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AFFDL-TR-75-99

DEVELOPMENT OF A TEMPERATURE CONTROLLER FOR A VUILLEUMIER (VM) CYCLE POWER CYLINDER

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASSACHUSETTS

1 OCTOBER 1975

TECHNICAL REPORT AFFDL-TR-75-99
FINAL REPORT FOR PERIOD 11 SEPTEMBER 1974 – 1 OCTOBER 1975

AIR FORCE FLIGHT DYNAMICS LABORATORY
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Vehicle Equipment Division
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Project Engineer

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Development of a temperature controller for the hot end of a Vuilleumier (VM) cryogenic cooler system is presented. The objectives of a low-cost, moderate reliability, environmentally tested controller are met in the design presented. Fundamental design factors include: use of an on/off controller operating from the 28-volt aircraft bus, use of a platinum resistance temperature sensor, packaging within 25 cubic inches, use of class P components, and an estimated mean-time-between-failure of more than 8000 hours.

Five controllers, together with their five associated load simulators, have been supplied to Wright-Patterson Air Force Base, together with complete documentation of EMI and environmental testing. Estimated production cost of the controllers is $314, plus the cost of a sensor which is estimated between $40 and $125.

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FOREWORD

This report, prepared by staff members of Arthur D. Little, Inc., Acorn Park, Cambridge, Massachusetts, is the final technical report on a study involving the development of a temperature controller for a Vuilleumier (VM) cycle power cylinder. The work was carried out under U.S.A.F. Contract F33615-75-C-3002 (Arthur D. Little, Inc., Case No. 77576). The contract was in support of Project No. 6146, Task 6146-03. The work was administered under the direction of the Air Force Flight Dynamics Laboratory, Vehicle Equipment Division with Lt. David C. Brubaker, AFFDL/FEE, as Project Engineer.

This report covers work from 1 September 1974 to 1 October 1975 and was released by the author in August 1975 for publication as a technical report.

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I. SUMMARY AND CONCLUSIONS

A. INTRODUCTION

The Air Force has sponsored the development of compact Vuilleumier (VM) cycle refrigerator systems for cooling airborne sensor systems. The Vuilleumier system is a heat-operated refrigerator system; an important element in its operation is the source of input heat and its control. The Air Force contemplates the use of a substantial number of VM refrigerators on aircraft to cool a variety of sensitive sensor systems. Experience has shown that previously available temperature controllers for the hot cylinder of the VM refrigerators were not reliable enough for the Air Force missions. These control systems were plagued with electric heater and temperature sensor problems, as well as control circuit deficiencies.

The work conducted by Arthur D. Little, Inc., under the subject contract covers the detailed design of a temperature control system designed to meet certain objectives of the Air Force, and tests have been conducted to prove the design. The Air Force's specific targets for reliability and cost are noted below:

- Reliability: greater than 8,000 hours mean-time-between-failure;
- Cost: less than $500 amortized over 300 units.

Under this contract, we have designed and tested a temperature controller to meet the following general environmental specifications: an operating temperature range (from -54°C to +55°C), EMI, acceleration, shock and explosive atmosphere tests.

The test also showed the temperature units' controlled the load temperature within a 1200°F to 1300°F range.

B. PROGRAM RESULTS

We completed the detailed design of a temperature controller for the hot end of a VM refrigeration system, and we verified this design by fabricating five prototype controllers. We subjected one of the units to complete EMI and environmental testing. Features of the design are:

1. Operation from the 28-volt bus of the aircraft;
2. Power control in a strictly "on/off" mode; and
3. Use of a platinum resistance temperature sensor.

The circuit includes both over-temperature protection in the event that the load temperature rises above a safe operating level and shutdown of the system in the event of a shorted sensor; both of these actions turn the power section of the controller "off," and it cannot be repowered until manually reset by an operator.

We selected passive electronic components of the P class of demonstrated reliability; this is nominally a one-failure-per-million-hour classification. We also chose active components of the JAN or JANTX class to assure reliable operation of the components used in the circuitry.

Our program included extensive testing of an elementary breadboard model of the unit, testing of a breadboard model of the assembled unit, long-duration testing of Serial No. 001 of the controller which passed laboratory, EMI, and environmental tests, and testing of the four other prototype units. During these tests, we never had to replace even a single active component in any one of these circuits.

We estimate that the mean time between failure (MTBF) for the prototype unit controllers will be greater than 8000 hours. Our calculations for the MTBF show considerable conservatism in the numbers used for individual components, and we fully expect that a reliability level higher than this will be realized by the controllers in actual operation.

Our estimates of the manufacturing costs of the unit show a per unit cost of $314 for the controller itself. To this cost must be added the cost of a platinum resistance temperature sensor, and we believe its cost will range from a low value of $40 per unit to a possible high of $125 for a unit specially designed for this purpose.

External packaging of the unit is such that the entire volume occupied is less than 25 cubic inches.

C. RECOMMENDATIONS

In this program we developed a control system which we feel will meet the requirements specified by the Air Force Flight Dynamics Laboratory. During the course of the study, a number of ideas occurred to us which we believe are worthy of further work. They are:

1. Test of the Controller with a Real VM Refrigeration System

The work we have done demonstrates the capability of the controller to maintain temperature in a load simulator. Nevertheless, the load simulator does not match perfectly the properties of the true hot end of a VM cooler. We believe it would be appropriate to operate the controller with a real cooler to verify that performance expectations are met, and we therefore recommend that this operation be implemented.

2. Alternate Platinum Resistance Temperature Sensors

In the prototype models of the control system, we used a custom-made platinum-resistance temperature sensor. We now believe that it is possible to use a commercially available platinum resistance temperature sensor. It is important that some laboratory tests be undertaken to verify the suitability of commercially available sensing elements for this purpose, and we recommend that they be conducted. If a commercially available element can be found, the costs to the Air Force for the sensors could be markedly reduced. A series of stability tests on the units would be necessary to determine whether they would withstand the long time exposure to the elevated temperatures, while still maintaining adequate calibration.

3. AC-Operated Unit

Our choice of operating a controller from the 28-volt DC bus of the aircraft was made on the basis that there would be no apparent advantage or disadvantage in the choice of power sources. It now seems apparent that, everything else being equal, it would be preferable to operate the unit from the AC power supply of the aircraft. We believe such operation is entirely feasible and therefore recommend that a single breadboard unit be designed and fabricated to verify the expectation that such an operation is completely feasible.

II. APPROACH

A. THE TEMPERATURE CONTROL PROBLEM

The basic temperature control problem for the VM refrigerators is maintenance of the temperature at the hot cylinder to within 50°F of a 1250°F setpoint. This control must be maintained in the presence of an ambient that normally varies from -54°C to +55°C and in the face of both a variable aircraft electric power supply voltage and of EMI and environmental variables including shock, vibration, and explosive atmosphere. Approximately 200 watts of power have to be supplied and the controller efficiency must reach at least an 80% level. There are almost countless ways in which the temperature controller could be designed to meet the needs of the Air Force. Therefore, as an introduction to our approach, we will first discuss the principle of the temperature controller in general.

B. THE GENERALIZED TEMPERATURE CONTROLLER

1. Power Control Element

A block diagram of a basic temperature control circuit capable of meeting Air Force requirements is shown in Figure 1. The diagram shows sensing, error measuring, and power control functions.

A major consideration in any temperature controller is the power control element. Many controllers use a continuously adjustable power control element, such as a series transistor, for use where DC power source is available, or a phase-back SCR control where an AC power source is available. A chopper control element is sometimes used to regulate direct current. In other temperature control systems the control element might be an electronic switch, a transistor for DC operation, or an SCR for AC operation. Most electronic temperature control systems that control electric heat operate in one of these modes.

2. Sensor

A wide variety of electronic sensors exists for measuring temperatures. The best known and widely used are thermocouples and resistance thermometers. In addition, there are less widely used, but important, methods, including state changes in certain materials, instrumented bi-metals, noise thermometers, optical pyrometers, acoustic methods, and others.

3. Error Measurement

Temperature controllers generally operate on the basis of controlling the power delivered to the heating element in accordance with a measured temperature error. Thus, a common feature of such controllers is a reference for the setpoint temperature. The departure from the setpoint is used to control the power to the load element. The precision of temperature control is in part determined by the "gain" of the system--how much temperature error is required to fully control the power-handling element. Dynamic considerations also enter as they do for any closed-loop control system.

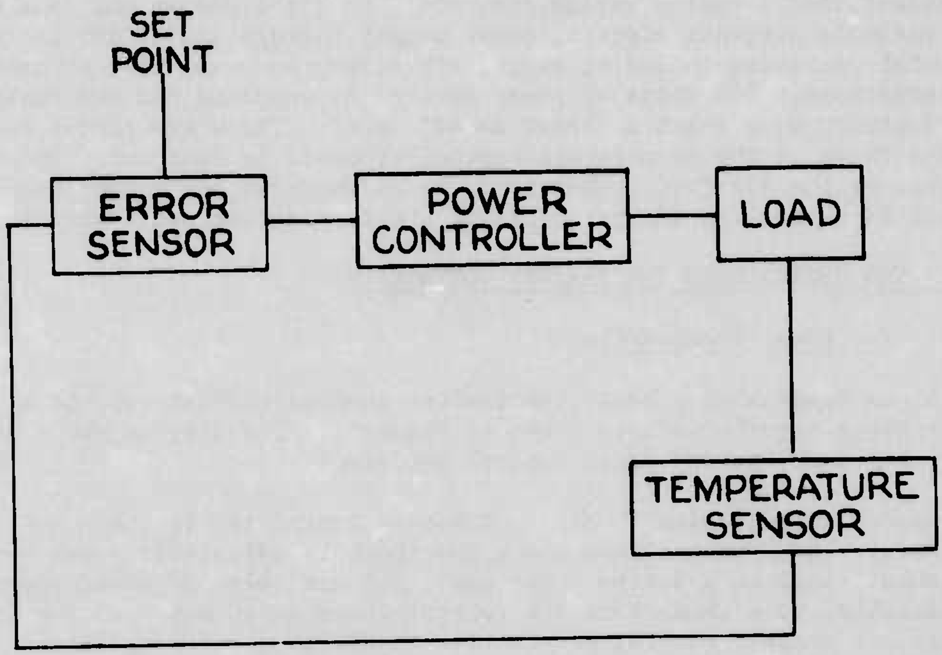


Figure 1 Block Diagram of Basic Temperature Controller

III. CIRCUIT FUNDAMENTALS

A. GENERAL CONSIDERATIONS

The twin objectives of low-cost, reliable operation for the temperature control system led us to two general conclusions:

1. The electronic components used in this unit should be well established, widely used devices so that there is positive evidence of their performance in terms of reliability; and

2. Concentration on the design should be directed toward the simplest possible circuit that would achieve all of the requirements that must be met by the controller. Using this approach would assure the least parts count which in turn should contribute to lower unit costs and also to achieving the desired reliability.

B. SELECTION OF POWER SOURCE

At the start of the program we were given the option of selecting either 115-volt, 400-Hz or 28-volt DC power to operate the controller. We chose to use the 28-volt DC source for several reasons.

First, it provides the low-level voltage at DC required for the electronics that perform the error determination for the controller. Such a power source would be needed regardless of the choice of input raw power. By using DC, one avoids the necessary conversion of 115-volt, 400-Hz power to a low-level DC with the attendant necessity of using a 400-Hz power transformer. Thus use of DC will allow a less complicated, smaller part-count circuit to be achievable.

Second, we chose DC because the EMI problems can be more easily handled than when AC is used.

The original Request for Proposal for this task gave no weight to the suitability of the controller that depended upon the choice of power source, i.e., equal utility was evident for either the 400-Hz or the 28-volt source.

C. THE POWER CONTROL ELEMENT

The temperature controller uses a series transistor that is either "on" or "off," depending upon the measured-temperature error. We chose to operate in this mode for two reasons. The implementation of this type of circuit requires a small number of components to provide the control function, and the EMI problem can be handled without resort to high-performance EMI filters that would be required had we chosen a chopper control mode of operation.

The elimination of a high-performance EMI filter is desirable both from the restricted size allowable for the controller and from the point of view of eliminating one more component from the circuit. The EMI filters typically would use a wire-wound inductor, an undesirable component from the point of view of reliability.

D. SENSOR

The subject RFP suggested the consideration of new, novel, or unusual types of temperature sensors, particularly those that might exhibit a state change at the required regulating temperature. Our examination of the technology in this area showed that, while certain devices were available, they were severely limited in terms of expected life. Others are not available at all and therefore no history of reliability performance is available.

Undertaking this activity would represent a sensor development program rather than the design of a working, reliable temperature controller. For this reason, early in the program, we gave up completely the search for such devices and concentrated on available temperature-measuring devices. The search was rapidly reduced to thermocouples and resistance thermometers. It is perfectly obvious that either thermocoupler or resistance thermometer devices could be used to achieve the objective of the program. We chose to use the resistance thermometer approach rather than thermocouple approach for several reasons:

- The resistance thermometer is a high-sensitivity device which yields a large signal in response to temperature changes, the magnitude of typical signals being millivolts per °F as compared to tens of microvolts per °F for thermocouple materials. This more than two orders of magnitude difference in sensitivity eases the control problem, particularly in view of the fact that the control electronics must perform within specifications, while the package containing them is subject to a more than a 100°C change of ambient temperature.

- The small thermocouple voltages could make it difficult to achieve the required performance level in the presence of the fields and voltages specified in the conducted and radiated susceptibility parts of the MIL-STD-461A to which the finished controller has to perform.

- The use of a thermocouple for a measuring device requires that a compensating thermocouple junction of some sort be included as part of the control device, one more set of components required to make such a controller operate.

- The low sensitivity of the thermocouple requires an extremely well balanced amplifier to raise the level of the thermocouple voltage to a point where it could be used for a control function. The amplifier drift problems indicated that a high-cost amplifying element would be required for this purpose. We decided that the trade-off between this high-cost element and the high cost of a platinum resistance thermometer was well worth the choice.

In addition, since the inception of this program, improvements have been made in semiconductor devices; in particular, sensitive low-drift amplifiers of fairly modest. Thus this one particular aspect of sensor choice might be viewed somewhat differently if the program were just beginning today, rather than a year ago.

E. ERROR SENSING

With a choice of a resistance thermometer for the sensing element, the use of a simple Wheatstone bridge configuration, together with a simple discriminator circuit, provides the basic control function.

F. BASIC CONTROL CIRCUIT

Figure 2 illustrates the basic circuit used in the controller. This circuit is based on the principles of control previously explained, and the principles of operation are clear from a study of this circuit. However, in the completed circuit which includes many other auxillary functions, the basic fundamental operation is not so clearly seen.

The figure shows the load resistor to which power is applied by the controller. The basic switching action which turns power "on" or "off" occurs in the 2N3771 transistors identified as Q3 and Q4. The 2N3771 transistor has a nominal current rating of 30 amperes. The maximum load current for the intended application is 10 amperes total or 5 amperes per transistor, thus achieving a highly derated operation resulting in a high degree of reliability in these components.

It is well known that power transistors are frequently the weakest link in an otherwise reliable circuit. One feature of this use of a parallel pair of transistors is that there are no emitter resistances to force current balance between the two transistors. These particular transistors operate in such a fashion that the variation of collector-to-

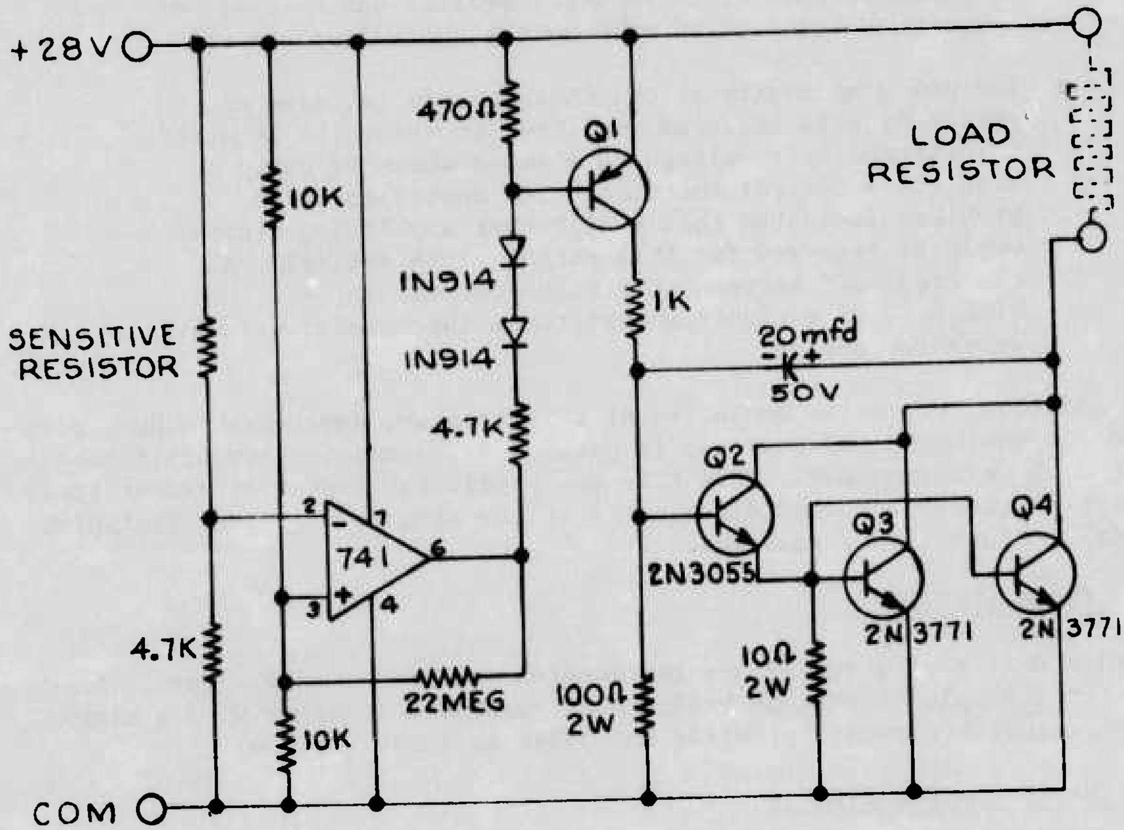
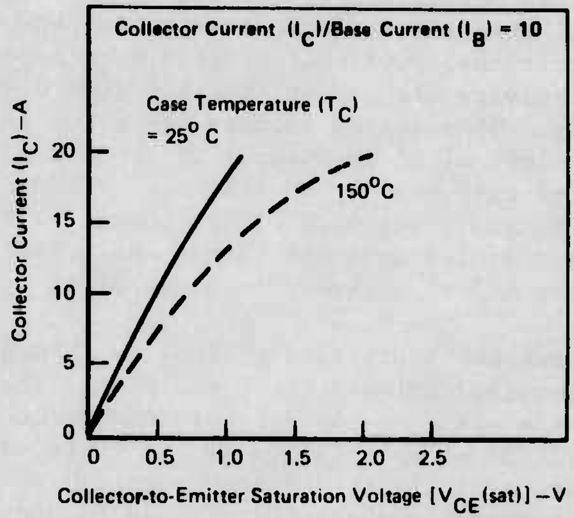


Figure 2 Basic Control Circuit of Controller Breadboard

emitter voltage with current causes an inherent balance between the two, thus saving the added component in the extra power dissipation that a pair of emitter resistors would require (see Figure 3). The configuration is a Darlington type with Q2 driving both Q3 and Q4, and also supplying its collector current to the load, thereby providing maximum efficiency for the circuit.



Source: RCA.

Figure 3 Typical Saturation-Voltage Characteristics for Type 2N3771 Transistor

The last feature of the power end is the use of a 20-μF feedback capacitor. This assures that, in response to a full "on" or full "off" command from the circuit, response is a ramp function of some 20- to 50-msec duration. Thus, abrupt changes in current are not possible. This eases considerably the EMI problem of conducted emission on the power leads, particularly in the high-frequency region where they are of most concern to the requirements of MIL-STD-461A.

The operation of the power end is thus clear and evident. Q1 operates either full "on" or full "off," turning the three power transistors (Q2, Q3 and Q4) full "on" or full "off," but in a ramp "up" and ramp "down" fashion caused by the negative feedback provided by the 20-μF capacitor.

In the front end of the circuit, there is a Wheatstone bridge configuration for sensing temperature error. The error detector is a 741 operational amplifier with a small amount of positive feedback applied, so that switching action is assured. This operation can be seen by noting that the sensing resistor is located in the upper left-hand part of the Wheatstone bridge. When this resistor has a temperature lower than the setpoint, it also has a resistance lower than the setpoint. With this low resistance, terminal 2 of the operational amplifier is more positive than it would be at balance; hence, a negative output occurs from the operational amplifier driving the output terminal 6 toward the minus bus of the power supply. This, in turn, drives current through the 4.7-kΩ resistor into transistor Q1, thereby assuring that it is in the "on" state and that power is thereby supplied to the load.

When power is supplied to the load, it is expected that the sensing resistor attached to the load will rise in temperature and eventually reach the setpoint as determined by the two 10-kΩ resistors of the Wheatstone bridge. When this balance is reached, the voltage on terminal 2 of the operational amplifier becomes more negative than at the setpoint, thereby driving the output at pin 6 toward the positive bus of the power supply. This action reduces the drive to Q1 and indeed turns it "off." Cutoff of Q1 is assured by the use of a pair of silicon diodes in series with the 4.7-kΩ resistor. These are used because the output at pin 6 cannot get much closer than 1 volt to the power supply, and if these diodes were not there, sufficient current could not flow through the 4.7-kΩ resistor to cause Q1 to turn "on."

The positive feedback and hysteresis control is through use of the 22-megohm resistor connected between pin 6 and pin 3, the plus input of the 741. In this way the state of the 741 will either be full "on" or full "off" and there will be no uncertainty in its state, and hence no uncertainty in the state of the transistors controlling the power. For this circuit the positive feedback corresponds to a dead band in the system of about 0.1% of the sensing resistor's value, and this can readily be equated to a dead band in temperature.

IV. DETAILED DESIGN

A. CONTROL CIRCUIT

Figure 4 is a schematic of the complete temperature controller. This circuit has many more components than the elemental circuit. Each one of these has its purpose; the reason for the added components is discussed in the paragraphs below. Use of the additional components is predicated largely on the constraints placed on circuit performance by the need to meet electromagnetic interference specifications, according to MIL-STD-461A, for which the unit must meet the requirements of CE03, CS01, CS02, CS06, RE02, RS02, and RS03. Other components in the circuit are included because of the need to meet the environmental requirements of MIL-STD-810B, including temperature, class 1, procedure 1, test method 504; vibration, procedure 1, part 1, curve z, part 2, curve ar, test method 515; acceleration, procedures 1 and 2, test method 513; explosive atmosphere, procedure 1, test method 511; shock, procedure 1, and the requirements for safety shutdown of the system in certain classes of failure of the sensor and, in addition, the requirements to perform over the expected power supply voltage range of 24 to 32 volts DC.

B. CIRCUIT FEATURES

1. Basic Temperature Control

Heater power is basically controlled by a U1B operational amplifier which detects the Wheatstone bridge error, and then either turns power to the heater element "on" or shuts the power from the heater element "off." This control is exercised through the transistor-chain Q3, Q4, Q5, Q6, and Q7. For the most part the circuit performs precisely as described in our discussion of the basic control circuit. The exception is that there is a single added stage of transistor gain prior to the output stages previously discussed. This added stage of gain is used so that transistor Q4 can be operated with a forced beta near 10--the desirable mode of operating a transistor when one wishes both to maintain the highest degree of reliability and to permit the widest degradation of performance before circuit failure occurs. Thus, it can be seen that the right-hand part of the circuit diagram is essentially that discussed before.

2. Over-Temperature Shutdown

According to the contract, the circuit was to include a feature which would shut down the temperature controller if the temperature of the hot cylinder rose above a safe operating limit, and circuit operation could not be restored without the assistance of a technician or operator.

We interpreted this to mean that should the shutdown event occur, the circuit would have to "remember" this fact, even though the raw DC power had been removed and reapplied. Thus, we decided that the most straightforward way of implementing this function was to use a snap-action switch. This switch is the Texas Instrument Klixon circuit breaker identified as K1.* The snap-action operation of this switch, once it has occurred, requires that the exposed pushbutton of the switch be manually actuated before power can be applied to the power side of the circuit. The operational amplifier U1A, in conjunction with transistors Q1, Q2, and the circuit breaker K1, provides this function. As noted in the diagram, the U1A amplifier is a detector for a second Wheatstone bridge element, the setpoint resistor set being comprised of R23, R3, and R5. When the temperature has risen to an over-temperature shutdown point, the sensor resistor has increased to the point where the output of the U1A, normally negative, becomes positive, turning on transistors Q1 and Q2, and thereby energizing K1's coil and thereafter the contact of K1. Thus the power from the power-handling portion of the circuit is shut down. Once again, a cascade of two transistors, Q1 and Q2, is used so that the maximum degree of circuit degradation can occur before the circuit ceases to operate.

3. Shorted Sensor Shutdown

If no provision for detection of a shorted sensor is made, the circuit would continue to supply power to the heater and there would no no recognition that the sensor was shorted, the operation of the circuit being such that low values of sensor resistor suggest adding power to the load. The operation of the low-sensor resistance circuit is provided by transistor Q8. In the event of a shorted sensor, or nearly shorted sensor, the potential on pin 8 of the circuit diagram rises almost to that of pin 12, thus turning on transistor Q8 and supplying current to transistor Q1 which, as already discussed, operates the shutdown relay. The particular transistor, the 2N2946, is a chopper transistor particularly designed to withstand large base-to-emitter voltages, such as would occur for an open sensor, or if no sensor is connected to the circuit.

4. Stable Power Supply Voltage

The zener diode, CR2, an 18-volt zener, is used in conjunction with resistor R1 to assure that the low-level circuits operate at a stable DC supply voltage in the presence of variations in the 28-volt bus (24 to 32 volts). In addition, it is subject to high-level AC voltages represented by the requirements of the MIL-STD-861B relating to EMI. The capacitor C3 (22 μF) also aids in maintaining a stable DC voltage in the

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*A data sheet for this device is included as Appendix C.

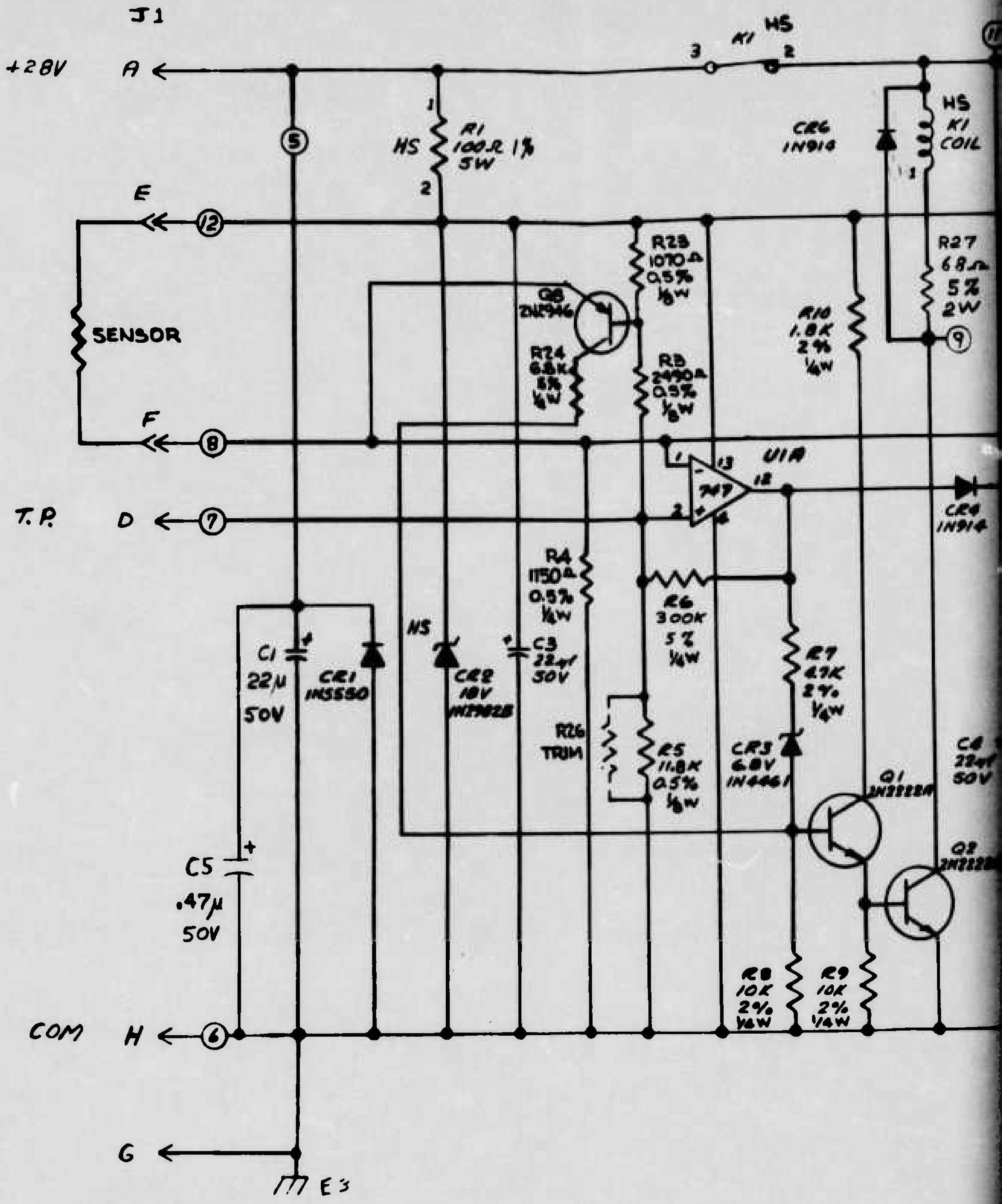


Figure 4 Schematic of C

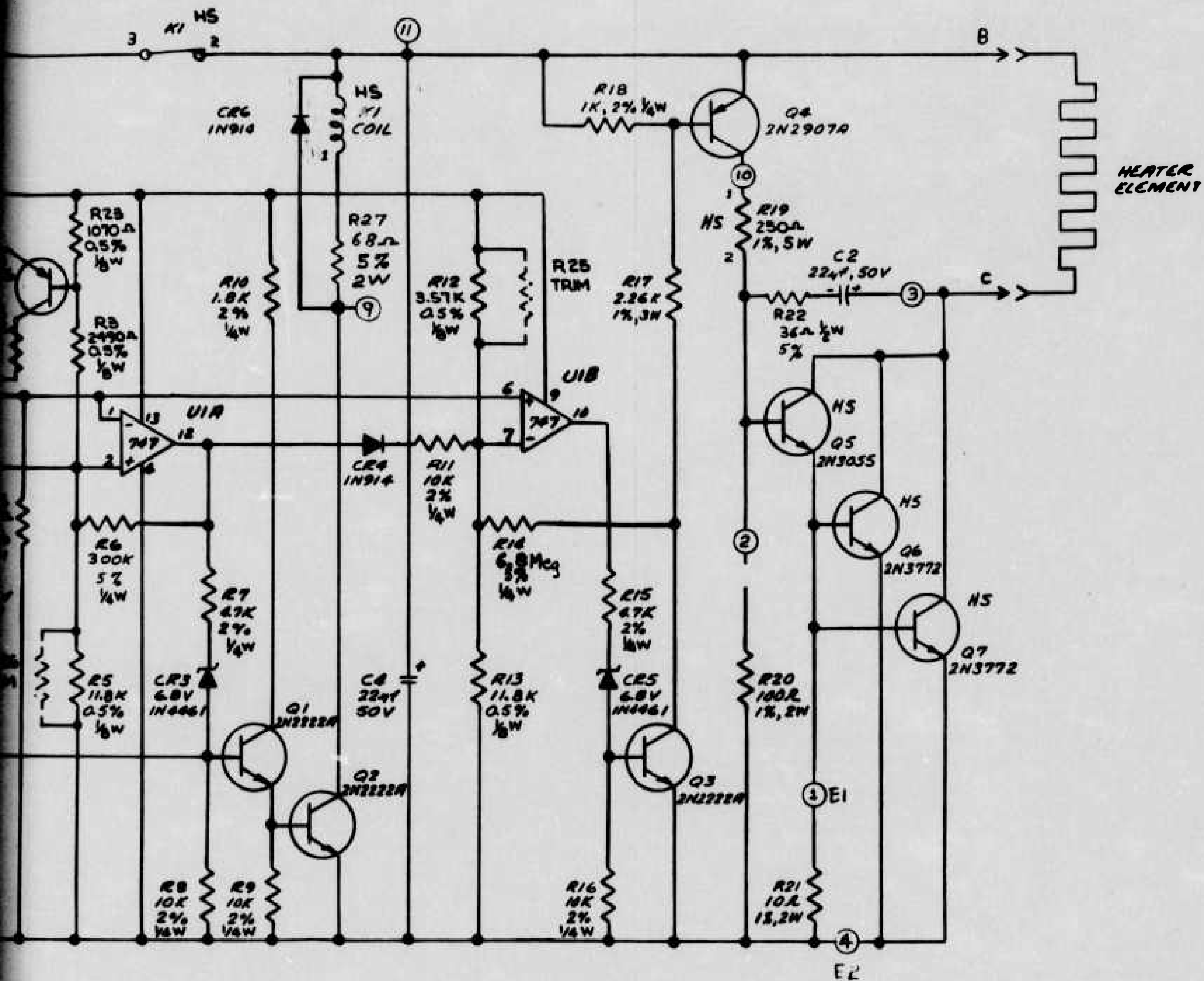


Figure 4 Schematic of Control Circuit

presence of this AC. The rectifier CR1, a 1N5550, serves the function of protecting the circuit against reverse voltage of the EMI test conditions wherein a 100-volt peak pulse is applied to the circuit in the polarity opposite the normal supply voltage. To prevent damage to the semiconductors, this diode is used and it effectively shorts out the pulse generator and prevents over-voltage in the wrong polarity from being applied to the circuit elements. Two 22-μF electrolytic capacitors, C1 and C4, are also used to assist in stabilizing the 18-volt operating supply against AC components in the 28-volt bus.

5. EMI Conducted Emission and Arc Suppression

Capacitor C5, a 0.47 μF foil capacitor, suppresses transient emission on the power lines that occur during turn "on" and turn "off" of the load current. This current remains despite the slow turn "on" and turn "off" discussed previously. This capacitor acts mainly on the higher frequency components of the transients that are not controlled by the much larger electrolytic capacitor C1, the high-frequency impedance of such electrolytic capacitors being too large to provide the suppression.

The diode, CR6, prevents the coil of K1 from excessive voltage from sudden de-energization of the coil.

6. Envelope

The envelope for the controller is illustrated in Figure 5. The volume represented by this enclosure, which is also shown in the drawing of Figure 6, is somewhat less than 25 $in.^3$

7. Safety Switch

The safety switch is designed to remove power from the heater element in the event that over-temperature is reached and the power cannot be restored until a manual reset of the safety switch is made. The safety switch is shown clearly in Figure 5.

C. COMPONENT SELECTION

The following bases were used for component selection for the controller circuit itself:

- Temperature Range - All components were selected to meet the full temperature range of -54°C to +71°C.

- Passive Components - Selection of passive components originally was made at the S level of reliability, that is, at a failure rate of 10^{-8} per hour, or 0.001% per 1000 hours. The resulting analyses showed that this was not in keeping with the cost

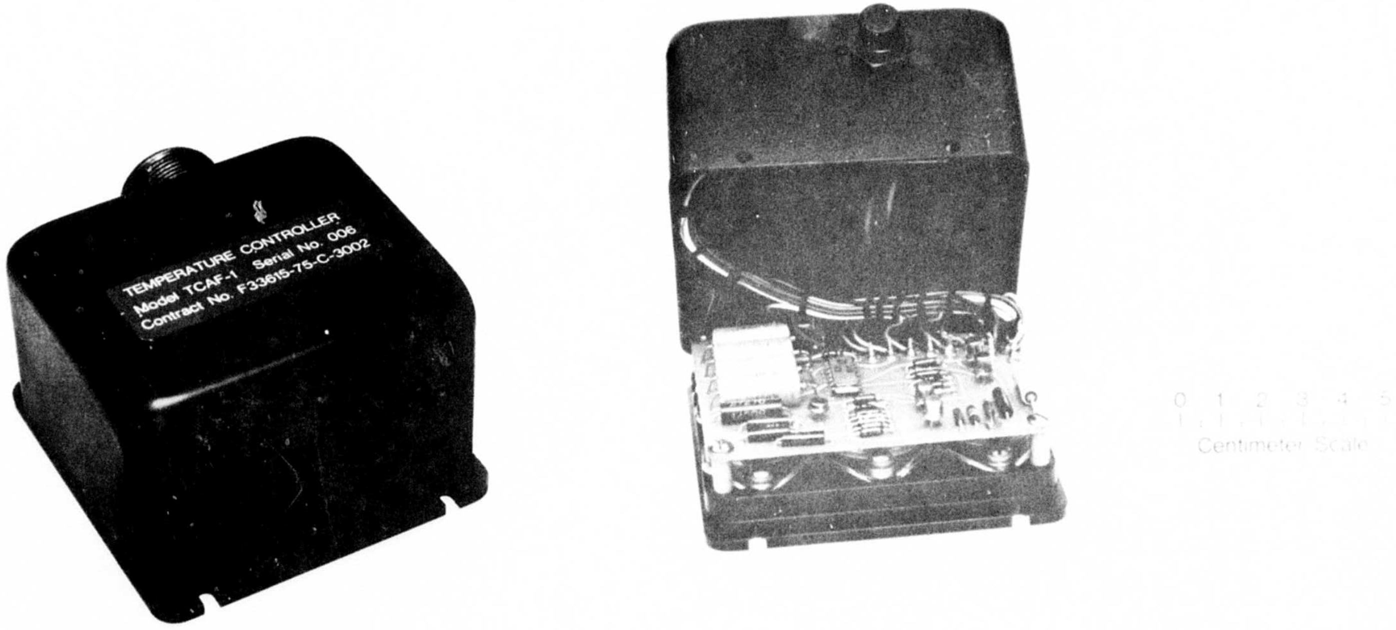


Figure 5 Envelope for the Controller

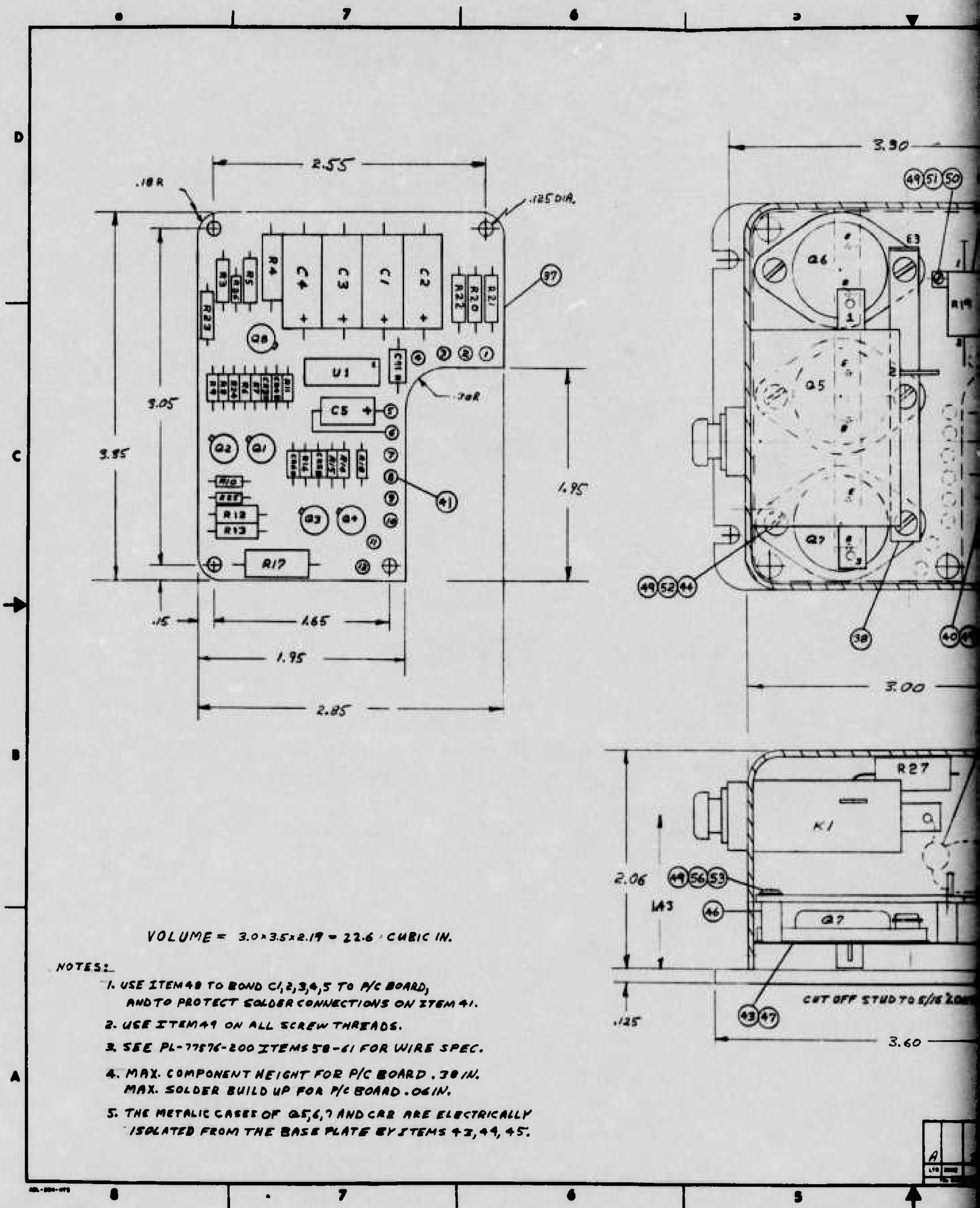
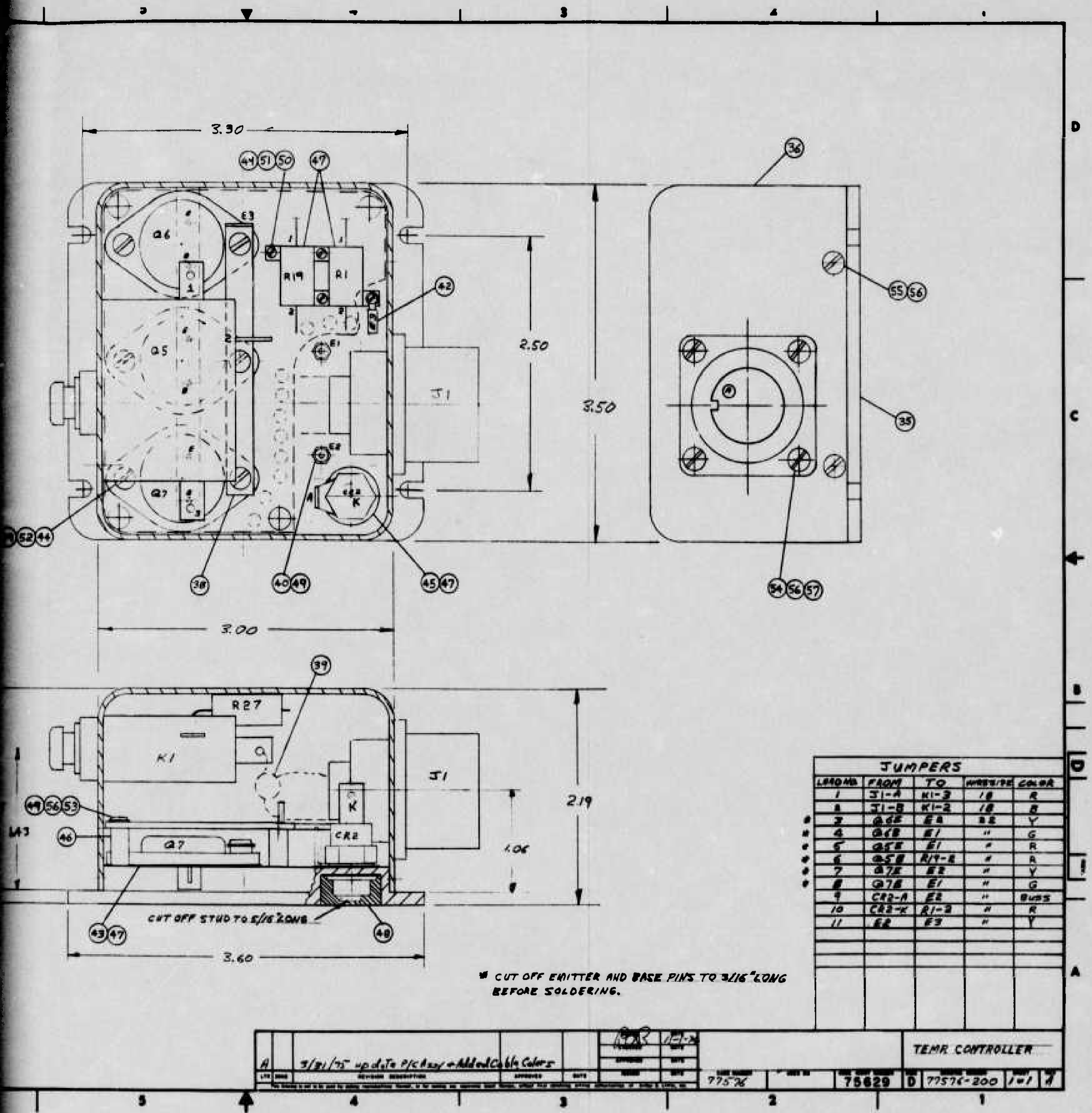


Figure 6 Controlle



JUMPERS					
	LEAD NO.	FROM	TO	WIRESIZE	COLOR
	1	J1-A	K1-3	18	R
	2	J1-B	K1-2	18	B
*	3	Q6E	E2	22	Y
*	4	Q6B	E1	"	G
*	5	Q5E	E1	"	R
*	6	Q5B	R19-2	"	R
*	7	Q7E	E2	"	Y
*	8	Q7B	E1	"	G
	9	CR2-A	E2	"	BUSS
	10	CR2-K	R1-2	"	R
	11	E2	E3	"	Y

Figure 6 Controller Assembly

guidelines established by WPAFB. Subsequently all passive components were backed off to the P level of reliability, a 10^{-6} failure rate per hour, or 0.1% per 1000 hours.

- Active Components - All active components were selected to be of the JAN or JANTX variety, thus assuring selection of components for military-qualified lines. These items fall under MIL-STD-19500 classification. The single IC was selected from MIL-38510.

- Circuit Board - Circuit board material corresponds to MIL-P13949 and the circuit was laid out according to MIL-STD-275.

- Stress Levels - Stress levels on the power semiconductors were purposely kept low by operating them in the switching mode, thus assuring low stress levels in terms of power dissipation in these components. In addition, all power switching transistors are operated with forced beta's of 10 or less, again to assure high reliability in the face of gradual degradation of the semiconductor's characteristics over time.

- Sensor Description - The platinum resistance temperature sensor chosen for use in the temperature controller is a modification of designs developed at Rosemount Engineering for military applications requiring long life and resistance to vibration and shock. A sketch of the construction of the sensor is shown in Figure 7. The important details of the construction include the external sheath being made of Inconel with a ceramic insulator to carry the lead wires to the junction point. The sensing element itself is wound on a ceramic bobbin and the intervening voids of the structure are thoroughly filled with alumina powder by a proprietary Rosemount process. The standard calibration curve for this sensor is included as Figure 8.

D. ESTIMATED CONTROLLER LIFE

In our design of the circuit we attempted to reach a reasonable economic trade-off between the component costs and the level of component reliability. In general, we chose to use Class P components, which have a nominal failure rate of 1 in 10^6 hours. Class R components, which have a nominal failure rate of 1 in 10^7 hours, would have cost substantially more if implemented in the circuit. Class M components with a failure rate of 1 in 10^5 hours would have made the design inadequate.

We estimated the life of the controller on a simple cascade basis; that is, any single failure of any component leads to a failure of the controller. In terms of operational effectiveness, there are a large number of components in the circuit which may fail completely and still

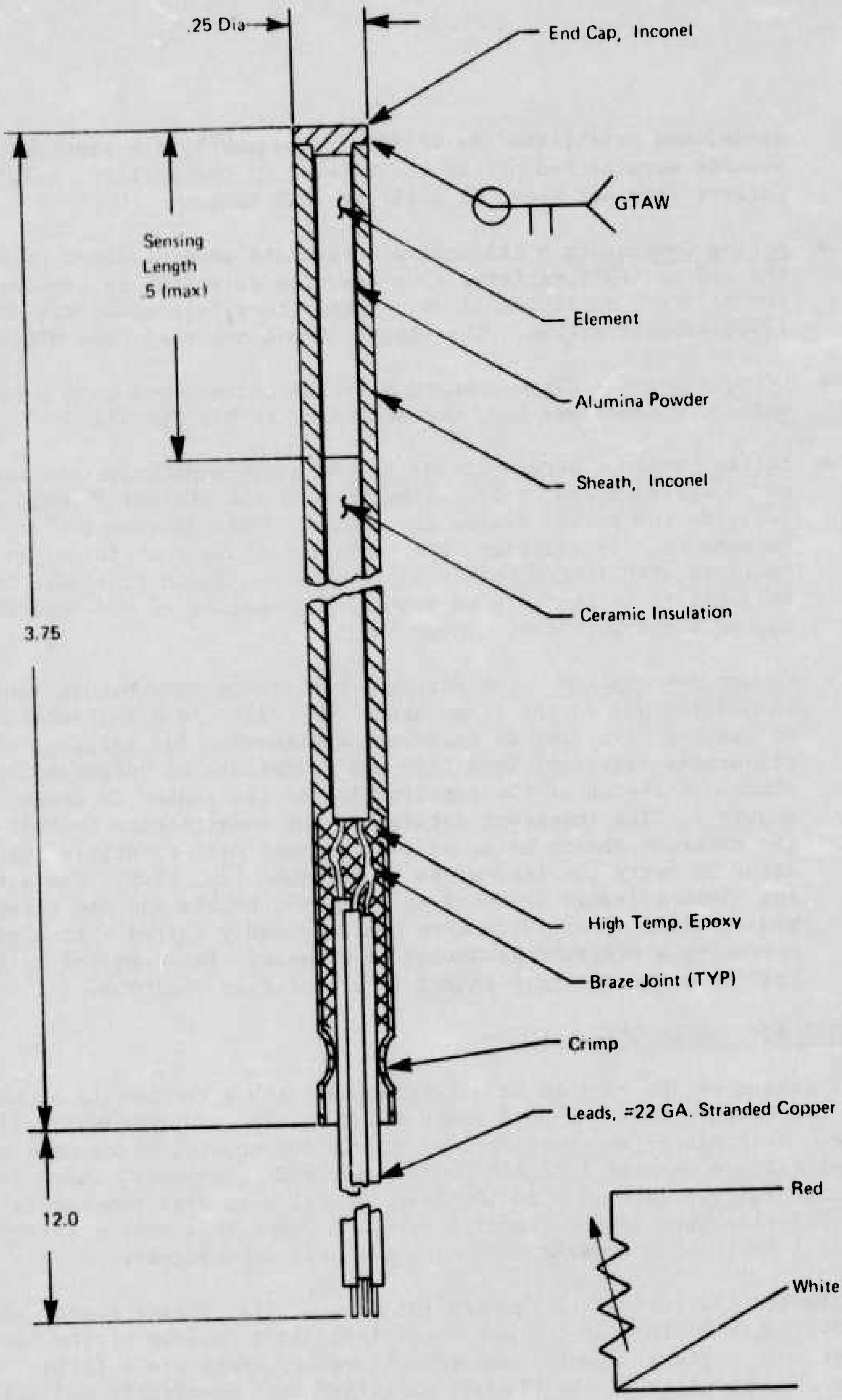


Figure 7 Rosemount Model 132JA Platinum Resistance Temperature Sensor

SPECIFICATIONS

1. DESCRIPTION. The Rosemount Model 132JA is designed to measure temperature over the range -100°F to 1300°F. The precision temperature sensitive element consists of a fully annealed, reference grade (very pure) platinum wire which produces a change in electrical resistance with respect to temperature. The platinum wire is mounted and electrically insulated within the sensor case in such a manner as to ensure stable, strain-free performance.

2. PERFORMANCE.

2.1 Temperature Range. -100°F to 1300°F.

2.2 Output. Table 1 shows the nominal resistance versus temperature relationship. Each sensor shall lie within the interchangeability band shown in the table.

2.3 Calibration. Unless otherwise specified, each sensor shall be calibrated at 32°F, accurate to within ±.03°F.

2.4 Insulation Resistance. At room temperature and with dry external surfaces, the insulation resistance between any lead and the sensor case shall exceed 100 megohms when measured at 100 VDC.

2.5 Pressure. Each sensor shall he capahle of withstanding operating pressures to 1000 psig.

2.6 Time Constant. The time required for 63.2 percent response to a step change in temperature from room temperature air to water at 170°F flowing at 3 fps, transverse to the sensor shall he less than 5.0 seconds.

2.7 Compatibility. The Model 132JA is suitable for use in any fluid or environment that is compatible with Inconel. Other materials exposed in the lead exit area are in epoxy and teflon.

2.8 Identification. Each 132JA shall have the following data electroetched in the location shown.

RMT Model 132JA

S/N __________

3. QUALITY ASSURANCE.

3.1 Repair and Maintenance. The sensor is non-repairahle and shall need no maintenance during its useful life.

3.2 Acceptance Testing. Prior to shipment, each sensor shall he examined for high quality workmansip, conformance to the dimensional requirements of this drawing, and shall undergo testing to ensure compliance to paragraphs 2.3 and 2.4 described above.

Table 1

RESISTANCE TEMPERATURE (°F) RELATIONSHIP

Temperature (°F)	Resistance (Ohms)	Interchangeability (± Ohms)	Interchangeability (± °F)
-100	70.51		
32	100.00	.10	0.5
100	114.93		
200	136.59		
300	157.38		
400	178.81		
500	199.38		
600	219.59		
700	239.44		
800	258.92		
900	278.05		
1000	295.97		
1100	314.13		
1200	331.91		
1300	349.30		

FIGURE 8. SENSOR CALIBRATION DATA

not affect the operational utility of the unit as a temperature controller. In this sense our computation is conservative.

We also adjusted the nominal failure rates upward in some instances on the basis of general reliability testing data supplied us by Philco-Ford. These are judgmental matters and a case could be made that this approach is overly conservative. We did not adjust failure rates downward, however, although the evidence from Philco-Ford and MIL-HDBK-217B would give some basis for adjusting the failure rates of some components substantially downward. We made estimates for the circuit breaker, the connector, the sensor, and the circuit board, all of which can contribute to failure.

The circuit breaker is a device which fails largely because of the number of cycles of use. In the application intended, the number of cycles of use will be extremely small, a few in the life of the controller. We believe that the estimate of 10 failures per 1,000,000 hours is conservative. The connector is again a device for which the basic failure mechanism is a use factor, i.e., how many times was the mating connector applied? Again, in our application, this action will occur relatively infrequently and therefore we believe that the failure rate chosen is conservative. For the circuit board we have made an estimate of 10×10^{-6} failures per hour in the computation. For the sensor, we have also chosen to use a 10×10^{-6} failure rate. We believe that our computation of failure rate which leads to a total of 117×10^{-6} failures per hour and a corresponding mean time between failure of 8500 hours is conservative. The proof of the design, of course, will be the reliability testing to be undertaken by Wright Patterson Air Force Base.

It is noteworthy that the failure rates we have used are 5 to 20 times larger than the rates obtained by using procedures and data from MIL-HDBK-217B. Hence, some credence can be given to our conservative estimates on controller life.

Table 1 shows the estimated failure rates for subject components.

E. ERROR BUDGET

The design of the circuit is based on the following errors in controller setpoint accuracy:

- Resistor Temperature Coefficient - The basic resistor elements within the Wheatstone bridge are comprised of 50 ppm/°C resistors. Three such resistors form the arms, together with the sensing resistor. The worst case error due to the resistors is $3 \times 65 \times (5 \times 10^{-5})$ or ±0.67% of resistance value. When referred to the 340-ohm sensor resistor, this corresponds to a 2.27-ohm sensor error due to this source.

TABLE 1

ESTIMATE FOR FAILURE RATES

All Passive Components of Class P (1 failure per 10^6 hours)

Component	No. in Circuit	Adjusted Failure Rate (rate per hour)	Failure Rate
Power Transistors	3	4×10^{-6}	12×10^{-6}
Signal Transistors	5	3×10^{-6}	15×10^{-6}
Power Resistors	3	3×10^{-6}	9×10^{-6}
Tantalum Capacitors	4	2×10^{-6}	8×10^{-6}
Zener Diodes	3	2×10^{-6}	6×10^{-6}
Film Resistors	20	1×10^{-6}	20×10^{-6}
Carbon Resistors	2	1×10^{-6}	2×10^{-6}
Plastic Capacitor	1	1×10^{-6}	1×10^{-6}
Switching Diodes	3	1×10^{-6}	3×10^{-6}
Analog IC	1	1×10^{-6}	1×10^{-6}
Circuit Breaker	1	10×10^{-6}	10×10^{-6}
Connector	1	10×10^{-6}	10×10^{-6}
Sensor	1	10×10^{-6}	10×10^{-6}
Circuit Board	1	10×10^{-6}	10×10^{-6}
		Total Failure Rate =	117×10^{-6}
		MTBF =	8500 hours

- Operational Amplifier - The operational amplifier specifications are such that over the full temperature range the offset voltage will remain constant to within ±3 mV. The sensitivity of the basic bridge operating at 18 volts is 9.6 mV per ohm. Therefore, the operational amplifier uncertainty corresponds to 0.313 ohm of sensor resistance.

- Sensor - The basic sensors provided by Rosemount are accurate at the operating temperature to ±1.3 ohms.

These three elements combine to give a total worst case error of 3.88 ohms of uncertainty corresponding to ±22°F of temperature error. This worst case error leaves ±28°F for all other sources of error, including long-term drift of the bridge resistors, the natural fluctuation of temperature because of the on-off character of the controller, and long-term changes in sensor resistance.

F. DETERMINATION OF TRIM RESISTORS

Figure 4 shows two trim points in the circuit, R25 and R26. These trims were included so that 0.5% tolerance bridge resistors could be used; these bridge resistors could be trimmed by nominal 5% or 10% carbon resistors. The trim resistors are selected by powering the unit with a load element which could either be a load simulator or a fixed resistive load. The sensor is replaced by a precision decade resistor box which is set to 360 ohms; a second decade box is connected across R5 which is the trim resistor position for R26. The decade box representing R26 is adjusted so that the over-temperature action takes place at the 360-ohm sensor. The value of trim resistor necessary for this is noted, and the nearest 5% standard resistor is then selected and placed in the trim position. This sets the over-temperature limit. After completion of the over-temperature setting, the decade box representing the trim resistor is attached across R12, the position for R25 trim; the precision decade resistor representing the sensor is set at 344.2 ohms, and the decade box representing the trim resistor is adjusted so that the temperature controller turns the current off at precisely the 342.2-ohm level, representing the sensor resistor. The value of the trim resistor is then noted and the nearest 5% tolerance resistor is selected and used as trim resistor R25.

V. LOAD SIMULATION

Figure 9 illustrates the load simulator used to exercise the controller. The extremely simple construction consists of a base plate to which is attached a stainless-steel pedestal around which is wrapped a Watlow heater. The device has an aluminum cover. The region between the heater and the cover is insulated with Q-felt around the base and a min K cap over the top to provide thermal insulation such that for the available heater power the temperature becomes approximately the correct value. In the base plate there are provision for either air or water cooling to keep the exterior of the unit from becoming overly hot during extended periods of tests.

We used both water and air to control the base temperature. The heater wires are brought out to a terminal strip as are the temperature sensor leads. The configuration of the heater and the temperature sensor are shown in the figure, as well as the configuration of the load temperature sensor, a thermocouple with the thermocouple metallically bonded to the sheath of the sensing element. The heater resistor equals approximately 4 ohms, so that at a 28-volt output from the controller 196 watts are consumed by the heater. The assembled load simulator is shown in Figure 10. The heater wires run to the terminal strip as well as the platinum resistance sensor leads. The thermocouple leads are provided with a thermocouple connector and its mating male piece.

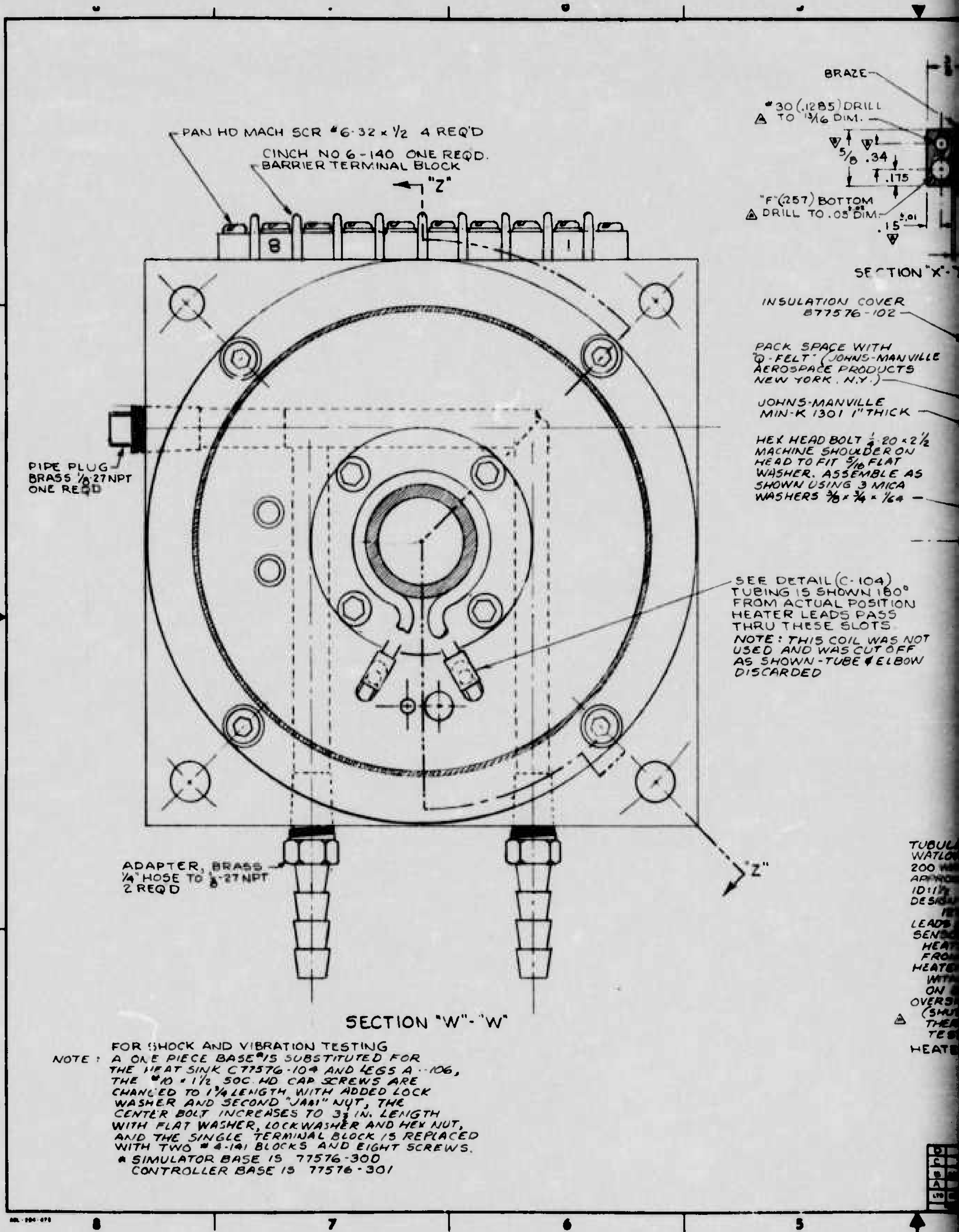


Figure 9 Load Si

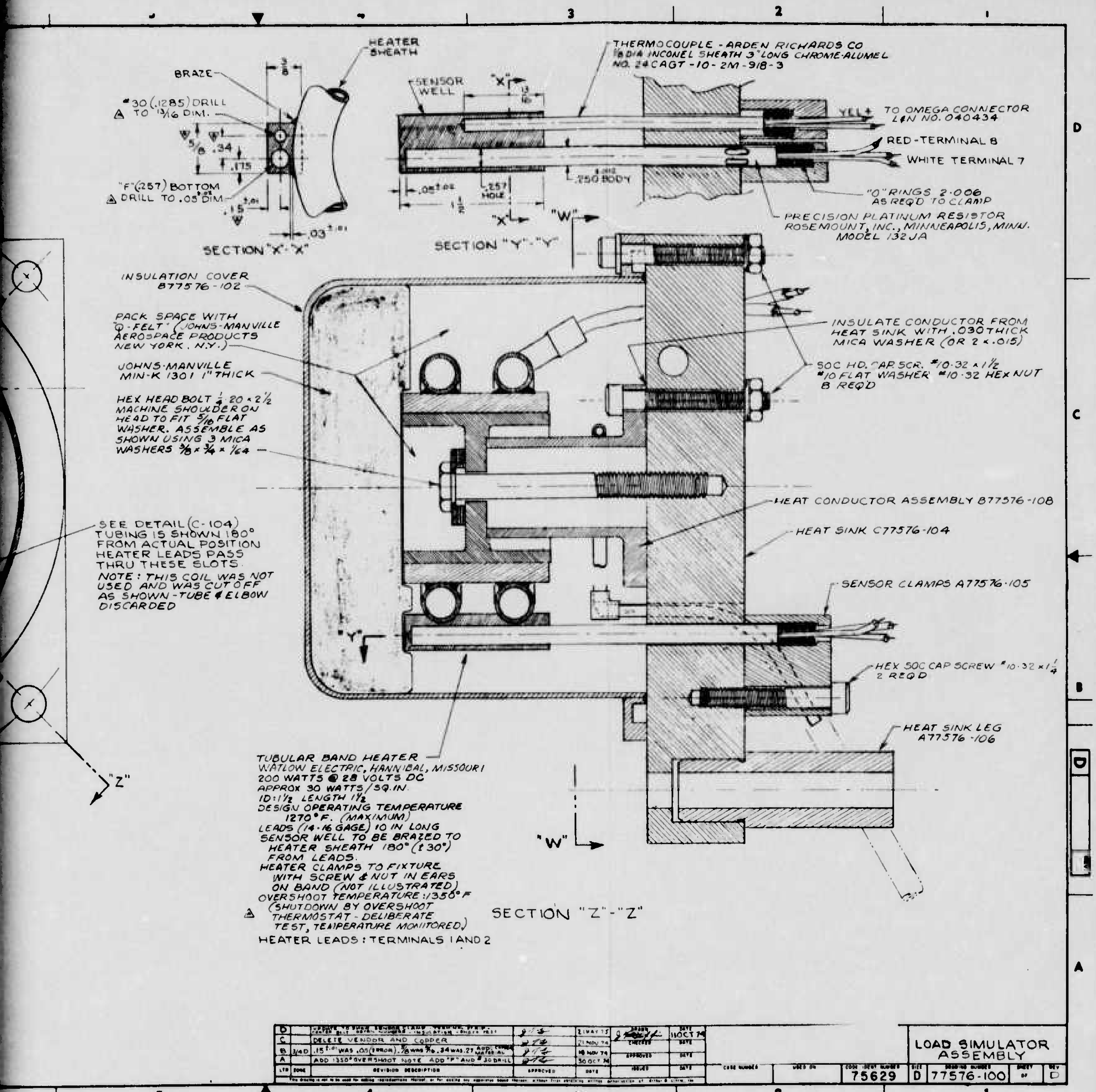


Figure 9 Load Simulator Assembly

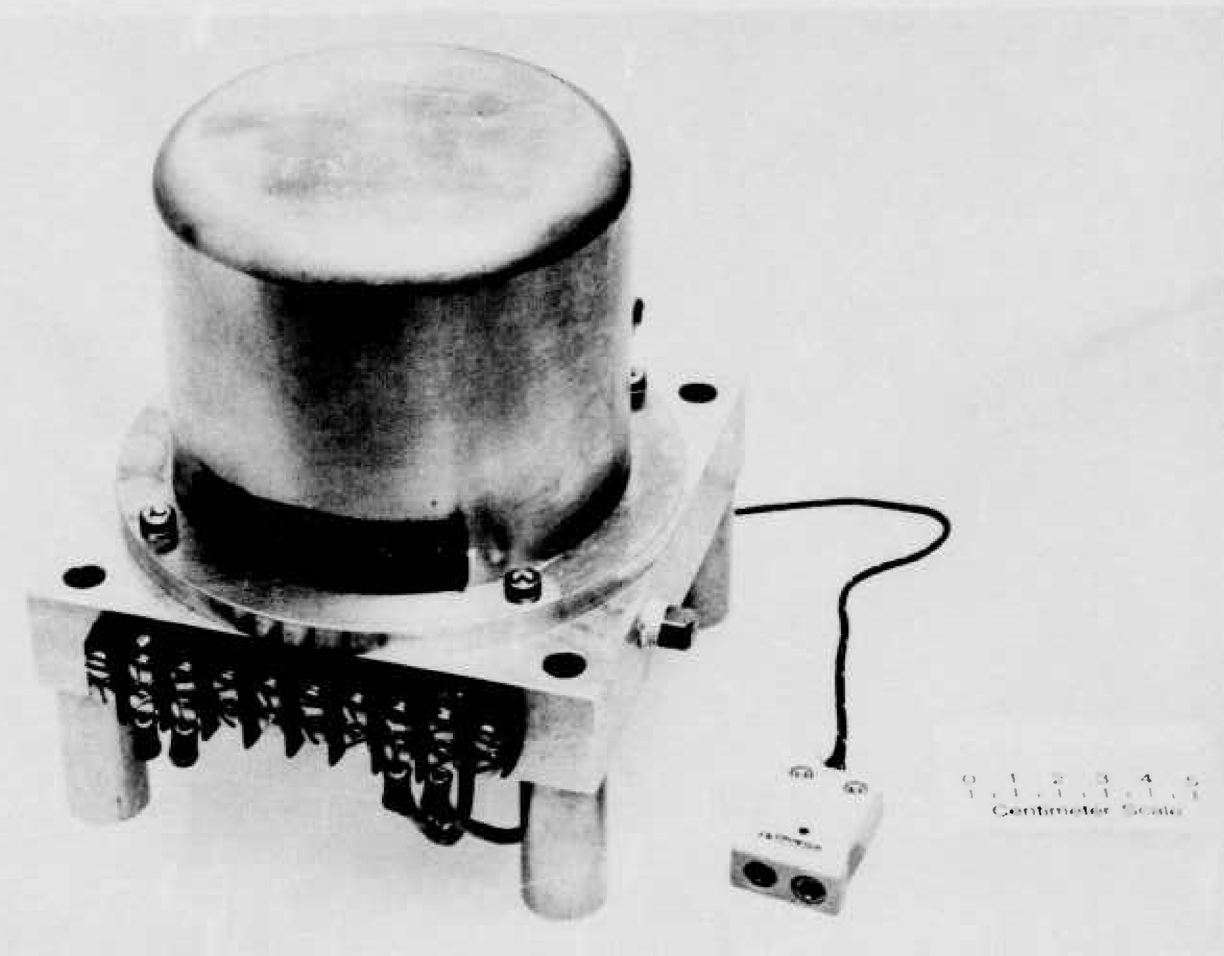


Figure 10 Assembled Load Simulator

VI. SYSTEM PERFORMANCE

Figure 11 illustrates the two parts of the temperature control system*--the controller and load simulator. We have designated the controller as Model TCAF-1, Serial Nos. 001 to 005, and the load simulator as Model LSAF-1, Serial Nos. 001 to 005.

Figure 12 illustrates the interconnections used to operate the system and the instrumentation we used to test the equipment in the laboratory.

A. MEASURED EFFICIENCY

The "on-off" mode of operation of the controller makes the efficiency slightly dependent on the duty cycle of the power supplied to the heater. Measurements show that at 100% duty cycle and 28 volts input with an external resistance load, the input power is 215 watts with an output power of 195 watts, yielding an efficiency of 90.8% at 100% duty cycle. The standby power, that is, the power consumed by the circuit when the load is not being operated, is 2.8 watts. Thus, at a 50% duty cycle the efficiency drops to 89.6%. Both of these figures are well within the target of a temperature controller that dissipates less than 20% of the power it controls.

B. TYPICAL TIME RESPONSE OF CONTROL UNIT

The temperature controller operates in an "on-off" fashion for the reasons discussed previously. This "on-off" operation leads to a temperature excursion at the control point which is caused by the time lags of both the mass being heated and the time constant of the sensor itself. The plot shown in Figure 13 represents performance typical of the controller when it is operated at 28 volts. This plot also shows the start-up transient which occurs as the simulator is heated up from ambient temperature. The specification limits for temperature are marked on the strip chart record reproduced in this figure and show performance to be within the requirements.

C. CONTROLLER PERFORMANCE CHARACTERISTICS

1. Controlled Temperature

Table 2 shows the performance of the temperature controllers in conjunction with the load simulators.

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*Operational instructions are presented in Appendix A.

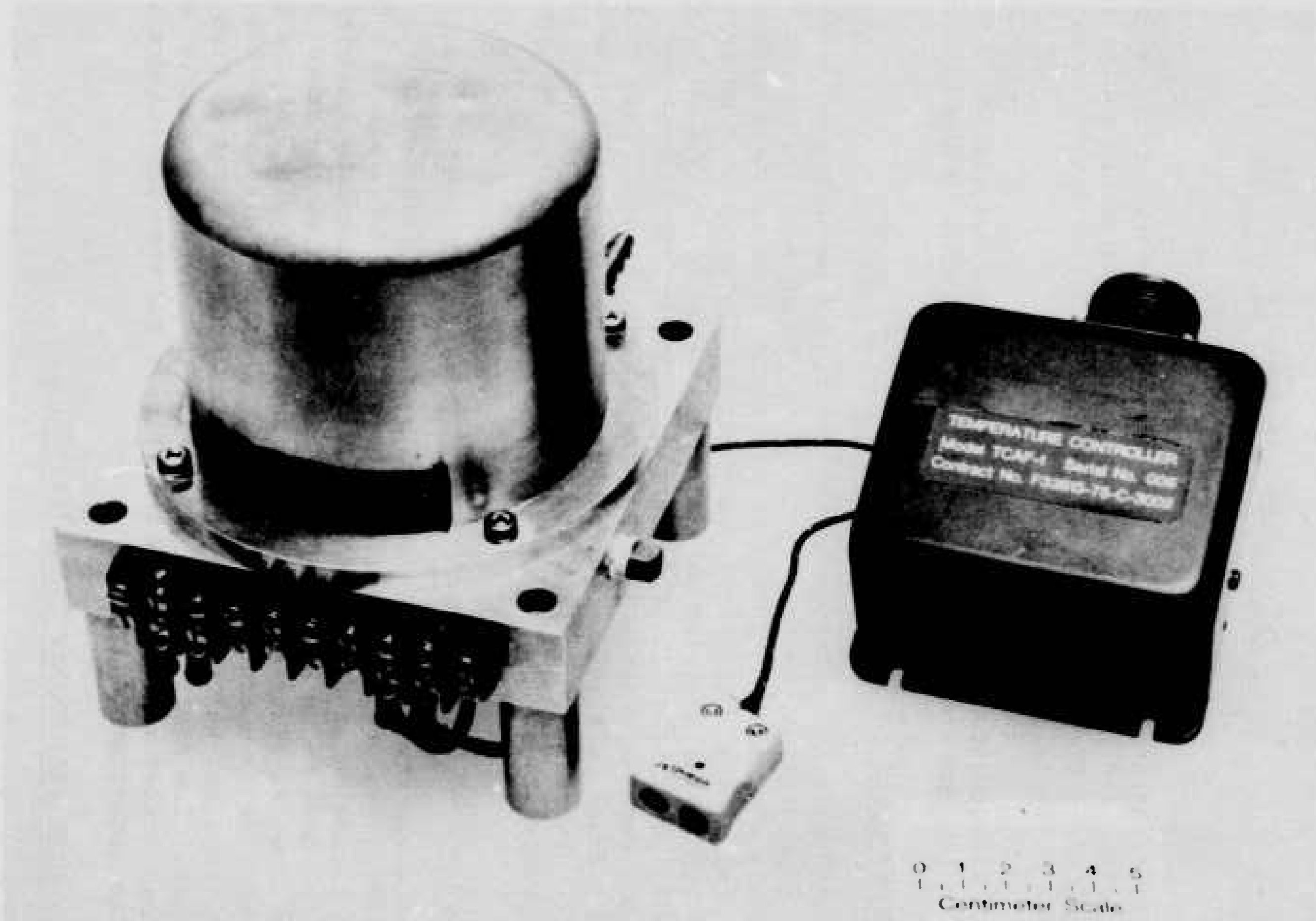
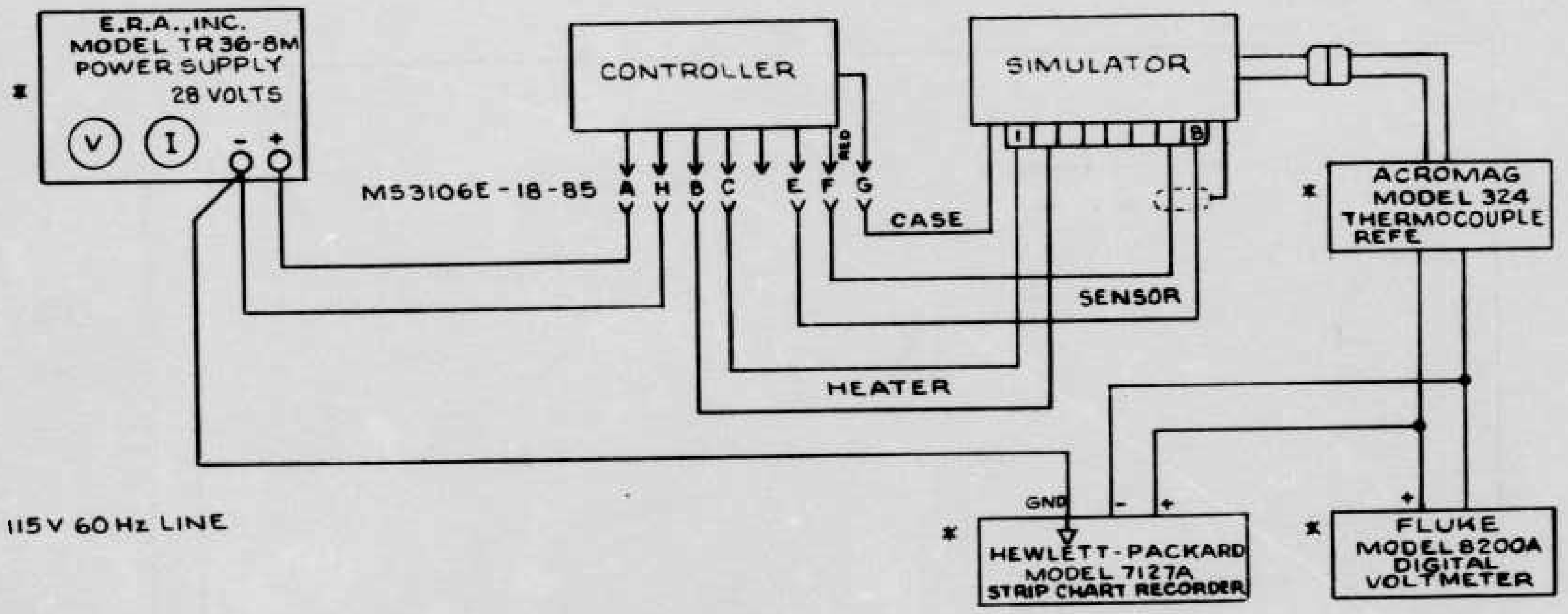


Figure 11 Load Simulator and Controller



* 115 V 60 Hz LINE

NOTE:
PROVIDE ADEQUATE HEATSINK
(MINIMUM 8 × 8 × 1/4 ALUMINUM)
FOR CONTROLLER AND
.4 LITERS/MIN (6 GAL/HOUR)
OF COLD WATER THRU
SIMULATOR HEAT SINK

Figure 12 System Test Set-up

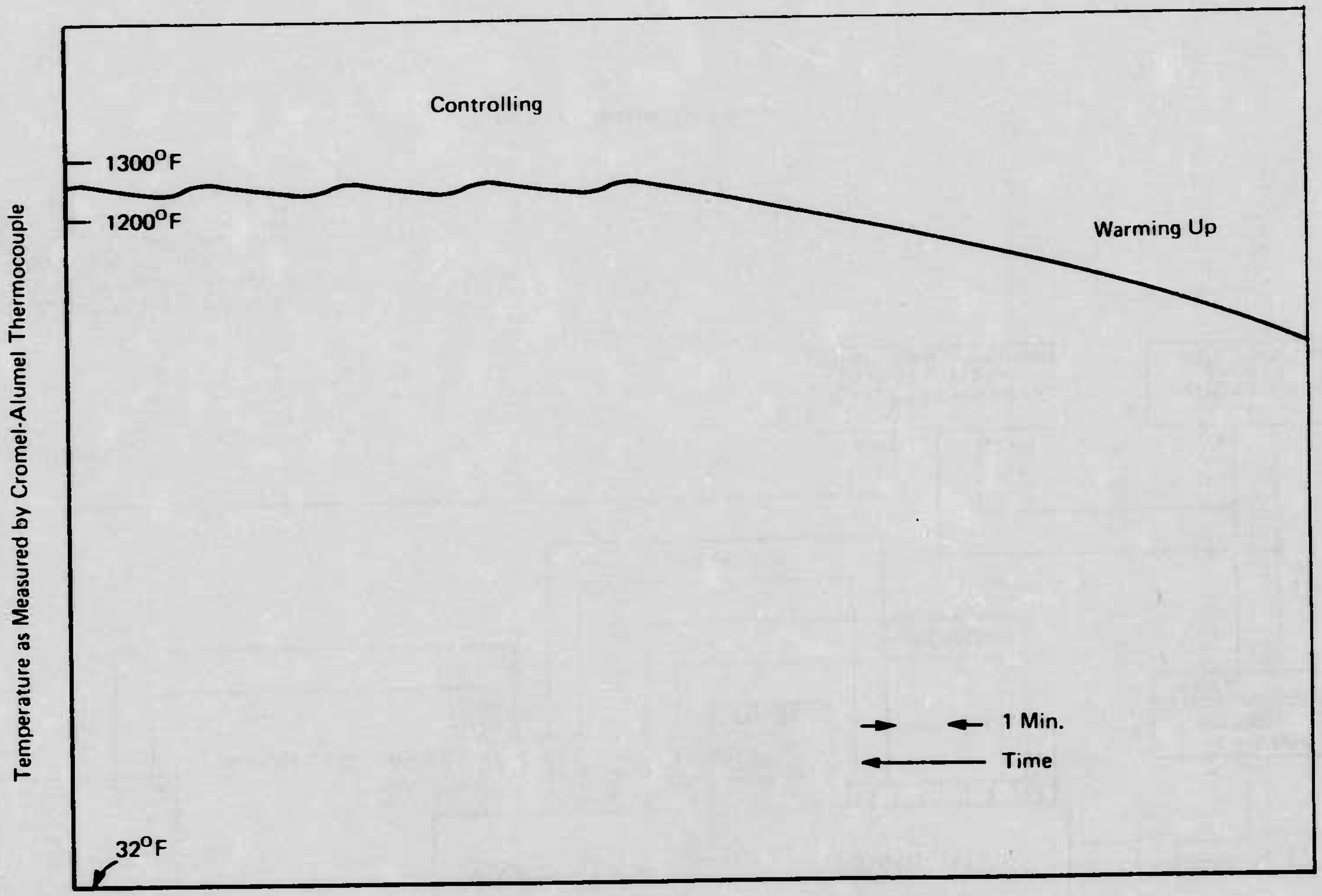


Figure 13 Typical Temperature Vs. Time for Controller

TABLE 2

PERFORMANCE OF TEMPERATURE CONTROLLERS

Load Simulator Serial No. 002 operated with Controllers Serial Nos. 001 through 005:

Conditions: Room Temperature: ~70°F
Power Supply Voltage: 28 volts

Controller Serial No.	Range of Load Temperature, °F	
	Low	High
001	1253	1275
002	1248	1274
003	1249	1274
004	1249	1274
005	1250	1275

Controller Serial No. 001 operating with Load Simulators Serial Nos. 001 through 005:

Load Simulator Serial No.	Range of Load Temperature, °F	
	Low	High
001	1243	1268
002	1251	1271
003	1249	1273
004	1251	1273
005	1257	1277

TABLE 2 (Continued)

PERFORMANCE OF TEMPERATURE CONTROLLERS

Load Simulator Serial No. 002 operated with Controller Serial No. 005 at various voltages:

Voltage	Range of Load Temperature, °F Low	High
32.0	1250	1280
28.0	1250	1275
24.0	1257	1257*

Cut-off Temperature versus Controller Ambient Temperature; Serial No. 001 Controller at 28 volts, as measured with controller in temperature-controlled chamber:

Ambient Temperature, °C	Sensor Resistance for Turn-off of Controller (ohms)	Equivalent Temperature, °F
-55	346 ± 1	1282 ± 6
0	344 ± 1	1270 ± 6
20	344 ± 1	1270 ± 6
40	344 ± 1	1270 ± 6
65	344 ± 1	1270 ± 6

*At 100% duty cycle

2. Environment and EMI

Complete details on the environmental tests are included in Appendix B of this report. They include temperature, vibration, acceleration, explosive atmosphere and shock. Complete details of the EMI tests are also included in the appendix.

These tests results show compliance with the EMI and environmental specifications.

VII. PRODUCTION COST ESTIMATE

A reasonable production cost estimate for this system requires the assumption of typical industry costs and some definitions of the conditions under which these units would be manufactured:

- Parts costs are based on procurement of 300 sets of parts at one time, to take advantage of quantity discount schedules.
- The overage parts buy of 10 percent is to cover losses due to breakage and test failures.
- The handling charge of 10 percent of the total parts buy is to cover receiving, stocking, and kitting costs.
- A typical direct assembly labor cost of $5.00 per hour is assumed for skilled persons employed in a diverse electronic assembly job shop. Fringe benefit costs of 33% must be added to obtain the total direct hourly labor cost of $6.65.
- Direct supervision and testing labor costs of $7.00 per hour with a 28% addition for fringe benefits is also assumed, for a total cost of $8.96 per hour.
- The factory overhead is defined as 150% of the direct labor costs. This covers the cost of the floor space and production equipment devoted to this project.
- A G&A cost of 20% of the factory labor costs is assumed.
- Profit is defined as 11% of net costs.
- To ensure the reliability level required, a 100% incoming inspection of critical electronic parts is assumed. Also, final testing and a full-power burn-in is assumed in the calculation of test labor costs.

Cost Breakdown

Parts Cost (per PL77576-200)		$107.33
Overage Allowance		10.73
Total Parts Buy		$118.06
Handling Charge		11.81
Total Parts Cost		$129.87
Direct Assembly Labor (5 hours)	$33.25	
Direct Supervision and Test Labor (2 hours)	17.92	
Total Direct Labor	$51.17	
Factory Overhead	76.76	
Factory Loaded Labor Cost		127.93
Total Manufacturing Cost		$257.80
G&A		25.59
Total Net Cost		$283.39
Profit		31.19
Sell Price		$314.58

The cost of a sensor element must be added to this estimate for the controller. If Rosemount 132JA sensors are used, an estimated cost per unit in 300 lots is $125.00. If it is found possible to use a Rosemount Series 78, the cost would drop to $40.00 per unit in lots of 300. Thus, the total controller cost would be:

$439.58 with the 132JA

or

$354.58 with the Series 78

	CODE 75629 IDENT NO	PARTS LIST	REVISION
		PL 77576-200 NUMBER	DATE
POB PREPARED BY / 6-9-75 DATE / APPROVED BY / DATE	77576 CASE NUMBER	Temperature Controller TITLE	1 OF 3 PAGE

ITEM NO	QTY	PART NUMBER OR IDENTIFYING NUMBER	NOMENCLATURE OR DESCRIPTION
1	4	CSR13G226KP	Capacitor, 22µf 50V (Kemet) C1, 2, 3, 4
2	1	MIL-C-27287	Capacitor, .47µf 50V (TRW, 463uw) C5
3	1	JAN1N5550	Diode, (Unitrode) CR1
4	1	JAN1N2982B	Diode, Zener (Motorola) CR2
5	2	JAN1N4461	Diode, Zener (Unitrode) CR3, 5
6	2	JAN1N914	Diode, (T.I.) CR4, 6
7	1	MIL-C-5809	Breaker, Circuit (T.I., 7MC6-3-0.1) K1
8	3	JAN2N2222A	Transistor, (Motorola) Q1, 2, 3
9	1	JAN2N2907A	Transistor, (Motorola) Q4
10	1	JAN2N3055	Transistor, (Motorola) Q5
11	2	JAN2N3772	Transistor, (RCA) Q6, 7
12	1	JAN2N2946	Transistor, (Motorola) Q8
13	1	RER60F100RP	Resistor, 100Ω ± 1% 5W R1
14	1	RNC60E2491DP	Resistor, 2490Ω ±0.5% 1/8W R3
15	1	RNC65E1151DP	Resistor, 1150Ω ± 0.5% 1/4W R4
16	2	RNC60E1182DP	Resistor, 11.8KΩ ± 0.5% 1/8W R5, 13
17	1	RCR07G3003JP	Resistor, 300KΩ ± 5% 1/4W R6
18	2	RLR07C472GP	Resistor, 4.7KΩ ± 2% 1/4W R7, 15
19	4	RLR07C103GP	Resistor, 10K ± 2% 1/4W R8, 9, 11, 16
20	1	RLR07C182GP	Resistor, 1.8KΩ ± 2% 1/4W R10
21	1	RNC60E3571DP	Resistor, 3.57KΩ ± 0.5% 1/8W R12

			CODE 75629 IDENT NO	PARTS LIST PL 77576-200 NUMBER	REVISION DATE
POB PREPARED BY	6-9-75 DATE	APPROVED BY / DATE	77756 CASE NUMBER	Temperature Controller TITLE	2 OF 3 PAGE

ITEM NO	QTY	PART NUMBER OR IDENTIFYING NUMBER	NOMENCLATURE OR DESCRIPTION
22	1	RCR07G6804JP	Resistor, 6.8 Meg ± 5% 1/4W R14
23	1	RWR89S2261FP	" , 2.26KΩ ± 1% 3W R17
24	1	RLR07C102GP	" , 1KΩ ± 2% 1/4W R18
25	1	RER60F250RP	" , 250Ω ± 1% 5W R19
26	1	RWR80S100RFP	" , 100Ω ± 1% 2W R20
27	1	RWR80S10RFP	" , 10Ω ± 1% 2W R21
28	1	RCR20G360JP	" , 36Ω ± 5% 1/2W R22
29	1	RNC60E1071DP	" , 1070Ω ± 0.5% 1/8W R23
30	1	RCR07G682JP	" , 6.8KΩ ± 5% 1/4W R24
31	AR		" , Trim if required R25
32	AR		" , " " " R26
33	1	M38510/101-02	Operational Amplifier U1
34	1	MS3102E-18-8P	Connector (Amphenol) J1
35	1	77576-203	Base Plate
36	1	77576-204	Cover
37	1	77576-205	Board, Printed Circuit
38	1	77576-206	Bus Strip
39	1	77576-202	Cable Assembly
40	2	4882-1-0516	Insulated Terminal, (Cambion) E1, 2
41	12	2043-2	Solder Terminal (Cambion) P/C1-12

				CODE IDENT NO	PARTS LIST	REVISION / DATE
				75629	PL 77756-200 NUMBER	
POB PREPARED BY	6-9-75 DATE	APPROVED BY	DATE	77756 CASE NUMBER	Temperature Controller TITLE	3 OF 3 PAGE

ITEM NO	QTY	PART NUMBER OR IDENTIFYING NUMBER	NOMENCLATURE OR DESCRIPTION
42	1	320733-300	Crimp Terminal (AMP) E3
43	3	7416	Mica Insulator (Amatom)
44	6	4 - 1/32	Nylon Screw Insulator (Non-Metallics)
45	1	MH745	Rectifier Mounting Kit (Motorola)
46	4	9211-A-0115-1A	Standoffs (Amatom)
47	AR	120-8	Thermal Joint Compound (Wakefield Eng.)
48	AR	3144RTV	Sealant (Dow Corning)
49	AR	Type C	Sealant (Loctite)
50	4		Screw, Pan Head, SS, 2-56 x 3/16
51	4		#2 Lockwashers, SS internal teeth, SS
52	6		Screw, Pan Head, SS, 4-40 x 1/4
53	4		Screw, Pan Head, SS, 4-40 x 9/16
54	4		" " " ", 4-40 x 3/8
55	6		" " " ", 4-40 x 3/16
56	14		#4 Lockwashers, SS internal teeth
57	4		Nuts, SS, 4-40
58	AR	MIL-C-7078	Wire, 24 AWG Stranded, insulated
59	AR	"	" , 22 AWG " , "
60	AR	"	" , 18 AWG " , "
61	AR	QQ-W-343	" , 22 AWG Solid, Tinned, Bus
62	REF	77576-201	SCHEMATIC
63	1	RCR42G RJP	Resistor, Ω ± 5% 2W R27

APPENDIX A

INSTRUCTIONS

A. OPERATION

The controller may be operated in conjunction with the circuit diagram of Figure A-1, which shows the extremely simple connection from the controller to the power supply and to the load simulator. There are only four connections of importance on the simulator; one of them consists of a pair of the wires that supply heater power, and it is unimportant which polarity is applied to the heater. The other pair of connections is to the sensor, and again it is unimportant which polarity is used in connecting to this pair of terminals. It is extremely important that the power supply be connected to the controller in the correct polarity as indicated.

The temperature of the load is monitored with a chromel-alumel thermocouple for which leads are supplied, together with a thermocouple connector and its male mate. If the temperature is to be monitored, a reference thermocouple junction must be included for use with the chromel-alumel sensor.

There is no provision for adjustment of the load simulator's temperature. This is set internally with fixed resistors within the regulator itself. Should it be desired to alter the load temperature, it is possible to add a fixed series resistance to the platinum resistance sensing element, with the leads going to the controller. This fixed resistance, in conjunction with the calibration data for the platinum resistance sensors, will enable temperatures lower than the nominal setpoint to be achieved. Should it be desired to raise the temperatures slightly, a parallel resistance may be attached across the sensor terminals on the load simulator to achieve this result. This is inadvisable, however, because the platinum resistance sensor is operating at a nominal 1250°F and should not be operated substantially higher than that value. Should it be desired to test the over-temperature feature, a larger series resistance may be inserted in series with the sensor element with a momentary switch, which upon actuation opens the contacts across the series resistor, thereby increasing the resistance seen by the controller. Thus, with the temperature being regulated, one can add resistance to observe the action of the over-temperature switch. The short-circuited sensor performance may be exercised the same way by shorting the sensor resistance.

In operation it is important that the control element be bolted to a surface which can dissipate the 20 or so watts of power lost in this unit. We used 8" x 8" aluminum plates with the unit screwed to the plates for this purpose.

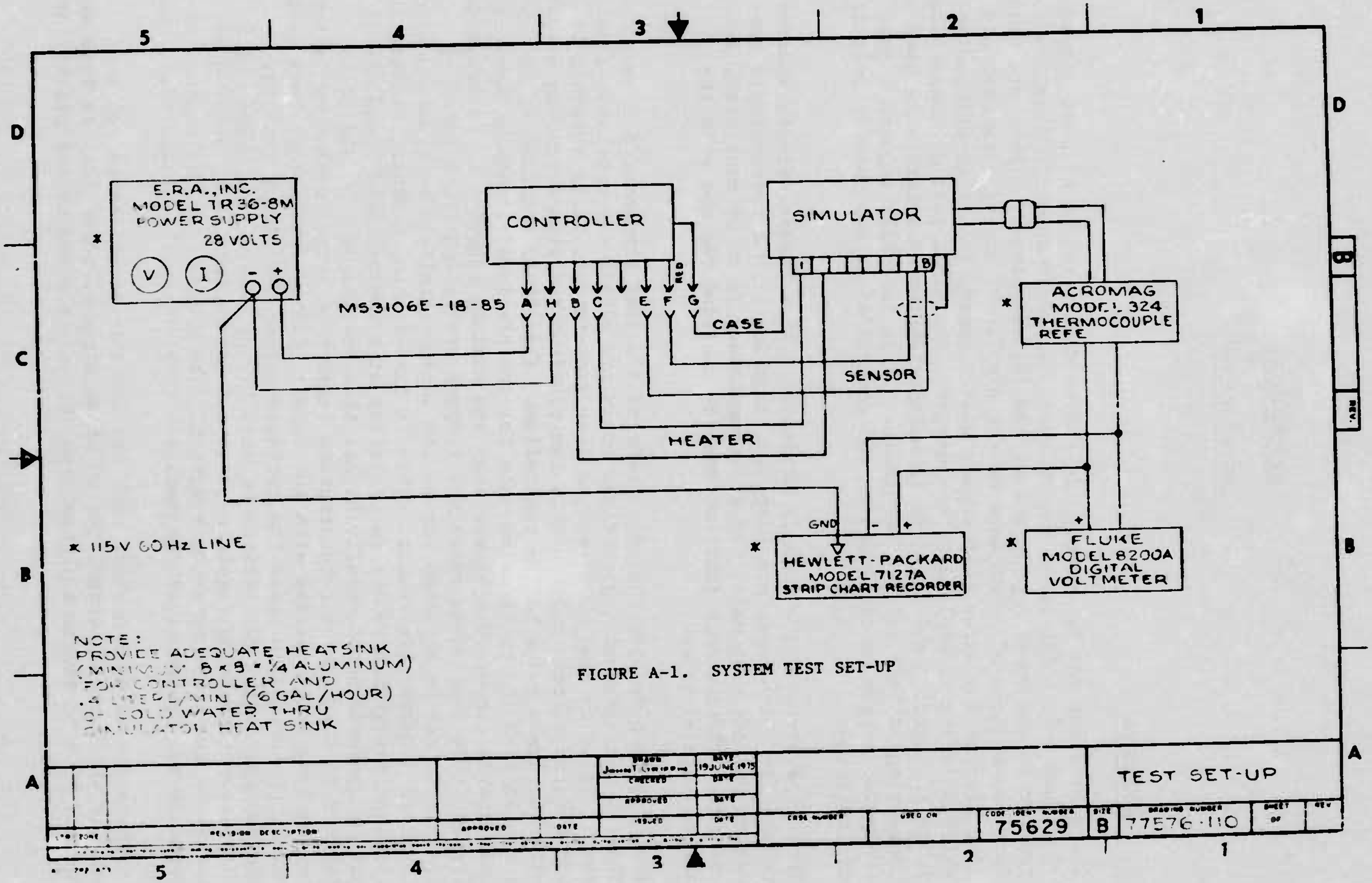


FIGURE A-1. SYSTEM TEST SET-UP

The controller-simulator dissipates nearly 200 watts, so we used tap water running through the base via the hose fittings of the base. This makes a stable reproducible system and keeps the exterior of the load simulator from getting too hot to touch.

B. TROUBLESHOOTING

The objectives of the program were to develop a reliable controller, and also to provide a test bed for evaluating the sensors associated with the controller. For this reason we anticipate there will be more problems with the load simulator than with the controller unit itself. Should evidence of improper functioning of the system occur, the first things to check are the characteristics of the load simulator. It is easy to check (1) the resistance of the simulator heater which nominally runs around 4 ohms, (2) the insulation resistance of the heater element to the frame of the simulator, (3) the platinum resistance thermometer's resistance and its leakage resistance, and it is also easy to evaluate whether the thermocouple has its integrity or not.

Internal controller malfunctions are nowhere nearly as obvious. In fact, since assembling the units, we have never found a malfunctioning part. Access to the internal parts of the controller is easy. By removing the four screws holding the cover, the cover may be lifted off. The unit may be operated in this configuration so that voltage probes can be made at various parts of the circuit. With the aid of the schematic diagram, one should be able to locate quite rapidly what particular part of the circuit is malfunctioning. For this purpose, one would want to use a skilled laboratory-trained technician or engineer.

C. REPAIR

We understand that the present five units are to be used at Wright Patterson AFB strictly for the purpose of assessing the reliability of the controller and its sensor. If a failure of a controller occurs during this series of tests, we do not know what purpose repair would serve. Looking ahead to possible widespread use of a controller of this type, it would seem inadvisable to attempt field repairs of the unit; instead, we feel that the failed unit should be returned to a central depot for repair by skilled technicians there. If an adequate degree of skill is available at such a depot, it is entirely possible that failed semiconductors, IC's, or passive components could then be installed.

We feel that, in view of the relatively modest cost of the controller, it might be better from a reliability point of view to return units to the manufacturer for factory repair or merely to discard failed units and replace them with new units. An intermediate step would be to keep spare sets of the power dissipating section, that is, the components attached permanently to the baseplate of the controller, together with a set of spares for the assembled printed circuit board. In this way simply resoldering the wire harness would enable one to put together operating units from the two parts.

APPENDIX B

ENVIRONMENTAL AND EMI TEST PLANS AND RESULTS

This appendix includes copies of the test plans for the EMI and environmental tests, together with the reports associated with these tests. Two points concerning these tests should be made. The EMI tests were conducted first in the series, and the first attempt showed one frequency for which conducted transient emissions were some 2 dB higher than the requirement. Subsequently, after consultation with EMI control engineers at the testing laboratory, Sanders Associates, Nashua, New Hampshire, a minimal EMI filter comprised of a 0.47-μF capacitor was used to reduce the conducted emissions to levels below the limits. This feature of the circuit was tested and the results are included in the addendum to the EMI report.

Concerning the environmental tests done at Acton Environmental Laboratories, a change was made to one circuit component and one circuit component only. Early in the tests, we observed the circuit breaker to be marginal in performance. Tests at ADL on the other five circuit breakers showed similar marginal performance. We contacted the manufacturer of the circuit breaker who agreed that the circuit breakers were not within the specifications that he had given us, and he supplied six new units for test. The only change to the unit during the environmental tests was the replacement of the circuit breaker by the new model.

TEST PROCEDURE NO. TP-1:77576

ENVIRONMENTAL TESTING

OF

VM HOT CYLINDER TEMPERATURE CONTROLLER

DEVELOPMENTAL MODEL

SERIAL NO. 001

UNDER

USAF CONTRACT F 33615-75-C-3002

Robert M. [signature] — 7 Nov 74

Arthur D. Little, Inc., Test Engineer — Date

Richard H Spence [signature] — NOV 7 1974

Arthur D. Little, Inc., Program Manager — Date

Revision No. Zero

Date: 31 October 1974

1.0 PURPOSE

The purpose of this test procedure is to: Define the test requirements, establish the test schedule, and serve as a means of recording the completion and certification of the various tests.

2.0 OBJECTIVE

The objective of the testing is to demonstrate the specified performance of one controller when subjected to the environments herein described or to demonstrate that the limits of the failure criteria described in Section 8.0, Failure Criteria, are not exceeded by the controller.

3.0 SCOPE

This test procedure is applicable to the controller, hard mounted by its normal mounting means, when applicable, to the appropriate test fixture or test equipment. The controller is defined as being the controller electronics module, its input connector and the hot cylinder sensor. This controller is subject to the failure criteria described in Section 8.0. The accompnaying hot cylinder simulator, to which the sensor is mounted and simulated over-temperature means, are not subject to the failure criteria.

4.0 APPLICABLE DOCUMENTS

The documents applicable to this test procedure are: Attachment No. 1, Statement of Work, dated 7 March 1974; Attachment No. 3, Date Item Description No. DI-T-3708/T-108-2/M, dated 1 November 1971, both part of Contract F 33615-75-C-3002, dated 4 September 1974; and MIL-STD-810B including change notices 1 through 4. In the event of conflicts between documents, this test procedure takes precedence.

5.0 TEST SCHEDULE

The test series listed in Table 5.1 is the preferred order. This test order is not essential, however, and may be altered to suit the availability of the test equipment or to allow the designated test equipment to be corrected, or substituted for, if the test equipment demonstrates the inability to achieve the required test conditions.

TABLE 5.1 ENVIRONMENTAL TEST SCHEDULE

Test Order	Section	Test Method Per MIL-STD-810-B	Working Days, Lapsed Time from Start Date
1	10.0	504 - Temperature-Altitude	0 - 8
2	11.0	511 - Explosive Atmosphere	9
3	12.0	513 - Acceleration	10 - 11
4	13.0	516 - Shock	12
5	14.0	514 - Vibration	13 - 15

6.0 TEST ROUTINE

6.1 Installation of Test Item in Test Facility

The controller shall be installed in the test facility under ambient conditions with appropriate test fixtures and in a manner that will simulate the intended service use. Axes orientation shall be noted when appropriate. The test equipment data block will be completed as appropriate.

6.2 Pretest Performance

Prior to conducting the Environmental Tests of Table 5.1, a pretest performance check of the controller, at ambient conditions, shall be made. The performance of the controller shall be compared to the failure criteria and the results noted in the data block.

6.3 Environmental Test Performance

When operation of the controller is required during the test exposure, the performance check shall be of sufficient duration or shall be repeated at appropriate intervals to insure obtaining representative data for comparison with the failure criteria. The results shall be noted in the data block.

6.4 Posttest Performance

Upon completion of the test at the specified environmental levels, the controller performance will be checked at ambient conditions. The results will be compared to the failure criteria and noted in the data block.

6.5 Certification and Test Records

At the conclusion of each test the blocks provided in this procedure shall contain the date and initials of the test engineer or his designated alternate thus certifying the completion of the specified test. Additional records of the applied environment or measured results also shall be dated and signed by the test engineer or his designated alternate. Such records or copies thereof shall be obtained by the test engineer and maintained in an accompanying bound laboratory notebook. Additional notes pertaining to any of the testing also shall be recorded in this notebook.

7.0 TEST CONDITIONS

7.1 Standard Ambient

The standard ambient test conditions are:

Temperature: 23° ± 10°C (73° ± 18°F)

Relative Humidity: 50% ± 30%

Atmospheric Pressure: $725 \begin{smallmatrix} +50 \\ -115 \end{smallmatrix}$ MM HG

($28.5 \begin{smallmatrix} +2.0 \\ -4.5 \end{smallmatrix}$ IN HG)

($14.0 \begin{smallmatrix} +0.97 \\ -2.22 \end{smallmatrix}$ PSIA)

7.2 Test Environment

The induced test environment will be that specified for each test in Sections 10.0 through 14.0.

7.3 Tolerances

Unless otherwise specified, the following tolerances shall apply.

7.3.1 Induced Environment

Air Temperature: ± 1.4°C (± 2.5°F) Temperature stabilization will have been obtained when the monitored temperatures do not change more than 2.0°C (3.6°F) per hour.

Pressure: ± 5% or ± 1.5 MM HG (0.059 inches HG), whichever is the greater accuracy.

Acceleration Amplitude: ± 10%

Vibration Frequency: ± 2% or ± 1/2 HZ below 20 HZ

Time Durations: ± 10%

7.3.2 Measured Results

See Section 8.0, Failure Criteria.

7.3.3 Instrumentation

The instrumentation for obtaining the measured values or controlling the induced environment shall be appropriate for measuring those parameters and shall conform to laboratory standards whose calibration is traceable to the prime standards at the U. S. Bureau of Standards. Such calibration shall be verified at least every 12 months, preferably every 6 months. The instrumentation shall have an accuracy of at least one-third of the tolerance allotted to the parameter being measured.

7.4 Overtest and Undertest

An overtest, that is, a value of the induced environment, that creates a greater stress on the controller shall not be deemed as a necessary cause for reconducting the test unless the limits of the failure criteria are exceeded. Any undertest shall be cause for reconducting the test.

7.5 Specimen Orientation

The controller and hot cylinder simulator each have three arbitrarily defined axes: x, y, and z orthogonal to each other. These permanently marked axes will serve to identify and record the directions of the induced environment, where appropriate.

8.0 FAILURE CRITERIA

Two classes of failure are identified for these tests:

1. Failure to hold hot cylinder simulator temperature at 1250°F ± 50°F;
2. Failure to shut down for over-temperature.

Failure of the first type will be monitored for by providing a continuous record of simulator temperature on a strip chart recorder. Prior to the tests the acceptable region of response will be marked off on the recorder and will be 1250°F ± 45°F leaving a 5°F guard band. Performance will be judged satisfactory if the simulator temperature remains within these bounds during the tests (with the exception of start-up when the temperature will be less than the operating value and for purposely imposed over-temperature).

Failure of the second type will be monitored for by using the same temperature recorder. For this test the simulator load temperature will be allowed to rise above the desired range by an externally applied temperature error signal that demands more heat from the controller. The temperature set point for this shut down is 1350°F. Shut down at any indicated temperature between 1300°F and 1400°F will be judged as a satisfactory over-temperature shutdown.

Should a failure as identified above be found to be attributable to the load simulator (other than failure of the sensing resistor) the failure is not considered a failure of the system. Another load simulator may replace the failed unit and tests will continue.

9.0 CONTROLLER EQUIPMENT REQUIRED

Hot Cylinder Temperature Recorder HP MODEL 7127A STRIP CHART

Range 5-500 MV, 1-100 V

Inventory Number 123-012 ADL

Serial Number 801-01168

Calibration Date 7/22/74 Calibration Due 7/21/75

10.0 TEMPERATURE-ALTITUDE

CONTROLLER & SIMULATED BASE TEMP. RECORDERS FOR STEPS 1 THRU 7:
BRISTOL'S DYNAMASTER RECORDER
MODEL: 64A-12PGC540-21
SERIAL NO: 66A-21,671
INVENTORY NO: RE322
CAL. DATE: 4/4/75 DUE 7/4/75

Method 504, Class 1, Procedure I.

10.1 Equipment Required

Chamber Tenney, 12ST 2'x2'x3'

Range -100 to 300°F (-73 to 149°C) 100K ft. max

Inventory Number ~~CH304~~ CH301

Serial Number 2762

Calibration Date WITH INSTRUMENTS Calibration Due —

TENNEY CHAMBER
TEMP CONT: BRISTOL
TE-1T500F33 3B
RANGE -100 TO +300°F
INVENTORY NO: PART OF CH 301
SERIAL NO: 657243
CAL DATE 5/27/75
CAL DUE: 8/27/75

Pressure Gage MERIAM MODEL C-1142WM

Range 0-30 INCHES MERCURY

Inventory Number PART OF CH 301

Serial Number 29

Calibration Date WITH CHAMBER Calibration Due WITH CHAMBER

Voltmeter FLUKE 8200A

Range 1-100MV, 1-1000V

Inventory Number 155-098 (ADL)

Serial Number 75941

Calibration Date 6/25/74 Calibration Due 6/24/75

Controller Temperature Recorder HP MOD 7127A

Range 5-500MV, 1-100V

Inventory Number 123-012 (ADL)

Serial Number 801-01168

Calibration Date 7/22/74 Calibration Due 7/21/75

10.2 Procedure

Install controller in accordance with Section 6.1. Axis Orientation UP

Pretest Performance

Ambient Temperature 75°F Relative Humidity 54%

Ambient Pressure 14.55 psi Controller Supply Voltage 28.07

Controller Temperature ~ 80°F Simulator Temperature 1252°F

Over-Temperature Activated - Simulator Temperature OK 1252°F

Mechanical Reset - Simulator Temperature OK

By D. M. [signature] Date 28 May 75

Test Performance

Step 1: Adjust chamber temperature to -62°C at ambient pressure and hold for 2 hours, controller non-operating.

Chamber Temperature -62°C → -62°C Time at temp 14:32 + 2 hrs → 16:32

Controller Temperature -48°C → -60°C Simulator Temperature -16°C block → -54°C; inside → -49°C

Visual Inspection OK

By D. M. [signature] Date 28 May 75

Step 2: Adjust chamber temperature to -54°C at ambient pressure and hold for test duration.

Controller non-operating, chamber temperature stabilized to -54°C:

Chamber Temperature -54°C Time 08.40 on 29 May 75

Controller Temperature -52.5°C Simulator Temperature -51°C

(1) Controller operating at 24 VDC:

Chamber Temperature -54°C Time 11:10

Controller Temperature -47.5°C Simulator Temperature 1203°F

Over-Temperature Activated - Simulator Temperature 1197°F

Mechanical Reset - Simulator Temperature Current back on, switch in, OK; temp up to 1198°

Controller non-operating, CHAMBER temperature stabilized to -54°C:

Chamber Temperature -54°C Time 1200 NOON

Controller Temperature -52°C & STABLE Simulator Temperature INSIDE 205°F (96°C) BASE -23°C

(2) Controller operating at 24 VDC:

Chamber Temperature -54°C Time (POWER ON 12:00 NOON) 13:18

Controller Temperature -47°C & STABLE Simulator Temperature 1202°F

Over-Temperature Activated - Simulator Temperature DROPPED TO 1197+°F CURRENT OFF

Mechanical Reset - Simulator Temperature CURRENT BACK ON, SWITCH IN OK TEMP UP TO 1199°F - POWER OFF 13:25

Controller non-operating, CHAMBER temperature stabilized to -54°C:

Chamber Temperature -54°C Time 14:10

Controller Temperature -52°C & STABLE Simulator Temperature INSIDE 195F BASE -23°C

(3) Controller operating at 24 VDC:

Chamber Temperature -54°C Time (POWER ON 14:10) 15:19

Controller Temperature -47°C & STABLE Simulator Temperature 1203°F

Over-Temperature Activated - Simulator Temperature DROPPED TO 1197°F CURRENT OFF

Mechanical Reset - Simulator Temperature CURRENT BACK ON, SWITCH IN OK TEMP UP TO 1198°F POWER OFF 15:20

Controller non-operating, CHAMBER temperature stabilized to -54°C:

Chamber Temperature -54°C Time 16:07

Controller Temperature -52°C Simulator Temperature 174°F INSIDE ~~-20°C~~ BASE

By R. M. [signature] Date 29 May 1975

STABILIZATION AT -54°C WILL CONTINUE OVERNIGHT

START 30 MAY 1975

Step 3: Adjust chamber temperature to -54°C (and hold for duration of test) with controller non-operating and temperature stabilized.

Chamber Temperature -54°C   Time 08:25

Controller Temperature -52.5°C   Simulator Temperature -52°C [illegible] (-61°F) -51.7°C INSIDE

Controller operating at 32 VDC, adjust chamber pressure to 3.44 inches HG:

Chamber Temperature -54°C   Time 10:26

Chamber Pressure 3.44 IN HG

Controller Temperature -35°C   Simulator Temperature BASE + 48°C INSIDE 126.1°F

Over-Temperature Activated - Simulator Temperature OK 126.1°F [illegible]

Mechanical Reset - Simulator Temperature OK [illegible] SWITCH [illegible]

By [signature]   Date 30 MAY 75

Step 4: Adjust chamber temperature to -10°C (+14°F) and pressure to ambient with controller non-operating. Stabilize controller temperature.

Chamber Temperature -10°C   Time 12.30

Controller Temperature -8.5°C   Simulator Temperature BASE - -7°C INSIDE - +37°F

Open chamber door and allow frost to form on controller surfaces. After the frost has just melted, close chamber door and operate controller at 32 VDC:

(1) Chamber Temperature (HOVER [illegible] 45°F 7°C) -6°C   Time (POWER ON 12 49) 13.05

Controller Temperature (AVER [illegible] 0°C) +0.5°C   Simulator Temperature (BASE -12 INSIDE 2.5) 15°C 125.6°F

Over-Temperature Activated - Simulator Temperature OK 125.6°F [illegible]

Mechanical Reset - Simulator Temperature OK [illegible] SWITCH [illegible]

Controller non-operating: POWER OFF 13:06

Chamber Temperature -6.6°C   Time 13:09

Controller Temperature -0.5°C   Simulator Temperature 114.4°F BASE 20°C

Controller operating at 32 VDC: POWER ON 13:10

(2) Chamber Temperature (15°F) −9°C   Time 13:20

Controller Temperature −1°C   Simulator Temperature BASE +28°C INSIDE 1244°F

Over-Temperature Activated - Simulator Temperature OK 1244°F CURRENT OFF

Mechanical Reset - Simulator Temperature OK CURRENT ON, SWITCH IN

Controller non-operating: POWER OFF 13:20

Chamber Temperature (17°F) −8.3°C   Time 13:23

Controller Temperature −1.5°C   Simulator Temperature BASE +33°C INSIDE 1180°F

Controller operating at 32 VDC: POWER ON 13:23

(3) Chamber Temperature (10°F) −9°C   Time 13:30

Controller Temperature −1.5°C   Simulator Temperature BASE +36°C INSIDE 1251°F

Over-Temperature Activated - Simulator Temperature OK 1251°F CURRENT OFF

Mechanical Reset - Simulator Temperature OK CURRENT ON, SWITCH IN

By R. M. [signature]   Date 30 May 1975

ALL POWER OFF 13:31

Step 4a: Ambient performance at 32 VDC (mid-test):

Ambient Temperature 78°F   Relative Humidity 52%

Ambient Pressure 14.60 PSI

Controller Temperature (33°C) 91.4°F   Simulator Temperature 1248°F

BASE (62°C) 144°F

Over-Temperature Activated - Simulator Temperature OK 1248°F CURRENT OFF

Mechanical Reset - Simulator Temperature OK CURRENT ON SWITCH IN

By R. M. [signature]   Date 30 May 76

AMBIENT TEST RUN ON 2 JUNE TO CHECK OUT EQUIP AFTER CHAMBER REPAIR. RUN MADE WITH WATER FLOW TO ALSO CHECK ABILITY TO KEEP SIMULATOR AT 300°F IN LATER RUNS. RAN OK IN ALL RESPECTS

Step 5: Adjust chamber temperature to 85°C at ambient pressure, stablize and maintain for 16 hours with controller non-operating.

Chamber Temperature 85°C Time 2 JUNE 15:30 TO 3 JUNE 08:30

Controller Temperature 84.5°C Simulator Temperature 21½°C OUTSIDE 20°C (68°F) INSIDE

Visual Inspection OK

By R. M. [signature] Date 3 JUNE 75

Step 6: Adjust chamber temperature to 55°C at ambient pressure with controller non-operating and stablized at 55°C.

Chamber Temperature 55°C Time (START 0832) 0954

Controller Temperature 54°C Simulator Temperature 17°C OUTSIDE CASE 61°F INSIDE

Controller operating at 32 VDC:

Clock Time	Lapsed Time, Min.	Chamber Temperature	Controller Temperature	Simulator Temperature BASE	Simulator Temperature INSIDE	
09:55	Start	55°C	54°C	17°C	61°F	H₂O ON
10:25	S + 30	55°C	59.5°C	23°C	1272°F	"
10:55	S + 60	55°C	61.5°C	23½°C	1263°F	"
11:25	S + 90	55°C	62°C	24°C	1244°F	"
11:55	S + 120	55°C	62°C	24°C	1248°F	"
12:25	S + 150	55°C	62½°C	24½°C	1243°F	"
12:55	S + 180	55°C	62½°C	24½°C	1264°F	"
13:25	S + 210	55°C	62½°C	24½°C	1256°F	"
13:55	S + 240	55°C	62½°C	24½°C	1244°F	"
4 HOURS		TOTAL LAPSED TIME				

Over Temperature Activated - Simulator Temperature OK 1250°F CURRENT OFF

Mechanical Reset - Simulator Temperature OK CURRENT ON, SWITCH IN

By R. M. [signature] Date 3 JUNE 75

Step 7: Adjust chamber temperature to 71°C at ambient pressure with controller non-operating and stabilized at 71°C.

Chamber Temperature 71°C Time 14:15

Controller Temperature 70°C Simulator Temperature ANODE 567°F / BASE 22°C

Controller operating at 32 VDC according to the schedule on page 13 following.

Upon completion of the schedule:

Over-Temperature Activated - Simulator Temperature OK 1296°F CURRENT OFF

Mechanical Reset - Simulator Temperature OK, CURRENT ON, SWITCH IN

By R. M. [signature] Date 3 JUNE 1975

STEP 7 SCHEDULE

Clock Time	Lapsed Time, Min	Controller Power	Chamber Temperature	Controller Temperature	Simulator Temperature Base	Simulator Temperature Inside	Notes
14:15	Start	ON	71°C	70°C	22½°C	534°F	
14:25	S + 10	ON	71°C	73°C	24°C	1170°F	Still warming up
14:35	S + 20	ON	71°C	74½°C	25½°C	1250°F	
14:45	S + 30	ON	71°C	75°C	26°C	1260°F	
"	S + 30	OFF	NA	NA	[redacted] NA		
14:55	S + 40	OFF	71°C	74°C	27°C	822°F	
15:00	S + 45	ON	NA	NA	NA		
15:05	S + 50	ON	71°C	74°C	23°C	1166°F	Still warming up
15:15	S + 60	ON	71°C	75½°C	25½°C	1256°F	
15:25	S + 70	ON	71°C	76°C	26½°C	1262°F	
15:30	S + 75	OFF	NA	NA	NA		
15:35	S + 80	OFF	71°C	75½°C	26°C	1022°F	
15:45	S + 90	OFF	71°C	73½°C	23½°C	645°F	
"	S + 90	ON	NA	NA	[redacted] NA		
15:55	S + 100	ON	71°C	75½°C	24°C	1169°F	Still warming up
16:05	S + 110	ON	71°C	76°C	26°C	1245°F	
16:15	S + 120	ON	71°C	77°C	26°C	1265°F	
"	S + 120	OFF	NA	NA	NA		
16:25	S + 130	OFF	71°C	75°C	25°C	808°F	
16:30	S + 135	ON	NA	NA	NA		
16:35	S + 140	ON	71°C	75°C	23½°C	966°F	Still warming up
16:45	S + 150	ON	71°C	76½°C	25½°C	1245°F	
16:55	S + 160	ON	71°C	77°C	26½°	1258°F	
16:00	S + 165	ON	71°C	77°C	26½	1279°F	
2 Hrs. 45 Min.		TOTAL LAPSED TIME					

Step 8: Omit for Class 1 equipment.

Step 9: Adjust chamber temperature to 30°C at ambient pressure with controller non-operating and stablized at 30°C: 4 JUNE 75

Chamber Temperature 30°C   Time 0852

Controller Temperature 30°C   Simulator Temperature 14½°C
H_2O FLOW STILL ON

Operate controller at 32 VDC and adjust chamber pressure to 5.56 IN HG:

Clock Time	Lapsed Time, Min.	Chamber Temperature	Controller Temperature	Simulator Temperature BASE / INSIDE
09:18	Start	30°C	36°C	18½°C 1271°F
09:48	S + 30	30°C	39°C	18½°C 1276°F
10:18	S + 60	30°C	41°C	18½°C 1244°F
10:48	S + 90	30°C	42°C	18½°C 1246°F
11:18	S + 120	30°C	42½°C	18½°C 1242°F
11:48	S + 150	30°C	43°C	18½°C 1256°F
12:18	S + 180	30°C	43°C	18½°C 1247°F
12:48	S + 210	30°C	43°C	18½°C 1263°F
13:18	S + 240	30°C	43°C	18½°C 1265°F
4 HOURS		TOTAL LAPSED TIME		

Over Temperature Activated - Simulator Temperature OK 1265°F CURRENT OFF

Mechanical Reset - Simulator Temperature OK CURRENT ON - SWITCH IN

By D. M. [signature]   Date 4 JUNE 75

CONTROLLER & SIMULATOR BASE TEMP. RECORDERS FOR: STEPS 8 THRU 14
BRISTOL'S DYNAMASTER RECORDER
MODEL: 64A 24 PG 590-21
SERIAL NO: 66A – 21,581
INVENTORY NO: RE 323
CAL DATE: 4/11/75 DUE DATE 7/11/75

Step 10: Adjust chamber temperature to 47°C at a pressure of 5.56 IN HG with controller non-operating and stabilized at 47°C:

Chamber Temperature 47°C

Chamber Pressure 5.56 IN HG   Time 13:45

Controller Temperature ~~47°C~~ 46°C   Simulator Temperature INSIDE 424°F BASE 16°C WATER COOLING ON

Operate controller at 32 VDC according to the schedule on page 16 following.

Upon completion of the schedule:

Over-Temperature Activated - Simulator Temperature OK 1246°F CURRENT OFF

Mechanical Reset - Simulator Temperature OK CURRENT ON SWITCH IN

By R. M. [illegible]   Date 4 JUNE 1975

STEP 10 SCHEDULE

Clock Time	Lapsed Time, Min	Controller Power	Chamber Temperature	Controller Temperature	Simulator Temperature CASE INSIDE	
13:45	Start	ON	47°C	46°C	16°C 424°F	
13:55	S + 10	ON	47°C	48°C	16½°C 1094°F	STILL WARMING UP
14:05	S + 20	ON	47°C	50½°C	19°C 1261°F	
14:15	S + 30	ON	47°C	51½°C	19°C 1262°F	
"	S + 30	OFF	NA	NA	NA	
14:25	S + 40	OFF	47°C	50°C	17½°C 810°F	
14:30	S + 45	ON	NA	NA	NA	
14:35	S + 50	ON	47°C	50½°C	16½°C 981°F	STILL WARMING UP
14:45	S + 60	ON	47°C	52°C	18½°C 1274°F	
14:55	S + 70	ON	47°C	53°C	19°C 1265°F	
15:00	S + 75	OFF	NA	NA	NA	
15:05	S + 80	OFF	47°C	52°C	18½°C 1016°F	
15:15	S + 90	OFF	47°C	50½°C	17°C 671°F	
"	S + 90	ON	NA	NA	NA	
15:25	S + 100	ON	47°C	52½°C	18°C 1214°F	STILL WARMING UP
15:35	S + 110	ON	47°C	53½°C	19°C 1273°F	
15:45	S + 120	ON	47°C	54°C	19°C 1272°F	
"	S + 120	OFF	NA	NA	NA	
15:55	S + 130	OFF	47°C	52°C	17°C 744°F	
16:00	S + 135	ON	NA	NA	NA	
16:05	S + 140	ON	47°C	52°C	17°C 1010°F	STILL WARMING UP
16:15	S + 150	ON	47°C	53°C	18½°C 1273°F	
16:25	S + 160	ON	47°C	54½°C	19°C 1268°F	
16:30	S + 165	ON	47°C	54½°C	19°C 1258°F	
2 Hrs. 45 Min.		TOTAL LAPSED TIME				

Step 11: Adjust chamber temperature to 20°C with controller non-operating.

5 JUNE 75

Operate controller at 32 VDC and then adjust chamber pressure to 3.44 IN HG.

Chamber Temperature 20°C Time 0830

Controller Temperature 19 1/2°C Simulator Temperature (65°F) 13°C INSIDE / 13°C BASE

H_2O FLOW STILL ON

Controller operating at 32 VDC:

Clock Time	Lapsed Time Min.	Chamber Temperature	Controller Temperature	Simulator Temperature BASE	Simulator Temperature INSIDE
0900	Start	20°C	24°C	16 1/2°C	1218°F
0930	S + 30	20°C	29 1/2°C	17°C	1292°F
1000	S + 60	20°C	32 1/2°C	17°C	1266°F
1030	S + 90	20°C	34°C	17°C	1269°F
1100	S + 120	20°C	35°C	17 1/2°C	1241°F
1130	S + 150	20°C	35 1/2°C	18°C	1267°F
1200	S + 180	20°C	36°C	18°C	1266°F
1230	S + 210	20°C	36°C	18°C	1258°F
1300	S + 240	20°C	36 1/2°C	18°C	1265°F
4 Hours		TOTAL LAPSED·TIME			

Over-Temperature Activated - Simulator Temperature 1239°F CURRENT OFF

Mechanical Reset - Simulator Temperature OK CURRENT ON - SWITCH IN

By D. M. [signature] Date 5 JUNE 75

Step 12: Adjust chamber temperature to 35°C at a pressure of 3.44 IN HG with controller non-operating and stablized at 35°C:

Chamber Temperature 35°C

Chamber Pressure 3.42 INHg Time 13:15

Controller Temperature 35°C Simulator Temperature INSIDE 683°F, CASE 16°C, H_2O FLOW STILL ON

Operate controller at 32 VDC according to the schedule on page 19 following.

Upon completion of the schedule:

Over-Temperature Activated - Simulator Temperature OK 1264°F CURRENT OFF

Mechanical Reset - Simulator Temperature OK CURRENT ON, SWITCH IN

By R. M. [signature] Date 5 JUNE 1975

STEP 12 SCHEDULE

Clock Time	Lapsed Time, Min	Controller Power	Chamber Temperature	Controller Temperature	Simulator Temperature BASE INSIDE	
13:15	Start	ON	35°C	35°C	16°C 683°F	
13:25	S + 10	ON	35°C	37°C	16½°C 1157°F	STILL WARMING UP
13 35	S + 20	ON	35°C	39°C	18°C 1246°F	
13:45	S + 30	ON	35°C	40½	18°C 1264°F	
1346	S + 30	OFF	NA	NA	NA	
1355	S + 40	OFF	35°C	39°C	17°C 854°F	
14:00	S + 45	ON	NA	NA	NA	
14:05	S + 50	ON	35°C	39°C	15½°C 988°F	STILL WARMING UP
14.15	S + 60	ON	35°C	41½°C	18°C 1267°F	
14 25	S + 70	ON	35°C	42½°C	18½°C 1259°F	
14.30	S + 75	OFF	NA	NA	NA ~~1022°F~~	
14:35	S + 80	OFF	35°C	42°C	18°C 1022°F	
1445	S + 90	OFF	35°C	40°C	16°C 627°F	
"	S + 90	ON	NA	NA	NA	
14:55	S + 100	ON	35°C	42°C	16½°C 1170°F	STILL WARMING UP
15:05	S + 110	ON	35°C	43°C	18°C 1235°F	
15:15	S + 120	ON	35°C	44°C	18½°C 1242°F	
"	S + 120	OFF	NA	NA	NA	
15:25	S + 130	OFF	35°C	42°C	17°C 812°F	
15:30	S + 135	ON	NA	NA	NA	
15:35	S + 140	ON	35°C	41½°C	15½°C 958°F	STILL WARMING UP
15:45	S + 150	ON	35°C	43½°C	18°C 1236°F	
15:55	S + 160	ON	35°C	44°C	18½°C 1249°F	
16:00	S + 165	ON	35°C	44½°C	18°C 1238°F	
2 Hrs. 45 Min.		TOTAL LAPSED TIME				

Step 13: Omit for Class 1 equipment.

Step 14:

Posttest Performance: Return chamber to ambient conditions with controller operating. WATER FLOW OFF, LINES OPENED

Ambient Temperature 79°F Relative Humidity 57%

Ambient Pressure 14.53 PSI Controller Supply Voltage 28.02 V

Controller Temperature 34½°C STABLE Simulator Temperature INSIDE 124.8°F BASE 75°C

Over-Temperature Activated - Simulator Temperature OK 175.2°F CURRENT OFF

Mechanical Reset - Simulator Temperature OK CURRENT ON, SWITCH IN

By [signature] Date 5 JUNE 1975

11.0 EXPLOSIVE ATMOSPHERE

Method 511, Procedure 1

11.1 Equipment Required

Chamber Tenney, , 3 ft diameter x 10 ft long

Range 85,000 ft

Inventory Number CH 302

Serial Number N.A.

Calibration Date N.A Calibration Due N.A.

Pressure Gage Wallace Tiernan

Range 0-15.0 PSIA

Inventory Number PI 323

Serial Number FA 129-LL 04304

Calibration Date 4/10/75 Calibration Due 4/10/76

Voltmeter FLUKE 8200A

Range 1-100 MV 1-1000V

Inventory Number 158-098 (ADL)

Serial Number 75941

Calibration Date 6/25/74 Calibration Due 6/24/75

Controller Temperature Recorder HP MOD 7127A

Range 5-500MV, 1-100V

Inventory Number 123-012 (ADL)

Serial Number 801-01168

Calibration Date 7/22/74 Calibration Due 7/21/75

11.2 Procedure

Install controller in accordance with Section 6.1. Use a 100/130 grade gasoline and mixture determinations as provided for chamber.

Axis Orientation CONTROLLER BASE +Z↑ COVER ±Y↑

Pretest Performance WITHIN CHAMBER

Ambient Temperature 76°F OUTSIDE ~~116.6°F INSIDE~~

Relative Humidity 67% OUTSIDE

Ambient Pressure 14.5 PSI

Controller Supply Voltage 31.00V

Controller Temperature 47°C or 116.6°F

Simulator Temperature ≈1248°F

By R. M. Lucas

Date 20 May 1975

Test Performance

Seal chamber and adjust temperature to 71 ± 3°C and maintain throughout test. Stabilization of chamber walls and controller is considered attained at a temperature of 60°C or higher.

Reduce chamber pressure to 1.05 psia. During the following schedule of pressure increases, a 13 to 1 air/fuel ratio shall be maintained within the chamber volume and the potential explosiveness of the sample mixture shall be verified by the ignition means provided. Introduction of the mixture shall be accomplished with 3 ± 1 minutes. Pressure increases shall be steady. The over-temperature activation and mechanical reset shall be accomplished at least once during the pressure increases.

CHAMBER TEMP MEASURED

EXPLOSIVE ATMOSPHERE TEST SCHEDULE

Pressure or Pressure Increase PSIA	Chamber Temperature	Controller Temperature	Simulator Temperature	Over-Temp Activate Ignition?	Mechan. Reset Ignition?	Sample Ignition Verified?
1.05	68.9°C	71.5°C	28.70 mV 1274°F	NA	NA	NA
1.05 to 1.33	68.9	71.8	28.43 1262°F	NA	NA	NA
1.33	operate controller at 28 ± 4 VDC					
1.33 to 2.15	68.3	72°	28.53 1279°F	No	No	NA
2.15	68	71.6	28.37 1259°F	NA	NA	OK Burn
2.15 to 3.47	68°	72	28.26 1255°F	No	No	NA
3.47	68.1	72	28.41 1261°F	NA	NA	YES
3.47 to 5.46	68	71.6	28.37 1259°F	No	No	NA
5.46	68	72	28.96 1285°F	NA	NA	YES
5.46 to 7.65	68	72	28.36 1259°F	No	No	NA
7.65	68.2	71.7	28.81 1278°F	NA	NA	YES
7.65 to 11.34	68.2	72	28.57 1268°F	No	No	NA
11.34	68.3	71.5	28.84 1280°F	NA	NA	YES
11.34 to 13.67	68.3	71.5	28.60 1269°F	No	No	NA
13.67	68.2	71.5	28.44 1284°F	NA	NA	YES
13.67 to Amb.	68.2	71.5	28.50 1265°F	No	No	NA
Ambient	NA	NA	NA	NA	NA	NA

Amb. 90°F [illegible]

By [illegible signature] Date 20 May 75

Posttest Performance

Return controller to ambient conditions and operate controller at 28 ± 4 VDC.

Ambient Temperature 84 °F   Relative Humidity 50%

Ambient Pressure 27.77 in Hg   Controller Supply Voltage 30.98

Controller Temperature ~90°F   Simulator Temperature 12.78

Over-Temperature Activated - Simulator Temperature OK

Mechanical Reset - Simulator Temperature OK

By R. M. [signature]   Date 20 May 75

12.0 ACCELERATION

Method 513.1, Procedures I and II

12.1 Equipment

Centrifuge AMF, LG-34

Range 300 g, 10,000 pounds, 0-500 RPM

Inventory Number PE 301

Serial Number 20

Calibration Date 4/7/75 Calibration Due 7/7/75

Voltmeter FLUKE 8200A

Range 1-100 mV & 1-1000V

Inventory Number 158-098 (ADL)

Serial Number 75941

Calibration Date 6/25/74 Calibration Due 6/24/75

Controller Temperature Recorder HP MOD 7127A

Range 5-500 mV & 1-100V

Inventory Number 123-012 (ADL)

Serial Number 801-01168

Calibration Date 7/22/74 Calibration Due 7/21/75

12.2 Procedure

Install controller in accordance with Section 6.1. Order of test axis is not specified. Axis orientation is in line with the G vector.

$$G = 0.00002841\,(\text{Arm Length})(\text{RPM})^2$$

$$\text{RPM} = \sqrt{\frac{G}{0.00002841\,(\text{ARM LENGTH})}}$$

Pretest Performance

Ambient Temperature 76°F   Relative Humidity 60%

Ambient Pressure 29.45 IN Hg   Controller Supply Voltage 28.1 B

Controller Temperature 48°C, 118.4°F   Simulator Temperature INSIDE 124.7°F, BASE ~~[illegible]~~, 150°F, CAN ~~[illegible]~~, 201°F

Over-Temperature Activated - Simulator Temperature 124.7°F OK CURRENT OFF

Mechanical Reset - Simulator Temperature OK CURRENT ON, SWITCH IN

By R. M. [signature]   Date 6 JUNE 1975

Test Performance Procedure I

Controller is non-operating and 13.5 g is to be induced for one minute in each of 6 directions.

Axis Orientation	Arm Length	RPM	G
+X	33.75	120	13.8
+Y	33.75	120	13.8
+Z	27.50	135	14.1
-X	33.75	120	13.8
-Y	33.75	120	13.8
-Z	39.50	110	13.6

By R. M. [signature]   Date 6 JUNE 1975

Posttest Performance Procedure I

Ambient Temperature 77°F Relative Humidity 61%

Ambient Pressure 29.39 inHg Controller Supply Voltage 28.00

Controller Temperature 80°F Simulator Temperature 1248°F [illegible]

Over-Temperature Activated - Simulator Temperature OK 1248°F CURRENT OFF

Mechanical Reset - Simulator Temperature OK CURRENT ON, SWITCH IN

By [signature] Date 6 JUNE 1975

Test Performance Procedure II

The induced test level is 9.0 G for at least one minute in each of 6 directions. Controller is to be operating at 28 ± 4 VDC throughout the following schedule.

Pretest Performance

The first line of entries satisfies this requirement.

PROCEDURE II

OPERATING ACCELERATION

Axis	Arm Length Inches	RPM	G	Controller Temperature	Simulator Temperature	Simulator Temp. Over-Temp. Activated	Simulator Temp. Mechan. Reset	Order Done
+X	NA	0	0	90°F	1245°F	1245°F OK CURRENT OFF	OK CURRENT ON SWITCH IN	
+X	33.75	100	9.59	90°F	1247°F	1247°F OK CURRENT OFF	OK CURRENT ON SWITCH IN	1
+X	NA	0	0	90°F	1234°F	1234°F OK CURRENT OFF	OK CURRENT ON SWITCH IN	
+Y	NA	0	0	102°F	1245°F	1245°F OK CURRENT OFF	OK CURRENT ON SWITCH IN	
+Y	33.75	100	9.59	102°F	1247°F	1247°F OK CURRENT OFF	OK CURRENT ON SWITCH IN	4
+Y	NA	0	0	102°F	1234°F	1234°F OK CURRENT OFF	OK CURRENT ON SWITCH IN	
+Z	NA	0	0	102°F	1234°F	1234°F OK CURRENT OFF	OK CURRENT ON SWITCH IN	
+Z	27.50	110	9.45	102°F	1244°F	1244°F OK CURRENT OFF	OK CURRENT ON SWITCH IN	6
+Z	NA	0	0	102°F	1248°F	1248°F OK CURRENT OFF	OK CURRENT ON SWITCH IN	
-X	NA	0	0	95°F	1245°F	1245°F OK CURRENT OFF	OK CURRENT ON SWITCH IN	
-X	33.75	100	9.59	95°F	1254°F	1254°F OK CURRENT OFF	OK CURRENT ON SWITCH IN	2
-X	NA	0	0	95°F	1238°F	1238°F OK CURRENT OFF	OK CURRENT ON SWITCH IN	
-Y	NA	0	0	104°F	1240°F	1240°F OK CURRENT OFF	OK CURRENT ON SWITCH IN	
-Y	33.75	100	9.59	104°F	1229°F	1229°F OK CURRENT OFF	OK CURRENT ON SWITCH IN	3
-Y	NA	0	0	104°F	1230°F	1230°F OK CURRENT OFF	OK CURRENT ON SWITCH IN	
-Z	NA	0	0	98.6°F	1239°F	1239°F OK CURRENT OFF	OK CURRENT ON SWITCH IN	
-Z	39.50	90	9.09	98.6°F	1250°F	1250°F OK CURRENT OFF	OK CURRENT ON SWITCH IN	5
-Z	NA	0	0	98.6°F	1241°F	1241°F OK CURRENT OFF	OK CURRENT ON SWITCH IN	

Posttest Performance

The last line of entries satisfies this requirement.

Ambient Temperature 71°F Relative Humidity 61%

Ambient Pressure 29.95 IN Hg

By R. M. [illegible] Date 9 JUNE 1975

13.0 SHOCK

Method 516.1, Procedure I, terminal sawtooth pulse

13.1 Equipment Required

~~Shock Machine AVCO, SM-110M2~~

~~Range 10-5,000 g~~

~~Inventory Number PE312~~ NOT USED

~~Serial Number 1029~~

~~Calibration in use~~

Accelerometer B&K TYPE 8302

Range

Inventory Number AC310

Serial Number 344 778

Calibration Date 4/15/75 Calibration Due 7/15/75

Oscilliscope TEKTRONIX

Range —

Inventory Number OS311

Serial Number 009027

Calibration Date 5/7/75 Calibration Due 8/7/75

Amplifier TEKTRONIX TYPE 3A1

Range —

Inventory Number OP314

Serial Number 013759

Calibration Date 5/7/75 Calibration Due 8/7/75

Filter SKL MODEL 302

Range 0-2000 HZ

Inventory Number AH328

Serial Number 498

Calibration Date 2/21/75 Calibration Due 8/21/75

Voltmeter FLUKE 8200A

Range 1-100 MV, 1-1000 V

Inventory Number 15B-098 (ADL)

Serial Number 75941

Calibration Date 6/25/74 Calibration Due 6/24/75

Controller Dummy Mass NOT NEEDED

Controller Temperature Recorder HP MOD 7127A

Range 5-500 MV, 1-100V

Inventory Number 123-012 (ADL)

Serial Number 601-01168

Calibration Date 7/22/74 Calibration Due 7/21/75

NOTE: This test environment may be induced using the vibration shaker and related equipment in appropriate sequence during the conduct of Test Procedure 14.0, Vibration. In this instance, the shock machine equipment will not be used and the following equipment will be substituted.

Wave Form Synthesizer EXACT

Range 1μsec - 100 msec

Inventory Number SG 336

Serial Number 8357

13.2 Procedure

Install controller dummy mass to the shock machine in accordance with Section 6.1. Calibrate the shock machine to the waveform specified in Figure 13.2 so that two consecutive applications of the load will produce waveforms within the specified tolerance. The shock machine is now calibrated.

Install controller in accordance with Section 6.1 and operate controller at 28 ± 4 VDC. Apply the load so determined above in each of the 6 directions according to the following schedule. The order of axes given is not fixed nor required. Photographs of each applied pulse will be taken.

Pretest Performance

The first line of entries satisfies this requirement.

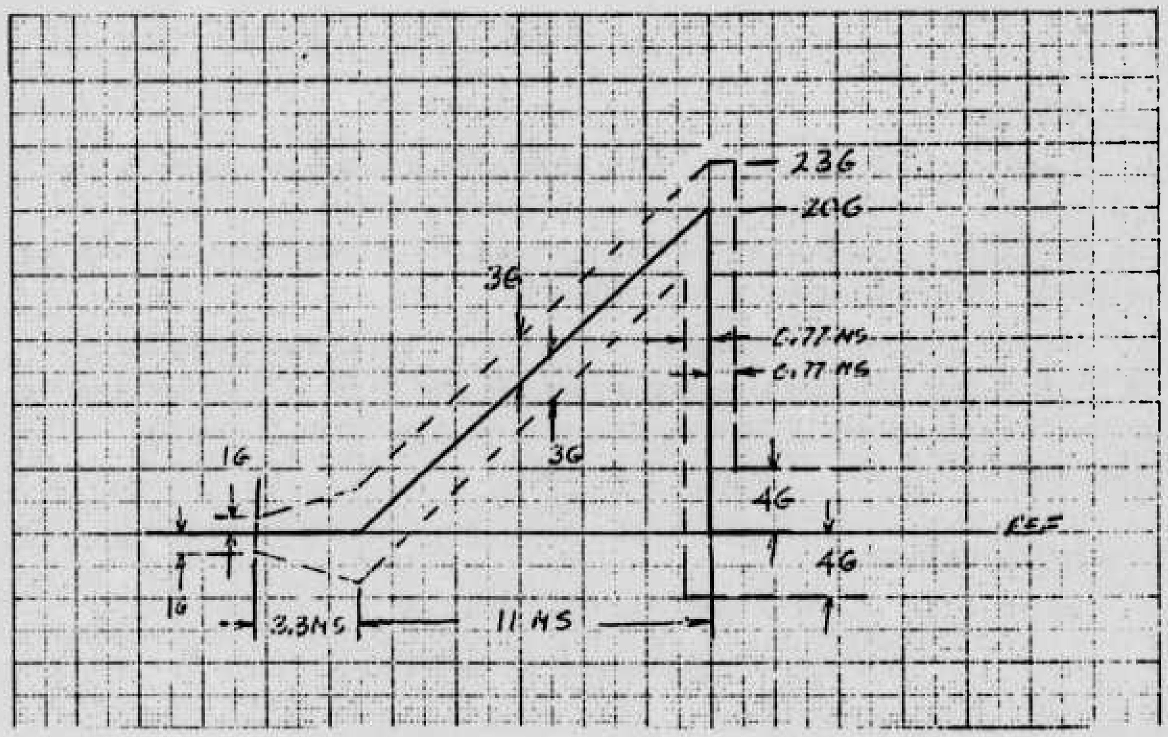


FIGURE 13.2 Shock Pulse Waveform and Tolerance Envelope

TEST PERFORMANCE

Axis	Event	Controller Temperature	Simulator Temperature	Simulator Temp. Over-Temp. Activated	Simulator Temp. Mechan. Reset
+X	Pretest	113°F	1274	OK	OK
+X	Pulse	NA	NA	NA	NA
+X	Posttest	113°F	1260	OK	OK
+Y	Pretest	110°F	1269	OK	OK
+Y	Pulse	NA	NA	NA	NA
+Y	Posttest	110°F	1269	OK	OK
+Z	Pretest	113°F	1257	OK	OK
+Z	Pulse	NA	NA	NA	NA
+Z	Posttest	113°F	1254	OK	OK
-X	Pretest	110°F	1276	OK	OK
-X	Pulse	NA	NA	NA	NA
-X	Posttest	110°F	1270	OK	OK
-Y	Pretest	110°F	1276	OK	OK
-Y	Pulse	NA	NA	NA	NA
-Y	Posttest	110°F	1276	OK	OK
-Z	Pretest	113°F	1253	OK	OK
-Z	Pulse	NA	NA	NA	NA
-Z	Posttest	113°F	1254	OK	OK

Posttest Performance

The last line of entries satisfies this requirement.

Ambient Temperature 75°F Relative Humidity 63 %

Ambient Pressure 29.71 in Hg Controller Supply Voltage 30V (note)

By R. W. [illegible] Date 16 May 75

14.0 VIBRATION

Method 514.1, Procedure I, Part 1, Curve 2, Figure 514.1-1.

14.1 Equipment Required

Shaker Ling A 300

Range 6000 lbs force

Inventory Number PE 314

Serial Number 59

Calibration in use

Amplifier CP10/16VC

Range 5 Hz to 5 KHz

Inventory Number PE 314

Serial Number 59

Calibration Date 5/2/75 Calibration Due 6/2/75

Accelerometer B & K TYPE 8302

Range

Inventory Number AC 310

Serial Number 344 778

Calibration Date 4/15/75 Calibration Due 7/15/75

Voltmeter FLUKE 8200A

Range 1-100 MV & 1-1000V

Inventory Number 158-098 (ADL)

Serial Number 75941

Calibration Date 6/25/74 Calibration Due 6/24/75

Controller Temperature Recorder HP MOD 7127A

Range 5-500 mV & 1-100 V

Inventory Number 123-012 (ADL)

Serial Number 801-01168

Calibration Date 7/22/74 Calibration Due 7/21/75

14.2 Procedure

Install recorder in accordance with Section 6.1. Operate controller at 28 ± 4 VDC throughout the testing. Activate the over-temperature and reset function once, and toward the end of, each 30 minute time period per axis. The order of axis testing is not fixed and not required.

The induced environment along each axis is as follows:

Cycling

Frequency, Hz	Level
5 - 20	0.10 in. D.A.
20 - 33	2 g Peak-to Peak
33 - 74	0.036 in. D.A.
74 - 500	10 g Peak-to-Peak

Sweep Time: 15 minutes per 5 to 500 to 5 Hz , 6.66 octaves/15 min. or 2.26 min/oct., or 0.443 oct/min.

Resonance Search

Search from 5 to 500 Hz at a minimum level to obtain a usable control signal (approximately 1.0 g), but not to exceed levels above.

Resonance Dwell

Dwell at a maximum for four frequencies per axis as obtained during Resonance Search, 30 minutes for each frequency, at the level determined from above.

Cycling Time

Cycle at the rate given above for 3 hours minus dwell time per axis.

Pretest Performance for Z axis on 16 May 75

Ambient Temperature 72°F — Relative Humidity 65%

Ambient Pressure 29.76 in Hg — Controller Supply Voltage 28.44 V

Controller Temperature N.A. — Simulator Temperature 1248 - 1272°F

Over-Temperature Activated - Simulator Temperature OK RML

Mechanical Reset - Simulator Temperature OK RML

By R. M. Lucas — Date 16 May 75

Pretest Performance for X and Y axes on 19 May 75

Ambient Temperature 71°F — Relative Humidity 61%

Ambient Pressure 29.80 in Hg — Controller Supply Voltage 24.45 V

Controller Temperature 72 — Simulator Temperature 1259°F (1251 to 1275°F)

Over-Temperature Activated - Simulator Temperature OK

Mechanical Reset - Simulator Temperature OK

By R. M. Lucas — Date 19 May 1975

VIBRATION SCHEDULE

X-AXIS DWELL

Clock Time Start Stop	Event	Freq	Controller Temperature	Simulator Temperature	Simulator Temperature Over-Temp. Activated	Simulator Temperature Mechan. Reset
[illegible]	Dwell 1	[illegible]				
	Dwell 2		No	RESONANCES		
	Dwell 3					
	Dwell 4					
0.0 HRS	TOTAL DWELL TIME					

X-AXIS CYCLING 19 MAY 1975

Time from Start, Min.	START 9:15AM	Controller Temperature	Simulator Temperature	Simulator Temperature Over Temp. Activated	Simulator Temperature Mechan. Reset	
+30	9:45	~80 °F	1263°F	OK	OK	30✓
+60	10:15	~80 °F	1257°F	OK	OK	28.00✓
+90	10 45	~90°F	1257°F	OK	OK	28.00✓
+120	11:16	~100°F	1259°F	OK	OK	28.00✓
+150	11:46	~110°F	1252°F	OK	OK TWICE	27.96✓
+180	12:14	~115°F	1268°F	OK	OK 3 TIMES	27.92✓
3 HRS	TOTAL CYCLING TIME					

3 Hours TOTAL X AXIS TIME

POPPED OPEN NEAR END RESET VOLTAGE TO 29.02✓

X-AXIS POSTTEST PERFORMANCE

Ambient Temperature 77°F

Relative Humidity 62%

Ambient Pressure 29.76

Controller Supply Voltage 29.02

Controller Temperature ~115°F

Simulator Temperature 1278°F

Over-Temperature Activated - Simulator Temperature OK

Mechanical Reset - Simulator Temperature OK

By R.M. [illegible]

Date 19 May 1975

VIBRATION SCHEDULE

Y-AXIS DWELL

Clock Time Start Stop	Event	Freq	Controller Temperature	Simulator Temperature	Simulator Temperature: Over-Temp. Activated	Simulator Temperature: Mechan. Reset
	Dwell 1					
	Dwell 2		NO	RESONANCES		
	Dwell 3					
	Dwell 4					
0.0	TOTAL DWELL TIME					

Y-AXIS CYCLING

Time from Start, Min.	START 13:12	Controller Temperature	Simulator Temperature	Simulator Temperature: Over Temp. Activated	Simulator Temperature: Mechan. Reset	24.06 ✓
+30	13 42	~125°F	1262	OK	OK BUT ACT TWICE	24.05 ✓ CHANGE TO 30.04
+60	14 12	~125°F	1257	OK	OK	
+90	14:42	~120°F	1259	OK	OK SOLID CLICK	30.01 ✓
+120	+18 MINUTES DOWN TIME 15:30	~120°F	1252	OK	OK	31.00 ✓
+150	16:00	116.6	1248	TOOK 3 TRIES TO ACTIVATE	OK	31.03 ✓
+180	16:30	117.5	1254	OK	OK	31.02 ✓
3.0	TOTAL CYCLING TIME	SIMULATOR "CAN" AT 168.8°F				

3 Hours TOTAL Y AXIS TIME — AT +90 TEMP = 80°F, REL. HUMIDITY = 52%

Y-AXIS POSTTEST PERFORMANCE

Ambient Temperature 80°F — Relative Humidity 52%

Ambient Pressure 29.71 IN HG — Controller Supply Voltage 31.02

Controller Temperature 117.5 — Simulator Temperature ______

Over-Temperature Activated - Simulator Temperature OK

Mechanical Reset - Simulator Temperature OK

By R. M. [illegible] — Date 19 MAY 1975

VIBRATION SCHEDULE

Z-AXIS DWELL

Clock Time Start	Clock Time Stop	Event	Freq	Controller Temperature	Simulator Temperature	Simulator Temperature: Over-Temp. Activated	Simulator Temperature: Mechan. Reset
10:55	11:25	Dwell 1	245	N A.	1275-1253	OK	OK
11.26	11:56	Dwell 2	350	N A.	1253	OK	OK
—		Dwell 3		—			
—		Dwell 4		—	—	—	—
1 HR		TOTAL DWELL TIME					

Z-AXIS CYCLING (VERNIER SWEEP RATE = 2.44)

Time from Start, Min.	START 12:38	Controller Temperature	Simulator Temperature	Simulator Temperature: Over Temp. Activated	Simulator Temperature: Mechan. Reset
+30	~~12:38~~ 13:08	FIXTURE ABOUT 130°F	1274	OK	OK
+60	13:38	FIX 127.4°F VIA THERMOCOUPLE	1263	OK	OK
+90	14:08	129.2°F	1253	OK	OK
+120	14:38	129.2°F	1253	OK	OK
~~+150~~	—		—	—	—
~~+180~~	—		—	—	—
2 HR	TOTAL CYCLING TIME		SIMULATOR "CAN" AT 165.2°F		

3 Hours TOTAL Z AXIS TIME

Z-AXIS POSTTEST PERFORMANCE

Ambient Temperature 76 Relative Humidity 66

Ambient Pressure 29.70 Controller Supply Voltage 28.49V

Controller Temperature 129.2°F Simulator Temperature 1270

Over-Temperature Activated - Simulator Temperature OK

Mechanical Reset - Simulator Temperature OK

By R. M. [signature] Date 16 May 75

Test Report No. 11685 No. of Pages 6

Report of Test on

VM HOT CYLINDER TEMPERATURE CONTROLLER
FOR
ARTHUR D. LITTLE, INC.
UNDER
PURCHASE ORDER NO. 536309

ENVIRONMENTAL TESTING ACTON CORPORATION

Date June 17, 1975

	Prepared	Checked	Approved
By	A.LeBourdais	R.Labrecque	M.L.Tolf
Signed	[signature]	[signature]	[signature]
Date	6/17/75	6-17-75	6/17/75

MLT:AL/hmf

Administrative Data

1.0 Purpose of Test: To subject Temperature Controller to temperature/altitude, explosive atmosphere, acceleration, shock and vibration exposures.

2.0 Manufacturer: Arthur D. Little, Inc.

3.0 Manufacturer's Type or Model No: Item identified as VM Hot Cylinder Temperature Controller

4.0 Drawing, Specification or Exhibit: Arthur D. Little, Inc. Test Procedure TP-1: 77576 dated 31 October 1974

5.0 Quantity of Items Tested: One (1), S/N 1

6.0 Security Classification of Items: Unclassified

7.0 Date Test Completed: June 5, 1975

8.0 Test Conducted By:

R.Labrecque
P.Lizotte
J.Martens

9.0 Disposition of Specimens: Returned to Arthur D. Little, Inc. by Arthur D. Little representative.

10.0 Abstract: Evaluation of the Temperature Controller during and after testing was made by Arthur D. Little representative.

Report No. 11685 Page 1

1.0 VIBRATION

Requirements. The temperature controller shall be subjected to vibration testing in accordance with para. 14.0 of Arthur D. Little, Inc. Test Procedure TP-1:77576.

Procedures. The temperature controller, mounted by its normal means to a non-resilient test fixture, was secured to the exciter of the vibration system. The temperature controller was then subjected to the required vibration test per requirements which consisted of resonance search, resonance dwell and vibration cycling.

Resonances were detected in the "Z" axis at 270 Hz (switch) and at 350 Hz (circuit board). The temperature controller was vibrated for a 30-minute period at each of the resonances detected and then vibration cycled for a 2-hour period. There were no resonances detected in the "X" and "Y" axes.

The temperature controller was vibration cycled for a 3-hour period in the "X" and "Y" axes per requirements.

Results. There was no visible or apparent evidence of damage or deterioration to the temperature controller. Evaluation of the controller during and after vibration testing was performed by Arthur D. Little, Inc. representative who witnessed testing.

Report No. 11685

2.0 SHOCK

Requirements. The temperature controller shall be subjected to shock testing in accordance with para. 13.0 of Arthur D. Little, Inc. Test Procedure TP-1:77576.

Procedures. The temperature controller mounted to the test fixture used for vibration testing was secured to the exciter of the vibration system. The temperature controller was then subjected to one shock in each direction in each of three mutualły perpendicular axes. Each shock was of 20g's magnitude, 11 milliseconds duration, sawtooth waveshape. The shock test was performed using a vibration system and utilizing a waeeform synthesizer to shape the shock pulse.

Results. Evaluation of the temperature controller during and after shock testing was perfonmed by Arthur D. Little, Inc. representative who witnessed testing.

3.0 ACCELERATION

Requirements. The temperature controller shall be subjected to acceleration testing in accordance with para. 12.0 of Arthur D. Little, Inc. Test Procedure TP-1:77576.

Procedures. The temperature controller, mounted by its normal means to a non-resilient test fixture, was secured to the platform of the centrifuge. The temperature controller was then subjected to the required operating and non-operating acceleration test per requirements. Operation and monitoring of the temperature controller during the operating acceleration test was performed by Arthur D.Little representative.

Results. There was no visible or apparent evidence of damage or deterioration to the temperature controller as a result of acceleration testing. Evaluation of the temperature controller during and after acceleration testing was made by Arthur D. Little, Inc. representative.

Report No. 11685

4.0 EXPLOSIVE ATMOSPHERE

Requirements. The temperature controller shall be subjected to an explosive atmosphere test in accordance with para. 11.0 of Arthur D. Little, Inc. Test Procedure TP-1:77576.

Procedures. The temperature controller was placed within the explosion chamber. Required electrical connections for operating and monitoring the temperature controller during testing were made through the chamber feedthroughs. The temperature controller was then subjected to the explosive atmosphere test per requirements. Operation and monitoring of the temperature controller during the explosive atmosphere test was made by Arthur D. Little, Inc. representative.

Results. Operation of the temperature controller during explosive atmosphere testing did not cause an explosion or burning of the surrounding explosive atmosphere. The temperature controller conformed to requirements.

5.0 TEMPERATURE/ALTITUDE

Requirements. The temperature controller shall be subjected to temperature/altitude testing in accordance with para. 10.0 of Arthur D. Little, Inc. Test Procedure TP-1:77576.

Procedures. The temperature controller was placed within the Temperature/Altitude Chamber. Required electrical connections for operating the temperature controller during testing were made through the chamber access port. The temperature controller was then subjected to the 14-step temperature/altitude test per requirements. Required operation and monitoring of the temperature controller during the 14-step temperature/altitude test was performed by Arthur D. Little, Inc. representative.

Results. There was no visible or apparent evidence of damage or deterioration to the temperature controller as a result of testing. Evaluation of the temperature controller during and after temperature/altitude testing was made by Arthur D. Little, Inc. repreeentative.

ELECTROMAGNETIC INTERFERENCE TEST PROCEDURE

FOR

ARTHUR D. LITTLE, INC.

ON A

TEMPERATURE CONTROLLER SYSTEM

Test Plan 2186

Sanders Associates, Inc.

95 Canal Street

Nashua, New Hampshire

1.0 SCOPE

This document specifies the test procedures, instrumentation and methods of measurement to be used during the electromagnetic emission and susceptibility evaluation of Arthur D. Little, Inc., Temperature Controller System.

2.0 PURPOSE

The purpose of the testing described herein is to determine the level of interference emanating from the Temperature Controller System, and to determine its susceptibility to external electromagnetic stimuli. The limits defined in the applicable portions of MIL-STD-461A, Notice 3 for class 1A equipment will be used to determine compliance or non-compliance.

2.1 EMI Test Requirements

The MIL-STD-462 test methods to be used in EMI qualification of the Temperature Controller System is listed bleow.

Test Plan Paragraph	Test Method	Test Title
7.0	CE03	20 kHz to 50 MHz, Power Leads
8.0	CS01	30 Hz to 50 kHz, Power Leads
9.0	CS02	50 kHz to 400 MHz, Power Leads
10.0	CS06	Spike Susceptibility
11.0	RE02	14 kHz to 10 GHz, Electric Field
12.0	RS02	Magnetic Field Induction
13.0	RS03	14 kHz to 10 GHz, Electric Field

2.2 Applicable Documents

MIL-STD-461A, Notice 3	Electromagnetic Interference Characteristics Requirements for Equipment
MIL-STD-462, Notice 2	Electromagnetic Interference Characteristics, Measurements of
MIL-STD-463	Definitions and Systems of Unit Electromagnetic Interference Technology

3.0 TEST FACILITY DESCRIPTION

3.1 Shielded Enclosure

The RF shielded enclosure used for EMI testing conforms with the design criteria of MIL-E-8881, Table II, Cell Type, Solid Metal, Class C. The room size is 6.1M x 3.0M x 2.4M. Door size clearance is 2.0M x 1.8M.

3.2 Power Availability

Power available inside the room is 115 VAC, 400 Hz, 3 phase; 115 VAC, 60 Hz, 1 phase; and 28 VDC. Power is routed through RayProof Power Line Filter 1B41-60, 60 ampere, providing 100 dB attenuation from 14 kHz to 10 GHz.

3.3 Enclosure Attenuation Characteristics

The attenuation characteristics of the enclosure when tested in accordance with MIL-STD-285 is 70 dB for magnetic field and 100 dB for electric field and plane wave.

3.4 Ground Plane

The Temperature Controller System equipment will be installed over a copper ground plane (solid plate) measurieg 4.9M x 0.92M. The grounding provisions included in the equipment design will be bonded to the ground plane. The ground plane is bonded to the shielded enclosure wall at intervals of less than 0.90M. The DC bonding resistance of the ground plane to the enclosure wall is 0.2 milliohms.

3.5 Ambient Profile

The shielded enclosure maintains an ambient electromagnetic environment at least 6 dB below the specification limits for radiated and conducted ambients. Ambient profile levels are shown in Figures 1 through 4.

4.0 TEST EQUIPMENT CALIBRATION

4.1 Field Intensity Meters

The principle means of determining frequency and amplitude during the test is one or more of the following field intensity meters:

Model No.	Mfr.	Frequency Range	Frequency Accuracy	Amplitude Accuracy
EMC-10 Calibrated every 6 months	Fairchild	20 Hz - 50 kHz	±(½% + 5 Hz)	±½ dB
EMC-25 Calibrated every 6 months	Fairchild	14 kHz - 1 GHz	±2%	±1.5 dB
EMA-910 Calibrated every 6 months	Singer/Empire	1 GHz - 26.5 GHz	±½%	±2 dB
NF-105 Basic Unit Calibrated every 12 months	Singer/Empire	14 kHz - 1 GHz	±2%	±1 dB

TX - 12 Months   TA - 9 Months   T1 - 12 Months

T2 - 9 Months   T3 - 9 Months

These instruments are calibrated by the Sanders Associates Instrumentation Calibration/Standards Laboratory, which operates a government approved calibration program in accordance with MIL-C-45662A, "Calibration System Requirements". The calibrating equipment accuracy required by MIL-C-45662A is several orders of magnitude greater than that of the EMC instrumentation listed above. This ensures the greatest possible frequency and amplitude data accuracy.

4.2 Transducers

All antennas--(with one exception)--and current probes use the correction factors supplied by their respective manufacturers. The single exception is the Empire VA-105 41-inch vertical rod antenna (150 kHz to 30 MHz) which is calibrated every six months by the Sanders' Calibration Laboratory.

4.3 Signal Sources

A variety of signal sources is used to develop the RF environment for system susceptibility tests. The field intensity is monitored by the field intensity meters described above, and so the signal source was not a primary consideration in determining the accuracy of measurement. The signal sources are calibrated by the S/A Instrument Calibration/Standards Laboratory on a 12 month cycle.

5.0 INTERFERENCE TYPE

Broadband interference is defined as a continuous spectrum of energy covering frequency range wider than the bandwidth of the measuring instrument.

Narrowband interference is energy with a bandwidth less than the bandwidth of the measuring instrument, and is sharply tunable.

Pulsed CW interference is narrowband energy modulated by a pulse train.

5.1 Measurement Techniques

Broadband and narrowband interference will be measured using the PEAK detector function. The aural slideback signal substitution method will be used for impulsive signals. A minimum of three frequencies per octave will not be preselected, but will be chosen to indicate maximum interference levels. A complete frequency scan will be made and broadband and narrowband determination will be made in accordance with Paragraph 4.2.6 of MIL-STD-462, Notice 2.

6.0 DESCRIPTION OF TEST ITEM

The test specimen will be the Arthur D. Little, Inc., Temperature Controller System consisting of the following components and associated equipment.

(a) Controller Unit
(b) Load Simulator
(c) Temperature Recorder

The Temperature Controller components will be installed as follows.

Control Unit - on copper ground plane inside the enclosure.

Load Simulator - on copper ground plane along side the control unit.

Temperature recorder - outside the enclosure.

6.1 Test Sample Operation

During the EMI testing the Temperature Controller System will be activated to normal operation as follows.

(a) Energize the Controller Unit with 28 volts DC.

(b) The Load Simulator shall be held to 1250 degrees fahrenheit.

6.2 Susceptibility Monitoring and Criteria

During susceptibility testing the temperature will be monitored on the temperature strip chart recorder. If the indicated load temperature falls outside the range of $1250^{o}F \pm 50^{o}F$ a failure is indicated.

TEST PARAGRAPH 7.0

TEST METHOD CE03

CONDUCTED EMISSION

POWER LEADS

20 kHz to 50 MHz

7.0 CE03, Conducted Emissions, 20 kHz to 50 MHz, Power Leads

(a) Purpose

Broadband and narrowband conducted emissions on the plus 28 volt DC and return power leads shall not exceed the limits shown in Figure 14 and 15 of MIL-STD-461A, Notice 3.

(b) Test Equipment

Description	Model/Mfg.	Serial No.
EMI Meter	EMC-25 Fairchild	214
Current Probe	91550-1 Stoddart	BF496
Capacitors	10 ufd Feedthrough Sanders Associates	N/A

(c) Test Conditions

(1) Setup the equipment as shown in Figure 5.

(2) Activate the Temperature Controller to normal operation.

(3) Clamp the current probe around the plus 28 volt DC power lead.

(d) Measurements

(1) Measure broadband and narrowband emissions using the EMC-25 EMI meter. (NF-105 EMI meter may be substituted).

(2) Calibrate the EMI meter according to the manufacturers instruction manual.

(3) Slolwy tune through the freauency range of 20 kHz to 50 MHz.

(4) Measure broadband emissions at the frequencies of the three highest peaks per octave. Record level in dBuV/MHz on data sheet shown in Figure 6. Convert to dBuA/MHz using the Stoddart current probe transfer impedance graph shown in Figure 7.

(5) Measure all narrowband signals, record level in dBuV, convert to dBuA using the Stoddart current probe transfer impedance graph.

(6) Move the current probe to the return power leads and repeat measurement steps above.

TEST PARAGRAPH 8.0

TEST METHOD CS01

CONDUCTED SUSCEPTIBILITY

POWER LEADS

30 Hz to 50 kHz

8.0 CS01, Conducted Susceptibility, 30 Hz to 50 kHz, Power Leads

(a) Purpose

The Temperature Controller System shall not malfunction when the electromagnetic energies shown in Figure 17 of MIL-STD-461A, Notice 3 are injected on 28 volt DC positive and return leads.

(b) Test Equipment

Description	Model/Mfg.	Serial No.
Oscillator	HP200S Hewlett Packard	7153
Power Amplifier	M0100 Bogen Presto	J52
Transformer	6220-1 Solar	N/A
Voltmeter	630PC Triplett	3905

(c) Test Conditions

(1) Setup the equipment as shown in Figure 8.

(2) Conducted susceptibility measurements will be performed separately on each power lead.

(3) Install the 6220-1 isolation transformer in series with the positive 28 volt DC power lead.

(4) Activate the Temperature Controller System to normal operation at 1250 degrees fahrenheit.

(d) Measurements

(1) Tune the oscillator slowly through the frequency range 30 Hz to 50 kHz.

(2) Maintain the test signal level shown in Figure 17 of MIL-STD-461A, Notice 3.

(3) Monitor the temperature recorder for change of more than ±50 degrees.

(4) Should the temperature change by 50 degrees or more, stop at that frequency. Reduce the injected signal level until normal operation is restored.

(5) Record the frequency and threshold level on the data sheet shown in Figure 6.

(6) Move the isolation transformer to the return power lead and repeat measurement steps 1 through 5.

TEST PARAGRAPH 9.0

TEST METHOD CS02

CONDUCTED SUSCEPTIBILITY

POWER LEADS

50 kHz to 400 MHz

9.0 CS02, Conducted Susceptibility, 50 kHz to 400 MHz, Power Leads

(a) Purpose

The Temperature Controller System shall not malfunction when 1 volt RMS test signal is injected on the plus 28 volt DC and return power leads. The 1 volt RMS requirement is per paragraph 6.5 of MIL-STD-461A, Notice 3.

(b) Test Equipment

Description	Model/Mfg.	Serial No.
Signal Generator	606A Hewlett Packard	3786
Signal Generator	608 Hewlett Packard	4499
Capacitor	CS02 Sanders Associates	N/A
RF Voltmeter	94D Boonton	7373

(c) Test Conditions

(1) Tune the signal generator slowly through the frequency range 50 kHz to 400 MHz.

(2) Maintain an input signal level of 1 volt RMS, modulated 50% with 400 Hz.

(3) Connect the line injection capacitor box to the plus 28 volt DC power lead.

(4) Activate the Temperature Controller System to normal operation.

(d) Measurements

(1) Tune the signal generator slowly through the frequency range 50 kHz to 400 MHz.

(2) Maintain an input signal level of 1 volt RMS modulated 50% with 400 Hz.

(3) Monitor the temperature recorder for changes of ±50 degrees or more.

(4) Should a temperature change of more than ±50 degrees occur, reduce the injected signal level until required temperature is obtained.

(5) Record the frequency and threshold level on data sheet shown in Figure 6.

(6) Move the injection capacitor box to the return power lead and repeat measurement steps 1 through 5.

TEST PARAGRAPH 10.0

TEST METHOD CS06

SPIKE

POWER LEADS

10. CS06, Spike Susceptibility, Power Leads

(a) Purpose

The Temperature Controller System shall not malfunction when 56 volt 10 microsecond spike interference of the waveshape shown in Figure 19 of MIL-STD-461A, Notice 3 is injected on the positive 28 volt DC power lead.

(b) Test Equipment

Description	Model/Mfg.	Serial No.
Spike Generator	6471-5 Solar	17536
Oscilloscope	565 Tektronix	1086
Capacitor	10 ufd Feedthrough Sanders Associates	N/A

(c) Test Conditions

(1) Setup the equipment as shown in Figure 10.

(2) Spike susceptibility testing will be performed on the positive power lead only.

(3) Connect the spike generator in series with the positive 28 volt DC power lead.

(4) Activate the Temperature Controller System to normal operation.

(d) Measurements

(1) Adjust the spike generator output control for a 56 volt waveform on the oscilloscope.

(2) Apply positive spikes, single and repetitive (6 to 10 PPS) for 5 minutes.

(3) Apply negative spikes, single and repetitive (6 to 10 PPS) for 5 minutes.

(4) Should temperature changes exceeding ±50 degrees occur, reduce the spike amplitude until normal operation is restored.

(5) Record the threshold level on the data sheet. (Figure 6).

TEST PARAGRAPH 11.0

TEST METHOD RE02

RADIATED EMISSIONS

14 kHz to 10 GHz

ELECTRIC FIELD

11. RE02, Radiated Emission, Electric Field, 14 kHz to 10 GHz

(a) Purpose

Radiated electric field emissions from the case, power leads, and interconnecting wiring of the Temperature Controller System shall not exceed the limits of Figures 21 and 22 of MIL-STD-461A, Notice 3.

(b) Test Equipment

Description	Model/Mfg.	Serial No.
EMI Meter	EMA-910 Singer	121
EMI Meter	EMC-25 Fairchild	217
Vertical Antenaa	RVR-25 Fairchild	217
Biconcial Antenna	7825 Honeywell	N/A
Cone Antenna	93490-1 Stoddart	N/A
Cone Antenna	93491-1 Stoddart	N/A
MP-105	Hand Probe	N/A
ALTERNATE EQUIPMENT		
EMI Meter	NF-105	2160
Vertical Antenna	VR-1-105	181
Vertical Antenna	VA-105	796

(c) Test Conditions

(1) Setup the equipment as shown in Figure 11.

(2) Activate the Temperature Controller System to normal operation.

(3) Determine placement of measurement antenna by probing the test sample for points of maximum emission using hand probe MP-105.

(4) Position the measurement antenna 1 meter from the test sample at point of maximum emission.

(5) Replace measurement antenna according to the following frequency schedule.

14 kHz to 25 MHz	41 Rod/Counterpoise
25 MHz to 200 MHz	Horizontal Biconical
25 MHz to 200 MHz	Vertical Biconical
200 MHz to 1000 MHz	Conical Log Spiral
1 GHz to 10 GHz	Conical Log Spiral

(d) Measurements

(1) Calibrate the EMI meter according to the manufacturers instruction manual.

(2) Measure broadband emissions from 14 kHz to 1000 MHz at three frequencies of maximum radiation per octave.

(3) Measure narrowband emissions from 14 kHz to 10 GHz.

(4) Slowly scan the test frequency range changing antennas as required.

(5) Record the frequency and level of detected signals on data sheet. (Figure 6).

(6) Add antenna factors shown in Figures 12 through 16.

(7) Final results will be recorded in terms of dBuV/M for narrowband emissions and dBuV/m/MHz for broadband emissions.

TEST PARAGRAPH 12.0

TEST METHOD RS02

RADIATED SUSCEPTIBILITY

MAGNETIC INDUCTION FIELD

12. RS02, Radiated Susceptibility, Magnetic Induction Field

(a) Purpose

The Temperature Controller System shall not malfunction when the equipment case, calbes and DC power leads are exposed to a power frequency test and spike test using the limits given in paragraph 6.18 of MIL-STD-461A, Notice 3.

(b) Test Equipment

Description	Model/Mfg.	Serial No.
Spike Generator	6471-5 Solar	17536
Variac	116 Superior	N/A
Transformer	N/A	N/A
Meter	25A Weston	CC673

(c) Test Conditions

(1) Setup the equipment as shown in Figure 17.

(2) Wrap the test wire around the control units equipment case.

(d) Measurements

(1) Connect the test wire to the power frequency test equipment.

(2) Apply 20 ampere of 400 Hz current to the test wire for one minute.

(3) Monitor the temperature recorder for a change ±50 degrees fahrenheit or more.

(4) Should performance degradation occur, reduce the current level until normal operation is restored.

(5) Record the threshold level on data sheets shown in Figure 6.

(6) Connect the test wires to the spike generator. Apply 100 volt spikes to the test wire at 6 to 10 PRR for one minute while monitoring the temperature recorder.

(7) If performance degradation occurs, reduce the spike voltage level until normal operation is resotred. Record spike voltage threshold level on data sheet (Figure 6).

(8) Wrap the test wire around the DC power leads and interconnecting cable at the spiral rate of two turns per meter for 1.5 meters, or less if the cable lenght is shorter. Maintain 15 cm separation from cable connectors.

(9) Repeat measurement steps 1 through 7.

TEST PARAGRAPH 13.0

TEST METHOD RS03

RADIATED SUSCEPTIBILITY

ELECTRIC FIELD

14 kHz to 10 GHz

13. RS03, Radiated Susceptibility, Electric Field, 14 kHz to 10 GHz

(a) Purpose

The Temperature Controller System shall not malfunction when immersed in an electric field intensity as follows:

14 kHz to 35 MHz - 10 V/m

35 MHz to 10 GHz - 5 V/m

(b) Test Equipment

Description	Model/Mfg.	Serial No.
EMI Meter	EMA-910 Singer	121
EMI Meter	NF-105 Empire	2160
Oscillator	HP200S Hewlett Packard	212-00620
Signal Generator	HP606 Hewlett Packard	038-03786
Power Amplifier	MO100 Bogen	J52
Power Oscillator	404A Microdot	32
Power Oscillator	406A Microdot	87
Power Oscillator	125 Airborne Instru. Lab.	12510
Signal Generator	616B Hewlett Packard	259-00099
Signal Generator	C772A Microlab	519
Signal Generator	X772A Microlab	324
Vertical Antenna	VR1-105 Empire	181
Vertical Antenna	VA-105	372
Biconical Antenna	7825 Honeywell	N/A
Cone Antenna	93490-1 Stoddart	N/A
Horn Antenna	CA-L, S, M, X Polarad	N/A

(c) Test Conditions

(1) Setup the equipment as shown in Figure 18.

(2) The radiating antenna shall be placed in front of the test sample at a distance of 1 meter.

(3) From .014 to 25 MHz the vertical rod antenna will be used. The counterpoise shall be at the same height as the ground plane.

(4) From 25 MHz to 200 MHz the biconical antenna shall be centered on the test sample. Position the antenna alternately to generate vertical and horizontal fields.

(5) From 200 to 1000 MHz the conical log spiral antenna shall be centered on the test sample, from 1 GHz to 10 GHz horn antenna shall be used.

(6) The field calibrating antenna shall be one meter to the side of the radiating antenna. The radiating antenna shall be rotated to face the calibrating antenna during measurements.

(7) The field intensity level of 1 volt per meter shall be verified at:

14 kHz to 26 MHz - three per octave

25 MHz to 10 GHz - at the lowest frequency of the antenna and at each octave thereafter.

(8) Activate the Temperature Controller System to normal operation.

(d) Measurements

(1) Starting at 14 kHz, scan through the frequency range with the power oscillator adjusted to produce 10 volts per meter radiated field intensity.

(2) Change antennas and signal sources as required.

(3) Monitor the temperature recorder for changes of ±50 degrees fahrenheit.

(4) Should performance degradation occur, reduce the power oscillator output until normal operation is restored.

(5) Rotate the transmit antenna to face the receive antenna and measure the threshold field intensity level.

(6) Record the frequency, field intensity level, and nature of malfunction on data sheet Figure 6.

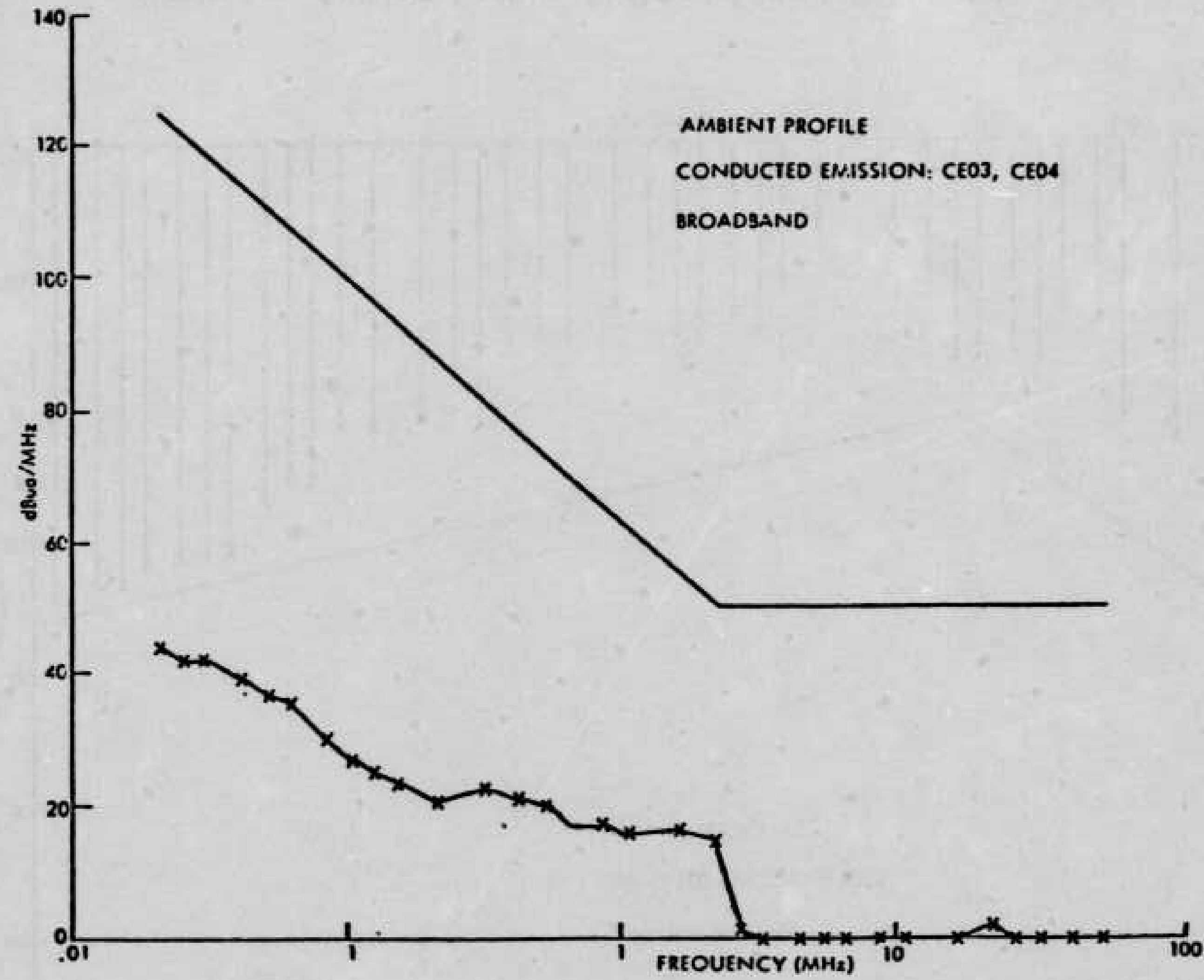


Figure 1 Ambient Profile, Conducted Emission - CE03, CE04 Broadband.

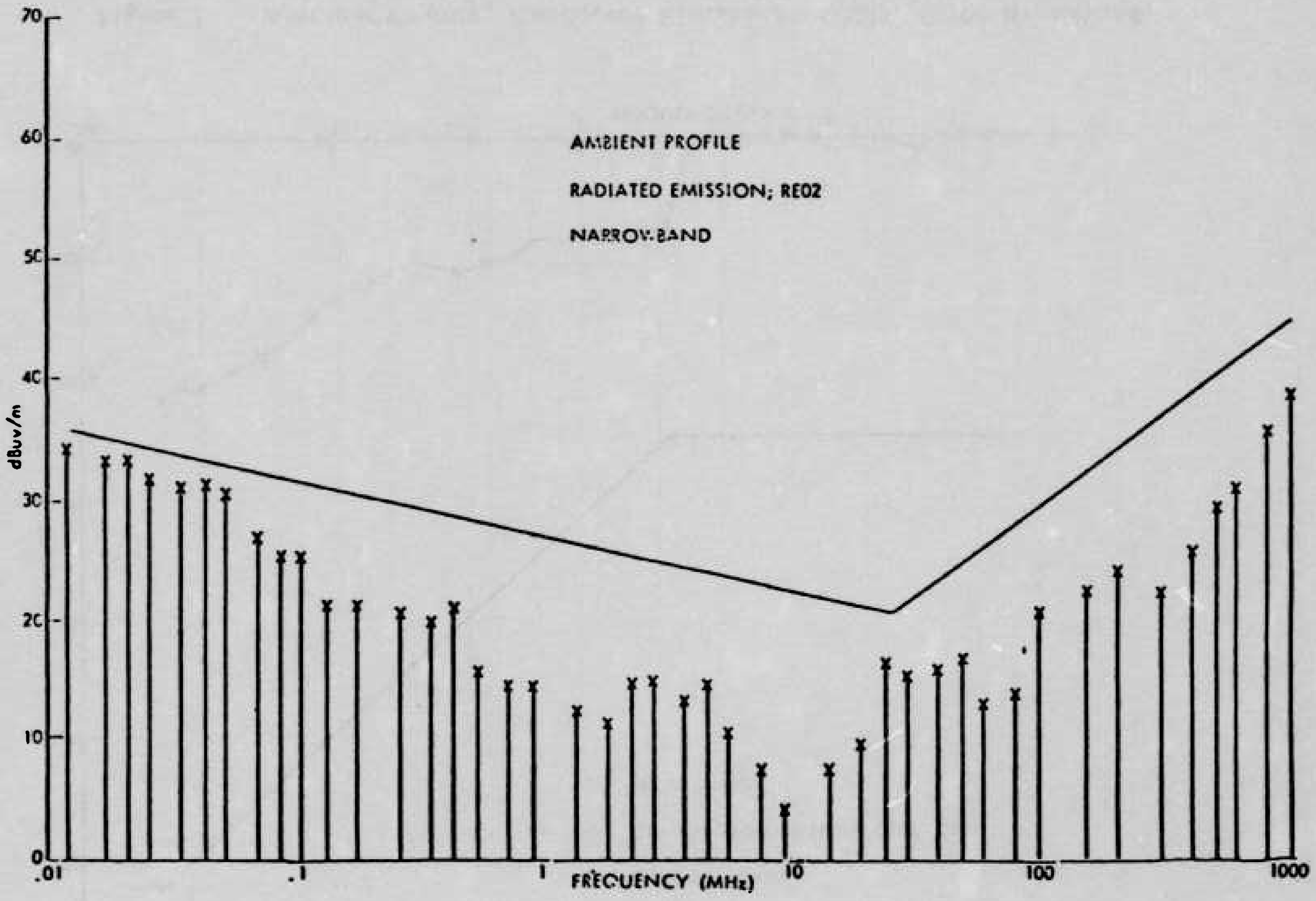


Figure 2 Ambient Profile, Radiated Emission - RE02 Narrowband.

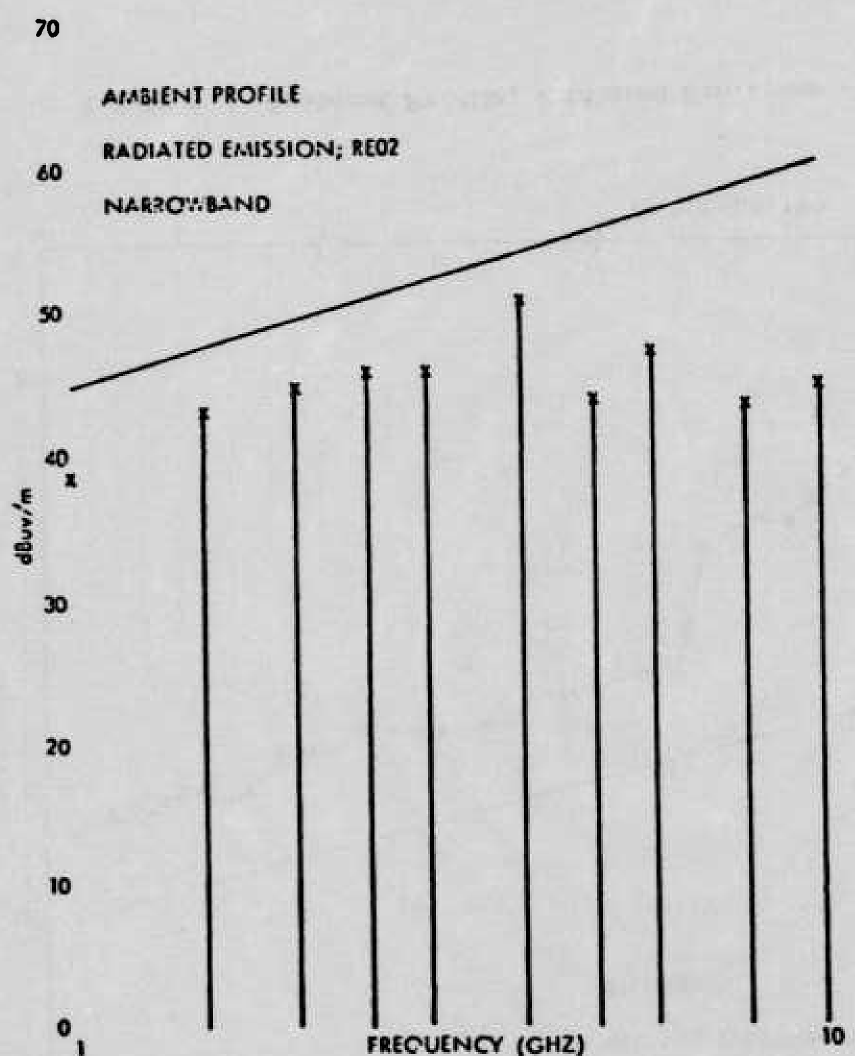


Figure 3 Ambient Profile, Radiated Emission - RE02 Narrowband.

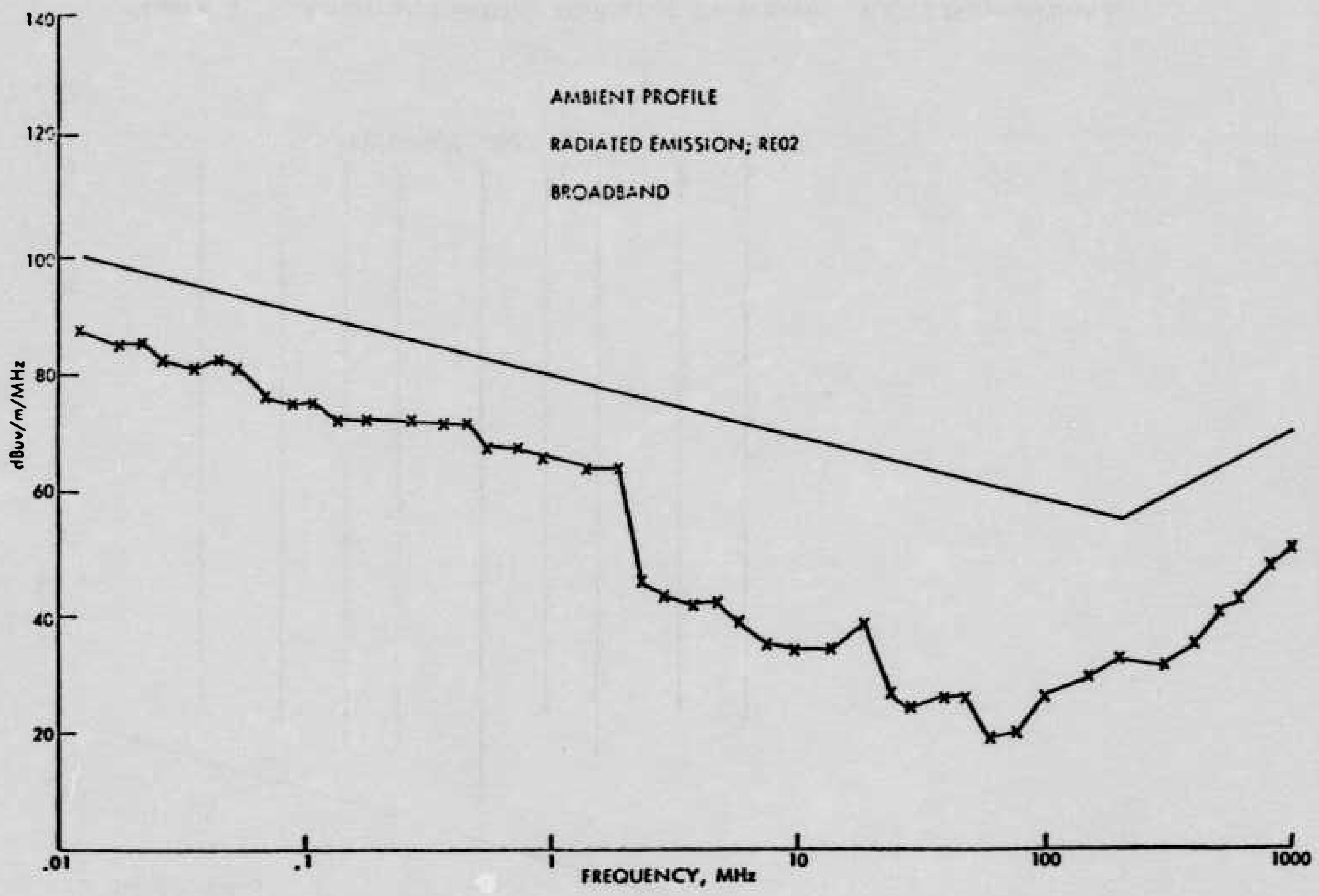


Figure 4 **Ambient Profile, Radiated Emission - RE02 Broadband.**

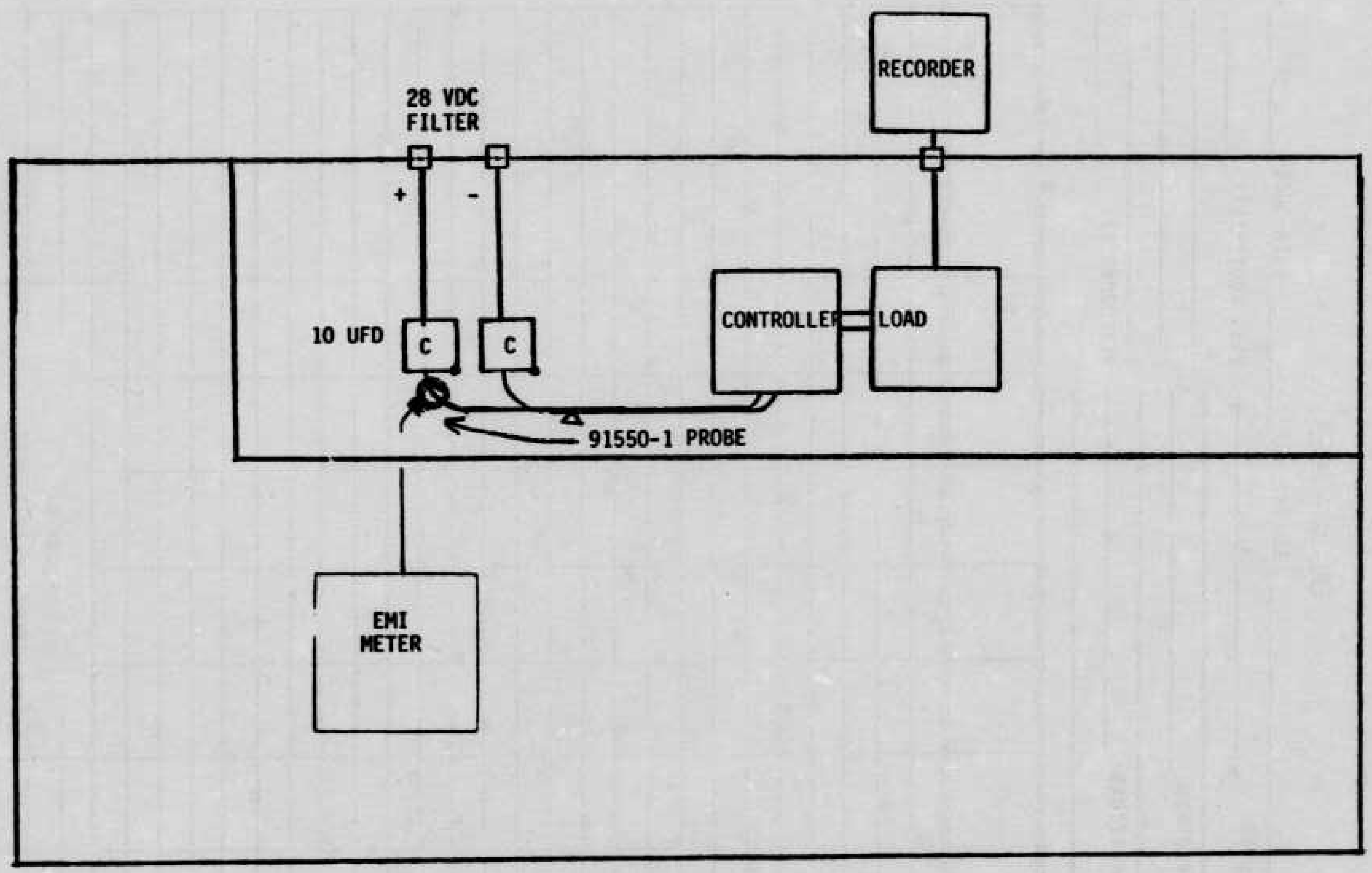


FIGURE 5
CE03 TEST SETUP

EMC DATA SHEET

DATE:________________ REPORT NO:________ DATA SHEET____ OF____

ITEM TESTED:____________________ TEST EQUIPMENT:____________

TEST PERFORMED:____________________

TEST CONDITIONS:____________________ PERFORMED BY:____________

FREQ.							

FIGURE 6
SAMPLE EMC DATA SHEET

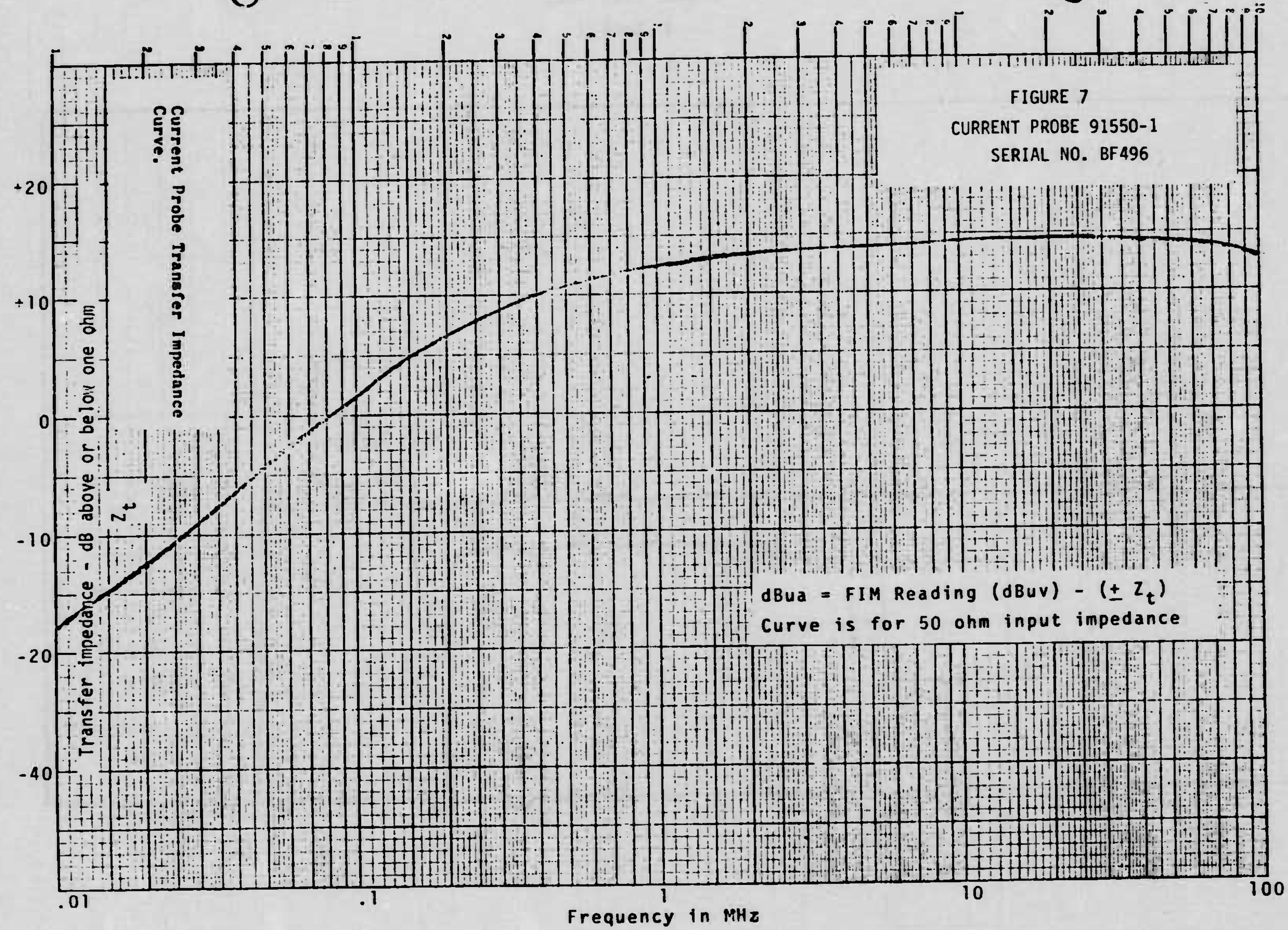


FIGURE 7
CURRENT PROBE 91550-1
SERIAL NO. BF496
Current Probe Transfer Impedance Curve.
dBua = FIM Reading (dBuv) - (± Z_t)
Curve is for 50 ohm input impedance
Z_t
Transfer impedance - dB above or below one ohm
+20
+10
0
-10
-20
-40
.01
.1
1
10
100
Frequency in MHz

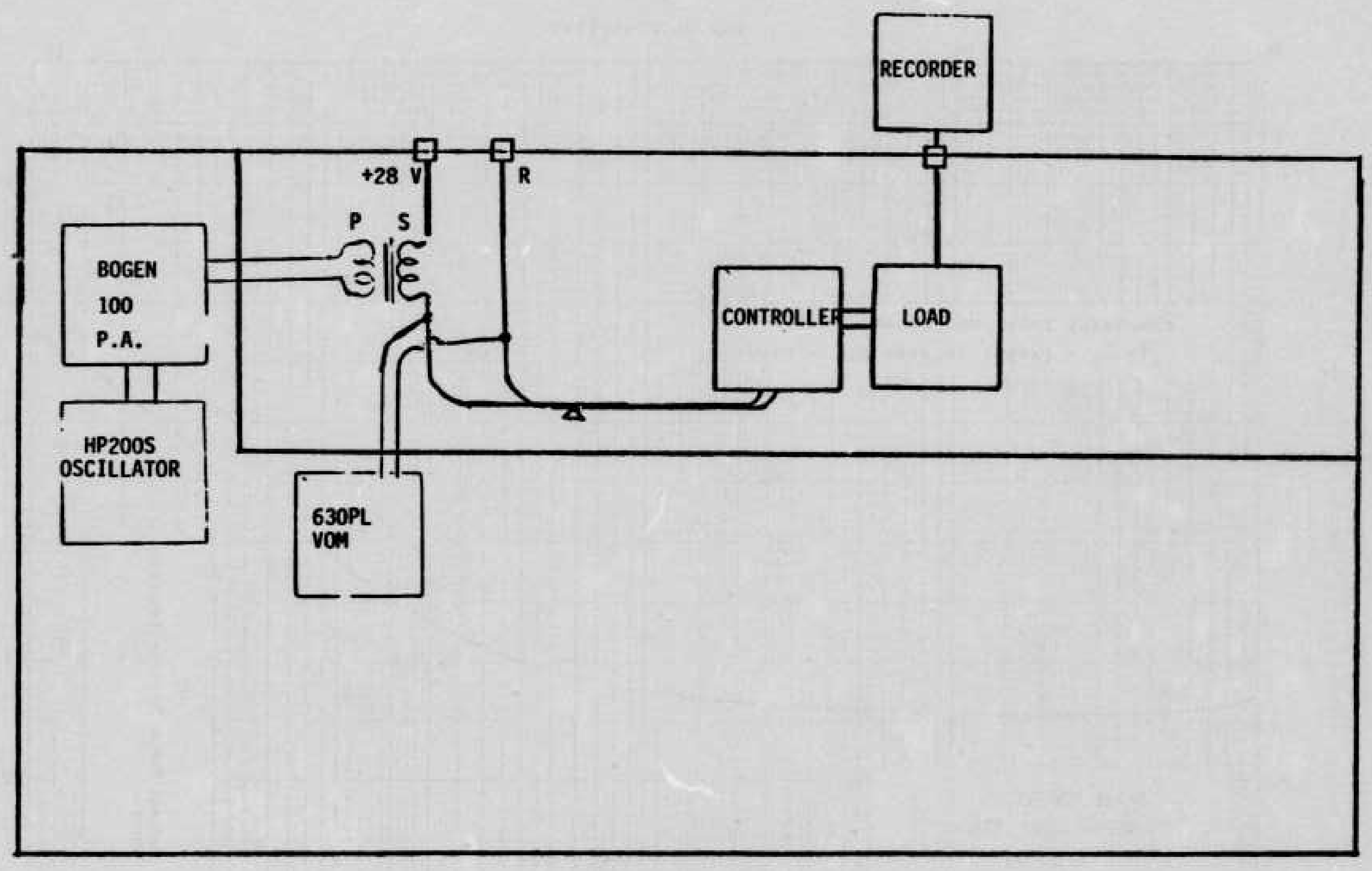


FIGURE 8
CS01 TEST SETUP

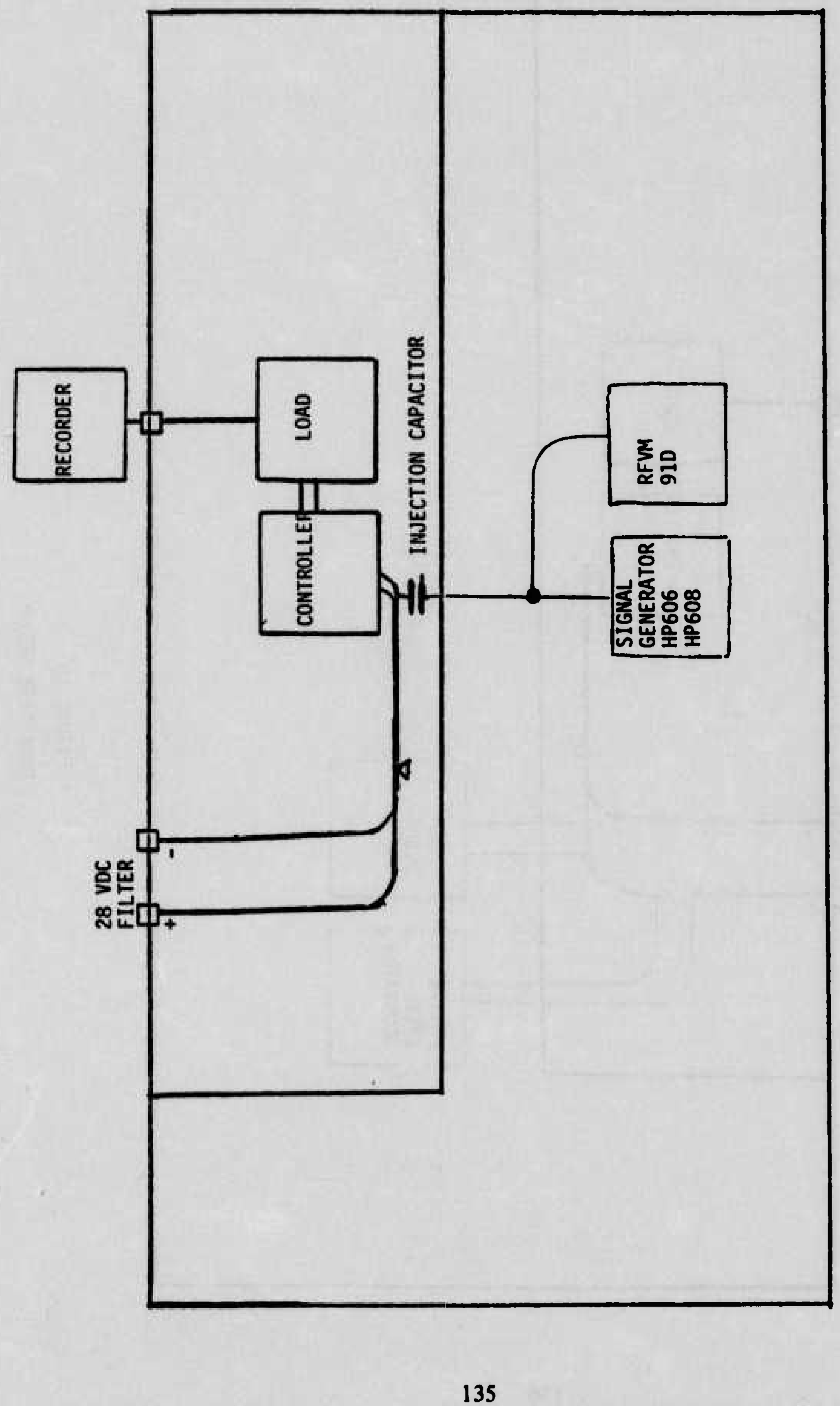


FIGURE 9
CS01 TEST SETUP

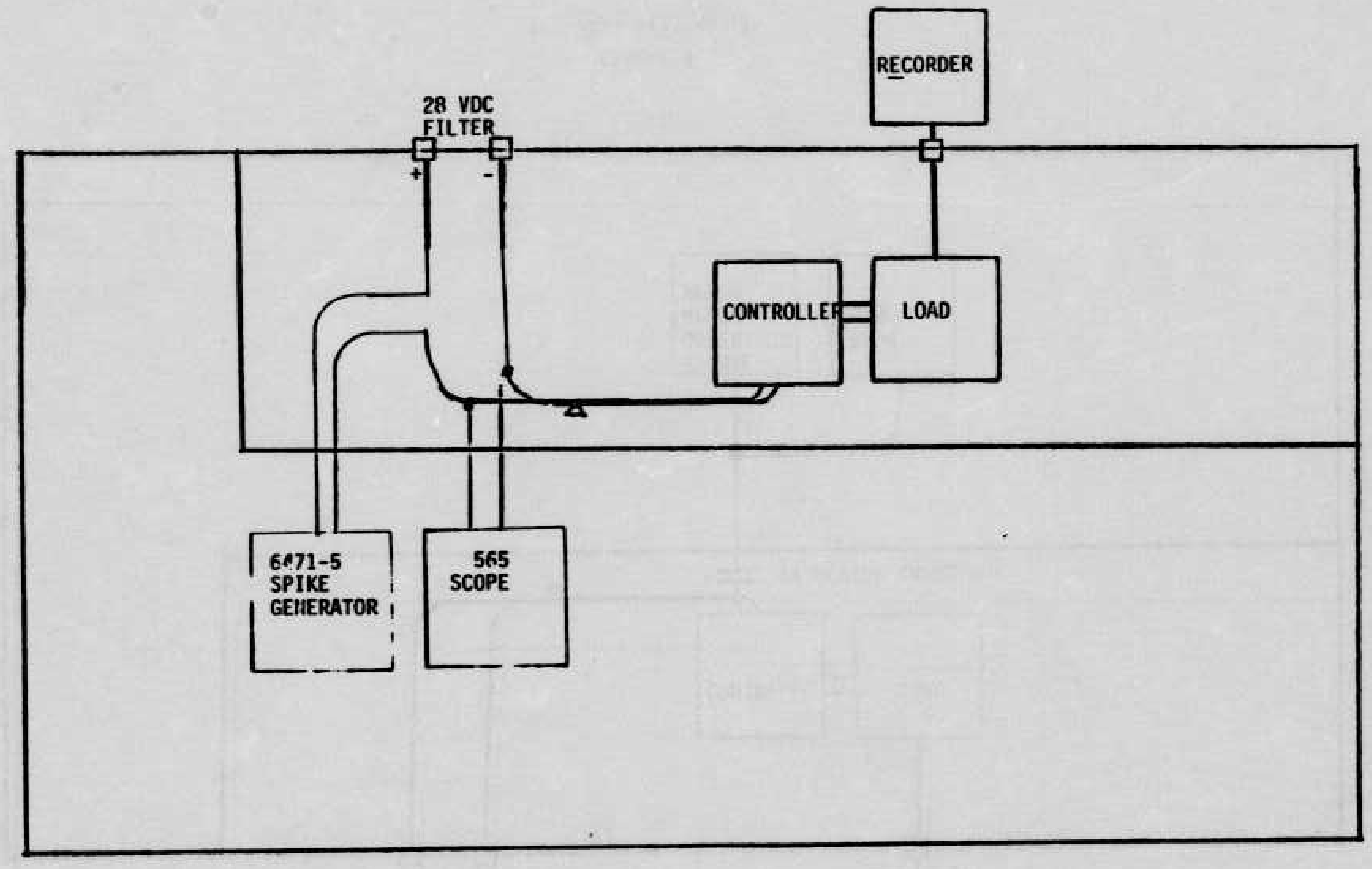


FIGURE 10
CS06 TEST SETUP

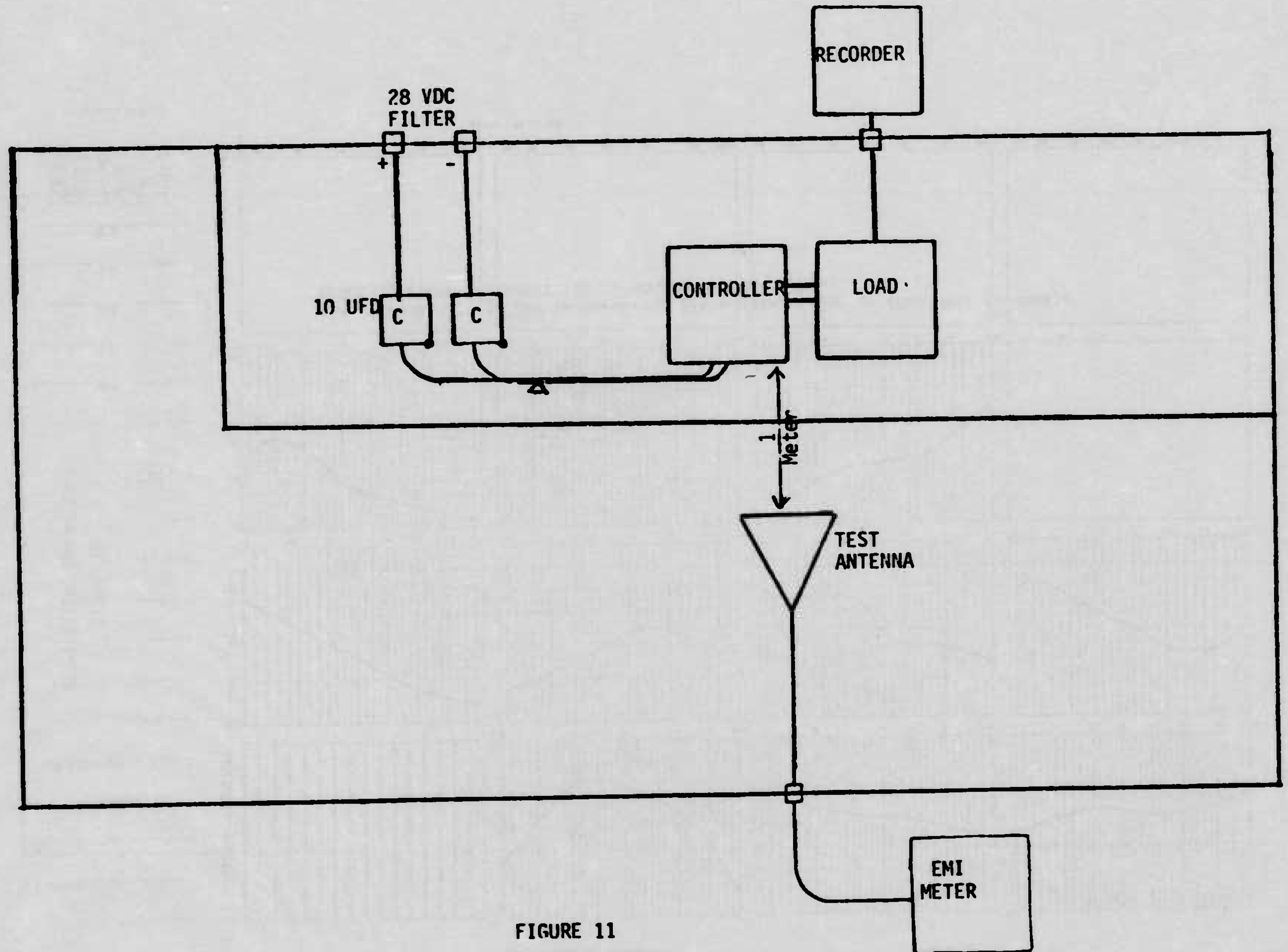


FIGURE 11
RE02 TEST SETUP

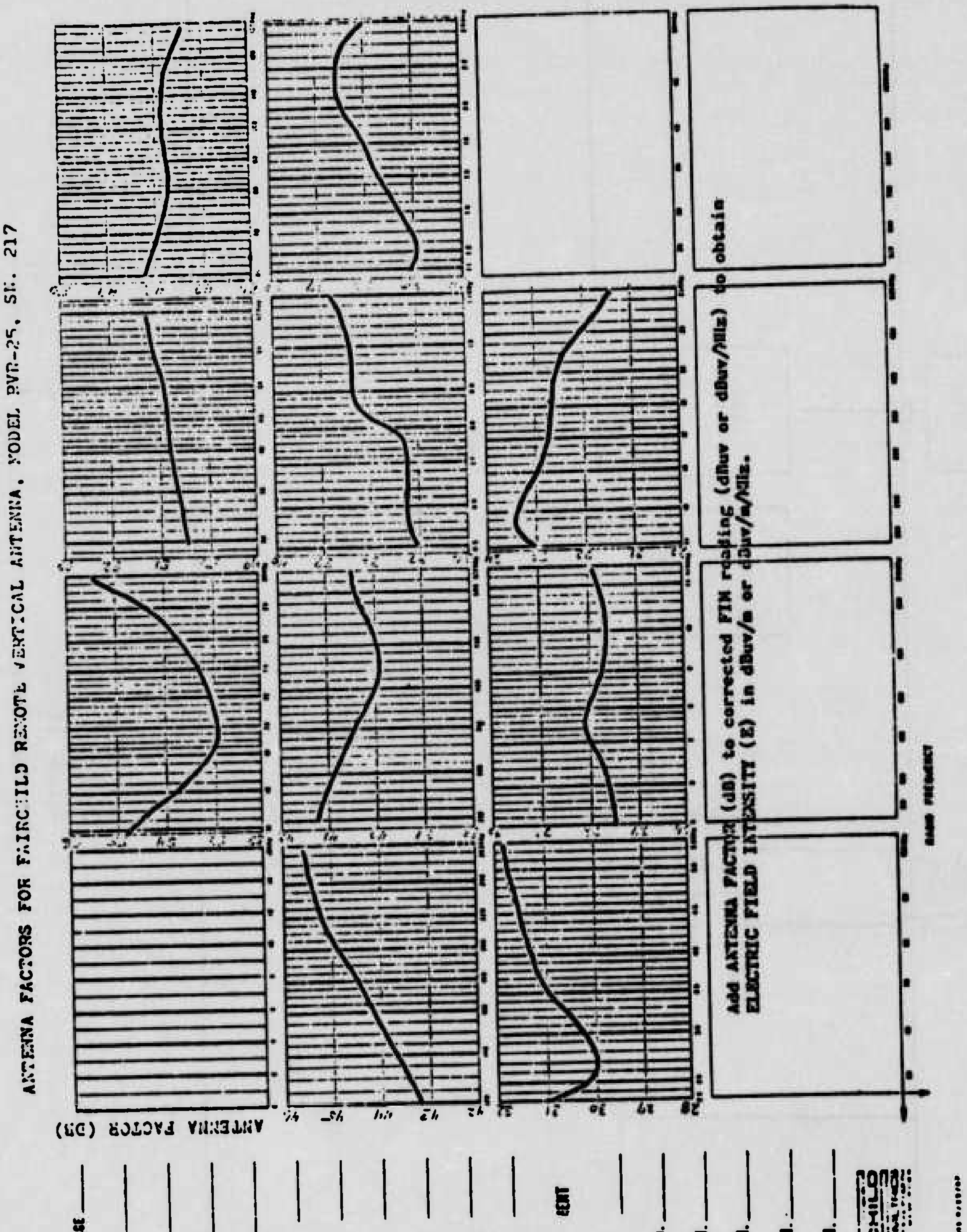


FIGURE 12
41" VERTICAL ROD ANTENNA

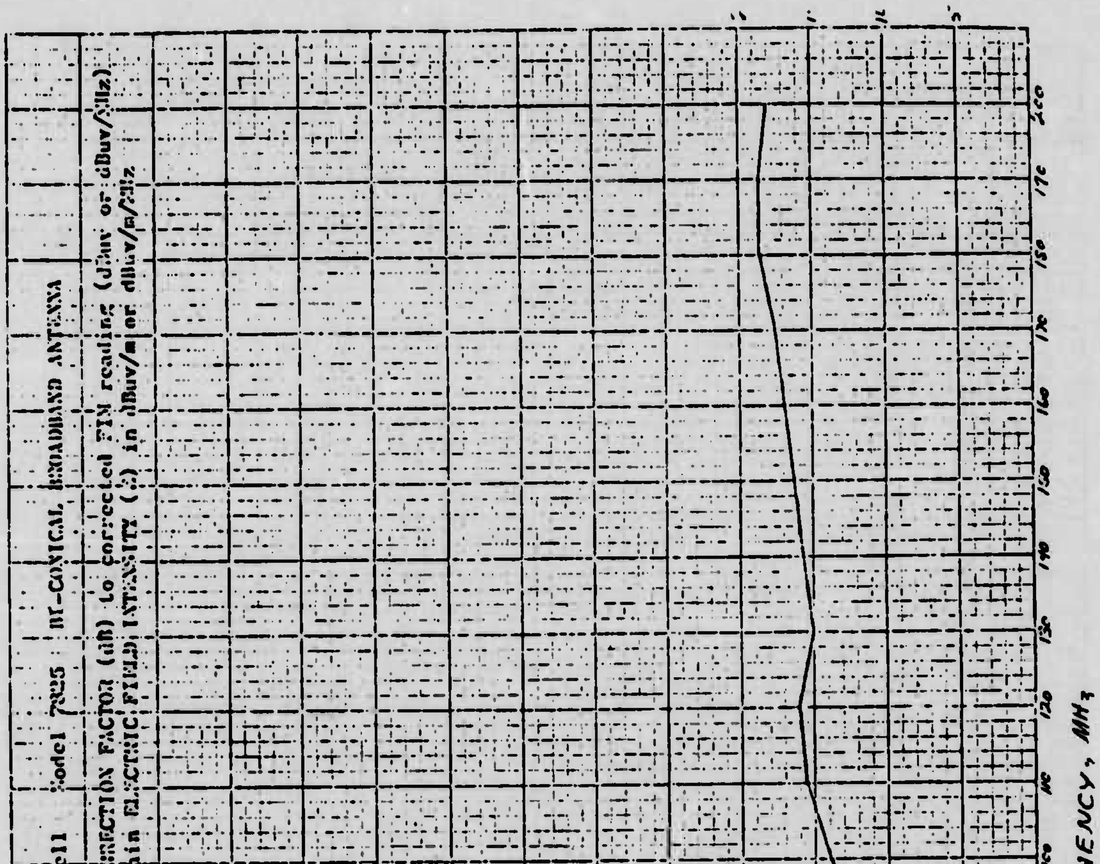


FIGURE 13

BICONICAL ANTENNA CORRECTION FACTORS, 20 MHz to 200 MHz

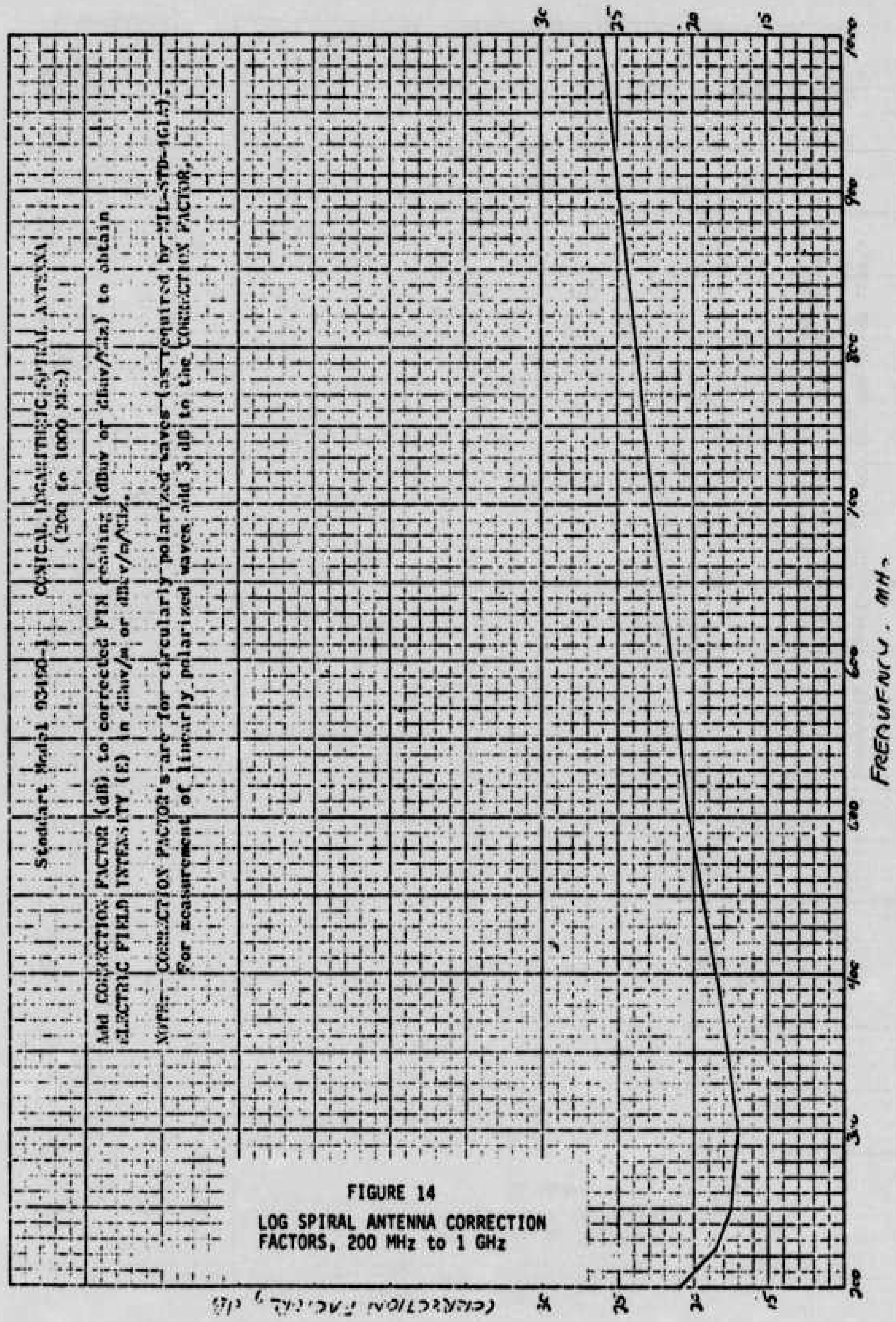


FIGURE 14

LOG SPIRAL ANTENNA CORRECTION FACTORS, 200 MHz to 1 GHz

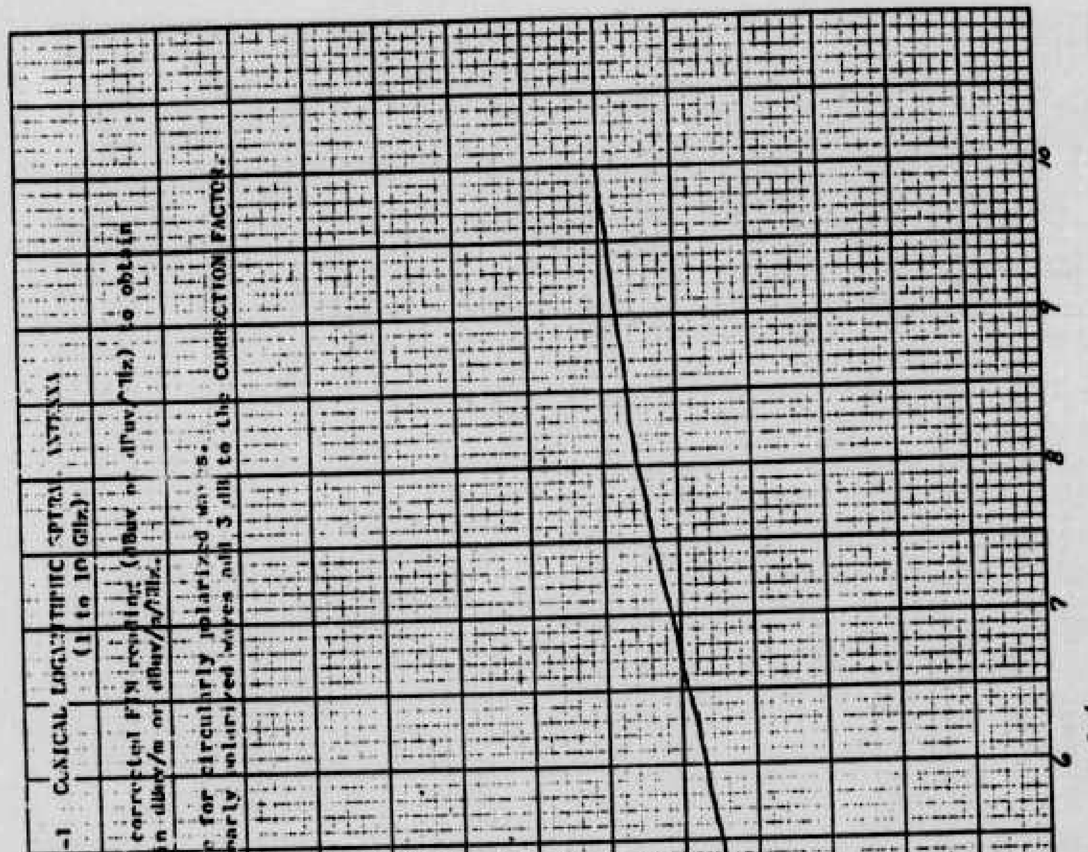


FIGURE 15

1 to 10 GHz LOG SPIRAL ANTENNA CORRECTION FACTORS

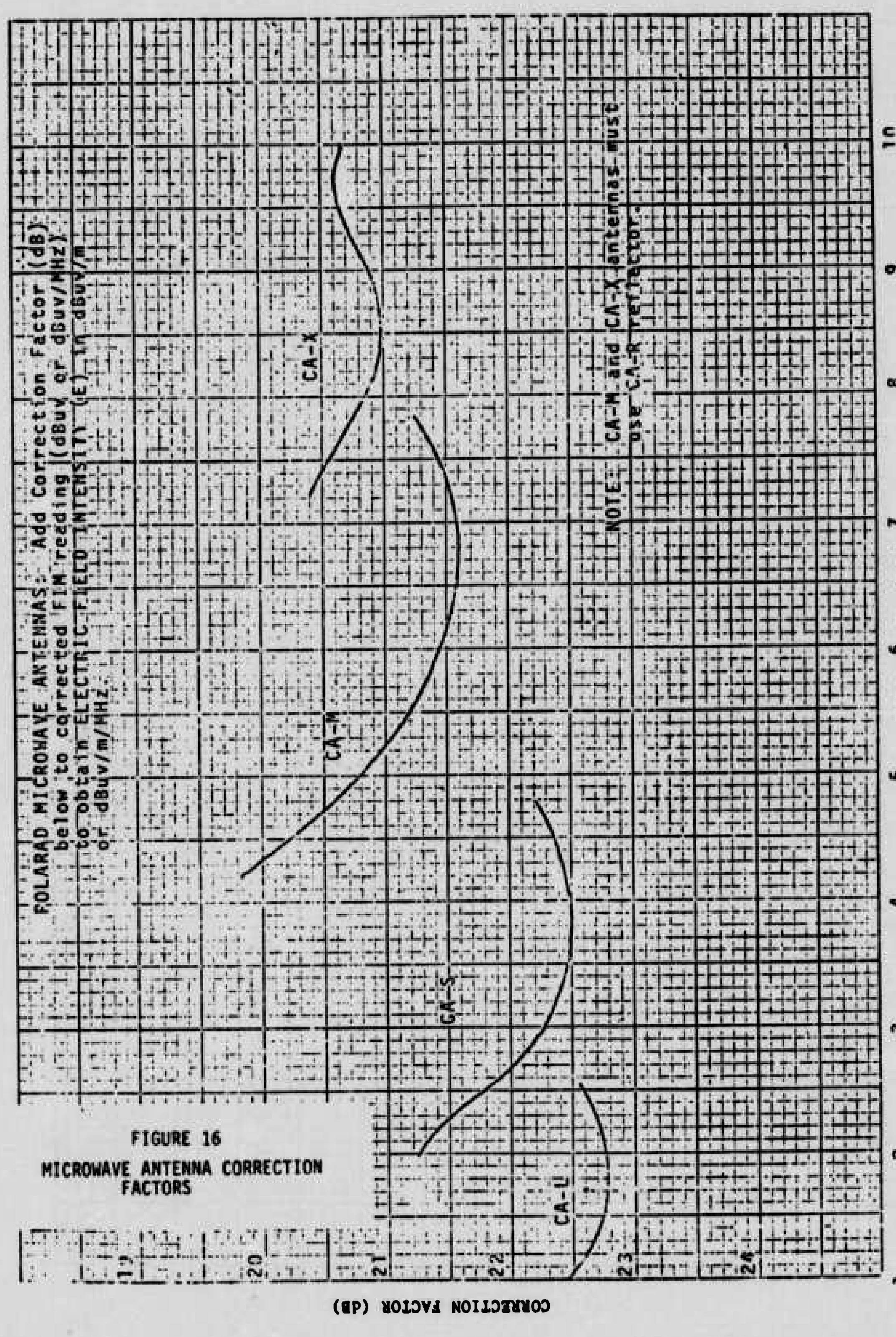


FIGURE 16

MICROWAVE ANTENNA CORRECTION FACTORS

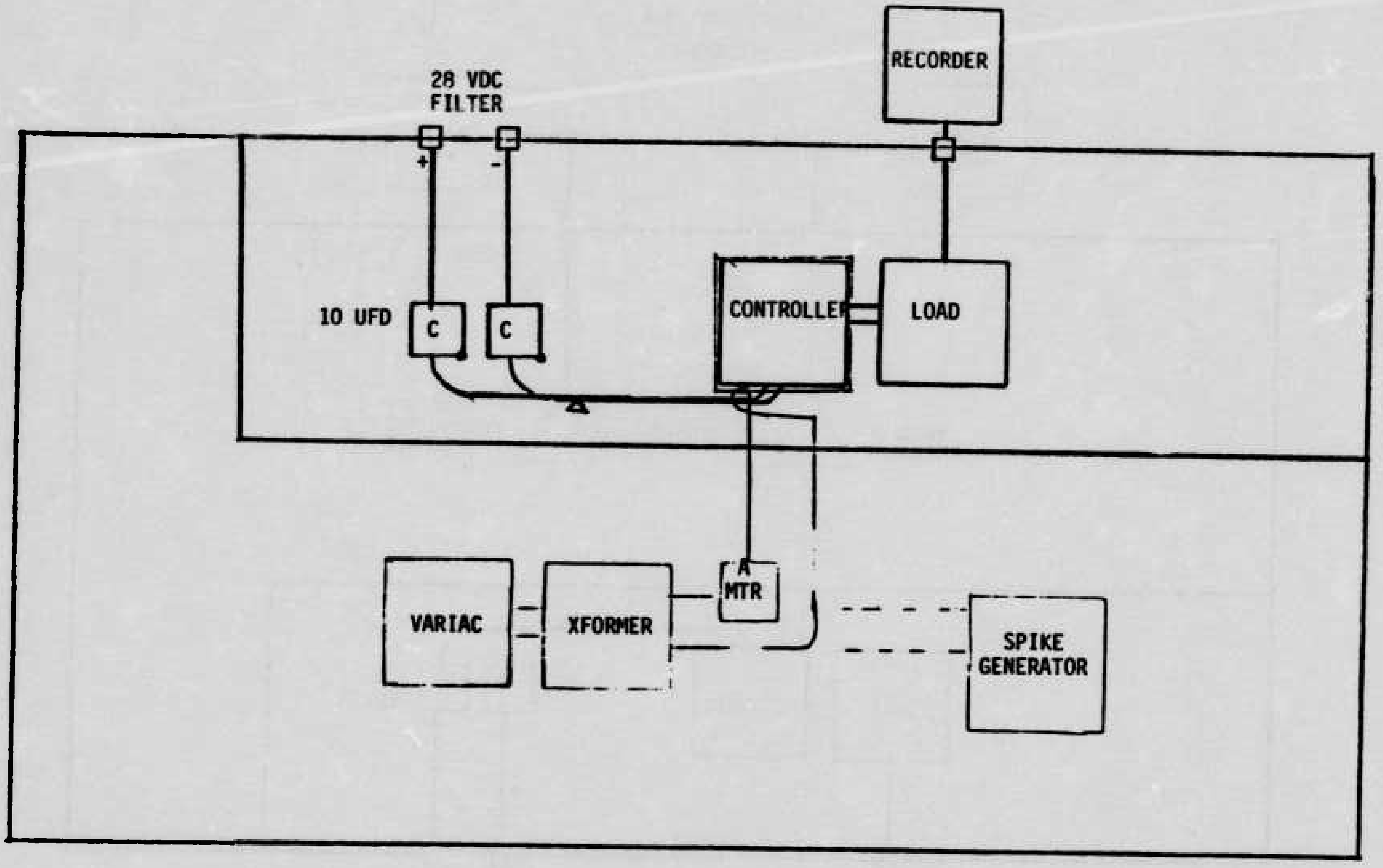


FIGURE 17

RS02 TEST SETUP

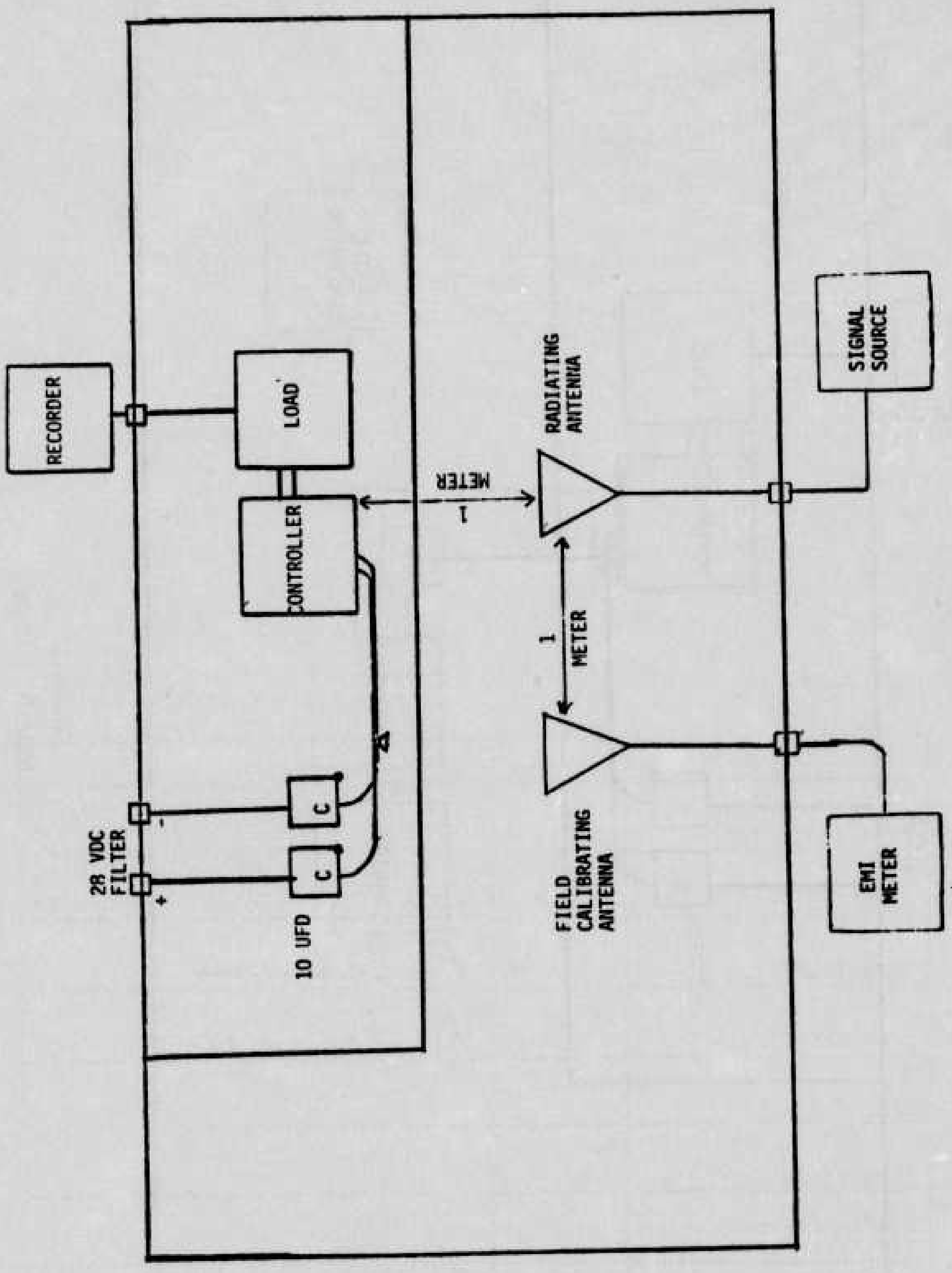


FIGURE 18
RS03 TEST SETUP

Report No. 2268

Revision ____________

REPORT OF

ELECTROMAGNETIC INTERFERENCE

TEST ON

ARTHUR D. LITTLE, INC.
TEMPERATURE CONTROLLER SYSTEM

TEST PERFORMED BY

SANDERS ASSOCIATES, INC.

95 CANAL STREET

NASHUA, NEW HAMPSHIRE

CONTRACT NO.

	DATE	SIGNATURE
TEST INITIATED	3/28/75	
TEST COMPLETED	3/31/75	
REPORT WRITTEN BY		R. Samson
TEST TECHNICIAN		R. Samson
TEST ENGINEER		
SUPERVISOR		
GOVERNMENT REP. (If Applicable)		
FINAL RELEASE		

ELECTROMAGNETIC INTERFERENCE REPORT TEST SUMMARY SHEET

TEST ITEM: Temperature Controller System	REPORT NO. 2268	DATE TEST COMPL. 3/31/75 DATE REPT. COMPL.
MANUFACTURER: Arthur D. Little, Inc.	SPECIFICATION MIL-STD-461A, Notice 3	

SUMMARY OF TEST RESULTS

TEST METHOD	TITLE	SPEC. PARA.	REMARKS	PASS	FAIL
CE03	20 kHz to 50 MHz, Power Leads	6.2	Broadband	X	
			Narrowband	X	
			Transient		X
CS01	30 Hz to 50 kHz, Power Leads	6.4		X	
CS02	50 kHz to 400 MHz, Power Leads	6.5		X	
CS06	Spike, Power Leads	6.9		X	
RE02	14 kHz to 10 GHz, Electric Field	6.12		X	
RS02	Magnetic Field Induction	6.18		X	
RS03	14 kHz to 10 GHz, Electric Field	6.19		X	

SUMMARY OF REPORT: CE03: Turn on transient exceeds limits by 4 dB at 800 kHz.

1.0 ADMINISTRATIVE DATA

1.1 Purpose/Reason for Test

To determine if Arthur D. Little, Inc., Temperature Controller System, SN 1 complies with the applicable limits of MIL-STD-461A, Notice 3 for Class 1A equipment..

1.2 Description of Test Sample

The Temperature Controller System powered with 28 volts DC consisted of the following components and associated equipment.

a) Controller Unit

b) Load Simulator

c) Temperature recording equipment. (Strip chart recorder and digital voltmeter)

1.3 Disposition of Test Sample

Returned to Arthur D. Little, Inc. by their personnel.

1.4 References

Test Plan 2186	Electromagnetic Interference Test Procedure for Temperature Controller System
MIL-STD-461A, Notice 3	Electromagnetic Interference Characteristics Requirements for Equipment
MIL-STD-462, Notice 2	Electromagnetic Rnterference Characteristics, Measurements of
MIL-STD-463	Definitions and Systems of Unit Electromagnetic Interference Technology

2.0 GENERAL

2.1 Accuracy of Measurements

2.1.1 Field Intensity Meters

The principle means of determining frequency and amplitude during the test was one or more of the following field intensity meters:

Model No.	Mfr.	Frequency Range	Frequency Accuracy	Amplitude Accuracy
EMC-10 Calibrated every 12 months	Fairchild	20 Hz - 50 kHz	±(½% + 5 Hz)	±½ dB
EMC-25 Calibrated every 12 months	Fairchild	14 kHz - 1 GHz	±2%	±1.5 dB
EMA-910 Calibrated every 12 months	Singer/Empire	1 GHz - 26.5 GHz	±½%	±2 dB
NF-105 Calibrated every 12 months Basic Unit	Singer/Empire	14 kHz - 1 GHz	±2%	±1 dB

TX	- 12 Months	TA	- 9 Months	T1	- 12 Months
T2	- 9 Months	T3	- 9 Months		

These instruments were calibrated by the Sanders Associates Instrumentation Calibration/Standards Laboratory, which operates a government approved calibration program in accordance with MIL-C-45662A, "Calibration System Requirements". The calibrating equipment accuracy required by MIL-C-45662A is several orders of magnitude greater than that of the EMC instrumentation listed above. This ensures the greatest possible frequency and amplitude data accuracy.

2.2 Transducers

All antennas--(with one exception)--and current probes use the correction factors supplied by their respective manufacturers. The single exception is the Empire VA-105 41-inch vertical rod antenna (150 kHz to 30 MHz) which is calibrated every six months by the Sanders' Calibration Laboratory.

2.3 Signal Sources

A variety of signal sources were used to develop the r.f. environment for system susceptibility tests. The field intensity was monitored by the field intensity meters described above, and so the signal source was not a primary consideration in determining the accuracy of measurement.

The signal sources are calibrated by the S/A Instrument Calibration/Standards Laboratory on a 12 month cycle.

2.4 Description of Shielded Enclosure

a)	Type Construction:	Per MIL-E-8881, Type IB per Table I, Single Shield, Solid Metal, Class C per Table II
b)	Manufacturer:	Ace Shielded Enclosure
c)	Model No:	MR10H20-G-2
d)	Size:	6M x 3M x 2.4M
e)	Door Clearance:	Double Door 2.3M x 1.7M
f)	Filters, Current & Voltage Rating:	Filtron - FSR - 1202 50 amp, 250 VAC 600 VDC, 400 Hz
g)	Ground Plane Size and Material:	Copper .92M x 4.9M x .79MM thick
h)	DC Bonding Resistance of Ground Plane:	.2 milliohms

2.5 Test Sample Operation

During EMI testing the Temperature Controller System was placed into normal operation as follows:

a) The Controller Unit was energized with 28 volts DC.

b) The Load Simulator was held to 1250 degrees fahrenheit

2.6 Susceptibility Monitoring and Criteria

During susceptibility testing the Temperature Controller System was monitored with a Temperature Strip Chart Recorder and Digital Voltmeter. The indicated load temperature of 1250°F shall not change by ±50°F.

2.7 Test Procedures

The test procedures used are those outlined in EMI Test Plan 2186, included as a separate appendix in this report.

APPENDIX A

TEST METHOD CE03
CONDUCTED EMISSION
POWER LEADS
20 kHz to 50 MHz

TEST EQUIPMENT

Description	Model/Mfg.	Serial No.	Cal Date
EMI Meter	EMC-25 Fairchild	214	12/74
Current Probe	91550-1 Stoddart	BF496	N/A
Capacitor	10 ufd Feedthrough Sanders Associates		N/A

TEST PROCEDURES

Broadband and narrowband conducted measurements were performed from 20 kHz to 50 MHz on the +28 volt DC and return power leads. Conducted transient measurements were made when going from "no current" to a 7 ampere current conditions at 0.020, 0.800, 8.0 and 25.0 MHz as specified in Paragraph 4.2.7 of MIL-STD-462, Notice 2. Conducted measurements were made using a current probe clamped around the lead under test and slowly tuning the EMI meter through the test frequency range. The test was performed as described in Paragraph 7 of EMI Test Plan 2186. The test setup was as shown in Figure 5 of the plan.

TEST RESULTS

Broadband conducted emissions comply with MIL-STD-461A, Notice 3, CE03 limits. No narrowband conducted emissions were detected. Conducted transients at 800 kHz on the +28 volt DC and return lead exceed CE03 limits by 4 dB and 2 dB respectively. Detailed test data is shown on data sheets 1 through 3.

APPENDIX B
TEST METHOD CS01
CONDUCTED SUSCEPTIBILITY
POWER LEADS
30 Hz to 50 kHz

TEST EQUIPMENT

Description	Model/Mfg.	Serial No.	Cal Date
Oscillator	HP200 Hewlett Packard	7152	N/A
Power Amplifier	M0100 Bogen Presto	J52	5/74
Transformer	6220-1 Solar	N/A	N/A
Voltmeter	630PL Triplett	3905	1/75

TEST PROCEDURES

The required CS01 test voltage of 2.8 volts RMS declining to 1 volt RMS was injected on the +28 volt DC and return power leads from 30 Hz to 50 kHz. While testing the temperature recorder was monitored for changes not to exceed ±50°F. The test was performed as detailed in Paragraph 8.0 of EMI Test Plan 2186. The test setup was as shown in Figure 8 of the plan.

TEST RESULTS

No observable temperature changes occurred during the test. The Temperature Controller System complies with MIL-STD-461A, Notice 3, CS01 requirements. See data sheet 4.

APPENDIX C
TEST METHOD CS02
CONDUCTED SUSCEPTIBILITY
POWER LEADS
50 kHz to 400 MHz

TEST EQUIPMENT

Description	Model/Mfg.	Serial No.	Cal Date
Signal Generator	606A Hewlett Packard	3786	2/75
Signal Generator	608 Hewlett Packard	4499	1/75
Capacitor	CS02 Sanders Associates	N/A	N/A
RF Voltmeter	94D Boonton	7373	2/75

TEST PROCEDURES

A 1 volt RMS signal was injected on the +28 VDC and return power leads from 50 kHz to 400 MHz. During testing the temperature recorder was visually monitored for changes of ±50^{o}F. The test was performed as detailed in Paragraph 9.0 of EMI Test Plan 2186. The test setup was as shown in Figure 9 of the plan.

TEST RESULTS

No observable temperature changes occurred during the test. The Temperature Controller System complies with MIL-STD-461A, Notice 3, CS02 requirements. See data sheet 5.

APPENDIX D
TEST METHOD CS06
SPIKE
POWER LEADS

Test Report 2268

TEST EQUIPMENT

Description	Model/Mfg.	Serial No.	Cal Date
Spike Generator	6471-5 Solar	17536	7/74
Oscilloscope	565 Tektronix	1086	9/74
Capacitor	10 ufd Feedthrough Sanders Associates	N/A	N/A

TEST PROCEDURE

A 6471-5 transient generator was used to inject positive and negative 56 Volt 10 usec spikes on the +28 volt DC power lead. During testing the strip chart recorder was visually monitored for temperature changes of $\pm 50^{o}F$. The test was performed as detailed in Paragraph 10.0 of EMI Test Plan 2186. The test setup was as shown in Figure 10 of the plan.

TEST RESULTS

No observable change in temperature occured during the test. See data sheet 6.

APPENDIX E
TEST METHOD RE02
RADIATED EMISSION
14 kHz to 10 GHz
ELECTRIC FIELD

TEST EQUIPMENT

Description	Model/Mfg.	Serial No.	Cal Date
EMI Meter	EMA-910 Singer	121	3/75
EMI Meter	EMC-25 Fairchild	217	12/74
Vertical Antenna	VR-1-105 Empire	181	8/74
Biconical Antenna	7825 Honeywell	N/A	N/A
Cone Antenna	93490-1 Stoddart	N/A	N/A
Cone Antenna	93491-1 Stoddart	N/A	N/A
MP-105	Hand Probe	N/A	N/A
Vertical Antenna	VA-105 Empire	10853	2/75

TEST PROCEDURES

Broadband and narrowband radiated emission measurements were performed from 14 kHz to 10 GHz. Radiated transients were measured during cycling from the no current to a 7 ampere current condition at 0.014, 0.200, 1.2, 14.8 and 400 MHz as specified in Paragraph 4.2.7 of MIL-STD-462, Notice 2. All measurements were made with the test antenna positioned 1 meter from the test sample at the point of maximum emission. The test was performed as described in Paragraph 11 of EMI Test Plan 2186. The test setup was as shown in Figure 11 of the plan.

TEST RESULTS

Broadband and transient radiated emissions comply with MIL-STD-461A, Notice 3, RE02 limits. No narrowband signals were detected. Detailed test data is shown on data sheets 7, 8 and 9.

APPENDIX G
TEST METHOD RS02
RADIATED SUSCEPTIBILITY
MAGNETIC INDUCTION FIELD

TEST EQUIPMENT

Description	Model/Mfg.	Serial No.	Cal Date
Spike Generator	6471-5 Solar	17536	7/74
Variac	116 Superior	N/A	N/A
Transformer	N/A	N/A	N/A
Meter	25A Weston	CC673	10/74

TEST PROCEDURES

A test wire carrying 20 amperes of 400 Hz current was wrapped around the cases of the controller unit and load unit for 5 minutes. A transient generator was then connected to the test wires and 100 volt 10 usec spikes at 6 to 10 pulses per second were applied for 5 minutes. The test wire was then wrapped around the DC power leads and interconnecting cable between the controller unit and load unit. The 20 ampere 400 Hz test and 100 volt 10 usec spike test was repeated. During the test the strip chart recorder was monitored for changes of $\pm 50^{\circ}$F. The test was performed as detailed in Paragraph 12.0 of EMI Test Plan 2186. The test setup was as shown in Figure 17 of the plan.

TEST RESULTS

No observable change in temperature occurred during the test. See data sheet 10.

APPENDIX H
TEST METHOD RS03
RADIATED SUSCEPTIBILITY
ELECTRIC FIELD
14 kHz to 10 GHz

TEST EQUIPMENT

Description	Model/Mfg.	Serial No.	Cal Date
EMI Meter	EMA-910 Singer	121	2/75
EMI Meter	NF-105 Empire	2160	12/74
Oscillator	HP200S Hewlett Packard	3786	N/A
Signal Generator	HP606 Hewlett Packard	4499	1/75
Power Amplifier	MO100 Bogen	J52	5/74
Power Oscillator	404A Microdot	32	N/A
Power Oscillator	406A Microdot	87	N/A
Power Oscillator	125 Airborne Instru. Lab.	12510	N/A
Signal Generator	616B Hewlett Packard	259-00099	2/75
Signal Generator	C772A Microlab	319	1/75
Signal Generator	X772A Microlab	324	2/75
Vertical Antenna	VR1-105 Empire	181	4/74
Vertical Antenna	VA-105	372	9/74
Biconical Antenna	7825 Honeywell	N/A	N/A
Cone Antenna	93490-1 Stoddart	N/A	N/A
Horn Antenna	CA-L, S, M, X Polarad	N/A	N/A

TEST PROCEDURES

The Temperature Controller System was immersed in an electric field intensity of 10 V/M from 14 kHz to 35 MHz and 5 V/M from 35 MHz to 10 GHz. During the test strip chart recorder was monitored for temperature changes of ±50°F. The test was performed as detailed in Paragraph 13 of Test Plan 2186. The test setup was as shown in Figure 18 of the plan.

TEST RESULTS

No observable change in temperature occurred during the test. See data sheet 11.

EMC DATA SHEET

DATE: 3/28/75 REPORT NO: 2268 DATA SHEET 1 OF ___

ITEM TESTED: TEMPERATURE CONTROLLER SYSTEM SN 1

TEST EQUIPMENT: EMC-25 91550-1 PROBE

TEST PERFORMED: CE03 20KHZ TO 50MHZ, POWER LEADS

TEST CONDITIONS: NORMAL OPERATION 1250

PERFORMED BY: RJJ

FREQ. MHz	METER dBμV	IBW dB	PROBE dB	CIRCUIT LEVEL dBμA/MHz		CE03 LIMIT dBμA/MHz	
.020	20	41	12	73		134	TEST +28VDC
.030	20	41	8	69		126	LEAD
.040	10	42	6	58		121	
.060	10	41	2	53		113	
.080	4	41	0	45		108	
.100	0	41	-2	39		104	
.150	2	40	-5	37		97	
.200	4	40	-7	37		92	
.300	2	42	-9	36		85	
.400	4	41	-10	35		79	
.600	2	42	-11	33		72	
.800	0	42	-12	30		66	
1.0	0	42	-12	30		62	
1.5	-4	42	-13	25		55	
2.0	-4	41	-14	27		50	
3.0	-2	22	-14	6		50	
4.0	-6	22	-14	2		50	
6.0	-5	20	-14	1		50	
8.0	-6	20	-14	0		50	
9.8	6	20	-14	12		50	
15.0	10	20	-15	15		50	
20.0	8	20	-15	13		50	
30.0	10	1	-15	-4		50	
40.0	10	1	-15	-4		50	NOTE: NO
50.0	10	0	-14	-4		50	NARROWBAND
							SIGNALS WERE
							DETECTED.

EMC DATA SHEET

DATE: 3/28/75 REPORT NO: 2268 DATA SHEET 2 OF

ITEM TESTED: TEMPERATURE CONTROLLER SYSTEM SN1

TEST EQUIPMENT: EMC-25 91550-1 PROBE

TEST PERFORMED: CE03 20KHZ TO 50MHZ POWER LEADS

TEST CONDITIONS: NORMAL OPERATION 1250

PERFORMED BY: RW

FREQ. MHZ	METER dBuV	IBW dB	PROBE dB	CONDUCT LEVEL dBuA /MHZ		CE03 LIMIT dBuA /MHZ	
.020	20	41	12	73		134	TEST 28VDC
.030	21	41	8	70		126	RETURN LEAD
.040	22	42	6	70		121	
.060	8	41	2	51		113	
.080	10	41	0	51		108	
.100	10	41	-2	49		104	
.150	10	40	-5	45		97	
.200	10	40	-7	43		92	
.300	8	42	-9	41		85	
.400	8	41	-10	39		79	
.600	8	42	-11	39		72	
.800	6	42	-12	36		66	
1.0	6	42	-12	36		62	
1.5	0	42	-13	29		55	
2.0	0	41	-14	27		50	
3.0	2	22	-14	10		50	
4.0	-2	22	-14	6		50	
6.0	-4	20	-14	2		50	
8.0	-4	20	-14	2		50	
10.0	-4	20	-14	2		50	
15.0	8	20	-15	13		51	
20.0	8	20	-15	13		50	
30.0	10	1	-15	-4		50	
40.0	10	1	-15	-4		50	NOTE: NO
50.0	10	0	-14	-4		50	NARROWBAND
							SIGNALS WERE
							DETECTED.

EMC DATA SHEET

DATE: 3/28/75 REPORT NO: 2268 DATA SHEET 3 OF ___

ITEM TESTED: TEMPERATURE CONTROLLER SYSTEM SN 1

TEST EQUIPMENT: EMC-25 91550-1 PROBE

TEST PERFORMED: CE03 20KHZ TO 50MHZ, POWER LEADS TRANSIENTS

TEST CONDITIONS: NORMAL OPERATION 1250

PERFORMED BY: RW

FREQ. MHZ	Meter dB	EBW	PROBE dB	CONDUC LEVEL dBuA MHZ		CE03 LIMIT dBuA MHZ	
.020	74	41	12	127		134	TEST +28VDC
.800	40	42	-12	70	✓	66	LEAD
8.0	12	20	-14	18		50	TRANSIENTS
25.0	18	20	-15	23		50	
.020	74	41	12	127		134	TEST 28VDC
.800	38	42	-12	68	✓	66	RETURN
8.0	12	20	-14	18		50	TRANSIENTS
25.0	18	20	-15	23		50	
							MEASUREMENTS MADE WHEN GOING FROM "NO CURRENT" TO 7 AMPERE CURRENT CONDITION

EMC DATA SHEET

DATE: 3/28/75 REPORT NO: 2268 DATA SHEET 4 OF ____

ITEM TESTED: TEMPERATURE CONTROLLER SYSTEM SN 1

TEST PERFORMED: CS01 30HZ TO 50KHZ POWER LEADS

TEST CONDITIONS: NORMAL OPERATION 1250

TEST EQUIPMENT: HP 3105, BOGEN 100, 6220-1 XFORMER, VM

PERFORMED BY: RW

FREQ.	INJECT LEVEL V/RMS		REQ LEVEL V/RMS				
							TEST + 28VDC
30HZ	2.8		2.8	NO OBSERVABLE TEMPERATURE CHANGE			
TO	TO		TO				
50KHZ	1.0		1.0				
30HZ	2.8		2.8				TEST 28VDC RETURN
TO	TO		TO				
50KHZ	1.0		1.0	NO OBSERVABLE TEMPRATURE CHANGE.			

EMC DATA SHEET

DATE: 3/28/75 REPORT NO: 2268 DATA SHEET 5 OF ___

ITEM TESTED: TEMPERATURE CONTROLLER SYSTEM SN1

TEST EQUIPMENT: HP606 HP608 RFVM 910 CAPACITOR BOX

TEST PERFORMED: CS02 50KHZ TO 50MHZ POWER LEADS

TEST CONDITIONS: NORMAL OPERATION 1250

PERFORMED BY: RL

FREQ. KHZ	INJECT LEVEL V/RMS		REQ LEVEL V/RMS				
							TEST 28VDC LEAD
.050	1.0		1.0				
TO	1.0		1.0	NO OBSERVABLE TEMPERATURE			
400.0	1.0		1.0	CHANGE			
							TEST 28VDC RETURN
.050	1.0		1.0				
TO	1.0		1.0	NO OBSERVABLE TEMPERATURE			
400	1.0		1.0	CHANGE.			

EMC DATA SHEET

DATE: 3/28/75 REPORT NO: 0268 DATA SHEET 6 OF ____

ITEM TESTED: TEMPERATURE CONTROLLER SYSTEM SN1

TEST PERFORMED: CS06 SPIKE SUSCEPTIBILITY

TEST CONDITIONS: NORMAL OPERATION 1250

TEST EQUIPMENT: 6471-5 TRANS GEN 545 SCOPE 10 ufd cap.

PERFORMED BY: RU

FREQ.							

POSITIVE AND NEGATIVE 56 VOLT 10 usec SPIKES WERE INJECTED ON THE 28 VOLT DC POWER LEADS FOR 5 MINUTES EACH POLARITY. SPIKE RATE SINGLE SHOT AND 10 PPS.

NO OBSERVABLE CHANGE IN TEMPERATURE.

EMC DATA SHEET

DATE: 3/28/75 REPORT NO: 8268 DATA SHEET 7 OF ___

ITEM TESTED: TEMPERATURE CONTROLLER SYSTEM SN 1

TEST EQUIPMENT: EMC-25 VR1-105

TEST PERFORMED: RE02 14KHZ TO 10GHZ ELECTRIC FIELD

TEST CONDITIONS: NORMAL OPERATION 1250

PERFORMED BY: RH

FREQ. MHz	METER dBuV	IBW dB	ANT. dB	FIELD dBuV/m/MHz		RE02 LIMIT dBuV/m/MHz	
.014	-10	43	46	79		110	VR-1-105
.020	-10	42	46	78		108	
.030	-10	41	51	82		107	
.040	-8	42	52	86		105	
.060	-10	41	52	83		103	
.080	-10	41	52	83		102	
.100	-10	41	52	83		101	
.150	-10	40	52	82		99	
.200	-10	40	44	74		97	VA-105 #10853
.300	-10	42	44	72		95	
.400	-10	41	38	69		94	
.600	-10	42	41	73		92	
.800	-10	42	42	74		91	
1.0	-10	42	33	65		90	
1.5	-10	42	33	65		88	
2.0	-10	41	35	66		86	
3.0	-10	22	30	42		85	
4.0	-6	22	31	47		83	
6.0	-6	21	27	41		81	
8.0	-6	20	25	39		80	
10.0	-6	20	24	38		79	
15.0	10	20	27	57		77	
20.0	6	20	25	51		76	
25.0	8	20	23	51		75	

EMC DATA SHEET

DATE: 3/28/75 REPORT NO: 2268 DATA SHEET ___ OF ___

ITEM TESTED: TEMPERATURE CONTROLLER SYSTEM SN1

TEST EQUIPMENT: EMC-25

TEST PERFORMED: RE02 CONTINUED

TEST CONDITIONS: NORMAL OPERATION 1250

PERFORMED BY: ___

FREQ. MHZ	METER dBuV	IBW dB	ANT. dB	FIELD dBuV/MHZ		RE02 Limit dBuV/MHZ	
30.0	10	2	12	24		74	VERTICAL
40.0	10	1	13	24		73	BICONICAL
60.0	10	1	9	20		70	
80.0	10	0	9	19		69	
100.0	12	0	14	26		68	
150.0	12	2	16	30		66	
200.0	12	2	18	32		65	
30.0	10	2	12	24		74	HORIZONTAL
40.0	10	1	13	24		73	BICONICAL
60.0	10	1	9	20		70	
80.0	10	0	9	19		69	
100.0	12	0	14	26		68	
150.0	12	2	16	30		66	
200.0	12	2	18	32		65	
300.0	12	3	17	32		69	CONICAL LOG
400.0	12	4	18	34		74	SPIRAL.
600.0	12	1	21	34		77	
800.0	12	0	24	36		78	
1000.0	12	-2	26	36		80	
2000	8	—	32	40		59	NOTE: NO
3000	8	—	36	44		60	NARROWBAND
4000	8	—	39	47		68	SIGNALS WERE
6000	8	—	44	52		61	DETECTED
8000	8	—	48	56		65	
10,000	8	—	50	58		70	

EMC DATA SHEET

DATE: 3/27/75 REPORT NO: 2268 DATA SHEET 9 OF

ITEM TESTED: TEMPERATURE CONTROLLER SYSTEM SN1

TEST EQUIPMENT: EMC-25 V

TEST PERFORMED: RE02 TRANSIENTS

TEST CONDITIONS: NORMAL OPERATION 1250

PERFORMED BY: RH

FREQ. MHZ	METER dBuV	IBW dB	ANT. dB	FIELD dBuV /M/MHZ		RE02 LIMIT dBuV /M/MHZ	
.014	12	43	46	101		110	
.200	0	40	44	84		97	
1.2	6	42	33	81		89	
14.8	10	20	27	57		78	
400.0	30	4	18	52		74	

EMC DATA SHEET

DATE: 3/08/75 REPORT NO: 2268 DATA SHEET 1? OF

ITEM TESTED: TEMPERATURE CONTROLLER SYSTEM SN1

TEST EQUIPMENT: VARIAC TRANSFORMER SPIKE GEN A.C METER

TEST PERFORMED: RS02 MAGNETIC INDUCTION SUSCEPTIBILITY

TEST CONDITIONS: NORMAL OPERATION 1250

PERFORMED BY: RJJ

FREQ.							

1. A TEST WIRE CARRYING 20 AMPERES OF 400HZ CURRENT WAS WRAPPED AROUND THE CASES AND CABLES.
   NO OBSERVABLE CHANGE IN TEMPERATURE

2. A TEST WIRE CARRYING 100 VOLT 10 USEC SPIKES WAS WRAPPED AROUND THE CASES AND CABLES.
   NO OBSERVABLE CHANGE IN TEMPERATURE

EMC DATA SHEET

DATE: 3/31/75 REPORT NO: 2268 DATA SHEET 11 OF ___

ITEM TESTED: TEMPERATURE CONTROLLER SYSTEM SN 1

TEST PERFORMED: RS03 14KHZ TO 10GHZ RADIATED SUSCEPTIBILITY

TEST CONDITIONS: NORMAL OPERATION 1250

TEST EQUIPMENT: ___

PERFORMED BY: RW

FREQ. MHZ	FIELD V/M		REQ FIELD V/M				
.014	10		10				VRI-105
TO	10		10	NO CHANGE IN TEMPERATURE			
.150	10		10				
.150	10		10				VR-105
TO	10		10	NO CHANGE			HORIZ +
55.0	10		10	IN TEMP			VERT. BICON
35	5		5				VERT. BICON
TO	5		5				
200	5		5				
35	5		5	NO CHANGE			HORIZ. BICON
TO	5		5	IN TEMP.			
200	5		5				
200	5.0		5	NO CHANGE			
TO	5.0		5	IN TEMP.			
1000	5.0		5				
1000	5.0		5	NO CHANGE			
TO	5.0		5	IN TEMP.			
10,000	5.0		5				

ADDENDUM

TO

TEST REPORT 2268

INTRODUCTION

On May 6, 1975, CE03 conducted transient measurements per MIL-STD-462, Notice 2 were repeated on A. D. Little, Inc., Temperature Controller System SN 1. The purpose of the test was to determine if a .5 ufd metallized foil capacitor installed across the 28 Volt DC power leads would provide specification compliance.

TEST RESULTS

With the .5 ufd capacitor installed across the 28 VDC power leads the Temperature Controller System complies with the conducted transient requirements of MIL-STD-461A, Notice 3. See data sheet A1.

EMC DATA SHEET

DATE: 5/16/75 REPORT NO: ______ DATA SHEET #1 OF ___

ITEM TESTED: TEMPERATURE CONTROLLER SYSTEM SN1

TEST EQUIPMENT: EMC-25 91550-1 PROBE

TEST PERFORMED: CE03 CONDUCTED TRANSIENTS

TEST CONDITIONS: NORMAL OPERATION 1250. With .5UFD METALLIZED FOIL CAPACITOR

PERFORMED BY: RJJ

FREQ. MHZ	METER dBuV	IBW dB	PROBE dB	CONDUCT LEVEL dBuA MHZ		CE03 LIMIT dBuA MHZ	
.020	80	41	12	133		134	TEST +28VDC
.800	32	42	-12	64		66	LEAD
8.0	18	20	-14	24		50	
25.0	10	20	-15	15		50	
.020	80	41	12	133		134	TEST 28VDC
.800	30	42	-12	60		66	RETURN LEAD
8.0	14	20	-14	20		50	
25.0	10	20	-15	15		50	
							NOTE .5UFD CAPACITOR ACROSS +28VDC AND RETURN

APPENDIX C

DATA SHEET FOR THE CIRCUIT DISCONNECT DEVICE

KLIXON® **MAGNETIC CIRCUIT BREAKERS**

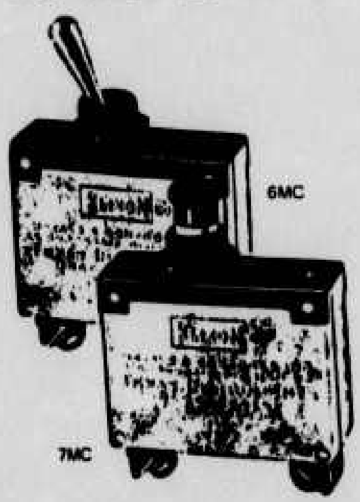
6MC & 7MC SERIES
SUB-MINIATURE
PUSH-PULL OR TOGGLE

- Meets MIL-C-5809 requirements
- High performance at minimum cost
- Sub-miniature size (1¾"x ⅔"x2½")
- Lightweight (2 oz max)
- Push-pull or toggle actuation
- From .050 to 25 amperes
- 32 v-dc, 240 v-ac, 60 & 400 cycle

The KLIXON 6MC and 7MC series magnetic circuit breakers are miniature, lightweight, and fast acting —and are the only circuit breakers of their type available with either toggle or push-pull actuation. The 6MC and 7MC series is designed for critical applications in airborne control systems, ground support equipment, launch systems, ordnance vehicles, radar, communications, weapons systems and other high-performance military and space applications.

Trip-free, the 6MC and 7MC will not sustain a fault even with the push button or the toggle held in the ON position.

Both the 6MC and 7MC can be furnished with one or two internal auxiliary switches plus a wide choice of terminal configurations for remote indication and ease of assembly. The 7MC is available with a silicone-rubber boot for a panel seal. Both the 6MC and 7MC are available with high temperature components for operation in demanding environments up to 125°C.



PERFORMANCE CHARACTERISTICS

Calibration .... Hold 110%—trip at 135% within limits of time current curve

Rupture ....

	Sea Level	60,000 Feet
32 v-dc	2500 amps	1000 amps
120 v-ac, 60 Hz	1000 amps	1000 amps
120 v-ac, 400 Hz	800 amps	800 amps
240 v-ac, 60 Hz	500 amps	400 amps
240 v-ac, 400 Hz	500 amps	400 amps

Voltage .... 32 v-dc, 120 v-ac, 60 and 400 Hz

Vibration .... Instantaneous trip type: 5-55 at .080 DA; 55-2000 at 5 G
Time delay type: 5-55 at .080 DA; 55-2000 at 10 G

Mechanical shock.... Instantaneous trip type: 25 G per MIL-C-5809
Time delay type: 50 G per MIL-C-5809

Acceleration .... 25 G per MIL-C-5809

Weight .... 2 oz max

Operating force
6MC (Toggle type) .. Open: 1 lb max Close: 3 lb max
7MC (Button type) .. Open: 5 lb max Close: 10 lb max

Endurance cycling ... 10,000 operations at 100% rating (resistive load)

Insulation resistance .. 100 megohms min at 500 v-dc per MIL-C-5809

Dielectric strength ... 1500 v-ac per MIL-C-5809

Temperature range ... -54°C to +71°C

Operating altitude .... 60,000 feet

Auxiliary switch rating .... 7 amps resistive, 4 amps inductive, 28 v-dc; 7 amps resistive & inductive, 115/130 v-ac, 60 cycle

Corrosion resistance. . Per MIL-C-5809

Humidity .... Per MIL-C-5809

Sand and dust ...... Per MIL-C-5809

Fungus .... Per MIL-E-5272, Procedure 1

TEXAS INSTRUMENTS
INCORPORATED

*PRECEDING PAGE BLANK-NOT FI

APPENDIX D

MISCELLANEOUS DATA SHEETS

—CONTINUED
TABLE IX

NICKEL-CHROMIUM vs. NICKEL-ALUMINUM

(Chromel-Alumel)

TYPE K

Temperature in Degrees F

Reference Junction at 32°F

THERMOELECTRIC VOLTAGE IN ABSOLUTE MILLIVOLTS

DEG F	0	1	2	3	4	5	6	7	8	9	10	DEG F
550	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	550
560	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	560
570	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	570
580	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	580
590	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	590
600	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	600
610	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	610
620	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	620
630	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	630
640	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	640
650	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	650
660	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	660
670	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	670
680	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	680
690	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	690
700	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	700
710	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	710
720	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	720
730	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	730
740	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	740
750	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	750
760	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	760
770	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	770
780	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	780
790	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	790
800	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	800
810	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	810
820	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	820
830	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	830
840	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	840
850	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	850
860	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	860
870	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	870
880	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	880
890	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	890
900	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	900
910	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	910
920	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	920
930	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	930
940	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	940
950	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	950
960	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	960
970	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	970
980	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	980
990	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	990
1,000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,000
1,010	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,010
1,020	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,020
1,030	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,030
1,040	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,040
1,050	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,050
1,060	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,060
1,070	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,070
1,080	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,080
1,090	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,090
1,100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,100
1,110	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,110
1,120	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,120
1,130	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,130
1,140	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,140
1,150	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,150
1,160	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,160
1,170	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,170
1,180	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,180
1,190	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,190
1,200	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,200
1,210	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,210
1,220	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,220
1,230	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,230
1,240	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,240
1,250	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,250
1,260	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,260
1,270	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,270
1,280	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,280
1,290	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,290
1,300	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,300
1,310	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,310
1,320	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,320
1,330	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,330
1,340	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,340
1,350	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,350
1,360	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,360
1,370	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,370
1,380	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,380
1,390	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,390
1,400	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,400
1,410	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,410
1,420	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,420
1,430	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,430
1,440	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,440
1,450	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,450
1,460	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,460
1,470	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,470
1,480	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,480
1,490	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,490
1,500	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,500
1,510	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,510
1,520	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,520
1,530	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,530
1,540	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,540
DEG F	0	1	2	3	4	5	6	7	8	9	10	DEG F

* CONVERTED FROM DEGREES C (IPTS 1968).

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