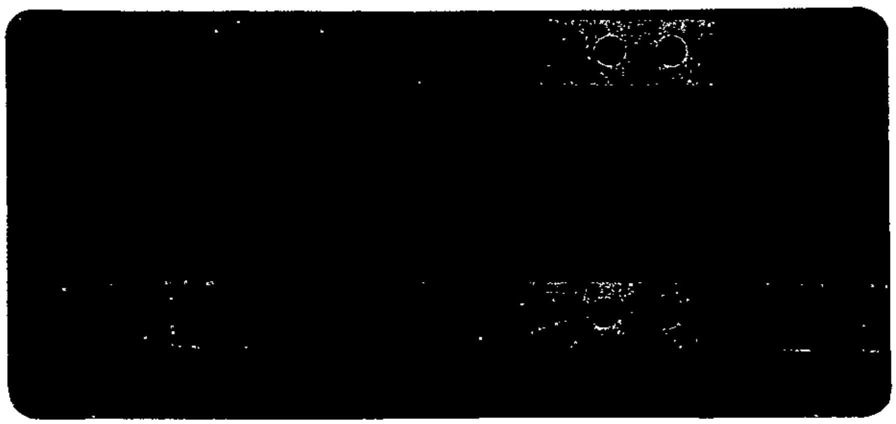

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AEROSPACE GROUP
SPACE SYSTEMS DIVISION
EL SEGUNDO, CALIFORNIA

QUARTERLY TECHNICAL REPORT
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ELECTRIC THRUSTER POWER CONDITIONER
CONTRACT NO. 952297
HUGHES AIRCRAFT COMPANY
EL SEGUNDO, CALIFORNIA

OCT 31 1968

W. J. Muldoon
W. J. Muldoon
Assistant Project Manager

J. A. Robertson
J. A. Robertson
Contract Administrator

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ABSTRACT

Quarterly report on JPL Contract 952297 for a 20 CM Electric Thruster Power Conditioner and Support Equipment, presents circuit and physical design description, efficiency analysis, reliability analysis, and test data taken on preliminary breadboards.

Report discusses techniques of high-efficiency regulation and control; i.e., single inverter pulse-width modulation, staggered-phase inverter modulation, line-regulator modulation, magnetic modulation. Design goal efficiency is 93 percent. Preliminary tests suggest this is feasible.

Techniques of analog thruster loop control are discussed, also overload trips, standby and active redundancy.

Report also discusses physical design approach for self-radiating cooling.

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INTRODUCTION

The objective of this contract is the design and fabrication of a power conditioning and control system for the JPL 20 cm electric thruster, which requires approximately 3 KW of conditioned power, with prime power from a solar array ranging from 40 volts out to 80 volts out.

The requirements of 1% regulation on all outputs, and a wide range of control, combined with a target efficiency of 93%, and a weight at eight pounds per kilowatt, necessitates the use of pulse-width modulation on all supplies. The large step-up for high voltage, d.c. supplies, and large step-down for high current, low voltage, a.c. supplies, requires the use of d.c. to a.c. inverters.

To satisfy the requirements of high efficiency and low weight, inverters must operate at relatively high frequency. The choice of transistors, with the high speed switching required for high efficiency, is limited to 20 amp. rating, usable at 10 amp. for reliability. At 40 volt low line, the resultant limit is 400 watts per inverter (paralleling transistors is costly in efficiency, due to need for equalizing techniques). Hence, in one supply requiring an output of 2000 volts at 1 amp (2 KW), the total power must be obtained from a group of inverters. For high efficiency, with wide range of regulation and control, to avoid the losses associated with separate modulation and inversion, pulse-width modulated inverters are used.

In this first three month period in the contract, principal efforts were in the design and development of the subsystems and circuits required by the system. The results of this development effort are described in this report, with emphasis on technology rather than description of the detailed embodiment of the techniques described, although detailed circuits are presented to illustrate the reduction to practice of these techniques.

TECHNICAL DISCUSSION

1. General

a. Objectives

The broad objectives are to design a system providing the outputs shown in Tables I and II, with prime power from a solar array varying from 40 V to 80 V, such as obtained on a Jupiter mission (40 V at earth, 80 V at Jupiter). The system weight should not exceed 23.5 pounds, and efficiency should not be less than 92%. Reliability for a 10,000 hour flight should exceed 96%.

Start-up and shut-down shall be commanded by pulse signals of 20 V to 31 V of 20 milliseconds duration, at 75 mA.

Control of thruster screen current shall be by an analog signal with 5 volts for 1 amp, continuously variable to 0.5 amps at 0 volts control.

Telemetry shall be supplied, as indicated in Table II, at a normalized full-scale output of 5 volts at a source impedance of 10K ohms or less.

b. System Description

All voltages delivered by the Power Conditioning System, delineated in Table I, are derived from inverters operating at two synchronized frequencies; i.e., 12.5 KHz and 5 KHz. Individual inverters deliver power in the range of 100 to 300 watts. Where higher power is required, such as the screen system at 2 KV and 1A, total power is derived from the series output of 300 watt inverters.

By restricting the maximum output per inverter to 300 watts, it is possible to use high speed transistors, and thereby retain high efficiency at reasonably high frequency such as 12.5 KHz, permitting low weight and high efficiency transformers. Further advantages from the modularization are adaptability to fractional redundancy for high reliability, and adaptability to staggered phasing to minimize ripple from pulse-width regulation. The staggered phase technique also minimizes the peaking of the screen output filters at no load.

The 5 KHz inverter frequency is used for a.c. heater loads where a higher frequency would result in excessive line and load inductive impedance

Group	Supply No.	Supply Name	Type	Output 1)	Max. Ratings			Nominal Ratings					Range of Control 5)	Frequency	
					E	I	I_{LIM} 2)	E	I	P	Regul.	Pk. Ripple		Output	Ripple
					V	A	A	V	A	W	%	%	A	kHz	kHz
I	1	Magnet Manifold Htr	DC	F	19	0.85	0.9	15	0.67	10.5	1.0(I)	5	---	---	10
I	3	Cath. Htr	AC	V	5	40	45	4.5	35	160	Loop	---	10 - 40	5	---
I	7	Neutr. Htr	AC	V	12	3.4	4	12	2.8	35	Loop	---	0.3- 3.4	5	---
I	8	Neutr. Kpr	DC	F	300V 5mA (4)	20mA 30V	0.55	10	0.50	5	1.0(E)	2 at 30V 5 at 10V	0.02-0.5	---	10
II	2	Vaporizer	AC	V	1.0	2.0	2.05	5.5	1.1	.6	Loop	---	0.5 - 1.2	5	---
II	4	Arc	DC	V	150V 20mA (4)	7at36V	8	34.5	6	210	1.0(E)	2	2 - 7	---	30
II	5	Beam	DC	V	2050	1.0	1.05	2000V	1.0	2kw	1.0(E)	5	0.5-1.0	---	30
II	6	Accel.	DC	F	2050	0.1 3)	0.105	2000V	0.01	20	1.0(E)	5 at 0.1 amp.	---	---	30

1) Output: V = Variable, F = Fixed

2) Current Limits or overload trips - Exact values to be specified by the manufacturer.

3) Current stays at this level for less than 10 minutes at very low rep. rate.

4) Starting Characteristics. (150V N_L to 36V at 20 ma)

5) Current varies as function of engine loop control. See Figures below

TABLE I

~~XXXXXXX~~
~~XXXXXXX~~
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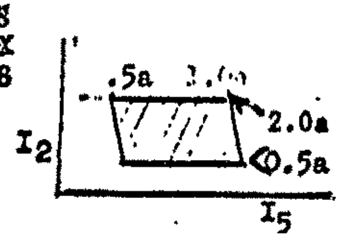
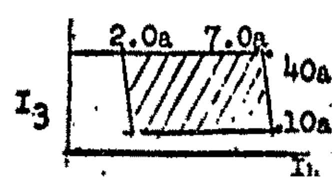
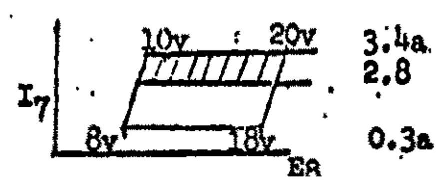






Supply #	Name	TELEMETRY				Shutdown Levels (Note 1)	
		0 - 5V TM Range		High Accuracy Part Of TM Range			
		Current	Voltage	Current	Voltage	Low	High
1	Magnet	0.3 - 0.9A	----	0.65 - 0.75A	----	----	----
2	Vapor.	0 - 3A	----	----	----	----	----
3	Cath. Htr.	10 - 45A	----	----	----	----	----
4	Arc	0 - 7A	30 - 40V	2 - 7	34 - 36V	----	----
5	Beam	0 - 1A	1700 - 2100	0.5 - 1A	1950 - 2050	$f\left(I_B \text{ Set}\right)$ 1750V	1.1 I_B Set 2100V
6	Accel.	0 - 20mA	1700 - 2100	----	1950 - 2050	1750V	2100V
7	Neutr. Htr.	0 - 4A	----	----	----	----	----
8	Neutr. Keeper	0 - 1A	0 - 30	----	----	----	----
	Neutr. Emission	0 - 1A	----	----	----		
	"Off"	----	5V Output	----	----		
	Arcings					10 Arc/Min	

NOTE 1: At these levels P.C. will be ordered to shut-down.

Table XI: Telemetry Data and

at relatively high currents and low-voltages required. It is also used for low power loads such as Magnet-Supply and Neutralizer Keeper to minimize circuit complexity.

The 12.5 KHz inverter frequency is used for dc-to-dc converters at high power (300 watts) for reasons stated above.

Referring to Functional Block Diagram, Drawing X3188131, regulated d.c. voltage of 35 volts is derived from the chopper line regulator, which regulates output within one percent over the range of 40 to 80 volt line. A master oscillator serves as the chopping frequency source for the regulator, and as the master oscillator for all pulse-width-regulated inverters. Also derived from the oscillator is synchronized 10 KHz for the 5 KHz heater inverter and 10 KHz for the cathode heater pulse-width-regulator.

The 5 KHz heater inverter supplies square-wave voltage to magnetically-regulated supplies for the Magnet (VI), vaporizer-heater (V2), neutralizer heater (V7) and neutralizer keeper (V8) supplies. Additionally, it supplies regulated d.c. voltages for driven inverters base drive (cathode, arc, accelerat and screen) and for miscellaneous logic and control functions.

The cathode, arc and screen inverters all use pulse-width modulated base drive for regulation, with prime power derived from the 40 to 80 volt line.

The accelerator inverter is a driven inverter, not modulated, but regulated by a chopper line regulator in series with the line, and controlled by feedback from the accelerator supply output. This technique was chosen rather than a modulated inverter, in view of the resonant ringing with high step-up, between output filter choke and transformer distributed capacity, the choke necessitated by the modulated inverter. By regulating (controlling) input d.c., inverter output is square-wave and requires only a small capacity for filtering, minimizing output ringing. Such ringing is, of course, highly undesirable at the 2 KV level of the output.

As mentioned above, in discussing the advantages of the modular system, the screen system inverters are stagger-phased. The phase shifting required is accomplished in the oscillator section, since this section includes the master oscillator, used as the reference frequency for phase-shifting. The screen inverters are phase-shifted 1/8 of a half-cycle apart with all inverter d.c. outputs (unfiltered) in series. All inverters are modulated under control of feedback from the total screen output voltage. In event of failure of one inverter, other inverters advance "On" time to compensate.

The cathode, arc and accelerator inverters consist of an "Operate" and "Standby" inverter in each supply, the "Standby" being switched on in event of a failure of the "Operate" inverter.

The Control Section provides the control and telemetry interface with the vehicle, provides the required control link between interdependent supplies (minor loop gain and transfer function), provides the necessary automatic sequencing and time delays in turn-on, monitors the system for overload trips, controls recycle time, senses inverter failures, and controls standby switching. It also contains the system master oscillator and phase shifter.

Details of the individual circuits will be discussed in later sections of this review.

2. Pulse-Width Modulation Techniques

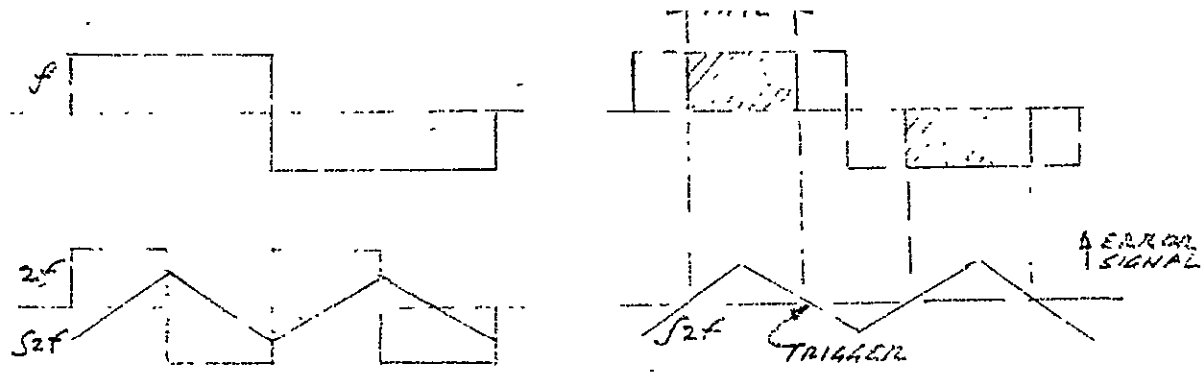
a. Single Inverter Modulation

Referring to System Diagram, Drawing X 3188131, cathode and arc systems shown use a single operating inverter with a standby inverter. Each inverter is pulse-width modulated for control and/or regulation. The cathode inverter operates at 5 KHz, and the arc inverter at 12.5 KHz.

In the following discussion, reference should be made to schematic of arc inverter, Dwg. X3188109.

The mode of inverter modulation chosen will maintain accurate balance on pulse-width of alternate half cycles of carrier, thereby minimizing ratcheting of output transformer from DC unbalance, restricting this unbalance to that due to unequal saturation or unequal storage time of output transistors.

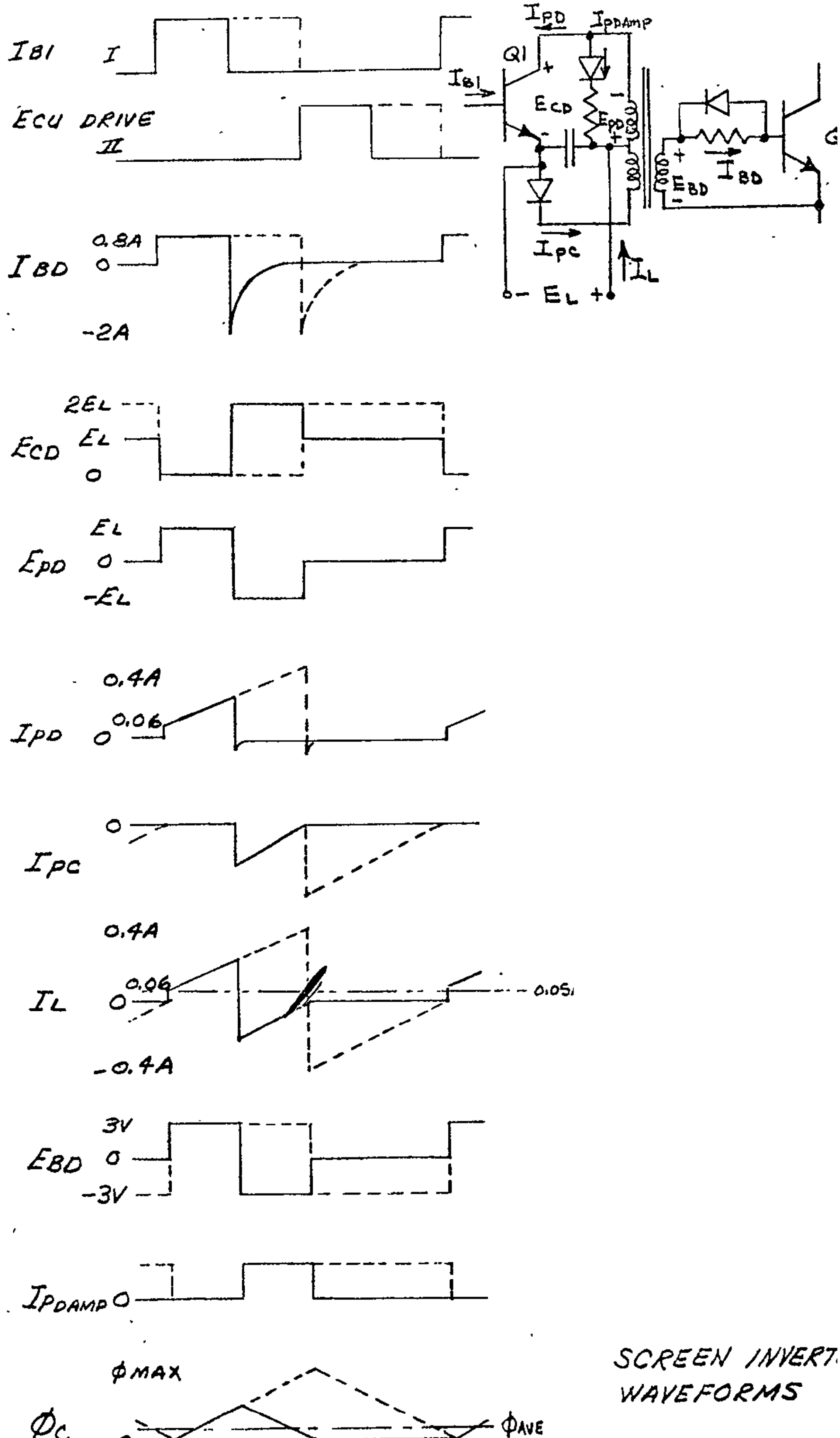
Modulation is achieved as follows: a modulation carrier of twice the output frequency (square-wave) is integrated (R26, C1) to obtain a triangular wave-form. The triangular wave-form is summed with the difference between output feedback and a reference bias, the net difference being applied to a comparitor amplifier Q15. A small "droop" error signal will swing the comparitor trigger from off to on for full half-cycle (see following figure):



Modifications in the conventional drive utilizing a single transformer ere necessary to accommodate a pulse width modulated drive. In the single ransformer drive circuits a pulse would not be transformed perfectly due to eakage inductances. The secondary overshoots in the negative direction and n an ECU application turns the off transistor on for a short period of time. his effect is undesirable and can be overcome by: 1) using two drive ransistors (turn-on and turn-off) directly connected to each of two power witches (eliminates the transformer) and 2) using two transformers. Alternate 1 as thoroughly investigated utilizing a variety of designs. The major disad- antages were power consumption, circuit complexity, and high failure rate omponents (power transistor drive).

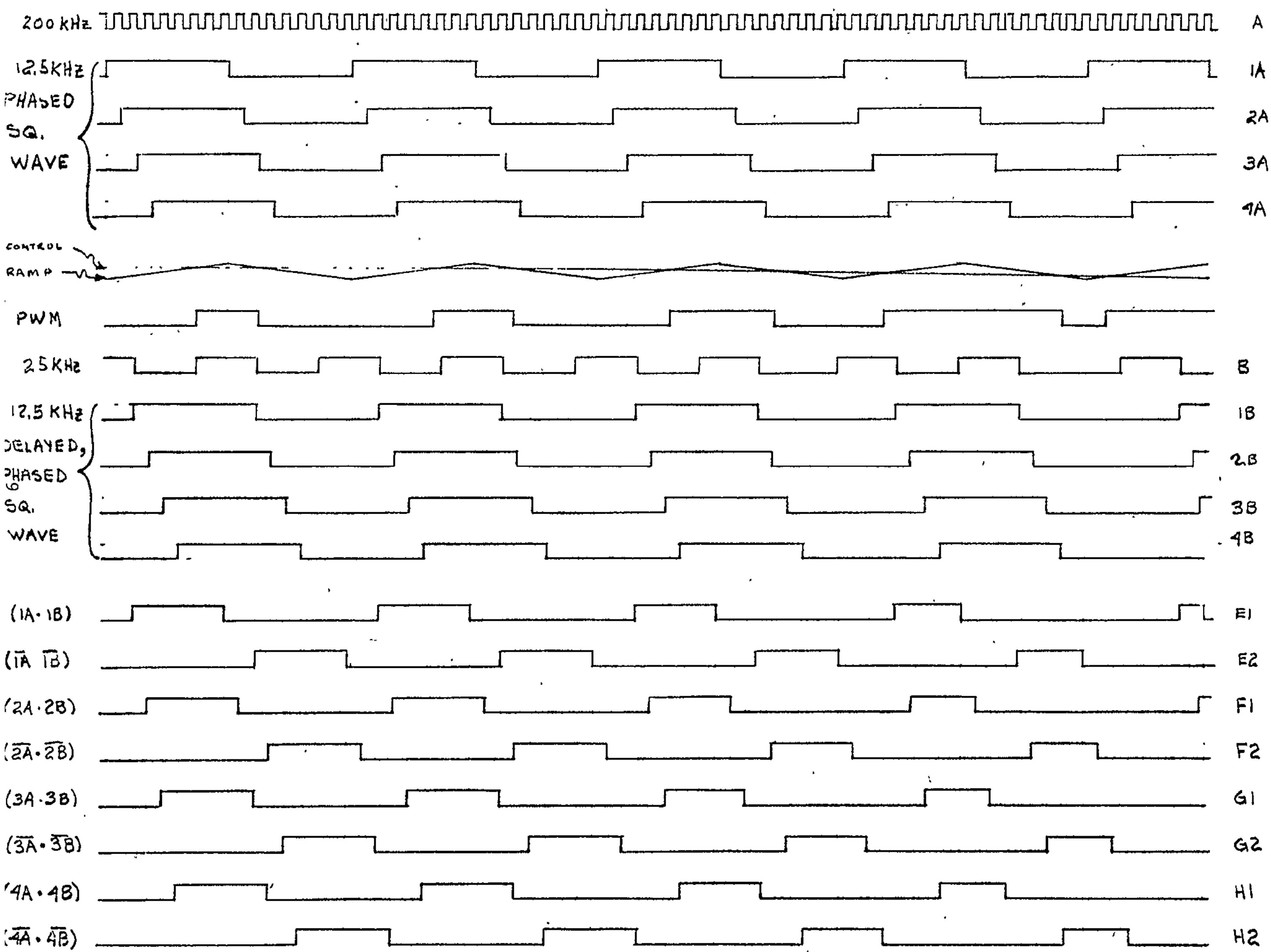
The circuit chosen is essentially two energy storage converters, one riving each side of the ECU. Several advantages result from this configura- ion; i.e., low failure rate components (signal transistor drive), low omplexity, and power savings. The natural kickback of the transformer is seful in supplying the needed turnoff bias, and with separate transformers oes not affect the off transistor. Also, the transformer coupling permits mpedance match from a 35 volt drive source to the 2 volt base drive. The basic ower drive stage for one-half the ECU is shown in Figure 2-1. The drive pulse or Q1 of Fig. 2-1 is shown and the resulting voltage and current waveforms re shown for each part of the circuit.

Referring to Fig. 2-1, upon application of power to the base of Q1, the 1 collector voltage drops to near zero impressing the supply voltage across he T1 primary. The voltage appearing at the secondary turns Q2 on. During he conduction period, the collector current increases as shown. The initial tep in current is the reflected base current. When base drive is removed from



SCREEN INVERT
WAVEFORMS

FIG. 2-1



MASTER OSCILLATOR & PHASE SHIFTER WAVEFORMS

FIG. 2-2

Q1, the stored energy in the transformer causes the voltages to reverse and CR1 clamps the primary. Since T1 is center tapped, the voltage developed at Q1 is twice the supply voltage and the voltage on the secondary is just the reverse of its previous value. The reverse base current is limited by CR2 and Q2 base impedances and when measured was found to be 2 amperes peak. The transistor is thus not subjected to high reverse base-emitter voltages and a low impedance path is provided to remove the stored charge. The commutation (fly-back) current at turn-off must be large enough to supply the turn-off current demand of Q2 when the transformer reverses. The peak design collector current for 100 percent duty cycle is 0.4 amperes and at 25 percent would be 0.15 amperes which, when reflected to the secondary, would be 1.95 amperes. The system is designed to operate a no less than 50 percent duty cycle, thus adequate turn-off current is assured.

A damping network is required to limit the overshoot voltage at Q1. The damping current is seen in Fig. 2-1. The line current is a composite of the collector and transformer fly-back currents and is also shown. A sketch of flux density is also given.

The drive pulse for Q1 is generated by a 932 gate. Part of the gate is used to "and" the flip-flop output and pulse amplifier output. The two gates are capacitance coupled as shown to prevent destruction of Q3 or Q4 due to loss of drive signal. (Dwg. X3188109)

This circuit was breadboarded and optimized, with a measured base drive power of 1.5 watts per side or 3.0 watts total drive power for 300 watts out (1.0 percent), which is within the design goal for the stage. The total weight of the two drive transformers is 28 grams, also within the design goal on weigh

The variable pulse-width output of the comparitor amplifier (see schematic) is summed with the output from a flip-flop, triggered at 2f, on a "nand" gate Q1, Q2, for each phase of the carrier. The output of each "nand" gate is invertered in a power gate, coupling to the driver amplifier, Q3, Q4.

The output transistor chosen, Q5, Q6, is the Solitron SDT 8805, rated at 325 volts Vcex, 300 volts Vcesust, and 20 amps with a minimum beta of 15 @ 10 amps. From the published data, the expected minimum beta at 8 amps (252 watts out) is 20, required a circuit beta of 15 for good saturation at 8 amps.

The switching time for the SDT 8805 is less than ½ microsecond, resulting in good switching efficiency at 12.5 KHz. The storage time will be about 1 to 2 microseconds, which requires compensation when full-on to prevent overlap of output transistors and resultant output current spikes and high switching dissipation. The compensation method chosen derives a "hold-off" bias from an output transformer winding T5 such that the drive on the "on-coming" transistor is held off until the current in the "off-going" transistor starts to collapse.

Diodes CR39 to CR40 are used to clamp the output transistors to a voltage close to double line voltage. The clamp operates through the tight coupling of the bifilar-primary, the induced voltage due to collapsing current being-clamped, on the opposite side of primary, to the voltage on the line capacitor through the clamping diodes.

The operating frequencies of 12.5 and 5 KHz were chosen as compatible with a master oscillator and consistent with maximum allowable frequency of 5 KHz for heaters (line drop at low voltage, high current, and engine heater inductance), and a frequency for DC-DC converters compatible with high efficiency and minimum size and weight. A discrete jump in size of available cores for output transformers suggests 12.5 KHz since the next smaller core is too small for 252 watts at 15 KC, and the core chosen permits operation at 12.5 KHz at 300 watts, hence higher efficiency than that at 15 KHz (higher switching losses).

The output transformer to be used with the inverter will be a ferrite cup-core, Indiana CF 217-05 material, with a 200°C Curie point. Tests have verified that this core will operate at 140°C without saturation at 2 kilogauss operating flux density, a temperature well above the expected maximum of 95°C. Core loss was verified as being within the expected 1% of output power. Copper loss was found to be significantly higher ($\approx$50%) than the DC value, due to skin effect. An approximation analysis using super-position of harmonic currents verified the measured loss as expected. Use of Litz wire, multi-filar, or foil windings would result in lower space factor, hence is not justified.

The choice of ferrite for the output transformer was made on the basis of low core loss at the frequency desired, comparable to that obtained with nickel-iron, 1 mil tape cores, plus the tolerance, in a cup-core, of some d.c. unbalance, inherent in the inverter. The residual air-gap in the cup-core is sufficient to permit a significant d.c. without excessive ratcheting. A further advantage is the ideal heat-transfer to the mounting inherent in the cup-core shape.

b. Staggered Phase Modulation

Referring to Dwg. X3188131, System Block Diagram, and X3188105, Screen Inverter Schematic, the screen system, delivering 2000 volts at 1 amp, uses eight (8) inverters with d.c. outputs in series, each inverter delivering 250 volts or 250 watts.

The modulation circuitry used in the screen inverter is similar to that described above for the cathode and arc inverter.

To minimize ripple, reduce size of ripple filter, and improve no-load to full load regulation, each inverter is driven at 12.5 KHz with phase displacement of 1/8 of 1/2 cycle between inverters, resulting in a ripple frequency of 200 KHz, and a maximum peak to peak ripple of 500 volts at 2000 volts, unfiltered, i.e., $\pm$ 250 volts.

Dwg. No. X3188121-2, Master Oscillator and Phase Shifter, indicates the method for obtaining the staggered phase drive for the screen inverters. Fig. 2-2 is the timing diagram for this circuit.

The digital staggered phase generator (SCPG) is designed to provide two sets of 12.5 KHz square waves. Each set consists of eight separate square waves separated by exactly 1/8 of ½ cycle. The two sets of staggered square waves are then logically combined to produce 16 modulated pulses which are buffered to provide current drive for the inverter transistors in the ECU's.

The 12.5 KHz staggered square waves are produced by shifting a 12.5 KHz square wave through a seven bit shift register at a 200 KHz clock rate. The 200 KHz square wave is given for reference. The 12.5 KHz waveform is the output from the second 16 bit counter in Channel A. Channel B is the delayed channel. The outputs from the first four bits of the shift register in Channel A are shown as 2A, 3A, 4A.

Channel B is a duplicate of Channel A. The Channel B counters are reset at the trailing edge of the pulse width modulator output. The pulse width modulator is of standard triangle wave zero crossing type. The output of the Channel A counter is integrated to obtain the triangle waveform. The ramp compared with the control voltage produces the PWM waveform shown.

By reseting the B counters at the end of the PWM pulse, the count is effectively delayed by one-half the PWM pulse width. By "anding" the two shift register outputs a delayed pulse equal in width to the PWM pulse is obtained for each phase of the system. The two required waveforms for each half of the inverters are shown as E1 and 2, F1 and 2, G1 and 2, and H1 and 2.

Since the counters change state only on the fall of the clock pulse, the phase difference between the two counters and hence the shift registers can be only increments of one clock pulse. This determines the accuracy to which the pulse width can be controlled. To achieve 1 percent regulation, the clock rate must be at least 200 times the inverter frequency since each one-half cycle must be controlled to within one percent. Since integer powers of two are available from binary counters, a factor of 256 is used. The oscillator frequency is thus 3.2 MHz.

The square-wave outputs of the phase shifter are "anded" on the inputs at the screen inverter input gates to produce the controlled pulse width.

The remaining inverter circuitry following the input gates is identical to that described for the arc inverter except in the output transformer rectifier.

c. <u>Line Regulator Modulation</u>

Referring to System Block Diagram,Dwg.X3188131, it will be noted that two (2) subsystems, the 5 KHz inverter and associated low voltage group, and the accelerator supply, use a line regulator.

In the case of the 5 KHz inverter and its associated low voltage supplies, the latter use individual load regulators (magnetic-amplifiers) since the low power required of these supplies permits a lower efficiency and higher per-unit weight to obtain minimum complexity (high reliability). Hence, the burden of regulation on the line regulator is that of line variation only.

The accelerator supply uses its associated line regulator for both line and load regulation, to permit a square-wave inverter for the high voltage step-up required in the inverter, and thereby minimize ringing of output transformer, and simplify filtering at high voltage.

The line regulator circuit, drawing no. 3188119, is identical for both applications, differing only in the voltage sense connection.

The regulator is a synchronized switching regulator. As a switching regulator it converts 80 VDC to 40 VDC line variation to a regulated or controlled nominal 35 VDC with an efficiency of approximately 94%. When R4 remote feedback is connected to ground; the filter regulated output power is connected to the local feedback point, 10 KHz signal (S6) is applied to the modulation signal input, and the line power connected to the line power input, the line regulator regulates d.c. voltage out.

The line regulator can also be utilized with remote feedback. Such is the case of the accelerator regulator. The connection for this mode of operation are as follows: regulated 35 VDC (from 5 KHz line regulator) to low voltage reference, 10 KHz S6 signal to input modulation signal, regulated output to accelerator inverter input, and line power to input power.

Circuit Operation Description

Time Zero* apply power and S6 10 KHz square wave to proper inputs.

Time One, current flows through R9 into the base of Q2, Q2 turns Q3 on, Q3 turns Q4 on.

Time Two, the voltage across C4 (S7) rises to 35 VDC and is fed back to the local feedback connection. Note: remote feedback is grounded.

Time Three, the feedback current flows through R1 achieving proper zener current through CR1 and CR2 therefore supplying A1 with a reference voltage and power for operation. S6 square wave is passed through a low pass filter and converted into a 10 KHz triangle wave (S8). S7 and S8 are summed together through R5 and R14 to the summing input of A1 (A_{1S}). A1 is utilized in a high gain switching amplifier configuration.

Time Four, the voltage at A1 summing point equals the reference voltage.

Time Five, the output of A1 switches to plus 18 VDC

Time Six, Q1 turns on and Q2, Q3, Q4 turn off

Time Seven, the current continues to flow through L1, therefore, CR7 conducts and the voltage at the junction of L1 and CR7 is minus .7 VDC, hence voltage at the junction of R11 and C3 is a minus .7 VDC.

*Time Zero, One, Two, etc., equals sequential timing, not real time

Time Eight, CR3 becomes forward biased and charges C3 to +35 VDC through R11.

Time Nine, the voltage at the summing point of A1 decreases below the reference voltage.

Time Ten, the output of A1 returns to zero and Q1 turns off.

Time Eleven, Q2, Q3 and Q4 conducts and the voltage at the junction point of C3 and R11 increases to line voltage plus 35 VDC.

Time Twelve, the voltage across C3 discharges through R11, R10, Q2, Q3 and Q4, therefore creating an efficient drive. The voltage at the junction of R9 and R10 is line voltage plus 1.6 V peak. Q2 is in super saturation, CR5 is back biased, and Q3 is in hard saturation. The voltage across Q4 is Q3 hard saturation voltage plus Q4 base to emitter voltage.

This completes one cycle of regulation.

d. Magnetic Modulation

Reference to System Block Diagram, X3188131, and Magnetic Modulator Schematic, Dwg. No. X3188123, will show that three supplies use magnetic modulation for load regulation. These are: 1) Magnet Supply, 2) Vaporizer Supply, and 3) Neutralizer Heater Supply (the Neutralizer Keeper Supply is simply reactance current limited).

The magnet supply regulates d.c. load current, while the vaporizer and neutralizer heater regulate a.c. load current (RMS regulation). However, the mode of modulation is similar in all 3 systems, differing only in current sense circuits. Therefore, the following explanation of the magnet modulator will substantially apply to the other supplies.

The magnet supply is required to furnish a regulated d.c. current at 0.85 amps at a maximum voltage of 19 volts, and is referenced to the screen + 2 KV supply.

The circuit used here is that of a conventional "doubler" mag-amp in series with the primary of the output transformer. Current is sensed by a current transformer in the primary circuit, with a peak sensitive filter on the rectified output of the current transformer.

The load inductance supplies the necessary filtering of the pulse-width modulated output current at 10 KHz fundamental with rich harmonics. Consequently, the output current is substantially constant while the average a.c. current varies substantially with load impedance. While the wave-form of primary current is substantially exponential, rather than square-wave, it has been determined experimentally that a peak current detector provides the necessary accuracy in current regulation, and is a substantially less complex, hence more reliable method than other techniques which might be used on the output floating at 2 KV. (Magnetic transductor, Hall effect devices, etc.)

The current feedback signal is nulled with a reference signal at the differential transistor. The resulting collector current due to null unbalance is used to control the mag-amp.

The bias winding insures that the mag-amp is driven close to saturation in absence of a null unbalance signal, thus eliminating the control range which might otherwise be lost due to residual reset.

Telemetry is supplied through an isolation resistor, permitting a short in telemetry with only small effect on regulated output (approx. 1%). 7 volt zener acts as a clamp on possible transients.

To minimize effect of temperature on regulation and telemetry, the current sense rectifier is supplied with 25 volts full scale, thereby minimizing effect of diode drop variation with temperature. The 25 volts is then scaled down to 5 volts for control and telemetry.

This circuit will hold substantially constant current into a short-circuited load. Fortunately, the exponential character of the output wave-form, due to finite saturated inductance in mag-amp and leakage inductance in transformer, results in a diminishing peak output voltage for small firing angles, and corresponding limited peak current into a short. This is, of course, desirable to prevent excessive current in inverter.

As noted above, the modulation of the vaporizer and neutralizer heater supplies is similar to that of the magnet, however, with differences in current sensing.

For the vaporizer and neutralizer heater supplies, two (2) modes of control are required: 1) constant RMS current, and 2) 100% control from on to off when under control of engine loops.

For RMS regulation an RMS approximation circuit was chosen as more reliable than thermal sensing. This consists, essentially, of a hybrid peak/average filter on the rectified output of the current transformer. (An averaging filter will indicate a current less than the RMS value, a peak filter will indicate a current greater than the RMS value). Since the line regulator will hold the input square-wave voltage constant to the magnetic modulator, the latter must only regulate for load changes, including, however, a shorted output.

3. Cathode RMS Current Regulator

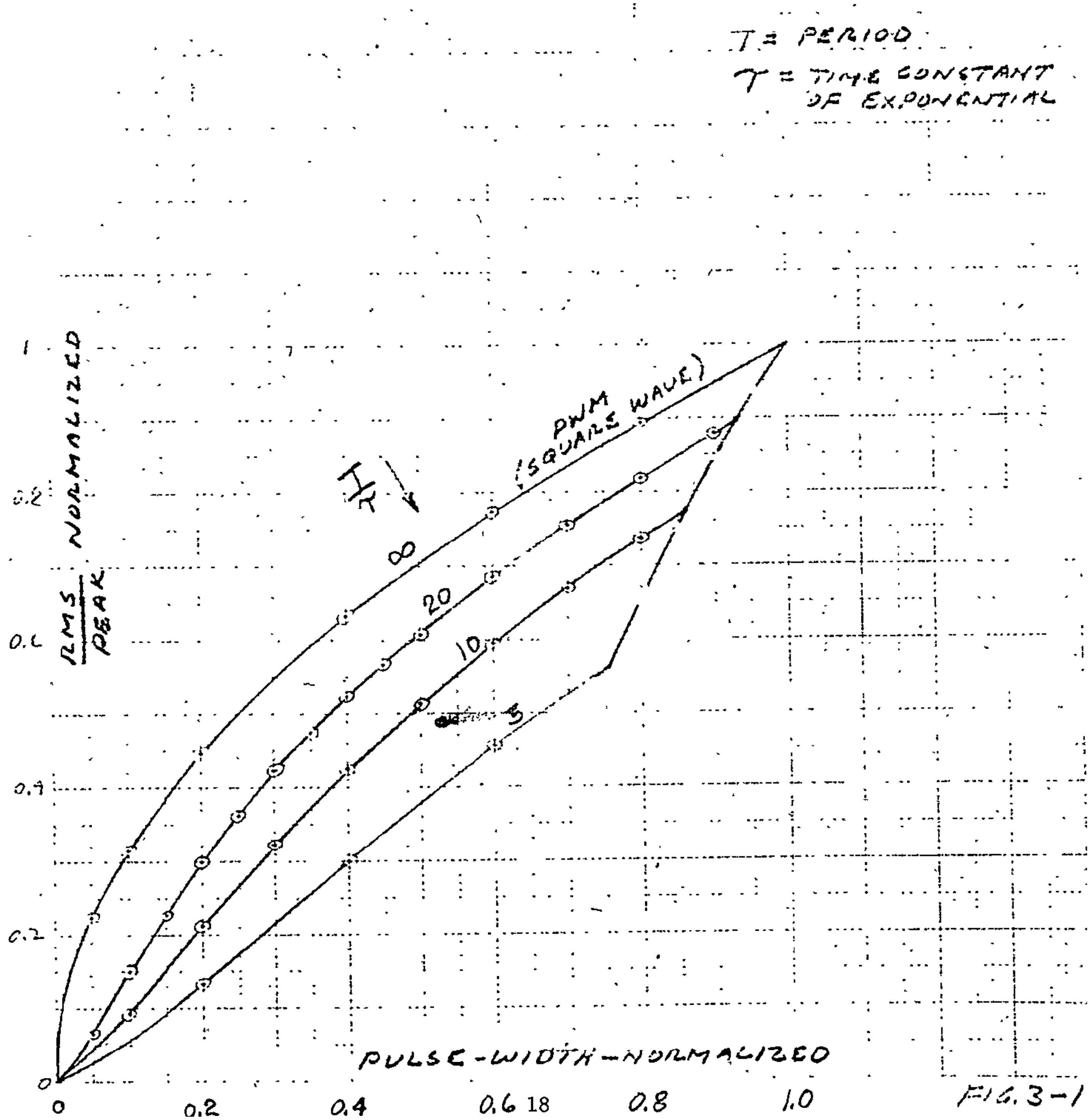
See Drawing No. X3188113 for schematic. As indicated above, in the discussion of single inverter modulation, the cathode supply uses a pulse-width modulated driven inverter. The output of this inverter, therefore, will, with a line voltage varying from 40 to 80 volts, be required to vary from nearly full on pulse-width, to a narrow pulse width, with the peak voltage varying 2 to 1.

With the large step-down from line voltage to 5 volts at 40 amps to the load, and the need for a remote transformer at the thruster to avoid excessive line drops, the transformer leakage inductance for the combined inverter auto-transformer and remote transformer results in a significantly inductive load. This inductive load will, therefore, result in a current waveform which is exponential, with a time constant significant relative to the half-period. It is this waveform, then, which must be modulated to maintain constant RMS current as the line voltage varies.

The detection circuit chosen for RMS control is an approximation circuit, rather than a "true RMS", thermal sensing circuit, since it offers higher reliability, greater independence of ambient temperature, and faster response (the latter is an important consideration in engine loop stability).

Referring to schematic, drawing no. X3188113, the network which provides the RMS approximation detector consists of the dual series R-C shunts across the current transformer T6, in combination with hybrid peak-average rectifier-filter, CR19, CR20, R10, and C13.

The output of the circuit shown closely tracks the desired function relating RMS current value to peak current value, as a function of pulse width. Fig. 3-1 is a plot of the analytical value of the desired functions.



T = PERIOD
τ = TIME CONSTANT OF EXPONENTIAL
RMS/PEAK NORMALIZED
PWM (SQUARE WAVE)
T/τ
∞
20
10
5
PULSE-WIDTH-NORMALIZED
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1.0

FIG. 3-1

As the line voltage increases from 40 to 80 volts, the inverter peak output voltage and peak current increases proportionately for a given load. For a constant RMS value, the pulse-width required will decrease and this decrease will be forced by the feedback to the pulse-width modulator.

As the pulse-width narrows the degree of shunting contributed by the current-transformer RC shunt loads will increase, reducing the voltage across the transformer secondary. Thus, the rate-of-change of detection output, as a function of pulse-width may be chosen to closely fit the desired function. Tests of this network at 25 amps and 40 amps load have verified a regulation accuracy of 1% between 40 and 80 volt line. Similarly, short circuit current is held to within 2% of regulated nominal.

Current telemetry for this circuit is derived from the detector emitter-follower, in parallel with the current feedback. Isolation resistors in telemetry circuit permit shorting of telemetry without shifting controlled current more than 1%.

Three modes of operation are required of this circuit: 1) regulated at 40 amps in a "preheat" condition; 2) regulated at 25 amps in a "preheat-standby" condition; and 3) controlled between 10 and 40 amps, as a function of "arc" current, i.e., when arc current exceeds a "set-point" value, cathode current will be cut back rapidly from 40 amps to 10 amps or less. Hence, in normal engine-loop operation, the cathode current will stabilize at some value between 40 amps and 10 amps, such as to maintain the desired arc current.

The control for the above indicated functions is derived from a function generator located in the control module described elsewhere. This control is shown as an input signal "command reference" on schematic X3188113. The circuit is mechanized to provide 40 amps with 0 volts command, and cut-off at +5 volts.

The basic inverter circuit, drawing X3188113, has been described under paragraph 2 (b) above, "Single Inverter Modulation".

4. D.C. Voltage Regulation

a. Arc Supply

See Drawing X3188109, and Drawing X3188117 for schematics of this circuit.

This circuit uses the pulse-width modulated inverter discussed above.

As in the cathode circuit discussed above, the arc circuit uses an "operate" and "standby" inverter, with a common output transformer.

The arc supply must provide a starting "boost" of 150 volts at no load, dropping to 36 volts at 20 ma, and regulated at 36 volts for line and load up to 7 amps. Also, the supply is to be tripped off for overloads in V4 (arc), V5 (screen), or V6 (accelerator). Telemetry is required for both current and voltage, with high calibration accuracy telemetry for current between 2 and 7 amps, and voltage between 34 and 36 volts.

The supply is floating at the screen potential of +2 KV.

In Drawing X3188117 the starting boost is provided through current-limiting reactor L1 to rectifier CR4. When load increases to 20 ma, voltage from boost circuit will drop below 36 volts, and load current will be drawn from main rectifier CR1, CR2, through filter L2, C1.

In Drawing X3188109, voltage telemetry and feedback are derived from output transformer through CR19, CR20, and associated averaging filter, since average AC voltage is linear proportional to DC output voltage, except for load regulation in rectifier and filter. The latter is compensated by load current feedback, summed with voltage feedback. Change in output due to temperature change in rectifier and choke will not be compensated but should be less than ½% for 50°C variation. This technique is less complex than a mag-amp voltage sensor or Hall effect voltage sensor and is expected to be as accurate.

In Drawing X3188117, current sensing is obtained with current transformer T1 located in load secondary. There will be a lack of linear correlation between AC current and DC load current, due to pulse-width modulation. Assuming perfect transformation and perfect square-waves, a linear correlation would exist between DC current and peak AC current. For exponential wave forms, however, this is not true. A quasi-peak detector filter gives adequate correlation.

Two (2) rectifier-filter circuits are shown with T1 transformer. These are necessary to provide positive telemetry and negative current feedback, the latter necessary for compensation summing with positive voltage feedback.

b. Accelerator Supply

See Drawings X3188125, X3188107 and X3188115 for schematics of this supply.

This circuit will use a driven square-wave inverter.

Regulation will be obtained by controlling the DC voltage input to the inverter. By this technique, transformer will put out square waves, requiring only capacitor filtering for switching period, and minimizing voltage ringing, which is high with a low-pass filter on output.

The line regulator used here is identical with that described above for the 5 KHz system, with feedback from accelerator output, instead of from line regulator output.

The accelerator supply uses one operating inverter and one standby inverter, with DC outputs from transformer rectifier in series, thus providing a redundant transformer rectifier.

A winding on the output transformer of the operating inverter senses failure of this inverter. The control module, on sensing failure will switch the standby inverter on by applying a gating "ON" signal to the 946 gates in the inverter base circuit while removing the gating signal from the 946 gate of the operating inverter.

Referring to Drawing X3188115, output of accelerator inverter rectifier is filtered with low-pass filter L1, C1. Choke L1 also provides arc suppression. Bleeder resister R1, R2, R3 provides voltage and current sense, for regulation, telemetry and overload trip.

c. Screen System

See Drawings X3188131, System Block Diagram, X3188105, Screen Inverter Schematic, and X3188115, High Voltage Filter Schematic.

The screen system uses eight pulse-width modulated inverters, phased 1/8 of a half-cycle apart, with rectified outputs in series, feeding a common L-C, low-pass filter. Frequency of inverters is 12.5 KHz, resulting in a ripple frequency of 200 KHz, with a peak-to-peak unfiltered ripple of 500 volts maximum at high line.

With the relatively high frequency ripple, the size and weight of the output filter is small for the high power out (2 kilowatts). A ferrite cup-core choke (42 mm diameter) is sufficient, weighing only 180 grams. The output capacitor is a small (.005 mfd) mica type, chosen for small size and tolerance of high frequency ripple.

The output filter is important in its contribution to high voltage arc suppression. Since the output capacitor may be relatively small for ripple suppression, the intensity of arc drawn from the capacitor is significantly less than that from the larger capacitor which would be required with a low-frequency ripple.

The output filter choke is also sized to provide arc suppression, by limiting the current which may be drawn from the inverters before overload trip shuts the inverters down.

The staggered phase technique has a further advantage relative to the size of the output filter choke. This is the relatively low peak ripple, unfiltered, i.e., 250 volts. Thus, at no load, or very light load, where choke is no longer critical, permitting output voltage to peak, the maximum rise in output voltage, due to peaking, will be 250 volts, during a step-load transient, before the closed-loop pulse modulation can reduce the pulse-width and drop the voltage.

Referring to Drawing X3188115 high voltage filter schematic, output voltage of the screen system is sensed with a tapped bleeder resistor, providing both voltage feedback for regulation, and voltage telemetry at 5 volts full scale (telemetry is isolated in control module).

Current is sensed with a resistor in the return, to provide an overcurrent trip in the control module, where isolation, amplification, and inversion is also provided for telemetry.

The technique of pulse-width modulation for regulating output voltage has been described before, under discussions of single inverter modulation, and staggered phase modulation.

5. System Control Techniques

a. General

See Drawing X3188121-1, Control Module Block Diagram. Control system accepts both high level digital command pulses and a low level analog command, processes and stores the commands and controls all functions of the power conditioner. The six input commands are listed below:

1. On I - turns on power to heaters to warm power conditioner.

2. On II - turns on Group I power supplies and starts the cathode preheat sequence.

3. On III - turns on Group II power supplies

4. Off I - turns off the vaporizer supply

5. Off II - turns off power conditioner heaters and all supplies. Resets all memory prior to application of power to input bus.

6. IBref - Used as reference in controlling the vaporizer and as an input to the function generator to produce a reference for controlling the cathode.

The command pulses are 20 ms or greater in duration and are zero volts when not present, transitioning to 20 to 31 VDC during the pulse period. The analog control voltage is a zero to +5 volt signal capable of driving a 10 k ohm load.

The control module functions are itemized below:

1. Command memory

2. Overload trip and recycling

    A. Slow turn on

    B. Magnet delay

3. Standby switching

    A. Arc

    B. Cathode

    C. Accelerator

4. Function generation

5. Control amplifiers

    A. Cathode

    B. Vaporizer

    C. Neutralizer heater

6. Preheat sequencing

b. <u>Command Controls</u>

<u>Command Interface Circuit (See Figure 5-1)</u>

All relays are initialized by a pulse command at the "Off II" input. When a "On I" command is received, K1 is set which closes the circuit to a P.C. preheat switch. The relay contacts are not heavy enough to carry the heater current. K1 is reset by applying an "Off II" command. An "On II" command sets K2 and also pulses the reset on the one minute timer which initializes the sequencer and the one minute timer. The line regulator is turned on which supplies power to the 5KHz inverter which in turn supplies power to the Group I supplies. The power for the timer and sequencer comes from the inverter and is expected to be available before the end of the "On II" command. The "On III" command sets K3 which allows the Group II supplies to come on and switches the cathode supply set point to 40A so that the cathode amplifier can control over the 10 to 40 A range. The "Off I" command resets K4 which supplies a bias to the vaporizer controller reducing the vaporizer current to near zero.

<u>One Minute Timer (See Figure 5-2)</u>

The one minute timer is used to control the timing of the preheat sequence and the sampling period of the overload trip counter. The timer is mechanized using a unijunction oscillator operating at .267 Hz which is counted down using a monolithic 4 bit counter and shaped using a monostable multivibrator. The output is a short pulse once per minute.

<u>Preheat Sequencer (See Figure 5-3)</u>

The preheat sequencer utilizes a monolithic four bit ripple counter for timing the 13 minute preheat sequence. Z1-A allows the one minute pulses to clock Z3 until 13 pulses have occurred. The flip-flop consisting of Z2-B and Z1-C is initially set so that the output to the cathode controller is at +5 volts, (Z2-B at +5v). After 10 minutes the inputs to Z1-B are true and the flip-flop changes state allowing the cathode current to go to 40A. Three minutes later the flip-flop is reset by Z2-A and the cathode current is returned to 25A. When the input from K3 is grounded the output drops to zero allowing the cathode current to rise to 40A.

c. Overload Trips

Overload Trip and Integration (See Figure 5-4)

The trip and integration circuit detects and counts overloads, provides a telemetry signal which represents the total number of overloads at any moment, and detects a solar panel undervoltage. When an overload occurs Z1 is triggered which clocks the overload counter and starts the trip sequence through Z3-A. As the total number of trips increase the output of Z8 steps in a positive direction until either a once-per-minute reset pulse occurs, 12 overloads are counted or the solar panel bus drops below 36 volts, at which time the power conditioner is shutdown. The ripple counter consisting of Z4 through 7 will probably be replaced by an MC939 for convenience of packaging and reliability.

Trip Timing Circuit (See Figure 5-5)

The trip timing circuit times the off period of the Group II supplies. The circuit consists of two monostable multivibrators constructed of discrete components due to the long time constants required. The overload trip and integration circuit triggers the first one-shot which gates off all Group II supplies and the magnet. At the end of the trip period the second one-shot is triggered and the Group II supplies are turned back on. The magnet supply is turned on at the end of the second one-shot pulse which lasts one second.

Trip Shutdown Circuit (See Figure 5-6)

The trip shutdown circuit provides slow turn-on for the accelerator, Arc and Screen supplies to prevent high voltage rate of change and provides buffering between the supplies and the control module. When the trip occurs, Q1 turns on turning Q2 on which turns Q3 and Q4 on clamping the output to zero. At the end of the trip, C1 charges up slowly causing the output to rise slowly. The output is used as the reference supply for the Arc, Screen and Accelerator supplies. The vaporizer is shut off by applying a turn-off bias to the input through CR9. Q5 keeps the magnet off by pulling current through the turn-off winding of the mag-amp. The input from relay K3 is released from ground at an "on III" command allowing the vaporizer, accelerator, arc, and screen supplies to come on.

d. Analog Controls

Analog Control Amplifiers (See Figures 5-7, 5-8, 5-9)

The system consists of three major control loops each of which will be discussed separately.

Neutralizer Heater - Neutralizer Keeper

This control function requires the neutralizer heater current to be reduced from the preheat level of 2.8 amps to zero when the neutralizer keeper voltage drops two volts below a preselected reference. The current reduction is to begin from the point at which the NK voltage equals the present reference. Under present requirements this level is between 10 and 20 volts. The NK supply rides on a bias of up to $\pm$ 30 volts. A differential amplifier is used to sense the voltage difference. The amplifier will be scaled so that a NK voltage of 0 - 30 volts will be 0 to 5 volts at the amplifier output.

The controller requires a zero to 5 volt signal to control the output current from full on to off. An intermediate amplifier is mechanized which provides the function below:

$$\text{Enhc} = 15\left[\frac{2\text{Enhref}}{3} - \text{Enks} + \frac{5}{3}\right], \ \text{Ench} \geq 0$$

$$\text{Enhc} = 0, \left[\frac{2\text{Enhref}}{3} - \text{Enks} + \frac{5}{3}\right] < 0$$

Where

Enhc is neutralizer heater control voltage

Enref is the reference voltage

Enks is the scaled neutralizer keeper voltage

5/3 is a bias used to allow Enhref to be a zero to 5 volt signal.

The neutralizer heater control amplifier schematic includes a bias supply consisting of a temperature compensated zener diode. This reference is used in the other two amplifiers. The diode at the output of the amplifier is to keep the output from going negative.

Vaporizer

The vaporizer is controlled by comparing a screen current reference voltage to the voltage scaler representing screen current. As the screen current exceeds the preset reference level by 10 ma, the vaporizer is proportionally reduced from 1.2 amps to less than 0.5 amps. Since the screen current is scaled 5 volts per ampere and the reference is 0 to 5 volts for 0.5 to 1 ampere and the vaporizer control requires a zero to 5 volt signal to reduce the output from 1.2 amps to near zero, an amplifier is required that mechanizes the following function:

$$Evapc = -200\left[Esr - Ess + 2.5\right], \ Evapc \geq 0$$

$$Evapc = 0, \left[Esr - Ess + 2.5\right] < 0$$

Where

Evapc is the vaporizer control voltage

Esr is the screen reference voltage

Ess is the screen current scales

The vaporizer control amplifier schematic shows the amplifier designed to perform the required function. To accomplish the required gain the input resistor was of necessity less than 10kΩ. To prevent loading of the IBref source, a voltage follower will be implemented.

Cathode Heater

The cathode heater is controlled by the arc current. If the arc current exceeds a reference by 0.1 amperes, the cathode current is cut back proportionally from 40 to 10 amperes. The reference is a 0 - 5 volt signal from function generator. The arc current is scaled at 5 volts for 8 amperes. The cathode controller requires a zero to 5 volt signal to reduce the output current from 40 to 10 amperes. To accomplish the required control function an amplifier is mechanized which provides the function given below

$$Ecc = -80\left[Eas - 1.25 - 5\frac{Earef}{8}\right], \ Ecc \geq 0$$

$$Ecc + 0\left[Eas - 1.25 - 5\frac{Earef}{8}\right] < 0$$

Where

Ecc is the cathode controller control voltage

Eas is the scaled arc current

Earef is the reference voltage.

Function Generator

The function generator converts the Beam reference to an Arc reference following a curve provided by JPL. The curve is approximated by three straight lines. The amplifier, Figure 5-10, consisting of Z1, Q1, Q2, and Q3 provides d.c. biasing and sufficient dynamic range to provide drive to the breakpoint network consisting of R6, R10, R14, R20, CR1 and CR2. Amplifier Z2 corrects for amplifications factor.

The breakpoint network utilizes temperature compensated diodes to provide the required switching points. The diode specification gives a temperature coefficient at one current only. At lower currents the coefficient is higher but not significant enough to effect the required performance. The current levels through the network are selected high enough to pass the critical knee area quickly. At the knee the zener contributions is not significant and the knee softness causes rounding of the curve at the breakpoint. Freon freeze tests showed that no significant shift occurred in the curve occurred for variations in temperature. A curve showing the output vs. input voltage is attached. The circled dots are the breakpoints and end points required to match the actual curve.

e. Standby Controls - See Figure 5-11

Cathode Standby Control - See Figure 5-11

The cathode standby control circuit operates exactly as does the Arc circuit of the Accelerator Arc standby control circuit explained below. The sense signal is either zero volts for off or minus 5 volts for on sense.

Accelerator & Arc Standby Control - See Figure 5-12

The Accelerator and Arc standby control circuit delays the "On III" command approximately 0.1 seconds and turns on the standby module if the primary module is inoperative. Transistor Q1 discharges and releases C2 at the end of the "On III" command. C2 charges to a voltage equal to VR2 and the base to emitter drops of Q2 and Q3 at which time Z1-A output goes high. If the accelerator primary on sense is not present, the Accelerator standby drive is turned on and the Accelerator primary drive is turned off. If the Arc on sense is present when Z1-A goes high, Z2-B is inhibited and Q5 cannot turn on. If, however, Z1-A goes high when the Arc sense is not present, Z2-B output goes low turning Q5 on and inhibiting the Z2-A gate.

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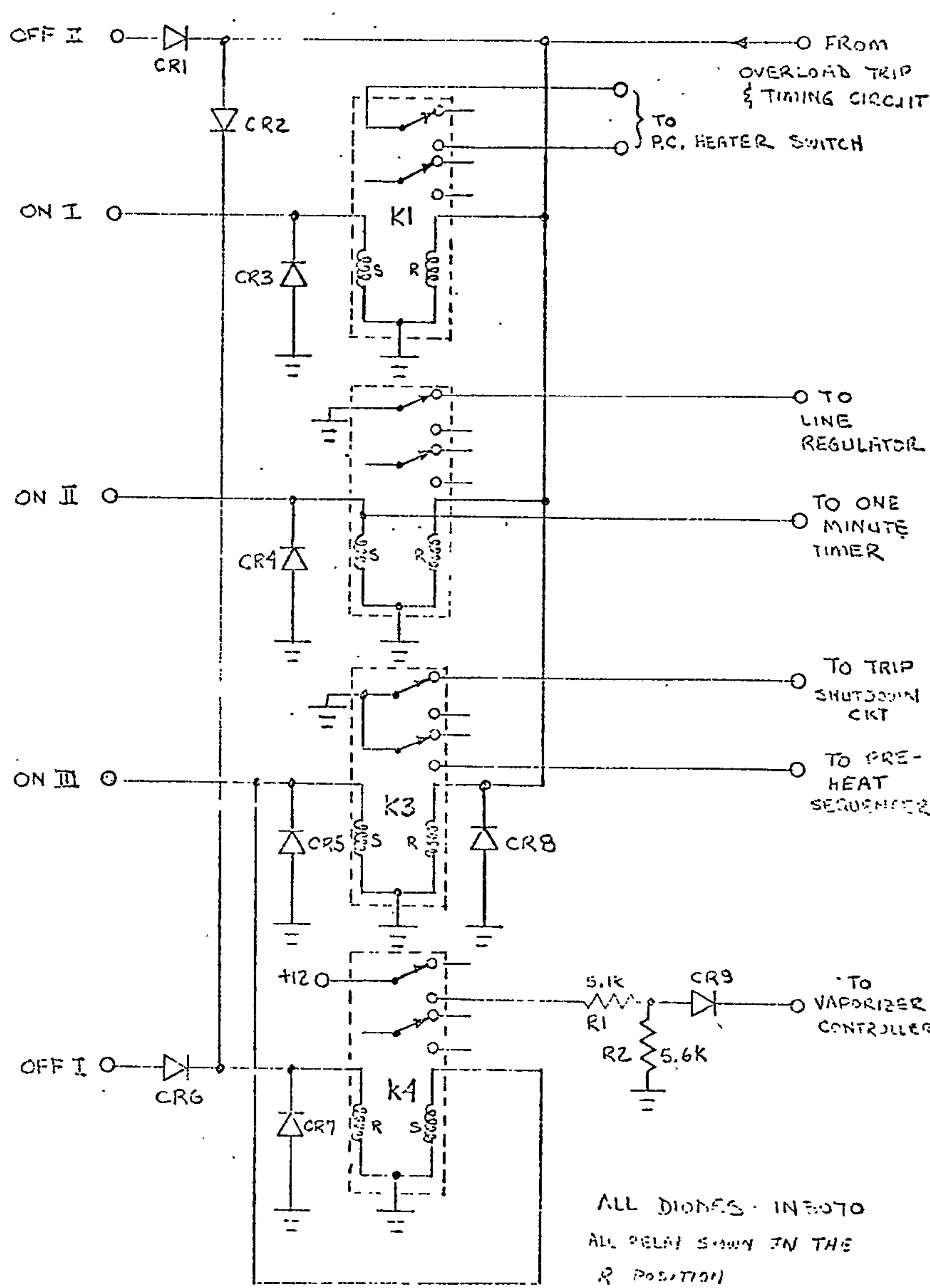
CONTROL MODULE
RELAY MEMORY



ALL DIODES IN3070

ALL RELAY SHOWN IN THE R POSITION

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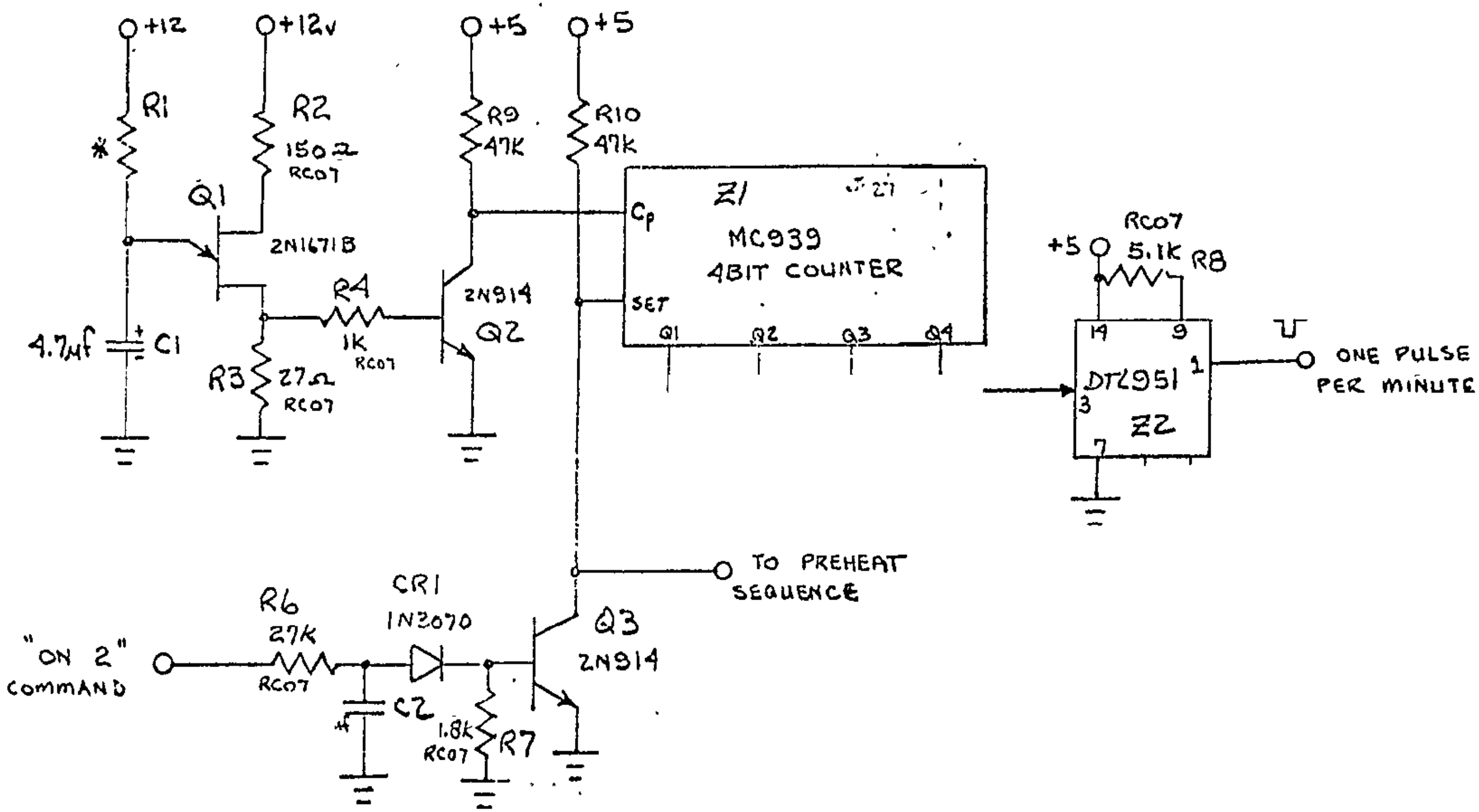
MODEL

REPORT NO

CONTROL MODULE, ONE MINUTE TIMER



* SELECT AT TEST (RN60C)

FIG. 52

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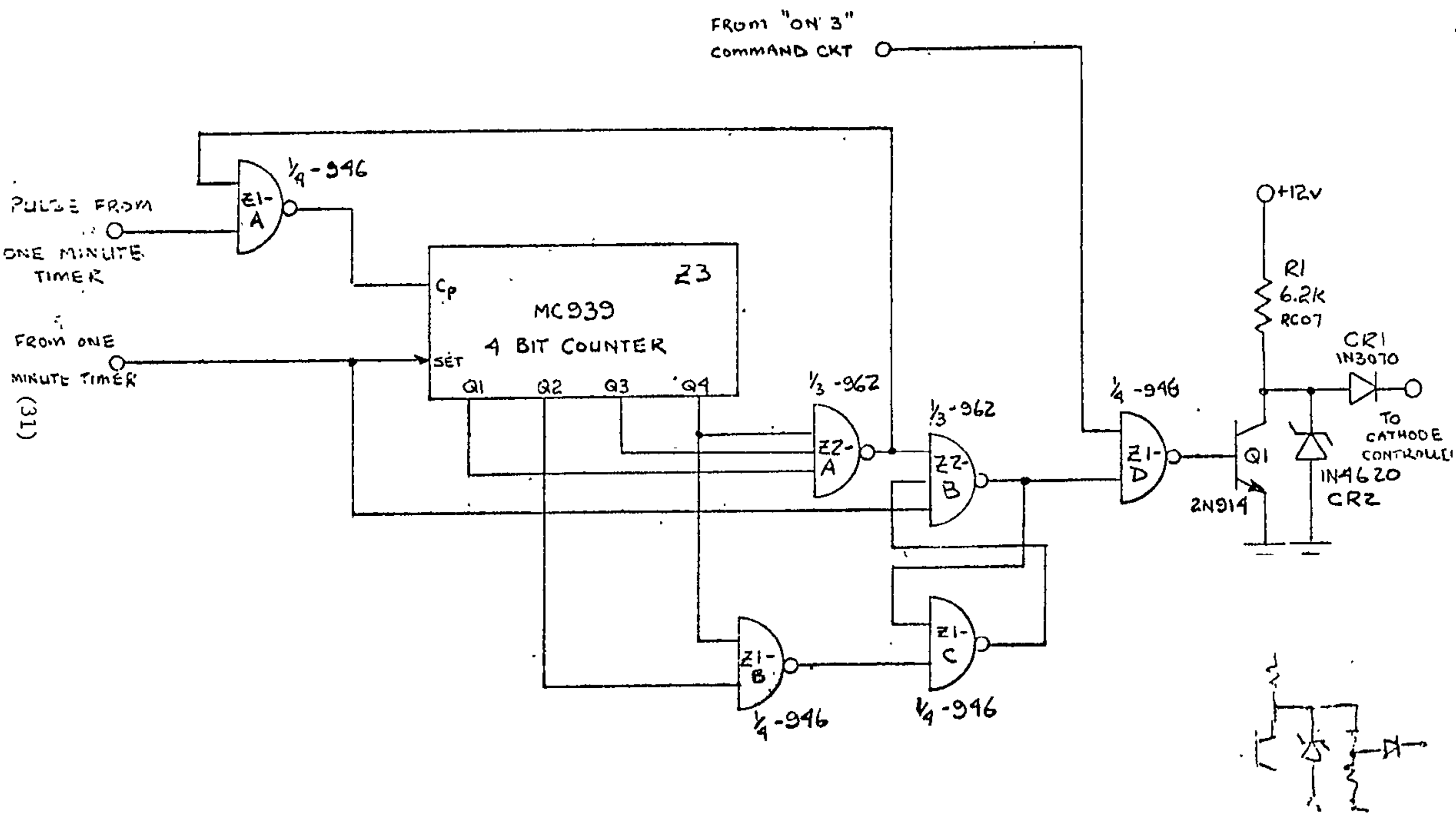
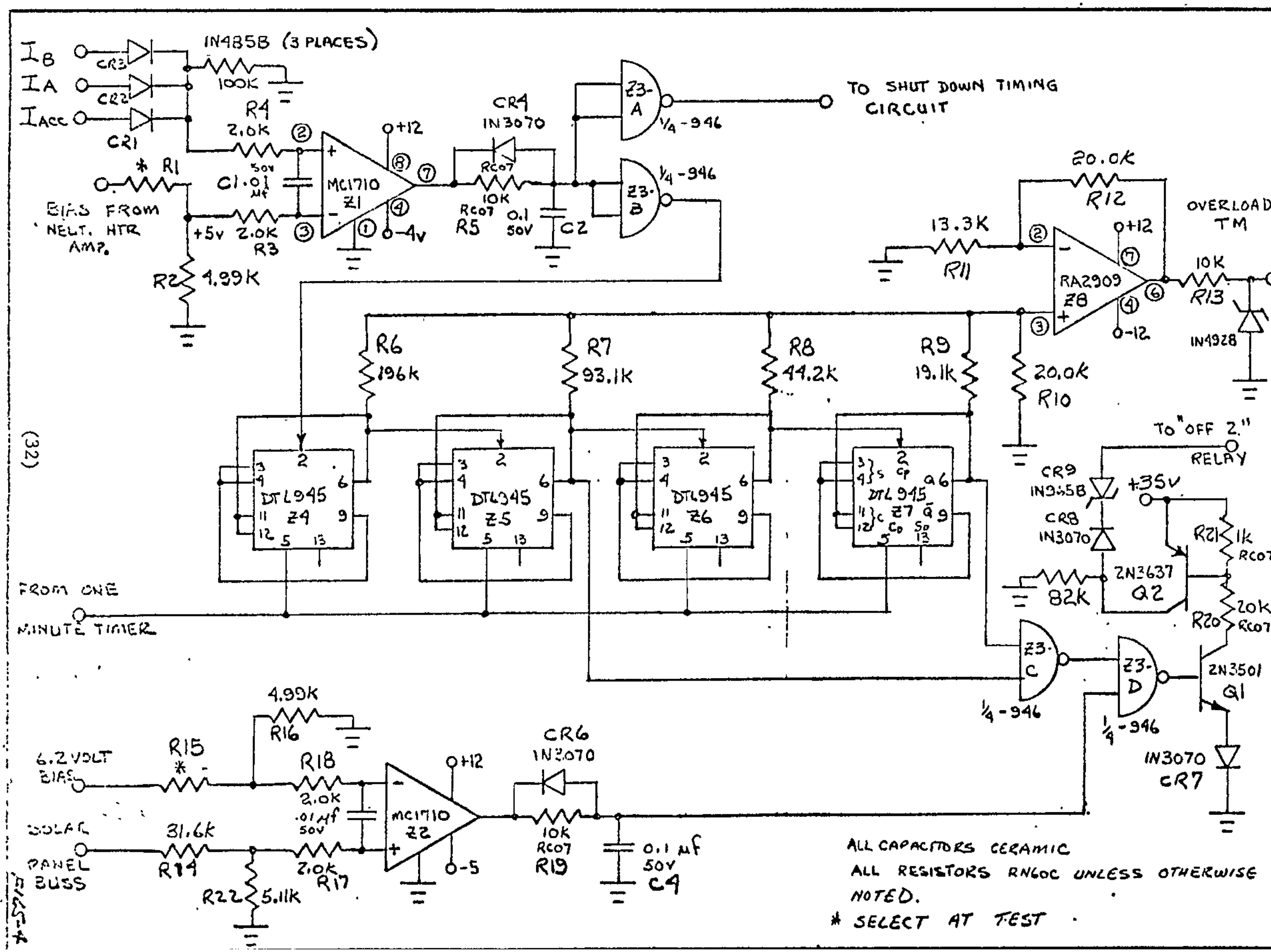
MODEL
REPORT NO

Control Module, Preheat Sequencer



(31)

FIG 5-3



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ANALYSIS ____
PREPARED BY ____
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MODEL: CONTROL MODULE, OVERLOAD TRIP AND INTEGRATION

REPORT NO.

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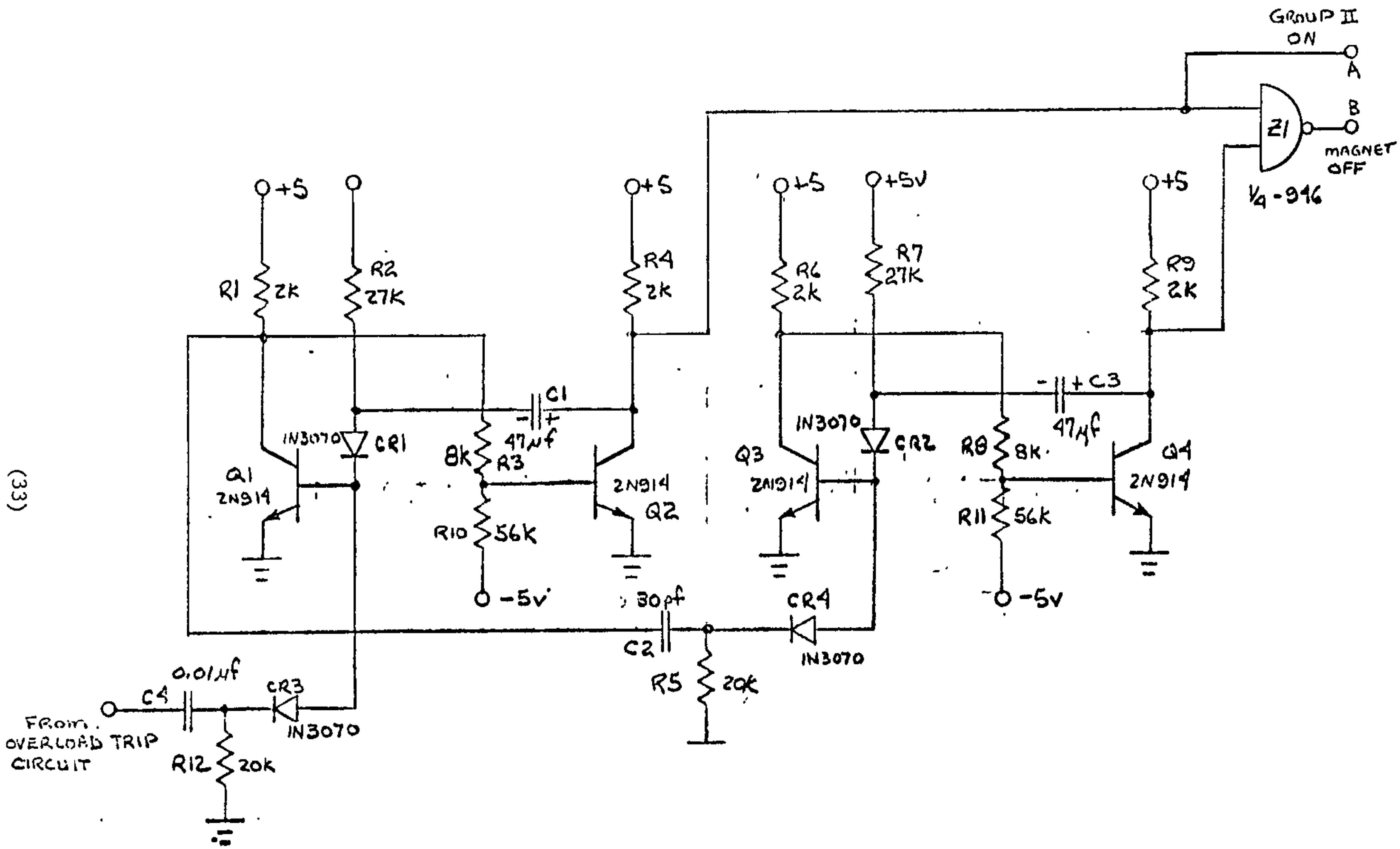
MODEL

CONTROL ... SHUT DO...

REPORT NO



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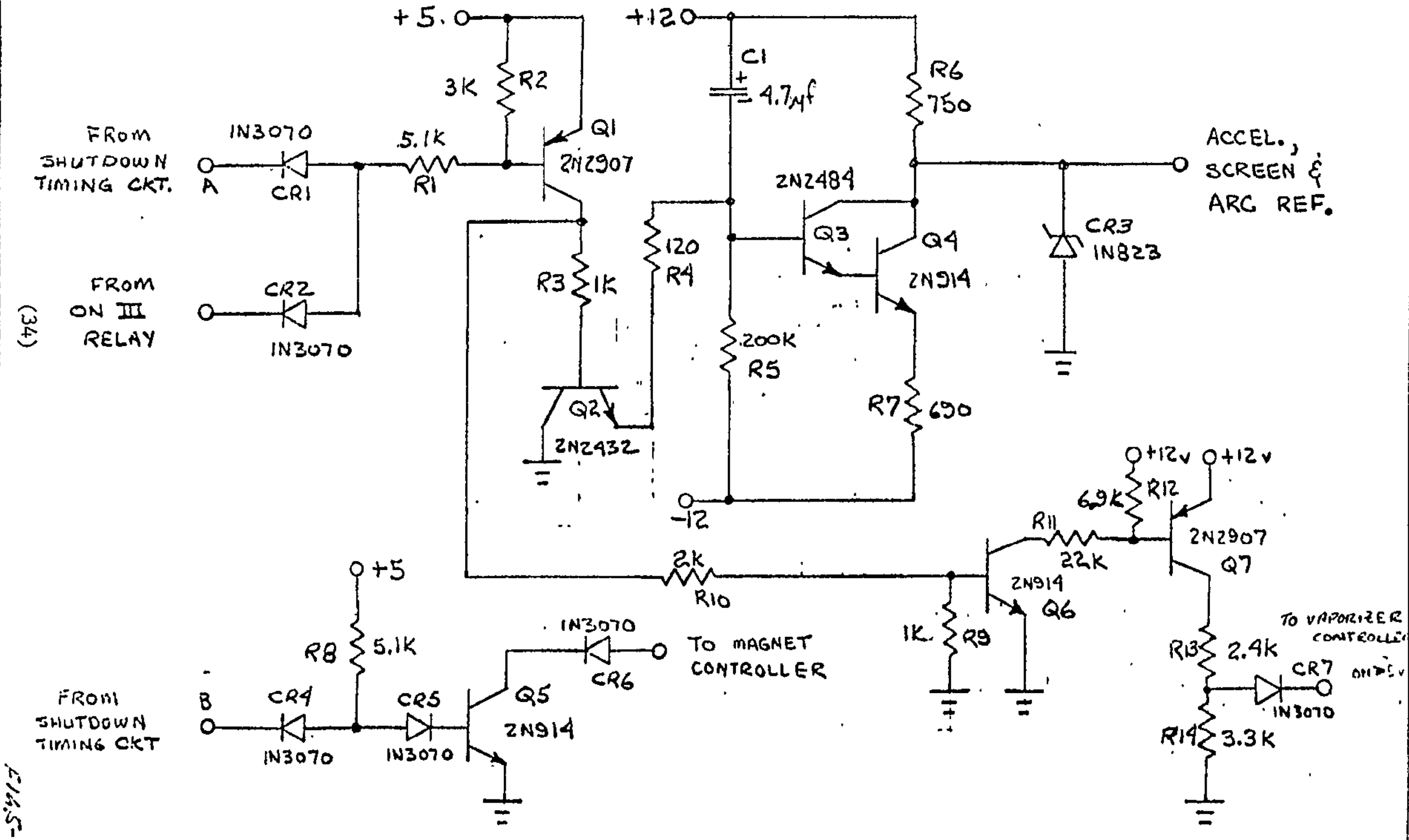
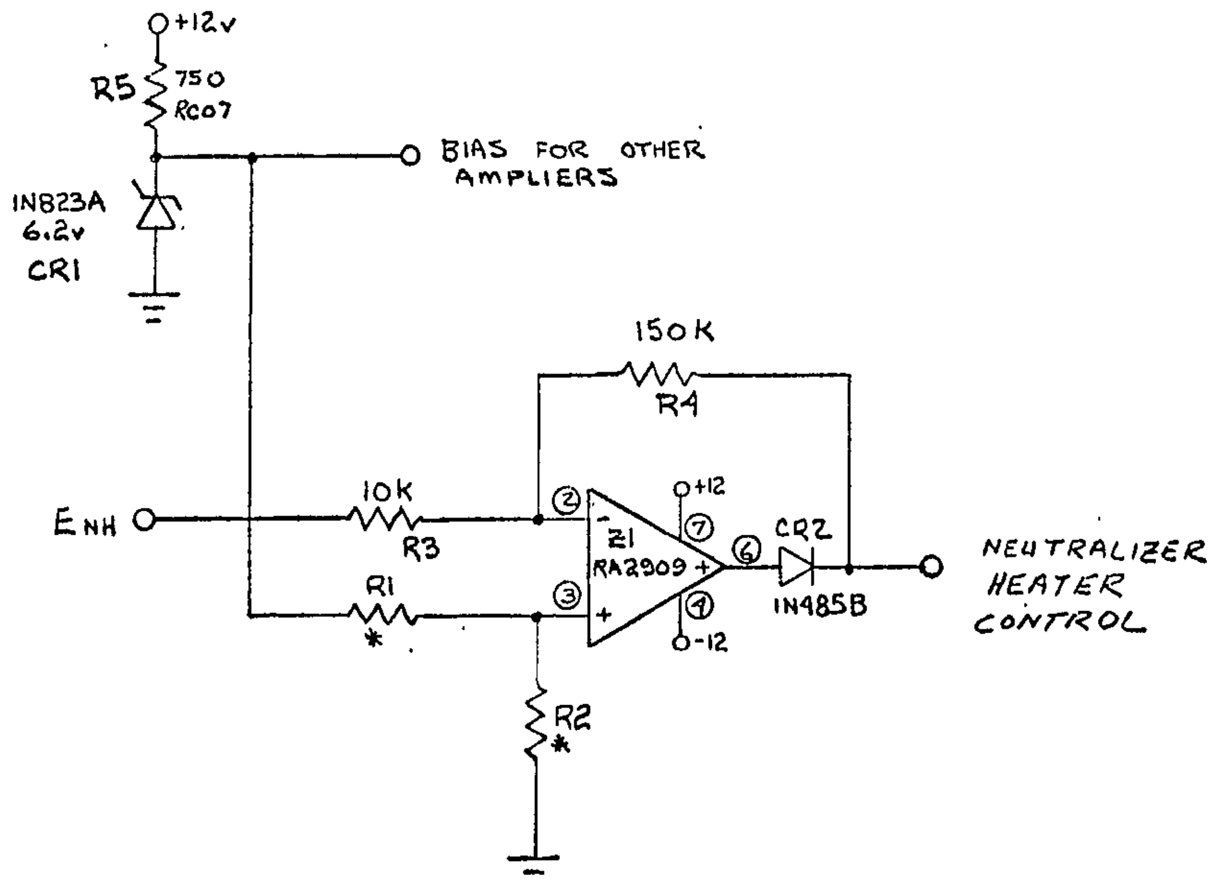
MODEL CONTROL MODULE
TRIP SHUTDOWN CIRCUIT

REPORT NO
PA
REV.A



(34)

F145-6

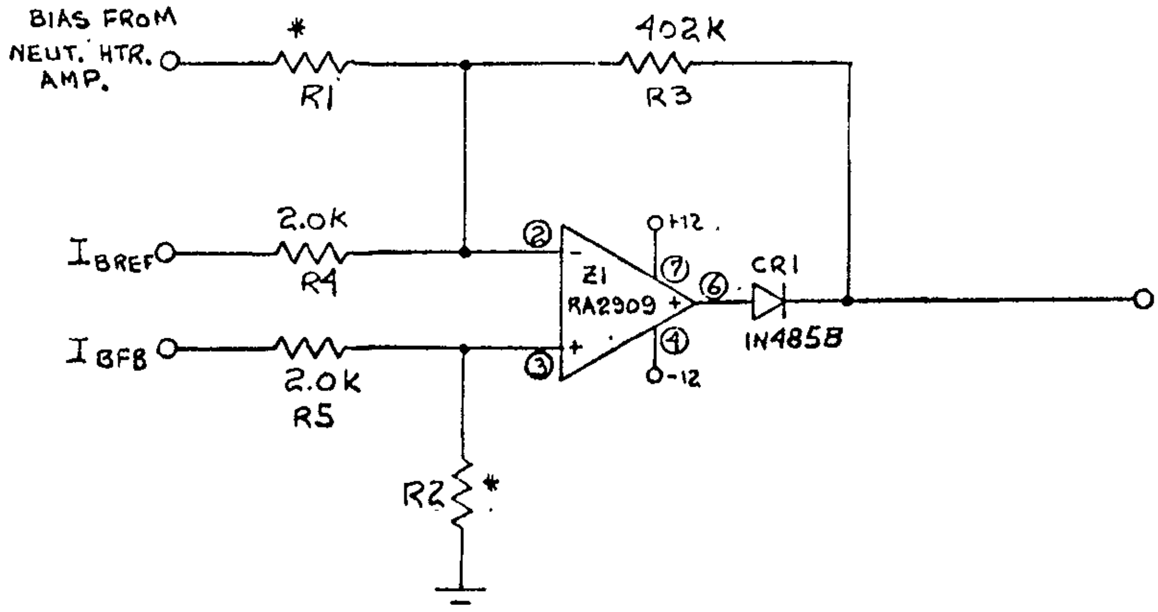


* SELECT AT TEST $\left\{ \frac{(R1)(R2)}{R1 + R2} = \frac{150}{.16} K \quad \& \quad \frac{R2}{R1+R2} V_z = \frac{E_{NKR} + 5}{3} \right\}$

ALL RESISTORS RN60C UNLESS

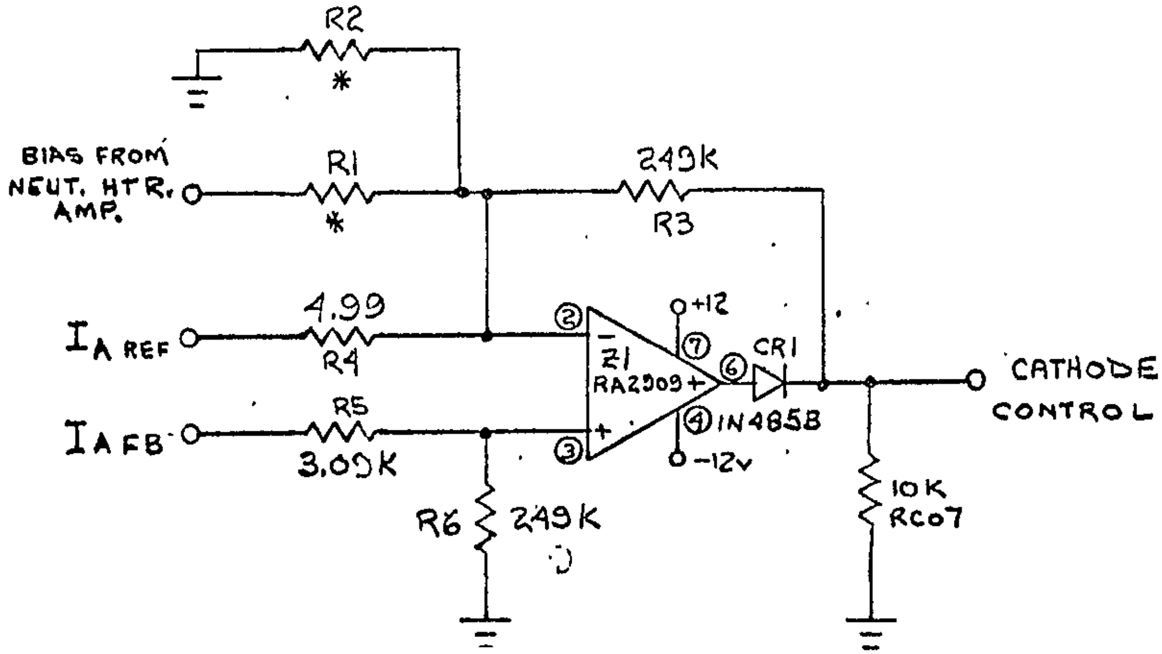
OTHERWISE SPECIFIED

FIG. 5-7



ALL RESISTORS RN60C

SELECT AT TEST $\left\{ R1 = 2k\,\frac{2V_z}{5}\ ,\quad R2 = \frac{(R1)(402k)}{R1 + 402k} \right\}$



ALL RESISTORS RN60C

* SELECT AT TEST $\left\{ R1 = 3.09K\frac{4\frac{1}{2}}{5}, \quad R2 = \dfrac{\frac{R1 \cdot R4}{R1+R4}\,R5}{\frac{R1 \cdot R4}{R1+R4} - R5} \right\}$

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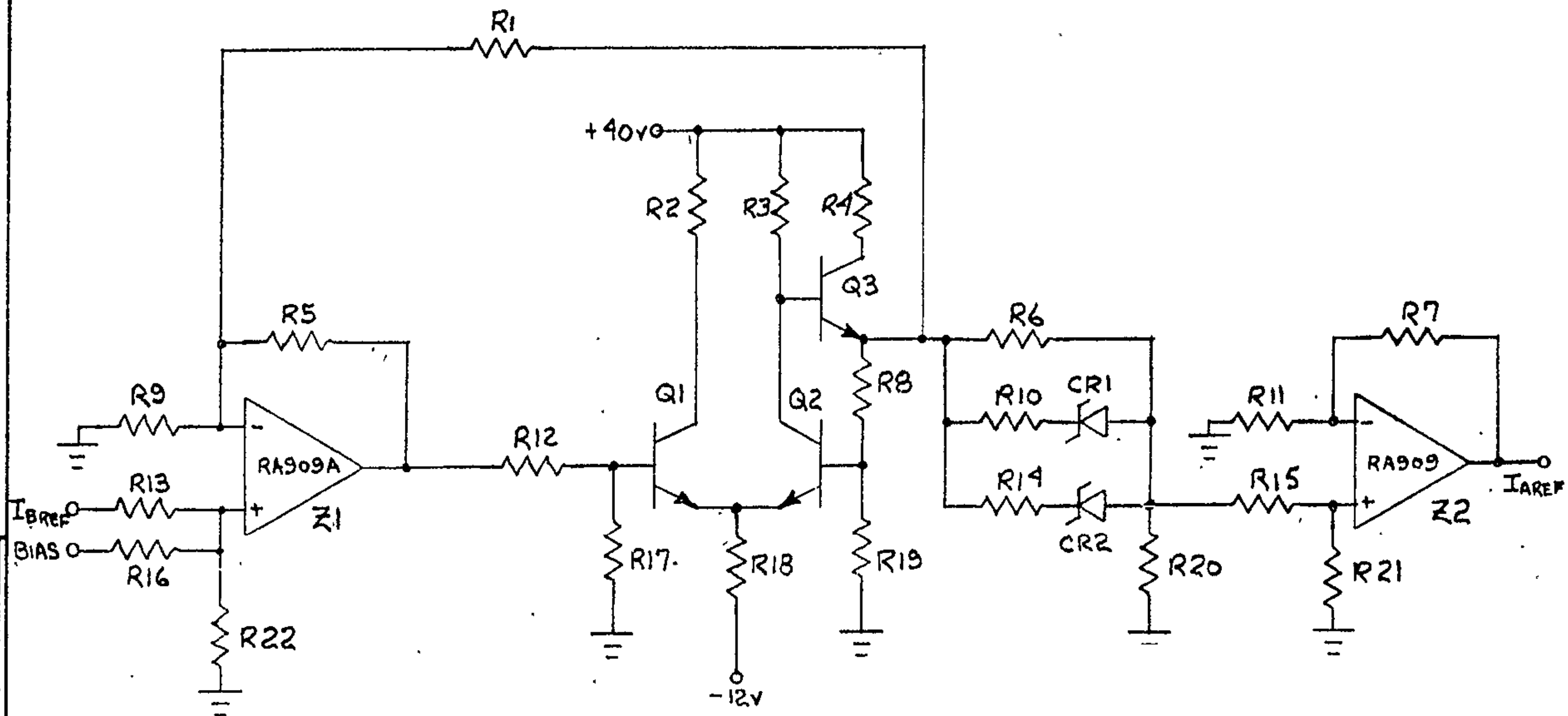
MODEL | REPORT NO | PAGE

FUNCTION GENERATOR, CONTROL MOD.



Z1, Z2 : RA909A, RA909 R1-R3 & R5-R22; RN60

Q1, Q2 : 2N2920 R4 ; RC22

Q3 ; 2N2484

CR1 ; 1N827A

CR2 ; 1N938B

ANALYSIS

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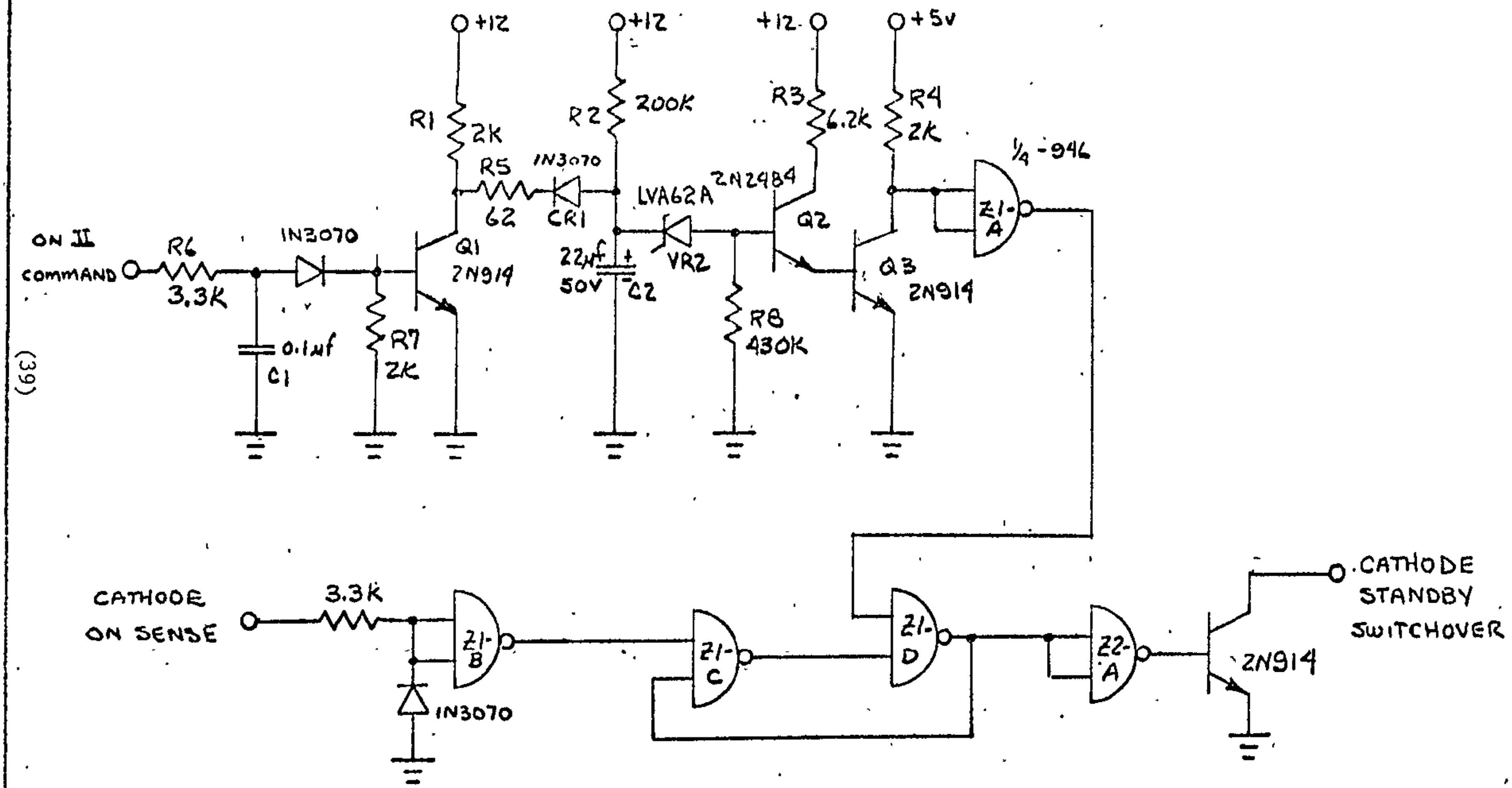

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MODEL CONTROL MODULE

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CATHODE STANDBY CONTROL

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MODEL
CONTROL MODULE, ACCEL. & ARC STANDBY CONTROL

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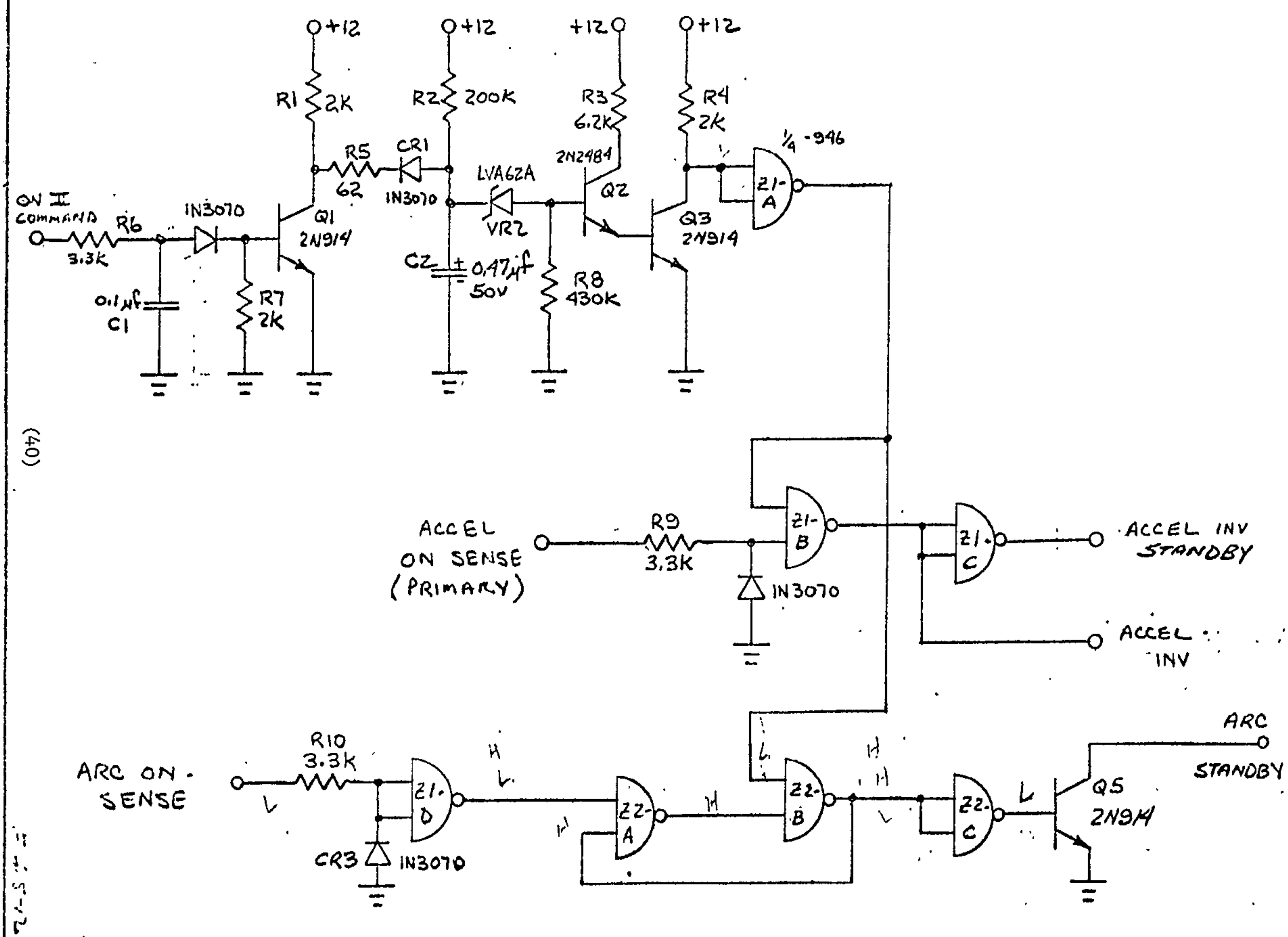
PAGE



(40)

6. Test Data

Presented herewith are test results taken on preliminary breadboards of key circuits of the system, together with data on critical components. Some subsystems, such as Screen Supply, require the assembly of a number of modular circuits which have not yet been built, hence cannot be reported on at this time.

a. Low Voltage Group

Data is presented on the Vaporizer, Neutralizer, Heater, Neutralizer Keeper, and Magnet Supplies, showing 1) regulations vs load (line regulation is performed by line regulator), 2) telemetry output vs load current, and 3) controlled current vs control voltage.

b. Modulated Power Inverter

Data is presented on losses measured in principal elements of a 300 watt screen inverter.

c. Cathode Heater Supply

Data is presented on load current regulation vs line voltage variation for 3 values of load current.

d. Function Generator

A plot of measured output is given for arc current reference as a function of commanded screen current reference.

e. Components

Data is given on switching speeds of power transistor used in inverters, also on P.I.V. of screen high voltage recterfier bridge.

f. Analog Control Circuits

Data presented shows the roll-off characteristics of the operational amplifiers for

1) Cathode Current vs Arc Control
2) Vaporizer Current vs Screens Control
3) Neutralizer Heater Current vs Neutralizer Keeper Control

HUGHES AIRCRAFT CO.

ANALYSIS
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REPORT NO.
PAGE

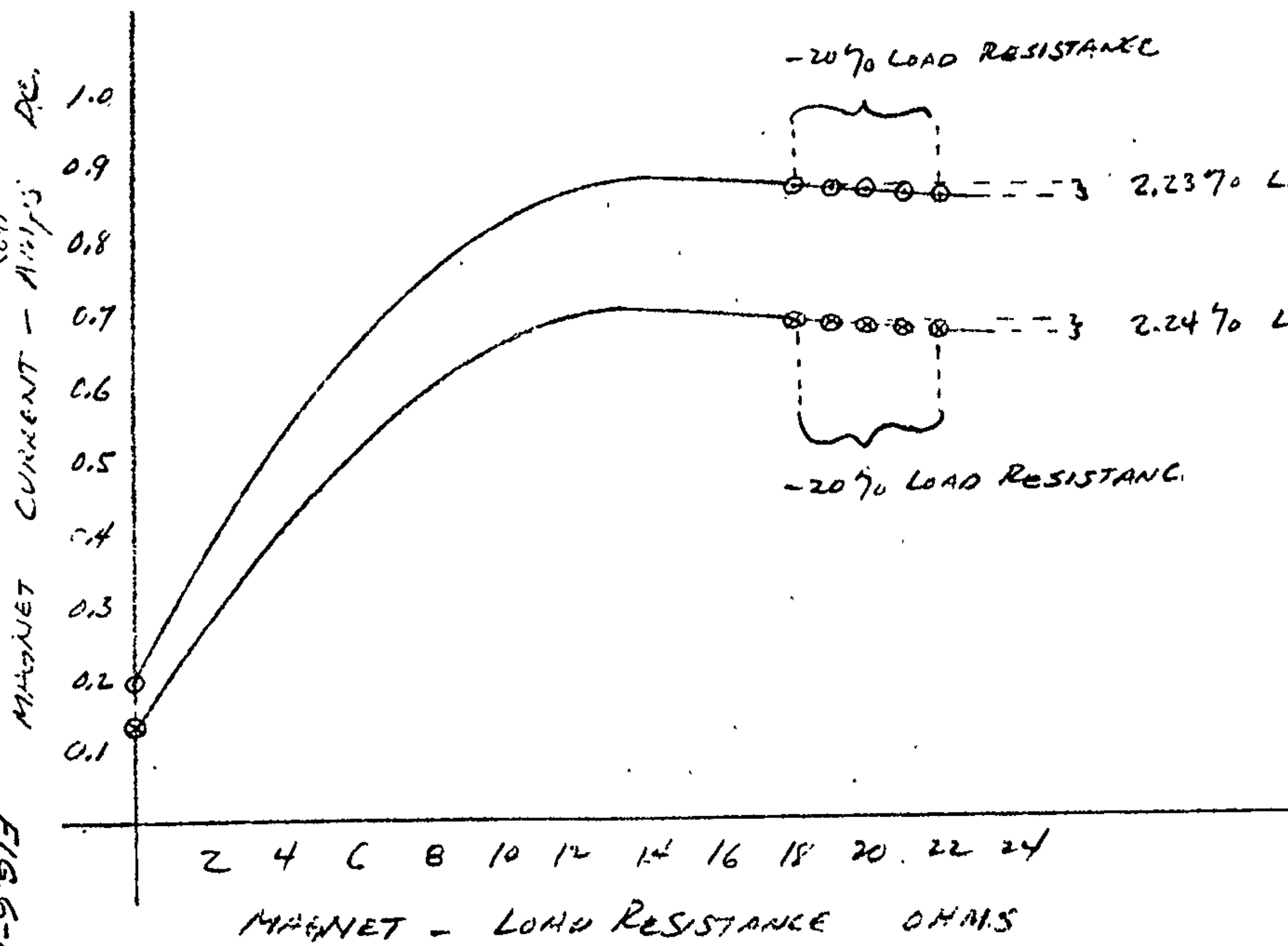

FIG. 6-1

THE SPECIFICATION FOR MAGNET TELEMETRY (CURRENT) IS 5 VOLTS FOR 0.9 AMPS LOAD CURRENT

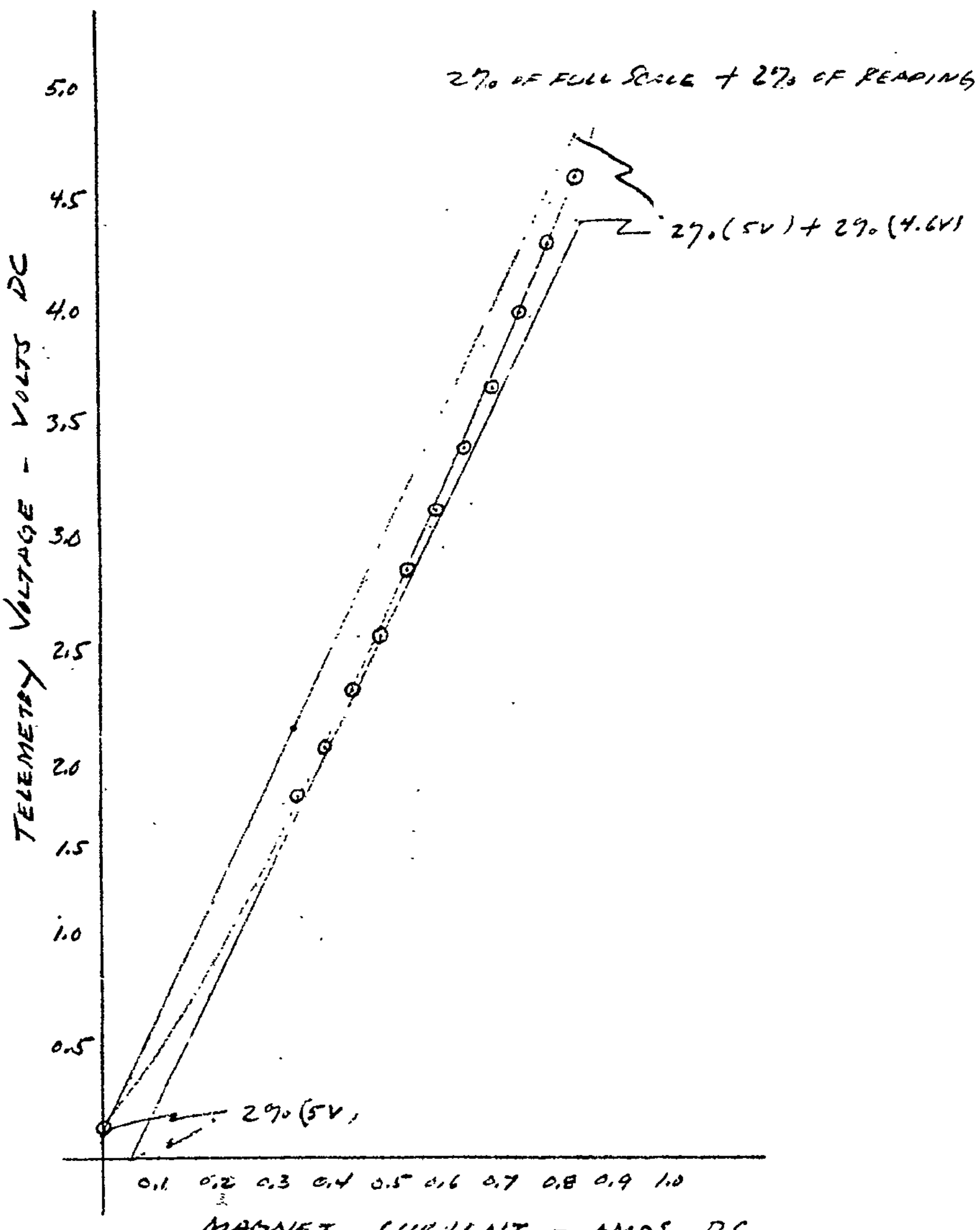

FIG 6-2

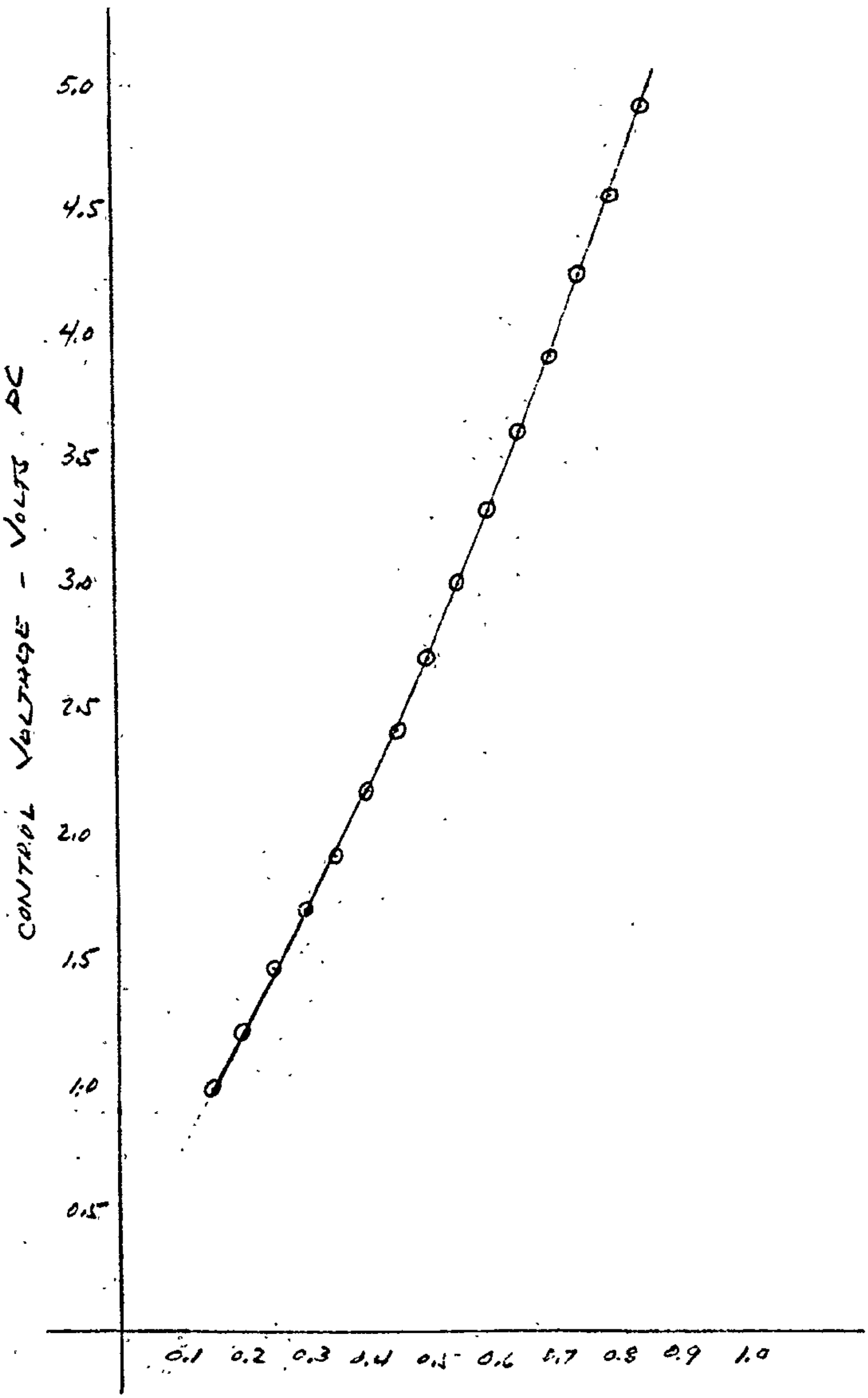
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
CONTROL VOLTAGE - VOLTS DC
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
MAGNET CURRENT - AMPS DC

FIG. 6-3

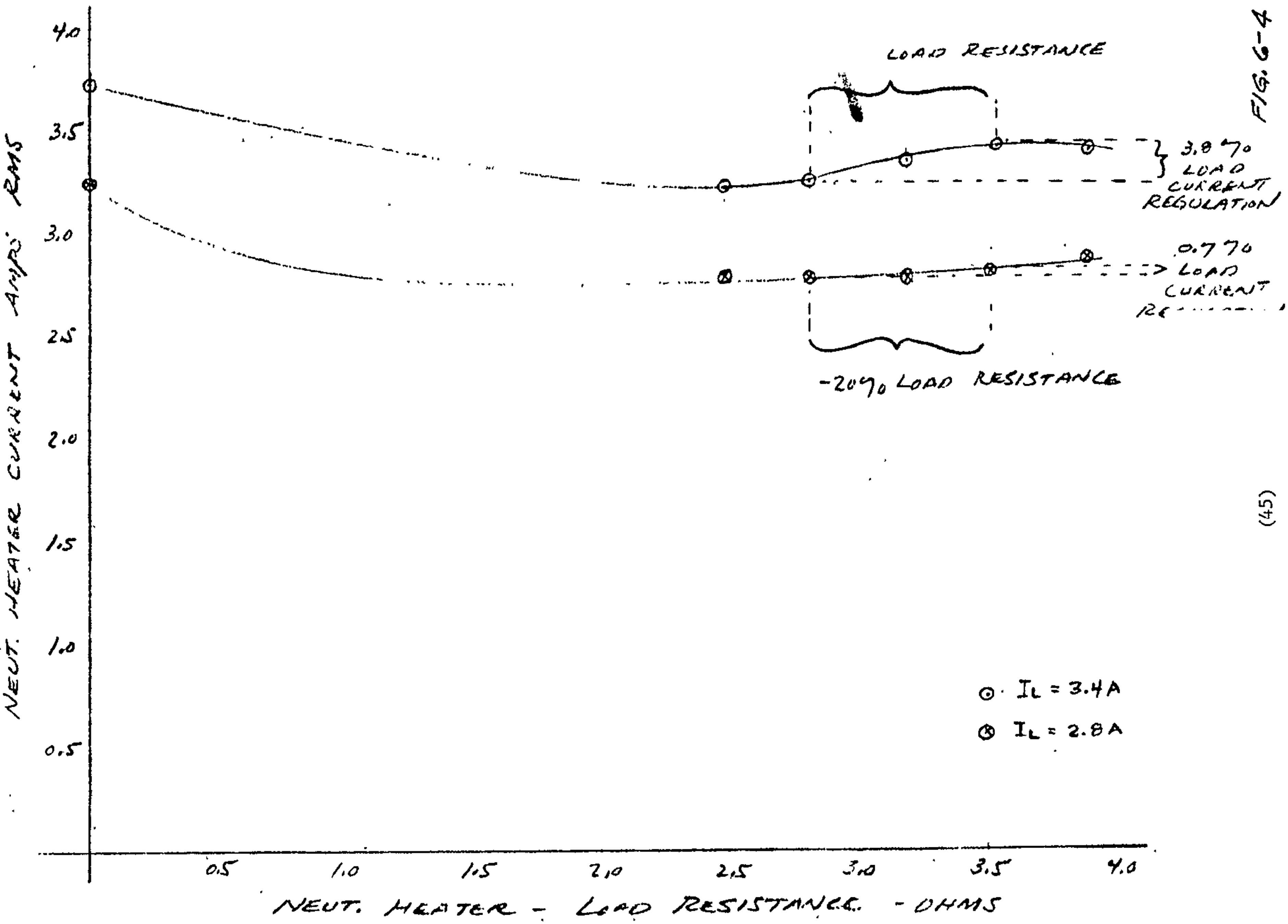
LOAD RESISTANCE
3.8% LOAD CURRENT REGULATION
0.7% LOAD CURRENT RE...
-20% LOAD RESISTANCE
NEUT. HEATER CURRENT AMPS RMS
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
NEUT. HEATER - LOAD RESISTANCE - OHMS
I_L = 3.4A
I_L = 2.8A

FIG. 6-4

ANALYSIS		MODEL	REPORT NO.	PAGE
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THE SPECIFICATION FOR N.H. TELEMETRY (CURRENT) IS 5 VOLTS FOR 4 AMP LOAD CURRENT

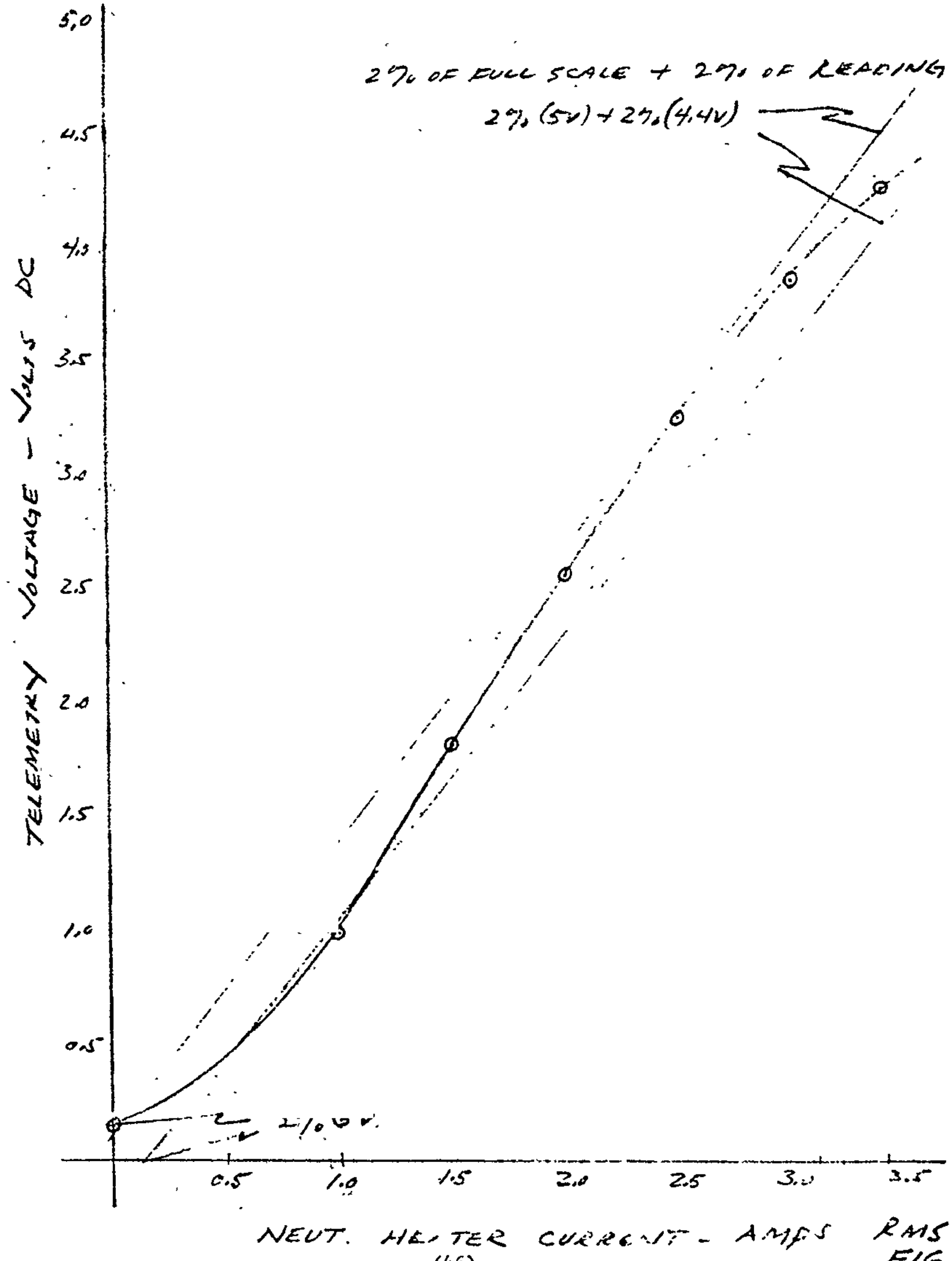

FIG. 6-5

THE SPECIFICATION FOR N.H TELEMETRY (CURRENT) IS 5 VOLTS FOR 4 AMPS LOAD CURRENT

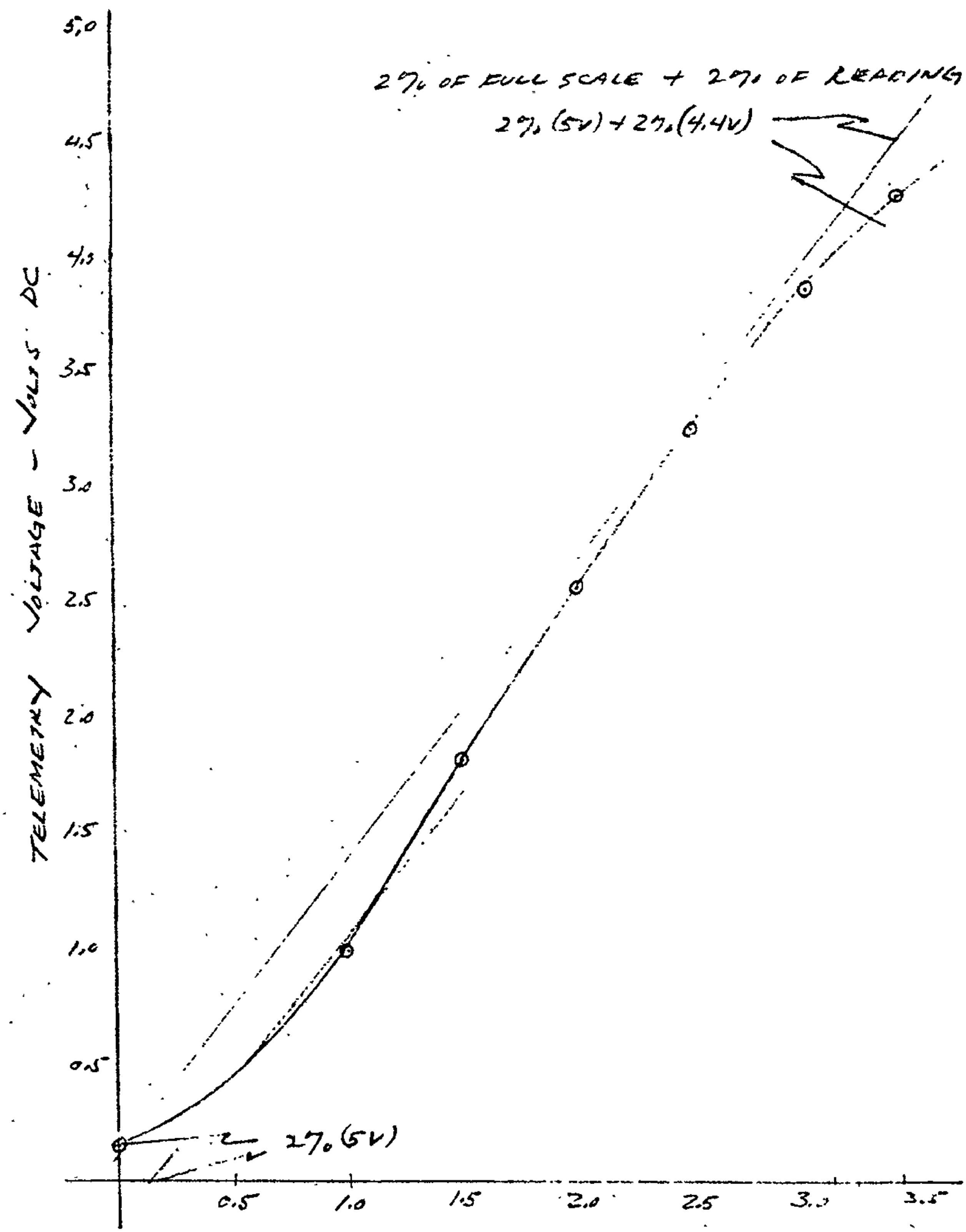

FIG. 6-5

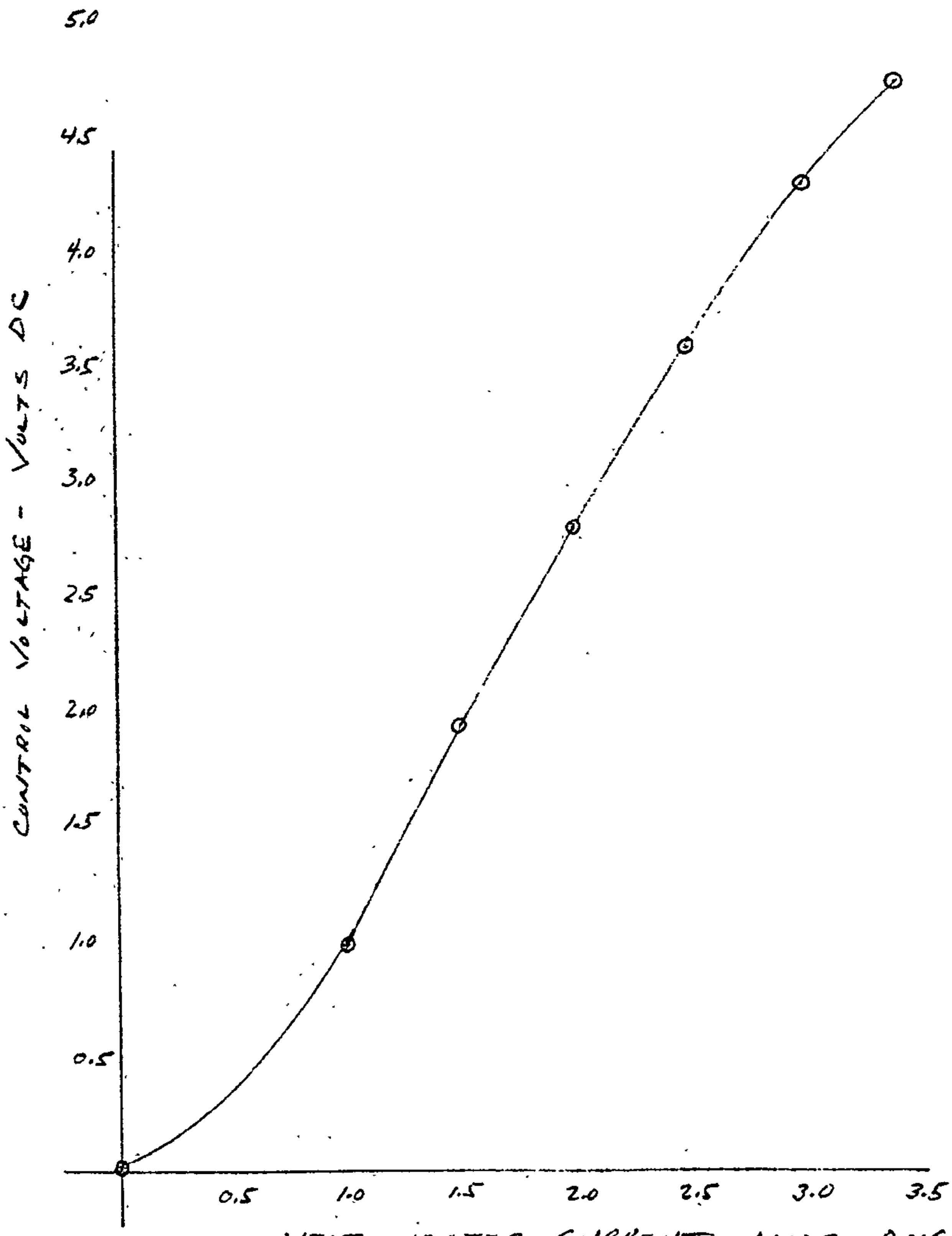
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
CONTROL VOLTAGE - VOLTS DC
0.5
1.0
1.5
2.0
2.5
3.0
3.5
NEUT. HEATER CURRENT - AMPS RMS

FIG. 6-6

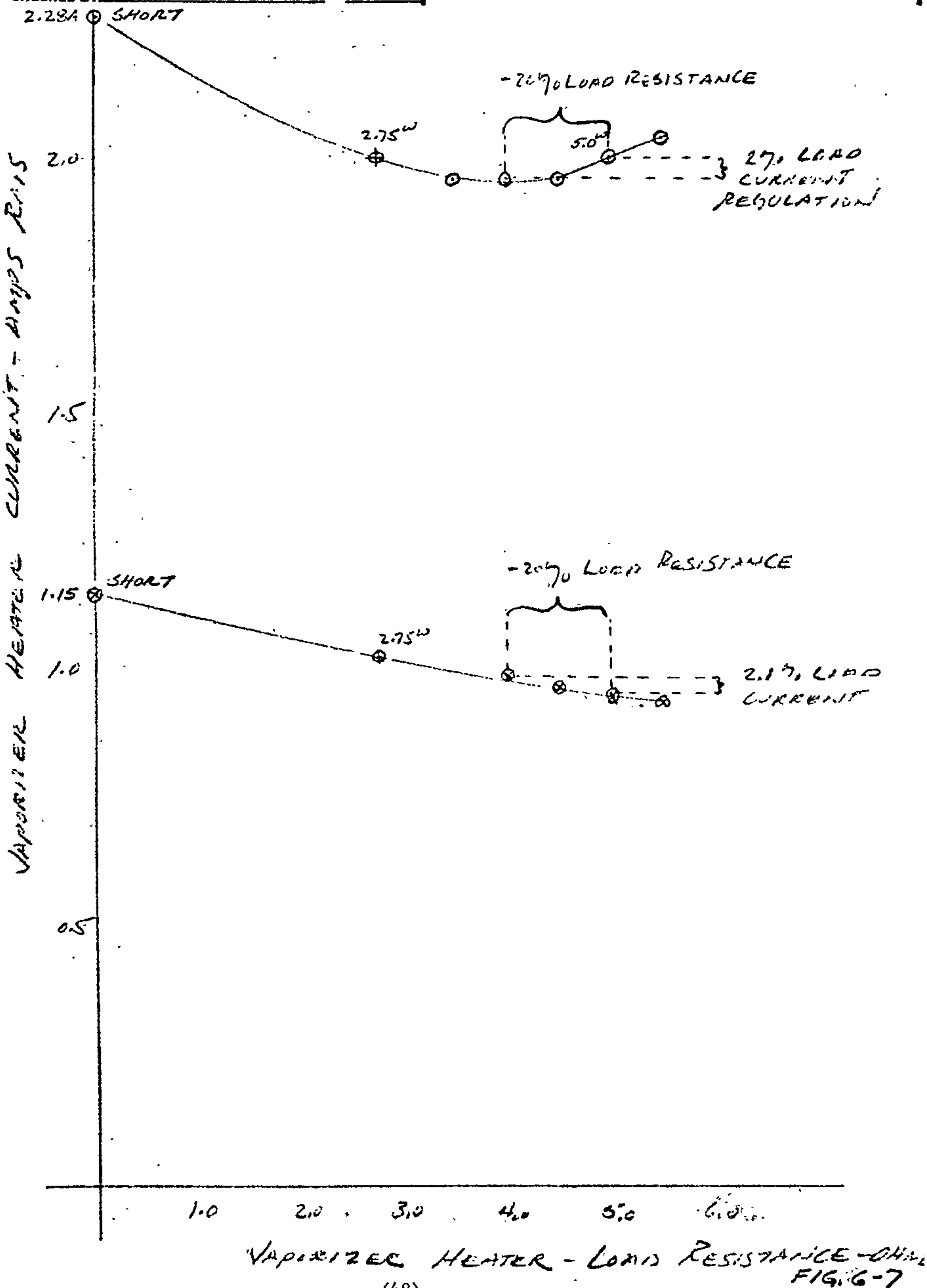
2.28A SHORT
-20% LOAD RESISTANCE
2.75W
5.0W
2% LOAD CURRENT REGULATION
2.0
1.5
1.15 SHORT
-20% LOAD RESISTANCE
2.75W
1.0
2.1% LOAD CURRENT
0.5
1.0
2.0
3.0
4.0
5.0
6.0
VAPORIZER HEATER CURRENT - AMPS RMS
VAPORIZER HEATER - LOAD RESISTANCE - OHMS

FIG. 6-7

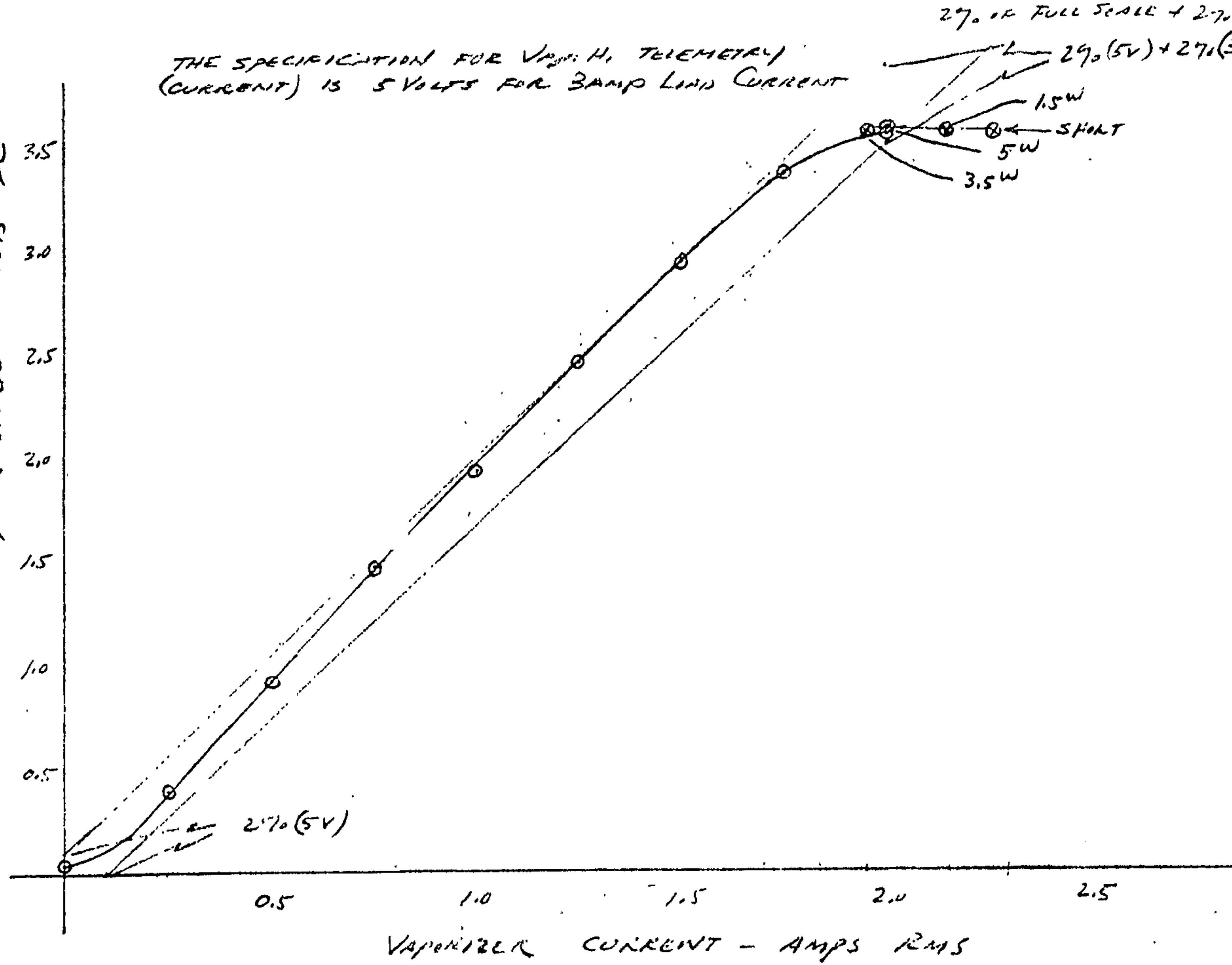

FIG. 6-8

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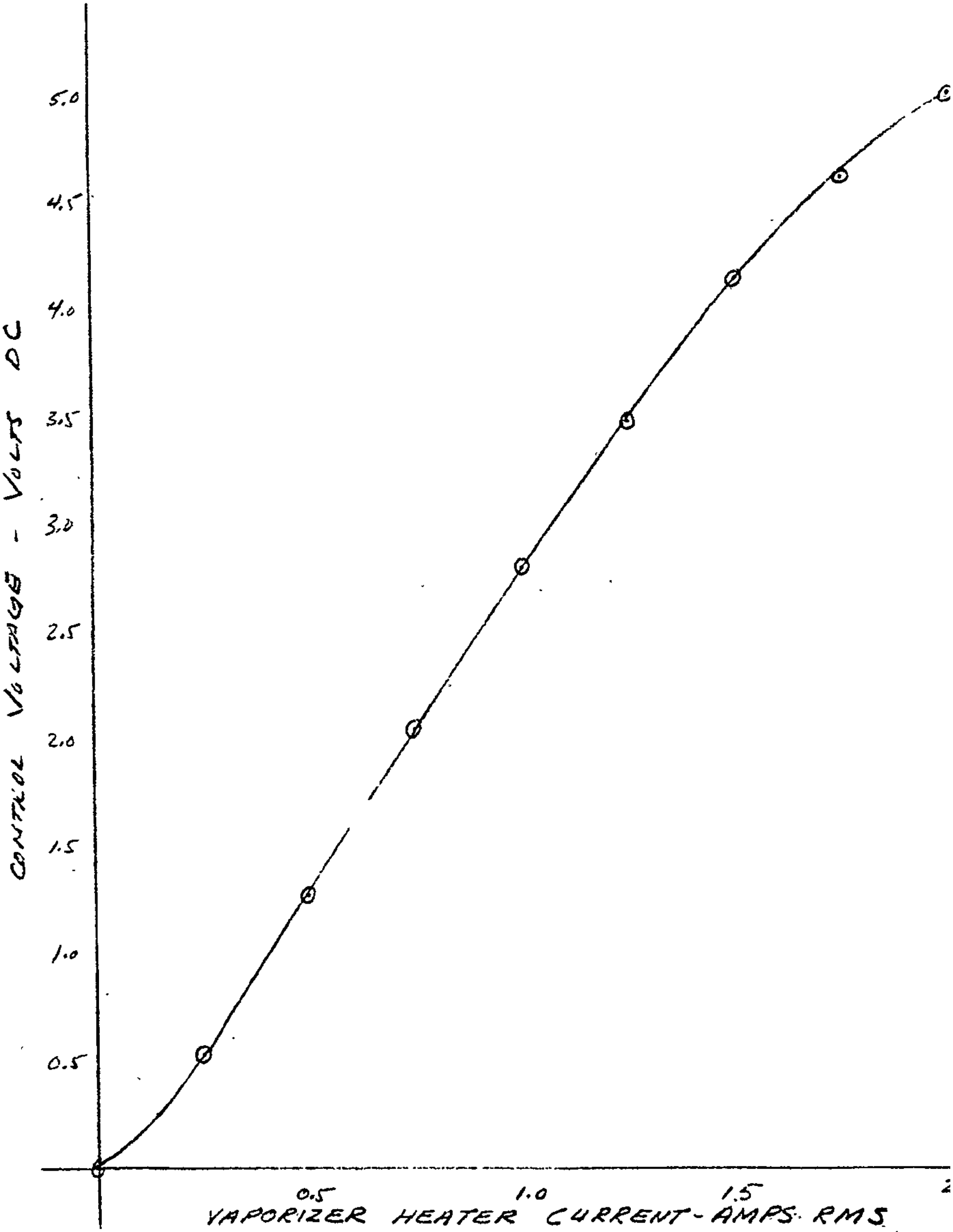


FIG. 6-9

FORM NO. 726

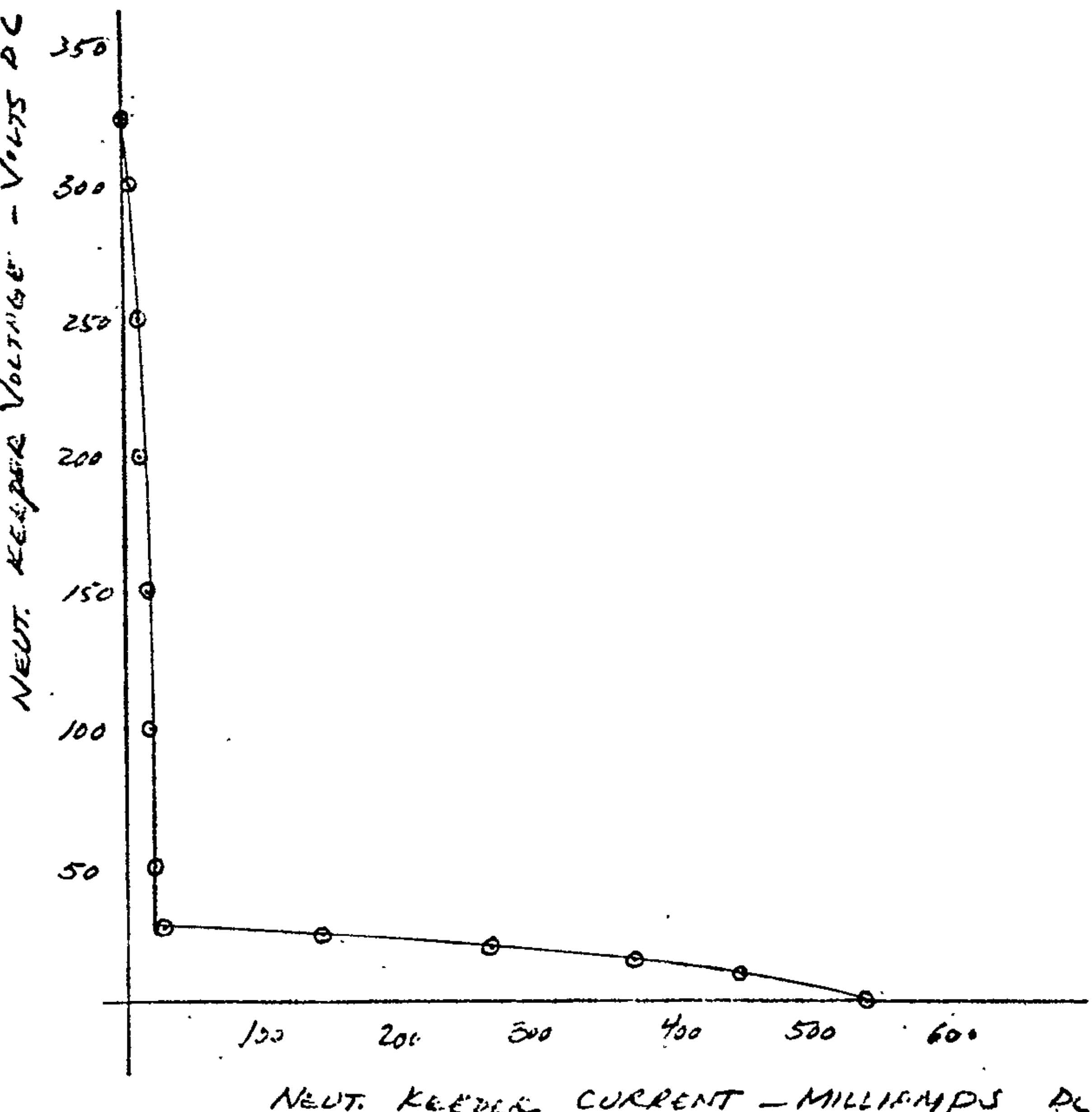

NEUT. KEEPER VOLTAGE - VOLTS DC
350
300
250
200
150
100
50
100
200
300
400
500
600
NEUT. KEEPER CURRENT - MILLIAMPS DC

FIG. 6-10

THE SPECIFICATION FOR N.K. TELEMETRY (CURRENT) IS 5 VOLTS

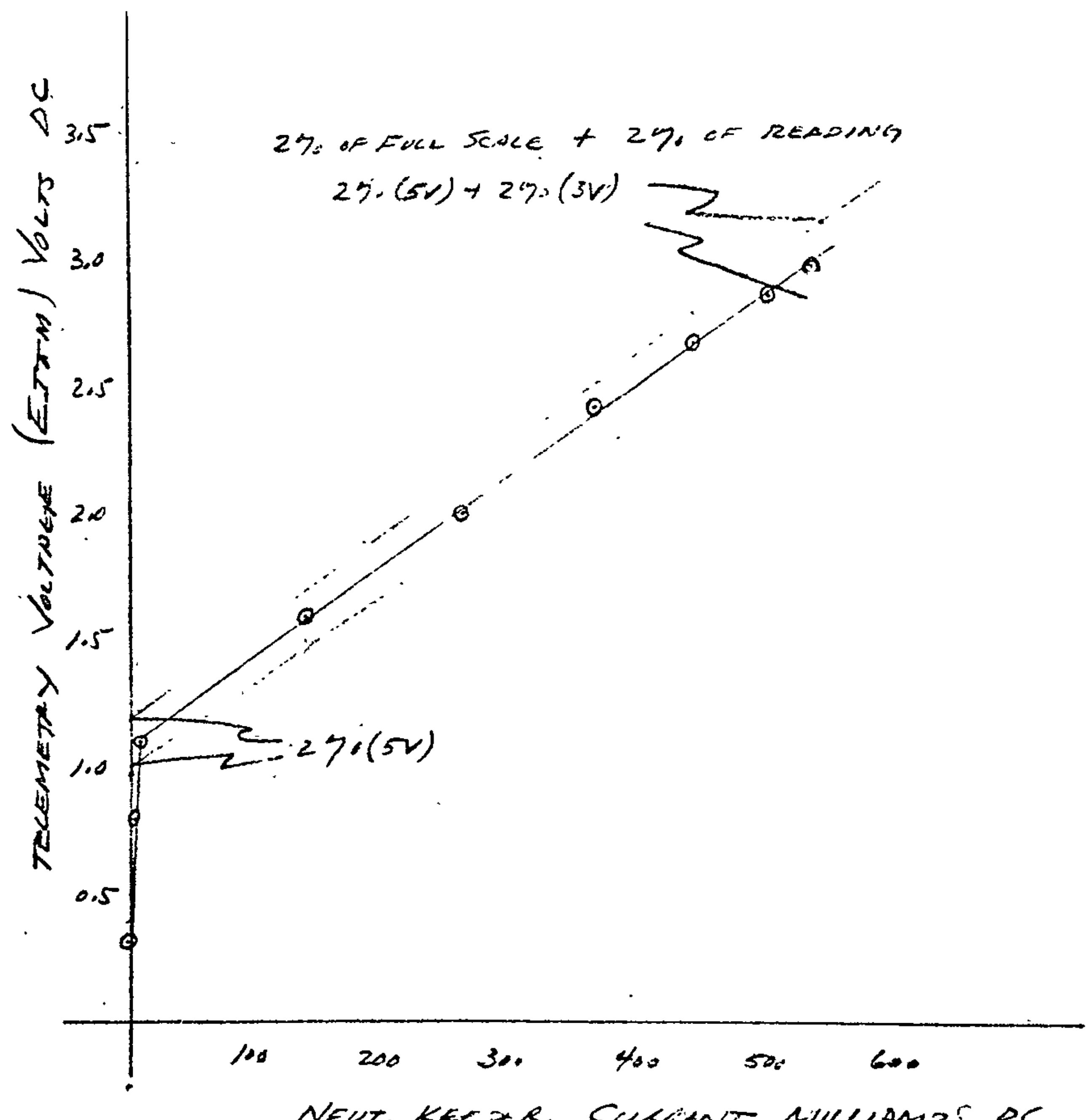


FIG. 6-11

THE SPECIFICATION FOR N.K. TELEMETRY (VOLTAGE)
IS 5VOLTS FOR 30V OUTPUT VOLTAGE
2% OF FULL SCALE + 2% OF READING

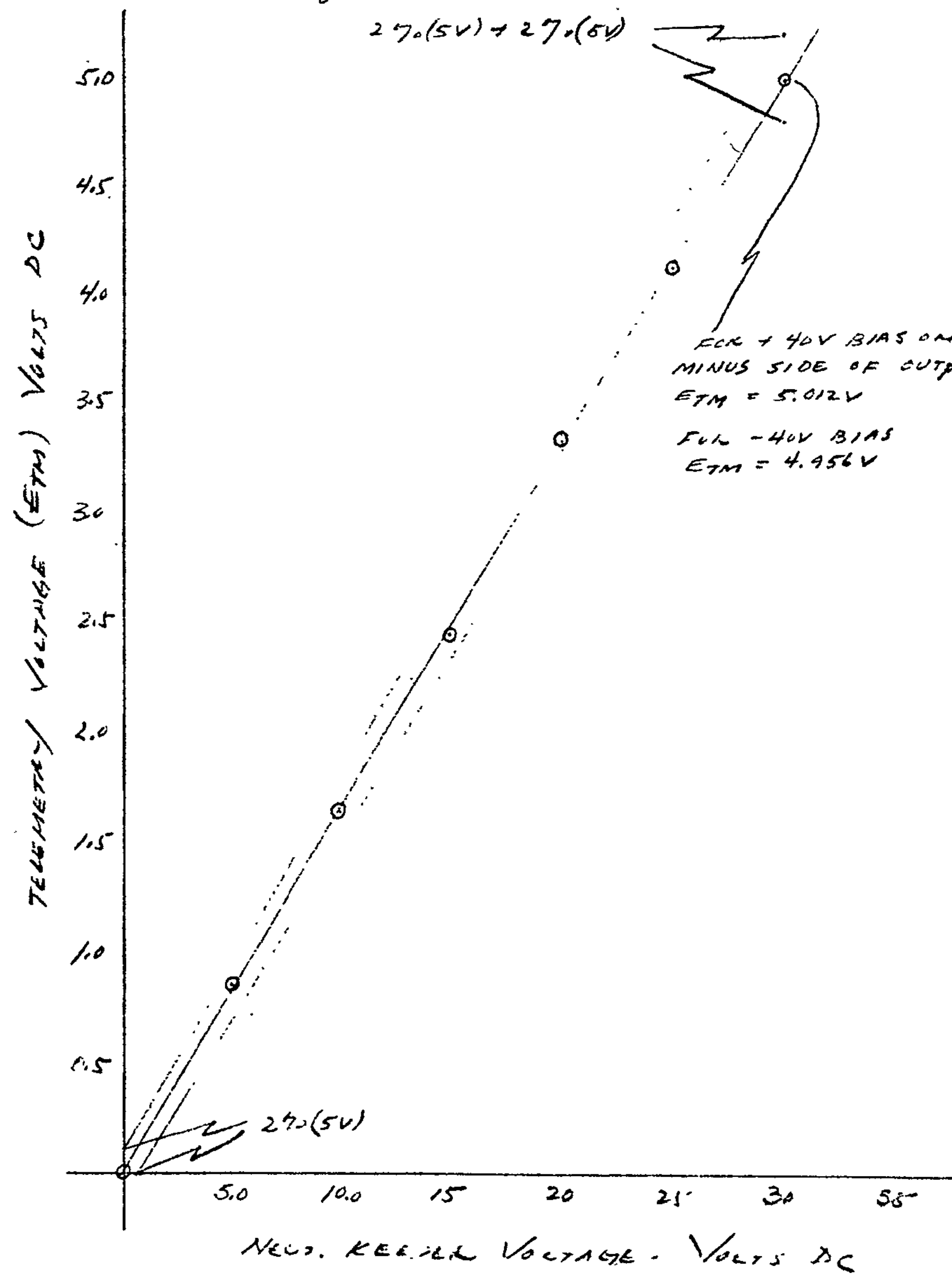


FIG 6-12

Losses in 300 Watt Inverter

Screen drive inverter circuit with 16 MH inductor and a .005μf 5000 VDC capacitor in output filter.

a. Power Loss in Power Transistor

Line 80 VDC

Pulse width	25μs
Power output	300 W
Room temperature	$82^{o}F$

Power transistor heat sink temperature $122^{o}F$

ΔT	$40^{o}F$

$6.1^{o}F$ rise = 1 watt

$40^{o}F \div 6.1 = 6.45$ watts loss in power transistor

Drive transformer voltage 35

Drive transformer average current 70 ma

Power for drive circuit - 70 ma x 35 v = 2.46 w

Base drive current 1.25 A pulse width 24μs

VBE $\approx$ 1.1V

Power VBE = 25μs/40μs x 1.25A x 1.1V = 0.86W

Corrected power transistor power loss equals 6.45W - 0.86W = 5.59W

b. Line Voltage 40VDC

Pulse width	36μs
Power output	300 W
Room temperature	$85^{o}F$
Heat Sink temperature	$136^{o}F$

$T = 51^{o}F$

Power in loss in power transistor = $51^{o}F \div 6.1 = 8.35$ W

Power in drive = 35 V x 115 ma = 4 W

Power loss in base = 1.25A x 1.1V x 35/40 $\approx$ 1.20 W

Corrected power loss in power transistors = 8.35 W - 1.20 W = 7.15 W

c. Summary of Transistor and Drive Loss

High Line 80 VDC	Transistor loss in power	5.59 W
	Drive Power	2.46 W
	Total	8.05 Watts loss
Low Line 40 VDC	Transistor Power Loss	7.15 W
	Drive Power	4.00 W
	Total	11.15 Watts loss

d. Output Transformer Loss

At 80V line, 50 percent duty cycle, output 300 V D.C. at 1A, measured loss (calorimeter) = 3.85 Watts.

Cathode Heater Regulation
(RMS Regulator)

Line Voltage	10A Load	25A	40A
40	10.0	25.0	40.1
45	10.0	25.1	40.2
50	10.1	25.1	40.2
55	10.0	25.1	40.3
60	10.0	25.2	40.4
65	10.0	25.1	40.4
70	10.0	25.1	40.5
75	10.0	25.1	40.4
80	10.0	25.1	40.4

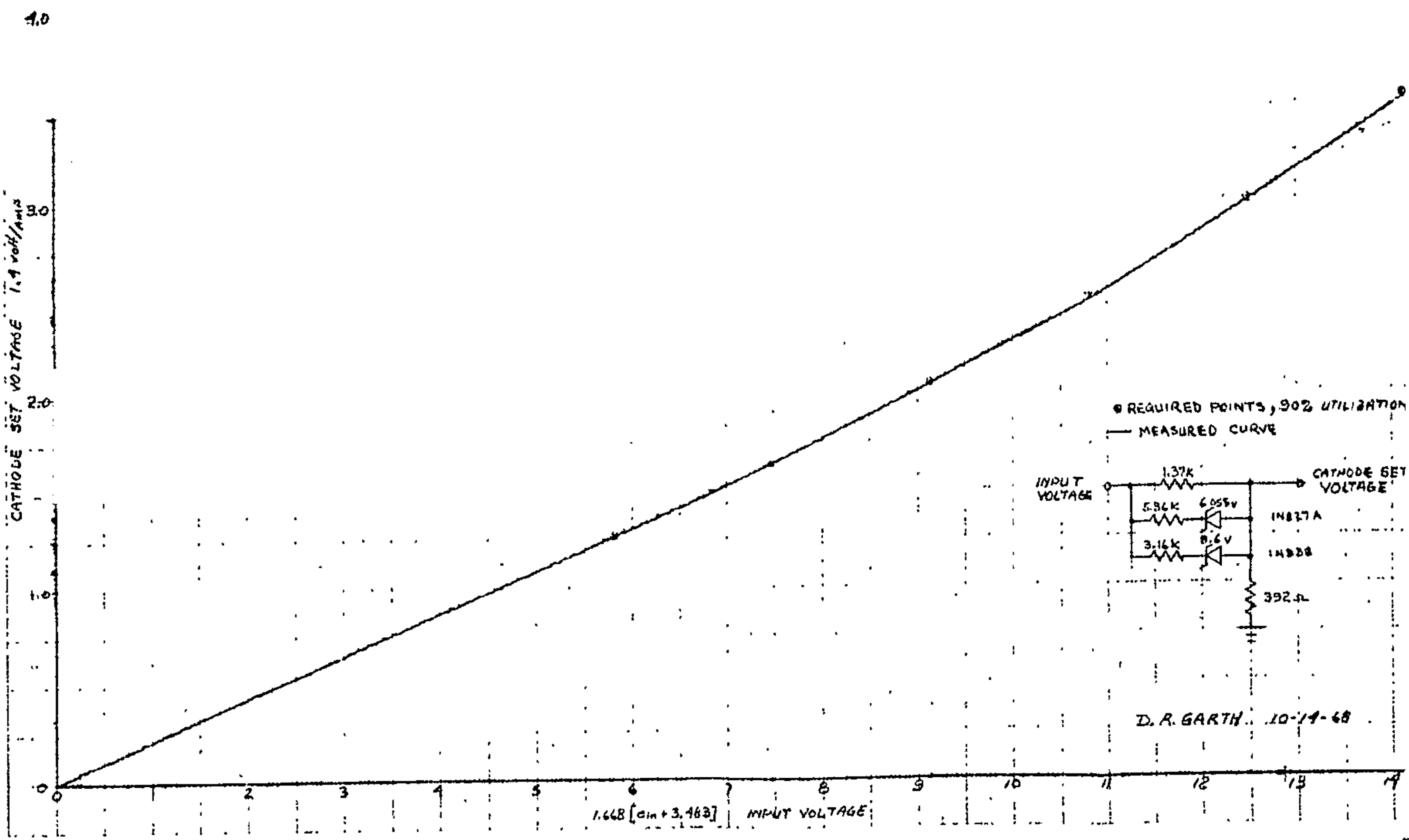

4.0
3.0
2.0
1.0
0
CATHODE SET VOLTAGE 1.4 volt/amp
0
2
3
4
5
6
7
8
9
10
11
12
13
14
1.668 [ein + 3.463] INPUT VOLTAGE
● REQUIRED POINTS, 90% UTILIZATION
— MEASURED CURVE
INPUT VOLTAGE
1.37k
CATHODE SET VOLTAGE
5.36k
6.055v
1N827A
3.16k
8.6v
392Ω
D. R. GARTH 10-14-68

FIG 5-13

Power Transistor Switching Speeds

Solitron SDT 325V101 Transistors

Collector Current = 7A

Serial No.	On	Off
31	.8	.7 x 10^{-6} sec
32	1.	1.0
33	1.	1.0
34	.9	.9
35	.8	.8
36	.9	.7
37	.9	.9
38	1.0	.7
39	1.1	.7
40	1.1	.8
41	1.1	.8
42	1.1	.8
43	1.0	.9
44	1.0	.8
45	1.0	.8
46	1.1	.9
47	1.0	.9
48	1.0	.7
49	1.1	.9
2-1	1.0	.8
2-2	1.2	.8
2-3	1.1	.8
2-4	1.1	.9

Solitron SDT 8805 Transistors

Collector Current = 7A

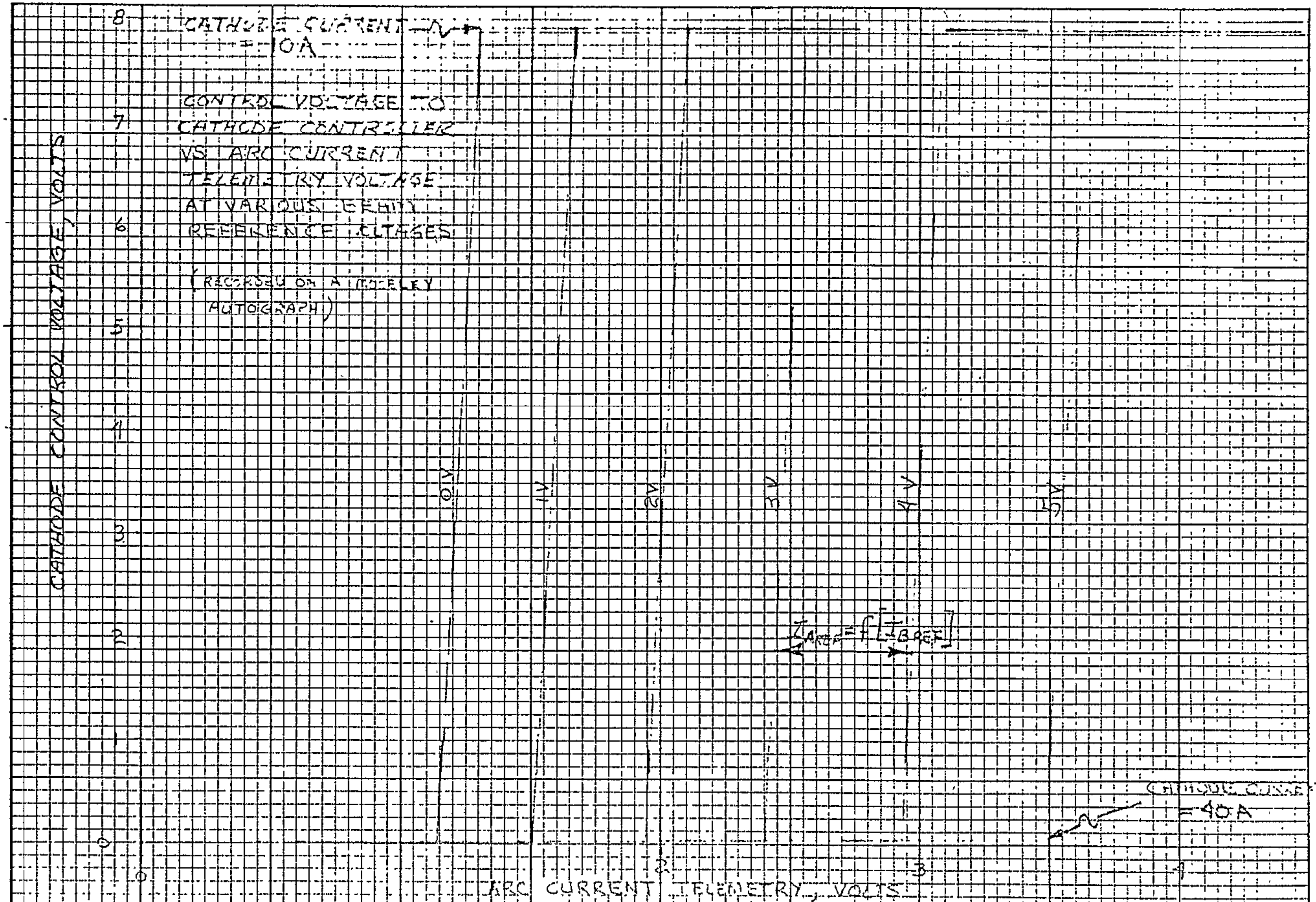
Serial No.	On	Off
1	2.	1.2 x 10^{-6} sec
2	1.8	1.0
3	2.2	1.5
4	2.0	1.5
5	2.5	1.0
6	2.5	1.0
7	2.0	1.0
8	2.0	1.0
9	2.2	0.8
10	2.5	1.0
11	3.0	1.4
12	2.0	1.0
13	2.5	1.5
14	1.7	1.0
15	2.0	1.0
16	2.5	1.5
17	2.2	1.2
18	2.5	1.0
19	2.2	1.0
20	3.0	1.5
21	3.0	1.5
22	2.0	1.5
23	1.5	1.5
24	1.0	1.0
25	2.5	1.0
26	2.0	0.8
27	2.0	1.0
28	1.5	0.8
29	1.5	0.6
30	1.5	0.6

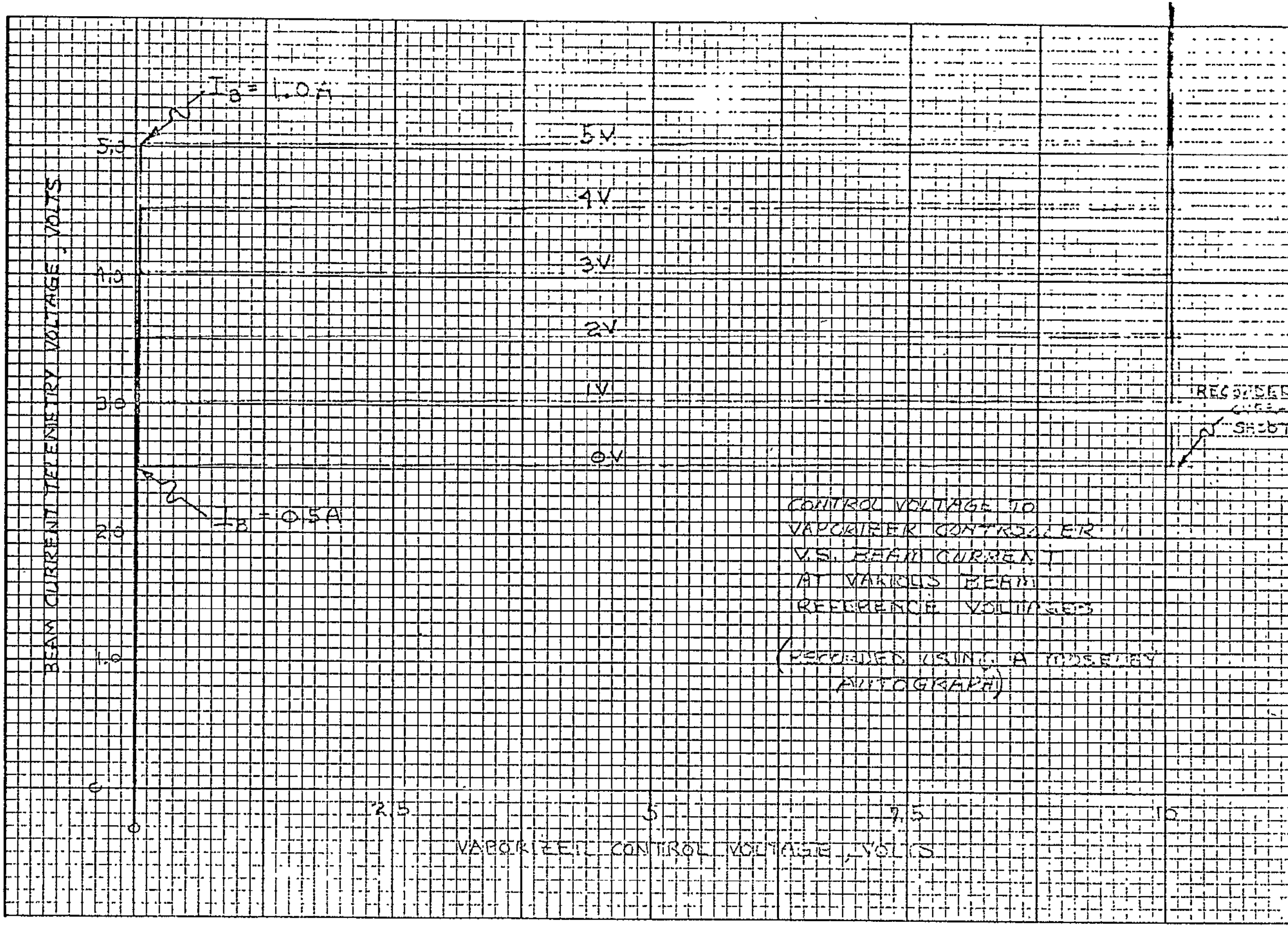
High Voltage Rectifier - PIV

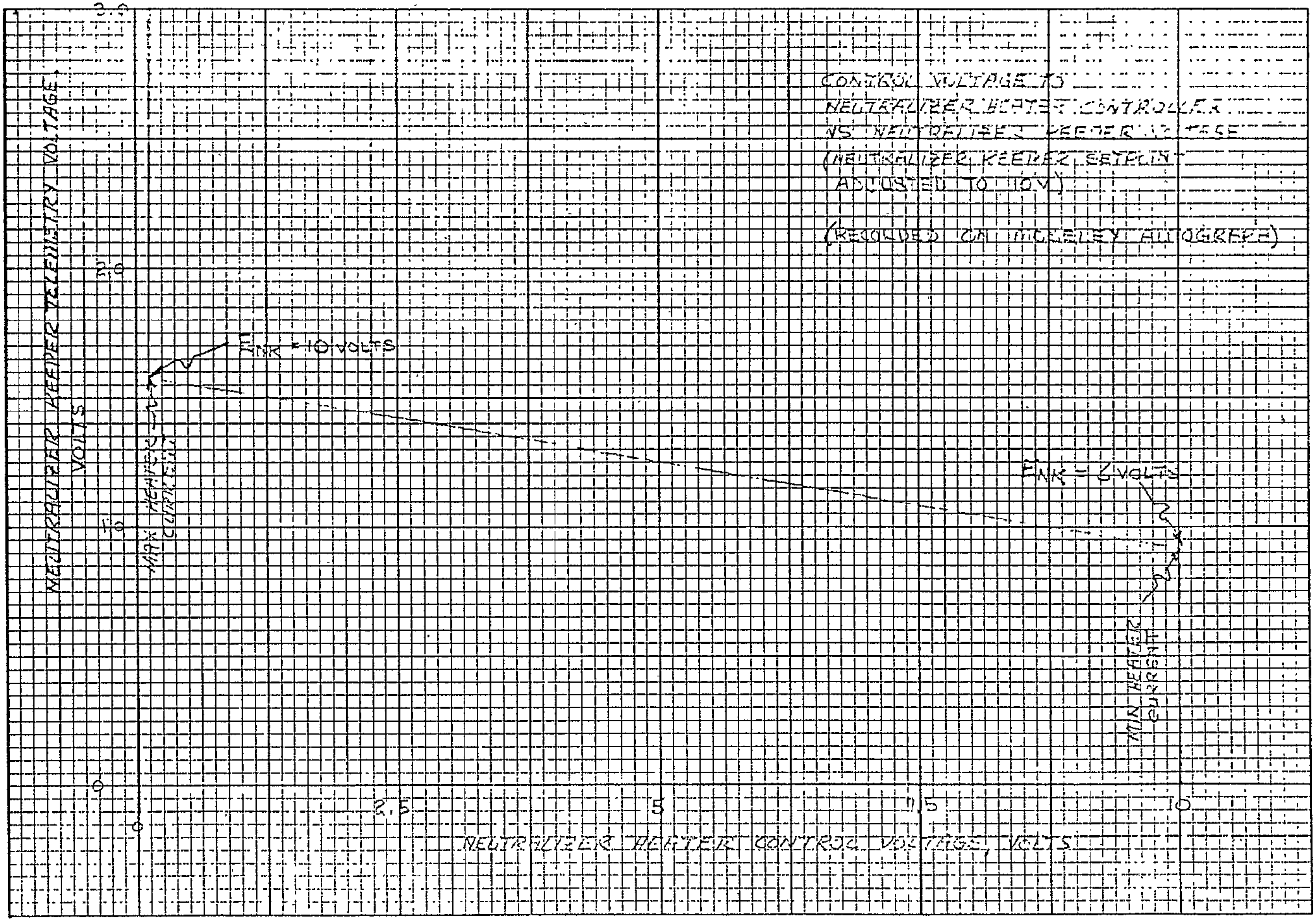
Semtech SA 2258 Diode Bridges (Rated 2A, 750V)

PIV @ 1.0 μA

Serial No.	RY_{cw}	RY_{ccw}	BY_{cw}	BY_{ccw}
1	1040	1000	1120	1160
2	1240	1040	1080	1080
3	1140	1040	1020	1200
4	1240	1100	1180	1150
5	1100	1140	1080	1200
6	1140	1180	1120	1240
7	1160	1120	1160	1240
8	1120	990	1160	1080
9	1080	1240	1140	1080
10	1160	1240	1200	1180
11	1000	1120	1180	1200
12	1000	1060	1120	1100
13	1030	1180	1000	1100
14	1210	1040	1080	1080
15	1080	1260	1300	1180
16	1220	1180	1220	1140
17	1220	1140	1260	1160
18	1140	1180	1060	1140
19	1130	1140	1120	1120
20	1040	1000	1000	1060
21	1220	1200	1180	1100
22	1100	1140	1200	1120
23	980	1160	1060	1240
24	1100	1080	1110	1220
25	1100	1110	980	1120
26	1180	1060	1120	1220
27	1060	1040	1140	1100
28	1120	1080	1200	1190
29	1190	1280	1060	1140
30	1160	1000	1040	1180
31	1040	1240	1240	1120
32	1180	1160	1080	1160
33	1100	1100	1160	1020
34	1160	1040	1160	1040
35	1000	960	1080	1200


CATHODE CURRENT = 10A
CONTROL VOLTAGE TO CATHODE CONTROLLER VS ARC CURRENT TELEMETRY VOLTAGE AT VARIOUS REFERENCE VOLTAGES
(RECORDED ON A MOSELEY AUTOGRAPH)
CATHODE CONTROL VOLTAGE, VOLTS
ARC CURRENT TELEMETRY, VOLTS
0V
1V
2V
3V
4V
5V
$I_{AREF} = f[I_{BREF}]$
= 40A
8
7
6
5
4
3
2
0
0
2
3
4


BEAM CURRENT TELEMETRY VOLTAGE, VOLTS
5.0
4.0
3.0
2.0
1.0
0
I_B = 1.0A
5V
4V
3V
2V
1V
0V
I_B = 0.5A
CONTROL VOLTAGE TO VAPORIZER CONTROLLER V.S. BEAM CURRENT AT VARIOUS BEAM REFERENCE VOLTAGES
AUTOGRAPH)
0
2.5
5
7.5
10
VAPORIZER CONTROL VOLTAGE, VOLTS



CONTROL VOLTAGE TO
NEUTRALIZER HEATER CONTROLLER
VS NEUTRALIZER KEEPER VOLTAGE
(NEUTRALIZER KEEPER SETPOINT
ADJUSTED TO 10V)
(RECORDED ON MOSELEY AUTOGRAPH)
NEUTRALIZER KEEPER TELEMETRY VOLTAGE
VOLTS
3.0
2.0
1.0
0
E_{NK} = 10 VOLTS
MAX HEATER CURRENT
E_{NK} = 6 VOLTS
MIN HEATER CURRENT
0
2.5
5
7.5
10
NEUTRALIZER HEATER CONTROL VOLTAGE, VOLTS

7. EFFICIENCY ANALYSIS

a. Screen Inverter Module

Worst Case: 300 watts out (2100 watts, seven inverters) (worst case = 7 inverters on, normal = eight inverters on)

At 40-Volt Line

1) Transistor saturated loss. Assume 93 percent efficiency, 95 percent duty cycle

$$I_c = \frac{300}{0.93 \times 39 \times 0.95} = 8.7 \text{ amperes peak}, = 8.7 \times 0.95 = 8.3 \text{ ampere average}$$

$$P_{sat} = I_c V_{ce\ sat} = 8.3 \times 0.7 - 5.8 \text{ watts (two transistors)}$$

2) Transistor switching loss. Assume partially inductive load. Assume t_s = 0.5 microsecond, f = 12.5 KH3

$$P_{sw} = 2/9\ E_m I_{c_p} t_s f \text{ per transistor}$$

$$= 4/9\ E_m I_c t_s f \text{ for two transistors}$$

$$= 4/9 \times 78 \times 8.7 \times 0.5 \times 10^{-6} \times 12.5 \times 10^3$$

$$= 1.90 \text{ watts (two transistors)}$$

3) $P_{sat} + P_{sw} = 5.8 + 1.9 = 7.7$ watts (excluding base loss)

4) Base drive loss (including modulator) (circuit $\beta = 9$)

P_{BD} = 2.0 volts x 1.0 = 2.00 watts + 1.0 watt in modulator (estimated) = 3.0 watts

5) Line capacitor loss (foil tantalum)*

$P_{c\ est} \approx 0.41$ watts

6) Transformer loss (from design data)

P_T = 5 watts (2.0 w. core loss, 3.0 w. copper loss)

7) Output rectifier loss (manufacturer's data)

4 diodes @ 0.8V drop/diode @ 1.0A = 3.2 watts

*G.E. Bulletin, 121EC for two 17.5 microfarad/200 volts, page 9

8) Total inverter loss at 40-volt line

Transistors	7.7 (6.5 w. measured)
Base drive	3.0 (3.3 w. measured)
Line capacitor	0.4
Transformer	5.0
Rectifiers	3.2
Total	19.3 watts

9) Input power = 300 + 19.3 = 319.3

10) Efficiency = $\frac{300}{319.3}$ = 94.0 percent

At 80-Volt Line

1) Transistor saturated loss (transistor on half time)

$P_{sat} = \frac{8.3 \times 0.7}{2} = 2.79$ watts (two transistors)

2) Transistor switching loss

$P_{sw} = 4/9 \times 156 \times 8.7 \times 0.5 \times 10^{-6} \times 12.5 \times 10^{3}$

$= 3.80$ watts (two transistors)

3) $P_{sat} + P_{sw} = 2.90 + 3.80 = 6.87$ watts

4) $P_{base\ drive} = \frac{3.00 \text{ watts}}{2}$ (on half time) - 1.50 watts

5) Line cap $P_c \approx 0.93$ watts*

6) Transformer loss, $P_{core\ loss}$ = 2.00 watts (from design data)

$P_{cop\ loss}$ = 3.0 x 0.5 = 1.5 W

= (same current as 40-volt line, on half time, PWM)

*G.E. Bulletin, 121EC, page 9

$P_T = 2.0 + 1.5 = 3.5$ watts

7) Output rectifier loss, $P_R = \frac{3.2 \text{watts}}{2} = 1.6$ watts (on 1/2 time-same current as volume)

8) Total inverter loss at 80-volt line

Transistors	6.70 (5.75 w. measured)
Base drive	1.50
Line capacitor	0.93
Transformer	3.50 (3.85 w. measured)
Rectifiers	1.60
Total	14.23 watts

9) Input power = 300 + 14.23 = 314.23

10) Efficiency = $\frac{300}{314.23}$ = 95.2 percent

Normal Case: 8 inverters on, $\frac{2100 \text{ w}}{8}$ = 262 watts out

At 40-Volt Line (Duty Cycle = .95 x 7/8 - 0.83)

1) Transistor saturated loss

$$I_c = \frac{262}{0.93 \times 30 \times 0.83} = 8.7 \text{ amps peak}$$
$$= 8.7 \times 0.83 \times 7.2 \text{ amps.aver.}$$

$P_{sat} = 7.2 \times 0.7 = 5.04$ w.

2) Transistor switching loss

$$P_{sw} = 4/9 \times 78 \times 8.7 \times 0.5 \times 10^{-6} \times 12.5 \times 10^{3}$$
$= 1.90$ watts (2 transistors)

3) $P_{sat} + P_{sw} = 5.04 + 1.90 = 6.94$ w

4) Base Drive Loss

$$P_{BD} = 3.0 \times \frac{0.83}{0.95} = 2.62 \text{ w}$$

5) Line Capacitor Loss = $0.41 \times \left(\frac{7.6}{8.7}\right)^2 = 0.31$ W

6) Transformer Loss

Core Loss $\alpha\ B_m^3$

$\alpha\ E_w^3$

$$P_{Core} = 2.0 \times (7/8)^3 = 1.34 \text{ w}$$

Copper Loss α Duty Cycle

$$P_{wp} = 3.0 \times \frac{0.83}{0.95} = 2.62 \text{ w}$$

$$P_T = 1.34 + 2.62 = 3.96 \text{ w}$$

7) Output Rectifier Loss

α Duty Cycle

$$P_r = 3.2 \times \frac{0.83}{0.95} = 2.8 \text{ w}$$

8) Total Inverter Loss at 40V line

Transistors	6.94
Base Drive	2.62
Line Capacitor	0.31
Transformer	3.96
Rectifiers	2.80
	16.63

9) Efficiency = $\frac{250}{266.6} = 94\%$

<u>At 80-Volt Line</u> (Duty Cycle = $\frac{0.83}{2} = 0.42$)

1) Transistor saturated loss

$$I_c \text{ av} = \frac{7.2}{2} = 3.6$$

$$P_{sat} \cong 3.6 \times 0.7 = 252 \text{ w}$$

2) Transistor switching loss

I_c peak same as 40 V line, voltage = 2x

$$P_{sw} = 1.90 \times 2 = 3.80 \text{ w.}$$

3) $P_{sat} + P_{sw} = 2.52 + 3.80 = 6.32$ w.

4) $P_{BD} = 2.62 \times 1/2 = 1.31$ w.

5) P_{Line} capac $= 0.93 \times \left(\frac{7.6}{8.7}\right)^2 = 0.71$ w.

6) Transformer Loss:

$P_{core} = 1.34$ w (same as 40V line)

$P_{copper} = 2.62 \times 1/2 = 1.31$ w (same current, 1/2 time)

$P_T = 1.34 + 1.31 = 2.65$ w

7) Output rectifier loss

$P_r = 2.8 \times 1/2 = 1.4$ w (same drop, 1/2 time)

8) Total inverter loss at 80V line

Transistors	6.32
Base drive	1.31
Line capacity	0.71
Transformer	2.65
Rectifier	1.40
	12.39 w

9) Efficiency $= \frac{250}{262.4} = 95.1\%$

b. Arc Inverter Module

1 operate, 1 standby, $P_o = 36V \times 7A = 252W$,

Scaling losses from screen inverter

At 40 Volt Line

1) Transistors $= \frac{252}{262} \times 6.94 =$ 6.68

2) Base Drive $= \frac{252}{262} \times 2.62 =$ 2.52

3) Line Capacity $= \frac{252}{262} \times 0.31 =$ 0.30

4) Transformer $= \frac{252}{262} \times 3.96 =$ 3.82

5) Total Inverter Losses = 13.32 w

6) Efficiency $= \frac{252}{265.3} = 95.0\%$

At 80 V Line

1) Transistors = $\frac{252}{262} \times 6.32$ = 6.10

2) Base Drive = $\frac{252}{262} \times 1.31$ = 1.26

3) Line Capacity = $\frac{252}{262} \times 0.71$ = 0.69

4) Transformer = $\frac{252}{262} \times 2.65$ = 2.55

5) Total Inverter Losses =10.60 W

6) Efficiency = $\frac{252}{260.6}$ =96.6%

c. Accelerator Inverter Module

1 operate, 1 standby inverter, P_{O_T} = 200 W transient

(2000 V, 0.1A transient)

(2000 V, 0.01A steady state) $P_{O_{SS}}$ = 20 W steady state

This inverter operates at duty cycle of 100% with a regulated input line of 35 volts.

A - Transient

$I_c = \frac{200}{.93 \times 34}$ = 6.32 A. peak = 6.32 A aver

1) Transistor Loss

$P_{sat} = 6.32 \times 0.7 = 4.4$ W

$P_{sw} = 4/9 \times 68 \times 6.32 \times 0.5 \times 10^{-6} \times 12.5 \times 10^3 \simeq 1.2$ W

$P_T = 4.4 + 1.2 = 5.6$ W

2) Base Drive Loss

$P_{BD} = 2V \times 0.8A = 1.6W$

3) Line capac. loss = negligible (low ripple)

4) Transformer loss = $\frac{200}{262} \times 3.36 = 3.02$ W

5) Rectifiers: (10 diodes in series)

$P_R = 0.1A \times 0.8V \times 10 = 0.8$ W

6) Total Inverter Loss (transient)

Transistors	5.6
Base Drive	1.6
Transformer	3.0
Rectifiers	0.8
Total	11.0 W

B - Steady State

I_c 6.32 x 1/10 = 0.62 A peak = average

1) Transistor Loss = 5.6 x 1/10 = 0.56

2) Base Drive Loss

3) Transformer:

$$P_{core} \times 1/2 \text{ total of transient loss} = \frac{3.02}{2} = 1.51$$

$$P_{copper} = 1.61 \times \left(\frac{1}{10}\right)^2 = \text{negligible}$$

$$\therefore P_T = 1.51$$

4) Rectifiers Loss = 0.8 x 1/10 = .08 W

5) Total inverter loss

Transistors	0.56
Base Drive	1.60
Transformer	1.51
Rectifiers	.08
Total	3.75 W

d. Cathode Inverter Module

1 operate, 1 standby inverter, P_O = 5V x 40A = 200 W

40V Line (95% duty cycle)

$$I_C = \frac{200}{.93 \times 39 \times .95} = 5.8\text{A peak}$$
$$= 5.8 \times .95 = 5.5\text{A aver.}$$

1) Transistor Loss:

$$P_{sat} = 5.5 \times 0.7 = 3.75 \text{ W}$$

$$P_{sw} = 4/9 \times 78 \times 5.8 \times 0.5 \times 10^{-6} \times 5 \times 10^3 = 0.5\text{W}$$

$$P_{Tot} = 3.75 + 0.5 = 4.25 \text{ W}$$

2) Base Drive Loss

$$P_{BO} = 2\text{V} \times 0.7\text{A} = 1.4\text{W}$$

3) Line Capac. Loss = 0.25W (from G. E. Bulletin 121 EC)

4) Transformer Loss = 200 W x .02 = 4 watts (98% effic.)

5) Total Inverter Loss

Transistors	4.25
Base Drive	1.40
Line Capacitor	0.25
Transformer	4.00
Total	9.90W

80 V Line

1) Transistor Loss

$$P_{sat} = \frac{5.5 \times 0.7}{2} = 1.87W$$

$$P_{sw} = 0.5 \times 2 = 1.00W$$

$$P_{Tot} = 1.87 + 1.00 = 2.87W$$

2) Base Drive Loss

$$P_{BO} = 2 \times 0.7 \times 1/2 = 0.7W$$

3) Line Capac. Loss $\approx$ 0.80 W (G. E. Bulletin 121 EC)

4) Transformer Loss

Since this is current regulator, same current as at 40V. For same RMS voltage, average voltage will be lower, but assume same ∴ same core loss

P_T = 4.00W (same as 40V)

5) Total Inverter Loss

Transistors	2.87
Base Drive	0.70
Line Capacity	0.80
Transformer	4.00
Total	6.37 W

e. 5 KHz Inverter Module

1 Operate, 1 Standby Inverter

Supplies: Magnet, Vaporizer, Neutralizer Heater, Neutralizer Keeper, $\pm$ 12V, $\pm$ 5V.

$$Po = 20 + 20 + 41 + 21 + 1.5 + 1.5 = 105 \text{ W}$$

This Inverter is supplied from Line Regulator at 35V out (constant)

$$I_c = \frac{105}{.93 \times 34} = 3.32 \text{ A peak} = \text{average}$$

1) Transistor Loss

$Psat = 3.32 \times 0.7 = 232$ W

$$Psw = \frac{4}{9} \times 68 \times 3.32 \times 0.5 \times 10^{-6} \times 5 \times 10^{3} = 0.25 \text{ W}$$

$Pt = 2.32 + 0.25 = 2.57$ W

2) Base Drive Loss

$Pbd = 2 \times 0.5 = 1.0$ W

3) Line Capac. Loss = negligible (low ripple)

4) Transformer Loss

@ 98% Effic., $Pt = 105 \times .02 = 2.1$ W

5) Total Inverter Loss

Transistors		2.57
Base Drive		1.00
Transformer		2.10
	TOTAL	5.67 W

f. 5 KHz Line Regulator

This Regulator supplies power at 35V to 5 KHz Inverter and to all PWM Inverters (10)

$$Po = 105 + 10 \times 3.0 = 105 + 30 = 135 \text{ W}$$

At 40V Line

$$Ic = \frac{135}{35} = 3.86 \text{ A peak}$$

$$= 3.86 \times .95 = 3.66 \text{ A}$$

1) Power Transistor Loss

$P_{sat} = 3.66 \times 0.7 = 2.56$ W

P_{sw} @ 104 Hz $= \frac{4}{9} \times 78 \times 3.86 \times 0.5 \times 10^{-6} \times 10 \times 10^{3} = 0.63$

$P_t = 2.56 + 0.63 = 3.19 \quad 3.2$ W

2) Choke Loss (Design Loss) = .02 x 135 = 2.7 W

3) Output Capac. Loss (est.) = 0.5 W

4) Line Capac. Loss (est.) = 0.5 W

5) Power Transistor Drive Loss (est.) = 1.0 W

6) $P_t = 3.2 + 2.7 + 0.5 + 0.5 + 1.0 = 7.9$ W

At 80V Line

1) Power Transistor Loss (On 1/2 Time)

$P_{sat} = \frac{2.56}{2} = 1.28$

$P_{sw} = 0.63 \times 2 = 1.26$ W (same current)

$P_t = 1.28 + 1.26 = 2.54$ W (2 x voltage)

2) Choke Loss (same current) = 2.7 W

3) Output Capac. Loss, est. = 1.0 W

4) Line Capac. Loss, est. = 1.0 W

5) Drive Loss, est. = 1.0 W

6) Pt = 8.30 W (measured loss = 8.2 W)

g. Accelerator Line Regulator (35 V out)

40 V Line

A. Transient

$Po = 211$ Watts

$Ic = \frac{211}{35} = 6.02$ A peak $= 6.02 \times .95 = 5.75$ A

1) Transistor Loss

$Psat = 5.75 \times 0.7 = 4.03$ W

$Psw = \frac{4}{9} \times 78 \times 6.02 \times 0.5 \times 10^{-6} \times 10 \times 10^{3} = 1.04$ W

$Pt = 4.03 + 1.04 = 5.07$ W

2) Choke Loss (Design Loss) $= .02 \times 200 = 4.0$ W

3) Output Capac. Loss (est.) $= 0.7$ W

4) Line Capac. Loss (est.) $= 0.7$ W

5) Drive Loss (est.) $= 1.5$ W

6) Total Loss $= 5.07 + 4.0 + 0.7 + 0.7 + 1.5 = 11.97$ W

B. Steady State

$Po = 21.1$ W

1) Transistor Loss $= 3.07 \times 0.1 = 0.51$ W

2) Choke Loss $= 4.0 \times .01 = 0.04$

3) Output Capac. Loss (est.) $= 0.0$

4) Line Capac. Loss (est.) $= 0.0$

5) Drive Loss (est.) $= 1.5$

6) Total Loss $= 2.05$ W

80V Line

	A. Transient	B. Steady State
1) Transistor Loss		
$P_{sat} = \frac{4.03}{2}$	= 2.02 W	
P_{sw} = 1.04 x 2	= 2.08 W	
P_t	= 4.10 W	= 0.41
2) Choke Loss (design)	= 4.0 W	= 0.04
3) Output Capac. Loss (est.)	= 1.5 W	= 0.00
4) Line Capac. Loss (est.)	= 1.5 W	= 0.00
5) Drive Loss (est.)	= 1.5 W	= 1.50
6) Total Loss	=12.5 W	= 1.95 W

h. Arc Rectifier Filter

40V,80V Line same, since current remains same except divides between Main Rectifiers and Commutating Rectifier

1) Rectifier Loss = 0.8 x 7.0 = 5.6 W
   (3)

2) Choke Loss (design) = 252 x .01 = 2.5 W

3) Output Capac. Loss (est.) = 2.0 W

4) Total Loss =10.1 W

i. H.V. Filter

Same at 40V and 80V Line

1) Screen Bleeder = 2000V x .001 A = 2 W

2) Accel. Bleeder = 2000V x .001 A = 2 W

3) Screen Current Sense Resistor = 1 W x 1 A = 1 W

4) Accel. Current Sense Resistor = 5V x 0.1A = 0.5 W

5) Screen Choke (design) = 2.0 W

6) Accel. Choke (design) = 0.5 W

7) TOTAL = 8.0

j. Magnetic Modulator

At 40-volt line & 80V line (regulated by 5 KHz Line Regulator)

1) Vaporizer

$P_{out} = 20$ Watts

$P_{transformer} = .02 \times 20 = 0.40$

$P_{mag\text{-}amp} = .02 \times 20 = 0.40$

$P_{diodes} = 20 \times \frac{1.0}{80} = 0.25$

2) Neutralizer Heater

$P_{out} = 41$ Watts

$P_{NH} = \frac{41}{20} \times 1.05 \approx 2.1$ Watts

) Neutralizer Keeper

$VA_{out} \approx 18.0$

a) $P_{transformer} = 18/0.98 = 18.4 = 0.4$ Watt

b) $P_{choke} \approx 18/.99 - 18 \approx 0.2$ watt

c) $P_{rectifiers}$ 0.5 ampere x 1.6 volts = 0.8 Watt

d) $P_T \approx 0.4 + 0.2 + 0.8 = 1.4$ Watt

4) Magnet

$P_{out} = 20$ Watts, $I_{out} = 0.85$ amperes

a) $P_{rectifier} = 0.85 \times 1.0 = 0.85$ Watts

b) $P_{transformer} = 20/0.98 - 20 = 0.40$ Watt

c) $P_{mag\text{-}amp} \approx 0.40$ Watt

d) $P_{total} \approx 1.65$ Watts

5) P_{total} at 40-volt line, magnetic regulators

$P_T = 1,05 + 2.1 + 1.4 + 1.65 = 4.80$ Watts

k. Summary of Losses

Module	Losses 40V Line	Losses 80V Line
1. Screen inverter - Worst Case - 7INV. x	(19.3W)	(14.23W)
Normal Case- 8INV. x	16.6W	12.39W
2. Arc Inverter -	13.3W	10.60W
3. Accel. Inverter - Transient	11.0W	11.0W
Normal	3.75W	3.75W
4. Cathode Inverter	9.90W	6.37W
5. 6KH$_3$ Inverter	5.67W	5.67W
6. 5KH$_3$ Line Regulator	7.9W	8.3W
7. Accel. Line Regulator - Transient	(11.97W)	(12.5W)
Normal	2.05W	1.95W
8. Arc Rectifier - Filter	10.1W	10.1W
9. High-Voltage Filter	8.0W	8.0W
10. Magnetic Modulator	4.8W	4.8W
11. Control Module	5.0W	5.0W

8. RELIABILITY

8.a Reliability Analysis

$R_M^{(t)}$, Mission Reliability calculated to 0.9702 where $R_M^{(t)} = \pi R_i$ and mission time is 10,000 hours. The reliability block diagram (Fig. 8-1) displays the complete system with all involved subsystems or units. The reliability for each of the units was determined by the relationship $R = e^{-\lambda t}$, except for those units where redundancy practices were followed (for which math models are noted). The set of failure rates utilized for the analysis effort were developed by utilization of Hughes Document R22-100DC. After determination, the subsystem failure rates were then modified by use of an E-factor, the Hughes Experience factor. The set of utilized failure rates and a rationale justifying use of these failure rates together with the E-factor follow. The resultant failure rate (λ) of each unit, modified by the E-factor (0.475) is noted on the applicable Parts List (see Section 8.a.4.).

See Table 8.1 for listing of unit failure rates and reliability values.

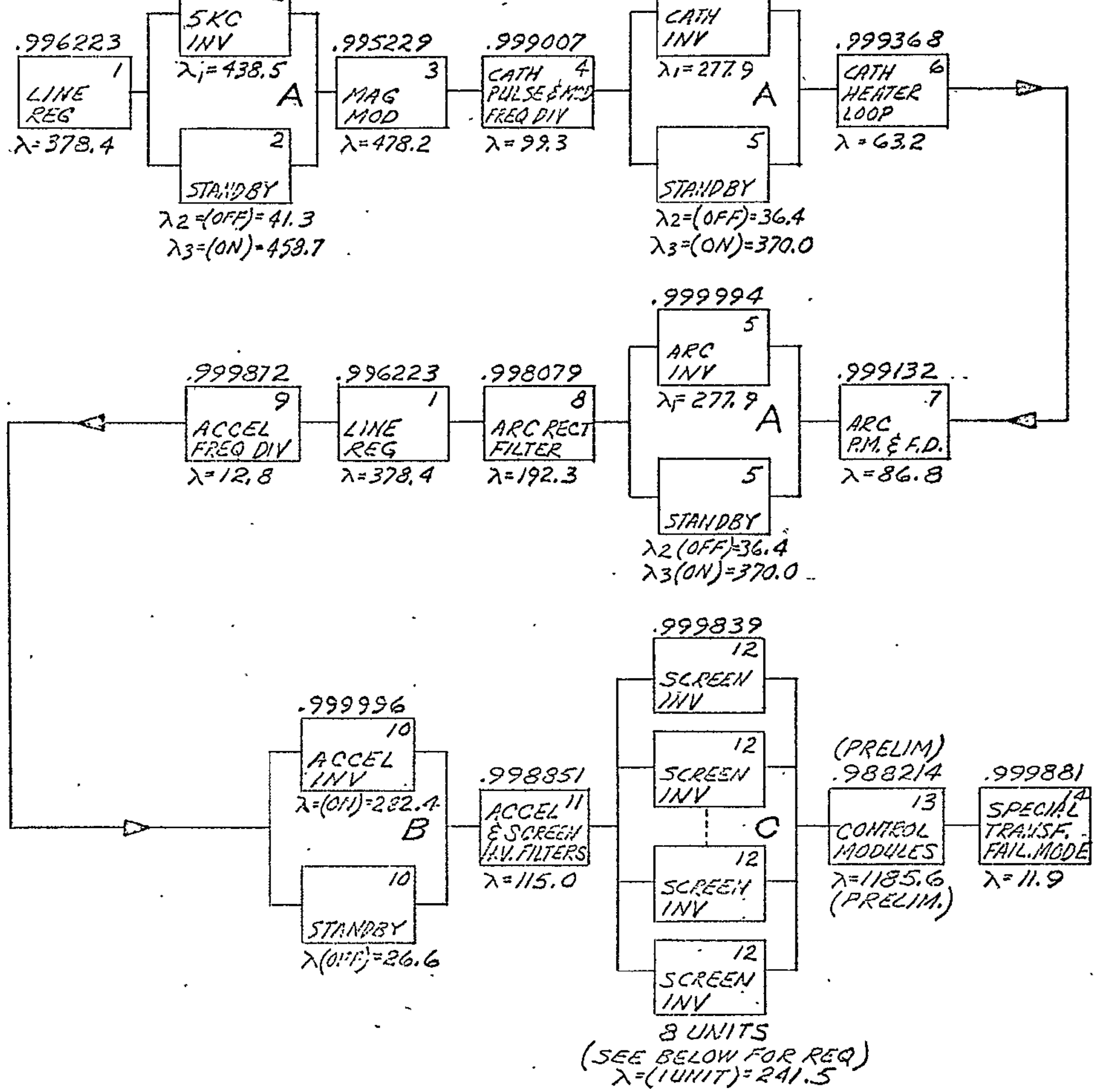
8.a.1) The Screen Inverters

For the purpose of this analysis the mission time of $(10)^4$ hours was broken into three intervals:

Interval	Time, Hours
1	0 to 2,500
2	2,500 to 5,000
3	5,000 to 10,000

At the start of flight, seven (of the eight active) Inverters are required. At the end of each interval, the requirement drops as follows:

FIG. 8-1



WHERE $R(t)=e^{-\lambda t}$; $t=(10)^4$ HRS; λ RATES ARE IN $(10)^{-9}$ HRS (EXCEPT FOR BLOCK 12)

SYSTEM (PRELIM) $R = .970218$

A) $R(t)=e^{-\lambda_1 t}+\frac{\lambda_1}{\lambda_1+\lambda_2-\lambda_3}\left[e^{-\lambda_3 t}-e^{-(\lambda_1+\lambda_2)t}\right]$

B) $R(t)=R_{ON}\left[1+\frac{\lambda_{ON}}{\lambda_{OFF}}\left(1-R_{OFF}\right)\right]$

C) $R(t)=f\left[\sum_{i=c}^{n}\binom{n}{i}R_{12}^{i}\left(1-R_{12}\right)^{n-i}\right]$

WHERE n = OPERATING UNITS
C = UNITS REQD AT END OF INTERVAL
t = INTERVAL TIME (NOTED BELOW)

INTERVAL	t	INTERVALS REQD
1	2,500	7
2	2,500	6
3	5,000	5

Interval	Inverters Required at End of Interval
1	7
2	6
3	5

The reliability probability of meeting these requirements for each interval was determined from the formula:

$$R_{Redund} = \sum_{i=c}^{n} \binom{n}{i} R_{12}^{i} (1 - R_{12})^{n-i}$$

where n = operating inverters

c = inverters required at end of each interval

R_{12} = $e^{-\lambda_{12} t}$, λ = failure rate

t = interval time.

The redundant screen inverter reliability calculated to 0.9998.

8.a.2) Transformer Short-to-Ground Failure Mode

Since the entire power conditioner will be inoperative if one of the output transformers of the Accelerator and The Screen Inverters fail in failure mode "short to ground"' and since each transformer is exposed to seven failure modes, a conservative failure rate of 5×10^{-9} (one/fifth of the transformer failure rate of 20×10^{-9}) has been placed in series with the other elements for each of those transformers (see block 14 on Figure 8.1).

Where those transformers are part of the redundant or standby circuitry, the failure rate has been accordingly modified from 20×10^{-9} Hrs. to 15×10^{-9} Hrs., to account for the balance of failure modes inside the redundant portion of the circuit.

8.a.3) <u>Assumptions and Considerations</u>

1. All parts exhibit constant failure rate.

2. Parts within a block on the logic diagram fail independently. Failure of any part in a block (except for several redundant Operational Amplifiers in the Control Module) causes block failure.

3. All blocks on the logic diagram fail independently.

4. Mission time is 10,000 hours.

5. Power Conditioner temperatures are $25^{\circ}C$ (base plate) and $35^{\circ}C$ (junction) except for the Control Module where the temperatures are $20^{\circ}C$ and $25^{\circ}C$ respectively.

6. Discrete semiconductors operating in digital circuits are derated to 10-15% of their rated power stress. All other parts (in general) are derated to 30-40% of their rated stress.

7. Part failure rates reflect Hughes spacecraft experience through 31 August 1968.

8. The reliability analysis predictions do not consider wearout failure.

9. The reliability mathematical models for standby redundancy consider that the dormant failure rates are greater than zero.

TABLE 8.1

FAILURE RATES FOR POWER CONDITIONER

PART-TYPE	FAILURE RATE x 10^{-9} HRS. Active	Dormant
Diode, Switching	2.4	1.0
General Purpose	6.0	1.0
Zener	24.0	2.0
Transistor, Switching	7.5	1.0
General Purpose	12.0	1.0
Power	120.0	10.0
Integrated Circuits, DTL (932, 946, 948, etc.)	14.0	5.0
MA741	84.0	30.0
Resistor, Carbon Comp. (RC)	1.0	0.1
Metal Film	2.2	0.02
Power (RW)	6.5	0.01
Precision	3.9	.01
Capacitor, Ceramic, etc.	6.0	.02
Tantalum	26.0	1.0
Magnetics, Transformer, Choke	20.0	0.5
Mag. Amplifier	30.0	1.0
Relay	100.0	10.0
Connector	25.0	2.5
Fuse	10.0	1.0

8-a-4: PART COUNTS

Ref. Dwg. #X3188119
(Issue with approval
date of 9-30-68)

LINE REGULATOR - Block #1

Part Type	Qty.	$\lambda (10)^{-9}$	Total λ
Resistor, Carbon Comp.	10	1.0	10.0
" Metal Film	2	2.2	4.4
" Power W. W.	1	6.5	6.5
Capacitor, Glass, Mylar, etc.	5	6.0	30.0
" Tantalum	2	26.0	52.0
Diode, Switching	7	2.4	16.8
" Zener	2	24.0	48.0
Transistor, Power	4	120.0	480.00
Operational Amplifier			84.0
Conductor			20.0
Fuse			20.0
Connector			25.0

$\Sigma \lambda = 796.7 \ (10)^{-9}$

$$\boxed{\text{Block \#1 } \lambda = (.475)\,(\Sigma \lambda) = 378.4 \ (10)^{-9}}$$

Ref. Dwg. No. X3188111
(Issue with approval
date of 9-30-68)

5K HZ POWER INVERTER - Block #2

Part Type	Quantity		$(10)^{-9}$		Total λ $(10)^{-9}$		
	Active	Standby	Active	Dormant	λ_1*	λ_2*	λ_3*
Resistor, Carbon Comp.	6	5	1.0	0.10	6.0	0.50	5.0
" Power, W. W.	1	1	6.5	0.01	6.5	0.01	6.5
Capacitor, Glass, Mylar, etc.	1	1	6.0	0.02	6.0	0.02	6.0
" Tantalum	6	6	26.0	1.00	156.0	6.00	156.00
Diode, General Purpose	9	8	2.4	1.0	21.6	9.00	19.2
Transistor, Power	5	4	120.00	10.0	600.0	40.00	480.00
Transformer	2	1	20.0	0.5	40.0	0.50	20.0
Relay	-	2	100.0	10.0	-	20.00	200.0
Integrated Circuit	3	2	14.0	5.0	42.0	10.00	28.0
Fuse	2	2	10.0	1.0	20.0	2.00	20.0
Connector	1	-	25.0	-	25.0	-	25.0
					923.1 ($\Sigma\lambda_1$)	87.03 ($\Sigma\lambda_2$)	965.7 ($\Sigma\lambda_3$)

Block 2 λ_1 = (.475)(923.1) = 438.5$(10)^{-9}$
Block 2 λ_2 = (.475)(87.03) = 41.3$(1)^{-9}$
Block 2 λ_3 = (.475)(965.7) = 458.7$(10)^{-9}$

* λ_1 = Active Unit

λ_2 = Standby Unit Off

λ_3 = Standby Unit On

Ref. Dwg. No. X3188123
(Issue with approval
date of 9-30-68)

MAGNETIC MODULATOR - Block #3

Part Type	Quantity	λ $(10)^{-9}$	Total $\lambda (10)^{-9}$
Operational Amplifier	1	84.0	84.0
Magnetic Amplifier	3	30.0	90.0
Diode, Switching	33	2.4	79.2
" Zener	10	24.0	240.0
Transistor, Switching	3	7.5	22.5
Capacitor, Glass, Mylar, etc.	3	6.0	18.0
" Tantalum	6	26.0	156.0
Resistor, Carbon Comp	11	1.0	11.0
" Metal Film	25	2.2	55.0
" Power W. W.	4	6.5	26.0
Transforme:	8	20.0	160.0
Inductor	2	20.0	40.0
Connector	1	25.0	25.0

$\Sigma \lambda = 1006.7 (10)^{-9}$

$$\boxed{\text{Block 3 } \lambda = (.475)(1,006.7) = 478.2 (10)^{-9}}$$

Ref. Dwg. #X3188113
(Issue with approval
date of 9/30/68)

CATHODE PULSE MOD. & FREQ. DIV. - Block #4

Part Type	Quantity	$\lambda(10)^{-9}$	Total λ $(10)^{-9}$
Integrated Circuit	1	14.0	14.0
Operational Amplifier	1	84.0	84.0
Diode, Gen'l Purpose	2	6.0	12.0
Resistor, Carbon Comp.	4	1.0	4.0
" Metal Film	5	2.2	11.0
Capacitor, Glass, Mylar, etc.	1	6.0	6.0
" Tantalum	3	26.0	78.0

$\Sigma\lambda = 209.0\ (10)^{-9}$

$\boxed{\text{Block \#4 } \lambda = (.475)(209.0) = 99.3(10)^{-9}}$

Ref. Dwg. Numbers
(Arc) X3188109 and
(Cathode) X3188113

(Issue with approval
date of 9/30/68)

CATHODE INVERTER AND ARC INVERTER - Block #5

Part Type	Quantity		$\lambda\ (10)^{-9}$		Total $\lambda\ (10)^{-9}$ *		
	Active	Standby	Active	Dormant	λ_1	λ_2	λ_3
Integrated Circuit	2	2	14.0	5.00	28.0	10.0	28.0
Transistor, Switching	2	2	7.5	1.00	15.0	2.00	15.0
Transistor, Power	2	2	120.0	10.00	240.0	20.00	240.0
Diode, General Purpose	18	18	6.0	1.00	108.0	18.00	108.0
Capacitor, Glass, Mylar, etc.	2	1	6.0	0.02	12.0	0.02	6.0
" Tantalum	3	3	26.0	1.00	78.0	3.00	78.0
Resistor, Carbon Comp.	6	6	1.0	0.10	6.0	0.60	6.0
" Power W. W.	2	2	6.5	0.01	13.0	0.02	13.0
Transformer	2	2	20.0	0.50	40.0	1.00	40.0
Relay	-	2	100.0	10.00	-	20.00	200.0
Fuse	2	2	10.0	1.00	20.0	2.00	20.0
Connector	1	-	25.0	-	25.0	-	25.0
					585.0	76.64	779.0
					$(\Sigma\ \lambda_1)$	$(\Sigma\ \lambda_2)$	$(\Sigma\ \lambda_3)$

Block #5 λ_1 = (.475)(585.0) = 277.9$(10)^{-9}$
Block #5 λ_2 = (.475)(76.64) = 36.4 $(10)^{-9}$
Block #4 λ_3 = (.475)(779.0) = 370.0$(10)^{-9}$

* λ_1 = Active Unit
λ_2 = Standby Unit Off
λ_3 = Standby Unit On

Ref. Dwg. #X3188113
(Issue with approval
date of 9/30/68)

CATHODE HEATER LOOP - Block #6

Part Type	Quantity	$\lambda(10)^{-9}$	Total $\lambda(10)^{-9}$
Resistor, Carbon Comp.	3	1.0	3.0
" Power W. W.	1	6.5	6.5
Diode, Gen'l Purpose	4	6.0	24.0
Transistor, Switching	1	7.5	7.5
Capacitor, Tantalum	2	26.0	52.0
Transformer	2	20.0	40.0

$\Sigma\lambda = 133.0(10)^{-9}$

$$\boxed{\text{Block \#6 } \lambda = (.475)\ (133.0) = 63.2(10)^{-9}}$$

Ref. Dwg. # X3188109
(Issue with approval date of 9-30-68)

ARC PULSE MOD. & FREQ. DIV. - Block #7

Part Type	Quantity	$\lambda (10)^{-9}$	Total λ $(10)^{-9}$
Integrated Circuit	1	14.0	14.0
Operational Amplifier	1	84.0	84.0
Diode, Gen'l Purpose	2	6.0	12.0
Resistor, Carbon Comp.	6	1.0	6.0
" Metal Film	4	2.2	8.8
Capacitor, Glass, Mylar, etc.	1	6.0	6.0
" Tantalum	2	26.0	52.0

$\Sigma\lambda = 182.8\ (10)^{-9}$

$\boxed{\text{Block \#7 } \lambda = (.475)(182.8) = 86.8(10)^{-9}}$

Ref. dwg. nos. are
X3188117 & X3188109
(Both issued with approval dates of 9/30/68)

ARC RECT. FILTER - Block #8

Part Type	Quantity	$\lambda(10)^{-9}$	Total $\lambda(10)^{-9}$
Diode, Switching	7	2.4	16.8
" Power	3	60.0	180.0
" Zener	2	24.0	48.0
Resistor, Carbon Comp.	6	1.0	6.0
" Metal Film	5	2.2	11.0
" Power W. W.	1	6.5	6.5
Transistor, Switching	1	7.5	7.5
Transformer	2	20.0	40.0
Inductor	2	20.0	40.0
Capacitor, Ceramic, Glass, etc.	4	6.0	24.0
Connector	1	25.0	25.0

$\Sigma\lambda = 404.8(10)^{-9}$

$$\boxed{\text{Block \#8 } \lambda = (.475)(404.8) = 192.3(10)^{-9}}$$

Ref. Dwg. # X3188107
(Issue with approval
date of 9/30/68)

ACCEL. FREQ. DN. - Block #9

Part Type	Quantity	$\lambda(10)^{-9}$	Total λ $(10)^{-9}$
Integrated Circuit	1	14.0	14.0
Diode, Gen'l Purpose	2	6.0	12.0
Resistor, Carbon Comp.	1	1.0	1.0

$\Sigma\lambda = 27.0(10)^{-9}$

$$\boxed{\text{Block \#9 } \lambda = (.475)(27.0) - 12.8(10)^{-9}}$$

Ref. Dwg. No. X3188107
(Issue with approval
date of 9/30/68)

ACCEL. INVERTER - Block #10

Part Type	Quantity Active	Quantity Dormant	$\lambda(10)^{-9}$ Active	$\lambda(10)^{-9}$ Dormant	Total $\lambda(10)^{-9}$ Active	Total $\lambda(10)^{-9}$ Dormant
Integrated Circuit	2	2	14.0	5.00	28.0	10.00
Transistor, Switching	2	2	7.5	1.00	15.0	2.00
" Power	2	2	120.0	10.00	240.0	20.00
Diode, Gen'l Purpose	8	7	6.0	1.00	48.0	7.00
Capacitor, Glass, Mylar, etc.	5	5	6.0	0.02	30.0	0.10
" Tantalum	4	3	26.0	1.00	104.0	3.00
Resistor, Carbon Comp.	4	4	1.0	0.10	4.0	0.40
" Power W. W.	1	1	6.5	0.01	6.5	0.01
Transformer	2	2	15.0*	0.50	30.0	1.00
Diode Assembly (10 CR's)	1	1	24.0	10.00	24.0	10.00
Inductor	1	1	20.0	0.50	20.0	0.50
Fuse	2	2	10.0	1.00	20.0	2.00
Connector	1	-	25.0	-	25.0	-
					594.5 ($\Sigma\lambda$ Active)	56.01 ($\Sigma\lambda$ Dorm.)

Block 10 λ_{Active}	$= (.475)(594.5) = 282.4(10)^{-9}$
Block 10 $\lambda_{Dorm.}$	$= (.475)(56.01) = 26.6(10)^{-9}$

* Normally 20.0, but one of the failure modes is allocated to Block 15.

Ref. Dwg. No. X318815
(Issue with approval
date of 9/30/68)

HIGH VOLTAGE FILTER - Block #11

Part Type	Quantity	$\lambda(10)^{-9}$	Total λ $(10)^{-9}$
Resistor, Carbon Comp.	2	1.0	2.0
" Power W. W.	2	6.5	13.0
Resistor Assy (10 Carbon Comp. Pcs.)	4	10.0	40.0
Capacitor, Ceramic, Mylar, etc.	4	6.0	24.0
" Tantalum	1	26.0	26.0
Diode, Zener	3	24.0	72.0
Inductor	2	20.0	40.0
Connector	1	25.0	25.0
		$\Sigma\lambda$ =	242.0

Block #11 λ = (.475)(242.0) = $115.0(10)^{-9}$

Ref. Dwg. No. X3188105
(Issue with approval
date of 9/30/68)

SCREEN INVERTER - Block #12

Part Type	Quantity	$\lambda(10)^{-9}$	Total $\lambda(10)^{-9}$
Integrated Circuit	2	14.0	28.0
Transistor, Switching	2	7.5	15.0
" Power	2	120.0	240.0
Diode, Switching	19	2.4	45.6
Diode Assembly (2-CR Pkg)	1	4.8	4.8
Capacitor, Glass, Mylar, etc.	4	6.0	24.0
" Tantalum	2	26.0	52.0
Transformer	3	15.0*	45.0
Resistor, Carbon Comp.	6	1.0	6.0
" Power W. W.	2	6.5	13.0
Fuse	1	10.0	10.0
Connector	1	25.0	25.0

$\Sigma\lambda = 5084.4(10)^{-9}$

$$\text{Block \#12 } \lambda = (.475)(508.4) = 241.5(10)^{-9}$$

* Normally 20.0, but one of the failure modes is allocated to Block 15.

Ref. Drawing
(See below)

PRELIMINARY CONTROL MODULES - Block #13

Utilized data from earlier design review

(See 2228/DR 1701, Rev. A, pages 60 seq, which lists):

$$\text{The total } \lambda = 2495.9\ (10)^{-9}$$

$$\text{Thus, Block \#13 } \lambda = (2495.9)(.475)(10)^{-9} = 1185.6(10)^{-9}$$

SPECIAL TRANSFORMER SHORT-TO-GROUND FAILURE MODE - Block #14

If any of the Accel. or Screen Inv. output transformers (a total of five) fail, the entire system fails. We assign a failure rate to this failure mode of a highly conservative nature, $5(10)^{-9}$, based on two factors.

1) The operating voltage of the involved transformers is 2 Kv. Several of the transformers have been tested in a destructive hi-pot test and insulation breakdown occurred at 15 to 17 Kv; the large safety factor in the amount is indicative of H.V. insulation supplied.

2) The total failure rate for transformers is $20(10)^{-9}$, which rate covers all the failure modes. These involve "short" or "open" in each of the three windings, "insulation breakdown", "arcing", and so on.

Thus λ is a product of (5 transformers)$(5)(10)^{-9} = 25(10)^{-9}$

Block #14 λ = $(.475((25.0) = 11.9(10)^{-9}$

8.b Rationale for Use of the Selected Failure Rates

The component part failure rates utilized for the program are based on failure rates taken from the high reliability Minuteman ballistic missile program, somewhat modified by Hughes, using engineering judgement. These failure rates (detailed in Hughes Document R22-100DC) were originally set up for the Hughes Space Satellite Systems. They are utilized for this program as basic rates, modified as necessary to allow for the estimated environmental stresses (temperature, electrical, etc.) that the system is expected to encounter in flight. These basic failure rates are then adjusted as a set by the Hughes Experience Factor (E-factor) described below.

8.b.1) E-Factor Usage

It is Hughes practice to modify the basic set of failure rates by a prediction factor,

$$E = \frac{k}{\lambda_i t_i} = \frac{\text{observed failures}}{\text{expected failures}},$$

based on flight experience of Hughes Satellite Systems (Syncom II, Syncom III, Early Bird, Intelsat II-F1, F2, F3 and F4, ATS-1, 2, and 3). Multiplication of the basic set of failure rates by the E-factor in effect will correct any optimistic or pessimistic bias in the basic rates. This utilization of the E-factor, when significant differences between the flight experience rates and the basic rates are observed, will cause the basic failure rates to converge to true values. The technique is asympototically unbiased regardless of the validity of the originally assumed basic failure rates. The data from the HAC Space Satellites are considered applicable to the subject program as the mission environments are similar and long time service and essentially free-fall operation are also involved here. The Hughes Satellites

8.b.1) (Cont'd)

to date have accumulated over 650 million operational component hours and over 400 million component hours in the dormant stage. The current value (as of 31 August 1968) of the E-factor is 0.475.

8.b.2) Internal Temperatures

Based on design considerations and calculations, which were confirmed by experimental tests in a vacuum chamber, the component mounting base plate temperature will be at $+25^{o}C \pm 5^{o}C$ and the junction temperature of semiconductors at $+35^{o}C + 5^{o}C$ except for the Control Module where the temperatures will be $+20^{o}C + 25^{o}C$ respectively. The utilized failure rates were subjected to (and modified by) derating curves in the aforementioned Hughes Document R22-100DC. In order to assure stability of these temperatures, the system is designed so that the solar panels will always face the sun, while the power unit is always facing away from the sun.

8.b.3) External Environment

The space environment to be encountered by the system in flight is considered to be gentler than that experienced by the presently operating Hughes Space Synchronous Satellites. The only large consideration is exposure to radiation from the Van Allen belt. The effect is judged to be very minor for the subject system, whereas the Hughes Synchronous Satellites see the radiation for several days while in transfer orbits. Even though this system could encounter solar flares in flight these are not considered as potentially harmful as the Van Allen belt radiation.

8.b.4) Part Selection

The component parts used in the subject system are high-reliability parts selected from a JPL Preferred Parts List. The specifications for these parts have extensive and stringent reliability-proof test requirements, which appear satisfactory to assure procurement of high reliability parts for the program.

The reliability proof tests include among others; a) qualification tests, such as - soaking at temperature extremes, humidity, shock, hermetic seal plus a high temperature test to demonstrate with 60 percent assurance that a tested lot's failure rate is less than 1 percent per 1,000 hours, and b) quality assurance tests, such as - life stability, environmental plus final visual and electrical tests.

8.b.5) <u>Conclusions</u>

The computed reliability of 0.9702 for 10,000 hours is somewhat higher than the design objective of 0.96, and somewhat lower than the proposal estimate of 0.9826.

The drop from the proposal estimate is substantially due to increased complexity resulting from mugh tighter regulation requirements introduced by JPL during the negotiation phase, for Screen and Accelerator supplies (no line regulation originally required, and 5 to 10 percent load regulation required, respectively now $\pm$ 1.0 percent for line and load). A small drop in reliability is due to somewhat higher temperature stresses than originally assumed in analysis for purposes of simplified analysis.

The present calculation should not be considered as representing the best effort at optimizing reliability, since it represents an interim cut at the total system. Now that a detailed analysis has been made, it will be apparent which areas deserve the most attention in reducing failure rate, and a trade-off study may be made on cost in efficiency and/or weight. Possibly in some areas it may be desirable to substitute lower failure rate components; i.e., a digital gate plus discrete transistor for an integrated circuit op-amp. Also, closer examination of stresses should result in lower failure rates, since in many cases, components are at substantially lower stress than than those assumed in this conservative calculation.

9. Physical Design

a. [illegible]

[illegible] Drawing X3188100-500, Installation Control, for outline and mounting dimensions of the assembly. As indicated maximum dimensions are 36" x 30" x 3.78".

System is designed for mounting from four (4) edges of the assembly, with one support point in center of rear face. Cover is removable from the back without dismounting the assembly, making accessible components and circuit connections, which are located on the rear face of individual module plates.

The system consists of an assembly of twenty (20) modules, mounted on an "egg-crate" structure. Individual modules are removable from the front after disconnecting from harness connectors on rear face.

Front face of assembly is electrically "dead" with protruding power transistor studs and must covered by epoxy conformal coating. All other components and connections are behind module plates. Thus the assembly, with its cover, is totally enclosed to provide EMI shielding and freedom from high voltage hazard during testing.

The clear front face, facing space in a vehicle, provides shielding from incident radiation. Since in a typical vehicle installation, the rear of the assembly would be shielded from radiation by the vehicle structure, and other power conditioning assemblies, the back cover may be perforated to reduce weight, and permit free outgassing, thereby preventing pressure build-up and transition to regions of voltage breakdown (paschen's curve). (Although all materils are selected for low outgassing.)

All external connections are made at connectors located at one end of assembly, with all low voltage connections, in one corner, made with space approved sub-miniature, rectangular connectors. All high voltage connections are made at the other corner to high voltage standoffs, with screw terminals. These connections are made behind a removable, small connection cover.

The various modules used in the system are sized in frontal area, for a worst-case thermal radiation of 0.3 watt per square inch, all from the front face, assuming no radiation from rear face, a conservative assumption, since in a typical vehicle, the vehicle structure to the rear is expected to be at a lower temperature than the Power Conditioner, with some radiation from the rear. At this level of radiation with no solar incidence, a worst-case plate temperature of 35° C may be expected, providing high reliability operation of components, which, with few exceptions, are mounted on the module plates.

With the design philosophy of low watts/square inch, each module is thermally self-sufficient and will not require conduction to structure and sharing of radiation area between modules. Thus hot spots are minimized.

Since high reliability is obtained by extensive use of redundant, or standby, circuits, the thermal design philosophy has resulted in packaging of redundant circuits on same module plate with operating circuits, intermixing the components on the plate to obtain uniform thermal density regardless of which circuit is operating.

b. SUPPORT STRUCTURE

Refer to HAC Drawing X3188101, "Frame, Module."

This supporting frame forms an "eggcrate" structure with a structural web, or "I" beam, running between all modules, and a channel section forming the edges. Holes, located in I beam webs reduce weight, without significantly reducing the section modulus. In order to provide a flat surface for module mounting, the structure is formed by assembling front and back plates, with module cut-outs, with webs interlaced in "eggcrate" fashion, the whole being dip-brazed. Material is 0.040" aluminum, 6061T4, chosen rather than lighter magnesium, to permit dip-brazing of thin sections. A riveted magnesium structure of the same strength would be heavier.

A stress analysis has been made of the structure (See Appendix), using conservative simplifying assumptions of no contribution to strength from attached module plates, and no reduction of stress due to interlacing of beams. This analysis shows that structure is more than adequate to survive vibration at launch phase.

Module mounting screws fit into steel "Pem" nuts, riveted to frame, providing a lightweight fastening which will permit frequent replacing of screws without damage to threads. The many screws provided will result in significant damping of the structure in vibration, as well as permitting ready replacement of modules during test or service.

Riveted "Pem" nuts are also used along edges of structure for mounting.

c. MODULE ASSEMBLIES

1. Screen Inverter (See HAC Drawing X3188104)

As indicated under "General" discussion, module is sized for a thermal radiation of 1/3 watt per square inch. Since this circuit will dissipate 21.8 watts for 300 watts out in worst case of one module failed out of eight, or 19.0 watts for normal operation, an area of 70.5 in^2 will result in 0.27 watts/in^2, or 25° C, normally, or 0.31 watts/in^2 maximum, with an operating plate temperature (maximum) of 35° C.

Principle sources of dissipation have been separated in the assembly to minimize local hot spots; i.e., power transistors, output transformer and output rectifiers.

Large area available permits mounting all components on base plate, which is 0.050" sheet magnesium for low weight, and maximum thermal conductivity per weight.

To obtain good thermal conductivity, yet conservative insulation of components, the area used by small components is covered with a 1 mil sheet of "Kapton" (H-Film), bonded to plate with epoxy adhesive. Thus the component may be placed against plate, and when conformally coated with epoxy will be thermally intimate with plate, solidly anchored against vibration, and sealed against moisture, with a minimum of weight.

To provide good thermal interface, and security from vibration, transformers and output rectifiers are bonded with a thin layer of RTV, in addition to mounting screws. RTV is sealed against out-gassing by epoxy conformal coating. Use of RTV for bond will permit ready replacement of component, if necessary, during tests.

The method shown for mounting power transistors is subject to tests in vacuum to confirm this technique. Previous practice of using beryllium-oxide washer and indium foil is subject to question due to possible cold-flow of indium and resultant opening up of interface. The relatively low wattage dissipated per transistor (approximately 3 watts) permits use of Kapton with its lower thermal conductivity than Be-O (even with 1 mil vs. 0.060 Be-O). Similarly, it is believed that a thin layer of RTV, in interfaces, may be superior long-term to indium foil.

Low-voltage connections are made through a sub-miniature rectangular connector shown at bottom edge. High-voltage connections are made at top to two stand-off screw terminals.

2. High-Voltage Filter (See Drawing No. X3188114)

This assembly consists of the Screen and Accelerator Output Filters and and bleeder resistors with voltage and current sensing networks. Since Screen output is at +2000 V, special attention must be given to voltage isolation.

The bleeder resistors R1, R2, R4, and R5 are potted in epoxy in a plastic case. The cases therefore provide a convenient mounting for the mica capacitors which are shunted across the bleeder. Cases provides a positive thermal path for losses in the capacitors, which are flat with a good interface, and also provides a secure mounting for vibration.

Low voltage components are mounted in the fashion described for the Screen Inverter.

High voltage input and output connections are made at stand-off screw terminals, with low voltage connections through a rectangular, sub-miniature connector.

Magnetic components and bleeder resistor assemblies are bonded to chassis for good thermal interface and resistance to vibration.

Entire assembly will be conformally coated with low-outgassing epoxy.

Loss on this assembly will be approximately 5 watts. Thus, with area of 38.6 in^2, and 0.135 watts/in^2 temperature will be between 0° C for a free body and 25° C of adjacent modules.

3. <u>5 KHz Heater Inverter</u> (See HAC Drawing No. X3188110)

This assembly is typical of design of inverters with "standby" circuits, where the "operating" and "Standby" inverters are packaged on the same plate, making the thermal radiation area available equally to either circuit.

In this case a common output transformer is switched between inverter circuits. In normal operation transistors Q6 and Q7 will be on. In standby transistors Q12 and Q13 will be on. It is thus apparent that a symmetrical thermal distribution is present in either case. With a dissipation of 9 watts expected, and an area of 47.5 in^2, or 0.19 watts/in^2, a plate temperature of 5° C would result for a free body, or close to average system temperature of 20° C when mounted. Mounting of small components, power transistors, and mágnetic components is similar to that described for Screen Inverter.

4. <u>Accelerator Inverter</u> (See HAC Drawing No. X3188106)

This chassis similar to the 5KHz inverter except for two (2) output transformers and two (2) output rectifiers (T3, T4, CR8, CR15). High voltage outputs are brought out to two (2) stand-off, screw terminals. To share radiation area equally between "operate" and "standby" conditions, active components are staggered. Thus, in "operate," Q7, Q6, T3 and CR8 will be on, in "standby," Q13, Q12, T4, and CR15 will be on.

In a transient mode, at system turn-on, dissipation will be 14 watts, whereas steady-state dissipation will be less than 3 watts. At 42.9 in^2, therefore, and 14 watts, or 0.29 watts/in^2, final value temperature would be 35° C, a safe value. However, since transient should not last more than 15 minutes, and thermal time constant will be about one hour, expected rise in 15 minutes is $15/60 \times 0.63 \times (35 - 0) = 5.5^\circ$ C rise above assumed 0° C starting conditions, free body.

At 3 watts or 0.078 watts/in^2, a final temperature of -50° C would be expected for a free body, or close to the average temperature of the system (about 20° C).

5/ <u>Line Regulator</u> (5KHz and Accelerator) See HAC Drawing No. X3188118)

This assembly is identical in layout for the 5KHz and Accelerator applications.

At a loss of 10.5 watts worst case, steady-state, for the 5KHz applications, and an area of 38.6 in^2, or 0.27 watts/in^2, temperature will be 25° C free body,

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Components are mounted with techniques similar to those described above.

6. Arc Inverter and Cathode Inverter (See HAC Drawings X3188108, X3188112)

These inverters are similar in layout, differing in only the few small components associated with output telemetry and feedback. Techniques are similar to those described above for the 5KHz and Accelerator inverters, where radiating area is shared between "operating" and "standby" inverters.

Dissipation will be approximately 12 watts for the Cathode inverter and 15 watts for the Arc inverter. With 47.9 in^2 of radiation, or 0.25 and 0.31 watts/in^2, respectively, free body temperatures would be 20^o C and 35^o C, respectively.

7. Arc Rectifier and Filter (See HAC Drawing X3188116)

This module is a unique case of mounting relatively high dissipation components at high voltage. This applies in particular to the output rectifiers, CR1, CR2, and CR3, which dissipate 7 watts, at a potential of 2KV. To accomplish the firm objective of good thermal conductivity and good insulation, the rectifiers are mounted on a magnesium bracket, which is bonded to an epoxy-glass insulator, in turn bonded to the chassis. By providing a liberal interface area of 3 in^2 between bracket and insulator, a temperature rise across interface of 6^o C will result, quite acceptable for the components with a plate temperature of 25^o C. The latter results from a total dissipation of 10 watts, with an area of 38.6 in^2, or 0.26 watts/in^2.

Choke L2 is a source of about 3 watts, and is a ferrite cup core directly heat-sunk to chassis with high-voltage insulation internally.

Capacitor C1 is a tantalum type which will dissipate about 1 watt due to high-frequency ripple losses. It is mounted in a fashion similar to that used for rectifiers.

Note that a ½ inch creepage path is maintained between high-voltage elements and chassis, a desirable minimum to prevent flash-over.

Except as noted other techniques are similar to those described before.

8. Magnetic Modulator (See HAC Drawing X3188122)

This is an assembly of magnetically-regulated supplies; i.e., Vaporizer, Neutralizer Heater, Neutralizer Keeper and Magnet Supplies. The only supply at high-voltage is the Magnet with its output at a reference of + 2KV. Estimated total dissipation is 4.8 watts, with a radiation area of 39.5 in^2, or 0.12 watts/in^2, thus an expected plate temperature of 10 ^{o}C, free body, or closed to average temperature of 20^o C mounted.

Thus, the mounting area required by components is the limit in this case, rather than temperature. As indicated in drawing, all magnetic components, the principal source of dissipation, are mounted on chassis, with small components mounted on a plate above the magnetics, with a thermal path to base plate through corner posts.

The components requiring high-voltage insulation are the output diodes of the Magnet Supply. Using a technique similar to that described before for the Arc Rectifier, these diodes are heat-sunk to a small, magnesium plate, which is bonded to a 0.032" epoxy-glass insulator, in turn bonded to a supporting magnesium bracket, which conducts heat to main plate (approximately 1 watt). A one-half inch creepage path is provided between the diode heat sink and the bracket, across the epoxy-glass. A thin, 0.002", H film layer insulates the diodes from the heat sink and, thus, from each other. The bracket also carries the high-voltage, screw-terminal stand-offs for the magnet output.

Techniques for mounting magnetics and small, low-voltage components, are similar to those described for other assemblies.

9. Control Module (See HAC Drawing X3188120)

This module is an assembly of low power components, both discrete and micro-circuit. Nevertheless, all components are mounted to heat sinks, with defined conductive paths to the base plate radiator. Total watts dissipated is estimated at approximately 5 watts maximum. Hence, temperature of assembly will be controlled primarily by heat conduction from adjacent modules, and should be close to the average temperature of the system; i.e., about 30° C.

Discrete components are mounted on a 1/32" epoxy-glass terminal board, bonded to a magnesium heat sink. All components will rest on terminal board and will be conformally coated with low-outgassing epoxy to improve heat transfer, seal against moisture, and secure against vibration during launch.

Microcircuits used here will be of the flat pack type, and will be mounted on a printed circuit board with an etched copper heat sink for a good thermal path to the main heat sink.

10. Low Voltage Connection Module (See HAC Drawing X3188127)

This module will mount all low voltage connectors interfacing with vehicle connectors,; i.e., Control and Telemetry, Low Voltage Loads, and Input Power. Connectors are all of the "Sub-Miniature" rectangular type, rated at 5 amps. per contact.

All internal connections will be made at the rear of the assembly, and all external connections on the front face. Each connector used is a different size from adjacent connectors, to prevent interchange of connectors.

Harness connectors will be provided with side access covers for maximum convenience in routing vehicle harness from edge of assembly.

11. High Voltage Connection Module (See HAC Drawing X3188126)

This module will mount all high-voltage connections to vehicle harness. Connections used are high-voltage standoff, screw terminal type, for minimum weight compatible with high-voltage insulation. A protective cover will be provided for personnel protection during tests.

d. MISCELLANEOUS CONSIDERATIONS

1. Thermal

System thermal design philosophy was discussed under "General," and detail thermal design was discussed under each module discussion. For overall summations, Figure 1, attached, gives heat loads for each module, watts/in^2, and expected temperatures.

Although not indicated in drawings, an array of power resistors will be arranged throughout the eggcrate frame, to be powered from vehicle control to pre-heat assembly to -20° C before starting up system, and insure minimum temperature above -40° C at any time.

2. Choice of Materials

Two (2) criteria have been used in selection of materials, over and above the usual criteria strength, insulation, etc. These are: 1) low outgassing, and 2) compatibility with Freon to be used in Calorimeter test. Choice of materials for first criterion are based on extensive data collected by HAC Materials Laboratory. Choice of materials for the second criterion has been made on the basis of tests for 24 hours immersion in Freon at 45° C (expected operating temperature) and previous experience with Surveyor batteries in Freon Calorimeters. These tests indicate that RTV is incompatible, hence must be sealed with epoxy (only hair-line joints must be sealed). However, nylon, adhesive mylar film, H film, teflon and epoxy have been verified as compatible insulations.

SCREEN INV. #1 19.0 W 0.27 W/IN² 25°C	SCREEN INV. #2 19.0 W 0.27 W/IN² 25°C	SCREEN INV. #3 19.0 W 0.27 W/IN² 25°C	SCREEN INV. #4 19.0 W 0.27 W/IN² 25°C
SCREEN INV. #5 19.0 W 0.27 W/IN² 25°C	SCREEN INV. #6 19.0 W 0.27 W/IN² 25°C	SCREEN INV. #7 19.0 W 0.27 W/IN² 25°C	SCREEN INV. #8 19.0 W 0.27 W/IN² 25°C
ACCEL. INV. 4 W 0.08 W/IN² 20°C	ARC INV. 15 W 0.31 W/IN² 35°C	5 KHZ INV. 9 W 0.18 W/IN² 20°C	CATHODE INV. 12 W 0.25 W/IN² 25°C
H.V. FILTER 5 W 0.13 W/IN² 20°C	ARC XFMR-RECT. & FILTER 10 W 0.25 W/IN² 25°C	LINE REG. (5KHZ) 10.5 W. 0.27 W/IN² 25°C	CONTROL MODULE 5 W 0.13 W/IN² 20°C
H.V. TERMINAL BOARD 0 W 0.00 W/IN² 20°C	MAG. MODULATOR 4.8 W 0.10 W/IN² 20°C	LINE REG. (ACCEL.) 4 W 0.10 W/IN² 20°C	LOW VOLTAGE TERMINAL BOARD 0 W 0.00 W/IN² 20°C

TOTAL LOSS = 231.3 WATTS, TOTAL AREA = 1080 IN²
AVER. WATTS/IN² = 0.23, AVER. TEMP. = 20°C

THERMAL MAP
ELECTRIC THRUSTER POWER CONDITIONER

FIG. 9-1

d. Miscellaneous Considerations (Cont'd.)

3. Gas Density Calculation for Arc Discharge Versus Altitude

Problem

Find the maximum gas density that will accumulate in a vented power conditioning housing of 47,000 cm^3. The gas being generated by the outgassing rate of a conformal coating. The vented area being a mesh screen plate with an area of 6800 cm^2. The holes in the mesh represent 40 percent of this area or approximately 2700 cm^2

Given

The Components and Materials Laboratory at Hughes Aircraft ran some preliminary tests on the conformal coating (used on the power conditioning components) with the following results:

a) The outgassing molecules consist of water and various absorbed gasses.

b) The molecular weight averages 100.

c) Approximately 3×10^{19} molecules/cm^2 does outgas from a coating 0.005 inch thick.

d) Temperature of the gas is 328° K.

e) Approximately 0.001 weight loss occurs in the first four hours in space. This is the maximum rate loss expected. This is equivalent to 70×10^{-6} grams per second.

f) The vented power conditioning housing contains 47,000 cm^3

g) One side of the housing is a mesh plate with a total hole area of 2700 cm^2

Find

The maximum gas density developed inside the power conditioning housing after launch and injection in orbit. Plot results on a gas density versus altitude from the surface of the earth. (Figure I)

Solution

1. Molecular velocity of the outgas is:

$$\bar{v}ag^2 = \frac{3k\ T}{m}$$

$$vag^2 = \frac{3 \times 1.38 \times 10^{-16} \times 3.28 \times 10^2}{16.6 \times 10^{-23}}$$

$$\bar{v}ag = 2.86 \times 10^4 \text{ cm/sec.}$$

where k = Boltzmann's constant

G. Density Calculation for Arc Discharge Versus Altitute

T = absolute temperature in kelvin

m = molecular mass (grams)

$\overline{vag}$ = velocity in cm/sec.

2. The maximum gas density developed inside the housing

$$D = \frac{R}{K\ A\ vag}$$

$$= \frac{70 \times 10^{-6}}{0.5 \times 2.700 \times 10^{3} \times 2.86 \times 10^{4}}$$

$$= 18.1 \times 10^{-13}\ \text{grams/cm}^3$$

$$\cong 3.6 \times 10^{-12}\ \text{slugs/ft}^3$$

where R = gas flow rate in grams/second

A = vented area in cm^2

vag = gas velocity in cm/sec.

K = flow efficiency taken as 0.5

Conclusion

The maximum gas density developed inside the vented housing, containing the power conditioning system, is approximately 3.6×10^{-12} slugs per cubic foot. This value corresponds to an altitude of 100 to 130 nautical miles on an atmospheric versus altitude graph.

Gas Pressure Calculation

Using the ideal gas law

$$Pv = n\ k\ T$$

$$P = \frac{5.1 \times 10^{14} \times 1.38 \times 10^{-16} \times 328}{4.7000 \times 10^{4}}$$

$$P = 4.9 \times 10^{-4}\ \text{dynes/cm}^2$$

or $$P = 4.9 \times 10^{-10}\ \text{atmospheres}$$

or $$P - 3.76 \times 10^{-7}\ \text{mm Hg}$$

where P = pressure in dynex/cm^2

v = volume of 47,000 in^3

n = number of molecules in v. 5.1×10^{14}

k = Boltmann's constant 1.38×10^{-16}

T = abs. temperature $328^{o}K$

Gas Pressure Calculation

Conclusion

The voltage breakdown for the power conditioning system will be above 10,000 volts for 0.5 inch terminal spacings. See Figure III.

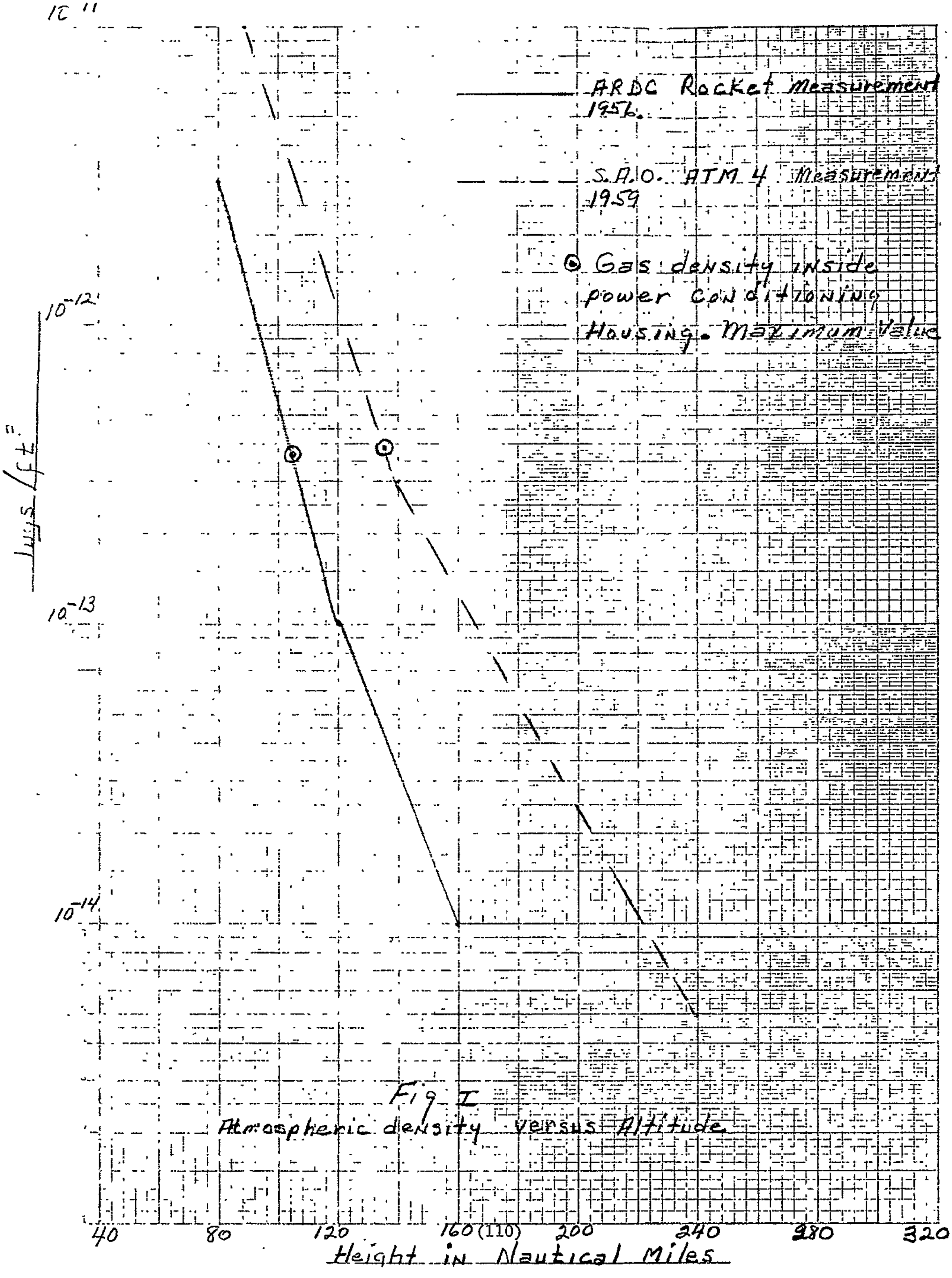


Fig I
Atmospheric density versus Altitude

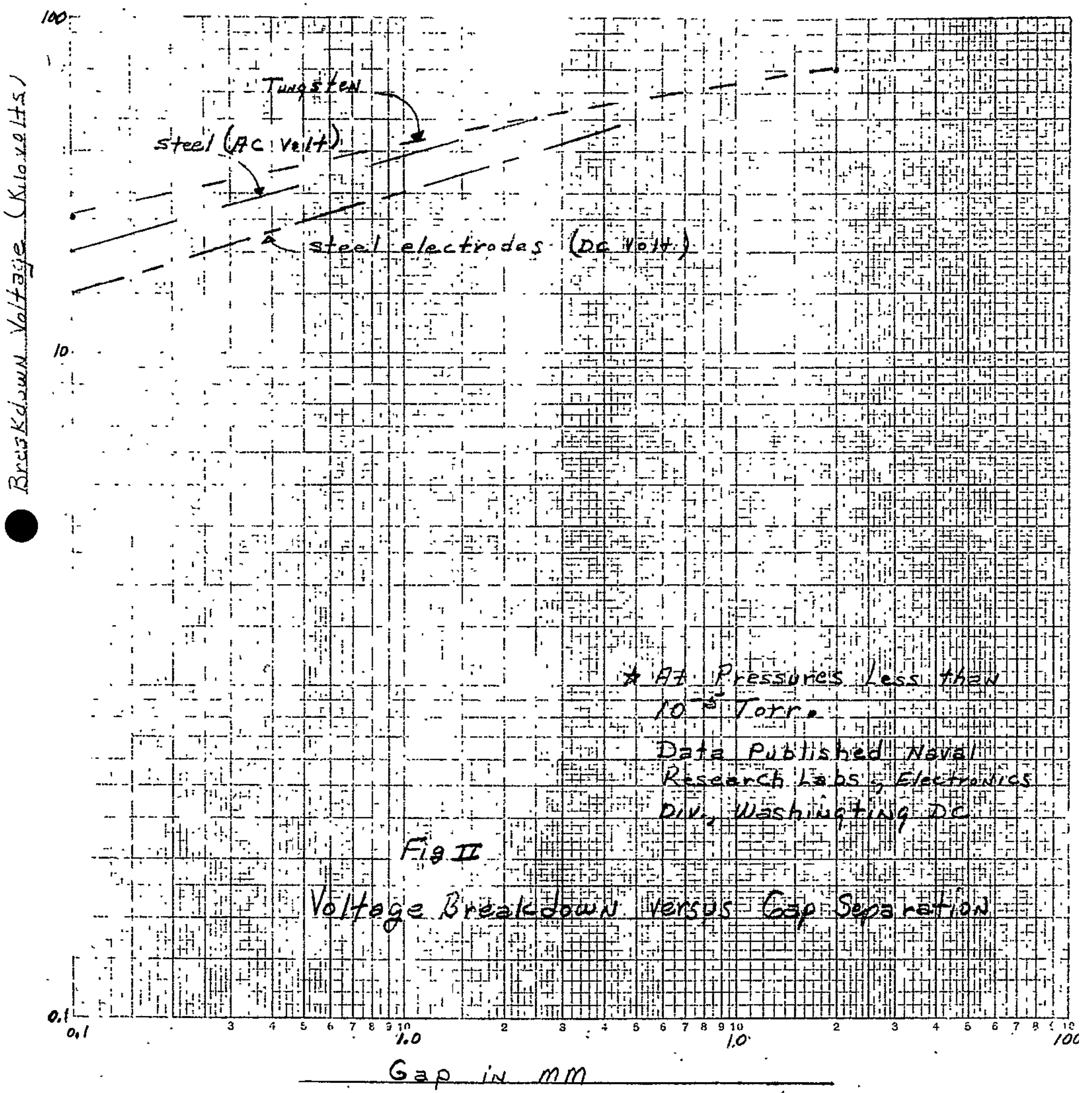


Fig II
Voltage Breakdown versus Gap Separation

10. POWER CONDITIONER SUPPORT EQUIPMENT SYSTEMS TEST CONSOLE

a. General

The test console will operate, test and evaluate the power conditioner during design, development, qualification and acceptance testing.

It provides the following basic functions:

1. Simulated loads for the power conditioner. Each of the eight power supplies are terminated in the correct impedance to operate the power conditioner and evaluate its performance.

2. Power input to the power conditioner power supplies. Four power supplies provide power to the power conditioner. An array of switches applies and removes power from each group of inverters. A master switch removes all power. Selector switches are provided to remove power from individual inverters to simulate failures and demonstrate the ability of the reserve circuits to cut in and maintain operation.

3. Instrumentation for monitoring voltage, current, waveform and temperature. All instrumentation consists of standard commercial equipment. All pertinent voltages, currents, and waveforms can be selected and displayed on the appropriate digital voltmeter, RMS voltmeter, and/or scope. Provisions for continual scanning and monitoring of 10 thermistors are provided.

4. Continual telemetry monitoring. All 15 telemetry outputs are terminated and individually monitored at all times.

5. The command generator will provide control commands to the power conditioner. The commands are 22 VDC positive pulses of 60 milliseconds duration (internally adjustable from 40-100 milliseconds). Any one of five command circuits can be selected. Command status is displayed by lights on the status panel. A 0 - 5 V analog command is provided continuously for screen reference current.

6. High voltage protection of personnel is provided by electrical interlock and shorting relays in the -2 KV and + 2 KV high voltage areas within the test console.

The test console block diagram displays the interconnection and flow between the above described functions.

The instrumentation, by selector switch, monitors the voltage, current and waveform of all eight dummy loads. In order to measure the relatively low voltages and currents, which are at 2000 volts with respect to ground under normal operating conditions, a meter enabling circuit has been provided. This circuit allows DVM or RMS meter connection only when all high voltage has been removed. The telemetry readout will provide continuous monitoring of all load voltages and currents. All loads for the power conditioner are provided by the test console, or transferred to the ion engine by the test console. This will enable the operator to recheck the calibration of the telemetry at any time that it should become necessary during the test with the ion engine.

The arc test will short any two supplies or any supply and ground by a thyratron ischarge when so commanded. There are also provisions to apply a direct short or xternal resistance between any two supplies or any supply and ground.

A main three pole circuit breaker is provided to remove all power. Individual ircuit breakers are provided for the 28V power supply, and the arc test power nput. All instrumentation and the remaining power supplies are commercial units ith front panel switches.

FUNCTIONAL/CIRCUIT DESCRIPTI

Schematic diagrams of the various circuits comprising the test console are ttached.

1. Control Panel

The DC power distribution consists of a main disconnect switch and five ower conditioner power disconnect switches. As each switch is closed, an indicator amp will glow on the status panel indicating the presence of power.

The main DC power switch is a DPDT center off switch. The upper switch osition connects the four main power supplies, two in series and two series groups n parallel. The lower switch position connects all four in parallel. The relay ontacts for each pair of power supplies will carry 60 amps.

All high voltage supplies are interlocked by a series string of switches. he switches are placed on all access panels to high voltage areas. When a panel s removed, the associated switch will open. This will open the circuit to the igh voltage warning lamp and a relay, that disconnects power to the high voltage upplies. The meter enable switch on the high voltage panel disconnects the etering circuits on the magnet (V_1), cathode (V_3), and anode (V_4) loads. This ircuit is discussed in a separate section. The scope, digital voltmeter, and rue RMS Voltmeter selector switches are located on this panel. The Arc Initiate, ommand and Command Selector are located in this panel. They are discussed in eparate sections. A means of disconnecting the power to all active inverters to imulate failure will be accomplished by opening the selected switch. A failure n the 5 KC, Cathode, and Arc Inverters is simulated by disconnecting the drive ith a relay located near the power conditioner.

2. Command Generator

The "Command" is initiated by a momentary "on" push-button switch. This pplies 28 volts across the 10K Ω and 4.7 µf time delay network. With the 10K Ω esistor adjusted to 5.8K Ω, the transistor will conduct enough to energize the elay in 60 milliseconds. The result is command circuit providing a positive DC 2 volt pulse of 60 milliseconds duration with less than a one millisecond rise and all time. 4K resistors are provided to effectively ground the command circuits and enerator when they are not selected or commanded. The second contact (normally open), f the relay, provides a means of displaying the command status.

"Off 2" must be commanded first or no DC power will be available to the power conditioner. The "Off 2" status light will remain lit (after command) until the selection switch is changed. As "On 1", "On 2", and "On 3" commands are enabled a status light turns on for each. When "Off 1" is commanded, the "Off 1" status light turns on. When "On 3" is commanded (this light is already on), the "Off 1" light turns off. "Off 2" command turns off all command status lights except "Off 2". A zero to five volt DC analog command is provided for screen reference current.

3. Telemetry Panel

Fifteen telemetry outputs are monitored continuously. They are terminated ≈90K ohms. This termination and the source impedance will provide a 5 volt indication on the 50μa meter for a 5VDC signal. Switches are provided at each meter to momentarily disconnect the meter load for more accurate readings on the DVM.

4. DC power is supplied by four 40V, 30A fast response power supplies connected in series parallel for normal operation or in parallel for low voltage operation.

5. Arc Test

A thyratron tube is used for the arc test. When energized, it can be discharged by depressing the "Arc initiate" momentary on switch. This energizes a control relay and applies a positive voltage to the grid circuit, driving the thyratron into full conduction. Conduction will cease when the anode-cathode voltage drops to a very low level or the "initiate" switch is released which opens the anode circuit. An RC network in the grid circuit limits the time the grid remains positive to less than 10 milliseconds.

6. Meter Enabling Circuit

All voltage monitoring is done at the power conditioner and not at the loads (except the cathode). It is necessary to protect the instrumentation from the application of 2000 volts when either the screen or accelerator supplies are operating. A 10:1 voltage divider is provided to measure 2 KV screen and accelerator voltages. A meter enabling circuit is provided to protect the instrumentation by disconnecting the instrumentation with high voltage relays. Under normal operating conditions the magnet (V_1), cathode (V_3), and anode (V_4) loads are connected to the +2KV screen supply. When measurements are to be made on these supplies, they are disconnected from the screen supply and grounded. The parameter to be measured is selected by a seven position selector switch. This circuit also prevents measurement at 2 KV when the power conditioner is not connected, such as when the load is transferred to the ion engine. This protection is required because all voltage monitoring is done direct. This circuit uses the ground leg of the vaporizer supply (V_2) to connect or disconnect the +28V transfer voltage. A red status light indicates when the circuit is disconnected.

7. Magnet Load (V_1)

The magnet load consists of a variable 4 ohm rheostat in series with a 7 mh choke and a 18.5 ohm resistor. The magnet load can be varied from 18.5 ohm cold to 22.5 ohm hot. This load is connected to the screen supply except when the instrumentation is in use. Provisions are made for open circuit, short and arc short to any supply and ground.

8. Vaporizer Load (V_2)

This load consists of a 5 ohm non-inductive resistor. It can be open circuited, shorted, and arc shorted to any supply and ground.

9. Cathode Load (V_3)

Provisions are made to mount the output transformer, supplied with the power conditioner, within the test console. The SERT II vaporizer and cathode loads were combined and rearranged to form this load. A breadboard was made. The best circuit arrangement consisted of seven parallel strings of three series 866A tube filaments shunted by approximately 0.28 ohms. The test arrangement consisted of this load, a 40A current limited DC power supply, and current and voltage recorders. Current was constant at 40A (except for initial surge). Voltage was 1.8V cold (0.045 ohms) 2.8V in 8 seconds and stabilized at 4.2V after 90 seconds (0.105 ohms). The 0.045 ohm cold will be reduced to 0.035 ohm by increasing wire size and reducing lead length. The center tap of the output transformer is connected to the arc load. Provisions are made to short and arc short to any supply and ground.

10. Arc Load (V_4)

The large rheostat from SERT II anode load and HV selector switch from the vaporizer keeper load were retained for this load. The load consists of a 5-position step switch and a combination of resistors and the rheostat. The load terminals are connected one to the cathode supply and the other to the screen supply via the meter enabling relay. The 5 positions will provide a load of: 1) open; 2) $\approx$2 ma @ 150V (75K ohms); 3) $\approx$ 20 ma @ 30V (1800 ohms); 4) $\approx$1 to 2.9A (12.4 to 47.4 ohms); 5) $\approx$ 5.8 to 8.4A (5.7 to 4.3 ohms). It can be shorted and arc shorted to any supply and ground. Note: The plus lead will not be common to the screen lead at the power conditioner; provisions for this connection are made in the meter enable circuit of the test console.

11. Screen Load (V_5)

Many of the resistors and the high voltage relays from the SERT II console are used in this load. Most of the resistors are operated at their published maximum wattages; therefore, a 700 CFM exhaust fan will be added at the top of the console immediately above this load to keep these resistors at below their rated temperatures. Three resistance banks are used in parallel combinations to provide loads at 2 KV of: 1) open (divider in meter circuit will draw 1 ma); 2) $\approx$ 0.41 to 0.53A; 3) $\approx$ 0.68A; 4) $\approx$ 0.8A; 5) $\approx$ 0.84 to 1.06 A. A make before break selector switch is used to make selection. This load can be shorted and arc shorted to any other supply and ground. A 0-0.75A current limited supply can be connected across the screen current sensing resistor in the power condition to simulate an analog load condition in the active range of the screen supply.

12. Accelerator Load (V_6)

This load consists of a 5-position selector switch and resistors which will provide these loads at 2KV: 1) Open (divider in meter circuit will draw 1 ma); 2) $\approx$ 10.5 ma (188K); 3) $\approx$ 53 ma (38K); 4) $\approx$ 77 ma (26K); 5 $\approx$ 0.1 to 0.11A (20K to 18K). This load can be shorted and arc shorted to any other supply and ground.

13. Neutralizer Cathode and Neutralizer Vaporizer Load (V7) (Same as SERT II)

The neutralizer cathode and neutralizer vaporizer loads consist of seven 866 tube filaments wired in series with an additional seven series connected 866 tube filaments shunted by one 1651 lamp (5V at 0.6A each). This circuit is an analytical design based on data received from the breadboard of the SERT II vaporizer load circuit. The mathematical results show the following:

a) The initial cold resistance should be 1.2 ohms.

b) The final (after 10 time constants) resistance will approach 5.3 ohms; Note: that the one time constant resistance is 3.8 ohms.

c) One time constant will be 40 seconds.

The specification requires a cold resistance of 1 ohm, a one-time constant resistance of 3.5 ohms, and a one-time constant value of 30 seconds.

14. Neutralizer Keeper Load (V_8) (Same as SERT II)

This load consists of a potentiometer and a high-voltage transistor. Adjustment of the potentiometer will cause the transistor to load the supply in the range of from approximately 300V minimum to 2V with a corresponding change in current of from approximately 0 ma to 500 ma. A vernier adjustment is provided for.

15. Status Panel

The following indicator lamps are displayed on the status panel:

Status Panel Lamps	Color
a) Warning High Voltage	Red
b) On 1	Green
c) On 2	Green
d) On 3	Green
e) Off 1	Green
f) Off 2	Green
g) Main AC Power	Neon (Amber)
h) Arc Test Power	Neon (Amber)
i) 28V Supply Power	Amber
j) Main DC Power	Amber
k) Line Regulator Power	Amber
l) Cathode Power (V_3)	Amber
m) Arc Power (V_4)	Amber
n) Screen Power (V_5)	Amber
o) Accelerator Power (V_6)	Amber
p) -2KV Shorting Switch Closed	Red
q) +2KV Shorting Switch Closed	Red
r) Short Test On	Red
s) Meter enable not ready	Red

c. HARDWARE/PACKAGING DESCRIPTION

The test console will be housed in two 6½ foot rack cabinets 25 inches deep. There will be a work shelf at approximately 29 inches from the floor. A pictorial diagram is included. Custom equipment will be placed as indicated in the pictorial diagram. Location of controls is approximate and will be determined during the mechanical design phase of this program.

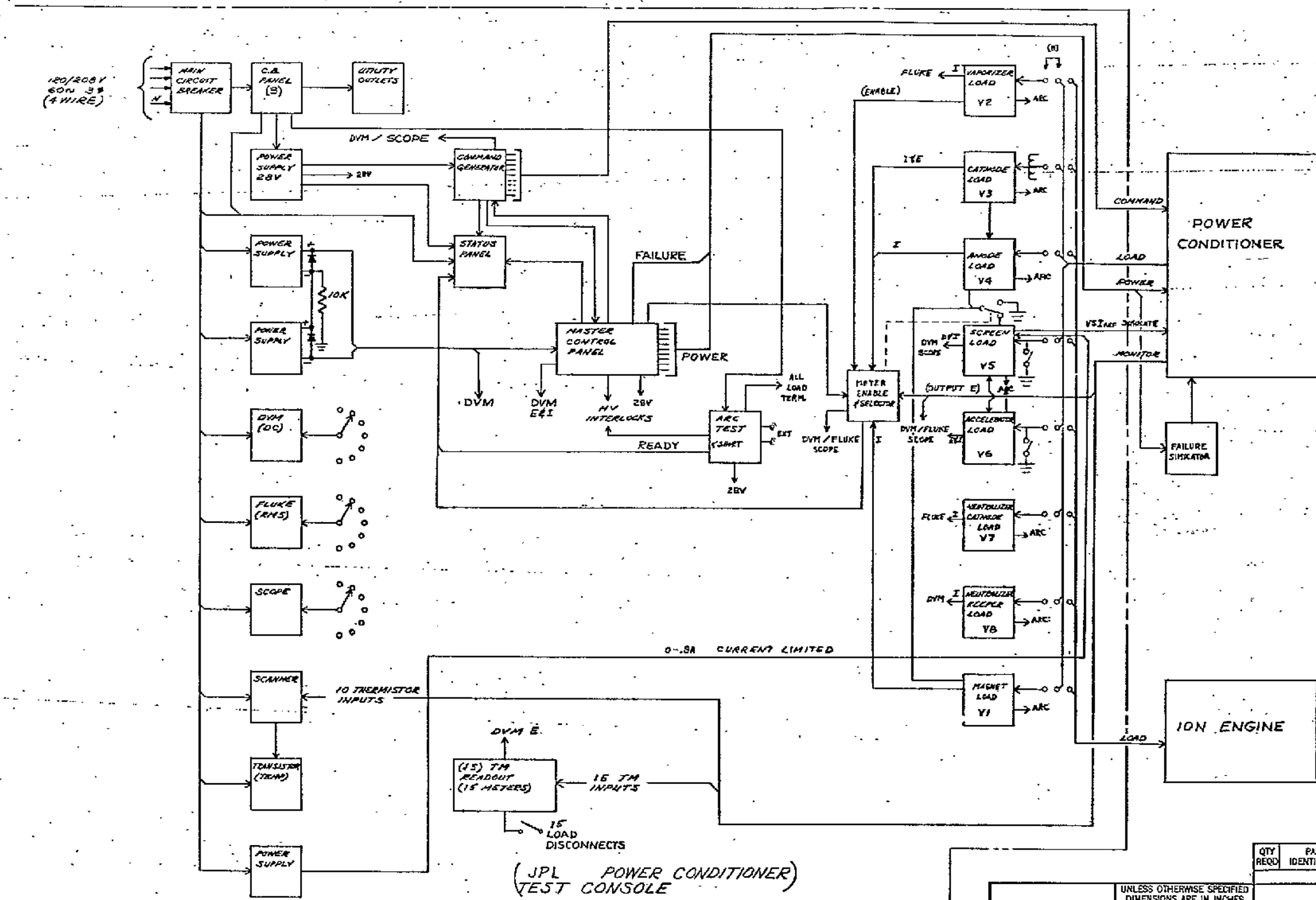
d. ENERGY NEEDS AND LOSSES

Energy requirements of the test console will be supplied by 120/208 VAC, 3-phase power source. Current loading will be divided between the three phases as equally as possible.

Two blowers and filters will be installed at the bottom of the cabinets to cool the test console. An exhaust fan will be installed over the high voltage section to adequately cool these components.

LIST OF DRAWINGS

POWER CONDITIONER TEST CONSOLE (BLOCK DIAGRAM) Fig. 10-1
CONTROL (SCHEMATIC) Fig. 10-2
COMMAND GENERATOR (SCHEMATIC) Fig. 10-3
TELEMETRY PANEL (SCHEMATIC) Fig. 10-4
ARC TEST (SCHEMATIC) Fig. 10-5
METER ENABLING CIRCUIT FOR VAPORIZER, THRUSTER CATHODE Fig. 10-6
MAGNET LOAD (V_1) (SCHEMATIC) Fig. 10-7
VAPORIZER LOAD (V_2)(SCHEMATIC) Fig. 10-8
CATHODE LOAD (V_3)(SCHEMATIC) Fig. 10-9
ARC LOAD (V_4)(SCHEMATIC) Fig. 10-10
SCREEN LOAD (V_5) (SCHEMATIC) Fig. 10-11
ACCELERATOR LOAD (V_6)(SCHEMATIC) Fig. 10-12
NEUTRALIZER HEATER LOAD (V_7)(SCHEMATIC) Fig. 10-13
NEUTRALIZER KEEPER LOAD (V_8)(SCHEMATIC) Fig. 10-14
CONSOLE DRAWING Fig. 10-15



REVISIONS

EFF	AUTHORITY	ZONE	LTR	DESCRIPTION	DATE	APPROVED

A

B

QTY REQD	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	ZONE	ITEM NO.

LIST OF MATERIALS

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES AND PER MIL-STD-8
XXX ±.010 XX ±.03 X ±.1 ANGLES ±0° 30'

MATERIAL

NEXT ASSY | USED ON
APPLICATION

DR [signature] DATE
CHK
APPD

HUGHES
HUGHES AIRCRAFT COMPANY
CULVER CITY, CALIFORNIA

BLOCK DIAGRAM, JPL - POWER CONDITIONER TEST CONSOLE (20 cm 88. MOD)

SIZE D CODE IDENT NO 82577 10-1

SCALE NONE SHEET

FORM NO. 11065-B CS-CC 1-65 OZALID 580-260

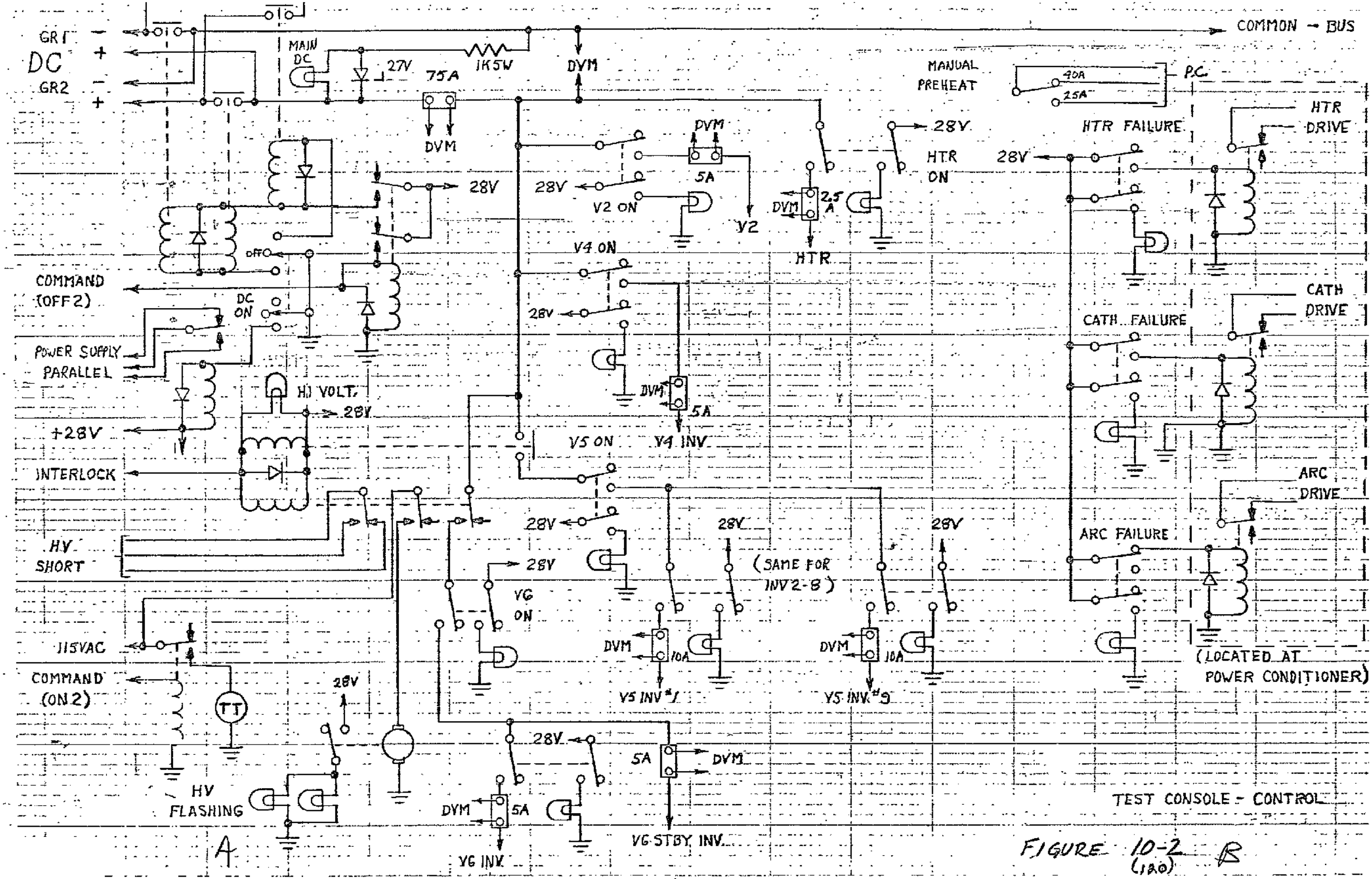


FIGURE 10-2 (120) B

HUGHES AIRCRAFT CO.

MODEL

REPORT NO

PAGE

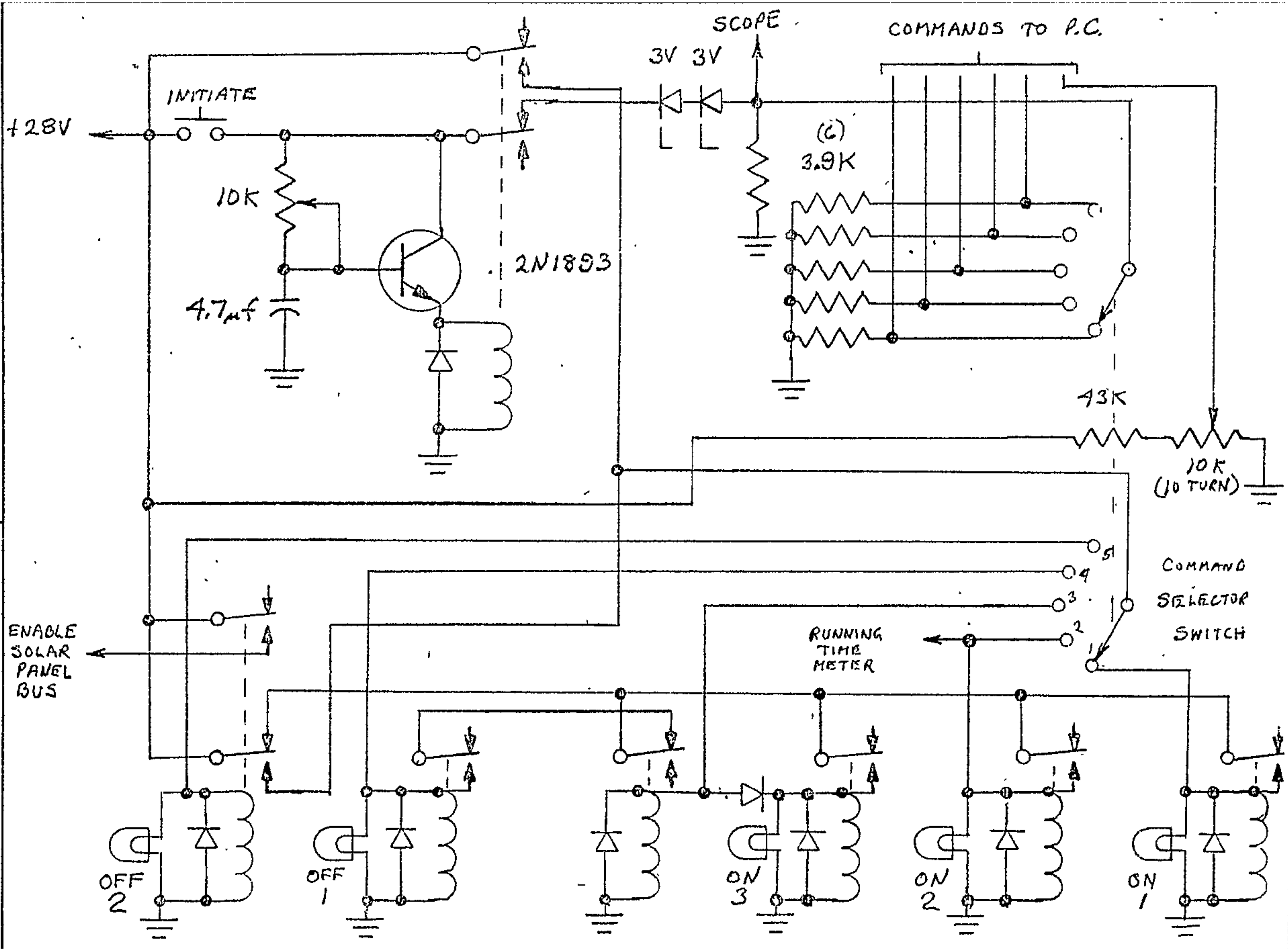
FIGURE 10-3

ANALYSIS TEST CONSOLE - COMMAND

PREPARED BY

CHECKED BY

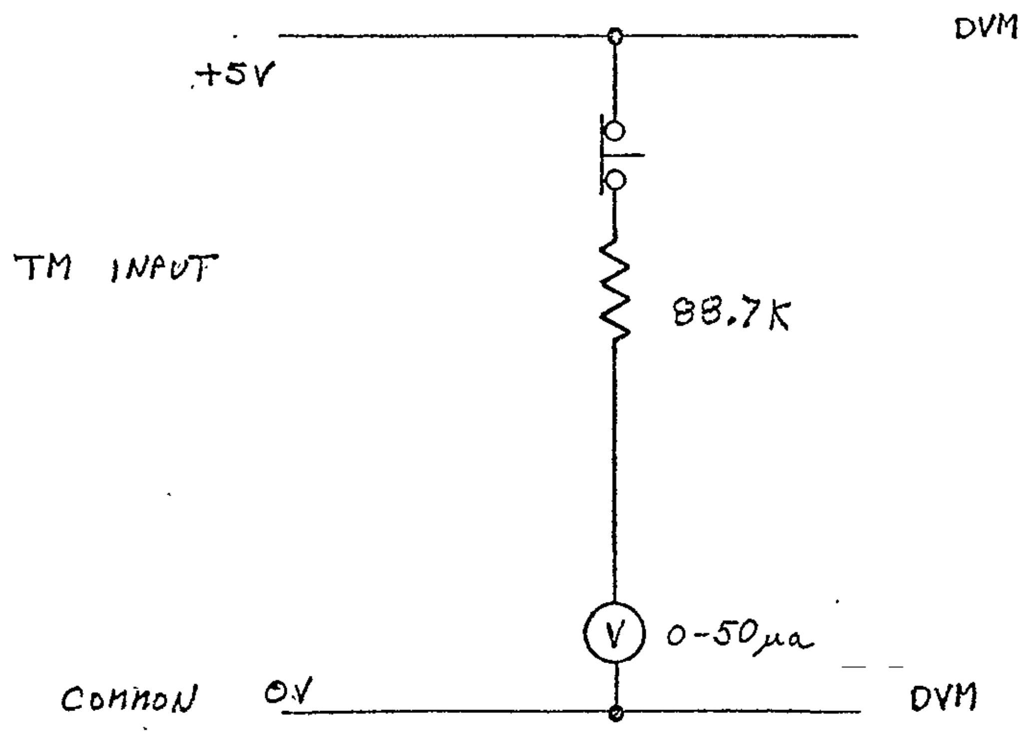
FORM 700



FORM 700

HUGHES AIRCRAFT CO.

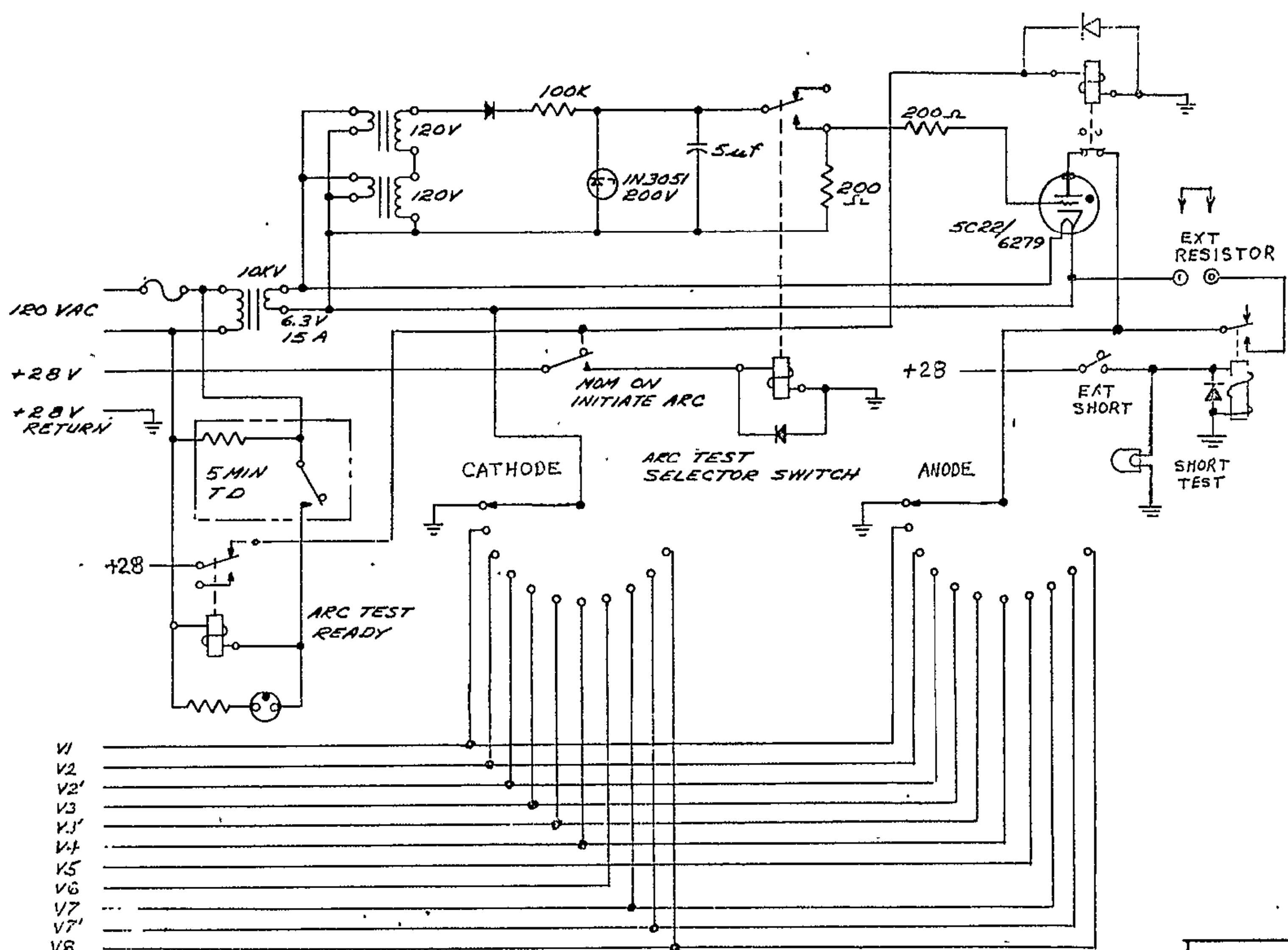
ANALYSIS TEST CONSOLE - TELEMETRY		MODEL	REPORT NO.	PAGE
PREPARED BY R. Cowan	7-8-68		FIGURE 10-4	
CHECKED BY	9-10-69			



TELEMETRY CHANNELS

1. V1 CURRENT
2. V2 CURRENT
3. V3 CURRENT
4. V4 VOLTAGE
5. V4 CURRENT
6. V5 VOLTAGE
7. V5 CURRENT
8. V6 VOLTAGE
9. V6 CURRENT
10. V7 CURRENT
11. V8 VOLTAGE
12. V8 CURRENT
13. NEUT. EMISSION
14. ARC/MIN
15. PWR. COND. OFF

REVISIONS						
EFF	AUTHORITY	ZONE	LTR	DESCRIPTION	DATE	APPROVED



NOMENCLATURE OR DESCRIPTION	ZONE	ITEM NO.

LIST OF MATERIALS

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES AND PER MIL STD 8
.XXX ±.010 XX ±.03 .X ±.1 ANGLES ±0° 30'

MATERIAL

DR J. Gunman DATE 30 APR 67
CHK
APPD

HUGHES
HUGHES AIRCRAFT COMPANY
CULVER CITY, CALIFORNIA

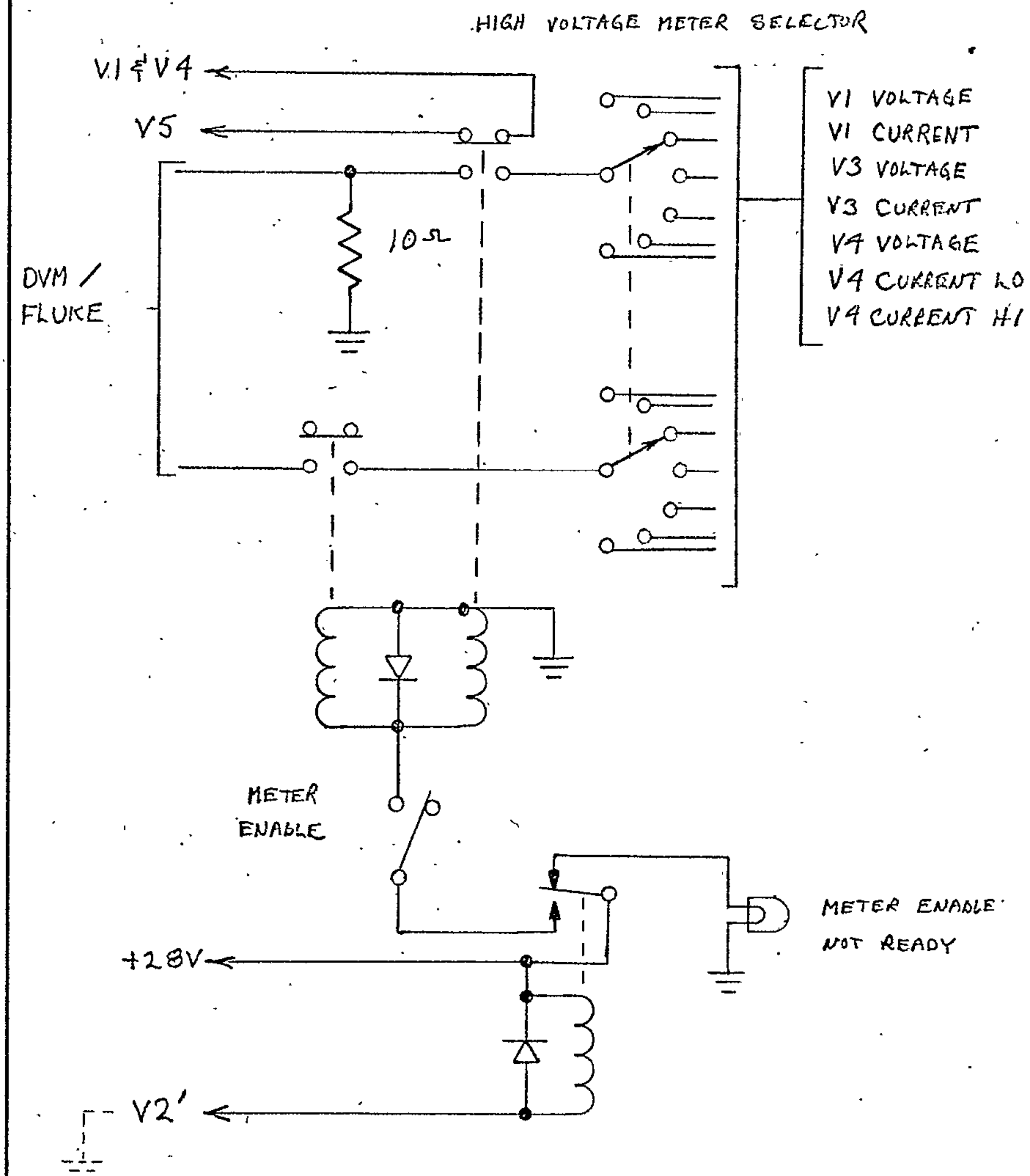
SCHEMATIC-HIGH VOLTAGE ARC TEST
(20 cm SB. MODIFICATION)

SIZE C | CODE IDENT NO 82577 | FIGURE 10-5

SCALE | SHEET

NEXT ASSY | USED ON
APPLICATION

FIGURE 10-6


HIGH VOLTAGE METER SELECTOR
V1 & V4
V5
10Ω
DVM / FLUKE
V1 VOLTAGE
V1 CURRENT
V3 VOLTAGE
V3 CURRENT
V4 VOLTAGE
V4 CURRENT LO
V4 CURRENT HI
METER ENABLE
METER ENABLE NOT READY
+28V
V2'

FORM 700

HUGHES AIRCRAFT CO.

ANALYSIS TEST CONSOLE - MAGNET

PREPARED BY [signature] 7-3-68

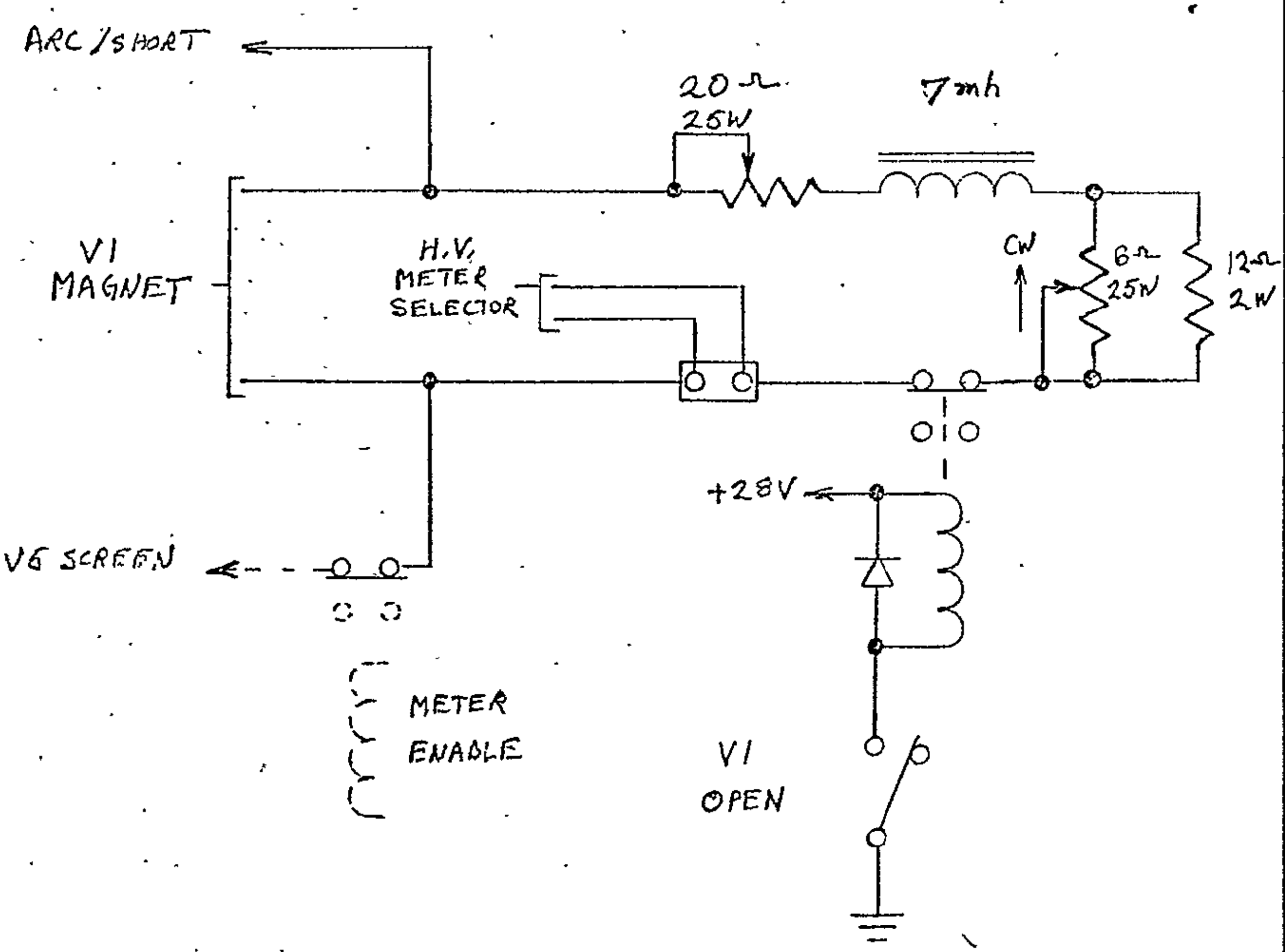
CHECKED BY

MODEL

REPORT NO

PAGE

FIGURE 10-7



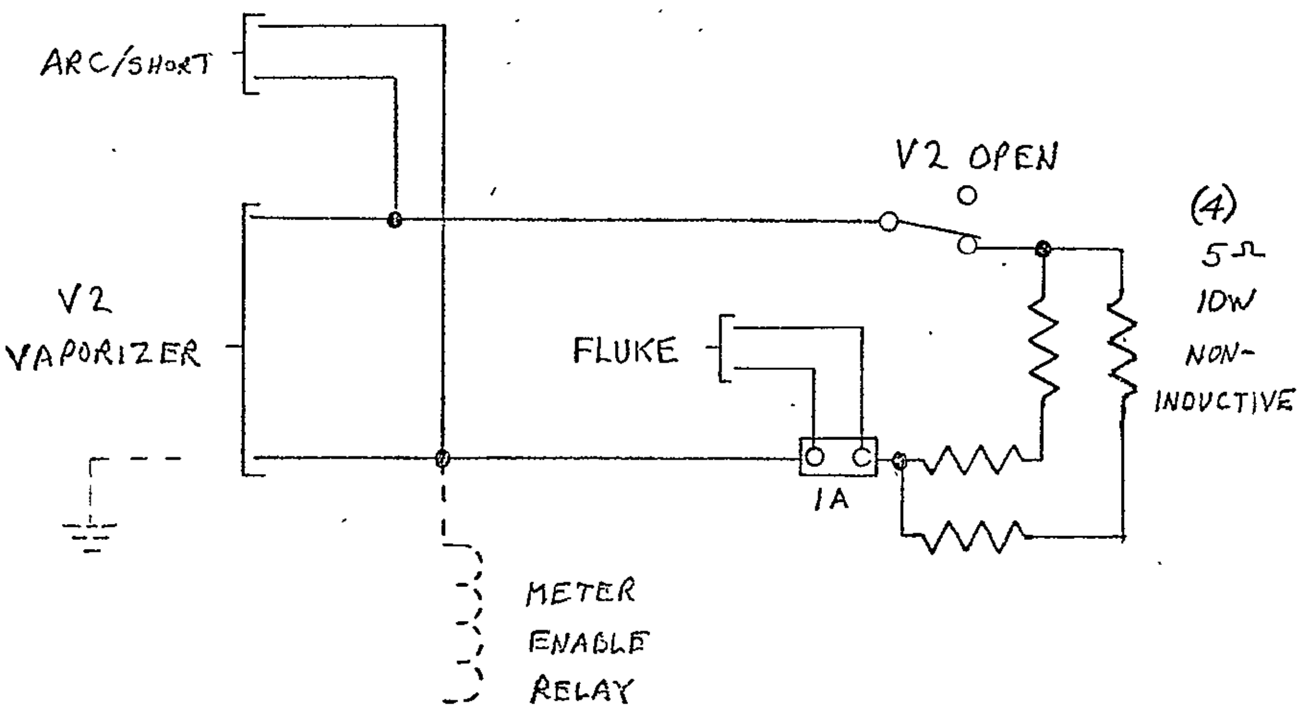
FORM 700

HUGHES AIRCRAFT CO.

ANALYSIS TEST CONSOLE - VAPORIZER
PREPARED BY [signature] 7-22-68
CHECKED BY

MODEL | REPORT NO. | PAGE

FIGURE 10-8

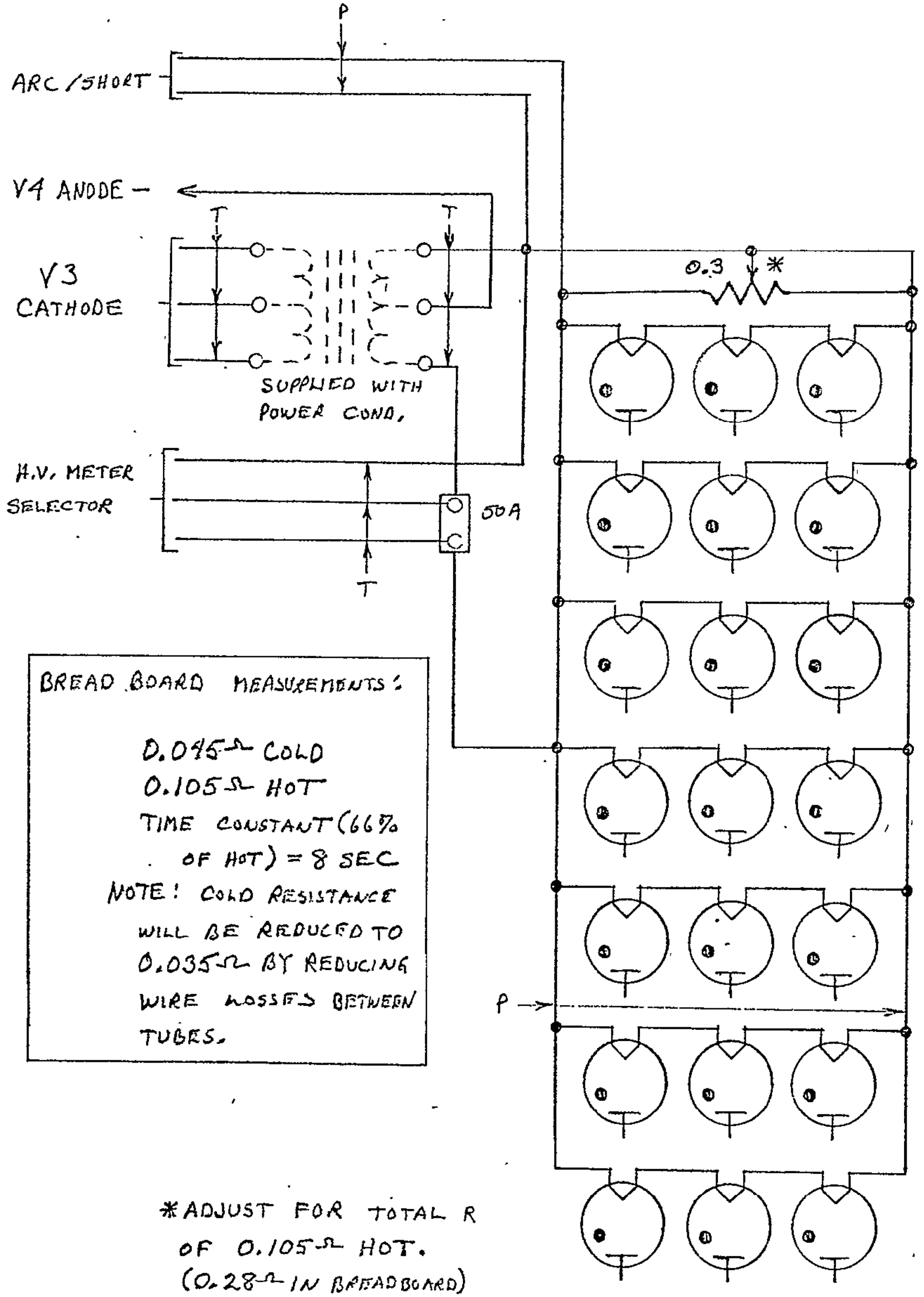


FORM 700

HUGHES AIRCRAFT CO.

ANALYSIS: TEST CONSOLE - CATHODE
PREPARED BY: [signature] 7-10-68
CHECKED BY:
MODEL
REPORT NO
PAGE

FIGURE 10-9



BREAD BOARD MEASUREMENTS:

0.095Ω COLD
0.105Ω HOT
TIME CONSTANT (66% OF HOT) = 8 SEC

NOTE: COLD RESISTANCE WILL BE REDUCED TO 0.035Ω BY REDUCING WIRE LOSSES BETWEEN TUBES.

*ADJUST FOR TOTAL R OF 0.105Ω HOT.
(0.28Ω IN BREADBOARD)

FORM 700

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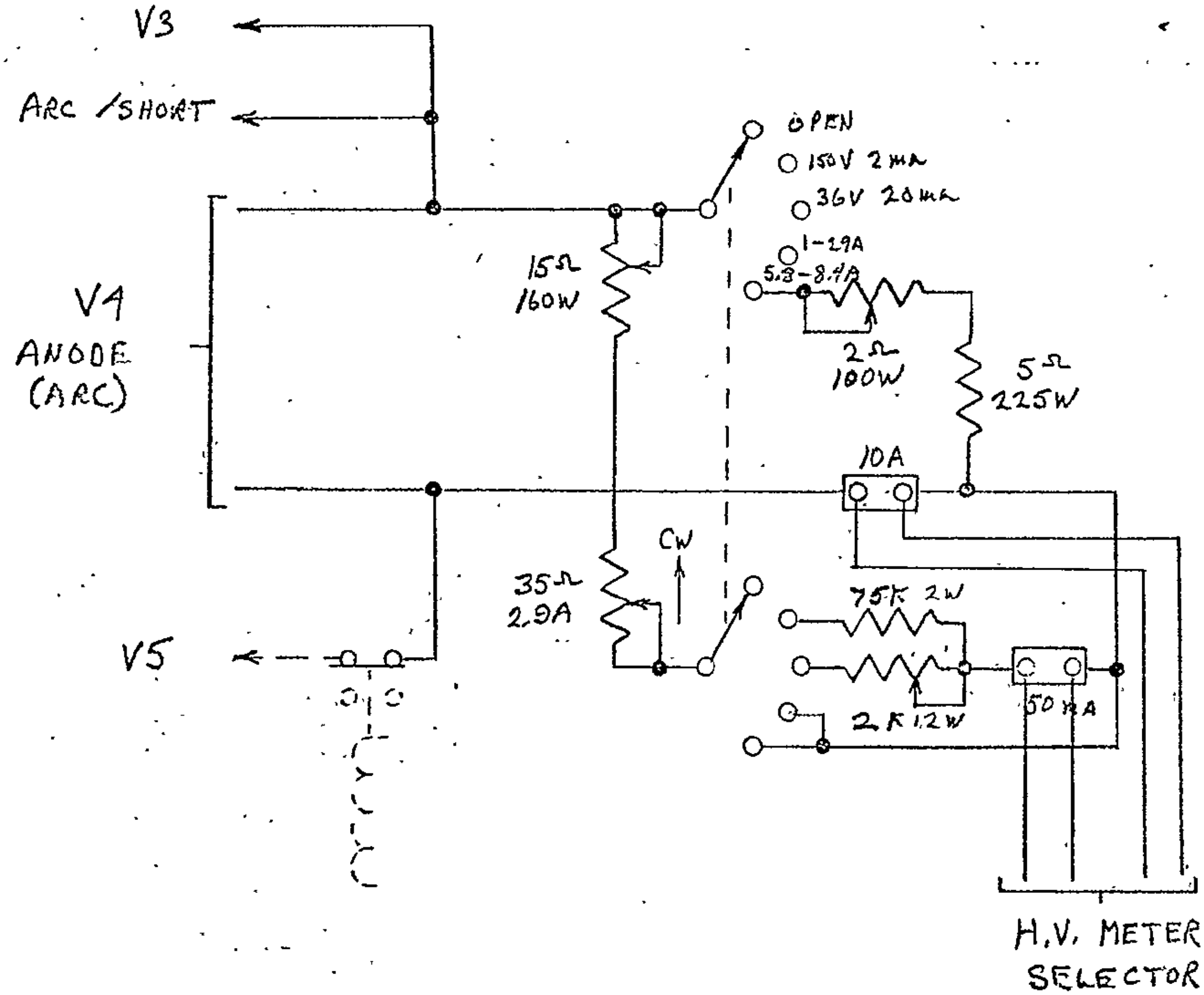
ANALYSIS TEST CONSOLE - ANODE | MODEL | REPORT NO. | PAGE

PREPARED BY [signature] 7-3-68

CHECKED BY 9-10-68

FIGURE 10-10



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MODEL REPORT NO PAGE

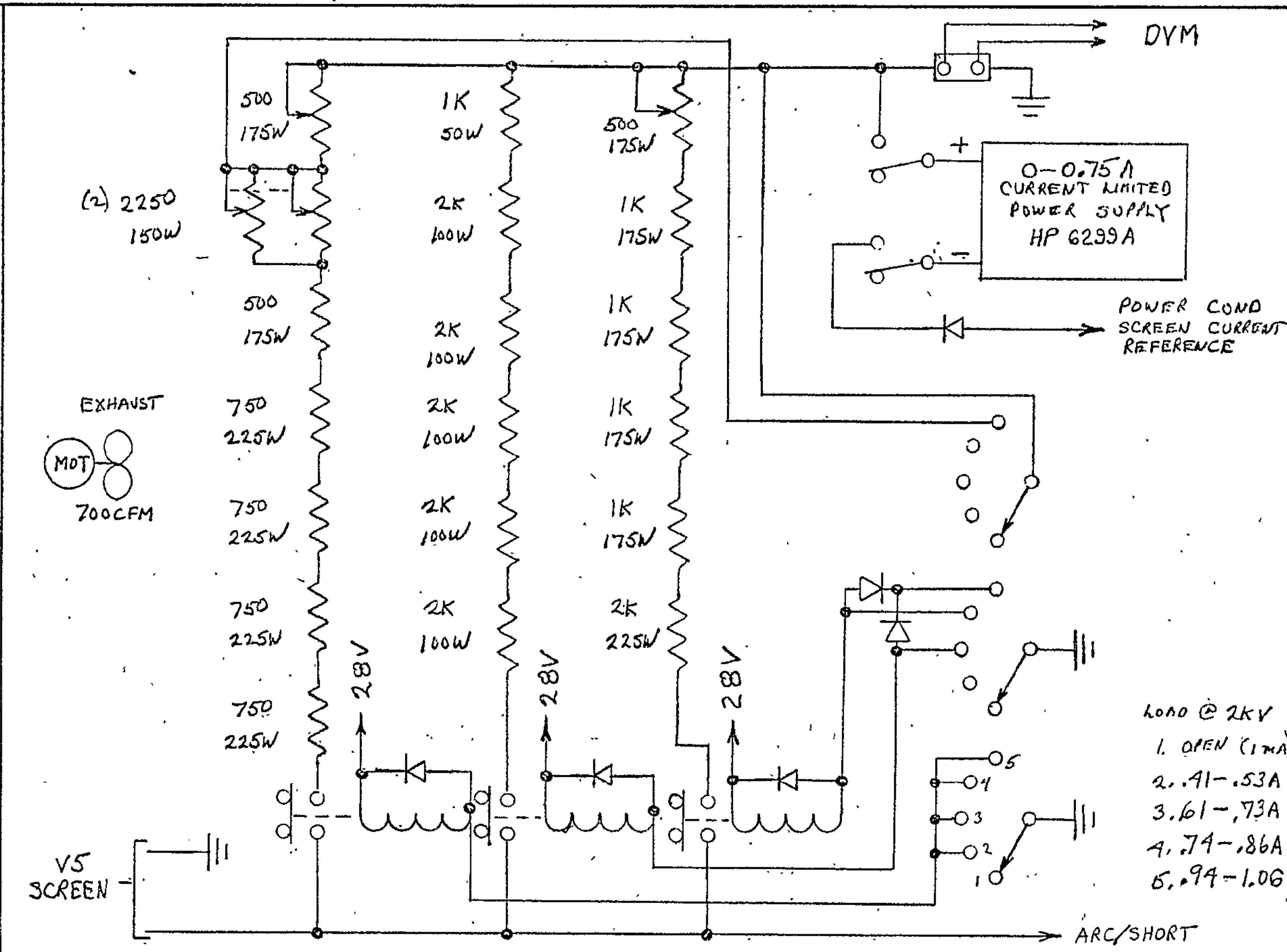
FIGURE 10-11

ANALYSIS TEST CONSOLE - SCREEN 7-3-68

PREPARED BY K. [illegible] 9-22-61

CHECKED BY

FORM 700



(129)

FORM 700

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ANALYSIS TEST CONSOLE - ACCEL

PREPARED BY [signature] 7-3-68

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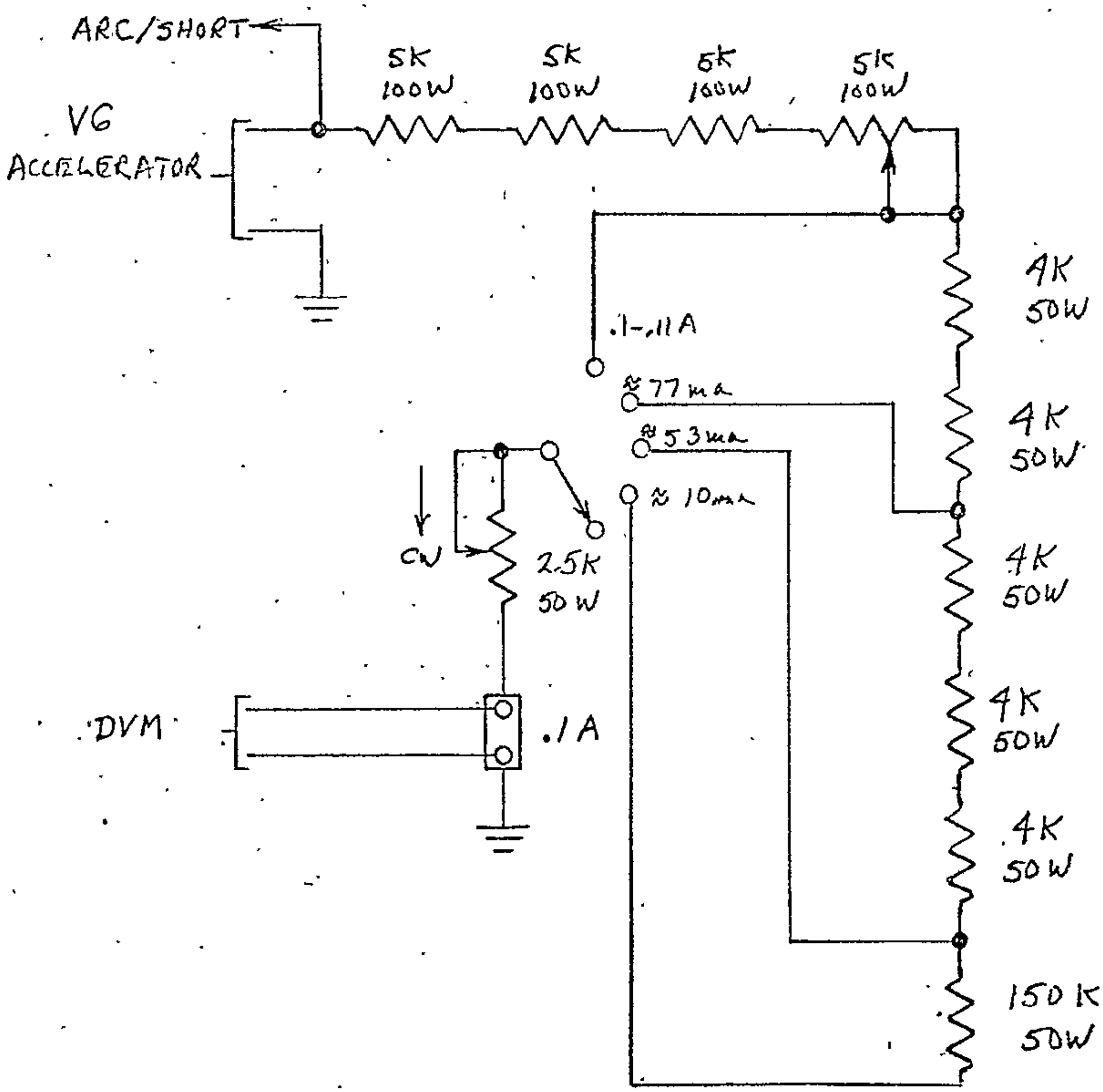
MODEL

REPORT NO.

PAGE

FIGURE 10-12



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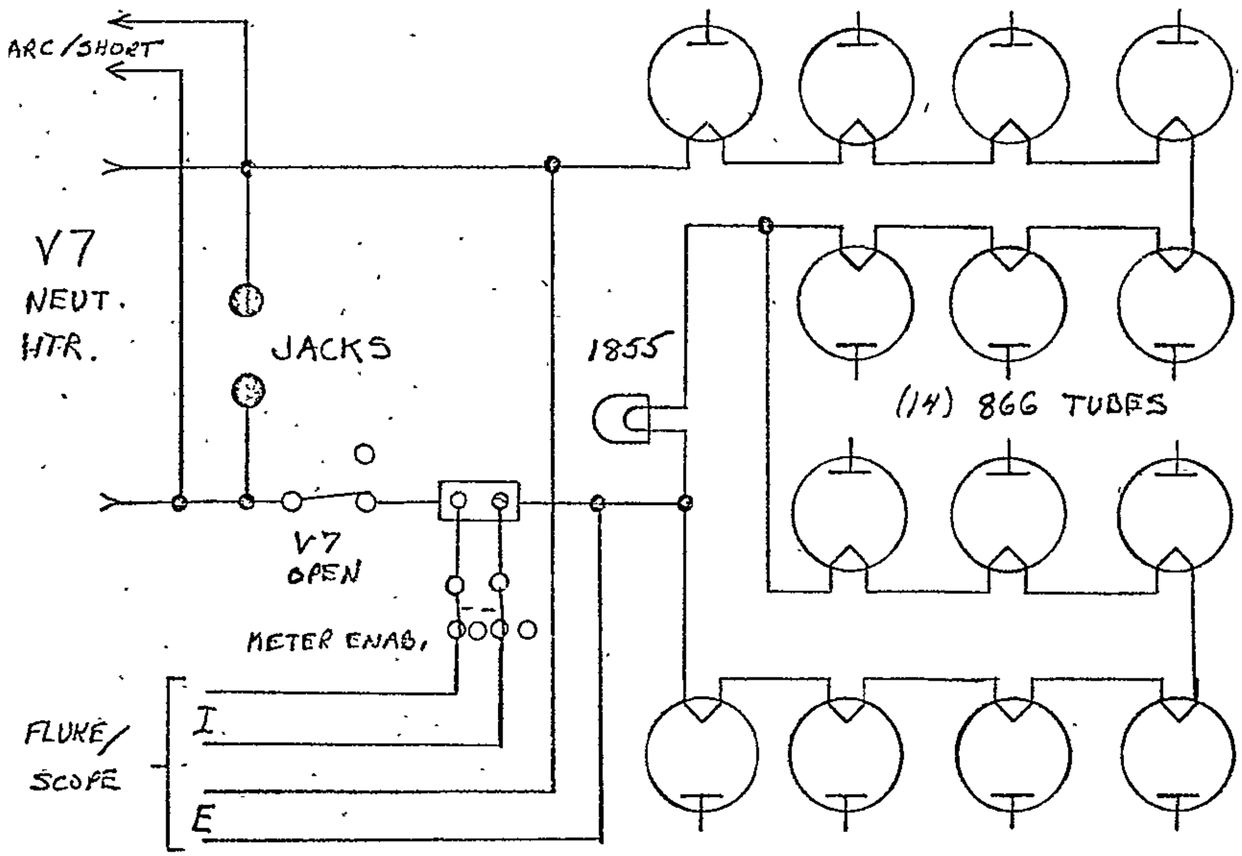
ANALYSIS TEST CONSOLE - NEUT. HTR.
PREPARED BY [signature] 7-1-68
CHECKED BY

MODEL REPORT NO PAGE

FIGURE 10-13



R COLD ≈ 1.2 Ω
R HOT ≈ 5.3 Ω
T.C. ≈ 40 SEC.

FORM 700

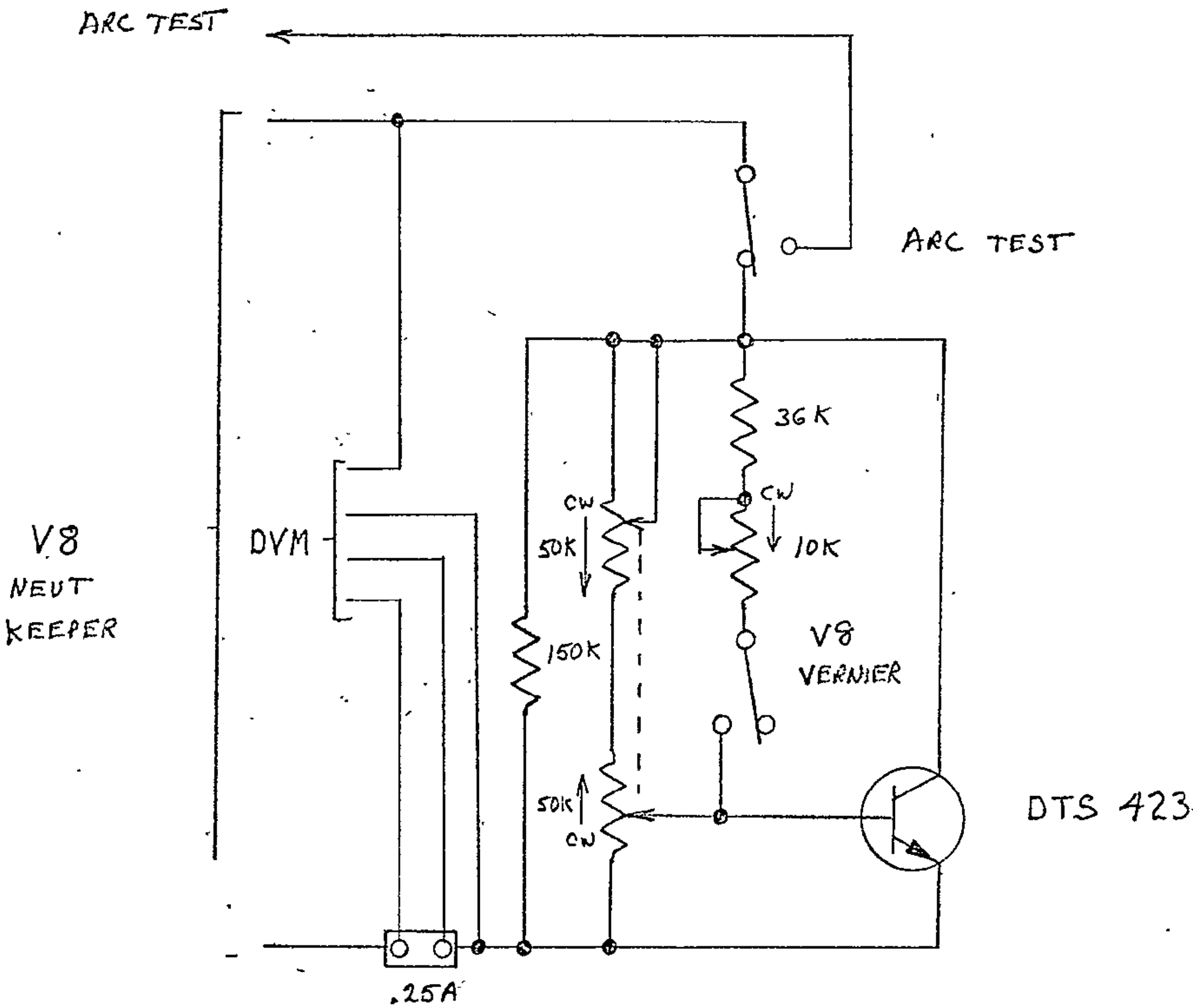
HUGHES AIRCRAFT CO.

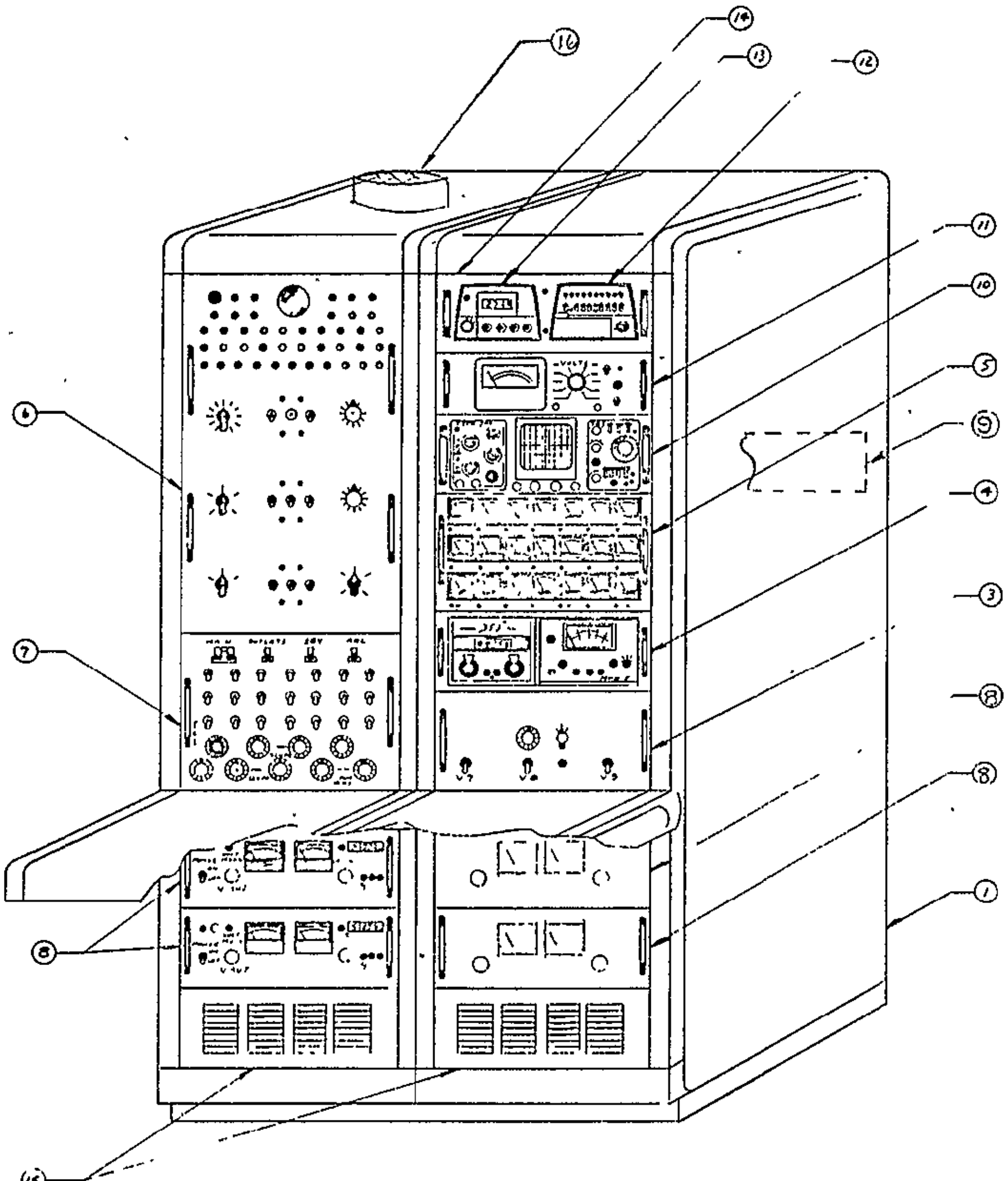
ANALYSIS TEST CONSOLE - NEUT. KPR. MODEL REPORT NO PAG

PREPARED BY [illegible] 7-2-68

CHECKED BY

FIGURE 10-14





1		EXHST-FAN 740CFM		[illegible]
2	PB 600	BLOWER, FILTER, 600 CFM STAITRON		[illegible]
1	719 D	ADAPTOR, MOUNTING RACK		[illegible]
1	515	DIGITAL THERMOMETER, DIGITEC		[illegible]
1	613	DIGITEC SCANNER		[illegible]
1	910 AR	VOLTMETER, FLUKE, RMS		11
1	RM 561 A	SCOPE, TEKTRONIX		[illegible]
1	QSB-28-8	POWER SUPPLY 28V SORENSEN		9
4	QRC 40-30A	POWER SUPPLY 40V SORENSEN		8
1		MASTER CONTROL PANEL, ASSEMBLE		7
1		VAPORIZER, THRUSTER, STATUS PANEL, ASSEMBLE		6
1		TELEMETRY PANEL ASSEMBLE		5
1		DVM & POWER SUPPLY ASSEMBLE		4
1		LOADS, V7 V8 & V9 NEUTRALIZER, ASS'Y		3
~~1~~		~~SOLAR PANEL SIMULATOR ASSEMBLE~~		2
1		CABINET, DOUBLE RACK ASSEMBLE		1
QTY REQD	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	ZONE	ITEM NO

LIST OF MATERIALS

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES AND PER MIL STD 8
XXX ±.010 XX ±.03 X ±.1 ANGLES ±0° 30'

MATERIAL

DR		DATE 6/1/7
CHK		7/1/7
APPD		

HUGHES

HUGHES AIRCRAFT COMPANY
CULVER CITY CALIFORNIA

TEST CONSOLE, DISPLAY (20-BB,

SIZE D | CODE IDENT NO 82577 | FIGURE 10-15

SCALE 3/16 | SHEET

11. Isothermal Calorimeter

A calorimeter is being constructed for the purpose of measuring the operating efficiencies of the power conditioner. The calorimetric method of measuring operating efficiences has the inherent advantage of measuring inefficiencies directly, so that a two percent error in measuring the inefficiency, for example, would lead to an error in calculating the efficiency of less than 0.2 percent if the efficiency is greater than 90 percent. This assumes, of course, that the input power can be measured to within less than 0.2 percent.

The calorimeter is of the isothermal type which indicates heat generation by measuring the rate of boil off of a liquid. The liquid used is one of the Freons (usually Freon 11 or Freon TF) because of their low toxicity, non-flammability, and non-conductance. The item under test is placed inside the inner chamber of the calorimeter X3182788. This chamber and the surrounding one are filled with Freon. A hole in the bottom of the inner chamber connects the Freon in the outer chamber with that in the inner one. The Freon in both chambers is maintained at the boiling point with heaters mounted in the chambers so that any additional heat input to the system, such as that from the item being tested, will be seen as an increase in the volume of the vapor. The reason for the outer chamber of Freon is to serve as a thermal insulator for the test chamber. The Freon vapor from both chambers is condensed in a condensor and returned to the outer chamber.

The vapor produced in the inner chamber goes through a small orifice in the lid and into the vapor space in the outer chamber before going to the condensor. A very sensitive differential pressure transducer, located on the lid to the inner chamber, senses the pressure difference between the inner and outer chambers caused by Freon vapor from the inner chamber as it passes through the small orifice into the outer chamber.

When the item under test begings to generate heat, the Freon flow rate increases which causes an increased pressure drop across the orifice. The increased output from the transducer causes the heater in the inner chamber to be turned down and a constant flow rate of Freon vapor (and, therefore, a constant heat output from the inner chamber) will be maintained, provided that the inner chamber heater was originally set at some value higher than the anticipated heat output of the item under test. The circuit includes a zero suppression so that this decreased is read directly. This readout obviates any data reduction. The heat generation rates can be read directly on a strip chart recorder, or they can be sent to any other data storage system.

In addition to the heaters which are part of the feedback system, the inner chamber also contains a calibration heater. This heater is used not only as a dummy load for calibrating but also assists in the initial warm-up. It can also be used to maintain a positive heat output when measuring endothermic reactions such as batteries under certain circumstances.

This calorimeter has been stressed for pressurization to 15 psig, with a safety factor of more than 4:1. This is to allow a range of operating temperatures to be attained. By adjusting the pressure in the range from 0 to 15 psig, for example, the boiling point of Freon 11 can be varied over the temperature range from 24 to 45^{o}C.

The assembly drawing is shown in Figure 1. The inner chamber, which is indicated by the dotted lines, has the following dimensions:

Length,	40" (inside)
Width,	10" (Inside)
Height,	35 3/8" (Inside)

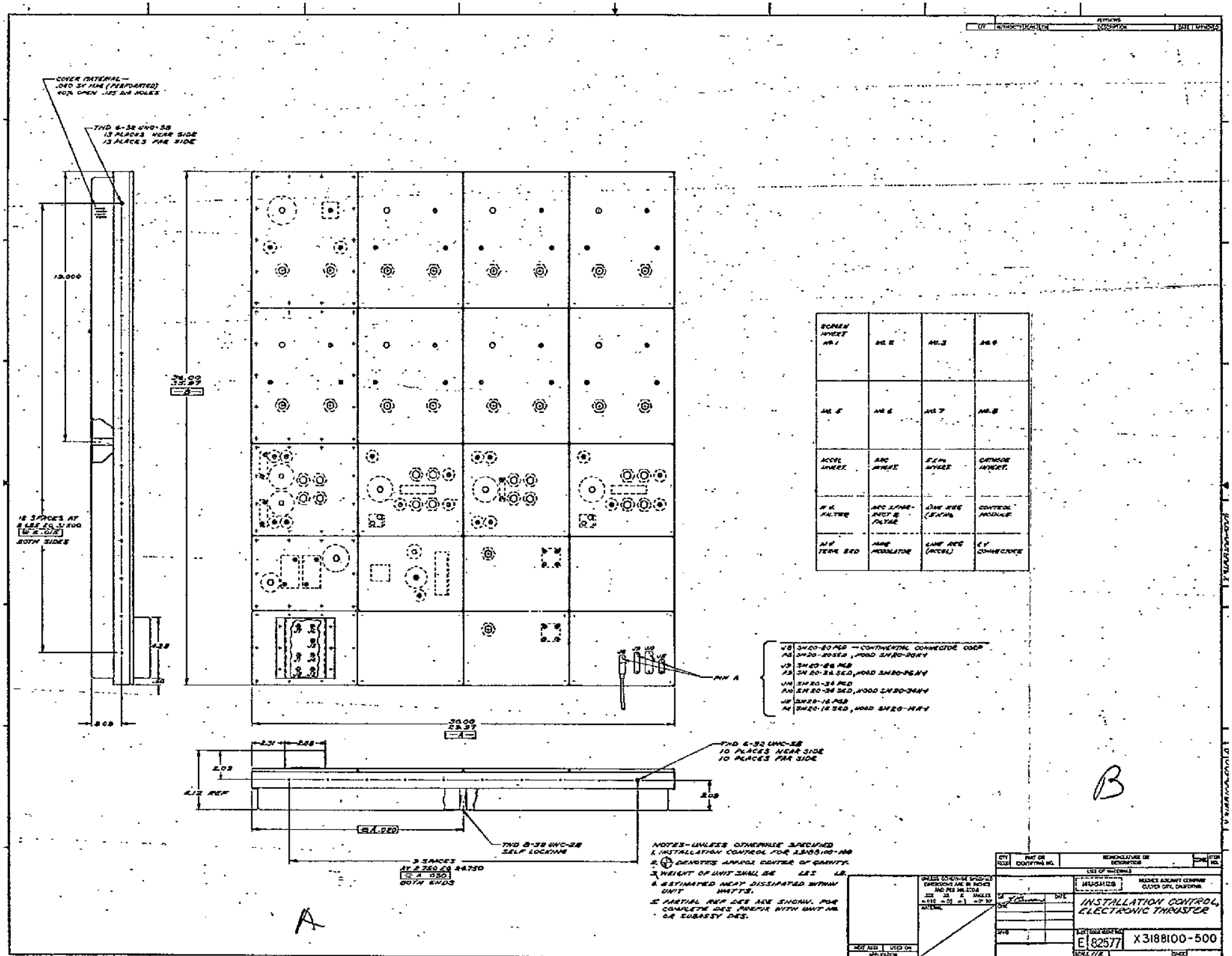
The maximum height available for an item being tested is about 32 inches, because the chamber must not be filled completely with Freon and the item under test must be completely submerged.

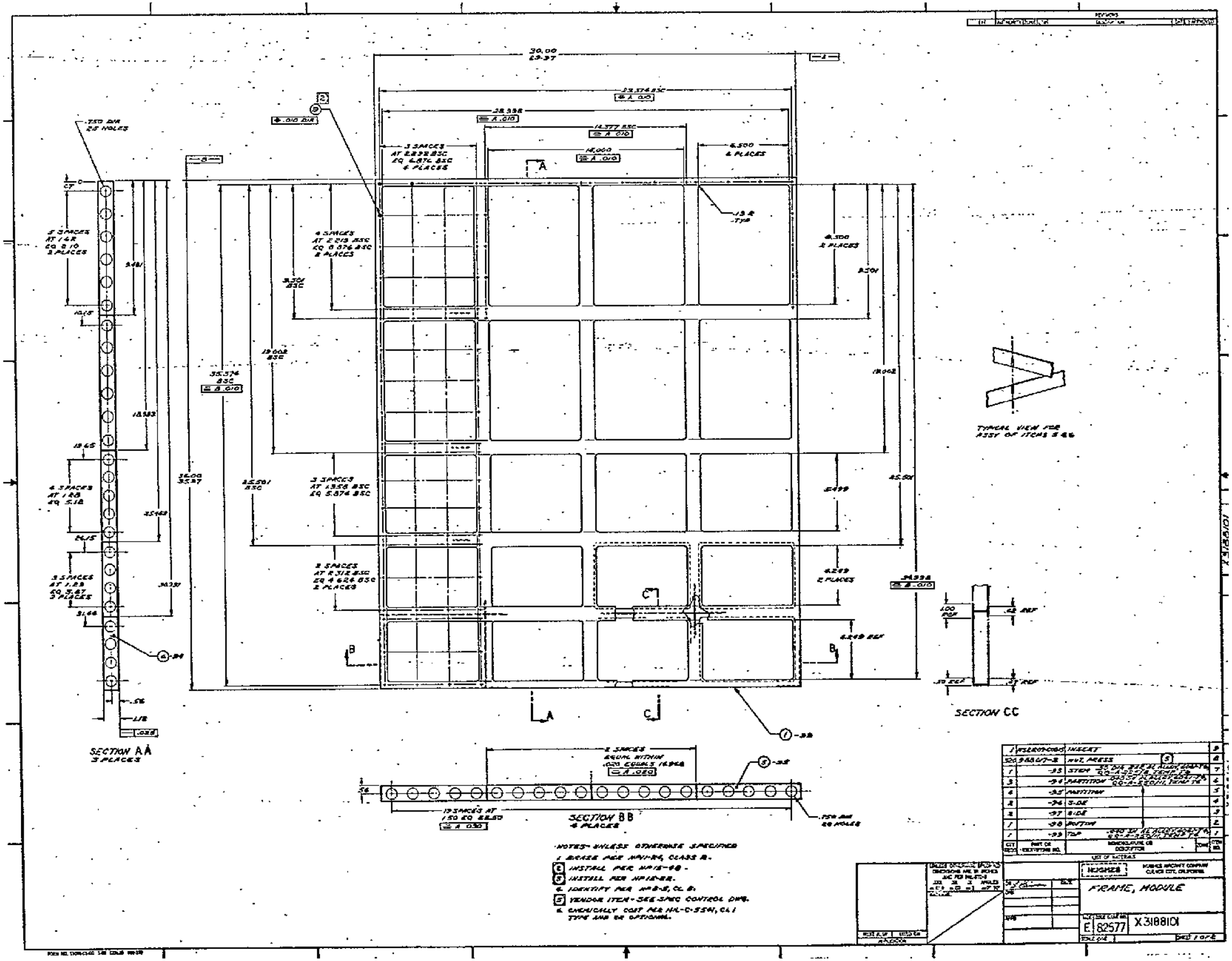
The total weight of the calorimeter is estimated to be 832 pounds, empty; and 2257 pounds filled with Freon 11.

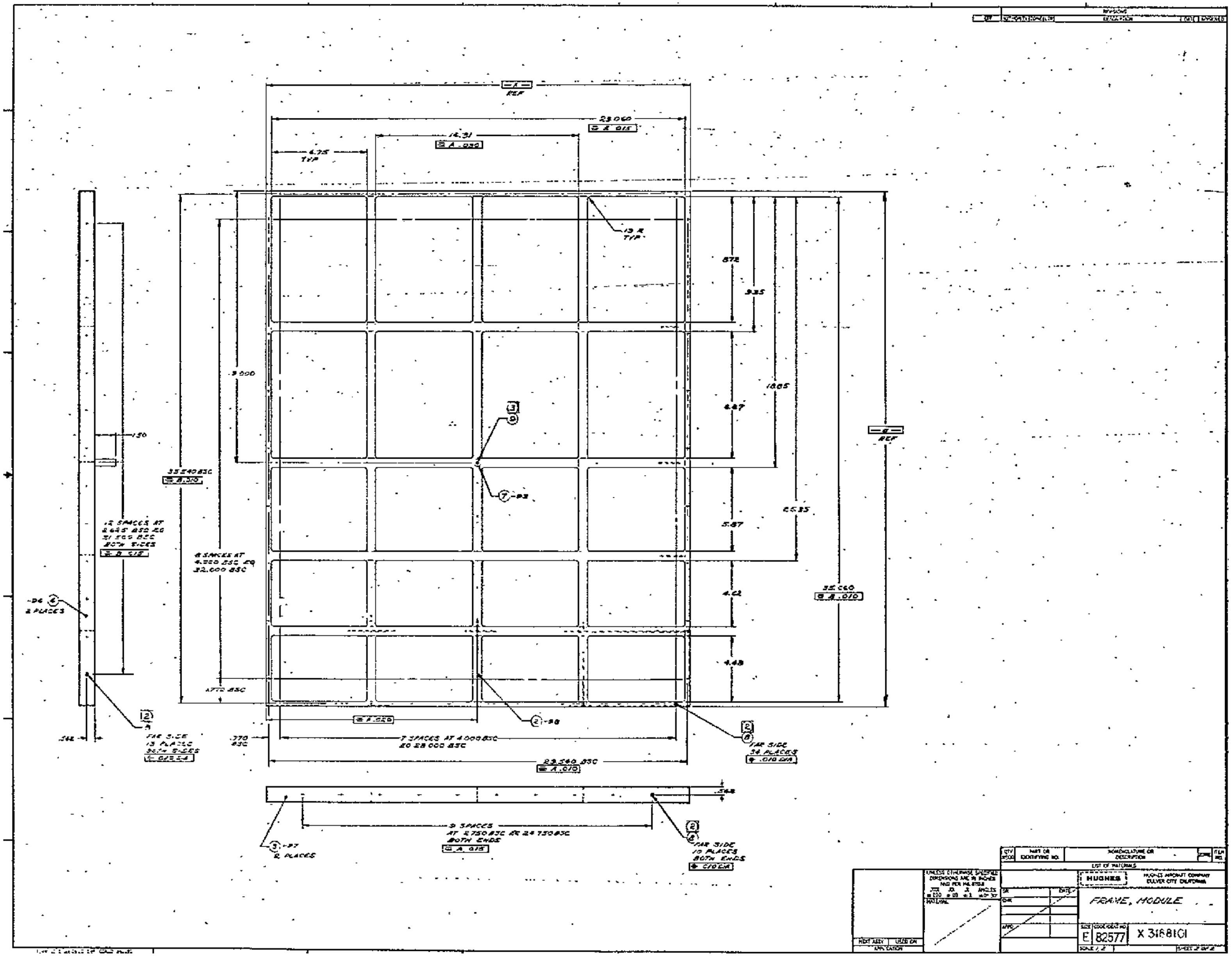
Power input to the feedback heater will be controlled by an SCR, which senses the signal from the differential pressure transducer. The unit is the Model 80035 made by the Thermo-Electric Company.

12. List of Drawings

Drawing Number	Title
X3188100-500	Installation Control
X3188101 (2 sheets)	Frame, Module
X3188103	Plate, Mounting
X3188104	Screen Inverter Assembly
X3188105	Screen Inverter Schematic
X3188106	Accelerator Inverter Assembly
X3188107	Accelerator Inverter Schematic
X3188109 (2 sheets)	Arc Inverter Schematic
X3188110	5 KHz Heater Inverter Assembly
X3188111	5 KHz Heater Inverter Schematic
X3188112	Cathode Inverter Assembly
X3188113	Cathode Inverter Schematic
X3188114	High Voltage Filter Assembly
X3188115	High Voltage Filter Schematic
X3188116	Arc Rectifier Filter Assembly
X3188117	Arc Rectifier Filter Schematic
X3188118	Line Regulator Assembly
X3188119	Line Regulator Schematic
X3188120 (2 sheets)	Control Module Assembly
X3188121-2	Master Oscillator & Phase Shifter Schematic
X3188122	Magnetic Modulator Assembly
X3188123 (2 sheets)	Magnetic Modulator Schematic
X3188126	High Voltage Connection Module Assembly
X3188127	Low Voltage Connection Module Assembly
X3188131	System Block Diagram
X3182788	Calorimeter Assembly Mark III


COVER MATERIAL—
THD 6-32 UNC-3B
13 PLACES NEAR SIDE
13 PLACES FAR SIDE
BOTH SIDES
BOTH ENDS
PIN A
CONTINENTAL CONNECTOR CORP
THD 6-32 UNC-3B
10 PLACES NEAR SIDE
10 PLACES FAR SIDE
THD 8-32 UNC-2B
SELF LOCKING
NOTES-UNLESS OTHERWISE SPECIFIED
2. DENOTES APPROX CENTER OF GRAVITY.
3. WEIGHT OF UNIT SHALL BE LBS LB.
4. ESTIMATED HEAT DISSIPATED WITHIN UNIT WATTS.
5. PARTIAL REF DES ARE SHOWN. FOR COMPLETE DES PREFIX WITH UNIT NO OR SUBASSY DES.
HUGHES
HUGHES AIRCRAFT COMPANY
CULVER CITY, CALIFORNIA
INSTALLATION CONTROL,
ELECTRONIC THRUSTER
E
82577
X3188100-500
A
B

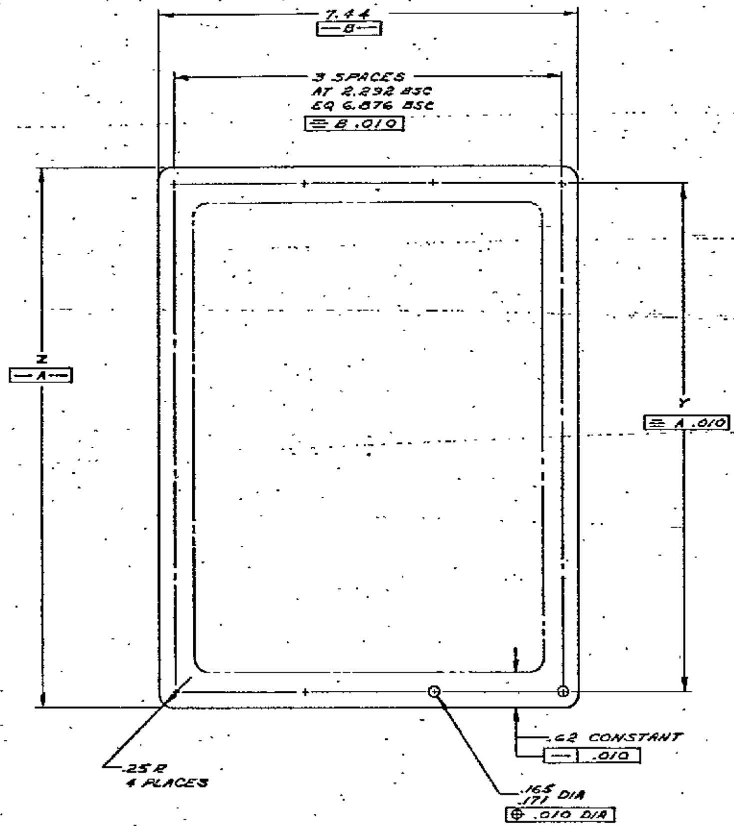

SECTION AA
3 PLACES
SECTION BB
4 PLACES
SECTION CC
TYPICAL VIEW FOR ASSY OF ITEMS 5 & 6
NOTES- UNLESS OTHERWISE SPECIFIED
1 BRAZE PER MPI-84, CLASS B.
INSTALL PER MPIS-48.
INSTALL PER MPIS-22.
4 IDENTIFY PER MPS-8, CL B.
5 VENDOR ITEM - SEE SPEC CONTROL DWG.
6 CHEMICALLY COAT PER MIL-C-5541, CL 1
TYPE AND OR OPTIONAL.
INSERT
NUT, PRESS
STEM
PARTITION
PARTITION
SIDE
SIDE
BOTTOM
TOP
LIST OF MATERIALS
HUGHES
HUGHES AIRCRAFT COMPANY
CULVER CITY, CALIFORNIA
FRAME, MODULE
E
82577
X3188101
X3188101



REF
23.060
TYP
13 R
TYP
35.560
35.560 BSC
25.560 BSC
7 SPACES AT 4.000 BSC
FAR SIDE
34 PLACES
BOTH ENDS
2 PLACES
9 SPACES
HUGHES
HUGHES AIRCRAFT COMPANY
CULVER CITY CALIFORNIA
LIST OF MATERIALS
NEXT ASSY
USED ON
APPLICATION
MATERIAL
FRAME, MODULE
E
82577
X 3188101

EFF	AUTHORITY	ZONE	LTR	DESCRIPTION	DATE	APPROVED

REVISIONS



DASH NO.	Z DIM.	Y DIM.
-1	5.19	2 SPACES AT 2.312 BSC EQ 4.624 BSC
-2	6.44	2 SPACES AT 1.958 BSC EQ 5.874 BSC
-3	9.44	4 SPACES AT 2.219 BSC EQ 8.876 BSC

NOTES - UNLESS OTHERWISE SPECIFIED

1. IDENTIFY PER HP8-5, CL B.
2. FINISH PER HP4-152.

QTY REQD	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	ZONE	ITEM NO.

LIST OF MATERIALS

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES AND PER MIL-STD-8
.XXX ±.010 .XX ±.03 .X ±.1 ANGLES ±0° 30'

MATERIAL
.050 SHEET
MAG ALLOY
AZ 31B-H24,
QQ-M-44,
TEMP H24

NEXT ASSY | USED ON
APPLICATION

DR [signature] DATE 5 SEP 68
CHK
APPD

HUGHES
HUGHES AIRCRAFT COMPANY
CULVER CITY, CALIFORNIA

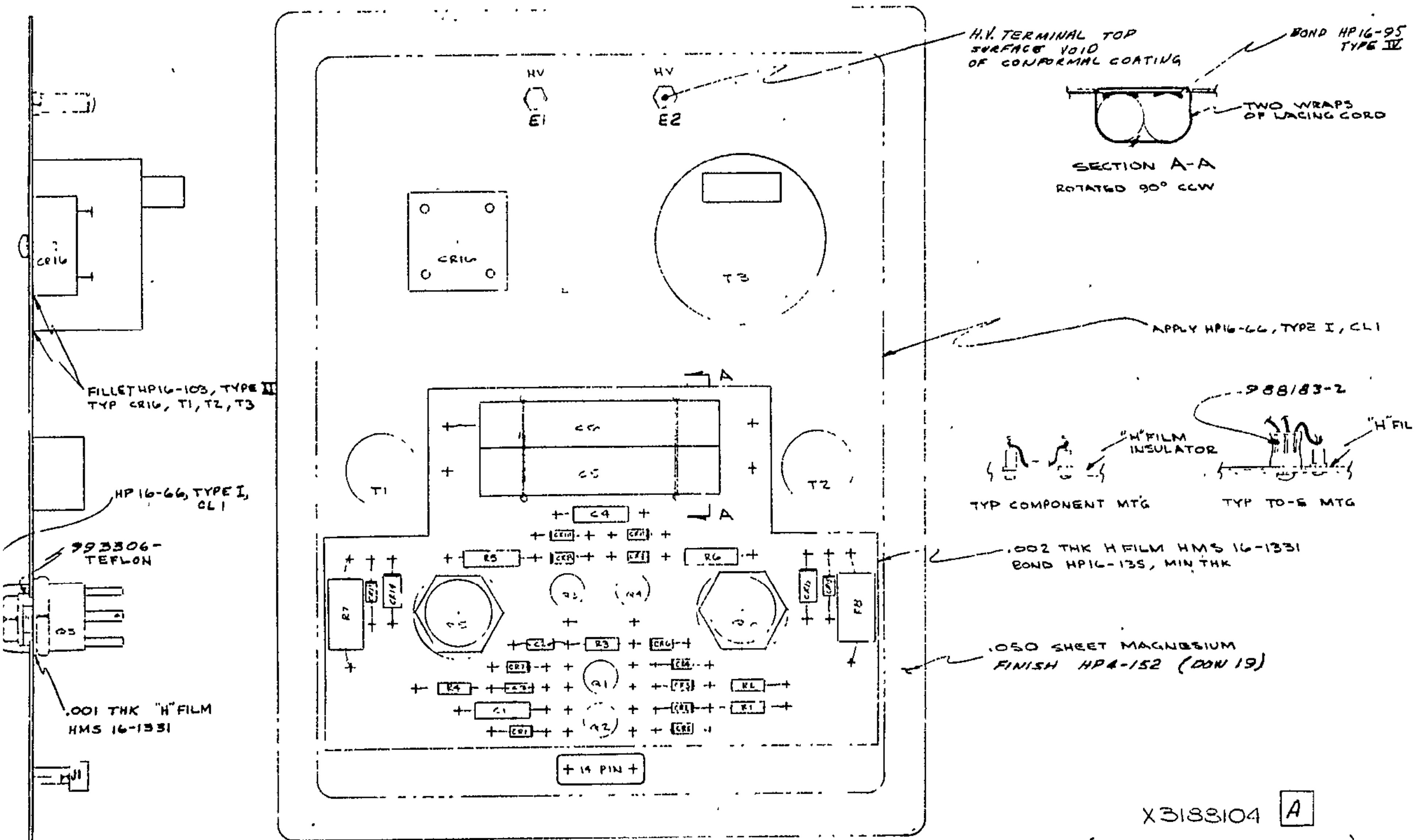
PLATE, MOUNTING

SIZE D CODE IDENT NO 82577 X3188103

SCALE 1/1 SHEET

NO. X3188103 REV A

FORM NO. 1103-C5-CC 1-65 OZALID 880-230

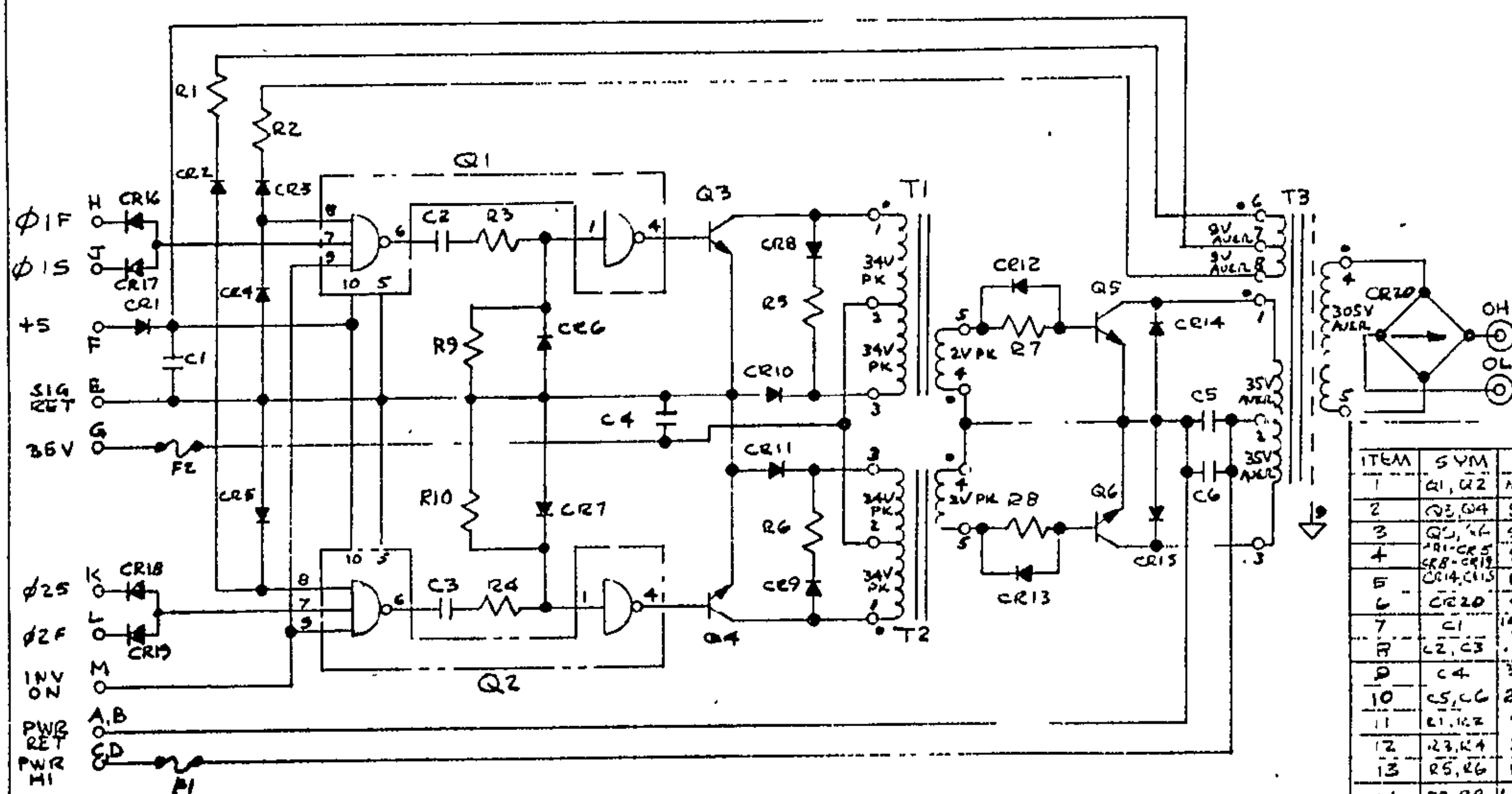


X3188104 A

(SIZE 7.44 X 9.44 X .25)

SCREEN INVERTER

9/18/68



PARTS LIST

ITEM	SYM	DESCRIP	SPEC	QTY	REV
1	Q1, Q2	MA 932 TO-5	FAIRCH	2	
2	Q3, Q4	SDT 5553	SOLITRON	2	
3	Q5, Q6	SDT 8805	"	2	
4	CR1-CR5 CR8-CR19	SEM 1N4942	SEMTECH	15	A
5	CR14, CR15	UTR 6440	UNITRODE	2	
6	CR20	SEM SA2258A	SEMTECH	1	
7	C1	10/20V CSR13SE106K	KEMET	1	
8	C2, C3	.1 /200V 55CCW104K	VITRAMON	2	A
9	C4	3.3/20V CSR13BH395K	KEMET	1	
10	C5, C6	20/200V 68F603H4 Herm. Seal	GE	2	
11	R1, R2	2K/1/4W-RC07GF202J	MIL-R-11	2	
12	R3, R4	30Ω/1/4W-RC07GF30RJ	"	2	A
13	R5, R6	10K/1/2W-RC20GF103J	"	2	
14	R7, R8	1Ω 3W WW-RW69V1R0	MIL-R-26	2	
15	T1, T2	HAC-SOTIF	HAC	2	
16	T3	HAC-SOTIF	HAC	1	
17	J1	14 PIN SUB.MIN. CONT. SERIES 20	CONTINENTAL	1	
18	F1	GFA-15A BUSSMAN	BUSSMAN	1	

PARTS CONTINUED

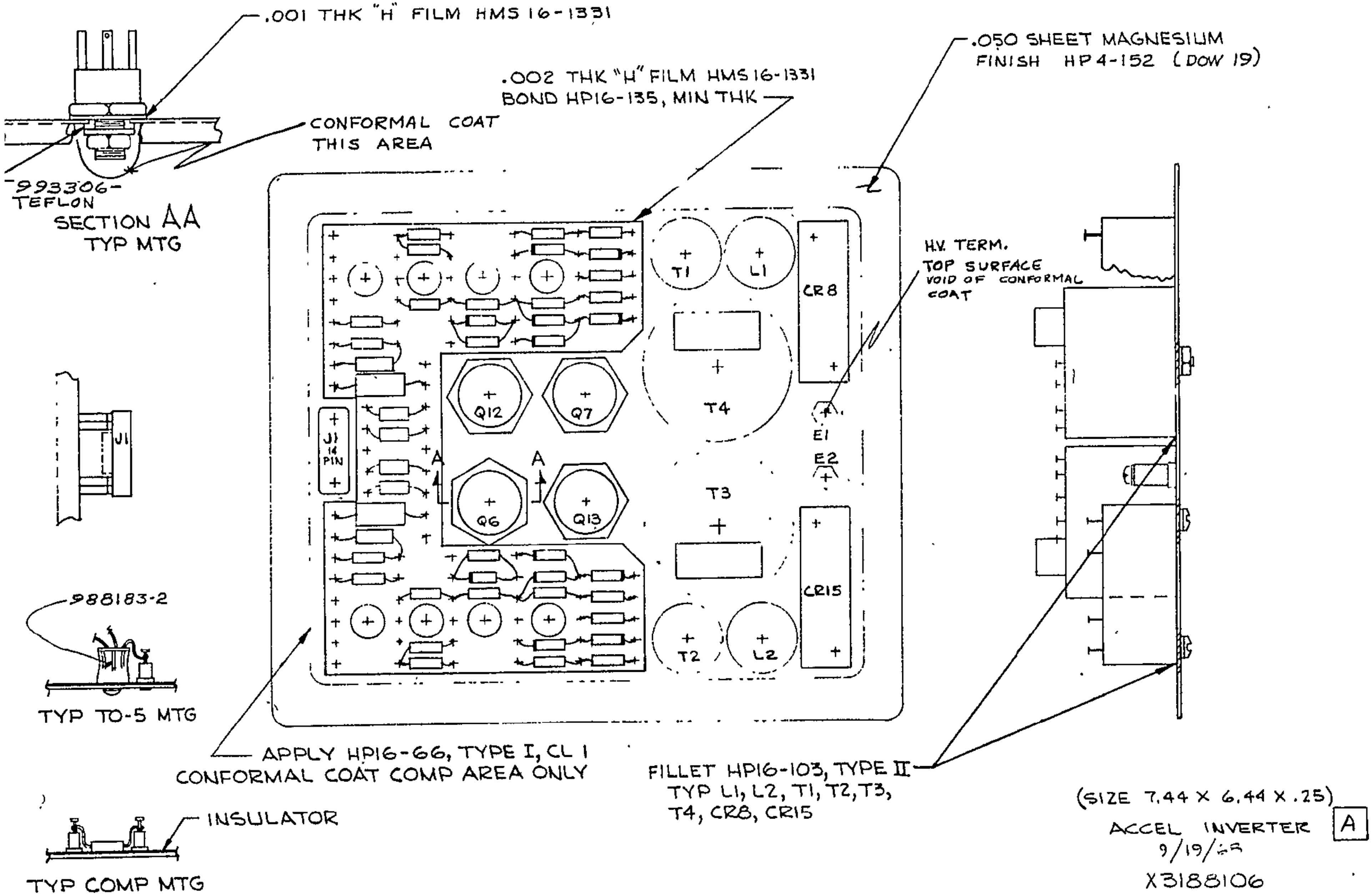
19	R9, R10	5.6Ω 1/4W RC07GF5R6IJ	MIL-R-11	2	A
20	CR6 CR7	IN 3070	TEX. INSTR	2	A
21	F2	GFA-1A	BUSSMAN	1	A

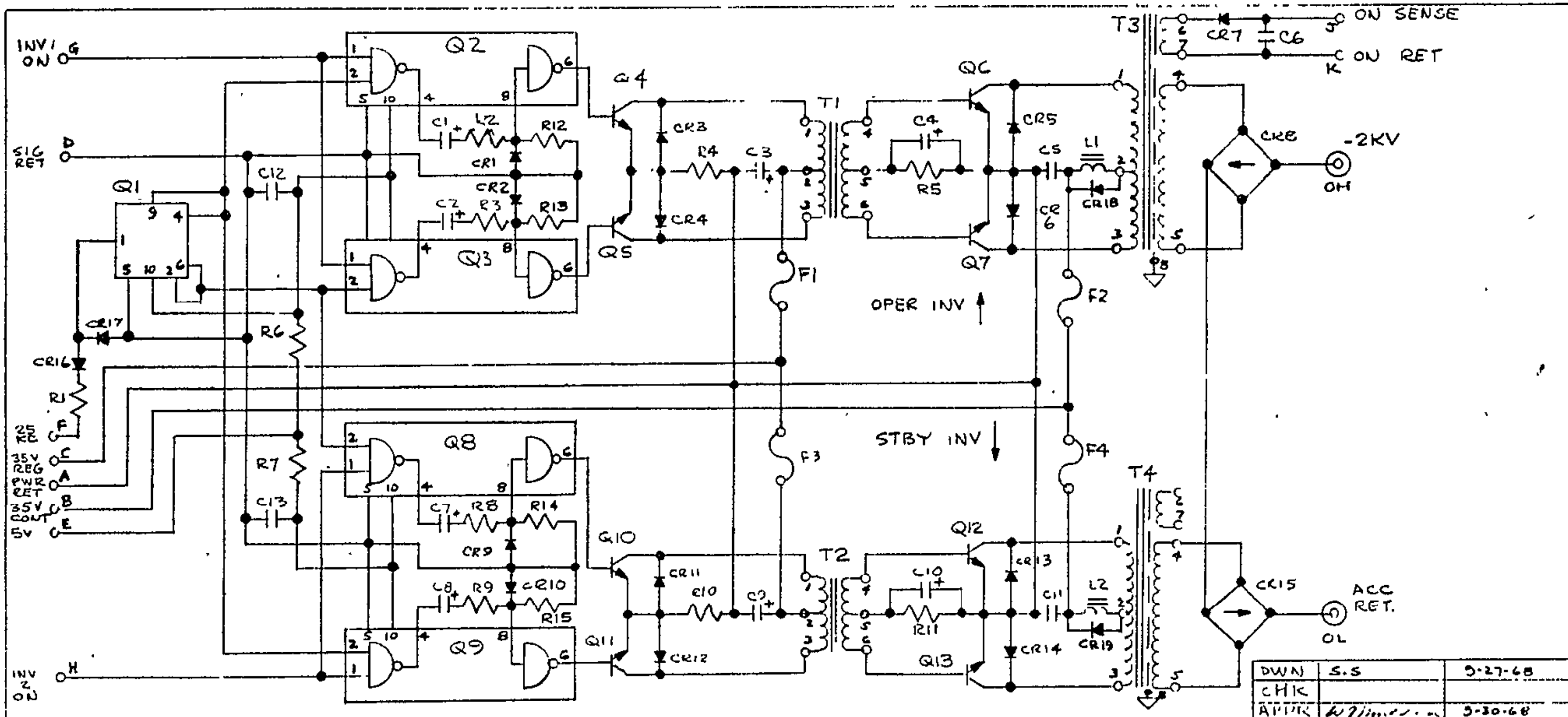
HUGHES AIRCRAFT CO.
EL SEGUNDO, CALIF.

TITLE

SCREEN INVERTER SCHEMATIC

DWN	S.S.	9-27-68	DWG NO X3188105	A 15OCT
CHK				
APPR	W. J. Madden	9-30-68		


.001 THK "H" FILM HMS 16-1331
CONFORMAL COAT THIS AREA
993306-TEFLON
SECTION AA
TYP MTG
.002 THK "H" FILM HMS 16-1331
BOND HP16-135, MIN THK
.050 SHEET MAGNESIUM
FINISH HP4-152 (DOW 19)
H.V. TERM.
TOP SURFACE
VOID OF CONFORMAL COAT
J1
J1 14 PIN
Q12
Q7
Q6
Q13
T1
L1
CR8
T4
E1
E2
T3
CR15
T2
L2
A
988183-2
TYP TO-5 MTG
APPLY HP16-66, TYPE I, CL I
CONFORMAL COAT COMP AREA ONLY
FILLET HP16-103, TYPE II
TYP L1, L2, T1, T2, T3,
T4, CR8, CR15
INSULATOR
TYP COMP MTG
(SIZE 7.44 X 6.44 X .25)
ACCEL INVERTER
9/19/63
X3188106



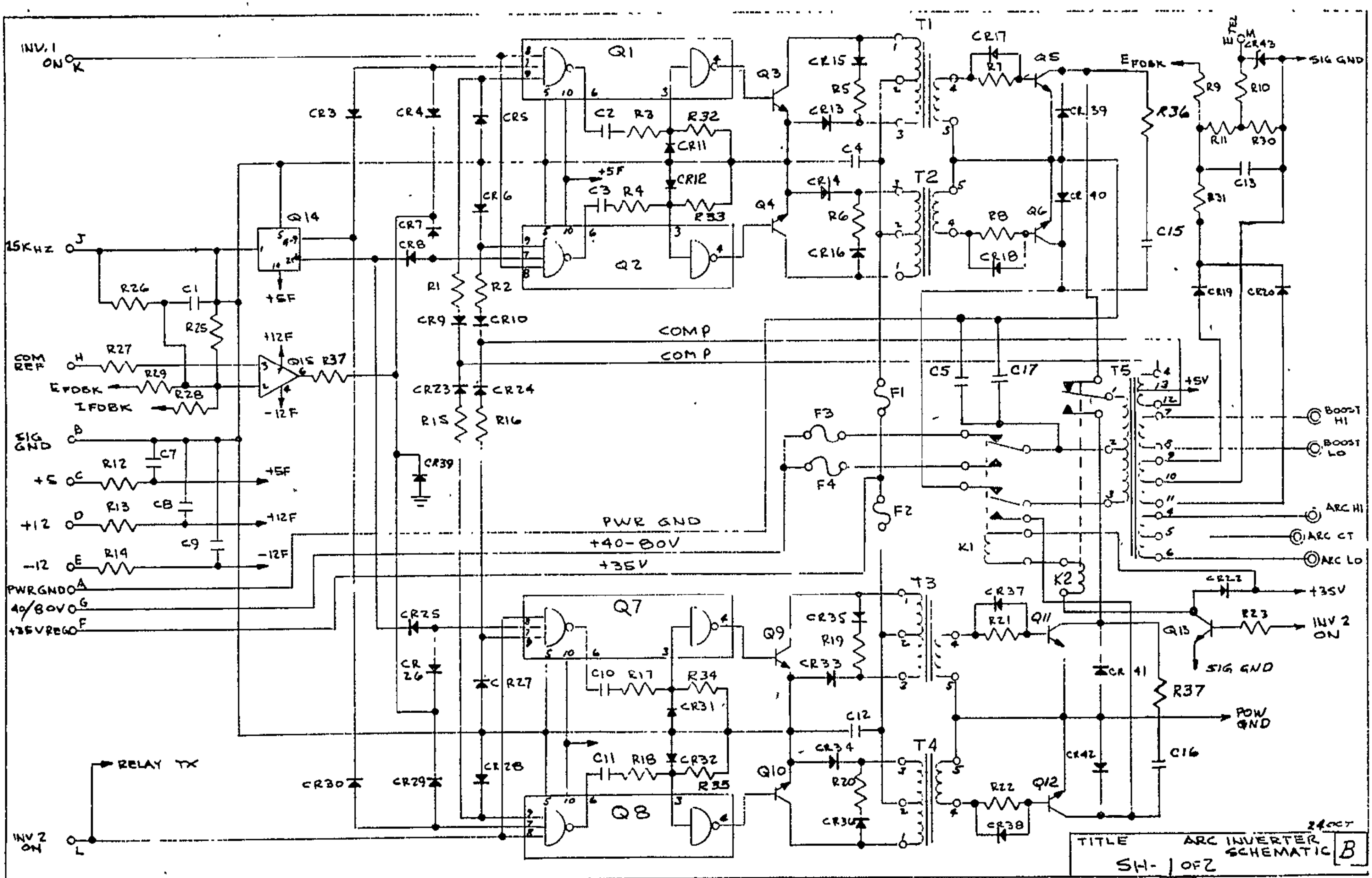
DWN	S.S	9-27-68
CHK		
APPR	W Jimerson	9-30-68

PARTS LIST

HUGHES AIRCRAFT CO.
EL SEGUNDO, CALIF

ITEM	SYM	DESCRIP	SPEC	QTY	REV
1	Q1	μA948 (TO-5)	FAIRCH	1	
2	Q2, Q8 Q3, Q9	μA932 (TO-5)	"	4	
3	Q4, Q5, Q10, Q11	SDT5553	SOLITRON	4	
4	Q6, Q7, Q12, Q13	SDT8905	"	4	
5	CR3, CR4, CR7, CR11, CR12, CR16, CR17	SEM-1N 4942	SEMTECH	7	A
6	CR6, CR5, CR13, CR14	SEM 35F2E	"	4	
7	CR8, CR15	SEM [illegible] 5KV, 200MA	"	2	
8	C3, C9	0.68/75 CSR13EH684	KEMET	2	
9	CR18, CR19	SEM 35F2E	SEMTECH	2	
10	C5, C11	15/75 CSR13EH156	KEMET	2	
11	C4, C6, C10	3.3/15 CSR13B0335	"	3	
12	R1	1K/1/4W	MIL-R-11	1	
13	R2, R3, R8, R9	30/1/4W	"	4	A
14	R6, R7	100Ω/1/4W	"	2	
15	R4, R10	22/1/4W	"	2	
16	R5, R11	3/3WWW	MIL-R-26	2	
17	F1, F2	1A GFA	BUSSMAN	2	
18	F2, F3	10A GFA	"	2	
19	C1, C2, C7, C8	0.1/100V CK06	MIL-C-1105	4	
20	J1	14 PIN SL B-MIN SERIES 20	CONTINENTAL	1	
21	T1, T2	HAC-ADT-1F		2	
22	T3, T4	HAC-AOT-1F		2	
23	L1, L2	HAC-AL-1F		2	
24	C1, C2, C7, C8	1.0/35V CSR13BF105	KEMET	4	B
25	C12, C13	0.1/100V CK06	MIL-C-1105	2	
26	CR1, CR2, CR9, CR10	1N 3070		4	A
27	R12, R13, R14, R15	5.6/1/4W	MIL-R-11	4	A

TITLE	DWG NO.	
ACCEL INVERTER SCHEMATIC	X3188107	B



TITLE ARC INVERTER SCHEMATIC B

24 OCT

SH- 1 OF 2

X3188109

PARTS LIST

ITEM	SYM	DESCRIP	SPEC	QTY	REV
33	C13	15UF/75V CSR13BF156	KEMET	1	
34		-			
35	CR11, CR12, CR31, CR32	IN 3070	TEX INSTR	4	A
36	R32, R33, R34, R35	5.6 / 1/4W RC07	MIL-R-11	4	A
37	R36, R37	51Ω 1W RC32	"	2	B
38	C15, C16	3300PF/500V CM06-332-3	CUSTOM ELEC	1	B

PARTS LIST

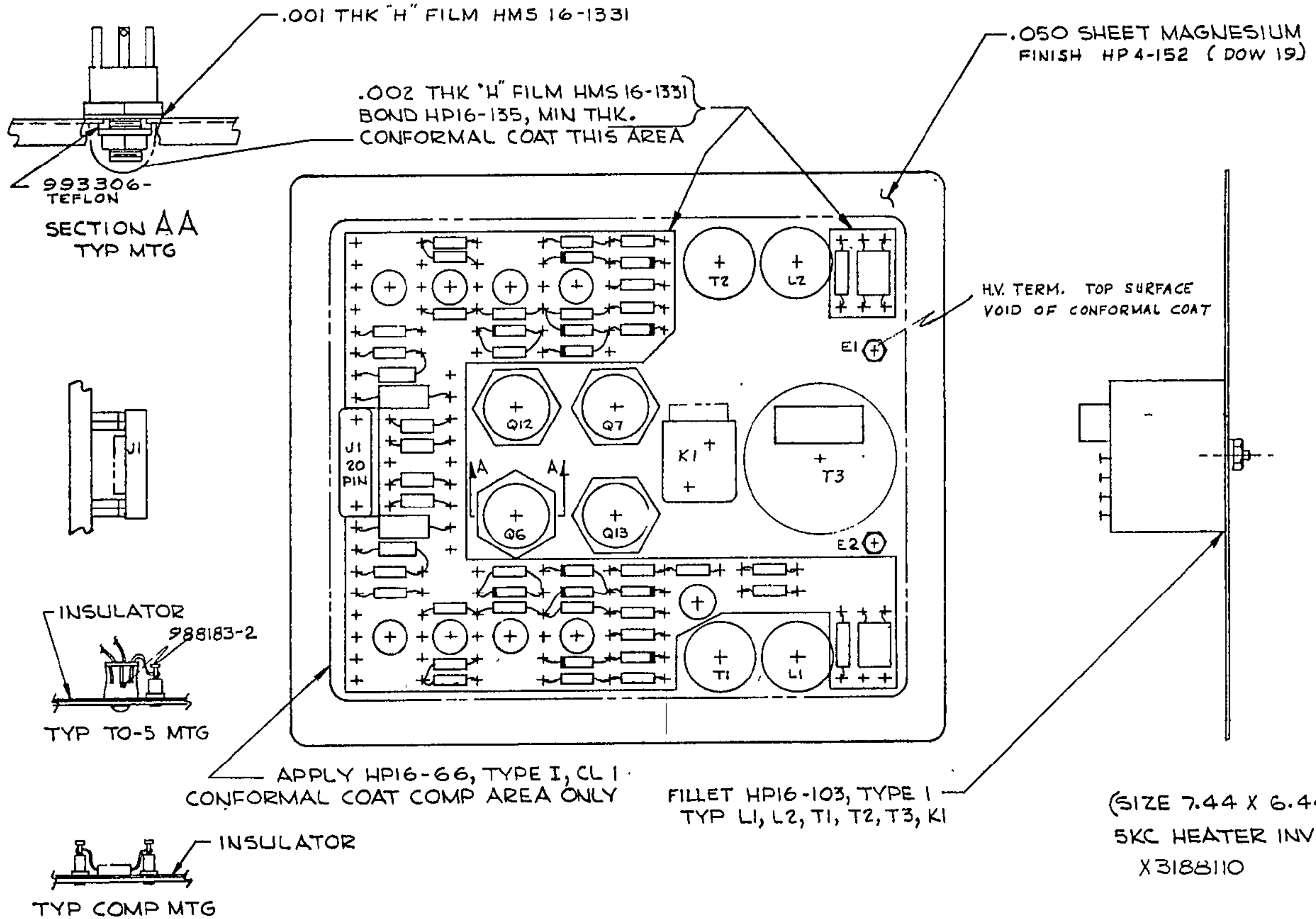
ITEM	SYM	DESCRIP.	SPEC	QTY.	REV
1	Q1 Q2 Q7 Q8	μA732 (TO-5)	FAIRCHILD	4	
2	Q3, Q4, Q9, Q10, Q13	SDT 5553	SOLITRON	5	
3	Q5, Q6, Q11, Q12	SDT 8975	"	4	
4	Q14	μA 948 (TO-5)	FAIRCHILD	1	
5	Q15	μA 709 (TO-5)	"	1	
6	CR3-10, CR13-20, CR23-30, CR33-39	IN 4942	SEMTECH	32	B
7	CR39 THRU CR42	UTR6440	UNITRODE	4	
8	C1, C2, C3, C10, C11, C14	.1/100V CK06CW104K	VITRAMON	6	
9					
10	C4, C12	39/15V CSR13BH395K	"	2	
11	C5, C17	20 UF/200V 29F603H4	GE	2	A
12	C7	33/15V CSR13BD335	KEMET	1	
13	C8, C9	1/35V CSR13BF105	"	2	
14	R1, R2, R15, R16	700/1/4W	MIL-R-11	4	
15	R3, R4, R17, R18	30/1/4W	"	4	A
16	R5, R6, R19, R20	5.1K /W RC32	"	4	B
17	R7, R8, R21, R22	1Ω/3W WW	MIL-R-26	4	
18	R9, R10, R11	10K/1/8W RN60	MIL-R-10509	3	B
19	R29, R28	SEL AT ASSY RN60	MIL-R-10509	2	B
20	R30, R31	3K/1/8W RN60	MIL-R-10509	2	B
21	R12, R13, R14	10W/1/4W	MIL-R-11	3	
22	R23	1.5K /1/4W	"	1	
23	R37	1K/1/8W RN60	MIL-R-10509	1	B
24	F1, F2	3A. GFA	BUSSMAN	2	
25	F3, F4	10A. GFA	"	2	
26	T1, T2 T3	HAC-SDT1F	HAC	3	
27	T5	HAC-AOT-1F	HAC	1	
28	CR43	LVA 68A	TRW	1	B
29	K1, K2	DEUTSCH JRZGEIP6A	DEUTSCH	2	A
30	R26	100K-1% 1/8W RN60	MIL-R-10509	1	
31	R27, R25	10K 1% 1/8W RN60	"	2	B
32	J1	14 PIN CONN 3EK20	CONTINENTAL	1	

HUGHES AIRCRAFT CO
EL SEGUNDO, CALIF

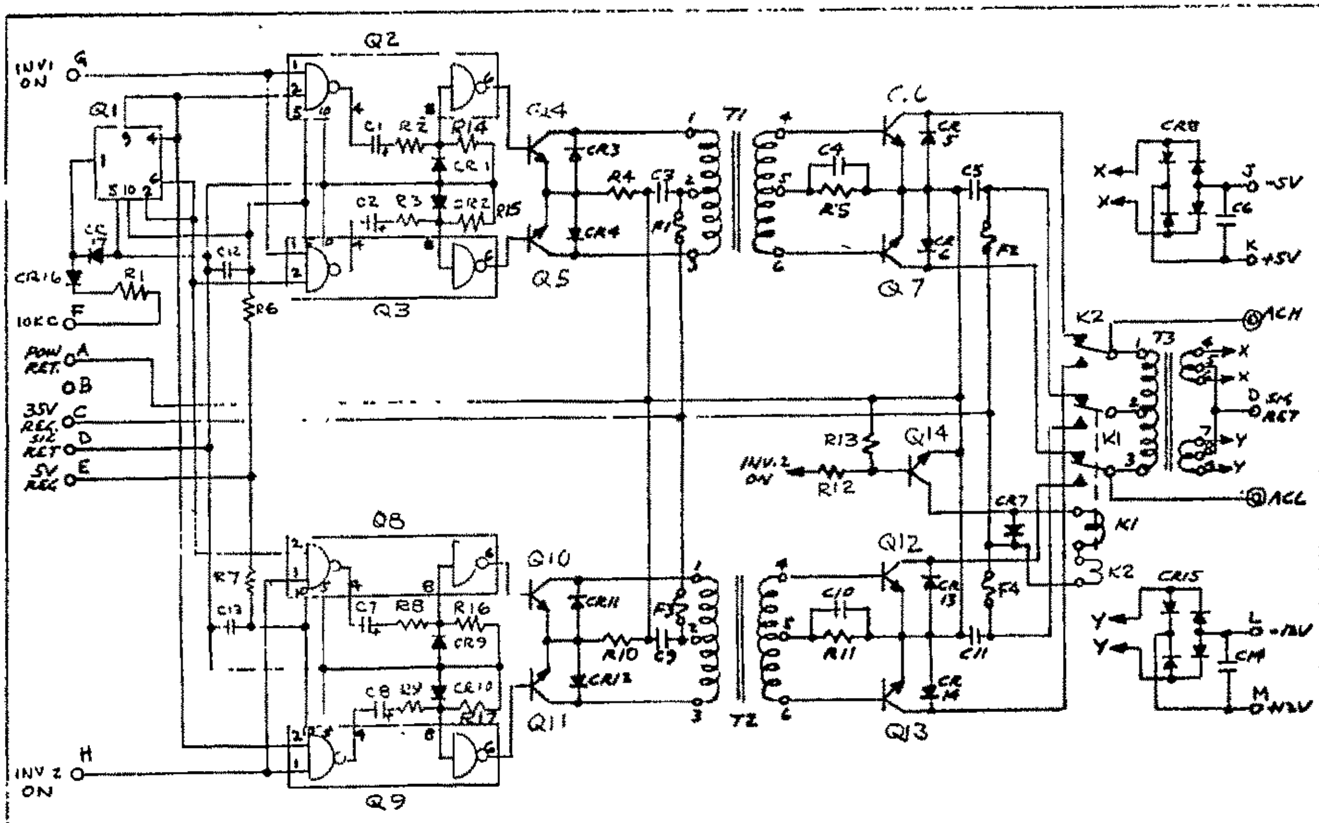
ARC INVERTER SCHEMATIC

24 KT

DWN	M.B.	9-30-68	DWG NO X3188109 — B
CHK			
APP	W/[illegible]	9-30-68	SHEET 2 OF 2



(SIZE 7.44 X 6.44 X .25)
5KC HEATER INVERTER $\boxed{A}$
X3188110
23 SEP 68



Ⓞ SCREW TERMINAL

PARTS LIST

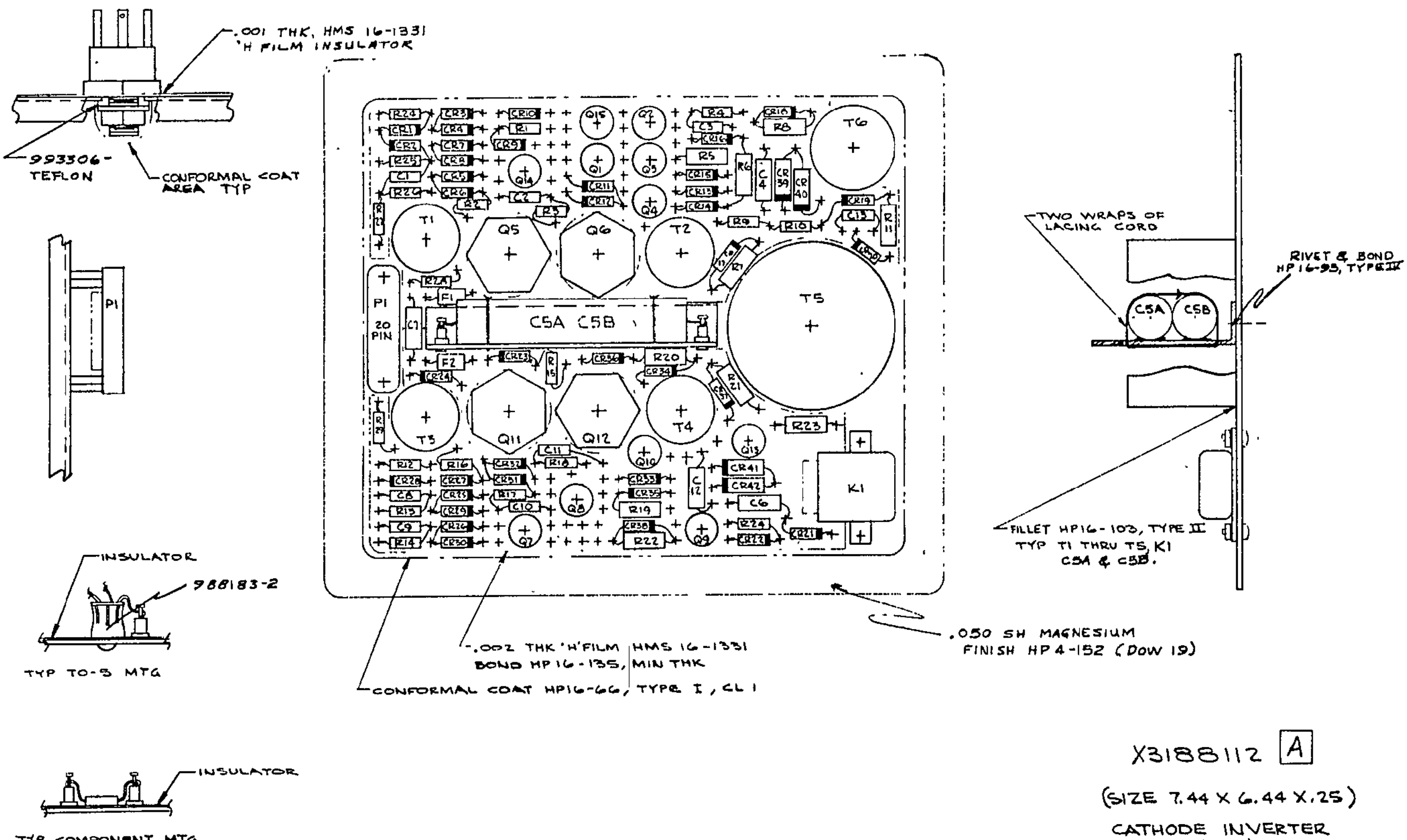
ITEM	SYM.	DESCRIP.	SPEC.	QUANT.	REV.
1	Q1	μA948 705	FAIRCH.	1	
2	Q2, Q3, Q8, Q9	μA932 705	"	4	
3	Q4, Q5, Q10, Q11, Q14	SDT 5553	SOLITRON	5	
4	Q6, Q7, Q12, Q13	SDT 8805	"	4	
5	CR1, CR2, CR9, CR10	IN 3070	SEMTECH	11	A
6	CR3, CR4, CR11, CR12	"	"		
7	CR7, CR16, CR17	"	"		
8	CR5, CR6, CR13, CR14	35F2E	"	4	
9	CR8, CR15	SBR1F	"	2	
10					
11	C1, C2, C7, C8	1μF 15V TANT CSR13BD105K	KEMET	4	A
12	C3, C9	0.68MFD/75V CSR13BH684	"	2	
13	C4, C10	3.9MFD/10V CSR13E395K	"	2	
14	C5, C11	15MFD/75V CSR13CH156	"	2	
15	C6, C14	1MFD/50V CSR13EG105	"	2	
16	C12, C13	0.1MFD/100V CK06	VITRAMON	2	
17	R1, R12	1K/¼W COMP	MIL-R-11	2	
18	R2, R3, R8, R9	30 " "	"	4	A
19	R13	10K " "	"	1	
20	R4, R10	22 " "	"	2	
21	R5, R11	3Ω/3W W.W.	MIL-R-26	2	
22	R6, R7	100/¼W COMP	MIL-R-11	2	
23	F1, F3	1A 6FA	BUSSMAN	2	
24	F2, F4	10A 6FA	"	2	
25	T1, T2	HAC-HDT-1F	HAC	2	
26	T3	" HDT-1F	"	1	
27	R14-R17	5.6/¼W RC07 GF5R6J	MIL-R-11	4	A
28	J1	15 PIN SUB-MIN SERIES 20	CONTINENTAL	1	
29	K1, K2	2PDT	DEUTSCH JR26B1P6A	2	

HUGHES AIRCRAFT CO.
EL SEGUNDO, CALIF.

TITLE: 5KHz HEATER INVERTER SCHEMATIC

A 15OCT

DWN	WJM	9-18-68	DWG. NO.
CHKD			X3188111
APPD	W J [illegible]	9-30-68	



X3188112 A

(SIZE 7.44 X 6.44 X .25)

CATHODE INVERTER
9/23/68

PARTS LIST

ITEM	SYM	DESCRIP		SPEC	QTY	REV
33	CR11, CR12, CR31, CR32	IN 3070		TEX. INSTR	4	A
34	R28, R29, R30, R31, R37, R38, R39, R40	5.6 / 1/4W	RC07	MIL-R-11	4	A
35	C15, C16	20μf/200V 29F603H4		GE	2	A
36	R32	910 Ω / 1/8 W	RN 60	MIL-R 10509		B
37	R33	5.1K / 1/8 W	RN 60	MIL-R-10509		
38	C13	10/50 V CSR 13 BG 106		KEMET		
39	R34	20K / 1/8 W	RN 60	MIL R 10509		
40	R35 R36	2.2K / 1/8 W	RN 60	MIL-R-10509		
41	C17	.03 μf / 500V CM 08E 303-3				
42	C18	.0068 μf / 500V CM07F682-3				
43	R41	750 / 1/4 W				
44	C19	0.1μf / 200V				
45	C20	.27μf / 10V				
46	R27, R42	3.16 K / 1/8 W	RN 60	MIL-R-10509		
47	CR 44	IN 827A				
48	C21	150μf / 15V CSR 13 BD 157		KEMET		
49	R43, R44, R45	SELECT - 1/8 W	RN 60	MIL-R-10509		
50	CR 45	LVA 68A		TRW		
51	C22	1/50 V				
52	C6	10/75 V				
53	R47	2.4 K / 1/2 W				
54	C24	150/15V				
55	C25	.0047 / 500V				
56	R49	300 / 1W				
57	C26	.01 μf / 500V				B

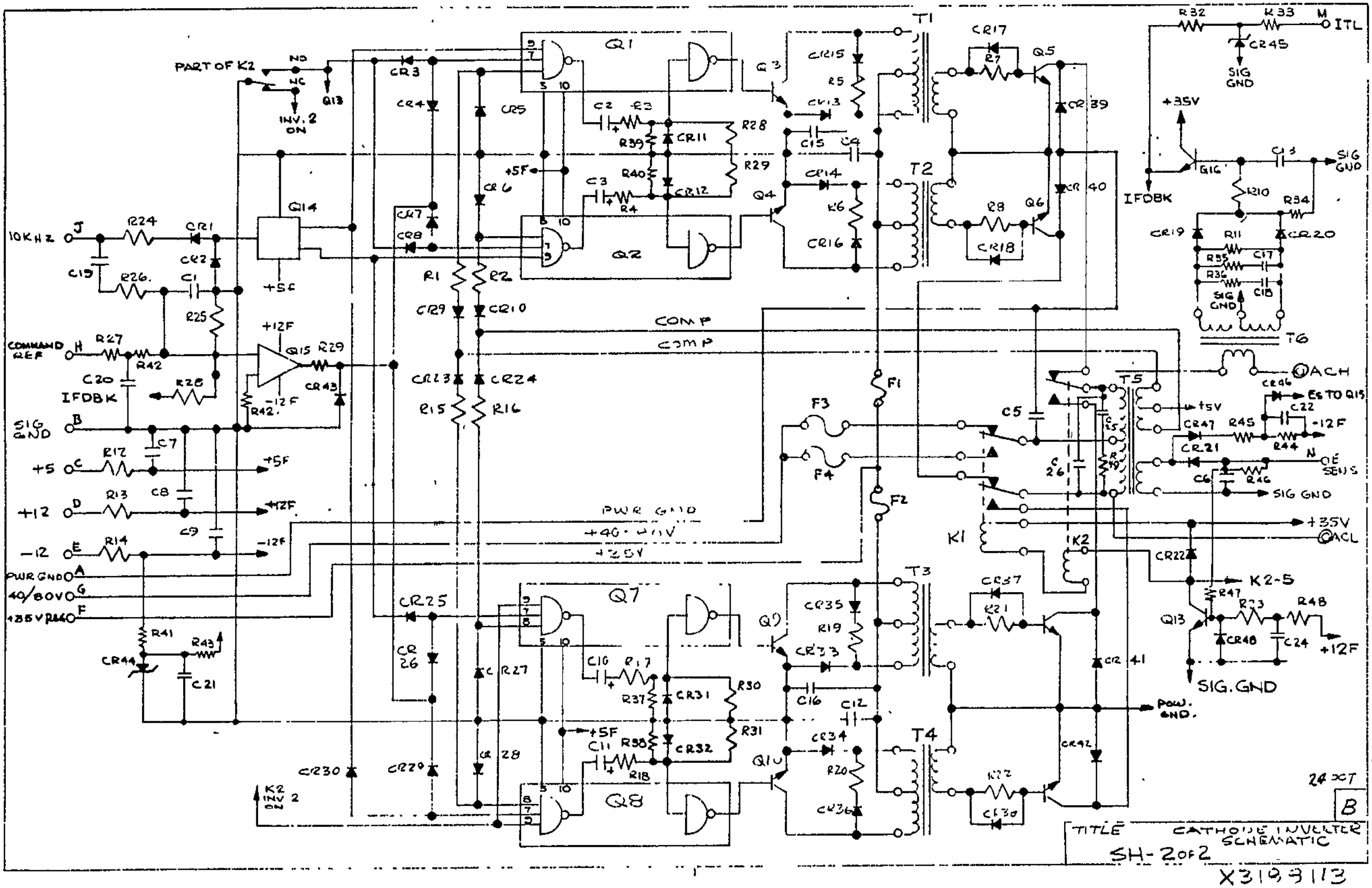
PARTS LIST

ITEM	SYM	DESCRIP	SPEC	QTY	REV
1	Q1, Q4, Q7, Q8	μA952 (TO-5)	FAIRCHILD	4	
2	Q3, Q4, Q9, Q10, Q13, Q16	SDT 5553	SOLITRON	5	
3	Q5, Q6, Q11, Q12	SDT 8805	"	4	
4	Q14	μA948 (TO-5)	FAIRCHILD	1	
5	Q15	μA 709 (TO-5)	"		
6	CR46, CR47, CR48 CR1-CR10, CR13-CR30, CR33-CR38, CR43	1N4942	SEMTECH	34	A
7	CR 39 THRU CR42	UTR6440	UNITRODE	4	
8	C1, C14	0.1/100V CK06CW103K	VITRAMON	2	
9	C2, C3, C10, C11	1μf/15V CSR13BD105K	KEMET	4	A
10	C4, C12	3.3/75V CSR13F335K	"	2	
11	C5	2/200V 29F2206 HERM SEAL	GE	1	A
12	C7	3.3/15V CSR13BD335	KEMET	2	
13	C8, C9	1/35V CSR13BF105	"	3	
14	R1, R2, R15, R16	20Ω/1/4W	MIL-R-11	4	
15	R3, R4, R17, R18	30/1/4W	"	4	A
16	R5, R6, R19, R20	10K/1/2W	"	4	
17	R7, R8, R21, R22	1Ω/3WWW	MIL-R-26	4	
18	R9, R42	10K/1/4W	MIL-R-11	1	
19	R10	1K/1/4W	"	1	
20	R11	1K-3W.W.W.	MIL-R-26	1	
21	R12, R13, R14	10K/1/4W	MIL-R-11	3	
22	R23, R48	3K/1/4W	"	1	
23	R24	1K-1/4W	MIL-R-11	1	
24	F1, F2	3A GFA	BUSSMAN	2	
25	F3, F4	10A - GFA	"	2	
26	T1, T2, T3, T4	HAC - CDT1F	HAC	4	
27	T5	HAC - COTF1	HAC	1	
28	T6	HAC - CCTF1	HAC	1	
29	K1, K2	DEUTSCH JR26EIPGA	DEUTSCH	2	
30	R26, R46	100K-1%-1/4W RN 60	MIL-R-10509	1	
31	R25	10K-1%-1/4W RN 60	"	2	
32	J1	14PIN CONNECTOR SER 20	CONTINENTAL	1	

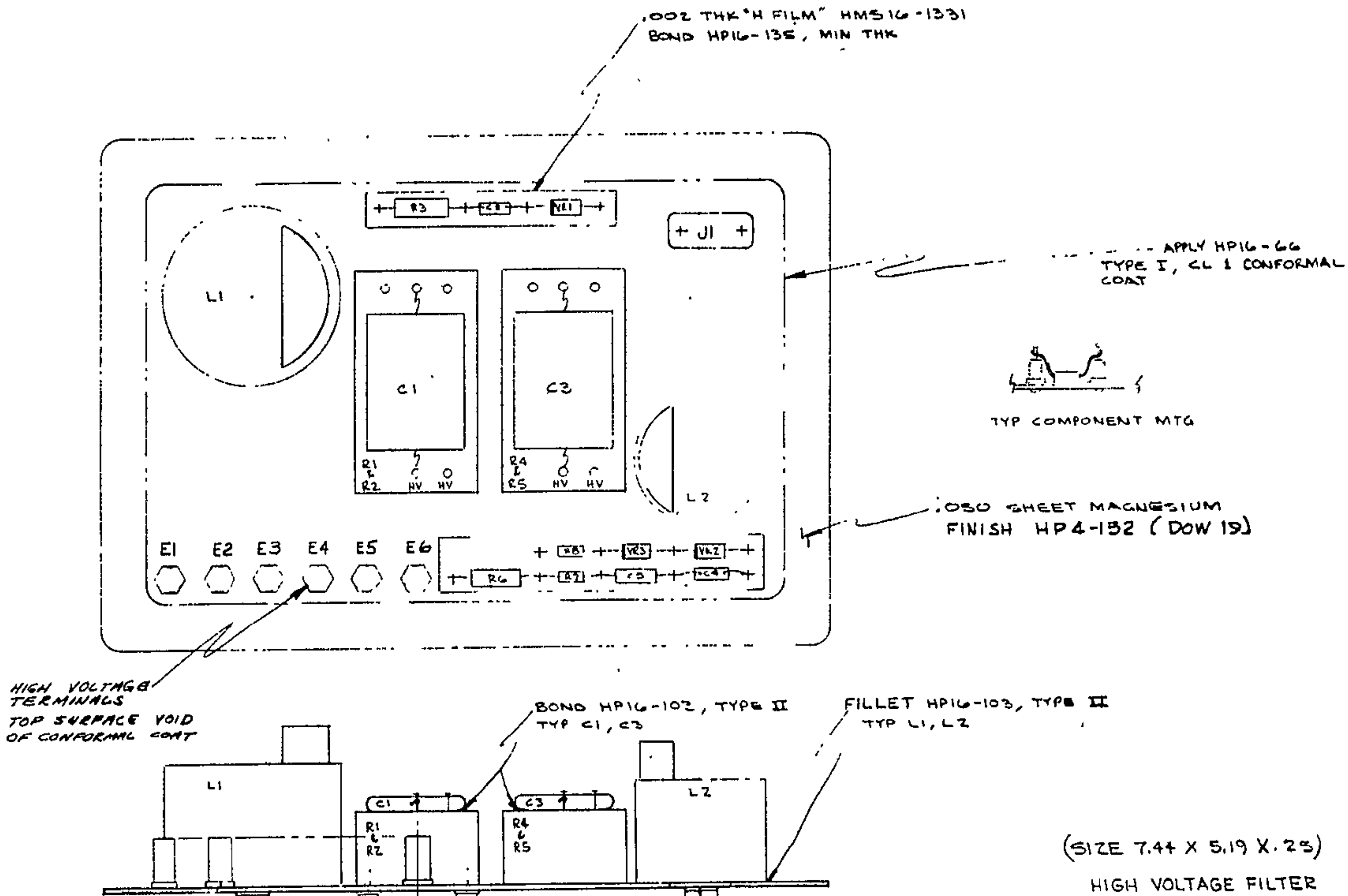
HUGHES AIRCRAFT CO
EL SEGUNDO, CALIF.

CATHODE INVERTER
SCHEMATIC

DWN	S.S.	9-27-68	DWG NO. X3188113 B 24 OCT
CHK			
APP	W. Jim [illegible]	9-30-68	SH 1 OF 2



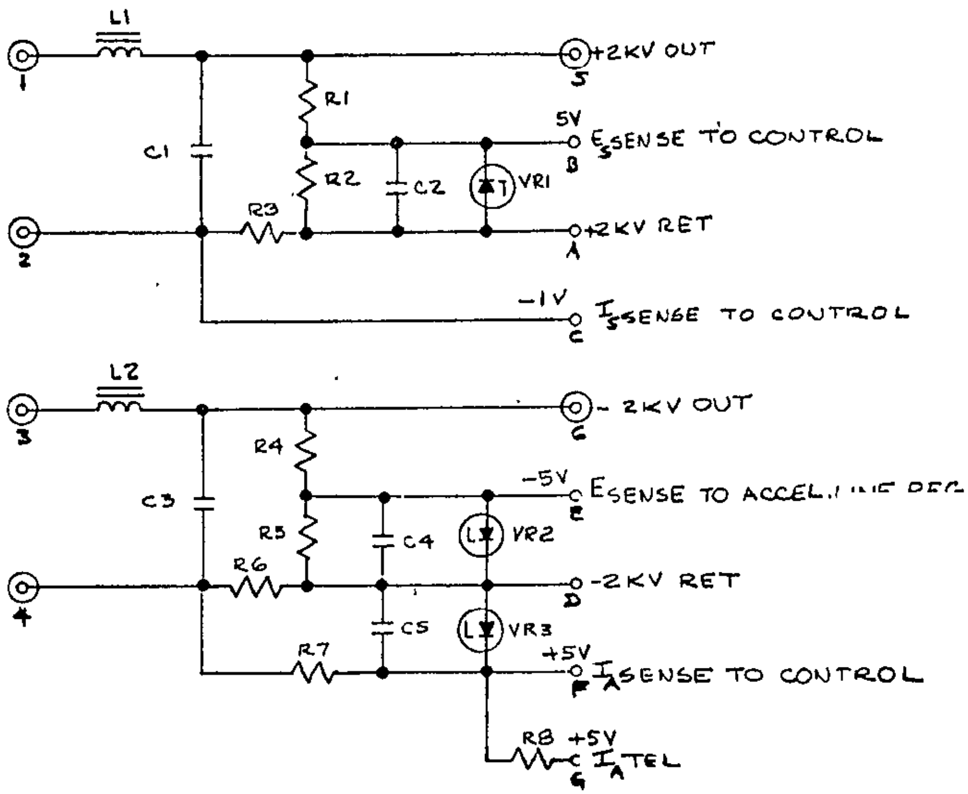
10KHZ J
COMMAND REF H
SIG GND B
+5 C
+12 D
-12 E
PWR GND A
40/80V G
+35V RTN F
PART OF K2
NO
NC
Q13
INV. 2 ON
Q14
Q15
Q1
Q2
Q3
Q4
Q5
Q6
Q7
Q8
Q9
Q10
T1
T2
T3
T4
T5
T6
F1
F2
F3
F4
K1
K2
COMP
PWR GND
+40/80V
+35V
+5F
+12F
-12F
IFDBK
ITL
SIG GND
+35V
ACH
ACL
ES TO Q15
E SENS
K2-5
POW. GND.
SIG. GND
K2 INV 2 ON
TITLE CATHODE INVERTER SCHEMATIC
SH-2 OF 2
B
X3193113



(SIZE 7.44 X 5.19 X .25)

HIGH VOLTAGE FILTER

X3188114 A



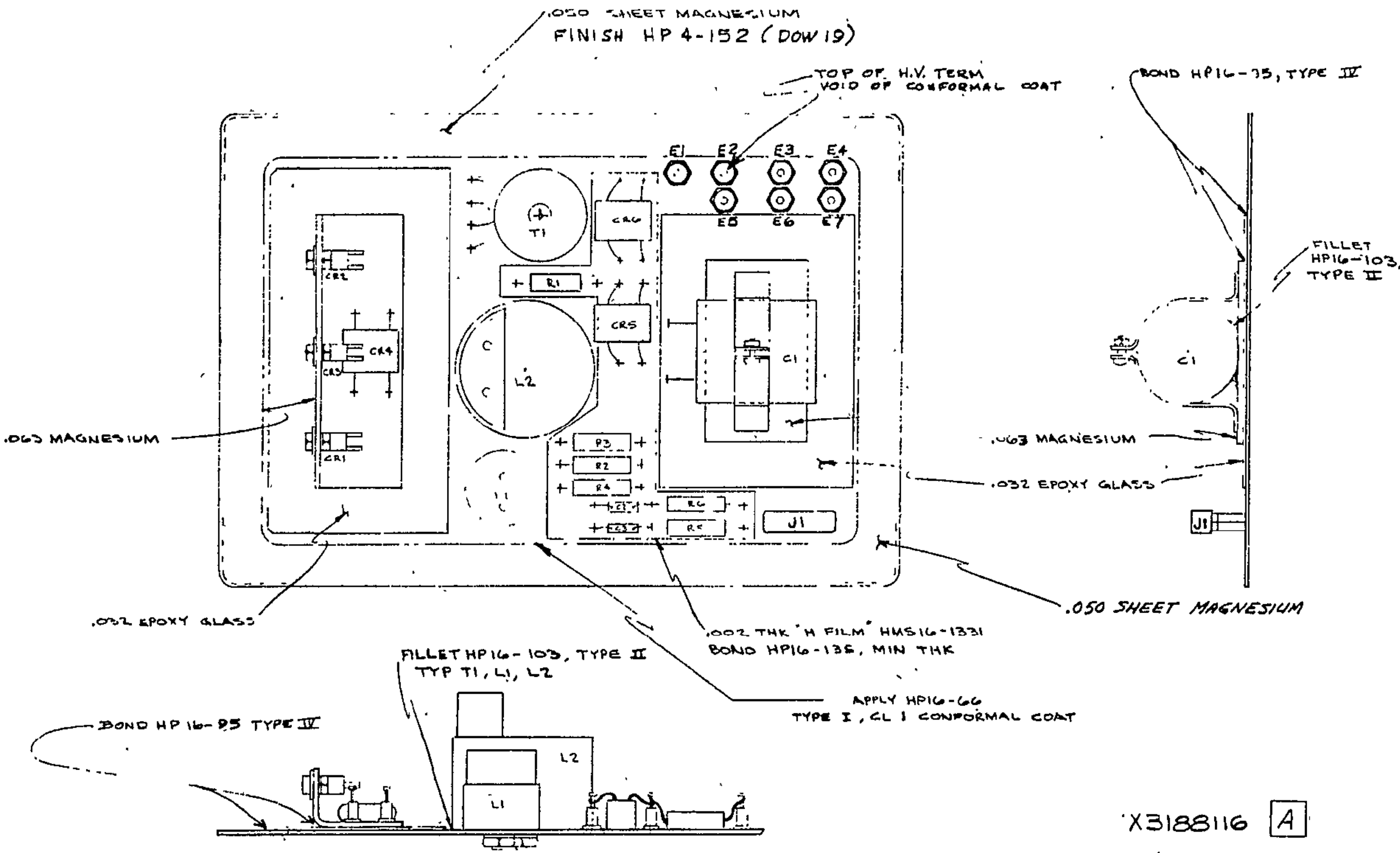
PARTS LIST

ITEM	SYM	DESCRIP	SPEC	QTY	REV
1	L1	HAC SFI-F	HAC	1	
2	L2	HAC AFI-F	"	1	
3	C1	CUSTOM CM RIA5C25C2K .005/5KV MICA	CUSTOM	1	
4	C3	CUSTOM CM RIA402502K 0.005/4KV MICA	"	1	
5	C2, C4	0.1MFD/100V CK06	VITRAMON	2	
6	C5	1/50V TANT CSR13BG105	KEMET	1	
7	VR1 VR2, VR3	7V/400MW 1N754A		3	
8	R1, R4, R2, R5	HAC SPECIAL	HAC	4	
9	R3	1Ω/3 WWW	MIL-R-26	1	
10	R6	50Ω/3WWW	"	1	
11	R7	470/1/4W COMP	MIL-R-11	1	A
12	R8	10K/1/4W COMP	"	1	
13	J1	9 PIN-SERIES SUB-MIN.	CONTINENTAL	1	

HUGHES AIRCRAFT CO.
EL SEGUNDO, CALIF.

TITLE
H.V. FILTER SCHEMATIC

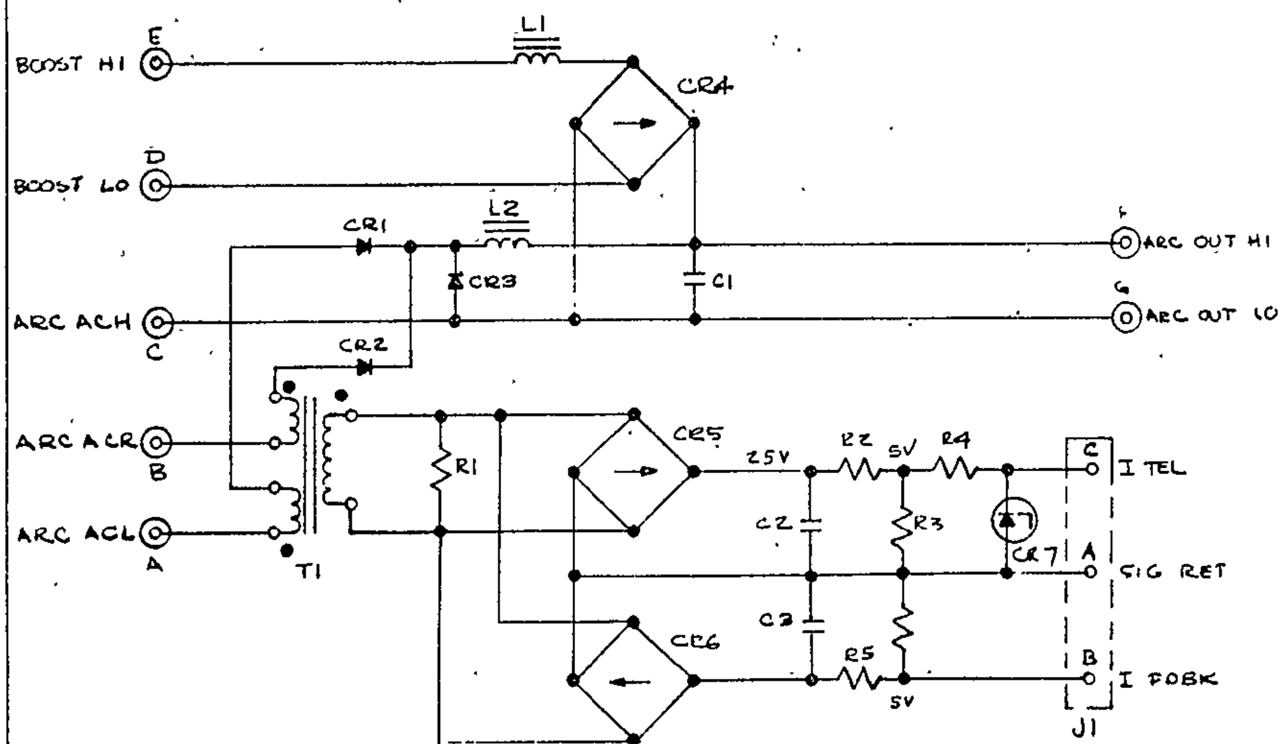
DWN	S.S.	9-25-68	DWG NO X3188115 A 15OCT
CHK			
APPR	[signature]	9-30-68	



X3188116 A

(SIZE 7.44 X 5.19 X .25)

ARC-RECT & FILTER
9/20/68



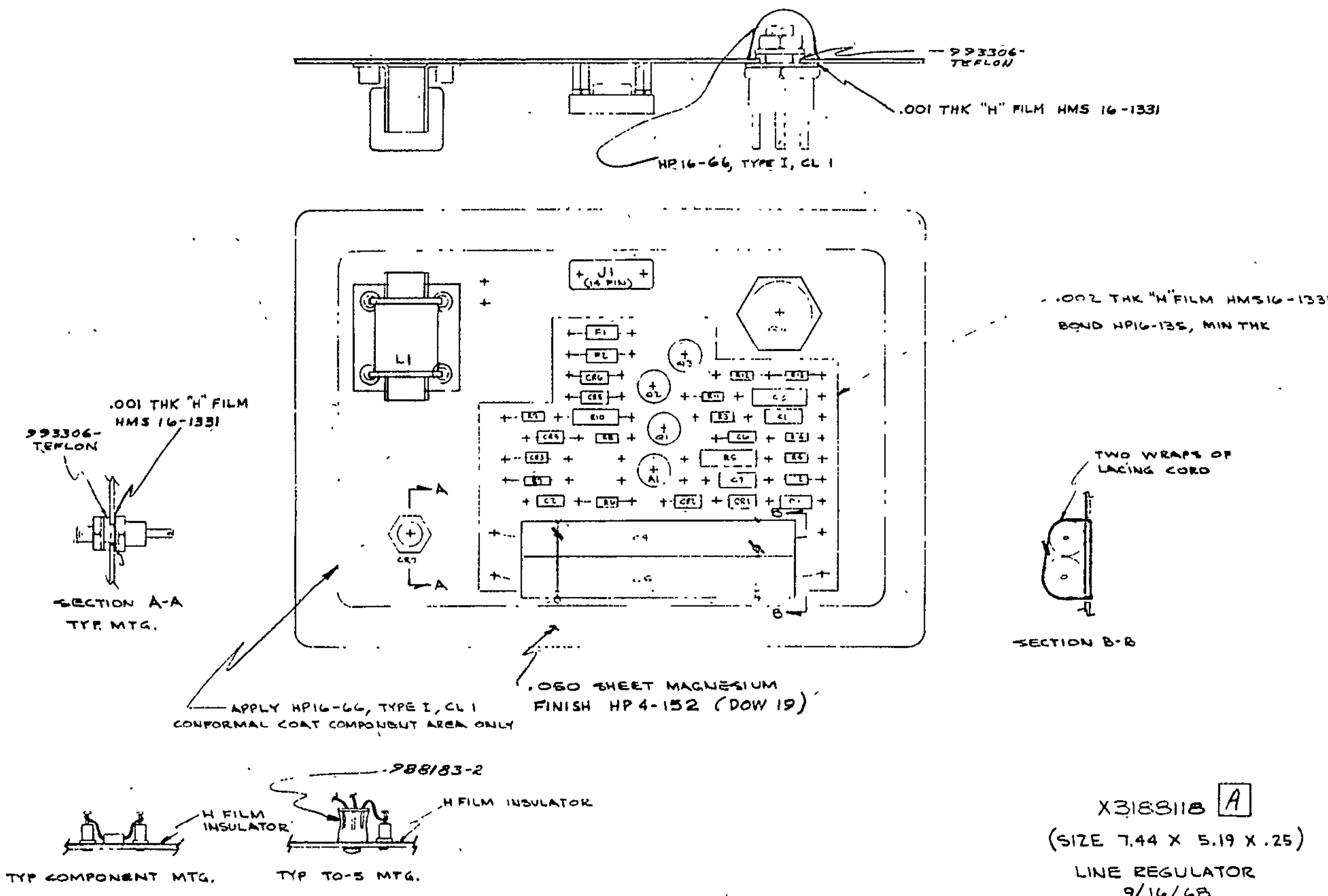
PARTS LIST

ITEM	SYM	DESCRIP	SPEC	QTY	REM
1	CR1, CR2, CR3	UTR 6440	UNITRODE	3	
2	CR4	SEM 5ER4F 0.1/300V	SEMTECH	1	
3	CR5, CR6	SEM 5BR1B 0.1A/100V	"	1	
4	CR7	7V/200 MW 1N754A		1	
5	R1	1K/3WWW	MIL-R-26	1	
6	R2, R5	8.2K-1/4W-1%	MIL-R-10509	2	
7	R3, R6	22K-1/4W-1%	"	2	
8	R4	8.2K-1/4W-1%	"	1	
9	C1	MALLORY XTV406T170P0C	MALLORY	1	
10	C2, C3	0.1/100 CER CK06	VITRAMON	2	
11	J1	SUB-MIN-5 PIN SER.20	CONTINENTAL	1	
12	T1	HAC ACTF1	HAC	1	
13	L1	HAC ABLF1	HAC	1	
14	L2	HAC AOLF1	HAC	1	

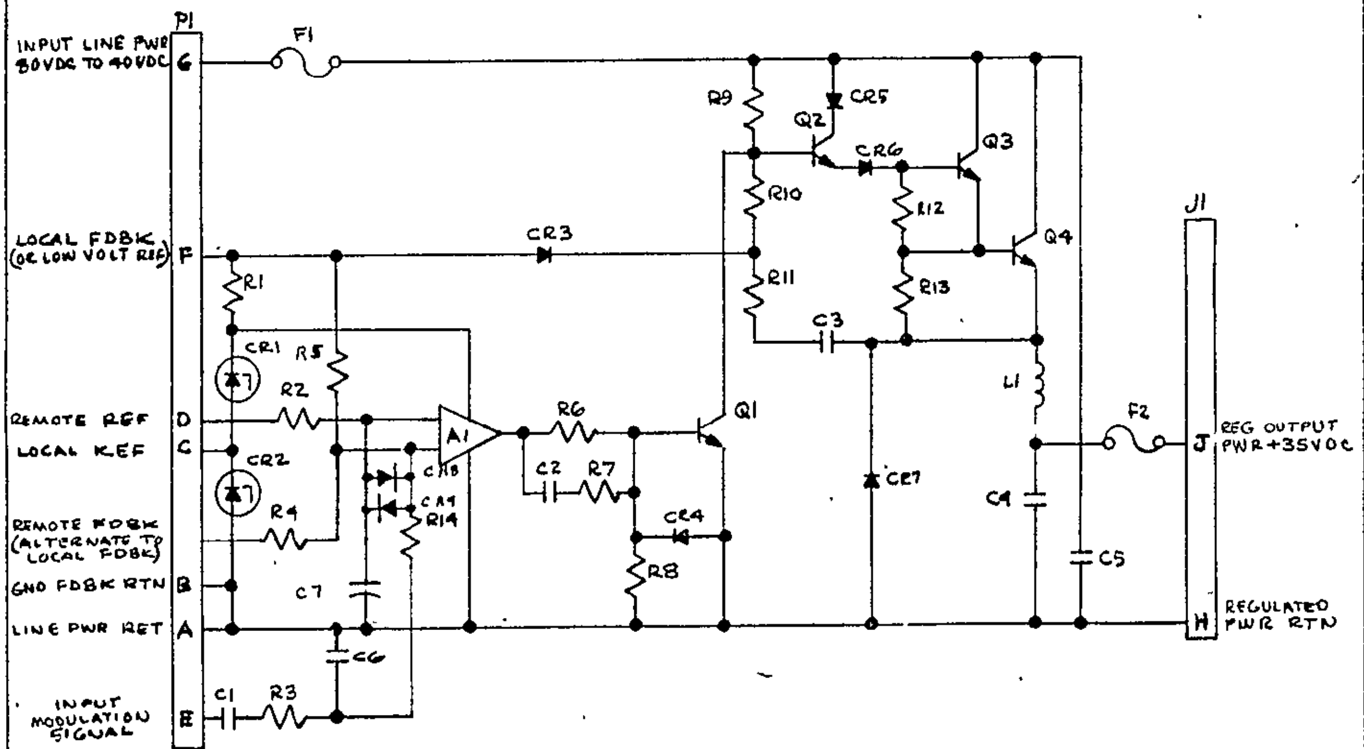
HUGHES AIRCRAFT CO
EL SEGUNDO, CALIF

TITLE
ARC-RECT-FILTER SCHEMATIC

DWN	S.S.	9-25-68	DWG NO X3188117
CHK			
APPR	[illegible signature]	9-30-68	



993306-TEFLON
.001 THK "H" FILM HMS 16-1331
HP16-66, TYPE I, CL I
.002 THK "H" FILM HMS16-1331
BOND HP16-135, MIN THK
J1 (14 PIN)
L1
CR7
A
B
.001 THK "H" FILM
HMS 16-1331
993306-
TEFLON
SECTION A-A
TYP. MTG.
TWO WRAPS OF
LACING CORD
SECTION B-B
APPLY HP16-66, TYPE I, CL I
CONFORMAL COAT COMPONENT AREA ONLY
.060 SHEET MAGNESIUM
FINISH HP 4-152 (DOW 19)
988183-2
H FILM
INSULATOR
H FILM INSULATOR
TYP COMPONENT MTG.
TYP TO-5 MTG.
X3188118 A
(SIZE 7.44 X 5.19 X .25)
LINE REGULATOR
9/16/68



PARTS. LIST

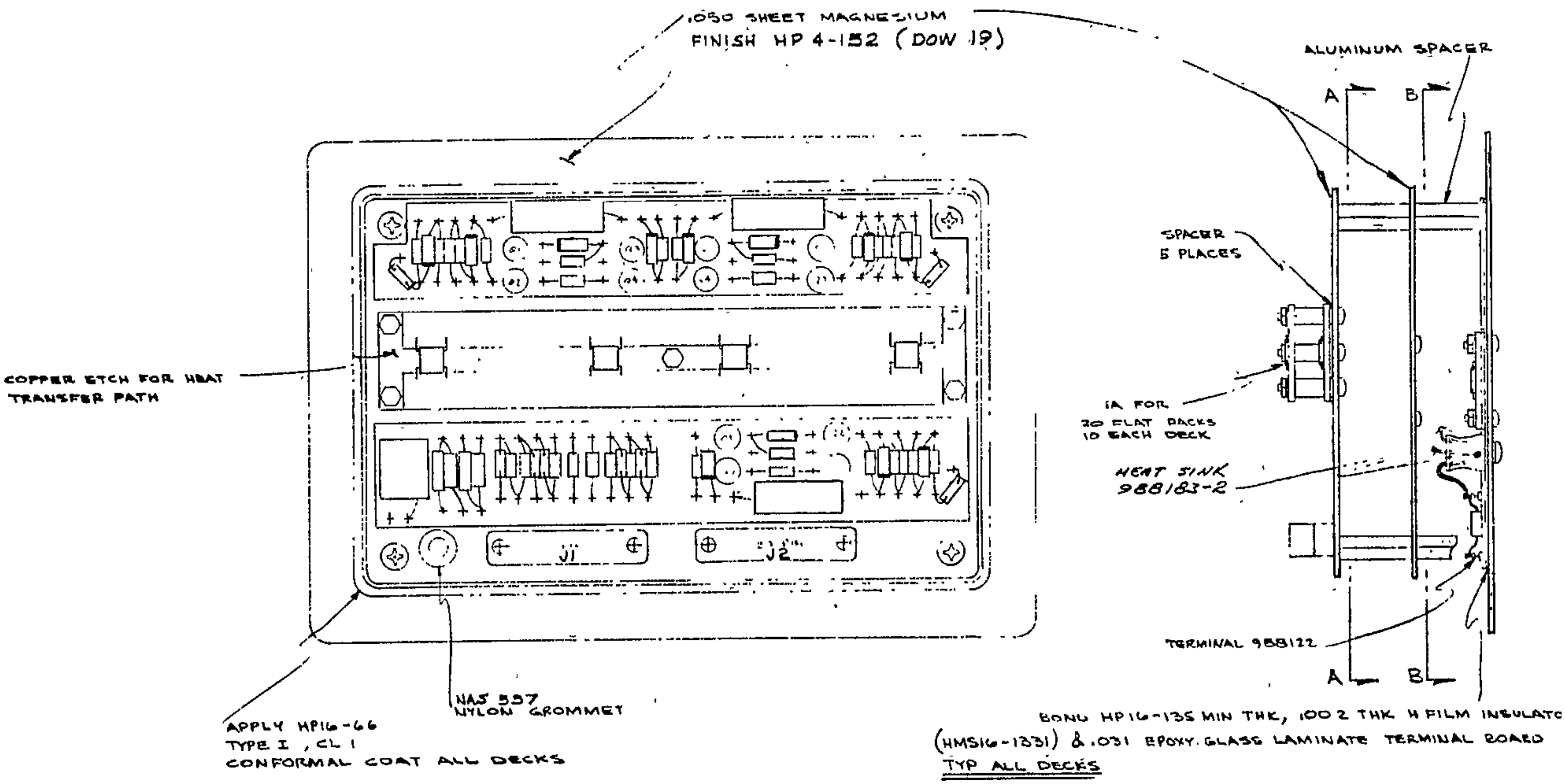
ITEM	SYM	DESCRIP	SPEC	QTY	REV
1	R1	3.9K-1/2W	MIL-R-11	1	
2	R2, R6, R7	5.1K-1/4W	"	4	
3	R4	RN6C SELECT	MIL-R-10509	1	
4	R5	10K-1%-1/2W. RN 65	"	1	
5	R8	1K-1/4W	MIL-R-11	1	
6	R9	10K-1/4W	"	1	
7	R10	1.5K-3W, W.W.	MIL-R 26	1	
8	R11	10-1/4W.	MIL-R-11	1	
9	R12	390-1/4W	"	1	
10	R13	5.1/ 1/4W	"	1	
11	C1,C2,C6	0.1MFD/100V CK 06	VITRAMON	3	
12					
13	C3	2.2MFD/100V CSR 13D 4...	KEMET	1	
14	CR1,CR2	1N758A		2	
15					
16	CR3 TO CR6 CR8, CR9	1N4942	SEMTECH	6	
17	CR7	UTR6440	UNITRODE	1	
18	A1	MC1709	MOTOROLA	1	
19	Q1, Q2, Q3	SDT5556	SOLITRON	3	
20	Q4	SDT8805	"	1	
21	L1	HAC 1MH	HAC	1	
22	C4	100MFD/75V 29F502 HERMSEAL	GE	1	
23	C5	20µf/200V 29F603H4 HERM. SEAL	"	1	A
24					
25	C7	1MFD/50V-CSR13B61K	KEMET	1	
26	R3	51K-1/4W	MIL-R-11	1	
27	F1	4A-GFA	BUSSMAN	1	
28	F2	8A-GFA	"	1	
29	J1	14 PIN-SUB-MIN SER. 20	CONTINENTAL	1	
30					

HUGHES AIRCRAFT CO.
EL SEGUNDO, CALIF

TITLE
LINE REGULATOR
3KW FLIGHT PWR CONDITIONER
SCHEMATIC

DWN	S.S.	9-25-68	DWG NO X3188119
CHK			
APP	W.J. [signature]	9-30-68	

A
15 OCT



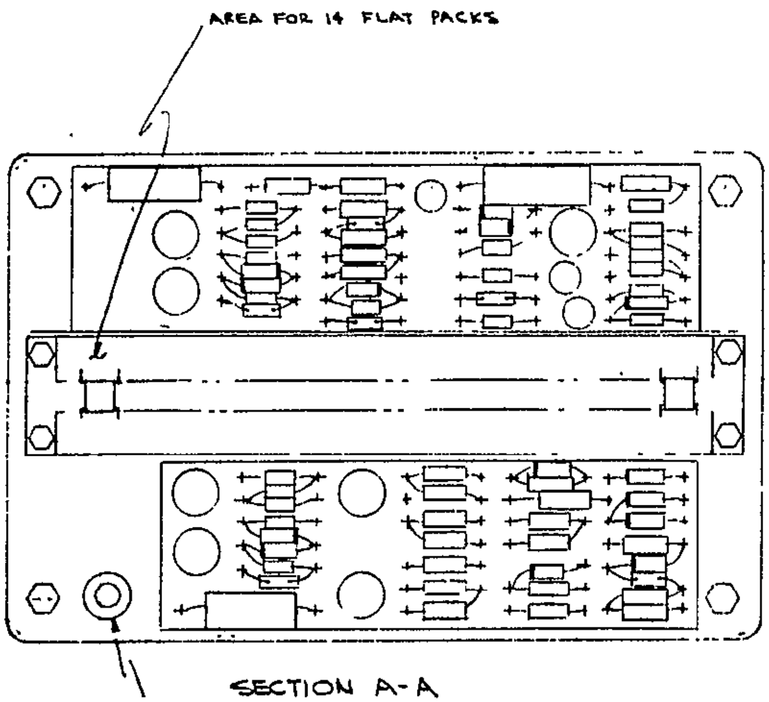
(SIZE 7.94 X 5.19 X .25)

CONTROL MODULE

9/24/68

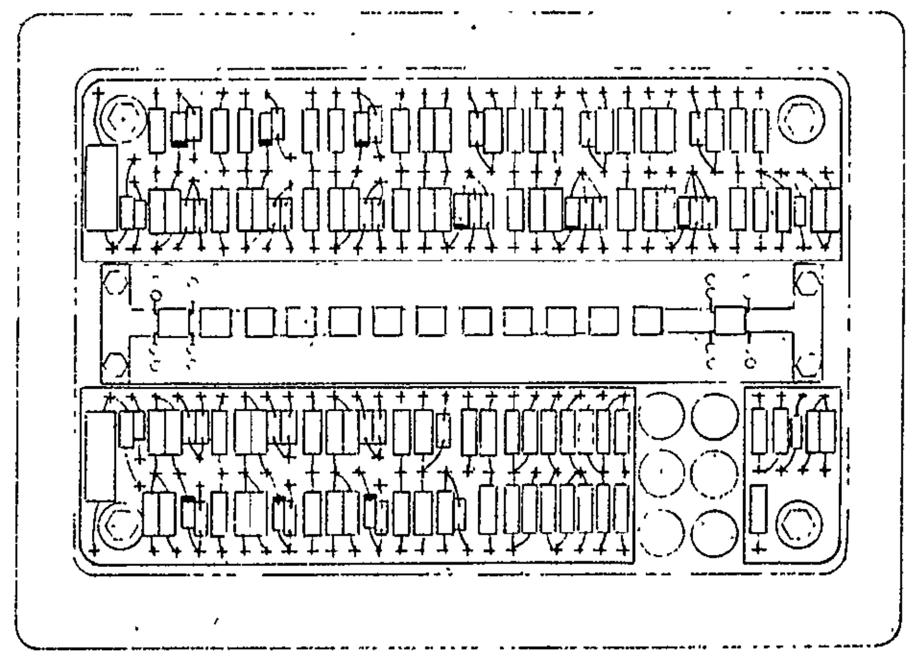
X3188120

SHEET 1 OF



SECTION A-A

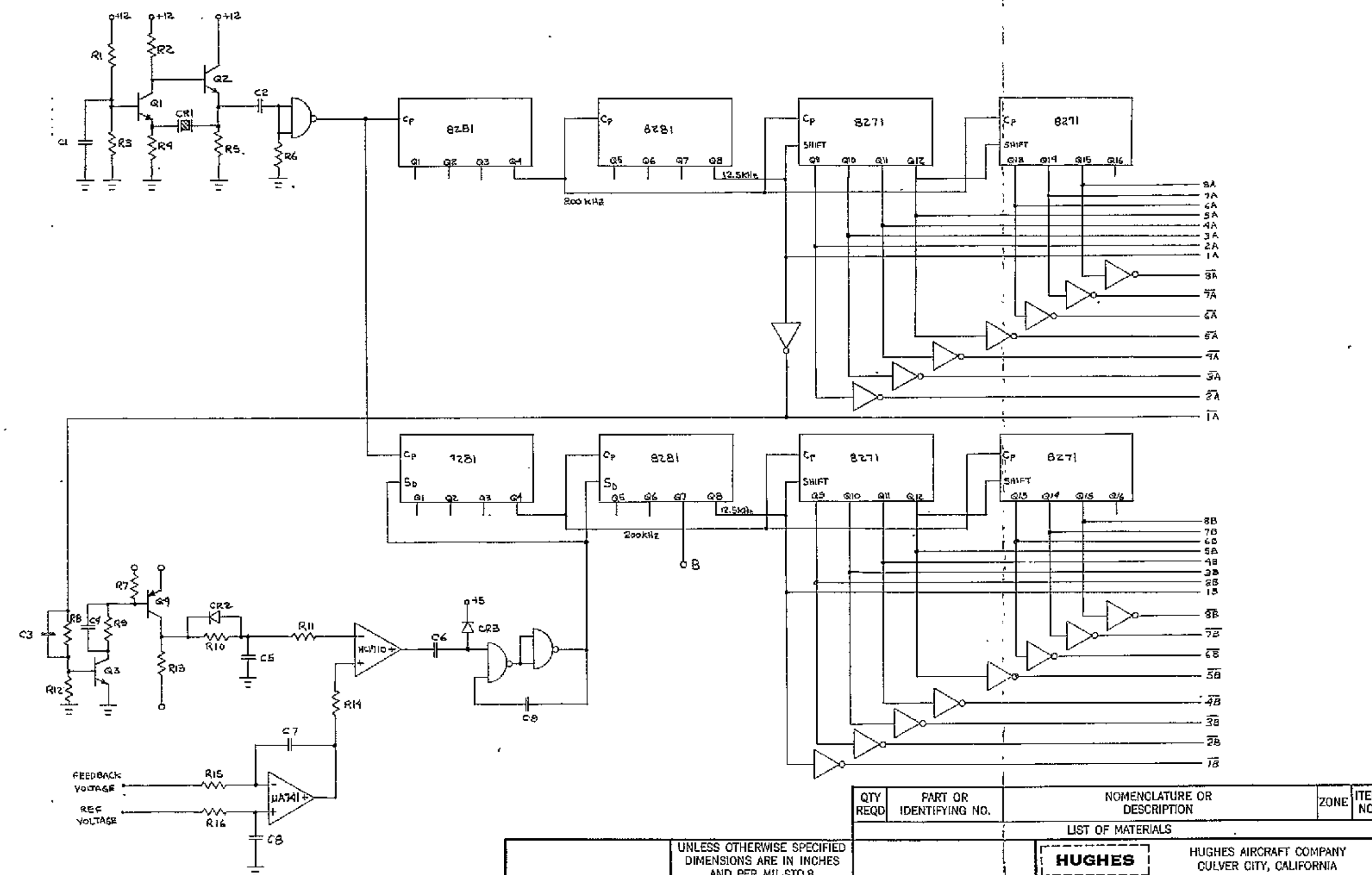
AN 557
ROMMET, NYLON



SECTION B-B

X 3188120
CONTROL MODULE
9/24 /68 SHEET 2 OF 2

EFF	AUTHORITY	ZONE	LTR	REVISIONS DESCRIPTION	DATE	APPROVED



QTY REQD	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	ZONE	ITEM NO.

LIST OF MATERIALS

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES AND PER MIL-STD-8

.XXX	.XX	.X	ANGLES
±.010	±.03	±.1	±0° 30'

MATERIAL

NEXT ASSY	USED ON
APPLICATION	

	DATE
DR	
CHK	
D GARTH	9-20-68
APPD	

HUGHES — HUGHES AIRCRAFT COMPANY, CULVER CITY, CALIFORNIA

MASTER OSCILLATOR & PHASE SHIFTER

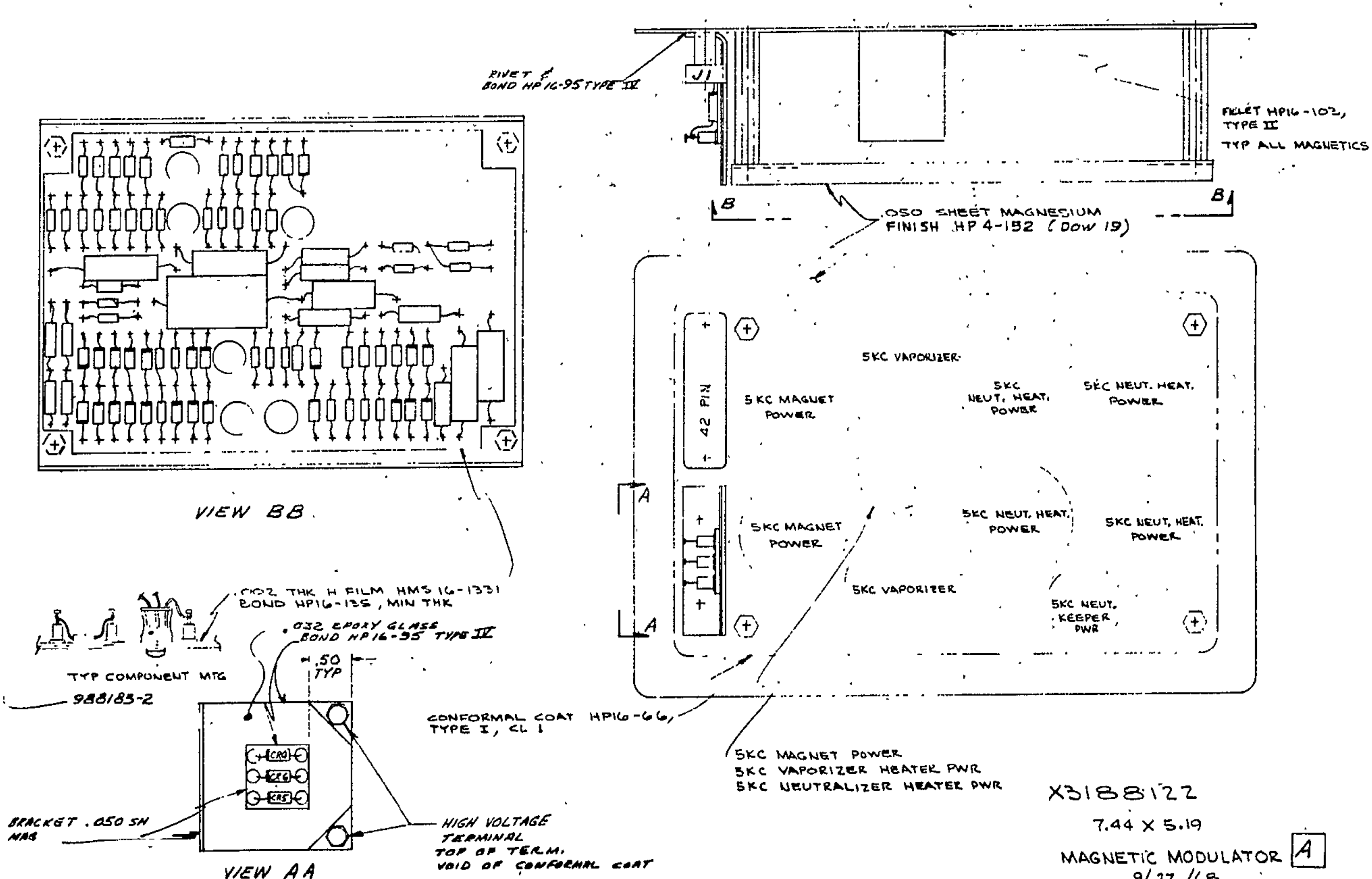
SIZE	CODE IDENT NO.	
C	82577	X3188121-2

SCALE | SHEET

FORM NO. 11064-B CS-CC 1-65 OZALID 880-260

A

B

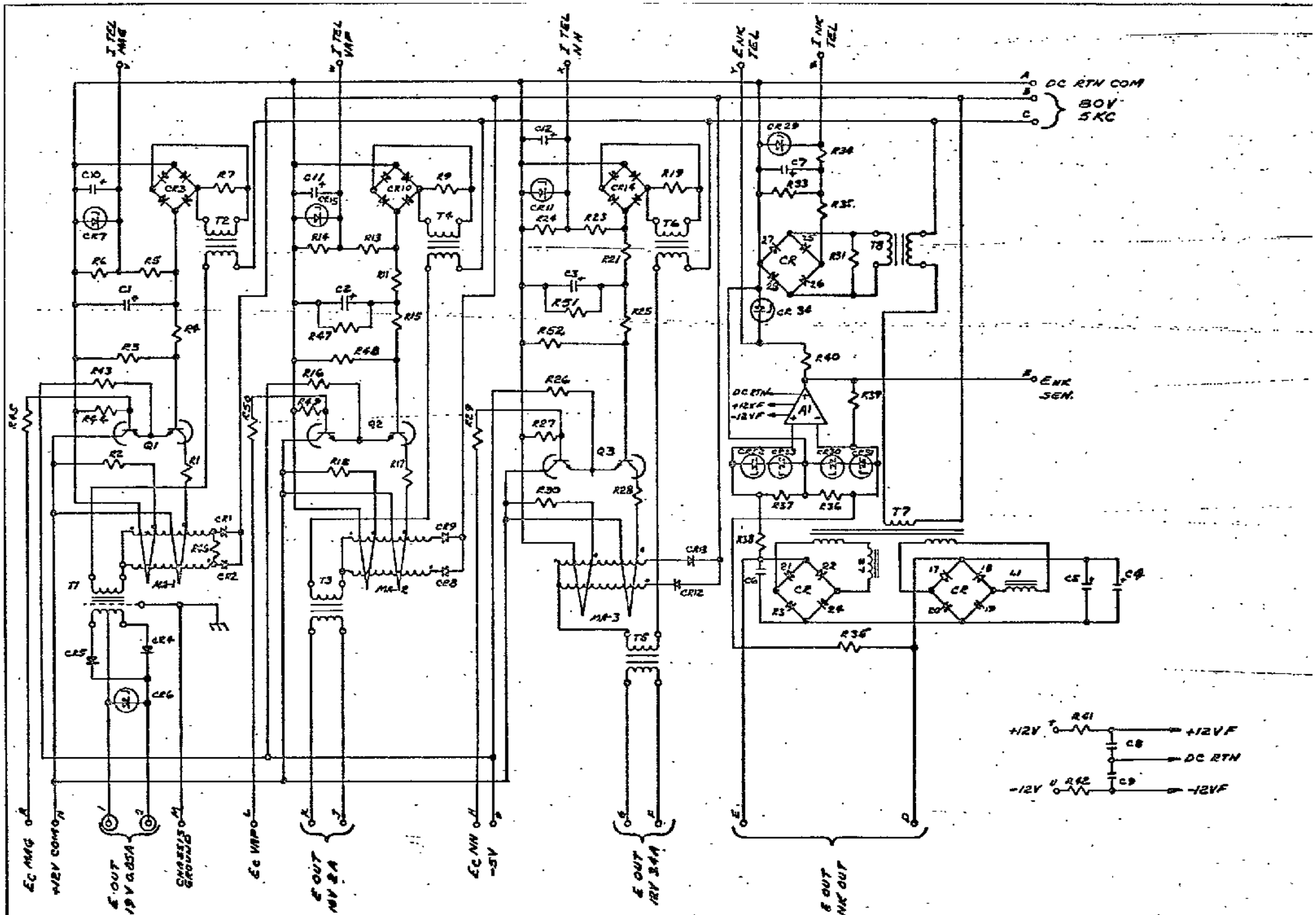


X3188122

7.44 X 5.19

MAGNETIC MODULATOR A

9/27/68



HUGHES AIRCRAFT CO
EL SEGUNDO CALIF

MAGNETIC MODULATOR
SCHEMATIC

DWN JG	9/30/68	DWG NO	B
CHK		X3188123	
APP	9/30/68	SHEET 1 OF 2	

PARTS LIST

ITEM	SYM	DESCRIP	SPEC	QTY	
1	CR1,8,9,12,13,17-20,CR2	1N4946	SEMTECH	10	B
2	CR3,10,14,25-28	1N4245	"	16	
3	CR4,5	35F2E	SEMTECH	2	B
4					B
5	CR7,11,15,29,34	LVA 68A	TRW	5	B
6	CR21-24	1N4247	SEMTECH	4	
7	CR6	UZ 5824		1	B
8	CR30-CR33	LVA 62A	TRW	4	B
9	Q1,2,3	2N2920	T.I.	3	B
10	C10,11,12	6.8μF/35V CSR13SF685	KEMET	3	B
11	C1,2,3,4,5	15/75V CSR13BH156	KEMET	5	B
12	C7	1.2/50V CSR13G125K	KEMET	1	
13	C6	.047/600V CWC9A1E473M	MIL-C-14157	1.	
14	R23	44.1K/⅛W 1% RN60	MIL-R-10509	1	B
15	R11	11.69K ⅛W 1% RN60	"	1	B
16	R18,30,R2	249K/⅛W1% RN60	MIL-R-10509	2	B
17	R4,15,25	20K/⅛W 1% RN60	"	3	
18	R6,14,24,	10K/⅛W 1% RN60	"	3	B
19	R33,R21	1.5K/⅛W1% RN60	"	2	B
20	R7,9,19,31	1.5K/3WWU	MIL-R-26	4	B
21	R5,	47.9K/⅛W1% RN60	MIL-R-10509	1	B
22	R20,R50	4.12K/1% ⅛W RN60	MIL-R-10509	2	B
23	R1,17,28,	1.5K/¼W RC07	MIL-R-11	3	B
24	R35,38	100K/1% ⅛W RN60	MIL-R-10509	2	
25	R36	11K/1% ⅛W RN60	"	1	
26	R39	16.5K/1% ⅛W RN60	"	1	B
27	R3,49,27,44,48,52	1K/⅛W1% RN60	MIL-R-10509	6	B
28	R16,26,43,	510Ω/½W RC07	MIL-R-11	3	B
29	MA-1	MMA-100	HAC	1	
30	T1	MOT-100	"	1	
31	MA-2	VHMA-100	"	1	
32	T3	VOT-100	"	1	
33	T4	VCT-100	"	1	
34	MA-3	NHMA-100	"	1	
35	T5	NHOT-100	"	1	
36	T6	NHCT-100	"	1	
37	T7	NKOT-100	"	1	
38	T8	NKCT-100	"	1	
39	L1	NKL1-100	"	1	
40	L2	NKL2-100	"	1	
41	T2	MCT-100	"	1	
42					
43	A1	μA741 (TO-5)	FAIRCHILD	1	
44	J1	26PIN SUB-MIN SEE 20	CONTINENTAL	1	
45	C8,C9	.1/100V 10% PDS510-2A		2	
46	R41,R42	100Ω/¼W 5% RC07	MIL-R-11	2	
47	R45	8.74K/⅛W RC07	"	1	B
48	R47,51,	15K/⅛W 1% RN55	MIL-R-10509	2	B
49	R46,R40	10K ¼W 5% RC07	MIL-R-11	2	B
50	R13	59K 1% RN60	MIL-R-10509	1	B
51	R32	604K 1% RN60	"	1	B
52	R37	6.65K 1% RN60	"	1	B
53	R34	8.45K 1% RN60	"	1	B
54				2	B
55					

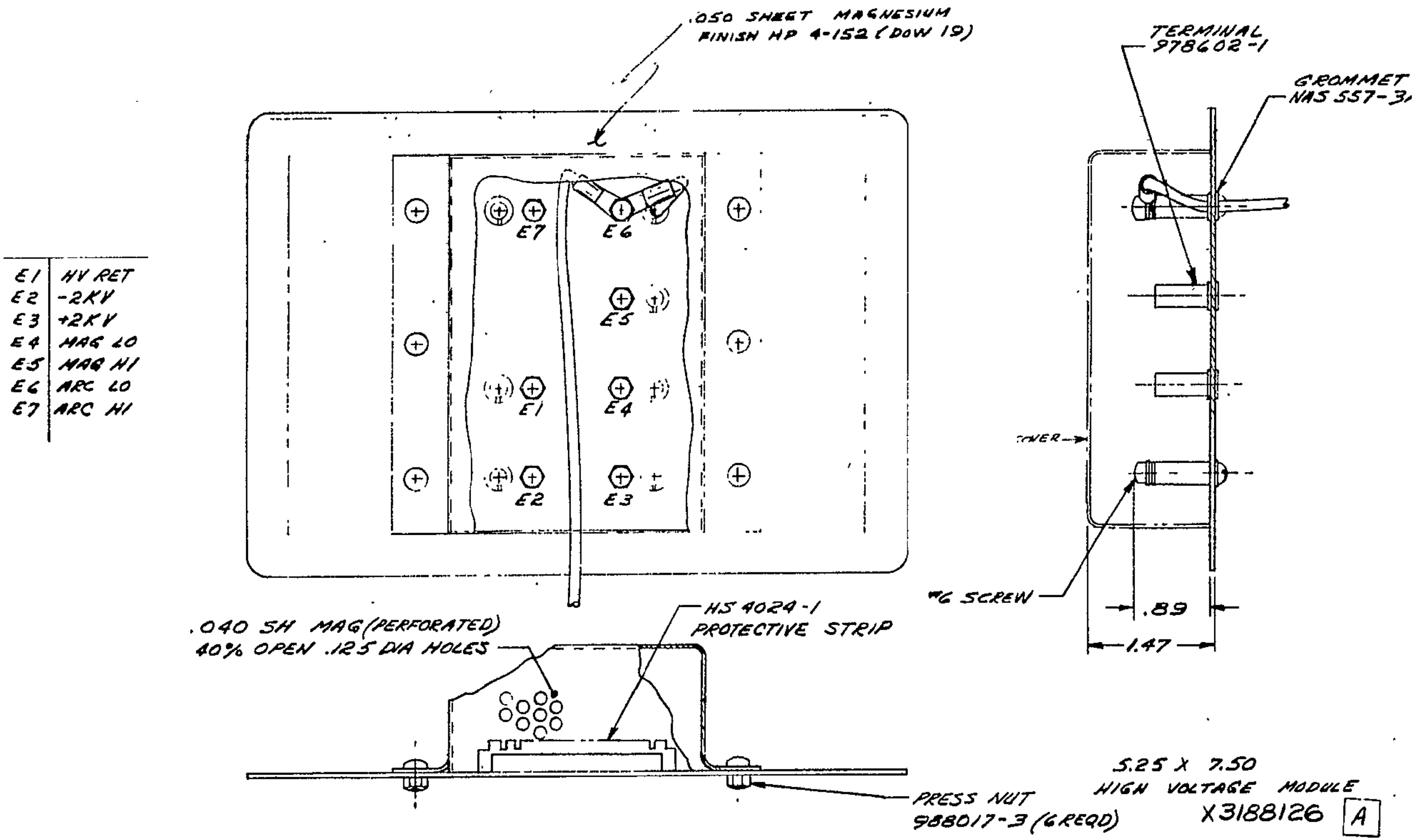
DESIG NOT USED
R8, R10, R12, R20, R22, CR16

LAST DESIG USED
R52
CR33
Q3
C12

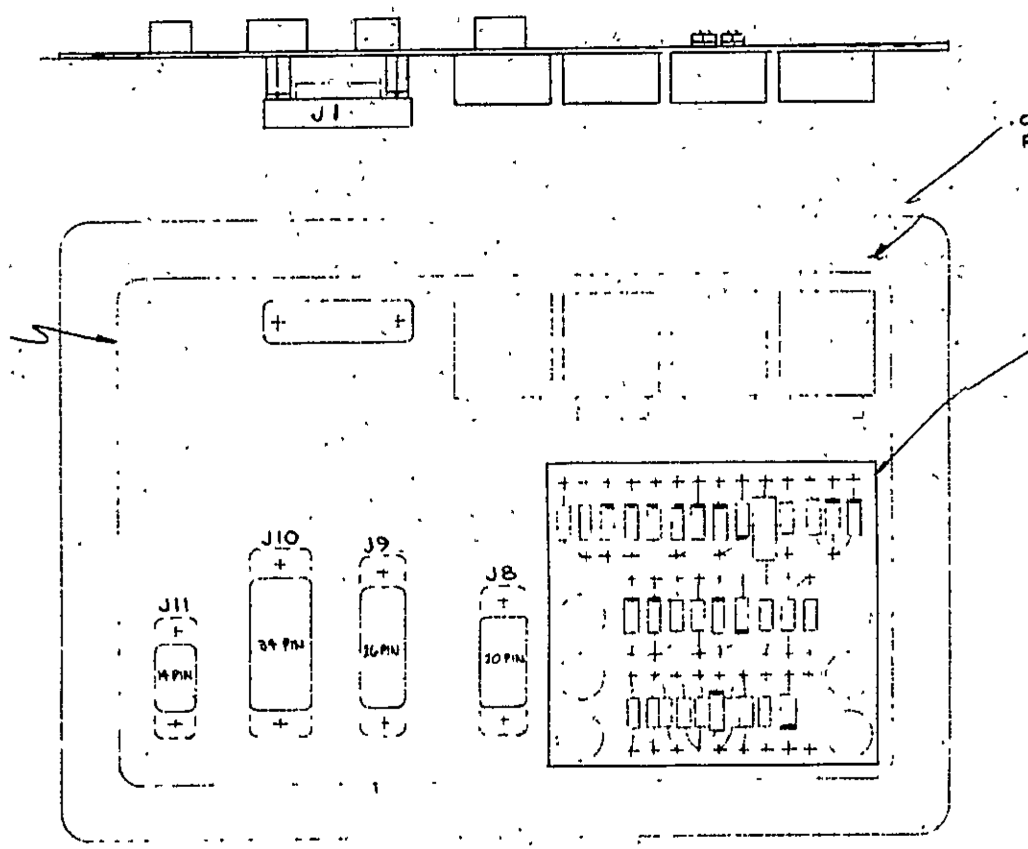
HUGHES AIRCRAFT CO
EL SEGUNDO CALIF

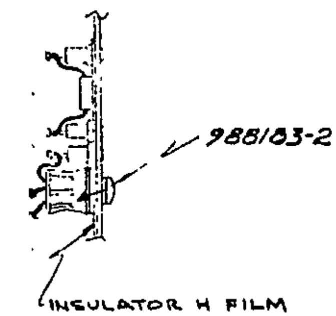
MAGNETIC MODULATOR
SCHEMATIC

DWN	M.B	9/10/68	DWG NO. X3188123 — B — 29 OCT
CHK			
APP			SHEET 2 OF 2



.050 SHEET MAGNESIUM
FINISH HP 4-152 (DOW 19)
TERMINAL
978602-1
GROMMET
NAS 557-3
E7
E6
E5
E1
E4
E2
E3
E1 HV RET
E2 -2KV
E3 +2KV
E4 MAG LO
E5 MAG HI
E6 ARC LO
E7 ARC HI
#6 SCREW
.89
1.47
.040 SH MAG (PERFORATED)
40% OPEN .125 DIA HOLES
HS 4024-1
PROTECTIVE STRIP
PRESS NUT
988017-3 (6 REQD)
5.25 X 7.50
HIGH VOLTAGE MODULE
X3188126 A





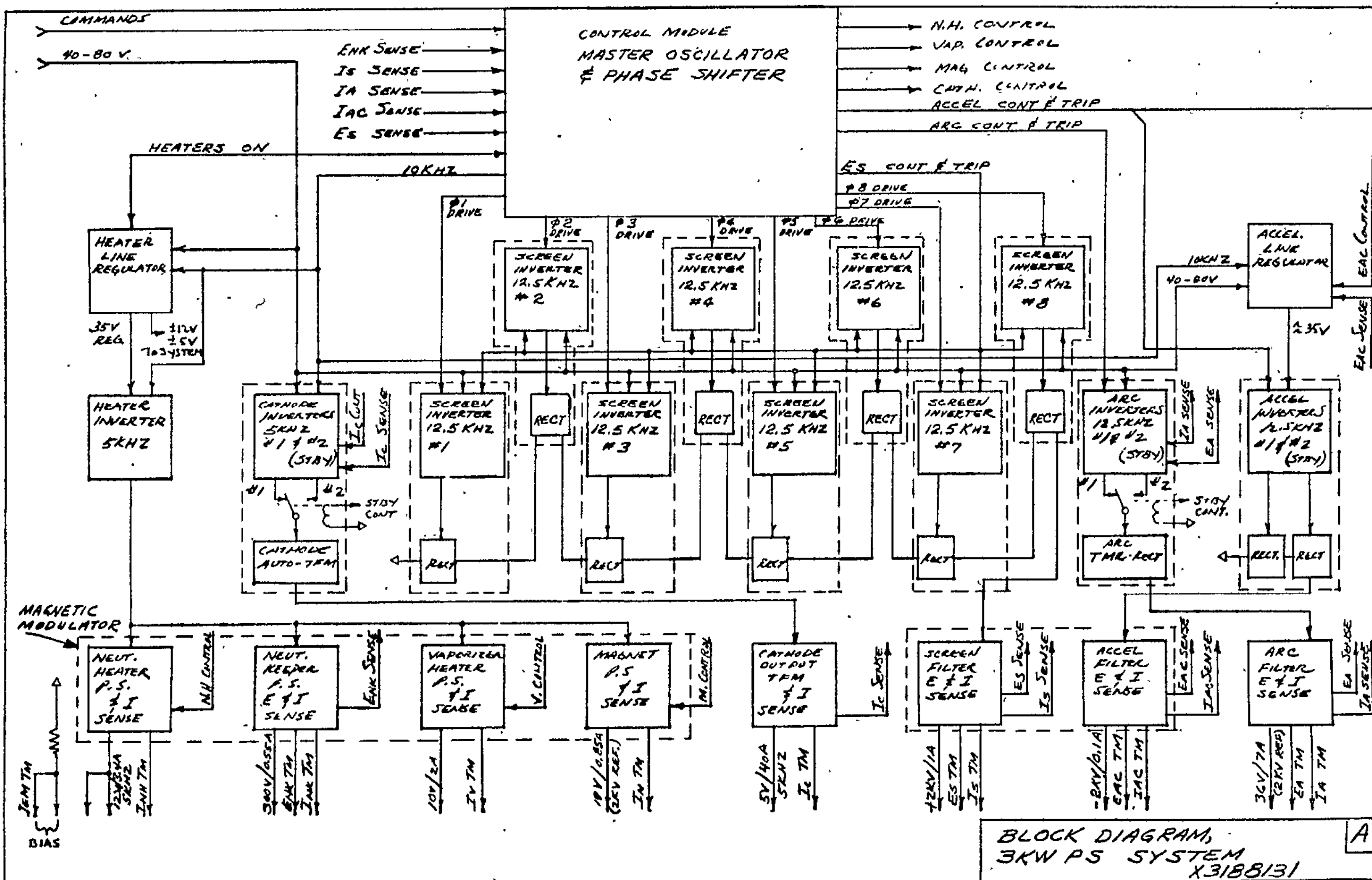
TYP COMPONENT MTG

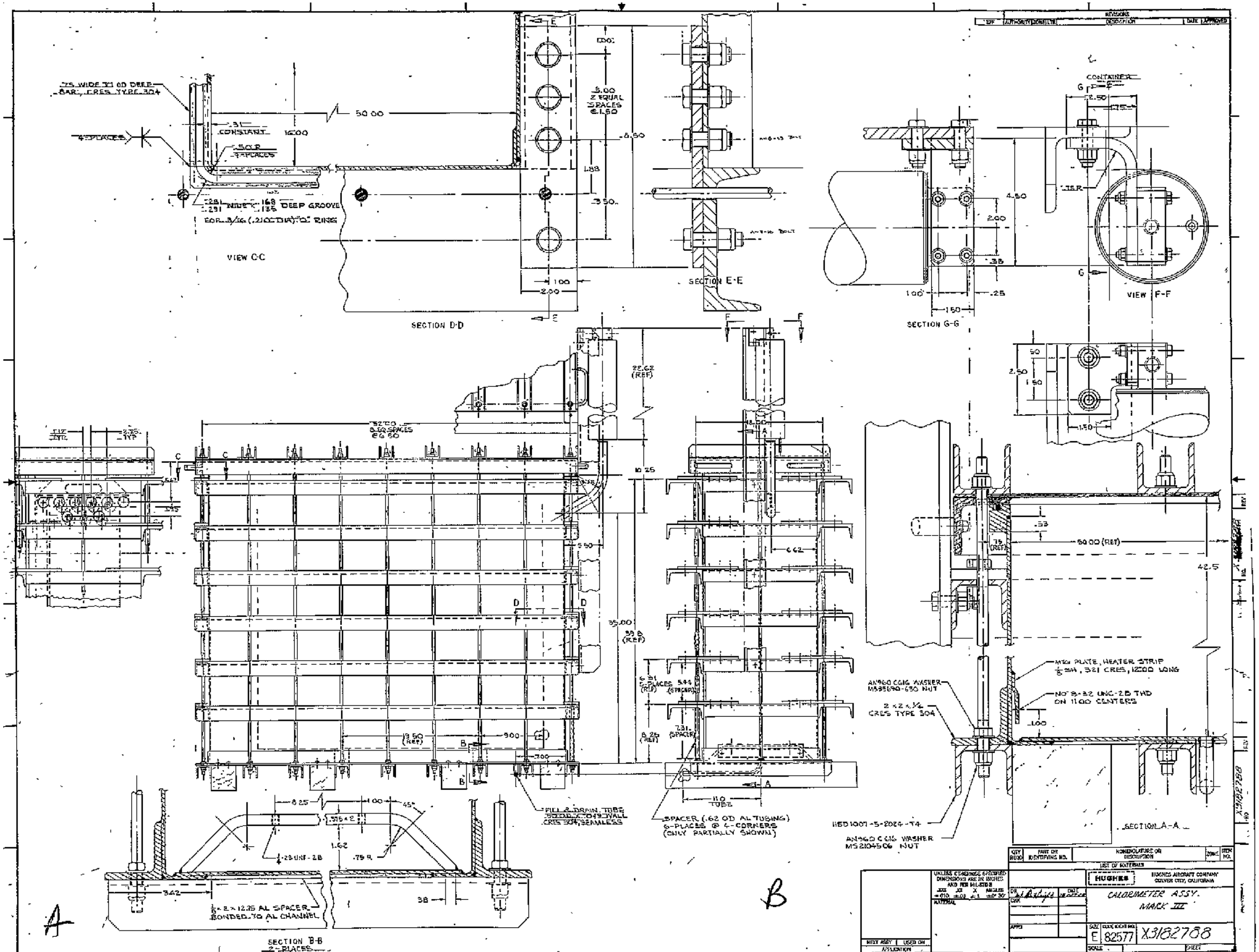
J8 L.V. LOADS
J9 CONTROL & TELE
J10 SCREEN INVERTER
J11 { ARC INVERTER
CATHODE INVERTER
ACCEL LINE REG
5 KC INVERTER }

X3188127 [A]

5.25 X 7.50

L.V. CONNECTOR MODULE
& CONTROL MODULE OVERFLOW


COMMANDS
40-80 V.
ENK SENSE
IS SENSE
IA SENSE
IAC SENSE
ES SENSE
HEATERS ON
10KHZ
CONTROL MODULE
MASTER OSCILLATOR
& PHASE SHIFTER
N.H. CONTROL
VAP. CONTROL
MAG CONTROL
CATH. CONTROL
ACCEL CONT & TRIP
ARC CONT & TRIP
ES CONT & TRIP
Φ8 DRIVE
Φ7 DRIVE
Φ1 DRIVE
Φ2 DRIVE
Φ3 DRIVE
Φ4 DRIVE
Φ5 DRIVE
Φ6 DRIVE
HEATER LINE REGULATOR
35V REG
±12V ±5V TO SYSTEM
HEATER INVERTER 5KHZ
SCREEN INVERTER 12.5KHZ #2
SCREEN INVERTER 12.5KHZ #4
SCREEN INVERTER 12.5KHZ #6
SCREEN INVERTER 12.5KHZ #8
ACCEL LINE REGULATOR
10KHZ
40-80V
EAC CONTROL
EAC SENSE
±35V
CATHODE INVERTERS 5KHZ #1 & #2 (STBY)
IC CONT
IC SENSE
#1
#2
STBY CONT
CATHODE AUTO-TFM
SCREEN INVERTER 12.5KHZ #1
SCREEN INVERTER 12.5KHZ #3
SCREEN INVERTER 12.5KHZ #5
SCREEN INVERTER 12.5KHZ #7
RECT
ARC INVERTERS 12.5KHZ #1 & #2 (STBY)
IA SENSE
EA SENSE
STBY CONT.
ARC TMR-RECT
ACCEL INVERTERS 12.5KHZ #1 & #2 (STBY)
RECT.
MAGNETIC MODULATOR
NEUT. HEATER P.S. & I SENSE
N.H. CONTROL
NEUT. KEEPER P.S. E & I SENSE
ENK SENSE
VAPORIZER HEATER P.S. & I SENSE
V. CONTROL
MAGNET P.S. & I SENSE
M. CONTROL
CATHODE OUTPUT TFM & I SENSE
IC SENSE
SCREEN FILTER E & I SENSE
ES SENSE
IS SENSE
ACCEL FILTER E & I SENSE
EAC SENSE
IAC SENSE
ARC FILTER E & I SENSE
EA SENSE
IA SENSE
IEM TM
BIAS
12V/3.5A 5KHZ
INH TM
300V/0.5A
ENK TM
INK TM
10V/2A
IV TM
18V/0.5A (2KV REF.)
IM TM
5V/40A 5KHZ
IC TM
+2KV/1A
ES TM
IS TM
-2KV/0.1A
EAC TM
IAC TM
36V/7A (2KV REF)
EA TM
IA TM
BLOCK DIAGRAM,
3KW PS SYSTEM
X3188131
A


.75 WIDE X 1.00 DEEP BAR, CRES TYPE 304
4 PLACES
.31 CONSTANT
.50 R 4 PLACES
50.00
16.00
DEEP GROOVE FOR 3/16 (.210 C DIA) "O" RING
VIEW C-C
SECTION D-D
SECTION E-E
3.00 2 EQUAL SPACES @ 1.50
4.60
1.88
.350
1.00
2.00
CONTAINER
VIEW F-F
SECTION G-G
4.50
2.00
1.50
2.50
1.50
28.62 (REF)
10.25
35.00
39.8 (REF)
6.62
5.50
19.50 (REF)
.900
.700
8.25
1.00
45°
1.62
.75 R
.25 UNF-2B
3.42
.38
1/8 x 2 x 12.25 AL SPACER BONDED TO AL CHANNEL
SECTION B-B 2-PLACES
FILL & DRAIN TUBE CRES 304, SEAMLESS
SPACER (.62 OD AL TUBING) 6-PLACES @ 4-CORNERS (ONLY PARTIALLY SHOWN)
1.10 TUBE
50.00 (REF)
42.5
.33
.75 (REF)
AN960 C616 WASHER MS35690-630 NUT
2 x 2 x 1/4 CRES TYPE 304
M&G PLATE, HEATER STRIP 1/8 SH, 321 CRES, 12.00 LONG
NO 8-32 UNC-2B THD ON 11.00 CENTERS
.100
AN960 C616 WASHER MS21045C6 NUT
SECTION A-A
A
B
HUGHES
HUGHES AIRCRAFT COMPANY CULVER CITY, CALIFORNIA
CALORIMETER ASSY. MARK III
E 82577 X3182788