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TECHNICAL MEMORANDUM

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TITLE: SNAP-8 Electrical Protective System Module Design Review

ABSTRACT

This Technical Memorandum covers a major design review of the Electrical Protective System Module (EPSM) featuring three single-phase undervoltage/overvoltage-overspeed sensing circuits and the elimination of a separate overspeed circuit. This latest design also features a two-out-of-three logic network in the output of the EPSM to prevent false shutdown signals from being generated in case of a failure of any one of the three separate single-phase circuits.

Included are all the backup data presented at the Design Review Meeting, plus additional pertinent data received after the meeting, including data generated by action items of the meeting. All of this data now forms a part of the permanent design file of the EPSM.

KEY WORDS: Electrical Protective System Module, EPSM, Major Design Review, undervoltage/overvoltage-overspeed sensing, two-out-of-three logic

APPROVED:
DEPARTMENT HEAD S. L. Bradley

S. L. Bradley

NOTE: The information in this document is subject to revision as analysis progresses and additional data are acquired.

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DESIGN REVIEW MEETING RECORD

Part Name: Electrical Protective System Module **Part No.** 1264931-1

Type of Review: Major **Date:** 1-7-70

Participants:

1. B. L. Amstadter	5. E. S. Chalpin	9. A. H. Kreeger
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Conclusions:

The design of the Electrical Protective System Module (EPSM) was approved as presented, and approval was given to complete the drawings necessary to build an EPSM according to this design and to release these drawings for fabrication.

Recommended Action:

B. L. Amstadter requested that the failure modes and effects analysis be expanded to show what would happen if the relay coils should short. Failure Modes 19, 20, 21, and 22 have been added to describe the effects of this type failure.

Corrective Action Recommendation Issued ________ Date ________ Memo No.

4925:66:108

SCOPE OF REVIEW

This design review presents the latest conception of the Electrical Protective System Module (EPSM) comparing the similarities to and differences from the features and provisions of preceding designs. Included is the backup data and analyses upon which this design is based. A complete set of fabrication and assembly drawings has been prepared and is ready to be submitted for drafting check and release pending approval by the Design Review Board.

DISCUSSION

Electrical Generating System Emergency Shutdown Parameters

There are 8 conditions in PCS-G which if any one or more occurs can initiate a programmed emergency shutdown of the EGS. These 8 were selected after careful consideration of past experience in the various SNAP-8 system test loops, especially as applicable to the specific requirements and operating conditions peculiar to PCS-G. These 8 conditions are as follows:

1. Failure to achieve alternator voltage during TAA acceleration.

2. PNL flow decay to 10% of nominal during startup prior to time when TAA reaches rated speed.

3. Condenser pressure greater than 40 psia.

4. PNL flow decay to 50% of nominal any time after startup after TAA reaches rated speed and prior to TAA deceleration to 220 Hz on shutdown.

5. HRL flow decay to 10% of nominal any time after completion of startup sequence and prior to initiation of shutdown sequence.

6. An extended drop in alternator output voltage of 10% or more, an extended rise in alternator output voltage of 10% or more, or combinations thereof, any time after the alternator voltage exceeds 108 volts rms.

7. A reactor fast setback signal.

8. An external command.

The circuits for Condition 1 and 2 are operative only during startup and are de-activated after completion of the startup sequence. The circuit for Condition 3 is operative any time there is flow in the heat rejection or the mercury loops and is de-activated at all other times.

The circuits for Conditions 4, 5, and 6 are operative essentially when the TAA is at rated speed and are de-activated at all other times. The circuits for Conditions 7 and 8 are active any time any portion of the EGS is operating.

Conditions 1, 2, 4, and 5 signals are provided by transducers via instrumentation signal conditioning equipment. Condition 3 signal is provided by a pressure actuated switch whose contacts are connected into the emergency shutdown circuit. Condition 6 signal is the actual 3 phase line-to-neutral alternator voltage itself. Condition 7 signal is supplied by the nuclear reactor subcontractor. Condition 8 signal is initiated by an astronaut in space or by a test engineer on the ground and consists of a manually operated switch. This switch can be used to shut down the EGS at any time an unsafe condition is considered or known to exist whether or not a protective circuit for this condition is included in the system.

Conditions 2-6 utilize a 2 out of 3 voting logic to cause an emergency shutdown. This means that each of these conditions have 3 separate sensing circuits from which at least 2 outputs are required to cause an emergency shutdown. This logic scheme allows one of the 3 circuits to fail in such a manner as to give a false shutdown signal without actually causing an emergency shutdown.

The voltage conditions in the EGS as a result of the possible short-circuit faults that can occur are discussed in Appendix A. It is shown that at least two voltage sensors will be activated for any of the faults considered and therefore a 2 out of 3 system will start protective action.

Of the 8 emergency shutdown conditions described in the foregoing, only Condition 6 is involved with the EPSM. The EPSM as the name implies provides protection to the Alternator and to all the electrical and electromechanical components receiving electrical power from the Alternator. The protection provided is against single or multiple phase short circuits or overloads, single or multiple phase open circuits, badly unbalanced 3 phase loads and load power factors, and excessive TAA rotational speed. The EPSM continuously monitors each phase of the 3 phase Alternator output voltage with no intermediate transducers or signal conditioners required. Since it must be ready to operate for the full rated life of the EGS at any time after the Alternator line-to-neutral voltage exceeds 108 volts rms, every effort has been made to use the most reliable components available and use them in a foolproof and reliable circuit.

EPSM Design Objectives

The addition to the NASA specifications of the requirements that the EGS be capable of several restarts and shutdowns, and that the design of the EGS be such that repair or replacement of most EGS components could be made while in flight by virtue of the mission being a manned rather than unmanned mission, has resulted in a number of changes in the design philosophy and design objectives of many EGS components and in the EGS itself.

EPSM Design Objectives for Unmanned Mission

For the original single start unmanned mission application, the design objectives for the various EGS components were to make them extremely rugged and reliable and capable of meeting or exceeding all performance requirements and design life when subjected to the various extremes of the rigorous SNAP-8 environment. On such a mission the EGS was to be started and kept running and producing electrical power for as long as possible even though to continue running might result in damage or destruction of the EGS or one or more of its components. Even if the EGS output power were severely reduced because of a failure or degradation of some internal component, some power output would be better than no power output. Thus, if the various EGS components had sufficient operating margin, a failure or degradation of one component could in some cases be offset by working another component or group of components somewhat beyond their rated capacity. Even though the life of the overloaded component or components might be severely decreased, the fact that the operation of the EGS might be prolonged was considered to be of even greater importance. For this mission loss of output power because of destruction of the EGS would be no worse than shutting down the EGS to prevent its being further damaged.

For this original application the EPSM had to sense merely that a fault condition existed. If the fault were to occur in the Vehicle Load, the EPSM would protect the EGS and keep it running. Besides the action of the EPSM to periodically remove the voltage applied to the Vehicle Load, by opening the VLB, any other protection for the Vehicle Load would have to come through the action of each load's individual protective device. If a fault were to occur in the EGS, the only hope for saving the EGS would be for the fault to clear itself spontaneously, or for the performance degradation to be small enough to be compensated for by other EGS components. To shut down the EGS would in effect be no different from the EGS running until it destroyed itself or one of its vital components. Therefore, if a fault were to occur in the EGS, the only action the EPSM would take would be to open the VLB to remove the effect of the Vehicle Load from the EGS.

EPSM Design Objectives for Manned Mission

The multiple start repairable components application of the EGS allows for the possibility of some components degrading or failing completely before the design life of the EGS is reached. While each of the EGS components would still be designed to be as reliable and as rugged as possible, the components and the EGS would also be designed so that repair or replacement could be made in flight by an astronaut. For this application, the EGS would be started and kept running and producing electrical power for as long as possible or until an electrical fault should occur.

For this application the EPSM had to distinguish between two fault conditions:

1. A fault in the Vehicle Load.

2. A fault within the EGS.

For the first condition, the EPSM would act to protect the EGS and keep it running. The protection for the Vehicle Load would be as before - periodically removing the voltage applied to the load and by action of each load's individual protective device. For the second condition, the EPSM has an added function. It must recognize the difference between this kind of fault and a fault in the Vehicle Load. Then as quickly as possible after an EGS fault is recognized, the EPSM must act to shut down the EGS to minimize any further damage to the part or parts responsible for the fault and to protect the other EGS parts from becoming damaged because of these failures. Once the EPSM action has opened the VLB or shut down the EGS, the astronaut can then safely repair or replace the defective component or components as required.

The EPSM has the primary function of protecting the TAA from damage caused by:

1. Short circuits anywhere in the electrical power distribution system.

2. Badly unbalanced Vehicle Loads and/or load power factors.

3. Excessively high TAA rotational speeds.

The EPSM has the secondary function of minimizing possible damage to other EGS components by shutting down the EGS as quickly as possible should any of the above listed malfunction conditions be detected within the EGS.

Since the EPSM is energized whenever the TAA is operating and must perform its intended functions whenever required during the rated life of the EGS, it must be constructed to be as rugged and as reliable as possible. Therefore, wherever practical the types of components, materials, and the design techniques which have proved successful in the Speed Controller, Voltage Regulator, and associated other electrical components shall be used in the design and fabrication of the EPSM.

EPSM Design Features

During the materials and components selection portion of the SNAP-8 Speed Controller development, the ability to resist damage by nuclear radiation and high temperature was the basic capability a material or component had to have before it could be further considered. Fortunately, resistance to nuclear radiation and high temperature are often found together in materials. When radiation and temperature resistant materials are found and used in a component, resistance to the other SNAP-8 environmental conditions can be achieved by proper packaging.

The life and reliability of a part can be improved if the radiation dose and temperature rise are kept as far from the tolerance limits as possible. For all of the materials used in the SNAP-8 Electrical Components the radiation threshold dose is two or more orders of magnitude above the rated life dose (see OP367736). Therefore, life and reliability of these parts can not be significantly improved by additional local radiation shielding. However, considerable improvement in life and reliability can be achieved for any given part by limiting its maximum hot spot temperature through careful consideration of the amount of heat generated within that part compared to its ability to reject that heat.

Generally speaking, the greater the surface area of a part the better its ability to dissipate heat. This is true for any of the three principle ways by which heat may be removed from a part - radiation, convection, and conduction. For the design of all SNAP-8 Electrical Controls including EPSM, all heat is considered to be transferred only by conduction to an actively cooled heat sink, none by radiation or convection. Therefore, as much surface area as possible of each individual part is placed in direct contact with the EPSM. Actually, some heat will be transferred by radiation and, for ground testing in particular, some by convection. However, by designing a part to have a safe operating temperature with heat transfer only by conduction, the actual operating temperature of the part will be less than design resulting in an improved reliability and confidence factor.

The primary consideration for locating each electrical part within the EPSM was the amount of power dissipated by that part in relation to its maximum temperature rating. All other things being equal, the higher power dissipating parts are located closer to the housing base plate than the lower power dissipating parts. In some cases, ease of wiring and assembly resulted in some deviation from this approach. Finally, obtaining a good packing factor of parts within the housing and keeping the center of gravity as low as possible resulted in some additional deviations.

It should be noted at this point that there are no critical thermal problems known to be present in the EPSM. (See Appendix B) The maximum power dissipated within the entire assembly is about 20 watts and the maximum power dissipated within any one part is 5.3 watts worst case. With a base plate area of about 234 square inches, the heat transfer rate is less than 0.1 watts per square inch. Furthermore, the EPSM housing is cast from aluminum which eliminates possible thermal interface barriers where the walls of the housing join the base plate. Also, the normal draft required on walls by standard casting practice gives a continuously increasing wall cross sectional area as the base plate is approached. This factor acts to reduce the resistance to heat flow and hence the temperature differential between any given point on the wall and the base plate.

Another technique which was used to improve the reliability of the SNAP-8 Speed Controller, and has also been applied to the EPSM, is that of derating. In the EPSM, in all cases except the relay actuating coils, the power dissipated in a part is one-third or less of the rated power dissipation of the part. For the rectifier and resistors the derating is applied to the power rating of each part when mounted by its leads and cooled by convection rather than the power rating when mounted on an aluminum heat sink plate as they are mounted in the EPSM.

Theoretically, the rectifiers and relay contacts are the parts most prone to failure although no failures have been experienced in the rectifiers through all the Speed Controller testing and the relays are made to one of the most stringent military relay specifications, MIL-R-6106, to which relays may be purchased. In each place where one rectifier is required four rectifiers connected in a series parallel redundant configuration (rectifier quad) are used. (See Figure 2) Each rectifier in a quad has sufficient capacity to operate in the circuit alone. Therefore, besides the benefit of the redundant connection which allows at least one rectifier failure with no effect on operation, the quad configuration also effectively derates each rectifier by an additional 0.5 for both power dissipation and reverse voltage.

To improve the reliability of the relay contacts, parallel redundant connection of normally open contacts is used. In addition, a 2 out of 3 relay contact logic network is employed which requires at least two sensing circuits to operate to produce a malfunction signal. (See Figure 2)

Finally, to provide the required 0.5 second time delay before a malfunction signal can result in an automatic shutdown, the constant volt-second integral saturation characteristic of a saturating reactor is used as the time reference. The use of this type of device results in an extremely simple timing circuit using very rugged and reliable parts. In Appendix C is shown the design equations and test results of an experimental timing reactor.

Functions of the Electrical Protective System Module

The functions to be performed by the EPSM for the multiple start repairable components EGS are as follows:

1. Open the Vehicle Load Breaker (VLB) (if it should be closed) prior to mercury injection.

2. Sense line-to-neutral voltage of each phase of the alternator voltage, and once two or more of these voltages reach a predetermined minimum value, provide a signal to enable the Programmer to close the VLB at the proper time during the startup sequence.

3. Also, after the alternator voltages reach this minimum value, provide a signal should two or more phases of the voltage vary below 108 volts or above 132 volts. This signal shall immediately do two things.

a. It shall open the VLB.

b. It shall start a 0.5 second timer.

With the VLB open, if the fault is on the load side of the VLB, the alternator voltages will return to normal in something less than 0.5 seconds. If this occurs the EPSM will stop the timer, reset it, and reclose the VLB. If the fault still exists, the alternator voltages will again vary outside the normal band, and the EPSM will re-open the VLB and restart the timer. This cycling of the VLB and timer will continue until one of the following events occur:

1. The load fault corrects itself by burning open or by tripping its own individual protective device. If the fault corrects itself, the alternator voltage will return to normal, the VLB will reclose and remain closed, and the 0.5 second timer will be reset.

2. The 0.5 second timer times out sending a signal to the Programmer to start an automatic shutdown of the EGS.

3. An external command signal is sent to hold the VLB open and stop the cycling. With the VLB held open, the alternator voltage will return to normal and the 0.5 second timer will be reset.

If the fault is in the EGS, the alternator voltages will not return to normal when the VLB is opened, the 0.5 second timer will time out and start an automatic shutdown of the EGS.

With the VLB open or the EGS shut down, an astronaut can safely proceed to locate the cause of the fault and repair, replace, or disconnect it. When the cause is corrected, the astronaut can then reclose the VLB or restart the EGS as applicable.

EPSM Operation

The EPSM consists of 3 identical circuits, one complete circuit monitoring the voltage in each of the 3 phases of the alternator output voltage. (See Figure 2) Each circuit consists of a single phase bi-stable magnetic amplifier whose output energizes two 4-pole double throw relays, a preset dual-voltage sensing circuit, a 0.5 second timing circuit, and a portion of the relay logic output circuitry. Each circuit monitors the line-to-neutral voltage of one phase of the alternator 3 phase output voltage. Two JAN high reliability type 10 watt silicon zener diodes in each circuit are the basic reference standards, one for the under-voltage limit and the second for the over-voltage limit.

Still referring to the electrical schematic Figure 2, Phase A to neutral of the alternator voltage is full-wave rectified by CR13 through CR20 and filtered by L1 and applied across the control winding circuits N2, N3, and N4 of magnetic amplifier AR1. Control winding N2 with zener diode VR2 controls the undervoltage trip point. Control winding N3 with zener diode VR3 controls the overvoltage trip point. Control winding N4 provides the necessary bias to keep the magnetic amplifier off during startup when the alternator voltage is building up from zero. Control winding N5 provides the positive feedback necessary to make the magnetic amplifier bi-stable. (See Appendix D for the magnetic amplifier design and control characteristics.) Control winding N6 with R6 provides some adjustable rate feedback to slow down the switching of the magnetic amplifier from one reference state to its alternate reference state. This delay is included to prevent the Vehicle Load Breaker (VLB) from being switched because of transient dips and rises which occur normally with step load changes.

The Phase A to neutral voltage of the Alternator is also applied to the gate windings N1A and N1B of magnetic amplifier AR1. The magnetic amplifier output is full-wave rectified by CR1 through CR8 and applied to the actuating coils of relays K1L1 and K1L2 and the positive feedback winding N5. Rectifiers CR9 through CR12 are called free wheeling rectifiers and cancel the inductive effect of the relay coils. When the net negative ampere-turns of control windings N2, N3, and N4 are reduced enough to start to turn the magnetic amplifier on, the magnetic amplifier output applied to N5 winding further decreases the net negative ampere-turns in the core which in turn increases the magnetic amplifier output further decreasing the net negative ampere-turns thereby driving the magnetic amplifier to full on. Conversely, when the net ampere-turns of N2, N3, and N4 become negative enough to reduce the magnetic amplifier output, the reduced voltage across N5 reduces the positive ampere-turns produced by N5. The effect of this is to increase the net negative ampere-turns in the core further reducing the magnetic amplifier output. This in turn further reduces the positive ampere-turns produced by N5. This action continues until the magnetic amplifier is driven to full off.

When K1L1 and K1L2 relays are energized, K1L1E2 and K1L2E2 close, K1L1E3 opens, and K1L1E4 closes. K1L1E2 and K1L2E2 closing energizes K2 which locks itself on through contacts K2E2 and K2E4. When K2 is energized the under-voltage/overvoltage circuit in Phase A is armed and ready to perform as designed. K1L1E4 closing energizes the reset winding of the timing reactor L2. K1L1E3 opening removes power from the timing winding of L2. With K1L1 and K1L2 energized, K1L1E6 and K1L2E6 contacts close and K1L1E7 and K1L2E7 contacts open. These contacts are in a 2 out of 3 logic circuit which in conjunction with the equivalent contacts in the Phase B and Phase C circuits control the automatic opening and closing of the VLB.

Once K2 is energized, any Phase A to neutral voltage excursions below 108 volts rms or above 132 volts rms will cause K1L1 and K1L2 relays to become de-energized. This will cause K1L1E2 and K1L2E2 to open. However, since K2 is energized and K2E2 and K2E4 are closed, this will have no effect. However, K1L1E3 will close and K1L1E4 will open. K1L1E3 closing will energize the timing winding of L2. K1L1E4 opening will de-energize the reset winding of L2.

If K1L1 and K1L2 relays are not re-energized before L2 timing reactor saturates, K3 will energize opening K3E1 and K3E3 contacts in the 2 out of 3 logic network in the automatic shutdown circuit. The timing reactor L2 will saturate in 0.5 seconds. An equivalent action in either the Phase B circuit or the Phase C circuit is all that is required to start an automatic shutdown of the EGS. The 0.5 second delay provided by the timing reactor L2 is included to allow time for the alternator voltage to recover to within the design range after the VLB is opened. This time was selected on the basis of transient test data obtained when adding and removing 35 kw step vehicle loads on the TAA during PCS-1 testing.

Overspeed Protection Circuit Limitations

The previous overspeed circuit (Figure 3) used in PCS-1 sensed the frequency of the alternator voltage with a series resonant L/C circuit. The resonant increase in current flowing through a trimming potentiometer in series with the resonant circuit produced a voltage across the potentiometer a portion of which was applied to the gate of an SCR. The value of this voltage could be adjusted to that required to trigger the SCR. The firing of the SCR energized a relay whose contact's operation produced the overspeed shutdown signal.

There were several disadvantages to this circuit especially if applied to a flight rated system. The primary disadvantage was the use of an SCR. In the SNAP-8 nuclear testing program, OP367736, performed at the Georgia Nuclear Laboratories of Lockheed-Georgia Company, the test data showed that the type 2N1778 SCR's which were evaluated had a fast neutron damage threshold at about 5×10^{11} nvt. This is about 5 times higher than the specified dose and 0.05 times lower than the next most sensitive component, the silicon rectifier. The rectifier threshold occurred at about 1×10^{13} nvt. There was considerable spread among the SCR's with one shorting before the end of the testing. Another disadvantage of SCR's is that they are extremely sensitive and can be triggered "on" by stray electrical noise even when precautions are taken to prevent this occurrence. The Electrical Components Section has experienced several instances of false triggering of SCR's by electrical noise in PCS-1 and in the laboratory even with noise protection techniques employed.

Another disadvantage of this circuit is that it is dependent upon the alternator voltage. If the alternator voltage were to be lost for whatever reason, the frequency information would also be lost. This could be a serious problem especially during EGS startup.

There has been included in the present design of the TAA a small permanent-magnet tachometer pickup. Unfortunately, the output of this pickup is very narrow positive and negative pulses having very little power and being very rich in harmonics. (See Figure 4) To use this signal some form of signal conditioner would be required. This then would require a signal conditioner having the same high reliability as the other electrical components. This is not available and would have to be developed.

Elimination of a Separate Overspeed Protection Circuit

A separate overspeed protection circuit as described in paragraph 2. of Appendix E was eliminated from the EPSM for the following reasons:

1. The output signal from the tachometer pickup in the TAA is inadequate to drive the standard frequency sensitive circuits which have already been developed for the SNAP-8 electrical controls without some form of signal conditioning.

2. The undervoltage/overvoltage sensing circuit can provide overspeed sensing because of the constant volts per cycle controlling characteristics of the SNAP-8 voltage regulator.

3. Because of the capability described in 2. above, the only need for a separate overspeed circuit is during startup to protect the TAA from overspeeding if for some reason the alternator should not produce an output voltage. Without an output voltage, no electrical load can be placed upon the alternator.

4. It was computed from energy balance conditions of the boiler and the TAA that even under the reduced power capability of the EGS during startup if the EGS were to be shutdown the instant an overspeed signal was received, there would still be sufficient energy in the hot gas to continue to increase the TAA speed to runaway speed where the TAA could be damaged. Therefore, this circuit could not really protect the TAA because it was impossible for it to act fast enough. (See Appendix F)

EPSM Overspeed Protection Provided

Since the SNAP-8 Voltage Regulator is required to regulate the Alternator voltage at a constant volts per cycle ratio, any change in TAA speed brings with it a proportional change in alternator voltage. Therefore, an increase in speed greater than 10% above rated will be accompanied by a proportional increase in voltage. If the Alternator voltage exceeds 132 volts rms for any reason, the overvoltage circuit of the EPSM will start the protective action provided by this system. As long as overspeed protective action occurring at a speed equivalent to 132 volts is compatible with system requirements, and as long as the same protective action is compatible with either condition, the EPSM is capable of providing overspeed as well as overvoltage protection.

The question naturally arises: if being dependent upon Alternator voltage was a disadvantage of the PCS-1 overspeed circuit, why is it not a disadvantage for this PCS-G circuit. The answer is that for TAA startup it still is a disadvantage. If during startup no voltage is developed by the Alternator, neither circuit can provide any overspeed protective action. To cover this possible malfunction condition is precisely why the Condition 1 emergency shutdown parameter was included in the list of shutdown parameters. The Condition 1 circuit monitors the TAA tachometer pickup output and the Alternator voltage during startup. If no Alternator voltage is developed after the pump motors are switched from inverter power to alternator power at 220 Hz, this circuit will act to shutdown the EGS. This circuit can start the necessary protective action to prevent TAA overspeed much earlier in the startup sequence than any of the other overspeed protection circuits previously described. These other circuits require an actual overspeed condition to exist before they can start any protective action. The Condition 1 circuit anticipates that an overspeed condition will occur if the alternator does not produce an output voltage to permit electrical loading of the TAA. Consequently, it can start shutting down the EGS sufficiently early that the likelihood of the TAA reaching runaway speed is greatly reduced. If the TAA startup is normal, the Condition 1 circuit is de-activated as soon as rated speed and voltage are achieved. At this point the undervoltage/overvoltage circuit of Condition 6 takes over. Since the Condition 1 circuit is active only during startup, the reliability requirements on it are less severe. For this and other reasons, the components of this circuit are included in the Programmer rather than in the EPSM.

Once the TAA reaches rated speed and voltage and activates the undervoltage/overvoltage circuit, a loss of Alternator voltage will again result in the TAA overspeeding. However, in this case, the protective action will be the result of an undervoltage condition rather than an overspeed. For the case where an overspeed condition is caused by loss of load, the resultant voltage rise will cause the overvoltage circuit to act to provide the protective action. Therefore, the dependency of the undervoltage/overvoltage circuit upon Alternator voltage for overspeed protection is no longer significant.

As was described in the "EPSM Operation" paragraphs of this report, there are two time delays associated with the protective action of the EPSM, one a variable delay in magamp action and the other a fixed delay produced by the 0.5 second timing circuit. These two delays will occur whether protective action of the EPSM is started by undervoltage, overvoltage, or overspeed. While it would be desirable as a matter of design philosophy to eliminate these delays for an overspeed condition, practically, this delay is of little significance since no action started by an overspeed condition can shut down the EGS fast enough to prevent the TAA reaching runaway speed. Figure 5 shows a curve of TAA speed versus time plotted from test data taken during an emergency shutdown of PCS-1. This curve shows the TAA reaching runaway speed in 0.5 to 1.0 seconds while the boiler continues to deliver sufficient hot gas to maintain runaway speed for 5 or 6 seconds. Therefore, there would be little to be gained and possibly much to be lost if the EPSM were to be further complicated to require it to make this additional distinction.

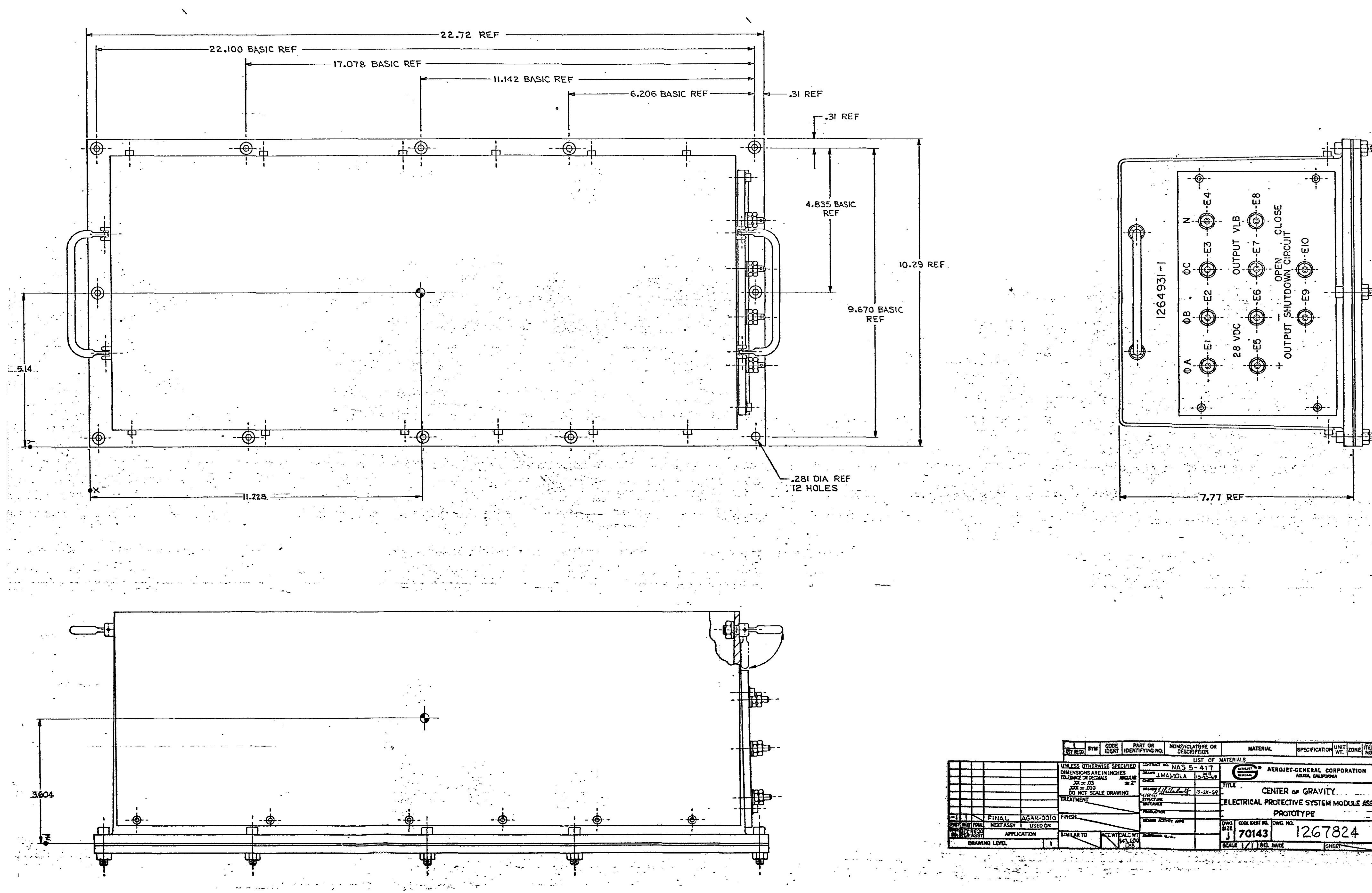
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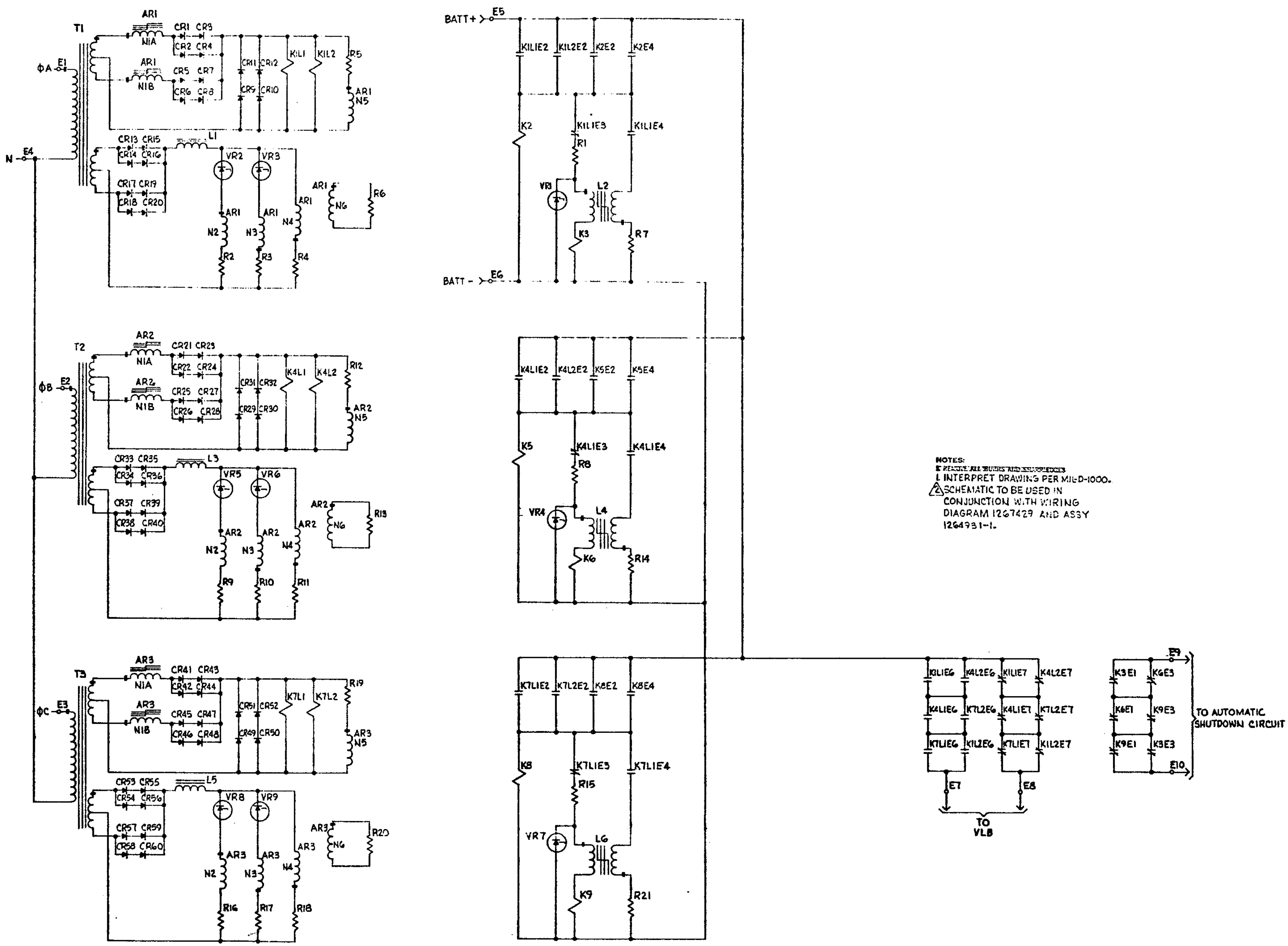
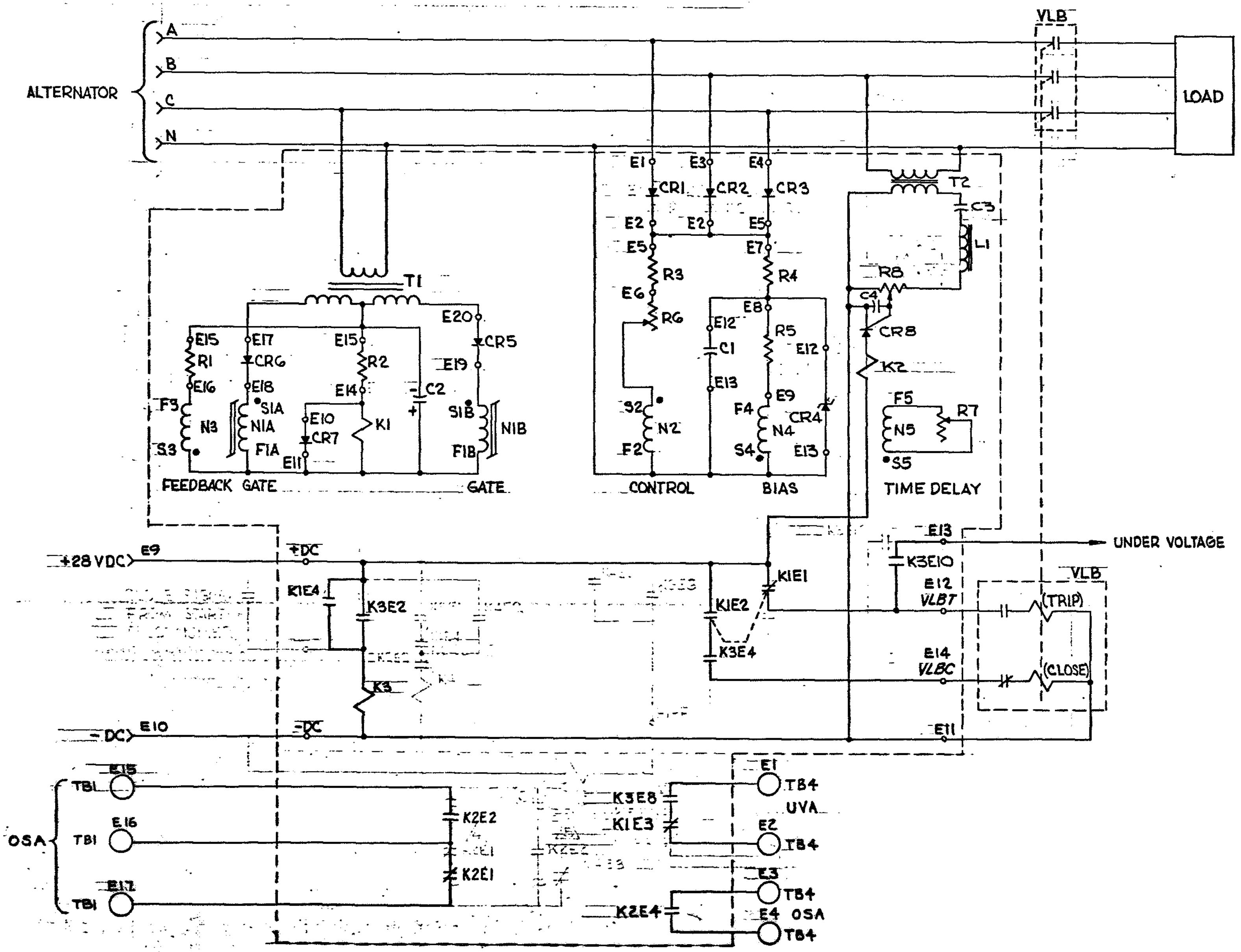
Figure 1



Electrical Schematic, Electrical Protective System Module (Aerojet Dwg 1267428)

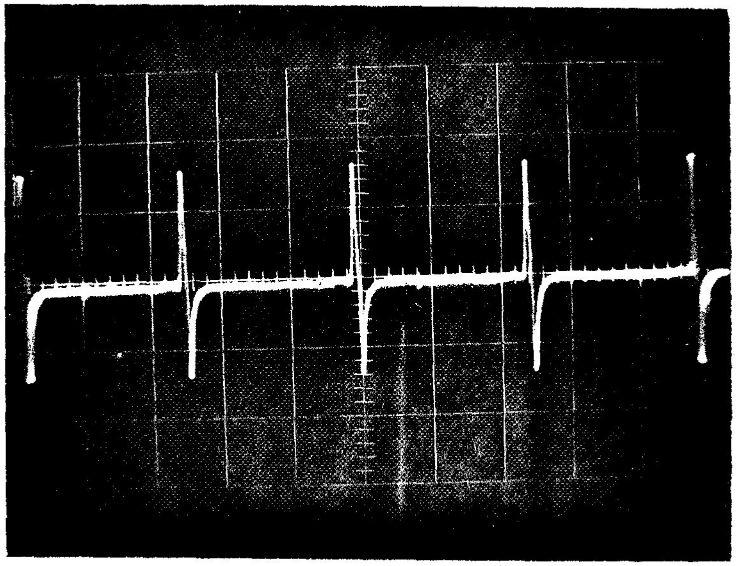
Figure 2

NOTES: 1. INTERPRET DRAWING PER STANDARDS PRESCRIBED IN MIL-D-70327.
2. ITEMS OUTSIDE OF DASH LINE ARE SHOWN FOR FUNCTIONAL PURPOSES ONLY.
3 FOR REFERENCE SEE WIRING DIAGRAM 095526.



Electrical Schematic, protective System -X Module (Aerojet Dwg 095381)

Figure 3



N-1

TAA 5/4 Tach Pickup Output Signal
3/22/68 at 1400 Hrs - PCS-1 Test

Scope Settings:

Vert. Sens. = 2 volts/cm
Sweep = 1 millisecond/cm

Results:

Output = 3 cm x 2 v/cm = 6 volts

$$\text{Speed} \simeq \frac{4 \text{ cycle}}{10 \text{ cm}} \times \frac{1 \text{ rev}}{2 \text{ cycles}} \times \frac{1 \text{ cm}}{1 \times 10^{-3} \text{sec}} \times \frac{60 \text{ sec}}{\text{min}} = 12{,}000 \text{ RPM}$$

400 PPS

$$\text{BASIC PULSE FREQ} = \frac{1 \text{ CYCLE}}{.4 \times 10^{-3} \text{SEC}} = 2500 \text{ CPS}$$

$$\text{OR} = \frac{1 \text{ CYCLE}}{.5 \times 10^{-3} \text{SEC}} = 2000 \text{ CPS} \quad \text{5th harm}$$

$$\text{OR} = \frac{1 \text{ cycle}}{.35 \times 10^{-3} \text{Sec}} = 2860 \text{ cps} \ (2800 \text{ cps 7th harm})$$

Figure 4

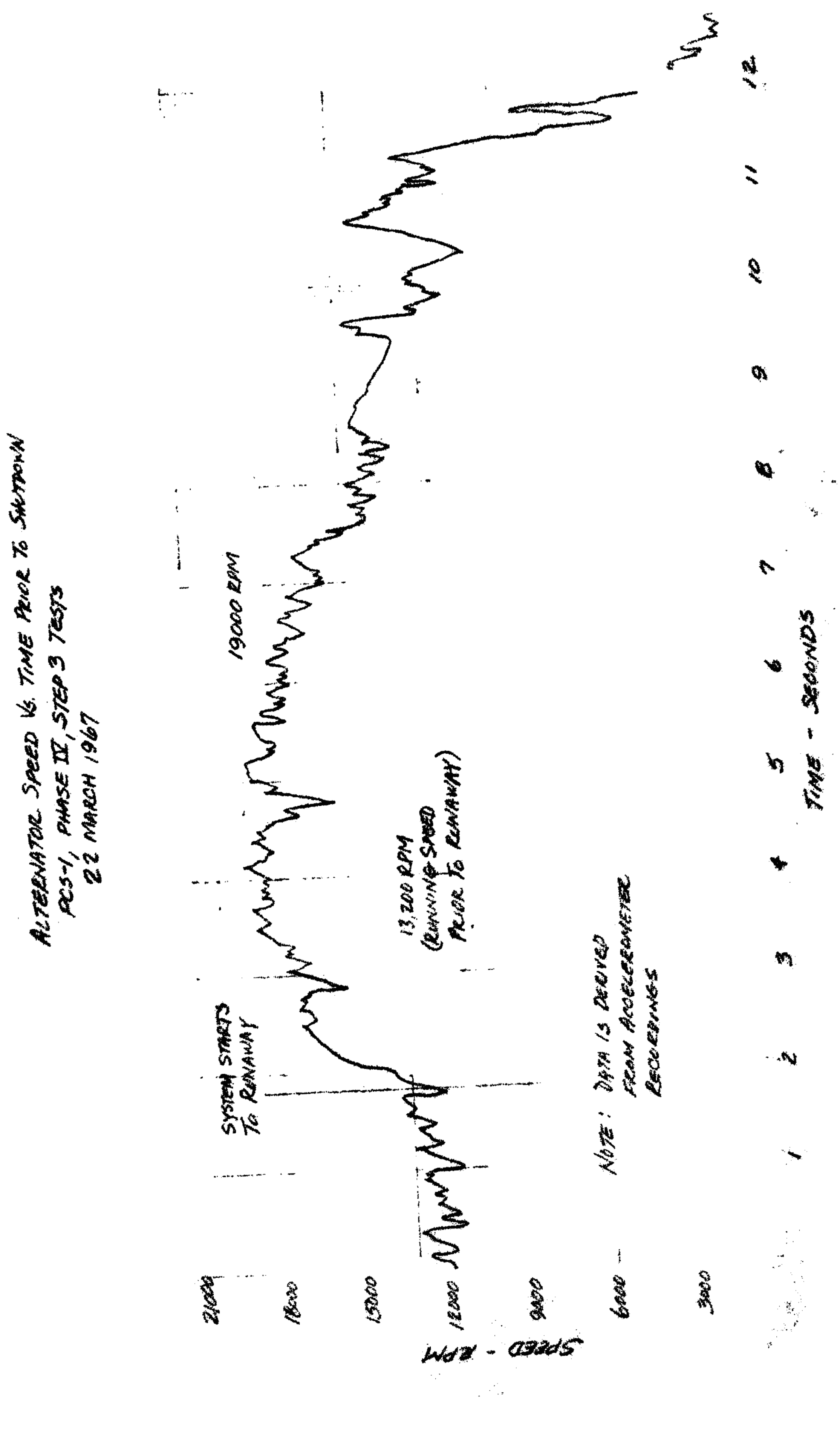

ALTERNATOR SPEED VS. TIME PRIOR TO SHUTDOWN
PCS-1, PHASE IV, STEP 3 TESTS
22 MARCH 1967
19000 RPM
13,200 RPM
(RUNNING SPEED
PRIOR TO RUNAWAY)
SYSTEM STARTS
TO RUNAWAY
NOTE: DATA IS DERIVED
FROM ACCELEROMETER
RECORDINGS
SPEED - RPM
21000
18000
15000
12000
9000
6000
3000
TIME - SECONDS
1
2
3
4
5
6
7
8
9
10
11
12

Figure 5

EPSM POWER DISSIPATION

8-7-6? [illegible]

			Worst Case Steady State	Over Voltage Shutdown Steady State
Magnetic Amplifier				
AR1, AR2, AR3			1.5 Watts Each	0 Watts Each
Filter Inductor				
L1, L3, L5			.25	0
Timing Inductor				
L2, L4, L6 Reset Coil			.03	0
L2, L4, L6 Timing Coil			0	.4
Power Transformer				
T1, T2, T3			1.53	0
Relays				
K1L1, K1L2; K4L1, K4L2; K7L1, K7L2			3.5	0
K2	K5	K8	3.5	3.5
K3	K6	K9	0	3.5
Wirewound Resistors HG-25				
R1	R8	R15	0	2.7
R2	R9	R16	.5	0
R3	R10	R17	.05	0
R4	R11	R18	1.5	0
R5	R12	R19	.5	0
R6	R13	R20	0	0
R7	R14	R21	3.6	0
Silicon Rectifiers				
CR1-CR12	CR21-CR32	CR41-CR52	1.0 Total For 12	0
CR13-CR20	CR33-CR40	CR53-CR60	.5 Total For 8	0
Zener Diodes				
VR1	VR4	VR7	0	5.3
VR2	VR5	VR8	1.7	0
VR3	VR6	VR9	1.0	0
			20.56	15.4

Figure 6

EPSM COMPONENT WEIGHT SUMMARY

8-7-67
RGW

HG-25 RESISTORS R1-7, R8-14, R9-21 (21)

W_R = 13 grams = $13 \times 2.205 \times 10^{-3}$ = .0287 lbs ea

E410-1034 RELAY K1-3, K4-6, K7-9 (12)

W_K = .17 lbs ea

JAN 1N2820B ZENER DIODE 24V 50W VR1, VR4, VR7 (3)

W_{VR1} = 18.5 grams = $18.5 \times 2.205 \times 10^{-3}$ = .0408 lbs ea

JAN 1N2986B ZENER DIODE 24V 10W VR2, VR5, VR8 (3)

JAN 1N2989B ZENER DIODE 30V 10W VR3, VR6, VR9 (3)

W_{VR2} = 5.6 grams W/O HARDWARE = $5.6 \times 2.205 \times 10^{-3}$ = .01235 lbs

8.2 grams WITH HARDWARE = $8.2 \times 2.205 \times 10^{-3}$ = .01807 lbs ea

1N2539 RECTIFIER CR1-20, CR21-40, CR41-60 (60)

W_{CR} = 8.3 grams WITH HARDWARE = $8.3 \times 2.205 \times 10^{-3}$ = .0183 lbs ea

MAGNETIC AMPLIFIER AR1, AR2, AR3 (3)

W_{AR} = 1.4 lb ea

POWER TRANSFORMER T1, T2, T3 (3)

W_T = 13 lb ea

FILTER INDUCTOR L1, L3, L5 (3)

W_L = 1.4 lb ea

TIMING INDUCTOR L2, L4, L6 (3)

W_L = 15.0 lb ea

RECTIFIER HEAT SINKS (6)

W_{HS} = 33 lbs

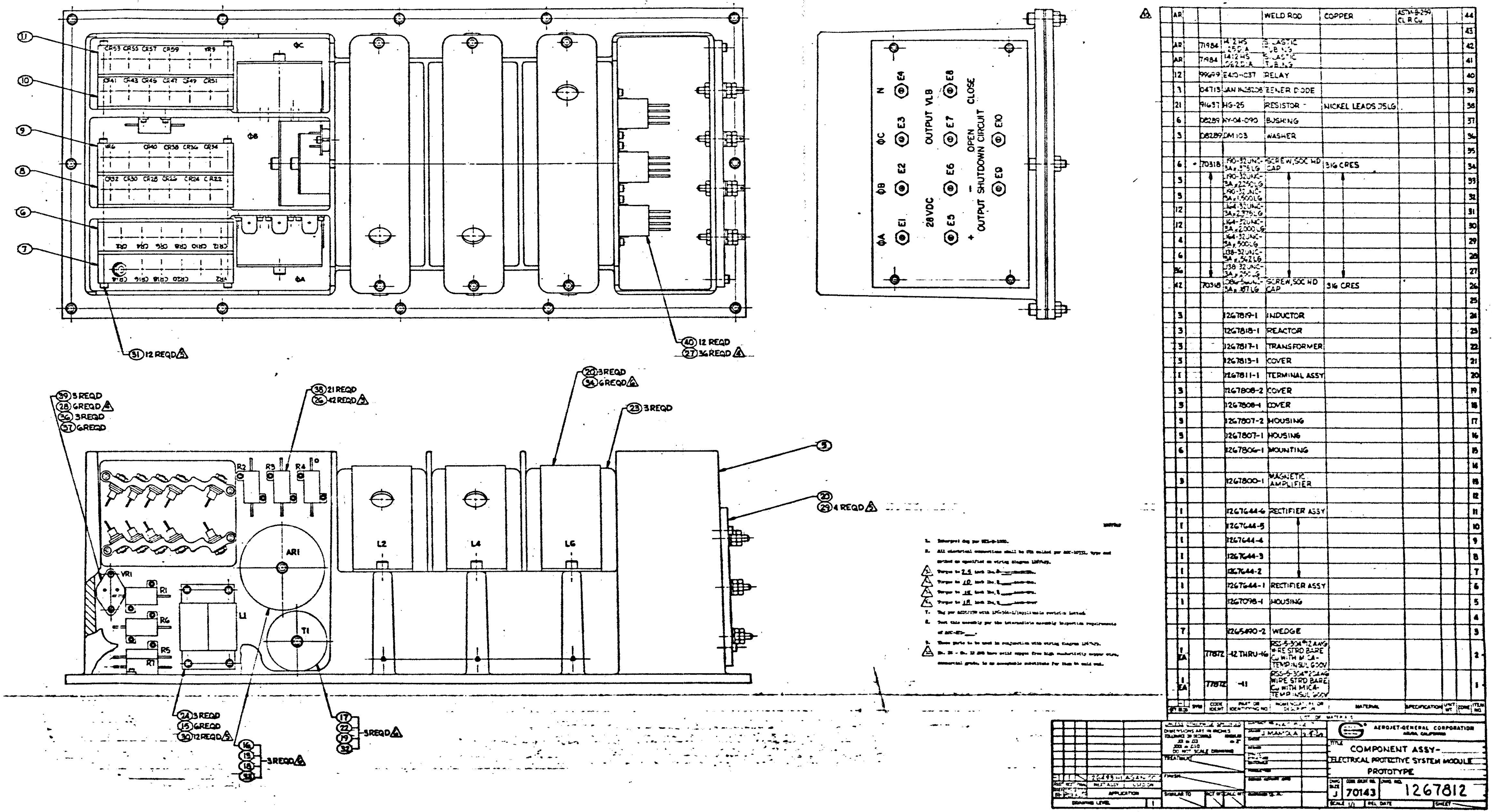
EPOXYLITE 813-9 38.4 lb
S.G. 1.6

DOW CORNING 3101
S.G. .67

$\frac{.67}{1.6}$ = .419

38.4 x .419 = 16.2 lb

Figure 7



5562

Figure 8

APPENDIX A

VOLTAGES IN THE SNAP-8 ELECTRICAL SYSTEM

AS THE RESULT OF POSSIBLE SHORT CIRCUIT FAULTS

VOLTAGES IN THE SNAP-8 ELECTRICAL SYSTEM AS THE RESULT

OF POSSIBLE SHORT CIRCUIT FAULTS

Short circuit faults on the SNAP-8 electrical system will consist of the following conditions:

1. Three-Phase short circuit
2. Phase-to-Phase short circuit
3. Phase-to-Phase-to-Neutral short circuit
4. Single-Phase-to-Neutral short circuit

The voltages existing in the system as a result of these faults are as follows:

1. <u>Three-Phase Short Circuit</u>

For this case all phase-to-phase and phase-to-neutral voltages are zero.

$$E_{1N} = E_{2N} = E_{3N} = 0$$

It is evident that three phase-to-neutral undervoltage sensors will trip on a three-phase short circuit.

2. <u>Phase-to-Phase Short Circuit</u>

For this case the faulted phase-to-phase voltage is zero.

Assume phase 1 to 2 is shorted, then

$$E_{12} = 0$$

By the method of symmetrical phase components it can be shown that

$$E_{1N} = E_{2N} = 1/2\ E_{3N} \ . \quad \text{(Reference 1)}$$

The results of a short circuit test on the SNAP-8 alternator are shown in Figure 1. For this test the alternator was separately excited.

Another test on the alternator with its Voltage Regulator-Exciter supplying the field current demonstrated that the phase current on a phase-to-phase short circuit is 670 amperes. (Reference Aerojet Report 3658.) From Figure 1 the voltage E_{3N} is shown to be 126 volts. Since as previously stated $E_{1N} = E_{2N} = 1/2\ E_{3N}$, $E_{1N} = E_{2N} = 126/2 = 63$ volts.

This shows that two of three phase-to-neutral undervoltage sensors set to trip at 108 volts will trip on a phase-to-phase short circuit.

3. <u>Phase-to-Phase-to-Neutral Short Circuit</u>

In this case all of the faulted phase-to-phase-to-neutral voltages are zero.

$$E_{12} = E_{1N} = E_{2N} = 0$$

Therefore, at least two of the three phase-to-neutral undervoltage sensors will trip on a phase-to-phase-to-neutral short circuit.

4. <u>Single-Phase-to-Neutral Short Circuit</u>

In this case the faulted phase-to-neutral voltage is zero.

Assume phase 1 to neutral is shorted.

$$E_{1N} = 0$$

For this condition the voltages, E_{2N} and E_{3N}, have been determined from tests on the SNAP-8 alternator. These results are summarized in Figure 2 and Figure 3.

The conclusion is that voltages E_{2N} and E_{3N} are less than 102 volts and 104 volts respectively, and that therefore all three phase-to-neutral under-voltage sensors set at 108 volts will trip on a single-phase-to-neutral fault.

<u>References</u>:

1. Symmetrical Components, Wagner and Evans, Chapter III, page 47-48, McGraw-Hill Book Company, Inc.

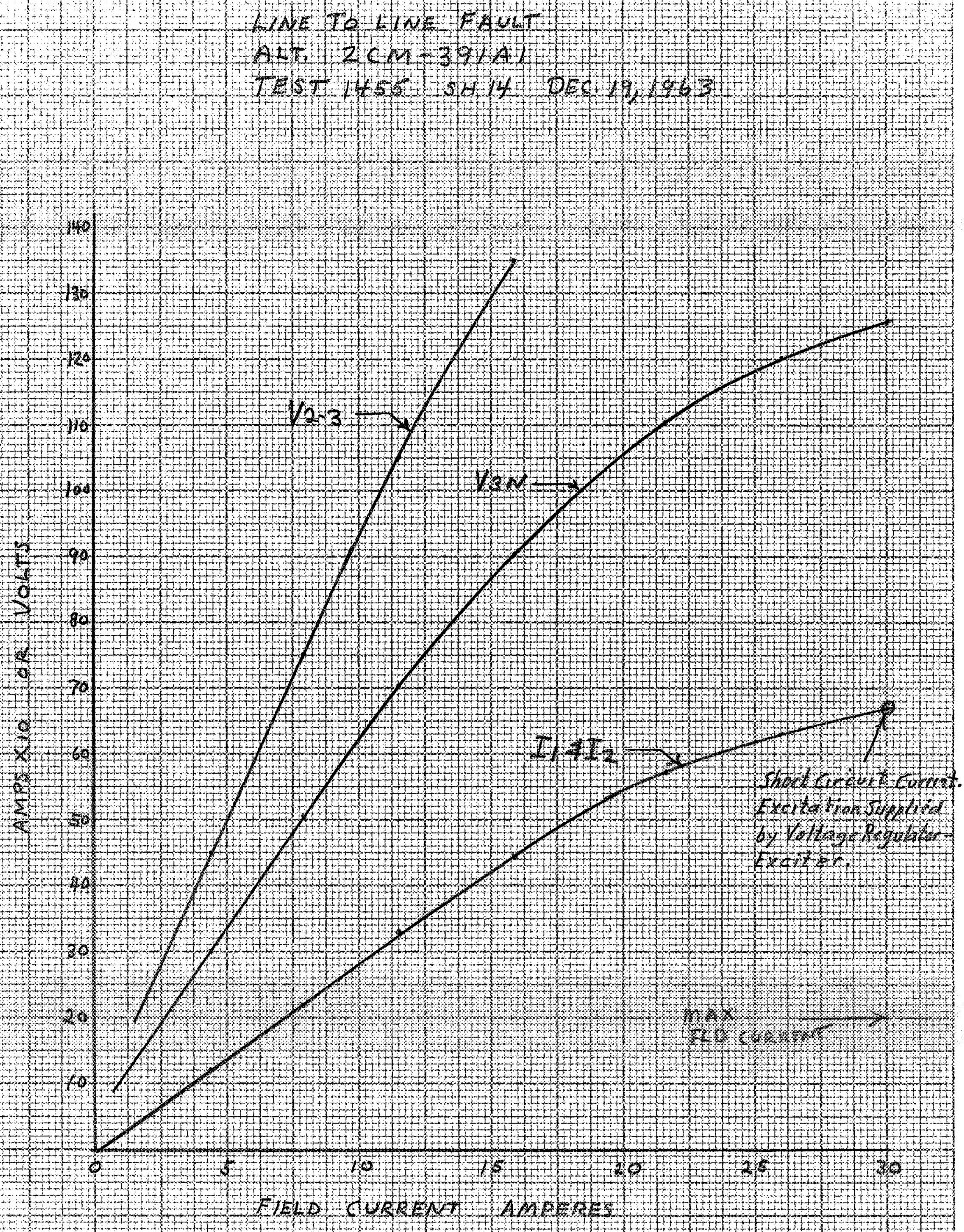

LINE TO LINE FAULT
ALT. 2CM-391A1
TEST 1455 SH 14 DEC 19, 1963
AMPS X 10 OR VOLTS
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
5
10
15
20
25
30
V2-3
V3N
I1 4 I2
Short Circuit Current.
Excitation Supplied by Voltage Regulator-Exciter.
MAX FLD CURRENT
FIELD CURRENT AMPERES

Figure 1

INTEROFFICE MEMO AEROJET-GENERAL CORPORATION 3 December 1969
4968:69:0082-FNC:if
160/X4207

TO: S. L. Bradley

FROM: F. N. Collamore

SUBJECT: Protective System - Single Line to Neutral Fault

DISTRIBUTION: N. E. Waldschmidt

ENCLOSURE: (1) Figure - Single Line to Ground Fault

A review of the SNAP-8 alternator and voltage regulator-exciter performance indicates that a single phase line to neutral fault will cause the protective system to trip. The under voltage trip point is set at 108 volts line to neutral. With a single phase to neutral fault all three phase voltages will be below 108 volts.

Enclosure (1) shows the alternator current and voltage vs field current with a single phase line to neutral short circuit. Phases 2 and 3 are open circuited. Short circuit tests of the alternator with its voltage regulator-exciter indicate a maximum single phase to neutral current of 940 amperes. (Reference Aerojet Report 3658) From Enclosure (1) the voltages on phases 2 and 3 under this condition are 102 volts and 104 volts respectively. It should be noted that data shown in Enclosure (1) is taken without the voltage regulator-exciter and that phases 2 and 3 are open circuited. With the voltage regulator-exciter connected, phases 2 and 3 would be loaded by the saturable current potential transformer which supplies the alternator field excitation. This would reduce the voltages below that shown on Enclosure (1).

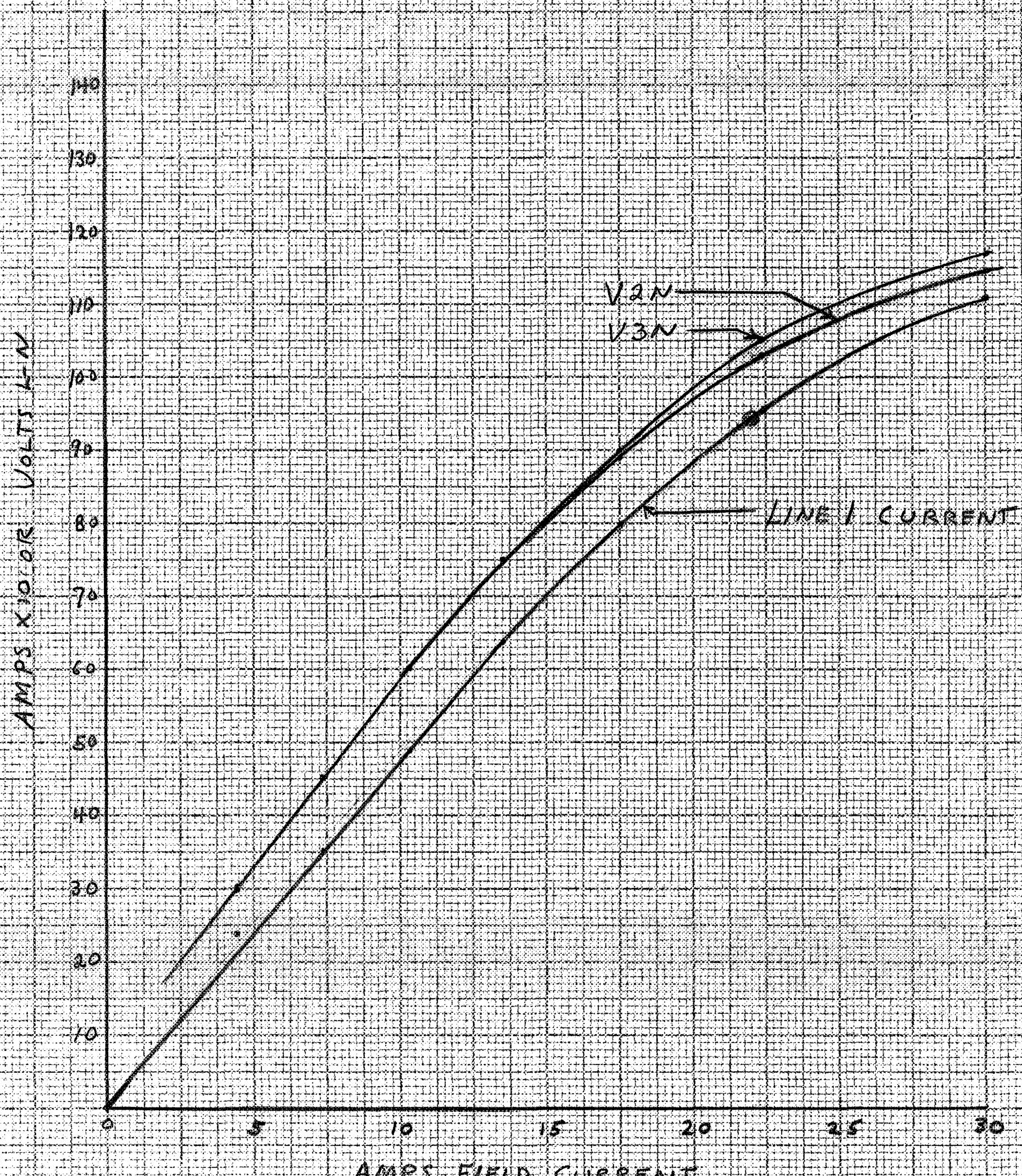
During normal operation of the SNAP-8 system the alternator is loaded by the system pumps, speed control system and vehicle load. If a line to neutral fault were to occur on one phase the load would remain on the other two phases causing a lower voltage than that shown on Enclosure (1).

F. N. Collamore

F. N. Collamore
Electrical Components Section
Power Systems Department

Figure 2

SINGLE LINE TO GROUND FAULT
ALT. 2CM-391A1
TEST 1455 SH 14 DEC. 19, 1963



APPENDIX B

STEADY STATE THERMAL ANALYSIS OF SNAP-8 ELECTRICAL PROTECTIVE SYSTEM MODULE

10-047-009 (REV. 6/63)

CR-72938

DIVISION Power Systems

TM 4903:70-609

DATE 2 February 1970

W.O. 1139-78-2000

TECHNICAL MEMORANDUM

AUTHOR(S): R. G. Rivera

TITLE: Steady-State Thermal Analysis of SNAP-8 Electrical Protective System Assembly

ABSTRACT

The "CINDA" computer program was used to thermally analyze the SNAP-8 Electrical Protective System Assembly. The results of this anlysis indicate that the assembly will operate within temperature limits at the worst case radiator conditions.

KEY WORDS: Electrical Protective System, thermal analysis, electrical equipment

APPROVED:

DEPARTMENT HEAD ______________________
L. P. Lopez

NOTE: The information in this document is subject to revision as analysis progresses and additional data are acquired.

TABLE OF CONTENTS

I	SYMBOLS AND NOMENCLATURE
II	RESULTS AND RECOMMENDATIONS
III	THEORY AND ASSUMPTIONS
IV	METHOD OF ANALYSIS
V	CALCULATED CONDUCTANCES
VI	REFERENCES
APPENDIX A	EPSM STEADY-STATE ANALYSIS
APPENDIX B	COMPUTER INPUT DATA
APPENDIX C	COMPUTER OUTPUT

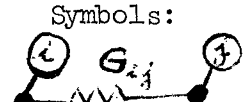
I SYMBOLS AND NOMENCLATURE

A	Area perpendicular to heat flow, ft^2
c_p	Specific heat at constant pressure, BTU/lb-$^{\circ}$F
F_A	Configuration shape factor, dimensionless
F_e	Emissivity factor, dimensionless
G	Thermal conductance, BTU/hr-$^{\circ}$F
h	Film conductance through a bolted connection, BTU/hr-ft^2-$^{\circ}$F
K	Thermal conductivity, BTU/hr-ft-$^{\circ}$F
Q	Heat dissipated, watts
U	Overall thermal conductance, BTU/hr-ft^2-$^{\circ}$F
w	Weight, lb
X	Heat flow path, ft
σ	Stefan Boltzmann constant, BTU/hr-ft^2-$^{\circ}$R^4
$\sum_{i=1}^{n}$	Summation from 1 to n

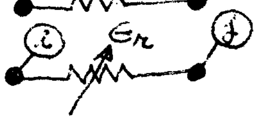
Subscripts:

r	refers to radiative
i	refers to node or element "i"
ij	refers to nodes "i" and "j"

Symbols:



Non radiative conductance between nodes "i" and "j"



Radiative conductance between nodes "i" and "j"

II RESULTS AND RECOMMENDATIONS

The steady-state computer solution for assumed radiator temperatures of 225°F, 390°F, and 550°F, respectively, is presented in Table 1. The results show that the only electronic component that reached its critical temperature limit of 125°C (257°F) was the electronic relay - Element Number 37 of the thermal network - which reached 258°F for the most severe radiator temperature of 550°F.

Because of the conservatism of the steady-state analysis no changes to the present design of the SNAP-8 Electrical Protective System Assembly are recommended.

Table 1 - Element Temperature in Degrees Fahrenheit vs. Assumed Radiator Temperature

Element Number	Element Description	Radiator Temperature 225°F	390°F	550°F
1	Lumped element consisting of inner housing aluminum wall, magnetic amplifier AR_1, transformer T_1, inductors L_1 and L_3, zener diode VR_1, and resistors R_1, R_2, R_3, R_4, R_5, and R_6.	158	168	184
2	Lumped element consisting of inner housing wall, magnetic amplifier AR_3, transformer T_3, inductor L_5, zener diode VR_7, and resistors R_8 and R_{20}.	160	170	187
3	Lumped element consisting of rectifier heat sink, diodes CR_{13} to CR_{20} and zener diodes VR_2 and VR_3.	265	276	292
4	Lumped element consisting of rectifier heat sink and diodes CR_1 to CR_{12}.	165	175	192
5	Lumped element consisting of rectifier heat sink and diodes CR_{21} to CR_{32}.	165	175	192

Table 1 - continued

Element Number	Element Description	Radiator Temperature 225°F	390°F	550°F
6	Lumped element consisting of rectifier heat sink, diodes CR_{33} to CR_{40} and zener diodes VR_5 and VR_6.	265	276	292
7	Lumped element consisting of rectifier heat sink and diodes CR_{41} to CR_{52}.	167	177	194
8	Lumped element consisting of rectifier heat sink, diodes CR_{53} to CR_{60} and zener diodes VR_8 and VR_9.	267	278	294
9	Housing wall - aluminum	153	163	179
10	Lumped element consisting of inner housing aluminum wall, magnetic amplifier AR_2, transmitter T_2, and zener diode VR_4.	155	165	181
11	Housing wall - aluminum	153	163	179
12	Housing wall - aluminum	154	167	187
13	Housing wall - aluminum	155	168	189
14	Housing wall - aluminum	154	167	188
15	Housing wall - aluminum	151	160	174
16	Housing wall - aluminum	150	160	175
17	Housing wall - aluminum	154	166	184
18	Housing wall - aluminum	157	178	210
19	Housing wall - aluminum	149	158	172
20	Housing wall - aluminum	150	160	176

Table 1 - continued

Element Number	Element Description	Radiator Temperature 225°F	390°F	550°F
21	Housing wall for relays - aluminum	172	187	209
22	Outer housing wall adjacent to doral glass element - aluminum	153	170	197
23	Housing wall - aluminum	150	160	174
24	Housing wall - aluminum	150	160	175
25	Housing wall - aluminum	154	166	184
26	Housing wall - aluminum	157	178	210
27	Housing bottom plate - left side - aluminum	147	152	160
28	Housing bottom plate - middle - aluminum	146	150	158
29	Housing bottom plate - right side - aluminum	146	154	166
30	Housing cover plate - left side - aluminum	177	267	396
31	Housing cover plate - middle - aluminum	174	256	375
32	Housing cover plate - right side - aluminum	168	228	317
33	Doral glass element	215	372	533
34	3.6 watts resistor (R_7) attached to Element 27, Compartment A	197	202	210
35	3.6 watts resistor (R_{14}) attached to Element 2, Compartment A	210	220	237

Table 1 - continued

Element Number	Element Description	Radiator Temperature 225°F	390°F	550°F
36	3.6 watts resistor (R_{21}) attached to Element 27, Compartment C	197	202	210
37	Typical relay element attached to Element 21, Compartment G	221	236	258

III THEORY AND ASSUMPTIONS

The analysis of thermal systems such as the one being considered (Figures 1 and 2) is so complex that the only successful approach to them is by the use of analogies between heat and electric flow. It was then necessary to make an electric network analogous to the thermal system being considered and to calculate thermal conductances between adjacent nodes or thermal elements.

In using electrical analogies temperature can be thought of as a potential that causes heat to flow. In steady-state processes the current of heat is governed by the potential difference and the resistance of the heat flow path. This concept indicates that for steady-state processes heat flow is analogous to electric current flow, temperature is analogous to voltage, and thermal resistance ($\frac{X}{KA}$) to electrical resistance. (For transient or periodic changes the effect of storage or capacity must be included, therefore, the thermal capacitance ($w\ c_p$) is analogous to the electrical capacitance.)

The simultaneous linear equations generated by making an energy balance on each node of the electric network are solved by the "CINDA" computer program of Reference (1) by using iterative finite differencing techniques very similar to Southwell's and Emmons' relaxation method. The essence of the method is to make a heat balance and arbitrarily select temperatures at each node so that the net heat transferred into each element is approximately zero. This of course cannot be done independently of the adjacent nodes on all sides of the one being considered. The procedure is to set up a pattern for the entire system and then to satisfy the requirements of zero unbalance or pre-established residual heat criteria for each node.

Non radiative conductances for the "CINDA" program were calculated by the formulae:

$$G_{ij} = U_i A_i$$

where,

$$U = \frac{1}{\sum_{i=1}^{n}\left(\frac{1}{h_i}\right) + \sum_{j=1}^{m}\left(\frac{x}{K}\right)_j}$$

or,

$$G_{ij} = \frac{K_i A_i}{x_{ij}}$$

Radiative conductances were calculated by using the formula:

$$Gr = \sigma \, Fa \, Fe \, A$$

Conductances through bolted connections were conservatively calculated by assuming that the contact flange area was equivalent to an area having a diameter four times the actual diameter of the bolt and using a parallel flow path, in which the total internal conductance is taken as,

$$G = \sum_{i=1}^{n} G_i = \sum_{i=1}^{n}\left(\frac{K_i A_i}{x_{ij}}\right)$$

and

$$UA = \frac{1}{\sum_{i=1}^{n}\left(\frac{1}{hA}\right)_i + \frac{1}{G}}$$

A value of 144 BTU/hr-ft^2-$^\circ$F was used for the film conductance through the air gap based upon past experience with similar systems and to simplify calculations.

Heat dissipated by electronic components were taken as given by Mr. Norman E. Waldschmidt of the Electronics Group, Section 4936, and were lumped accordingly, i.e., either in the critical component per se or in the corresponding wall, as applicable.

The heat dissipated in watts into each electronic component or wall is given below, in which "Q_i" refers to the heat dissipated into - or by - the thermal element "i".

Heat dissipated by electronic components:

q_1	= 6.08 watts	q_{16}	= .015 watts
q_2	= 8.38 watts	q_{17}	= .015 watts
q_3	= 3.20 watts	q_{21}	= 28.0 watts
q_4	= 1.0 watts	q_{23}	= .015 watts
q_5	= 1.0 watts	q_{24}	= .015 watts
q_6	= 3.20 watts	q_{25}	= .015 watts
q_7	= 1.0 watts	q_{34}	= 3.60 watts
q_8	= 3.20 watts	q_{35}	= 3.60 watts
q_{10}	= 3.03 watts	q_{36}	= 3.60 watts
q_{15}	= .015 watts	q_{37}	= 3.50 watts

All of the above heat dissipated values were multiplied by a 3.413 factor in the "CINDA" program to convert them to BTU/hr.

As mentioned previously it was not considered necessary to model all electronic components since it was obvious that some of them were not critical, i.e., the inductors which had a very large mass dissipated only .030 watts, each. Rather than modeling each inductor as a separate element and calculating conductances to this element it was assumed that the heat dissipated by the inductor will be divided equally among the two walls at which the inductor was attached, each receiving .015 watts.

Critical elements such as resistors R_7, R_{14}, and R_{21} which dissipated 3.6 watts steady-state each, were given a node number so that a correct temperature could be calculated by the computer program of Reference (1) for each one. (This was also done for a typical relay attached to Element 21 since it dissipated 3.5 watts steady-state.)

IV METHOD OF ANALYSIS

The analogy between heat and electric flow was used in the preliminary steady-state thermal analysis of the SNAP-8 Electrical Protective System Assembly. The thermal configuration shown in Figures 1 and 2 was subdivided into seven compartments, namely, A, B, C, D, E, F, and G.

The electrical components in each individual compartment are as follows:

A. Components in Compartment "A"

1. Components attached to Elements #1, #3, and #4

a) Rectifier Heat Sink including diodes CR_1 to CR_{20} and zener diodes VR_2 and VR_3

b) Zener Diode VR_1

c) Inductor L_1

d) Magnetic Amplifier AR_1

e) Transformer T_1

f) Resistors R_1 to R_6

2. Components attached to Element #27

a) Resistor R_7

B. Components in Compartment "B"

1. Components attached to Elements #1, #5, and #6

a) Rectifier Heat Sink including diodes CR_{21} to CR_{40} and zener diodes VR_5 and VR_6

b) Inductor L_3

2. Components attached to Element #2

a) Resistors R_8 to R_{14}

3. Components attached to Element #10

a) Magnetic Amplifier AR_2

b) Transformer T_2

c) Zener Diode VR_4

C. Components in Compartment "C"

1. Components attached to Elements #2, #7, and #8

a) Rectifier Heat Sink including diodes CR_{41} to CR_{60} and zener diodes VR_8 and VR_9

b) Zener Diode VR_7

c) Inductor L_5

d) Magnetic Amplifier AR_3

e) Transformer T_3

f) Resistors R_{15} to R_{20}

2. Components attached to Element #27

a) Resistor R_{21}

D. Components in Compartment "D"

1. Reactor Inductor L_2

E. Components in Compartment "E"

1. Reactor Inductor L_4

F. Components in Compartment "F"

1. Reactor Inductor L_6

G. Components in Compartment "G"

1. Relays K_1L_1, K_1L_2, K_2, and K_3

2. Relays K_4L_1, K_4L_2, K_5, and K_6

3. Relays K_7L_1, K_7L_2, K_8, and K_9

The thermal configuration was subsequently subdivided into 39 thermal nodes or elements described at the end of this section. In order to keep computer time to a minimum it was necessary to lump certain non-critical elements into an equivalent thermal element whose temperature will be representative of the average temperature of each of the individual elements lumped. In doing this, it was kept in mind that the results of the analysis will indicate whether or not a finer element subdivision or a more refined thermal analysis should be made.

An electrical network analogous to the thermal system (Figures 2 and 3) was then made and thermal conductances between adjacent nodes were calculated. The temperatures at each individual node were calculated by using the computer program of Reference (1) and the thermal properties given in Table 2.

Table 2 - Steady-State Thermal Properties

Material	Thermal Conductivity BTU/hr-ft^2-$^\circ$F/ft
A 356-T6 Aluminum	92
6061-T6 Aluminum	92
Beryllium Oxide	64
Steel	33
Steatite	1.5
Copper	226
Doral Glass	0.1815

Note: Thermal conductivities were obtained from References (2), (3), (4), and (5).

Thermal Element Description:

1. Lumped element consisting of inner housing aluminum wall, magnetic amplifier AR_1, transformer T_1, inductors L_1 and L_3, zener diode VR_1, and resistors R_1 to R_6.

2. Lumped element consisting of inner housing wall, magnetic amplifier AR_3, transformer T_3, inductor L_5, zener diode VR_7, and resistors R_8 to R_{20}.

3. Lumped element consisting of rectifier heat sink, diodes CR_{13} to CR_{20} and zener diodes VR_2 and VR_3.

4. Lumped element consisting of rectifier heat sink and diodes CR_1 to CR_{12}.

5. Lumped element consisting of rectifier heat sink and diodes CR_{21} CR_{32}.

6. Lumped element consisting of rectifier heat sink, diodes CR_{33} to CR_{40} and zener diodes VR_5 and VR_6.

7. Lumped element consisting of rectifier heat sink and diodes CR_{41} to CR_{52}.

8. Lumped element consisting of rectifier heat sink, diodes CR_{53} to CR_{60} and zener diodes VR_9.

9. Housing wall - aluminum

10. Lumped element consisting of inner housing aluminum wall, magnetic amplifier AR_2, transmitter T_2, and zener diode VR_4.

11. Housing wall - aluminum

12. Housing wall - aluminum

13. Housing wall - aluminum

14. Housing wall - aluminum

15. Housing wall - aluminum

16. Housing wall - aluminum

17. Housing wall - aluminum

18. Housing wall - aluminum

19. Housing wall - aluminum

20. Housing wall - aluminum

21. Housing wall for relays - aluminum

22. Outer housing wall adjacent to doral glass element - aluminum

23. Housing wall - aluminum

24. Housing wall - aluminum

25. Housing wall - aluminum

26. Housing wall - aluminum

27. Housing bottom plate - left side - aluminum

28. Housing bottom plate - middle - aluminum

29. Housing bottom plate - right side - aluminum

30. Housing cover plate - left side - aluminum

31. Housing cover plate - middle - aluminum

32. Housing cover plate - right side - aluminum

33. Doral glass element

34. 3.6 watts resistor (R_7) attached to Element 27, Compartment A

35. 3.6 watts resistor (R_{14}) attached to Element 2, Compartment B

36. 3.6 watts resistor (R_{21}) attached to Element 27, Compartment C

37. Typical relay element attached to Element 21, Compartment G

38. Heat sink boundary plate @ 140°F

39. Constant radiator heat source temperature

V CALCULATED CONDUCTANCES

The calculated conductances for the steady-state computer run were as follows:

Non-Radiative Conductances

G1	=	1.528	BTU/hr-°F	G20	=	0.0905	BTU/hr-°F
G2	=	1.945	"	G21	=	0.1089	"
G3	=	1.910	"	G22	=	3.520	"
G4	=	1.910	"	G23	=	0.1531	"
G5	=	1.945	"	G24	=	0.0328	"
G6	=	0.1089	"	G25	=	3.52	"
G7	=	0.0273	"	G26	=	0.1531	"
G8	=	0.1531	"	G27	=	0.0273	"
G9	=	3.520	"	G28	=	0.1089	"
G10	=	3.080	"	G29	=	0.1531	"
G11	=	1.528	"	G30	=	1.81	"
G12	=	3.52	"	G31	=	0.093	"
G13	=	3.08	"	G32	=	1.126	"
G14	=	0.0328	"	G33	=	1.126	"
G15	=	0.0857	"	G34	=	0.093	"
G16	=	0.910	"	G35	=	2.038	"
G17	=	0.945	"	G36	=	0.093	"
G18	=	1.527	"	G37	=	1.126	"
G19	=	1.527	"	G38	=	0.0858	"

Non-Radiative Conductances (continued)

G39	=	0.093	BTU/hr-°F	G61	=	1.273	BTU/hr-°F
G40	=	1.126	"	G62	=	1.126	"
G41	=	2.038	"	G63	=	0.093	"
G42	=	1.126	"	G64	=	2.038	"
G43	=	2.038	"	G65	=	1.126	"
G44	=	0.093	"	G66	=	0.910	"
G45	=	1.126	"	G67	=	0.0905	"
G46	=	1.126	"	G68	=	1.095	"
G47	=	1.273	"	G69	=	2.585	"
G48	=	1.187	"	G70	=	3.150	"
G49	=	3.659	"	G71	=	2.395	"
G50	=	.934	"	G72	=	3.01	"
G51	=	6.29	"	G73	=	1.518	"
G52	=	0.934	"	G74	=	0.937	"
G53	=	0.097	"	G75	=	1.518	"
G54	=	0.1332	"	G76	=	2.494	"
G55	=	3.659	"	G77	=	0.937	"
G56	=	2.54	"	G78	=	2.494	"
G57	=	1.187	"	G79	=	1.945	"
G58	=	1.095	"	G80	=	1.945	"
G59	=	1.126	"	G81	=	1.945	"
G60	=	0.0857	"	G82	=	1.945	"

Non-Radiative Conductances (continued)

G83	=	1.945	BTU/hr-$^{\circ}$F	G89	=	0.2443	BTU/hr-$^{\circ}$F
G84	=	1.945	"	G90	=	0.2443	"
G85	=	2.065	"	G91	=	0.2452	"
G86	=	2.065	"	G100	=	22.901	"
G87	=	1.310	"	G101	=	23.239	"
G88	=	0.2452	"	G102	=	10.642	"

Radiative Conductances

G92	=	4.375×10^{-10}	BTU/hr-$^{\circ}$R^4	G98	=	5.070×10^{-11}	BTU/hr-$^{\circ}$R^4
G93	=	4.895×10^{-10}	"	G99	=	4.675×10^{-10}	"
G94	=	1.760×10^{-10}	"	G103	=	5.02×10^{-11}	"
G95	=	4.215×10^{-11}	"	G104	=	3.31×10^{-11}	"
G96	=	5.585×10^{-11}	"	G105	=	3.485×10^{-11}	"
G97	=	4.215×10^{-11}	"				

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10. J 70143-1267097, "Housing Component - Electrical Protective System Module Prototype", dated 7-28-69

11. E 70143-1267097, "Housing Component - Electrical Protective System Module Prototype, Sheet 2, dated 7-28-69

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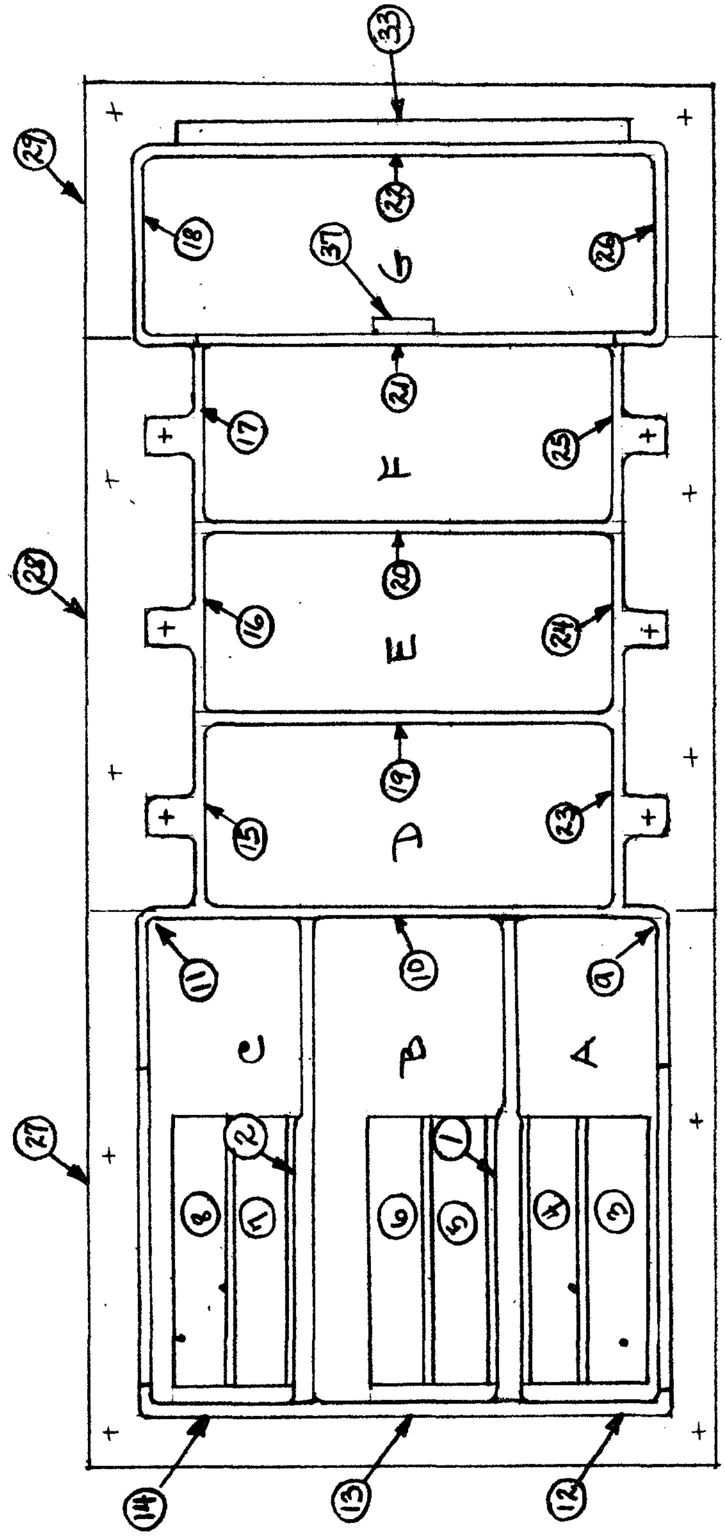
SUBJECT EPSM ANALYSIS BY R.G.R.

THERMAL ELEMENT SUBDIVISION
1267098-HOUSING



NOTE:
1. HOUSING WAS SUBDIVIDED INTO COMPARTMENTS A, B, C, D, E, F, AND G.
2. REFER TO APPENDIX A FOR CORRESPONDING COMPONENTS IN EACH INDIVIDUAL COMPARTMENT.

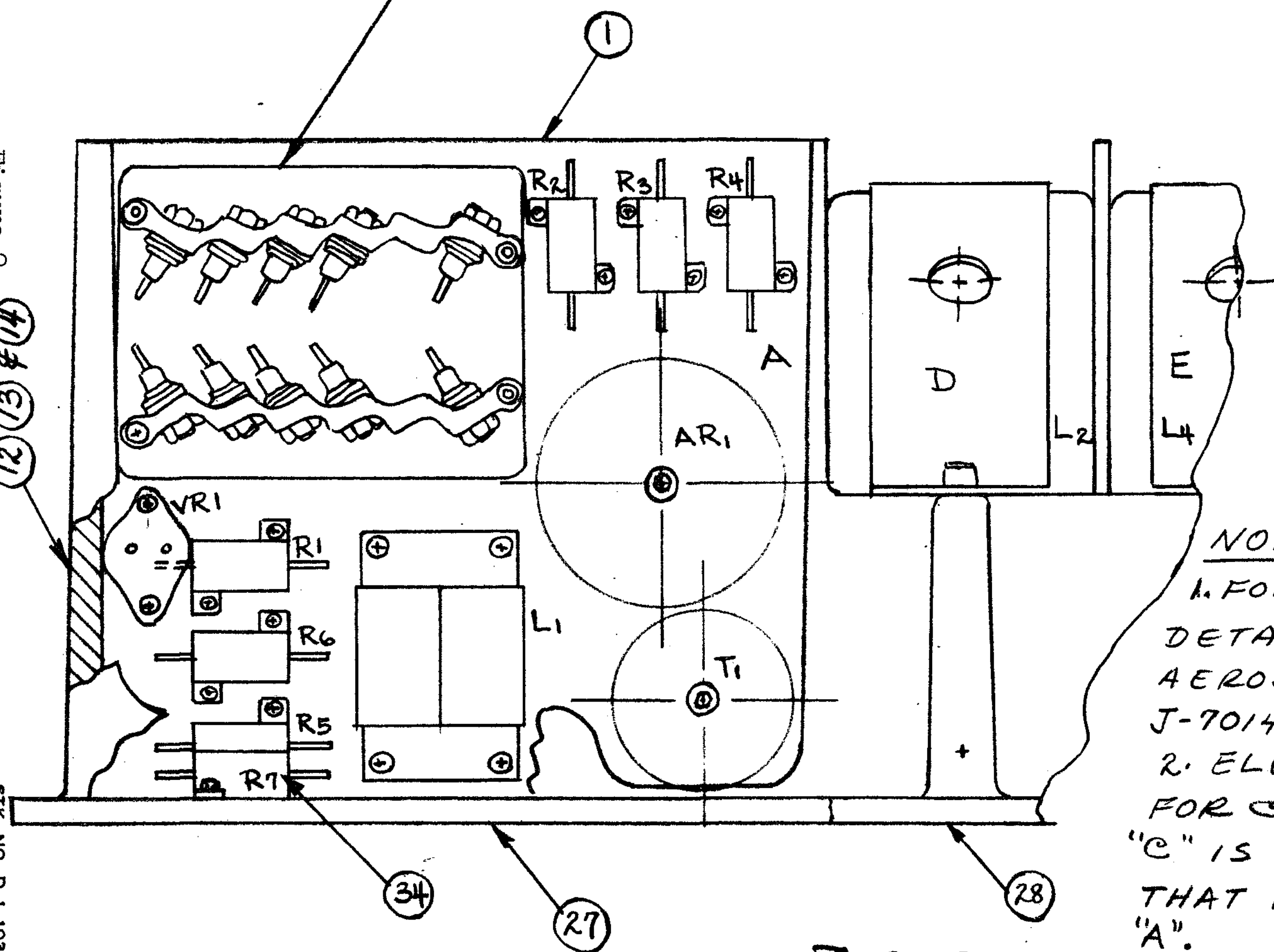
FIG 1

Figure 1

THERMAL ELEMENT SUBDIVISION (CONT'D)

ELEVATION VIEW SHOWING ELECTRONIC COMPONENTS IN COMPARTMENTS "A", "D", AND "E".

(3) (ELEMENT (4) IS ATTACHED TO WALL ELEMENT (1) DIRECTLY BEHIND (3))



NOTE:
1. FOR COMPLETE DETAILS REFER TO AEROJET DRAWING J-70143-1267812.
2. ELEVATION VIEW FOR COMPARTMENT "C" IS IDENTICAL TO THAT FOR COMPARTMENT "A".

FIG 2.

Figure 2 (12)(13) & (14)

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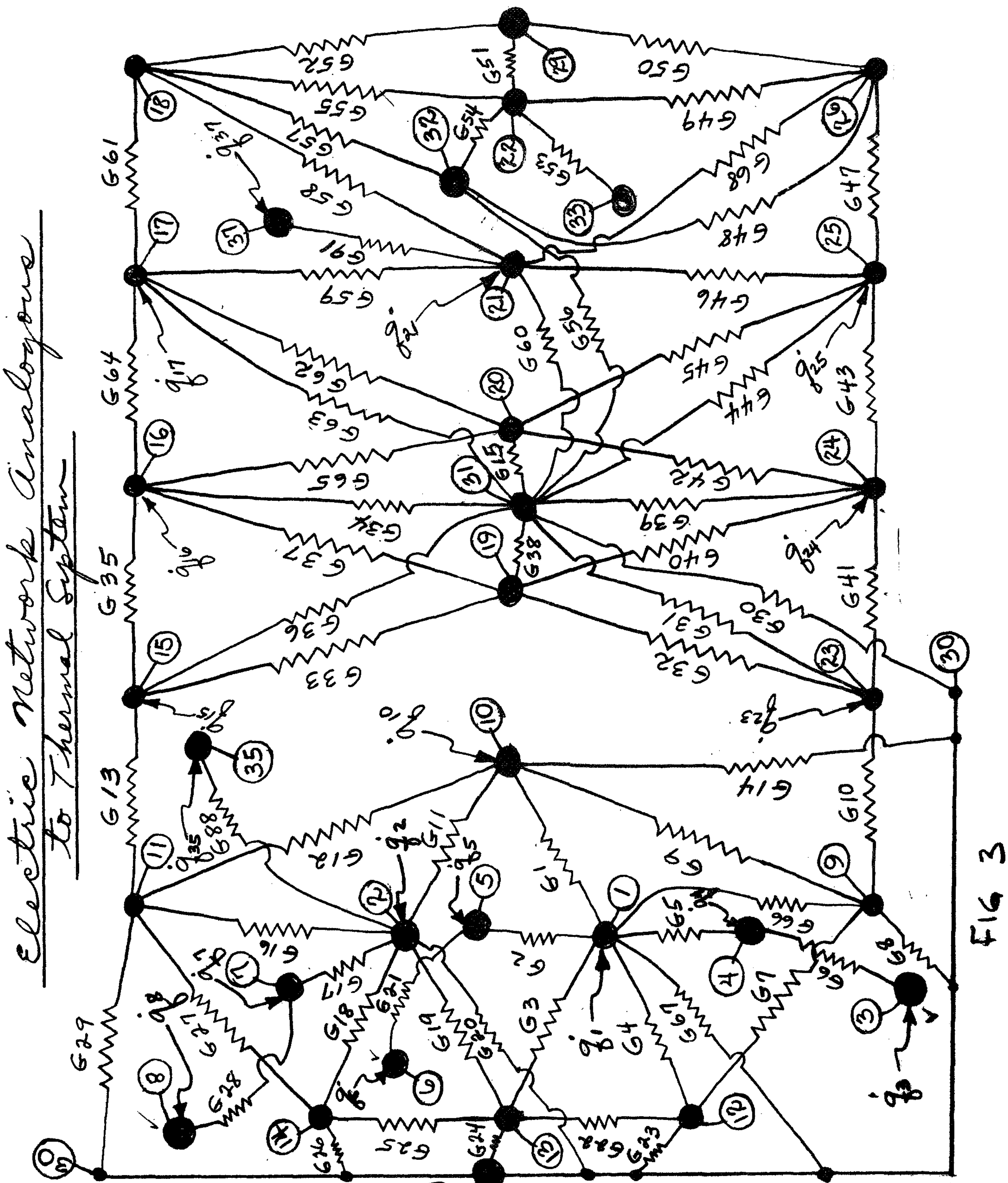

Figure 3

01-071-002

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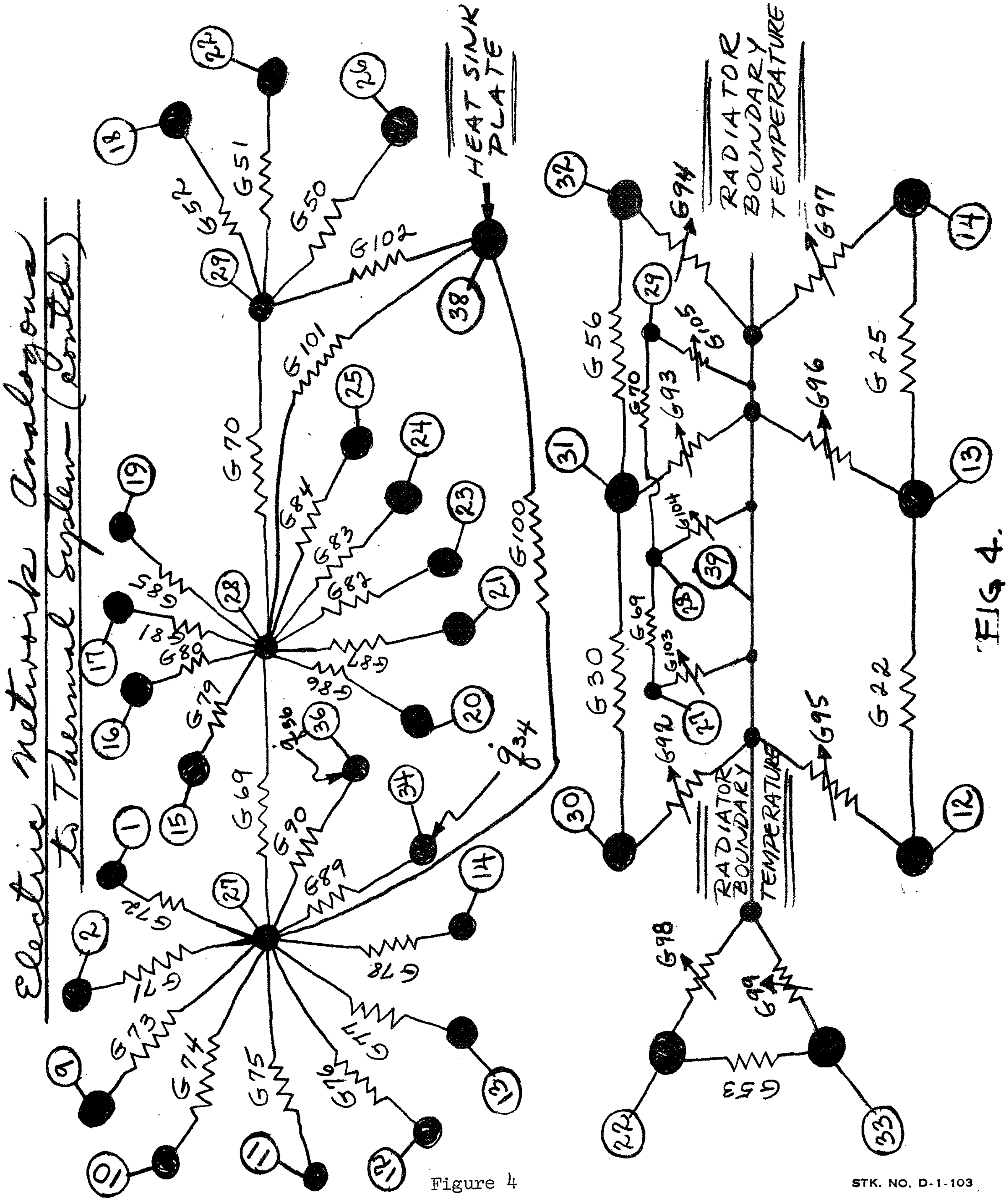

Figure 4

$$G38 = UA_{19-31} = \frac{1}{\left(\frac{1}{144}\right)\left(\frac{144}{6.75 \times .0215}\right) + \frac{5.295 \times 144}{12 \times 92 \times 6.75 \times .0215}} = \frac{1}{11.64}$$

(6.89) (4.75)

$$= \underline{0.0858} \text{ BTU/hr-°F}$$

$$G39 = UA_{24-31} = UA_{23-31} = G31 = \underline{0.093} \text{ BTU/hr-°F}$$

$$G40 = \left(\frac{KA}{x}\right)_{24-19} = \left(\frac{KA}{x}\right)_{19-23} = G32 = \underline{1.126} \text{ BTU/hr-°F}$$

$$G41 = \left(\frac{KA}{x}\right)_{23-24} = \left(\frac{KA}{x}\right)_{15-16} = G35 = \underline{2.038} \text{ BTU/hr-°F}$$

$$G42 = \left(\frac{KA}{x}\right)_{24-20} = \left(\frac{KA}{x}\right)_{19-24} = G40 = \underline{1.126} \text{ BTU/hr-°F}$$

$$G43 = \left(\frac{KA}{x}\right)_{24-25} = \left(\frac{KA}{x}\right)_{23-24} = G41 = \underline{2.038} \text{ BTU/hr-°F}$$

$$G44 = UA_{25-31} = UA_{23-31} = G31 = \underline{0.093} \text{ BTU/hr-°F}$$

$$G45 = \left(\frac{KA}{x}\right)_{25-20} = \left(\frac{KA}{x}\right)_{24-20} = G42 = \underline{1.126} \text{ BTU/hr-°F}$$

$$G46 = \left(\frac{KA}{x}\right)_{25-21} = \left(\frac{KA}{x}\right)_{24-20} = G42 = \underline{1.126} \text{ BTU/hr-°F}$$

$$G47 = \left(\frac{KA}{x}\right)_{25-26} = \frac{92 \times .215 \times 3.40}{12 \times 4.40} = \underline{1.273} \text{ BTU/hr-°F}$$

$$G48 = UA_{26-32} = \frac{1}{\left(\frac{1}{144}\right)\left(\frac{144}{3.36 \times 0.712}\right) + \frac{7.98 \times 144}{12 \times 92 \times 3.36 \times .712}} +$$

(.4175) (.435)

$$\frac{1}{\left(\frac{1}{144}\right)\left(\frac{144}{1.045 \times .0215}\right) + \frac{5.28 \times 144}{12 \times 92 \times 1.045 \times .0215}} = \frac{1}{.8525} + \frac{1}{75.2}$$

(44.5) (30.7) 1.174 .0133

$G48 = \underline{1.187}$ BTU/hr-°F

$$G49 = \sum\left(\frac{KA}{x}\right)_{26-22} = \frac{92 \times .215 \times 2.26}{12 \times 6.07} + \frac{92 \times .215 \times 5.12}{12 \times 2.775}$$

$= \underline{3.659}$ BTU/hr-°F

$$G50 = \left(\frac{KA}{x}\right)_{26-29} = \frac{92 \times .215 \times 3.86 \times .563}{12 \times 3.84} = \underline{0.934} \text{ BTU/hr-°F}$$

$$G51 = \sum\left(\frac{KA}{x}\right)_{29-22} = \frac{92 \times .215 \times 2.41}{12 \times 5.515} + \frac{92 \times .215 \times 6.59}{12 \times 1.95}$$

$= \underline{6.290}$ BTU/hr-°F

$$G52 = \left(\frac{KA}{x}\right)_{29-18} = \left(\frac{KA}{x}\right)_{29-26} = G50 = \underline{0.934} \text{ BTU/hr-°F}$$

$$G53 = UA_{33-22} = \frac{1}{\left(\frac{1}{144}\right)\left(\frac{144}{9 \times .10}\right) + \frac{.125 \times 144}{12 \times .1815 \times .90} + \frac{.108 \times 144}{12 \times 92 \times .90}}$$

$$= \frac{1}{10.306} = \underline{0.097} \text{ BTU/hr-°F}$$

$$G54 = UA_{32-22} = \frac{1}{\left(\frac{1}{144}\right)\left(\frac{144}{2.28 \times .0215}\right) + \frac{5.28 \times 144}{12 \times 92 \times 2.28 \times .0215}} +$$

$$= \frac{1}{\left(\frac{1}{144}\right)\left(\frac{144}{6.57 \times .0215}\right) + \frac{2.719 \times 144}{12 \times 92 \times 6.57 \times .0215}} = \underline{0.1332} \frac{\text{BTU}}{\text{hr-°F}}$$

$$G55 = \left(\frac{KA}{x}\right)_{22-18} = \left(\frac{KA}{x}\right)_{22-26} = G49 = \underline{3.659} \text{ BTU/hr-°F}$$

$$G56 = \left(\frac{KA}{x}\right)_{31-32} = \frac{92 \times 23.17 \times .090}{12 \times 6.30} = \underline{2.54} \text{ BTU/hr-°F}$$

$$G57 = UA_{32-18} = UA_{32-26} = G48 = \underline{1.187} \text{ BTU/hr-°F}$$

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$$G58 = \left(\frac{KA}{x}\right)_{18-21} = \left(\frac{KA}{x}\right)_{21-26} = \frac{92 \times .108 \times 7.38}{12 \times 5.573}$$
$$= \underline{\underline{1.095}} \text{ BTU/hr-°F}$$

$$G59 = \left(\frac{KA}{x}\right)_{21-17} = \left(\frac{KA}{x}\right)_{21-25} = G46 = \underline{\underline{1.126}} \text{ BTU/hr-°F}$$

$$G60 = UA_{21-31} = UA_{31-20} = G15 = \underline{\underline{0.0857}} \text{ BTU/hr-°F}$$

$$G61 = \left(\frac{KA}{x}\right)_{17-18} = \left(\frac{KA}{x}\right)_{25-26} = G47 = \underline{\underline{1.273}} \text{ BTU/hr-°F}$$

$$G62 = \left(\frac{KA}{x}\right)_{20-17} = \left(\frac{KA}{x}\right)_{20-25} = G45 = \underline{\underline{1.126}} \text{ BTU/hr-°F}$$

$$G63 = UA_{31-17} = UA_{31-25} = G44 = \underline{\underline{0.093}} \text{ BTU/hr-°F}$$

$$G64 = \left(\frac{KA}{x}\right)_{16-17} = \left(\frac{KA}{x}\right)_{24-25} = G43 = \underline{\underline{2.038}} \text{ BTU/hr-°F}$$

$$G65 = \left(\frac{KA}{x}\right)_{16-20} = \left(\frac{KA}{x}\right)_{24-20} = G42 = \underline{\underline{1.126}} \text{ BTU/hr-°F}$$

$$G66 = \left(\frac{KA}{x}\right)_{1-9} = \left(\frac{KA}{x}\right)_{2-11} = G16 = \underline{\underline{0.91}} \text{ BTU/hr-°F}$$

$$G67 = UA_{1-30} = UA_{2-30} = G20 = \underline{\underline{0.0905}} \text{ BTU/hr-°F}$$

$$G68 = \left(\frac{KA}{x}\right)_{21-26} = \left(\frac{KA}{x}\right)_{21-18} = G58 = \underline{\underline{1.095}} \text{ BTU/hr-°F}$$

$$G69 = \left(\frac{KA}{x}\right)_{27-28} = \frac{92 \times 10.29 \times .30}{12 \times 8.895} = \underline{\underline{2.585}} \text{ BTU/hr-°F}$$

$$G70 = \left(\frac{KA}{x}\right)_{28-29} = \frac{G69 \times 8.895}{7.29} = \underline{\underline{3.150}} \text{ BTU/hr-°F}$$

SUBJECT EPSM ANALYSIS BY RGR

$$G71 = \left(\frac{KA}{x}\right)_{27-2} = \frac{92 \times .215 \times 8.0}{12 \times 5.51} = \underline{\underline{2.395}} \text{ BTU/hr-°F}$$

$$G72 = \left(\frac{KA}{x}\right)_{27-1} = \frac{G71 \times .270}{.215} = \underline{\underline{3.01}} \text{ BTU/hr-°F}$$

$$G73 = \Sigma\left(\frac{KA}{x}\right)_{27-9} = \frac{92 \times .215 \times 2.75}{12 \times 8.29} + \frac{92 \times .215 \times 2.65}{12 \times 4.49}$$

(.547) (.971)

$$= \underline{\underline{1.518}} \text{ BTU/hr-°F}$$

$$G74 = \left(\frac{KA}{x}\right)_{27-10} = \frac{G71 \times 3.125}{8.0} = \underline{\underline{0.937}} \text{ BTU/hr-°F}$$

$$G75 = \Sigma\left(\frac{KA}{x}\right)_{27-11} = \Sigma\left(\frac{KA}{x}\right)_{27-9} = G73 = \underline{\underline{1.518}} \text{ BTU/hr-°F}$$

$$G76 = \Sigma\left(\frac{KA}{x}\right)_{27-12} = \frac{92 \times .215 \times 2.75}{12 \times 7.59} + \frac{92 \times .215 \times .55}{12 \times 8.09} + \frac{92 \times .215 \times 5.30}{12 \times 4.90} = \underline{\underline{2.494}} \frac{\text{BTU}}{\text{hr-°F}}$$

(.597) (.112) (1.785)

$$G77 = \left(\frac{KA}{x}\right)_{27-13} = \left(\frac{KA}{x}\right)_{27-10} = G74 = \underline{\underline{0.937}} \frac{\text{BTU}}{\text{hr-°F}}$$

$$G78 = \Sigma\left(\frac{KA}{x}\right)_{27-14} = \Sigma\left(\frac{KA}{x}\right)_{27-12} = G76 = \underline{\underline{2.494}} \frac{\text{BTU}}{\text{hr-°F}}$$

$$G79 = \Sigma\left(\frac{KA}{x}\right)_{28-15} = \frac{92 \times .85 \times .85}{12 \times 5.65} + \frac{92 \times .215 \times 3.1}{12 \times 5.30}$$

(.980) (.965)

$$= \underline{\underline{1.945}} \text{ BTU/hr-°F}$$

$$G80 = \Sigma\left(\frac{KA}{x}\right)_{28-16} = \Sigma\left(\frac{KA}{x}\right)_{28-15} = G79 = \underline{\underline{1.945}} \frac{\text{BTU}}{\text{hr-°F}}$$

$$G81 = \Sigma\left(\frac{KA}{x}\right)_{28-17} = \Sigma\left(\frac{KA}{x}\right)_{28-15} = G79 = \underline{\underline{1.945}} \text{ BTU/hr-°F}$$

$$G82 = \Sigma\left(\frac{KA}{x}\right)_{28-23} = \Sigma\left(\frac{KA}{x}\right)_{28-15} = G79 = \underline{\underline{1.945}}\ BTU/hr\text{-}°F$$

$$G83 = \Sigma\left(\frac{KA}{x}\right)_{28-24} = \Sigma\left(\frac{KA}{x}\right)_{28-15} = G79 = \underline{\underline{1.945}}\ BTU/hr\text{-}°F$$

$$G84 = \Sigma\left(\frac{KA}{x}\right)_{28-25} = \Sigma\left(\frac{KA}{x}\right)_{28-15} = G79 = \underline{\underline{1.945}}\ BTU/hr\text{-}°F$$

$$G85 = \left(\frac{KA}{x}\right)_{28-19} = \frac{92 \times .215 \times 6.75}{12 \times 5.39} = \underline{\underline{2.065}}\ BTU/hr\text{-}°F$$

$$G86 = \left(\frac{KA}{x}\right)_{28-20} = \left(\frac{KA}{x}\right)_{28-19} = G85 = \underline{\underline{2.065}}\ BTU/hr\text{-}°F$$

$$G87 = \left(\frac{KA}{x}\right)_{28-21} = \frac{G85 \times 5.39}{8.50} = \underline{\underline{1.310}}\ BTU/hr\text{-}°F$$

$$G88 = \Sigma\, UA_{2\text{-}35} = UA_{\substack{BOLTED\\JOINT}} + UA_{\substack{CORE\\PLATE\text{-}11\\RESISTORS}}$$

$$UA_{\substack{BOLTED\\JOINT}} = \frac{1}{\left(\frac{1}{144}\right)\left(\frac{144}{.230 \times .344}\right) + \frac{.152 \times 144}{12 \times 92 \times .230 \times .344}} \times 2$$

(12.64) (.2505)

$$= \underline{\underline{0.1552}}\ BTU/hr\text{-}°F$$

$$UA_{\substack{CORE\\PLATE\\11\ RES.}} = \frac{1}{\frac{1}{hA} + \frac{1}{K_{ij}}}$$

$$K_{ij} = \Sigma\left(\frac{KA}{x}\right) = \left(\frac{KA}{x}\right)_{Steel} + \left(\frac{KA}{x}\right)_{Be\text{-}O} + \left(\frac{KA}{x}\right)_{STEATITE} + \left(\frac{KA}{x}\right)_{AL}$$

$$= \frac{33 \times .785 \times \overline{.25}^2}{12 \times .080} + \frac{64 \times \pi \times .25 \times 1.062}{24 \times .125} + \frac{1.5 \times .785 \times \overline{.125}^2}{12 \times .080}$$

(1.688) (17.78) (.0767)

$$+ \frac{92 \times .80 \times 1.062}{12 \times .381}$$

(17.1)

$$= \underline{\underline{36.645}}\ BTU/hr\text{-}°F$$

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$$UA_{\substack{CORE\\PLATE\\ \parallel RES}} = \frac{1}{\left(\frac{1}{144}\right)\left(\frac{144}{1.062 \times 0.085}\right) + \frac{1}{36.645}}$$

(11.080; .02725)

$$= \underline{0.090} \ BTU/hr\text{-}°F$$

$$\therefore G88 = .1552 + .090 = \underline{\underline{0.2452}} \ BTU/hr\text{-}°F$$

$$G89 = UA_{27-34} = UA_{\substack{BOLTED\\JOINT}} + UA_{\substack{CORE\ PLATE\\ \parallel RESISTORS}}$$ (REFER TO G88 CALC)

$$UA_{\substack{BOLTED\\JOINTS}} = \frac{2}{12.64 + \frac{.2505 \times .194}{.152}} = \frac{2}{12.96}$$

(.320)

$$= \underline{\underline{0.1543}} \ BTU/hr\text{-}°F$$

$$K_{ij} = 1.688 + 17.78 + .0767 + \frac{17.1 \times .381}{.423}$$

(15.40)

$$= \underline{\underline{34.945}} \ BTU/hr\text{-}°F$$

$$UA_{\substack{CORE\ PLATE\\PARALLEL\ RES}} = \frac{1}{11.080 + \frac{1}{34.945}} = \frac{1}{11.109}$$

(.0286)

$$= \underline{\underline{0.090}} \ \frac{BTU}{hr\text{-}°F}$$

$$\therefore G89 = 0.1543 + 0.090 = \underline{\underline{0.2443}} \ \frac{BTU}{hr\text{-}°F}$$

$$G90 = UA_{27-36} = UA_{27-34} = \underline{\underline{0.2443}} \ \frac{BTU}{hr\text{-}°F}$$

$$G91 = UA_{21-37} \approx UA_{2-35}$$ (ASSUMED FOR LACK OF INFO.)

$$\approx G88 = \underline{\underline{0.2452}} \ BTU/hr\text{-}°F$$

CONDUCTANCE TO HEAT SINK PLATE:

$$G100 = UA_{27-H.S.} = UA_{\substack{BOLTED\\JOINT}} + UA_{PLATES}$$

$$= \frac{1}{\left(\frac{1}{144}\right)\left(\frac{5\times 144}{.785\times 1}\right) + \frac{.30\times 144\times 5}{12\times 92\times .785\times 1}} +$$

(6.37, 0.249)

$$\frac{1}{\left(\frac{1}{144}\right)\left(\frac{144}{9.20\times 10.29\times .25}\right) + \frac{.30\times 144}{12\times 92\times 9.20\times 10.29\times .70}}$$

(.0423, .001652)

$$= \frac{1}{6.619} + \frac{1}{.04395}$$

(.1512, 22.75)

$$= \underline{\underline{22.901}} \text{ BTU/hr-°F}$$

$$G101 = UA_{28-HS} = UA_{\substack{BOLTED\\JOINT}} + UA_{PLATES}$$

(.189, 23.05)

$$= \frac{.1512\times 5}{4} + \frac{22.75\times 9.32}{9.20}$$

$$= \underline{\underline{23.239}} \text{ BTU/hr-°F}$$

$$G102 = UA_{29-HS} = UA_{\substack{BOLTED\\JOINT}} + UA_{PLATES}$$

$$= \frac{.1512\times 5}{3} + \frac{22.75\times 4.20}{9.20}$$

(.252, 10.39)

$$= \underline{10.642} \text{ BTU/hr-°F}$$

Assumed Temperatures:

1. Heat Sink Plate — 140°F
2. Radiator — 225°F (RUN 1), 390°F (RUN 2), 550°F (RUN 3)

RADIATIVE CONDUCTORS:

$G92 = \sigma F_A F_e A_{30\text{-}BOUND} = .173 \times 10^{-8} \times 1 \times .19 \times \left(\frac{8.33 \times 23.0}{144}\right)$

$= \underline{4.375 \times 10^{-10}}\ BTU/hr\text{-}°R^4$

$G93 = \sigma F_A F_e A_{31\text{-}BOUND} = G92 \times 9.32/8.33$

$= \underline{4.895 \times 10^{-10}}\ BTU/hr\text{-}°R^4$

$G94 = \sigma F_A F_e A_{32\text{-}BOUND} = G92 \times 3.35/8.33$

$= \underline{1.760 \times 10^{-10}}\ BTU/hr\text{-}°R^4$

$G95 = \sigma F_A F_e A_{12\text{-}BOUND} = G92 \times \left(\frac{2.50 \times 7.38}{8.33 \times 23}\right)$

$= \underline{4.215 \times 10^{-11}}\ BTU/hr\text{-}°R^4$

$G96 = \sigma F_A F_e A_{13\text{-}BOUND} = G95 \times \left(\frac{3.35}{2.50}\right)$

$= \underline{5.585 \times 10^{-11}}\ BTU/hr\text{-}°R^4$

$G97 = \sigma F_A F_e A_{14\text{-}BOUND} = G95 = \underline{4.215 \times 10^{-11}}\ \frac{BTU}{hr\text{-}°R^4}$

$G98 = \sigma F_A F_e A_{22\text{-}BOUND} = .173 \times 10^{-8} \times \left(\frac{.19 \times 22.2}{144}\right)$

$= \underline{5.070 \times 10^{-11}}\ BTU/hr\text{-}°R^4$

$G99 = \sigma F_A F_e A_{33\text{-}BOUND} = G98 \times \left(\frac{43.2 \times .90}{22.2 \times .19}\right)$

$= \underline{4.675 \times 10^{-10}}\ BTU/hr\text{-}°R^4$

$G103 = \sigma F_A F_e A_{27\text{-}39} = .173 \times 10^{-8} \times .19 \times (22/144)$

$= \underline{5.020 \times 10^{-11}}\ BTU/hr\text{-}°R^4$

QUADRILLE WORK SHEET

AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

DATE 11/13/69

SUBJECT EPSM ANALYSIS BY R.G.R. WORK ORDER 1140-15-0800

$$G104 = \sigma F_A F_e A_{28-39} = G103 \times 14.5/22$$

$$= \underline{3.310 \times 10^{-11}}\ BTU/hr\text{-}{}^{\circ}R^4$$

$$G105 = \sigma F_A F_e A_{29-39} = G103 \times 15.3/22$$

$$= \underline{3.485 \times 10^{-11}}\ BTU/hr\text{-}{}^{\circ}R^4$$

```
//A1COCIND JOB (L3C5CECCRR,10),'RIVERA         45'            11-241130    4942T
//JOBLIB DD DSN=VKC.CINDAPRE,DISP=SHR
//A       EXEC CINCA
XX         PROC CLASS=A                                                  00000500
XXCINCA    EXEC PGM=CINPRE,REGICN=240K                                   00001000
XXSYSUDUMP DD SYSOUT=A                                                   00002000
XXFT08FC01      CD   UNIT=SYSDA,DISP=(NEW,PASS),SPACE=(TRK,(10,5)),      00003000
XX              DCB=(RECFM=FB,LRECL=90,BLKSIZE=3600)                     00004000
XXFTO1F001      CD   UNIT=SYSDA,DISP=(NEW,PASS),SPACE=(TRK,(5,2)),       00005000
XX              CCB=(RECFM=FB,LRECL=80,BLKSIZE=3200)                     00006000
XXFTC2FC01      DD   UNIT=SYSDA,DISP=(NEW,PASS),SPACE=(TRK,(10,5)),      00007000
XX              CCB=(RECFM=VB,LRECL=400,BLKSIZE=2004)                    00008000
XXFT1CF001      CC   UNIT=SYSDA,DISP=(NEW,PASS),SPACE=(TRK,(10,5)),      00009000
XX              CCB=(RECFM=VB,LRECL=400,BLKSIZE=2004)                    00010000
XXFT03F001      DD   UNIT=SYSDA,DISP=(NEW,PASS),SPACE=(TRK,(10,5)),      00011000
XX              CCB=(RECFM=VB,LRECL=400,BLKSIZE=2004)                    00012000
XXFTO4F001      DD   UNIT=SYSDA,DISP=(NEW,PASS),SPACE=(TRK,(10,5)),      00013000
XX              DCB=(RECFM=VB,LRECL=400,BLKSIZE=2004)                    00014000
XXFT11F001      CC   UNIT=SYSDA,DISP=(NEW,PASS),SPACE=(TRK,(10,5)),      00015000
XX              CCB=(RECFM=VB,LRECL=400,BLKSIZE=2004)                    00016000
XXFTO6FC01      CC   SYSOUT=&CLASS                                       00017000
XXFTO1F002      DD   DUMMY                                               00019000
XXFTC5F001      CD   DDNAME=SYSIN                                        00020000
//CINCA.SYSIN DC *
**JOB A1OCCIND START DATE 69.328 TIME 13.21.10
IEF236I ALLOC. FOR A1OCCIND CINDA     A
IEF237I JOBLIB   CN 137
IEF237I SYSUDUMP CN 136
IEF237I FTC8F001 CN 136
IEF237I FTC1F001 ON 136
IEF237I FTC2FC01 CN 341
IEF237I FT1CF001 ON 136
IEF237I FTC3FC01 CN 341
IEF237I FTC4FC01 CN 132
IEF237I FT11FC01 CN 340
IEF237I FTC6FC01 ON 126
IEF237I FTC5FC01 CN 134
```

```
BCD 3THERMAL LPCS
BCC 9STEACY  STATE ANALYSIS CF PROTOTYPE PROTECTIVE SYSTEM
END
BCD 3NODE DATA
GEN 1,37,1,160.,1.,1.,1.,1.
    -38,140.,0.
    -39,225.,0.
END

RELATIVE NODE NUMBERS                        ACTUAL NODE NUMBERS

   1  THRU     10          1      2      3      4      5      6      7      8      9     10
  11  THRU     20         11     12     13     14     15     16     17     18     19     20
  21  THRU     30         21     22     23     24     25     26     27     28     29     30
  31  THRU     39         31     32     33     34     35     36     37     38     39
BCC 3CONDUCTOR DATA
    104,1,10,2,10,2,14,2,13,1.528
    203,1,5,1,4,2,7,1.945
    302,1,13,1,12,1.91
    403,3,4,5,6,7,8,0.1089
    502,9,12,11,14,0.0273
    604,9,30,12,30,14,30,11,30,0.1531
    704,9,10,10,11,13,12,13,14,3.52
    802,9,23,11,15,3.08
    902,10,30,13,30,0.0328
    1003,20,31,19,31,21,31,0.0857
    1102,2,30,1,30,0.0905
    1206,23,31,16,31,15,31,24,31,25,31,17,31,0.093
    1309,19,23,15,19,16,19,19,24,20,24,20,25,21,25,17,21,17,20,1.126
    14,16,20,1.126
    1504,15,16,23,24,24,25,16,17,2.038
    1602,25,26,17,18,1.273
    1702,26,32,18,32,1.187
    1802,22,26,18,22,3.659
    1902,26,29,18,29,0.934
    2002,18,21,21,26,1.095
    2102,11,2,1,9,0.91
    22,30,31,1.810
    23,22,29,6.290
    24,22,32,0.1332
    25,31,32,2.540
    26,22,33,0.097,35,21,28,1.31,39,27,38,22.901
    27,27,28,2.585,28,28,29,3.150,29,2,27,2.395,30,1,27,3.01
    3102,9,27,11,27,1.518
    3202,12,27,14,27,2.494
```

```
     3302,10,27,13,27,0.937
     3406,15,28,16,28,17,28,23,28,24,28,25,28,1.945
     3602,19,28,20,28,2.065
     3702,2,35,21,37,0.2452
     3802,27,34,27,36,0.2443
     40,28,38,23.239,41,29,38,10.642
     -42,30,39,4.275E-10,-43,31,39,4.895E-10,-44,32,39,1.760E-10
     -45,12,39,4.215E-11,-46,13,39,5.585E-11,-47,14,39,4.215E-11
     -48,22,39,5.070E-11,-49,33,39,4.675E-10
     -50,27,39,5.02E-11,-51,28,39,3.31E-11,-52,29,39,3.485E-11
 END

 RELATIVE CONDUCTOR NUMBERS                           ACTUAL CONDUCTOR NUMBERS

     1  THRU    10         104    203    302    403    502    604    704    802    902   1003
    11  THRU    20        1102   1206   1309     14   1504   1602   1702   1802   1902   2002
    21  THRU    30        2102     22     23     24     25     26     35     39     27     28
    31  THRU    40          29     30   3102   3202   3302   3406   3602   3702   3802     40
    41  THRU    50          41     42     43     44     45     46     47     48     49     50
    51  THRU    52          51     52
 BCD 3CONSTANTS DATA
     NLOOP,200,DRLXCA,0.30
 END
 BCD 3ARRAY DATA
 END
 BCD 3EXECUTION
DIMENSION X(5000)                                        F
NDIM= 5000                                               F
NTH= 0                                                   F
     CSGDMP
     CINDSL
 END
 BCD 3VARIABLES 1
     SCALE(6.08,Q1,3.413)
     SCALE(8.38,Q2,3.413)
     SCALE(3.20,Q3,3.413,Q6,3.413,Q8,3.413)
     SCALE(1.0,Q4,3.413,Q5,3.413,Q7,3.413)
     SCALE(3.03,Q10,3.413)
     SCALE(0.015,Q15,3.413,Q16,3.413,Q17,3.413,Q23,3.413)
     SCALE(0.015,Q25,3.413,Q24,3.413)
     SCALE(28.0,Q21,3.413)
     SCALE(3.60,Q34,3.413,Q35,3.413,Q36,3.413)
     SCALE(3.50,Q37,3.413)
 END
 BCD 3VARIABLES 2
 END
 BCD 3OUTPUT CALLS
     TPRINT
 END
```

```
   STEADY  STATE ANALYSIS OF PROTOTYPE PROTECTIVE SYSTEM  225 °F
 37 1.000E 00 4.078E 00
                              38  LIN 2.452E-01   21 DIFF

*  *  *  *
TIME  0.0         CTIMEU  0.0         CSGMIN(    0)   0.0         DTMPCC(    0)   0.0         ARLXCC(    0)   0.0

T    1=  1.60000E 02  T    2=  1.60000E 02  T    3=  1.60000E 02  T    4=  1.60000E 02  T    5=  1.60000E 02  T    6=  1.60000E 02
T    7=  1.60000E 02  T    8=  1.60000E 02  T    9=  1.60000E 02  T   10=  1.60000E 02  T   11=  1.60000E 02  T   12=  1.60000E 02
T   13=  1.60000E 02  T   14=  1.60000E 02  T   15=  1.60000E 02  T   16=  1.60000E 02  T   17=  1.60000E 02  T   18=  1.60000E 02
T   19=  1.60000E 02  T   20=  1.60000E 02  T   21=  1.60000E 02  T   22=  1.60000E 02  T   23=  1.60000E 02  T   24=  1.60000E 02
T   25=  1.60000E 02  T   26=  1.60000E 02  T   27=  1.60000E 02  T   28=  1.60000E 02  T   29=  1.60000E 02  T   30=  1.60000E 02
T   31=  1.60000E 02  T   32=  1.60000E 02  T   33=  1.60000E 02  T   34=  1.60000E 02  T   35=  1.60000E 02  T   36=  1.60000E 02
T   37=  1.60000E 02  T   38=  1.40000E 02  T   39=  2.25000E 02

*  *  *  *
TIME  0.0         CTIMEU  0.0         CSGMIN(    0)   0.0         DTMPCC(    0)   0.0         ARLXCC(   17)   2.64954E-01

T    1=  1.57533E 02  T    2=  1.59563E 02  T    3=  2.65163E 02  T    4=  1.64902E 02  T    5=  1.64902E 02  T    6=  2.65191E 02
T    7=  1.66941E 02  T    8=  2.67230E 02  T    9=  1.52939E 02  T   10=  1.55114E 02  T   11=  1.53106E 02  T   12=  1.53995E 02
T   13=  1.55290E 02  T   14=  1.54282E 02  T   15=  1.50501E 02  T   16=  1.50399E 02  T   17=  1.53812E 02  T   18=  1.56933E 02
T   19=  1.49288E 02  T   20=  1.50403E 02  T   21=  1.71884E 02  T   22=  1.52786E 02  T   23=  1.50362E 02  T   24=  1.50251E 02
T   25=  1.53722E 02  T   26=  1.56920E 02  T   27=  1.46903E 02  T   28=  1.45565E 02  T   29=  1.46038E 02  T   30=  1.77117E 02
T   31=  1.74324E 02  T   32=  1.67832E 02  T   33=  2.14770E 02  T   34=  1.97197E 02  T   35=  2.09672E 02  T   36=  1.97197E 02
T   37=  2.20602E 02  T   38=  1.40000E 02  T   39=  2.25000E 02

LOOPCT =      8 ENGBAL =  0.91933E 01
```

```
   RUN NUMBER 2   35C F RADIATOR TEMPERATURE
 37 1.000E 00 4.078E 00
                          38  LIN 2.452E-01   21 DIFF

*  *  *  *
TIME  0.0         DTIMEU  0.0        CSGMIN(    0)   0.0        DTMPCC(    0)   0.0        ARLXCC(    0)  0.0

T    1=  1.60000E 02  T    2=  1.60000E 02  T    3=  1.60000E 02  T    4=  1.60000E 02  T    5=  1.60000E 02  T    6=  1.60000E 02
T    7=  1.60000E 02  T    8=  1.60000E 02  T    9=  1.60000E 02  T   10=  1.60000E 02  T   11=  1.60000E 02  T   12=  1.60000E 02
T   13=  1.60000E 02  T   14=  1.60000E 02  T   15=  1.60000E 02  T   16=  1.60000E 02  T   17=  1.60000E 02  T   18=  1.60000E 02
T   19=  1.60000E 02  T   20=  1.60000E 02  T   21=  1.60000E 02  T   22=  1.60000E 02  T   23=  1.60000E 02  T   24=  1.60000E 02
T   25=  1.60000E 02  T   26=  1.60000E 02  T   27=  1.60000E 02  T   28=  1.60000E 02  T   29=  1.60000E 02  T   30=  1.60000E 02
T   31=  1.60000E 02  T   32=  1.60000E 02  T   33=  1.60000E 02  T   34=  1.60000E 02  T   35=  1.60000E 02  T   36=  1.60000E 02
T   37=  1.60000E 02  T   38=  1.40000E 02  T   39=  3.90000E 02

*  *  *  *
TIME  0.0         DTIMEU  0.0        CSGMIN(    0)   0.0        DTMPCC(    0)   0.0        ARLXCC(    3)  6.25000E-02

T    1=  1.67942E 02  T    2=  1.70015E 02  T    3=  2.75606E 02  T    4=  1.75312E 02  T    5=  1.75312E 02  T    6=  2.75602E 02
T    7=  1.77382E 02  T    8=  2.77672E 02  T    9=  1.63053E 02  T   10=  1.65045E 02  T   11=  1.63289E 02  T   12=  1.66961E 02
T   13=  1.68472E 02  T   14=  1.67335E 02  T   15=  1.59809E 02  T   16=  1.59999E 02  T   17=  1.65826E 02  T   18=  1.78405E 02
T   19=  1.58193E 02  T   20=  1.60246E 02  T   21=  1.86834E 02  T   22=  1.70530E 02  T   23=  1.59731E 02  T   24=  1.59999E 02
T   25=  1.65836E 02  T   26=  1.78414E 02  T   27=  1.51835E 02  T   28=  1.50495E 02  T   29=  1.54127E 02  T   30=  2.66773E 02
T   31=  2.55844E 02  T   32=  2.27579E 02  T   33=  3.72410E 02  T   34=  2.02129E 02  T   35=  2.20124E 02  T   36=  2.02129E 02
T   37=  2.35551E 02  T   38=  1.40000E 02  T   39=  3.90000E 02

LOOPCT =      12 ENGEAL =  0.248000E 01
```

```
TRW SYSTEMS IMPROVED NUMERICAL DIFFERENCING ANALYZER  - - SINDA - - IBM-360/75 VERSION, IDAHO NUCLEAR CORP.    PAGE   6

   RUN NUMBER 3   55C F RADIATCR TEMPERATURE
 37 1.0CCE 00 4.C7EE CC
                          38  LIN 2.452E-01   21 DIFF

*   *   *   *
TIME  0.0          DTIMEU  0.0          CSGMIN(    0)   0.0          DTMPCC(    0)   0.0          ARLXCC(    0)  0.0

T     1=  1.60CCCE 02  T    2=  1.60000E 02  T    3=  1.60000E 02  T    4=  1.60000E 02  T    5=  1.60000E 02  T    6=  1.60000E 02
T     7=  1.60CCCE 02  T    8=  1.60000E 02  T    9=  1.60000E 02  T   10=  1.60000E 02  T   11=  1.60000E 02  T   12=  1.60000E 02
T    13=  1.60CCCE 02  T   14=  1.6CC00E 02  T   15=  1.60000E 02  T   16=  1.60000E 02  T   17=  1.60000E 02  T   18=  1.60000E 02
T    19=  1.60C00E 02  T   20=  1.60000E 02  T   21=  1.60000E 02  T   22=  1.60000E 02  T   23=  1.60000E 02  T   24=  1.60000E 02
T    25=  1.6CCCCE C2  T   26=  1.60000E 02  T   27=  1.60000E 02  T   28=  1.600C0E 02  T   29=  1.60000E 02  T   30=  1.60000E 02
T    31=  1.600C0E 02  T   32=  1.60000E 02  T   33=  1.60000E 02  T   34=  1.60000E 02  T   35=  1.60000E 02  T   36=  1.60000E 02
T    37=  1.60CCCE 02  T   38=  1.4CC00E 02  T   39=  5.50000E 02

*   *   *   *
TIME  0.0          DTIMEU  0.0          CSGMIN(    0)   0.0          DTMPCC(    0)   0.0          ARLXCC(   10)  1.66931E-01

T     1=  1.84146E 02  T    2=  1.86546E 02  T    3=  2.91710E 02  T    4=  1.91511E 02  T    5=  1.91511E 02  T    6=  2.91801E 02
T     7=  1.93910E 02  T    8=  2.94199E 02  T    9=  1.78965E 02  T   10=  1.80732E 02  T   11=  1.79312E 02  T   12=  1.87339E 02
T    13=  1.89422E 02  T   14=  1.88C06E 02  T   15=  1.74495E 02  T   16=  1.75077E 02  T   17=  1.84281E 02  T   18=  2.10524E 02
T    19=  1.72165E 02  T   20=  1.75511E 02  T   21=  2.09471E 02  T   22=  1.96822E 02  T   23=  1.74405E 02  T   24=  1.75111E 02
T    25=  1.84298E C2  T   26=  2.10530E 02  T   27=  1.59654E 02  T   28=  1.58158E 02  T   29=  1.66299E 02  T   30=  3.96231E 02
T    31=  3.75495E 02  T   32=  3.16774E 02  T   33=  5.32650E 02  T   34=  2.09948E 02  T   35=  2.36655E 02  T   36=  2.09948E 02
T    37=  2.58188E C2  T   38=  1.40C00E 02  T   39=  5.50000E 02

LOOPCT =      12 ENGBAL =  0.77824E C1


         END OF DATA
```

APPENDIX C

EXPERIMENTAL TIMING REACTOR DESIGN AND ANALYSIS

PSM TIMING INDUCTOR

$$B_{SAT} = \frac{3.49\ V \times 10^6}{f A K_1 N}$$

where V is rms value of a sinusoidal voltage

if V is given in average or DC volts

$$V_{rms} = \frac{\pi}{\sqrt{2}} V_{av}$$ For ½ sine wave averaged over period 2π

$$B_{SAT} = \frac{3.49 \times \frac{\pi}{\sqrt{2}} V_{av} \times 10^6}{f A_i K_1 N}$$

$$f = \frac{1}{T}$$

$$B_{SAT} = \frac{3.49 \times \frac{\pi}{\sqrt{2}} V_{av} T \times 10^6}{N A_i K_1} = \frac{.775\ V_{av} T \times 10^7}{N A_i K_1}$$

$$N = \frac{.775\ V_{av} T \times 10^7}{B_{SAT} A_i K_1}$$

$$T = \frac{B_{SAT} N A_i K_1}{.775\ V_{av} \times 10^7}$$

For Experimental Timing Reactor

Core 6T5468-D2 $A_i = .5\ in^2$ $K_1 = .85$

$N = 4255$ turns

$V_{DC} = 20.V$

$$T = \frac{14700 \times 4255 \times .5 \times .85 \times 10^{-7}}{.775 \times 20} = \frac{1.47 \times 4.255 \times .5 \times .85}{.775 \times 2 \times 10^1} = .1718\ sec$$

measured $T = .05 \frac{sec}{cm} \times 3.5\,cm = .175\ sec$ % error $= \frac{.172 - .175}{.175} \times 100 = \frac{-.3}{.175} = -1.71\%$

$V_{DC} = 15V$

$$T = \frac{1.47 \times 4.255 \times .5 \times .85}{.775 \times 1.5 \times 10^1} = .229\ sec$$

measured $T = .05 \frac{sec}{cm} \times 4.7\,cm = .235\ sec$ % error $= \frac{.229 - .235}{.235} \times 100 = \frac{-.6}{.235} = -2.55\%$

EXPERIMENTAL TIMING REACTOR DESIGN & ANALYSIS

7-16-69

6T-5468-D2

$d_2 = 2.352 \quad d_3 = 3.648 \quad h_3 = 1.151 \quad A_i = .500\ in^2 \quad A_w = 4.40\ in^2$

T = .172 sec V = 20 VDC

$$N = \frac{.775 \times V_{av}\ T \times 10^7}{B_{SAT}\ A_i\ K_1} = \frac{.775 \times 20 \times .172 \times 10^7}{14200 \times .5 \times .85} = 4260 \text{ turns}$$

$$A' = K_2\ A_W = .35 \times 4.40 = 1.54\ in^2$$

$$a = \frac{1.54}{4260} = 3.72 \times 10^{-4}\ in^2$$ 24 AWG $a = 3.173 \times 10^{-4}\ in^2$ $\Omega/ft = 25.67 \times 10^{-3}$

$$d_1 = \sqrt{d_2^2 - \frac{4Na}{\pi K_3}} = \sqrt{(2.352)^2 - \frac{4 \times 4260 \times 3.173 \times 10^{-4}}{\pi \times .5}} = \sqrt{5.58 - \frac{4 \times .426 \times 3.173}{\pi \times .5}}$$

$$d_1 = \sqrt{5.58 - 3.44} = \sqrt{2.14} = 1.46\ in$$ meas 1.46 in

use $K_3 = .5$ if a is for bare wire

use $K_3 = .6$ if a is for insulated wire

$$d_4 = \sqrt{d_3^2 + d_2^2 - d_1^2} = \sqrt{(3.648)^2 + (2.352)^2 - (1.46)^2}$$

$$= \sqrt{13.31 + 5.58 - 2.14} = \sqrt{18.89 - 2.14} = \sqrt{16.75}$$

$= 4.09\ in$ meas 4.15 in -1.4%

$$h_4 = h_3 + \frac{d_2^2 - d_1^2}{2 d_2} = 1.151 + \frac{(2.352)^2 - (1.46)^2}{2 \times 2.352} = 1.151 + \frac{5.58 - 2.14}{4.704} = 1.151 + \frac{3.44}{4.704} = 1.151 + .731$$

$h_4 = 1.882$

$$h_4 = h_3 + \frac{d_4^2 - d_3^2}{2 d_2} = 1.151 + \frac{16.75 - 13.31}{4.704} = 1.151 + \frac{3.44}{4.704} = 1.151 + .731 =$$

$h_4 = 1.882$ meas 1.80 in $+4.4\%$

7-17-69
KGW
(2)

$$MLT = 2l_3 + d_3 - d_2 + \frac{\pi}{4}(r_1 + r_2 + r_3 + r_4)$$

$$r_1 = \frac{d_2 - d_1}{2} = \frac{2.352 - 1.46}{2} = \frac{.892}{2} = .446 \text{ in}$$

$$r_2 = \frac{d_2^2 - d_1^2}{4d_2} = \frac{(2.352)^2 - (1.46)^2}{4 \times 2.352} = \frac{5.58 - 2.14}{9.408} = \frac{3.44}{9.408} = .366 \text{ in}$$

$$r_2 = \frac{d_4^2 - d_3^2}{4d_2} = \frac{(4.09)^2 - (3.648)^2}{4 \times 2.352} = \frac{16.75 - 13.31}{9.408} = \frac{3.44}{9.408} = .366 \text{ in}$$

$$r_3 = \frac{d_2^2 - d_1^2}{4d_3} = \frac{(2.352)^2 - (1.46)^2}{4 \times 3.648} = \frac{5.58 - 2.14}{14.592} = \frac{3.44}{14.592} = .236 \text{ in}$$

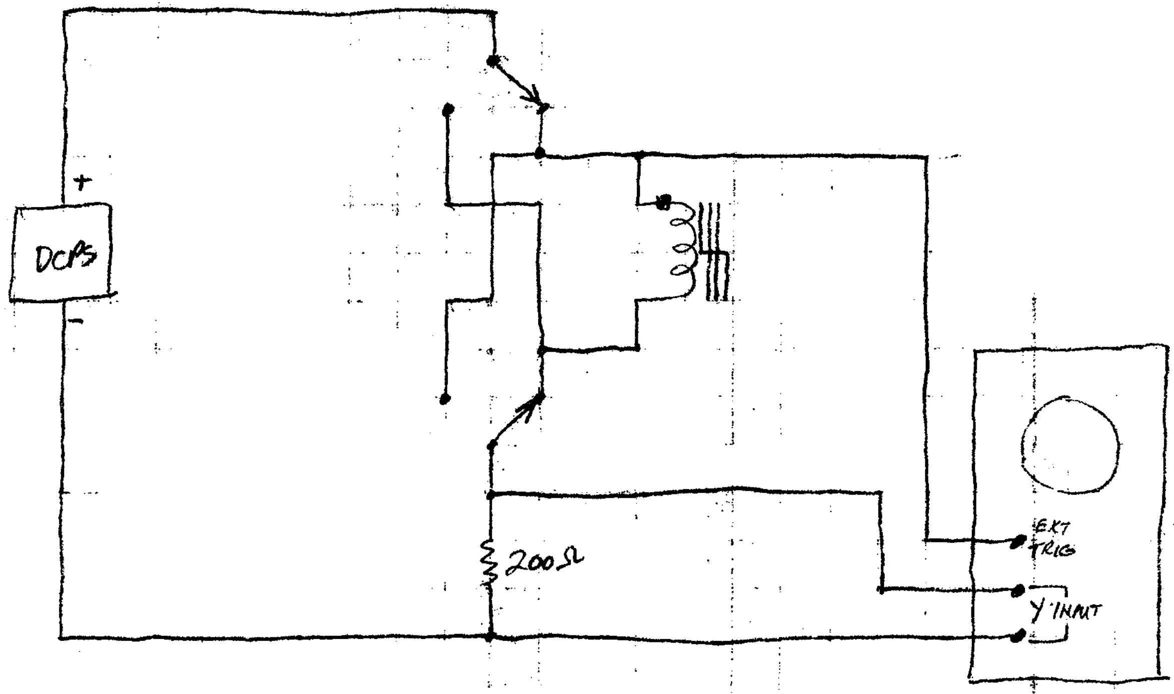
$$r_3 = \frac{d_4^2 - d_3^2}{4d_3} = \frac{(4.09)^2 - (3.648)^2}{4 \times 3.648} = \frac{16.75 - 13.31}{14.592} = \frac{3.44}{14.592} = .236 \text{ in}$$

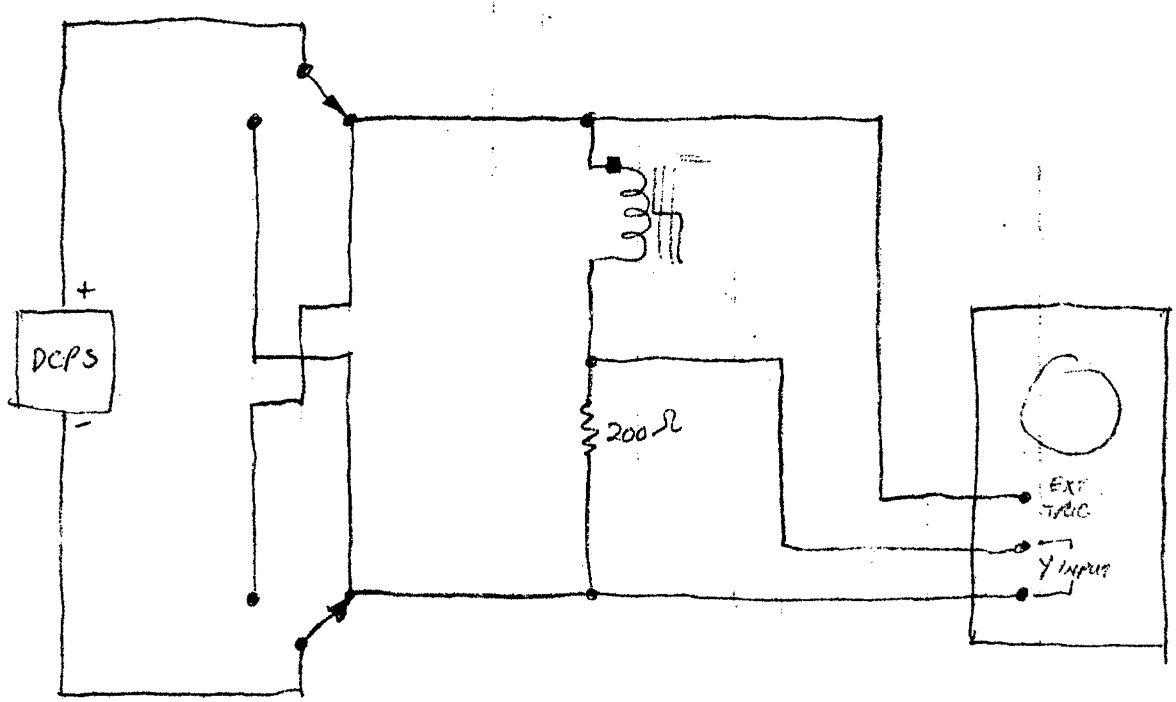
$$r_4 = \frac{d_4 - d_3}{2} = \frac{4.09 - 3.648}{2} = \frac{.442}{2} = .221 \text{ in}$$

$$MLT = 2 \times 1.151 + 3.648 - 2.352 + \frac{\pi}{4}(.446 + .366 + .236 + .221)$$

$$= 2.302 + 1.296 + \frac{\pi}{4}(1.269) = 3.598 + .996 = 4.594 \text{ in} = .383 \text{ ft}$$

$R_N = 4260 \times .383 \times 25.67 \times 10^{-3} = 41.9\ \Omega$ max $40\ \Omega$ $+4.8\%$


+
DCPS
−
200Ω
EXT TRIG
Y INPUT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DCPS
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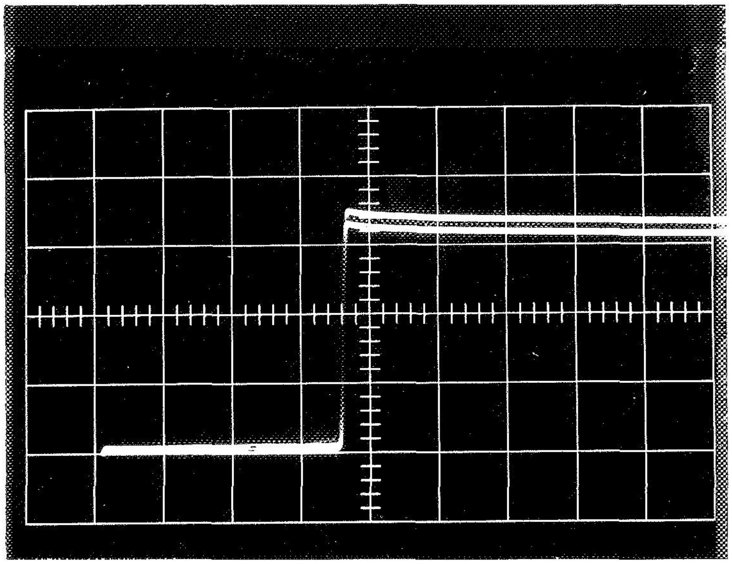
EXT TRIG
Y INPUT

4-8-69

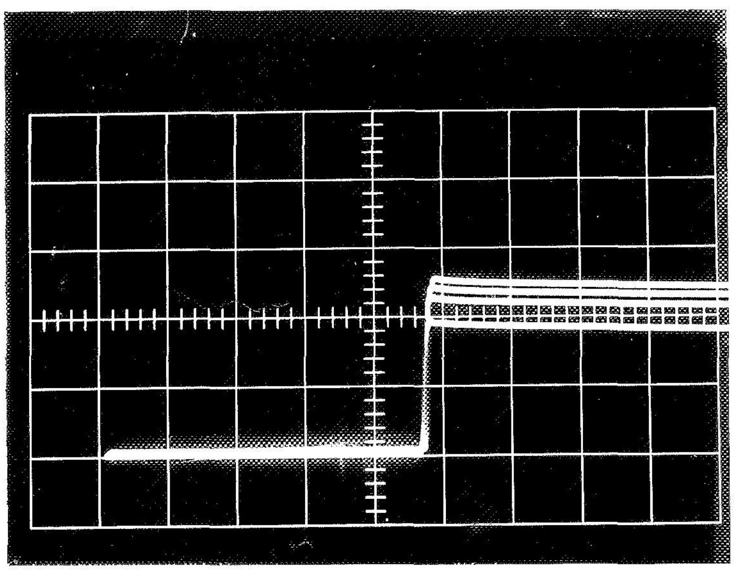


V_{DC} = 20 VOLTS

R_L = 500 Ω TOP
R_L = 300 Ω BOTTOM

TIME DELAY

$.05 \frac{sec}{cm} \times 3.5 cm = .175$ SEC



V_{DC} = 15 VOLTS

R_L = 500 Ω TOP
R_L = 300 Ω
R_L = 200 Ω
R_L = 100 Ω BOTTOM

TIME DELAY

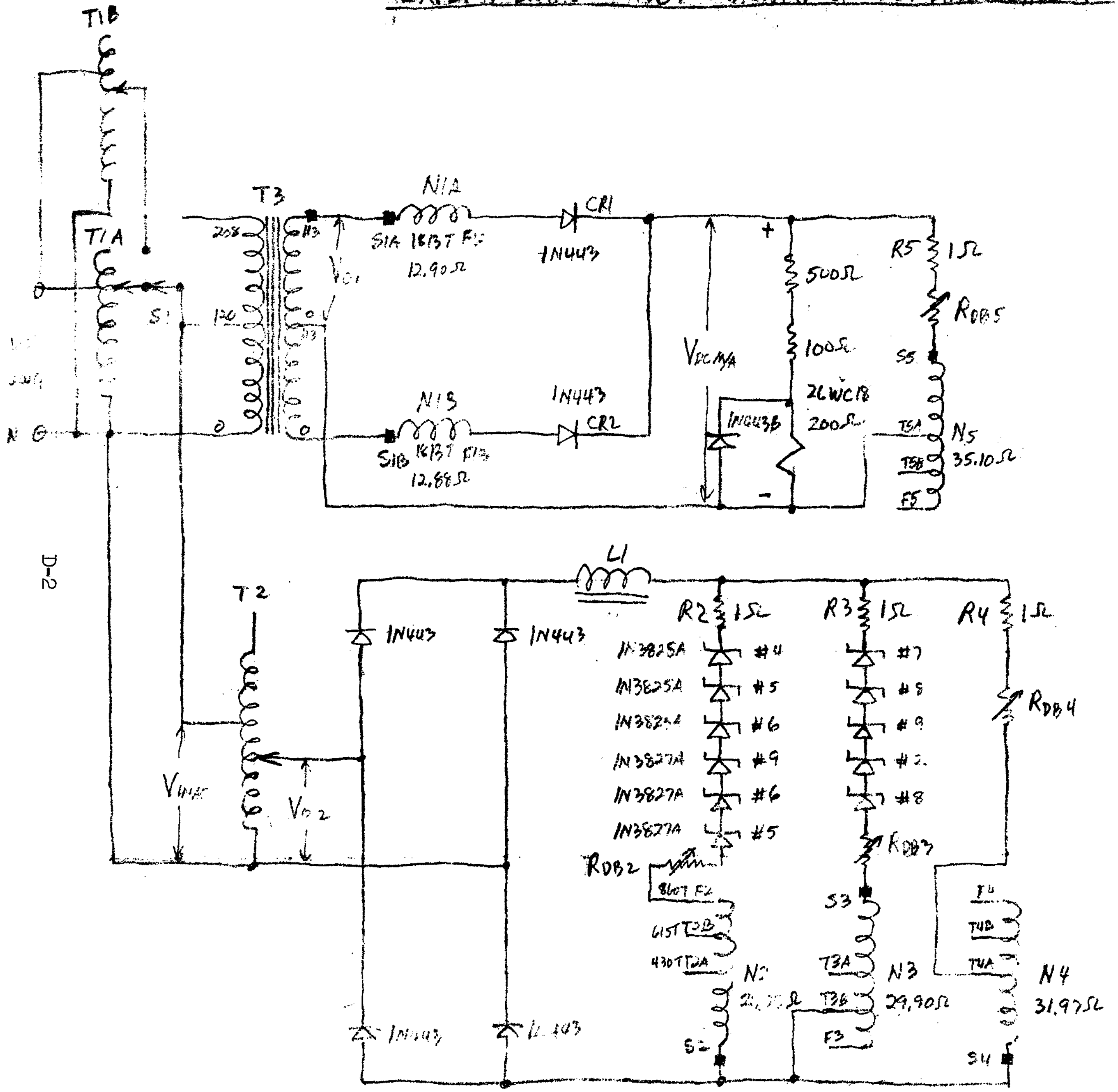
$.05 \frac{sec}{cm} \times 4.7 cm = .235$ SEC

APPENDIX D

EXPERIMENTAL UV/OV MAGAMP DESIGN

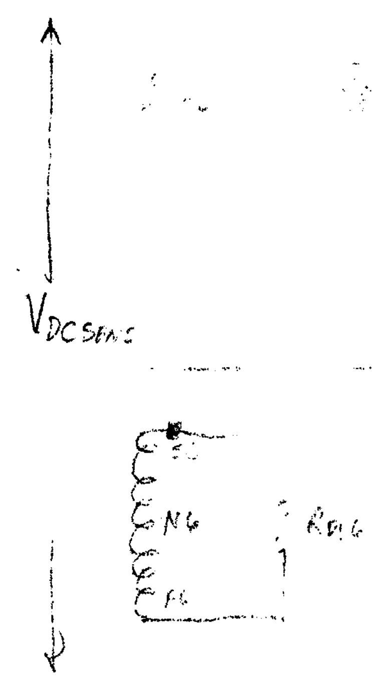
AND CONTROL CHARACTERISTICS

EXPERIMENTAL UV/OV MAGAMP & SENSING CIRCUIT



S1A – F1A	12.90 Ω	
S1B – F1B	12.88 Ω	
S2 – T2A	14.07 Ω	
S2 – T2B	19.90	
S2 – F2	27.75	*
S3 – T2A	15.04 Ω	
S3 – T2B	21.54	*
S3 – F3	29.90	
S4 – T4A	16.00 Ω	*
S4 – T4B	22.91	
S4 – F4	31.97	
S5 – T5A	17.39 Ω	*
S5 – T5B	25.15	
S5 – F5	35.10	

~~3-11-69~~
RW
~~5-22-69~~
~~5-29-69~~
6-10-69



PSM UV/OV PRELIMINARY MAGAMP [illegible]

RAW

6T-5468-D2

core id = 2.500 od = 3.500 h = 1.000 $\frac{id}{od} = .70$ Ac = .500 l_c = 9.43 AcAw = 2.2[illegible]

case OD = 2.366 OD = 3.634 H = 1.161 Aw = 4.40 in² = 5.60 x 10⁶ cm

* 4179-D2

core id = 1.625 od = 2.000 h = .250 $\frac{id}{od} = .81$ Ac = .0469 l_c = 5.69 AcAw = .0743

case ID = 1.521 OD = 2.104 h = .383 Aw = 1.82 in² = 2.31 x 10⁶ cm

net Aw = .3 x Aw = .3 x 2.31 x 10⁶ = .693 x 10⁶ cm

if ½ for control wind & ½ for gate

net control A = .5 x .693 x 10⁶ cm = .3465 x 10⁶ cm

= 346,500 cm

if all control is #30 & all have same # turns

$$N = \frac{346500}{100.5} = 3440 \text{ turns} \qquad N_{each} = \frac{3440}{4} = 860$$

$$N_g = \frac{3.49 \times V \times 10^6}{400 \times .0469 \times .85 \times 14.5 \times 10^3} = \frac{3.49 \times 10^2 \, V}{4 \times 4.69 \times .85 \times 1.45} = 15.11\,V$$

if V = 120 v

$$N_g = 15.11 \times 120 = 1813$$

$$I_c = \frac{.36 \times 5.69}{.495 \times 860} = \frac{3.6 \times 5.69 \times 10^{-1}}{4.95 \times .86 \times 10^{1}} = 4.81 \times 10^{-2} = .481 \times 10^{-3}\,a$$

461000
346500
807500
$\frac{.807}{2.31} = .35$

A_g = 1813 x 1022 = 1856,000 if gate is #20

$$a_g = \frac{346500}{1813} = 190.8 \text{ cm/turn} \approx \#27$$ #26 1813 x 254.1 = 461000

Core 4T-4179-D2 1 matched pair (2 cores)

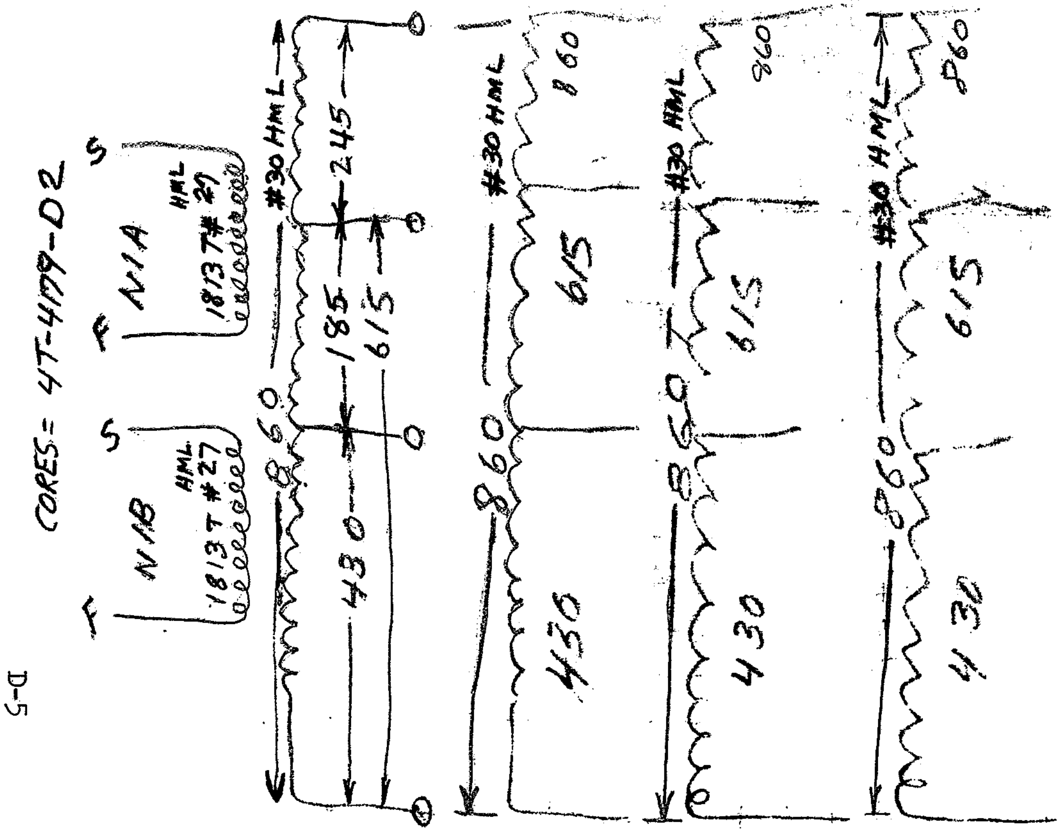
1. Attach #20 vinyl lead to start of each gate winding. Insulate & anchor with Mystik 7000 glass tape (or 3M #27 glass tape) on OD of core.
2. Progressive wind on each core in CCW direction 1813 turns #27 HML or HF magnet wire. Overlap start by finish approx 1/4 inch & insulate between with Mystik 7000 glass tape .5 wide, 3 layers. Check Vout at 400CPS = 120v adjust as required. Check Iex [illegible] record
3. Attach finish lead. Insulate & anchor with Mystik 7000 glass tape on OD of coil.
4. Cover each gate winding with 2 layers 1/2 lapped of type B glass fabric .5 wide. Anchor ends with 7000 glass tape.
5. Maintain same orientation for both gates & stack one on top of the other & tie together with glass sleeving in about 3 or 4 places. Locate knots on OD of coil.
6. Progressive wind 860 turns #30 HML or HF magnet wire in CCW direction over stacked assembly. Attach #24 or #26 vinyl leads to start & finish & anchor with 7000 tape on OD of coil. Pull taps at 430 & 615 turns & attach leads.
7. Cover with 1 layer 1/2 lapped type B glass tape. Anchor ends with 7000 glass tape.
8. Repeat 6 & 7 3 more times one on top of the other for a total of 4 windings of #30 wire.
9. Cover final layer with 2 layers 1/2 lapped type B glass fabric .5 wide
10. Measure DCR of each winding & record. See N.E. WALDSCHMIDT for other tests

EXPERIMENT I
UNDER/OVER VOLTA[illegible]
MAG-AMP

N1A [illegible] SV = 120 [illegible] @ 400 ~

N1B SV = 120 [illegible] @ 400 ~

TURNS - 1813 = .00552



with wheatstone DC R
#39549
3/11/69

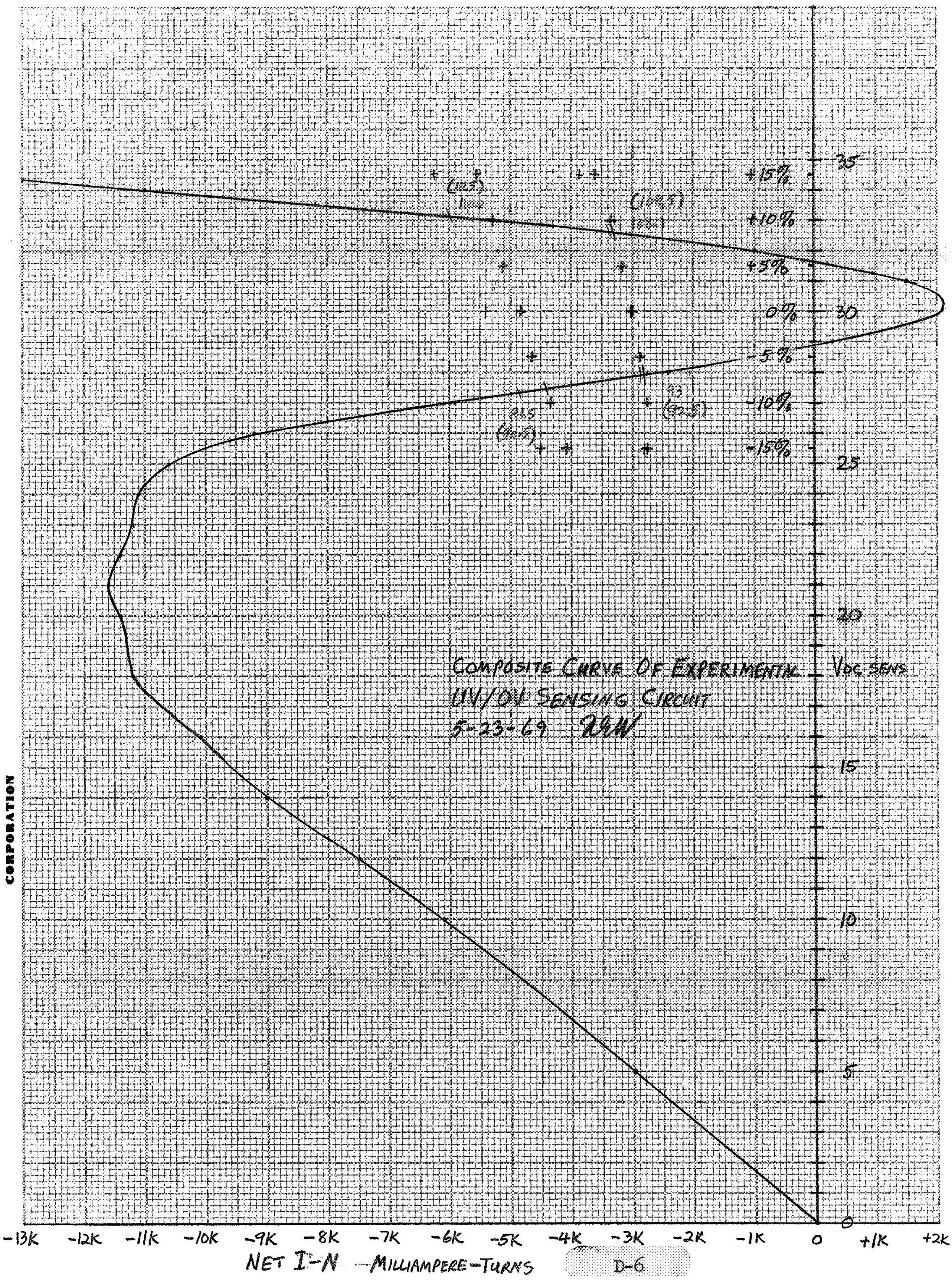
N1A — 12.90
N1B — 12.88

N2 S/430T = 14.07
N2 S/615T = 19.90
N2 S/F = 27.95

N3 S/430T = 15.04
N3 S/615T = 21.54
N3 S/F = 29.90

N4 S/430T = 16.00
N4 S/615T = 22.91
N4 S/F = 31.9[illegible]

N5 S/430T = 17.39
S/615T = 25.15
S/F = 35.10


COMPOSITE CURVE OF EXPERIMENTAL
UV/OV SENSING CIRCUIT
5-23-69
VDC SENS
+15%
+10%
+5%
0%
-5%
-10%
-15%
35
30
25
20
15
10
5
0
-13K
-12K
-11K
-10K
-9K
-8K
-7K
-6K
-5K
-4K
-3K
-2K
-1K
0
+1K
+2K
NET I-N — MILLIAMPERE-TURNS

N_2 = 860T N_3 = 615T N_4 = 430T N_5 = 430T

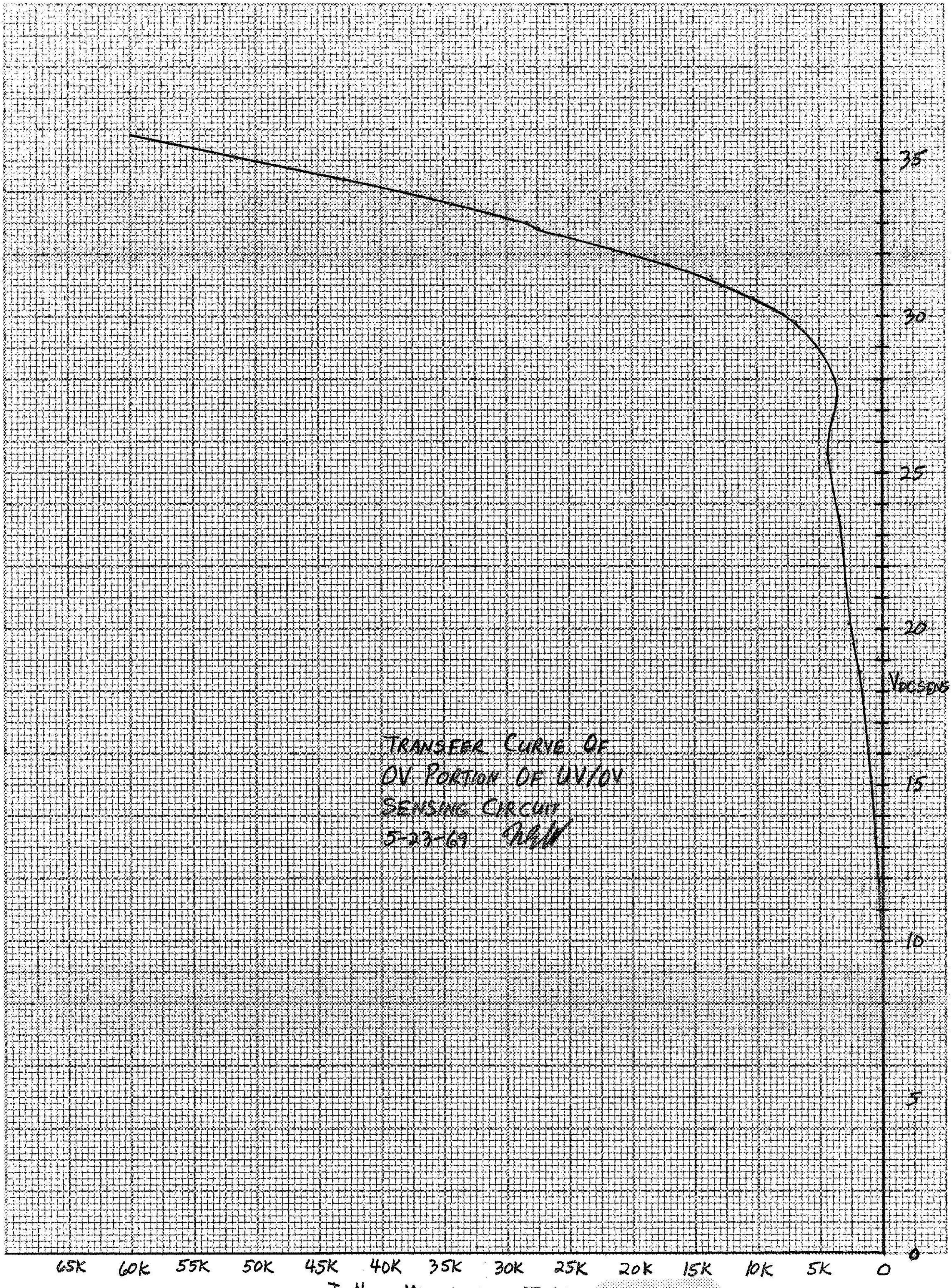
R_{DB2} = 35Ω R_{DB3} = 85Ω R_{DB4} = 700Ω R_{DB5} = 7500Ω

ZD2 = 3 4.7V IN3825A (#4, #5, #6) & 3 5.6V IN3827A (#5, #6, #9)

ZD3 = 3 4.7V IN3825A (#7, #8, #9) & 2 5.6V IN3827A (#2, #8)

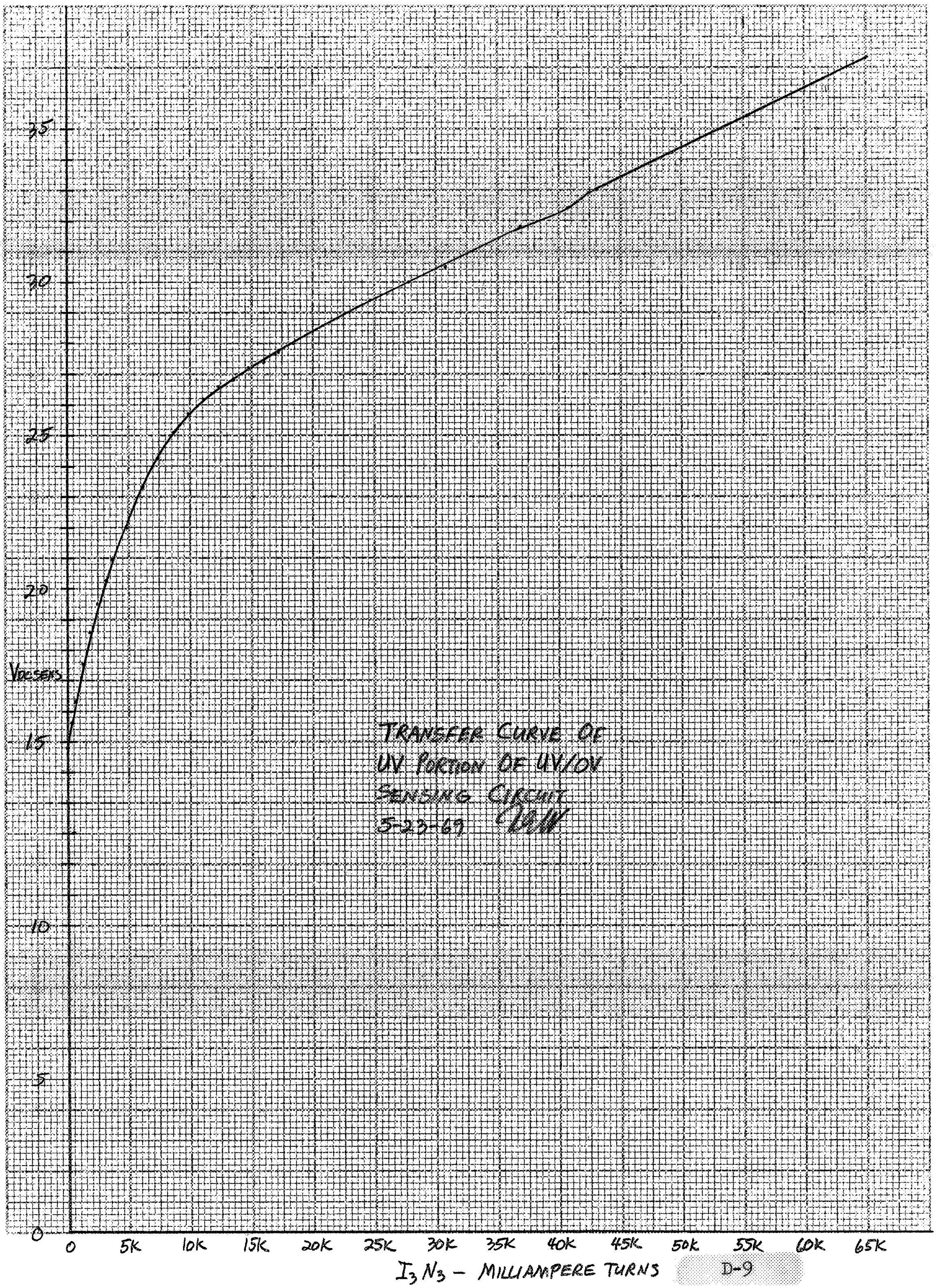
M/A GATES ENERGIZED – MAINTAINED V_{O1} = 100.0 V I_L = 0.2 A

V_{DC} SENS	I_2N_2	I_4N_4	$I_2N_2+I_4N_4$	I_3N_3	IN_{NET}
0	0	0	0	0	0
5.0	0	-3000	-3000	0	-3000
10.0	0	-6100	-6100	0	-6100
12.0	-300	-7200	-7500	0	-7500
14.0	-600	-8400	-9000	0	-9000
16.0	-1100	-9600	-10700	+600	-10100
18.0	-2100	-10800	-12900	+1700	-11200
20.0	-2400	-12000	-14400	+3000	-11400
21.0	-2800	-12600	-15400	+3800	-11600
22.0	-3000	-13200	-16200	+4800	-11400
23.0	-3200	-13800	-17000	+5800	-11200
24.0	-3700	-14400	-18100	+7000	-11100
25.0	-4100	-15000	-19100	+8500	-10600
26.0	-4300	-15600	-19900	+10700	-9200
27.0	-3800	-16200	-20000	+14100	-5900
28.0	-3800	-16800	-20600	+18200	-2400
29.0	-5100	-17400	-22500	+22800	+ 300
30.0	-7700	-18000	-25700	+27800	+ 2100
31.0	-12700	-18600	-31300	+32800	+ 1500
32.0	-20200	-19200	-39400	+38400	- 1000
33.0	-28400	-19800	-48200	+43000	- 5200
34.0	-38600	-20400	-59000	+48000	-11000
35.0	-50200	-21000	-71200	+53200	-18000



$I_2 N_2$ - MILLIAMPERE TURNS

Aerojet-General® CORPORATION


TRANSFER CURVE OF
UV PORTION OF UV/OV
SENSING CIRCUIT
5-23-69
VDCSENS
0
5
10
15
20
25
30
35
0
5K
10K
15K
20K
25K
30K
35K
40K
45K
50K
55K
60K
65K
$I_3 N_3$ – MILLIAMPERE TURNS

5-23-69

$N_2 = 860T$ $N_3 = 615T$ $N_4 = 430T$ $N_5 = 430T$

$R_{DB2} = 35\Omega$ $R_{DB3} = 85\Omega$ $R_{DB4} = 700\Omega$ $R_{DB5} = 7500\Omega$

ZD2 = 3 4.7V IN3825A (#4, #5, #6) & 3 5.6V IN3827A (#5, #6, #9)

ZD3 = 3 4.7V IN3825A (#7, #8, #9) & 2 5.6V IN3827A (#2, #8)

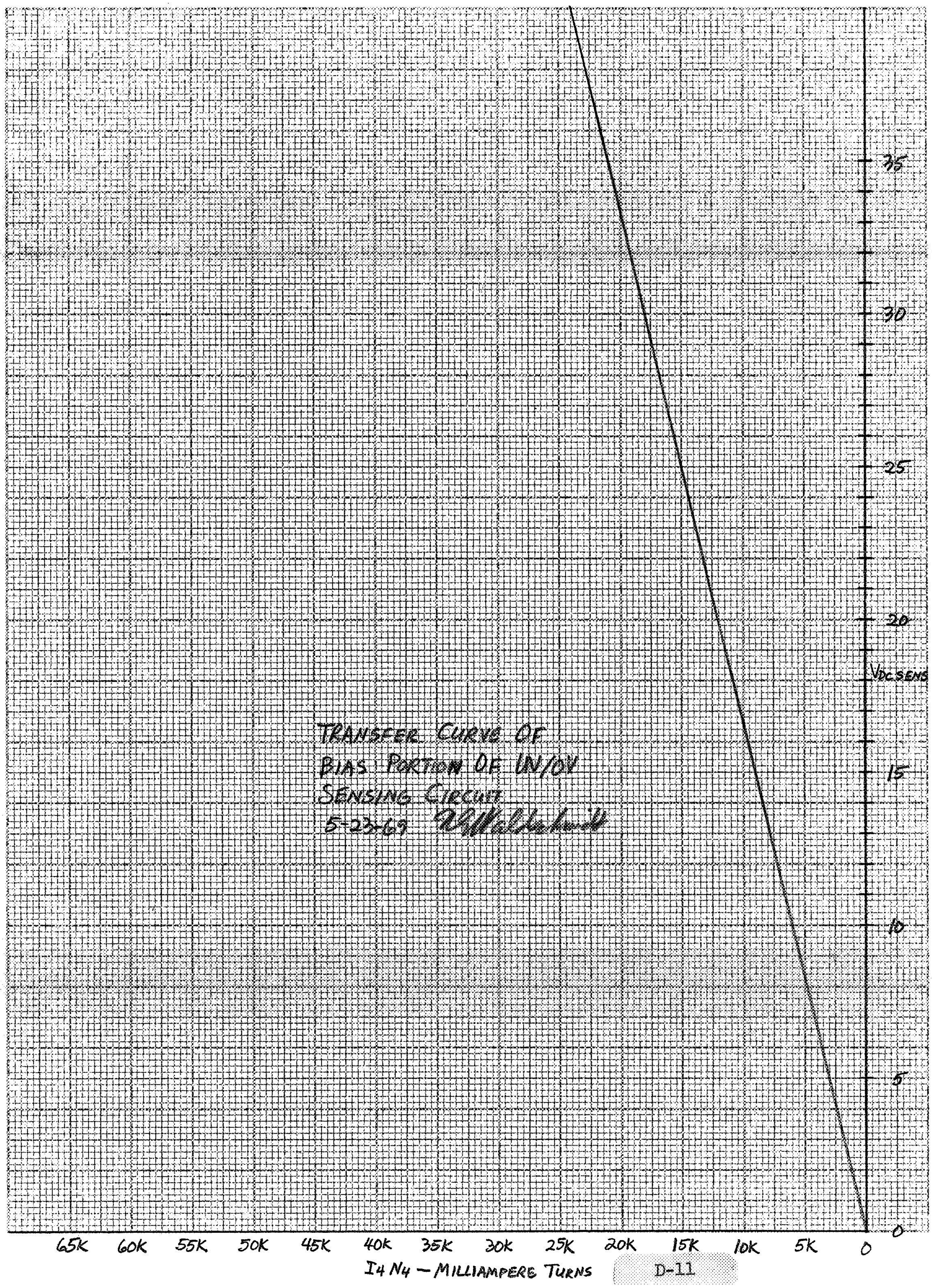
M/A GATES ENERGIZED – MAINTAINED V_{O1} = 100.0V L_1 = .2 h

I_2	I_2N_2	$V_{DC\,SENS}$	$V_{DC\,M/A}$
0	0	3.3	84.9
.004	3	7.5	77.0
.007	6	8.0	2.90
.30	258	11.9	5.70
.60	516	13.3	6.00
.80	688	14.2	6.20
1.00	860	15.1	6.50
2.00	1720	18.6	7.08
3.00	2580	21.15	7.20
4.00	3440	23.58	7.10
5.00	4300	25.30	6.90
5.10	4380	25.6	6.70
4.60	3960	26.7	4.60
4.20	3620	27.35	3.00
4.40	3780	28.0	86.5
6.0	5160	29.05	87.0
8.0	6880	29.8	87.0
10.0	8600	30.2	87.0
12.0	10320	30.6	87.0
15.0	12900	31.0	87.1
20.0	17200	31.65	87.0
25.0	21500	32.1	86.5
30.0	25800	32.6	84.2
32.0	27500	32.8	79.0

I_2	I_2N_2	$V_{DC\,SENS}$	$V_{DC\,M/A}$
33.0	28400	33.0	7.50
40.0	34400	33.6	5.5
50.0	43000	34.4	8.5
60.0	51600	35.1	11.2

I_3	I_3N_2	$V_{DC\,SENS}$	$V_{DC\,M/A}$
-0.60	-369	.47	85.7
-0.40	-246	1.545	85.7
-0.30	-184	5.90	82.2
-0.23	-141	7.33	77.8
-0.215	-132	7.60	75.7
-0.735	-452	8.30	3.8
-0.90	-554	8.90	4.1
-1.10	-676	11.0	5.1
-1.00	-615	12.0	5.6
-0.60	-369	13.05	6.0
-0.40	-246	14.0	6.0
-0.20	-123	14.44	6.1
-0.10	-62	14.65	6.2
0.0	0	14.82	6.3
0.5	+308	15.6	6.3
1.0	615	16.3	6.5
2.0	1230	17.55	6.8
3.0	1845	18.6	7.0

I_3	I_3N_3	$V_{DC\,SENS}$	$V_{DC\,M/A}$
4.0	2460	19.5	7.0
5.0	3075	20.25	7.0
6.0	3690	20.95	7.0
8.0	4920	22.2	7.0
10.0	6150	23.3	7.0
12.0	7380	24.25	6.9
14.0	8610	25.1	6.8
16.0	9840	25.7	6.3
18.0	11070	26.2	5.8
20.0	12300	26.6	4.9
22.0	13530	26.8	4.0
24.0	14760	27.2	3.2
26.0	15990	27.4	2.8
27.5	16900	27.65	2.5
28.0	17220	27.7	86.0
30.0	18450	28.0	86.6
40.0	24600	29.4	87.1
50.0	30750	30.5	87.0
60.0	36900	31.8	87.0
66.0	40600	32.4	85.8
68.0	41800	32.7	81.7
69.0	42400	32.9	[illegible]
70.0	43000	33.0	3.5
80.0	49200	34.2	8.0
90.0	55400	35.4	12.2


TRANSFER CURVE OF
BIAS PORTION OF UN/OV
SENSING CIRCUIT
5-23-69
35
30
25
20
VDC SENS
15
10
5
0
65K 60K 55K 50K 45K 40K 35K 30K 25K 20K 15K 10K 5K 0
I4 N4 — MILLIAMPERE TURNS

N_2 = 860T N_3 = 615T N_4 = 430T N_5 = 430T

R_{DB2} = 35Ω R_{DB3} = 85Ω R_{DB4} = 20Ω R_{DB5} = 7500Ω

ZD2 = 3 4.7V 1N3825A (#4, #5, #6) & 3 5.6V 1N3827A (#5, #6, #9)

ZD3 = 3 4.7V 1N3825A (#7, #8, #9) & 2 5.6V 1N3827A (#2, #8)

M/A GATES ENERGIZED – MAINTAINED V_{01} = 100.0V L_1 = 0.2 k

I_4	$I_4 N_4$	$V_{DC SENS}$	$V_{DC M/A}$
0.62	266	0.44	85.8
1.00	430	0.7[illegible]	85.8
1.40	602	0.985	85.8
3.00	1290	2.15	85.3
10.0	4300	7.18	79.7
10.7	4600	7.62	75.7
11.0	4730	7.90	3.8
15.0	6450	10.7	5.0
20.0	8600	14.35	6.2
25.0	10750	17.95	7.0
30.0	12900	21.16	7.2
38.0	16340	27.12	3.3
39.0	16770	28.0	86.5
44.0	18920	31.5	87.0
45.0	19350	32.1	86.5
46.0	19780	33.0	3.5
50.0	21500	35.8	14.0

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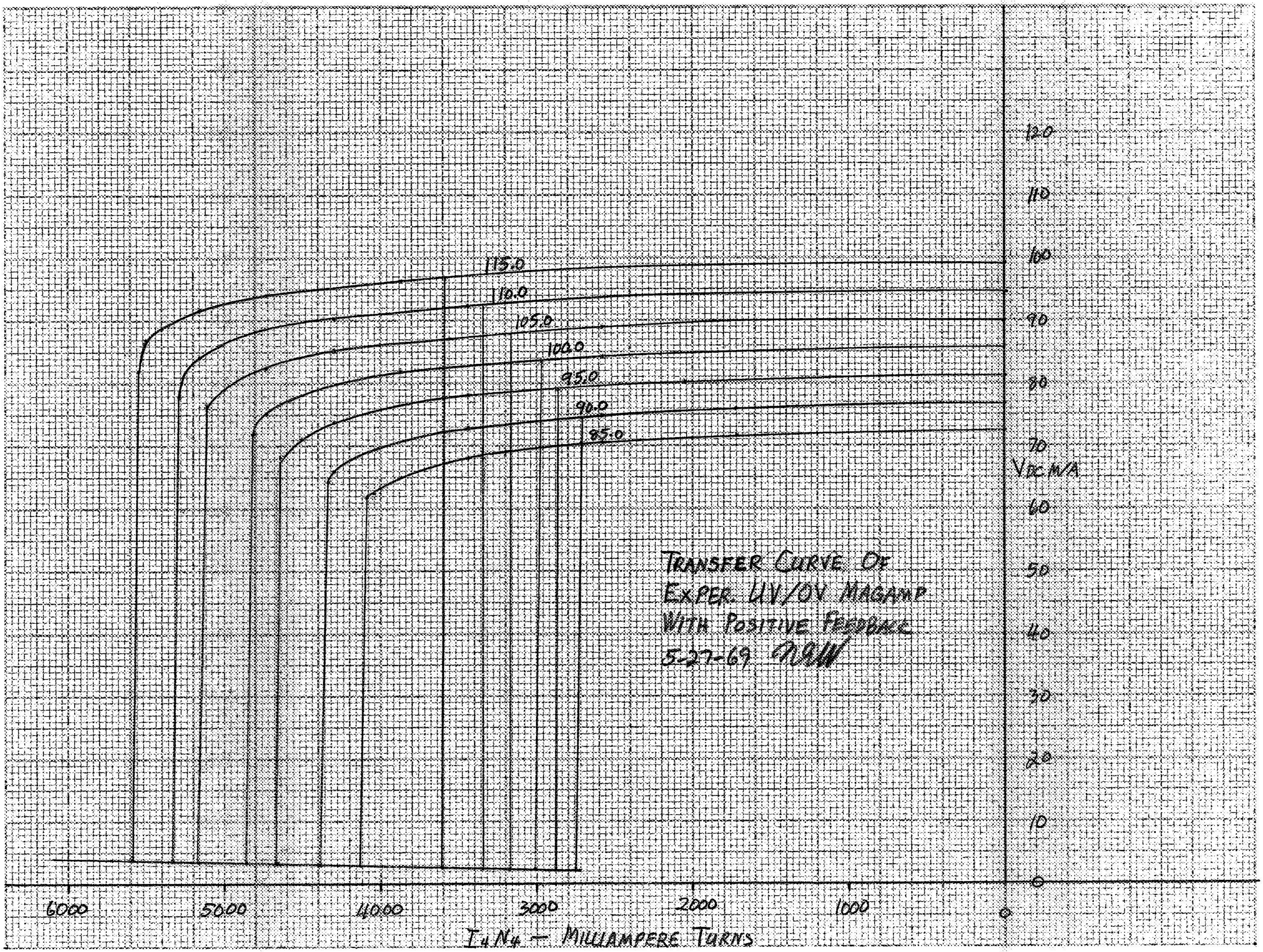


5-27-69

$R_{DB4} = 700\Omega$ $R_{DB5} = 7500\Omega$

$N_4 = 430T$ $N_5 = 430T$

$L_1 = 0.2$ h

V_{01}	$V_{DC\,M/A}$	$V_{DC\,SENS}$	I_4	$I_4 N_4$
85.0	72.5	0	0	0
	71.8	2.85	4.0	1720
	70.6	4.30	6.0	2580
	68.0	5.73	8.0	3440
	65.0	6.45	9.0	3870
	63.3	6.63	9.3	4000
	62.3	6.73	9.4	4040
	61.8	6.80	9.5	4090
	3.0	6.85	9.6	4130
	2.3	5.00	7.0	3010
	2.2	4.58	6.4	2750
	70.1	4.50	6.3	2710
	70.3	4.28	6.0	2580
↓	71.8	2.85	4.0	1720

V_{01}	$V_{DC\,M/A}$	$V_{DC\,SENS}$	I_4	$I_4 N_4$
90.0	76.8	0	0	0
	76.0	2.88	4.0	1720
	75.0	4.30	6.0	2580
	73.0	5.72	8.0	3440
	66.0	7.18	10.0	4300
	64.2	7.28	10.1	4340
	3.2	7.52	10.2	4390
	2.3	5.10	7.0	3010
		4.81	6.6	2840
	2.2	4.66	6.4	2750
	74.8	4.53	6.35	2730
↓	75.0	4.30	6.0	2580

V_{01}	$V_{DC\,M/A}$	$V_{DC\,SENS}$	I_4	$I_4 N_4$
95.0	81.2	0	0	0
	80.1	3.54	5.0	2150
	78.1	5.72	8.0	3440
	73.7	7.20	10.0	4300
	71.0	7.50	10.5	4510
	68.1	7.68	10.8	4640
	3.2	7.74	10.9	4690
	3.7	8.57	12.0	5160
	2.4	5.0	7.0	3010
	2.4	4.86	6.8	2920
	2.4	4.80	6.7	2880
	79.1	4.77	6.65	2860
↓	79.5	4.29	6.0	2580

V_{01}	$V_{DC\,M/A}$	$V_{DC\,SENS}$	I_4	$I_4 N_4$
100.0	85.7	0	0	0
	84.2	4.29	6.0	2580
	81.8	6.43	9.0	3870
	75.2	7.86	11.0	4730
	72.0	8.08	11.2	4810
	3.6	8.14	11.3	4860
		8.53	12.0	5160
	2.8	5.72	8.0	3440
	2.7	5.28	7.4	3180
	2.5	5.16	7.2	3100
	2.5	5.07	7.1	3050
	2.5	5.03	7.05	3030
	2.5	5.00	7.0	3010
	83.2	4.91	6.90	2970
	84.2	4.29	6.0	2580

5-27-69

$R_{DB4} = 700\,\Omega$ $R_{DB5} = 7500\,\Omega$

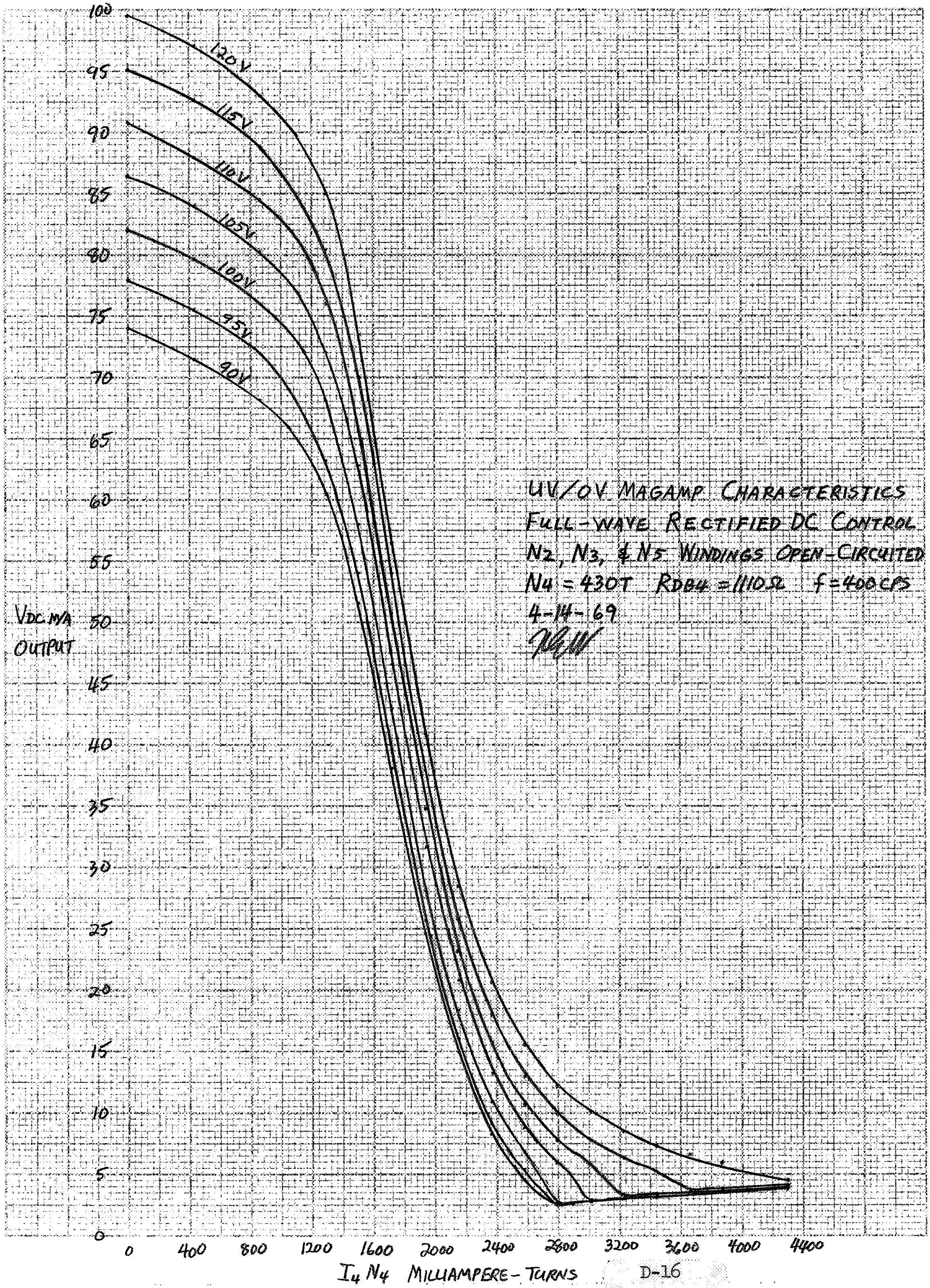
$N_4 = 4307$ $N_5 = 4307$

$L_1 = 0.2\,h$

I_{c1}	$V_{DC\,M/A}$	$V_{DC\,SENS}$	I_4	I_4N_4
105.0	90.0	0	0	0
	89.0	4.29	6.0	2580
	85.2	7.18	10.0	4300
	82.4	7.88	11.0	4730
	76.4	8.44	11.9	5110
	3.8	8.53	12.0	5160
	4.0	9.25	13.0	5590
	2.8	5.71	8.0	3440
	2.8	5.41	7.6	3270
	2.8	5.33	7.5	3225
	2.8	5.28	7.4	3180
	88.1	5.22	7.35	3160
	89.0	4.29	6.0	2580

I_{c1}	$V_{DC\,M/A}$	$V_{DC\,SENS}$	I_4	I_4N_4
115.0	99.2	0	0	0
	96.4	6.43	9.0	3870
	94.0	7.83	11.0	4770
	91.7	8.56	12.0	5160
	87.0	9.08	12.8	5500
	82.0	9.15	12.9	5550
	4.2	9.27	13.0	5590
	3.2	6.42	9.0	3870
	3.2	6.13	8.6	3700
	3.2	6.0	8.4	3610
	97.0	5.95	8.35	3590
	98.0	4.29	6.0	2580

V_{o1}	$V_{DC\,M/A}$	$V_{DC\,SENS}$	I_4	I_4N_4
110.0	94.7	0	0	0
	92.3	5.72	8.0	3440
	90.2	7.19	10.0	4300
	84.2	8.52	12.0	5160
	78.0	8.80	12.3	5290
	4.0	8.9	12.4	5330
	3.0	6.42	9.0	3870
	3.0	5.71	8.0	3440
	3.0	5.62	7.9	3400
	3.0	5.57	7.8	3350
	92.1	5.50	7.75	3340
	93.3	4.29	6.0	2580


UV/OV MAGAMP CHARACTERISTICS
FULL-WAVE RECTIFIED DC CONTROL
N2, N3, & N5 WINDINGS OPEN-CIRCUITED
N4 = 430T RDB4 = 1110Ω f = 400 CPS
4-14-69
120V
115V
110V
105V
100V
95V
90V
VDC N/A OUTPUT
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0
400
800
1200
1600
2000
2400
2800
3200
3600
4000
4400
I4 N4 MILLIAMPERE-TURNS

Protective System UV/OV Mapping Characteristics 4-11-69

$R_{DBU} = 1110\ \Omega$ $N_U = 430\ T$

N_2, N_3, & $N5$ OPEN-CIRCUITED

I_U	$I_U N_U$	V_{01}	$V_{DC M/A}$	V_{01}	$V_{DC M/A}$	V_{01}	$V_{DC M/A}$
0	0	95.0	77.9	104.0	82.0	105.0	86.5
1.0	430	↓	75.5	↓	79.6	↓	84.0
2.0	860		72.0		76.0		80.3
3.0	1290		63.2		68.1		72.0
3.5	1505		54.0		58.0		62.8
4.0	1720		39.6		42.9		46.6
4.5	1935		25.7		28.2		31.7
5.0	2150		16.0		18.3		20.8
5.5	2365		9.18		10.9		13.15
6.0	2580		5.40		6.82		8.8
6.5	2795		2.60		2.70		5.90
7.0	3010		2.71		2.79		2.88
7.5	3225		—		—		—
8.0	3440		3.0		3.22		3.28
8.5	3655		—		—		—
9.0	3870		—		—		—
10.0	4300	↓	3.80	↓	3.88	↓	3.92

I_U	$I_U N_U$	V_{01}	$V_{DC M/A}$	V_{01}	$V_{DC M/A}$	V_{01}	$V_{DC M/A}$
0	0	110.0	90.8	115.0	95.1	120.0	99.5
1.0	430	↓	88.0	↓	92.6	↓	97.0
2.0	860		84.5		88.8		93.0
3.0	1290		76.0		80.4		85.0
3.5	1505		65.7		70.0		73.4
4.0	1720		50.7		54.0		56.5
4.5	1935		34.8		37.9		40.9
5.0	2150		23.15		25.7		28.4
5.5	2365		15.75		18.1		20.7
6.0	2580		10.7		12.98		15.6
6.5	2795		7.90		10.0		12.33
7.0	3010		5.82		7.75		10.1
7.5	3225		3.25		6.30		8.5
8.0	3440		3.37		5.15		7.4
8.5	3655		—		3.70		6.6
9.0	3870		—		3.78		5.87
10.0	4300	↓	3.98	↓	4.06	↓	4.50

Protective System UV/OV Tripping characteristics

4-14-69

RGW

$R_{DBU} = 1110\Omega$ $N_4 = 430T$ N_2, N_3 & N_5 OPEN-CIRCUITED

V_{01}	$V_{DCM/A}$	I_4	$I_4 N_4$
90.0	74.0	0	0
	71.5	1.0	430
	68.1	2.0	860
	60.4	3.0	1290
	51.6	3.5	1505
	38.1	4.0	1720
	24.6	4.5	1935
	14.9	5.0	2150
	8.35	5.5	2365
	4.60	6.0	2580
	2.55	6.5	2795
	2.66	7.0	3010
	—	7.5	3225
	2.98	8.0	3440
	—	8.5	3655
	—	9.0	3870
	3.78	10.0	4300

V_{01}	$V_{DCM/A}$	I_4
		0
		1.0
		2.0
		3.0
		3.5
		4.0
		4.5
		5.0
		5.5
		6.0
		6.5
		7.0
		7.5
		8.0
		8.5
		9.0
		10.0

V_{01}	$V_{DCM/A}$	I_4	$I_4 N_4$
		0	
		1.0	
		2.0	
		3.0	
		3.5	
		4.0	
		4.5	
		5.0	
		5.5	
		6.0	
		6.5	
		7.0	
		7.5	
		8.0	
		8.5	
		9.0	
		10.0	

V_{01}	$V_{DCM/A}$	I_4
		0
		1.0
		2.0
		3.0
		3.5
		4.0
		4.5
		5.0
		5.5
		6.0
		6.5
		7.0
		7.5
		8.0
		8.5
		9.0
		10.0

APPENDIX E

PROTECTIVE SYSTEM FOR PCS-G

00-007-022 (REV. 7-62)

INTER-OFFICE MEMO

AEROJET-GENERAL CORPORATION

TO: J. Coff

FROM: S. L. Bradley

DATE 15 November 1968
4936-68-0115:SLB:vc

SUBJECT: Protective System for PCS-G

DISTRIBUTION: FN Collamore, EG Brittain, LP Lopez, File

Enclosure: (1) Protective System Requirements

Enclosure (1) is the engineering input of the protective system requirements for PCS-G. The requirements provided here are for protection of the electrical system only. The protective system requirements for the hydraulic system involving flows and pressures will be supplied as part of the programmer requirements.

S. L. Bradley
Electrical Components Group
Power Systems Department

PROTECTIVE SYSTEM REQUIREMENTS

1. Electrical System Protection The electrical system shall be protected from internal and external faults. In the event of a fault in the vehicle load (extrernal) the fault shall be isolated from the PCS by opening the vehicle load breaker (VLB). In the event of an internal fault the PCS shall be shut down in such a manner to minimize the damage resulting from the fault.

1.1 Fault Sensing

Faults on the electrical system may consist of one or more of the following conditions:

(a) Three phase short circuit

(b) Phase to ground short circuit

(c) Phase to phase short circuit

(d) System overload

(e) Severe unbalanced loads

(f) Speed Control failure

(g) Voltage regulator failure

The existance of one or more of these faults will be sensed by voltage bandpass sensors connected from each phase of the power system to neutral. Each of the three sensors shall be independent from each other sensor and operate in a completely independent manner. The performance of the voltage sensors shall be defined in the following paragraphs.

1.1.1 Power Supply - The voltage sensors shall operate from the voltage which they are sensing. No additional source of power shall be required.

1.1.2 Output Relay - The output of the voltage sensor shall operate a double pole double throw relay rated at 2 amps minimum resistive 28 volts D.C.

1.1.3 Steady Stage Voltage Limits - The voltage sensor shall actuate the relay at the voltage limits shown in Figure 1A. The deviation from the specified value for all factors including environmental conditions shall not exceed ± 1.5 volts. The differential between the pickup and drop out of the relay shall not exceed 4.0 volts.

1.1.4 Transient Voltage Limits - The voltage sensor shall have an inverse time delay before operation so that momentary voltage transients resulting from sudden changes in vehicle load will not cause drop out. The required inverse time characteristic is shown in Figure 1B.

1.1.5 Operating Frequency - The voltage sensors shall perform as specified when the supply frequency is within the range of 300 to 500 HZ.

1.2 Fault Tripping - The faults on the electrical system shall be sensed by fault sensors as described in paragraph 1.1. Protective action will be initiated in the event that two of the three fault sensors indicate that a fault condition exists.

1.3 Fault Discrimination - The protective system shall discriminate between internal and external system faults.

1.3.1 External Faults - External faults will be isolated from the systems by opening the vehicle load breaker (VLB)immediately upon indication of a fault.

1.3.2 Internal Faults - Internal faults will be determined by a time delay which will allow the system to recover from an external fault after the VLB has opened. In the event that the fault condition remains on the system for periods longer than 0.5 seconds a signal will be initiated to shut down the power conversion system (PCS).

1.3.3 Fault Clearing - In order that maximum effort be made to clear external faults the protective system will reclose the VLB as soon as the electrical system recovers to specified conditions. If the fault remains it will be sensed and the VLB reopened. This action will be repeated until the fault is cleared or the PCS is shut down by operator action.

1.4 Interface Requirements - The protective system shall interface with the system programmer to effect the necessary action in the event a fault is sensed. The points of interface shall be determined by mutual agreement by the designers of the protective system and system programmer.

2. Turbine Overspeed Protection. Overspeed protection shall be provided which will shut down the PCS in the event of turbine overspeed in excess of 13200 RPM plus or minus 132 RPM .

2.1 Speed Sensor - The turbine speed shall be sensed by a speed pickup mounted in the turbine assembly. The speed sensor shall be completely independent from the alternator and not require alternator voltage to function.

2.2 Power Supply - The speed sensor shall operate from the output of the speed pickup and 28 volts D.C. supplied by the system programmer.

2.3 Output Relay. The output of the speed sensor shall operate a double pole double throw relay rated at 2 amps minimum resistive 28 volts D.C. The relay shall be energized only when an overspeed condition exists. During normal operation the relay coil will be unexcited.

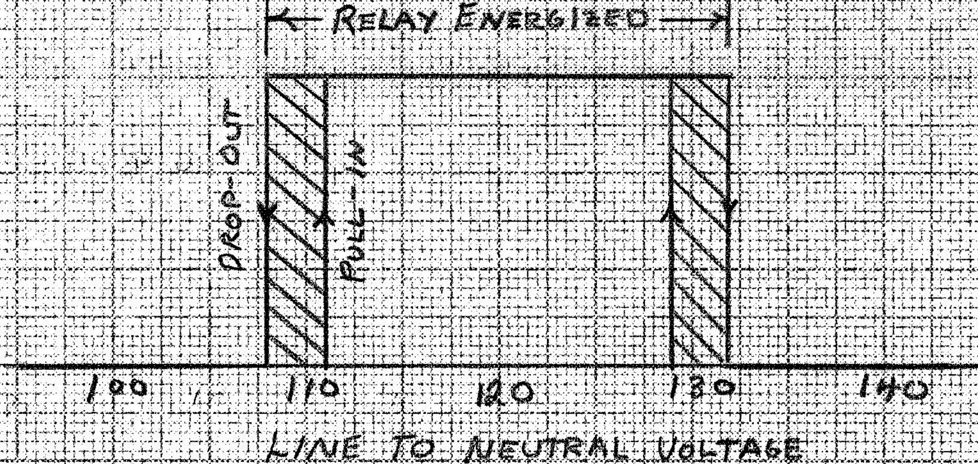

RELAY ENERGIZED
DROP-OUT
PULL-IN
100
110
120
130
140
LINE TO NEUTRAL VOLTAGE

FIG. 1A

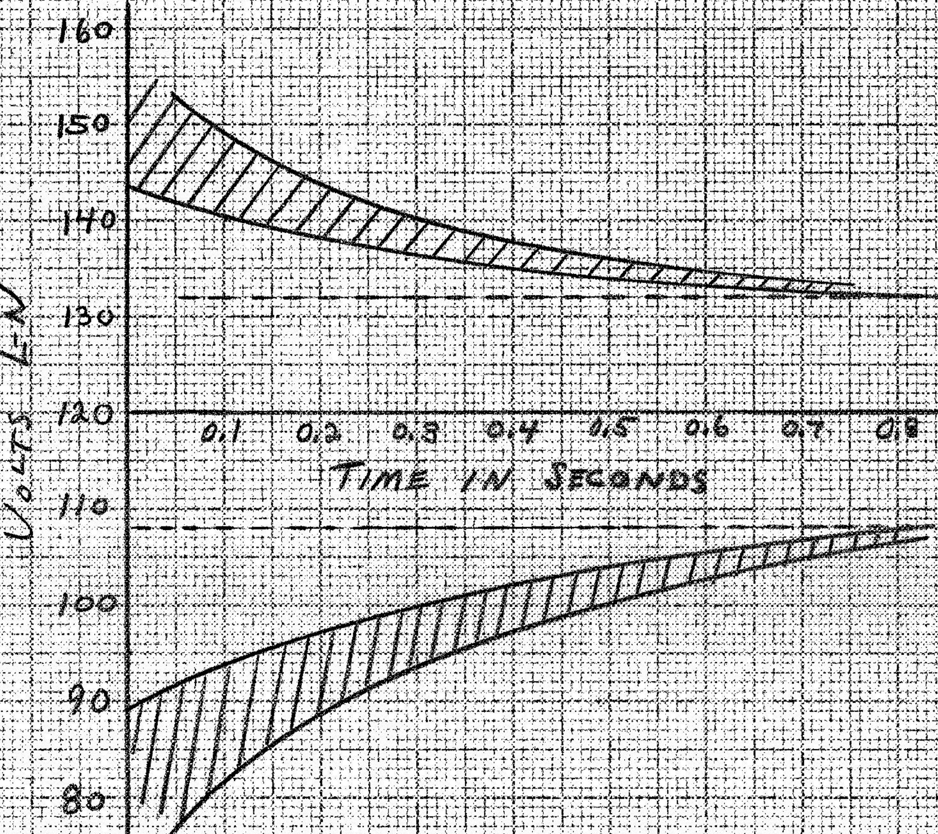

160
150
140
130
120
110
100
90
80
VOLTS L-N
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
TIME IN SECONDS

FIG. 1B

APPENDIX F

TAA TERMINAL SPEED DURING EMERGENCY SHUTDOWN

(Memo 4966-70-0701)

INTEROFFICE MEMO

AEROJET-GENERAL CORPORATION

TO: N. E. Waldschmidt

DATE 14 January 1970
4966-70-0701:MGC:djm

FROM: M. G. Cherry

SUBJECT: TAA Terminal Speed During Emergency Shutdown

COPIES TO: S. L. Bradley, E. G. Brittain, J. R. Pope, File

In answer to your inquiry, an inspection of PCS-1 data regarding the effect of emergency shutdown, initiated in the region of 200 cps indicates the following:

1. If the mercury flow rate is 1500 to 2500 lb/hr at the moment the shutdown signal is initiated, the TAA would reach and possibly exceed by a small margin (≈5-10%) of its operating speed of 12,000 rpm.

2. If the flow rate is 3000 - 4500 lb/hr at the moment the shutdown signal is initiated, the TAA will reach and exceed the overspeed limit of 13,500 RPM and possibly approach runaway speed of 19,000 RPM.

M. G. Cherry
Rotating Components
Power Systems Department

APPENDIX G

STRUCTURAL ANALYSIS

ELECTRICAL PROTECTIVE SYSTEM MODULE

Dept. 4927

ANALYSIS NO. SA-E-182

DATE 7 August 1969

SUMMARY OF ANALYSIS

Project SNAP-8	Component Electrical		Distribution:
Part Component Protective System	Drawing No. 1267097		S. L. Bradley
Subject Structural Analyses			R. M. Hill
Reference(s) 1. AGC Spec. 10512			
Engineer O. H. Cano	Approved		File: SS 1090-02

OBJECTIVE:

Evaluate structural integrity of part (casting)

ASSUMPTIONS:

1. Drawings ~ Dimensional
2. Spec. ~ Loads

REFERENCES (Analysis Methods):

Std. Analyses

RESULTS AND CONCLUSIONS:

Part is acceptable

RECOMMENDATIONS AND COMMENTS:

Part is acceptable -- Installation of part by means of 16 screws is acceptable. No further recommendations -- Sign off.

AEROJET NUCLEAR SYSTEMS COMPANY

To: N. E. Waldschmidt

Date: 6 March 1970
4927-70-0012:WW:eh

From: W. Weleff

Subject: Stress Analysis for the Electrical Protective System Module Assembly

Copy to: S. L. Bradley, O. Cano, J. Shen, V. A. Pineda, file

Reference: (a) Component Protective System Structural Analysis SA-E-182, dated 7 August 1969

Enclosure: (1) Stress Analysis SA-E-186, Electrical Protective System Module Assembly, dated 20 January 1970

Enclosure (1), representing additional stress analysis for the components of the Protective System Module Assembly, is forwarded herewith for your use and retention. This analysis contains investigation of the structural integrity of the components contained in the assembly module such as: the relay compartment; reactor inductor compartment; ØA and Ø3 compartments, containing the resistors, rectifiers, transformers, filters; etc.

To account for the dynamic effects on these components, an equivalent static load of 20 g was assumed and utilized in this analysis. The properties of the cast aluminum alloy A-356 in the T-6 condition were used in this analysis.

All stresses were found to be within the allowable yield strength of the material, resulting in positive safety margins for all components.

This analysis should be considered as supplemental to the previous analysis, reference (a), which contained the evaluation of the structural integrity of the housing.

W. Weleff

W. Weleff, Supervisor
Stress Group
Engineering Department
Power Systems Operations

Dept. 4927

ANALYSIS NO. SA-E-186

DATE 1-20-70

SUMMARY OF ANALYSIS

Project SNAP-8

Component Electrical

Part Electrical Protective System Module Assembly

Drawing No.

Subject 20 g Loading

Reference(s)

Engineer J. Shen

Approved W. Welff

Distribution:

S. L. Bradley

N. E. Waldeschmidt

File: SS 1090-03

OBJECTIVE:

To calculate stresses and sign-out drawings.

ASSUMPTIONS:

20 g loadings assumed and used.

REFERENCES (Analysis Methods):

RESULTS AND CONCLUSIONS:

1. Reactor-Indicator Cover (Dwg. 1267813). Relocate tie-down screw insert to give better edge distance (original 018" edge distance for #10-32 screws)
2. Corrected torque values for #10-32 and #8-32 screws (Dwg. 1267812).

All stresses are within allowables and with sufficient margins for 20 g loadings.

RECOMMENDATIONS AND COMMENTS:

Sign-out Drawings:

1264931	1267643	1267808	1267814
1267058	1267646	1267809	1267817
1267089	1267800	1267810	1267818
1267097	1267803	1267811	1267819
1267098	1267806	1267812	1267824
1267425	1267807	1267813	

QUADRILLE WORK SHEET

AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

PAGE 1 OF ____ PAGES

DATE 1-20-70

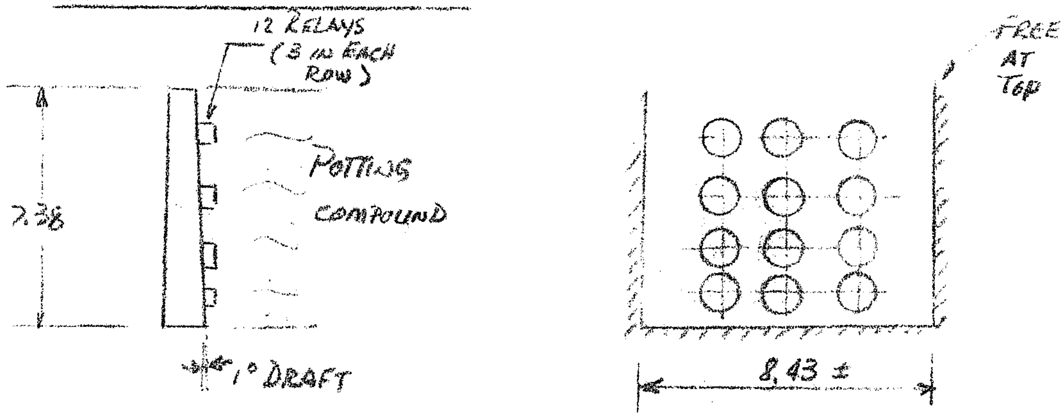
SUBJECT ELECTRICAL PROTECTIVE SYSTEM MODULE ASSEMBLY

BY J. SHEN

WORK ORDER ____

RELAY COMPARTMENT WALL WITH RELAYS

DWG. 1267098



FROM J. MAMOLA - THE WEIGHTS ARE

12 RELAYS @ 0.17 LBS	=	2.04 LBS
POTTING COMPOUND	=	10.12 "
MISC. (SCREWS) ASSUMED	=	2.84 "
		15.0 "

DESIGN FOR 20 g (PER W. WOLFF)

$\therefore$ TOTAL LOAD $= 15.0^{\#}(20+1)$
$= 315$ LBS.

CONSIDER AS UNIFORMLY DISTRIBUTED

$$q = \frac{315}{7.38 \times 8.43} = 5.1 \text{ LBS/IN}^2$$

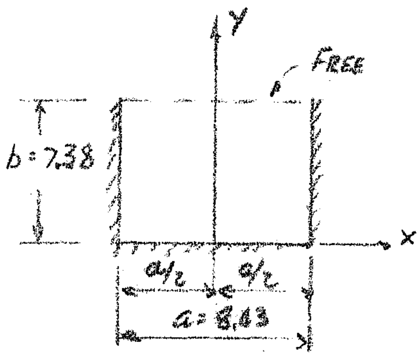
BY TIMOSHENKO, THEORY OF PLATES & SHELLS PAGE 215 TABLE 44. SINCE TIMOSHENKO'S TABLE IS COMPILED USING $\nu = \frac{1}{6}$, THE CORRECTION FOR AL 356-T6 MATERIAL OF $\nu = 0.3$ IS NEEDED, AS THE STRUCTURAL STRENGTH IS MEASURED BY THE FLEXURAL RIGIDITY $D = Et^3/12(1-\nu^2)$, HENCE

STK. NO. D-1-103

THE CORRECTION SHALL BE :

$$C.F. = \frac{1/(1-\nu_{AL}^2)}{1/(1-\nu_0^2)} \qquad \text{WHERE } \nu_0 = \frac{1}{6}$$

$$= \frac{1-\frac{1}{6}^2}{1-0.3^2} = 1.07$$



$$\text{ASPECT RATIO} = \frac{b}{a} = \frac{7.38}{8.43} = 0.875$$

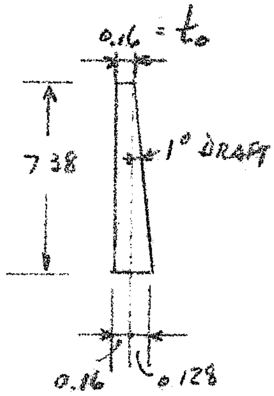
INTERPOLATING FROM TIMOSHENKO'S TABLE WITH CORRECTION C.F. = 1.07

BOUNDARY	M_x COEFF	M_y COEFF	V_x COEFF	V_y COEFF
$x=0,\ y=0$	1.07×0.0419 = 0.0447	—	—	—
$x=0,\ y=\frac{b}{2}$	1.07×0.0212 = 0.0227	1.07×0.0126 = 0.0135	—	—
$x=\frac{a}{2},\ y=b$	1.07×(−0.0830) = −0.0888	—	1.07×0.663 = 0.709	—
$x=\frac{a}{2},\ y=\frac{b}{2}$	1.07×(−0.0549) = −0.0586	—	1.07×0.407 = 0.435	—
$x=0,\ y=0$	—	1.07×0.0526 = 0.0564	—	1.07×0.403 = 0.0562

GENERAL FORMULAS

$$M_i = \text{COEFF} \times q\,a^2$$

$$V_i = \text{COEFF} \times q\,a$$



THICKNESS AT BASE

$$t = t_o + 7.38 \tan 1^\circ$$
$$= 0.16 + 7.38 \times .01746$$
$$= 0.16 + 0.128 \quad = 0.288 \text{ IN.}$$

FROM THE PREVIOUS PAGE

AT $x = a/2$, $y = b$ – $t_o = 0.16$ IN

$$\text{MAX } M_x = -0.0888\, q a^2$$
$$= -0.0888 \times 5.1 (8.43)^2$$
$$= -32.1 \text{ IN-LBS/IN}$$

$$\text{MAX } V_x = +0.709\, q a$$
$$= +0.709 \times 5.1 \times 8.43$$
$$= 31.4 \text{ LBS/IN}$$

AT $x = 0$, $y = 0$ – $t = 0.288$ IN.

$$\text{MAX. } M_y = 0.0564\, q a^2$$
$$= 0.0564 \times 5.1 (8.43)^2 = 20.4 \text{ IN-LBS/IN}$$

$$\text{MAX } V_y = 0.0564\, q a$$
$$= 0.0564 \times 5.1 (8.43) = 2.42 \text{ LBS/IN}$$

MOST CRITICAL AT $x = a/2$, $y = b$ – WHERE $t_o = 0.16$ IN.

$$\text{MAX } \sigma = \frac{V_x}{t} \pm \frac{6 M_x}{t^2}$$
$$= \frac{31.4}{0.16} \pm \frac{6 \times 32.1}{(.16)^2}$$
$$= 196 \pm 7{,}525 = 7{,}721 \text{ LBS/IN}^2 \text{ MAX}$$

MATERIAL – AL 356-T6, MAX. AT 260 °F

$$F_{ty} = 23{,}000 \text{ LBS/IN}^2$$

$F_{RUPTURE} = 19{,}000$ " (40,000 HRS)

$$MS = \frac{19000}{7271} - 1 = +1.61$$

AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

QUADRILLE WORK SHEET

DATE ____

SUBJECT ____ BY ____ WORK ORDER ____

WALL WITH TERMINALS

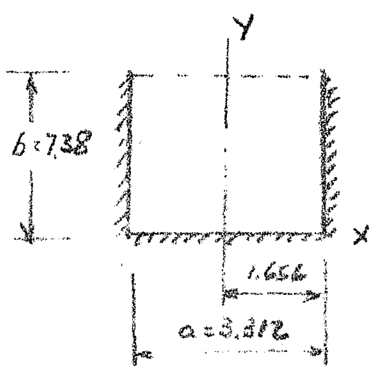
THE LOADS ON THIS WALL

10 TERMINALS @ 0.07#	=	0.700 LBS
DORAL GLASS LAM. PL	=	0.389 "
POTTING COMPOUND	=	10.120 "
		11.209 "

THIS WALL IS NOT AS CRITICALLY LOADED AS THE WALL WITH RELAYS. ANALYSIS IS NEGLECTED

WALLS WITH NO ATTACHMENT EXCEPT CAVITY (POTTING COMPOUND) LOAD

WITH 20 g



POTTING C'PD = 10.12 × (20 + 1)
= 213 LBS

$q = \frac{213}{7.38 \times 3.312} = 8.74$ LBS/IN²

ASPECT RATIO $\frac{b}{a} = \frac{7.38}{3.312}$
= 2.23

FROM TIMOSHENKO'S TABLE, IT IS SEEN THAT

BOUNDARY	$\frac{b}{a}$	M_x	V_x	M_y	V_y
$x = \frac{a}{2}$, $y = 0$	1.25	-0.0867	0.507	-0.0470	0.388
$x = 0$, $y = 0$	1.50	-0.0842	0.527	-0.0418	0.373

HENCE WE SHALL USE $\frac{b}{a} = 1.50$ VALUES CONSERVATIVELY (SINCE NONE GIVEN FOR HIGHER b/a FIGURES)

STK. NO. D-1-103

USING CORRECTION FACTOR C.F = 1.07 AS BEFORE

AT $X = \frac{a}{2}$ $Y = b$ - MOST CRITICAL @ $t_0 = 0.16$ IN.

$$\text{MAX. } M_x = -0.0867\, q a^2 \times (C.F.)$$
$$= -0.0867\,(8.74)(3.312)^2(1.07)$$
$$= -8.97 \text{ IN-LBS/IN}^2$$

$$\text{MAX } V_x = 0.507\, q a \times (C.F.)$$
$$= 0.507\,(8.74)(3.312)(1.07)$$
$$= 15.7 \text{ LBS/IN}$$

$$\text{MAX } \sigma = \frac{V_x}{t} + \frac{6M}{t^2}$$
$$= \frac{15.7}{0.16} \pm \frac{6 \times 8.97}{0.16^2}$$
$$= 99 \pm 2{,}100 = 2{,}199 \text{ LBS/IN}^2$$

$$MS = \frac{19{,}000}{2{,}199} - 1 = \underline{HIGH}$$

ΦA, ΦB & ΦB COMPARTMENTS

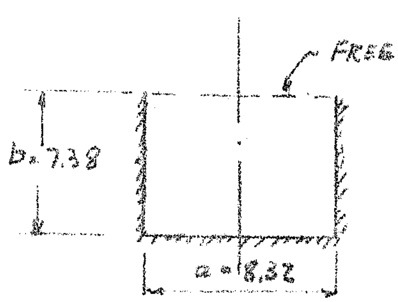
WALL JOINING ΦA & ΦB - MOST CRITICALLY LOADED.

THE BREAKING DOWN OF LOADS ARE:

7	RESISTORS	@ .00287	=	0.201 LBS.
1	ZENER DIODE	@ .0208	=	.041
24	RECTIFIER	@ .0183	=	.429
1	MAG. AMP.	@ 1.000	=	1.000
4	RECT. HEAT SINK	@ .330	=	1.320
1	TRANSF.	@ .900	=	.900
1	FILTER/INDUCER	@ 1.500	=	1.500
4	INDUC MTR.	@ .123	=	.492
1	MAG. AMP. CAN	@ .089	=	.089
1	TRANF. CAN	@ .039	=	.028
1	MAG. AMP COVER	@ .028	=	.028
1	TRANSF. COVER	@ .014	=	.014
1	POTTING IN ΦA		=	8.951
½	" " " ΦB (CONTRIBUTING)		=	5.233
		Σ	=	20.226 LBS

DESIGN FOR 20 g

TOTAL LOAD = 20.226 × (20+1)
= 426 LBS.



ASPECT RATIO $\frac{b}{a} = \frac{7.38}{8.32} = 0.88$

CORRECTION FACTOR CF = 1.07

$q = \frac{426^{\#}}{7.38 \times 8.32} = 6.98\ LBS/in^2$

CRITICAL AT TOP WHERE $t_0 = 0.16$ IN, FROM TIMOSHENKO'S TABLE 44 & INTERPOLATING

AT $x = \frac{a}{2}$ $y = b$

$$\text{MAX. } M_x = -0.0831\, q a^2 \times (C.F.)$$
$$= -0.0831\,(6.98)(8.32)^2(1.07)$$
$$= -430 \text{ IN-LBS/IN}$$

$$\text{MAX } V_x = 0.662\, q a \times (CF)$$
$$= 0.662\,(6.98)(8.32)(1.07)$$
$$= 41 \text{ LBS/IN}$$

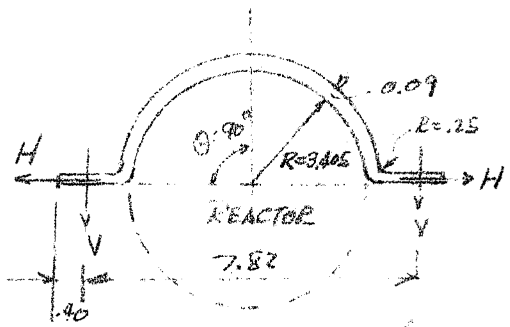
$$\text{MAX } \sigma = \frac{V_x}{t} \pm \frac{6 M_x}{t^2}$$
$$= \frac{41}{0.16} \pm \frac{6 \times 430}{(0.16)^2}$$
$$= 256 \pm 10{,}700 = 10{,}956 \text{ LBS/IN}^2$$

$$\left(\begin{matrix}\text{RUPTURE}\\ \text{40,000 HRS}\end{matrix}\right) M.S. = \frac{19{,}000}{10{,}956} - 1 = +0.73$$

OTHER WALLS — NOT CRITICALLY LOADED AS THE ABOVE ONE. HENCE NEGLECTED.

REACTOR - INDUCTOR

COVER (DWG. 1267813) - MATERIAL AL 6061-T6



COVER WIDTH = 2.0"

TOTAL REACTOR-INDUCTOR = 60.261 LBS

THERE ARE THREE SUCH ELEMENTS - WITH 20 g LOADING. (g LOADINGS)

$$W = \frac{60.261}{3} \times (20+1)$$

$$= 421.09 \text{ LBS}$$

$$w = \frac{421.09}{2R} \text{ LBS/IN}$$

$$R_{\mathfrak{c}} = 3.405 + \frac{0.09}{2}$$

$$= 3.45 \text{ IN}$$

BY ROARK - FORMULAS FOR STRESS & STRAIN
PAGE 163, CASE 29

$$V = \frac{W}{2} = \frac{421.09}{2} = 210.5 \text{ LBS}$$

$$H = wR\left[\frac{\frac{4}{3}s^3 + \theta c - 2\theta s^2 c - sc^2 + \alpha(\theta c^2 - \frac{1}{2}\theta - \frac{1}{2}sc)}{2\theta c^2 + \theta - 3sc + \alpha(\theta + sc)}\right]$$

HERE

$\theta = 90° = 1.5708$ RAD.

$s = \sin\theta = \sin 90° = 1.0$

$c = \cos\theta = \cos 90° \quad 0$

$A = 2'' \times 0.09'' = 0.18 \text{ IN}^2$

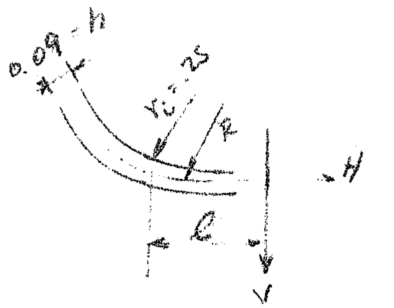
$$\alpha = \frac{I}{AR^2} = \frac{At^2/12}{AR^2} = \frac{t^2}{12R^2}$$

$$= \frac{0.09^2}{12 \times 3.45^2} \doteq 0$$

$$\therefore H = \frac{421.09}{2R} \cdot R\left[\frac{4/3}{1.5708}\right]$$

$$= 178 \text{ LBS}$$

STRESS AT CURVATURE CORNER



$r_i = 0.25$ IN.

$r_o = r_i + 0.09 = 0.34$ IN

$R = r_i + \frac{0.09}{2} = 0.295$ IN.

$r_n = r_{neutral} = \frac{h}{\log_e \frac{r_o}{r_i}} = \frac{0.09}{\log_e \frac{.34}{.25}} = \frac{0.09}{.30748} = 0.282$

$e = R - r_n = 0.295 - 0.282 = 0.013$

$h_i = r_n - r_i = 0.282 - 0.25 = 0.032$

$h_o = r_o - r_n = 0.34 - 0.282 = 0.058$

$\ell = \frac{7.48}{2} - 3.405$
$= 0.335$ IN.

$M = V\ell$
$= 210.5 \times 0.335 = 70.6$ IN-LBS

MATERIAL - AL 6061-T6 AT 260°F

$F_{RUPT} = 23{,}000$ LBS/IN² (40,000 HRS)

$F_{ty} = 30{,}000$ "

AT OUTER FIBER

$\sigma_o = \frac{M h_o}{A e r_o}$

$= \frac{70.6 \times 0.058}{0.18 \times .013 \times 0.34} = 5{,}150$ LBS/IN² TENSION

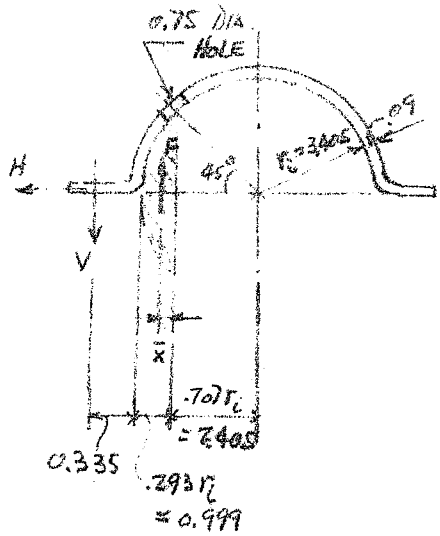
AT INNER FIBER

$\sigma_i = \frac{M h_i}{A e r_i}$

$= \frac{70.6 \times 0.032}{0.18 \times .013 \times 0.25} = 3{,}860$ LBS/IN² COMP.

$MS = \frac{23{,}000}{5{,}150} - 1 = +3.46$

STRESS AT HOLE



$r_i = 3.405$ IN.

$r_o = r_i + 0.09 = 3.495$ IN.

$R = r_i + \frac{0.09}{2} = 3.450$ IN.

$r_n = \frac{h}{\log_e \frac{r_o}{r_i}} = \frac{0.09}{\log_e \frac{3.495}{3.405}} = \frac{0.09}{\log_e 1.023}$

$= \frac{0.09}{0.02272} = 3.96$ IN

$e = R - r_n = 3.45 - 3.96 = -0.51$ IN.

$h_i = r_n - r_i = 3.96 - 3.405 = 0.555$ "

$h_o = r_o - r_n = 3.495 - 3.96 = -0.465$ "

$A = (2 - 0.75) \times .09 = 0.1125$ IN²

$F =$ PORTION OF REACTOR-INDUCTOR WT

$= \frac{A_{SEGMENT}}{A_{WHOLE}} \times 421.09$#

$= \frac{\frac{1}{4}\pi r_i^2 - \frac{1}{2}\left(\frac{r_i}{\sqrt{2}}\right)\left(2 \times \frac{r_i}{\sqrt{2}}\right)}{\pi r_i^2} \times 421.09$

$= \left[\frac{1}{4} - \frac{1}{2\pi}\right] \times 421.09 = 38.4$ LBS.

$\bar{x} = \frac{4 r_i \sin^3\theta}{6\theta - 3\sin 2\theta} - r_i \cos\theta$ $(\theta = 45° = 0.7854$ RAD$)$

$= 3.405\left[\frac{4 \times \frac{1}{2\sqrt{2}}}{3(1.5708 - 1.0)} - \frac{1}{\sqrt{2}}\right]$

$= 0.118$ IN.

$M = V(0.335 + 0.999) - H \times 2.405 - F \times \bar{x}$

$= 210.5(1.334) - 178 \times 2.405 - 38.4 \times 0.118$

$= 282 - 429 - 4.6$

$= -151.6$ IN-LBS

STRESS CONCENTRATION FACTOR (SCF) AT HOLE

BY FAUPEL - ENGINEERING DESIGN, FIG. 11.46

$$\text{RATIO } \frac{a}{h} = \frac{0.75}{0.09} = 8.33$$

$$SCF = 1.95$$

STRESS AT OUTER FIBER

$$\sigma_o = \frac{M h_o}{A e r_o} \times SCF$$

$$= \frac{151.6 \times 0.465}{0.1125 \times .51 \times 3.495} \times 1.95 = 687 \text{ LBS/IN}^2 \text{ C.}$$

(0.20)

STRESS AT INNER FIBER

$$\sigma_i = \frac{M h_i}{A e r_i} \times SCF$$

$$= \frac{151.6 \times .555}{0.1125 \times .51 \times 3.405} \times 1.95 = 840 \text{ LBS/IN}^2 \text{ C.}$$

(1.955)

$$MS = \frac{23000}{840} - 1 = \underline{HIGH}$$

SCREWS - TIED DOWN

#10-32 SCREWS OF 316 SS MATERIAL (KNL 1032)

STRESS AREA = 0.0199 IN^2

$$\tau_c = \frac{V}{A} = \frac{210.5}{0.0199} = 10,600 \text{ LBS/IN}^2$$

$$\sigma_t = \frac{H}{A} = \frac{178}{0.0199} = 8,950 \text{ LBS/IN}^2$$

MATERIAL ALLOWABLE AT 260°F (316 SS)

$F_{ty} = 27{,}300$ LBS/IN²

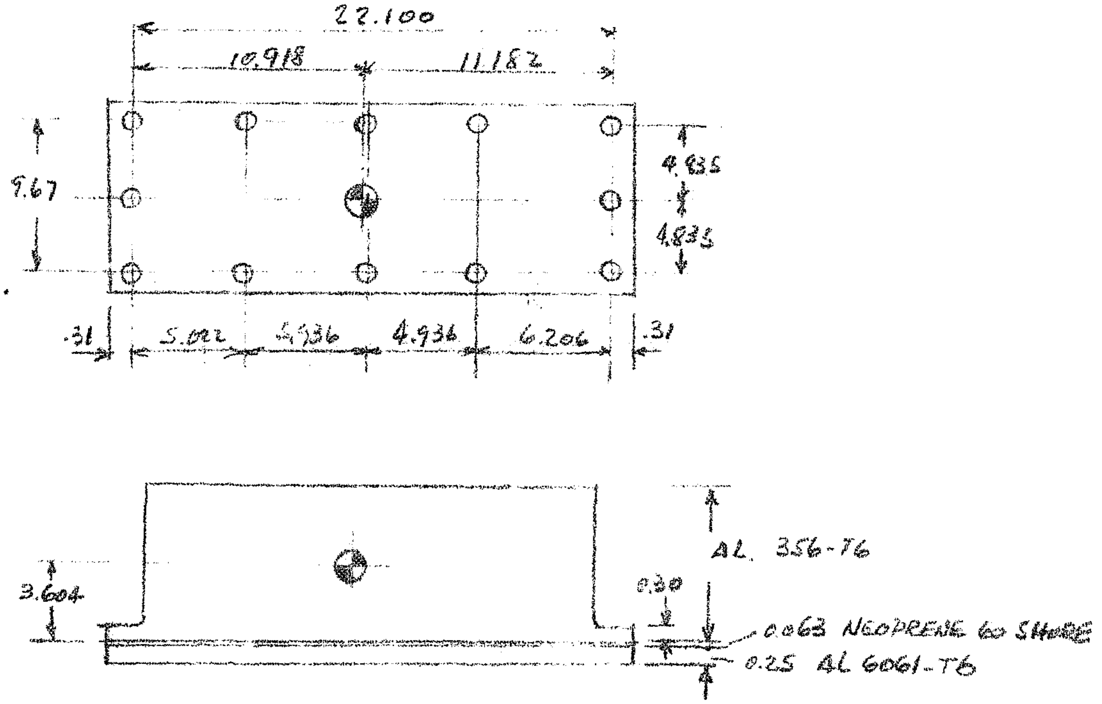
$F_{RUPTURE} \doteq F_{tu} = 75{,}000$ LBS/IN²
(100000 HRS)

$R_c = \frac{10{,}600}{27{,}300} = 0.390$

$R_s = \frac{8950}{0.56 \times 27{,}300} = 0.586$

(YIELD) $M.S. = \frac{2}{R_c^2 + \sqrt{R_c^2 + 4R_s^2}} - 1 = +0.35$

BASE - DWG 1267824 & 1267098



TOTAL WT. OF THIS MODULE ASSEMBLY - WITH 20 g LOADINGS

$$W = 144^{\#} \times (20+1)$$
$$= 3,024 \text{ LBS}$$

ALLOWABLE RUPTURE STRENGTH OF MATERIALS AT 260°F & 40,000 HOURS ARE

AL 356-T6 $F_{RUPT.} = 19,000$ LBS/IN², $F_{ty} = 24,000$ LBS/IN²

6061-T6 " = 23,000 " , $F_{ty} = 30000$ "

TOTAL EQUIVALENT BASE THICKNESS OF AL 356-T6

$$t = 0.30 + 0.25 \frac{23,000}{19,000}$$
$$= 0.30 + 0.302 = 0.602 \text{ IN.}$$

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BY ROARK - FORMULAS FOR STRESS & STRAIN, PAGE 203
CASE 36

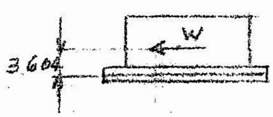
$$\alpha = \frac{b}{a} = \frac{9.67}{22.10} = 0.437$$

$$\text{MAX } \sigma_b = \frac{0.75\, w b^2}{t^2(1+1.61\alpha^3)} \qquad \left(w = \frac{3024}{22.72 \times 10.29} = 13 \, \#/in^2 \right)$$

$$= \frac{0.75 \times 13 \times 9.67^2}{(0.602)^2(1+1.61\times .437^3)} = 2{,}210 \ \text{LBS/IN}^2$$

(RUPTURE 40,000 HRS) $MS = \frac{19000}{2{,}210} - 1$ = HIGH

CONSIDER THE CASE OF LOADING AS SHOWN IN THE SKETCH (SUCH AS IN FLIGHT) - BEING MORE CRITICAL WITH SAME 20 g LOADINGS



$$M = 137 \, \#/in \times 3.604'' = 495 \ \text{IN-LBS/IN}$$

ASSUME W AS UNIFORMLY DISTRIBUTED EQUALLY PER LENGTH

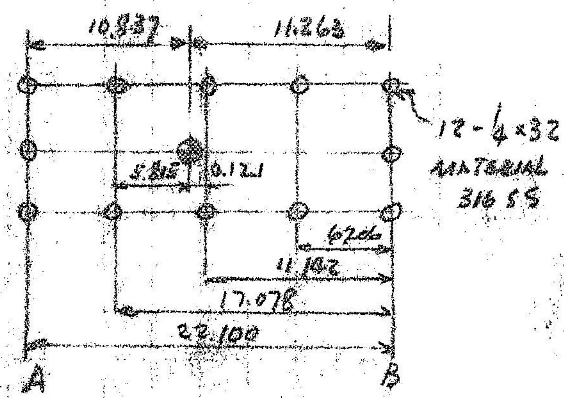
$$W = \frac{3024}{22.1} = 137 \, \#/in$$

$$\sigma_b = \frac{6M}{t^2} = \frac{6 \times 495}{(.602)^2} = 8{,}220 \ \text{LBS/IN}^2$$

(RUPTURE 40,000 HRS) $MS = \frac{19{,}000}{8{,}220} - 1 = +1.31$

(YIELD) $MS = \frac{24{,}000}{8{,}220} - 1 = +1.92$

BASE FASTENERS



C.G. OF FASTENER GROUP:

$$CG = \frac{1}{12}\left[2(6.206) + 2(11.182) + 2(17.078) + 3(22.100)\right]$$

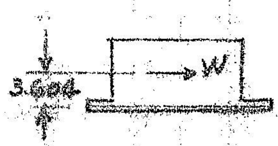
$$= \frac{1}{6}(34.426) + \frac{1}{4}(22.100)$$

$$= 11.263 \text{ IN.}$$

$$\Sigma I = 2\left[0.121^2 + 5.057^2 + 5.815^2\right] + 3\left[10.836^2 + 11.263^2\right]$$

$$= 841.5$$

CONSIDER THE CRITICAL CONDITION OF LOADS APPLIED HORIZONTALLY, THEN EACH FASTENER



$$F_S = \frac{W}{N} \qquad (N = \text{NO. OF FASTENERS} = 12)$$

$$= \frac{3024}{12} = 252 \text{ LBS}$$

FOR THE $M = 3024^{\#} \times 3.604'' = 10{,}910$ IN-LBS, IN EACH FASTENER IN COL. B

$$F_C = \frac{Mc}{\Sigma I}$$

$$= \frac{10{,}910 \times 11.263}{841.5} = 146 \text{ LBS}$$

FOR FASTENER OF 1/4"-32 MATERIAL 316 SS

STRESS $A = 0.0377 \text{ IN}^2$

$$\sigma_s = \frac{F_s}{A} = \frac{252}{0.0377} = 6{,}680 \text{ LBS/IN}^2$$

$$\sigma_c = \frac{F_c}{A} = \frac{146}{.0377} = 3{,}880 \text{ "}$$

FROM DESIGN HANDBOOK H-100, FOR 316 S.S. AT 260° F

$$F_{ty} = 27{,}300 \text{ LBS/IN}^2$$

$$F_{RUPTURE} = F_{tu} = 75{,}000 \text{ LBS/IN}^2$$

STRESS RATIO'S

$$R_s = \frac{6680}{0.56 \times 27{,}300} = 0.437$$

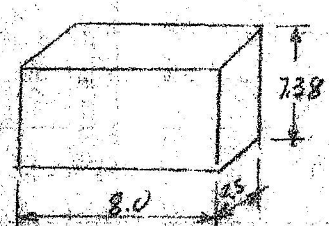
$$R_c = \frac{3880}{27{,}300} = 0.142$$

$$(\text{YIELD})\ M.S. = \frac{2}{R_c + \sqrt{R_c^2 + 4R_s^2}} - 1 = +0.93$$

COVER - FOR WHOLE ASSEMBLY (DWG: 1267809)

PER J MANOLA THIS COVER DOES NOT TAKE ANY LOAD SINCE ALL ELECTRICAL COMPONENTS ARE ATTACHED TO THE COMPARTMENT WALLS AND POTTING COMPOUND WHEN SOLIDIFIED CEMENTS ALL COMPONENTS TO THE WALLS.

POTTING



POTTING IN

ϕA = 8.951 LBS

ϕB = 10.465 "

ϕC = 8.951 "

WITH 20 g LOADING

$$q = \frac{10.465^{\#}}{8.0 \times 2.5} \times 21 \quad \text{(g LOADING)}$$

$$= 10.98 \ \text{LBS/IN}^2$$

BY ROARK - PAGE 203, CASE 36

$$\text{MAX } \sigma_b = \frac{0.75\, \omega\, b^2}{t^2 (1 + 1.61 \alpha^3)}$$

$$\alpha = \frac{2.5}{8.0} = 0.312$$

$$\alpha^3 = 0.0304$$

$$= \frac{0.75\,(10.98)(2.5)^2}{(7.38)^2 (1 + 1.61 \times .0304)}$$

$$= \frac{51.5}{56.5} = 1 \ \text{LBS/IN}^2 \quad \text{(SMALL)}$$

APPENDIX H

PROTECTIVE SYSTEM FOR SNAP-8 FLIGHT APPLICATION

S Bradley

DIVISION SNAP-8
TM 4931:66:405
DATE 16 June 1966
W.O. 0740-05-2041

TECHNICAL MEMORANDUM

AUTHOR(S): S. L. Bradley

TITLE: Protective System for SNAP-8 Flight Application

ABSTRACT

A general concept of a flight protective system is suggested and a specific circuit which will accomplish the desired results is recommended.

APPROVED:
DEPARTMENT HEAD S L Bradley
S. L. Bradley

NOTE: The information in this document is subject to revision as analysis progresses and additional data are acquired.

PROTECTIVE SYSTEM

I. REQUIREMENTS

1. The flight protective system can only protect the Electrical Generating System (EGS) for faults occurring in the vehicle load. It will not be possible to protect the plant against faults in the EGS, for if any of the loads or circuits in the Electrical Generating System (EGS) are faulted or lost, the plant will fail. It is therefore possible to protect the EGS against these failures only by designing the electrical wiring system and components with enough margin and redundancy so that electrical faults and failures in the EGS are very unlikely.

2. Although the exact nature of the load the SNAP-8 EGS will supply is unknown. The nature of the failures and faults that will occur is known, for they will be the same regardless of the type of load. The faults and failures will be three-phase faults line-to-line, single-phase faults line-to-line, and line-to-neutral, overloads and open circuits.

3. Although there will be a high current when there is a three-phase fault, the impedance to the fault will be mostly reactive so there will be little real power in the fault current and the turbine will be essentially unloaded. Because the fault will reduce the alternator output voltage to a very low level, the parasitic load system cannot apply appreciable load to maintain the speed at normal levels. There is thus very little load on the TAA, consequently it overspeeds.

4. The alternator and the excitation system are capable of producing high short circuit currents when faults occur. A three-phase fault will produce 2.85 Per Unit (P.U.) current (2.85 times rated current); a single-phase line-to-line fault will produce 3.05 P.U. current, and a single-phase line-to-neutral fault will produce 4.2 P.U. current. The winding of the alternator can withstand 4.2 P.U. current only about 18 seconds before the winding temperature rises to approximately 600°F (316°C). This temperature will soon damage the insulation sufficiently to cause winding failure.

5. It is clear that some protective action should be taken, for if the Vehicle Load Breaker (VLB) is opened when a fault occurs, EGS can continue to operate and produce power. Whereas if the VLB is not opened, the TAA is in danger of destroying itself because of overspeed or because of high alternator winding temperature caused by high fault currents or both.

6. The flight protective system must be highly reliable in order to perform successfully. For over 10,000 hours the system must avoid any false signals and consistently provide trip signals when true faults occur. Performance like this can only be realized because of inherent reliability achieved by simplicity of circuitry, natural ruggedness of components, and integrity of fabrication. When less reliable components cannot be avoided redundancy of components and/or conservative ratings are essential.

II. AVAILABLE SYSTEMS

1. A review of other protective systems has established that they are not suitable for use in the SNAP-8. In most cases, the aircraft protective systems are based on prevention of damage to the power generating components (whereas the goal for the SNAP-8 PCS EGS is to keep it in operation) and depend upon disconnecting them from the rest of the system, removing the field excitation and reducing or removing the shaft input power. In systems containing multiple generators, the load can be reduced or redistributed to maintain the essential functions. In single generator systems, the same type of protection is used, but with an emergency power supply to maintain the essential functions.

III. FLIGHT SYSTEM CONCEPT

1. The protective system concept suggested here is based on an effort to maintain the EGS in operation for as long as possible. Faults in the vehicle load will be detected and the load breaker opened to isolate the fault and maintain the EGS in operation. The load breaker will be reclosed when the output voltage returns to normal, and normal operation can be resumed if the fault has been cleared. If the fault condition persists, the breaker tripping and closing operation will be repeated. This method of operation will give the EGS every opportunity to resume completely normal operation if the fault has been cleared. If the fault still exists when the breaker is reclosed, (since normal voltage output conditions will have been reestablished in the EGS) another attempt can

be made to clear the fault by either burning it clear or by tripping a branch or individual circuit protective device in the vehicle load system.

2. No attempt will be made to detect or clear internal faults within the EGS. Each major power consuming or producing component is essential to the operation of the system and cannot be isolated without resulting in system failure.

3. It is considered necessary to detect single or three phase faults that will result in excessive current in the system, will cause excessive voltage unbalance or will result in overspeed of the TAA.

4. Faults that result in overload and overcurrent will decrease the output voltage directly as a result of alternator or exciter limitations or indirectly as a result of the decrease in turbine speed and the proportional relationship of the frequency and output voltage. Low impedance faults on single or multiple phases will result in a direct reduction of voltage. The use of single phase sensing on each of three phases will provide protection for either single or multiple phase faults.

5. Faults that can cause either an increase in voltage or an increase in frequency without a decrease in voltage will not be eliminated by opening the breaker and therefore do not need to be sensed separately.

6. All vehicle-load faults which can be cleared by opening of the vehicle load breaker will be sensed by this system.

7. The protective system designed for ground testing of the PCS as shown in schematic diagram 095381, Figure 1, is basically an under-voltage protective system. It, however, does include an over-frequency protective circuit which will not be needed on a flight system.

8. The over-frequency circuit protects the TAA from failure of the speed control subsystem or loss of load due to line breakage or other open circuit or any other malfunction which would cause overspeed of the TAA but which is not accompanied by a drop in voltage. However, to protect the TAA from overspeed the PCS must be shut down. This of course violates the principle that the EGS should be kept in operation as long as possible, so over-frequency protection should not be included in a flight protective system.

VI. SPECIFIC CIRCUITRY RECOMMENDATIONS

1. A 28 V DC power requirement is shown on the schematic diagram 095381, Figure 1. If a restart capability is included for the EGS, this power will be available from the battery which must be kept charged for the full mission. If no restart capability is necessary, a means will be provided to trip the Vehicle Load Breaker when there is little voltage output of the alternator. This can be done with a current transformer power supply or by capacitor energy storage.

2. As shown on drawing 095381, Figure 1, undervoltage sensing is accomplished by means of a bistable magnetic amplifier which receives the input from three phases into one control winding. When input voltage is above an established value, the bistable stays on and relay K1 is energized. If any one phase voltage or all three drop below established levels the bistable will switch off and relay K1 will be de-energized. When relay K1 is energized, the vehicle load breaker (VLB) is closed. When relay K1 is de-energized, the VLB is tripped.

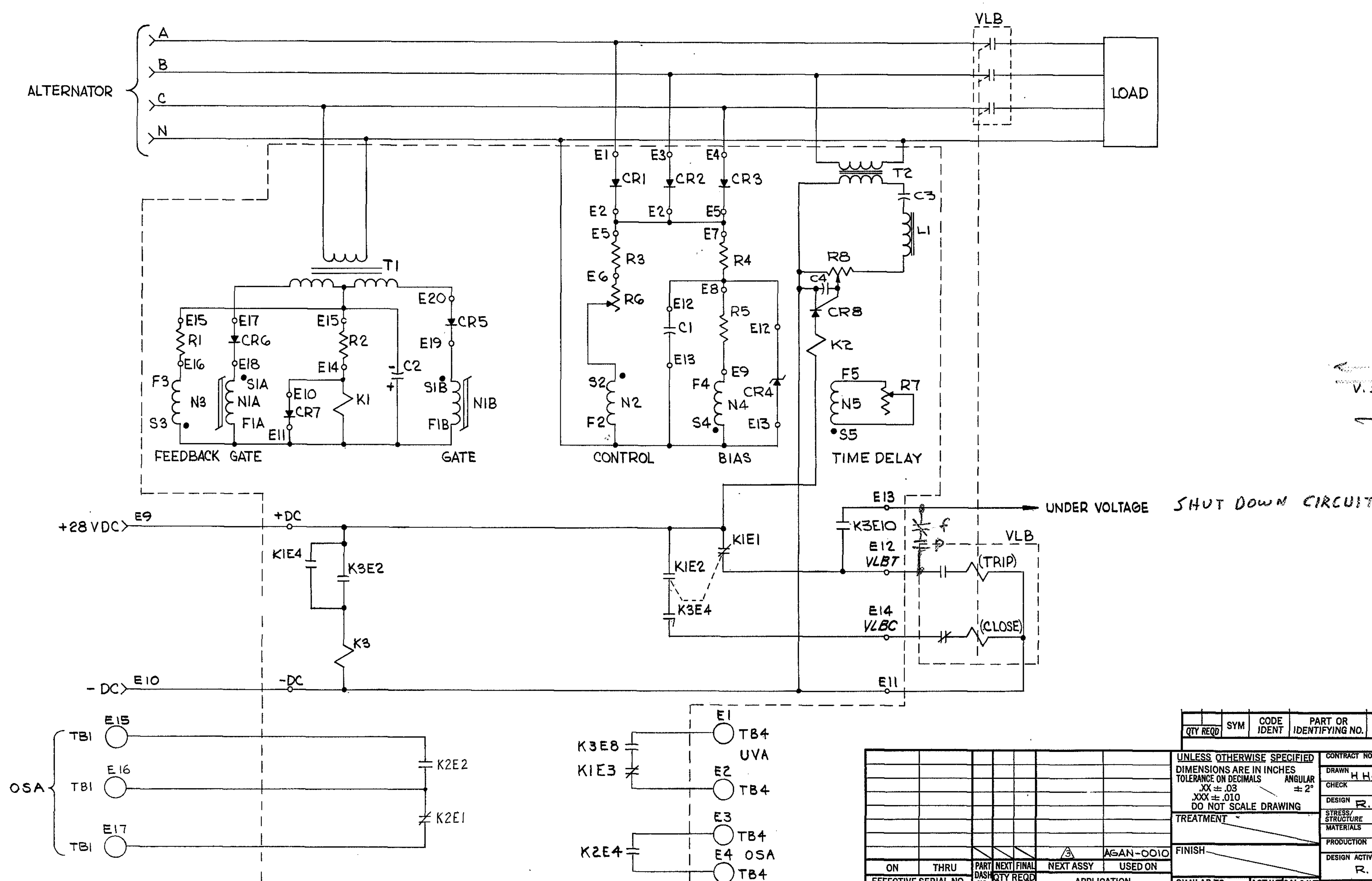
3. To prevent tripping on transients, a time delay is provided which will allow the system to ride through fast voltage dips caused by load changes. There is also a time delay provided on reclosing of the breaker. This is provided to allow the regulating system to reestablish normal voltage conditions before the VLB is reclosed. The time delays are obtained by means of a time delay winding in the magnetic amplifier and by RC circuits. No separate time delay relays are required.

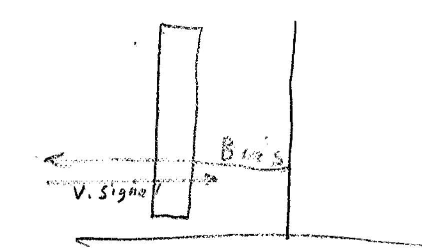
V. CONCLUSION

1. A protective system specifically developed for the peculiar requirements of the SNAP-8 EGS must be provided. No standard system is available which will satisfy these unique requirements. The system must achieve high reliability essentially from simplicity of circuitry, through use of inherently sturdy components and by careful, knowledgeable and experienced fabrication.

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED
	F	REDRAWN WITH CHANGES SEE DCN	12-21-65	

NOTES: 1. INTERPRET DRAWING PER STANDARDS PRESCRIBED IN MIL-D-70327.
2. ITEMS OUTSIDE OF DASH LINE ARE SHOWN FOR FUNCTIONAL PURPOSES ONLY.
3. FOR REFERENCE SEE WIRING DIAGRAM 095526.





QTY REQD	SYM	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	UNIT WT.	ZONE	ITEM NO.

LIST OF MATERIALS

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCE ON DECIMALS .XX ± .03 .XXX ± .010 ANGULAR ± 2°
DO NOT SCALE DRAWING
TREATMENT
FINISH
SIMILAR TO | ACT. WT | CALC WT

CONTRACT NO. NAS-5-417
DRAWN H HUNT 12-21-65
CHECK
DESIGN R. HILL 11-12-64
STRESS/STRUCTURE
MATERIALS
PRODUCTION
DESIGN ACTIVITY APPD R. HILL 11-12-64
CUSTOMER

AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

TITLE ELECTRICAL SCHEMATIC PROTECTIVE SYSTEM -X MODEL

DWG SIZE D | CODE IDENT NO. 70143 | DWG NO. 095381
SCALE NONE | RELEASE DATE 1-13-66 | SHEET

ON	THRU	PART DASH NO.	NEXT QTY REQD	FINAL PER ASSY	NEXT ASSY: 3 / USED ON: AGAN-0010
EFFECTIVE SERIAL NO. USAGE DATA					APPLICATION
		DRAWING LEVEL			O

095381 F

COPY

Figure 1

APPENDIX I

RECOMMENDED ELECTRICAL PROTECTIVE SYSTEMS FOR THE SNAP-8 ELECTRICAL GENERATING SYSTEM

10-047-009 (REV. 6/63)

CR-72938

DIVISION Mech. Sys. Oper.

TM 4936:68-537

DATE 5 June 1968

W.O. 1140-59-1520

TECHNICAL MEMORANDUM

AUTHOR(S): S. L. Bradley

TITLE: Recommended Electrical Protective Systems for the SNAP-8 Electrical Generating System

ABSTRACT

The requirements for protection of electrical components and circuits of the SNAP-8 EGS are discussed. Three classes of operation for the SNAP-8 EGS are considered:

Class I - Development Ground Testing

Class II - Space Operation - Unmanned

Class III - Space Operation - Manned

Recommendations are given for Protective Systems for each of the classes of service.

APPROVED:

DEPARTMENT HEAD ______________________

R. J. Hefner

NOTE: The information in this document is subject to revision as analysis progresses and additional data are acquired.

AEROJET-GENERAL CORPORATION

COPY NO.

PAGES:

I. INTRODUCTION

The protective requirements for the SNAP-8 EGS depend to some extent on the function of the system. If the function of the EGS is to operate in ground development tests, the protective requirements are different than for an unmanned power plant operating in space. Consequently, this discussion of protective requirements will be divided into three functional classes:

Class I - Protective System for Development Ground Testing

Class II - Protective System for Space Operation - Unmanned

Class III - Protective System for Space Operation - Manned

Each of these classes has distinct protective requirements; each is somewhat like the other, but each is different from the other.

This discussion will be concerned with the protective system for the electrical system only. Protection for the hydraulic system involving pressure, flow, etc. will be considered separately.

II. GENERAL DISCUSSION OF FAULTS AND FAILURES

The most common electrical hazard against which protection is required is the short circuit, and this fault will be given special consideration. However, there are other faults and failures which must be considered. Open circuits, overvoltage, undervoltage, overfrequency, underfrequency, overtemperature and unbalanced voltage are faulty conditions which must be considered. These failures are not independant of each other. One fault may be responsible for the appearance of other undesirable conditions. For example, a line-to-ground short circuit in a grounded system will not only result in high current in the faulted phase but will also cause low voltage across the same phase. In fact, any short circuit that results in excessive current will also produce abnormal voltages.

The SNAP-8 EGS is basically different from most power systems because speed is regulated by maintaining a controlled load on the system and the voltage is regulated to a value proportional to frequency rather than being independent of frequency. These unique characteristics have an important influence on the protective system required.

For example, an overload beyond the ability of the system will result in a drop in speed and voltage, so that overloads need not be sensed directly, but can be detected by an undervoltage sensor.

Also, a substantial loss of load caused by an open circuit or for other reasons will result in overspeed of the Turbine Alternator, so this component must be protected by an overspeed or overfrequency sensor which will sense an overspeed and shut the loop down rapidly enough to prevent damage to the TAA.

The SNAP-8 alternator and the excitation system are capable of producing high short circuit currents when faults occur. A three-phase fault will produce 2.85 Per Unit (P.U.) current (2.85 times rated current); a single-phase line-to-line fault will produce 3.05 P.U. current, and a single-phase line-to-neutral fault will produce 4.2 P.U. current. The winding of the alternator can withstand 4.2 P.U. current only about 18 seconds before the winding temperature rises to approximately 600°F (316°C). This temperature will soon damage the insulation sufficiently to cause winding failure.

Although there will be a high current when there is a three-phase fault, the impedance to the fault will be mostly reactive so there will be little real power in the fault current and the turbine will be essentially unloaded. Because the fault will reduce the alternator output voltage to a very low level, the parasitic-load speed-control system cannot apply appreciable load to maintain the speed at normal levels. There is thus very little load on the TAA; consequently it overspeeds. Thus a three-phase short circuit requires the same protective device as a loss of load on the TAA - an overfrequency sensor with the ability to shut the loop down rapidly.

All of the fault conditions discussed can occur in any SNAP-8 power system regardless of the class of service it is providing. However, the protective action that should be taken is different for different classes of service, so the protective system discussion that follows will be divided into three classes.

III. CLASS I - PROTECTIVE SYSTEM FOR DEVELOPMENT GROUND TESTING

A. REQUIREMENTS

The primary purpose of the protective system for development ground testing is to prevent damage to the Power Conversion System equipment. A shut down of the test facility will be tolerated to prevent damage to the

TAA, the pumps, the electrical equipment and other PCS apparatus. It is therefore required that failures anywhere in the PCS or test support equipment be detected and protective action taken to minimize damage. It, however, is also important that false shutdowns do not occur because endurance operation with a minimum number of shutdowns is one of the goals of the testing program.

A protective system for ground testing must provide protection for faults and failures in the PCS or in the Vehicle Load. It must open the vehicle load breaker when faults occur in the vehicle load. It must shut the plant down and remove the field excitation from the alternator for faults in the PCS.

The Turbine Alternator Assembly (TAA) must be automatically protected against destructive overspeeds and damaging fault currents.

It is not necessary that the pump motors be automatically protected from overload currents, but they should have overload alarms which sense high currents and high temperatures. Action to correct the condition existing can then be taken by the operator.

The Speed Control, Voltage Regulator, Programmer, Protective System and Inverter must be provided with temperature sensing means although it doesn't appear necessary to provide for high temperature alarms on these systems. The temperatures should be closely monitored during the initial operation of the system, but after a few hours of satisfactory operation close monitoring will not be necessary.

B. SYSTEM CONCEPT

For sensing of faults within the Power Conversion System (PCS) and the Vehicle Load (VL) an under-unbalanced voltage (U-UV) and overfrequency (OF) sensing system is required. The U-UV sensor will detect both undervoltage and unbalanced voltage in the system, and the OF sensor will detect Turbine Alternator overspeed.

In order for the protective system to distinguish between a fault in the PCS and one in the VL there should be two U-UV circuits. One (U-UV1) will open the Vehicle Load Breaker (VLB); the other (U-UV2), which will be delayed longer than the first, will start a controlled shutdown of the loop.

U-UV1 will protect for faults in the Vehicle Load.

U-UV2 will protect for faults in the Power Conversion System, including the more severe internal faults in the alternator.

Both under-unbalanced voltage sensors must be set so they do not trip when vehicle load is suddenly applied. Therefore they must have a time delay sufficiently long to ride through suddenly applied loads or the under-voltage must be set low enough that tripping does not occur on voltage dips caused by suddenly applied loads.

When an undervoltage occurs the U-UV1 sensor will open the VLB before the U-UV2 sensor starts a loop shutdown. If the fault is in the vehicle load, normal voltage conditions will be restored and U-UV2 sensor will not act. This is accomplished by providing a longer time delay for activation of the U-UV2 sensor than for the U-UV1 sensor. In other respects the two sensors are expected to be identical. If the fault is in the PCS the U-UV1 sensor will first open the VLB, but since this action will not clear the fault the abnormal voltage condition will persist so a predetermined time after the VLB opens, the U-UV2 sensor will initiate a controlled shutdown of the system.

These two U-UV sensors will detect nearly all the significant faults that could occur in the vehicle load and in the PCS electrical system. However, they will not detect a situation in which the voltage does not drop but the load on the TAA is lost. This is a condition which could occur if the vehicle load is lost by open circuit fault of all three phases provided the fault results in loss of the parasitic load system.

If this situation should develop the turbine will overspeed. The alternator output voltage will remain balanced but will rise proportional to speed. The U-UV sensors will not be actuated, so no protective action will be taken. An overvoltage (OV) sensor would detect this described malfunction and provide a loop shutdown signal. However, the (OV) sensor would not detect an overspeed which was caused by a loss of voltage output and consequently a loss of load on the TAA. This situation would be detected by the U-UV sensors and the U-UV2 sensor would initiate a controlled shutdown after a preset time delay.

The delay in start of a shutdown might result in overspeed sufficiently high to damage the TAA. It is therefore unlikely that an overvoltage (OV) sensor will be satisfactory to provide protection for all overspeed conditions.

To provide protection for TAA overspeed an overfrequency (OF) sensor should be provided. This sensor must be capable of detecting an overfrequency malfunction even though the alternator output voltage is higher than normal or if the voltage has been reduced to zero. This OF sensor must act to shut the loop down sufficiently fast to prevent damage to the TAA.

With the three sensors, U-UV1, U-UV2 and the OF, there is no need for an overload sensor per se.

Real power, kilowatt, overloads either in the vehicle load or in the PCS will result in a reduction in parasitic load as the speed control system attempts to maintain rated speed. When the speed control system can reduce the parasitic load no further, and if there is still an overload on the system, the speed and the voltage will decrease below normal until the under voltage setting of U-UV1 and U-UV2 is reached. At this point the sensors will be actuated, the VLB will be opened and a controlled shutdown will be started, providing protection for the overload condition.

A differential protection scheme will protect the Alternator from phase-to-ground faults within the Alternator winding. The Under-Unbalanced Sensor U-UV2 will also protect the Alternator against the more severe internal faults. However, it will not protect for faults at a point near the neutral point or for high resistance faults which do not result in excessive currents.

To obtain the maximum protection from internal Alternator faults a differential protective scheme should be added to the protective system. When it functions it should start a loop shutdown and after an appropriate time delay it should operate the field shorting switch.

A differential protective system is complicated, requiring four current transformers and a differential relay device. It should be included in the Development Ground Testing System but not in a space system.

C. GROUNDING OF ALTERNATOR NEUTRAL

If the neutral of the Alternator winding is grounded, faults to ground will result in high current and low or unbalanced voltages. These conditions will be detected by the protective system and appropriate action taken. Also if the neutral is grounded, a differential protective scheme will be able to detect internal ground faults within the Alternator that cannot be detected by any other means.

If the neutral is not grounded fault currents will not flow when a single short to ground occurs, so the protective system will not take any protective action. Thus the system will continue to operate with one ground fault. If a second ground fault occurs the protective system will be actuated.

It is recommended that for the Development Ground Testing System the neutral of the Alternator be solidly grounded. The Alternator neutral should not be grounded when the EGS is operating as a space power plant.

D. OTHER PROTECTIVE DEVICES

There are other conditions for which protection could be added, but such protection does not seem justified because of the increased complication.

1. Reverse Phase Rotation Sensor

This device would only be useful when the system is first started or after a repair. The extra complication is not justified, because this device checks only on workmanship and should not be required as a permanent device.

2. Over Current or Over Load Sensor

Neither of these devices is required because damaging overloads will also result in undervoltage which will operate the undervoltage sensor to provide required protection.

E. SUMMARY

Table 1 summarizes the possible fault conditions that could be experienced and the protective action that will be taken by the proposed Protective System.

IV. CLASS II - PROTECTIVE SYSTEM FOR SPACE OPERATION - UNMANNED

A. REQUIREMENTS

The protective system for an unmanned space power system can only protect the Electrical Generating System (EGS) for faults occurring in the vehicle load. It will not be possible to protect the plant against faults in the EGS, for if any of the loads or circuits in the Electrical Generating System (EGS) are faulted or lost, the plant will fail. It is therefore possible to protect the EGS against these failures only by designing the electrical wiring system and components with enough margin and redundancy so that electrical faults and failures in the EGS are very unlikely.

If the Vehicle Load Breaker (VLB) is opened when a fault occurs in the vehicle load, the EGS can continue to operate and produce power. Whereas if the VLB is not opened, the TAA is in danger of destroying itself because of overspeed or because of high alternator winding temperature caused by high fault currents or both.

The protective system must be highly reliable in order to perform successfully. For over 10,000 hours the system must avoid any false signals and consistently provide trip signals when true faults occur. Performance like this can only be realized because of inherent reliability achieved by simplicity of circuitry, natural ruggedness of components, and integrity of fabrication. When less reliable components cannot be avoided, redundancy of components and/or conservative ratings are essential.

B. SYSTEM CONCEPT

The protective system concept suggested here is based on the intent to maintain the EGS in operation for as long as possible. Faults in the vehicle load will be detected and the load breaker opened to isolate the fault and maintain the EGS in operation. The load breaker will be reclosed when the output voltage returns to normal, and normal operation can be resumed if the fault has been cleared. If the fault condition persists, the breaker tripping and closing operation will be repeated. This method of operation will give the EGS every opportunity to resume completely normal operation if the fault has been cleared. If the fault still exists when the breaker is reclosed, (since normal voltage output conditions will have been reestablished in the EGS) another attempt can be made to clear the fault by either burning it clear or by tripping a branch or individual circuit protective device in the vehicle load system. This opening and reclosing action will continue until the fault is cleared or until the VLB is locked open by an external signal.

No attempt will be made to detect or clear internal faults within the EGS. Each major power consuming or producing component is essential to the operation of the system and cannot be isolated without resulting in system failure.

It is considered necessary to detect single or three-phase faults in the Vehicle Load that will result in excessive current in the system, will cause excessive voltage unbalance or will result in overspeed of the TAA.

Faults that result in overload and overcurrent will decrease the output voltage directly as a result of alternator or exciter limitations or indirectly as a result of the decrease in turbine speed and the proportional relationship of the frequency and output voltage. Low impedance faults on single or multiple phases will result in a direct reduction of voltage. The use of single phase sensing on each of three phases will provide protection for either single or multiple phase faults.

Faults that can cause either an increase in voltage or an increase in frequency without a decrease in voltage will not be eliminated by opening the VLB and therefore do not need to be sensed separately.

All vehicle-load faults which can be cleared by opening of the vehicle load breaker will be sensed by this system.

C. SUMMARY

The Protective System for unmanned space operation will consist of an undervoltage (UV) sensor which will open the Vehicle Load Breaker (VLB) when a fault in the Vehicle Load is detected. It will reclose the VLB after normal voltage conditions are restored. This opening and reclosing action will be repeated until the fault is cleared or until the VLB is locked open by external signal.

V. CLASS III - PROTECTIVE SYSTEM FOR SPACE OPERATION - MANNED

A. REQUIREMENTS

The purpose of a protective system for a manned space power system is two fold: (1) The equipment that is repairable or replacable in space must be protected so that it sustains minimum damage when a fault or failure occurs. (2) Equipment that is not repairable or replacable in space must be kept in service as long as possible even though that equipment may be destroyed.

For the purpose of this discussion the following assumptions are made:

1. An astronaut will be able to monitor instruments and make limited corrective adjustments from time to time, but will not be in regular attendance.

2. Spare electrical modules, TAA and PMA's, will be available to the astronaut for replacement of defective units.

3. An astronaut will be able to determine which electrical modules and components are malfunctioning and will be capable of replacing them with spare units after the EGS is shut down.

4. The EGS can be shut down without causing damage which would prevent restart of the system.

5. The system can be shut down quickly so that damaging overspeed of the Turbine Alternator Assembly can be avoided.

Any faults or failures which would result in destructive overspeed or destructive temperatures to the Turbine Alternator must be sensed and protective action taken to prevent damage.

Faults in the vehicle load which are not cleared by local protective equipment must be sensed and the vehicle load breaker (VLB) opened. As discussed for the Class II system, an undervoltage sensing system which opens the VLB and then recloses it after a time delay is the recommended way to protect for vehicle load faults.

Faults within the PCS must be handled in a different way than those in the vehicle load. PCS faults cannot be cleared by opening a protective breaker to isolate the failure from the rest of the system, because if this is done a vital function will be lost and the system will stop operating, with the possibility that damage will result. When an electrical fault within the PCS is detected, the only action that can be taken is to shut the system down in such a way as to minimize the resulting damage.

B. SYSTEM CONCEPT

For sensing of faults within the PCS and the VL an undervoltage-voltage unbalance and overfrequency sensing system is required identical to that recommended for the Class I system, except that the U-UV1 Sensor which protects against faults in the Vehicle Load will be able to open and reclose the VLB in the manner described in the discussion of the Class II system.

This protective system consisting of two undervoltage-unbalanced voltage sensors and an overfrequency sensor will detect all faults which could result in rapid and catastrophic failure of an electrical element. If a fault occurs in the Vehicle Load the VLB will be opened. The VLB will be reclosed when the output voltage returns to normal. This protection method will give the EGS every opportunity to resume completely normal operation if the fault in the Vehicle Load clears.

The protective system proposed is not complex. It consists of only three sensors which can detect any of the fault conditions which would cause a replaceable item to fail. The simplicity of the system minimizes the failures that can occur to the protective system which would cause false shutdowns of the system.

C. SUMMARY

The Protective System recommended for manned space operation will consist of two under voltage-unbalanced voltage sensors, U-UV1 and U-UV2, and an overfrequency (OF) sensor. No other protective sensors are required to provide the required protection.

TABLE 1

FAULTS AND PROTECTIVE ACTION
FOR DEVELOPMENT GROUND TESTING

Fault or Failure in Vehicle Load	Condition Sensed	Protective Action
3 phase Short	Undervoltage (U-UV-1)	Open VLB
1 phase Short Line to Ground	Unbalanced Voltage (U-UV-1)	Open VLB
1 phase Short Line to Line	Unbalanced Voltage (U-UV-1)	Open VLB
Overload	Undervoltage (U-UV-1)	Open VLB
Open Circuit	Current to Vehicle Load	Operator Action

Fault or Failure in PCS	Condition Sensed	Protective Action
3 phase Short	Undervoltage (U-UV2)	Shutdown Loop & Short Field
1 phase Short Line to Ground	Undervoltage (U-UV2)	Shutdown Loop & Short Field
1 phase Short Line to Line	Undervoltage (U-UV2)	Shutdown Loop & Short Field
Internal Faults in Pump Motors		
Phase to Ground Short	Undervoltage (U-UV2)	Shutdown Loop & Short Field
	or	
	Unbalanced Currents - Overtemperature	Operator Action
Phase to Phase Short	Undervoltage (U-UV2)	Shutdown Loop & Short Field
	or	
	Unbalanced Currents - Overtemperature	Operator Action

Table 1
Sheet 1 of 2

TABLE I

FAULTS AND PROTECTIVE ACTION
FOR DEVELOPMENT GROUND TESTING

Fault or Failure in PCS	Condition Sensed	Protective Action
Internal Faults in Pump Motors		
Open Circuit One Phase	Unbalanced Currents - Overtemperature	Operator Action
Stalled Motor	Over Current - High Temperature	Operator Action
Internal Fault in Alternator		
Phase to Ground Short	Differential Current	Shutdown Loop & Short Field
	or Unbalanced Voltage (U-UV2)	" "
Phase to Phase Short	Unbalanced Voltage (U-UV2)	Shutdown Loop & Short Field
Speed Control Failure	Overspeed (OF) or Undervoltage (U-UV2)	Shutdown Loop
Voltage Regulator Failure	Undervoltage (U-UV2) or Over Voltage	Shutdown Loop Operator Action

Table 1
Sheet 2 of 2

APPENDIX J

DESIGN REVIEW CHECK LIST

AND FAILURE MODES AND EFFECTS ANALYSIS

POWER SYSTEMS DIVISION

DESIGN REVIEW CHECK LIST

SUBJECT UNDER REVIEW (Name, Part No.): Electrical Protective System Module P/N 1264931-1

This Design Review Check List is an integral part of the design review documentation package, required by Power Systems Division Procedure I-A6c, "Design Review Plan."

The items specified on the Design Review Check List provide the basis for a comprehensive review. However, they are not necessarily all inclusive. The design engineer shall be guided by the basic requirement for a thorough and detailed evaluation of a design, as stated under Section 3, "SCOPE," of this procedure, and shall expand the list where necessary.

Check List entries shown herein provide current information on the design under review and are intended to reflect the basis for and readiness of the design for entry into its next evolutionary phase.

REVIEWED BY:

A. Aleloff — 9 March 1970
Stress — Date

B. J. Amstadter — 3/10/70
Reliability — Date

G. G. Takach — 3/13/70
Quality Assurance — Date

PRESENTED BY:

N. G. Waldschmidt — 1-7-70
Design Engineer — Date

DESIGN APPROVAL:

S. L. Bradley — 3-13-70
Department Manager — Date

SUBJECT NAME: Electrical Protective System Module

P/N 1264931-1

DESIGN ENGINEER: [signature] DATE 12-18-69

Item No.	General	YES	NO	N/A	REFERENCE DOCUMENTS
1.	Is the basic design objective clearly defined?	X			4936-68-0115
2.	Are the performance parameters and output requirements definitive and not subject to misinterpretation?	X			4936-68-0115
3.	Are performance tolerances delineated?	X			4936-68-0115
4.	Are failure criteria delineated?				
5.	Were alternate designs considered in selecting the present design?	X			Concept. Des. Rev. 354:63-147 & 095521
6.	Were redundancy needs analyzed and results used in the design?	X			1267428
7.	Were simplification techniques applied?	X			1267428
8.	Was a failure modes and effects analysis made?				
9.	Have adequate safety margins been incorporated for each important failure mode?	X			All parts derated to 30% or lower
10.	If item has a limited life, is it so designated?			X	
11.	Have maintainability requirements been considered?	X			1264931
12.	Have previous test data and failure reports been reviewed and results used in the design?	X			PCS-1 Log
13.	Is the method of component identification specified? (The method of marking and location must be compatible with use-environment.)	X			See Dwgs
14.	If documentation of inspection findings is required, are the characteristics to be observed and their frequency and method of inspection defined?		X		In process
15.	If operational or functional acceptance testing is required, are the parameters, mode of testing, and equipment defined?		X		In process

SUBJECT NAME: ____________________

____________________ P/N ____________________

DESIGN ENGINEER: ____________________ DATE ____________________

Item No.	General	YES	NO	N/A	REFERENCE DOCUMENTS
16.	Are required special inspection equipments, tools, and gages defined?			X	
17.	Has a procurement plan for this material been established?	X			Dwgs
18.	Have qualified and preferred parts been used where applicable?	X			AGC, JPL PPL QPL-6106
19.	Is the design notebook and file up to date and ready for audit?			X	
20.	Have provisions been made for preservation, packaging, handling, storage, and shipping?	X			Dwgs
21.	Were trade-off studies made and utilized in selecting the design?	X			354:63-147 TM 4931:66:405 TM 4936:68-537
22.	Does the design minimize the probability of human errors during installation, checkout, and operation, such as reversed connections, parts installed backward, no lubrication during startup, etc.?	X			See Dwgs
23.	Does the design make appropriate use of "fail-safe" devices or techniques?	X			2 out of 3 logic See 1267428
24.	Does the design comply with all applicable specifications?	X			4936-68-0115
25.	Were the action items from the previous Design Review carried out?			X	
26.	Is the design compatible with the requirements of the end item?	X			4942-69-0080 Appendix C

SUBJECT NAME: ______________________

______________________ P/N ______________

DESIGN ENGINEER: ______________________ DATE ______________

Item No.	Mechanical	YES	NO	N/A	REFERENCE DOCUMENTS
1.	Has a stress analysis been made?	X			SA-E-182
2.	Have areas of high stress concentrations such as sharp corners, radii, and re-entrant angles been eliminated?	X			See Dwgs
3.	Has a thermal analysis been made?	X			4942-69-0095
4.	Is thermal expansion likely to have adverse effects on dimensions and tolerances?		X		
5.	Has a tolerance analysis been made to verify proper fitting of parts under extremes of tolerance buildup?	X			Dwg. check
6.	Did the tolerance analysis consider operating loads and temperatures?			X	
7.	Were static, dynamic and magnetic balances and their tolerances considered?			X	
8.	Has a wearout analysis for all rubbing and rolling parts been made?			X	
9.	Have the installation torques and tolerances of all fasteners and their stress effects been evaluated?	X			Same as SCM See Dwgs
10.	Is the inspectability of the component assured? (Are the true positioning and contour requirements designed to enable inspection of part?)	X			See Dwgs
11.	Has the mechanical compatibility with the complete system been verified?	X			Next assy not defined
12.	Does mechanical design reflect simplest method, from manufacturing view, to meet needed parameters?	X			See Dwgs
13.	Were environmental effects (including those of nuclear radiation) considered along with safety requirements during design?	X			Similar to SCM 1266898

SUBJECT NAME: ______________________

______________________ P/N ______________

DESIGN ENGINEER: ______________ DATE ________

Item No.	Electrical	YES	NO	N/A	REFERENCE DOCUMENTS
1.	Are the design essentials adequately defined, including performance, longevity, and repetitive operation requirements?	X			4942-69-0080
2.	Is the design compatible with the life cycle conditions to which the equipment will be exposed?	X			4942-69-0080
3.	Have the stability and drift requirements and the effects of environments on these characteristics been considered?	X			Zener diode T. C. See Handbook
4.	Was a simplification study made and applied?	X			Preliminary Design
5.	Is redundancy employed where beneficial; are possible side effects taken into consideration?	X			1267428
6.	Were reliability characteristics considered and documented in parts and materials selection?	X			1264931
7.	Are the part tolerances consistent with design requirements?	X			Dwgs & Specs
8.	Was adequate derating employed, including sufficient margin for transients and other excessive stresses?	X			Derated to 30% or lower
9.	Can the parts operation result in undesirable conditions of temperature, voltage, current, or RFI for other parts or assemblies? If so, was this info used in the design?	X			Will generate RFI
10.	Are the dielectric breakdown and insulation resistance properties adequate for the most severe environments?	X			See Magnetic Comp. Dwgs (add nos.)
11.	Is hermetic sealing employed where beneficial?	X			
12.	Are type of connections employed reliable?	X			All are welded

SUBJECT NAME: ______	YES	NO	N/A	REFERENCE DOCUMENTS
______ P/N ______				
DESIGN ENGINEER: ______ DATE ______				
Item No. **Electrical**				
13. Have all applicable specifications been called out?	X			See Dwgs
14. Have the preferred parts lists (JPL Specification No. 20061C and CSFC-PPL-1) been used?	X			AGC, JPL QPL-6106
15. Has expected hot spot temperatures been determined and considered?	X			4942-69-0095
16. Has effect of component operation on primary power wave form been considered?	X			Similar to SCM
17. Has nuclear radiation environment effects been considered?	X			Similar to SCM
NOTE: The following electrical characteristics should be considered: inductance, capacitance, resistance, sensitivity, leakage, insulation, shielding; distortion, gain, phase, attenuation; slope, harmonics, eddy currents; time, spikes, peaks, contact resistance, contact rating, torque, wire size				

SUBJECT NAME: ____________________

P/N ____________________

DESIGN ENGINEER: ____________ DATE ____________

Item No.	Materials	YES	NO	N/A	REFERENCE DOCUMENTS
1.	Are all materials adequately identified by MIL, Fed, AGC, or comparable specifications?*	X			See Dwgs
2.	Is the source of supply specified for qualified/preferred materials?	X			See Dwgs
3.	Are the strength characteristics of the materials including tensile, compressive, shear, yield, bending, creep, and fatigue satisfactory for intended use?	X			SA-E-182
4.	Is each material employed within limits defined by its endurance limit curve?	X			SA-E-182
5.	Have adequate safety margins been used to provide protection from failure due to corrosion, vibration, shock, fatigue, and other stress factors?	X			Similar to SCM
6.	Are the hardness, ductility, and other characteristics suitable for both the manufacturing processes and application?	X			Similar to SCM
7.	Will the material characteristics be significantly changed by exposure to environments, particularly radiation?	X			Threshold of all parts 100 times greater than dose OP 367736
8.	Are the special inspection and test processes compatible with the parts and materials?			X	
9.	Are the thermal expansion characteristics suitable for the intended use?	X			Similar to SCM
10.	Will the materials be compatible with mating parts, fluids, and gases and not act as catalytic agents?	X			Similar to SCM
11.	Does each material have suitable electrical and magnetic properties for its application?	X			Similar to SCM

* The order of precedence for specifications must meet MIL-STD-143 requirements.

SUBJECT NAME: ______ P/N ______ DESIGN ENGINEER: ______ DATE ______	YES	NO	N/A	REFERENCE DOCUMENTS
Item No. **Materials**				
12. Have adequate metallurgical controls been imposed to assure that each material conforms to its specification?	X			See Dwgs
13. Are all tolerances specified and are they compatible with the materials and required manufacturing methods?	X			See Dwgs
14. If mechanical, metallurgical, and/or chemical testing is required, are the necessary samples, coupons, or test bars defined, and test methods established?			X	

SUBJECT NAME: ____________________

____________ P/N ____________

DESIGN ENGINEER: ____________ DATE ____________

Item No.	Manufacturing Processes	YES	NO	N/A	REFERENCE DOCUMENTS
1.	Are the specified fabrication methods suited to the design and materials?	X			See Dwgs
2.	Are the process capabilities consistent with component requirements?	X			See Dwgs
3.	Is heat treating, stress relief, nitriting, flame hardening, or other special process required?	X			See Dwgs
4.	Will processing and assembly affect the dimensions?		X		
5.	Are process specifications and tolerances designated?	X			See Dwgs
6.	Are requirements after processing and assembly specified?	X			See Dwgs
7.	Have joining methods (welding, brazing, soldering, fastening) been selected to minimize effect on tolerances and part variations?			X	
8.	Are special inspection and test processes such as radiograph, helium leak test, and penetrant dye check required?	X			See Dwgs
9.	If so, are acceptance criteria specified?	X			See Dwgs
10.	Has the most suitable cleaning method been specified?			X	
11.	Is a protective coating required?	X			4923:68:8186
12.	If so, will protective coating affect mating parts?		X		
13.	Are special assembly requirements such as slignment, torque, lock wiring, static balancing, or dynamic balancing defined and documented?	X			See Dwgs
14.	Is there an assembly instruction or specification?		X		

SUBJECT NAME: ______________________ P/N ______________ DESIGN ENGINEER: ______________ DATE ______________	YES	NO	N/A	REFERENCE DOCUMENTS
<u>Item No.</u> <u>Manufacturing Processes</u>				
15. Are the clean room environmental characteristics defined (such as maximum particle size, count, temperature, flow rate, etc.)?			X	
16. Are there special packaging, handling, or storage requirements?	X			See Dwgs
17. Are the special process operator and equipment qualification requirements specified?	X			See Dwgs
18. Are the surface finish, waviness, and lay adequately defined?	X			See Dwgs
19. Are workmanship acceptance standards defined?	X			AGC-10331
20. Are the applicable workmanship specifications referenced?	X			See Dwgs
21. Is a Build-up and Assembly Log required?	X			417-2

SUBJECT NAME: ____ P/N ____ DESIGN ENGINEER: ____ DATE ____	YES	NO	N/A	REFERENCE DOCUMENTS
Item No. **Environment**				
1. Have the environmental exposures, levels, and durations been fully determined?	X			PCS-G Spec AGC-105120
2. Have the environmental effects on component performance, longevity, and reliability been evaluated?	X			Similar to SCM
3. Does operation of the component generate environments which are detrimental to the component or to other assemblies or subsystems?	X			RFI
4. Can the component withstand external and self-generated environments without employment of isolation devices?	X			See Dwgs
5. Is adequate protection from environments specified in detail where required?	X			See Dwgs
6. Were the relationships between environments and modes of failure considered in the failure mode and effects analysis?	X			See FM & E Anal.
NOTE: The following environments should be considered: heat, cold, thermal shock, high pressure, vacuum, pressure shock, humidity; vibration, acoustic noise, acceleration, shock, RFI-radiated, RFI-conducted, RFI-susceptibility; explosive atmosphere, solar radiation, nuclear radiation, salt atmosphere, fungus, meteoroids, zero-gravity, sand, dust, wind.				

SUBJECT NAME:	YES	NO	N/A	REFERENCE DOCUMENTS
P/N				
DESIGN ENGINEER: DATE				
Item No. **Instrumentation**				
1. Have accuracy and precision requirements been specified for performance parameters?	X			AGC-STD-1245
2. Have provisions been made for instrumentation to meet these requirements?			X	None required
3. Have sensor installation requirements, including hermetic sealing and removal or replacement, been considered?	X			May install thermocouples
4. Will the insertion of sensors affect the operation of the component?		X		
5. Is adequate instrumentation available for anticipated operating conditions?	X			ECTF
6. Is an instrumentation development program necessary?		X		
7. Are written calibration instructions available for the calibration of data gathering equipment?	X			AGC & Mil Spec
8. Has an adequate and reliable instrumentation wiring system been defined?			X	

MECHANICAL SYSTEMS OPERATIONS
FAILURE MODES AND EFFECTS ANALYSIS

PART NO. 1264931-1
PART NAME Electrical Protective System Module
ITEM NO. ______

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INITIAL ☐ REVISION ☐

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FAILURE MODE	FAILURE CAUSE	COMPONENT	SYSTEM	PROBABILITY OF OCCURRENCE*	CRITICALITY OF FAILURE**	REMARKS AND RECOMMENDATIONS
1. K1L1 (or K4L1 or K7L1) coil open	Lead wire broken internally	Minor	Minor	Low	Minor	Failure will not result in false protective action. Protective action when called for will be normal for symmetrical, 2 phase and certain 1 phase faults. False protective action may occur for certain other 1 phase faults.
2. K1L2 (or K4L2 or K7L2) coil open	Lead wire broken internally	Minor	Minor	Low	Minor	Failure will not result in false protective action. Protective action when called for will be normal for all fault conditions.
3. K1L1E2 (or K4L1E2 or K7L1E2) will not close	Mechanical defect or oxide film	Minor	Minor	Low	Minor	Failure will not result in false protective action. Protective action when called for will be normal for all fault conditions.

* HIGH - Two or more occurrences of failure mode in testing.
MODerate - One recorded occurrence.
LOW - No recorded occurrences.

** CRITICAL - Failure which aborts the test in progress or creates an intolerable safety hazard.
MAJOR - A failure or performance degradation in excess of tolerance limits or causes loss of next mission.
MINOR - Failures other than critical or major which have no significant effect on the ability of the system to perform its primary function.

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MECHANICAL SYSTEMS OPERATIONS
FAILURE MODES AND EFFECTS ANALYSIS

PART NO. 1264931-1
PART NAME Electrical Protective System Module
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1 FAILURE MODE	2 FAILURE CAUSE	3 COMPONENT	3 SYSTEM	4 PROBABILITY OF OCCURRENCE*	5 CRITICALITY OF FAILURE**	6 REMARKS AND RECOMMENDATIONS
4. K1L1E3 (or K4L1E3 or K7K1E3) will not open	Mechanical defect	Minor	Minor	Low	Minor	Failure will not result in false protective action. Protective action when called for will be same as for Failure Mode 1.
5. K1L1E4 (or K4L1E4 or K7L1E4) will not close	Mechanical defect or oxide film	Minor	Minor	Low	Minor	Failure will not result in false protective action. Timing reactor L2 (or L4 or L6) will not be reset. Time delay on fault in Phase A (or Phase B or Phase C) may be very short. Because of 2 out of 3 output logic, protective action when called for will be normal for all fault conditions.
6. Any 1 of these contacts failing to close: K1L1E6, K1L2E6, K4L1E6, K4L2E6, K7L1E6, K7L2E6	Mechanical defect or oxide film	Minor	Minor	Low	Minor	Failure will not result in false protective action. Protective action when called for will be normal for all fault conditions.

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MECHANICAL SYSTEMS OPERATIONS
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PART NO. 1264931-1
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FAILURE MODE	FAILURE CAUSE	COMPONENT	SYSTEM	PROBABILITY OF OCCURRENCE*	CRITICALITY OF FAILURE**	REMARKS AND RECOMMENDATIONS
7. Any 1 of these contacts failing to open: K1L1E7, K1L2E7, K4L1E7, K4L2E7, K7L1E7, K7L2E7	Mechanical defects	Minor	Minor	Low	Minor	Failure will not result in false protective action. Protective action when called for will be normal for all fault conditions.
8. K2 (or K5 or K8) coil open	Lead wire broken internally	Minor	Minor	Low	Minor to critical	Failure will not result in false protective action. Protective action when called for will be normal for symmetrical and certain 2 phase and 1 phase faults, and will not occur for certain other 2 phase and 1 phase faults.
9. K2E2 (or K5E2 or K8E2) contact will not close	Mechanical defect or oxide film	Minor	Minor	Low	Minor	Failure will not result in false protective action. Protective action when called for will be normal for all fault conditions.

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MODerate - One recorded occurrence.
LOW - No recorded occurrences.

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FAILURE MODE	FAILURE CAUSE	COMPONENT	SYSTEM	PROBABILITY OF OCCURRENCE*	CRITICALITY OF FAILURE**	REMARKS AND RECOMMENDATIONS
10. K3 (or K6 or K9) coil open	Lead wire broken internally	Minor	Minor	Low	Minor to critical	Failure will not result in false protective action. Protective action when called for will be the same as for Failure Mode 8.
11. K3E1 (or K6E1 or K9E1) contact will not open	Mechanical defect	Minor	Minor	Low	Minor to critical	Failure will not result in false protective action. Protective action when called for will be the same as for Failure Mode 8.
12. Any one rectifier in a rectifier quad either opens or shorts	Manufacturing defect	Minor	Minor	Low	Minor	Failure will not result in false protective action. Protective action when called for will be normal for all fault conditions.

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MODerate - One recorded occurrence.
LOW - No recorded occurrences.

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				PROBABILITY OF OCCURRENCE*	CRITICALITY OF FAILURE**	
FAILURE MODE	FAILURE CAUSE	COMPONENT	SYSTEM			REMARKS AND RECOMMENDATIONS
13. L1 (or L3 or L5) open	Lead wire broken internally	Minor	Minor	Low	Minor to critical	Failure will not result in false protective action. Protective action when called for will be normal for symmetrical and certain 2 phase and 1 phase faults if alternator voltage in Phase A (or Phase B or Phase C) when involved drops to zero. Protective action will not occur for other 2 phase and 1 phase faults.
14. VR2 (or VR5 or VR8) opens or VR3 (or VR6 or VR9) shorts	Manufacturing defect	Minor	Minor	Low	Minor to critical	K1L1 and K1L2 (or K4 or K7) will not energize. Failure will not result in false protective action. Protective action when called for will be normal for symmetrical and certain 2 phase and 1 phase faults, and will not occur for certain other 2 phase and 1 phase faults.

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MODerate - One recorded occurrence.
LOW - No recorded occurrences.

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MAJOR - A failure or performance degradation in excess of tolerance limits or causes loss of next mission.
MINOR - Failures other than critical or major which have no significant effect on the ability of the system to perform its primary function.

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FAILURE MODE	FAILURE CAUSE	COMPONENT	SYSTEM	PROBABILITY OF OCCURRENCE*	CRITICALITY OF FAILURE**	REMARKS AND RECOMMENDATIONS
15. VR2 (or VR5 or VR8) shorts	Manufacturing defect	Minor	Minor	Low	Minor to critical	K1L1 and K1L2 (or K4L1 and K4L2 or K7L1 and K7L2 will energize on low voltage and will not de-energize on overvoltage or undervoltage unless voltage in Phase A (or Phase B or Phase C) drops to zero. Failure will not result in false protective action. Protective action when called for will be same as for Failure Mode 14.
16. VR3 (or VR6 or VR9) opens	Manufacturing defect	Minor	Minor	Low	Minor	K1L1 and K1L2 (or K4L1 and K4L2 or K7L1 and K7L2) will not de-energize on overvoltage or overspeed. Protective action when called for will be normal for all fault conditions including overspeed.

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MODerate - One recorded occurrence.
LOW - No recorded occurrences.

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MINOR - Failures other than critical or major which have no significant effect on the ability of the system to perform its primary function.

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FAILURE MODE	FAILURE CAUSE	COMPONENT	SYSTEM	PROBABILITY OF OCCURRENCE*	CRITICALITY OF FAILURE**	REMARKS AND RECOMMENDATIONS
17. VR1 (VR4 or VR7) open	Manufacturing defect	Minor	Minor	Low	Minor	Failure will not result in false protective action. Time delay provided by saturating reactor will vary inversely with battery voltage protective action otherwise normal. May occasionally on load change transient get 1 set of contacts open in the 2 out of 3 shutdown circuit, but no false protective action.
18. VR1 (VR4 or VR7) short	Manufacturing defect	Minor	Minor	Low	Minor to critical	K3 (or K6 or K9) will not energize. Failure will not result in false protective action. Protective action when called for will be normal for symmetrical and certain 2 phase and 1 phase faults, and will not occur for certain other 2 phase and 1 phase faults.

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MODerate - One recorded occurrence.
LOW - No recorded occurrences.

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MAJOR - A failure or performance degradation in excess of tolerance limits or causes loss of next mission.
MINOR - Failures other than critical or major which have no significant effect on the ability of the system to perform its primary function.

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1 FAILURE MODE	2 FAILURE CAUSE	3 COMPONENT	3 SYSTEM	4 PROBABILITY OF OCCURRENCE*	5 CRITICALITY OF FAILURE**	6 REMARKS AND RECOMMENDATIONS
19. K1L1 (or K4L1 or K7L1) coil shorted	Failure of coil insulation because of temperature, radiation, vibration, or combination thereof	Minor	Minor	Low	Minor	Failure will not result in false protective action. Short will probably burn itself open but will de-energize K1L2 (or K4L1 or K7L2) until burn open occurs. Whether shorted or burned open, protective action when called for will be the same as described in Failure Mode 1
20. K1L2 (or K4L2) or K7L2) coil shorted	Failure of coil insulation because of temperature, radiation, vibration, or combination thereof	Minor	Minor	Low	Minor	Failure will not result in false protective action. Short will probably burn itself open but will de-energize K1L1 (or K4L1 or K7L1) until burn open occurs. While shorted, protective action when called for will be the same as described in Failure Mode 1. After burn open occurs, protective actions when called for will be the same as described in Failure Mode 2.

* HIGH - Two or more occurrences of failure mode in testing.
MODerate - One recorded occurrence.
LOW - No recorded occurrences.

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MINOR - Failures other than critical or major which have no significant effect on the ability of the system to perform its primary function.

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FAILURE MODE	FAILURE CAUSE	COMPONENT	SYSTEM	PROBABILITY OF OCCURRENCE*	CRITICALITY OF FAILURE**	REMARKS AND RECOMMENDATIONS
21. K2 (or K5 or K8) coil shorted	Failure of coil insulation because of temperature, radiation, vibration, or combinations thereof	Minor	Minor to critical	Low	Minor to critical	Failure will not result in false protective action unless triggered indirectly by effect of short on DC power source. Short will quickly burn itself open. Protective action when called for will be the same as described in Failure Mode 8.
22. K3 (or K6 or K9) coil shorted	Failure of coil insulation because of temperature, radiation, vibration, or combinations thereof	Minor	Minor	Very low	Minor	Failure will not result in false protective action. Short may or may not burn itself open. In either case protective action when called for will be the same as described in Failure Mode 8.

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MODerate - One recorded occurrence.
LOW - No recorded occurrences.

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MINOR - Failures other than critical or major which have no significant effect on the ability of the system to perform its primary function.

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