The Ferroresonant AC Voltage Regulator

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Unfamiliar to many electronics enthusiasts, here's a device to smooth out power-line voltage variations and protect sensitive equipment

THERE are numerous devices and circuits that can deliver regulated dc voltages. One voltage-regulating device—the ferroresonant transformer—gives regulated *ac* voltages and incorporates some special advantages. Capable of acting as a step-up or step-down voltage transformer as well as an ac voltage regulator, this component delivers a more or less constant ac output voltage even if the magnitude of the input voltage changes. In addition, the ferroresonant transformer is efficient, inexpensive, rugged, and requires no heat sink. It generates no high levels of electrical noise and provides a degree of protection from transients riding on the ac power line. Ferroresonant transformers are available in a variety of winding configurations and VA ratings and at reasonable cost from several surplus electronics dealers.

How It Works. A ferroresonant transformer has several windings and an air-gapped ferromagnetic core. It combines a high leakage-reluctance magnetic circuit and a resonant *LC* electrical circuit. A cross-sectional view of a typical ferroresonant transformer appears in Fig. 1A, and the schematic diagram appears in Fig. 1B. The transformer's primary winding (1) is wound first on the *X* portion of the core, and then the *compensation winding* (3) is wound on top of it. Similarly, the *resonant winding* (2) is wound on the *Y* portion of the core, and the secondary winding (4) is wound on top of it. Two air gaps form a magnetic shunt that isolates the resonant (2) and secondary (4) windings from the primary (1) and compensation (3) windings.

When an ac voltage is applied across the primary winding, a magnetic flux is set up in the ferromagnetic core. This flux induces voltages in the other three windings. Because of the reluctance of the air gaps in the magnetic shunt path, the induced voltages essentially correspond to the turns ratios between the primary and three other windings. If the magnitude of the voltage applied across the primary is increased, the flux in the *Y* portion of the core increases. If the flux density attains a sufficient value, the magnitude of the inductive reactance of winding (2) equals the capacitive reactance of external capacitor *C*. The *LC* network then resonates at the power-line frequency, and the voltage appearing across winding (2) increases to a stable value greater than the primary/resonant turns ratio would suggest.

This increases the flux density in the magnetic circuit path traversing the resonant winding and significantly decreases the relative reluctance of the magnetic shunt. Any variations in flux density caused by changes in the voltage applied across the primary winding are for the most part swamped by the mag-

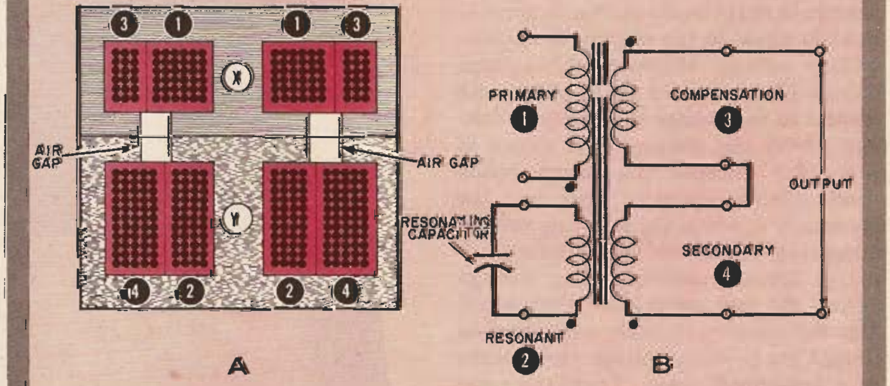

Fig. 1. Cross-sectional view of a typical ferroresonant transformer (A) and the transformer's schematic diagram (B).

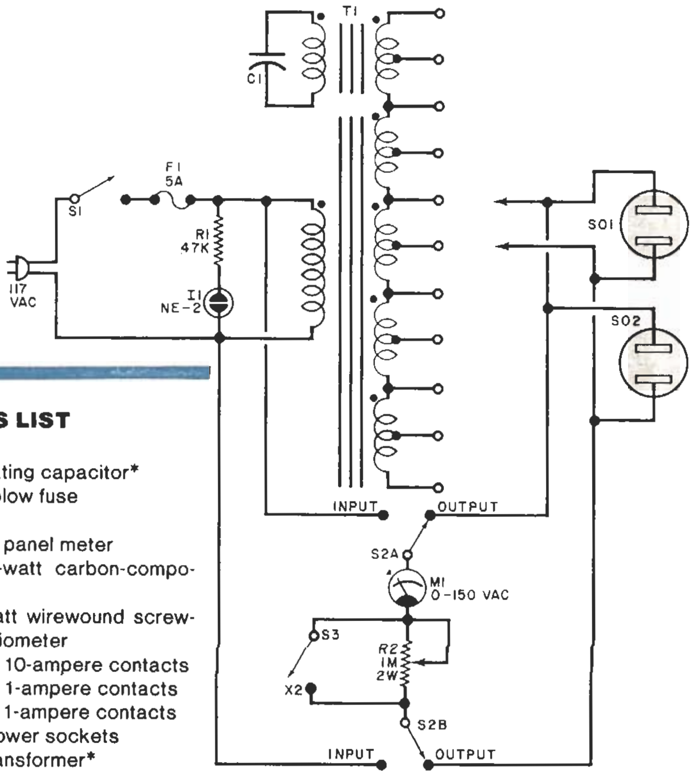

Fig. 2. Schematic diagram of the author's project employing a ferroresonant transformer.

PARTS LIST

C1—Nonpolar resonating capacitor*
F1—5-ampere slow-blow fuse
I1—NE-2 neon lamp
M1—0-to-150-volt ac panel meter
R1—47,000-ohm, ½-watt carbon-composition resistor
R2—1-megohm, 2-watt wirewound screwdriver-adjust potentiometer
S1—Spst switch with 10-ampere contacts
S2—Dpdt switch with 1-ampere contacts
S3—Spst switch with 1-ampere contacts
SO1, SO2—Duplex power sockets
T1—Ferroresonant transformer*
Misc.—Suitable enclosure, fuseholder, 14-gauge stranded insulated hookup wire, banana plugs and jacks, machine hardware, solder, etc.
*See text.

netic shunt, and variations in the voltage appearing across the resonant winding are suppressed.

The compensation winding (when present) acts in a complementary way to compensate for variations in the voltage applied across the primary. This winding is designed so that any variation in the voltage induced across it caused by a change in the primary voltage is approximately equal to the change in the secondary voltage. However, this voltage change is 180 degrees out of phase with respect to the change in secondary voltage. (Note the phasing dots shown in Fig. 1B.) Because the compensation winding is connected in series with the secondary winding, the resulting voltage appearing across the two windings remains almost constant. The voltage across the two series-connected windings will remain relatively constant even though the primary voltage varies within a prescribed range. Thus, the compensation winding (which is not found in every ferroresonant transformer) enhances the component's voltage-regulating action.

In normal operation, the *X* portion of the core (on which the primary and compensation windings are wound) does not magnetically saturate. However, the *Y* portion of the core (on which the resonant and secondary windings are wound) does. Owing to this, the waveform set up across the secondary is nonsinusoidal and has significant harmonic content. Certain types of electronic equipment are sensitive to such harmonic distortion, so some ferroresonant transformers have a fifth, *neutralization* winding. This winding is wound on the *Y* portion of the core. It's connected in series with the secondary and compensating windings in such a way that it introduces the proper amount of inverse distortion to cancel out most (if not all) of the harmonic content in the secondary waveform. Such transformers typically produce a sinusoidal output waveform with approximately 3% harmonic distortion.

Employing the Transformer. The following project, assembled by the author, uses a surplus ferroresonant transformer that generates a regulated ac output ranging from approximately 24 to 187 volts rms. This wide range of output voltage is made possible by the transformer employed—a multisecondary device whose secondary windings can be connected in series.

A schematic diagram of the author's ferroresonant ac regulator appears in Fig. 2. Ferroresonant transformer *T1* is a surplus component obtained from Delta Electronics, 7 Oakland Street, Amesbury, MA 01903, Part No. 9859. Its sec-

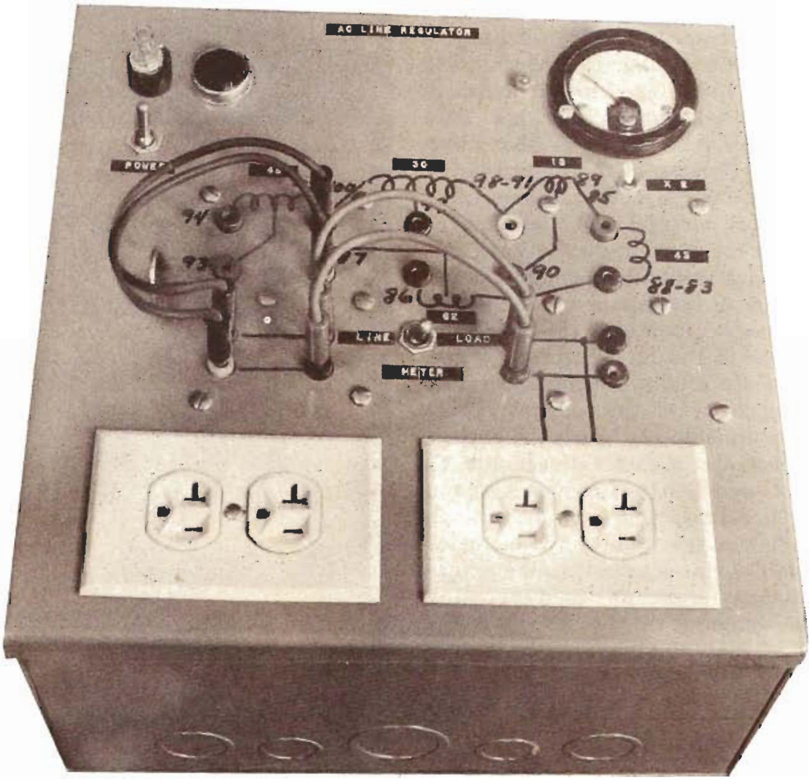

Fig. 3. Top view of the prototype shows how components were mounted in a NEMA electrical junction box.

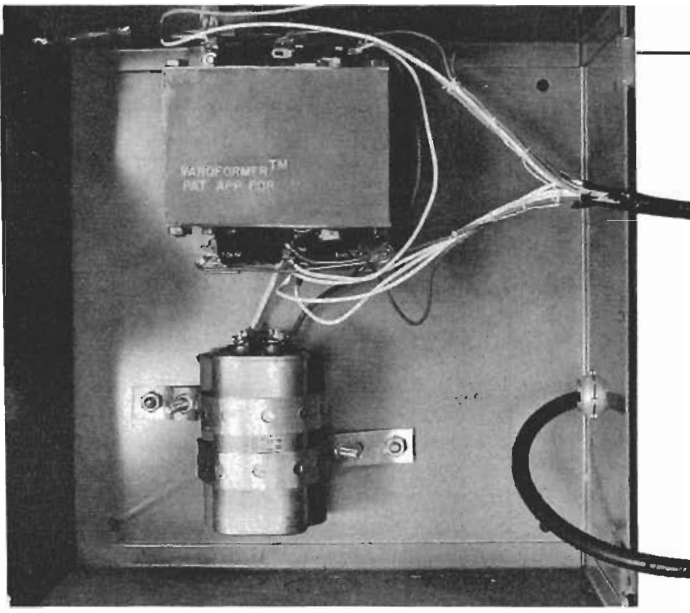

Fig. 4. Interior view illustrates how the transformer, T1, and the resonating capacitor, C1, were mounted in the enclosure.

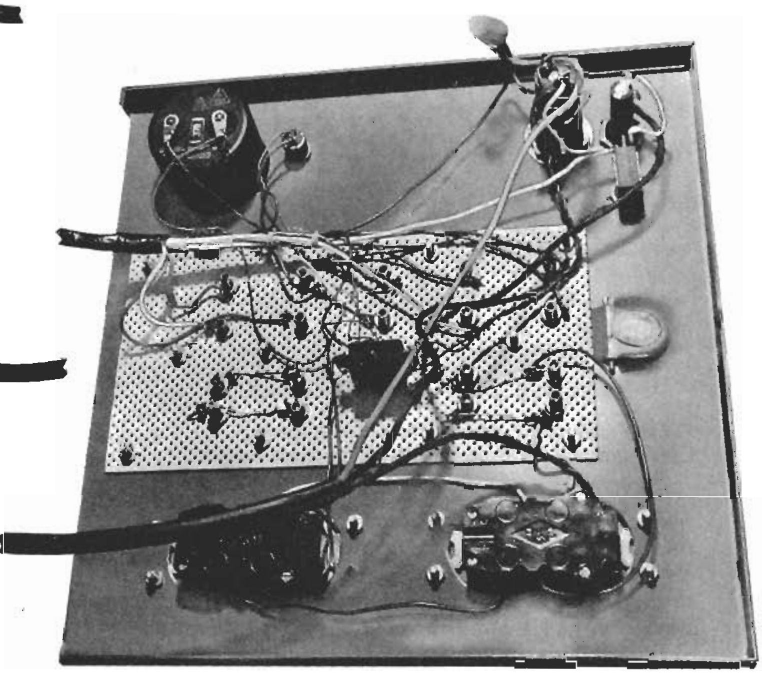

Fig. 5. This view shows the bottom of the board in the prototype with point-to-point wiring using No. 14 stranded copper hookup wire.

ondaries have the following ratings:

- •60 volts center-tapped at 3 amperes;
- •36 volts center-tapped at 4 amperes;
- •34 volts center-tapped at 4 amperes;
- •33 volts center-tapped at 5 amperes;
- •24 volts center-tapped at 4 amperes.

The author connected the secondaries of *T1* in series and brought each side as well as the center taps out to banana jacks mounted on the project enclosure. Power sockets *SO1* and *SO2* facilitate connection of the regulator to the loads with which it will be used. They are connected to short jumper wires terminated with banana plugs and to two of the position lugs of dpdt switch *S2*, which is part of the metering circuit. Banana plugs simplify the selection of particular points on the secondary string.

Nonpolar capacitor *C1* (usually supplied with the transformer) is the resonating capacitor and is connected across the resonant winding of *T1*. The transformer's primary winding is energized by the ac power line via *S1* and is protected by fuse *F1*. Neon indicator *I1* functions as a pilot light. Current through it is limited to a safe value by resistor *R1*.

The transformer's primary is also connected to the remaining two position lugs of switch *S2*. The poles of this switch are connected to the meter circuit comprising *M1*, a 0-to-150-volt ac panel meter, *R2*, a one-megohm, screwdriver-adjust potentiometer, and *S3*, an spst switch which when closed halves the sensitivity of *M1*.

Photographs of the author's prototype appear in Figs. 3, 4, and 5. The top view, Fig. 3, shows how the author mounted the switches, meter, banana jacks, power sockets and other components in the enclosure. (A standard NEMA hinged electrical junction box measuring 12″ × 12″ × 6″ or 30.5 cm × 30.5 cm × 15.3 cm was used to house the prototype.) Also visible in this photograph are jumper wires used to select taps on the secondary string and a labelling system which identifies transformer windings and their voltages. Figures 4 and 5 are interior views of the prototype showing the ferroresonant transformer and resonating capacitor, and the wired side of the panel seen in Fig. 3. Note that point-to-point wiring using No. 14 stranded copper hookup wire was employed in the construction of the prototype.

Project Performance. Several experiments were conducted to determine how effective a regulator the prototype was. The results of some of these tests appear in Figs. 6 and 7.

First, a variable autotransformer connected to the ac power line was used as a source of variable-voltage ac. Loads drawing various amounts of power were connected to the output of the project and the input and output voltages were monitored as the input voltage was slowly brought up to 130 volts. The resulting input/output voltage characteristics appear in the plots of Fig. 6. Then the autotransformer was adjusted to provide a constant 115-volt ac input and a test load was adjusted to draw varying amounts of power from the prototype. The output voltage was monitored as the power demand of the load was increased from 30 to 250 watts, and the resulting output-power/output-voltage was plotted as shown in Fig. 7.

Voltage-regulating action of the ferroresonant transformer is clear from an inspection of Fig. 6. When a 40-watt load was connected to the output of the prototype, the output varied only three volts (from 112 to 115 volts) even though the input changed from 90 to 130 volts! When a 150-watt load was connected to the output of the prototype, the output voltage varied over the same three-volt range while the input voltage was increased from 110 to 130 volts.

In Fig. 7, it can be seen that the output voltage slowly decreased from 115 to 110 volts when the power drawn by the test load increased from 30 to 180 watts. This might not seem to be good voltage regulation, but it is impressive when compared to the performance of a standard isolation transformer with a comparable VA rating. Also, the author's ferroresonant transformer does not have compensation or neutralization windings. A compensation winding would, of

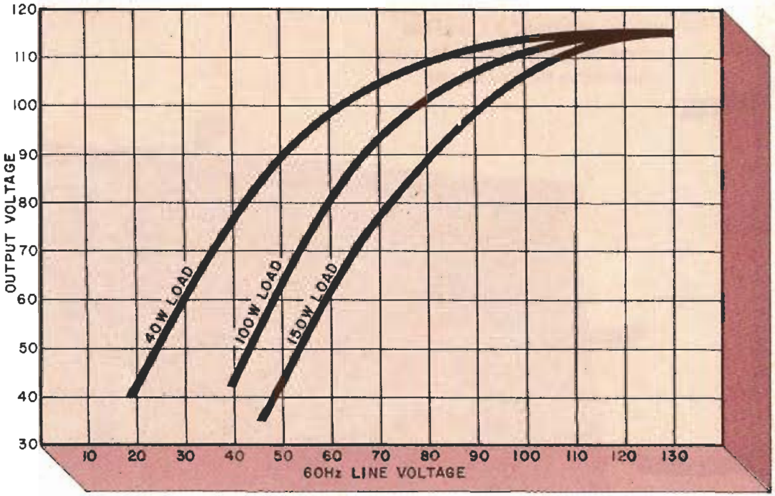

Fig. 6. Family of curves for three different loads shows prototype's input/output voltage characteristic.

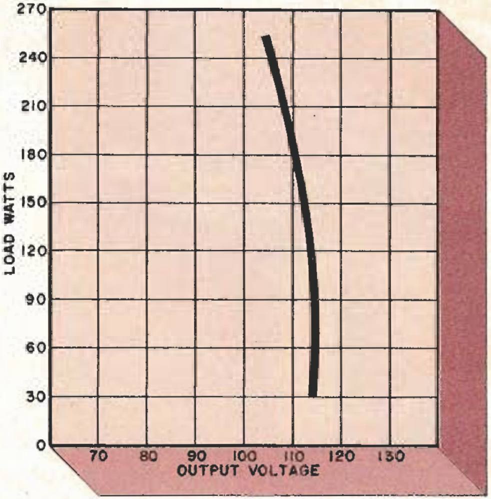

Fig. 7. Curve shows transformer's relatively constant output for an increasing load.

course, further enhance the prototype's voltage regulation. To determine how distorted the output waveform was, it was observed on an oscilloscope. The waveform had a more rounded appearance than a true sinusoid would, but at no time was flattening of the peaks (clipping) observed.

In Conclusion. We have seen that ferroresonant transformers are efficient, relatively inexpensive ac voltage regulators. Their benefits include some degree of protection from high-amplitude power-line transients and isolation from the ac power line. The former is useful if transient-sensitive solid-state equipment is to be powered. The latter makes ferroresonant transformers especially useful in computer applications where a transformerless TV receiver is employed as a video terminal. It eliminates the possibility of a catastrophic pyrotechnics display when the TV chassis is connected to the data system's ground. ◇