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CONTROL SYSTEMS DEVELOPMENT DIVISION

INTERNAL NOTE 74-EG-13

FINAL REPORT

IN-LINE TASK 57 -- COMPONENT EVALUATION

National Aeronautics and Space Administration

LYNDON B. JOHNSON SPACE CENTER

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FINAL REPORT

IN-LINE TASK 57 -- COMPONENT EVALUATION

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1.0 INTRODUCTION

1.1 BACKGROUND

Task 57 — Component Evaluation was performed by JSC to determine the applicability of off-the-shelf devices in the Space Shuttle power distribution and control system. Detailed selection of the test requirements and candidate devices to be considered in this program was established in an agreement between JSC and Rockwell Space Division.

- The Rockwell Space Division power distribution and control system baseline configuration included power switching components which have not been evaluated for space application.
- The detailed characteristics of the proposed switching devices were not well enough defined to determine interfacing requirements.
- JSC had been in the past and was currently involved in developmental programs aimed at providing improved spacecraft switching devices.
- JSC had the technical expertise and the laboratory facilities to accomplish the task.
- JSC had already invested 6 Civil Service man-months, 6 support contractor man-months, and $160,000 in programs that would contribute directly to this effort.

1.2 OBJECTIVE

The objective of Task 57 was for JSC to perform design analysis, tests, and evaluation of selected power switching components to determine the possible applicability of off-the-shelf hardware to Shuttle, and to evaluate the various characteristics available in those devices to determine the most desirable characteristics for the Space Shuttle.

1.3 SCHEDULE

On April 17, 1973, JSC submitted a program schedule of major milestones for Task 57 in an effort to assure that the program objectives would be effectively met. The milestones were discussed and mutually agreed upon by the cognizant NASA and Rockwell managers for WBS 1.3.4.6. Due to hardware delivery delays by component suppliers, some of the original milestones could not be met. These milestones were amended by mutual agreement of the WBS managers with the understanding that the objectives of Task 57 could still be fulfilled.

Due to additional hardware delivery delays by component suppliers, two of the four RPC (remote power controller) designs originally cited for evaluation will not have significant data generated through tests in time to meet the milestones of this task. Tests on these RPC's, as well as evaluation of other hardware as it becomes available to NASA, will be continued at NASA facilities, and data and analysis will be provided to Rockwell to support Shuttle procurement and development activities. The final schedule for Task 57 was as follows:

Requirement	Responsibility	Due Date	Actual Date
Initiate Hardware Procurement and Tests	JSC	10/72	10/72
Establish Shuttle Environmental Requirements	Rockwell	2/72	Open
Provide Preliminary Test Results	JSC	9/73	9/73
Provide Interim Report	JSC	12/73	12/73
Provide Final Report	JSC	3/74	3/74

Preliminary environmental requirements were established by Rockwell in most areas so that testing could progress; however, complete requirements definition has not been officially provided. Some changes in test requirements were informally requested by Rockwell engineering as they became known, and these were incorporated into the test programs where feasible (see individual test activity section 3.2). The submittal of this final report satisfies the JSC milestones of this task.

2.0 COMPONENT SELECTION

2.1 SELECTION CRITERIA

The components were selected for Task 57 evaluation according to several criteria, the main two criteria being the Shuttle requirements and the feasibility/availability of hardware.

2.1.1 Shuttle Requirements

The Rockwell power distribution and control system baseline configuration included RPC's, RCCB's (remote control circuit breakers), and very high current d.c. contactors in addition to the hardware qualified in past programs. RCCB's and high current d.c. contactors are devices that have been used on aircraft programs but never tested for space application. RPC's are essentially a developmental device with no program application history.

The Space Shuttle systems' physical sizes almost force the distribution system's designer to use remote control switching devices to eliminate many pounds of power distribution wiring. The ever-present overload protection requirements combined with the desirability of the remote control make the RPC's and RCCB's very attractive potential Space Shuttle hardware. The power profiles for the Space Shuttle presently require d.c. power distribution for 15-20 kilowatts of power, far above past spacecraft levels. D.C. contactors of 500 amps or more will be required to manage the power sources for the Shuttle.

2.1.2 Feasibility/Availability of Hardware

Another factor in the selection of components for evaluation was the feasibility/availability of the hardware. JSC had several different designs of RPC's already on contract for developmental projects. It was felt that these units had enough variety in design characteristics to evaluate RPC's without further procurements. RPC's of current ratings higher than 10 amps have been proven feasible by several manufacturers; however, the availability of those units would be dependent on a significant amount of developmental dollars and so could not be included in Task 57.

RCCB's have not been applied in spacecraft systems, but are used on several commercial aircraft, making them not only feasible but commercially available off-the-shelf. High current d.c. contactors rated at 500 amps and greater are available from some aircraft and ground systems programs; however, no spacecraft experience near these ratings is to be had.

There are no special requirements on Space Shuttle toggle switches that cannot be met by past proven devices. The cost associated with spacecraft developed switches, however, is excessive in comparison to aircraft qualified units; therefore, some MIL-S-3950 aircraft type toggle switches were procured for evaluation as a low cost unit. Contamination, contact degradation, and other problems present with any electromechanical switch make a solid-state switch very desirable for Shuttle application. A JSC research and development program supplied several versions of solid-state switches for evaluation, and two additional rotary solid-state switches were obtained from an Air Force developmental program.

2.2 COMPONENT LIST

Components were selected for evaluation in Task 57 according to the criteria of section 2.1. General descriptions of the selected components are given in the following paragraphs. A detailed list of components to be evaluated in Task 57, including vendor model numbers, is given in section 3.0 - Evaluation Activities.

2.2.1 Remote Control Circuit Breakers

One device selected as a prime candidate for use on the Shuttle to meet some of the remote switching and protection requirements is the RCCB (remote control circuit breaker) as developed for commercial aircraft application. An RCCB is basically a combination of a relay and a circuit breaker, and can operate as either or both. It utilizes coils (intermittent duty) and contact mechanisms in much the same manner as relays and contactors.

RCCB's utilize bimetallic sensing of overloads much the same as thermal circuit breakers. When triggered by movement of the bimetal due to heat generated by overcurrent, the appropriate mechanical latches will trip the RCCB to an open contact position. Electronic circuitry/ components are employed for power supply, coil suppression and logic requirements to obtain proper operation.

The basic operation of the commercially designed RCCB's centers around a single wire, ground switching control line. Utilizing input line power to perform the logic and coil operations, the RCCB controls its contactors such that if the single control wire is grounded, the contacts are closed, and if the control wire is opened, the contacts are opened. While in the closed position, if an overcurrent condition exists, the bimetal sensor triggers the trip circuitry to open the contacts. Resetting the RCCB after a trip is accomplished by merely cycling the control function off and back on. Details of the designs and operations of RCCB's are given in Cutler-Hammer Bulletin 7204 HB-1A, February 1972, and Texas Instruments Technical Product Specification No. 181.

2.2.2 Remote Power Controllers

For the past 8 to 10 years, designers have worked towards providing a solid-state power control device to replace the conventional electromechanical parts. The culmination of these efforts appears to be the RPC (remote power controller). This device is a sophisticated power control device that includes many features over and above the turn-on or off and overload tripping provided by relays and/or circuit breakers. The detailed operating characteristics of the particular RPC's to be evaluated in Task 57 vary from one vendor to another, but all have the same general intent. The RPC is completely solid-state in nature, using no moving contacts. The RPC has a current sensing circuit that feeds into the control circuit to provide overload protection. In a.c. units, the overload protection is simply a turn-off function, whereas the d.c. units generally include a current limiting capability in addition to the turn-off function. The RPC also has an overload "trip" indication circuit that can be used for monitoring and management of the distribution system. Other specific operational characteristics can be determined by the requirements given in the specific design specification for each RPC design.

2.2.3 Panel Mounted Switches

Design analysis and modifications are a continuing process in toggle switch application, with engineers striving for designs, manufacturing processes and test and inspection procedures that could eliminate or minimize problems associated with panel mounted switches. In addition to designs which have been developed for space application after unique space problems were experienced, several other designs qualified by aircraft programs have been selected for evaluation mainly as a possible low cost component. Developmental solid-state components will be evaluated as they become available.

2.2.4 Power Contactors

A survey of off-the-shelf hardware capabilities to switch d.c. currents in excess of 500 amperes indicated very little experience in this area was available. The only candidate off-the-shelf high current d.c. device uncovered for evaluation was a Hartman reverse current cut-out unit. A modified version of this unit was procured that included a hermetic seal and overcurrent cutout characteristics.

3.0 ACTIVITY

3.1 EVALUATION APPROACH

The general approach for Task 57 component evaluation efforts consists of test requirements establishment, lab test activities, and data analysis. Establishing the Space Shuttle test requirements has proved to be impossible up to this time. Changing mission requirements, major vehicle and engine characteristics modifications, as well as changes in program considerations to place more emphasis on the influences of cost and weight have all contributed to the problem such that Rockwell has not provided firm test requirements for Shuttle which could be applied to Task 57. For the purpose of obtaining some timely evaluation data in Task 57, however, the best available requirements definition was put together from Rockwell data and data from JSC Test Division documentation. These test requirements are being used for Task 57 efforts, and will be updated as actual requirements become better defined. Table I lists the requirements as established for Task 57.

Lab activities on any one component do not necessarily involve all of the test requirements listed in Table I. The first step for each component to be evaluated is an analysis of the component's test history. Many of the components have had documented test programs run on them, and these programs are evaluated against the Shuttle requirements to establish a delta test requirement for the individual components. Some Shuttle requirements may be eliminated from the Task 57 efforts due to known design characteristics for a particular component, or due to similarity of design requirements imposed by two or more tests. The specific test plan for each component for Task 57 is to be included in the test activity report for that component.

During and after the test activities, data analysis is to be performed to determine the ability of the components to meet the test requirements. The analysis effort will contain minimal failure analysis, since the purpose of this program is generally to investigate existing hardware designs for their possible direct applicability.

3.2 ACTIVITY STATUS

The basic activities for Task 57 have been component selection, test requirements definition, hardware procurement, and laboratory testing. The following list gives the vendor's model numbers of the components selected for evaluation according to the criteria of section 2.1. A status of activities on each component is presented in the paragraphs following the list.

- Remote Control Circuit Breakers
  - Cutler-Hammer Model No. SM600 BA XXX A1
  - Texas Instruments Model No. 3 RC 1-B
  - Texas Instruments Model No. 4 RC 1-A
- Remote Power Controllers
  - SCI Electronics Inc. Model No. 10 I/1 and 10 I/5
  - SCI Electronics Inc. RPC's for NAS 8-26082 (no model number)
  - Teledyne Relays Model No. 673-1000X
  - Leach Corporation RPC's for NAS 9-12000 (no model number)

- o Panel Mounted Switches

  Cutler-Hammer P/N 850x Kx

  Micro Switch P/N x TL1-x

  Edison Electronics P/N 45000-XXX

  Texas Instruments P/N 1XLSX-X

  EDC Model No. 8-08C-01

  Raven Electronics Model Nos. 203A, 203B, 202C

  Singer Kearfott Solid State Switches (NAS [illegible]144)

- o Power Contactor

  Hartman Model No. AH-711

3.2.1 RCCB Evaluation Status

RCCB's were procured from Cutler-Hammer and Texas Instruments as the only two manufacturers presently in production of this family of hardware for commercial application. The Cutler-Hammer RCCB's are being applied in the DC-10 and Texas Instruments RCCB's are used in the L-1011 aircraft. In order to establish the test requirements for Shuttle evaluation of these aircraft qualified components, the vendor qualification test reports* were compared against the Shuttle requirements of Table I. There was an adequate test history to provide a reasonable level of confidence in the ability of the RCCB's to meet the Shuttle requirements defined by Table I except for the acceleration, space simulation and vibration requirements. The actual test program at JSC was, therefore, limited to those three tests. Detailed test

*Cutler-Hammer Qualification Report Number 72-4 and Texas Instruments Qualification Test Report Document No. EX 1190-235.

procedures and data sheets for RCCB testing are included as Appendix A to this report. Twenty-six RCCB's were selected as test samples, with samples of both vendors hardware covering the complete range of current ratings available. A summary of the test results is presented in the following paragraphs.

3.2.1.1 Electrical Characteristics

The test samples were tested for performance under room ambient conditions against the electrical characteristics requirements as defined by the vendors. This effort consisted of the following tests:

a. Insulation Resistance.

b. Dielectric Strength.

c. Contact Voltage Drop.

d. Overload Trip Calibration.

e. External Switching.

f. Pushbutton Switching (Texas Instruments only).

g. External Indication (Auxiliary Contacts).

h. Visual Operation Indication.

i. Shock Hazard.

j. Voltage Extreme Operation.

k. Backup Control Operation (Cutler-Hammer only).

The RCCB's all conformed to vendor requirements except for one Cutler-Hammer 25 amp unit and one Texas Instruments three-phase 10 amp a... unit. The Cutler-Hammer unit tripped in 335 seconds under 115%

load, not meeting the requirement to carry 115% load for 60 minutes without tripping. All other characteristics of this unit were within specifications. A phase of the Texas Instruments unit did not trip within 60 minutes under 138% load as required, but all other characteristics of this unit were within specifications. Several units of both vendors exhibited case temperatures higher than vendor specifications during overload operation; however, no electrical characteristic degradation was noted due to this temperature excursion and the units were retained in the test sample group.

3.2.1.2 Space Simulation Test

Twenty-two samples were subjected to a space simulation test in accordance with the requirements of Table I. Failure of two Texas Instruments a.c. units was noted when external switching could not be performed at -34°C. The units could not be switched externally at the completion of the test either. Pose test electrical measurements were made on the remaining RCCB's including contact voltage drop, shock hazard, and 200% tripping time. No changes were noted in the electrical characteristics.

3.2.1.3 Acceleration Test

Twenty-two samples were subjected to an acceleration test in accordance with the requirements of Table I. No failures were incurred and no contact chatter was observed. No changes in characteristics were noted in post acceleration electrical testing.

3.2.1.4 Vibration Test

Seven samples were subjected to the random vibration test in accordance with the requirements of Table I. The Space Shuttle test philosophy provides a major impact to vibration test programs relative to past programs. The 2-hour per axis test requirements for Shuttle hardware is an order of magnitude greater than past manned spacecraft requirements. This test requirement not only involves a considerable amount of test time and manpower, but also reduces the visibility of hardware performance if failures do occur during testing. In order to provide as meaningful a test as possible in the vibration effort, a mission cycling plan was established by the JSC Test Division per June 27, 1973, memo WT-031, which provided that vibration testing be conducted in a cyclic manner as follows: (a) Run one mission simulation in each axis, (b) run five mission durations in each axis, (c) run five mission durations in each axis, (d) run ten mission durations in each axis, (e) run 30 mission cycles in each axis, and (f) complete the testing with 50 mission cycles in each axis. This plan results in a vibration exposure profile of 101 mission cycles and approximately 2 hours. It is felt that testing in this method allows a better identification of the capabilities of candidate hardware that may be capable of meeting the requirements of the Shuttle program but may require refurbishment plans. This reading of "fatigue" life becomes unnecessary, of course, if no failure or degradation is encountered.

Contact chatter was monitored for both the main contacts and the auxiliary contacts during testing. The Cutler-Hammer units indicated no chatter on any circuits except for three isolated instances of single openings. Considering the length of the test, the fact that only single discontinuities were indicated, and the sensitivity of the monitoring circuits involved, it is concluded that the Cutler-Hammer RCCB's can meet the random vibration requirements of Table I. The Texas Instruments RCCB's exhibited random contact chatter in both the main and auxiliary contacts, with chatter susceptibility increasing as the mission cycles progressed. By completion of the 101 mission cycles, two of the three Texas Instruments units tested exhibited continuous chatter. Other than the chatter indications, it was detected that the Texas Instruments three-phase unit failed catastrophically in that it could not be externally operated. Post vibration testing of the electrical characteristics indicated no changes from the normal in any of the other units.

3.2.1.5 Conclusions

The test history of commercially available RCCB's, combined with the initial results of the JSC test program, indicates very promising "off-the-shelf" components that may be directly applicable to the Space Shuttle distribution system. The susceptibility to vibration previously noted was confined to the Texas Instruments units with the apparent design deficiency probably due to the manual push-button requirement. The pushbutton mechanism on the RCCB can be a useful tool for laboratory test and possibly for ground maintenance purposes; however, it has no operational phase advantages and apparently jeopardizes the structural integrity of the hardware. A requirement for manual pushbutton operation capability is, therefore, not recommended for Space Shuttle hardware specifications. The failure of the two a.c. units during space simulation is not considered to be an inherent design deficiency since four other units of essentially the same design experienced no degradation under the same test conditions. No detailed failure analysis was performed on the two units for the following reasons: (1) the test was successfully completed on four other units, (2) the vibration sensitivity of this particular hardware design makes serious consideration unlikely, and (3) the physical configuration of this RCCB design is such that disassembly for failure analysis would be a very difficult and time consuming task. In summary, it is felt that commercially available RCCB's have demonstrated the ability to meet the Shuttle requirements as defined in Table I as well as providing a sound electrical component to meet requirements for a remotely operated circuit protection device.

3.2.2 Toggle Switch Evaluation Status

Final test activities on toggle switches were limited to consideration of the Cutler-Hammer, Micro Switch, Edison Electronics and Texas I. truments devices listed in paragraph 3.2.

Review of the hardware and the development and test reports on the EDC Model No. 8-080-01 Solid-State Rotary Switch developed for the AFAPL (Air Force Aero Propulsion Laboratory) led to a decision not to perform further testing on these units at JSC. Though designed, fabricated, and tested successfully within the bounds of the AFAPL program requirements, these switches could not be considered as off-the-shelf or modifiable Shuttle hardware since no design and packaging considerations were included for active flight environmental requirements. Therefore, no JSC test efforts were expended on this hardware.

The Singer Kearfott solid-state switches developed for JSC under Contract NAS 9-13144 were scheduled for delivery in October 1973. Due to component parts unavailability for the switch circuits, the Kearfott delivery was slipped to January 1974. Electrical acceptance tests were performed at JSC with multiple failures noted, ranging from out-of-tolerance voltage outputs to completely inoperative switches. Since these switches have not been contractually accepted, and since they are provided in a panel-mounted configuration, no further evaluation can be done prior to repair or replacement. Evaluation data cannot be provided, therefore, as part of this report, but will be conveyed to Rockwell as it becomes available. The Singer Kearfott Final Report on this project is included as Appendix C to this report to provide the design and development data available at this time.

The Cutler-Hammer and Micro Switch switches were previously qualified to MIL-S-3950 requirements and offered a potential low cost toggle switch for Shuttle application. In order to establish the test requirements for Shuttle evaluation of these switches, the MIL-S-3950 specifications were compared against the Shuttle requirements of Table I. The MIL-S-3950 requirements are sufficient to prove the capabilities of the switches except for space simulation, acceleration and random vibration.

After completion of test efforts on the MIL-S-3950 toggle switches, Rockwell informally requested that the random vibration levels of Table I be changed due to more up-to-date dynamics data. In response to the Rockwell informal telecon request, the vibration spectrum for testing these switches was changed from the previous toggle switch spectrum used (spectrum 1) to the higher levels of spectrum 2. Retest of the MIL-S-3950 switches at the higher level was not considered necessary since chatter susceptibility was proven to be excessive even at the lower levels.

The Edison Electronics and Texas Instruments switches have previously been tested to spacecraft specifications to prove their general capabilities. In order to establish the test requirements for Shuttle evaluation of these switches, the Shuttle requirements of Table I were compared to the specifications of ME452-0102-XXXX for the Texas Instruments switches and MSFC 40M38202 for the Edison Electronics switches. Comparison of these specifications revealed that random vibration was the only area where previous test requirements were insufficient to prove the switches adequate for Shuttle application. Although both types of switches have been tested to comparable energy levels in meeting the given specification requirements for random vibration, it is questionable whether the exposure duration adequately demonstrated reliable switch life for as many as 100 Space Shuttle missions. During previous inhouse testing of the MIL-S-3950 switches, a marked increase in contact chatter was noted after vibration exposure totaling approximately 20 missions per axis. It was, therefore, decided to perform random vibration on both types of switches. Detailed test procedures and data sheets for these tests are included as Appendix B to this report.

3.2.2.1 MIL-S-3950 Toggle Switch Testing

3.2.2.1.1 Space Simulation Test

Space simulation tests were performed on samples of both vendors' hardware covering all available toggle configurations. No hardware failures were noted and post test electrical characteristics indicated no degradation.

3.2.2.1.2 Acceleration Test

Acceleration tests were performed on samples of both vendors' hardware covering all available toggle configurations. No chatter was indicated during testing and post test electrical characteristics indicated no degradation.

3.2.2.1.3 Vibration Test

Random vibration tests were performed on samples of both vendors hardware covering all available toggle configurations. Chatter was detected on every test sample, with chatter frequency ranging from 16 individual indications minimum for single and double pole maintain contacts to continuous chatter for all quadrapole or momentary switches. Post test electrical characteristics indicated no changes for any of the switches.

3.2.2.1.4 Conclusions

These MIL qualified switches offer a low cost, off-the-shelf candidate component capable of meeting all of the Shuttle requirements of Table I except for vibration. Although no electrical characteristics were degraded in the course of the tests, the chatter indications pointed out an apparent mechanical degradation that would have to be evaluated for systems criticality before these switches could be considered for Shuttle application.

3.2.2.2 Texas Instruments and Edison Electronics Toggle Switch Testing

3.2.2.2.1 Vibration Test

Random vibration tests were performed on samples of both vendors hardware covering all available toggle configurations. Fifteen of the 24 total samples had no contact chatter indications over the complete vibration duration. Seven samples exhibited discrete chatter indications of three (3) times or less, and the remaining switch (an Edison Electronics unit) gave a continuous chatter indication after ten mission cycles. Post test electrical characteristics indicated no significant changes for any of the switches.

3.2.2.2.2 Conclusions

Most of the chatter indications recorded for these switches were isolated, discrete indications with no apparent pattern or trend. It was noted during testing that most of the chatter indications occurred on more than one channel simultaneously. Given the transient susceptibility of the chatter detector circuitry, this would indicate that many of the simultaneous indications were transient responses rather than real multiple channel chatter indications. Even assuming all indications to be real, it would have to be concluded that these switches performed well enough under the vibration requirements to be considered for off-the-shelf Shuttle hardware with only minimal delta qual tests. With respect to the one Edison Electronics switch that exhibited continuous chatter, preliminary analysis of all of the data available indicates that this was a defective switch rather than a design deficiency. This position is strengthened by the good performance of the other switches tested with the same basic design, as well as the perfect performance of another switch of the identical part number The chatter susceptibility of this one switch should not, therefore, distract from the proof of capability of these switches, but rather serve as a data point in establishing minimum vibration test requirements for acceptance testing of toggle switches procured for the Shuttle.

3.2.3 RPC Evaluation Status

Evaluation activities to date on RPC's for Task 57 have been limited to consideration of the SCI devices and the Teledyne Model No. 673-1000X. The Leach RPC's have not been delivered to JSC yet, and no evaluation efforts can be accomplished on them in time for this report.

The SCI 10 I RPC's were developed for the Marshall Space Flight Center in an effort to obtain a flight packaged solid-state switching and protection device. No qualification test history was available on this R&D device, so the full requirements of Table I were considered for evaluation of this device. These devices are environmentally sealed, however, and considering the time and cost involved with the tests concerned with seal capability (such as humidity, salt-fog, etc.), environmental testing of these units was limited to high-low temperature, acceleration, shock, and vibration. The Teledyne RPC's were developed for JSC in an effort to evaluate some design options which varied from the requirements of the Military Specification for RPC's (MIL-P-81653). No qualification test history was available on this R&D device, so again the full requirements of Table I were considered for evaluation of this device. These devices are hermetically sealed, and for the same reasons as with the SCI 10 I devices, environmental testing of these units will be limited to high-low temperature, acceleration, shock, and vibration.

The SCI 3I RPC's have been developed for the Marshall Space Flight Center as part of the continuing NASA programs to develop flight capable hardware. SCI experienced several schedule delays due to redesign efforts and parts delivery from component manufacturers. With delivery not accomplished until January 1974, the MSFC test efforts to date have been limited to initial electrical testing. All units performed satisfactorily under normal operating conditions, except for insulation resistance and dielectric strength. All units failed to meet the requirements of these tests and it was determined that the potting material used by SCI in these units simply cannot meet these requirements. Further testing will continue at MSFC and data and analysis will be provided to Rockwell as it becomes available. It should be noted that these SCI RPC's are considerably larger and heavier than the basic MIL-SPEC outlines, and that consideration of these units as off-the-shelf units after the MSFC qual program would mean a substantial weight and volume penalty to the user.

3.2.3.1 Evaluation Testing of SCI 10 I RPC's

3.2.3.1.1 Electrical Characteristics

Using the MIL-P-81653 design characteristics and specifications as the baseline for comparison, the SCI 10 I RPC has many design differences. These are not to be considered failures, but rather exceptions to the MIL-SPEC requirements taken by SCI when designing the 10 I device. A major exception taken is denoted by the nomenclature of the device; i.e., 10 I literally means that the instantaneous trip level for these units is 10 times the normal rating of the device, with trips at levels lower than 10 I time dependent on the degree of overload. This gives a trip curve proportional to the time and overload as approximately an I^2t function with t approaching zero as I approaches 10. The trip curve for these devices is shown in Figure 1.

Another exception with this design is essentially no delay times in response to turn-on and turn-off signals. Whereas the MIL-SPEC requires some few milliseconds of signal application or removal to effect a change of state of the RPC, the 10 I design responds in approximately 2 to 6 microseconds. Combined with the very clean switching characteristics of the unit, the fast switching could make this design applicable where extremely time critical coordination switching is required. This design characteristic, however, would apparently make this device more susceptible to interference than a MIL-SPEC unit, and EMI testing is being performed on these devices. Preliminary results of testing to MIL-STD-704 and MIL-STD-6181 indicates no adverse characteristics in these units.

Another exception with this design is the lack of isolation between the control and the output state. The importance of such isolation from a user's standpoint must be assessed once the system application is defined. From the component standpoint, the lack of isolation and the allowed very fast turn-on and turn-off times combine to reduce any standby power requirements to essentially zero. This benefits the user by cutting the OFF state power dissipation to essentially zero, with leakage currents of a few microamperes contributing the only losses.

The final two exceptions have negligible advantages or disadvantages from a component standpoint, and should not affect systems application significantly either. The exceptions are (1) the maximum turn-OFF voltage is 1.0 Vdc rather than 2.5 Vdc, and (2) the trip indication circuit is designed to output 5.0 Vdc at 1.0 milliamperes instead of the 10 milliamperes of the MIL-SPEC design, thereby requiring the monitoring circuit to provide a 5000 ohm impedance.

The electrical characteristics of the 10 I units could be summarized as follows:

Contact Drop (Rated Load)	-	0.250 Vdc
Turn On Voltage (Minimum)	-	3.5 Vdc
Turn Off Voltage (Maximum)	-	1.0 Vdc
Control Input Resistance	-	500 Ohms
Leakage Current (Maximum)	-	100 Microamps
Trip Indication Voltage	-	5.0 Vdc at 1.0 Milliamps

3.2.3.1.2 High-Low Temperature Test

High-low temperature tests were performed on the 10 I units of both 1 and 5 amp ratings. Performance characteristics during and after these tests were well within specifications except for leakage current readings of one 5 amp unit during high temperature operation. The specification requirement for leakage on 5 amp RPC's is 500 microamps maximum. The average leakage currents actually measured on the 10 I 5 amp units was less than 20 microamps. One of the 5 amp units exhibited 400 microamps leakage at ambient conditions, however, and under high temperature (71°C) this unit had 640 microamps leakage. Post test measurements were within specifications, but still remained above the average.

3.2.3.1.3 Shock Test

Shock tests to the levels of Table I were performed on the 10 I units of both 1 and 5 amp ratings. Performance specifications before and after these tests were within limits.

3.2.3.1.4 Acceleration Test

Acceleration tests to the levels of Table I were performed on the 10 I units of both 1 and 5 amp ratings. Performance specifications before and after these tests were within limits.

3.2.3.1.5 Vibration Test

Sinusoidal and random vibration tests to the levels of Table I were performed on the 10 I units of both 1 and 5 amp ratings. The RPC's were monitored for changes of state during vibration, with none noted. Post test electrical characteristics indicated no degradation in performance.

3.2.3.1.6 Life Cycle Test

Life cycle testing was performed on 10 I units of both 1 and 5 amp ratings. These units were cycled on and off for approximately 500,000 cycles at rated load with no failures or degradation in performance.

3.2.3.1.7 Conclusions

The characteristics of the SCI 10 I RPC's have been demonstrated, including the ability to meet Shuttle environmental requirements. With respect to this specific piece of hardware, the only anomalies experienced under test were indicated during acceptance type checks that could have weeded out those units before application. This leads to the position that the SCI 10 I RPC appears capable of being qualified to its particular characteristics and that application of the device is mostly dependent on the compatibility of these particular electrical characteristics within the proposed system.

3.2.3.2 Evaluation Testing of Teledyne Model No. 673-1000X RPC's

3.2.3.2.1 Electrical Characteristics

The Teledyne RPC's developed under Contract NAS 9-12914 applied the general switching and protection specifications of MIL-P-81653, but incorporated several major design options chosen through optimization studies performed by Teledyne. Details of the Teledyne electrical characteristics, packaging concepts, and selection rationale for these characteristics are included in Appendix D, the Teledyne Final Report for Contract NAS 9-12914, dated August 30, 1973.

One of the major design variations chosen by Teledyne was to eliminate the power ground terminal and make the RPC a two terminal device with reference to the power circuits. The functional circuitry for this design is shown in Figure 2. This design has the advantage that no power is taken from the load supply for the switching function. The base drive is essentially independent of the load voltage, resulting in the RPC having uniform capabilities from 0.5 to 30 volts. The 2 terminal unit, therefore, allows for location of the RPC on either the supply or ground side of the load voltage. In a MIL-P-81653 design, the RPC is limited to the supply side of the load voltage. A possible disadvantage of the two terminal RPC is that the power for the base drive must be derived from the control signal, requiring higher control currents than an equivalent 3 terminal device. This current drain is in the range of 10-25 milliamperes for 1 and 5 ampere RPC's, and is only required in the <u>ON</u> state, with the <u>OFF</u> state requirement being essentially zero. In a system's application, the end results on overall power dissipation would depend on the number of units <u>ON</u> and <u>OFF</u> for the total mission, with the 2 terminal device looking more attractive as the number and time of <u>OFF</u> state RPC's increased.

The other major design variation selected by Teledyne was to increase the control voltage level from 5 volts to 28 volts. This increase makes the RPC less susceptible to noise as well as making the normal spacecraft bus power directly usable if desired. When combined with the two terminal design, this variation allows less complex drive circuitry, resulting in component reduction and inherently improved cost, weight, and reliability parameters.

Actual test efforts on these Teledyne units at JSC have been halted due to failures. Four d.c. RPC's were delivered by Teledyne, two 5 amp and two 1 amp units. Both 1 amp units failed to operate after insulation resistance and dielectric withstanding strength testing. The two 5 amp units successfully completed all of the electrical functional tests, but failed upon application of negative transients on the control circuit. The units have been returned to Teledyne for analysis and replacement. Neither the failure analysis nor the new units have been received as of this writing. Completion of the detailed electrical evaluation and the environmental testing of the Teledyne units must of course be delayed until the new units are received. Estimated delivery of the new units is March 15, 1974.

3.2.3.3 Evaluation Testing of Hartman Contactors

High current d.c. contactors were purchased from Hartman for evaluation as modified off-the-shelf candidates for source and bus switching. Testing was accomplished at Marshall Space Flight Center on February 8, 1974, and the test report is presently being written.

The official test report will be provided to Rockwell as soon as it becomes available. A summary of the test efforts is presented in the paragraphs below.

The Hartman AH711 contactor procured for this program is a modification of the Hartman A702AP contactor. The modifications were to change the internal logic package from a reverse current cutout to an overload cutout and to incorporate a hermetic seal into the unit design. Since this unit has been listed on the Military Qualified Parts List No. QPL-005026(AS)-1, it was determined that the most objective and cost effective test program for this hardware should include electrical characteristics, life cycling, acceleration, shock, and random vibration.

3.2.3.3.1 Electrical Characteristics

Initial electrical characteristics were measured for five contactors including contact resistance, pickup and dropout voltage, coil currents, operation times, voltage drops at various loads, and overload tripout calibration. All units performed satisfactorily in these initial tests.

3.2.3.3.2 Life Cycle Test

One contactor was exposed to a life cycle test with 50,000 cycles as the design requirement. The unit was loaded at 500 amperes on the main contacts and 5.0 amperes on the auxiliary contacts. The cycle rate was set at twenty (20) cycles per minute. This unit performed with no discrepancies for 43,217 cycles. The main contacts failed to operate for one cycle at 43,218 and the auxiliary contacts failed for one cycle at 43,219. All functions resumed correct operation through 50,000 cycles. Cycling was continued and the main contacts failed again at 52,509 cycles through 52,582 cycles (contacts remained open for entire period). The main contacts resumed proper operation again at this point and no other failures were noted through 55,211 cycles, at which point the test was stopped. The auxiliary contacts failed to transfer one more time at 52,584 cycles.

Electrical tests were performed at the completion of the life cycling and all characteristics were within limits. Some loose object was noted inside the contactor after the test, with no apparent effect on operating characteristics. This unit will be opened for contact inspection and investigation of the loose object, with findings to be provided in the MSFC official test report.

3.2.3.3.3 Acceleration Test

Acceleration tests were performed on two contactors, monitoring for chatter in excess of 10 microseconds and checking pickup and drop-out voltages during test. A variation in pickup voltage was noted during acceleration with the worse case axis moving to greater than 26 volts. Both units indicate transfers (continuous chatter indication) at the maximum g's imposed (22.5 g's). Both units operated successfully up to 11.7 g's in all axes. Post test electrical characteristics indicated no degradation.

3.2.3.3.4 Shock Test

Shock tests were performed on two contactors, monitoring for chatter in excess of 10 microseconds. The shock level used was 30 g peak/half-sine. Both units indicated chatter in the worse case axis and passed in all other axes. Some lower level shocks were performed in the most critical axis and all contacts passed at 6.5 g's.

3.2.3.3.5 Vibration Test

Random vibration tests were run on two contactors according to the latest spectrum as provided by Rockwell and JSC Test Division agreement. This spectrum contains a peak excitation of 0.2 g^2/Hz, and immediate continuous chatter was detected for both units at this level. The test level was dropped 10 db and runs of 1 minute duration were started at this level, increasing 1 db after each run. Auxiliary contacts exhibited chatter at every level greater than -9 db, but the main contacts had no chatter prior to the -3 db level. Longer runs were then started at the -4 db level (main contacts had passed 1 minute runs at this level), but both units indicated intermittent chatter at this level. Levels were reduced further for longer runs with main contact total success (no chatter) achieved on one unit at -6 db (0.05 g^2/Hz peak). The second unit experienced intermittent failures at this level on its main contacts. Post test electrical characteristics indicate no degradation other than some changes in trip calibration.

3.2.3.3.6 Conclusions

Although the final test report has not been completed by MSFC, several conclusions may be drawn from the preliminary data reports. A major observation for these tests was the apparent susceptibility of these units to the mechanical requirements as established for the Shuttle. Post test discussions with Rockwell and JSC Test Division personnel indicate the acceleration and shock discrepancies may have occurred at levels higher than the present Shuttle requirements. The data must be evaluated against the present requirements to determine the compatibility of this hardware in these areas. With respect to random vibration, it is obvious that this hardware is susceptible to chatter at levels considerably lower than Shuttle requirements. Consideration should be given to this point in discussions with potential manufacturers to determine the possibility of vibration isolation mounting of this hardware for Shuttle application.

3.3 TASK 57 SUMMARY

The optimum completion of the objectives of this task has been inhibited due to schedule delays in hardware delivery by vendors and lack of firm test requirements definition. These delivery problems may be an important factor to remember in supplier selection to the degree that considerable weighting should be given to in-house integrated circuit design and manufacturing capabilities, as well as in-house facilities for production line manufacturing. This consideration, plus the availability of electronic components, appear to be the most critical delivery factors for remote power controllers.

Continued test efforts in those areas impacted by delivery problems will be reported to Rockwell Space Division as information becomes available. With test inputs, this Final Report, and a continued transfer of requirements and information between the cognizant NASA and Rockwell Space Division personnel, the primary objective of providing full evaluation of available hardware and design concepts will have been accomplished.

3.4 PLANNED ACTIVITIES

Test and evaluation efforts will be completed on the Hartman contactors and the Teledyne RPC's. Evaluation progress of the other hardware under consideration is contingent upon its delivery. The cognizant Rockwell Space Division personnel will be continuously informed of the status of the deliveries and the test efforts.

TABLE I.

TEST CRITERIA FOR COMPONENT ENVIRONMENTAL TESTING

TEST	PROCEDURES AND PARAMETERS
Humidity	MIL-STD 810B, Meth. 507, Proc. 1 Temp. (Max/Min) - 71°C/28°C Rel. Hum. (Max/Min) - 95%/85% Pressure - Room Amb. Duration - 240 Hrs.
Salt Fog	MIL-STD 810B, Meth. 509, Proc. 1 Temp. - 90 ± 5°F Salt Concen. - $1.0 {+0.5 \atop -0}$ % Chamber Humidity - $85 {+15 \atop -10}$ %
Fungus	MIL-STD 810B, Meth. 508, Proc. 1
Sand and Dust	MIL-STD 810B, Meth. 510, Proc. 1 Material - $Si\ O_2$ (97-99%) Concentration - 0.3 gm/cu. ft. Air Vel. - 250-1750 ft/min Amb. Temp. - 23°C - 63°C
Pressure	Per Shuttle Master Verification Plan, General Approach and Guideline, Vol. I, paragraph 3.5.14 (6)
Altitude	MIL-STD 810B, Meth. 500, Proc. I and II Temp. (Max/Min) - 80°C/-54°C Pressure (Max/Min) - 1.0 atm./87.5 Torr
Space Simulation	MIL-STD 810B, Meth. 517, Proc. II Temp. (Max/Min) - 80°C/-54°C Pressure - 3.8×10^{-5} Torr

TABLE I.
(continued)

TEST	PROCEDURES AND PARAMETERS
Acceleration	MIL-STD 810C, Meth. 513, Proc. I and II Room Ambient Conditions G (Max/Min) - 22.5/3.3 G RMS Duration - 2 minutes
Shock	MIL-STD 810B, Meth. 516, Proc. IV Room Ambient Conditions G (Peak) - 30 G Pulse Shape - Half Sine
Acoustic Noise	MIL-STD 810B, Meth. 515, Proc. I
Vibration	Per Shuttle Master Verification Plan, General Approach and Guidelines, Vol. I, paragraph 3.5.14 (12) Sinusoidal: 5-2000 Hz, 2 min/Octave 1.0 G Peak Random: Spectrum 1 MIL-S-3950 T.S. 20 - 80 Hz, increasing 3 db/Oct 80 - 350 Hz, constant 0.06 g^2/Hz 350 - 2000 Hz, decreasing 3 db/Oct 2 Hrs./Axis Spectrum 2 10 - 24 Hz, increasing 12 db/Oct 24 - 160 Hz, constant 0.1 g^2/Hz 160 - 2000 Hz, decreasing 6 db/Oct 2 Hrs./Axis Spectrum 3 10 - 20 Hz, increasing 6 db/Oct 20 - 30 Hz, constant 0.05 g^2/Hz 30 - 85 Hz, decreasing 6 db/Oct 85 - 2000 Hz, constant 0.006 g^2/Hz 15 Hrs./Axis

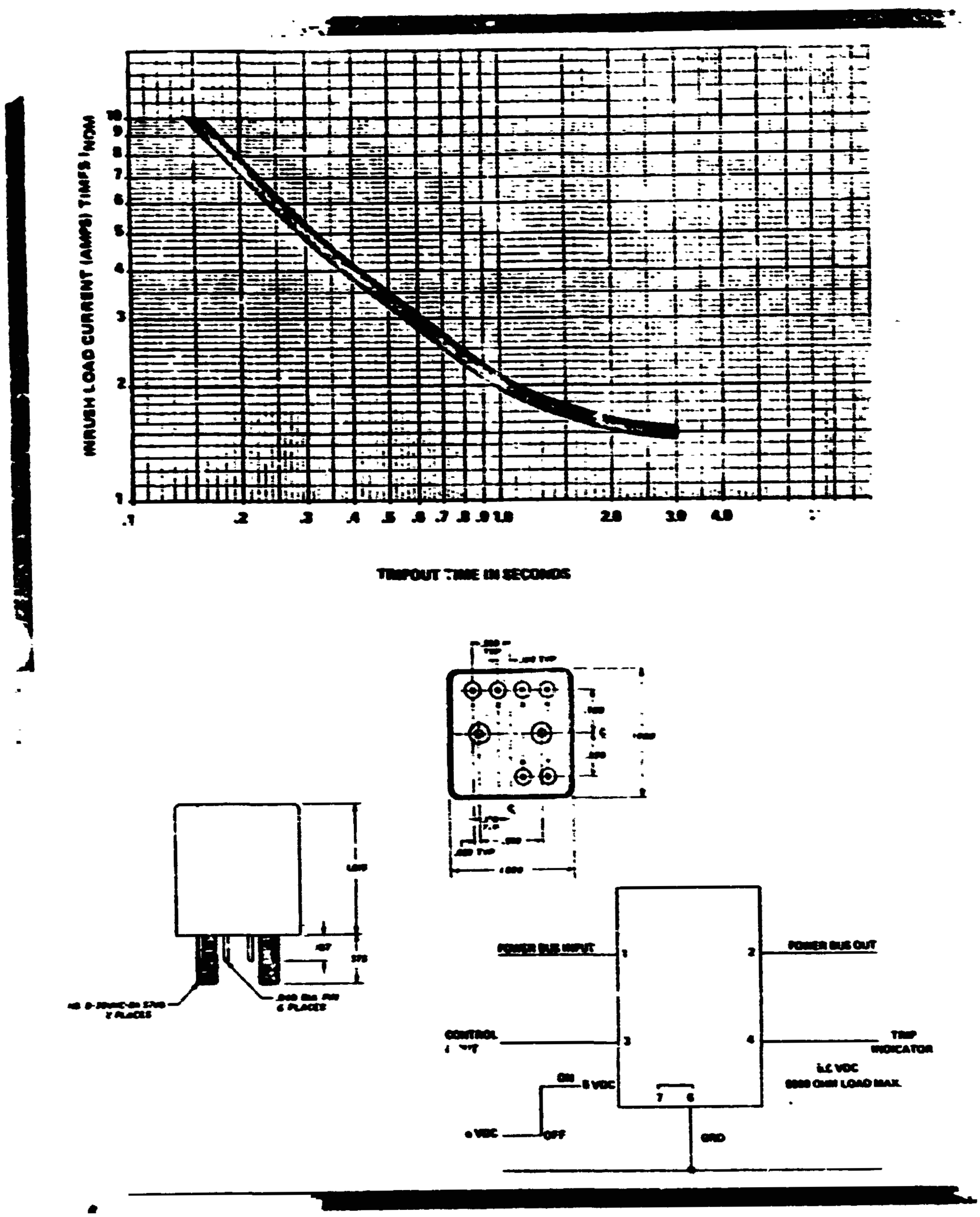

FIGURE 1. SCI 10 I RPC

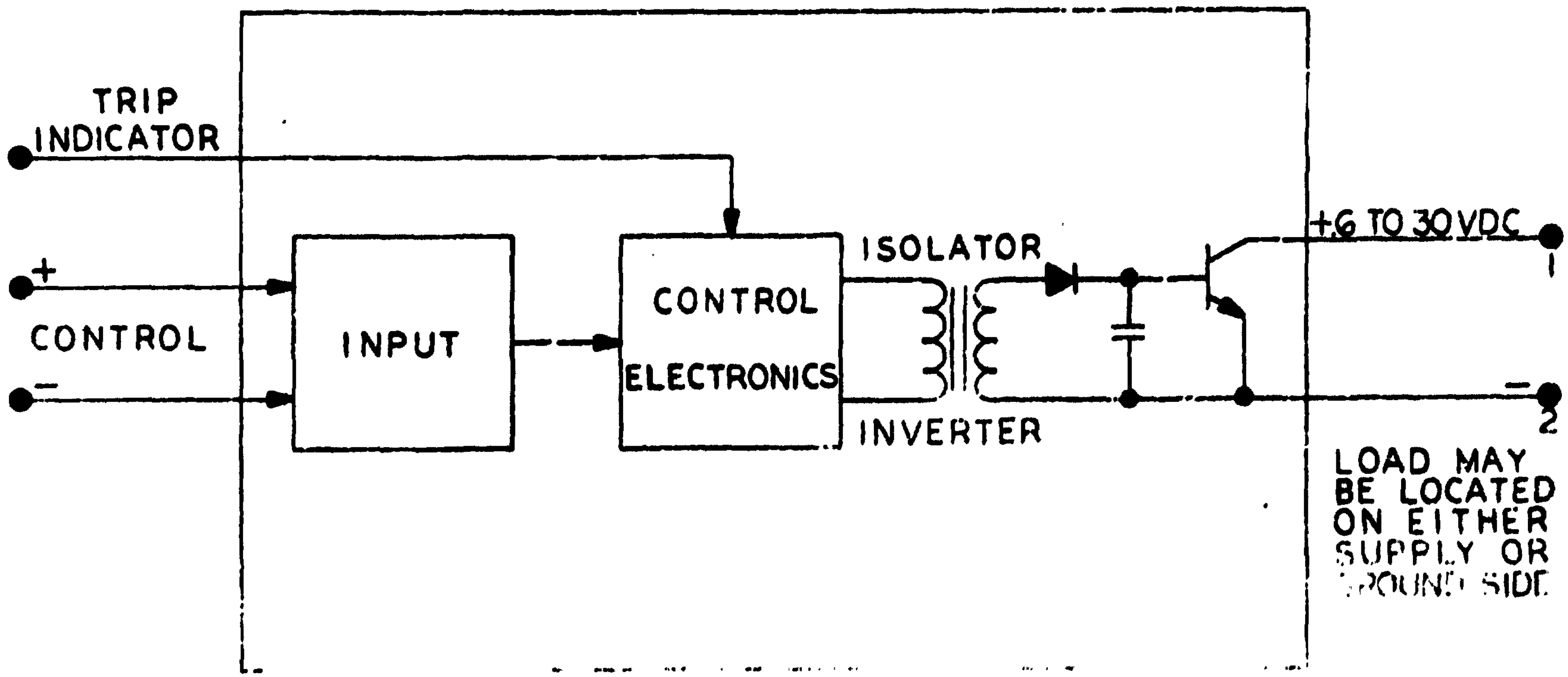

FIG. 2 TELEDYNE 2 TERMINAL CONTROLLER

NASA-JSC

APPENDIX A

REMOTE CONTROL CIRCUIT BREAKER TEST REPORT

LEC 0921, REV. A

REMOTE CONTROL CIRCUIT BREAKER EVALUATION TESTING

Prepared By
Lockheed Electronics Company, Inc.
Aerospace Systems Division
Houston, Texas

Under Contract NAS 9-12200

For

POWER DISTRIBUTION AND CONTROL BRANCH

National Aeronautics and Space Administration
LYNDON B. JOHNSON SPACE CENTER
Houston, Texas

September 1973

LEC-0921
Revision A

REMOTE CONTRCL CIRCUIT BREAKER

EVALUATION TESTING

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For

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER
HOUSTON, TEXAS

September 1973

LEC-0921
Revision A

N74-35270

ABSTRACT

Engineering evaluation tests were performed on several models/types of Remote Control Circuit Breakers (RCCB) marketed by Cutler-Hammer and Texas Instruments in an attempt to gain some insight into their potential suitability for use on the Space Shuttle vehicle. Tests included the measurement of several electrical and operational performance parameters under laboratory ambient, space simulation, acceleration and vibration environmental conditions. Although some undesirable operation was noted, sufficient manpower and facilities were not available to allow a comprehensive enough test program to provide the basis for drawing a firm conclusion as to the RCCBs' suitability or unsuitability for the Space Shuttle vehicle. A further obstacle to drawing such a conclusion is the unavailability, at the time this report is being written, of firm environmental specifications for that vehicle.

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1.0 INTRODUCTION

1.1 Purpose

The purpose of the Remote Control Circuit Breaker (RCCB) testing discussed in this report has been to verify electrical and operational characteristics of RCCB's, manufactured by Cutler-Hammer (C-H) and Texas Instruments (T.I.), as specified by the vendors, and to explore the feasibility of their application in the Space Shuttle vehicle.

1.2 RCCB Background

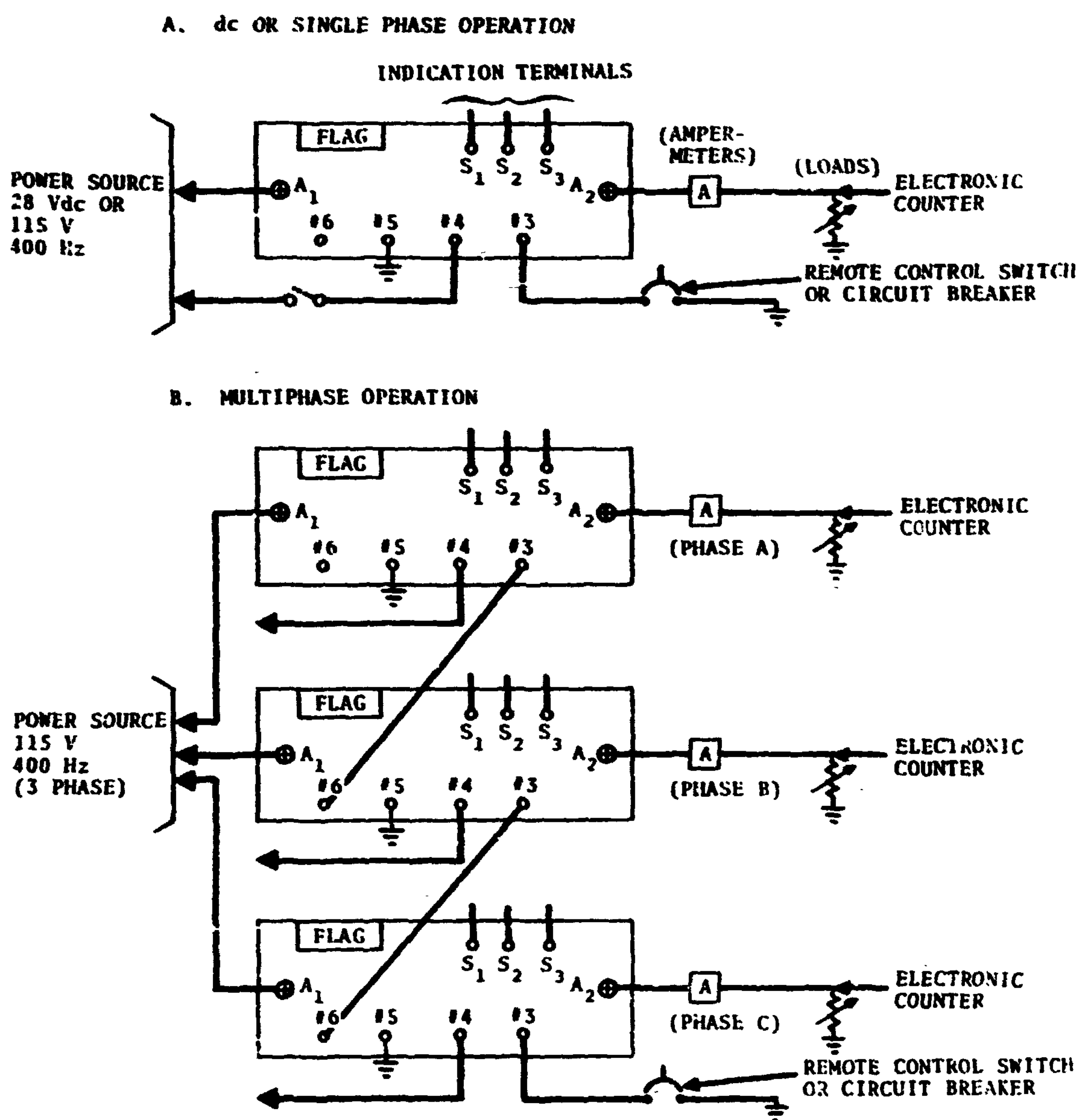
The Remote Control Circuit Breaker (RCCB) was developed to meet the requirements of power control in super sized jet aircraft. It is an electronically controlled electromechanical device which physically separates the power switching from the switching control. While the package containing the relay and circuit breaker can be installed close to the power source and/or to the load, the control, i.e., the actuating and resetting functions, can be performed via a single #22 gauge wire from the cockpit or any remote location. RCCS's now available on the market have ratings from 5 to 100 amperes. Some of the most notable characteristics of the units tested are described below. Some of the basic differences between them can be more clearly understood by referring to figures 1 and 2. Additional particulars and characteristics are shown in reference 1.

The successful application of RCCB's in aircraft introduced them to the space industry. This prompted the recently initiated and executed test program for exploring the RCCB's feasibility for the Space Shuttle.

1.2.1 Cutler-Hammer models' characteristics.— The Cutler-Hammer models can be used alternatively for dc (28 volts) or ac (155 V,400 Hz operations). In the latter case they can be interconnected for multiphase operation by utilizing control terminal No. 6 (fig. 1).

The state of the main contacts (A_1-A_2) is shown by the indicating terminals (S_1, S_2 and S_3) and by a mechanical FLAG exposing either OPEN or CLOSED signs.

The remote switch connected to terminal No. 3 controls the main contacts if the primary power source is connected to A_1 or if any suitable power source is connected to terminal No. 4, referred to as Backup Power. Thus, if power is inadvertantly lost from A_1, terminal No. 4 can be attached to a power source and the main contacts can be opened by operating the remote switch. In this way, shock hazard (the time delay from commanding the circuit to open until the output power terminal is actually disconnected from the source terminal) is eliminated. Because these RCCB's normally derive their actuating power from the primary power source, opening the remote control switch after loss of power to terminal A_1 would not cause the RCCB's main power contacts to open. Thus, if primary power to A_1 was restored, the load terminal, A_2, would be energized for the short but finite time required for the RCCB to actuate even though the remote-control switch had been opened prior to restoration of the primary power. Providing the RCCB



NOTE:

ELECTRONIC COUNTER FOR MEASUREMENT OF SHOCK-HAZARD DURATION AND TRIPPING-TIME DURING OVERLOAD OPERATION.

Figure 1. – External wiring diagram of Cutler-Hammer model RCCB's.

with actuating power via terminal No. 4 provides the means of preventing this temporary energizing of A_2 .

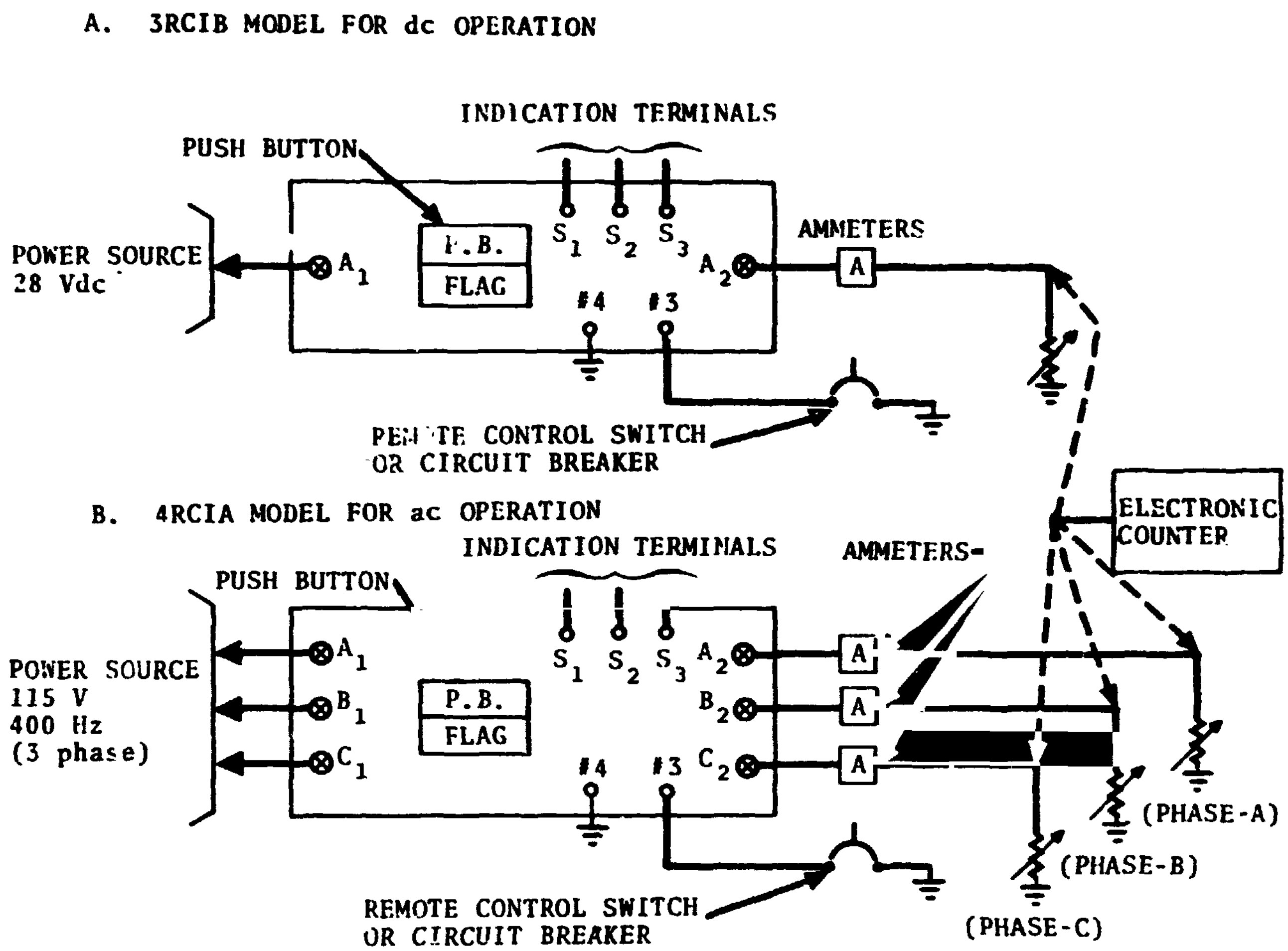
Terminals No. 6, for multiphase operation, and No. 4, for Backup Power, are unique features of the C-H models not available in Texas Instruments units.

1.2.2 <u>Texas Instruments models' characteristics</u>.— Texas Instruments provides two models of RCCBs, one for dc (28 V) and another for ac (115 V, 400 Hz) applications. Both models have a Push Button arrangement not available in C-H models. The ac models are assembled for 3-phase operation (fig. 2).

The state of the main contacts (A_1 - A_2) is shown by the indicating contacts (S_1, S_2 and S_3) and by a FLAG, located beneath the Push Button, which exposes or conceals an ON sign.

The main contacts are controlled by a remote switch connected to terminal No. 3 provided the power source is connected to the line terminal (A, or A_1, B_1, C_1). Actuating the Push Button temporarily overrides the control of the external switch. Its effect is similar to that of a "momentary switch."

When the power source is lost from the line terminal(s) while the remote switch is closed, the shock hazard is eliminated by opening the remote switch and actuating the Push Button (pulling it up) so that the main contacts open.



NOTE:

ELECTRONIC COUNTER FOR MEASUREMENT OF SHOCK-HAZARD DURATION AND TRIPPING-TIME DURING OVERLOAD OPERATION.

Figure 2. – External wiring diagram of Texas Instruments model RCCB.

Because the Push Button is mechanically coupled to the main power contacts, an alternate or back-up power source is not required to open those contacts when primary power is lost, as is the case with the Cutler-Hammer unit, but the capability for remote operation, which is retained by the Cutler-Hammer unit, is lost.

1.3 Test Program Summary

Because of the similarity of environmental parameters of altitude and high/low temperature tests with space simulation tests and because the vendors' documentation of humidity and shock tests were deemed adequate for purposes of this initial evaluation, the Qualification testing (environmental exposure) was limited to:

- Space Simulation
- Acceleration
- Vibration

Acceptance testing, the measurement of electrical and operational performance parameters under laboratory ambient-environment conditions, was performed on 305 samples of several models/types from the two vendors. Of these, 26 were exposed to space simulation, 22 to acceleration and 10 to vibration.

In several instances units tested failed to meet the vendors' specifications or did not operate as desired during/after environmental exposure. The results of the tests are summarized in TABLE I.

TABLE 1. - SUMMARY OF TESTS RESULTS

PCCB - MODEL - VENDOR - RATING (AMP)	NUMBER OF SAMPLES TESTED	ACCEPTANCE TESTS: NUMBER OF SAMPLES FAILED VENDORS SPEC'S: ELECTRIC CHARACTERISTICS (1)	OPERATIONAL CHARACTERISTICS: GEN (2)	OVERLOAD 200 %	OVERLOAD 150 %	OVERLOAD 115 %	OVERLOAD TEMP LIM (115%)	TOTAL	QUALIFICATION TESTING: SPACE SIMULATION (3) SAMPLES TESTED	SPACE SIMULATION FAIL.	ACCELERATION SAMPLES TESTED	ACCELERATION FAIL.	VIBRATION SAMPLES TESTED	VIBRATION FAIL.	BECAME INOPERATIVE DURING TESTING
SM600BA-100 A1 C-H 100 AMP	25					6	16	21	2		2		1		
SM600BA-75 A1 C-H 75 AMP	25		[1]			1	6	[illegible]	2		2				[1]
SM600BA-50 A1 C-H 50 AMP	25					1	5	[illegible]	2		2		1		
SM600BA-35 A1 C-H 35 AMP	25			1	[1] 1			[illegible]	1						[1]
SM600BA-25 A1 C-H 25 AMP	25		[1]			2	1	[illegible]	2		2		1		[1]
SM600BA-20 A1 C-H 20 AMP	25	1						[illegible]							
SM600BA-10 A1 C-H 10 AMP	25	3				1		[illegible]	2		2		1		
SM600BA-5 A1 C-H 5 AMP	25			[1]	3			[illegible]	3		2				[1]
3RC1R-50 T.I.-50A. DC	25				5		16	21	2		2		2		
3RL16-15 T.I.-15A. DC	25		[illegible]			[1]		2	1						[1]
3RC1R-10 T.I.-10A. DC	25	1	2			2		5	3		2		1		
4RC1A-35 T.I.-35A. AC	10								2				1		
4RC1A-10 T.I.-10A. AC	10	1		[1]	1			3	2	[2]	3				[3]
4RC1A-7 T.I.-7.5A. AC	10			[1]				1	2		3		1	[1]	[2]
TOTAL	305	6	5	4	11	14	43	82	26	[2]	22	0	10	[1]	[10]

(1) ELECTRIC CHARACTERISTICS:
- INSOLATION RESISTANCE
- DIELECTRIC STRENGTH
- CONTACT VOLTAGE DROP

(2) OPERATIONAL CHARACTERISTICS (GEN):
- EXTERNAL SWITCHING
- EXTERNAL INDICATION ($S_1 S_2 S_3$)
- FLAG OPERATION
- SHOCK HAZARD
- VOLTAGE EXTREMES
- PUSH BUTTON OP'N (T.I.) BACK-UP POWER OP'N (C-H)

(3) INCLUDED ARE 4 SAMPLES SUBJECTED TO HIGH-TEMP. TEST

[ ] TEST UNIT BECAME INOPERATIVE DURING TESTING

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

2.0 REFERENCE DOCUMENTS

1. RCCB-Remote Control Circuit Breaker Bulletin 7204 HB-1A Cutler-Hammer, February 1972.

2. Remote Control Circuit Breaker Technical Product Specifications Single Pole Series SM600BA Number 181, Cutler-Hammer, Milwaukee, Wisconsin.

3. Overhaul manual with illustrated parts for Remote Control Circuit Breaker, part no. 3RCIA, 3RCIB, 4RCIA, H.B.47-EG71, December 15, 1971, Texas Instruments, Inc.

3.0 TEST PROCEDURE

All tests were classified into either Acceptance or Qualification tests. The first of these included those measurements intended to verify electrical and operational characteristics of the RCCB's while the second involved exploring their feasibility for application in the Space Shuttle vehicle.

The specific RCCB models (or types) tested and the tests performed on each model are tabulated in Table I. Test instrumentation is shown in Table II.

3.1 Acceptance Tests

3.1.1 Electrical characteristics.— The first part of the Acceptance testing consisted of measuring the RCCBs' electrical characteristics--insulation resistance, dielectric strength, and contact voltage drop.

Insulation resistance between the mutually insulated parts of each RCCB, illustrated in figure 3, was measured with the application of 500 volts dc between all possible pairs of these parts on any one RCCB. The mutually insulated parts considered were the RCCB case, mounting base, line terminal (A_1, or A_1, B_1, C_1 in T.I. ac models) and load terminals (A_2, or A_2, B_2, C_2 in T.I. ac models).

Dielectric strength was measured in a manner similar to insulation resistance by measuring the leakage current

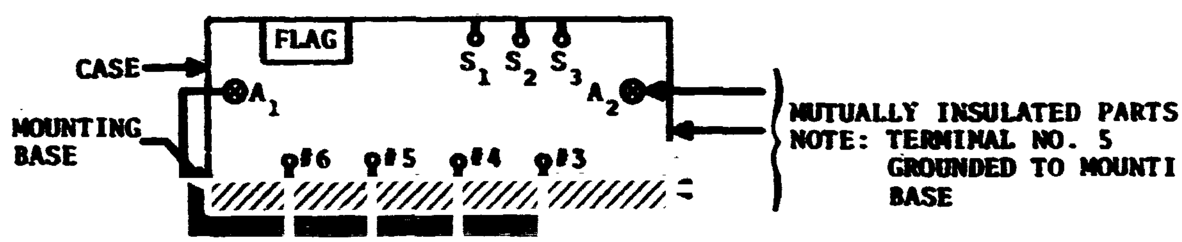
TABLE II. – TEST INSTRUMENTATION AND FACILITIES

• dc voltmeter, Weston, model 931	(ID: C07820)
• dc millivoltmeter, Weston, model 931	(ID: C00228)
• dc Ammeter, Weston, model 931	(ID: C07828)
• Shunt, Weston, 50 mv/200 a	(–)
• dc Microammeter, Weston model 1011	(–)
• ac voltmeter, Weston, model 433	(ID: C01084)
• dc ammeter, Weston, model 904	(ID: C09874)
• dc ammeter, Weston, model 904	(ID: C09878)
• dc ammeter, Weston, model 904	(ID: C09879)
• Oscilloscope, Tektronics, RM45A	(ID: NAS3-6438)
• Plug-In, type D, Tektronics	(ID: NAS2-9487)
• Electronic Timer, H.P., model 5243L	(ID: NAS3-8612)
• Plug-In, H.P. model 5262A	(ID: C05600)
• ac-dc nondestructive insulation tester, Telemet Co., Amityville, N.Y.	(ID: NAS6-0093)
• Discontinuity Time Monitor, CTL, Fern Park, Fla.	(ID: NAS8-2732)
• Reg. dc power supply, Kepco, model CK 40-0.8	(ID: NAS5-2084)
• Precision dc power supply, Kristie Electric Co.	(–)
• Ohmmeter, Simpson, model 270	(ID: NAS6-0988)
• 3 phase 400 Hz 115 V/phase power source (wall-plug)	In House
• dc load bank	In House

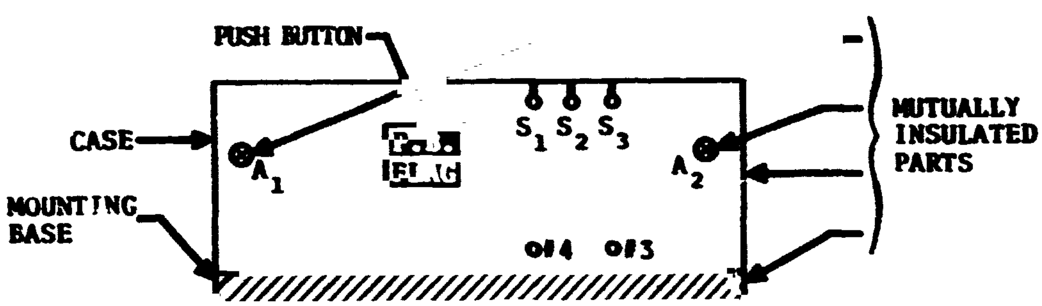
TABLE II. – TEST INSTRUMENTATION AND FACILITIES (Concluded)

• ac load bank	In House
• Space Simulation Test facility; RCA High Vacuum Chamber (with accessories)	(ID: NAS4-1272)
Temperature monitoring device, Honeywell, Philadelphia, Pa.	(ID: NAS6-4453)
• Acceleration test facility: Centrifugal Acceleration, S/N G264A-0, Ser.: 010; Trio-Tech, Burbank, Calif. (with accessories)	(ID: NAS4-5212)
• Vibration test facility: Ling Electronics –	
Vibrator, model 249-2, Ser. 56; X-axis	(ID: NAS5-16523)
Vibrator, model 310, Ser. 20; Y-axis	(–)
Vibrator, model 310, Ser. 31, Z-axis	(ID: NAS7-0775)
Random Analyzer, Ling, model ASDE-80	(ID: NAS5-2289)
VTVM, BRUEL and KJAER, model 2416	(ID: CD4643)
Accelerometer, Columbia, model 440-1-H	(ID: C01374)
Charge Amplifier, UNHOLZ-DICKIE, Model 8 PMC V	(ID: NAS6-1356)
Log Converter, H.P., model 7562A	(ID: NAS8-3657)

A. CUTLER-HAMMER MODEL



B. TEXAS INSTRUMENTS MODEL FOR dc OPERATION.



TEXAS INSTRUMENTS MODEL FOR ac OPERATION.

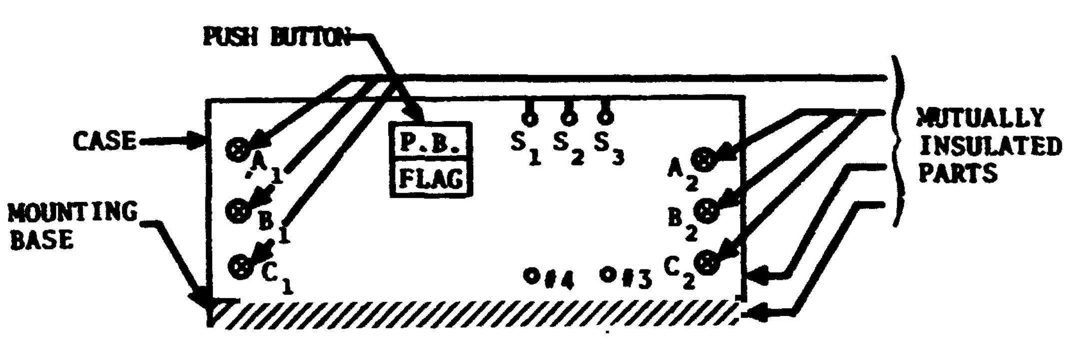


Figure 3. – Mutually insulated parts of RCCBs for insulation resistence and dielectric strength tests.

between the mutually insulated parts under application of 1500 V, 50 Hz (for C-H models) or 1250 V, 60 Hz (for T.I. models).

Following the vendors' instructions, terminals Nos. 3, 4, 5, 6, and A_1 of the C-H models were shorted together during both tests. The ac potential was not applied between the open contacts A_1 and A_2 of the T.I. dc models.

Contact voltage drop was measured between the line and the load terminals while passing the rated full-load current (ref. Table I). The test setups are shown in figures 1 and 2.

3.1.2 Operational characteristics.– Operational characteristics of the RCCB's include:

a. Performance of the main power switching, performance of the indicating terminals (S_1, S_2, and S_3) and of the FLAG and duration of shock-hazard before its elimination.

b. Effects of overloads and the extremes of line voltage upon the overall operation.

c. Specific features of Cutler-Hammer' and Texas Instruments' models.

All tests were performed using the test setups shown in figures 1 and 2.

The performance of the main power switching was tested by actuating the remote control switch while power was applied to the line terminal of the RCCB.

The operation of the indicating terminals S_1, S_2, and S_3 was checked with an ohmmeter attached alternately to S_1 and S_2, and to S_1 and S_3. (S_1, S_2, and S_3 are the three terminals of a SPDT switch with S_1 being the common terminal.)

The performance of the FLAG was checked by visual observation.

The shock hazard duration was measured with an electronic counter as follows:

1. The remote control switch was turned ON.
2. Power was disconnected from A_1.
3. The remote control switch was turned OFF.
4. Power was reconnected to A_1.

The counter was connected to count milliseconds from its internal clock for the period from step 4 until the RCCB automatically disconnected A_2 from A_1.

The overload tripping operation was tested by increasing the load current from rated full-load stepwise to 200, 138, or 115 percent. The tripping time was measured with an electronic counter connected to the individual loads. At the end of the 115-percent overload run, the temperature of the RCCB was measured at the line terminal of the particular sample. While testing T.I. ac models, the overloads were applied consecutively to three individual phases. Due to the limitation of the test facility, no overload tests could be performed on T.I. ac models rated for 35 amp per phase.

Again because of test facility limitations, the tests for effects of extreme line voltages were limited to dc. The test sample was turned ON and the line voltage was first reduced to the specified minimum (18 V for T.I. models, and 21 V for C-H models) and then increased to the specified maximum (30.5 volts for T.I. and 32 volts for C-H models). During both extremes, the operation of the main power switching and the duration of shock hazard were measured in the way explained above.

The operation of the Push-Button, a unique feature of T.I. models, was checked on its similarity with the action of a "momentary switch," and on its ability to eliminate the shock-hazard. In the first case the Push-Button was pulled up to interrupt the load current when the sample was turned ON by the remote control switch, or the Push-Button was pressed down to affect the flow of the load current when the sample was OFF. Elimination of the shock-hazard was tested as follows:

1. The remote control switch was turned ON.
2. Power was disconnected from the line terminal.
3. The remote control switch was turned OFF.
4. The Push-Button was pulled up.
5. Power was reconnected to the line terminal.

The duration, or presence, of shock-hazard was checked via an electronic counter connected to the load of the particular test sample, as described previously.

Operation of the Backup Power arrangement, available in C-H models, was tested by disconnecting the power source from terminal A_1 and attaching it to terminal No. 4. The remote control switch was then repeatedly actuated and the state of the main contacts was monitored by the FLAG indication and the indicating terminals S_1, S_2, and S_3. Elimination of the shock-hazard was tested as follows:

1. The remote control switch was turned ON.
2. Power was disconnected from terminal A_1.
3. The remote control switch was turned OFF.
4. Terminal No. 4 was attached to the power source for a few seconds.
5. Power was reconnected to terminal A_1.

Duration of the shock-hazard was measured in the same way as described previously.

The multiphase operation of the C-H models was tested with the setup shown in figure 1 by actuating the remote control switch and by increasing the individual phase loads stepwise from 100 to 200 percent. The individual phase loads were changed sequentially one after another, and the corresponding trip times were measured with the counter.

3.2 Qualification Tests

Facility and manpower availability procluded subjecting all 305 RCCB's to environmental exposure.

Twenty two samples were actually exposed to space simulation--altitude and temperature extremes combined.

Preliminary to this, four additional samples were subjected to an abbreviated temperature extreme cycling at ambient pressure to verify the basic temperature capabilities of the devices.

The same 22 units were exposed to acceleration.

Again because of resource limitations, the total number of RCCB's subjected to vibration was reduced to 10. Of these, three were subjected to a preliminary test to verify the basic mechanical integrety of the devices. The seven others were then subjected to the full duration cycling described below.

3.2.1 Space simulation test.— The test was performed with the setup shown in figure 4. The main contacts of one-half of the test samples were open and those of the other half were closed.

Twenty-two test samples were placed in the chamber which was evacuated to 3.8×10^{-5} Torr, equivalent to 360,000 ft altitude. The internal temperature of the chamber was kept constant for one hour at each of the following temperatures: -54° C, -34° C, +25° C, +74° C, and +84° C. During the -34° C and +74° C periods, the samples were subjected to remote ON/OFF switching, and during the +25° C period, a dielectric strength test was performed on the T.I. models at 500 V, 60 Hz in the way discussed for acceptance tests.

Measurements of contact voltage drop, of shock hazard duration, and of tripping time at 200 percent overload were made after Space Simulation testing.

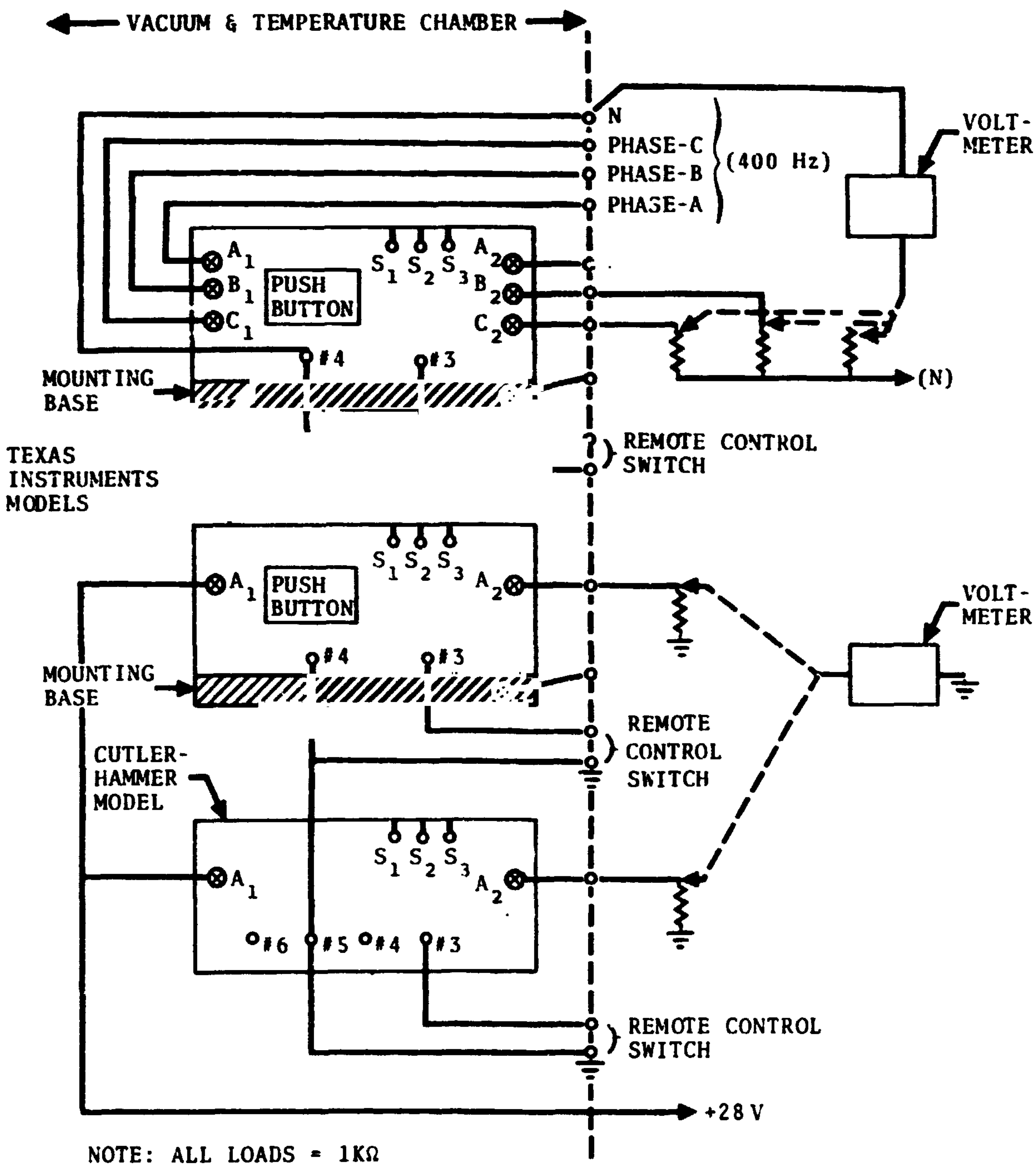


Figure 4. – Space simulation test setup (wiring diagram)

3.2.2 Acceleration test.— Twenty-two samples, wired as shown in figure 5, were accelerated in both directions along three mutually perpendicular axes. Acceleration of 22.5 G was applied to the RCCB's for 2 minutes with their contacts open and then for 2 minutes with their contacts closed.

The main contacts were controlled by the Push-Buttons in T.I. models and by remote control switches in C-H models. The testing was performed at room ambient conditions.

Contact chatter was monitored with a chatter detector (Discontinuity Time Monitor) during each test run.

Measurement of contact voltage drop, of shock hazard duration and of tripping time at 200 percent overload was made after conclusion of the acceleration test.

3.2.3 Vibration test.— Ten samples were subjected to random vibration with the following spectrum:

10 Hz at 3 mg^2/Hz

10 Hz – 24 Hz, increase @ 12 dB/octave

24 Hz – 160 Hz at 100 mg^2/Hz

160 Hz – 2000 Hz decrease @ 6 dB/octave

2000 Hz at 0.65 mg^2/Hz

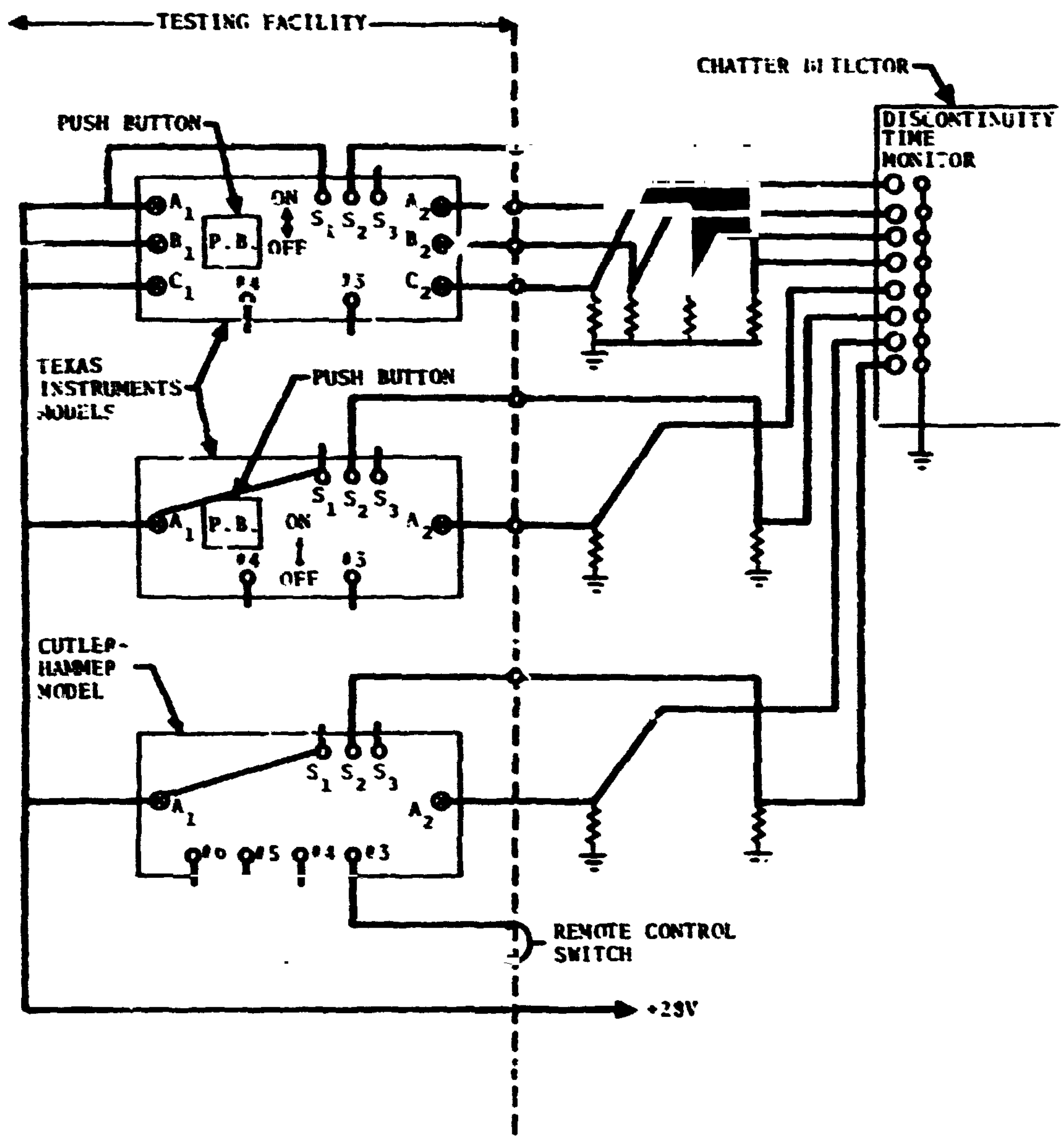
Overall level: 5.37 G rms per run. Vibration was applied along three mutually perpendicular axes as follows:

Test Run	Duration	Contacts	Sequence of Axis
1	2 min. 20 sec (2 Missions)	(closed)	X, Z, Y
2	5 min. 50 sec (5 Missions)	(closed)	Y, Z, X
3	5 min. 50 sec (5 Missions)	(open)	X, Y, Z
4	11 min. 40 sec (10 Missions)	(open)	Z, Y, X
5	35 min. 0 sec (30 Missions)	(closed)	X, Y, Z
6	58 min. 20 sec (50 Missions)	(closed)	Z, Y, X

The axes of the test samples are defined in figure 7. The test setups are shown in figures 5 (with closed contacts) and 6 (with open contacts). Testing was performed at room ambient conditions.

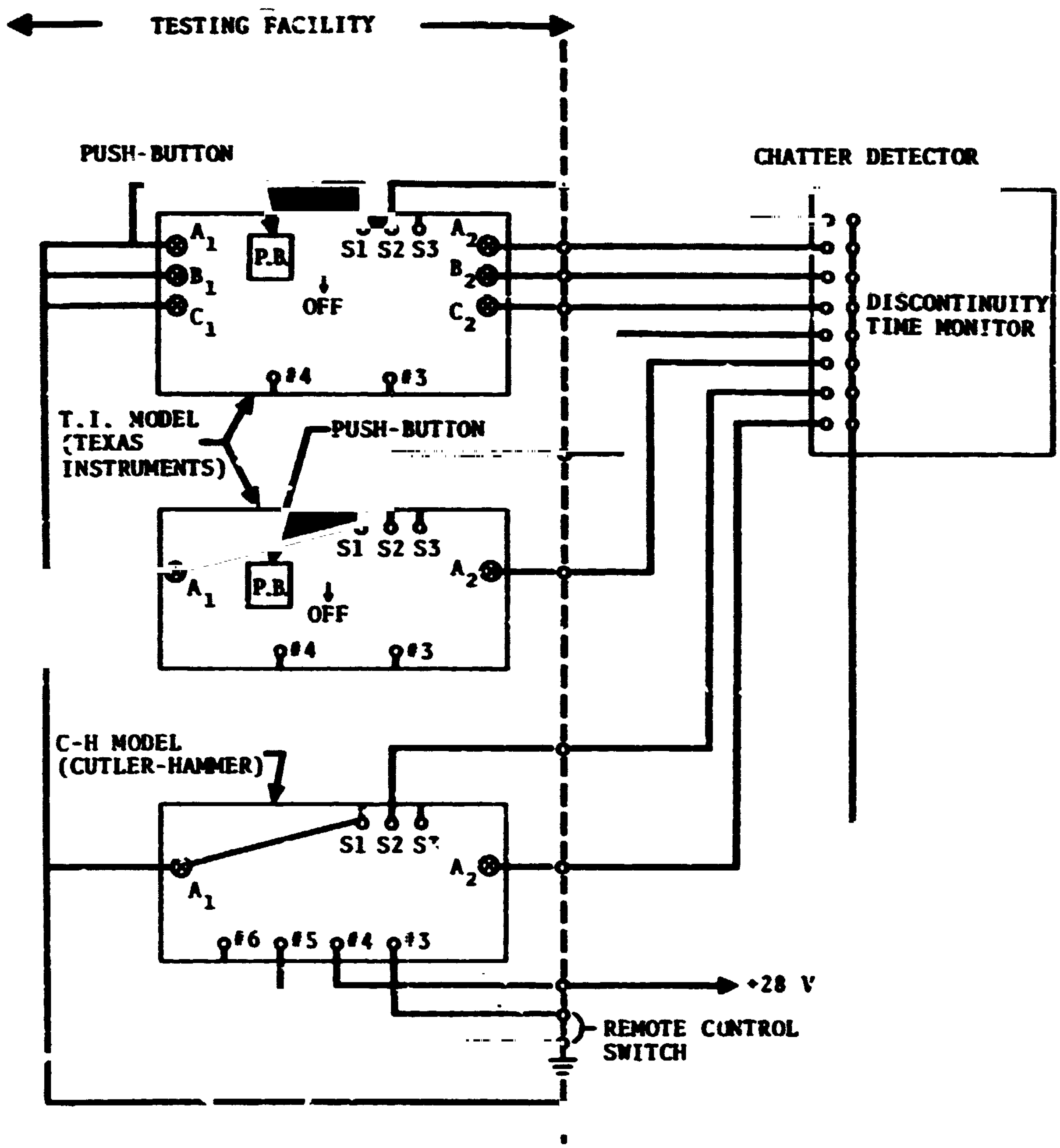
Chatter of the main contacts and of the indicating contacts, S_1 - S_2, was monitored with the chatter detector.

Measurement of contact voltage drop, of shock hazard duration and of tripping time at 200 percent overload was made after conclusion of the vibration test.



NOTE: ALL LOADS: 1 Kohm
CONTACT CHATTER MONITORING DEVICE WAS NOT USED FOR INDICATING TERMINALS S_1-S_2 DURING ACCELERATION TEST.
TEXAS INSTRUMENTS MODELS WERE CONTROLLED BY PUSH-BUTTON (P.B.) ONLY.

Figure 5. – Acceleration and vibration test setup (closed con cts; wiring diag. .



NOTE: T.I. MODEL CONTROLLED BY PUSH-BUTTON (P.B.) ONLY.
C-H MODELS CONTROLLED BY BACK-UP-POWER (#4 TERMINAL).

Figure 6. – Vibration test setup (open contacts; wiring diagram).

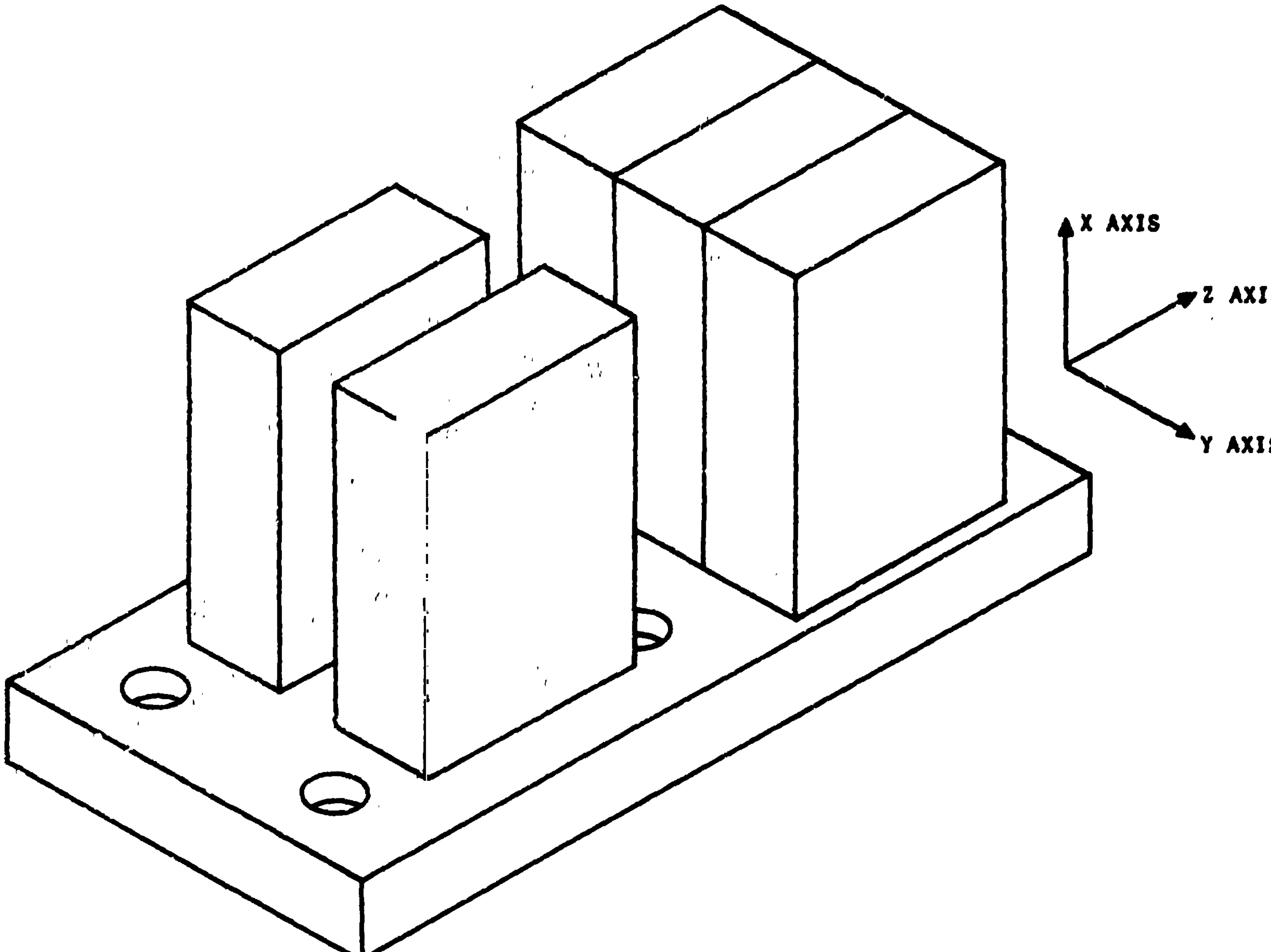


Figure 7. — Test samples - definition of axes for vibration test.

4.0 TEST RESULTS

The results of testing, performed in accordance with the test procedure outlined in the preceeding paragraph, are summarized in Table I. The test data sheets are in the appendix.

Of the 305 samples on which acceptance tests were performed, 82 did not meet the requirements specified by the vendor. Of those 82, seven samples failed; i.e., became totally inoperative.

Qualification testing was performed on 26 samples, three of which failed during, or as a result of, the environmental exposure.

The list of the failed samples in TABLE III shows the circumstances and symptoms of failures. No failure analysis has been performed.

4.1 Acceptance Tests

4.1.1 Electrical characteristics.— The insulation resistance is specified by the vendor to be a minimum of 50 (10^6) ohms when measured at 500 Vdc. The minimum insulation resistance was found to be 40 (10^9) ohms in the T. ac and C-H models and 1.4 (10^9) ohms in the T.I. dc models.

Dieleccric strength is defined by the vendors in terms of leakage current which is specified as 0.5 mA maximum at 1500 V rms, 60 Hz for C-H models or at 1250 V rms, 60 Hz

TABLE III. – RCCB – FAILURES DURING TESTING

Sample	Time/Cause	Symptoms/Effect
T.I. 7.5 ac; S/N 26887 (test #36; 12/9/72)	During 200 percent overload on phase A	Cracking sound and smoke; not operating thereafter.
C-H, S/N 8/5 (test #73; 1/17/73)	During 200 percent overload	Contact chatter; FLASH over when No. 4 terminal was used.
C-H, S/N 11/35 (test #137; 1/26/73)	During 138 percent overload (before 200 percent overload)	400 Hz emanates whenever turned ON with A_1, or No. 4 connected to power source.
T.I. 15 dc; S/N 29055 (test #167; 2/2/73)	After 115 percent overload (before 138 percent overload)	Main contacts OPEN/CLOSE randomly when external switch is used.
C-H, S/N 13/75 (test #215; 2/9/73)	Testing operational characteristics, external switch	400 Hz emanates whenever turned ON.
C-H, S/N 11/25 (test # 269; 2/16/73)	During shock hazard test when attempting to switch the unit	Contact voltage drop -10.0 volts.

TABLE III. – RCCB – FAILURES DURING TESTING (Concluded)

Sample	Time/Cause	Symptoms/Effect
T.I. 10 ac; S/N 26268 (test #30; 5/29/73)	During Space Simulation Test at -34° C	Could not be switched externally during and after testing.
T.I. 10 ac; S/N 26317 (test #31; 5/29/73)	During Space Simulation Test at -34° C	Could not be switched externally during and after testing.
T.I. 7 ac; S/N 30156 (test #301; 6/26/73)	After Vibration Testing.	During post test checking external switch did not operate.
T.I. 10 ac; S/N 26427 (test #31; 12/13/72)	After 200 percent overload	External switching does not work.

for T.I. models. T.I. dc models, exhibited 4 to 7 μA, and T.I. ac models 30 to 45 μA leakage current. C-H models had leakage current up to 78 μA. Three C-H samples exhibited an exponential increase of leakage current at 800 V, 60 Hz, and were defined as faulty.

The maximum contact voltate (CV) drop, specified in reference to current rating* of the samples, was not exceeded.

4.1.2 Operational characteristics.— The FLAG and remote indication (S_1, S_2, S_3 terminals) were found correct in all samples.

Remotely controlled switching did not operate properly in two T.I. dc models, which required a minimum load at the A_2 terminal before switching would occur. One C-H unit failed during ON/OFF switching of the rated load.

Shock hazard duration is specified, for Cutler-Hammer samples only, to be a maximum of 12 ms, which was met in all units. One sample failed in the course of this test. Shock hazard duration was 1 to 20 ms in T.I. dc and 35 to 45 ms in T.I. ac samples. It is not specified for Texas Instruments models. Shock hazard could be eliminated in

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*

RATING	SPECIFIED MAXIMUM CV DROP
5.0 amps	C-H: 0.50 V; T.I.: 0.45 V
7.5 amps	T.I.: 0.35 V
10.0 amps	C-H: 0.30 V; T.I.: 0.30 V
above 10.0 amps	C-H: 0.20 V; T.I.: 0.25 V

the T.I. models by operating the Push-Button and in the C-H models by utilizing the Back-up Power arrangement (terminal No. 4)

Vendor-specified line voltage extremes are 18-30.5 Vdc and 95-130 V rms, 400 Hz for T.I. models and 21-32 Vdc and 104-122 V rms, 400 Hz for C-H models. Limitations of the test facility dictated that the RCCB's be tested under extremes of only the dc line voltage. The vendors' specifications were met by all samples except one T.I. dc unit which could not be controlled remotely when the line voltage was 19 volts.

Vendor specifications for overload operation are in terms of tripping time and temperature of the RCCB. At 115 percent overload, the RCCB should not trip within 60 minutes and its temperature should not exceed 75° C. At 138 percent overload, the units should trip within 60 minutes. At 200 percent overload the specified tripping time depends on load rating of the unit as follows:

Rating	Specified Tripping Time
5.0 amps	C-H unit: 7-40 sec; T.I. unit: *
7.5 amps	C-H unit: * ; T.I. unit: 40 sec max
10.0 amps	C-H unit: 12-42 sec; T.I. unit: 42 sec max
15.0 amps	C-H unit: * ; T.I. unit: 55 sec max
20.0 amps	C-H unit: 14-47 sec; T.I. unit: *
25.0 amps	C-H unit: 15-55 sec; T.I. unit: *

*Not available for testing.

Rating	Specified Tripping Time
35.0 amps	C-H unit: 15-55 sec: T.I. unit: 65 sec max
50.0 amps	C-H unit: 13-55 sec; T.I. unit: 65 sec max
75.0 amps	C-H unit: 13-60 sec: T.I. unit: *
100.0 amps	C-H unit: 17-62 sec; T.I. unit: *

In the course of testing:

- One C-H sample exceeded the specified maximum tripping time at 200 percent overload, while one C-H and two T.I. ac units failed during this test.
- Four C-H and eight T.I. units did not trip within 60 minutes at 138 percent overload, and one C-H sample failed in course of this test.
- Eleven C-H and two T.I. units tripped within 60 minutes at 115 percent overload, and one T.I. sample became inoperative after this test.
- Twenty-six C-H and 16 T.I. samples (of 50 amps and higher current rating) exceeded the temperature limitation at 115 percent overload.

When T.I. ac samples (3 phase) were tested by overloading one phase while the other two phases were not loaded (passing no current), the samples tripped as specified. When the two other phases were carrying 100-percent rated loads, overloading of the third phase (200 or 138 percent overload)

*Not available for testing.

caused, in most cases, a tripping off of the over-loaded phase only. This could cause severe problems during actual use of the units.

Operation of the Push-Button in T.I. models, and of the Back-Up Power feature (applications of No. 4 terminal) in C-H models was found within the vendors' specifications.

Cutler-Hammer models were wired for 3 phase operation and their performance was as specified, i.e., with two phases unloaded, overloading of third phase caused tripping off of all three units. It was noticed, as in the case of T.I. ac models, that when the two other phases were carrying normal loads, an overloading of the third phase resulted, in most cases, in tripping off of only the overloaded phase.

4.2 Qualification Tests

4.2.1 Space simulation test.– Prior to the space simulation test, two C-H and two T.I. samples were subjected for 3 hours to +80° C temperature at normal atmospheric pressure to explore any detrimental effects upon the RCCB. Checks of contact voltage drop, shock hazard duration, and tripping time at 200 percent overload, performed after completion of this test, did not reveal any changes in the characteristics of the test samples.

Twenty-two samples were subjected to space simulation, following the procedure outlined in paragraph 3.2.1. Failure of two T.I. units was noticed when remotely controlled switching could not be performed at -34° C. Also, these units could not be switched remotely after completion of test. Measurement of contact voltage drop, shock hazard duration and tripping time at 200 percent overload on the remaining units thereafter did not show any changes in their characteristics.

4.2.2 Acceleration test.— Twenty-two test samples subjected to acceleration, following the procedure outlined in paragraph 3.2.2, did not exhibit any contact chatter.

No changes in their characteristics were detected in the course of after-test measurement of contact voltage drop, shock hazard duration and tripping time at 200 percent overload.

4.2.3 Vibration test.— Seven samples were subjected to vibration, following the procedure outlined in paragraph 3.2.3, and three units were subjected to preliminary test runs to explore any detrimental effects of this type of vibration upon the RCCB's.

The contact chatter observed during the initial part of testing was found to be caused by faulty cabling and improper test wiring. Both were corrected and testing was resumed.

In general, most contact chatter occurred when the samples were vibrated along the Y-axis (ref. to fig. 7). The chatter was either reduced and/or disappeared during the subsequent vibration along the other axes, or it was sustained and/or enhanced, especially during the long test runs, suggesting a deterioration of the sample's performance.

As can be seen from Table IV, showing the vibration test results in detail, three units (out of 10) did not exhibit any contact chatter. Two units exhibited contact chatter once during the 50-mission run (Y-axis), and one sample showed contact chatter twice during the 30-mission run (Z-axis).

Two T.I. dc samples exhibited repeated contact chatter during the 50-mission run along the Y-axis, while their indicating contacts exhibited chatter also during the 30-mission run along the Y-axis.

In one T.I. ac unit (3-phase) contact chatter was observed during the 50-mission run, but only in two phases. Indicating contacts were not monitored in this unit (preliminary test runs).

In other T.I. ac samples, contact chatter (phase c) started during the 30-mission run when it was vibrated along the Y and X axes and prevailed until the end of vibration exposure.

During after-test measurement of contact-voltage drop, shock hazard duration and tripping time at 200 percent overload, only one sample showed any changes in characteristics. One T.I. ac unit (S/N 30156) could not be controlled remotely and was defined as faulty.

TABLE IV. – RCCB - VIBRATION TEST RESULTS (CONTACT CHATTER)

MISSIONS PER TEST RUN (1)		2				5				5				10				30				50			
		(2)	(3)			(2)	(3)			(2)	(3)			(2)	(3)			(2)	(3)			(2)	(3)		
SEQUENCE OF AXIS DURING TEST RUN			X	Y	Z		Z	Y	Y		Z	Y	X		Z	Y	X		X	Y	Z		Z	Y	X
CUTLER-HAMMER 10 AMP S/N 11/10	CONTACTS:	CLOSED				CLOSED				CLOSED				CLOSED				OPEN				CLOSED			
	INDICATING		-	-	-		-	-	-		-	-	-		-	-	-		-	-	-		-	-	-
	MAIN: A_1-A_2		-	-	-		-	-	-		-	0	0		0	0	0		0	0	2		0	0	0
TEXAS INSTRUMENTS 10 AMP DC S/N 29432	CONTACTS:	CLOSED				CLOSED				CLOSED				CLOSED				OPEN				CLOSED			
	INDICATING		-	-	-		-	-	-		-	-	-		-	-	-		-	-	-		-	-	-
	MAIN: A_1-A_2		-	-	-		-	-	-		-	0	0		0	0	0		0	0	0		0	0	0
TEXAS INSTRUMENTS 7 AMP AC S/N 30156	CONTACTS:	CLOSED				CLOSED				CLOSED				CLOSED				OPEN				CLOSED			
	INDICATING		-	-	-		-	-	-		-	-	-		-	-	-		-	-	-		-	-	-
	MAIN: A_1-A_2		-	-	-		-	-	-		-	0	0		0	2.	0		0	0	0		0	0	0
	MAIN: B_1-B_2		-	-	-		-	-	-		-	0	0		0	0	0		0	0	0		0	CC	CC
	MAIN: C_1-C_2		-	-	-		-	-	-		-	0	0		0	0	0		0	0	0		0	0	CC
CUTLER-HAMMER 25 AMP S/N 2/25	CONTACTS:	CLOSED				CLOSED				OPEN				OPEN				CLOSED				CLOSED			
	INDICATING: S_1-S_2		0	C			0	0	0		0	0	0		0	0	0		0	0	0		0	0	0
	MAIN: A_1-A_2		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0
CUTLER-HAMMER 50 AMP S/N 19/50	CONTACTS:	CLOSED				CLOSED				OPEN				OPEN				CLOSED				CLOSED			
	INDICATING: S_1-S_2		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	1	0
	MAIN: A_1-A_2		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	1	0
CUTLER-HAMMER 75 AMP S/N 14/75	CONTACTS:	CLOSED				CLOSED				OPEN				OPEN				CLOSED				CLOSED			
	INDICATING: S_1-S_2		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0
	MAIN: A_1-A_2		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0
CUTLER-HAMMER 100 AMP S/N 11/100	CONTACTS:	CLOSED				CLOSED				OPEN				OPEN				CLOSED				CLOSED			
	INDICATING: S_1-S_2		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0
	MAIN: A_1-A_2		0	0	0		0	0	0		0	0	0		0	0	0		0	0	0		0	1	0
TEXAS INSTRUMENTS 50 AMP DC S/N 29017	CONTACTS:	CLOSED	(V)			CLOSED				OPEN		(V)	(V)	OPEN		(V)	(V)	CLOSED				CLOSED			
	INDICATING: S_1-S_2		[13]	0	0		0	0	0		0	0	0		0	0	0		0	8	0		0	180	0
	MAIN: A_1-A_2		0	0	0		0	0	4		0	[85]	[3]		0	[13]	[1]		0	0	0		0	4	0
TEXAS INSTRUMENTS 50 AMP DC S/N 29237	CONTACTS:	CLOSED				CLOSED				OPEN	(V)			OPEN				CLOSED				CLOSED			
	INDICATING: S_1-S_2		0	20.	0		0	62.	0		0	0	0		0	0	0		0	CC	20		146	CC	0
	MAIN: A_1-A_2		0	0	0		2	0	0		[44]	0	0		0	0	0		0	0	0		0	14	0
TEXAS INSTRUMENTS 35 AMP AC S/N 30034	CONTACTS:	CLOSED	(V)		(V)	CLOSED				OPEN				OPEN				CLOSED				CLOSED			
	INDICATING: S_1-S_2		0	5	0		0	0	0		0	0	0		0	0	C		0	CC	CC		CC	CC	CC
	MAIN: A_1-A_2		0	0	0		0	0	0		0	0	0		0	0	0		0	CC	CC		CC	CC	CC
	MAIN: B_1-B_2		[13]	0	[17]		97	0	1.		0	0	0		0	0	0		0	3	CC		CC	CC	(59)
	MAIN: C_1-C_2		0	0	0		0	0	0		0	0	0		0	0	0		0	0	59		CC		CC

PRELIMINARY TEST RUNS 6/26/73

NOTES:

(1) MISSION = 70 SEC.

(2) STATE OF CONTACTS

(3) FAILURE INDICATION: NUMBER OF TIMES CONTACT CHATTERS DETECTED

– CONTACT CHATTER NOT MONITORED.

CC CONTINUOUS CONTACT CHATTER

(V) (VOID) FAILURE

[x] INDICATION DUE TO FAULTY CABLE OR WRONG TEST SETUP.

(59) CONTACTS STUCK OPEN.

APPENDIX

TEST DATA

5.0 CONCLUSIONS AND RECOMMENDATIONS

Limitations on available manpower and facilities precluded the performance of sufficient tests to provide the basis for a firm conclusion as to the suitability or unsuitability of these Texas Instruments and Cutler-Hammer RCCB's for use on the Space Shuttle vehicle. A further barrier to making such a conclusion is the unavailability, at the time this report is being prepared, of firm specifications for the environmental requirements for the Space Shuttle vehicle. It is, therefore, recommended that no such conclusion be drawn until additional RCCB test data and Space Shuttle specifications are available.

APPENDIX

TEST DATA

APPENDIX — TEST DATA

RCCB-ACCEPTANCE TESTING (Notes)

Notes

1. All testing performed at room-ambient condition.
2. Insulation Resistance measured at 500 Vdc.
3. Dielectric Strength measured at 1250 V (60 Hz) for Texas Instrument's models, and at 1500 V (60 Hz) for Cutler-Hammer models.
4. Vendor's Instruction: No ac-potential to be applied between open contacts (A_1-A_2).
5. Test-unit did not trip-off within 3605 seconds.
6. OPERATIONAL CHARACTERISTICS:

   – Load Control Switch;

   – Trip free operation;

   – High-low line voltage:

Cutler-Hammer	– 122.	-	104.	V (400 Hz)
	32.	-	21.	V (dc)
Texas Instrument	– 130.	-	95.	V (400 Hz)
	30.5	-	18.	V (dc)

   – Auxiliary, or indicating terminals' operation;

   – Back-up power operation (Cutler-Hammer only);
   Push button operation (Texas Instrument only).
7. 10. amp.-load per phase.
8. High-low line voltage test not performed.

RCCB-ACCEPTANCE TESTING [1] (test data) 10-16-72

TEST #	Vendor	S/N	Rating	Insulation Res. Open Contacts [2]	Insulation Res. Insul'd Parts [2]	Dielectric Strength [3]	Contact V-Drop	Overload Operation 200% (Trip-off time)	Overload Operation 135% (Trip-off time)	Overload Operation 115% (Trip-off time)	Overload Operation Temp. at 115%	SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS [6]
			(Amp.)	(K M-OHM)		(μA)	(Volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
1	Cutl r -Har ver	2/50	50.	50.	50.	30.	0.18	12.6	42.	[5]	217	5.6	OK
2	"	3/50	50.	50.	50.	8.	0.15	10.1	47.	345.	(160)	5.2	OK
3	"	4/50	50.	50.	50.	9.	0.10	14.2	92.	[5]	202	5.4	OK
4	"	1/50	50.	50.	60.	12.	0.08	15.7	98.	[5]	180	4.6	OK
5	"	5/50	50.	60.	60.	9.	0.10	13.5	80.	[5]	195	5.3	OK
6	"	6/50	50.	50.	60.	9.	0.10	12.4	55.	[5]	199	5.0	OK
7	"	2/100	100.	40.	75.	13.	0.10	20.	48.	273	(126)	11.3	

RCCB-ACCEPTANCE TESTING [1] (test data) 10-30-72

TEST #	Vendor	S/N	Rating	Insulation Res. Open Contacts [2]	Insulation Res. Insul'd Parts [2]	Dielectric Strength [3]	Contact V-Drop	Overload Operation 200% (Trip-off time)	Overload Operation 138% (Trip-off time)	Overload Operation 115% (Trip-off time)	Overload Operation Temp. at 115%	SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS [6]
			(Amp.)	(K M-OHM)		(μA)	(Volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
8	Texas Instr.	29410	10. (dc)	4.0	75.	4. [4]	0.20	26.9	120.0	[5]	125.	5.5	OK
9	"	214-8	"	5.5	60.	4.5 [4]	0.18	21.1	95.0	[5]	122.	5.8	OK
10	"	29729	"	1.7	100.	4.5 [4]	0.18	28.	168.9	[5]	112.	5.0	OK
11	"	24322	"	2.0	75.	4. [4]	0.17	29.4	116.7	[5]	127.	5.8	OK
12	"	29929	"	4.0	75.	4. [4]	0.18	29.6	168.9	[5]	118.	5.6	OK
13	"	29309	"	2.3	100.	5. [4]	0.17	28.1	103.4	[5]	1.2.	5.6	OK
14	"	29928	"	2.5	100.	4.5 [4]	0.17	25.6	87.3	[5]	119.	5.5	OK

RCCB-ACCEPTANCE TESTING [1] (test data) 11-28-72

TEST #	Vendor	S/N	Rating	Insulation Res. Open Contacts [2]	Insulation Res. Insul'd Parts [2]	Dielectric Strength [3]	Contact V-Drop	Overload Operation 200% (Trip-off time)	Overload Operation 138% (Trip-off time)	Overload Operation 115% (Trip-off time)	Overload Operation Temp. at 115%	SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS [6]
			(Amp.)	(K M-OHM)	(K M-OHM)	(μA)	(Volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
15	Texas Instr.	25345	15. (dc)	2.0	100.	3. [4]	0.15	30.0	154.5	[5]	133.	5.5	OK
16	"	25343	"	4.0	75.	4. [4]	0.13	32.5	180.5	[5]	118.	5.5	OK
17	"	25344	"	1.4	60.	4.5 [4]	0.14	33.8	234.3	[5]	130.	5.1	OK
18	"	26245	50. (dc)	3.0	100.	4.5 [4]	0.13	57.0	[5]	[5]	183.	1.2	OK
19	"	26237	"	7.0	60.	4.5 [4]	0.10	47.3	[5]	[5]	174.	1.1	OK
20	"	26360	"	5.0	75.	4.5 [4]	0.08	43.0	855.9	[5]	205.	1.2	OK
21	"	26258	"	3.0	100.	4.0 [4]	0.08	45.2	712.8	[5]	195	0.9	OK

RCCB-ACCEPTANCE TESTING [1] (test data) 11-28-72

TEST #	Vendor	S/N	Rating	Insulation Res. Open Contacts [2]	Insulation Res. Insul'd Parts [2]	Dielectric Strength [3]	Contact V-Drop	Overload Operation (Trip-off time) 200%	Overload Operation 135%	Overload Operation 115%	Overload Operation Temp. at 115%	SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS [6]
			(Amp.)	(K M-OHM)		(μA)	( )	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
22	Texas Instr.	26248	50.	1.2	100.	4.5	0.08	116.6	[5]	[5]	195	1.2	OK
			(dc)			[4]							
23	"	26034	35.ph A	100.	90.	30.	0.12	Not Tested [7]				45.	OK [8]
		-35	(ac)ph B	60.	90.	45.	0.09					45.	
		-36	ph C	45.	100.	50.	0.12					45.	
24	"	-043	"	100.	90.	42.	0.14	Not Tested [7]				40.	OK [8]
		-44		45.	90.	35.	0.10					40.	
		-45		50.	90.	40.	0.09					40.	
25	"	27441	"	75.	100.	30.	0.11	Not Tested [7]				43.	OK [8]
		-42		75.	75.	45.	0.13					45.	
		-43		75.	75.	36.	0.32					41	
26	"	27438	"	75.	75.	34.	0.09	Not Tested [7]				44.	OK [8]
		-39		75.	75.	38.	0.07					44.	
		-40		60.	90.	46.	0.07					44.	
27	"	26989	10.ph A	90.	60.	35.	0.32	35.	136.	[5]	121	44.	OK [8]
		-90	(ac)ph B	75.	60.	35.	0.25	23.	119.	[5]	121	44.	
		-91	ph C	50.	50.	35.	0.25	27.	115.	[5]	121	44.	
28	"	26318	"	75.	90.	38.	0.21	28	124.	[5]	110	40.	OK [8]
		-19		75.	100.	46.	0.21	32.	476.	[5]	110	40.	
		-20		75.	75.	44.	0.21	27.	208.	[5]	115	45.	

RCCB-ACCEPTANCE TESTING [1] (test data) 12-13-72

TEST #	Vendor	S/N	Rating	Insulation Res. Open Contacts [2]	Insulation Res. Insul'd Parts [2]	Dielectric Strength [3]	Contact V-Drop	Overload Operation (Trip-off time) 200%	138%	115%	Temp. at 115%	S. 'K HAZARD (time-delay)	OPERATIONAL CHARACTERISTICS [6]
			(Amp.)	(K M-OHM)		'μA)	(Volt)	(msc.)	(sec.)	(sec.)	(°F)	(msec)	
29	Texas Instr.	26430	10.ph A	100.	100.	44.	0.25	27.	110	[5]	130	44.	OK [6]
		-31	(ac)ph B	90.	90.	37.	0.30	23.	100	[5]	25	44.	
		-32	ph C	75.	7..	35.	0.21	2..	125	[5]	130	43.	
30	"	26268	"	60.	100.	45.	0.25	29.	158	[5]	134	44.	OK [6]
		-69		50.	100.	30.	0.25	25.	116	[5]	132	44.	
		-70		50.	90.	37.	0.25	28.	157	[5]	132	44.	
31	"	26315	"	35.	90.	43.	0.28	30.	[3]	[5]	127	44.	OK [6]
		-16		75.	90.	42.	0.23	24.	76	[5]	125	44.	
		-17		75.	90.	32.	0.21	28.	108	[5]	115	42.	
32	"	26427	"	50.	75.	33.	0.28	26.				43.	OK [6] Failed
		-28		60.	90.	37.	0.21	26.	Failed (see Table III)			44.	
		-29		60.	90.	43.	0.21	27.				44.	
33	"	26920	7.5 phA	60.	60.	38.	0.32	30.	134	[5]	118	44.	OK [6]
		-21	(ac)phB	75.	90.	34.	0.32	24.	94	[5]	118	43.	
		-22	phC	60.	90.	30.	0.32	25.	112	[5]	118	42.	
34	"	26887	"	50.	75.	39.	0.35	27.				58.	OK [6] Failed
		-88		50.	90.	39.	0.33		Failed (see Table III)			60.	
		-89		50.	100.	47.	0.32					60.	
35	"	26721	35.ph A	100.	75.	33.	0.10	Not Tested [7]				43.	OK [6]
		-22	(ac)ph B	75.	75.	36.	0.34					42.	
		-23	ph C	75.	75.	41.	0.09					43.	

RCCB-ACCEPTANCE TESTING [1] (test data)

12-20-72

TEST #	Vendor	S/N	Rating	Insulation Res. Open Contacts [2]	Insulation Res. Insul'd Parts [2]	Dielectric Strength [3]	Contact V-Drop	Overload Operation 200% (trip-off time)	Overload Operation 135% (trip-off time)	Overload Operation 115% (trip-off time)	Overload Operation Temp. at 115%	SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS [6]
			(Amp.)	(K M-OHM)	(K M-OHM)	(μA)	(Volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
36	Texas Instr.	27719	35 ph A	90.	75.	31.	0.07	Not Tested [7]				43.	OK [8]
		-20	(ac)ph B	75.	90.	37.	0.07					42.	
		-21	ph C	75.	90.	56.	0.04					43.	
37	"	26727	"	75.	100.	30.	0.09	Not Tested [7]				42.	OK [8]
		-28		60.	100.	87.	0.07					43.	
		-29		75.	100.	31.	0.04					40.	
38	"	27225	"	100.	75.	35.	0.09	Not Tested [7]				40.	OK [8]
		-26		100.	90.	39.	0.08					42.	
		-27		90.	90.	41.	0.07					43.	
39	Cutler Hammer	1/100	100.	50.	45.	11.	0.09	27.	72.	2387	(160)	10.2	OK
40	Texas Instr.	27399	15. (dc)	20.	90.	3.5 [4]	0.17	29.2	166.6	[5]	104	0.7	OK
41	"	27401	"	7.0	90.	4.5 [4]	0.17	27.4	83.9	[5]	104	0.6	OK
42	"	27394	"	3.5	7.5	4. [4]	0.15	28.6	122.7	[5]	107	0.6	OK

RCCB-ACCEPTANCE TESTING [1] (test data) 12-20-72

TEST #	Vendor	S/N	Rating	Insulation Res. Open Contacts [2]	Insulation Res. Insul'd Parts [2]	Dielectric Strength [3]	Contact V-Drop	Overload Operation 200% (Trip-off time)	Overload Operation 138% (Trip-off time)	Overload Operation 115% (Trip-off time)	Overload Operation Temp. at 115%	SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS [6]
			(Amp.)	(K M-OHM)		(μA)	(Volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
43	Texas Instr.	27398	15.	5.0	90.	5.	0.13	26.5	104.5		104.	0.5	OK
			(dc)			[4]				[5]			
44	"	27395	"	4.0	90.	4.5	0.15	27.0	130.8	[5]	110.	0.5	OK
						[4]							
45	"	28527	10 ph A	75.	100.	41.	0.18	30.0	134.	[5]	128.	43.	OK [8]
		-28	(ac)ph B	75.	100.	46.	0.18	28.0	268.	[5]	141.	40.	
		-29	ph C	75.	100.	41.	0.18	26.0	127.	[5]	135.	40.	
46	"	28536	"	75.	75.	35.	0.20	30.0	222.	[5]	131.	45.	OK [8]
		-37		60.	75.	43.	0.16	24.5	102.	[5]	131.	41.	
		-38		80.	60.	42.	0.16	25.0	109.	[5]	131.	41.	
47	"	28605	"	75.	80.	39.	0.18	24.0	118.	[5]	128.	43.	OK [8]
		-06		100.	80.	49.	0.16	27.0	148.	[5]	135.	43.	
		-07		100.	60.	39.	0.16	27.0	295.	[5]	130.	43.	
48	"	28647	"	90.	75.	39.	0.20	27.0	137.	[5]	130.	41.	OK [8]
		-48		90.	90.	44.	0.18	24.0	113.	[5]	130	41.	
		-49		60.	75.	45.	0.18	24.0	95.	[5]	128	41.	
49	"	28093	10	5.5	75.	5.	0.15	30.0	167	[5]	101	0.6	OK
			dc)			[4]							

RCCB-ACCEPTANCE TESTING [1] (test data) 1-16-73

TEST #	Vendor	S/N	Rating	Insulation Res. Open Contacts [2]	Insulation Res. Insul'd Parts [2]	Dielectric Strength [3]	Contact V-Drop	Overload Operation 200% (Trip-off time)	Overload Operation 138% (Trip-off time)	Overload Operation 115% (Trip-off time)	Overload Operation Temp. at 115%	SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS [6]
			(Amp.)	(K M-OHM)		(μA)	(Volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
50	Texas Instr.	28967	15.	4.5	75.	5.	0.15	32.0	256.	[5]	105	0.7	OK
			(dc)			[4]							
51	"	28968	"	4.8	80.	5.	0.17	27.0	469.	[5]	105	0.8	OK
						[4]							
52	"	28090	50.	4.3	90.	5.	0.10	44.4	1349.	[5]	145	50.9	OK
			(dc)			[4]							
53	"	28118	"	4.2	100.	5.	0.11	38.1	491.1	[5]	138	43.0	OK
						[4]							
54	"	28119	"	4.2	100.	5.	0.11	45.5	[5]	[5]	145	24.0	OK
						[4]							
55	Cutler-Hammer	7/50	50.	100.	100.	52.	0.1[illegible]	14.4	67.4	[5]	151	6.5	OK
56	"	8/50	50.	100.	100.	10.	0.10	15.5	78.0	[5]	141	5.7	OK

RCCB-ACCEPTANCE TESTING [1] (test data) 1-16-73

TEST #	Vendor	S/N	Rating	Insulation Res. Open Contacts [2]	Insulation Res. Insul'd Parts [2]	Dielectric Strength [3]	Contact V-Drop	Overload Operation 200%	Overload Operation 138%	Overload Operation 115%	Overload Operation Temp. at 115%	SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS [6]
								(Trip-off time)					
			(Amp.)	(K M-OHM)		(μA)	(Volt)	(msc.)	(sec.)	(sec.)	(°F)	(msec)	
57	Cutler-Hammer	9/50	50.	100.	100.	11.	0.11	15.1	72.	[5]	145	6.5	OK
58	"	1/5	5.	100.	100.	9.	0.34	31.0	[5]	[5]	109	5.0	OK
59	"	2/5	5.	75.	90.	9.	0.38	16.0	340.0	[5]	107	6.0	OK
60	"	3/5	5.	90.	75.	10.	0.38	20.0	2193.	[5]	107	6.5	OK
61	"	10/50	50.	90.	90.	20.	0.12	14.4	56.6	[5]	142	5.6	OK
62	"	11/50	50.	75.	65.	11.	0.12	12.5	70.7	[5]	143	7.2	OK
63	"	12/50	50.	75.	60.	35.	0.11	16.3	74.0	[5]	144	6.8	OK

RCCB-ACCEPTANCE TESTING [1] (test data)

TEST #	Vendor	S/N	Rating	Insulation Res. Open Contacts [2]	Insulation Res. Insul'd Parts [2]	Dielectric Strength [3]	Contact V-Drop	Overload Operation 200%	Overload Operation 138%	Overload Operation 115%	Overload Operation Temp. at 115%	SHOCK HAZARD (time-delay)	OPERATIONAL CHARACTERISTICS [6]
								(trip-off time)					
			(Amp.)	(K M OHM)		(kV)	(Volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
64	Cutler-Hammer	13/50	50.	90.	90.	37.	0.13	10.5	60.5	[5]	148	0.0	OK
65	"	14/50	50.	100.	90.	11.	0.13	14.4	51.2	[5]	142	0.5	OK
66	"	15/50	50.	75.	75.	[illegible]	0.14	13.0	59.3	[5]	152	4.0	OK
67	"	16/50	50.	100.	90.	27.	0.13	15.4	56.3	[5]	151	0.5	OK
68	"	4/5	5.	100.	90.	10.	0.39	21.0	315.0	[5]	105	0.9	OK
69	"	5/5	5.	95.	80	9.	0.33	18.0	150.0	[5]	108	[illegible]	OK
70	"	6/5	5.	90.	90.	9.	0.33	23.0	630.0	[5]	110	0.0	OK

RCCB-ACCEPTANCE TESTING [1] (test data) 1-17-73

TEST #	Vendor	S/N	Rating	Insulation Res. Open Contacts [2]	Insulation Res. Insul'd Parts [2]	Dielectric Strength [3]	Contact V-Drop	Overload Operation 200% (Trip-of. time)	Overload Operation 138% (Trip-of. time)	Overload Operation 115% (Trip-of. time)	Overload Operation Temp. at 115%	SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS [6]
			(Amp.)	(K M-OHM)		(μA)	(volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
71	Cutler-Hammer	7/5	5.	75.	75.	10.	0.40	23.5	[5]	[5]	103	7.5	OK
72	"	1/75	75.	90.	75.	12.	0.03	15.8	150 5	[5]	170	7.	OK
73	"	8/5	5.	75.	75.	10.	0.42	25.0	Failed (see Table III)			6.5	OK Failed
74	"	9/5	5.	100	100.	9.	0.39	16.0	40.0	[5]	106	7.5	OK
75	"	2/75	75.	90.	90.	48.	0.09	16.3	72.4	[5]	107	6.9	OK
76	"	11/5	5.	60.	60.	9.	0.39	14.0	118.0	[5]	106	5.5	OK
77	"	12/5	5.	75.	60.	9.	0.35	14.5	63.0	[5]	109	7.5	OK

RCCB-ACCEPTANCE TESTING $\boxed{1}$ (test data) 1-17-73

TEST #	Vendor	S/N	Rating	Insulation Res. Open Contacts $\boxed{2}$	Insulation Res. Insul'd Parts $\boxed{2}$	Dielectric Strength $\boxed{3}$	Contact V-Drop	Overload Operation 200% (Trip-off time)	Overload Operation 138% (Trip-off time)	Overload Operation 115% (Trip-off time)	Overload Operation Temp. 115%	SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS $\boxed{6}$
			(Amp.)	(K M-OHM)		(µA)	(Volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
78	Cutler-Hammer	13/5	5.	100.	100.	9.	0.35	20.5	380.0	$\boxed{5}$	106	7.5	OK
79	"	3/75	75.	100.	75.	74.	0.10	16.7	70.0	$\boxed{5}$	175.	6.2	OK
80	"	10/5	5.	75.	75.	9.	0.30	20.4	$\boxed{5}$	$\boxed{5}$	107	0.7	OK
81	"	1/10	10.	80.	80.	TRIP OFF AT 1000 V	0.25	17.0	80.0	$\boxed{5}$	117	8.	OK
82	"	2/10	10.	75.	75.	30.	0.27	24.5	160.0	$\boxed{5}$	117	6.9	OK
83	"	3/10	10.	75.	75.	31.	0.25	23.7	155.0	$\boxed{5}$	113	6.5	OK
84	"	4/75	75.	75.	75.	12.	0.11	21.3	298.6	$\boxed{5}$	175.	6.6	OK

RCCB-ACCEPTANCE TESTING $\boxed{1}$ (test data) 1-18-73

TEST #	Vendor	S/N	Rating	Insulation Res. Open Contacts $\boxed{2}$	Insulation Res. Insul'd Parts $\boxed{2}$	Dielectric Strength $\boxed{3}$	Contact V.-Drop	Overload Operation (Trip-off time) 200%	135%	115%	Temp. at 115%	SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS $\boxed{6}$
			(Amp.)	(K M-OHM)		(μA)	(Volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
85	Cutler-Hammer	4/10	10.	100.	100.	10.	0.25	18.2	108.4	$\boxed{5}$	107	7.5	OK
86	"	5/10	10.	100.	100.	9.	0.25	17.0	91.0	400.	(-)	7.0	OK
87	"	6/10	10.	75.	75.	27.	0.25	16.5	63.0	$\boxed{5}$	119	6.0	OK
88	"	7/10	10.	100.	90.	10.	0.25	20.5	140.0	$\boxed{5}$	119	7.0	OK
89	"	5/75	75.	60.	60.	11.	0.12	18.5	157.8	$\boxed{5}$	154	6.8	OK
90	"	6/75	75.	60.	40.	10.	0.11	19.0	220.7	$\boxed{5}$	157	6.9	OK
91	"	7/75	75.	75.	75.	25.	0.11	18.0	144.9	$\boxed{5}$	150	6.5	OK

RCCB-ACCEPTANCE TESTING $\boxed{1}$ (test date) 1-19-73

TEST #	Vendor	S/N	Rating	Insulation Res.		Dielectric Strength $\boxed{3}$	Contact V.-Drop	Overload Operation				SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS $\boxed{6}$
				Open Contacts $\boxed{2}$	Insul'd Parts $\boxed{2}$			200% (Trip-off time)	138% (Trip-off time)	115% (Trip-off time)	Temp. at 115%		
			(Amp.)	(K M-OHM)	(K M-OHM)	(μA)	(Volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
92	Cutler-Hammer	8/75	75.	60.	60.	30.	0.10	15.5	141.1	$\boxed{5}$	180	7.1	OK
93	"	1/20	20.	90.	90.	23.	0.12	17.6	69.6	$\boxed{5}$	111	5.2	OK
94	"	2/20	20.	90.	90.	25.	0.13	19.0	91.3	$\boxed{5}$	110	5.3	OK
95	"	3/20	20.	100.	90.	9.	0.14	17.9	86.1	$\boxed{5}$	114	4.9	OK
96	"	3/100	100.	100.	75.	11.	0.10	27.2	115.6	$\boxed{5}$	165	5.9	OK
97	"	4/100	100.	90.	75.	12.	0.39	26.6	288.4	$\boxed{5}$	163	5.6	OK
98	"	4/20	20.	80.	80.	22.	0.13	15.1	98.1	$\boxed{5}$	120	5.1	OK

RCCB-ACCEPTANCE TESTING [1] (test data) 1-22-73

TEST #	Vendor	S/N	Rating	Insulation Res. Open Contacts [2]	Insulation Res. Insul'd Parts [2]	Dielectric Strength [3]	Contact V-Drop	Overload Operation 200% (Trip-off time)	Overload Operation 135% (Trip-off time)	Overload Operation 115% (Trip-off time)	Overload Operation Temp. at 115%	SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS [6]
			(Amp.)	(K M-OHM)	(K M-OHM)	(μA)	(Volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
99	Cutler-Hammer	5/20	20.	60.	60.	50.	0.20	20.2	734.3	[5]	105	5.2	OK
100	"	5/100	100.	50.	50.	12.	0.11	27.3	196.3	[5]	163	6.0	OK
101	"	6/100	100.	80.	80.	13.	0.11	17.9	93.6	[5]	169	5.6	OK
102	"	6/20	20.	90.	90.	27.	0.13	19.3	57.0	[5]	109	5.4	OK
103	"	7/20	20.	90.	80.	10.	0.10	18.1	52.0	[5]	102	5.3	OK
104	"	[illegible]	100.	80.	5.	11.	0.11	20.0	287.4	[5]	173	5.6	OK
105	"	8/20	20.	75.	75.	24.	0.13	21.1	58.8	[5]	110	5.2	OK

RCCB-ACCEPTANCE TESTING [1] (test data)

TEST #	Vendor	S/N	Rating	Insulation Res. Open Contacts [2]	Insulation Res. Insul'd Parts [2]	Dielectric Strength [3]	Contact V.-Drop	Overload Operation 200% (Trip-off time)	Overload Operation 135% (Trip-off time)	Overload Operation 115% (Trip-off time)	Overload Operation Temp. at 115%	SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS [6]
			(Amp.)	(K M-OHM)	(K M-OHM)	(μA)	(Volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
106	Cutler-Hammer	9/20	20.	80.	80.	30.	0.17	22.6	1502.0	[5]	115	5.0	OK
107	"	10/20	20.	100.	75.	10.	0.13	17.0	56.8	[5]	104	5.5	OK
108	"	8/100	100.	80.	80.	11.	0.09	24.8	305.8	[5]	186	5.5	OK
109	"	9/100	100.	100.	75.	11.	0.11	29.6	425.7	[5]	175	5.4	OK
110	"	11/20	20.	75.	75.	TRIP OFF AT 1000 V	0.12	19.3	79.3	[5]	110	5.0	OK
111	"	10/100	100.	100.	80.	10.	0.12	24.1	120.0	[2]	177	5.2	OK
112	"	11/100	100.	100.	100.	11.	0.11	24.2	157.8	[5]	181	5.9	OK

RCCB-ACCEPTANCE TESTING $\boxed{1}$ (test data) 1-22-73

TEST #	Vendor	S/N	Rating	Insulation Res. Open Contacts $\boxed{2}$	Insulation Res. Insul'd Parts $\boxed{2}$	Dielectric Strength $\boxed{3}$	Contact V-Drop	Overload Operation 200% (Trip-off time)	Overload Operation 138% (Trip-off time)	Overload Operation 115% (Trip-off time)	Temp. at 115%	SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS $\boxed{6}$
			(Amp.)	(K M-OHM)		(µA)	(Volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
113	Cutler-Hammer	13/100	100.	80.	80.	24.	0.15	23.8	812.6	$\boxed{5}$	188	5.5	OK
114	"	1/25	25.	100.	90.	10.	0.10	18.9	460.5	$\boxed{5}$	115	5.7	OK
115	"	2/25	25.	75.	80.	10.	0.13	18.7	67.4	335.	(110)	5.2	OK
116	"	12/100	100.	80.	75.	16.	0.10	16.5	179.8	$\boxed{5}$	185	6.4	OK
117	"	14/100	100.	60.	75.	11.	0.11	29.3	1500.	$\boxed{5}$	187	5.9	OK
118	"	15/100	100.	100.	75.	11.	0.11	19.9	177.5	$\boxed{5}$	192	5.5	OK
119	"	3/25	25.	100.	75.	27.	0.17	16.5	60.4	$\boxed{5}$	126	5.0	OK

RCCB-ACCEPTANCE TESTING $\boxed{1}$ (test data) 1-24-73

TEST† #	Vendor	S/N	Rating	Insulation Res. Open Contacts $\boxed{2}$	Insulation Res. Insul'd Parts $\boxed{2}$	Dielectric Strength $\boxed{3}$	Contact V-Drop	Overload Operation 200% (Trip-off time)	Overload Operation 138% (Trip-off time)	Overload Operation 115% (Trip-off time)	Overload Operation Temp. at 115%	SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS $\boxed{6}$
			(Amp.)	(K M-OHM)		(μA)	(Volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
120	Cutler-Hammer	4/25	25.	75.	40.	10.	0.13	19.6	57.1	$\boxed{5}$	120	5.2	OK
121	"	5/25	25.	80.	75.	10.	0.13	18.2	56.8	$\boxed{5}$	122	5.2	OK
122	"	6/25	25.	60.	75	10.	0.15	17.1	56.0	$\boxed{5}$	112	4.9	OK
123	"	7/25	25.	75.	75.	11.	0.13	18.0	54.6	$\boxed{5}$	117	4.7	OK
124	"	8/25	25.	90.	80.	72.	0.14	18.0	76.2	$\boxed{5}$	124	5.1	OK
125	"	9/25	25.	80.	75.	10.	0.12	17.7	72.3	$\boxed{5}$	115	5.3	OK
126	"	10/25	25.	50.	75.	11.	0.13	19.6	73.8	$\boxed{5}$	117	4.8	OK

RCCB-ACCEPTANCE TESTING $\boxed{1}$ (test data) 1-24-73

TEST #	Vendor	S/N	Rating	Insulation Res. Open Contacts $\boxed{2}$	Insulation Res. Insul'd Parts $\boxed{2}$	Dielectric Strength $\boxed{3}$	Contact V-Drop	Overload Operation 200% (Trip-off time)	Overload Operation 138% (Trip-off time)	Overload Operation 115% (Trip-off time)	Overload Operation Temp. at 115%	SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS $\boxed{6}$
			(Amp.)	(K M-OHM)		(μA)	(Volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
127	Cutler -Hammer	1/35	35.	90.	100.	37.	0.11	20.5	82.7	$\boxed{5}$	138	5.2	OK
128	"	2/35	35.	75.	80.	11.	0.13	21.3	84.4	$\boxed{5}$	142	5.1	OK
129	"	3/35	35.	80.	90.	47.	0.14	22.0	66.5	$\boxed{5}$	141	5.0	OK
130	"	4/35	35.	80.	80.	10.	0.11	20.7	88.9	$\boxed{5}$	139	5.4	OK
131	"	5/35	35.	75.	80.	21.	0.17	16.7	81.7	$\boxed{5}$	142	5.5	OK
132	"	6/35	35.	100.	90.	25.	0.10	21.4	94.2	$\boxed{5}$	145	5.2	OK
133	"	7/35	35.	60.	60.	28.	0.12	21.5	82.9	$\boxed{5}$	137	5.3	OK

RCCB-ACCEPTANCE TESTING [1] (test data) 1-26-73

TEST #	Vendor	S/N	Rating	Insulation Res. Open Contacts [2]	Insulation Res. Insul'd Parts [2]	Dielectric Strength [3]	Contact V-Drop	Overload Operation 200% (Trip-off time)	Overload Operation 138% (Trip-off time)	Overload Operation 115% (Trip-off time)	Overload Operation Temp. at 115%	SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS [6]
			(Amp.)	(K M-OHM)		(μA)	(Volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
134	Cutler-Hammer	8/35	35.	100.	100.	27.	0.11	19.6	65.6	[5]	136	4.9	OK
135	"	9/35	35.	80.	100.	22.	0.11	19.3	74.3	[5]	135	5.0	OK
136	"	10/35	35.	80.	100.	17.	0.11	17.4	50.4	[5]	125	4.8	OK
137	"	11/35	35.	100.	80.	41.	Failed (see Table III)			[5]	128.	Failed	OK Failed
138	Texas Instr.	29018	50. (dc)	6.0	100.	6. [4]	0.15	38.6	553.1	[5]	179	20.7	OK
139	"	29019	"	9.0	80.	5. [4]	0.13	46.3	2906.3	[5]	300	19.0	OK
140	"	29020	"	6.0	60.	5. [4]	0.13	38.9	771.8	[5]	160	21.4	OK

RCCB-ACCEPTANCE TESTING [1] (test data) 1-29-73

TEST #	Vendor	S/N	Rating	Insulation Res. Open Contacts [2]	Insulation Res. Insul'd Parts [2]	Dielectric Strength [3]	Contact V-Drop	Overload Operation 200% (Trip-off time)	Overload Operation 138% (Trip-off time)	Overload Operation 115% (Trip-off time)	Overload Operation Temp. at 115%	SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERIGTICS [6]
			(Amp.)	(K M-OHM)		(μA)	(Volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
141	Texas Instr.	29021	50. (dc)	8.0	75.	5. [4]	0.16	37.7	833.4	[5]	235	22.5	OK
142	"	29022	"	10.0	15.	5. [4]	0.16	38.1	390.0	[5]	260	19.6	OK
143	"	29023	"	1.45	20.	4. [4]	0.10	45.2	1277.0	[5]	218	23.5	OK
144	"	29024	"	9.0	15.	5. [4]	0.15	37.9	408.0	[5]	300	20.5	OK
145	"	29010	15. (dc)	6.0	75.	5. [4]	0.17	29.0	543.0	[5]	110	18.5	OK
146	"	29011	"	8.0	100.	5.5 [4]	0.15	33.8	372.8	[5]	137	20.4	OK
147	"	29012	"	5.5	60.	5. [4]	0.18	26.	110.0	[5]	150	18.1	OK

RCCB-ACCEPTANCE TESTING [1] (test data) 1-29-73

TEST #	Vendor	S/N	Rating	Insulation Res. Open Contacts [2]	Insulation Res. Insul'd Parts [2]	Dielectric Strength [3]	Contact V-Drop	Overload Operation (Trip-off time) 200%	138%	115%	Temp. at 115%	SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS [6]
			(Amp.)	(K M-OHM)		(uA)	(Volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
148	Texas Instr.	29013	15. (dc)	3.5	60.	5. [4]	0.17	29.0	205.	[5]	135	18.5	OK
149	"	29014	"	9.0	90.	5. [4]	0.17	22.1	177.5	[5]	112	22.5	OK
150	"	29015	"	3.5	100.	5. [4]	0.15	24.4	113.9	[5]	117	19.9	OK
151	"	29017	50. (dc)	4.5	75.	4. [4]	0.13	44.2	2320.	[5]	160	20.8	OK
152	"	28963	"	1.6	100.	5. [4]	0.14	46.3	[5]	[5]	172	21.4	OK
153	"	28965	"	0.5	100.	5. [4]	0.11	30.4	700	[5]	212	20.8	OK
154	"	29319	"	2.7	60.	5. [4]	0.13	41.0	838.0	[5]	179	21.6	OK

RCCB-ACCEPTANCE TESTING [1] (test data) 1-30-73

TEST #	Vendor	S/N	Rating	Insulation Res. Open Contacts [2]	Insulation Res. Insul'd Parts [2]	Dielectric Strength [3]	Contact V-Drop	Overload Operation (Trip-off time) 200%	Overload Operation (Trip-off time) 138%	Overload Operation (Trip-off time) 115%	Overload Operation Temp. at 115%	SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS [6]
			(Amp.)	(K M-OHM)		(µA)	(Volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
155	Texas Instr.	29061	50.	1.4	75.	5.5	0.16	39.2	770.0	[5]	295	1.3	OK
			(dc)			[4]							
156	"	29067	"	9.0	100.	5.	0.11	31.7	715.8	[5]	172	18.3	OK
						[4]							
157	"	29235	"	6.0	100.	5.	0.13	40.4	2106.0	[5]	185	19.6	OK
						[4]							
158	"	29236	"	9.5	75.	5.	0.14	36.4	960.0	[5]	252	21.9	OK
						[4]							
159	"	29237	"	2.5	80.	5.	0.11	46.2	3300.0	[5]	300	21.9	OK
						[4]							
160	"	29296	"	2.7	100.	5.	0.11	39.3	923.0	[5]	180	20.9	OK
						[4]							
161	"	29000	15.	5.5	100.	5.	0.18	30.6	135.8	[5]	112	18.8	OK
			(dc)			[4]							

RCCB-ACCEPTANCE TESTING [1] (test data) 1-31-73

TEST #	Vendor	S/N	Rating	Insulation Res. Open Contacts [2]	Insulation Res. Insul'd Parts [2]	Dielectric Strength [3]	Contact V-Drop	Overload Operation 200%	Overload Operation 135%	Overload Operation 115%	Temp. at 115%	SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS [6]
								(Trip-off time)					
			(Amp.)	(K M-OHM)		(μA)	(Volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
162	Texas Instr.	29006	15. (dc)	3.5	100	5. [4]	0.16	31.5	716.3	[5]	125	23.2	OK
163	"	29050	"	[illegible]	75.	5. [4]	0.15	28.6	125.0	[5]	107	22.1	OK
164	"	29051	"	7.0	75.	5. [4]	0.17	28.1	148.9	[5]	130	20.3	OK
165	"	29052	"	6.0	90.	5. [4]	0.14	25.6	87.1	[5]	110	19.8	OK
166	"	29054	"	20.0	8[illegible].	5. [4]	0.15	29.1	156.2	[5]	124	19.9	OK
167	"	29055	"	[illegible]	100.	5. [4]	0.17	Failed (see Table III)		[5]	118	Failed	OK Failed
168	"	29056	"	4.5	100.	5. [4]	0.18	21.3	145.8	[5]	130	21.1	OK

RCCB-ACCEPTANCE TESTING [1] (test data) 1-31-73

TEST #	Vendor	S/N	Rating	Insulation Res. Open Contacts [2]	Insulation Res. Insul'd Parts [2]	Dielectric Strength [3]	Contact V-Drop	Overload Operation 200% (Trip-off time)	Overload Operation 138% (Trip-off time)	Overload Operation 115% (Trip-off time)	Overload Operation Temp. at 115%	SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS [6]
			(Amp.)	(M OHM)		(μA)	(Volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
169	Texas Inst..	29057	15. (dc)	5.0	75.	5. [4]	0.15	20.7	133.1	[5]	100	0 95	Low-Line Voltage 120 V
170	"	29059	10. (dc)	1.5	90.	5. [4]	0.19	24.0	134.5	[5]	99	18 0	OK
171	"	29068	"	2.5	60.	4. [4]	0.20	23.8	85.0	3300	(110)	19.4	OK
172	"	29069	"	1.1	60.	4. [4]	0.19	26.1	90.2	[5]	110	19.8	OK
173	"	29070	"	4.0	75.	4 [4]	0.18	23.8	128.2	2520	(112)	24.1	OK
174	"	29071	"	4.0	75.	1. [3]	0.20	24.1	78.4	[5]	102	19.0	OK
175	"	29289	"	3.5	75.	4. [4]	0.19	19.5	92.1	[5]	112	20.6	OK

RCCB-ACCEPTANCE TESTING [1] (test data) 2-1-73

TEST #	Vendor	S/N	Rating	Insulation Res. Open Contacts [2]	Insulation Res. Insul'd Parts [2]	Dielectric Strength [3]	Contact V-Drop	Overload Operation 200% (Trip-off time)	Overload Operation 138% (Trip-off time)	Overload Operation 115% (Trip-off time)	Temp. at 115%	SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS [6]
			(Amp.)	(K M-OHM)		(μA)	(Volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
176	Texas Instr.	29290	10.	9.	75.	4.	0.19	24.0	91.0	[5]	103	19.2	Ext. SW operates only under load.
			(dc)			[4]							
177	"	29291	"	3.5	75.	4.	0.20	20.1	87.7	[5]	112	20.0	OK
						[4]							
178	"	29292	"	5.2	100.	4.	0.20	27.2	89.5	[5]	120	20.6	OK
						[4]							
179	"	29293	"	2.9	100.	4.	0.18	23.8	89.9	[5]	110	20.6	OK
						[4]							
180	"	29294	"	6.0	100.	4.	0.19	26.9	96.6	[5]	103	21.4	Ext. SW operates only under load.
						[4]							
181	"	[illegible]	"	8.0	100.	4.	0.19	24.3	87.6	[5]	115	18.4	OK
						[4]							
182	"	29430	"	6.0	75.	4.	0.20	25.5	87.8	[5]	102	22.9	OK
						[4]							

RCCB-ACCEPTANCE TESTING [1] (test data) 2-2-73

TEST #	Vendor	S/N	Rating	Insulation Res. Open Contacts [2]	Insulation Res. Insul'd Parts [2]	Dielectric Strength [3]	Contact V-Drop	Overload Operation 200% (Trip-off time)	Overload Operation 138% (Trip-off time)	Overload Operation 115% (Trip-off time)	Overload Operation Temp. at 115%	SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS [6]
			(Amp.)	(K M-OHM)		(μA)	(Volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
183	Texas Instr.	29431	10.	4.7	80.	4.	0.19	22.1	64.2	[5]	116	49.3	OK
			(dc)			[4]							
184	"	29432	"	1.7	60.	4.	0.37	25.7	86.8	[5]	110	22.3	OK
						[4]							
185	"	29433	"	7.0	60.	5.	0.10	26.0	134.5	[5]	115	19.3	OK
						[4]							
186	"	29434	"	3.5	80.	5.	0.21	28.0	126.5	[5]	98	21.9	OK
						[4]							
187	"	30033	35. ph A	60.	100.	35.	0.09	Not Tested [7]				35.	OK [8]
			(ac) ph B	75.	90.	35.	0.10					33.	
			ph C	100.	60.	30.	0.14					32.	
188	"	30033	"	100.	100.	30.	0.08	Not Tested [7]				[illegible]	OK [8]
				90.	100.	35.	0.32					35.	
				75.	100.	35.	0.06					35.	
189	Cutler-Hammer	16/100	100.	60.	60.	10.	0.12	30.4	219.3	2340	(222)	5.6	OK

RCCB-ACCEPTANCE TESTING [1] (test data) 2-5-73

TEST #	Vendor	S/N	Rating	Insulation Res. Open Contacts [2]	Insulation Res. Insul'd Parts [2]	Dielectric Strength [3]	Contact V-Drop	Overload Operation 200% (Trip-off time)	Overload Operation 138% (Trip-off time)	Overload Operation 115% (Trip-off time)	Overload Operation Temp. at 115%	SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS [6]
			(Amp.)	(K M-OHM)		(μA)	(Volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
190	Cutler Hammer	17/100	100.	90.	90.	11.	0.09	21.2	129.1	[5]	181	5.6	OK
191	"	18/100	100.	75.	90.	10.	0.13	23.4	135.1	1082.	(169)	5.7	OK
192	"	19/100	100.	75.	90.	11.	0.13	36.0	264.4	1800.	(247)	5.3	OK
193	"	20/100	100.	100.	90.	11.	0.15	23.6	252.7	170.5	(160)	5.7	OK
194	"	21/100	100.	75.	80.	50.	0.12	24.7	190.3	[5]	165	6.0	OK
195	"	22/100	100.	60.	80.	16.	0.00	22.1	104.1	[5]	230	5.5	OK
196	"	23/100	100.	100.	[illegible]	14.	0.13	21.9	95.3	[5]	175	5.1	OK

RCCB-ACCEPTANCE TESTING [1] (test data) 2-[illegible]-73

TEST #	Vendor	S/N	Rating	Insulation Res. Open Contacts [2]	Insulation Res. Insul'd Parts [2]	Dielectric Strength [3]	Contact V. Drop	Overload Operation 200% (Trip-off time)	Overload Operation [illegible] (Trip-off time)	Overload Operation [illegible] (Trip-off time)	Temp. [illegible]	SHOCK HAZARD [illegible] delay)	OPERATIONAL CHARACTERISTICS [6]
			(Amp.)	(K M-OHM)		(μA)	(Volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
197	Cutler-Hammer	[illegible]/100	100.	100.	80.	10.	0.13	22.7	146.2	[5]	230	5.6	OK
198	"	25/100	100.	60.	75.	15.	0.11	23.5	145.9	[5]	187	5.4	OK
199	"	14/5	5.	100.	100.	12.	0.42	8.0	70.	[5]	107	7.	OK
200	"	15/5	5.	60.	80.	25.	0.42	17.0	293.	[5]	106	6.	OK
201	"	16/5	5.	60.	80.	10.	0.39	17.0	722.	[5]	103	8.	OK
202	"	17/5	5.	[illegible]	90.	10.	0.35	17.0	630.	[5]	105	5.	OK
203	"	18/5	5.	60.	80.	9.	0.39	19.5	538.	[5]	105	5.	OK

RCCB-ACCEPTANCE TESTING $\boxed{1}$ (test data) 2-5-73

TEST #	Vendor	S/N	Rating	Insulation Res.		Dielectric Strength $\boxed{3}$	Contact V-Drop	OverLoad Operation				SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS $\boxed{6}$
				Open Contacts $\boxed{2}$	Insul'd Parts $\boxed{2}$			200%	138%	115%	Temp. at 115%		
								(Trip-off time)					
			(Amp.)	(K M-OHM)		(uA)	(Volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
204	Cutler-Hammer	19/5	5.	100.	75.	9.	0.39	9.5	124.	$\boxed{5}$	101	7.5	OK
205	"	20/5	5.	100.	90.	9.	0.42	21.6	505.	$\boxed{5}$	104	6.5	OK
206	"	21/5	5.	100	80.	9.	0.42	22.0	420.	$\boxed{5}$	104	4.5	OK
207	"	22/5	5.	90.	100.	9.	0.35	19.5	356.	$\boxed{5}$	99	5.	OK
208	"	23/5	5.	90.	100.	9.	0.36	22.0	1115.0	$\boxed{5}$	105	8.	OK
209	"	24/5	5.	75.	80.	9.	0.42	16.0	145.	$\boxed{5}$	105	6.	OK
210	"	25/5	5.	100.	75.	9.	0.42	21.0	200.	$\boxed{5}$	103	5.	OK

RCCB-ACCEPTANCE TESTING [1] (test data) 2-6-73

TEST #	Vendor	S/N	Rating	Insulation Res. Open Contacts [2]	Insulation Res. Insul'd Parts [2]	Dielectric Strength [3]	Contact V-Drop	Overload Operation 200% (Trip-off time)	Overload Operation 138%	Overload Operation 115%	Temp. at 115%	SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS [4]
			(Amp.)	(K M-OHM)		(μA)	(Volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
211	Cutler-Hammer	9/75	75.	90.	90.	11.	0.13	16.5	69.5	790	(145)	5.6	OK
212	"	10/75	75.	90.	90.	39.	0.12	28.7	667.5	[5]	164	5.9	OK
213	"	11/75	75.	60.	75.	18.	0.12	15.1	80.4	[5]	138	5.6	OK
214	"	12/75	75.	100.	90.	25.	0.12	17.5	108.4	[5]	159	5.8	OK
215	"	13/75	75.	60.	80.	45.	Failed (see Table III)					Failed	Failed
216	"	14/75	75.	100.	90.	27.	0.12	16.1	605.9	[5]	147	5.5	OK
217	"	15/75	75.	80.	90.	11.	0.13	16.6	57.7	[5]	170	5.5	OK

RCCB-ACCEPTANCE TESTING [1] (test data) 2-7-73

TEST #	Vendor	S/N	Rating	Insulation Res. Open Contacts [2]	Insulation Res. Insul'd Parts [2]	Dielectric Strength [3]	Contact V-Drop	Overload Operation 200% (Trip-off time)	Overload Operation 138% (Trip-off time)	Overload Operation 115% (Trip-off time)	Temp. at 115%	SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS [6]
			(Amp.)	(K M-OHM)	(K M-OHM)	(μA)	(Volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
218	Cutler-Hammar	16/75	75.	80.	75.	15.	0.15	16.6	57.7	[5]	170	6.1	OK
219	"	17/75	75.	100.	80.	33.	0.17	24.4	425.6	[5]	162	5.2	OK
220	"	18/75	75.	60.	60.	25.	0.10	15.1	77.3	[5]	136	6.0	OK
221	"	19/75	75.	80.	90.	20.	0.11	17.2	326.7	[5]	147	5.9	OK
222	"	20/75	75.	80.	90.	40.	0.13	12.3	118.8	[4]	140	5.7	OK
223	"	21/75	75.	90.	90.	11.	0.09	13.8	68.0	[5]	138	5.9	OK
224	"	22/75	75.	60.	80.	30.	0.09	12.0	75.7	[5]	145	5.7	OK

RCCB-ACCEPTANCE TESTING [1] (test data) 2-8-73

TEST #	Vendor	S/N	Rating	Insulation Res. Open Contacts [2]	Insulation Res. Insul'd Parts [2]	Dielectric Strength [3]	Contact V-Drop	Overload Operation 200%	Overload Operation 138%	Overload Operation 115%	Overload Operation Temp. at 115%	SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS [6]
			(Amp.)	(K M-OHM)	(K M-OHM)	(μA)	(Volt)	(sec.) (Trip-off time)	(sec.) (Trip-off time)	(sec.) (Trip-off time)	(°F)	(msec)	
225	Cutler-Hammer	23/75	75.	75.	80.	11.	0.17	26.0	444.6	[5]	145	5.9	OK
226	"	24/75	75.	75.	80.	11.	0.10	19.1	471.2	[5]	147	5.3	OK
227	"	25/75	75.	80.	100.	17.	0.10	14.0	69.3	[5]	147	5.7	OK
228	"	6/10	10.	75.	90.	32.	0.25	18.0	160.	[5]	115	7.5	OK
229	"	9/10	10.	100.	100.	10.	0.23	16.0	40.	[5]	115	8.	OK
230	"	10/10	10.	[illegible]	100.	39.	0.2[illegible]	27.0	105.	[5]	109	6.	OK
231	"	11/10	10.	100.	100.	25.	0.31	20.0	120.	[5]	120	5.	OK

RCCB-ACCEPTANCE TESTING $\boxed{1}$ (test data) 2-8-73

TEST #	Vendor	S/N	Rating	Insulation Res.		Dielectric Strength $\boxed{3}$	Contact V-Drop	Overload Operation				SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS $\boxed{6}$
				Open Contacts $\boxed{2}$	Insul'd Parts $\boxed{2}$			200% (Trip-off time)	138% (Trip-off time)	115% (Trip-off time)	Temp. at 115%		
			(Amp.)	(K M-OHM)	(K M-OHM)	(µA)	(Volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
232	Cutler-Hammer	12/10	10.	50.	80.	50.	0.25	19.5	65.	$\boxed{5}$	111	6.	OK
233	"	13/10	10.	60.	100.	30.	0.26	20.3	110.	$\boxed{5}$	108	5.	OK
234	"	14/10	10.	75.	90.	35.	0.25	20.0	140.	$\boxed{5}$	109	8.	OK
235	"	15/10	10.	60.	90.	43.	0.23	26.0	150.	$\boxed{5}$	110	6.	OK
236	"	16/10	10.	75.	75.	25.	0.23	22.5	92.	$\boxed{5}$	105	6.	OK
237	"	17/10	10.	50.	90.	10.	0.23	25.0	155.	$\boxed{5}$	110	6.	OK
238	"	18/10	10.	60.	75.	50.	0.26	10.5	75.	$\boxed{5}$	106	6.5	OK

RCCB-ACCEPTANCE TESTING [1] (test data) 2-9-73

TEST #	Vendor	S/N	Rating	Insulation Res. Open Contacts [2]	Insulation Res. Insul'd Parts [2]	Dielectric Strength [3]	Contact V-Drop	Overload Operation 200% (Trip-off time)	Overload Operation 138% (Trip-off time)	Overload Operation 115% (Trip-off time)	Overload Operation Temp. at 115%	SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS [6]
			(Amp.)	(K M-OHM)	(K M-OHM)	(μA)	(Volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
239	Cutler-Hammer	19/10	10.	90.	100.	43.	0.25	24.0	147.	[5]	109	5.	OK
240	"	20/10	10.	100.	80.	72.	0.21	21.0	122.	[5]	115	6.	OK
241	"	21/10	10.	100.	80.	72.	0.23	22.5	130.	[5]	115	6.	OK
242	"	22/10	10.	75.	80.	TRIP OFF AT 600 V	0.21	22.0	122.	[5]	110	5.5	OK
243	"	23/10	10.	75.	80.	30.	0.21	23 5	165.	[5]	114	5.5	OK
244	"	24/10	10.	100.	75.	50.	0.20	22.5	175.	[5]	111	5.5	OK
245	"	25/10	10.	75.	80.	10.	0.25	35.	420.	[5]	111	6.	OK

RCCB-ACCEPTANCE TESTING [1] (test data) 2-12-73

TEST #	Vendor	S/N	Rating	Insulation Res. Open Contacts [2]	Insulation Res. Insul'd Parts [2]	Dielectric Strength [3]	Contact V-Drop	Overload Operation 200% (Trip-off time)	Overload Operation 138% (Trip-off time)	Overload Operation 115% (Trip-off time)	Overload Operation Temp. at 115%	SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS [6]
			(Amp.)	(K M-OHM)		(μA)	(Volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
246	Cutler-Hammer	12/20	20.	60.	100.	9.	0.13	24.1	116.0	[5]	111	5.7	OK
247	"	13/20	20.	100.	100.	11.	0.11	15.7	77.3	[5]	106	5.9	OK
248	"	14/20	20.	100.	100.	25.	0.17	11.6	57.0	[5]	115	5.5	OK
249	"	15/20	20.	100.	60.	10.	0.10	16.0	68.1	[5]	108	5.5	OK
250	"	16/20	20.	100.	100.	10.	0.11	18.9	80.0	[5]	114	5.8	OK
251	"	17/20	20.	90.	100.	10.	0.12	16.0	125.3	[5]	105	6.2	OK
252	"	18/20	20.	75.	80.	10.	0.10	14.8	47.8	[5]	124	6.0	OK

RCCB-ACCEPTANCE TESTING [1] (test data)

2-13-73

TEST #	Vendor	S/N	Rating	Insulation Res.		Dielectric Strength [3]	Contact V-Drop	Overload Operation				SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS [6]
				Open Contacts [2]	Insul'd Parts [2]			200%	138%	115%	Temp. at 115%		
								(Trip-off time)					
			(Amp.)	(K M-OHM)		(μA)	(Volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
253	Cutler-Hammer	19/20	20.	100.	80.	10.	0.11	19.5	75.6	[5]	111	5.[illegible]	OK
254	"	20/20	20.	75.	100.	39.	0.13	14.8	76.1	[5]	140	4.9	OK
255	"	21/20	20.	100.	90.	9.	0.11	17.6	81.7	[5]	112	5.8	OK
256	"	22/20	20.	100.	100.	10.	0.11	15.2	42.6	[5]	118	6.2	OK
257	"	23/20	20.	100.	100.	9.	0.11	25.0	59.6	[5]	112	5.7	OK
258	"	24/20	20.	80.	100.	68.	0.11	20.3	66.5	[5]	124	5.7	OK
259	"	25/20	20.	80.	90.	9.	0.14	19.2	73.7	[5]	107	4.5	OK

RCCB-ACCEPTANCE TESTING [1] (test data) 2-13-73

TEST #	Vendor	S/N	Rating	Insulation Res. Open Contacts [2]	Insulation Res. Insul'd Parts [2]	Dielectric Strength [3]	Contact V-Drop	Overload Operation 200% (Trip-off time)	Overload Operation 138% (Trip-off time)	Overload Operation 115% (Trip-off time)	Overload Operation Temp. at 115%	SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS [6]
			(Amp.)	(K M-OHM)		(μA)	(Volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
260	Cutler-Hammer	17/50	50.	90.	100.	35.	0.11	14.5	97.8	[5]	156	[illegible].5	OK
261	"	18/50	50.	90.	100.	10.	0.17	15.6	62.3	[5]	155	6.3	OK
262	"	19/50	50.	80.	100.	10.	0.14	15.7	84.8	[5]	147	6.2	OK
263	"	20/50	50.	80.	100	35.	0.11	13.1	84.0	[5]	151	6.3	OK
264	"	21/50	50.	100.	75.	55.	0.12	14.1	109.7	[5]	145	5	OK
265	"	22/50	50.	75.	100.	10.	0.18	16.2	85.5	[5]	145	5.3	OK
266	"	23/50	50.	75.	80.	32.	0.13	12.8	67.4	[5]	[illegible]	4.8	OK

RCCB-ACCEPTANCE TESTING [1] (test data) 2-16-73

TEST #	Vendor	S/N	Rating	Insulation Res. Open Contacts [2]	Insulation Res. Insul'd Part [2]	Dielectric Strength [3]	Contact V-Drop	Overload Operation 200% (Trip-off time)	Overload Operation 135% (Trip-off time)	Overload Operation 115% (Trip-off time)	Overload Operation Temp. at 115%	SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS [6]
			(Amp.)	(K M-OHM)	(K M-OHM)	(μA)	(Volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
267	Cutler Hammer	24/50	50.	75.	80.	17.	0.12	10.9	45.7	[5]	155	5.7	OK
268	"	25/50	50.	100.	80.	10.	0.11	13.0	503.0	[5]	138	6.0	OK
269	"	11/25	25.	100.	90.	10.	0.11	18.0	64.2	[5]	128	7.5	Failed (see Table III)
270	"	12/25	25.	100.	100.	10.	0.10	15.5	80.2	[5]	135	5.6	OK
271	"	13/25	25.	75.	80.	27.	0.12	17.0	70.6	[5]	135	5.4	OK
272	"	14/25	25.	100.	100.	10	0.11	16.4	65.2	[5]	136	5.6	OK
273	"	15/25	25.	100.	100	9.	0.10	17.8	65.2	[5]	130	5.4	OK

RCCB-ACCEPTANCE TESTING [1] (test data) 2-21-73

TEST #	Vendor	S/N	Rating	Insulation Res. Open Contacts [2]	Insulation Res. Insul'd Parts [2]	Dielectric Strength [3]	Contact V-Drop	Overload Operation 200% (Trip-off time)	Overload Operation 135% (Trip-off time)	Overload Operation 115% (Trip-off time)	Overload Operation Temp. at 115%	SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS [6]
			(Amp.)	(K M-OHM)	(K M-OHM)	(μA)	(Volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
274	Cutler-Hammer	16/25	25.	100.	100.	55.	0.10	18.0	61.2	[5]	135	5.9	OK
275	"	17/25	25.	80.	80.	25.	0.14	18.0	79.4	[5]	165	5.6	OK
276	"	18/25	25.	90.	100.	10.	0.11	17.2	50.7	[5]	130	5.6	OK
277	"	19/25	25.	80.	75.	9.	0.16	18.0	71.5	[5]	138	5.5	OK
278	"	20/25	25.	100.	100.	9.	0.12	17.3	67.9	[5]	136	5.4	OK
279	"	21/25	25.	100.	75.	9.	0.13	16.1	45.1	[5]	152	5.5	OK
280	"	22/25	25.	100.	100.	16.	0.14	9.7	37.7	240.	(90)	5.5	OK

RCCB-ACCEPTANCE TESTING [1] (test data) 2-2-73

TEST #	Vendor	S/N	Rating	Insulation Res. Open Contact [2]	Insulation Res. Insul'd Parts [2]	Dielectric Strength [3]	Contact V.-Drop	Overload Operation 200% (Trip-off time)	Overload Operation 138% (Trip-off time)	Overload Operation 115% (Trip-off time)	Overload Operation Temp. at 115%	SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS [6]
			(Amp.)	(K M-OHM)	(K M-OHM)	(uA)	(Volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
281	Cutler-Hammer	23/25	25.	80.	90.	9.	0.14	36.0	55.5	[5]	140	5.6	OK
282	"	24/25	25.	80.	100.	10.	0.13	18.6	70.8	[5]	140	5.5	OK
283	"	25/25	25.	90.	90.	10.	0.11	14.6	41.5	[5]	149	5.9	OK
284	"	12/35	35.	75.	80.	23.	0.15	34.2	[5]	[5]	121	6.1	OK
285	"	13/35	35.	100.	100.	38.	0.14	19.7	105.	[5]	116	6.2	OK
286	"	14/35	35.	75.	75.	70.	0.13	18.8	128.2	[5]	[illegible]	6.8	OK
287	"	15/35	35.	50.	75.	50.	0.10	16.7	106.4	[5]	114	6.5	OK

RCCF-ACCEPTANCE TESTING [1] (test data)

TEST #	Vendor	S/N	Rating	Insulation Res. Open Contacts [2]	Insulation Res. Insul'd Parts [2]	Dielectric Strength [3]	Contact V.-Drop	Overload Operation 200% (Trip-off time)	Overload Operation 138% (Trip-off time)	Overload Operation 115% (Trip-off time)	Overload Operation Temp. at 115%	SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS [6]
			(Amp.)	(K M-OHM)	(K M-OHM)	(μA)	(Volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
288	Cutler-Hammer	16/35	35.	80.	100.	10.	0.15	22.1	172.3	[5]	122	6.0	OK
289	"	17/35	35.	60.	100.	10.	0.14	20.6	207.0	[5]	115	5.8	OK
290	"	18/35	35.	90.	80.	42.	0.15	15.2	67.9	[5]	125	1.4	OK
291	"	19/35	35.	75.	90.	45.	0.11	15.7	79.5	[5]	125	7.5	OK
292	"	20/35	35.	80.	90.	5.	0.10	22.1	104.3	[5]	125	5.6	OK
293	"	21/35	35.	80.	90.	10.	0.13	32.3	585.0	[5]	115	6.9	OK
294	"	22/35	35.	75.	80.	9.	0.10	30.4	69.0	[5]	120	6.3	OK

RCCB-ACCEPTANCE TESTING [1] (test data) 7-26-73

TEST #	Vendor	S/N	Rating	Insulation Res. Open Contacts [2]	Insulation Res. Insul'd Parts [2]	Dielectric Strength [3]	Contact V-Drop	Overload Operation 200% (Trip-off time)	Overload Operation 135% (Trip-off time)	Overload Operation 115% (Trip-off time)	Temp. at 115%	SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS [6]
			(Amp.)	(K M-OHM)	(K M-OHM)	(μA)	(Volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
295	Cutler-Hammer	23/35	35.	75.	80.	11.	0.11	19.8	153.2	[5]	130	6.2	OK
295	"	24/35	35.	80.	80.	19.	0.10	83.0	362.	[5]	130	6.1	OK
297	"	25/35	35.	75.	80.	30.	0.10	17.5	128.6	[5]	152	4.8	OK
298	Texas Instr.	30150	7.5 phA	100.	80.	31.	0.30	24.	70.	[5]	125	34.	OK [8]
			(ac)ph B	80.	80.	33.	0.28	27.5	77.	[5]	128	34.	
			ph C	75.	75.	38.	0.29	26.	78.5	[5]	122	33.	
299	"	30154	"	75.	75.	31.	0.28	31.3	80.6	[5]	125	35.	OK [8]
				60.	75.	35.	0.34	35.9	101.2	[5]	130.	35.	
				65.	80.	36.	0.28	29.6	90.5	[5]	122.	36.	
300	"	30155	"	75.	75.	31.	0.32	38.3	105.	[5]	122	33.	OK [8]
				100.	80.	34.	0.32	30.7	86.8	[5]	13[illegible]	34.	
				100.	75.	38.	0.32	30.0	120.	[5]	105	36.	
301	"	30156	"	75.	100.	30.	0.35	33.5	128.7	[5]	117	35.	OK [8]
				75.	100.	36.	0.34	34.2	142.6	[5]	129	36.	
				80.	100.	37.	0.32	27.9	101.5	[5]	105	36.	

RCCB-ACCEPTANCE TESTING [1] (test data) 2-27-73

TEST #	Vendor	S/N	Rating	Insulation Res. Open Contacts [2]	Insulation Res. Insul'd Parts [2]	Dielectric Strength [3]	Contact V-Drop	Overload Operation (Trip-off time) 200%	130%	115%	Temp. at 115%	SHOCK HAZZARD (time-delay)	OPERATIONAL CHARACTERISTICS [6]
			(Amp.)	(K M-OHM)		(μA)	(Volt)	(sec.)	(sec.)	(sec.)	(°F)	(msec)	
302	Texas Instr.	30179	7.5 phA	80.	80.	31.	0.35	24.3	87.1	[5]	115	35.	OK
			(ac)ph B	75	90.	35.	0.35	25.5	87.0	[5]	117	35.	
			ph C	60.	100.	33.	0.35	22.8	73.3	[5]	112	34.	
303	"	30180	"	90.	90.	31.	0.35	27.7	116.7	[5]	126	35.	OK
				100.	90.	33.	0.35	24.0	97.0	[5]	133	34.	
				60.	80.	38.	0.34	25.0	88.6	[5]	126	32.	
304	"	30182	"	60.	75.	28.	0.34	21.6	94.0	[5]	128	33.	OK
				75.	100.	35.	0.28	23.8	94.4	[5]	135	35.	
				100.	90.	39.	0.32	20.5	75.5	[5]	125	33.	
305	"	30183	"	90.	75.	23.	0.34	25.0	83.3	[5]	132	34.	OK
				100.	100.	36.	0.28	24.6	89.9	[5]	136	35.	
				100.	90.	37.	0.34	24.4	101.1	[5]	129	32.	

APPENDIX B

TOGGLE SWITCH TEST REPORTS

LEC 1124 AND LEC 1667

N74-35271

EVALUATION REPORT

FOR

TOGGLE SWITCHES

Micro Switch and Cutler-Hammer

Models per MIL-S-3950

Prepared by

Lockheed Electronics Company, Inc.

Aerospace Systems Division

Houston, Texas

Under Contract NAS 9-12200

For

POWER DISTRIBUTION AND CONTROL BRANCH

National Aeronautics and Space Administration

LYNDON B. JOHNSON SPACE CENTER

Houston, Texas

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ABSTRACT

Several models of hermetically sealed toggle switches marketed by two vendors, Micro Switch and Cutler-Hammer, as meeting the requirements of MIL-S-3950, were evaluated to determine the probability that they could withstand the environmental requirements of, and therefore be suitable for use on, the Space Shuttle vehicle. The evaluation was started with a comparison of the environmental requirements of vendor-performed testing and specifications for Space Shuttle hardware. This was followed with in-house testing for those environments where a reasonably firm conclusion could not be drawn in the comparison. Space simulation, acceleration and vibration testing were performed in-house. After the latter of these, the switches were judged to be unsuitable for use on the Space Shuttle vehicle and the evaluation effort was terminated.

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EVALUATION REPORT

FOR

TOGGLE SWITCHES

MICRO SWITCH AND CUTLER-HAMMER

MODELS PER MIL-S-3950

1.0 INTRODUCTION

1.1 Background

As a result of a problem experienced with toggle switches during the Apollo program, the Power Distribution and Control Branch at Lyndon B. Johnson Space Center has initiated evaluation of several types of toggle switches per the environmental requirements of the Space Shuttle vehicle. The results of this evaluation for three types of environmentally sealed toggle switches marketed by two different vendors (Micro Switch and Cutler-Hammer) as meeting the requirements of MIL-S-3950, are reported in this document.

1.2 Summary of Evaluation Program

For purposes of this evaluation, these switches were considered to be, by virtue of the vendors' test data, in full compliance with the requirements of MIL-S-3950. A comparison of this specification, in mid-April of 1973, with the then-available documentation specifying the environmental requirements for components of the Space Shuttle vehicle indicated that space simulation (temperature-altitude), acceleration, vibration and shock testing should be performed. Other environmental requirements of these two specifications were similar enough to warrant reasonable confidence that the switches could successfully complete Space Shuttle qualification testing. Several samples, including different contact configurations, of the three types of switches were subjected to space simulation and acceleration testing and exhibited no performance anomalies. A smaller group of samples was subjected to vibration testing and, when subjected to vibration for a total duration simulating up to 20 Space Shuttle mission-cycles along an axis approximately parallel to the switches' actuating handle, exhibited frequent chatter of normally-closed contacts. Because the requirements for the Space Shuttle include a total reliable life expectancy of 100 missions, these switches were judged to be unsuitable for Space Shuttle use. Shock testing, therefore, was not performed.

2.0 EVALUATION PROGRAM

2.1 Specification Comparison

The environmental requirements of MIL-STD-3950E, to which the switches were designed and tested by the vendors, and the corresponding requirements for the Space Shuttle vehicle as specified in NASA MSC document SP-T-0023, dated June 30, 1972, entitled, "Specification Environmental Acceptance Testing", were compared. The purpose of this comparison was to provide a basis for deciding which environmental tests to include in the in-house test program and which environmental tests could reasonably be excluded from it. Because the Space Shuttle environmental requirements had not yet been finalized, George C. Marshall Space Flight Center Specification 40M38202 was included in the comparison as a means of broadening the total information base upon which to base the test/no-test decisions.

The results of this comparison are shown in Table I. Based on this information, it was decided to test the effects on the switches of space simulation (temperature-altitude), acceleration, vibration and shock.

2.2 Space Simulation (Temperature-Altitude) Testing

2.2.1 <u>Test sample</u>. - A total of 36 individual switches of the military standard types MS 24523 (one pole), MS 24524 (two pole) and MS 24525 (four pole) were subjected to the environmental stresses of space simulation. A complete list of the switches, including types, contact configurations and manufacturer, is shown in Table II.

2.2.2 <u>Test procedure</u>. - Because of the difficulty of activating mechanical switches while they are sealed inside a vacuum chamber, the test sample was subjected to the temperature and altitude conditions prescribed in MIL-STD-810B, Method 517.1, Procedure II without being operated either electrically or mechanically. The voltage drop across closed contacts while passing DC currents of 0.1 and 10 amperes was measured both before and after the environmental exposure.

2.2.3 <u>Test results</u>. - None of the 36 switches exhibited any noticeable change in voltage drop across closed contacts after exposure to space simulation as compared to before this exposure.

2.3 Acceleration Testing

2.3.1 <u>Test sample</u>. - The same 36 switches, as listed in Table II, that were subjected to space simulation, were subjected to acceleration testing.

2.3.2 Test Procedure. - The switches were subjected to an acceleration of 22.5g for a duration of two minutes in each direction of three mutually perpendicular axes. As with the space simulation test, before and after exposure to the acceleration, the voltage drop across closed contacts while passing 0.1 and 10 amperes DC was measured. In addition, using the same equipment and technique described below under vibration testing, chatter (undesired momentary opening) of normally-closed contacts was monitored during exposure to the acceleration.

2.3.3 Test Results. - No contact chatter was detected during any of the acceleration exposure nor was there any degradation of the voltage drop across closed contacts as a result of this exposure.

2.4 Vibration Testing

2.4.1 Test sample. - Because one-half of the total of 36 switches had been exposed to vibration previously and because three of those remaining had only momentary action, only 15 of the switches were subjected to vibration testing. The detailed list of these 15 is shown in Table II.

2.4.2 Test procedure. -

2.4.2.1 Environmental: The 15 switches were divided into two groups, one of eight (group A) and one of seven (group B). Each group, one at a time, was subjected to a series of simulated missions. Each simulated mission consisted of random vibration for a duration of 70 seconds with an acceleration spectral density increasing at a rate of 3 dB/octave from 20 Hz to 80 Hz, remaining constant at $0.06g^2/Hz$ from 80 Hz to 350 Hz and decreasing at a rate of 3dB/octave from 350 Hz to 2000 Hz.

The first test phase consisted of simulating two missions, i.e., a total of 140 seconds, in each of the three axes. (The vibration axes are shown in figure 1.) The next phase consisted of simulating five missions, i.e., a total of 350 seconds, in each of the three axes. This was followed by another five-mission phase and then phases of 10 missions, 30 missions and 50 missions each. (The 50 mission phase was not performed on the second group of switch s.) This resulted in a total vibration duration cf approximately two hours in each axis.

2.4.2.2 Electrical: As previously discussed for space simulation and acceleration testing, the voltage drop across closed contacts with DC currents of 0 and 10 amperes was measured before and after the total vibration exposure.

During vibration, contact chatter was monitored using a Continental Testing Laboratories, Inc., Model TM-5100 Transient Monitor. The test setup is shown schematically in figure 2. All fixed contacts of all switches (one group at a time) were connected together and to the positive terminal of the 28-volt DC power supply. All movable contacts of any one switch were connected together, to a 1000-ohm resistor and to one channel of the transient monitor. The other side of the 1000-ohm resistor was connected to the negative terminal of the power supply.

With the exception of the first five-mission phase of the vibration, only normally closed contacts were monitored for chatter. During that first five-mission phase, the same pairs of contacts were monitored but the switches were activated so that these contacts were in a normally open position.

2.4.3 Test results. - No degradation of voltage drop across closed contacts as a result of the vibration exposure was noted.

The number of undesired contact openings detected during each phase of vibration for each of the three axes is tabulated in Tables III and IV for groups A and B respectively. It can be seen that, with vibration applied along the X axis (parallel to the switches' actuating handles) the number of undesired contact openings shows a marked increase during the 10-mission phase, or after a total exposure corresponding to approximately 20 missions. The switches were much less susceptible to vibration along the Y and Z axes. For group B, because two of the switches during the 10-mission phase and all of the switches during the 30-mission phase reached a state of continuous chatter on the X axis, the 50-mission phase was not performed.

2.5 Shock Testing

Because the performance of these switches during the vibration testing caused them to be judged unsatisfactory for Space Shuttle use, no shock testing was performed.

3.0 CONCLUSIONS

The contact chatter detected during vibration exposure after a duration simulating approximately 20 Space Shuttle missions shows them to be unsuited for use in flight systems for this program.

The limitations of the contact chatter test equipment and techniques only served to give the switches the benefit of the doubt. The transient monitor used to detect the chatter has to be reset manually after the operator has noted and recorded the occurence of a transient (contact opening). Thus numerous transients could have occurred which were not recorded by the operator. The fact that all poles in each multi-pole switch were connected in parallel could only have prevented recognition of possibly more contact-openings than were noted.

4.0 RECOMMENDATIONS

It is recommended that switches marketed by Micro Switch and Cutler-Hammer as satisfying the requirements of MIL-S-3950 and military standards MS 24523, MS 24524 and MS 24525 be considered unsatisfactory for use on the Space Shuttle vehicle unless and until additional information to the contrary is provided by other sources.

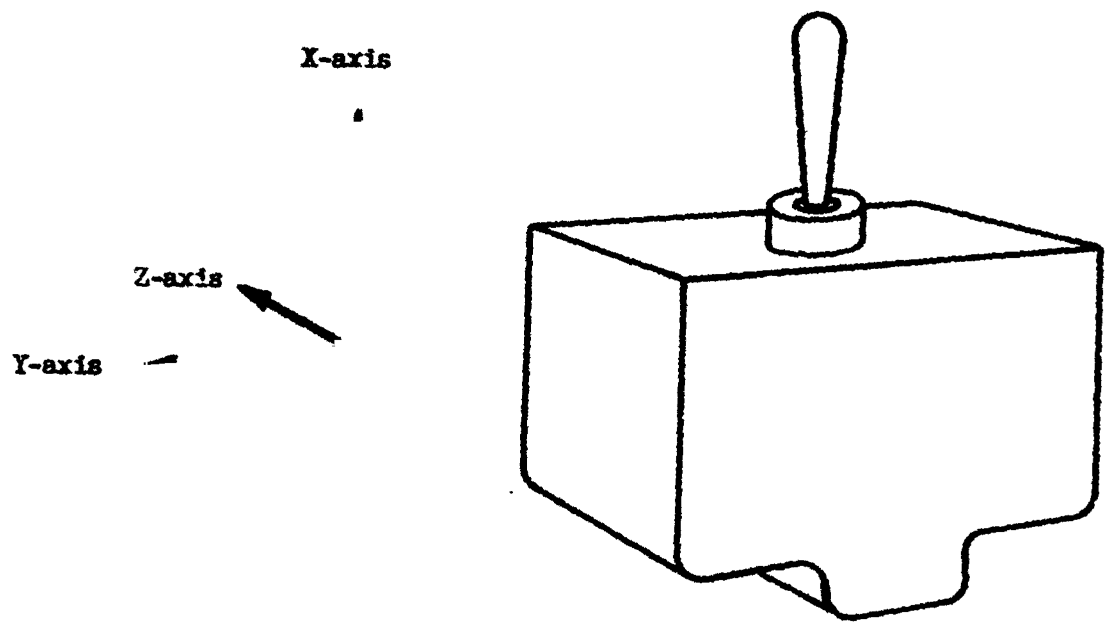

Figure 1. - Vibration Axes

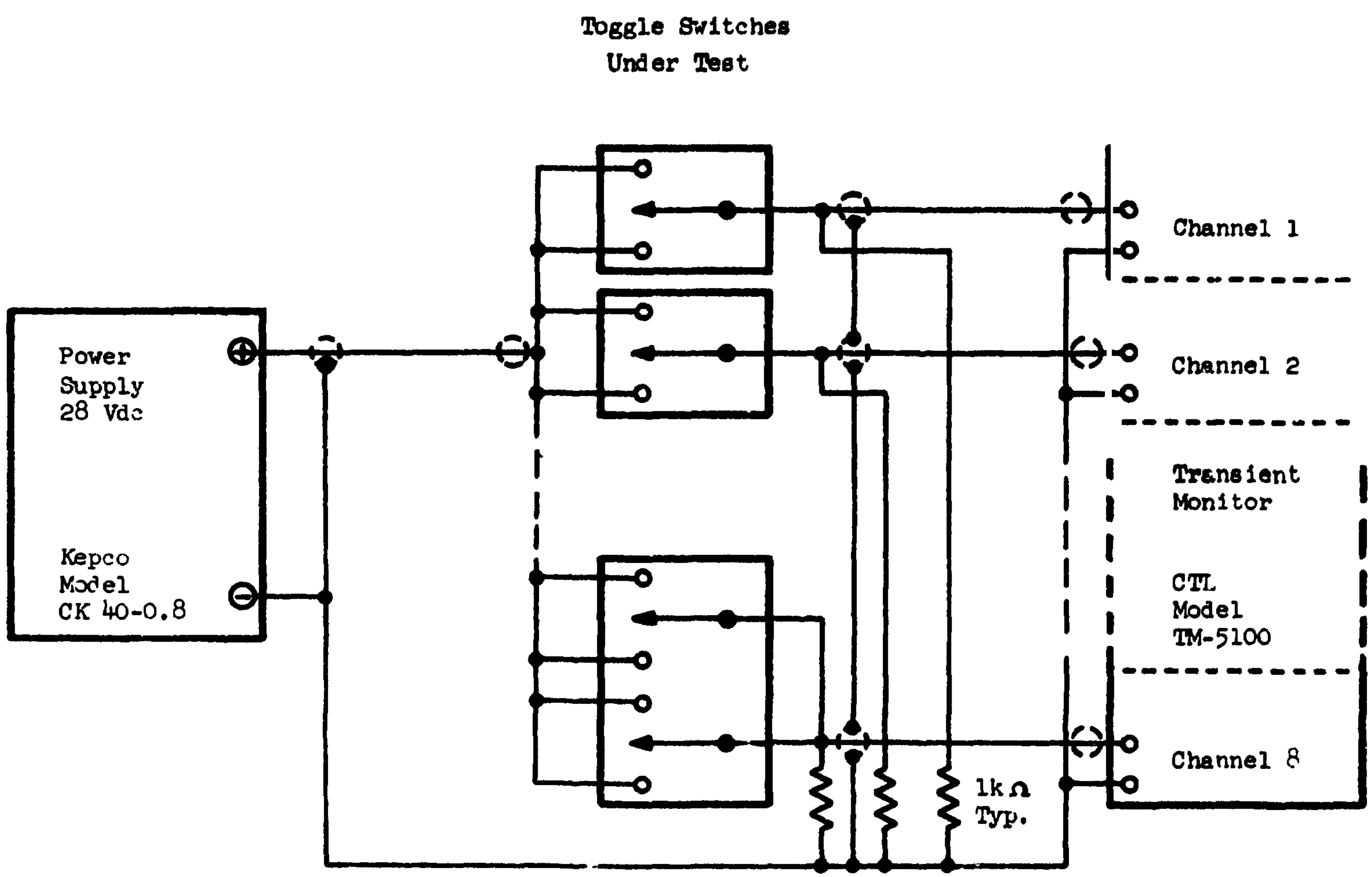

Figure 2. - Test Setup for Monitoring Contact Chatter

Table I.- Comparison of Environmental Requirements

ENVIRONMENT	MSC SP-T-0023 (SPACE SHUTTLE)	MIL-S-3950E	MSFC 40M38202
Salt Spray	Exposure to 5% NaCl solution	(same)	(same)
	Duration: 48 hours	(same)	Duration: 96 hours
	Amb. Temp.: 35°C	(same)	(same)
	Ref.: MIL-STD-810B Method 509 Procedure I	Ref.: MIL-STD-202D Method 101 Test Condition B	Ref.: MIL-STD-202D Method 101 Test Condition A
Humidity	Cycling at 95% R.H. Temp.(°C) Time(Hrs) 23-40.5 2 40.5 16 40.5-21 2 21 2 Repeat 20 times	Cycling: R.H.(%) Temp.(°C) Time(Hrs) 90-98 25-65 2.5 90-98 65 3 80-98 65-25 2.5 90-98 25-65 2.5 90-98 65 3 80-98 65-25 2.5 Repeat 10 times	Exposure to 90-95% R.H. at Amb. Temp. of 45±5°C for 46 hrs.
	Ref.: MIL-STD-810B Method 507 Procedure V	Ref.: MIL-STD-202D Method 106	Ref.: MIL-STD-202D Method 103 Test Condition B

Table I. - Comparison of Environmental Requirements (Continued)

Temperature	Temperature range from 17°C to 50°C	Cycling: Temp.(°C) / Time(min.) -65 / 30 +25 / 5 +125 / 30 +25 / 5 Repeat 5 times	Cycling: Temp.(°C) / Time(min.) -55 / 30 +25 / 10-15 +95 / 30 +25 / 10-15 Repeat 5 times
	No procedure suggested	Ref.: MIL-STD-202D Method 107 Test Condition B	Ref.: MIL-STD-202D Method 102 Test Condition D
Shock	Form: Half-sine	(same)	(same)
	Peak: 10g	Peak: 75g	Peak: 50g
	Duration: 11 ±1 msec	Duration: 6 msec	Duration: 11 msec
	V_1: not specified	V_1: 9.2 ft./sec.	V_1: 11.3 ft./sec.
	No procedure suggested	Ref.: MIL-STD-202D Method 213 Test Condition B	Ref.: MIL-STD-202D Method 213 Test Condition A
Vibration	Random: up to 2000 Hz Spectral Power: up to 18 dB (relative to $10^{-3}g/Hz$) Total g_{rms}: 5 Duration: 40 min./axis	Logarithmic Sweep: 10-500-10 Hz Maximum Excursion: 0.06 inches Peak: 10g Sweep Duration: 15 min 12 sweeps per axis	Extensive sinusoidal and random - see 40M39202 (not enclosed)

Table II. - Type, Manufacturer and Quantity of Switches Tested

	Quantity			
	Micro Switch		Cutler-Hammer	
	Space Sim. & Accel.	Vib.	Space Sim. & Accel.	Vib.
MS-24523 (one pole)				
-21 (on/off/on)	2	1	2	1
-22 (off/on)	2	1	2	1
-27 (mom on/off/mom on)	2	-	-	-
-31 (mom on/off/on)		-	2	1
MS-24524 (two pole)				
-21 (on/off/on)	2	1	2	1
-22 (off/on)	2	1	2	1
-27 (mom on/off/mom on)	2	-	-	-
-31 (mom on/off/on)	-	-	2	1
MS-24525 (four pole)				
-21 (on/off/on)	2	1	2	1
-22 (off/on)	2	1	2	1
-27 (mom on/off/mom on)	2	-	-	-
-31 (mom on/off/on)	-	-	2	1

Table III. - Analomalies Detected During Vibration Exposure - Group A

AXIS	NUMBER OF ANOMALIES DETECTED																	
	X						Y						Z					
VIBRATION DURATION (Simulated Missions)	2	*5	5	10	30	50	2	*5	5	10	30	50	2	*5	5	10	30	50
MS 24523-21 one pole-on/off/on — Micro Switch / Cutler-Hammer	2/3	0/0	0/0	8/7	6/6	1/1	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
MS 24523-22 one pole-on/off — Micro Switch / Cutler-Hammer	2/2	0/0	8/0	A/7	A/6	1/1	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
MS 24524-21 two pole-on/off/on — Micro Switch / Cutler-Hammer	2/2	0/0	0/0	7/7	6/6	1/2	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
MS 24524-22 two pole-on/off — Micro Switch / Cutler-Hammer	2/2	0/0	0/0	11/7	A/6	5/1	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	A/0	0/0	2/0

NOTES: *Contacts open for first 5-mission phase, closed for all others.

A = Excess anomalies due to loose connection

Table IV. - Anomalies Detected During Vibration Exposure - Group B

AXIS	NUMBER OF ANOMALIES DETECTED																	
	X						Y						Z					
VIBRATION DURATION (Simulated Missions)	2	*5	5	10	30	50	2	*5	5	10	30	50	2	*5	5	10	30	50
MS 24525-21 four pole-on/off/on																		
Micro Switch / Cutler-Hammer	0/0	0/0	1/1	8/2	F/F		0/0	0/0	1/1	0/0	3/9		0/0	0/0	0/0	0/0	0/6	
MS 24525-22 four pole-on/off																		
Micro Switch / Cutler-Hammer	1/0	0/0	38/1	F/2	F/F		0/0	0/0	1/1	0/0	7/11		0/0	0/0	0/0	0/1	61/6	
MS 24523-31 one pole-on/off/mom on																		
Cutler-Hammer	0	0	1	2	F		0	0	1	0	5		0	0	0	0	5	
MS 24524-31 two pole-on/off/mom on																		
Cutler-Hammer	0	0	1	F	F		0	0	1	0	10		0	0	0	1	9	
MS 24525-31 four pole-on/off/mom on																		
Cutler-Hammer	0	0	1	21	F		0	0	1	0	6		0	0	0	0	6	

NOTES: *Contacts open for first 5-mission phase, closed for all others.
F = Continuous contact chatter

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EVALUATION REPORT FOR TOGGLE SWITCHES

Texas Instruments, Inc. – Apollo-Type

And

Daven Measurements Part Number 45000-XXX

Job Order 32-139

Prepared By

Lockheed Electronics Company, Inc.
Aerospace Systems Division
Houston, Texas

Contract NAS 9-12200

For

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CONTENTS

1.0 INTRODUCTION

1.1 Background

As a part of a continuing program to find suitable candidate hardware for panel switches in the Space Shuttle, a preliminary evaluation of environmental capabilities was undertaken on toggle switches manufactured by Daven Measurements Division of Edison Electronics (Daven part number 45000-xxx) and on Apollo-type toggle switches manufactured by Texas Instruments, Inc. (Klixon xxLSx-x). It was not the purpose of this evaluation to qualify these two types of switches to the detailed requirements of the Space Shuttle environmental specifications, but rather to take a "first look" at their tested capabilities for the purpose of determining whether the candidate hardware appears to have a good chance of successfully completing a detailed environmental qualification test program.

1.2 Summary of Evaluation Program

The initial phase of the evaluation reported herein consisted of comparing the demonstrated environmental capabilities of the two candidate switch types to the latest available Space Shuttle environmental requirements. The documents used for this comparison were:

- Certification Test Requirement, Apollo Block II, Part No. ME452-0102-1101, North American Aviation, Inc., 18 February 1969 (for Klixon switches).

- Specification 40M38202, George C. Marshall Space Flight Center, 3-27-70 (for Daven switches).
- Specification MC450-0016, "Controller, Master Events", North American Rockwell Corporation, 22 August 1973 (Shuttle requirements).

Based on the comparison of environmental parameters in these three documents, it was decided that additional information was needed concerning the capability of the switches to withstand exposure to random vibration without contact chatter.

The Space Shuttle temperature and linear acceleration requirements were not judged to be severe enough to necessitate additional tests to satisfy the purposes of this evaluation. Successful techniques for hermetically sealing such switches have been in use for some time and hence it was felt that the purposes of this evaluation could be well satisfied without particular concern for the survivability of the switches in vacuum, explosive atmosphere, and sand and dust.

As described below, 16 Klixon and 8 Daven switches, of several different contact configurations, were subjected to random vibration with the most recently defined power spectral density for the Space Shuttle as of the date of the test.

2.0 EVALUATION PROGRAM

2.1 Specification Comparison

As indicated in section 1, the tested capabilities of the Texas Instruments (TI) switches and of the Daven Measurements switches were compared to the most recent statement of environmental exposure requirements for the Space Shuttle available at the time the comparison was made. The contents of the three documents used for this comparison that were deemed pertinent to the purposes of this evaluation are summarized in table I.

Although the tested capabilities of the two types of switches for *salt spray* and *humidity* do not match the stated Shuttle requirements, most notably with respect to the duration of exposure, the ability of devices to withstand these environments should be primarily dependent upon the materials used for the exposed surfaces and the techniques used to seal the package. Similar components have been made that can withstand such extended exposures, so it was felt that these two types of switches could successfully complete detailed qualification testing without redesign, and that actual testing, for this evaluation, was unnecessary.

The tested *temperature* capabilities of the switches are reasonably close to the Shuttle requirements for equipment located in the crew compartment. Even the temperature requirements for qualification tests, which are slightly more severe than those actually expected (and quoted in table I), are not so severe that evaluation tests at temperature extremes were deemed to be a necessary part of this evaluation.

TABLE I.- COMPARISON OF ENVIRONMENTAL SPECIFICATION REQUIREMENTS FOR TEXAS INSTRUMENTS AND DAVEN MEASUREMENTS TOGGLE SWITCHES VS SPACE SHUTTLE TENTATIVE REQUIREMENTS

ENVIRONMENT	TEXAS INSTRUMENTS INC. T.I. QAS 758 & NR ME452-0102-XXX	DAVEN MEASUREMENTS MSFC 40M38202	SHUTTLE-TENTATIVE NR MC450-0016 (CONTROLLER, MASTER EVENTS)
SALT SPRAY	Solution: 1% NaCl Duration: 1 hour Ref.: MIL-STD-810	5% NaCl 96 hours @ 35° C MIL-STD-202D Method 101 Test Condition A	5% NaCl 30 days MIL-STD-810 Method 509 Procedure I
HUMIDITY	Exposure: 95±5% R.H.; 95±5% O_2 Duration: 120 hours Temperature: 100°±5° F Ref: MIL-STD-810	90-95% R.H. 96 hours 40°±2° C (104° F) MIL-STD-202D Method 103 Test Condition B	95% R.H. 240 hours 71° C (160° F) MIL-STD-810B Method 507 Procedure I
TEMP.	Cycling from +40° F to +135° F under reduced pressure $\times 10^{-4}$ Torr) Ref: ME452-0102 par 10	Cycling from -55° C to +85° C (-67° F to +185° F) MIL-STD-202 Method 102 Test Condition D	Cycling from +70° F to +150° F to +30° F to +70° F MC450-0016 par 4.2.2.4
SHOCK	Form: Sawtooth Peak: 78 g Duration: 10-15 msec Ref: ME452-0102 par 4.4.3	Half-Sine 50 g 11 msec MIL-STD-202 Method 213 Test Condition A	Sawtooth 40 g 11 msec MC450-0016 par 3.2.5.2, f. 2
VIBRATION	Random — 20-80 Hz +3 dB/octave to 0.06g^2/Hz 80-2000 Hz constant at 0.06g^2/Hz (totals 10.84 g rms) for 2-1/2 min/axis Ref: ME452-0102 par 4.4.2.2	Extensive sinusoidal and random. See MSFC 40M38202 par 3.7.8 (subpar. d requires a random spectrum totaling 7.42 g rms for 20 min/axis)	Random — 20-200 Hz +9 dB/octave 200-400 Hz constant at 0.05g^2/Hz 400-2000 Hz -9 dB/octave (totals 4.70 g rms) for 6 min/axis/mission (previous inhouse test of MS3950 toggle switches was random totaling 7.41 g rms for 70 sec/axis/mission)

The Shuttle qualification test requirements include *vacuum* conditions (10^{-9} torr) in association with temperature cycling. The TI switches have demonstrated an ability to withstand pressures at least as low as 10^{-4} torr. No evidence was found of similar tested capabilities for the Daven switches. However, this capability should also be a function of a properly sealed package, and not the basic switch design. Hence, supplemental vacuum testing was not considered a necessary part of this evaluation.

Although there is some minor difference in wave shape, both types of switches have been tested at higher levels of *shock* than those required for the Shuttle. Hence, no shock tests were performed.

The Shuttle *vibration* requirements have total energy levels approximately equal to or below those at which both switch types have been tested. However, the distribution of this energy across the frequency spectrum is different in all cases. Because of this, supplemental vibration testing of both types of switches was considered necessary. (Note: The power spectral density (PSD) used for these tests was different from the requirements stated in the reference document for the Shuttle. The PSD to which the switches were actually exposed was chosen because of a more recent statement of Shuttle requirements than that quoted in MC450-0016).

Neither the TI nor the Daven switches apparently have been tested for satisfactory operation while being exposed to linear *acceleration*. Although the Shuttle requirements include exposure to such an environment (±4 g's for

5 min/axis), the level is so low that no anomalies should reasonably be expected after successful completion of the shock and vibration tests which are documented. For this reason, no supplemental linear acceleration testing was deemed necessary.

2.2 Vibration Testing

2.2.1 Test Sample

A total of 24 switches were exposed to the random vibration spectrum described in paragraph 2.2.2.1 below. To facilitate this exposure these were divided into three groups of eight switches each. Two of the groups, i.e., a total of 16 switches, were comprised of Texas Instruments' "Klixon" switches, as follows:

	Quantity	Type No.		Configuration*
Group 1 --	2	11LS2-2	1P2T	MA-MA
	2	23LS3-2	3P3T	LK MA-LK MA-LK MA
	2	14LS2-3	4P3T	MA-OFF-MA
	2	13LS3-2	3P2T	LK MA-LK MA
Group 2 --	2	12LS2-2	2P3T	MO-OFF-MO
	2	12LS3-3	2P3T	MO-LK OFF-MO

*MA = Maintained
MO = Momentary
LK = Locked

	Quantity	Type No.		Configuration*
Group 2 –				MA-MA-OFF
(con't)	2	23LS2-5	3P3T	OFF-MA-OFF
				MA-MA-OFF
	2	18LS2-1	3P3T	MO-LK CFF-MO

The last group was comprised of the Daven Measurement switches, type 45000-xxx, as follows:

	Quantity	Type No.		Configuration*
Group 3 –	1	-201	2P2T	MA-MA
	1	-202	2P2T	MA-MO
	2	-308	3P3T	MA-OFF-MA
	2	-204	2P3T	MA-OFF-MA
	2	-207	2P3T	MO-OFF-MO

As can be seen, two of each type except the Daven -201 and -202 were included in the total test sample. Only one of these two Daven types was tested because additional switches were not available.

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*MA = Maintained

MO = Momentary

LK = Locked

2.2.2 Test Procedure

2.2.2.1 Environmental. The test sample was exposed to the following random vibration under room ambient temperature and pressure:

10 Hz @ 3 mg^2/Hz

10 Hz to 24 Hz @ +12 dB/octave

24 Hz to 160 Hz @ 100 mg^2/Hz

160 Hz to 2 kHz @ -6 dB/octave

2 kHz @ 0.65 mg^2/Hz

(Overall level of 5.37g rms)

The total duration of the exposure was 1 hour and 59 minutes in each of three orthogonal axes. Definition of these axes relative to the physical characteristics of the switches (viewed from the terminal side) is included in figures A-1 through A-3. In order to maintain the accumulated exposure duration equal, within practical limits, in each of the three axes, the switches were first exposed for two simulated missions in each of the three axes. (A simulated mission was defined as an exposure of 70 seconds.) Next, they were exposed for five missions in each axis. This was followed by a second 5-mission exposure in each axis, then 10 missions, 30 missions, and finally 50 missions in each axis.

2.2.2.2 Electrical. Before and after vibration exposure, the voltage drop across all possible closed contacts of each switch was measured at load currents of both 0.1 and 10.0 amps. Because, in most instances, slight variations in the test setup prevented exact repeatability of these measurements, a minimum of three readings were taken for each terminal-pair at each load current. Both the minimum and maximum readings were recorded.

During vibration exposure contact chatter (inadvertent opening of normally closed, or closing of normally open contacts for 10 μs or more) was monitored. The test setups are shown in figures A-1 through A-3. On all switches having maintained normally closed positions, the contacts were set to these positions. Insofar as possible within available maintained positions, the two switches of the same type were set to different positions. For these normally closed contacts, all such pairs of contacts on each switch were connected in series, thus providing a single signal for that switch to the chatter detector. On those switches where normally open was the only maintained position available, all contact pairs were connected in parallel, thereby again providing a single signal for that switch to the chatter detector.

2.2.3 Test Results

The test data forms appendix A to this document. With one exception, very little or no contact chatter was detected during vibration exposure. Although there were differences (both increases and decreases) between the contact voltage drops measured before and after vibration exposure, no definite degradation in the performance of any of the switches, including the one which exhibited excessive contact chatter during vibration, was detected.

Of the 16 TI Klixon switches tested, no contact chatter was detected in 10 of them. All chatter detected in the other six switches was noted in at least two switches simultaneously, indicating that at least half of the detected signals were erroneous. (The chatter monitor used exhibited not only this channel-to-channel crosstalk, but also susceptibility to noise on its power line. Several channels indicated detected chatter when a large rollup door in the bi-bay near the vibration facility was opened.)

Of the eight Daven switches tested, no chatter was detected in two of them. Unlike the results for the Klixon switches, however, only part of chatter detected in the other six occurred in two switches simultaneously. One of the six, a -308 (3P3T, MA-OFF-MA) exhibited continuous chatter, starting during the 10-minute exposure and continuing through the 50-minute exposure. During this time, the chatter monitor channel was changed to verify that the monitor was not at fault. It should be noted that no significant degradation in contact voltage drop was measured on this switch after vibration exposure. It should also be noted that another -308 switch was tested, with its toggle in a different position, at the same time and this switch exhibited no chatter at all.

3.0 CONCLUSIONS

No previously documented or in-house test data was found which should disqualify either of these two types of switches from further detailed evaluation. The continuous chatter exhibited by the one Daven switch was unique and is felt to be a result of some flaw in that particular switch rather than the basic switch design.

4.0 RECOMMENDATIONS

It is recommended that both of the two types of switches evaluated herein be considered candidate for use on the Space Shuttle unless additional information or considerations indicate otherwise.

APPENDIX A

TEST DATA

TEST SAMPLE		CONTACT VOLTAGE DROP (millivolts) [1]						VIBRATION Spectrum: [2] Performed: 11/27-30/73			
				Before Vibration Measured: 11/19-23/73		After Vibration Measured: 12/4-5/73			Contact Chatter Signals		
Number	Vendor Part Number (S/N)	Terminal Pair	Toggle Position	@10A	@0.1A	@10A	@0.1A	Toggle Position	Number	Exposure Duration (Missions)	Axis
1	KLIXON 11LS2-2 (225)	2-1	KW	37.0-34.8	0.4-0.3	37.1-31.5	0.4-0.4	KW [1]	None		
		2-3	OKW	39.2-37.3	0.4-0.4	39.2-39.0	0.4-0.4				
2	KLIXON 11LS2-2 (228)	2-1	KW	49.6-39.0	0.5-0.4	32.3-30.4	0.3-0.3	OKW [1]	None		
		2-3	OKW	39.4-41.5	0.4-0.4	30.1-31.5	0.2-0.4				
3	KLIXON 23LS3-2 (171)	2-4	CTR	47.6-50.8	0.5-0.5	49.5-48.4	0.5-0.5	CTR [1]	None		
		6-8	CTR	19.4-31.5	0.2-0.3	51.4-56.7	0.6-0.5				
		10-12	CTR	31.5-40.5	0.3-0.4	46.2-46.3	0.5-0.4				
		2-3	OKW	52.6-51.5	0.5-0.5	38.9-34.1	0.4-0.4				
		6-7	OKW	62.5-61.7	0.6-0.6	42.5-49.1	0.5-0.4				
		10-11	OKW	49.0-50.5	0.5-0.5	37.3-39.9	0.3-0.3				
		2-1	KW	49.2-47.6	0.5-0.5	51.2-51.6	0.5-0.4				
		6-5	KW	59.8-59.2	0.6-0.6	20.5-30.0	0.3-0.3				
		10-9	KW	47.7-47.3	0.5-0.5	48.0-42.0	0.4-0.4				
4	KLIXON 23LS3-2 (177)	2-4	CTR	46.8-45.8	0.5-0.5	45.4-34.5	0.5-0.4	KW [1]	None		
		6-8	CTR	45.8-44.8	0.5-0.5	46.3-45.4	0.4-0.4				
		10-12	CTR	48.6-46.7	0.5-0.5	53.6-49.8	0.5-0.5				
		2-3	OKW	55.1-53.9	0.6-0.5	50.1-56.6	0.5-0.5				
		6-7	OKW	49.6-46.3	0.5-0.5	50.2-49.2	0.5-0.4				
		10-11	OKW	50.0-46.1	0.5-0.5	53.8-54.8	0.5-0.5				
		2-1	KW	50.4-49.6	0.5-0.5	46.5-42.8	0.5-0.4				
		6-5	KW	41.9-45.1	0.4-0.4	43.8-42.8	0.5-0.4				
		10-9	KW	45.8-48.2	0.5-0.5	49.2-47.4	0.5-0.4				
5	KLIXON 14LS2-3 (215)	2-3	OKW	34.9-38.0	0.4-0.4	37.2-36.8	0.4-0.3	KW [1]	1	30	2 [3]
		5-6	OKW	48.0-45.1	0.4-0.4	42.6-48.5	0.4-0.4				
		9-9	OKW	54.1-52.7	0.5-0.5	50.2-55.9	0.5-0.5				
		11-12	OKW	38.9-38.1	0.4-0.4	18.3-37.9	0.2-0.3				
		2-1	KW	40.6-42.4	0.4-0.4	38.6-39.0	0.4-0.4				
		5-4	KW	43.2-42.2	0.4-0.4	38.2-38.2	0.4-0.4				
		8-7	KW	44.7-42.8	0.4-0.4	43.8-45.1	0.4-0.4				
		11-10	KW	33.0-34.5	0.3-0.3	36.3-33.1	0.4-0.2				
			CTR	ALL CONTACTS OPEN							

TEST SAMPLE		CONTACT VOLTAGE DROP (millivolts) [1]						VIBRATION Spectrum: [2] Performed: 11/27-30/73			
				Before Vibration Measured: 11/19-23/73		After Vibration Measured: 12/4-5/73			Contact Chatter Signals		
Number	Vendor Part Number (S/N)	Terminal Pair	Toggle Position	@10A	@0.1A	@10A	@0.1A	Toggle Position	Number	Exposure Duration (Missions)	Axis
6	KLIXON 14LS2-2 (220)	2-3	OKW	10.3-12.2	0.1-0.1	38.2-38.1	0.4-0.3	OKW [11]	1	30	X
		5-6	OKW	11.1-16.1	0.1-0.1	36.5-38.7	0.4-0.3				
		8-9	OKW	10.4-10.5	0.1-0.1	36.8-37.0	0.4-0.3		1	30	Z [4]
		11-12	OKW	14.6-16.8	0.1-0.2	17.0-17.6	0.2-0.2				
		2-1	KW	20.3-38.6	0.2-0.4	40.0-40.0	0.4-0.4				
		5-4	KW	42.6-40.5	0.4-0.4	43.5-39.0	0.4-0.3				
		8-7	KW	13.4-13.2	0.2-0.2	36.5-35.1	0.4-0.3				
		11-10	KW	40.0-43.2	0.4-0.4	42.7-43.3	0.5-0.3				
			CTR		ALL CONTACTS OPEN						
7	KLIXON 13LS3-2 (159)	2-3	OKW	41.0-41.0	0.4-0.4	40.3-43.5	0.4-0.4				
		5-6	OKW	41.2-39.7	0.4-0.3	41.8-42.2	0.4-0.4				
		8-9	OKW	38.0-38.2	0.3-0.4	39.5-39.7	0.4-0.4				
		2-1	KW	11.6-11.6	0.1-0.1	38.5-38.4	0.4-0.4				
		5-4	KW	10.8-11.2	0.1-0.1	37.0-39.5	0.4-0.4				
		8-7	KW	10.4-10.4	0.1-0.1	36.8-36.7	0.4-0.4				
8	KLIXON 13LS3-2 (161)	2-3	OKW	12.1-15.1	0.1-0.1	41.8-38.3	0.4-0.4	OKW [11]	None		
		5-6	OKW	40.7-42.7	0.4-0.4	44.7-44.9	0.3-0.5				
		8-9	OKW	36.5-35.1	0.4-0.4	38.4-37.9	0.4-0.3				
		2-1	KW	37.1-40.0	0.4-0.4	37.2-33.5	0.3-0.3				
		5-4	KW	19.4-18.6	0.2-0.2	37.4-37.2	0.3-0.2				
		8-7	KW	12.7-13.5	0.1-0.1	43.9-46.0	0.3-0.2				
9	KLIXON 12LS3-3 (346)	2-3	OKW	36.4-32.9	0.3-0.3	33.0-32.8	0.3-0.3	CTR [12]	None		
		5-6	OKW	34.0-33.8	0.3-0.3	32.5-41.0	0.3-0.4				
		2-1	KW	34.1-33.2	0.3-0.3	34.8-35.9	0.4-0.4				
		5-4	KW	55.0-50.5	0.5-0.5	40.6-37.2	0.4-0.4				
			CTR		ALL CONTACTS OPEN						
10	KLIXON 12LS3-3 (307)	2-3	OKW	38.4-39.8	0.4-0.4	36.5-37.6	0.4-0.4	CTR [12]	None		
		5-6	OKW	35.2-34.8	0.3-0.3	35.6-37.1	0.3-0.4				
		2-1	KW	38.2-35.8	0.4-0.3	37.1-35.6	0.4-0.3				
		5-4	KW	33.2-33.6	0.3-0.3	33.3-37.3	0.3-0.3				
			CTR		ALL CONTACTS OPEN						

TEST SAMPLE Number	TEST SAMPLE Ven or Part Number (S/N)	CONTACT VOLTAGE DROP (millivolts) [1] Terminal Pair	Toggle Position	Before Vibration Measured: 11/19-27/73 @10A	Before Vibration Measured: 11/19-27/73 @0.1A	After Vibration Measured: 12/4-5/73 @10A	After Vibration Measured: 12/4-5/73 @0.1A	VIBRATION Spectrum: [2] Performed: 11/27-30/73 Toggle Position	Contact Chatter Signals Number	Exposure Duration (Missions)	Axis
11	KLIXON 12LS2-2 (461)	2-3	OKW	36.8-35.7	0.3-0.3	34.1-35.4	0.4-0.4	CTR [12]	None		
		5-6	OKW	40.2-39.8	0.4-0.4	33.1-33.?	0.4-0.4				
		2-1	KW	32.5-36.8	0.3-0.3	36.5-35.4	0.4-0.4				
		5-4	KW	46.8-41.5	0.5-0.4	36.2-37.8	0.4-0.4				
			CTR	ALL CONTACTS OPEN							
12	KLIXON 12LS2-2 (495)	2-3	OKW	37.7-37.8	0.4-0.4	34.3-34.6	0.3-0.3	CTR [12]	None		
		5-6	OKW	32.5-33.0	0.3-0.3	34.9-34.9	0.3-0.3				
		2-1	KW	38.3-37.6	0.3-0.3	38.4-37.5	0.4-0.4				
		5-4	KW	33.0-33.8	0.4-0.4	34.7-35.2	0.4-0.3				
			CTR								
13	KLIXON 18LS2-1 (328)	2-3	OKW	36.3-36.3	0.4-0.4	41.0-34.8	0.3-0.3	CTR [12]	3	50	Z [5]
		5-6	OKW	52.2-52.1	0.5-0.5	38.8-36.1	0.3-0.3		2	50	X [5]
		8-9	OKW	32.5-31.3	0.3-0.5	35.8-36.3	0.2-0.3		1	50	Y [5]
		2-1	KW	37.1-36.0	0.4-0.4	34.2-34.6	0.3-0.3				
		5-4	KW	53.5-49.1	0.5-0.5	35.9-35.8	0.3-0.3				
		8-7	KW	32.0-32.6	0.3-0.3	34.9-35.4	0.3-0.3				
			CTR	ALL CONTACTS OPEN							
14	KLIXON 18LS2-1 (309)	2-3	OKW	42.2-41.1	0.4-0.4	42.8-42.4	0.5-0.5	CTR [12]	2	10	Z [6]
		5-6	OKW	34.9-35.6	0.3-0.3	35.9-32.5	0.4-0.3		2	50	Z [5]
		8-9	OKW	36.3-35.8	0.3-0.3	32.1-39.4	0.4-0.4		1	50	Y [5]
		2-1	KW	47.1-41.3	0.4-0.3	55.1-57.5	0.6-0.6				
		5-4	KW	36.0-35.1	0.4-0.3	36.6-37.6	0.3-0.3				
		8-7	KW	35.5-35.0	0.3-0.3	38.0-38.5	0.4-0.4				
			CTR	ALL CONTACTS OPEN							
15	KLIXON 23LS2-5 (157)	2-1	CTR	42.0-43.6	0.4-0.4	42.9-43.5	0.4-0.5	OKW [12]	1	30	Z [6]
		6-5	CTR	98.9-92.3	0.4-0.4	86.5-86.0	0.9-0.9		6	50	Z [5]
		4-3	CTR	46.3-46.9	0.5-0.5	42.5-40.3	0.4-0.4		2	50	X [5]
		2-1	OKW	42.5-40.4	0.1-0.4	39.5-41.1	0.4-0.4		2	50	Y [5]
		4-3	OKW	42.5-41.1	0.4-0.4	41.0-41.0	0.4-0.5				
			KW	ALL CONTACTS OPEN							

TEST SAMPLE		CONTACT VOLTAGE DROP (millivolts) [1]						VIBRATION Spectrum: [2] Performed: 11/27-30/73			
				Before Vibration Measured: 11/19-2 3		After Vibration Measured: 12/4-5/73			Contact Chatter Signals		
Number	Vendor Part Number (S/N)	Terminal Pair	Toggle Position	@10A	@0.1A	@10A	@0.1A	Toggle Position	Number	Exposure Duration (Passions)	Axis
16	KLIXON 23LS2-5 (171)	2-1	CTR	46.5-45.9	0.5-0.5	46.5-44.3	0.4-0.4	CTR [12]	2	10	Z [7]
		6-5	CTR	105.3-105.5	1.1-1.1	102.4-102.1	1.0-1.0				
		4-3	CTR	41.2-40.4	0.4-0.4	44.1-45.8	0.4-0.4		1	30	Z [illegible]
		2-1	OKW	45.9-47.7	0.4-0.5	45.3-43.0	0.5-0.5		1	30	Z
		4-3	OKW	39.4-39.4	0.4-0.4	41.8-41.8	0.4-0.4				
			KW	ALL CONTACTS OPEN					6	50	Z [5]
									3	50	X [5]
									1	50	Y [5]
17	DAVEN 45000 -308 (032)	1-3	CTR	22.5-22.2	0.2-0.2	22.4-22.4	0.1-0.1	CTR [13]	None		
		5-7	CTR	25.7-25.7	0.2-0.2	26.2-26.2	0.2-0.2				
		9-11	CTR	31.5-31.0	0.3-0.3	28.4-28.0	0.2-0.2				
		1-4	OKW	31.7-30.5	0.3-0.3	32.5-32.1	0.3-0.3				
		5-8	OKW	33.6-32.7	0.3-0.3	38.5-39.3	0.3-0.3				
		9-12	OKW	20.1-20.9	0.2-0.2	27.5-26.8	0.2-0.2				
		1-2	KW	22.3-20.8	0.2-0.2	24.9-24.4	0.2-0.2				
		5-6	KW	41.7-41.4	0.4-0.4	34.1-34.4	0.2-0.2				
		9-10	KW	41.9-42.9	0.4-0.4	19.4-19.2	0.2-0.2				
18	DAVEN 45000 -308 (029)	1-3	CTR	13.4-13.0	0.1-0.1	13.5-13.4	0.1-0.1	KW [13]	1	2	X
		5-7	CTR	14.6-14.5	0.1-0.1	23.6-23.4	0.1-0.1				
		9-11	CTR	36.7-36.8	0.4-0.4	31.3-31.0	0.2-0.2		2	5	Z
		1-4	OKW	19.0-20.2	0.2-0.2	21.8-21.7	0.2-0.1		Continuous	10, 30, 50	X, Y, Z
		5-8	OKW	21.7-22.2	0.2-0.2	25.1-25.6	0.1-0.1				
		9-12	OKW	24.5-24.2	0.2-0.2	27.1-23.7	0.1-0.1				
		1-2	KW	16.7-16.3	0.2-0.2	19.7-18.7	0.1-0.[illegible]				
		5-6	KW	47.5-49.0	0.5-0.5	58.7-73.1	0.5-0.7				
		9-10	KW	35.8-36.0	0.4-0.4	65.7-66.8	0.5-0.4				

TEST SAMPLE Number	Vendor Part Number (S/N)	Terminal Pair	Toggle Position	CONTACT VOLTAGE DROP (millivolts) [1] Before Vibration Measured: 11/19-23/73 #10A	#0.1A	After Vibration Measured: 12/4-5/73 #10A	#0.1A	VIBRATION Spectrum: [2] Performed: 11/27-30/73 Toggle Position	Contact Chatter Signals Number	Exposure Duration (Missions)	Axis
19	DAVEN 45000 -204 (027)	2-3 5-6	OKW OKW	36.4-36.4 22.6-24.8	0.3-0.4 0.2-0.2	20.2-19.8 20.7-19.8	0.1-0.1 0.1-0.1	KW [13]	None		
		2-1 5-4	KW KW	23.6-23.3 32.4-34.5	0.2-0.2 0.3-0.3	26.7-26.9 27.7-27.2	0.2-0.2 0.2-0.2				
			CTR		ALL CONTACTS OPEN						
20	DAVEN 45000 -204 (030)	2-3 5-6	OKW OKW	36.6-36.3 37.0-37.8	0.4-0.4 0.4-0.4	28.8-28.8 28.8-28.9	0.2-0.2 0.2-0.2	OKW [13]	2	50	Z
		2-1 5-4	KW KW	23.5-23.4 33.4-32.7	0.2-0.2 0.3-0.3	24.4-23.9 38.9-36.2	0.2-0.2 0.3-0.3				
			CTR		ALL CONTACTS OPEN						
21	DAVEN 45000 -207 (028)	2-3 5-6	OKW OKW	26.6-28.9 26.4-22.7	0.2-0.3 0.3-0.2	32.5-31.5 33.3-29.1	0.2-0.2 0.3-0.2	CTR [13]	3	50	Y [9]
		2-1 5-4	KW KW	43.5-37.5 31.2-29.6	0.5-0.3 0.3-0.3	37.6-38.3 37.2-38.1	0.2-0.3 0.3-0.3				
			CTR		ALL CONTACTS OPEN						
22	DAVEN 45000 -207 (031)	2-3 5-6	OKW OKW	23.7-26.8 26.1-24.7	0.2-0.2 0.3-0.3	27.1-24.4 30.3-33.3	0.2-0.2 0.2-0.2	CTR [13]	1	10	Z
		2-1 5-4	KW KW	29.6-26.8 25.1-29.2	0.3-0.3 0.2-0.3	28.8-27.7 21.8-21.8	0.2-0.2 0.1-0.1		1 3	50 50	Y Y [10]
			CTR		ALL CONTACTS OPEN						
23	DAVEN 45000 -202 (025)	2-3 5-6	OKW OKW	79.6-62.5 66.3-67.0	0.8-0.5 0.6-0.6	90.2-89.8 48.3-49.7	0.9-0.8 0.4-0.4	OKW [13]	None		
		2-1 5-4	KW KW	67.6-90.1 75.3-78.8	0.7-0.8 0.8-1.1	94.6-90.9 89.1-63.0	0.9-0.2 0.8-0.6				
24	DAVEN 45000 -201 (024)	2-3 5-6	OKW OKW	29.0-28.5 19.9-20.0	0.3-0.3 0.2-0.2	36.5-31.8 16.9-16.9	0.3-0.3 0.1-0.1	KW [13]	1	50	Y
		2-1 5-4	KW KW	50.5-45.2 25.2-25.2	0.5-0.5 0.3-0.3	43.2-38.4 30.8-29.6	0.4-0.4 0.2-0.2				

Notes:

1 Instrumentation Used:

- Digital Multimeter, Fairchild Model 7000, NASA Inv. #87404
- Power Supply B, Christie Electric Corp., NASA Inv. #(none)
- Load Bank (in-house)
- Discontinunity Time Monitor, Continental Testing Laboratory, NASA Inv. #82732

2 Spectrum:
10 Hz @3 mg^2/Hz
10 Hz to 24 Hz +12 dB/octave
24 Hz to 160 Hz @100 mg^2/Hz
160 Hz to 2000 Hz -6 dB/octave
2000 Hz @0.65 mg^2/Hz
overall level of 5.37g rms

3 Simultaneously with Test Sample 6

4 Simultaneously with Test Sample 5

Notes:

$\boxed{5}$ Simultaneous contact-chatter signals during 50-mission run (time of day):

Sample No.	(Contacts)	Axis Z 0923						Axis X 1030			Axis Y 1133	
16	(NC)	0928	0940	0948	0955	1011	1015	1037	1050	1052		1220
15	(NC)	0928	0940	0948	0955	1011	1015		1050	1052	1150	1220
14	(NO)	0928										1220
13	(NO)		0940			1011	1015		1050	1052		1220

$\boxed{6}$ Simultaneously with Test Sample 16

$\boxed{7}$ Simultaneously with Test Sample 14

$\boxed{8}$ Simultaneously with Test Sample 15

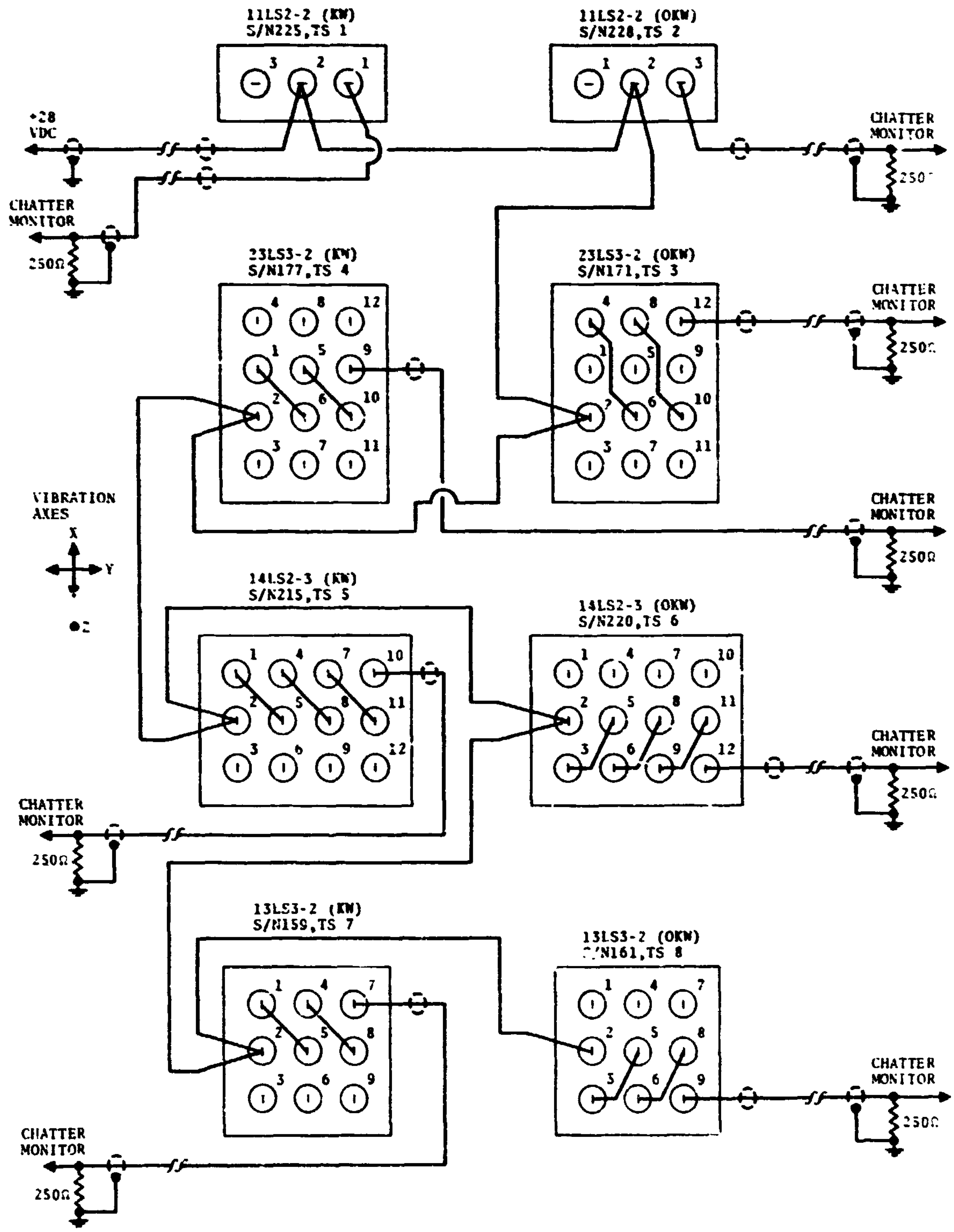
$\boxed{9}$ Simultaneously with Test Sample 22

$\boxed{10}$ Simultaneously with Test Sample 21

$\boxed{11}$ See wiring diagram, figure A-1

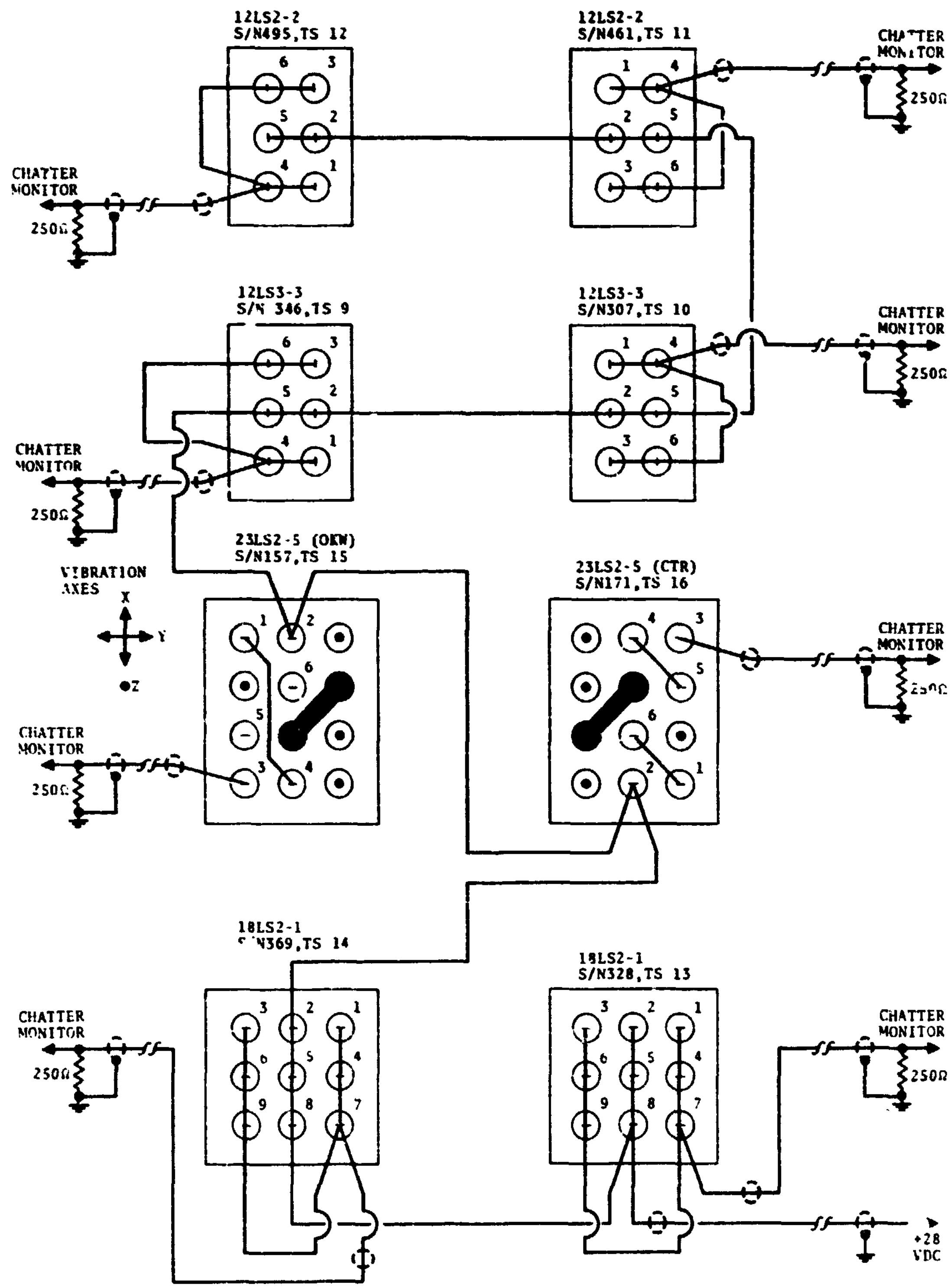
$\boxed{12}$ See wiring diagram, figure A-2

$\boxed{13}$ See wiring diagram, figure A-3



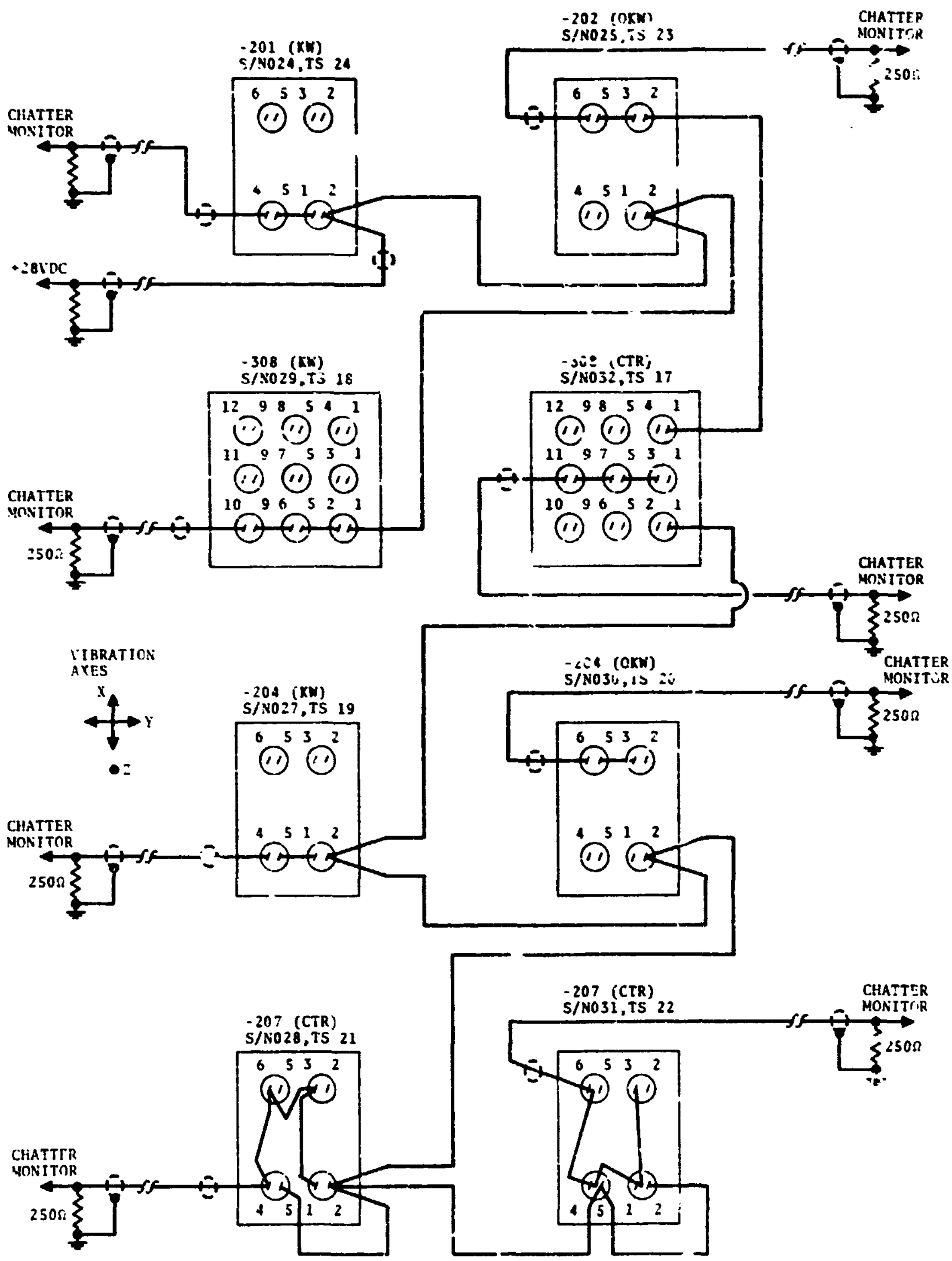
KW = KEY WAY
OKW = OPPOSITE KEY WAY
TS = TEST SAMPLE

Figure A-1. – Vibration test setup - TI switches, group 1.



OKW = OPPOSITE KEY WAY
CTR = CENTER
TS = TEST SAMPLE

Figure A-2. – Vibration test setup - TI switches, group 2.



KW = KEY WAY
OKW = OPPOSITE DEY WAY
CTR = CENTER
TS = TEST SAMPLE

Figure A-3. – Vibration test setup - Daven switches.

APPENDIX C

FINAL REPORT FOR SOLID-STATE SWITCH PANEL

N74-35273

DOCUMENT NO. Y256A226 REV -

CONTRACT NO. NAS 9-13144
DRD NO. MA-129TA

ENGINEERING TECHNICAL REPORT

FINAL REPORT FOR SOLID STATE SWITCH PANEL

26 NOVEMBER 1973

SINGER
AEROSPACE & MARINE SYSTEMS

DRR NO. 01361(NP)

THE SINGER COMPANY • KEARFOTT DIVISION • 1150 MCBRIDE AVENUE • LITTLE FALLS, N. J. 07424

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THE SINGER COMPANY
KEARFOTT DIVISION

Y256A226 REV. -

CONTRACT NO. NAS 9-13144
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FINAL REPORT

FOR

SOLID STATE SWITCH PANEL

26 NOVEMBER 1973

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ABSTRACT

An intensive study of various forms of transducers was conducted with application towards hermetically sealing the transducer pick off and all electronics. The results of the study indicated that the Hall effect devices and a LED/phototransistor combination were the most practical for this type of application. Therefore, hardware was developed utilizing a magnet/Hall effect transducer for single action switches and LED/phototransistor transducers for rotary multiposition or potentiometer applications. All electronics could be housed in a hermetically sealed compartment. A number of switches were built and models were hermetically sealed to prove the feasibility of this type of fabrication. One of each type of switch was subjected to temperature cycling, vibration, and EMI tests. The results of these tests are indicated in the following report.

TABLE OF CONTENTS

RESULTS

The results of this project are:

1. An operating switch panel conforming to the requirements of NAS-9-13144.

2. Test data taken during environmental tests performed on selected switch and rotary components. The tests performed were comparable to tests run on NASA flight hardware delivered on the skylab project. Satisfactory results were obtained on all tests.

3. Reliability data indicating MTBF for selected devices.

4. A project report covering the study phase of the project and containing test data, schematics, and outline drawings of the switch devices and the mounting panel.

CONCLUSIONS

The results of this project indicate that solid state switches and rotary components capable of meeting the requirements of manned space flight are feasable and well within the current state of the art. The environmental and reliability data indicate that a production unit would have the superior reliability associated with solid state equipment. The large selection of contact closure types will allow switches to be fitted to various requirements. A phase II production type unit would be packaged in a smaller and lighter housing. The feel of each switch and the front panel appearance would be improved in the phase II design.

RECOMMENDATION

The study indicated that the most efficient switch is one designed to switch a specified voltage and current. Using a high current switch to handle a low current is inefficient. Any production switches should be designed for a specific power level.

In production quantities a hybrid package containing all the electronics is recommended as a way to save size and increase reliability of the solid state switch devices.

Reduction of switch size would allow the toggle section of the switch to be brought flush to the panel surface and otherwise improve the appearance of the switches.

It is also recommended that a closer analysis of the front panel removability criteria be made with an effort to reduce the panel area used for fastening.

INTRODUCTION

The purpose of this report is to summarize the results of a study conducted to determine the optimum transducer type and output circuitry for a solid state switch configuration and to demonstrate with hardware, the feasibility of the resulting designs. Two basic types of switches are required, a single action switch (toggle, pushbutton) and a multiposition rotary switch and/or potentiometer. The switches will be designed to be hermetically sealed and removable as an integral unit from the front of the panel. Selected switches contain a Light Emitting Diode (LED) display indicating the status of the switch position and/or operable or failure mode.

The various types of transducers studied included the following:

- Light
- Capacitive
- Hall effect
- Magneto-resistor

Many factors were considered in selecting the appropriate transducer for the application and the necessary circuitry for the switch output. They were as follows:

- Type of excitation required
- Power required
- Cost
- Size
- Reliability
- Hermetic sealing capability
- Cross talk effects
- Packaging
- Switching characteristics

A matrix indicating these characteristics of the various transducers are shown in Table I.

TABLE I. TRANSDUCER MATRIX

	LIGHT	CAPACITANCE	HALL EFFECT	MAGNETO RESISTOR
POWER	.150 WATTS	.100 WATT	.050 WATT	.050 WATT
EXCITATION	DC 5-10V	AC 10 KHZ	DC 5-10V	DC 5-10W
COST	MODERATE	HIGH	LOW	MODERATE
CROSS TALK	NONE	PROBLEM AREA	NONE	NONE
HERMETIC SEAL	PROBLEM AREA GLASS TO METAL SEAL	PROBLEM AREA GLASS TO METAL SEAL	COMPATABLE	COMPATABLE
SIZE	MODERATE	LARGE	SMALL	MODERATE
COMPONENTS	TWO SILICON SEMI-CONDUCTORS AND GLASS SEAL	TWO SEALED METAL PLATES AND DRIVE CIRCUITRY	ONE INTEGRATED CIRCUIT AND MAGNET	ONE SEMI-CONDUCTOR AND DRIVE CIRCUITRY
SWITCHING CHARACTERISTICS	REQUIRES TRIGGER	REQUIRES TRIGGER	TRIGGER PART OF IC	TRIGGER REQUIRED

The results of the study indicated that the Hall effect transducer is the most effective for the single action switch and the LED/phototransistor is the optimum device for the multiposition rotary switch and potentiometer.

Dependent upon the function of the switch, four types of output circuits were selected to interface with peripheral equipment. The determining factor in the circuitry was the contact rating of the switch.

• High current	DC	(10 AMP)
• Medium current	DC	(400 MA)
• Low current	Analog	(50 MA)
• Low current	AC	(I AMP)

To insure reliable operation, redundant circuitry has been included wherever size and circuitry dictates practicability. The subject of man-hardware interface has not been discussed because standard mechanical switch actuating devices are used for inputs with normal actuating pressure loads and travel.

Envelope drawings and schematics are included in the appendices (Section 8) indicating the design approach configurations for the Phase I program. Production versions of these modules would require some modification for facility of fabrication and appearance. As a result of the study program, a panel was fabricated including 25 single pole or double pole toggle and pushbutton switches, two rotary 10 position switches and two potentiometers as indicated in Figure 1.

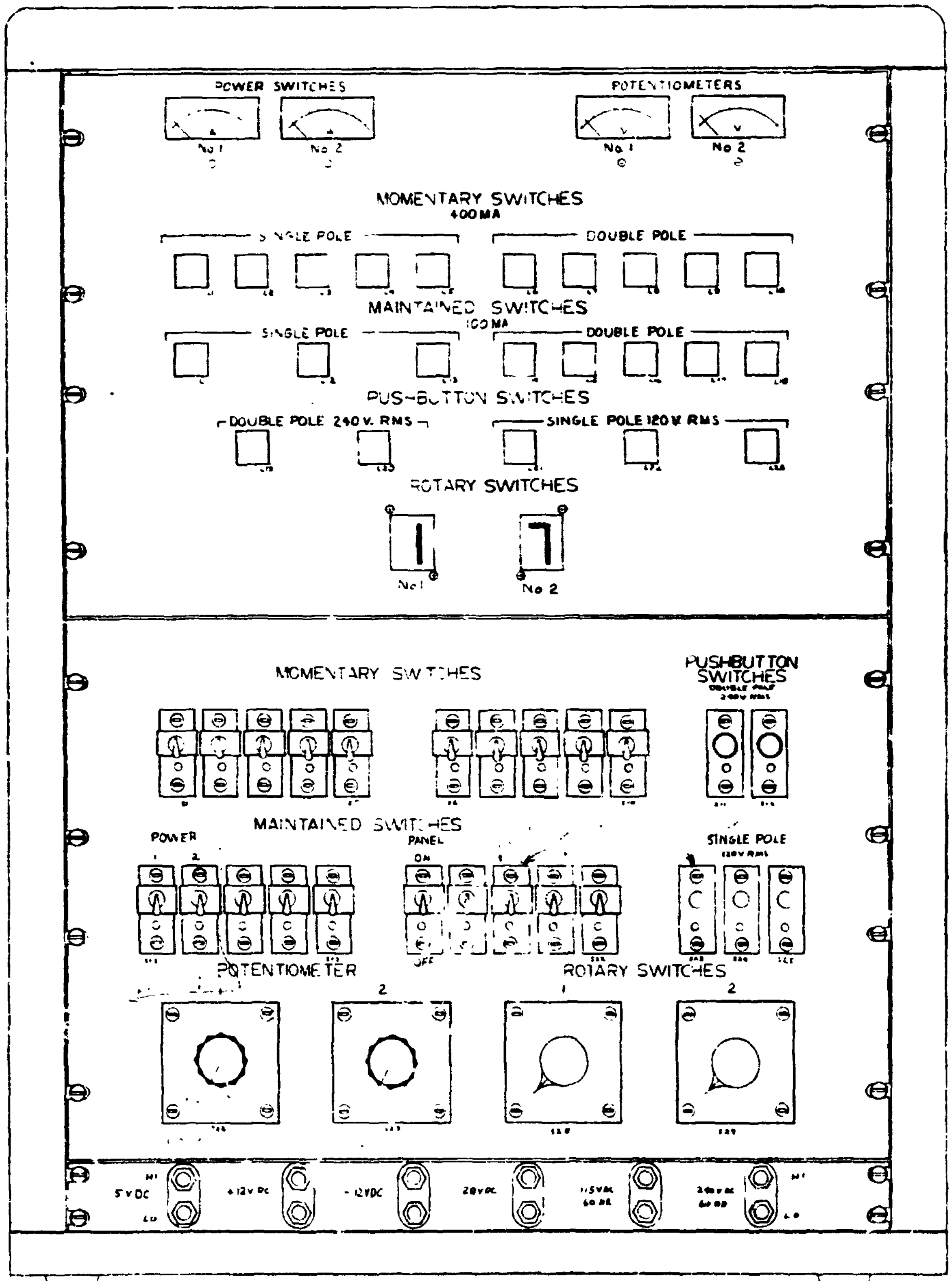

FIGURE 1 SOLID STATE SWITCH PANEL

TECHNICAL DESCRIPTION

The following four basic areas were studied in order to produce the required switch/potentiometer configurations for the switch panel:

- Transducers
- Mechanical Packaging
- Output (switch contact) circuitry
- Solid state potentiometer circuit configurations

TRANSDUCERS

Many types of transducers were evaluated to determine the optimum switch transfer. For each transducer the source and s r of the switching medium is discussed along with the various configurations.

MAGNETIC CIRCUIT TRANSDUCER

A magnetic circuit transducer depends on changing magnetic flux for switching action. A mechanical switch change occurring external to the hermetic seal changes the reluctance of the magnetic circuit. This flux change is sensed inside the hermetic seal and interfaced with the logic section of the switch. Both alternating and direct flux devices have been reviewed.

DC Devices

The flux flows in only one direction in a direct flux circuit and is a function of the following relationship.

$$\Phi = \frac{MMF}{R}$$

A change in the flux is sensed and a typical simple switch is illustrated in Figure 2. With the switch open as in Figure 2 a high reluctance air gap exists in the magnetic circuit. If the missing slug is moved into the gap, the reluctance is diminished. This incre es the flux and changes the characteristics of the flux sensing element. Two sources of mmf appear most appropriate for switch applications: permanent magnets or solenoid coils. Permanent magnets require the following characteristics to be effective.

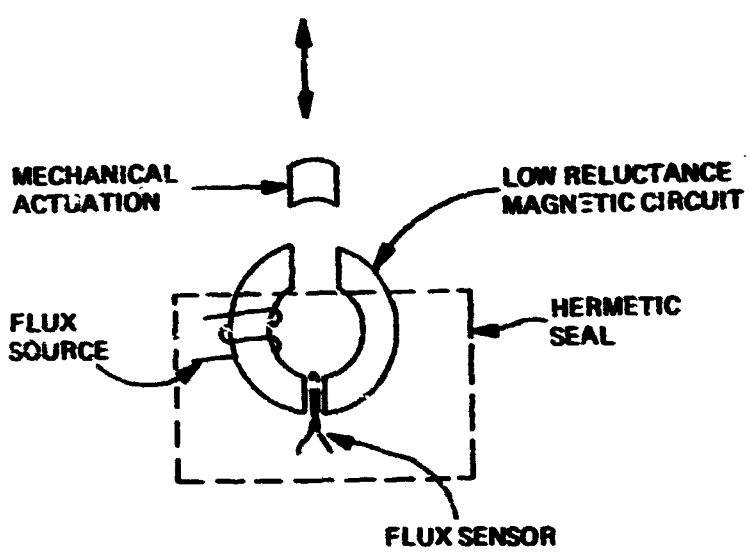

FIGURE 2

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- Small size
- High induction
- High demagnetization force

Of the present commercially available magnetic materials, the following best suit these characteristics:

- Ceramic permanent magnets
- ALNICO SERIES*
- Gecor*

The life characteristic of these materials (time of retention of useful magnetic properties) has been estimated at approximately 15 years.

Solenoid coils require electrical power in order to operate. However, these devices utilize materials which are more readily available than magnets and do not require any special handling techniques as is sometimes the case with magnets. Of the flux sensing elements available the following exhibit the most suitable properties for switch application:

- Pick up coil
- Hall effect device
- Magnetic resistor

- Pick Up Coil - The simplest of the three devices is a pick up coil which is a coil of wire of many turns wound around the magnetic core. This coil does not require a gap in the magnetic circuit which greatly increases the reluctance and, therefore, reduces the magnetic strength required. Many magnetic materials can be used for this application. The greatest disadvantage of using a pick up coil in a direct flux circuit is the fact that a coil can only sense a change in flux. Therefore, an output voltage would only be available from the coil during switching transition. After the coil has reached a different steady state valve as a result of the new switch position no voltage is present at the coil. The logic necessary to sense these

---

*Trade name of a General Electric Co. product transient pulses is relatively simple, however, the problem exists in the initial start up procedure. The use of this device is limited to momentary switch applications where the switch mode of operation is in the normally off condition.

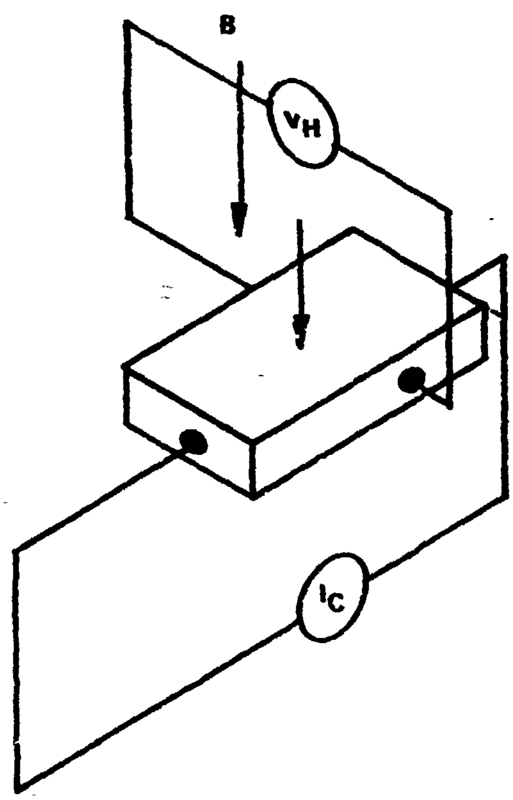
- Hall Effect Device - The Hall effect element is a semiconductor device that generates a voltage as a function of control current and magnetic field. As illustrated in Figure 3 control current is passed through one axis of the semiconductor. The Hall voltage will appear perpendicular to the control current at the edges of the semiconductor chip. This voltage will be a function of the magnetic flux passing through the chip perpendicular to both control current and the output voltage. In the switch application, this voltage is used to control the switch output. The advantages of the Hall effect device are:

  - Small size
  - Detection of steady state flux levels
  - Life and reliability similar to silicon semiconductors

  Because the Hall effect device has a relatively low output voltage (in the order of 50mv) an amplification stage is necessary as an interface between the transducer and the switch output circuitry. The control current required for the Hall effect device is approximately 5 → 50 MA. The Hall effect device is made very thin (.006 inches typical) in order to retain a high flux density across the Hall device in the on condition.

  A device available from Honeywell Microswitch incorporates a Hall effect device and an amplifier and trigger circuit in one integrated chip. This device operates on low levels of flux and provides as an output two current sinks. In addition to being small and sensitive this magnetic switch requires very little power to operate (30 mw max. at 5 volts). This power level is equivalent or lower than most flux sensing devices made of discrete parts.

  The device has been designed to operate over the standard Military temperature range (-55°C -- +125°C) and is available off the shelf from Micro-Switch. The device is sensitive enough that no specific flux path need be incorporated in the hermetic seal. The switch will sense



V_H = HALL VOLTAGE

I_C = CONTROL CURRENT

B = FLUX

FIGURE 3

the presence of a small magnet at distance of .090 in. with any non-magnetic material between the magnet and the sensor. This feature will greatly simplify the process of hermetically sealing the final package.

- Magneto Resistor - Magneto resistors are solid state passive devices that change their resistance in the presence of a magnetic field. The devices are thin crystals of Indium Antimonide with electrical connections at both ends (Reference Figure 4a). The crystal is a semiconductor with a grid-like conducting material running perpendicular to the direction of the current flow. With no flux passing through the device current flows perpendicular to the conducting bands implanted in the semiconductor. Under these conditions the device exhibits its lowest resistance. If flux is allowed to pass through the device, the current is forced to travel a greater distance between conducting bands (Reference Figure 4b). The longer current path increases the resistance between the ends of the device. Typical ratios between maximum and minimum resistance are on the order of 13 to 18 for sensitive devices. The application of the magneto resistor is similar to the Hall effect devices in that they are mounted in the gap in the magnetic circuit. Magneto resistors have the following advantages:

- Small size

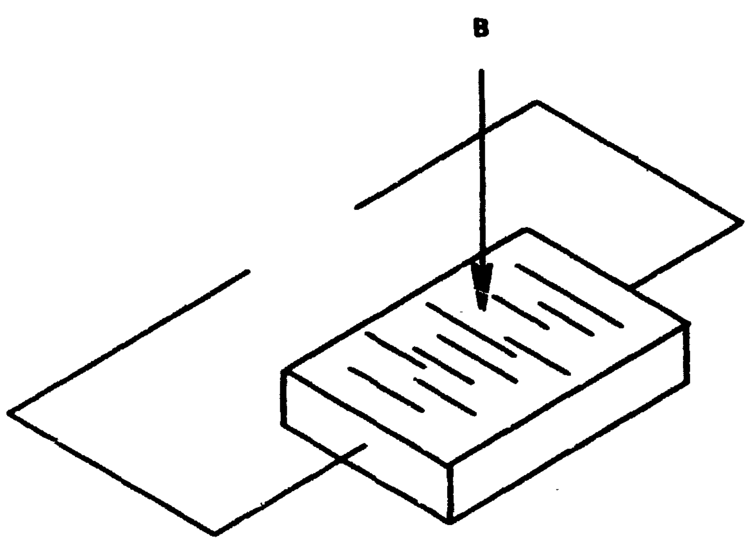
- Low power

- Life and reliability similar to silicon semiconductors

Power consumption of magneto resistors is a function of the input current and resistance and is, therefore, in the order of mw.

Alternating Magnetic Flux Devices

Alternating magnetic flux can also be used to convey mechanical switch status through a hermetic seal. Switches of this type operate using transformer coupling. This method would require the use of AC signals inside the hermetic seal. Because AC signals must be generated to produce the alternating flux and later rectified to interface with the logic and switch sections, this method will consume more power and be more complex than direct flux circuits.



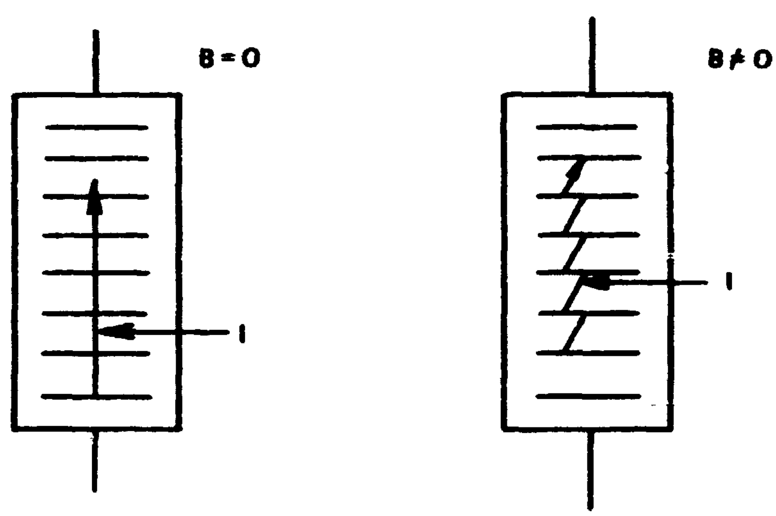
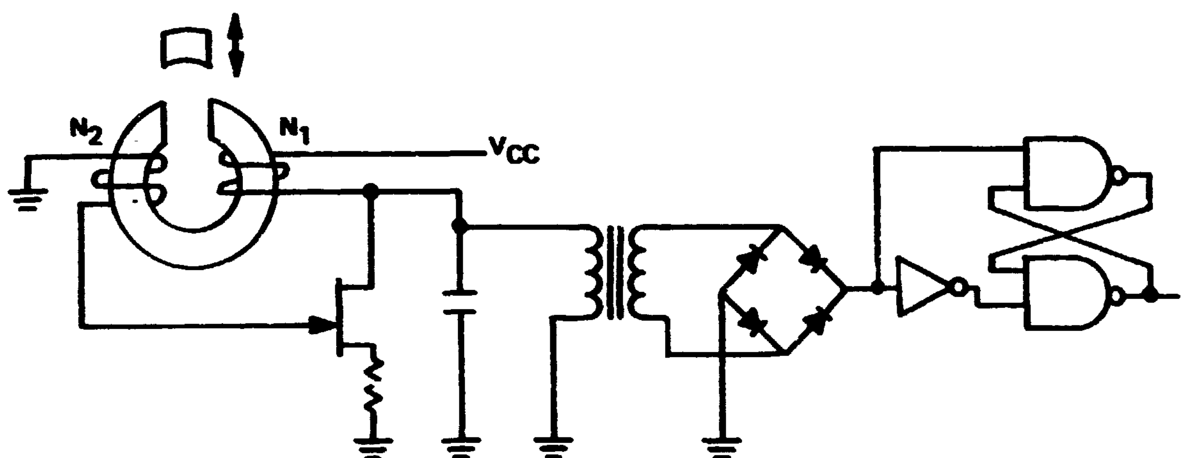


FIGURE 4

The only source of alternating flux convenient for use in this application is a coil of wire around the magnetic flux path. The optimum frequency at which the flux should oscillate will be a function of core losses in the magnetic circuit, the size of the oscillator, and the amount of radiated energy acceptable.

The greatest disadvantage to this type of design is the possible energy radiated to other switches and circuitry behind the switch. This radiation can be minimized to some extent by placing a magnetic shielding around the switch and EMI filters on the electrical lines, however, this would complicate both the packaging and the manufacture of the final switch.

All the sensors which sense direct flux also sense alternating flux. Of the three types discussed (pick up coil, Hall effect, magneto resistor), the pick up coil is the most adaptable to alternating flux. A transformer type switch using coils might operate as follows:



In the configuration above, coil N_1 is not strongly coupled with coil N_2. Coil N_2 is a feedback circuit for the oscillator. With the slug removed from the magnetic path the feedback is insufficient to maintain oscillation. This results is a zero voltage output at the full wave rectifier. If the missing part of the core is placed into the magnetic circuit, coil N_1 is coupled to coil N_2 providing feedback to the circuit. This causes the circuit to break into oscillations and provides a DC voltage at the full wave rectifier switching the latching logic.

The selection of the material to form the magnetic core, is based on a number of factors.

- Magnetic properties
- Ease of machining
- Compatibility with switch housing material
- Ability to form hermetic seal.

A material of high relative permeability and low magnetic retentivity is most desirable. This would insure the greatest change in flux for a given magnet. Two materials appear best suited to this requirement.

1. Cold rolled armco Magnetic input iron.
2. Cold rolled electro-magnetic iron.

When properly heat treated these materials are easily machined and can be soldered or brazed in the normal fashion.

One other consideration must be made if alternating flux is to be used. Core losses must be kept to a minimum which will require either a laminated core or a ferrite core. Both of these cores would be difficult to hermetically seal and will complicate the machining and manufacture of the transducer unit.

Transducer Evaluation

In the following section each of the sensor and sources are evaluated, thereby, allowing the best possible combination to be determined. A summary at the end of this section compares all the combinations.

Coil Source With Coil Sensor

This approach is not acceptable because of the inability of the coil sensor to detect a steady state flux. A memory device of some type would be required to hold the switch in either the on or off state after a change in the flux level. Such a transducer would be further complicated by the circuitry required to guarantee proper start up. When power is first applied to the switch, circuitry must be provided to set the memory in either the on or off position depending on the position of the moveable core section.

Another disadvantage of this method is the coil source which dissipates electrical power to provide a steady state flux. Permanent magnets use no power to accomplish the same thing.

Coil Source With Hall Effect Sensor

A transducer of this type is feasible. It has two major disadvantages which make it less acceptable than other methods to be described.

1. Power must be supplied to both the coil and the Hall effect device for proper operation. This current would be on the order of 30 ma which is much higher than other types of transducers.

2. The Hall effect device puts out a low voltage (40 - 400 mv) when magnetic flux passes through it. This voltage level would have to be amplified in order to drive logic. The addition of an amplifier would consume more power and space in the final design and is therefore not desirable.

Coil Source With Magneto Resistor Sensor

A transducer of this type offers many advantages. The magneto resistor requires no control current as does the Hall effect device so the total power consumption will be smaller than the Hall effect. With a flux change of 10 kilogauss the magneto resister changes its resistance by a factor of 7 from its 0 kilogauss level. This change is enough to actuate logic without amplification. At worst a single transistor will interface between the transducer and the logic section.

The only drawback to this combination is the coil source which will draw current to generate the flux.

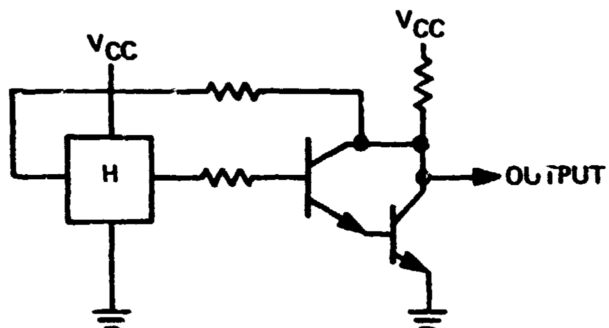
Permanent Magnet With Coil Pick Up

This method is unacceptable for reasons mentioned under coil source coil pick up.

Permanent Magnet With Hall Effect Device

This arrangement has the same drawbacks as the one using Hall effect with coil source. The only advantage is the fact that no current would be required to generate the flux.

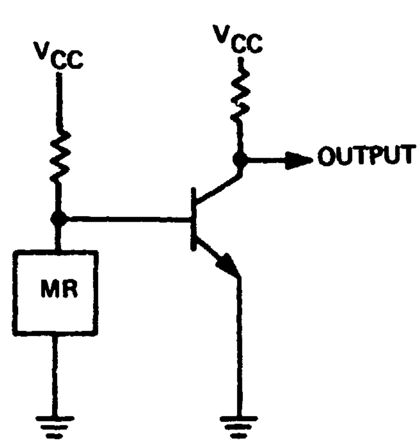
The complete transducer circuit is indicated as follows:



Permanent Magnet With Magneto Resistor

This combination is acceptable because the flux is generated without the use of power and the Magneto resistor requires few additional components and uses little power.

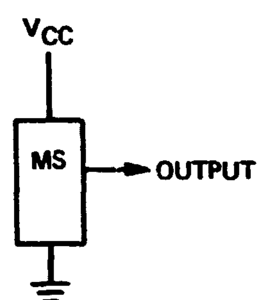
The complete transducer is as follows:



Permanent Magnet With Micro-Switch Sensor (Hall Effect/Amplifier/Trigger)

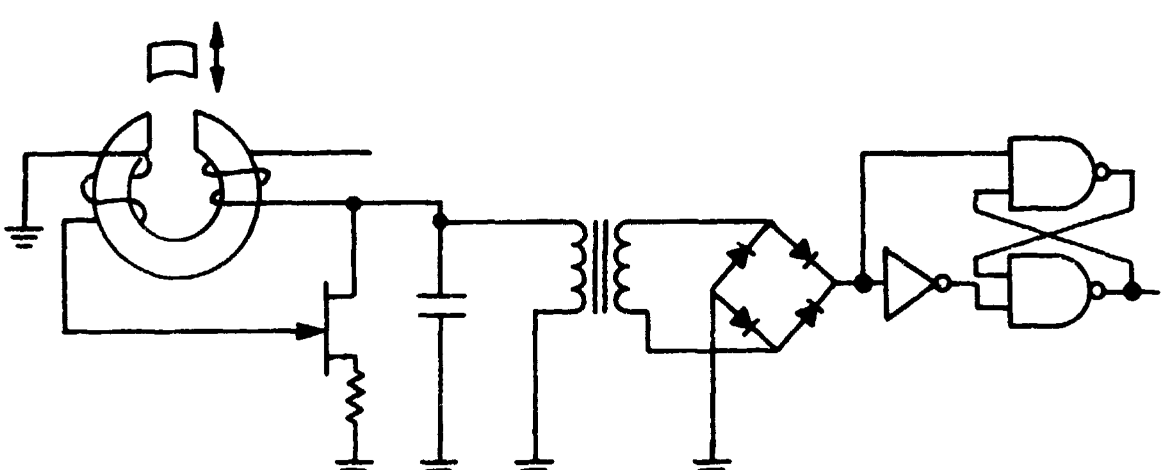
Because this device is very sensitive and comes packaged with a trigger and amplifier on the same chip it appears to be by far the most advantageous transducer. It is sensitive enough that no pole pieces would have to pass through the hermetic seal barrier. This would greatly simplify the sealing process. Furthermore, the device comes in a small package allowing the overall switch size to remain small.

The complete circuit is shown below:



Coil Source With Coil Sensor (ac)

A transducer operating with these components would require the following circuitry:



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The variable inductive coupling between the output and the input controls the feedback to the oscillator. Thus, by changing the feedback, the oscillator can be driven out of oscillation. By rectifying the output and using this signal to control the logic section, switch operation can be made.

The following problems complicate this approach to the transducer problem.

1. The oscillation inherent in this type of switch will be difficult to shield from the outside world. Use of large RF filters would be difficult due to the small package size required.

2. The difficulty in hermetically sealing a low loss AC type core (laminated or ferrite) would necessitate use of a DC type core. This would force the oscillator to work at a higher power level to offset core losses.

3. Part count for this type of transducer would be high making a small package size difficult.

Coil Source With Hall Effect Sensor (ac)

This type of transducer would have all the drawbacks mentioned under coil source and coil sensor plus the following:

The Hall effect device must be placed in the path of magnetic flux requiring a gap in the core of the oscillator decreasing the coupling. The output from a Hall effect device would be a very small voltage (40 - 10 mv).

The Hall effect device requires a control current for operation which is an added power requirement not necessary with a coil pick up. This type of transducer is not acceptable because of the poor AC flux characteristics of the Hall effect device. A coil pickup is far superior in every respect for this application.

Coil Source With Magneto Resistor Pick Up

This transducer is unacceptable for the same reasons mentioned under coil source Hall effect device pick up.

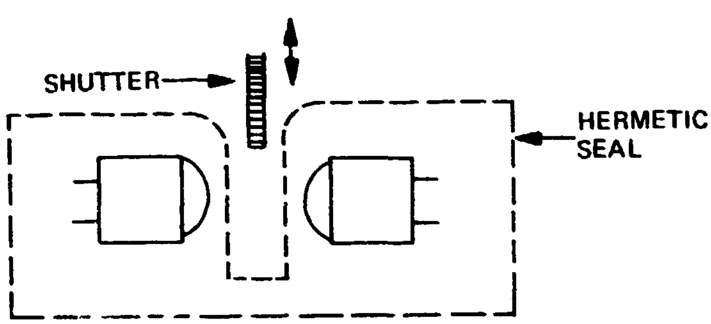
Conclusions

Of all the magnetic transducers discussed in this section, the most acceptable is the Honeywell magnetic switch used in combination with a permanent magnet. It is the best selection for the following reasons.

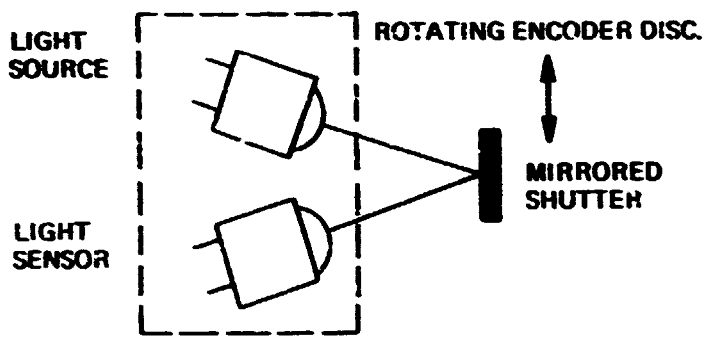
- Low power
- Smallest size of any magnetic transducer
- Lowest component count.

LIGHT TRANSDUCERS

Transducers of this type will direct a beam of light from a light source through a shutter arrangement to a light sensor. Both light sensor and source will be contained inside a hermetic seal. The shutter arrangement will be external to the hermetic seal. By either allowing the light beam to strike the sensor or interrupting the light beam with the shutter, switch control of the light sensor can be obtained.



The shutter type of transducer would require that the hermetic seal wrap around the movable shutter. This means a transparent hermetic seal would have to be made at each side of the shutter. To avoid this complicated seal, an alternate configuration with a reflective surface can be used. In this method light is directed through a transparent hermetic seal towards a reflective surface. Upon striking the surface the light beam is directed back toward the light sensor through the same transparent seal through which it originally passed. In this way only one transparent seal is required and both source and sensor can be placed in the same place. Switching is obtained by either reflecting or not reflecting the light beam back to the sensor. No moving parts are required within the hermetic seal.



Light Sources

A beam of light can be obtained from the following sources:

- Incandescent lamp
- Light emitting diode
- Electro luminescent lamp

The following characteristics would be desirable in a light source:

- Small size
- High brightness
- Low power
- Long life

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It would also be desirable to have the light eminate from a single point source. As the light must be gathered into a beam to pass to the detector a single point source would simplify this requirement.

- Incandescent lamps - A light source of this type satisfies the size and brightness requirements with no difficulty. Light intensities as high as 2,400 foot LAMBERTS can be obtained in package sizes as small as Figure 5. The drawbacks of this source are its power consumption and its limited life. There would be no way to conveniently replace the lamp because of the hermetic seal. This factor alone makes use of incandescent lamps PROHIBITIVE.

- Light emitting diode - Light emitting diodes satisfy most of the requirements. They are small, have a very long life time, moderate power consumption with moderate brightness. A further advantage of the LED source is its narrow frequency band of light output.

Many types of photo diodes and photo transistors are optimized for use at a single frequency. This means that the proper combination of LED and photo diode will make more efficient use of the light than a combination of photo transistor and any other light source.

LED's come in a variety of package sizes. The device pictured in Figure 6 would be most suited to the requirements of this application. This device was designed to be used with a particular photo transistor in high speed card and tape readers. The characteristics of this device are listed in Table II.

- Electro-Luminescent Lamps - This type of lamp would not be suitable for this application. Electro-luminescent lamps have very low brightness (20 fL) and are better suited to surface illumination.

Light Sensors

Light emitting diodes are the best choice for light sources so only sensors which interface with LED's will be considered. The following devices are specifically designed to interface with LED's.

- Photo - Diodes

- Photo - transistors

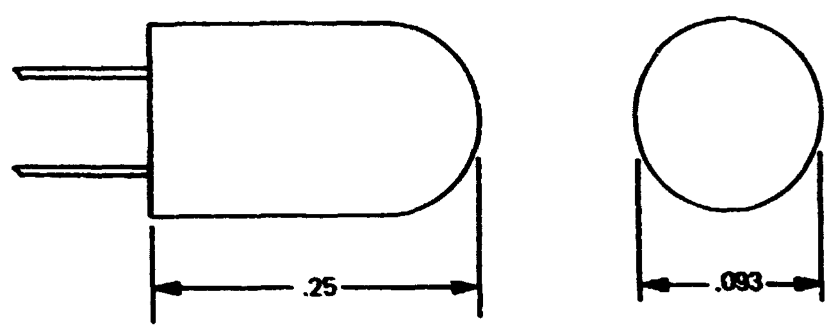


FIGURE 5

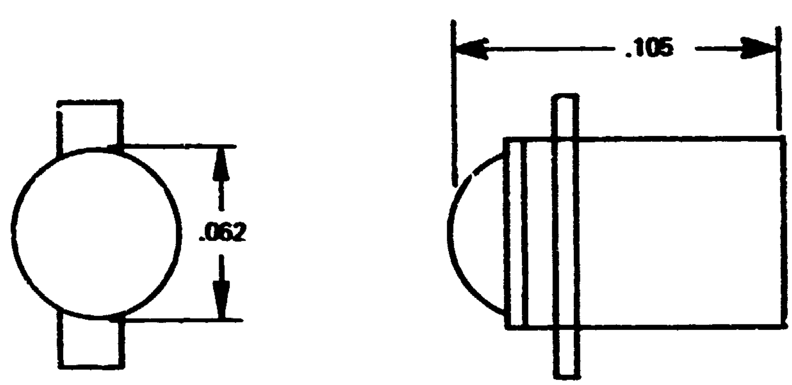


FIGURE 6

TABLE II. LIGHT EMITTING CHARACTERISTICS

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic	Fig. No.	Symbol	Min	Typ	Max	Unit
Reverse Leakage Current (V_R = 3.0 V, R_L = 1.0 Megohm)	-	I_R	-	50	-	nA
Reverse Breakdown Voltage (I_R = 100 µA)	-	BV_R	3.0	-	-	Volts
Forward Voltage (I_F = 50 mA)	2	V_F	-	1.2	1.5	Volts
Total Capacitance (V_R = 0 V, f = 1.0 MHz)	-	C_T	-	150	-	pF

OPTICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

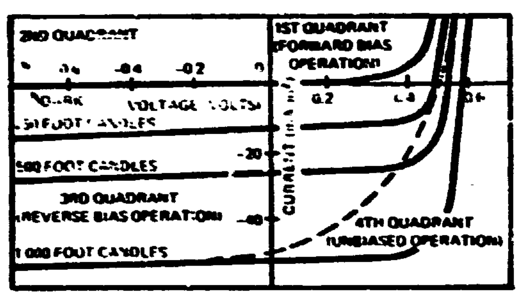
Characteristic	Fig. No.	Symbol	Min	Typ	Max	Unit
Total Power Output (Note 1) (I_F = 50 mA)	3,4	P_O	50	150	-	µW
Radiant Intensity (Note 2) (I_F = 50 mA)		I_O	-	0.66	-	mW/steradian
Peak Emission Wavelength	1	λP	-	9000	-	Å
Spectral Line Half Width	1	Δλ	-	400	-	Å

The characteristics desirable for this application are:

- Small size
- Compatible with LED light sources
- High light sensitivity
- Low power consumption

- Photo Diodes - Photo diodes are P on N or N on P silicon function devices that generate a photo current in response to a beam of light focused on the sensitive junction.

Being composed of silicon, these devices are small, rugged and reliable. The photo-diode is the basic photo sensitive device in all of the photo transistor varieties, so in one form or another it will be used in any kind of light transducer. The current voltage curves for a typical photo diode are shown below.

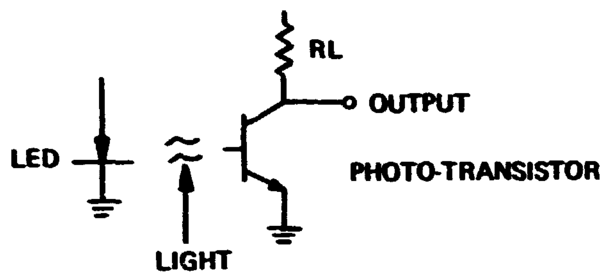


The voltage and current levels are sufficient to drive the logic section without further amplification. However, if a photo transistor were used, lower light intensities would be able to drive the same logic section. This would mean lower power consumption in the LED.

- Photo-transistors - The photo-transistor uses a photo diode to generate base current for a normal transistor. This, in effect, amplifies the current sensitivity of the device by the β of the transistor. There is no difference in package sizes between the photo diode and photo transistor, both can be obtained in packages as small as Figure 6.

Photo FETS take advantage of the photo voltaic effect of photo diodes. This is the change in output voltage as a function of light intensity of an open circuited photo diode. The increase of current gain available using a photo FET is of the same order of magnitude as that of a photo-transistor.

Configurations - The simplest configuration of a light transducer would look as follows:



In this configuration the light from the LED provides base current for the photo transistor turning it on. The shutter can be placed in the path of the light beam turning off the transistor.

The LED must be provided with from 20 to 50 ma of current depending on the distance between the diode and the transistor, the load RL on the transistor, and any attenuating devices between the diode and the transistor (glass, light pipes, etc.).

The configuration of the reflective type transducer would be identical to that pictured above except for the shutter which would become a mirrored surface.

Conclusions

Of the light type transducers the light emitting diode in conjunction with the photo-transducer is the only method which will adequately meet the requirements of this application.

Table III below lists the characteristics of this type of transducer.

TABLE III. LIGHT TRANSDUCER CHARACTERISTICS

POWER	.150 WATTS
COMPONENT COUNT	3
CROSS TALK	NONE
EXCITATION	DC-5-10V
HERMETIC SEAL	PROBLEM AREA GLASS TO METAL SEAL

CAPACITANCE TRANSDUCERS

A transducer of this type would operate by sensing the change of a capacitor and operating a trigger circuit from this change. Because all electrical components must be contained inside a hermetic seal the only portion of a capacitor which could be used to change the capacitance would be the dielectric. The plates of the capacitor being current carrying devices must lie within the hermetic seal and are therefore inaccessable for mechanical change.

This factor makes it very difficult to implement this type of transducer. Both plates must be sealed behind at least .050 thick sheets of glass while the dielectric contained within the environmentally sealed section is moved in or out of the plate gap.

A further complicating factor is the dielectric itself. It would be desirable to have the capacitor make a very large change in capacitance. This would mean using a material with a high dielectric constant. Most materials with this characteristic are unacceptable for use in a space cabin environment.

A variable capacitance transducer is therefore unacceptable for use in this application.

CIRCUITRY

SINGLE ACTION SWITCH

The basic circuitry of the switch consists of a magnet and Hall effect transducer, amplifier and output solid state relay switch as shown in schematic SW201 (Appendix I). The Hall effect device is an integrated hybrid chip containing the Hall effect pick off, an amplifier and a Schmitt trigger. The output of the Schmitt trigger drives a transistor amplifier which supplies current to the coil of the solid state relay switch. The output of the solid state relay directly supplies the load. The solid state relay coil is in series with the transistor driver and a light emitting diode. The light emitting diode provides an indication that the switch is in the ON condition and that approximately 80 percent of the circuitry is operating normally. The only difference between the single pole and double pole switch is the addition of a solid state relay, the coil of which is in series with the original solid state relay coil, and an increased supply voltage to provide additional drive power.

TEN POSITION ROTARY SWITCH

The circuitry of the ten position rotary switch is shown in Schematic RD001 (Appendix I). Four LED - phototransistor transducers provide the initial BCD triggering to obtain 10 discrete switch position outputs. The output of the phototransistors provides triggers to exclusive or gates which inserts the proper logic format into a BCD to one of ten decoders. The output of the decoder supplies through transistor amplifiers the current to drive the appropriate coil of solid state relay matrix. The output of the solid state relay directly supplies the load.

POTENTIOMETER

The input to the potentiometer consists of 7 LED - phototransistor transducers providing a resolution of 128 bits. The output of the phototransistors provides logic states to exclusive or gates, the outputs of which supply the necessary binary data to the digital to analog decoder. The decoder utilizes a ladder network with an operational amplifier output. The output is a 0 to 10 volt analog voltage capable of supplying a 1000 ohm or greater load. A visible LED on both the rotary switch and potentiometer indicate that all internal LEDs are energized.

OUTPUT SWITCH CIRCUITRY

The output characteristics of the switches are tabulated in Table IV. Physically all chips are the same size so that any possible combination of switch outputs is available. An important consideration with all types of switches is that the input to output isolation impedance is in excess of 10" ohms.

SWITCH CONFIGURATION

The following types of mechanical packages must be produced to comply with the contract.

- Toggle switch (maintained)
- Toggle switch (momentary)
- Push button
- Potentiometer
- Rotary switch

TABLE IV. SWITCH CHARACTERISTICS

SWITCH TYPE	100 MA DC	140V AC	28V AC	400 MA DC
LOAD VOLTAGE	±50V MAX PEAK	140 VAC RMS	280 VAC RMS	60 VDC

INPUT (CONTROL) SPECIFICATIONS

CONTROL VOLTAGE RANGE	3.8-10 VDC	3.8-10 VDC	3.8-10 VDC	3.8-10 VDC
MAX INPUT CURRENT @ 5V	22 MA DC	15 MA DC	15 MA DC	15 MA DC
TURN OFF VOLTAGE (MAX)	0.4 VDC	0.8 VDC	0.8 VDC	0.4 VDC
DIELECTRIC STRENGTH INPUT TO OUTPUT	1000 VAC (PP)	2500 VAC (RMS)	2500 VAC (RMS)	1500 VAC (PP)
ISOLATION INPUT TO OUTPUT	10^{11} Ω MIN	10^{11} Ω MIN	10^{11} Ω MIN	10^{11} Ω MIN

OUTPUT (LOAD) SPECIFICATIONS

OUTPUT CURRENT RATING	±100 MA PEAK	1.0 AMP	1.0 AMP	400 MA
OUTPUT VOLTAGE	±50 MAX PEAK	140 VAC RMS	280 VAC RMS	60 VDC
OFFSET VOLTAGE	±5.0 MV MAX	-	-	-
CONTACT "ON" RESISTANCE (OHMS)	5.0 MAX	-	-	-
CONTACT "OFF" RESISTANCE (OHMS)	10^9 MIN	2×10^5 MIN	2×10^5 MIN	10^7 MIN
MAX DRIVE FREQUENCY (Hz)	100K	500	500	30K
MAX SURGE RATING	0.1 JOULE	10 AMP	10 AMP	-
CONTACT VOLTAGE DROP AT RATED CURRENT (MAX)	250 MV	1.5V RMS	1.5V RMS	1.5VDC

Each type must have the electronics hermetically sealed. The packages for each type therefore have two sections, a hermetically sealed section and an environmentally sealed section. The hermetically sealed section contains the drive electronics. The mechanical actuation is contained in the environmentally sealed section.

There are two basic types of package. One contains all the single action switch configuration and the other houses the rotary switch and potentiometer.

SINGLE ACTION SWITCH

The single action switch is packaged in a rectangular case of the same approximate dimensions as the present hermetically sealed single pole double throw mechanical switch made by Texas Instruments for the LEM and Apollo missions.

Of all approaches tried, Hall effect devices and magneto resistors were the most acceptable. The Hall effect device, because of the higher sensitivity of the Micro-switch device, results in no pole pieces extending through the hermetic seal and, therefore, is the optimum selection.

Figure 7 depicts the layout of the single action switch using this Hall effect device.

POTENTIOMETER AND ROTARY SWITCH

A potentiometer with a resolution of 3.6 degrees is provided. The potentiometer is not a variable resistor but a variable voltage supply which should serve all the functions normally performed by a potentiometer. Rotation of the pot shaft varys the digital input to a D to A converter (DAC) producing a variable voltage. The pot is, in effect, a 7 bit encoder connected to a DAC.

The encoder portion of the potentiometer is a mirrored disk outside of the hermetic seal. Inside the hermetic seal a series of photo diodes and light emitting diodes operating through a transparent seal senses the position of the mirrored disk. This digital information is connected to a DAC to provide the output.

The rotary switch is of the same configuration as the potentiometer. An encoder disk is mirrored into 10 sections. A series of photo diodes and light emitting diodes senses the position of the encoder disk and operates 10 individual switches. Any of the switch outputs shown in Table IV can be provided in the rotary switch.

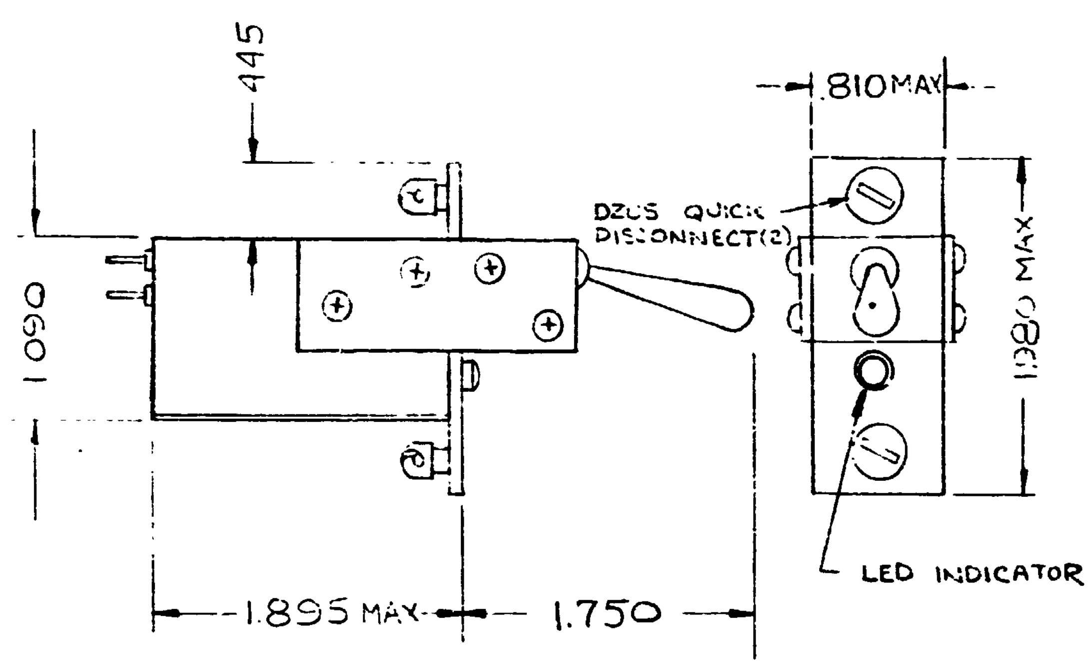


FIGURE 7. SOLID STATE TOGGLE SWITCH OUTLINE DRAWING
(Sheet 1 of 2)

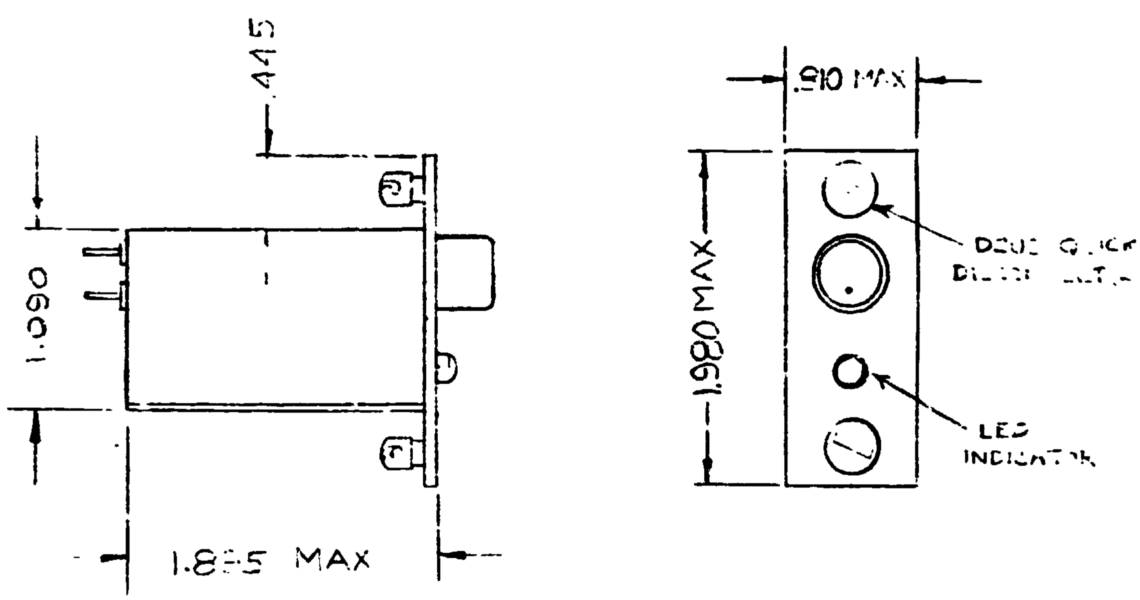


FIGURE 7. SOLID STATE TOGGLE SWITCH OUTLINE DRAWING
(Sheet 2 of 2)

The potentiometer and rotary switch are both packaged in a cylindrical housing approximately 2.5 inches in diameter and 1.5 inches in depth. Figure 8 depicts the layout for the solid state pot and rotary switch. A glass seal separates the hermetic section from the encoder wheel. The encoder wheel is environmentally sealed at the shaft with an O- ring. Light from the LEDs passes through the glass seal, is reflected by the silvered encoder disk and after again passing through the glass seal turns on the phototransistor. Seven LED phototransistors are arranged to align with a Gray code disc providing seven bits of non-redundant binary information. This information is converted into a variable voltage in the D to A section located on the two PC boards in the sealed area.

HERMETIC SEAL

A sample of each package style is hermetically sealed. The hermetically sealed portions of these packages constructed as gas tight enclosures completely sealed by fusion of glass to metal or bonding of metal to metal. Special sapphire glass discs already hermetically sealed to a metal ring are brazed into the brass casing to provide the chamber hermetic seal. After the electronics are inserted into the chamber and leads attached to the soldered glass/metal interconnect the back cover is soldered into place. Prior to sealing, the enclosure is cleaned and dried. The enclosure is purged of all air and backfilled with one atmosphere of gas consisting of 95 percent nitrogen/5 percent helium. A primary consideration in the selection of enclosure materials is the ease of welding, brazing or soldering the bonding methods typically employed for metal to metal hermetic seals. Final material selection provides for brass casings for ease of brazing and soldering.

Environmental Seals

Environmental sealing is accomplished primarily by gasketing. Silicone O-rings and gaskets are utilized at closure points to prevent dirt or moisture infiltration and other contaminants.

PANEL CONFIGURATION

The sold state switch panel contains the following types and quantities of switches.

Toggle maintained	SPST	5
Toggle maintained	DPST	5

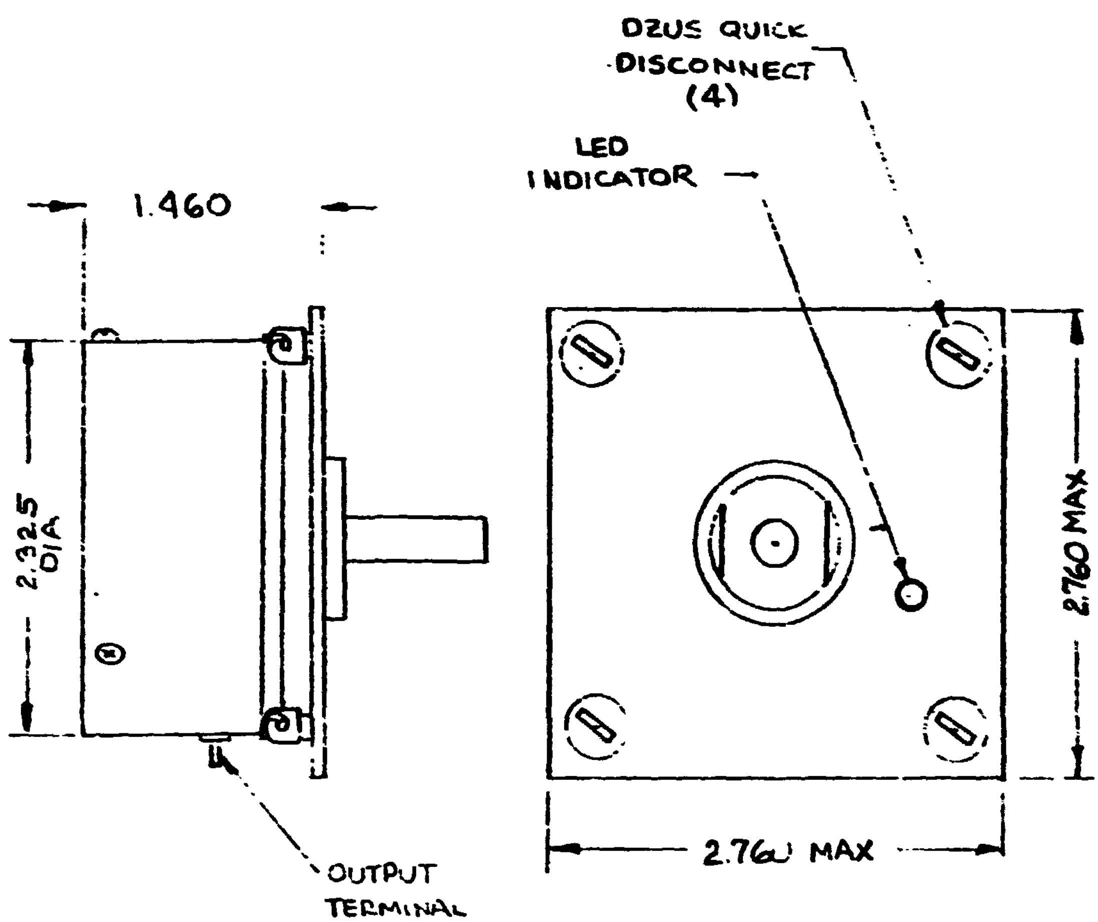


FIGURE 8. SOLID STATE POTENTIOMETER (Sheet 1 of 2)

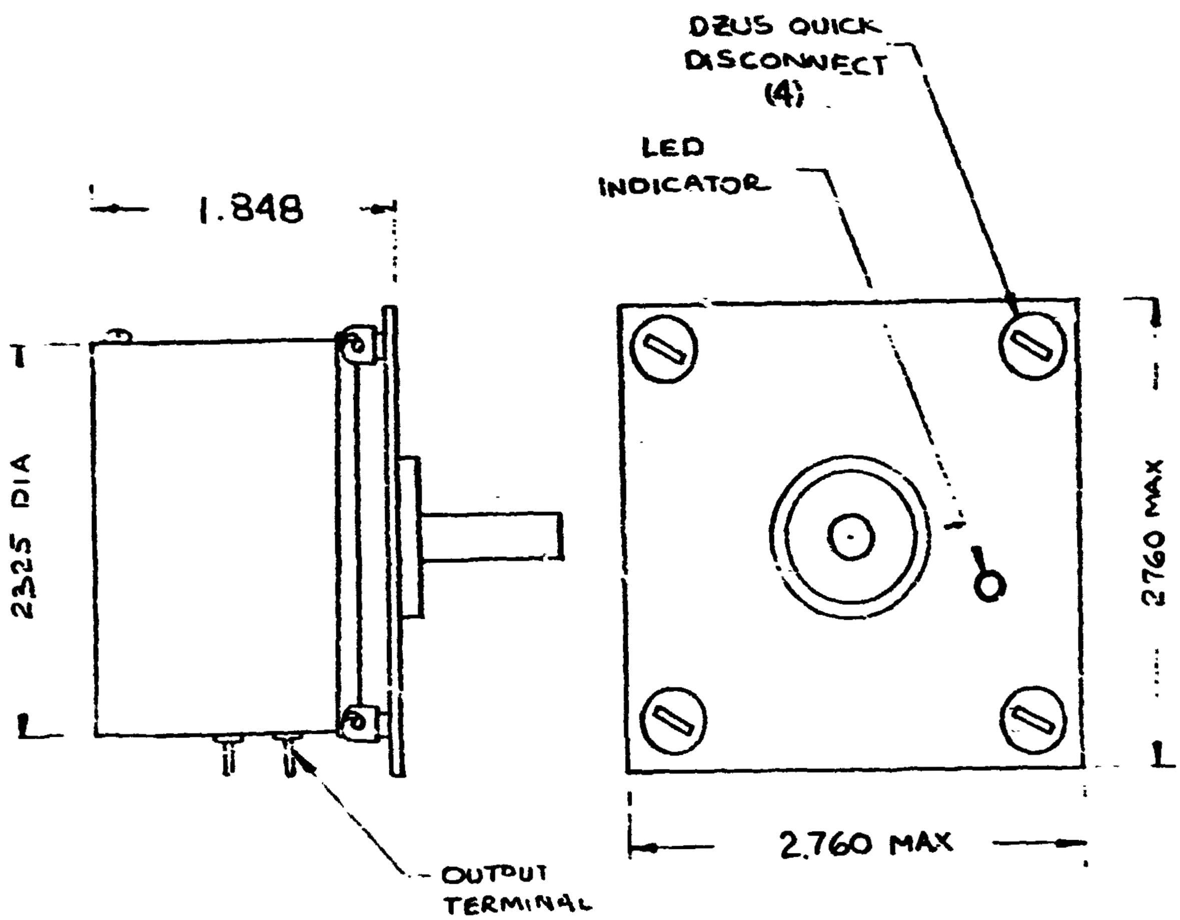


FIGURE 8. SOLID STATE 10 POSITION SWITCH (Sheet 2 of 2)

Toggle momentary	SPST	5
Toggle momentary	DPST	5
Pushbutton	SPST	3
Pushbutton	DPST	2
Rotary	10 position	2
Potentiometer		2

These switches are mounted on a 19-inch wide rack. Two of these switches control high powered 10 amp switches mounted directly on the test panel. The test panel also contains the rated loads for all the switches and potentiometers and provides an indication as to which switches are being operated. The switches are grouped relative to contact rating and identified accordingly on the test panel.

SUMMARY

For the small number of switches produced, several techniques were utilized which would not necessarily remain in the production unit. The same housing was used for both pushbutton and toggle switches which necessitated the use of an add-on toggle assembly. In production units, the toggle assembly would become an integral part of the switch body thereby enhancing the usual outline of the toggle switch.

In production quantities, all switch and rotary components would be hybridized to miniaturize the electronics. This would diminish the package size and simplify hermetic sealing.

POWER CONSUMPTION

Excluding the switch contact ratings, the following power is required in the quiescent (non-operating) state and the operating mode for each type of switch.

Switch	Voltage (volts)	Power Quiescent (mw)	Power Operating (mw)
Pushbutton/toggle SPST	5 & 12	20	320 mw
Pushbutton/toggle DPST	5 & 28	20	720 mw
10 Position Rotary	5 & 12	500 mw	500 mw
Potentiometer	5 & ±12	450 mw	450 mw

total panel power quiescent 3.[illegible] watts

Operating 14.[illegible] watts

PANEL OPERATION

POWER APPLICATION

Place all switches in the off (down) position. Apply the power to the proper pins on the input jack panel located at the bottom of the switch panel. The positive side of the -12 volt input connects to the black input jack and the negative connects to the red jack. The 28V power supply shall be capable of suppling 25 amps in order to test the power switches.

The AC voltages (120 VAC, 240 VAC) are only used to provide contact voltage ratings on the 5 pushbutton AC switches. The AC need not be connected for proper check out of all DC switches and rotary components.

OPERATION

The switch labeled panel controls power to the entire panel. Power is connected to this switch whenever power is present on the jack panel. When it is switched to the ON position, power is applied to all other switches.

With power connected to the panel and the panel switch on, all switches will operate. Switching any toggle momentary or maintained to the ON (up) position or operating any pushbutton will cause the appropriate load light to illuminate. For the two power switches there are no load lights. Closure indication for these switches is given by two current meters located at the top of the panels.

The rotary devices are also actuated by the panel switch. The outputs of the potentiometers are indicated by two volt meters located at the top of the panel. The rotary switches are connected to decimal displays which indicate the position of the switch.

LOAD CONNECTOR PIN OUT.

PIN	LOAD	PIN	LOAD	
1	S10	35		
2	S9	36		
3	S8	37		
4	S7	38		
5	S6	39		
6	S5	40		
7	S4	41		
8	S3	42		
9	S2	43		
10	S1	44		
11	S22	45		
12	S21	46		
13	S20	47		
14	S19	48		
15	S18	49		
16	S17	50	POWER SWITCH 2	S14
17	S16	51	POWER SWITCH 1	S13
18	S15	52	ROTARY SWITCH 2	0
19	S23	53		9
20	S22	54		8
21	S21	55		7
22	S20	56		6
23	S19	57		5
24	POTENTIOMETER # 1	58		4
25	POTENTIOMETER # 2	59		3
26	ROTARY SWITCH 1 POSITION 1	60		2
27	ROTARY SWITCH 1 POSITION 2	61		1
28	ROTARY SWITCH 1 POSITION 3	62	ROTARY SWITCH 1 POSITION	0
29	ROTARY SWITCH 1 POSITION 4	63	ROTARY SWITCH 1 POSITION	9
30	ROTARY SWITCH 1 POSITION 5	64	ROTARY SWITCH 1 POSITION	8
31	ROTARY SWITCH 1 POSITION 6			
32	ROTARY SWITCH 1 POSITION 7			
33				
34				

TESTS

FUNCTIONAL TESTS

All switches were tested at standard ambient conditions to insure proper operation at rated voltage and 10 percent under and over voltages. Power at nonoperating (quiesent) and operation conditions were measured for the entire panel with the following results:

Panel Quiesent Power	2.4 Watts
Panel Operating Power	14.7 Watts

The panel operated satisfactorily when submitted to the various functional tests.

ENVIRONMENTAL TESTS

One type of each switch: toggle, pushbutton, rotary and potentiometer were submitted to the following environmental tests.

TEMPERATURE

2 Hour Soak at 0°C

Functionally tested

2-Hour Soak at 70°C

Functionally tested

RESULTS

SPST, DPST, and Rotary Switch operated satisfactorily. Potentiometer intermittent at high temperature as a result of low current through LED's. Increasing current through LED's provides stability over temperature range, however, higher power dissipation results.

RANDOM VIBRATION

Procedure

A random vibration equal to the total G level utilized on the LEM and Skylab was impressed on the switches. Period of application is 2 minutes.

1150-2000 Hz 20-2000 Hz .02 g^2/Hz

Switches Tested

Pushbutton

Toggle

Rotary Switch

RESULTS

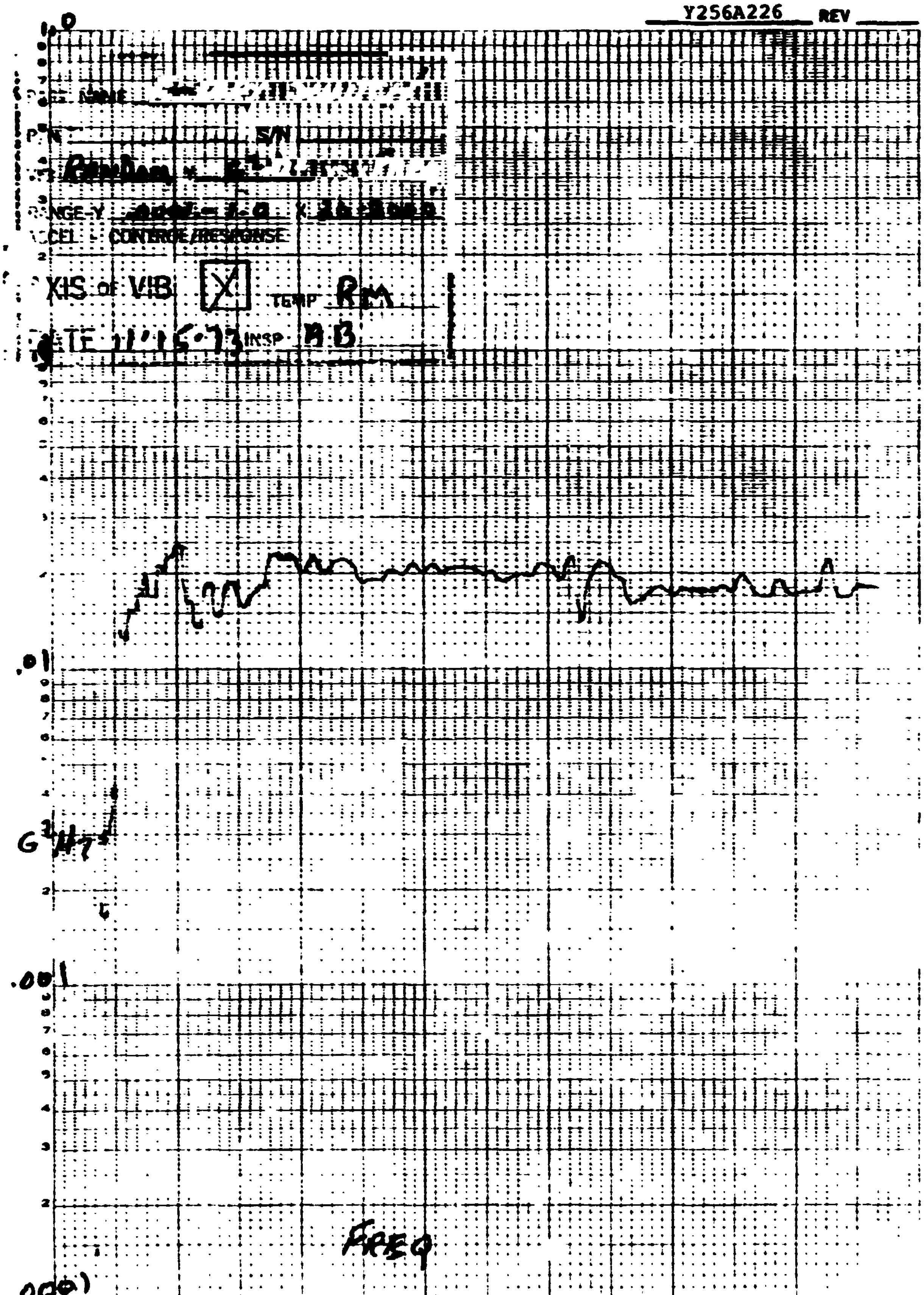
All switches functioned throughout the random vibration. The pushbutton normally open remained in the normally open state, the toggle maintained in a closed switch position remained in that state without interruption and the rotary switch set at position 5 remained closed in that position with all other positions normally open. The graphs on the following pages visually depict the vibration levels applied ~~in the~~ during the test.

EMI TESTS

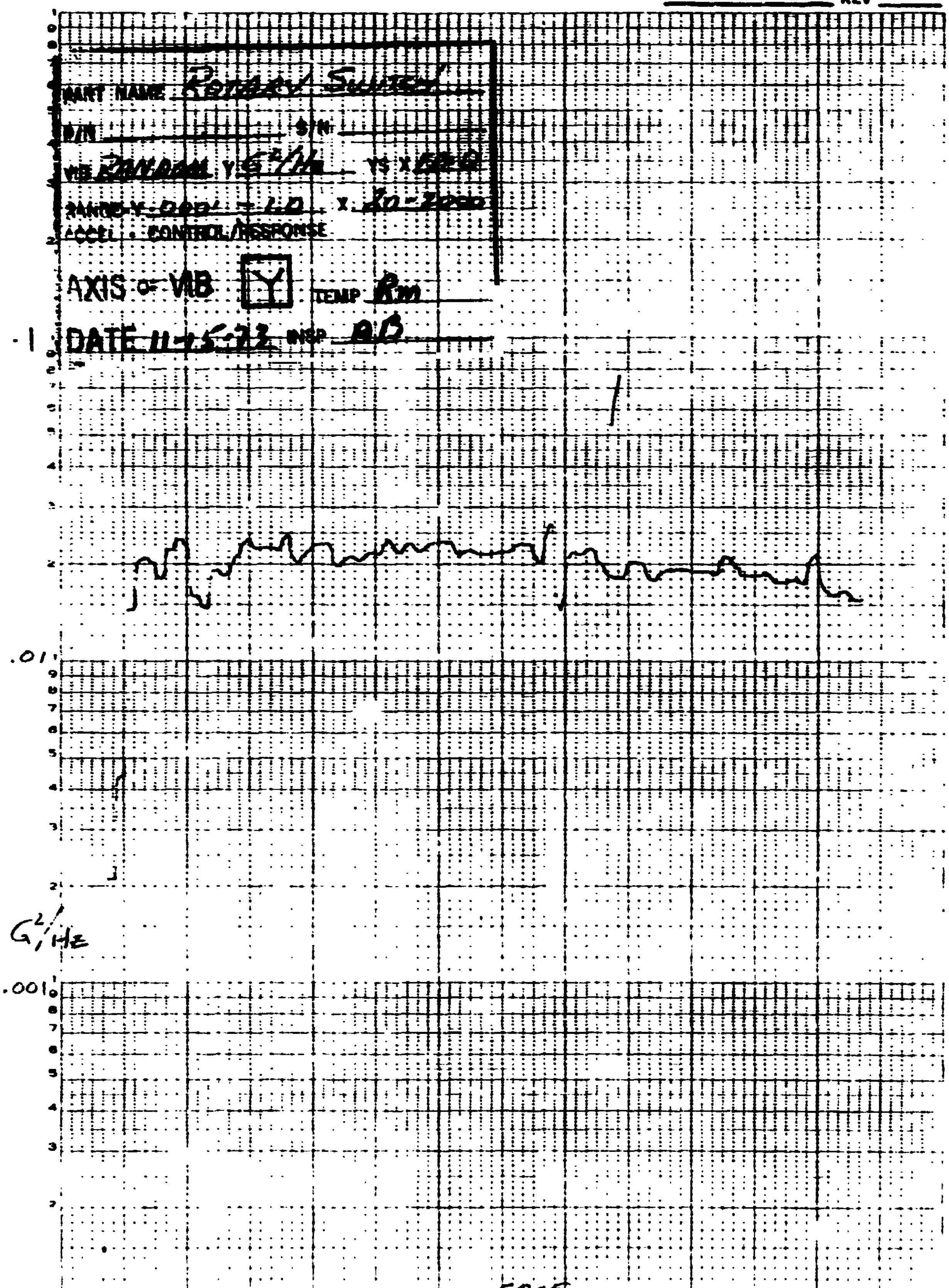
EMI tests were conducted on the double pole, single pole and the potentiometer in accordance with MIL-STD-461. The tests performed were CE01, CE03 and CS06. CE01 and CE03 were preformed on every lead of the device under test. CS06 was preformed on all power leads with the spike equal to 50% of the nominal line voltage.

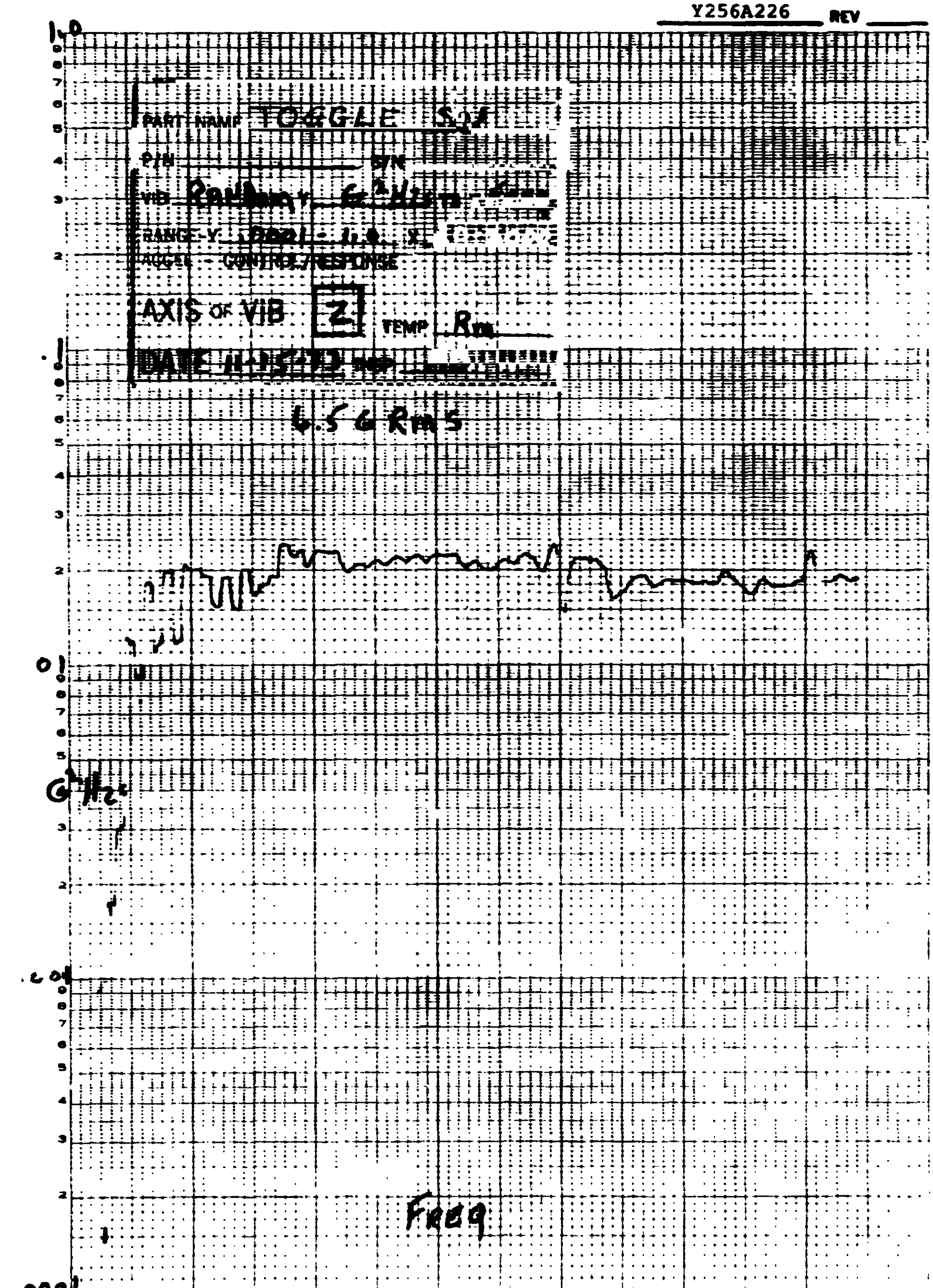
RESULTS

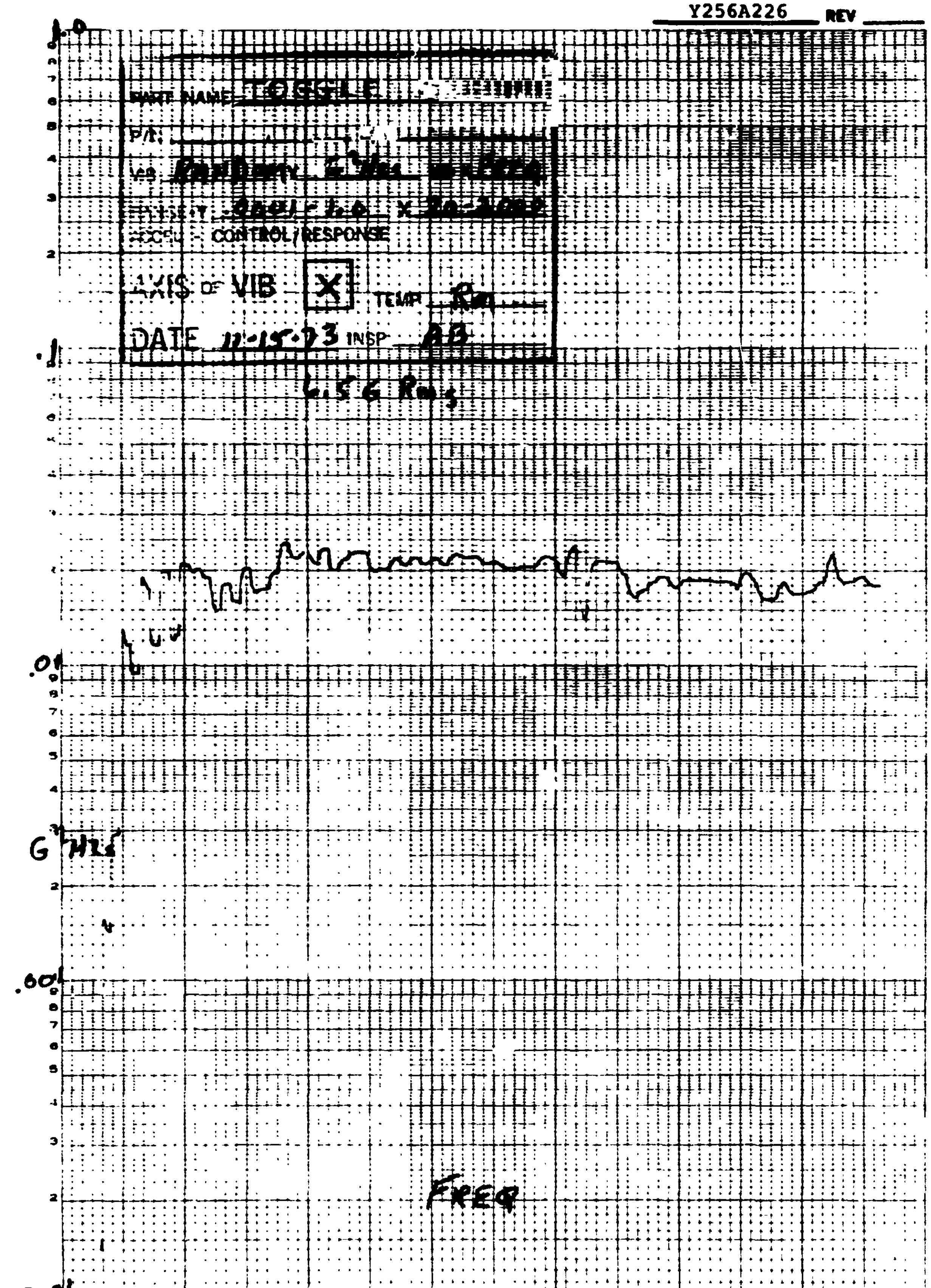
The results of the CE01 & CE03 tests are contained in the attached data. Emissions for all devices were within the max specification limit. All devices operated successfully during the CS06 tests.



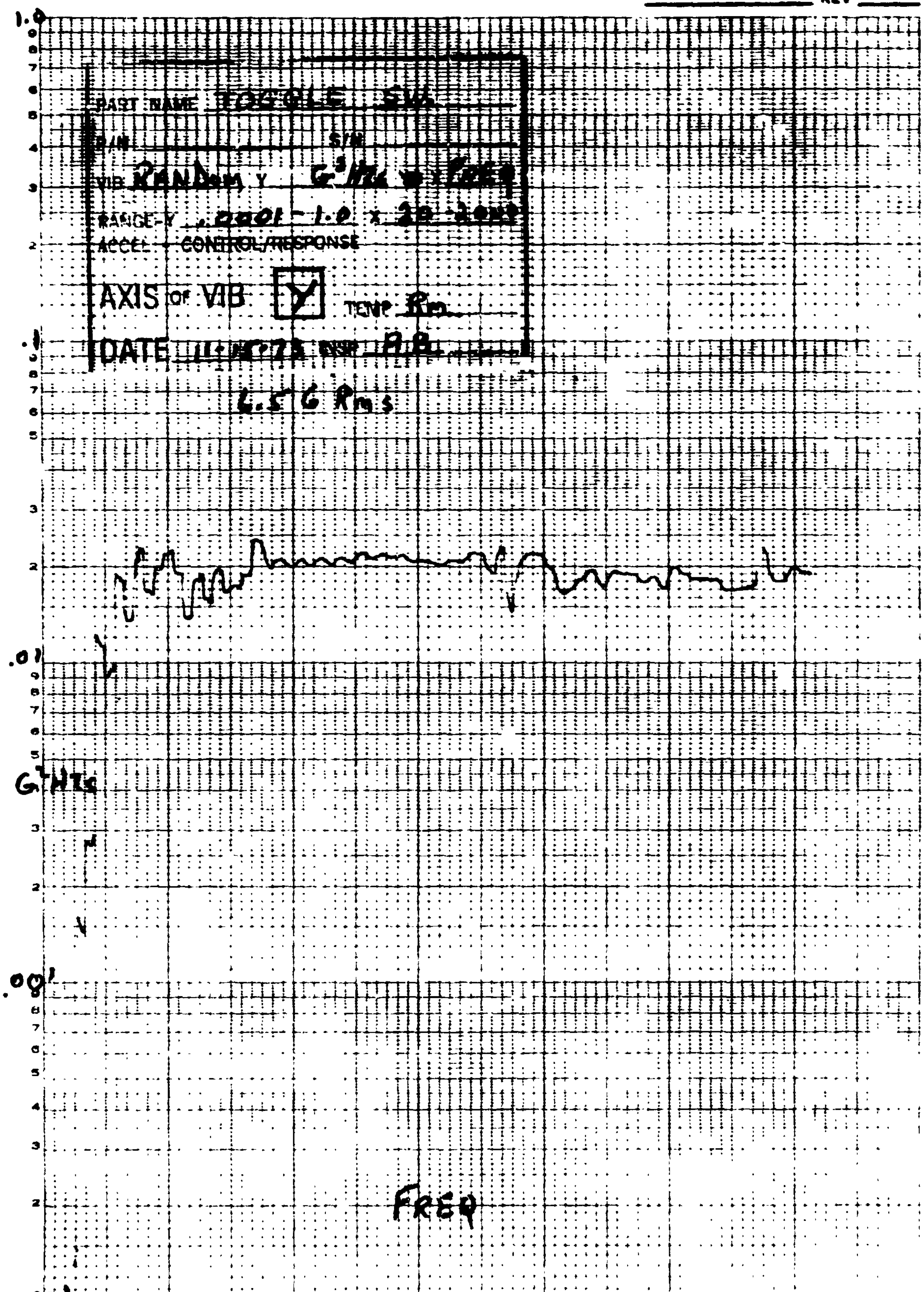
1.0
P/N
S/N
RANGE-Y
ACCEL - CONTROL/RESPONSE
AXIS OF VIB
X
TEMP
DATE 11'15'73
INSP
.01
G^2/Hz
.001
FREQ
.0001

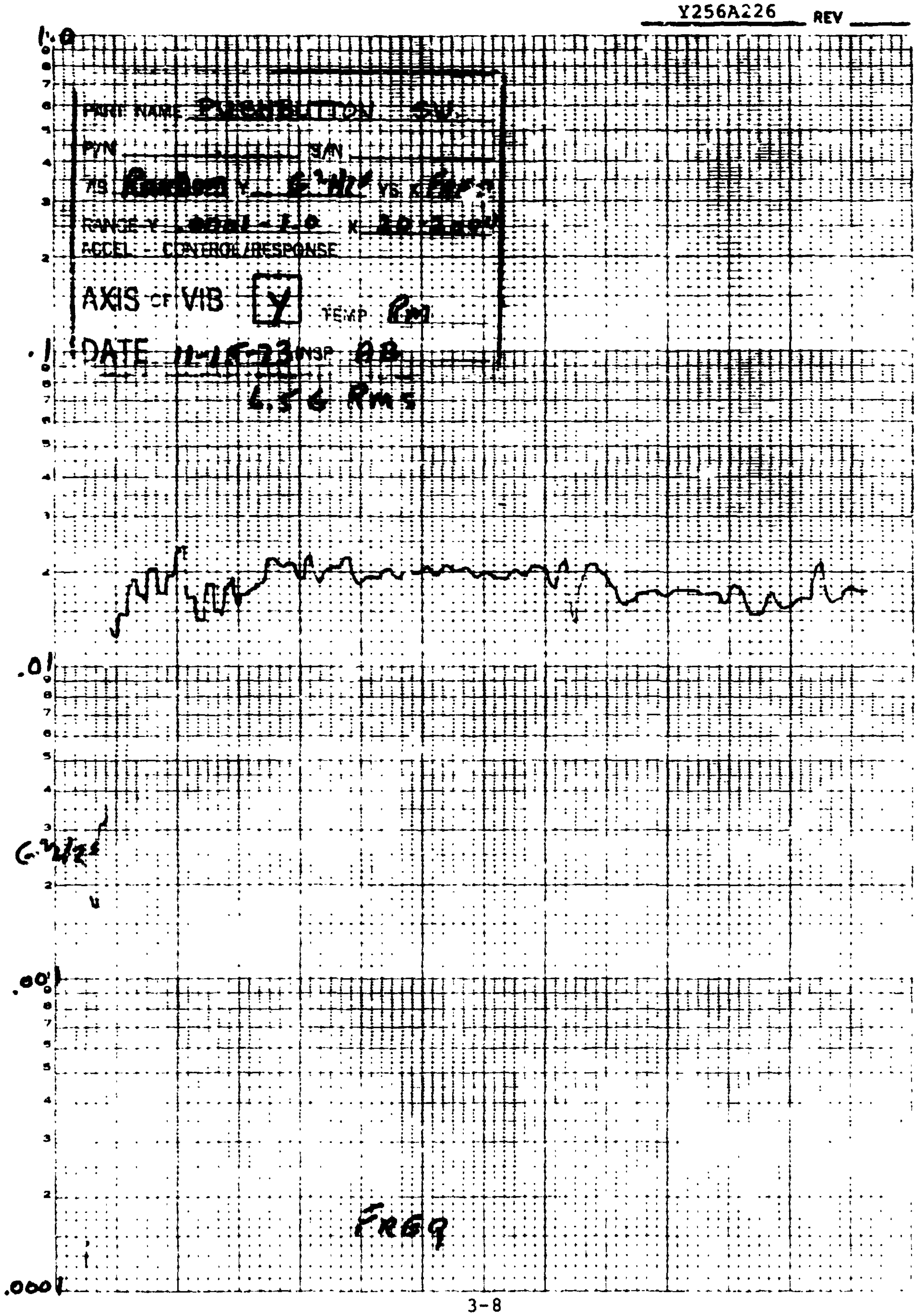

PART NAME Rotary Switch
P/N
S/N
VIB Random
ACCEL: CONTROL/RESPONSE
AXIS OF VIB Y
TEMP Rm
DATE 11-15-72
INSP RB
.1
.01
.001
G²/Hz
FREQ


PART NAME TOGGLE SW
P/N
S/N
VIB
RANGE-Y .0001 - 1.0
CONTROL/RESPONSE
AXIS OF VIB Z
TEMP Rm
DATE
6.5 G RMS
1.0
.1
.01
.001
.0001
G²/Hz
Freq

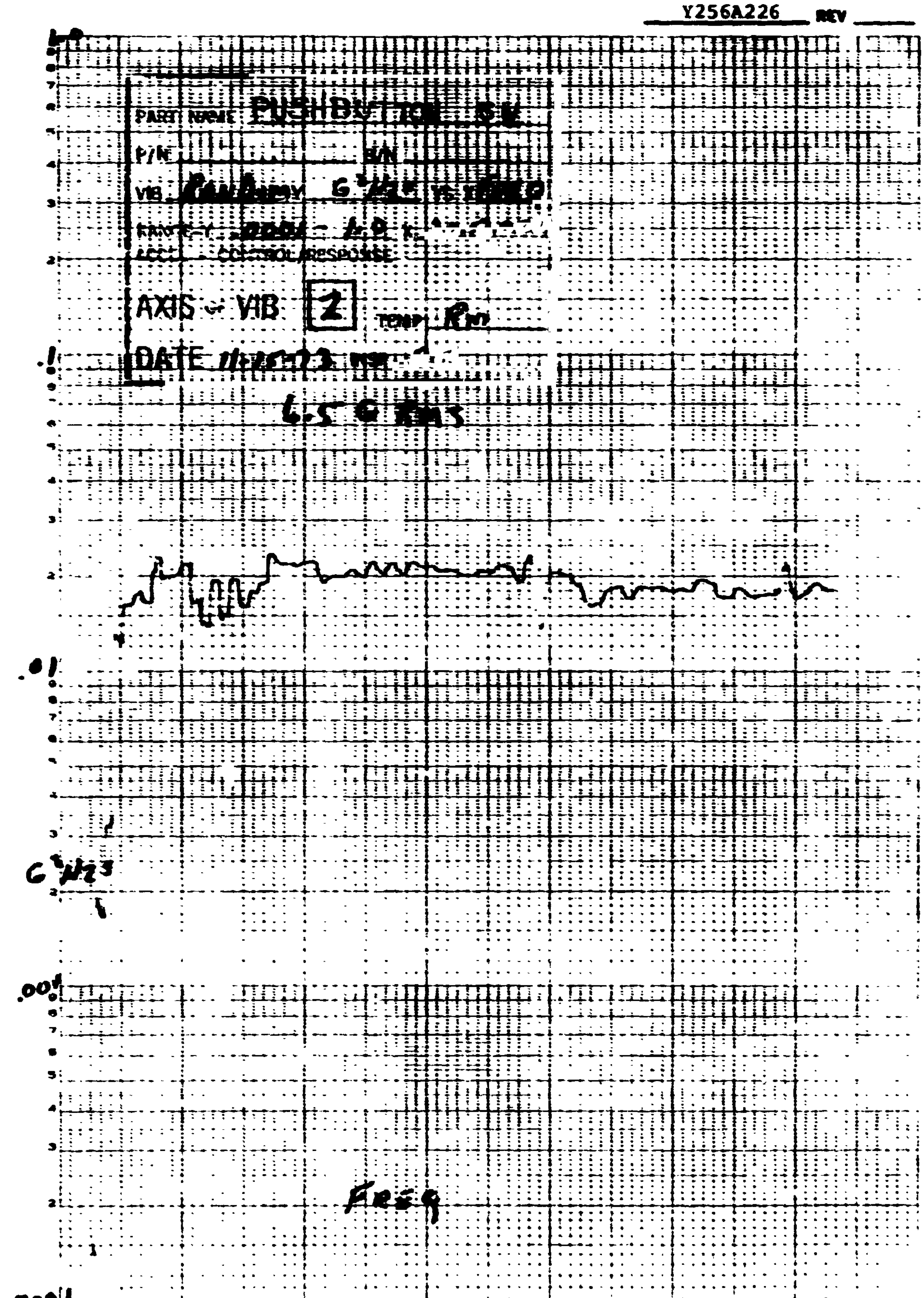


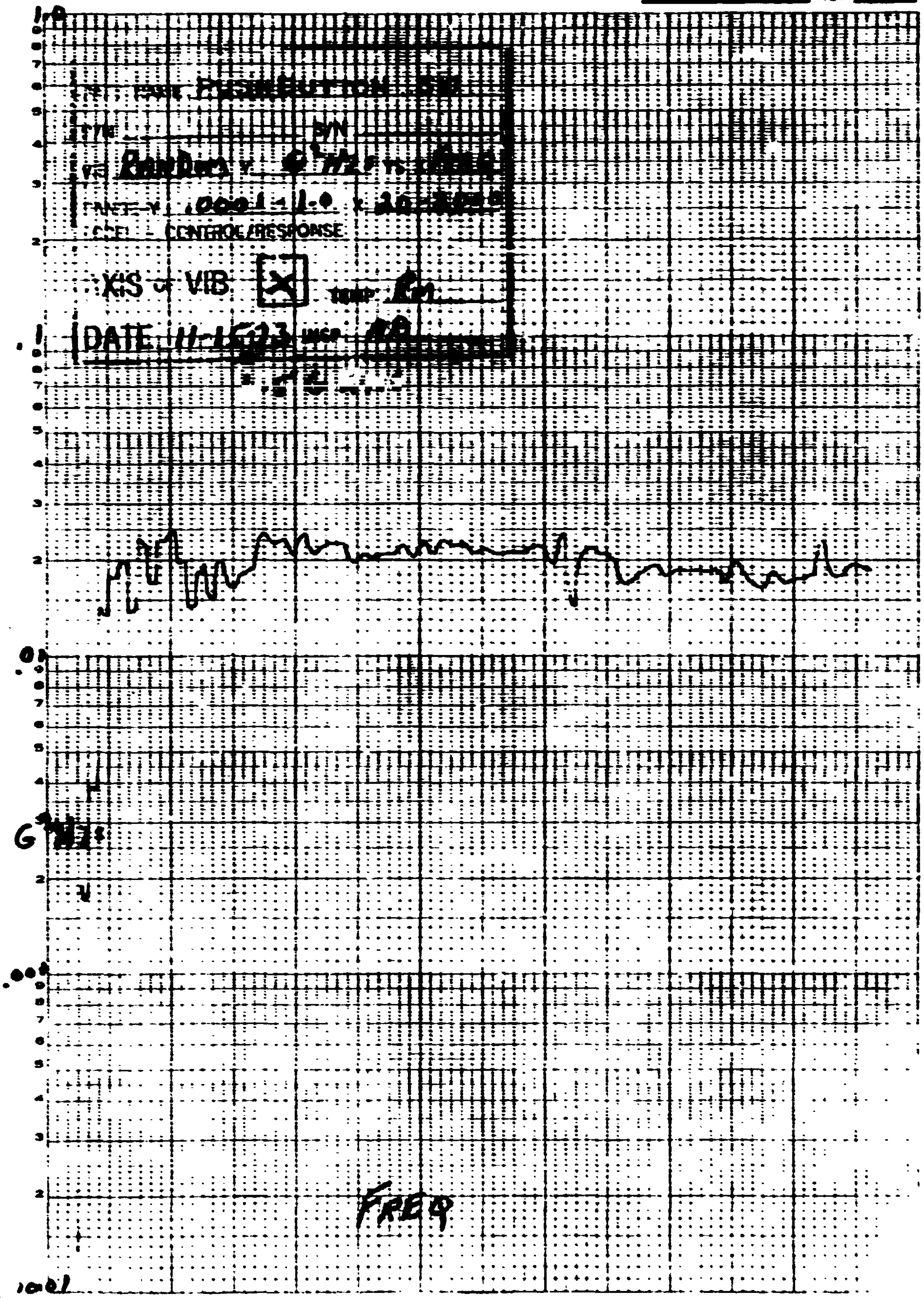
1.0
PART NAME TOGGLE
P/N
CONTROL/RESPONSE
AXIS OF VIB
X
TEMP
DATE 11-15-73 INSP AB
6.5 G Rms
.1
.01
G²/Hz
.001
FREQ
.0001


PART NAME TOGGLE SW.
P/N
S/N
VIB RANDOM Y G²/Hz vs FREQ
RANGE-Y .0001-1.0 X 20-2000
ACCEL CONTROL/RESPONSE
AXIS OF VIB Y
TEMP Rm
DATE
INSP R.B.
6.5 G Rms
1.0
.1
.01
G²/Hz
.001
.0001
FREQ



PART NAME PUSHBUTTON SW.
P/N
S/N
RANGE Y
ACCEL - CONTROL/RESPONSE
AXIS OF VIB Y
TEMP
DATE
INSP
1.0
.1
.01
.001
.0001
FREQ


PART NAME PUSHBUTTON SW
P/N
S/N
VIB.
ACCEL CONTROL/RESPONSE
AXIS OF VIB
TEMP
DATE
6.5 G RMS
.1
.01
.001
.0001
Freq


S/N
CONTROL/RESPONSE
X/S or VIB
DATE
FREQ

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

Y256A226 REV —

SINGER
KEARFOTT DIVISION

Electromagnetic Compatibility Test Data Sheet

TEST SPECIMEN	MODEL NO	SER NO.
POTENTIOMETER	NASA	

TEST MODE: POWER ON

SPECIFICATION	PARAGRAPH	TEST
		+5V.D.C.

CONDUCTED BY	DATE	CHECKED BY	DATE
A.G	11-17-73	B.J	11-17-73

TEST FREQ	METER SETTING	CORRECTION FACTOR	FINAL SETTING	SPECIFICATION LIMIT	INTER. TYPE (SEE NOTE B)	REMARKS
	[illegible]	C.F.	[illegible]	[illegible]		PROBE
.020	4.	[illegible]	37	124	1	
[illegible]	45	10	54	[illegible]	1	
[illegible]	38	7	45	[illegible]	1	
[illegible]	35	5	40	112	1	
.065	37	[illegible]	36	[illegible]	1	
.080	32	3	35	[illegible]	1	
.100	11	2	13	[illegible]	1	
.120	30	1	31	[illegible]	1	
.150	33	1	34	[illegible]	1	
.200	30	0	30	87	1	
.300	30		30	80	1	
.400	30		30	76	1	
[illegible]	30			72	1	
.800	30			64		
1.0	30			63		
1.5	30			53	1	
2.0	30			52	1	
3.0	30				1	
4.0	30				1	
5.0	30				1	
6.0	30				1	
9.0	30				1	
12.0	30				1	
15.0	30				1	
20.0	30				1	
30.0	30				1	
40.0	30				1	
50.0	30				1	

NOTE: A – All frequencies not listed are scanned for maximum interference.
B – Interference Type: (1) Broadband, Steady–State
(2) Broadband, Transients
(3) Narrowband (CW)

PL 393A 9/70

TEST NO.

SINGER
KEARFOTT DIVISION

Electromagnetic Compatibility Test Data Sheet

TEST SPECIMEN	MODEL NO	SER NO.
POTENTIOMETER	NASA	

TEST MODE: POWER ON

SPECIFICATION	PARAGRAPH	TEST
		+ 12 V.D.C

CONDUCTED BY	DATE	CHECKED BY	DATE
AG	11-20-73	B.J	11-20-73

TEST FREQ	METER READING	CORRECTION FACTOR	FINAL READING	SPECIFICATION LIMIT	INTER. TYPE (SEE NOTE B)	REMARKS
	[illegible]	C.F	[illegible]	[illegible]		PROBE
.020	62	11	73	124	1	
.025	62	10	72	120	1	
.035	61	7	68	115	1	
.045	58	5	63	112	1	
.060	47	4	51	106	1	
.080	45	3	49	102	1	
.100	40	2	42	98	1	
.120	41	1	42	[illegible]	1	
.150	37	1	38	92	1	
.200	35	0	35	87	1	
.300	38		38	80	1	
.400	36		36	76	1	
.500	31		31	72	1	
.800	30		30	64	1	
1.0	30		30	60	1	
1.5	30		30	54	1	
2.0	30		30	50	1	
3.0	30		30		1	
4.0	30		30		1	
5.0	30		30		1	
6.0	30		30		1	
9.0	30		30		1	
12.0	30		30		1	
15.0	30		30		1	
20.0	31		31		1	
30.0	30		30		1	
40.0	30		30		1	
50.0	30		30		1	

NOTE: A – All frequencies not listed are scanned for maximum interference.
B – Interference Type: (1) Broadband, Steady–State
(2) Broadband, Transients
(3) Narrowband (CW)

X256A226 REV —

SINGER
KEARFOTT DIVISION

Electromagnetic Compatibility Test Data Sheet

TEST SPECIMEN	MODEL NO	SER NO.
POTENTIOMETER	NASA	

TEST MODE
POWER ON

SPECIFICATION	PARAGRAPH	TEST
		−12 V.D.C.

CONDUCTED BY	DATE	CHECKED BY	DATE
A.G.	11/20/73	BJ.	11-20-73

TEST FREQ	METER READING	CORRECTION FACTOR	FINAL READING	SPECIFICATION LIMIT	INTER. TYPE (SEE NOTE B)	REMARKS
	DBµV/MHz	C.F.	DBµV/MHz	DBµV/MHz		
.020	68	11	79	127	1	PASS
.025	[illegible]	10	78	120	1	
.035	[illegible]	7	73	116	1	
.045	62	5	67	112	1	
.065	51	4	55	106	1	
.080	46	3	49	102	1	
.100	45	2	47	98	1	
.120	41	1	43	96	1	
.150	35	1	36	92	1	
.200	30	0	30	87	1	
.300	30		30	80	1	
.400	30		30	76	1	
.500	30		30	72	1	
.800	30		30	64	1	
1.0	30		30	60	1	
1.5	30		30	[illegible]		
2.0	[illegible]		30	[illegible]		
3.0	30		30		1	
4.0	30		30		1	
5.0	30		30		1	
6.0	30		30		1	
9.0	30		30		1	
12.0	30		30		1	
15.0	30		30		1	
20.0	30		30		1	
30.0	30		30		1	
40.0	30		[illegible]		1	
50.0	30		30		1	

NOTE: A — All frequencies not listed are scanned for maximum interference.
B — Interference Type: (1) Broadband, Steady-State
(2) Broadband, Transients
(3) Narrowband (CW)

SINGER
KEARFOTT DIVISION

Electromagnetic Compatibility Test Data Sheet

TEST SPECIMEN	MODEL NO	SER NO.
POTENTIOMETER	NASA	

TEST MODE: POWER ON

SPECIFICATION	PARAGRAPH	TEST
		SIGNAL LEADS

CONDUCTED BY	DATE	CHECKED BY	DATE
AG	11-20-73	BJ	11-20-73

TEST FREQ	METER READING	CORRECTION FACTOR	FINAL READING	SPECIFICATION LIMIT	INTER. TYPE (SEE NOTE B)	REMARKS
	[illegible]	C.F.	db/µa/MHz	db/µa/MHz		
.020	105	11	116	[illegible]	1	PROBE
.025	101	10	111	[illegible]	1	
.035	90	7	97	116	1	
.045	85	5	90	112	1	
.065	71	4	75	106	1	
.083	71	3	74	102	1	
.100	71	2	73	98	1	
.120	65	1	66	96	1	
.150	60	1	61	92	1	
.200	52	0	52	87	1	
.300	41		41	80	1	
.400	41		41	76	1	
.500	37		37	72	1	
.800	30		30	64	1	
1.0	30		30	60	1	
1.5	30		30	54	1	
2.0	30		30	50	1	
3.0	30		30		1	
4.0	30		30		1	
5.0	30		30		1	
6.0	30		30		1	
9.0	30		30		1	
12.0	30		30		1	
15.0	30		30		1	
20.0	30		30		1	
30.0	31		31		1	
40.0	30		30			
50.0	30	V	30			

NOTE: A – All frequencies not listed are scanned for maximum interference.
B – Interference Type: (1) Broadband, Steady-State
(2) Broadband, Transients
(3) Narrowband (CW)

SINGER
KEARFOTT DIVISION

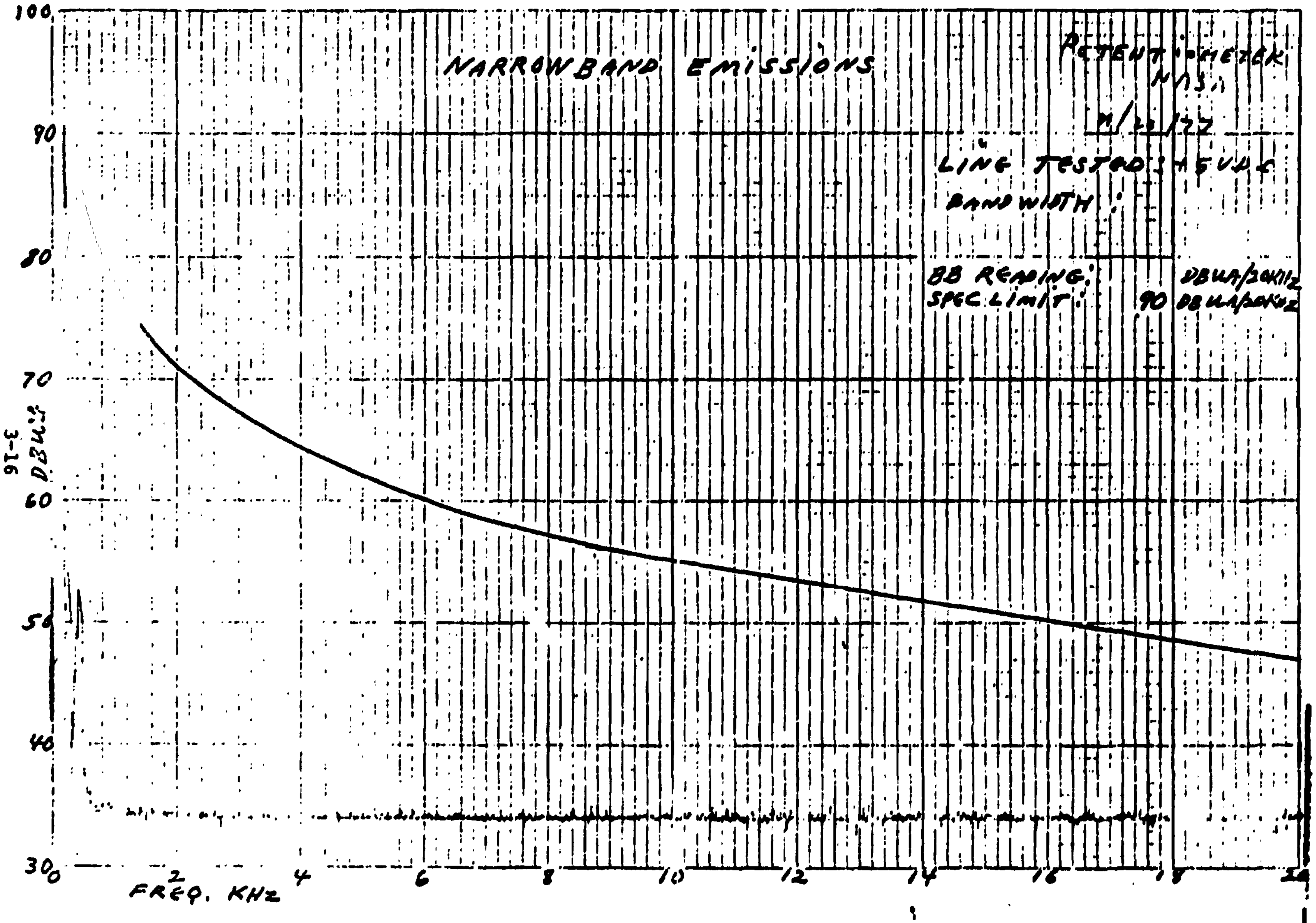
Electromagnetic Compatibility Test Data Sheet

TEST SPECIMEN: POTENTIOMETER	MODEL NO: NASA	SER NO.:
TEST MODE: POWER ON		
SPECIFICATION:	PARAGRAPH:	TEST: -12 V. D.C

CONDUCTED BY	DATE	CHECKED BY	DATE
A.G.	11/20/73	B.J	11-20-73

TEST FREQ	METER READING	CORRECTION FACTOR	FINAL READING	SPECIFICATION LIMIT	INTER. TYPE (SEE NOTE B)	REMARKS
	[illegible]	C.F.	[illegible]	[illegible]		
.200	37	0	37	[illegible]	3	[illegible]
.300	43	[illegible]	43	80	3	[illegible]
.400	[illegible]	0	[illegible]	76	3	[illegible]
.500	33	0	[illegible]	72	3	[illegible]

NOTE: A – All frequencies not listed are scanned for maximum interference.
B – Interference Type: (1) Broadband, Steady-State
(2) Broadband, Transients
(3) Narrowband (CW)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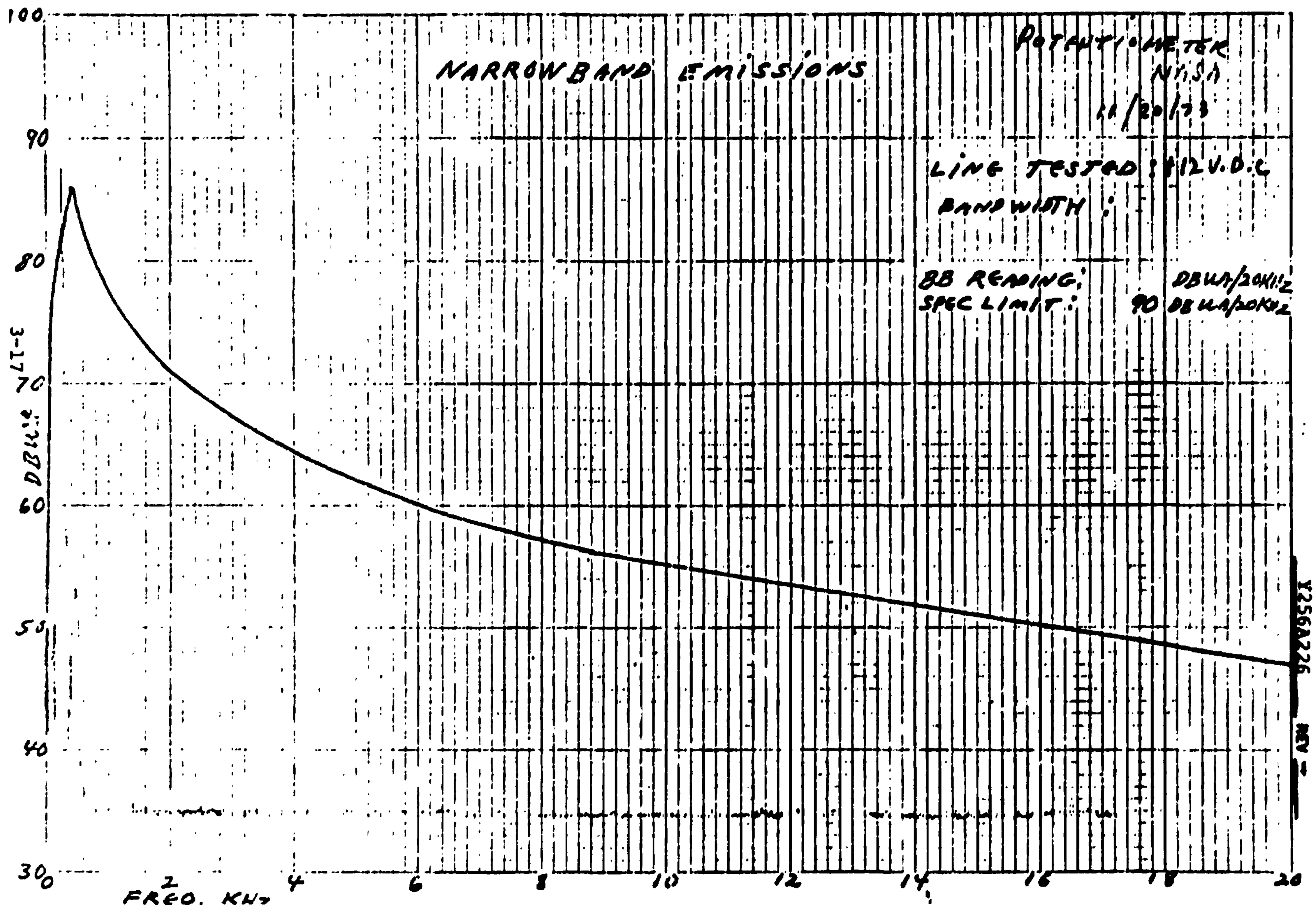
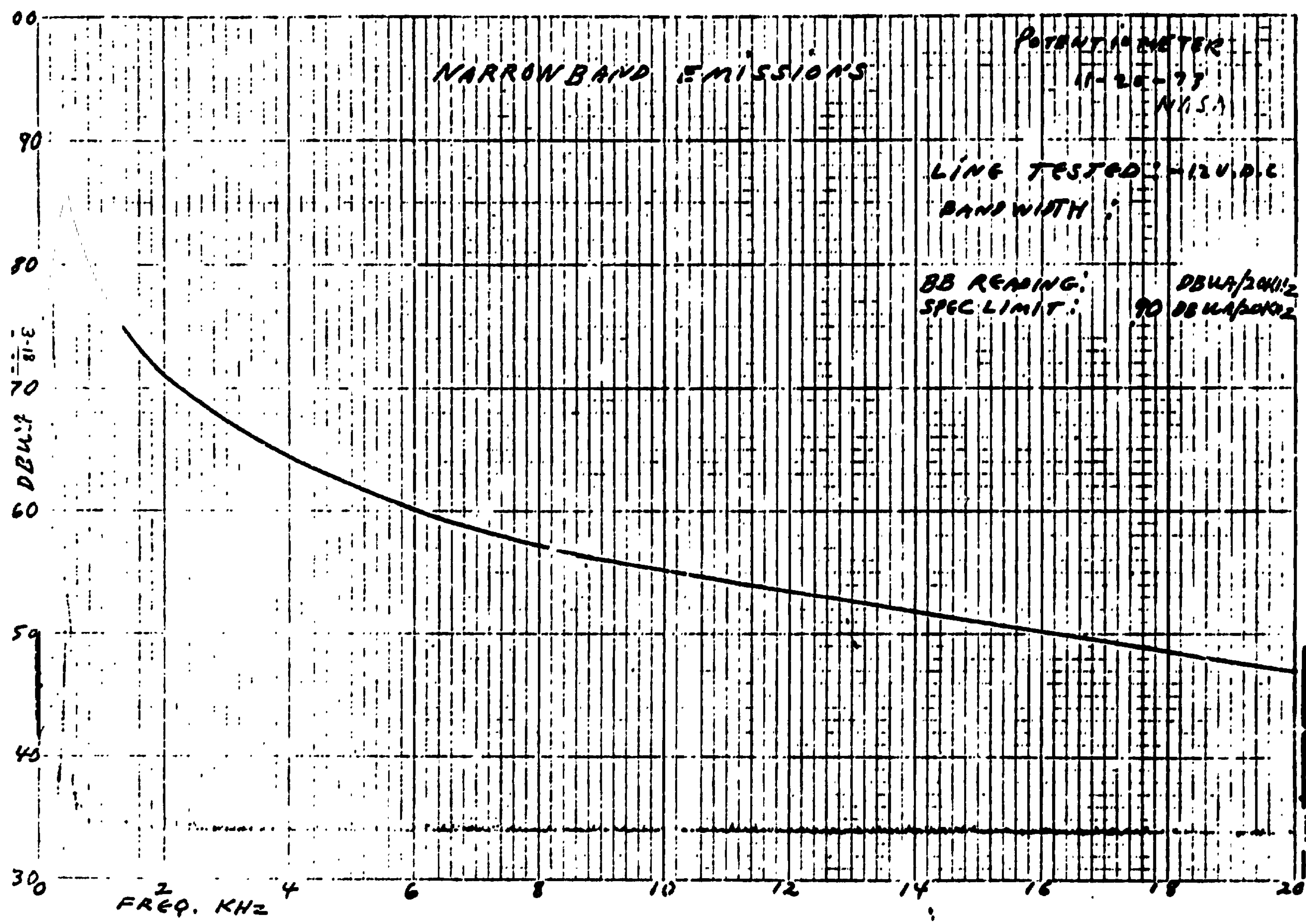
LINE TESTED:
BANDWIDTH:
BB READING:
SPEC LIMIT: 90 DBUA/20KHZ
DBUA/20KHZ
100
90
80
70
60
50
40
30
DBUA
0
2
4
6
8
10
12
14
16
18
20
FREQ. KHZ


NARROWBAND EMISSIONS
POTENTIOMETER
NASA
11/20/73
LINE TESTED: +12 V.D.C
BANDWIDTH:
BB READING: DBUA/20KHz
SPEC LIMIT: 90 DBUA/20KHz
DBUA
FREQ. KHz
100
90
80
70
60
50
40
30
0
2
4
6
8
10
12
14
16
18
20
Y256A226
REV

MIL-STD-461A



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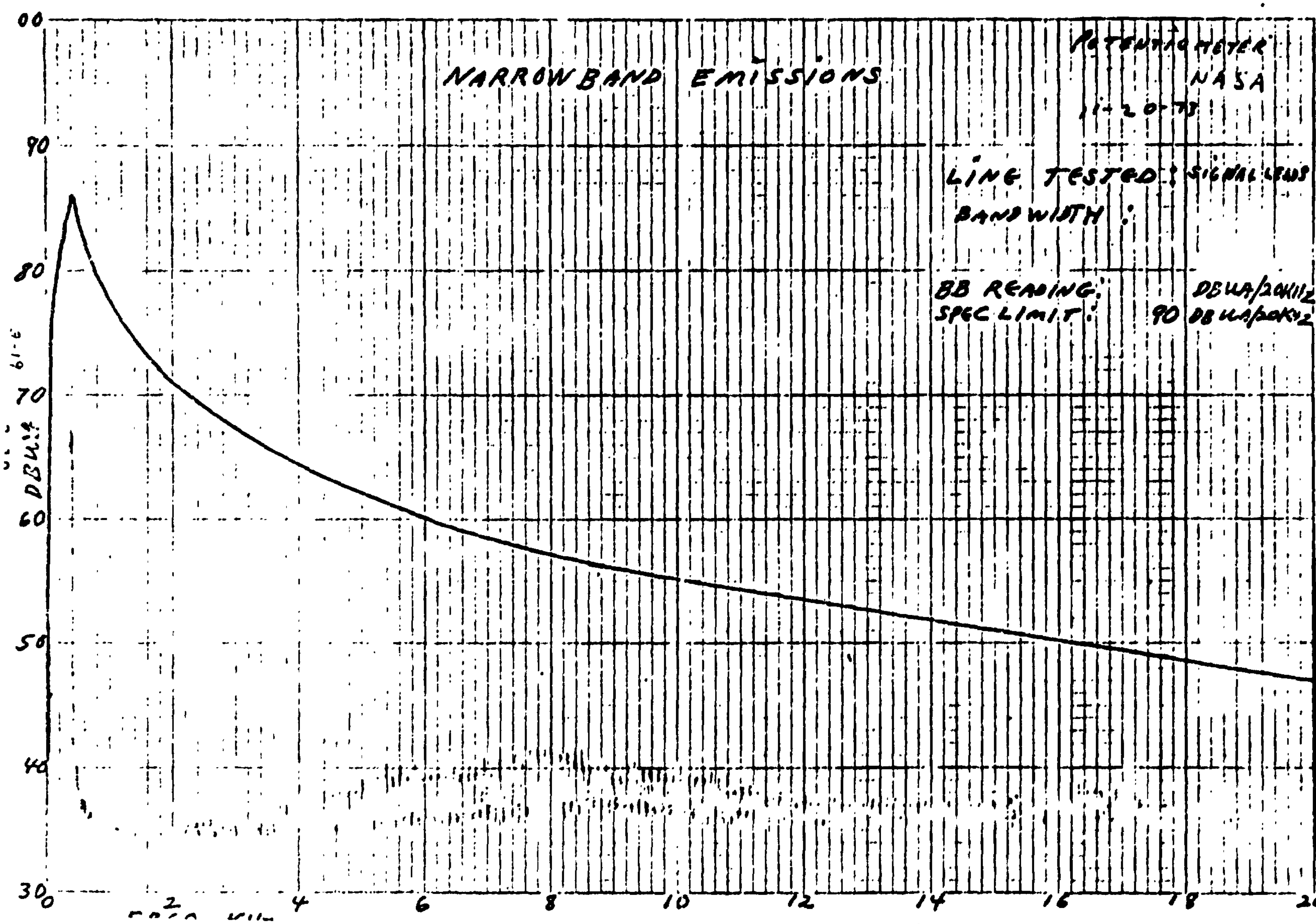

Y256A226 REV -

Y256A226

SINGER
KEARFOTT DIVISION

Electromagnetic Compatibility Test Data Sheet

TEST SPECIMEN	MODEL NO	SER NO.
NASA	0-1-2	

TEST MODE: Power on

SPECIFICATION	PARAGRAPH	TEST
		OUTPUT #1

CONDUCTED BY	DATE	CHECKED BY	DATE
A. G.	11/ 2/73	B. J.	11/18/73

TEST FREQ	METER READING	CORRECTION FACTOR	FINAL READING	SPECIFICATION LIMIT	INTER. TYPE (SEE NOTE B)	REMARKS
	[illegible]		[illegible]			
4.1	22	0	22	20	3	PROBE
10.7	16	0	16	20	3	"
22.0	22	0	22	20	3	"

NOTE: A – All frequencies not listed are scanned for maximum interference.
B – Interference Type: (1) Broadband, Steady-State
(2) Broadband, Transients
(3) Narrowband (CW)

Y256A226 REV

SINGER
KEARFOTT DIVISION

Electromagnetic Compatibility Test Data Sheet

TEST SPECIMEN	MODEL NO	SER NO.
NASA	0-1-2	

TEST MODE: Power on

SPECIFICATION	PARAGRAPH	TEST
		[illegible]

CONDUCTED BY	DATE	CHECKED BY	DATE
[illegible]	11/18/73	[illegible]	11/18/73

TEST FREQ	METER READING	CORRECTION FACTOR	FINAL READING	SPECIFICATION LIMIT	INTER. TYPE (SEE NOTE B)	REMARKS
	[illegible]		[illegible]			
[illegible]	11	0	11	20	2	[illegible]
15.[illegible]	12	0	12	20	2	[illegible]
21.5	27	0	27	20	2	[illegible]

NOTE: A – All frequencies not listed are scanned for maximum interference.
B – Interference Type: (1) Broadband, Steady-State
(2) Broadband, Transients
(3) Narrowband (CW)

PL 300A 9/70

TEST NO.

Y256A226 REV

SINGER
KEARFOTT DIVISION

Electromagnetic Compatibility Test Data Sheet

TEST SPECIMEN NASA	MODEL NO 0-1-2	SER NO.
TEST MODE Power on		
SPECIFICATION	PARAGRAPH	TEST +50 V.D.C.

CONDUCTED BY R.S.	DATE 11-16-73	CHECKED BY	DATE 11-16-73

TEST FREQ	METER READING	CORRECTION FACTOR	FINAL READING	SPECIFICATION LIMIT	INTER. TYPE (SEE NOTE B)	REMARKS
	DB					
7.1	50	0	50	20	3	PROBE
15.7	26	0	26	20	3	"
22.5	22	0	22	20	3	"

NOTE: A – All frequencies not listed are scanned for maximum interference.
B – Interference Type: (1) Broadband, Steady-State
(2) Broadband, Transients
(3) Narrowband (CW)

PL 350A 9/70

SINGER KEARFOTT DIVISION

Electromagnetic Compatibility Test Data Sheet

TEST SPECIMEN: NASA	MODEL NO: 0-1-2	SER NO.
TEST MODE: Power on		
SPECIFICATION	PARAGRAPH	TEST: 28 V.D.C.
CONDUCTED BY: A.G. DATE: 7/18/77	CHECKED BY: B.J.	DATE: 7/18/73

TEST FREQ	METER READING	CORRECTION FACTOR	FINAL READING	SPECIFICATION LIMIT	INTER. TYPE (SEE NOTE B)	REMARKS
[illegible]	56	0	56	20	3	Pass
12.7	42	0	42	20	3	"
15.7	21	0	21	20	3	"

NOTE: A – All frequencies not listed are scanned for maximum interference.
B – Interference Type: (1) Broadband, Steady-State
(2) Broadband, Transients
(3) Narrowband (CW)

PL 300A 6/70

TEST NO.

SINGER
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Electromagnetic Compatibility Test Data Sheet

TEST SPECIMEN	MODEL NO.	SER NO.
NASA DOUBLE POLE	01-2	

TEST MODE: P[illegible]R ON

SPECIFICATION	PARAGRAPH	TEST
		28V. D.C.

CONDUCTED BY	DATE	CHECKED BY	DATE
A.G.	11-17-73	B.J.	11-17-73

TEST FREQ	METER READING	CORRECTION FACTOR	FINAL READING	SPECIFICATION LIMIT	INTER. TYPE (SEE NOTE B)	REMARKS
	[illegible]	C.P.	[illegible]	[illegible]		
.020	43	11	54	126	1	PROBE
.025	42	10	52	120		
.035	32	7	37	116		
.045	34	5	39	112		
.065	32	4	36	106		
.085	30	3	33	102		
.100	30	2	32	98		
.120	30	1	31	96		
.150	30	1	31	92		
.200	30	0	30	87		
.300	30	0	30	80		
.400	30		30	76		
.500	55		55	72		
.800	30		30	64		
1.0	30		30	60		
1.5	35		35	57		
2.0	30		30	50		
3.0	30		30			
4.0	30		30			
5.0	55		55			
6.0	37		37			
9.2	38		38			
12.0	30		30			
15.0	30		30			
20.0	30		30			
26.0	30		30			
40.0	30		30			
50.0	32		32			

NOTE: A – All frequencies not listed are scanned for maximum interference.
B – Interference Type: (1) Broadband, Steady–State
(2) Broadband, Transients
(3) Narrowband (CW)

X256A226 REV.

SINGER
KEARFOTT DIVISION

Electromagnetic Compatibility Test Data Sheet

TEST SPECIMEN	MODEL NO.	SER NO.
NASA	0-1-2	

TEST	
[illegible]	

SPECIFICATION	PARAGRAPH	TEST
		007 P07 #2

CONDUCTED BY	DATE	CHECKED BY	DATE
AG	11-17-73	[illegible]	11-17-73

TEST FREQ	METER READING	CORRECTION FACTOR	FINAL READING	SPECIFICATION LIMIT	INTER. TYPE (SEE NOTE B)	REMARKS
	[illegible]	C.P.	[illegible]	[illegible]		
[illegible]	4[illegible]	[illegible]	51	120	2	PROBE
[illegible]	42	[illegible]	52	160		
.035	[illegible]	7	48	[illegible]		
.045	[illegible]	5	46	112		
.050	43	4	47	106		
.060	42	3	45	102		
.100	42	2	44	[illegible]		
.120	42	1	43	[illegible]		
.150	35	1	36	72		
.200	33	0	33	67		
.300	33	0	33	[illegible]		
1.5	32	0	32	54		

NOTE: A – All frequencies not listed are scanned for maximum interference.
B – Interference Type: (1) Broadband, Steady-State
(2) Broadband, Transients
(3) Narrowband (CW)

Y256A226 REV –

SINGER
KEARFOTT DIVISION

Electromagnetic Compatibility Test Data Sheet

TEST SPECIMEN: NASA	MODEL NO: 0-1-2	SER NO.
TEST MODE: POWER ON		
SPECIFICATION	PARAGRAPH	TEST: OUTPUT NO ONE
CONDUCTED BY: A.G.	DATE	CHECKED BY: B.J. — DATE: 11-17-73

TEST FREQ	METER READING	CORRECTION FACTOR	FINAL READING	SPECIFICATION LIMIT	INTER. TYPE (SEE NOTE B)	REMARKS
	[illegible]	C.F.	[illegible]/MHZ	[illegible]/MHZ		
.020	[illegible]	11	[illegible]	124	1	PEAK
[illegible]	[illegible]	10	51	120		
[illegible]	34	7	41	[illegible]		
.045	34	5	[illegible]	112		
[illegible]	32	4	36	106		
[illegible]	31	3	34	102		
.100	30	2	32	[illegible]		
[illegible]	[illegible]	1	31	[illegible]		
.150	30	1	31	92		
.200	30	0	30	87		
[illegible]	30		30	82		
.400	30		30	76		
.500	30		30	72		
.800	30		30	64		
1.0	30		30	60		
1.5	30		30	54		
2.0	30		30	56		
3.0	30		30			
4.0	[illegible]		30			
5.0	30		30			
6.0	30		30			
[illegible]	30		30			
10.0	30		30			
15.0	30		30			
20.0	30		30			
25.0	30		30			
30.0	32		32			
40.0	30		30			
50.0	43		43			

NOTE: A – All frequencies not listed are scanned for maximum interference.
B – Interference Type: (1) Broadband, Steady-State
(2) Broadband, Transients
(3) Narrowband (CW)

PL 309A 8/70

TEST NO.

SINGER
KEARFOTT DIVISION

Electromagnetic Compatibility Test Data Sheet

TEST SPECIMEN	MODEL NO	SER NO.
NASA	0-1-2	

TEST MODE: POWER ON.

SPECIFICATION	PARAGRAPH	TEST
		OUTPUT # 1

CONDUCTED BY	DATE	CHECKED BY	DATE
AG	11-17-73	BJ	11-17-73

TEST FREQ	METER READING	CORRECTION FACTOR	FINAL READING	SPECIFICATION LIMIT	INTER. TYPE (SEE NOTE B)	REMARKS
.020	[illegible]	11	62	124	2	[illegible]
.025	[illegible]	13	56	120		
.035	[illegible]	[illegible]	49	116		
.045	[illegible]	5	46	112		
.055	43	4	47	106		
.070	43	3	46	102		
.100	42	2	40	98		
.120	42	1	43	96		
.150	34	1	35	92		
.200	34	0	34	87		
.300	33		33	80		
.400	33		33	76		
.500	32		32	72		
.800	32		32	64		
1.0	32		32	59		
1.5	33		33	54		
2.0	35		35	50		

NOTE: A — All frequencies not listed are scanned for maximum interference.
B — Interference Type: (1) Broadband, Steady—State
(2) Broadband, Transients
(3) Narrowband (CW)

Y256A226 REV —

SINGER
KEARFOTT DIVISION

Electromagnetic Compatibility Test Data Sheet

TEST SPECIMEN	MODEL NO	SER NO.
NASA	0-1-2	

TEST: POWER ON

SPECIFICATION	PARAGRAPH	TEST
		5 V. D.C

CONDUCTED BY	DATE	CHECKED BY	DATE
A.G	11-17-73	B.J.	11-17-73

TEST FREQ	METER READING	CORRECTION FACTOR	FINAL READING	SPECIFICATION LIMIT	INTER. TYPE (SEE NOTE B)	REMARKS
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
.020	[illegible]	1[illegible]	5[illegible]	124	2	PROBE
.025	43	10	53	120		
.035	3[illegible]	[illegible]	45	1[illegible]6		
.045	38	5	43	112		
.065	44	4	48	106		
.080	42	3	45	102		
.100	41	2	43	98		
.120	40	1	41	96		
.150	38	1	39	92		
.200	37	0	37	57		
.300	37		37	50		
.400	34		34	76		
.500	33		33	72		
.800	31		31	64		
1.0	35		35	60		
1.5	32		32	54		
2.0	32		32	50		
5.0	37		37	52		
60	56		56	50		

NOTE: A – All frequencies not listed are scanned for maximum interference.
B – Interference Type: (1) Broadband, Steady-State
(2) Broadband, Transients
(3) Narrowband (CW)

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Y256A226 REV —

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Electromagnetic Compatibility Test Data Sheet

TEST SPECIMEN	MODEL NO	SER NO.
NASA	0-1-2	

TEST MODE: POWER ON

SPECIFICATION	PARAGRAPH	TEST
		5 V, D.C

CONDUCTED BY	DATE	CHECKED BY	DATE
AG	11/17/73	PJ	11/17/73

TEST FREQ	METER READING	CORRECTION FACTOR	FINAL READING	SPECIFICATION LIMIT	INTER. TYPE (SEE NOTE B)	REMARKS
	[illegible]	C.F.	[illegible]	[illegible]		
[illegible]	42	11	53	124	1	PROBE
.025	[illegible]	10	45	120		
.035	[illegible]	7	46	116		
.045	32	5	37	106		
.065	32	4	36	[illegible]		
.085	30	3	33	98		
.100	30	2	32	96		
.120	30	1	31	92		
.150	30	1	31	87		
.200	30	0	30	80		
.300	30		30	75		
.430	30		30	76		
.500	30		30	65		
.800	30		30	60		
1.0	30		30	54		
1.5	30		30	50		
2.0	30		30			
3.0	30		30			
4.0	30		30			
5.0	31		31			
6.0	50		50			
9.0	54		54			
12.0	30		30			
15.0	30		30			
20.00	30		30			
25.0	36		36			
30.0	30		[illegible]			
40.0	33		33			
50.0	32		32			

NOTE: A — All frequencies not listed are scanned for maximum interference.
B — Interference Type: (1) Broadband, Steady-State
(2) Broadband, Transients
(3) Narrowband (CW)

X256A226 REV

SINGER
KEARFOTT DIVISION

Electromagnetic Compatibility Test Data Sheet

TEST SPECIMEN	MODEL NO	SER NO.
NASA	0-1-2	

TEST MODE: Power on

SPECIFICATION	PARAGRAPH	TEST
		28 V.D.C.

CONDUCTED BY	DATE	CHECKED BY	DATE
A G	11-17-73	BJ	11-17-73

TEST FREQ	METER READING	CORRECTION FACTOR	FINAL READING	SPECIFICATION LIMIT	INTER. TYPE (SEE NOTE B)	REMARKS
.020	51	11	61	120	2	PROBE
.025	41	10	59	120		
.035	[illegible]	7	45	115		
.045	40	5	45	112		
.055	48	4	52	106		
.080	42	3	45	102		
.100	42	2	44	78		
.120	42	1	43	46		
.150	38	1	39	42		
.260	[illegible]	0	38	87		
.300	35		35	80		
.400	34		34	7-		
.500	55		58	72		
.800	34		34	[illegible]		
1.0	34		34	60		
1.5	37		35	56		
2.0	32		32	[illegible]		
[illegible]	37		37	50		
4.2	41		41	50		

NOTE: A – All frequencies not listed are scanned for maximum interference.
B – Interference Type: (1) Broadband, Steady-State
(2) Broadband, Transients
(3) Narrowband (CW)

Y256A226 REV

SINGER
KEARFOTT DIVISION

Electromagnetic Compatibility Test Data Sheet

TEST SPECIMEN	MODEL NO	SER NO.
NASA	0-1-1	

TEST MODE: Power on

SPECIFICATION	PARAGRAPH	TEST
		OUTPUT #2

CONDUCTED BY	DATE	CHECKED BY	DATE
A G	11-17-73	B.J.	11-17-73

TEST FREQ	METER READING	CORRECTION FACTOR	FINAL READING	SPECIFICATION LIMIT	INTER. TYPE (SEE NOTE B)	REMARKS
	[illegible]	[illegible]	[illegible]	[illegible]		
[illegible]	[illegible]	[illegible]	53	124	1	[illegible]
.025	[illegible]	[illegible]	45	120		
[illegible]	[illegible]	7	42	[illegible]		
.045	[illegible]	5	[illegible]	112		
.065	32	4	[illegible]	106		
.080	[illegible]	3	[illegible]	102		
.100	30	2	32	98		
.120	30	1	31	96		
.150	30	1	31	92		
.200	30	0	30	87		
.300	30		30	80		
.400	30		30	76		
.500	30		30	72		
.800	30		30	64		
1.0	30		30	66		
1.5	30		30	[illegible]		
2.0	30		30	[illegible]		
[illegible]	30		30			
[illegible]	30		30			
[illegible]	30		30			
[illegible]	30		30			
[illegible]	30		30			
12.0	30		30			
15.0	30		30			
20.0	30		30			
25.0	[illegible]		30			
30.0	[illegible]		[illegible]			
40.0	[illegible]		[illegible]			
50.0	30		30			

NOTE: A – All frequencies not listed are scanned for maximum interference.
B – Interference Type: (1) Broadband, Steady-State
(2) Broadband, Transients
(3) Narrowband (CW)

Y256A226 REV —

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KEARFOTT DIVISION

Electromagnetic Compatibility Test Data Sheet

TEST SPECIMEN: NASA
MODEL NO: C-1-1
SER NO.:
TEST MODE: Power ...
SPECIFICATION:
PARAGRAPH:
TEST: 5 V.D.C. Line
CONDUCTED BY: A.G.
DATE: 11/17/73
CHECKED BY: B.J
DATE: 11/17/73

TEST FREQ	METER READING	CORRECTION FACTOR	FINAL READING	SPECIFICATION LIMIT	INTER. TYPE (SEE NOTE B)	REMARKS
	[illegible]		[illegible]	dB/ua/MHz		
.020	63	17	50	124	1	PROBE
.025	40	10	50	120		
.035	33	7	40	116		
.045	34	5	39	112		
.065	30	4	34	106		
.080	30	3	33	102		
.100	30	2	32	98		
.120	30	1	31	96		
.150	30	1	31	92		
.200	30	0	30	87		
.300	30		30	80		
.400	30		30	76		
.500	30		30	72		
.800	30		30	64		
1.0	30		30	60		
1.5	30		30	54		
2.0	30		30	50		
3.0	30		30			
4.0	30		30			
5.0	[illegible]		30			
6.0	30		30			
9.2	79		80			
12.0	30		30			
15.0	30		30			
20.0	31		30			
25.0	30		30			
30.0	30		30			
40.0	30		30			
50.0	30		30			

NOTE: A — All frequencies not listed are scanned for maximum interference.
B — Interference Type: (1) Broadband, Steady-State
(2) Broadband, Transients
(3) Narrowband (CW)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

X256A226 REV –

SINGER
KEARFOTT DIVISION

Electromagnetic Compatibility Test Data Sheet

TEST SPECIMEN	MODEL NO	SER NO.
NASA	U-1-1	

TEST MODE: POWER ON

SPECIFICATION	PARAGRAPH	TEST
		OUTPUT #2

CONDUCTED BY	DATE	CHECKED BY	DATE
A.G	11-17-73	B.J	11-17-73

TEST FREQ	METER READING	CORRECTION FACTOR	FINAL READING	SPECIFICATION LIMIT	INTER. TYPE (SEE NOTE B)	REMARKS
	[illegible]	C.F	[illegible]	dB/uA/MHz		
.020	[illegible]	11	53	120	1	PROBE
.025	[illegible]	15	51	120		
.033	[illegible]	7	43	116		
.045	34	5	39	112		
.065	34	4	38	106		
.080	32	3	35	102		
.100	30	2	32	98		
.120	30	1	31	96		
.150	30	1	31	92		
.200	30	0	30	87		
.300	30		30	80		
.400	30		30	76		
.500	30		30	72		
.800	30		30	64		
1.0	30		30	60		
1.5	30		30	54		
2.0	30		30	50		
3.0	30		30			
4.0	30		30			
5.0	[illegible]		30			
6.0	[illegible]		30			
9.2	61		61			
12.0	30		30			
15.0	30		30			
20.0	[illegible]		30			
25.0	[illegible]		30			
[illegible]	[illegible]		30			
40.0	30		30			
50.0	30		30			

NOTE: A – All frequencies not listed are scanned for maximum interference.
B – Interference Type: (1) Broadband, Steady-State
(2) Broadband, Transients
(3) Narrowband (CW)

X256A226 REV —

SINGER
KEARFOTT DIVISION

Electromagnetic Compatibility Test Data Sheet

TEST SPECIMEN	MODEL NO	SER NO.
NASA	0-1-1	

TEST MODE: POWER ON

SPECIFICATION	PARAGRAPH	TEST
		12 V.D.C. LINE

CONDUCTED BY	DATE	CHECKED BY	DATE
A G	11-17-73	B.J.	11/17/73

TEST FREQ	METER READING		CORRECTION FACTOR	FINAL READING		SPECIFICATION LIMIT	INTER. TYPE (SEE NOTE B)	REMARKS
MHZ	SW OFF	SW ON	DB	SW OFF	SW ON	DB/uA/MHZ		
.020	44		11	55		124	1	[illegible]
.025	40		10	50		120		
.035	33		7	40		116		
.045	34		5	39		112		
.060	37		4	41		106		
.080	38		3	41		102		
.100	38		2	40		98		
.120	30		1	31		96		
.150	30	46	1	31	46	92		
.200	30	43	0	30	43	87		
.300	30	44		30	44	80		
.400	30	49		30	49	76		
.500	30	47		30	47	72		
.800	30	51		30	51	64		
1.0	30	56		30	56	60		
1.5	30	57		30	57	54		
2.0	30	54		30	54	50		
3.0	30	49		30	49			
4.0	30	40		30	45			
5.0	48	48		48	48			
6.0	30	50		30	50			
9.2	38	73		38	73			
12.0	30	42		30	42			
15.0	30	35		30	35			
20.0	30	36		30	36			
25.0	30	30		30	30			
30.0	30	30		30	30			
[illegible]	[illegible]	30		30	30			
[illegible]	[illegible]	[illegible]		30	30			

NOTE: A — All frequencies not listed are scanned for maximum interference.
B — Interference Type: ✓(1) Broadband, Steady-State
(2) Broadband, Transients
(3) Narrowband (CW)

X256A326 REV 1

SINGER KEARFOTT DIVISION

Electromagnetic Compatibility Test Data Sheet

TEST SPECIMEN	MODEL NO	SER NO.
NASA	0-1-1	

TEST MODE: POWER ON

SPECIFICATION	PARAGRAPH	TEST
		12.0 V.D.C

CONDUCTED BY	DATE	CHECKED BY	DATE
A.G.	11/1/73	B.J.	11/1/73

TEST FREQ	METER READING	CORRECTION FACTOR	FINAL READING	SPECIFICATION LIMIT	INTER. TYPE (SEE NOTE B)	REMARKS
	[illegible]					C.W.
5.1	[illegible]	0	[illegible]	20	3	PASS
10.0	40	0	40	20	3	"
26.0	26	0	26	20	3	"

NOTE: A — All frequencies not listed are scanned for maximum interference.
B — Interference Type: (1) Broadband, Steady—State
(2) Broadband, Transients
(3) Narrowband (CW)

Y256A226 REV —

SINGER
KEARFOTT DIVISION

Electromagnetic Compatibility Test Data Sheet

TEST SPECIMEN	MODEL NO	SER NO.
NASA	0-1-1	

TEST MODE: POWER ON

SPECIFICATION	PARAGRAPH	TEST
		+5.0 V.D.C

CONDUCTED BY	DATE	CHECKED BY	DATE
A. G		B.J	11-15-73

TEST FREQ	METER READING	CORRECTION FACTOR	FINAL READING	SPECIFICATION LIMIT	INTER. TYPE (SEE NOTE B)	REMARKS
	[illegible]			[illegible]		C.W.
5.1	30	0	30	20	3	PASS
10.0	27	0	27	20	3	"
15.8	26	0	26	20	3	"

NOTE: A – All frequencies not listed are scanned for maximum interference.
B – Interference Type: (1) Broadband, Steady–State
(2) Broadband, Transients
(3) Narrowband (CW)

PL 890A 9/70

TEST NO.

2564-26 REV

SINGER
KEARFOTT DIVISION

Electromagnetic Compatibility Test Data Sheet

TEST SPECIMEN: NASA	MODEL NO: 5-1-1	SER NO.:
TEST MODE: Power on		
SPECIFICATION:	PARAGRAPH:	TEST: OUTPUT #1
CONDUCTED BY: A.G.	DATE: 11/12/73	CHECKED BY: B.J. — DATE: 11/12/73

TEST FREQ	METER READING	CORRECTION FACTOR	FINAL READING	SPECIFICATION LIMIT	INTER. TYPE (SEE NOTE B)	REMARKS
5.1	20	0	20	20	3	Pass
10.0	12	0	20	20	3	"
20.0	27	0	27	20	3	"

NOTE: A — All frequencies not listed are scanned for maximum interference.
B — Interference Type: (1) Broadband, Steady-State
(2) Broadband, Transients
(3) Narrowband (CW)

X256A226 REV =

SINGER
KEARFOTT DIVISION

Electromagnetic Compatibility Test Data Sheet

TEST SPECIMEN	MODEL NO	SER NO.
NASA	0-1-1	

TEST MODE: Power [illegible]

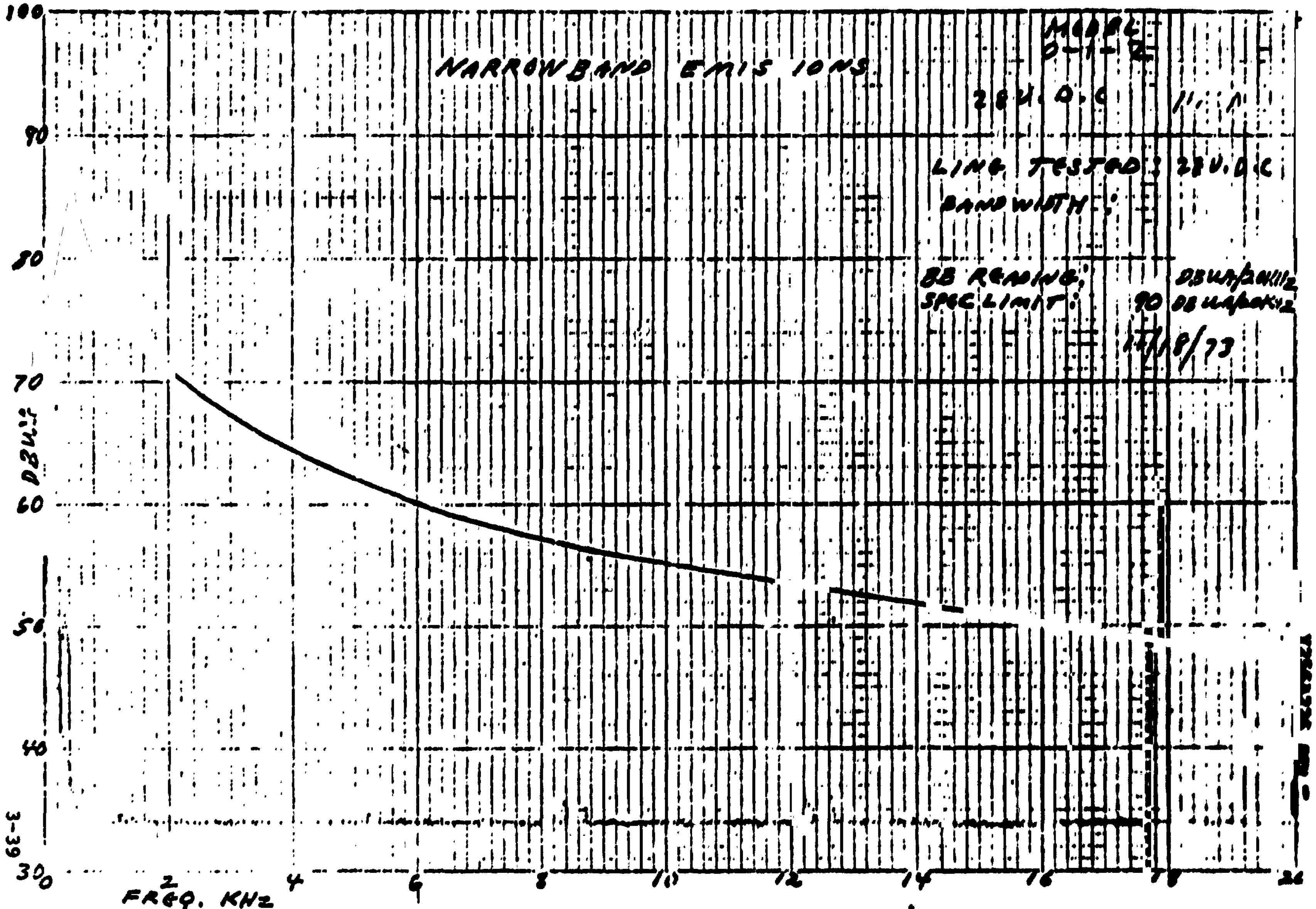
SPECIFICATION	PARAGRAPH	TEST
		OUTPUT # 2

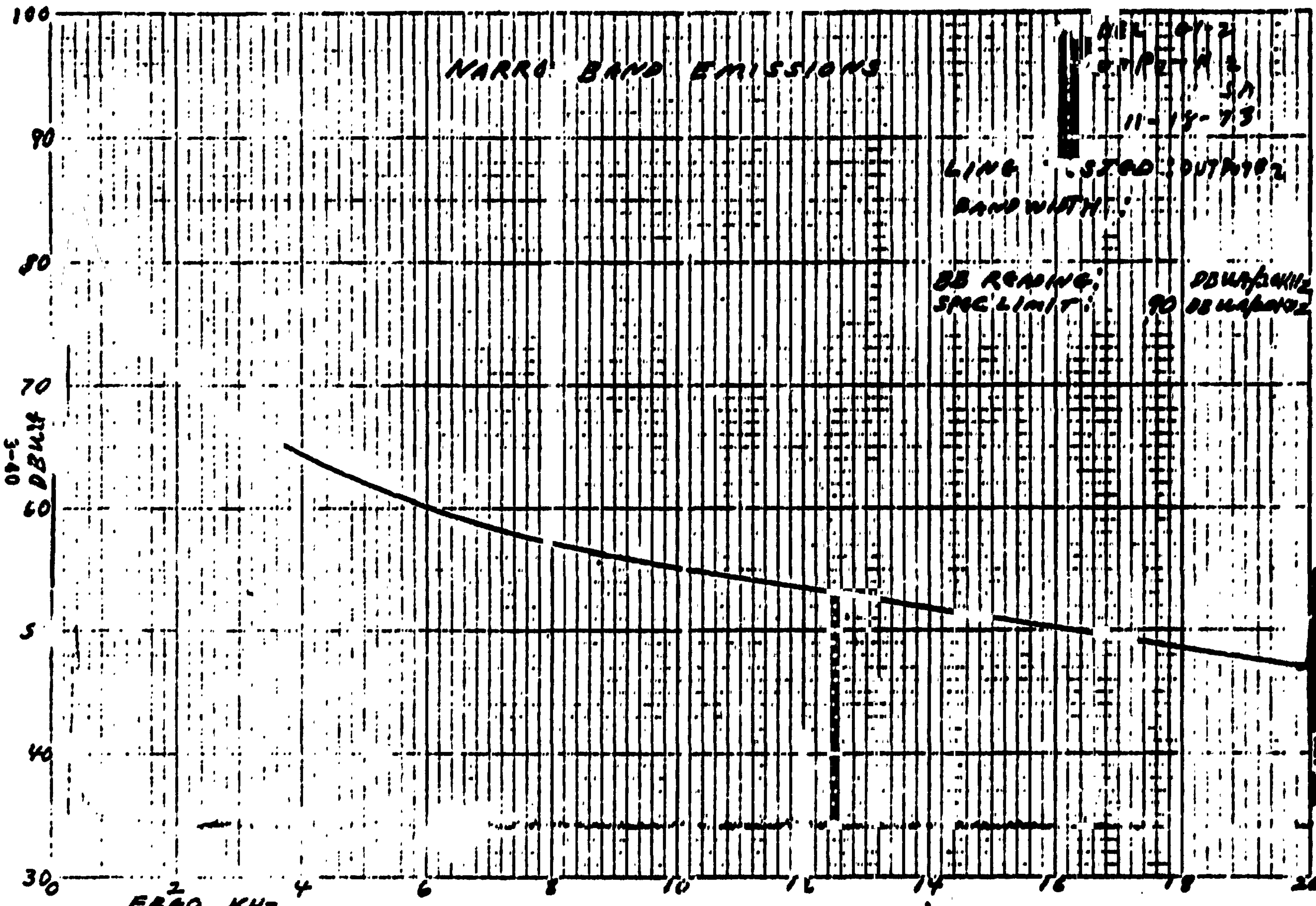
CONDUCTED BY	DATE	CHECKED BY	DATE
[illegible]	11/1/73	B.T	11-18-73

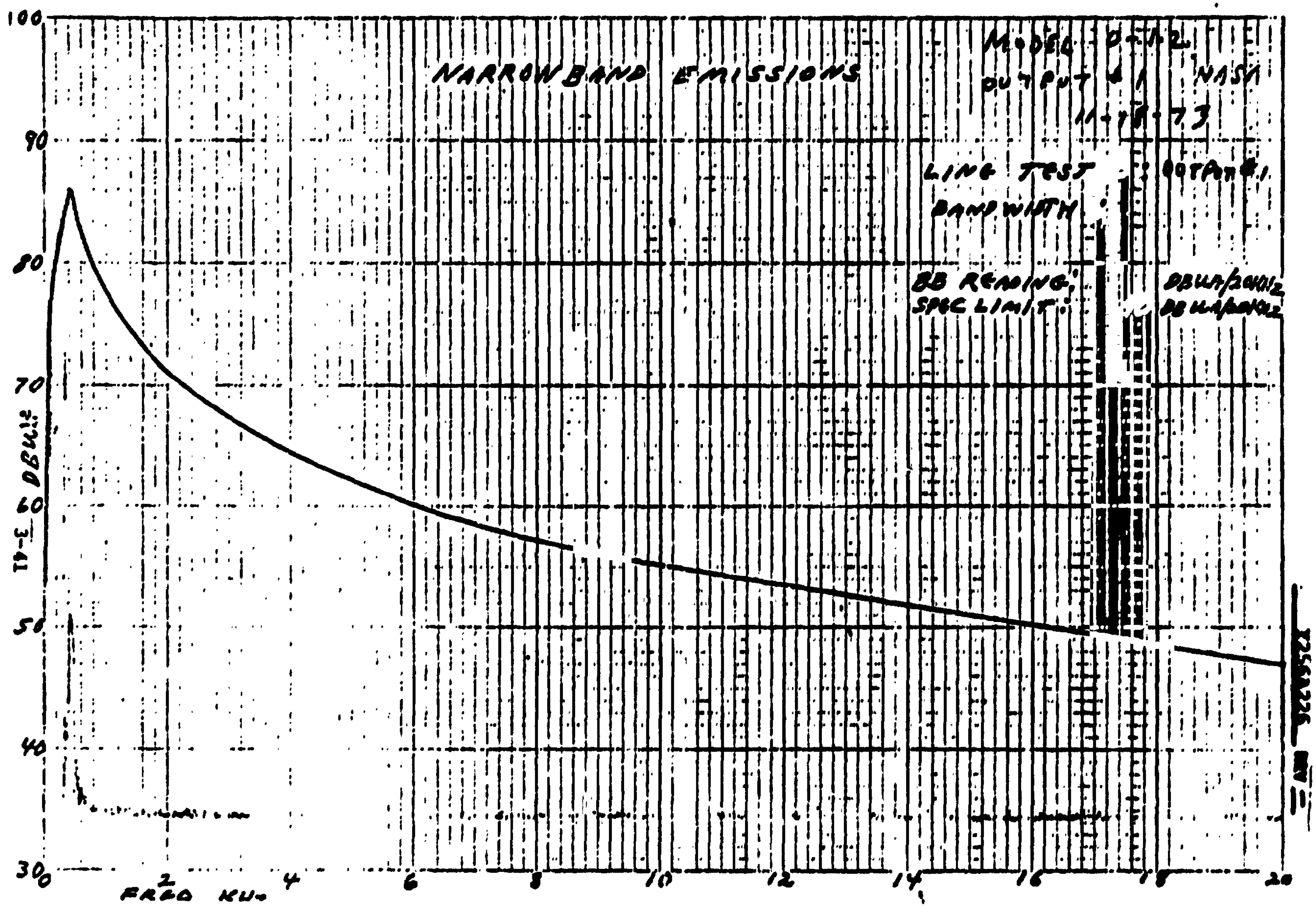
TEST FREQ	METER READING	CORRECTION FACTOR	FINAL READING	SPECIFICATION LIMIT	INTER. TYPE (SEE NOTE B)	REMARKS
5.1	22	0	22	20	3	FRAME
10.1	12	0	12	23	3	"
20.6	6	0	6	23	3	"

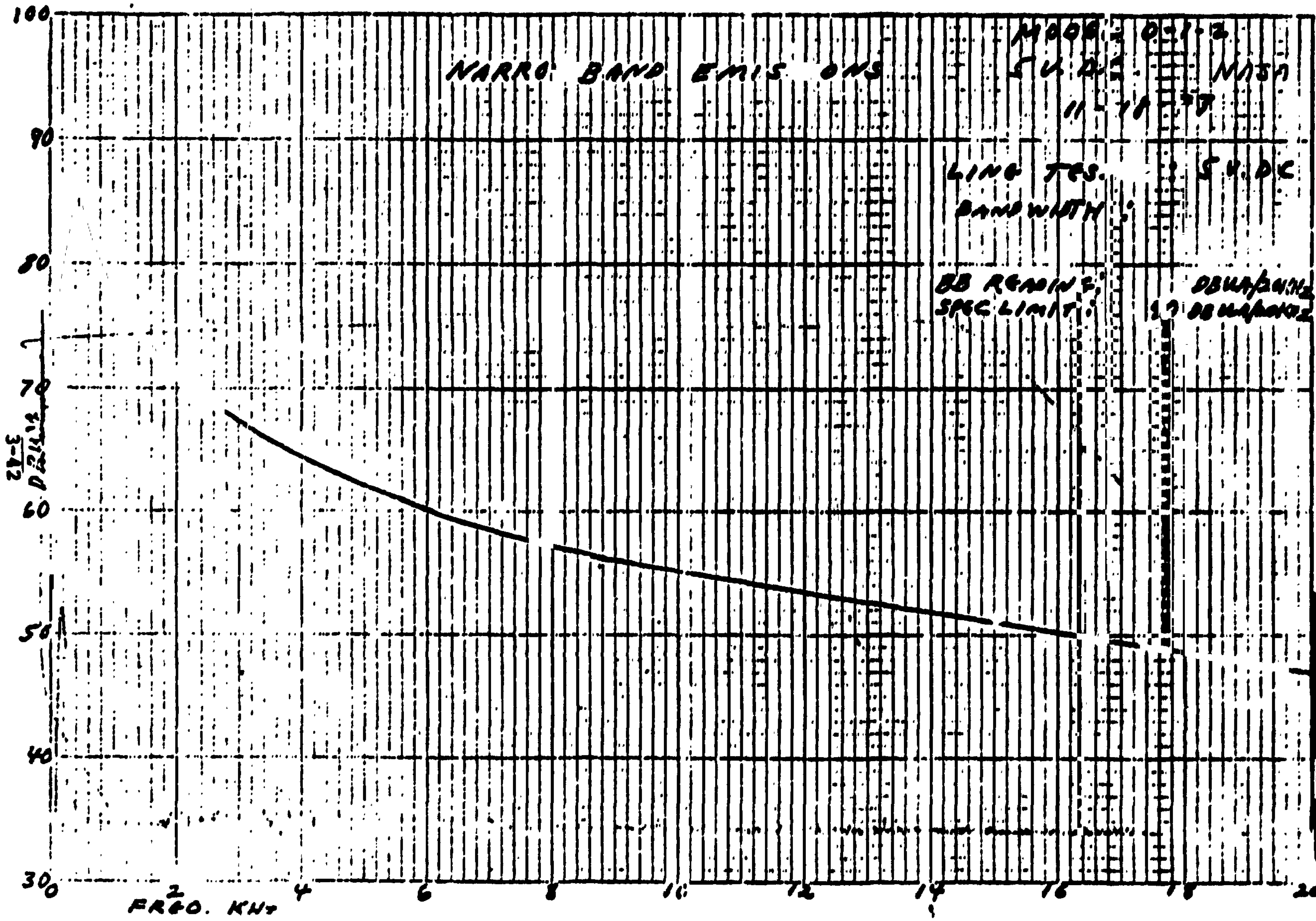
NOTE: A – All frequencies not listed are scanned for maximum interference.
B – Interference Type: (1) Broadband, Steady–State
(2) Broadband, Transients
(3) Narrowband (CW)

PL 300A 6/70


NARROWBAND EMISSIONS
28V D.C
LINE TESTED: 28V.DC
BANDWIDTH:
BB READING:
SPEC LIMIT: 90
DB UA/MHz
100
90
80
70
60
50
40
30
0
2
4
6
8
10
12
14
16
18
20
DBUA
FREQ. KHz


NARRO BAND EMISSIONS
11-14-73
LINE:
BANDWIDTH:
BB READING:
SPEC LIMIT:
90
DBUH
FREQ. KHz
100
90
80
70
60
40
30
2
4
6
8
10
14
16
18
20


NARROWBAND EMISSIONS
MODEL
OUTPUT
NASA
11-73
LINE TEST
BANDWIDTH
BB READING:
SPEC LIMIT:
DBUA/
DBUA/
OUTPUT 1
DBUA
FREQ KHz
100
90
80
70
60
50
40
30
0
2
4
6
8
10
12
14
16
18
20


NARRO BAND EMIS ONS
LINE TES.
BANDWIDTH
BB REMAIN
SPEC LIMIT
FREQ. KHz
100
90
80
70
60
50
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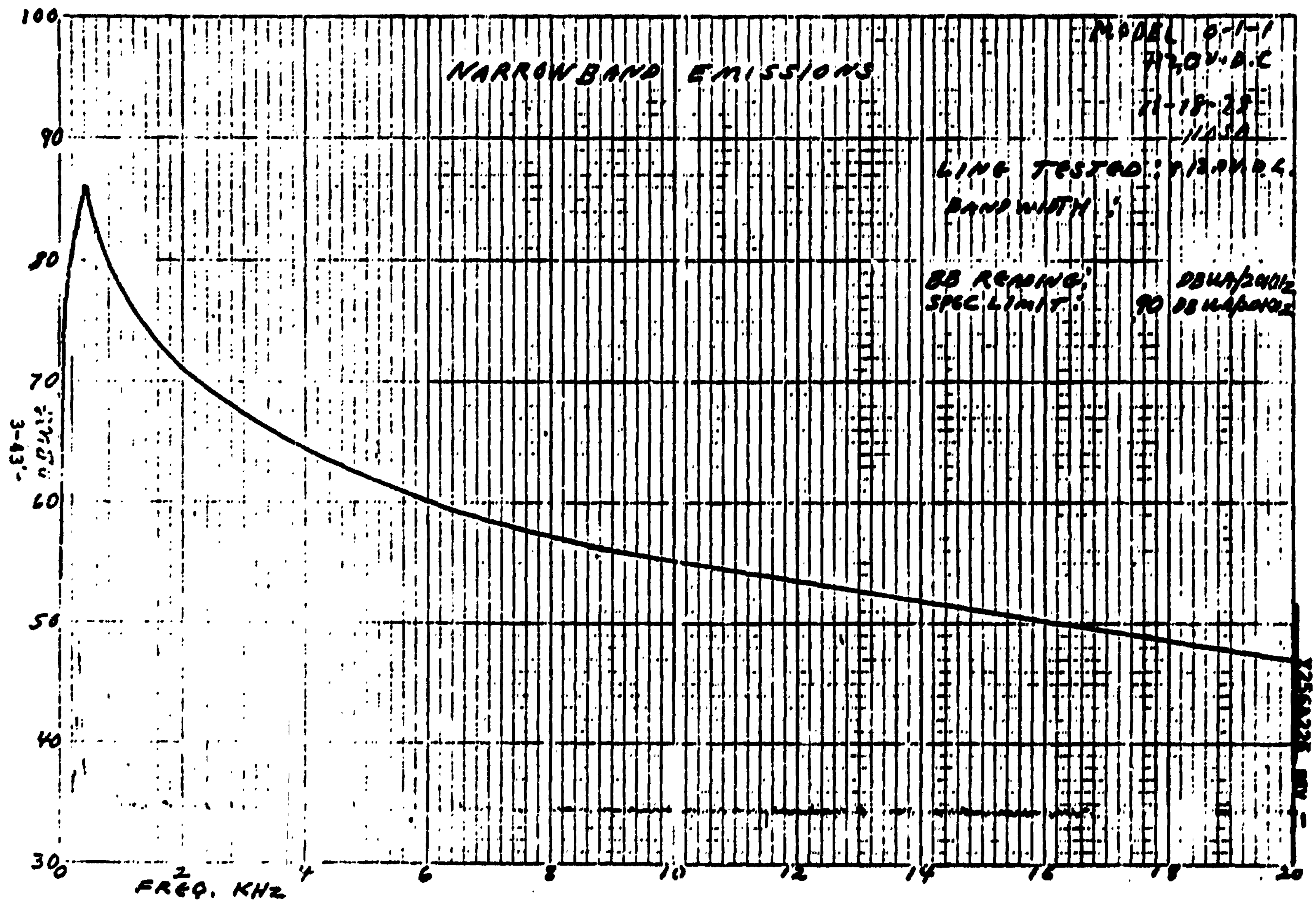
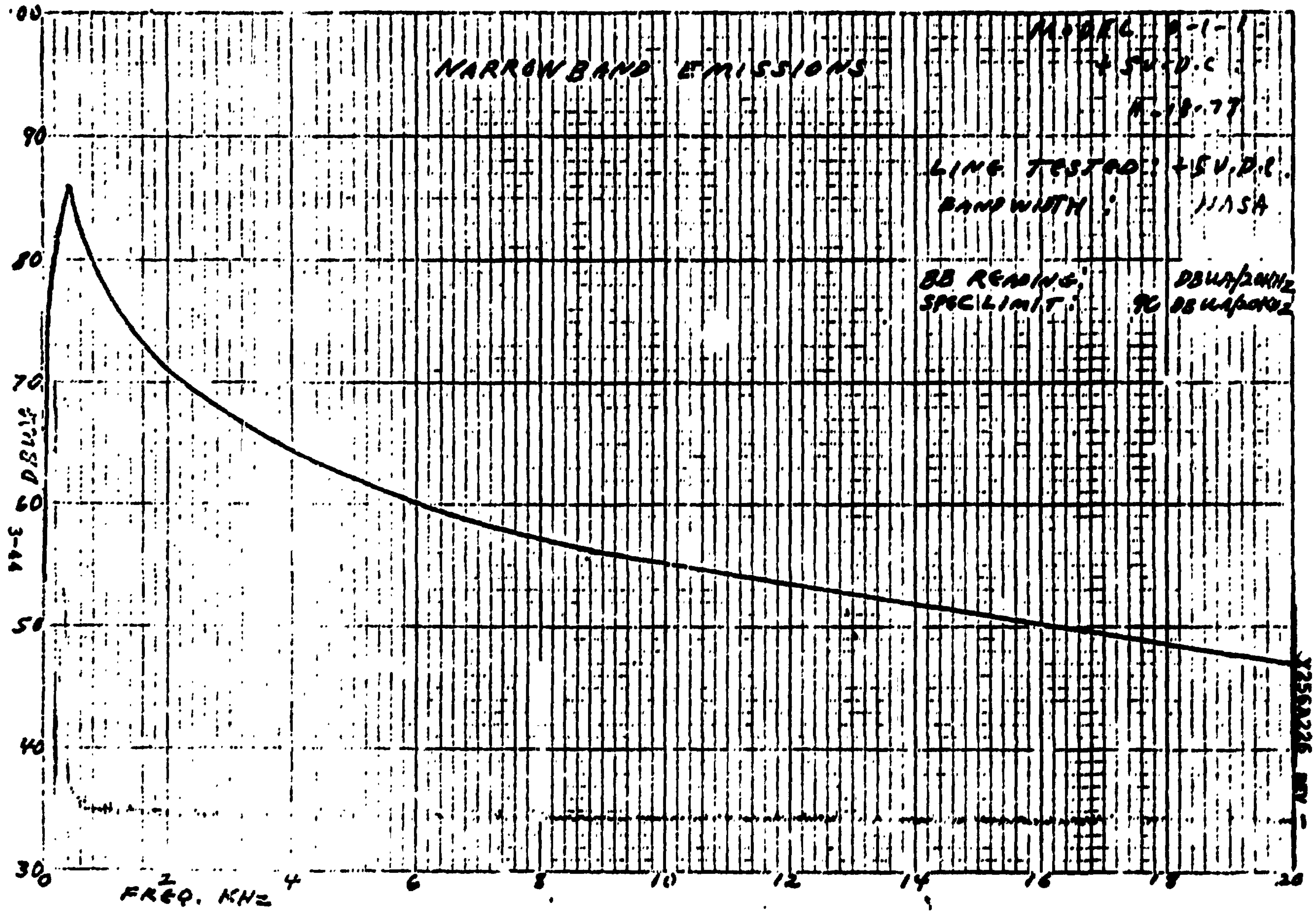
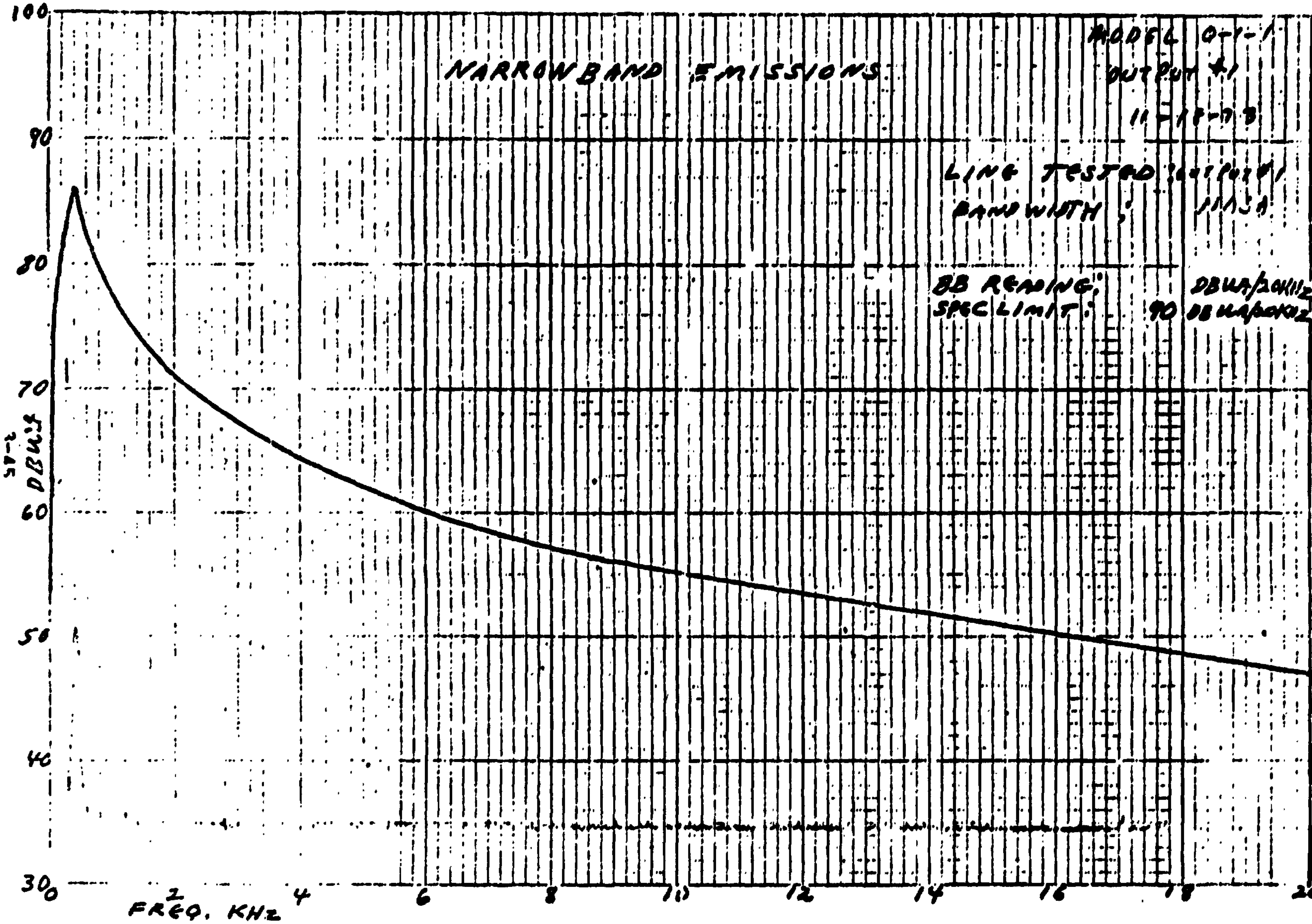
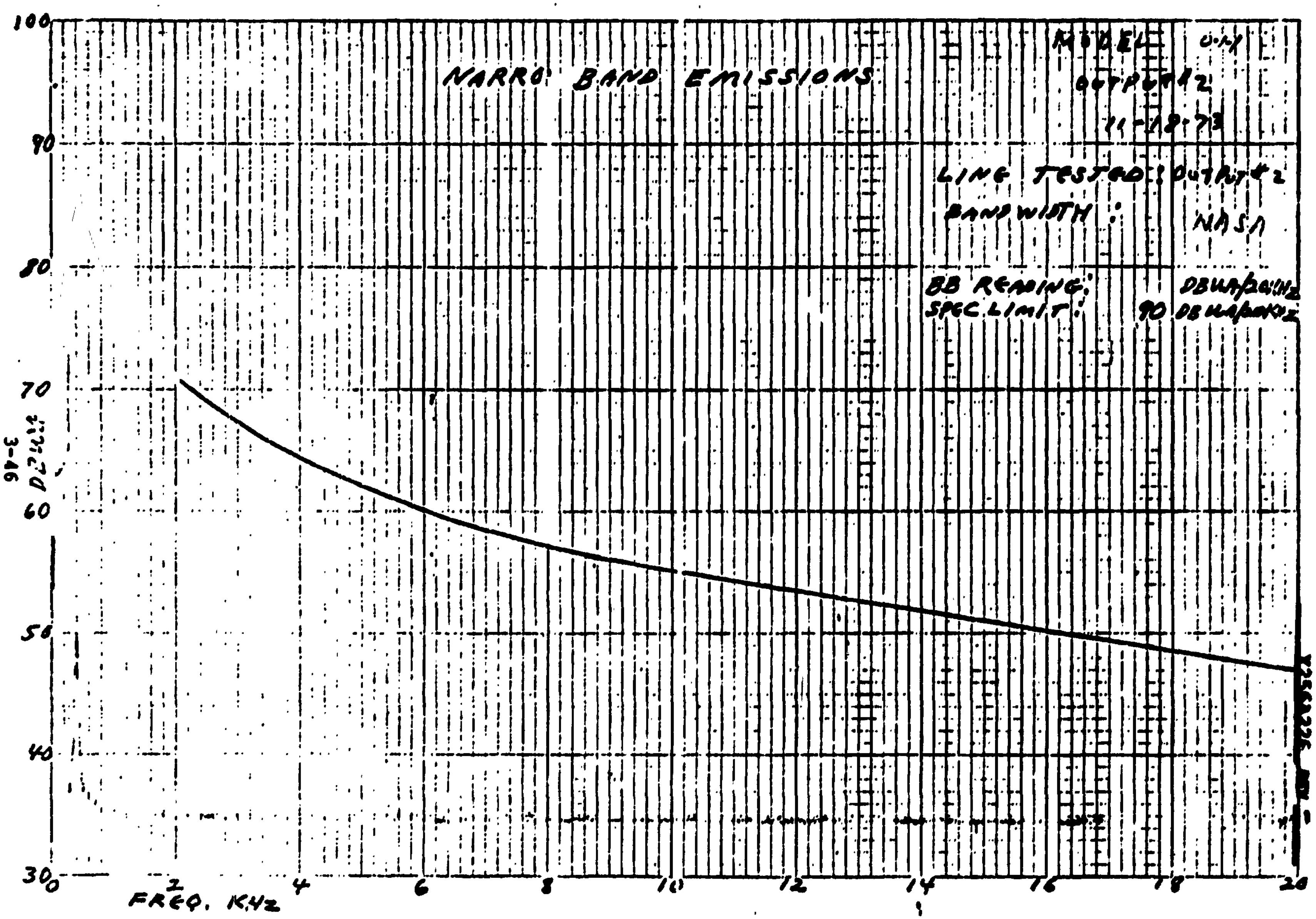
0
2
4
6
8
10
12
14
16
18
20


NARROWBAND EMISSIONS
LINE TESTED:
BANDWIDTH:
BB READING:
SPEC LIMIT: 90
100
90
80
70
60
50
40
30
0
2
4
6
8
10
12
14
16
18
20
FREQ. KHz


NARROWBAND EMISSIONS
LINE TESTED: +5V.D.C.
BANDWITH:
BB READING:
SPEC LIMIT:
90
80
70
60
50
40
30
0
2
4
6
8
10
12
14
16
18
20
FREQ. KHz
DBUA
Y256A226 REV -


NARROWBAND EMISSIONS
MODEL 0-1-1
OUTPUT #1
11-15-73
LINE TESTED
BANDWIDTH
BB READING: DBUA/20KHZ
SPEC LIMIT: 90 DBUA/20KHZ
DBUA
FREQ. KHZ
100
90
80
70
60
50
40
30
0
2
4
6
8
10
12
14
16
18
20
REV


NARRO BAND EMISSIONS
MODEL
OUTPUT #2
11-18-73
LINE TESTED: OUTPUT #2
BANDWIDTH: NASA
BB READING: DBUA/MHz
SPEC LIMIT: 90 DBUA/MHz
100
90
80
70
60
50
40
30
0
2
4
6
8
10
12
14
16
18
20
FREQ. KHZ

RELIABILITY

A reliability prediction was preformed to establish the failure rate of each of the solid state switch devices. This data is summarized on the attached computer data sheets. Also included in this section is a reliability failure mode and effects analysis. This analysis was made on the 10 position rotary, potentiometer, and the double pole switch.

FIXED GROUND ENVIRONMENT NOV. 8,1973

SUBASSEMBLY -- CIRCUIT BOARD #1

AMBIENT TEMPERATURE = 40C

PART TYPE	QUANTITY	K(ENV)	FR	Q.F.R	STRESS
DIODE ZENER	1.0	1.0000	1.0700	1.0700	50
RES COMP RC	2.0	6.0000	0.0035	0.0420	25
RES COMP RC	4.0	6.0000	0.0035	0.0840	10
SOLID STATE RELAY	10.0	1.0000	0.0045	0.0450	10
TRANSISTOR NPN	4.0	1.5000	0.1975	1.1850	10
CIRCUIT BOARD	1.0	1.0000	0.0630	0.0630	10
SUBASSEMBLY TOTAL				2.489	

SUBASSEMBLY — CIRCUIT BOARD #2

AMBIENT TEMPERATURE = 40C

PART TYPE	QUANTITY	K(ENV)	FR	Q.F.R	STRESS
CIRCUIT BOARD	1.0	1.0000	0.0630	0.0630	.10
DIODE LED	4.0	1.5000	0.2600	1.5600	20
TRANSISTOR NPN PHOTOTRANSISTOR	4.0	1.5000	0.1975	1.1850	10
TRANSISTOR NPN	7.0	1.5000	0.1975	2.0737	10
RES COMP RC	11.0	6.0000	.0035	0.2310	10
RES COMP RC	1.0	6.0000	0.0035	0.0210	25
HI-R INTEGRATED CIRCUIT	1.0	1.2000	0.0300	0.0360	10
HI-R INTEGRATED CKT MSI	1.0	1.2000	0.0600	0.0720	10

SUBASSEMBLY TOTAL 5.242

Y256A226 REV –

SUBASSEMBLY -- SWITCH ASSY

AMBIENT TEMPERATURE = 40C

PART TYPE	QUANTITY	K(ENV)	FR	Q.F.K	STRESS
SHAFT	1.0	1.0000	0.3500	0.3500	10
BEARING	3.0	1.0000	0.5000	1.5000	10
DIODE LED	1.0	1.5000	0.4175	0.6262	40

SUBASSEMBLY TOTAL 2.476

FIXED GROUND ENVIRONMENT NOV. 8,1973

SUBASSEMBLY -- START SW IC FCE

AMBIENT TEMPERATURE = 40C

PART TYPE	QUANTITY	K(ENV)	FR	W.F.R	STRESS
CIRCUIT BOARD #1	1.0	1.0000	2.4890	2.4890	10
CIRCUIT BOARD #2	1.0	1.0000	5.2417	5.2417	10
SWITCH ASSY	1.0	1.0000	2.4762	2.4762	10

SUBASSEMBLY TOTAL 10.207

SUBASSEMBLY -- PC BOARD #1

AMBIENT TEMPERATURE = 40C

PART TYPE	QUANTITY	KE(AV)	FR	Q.F.R	STRESS
CIRCUIT BOARD	1.0	1.0000	0.0630	0.0630	(1)
DIODE ZENER	1.0	1.0000	1.0700	1.0700	50
TRANSISTOR NPN	1.0	1.5000	0.1975	0.2962	10
RES COMP RC	5.0	6.0000	0.0035	0.1050	10
CAPACITOR CER CK	2.0	1.0000	0.0020	0.0041	15
MI-R INTEGRATED CIRCUIT	2.0	1.2000	0.0300	0.0720	10
M.-R INTEGRATED CKT MSI	1.0	1.2000	0.0600	0.0720	10

SUBASSEMBLY TOTAL 1.662

SUBASSEMBLY -- PC BOARD #2

AMBIENT TEMPERATURE = 40C

PART TYPE	QUANTITY	K(ENV)	FR	Q.F.K	STRESS
CIRCUIT BOARD	1.0	1.0000	0.0630	0.0630	.10
DIODE LED	7.0	1.5000	0.[illegible]600	[illegible].7300	20
TRANSISTOR NPN PHOTOTRANSISTOR	7.0	1.5000	0.1975	2.0737	10
RES COMP RC	7.0	6.0000	0.0035	0.1070	10

SUBASSEMBLY TOTAL 5.014

SUBASSEMBLY -- PUT ASSY

AMBIENT TEMPERATURE = 40C

PART TYPE	QUANTITY	K(ENV)	FR	W.P.R	STRESS
SHAFT	1.0	1.0000	0.3500	0.3500	10
BEARING	2.0	1.0000	0.5000	1.0000	10
DIODE LED	1.0	1.5000	0.4175	0.6202	40

SUBASSEMBLY TOTAL 2.476

SUBASSEMBLY — SOLID STATE PUT

AMBIENT TEMPERATURE = 30C

PART TYPE	QUANTITY	K(ENV)	FK	Q.F.K	STRESS
PC BOARD #1	1.0	1.0000	1.6823	1.6823	10
PC BOARD #2	1.0	1.0000	5.0137	5.0137	10
PUT ASSY	1.0	1.0000	2.4762	2.4762	10

SUBASSEMBLY TOTAL 9.172

SUBASSEMBLY -- TOGGLE SWITCH SP

AMBIENT TEMPERATURE = 40C

	PART TYPE	QUANTITY	K(ENV)	FR	U.F.R	STRESS
	DIODE LED	1.0	1.5000	0.4175	0.6262	40
	CIRCUIT BOARD	1.0	1.0000	0.0630	0.0630	10
	TRANSISTOR NPN	1.0	1.5000	0.5100	0.7650	50
	SOLID STATE RELAY	1.0	1.0000	0.0045	0.0045	10
MI-[illegible]	INTEGRATED CIRCUIT	1.0	1.2000	0.0300	0.0360	10
	SWITCH TOGGLE	1.0	1.0000	0.2500	0.2500	10
	MAGNET	1.0	1.0000	0.5500	0.5500	10

SUBASSEMBLY TOTAL 2.295

FIXED GROUND ENVIRONMENT NOV. 8,1973

ASSEMBLY -- TOGGLE SWITCH UP

AMBIENT TEMPERATURE = 40C

PART TYPE	QUANTITY	K(ENV)	FR	U.F.R	STRESS
DIODE LED	1.0	1.5000	0.4175	0.6262	40
CIRCUIT BOARD	1.0	1.0000	0.0630	0.0630	10
TRANSISTOR NPN	1.0	1.5000	0.5100	0.7650	50
SOLID STATE RELAY	2.0	1.0000	0.0045	0.0090	10
HI-R INTEGRATED CIRCUIT	1.0	1.2000	0.0300	0.0360	10
SWITCH TOGGLE	1.0	1.0000	0.2500	0.2500	10
MAGNET	1.0	1.0000	0.5500	0.5500	10

SUBASSEMBLY TOTAL 2.299

EQUIPMENT -- SOLID STATE KEYBOARD

AMBIENT TEMPERATURE = 40C

PART TYPE	QUANTITY	KTENV1	FR	Q.F.R	STRESS
ROTARY SW 10 POS	2.	1.0000	10.2070	20.4140	10
SOLID STATE POT	2.	1.0000	9.1723	18.3447	10
TOGGLE SWITCH SP	10.	1.0000	2.2947	22.9475	10
TOGGLE SWITCH DP	15.	1.0000	2.2992	34.4887	10
TOTALS				96.195	

TEMPERATURE/TIME PROFILE

PERCENT OF TIME AT TEMPERATURE 1.0000

EQUIVALENT PROFILE FAILURE RATE = 96.1946

PROFILE MTBF = 10[illegible] HOURS

EQUIPMENT -- SOLID STATE KEYBOARD

AMBIENT TEMPERATURE 40C

FIXED GROUND ENVIRONMENT

PREDICTION BY PART TYPE

PART TYPE	QUANTITY	TOTAL F.R.	SOURCE OF DATA
CIRCUIT BOARD #1	2.	4.978	PREDICTED SUBASSEMBLY
CIRCUIT BOARD #2	2.	10.463	PREDICTED SUBASSEMBLY
SWITCH ASSY	2.	4.952	PREDICTED SUBASSEMBLY
PC BOARD #1	2.	3.365	PREDICTED SUBASSEMBLY
PC BOARD #2	2.	10.027	PREDICTED SUBASSEMBLY
POT ASSY	2.	4.952	PREDICTED SUBASSEMBLY
DIODE	25.	15.656	MIL-HDBK-217A FIGURE 7.4.3B (MIL-S-19500)
CIRCUIT BOARD	25.	1.575	NINTH SYMPOSIUM (EARLES/EDDINS)
TRANSISTOR NPN	25.	19.125	MIL-HDBK-217A FIGURE 7.4.4B (MIL-S-19500)
SOLID STATE RELAY	40.	0.180	KEARFOTT SECONDARY DATA
SWITCH TOGGLE	25.	6.250	MIL-HDBK-217A FIGURE 7.10.2 (TYPE A)
MAGNET	25.	13.750	KEARFOTT SECONDARY DATA
HI-K INTEGRATED CIRCUIT	25.	0.900	KEARFOTT EXPERIENCE

202. TOTAL PARTS

TOTAL FAILURE RATE = 96.19

MTBF = 10395.57 HOURS

SUBSYSTEM: SOLID STATE KEYBOARD

40C AMBIENT TEMPERATURE

FIXED GROUND ENVIRONMENT

SUBASSEMBLY	FAILURE RATE
ROTARY SW 10 POS	28.41
SOLID STATE POT	10.34
TOGGLE SWITCH SP	22.95
TOGGLE SWITCH DP	34.49
TOTAL FAILURE RATE =	96.19

MTBF = 10395.57 HOURS

Y2568226 REV

SINGER
KEARFOTT DIVISION

KEARFOTT DIVISION
SINGER-GENERAL PRECISION, INC.
LITTLE FALLS, NEW JERSEY

RELIABILITY FAILURE MODE & EFFECTS ANALYSIS

10 POSITION SOLID STATE ROTARY SWITCH

TAG	DESCRIPTION	SYMBOL	FUNCTION	FAILURE MODES	FAILURE RATE PERCENT	FAILURE RATE TOTAL	FAILURE RATE MODE	CAUSE OF FAILURE	FUNCTIONAL FAILURE EFFECT	EQUIPMENT FAILURE EFFECT	CRITICALITY FUNCTION	CRITICALITY EQUIPMENT
	LIGHT EMITTING DIODE PN MLED 910 MOTOROLA	CR1 THRU CR4	TRANSDUCER LIGHT SOURCE	OPEN	100				IMPROPER OUTPUT			
	PHOTO TRANSISTOR PN MRD 604 MOTOROLA	Q1 THRU Q4	TRANSDUCER SWITCH OUTPUT	OPEN SHORT	75 25				IMPROPER OUTPUT IMPROPER OUTPUT			
	DUAL INPUT QUAD EXCLUSIVE "OR" GATE PN CD4030AK RCA	U2	DECODER LOGIC CONTROL	OPEN SHORT TO +5V SHORT TO 0V	80 10 10				IMPROPER OUTPUT IMPROPER OUTPUT IMPROPER OUTPUT			
	BCD TO 1 OUT OF 10 DECODER PN CD4028AK RCA	U1	TRANSDUCER INPUT TO OUTPUT SWITCH DECODER	NO OUTPUT IMPROPER OUTPUT	20 80				NO OUTPUT IMPROPER OUTPUT			
	RESISTOR PN RC05GF 4K	R1 THRU R4	GATE INPUT GAIN ADJUST	OPEN	100				INCREASED NOISE SUSCEPTIBILITY			
	RESISTOR PN RC05GF102K	R8 THRU R17	TRANSISTOR BASE BIAS	OPEN	100				INCREASED NOISE SUSCEPTIBILITY			
	TRANSISTOR PN 2N5845	Q6 THRU Q15	RELAY COIL DRIVER	OPEN SHORT	75 25				IMPROPER OUTPUT IMPROPER OUTPUT			
	SOLID STATE RELAY PN 601-1 TELEDYNE	K1 THRU K10	OUTPUT SWITCH CONTACT	OPEN OUTPUT SHORTED OUTPUT OPEN COIL SHORTED COIL	60 15 15 15				IMPROPER OUTPUT IMPROPER OUTPUT IMPROPER OUTPUT IMPROPER OUTPUT			
	LIGHT EMITTING DIODE PN 5082-4420	CR5	SWITCH FAIL INDICATOR	OPEN	100				NO FAIL INDICATION			
	RESISTOR PN	R5	LED CURRENT LIMITER	OPEN	100				NO FAIL INDICATION INCREASED BRIGHTNESS FAIL IND			
	TRANSISTOR PN 2N2222A	Q5	LED DRIVER	OPEN SHORT	75 25				NO FAIL INDICATION CONTINUOUS FAIL IND			
	ZENER DIODE PN 1Z4.7	CR6	LED VOLTAGE LIMITER	OPEN SHORT	80 20				DECREASED FAIL IND DRIVE NO FAIL INDICATION			
	RESISTOR PN RC05GF2.2K	R7	TRANSISTOR BASE BIAS	OPEN	100				CONTINUOUS FAIL IND			
	RESISTOR PN RC05	R6	DIODE CURRENT LIMITER	OPEN	100				NO FAIL INDICATION			

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RELIABILITY FAILURE MODE & EFFECTS ANALYSIS

DOUBLE POLE TOGGLE/PUSHBUTTON SWITCH (SOLID STATE)

ITEM	DESCRIPTION	SYMBOL	FUNCTION	FAILURE MODES	FAILURE RATE PERCENT	FAILURE RATE TOTAL	FAILURE RATE MODE	CAUSE OF FAILURE	FUNCTIONAL FAILURE EFFECT	EQUIPMENT FAILURE EFFECT	CRITICALITY	
	HALL EFFECT DEVICE PN 2SS1 MICROSWITCH	A1	TRANSDUCER SWITCH OUTPUT	OPEN SHORT					SWITCH OUTPUT OPEN SWITCH OUTPUT SHORT			
	TRANSISTOR PN 2N5845	Q1	RELAY COIL DRIVER	OPEN SHORT	75 25				SWITCH OUTPUT OPEN SWITCH OUTPUT SHORT			
	RESISTOR PN RC05GF271K	R1	HALL EFFECT CURRENT LIMITER	OPEN	100				SWITCH OUTPUT OPEN			
	RESISTOR PN RC05GF272K	R2	TRANSISTOR BASE BIAS	OPEN	100				IMPROPER OUTPUT			
	SOLID STATE RELAY PN 640-1 TELEDYNE	K1/K2	OUTPUT SWITCH CONTACT	OPEN OUTPUT SHORTED OUTPUT OPEN COIL SHORTED COIL	60 15 13 12				SWITCH OUTPUT OPEN SWITCH OUTPUT SHORT SWITCH OUTPUT OPEN SWITCH OUTPUT SHORT			
	MAGNET PN 102SS12 MICROSWITCH		TRANSDUCER ACTUATOR									
	LIGHT EMITTING DIODE PN 5082-4420-HP	CR1	SWITCH FAIL INDICATOR	OPEN	100				SWITCH OUTPUT OPEN			

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RELIABILITY FAILURE MODE & EFFECTS ANALYSIS

SOLID STATE POTENTIOMETER

ITEM	DESCRIPTION	SYMBOL	FUNCTION	FAILURE MODES	FAILURE RATE PERCENT	FAILURE RATE TOTAL	FAILURE RATE MODE	CAUSE OF FAILURE	FUNCTIONAL FAILURE EFFECT	EQUIPMENT FAILURE EFFECT	CRITICALITY	
	LIGHT EMITTING DIODE PN MLED910 MOTOROLA	CR1 THRU CR7	TRANSDUCER LIGHT SOURCE	OPEN	100				IMPROPER OUTPUT			
	PHOTOTRANSISTOR PN MRD604 MOTOROLA	Q1 THRU Q7	TRANSDUCER SWITCH OUTPUT	OPEN SHORT	75 25				IMPROPER OUTPUT IMPROPER OUTPUT			
	RESISTOR PN RC05GF104J	R1 THRU R7	GATE INPUT GAIN ADJUST	OPEN	100				INCREASED NOISE SUSCEPTIBILITY			
	DUAL INPUT QUAD EXCLUSIVE "OR" GATE PN CD4030AK RCA	U1/U2	CONVERTER LOGIC CONTROL	OPEN SHORT TO 15V SHORT TO 0V	80 10 10				IMPROPER OUTPUT IMPROPER OUTPUT IMPROPER OUTPUT			
	DIGITAL TO ANALOG CONVERTER PN DAC 02ACUL PREC MON	U3	DIGITAL INPUT TO CONTINUOUS ANALOG VOLTAGE OUTPUT	NO OUTPUT INCORRECT OUTPUT	20 80				NO OUTPUT IMPROPER OUTPUT			
	CAPACITOR PN CK06BX104K	C1/C2	POWER SUPPLY FILTERING	OPEN SHORT	90 10				INCREASED NOISE SUS IMPROPER OUTPUT			
	TRANSISTOR PN 2N2222A	Q8	LED DRIVER	OPEN SHORT	75 25				NO FAIL INDICATION CONTINUOUS FAIL IND			
	ZENER DIODE PN MZ4619 MOTOROLA	CR9	TRANSISTOR BASE VOLTAGE REF	OPEN SHORT	80 20				DECREASED FAIL IND BRT NO FAIL INDICATION			
	LIGHT EMITTING DIODE PN 5082-4420 HP	CR8	POTENTIOMETER FAIL INDICATOR	OPEN	100				NO FAIL INDICATION			
	RESISTOR PN RC05GF272K	R8	TRANSISTOR BASE BIAS	OPEN	100				CONTINUOUS FAIL IND			
	RESISTOR PN RC05GF560K	R10	LED VOLTAGE LIMITER	OPEN	100				NO FAIL INDICATION			
	RESISTOR PN RC05GF750K	R9	LED CURRENT LIMITER	OPEN	100				INCREASED FAIL IND BRIGHTNESS			
	RESISTOR PN RC05	R11	ANALOG SCALE ADJUST	OPEN	100				INACCURATE OUTPUT			
	RESISTOR PN RC05	R12	ANALOG SCALE ADJUST	OPEN	100				INACCURATE OUTPUT			

APPENDIX I

SCHEMATIC DIAGRAMS

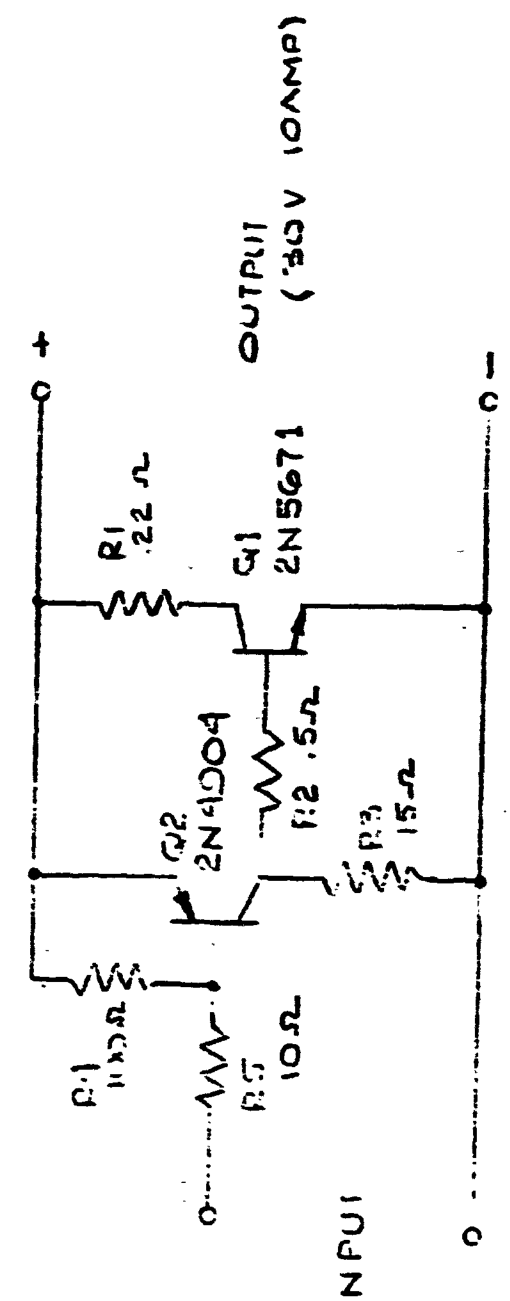

FIGURE I-1. SCHEMATIC DIAGRAM POWER SWITCH

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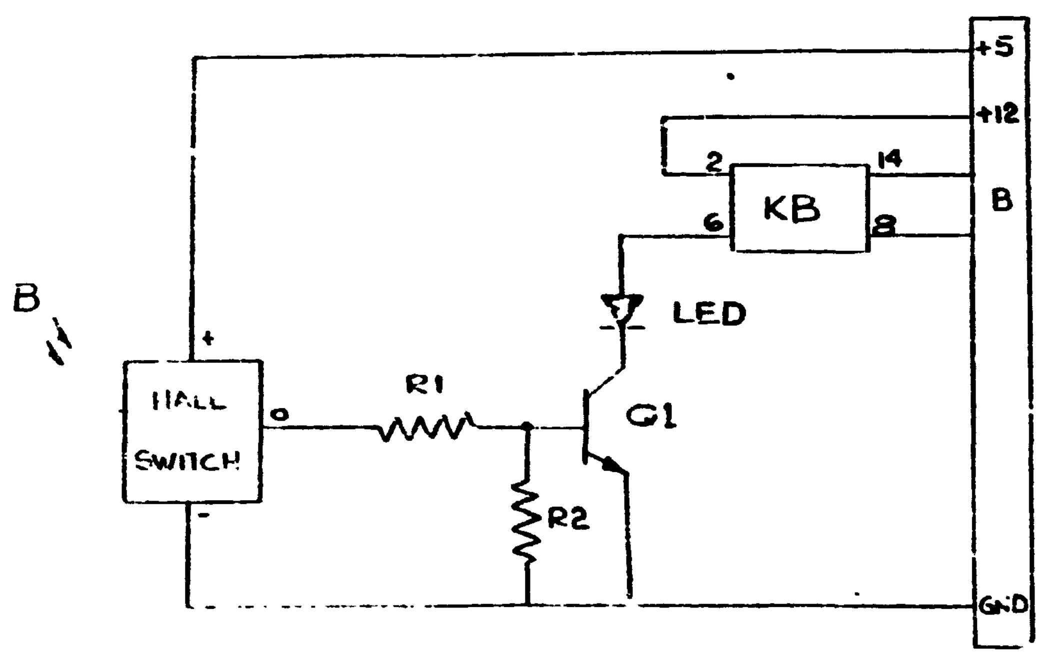

FIGURE I-2. SCHEMATIC DIAGRAM SINGLE POLE SWITCH

W201

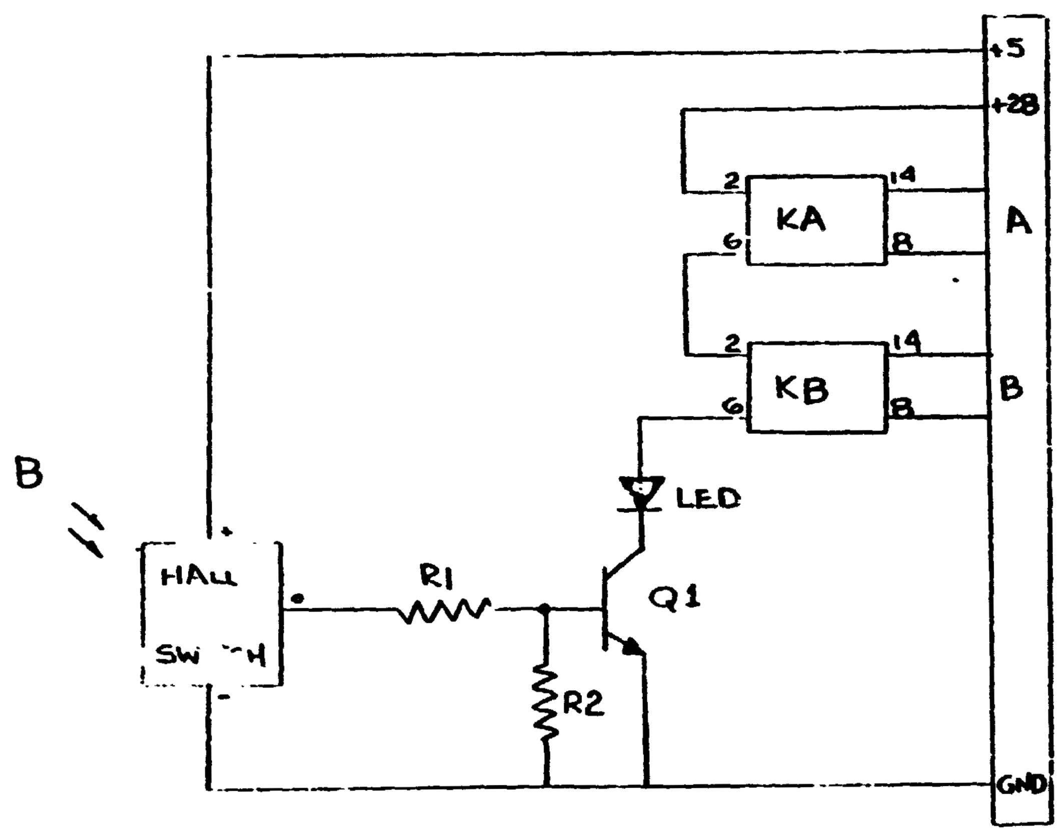

FIGURE I-3. SCHEMATIC DIAGRAM DOUBLE POLE SWITCH

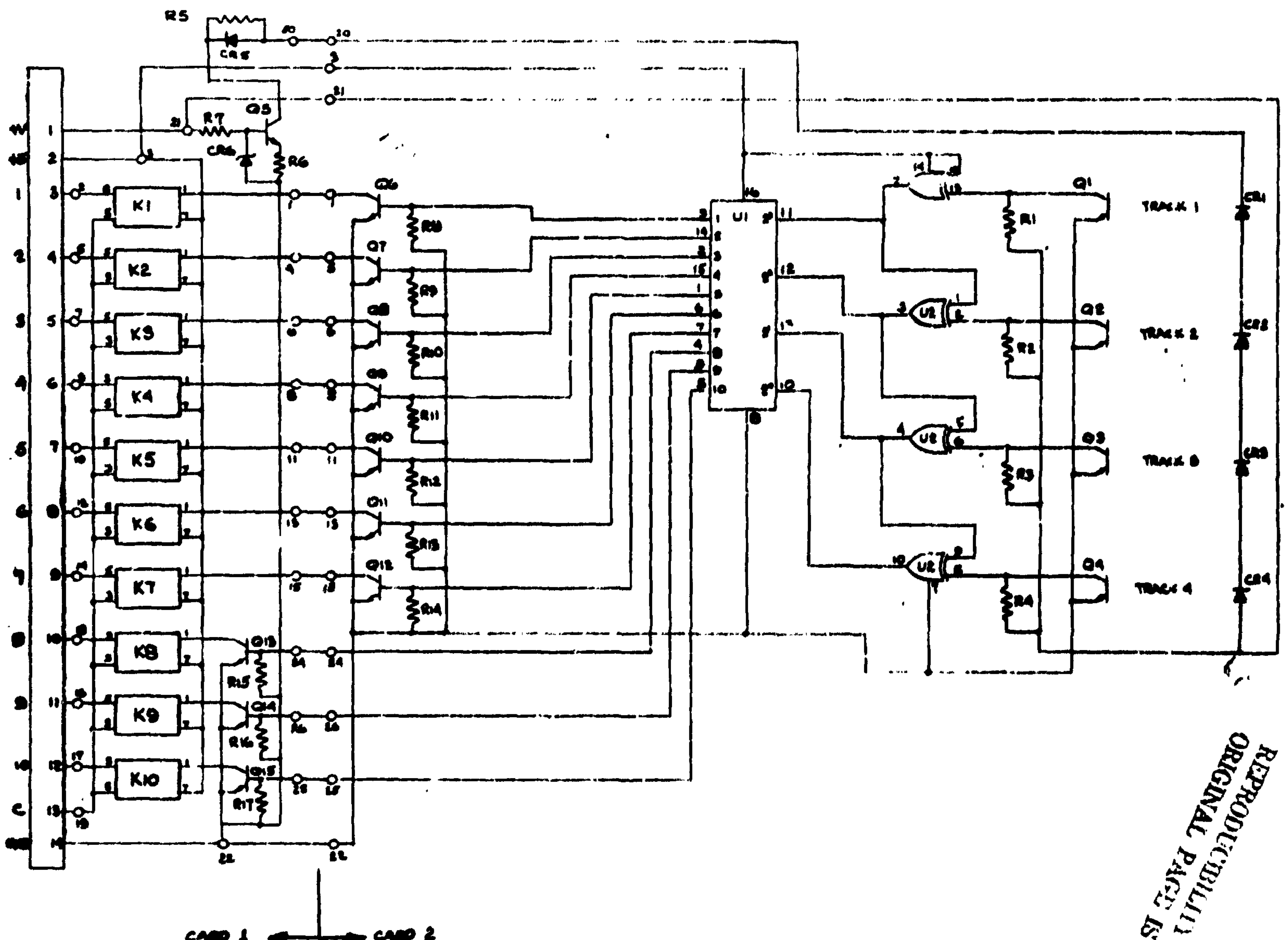

FIGURE 1-4 SCHEMATIC DIAGRAM 10 POSITION SOLID STATE ROTARY SWITCH

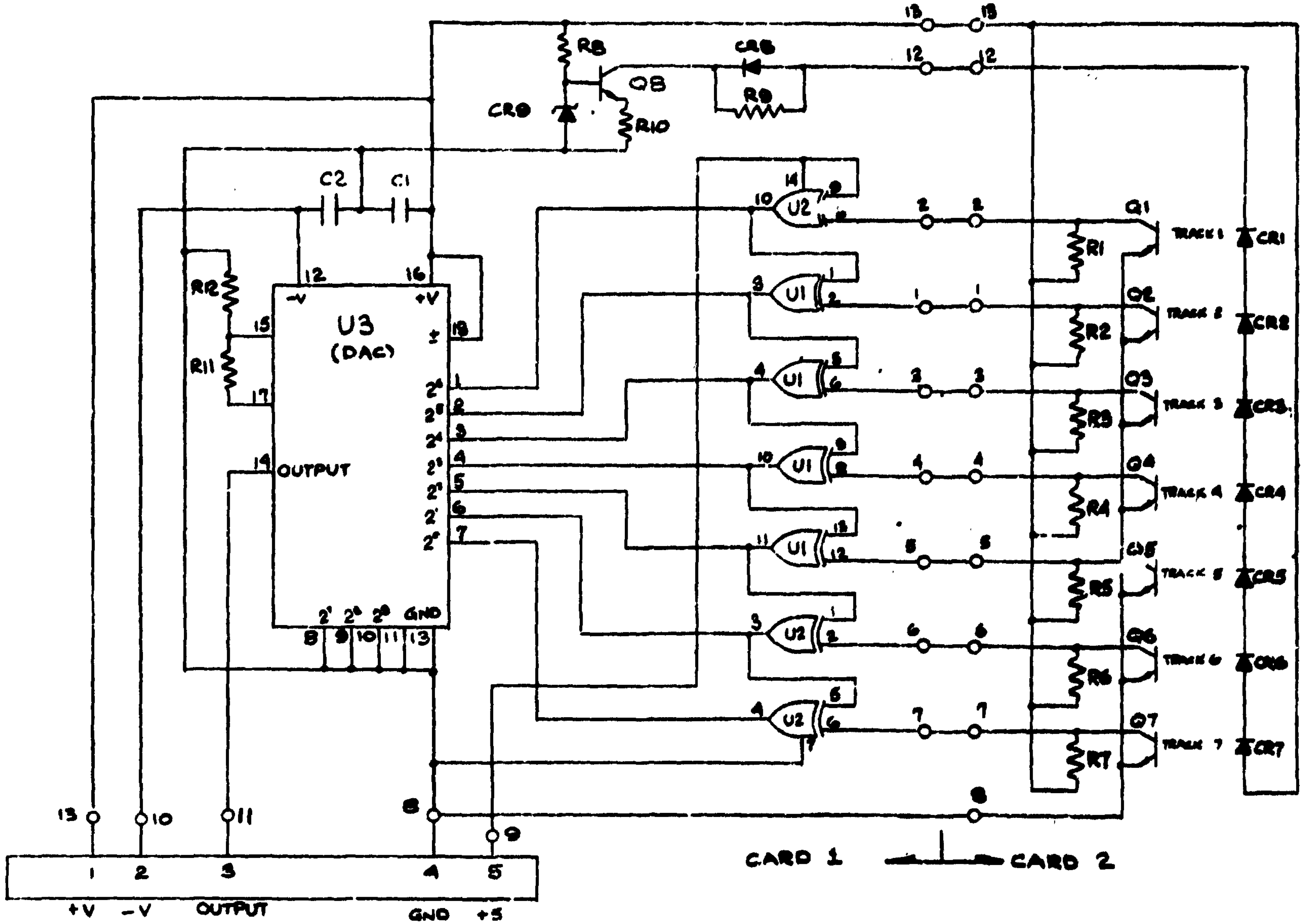

FIGURE I-5 SCHEMATIC DIAGRAM POTENTIOMETER

APPENDIX D

TELEDYNE FINAL REPORT FOR CONTRACT NAS 9-12914

SOLID STATE POWER CONTROLLERS

N74-35274

NAS CONTRACT # NAS 9-12914
DRL LINE ITEM # 2
DRD # MA-129T

SOLID STATE POWER CONTROLLERS

FINAL REPORT
DATE 30 AUG 1973

TELEDYNE RELAYS

NAS CONTRACT #NAS 9-12914
DRL LINE ITEM #2
DRD #MA-129T

SOLID STATE POWER CONTROLLERS

FINAL REPORT

DATE 30 AUG 1973

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ABSTRACT

The report is comprised of the rationale, analysis, design, breadboarding and testing of the incremental functional requirements that led to the development of prototype 1 and 5 Amp DC and 1 Amp AC Solid State Power Controllers (SSPC's). The SSPC's are to be considered for use as a replacement of electro-mechanical relays and circuit breakers in future spacecraft and aircraft. They satisfy the combined function of both the relay and circuit breaker and can be remotely controlled by small signals, typically 10 mA, 5 to 28 vDC.

They have the advantage over conventional relay/circuit breaker systems in that they can be located near the utilization equipment and the primary AC or DC bus. The low level control, trip indication and status signals can be circuited by small gauge wire for control, computer interface, logic, electrical multiplexing, unboard testing, and power management and distribution purposes. This results in increased system versatility at appreciable weight saving and increased reliability. Conventional systems require the heavy gauge load wiring and the control wiring to be routed from the bus to the load to other remote relay contacts, switches, sensors, etc. and to the circuit breaker located in the flight engineer's compartment for purposes of manual reset. Solid state switching reduces the conducted EMI substantially. The SSPC is intended to protect itself, the load, and the systems wiring against overload, short-circuit and voltage transients.

SUMMARY

Following analysis, design and breadboard testing, 1 and 5 Amp DC and 1 Amp AC prototype Solid State Power Controllers were produced and delivered to NASA MANNED SPACECRAFT CENTER/Houston. The specifications of the Statement of Work were satisfied with a few exceptions. These exceptions were due to compromises in arriving at optimum design with respect to weight, size, reliability and cost. Many options in design were evident and are discussed.

Due to the small quantity of units contracted and problems of high density packaging of discrete components, some optional features of the SSPC's were not included in the delivered articles, particularly "status indication". Circuits for this feature were analyzed, breadboarded and tested. Production requirements would utilize hybrid microelectronic manufacturing techniques, and the inclusion of many optional functions can be realized.

In addition to meeting functional requirements, the design objective was simplicity for reasons of reliability, weight, size and cost. The design leading to the prototype units met this requirement. Relaxation of some specification parameters without sacrifice to overall performance could lead to further optimization of design and are discussed.

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FIGURES

FIGURES (cont.)

TABLES

CONCLUSIONS

Solid State Power Controllers can be made in the envelope proposed, satisfy the functions and meet the environmental conditions. This makes possible a fully automatic electrical control system with built-in safety factors to protect the SSPC, the load and wiring against overload, short-circuit and voltage transients.

RECOMMENDATIONS

Since the efforts of the study and the production and testing of functional SSPC's proves the concept, final specifications for production flight SSPC's should be generated. Efforts should be made between NASA, cognizant military services, aircraft manufacturers and potential suppliers to arrive at a mutual agreement concerning basic packaging, functional requirements, control voltage levels, trip indication, status indication, etc. To meet functional requirements in optimum packaging, hybrid microelectronic manufacturing techniques will be required. Poor economics as well as reliability exist in relatively small quantity of hybrid microelectronic production. Standardization of basics would encourage more multiple and universal usage with resulting improvements in economics and reliability. Economy, rather than design or production, appears to be the only obstacle to widespread practical usage of SSPC's. An advanced system utilizing SSPC's would be cost-competitive with conventional systems if reasonable production could be anticipated.

Although the contract requested study and development in the 1 Amp to 5 Amp range, higher current SSPC's are being considered. For the high DC current range, 10 Amp to 50 Amp, the availability of transistor chips with good secondary break-down characteristics are limited and only available at considerable cost. Encouragement to the semi-conductor industry to produce an acceptable chip at reasonable cost is highly recommended.

Industry has recently reported on some SSPC failures in switching into transformer loads where core saturation can occur. Teledyne has not experienced this failure mode. Since reported failures have been catastrophic in nature, further study of the problem is suggested and resulting specifications derived to protect against this possible failure mode.

INTRODUCTION

It was suggested that a study be made of DC and AC Solid State Power Controllers (SSPC's) with respect to each of the functional requirements such as control voltage, trip indication, status indication, and isolation. Teledyne Relays was to analyze optional circuitry for each function and to weigh the results with respect to size, cost, weight and reliability. Optimum packaging was to be a main consideration. The final objective was to fabricate and test prototype units incorp 'ing the analysis and breadboard testing results. Although the guiding s cification was MIL-P-81653, "General Specifications for Power Controller, Solid State", deviations were allowed to optimize the design. The basic functions and switching characteristics were to be satisfied in principal. The following functions and points of design analysis were considered for both the DC and AC SSPC's.

DC SOLID STATE POWER CONTROLLERS

- Power Output Termination
- Power Chip Selection
- Power Dissipation
- Isolation
- Current Limiting and Short-Circuit Protection
- Control Voltage Selection
- Trip Indication
- Status Indication
- Reset
- Transient Voltage Protection
- Fusing
- Foul-up Protection
- Circuit Schematic
- Packaging
- Reliability
- Specifications
- Test Results

AC SOLID STATE POWER CONTROLLERS

- Zero Axis Switching
- Power Output Termination
- Power Chip Selection
- Power Dissipation
- Isolation
- Short-Circuit Protection
- Control Voltage Selection
- Trip Indication
- Status Indication
- Waveform Distortion
- Reset
- Transient Voltage Protection
- Fusing
- Foul-up Protection
- Circuit Schematic
- Packaging
- Reliability
- Specifications
- Test Results

In analysis and design, the axiom was taken that reliability was inversely proportional and cost-, weight- and size-proportional to total component count of the circuit. Emphasis was on simplicity.

DC SOLID STATE POWER CONTROLLERS

POWER OUTPUT TERMINATION

MIL-P-81653 solid state power controller specification requires the functional circuitry illustrated in Fig. 1, requiring three terminals in the output section. The ground terminal is used for establishing an internal power supply for switching and status function. This current arrangement has distinct disadvantages in that the base current necessary to drive the power switching transistor must be established for the minimum load voltage, resulting in excessive power dissipation at maximum load voltages. Circuitry for the isolation and control function requires a relatively high component count. The principle objective of the study was to reduce the component count for reasons of size, weight, cost and reliability. Transformer coupling is required to obtain the necessary base drive to saturate the power transistor, introducing probable RFI elements unless elaborate filtering is employed.

A 2-terminal design was investigated and the functional circuitry is illustrated in Fig. 2. This arrangement has the advantage that no power is taken from the load supply for the switching function. The base drive is independent of the load voltage, resulting in the controller having uniform switching capabilities from .5 volts to 30 volts. The 2-terminal design allows for location of the power switching transistor on either the supply or ground side of the load voltage. In the case of the 3-terminal design, the load is dedicated to the ground side. The disadvantage is that the power for the base drive of the switching function must be derived from the control signal. The current required for low control voltages is appreciably more than that required for the 3-terminal controller. With a 28 volt control voltage current, drain is not excessive for 1 and 5 Amp controllers. For higher ratings, control current requirements may be excessive. RFI problems will also exist for the 2-terminal controller, as transformer coupling is required for isolation. The induced power of the RFI element is considerably less for the 2-terminal controller. Status indication requirement is more complex for the 2-terminal controller without the ground reference. It can be accomplished by sensing current in the load line versus sensing voltage at the load in the 3-terminal controller.

An alternate 3-terminal design was investigated, as shown in Fig. 3. For 1 Amp loads a PNP transistor may be used for Q1, with Q2 omitted. For higher currents, PNP transistors are not readily available with sufficient Beta for efficient drive. The NPN power transistor, driven by a PNP transistor, allows for efficient switching. The only disadvantage is the increased voltage drop across the combined switching transistors. Fig. 4 shows load current vs voltage drop. It might appear that the larger voltage drop would cause considerably more power dissipation resulting in a less efficient power distribution system. However, calculations taking

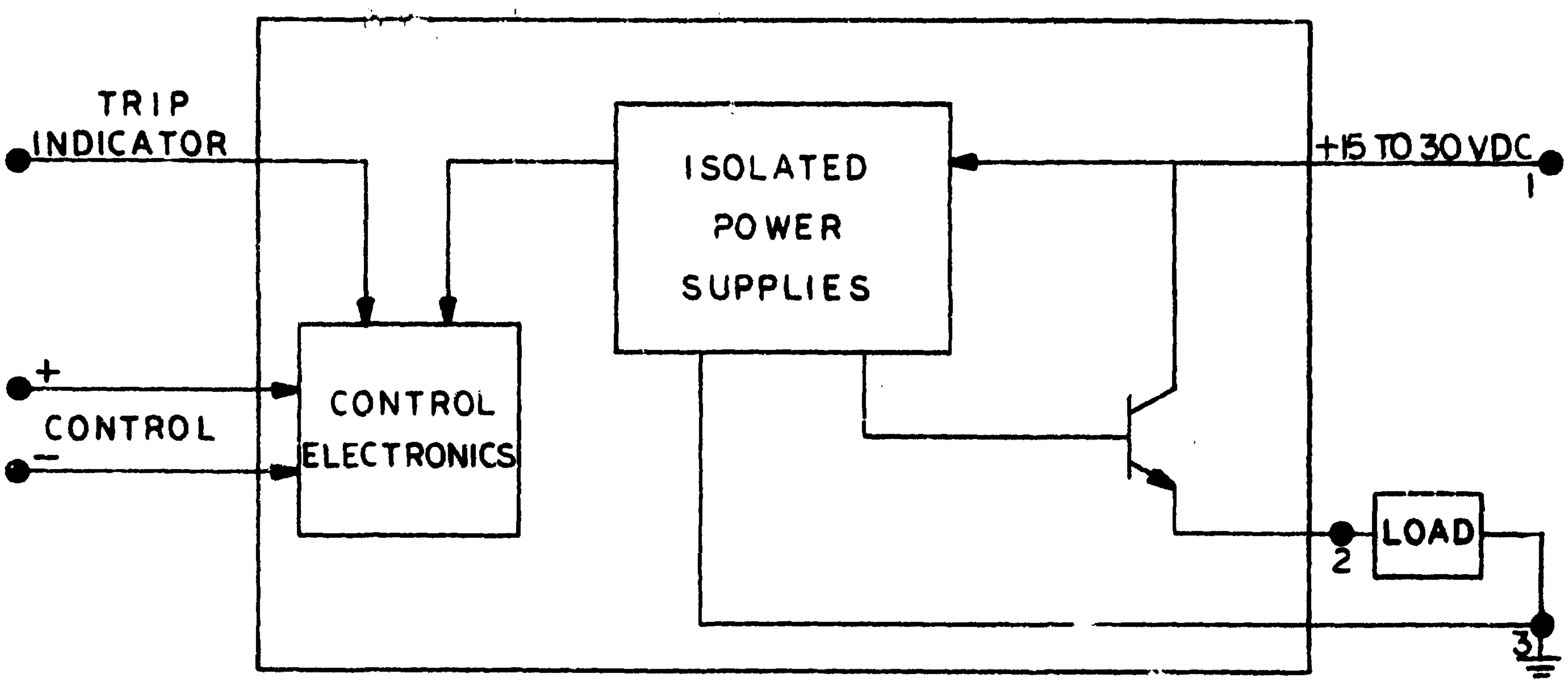


FIG.1 MIL-P-81653 3 TERMINAL CONTROLLER

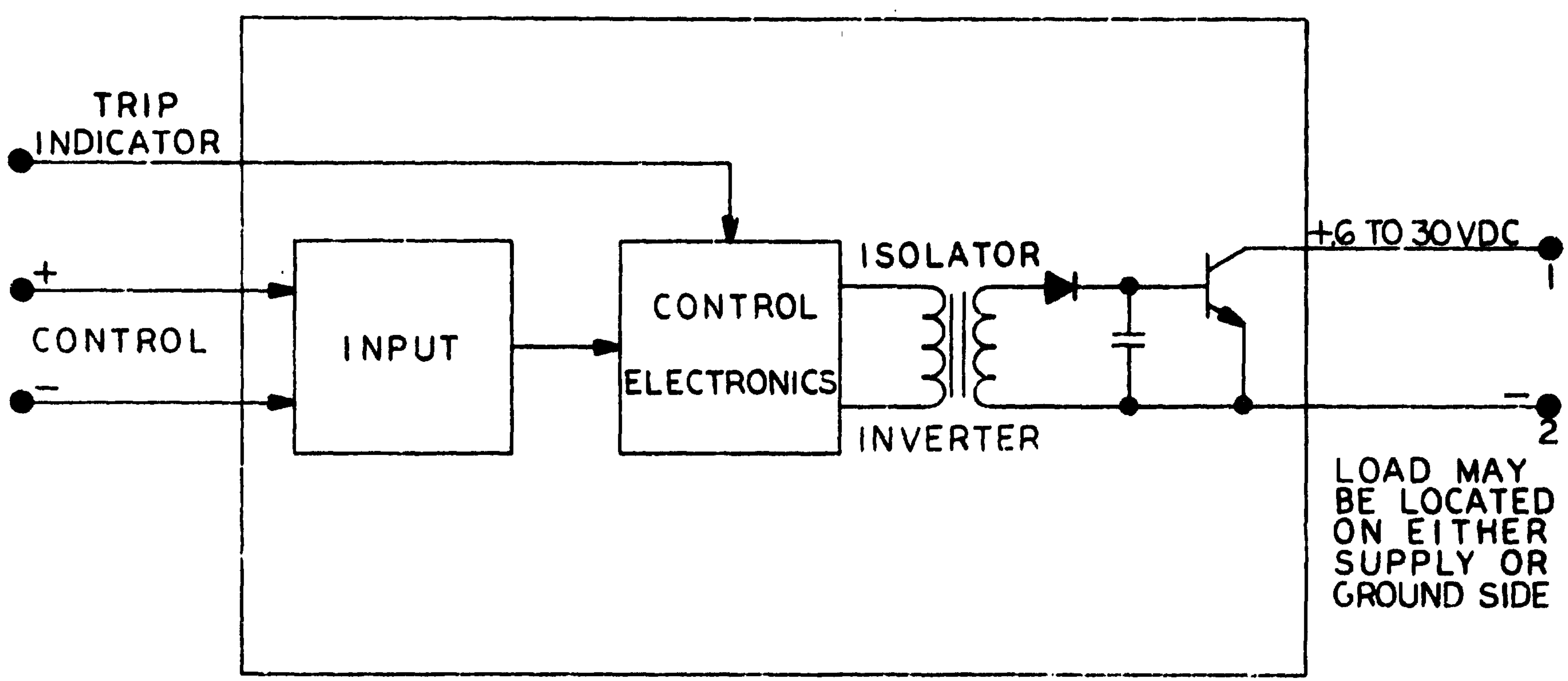


FIG. 2 TELEDYNE 2 TERMINAL CONTROLLER

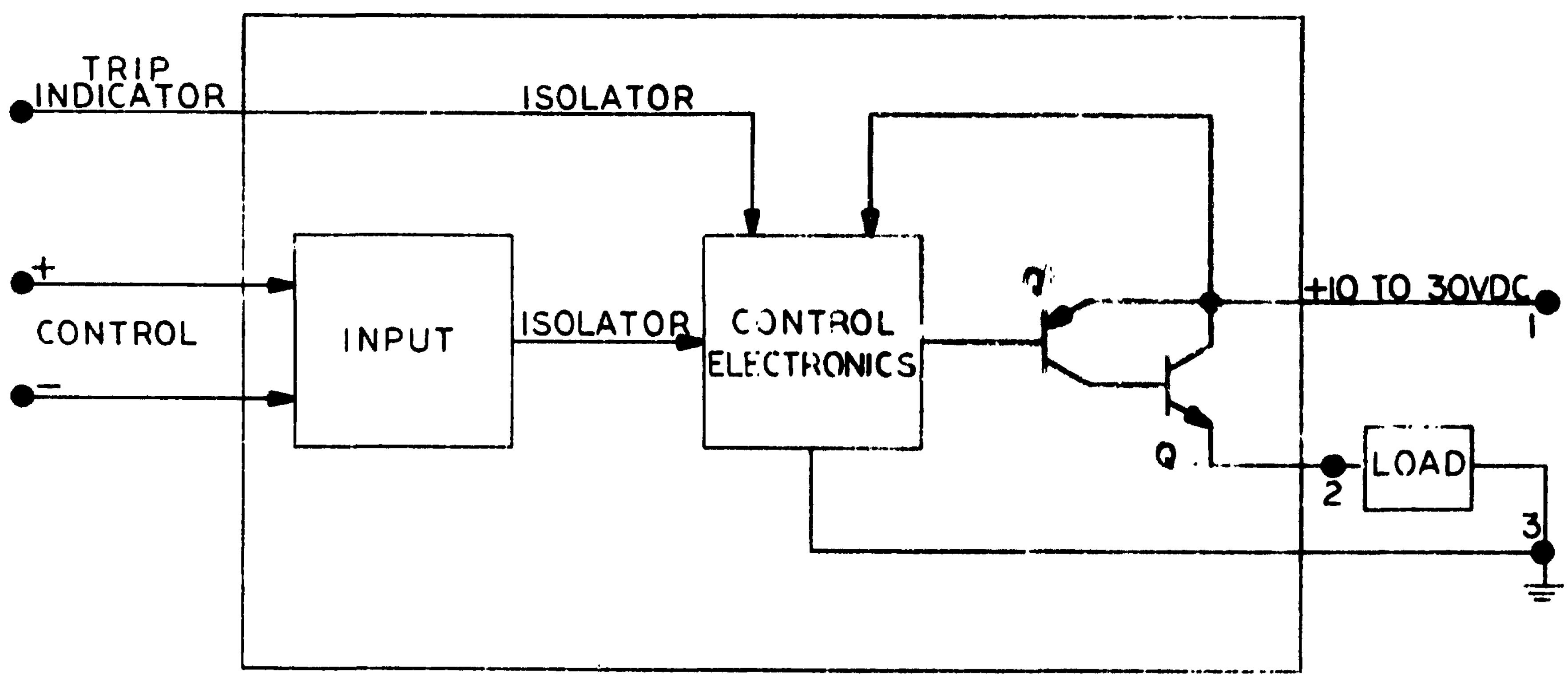


FIG.3 3 TERMINAL EMITTER FOLLOWER CONTROLLER

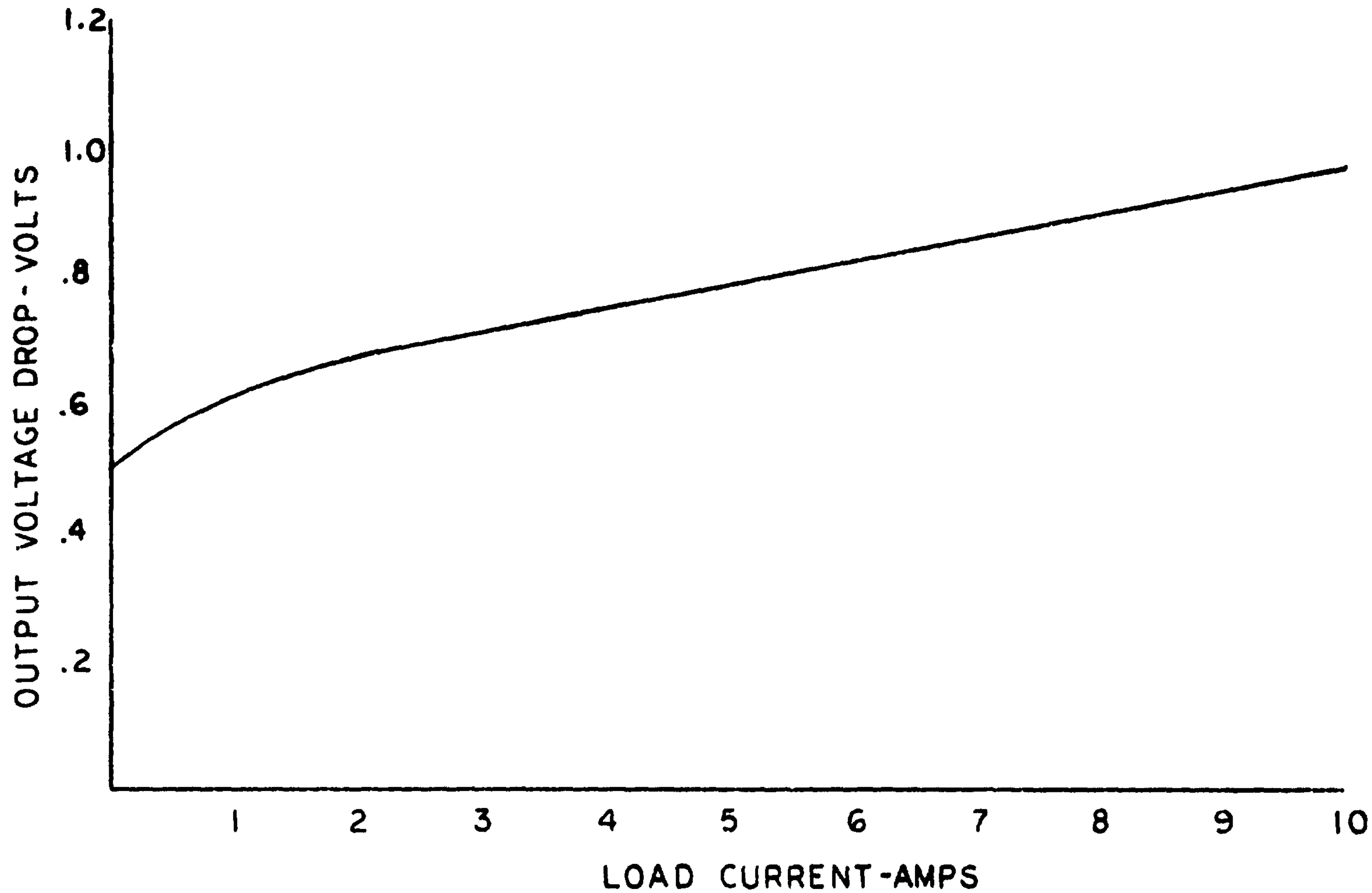


FIG.4 OUTPUT VOLTAGE DROP VS. LOAD CURRENT-EMITTER FOLLOWER CONTROLLER

into consideration the internal power requirements for drive as well as the power dissipation of the power switching transistor, indicate that this 3-terminal arrangement is more efficient for loads up to 7.5 Amps. Above 7.5 Amps, - MIL-P-81653 controller is more efficient. It has been estimated that from 76% to 90% of controllers on actual aircraft systems (A-7, F-14, SST, etc.) are for loads of 7.5 Amps or less. There may be loads which suffer in performance due to the slightly reduced output voltage. Trade-off studies are required to isolate the areas. Another major advantage of the 3-terminal controller illustrated in Fig. 3, is that isolation can be accomodated by opto-electro means, resulting in elimination of RFI-induced elements, reduced weight, size, cost, and improved reliability.

The design used for prototype units incorporated the 2-terminal configuration, Fig. 2, because of the 1 and 5 Amp rating specified and the available 28 volt control voltage. The 3-terminal controller, Fig. 3, should be considered in future studies if the resulting slight increase in output voltage drop is acceptable.

POWER CHIP SELECTION

The output power switching transistor is the only highly stressed component in the entire circuit. In the current limiting mode, it must dissipate at a minimum 105% of rated load X 37.5 volts, or 195 watts for a 5 Amp controller. The chip failure mode is determined by secondary breakdown characteristics. Power transistor chips with 75 Amp rating failed for the 5 Amp rated controller in the current limiting mode due to secondary breakdown characteristics. Chip size and geometry, rather than rating, determine the secondary breakdown characteristics. Power Tech MT-1010 was selected after comparison evalution with several other manufacturers' power chips. Power Tech discrete equivalent to the MT-1010 is their P/N PT-7501.

POWER DISSIPATION

While the controller is in short-circuit or current limiting mode, it is necessary to dissipate the heat generated in the power chip to the heat sink as rapidly as possible to limit the transistor maximum junction temperature to a safe value. The problem is complicated by the need to isolate the power chip from the controller case to meet the 1000V dielectric test. Further complications arise in that the temperature rise is rapid in the event of a short-circuit, and a temperature gradient develops from the heat sink to the isolator to the power chip. This develops mechanical stresses due to differences between coefficients of thermal expansion of the different materials involved. Large power chips are required for reasons of secondary breakdown characteristics, thus making thermal expansion problems more acute. Two methods of power chip mounting were investigated. One was to mount the chip with hard solder directly to a copper surge block of sufficient size to rapidly absorb the heat generated under fault conditions, in turn isolating the copper surge block from the controller case. Fig. 5. This procedure proved efficient. Another approach was to mount the power chip to the metalized Beryllia (BeO), which acts both as an insulator and a thermal conductor. The power chip and BeO assembly is in turn mounted to the copper header making up the case, which acts as an additional heat sink, Fig. 6. This method allows for appreciable weight saving and would be adequate for the 1 Amp controller. However, the heat problems are critical for the 5 Amp controller, and copper surge blocks were used for both the 1 Amp and 5 Amp controllers.

ISOLATION

A dielectric withstanding voltage of 1000 vAC (RMS) with a maximum leakage of 1.0 mA is required between all input terminals and output terminals. This applies for control (on-off and reset), short-circuit and current limiting interface,and trip indication. Isolation between control, short-circuit and current limiting, and trip indication is not required since all of these functions have a common DC ground in most applications. They can be isolated at the expense of additional componentry, cost, size and weight. Wherever applicable, opto-electro couplers are more efficient with respect to cost, size, weight, RFI and reliability than DC-DC converters utilizing transformers. Care is taken in the use of opto-electro couplers to allow for leakage currents at elevated temperatures and exposures to radiation.

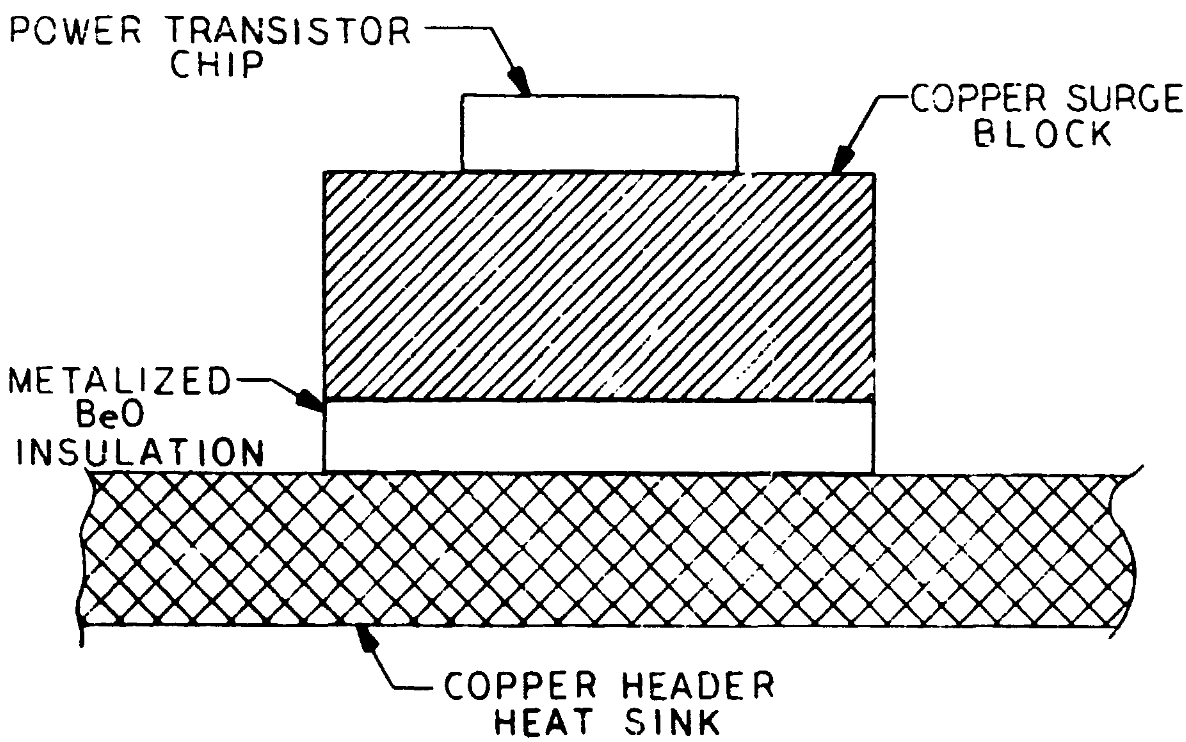


FIG. 5 POWER TRANSISTOR CHIP MOUNTED DIRECTLY TO COPPER SURGE BLOCK

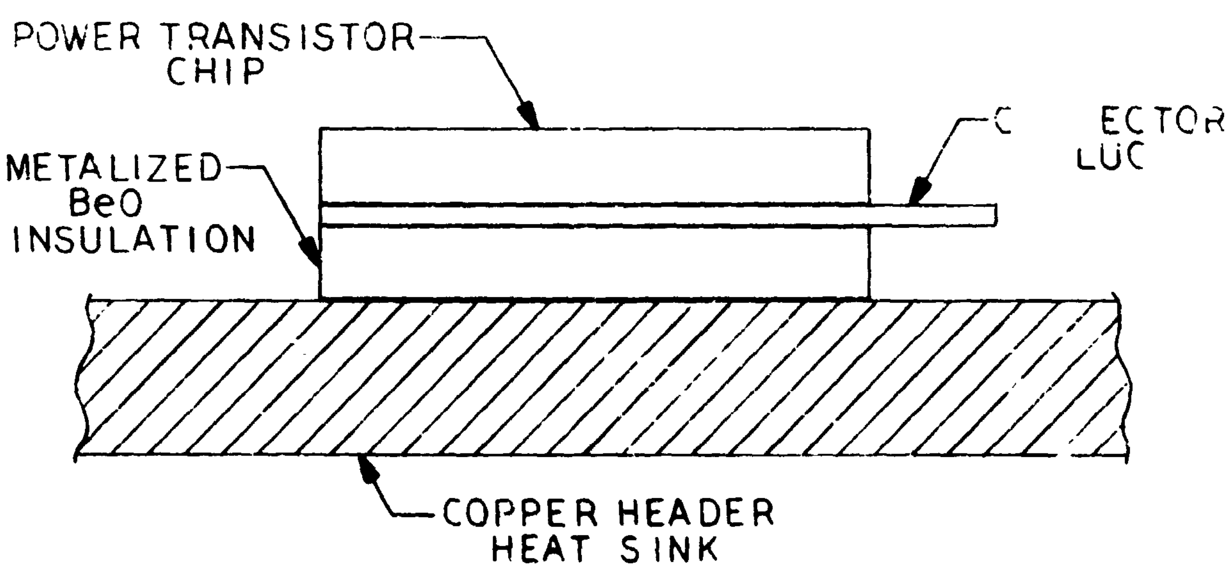


FIG. 6 POWER TRANSISTOR CHIP MOUNTED TO BeO INSULATOR TO COPPER HEADER HEAT SINK

CURRENT LIMITING

The characteristics and mounting of the power transistor chip determine the current limiting capabilities. It is believed that the optimum available chip has been selected. Its safe operating characteristics are illustrated in Fig. 7. Fig. 8 shows the voltage drop across the collector and emitter, with an 80 volt supply voltage fc ne 5 Amp rated controller. A locus of points for 105%, 110%, 120%, 130% and 140% current limiting conditions vs their respective voltage drops across the collector-emitter are superimposed on Fig. 7. These points are in a marginal regio f the Safe Operating Region curves. The current limiting charac eristics of MIL-P-81653 are shown in Fig. 9, which dictates fold-back cu rent limiting. This is not recommended as it does not allow for full rated load to be applied under transient voltage conditions. Also, fold-back current limiting has a negative resistance characteristic which may cause s us instability (oscillation) with many reactive loads.

Analysis of the overvoltage problem yielded the following conclusion. The object is to protect the power transistor chip from excessive power dissipation and secondary breakdown. The most efficient method of doing this is to monitor the voltage across the power chip itself, rather than the supply voltage. With up to 37.5 volts across the controller, full curre is delivered to the load. Above that voltage, the controller switches off if it is in a current limiting mode. (see Fig. 10) The 37.5 volt value was selected in order that with an 80 volt line surge, the controller would still deliver full rated current to the load. This system protects the power chip only when needed and does not interfere with normal operation. If the voltage surge (above 37.5 volts) occured simultaneously with a short-circuit, the actuator would trip-out immediately. If required, a 100 msec delay could be implemented before trip-out and still remain within the safe operating range of the power transistor chip. The controller will not trip-out under the increased load currents resulting from the voltage transients of MIL-STD-704 (Fig. 11). The time delay of 2 to 3 seconds is fixed for all conditions except the combined condition of overvoltage and short or near-short conditions, in which case the trip-out is immediate (or delayed for 100 msec if desired). Fig. 12 block diagram shows the basic function. The controller will be tripped after a 2 to 3 second delay if the overvoltage indication is not present. In the event of overvoltage, the trip-out is immediate. An overvoltage condition can not trip the controller by itself. It must be AND functioned with the controller in the current limiting mode for trip-out.

Schematic shown in Fig. 13 for the 1 and 5 Amp DC controller illustrates how current limiting and overvoltage projection are accomplished. Voltage across current sensing resistor R16 is supplied to operational amplifier U4. When over current exists, voltage is applied through emitter diode of opto-isolator U2, initating a timing circuit comp ised of C1, R1, and R2. The output voltage through diode of U2 continues through R19, R20 and R17, providing feedback to operational amplifier U4 with Q7 being

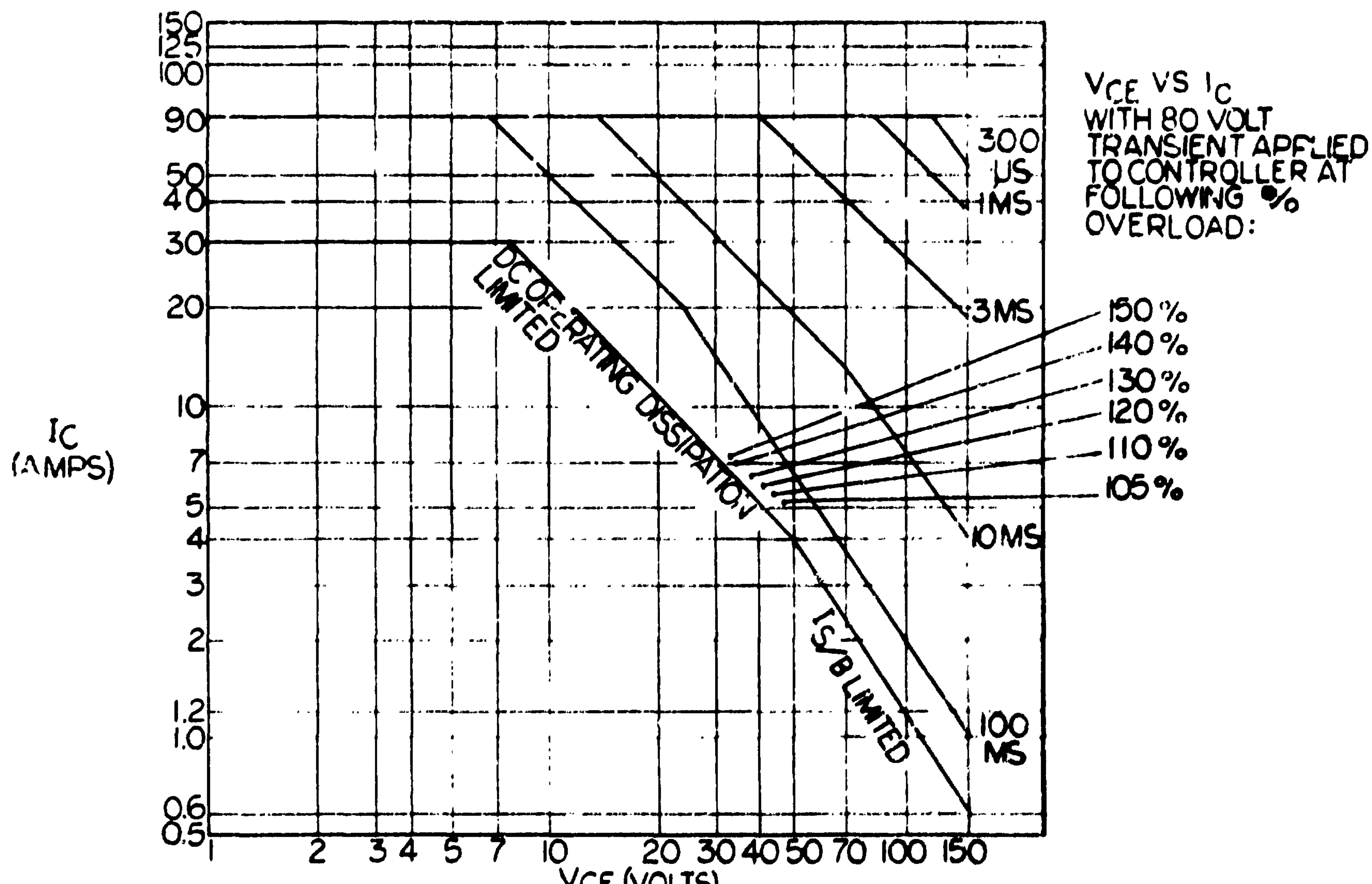


FIG.7 SAFE OPERATING AREA POWERTECH MT-1010 POWER TRANSISTOR CHIP

% OVER LOAD TRIP POINT	I_L AMPS	R_L OHMS	$I_L R_L$ VOLTS	V_{CE} VOLTS	$V_{CE} I_L$ WATTS
150	7.5	6	45	35	262.5
140	7.0	6	42	38	266.0
130	6.5	6	39	41	266.5
120	6.0	6	36	44	264.0
110	5.5	6	33	47	258.5
105	5.25	6	31.5	48.5	254

I_L = LOAD CURRENT

R_L = LOAD RESISTANCE

V_{CE} = VOLTAGE DROP ACROSS CONTROLLER

FIG. 8 EFFECT OF 80 VOLT TRANSITENT ON 5 AMP CONTROLLER SWITCHING INTO RATED LOAD

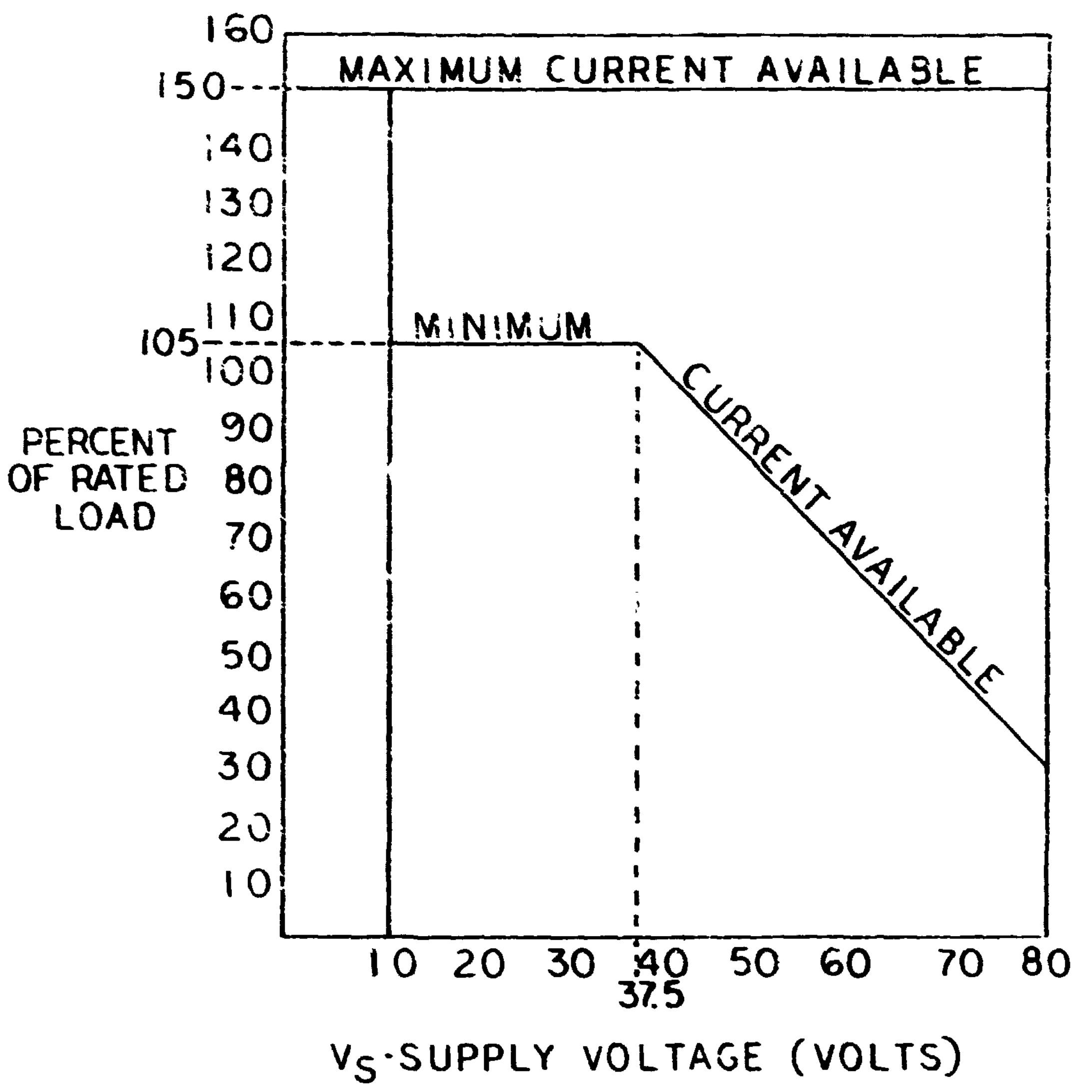


FIG. 9 MIL-P-81653 CURRENT LIMITING CHARACTERISTICS OF DC CONTROLLERS

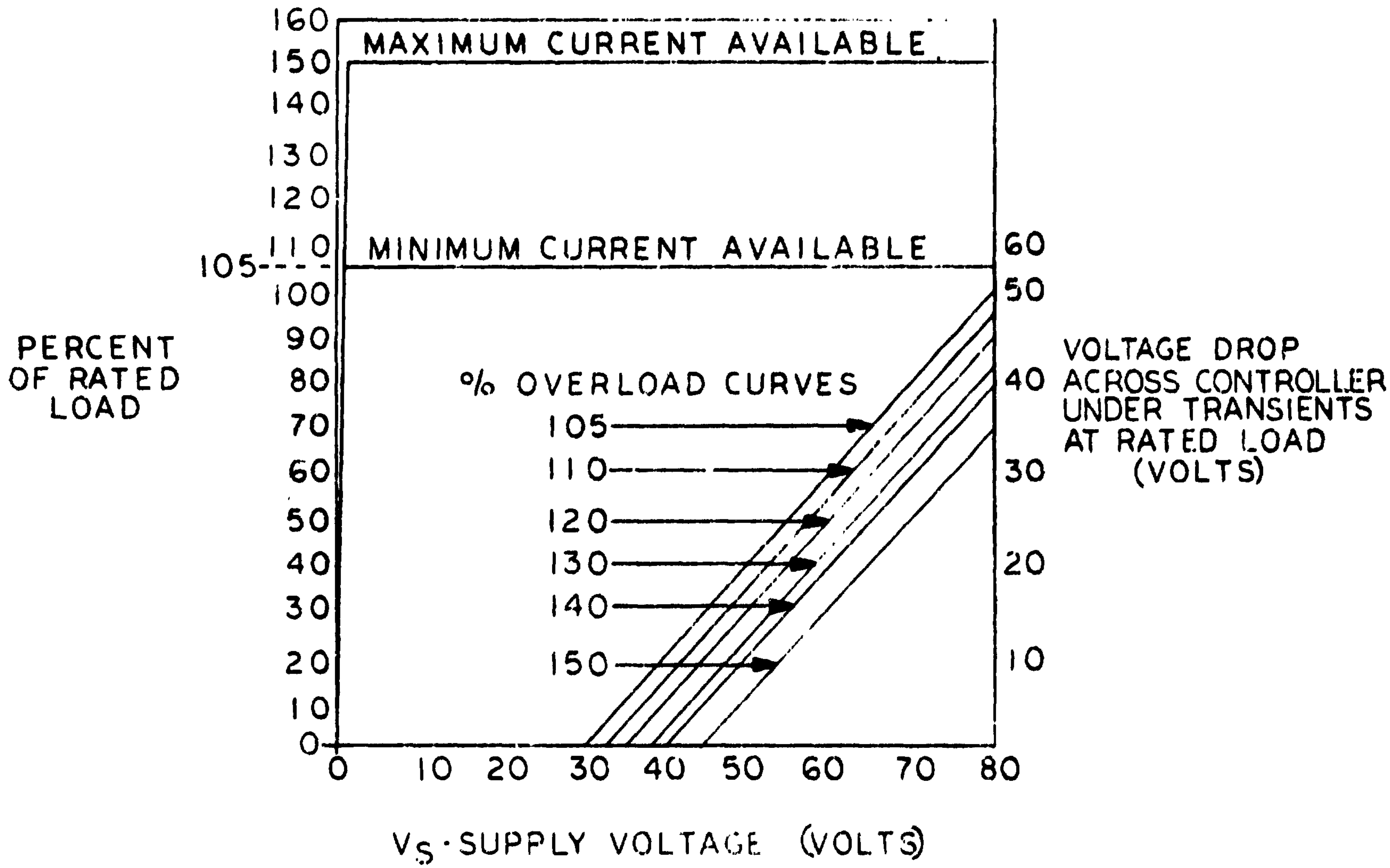


FIG. 10 CURRENT LIMITING CHARACTERISTICS TELEDYNE DC CONTROLLER AND VOLTAGE DROP ACROSS CONTROLLER UNDER TRANSIENTS

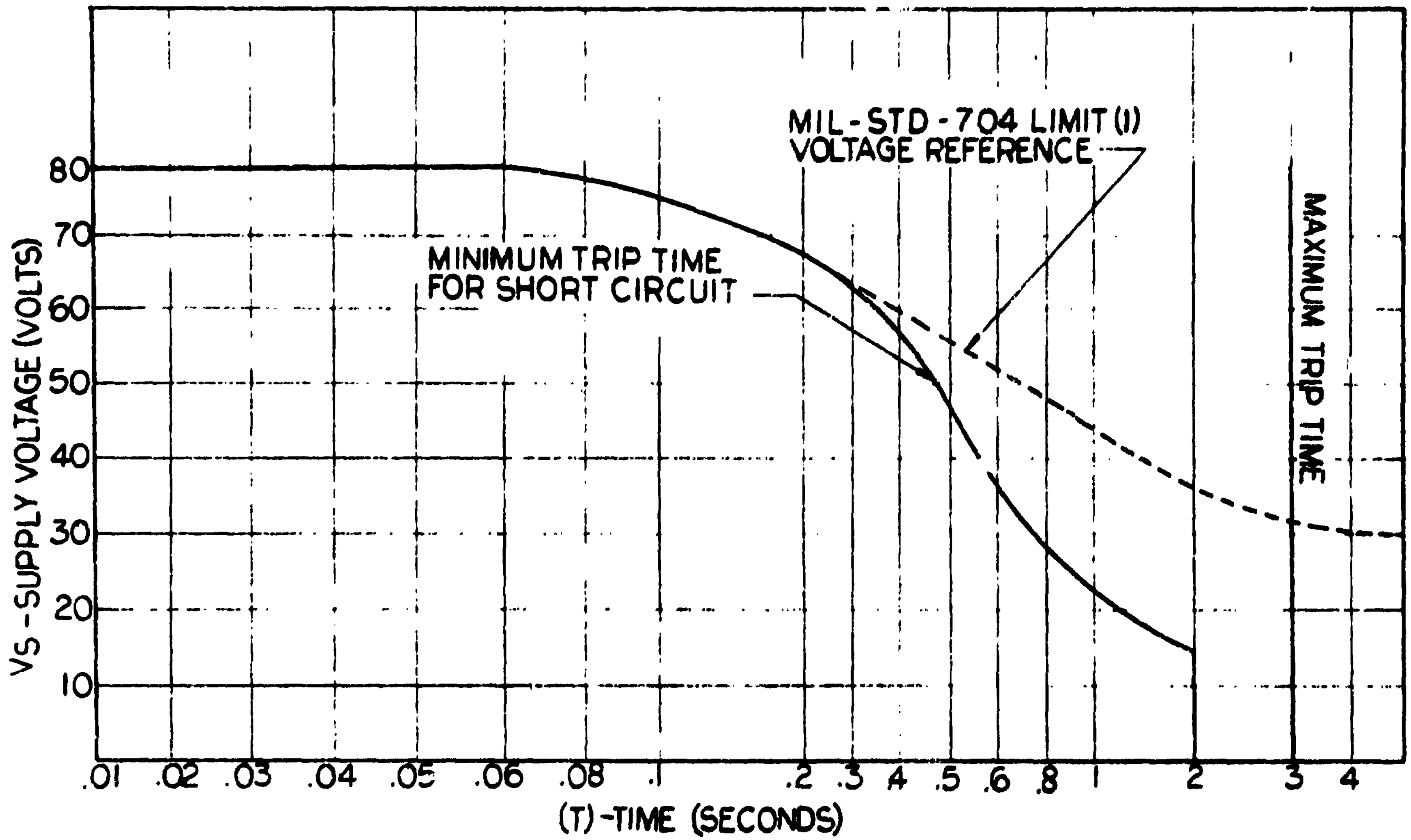


FIG. 11 MIL-P-81653 TRIP CHARACTERISTICS FOR DC CONTROLLERS IN CURRENT LIMIT MODE

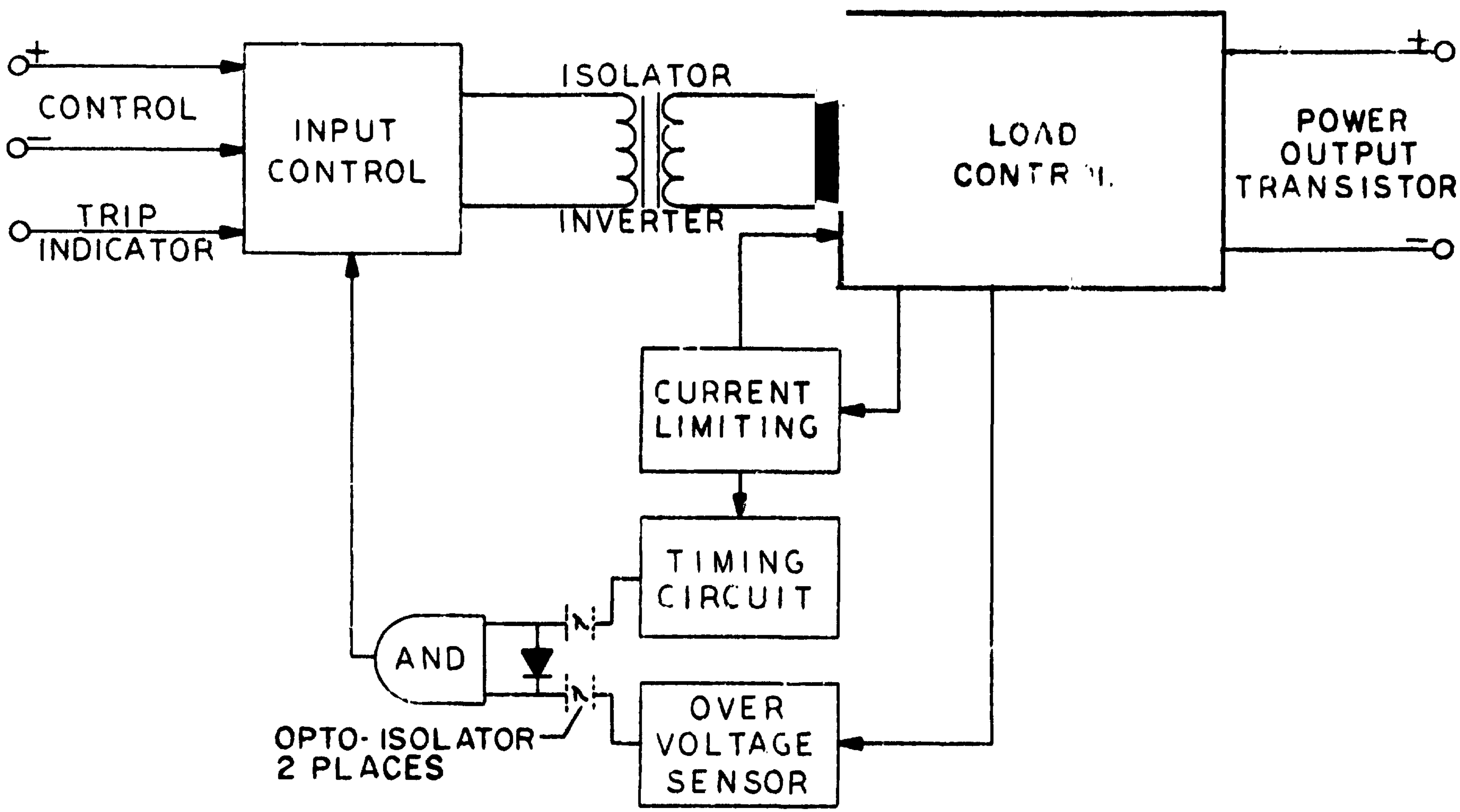


FIG. 12 FUNCTIONAL BLOCK DIAGRAM DC CONTROLLER

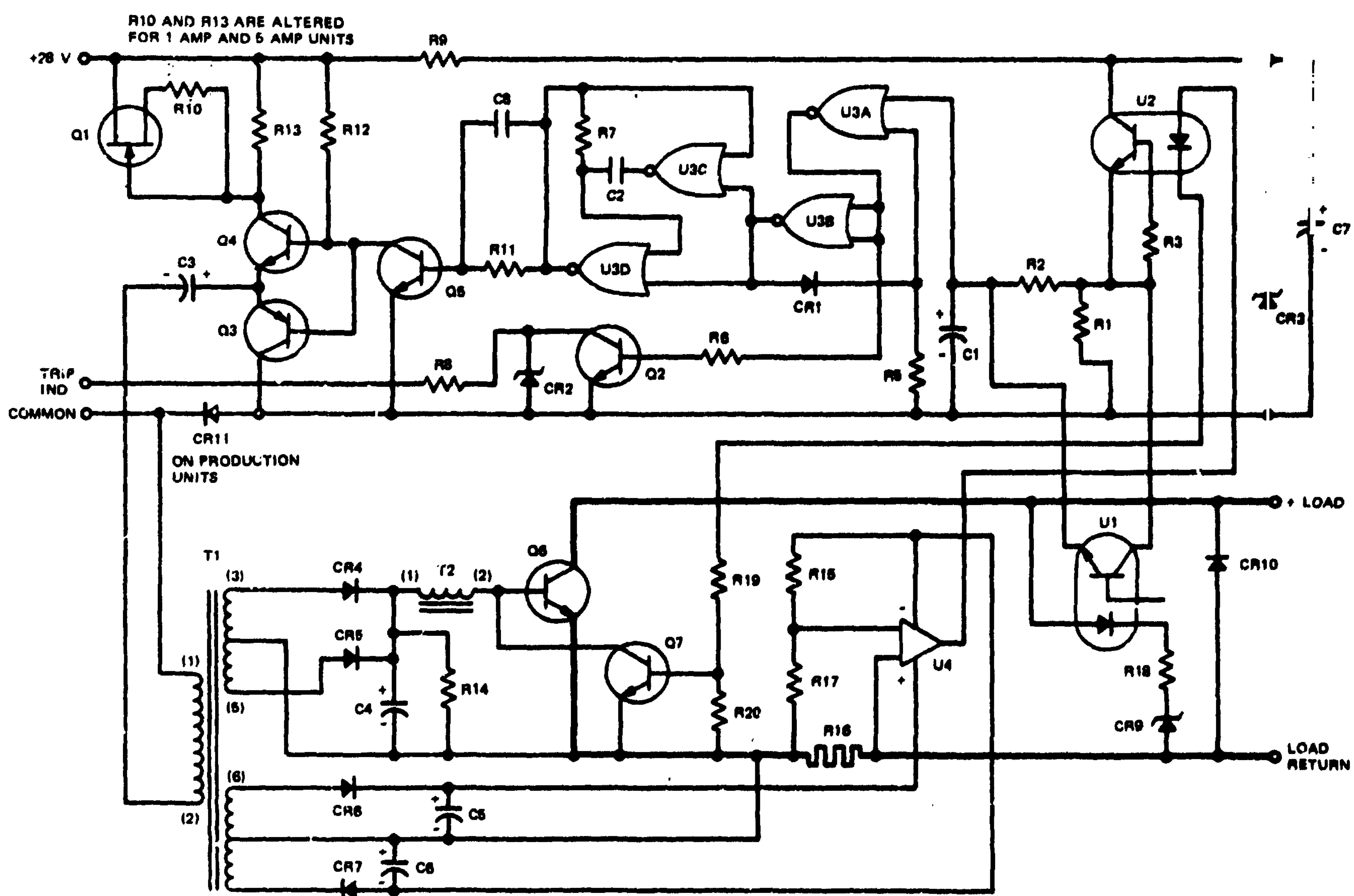


FIG. 13. SCHEMATIC DIAGRAM – DC CONTROLLER

biased to put Q6, the power transistor, in a constant current mode by virtue of the above-mentioned feedback. After the time delay of 2 to 3 seconds the gate of U3A goes to logic 1, inhibiting the oscillator consisting of U3C, U3D, C2, C8, R11 and R7, and the push-pull amplifier consisting of Q5, Q3, Q4, R13, R12 and C3. The trip-out is latched by virtue of feedback via CR1.

The overvoltage sensing circuit consists of opto-isolator U1, R18 and CR9. With 37.5 volts (36 volts zener and 1.5 volts diode drop of U1), current flow through diode of U1 with the transistor of U1 effectively short-circuiting R2 of the timing circuit allowing for immediate inhibition of the oscillator if the controller is in the current limiting mode. Remember the 37.5 volts is the voltage across the controller and not the supply voltage.

This circuit offers power transistor chip protection for overload and overcurrent conditions. It is protected against short-circuits in normal and overvoltage conditions. It allows the controller to supply full rated loads from 1 to 30 volts, and through transients to 80 volts with a wider margin against nuisnace trips. It deviates from MIL-P-81653 controller in that trip-out is faster under the combined conditions of overvoltage and short-circuit. In some schools of thought this is an attribute. Regardless, the overall advantages far outweigh the disadvantages of the above-mentioned current fold-back systems.

MIL-P-81653 allows for current limiting within 150% maximum and 105% minimum. Current limiting can be accomplished within a 20% band through temperature anywhere within the 105% to 150% range. Its location is optional. Prototype units were fixed at a 110% to 130% band. A band of 130% to 150% would provide greater pass current capabilities without effecting nominal load conditions.

CONTROL VOLTAGE SELECTION

MIL-P-81653 control voltage refers to Para. 3.1 , making control voltage a specification requirement for a specific controller. A 5 volt TTL compatible control voltage has been generally specified. It is considered that this control voltage is too low for aircraft and spacecraft use. The 2.5 volt threshold between "ON" and "OFF" conditions of the controller would be susceptable to voltage-induced noise. The 5 volt level increases the current requirements for transformer isolation and power transistor base drive.

The most efficient voltage to use would be the existing 28 volt bus. Transients can be readily suppressed and voltage levels reduced for internal logic functions. The 28 volt supply would prove most efficient for transformer coupling and opto-isolation. The controller would also be compatible with existing 28 volt systems. The 28 volt control system was employed in the prototype DC controllers after weighing size, cost, weight and reliability.

The purpose of the 5 volt TTL control is to have the controller operated directly from the computer. If direct computer control is essential, then HTL (High Threshold Logic) control voltage levels should be considered. HTL was specifically developed for the purpose of noise immunity for systems with far less hostile noise environment than aircraft or spacecraft. HTL has a minimum of 5.0 volt noise immunity and operates from a 15 volt supply which would be adequate for transformer coupling and opto-isolators.

TRIP INDICATION

Trip indication can be readily satisfied by either current sinking or voltage indication. Current sinking can be performed in either one of two conditions, light indication when controller is tripped or light off when controller is tripped. The latter method has the advantage in that it also gives positive indication that control voltage has reached the controller by having the light "ON" in the untripped condition. It has the disadvantage that a light turning off is not as distinct a visual indicator of a change in condition as a light turning on. This method was used in the prototype controllers since the current sinking method of trip indication was to be investigated, and this method does afford the dual function of trip indication and wiring integrity to the controller. The circuit schematic, Fig. 13, shows how trip indicating transistor Q2 is forward biased from NOR gate output of U3A. By connecting the base of Q2 to NOR gate output of U3B, trip indication with the light going on rather than off would be accomplished.

Trip indication by means of voltage indication can be readily performed by connecting the collector of Q2 through a resistor to the 28 volt control supply, and Q2 forward biased as an indication of trip; that is, connecting the base of Q2 to the NOR gate output of U3B. This system would give both trip indication and control voltage wiring integrity indication. By simple circuitry at the receiving point of indication, a lamp could be turned on when trip occurs. Voltage indication would be 28 volts no trio and .4 volts tripped.

STATUS INDICATION

An ideal status indicator would show flow of current to the load with the controller on. This would indicate wiring integrity to the controller and from the controller to the load. A pure voltage indication at the controller output does not indicate voltage to the load, only voltage to the controller output. It does not indicate wiring integrity from the controller to the load. A status indicator based upon current flow to the load was developed. The principal was similar to the current limiting approach described earlier, ie. a voltage differential was detected across a current sense resistor in the power line and fed into an operational amplifier which biased a signalling transistor. The gain of the amplifier was set to detect current flow of 50 mA or more. A simplified schematic is shown in Fig. 14. Supply voltages for the operational amplifier were from the same source as for the operational amplifier used in the current limiting function. Because of the limited number of prototype units contracted which eliminated hybrid-microelectronic manufacturing concepts, it was impossible to package this status indicating circuit in the size package established for the prototype units. This status indicating feature could be incorporated in production warranting hybrid-micorelectronics.

If it is desirable to fully isolate a fault to the load, to the controller, to control wiring, to load wiring (from the load supply to the controller and controller to the load), a load voltage sensor would be required at the controller load input and controller load output. This would mandate a 3-terminal output configuration.

RESET

After the controller has tripped, resetting is accomplished by removal of control voltage and re-application of control voltage. A seperate reset circuit could be implemented by forward biasing through a coupling capacitor, a transistor located between output of U3B NOR gate and input to U3A NOR gate, Fig. 13. This would remove the latch voltage applied to input of U3A through diode CR1.

The time for re-applying control voltage for resetting is 80 msec minimum. This time is dictated by capacitor C7 of Fig. 13. In addition, the capacitor must be of sufficient capacity to filter high voltage transient spikes. The 80 msec interval requested before re-applying control voltage following a trip-out should not be detremental to circuit function.

TRANSIENT VOLTAGE PROTECTION

Control Input Transients as specified in MIL-P-81653 will not damage the controller. The Operating Voltage Transients as specified in MIL-P-81653 can be satisfied. The requirements of Transient Spike Overvoltage ($\pm$ 600 volts) of MIL-P-81653 cannot be satisfied. The controller will not be damaged by these transients. A $\pm$ 600 volt transient applied to the power input terminal will be passed to the power output terminal for the duration of the transient (.6 μsec.). Power transistors suitable in chip form that would satisfy all the requirements of the power chip are not available with a 600 Vceo rating.

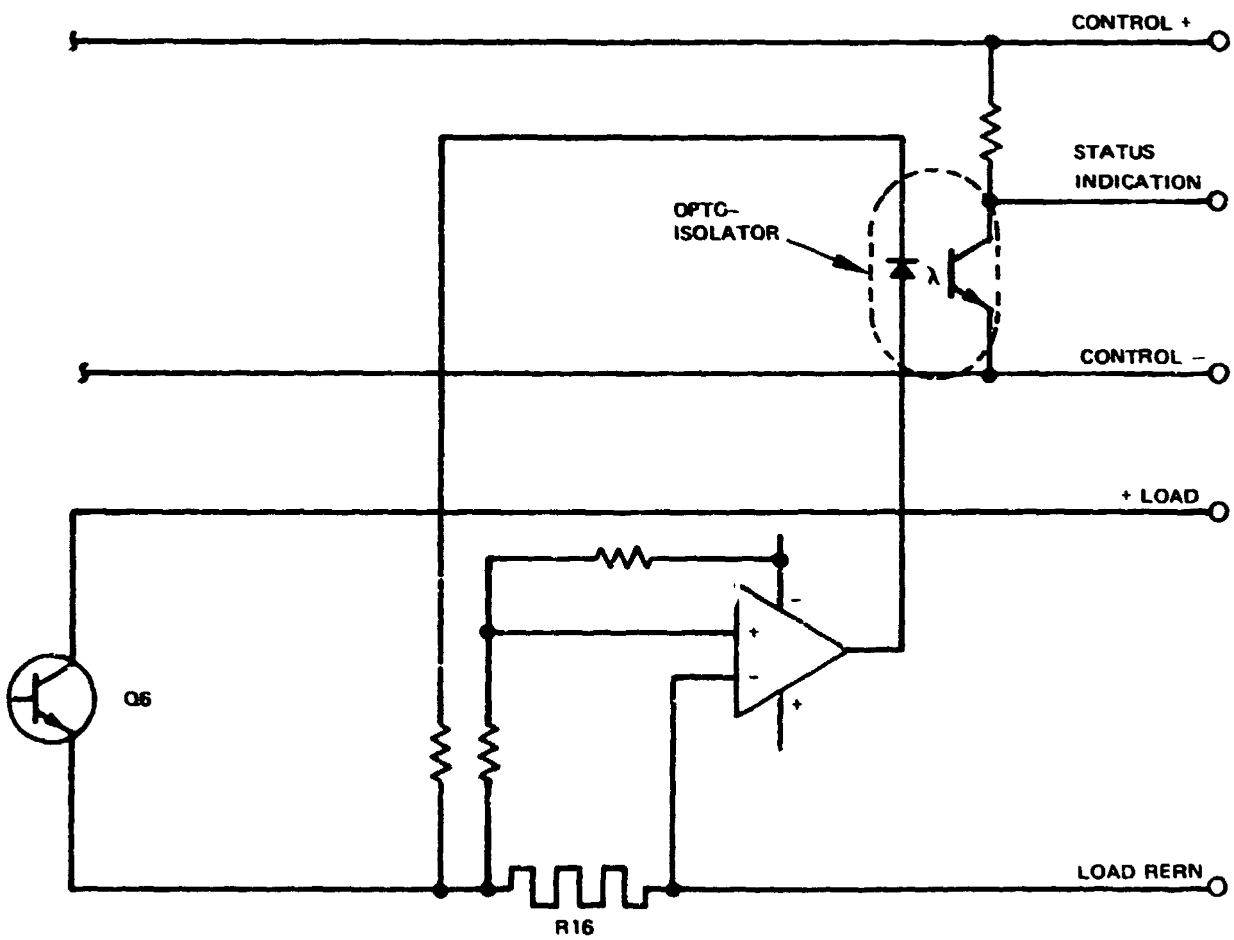


FIG. 14. STATUS INDICATOR SIMPLIFIED SCHEMATIC

FUSING (FAIL SAFE)

The fusable link requirement is met by insuring that the bond from the emitter of the power transistor is the smallest cross-section conductor in the power system. MIL-P-81653 specifies that in the event of a failure of the controller in a shorted condition, the controller shall fail open within 4 seconds when a current corresponding to 50% of the square root of the specified I^2t value is applied, namely 18 Amps for the 1 Amp controller and 32 Amps for the 5 Amp controller. The fusable link requirement was included in the prototype controllers. Tests were not conducted to determine exact current/time limits. In flight hardware, this specification can be met.

The fuse link raises problems of arc extinction and other phenomenon in high current fuses, to ensure the desired protection of the spacecraft. The proposed method of controlling this is with the use of a stable liquid such as silicone oil or a flourocarbon. There has been previous experience using these types of fluid for purposes of controlling arcing. There are other benefits to be derived from fluid filling. One is the additional heat paths due to conduction and convection that tend to equalize temperatures within the package and minimize hot spots. This would be particularly beneficial to solid state switches. There are also proven benefits of fluid-filled devices with respect to mechanical shock and vibration conditions. Under short duration mechanical shock, the fluid acts as a solid and gives support to all the components it surrounds. Under mechanical vibration, the oil acts as a viscous damper for any resonant conditions. Considerations are made for fluid expansion under differentials to atmospheric pressure and temperature. Fluid filling is proposed for flight controllers, and the possibilities of a replaceable fuselink should be considered in future studies.

FOUL-UP PROTECTION

Since the controller is polarity-sensitive, it can be destroyed in test and installation by improper wiring, ie. not observing polarities. Diodes could be used to protect against this condition, but would constitute a .7 plus additional voltage drop in the power circuit. Diode protection can be used in the control and trip-indicating circuits without difficulty. They were omitted in the prototype units and can be included in flight units as indicated in the schematic, Fig. 13.

The controller is intended to operate on bi-level control voltages. Slow ramp or gradual increase or decrease of control voltage could destroy the controller. This possible problem area could be eliminated by snap-action on turn-on and turn-off, however this feature would be at the expense of size, weight, cost and reliability due to the additional components.

Rapid sequential switching of reset with the controller switching into a short-circuit, could be damaging. The controller can be reset once within the 80 msec minimum. No positive protection against damage from repetitive rapid cycling can be incorporated without extensive circuitry. Functionally, repetitive recycling is not required. Caution should be exercised in testing and computer programming of the reset function of the controller.

FOUL-UP PROTECTION (Continued)

The controller is designed for considerable abuse. Properly wired, tested and installed, it should prove trouble-free. With the theory, "If something can be fouled-up, it will be", the above possible areas of concern are noted.

CIRCUIT SCHEMATIC

The circuit schematic of the 1 Amp and 5 Amp DC controller is shown in Fig. 13. The two units are identical except for input impedance and gain of the operational amplifier for current limiting. The functions of the schematic have been discussed under each individual function heading.

PACKAGING

The prototype 1 Amp and 5 Amp DC controllers delivered to NASA Manned Spacecraft Center consisted of discrete component packaging, with the exception of the power transistor chip. The outline drawing of the 1 Amp and 5 Amp DC controller is shown in Fig. 15. The method of internal assembly is shown in Figs. 16, 17 and 18.

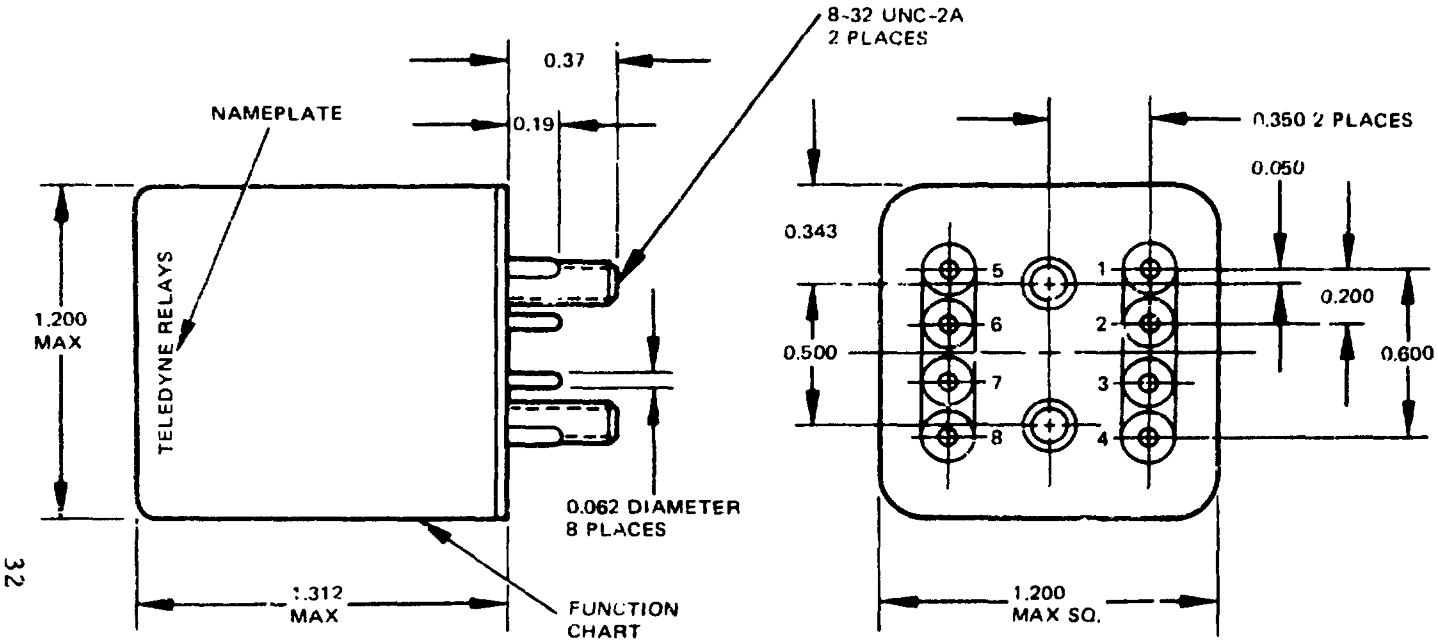
Intensive study was made of packaging for flight hardware controllers utilizing hybrid-microelectronic principals. Based on an analysis of the circuit complexity and the thermal and environmental considerations, the following was established as reasonable size and weight targets.

Size: 1 cu. in. max.
Weight: 2.5 oz. max.

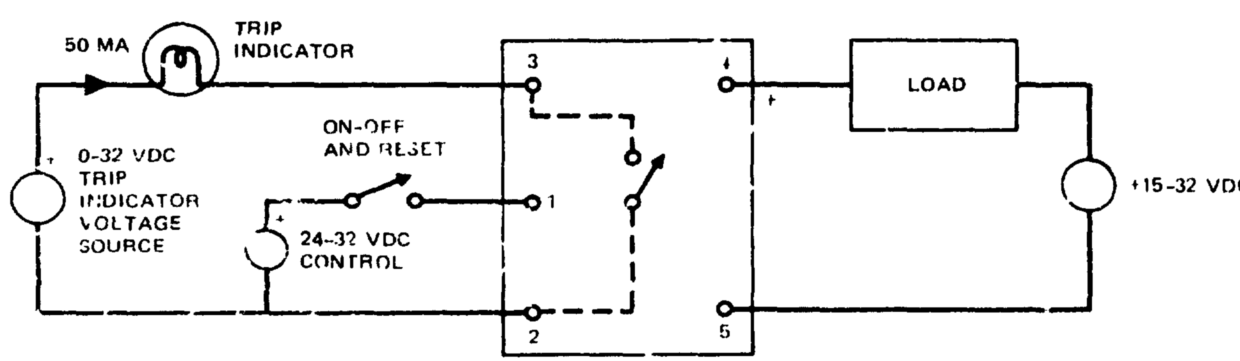
The control circuitry will be in one hybrid-microelectronic package.

Teledyne, through its Microelectronic Operations, has been engaged in the development and production of hybrid-microelectronics for the past nine years. Over 500 different configurations have been designed and produced, with a total quantity of over 400,000 packages delivered. Teledyne pioneered in the technology of manufacturing and testing of these devices in large-scale economic production. These hybrid packages have been used in numerous high reliability aerospace systems. This has demanded the development of extensive 100% screening procedures that in some cases exceeded the requirements of MIL-STD-883 to ensure the necessary reliability.

The circuits involved are both analog and digital and the circuit components include bipolar integrated circuits and transistors, FET devices, diodes, resistors and capacitors. For digital applications, a package typically houses 25 integrated circuits, with some as high as 32. For analog applications, a typical package may contain up to 70 components with a mix of integrated circuits, transistors, resistors and capacitors. The range of power densities has been from 6 watt/in to 32 watts/in and all package designs have provided for heat sinking in the system application. Since some system applications have used from 200 to 1000 of these packages in an extremely



FUNCTION CHART	
PIN	DESCRIPTION
1	CONTROL +28 V
2	SIGNAL RETURN
3	TRIP IND.
4	+ POWER IN
5	POWER OUT
6	NO CONNECTION
7	TEST POINT (EMITTER)
8	TEST POINT (BASE)



P/N 673 10001 5 AMP
P/N 673 10004 1 AMP

FIG. 15. OUTLINE DWG - DC CONTROLLER

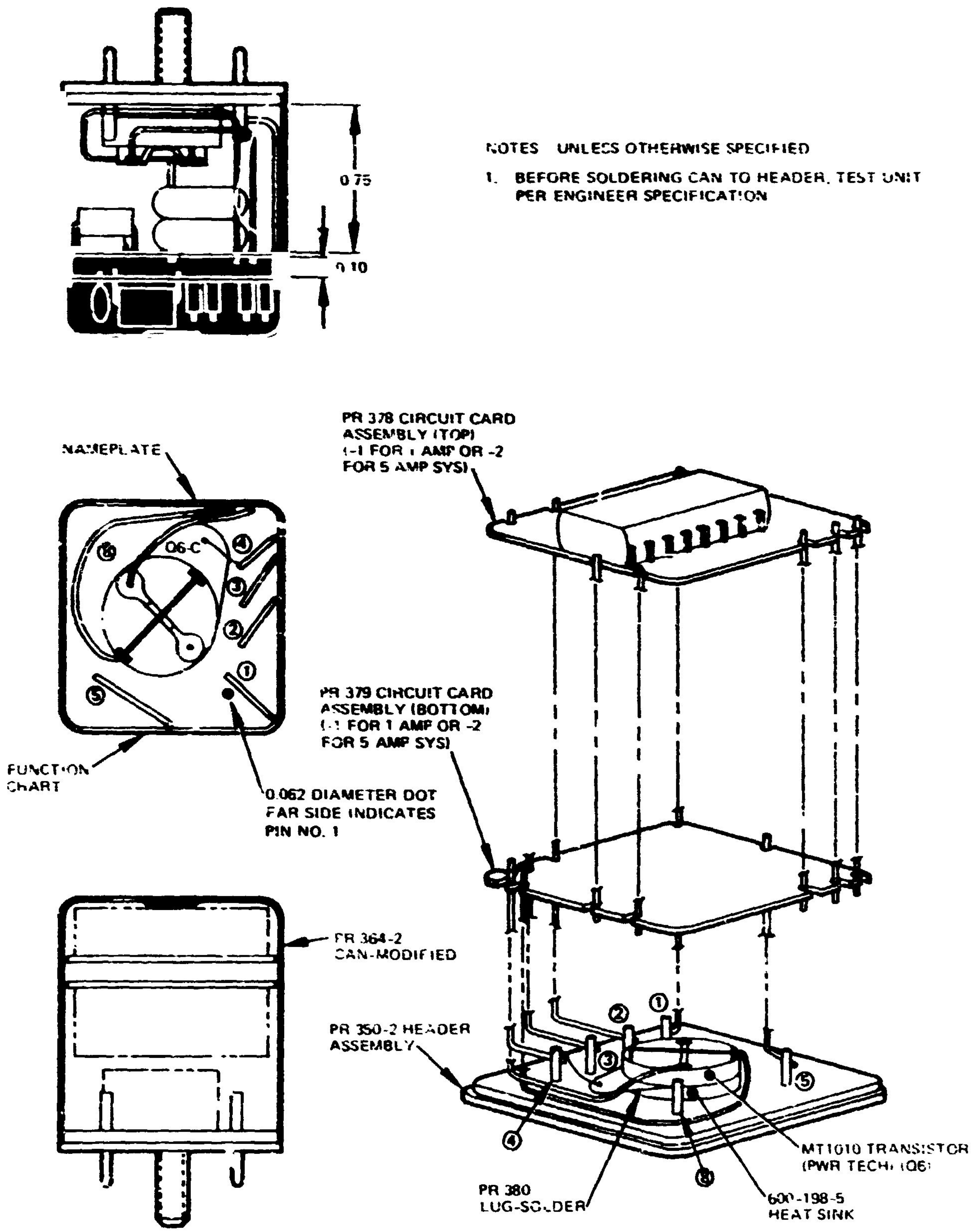


FIG. 16. ASSEMBLY LAYOUT 1 AMP AND 5 AMP DC CONTROLLERS

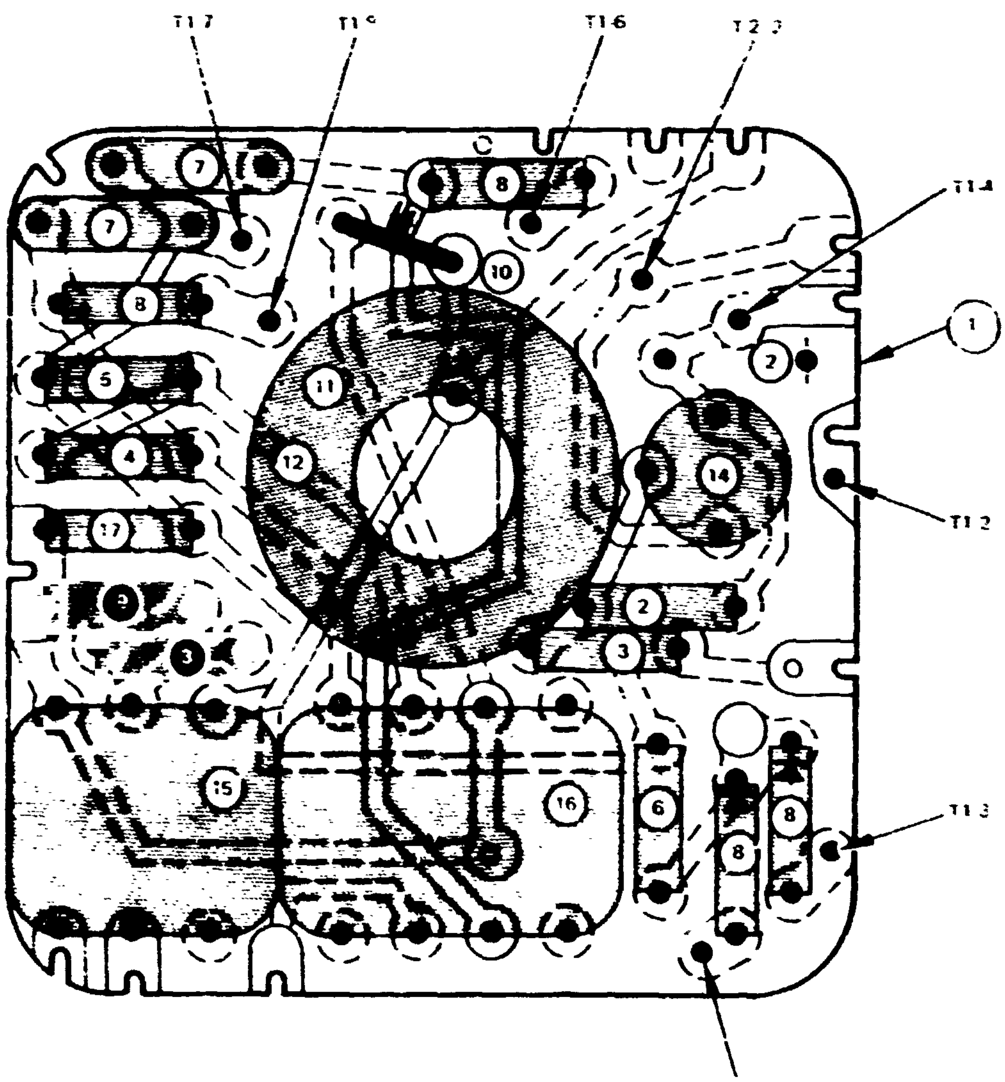


FIG 17 CIRCUIT BOARD ASSEMBLY BOTTOM DC CONTROLLERS

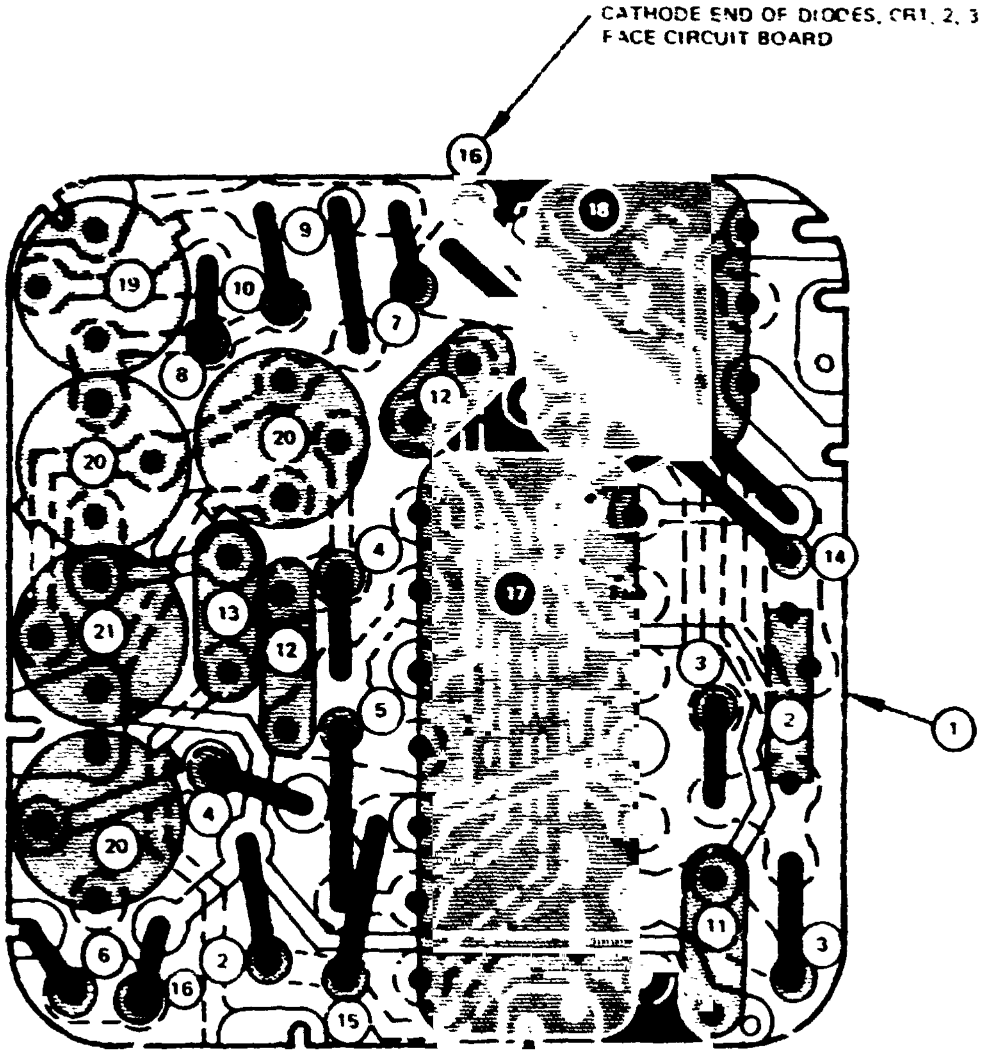


FIG. 18. CIRCUIT BOARD ASSEMBLY -- TOP, DC CONTROLLER

dense array, the thermal problem has received considerable attention. This extensive background is directly and ideally applicable to the specific problems of the solid state power controllers.

Some of the control circuitry will be in the form of MSI integrated circuits and it appears the component count to be packaged will be in the order of 40. This would exclude the optical isolators and a few additional power devices. The mechanical dimensions of the end item power controller establishes the size of the hybrid package, but from preliminary estimates it appears that a package size of approximately 0.8 inch X 0.8 inch X 0.160 inch would result. This size package could reasonably accommodate the components mentioned above, and therefore there would be one hybrid control package per power controller. The substrate power dissipation is estimated to be in the range of ½ watt.

The key factors determining the hybrid package design for this application are the reasonably high power dissipations mentioned above and the maximum heat sink temperature. This dictates that this hybrid package must have the lowest possible thermal resistance from the components to the heat sink, and rules out any simple mechanical contact interfaces between the substrate and the heat sink. The substrate will be beryllium oxide ceramic which has the highest thermal conductivity of any known electrical insulating material (2.6 watts/CM/°C). The ceramic will be 0.025 inches, which will give adequate strength for this size substrate. To implement the maximum thermal conductivity rule, a copper strip in the order of 0.025 inch thick would be brazed to the bottom of the ceramic substrate, providing the best possible thermal path to the heat sink. This copper would equal the width of the ceramic in one dimension, and extend beyond it in the other dimension to engage a support structure for mechanical mounting in the power controller, which is also the heat path. This is shown in Fig. 19.

The ceramic metallization required to provide a base for this copper braze operation can be either moly manganese or thick film gold-palladium. The advantage of gold-palladium metallizing is that its firing temperature of 900°C causes no warping or introduction of camber to the ceramic, as opposed to the 1540°C firing temperature for moly manganese which can reintroduce cambers in the order of 1 mil/inch, which are acceptable but less desirable.

Therefore, the program would proceed with the thick film gold-palladium approach for ceramic metallization. The exit pads for the package, as shown in Fig. 19, would be thick film stripes emerging from under the cover seal area, appearing as exposed pads on the ceramic surface along two edges. They would be on 0.050 inch centers, which is industry standard, and leads can be bonded by either welding or reflow solder techniques. The insulation for the cover seal land area is provided by silk-screened and fired glass inks or fired glass preforms, to give adequate insulation path to the cover to meet the electrical requirements of the specification. Gold-palladium metallization on the top of this glass insulation provides the solder base for cover seal. The proposed metallization system for the active portion of the substrate is a dual system. Gold-palladium ink would be screened on and fired to form the component mounting pads. This would actually take place at the

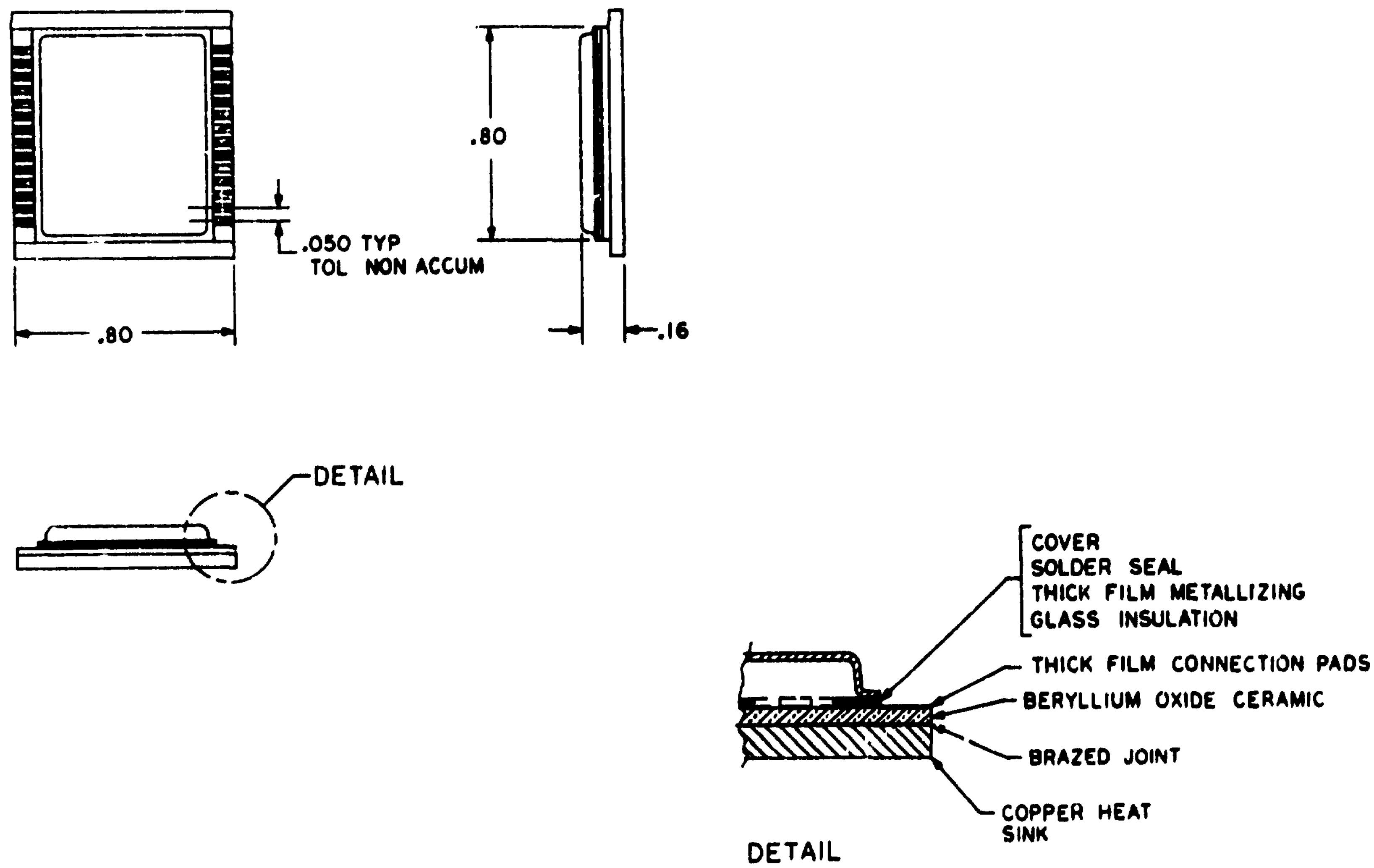


FIG. 19. CONCEPTUAL PACKAGING LAYOUT FOR HYBRID CONTROL CIRCUIT ASSEMBLY

same screening operation as the package exit pads. Aluminum would be evaporated with an undercoat of nichrome over the entire active area. The aluminum thickness would be 250 microinches, which gives the desired resistivity of 5 milliohms per square. The surface would then be coated with photo resist and exposed with the desired substrate wiring pattern.

After developing and processing, the aluminum is protected by resist, where the conductive pattern is desired, and the aluminum is bare where it is to be removed. The substrate is immersed in an etch bath and the aluminum is removed from between the desired conductive strips in the circuit pattern, and also from the component bond pads to re-expose the bare gold-palladium surface.

The aluminum system was chosen to allow a monometallic bonding system with aluminum dice pads, aluminum wire and aluminum substrate bond areas. The advantage of this is the total elimination of potential intermetallic problems. This is particularly important in this application since the temperatures will be in the region of 125°C or slightly higher, and long life at these temperatures is required.

The dual system with gold-palladium is necessary to provide a solderable metallization for component attach, since aluminum is not wettable by solders on a practical basis. The role of the evaporated film of nichrome under the aluminum is twofold. First, it is routinely used as an intermediary to strengthen the bond between evaporated metal films and either glass or ceramic substrates. In this case it serves an important secondary role of acting as an effective diffusion barrier between the aluminum and gold-palladium where they are in contact. Engineering tests involving thousands of hours at 200°C indicate that the nichrome is an excellent diffusion barrier, and no evidence of intermetallics have ever been found in the proposed metallurgical system.

Component attach technology will follow standard production procedures. The component wire bonding will use aluminum wire with ultrasonic welding, which is standard procedure. Circuit analysis is routinely done to establish electrical current values in the wire bonds to determine wire size requirements. For typical signal type currents, 1 mil diameter wire is used. For higher current capability, 1-½ mil or 2 mil diameter wires are used, and in some cases multiple parallel wires have been used.

The hybrid control package will be covered and hermetically sealed by normal processes, even though it will be contained in the hermetically sealed solid state controller case. This is to give adequate protection for internal handling through screening and environmental test procedures, as well as handling during final assembly in the end product. It is also necessary in view of the propose fluid filling of the end item device.

The normal Teledyne high reliability screening procedure will be used on a 100% basis for all the hybrid packages for this program. These screening procedures are listed in detail in Table 1.

TABLE 1. Screening Procedures for Hybrid Control Circuits

TEST	SCREENING CRITERIA
1. Incoming dice visual inspection	Criteria based on MIL-STD-883 method 2010 test Condition A.
2. Post-die attach visual inspection	
3. Pre-cover visual inspection	
4. Stabilization bake	MIL-STD-883 method 1008 test Condition C (150 C) 72 hrs.
5. Temperature cycling	MIL-STD-883 method 1010 test Condition C (-65°C) and +150°C) 22 cycles.
6. Mechanical shock	MIL-STD-883 method 2002 test Condition B (1500G, ½ ms) 5 impacts Y axis.
7. Hermeticity a) Gross	MIL-STD-883 method 1014 test Condition C, step 1.
b) Fine	MIL-STD-883 method 1014 test Condition A except packages are helium filled at seal.
8. Burn-in	MIL-STD-883 method 1015 test Condition B 160 hrs. @ 125°C junction temperature.
9. Electrical test	Per hybrid specification.
a) DC parameters at 25°C and at max. and min. rated operational temperature.	
b) AC parameters at 25°C and at max. and min. operational temperature.	
c) Final Functional test at 25°C.	
10. External visual	MIL-STD-883 method 2009.

TECHNIQUES

The packaging utilizing hybrid-microelectronics and in accordance with MIL-P-81653 concepts is shown in Fig. 20. In this case, the basic assembly would consist of the copper heat sink base, power chip, hybrid control circuit package and miscellaneous components such as the optical isolators (which are themselves hybrid circuits). The hybrid control circuit with its copper heat sink strip is mounted to copper support members which are brazed to the copper heat sink base. It is proposed to use slots in these members as shown in the drawing, to engage the copper strip of the hybrid package and solder this joint to minimize thermal drops. Any diaphram effects in this mechanical mounting system would be minimized by fluid filling.

A deck is provided above the hybrid circuit to provide a mounting board for the optical isolators. These are very low power generating components and the increased distance from the heat sink has no adverse thermal effects.

The method of fluid filling electrical devices must contend with the temperature coefficient of expansion of the fluid, which should be minimized. One common method is to fill the device and seal it off at the maximum operating temperature or slightly over. In this case, about 125°C. Then at all future operating conditions, there will be less than atmospheric pressure within the device, and the differential to atmosphere can never exceed 15 psi under any conditions. If the unit were sealed cold, the interior pressure would be higher than atmospheric at elevated temperature, and there is no limit to the pressure differential that could build up.

The hermetic seal of the package cover seam would be done prior to fluid filling and it is proposed to use either electron beam welding or laser welding. The final seal would be accomplished with a pinch-off tube.

An alternate approach to packaging is shown in Fig. 21, with two significant modifications. First, the terminations are brought out on a surface 90 from the mounting (heat sink) surface. This affords several benefits:

a. Increases heat sink area.
b. Facilitates implementation of an Integrated Wiring Termination System (IWTS).
c. Improves ease of replacement.

Secondly, it is proposed to use mounting flanges in lieu of mounting studs to further maximize heat sinking.

Referring to Fig. 21, an L-shaped structure is proposed to provide rigidity and mechanical strength between the heat sink plane and the lead/terminal plane. The power switching devices are again mounted on the heat sink as discussed previously. The hybrid package is mounted to the heat sink by the same structure proposed for the 1 inch cube package, and the transformer deck is the same. This package calls for wire exit leads. To maintain hermeticity and still provide leads, it is proposed to use a hermetically sealed header to bring the leads through the package wall. The external wires would be soldered to the header pins and potted for general protection in that area.

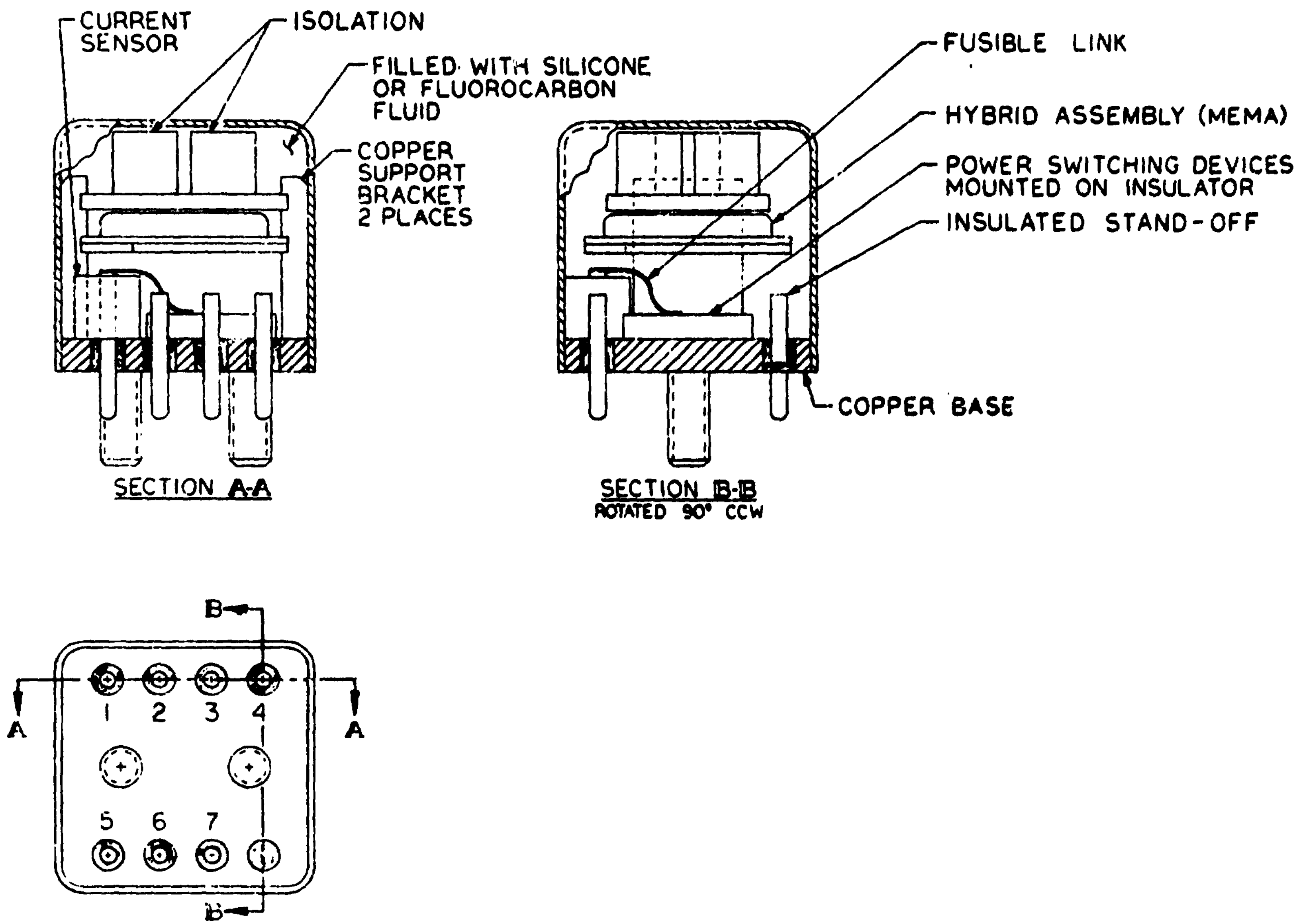


FIG. 20. CONCEPTUAL PACKAGING FOR 1" CUBE CONTROLLER WITH MIL-P-81653 MOUNTING CONCEPT

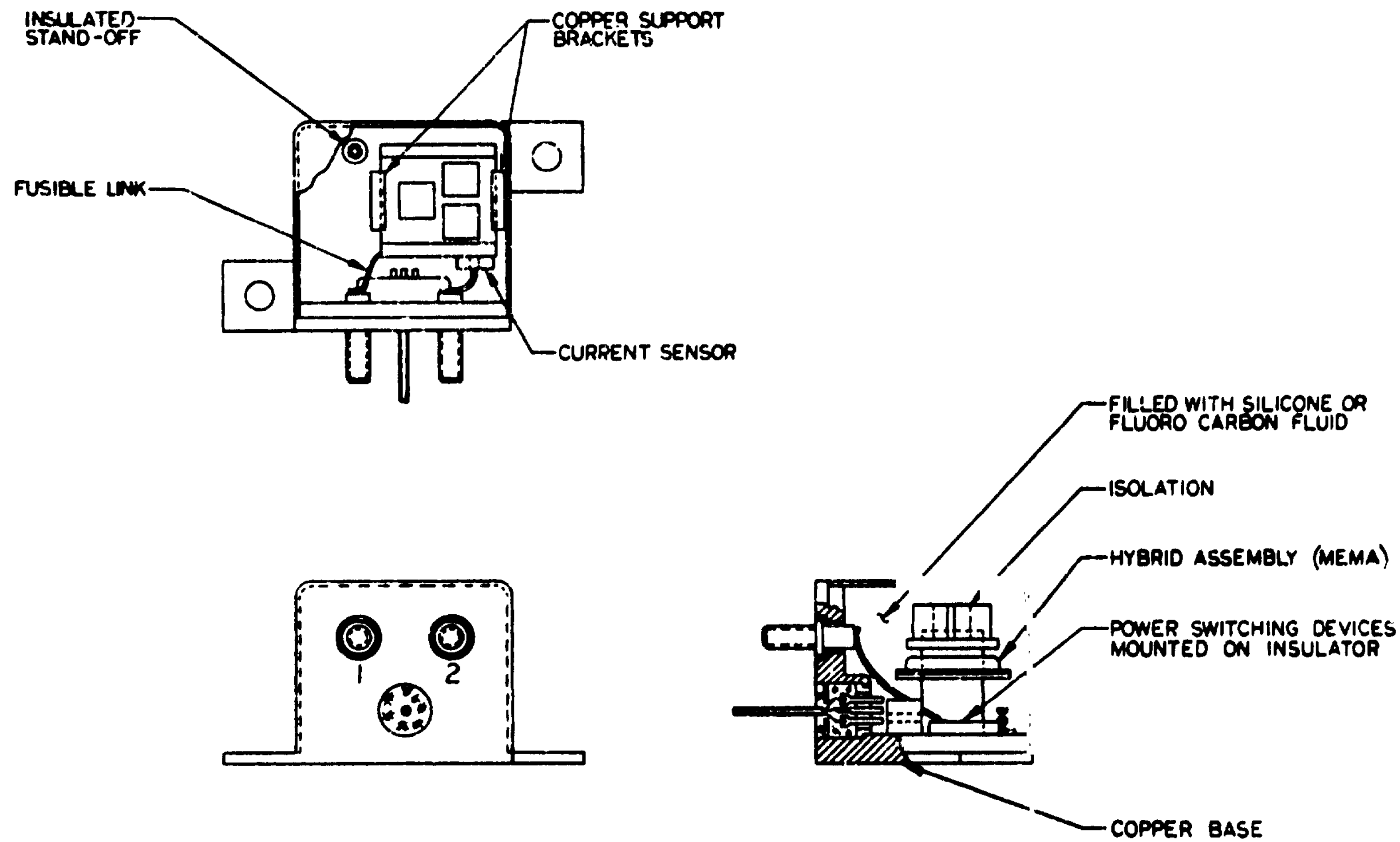


FIG. 21. CONCEPTUAL PACKAGING FOR 1" CUBE CONTROLLER WITH ALTERNATE MOUNTING CONCEPT

RELIABILITY

A preliminary reliability prediction analysis has been conducted to determine the failure rate of DC Solid State Power Controllers using hybrid-microelectronics for flight hardware. The predictions are based on the service and environmental conditions of the specifications.

The approaches and assumptions used consisted of a functional analysis of the design. It indicated that the functional blocks in each design assume a totally serial relationship. This results in a conservative estimate of the circuit capability. The basic failure rates of each chip or die comprising the hybrid-microelectronic control package was calculated at the maximum hybrid package case temperature of +125°C, which is +5°C over the specified 120°C maximum case temperature of the controller. Thermal analysis of the design shows that the use of beryllia substrate and the method of mounting the HYBRID internally insures a low order of thermal resistivity. For prediction purposes, the junction temperature of integrated circuits and semiconductor dice was assured to be at HYBRID case temperature plus 10°C, or 135°C. This is in accord with recommendations of the RADC Reliability Handbook, Volume II. Failure rates for capacitor and resistor elements was based on using +125°C as the component ambient temperature. MIL-HDBK-217A was used as the source of failure rates except as otherwise noted in the discussion below. The use of silicone or fluidcarbon oil as a filler within the controller housing, facilitates heat sinking and provides a dampening effect on other environments such as shock and vibration. Therefore, an environmental K factor of 1.0 was applied to all calculated failure rates.

The failure rate for the hybrid-microelectronic control package can be estimated by analysing its constituent elements. The I.C. failure rate used for this prediction was based on life test data published by Fairchild Semiconductor* for devices which have received 100% burn-in screening prior to usage. That figure is .030 failure per 10^6 hours (+135°C junction temperature) and is applicable to packaged devices.

In order to predict the failure rate of the hybrid-microelectronic control assembly it is necessary to estimate the intrinsic failure rate of "bare" dice by removing the failures of the packaged device which cannot be attributed to the "bare" die. The approach then is to eliminate the effects due to leads, base, package, etc., leaving the failure rate due to dice alone. I.C.'s used in Teledyne HYBRIDS are subjected to extensive pre-use screening and testing as follows:

100% AC Testing
100% DC Testing
100% Thermal Testing
100% Optical Inspection (at dice level and again at MEMA precover)

* Microcircuits Reliability Report - Fairchild Semiconductors, May 6, 1969; 83.8 million part hours (all devices).

RELIABILITY (Continued)

When the intrinsic die failure rates are estimated as outlined, and the effects due to extensive screening and inspection are taken into account, a dice failure rate of .020 failures per 10^6 hours results.

A similar rationale is applicable to other types of dice. Failure rates from MIL-HDBK-217 for Minutemen quality parts were used to represent intrinsic die failure rates. These rates were normalized for operation at +125°C (capacitors, resistors) and at +135°C junction temperature for semiconductors in accordance with factors of MIL-HDBK-217. Table 2 shows the failure rate for 1 Amp and 5 Amp DC Controllers.

TABLE 2. 1 Amp and 5 Amp DC Controller

FAILURE RATE ESTIMATE

(Failures per 10^6 hours)

QTY.	COMPONENT		FR SOURCE	FR
4	Integrated Circuits (I.C.'s)	@ .020	1	.080
18	Resistors, film	@ .007	2	.126
8	Capacitors, ceramic	@ .038	2	.304
6	Diodes, general purpose	@ .005	2	.030
6	Transistors	@ .010	2	.060
3	Diode - Zener	@ .102	2	.306
1	Power Transistor	@2.000	2	2.000
2	Transformers	@ .200	2	.400
100	Lead Bonds	@ .00007	3	.007
	Substrate, Frame & Cover		4	.004
24	External Leads	@ .00005	5	.001
			Total Failure Rate	3.318

Failure Rate Sources:

1. See discussion above.
2. Normalized MIL-HDBK-217A, Minutemen level failure rates.
3. Ultrasonic lead bond estimate based on Teledyne and industry data.
4. Best engineering estimate.
5. Welded termination estimate based on Teledyne and industry data.

TABLE 3. SPECIFICATIONS - Teledyne 1 Amp and 5 Amp Solid State Power Controllers

REQUIREMENTS	1 AMP DC CONTROLLER Teledyne P/N 673-10004	5 AMP DC CONTROLLER Teledyne P/N 673-1000[illegible]
Mechanical & Dimensional Characteristics		
Configuration	See Fig. 15	See Fig. 15
Dimension	See Fig. 15	See Fig. 15
Enclosure	Hermetic Seal	Hermetic Seal
Weight	3.0 ounces maximum	3.0 ounces maximum
Mounting Torque	15 in. lbs.	15 in. lbs.
Thermal Characteristics		
Thermal Resistance Case-to-Sink	0.5 C/watt with specified mounting torque	0.5 C/watt with specified mounting torque
Heat Sink Temperature (Design Consideration)	+118°C maximum	+118°C maximum
Electrical Characteristics	-54° to +120°C case temperature (unless otherwise specified)	-54° to +120°C case temperature (unless otherwise specified)
General		
Terminal Arrangement	SPST (normally open)	SPST (normally open)
Insulation Resistance	100 megohm minimum	100 megohm minimum
Dielectric Withstanding Voltage	1000 vAC (RMS)	1000 vAC (RMS)
Isolation Between control and trip terminals shorted and output terminals shorted	1000 vAC (RMS)	1000 vAC (RMS)
Life (operating cycles)	10^6 minimum	10^6 minimum
Radio Interface	MIL-STD-461	MIL-STD-461
Power Dissipation (maximum @ 25°C ambient)		
"ON"-rated load	1.5 watt, maximum	4.5 watt maximum
"OFF"	.150 watt, maximum	.164 watt, maximum

TABLE 3. SPECIFICATIONS - Teledyne 1 Amp and 5 Amp Solid State Power Controllers (cont.)

REQUIREMENTS	1 AMP DC CONTROLLER Teledyne P/N 673-10004	5 AMP DC CONTROLLER Teledyne P/N 673-10001
Power Circuit		
Supply Voltage Limits - Curves 1 & 6 MIL-STD-704A	30 vDC, maximum 15 vDC, minimum	30 vDC, maximum 15 vDC, minimum
Current (rated)	1 Ampere	5 Amperes
Voltage Drop	.5 volts DC, maximum	.5 volts DC, maximum
Leakage Current	100μ Amps, maximum	500μ Amps, maximum
Current Limiting	Applicable	Applicabl
DC ripple	5% rated load (peak to peak), maximum	5% rated load (peak to peak), maximum
Fail Safe (I^2t)	1200	1200
Transients		
Operating Voltage	Applicable	Applicable
Spike Overvoltage	Applicable	Applicable
Response		
Turn-On Time	1.0 mSec, maximum	1.0 mSec, maximum
Rise Time	.1 mSec, minimum .5 mSec, maximum	.1 mSec, minimum .5 mSec, maximum
Turn-Off Time	6.0 mSec, maximum	6.0 mSec, maximum
Fall Time	.5 mSec, minimum 5.0 mSec, maximum	.5 mSec, minimum 5.0 mSec, maximum
Trip Free	Applicable	Applicable
Trip-Out Time		
Non-repetitive Reset	Applicable (30 seconds minimum between resets)	Applicable (30 seconds minimum between resets)
Repetitive Reset	Applicable	Applicable
Trip Indication		
Not Tripped	Current sink, 0 to 50 mA	Current sink, 0 to 50 mA
Tripped	Open circuit, 0 to 32 vDC	Open circuit, 0 to 32 vDC
Control Circuit		
Supply Voltage		
Maximum	32 vDC	32 vDC
Rated	28 vDC	28 vDC
Minimum	20 vDC	20 vDC

TABLE 3. SPECIFICATIONS - Teledyne 1 Amp and 5 Amp Solid State Power Controllers (cont.)

REQUIREMENTS	1 AMP DC CONTROLLER Teledyne P/N 673-10004	5 AMP DC CONTROLLER Teledyne P/N 673-10001
Control Circuit (cont.)		
Turn-On Voltage	24 vDC, minimum	24 vDC, minimum
Rate of Change	.5 vDC/mSec, minimum	.5 vDC/mSec, minimum
Turn-Off Voltage	5.0 vDC, maximum	5.0 vDC, maximum
Rate of Change	.5 vDC/mSec, minimum	.5 vDC/mSec, minimum
Input Current	20 mA, maximum	25 mA, maximum
Input Transients	Applicable	Applicable
Noise Immunity	Applicable	Applicable
Reset	By removing and re-applying DC control voltage	By removing and re-applying DC control voltage
Time to Reset (removal)	5 mSec, minimum 80 mSec, maximum	5 mSec, minimum 80 mSec, maximum
Environmental Characteristics		
Case Temperature		
Operating	-54°C to +120°C	-54°C to +120°C
Storage	-65°C to +150°C	-65°C to +150°C
Shock		
Mechanical	40 G's for 11.0 +1.0 mSec	40 G's for 11.0 +1.0 mSec
Temperature	-54°C to +120°C ambient	-54°C to +120°C ambient
Vibration		
Sinusoidal (operating)		
G Level	15 G's, maximum	15 G's, maximum
Frequency Range	5 to 2000 Hz	5 to 2000 Hz
Random (operating)		
Power Spectral Density	0.2 G^2/Hz, maximum	0.2 G^2/Hz, maximum
Frequency Range	20 to 2000 Hz	20 to 2000 Hz
Acceleration	100 G's	100 G's
Salt Fog	Applicable	Applicable
Humidity	Applicable	Applicable
Temperature-Altitude		
Operating Ambient Temperature	-54°C to +120°C	-54°C to +120°C
Altitude	Sea Level to 100 K ft.	Sea Level to 100 K ft.
Non-Operating Ambient	-65°C to + 150°C	-65°C to +150°C
Altitude	0.65 to 15.4 psia	0.65 to 15.4 psia
Explosive Decompression	Not Applicable	Not Applicable

TEST RESULTS

Teledyne 1 Amp DC Solid State Power Controller
P/N 673-10004

Pin Identification

Pin No.	Function
1	Control Voltage (+)
2	Signal Common
3	Trip Indicator
4	Power In (+)
5	Power Out (-)
6	No Connection
7	Test Point (Emitter)
8	Test Point (Base)

Terminal Arrangement - SPST (Normally Open)

TEST	REQUIREMENT	RESULTS
Insulation Resistance	100 megohms, min.	>100 megohms
Dielectric Withstanding		
Voltage	1000 vAC (RMS), min.	>1000 vAC (RMS)
Isolation	1000 vAC (RMS), min.	>1000 vAC (RMS)
Power Dissipation		
"ON" (rated load)	1.5 watts, max.	1.0 watt
"OFF"	.150 watt, max.	.003 watt
Voltage Drop		
Serial No. 1	.5 volts, max. @ 1 Amp	150 millivolts
Serial No. 3	.5 volts, max. @ 1 Amp	250 millivolts
Overshoot		<25%
Response		
Serial No. 1		
Turn ON Time	1.0 mSec, max.	2.8 mSec
Rise Time	.1 mSec, min.; .5 mSec, max.	.7 mSec
Turn OFF Time	6.0 mSec, max.	1.0 mSec
Fall Time	.5 mSec, min.;5.0 mSec, max.	.5 mSec
Serial No. 2		
Turn ON Time	1.0 mSec, max.	2.5 mSec
Rise Time	.1 mSec, min.; .5 mSec, max.	.5 mSec
Turn OFF Time	6.0 mSec, max.	1.0 mSec
Fall Time	.5 mSec, min.;5.0 mSec, max.	.5 mSec

TEST RESULTS (cont.)

Teledyne 1 Amp Solid State Power Controller
P/N 673-10004

TEST	REQUIREMENT	RESULTS
Leakage Current	100 μAmps, max.	<100 μAmps
Time to Rest (removal)	5.0 mSec, min.; 80 mSec, max.	80 mSec
Trip Indication		
Not Tripped	Current Sink, 0 to 50 mA	0 to 50 mA
Tripped	Open Circuit, 0 to 32 vAC	0 to 32 vDC
Turn ON Voltage	24 vDC, min.	<24 vDC
Turn OFF Voltage	5 vDC, max.	<5 vDC
Control Voltage Rate of Change	.5 vDC/μSec, min.	>.5 vDC/μSec
Control Current	20 mA, max.	12 mA @ 24 vDC 13 mA @ 28 vDC 15 mA @ 32 vDC

			Serial #1	Serial #2
Current Limiting				
Trip Current		@ 25°C	1.4 Amp	1.4 Amp
		@-55°C	1.5 Amp	1.5 Amp
		@ 90°C	1.3 Amp	1.3 Amp
Time to Trip @ 300% Load		@ 25°C	4.0 Sec	4.0 Sec
		@-55°C	5.0 Sec	5.0 Sec
		@ 90°C	3.0 Sec	3.0 Sec
Time to Trip				
30 vDC Supply Voltage	100% Output Current		No Trip	No Trip
30 vDC " "	150% " "		4.0 Sec	4.0 Sec
30 vDC " "	500% " "		4.0 Sec	4.0 Sec
40 vDC " "	150% " "		4.0 Sec	4.0 Sec
60 vDC " "	150% " "		4.0 Sec	4.0 Sec
80 vDC " "	150% " "		.02 Sec	.02 Sec
40 vDC " "	500% " "		4.0 Sec	4.0 Sec
60 vDC " "	500% " "		.02 Sec	.02 Sec
80 vDC " "	500% " "		.02 Sec	.02 Sec

TEST RESULTS (cont.)

Teledyne 1 Amp Solid State Power Controller
P/N 673-10004

Temperature Tests at -55°C and +90°C

Note. Units did not operate satisfactorily above 100°C because of improper transformer core. This can be readily corrected in future units.

Insulation Resistance	All	Units	Tested	Satisfactorily
Dielectric Withstanding Voltage	"	"	"	"
Isolation	"	"	"	"
Power Dissipation	"	"	"	"
Rated Current and Voltage	"	"	"	"
Voltage Drop of Rated Current	"	"	"	"

Control Input Transients

A single pulse of plus and minus 100 volts peak amplitude and 100 μSec duration, repeated 10 times at 3 second intervals. All units tested satisfactorily.

A train of 10 pulses of plus and minus 100 volts peak amplitude and 100 μSec duration each, repeated 10 times at 3 second intervals. All units tested satisfactorily.

Above tests repeated between trip indicator terminal and ground (DC return) terminal. All units tested satisfactorily.

Test Circuit

The test circuit for DC controllers is shown in Fig. 22.

TEST RESULTS

Teledyne 5 Amp DC Solid State Power Controller
P/N 673-10001

Pin Identification

Pin No.	Function
1	Control Voltage (+)
2	Signal Common
3	Trip Indicator
4	Power In (+)
5	Power Out (-)
6	No Connection
7	Test Point (Emitter)
8	Test Point (Base)

Terminal Arrangement - SPST (Normally Open)

TEST	REQUIREMENT	RESULT
Insulation Resistance	100 megohms, min.	>100 megohms
Dielectric Withstanding Voltage	1000 vAC (RMS), min.	>1000 vAC (RMS)
Isolation	1000 vAC (RMS), min.	>1000 vAC (RMS)
Power Dissipation		
"ON" (rated load)	4.5 watts, max.	3.5 watts
"OFF"	.164 watt, max.	.015 watt
Voltage Drop		
Serial No. 4	.5 volts, max.	350 mV @ 5 Amps
Serial No. 5	.5 volts, max.	350 mV @ 5 Amps
Overshoot		<25%
Response		
Serial No. 4		
Turn ON Time	1.0 mSec, max.	1.8 mSec
Rise Time	.1 mSec, min.; .5 mSec, max.	.5 mSec
Turn OFF Time	6.0 mSec, max.	1.3 mSec
Fall Time	.5 mSec, min.;5.0 mSec, max.	1.6 mSec
Serial No. 5		
Turn ON Time	1.0 mSec, max.	1.6 mSec
Rise Time	.1 mSec min. ; .5 mSec, max.	.35 mSec
Turn OFF Time	6.0 mSec, max.	1.4 mSec
Fall Time	.5 mSec, min.;5.0 mSec, max.	1.5 mSec

TEST RESULTS (cont.)

Teledyne 5 Amp Solid State Power Controller
P/N 673-10001

TEST	REQUIREMENT	RESULT
Leakage Current	500 μAmps, max.	<500 μAmps
Time to Reset (removal)	5.0 mSec, min; 80 mSec, max.	80 mSec
Trip Indication		
Not Tripped	Current Sink, 0 to 50 mA	0 to 50 mA
Tripped	Open Circuit, 0 to 32 vDC	0 to 32 vDC
Turn ON Voltage	24 vDC, min.	<24 vDC
Turn OFF Voltage	5 vDC, max.	> 5 vDC
Control Voltage Rate of Change	.5 vDC/μSec, min.	>.5 vDC/μSec
Control Current	25 mA, max.	19 mA @ 24 vDC 20 mA @ 28 vDC 21 mA @ 32 vDC

			Serial #4	Serial #5
Current Limiting				
Trip Current		@ 25°C	5.9 Amps	6.1 Amps
		@ 90°C	5.2 Amps	6.0 Amps
		@-55°C	5.8 Amps	6.3 Amps
Time to Trip @ 300% Load		@ 25°C	2.5 Sec	2.0 Sec
		@ 90°C	2.0 Sec	1.8 Sec
		@-55°C	3.0 Sec	2.2 Sec
Time to Trip				
30 vDC	Supply Voltage	100% Output Current	No Trip	No Trip
30 vDC	" "	150% " "	2.2 Sec	2.0 Sec
30 vDC	" "	500% " "	2.5 Sec	2.0 Sec
	" "	150% " "	2.5 Sec	2.0 Sec
	" "	150% " "	2.5 Sec	2.0 Sec
	" "	150% " "	.02 Sec	.02 Sec
	" "	500% " "	2.5 Sec	2.0 Sec
	" "	500% " "	.02 Sec	.02 Sec
	" "	500% " "	.02 Sec	.02 Sec

TEST RESULTS (cont.)

Teledyne 5 Amp DC Solid State Power Controller
P/N 673-10001

Temperature Tests at -55°C and +90°C

Note. Units did not operate satisfactorily above 100°C because of improper transformer care. This can be readily corrected in future units.

Insulation Resistance	All units tested satisfactorily
Dielectric Withstanding Voltage	" " " "
Isolation	" " " "
Power Dissipation	" " " "
Rated Current and Voltage	" " " "
Voltage Drop at Rated Current	" " " "

Control Input Transients

A single pulse of plus and minus 100 volt peak amplitude and 100 μSec duration, repeated 10 times at 3 second intervals. All units tested satisfactorily.

A train of 10 pulses of plus and minus 100 volt peak amplitude and 100 μSec duration each, repeated 10 times at 3 second intervals. All units tested satisfactorily.

Above tests repeated between trip indicator terminal and ground (DC return) terminal. All units tested satisfactorily.

Test Circuit

The test circuit for DC controllers is shown in Fig.22.

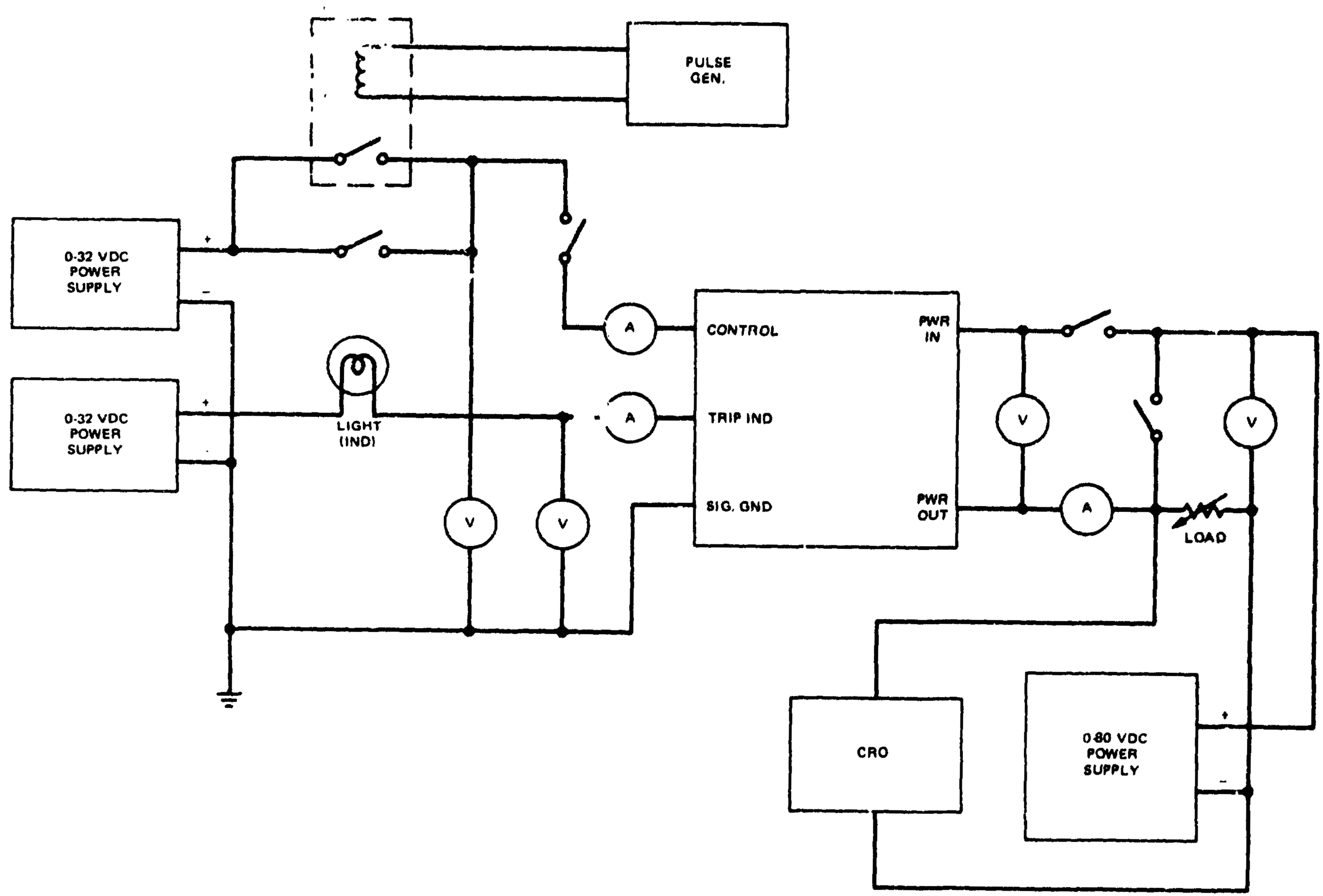


FIG. 22. TEST CIRCUIT FOR DC CONTROLLERS

AC SOLLID STATE POWER CONTROLLERS

ZERO AXIS SWITCHING

It is desirable in solid state switching of AC voltages to have the controller turn ON at zero voltage and turn OFF at zero current to minimize the effects of EMI. By proper gating of the solid state switching element (Triac or inverse parallel Silicon Controlled Rectifier), this is readily accomplished. Continuous switching ON and OFF can be at each half cycle or at each full cycle.

In the switching of AC inductive loads, particularly transformers, care must be taken to avoid a DC component being developed in switching. A core may be saturated to such an extent that this is possible. Full cycle switching minimizes the problem. Full cycle gating is more complex than half cycle gating as memory has to be established in the circuitry. The scope of the contract was such that hybrid-microelectronic packaging was not feasible. Consequently, it was not possible to package the additional circuitry required for full cycle switching. A circuit has been developed (Pat. Pending) which incorporates a CMOS logic gate in conjunction with an existing circuit to form full cycle control. When quantities warrant hybrid-microelectronic assembly, full cycle control can be included in optimum packaging. Half cycle zero voltage switching was used in the prototype units utilizing a unique circuit developed by Teledyne and covered by patent #3,648,075. This circuit will be discussed in detail later in the report.

POWER OUTPUT TERMINATION

MIL-P-81653 specifies a 3 terminal power output configuration, as indicated in Fig. 23. The zero voltage switching circuitry developed by Teledyne permits a two wire output configuration, as shown in Fig. 24. The arguments for or against the two or three wire system are identical for AC controllers as those for the already-discussed DC controllers. The main disadvantage of the two wire system is that status indication requires slightly more circuitry. The two wire system was employed in the prototype AC controllers.

POWER CHIP SELECTION

Three silicon devices are available for AC voltage switching, namely Transistors, Silicon Controlled Rectifiers and Triacs. Transistors are seldom used as they must be connected within a full wave bridge for AC operation, resulting in two diode voltage drops plus the voltage drop of the transistor itself. They also do not possess the current surge capabilities of Silicon Controlled Rectifiers or Triacs. Current limiting would be possible with a Transistor switching element where it is not practical with either the Silicon Controlled Rectifier or Triac switching element.

Silicon Controlled Rectifiers used in inverse parallel configuration are widely used in AC voltage switching. They are available with high current ratings, high voltage ratings and possess high current surge capabilities. Care must be used in gating for transformer loads. It is particularly important to ensure that two SCR's are fired exactly at 180° relative to each other.

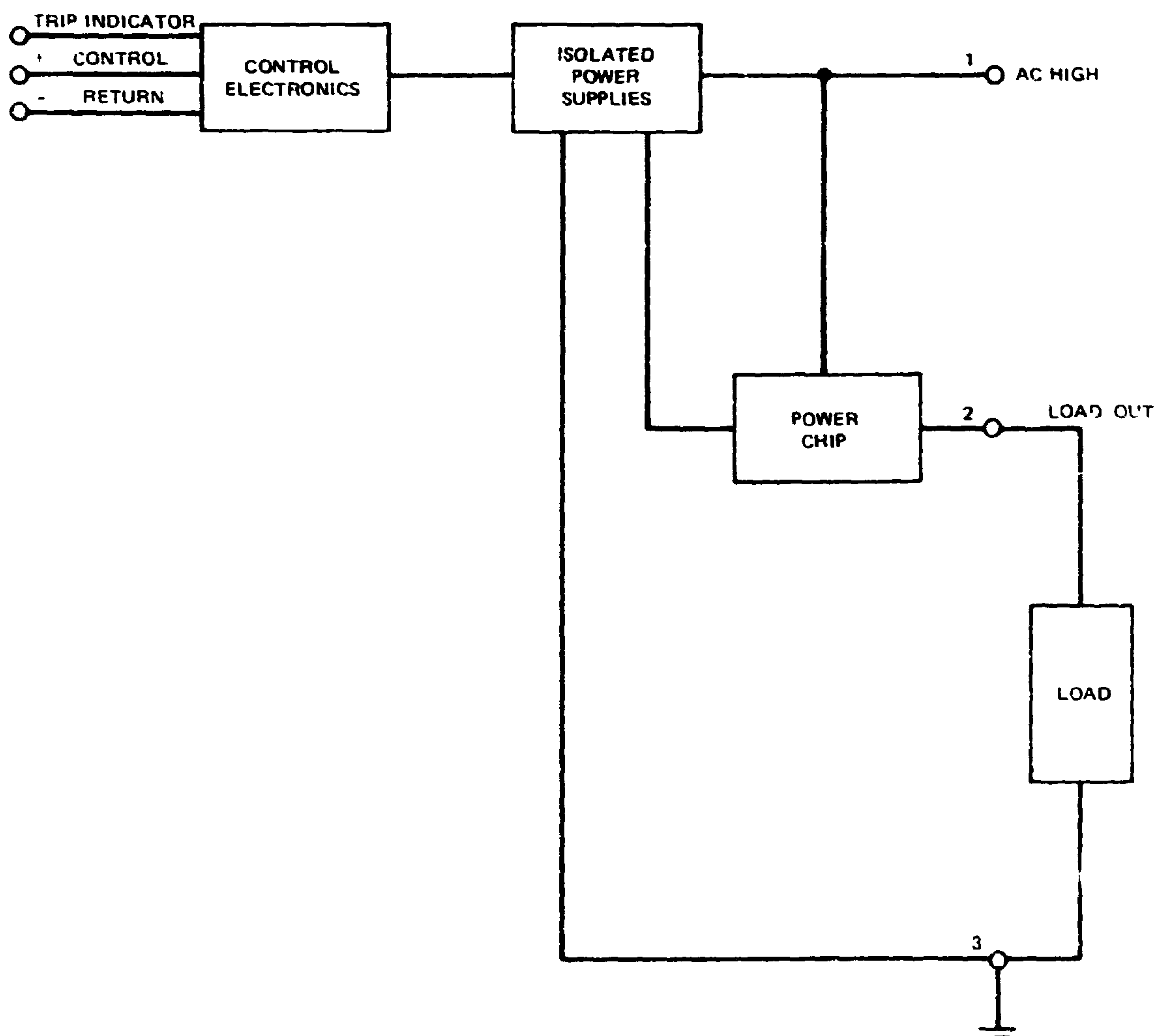


FIG. 23. MIL-P-81653 3-TERMINAL OUTPUT AC CONTROLLER

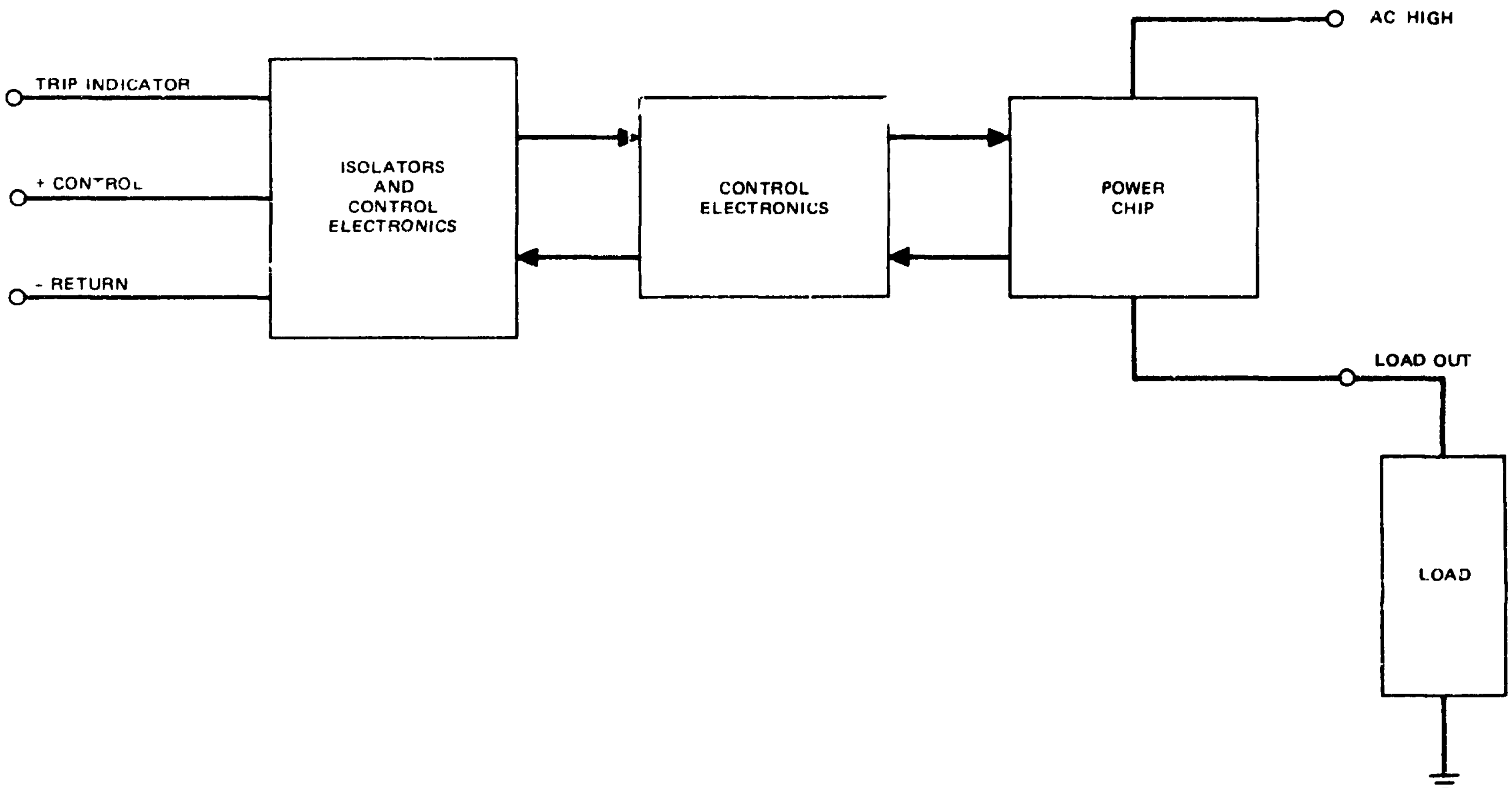


FIG. 24. 2-TERMINAL OUTPUT AC CONTROLLER

POWER CHIP SELECTION (cont.)

If this is not accomplished, the positive and negative current loops will differ in magnitude and a resultant DC will flow through the low impedance of the primary of the transformer.

Triacs (silicon bi-directional thyristors) possess most of the same features as Silicon Controlled Rectifiers. The distinct advantage is that only a single component is required for the switching element, and reduced component count is a major objective in the development of the controller. The single gate assists in minimizing DC offset problems. It is not completely eliminated because of inherent small differences that exist within the Triac itself when conducting in one direction and then in the opposite direction. Less componentry is required for zero axis switching with the Triac. The required rupture capacity of the specification can be satisfied with a Triac. For higher rated AC controllers, and where very high rupture capacities are specified, the inverse parallel SCR's should be considered. Selected Triac chips from the 2N5443 family were used for the prototype AC controllers. These chips have a 40 Amp continuous duty rating and a 400 Ampere surge capability for 1 cycle of a 400 Hz voltage line. A further consideration in selection of this particular chip was its center firing gate and glass passivation.

POWER DISSIPATION

Since current limiting is not practical in solid state switching of AC voltages, power dissipation requirements are not as critical as those for DC controllers. The main consideration on power dissipation is through the period when overcurrent is detected and trip-out takes place. The AC power controllers trip-out within one half cycle in the event of a short-circuit. The surge capacity of the chip is more meaningful than power dissipation in short-circuit conditions. The one half cycle trip-out does not allow sufficient time for appreciable heat dissipation. As a result, chip mounting similar to that shown in Fig. 6 was used in the prototype AC controllers.

ISOLATION

Isolation between the load circuit and the control circuit is performed by opto-couplers for the control, short-circuit protection and waveform distortion functions. Transformer coupling is used for the trip-out function. Referring to the circuit schematic, Fig. 27, the control function in the absence of overload, short-circuit and waveform distortion results in both of the inputs of NOR gate U4A to be at ground potential with output of U4A high, which is coupled to inputs of U4C with a resulting low output, allowing light emitter diode of U5 to conduct. This is with a positive 28V control voltage applied. With the emitter diode of U5 conducting, the SCR portion of U5 is also conducting. At low voltages of the AC power line, Q3 is biased OFF. This allows the DC voltage developed by BR1 to be passed by the SCR of U5 to the gate of Triac Q4, turning it ON. As the DC voltage increases, Q3 is forwarded to biased ON by voltage divider formed by R13 and R11, shorting the gate of the SCR of U5 to ground and turning it OFF. This is the principle of zero voltage gating covered by Teledyne patent #3.648,075. The isolation circuits of the other functions will be discussed later.

SHORT-CIRCUIT PROTECTION

Short-circuit protection is obtained by developing a voltage across R17, full wave rectifying it to DC by means of BR2 and causing a light emitter diode of U2 to conduct. This forward biases the transistor of U2 putting a logic 1 voltage to input of NOR gate U4A. As a result, the output of U4A and inputs of U4C go low. The output of U4C goes high and the Triac is turned off instantly, in a half cycle or less. Problems were encountered in testing where at a combination of overload current and temperatures above 90°C the controller would not trip-out. By either reducing the temperature to 85°C or reducing the frequency, trip-out was successful. This failure was completely due to the characteristics of the Triac used at 400 Hz. This problem can be corrected by selecting a Triac with more favorable 400 Hz characteristics.

CONTROL VOLTAGE SELECTION

The rationale for control voltage selection is the same for AC controllers as that previously discussed for DC controllers.

TRIP INDICATION

Trip-out time as a function of overload should be within the limits indicated in Fig. 25. Trip-out is obtained by sensing a current by transformer T1 and feeding its corresponding voltage pulses to operational amplifier U1. This forward biases Q1 and through the timing and shaping circuit consisting of R1, R3, CR2, R2 and C2, the input of NOR gate U4A is brought to logic level 1. This results in the output of U4C going high and turning off the controller.

Trip indication is obtained by the successive gating of U4A, U4B, U4D and eventual biasing of Q2. The logic is such that in a non-tripped condition, Q2 is conducting, and in a tripped condition, Q2 is cut-off. The logic may be reversed by connecting the base of Q2 to the output of U4B. A voltage indication rather than current sink indication may be accomplished by connecting the collector of Q2 through a resistor to the 28 volt control supply. The collector output of Q2 is transient protected by R9 and CR4. The trip-out is latched by positive feedback to the output of U4B through CR3 to one of the inputs of U4A.

STATUS INDICATION

The general rationale for status indication is the same for AC controllers as that previously discussed for DC controllers. Status indication was not provided in the prototype AC controllers as the scope of the contract did not warrant the use of hybrid-microelectronics, and it was impossible to add this feature in the packaging desired. Status indication could be provided in the desired packaging using hybrid-microelectronic packaging concepts.

A status indication circuit was developed and is shown in simplified form in Fig. 26. Current is sensed by toroid transformer T1 (same transformer core and primary used in trip-indicating circuit). It is transformer coupled to operational amplifier A1, forward biasing Q1 ON and gating G1 high. G1 output goes low, biasing OFF Q2. Current sinking logic could be reversed as described

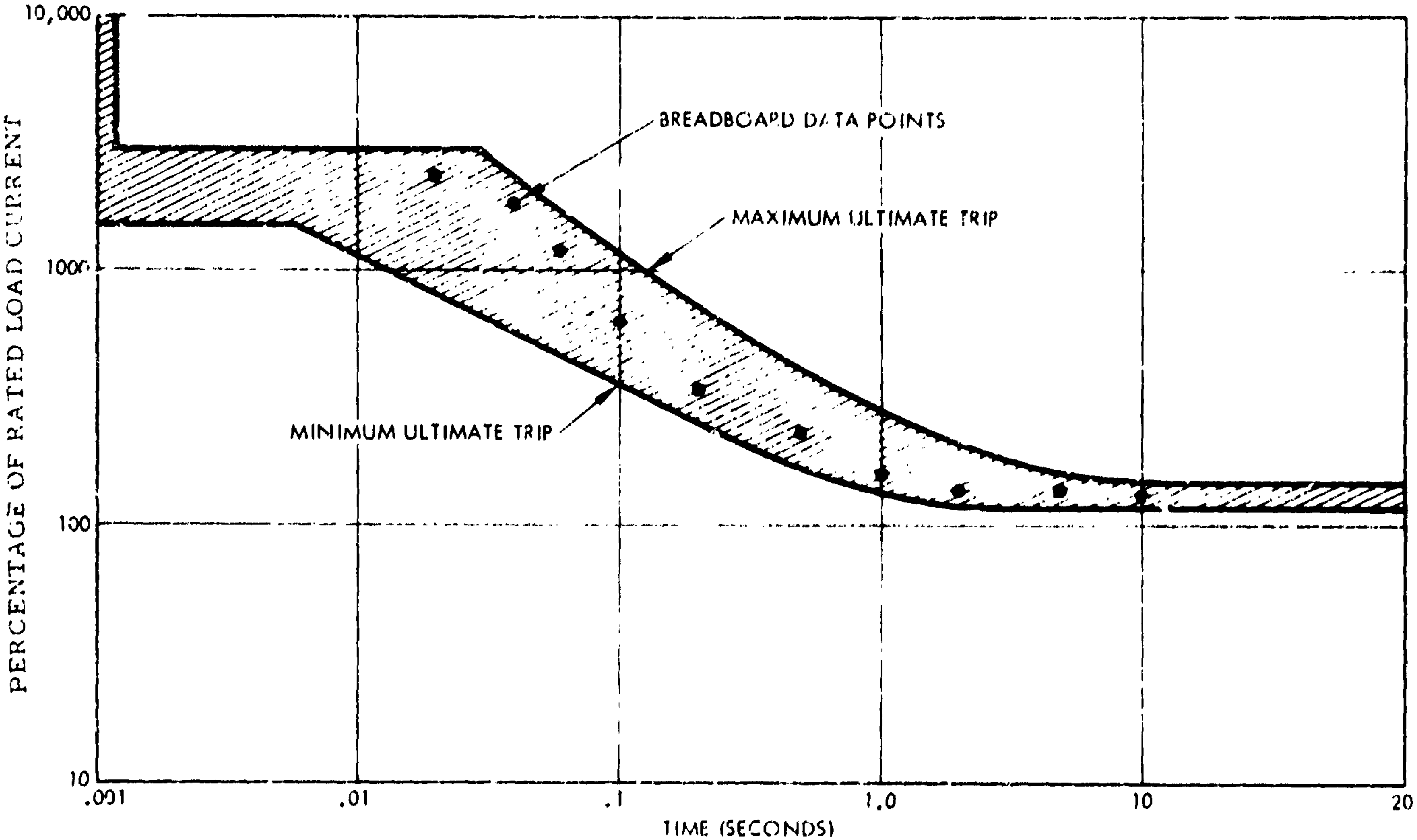


FIG. 25. MIL-P-81653 AC POWER CONTROLLER
TRIP CHARACTERISTICS

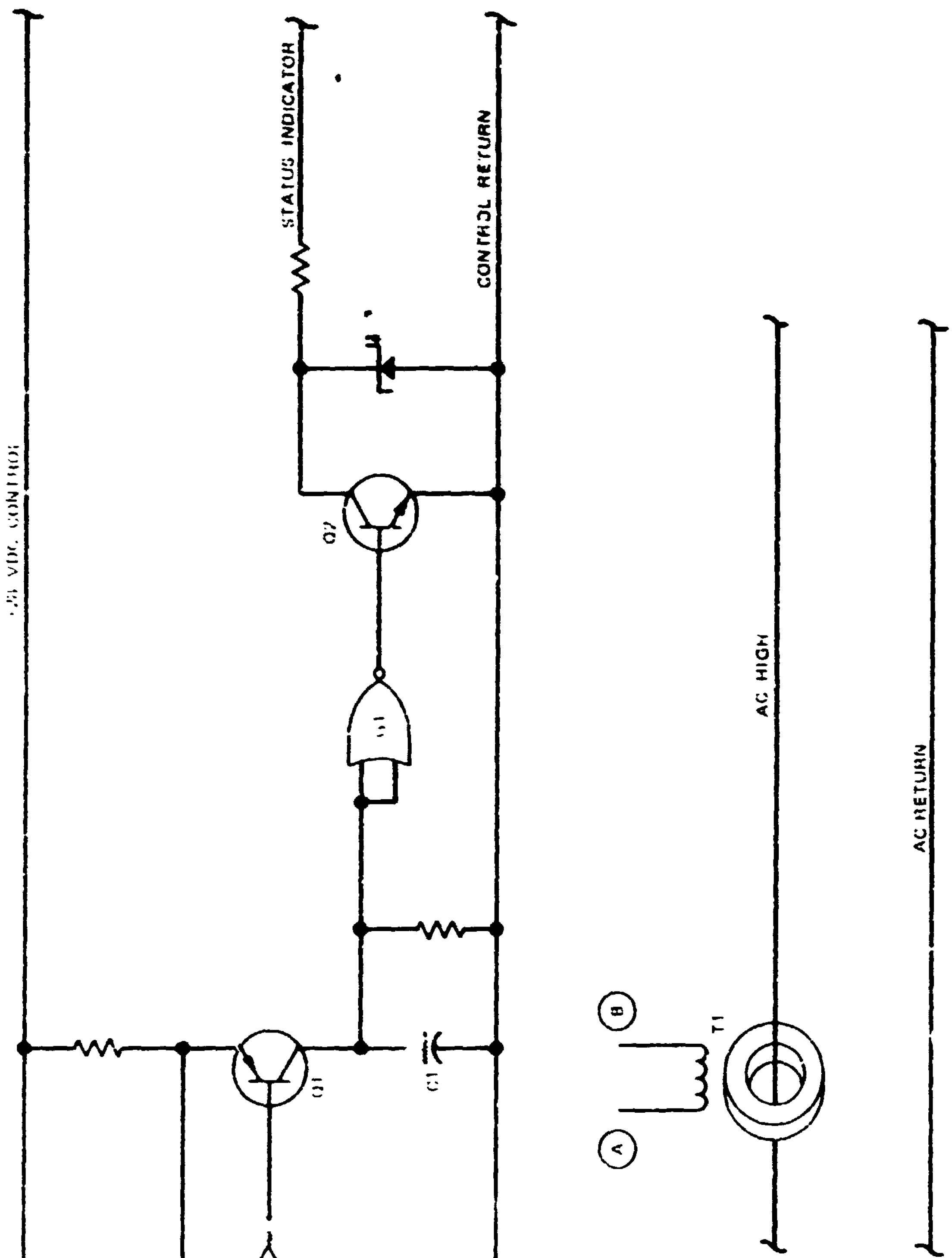


FIG. 26 AC CONTROLLER STATUS INDICATOR
SIMPLIFIED SCHEMATIC

in trip-out circuit. Also, a voltage level signal could be furnished. An analog signal with the output of A1 a function of current, could also be furnished.

WAVEFORM DISTORTION

If the core of an inductor becomes sufficiently saturated to cause a DC offset or half waving load current conditions, it is sensed by the voltage drop across R12 of the schematic, Fig. 27. This causes light emitter diode of opto-isolator U3 to conduct and forward bias ON the transistor of U3, gating U4A high, which through U4C and U5 turns power circuit OFF instantly in less than a half cycle.

RESET

Reset of the AC controller is accomplished by removing and re-applying the control voltage as previously described for DC controllers. Control voltage should be removed a minimum of 100 mSec before re-applying. The controller is latched in trip-out condition under overload, short-circuit and waveform distortion fault conditions.

TRANSIENT VOLTAGE PROTECTION

The power output circuit is protected by the breakdown voltage rating of Q4, the power Triac. Further protection is offered by the filter consisting of R16 and C5. This filter increases the effective circuit dv/dt to over 200V/μSec. This R-C network does contribute to higher leakage current. The network appears as a capacitive reactance in excess of 30K at 400 Hz. Since a low power factor exists between this current and applied voltage, almost no power dissipation occurs either in load or controller output.

The control input circuit is transient protected by R7, CR1 and C1. C1 also serves to set the 5 mSec time-to-reset. The trip indicator circuit is protected by R9 and CR4.

FUSING (Fail Safe)

The fusing requirements for the AC controller are met in the same manner as previously discussed for the DC controller.

FOUL-UP PROTECTION

The AC power controller is not as susceptable to damage by improper wiring as is the case for the DC controller. A diode which was omitted in the prototype AC controllers is shown in the schematic, Fig. 27. This offers protection against improper wiring of the control circuit.

AC POWER CONTROLLER CIRCUIT SCHEMATIC

The AC power controller circuit schematic is shown in Fig. 27. This is the circuit of the 1 Amp AC power controller delivered to NASA Manned Space-

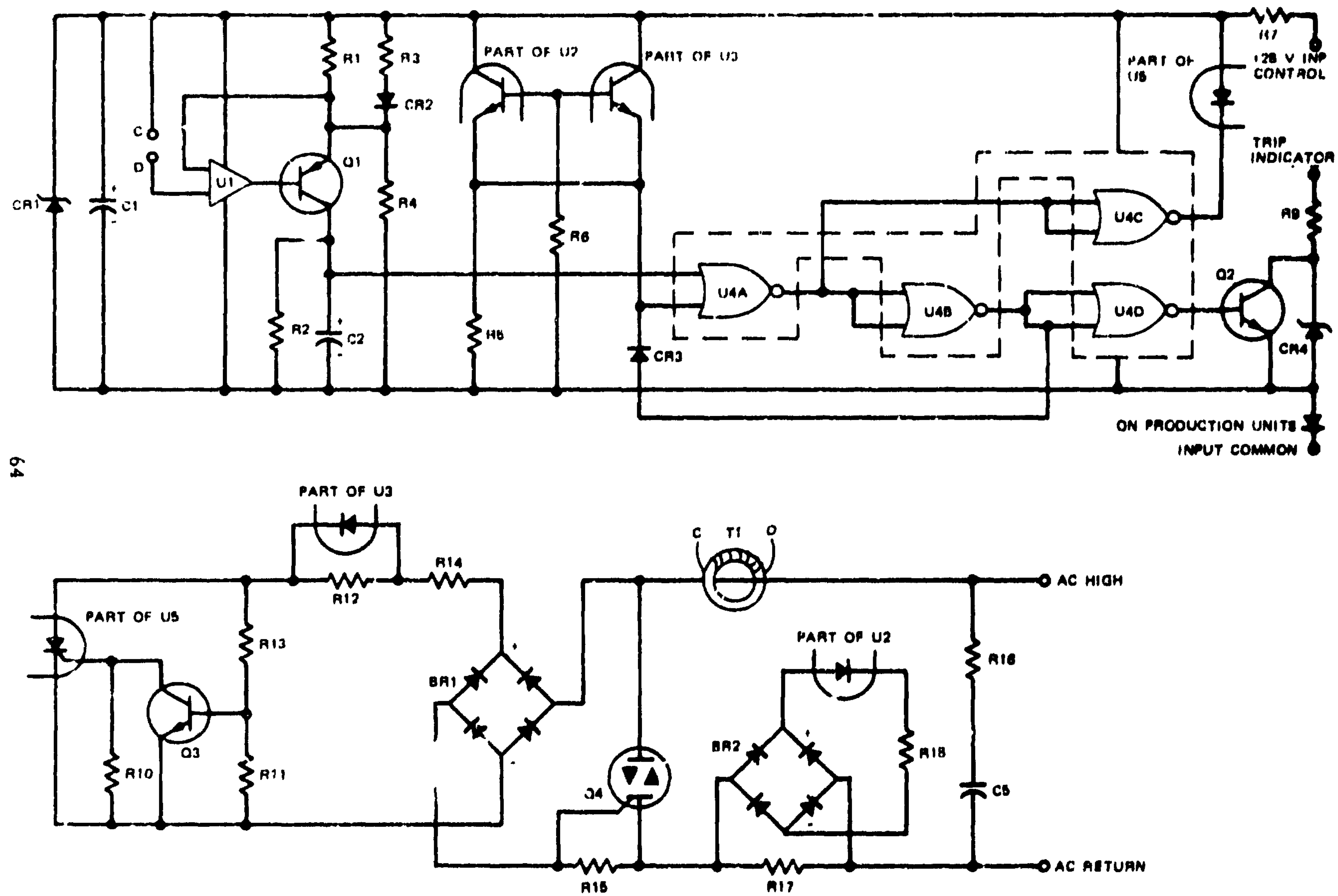


FIG. 27. AC POWER CONTROLLER CIRCUIT SCHEMATIC

craft Center/Houston ; Teledyne P/N 673-10005. The block diagram illustrating the functions is shown in Fig. 28.

PACKAGING

The 1 Amp AC power controller was packaged as shown in Fig. 29. An exploded view of the assembly is shown in Fig. 30. and the bottom and top circuit board assemblies are shown in Figs. 31 and 32.

The 1 Amp AC power controller using hybrid-microelectronic assembly concepts could be packaged as shown in Figs. 19, 20 and 21, where conceptual packaging for the DC controller was illustrated and discussed.

RELIABILITY

The rationale in arriving at predicted reliability is the same for the AC controller as for the previously discussed DC controller. The failure rate is shown in Table 4.

TABLE 4. AC POWER CONTROLLER FAILURE RATE ESTIMATE
(failures per 10^6 Hours)

QTY	COMPONENT		FR SOURCE	FR
2	Integrated Circuits	@ .020	1	.040
16	Resistors, Film	@ .007	2	.112
3	Capacitors	@ .038	2	.114
3	Diodes, Gen. Purpose	@ .005	2	.015
3	Transistors	@ .010	2	.030
1	Triac	@1.3	6	1.300
3	Optical Couplers	@ .20	6	.600
2	Rectifier Bridges	@ .02	2	.040
100	Lead Bonds	@ .00007	3	.007
24	External Leads	@ .00005	5	.0012
2	Diodes, Zener	@ .102	2	.204
1	Transformer	@ .200	2	.200
	Substrate, Frame and Cover		4	.004
			Total Estimated Failure Rate	2.667

Failure Rate Sources

1. See discussion above (Reliability, DC Controllers).
2. Normalized MIL-HDBK-217A Minuteman level failure rates.
3. Ultrasonic lead bond estimate based on Teledyne and industry data.
4. Best engineering estimate.
5. Welded termination estimate based on Teledyne and industry data.
6. Industry normalized life test data.

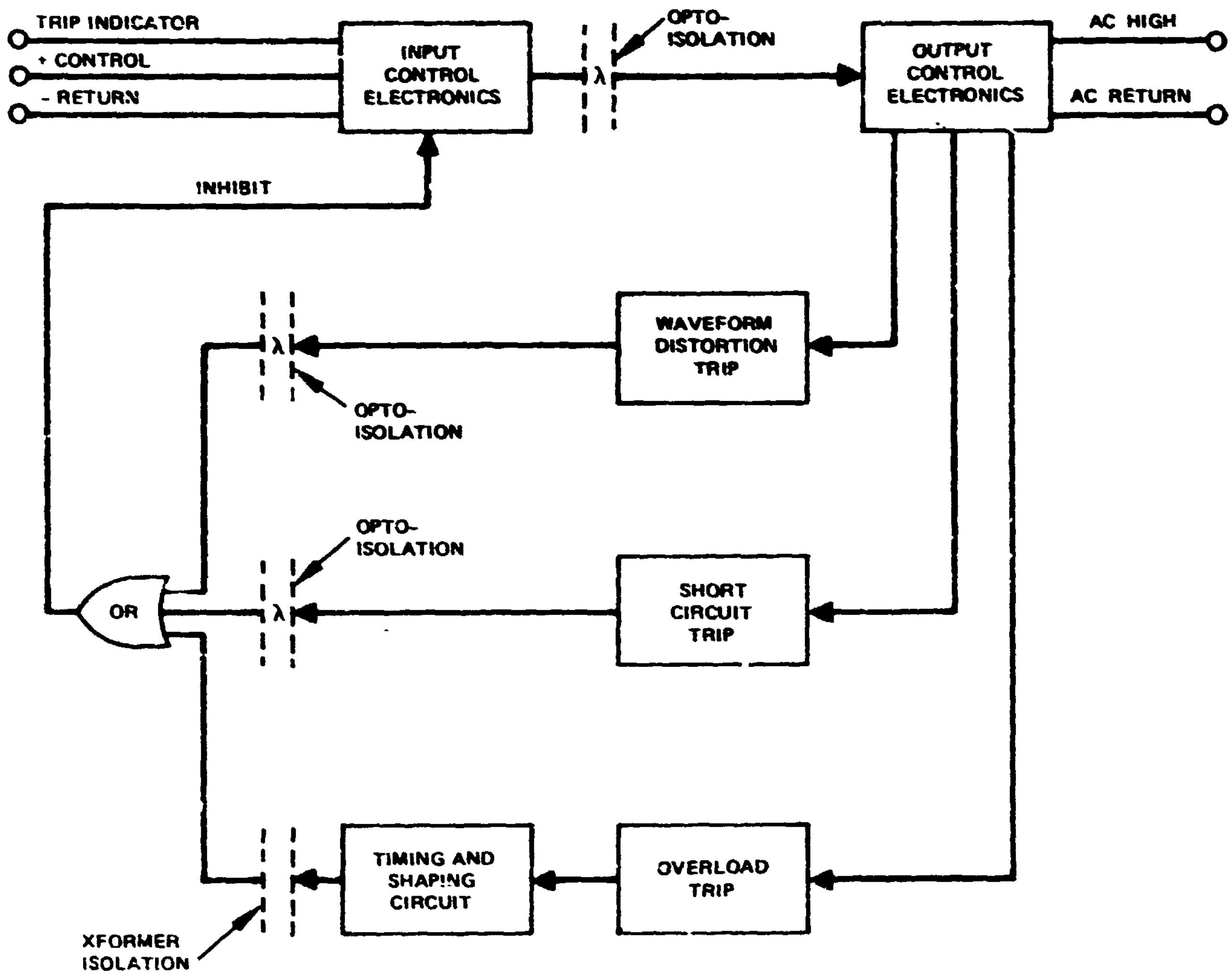
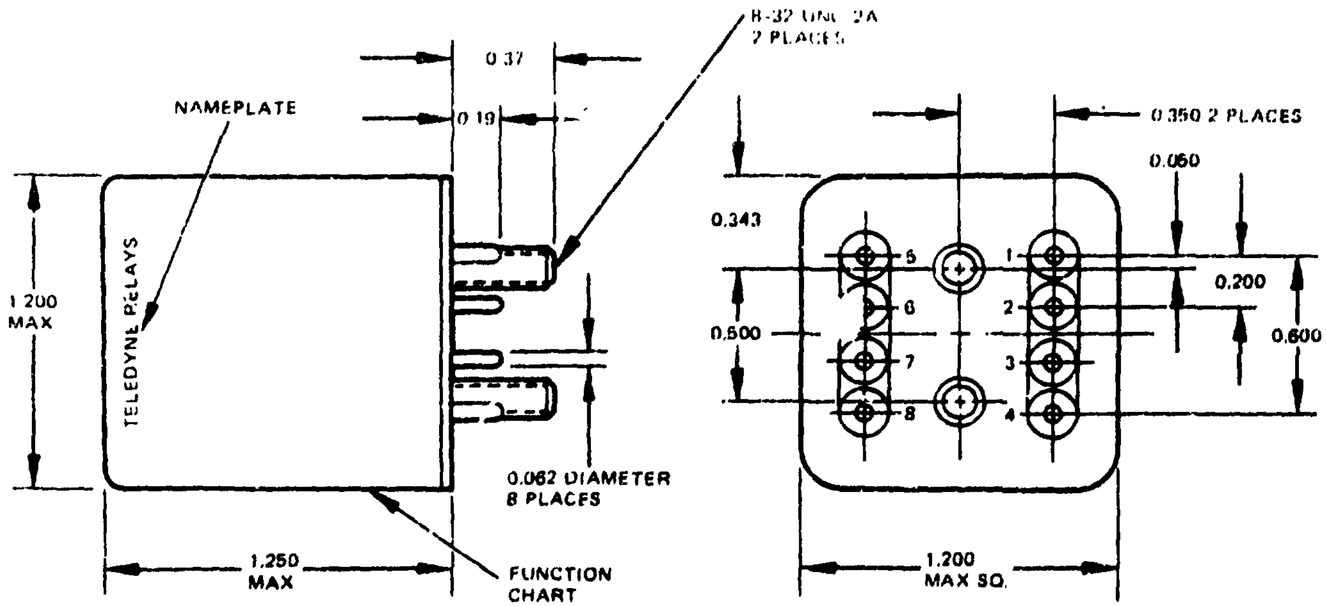
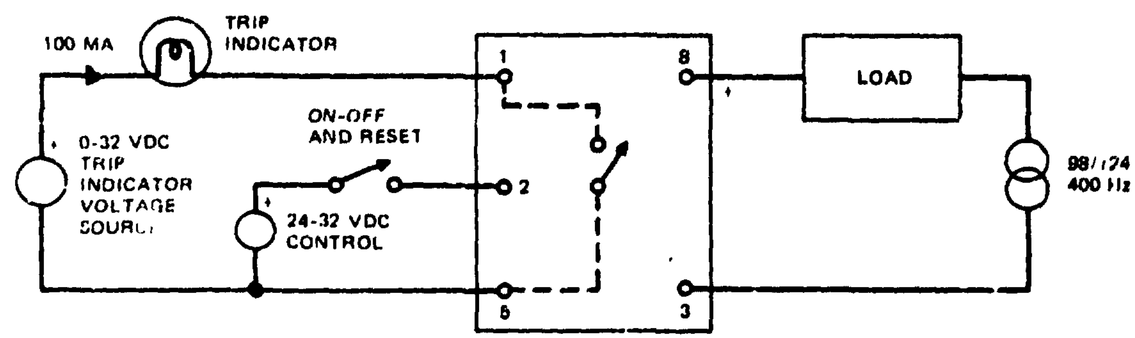


FIG. 28. FUNCTIONAL DIAGRAM AC POWER CONTROLLER

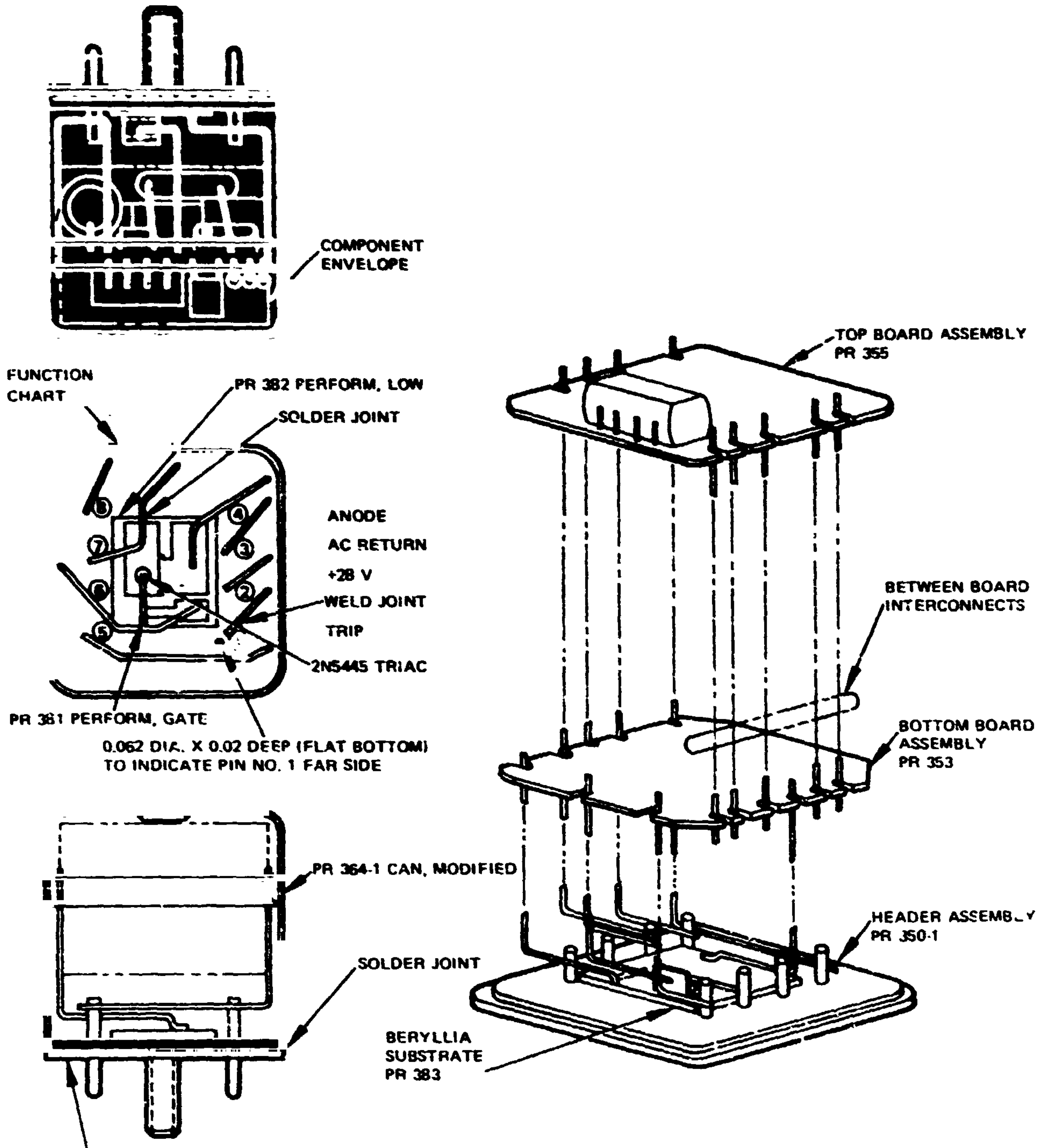


FUNCTION CHART	
PIN	DESCRIPTION
1	TRIP IND.
2	INPUT +28 VDC
3	AC RETURN
4	TEST POINT (A)
5	DC RETURN
6	TEST POINT (G)
7	TEST POINT (K)
8	AC HI



P/N 672-10005 1 AMP

FIG. 29. OUTLINE DWG 1 AMP AC POWER CONTROLLER



NOTES

1. FOR SCHEMATIC, SEE DRAWING PR 357
2. FOR OUTLINE DIM. DRAWING, SEE PR 366

FUNCTION CHART	
PIN	DESCRIPTION
1	TRIP IND
2	INPUT +28 VDC
3	AC RETURN
4	TEST POINT (A)
5	DC RETURN
6	TEST POINT (G)
7	TEST POINT (K)
8	A C HI

FIG. 30. ASSEMBLY LAYOUT LAMP AC POWER CONTROLLER

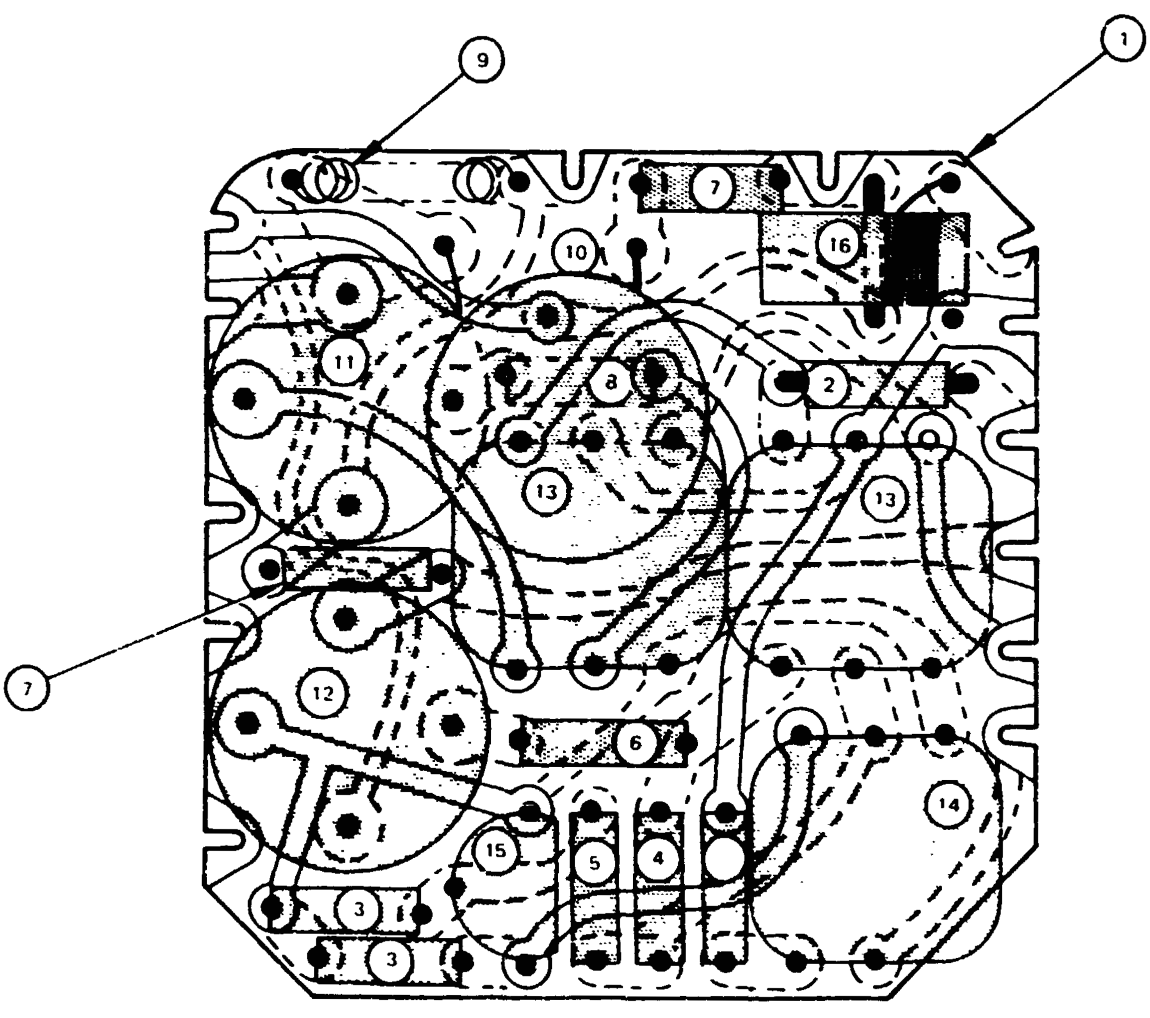


FIG 31. CIRCUIT BOARD ASSEMBLY - BOTTOM 1 AMP AC POWER CONTROLLER

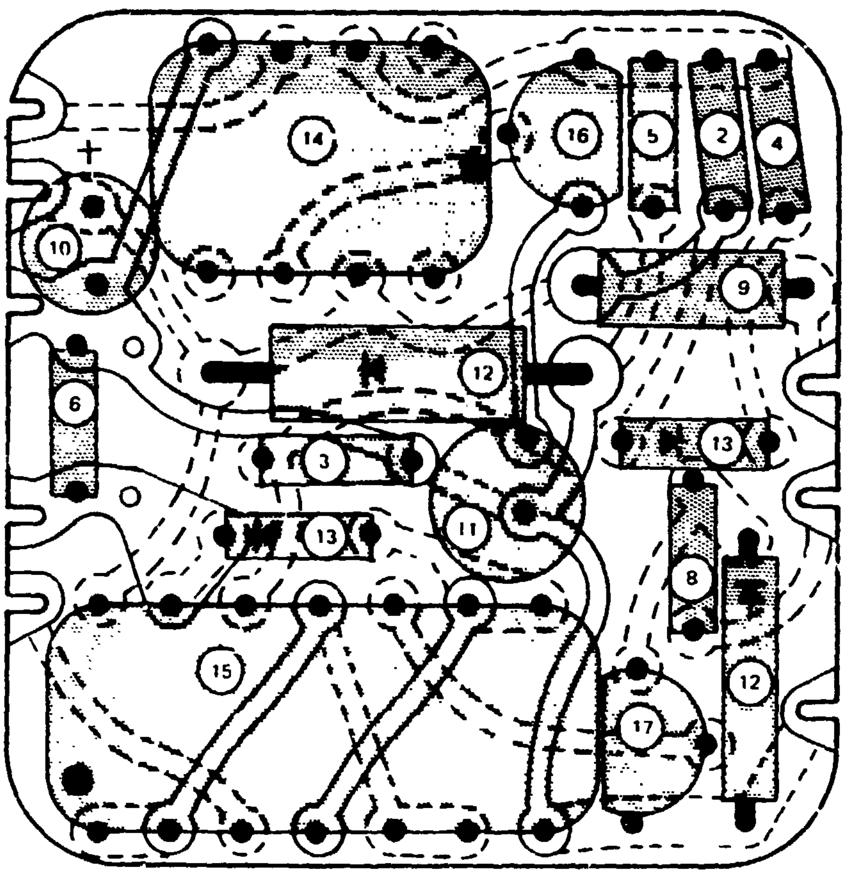


FIG. 32. CIRCUIT BOARD ASSEMBLY – TOP 1 AMP AC POWER CONTROLLER

TABLE 5. SPECIFICATIONS - 1 Amp AC Solid State Power Controller
Teledyne P/N 673-10005

REQUIREMENTS	TELEDYNE P/N 673-10005
Mechanical and Dimensional Characteristics	
Configuration	See Fig. 29
Dimensions	See Fig. 29
Enclosure	Hermetic Seal
Weight	3.0 ounces max.
Mounting Torque	15 in. lbs.
Thermal Characteristics	
Thermal Resistance Case-to-Sink	0.5°C/W with specified mounting torque
Heat Sink Temperature (Design Consideration)	118°C, maximum
Electrical Characteristics	-54°C to +120°C case temperature unless otherwise specified
General	
Terminal Arrangement	SPST (Normally Open)
Insulation Resistance	100 megohms
Dielectric Withstanding Voltage	1000 vAC (RMS)
Isolation	
Between control and trip terminals shorted and output terminals shorted	1000 vAC (RMS)
Life (operating cycles)	10^6 minimum
Radio Interference	MIL-STD-461
Leakage Current	4 + j13 mA *
Power Dissipation (maximum @ 25°C ambient)	
"ON" at rated load	1.75 watt maximum
"OFF"	.311 watt maximum

* j13 mA leakage is due to dV/dT suppression network which appears as a capacitive reactance in excess of 3CK @ 400 Hz.
Since a low power factor exists between this current and applied voltage, almost no power dissipation occurs either in load or controller output.

TABLE 5. SPECIFICATIONS - 1 Amp AC Solid State Power Controller (cont.)
Teledyne P/N 673-10005

REQUIREMENTS	TELEDYNE P/N 673-10005
POWER CIRCUIT	
Supply Voltage	124 vAC (RMS) maximum
Limits 1 & 6 of Curve 1 MIL-STD-704A	98 vAC (RMS) minimum
Current (Rated)	1.0 Amperes
Frequency (Rated)	400 Hz ±5%
Voltage Drop	1.5 vAC (RMS) maximum
Rupture Capacity	400 Amperes Peak
Waveform Distortion	1.5 vAC (RMS) or 6V Peak
Fail-Safe	I^2t = 1200 A^2 seconds
Transients	
Operating Voltage	180 vAC (RMS)
Response	
Turn-ON Time (from application of control)	2.5 mSec maximum
Turn-OFF Time (from removal of control)	2.5 mSec maximum
Trip-Free	Applicable
Trip-Out Time	Applicable
Non-repetitive Reset	Applicable
Repetitive Reset	Applicable
Trip Indication	
Tripped	Switch closed, .025 mA maximum leakage
Not-Tripped	Current Sink, 0 to 100 mA
Zero Voltage Turn-ON	Applicable - half cycle control
Zero Voltage Turn-OFF	Applicable - half cycle control
CONTROL CIRCUIT	
Supply Voltage	
Maximum	32 vDC
Rated	28 vDC
Turn ON Voltage	20 vDC minimum
Rate of Change	.5 V/μSec minimum
Turn OFF Voltage	5 vDC maximum
Rate of Change	.5 V/μSec minimum
Input Resistance	2.2 K ohms

TABLE 5. SPECIFICATIONS - 1 Amp AC Solid State Power Controller (cont., Teledyne P/N 673-10005

REQUIREMENTS	TELEDYNE P/N 673-10005
CONTROL CIRCUIT (cont.)	
Input Transients	Applicable
Noise Immunity	Applicable
Reset	By removing and re-applying DC control voltage
Time to Reset (removal)	5 mSec minimum 100 mSec maximum
ENVIRONMENTAL CHARACTERISTICS	
Case Temperature	
Operating	-54°C to +120°C
Storage	-65°C to +150°C
Shock	
Mechanical	40 G's for 11 mSec
Temperature	-54°C to +120°C Ambient
Vibration	
Sinusoidal (operating)	
G level	15 G maximum
Frequency Range	5 to 2000 Hz
Acceleration	100 G's
Salt Fog	Applicable
Humidity	Applicable
Temperature Altitude	Applicable
Operating Ambient Temperature	-54°C to +120°C
Altitude	Sea level to 100 K ft.
Non-Operating Ambient	-54°C to +120°C
Operating Ambient	-54°C to +120°C
Altitude	.63 to 15.4 psia
Explosive Decompression	Not Applicable

TEST RESULTS - 1 Amp AC Solid State Power Controller
Teledyne P/N 673-10005

PIN IDENTIFICATION

PIN NO.	FUNCTION
1	Trip Indicator
2	Control Input +28 vDC
3	Power Out , AC Return
4	Test Point , A
5	Control Input Return
6	Test Point , G
7	Test Point , K
8	Power In , AC High

TEST	REQUIREMENT MIL-P-81653	RESULTS
GENERAL (all units unless noted)		
Terminal Arrangement	SPST-Normally Open	100 megohms
Insulation Resistance	100 megohms	100 megohms
Dielectric Withstanding Voltage to Case	1500 vAC (RMS)	1500 vAC (RMS)
Isolation Between control and trip terminals shorted and output terminals shorted	1000 vAC (RMS)	1500 vAC (RMS)
Radio Interference	Applicable	MIL-STD-461 Class 1D
Leakage current	6 mA maximum	All units below 2 mA
Power Dissipation		
ON	1.75 watts maximum	1.65 watts
OFF	.310 watt maximum	.300 watt
POWER CIRCUIT (all units unless noted)		
Supply voltage	124 vAC (RMS) max.	All units OK
	98 vAC (RMS) min.	All units OK
Current		
Rated	1 Ampere	All units OK
Minimum	100 mA	All units OK

TEST RESULTS - 1 Amp AC Solid State Power Controller (cont.)
Teledyne P/N 673-10005

TEST	REQUIREMENT MIL-P-81653	RESULTS
POWER CIRCUIT (cont.)		
Frequency	400 Hz ±5%	All Units OK
Voltage Drop		
No Load to Rated	1.5 vAC (RMS) max.	All Units <1.4 vAC (RMS)
Fail Safe	Applicable	Not Tested
Response		
Turn ON Time	1 cycle max.	½ cycle max.
Turn OFF Time	1 cycle max.	½ cycle max.
Trip-Out Time		
Non-repetitive reset	2 sec. max.	<2 sec. all units
Trip Indication		
Current Sink Method		
Tripped	Not Specified	Open Contact 0-32 vDC
Not Tripped	Not Specified	Current Sink 0-100 mA
CONTROL CIRCUIT (all units unless specified)		
Supply Voltage	3.5 to 8.0 vDC	20 to 32 vDC
Turn ON Voltage	3.5 vDC min.	20 vDC min.
Rate of Change	.5 vDC/μSec min.	>.5 vDC/μSec
Turn OFF Voltage	2.5 vDC max.	5 vDC max.
Rate of Change	.5 vDC/μSec min.	>.5 vDC/μSec.
Time to Reset	5 mSec min., 20 mSec max.	5 mSec min., 100 mSec max.

CONTROL INPUT TRANSIENTS (all units unless noted)

A single pulse of plus and minus 100 volt peak amplitude and 100μSec duration repeated 10 times at 3 second intervals. All units tested satisfactorily.

A train of 10 pulses of plus and minus 100 volt peak amplitude and 100μSec duration each, repeated 10 times at 3 second intervals. All units tested satisfactorily.

Repeated above tests between trip terminal and control input return terminal. All units tested satisfactorily.

TEST RESULTS: 1 Amp AC Solid State Power Controller (cont.)
Teledyne P/N 673-10005

TEMPERATURE TESTS (all units unless noted)

The following tests were made at -55°C and +120°C (unless otherwise noted)

Insulation Resistance
Dielectric Withstanding Voltage
Isolation
Leakage Current
Rated Current and Voltage (-55°C and +125°C)
Voltage Drop (-55°C and +125°C)
Control Circuit (-55°C and +125°C)
Reset Circuit (-55°C and +125°C)

On the above tests, all units tested satisfactorily.

Trip-Out under overload (-55°C to +85°C)

Note: The Triac chip that was used failed to turn off when an overload @ 125°C was applied. The controller operated satisfactorily to +85°C under all overload conditions. This situation can be corrected by using a power Triac chip of different characteristics.

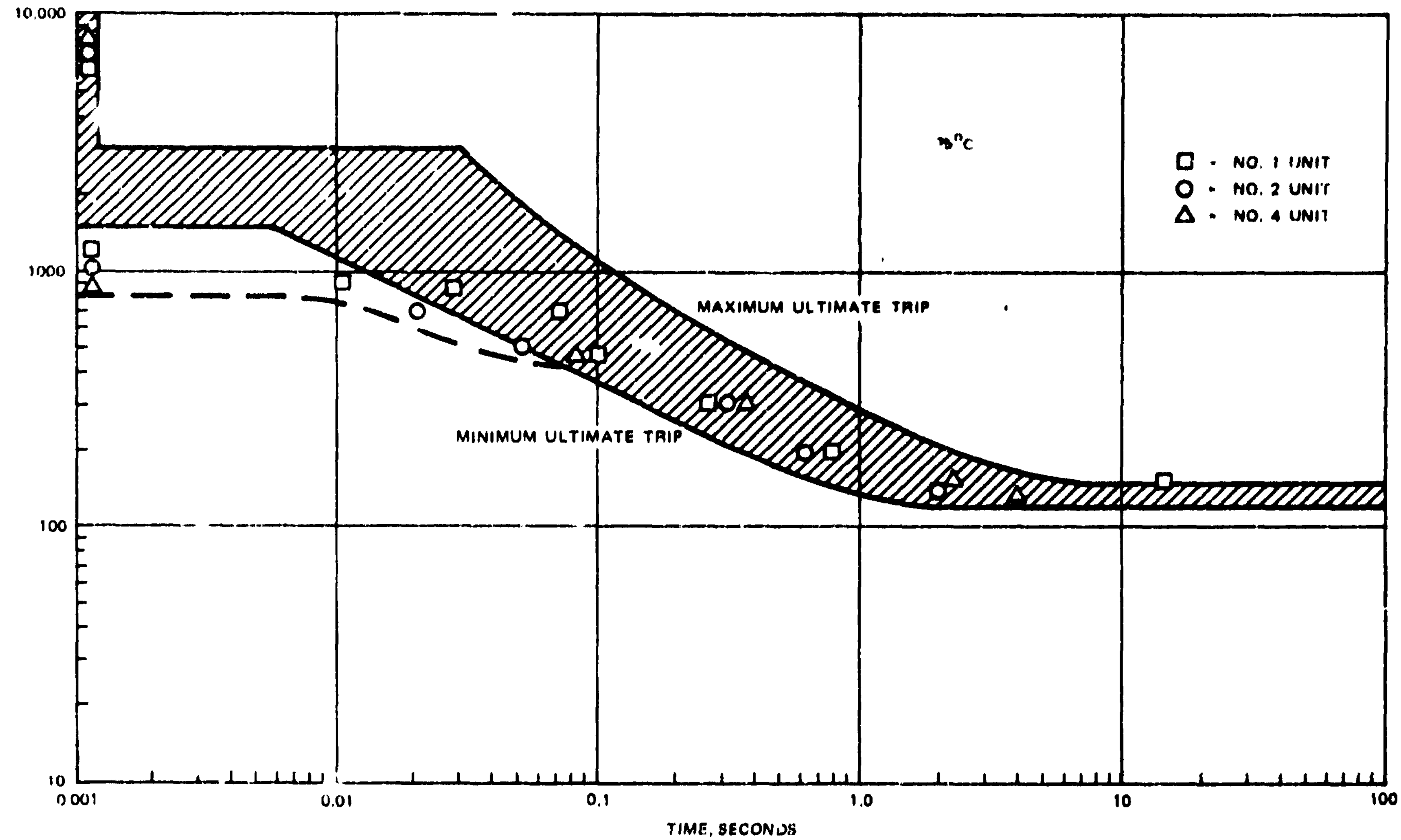
TRIPOUT TIME CHARACTERISTICS

Tripout time versus percentage of overload are shown in Figs. 33, 34, 35 and 36 for 3 prototype AC controllers.

Note: Where units failed to fall within the trip-out time versus overload, this situation can be corrected by putting more effort on the timing and shaping circuit controlling trip-out.

TEST CIRCUITS FOR AC POWER CONTROLLERS

The test circuits for AC power controllers are shown in Fig. 37 and Fig. 38.



F!G. 33. TRIP CHARACTERISTICS 1 AMP AC POWER CONTROLLER +26°C

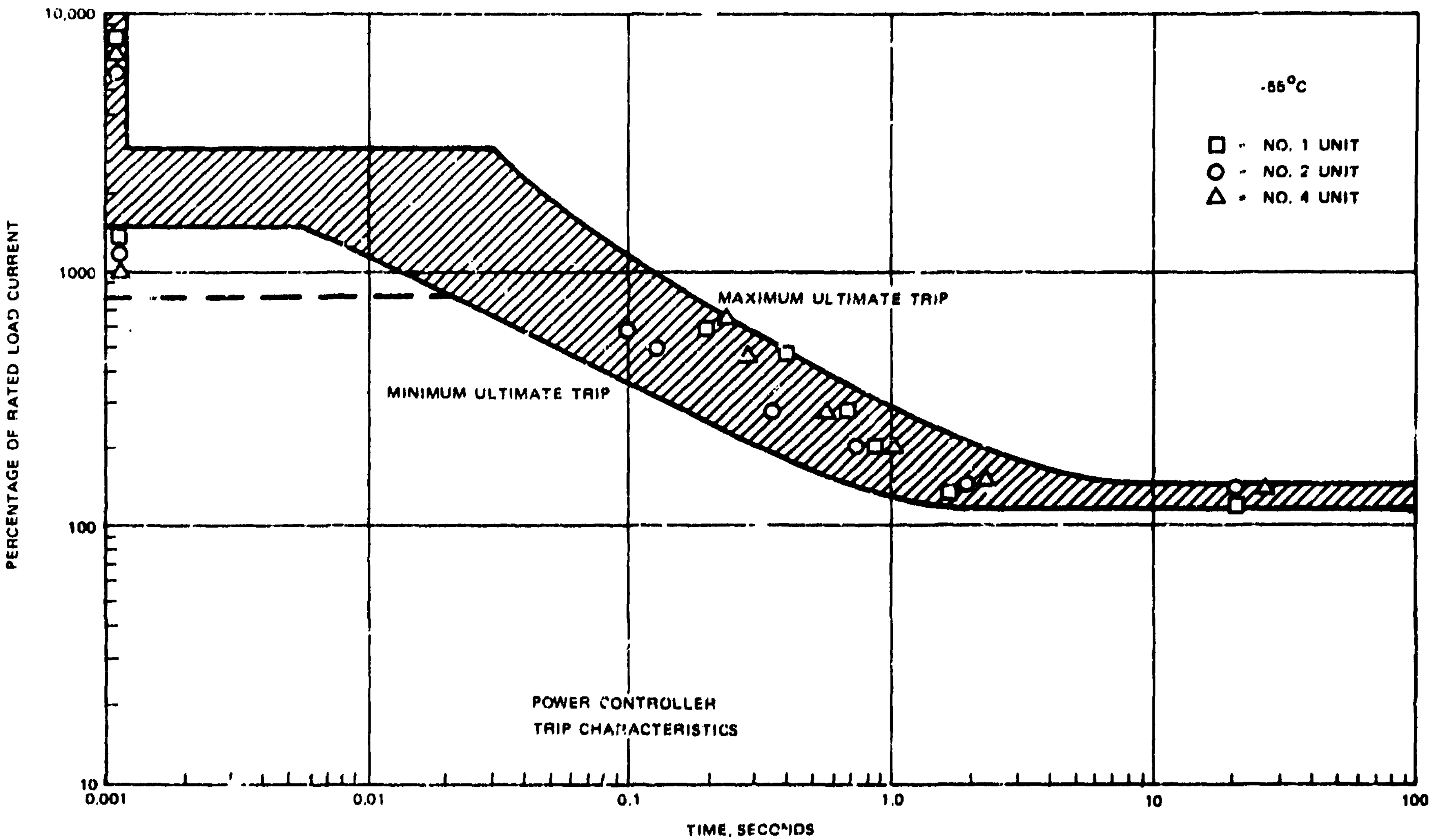


FIG. 34. TRIP CHARACTERISTICS 1 AMP AC
POWER CONTROLLER -55°C

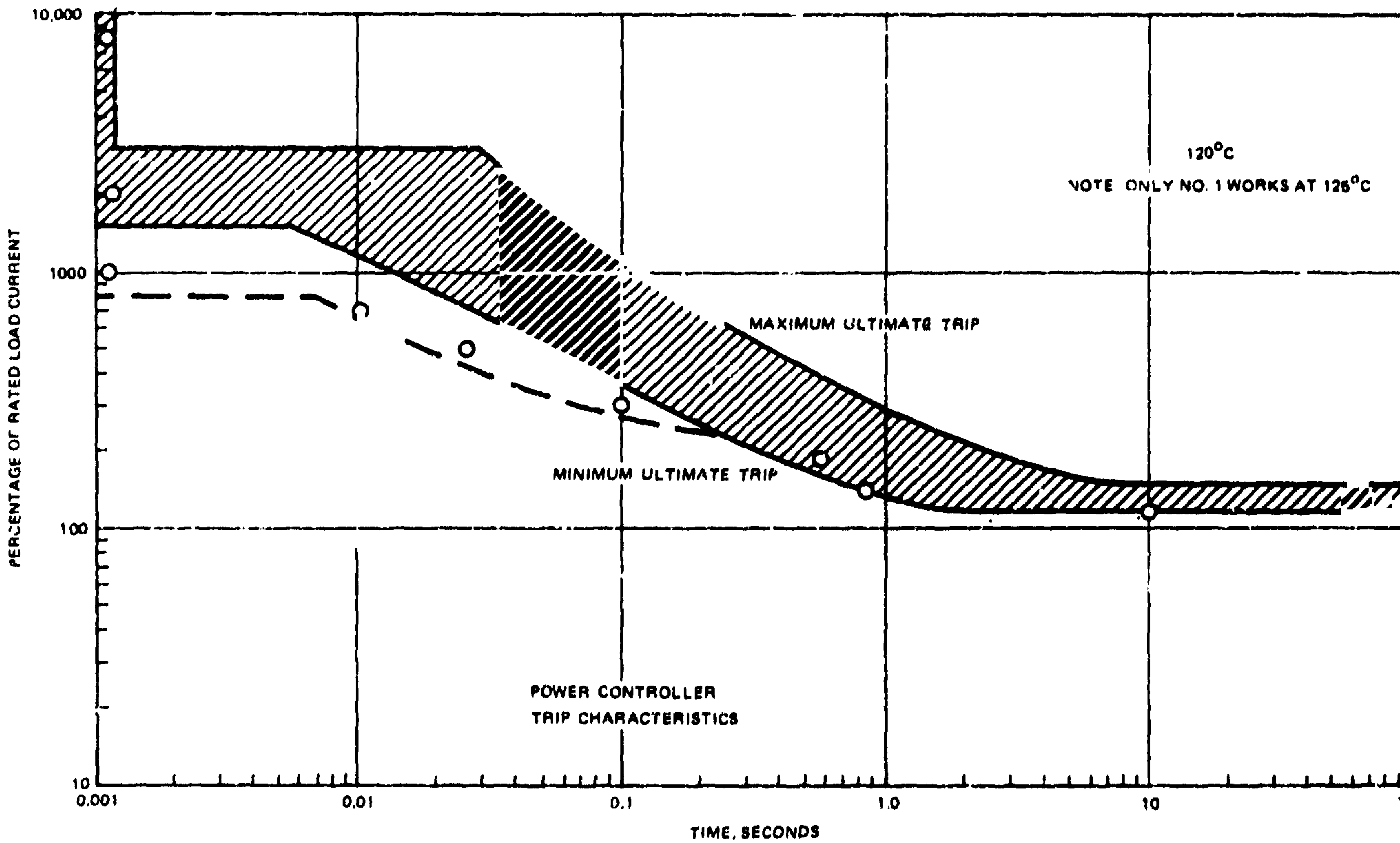


FIG. 35. TRIP CHARACTERISTICS 1 AMP AC POWER CONTROLLER +120°C

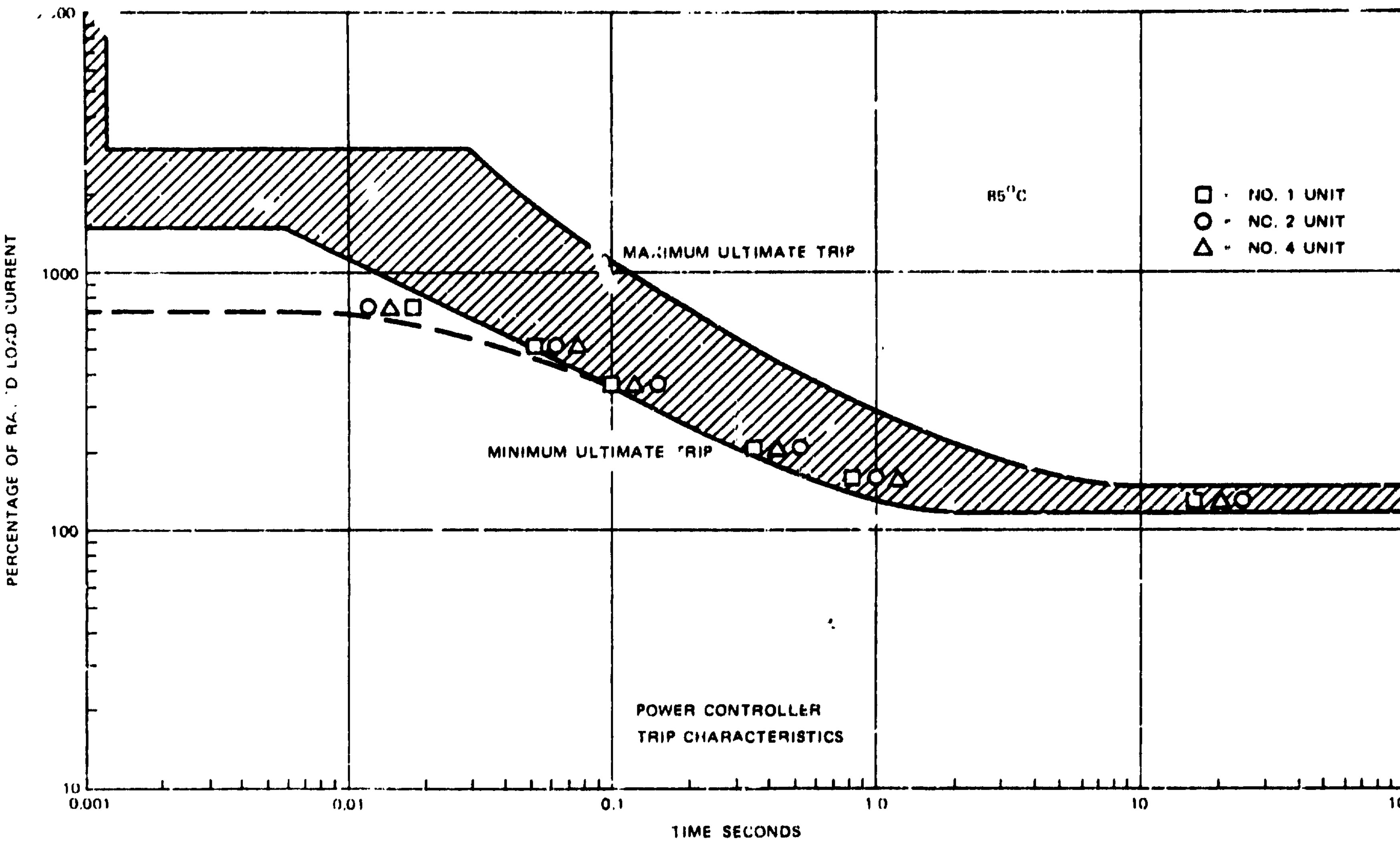


FIG. 30. TRIP CHARACTERISTICS 1 AMP AC
POWER CONTROLLER +85°C

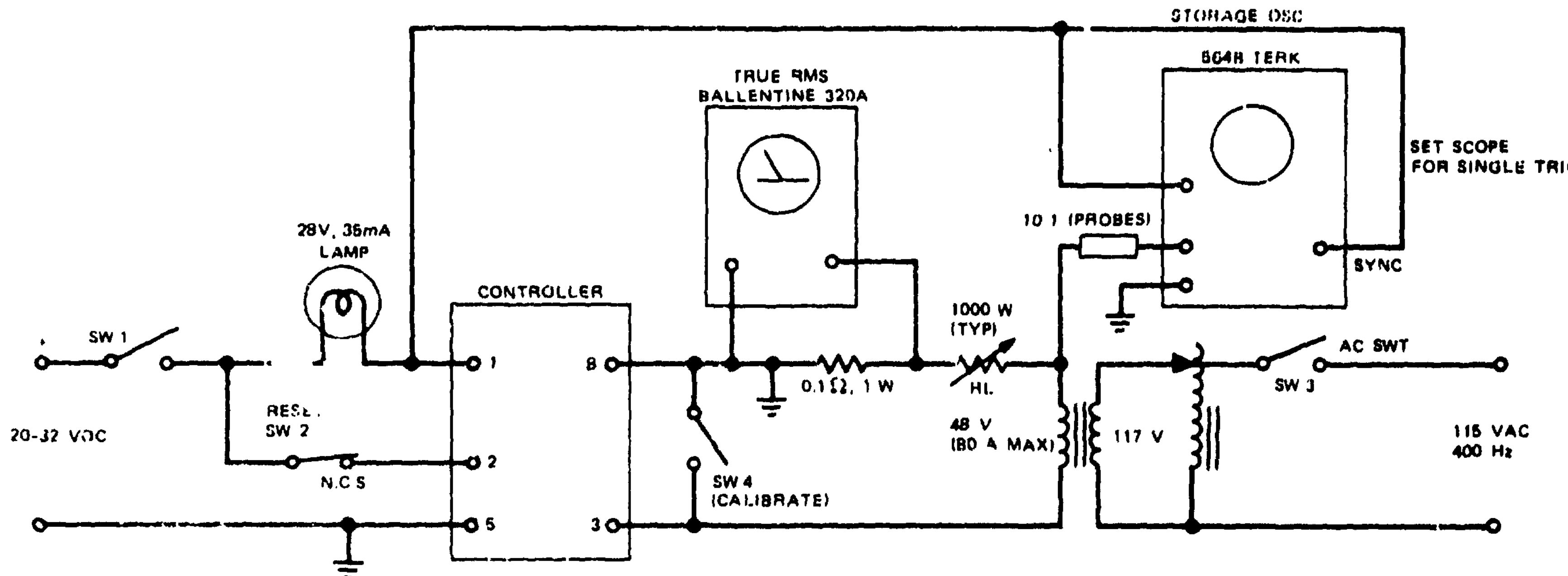


FIG. 37. TEST CIRCUIT FOR TRIP-OUT TIME vs OVERLOAD

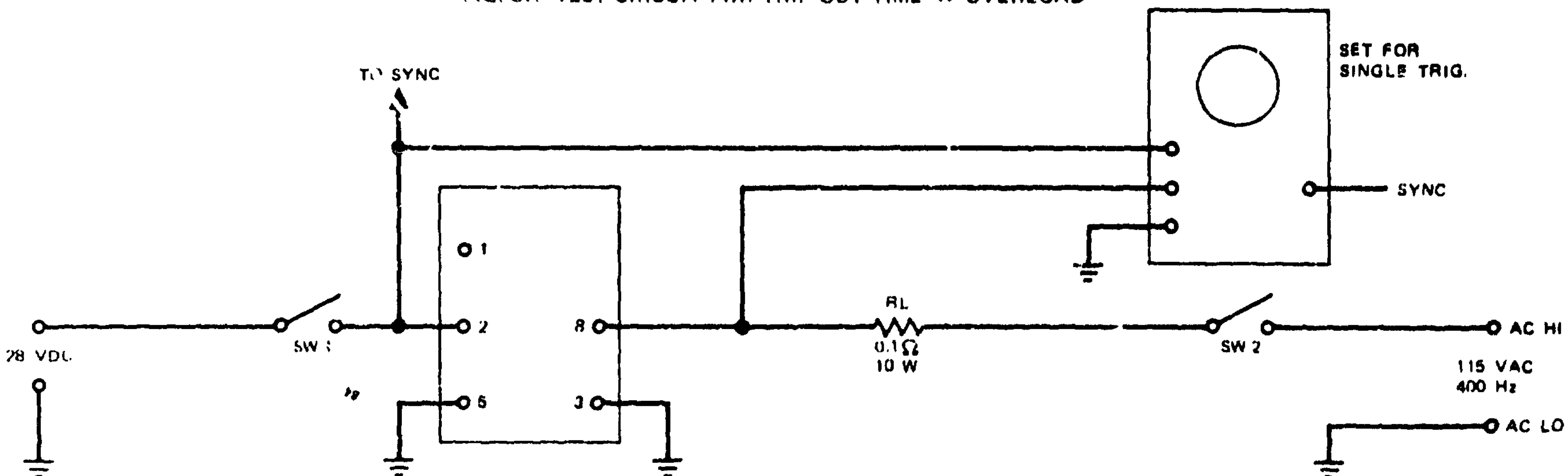


FIG. 38. TEST CIRCUIT FOR SHORT CIRCUIT

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