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Shedding Some Light on Dimmers

Why not put one of these triacs to use?

When you need to control the AC mains and an auto transformer like a Variac is not available, the line voltage can be controlled with an inexpensive light dimmer. Light dimmers are available from the local hardware store or one is easy to build.

Controlling the voltage to an inductive load like a transformer's primary with a light dimmer may require a little cut-and-try, because light dimmers are intended to control a resistive load and not an inductive load. An appropriate RC in parallel with an inductive load can make it look resistive.

In a light dimmer, a triac or bidirectional triode thyristor switches the voltage to the load for part of every half-cycle. The voltage across the load will be near maximum if the triac switches on at the start of the half-cycle and be less if the switching occurs later in the cycle. The switched voltage is no longer a sinusoid and in some cases may cause difficulties. For example, a power supply with a capacitor input filter. More about that later.

A triac that controls the conduction angle of the dimmer is switched on by a voltage applied between the gate and terminal 2, the cathode. **Fig. 1(a)** shows the voltage-current characteristics of a triac. The device is bistable; the triac exhibits either a high impedance (Off state) or low impedance (On state). For either polarity of applied voltage, the device can be triggered into the on state by a pulse of current of either polarity into the gate. Once triggered, the triac remains in the On state until anode current is reduced to zero by the external circuitry.

The pulse of trigger current to the gate is obtained with a diac. The diac is a two-terminal bistable bidirectional switch with voltage-current characteristics shown in **Fig. 1(b)**. The diac exhibits either a high impedance (Off state) or low impedance (On state). The device exhibits a high impedance, low-leakage-current characteristic until the applied voltage reaches the breakover voltage. The breakover voltage is in the order of 35 volts. Above breakover, the device exhibits a negative resistance, so that the voltage decreases as current increases. When the diac turns on, a pulse of current triggers the triac on. Some triacs have the diac function built-in, but a dimmer using a simple triac requiring a diac is described. An SBS (silicon bilateral switch) like the 2N4991 can be used instead of a diac. They both perform the same function and are essentially equivalent devices.

In the basic light dimmer shown in **Fig. 2**, a diac is used in conjunction with a capacitor to generate current pulses to trigger the triac into conduction. The voltage on the capacitor increases until it reaches the breakover voltage of the diac, at which point the diac voltage becomes low and the capacitor discharges into the triac gate.

At the beginning of each half-cycle, the current in the triac and load is zero and the triac is in the Off state. The triac acts like an open switch. The entire line voltage appears across the triac and none appears across the load. The voltage across the triac drives current through the pot R1 and charges the capacitor C1. When the capacitor voltage reaches the breakover voltage of the diac, the triac is triggered on. At this point, the triac looks like a closed switch and the voltage is applied to the load for the remainder of that half-cycle.

The resistance of the potentiometer determines how quickly the capacitor charges. When the resistance of R1 is low, C1 charges more rapidly, breakover of the diac is reached earlier in the cycle, and the power applied to the load increases.

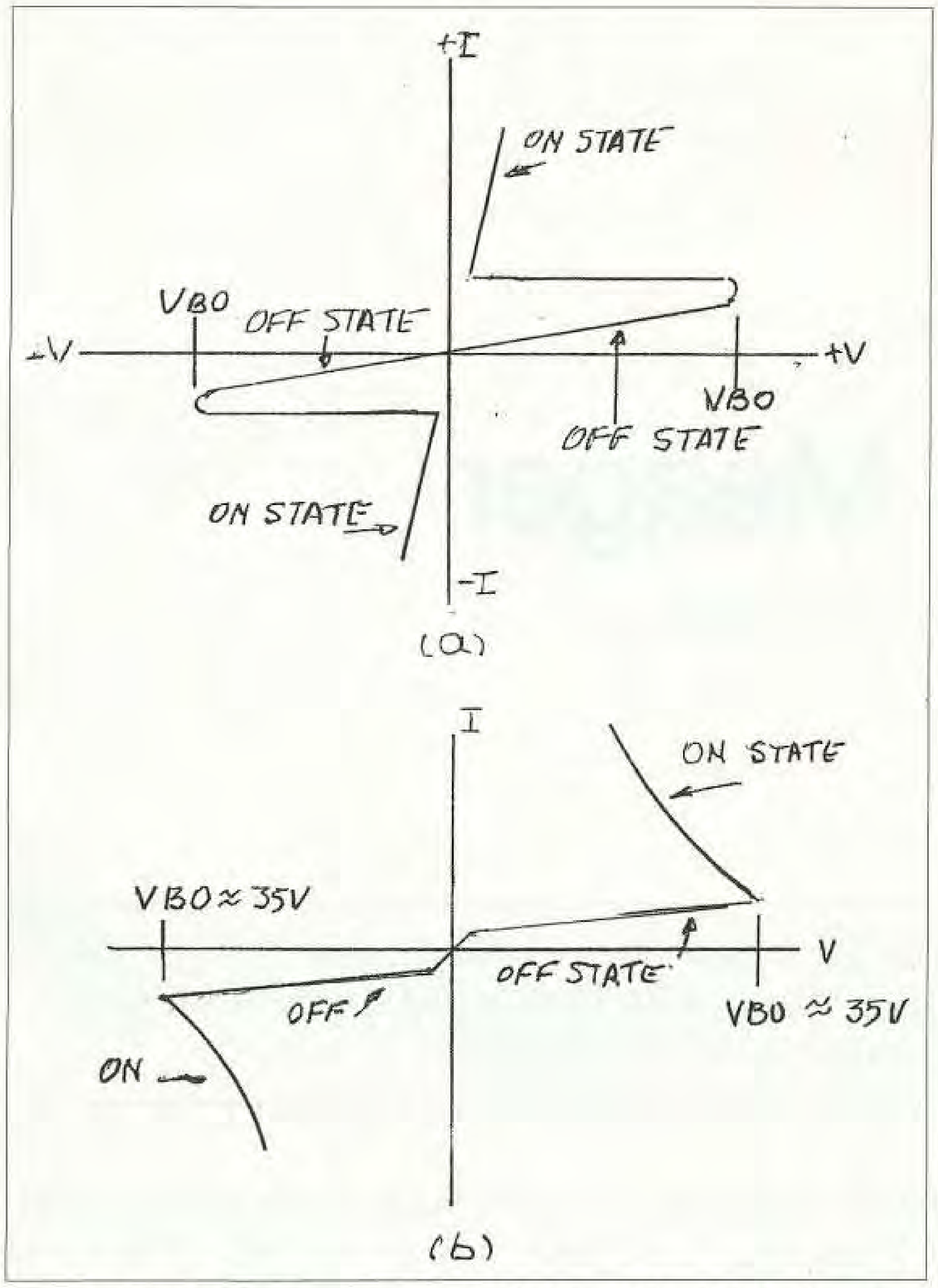

Fig. 1. (a) A triac is gate-controlled bistable. (b) A diac is a bistable diode.

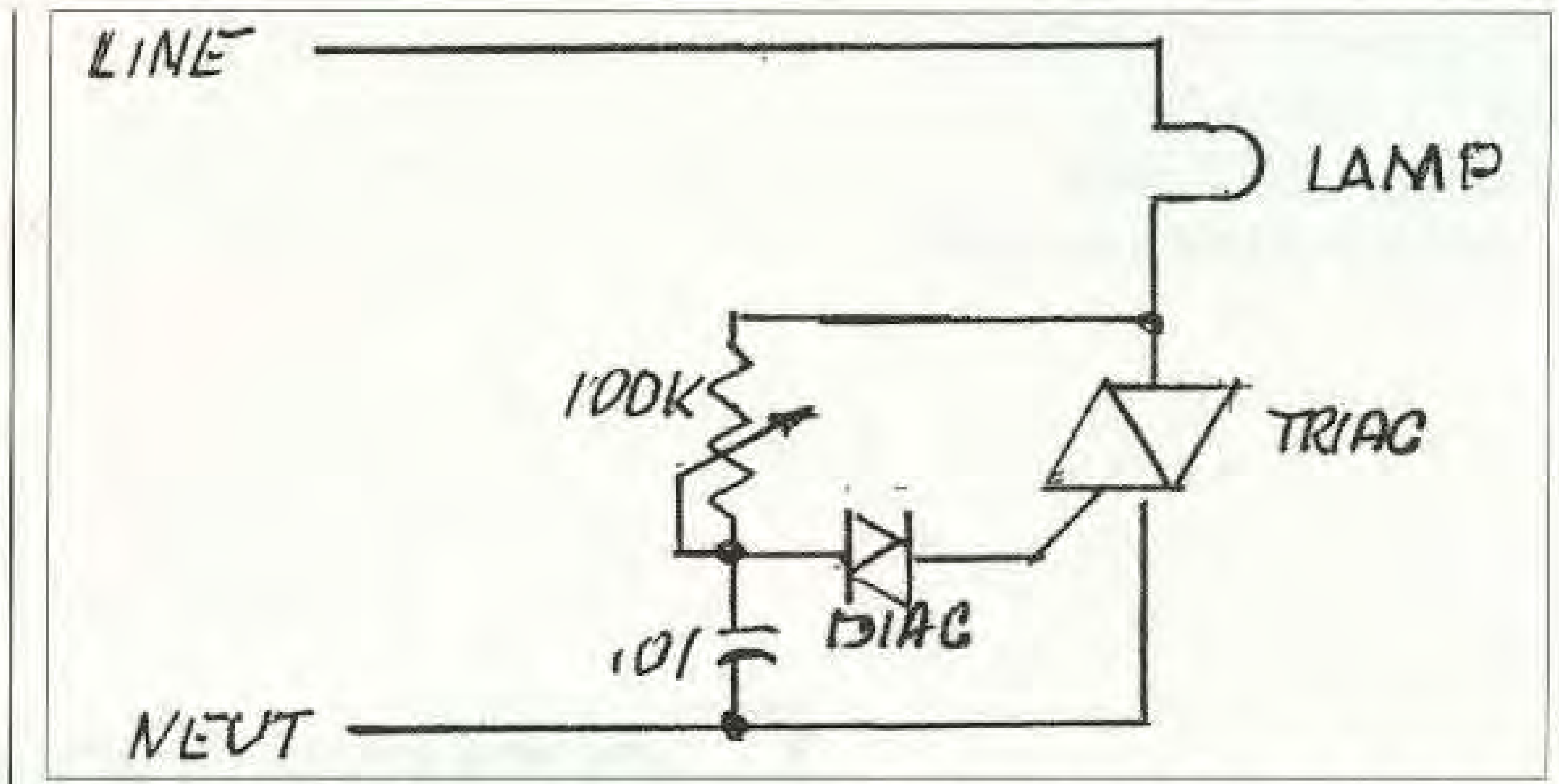

Fig. 2. A light dimmer phase-controls the voltage across the load.

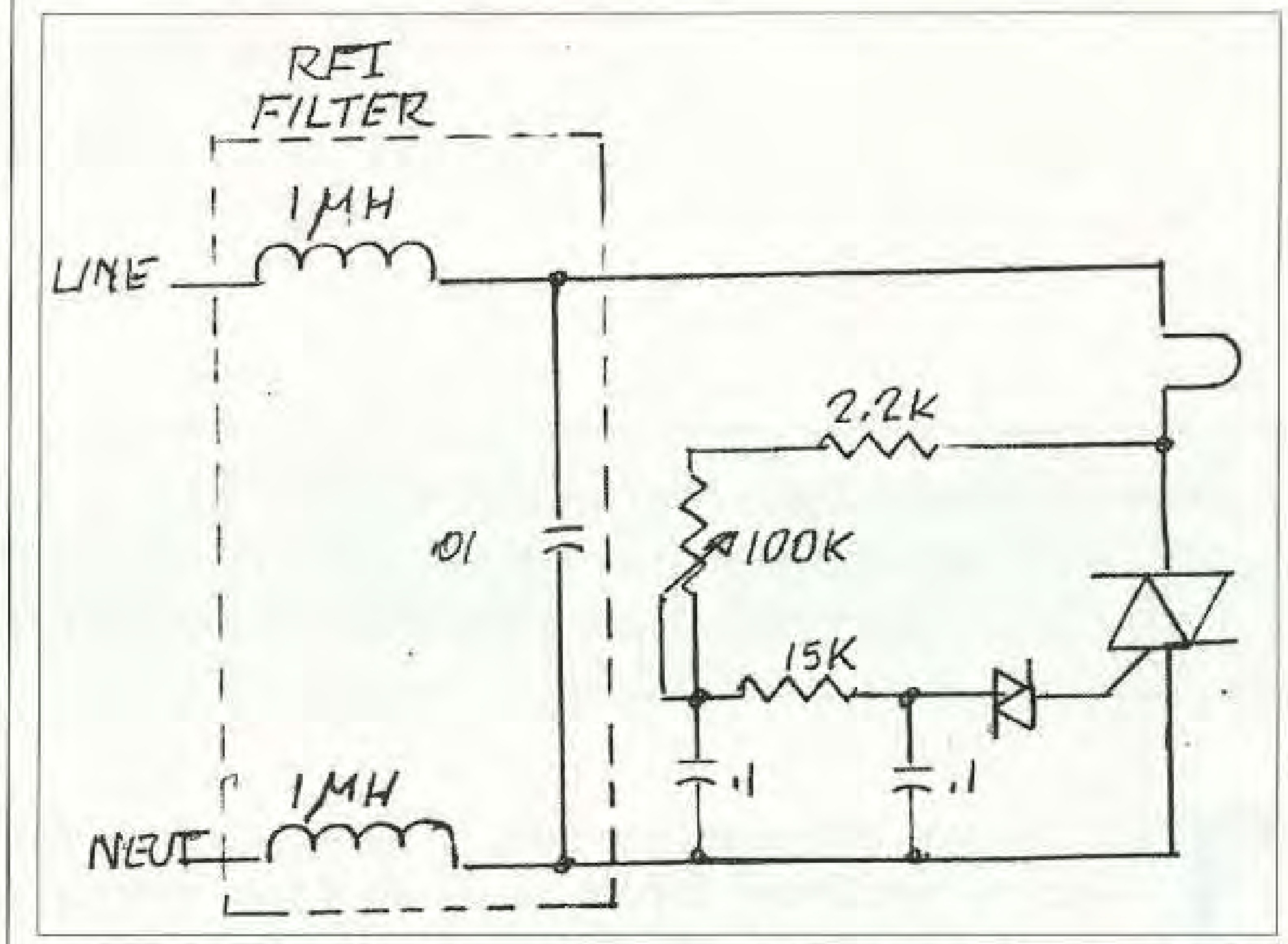

Fig. 3. An extra RC reduces hysteresis. A filter can reduce conducted interference.

Most commercial light dimmers have the circuit shown in Fig. **2**. This circuit has hysteresis. That is, the triac doesn't switch on when the control is set for minimum load voltage. Adding an additional R and C as shown in **Fig. 3** reduces hysteresis effects and extends the effective control range of the light-control potentiometer. Since including the extra R and C increases cost, most commercial light dimmers expect you to accept the hysteresis.

Since the triac switches when the line voltage is nonzero, noise can be produced when the triac switches on. Again, adding the noise-reducing filter increases cost, so noise is ignored. However, a 0.01μF capacitor and two small inductors can filter the noise from the line. Many times, the inductors are just a few turns wound on a piece of ferrite. This arrangement takes care of the conducted noise but doesn't do anything for radiated noise — a metal minibox enclosure is needed to control the radiated noise. If you have only a plastic project box, line it with aluminum foil and you'll be in business.

The light dimmer is intended to control a resistance, a light bulb, in which the voltage and current are in phase, but when the load is inductive, like a transformer or universal wound motor, the voltage and current are no longer in phase. The inductance tends to keep the current flowing even when the voltage is zero. The inductive current in the anode holds the triac on while the line voltage goes though zero.

A series RC in shunt with the inductor can put the voltage and current back in phase. That's where the cut-and-try comes in. A capacitor across the load can absorb the inductor's current and make the current in the triac zero when the voltage is zero. The resistor in series with the capacitor damps any tendency of the L and C to ring.

Accommodating the inductance is straightforward if the exact inductance is known. But usually the inductance isn't known. Finding the capacitor that will absorb the inductive current and a resistor to eliminate ringing requires some cut-and-try. The ringing suppressing resistor is not terribly critical, but if it is too large the effects of the capacitor can be compromised. Something in the order of 100 ohms is a good starting point.

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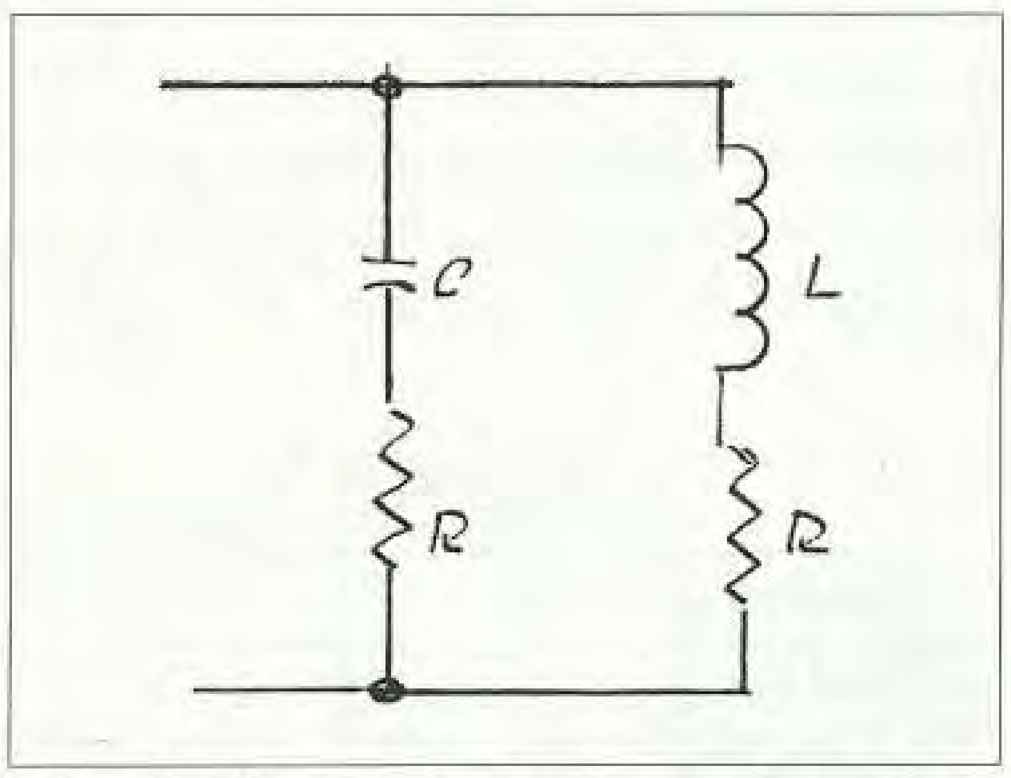

Fig. 4. The load can be made to look resistive.

Championships, November 20 to December 3, 2003, near Ballarat, Victoria, Australia. Visitors from countries outside Region 3 are welcome at the Australia events, just as visitors from around the world will be welcome at our 2003 championships in Cincinnati. Several radio-orienteers from USA are already planning a trip "Down Under" next year.

If it's too cold to have a practice radio-orienteering session in your home town this month, warm up the soldering iron and start planning for spring by building fox transmitters and RDF antennas for yourself and to loan to your local Scout troop. There are lots of equipment ideas at the "Homing In" Web site. Be sure to send photos and stories of the mobile and on-foot transmitter hunts in your hometown. E-mail and postal mail addresses are at the beginning of this article. 73

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Fig. 4 shows the circuit that can make the transformer look resistive. The value of the R and C can be calculated when the inductance and the reflected series resistance of the inductor are known: $4L/R^2C = 1$, where L is the inductance of the load and R is the sum of the resistance R in series with the capacitor and the resistance in series with the inductor.

It's probable that L won't be known, so make a stab at a capacitor and resistor, 0.22 µF and a 100 ohm resistor are a good starting point. If the triac turns off, that's close enough. A capacitive diddle box (a capacitor substitution box) makes finding an acceptable value of capacitor easy — just increase the capacitance until the triac regains control.

You can find the R and C without the triac: Connect the inductive load with the R and C across an AC or DC source through a switch with visible contacts. Select an R that is equal to the resistance of the inductor and the minimum capacitor. As the switch is opened an arc will probably be seen. When an AC source is used, make several openings and closings to make sure you're not switching at the zero crossing of the voltage, then increase the capacitor until there is no arc.

Controlling the AC voltage to a universal wound motor makes a speed control. Also, a variable AC voltage can make a simple unregulated supply variable (of course, it will still be unregulated). Applying a variable voltage to the soldering iron will keep the temperature where you want it without burning the tip. A variable voltage to the coffee pot heater will keep your coffee at the right temperature, too. You could even use it to control the brightness of a lamp.

A word about controlling a power supply with a capacitor input filter: This kind of supply has an output voltage that is approximately equal to the peak of the rectified AC. Phase-controlled AC doesn't change the peak voltage until the conduction is delayed for more than 90°. When the power supply filter has either a choke input or a resistor input, the DC output approaches the average value of the rectified AC, and a dimmer does control the average.

Adding a resistor between the rectifiers and the filter capacitive reduces the supply's maximum output voltage by about 40%. The average voltage, the DC voltage, is 0.636 x E_{peak} or 0.9 x E_{RMS}. The resistor need not be large: A value in the order of 100 ohms when the capacitor is 100 µF or larger will do the job.

When you need to vary the AC line voltage and a variable autotransformer isn't available, the light dimmer may save your bacon. The cost isn't great, and construction time won't interfere with watching the 10 o'clock news. The cost won't break the bank either; the parts are available from Radio Shack or Mouser Electronics (1-800-346-6873). 73

Shack Switch for Foot Fetishists

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auto stores, like Strauss and Pep Boys, that still carry some of the nostalgia items from the '50s and '60s. At the Strauss auto store I saw the fuzzy dice, and right below was my Big Foot pedal.

I'm sure that you know that good