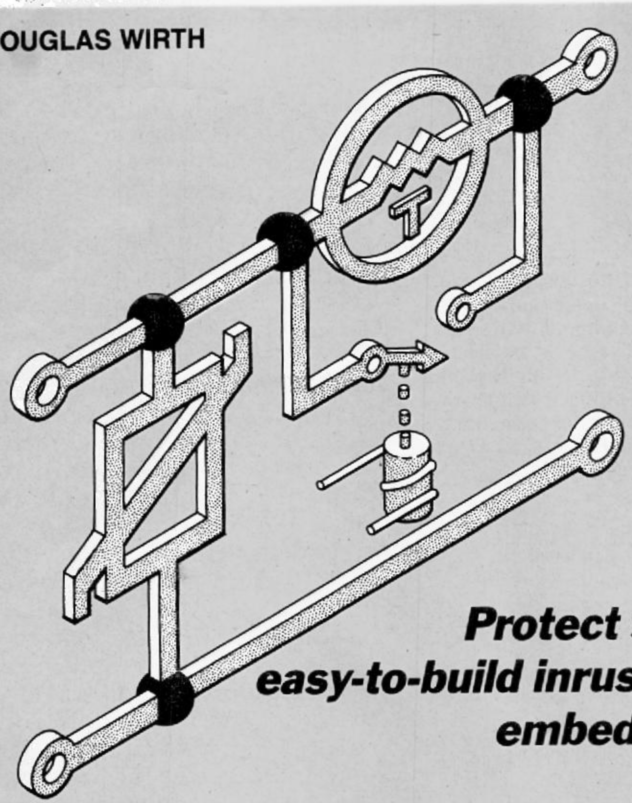
DOUGLAS WIRTH



INRUSH CURRENT LIMITER

Protect sensitive electronics with an easy-to-build inrush-current limiter that can be embedded in host equipment or be a stand-alone unit.

THE INRUSH-CURRENT LIMITER DEscribed here can protect sensitive line-powered electronics against normal current surges that occur when that circuitry is powered up. The limiter gives a "soft start," to any product or system it protects, and it can be expected to lengthen the operating life and improve the reliability of the host. A thermistor and relay protect against normal "turn-on" overcurrent, and a metal-oxide varistor protects against unwanted overvoltages and overcurrents occuring after startup.

Our inrush-current limiter, shown packaged in an enclosure in Fig. 1, can protect any equipment operated from 120-volt, 60-Hz AC. It can also protect non-electronic circuits such as lighting networks and appliances, provided that they do not include motors. (Many appliance motors depend on surge current for starting.) The circuit can be modified for protection at higher or lower AC voltages or DC voltages.

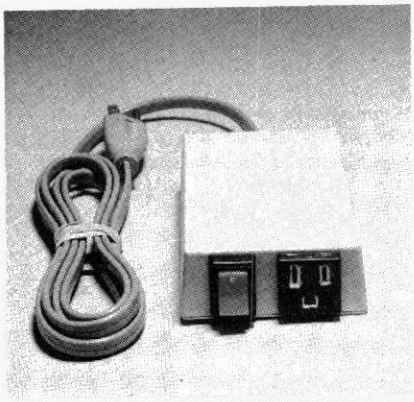


FIG. 1—INRUSH-CURRENT LIMITER circuit as a stand-alone component.

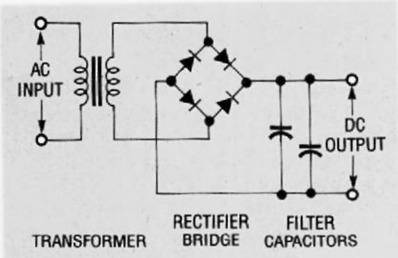


FIG. 2—SIMPLIFIED SCHEMATIC for a linear power supply with a full-wave rectifier and capacitor filter.

Current limiting

Most power supplies for electronic equipment that are embedded within the enclosure (typically sharing a PC board with other circuitry) are conventional linear circuits. As shown in Fig. 2, they consist of a transformer, bridge rectifier circuit, and one or more filter capacitors. When AC power is applied to such equipment, there is no charge on its capacitors, and the circuit components present an extremely low impedance to the line voltage.

As a result, a large inrush current surge with a fast rise time occurs, and it decays exponentially only as the filter capacitors charge. The peak inrush current is orders of magnitude greater than the circuit's steady state current. It is limited primarily by the short circuit characteristics of the power transformer and rectifier, which are determined by their internal resistance and inductance values and the wiring, as shown in Fig. 3.

An inrush-current limiter, as its name implies, limits inrush current and allows the voltage to rise gradually across the protected circuit. The limiter was designed for high-power stereo amplifiers to avoid the excessive current surges that occur at turn-on. The current drain of large stereo amplifiers is high enough to dim the lights in an average home when it is turned on.

Electronic-equipment and power-supply manufacturers typically limit inrush current by placing a momentary switching device with a fixed resistance at the power input terminal of the circuitry to be protected. After a predetermined time interval, relay contacts close, shorting out the input resistor so that full voltage is applied to the load.

Our inrush-current limiter circuit takes that conventional approach one step further. The fixed-value protective resistor is replaced by a temperature-variable resistor whose resistance value declines with increasing inrush current. A negative temperature-coefficient (NTC) thermistor optimized for inrush-current protection, its manufacturer refers to it as an *inrush-current limiter.*

A typical temperature vs. resistance curve for an inrush current limiter device is shown in Fig. 4. These devices are widely used in AC/DC switching power supplies. The unit specified for this project has a resistance of 120 ohms ± 25 % at 25°.C, a maximum steady state current of 2 amperes, and an approximate resistance of 1.18 ohms at maximum current.

Inrush-current limiting

Refer to the simplified block diagram, Fig. 5. The hot side of the AC line is fed through the inrush-current limiter (shown as a resistor with the letter "T.") Actual resistance change depends on the magnitude and duration of the current drawn. With a nominal resistance of 120 ohms, the maximum instantaneous current through any connected circuit will be limited to 120 volts/120 ohms = 1.0 ampere. (The current drawn will be less than the theoretical value because of the impedance of other components.)

At the end of a preset elapsed time after power is applied, a relay is actuated and it shorts out thermistor R9; that applies full power to the protected circuitry. The time delay is adjustable and determined by the value of a single resistor or potentiometer; it can range from less that a second to more than a minute.

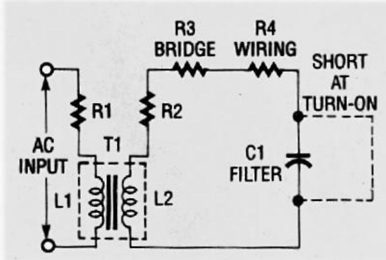


FIG. 3—EFFECTIVE RESISTANCE and inductance of transformer primary and secondary are represented by R1, L1 and R2, L2, respectively; R3 and R4 are the effective resistances of the rectifier bridge and circuit wiring, respectively. The dotted line across filter capacitor C1 represents zero resistance at power turn-on.

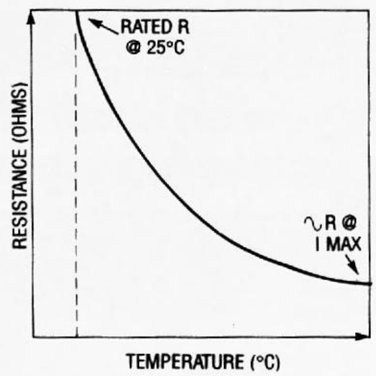


FIG. 4—INRUSH-CURRENT LIMITER device shows negative-temperature coefficient (NTC) characteristics. A thermistor optimized for circuit protection, its resistance declines as temperature increases due to current flow.

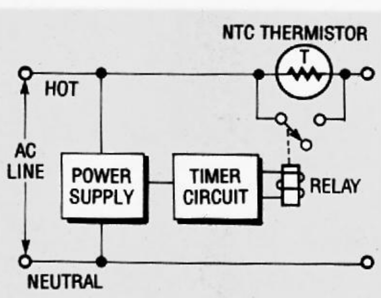


FIG. 5—BLOCK DIAGRAM OF INRUSH-current limiter circuit shows relay power supply and an inrush-current limiter component to protect against current surges at turn-on.

How the limiter works

The schematic of the inrush-current limiter circuit is given in Fig. 6. The 24-volt DC for the timer circuitry and relay are derived from a regulated power supply made up of resistor R1, capacitors C1 and C2, and diodes D1 to D3. The 120-volt input voltage is dropped primarily by C1, and applied to the two series-connected Zener diodes, D1 and D2.

When the polarity of the hot (upper) AC line is positive with respect to the neutral (bottom) AC line, a positive voltage is developed across the Zener diodes. That voltage charges filter capacitor C2 through diode D3. Resistor R1 and parallel metal-oxide varistor MOV1 limit the peak current in the circuit. Resistor R2 discharges C1 and resistor R3 discharges the filter and timing capacitors when power is removed, readying the circuit for immediate restart.

The relay power supply in Fig. 6 is popular in isolated electronics products where only small DC currents are needed to power circuitry. It eliminates the bulk and expense of a power transformer. However, appropriate safeguards must be taken because the supply is not isolated from the AC line. The timing circuit consists of resistors R4 to R7, capacitors C3, diode D4, transistors Q1 and Q2, and relay RY1. Timing capacitor C3 charges through timing resistor R4. (With a value of 150 K, the time delay will be 11 seconds.)

The PC board provides three holes for 1 megohm board-mounted potentiometer R9. Its adjustment will give a continuous range of time delays from about 1 second to 60 seconds. As an alternative, Table 1 lists the values of resistor R4 needed to obtain time delays from 1.5 to 180 seconds in discrete increments. The time delays given in the table can vary because of the wide tolerances of electrolytic capacitors.

When the voltage on C3 reaches the 12-volt breakdown threshold of Zener diode D4, it conducts and applies base drive to turn on NPN Darlington transistor Q1. When Q1 conducts, its collector voltage decreases, turning on PNP Darlington transistor Q2, whose collector current actuates relay RY1. The

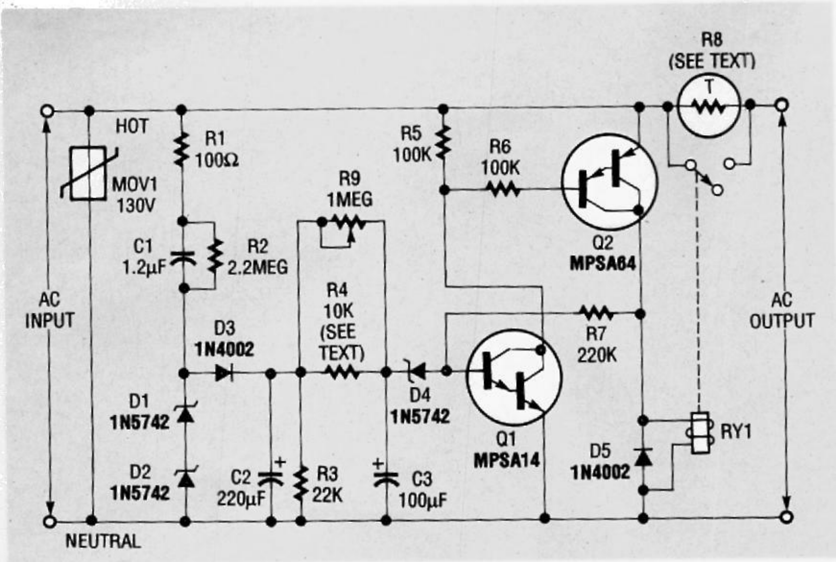


FIG. 6—SCHEMATIC OF INRUSH CURRENT LIMITER. Note that Q1 is a an NPN Darlington and Q2 is a PNP Darlington. MOV1 is a metal-oxide varistor and R8 is an NTC thermistor for limiting inrush current.

relay's normally open contacts are connected across the inrush current limiting device. When closed, the contacts apply full power to any connected load. Resistor R7 provides positive feedback to Q1's base, ensuring positive turn-on of the relay.

Diode D5 protects the circuit from the inductive "kickback" of the relay coil when it is de-energized. The resistance of the relay's coil must be at least 1.3 K for effective relay operation. The metal-oxide varistor MOV1 will protect the load against voltage spikes and transients, but it is not a requirement for the operation of this circuit. It has symmetrical bidirectional "breakdown" characteristics similar to those of back-to-back-connected Zener diodes.

Construction

All of the circuitry fits on a PC board measuring 2.5 x 2.5 inches. However, you might want to make the PC board's outer dimensions larger or smaller. If you plan to mount the circuit in a case, the board size and the hold-down screw spacing will depend on the case selected. The complete circuit assembly can also be mounted within the enclosure of its host equipment with mounting holes and insulating standoffs, if desired.

The PC board for this project is simple enough for an amateur to make, so its foil pattern is included here. However, because there are no critical components on the board, the components can be assembled on prepunched insulating board and connected by point-to-point wiring. Before doing any assembly work, drill the four corner holes in the board for the screws to mount the board to the case or inside the host's enclosure with standoffs.

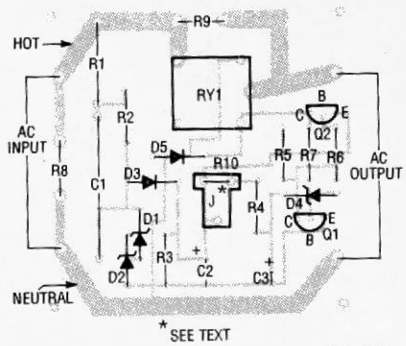
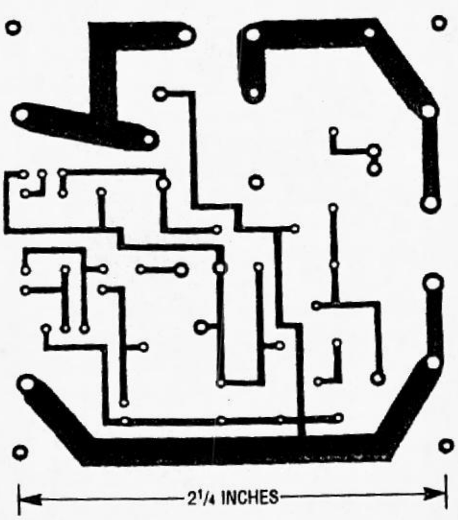


FIG. 7—PARTS-PLACEMENT DIAGRAM for the inrush-current limiter circuit.



FOIL FOR INRUSH-CURRENT LIMITER PC board.

Figure 7 is the parts-placement diagram. Install the resistors, capacitors and diodes first, observing the proper polarities for the capacitors and diodes. If you elect not to use the 1 megohm potentiometer R9, the value of R4 should be 150 K ohms rather than the 10 K shown on Fig. 6, and a jumper should be installed across two of the holes as shown. (Table 1 gives values of R4 for specific time delays.) After all the components are assembled on the board (see Fig. 8), solder them, and trim all excess leads. Recheck your work, carefully examining the circuit for shorts before continuing with the checkout.

Checkout procedure

Warning: This is a line-operated device, so perform all testing and troubleshooting with a line-isolation transformer. *Never* operate the circuit outside of an insulating housing and *never* make adjustments or any kind of modifications to it when it is directly connected to the AC line.

An isolation transformer is recommended for testing this circuit. If you cannot obtain a commercial unit, you can build one by connecting the secondaries of two identical transformers back-to-back as shown in

TABLE 1
TIME DELAY VS. RESISTANCE

Resistance (R4) (ohms)	Time delay (seconds)
22 K	1.5
47 K	3.0
68 K	5.0
100 K	7.0
150 K	11.0
220 K	17.0
470 K	40.0
1.0 MEG	80.0
2.2 MEG	180.0

Fig. 9. (It can also be used to test other transformerless electronic circuits.) The 120-volt line is stepped down, and then stepped back up to 120 volts. Use only transformers with the same secondary voltages, and do not exceed the current or power ratings of each of the transformers.

With no power applied to the circuit, perform the following resistance checks:

• Measure the resistance between the AC inputs, the hot AC line connected to R1, and the neutral AC line connected to the anode of D2. The readings should be greater than 10 megohms—anything less could indicate a problem.

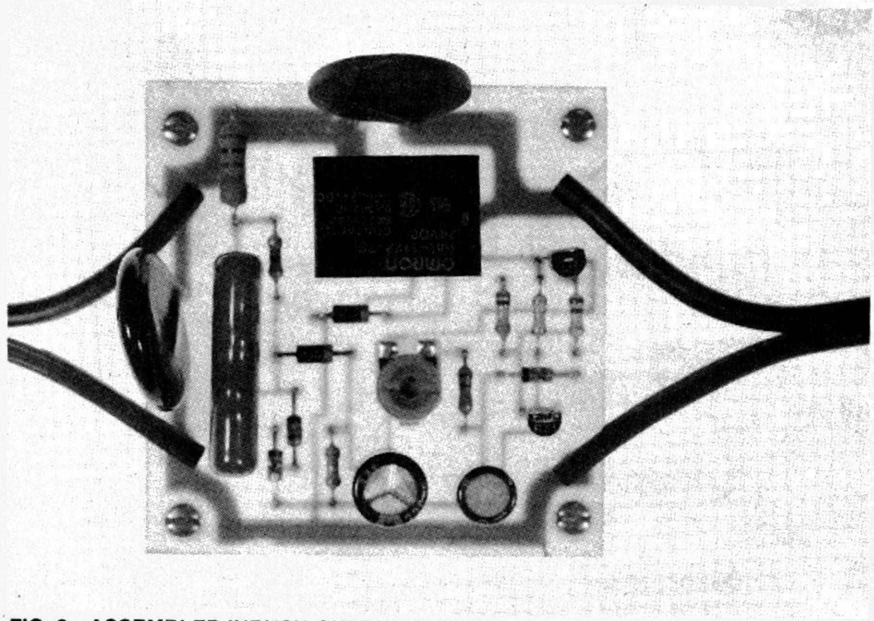


FIG. 8—ASSEMBLED INRUSH-CURRENT LIMITER circuit.

PARTS LIST

All resistors are ¼-watt, 5%, unless otherwise stated

R1—100 ohms, 2 watt, 5%, metal-oxide
R2—2,200,000 ohms
R3—22,000 ohms
R4—10,000 ohms (see text)
R5, R6—100,000 ohms
R7—220,000 ohms
R8—120 ohms inrush-current limiter (NTC thermistor) 2-ampere (Keystone) CL-90 or equivalent
R9—1,000,000 ohms potentiometer, 3-pin, PC board-mount, insulated knob.

Capacitors

C1—1.2 µF, 250-volt, polyester-film
C2—220 µF, 35-volt, aluminum electrolytic
C3—100 µF, 16-volt, aluminum electrolytic

Semiconductors

D1, D2, D4—1N5742, Zener diode, 12-volt, 1-watt
D3, D5—1N4002, 1 ampere, 100 peak volts
Q1—MPSA14, NPN Darlington transistor, (National Semiconductor) or equivalent
Q2—MPSA64 PNP Darlington transistor, (National Semiconductor) or equivalent

Other components

MOV1—metal-oxide varistor, 130-volt AC, (Panasonic) 20K201U, or equivalent
RY1—SPST relay, coil: 24-V, contact: 5 A, 250-V AC, 30-V DC, coil resistance 1300 ohms, PC-mount, (Omron) G5L-112P-Ps or equivalent
S1—toggle or rocker switch, panel-mounted, 350-volt, 3 amp

Miscellaneous: circuit board, panel-mounted receptacle (three-prong), length of 3-conductor power cord 18 AWG with 3-prong plug, four 1/4-inch insulated standoffs (see text), insulated case with cover, cable grommet, screws as needed, and solder.

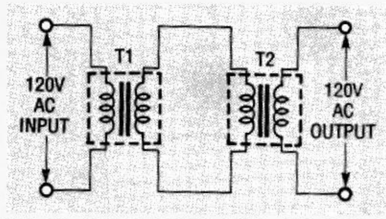


FIG. 9—SCHEMATIC FOR AN ISOLATION transformer to be used in testing the circuit. All turns ratios must be equal.

• Measure the resistance between the same end of R1 and the end of R2 connected to D1. The readings should be 2.2 megohms. Those measurements assure that there are no shorts or low resistances across the AC line.

• Connect the circuit to the isolation transformer and apply power. If the circuit is operating properly, you should hear the faint click of the relay contacts closing after the appropriate time delay.

• Check for proper operation of the power supply by measuring the voltage across filter capacitor C2. The reading should be about 22 volts DC when the relay is energized.

When testing and experimenting with loads connected to the inrush-current limiter, allow several minutes for the circuit to cool down to room temperatures and the nominal resistance values to be restored. The allowed time should depend on the magnitude and duration of the current drawn through the device. In normal operation, allow about a minute after power is removed for timing capacitor C3 to discharge before initiating a new time delay sequence.

Installation

The inrush current limiter can be installed within the enclosure of the host equipment. Connect the circuit to the AC line after the host equipment power switch and preferably after the line fuse or circuit breaker. Install the circuit so that the hot leg of the AC line is connected to the surge limiter, as shown in Fig. 6. Cut the AC line to the host and install the circuit in series, as shown in Fig. 8. Be sure the circuit board for the inrush-current limiter and all components are insulated from the equipment's chassis and all other components with insulated standoffs.

As an alternative, install the inrush-current limiter in a suitable insulated case with a line cord, power receptacle, and ON-OFF power switch as shown in Fig. 9. The prototype case measured 4⅜ × 3¼ × 1½ inches deep.

It might be necessary to cut down the four standoff posts within the case to accommodate

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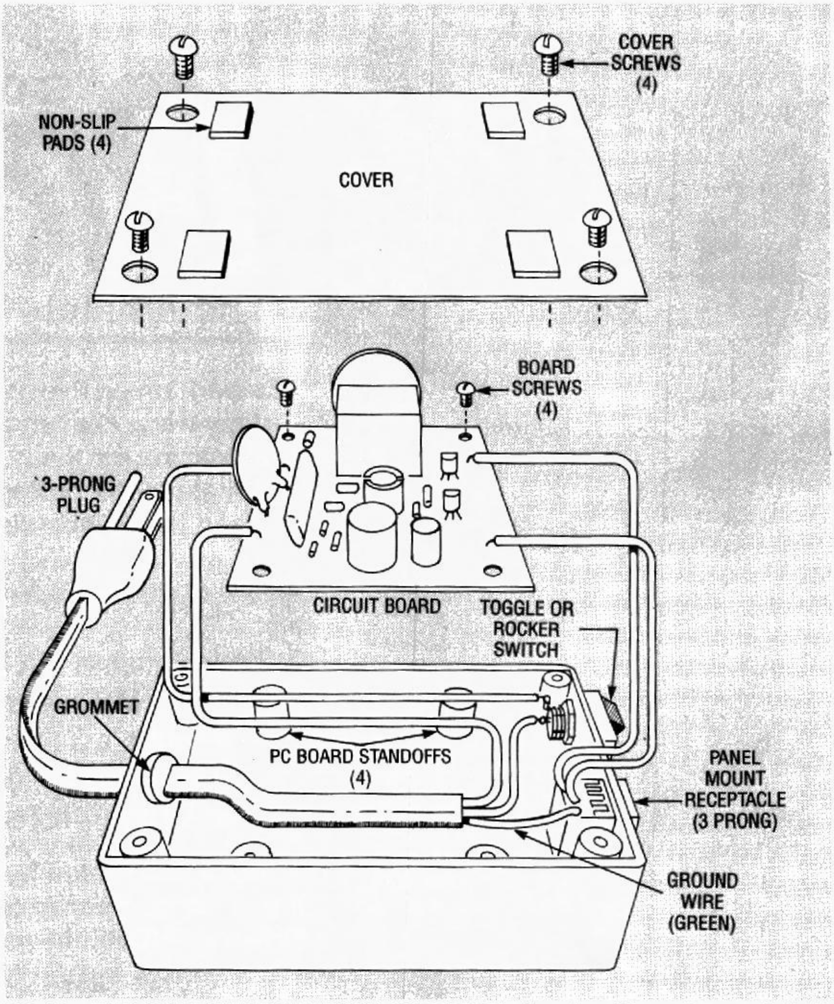

FIG. 10—EXPLODED VIEW OF INRUSH-CURRENT limiter circuit in enclosure. Note the completion of ground within the case with a 3-wire power cord.

the completed circuit. Pull the three-wire cable through a grommet in the case sidewall as shown. Strip the jacket from the cable in the case, strip the end of the green ground wire, and connect it to the ground terminal of the three-prong receptacle. Solder one of the cable's conductors to the PC board, as shown, and solder the other conductor to one terminal of the switch.

Using short insulated lengths of the same cable conductor, solder a connection from the switch to the other side of the PC board, as shown. Solder two more short lengths of conductor to the output pads on the PC board, and connect their other ends to the panel-mount receptacle.

Fasten the circuit assembly in in the case with hold-down screws and close the cover. Fasten the cover in position with the four screws included. The inrush-current limiter then becomes a plug-in accessory and the host equipment need not be altered. The equipment's power switch should be clamped in the "on"position so that power to the equipment is then applied with the limiter's ON-OFF toggle or rocker switch.

Although the surge protector is in the circuit only for short time intervals, be sure that any protected equipment does not draw more than 2 amperes. **R-E**