CR72529

REPORT NO: 2390

DC POWER SUPPLY

FOR

BRAYTON CYCLE POWER CONVERSION SYSTEM

by

M. KRUSE

GULTON INDUSTRIES, INC.
Engineered Magnetics Division

Prepared For

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA Lewis Research Center
Contract NAS3-10936

Jack H. Shank, Project Manager

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FINAL REPORT

DC POWER SUPPLY
ENGINEERED MAGNETICS MODEL EMPS252
FOR
BRAYTON CYCLE POWER CONVERSION SYSTEM

by

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Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

AUGUST 27, 1970

CONTRACT NAS3-10936

NASA-LEWIS RESEARCH CENTER
CLEVELAND, OHIO

Jack H. Shank, Project Manager
Space Power Systems Division

FORWARD

This report describes work undertaken by the Engineered Magnetics Division of Gulton Industries for the NASA, Lewis Research Center under Contract NAS3-10936. The effort undertaken was the design, development, and testing of the DC Power Supply portion of the Brayton cycle test engine which is under development at the Lewis Center. The report describes the work performed by Engineered Magnetics and the results of the described equipment development.

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ABSTRACT

The Brayton DC Power Supply converts 1200 Hz AC power to positive 28 volt and negative 28 volt DC power for use in the Brayton Space Power System. This Supply also includes a positive and a negative 28 volt battery with chargers and control logic that directly supplies DC output power when AC input power is not available for conversion. The measured AC to DC conversion efficiency is 93%. The calculated Mean Time Between Failures is approximately 60,000 hours.

This report presents the theory of operation, electrical and mechanical design drawings, reliability calculations, parts selections, thermal measurements, and test results.

SUMMARY

The NASA Lewis Research Center is currently engaged in a Brayton Space Power Technology Program. The Brayton Power Conversion System (PCS) has applicability for solar, radioisotope, and nuclear space power systems. The Brayton system has a net output power range of 2.25 to 10.5 kW at 1200 Hz. The Brayton PCS is designed to operate unattended in space for five (5) years.

The DC Power Supply Program was conducted at Gulton Industries, Inc., Engineered Magnetics Division, under a contract with the NASA Lewis Research Center. This program included the design, development, fabrication, testing, and delivery of four DC Power Supplies.

A portion of the 1200 Hz Brayton PCS electrical output serves as an input to the DC Power Supply, which converts the AC power to DC power. Both positive and negative 28 VDC are furnished to the coolant pump static inverters and to the engine control system of the Brayton System. The DC Power Supply also includes positive and negative 28 volt batteries which will provide DC power when the AC input power is not available for conversion.

The DC Power Supply, which has a complete redundancy of its power conversion elements, requires only slight output filtering due to its advanced transformer configuration. It has a tested AC to DC conversion efficiency of 93%. The calculated Mean Time Between Failure of the DC Power Supply is 62,464 hours; with the use of Ultra-High Reliability components, Mean Time Between Failure exceeding the five-year system goal has been achieved.

The DC Power Supply theory of operation, electrical and mechanical design drawings, reliability calculations, parts selections, thermal measurements, and typical test results are presented in

this report.

The DC Power Supply meets or exceeds all requirements of the purchase specification with the exception of the Silver Cadmium batteries. The state-of-the-art in Silver Cadmium batteries was not compatible with the five (5) year life objective of the Brayton program.

I. INTRODUCTION

This Final Report describes, in detail, the DC Power Supply Program conducted at Gulton Industries, Inc., Engineered Magnetics Division. The program for Engineered Magnetics Model EMPS252 DC Power Supply for the Brayton Cycle Power Conversion System (PCS) was initiated in August 1967.

The program objectives included design, development, fabrication, testing, and delivery of four DC Power Supply units to NASA-Lewis Research Center.

The primary function of the DC Power Supply of the Brayton Cycle Power Conversion System is to supply power to the DC bus during all operational conditions. When 208/120 volt, three phase, 1200 Hz power is available from the Brayton alternator, the DC Power Supply converts this AC power into the desired positive and negative 28 VDC to supply the DC bus. When the AC power is not available, the DC Power Supply provides power to the DC bus from the Silver Cadmium batteries which are part of the DC Power Supply. The design load on the DC bus is 1.5 kW. Engineered Magnetics Model EMPS252 DC Power Supply is completely self-contained, and includes provisions for external manual control of system functions.

The NASA contract defined the specific work requirements in four task groups, which were accomplished in the following sequence:

Task I - Preliminary Design Study.

During the Task I phase of the program, preliminary design and assembly details defining system parameters and design envelope for Engineered Magnetics Model EMPS252 DC Power Supply were accomplished, a satisfactory baseline was established, and a preliminary schematic drawing of the DC Power Supply was obtained. The DC Power Supply function and operation were defined. The Power Supply circuits were sectionalized as follows:

Logic
Transformer-Rectifier
Battery Charging
Ampère-Hour Meter
Telemetry
Power Relay
Battery

Operational characteristics and requirements for each of the above listed sections were established. The preliminary design of the DC Power Supply was defined. The circuits comprising the DC Power Supply were catagorized as follows:

1. Logic Circuits
   - Transformer-Rectifier Output Sensing
   - Battery Discharge Sensing
   - Battery Overtemperature Protection
   - Battery Fullycharged Protection
   - Battery Disconnect From Ground Command
2. Transformer-Rectifier Power Supply
   - Transformer-Rectifier Power Supply
   - Battery Charger
3. Ampere-Hour Meter
4. Telemetry Monitor
   - Unidirectional Current Monitor
   - Bidirectional Current Monitor
   - Battery Voltage Monitor
   - Output Bus Positive/Negative 28 Volt Monitor
   - State of Charge Monitor
   - Power ON/OFF Signal Monitor
   - Battery Temperature Monitor

The mechanical design of the DC Power Supply was defined in outline form during Task I. Sufficient design was accomplished to establish system demands and to determine that no major problems were anticipated in the areas of heat transfer, mounting position or packaging.

Task I concluded with preliminary electrical and mechanical design of the DC Power Supply.

Task II - Detail Design and Test Plan.

Finalization of electrical and mechanical design and definition of a test plan for each section of the Power Supply were the major objectives of the Task II phase of the program. The objectives of Task II were realized with no major problems encountered.

During Task II, NASA revised the original power system requirements which necessitated modifications of the EMPS252 DC Power Supply design. In addition to the NASA revision, Yardney Electric Company suggested an alternate battery charging method which resulted in further redesign of the DC Power Supply.

Power system design modifications were incorporated to provide a ground command signal circuit to override all logic functions; to accommodate manual control of the power relay; and include power transistors momentarily to by-pass the power relay contacts. The battery charger logic was designed to provide cut-off of the 8 ampere charge rate of 37 volts and cut-off of the 4 ampere charge at 38 volts respectively. The Ampere-Hour meter logic was designed to reset to 100% when the battery voltage, while under 4 ampere charge, reached 38 volts.

Design revisions accomplished during the "B" revision period of the study (March 1, 1968 to September 1, 1968) were made at NASA request or as a result if EMD engineering tests. The revisions include: Additional terminal lugs on the battery and power system cases; a provision for a system gas bottle heater; removal of the manual/automatic parallel provision for ground commands, and changing the power relay trip point to a higher value.

A complete description of system circuit functions is presented in Section III and the EMPS252 Drawing Package is presented in Appendix I. The block diagram of the DC Power Supply is presented on Figure 1.

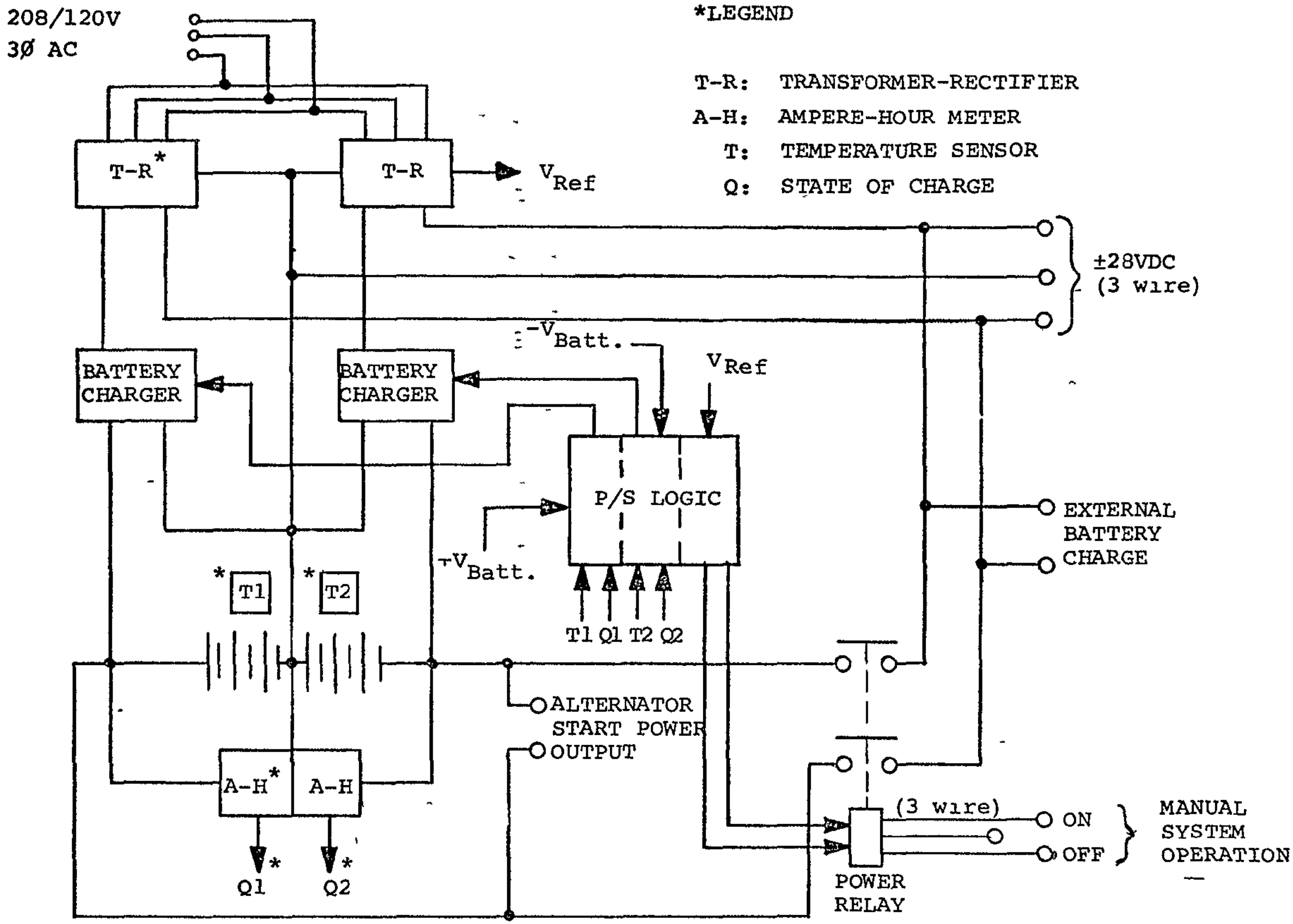


FIGURE 1. EMPS252 DC POWER SUPPLY,
SIMPLIFIED BLOCK DIAGRAM

Task III - Development (Model) DC Power Supply Fabrication.

EMPS252 DC Power Supply Unit No. 1 (Serial No. 26268) was fabricated to the configuration of Schematic Drawing No. 513911. The DC Power Supply was then tested in accordance with the Acceptance Test Procedure. Test data recorded during the Acceptance Test are presented in Appendix II, pages 14 through 16. During performance of the Acceptance Test a thermal heat map of Unit No. 1 was obtained. The Thermal Test Report is presented in Appendix III. After successful completion of the Acceptance Test, a 10,000-hour life test was initiated on Unit No. 1. The Life Test is scheduled for completion in September 1970. After completion of the 10,000 hour life test, a second 10,000 life test will be started. At the conclusion of the Life Test a Life Test Report will be submitted to NASA-Lewis Project Personnel.

Task IV - DC Power Supply Fabrication.

DC Power Supply Units 2, 3, and 4 were fabricated in accordance with the drawings presented in Appendix I. The Acceptance Test was performed on each of the three units at room ambient conditions only. These units were then subjected to a 100 hour cycling and burn-in test program. Acceptance Test Data recorded for Units 2, 3, and 4 are presented in Appendix II, pages 17 through 39.

II. DESIGN DISCUSSION

A. Power Supply Function

The primary function of the DC Power Supply is to supply power to the DC bus during all operational conditions. In addition, the DC Power Supply recharges its silver cadmium batteries while AC power is available from the Brayton alternator.

The DC Power Supply consists of two identical sections (not including logic and control functions) which constitute the +28 VDC and -28 VDC supplies. These two sections function in concert and simultaneously provide a level of fault isolation and redundancy.

The DC Power Supply system provides numerous telemetry outputs for overall system monitoring. These outputs also supply four separate control command operations which may be generated externally from the system. Successful system recycling is dependent upon the initiation of one of these commands.

B. Power Supply Design

The DC Power Supply consists of three individual subsections in three interconnected containers as shown on Figure 2. The positive and the negative batteries comprise two similar battery package subsections. The third subsection is the electronics package. All of the Power Supply elements except current shunts, thermistors, and batteries are contained in the electronics package. The physical characteristics of the DC Power Supply are presented on the following table.

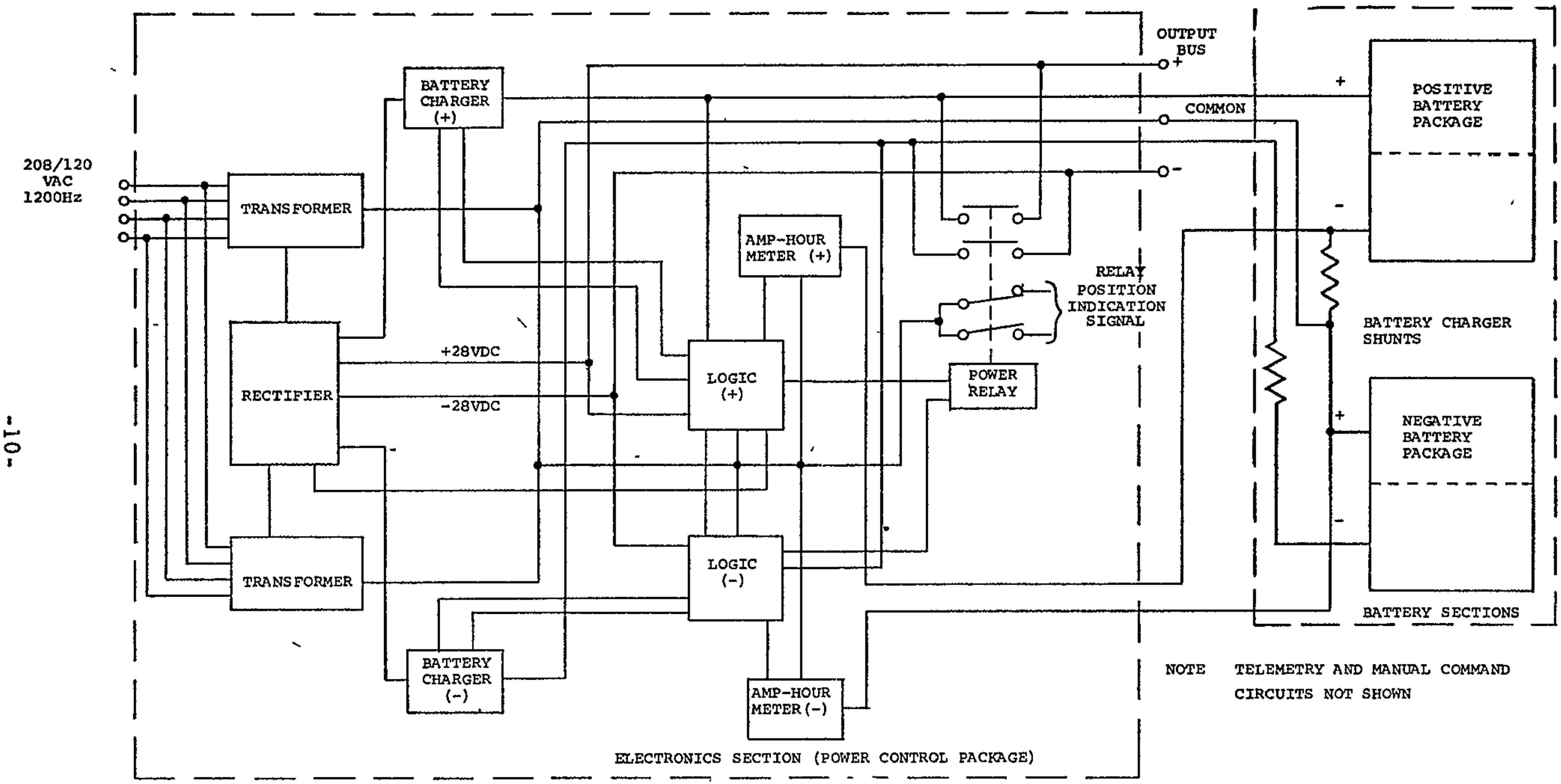


FIGURE 2 BRAYTON CYCLE DC POWER SUPPLY BLOCK DIAGRAM

DC POWER SUPPLY PHYSICAL CHARACTERISTICS

POWER SUPPLY SUBSECTION	BASE DIMENSION (inches)	HEIGHT (inches)	WEIGHT (pounds)
Battery Package #1	10 x 10	10 1/4	140
Battery Package #2	10 x 10	10 1/4	140
Electronics Package	20 x 10	4	30
		TOTAL WEIGHT:	310 pounds

The following paragraphs describe the elements of the DC Power Supply:

<u>Logic Circuit</u>: An assembly of voltage comparators and multivibrators (a majority of which are duplicated for the +28 volt and -28 volt power units) which control the Power Supply during normal operating modes, provide external command interfaces, and dictate the priority and relationship of the DC Power Supply automatic functions.

<u>Transformer-Rectifier</u>: Two multiple winding transformers and a diode assembly which convert the 208/120 VAC input from the system alternator to ±28 VDC bus power and ± 42 VDC for battery charging.

<u>Battery Charger</u>: Two very similar series regulator current limited circuits--one for the +28 volt battery and one for the -28 volt battery. Each charger has two separately controlled sections. Each section supplies a 4 ampere charging current (total of four 4 amp sections).

<u>Battery</u>: A fifty cell silver-cadmium unit with a common center point is physically divided into two packages which comprise the +28 volt and -28 volt batteries.

<u>Ampere-Hour Meters</u>: Two separate sections which indicate the charge state of the +28 volt and -28 volt batteries, respectively, and also initiate battery charger action.

<u>Telemetry</u>: The composite of sense and conditioning circuits which sample DC Power Supply parameters and present them in standard form (0-5 VDC) for remote monitoring.

Power Relay: A bistable latching relay, which connects the DC Power Supply batteries to or removes them from the DC bus, is controlled either by internal logic or external command.

The elements described above are related to one another in the DC Power Supply system as shown in Figure 2. The output of the Brayton alternator (208/120 VAC, 1200 Hz, 3Ø) is fed to the transformer-rectifier (T-R) where it is converted to +28 VDC and ± 42 VDC. The ± 28 VDC power is connected directly to the DC Power Supply output terminals and serves as the Brayton System sources of DC power in the normal mode of operation. The positive and negative 42 VDC power is directed to the positive and negative battery chargers, respectively, and conditions the two twenty-five cell AgCd batteries. The T-R has one additional set of secondary windings which furnish a T-R undervoltage signal to the logic circuit.

The battery chargers for the positive and negative batteries are similar and are hard wired to their associated batteries. The positive or negative 42 VDC is series regulated by the chargers to a level associated with a fixed current value and the existing battery charge state. Each of the two battery charger sections is separately controlled by the logic circuit. During the charge mode either battery is thus charged by an 8 ampere current with both sections operating; this charge rate is reduced to 4 amperes when the charging voltage reaches a pre-determined point and one of the charger sections is turned off by the logic.

A power relay controls the basic operating mode of the DC Power Supply. During normal operation the positive and negative 28 VDC output from the T-R supplies bus power. If the alternator output drops below a pre-selected level (or if the alternator is shut down) the relay automatically connects the Power Supply batteries to the bus as an additional source of power. The same relay also removes the battery from the bus after the shutdown cycle, and prevents battery drain during these possibly extended periods. The power relay is controlled either by internal logic or external commands.

The logic telemetry, and Amp-Hour Meter circuits monitor and control the internal operations of the DC Power Supply and the primary power functions described above. The details of these circuits are explained fully later in this report.

C. System Operation.

The Brayton Cycle Power Conversion System has five major operating modes: Normal Operation, Battery Charging, Alternator or Battery Operation, Manual Control, and System Shutoff. With the exclusion of the Manual Control mode (which is for emergency operation) the other (four) modes are required to complete one full system cycle. Each of these modes is discussed in detail below. Table I shows the various logic functions.

1. Normal Operation

The normal operation function of the DC Power Supply is to receive 120/208 volt, 3 phase, 1200 Hz power from the Brayton alternator and convert this to +28 and -28 volts DC for use in the Brayton PCS. The transformer-rectifier combination supplies the +28 and -28 volts output at currents up to and including 25 amps for both the positive and negative voltages. During normal operation the system battery is in a state of full charge and neither of the system's battery chargers are in operation. Only the bus monitor undervoltage circuit must remain functionally active.

UNIT	POSITION		OPERATING CONDITION OR COMMAND	REMARKS
POWER RELAY	CLOSED		1) ≦ 24V T-R Output 2) Manual "Close" Command	1) Manual command will override the logic by setting of control panel. 2) There are separate "open" and "close" commands. 3) T-R output sensed by separate secondary. 4) Any signal operates <u>both</u> Power Supply halves.
	OPEN		1) ≧ 25V T-R Output (with 5 Sec. Delay) 2) Manual "Open" Command	
BATTERY CHARGERS (Two chargers of two sections each)	ON	Lower half of one charger	Battery Voltage of 30.0V	1) Manual command overrides logic. 2) There are separate "on" and "off" commands. 3) Battery overtemp overrides other automatic logic functions. 4) Manual commands operate both chargers--automatic commands operate relevant charger.
		Upper half of one charger.	Battery Voltage of 30.5V	
		One charger.	Amp-Hour Meter ≤ 90%	
		Both chargers.	Manual "On" Command	
	OFF	Lower half of one charger.	Battery Voltage of 37.0V	
		Upper half of one charger.	Battery Voltage of 38.0V	
		One charger.	Battery Temp ≥ 185°F	
		Both chargers.	Manual "Off" Command	

TABLE I. LOGIC FUNCTIONS OF THE EMPS252 DC POWER SUPPLY

The Amp-Hour meters are idle during normal operation, as no current is being supplied to, or being taken from, the system batteries. The telemetry circuits which provide, remotely, the parameters for a continuous system check, are functional in all the modes. During normal operation of the DC Power Supply, a minimum number of the system components are required to satisfactorily accomplish the DC Power Supply objectives. This condition is significant not only from the reliability standpoint, but also from the standpoint of heat dissipation. The Normal Operating mode will continue indefinitely as long as 1200 Hz power is supplied to the unit and if no external control is exercised. When the AC input voltage is reduced to a level below a pre-selected point, the secondary windings of the transformer will detect a bus undervoltage condition. When this undervoltage condition reaches the equivalent of 24 volts total, the appropriate voltage comparator circuit of the logic will energize power relay K1 and connect the battery in parallel with the transformer-rectifier output on the DC bus. When the bus voltage reaches the equivalent of 25 volts, the relay will open and cause the transformer-rectifier to supply the full load. There is a 5 second delay (a special feature of the reset) associated with the opening of the relay. This delay is provided to allow the Brayton alternator, at initial start condition, an opportunity to reach an operating point where it can supply the required voltage and current. Power relay K1 may be operated manually. For manual K1 operation a switch is provided on the control panel which overrides the automatic control of the relay by the logic power supply circuit and locks the relay in either the ON or OFF position.

Manual relay operation is fully discussed in Paragraph 4, which describes manual operation of the DC Power Supply.

2. Battery Charging Operation

The battery charging mode of the DC Power Supply may be defined as a supplement to normal operation. In this mode of operation the transformer-rectifiers are supplying +28 and -28 volts as previously stated. The transformers are also supplying +42 and -42 volts to the battery chargers through a separate set of rectifiers. There are two battery chargers consisting of four battery charging circuits. One battery charger is for the +28 volt battery and the other battery charger is for the -28 volt battery. These four circuits are almost identical except for slight variances in biasing due to their positive and negative placements within the system. Each of these battery charging circuits is a series voltage regulator which is current limited to 4 amps. The combination of two of these circuits in parallel will supply the associated battery with maximum charging current of 8 amps. From the system operation standpoint, the battery charging mode starts either when the Amp-Hour meter associated with the particular battery indicates a charge state below 90% or when the open terminal voltage of the battery reaches 30.5 volts. Under the first of these conditions the logic circuit associated with the specific battery charger will turn on both of the 4 amp sections. An 8 amp charging rate will continue until the terminal voltage of the battery reaches 37.0 volts. At this 37 volt point, one of the two chargers is turned off reducing the charging current to a 4 amp level. This 4 amp level continues until the charging terminal voltage of the battery reaches a level of 38.0 volts at which time the logic turns off the second of the two charger circuits and the battery is assumed to be fully charged. The charging operation is accomplished concurrently with the normal operation of the transformer-rectifiers supplying bus power. Either one or both of the batteries may be charged during this mode, depending on their individual charge states. It is during this battery charging mode of operation, which obviously requires more power for the transformers and alternator, that the most demanding heat transfer condition is experienced. It is also during this operational mode that the logic circuits pertaining to battery over-temperature and the voltage comparators which sense battery terminal voltage commence to function. The battery temperature sensors will shut down the associated battery chargers if the battery reaches a temperature at which continued charging will injure the battery. The battery voltage comparators automatically control the operation of the battery chargers in shifting from an 8 amp charging current to a 4 amp charging current and then shutting off the battery charger. The battery charging mode may be initiated manually as well as through the automatic control circuits. The manual control (which is discussed in paragraph 4) will over-ride the automatic circuits. The manual control command circuits may also be used to initiate a charge cycle which will then be controlled automatically. This function was included within the system capability at the request of the battery manufacturer as the battery should be jolted to full charge every month or two rather than be supplied with a continuous trickle charge. If the battery is fully charged when the manual control is actuated momentarily, the battery chargers will be sequentially turned off within a very short period.

3. Alternator or Battery Operation Mode

When the output voltage of the transformer rectifier of the DC Power Supply drops below the 24 volt level, the system logic will energize power relay K1 and the system battery will be connected in parallel with the transformer-rectifier output. In the unlikely event of a partial failure of the system alternator, the battery and the transformer-rectifier will remain connected in parallel and each section will supply a portion of the system DC power requirements. However, it is likely that if the voltage from the transformer-rectifier drops below the 24 volt level, the alternator will have been removed as the source of input to the power system and the battery will remain connected across the output bus to furnish power to the bus loads such as in a normal phase of operation during a Brayton Cycle System shutdown. During this period, the Amp-Hour meters will record the discharge level of the batteries. The telemetry and logic circuits will be available for system control and monitoring. Since relay K1 is a bistable device, this condition will exist until either the alternator attains the required voltage level during start up or the system is being shut down.

4. Manual Control

Manual operation of the power relay is required when the Power Supply is to be completely shut down. It also provides an override function in the event that the automatic control circuits fail or if the battery must be placed on the bus to accommodate an unusually heavy load.

The configuration of the DC Power Supply operational cycle may be changed in the normal method through functioning of the system's automatic controls and also by manipulation of the manual override features of the DC Power Supply. As stated previously, the power relay may be opened or closed manually. This manual function will completely override the automatic control circuits.

The battery chargers can also be operated in a manual mode. In this case, both of the battery chargers each containing the two 4 amp sections are operated simultaneously. The same is not true when the battery chargers are operated automatically by the logic circuits, in which case only the battery requiring a charge is serviced by its particular charger and comparator circuits. Manual battery charger operation completely overrides the automatic circuits of the power system and is provided only for emergency use. In the event that the logic circuits do not turn on a battery charger and it is known that the state of charge of the battery is low, the manual command can be used to initiate such a charge. Through careful monitoring of the telemetry signals, the battery charger can be turned off at the appropriate state of charge. If a battery charger should continue charging the battery beyond its full state of charge condition, or in the case where the battery temperature has exceeded its maximum safe charging level, the battery charger can be manually turned off.

The manual control function is also provided for another purpose. The battery manufacturer requested that a method of jolting the battery to full charge be provided within the system, this instead of the trickle charge which is often used in similar situations. The time interval between charge jolts has been suggested to be between 4 to 8 weeks. It is not practical to include in the logic circuit a timing function to automatically turn on the battery chargers from within the system at these periods. (Engineered Magnetics suggested that the Battery Charger-On manual control be used to accomplish this function).

When the jolt charge is required, the battery charger manual on control is momentarily actuated and the chargers of both batteries will start their normal charging operation. Once started, this normal charging operation will be turned off by the normal (automatic) sequence of operation when the charging terminal voltage of the batteries reaches levels which indicate a state of full charge. This function has the advantage of being able to manually initiate battery charging while not having the fault of possible over-charging the battery due to inadequate monitoring.

5. Shutdown Mode

During the Brayton Cycle System shutdown, the battery is supplying power to the inverter coolant pumps and other bus loads. This is a normal mode of operation which has previously been discussed in the battery operation section.

When the system heat is dissipated or distributed, the shutdown cycle is completed, and it is desirable to have the battery placed on a stand-by condition in the event that it will be used in the motor mode of starting the Brayton alternator. The battery must therefore be disconnected from the bus but must be prepared to supply sufficient power to the logic circuits to enable the system to be turned on again. A manual command is first required to open power relay

K1. Now the battery is removed from the bus and is also removed from a position where it will supply power to the logic circuits, telemetry circuits, and the ampere-hour meters.

The power activating circuits for power relay K1 are connected directly across the battery and provide the capability of turning on the system again. The slight power loss due to the sense portion of the circuit will be less than internal losses in the battery during the inactive period and will not significantly effect the battery even during a shutdown period of several years.

D. Mechanical Design

The mechanical design of the EMPS252 DC Power Supply was determined in outline form only for Task I of the program. The outline characteristics and weight have not changed. In Appendix I are the outline drawing and the layout drawing the unit. The battery drawings were supplied to NASA under separate cover.

The DC Power Supply is contained in three sections. Two sections each contain one of the two battery packages. The third section contains the electronic components. Each of the sections are mounted on heat sinks provided by NASA.

1. Packaging Concept

The electronic circuit packaging concepts for the DC Power Supply shown in Appendix I are based on standard techniques which have been used successfully on many space power systems. Exceptions to standard approaches exist in areas relating to the high reliability and long life requirements of the Brayton Cycle Power Conversion System.

The package configuration is one of low profile and large baseplate area. This design incorporates maximum heat transfer area to the coldplate, short thermal paths to the baseplate, and rigid mounting surfaces for the internal electronic components. The main structural member of the unit is an aluminum baseplate. Cover mounting flanges, connector support brackets, internal heat sink brackets, and component mounting brackets are dip brazed to the baseplate. This method of construction optimizes weight, thermal, and structural considerations.

Weight savings are realized through use of brackets fabricated from thin aluminum sheets brazed to the baseplate. Arriving at the same configuration using machined parts would result in thicker sections and unnecessary excess metal in certain areas. In addition, machined parts are inherently more costly and time consuming to fabricate and more restrictive of design flexibility.

Thermal performance is enhanced by dip brazed construction thus eliminating heat barriers that exist if semiconductor brackets, for instance, are bolted to the baseplate instead of being joined by a continuous faying surface fusion of metals.

Structurally, brazed joints offer good resistance to fatigue failures during vibratory loading. Relative motion, as would occur between bolted joints, is elimated by brazing the joint. Brazing provides a ductile interfacial material that is not brittle or susceptible to fatigue cracks that can occur with welding.

The cover of the container is of formed aluminum sheet. It is attached to the base assembly by screws to a mounting flange. This type of attachment, with the cover overlapping the flange, provides EMI shielding and protection from foreign contaminants.

The basic approach being established, the detailed design considerations were governed by reliability and long life requirements. Due to size of the unit and nature of components it is not practical to hermetically seal the case. Instead, the unit is protected from earth associated contaminants such as moisture, salt spray, and sand and dust. Materials that out-gas or deteriorate under extended periods in hard vacuum are not used. Heavy current carriers are terminated at bolt and lug connections rather than by ordinary pin and socket connectors.

2. Thermal Considerations

The only mode of heat transfer from the unit is conduction to the coldplate. Temperature gradients between the coldplate and unit baseplate are minimized by closely spaced mounting attachments. The baseplate surface in the vicinity of the mounting attachments is machined smooth and flat in accordance with NASA requirements. Only four square inches of base area around each attachment are considered as heat transfer area. A joint conductance of 100 Btu/Hr Ft^2 ^oF is assumed for this area. The internal components are arranged to distribute the heat evenly to minimize thermal path lengths to the heat transfer area. The heavy power transformers are mounted directly to the baseplate. The lighter windings, power diodes and charger diodes are mounted on a vertical bracket with direct thermal paths to the baseplate. Battery charger and power supply components are also paths to the baseplate. Series regulator transistors are the most critical components from a thermal viewpoint. Special considerations such as indium foil interfacing materials and installation at a favorable coldplate location are required in order to maintain their temperatures at a reliable limit. Low level circuits are mounted on circuit boards grouped in a subassembly. These components do not require special treatment or close scrutiny for thermal considerations.

The power dissipation characteristics of the DC Power Supply subsections are presented in the following table. Based on the dissipations shown on the table, a heat transfer area of 120 square inches and a joint conductance of 100 Btu/Hr Ft^2 $^{\circ}F$, a baseplate thermal profile was calculated. The maximum baseplate temperature occurs immediately under the power transformer. This temperature, which is approximately 110°C, allows a gradient of 70°C to the transformer rated temperature. The series regulator transistor junction temperature is approximately 140°C. This can be decreased to be less than 110°C with indium foil mounting on the transistor insulator and a location on the coldplate that provides a collant temperature of 125°F instead of 150°F. For proper derating of the transistor, its temperature should not exceed 110°C in this application. The balance of the baseplate is within 5°C of the coldplate surface.

UNIT	Power Dissipation (Watts) Full Load Full Charge	Full Load Half Charge	Full Load No Charge
Transformers	120	95	70
Power Rectifiers	25	25	25
Charging Rectifiers	8	4	0
Battery Chargers	160	55	0
Logic and Telemetry	8	8	8
Amp-Hour Meters	12	12	3
TOTAL	333	199	106

III. POWER SUPPLY CIRCUIT DESCRIPTION

A. Control Logic

The control logic (shown in two blocks of Figure 2) selects the rate of charge to the batteries, determines whether the batteries are to be connected to the DC bus, and determines when the ampere-hour meters are to be reset to show that the individual batteries are fully charged. In addition to the logic diagram on Figure 3, a table of logic functions is provided on Table I. The table presents information on the state of the system for various operating conditions without tracing through the logic diagram.

Automatic control inputs to the logic are battery voltage, battery state of charge from the ampere-hour meter, battery temperature and bus voltage. In addition to the automatic control inputs, two manual commands are provided that can override all other inputs. One manual command turns the chargers full on or off, the other manual command closes or opens the relay that connects the batteries to the DC bus. The logic circuits (except for the circuit that drives the relay) are powered from the +28 volt DC bus and not directly from the battery. The relay drive circuits are connected directly to the battery and require power only during the instant that the relay changes state.

Figure 3 is the block diagram of the control logic. All the controlling inputs are shown on the left side of the figure and all the controlled outputs on the right side of the figure. Amplifier designations and input-output tie points are included so that functional areas of schematic diagram 513911, can be identified.

Logic operation is normally automatic, with the comparators providing an "on" or off" output signal depending upon the magnitude and the previous state of the parameter measured.

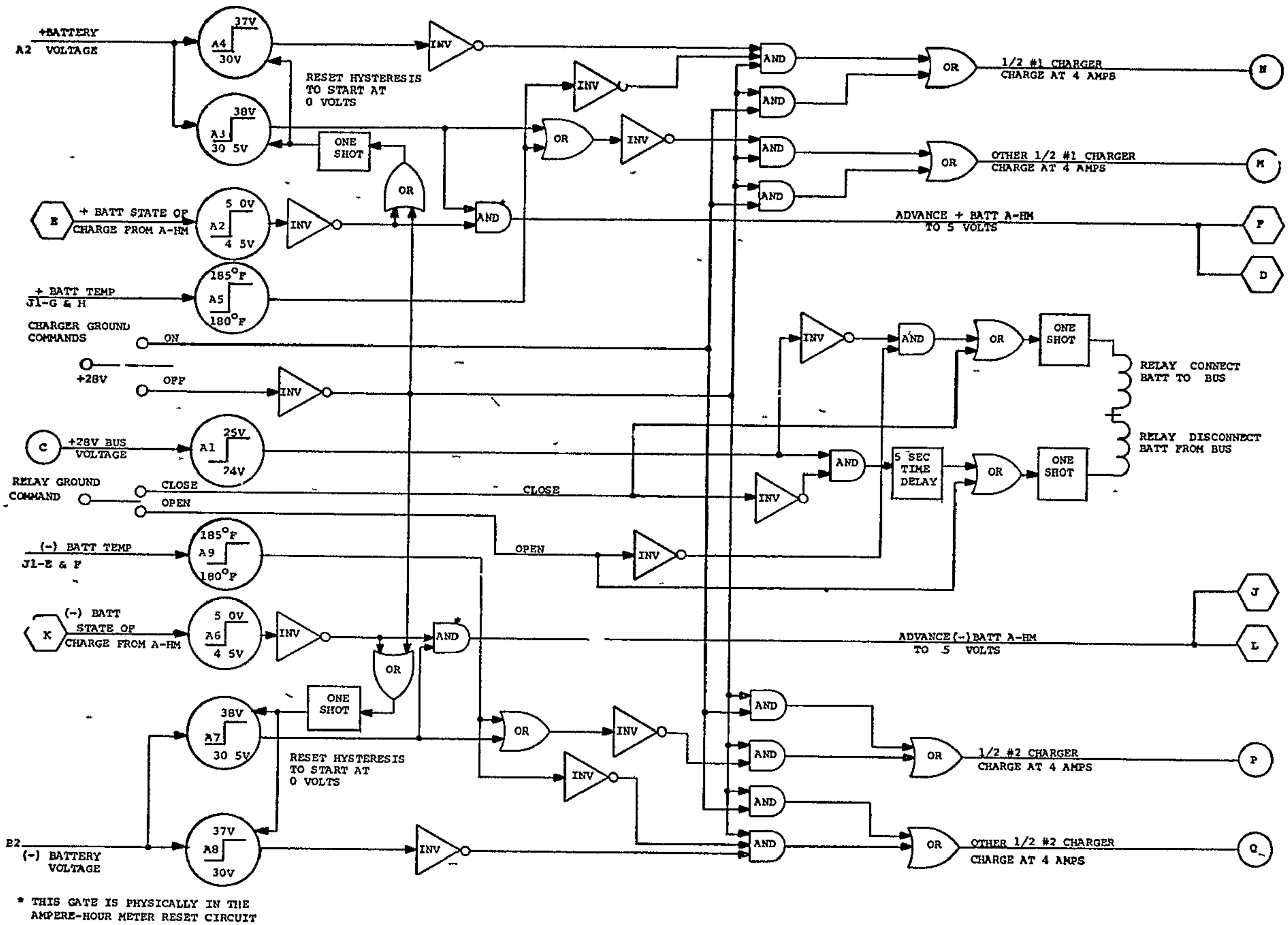


FIGURE 3 EMPS252 DC POWER SUPPLY CONTROL LOGIC BLOCK DIAGRAM

Each comparator has a turn on level and lower turn off level. The output state of the comparator between the "on" level and the "off" level is that of the last level crossed. All logic outputs are "on" or "off" states (the chargers operating at 0, 4, or 4 + 4 amperes) so the "on" or "off" states of the comparators coupled through the appropriate gates and time delays shown in Figure 3 are used to control the logic outputs. Besides using the comparator output states for control, the output on-to-off transition at the 90% full charge level of the ampere-hour meter comparators is used to start the battery charge. This step is necessary because the battery voltage at 90% full charge is at almost the same level as the battery voltage at full charge, while the difference between the upper and lower levels of the battery voltage comparators is a much larger voltage. So if charging is stopped at a battery voltage of 38 volts it will normally not start charging until the battery voltage drops to approximately 30 volts unless the charge is started by using the on-to-off transition of the ampere-hour meter comparator to momentarily reset the battery voltage comparators back to start at 0 volts. This condition forces the battery voltage comparator output state between the higher and lower sensing levels to be that of the lower sensing level allowing charge to continue until maximum battery voltage is reached. The only other logic function is the 5 second time delay that delays removal of the battery from the bus.

To understand the relationship of the logic functions shown in the block diagram, Figure 3, and schematic drawing 512911, first it is noted that the actual mechanization of some logic blocks can be combined into one logic circuit element and the logic functions may be accomplished with more logic blocks than those shown. However, all of the comparators and connection points shown in the block diagram are identical to those on the schematic. In addition, many of the circuits can be associated with single logic blocks.

Since most of the logic functions are performed with transistors that are either "on or "off" or with simple diode OR gates, the detailed circuit description of the logic will be confined to the comparators, one shots, flip flops, time delay, and relay drivers. Power for the logic circuits is supplied from a series regulator operating from the +28 volt DC bus and froma a Zener diode shunt regulator operating from th -28 volt DC bus.

Comparators: The nine integrated circuit comparators are Fairchild type μA710, which have inverting and non-inverting input terminals. A voltage proportional to the controlling parameter is applied to either the inverting or non-inverting input and a reference voltage is connected to the opposite input. Adjustable hysteresis is obtained by connecting a selected-in-test resistor from the comparator output to the non-inverting comparator input. When the comparator turns on, the voltage level at the non-inverting input is raised.

This addition of some of the output current to the input signal results in lowering the signal voltage to the level at which the comparator will turn off. Once the comparator turns off, however, the turn-on level is restored to the previous, higher voltage state.

One Shots: All of the one shots used in the logic circuits, capacitor couple the off-to-on transition of a comparator (or transistor switch) through a series connected resistor and capacitor to the base of another transistor. The time constant of the series connected resistor-capacitor is approximately the duration of the resulting pulse.

Time Delay: Whenever the battery is to be disconnected from the 28 volt DC Bus, a 5 second time delay is initiated and the battery is disconnected. The time delay period is the time required to charge C2 through R14, (see schematic 513911) until the base-emitter junction of Q7 starts to conduct.

The time delay is started by turning off Q8. The firing of Q7 momentarily turns on Q6 which resets bistable flip flop FF1 to the reset state where output pin 9 is in the on state and output pin 6 is in the off state. FF1's transition is then coupled through C1 and R7 to momentarily turn on the appropriate relay drivers.

FF1 is placed in the set state (output pin 9 is off and output pin 6 is on) by giving the "connect battery" relay manual command at initial system turn on or by the bus voltage dropping below 24 volts. Setting of FF1 is accomplished by the turning on of Q5 when comparator A1 is turned on by a low bus voltage or by a momentary ground command to close the relay.

FF1 also performs additional functions. When FF1 is in the reset state (output pin 9 is on and comparator A1 is off) the time delay is prevented from oscillating by the signal from FF1, pin 9 through CR9 because Q8 is then held on thus shorting out time delay capacitor C2.

The output of pin 6 of FF1 through its relay drivers connects the battery to the bus in the same way that the output of pin 9 disconnects the battery from the bus.

Relay Drivers: The relay drivers provide the momentary 28 volt signal used to change the state of the relay. The two relay drivers are the combination of Q3 and Q4 and the combination of Q9 and Q10. The relay drivers are simply Darlington connected transistors (DC current gain ≈ 1000) in series with the battery and relay coils. Momentary base current for turn-on is provided through the series coupling capacitors from the change in state of FF1.

B. Transformer-Rectifier and Battery Charger

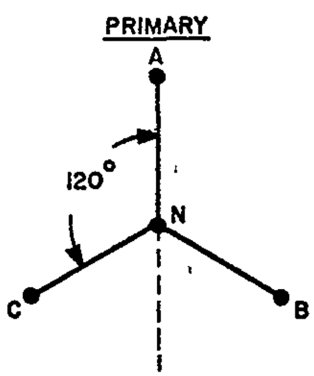
<u>Transformer-Rectifier</u>

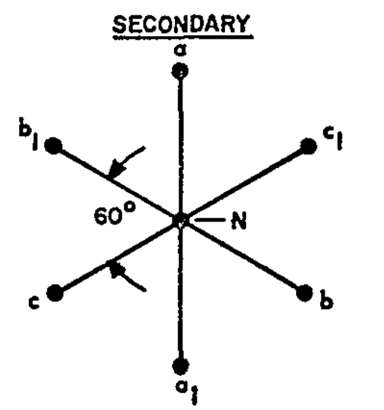
The transformer-rectifier circuit of the DC Power Supply, shown on Drawing 513911, is a 3 phase input, 12 phase output configuration.

The following characteristics were the major considerations for the selection:

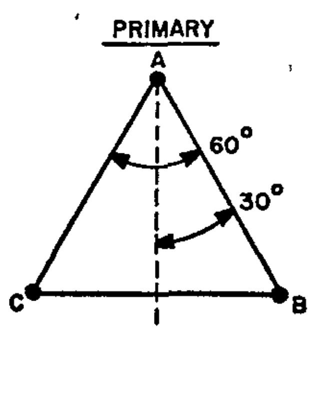
High efficiency
Low ripple
Low internal impedance
Low input power waveform distortion
High input power factor
Redundancy.

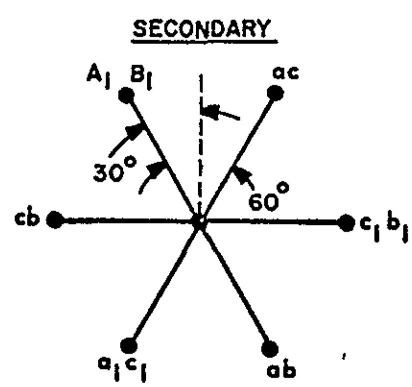
Two transformers are connected to produce a 12 phase output from a 3 phase input. One transformer has a 3 phase Wye primary and a 6 phase star secondary winding.



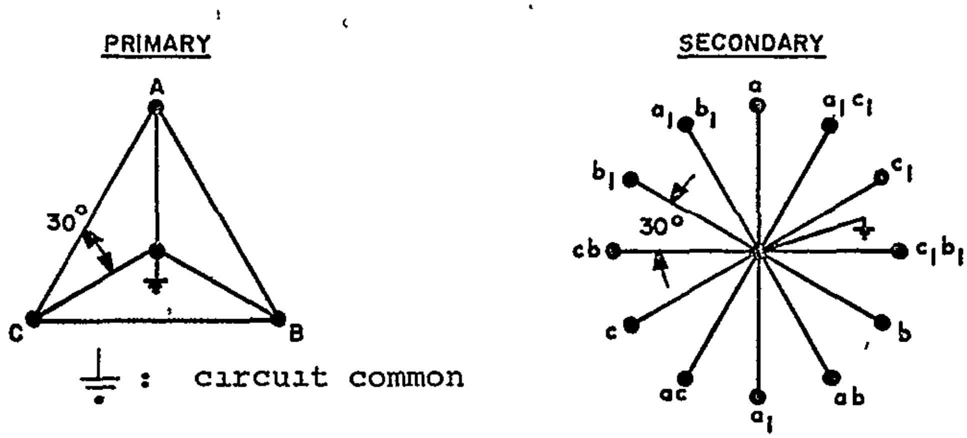


The other transformer has a 3 phase Delta primary and a 6 phase star secondary winding.





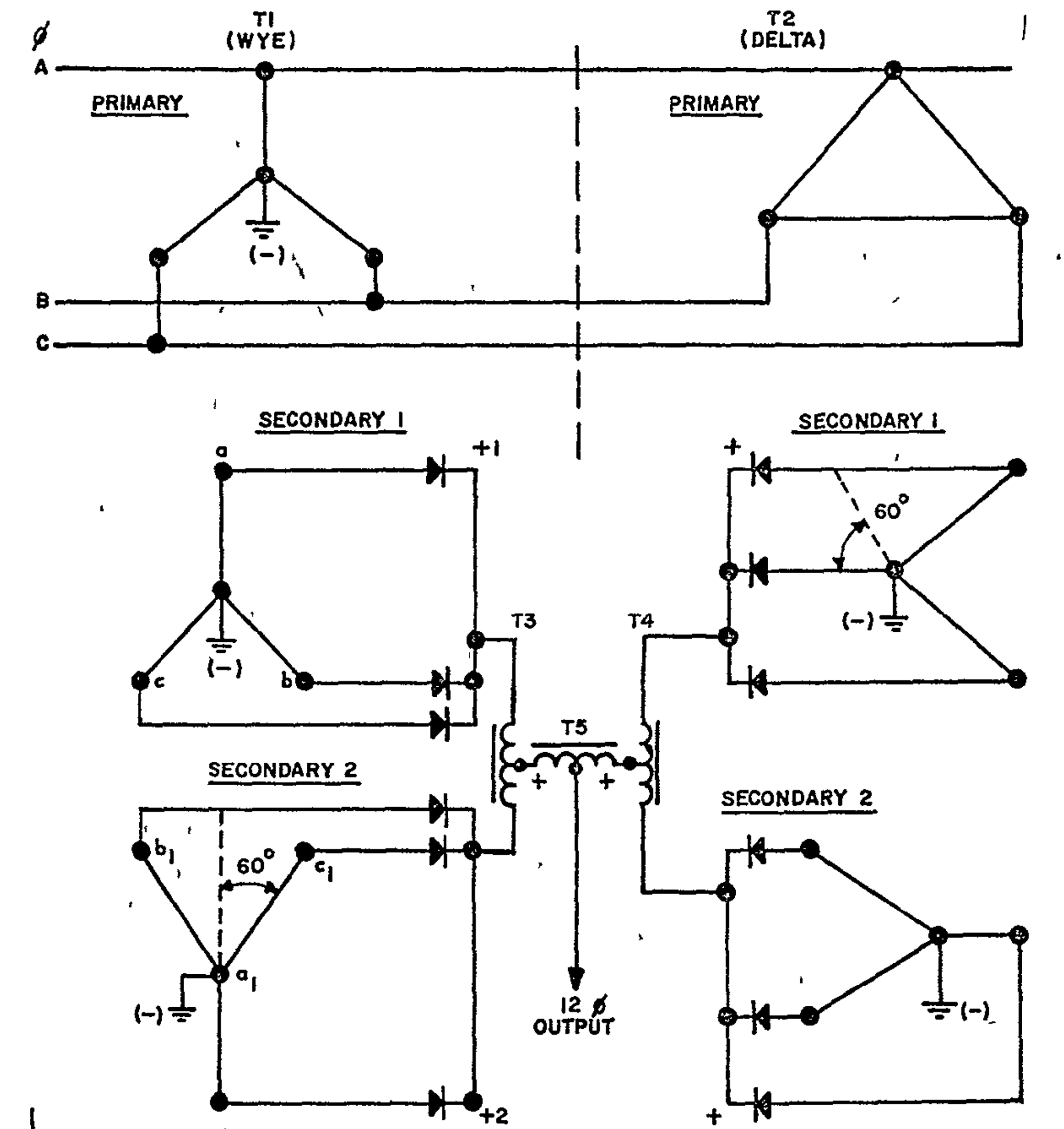
When combined, the corresponding windings of the two transformers are 30° out of phase, and form a system circuit having a 12 phase secondary:



By connecting each secondary winding to rectifier anodes and connecting the rectifier cathodes to the positive terminals, a 12 phase half wave transformer-rectifier circuit with a negative common is obtained. (See diagram below.) The DC output will have a theoretical 12 phase ripple of 3.41% peak-to-peak amplitude. The major disadvantage of this circuit is that each rectifier carries the full load for 1/12 of the cycle, or 30°. Only one rectifier, the one with the highest voltage, conducts at any given time. As soon as the voltage of one rectifier becomes highest, all other rectifiers are back biased and stop conducting until the next rectifier in sequence conducts for 1/12 of a cycle. This individual load carrying characteristic subjects each rectifier and transformer winding to high peak currents which are also reflected into the power source.

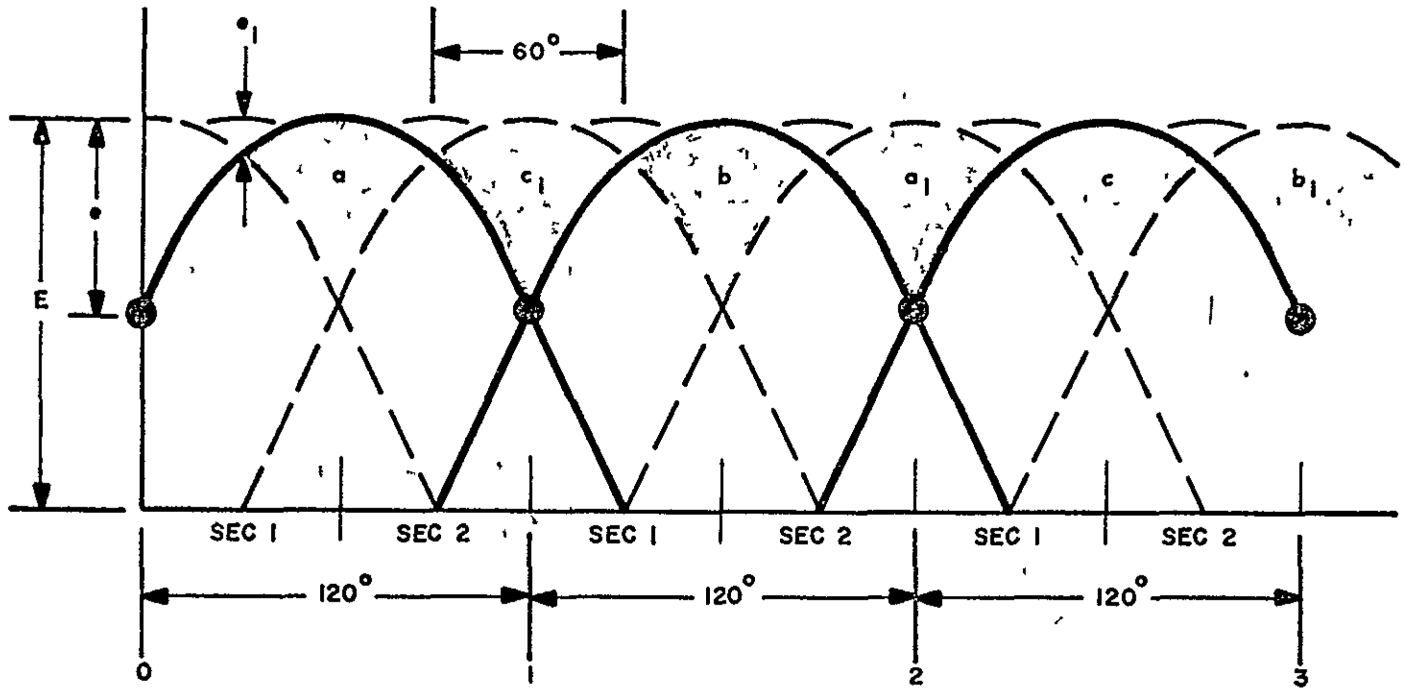
The following diagram shows 2 transformers, one with a Wye and one with a Delta primary, and both transformers with two 3 phase Wye half wave rectifier secondaries connected 60° out of phase.

12 PHASE OUTPUT TRANSFORMER CIRCUIT



: circuit common

Each of the four 3 phase Wye secondary half wave rectifiers will have a wave shape of the following configuration:

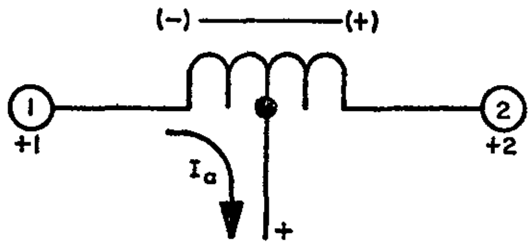


In a circuit with three interphase transformers, (T3, T4 and T5), the conduction time of each rectifier increases from 30° to 120° which causes the conduction time of the four half wave rectifiers to overlap and each will conduct 1/4 of the load simultaneously, drawing current from four primary and four secondary windings, and reducing internal impedance by 4.

In the above waveform, rectifier a conducts 120° from 0 to 1. Rectifier b assumes the load and rectifier a is back biased. At point 2 rectifier c assumes the load, and b is back biased.

With independent loads, the SEC 2 wave shape is the same as SEC 1 except it is shifted 60° (broken line). Without an interphase transformer and with a single load applied at points +1 and +2 (reference transformer diagram), or with points +1 and +2 connected together, the interference between SEC 1 and SEC 2 will limit conduction time to 60°. The interference zone is indicated by the shaded area of the waveform illustration.

By connecting point +1 to point +2 through interphase transformer T3, which is a center tapped autotransformer, a peak-to-peak triangular shaped voltage of $\underline{e} = 1/2\ E$, at three times the fundamental frequency is developed.



When the potential of the Øa diode is higher than the potential of the Øc diode, I_a flows from +1 to + and the voltage developed across +1 and +2 is such that +1 is negative (-) and +2 is positive (+). This condition raises the level at the Øc diode and lowers the level at the Øa diode. The amplitude of the Øc voltage is raised and the potential of the two rectifiers are equal, causing them to conduct simultaneously every 120° with half of the load current carried by each rectifier.

In the transformer circuit, the 12 phase output is obtained by using two 6 phase circuits with interphase connections (T3 and T4). The two circuits are connected together by a third interphase transformer (T5). The voltage across transformer T5 is $e_1 = .14E$, with a frequency that is six times the fundamental with the two sets of six phases overlapping.

The diode cathodes, connected to the secondary winding, also attain the negative to ground output. Each negative diode conducts 180° out of phase with the positive diode and a sine wave is produced.

In the final circuit design shown in Appendix I, taps 4 and 7 of transformers T301 and T302 are connected to interphase transformer T306. Transformer T306 with the associated rectifier circuit provides the +40 VDC to the battery charger. Taps 4 and 7 of T301 and T302 are connected to interphase transformer T307 to obtain the -40 VDC for the battery charger.

Taps 3 and 8 of T301 and T302 are connected to T304 to obtain +28 VDC output. Taps 3 and 8 of T301 and T302 connected to T305 produce a -28VDC. The positive and negative 28 VDC is the power supplied to the system bus. Input power waveform distortion is maintained at a very low level by the continuous conduction of the primary windings.

Through the use of two transformers(i.e.,T301 and T302), redundancy is obtained. In the event of a failure of one transformer, fuses will remove it from the circuit and the other transformer remains on the line. The remaining transformer will supply full output power, although the output ripple will be increased and the efficiency will be lower.

Battery Charger

The positive and negative 40 VDC battery chargers each contain two charging regulators. At battery full charge conditions, all four regulators are maintained at the off condition by a 1 volt signal applied to the individual turn on-turn off regulator control transistor circuits. For the positive 8 ampere charger output, two positive charging regulators are connected to charge the battery by the application of a zero volt signal to their control transistors. By applying the 1 volt turn off signal to one regulator control transistor and the zero volt signal to the other regulator control transistor, the 4 ampere charge mode is obtained.

When the 1 volt signal is applied, simultaneously, to the two regulator control transistors, the no-charge (charger off) mode is obtained. The negative charger regulator circuits are on or off as controlled by signals to the two negative regulator control transistors.

The positive charge voltage is obtained from tap 5 of T306. The negative charge voltage is obtained from tap 5 of T307.

Positive Charger Section 1: When the positive battery package is being charged at the 4 ampere rate, one positive regulator is on and one positive regulator is off. The charging current is high and the voltage to control transistor Q309 is zero, holding Q309 off. The parallel connected sensing circuit resistors R301 and R304 carry the full 4 amp charge current. Resistor R305 and Zener diode CR360 are the current limiting circuit. The voltage divider R302 and R305 provides the reference voltage comparison between the base voltage of Q309 and the positive 40 VDC. When the voltage across current measuring resistors R301 and R304 reaches the level determined by Q300, R303, R302 and CR360, the circuit operates as a current regulator.

When the voltage at Q309 switches to 1 volt, Q309 is saturated switching off Q304, Q303, and Q302, thus switching to the charger off condition.

Positive Charger Section 2: The second 4 ampere regulator functions through its respective circuits in the same sequence as the first 4 ampere section. The control transistor is Q310. CR363 and R306 are the current limiting circuit, and the voltage across CR362 is divided by R306 and R311. The second current regulator circuit is hence Q323, R312, R311, CR362, Q310, Q308, Q307, Q306.

Negative Charger Section 1: The zero volt signal applied to control transistor Q316 holds Q316 and Q312 off and the 4 ampere charge current is applied to the negative battery package. The current limiting circuit consists of diode CR366, Zener diode CR364 and resistor R320. The sum of the BVe of Q311, Q313, and Q314, plus the voltage of R323 is held constant by the current limiting circuit. When the voltage across R323 and R329 reaches the level determined by Q314, Q315, Q313, Q311, CR364, and CR366, the circuit operates as a constant current regulator.

The 1 volt charger off signal saturates Q316 turning on Q312, shorting out the CR366 and CR364, and the voltage of the current limiting circuit becomes zero.

Negative Charger Section 2: This 4 ampere charging section functions through its respective components in the same manner as described for the first negative 4 ampere section.

C. Ampere-Hour Meter

The basic function of the two ampere-hour meters is to integrate current flowing in the battery This measure of integrated current or charge is then stored for readout as a voltage that is directly proportional to the charge in the battery The block diagram on Figure 4 illustrates the principal functional elements of the ampere-hour meter. The ampere-hour meter uses the shunt method of current detection and a readout that is a bi-directional stepping motor coupled to a potentiometer. Power is supplied to the ampere-hour meters either from the 28 volt DC bus or from the battery when the system gas bottle heaters are operating. For simplicity, the power supply connections are omitted from the block diagram. The millivolt signal from the shunt is applied at the input of the ampere-hour meter circuit. In essence, it looks directly at an R/C charge circuit.

The capacitor of the R/C charge circuit is periodically pulled down to a negative voltage by the feedback path each time the input capacitor voltage reaches zero volts. The time it takes the voltage across this capacitor to return to zero is a function of the R/C time constant and the voltage appearing across the shunt which is proportional to the charge or discharge current. From this information it can be seen that the frequency of this sawtooth waveshape appearing across the R/C charge circuit will vary. If a memory of the total number of pulses during any charge or discharge cycle is maintained, the total current to or from the battery is integrated with respect to time. As the voltage across this capacitor rises to a predetermined point, it is necessary to detect the level in some manner.

With this integrator, this point is selected to be zero volts rather than some other level for several reasons. First, and perhaps the most important reason, zero detectors

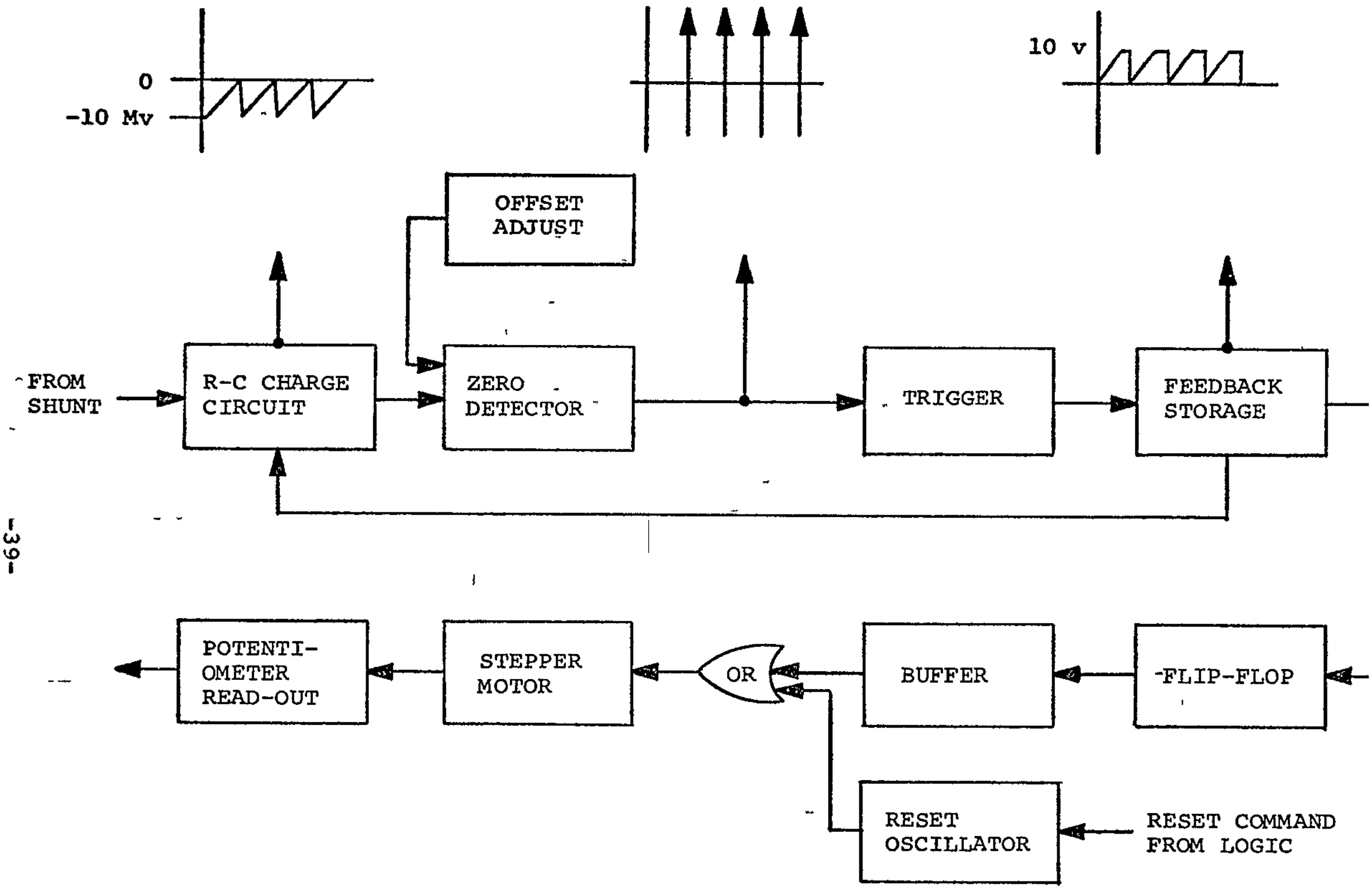


FIGURE 4. AMPERE-HOUR METER BLOCK DIAGRAM

are inherently more accurate devices than are other types of level detectors, such as Schmitt trigger, unijunction, or SCR devices. In addition, resetting poses no difficulty and zero detectors can operate from an extremely low level signal.

The trigger portion of the circuit is simply an actuator of the feedback signal which "discharges" the input capacitor to a negative voltage. The number of pulses is sensed at the feedback point. Each pulse registers on a flip-flop which changes state on each successive pulse. The output of this flip-flop is conditioned by three cascaded flip-flops, each dividing the number of pulses by 2, and a Darlington connected buffer circuit which drives the stepper motor. After every 8th pulse the stepper motor rotates another increment. It is this device that provides the memory and accomplishes the integrating. The readout is simply a state-of-charge indicating potentiometer driven directly by the stepper motor.

In order to eliminate cumulative errors, the ampere-hour meter memory is reset when the battery is fully charged as indicated by the battery voltage comparator. The ampere-hour meter reset function is performed by a unijunction oscillator coupled through an "OR" gate to the stepper motor.

A basic schematic for the ampere-hour meter is presented on Figure 5. With the exception of the power supply, each of the functional elements of this circuit corresponds to the block diagram. The purpose of

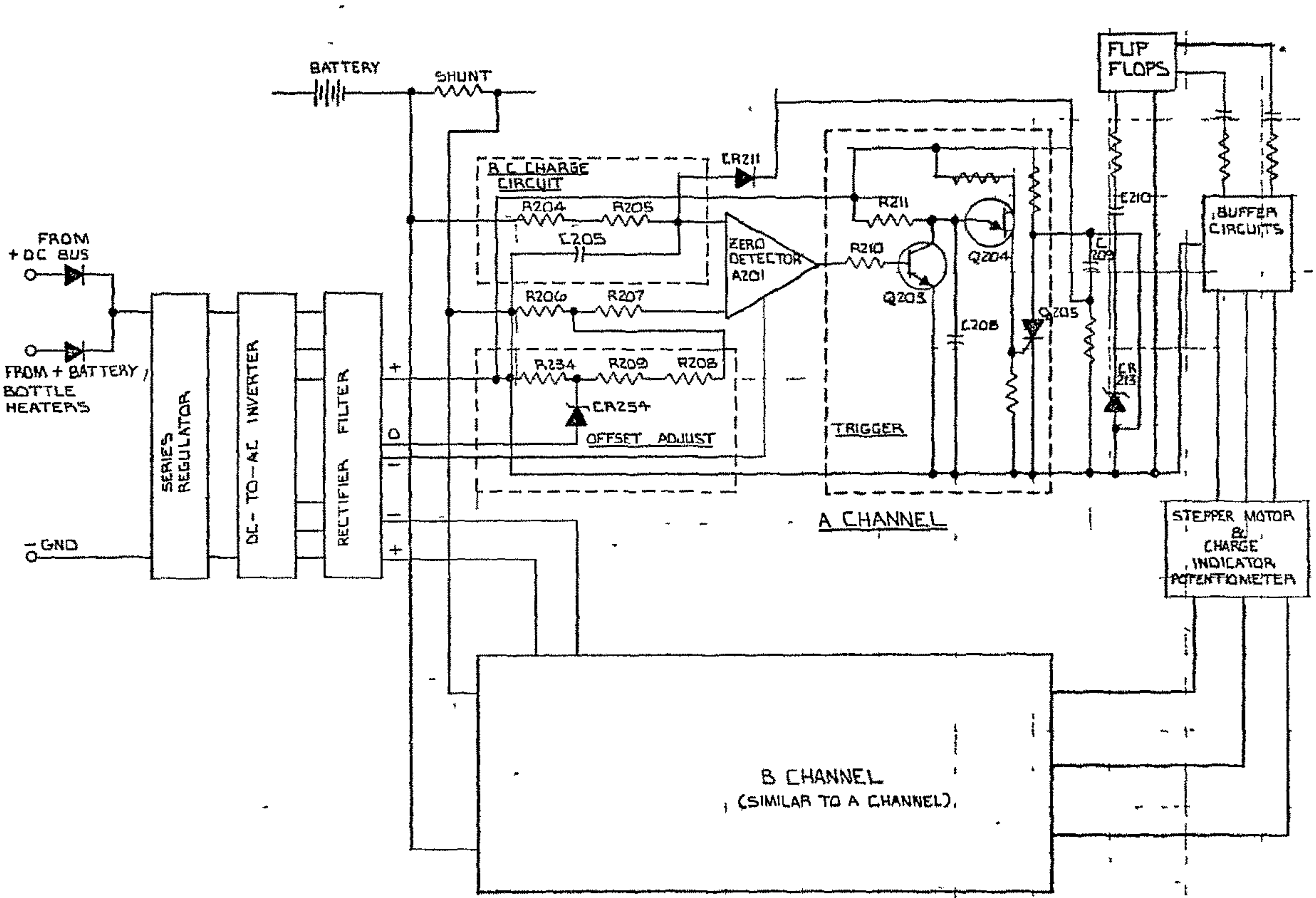


FIGURE 5 AMPERE-HOUR METER SIMPLIFIED SCHEMATIC

having the two identical channels shown on the schematic, is to allow integration of both charge and discharge battery current. Because of its secondary importance, the power supply will be discussed last; although it would appear from the schematic to be first in line

The input signal is derived from the current shunt in the battery bus line. This signal is in the order of a very few millivolts and is directly proportional to the charge or discharge current of the battery. The polarity of the signal determines which channel is activated. While one channel is integrating, the other one does not operate since it is designed to operate with a signal of the opposite polarity.

The R/C charge circuit is composed of resistors R204 and R205,and capacitor C205. The resistor arrangement in the R/C charge circuit is incorporated to allow for the calibration of each instrument. This adjustment is necessary to get maximum accuracy. As shunt voltage is applied to the R/C charge circuit, the voltage across capacitor C205 will begin to rise at a rate determined by the R/C time constant. The voltage across the capacitor is applied directly to the input terminals of the integrated circuit amplifier, A201. This amplifier is connected to operate as a zero detector. The voltage divider arrangements, resistors R206 through R209, provide the necessary offset adjustment shown in the block diagram. It is in this network that final resistance values are determined during production testing.

After Q205 fires, the change of voltage in C209 will be

$$\Delta V_{C209} = V_{FWD}\ \mathrm{SCR\ Q205} - V_{Zener} \tag{1}$$

and, neglecting i^2R losses, the corresponding voltage change on C205 will be

$$\Delta V_{C205} = (V_{FWD}\mathrm{SCR\ Q205} - V_{Zener} + V_{FWD}\ \mathrm{CR211})\frac{\mathrm{C209}}{\mathrm{C205 + C209}} \tag{2}$$

If C209 $\ll$ C205

Then,

$$\Delta V_{C205} = (V_{FWD}\mathrm{SCR\ Q205} - V_{Zener} + V_{FWD}\mathrm{CR211})\ \frac{\mathrm{C209}}{\mathrm{C205}} \tag{3}$$

In general,

$$Q = CV = \int_0^T i\ dt \tag{4}$$

So during reset,

$$Q_{C205} = \mathrm{C205}\ (V_{FWD}\mathrm{SCR\ Q205} - V_{Zener} + V_{FWD}\mathrm{CR211})\frac{\mathrm{C209}}{\mathrm{C205}} \tag{5}$$

and after reset

$$\int_0^T i_{in}dt = \mathrm{C209}\ (V_{FWD}\mathrm{SCR\ Q205} - V_{Zener} + V_{FWD}\mathrm{CR211}) \tag{6}$$

Assuming I_{in} is approximately constant,

$$I_{in} = \frac{E_{in}}{R_{in}} \tag{7}$$

then,

$$\frac{E_{in}}{R_{in}}\ T = \mathrm{C209}\ (V_{FWD}\mathrm{SCR\ Q205} - V_{Zener} + V_{FWD}\mathrm{CR211}) \tag{8}$$

from which,

$$T = \frac{R_{in}}{E_{in}}\ \mathrm{C209}\ (V_{FWD}\mathrm{SCR\ Q205} - V_{Zener} + V_{FWD}\mathrm{CR211}) \tag{9}$$

As shown by equation 9, the frequency of the ripple voltage on the R/C charge circuit is proportional to the input voltage and several other parameters which remain constant and is independent of the value of C205. These constants are the only sources of error in the system. It is, therefore, necessary to direct particular attention to the stability of these components. If extreme accuracy were required it would be necessary to temperature compensate for V_{FWD} SCR Q205 and V_{FWD} CR211 voltage changes.

As the feedback storage capacitor C209 is cycling at the frequency of the input ripple voltage, by AC coupling this device through C210 to the integrated circuit flip-flops each successive pulse registers a distinct change of state. Each output channel of the flip-flops is coupled to the Darlington buffer circuits.

The output of the buffer circuits appears in the form of a pulse. These pulses are used to sequence the stepper motor. Each successive pulse appears on alternate channels. Regardless of which channel produces the pulse, the stepper motor is sequenced another increment. With this action, accurate integration is accomplished.

The DC Power Supply furnishes all of the bias voltages required for the integrator. The power supply itself is simple. It comprises an input series regulator and a magnetically coupled DC converter to perform the DC to AC conversion. The AC output of the converter is full wave rectified to provide the appropriate DC output voltages.

D. Telemetry

The DC Power System telemetry provides standard 0 to 5 volt analog signals to measure temperatures, voltages, currents and battery states of charge. The telemetry is designed so that a short circuit or open circuit of any of the telemetry outputs will not disable any of the main system functions. The output load for the telemetry should be greater than 100,000 ohms, (1 megohm is standard) for good accuracy.

Battery State of Charge Telemetry

Battery state of charge is taken directly from the ampere-hour meter potentiometer readout through a series failsafe isolation resistor. State of charge is directly proportional to telemetry voltage.

Voltage Telemetry

Voltage sensors are simply voltage dividers composed of resistors with better than ± 100 parts per million per degree centigrade temperature coefficients.

Temperature Telemetry

Battery temperature is sensed by internal thermistors that are part of a simple resistor voltage divider network supplied from a reference Zener diode. The temperature versus voltage characteristic is non-linear so temperature versus output voltage calibration curves are necessary for each channel.

Current Telemetry

Current transductors are used to measure the current in the + 28 volt bus and in the -28 volt bus and the currents into or out of the batteries.

Each of the four transductors is supplied from a separate DC to AC converter that is fused so that failure of any one converter will not damage the system and will not destroy all of the current monitors. The 28 volt bus current range is from 0 to 50 amperes and the battery monitor current range is from -10 amperes to + 40 amperes. Charge current is considered negative.

E. Power Relay

The power relay functions to connect or disconnect the batteries from the positive and negative 28 VDC buses. This bistable latching type relay is energized by a pulse supplied by the logic circuits. In addition to the bus contacts, the relay has two sets of contacts used for signaling the position of the relay. One set of contacts closes to provide a relay position indication signal when the bus relay contacts are closed. The other set of contacts closes to provide a relay position indication signal when the bus relay contacts are open.

F. Battery System

The battery system for the EMPS252 DC Power Supply is composed of two identical canisters, each of which contains twenty-five sealed silver-cadmium cells, two thermistors and current measuring shunt. These units function as the + 28V and - 28V batteries within the system. The batteries are rechargeable and provide output bus backup capability as well as required energy for start-up and shutdown of the Brayton System.

The cells within the batteries are Yardney type YS-85(S) cells and have a nominal power rating of 85 ampere-hours. Each cell was epoxy sealed after test and no preventive maintenance is required.

The thermistors used in each canister are Gulton Model 35TD25 devices. The units are attached to the center cell within the 5 x 5 battery matrix. One thermistor is provided as a telemetry output, the other thermistor indicates battery temperature to the DC Power Supply internal logic.

Each battery canister also contains an Empro type A-50-100 current shunt in the negative leg of the circuit. The voltage signal from this shunt is directed to the appropriate ampere-hour meter within the DC Power Supply logic which indicates at all times the state-of-charge of the associated battery.

IV. RELIABILITY

Reliability Estimate.

The following reliability estimate for the DC Power Supply is based on the total electrical component parts count and utilizes component part failure rates and other estimating techniques as outlined in the Engineered Magnetics Reliability Handbook. As substantial circuit changes have occurred since the previous Reliability Estimate was submitted to NASA, this Reliability Estimate updates that report as a final submittal.

Certain basic assumptions were used in the preparation of this Reliability estimate and are defined as follows:

1. No workmanship errors exist in the assembling of the components into a complete unit at EMD to contribute to a system failure (i.e. special controls and procedures were devised to eliminate this failure mode).

2. Failure of any part used in the calculation will constitute a system failure.

3. Ambient temperature is 40°C.

4. All component parts are used with proper deratings at the maximum temperature and load condition(s).

The MTBF is calculated by using the reciprocal of the summation of the individual component part failure rates, i.e.,

$$\text{MTBF} = \frac{1}{\sum \lambda_i}$$

where: λ_i = failure rate of individual component part.

The MTBF for the DC Power Supply is 62,464 hours. The reliability of the individual sections was calculated and the failure rate (failures/10^8 hours) for the section was determined. The summation of these sections was accomplished as indicated in the following:

$$\Sigma\lambda_s = \lambda_{ps} + \lambda_{+42} + \lambda_{-42} + \lambda_L + \lambda_{AH}$$

$$+ \lambda_T + \lambda_B + \lambda_{PR}$$

where: λ_S = failure rate of the section

λ_{PS} = failure rate of Power Supply

λ_{+42} = failure rate of +42V Regulator

λ_{-42} = failure rate of -42V Regulator

λ_L = failure rate of Logic

λ_{AH} = failure rate of Ampere-Hour meter

λ_T = failure rate of Telemetry

λ_B = failure rate of Battery

λ_{PR} = failure rate of Power Relay

$$\sum \lambda_s = 150 + 119.82 + 113.81 + 387.64 + 492.60$$
$$+ 197.04 + 100 + 40$$
$$= 1600.91 \text{ failures}/10^8 \text{ hours}$$

The MTBF is

$$\text{MTBF} = \frac{10^8}{1600.91} \text{ hours}$$
$$= 62{,}464 \text{ hours}$$

V. TEST PLAN

Development Test

Circuit operation tests were conducted on the engineering breadboards of the A-H Meter, logic, battery charger, and telemetry functions to determine proper circuit operation, circuit stability and to verify set points and biasing. Tests were conducted on the first unit transformer-rectifier to confirm functional characteristics and operation.

Battery Characteristics: These tests function to confirm the charge, discharge, and steady state characteristics of the battery assembly.

Operation: Tests were conducted on the assembled Power Supplies (including battery) to determine integration problems, unstable modes of operation or mismatches in circuit set points and biasing. The functioning of the manual commands and power relay was also checked at this time.

DC Power Supply Characteristics: The first assembled DC Power Supply unit was tested to determine functional characteristics. During these tests the steady state power quality and output transients due to input power variations (including operation of the power relay) were measured and sample measurements obtained are to confirm the assumed reliability stress levels.

Thermal Test

Thermal map measurements determine the internal and interface heat transfer characteristics of the system electronic package of the first deliverable system after completion of other functional tests. These tests function to confirm the thermal analysis and locate critical component temperature levels. See Appendix III for the Thermal Test Report.

Acceptance Test

Engineered Magnetics Test Procedure for EMPS252 Brayton Cycle

DC Power System (EMD Procedure No. 713331) presented in Appendix II, is the Acceptance Test Procedure for the DC Power Supply. The Acceptance Test, functional in nature, was performed to assure circuit operation.

Life Test

At the completion of the operational tests of Unit No. 1, a 50 cycle, 10,000 hour endurance test (Life Test) was initiated. When this test is completed, another 10,000 hour, 75 cycle life test will be performed using battery simulators instead of actual batteries. A special secured area was established for the purpose of preserving the test. This area is immediately adjacent to the installation location of the 1200-cycle, four-wire, three-phase, extended-life motor generator set, which was purchased under the contract specifically for the life test. The equipment within the secured test area are:

1. The DC Power Supply
2. Battery canisters 1A and 1B
3. Motor generator control panel
4. Power Supply load bank
5. Two Rustrak, dual-channel, Tymeshare recorders which continuously record the following system parameters: positive and negative output voltages, positive and negative output current, positive and negative battery terminal voltages, positive and negative battery current (bi-directional)
6. Ventilation equipment for system loads and test equipment
7. Overload and battery protection circuits, and
8. Test failure alarm system.

Since its initiation, the Life Test has proceeded continuously, on a 24-hour-a-day biasis (except for several equipment malfunctions and two commercial power interruptions). Monitoring by the Rustrak recorders is continuous. Operational time is recorded from the operating hoursmeter of the motor generator control panel which is directly related to the number of hours the

DC Power Supply has been under test.

Except when an operational cycle is run, monitoring of the test setup takes place on a daily basis. Protective circuits associated with the motor generator, the input fusing to the unit under test, and the external protective circuits which will remove a badly discharged battery from the test setup loads insure that a malfunction will not cause permanent equipment damage between monitoring periods. When a test cycle is to be performed, the unit is manually sequenced through battery loading during the beginning of a normal day shift. The unit is then set to perform the automatic battery charging operation and is monitored at approximately one hour intervals. A provision is made so that additional monitoring at the same periods takes place during the second shift. To date, the Life Test has continued satisfactorily.

VI. CONCLUSIONS

Design and development of the DC Power Supply (EMPS252) were satisfactorily completed by the Engineered Magnetics Division of Gulton Industries, Inc., and the four fabricated DC Power Supplies (with the exception of the batteries) met or exceeded the purchase specification for the unit with no deviations or waivers required. System testing of the DC Power Supply, as a part of the Brayton Cycle Power Conversion System program at the NASA Lewis Research Center and its Plumbrook facility, has demonstrated the compatibility of the DC Power Supply with other Brayton Engine components. The life testing presently being conducted at the Gulton, Hawthorne, California facility also demonstrates that the DC Power Supply meets its required performance goals.

High reliability components were used in the fabrication of the DC Power Supply units of this contract, to support the developmental philosophy of the entire Brayton Program. Provision was made, however, for upgrading the MTBF of the DC Power Supply by using in its design only components which can be replaced by Ultra-High Reliability parts such as JANTX parts. Such units, which can be fabricated by the simple expedient of substituting the Ultra-High Reliability parts upon a part-for-part basis in the present design, will considerably enhance the MTBF of the DC Power Supply. Since the present units meet the projected life requirements for an unattended Brayton Power System, the improved unit can exceed the projected requirements.

A considerable amount of redundancy or component failure tolerance was designed into the DC Power Supply, particularly in its transformer-rectifier power conversion section. This section, which accomplishes the primary work of the DC Power Supply by converting the 208 volt, 3 phase, 1200 Hz, AC power into positive and negative 28 volt DC power can withstand the loss of one of its two power transformers and approximately half of its rectification elements and still deliver full rated output power, although at a somewhat decreased efficiency and higher ripple level. The control and logic sections of the DC Power Supply also provide, wherever possible, several alternate channels of control or backup logic modes. The Power Supply, which was designed for unattended space use of long duration, is completely satisfactory in its present configuration for its intended final mission use.

The DC Power Supply Program was thoroughly planned and conducted with a minimum of design and development work. While this approach proved to be quite successful, it did not provide the usual number of opportunities between breadboards, prototypes, and qualification units to incorporate design changes as such improvements presented themselves. The DC Power Supply's present configuration with the exception of the battery meets or exceeds all the requirements of its purchase specification, but a review of the overall program indicates four areas for further consideration in regard to modifications of future DC Power Supply designs.

1. The Power Supply control circuits were changed several times during the program to match slight modifications in the overall system control philosophy. Due to the program schedule, these changes were usually additions or modifications to the existing circuits. A review of the final control circuits, as compared with the latest system requirements, may result in some design simplification.

2. The charge scheme used in the presently configured Power Supply, including the use of ampere-hour meters for indication and control, should be reviewed for compatibility with other types of batteries (such as silver-zinc). In addition, Gulton

has developed and tested a circuit which charges batteries by a pulse demand method. This circuit, developed after the design of the DC Power Supply was completed, provides a method for improving the battery charging and battery charge control portions of the presently configured Power Supply, and has the additional capability of battery conditioning. A trade-off study of these possibilities should be undertaken before fabrication of future DC Power Supplies of this type.

3. The thermal heat map measurements has indicated the possibility of several improvements of the heat paths within the Power Supply. Improved reliability and optimization of these heat paths to "obtain" a more even distribution of the heat generated within the Power Supply can be accomplished by performing several simple physical design modifications to the Power Supply.

4. The state-of-the-art in Silver Cadmium batteries was not compatible with the five (5) year life objective of the Brayton program. Additional work is necessary to acquire a battery which can meet this five (5) year life requirement in the anticipated Brayton environment.

APPENDIX I

DRAWING PACKAGE

1. List of Material LM 513260
2. Outline and Specification 413249
3. Schematic Diagram 513911
4. Final Assémbly Drawing 513260

SYM	DESCRIPTION	DATE	APPROVED
A	REVISED PER E.O. 24951	12/9/68	

DATE 10-3-68	**Gulton Industries, Inc.** HAWTHORNE, CALIFORNIA				
DR L. C. JENKINS					
CHK Lopez-Adams 10/22/68	LIST OF MATERIALS EMPS-252				
ENGR					
MECH ENGR					
REL ENGR					
PROJ ENGR B. 10-23-68					
APPD M. Kruse 10/23/68	CODE IDENT NO. 06509	SIZE A	LM513260	A	
APPD B J McComb	SCALE ——		SHEET 1 OF 32		

EM17760

NOTES: (UNLESS OTHERWISE SPECIFIED).

1. PURCHASE COUPLING WITH SOCKET HD CUP POINT SET SCREW PIC DESIGN P/N BE-1-B.

2. GRIND SHAFT FLAT ON ONE SURFACE 5/16 LG X 1/32 DEEP BEFORE ASSY.

CODE IDENT NO	SIZE		
06509	A	LM513260	A
SCALE ——		SHEET 2	

RM 17761

ITEM	PART NUMBER	ASSY LEVEL 1 2 3 4 5 6	DESCRIPTION, SYM, SPEC, CODE IDENT NO.	QTY REQ
1	413249		OUTLINE & SPEC.	
	513911		SCHEMATIC	
5	WL 513260		WIRE LIST	
10	79400		WORKMANSHIP STANDARD	
	79492		HAND SOLDERING OF ELECT	
			CONNECTIONS	
	EMP 74960		MFR TOROIDAL WINDINGS	
	EMP 77430		PROCESS SPEC. COATINGS &	
15			ADHESIVES	
	EMP 77431		PROCESS SPEC. MIX & CURE	
			EPOCAST 202	
	710410		INST'L OF SOLID RIVETS	
	EMP 74444		IDENT & MARKING SPEC	
20	EMP 11019		POTTING & HANDLING PROCEDURE	
			FOR FLEXIBLE EPOXY RESIN	
	EMP 74446		PROCESS SPEC MTG METHODS	
			OF SEMI-CONDUCTORS	
	EMP 74447		PROCESS SPEC MTG METHODS	
25			OF SEMI-CONDUCTORS	
	EMP 711304		MTG INSTRUCTIONS OF FLAT	
			PACK SEMI-CONDUCTORS	
	#997		SILICONE VARNISH - DOW CORNING	
30				
35				

SIZE	CODE IDENT NO	
A	06509	LM 513260
SCALE ——	REV A	SHEET 3

ITEM	PART NUMBER	ASSY LEVEL 1 2 3 4 5 6	DESCRIPTION, SYM, SPEC, CODE IDENT NO	QTY REQ
1	413249		OUTLINE & SPEC.	
	513911		SCHEMATIC	
5	WL 513260		WIRE LIST	
10	79400		WORKMANSHIP STANDARD	
	79492		HAND SOLDERING OF ELECT	
			CONNECTIONS	
	EMP. 74960		MFR TOROIDAL WINDINGS	
	EMP 77430		PROCESS SPEC. COATINGS &	
15			ADHESIVES	
	EMP 77431		PROCESS SPEC. MIX & CURE	
			EPOCAST 202	
	710410		INST'L OF SOLID RIVETS	
	EMP 74444		IDENT & MARKING SPEC	
20	EMP 11019		POTTING & HANDLING PROCEDURE	
			FOR FLEXIBLE EPOXY RESIN	
	EMP 74446		PROCESS SPEC MTG METHODS	
			OF SEMI-CONDUCTORS	
	EMP 74447		PROCESS SPEC MTG METHODS	
25			OF SEMI-CONDUCTORS	
	EMP 711304		MTG INSTRUCTIONS OF FLAT	
			PACK SEMI-CONDUCTORS	
	#997		SILICONE VARNISH - DOW CORNING	
30				
35				

SIZE	CODE IDENT NO	
A	06509	LM 513260
SCALE ——	REV A	SHEET 3

EM FORM 17759C

ITEM	PART NUMBER	ASSY LEVEL 1	2	3	4	5	6	DESCRIPTION, SYM, SPEC, CODE IDENT NO	QTY REQ
36									
	513260	/						FINAL ASSY	1
	413283-1		/					SUB CHASSIS COMP ASSY	1
40									
	413964-1			/				COMP ASSY TB-10	1
	313963-1				/			TERM BRD TB-10	1
45	313963 -2					/		BRD. BLANK	1
	313963 -3					/		INSULATOR	1
	3025B					/		TERMINAL LERCO	143
50									
	1247-14					/		SPACER CAMBION	6
55	EM79451				/			TSTR Q15 SOLITRON	1
	EM78324				/			TSTR Q219-222,	8
								219A-222A	
60	EM79430-1				/			DIODE, ZENER CR253	1
	AFIN645				/			DIODE CR233-244, 247,	28
								248, 223A-244A	
								247A, 248A	
65								MIL-S-19500/240	
	G1712939				/			DIODE, ZENER CR15 MOTOROLA	1
								(IN3022B MIL-S-19500/115)	
	G2-53 -80Ω				/			RES R39 DALE	1
70									

SIZE	CODE IDENT NO	
A	06509	LM 513260
SCALE —	REV A	SHEET 4

ITEM	PART NUMBER	ASSY LEVEL 1 2 3 4 5 6	DESCRIPTION, SYM, SPEC, CODE IDENT NO.	QTY REQ
71				
	G1 -1.5K	/	RES R40 DALE	1
75	RN55C5110F	/	RES R273, 275,	8
			276, 278, 273A	
			275A, 276A, 278A	
			MIL-R-10509/7	
	RN55C1620F	/	RES R281, 281A	2
80				
	RN55C1542F	/	RES R285, 286,	4
			295, 296	
	RN55C1960F	/	RES R283, 283A	2
85				
	RN55C1003F	/	RES R284, 287	4
			294, 297	
	RN55C5361F	/	RES R288, 293	2
90	RN55C1002F	/	RES R274, 277, 274A, 277A	4
	RN55C2261F	/	RES R299	1
	RN55C----F	/	RES R289, 292 S.I.T.	2
			≅ 20K TO 50K	
95				
	RN55C----F	/	RES R280, 282	4
			280A, 282A S.I.T.	
			≅ 50 TO 150Ω	
	RN55C----F	/	RES R279, 279A, S.I.T.	2
100			≅ 100Ω TO 1K	
			MIL-R-10509/7	
	G1 1K	/	RES R290, 290A	2
105				

SIZE	CODE IDENT NO	
A	06509	LM 513260
SCALE —	REV A	SHEET 5

ITEM	PART NUMBER	ASSY LEVEL 1 2 3 4 5 6	DESCRIPTION, SYM, SPEC, CODE IDENT NO	QTY REQ
106				
	EM710454H-12	/	CAP 39 ufd 60V, C213	1
	EMUCYK01BT103M	/	CAP .01 ufd, 50V, C4 EM711411	1
110				
	M39003/01-2043	/	CAP 2.2 ufd, 20V, C20, 224, 225,	5
			224A, 225A	
			(CSR13E225KL) MIL-C-39003/1A	
115	M39003/01-2116	/	CAP 1 ufd, 50V, C226-231	6
			(CSR13G105KL) MIL-C-39003/1A	
	SERIES 27500	/	FUSE 0.25A F201, 202,	
			F201A, 202A LITTELFUSE	4
120	313286-1	/	XFMR T202, 203	4
			202A, 203A	
	52063-1D	/	CORE MAG INC	1
	6001	/	CENTER WASHER OHMITE	4
125	1855-2	/	GASKET	4
	MS24962-C7	/	SCREW	4
	MS21043-04	/	SELF LOCK NUT	4
130				
	MS15795-303	/	WASHER-FLAT	4
	10038-DAP	/	TRANSIPAD THE MILTON ROSS CO	9
135	1N2976B	/	DIODE, CR46, MIL-S-19500-124	1
	RH10-125Ω	/	RES., R141 DALE	1
	RH10-200Ω	/	RES., R300 DALE	1
140				

SIZE	CODE IDENT NO	
A	06509	LM 513260
SCALE	REV A	SHEET 6

ITEM	PART NUMBER	ASSY LEVEL 1	2	3	4	5	6	DESCRIPTION, SYM, SPEC, CODE IDENT NO.	QTY REQ
141									
	413278-1			/				COMP ASSY TB4	1
	413277-1				/			P.C. BRD ASSY TB4	1
145									
	413277-2					/		BRD BLANK	1
	5075B					/		TERM LERCO	38
150	1247-9					/		STANDOFF CAMBION	6
	M39003/01-2043				/			CAP C26,27 MIL-C-39003/1A	2
								(CSR13E225KL)	
	U3H7710 31X				/			COMPARATOR A6-9	4
								FLAT PACK FAIRCHILD	
155									
	EM79451				/			TRANS Q9 SOLITRON	1
	EM73531				/			TRANS Q10 RAYTHEON	1
160	EM74706				/			TRANS Q25-29,32 RAYTHEON	6
	EM74709				/			TRANS Q13,24,30, RAYTHEON	6
								31,33,34	
165	EM711477				/			TRANS Q14 MOTOROLA	1
	AF1N645				/			DIODE CR33-41,43-45,12,13	
								MIL-S-19500/240	14
	EM79430-1				/			DIODE, ZENER CR42 TRW	1
170									
	G2-53-2K				/			RES R87 DALE	1
	RS-2B-400Ω				/			RES R32 DALE	1
175	RC07GF391J				/			RES R142 MIL-R-11/8	1

SIZE	CODE IDENT NO	
A	06509	LM 513260
SCALE —	REV A	SHEET 7

EM FORM 17759C

ITEM	PART NUMBER	ASSY LEVEL 1 2 3 4 5 6	DESCRIPTION, SYM, SPEC, CODE IDENT NO	QTY REQ
176	RC20GF362J	/ (4)	RES R88 MIL-R-11/8	1
	RC20GF152J	/ (4)	RES R33,34 MIL-R-11/8	2
	RN55C51R1F	/ (4)	RES R106 MIL-R-10509/7	1
180				
	RN55C8660F	/ (4)	RES R113	1
	RN55C1001F	/ (4)	RES R24,26	2
185	RN55C3321F	/ (4)	RES R30,135,137,91,	14
			139,123,125,127,93,	
			115,116,117,140,120	
	RN55C4021F	/ (4)	RES R97	1
190				
	RN55C1002F	/ (4)	RES R4,35,36	21
			89,94,95,99	
			100,101,107,108	
			110,111,112,121,	
195			122,124,126,	
			128,[illegible],134	
	RN55C2152F	/ (4)	RES R86,90,132,	5
			136,138	
200				
	RN55C6812F	/ (4)	RES R102,105	2
	RN55C1003F	/ (4)	RES R114	1
205	RN55C----F	/ (4)	RES R96 S.I.T.	1
			≅ 100Ω TO 1K	
	RN55C----F	/ (4)	RES R104,103 S.I.T.	2
			≅ 5K TO 20K	
210	RN55C3322F	/ (4)	RES R23,25 MIL-R-10509/7	2

SIZE	CODE IDENT NO	
A	06509	LM 513260
SCALE —	REV A	SHEET 8

EM FORM 17759C

ITEM	PART NUMBER	ASSY LEVEL 1	2	3	4	5	6	DESCRIPTION, SYM, SPEC, CODE IDENT NO	QTY REQ
211									
	RN55C----F				/			RES R92,98,109	3
								S.I.T. ≅ 10K TO 60K	
								MIL-R-10509/7	
215	RN55C----F				/			RES R118 S.I.T.	1
								≅ 20K TO 100K	
	RN55C----F				/			RES R119 S.I.T.	1
								≅ 2.49K TO 2.74K	
220								MIL-R-10509/7	
	M39003/01-2116				/			CAP C12-17,19 MIL-C-39003/01	7
								(CSR13G105KL)	
	M39003/01-2043				/			CAP C18 MIL-C-39003/01	1
								(CSR13E225KL)	
225	M39003/01-2139				/			CAP C3 MIL-C-39003/01	1
								(CSR13G186KL)	
	10034-NYL				/			TRANSIPAD THE MILTON ROSS CO	12
	10038-DAP				/			TRANSIPAD THE MILTON ROSS CO	3
	EMUCYK01BT103M				/			CAP C21,28 EM711411	2
230	413276-1			/				COMP ASSY TB-3	1
	413275-1				/			P.C. BRD ASSY TB-3	1
	413275-2					/		BRD BLANK	1
235									
	5075B					/		TERM LERCO	43
	1247-9					/		STANDOFF CAMBION	6
240									
	U3I993151X				/			FLIP FLOP FF1 FAIRCHILD	1
245									

SIZE	CODE IDENT NO	
A	06509	LM 513260
SCALE —	REV A	SHEET 9

EM FORM 17759C

ITEM	PART NUMBER	ASSY LEVEL 1 2 3 4 5 6	DESCRIPTION, SYM, SPEC, CODE IDENT NO	QTY REQ
246				
	U3H771031X	/	COMPARATOR A1,2,3,4,5	5
			FAIRCHILD	
250	EM73531	/	TSTR Q4 RAYTHEON	1
	EM79451	/	TSTR Q3 SOLITRON	1
	EM79458	/	TSTR Q7 G.E.	1
	EM74706	/	TSTR Q5,6,8,16-22, RAYTHEON	10
255				
	AF1N645	/	DIODE CR2,6,8-11,14	24
			16-22,24-26	
			28-32,3,5	
			MIL-S-19500/240	
260	1N752A	/	DIODE, ZENER, CR7,	1
			MIL-S-19500/127	
	1N753A	/	DIODE, ZENER CR23	1
			MIL-S-19500/127	
	EM79430-1	/	DIODE CR27 TRW	1
265				
	G-2-53 -80Ω	/	RES R62 DALE	1
	RC07GF431J	/	RES R11 MIL-R-11/8	1
270	RC20GF362J	/	RES R37 MIL-R-11/8	1
	RN55C51R1F	/	RES R59,18 MIL-R-10509/7	2
	RN55C2740F	/	RES R13,129	2
275				
	RN55C6490F	/	RES R67	1
	RN55C1001F	/	RES R5,7,17,19,22 MIL-R-10509/7	5
280				

SIZE	CODE IDENT NO	
A	06509	LM 513260
SCALE —		REV A · SHEET 10

PART NUMBER	ASSY LEVEL	DESCRIPTION, SYM, SPEC, CODE IDENT NO	QTY REQ
RN55C3321F	/	RES R38,44,45,46,31	12
		69,70,71,75,77,79,81	
		MIL-R-10509/7	
RN55C1002F	/	RES R9,10,12,131,	22
		15,16,80,82,84,	
		47,48,52,53,	
		54,60,61,64,65,	
		66,74,76,78,	
RN55C2052F	/	RES R42	1
RN55C3322F	/	RES R83,85,6,20,21	5
RN55C4641F	/	RES R50	1
RN55C6812F	/	RES R55,58	2
RN55C1003F	/	RES R14,68,8	3
RN55C----F	/	RES R49 S.I.T.	1
		≅ 100Ω TO 1K	
RN55C----F	/	RES R56,57 S.I.T.	2
		≅ 5K TO 20K	
RN55C----F	/	RES R43,130,51,63 S.I.T.	4
		≅ 10K TO 60K	
RN55C----F	/	RES R72 S.I.T.	1
		≅ 20K TO 100K	
RN55C----F	/	RES R73 S.I.T.	1
		≅ 2.49K TO 2.74K	
		MIL-R-10509/7	

SIZE	CODE IDENT NO	
A	06509	LM 513260
SCALE —	REV A	SHEET 11

ITEM	PART NUMBER	ASSY LEVEL 1 2 3 4 5 6	DESCRIPTION, SYM, SPEC, CODE IDENT NO	QTY REQ'D
316				
	RN55C----F	/	RES R41 S,I,T	1
			≅ 500Ω TO 2.5K	
			MIL-R-10509/7	
320	M39003/01-2116	/	CAP-C5-9,11,24,25 MIL-C-39003/1A	8
			(CSR13G105KL)	
	M39003/01-2043	/	CAP C10	1
			(CSR13E225KL)	
	M39003/01-2139	/	CAP C1	1
325			(CSR13G186KL)	
	M39003/01-2055	/	CAP C2 MIL-C-39003/1A	1
			(CSR13E476KL)	
	10034-NYL	/	TRANSIPAD THE MILTON ROSS CO	11
	10038-DAP	/	TRANSIPAD THE MILTON ROSS CO	2
330	EMUCYK01BT103M	/	CAP C22,23,31 EM711411	3
	413280-1	/	COMP ASSY TB5&6	2
	413279-1	/	P.C. BRD ASSY TB5&6	1
335	413279-2	/	BRD BLANK	1
	5075B	/	TERM LERCO	26
	1247-13	/	STANDOFF CAMBION	6
340				
	U3A770931X	/	COMPARATOR A201,202	
			FAIRCHILD	2
	U3I993151X	/	FLIP-FLOP FF201-FF208	8
			FLAT PACK FAIRCHILD	
345				
	G174706H	/	TSTR Q203,209,211	7
			208,215,217,	
			225	
350	GI 74709H	/	TSTR Q207 RAYTHEON	1

SIZE	CODE IDENT NO	
A	06509	LM 513260
SCALE ——	REV A	SHEET 12

EM FORM 17759C

ITEM	PART NUMBER	ASSY LEVEL 1 2 3 4 5 6	DESCRIPTION, SYM, SPEC, CODE IDENT NO	QTY REQ
351				
	G173531H	/	TSTR Q212,210,	4
			216,218 RAYTHEON	
355	GI79458	/	TSTR Q204,206,213 G.E	3
	GI76096	/	TSTR Q205,214 G.E	2
	IN751A	/	DIODE,ZENER CR214	1
360			MIL-S-19500/127	
	GI79430	/	DIODE,ZENER,CR254,255,213,	4
			CR 221 TRW	
	AFIN645	/	DIODE CR211,212,222,251,	17
			223,224,230,252,249,	
365			215-220,250,256	
			MIL-S-19500/240	
	RN55C51R1F	/	RES R212,216,218	6
			224,248,249	
370			MIL-R-10509/7	
	RN55C2050F	/	RES R250	1
	RN55C5621F	/	RES 205, 241	2
	RN55C6191F	/	RES R207, 243	2
375				
	RN55C2261F	/	RES R234,235	2
	RN55C1472F	/	RES R221	1
	RN55C75R0F	/	RES R247	1
380	RN55C3320F	/	RES R217,253	2
	RN55C5111F	/	RES R220, MIL-R-10509/7	3
			254,255	
385	RC07GF150J	/	RES R215 MIL-R-11/8	1

SIZE	CODE IDENT NO	
A	06509	LM 513260
SCALE ——	REV A	SHEET 13

EM FORM 17759C

ITEM	PART NUMBER	ASSY LEVEL 1 2 3 4 5 6	DESCRIPTION SYM, SPEC, CODE IDENT NO	QTY REQ
386				
	RN55C1001F	/	RES R222, 223,	5
			226, 256, 257	
			MIL-R-10509/7	
390	RN55C1102F	/	RES R210, 228, 238,	12
			211, 261, 236, 259, 260,	
			237, 246, 239, 262	
	RN55C3012F	/	RES R213, 252, 225	5
395			227, 229	
	RN55C2152F	/	RES R221, 232	2
	RN55C____F	/	RES R204, 240 S.I.T.	2
400			≅ 50Ω TO 1K	
	RN55C____F	/	RES R208, 244 S.I.T.	2
			≅ 5K TO 50K	
405	RN55C____F	/	RES R209, 245,	2
			30K TO 100K	
			MIL-R-10509/7	
	G2 100Ω	/	RES R219 DALE	1
410	G1 10Ω	/	RES R20_, 242 DALE	2
	78351-6	/	CAP C209, 220 SPRAGUE	2
415				
	M39003/01-2098	/	CAP C208, 223, MIL-C-39003/1A	3
			214 (CSR13G 104 KLU)	
	AGS-2 -1Ω	/	RES R214, 251 DALE	2
420				

SIZE	CODE IDENT NO	
A	06509	LM 513260
SCALE ——		REV A · SHEET 14

EM FORM 17759C

ITEM	PART NUMBER	ASSY LEVEL 1 2 3 4 5 6	DESCRIPTION, SYM, SPEC, CODE IDENT NO	QTY REQ
421				
	M39003/01-2128	/	CAP C211,212 MIL-C-39003/1A	4
			221,222 (CSR13G475KLU)	
425	M39003/01-2095	/	CAP C219 MIL-C-39003/1A	1
			(CSR13G683KLU)	
	M39003/01-2491	/	CAP C205A,B,215A,B	4
			(CSR13B337KPU) MIL-C-39003/1A	
430	EMUCYK01BT103M	/	CAP C210,200, EM711411	4
			C233,234	
	EMUCYK01BT333M	/	CAP C218 EM711411	1
	CK12AX470M	/	CAP C207,217 MIL-C-11015/20	2
435				
	CK12AX101M	/	CAP C206,216 MIL-C-11015/20	2
	10227-NYL	/	TRANSIPAD THE MILTON ROSS CO	2
	10038-DAP	/	TRANSIPAD THE MILTON ROSS CO	4
	10034-NYL	/	TRANSIPAD THE MILTON ROSS CO	11
440	TXP0508B	/	RETAINER IERC	1
	1747-2	/	WASHER, MICA	1
	14092-5	/	WASHER, EPOXY	1
	MS51957-35	/	SCREW	10
445	MS51957-5	/	SCREW	4
	MS51957-38	/	SCREW	4
	MS51957-28	/	SCREW	4
450	MS24693-C26	/	SCREW	2
	MS24693-C38	/	SCREW	2
	MS15795-308	/	WASHER, FLAT	1
455	MS15795-302	/	WASHER, FLAT	4

SIZE	CODE IDENT NO	
A	06509	LM 513260
SCALE —	REV A	SHEET 15

EM FORM 17759C

ITEM	PART NUMBER	ASSY LEVEL 1 2 3 4 5 6	DESCRIPTION, SYM, SPEC, CODE IDENT NO	QTY REQ
456	MS15795-305	3	WASHER FLAT	12
	MS15795-303	3	WASHER FLAT	1
	MS35337-78	3	WASHER LOCK	1
	MS35337 79	3	WASHER LOCK	12
460	MS35649-24	3	NUT	4
	MS35649-64	3	NUT	12
	MS35650-104	3	NUT	1
	115 X .196	3	LUG ZIERICK	1
	313970-1	3	XFMR ASSY TB9	1
465	313966-1	4	POTTING CUP TB9	1
	313966-2	5	BRD BLANK	1
	5026B	5	TERMINAL LERCO	20
	NAS43DD1-52	5	SPACER	4
	3025B	5	TERMINAL LERCO	12
470	313287-1	4	XFMR T204, 204A	2
	52134-1D	5	CORE MAG. INC	2
	313288-1	4	XFMR T205, 205A	2
	A22D1	5	CORE	2
		4	WIRE	A/R
475	MS51957-13	3	SCREW	1
	14092-2	3	WASHER	1
	25429-1-4	3	INSERT	1
	25429-4-3	3	INSERT	1
	413282-1	3	SUB CHASSIS ASSY	1
480	413282-2	4	SUB CHASSIS	1
	413282-3	4	STIFFNER	1
	MF6031-06	4	NUT ANCHOR KAYNAR	4
	MF1331-06	4	NUT ANCHOR KAYNAR	10
485	MS20426AD3	4	RIVET	8
	MS20426AD2	4	RIVET	20
	MS35337-77		WASHER, LOCK	4
490	MS35337-81	3	WASHER, LOCK	1

SIZE	CODE IDENT NO	
A	06509	LM 51[illegible]
SCALE		REV A / SHEET 16

EM FORM 17759C

ITEM	PART NUMBER	ASSY LEVEL 1	2	3	4	5	6	DESCRIPTION, SYM, SPEC, CODE IDENT NO.	QTY REQ
491									
	313268-1		/					COMP ASSY TB1	1
	313267-1			/				BOARD ASSY TB1	1
495									
	313267-2				/			BOARD BLANK	1
	3025-B				/			TERM LERCO	48
500	3535-B				/			TERM LERCO	18
	1247-10				/			STANDOFF CAMBION	4
505									
	313261-1			/				XFMR ASSY T301	1
	113263				/			CORE	1
510									
	113264				/			COIL FORM	3
	313265-1				/			BRACKET ASSY	2
515	313265-2					/		BRACKET	1
	MF1331-06					/		NUT-ANCHOR KAYNAR	2
	MS20426AD2					/		RIVET	4
520									
	213266				/			INSULATOR	A/R
525									

SIZE	CODE IDENT NO	
A	06509	LM 513260
SCALE ——	REV A	SHEET 17

ITEM	PART NUMBER	ASSY LEVEL 1	2	3	4	5	6	DESCRIPTION, SYM, SPEC, CODE IDENT NO	QTY REQ
526									
	EM710456			/				DIODE, CR300-305	6
	GFA - 4/10			/				FUSE, F307-312 BUSSMANN	6
530									
	- 15			/				FUSE, F320-325,	12
								F332-337	
	- 5			/				FUSE, F344-349,	12
								F356-361	
535	GFA - 15			/				FUSE F301-303 BUSSMANN	3
	MS51957-17			/				SCREW	4
	NAS671-C4			/				NUT	4
540									
	MS15795-302			/				WASHER FLAT	4
	MS35337-78			/				WASHER LOCK	4
545	#24			/				WIRE BUSS	A/R
	#24 WHT			/				WIRE FLEX	A/R
	TYPE RA			/				SOLDER QQ-S-571	A/R
550								SN60 OR63	
	313269-1		/					COMP ASSY TB2	1
555									
	313267-6			/				BRD ASSY TB2	1
	313267-7				/			BRD BLANK	1
560									

SIZE	CODE IDENT NO	
A	06509	LM 5'----
SCALE ——	REV A	SHEET 18

EM FORM 17759C

ITEM	PART NUMBER	ASSY LEVEL 1	2	3	4	5	6	DESCRIPTION, SYM, SPEC, CODE IDENT NO	QTY REQ
561									
	3025-B				/			TERM LERCO	48
	3535-B				/			TERM LERCO	17
565									
	1247-10				/			TERM CAMBION	4
570	313262-1			/				XMFR ASSY T302	1
	113263				/			CORE	1
	113264				/			COIL FORM	3
575									
	313265-1				/			BRACKET ASSY	2
	313265-2					/		BRACKET	1
580	MF1331-06					/		NUT ANCHOR KAYNAR	2
	MS20426AD2					/		RIVET	4
585									
	213266				/			INSULATOR	A/R
590									
	EM710456			/				DIODE CR306-311	6
595									

SIZE	CODE IDENT NO	
A	06509	LM 313260
SCALE —	REV A	SHEET 19

EM FORM 17759C

ITEM	PART NUMBER	ASSY LEVEL 1	2	3	4	5	6	DESCRIPTION, SYM, SPEC, CODE IDENT NO	QTY REQ
596									
	GFA - 4/10			/				FUSE F313-316, 318, 319, BUSSMANN	6
	-15			/				FUSE F326-331,	12
600								F338-343	
	-5			/				FUSE F350-355,	12
								F362-367	
	GFA -15			/				FUSE F304-306 BUSSMANN	3
605	MS51957-17			/				SCREW	4
	NAS671-C4			/				NUT	4
	MS15795-303			/				WASHER-FLAT	4
610									
	MS35337-78			/				WASHER-LOCK	4
	#24			/				WIRE BUSS	A/R
615	#24 WHT			/				WIRE-FLEX	A/R
	TYPE RA			/				SOLDER QQ-S-571	A/R
								SN600R63	
620									
	313969-1		/					XFMR ASSY TB-11	1
	313968-1			/				POTTING CUP	1
625									
	313968-2				/			CUP	1
	313968 -3				/			BASE	1
630	NAS43DD1-60				/			SPACER	4

SIZE	CODE IDENT NO	
A	06509	LM 513260
SCALE ——	REV A	SHEET 20

EM FORM 17759C

ITEM	PART NUMBER	ASSY LEVEL 1	2	3	4	5	6	DESCRIPTION, SYM, SPEC, CODE IDENT NO	QTY REQ
631									
	5026B				/			TERM LERCO	16
635	213973			/				XMFR T304	1
	52061-1A				/			CORE MAG INC	3
640									
	213974			/				XMFR T306	1
	52061-1A				/			CORE MAG INC	3
645									
	#24 BUSS			/				WIRE	A/R
650									
	313969-2		/					XMFR ASSY TB12	1
	313968-1			/				POTTING CUP	1
655	313968 -2				/			CUP	1
	313968 -3				/			BASE	1
	NAS43DD1-60				/			SPACER	4
660									
	5026B				/			TERMINAL LERCO	16
665									

SIZE	CODE IDENT NO	
A	06509	LM 513260
SCALE ——	REV A	SHEET 21

EM FORM 17759C

ITEM	PART NUMBER	ASSY LEVEL	DESCRIPTION, SYM, SPEC, CODE IDENT NO.	QTY REQ
666				
	213973	3	XMFR T305	1
	52061-1A	4	CORE MAG INC	3
670				
	213974	3	XMFR T307	1
	52061-1A	4	CORE MAG INC	3
675				
	#24 BUSS	3	WIRE	A/R
680				
	413254-1	2	MOTOR ASSY	1
	413252-1	3	MOTOR BRACKET ASSY	1
685	413252-2	4	BRACKET	1
	NAS1068C06M	4	NUT PLATE	4
	MS20426AD2	4	RIVET	8
690				
	B18808	3	MOTOR M201, 201A	2
			[2] A.W. HAYDON	
	177SJ	3	POT 1KΩ 1¾W S.TURN	2
695			1/8 X 3/8 SHAFT R263, 265	
			[2] COMPUTER INSTR CO.	
700				

SIZE	CODE IDENT NO	
A	06509	LM 513200
SCALE ——	REV A	SHEET 22

EM FORM 17759C

ITEM	PART NUMBER	ASSY LEVEL 1	2	3	4	5	6	DESCRIPTION, SYM, SPEC, CODE IDENT NO.	QTY REQ
666									
	213973			/				XMFR T305	1
	52061-1A				/			CORE MAG INC	3
670									
	213974			/				XMFR T307	1
	52061-1A				/			CORE MAG INC	3
675									
	#24 BUSS			/				WIRE	A/R
680									
	413254-1		/					MOTOR ASSY	1
	413252-1			/				MOTOR BRACKET ASSY	1
685	413252-2				/			BRACKET	1
	NAS1068C06M				/			NUT PLATE	4
	MS20426AD2				/			RIVET	8
690									
	B18808			/				MOTOR M201, 201A	2
								2 A.W. HAYDON	
	1775J			/				POT 1KΩ 1 3/4 IN S.TURN	2
695								1/8 X 3/8 SHAFT R263, 265	
								2 COMPUTER INSTR CO	
700									

SIZE	CODE IDENT NO	
A	06509	LM 513260
SCALE —		REV A / SHEET 22

EM FORM 17759C

ITEM	PART NUMBER	ASSY LEVEL 1	2	3	4	5	6	DESCRIPTION, SYM, SPEC, CODE IDENT NO	QTY REQ
701									
	313253-1			/				COMPONENT ASSY TB7	1
	313253 -2				/			TERM BRD ASSY	1
705									
	313253 -3					/		BRD BLANK	1
	313253 -4					/		INSULATOR	1
710	3025B					/		TERMINAL LERCO	24
	RN55C____F				/			RES R258 S.I.T.	1
								≅ 50Ω TO 250Ω	
								MIL-R-10509/7	
	RN55C1102K				/			RES R233,230 MIL-R-10509/7	2
715									
	GI79430				/			DIODE-ZENER CR229	1
								TRW	
	AF1N645				/			DIODE CR225,226,227	8
								228,225A,226A,	
720								227A, & 228A	
								MIL-S-19500/240	
	F24GA				/			WIRE BUSS QQ-W-343	A/R
								TYPE S	
725									
	T7-1			/				COUPLING PIC DESIGN	2
								$\boxed{1}$ CORP	
	MS51957-29			/				SCREW	4
730									
	MS24693-C6			/				SCREW	3
	MS35337-79			/				WASHER-LOCK	4
735									

SIZE	CODE IDENT NO	
A	06509	LM 513260
SCALE ——	REV A	SHEET 23

EM FORM 17759C

ITEM	PART NUMBER	ASSY LEVEL 1	2	3	4	5	6	DESCRIPTION, SYM, SPEC, CODE IDENT NO	QTY. REQ
736									
	MS35327-78			/				WASHER-LOCK	2
	MS15795-305			/				WASHER-FLAT	4
740									
	MS35649-44			/				NUT	2
	MS35649-64			/				NUT	4
745	TRT24(7)U-9			/				WIRE MIL-W-16878TYPEE	A/R
	AF1N645		/					DIODE CR1,4 MIL-S-19500/240	2
	XN-407		/					RELAY HARTMAN ELECT	1
750								K1, MFG. CO.	
	NAS1652R18B32PN		/					CONN J1	1
	NAS1652R16B26PN		/					CONN J2	1
755									
	NAS1652R10B6SN		/					CONN J3	1
	413257-1		/					TERM BLOCK ASSY J4	1
760									
	413257 -2			/				TERM BLOCK	1
	1629-4-01			/				STUD. CAMBION	20
765	AN316-C4			/				NUT	20
	313256-1			/				BUS STRAP	2
	NO.115 H .250			/				LUG, TERM ZIERICK	4
	313256-2			/				BUS STRAP	1
770	EM77308-4			/				CAPACITOR, 2.0uf 100V, C29 C30	2

SIZE	CODE IDENT NO	
A	06509	LM 313280
SCALE ———	REV A	SHEET 24

EM FORM 17759C

ITEM	PART NUMBER	ASSY LEVEL 1	2	3	4	5	6	DESCRIPTION, SYM, SPEC, CODE IDENT NO	QTY REQ
771	413965-1		/					COMP ASSY TB8	1
	413972-1			/				BOARD ASSY	1
775	413972-2				/			BOARD BLANK	1
	413972-3				/			INSULATOR	1
	413972-4				/			HEATSINK	1
780									
	3025-B				/			TERMINAL LERCO	102
	4535-B				/				10
785	5026-B				/			TERMINAL LERCO	8
	MS20426-AD4				/			RIVET	5
790									
	AN743-BC13R				/			BRACKET	1
	313285-1			/				XMFR & CUP ASSY T201	1
	313285-2				/			XMFR ASSY T201	1
795	52033-1D					/		CORE MAG INC	1
	313285-5				/			CUP ASSY	1
	313286-6					/		CUP	1
800	5025-A					/		TERM	12
	NAS43DD0-40					/		SPACER	1
	213976			/				XMFR T303	1
805	52056-1A				/			CORE MAG INC	3

SIZE	CODE IDENT NO	
A	06509	LM 513260
SCALE ——	REV A	SHEET 25

EM FORM 17759C

ITEM	PART NUMBER	ASSY LEVEL 1 2 3 4 5 6	DESCRIPTION, SYM, SPEC, CODE IDENT NO.	QTY. REQ
806				
	EM710456	/	DIODE CR 366,367	2
810	JAN IN752 A	/	DIODE CR360,362	
			MIL-S-19500/127	2
	69-7300	/	DIODE, ZENER CR364,365 IRC	2
815				
	AFIN645	/	DIODE CR201-205, 207-210	
			MIL-S-19500/240	9
820				
	JANIN2984 B	/	DIODE, ZENER CR232	
			MIL-S-19500/272	1
	GI 79466	/	DIODE CR245,246,47,48	4
825				
	EM78324U	/	TSTR Q303,307,313,320	4
830				
	EM73531U	/	TSTR Q 304,308-312,318,319	8
	EM711347	/	TSTR Q1,11 TI	2
835				
	EM79451	/	TSTR Q2,12 SOLITRON	2
840	EM 74709U	/	TSTR Q300,316,317,323	4

SIZE	CODE IDENT NO	
A	06509	LM 513260
SCALE ——	REV A	SHEET 26

ITEM	PART NUMBER	ASSY LEVEL 1 2 3 4 5 6	DESCRIPTION, SYM, SPEC, CODE IDENT NO	QTY REQ
841	GI 73531 H	/	TSTR Q224 RAYTHEON	1
	GI 78324	/	TSTR Q201, 202 SOLITRON	2
845	GI 78324 H1	/	TSTR Q223	1
	AGS-3-1K	/	RES R307, 316 DALE	2
850				
	AGS-1-1K	/	RES R336, 325 DALE	2
	AGS-1-3K	/	RES R326, 337 DALE	2
855				
	AGS-3-5K	/	RES R305, 306 DALE	2
	GI -20Ω	/	RES R270 DALE	1
860	AGS-5-5Ω	/	RES R271 DALE	1
	AGS-5-2Ω	/	RES R1, 27 DALE	2
	AGS-3-1K	/	RES R309, 318 DALE	2
865	G2 -300Ω	/	RES. R272 DALE	1
	AGS-3-S.I.T.	/	RES. ≅ 7K R331 DALE	1
	AGS-3-S.I.T.	/	RES ≅ 4K R320 DALE	1
870				
	RN55C1001F	/	RES R2, 28, 341, 342, 314, 317,	
			R321, 330 MIL-R-10509/7	8
	RN55C3321F	/	RES R343, 344 MIL-R-10509/7	2
875				

SIZE	CODE IDENT NO	
A	06509	LM 513260
SCALE ——		REV A / SHEET 27

EM FORM 17759C

ITEM	PART NUMBER	ASSY LEVEL 1 2 3 4 5 6	DESCRIPTION, SYM, SPEC, CODE IDENT NO	QTY, REQ
876				
	RN55C2491F	/	RES R302,311 MIL-R-10509/7	2
	RN55C2051F	/	RES R345-348	4
880				
	RN55C----F	/	RES R303,312 S.I.T.	2
			≅ 1.1K	
	RN55C1002F	/	RES R3,29 MIL-R-10509/7	2
885				
	RC07GF301J	/	RES R202,203 MIL-R-11/8	2
	RC07GF472J	/	RES R201 MIL-R-11/8	1
890				
	RN55C4870F	/	RES R319,332 MIL-R-10509/7	2
	EM710454H-12	/	CAP C201-204,232	5
	EMUCYK01BT103M	/	CAP C300,301 EM711411	2
895				
	25429-4-4	/	INSERT	1
	1747-2	/	WASHER-MICA	1
900	14092-5	/	WASHER-EPOXY	1
	NAS620A10	/	WASHER-FLAT	2
	MS35337-81	/	WASHER-LOCK	2
905				
	MS15795-303	/	WASHER-FLAT	1
	NAS671-C10	/	NUT	2
910	MS21043-04	/	NUT	1

SIZE	CODE IDENT NO	
A	06509	LM 513260
SCALE ———	REV A	SHEET 28

EM FORM 17759C

ITEM	PART NUMBER	ASSY LEVEL 1	2	3	4	5	6	DESCRIPTION, SYM, SPEC, CODE IDENT NO	QTY REQ
911									
	MS24693-C10			/				SCREW	1
	BBD-625-062			/				WASHER-INSULATOR	
915								BRUSH BERYLLIUM	2
	115 X .196			/				LUG ZIERICK	1
	10038-DAP			/				TRANSIPAD THE MILTON ROSS CO	17
920									
	10018-DAP			/				TRANSIPAD THE MILTON ROSS CO	2
	CKR06BX104KP			/				CAPACITOR, C302-304, MIL-C-39014/2	3
								.1uf 100V	
925									
930									
935									
	S3420(IN3968)		/					DIODE CR312-335 SYNTRON	24
	S2120(IN3964)		/					DIODE CR336-359 SYNTRON	24
940									
	RN55C4870F		/					RES R308,315 MIL-R-10509/7	2
945									

SIZE	CODE IDENT NO	
A	06509	LM 513260
SCALE ——	REV A	SHEET 29

EM FORM 17759C

ITEM	PART NUMBER	ASSY LEVEL 1 2 3 4 5 6	DESCRIPTION, SYM, SPEC, CODE IDENT NO	QTY, REQ
946				
	EM77684U	/	TSTR Q301, 302, 305	8
			306, 314, 315	
			321, 322	
950	RH-25 0.6Ω	/	RES R301, 304, 334	8
			340, 310, 313	
			323, 329 DALE	
	MS51957-28	/	SCREW	37
955				
	MS51957-16	/	SCREW	8
	MS24693-C29	/	SCREW	24
960	MS51957-8	/	SCREW	8
	25429-6	/	INSERT	8
965	25429-5	/	INSERT	24
	25429-4	/	INSERT	24
	BBW-800-320-60	/	WASHER BRUSH BERYLLIUM	8
970				
	1747-1	/	WASHER, MICA	24
	1747-2	/	WASHER, MICA	24
975	NAS671-C2	/	NUT	8
	MS21043-5	/	NUT-LOCK	8
	MS21043-4	/	NUT-LOCK	24
980	MS21043-3	/	NUT-LOCK	24

SIZE	CODE IDENT NO	
A	06509	LM 513[illegible]
SCALE —		REV A / SHEET 30

EM FORM 17759C

ITEM	PART NUMBER	ASSY LEVEL 1 2 3 4 5 6	DESCRIPTION, SYM, SPEC, CODE IDENT NO.	QTY REQ
981				
	MS24693-C30	/	SCREW	6
	MS21043-06	/	NUT-LOCK	26
985				
	513250 -1	/	BASE ASSY	1
	513 250 -2	/	BASE BRAZE ASSY	1
990				
	MF6031-06	/	NUT ANCHOR KAYNAR	3
	MS20470AD3-	/	RIVET	6
995	MF1331-06	/	NUT-ANCHOR KAYNAR	34
	MS20426AD2-	/	RIVET	68
1000	F-440-2	/	NUT-CLINH PEM	8
	513255 -1	/	COVER ASSY	1
	513255 -2	/	COVER	1
1005				
	PA6368	/	CHANNEL PIONEER	4
	115X.250	/	LUG ZIERICK	28
	115 X.196	/	LUG ZIERICK	28
1010	27999C06-22	/	SCREW	8
	MS15795-305	/	WASHER-FLAT	20
	NAS620A2	/	WASHER- FLAT	8
1015				

SIZE	CODE IDENT NO	
A	06509	LM 513260
SCALE —	REV A	SHEET 31

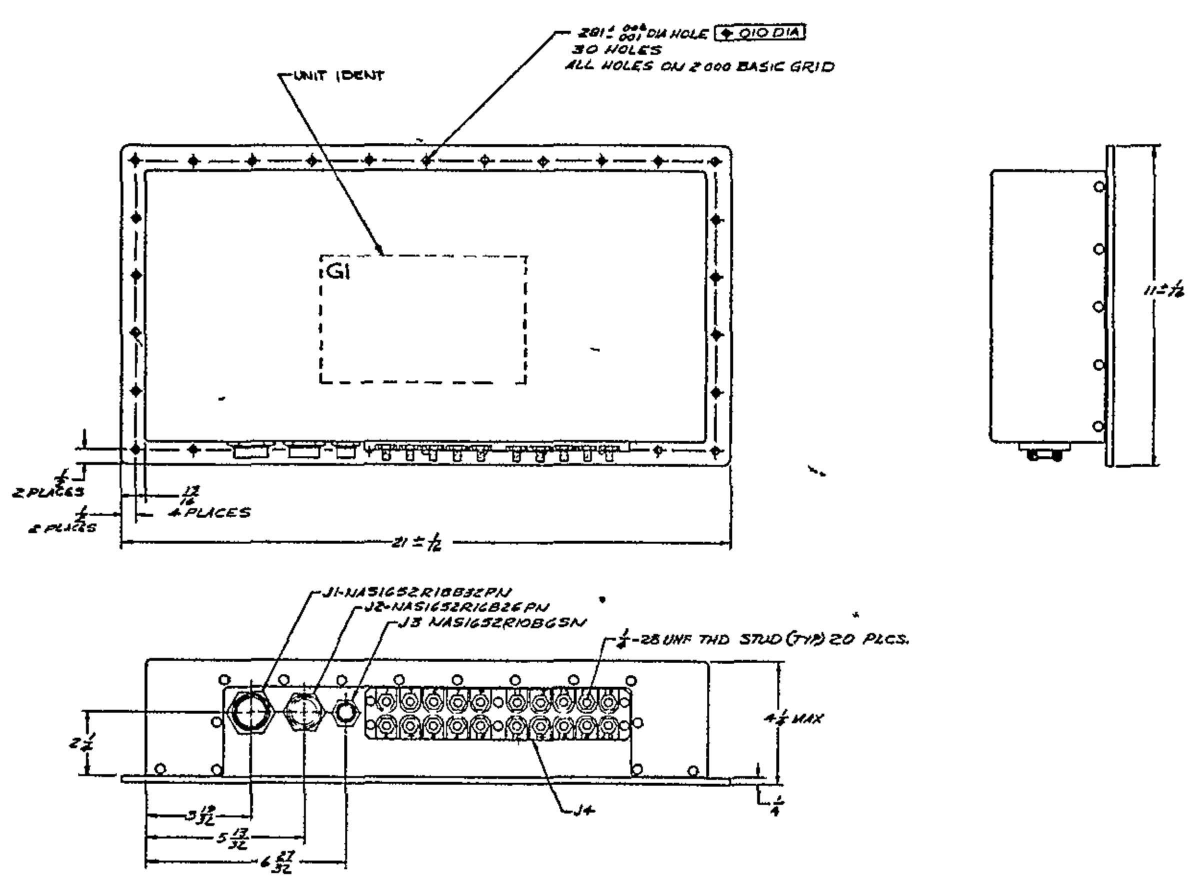
EM FORM 17759C

ITEM	PART NUMBER	ASSY LEVEL 1 2 3 4 5 6	DESCRIPTION, SYM, SPEC, CODE IDENT NO	QTY REQ
1016				
	14092-5	/	WASHER - EPOXY	24
1020	14092-6	/	WASHER - EPOXY	24
	14092-7	/	WASHER - EPOXY	8
1025	MS35337-77	/	WASHER - LOCK	8
	MS51957-30	/	SCREW	3
1030	313975	/	NAMEPLATE	1
	NAS1665-10	/	BACK SHELL	1
	NAS1665-16	/	BACK SHELL	1
	NAS1665-18	/	BACK SHELL	1
1035				
	REF BATTERY		ASSY	
	11991	/	BATTERY ASSY	2
1040			25XYS 85(S)	
			YARDNEY ELECT	
			CORP	
	A-50-100	/	SHUNT 100MV	
1045			EMPRO MFG CO	2
	35TD25-5K	/	THERMISTOR RT1, RT2, R269,	4
			R298 GULTON	
1050				

SIZE	CODE IDENT NO	
A	06509	LM 513360
SCALE ——	REV A	SHEET 32

EM FORM 17759C

REVISIONS			
SYM	DESCRIPTION	DATE	APPROVED



413249

QTY REQ'D	PART NUMBER	DESCRIPTION	CODE IDENT	SPECIFICATION	MATERIAL	ITEM NO.

LIST OF MATERIAL

NEXT ASSY	USED ON	NEXT ASSY	FINAL ASSY
—	EMPS252	—	—

APPLICATION | QTY REQD

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES.
TOLERANCES ON
FRACTIONS ±1/32 DECIMALS ±.010 ANGLES ±½
REMOVE SHARP EDGES AND BURRS.
MACHINED SURFACES 125

FINISH NA

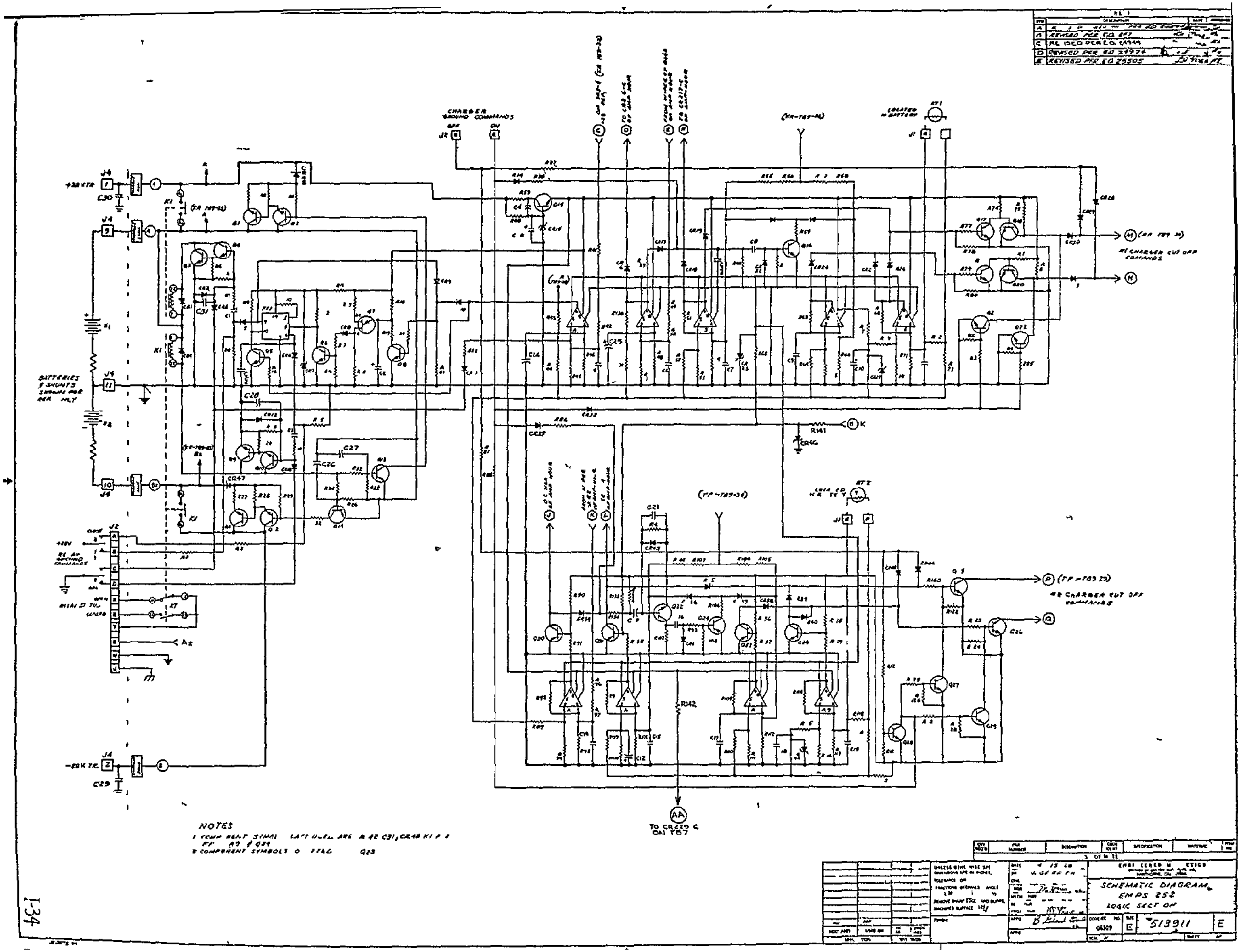
DATE 3 MAY 68
DR H MYERS
CHK
ENGR
MECH ENGR
REL ENGR
PROJ ENGR
APPD B J McCone
APPD

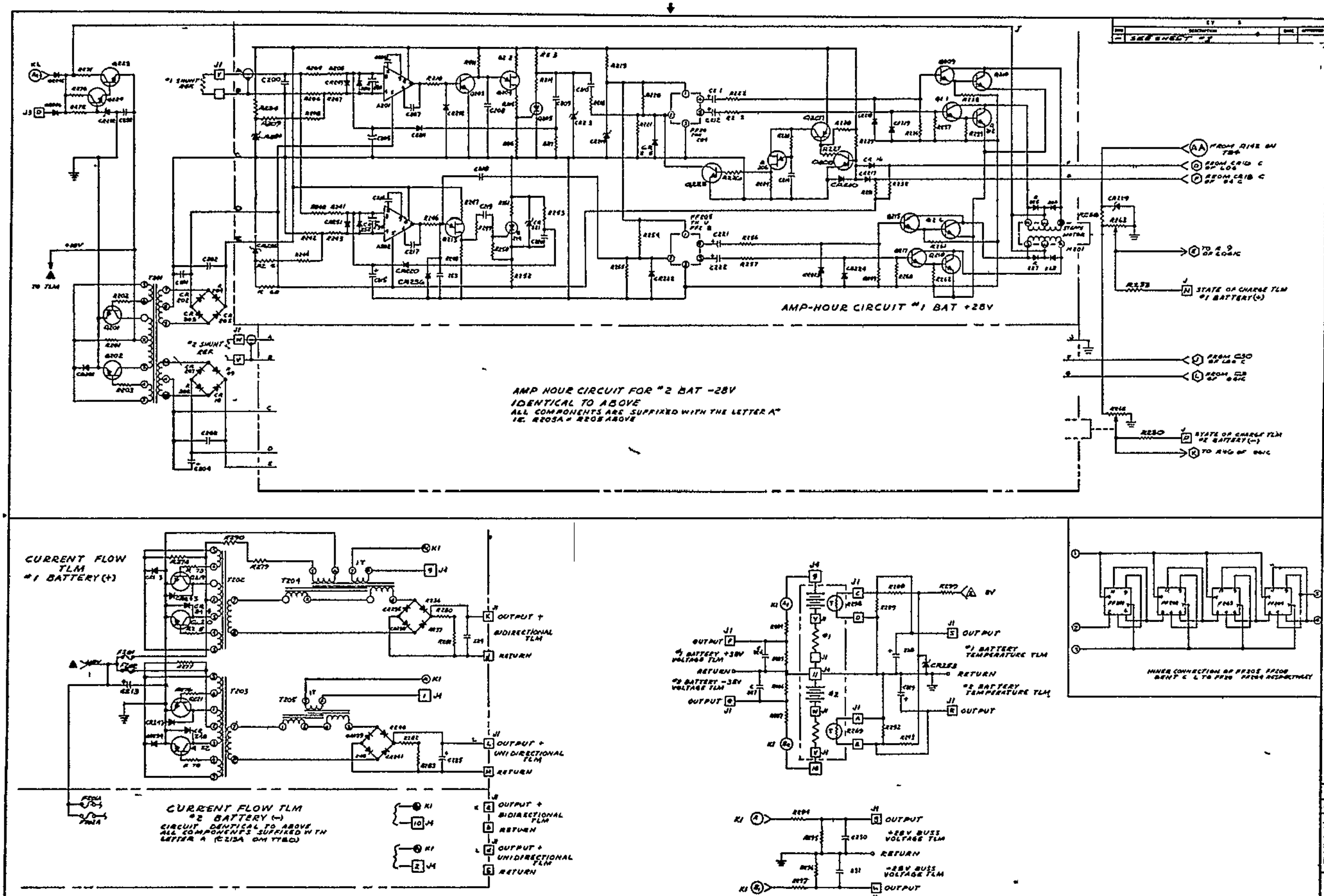
Gulton Industries, Inc
HAWTHORNE, CALIFORNIA

OUTLINE & SPECIFICATION
EMPS 252

CODE IDENT NO. 06509 | SIZE D | 413249

SCALE 1/2 | SHEET 1 OF 1

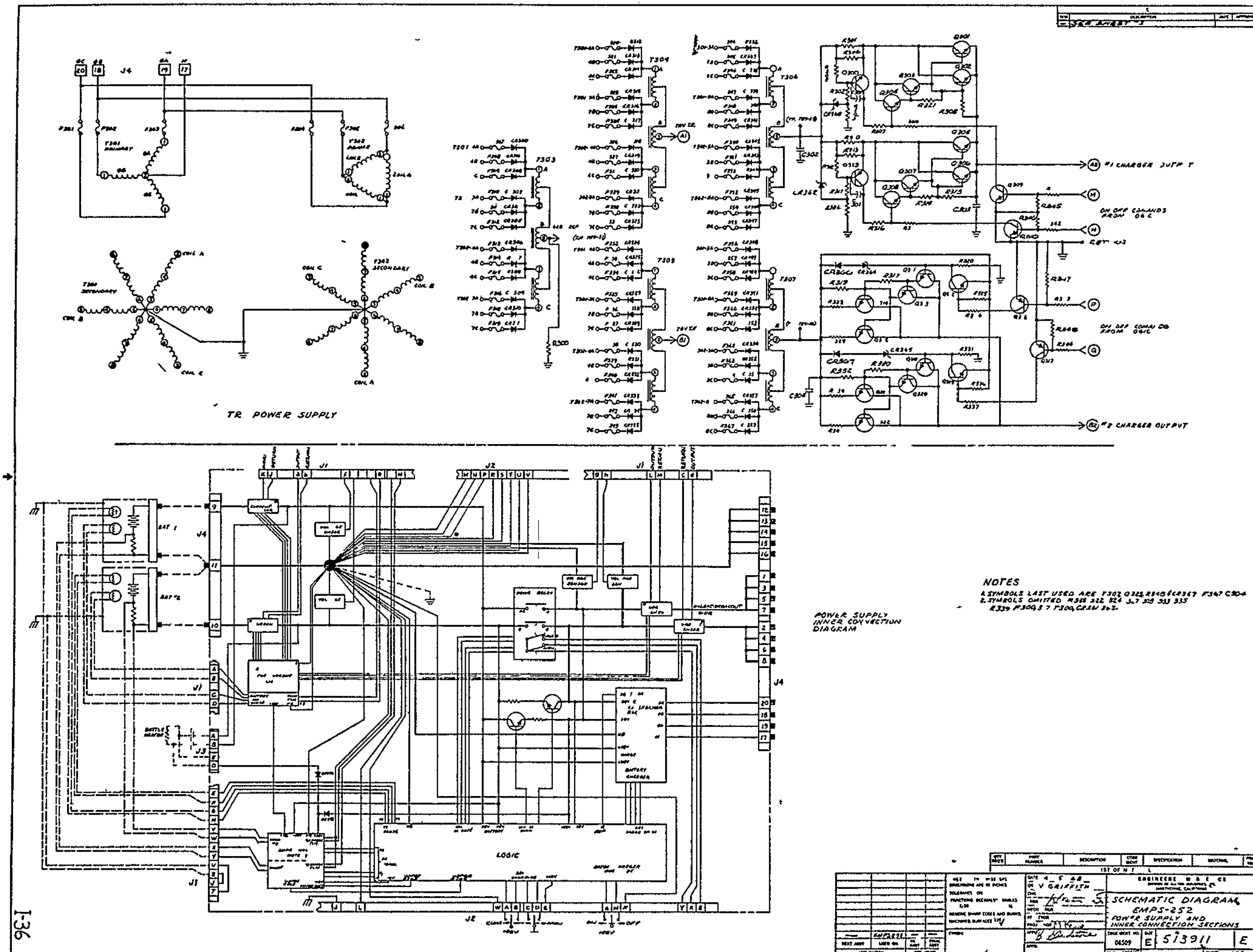

SCHEMATIC DIAGRAM
EMPS 252
LOGIC SECTION
513911
E
06509
CHARGER GROUND COMMANDS
BATTERIES & SHUNTS SHOWN FOR REF. ONLY
TO CR229 C ON TB7
#1 CHARGER CUT OFF COMMANDS
#2 CHARGER CUT OFF COMMANDS
NOTES



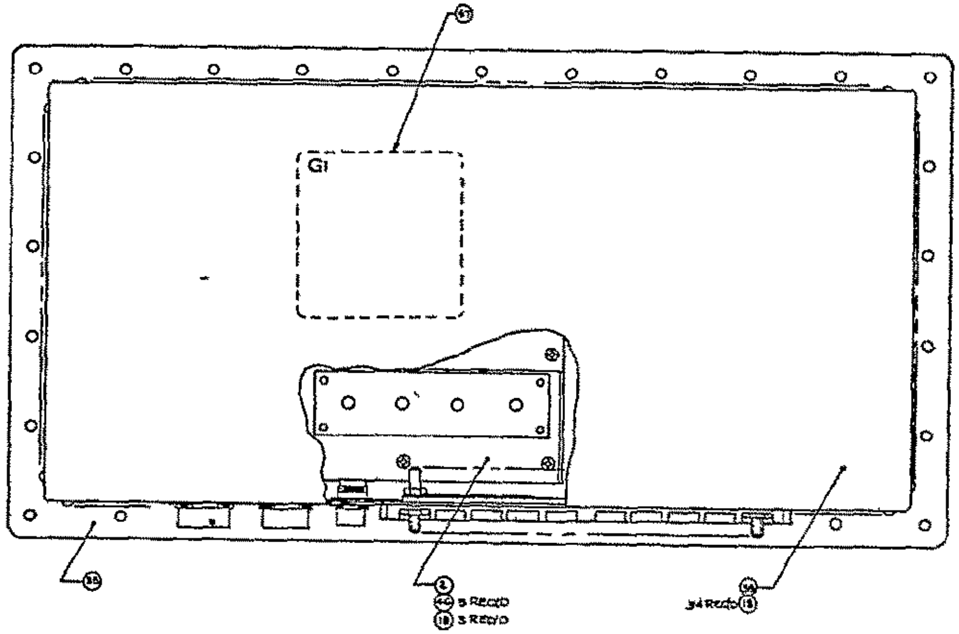
NOTES
1. SYMBOLS LAST USED ARE T205 M201 A202 FF208
Q225, CR256 CR216 R299 FF202
2. SYMBOLS OMITTED CR254, R264 268,291, 20-
CR220 231 F200 A200 M200, T200, FF205, Q260.

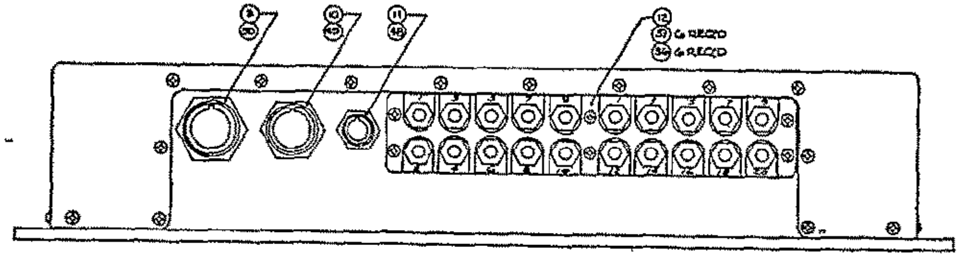
SCHEMATIC DIAGRAM
EMPS 252
TLM & AMP-HOUR SECTIONS

E 513911 E


TR POWER SUPPLY
#1 CHARGER OUTPUT
ON OFF COMMANDS FROM 06C
#2 CHARGER OUTPUT
BAT 1
BAT 2
POWER SUPPLY INNER CONNECTION DIAGRAM
NOTES
1. SYMBOLS LAST USED ARE
2. SYMBOLS OMITTED
LOGIC
BATTERY CHARGER
SCHEMATIC DIAGRAM
EMPS-252
POWER SUPPLY AND INNER CONNECTION SECTIONS
V GRIFFITH
06509
E
513911
E

		E	1810 8			
	REVISED PER ECO 13815					





NOTES:
1. WORKMANSHIP PER 79400
2. ASSEMBLE PER 79492
3. ASSEMBLE PER 74446
4. ASSEMBLE PER 74467

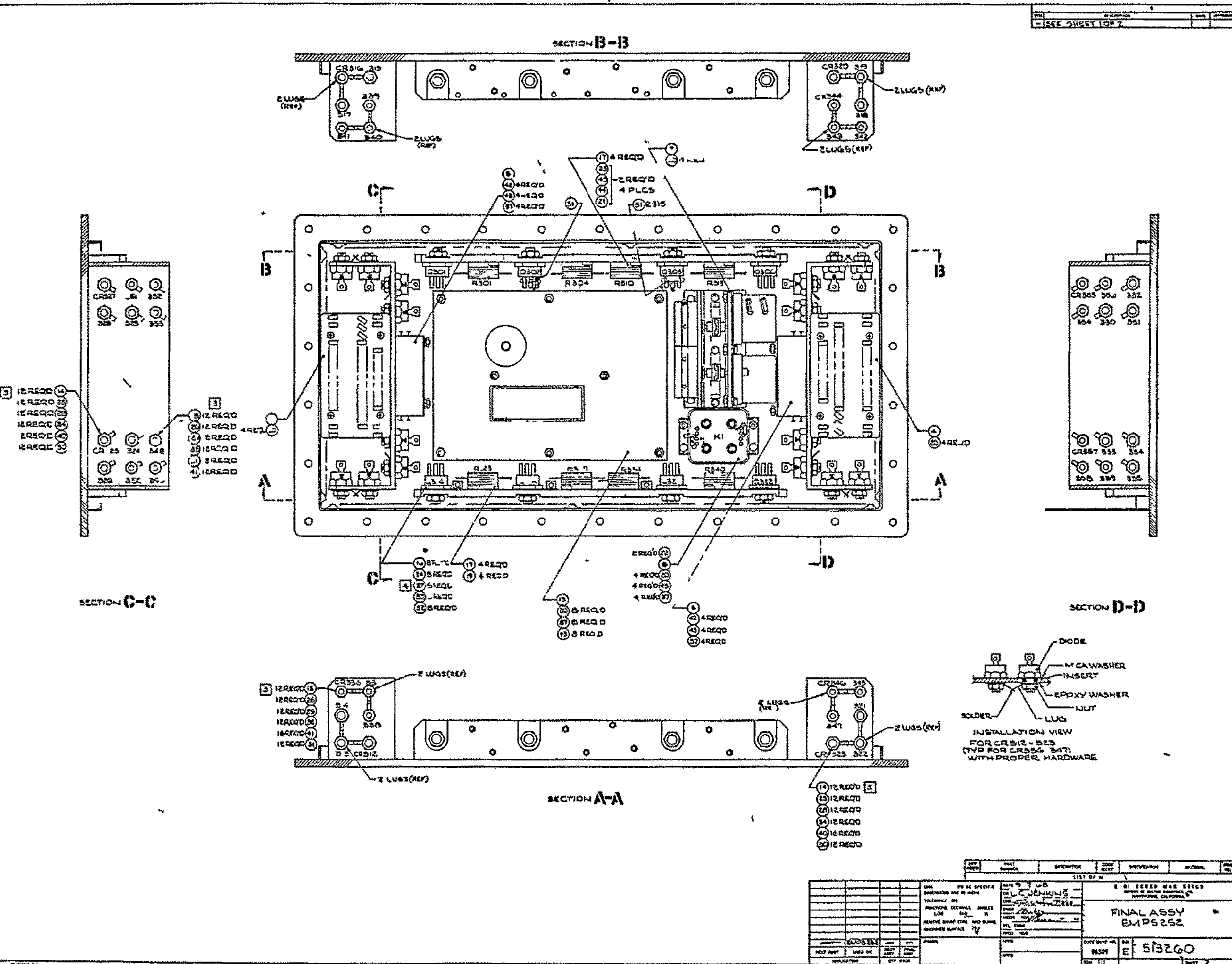
QTY REQD	PART NUMBER	DESCRIPTION	CODE IDENT	[illegible]	VENDOR	ITEM NO
3	RN55C4870F	RES		DR # 1807/7	R308 313	54
1	NAS1665-18	BACK SHELL		-		50
1	NAS1665-16	BACK SHELL				49
1	NAS1665-10	BACK SHELL				48
1	313975	NAMEPLATE				47
8	MS51957-30	SCREW				46
8	MS35337 77	WASHER LOCK				45
8	NAS620-A2	WASHER FLAT				44
8	MS15795-305	WASHER FLAT				43
8	27999C06-22	SCREW				42
28	15X 196	LUG	79963		ZIERICK	41
28	119X 250	LUG	79963		ZIERICK	40
1	513259 1	COVER				39
1	513260-1	BASE ASSY				38
26	MS21043-06	NUT LOCK				37
6	MS24693-C70	SCREW				36
24	MS21043-3	NUT LOCK				35
24	MS21043 4	NUT LOCK				34
8	MS21043 5	NUT LOCK				33
8	14092 7	WASHER,EPOXY				32
24	14092 5	WASHER,EPOXY				31
24	14092 6	WASHER,EPOXY				30
24	1747 2	WASHER,MICA				29
24	1747 1	WASHER,MICA				28
8	BBW 800-520-60	WASHER	05451		BRUSH BERYLLIUM	27
24	25429 4	INSERT				26
24	25429 6	INSERT				25
8	25429 5	INSERT				24
8	MS51957 8	SCREW				23
2	1N1345	DIODE			CR1 4	22
8	NAS671 C2	NUT				21
24	MS24693-C29	SCREW				20
8	MS51957 16	SCREW				19
87	MS51957 28	SCREW				18
8	RH 25 0.6A	RES		R301304 334342310 313 323 329		17
8	EM77G84U	TSTR		Q301,302,303 304,314,315 321,322		16
24	SZ12C(1N3994)	DIODE	81095	CR356 359	SYNTRON	15
24	SZ120(1N3996)	DIODE	81095	CR3 Z 339	SYNTRON	14
1	413966-1	COMP ASSY		TB6		13
1	413257-1	TERM BLOCK ASSY		J4		12
1	NAS1652R10BG5N	CONN		J3		11
1	NAS1652R16B26N	CONN		J2		10
1	NAS1652R18B32N	CONN		J1		9
1	XN-407	RELAY	79406	K1	HARTMAN ELECT MFG CO	8
1	413264 1	MOTOR ASSY				7
1	313969 2	COMP ASSY		TB12		6
1	313969 1	COMP ASSY		TB11		5
1	313269 1	COMP ASSY		TB2		4
1	313268 1	COMP ASSY		TB1		3
1	413263-1	SUB CHASSIS ASSY				2
	-1	ASSY				1

LIST OF MATERIAL

DATE 5 6 65	ENGINEERED BY ELECTRO		
DR L.C. JENKINS	FINAL ASSEMBLY EMPS 252		
	CODE IDENT NO. 81309	SIZE E	513260
	SCALE 1/1		SHEET

NEXT ASSY	USED ON		
	EMPS252		

I-37


SEE SHEET 1 OF 2
SECTION B-B
SECTION C-C
SECTION D-D
SECTION A-A
2 LUGS (REF)
K1
R301
R304
R510
DIODE
MICA WASHER
INSERT
EPOXY WASHER
NUT
LUG
SOLDER
INSTALLATION VIEW
FOR CR512 - 523
(TYP FOR CR356 - 347)
WITH PROPER HARDWARE
L.C. JENKINS
FINAL ASSY
EMPS252
E 513260

APPENDIX II

EMPS252 TEST PROCEDURE

AND

OPERATIONAL TEST DATA

REVISIONS			
SYM	DESCRIPTION	DATE	APPROVED
A	FORMAL RELEASE	1-6-69	K. Jaco

DATE	12/20/68
DR	C. Ghiselline
CHK	
ENGR	H. Grose
MECH ENGR	
REL ENGR	
PROJ ENGR	
APPD	M. Kruse
APPD	

Gulton Industries, Inc.
HAWTHORNE, CALIFORNIA

TEST PROCEDURE FOR EMPS252
BRAYTON CYCLE D.C. POWER SYSTEM

CODE IDENT NO.	SIZE	
06509	A	713331
SCALE		SHEET 1 of 21

EH17760

1.0 INTRODUCTION

The D.C. power system for the Brayton Cycle alternator provides +28VDC and -28VDC from transformer rectifiers or from two batteries. In addition the system has charge control logic ampere hour meters, voltage, temperature, current and state of charge telemetry.

This series of tests will verify that system meets certain minimum performance requirements at various temperature.

2.0 SYSTEM DESCRIPTION

Page 4 through 16 final report.

3.0 TEST OBJECTIVES

The following tests will verify that the system will operate as designed. Criteria for this verification are based on breadboard performance data[1] and on calculations taking into account guaranteed component limitations and previous experience with these components. Complete test records will detail system performance against the worst expected variations. In addition telemetry calibration curves will be provided where necessary.

4.0 LIST OF APPLICABLE DOCUMENTS

4.1 NASA Contract NAS3-10936, Exhibit B. Scope of work as amended.

4.2 Test Fixture Schematic EM313290.

5.0 LIST OF TEST EQUIPMENT, OR SIMILAR

5.1 Oscilloscope, Tektronix 531
5.2 Digital Voltmeter, HP3440A
5.3 Temperature Chamber, Bemco
5.4 Multimeter, Triplett 630A
5.5 Power Supply, Power Design 4005
5.6 Power Supply, Engineered Magnetics 50 Amp
5.7 Digital Frequency Counter, HP5243L
5.8 Ammeter, Weston 0-10 Amp
5.9 2 ea. 3.5 ohm, 500W. Power Resistors
5.10 Test Fixture, EM 313290
5.11 Power Supply, General Resistance No. DAS-46L
5.12 Resistance Decade Box, GR Type 1432-N

6.0 TEST SEQUENCE

All tests are at room temperature and atmospheric pressure unless otherwise noted.

6.1 General Procedures

6.1.1 Record all measurements on the test record form and check that data are within the limits specified.

6.1.2 Use Digital Volt Meter for all voltage adjustments and readings unless otherwise noted.

6.1.3 Positive Side Transformer, Rectifier, Logic and Charger Tests.

6.1.3.1 Connect the unit under test to the test fixture and its positive battery connection to the 0-10A ammeter in series with the 3.5 ohm power resistor to ground. Connect the 0-50A test supply in series with a silicon diode, having a rating of at least 6A and 50V, across the 3.5 ohm power resistor in order to simulate the battery voltage when the charger is off. Set the supply for 21 to 26 volts. Use this method of battery voltage simulation for the remainder of the test procedure whenever the use of the 3.5 or 7 ohm power resistor is called for.

Connect a test lead from Pin V of J1 to Pin 10 of J4, and another test lead from Pin X of J1 to Pin 11 of J4. These two leads must be connected whenever the unit is operated without the two batteries and their current shunts connected.

Connect the 0-40V test supply for a positive voltage of 39.5V between test point TB9-36 and ground. Turn on the AC generator, then set the test fixture for relay open and charger off. Record the voltage at Pin 1 of J4 and record the current readings for the following conditions:

6.1.3.2 Charger Command- Off

6.1.3.3 Charger Command- On

6.1.3.4 Charger Command- Auto

6.1.3.5 Re-adjust the test supply to 28.5 volts

6.1.3.6 Charger Command- On

6.1.3.7 Charger Command- Off

6.1.3.8 Change the 3.5 ohm power resistor to 7 ohms, re-adjust the test supply to 37.5 volts. Set Charger Command to ON and check that ammeter reads more than 5.0 amperes.

6.1.3.9 Set Charger Command to Auto and record the current reading.

6.1.3.10 Slowly increase the test supply voltage until the previous 3-5 ampere reading drops suddenly to less than 0.1 ampere. Record the test supply voltage for this condition and the following:

6.1.3.11 Slowly decrease the test supply voltage until the current increases suddenly to 3-5 amperes.

6.1.3.12 With the multimeter on the 12VDC range, check to see that the voltage at test point TB9-30 is less than ±0.5 volts.

6.1.3.13 Continue to slowly decrease the test supply voltage until the 3-5 ampere reading increases suddenly to more than 5.0 amperes.

6.1.3.14 Slowly increase the test supply voltage until the current drops suddenly back to 3-5 amperes.

6.1.3.15 Measure and record the voltage at test point TB9-25.

6.1.3.16 Increase the test supply voltage to 39.5 volts and then slowly decrease it to 33 volts, checking that the current now reads less than 0.1 amperes.

6.1.3.17 Set Charger Command to On and then back to Auto, checking that the current is now more than 5.0 amperes.

6.1.3.18 Connect the resistance decade box to pins G and H of J1. Decrease the resistance until the current drops to less than 0.1 amperes, and record this value of resistance.

6.1.3.19 Increase the resistance until the current returns to more than 5.0 amperes, and record this value of resistance. Turn off the AC generator.

6.1.4 Negative Side Transformer, Rectifier, Logic and Charger Tests.

6.1.4.1 Connect the 0-10A ammeter in series with the 3.5 ohm power resistor from the units negative battery connection to ground. Connect the 0-40V test supply for a negative voltage of 39.5V between test point TB9-34 and ground. Turn on the AC generator, record the voltage at Pin 2 of J4, and the current readings for the following conditions:

6.1.4.2 Charger Command - Off

6.1.4.3 Charger Command - On

6.1.4.4 Charger Command - Auto

6.1.4.5 Re-adjust the test supply to 28.5 volts.

6.1.4.6 Charger Command - On

6.1.4.7 Charger Command - Off

6.1.4.8 Change the 3.5 ohm power resistor to 7 ohms, re-adjust the test supply to 37.5 volts. Set Charger Command to On and check that ammeter reads more than 5.0 amperes.

6.1.4.9 Set Charger Command to Auto and record the current reading.

6.1.4.10 Slowly increase the test supply voltage until the previous 3-5 ampere reading drops suddenly to less than 0.1 ampere. Record the test supply voltage for this condition and the following:

6.1.4.11 Slowly decrease the test supply voltage until the current increases suddenly to 3-5 amperes.

6.1.4.12 With the multimeter on the 12VDC range, check to see that the voltage at test point TB9-29 is less than ±0.5 volts.

6.1.4.13 Continue to slowly decrease the test supply voltage until the 3-5 ampere reading increases suddenly to more than 5.0 amperes.

6.1.4.14 Slowly increase the test supply voltage until the current drops suddenly back to 3-5 amperes.

6.1.4.15 Measure and record the voltage at test point TB9-26.

6.1.4.16 Increase the test supply voltage to 39.5 volts and then slowly decrease it to 33 volts, checking that the current now reads less than 0.1 amperes.

6.1.4.17 Set Charger Command to On and then back to Auto, checking that the current is now more than 5.0 amperes.

6.1.4.18 Connect the resistance decade box to pins E and F of J1. Decrease the resistance until the current drops to less than 0.1 amperes, and record this value of resistance.

6.1.4.19 Increase the resistance until the current returns to more than 5.0 amperes, and record this value of resistance. Turn off the AC generator.

6.1.5 Negative Side Ampere Hour Meter Tests

6.1.5.1 Connect the millivolt test supply for a negative voltage to pin W with respect to pin V of J1. Connect a test lead from pin V of J1 to pin 10 of J4. Connect the frequency counter to the collector of Q216A, turn on the AC generator and record the period of the pulses for the following conditions:

6.1.5.2 Set the test supply to 8 MV.

6.1.5.3 Set the test supply to 80 MV.

6.1.5.4 Shift the decimal point one place to the right of the reading at 80 MV (6.1.5.3) and check to see that it is within 5% of the reading at 8 MV (6.1.5.2).

6.1.5.5 Reverse the polarity of the millivolt supply, connect the counter to the collector of Q210A and repeat (6.1.5.2, 3 and 4), recording the data at (6.1.5.6, 7 and 8).

6.1.5.9 Reverse the polarity of the millivolt supply and decrease the ampere hour meter output voltage setting until the voltage at pin P of J1 is 0 volts. Turn off the millivolt supply and increase the voltage of the test supply at test point TB9-34 to -39.5 volts. Note the time when the counter starts indicating the pulse period.

6.1.5.10 Record the period.

6.1.5.11 Note the time when the counter stops indicating the pulse period. Divide the interval, in seconds, by the pulse period, in seconds and record this number.

6.1.5.12 Record the voltage at pin P of J1.

6.1.5.13 Slowly decrease the test supply voltage at test point TB9-34 to 37.5 volts, checking that the current now reads less than 0.1 amperes.

6.1.5.14 Turn on the millivolt supply, decreasing the amp hour meter setting until the current increases suddenly to 3-5 amperes. At this time turn off the millivolt supply and record the voltage at pin P of J1. Turn off the AC generator.

6.1.6 Positive Side Ampere Hour Meter Tests

6.1.6.1 Connect the millivolt test supply for a negative voltage to pin Y with respect to pin X of J1. Connect a test lead from pin X of J1 to pin 11 of J4. Connect the frequency counter to the collector of Q216, turn on the AC generator.

6.1.6.2 Set the test supply to 8 MV.

6.1.6.3 Set the test supply to 80 MV.

6.1.6.4 Shift the decimal point one place to the right of the reading at 80 MV (6.1.6.3) and check to see that it is within 5% of the reading at 8 MV (6.1.6.2).

6.1.6.5 Reverse the polarity of the millivolt supply, connect the counter to the collector of Q210 and repeat (6.1.6.2, 3 and 4), recording the data at 6.1.6.6, 7 and 8).

6.1.6.9 Reverse the polarity of the millivolt supply and decrease the ampere hour meter output voltage setting until the voltage

6.1.6.9 cont'd. at pin N of J1 is 0 volts. Turn off the millivolt supply and increase the voltage of the test supply at test point TB9-36 to +39.5 volts. Note the time when the counter starts indicating the pulse period.

6.1.6.10 Record the period.

6.1.6.11 Note the time when the counter stops indicating the pulse period. Divide the interval, in seconds, by the pulse period, in seconds and record this number.

6.1.6.12 Record the voltage at pin N of J1.

6.1.6.13 Connect the 0-10 ammeter in series with the 7 ohm resistor to the units positive battery connection. Slowly decrease the test supply voltage at test point TB9-36 to 37.5 volts, checking that the current now reads less than 0.1 amperes.

6.1.6.14 Turn on the millivolt supply, decreasing the amp hour meter setting until the current increases suddenly to 3-5 amperes. At this time turn off the millivolt supply and record the voltage at pin N of J1. Turn off the AC generator.

6.1.7 Relay and Time Delay Tests

6.1.7.1 Connect the test supply for a positive voltage of 30V between test point TB9-32 and ground.
Set test fixture for charger off and relay open. Connect a test lead between Pin 1 and 9 of J4, and turn on the AC generator.

6.1.7.1 cont'd. Set relay to close.

6.1.7.2 Check that relay status is closed.

6.1.7.3 Set relay to Auto and check the time required for the relay to open.

6.1.7.4 Slowly decrease the test supply voltage until the relay closes and record this voltage.

6.1.7.5 Set relay to open and check that it does.

6.1.7.6 Slowly increase the test supply voltage until the voltage at test point TB9-28 suddenly drops to between -1 and 0 volts. Record the test supply voltage.

6.1.8 Telemetry Tests

6.1.8.1 Set charger to off and relay to close. Measure the voltage at pin 9 of J4 and record the ratio of this voltage to those measured at the following places:

6.1.8.2 Pin f of J1

6.1.8.3 Pin g of J1

6.1.8.4 Measure the voltage at pin 10 of J4 and record the ratio of this voltage to those measured at the following places:

6.1.8.5 Pin e of J1

6.1.8.6 Pin h of J1

6.1.8.7 Record and graph the output voltage for each of the four current sensors on test record form, figure 1, 2, 3 and 4. Make measurements at 0,10 and 25 amperes.

6.1.8.8 Record and graph the output voltage of both battery temperature sensors on Test Record Form, Figure 5 and 6. Use the resistance decade box to simulate the thermistor resistance at each of the following temperature/resistance points:

(a) $14^{\circ}F = 27{,}800\Omega$

(b) $68^{\circ}F = 6{,}250\Omega$

(c) $122^{\circ}F = 1{,}798\Omega$

(d) $176^{\circ}F = 626\Omega$

(e) $194^{\circ}F = 456\Omega$

6.1.' Buss and Solder Test Point TB9-31 to TB9-32, TB9-33 to TB9-34 and TB9-35 to TB9-36.

UNIT #1, SERIAL NO. 26268

EMPS252 TEST RECORD FORM

Date MARCH 27, 1969 Technician J. MATSUMOTO

Test Procedure Para.	0°F (-10°F AMB, 0° BASEPLATE)	+70°F	+120°F	+160°F (120° AMB, 157° BASEPLATE)	Range
6.1.3.1	28.18	28.35		27.83	+27-34 Volts
6.1.3.2	✓	✓		✓	0-0.1 Amperes *
6.1.3.3	6.4	7.8		8.5	6-10 Amperes
6.1.3.4	✓	✓		✓	0-0.1 Amperes
6.1.3.5	6.4	7.9		8.5	6-10 Amperes
6.1.3.6	6.4	7.9		8.5	6-10 Amperes
6.1.3.7	✓	✓		✓	0-0.1 Amperes
6.1.3.8	✓	✓		✓	≥5.0 Amperes
6.1.3.9	3.4	4.1		3.7	3-5 Amperes
6.1.3.10	38.2	38.0		37.6	+37.5-39.0 Volts
6.1.3.11	31.0	30.7		30.6	+29.5-31.5 Volts
6.1.3.12	✓	✓		✓	≤+0.5 Volts
6.1.3.13	30.6	30.3		30.1	+29-31 Volts
6.1.3.14	37.2	36.9		36.5	+36.0-38.0 Volts
6.1.3.15	41.3	41.2		41.4	+40-46 Volts
6.1.3.16	✓	✓		✓	0-0.1 Amperes
6.1.3.17	✓	✓		✓	≥5.0 Amperes
6.1.3.18	565	570		575	450-650 Ohms
6.1.3.19	660	667		672	500-750 Ohms
6.1.4.1	27.99	28.18		28.23	-27-34 Volts
6.1.4.2	✓	✓		✓	0-0.1 Amperes
6.1.4.3	7.8	8.3		8.7	6-10 Amperes
6.1.4.4	✓	✓		✓	0-0.1 Amperes
6.1.4.5	7.8	8.3		8.7	6-10 Amperes
6.1.4.6	7.8	8.3		8.7	6-10 Amperes
6.1.4.7	✓	✓		✓	0-0.1 Amperes
6.1.4.8	✓	✓		✓	≥5.0 Amperes
6.1.4.9	4.1	4.2		4.5	3-5 Amperes
6.1.4.10	37.9	38.2		38.4	-37.5-39.0 Volts

* BATTERY SIMULATOR SET AT 26V

UNIT #1, SERIAL NO. 26268

EMPS252 TEST RECORD FORM cont'd.

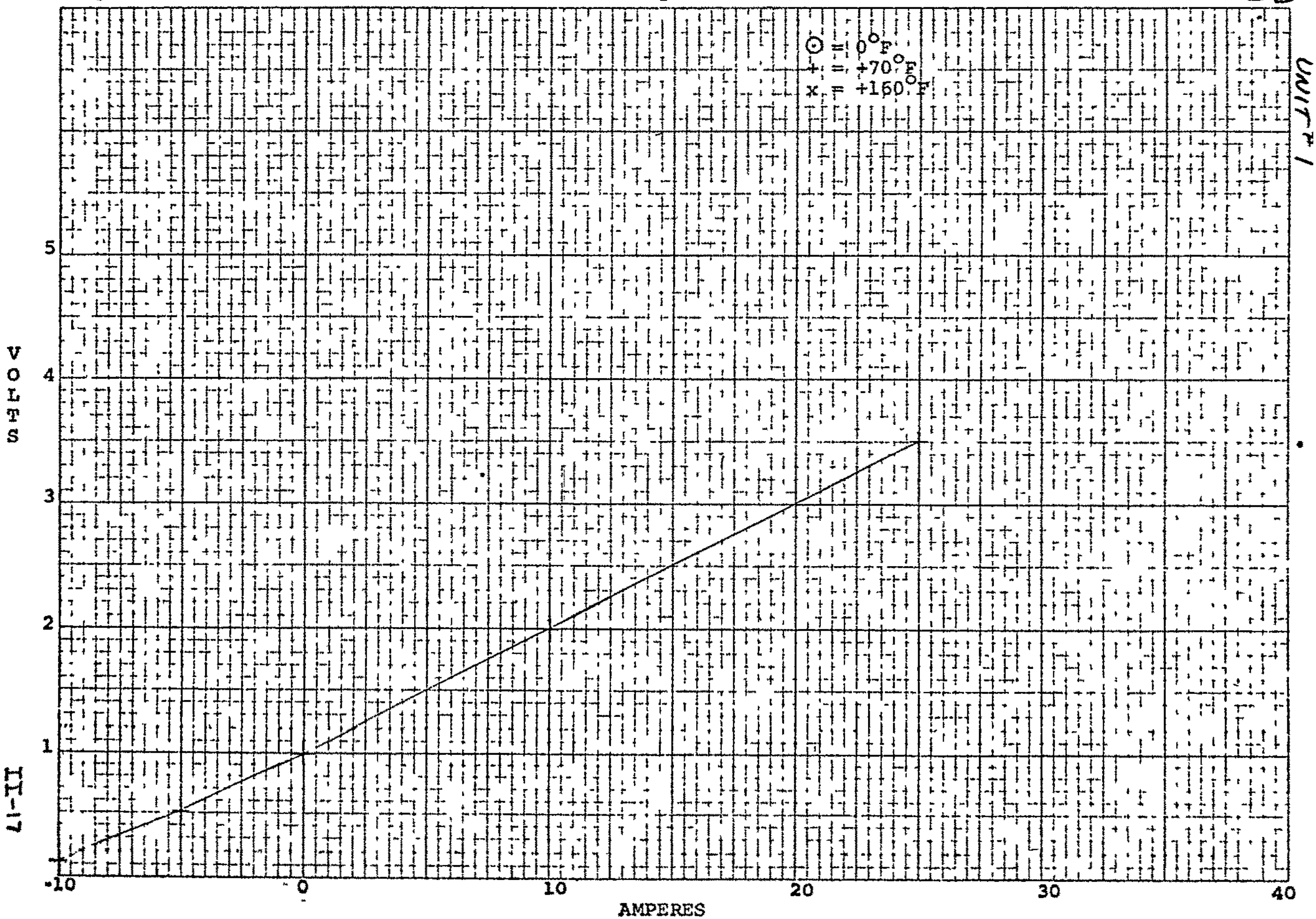
Test Procedure Para.	$0^{o}F$	$+70^{o}F$	$+120^{o}F$	$+160^{o}F$	Range
6.1.4.11	30.2	30.4		30.7	-29.5-31.5 Volts
6.1.4.12	✓	✓		✓	≤-0.5 Volts
6.1.4.13	30.1	30.3		30.6	-29-31 Volts
6.1.4.14	36.6	36.9		37.0	-36.0-38.0 Volts
6.1.4.15	41.2	41.2		41.3	-40-46 Volts
6.1.4.16	✓	✓		✓	0-0.1 Amperes
6.1.4.17	✓	✓		✓	≥5.0 Amperes
6.1.4.18	442	507		511	450-650 Ohms
6.1.4.19	449	606		603	500-750 Ohms
6.1.5.2	13.3	13.8		14.8	12.1-14.7 Seconds
6.1.5.3	1.32	1.34		1.40	1.21-1.47 Seconds
6.1.5.4	✓	✓		x	≤5%
6.1.5.6	12.5	12.9		13.0	12.1-14.7 Seconds
6.1.5.7	1.34	1.37		1.41	1.21-1.47 Seconds
6.1.5.8	x	x		x	≤5%
6.1.5.10	X		X	X	30-50 MS
6.1.5.11	X		X	X	5400-5900 p.f.s.
6.1.5.12	4.99	4.98		4.98	+4.8-5.1 Volts
6.1.5.13	✓	✓		✓	0-0.1 Amperes
6.1.5.14	4.48	4.47		4.48	+4.35-4.65 Volts
6.1.6.2	12.7	13.4		13.8	12.1-14.7 Seconds
6.1.6.3	1.30	1.34		1.37	1.21-1.47 Seconds
6.1.6.4	✓	✓		✓	≤5%
6.1.6.6	13.3	13.8		14.0	12.1-14.7 Seconds
6.1.6.7	1.32	1.36		1.40	1.21-1.47 Seconds
6.1.6.8	✓	✓		✓	≤5%
6.1.6.10	X		X	X	30-50MS
6.1.6.11	X		X	X	5400-5900 p.f.s.
6.1.6.12	5.03	5.06		5.07	+4.8-5.1 Volts
6.1.6.13	✓	✓		✓	0-0.1 Amperes
6.1.6.14	4.49	4.49		4.51	+4.35-4.65 Volts

UNIT #1, SERIAL NO. 26268

EMPS252 TEST RECORD FORM cont'd.

Test Procedure Para.	0°F	+70°F	+120°F	+160°F	Range
6.1.7.2	✓	✓		✓	Relay Closed
6.1.7.3	4.0	4.5		4.5	3-7 Seconds, Open
6.1.7.4	24.0	24.0		24.1	+23-25 Volts
6.1.7.5	✓	✓		✓	Relay Open
6.1.7.6	25.1	25.2		25.2	+24-26 Volts
6.1.8.2	X		X	X	7.3-7.7:1
6.1.8.3	X		X	X	7.3-7.7:1
6.1.8.5	X		X	X	7.3-7.7:1
6.1.8.6	X		X	X	7.3-7.7:1

Figure 1 Positive Battery Current Sensor Unit Serial No. 26268



10 X 10 PER INCH MADE IN U.S.A.

Figure 2 Negative Battery Current Sensor Unit Serial No. 26268

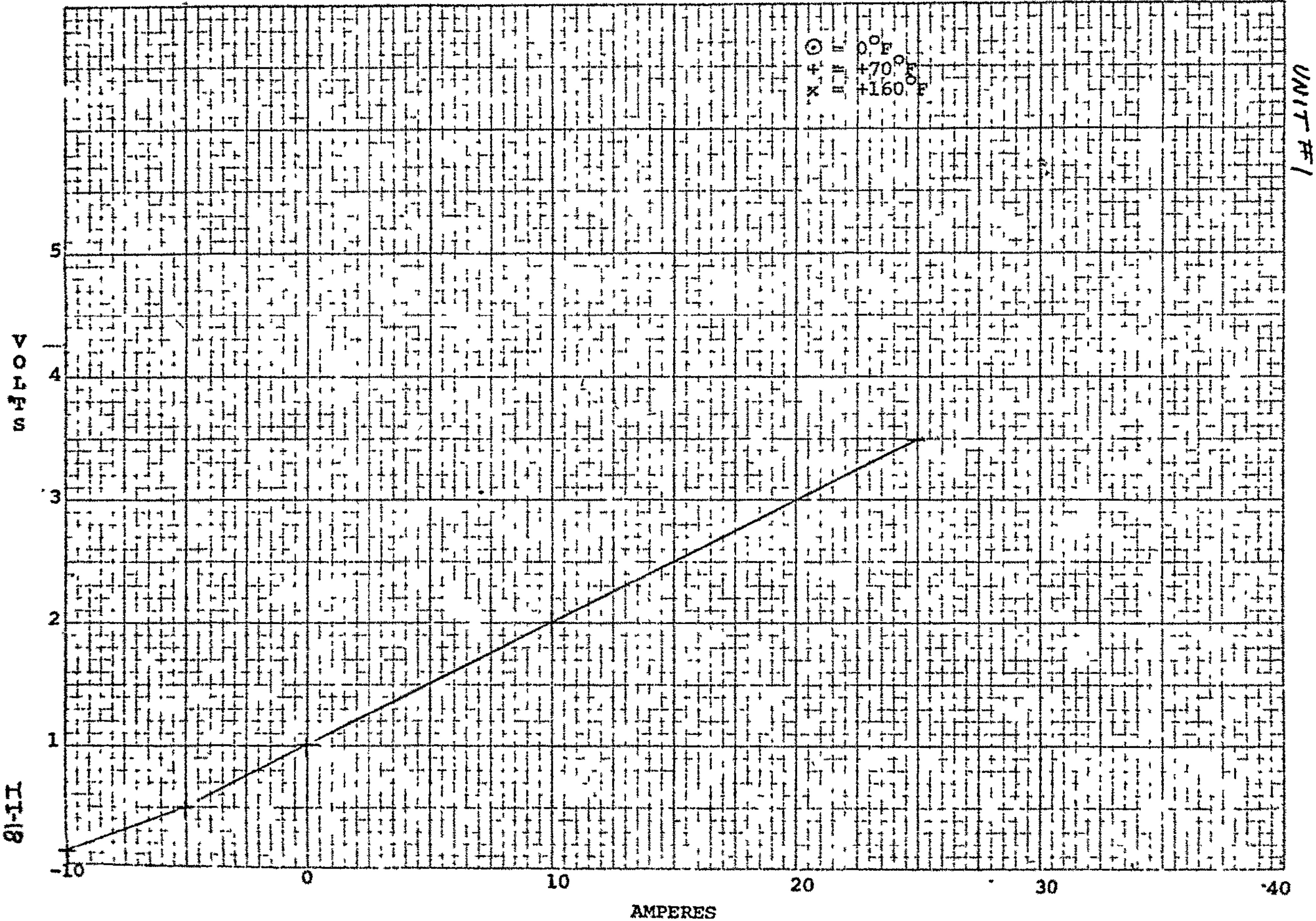
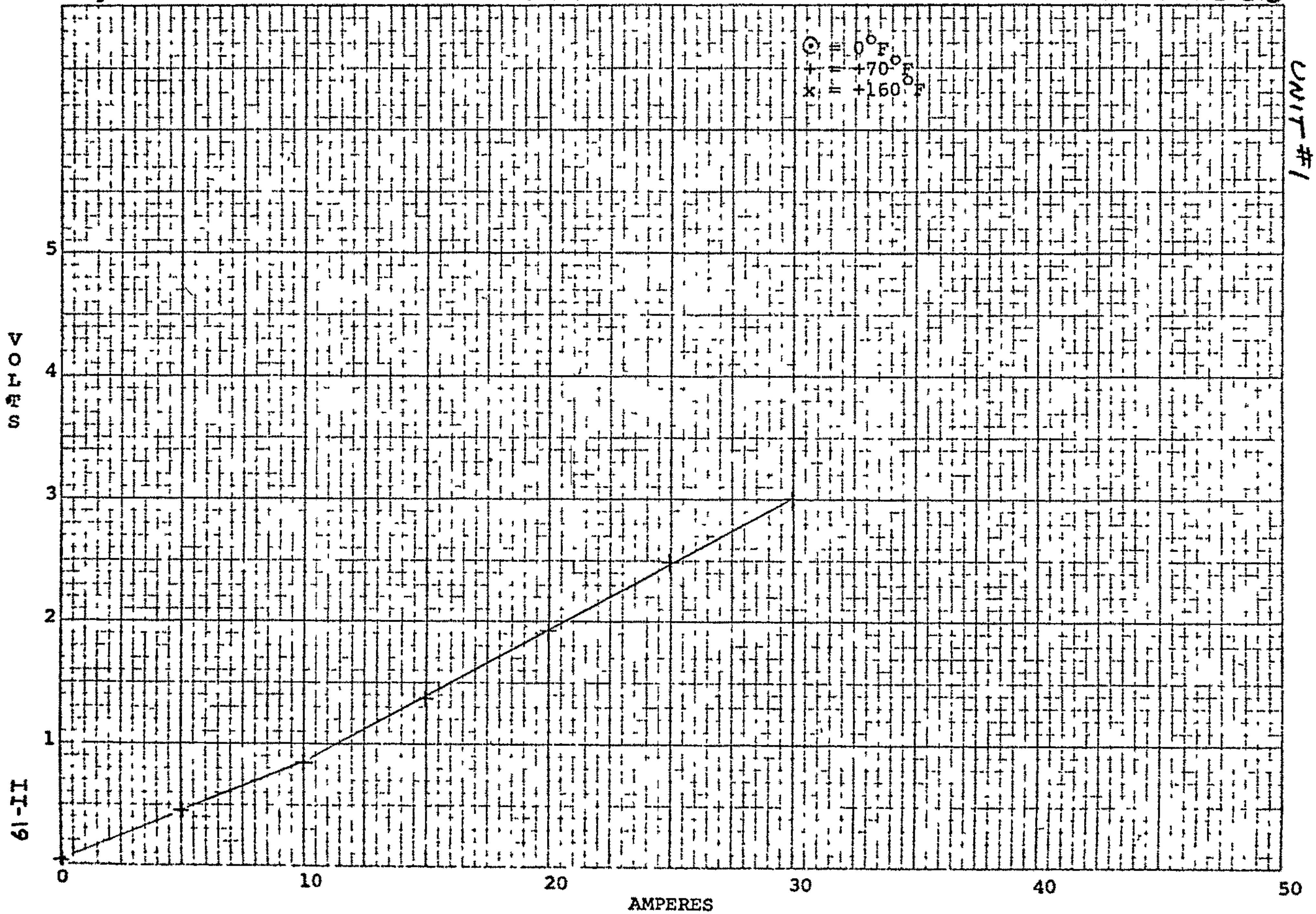
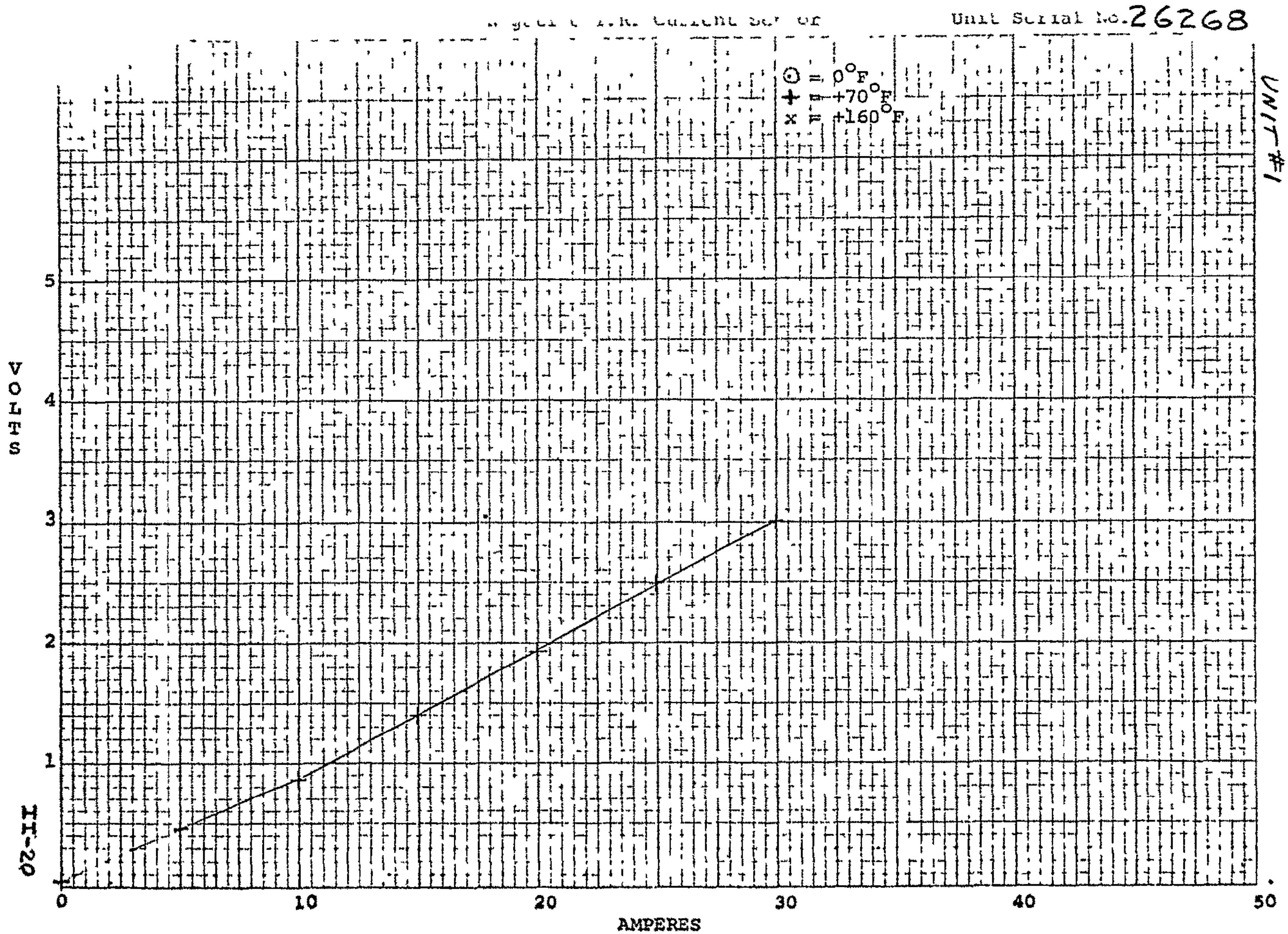


Figure 3 Positive T.R. Current Sensor Unit Serial No. 26268




Unit Serial No. 26268
UNIT #1
⊙ = 0°F
+ = +70°F
x = +160°F
VOLTS
1
2
3
4
5
AMPERES
0
10
20
30
40
50
HI-20

26268

Figure 5 Positive Battery Temperature Sensor Unit Serial No.

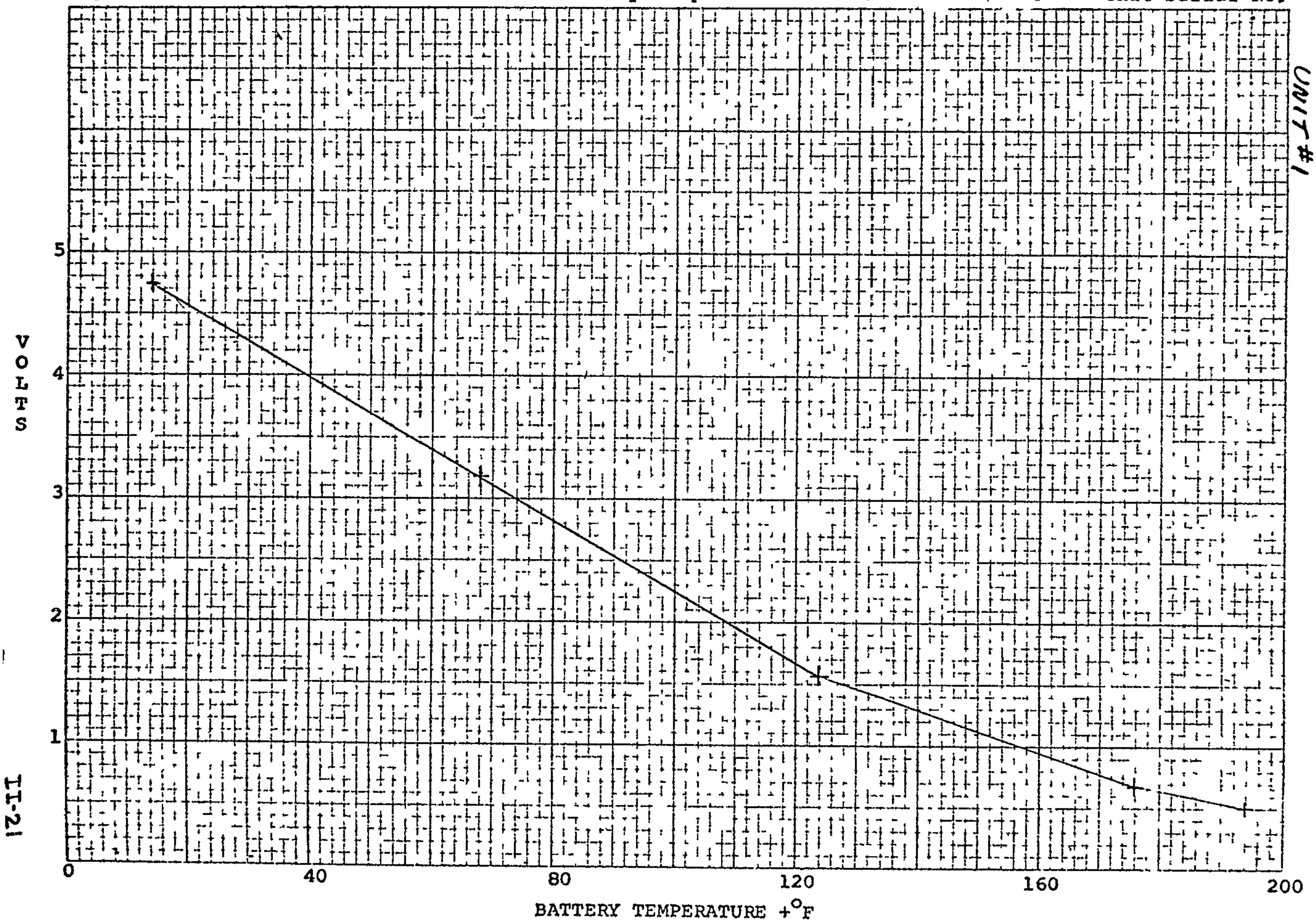
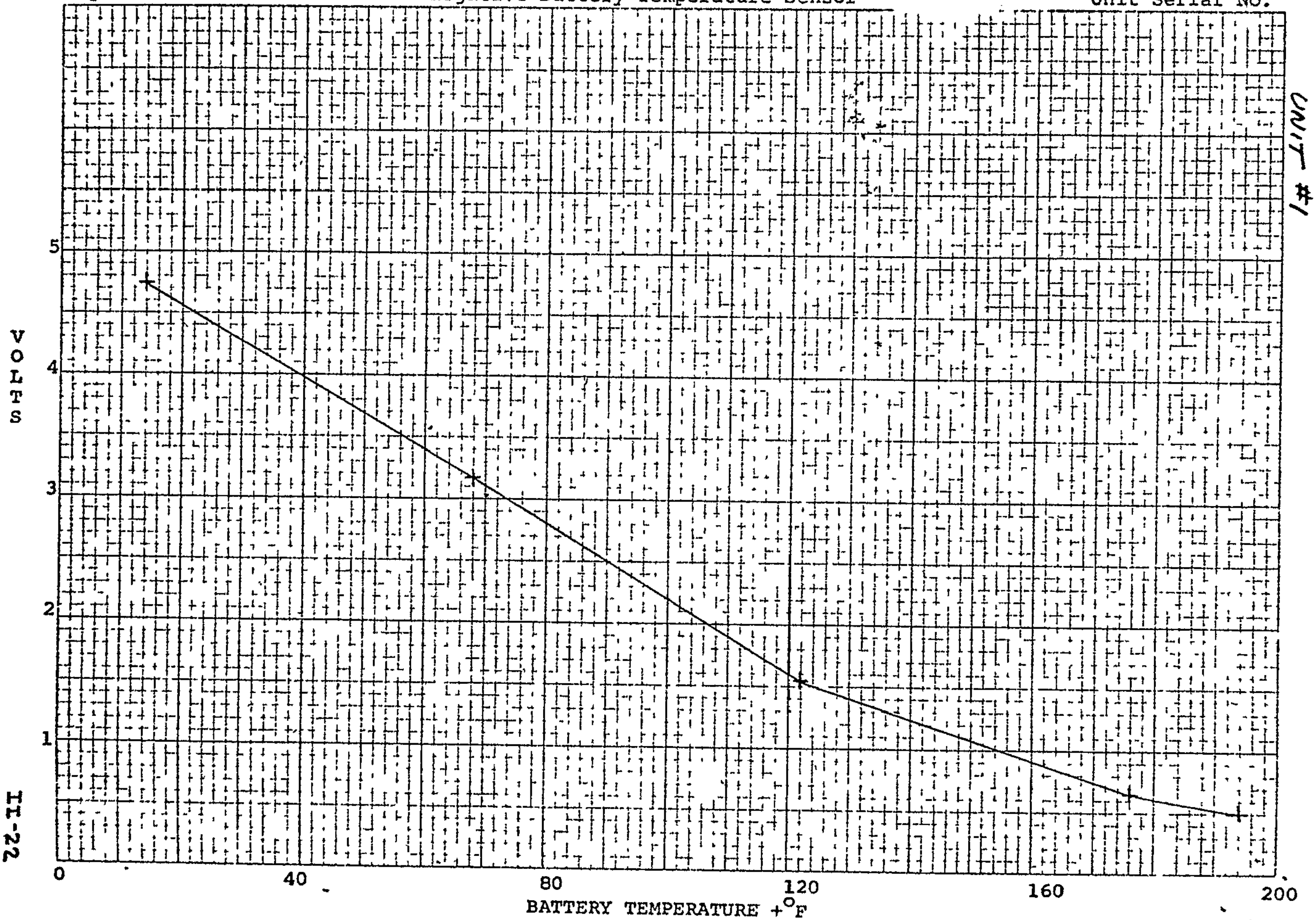


Figure 6

Negative Battery Temperature Sensor

-26268
Unit Serial No.



UNIT # 2, SERIAL NO. 26267

EMPS252 TEST RECORD FORM cont'd.

Test Procedure Para.	0^0F	$+70^oF$	$+120^oF$	$+160^oF$	Range
6.1.4.11		30.5			-29.5-31.5 Volts
6.1.4.12		✓			≤ -0.5 Volts
6.1.4.13		30.4			-29-31 Volts
6.1.4.14		36.5			-36.0-38.0 Volts
6.1.4.15		41.5			-40-46 Volts
6.1.4.16		✓			0-0.1 Amperes
6.1.4.17		5.5			≥ 5.0 Amperes
6.1.4.18		535			450-650 Ohms
6.1.4.19		636			500-750 Ohms
6.1.5.2		13.4			12.1-14.7 Seconds
6.1.5.3		1.35			1.21-1.47 Seconds
6.1.5.4		✓			≤ 5%
6.1.5.6		13.6			12.1-14.7 Seconds
6.1.5.7		1.30			1.21-1.47 Seconds
6.1.5.8		✓			≤ 5%
6.1.5.10	X		X	X	30-50 MS
6.1.5.11	X		X	X	5400-5900 p.f.s.
6.1.5.12		5.03			+4.8-5.1 Volts
6.1.5.13		✓			0-0.1 Amperes
6.1.5.14		4.51			+4.35-4.65 Volts
6.1.6.2		13.5			12.1-14.7 Seconds
6.1.6.3		1.35			1.21-1.47 Seconds
6.1.6.4		✓			≤5%
6.1.6.6		13.9			12.1-14.7 Seconds
6.1.6.7		1.38			1.21-1.47 Seconds
6.1.6.8		✓			≤ 5%
6.1.6.10	X		X	X	30-50MS
6.1.6.11	X		X	X	5400-5900 p.f.s.
6.1.6.12		4.97			+4.8-5.1 Volts
6.1.6.13		✓			0-0.1 Amperes
6.1.6.14		4.48			+4.35-4.65 Volts

EMPS252 TEST RECORD FORM

UNIT # 2, SERIAL # 26267

Date MARCH 28, 1969 Technician J. MATSUMOTO

Test Procedure Para.	0°F	+70°F	+120°F	+160°F	Range
6.1.3.1		28.6			+27-34 Volts
6.1.3.2		✓			0-0.1 Amperes
6.1.3.3		8.3			6-10 Amperes
6.1.3.4		✓			0-0.1 Amperes
6.1.3.5		8.3			6-10 Amperes
6.1.3.6		8.3			6-10 Amperes
6.1.3.7		✓			0-0.1 Amperes
6.1.3.8		5.5			≥5.0 Amperes
6.1.3.9		4.3			3-5 Amperes
6.1.3.10		37.8			+37.5-39.0 Volts
6.1.3.11		30.5			+29.5-31.5 Volts
6.1.3.12		✓			≤+0.5 Volts
6.1.3.13		30.2			+29-31 Volts
6.1.3.14		36.8			+36.0-38.0 Volts
6.1.3.15		41.4			+40-46 Volts
6.1.3.16		✓			0-0.1 Amperes
6.1.3.17		5.5			≥5.0 Amperes
6.1.3.18		540			450-650 Ohms
6.1.3.19		625			500-750 Ohms
6.1.4.1		28.33			-27-34 Volts
6.1.4.2		✓			0-0.1 Amperes
6.1.4.3		8.1			6-10 Amperes
6.1.4.4		✓			0-0.1 Amperes
6.1.4.5		8.1			6-10 Amperes
6.1.4.6		8.1			6-10 Amperes
6.1.4.7		✓			0-0.1 Amperes
6.1.4.8		5.5			≥5.0 Amperes
6.1.4.9		4.2			3-5 Amperes
6.1.4.10		38.1			-37.5-39.0 Volts

UNIT # 2, SERIAL NO. 26267

EMPS252 TEST RECORD FORM cont'd.

Test Procedure Para.	0°F	+70°F	+120°F	+160°F	Range
6.1.7.2		✓			Relay Closed
6.1.7.3		5			3-7 Seconds, Open
6.1.7.4		23.9			+23-25 Volts
6.1.7.5		✓			Relay Open
6.1.7.6		24.9			+24-26 Volts
6.1.8.2	X		X	X	7.3-7.7:1
6.1.8.3	X		X	X	7.3-7.7:1
6.1.8.5	X		X	X	7.3-7.7:1
6.1.8.6	X		X	X	7.3-7.7:1

Figure 1 - Positive Battery Current Sensor Unit Serial No. 26267

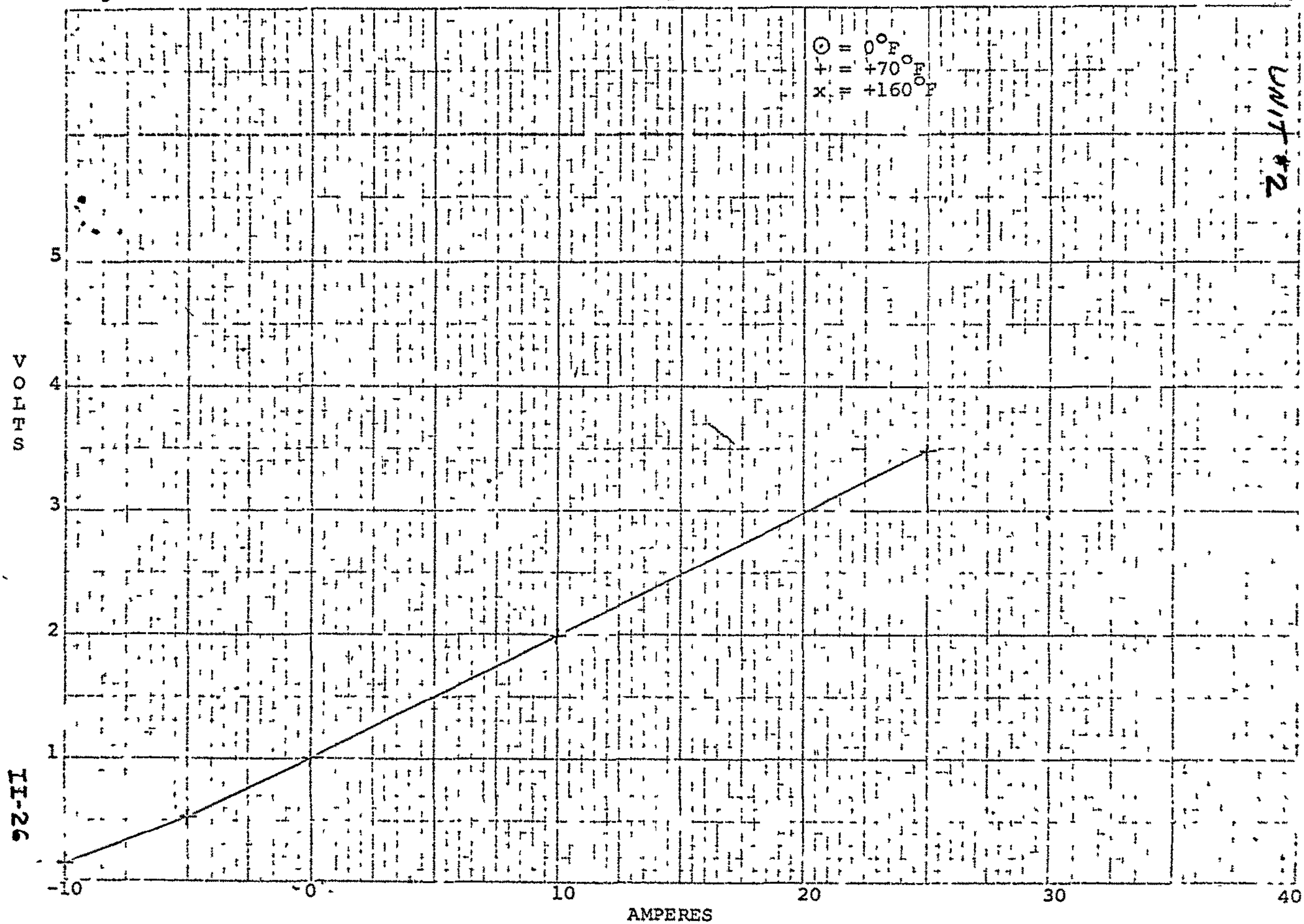


Figure 7 Negative Battery Current Sensor Unit Serial No. 26267

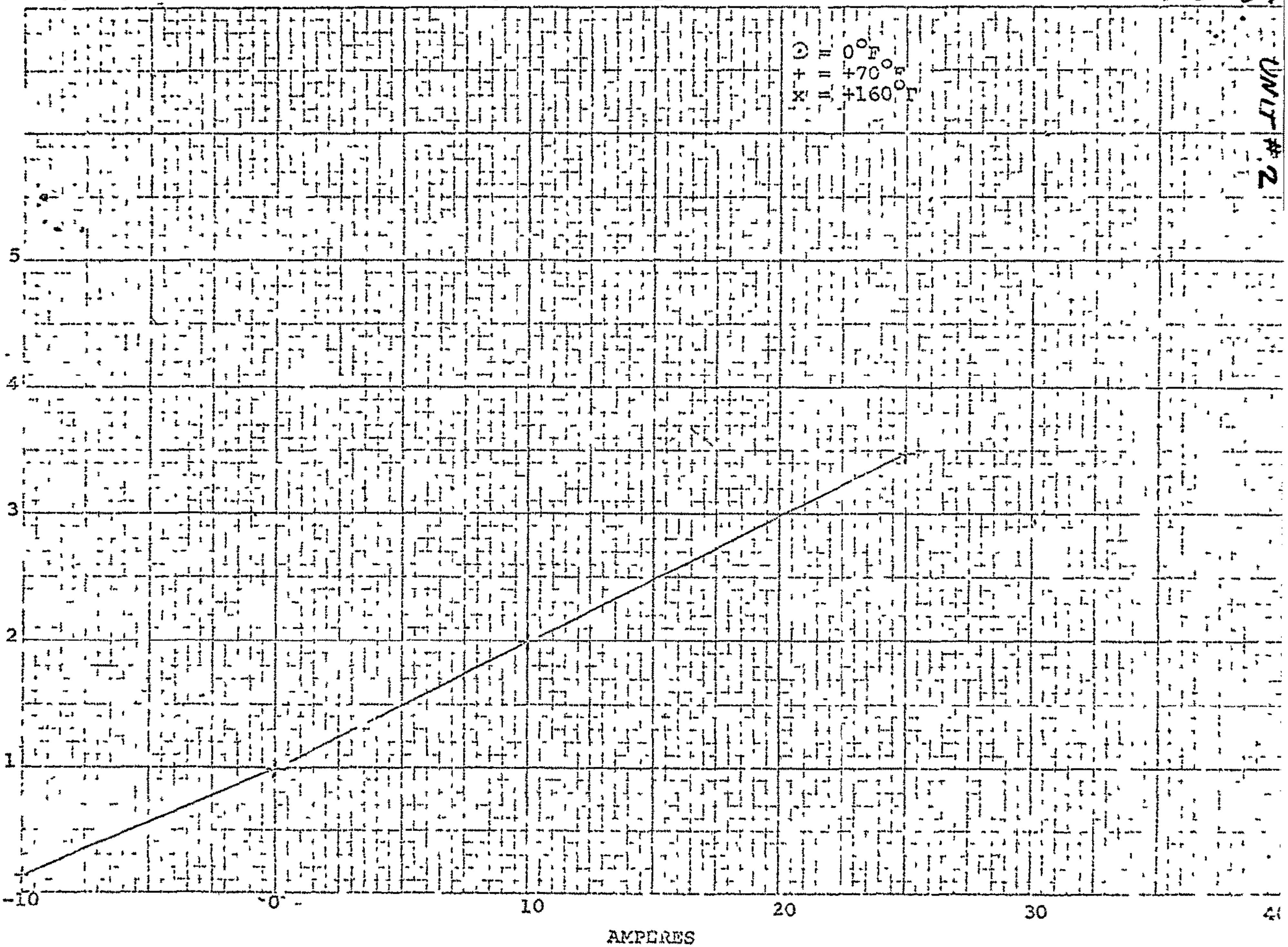


Figure 3 Positive T.R. Current Sensor Unit Serial No. 26267

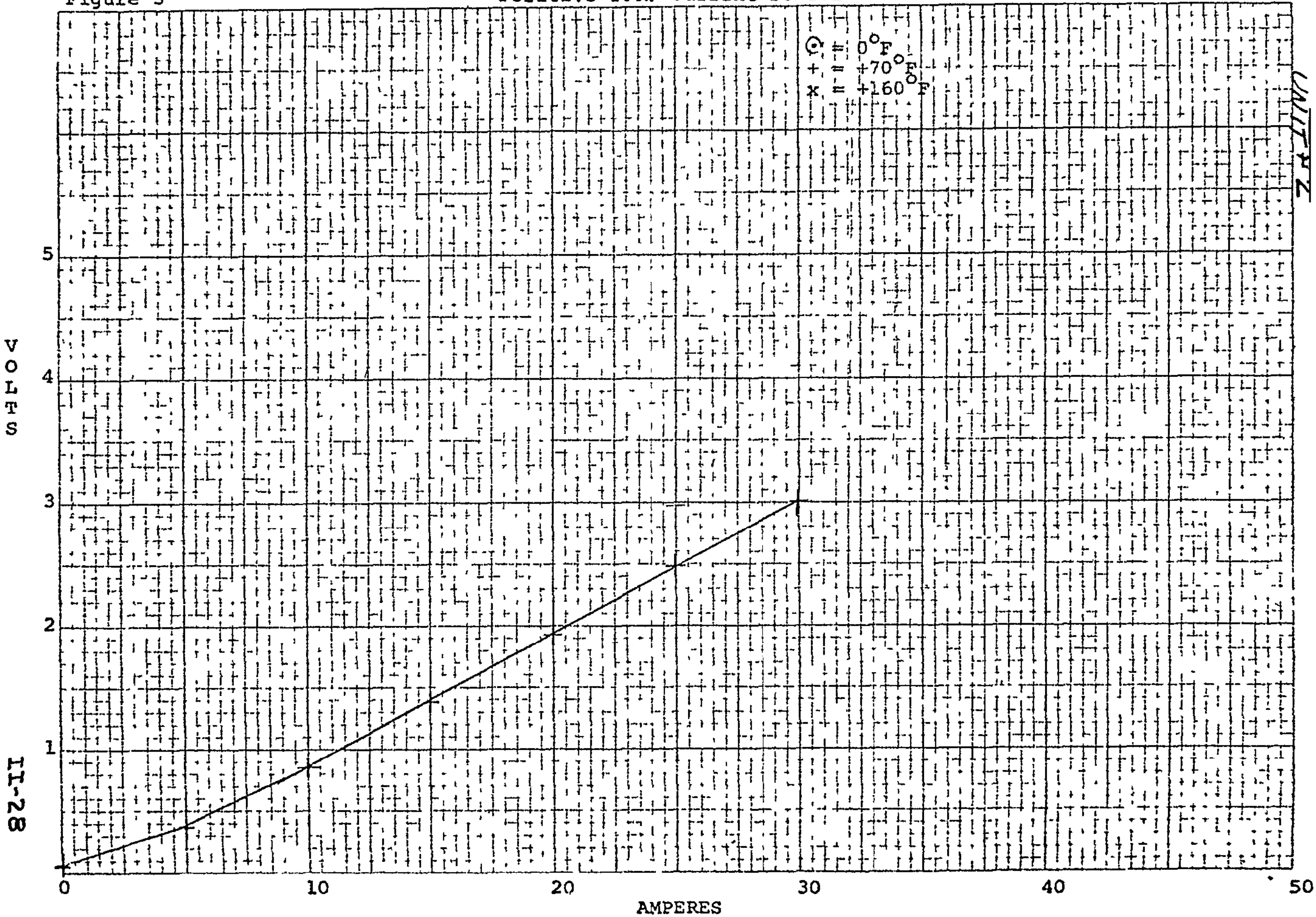


Figure 4 Negative T.R. Current Sensor Unit Serial No. 26267.

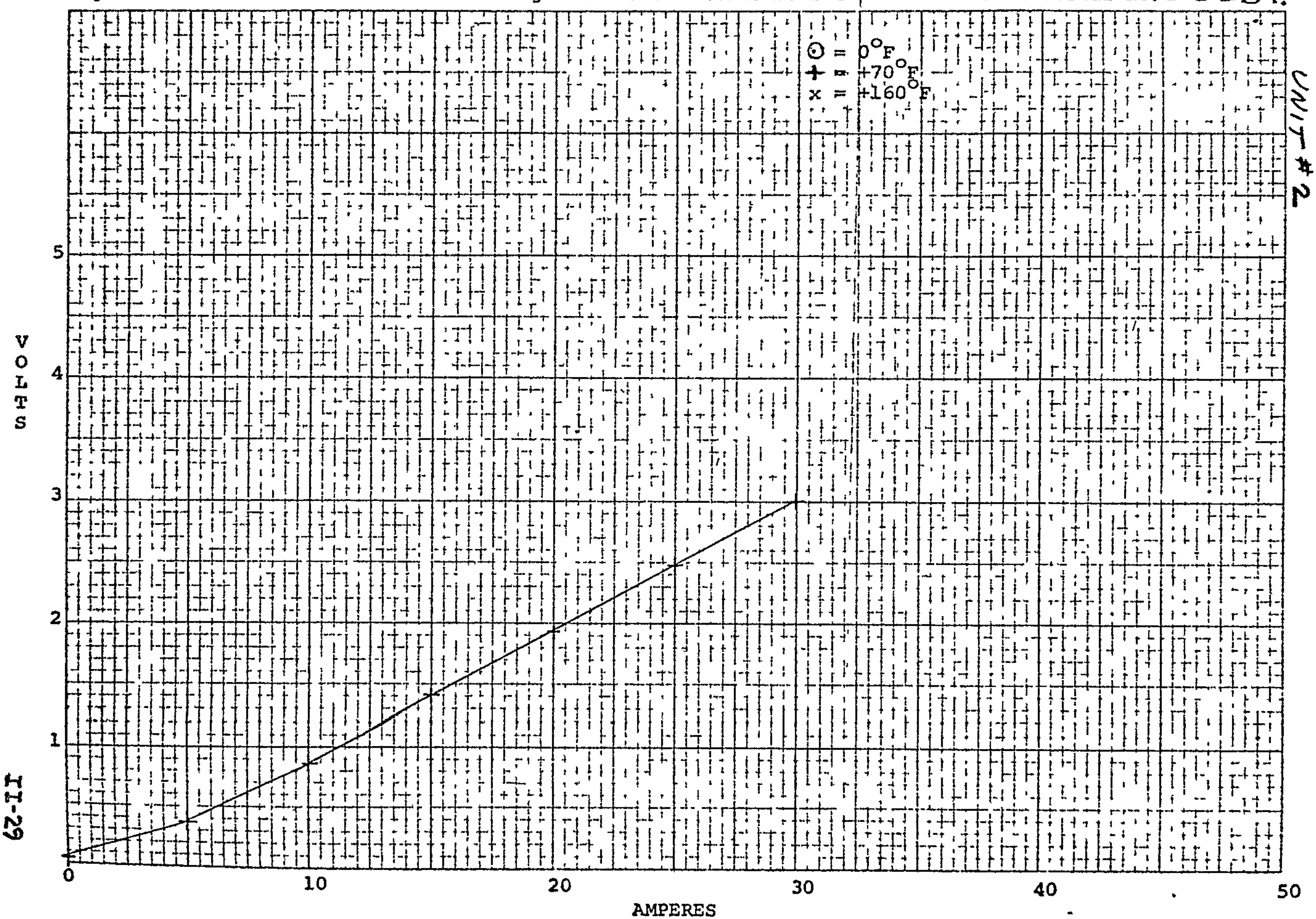
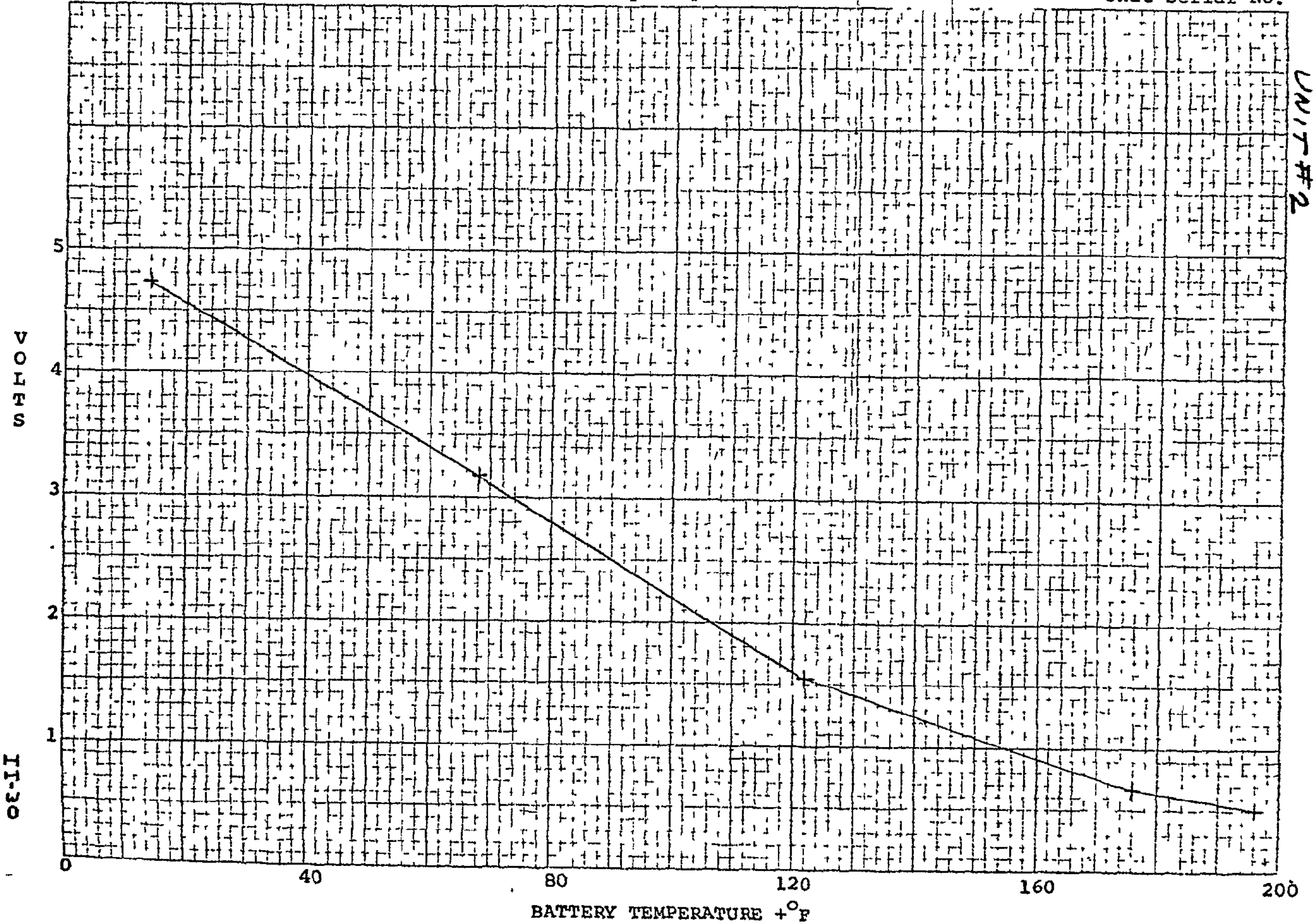


Figure 5

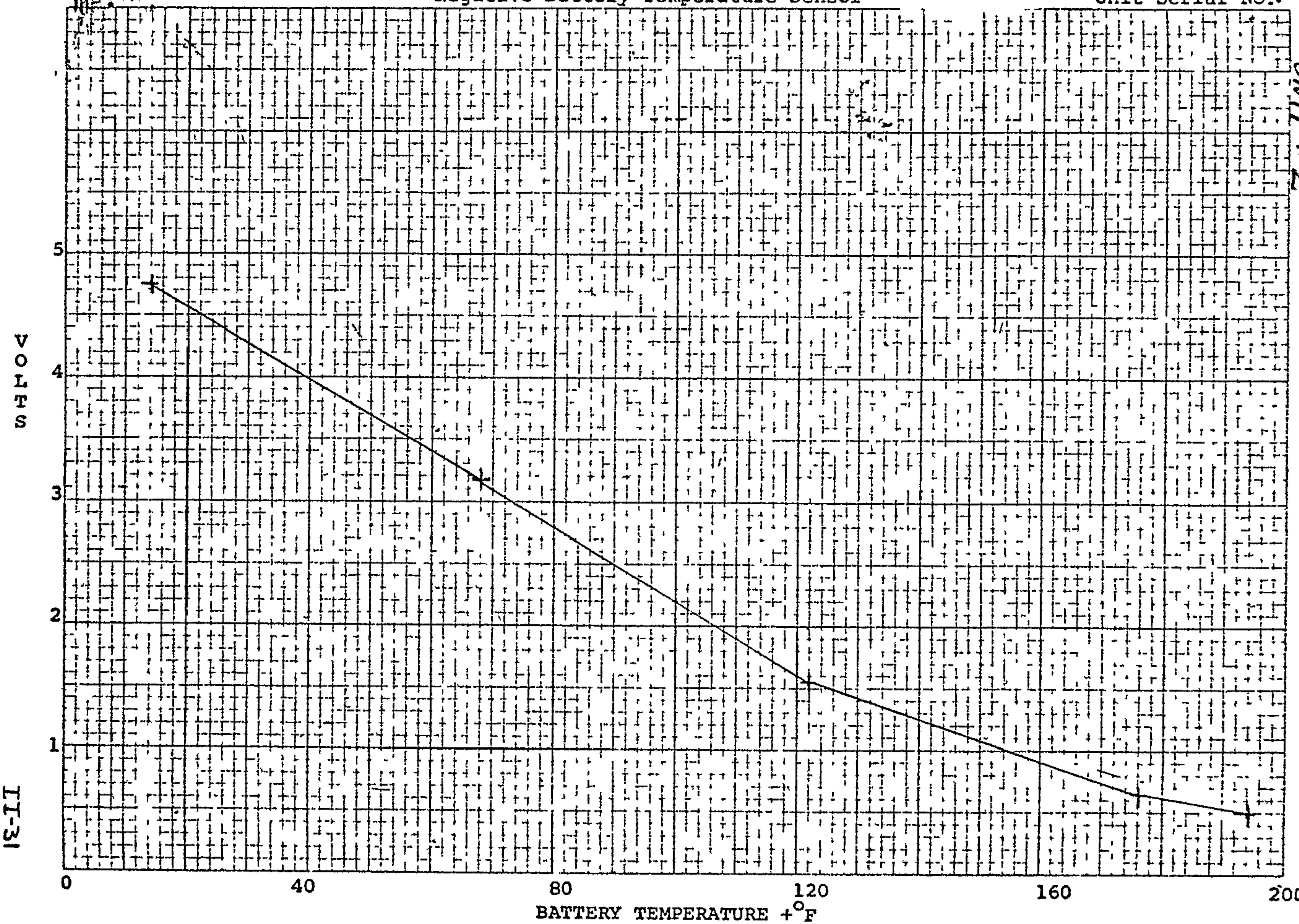
Positive Battery Temperature Sensor

26267
Unit Serial No.



26267

Figure 6 Negative Battery Temperature Sensor Unit Serial No.



UNIT #3, SERIAL No. 26269

EMPS252 TEST RECORD FORM

Date 2-21-69 Technician [illegible]

Test Procedure Para.	0°F	+70°F	+120°F	+160°F	Range
6.1.3.1		28.3			+27-34 Volts
6.1.3.2		✓			0-0.1 Amperes
6.1.3.3		8.2			6-10 Amperes
6.1.3.4		✓			0-0.1 Amperes
6.1.3.5		8.2			6-10 Amperes
6.1.3.6		8.2			6-10 Amperes
6.1.3.7		✓			0-0.1 Amperes
6.1.3.8		✓			≥5.0 Amperes
6.1.3.9		4.0			3-5 Amperes
6.1.3.10		37.7			+37.5-39.0 Volts
6.1.3.11		30.6			+29.5-31.5 Volts
6.1.3.12		✓			≤+0.5 Volts
6.1.3.13		30.0			+29-31 Volts
6.1.3.14		37.1			+36.0-38.0 Volts
6.1.3.15		41.23			+40-46 Volts
6.1.3.16		✓			0-0.1 Amperes
6.1.3.17		✓			≥5.0 Amperes
6.1.3.18		570			450-650 Ohms
6.1.3.19		660			500-750 Ohms
6.1.4.1		28.2			-27-34 Volts
6.1.4.2		✓			0-0.1 Amperes
6.1.4.3		7.9			6-10 Amperes
6.1.4.4		✓			0-0.1 Amperes
6.1.4.5		7.9			6-10 Amperes
6.1.4.6		7.9			6-10 Amperes
6.1.4.7		✓			0-0.1 Amperes
6.1.4.8		✓			≥5.0 Amperes
6.1.4.9		4.7			3-5 Amperes
6.1.4.10		38.1			-37.5-39.0 Volts

UNIT #3, SERIAL NO. 26269

EMPS252 TEST RECORD FORM cont'd.

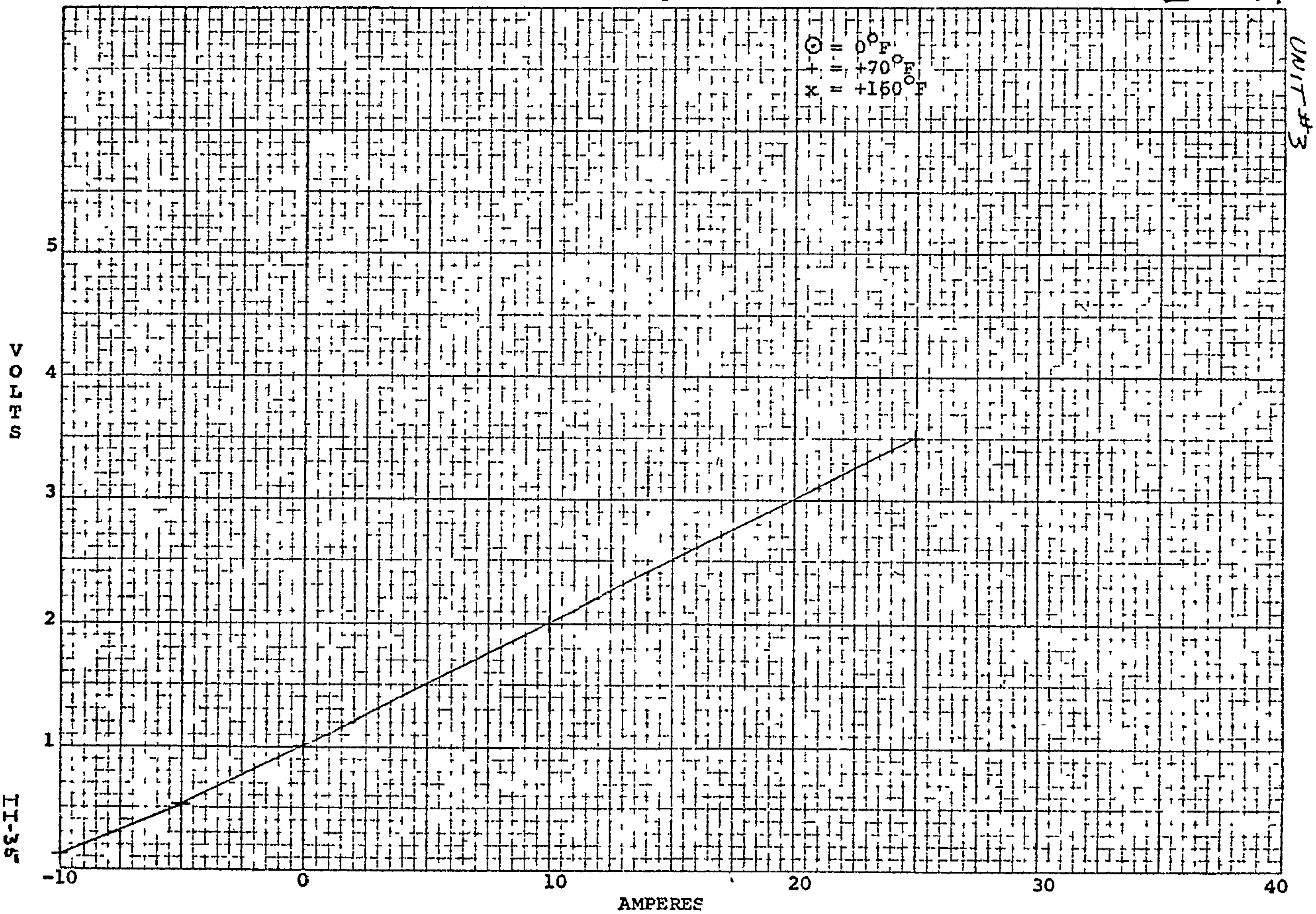
Test Procedure Para.	0^0F	$+70^oF$	$+120^oF$	$+160^oF$	Range
6.1.4.11		30.6			-29.5-31.5 Volts
6.1.4.12		✓			≤ -0.5 Volts
6.1.4.13		30.1			-29-31 Volts
6.1.4.14		36.9			-36.0-38.0 Volts
6.1.4.15		41.2			-40-46 Volts
6.1.4.16		✓			0-0.1 Amperes
6.1.4.17		✓			≥ 5.0 Amperes
6.1.4.18		520			450-650 Ohms
6.1.4.19		620			500-750 Ohms
6.1.5.2		13.8			12.1-14.7 Seconds
6.1.5.3		1.34			1.21-1.47 Seconds
6.1.5.4		✓			≤ 5%
6.1.5.6		14.5			12.1-14.7 Seconds
6.1.5.7		1.36			1.21-1.47 Seconds
6.1.5.8		6.2			≤ 5%
6.1.5.10	X	45.2	X	X	30-50 MS
6.1.5.11	X	5818	X	X	5400-5900 p.f.s.
6.1.5.12		4.99			+4.8-5.1 Volts
6.1.5.13		✓			0-0.1 Amperes
6.1.5.14		4.49			+4.35-4.65 Volts
6.1.6.2		14.4			12.1-14.7 Seconds
6.1.6.3		1.36			1.21-1.47 Seconds
6.1.6.4		5.5			≤ 5%
6.1.6.6		12.9			12.1-14.7 Seconds
6.1.6.7		1.33			1.21-1.47 Seconds
6.1.6.8		✓			≤ 5%
6.1.6.10	X	40.9	X	X	30-50MS
6.1.6.11	X	5770	X	X	5400-5900 p.f.s.
6.1.6.12		5.01			+4.8-5.1 Volts
6.1.6.13		✓			0-0.1 Amperes
6.1.6.14		4.48			+4.35-4.65 Volts

UNIT #3, SERIAL NO. 26269

EMPS252 TEST RECORD FORM cont'd.

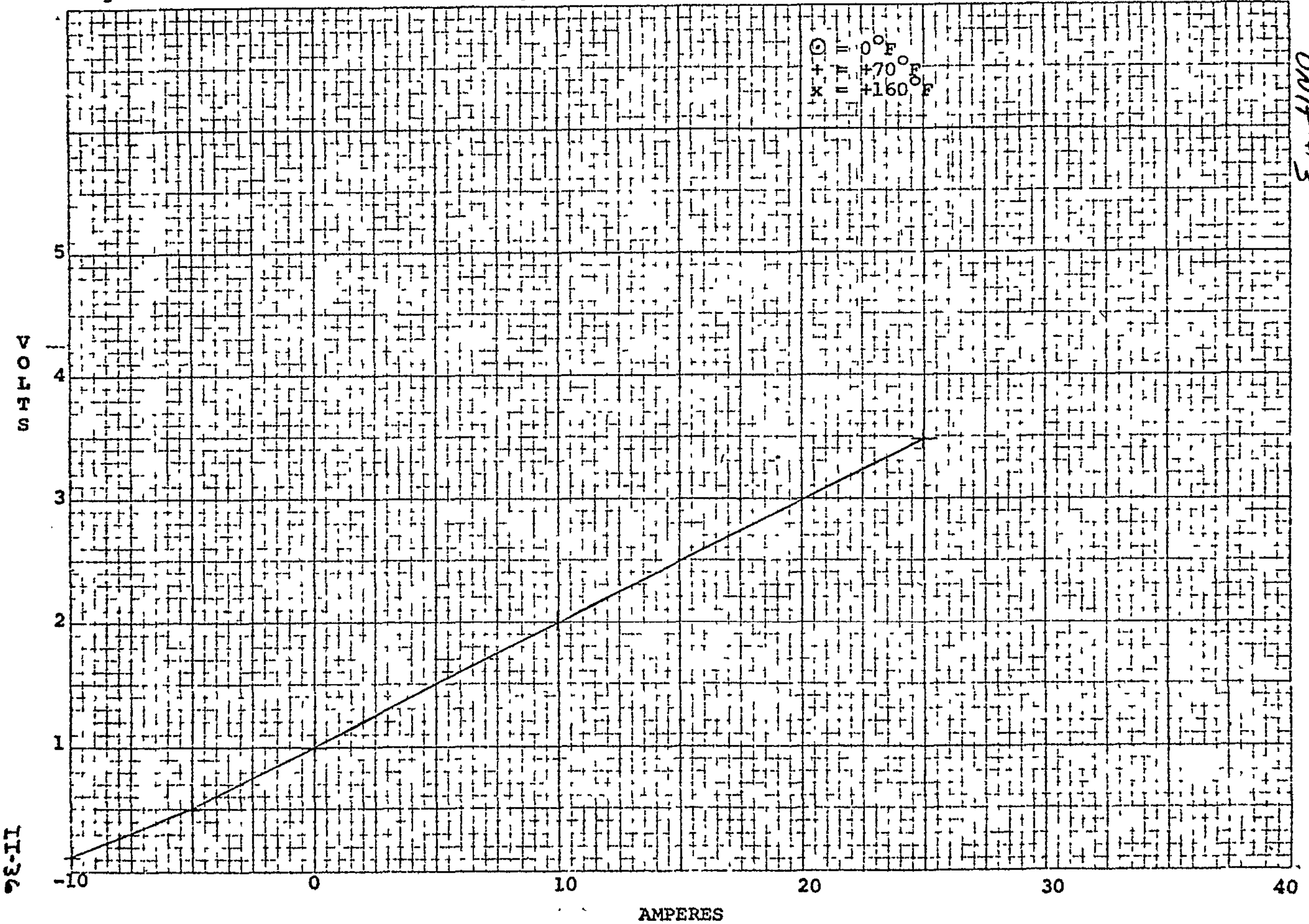
Test Procedure Para.	$0^{o}F$	$+70^{o}F$	$+120^{o}F$	$+160^{o}F$	Range
6.1.7.2		✓			Relay Closed
6.1.7.3		4.5			3-7 Seconds, Open
6.1.7.4		24.12			+23-25 Volts
6.1.7.5		✓			Relay Open
6.1.7.6		25.1			+24-26 Volts
6.1.8.2	X	7.5:1	X	X	7.3-7.7:1
6.1.8.3	X	7.5:1	X	X	7.3-7.7:1
6.1.8.5	X	7.5:1	X	X	7.3-7.7:1
6.1.8.6	X	7.5:1	X	X	7.3-7.7:1

Figure 1 Positive Battery Current Sensor Unit Serial No. 26269



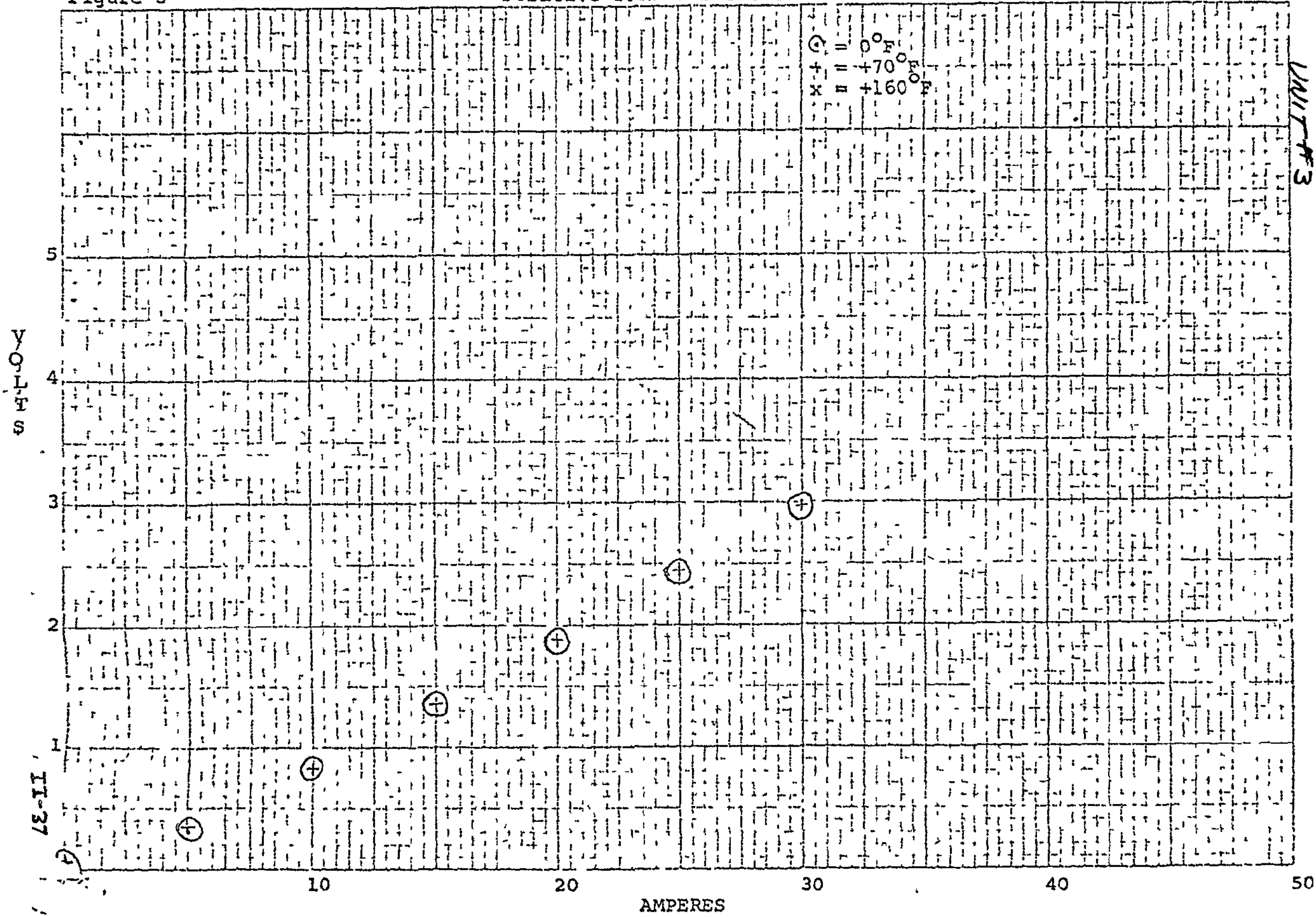
HI-35

Figure 2 Negative Battery Current Sensor Unit Serial No. 26269



26269

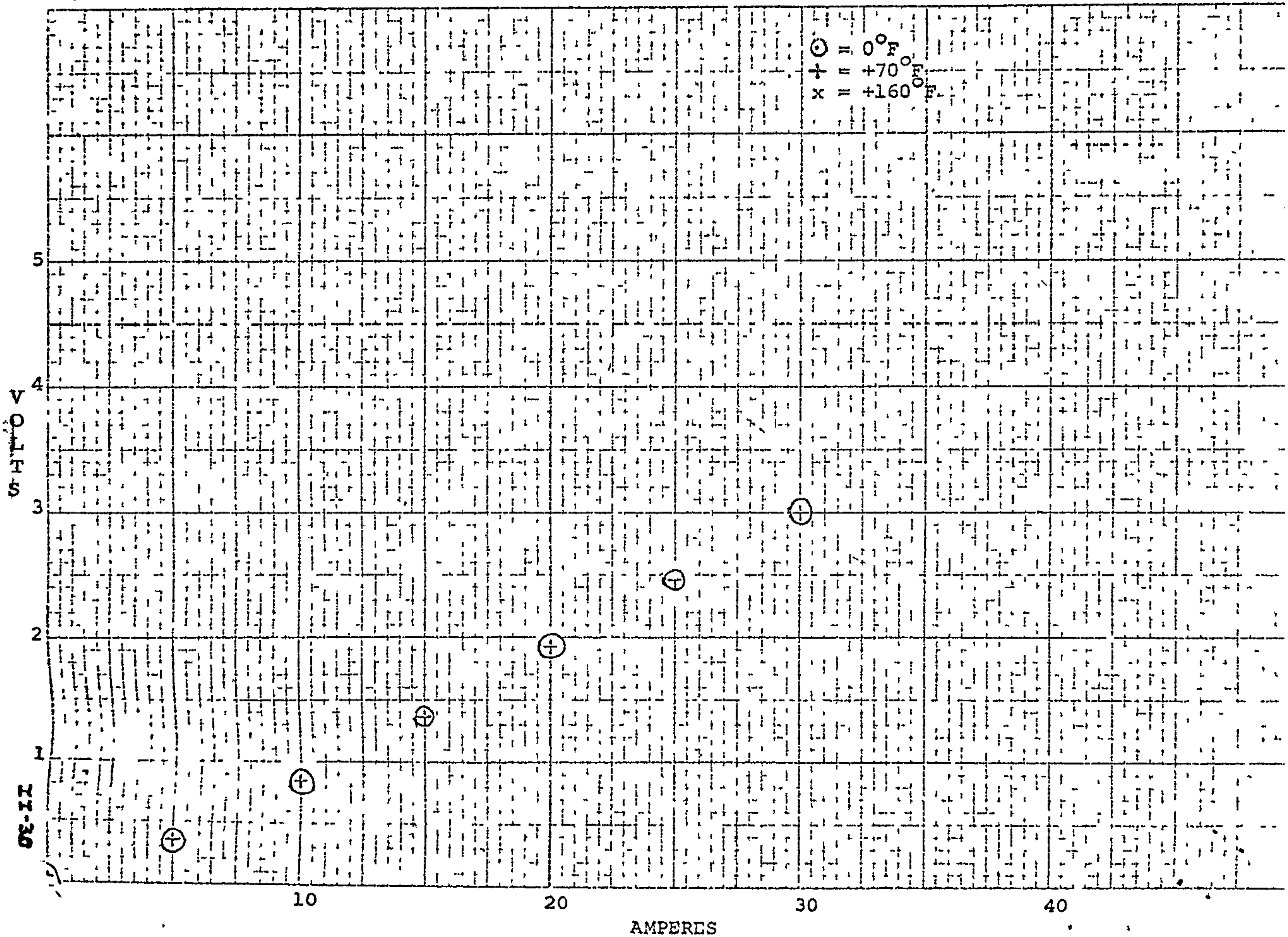
Figure 3 Positive T.R. Current Sensor Unit Serial No.



II-37

26269

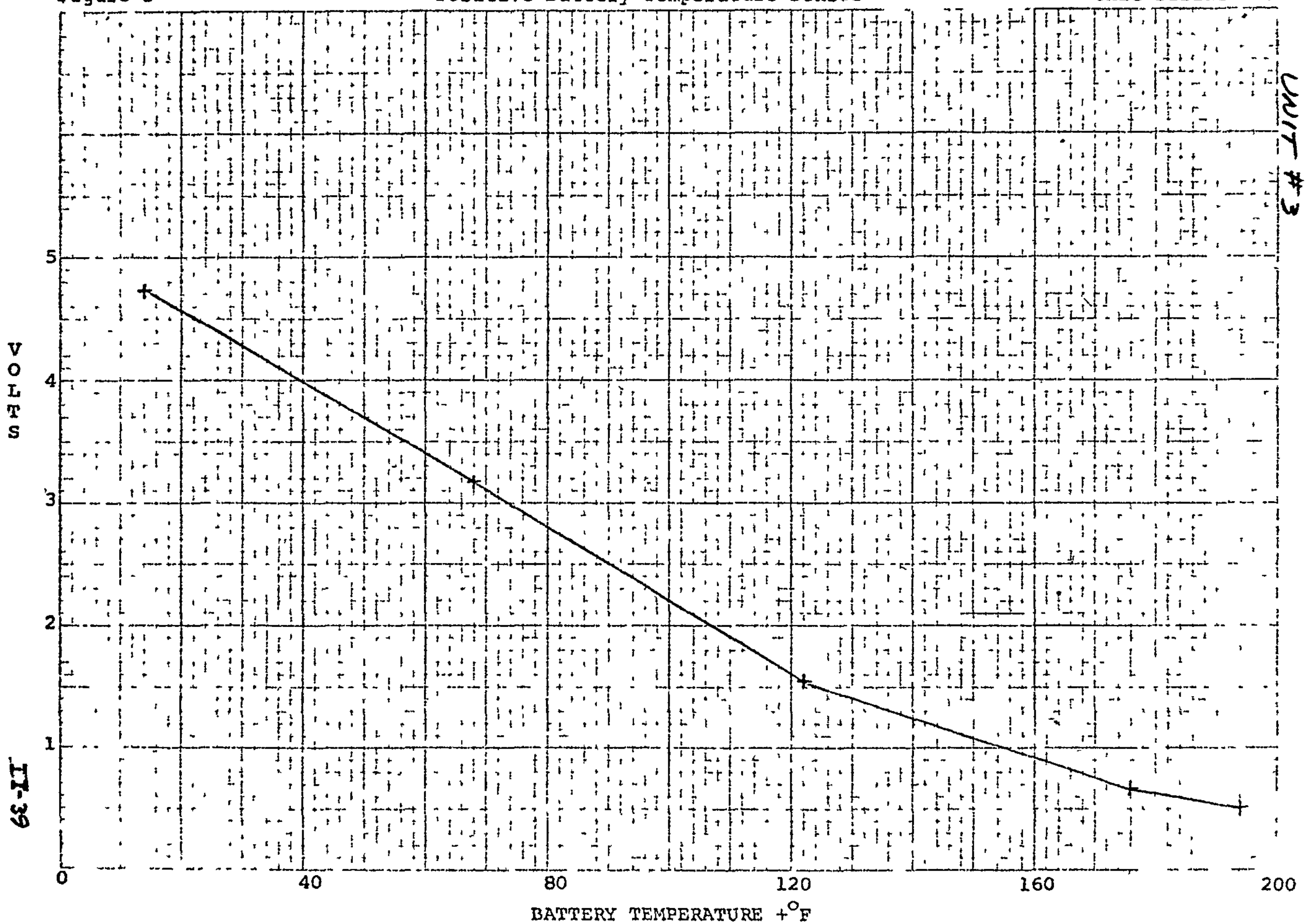
Figure 4 Negative T.R. Current Sensor Unit Serial No.



TO 2ORT DIETZGEN GRAPH PAPER 10 X 10 PER INCH EUGENE DIETZGEN CO MADE IN U.S.A.

26269

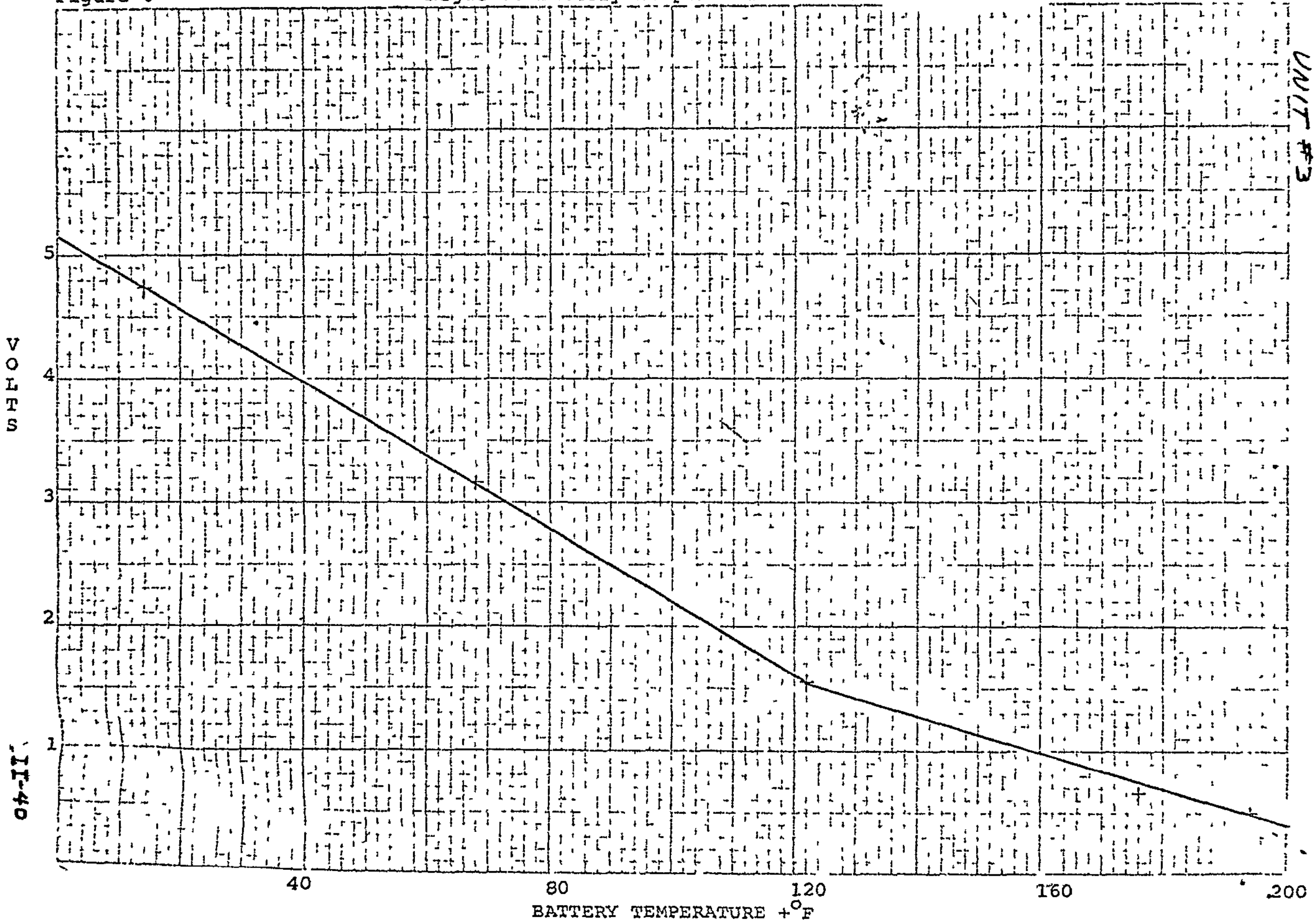
Figure 5 Positive Battery Temperature Sensor Unit Serial No.



63-II-39

26269

Figure 6 Negative Battery Temperature Sensor Unit Serial No



II-40

Unit No. 1

EMPS252 TEST RECORD FORM

SERIAL NO. 26270

Date 3-5-69 Technician [illegible]

Test Procedure Para.	0°F	+70°F	+120°F	+160°F	Range
6.1.3.1		28.5			+27-34 Volts
6.1.3.2		✓			0-0.1 Amperes
6.1.3.3		8.6			6-10 Amperes
6.1.3.4		✓			0-0.1 Amperes
6.1.3.5		8.6			6-10 Amperes
6.1.3.6		8.6			6-10 Amperes
6.1.3.7		✓			0-0.1 Amperes
6.1.3.8		5.5			≥5.0 Amperes
6.1.3.9		4.4			3-5 Amperes
6.1.3.10		38.1			+37.5-39.0 Volts
6.1.3.11		30.6			+29.5-31.5 Volts
6.1.3.12		✓			≤+0.5 Volts
6.1.3.13		29.9			+29-31 Volts
6.1.3.14		36.8			+36.0-38.0 Volts
6.1.3.15		41.3			+40-46 Volts
6.1.3.16		✓			0-0.1 Amperes
6.1.3.17		5.5			≥5.0 Amperes
6.1.3.18		540			450-650 Ohms
6.1.3.19		630			500-750 Ohms
6.1.4.1		28.0			-27-34 Volts
6.1.4.2		✓			0-0.1 Amperes
6.1.4.3		8.2			6-10 Amperes
6.1.4.4		✓			0-0.1 Amperes
6.1.4.5		8.2			6-10 Amperes
6.1.4.6		8.2			6-10 Amperes
6.1.4.7		✓			0-0.1 Amperes
6.1.4.8		5.6			≥5.0 Amperes
6.1.4.9		4.3			3-5 Amperes
6.1.4.10		38.2			-37.5-39.0 Volts

EMPS252 TEST RECORD FORM (cont'd)

SERIAL NO. 26270

Test Procedure Para.	0^{0}F	$+70^{0}$F	$+120^{0}$F	$+160^{0}$F	Range
6.1.4.11		30.5			-29.5-31.5 Volts
6.1.4.12		✓			≤ -0.5 Volts
6.1.4.13		30.1			-29-31 Volts
6.1.4.14		36.9			-36.0-38.0 Volts
6.1.4.15		41.4			-40-46 Volts
6.1.4.16		✓			0-0.1 Amperes
6.1.4.17		5.6			≥ 5.0 Amperes
6.1.4.18		530			450-650 Ohms
6.1.4.19		630			500-750 Ohms
6.1.5.2		13.4			12.1-14.7 Seconds
6.1.5.3		1.36			1.21-1.47 Seconds
6.1.5.4		✓			≃ 5%
6.1.5.6		14.1			12.1-14.7 Seconds
6.1.5.7		1.35			1.21-1.47 Seconds
6.1.5.8		✓			≃ 5%
6.1.5.10	X	40.7	X	X	30-50 MS
6.1.5.11	X	5,798	X	X	5400-5900 p.f.s.
6.1.5.12		5.00			+4.8-5.1 Volts
6.1.5.13		✓			0-0.1 Amperes
6.1.5.14		4.51			+4.35-4.65 Volts
6.1.6.2		13.4			12.1-14.7 Seconds
6.1.6.3		1.35			1.21-1.47 Seconds
6.1.6.4		✓			≃ 5%
6.1.6.6		13.5			12.1-14.7 Seconds
6.1.6.7		1.35			1.21-1.47 Seconds
6.1.6.8		✓			≃ 5%
6.1.6.10	X	40.6	X	X	30-50MS
6.1.6.11	X	5,785	X	X	5400-5900 p.f.s.
6.1.6.12		4.99			+4.8-5.1 Volts
6.1.6.13		✓			0-0.1 Amperes
6.1.6.14		4.49			+4.35-4.65 Volts

Vault 4

EMPS252 TEST RECORD FORM (cont'd).

SERIAL NO. 26270

Test Procedure Para.	0°F	+70°F	+120°F	+160°F	Range
6.1.7.2		✓			Relay Closed
6.1.7.3		5			3-7 Seconds, Open
6.1.7.4		23.98			+23-25 Volts
6.1.7.5		✓			Relay Open
6.1.7.6		24.95			+24-26 Volts
6.1.8.2	X	7.5:1	X	X	7.3-7.7:1
6.1.8.3	X	7.5:1	X	X	7.3-7.7:1
6.1.8.5	X	7.5:1	X	X	7.3-7.7:1
6.1.8.6	X	7.5:1	X	X	7.3-7.7:1

Figure 1 Positive Battery Current Sensor Unit Serial No. 26270

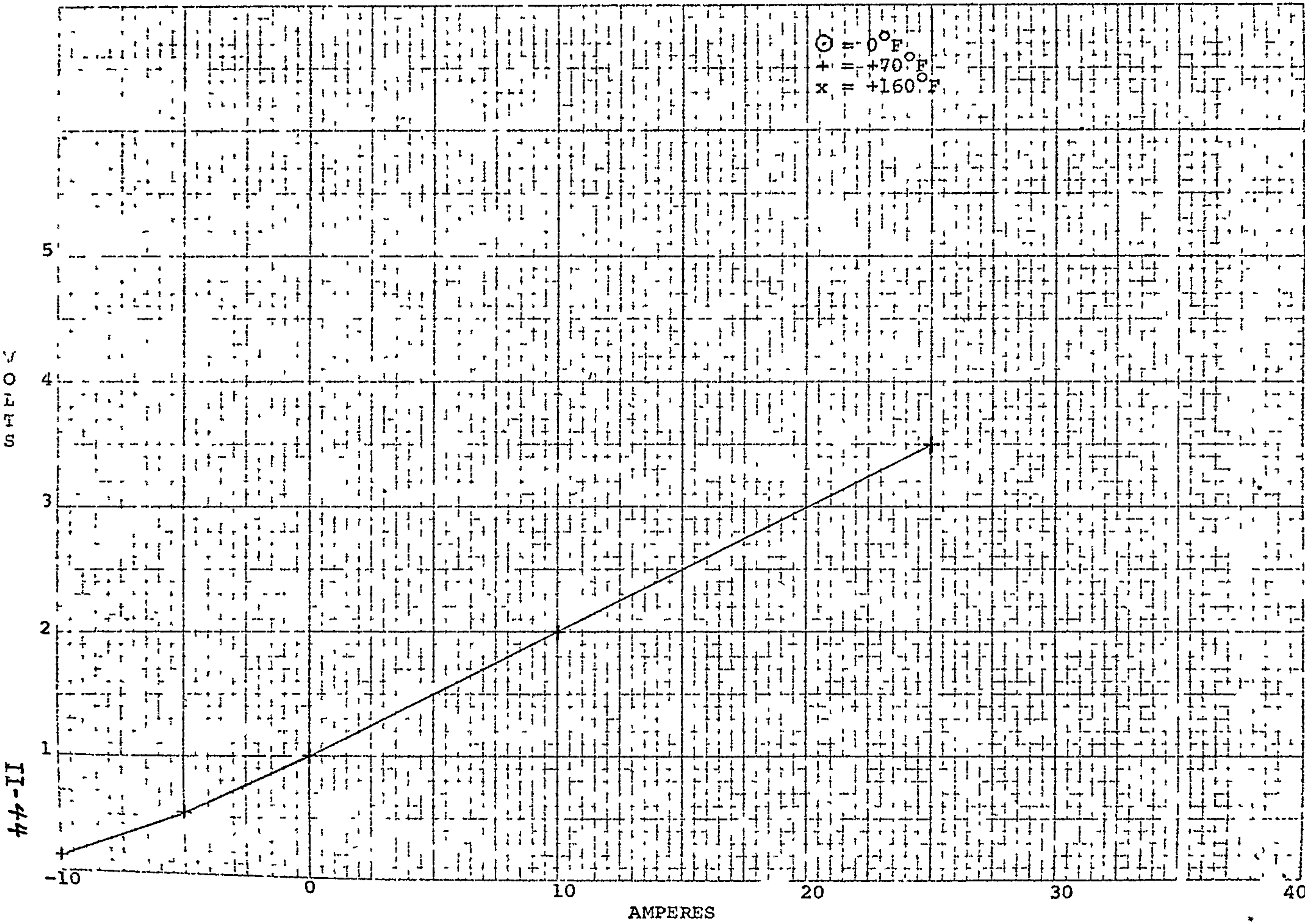


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Figure 2 Negative Battery Current Sensor Unit Serial No. 262.70.

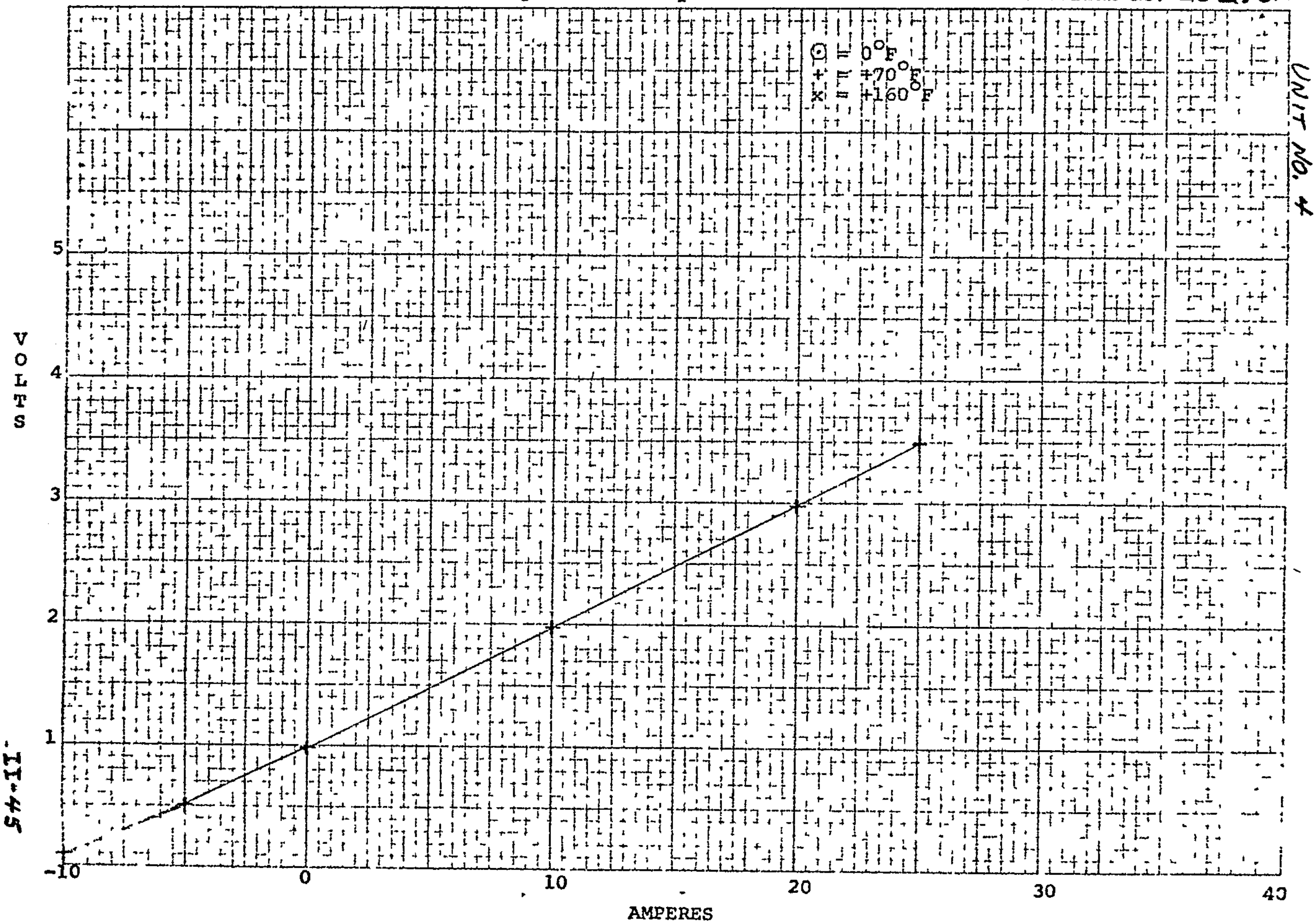

Figure 3 Positive T.R. Current Sensor Unit Serial No. 26270

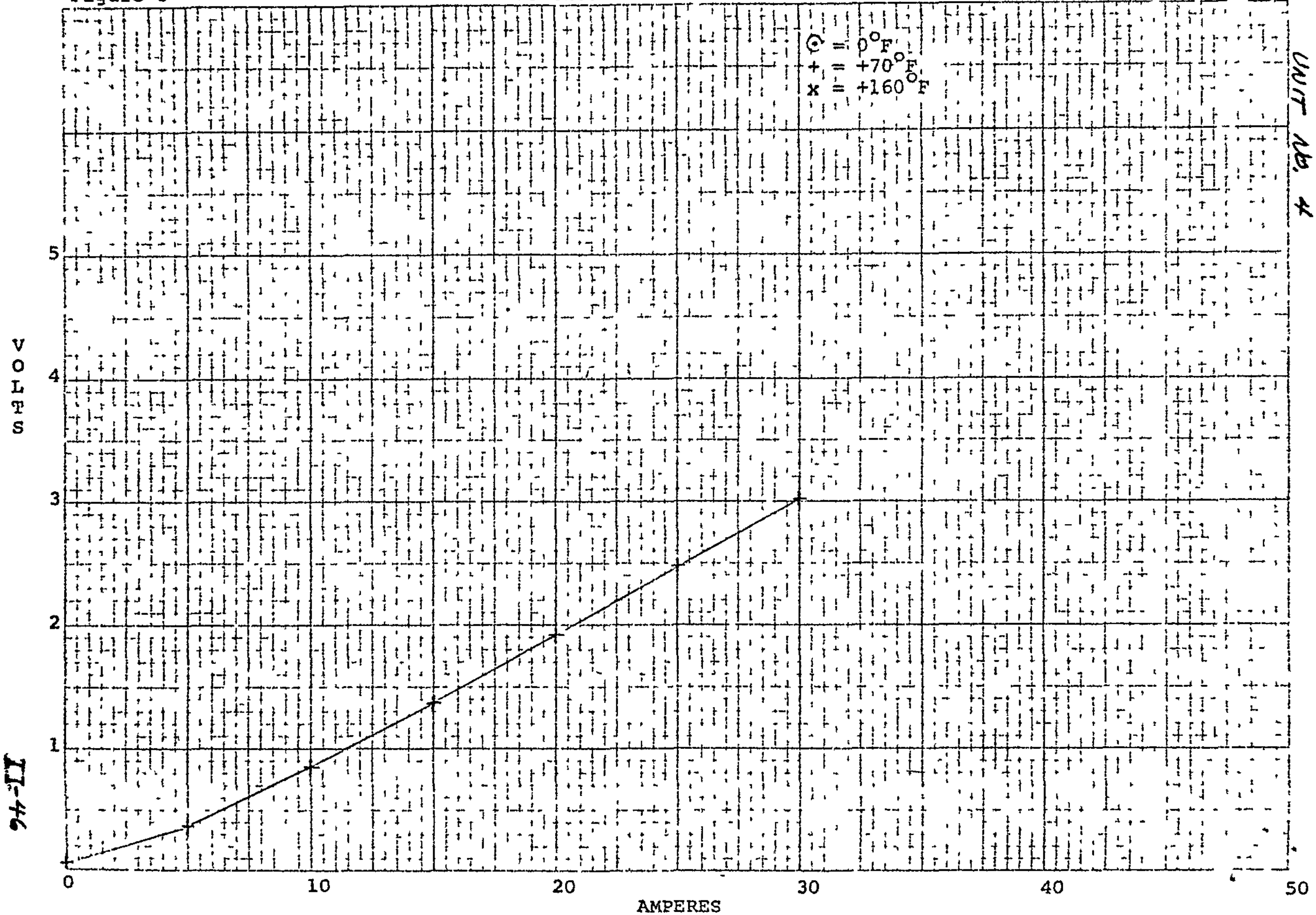

Figure 4 Negative T.R. Current Sensor Unit Serial No. 26270

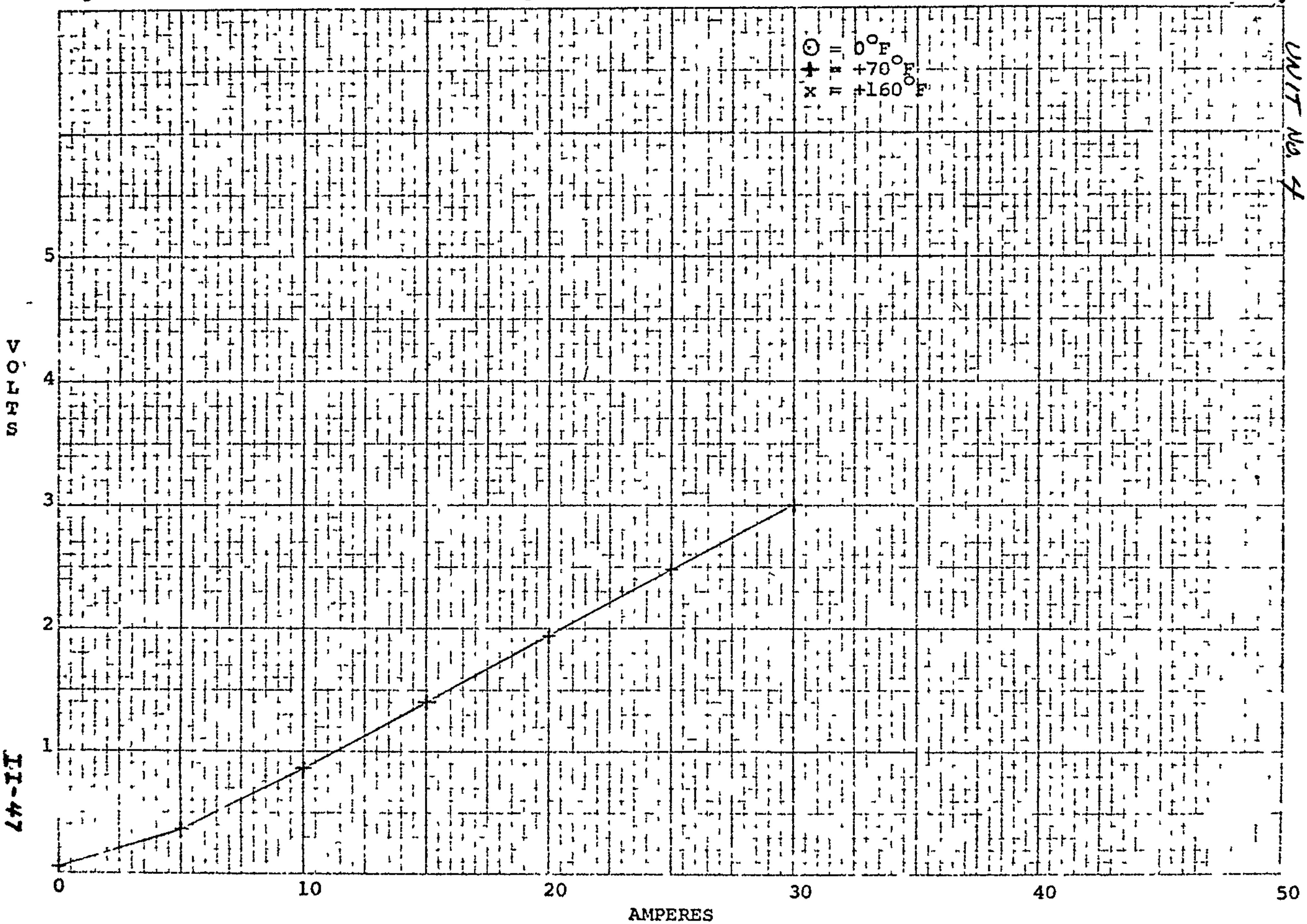

Figure 5 Positive Battery Temperature Sensor Unit Serial No. 26270

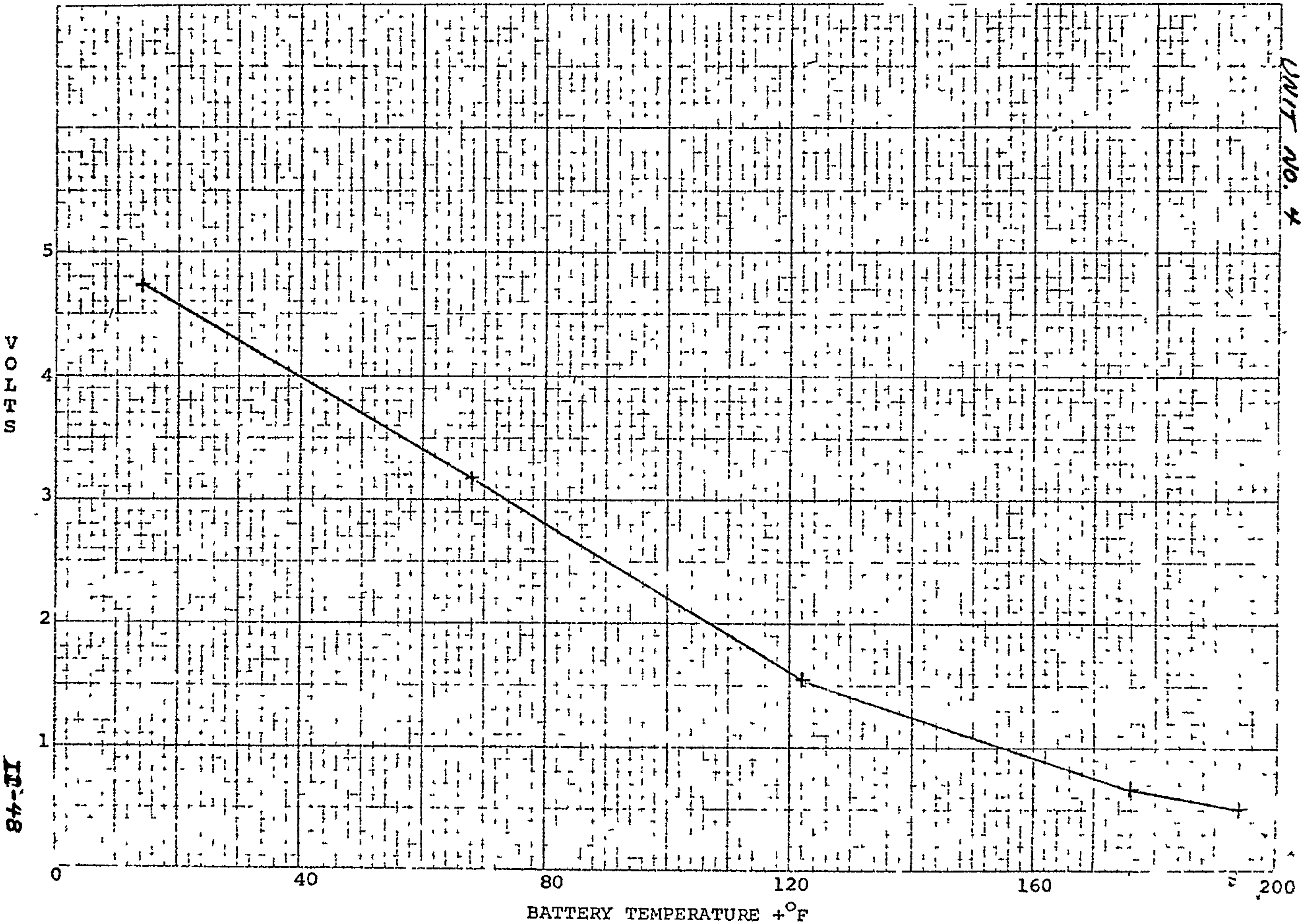

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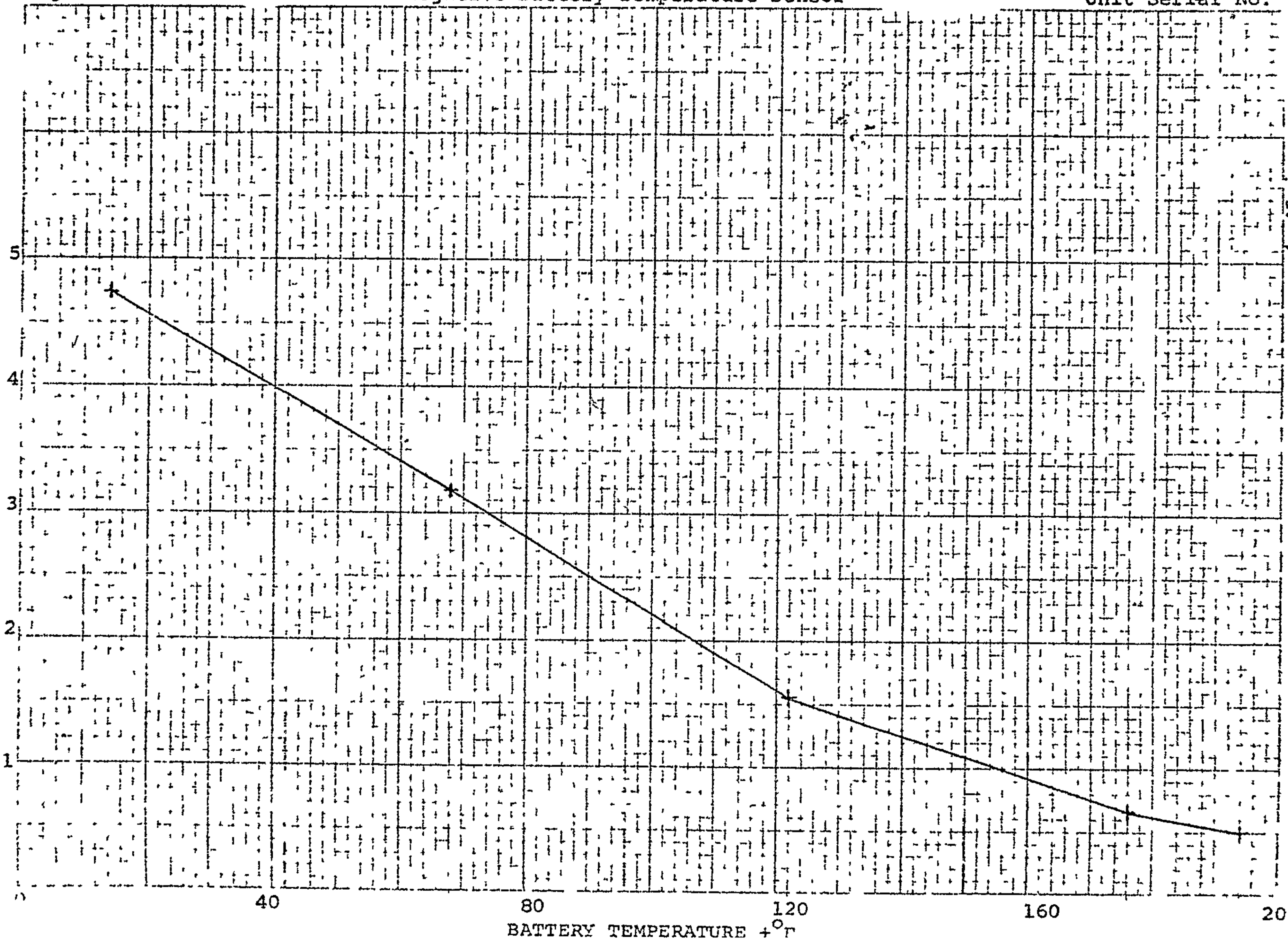
Figure 6 Negative Battery Temperature Sensor

26270
Unit Serial No.



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APPENDIX III

THERMAL TEST REPORT

THERMAL TEST REPORT
EMPS252 DC POWER SUPPLY

PURPOSE: To determine maximum operating temperatures of certain significant heat dissipating components within the EMPS252 DC Power Supply.

METHOD: Maximum temperatures were measured while operating the unit in a temperature controlled oven.

PROCEDURE: Thermocouples were installed on major heat dissipating components and on the baseplate mounting flange. The unit was installed with 1/4 - 28 bolts torqued to 85 - 90 inch pounds on a one inch thick, finned aluminum heat sink plate. A styrofoam insulating box enclosed the unit to minimize radiation and convection heat losses. The unit was placed in a Bemco temperature controlled oven and operated at full electrical load while controlling oven temperature to maintain the heat sink at 155°F. This was to simulate a coolant fluid temperature of 150°F and a thermal conductance of 300 BTU/ $HrFt^{2}$°F between the coolant and the coldplate surface. Thermocouple outputs were recorded on a Honeywell Brown Electronik millivolt recorder.

RESULTS: The maximum observed temperatures are tabulated in the attached Thermal Test Summary. All temperatures are well below their reliable operating limit with the exception of the power transformer, T302. A temperature in excess of 300°F was measured on the core of T302. While this is not detrimental to the core itself it could have an adverse effect on adjacent circuitry.

DISCUSSION: Visual examination of T302 revealed several areas of poor thermal contact. The varnish dip coating on the transformer prevents good contact to the aluminum mounting bracket. Irregularities in the core prevent firm contact between the core and the baseplate of the unit. Since these thermal deficiencies are somewhat inherent in the transformer construction, improvement in heat transfer must be accomplished by other means. A high thermal conductivity epoxy could be applied at the base of the transformer to fill the gap between core and unit baseplate and at the side of the transformer to provide an additional heat transfer path to the vertical mounting bracket that is brazed to the baseplate. In addition, the inside of the cover could be painted flat black to increase radiation heat losses from the transformer.

CONCLUSIONS: The DC Power Supply meets the specified requirements. With minor changes, the thermal design of the EMPS252 DC Power Supply will be even further improved.

EMPS252 DC POWER SUPPLY

THERMAL TEST SUMMARY

THERMOCOUPLE LOCATION	MAXIMUM OBSERVED TEMPERATURE °F
CR 323	173
CR 343	184
CR 346	185
CR 357	190
Q 1	170
Q 9	195
Q 15	207
Q 212	185
Q 305	170
Q 314	172
Q 321	169
R 323	174
R 340	169
T 302 MTG BRKT	234
T 302 CORE	325
BASEPLATE	157
COLDPLATE*	155

* ACTUAL COLDPLATE TEMPERATURE DURING TEST REACHED 169°F. TEMPERATURES LISTED HAVE BEEN ADJUSTED TO CORRESPOND WITH 155°F COLDPLATE SURFACE.

EMPS252 DC POWER SUPPLY

SUPPLEMENTARY THERMAL TEST

AN ADDITIONAL THERMAL TEST WAS PERFORMED TO DETERMINE THE AMOUNT OF IMPROVEMENT ACHIEVED BY ADDING THERMAL BOND 312 EPOXY FILLING BETWEEN POWER TRANSFORMER T 302 and THE UNIT CASE.

T 302 MTG BRKT TEMPERATURE CHANGED FROM 234 to 218°F

T 302 CORE TEMPERATURE CHANGED FROM 325 to 311°F

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