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TROUBLESHOOTING THE ALTERNATOR AND VOLTAGE REGULATOR

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1 PRINCIPLES OF THE ZERO ALTERNATOR SYSTEM

1.1 Z.E.R.O. uses 400 cycle alternators to power most of the transmitters used in the field. These alternators produce a balanced 3-phase alternating current (AC). Additionally, certain intrinsic advantages are obtained from a 400 cycle source. The motor and generator efficiency is increased compared to the efficiency of 60 cycle devices. Also, it is lighter in mass and smaller in size than an equivalent 60 cycle system.

1.2 Physical laws of electricity and magnetism state that when a magnetic field is rotated within a stationary coil, current is generated in this coil by induction. This is the basic principle behind the design of the alternators used by Z.E.R.O. The primary components of these alternators are the stationary coils or output power stator (Figure 8) and the rotating field windings located on the rotor, (Figure 9) which generate the rotating magnetic fields.

1.3 The sequence of mechanical and electrical steps necessary for the operation may be described in three stages.

1. Start. The gasoline engine turns the rotor (Figure 9), and because the rotor maintains a small amount of remnant magnetism (generally from previous use), it creates a rotating magnetic field. This rotating field permeates the rotor and is intercepted by the shunt field windings (Figure 7), inducing a current. The shunt windings now act as an electromagnet creating their own magnetic field which excites the armature windings (Figure 9), which are coaxial with the shunt field windings. The output voltage from the armature windings is commutated, (e.g. by insulated copper bars, Figure 9) resulting in a rectified, or DC output. The DC output from the commutator brushes is fed back through the slip ring brushes (Figures 2, 5 and 9) to the rotating field windings. The rotating field windings then are energized, and act as a DC excited electromagnet. When the alternator is running, it is the rotating field windings that create the magnetic field that intercepts the output power stator thereby generating power.

2. Run. The rotating field windings, being energized by the commutated output of the armature windings, act as a permanent magnet. As this magnet is rotated, a rotating magnetic field is created which excites the output power stator. In this way output power is generated. To vary the output power a portion of the shunt field windings output is fed through the voltage regulator (VR) and then to the armature windings. The VR alters the current in the shunt field windings so that the desired AC output is maintained.

3. Boost. The boost sequence will cause current to flow in the shunt field windings, and is necessary only if the rotor has lost its residual magnetism (as a magnetized nail might after a period of time).

1.4 The frequency of the alternating current induced in the stationary field windings is regulated by the speed of the rotor. This speed, in turn is regulated by the speed of the gasoline engine; i.e., increasing the RPM's of the engine will increase the frequency of the alternating current.. Normally the Z.E.R.O. system operates at 400 Hz.

1.5 The voltage output of the alternator is regulated by the amount of direct current (DC) provided to the armature (Figure 9) by the shunt field windings. The more direct current provided, the higher the voltage output of the alternator. This is the primary function of the voltage regulator.

1.6 The Z.E.R.O. voltage regulator (VR) monitors and adjusts the alternator output by establishing both a fixed, and a dependent (adjustable) voltage reference. The 741 op-amp, shown in Figure 11 (RP1), and Figure 13 (RP1), has its positive input tied to the fixed reference voltage. The dependent reference, the sum of the 3-phase alternator output, is tied to the negative input terminal (T2).

1.7 The sequence of operations that the VR must perform (see Figure 13) are as follows:

1.7.1 All three phases, phase A (T13), phase B (T14) and phase C (T15), from the alternator, are added together after passing through three separate diodes (RP3). The phase A signal is arbitrarily chosen as the reference phase. This signal passes through the step-down transformer (RP4) to the full-wave rectifier (RP5).

1.7.2 The output of the full-wave rectifier (RP5) is limited to +/- 12 volts by the Zener diodes (RP6), and is used to power the 741 (RP1) op-amp.

NOTE: Some early model Z.E.R.O. VR's do not use a transformer to provide voltage stepdown to bias the op-amp power input. Instead two 4.3 k-ohm, 11 watt resistors serve this purpose. These are currently being phased out because of heat build up and related problems.

1.7.3 The 741 op-amp compares the signal input into terminals 2 (T2) and 3 (T3). The signal at terminal 3 is a voltage reference which is fixed at 6.2 volts by the Zener diode (RP2) shown in the upper left corner in Figure 11. The signal at terminal 2 is the average positive peak voltage of the three phase signals. This average voltage is obtained by passing each of the phase outputs of the alternator through a diode and combining the resulting halfwave rectified signals. A filter capacitor acts to average the signal at terminal 2; however, a small 1200 Hz ripple will remain. This is because the output signals (phase A, phase B, and phase C) are displaced 120 degrees from each other. Rectifying gives a positive DC peak voltage and adding these signals results in the 1200 Hz ripple.

1.7.4 The most important step in regulating the alternator output takes place if the voltage at terminal 2 exceeds 6.2 volts. When this happens the op-amp turns-on, and produces a -10 volt DC output. Conversely if the voltage at terminal 2 falls below the 6.2 volt fixed reference the op-amp produces a +10 volt DC output. The voltage at terminal 2 may be adjusted by varying the potentiometer resistance (i.e. the VOLTAGE ADJUST screw on the front panel). This adjustment establishes the duration time of the op-amp output (i.e., sets the pulse width of the +/- 10 volt signal).

The transistors 2N2222 or 2N5335, 2N4037 or 2N3741, 2N3714 or 2N3732 shown in Figure 13, (RP9), comprise what will be referred to as a transistor bank. Transistors 2N2222 and 2N4037 are on the main circuit board, while two 2N3714 transistors are located on a separate heat sink (Figure 12) directly beneath the main board. On VR units modified for high power output the 2N2222 is replaced by a 2N5335 and the 2N4037 is replaced by a 2N3741 on the heat sink.

1.7.5 The transistor bank is controlled by the op-amp. When the op-amp turns on, it turns on the transistor bank causing there to be a conducting path from the DC output of the armature windings (A+) to the shunt field windings (F). The added current in the shunt field windings causes the magnetic field coupled to the armature winding to increase. This in turn causes an increasing output of the armature windings which is fed directly to the rotating field windings. This causes the strength of the rotating field to increase which causes the output voltage to go up.

1.7.6 To cause the output voltage to drop, the op-amp need only be turned off. This opens the path between the armature windings and the shunt field windings. All of the currents and magnetic fields get smaller and the output voltage drops.

2 STEP-BY-STEP TROUBLESHOOTING

NOTE: Refer to the appendix if unfamiliar with testing procedures. REMEMBER: There may be very high voltages exposed during some of the following tests. USE CAUTION.

2.1 Alternator will not come up to operating voltage.

2.1.1 Boost the alternator with an external 12 volt battery. Connect the battery to the EXTERNAL jacks on the VR (be sure to observe proper polarity), and set the INTERNAL/EXTERNAL switch to EXTERNAL (see Figure 1).

2.2 To determine whether the problem is with the alternator or the VOLTAGE REGULATOR, attempt to bring the alternator up to voltage as follows:

2.2.1 Start the engine and bring the RPM up to the required 400 cycles. The frequency will be displayed on the LCD meter (with the toggle switch set to FREQ, see Figure 1).

2.2.2 Set the INTERNAL/EXTERNAL select to EXTERNAL. The ON/OFF switch must be in the OFF position.

2.2.3 Connect a 12 volt DC source to the EXTERNAL jacks.

2.2.4 These steps will remove the internal circuitry of the VR from the alternator circuit.

2.2.5 Regulate the dependent reference voltage potentiometer (EXTERNAL CONTROL), until 120 volts is displayed on the LCD meter on the VR cover plate.

2.2.6 Examine the output of the alternator with an oscilloscope. Each of the phases (Figure 2, T1, T2, and T3) should be a smooth 120V 400 Hz sinewave.

2.3 Alternator will not come up to operating voltage with boost.

2.3.1 Preliminary inspection.

2.3.1.1 Check the fuses, or circuit breakers in the VR. These are accessible on the VR front panel (Figure 1).

2.3.1.2 Check all the connections on the alternator bakelite terminal block. Make sure all the terminal base nuts are tight (see Figure 2).

2.3.1.3 Check all the wires and wire ends from the alternator to the VR.

2.3.1.4 Try to boost again.

2.3.2 External circuitry check.

2.3.2.1 Check the continuity of the voltage regulator cable. (Figure 3). Touch one test lead of an ohm-meter to each pin in the military connector on one end of the VR cable. Touch the other ohm-meter lead to each pin on the other end of the VR cable. Each reading should be infinite except for corresponding pins (see Figure 10). Now plug the alternator end back into the connector (Figure 4) and touch each pin in the military connector while holding the other lead on the neutral bar. There should be less than 3 ohm resistance between each pin and neutral.

NOTE: The neutral point of the 3-phase source is connected to terminal posts T4, T5, and T6, which comprise the neutral bar (see Figures 2 and 10).

2.3.2.2 Set INTERNAL/EXTERNAL switch to EXTERNAL. With the alternator running measure the voltage between the alternator neutral bar and the A+ terminal, (positive side of the armature winding), see Figure 2. It should be 12 volts.

Failure to detect the full 12 volts indicates that internal circuit tests must be made. Loosen the VR front panel and remove the VR from its case. Initially make a check of the 2 ohm resistor (T6), diode IN5625 (T7), and EXTERNAL CONTROL voltage adjustment potentiometer (T8), refer to the schematic, Figure 13 and Figure 11. If the tests indicate proper operation, continue to trace the external circuit back to the neutral bar.

2.3.3 Internal circuitry tests of alternator.

2.3.3.1 If steps 2.2.1 and 2.2.2 fail to disclose a problem, the next step is to check the alternator itself. Remove the sheet metal protector from around the alternator, see Figures 2 and 5. This will expose the brushes and commutator. Slip each brush out of its holder (use care, they are carbon, and are delicate). Make sure all connecting wires, and brushes are in satisfactory condition. When replacing the brush make sure to put it back in the guide the same way it came out.

2.3.3.2 If the end of the brush is pitted try to clean surface with a knife or fine emery cloth (never use sand paper). The best technique is to lay the emery cloth on a flat surface and slide the end of the brush back and forth across the emery cloth. If the condition is severe or if the brush is cracked, replace the brush. Do not take a chance on a worn brush scoring the commutator or slip rings.

2.3.3.3 Check the commutator for burning, pitting, or thrown solder. Clean with crocus cloth. Wrap the cloth around the commutator, or slip ring, and pull back and forth on either end in a polishing type of motion.

2.3.3.4 Check the spring tension on the brushes. The spring tension should be adequate to press the brush uniformly against the commutator.

2.3.3.5 Check the brush lengths. Minimum brush lengths are:

Westinghouse

Slip ring brush 3/4"
Commutator brush 3/4"

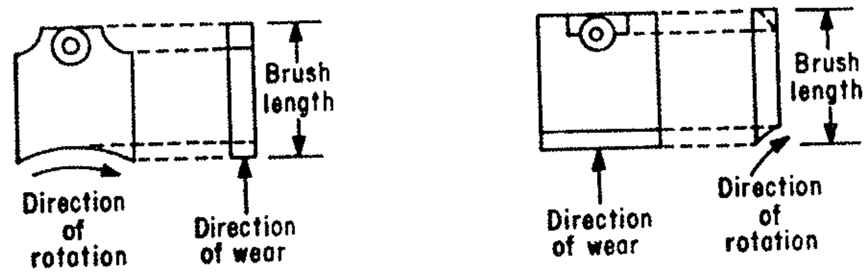
General Electric

Slip ring brush 1-1/2"
Commutator brush 1"

Measurements are made as shown in Figure 6.

NOTE: Brush problems account for a large portion of alternator failures.

WESTINGHOUSE:



GENERAL ELECTRIC:

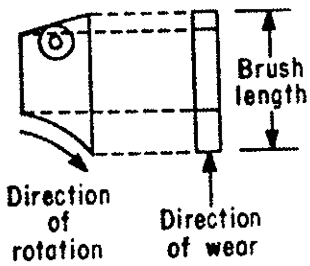


Figure 6. Correct proceedures for measuring brush length.

2.3.3.6 Disconnect all wires from the neutral bar (see Figure 2). Remove the neutral bar (plate which connects all three posts on upper postion of Bakelite terminal block).

2.3.3.7 Measure the resistance between each of the three neutral terminal posts and the alternator case (find a shiny exposed metal surface). All combinations should have infinite resistance.

If this test fails, a short exists somewhere between the 3-phase neutral, and case ground.

2.3.3.8 Measure the resistances between the following pairs of terminal posts. They should measure as indicated:

T 1-T 4	.2 ohm-.8 ohm
T 2-T 5	.2 ohm-.8 ohm
T 3-T 6	.2 ohm-.8 ohm
F or F 1-A-	.2 ohm-.8 ohm
F or F 1-A+	.2 ohm-.6 ohm

All other combinations should be infinite.

2.3.3.9 Failure of the measurements above indicates the following:

- o less than .2 ohm indicates a short most likely in the armature windings. In most cases, this is a condition that cannot be repaired in the field.

- o greater than .8 ohm indicates the commutator slip rings need to be cleaned with a crocus cloth. Polish until a shiny fresh surface is exposed. This is only a temporary cure. The rotor will have to be removed and the commutator polished.

2.4 Alternator exhibits voltage runaway.

2.4.1 Possible causes are:

2.4.1.1 The transistor bank (see Figure 13, RP9) is turned on hard, either by burning out a resistor, or an emitter base junction in a transistor. This forces maximum current to the shunt field. One or several components in the area of the transistor bank (RP9) could be bad. Find and replace the defective part.

2.4.1.2 There is unusually high remanent magnetism in the rotor. This usually does not cause voltage runaway. Rather, the normal effect is that the alternator comes up on its own as soon as you switch ON/OFF to ON, before you push the START button. The alternator will require shop service to replace it.

2.5 Alternator will come up to voltage but will not hold it

2.5.1 Perform previous checks, 2.2.3 and 2.2.4.

2.5.2 Internal Circuit tests on VR.

NOTE: On some of the tests it may be necessary to shut down the alternator, turn the VR off and remove the respective component. This is usually the case when examining semi-conductor components. Continuity tests must be made under no-load conditions.

2.5.2.1 Remove the VR from its case. Examine the wiring for loose, frayed wires. Examine the printed circuit (PC) board for loose parts, burned tracks, signs of arcing, or solder splashes. Take corrective action if needed.

2.5.2.2 Remove and check the power transistors (see Figures 12, and 13, T9), refer to the appendix if unfamiliar with transistor testing. Replace any defective parts.

2.5.2.3 Examine the two .1 ohm resistors (between T9 and T10) refer to Figures 11 and 13. Replace if necessary.

2.5.3 Check the op-amp power supply voltages. Set the multimeter to measure DC volts and a range appropriate for 12 volts. Connect the common lead (black) to the ground (T19), see Figures 11 and 13. Connect the positive lead (red) to the +12 volt side of the power supply, (T11). This voltage should be between +11.5 and +12.5 volts. Move the positive lead to the -12 volt side of power supply, (T12). This voltage should be between -12.5 and -11.5 volts.

2.5.3.1 If step 2.4.3 fails to show the proper power supply voltage, examine the A phase line for proper signal strength. Set the multimeter to measure AC volts and a range suitable for 120 volts. Connect the common lead (black) to ground (T19) and the positive lead (red) to A phase. This voltage should be approximately 120 volts. If the A phase reading measures substantially less than 115 volts the alternator is not functioning properly. Possible problem areas would be the stator windings.

2.5.3.2 If the A phase reading supply voltage is correct, perform the following checks:

2.5.3.2.1 Test the signal output from the transformer, Figures 11 and 13 (T16 and T17). The multimeter should be set for 12 volt AC. The common lead (black) should be connected to ground (T19). The output should be a 24 volt peak to peak sinewave.

2.5.3.2.2 Test the output of the rectifier bridge (RP5). If the output is not between 11.5 and 12.5 volts, the rectifier may need to be replaced.

2.5.3.2.3 Test the 1.2 k-ohm resistor for an open circuit or short (see Figures 11 and 13, T4). Replace if necessary.

2.5.3.2.4 If the rectifier bridge seems to be operating, test the Zener diodes (T4 and T5). The voltage should be between 11.5 and 12.5 volts. If this is not the case replace the Zener diodes.

2.5.3.2.5 If all the previous tests confirm that the proper input voltage and appropriate power supply levels are met, proceed to trace the circuit further for other problem areas.

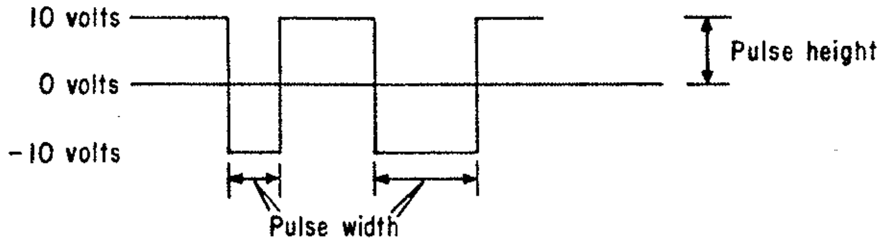
2.5.4 Check the fixed voltage reference (T3). If the observed measurement is less than 5.6 volts, the Zener diode 1N821 (RP2) must be replaced.

2.5.5 Next examine the 1200 Hz ripple on the dependent voltage. To do this use an oscilloscope with the dials set to 2 volts/div, and 1 msec/div. Connect the ground lead to ground (T19). Examine the dependent voltage (T18). The scope display should be similar to:

The amplitude of the ripple should be in the range of 6 to 9 volts. If it is not, then there is too much resistance in the stator windings, or between the alternator output and test the point (T18). Test the components between these points.

If any section (or hump) of the ripple signal is missing this indicates that one of the diodes RP3, is defective, or an output phase of the alternator is disconnected.

2.5.6 Check the 741 op-amp output (T1) with an oscilloscope. Set the scope dials 5 volts/div and 5 msec/div. Connect the ground lead to ground (T19). Put the probe at the output of the op-amp (T1). To keep the signal steady on the screen, the trigger level may have to be adjusted. The output signal should look similar to:



If the pulse height is greater than 10 volts, this increased voltage could damage the transistor bank, Figure 13 (RP9).

NOTE: Damage to the transistor bank can cause overvoltage conditions to exist at the transmitter, and/or runaway voltage conditions in the alternator.

The pulse width will not necessarily be constant. Turn the voltage adjust potentiometer (on VR front panel) slightly clockwise and counterclockwise, the pulse widths should lengthen, and shorten respectively.

If no signal output is seen at this point, and all previous steps check out, the op-amp is defective.

2.5.7 Check the 2N2222 or 2N5335 transistor (T20) with the oscilloscope. Set the scope dials to 2 volts/div and 1 msec/div. Connect the ground lead to ground (T19). Put the probe on the collector (T20) of transistor 2N2222 or 2N5335.

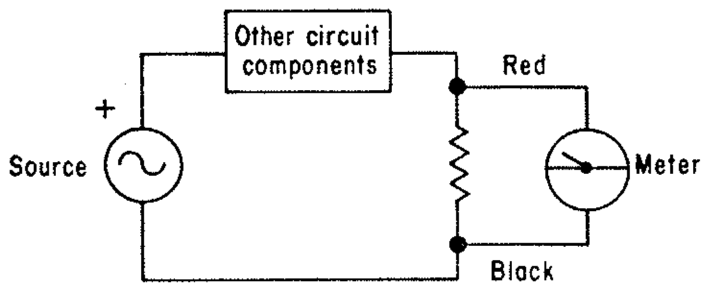
The scope should display a series of positive pulses approximately 5.5 volts in magnitude.

NOTE: If one transistor is defective, generally all of the connected pairs are similarly affected. For futher tests, and procedure instructions for out of circuit continuity tests on semi-conductor devices, refer to the appendix.

APPENDIX

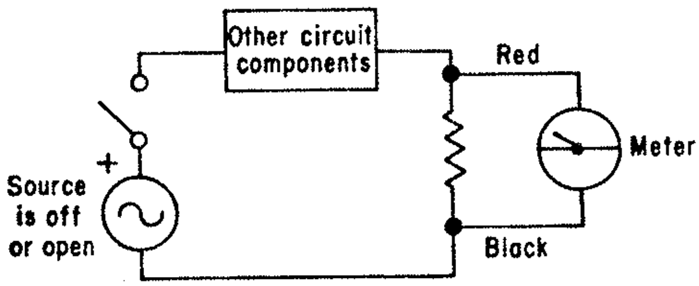
A.1 In operating, maintaining, and repairing the electrical field equipment used by Z.E.R.O. it is frequently necessary to measure voltages and resistances throughout a circuit in order to isolate problem areas. A multimeter and oscilloscope prove useful for troubleshooting purposes. The objective here is to briefly discuss the operation of the multimeter and oscilloscope, and to describe the test procedures used to detect defective components.

A.2 To troubleshoot voltages in the circuit the meter should be connected in the following configuration:

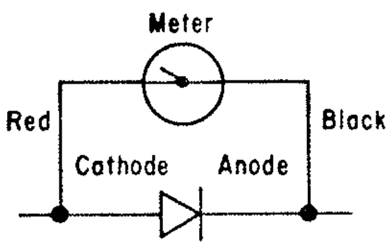


A. 3 To perform continuity tests or check resistance values make sure that the SOURCE IS OFF. Measurements of resistance can be adversely affected by the source and may even be DANGEROUS to the meter and operator.

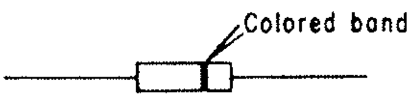
To test for open or short circuits, or resistance values of a particular resistor set the multimeter up as shown below:



A. 4 To test continuity of the diode connect the meter to the diode shown:

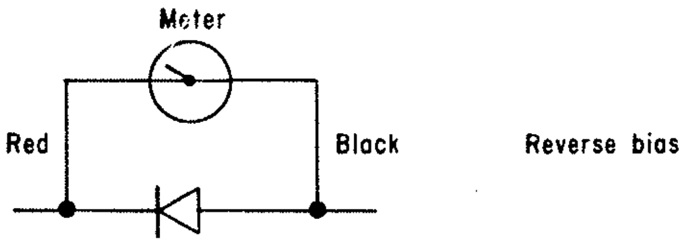


Forward bias

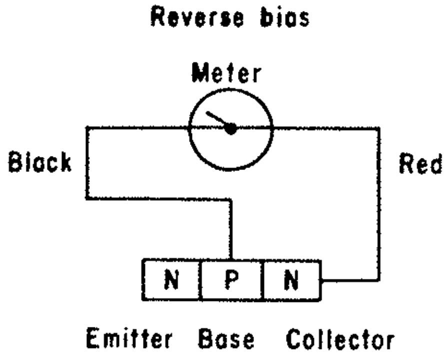


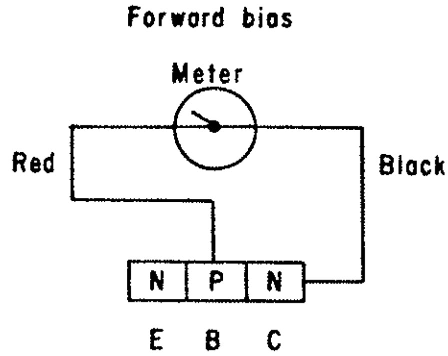
Actual circuit component

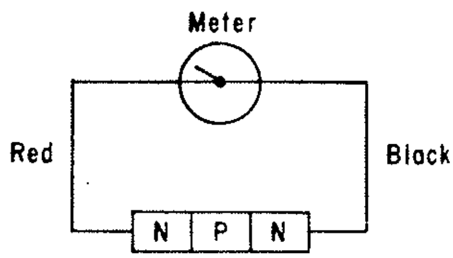
In this configuration the meter should measure an approximate short circuit. And, in the second position an open circuit.

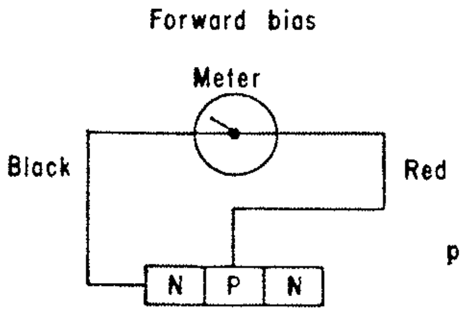


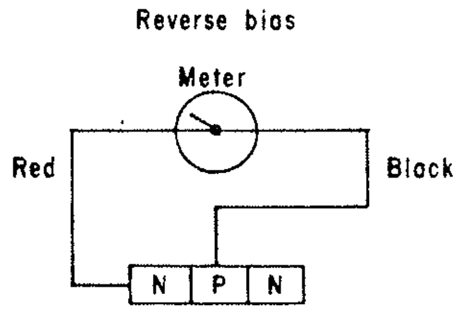
A.5 To test continuity of a transistor connect the multimeter as shown in the following:



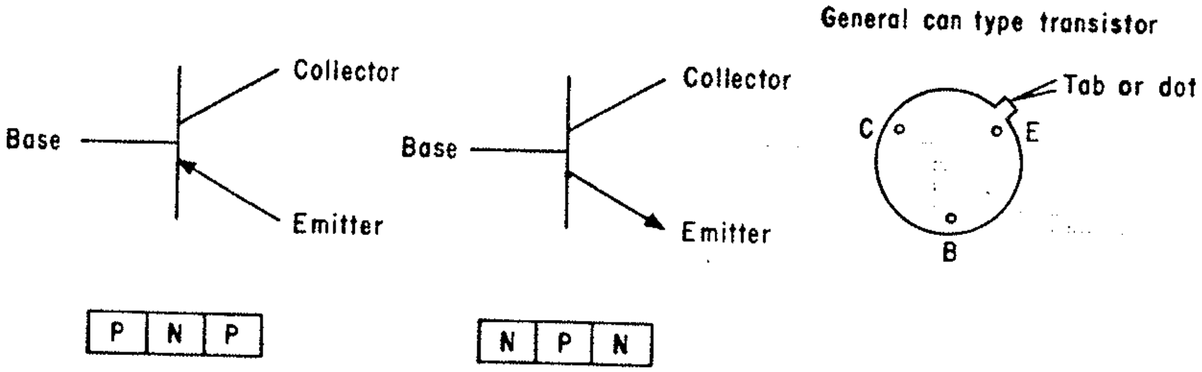








The corresponding circuit diagrams are:



When measuring a PNP transistor reverse the meter test leads; but follow the same diagrams. The measurements should be the same if the transistor is functioning properly.

A.6 An oscilloscope can be used as an AC, or DC multimeter, an ammeter, a frequency meter, and a phase difference meter. Primarily it is used to display voltage or current wave forms on a cathode ray tube. Several controls are necessary to make the 'scope the versatile instrument it is. Briefly, the steps that should be followed to operate the oscilloscope successfully are outlined in the following:

1. Getting started

a. ON/OFF power switch

b. INTENSITY controls brightness of trace beam or spot.

2. Input and Channel terminals

a. VOLTS/DIVISION will regulate the height of the displayed wave form.

b. GAIN CONTROL provides continuous gain adjustment between the calibrated positions of the VOLTS/DIV switch. It is best left in calibrated position.

c. AC-DC-GND switch determines whether only AC beam deflection or AC and DC beam deflection (DC setting), or no beam deflection will occur (GND setting). The GND is used to establish a reference line in case of voltage drifts.

3. Positioning

a. HORIZONTAL moves the trace left or right.

b. VERTICAL moves the trace up or down.

4. Time base

a. TIME/DIV switch selects the calibrated trace sweep speed, as it moves across the screen.

b. TRIGGER SOURCE switch selects an AC, DC, or AC+DC signal to start the horizontal oscillator for each sweep. For INTERNAL the sweep triggers on the signal applied to the vertical amplifier. For LINE the sweep triggers on the 60 Hz power line signal. For EXTERNAL the sweep triggers on an externally applied signal.

c. TRIGGER LEVEL adjusts the instantaneous voltage level at which the horizontal sweep is triggered.

d. AUTO/NORMAL switch selects between automatic triggering, which disables the above settings, or normal which uses the above switch settings. This is necessary for complex wave forms.

Additionally make sure that the test probe can be grounded, with some sort of ground wire. This is not always necessary but in some cases it is essential.

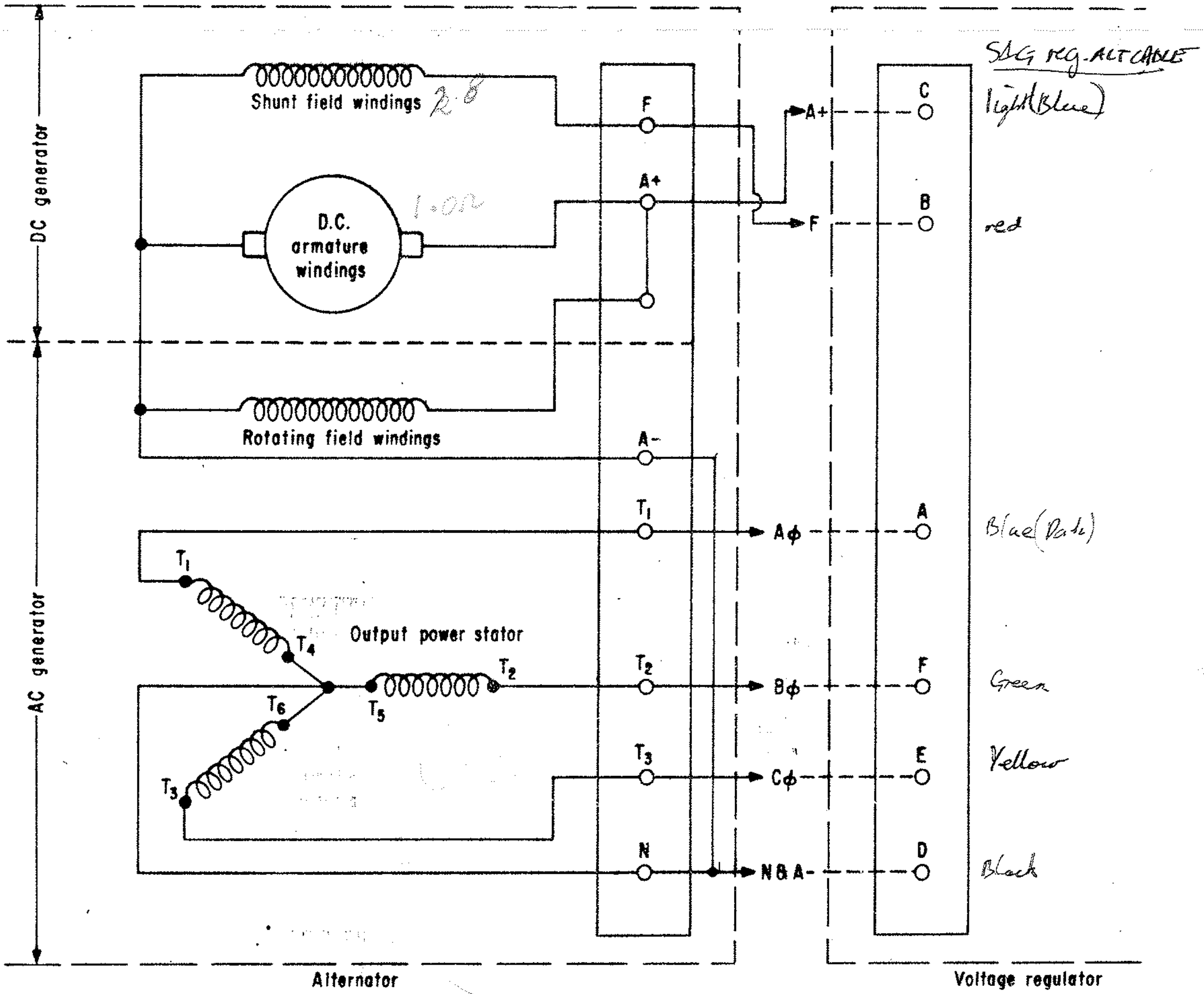
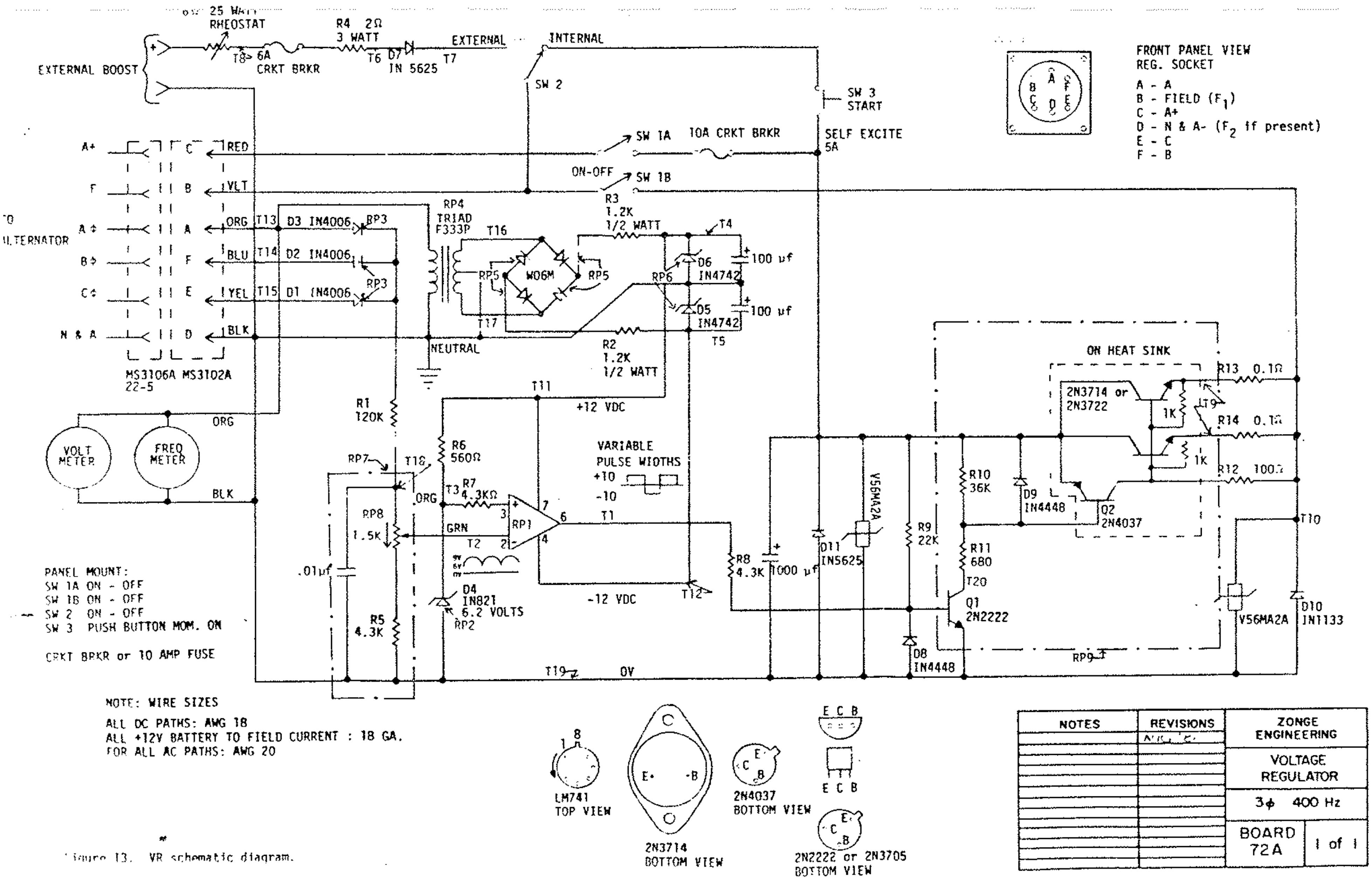


FIGURE 10. General Electric Alternator and VR-1 Voltage Regulator Wiring Diagram.



PANEL MOUNT:
SW 1A ON - OFF
SW 1B ON - OFF
SW 2 ON - OFF
SW 3 PUSH BUTTON MOM. ON

CRKT BRKR or 10 AMP FUSE

NOTE: WIRE SIZES
ALL DC PATHS: AWG 18
ALL +12V BATTERY TO FIELD CURRENT : 18 GA.
FOR ALL AC PATHS: AWG 20

NOTES	REVISIONS	ZONGE ENGINEERING
		VOLTAGE REGULATOR
		3ϕ 400 Hz
		BOARD 72A — 1 of 1

Figure 13. VR schematic diagram.

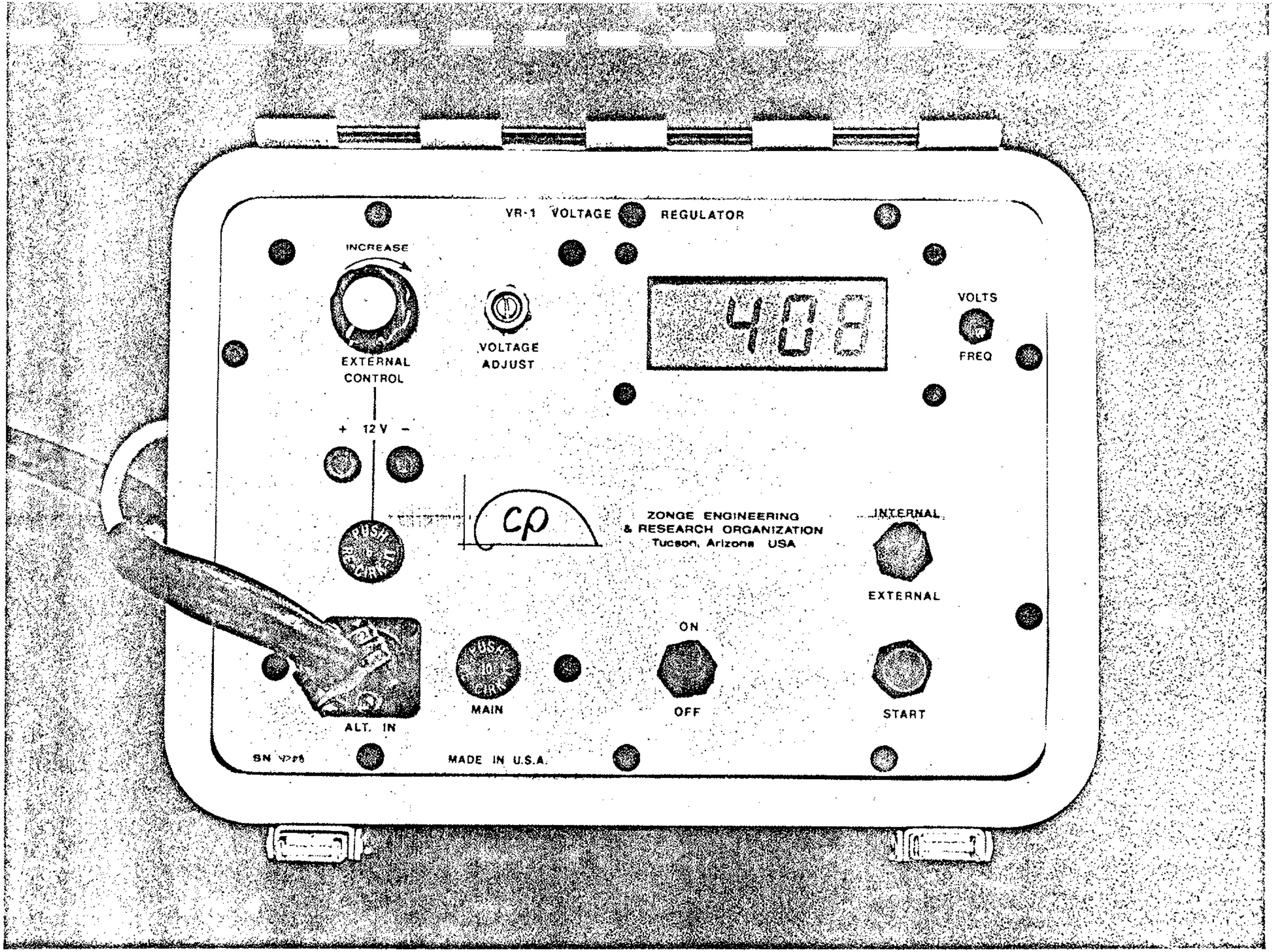


Figure 1. Z.E.R.O. VR-1 regulator front panel. Note: The old model voltage regulators have two separate analog meters for voltage and frequency rather than the single LCD display and switch.

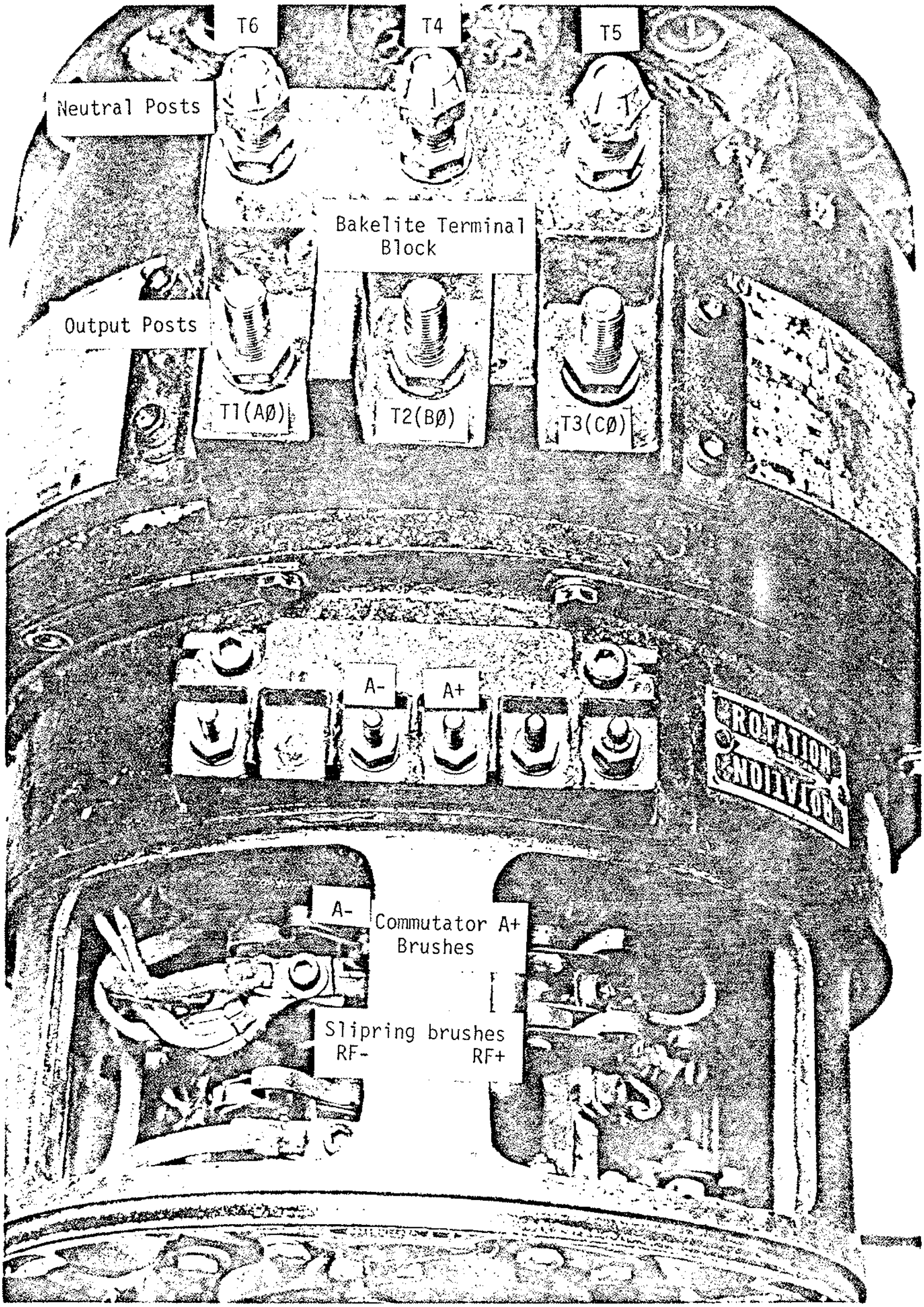


Figure 2. General Electric 3 phase 400 cycle aircraft alternator (30kw) with protective brush cover removed.

Figure 4. Recepticle for military connector on bakalite block of alternator.

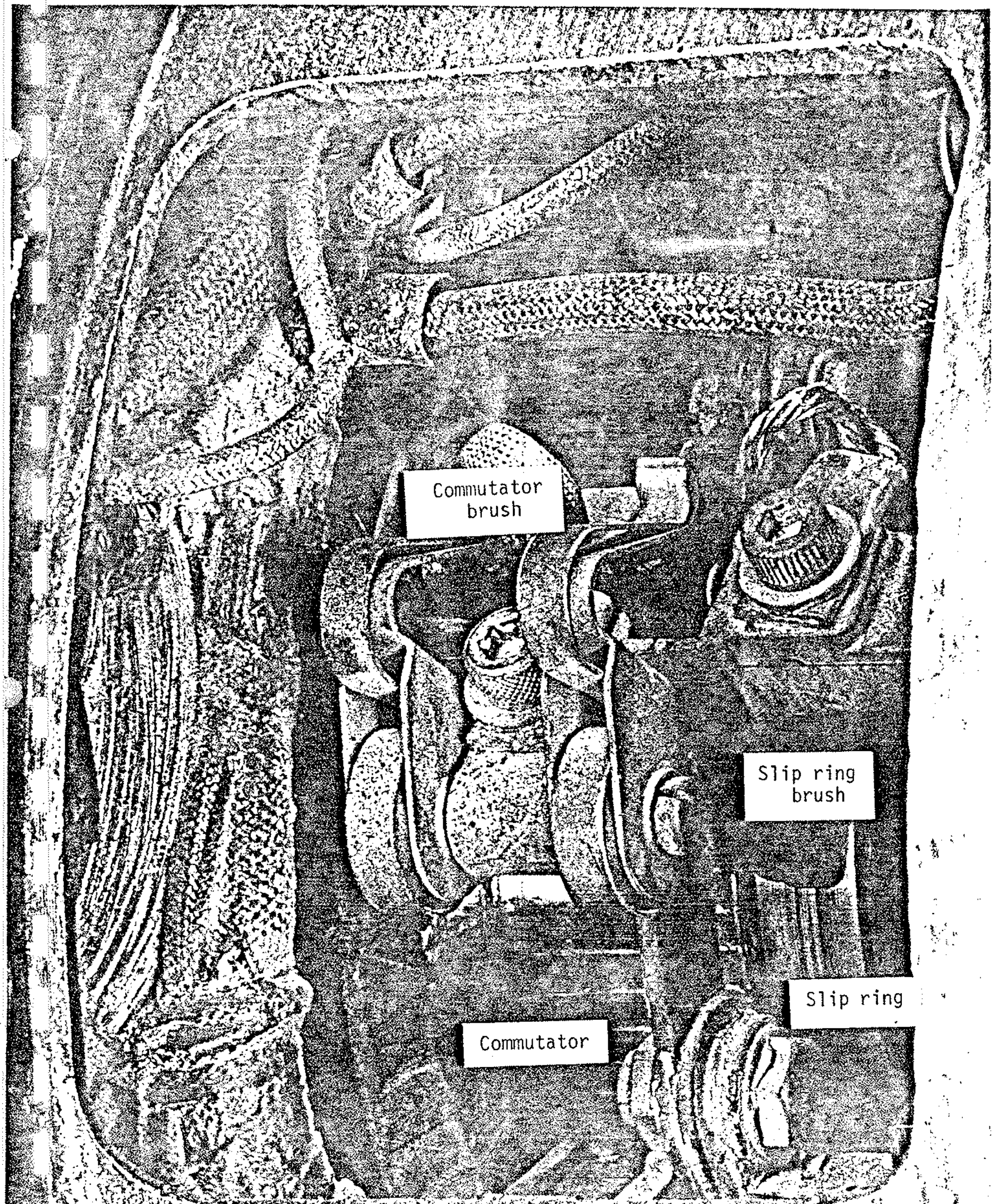


Figure 5. Close-up of brushes, slip ring, and commutator on the General Electric 3 phase 400 cycle aircraft alternator (30kw).

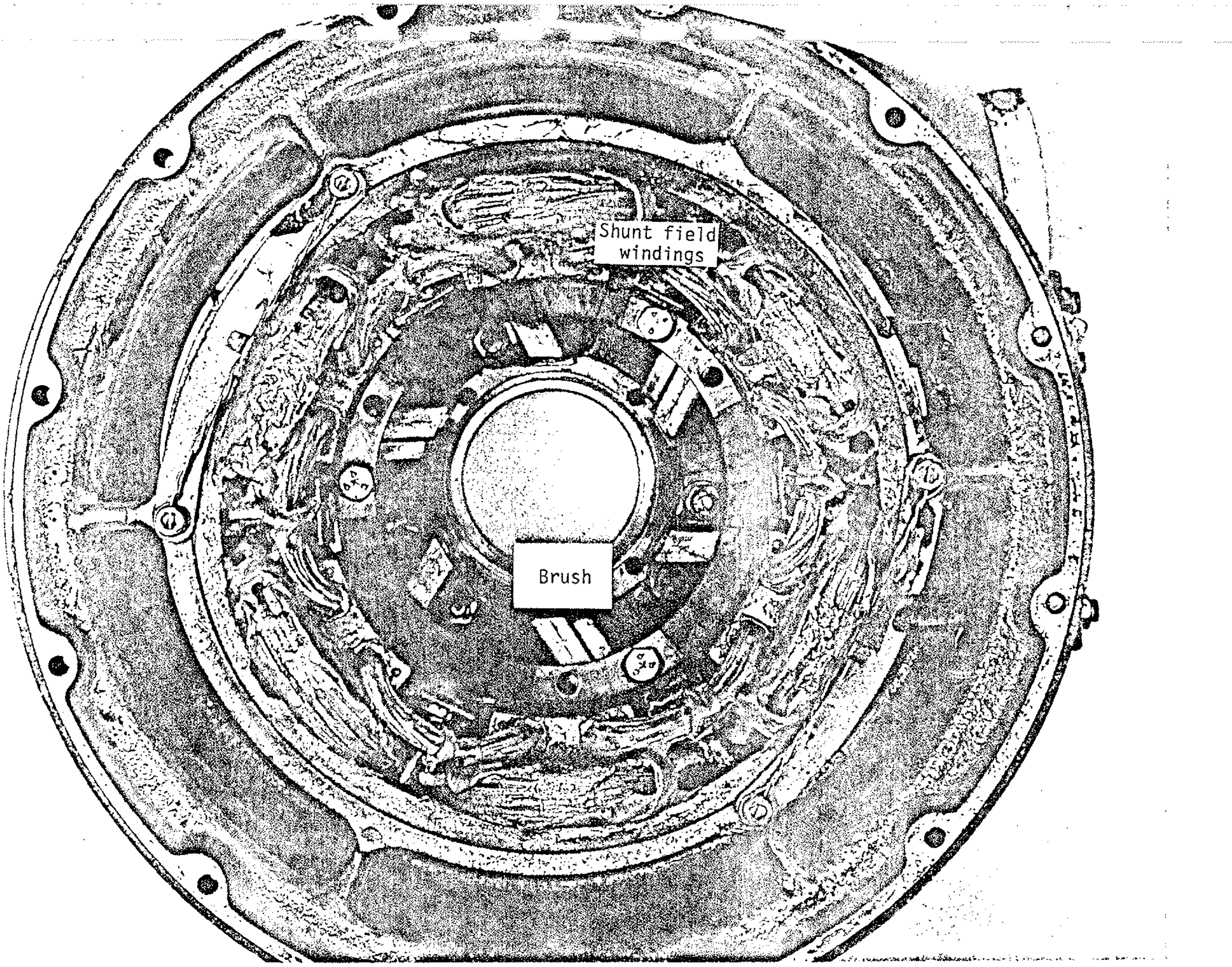


Figure 7. Shunt field windings, and brushes on the General Electric 3 phase 400 cycle aircraft alternator (30kw).

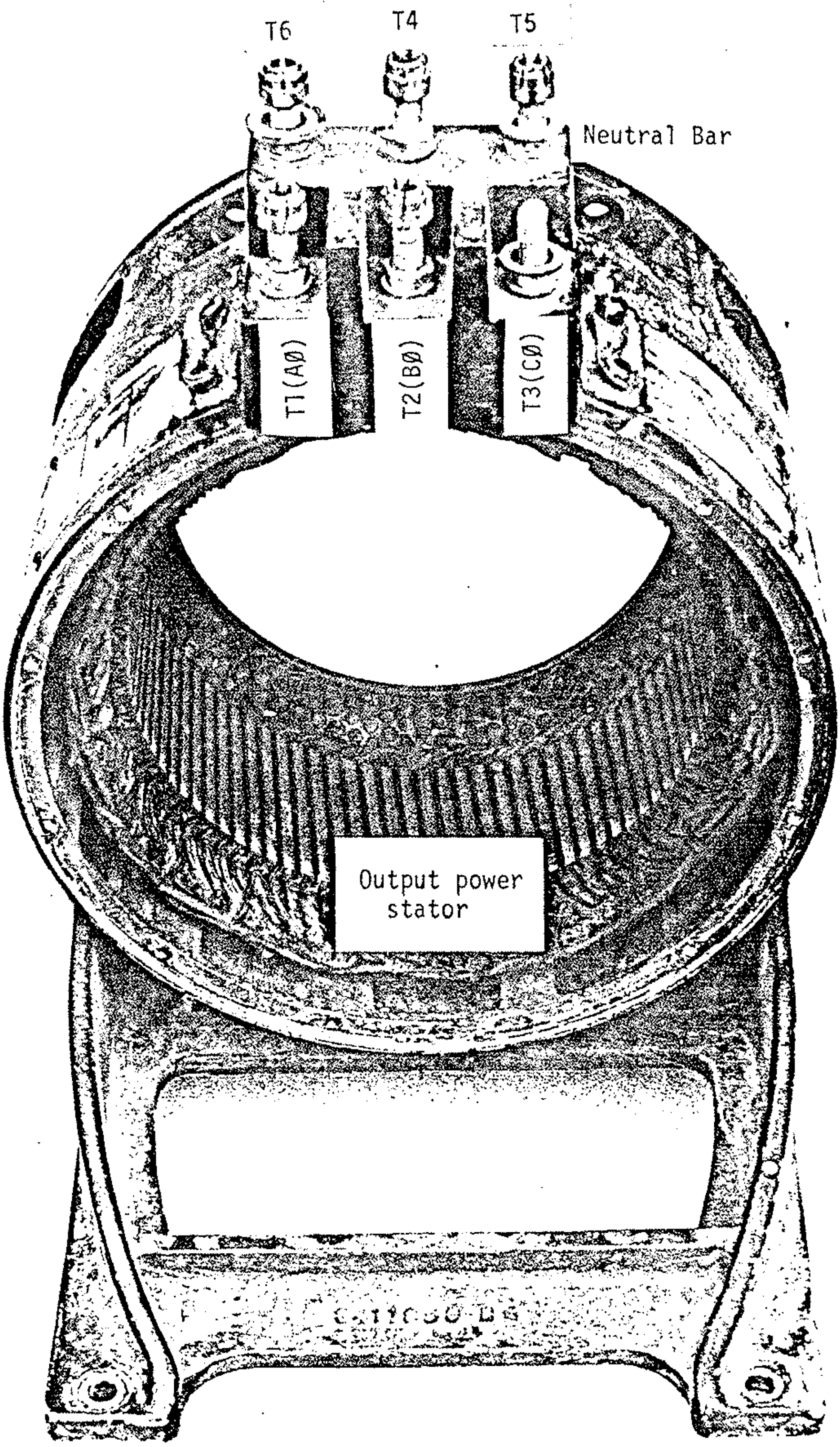


Figure 8. Stator windings and 3-phase output terminals of the General Electric 3 phase 400 cycle aircraft alternator (30kw).

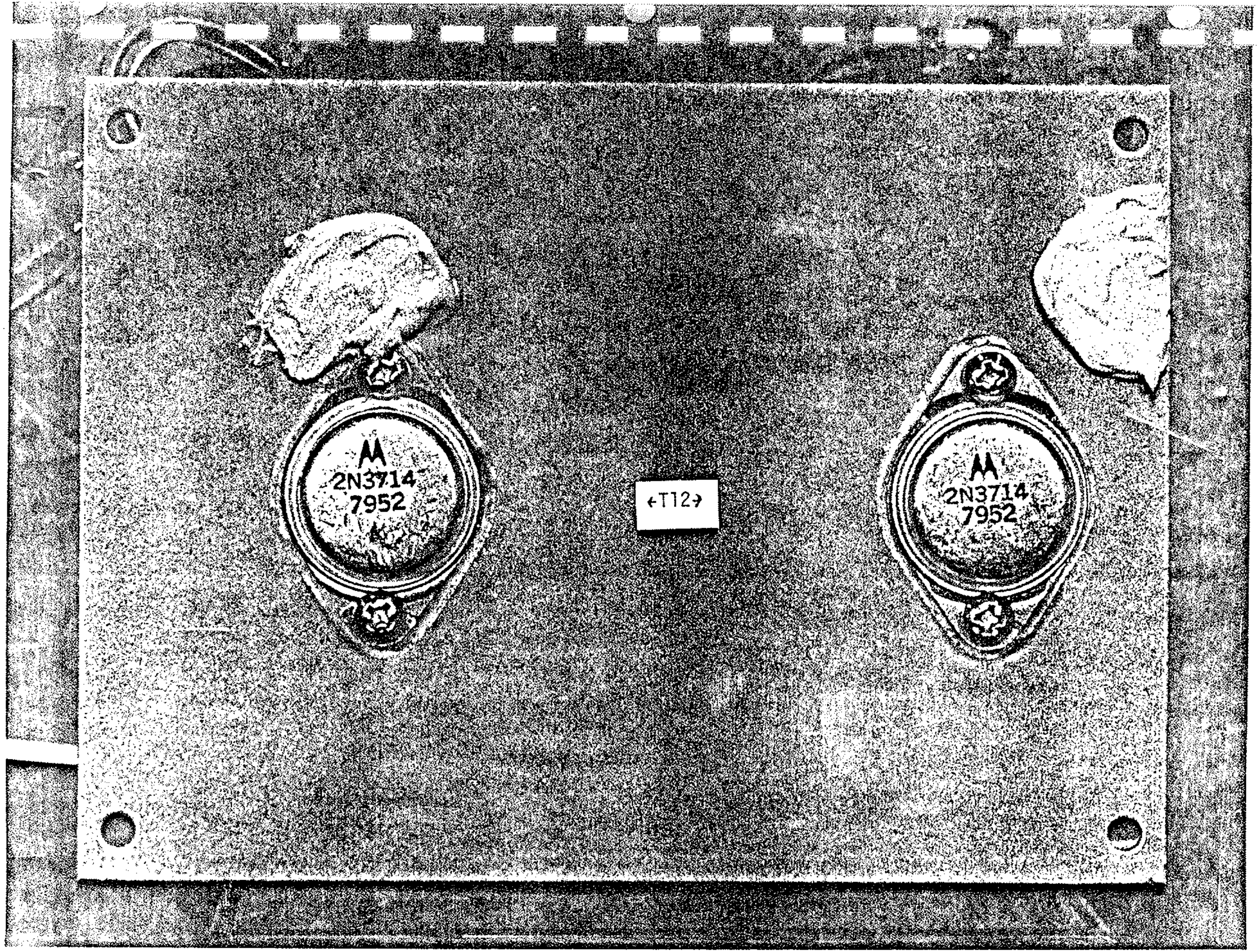


Figure 12. The large power transistors (2N3714) are located on a heat sink separate from the main PC board shown on Figure 2.

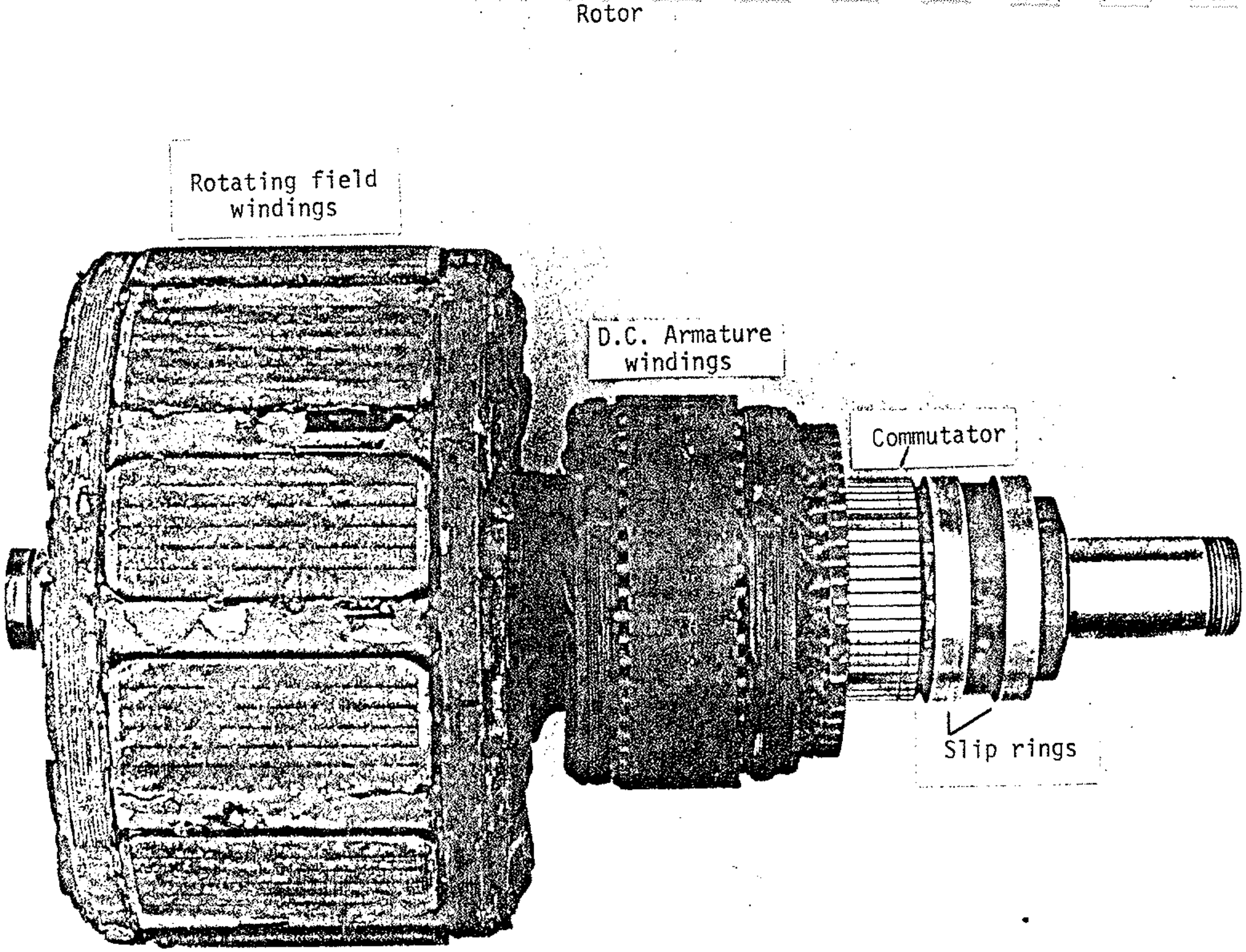


Figure 9. Rotating field windings of the General Electric 3 phase 400 cycle aircraft alternation (30kw).

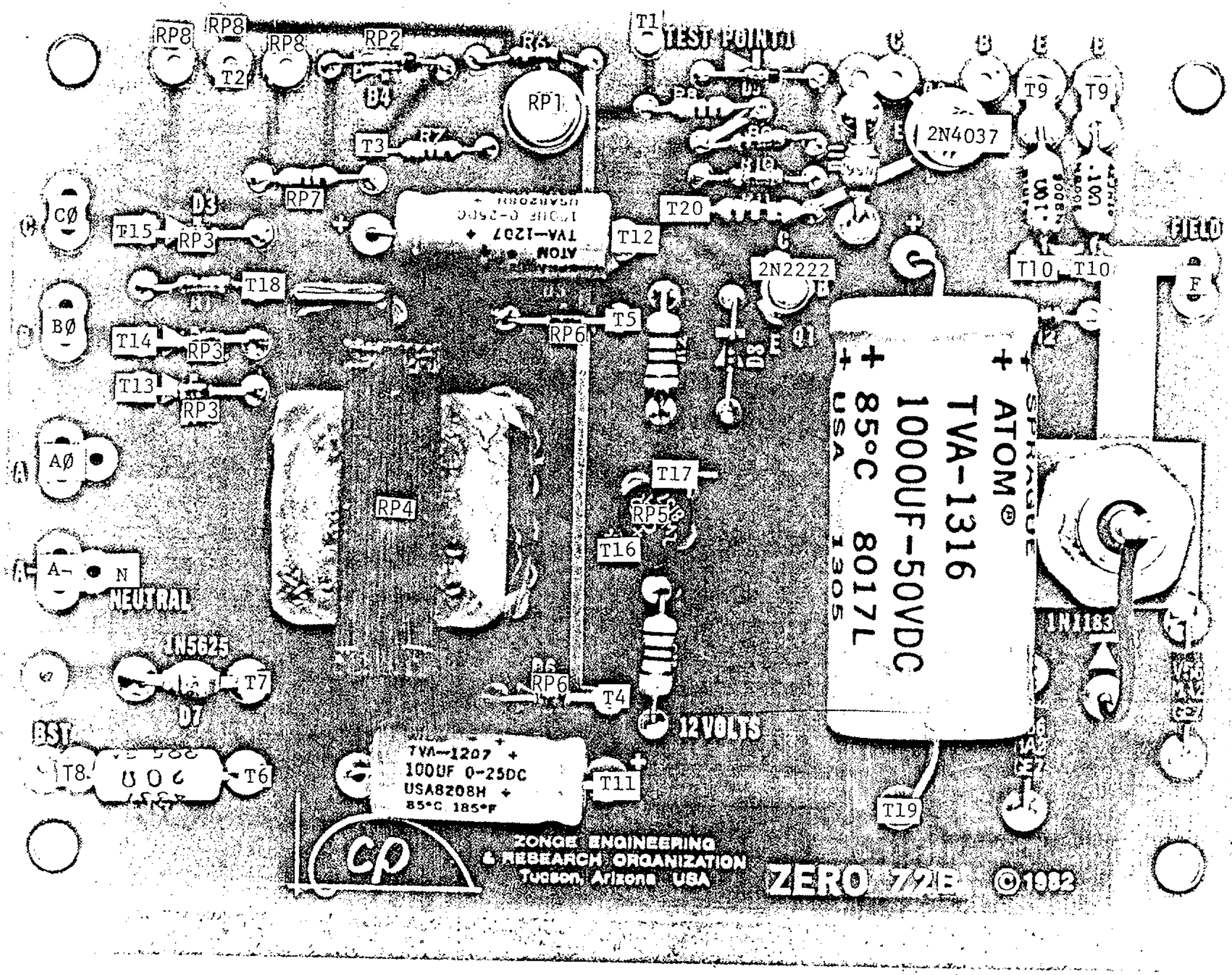


Figure 11 B. Voltage regulator circuit board 72B. Note: All reference numbers on components correspond with reference numbers on the schematic diagram.