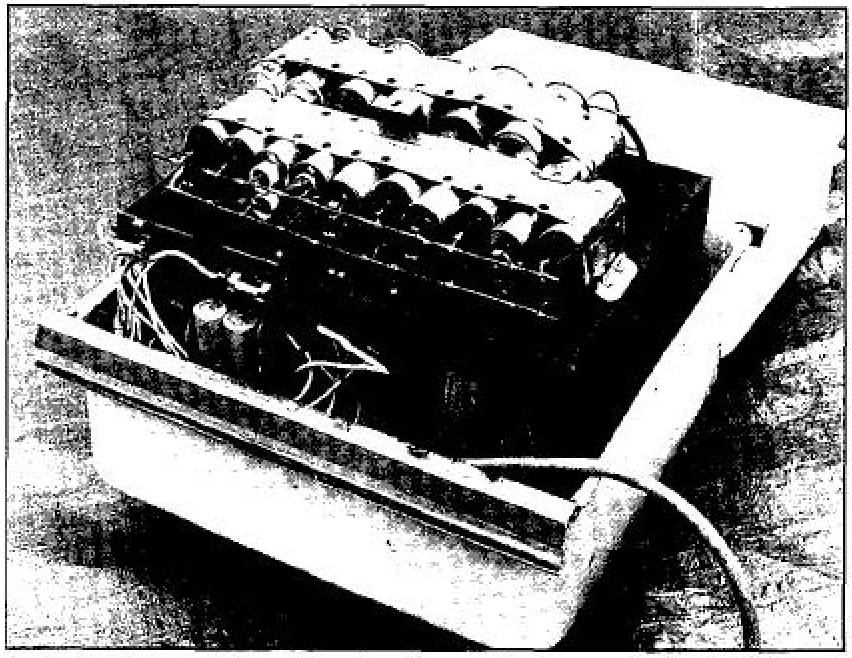

Fig 4—Double-backed tape and small cardboard strips between the oil-filled capacitors hold them in place, while fastening the strapping. All fuses are accessible with the cover in this position.

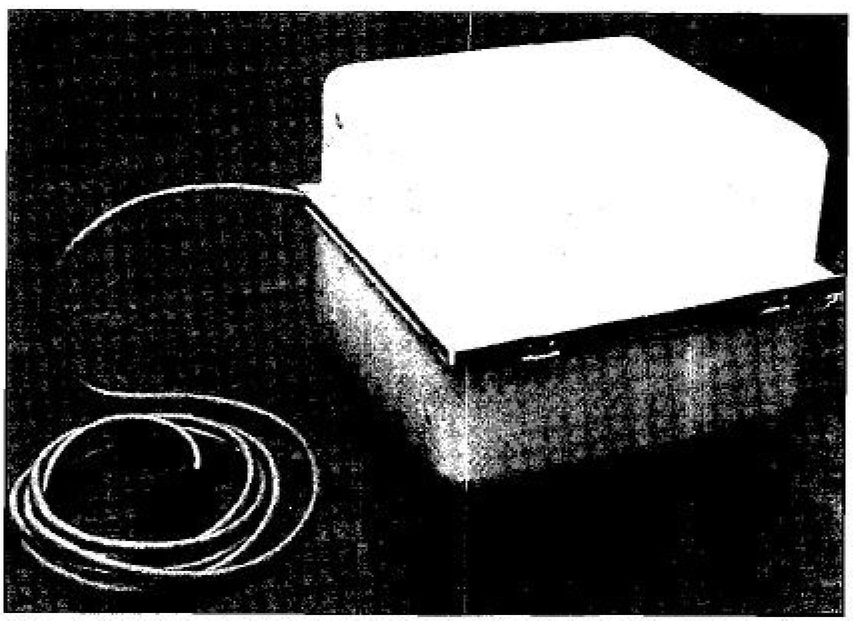

Fig 5—In addition to other features mentioned in the text, this power supply features a two-tone color scheme, four-wheel independent steering and chrome plated bumpers (handles). Mileage in QSOs per kilowatt hour is yet to be determined.

age connectors. Two screws, opposite the hinges, hold the lid closed.

Because of the mass of this power supply, I mounted four small swiveling casters on the bottom. The hinged top and casters prove most convenient when working on the amplifier and power supply.

Operation

A power supply like this one should be operated safely: with all high-voltage points inaccessible to the operator and others. I always make sure the ac plug is *not* in the outlet and within sight when I work on the amplifier or power supply. Use extreme caution when testing and troubleshooting. *Your first contact with high voltage could very well be your last!*

The efficiency of microwave-oven transformers seems lower than some others when lightly loaded. (The rectifier connections shown in Fig 3 result in half-wave operation of each transformer, with dc in the windings. This may lead to increased core loss and possibly some core saturation on voltage peaks. This may account for greater heating—along with the probability that the most economical core materials are used.) I've not experienced any heat-related failures, however, the enclosure becomes warm enough during extended operation that I may include some forced ventilation in the future.

Overall, I'm very satisfied with the performance of this power supply. It seems to loaf along with loads drawing 1000 to 1400 W dc input and could handle even heavier loads with a larger C4.

References

[1] Many microwave ovens have the wiring diagram glued to the inside of their enclosure. I've had the privilege(?) of dismantling approximately 20 microwave ovens of assorted brands and models. Some were repaired. The rest were taking up the valuable space of a store owner who repairs, sells and rents appliances. Each of us took some of the salvaged parts. If you negotiate a deal like this, make sure you have (or get) the training necessary to safely repair and test these appliances.

[2] Steve Bender, "The Bender 2pp Tube Push-Pull Amplifier Rebuild Project, Part 3," *Nuts and Volts Magazine*, Apr 1997, Vol 18, No. 4, pp 65 to 70.

[3] Ian White, G3SEK, "Power and Protection for Modern Tetrodes," *QEX*, Oct 1997, p 15.