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MILITARIZED LINE VOLTAGE REGULATOR

Also IN THIS ISSUE

	Page
VARIAC® RATINGS VS. DUTY CYCLE	6
NEW SALES ENGINEERS	7
NEW YORK OFFICE MOVES TO RIDGEFIELD	8

Where circuit reliability is of prime importance, the need for adequate line-voltage regulation has long been recognized. Not only can vacuum-tube life be extended by operation of the heaters at a slightly reduced but constant voltage,[1] but also performance can be improved by eliminating large plate-supply variations. In many applications, proper power-supply design and the use of a line-voltage regulator can eliminate the need for inefficient, and often less-reliable, series-tube plate-supply regulators. For such applications, the servo-controlled TYPE 1570-A Line Voltage Regulator[2] with its advantages of high accuracy, no distortion, large power rating, high efficiency, and excellent transient response, has become well established.

The importance of longer tube life and increased circuit reliability has created a demand for such a regulator built to military specifications. In the past few years, the General Radio Company has designed and built a number of specialized regulators for a variety of military end-use applications. A new regulator (Figure 1), the TYPE 1570-ALS15 is now offered, which incorporates the best of the de-

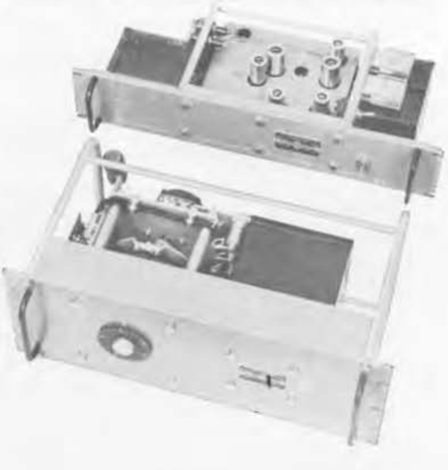

Figure 1. View of the militarized voltage regulator. Regulator unit is in the foreground, control unit at the rear.

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[1] W. S. Bowie, "The Effects of Heater Cycling and Heater Voltage," *1956 I. R. E. Convention Record*, Part 6.

[2] M. C. Holtje, "An Accurate, High-Speed, Automatic Line-Voltage Regulator," *General Radio Experimenter*, Vol. 29, No. 2, July, 1954.

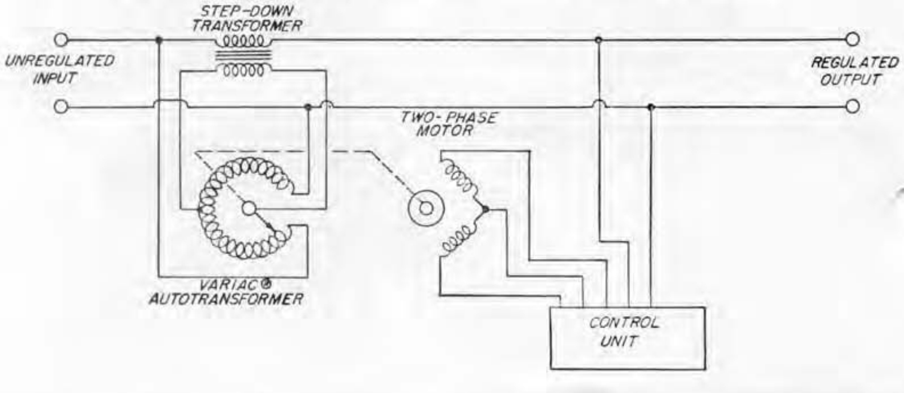
sign and performance features of these special units. In addition to the obvious military environmental requirements of shock, vibration, temperature, humidity, etc., the unit is designed with particular emphasis on flexibility, ease of maintenance, reliability, and long life.

Basically, the regulator (Figure 2) consists of a Variac® autotransformer that adjusts the output voltage, a "buck-or-boost" step-down transformer that effectively multiplies the power rating of the Variac, and a servomechanism that positions the Variac. The "buck-or-boost" circuit, which is often used for manual line-voltage correction, is shown at the left of Figure 2.

For flexibility and ease of maintenance, this 6-kva regulator has been built in two units (Figure 1). The larger unit contains a special motor-driven Variac and a hermetically sealed "buck-or-boost" transformer. The smaller unit contains the electronic circuitry for sampling the output voltage and controlling the two-phase servo motor on the Variac to maintain the output voltage constant well within 0.25%. Thus, with different combinations of Variacs and "buck-or-boost" transformers, regulators of different ratings can be assembled using the same electronic control circuit. This not only provides design flexibility, but also simplifies service problems, since only one type of control circuit, interchangeable for all regulators, is required. Furthermore, when service of the electronic circuitry is required, only the small control unit need be removed. The larger unit with all its power wiring can stay in service supplying uninterrupted (but unregulated) power, while the control unit is being replaced or repaired. Manual control of output voltage is possible during these intervals by means of the Variac dial on the front panel.

Ease of maintenance was a prime consideration in the original design of this regulator. Tubes can be replaced without the removal of any covers other than tube shields. Removal of a single dust cover (Figure 3) exposes all other components. Component wiring is accomplished with an etched circuit to provide a high degree of uniformity between units. Each component is marked with its magnitude and rating and is identified by a component number permanently etched on the mounting board. The removal of the bottom cover plate (Figure 4) exposes all etched wiring. The complete circuit diagram is silk screened on the inside of this plate.

Figure 2. Functional diagram of the regulator, showing the buck-or-boost circuit.



For protection against the effects of moisture and fungus growths, the etched board is sealed with a fungus-resistant varnish.

Reliability and long life have been assured by conservative ratings and the use of the best materials and components in simple circuits that have proved reliable in long field experience.

Figure 5 is an elementary circuit diagram of the control unit. A d-c voltage proportional to the average amplitude of the a-c output voltage is produced by a full-wave silicon rectifier with a resistive load. The magnitude of the load resistance is chosen to minimize the effect of temperature, and the change in the average value of the rectifier output is less than 0.1% for temperatures up to 135°F (75°C). A ripple filter is included, which provides infinite rejection at the 120-cycle ripple frequency and has negligible phase shift below 5 cycles per second.

The filtered voltage, which is proportional to the a-c output voltage, is compared with a standard voltage from a 5651WA voltage reference tube to obtain a difference, or error, voltage. For maximum stability, a 0A2WA regulator tube is used to provide constant current to the reference tube. These tubes were developed for military use where a voltage reference free from the usual voltage jumps was required.

The error voltage is amplified by a differential amplifier (Figure 5) which uses 5751 tubes operating very conservatively, at constant heater voltage (the unit operates on its own regulated output), to give the longest possible life. Appropriate lead and lag networks are used for optimum regulator performance. This amplified error voltage is applied in push pull to a thyratron (2D21WA) motor-control circuit. The thyratrons are provided with a 60-cycle bias voltage at a 90° phase angle with respect to the a-c plate voltage. The amplified d-c error voltage superimposed on this a-c bias voltage smoothly changes the thyratron firing angle from near 0° to 180°.

A two-phase motor is supplied with 60-cycle power from the power line through the thyratron control circuit. Through changes in their firing angles, the thyratrons control the relative phase angle between the motor-winding voltages. Their distorted output voltages are filtered with resonant circuits, and applied to the motor windings. As the thyratron firing angle changes from 0° to 180°, the angle between the motor voltages changes continuously from approximately +90° to −90°. At balance, full voltage is applied to both motor windings at a zero-degree phase angle. The resultant dynamic braking improves the transient response.

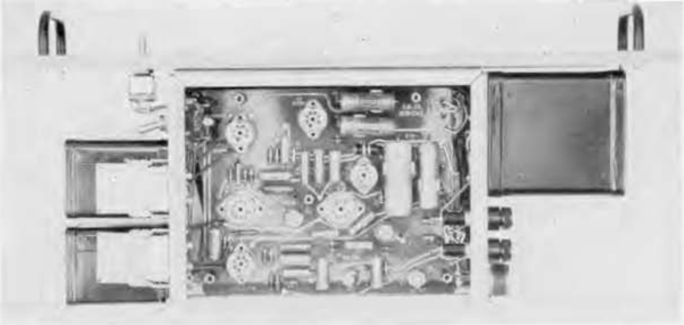


Figure 3. View of the top of the control unit with dust cover removed, showing component identification. Tubes are replaceable without removal of dust cover.

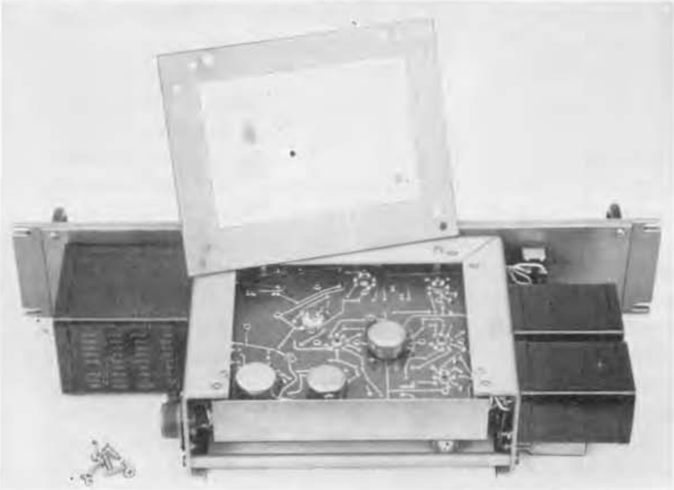


Figure 4. View of the bottom of the control unit with dust cover removed, showing the etched circuit and circuit diagram.

For maximum versatility, a switch is provided inside the control unit for 50-cycle operation of the regulator. In the 50-cycle switch position, the range of operation is 45 to 55 c; in the 60-cycle position, it is 55 to 65 c. Space is also provided for the installation of a separate output-voltage-sampling transformer to permit control of 400-cycle power, although 50- or 60-cycle power must be available to operate the control unit.

The motor-driven Variac is a special ball-bearing model similar in design to the new motor-driven "W" type recently announced.[3] A front-panel dial on the Variac shaft indicates the input line voltage. This dial also indicates the reserve working range of the regulator and permits manual adjustment in case of a control-unit failure. An additional carbon brush to make contact with the radiator in place of the usual metal take-off ring minimizes friction and gives long life in a service demanding continual motion of the Variac brush.

The Variac motor is a two-phase induction motor. Long trouble-free life has been assured by the use of a thyratron motor control circuit rather than relays with their contact maintenance problems. This circuit also results in a superior proportional-type control rather than the usual on-off control.

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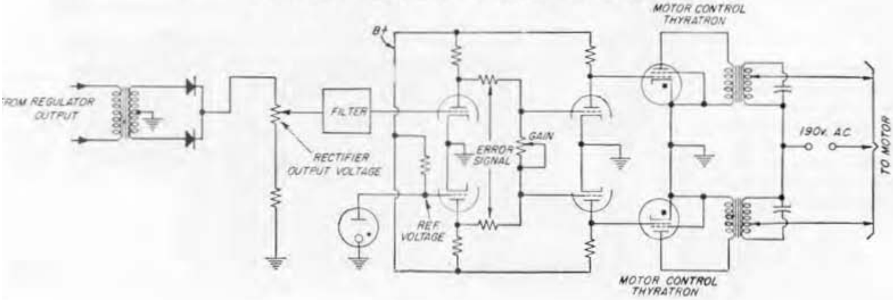
[3] "Motor Drives for W-Series Variacs®," *General Radio Experimenter*, Vol. 31, No. 2, August, 1956.

Figure 5. Elementary circuit diagram of the control unit. To preserve simplicity, the lead and lag networks and the thyratron bias circuits are not shown.



The motor windings are completely encapsulated to prevent deterioration from moisture or fungus growths, and the output shaft is stainless steel to resist corrosion.

As the brush moves across the Variac winding, it is in contact with more than one turn at a time, thus providing a commutating action and, therefore, a smooth change in output voltage. While this commutating action is necessary for the normal operation of the Variac, the shorting action of the brush causes current surges which can be detected as small radio-frequency noises on the power line. Although, in most applications, this noise is completely insignificant, a noise-reducing filter is provided and is mounted on the Variac terminal board. Further noise reduction is provided by five through-pass capacitors located on the main terminal board at the rear of the regulator, which by-pass the Variac connections at the "buck-or-boost" transformer and the input and output connections to the regulator. This filtering is adequate to meet critical military interference specifications.

To provide adequate strength for military shock and vibration requirements, the regulator unit is built on a seven-inch, U-shaped, extruded-aluminum channel. The smaller control unit mounts on a $\frac{3}{8}''$ aluminum panel. Both units will withstand the standard 1200-ft-lb shock test, and they show no significant mechanical resonances up to 55 cycles per second.

Figure 6. View of a three-phase, 18 KVA assembly of General Radio militarized regulators as used by Raytheon Manufacturing Company to provide constant line voltage for radar stations.

The regulator is designed to meet or to exceed the general requirements of MIL-E-4158A. It will operate at full load over the ambient temperature range from −29°C to +52°C (−20° to +125°F) and for non-operating storage from −54°C to +54°C (−65° to +130°F). With special motor lubricants, operation is possible at far lower temperatures. Higher-temperature operation is possible at lower power rating or with restricted duty cycle. Operation is possible with relative humidity up to 100 percent, including condensation caused by temperature changes.

While these military specifications are generally more severe than those encountered in most industrial applications, the increased reliability and ease of maintenance may often justify the use of the militarized regulator in critical industrial applications. This is particularly true for applications at high ambient temperatures or for portable installations where mechanical shock or vibration is encountered.

— M. C. Holtje

SPECIFICATIONS

Input Voltage Range: The desired output voltage will be maintained if the input voltage does not vary by more than ±10% from this value of output voltage. A ±20% range connection is also available.

Output Voltage: Adjustable over a range of ±10% from a base value of 115 volts by means of a screw-driver adjustment on panel.

Output Voltage	*115 Nominal Adjustable ±10%*	
Input voltage as a percentage of output voltage*	90% to 110%	80% to 120%
Output current amperes	50	25
KVA	6	3
Accuracy in % of output voltage	0.25%	0.5%
Speed of Response volts per second†	10	20

* Instruments are shipped connected for ±10% range unless 20% range is specified in order.
† Slightly less for very small voltage corrections.

Tube Complement: 2-5751, 1-5651WA, 1-0A2WA, 2-2D21WA

Waveform Distortion: None.

Accessories Supplied: Spare fuses.

Waveform Error: The average value of the output voltage is held constant, and a d-c power supply with resistive load operated from the output of the regulator will give constant output voltage regardless of the harmonic distortion present in the power line. The rms output voltage will also remain constant, regardless of the harmonic distortion present, as long as the phase and amplitude of these harmonics are constant. If the harmonic content changes, the rms value will change by an amount less than $\Delta R/n$, where ΔR is the change in the harmonic amplitude and n is the harmonic number.

Ambient Temperature: Full ratings apply up to 55°C.

Frequency: From 55 to 65 cycles or from 45 to 55 cycles, as selected by a switch.

Power Consumption: No Load 35 watts
Full Load 100 watts

Mountings: Relay Rack.

Dimensions:

	Regulator Unit	Control Unit
Height	7 in.	3½ in.
Width	19 in.	19 in.
Weight	50 lb.	13¾ lb.

Type		*Code Word*	*Price*
1570-ALS15	**Automatic Voltage Regulator**	CLOTH	**$625.00**

Quantity prices on request.

VARIAC® RATINGS VS. DUTY CYCLE

One of the important advantages of Variac® autotransformers with *Duratrak* contact surface is their ability to operate under short-period overloads without damage. For short-time operation, rated current can be multiplied by a factor that varies between 1 and 10, depending upon the time that the load is applied, as shown in Figure 1. The same properties that prevent deterioration under these high overloads also permit substantial increases in rating for intermittent operation, with the magnitude of the increase depending upon the duty-cycle ratio. If the total number of duty cycles comprise only a relatively short operating period, the current can be further increased to that determined by the short-time rating factor shown in Figure 1.

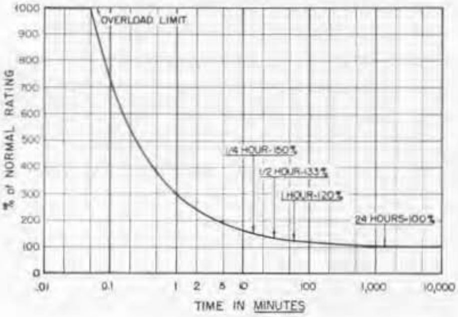


Figure 1. For short-time overloads, the normal Variac current may be exceeded as shown in this curve.

If duty-cycle ratio is defined as the ratio of off-plus-on time to on time, the Variac rated current may be multiplied by the square root of this ratio. The following examples will illustrate the calculation of permissible overload for the TYPE W5 Variac, whose rated current is 6 amperes.

Example 1

Duty cycle: 15 seconds on, out of every 4 minutes (240 seconds).

$$\sqrt{\text{duty cycle ratio}} = \sqrt{\frac{240}{15}} = 4$$

Up-rated current = 6 x 4 = 24 amperes.

15-second short-time overload (Figure 1 = 500% = 30 amperes. Since this is greater than that calculated from the duty-cycle ratio, the latter controls, and the permissible current is 24 amperes.

Example 2

Duty cycle: 30 seconds on, 8 minutes off.

$$\sqrt{\text{duty-cycle ratio}} = \sqrt{\frac{510}{30}} = 4.2$$

Up-rated current = 4.2 x 6 = 25.2 amperes.

30-second short-time overload (Figure 1) = 380% = 22.8. This figure, being lower than that calculated from the duty-cycle ratio, is the limiting value, and therefore, the permissible current is 22.8 amperes.

Example 3

Duty cycle: 6 seconds on each minute, repeated for one-half hour, maximum.

$$\sqrt{\text{duty-cycle ratio}} = \sqrt{\frac{60}{6}} = 3.16$$

Short-time rating (Figure 1) for 30 minutes = 133%

Up-rated current = 6 x 3.16 x 1.3 = 24.6 amperes.

6-second short-time overload (Figure 1) = 725% = 42.7 amperes.

Permissible current is 24.6 amperes.

— GILBERT SMILEY

NEW SALES ENGINEERS

LOS ANGELES

Alan O. Abel has been transferred to the Los Angeles Office of the General Radio Company. Mr. Abel, a B.S. from Purdue University in Electrical Engineering and an M.B.A. from the Harvard Graduate School of Business Administration, has been a Sales Engineer at the Cambridge Office for the past two years.

Frank J. Thoma, of Los Angeles, has joined the staff of the Los Angeles Office as a Sales Engineer. Mr. Thoma holds a B.S. degree in Electrical Engineering from the University of Illinois. He was previously associated with the Sangamo Electric Company and later with Edward S. Sievers as a Sales Engineer for Weston instruments.

PHILADELPHIA

John E. Snook, who joined the Sales Engineering staff at Cambridge in 1955, has been transferred to the Philadelphia (Abington, Pennsylvania) Office. Mr. Snook received his

ALAN O. ABEL

FRANK J. THOMA

JOHN E. SNOOK

JOHN C. HELD

B.S. in Electrical Engineering from Pennsylvania State University in 1950, and for the succeeding five years, was with Sylvania Electric Products at Williamsport, Pennsylvania.

WASHINGTON

John C. Held joined the staff of the Washington (Silver Spring, Maryland) Office on May 1. Mr. Held, a graduate of George Washington University, was for five years an engineer at the Naval Research Laboratory and for the past year and a half has been a manufacturers' representative in the Washington area.

NEW YORK OFFICE MOVES TO RIDGEFIELD

The Metropolitan New York Office of the General Radio Company is now located at

Broad Avenue at Linden
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From New York: WOrth 4-2722
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The new office is staffed by the same capable General Radio engineers that operated our former West Street Office, George G. Ross and C. William Harrison, who can supply technical and commercial information on all General Radio products.

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