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ENABLE/OPTION DEVICE DESIGN AND DEVELOPMENT PROGRAM.(U)
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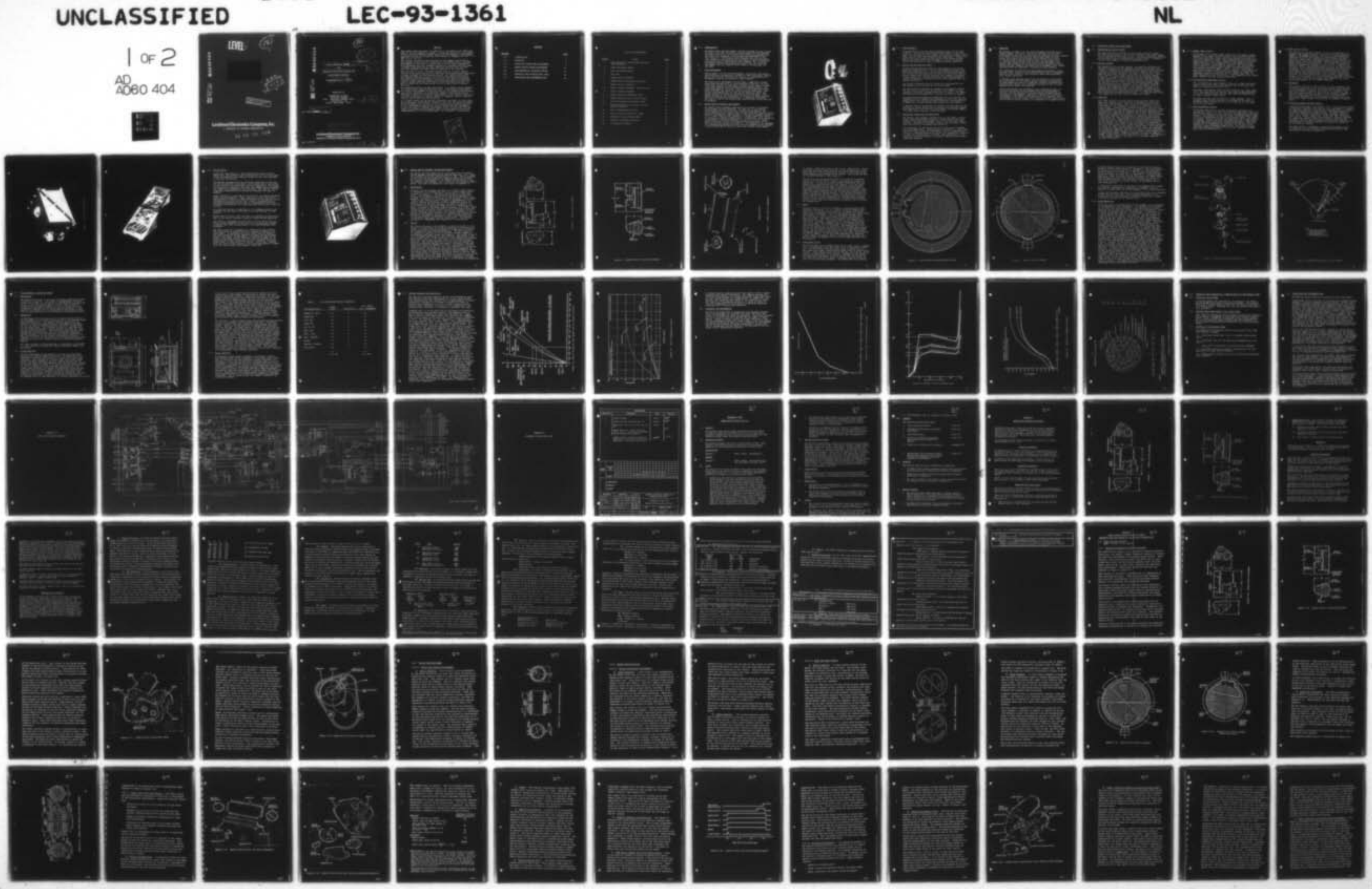

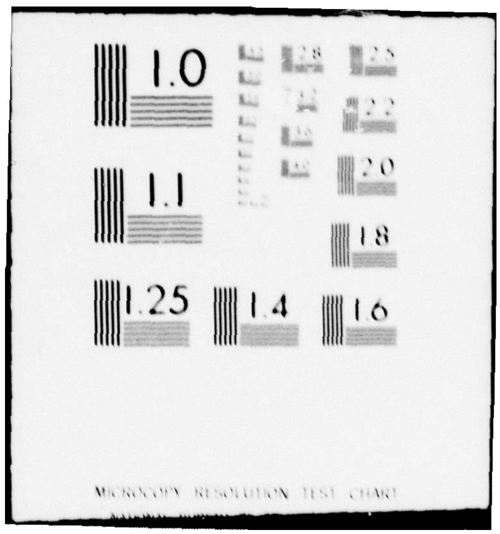
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LEVEL II

(15)

Lockheed Electronics Company, Inc.

A SUBSIDIARY OF LOCKHEED CORPORATION

FINAL TECHNICAL REPORT.

14 Feb-31 Dec 77 on Phase 1.

FOR

ENABLE/OPTION DEVICE DESIGN AND DEVELOPMENT PROGRAM.

CONTRACT DAAK10-77-C-002

1978

SUBMITTED TO

COMMANDING OFFICER
PICATINNY ARSENAL
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LEC PROJECT NUMBER 93-1361

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ABSTRACT

This final technical report is submitted in accordance with CDRL Item A007 of Contract DAAK10-77-C-0002. It describes the effort and progress made on the Enable/Option Device Design and Development Program Phase I, during the period 14 February 1977 through 31 December 1977 on the subject contract.

The program included hardware design and development and technical data package generation and submission. The hardware effort involved development of electronic circuits, motor driver switch assemblies, E/OD packaging and test equipment generation. Drawings and data items included a TDP generated to best commercial practice for the E/OD and test equipment and CDRL items as required in the contract.

The electronics effort included breadboarding of a single channel E/OD to allow investigation into isolation requirements and minimization of power dissipation; manufacture and test of a dual channel E/OD preliminary model built to the functional requirements as given in the contract; and development of a test set. The test set provides simulated input data and output load conditions typical of Pershing missile system interface and monitors E/OD electronic function, as well as Enable Switch function per contract specification requirements.

The mechnical design included development of an Enable Switch Assembly via subcontractor Applied Resources Corp., and mechanical packaging of overall E/OD assembly by LEC engineering. The Enable Switch development effort resulted in a lightweight compact motor-driven switch designed to meet the functional requirements of the contract specification which achieved an inherent degree of component safety by making prudent use of materials and processes.

An in-depth Safety and Reliability Assessment was made to guide both the electrical and mechanical design of the E/OD, including the Enable Switch Assembly. The results of this assessment form a major portion of this development program and include conclusions and recommendations pertinent to advanced development effort of the E/OD. The S&R report is provided under separate cover entitled "Basic results and recommendations of the S&R Assessment" are included in this report.

CONTENTS

LIST OF ILLUSTRATIONS

1.0 INTRODUCTION

The E/OD Design and DEvelopment Program included two major areas of effort: the E/OD electronics and the Enable Switch Assembly. The E/OD electronics, the overall E/OD mechanical package, and ancillary test equipment were designed and developed by LEC (see figure 1). The Enable Switch Assembly and its ancillary test equipment were designed and developed by Applied Resources Corporation with Lockheed Electronics Company, Inc. providing the overall design requirements and monitoring the technical development for this subunit which forms a critical part of the E/OD.

1.1 E/OD Development

During Phase I of the E/OD development, electronics and overall E/OD mechanical package were designed to meet functional requirements, but did not include size, weight, or configuration requirements relative to production type hardware.

The electronics development during Phase I comprised a breadboard-type configuration to allow maximum flexibility for specification changes in coded data information and power and load level requirements during subsequent development phases. The technology used for the logic circuits in the E/OD preliminary model was CMOS flat packs or ceramic printed substrates. Substrate interconnections are hard wired except for power and ground connections which are printed on the substrates. The power sections of the electronics are mounted on epoxy terminal boards with hardwired interconnects. Crimp-type connectors are used in lieu of the solder-type specified due to availability of hardware.

1.2 Enable Switch Assembly Development

The Enable Switch Assembly developed during Phase I represents quasi-production-type hardware. In addition to functioning in accordance with contract specification requirements, the switch assembly size, weight, and configuration meet specifications typical of production type hardware. The switch assembly consists of a 17 deck rotary switch coupled to a Geneva gear drive which is driven by a 4-phase stepper motor. A mechanical reset mechanism is included in the switch assembly to return it to the "safe" (start) position without electrical power should power to the motor be lost during switch actuation. Each Enable Switch Assembly is a hermetically sealed unit and two such assemblies are provided in each Enable/Option Device to meet dual channel requirements.

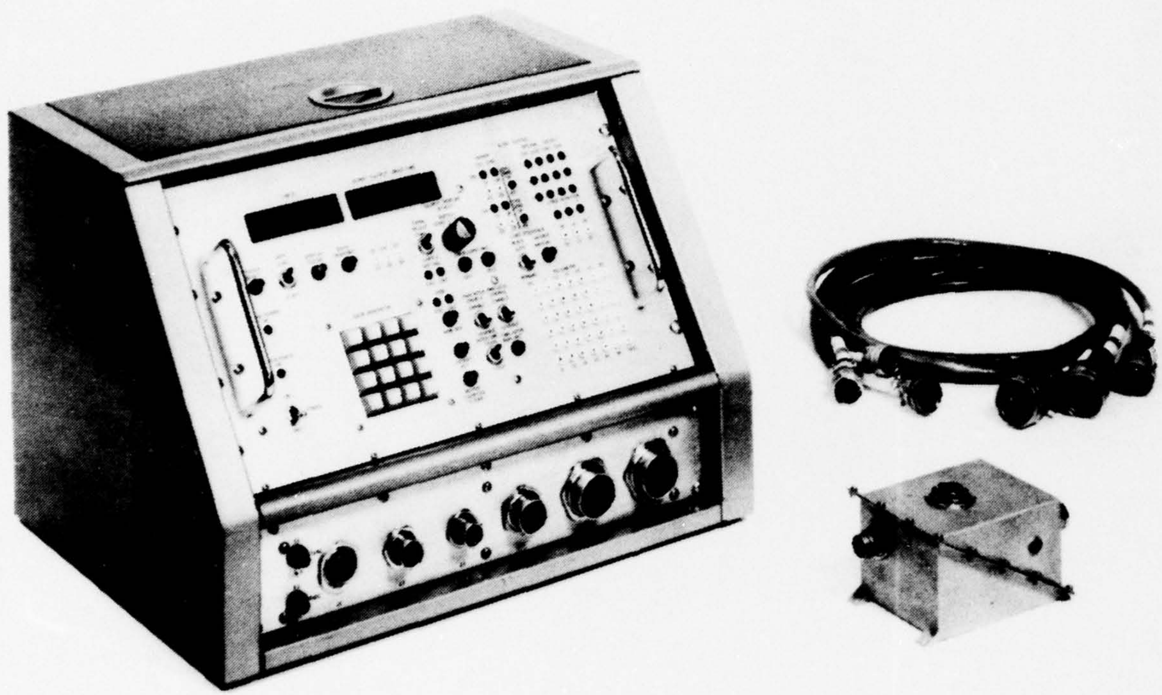


Figure 1. E/OD Mechanical Package and Ancillery Test Equipment

1.3 Test Equipment

A pre-production test set was developed as part of the Phase I effort. The set provides simulated PAC Inputs to the unit under test and monitors the outputs and various telemetry points under varying loads simulating AK load conditions. Visual displays were used to monitor E/OD function and output signals. The set monitors Enable Switch Assembly critical timing and electrical function, as well as E/OD electronics operation.

1.4 Safety and Reliability Effort

A Safety and Reliability study was performed on a prototype model developed during the Phase I Development Program of the Pershing II Adaption Kit. This study consisted of evaluating the reliability and assessing the safety of the Enable Option Device (E/OD) under normal ranges of environmental and operational conditions. The safety analysis was also extended to include a qualitative analysis of the safety aspects under abnormal conditions.

The results obtained from this study were incorporated into the design of the E/OD during the design phase.

The LEC-estimated reliability probability of mission success for the E/OD is 0.9955 for one channel and 0.99966 for both channels, including a dormancy period of 20 years. The specified reliability probability of success is 0.985 per channel.

The LEC-estimated premature probability prior to lift-off is 0.0000032 for one channel and 0.0000064 for both E/OD channels. These results are within the specified safety requirements of 0.000005 for a single channel and 0.00001 for two channels.

A detailed Safety and Reliability Analysis can be found in the Pershing II Enable Option Device Reliability and Safety Assessment generated to fulfill the requirements of Contract DAAK10-77-C-0002, Data Items A013, A014 and A015.

1.5 Mechanical Packaging Considerations

The Overall E/OD package configuration for the Phase I preliminary operational model occupies a volume greater than that shown for the "production-type" units in the contract scope of work. Likewise, the weight is higher for the Phase I model than the goal for the production-type units.

The increased size and weight was due to the use of standard flat pack CMOS logic. This permitted flexibility in the design during the early stage of development. Use of integrated circuitry in subsequent phases will allow for substantial reduction in both size and weight of the E/OD. The weight goal of 2.5 pounds for the E/OD remains a reasonable objective for production-type hardware.

2.0 OBJECTIVE

The purpose of Phase I of the E/OD Development Program was to expand, update, and detail the design approach for the E/OD as proposed by LEC and its subcontractor, Applied Resources Corporation, and to build a preliminary operational model to this design which meets the functional requirements as set forth in the pertinent contract scope of work. In accordance with the contract scope of work, the E/OD preliminary model size, weight, and configuration did not meet final "production unit" specifications; however, the Enable Switch Assembly size, weight configurations are adaptable to production-type hardware.

Test equipment was designed and developed during Phase I which provides input stimuli to the E/OD and Enable Switch Assemblies, monitors their function, and provides output data confirming their proper operation.

A technical data package describing the design of the preliminary E/OD model and the Enable Switch Assembly was generated to good commercial practice standards. Likewise, drawings were generated for special test equipment designed as part of engineering effort under this contract.

Safety and Reliability assessments were conducted as part of the E/OD and Enable Switch Assembly design and development efforts. The S&R evaluations provided design guidance during this phase of development. Qualitative safety and reliability information is provided in accordance with the contract data requirements list and forms a major section of this report which can be used as design guidance in subsequent development efforts.

3.0 ELECTRICAL DESIGN AND DEVELOPMENT

3.1 Enable/Option Device (E/OD)

The E/OD electronics consists of seven major sections. These are the current limiter, the 12 volt regulator, the common input, the initialization and reset circuit, the data processing, decoding and storage circuit, the motor drive circuit, and the telemetry circuit. See schematic included as Appendix No. A.

3.1.1 Current Limiter

The purpose of the current limiter is to provide isolation of 28V power between the two redundant channels of the E/OD. Initially, two methods of accomplishing this function were outlined: a fusible resistor and an active current limiter. The latter approach was chosen because it provides a "non-one shot" resettable function. The limiter operates in the following manner. A resistor is used to sense the current flow passing through a power transistor. This transistor acts as a normal "closed" switch. When an overcurrent condition exists, the voltage across the sensing resistor fires a Silicon Controlled Switch (SCS) device which turns the transistor "off", disconnecting power from the malfunctioning channel. The limiter can be reset by removing and reapplying power to the channel affected. This approach was chosen over the fusible resistor to enhance unit maintainability by eliminating the need for component replacement should an overload condition occur. It also provides bench test capability of this circuit without unit rework.

3.1.2 Regulator

The 12Vdc regulator section takes the unregulated 28Vdc input power and converts it to regulated 12Vdc power for both the E/OD logic and the SACA. The initial design approach used an integrated circuit dissipative regulator to generate the logic bias voltage. Investigation revealed that due to the high in-flight temperature environments, the 15 watts of heat per channel dissipated by this type of regulator would cause extremely high internal unit temperatures (~400°F) and, hence, disasterously degrade both safety and reliability of the unit. For this reason, a switching regulator was designed to reduce the input power by switching the input voltage on and off and integrating the resulting pulses. Compensation for varying loads is achieved by varying the "on" duty cycle of the pass switching transistor. In this design, the output voltage is sensed by a comparator. When the output falls below a specified limit, the pass transistor is turned on. When it rises above a second limit, the transistor is turned off. The pulses produced by this action are smoothed by an Inductor-Capacitor (LC) circuit. This LC circuit provides the regulated output voltage with a constant ripple characteristic of 40mV peak-to-peak. Chopping frequency varies from 20KHz to 150KHz, proportional to the load current at 12Vdc. Implementation of the chopper regulator resulted in a 73 percent reduction in power dissipation.

3.1.3 Common Input Circuit

The purpose of the common input circuitry is to convert single channel input signals to dual channel, and to provide channel isolation. The data, clock, and strobe signals enter the circuit in differential format. Three comparators of an LM139 quad comparator device are used to convert these signals to single-ended format at a level compatible with the CMOS circuitry. Channel isolation is provided by resistors. The fourth comparator shifts the signal level to 28Vdc for data echo back to the Pershing Airborne Computer (PAC). The 28 volt HOB and separation signals are split into two channels. The comparators were used in lieu of line receivers to reduce the number of components required, eliminate the +5V supply, and lower the power dissipation from this circuit. The comparators use +12Vdc power "OR'ed" from the internal regulators.

3.1.4 Initialization and Reset Circuit

The initialization circuit senses "turn-on" of power and generates a "power on" reset pulse to place all of the logic and memory to a specified initial state.

The power interruption reset circuitry monitors the input power line. An interruption of greater than 120us causes generation of a reset pulse to place all the logic and the enable switch in their "initial" (safe) state.

The E/OD unit may also be reset by a reset command. This is a coded signal from the PAC which is decoded by the logic to generate a reset signal which, in turn, sets all of the logic to its initial state.

3.1.5 Data Processing Circuit

The primary function of the data processing, decoding, and storage circuitry is to convert the serial input data to parallel data format, decode the data, and store the appropriate discrete signals. The decoding is done by using a Read Only Memory (ROM). It has two advantages over hard wire decoding used in the proposal design. First, the number of components used in the circuit is reduced. Second, and more important, the use of ROM allows considerably more flexibility in code modification. Code word changes can be implemented by replacing the old chip in the E/OD with a new, programmed memory chip. The initial design required redesign and rewiring of the logic assembly to implement code word modification.

3.1.6 Motor Drive Circuit

The function of the motor driver circuit is to generate, on command, the signals necessary to drive the enable switch assembly to the ARMED position. The circuit also accomplishes resetting of the switch assembly to the SAFE position when required. LM195 Power Integrated Drivers, which dissipate 20 percent less power than the power transistors used in the proposal design, are being employed. Logic redesign reduced the number of components required in this circuit. A portion of the motor driver logic senses the position of the Enable Switch contacts. This information controls the power to the drivers to prevent driving of the motor when Enable Switch contacts are closed. This sensing circuit also controls the return or reset of the Enable Switch when a reset signal is generated by either the initialization circuits or by the common reset signal. If the switch is in an intermediate position (not Armed or not Safe), the logic will sense this condition and drive the switch assembly to its "SAFE" condition.

3.1.7 Telemetry

This section consists of 10K resistors in the telemetry lines to provide isolation of the unit from external sign entering via the telemetry connector. Forty-one (41) telemetry points have been chosen to monitor the function of the E/OD. The monitor points selected are shown on the schematic, Appendix A. Both the common and dual channel circuitry are monitored and design consideration has precluded the possibility of bypassing the Enable Switch via shorting of telemetry connector pins.

3.1.8 Preliminary Model Hardware Effort

The preliminary model, see Figures 2 and 3, of the E/OD included a completely functional duel channel unit, packaged in a mechanical enclosure capable of limited environmental testing, as well as normal handling and transportation. The model contained electronic components mounted on epoxy "terminal" boards or thick film ceramic substrates. Crimp type "MS" connectors were used for input, output, and telemetry. The unit was made of lightweight aluminum sheet metal and was completely EMI shielded. The unit was suitably protected with a chemical film and designed to withstand exposure to moisture by gasketing of all interior flanges.

The model design is adaptable to advanced development effort by reduction of size and weight while maintaining the same construction and basic configuration.

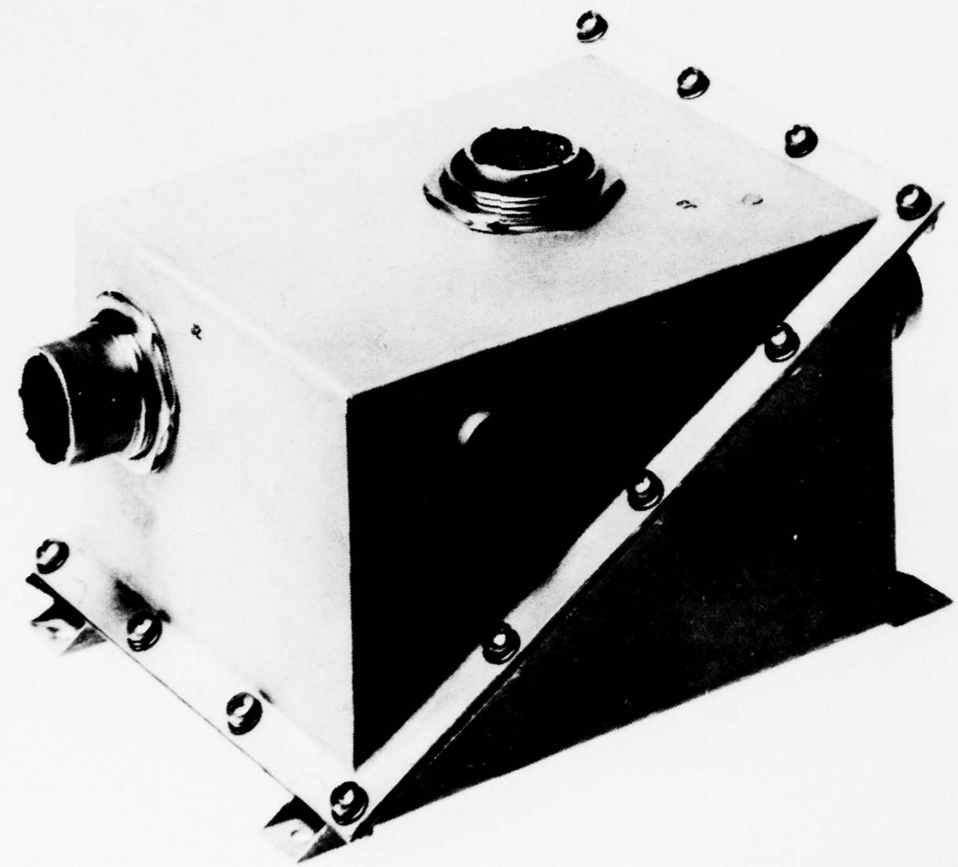


Figure 2. E/OD Preliminary Model

Figure 3. E/OD Preliminary Model

3.2 Tester Effort

A test set (see figure 4), was developed using dual incline CMOS logic, and mounted on wire wrap boards. All critical functions, as defined in the contract scope of work, were included in the test set design.

Hexidecimal displays show the coded data generated in the test set and transmitted to the E/OD. The displays allow monitoring of this data at the E/OD output and echo connectors. The tester electronics also generates the CLOCK and STROBE signals necessary for coded data transmission into the E/OD. The test set stores coded data transmitted by the E/OD and displays this data on command.

Power regulation is provided in the test set to simulate Pershing missile system supplies. Power regulation within the E/OD is monitored by the tester as load conditions to the E/OD are varied automatically within the test set. Power loss operation of the E/OD is monitored as the test set establishes overcurrent conditions and monitors the resulting E/OD function as a function of time.

Critical test points, in addition to all telemetry points, are available on the tester front panel to allow probing of these points.

Enable Switch closure time functions are measured and made available to the tester displays to monitor Enable Switch operation.

The tester is equipped with self-test circuitry which uses the tester cables connected to the test set in a particular manner to permit self test, as described in the E/OD Acceptance Test Procedure.

The entire test set is housed in a sloped steel gray cabinet. The electronics is contained within a chassis attached to the front panel. By detaching the front panel from the cabinet, the entire test set can be removed for repair and maintenance. An auxillary 28Vdc, 10 amp supply is required as input to the tester. Auxillary digital volt meter and oscilloscope can be used with the tester to monitor critical or special functions. 115Vac power is also used in the tester. The tester, together with its three, 6-foot cables, is fully portable making it adaptable for testing under environmental conditions.

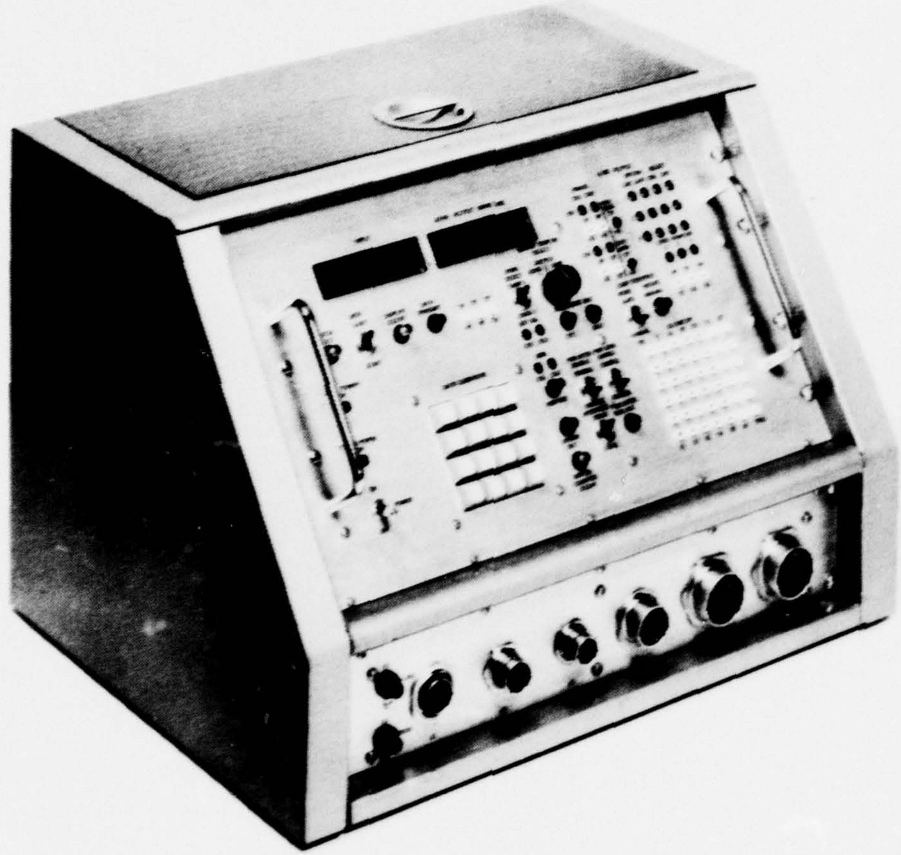


Figure 4. Test Set

4.0 ENABLE SWITCH ASSEMBLY DESIGN/DEVELOPMENT

The design and development effort associated with the Enable Switch Assembly was performed by Applied Resources, Inc., under the technical direction and monitoring of LEC. LEC's Statement of Work W/S 1360 was supplied to Applied Resources defining the technical requirements of the Enable Switch design as well as hardware, data package, test, inspection and schedule requirements. W/S 1360 is attached to this report as Appendix B.

4.1 Description

An Enable Switch Assembly consists of a 17 deck rotary switch, a Geneva/gear drive mechanism and a four-phase stepper motor, as shown in figure 5. The outer construction is stainless steel. The assembly is hermetically sealed and purged with nitrogen to extend the shelf life of the drive and switch components. The weight of an Enable Switch Assembly is 9.4 ounces (.585 pounds) and the overall length is approximately 3-1/4 inches. Unique construction of these assemblies allows for interlocking of two such switches, as shown in figure 6, so as to yield a more practical shape factor for packaging in an E/OD. Included in the Enable Switch Assembly is a visual status indicator which provides information as to "arm/safe" position of the switch and switch drive. Each switch assembly is completely testable and resettable for repeated functioning without access to the assembly interior or special manual actuation. The entire assembly is designed for more than 100 operations in accordance with specification requirements. The assembly operation is independent and insensitive to orientation.

4.2 Switch

The switch portion of the assembly, as shown in figure 7, consists of 17 individual interlocking decks which are pinned together to maintain precise alignment of decks and to reinforce the strength of the interlocking design. The deck material is alumina (95 percent of 97-1/2 percent) ceramic capable of withstanding abnormal thermal environments. The switch contacts are "Z"-shaped configuration each providing approximately 100 gram contact force. A 90° rotation of the contact/deck assembly moves the switch from the open (safe) to the closed (armed) position. The contact material is nickel with an appropriate plating to minimize contact resistance. Stationary input and output terminals are imbedded in alumina (95 percent) ceramic insulation sleeves which, in turn, are installed in a stainless steel housing. The terminals are nickel alloy adaptable for use with printed cabling for subsequent E/OD development effort. The Geneva shaft is pinned to the switch decks to form an integral rotating part. The power terminals of the switch are offset approximately 10 degrees from the signal terminals to provide for settling time in the SACA prior to transmission of signal data. The power decks are 2, 3, and 4 of the switch corresponding

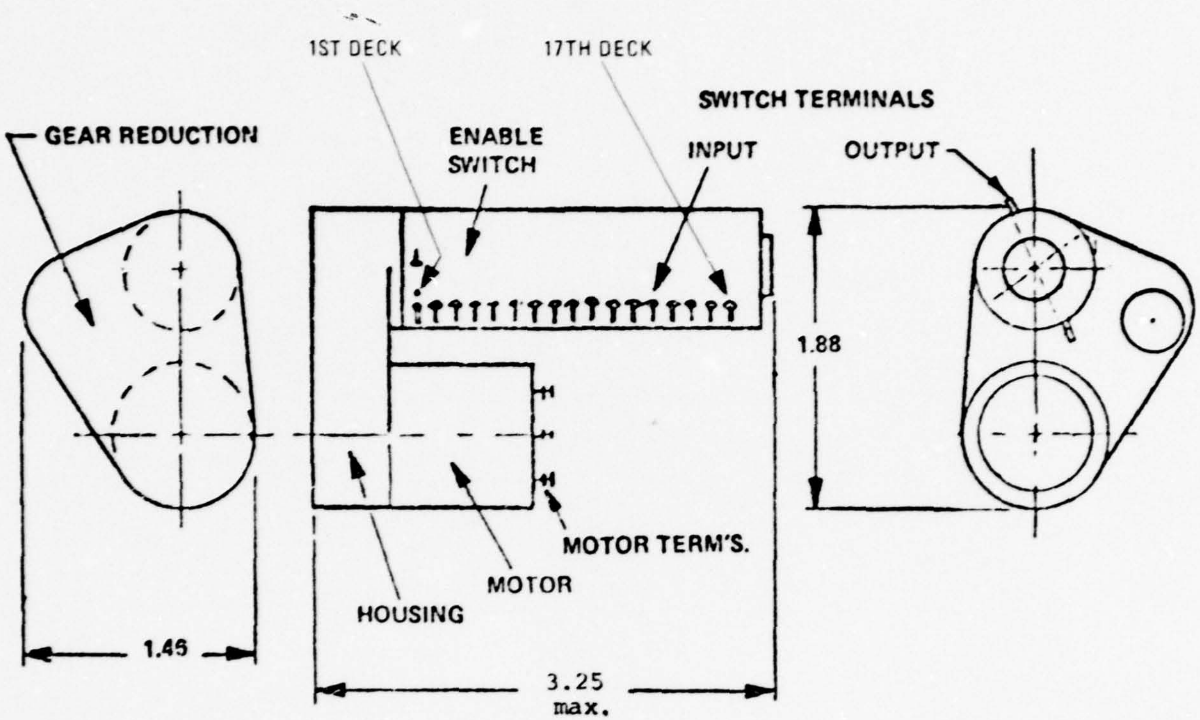


Figure 5. Enable Switch Assembly

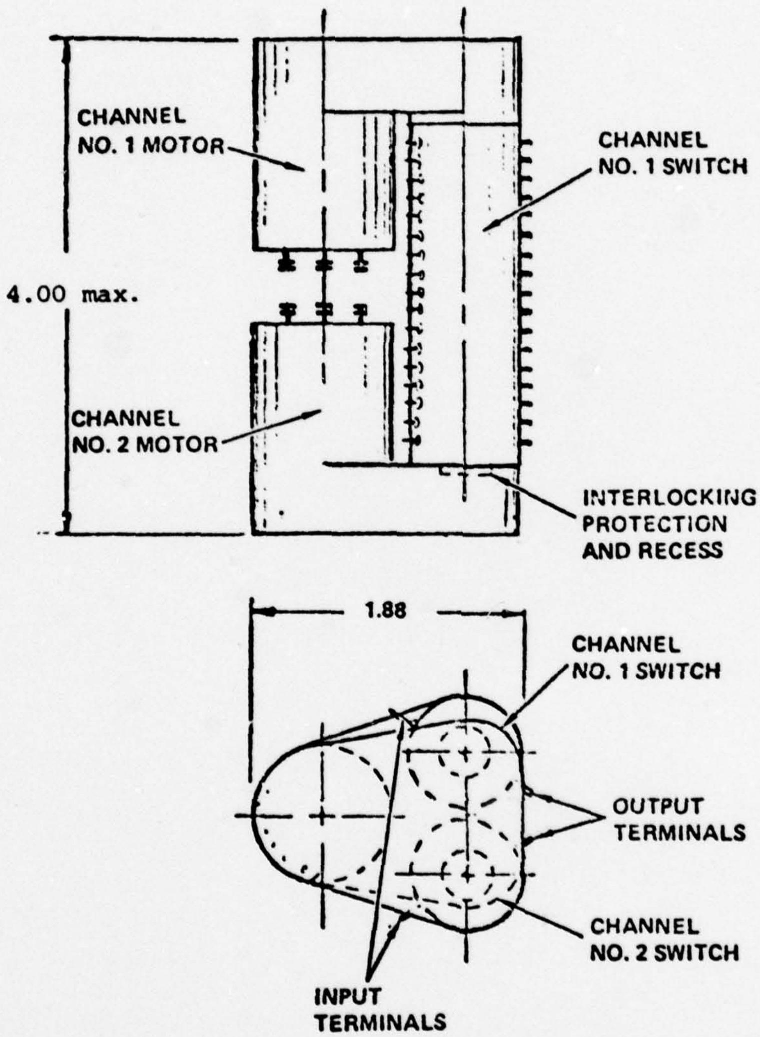


Figure 6. Enable Switch Interlocking Design

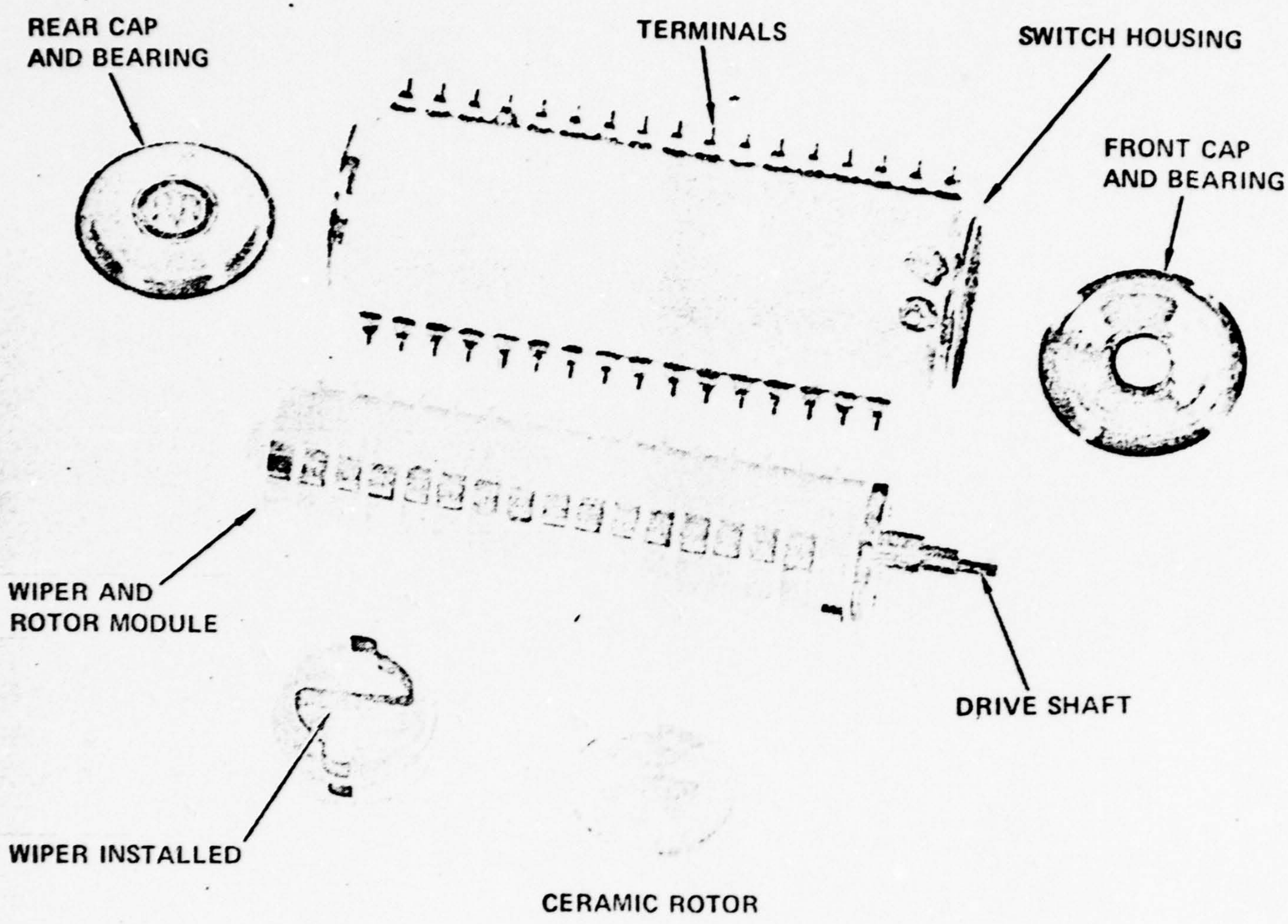


Figure 7. Enable Switch Components

to +28Vdc, +12Vdc and return signal lines, respectively. These functions were positioned close to the drive mechanism to maximize control of the critical power signals in the event of abnormal damage being imposed on the switch. The 1st switch deck is a monitoring deck. (See figure 5).

The function of the monitoring deck is to provide a feedback signal to the switch drive circuit signifying the closure of the switch. It carries no other signals associated with the adaption kit function and, for that reason, it is also used as the telemetered switch point to identify switch closure. The configuration of the ceramic deck and the positioning of terminals is different for the 1st deck from all others. Both input and output terminals of the 1st deck are located on the output side of the switch housing. This feature precludes premature transmission of data or power signals were a short to occur from the 1st deck terminals are so positioned to assure closure of all switch contacts prior to switch drive shutoff. Figure 8 and 9 show the configuration of Decks 1 and 2 through 16, respectively.

4.3 Motor

The motor used in the switch assembly is manufactured by MPC Products Corporation. It is a highly efficient stepper motor providing 1.2 inch/ounce of torque at 122 pulses per second (pps) while occupying a volume of approximately 0.48 cubic inches and weighing 3.1 ounces. It is a four-phase stepper motor, 90° rotation per step, using 28Vdc DC power and drawing 0.7 amps per phase. Two phases are energized simultaneously to cause motor rotation. The output shaft is a 13 tooth spline, 120 pitch. The motor response rate is 220 pps and the slew rate is 300 pps. The holding torque is 2.6 ounce/inches and the detent torque is 0.1 ounce/inch. MPC specializes in the design and manufacture of highly efficient stepper motors without use of rare earth-cobalt materials in the permanent magnet rotor. MPC has been in business since 1964 under the present management and was previously known as G. M. Labs, which started in the mid-1940's. It has provided components for Pershing ground support equipment, Sprint, various Army helicopter programs, as well as antenna servo drives for Navy and Air Force helicopters.

4.4 Geneva/Gear Drive

The Geneva/gear drive assembly consists of a gear train, a Geneva drive, a mechanical reset mechanism, and a visual status indicator. Two gear passes provide a 48:1 input to output ratio. The Geneva drive gear rotates approximately 390° to cause switch closure. With a motor pulse rate of 122 pps, the time for switch closure is approximtely 1.72 seconds. Movement of the Geneva and attached switch decks occur during the last 90° motion of the drive gear and switch contact engagement occurs during the last 25° of drive gear movement. The Geneva/gear drive design

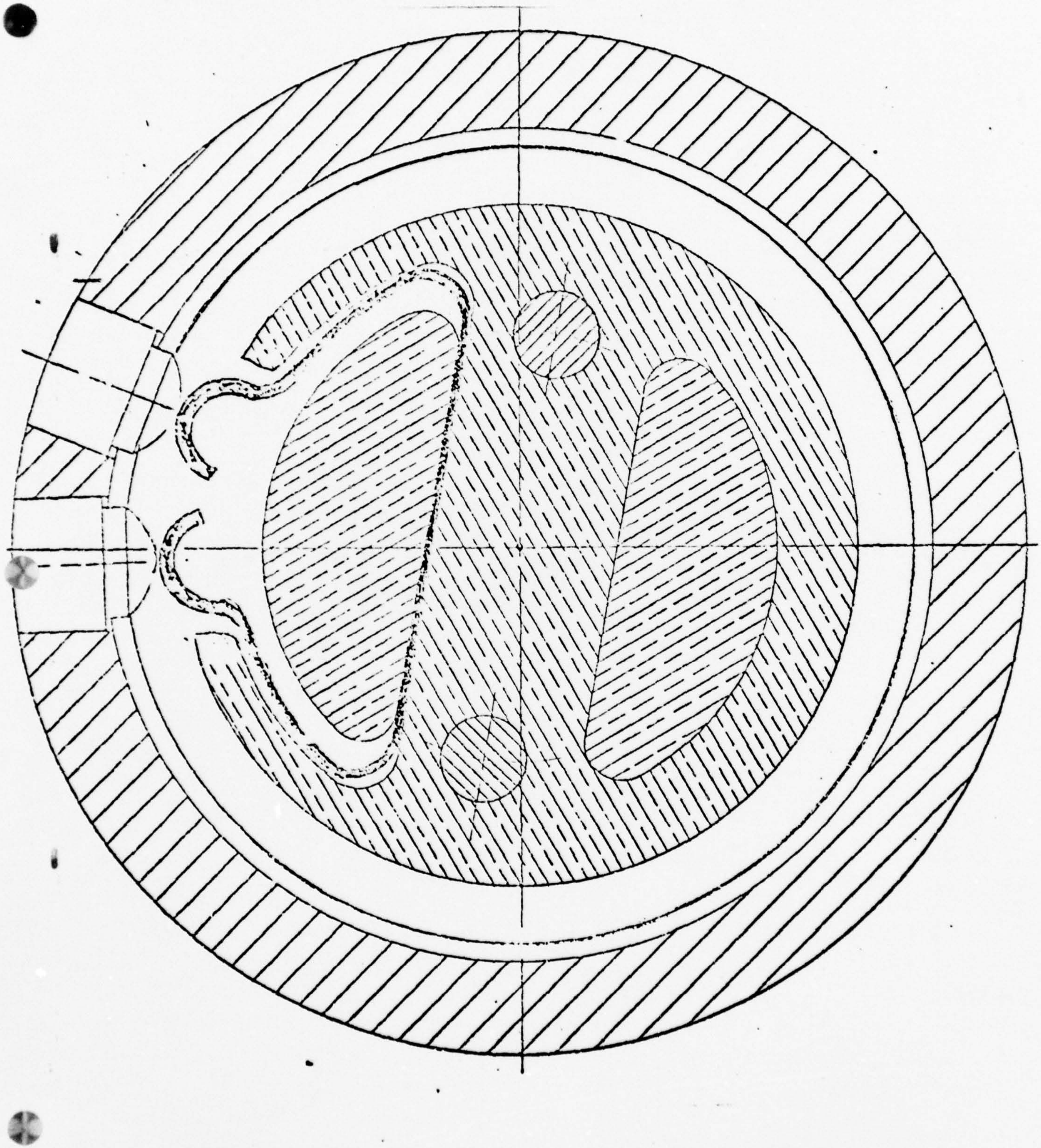


Figure 8. Switch Contact assembly-Monitor Deck

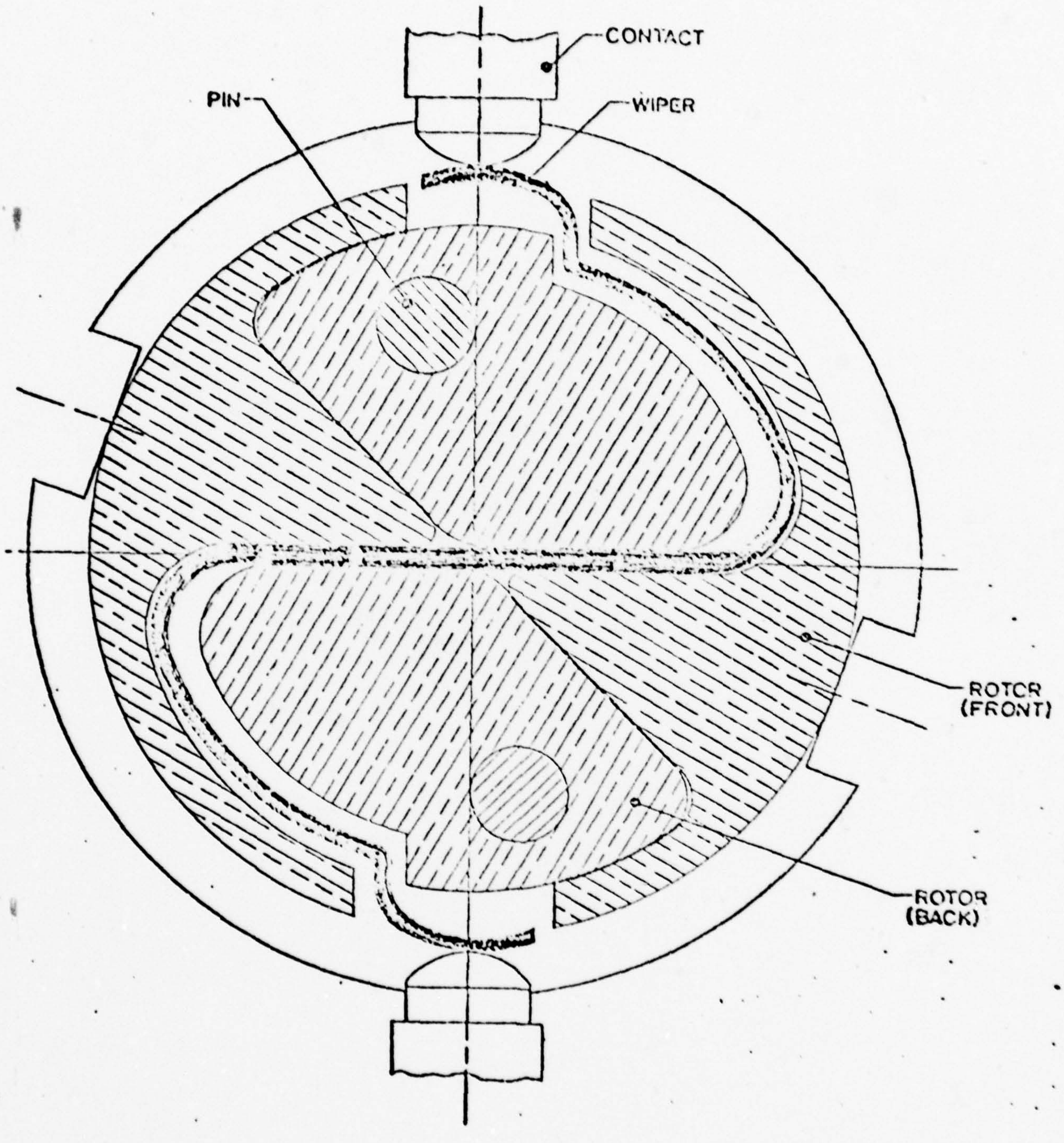


Figure 9. Switch Contact Assembly

provides maximum torque to the Geneva at initiation of Geneva movement and of switch contact(s) engagement. The Geneva design is concave along its sides to fit against a circular shoulder which is part of the drive gear. The shoulder is designed to allow the Geneva to rotate into an opening in it during normal operation. When not driven by the drive gear, the Geneva shoulders against the drive gear, thereby locking it in either the safe or armed position. An additional locking feature is a ball detent which secures into a cutout in the Geneva when in the armed position.

A light path is provided in the gear train assembly and is used with optical components for generating a feedback signal to shutoff the motor when the switch assembly is in its safe position.

Visual switch status indicators are provided in the driver assembly as part of the drive gear. These provide information as to switch position; safe, armed or intermediate position, through a window in the gear drive housing cover.

4.5.1 Reset Mechanism

The final area of the Geneva/gear drive assembly to be discussed is the mechanical reset mechanism. The purpose of this feature is to return the switch assembly to its safe position should power be lost to the motor during normal drive actuation. Figure 10 shows an exploded view of this mechanism. It consists of a return spring and retainer, a reset latch, a latch stop, and a spring latch (not shown in the figure). The drive gear is fixed to the return spring. As the drive gear is rotated, it winds the spring. Rotation of the drive gear causes movement of the Geneva and Geneva shaft which, in turn, cause rotation of a latch stop which is pinned to the Geneva shaft. This latch stop forms a restraint for the reset latch and prevents its movement away from the spring retainer. When the latch stop is rotated clear of the latch, the latch is rotated away from the spring retainer allowing the retainer to rotate, thereby dissipating the wound spring energy. Rotation of the retainer causes no movement of the gear drive assembly. The drive assembly continues its normal movement to cause switch closure. Return of the drive assembly via motor power returns all latches to their starting position and the entire device is ready for reactuation. This situation represents normal switch actuation with the reset mechanism releasing its energy as switch closure occurs. If power is lost prior to switch closure and, hence, prior to release of the reset latch, the energy in the return spring will drive the entire mechanism directly to its safe position. A spring latch is included as part of the spring retainer. It acts as the "start position" pad for the spring. As the spring is wound with the drive gear (390°), it flips the spring latch out of its way to allow for greater than 360° rotation. When the spring is released, the latch is flipped back to its "in line" position and retains the spring as it comes around to its initial position. The events which take place as the drive gear rotates through its 390° travel are shown in Figure 11 to summarize the previous discussion of the Geneva/gear drive functional operation.

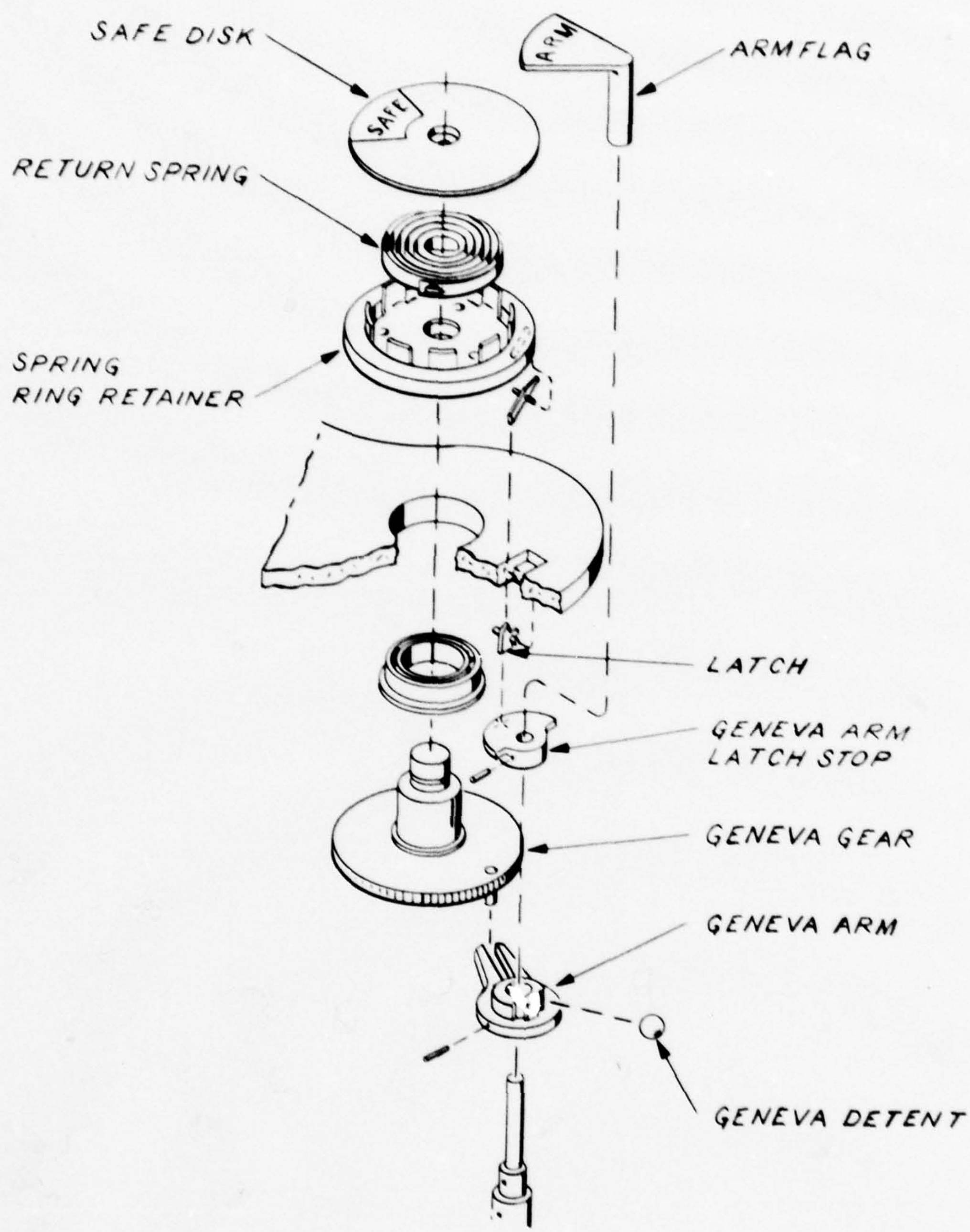


Figure 10. Reset Mechanism (Exploded View)

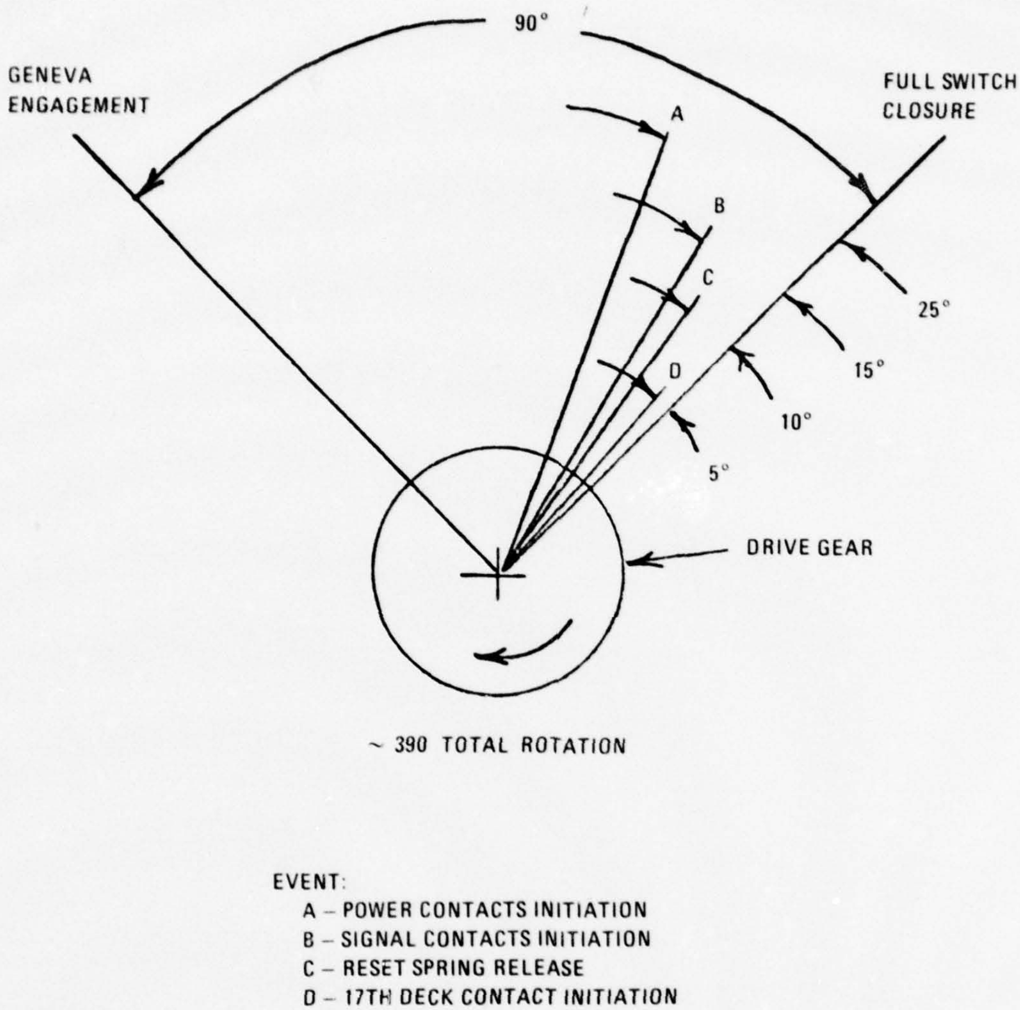


Figure 11. Enable Switch Drive Critical Events

5.0 E/OD MECHANICAL PACKAGING DESIGN

5.1 Description

The mechanical package of the E/OD prelimimary operational model is shown in figure 12. Its volume is approximately 78 cubic inches, three times the volume of the "production configuration" unit given in the contract scope of work. The increase in volume of the preliminary model is a direct result of using a breadboard approach to the electronics during Phase I. The weight is 3.5 pounds which is approximatley 40 percent greater than the specification for the "production configuration" units.

5.2 Background

In accordance with direction from the Contract Project Office, the development of the E/OD electronics was to be advanced breadboard configuration. This permits maximum flexibility for changes in functional requirements as development progresses. The initial Phase I packaging concept used dual-in-line packs on wire wrap boards. This concept resulted in a package size for the preliminary model of approximately ten times the "production version hardware". The unit would weigh several times "production version" weight and little knowledge regarding thermal analysis, could be obtained from such a configuration, EMI investigations, or any limited environmental testing. Likewise, a unit of this size would be out of balance with other adaption kit units for interface work to be done by Picatinny Arsenal.

For these reasons, a second approach, as explained in paragraph 5.3, was considered and greatly reduced preliminary model size and weight.

5.3 Design Approach

The prototype model design approach utilized flat pack CMOS devices on insulated ceramic substrates. The substrates were developed for missile application to isolate heat, shock, and vibration. They consist of a ceramic layer with thick filmed ground and power conductors as well as mounting patterns for 16 pin flat packs and edge connector pads printed on the surface. The ceramic layer is bonded to a layer of silicon rubber which, in turn, is bonded to a thin aluminum mounting plate. The rubber layer provides the thermal and mechanical isolation and the metal plate provides a means of mechanically securing the substrate to the unit. Discrete resistors, capacitors, and diodes are also mounted on the substrate as the design dictates. A substrate and layer of rubber are mounted on each side of an aluminum plate in the E/OD model to increase packaging efficiency.

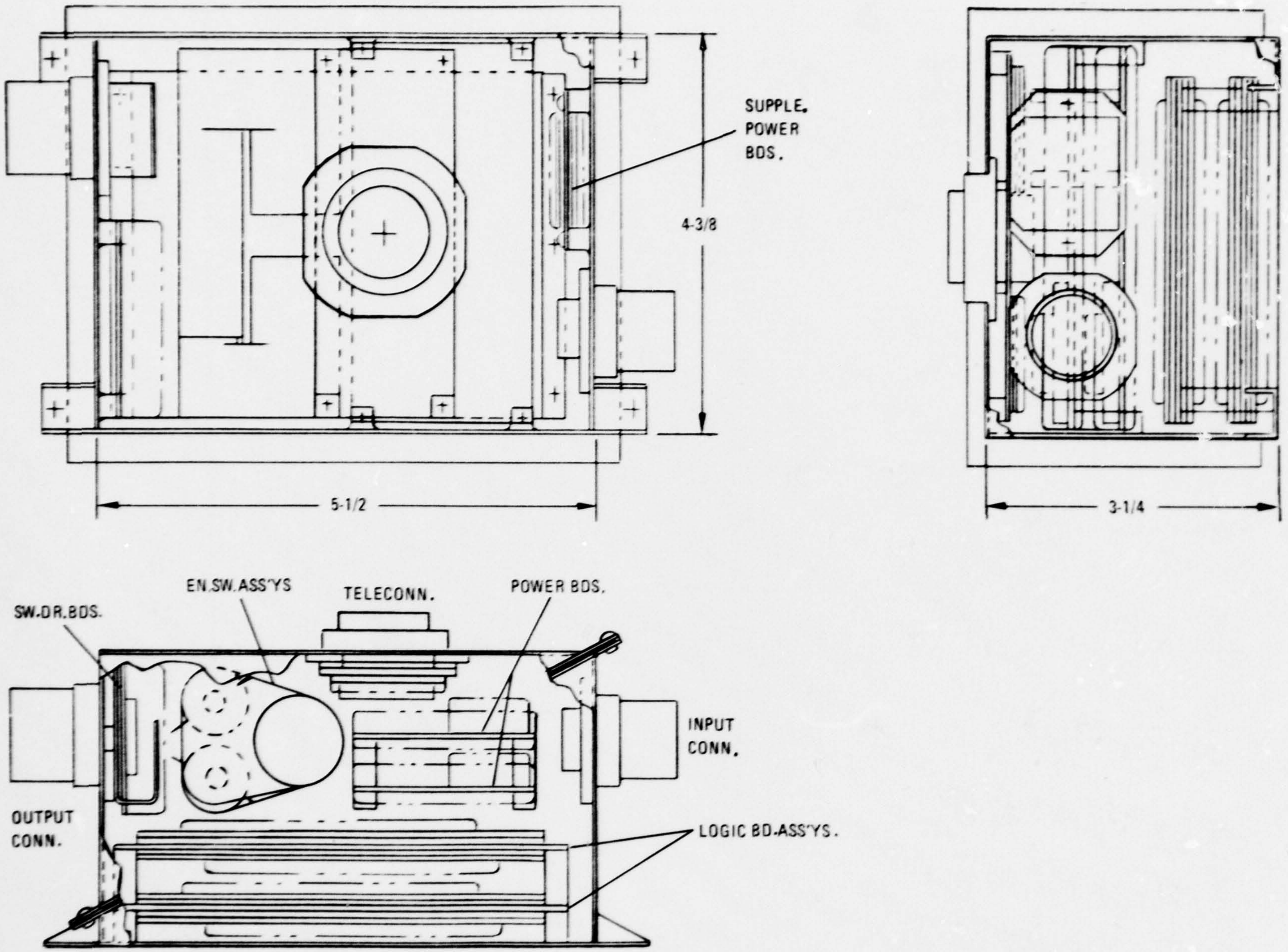


Figure 12. E/OD Preliminary Operational Model

In addition to the ceramic substrates which contain the electronic logic, power boards are provided to contain the isolation and regulator circuits. Referring the figure 12, the input signals from J1 connector enter the unit and flow to the power boards and logic boards located adjacent to the connector. The output of the power boards also connects to the logic board input. The output from the logic boards occurs at the opposite end from the input and goes to the input terminals of the enable switch assemblies and to the switch driver board located adjacent to the substrates. The switch driver board is connected to the enable switch motors. The output from the enable switch jumpers to the output connector J2. Telemetry points running to J3 are jumpered from the output of the logic boards. The preliminary model signal flow is effective in that no redundant wiring exists and cabling lengths are minimized.

The housing is a split construction type providing maximum accessibility to the hardware during assembly and test. The bottom section contains the input connector, power boards, and logic boards. These can be pre-wired as an assembly and installed into the housing. The upper section contains the switch driver board, the enable switch assemblies, and the telemetry and output connectors. They can also be pre-wired and installed into the upper housing leaving only the wiring from the logic boards to the enable switch and switch driver board for final assembly interconnection work. Transparent EMI shielded windows in the upper housing walls allow for monitoring of the switch visual status indicators. In addition to providing good accessibility, the split housing construction provides inherent rigidity to the housing walls. The housing is 0.040 thick aluminum sheet metal construction with brazed seams. Angled channel pieces are brazed to the unit base for mounting feet. All mounting bosses and flanges are brazed to the walls of the unit, resulting in a lightweight, high strength enclosure.

5.4 Weight Analysis

A preliminary model weight breakdown is provided in Table 1. The advanced model weight assessment is contingent upon refinement of the electrical and mechanical design, including: replacement of flat pack devices with integrated hybrid circuits; replacement of low wattage discrete resistors with thick film resistors; replacement of hard wire interconnections with printed cable; replacement of low wattage discrete capacitors and diodes with "chip" versions of the same combined in hybrid packages; and updated load-time requirements to affect simplified regulator design. Estimates for the advanced model weight is based upon actual weights taken of a non-functioning production configuration model. The 2.5 pound weight goal appears reasonable for production hardware.

TABLE 1 E/OD PRELIMINARY WEIGHT BREAKDOWN

ITEM DESCRIPTION	WEIGHT (LBS)	DERIVATION *	ADV. MODEL PREL. ASSESSMENT
ENABLE SW. ASS'Y	1.17	E	1.10
CONNECTORS	.16	A	.16
LOGIC BDS	.83	A	.15
POWER BDS	.44	A	.40
SW. DR. BD	.07	A	.07
TELE. BDS	.04	A	.04
ENCL. (TOP)	.23	A	.15
ENCL. (BOTTOM)	.30	A	.24
GASKET	.01	E	.01
CABLING & SOLDER	.05	E	.02
MISC HD'WR	.20	A	.05
	3.50 LBS		2.43 LBS

5.5 Thermal Analysis and Evaluation

The need for efficient regulator design (non-dissipative type) and realistic load-time requirements for a unit whose production configuration total surface area is approximately 55 square inches with a height of 2.0 inches, is shown in figure 13. An E/OD unit dissipation of 7.5 to 8 watts, using a non-dissipative power regulator, results in a unit temperature rise substantially less than if a dissipative regulator were used.

Assuming that 1.5 to 2.0 watts can be dissipated via conduction, as preliminary calculations indicate, the remaining heat (6 watts) must be released via convection and radiation. Dependent on ambient sink temperatures, the container skin temperature rise is shown for 0.1 watts/in^2 (6 watts total) dissipation as 10°C. The internal unit air temperature is approximately twice this thermal rise, or 20°C (36°F). For a maximum ambient air temperature of 195°F, per the contract specification, the worst case internal unit air temperature would be 231°F. Although this is not a precise calculation, the curves do provide a feeling for the operating temperatures which may be encountered. The conducted heat transfer estimate is based on a honeycomb sandwich mounting plate whose thermal resistance factor is 0.055 HRFT^{2}F/BTU-IN. This assumes use of a low-density aluminum core material and aluminum facing bonded by a good grade of thermal conductive compound. If no conduction is assumed, the thermal rises give above would increase approximately 25 percent. Experiments performed on a dummy thermal production model of the E/OD show these figures to be conservative. Figure 14 shows a plot of temperature points where no conduction was present, the ambient temperature was maintained at 195°F, and heat dissipation was maintained at 6 watts. Internal air temperature rose to 230°F under these conditions. If conduction were included in this experiment, a 220°F air temperature could be expected. A point on the curves corresponding to 0.62 watts/square inch (32 watts total) dissipation is given representing the use of a dissipative type regulator. It should be clear that with the load-time curve given for the E/OD, a dissipative type regulator cannot be considered without approaching unit air temperatures of 360°F. From this, the need for a non-dissipative type regulator was obvious. A non-dissipative "chopper" type regulator was designed and used in the preliminary model. This type of regulator was found to perform approximately 80 percent efficient and resulted in a 3 watt heat dissipation per channel. The total dissipation for the entire E/OD was found to be 8 watts. Based on thermal experiments conducted on the non-functioning production configuration model, the results indicate the compatibility of the unit size with the internal heat dissipation requirements to yield a maximum internal unit air temperature of 220°F. This temperature is acceptable based on reliability assessments of components operating at this temperature.

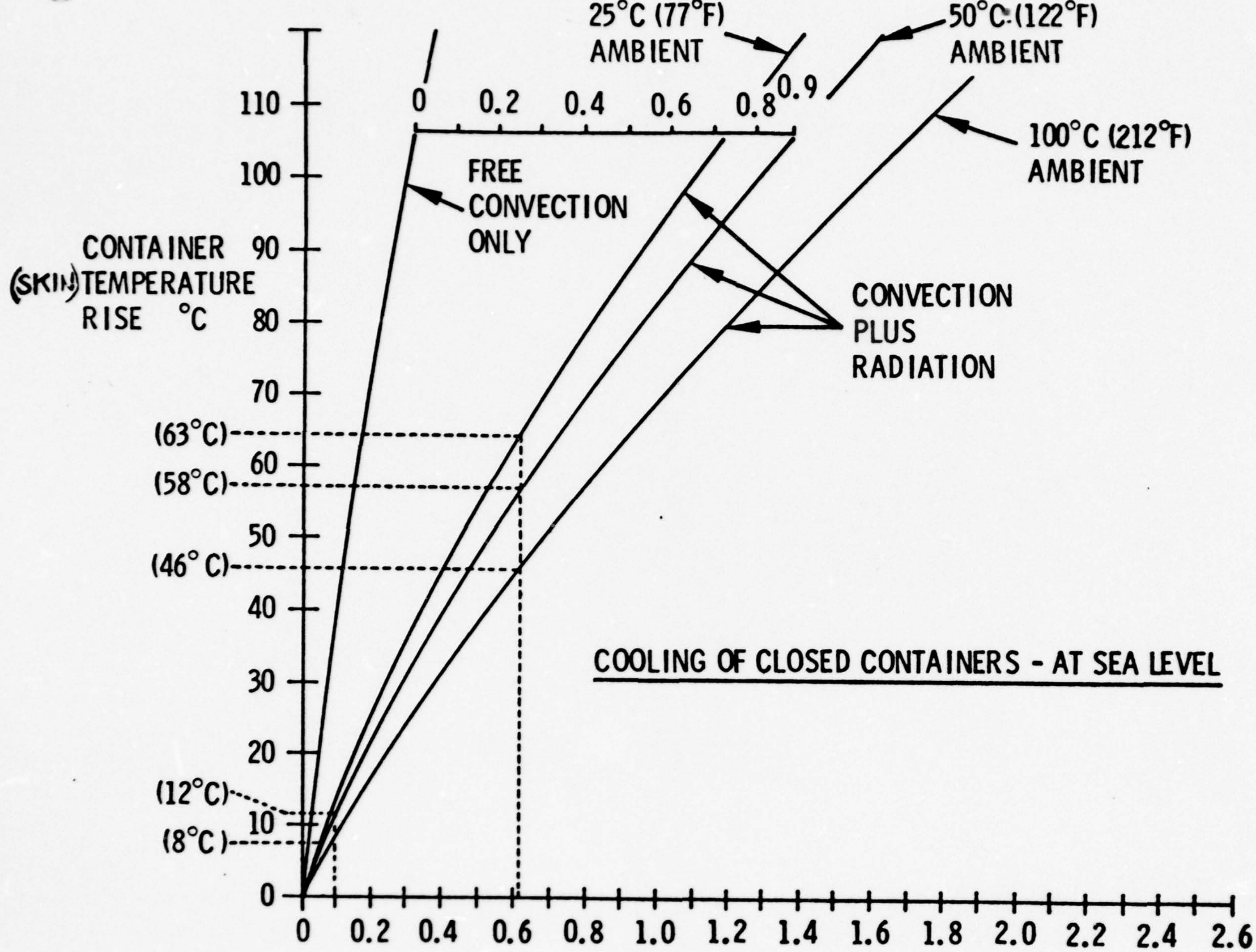


Figure 13. Watts Dissipation per Square Inch of External Surface

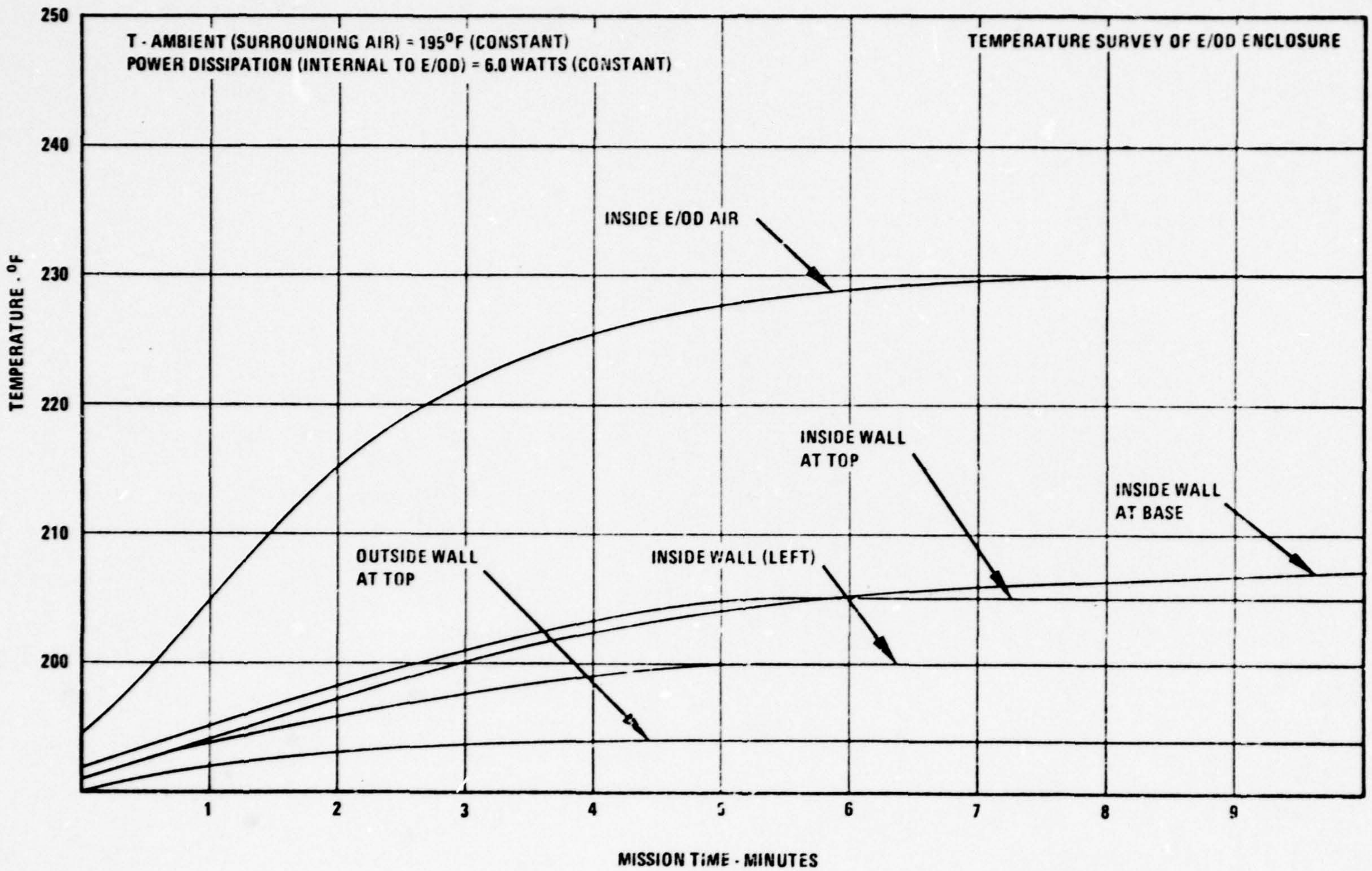


Figure 14. Plot of Temperature Points

A thermal analysis computer program was used to further refine the previously stated information. The computer program provided for consideration of varying electrical loads (see figure 15) and varying thermal sink temperatures for conduction, convection, and radiation (see figure 16 as a function of time.) The results of the computer analysis, as shown in figure 17, give the temperatures at three points in the E/OD and agree reasonably with the previous discussion.

5.6 Connector Pin Assignments

The use of printed cable in production type hardware necessitates the assignment of connector pins such that power and return lines occupy the outer pin perimeter. This allows accessibility to interior pins while minimizing the number of cable layers. Figure 18 shows a layout of output connector J2 and the pin assignments which will readily adapt to printed cabling. Consideration should be made for all connectors pin assignments during the early phases of system development to permit the use of lightweight printed cabling in all portions of the Pershing II A.K. system where practical.

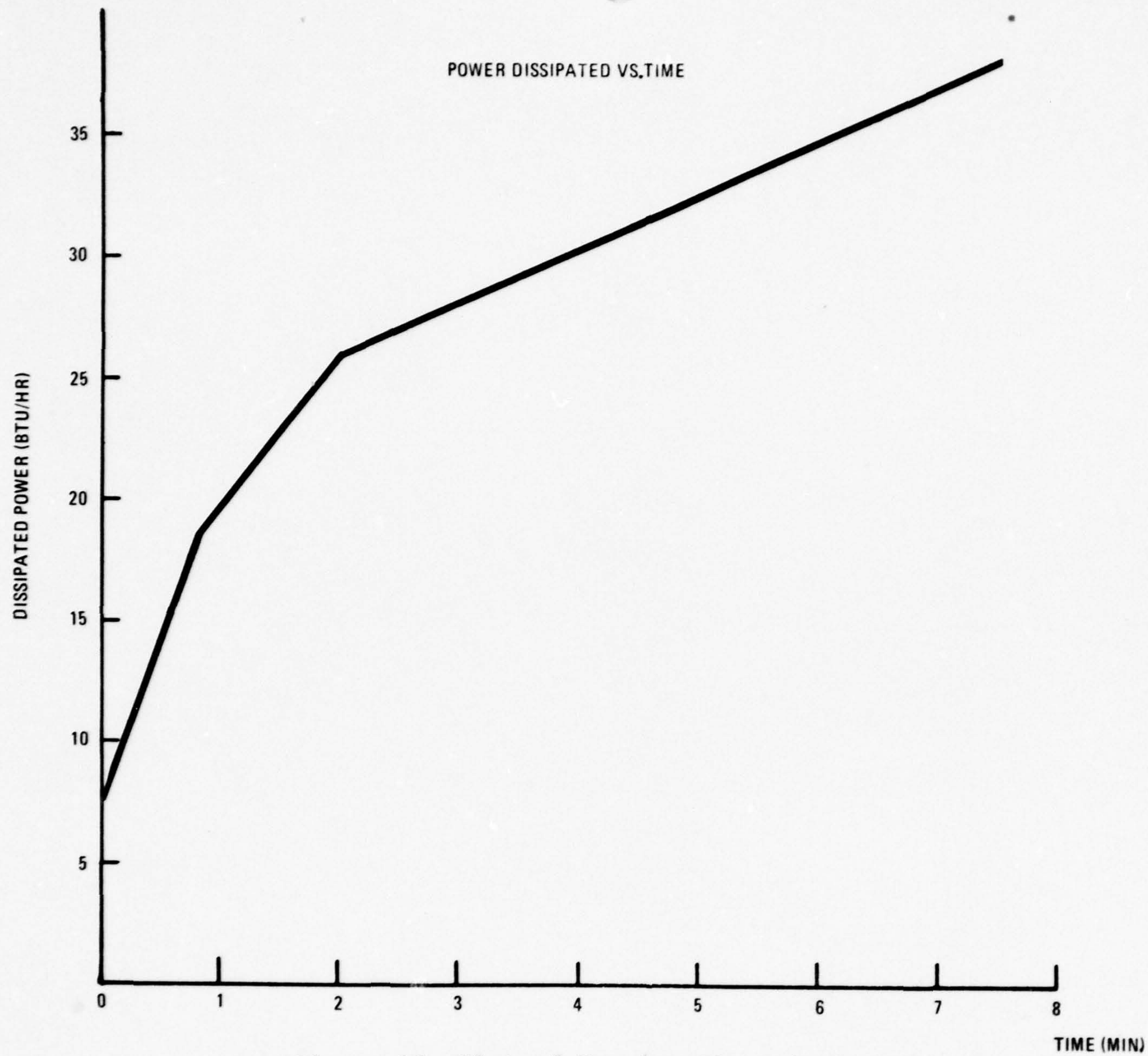


Figure 15. Plot of Varying Electrical Loads

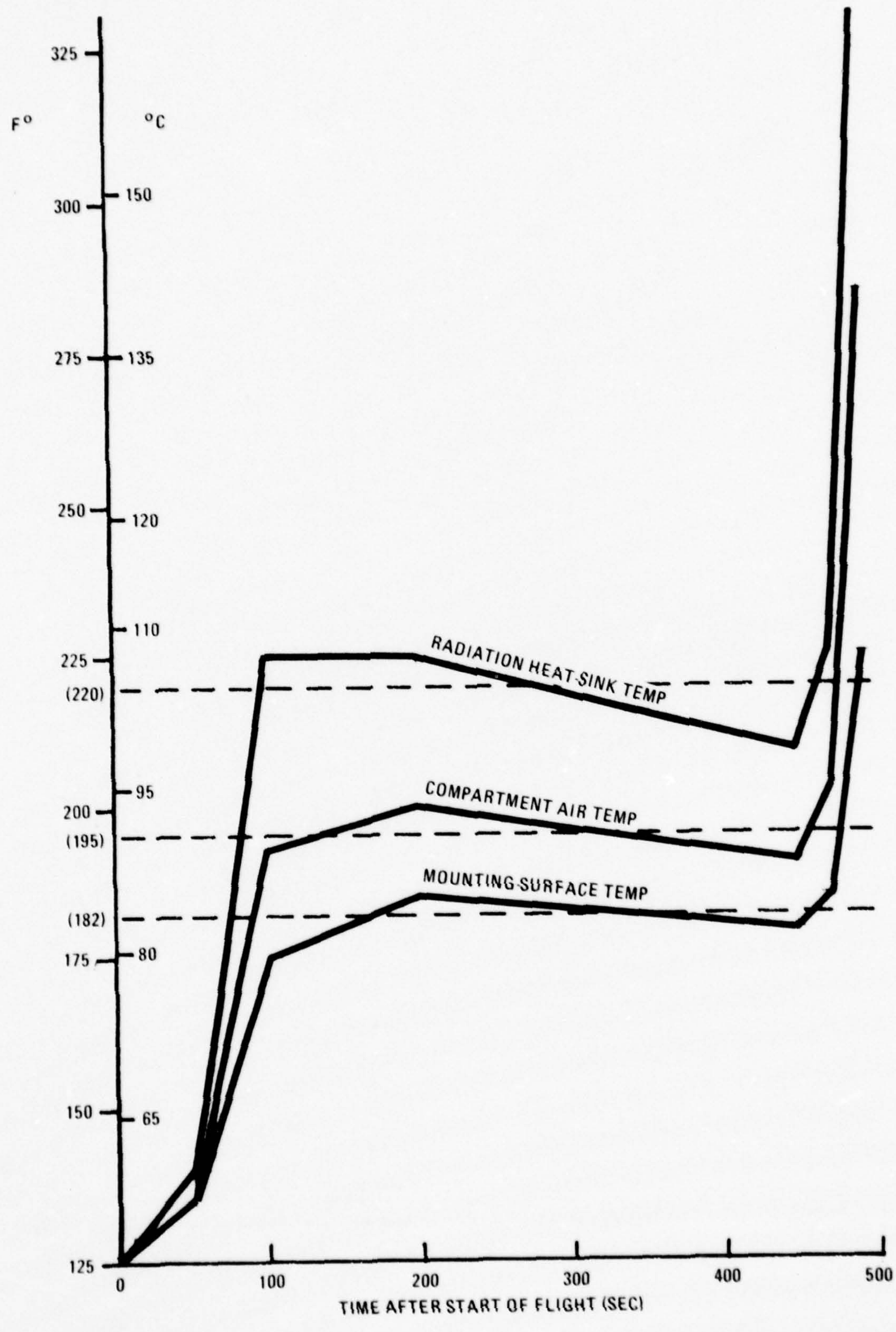


Figure 16. Thermal 6 Profile/Flight Time

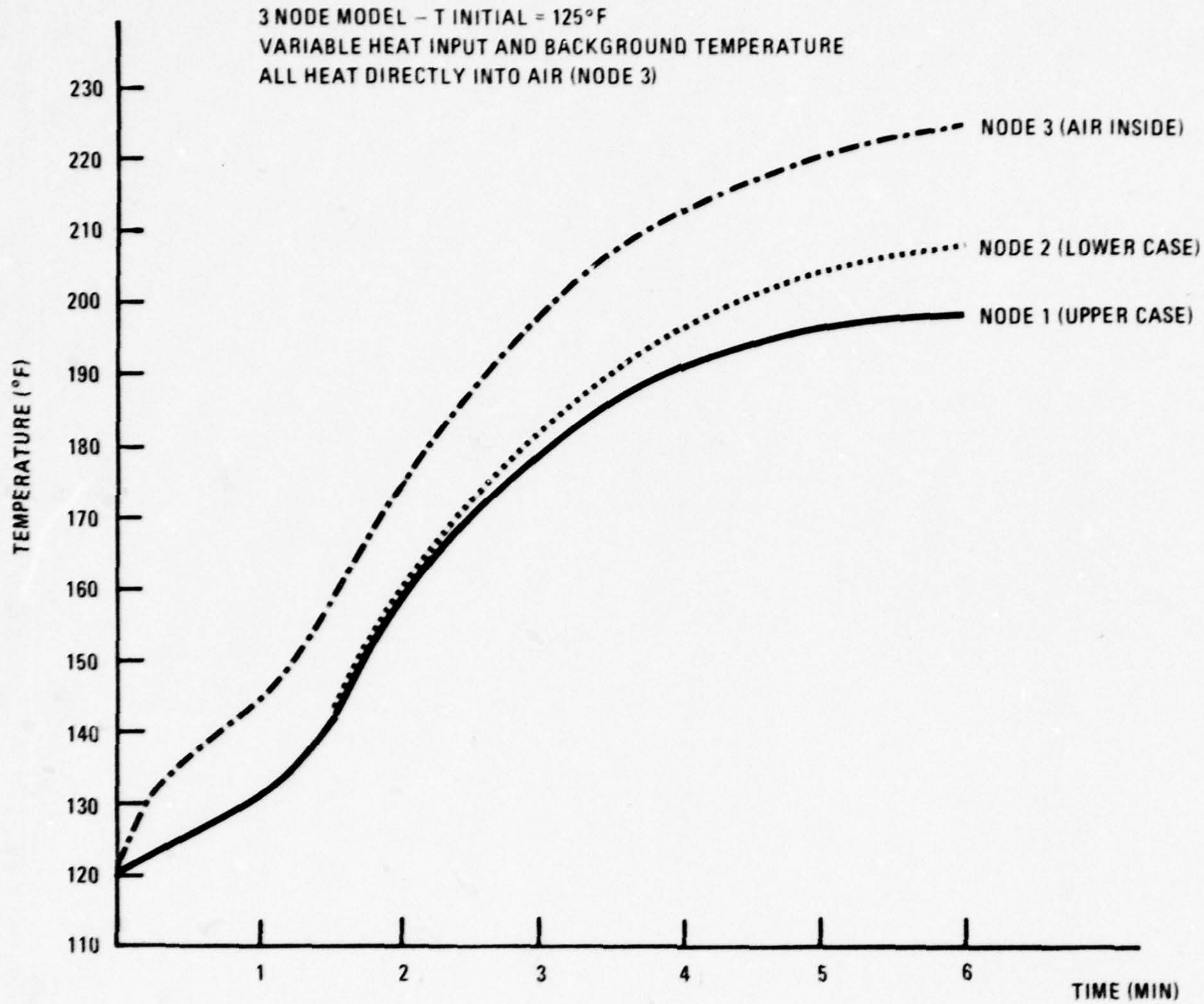
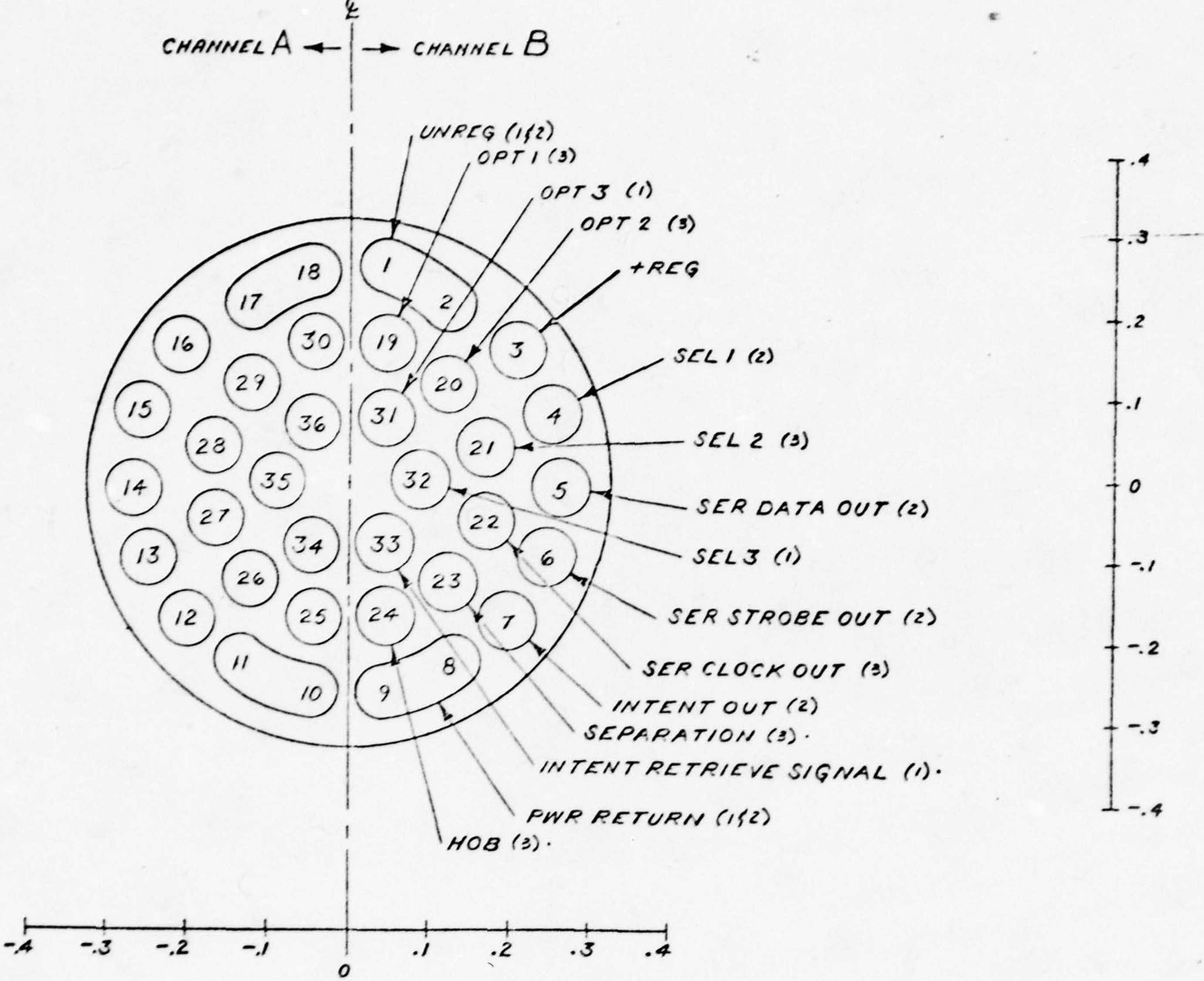


Figure 17. Results of Computer Analysis



NOTE:

1. NUMBERS IN PARENTNESIS ( ) REPRESENT THE LAYER OF THE PRINTED CABLE WHICH CARRIES THAT SIGNAL.

Figure 18. J2 Connector Pinouts

6.0 TECHNICAL DATA PACKAGE/CDRL ITEMS/SCHEDULE OF DELIVERABLE ITEMS

6.1 Technical Data Package

A drawing package was generated as the designs of the Enable Switch Assembly and overall E/OD were developed. The drawings were made to "good commercial practice" for future conversion to military format. Drawings will also be generated for special test equipment.

6.2 Contract Data Requirements List Items (CDRL)

CDRL items as required by contract specifications were generated and submitted to ARRADCOM in accordance with contract requirements. These included an engineering technical data package, an interim technical report, monthly cost and performance reports, Safety and Reliability Assessments and a final technical report.

6.3 Schedule of Deliverable Items

The schedule of deliverable hardware and technical data under this contract includes:

(1) - Preliminary E/OD model (incl. (2) Enable Switch Assemblies)

(1) - E/OD Model test set and Associated Acceptance Test Procedure

\- - Spare parts of portions of the electronics euqipment

(1) - E/OD TDP (engineering format) including test set documentation and enable switch drawings.

(1) - Enable Switch Assembly test set and Associated Acceptance Test Procedure.

7.0 CONCLUSIONS AND RECOMMENDATIONS

An E/OD preliminary model was successfully built and tested.

Considerable effort was given to the design of the Enable Switch Assembly to minimize component size and weight. Prudent choice of Switch Assembly materials and processes resulted in a subassembly which can withstand high temperature and humidity conditions. The switch housing was designed to form a ruggedized enclosure surrounding the ceramic rotor section protecting the switch from transportation and operating shock. The use of a Geneva gear drive mechanism provides a 1 - 2 second time delay as required between motor drive and switch movement. The use of a lightweight high power motor resulted in the weight of .585 pounds per switch assembly. A spring reset feature was included in the Geneva gear drive to return the switch to the safe position in case of power loss during switch actuation. The inclusion of the reset feature reduced component reliability considerably such that additional development to simplify this area of design appears prudent.

The overall E/OD preliminary model weighed 3.5 pounds and occupied a volume of 78 cu. inches. Replacement of the standard flat pack CMOS logic by integrated hybrid devices and utilization of thick film resistor technology would make the production unit goal of 2.5 pounds and 26 cu. inches feasible. The chopper regulator designed for this unit has eliminated the heat build-up problem in the E/OD. This too will allow for reduction in package size for advanced model work. The preliminary model performed all electrical functions to specification.

A test set was designed and fabricated which checked all critical aspects of both switch assembly and E/OD electronic operation. The test set was so designed to be expandable in function for use in subsequent phases of E/OD development work.

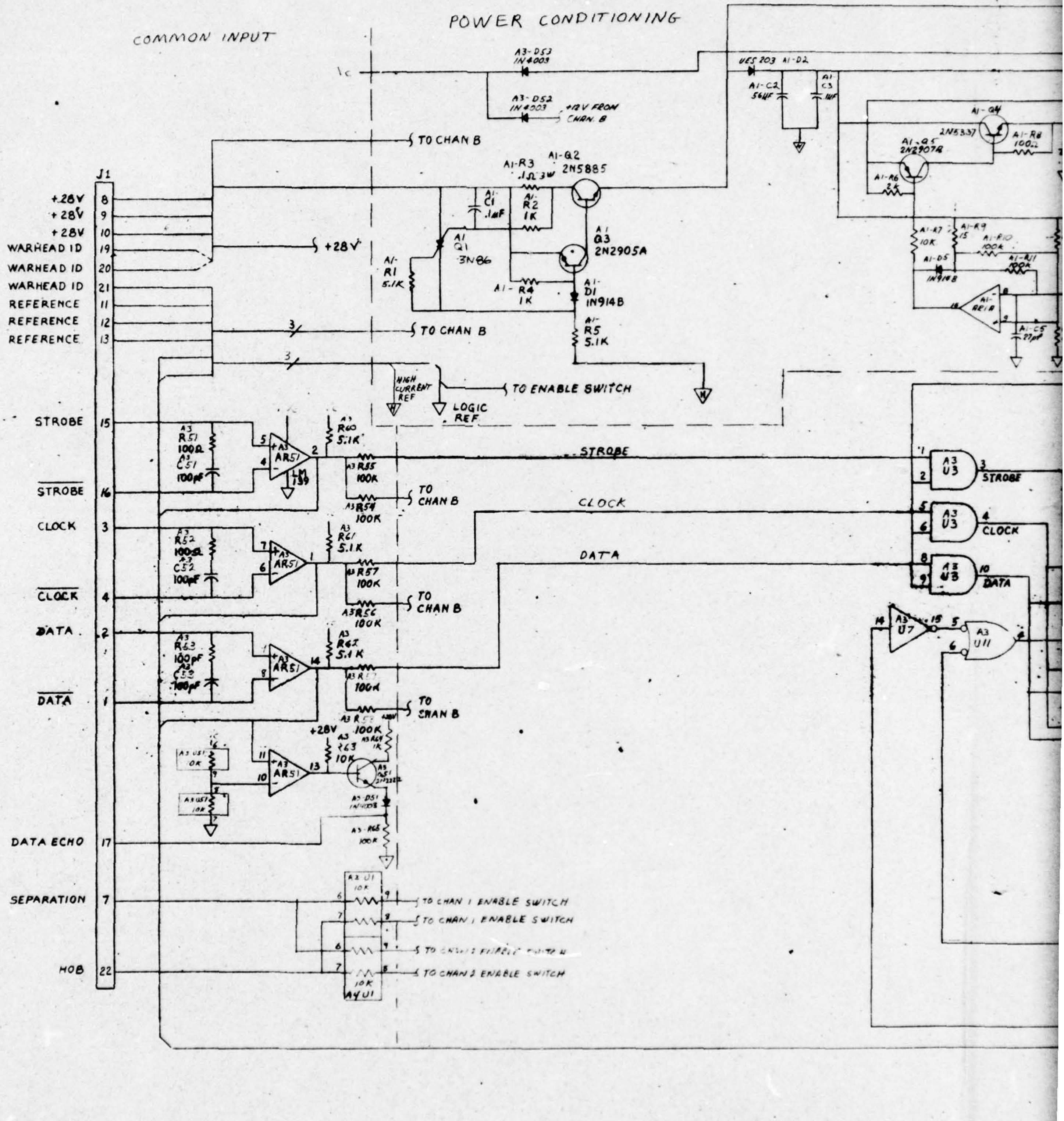
All contract data requirements list (CDRL) items were provided per contract requirements. An engineering data package for the switch assembly, E/OD electronics and housing and test set was provided which was intended to allow complete technical understanding of the design and hardware provided under the contract.

Three major CDRL items dealt with Safety and Reliability Assessments of the E/OD design. These items are included as a separate report due to their complexity and volume.

The Enable/Option Device Design and Development program provide to be highly successful. All contractual requirements as set forth were achievable. Valuable information was obtained concerning switch design approach, E/OD electronics design and packaging and the S & R studies which formed a part of this program. This knowledge will be of great use in subsequent development efforts on the PII system and well as similar missile programs.

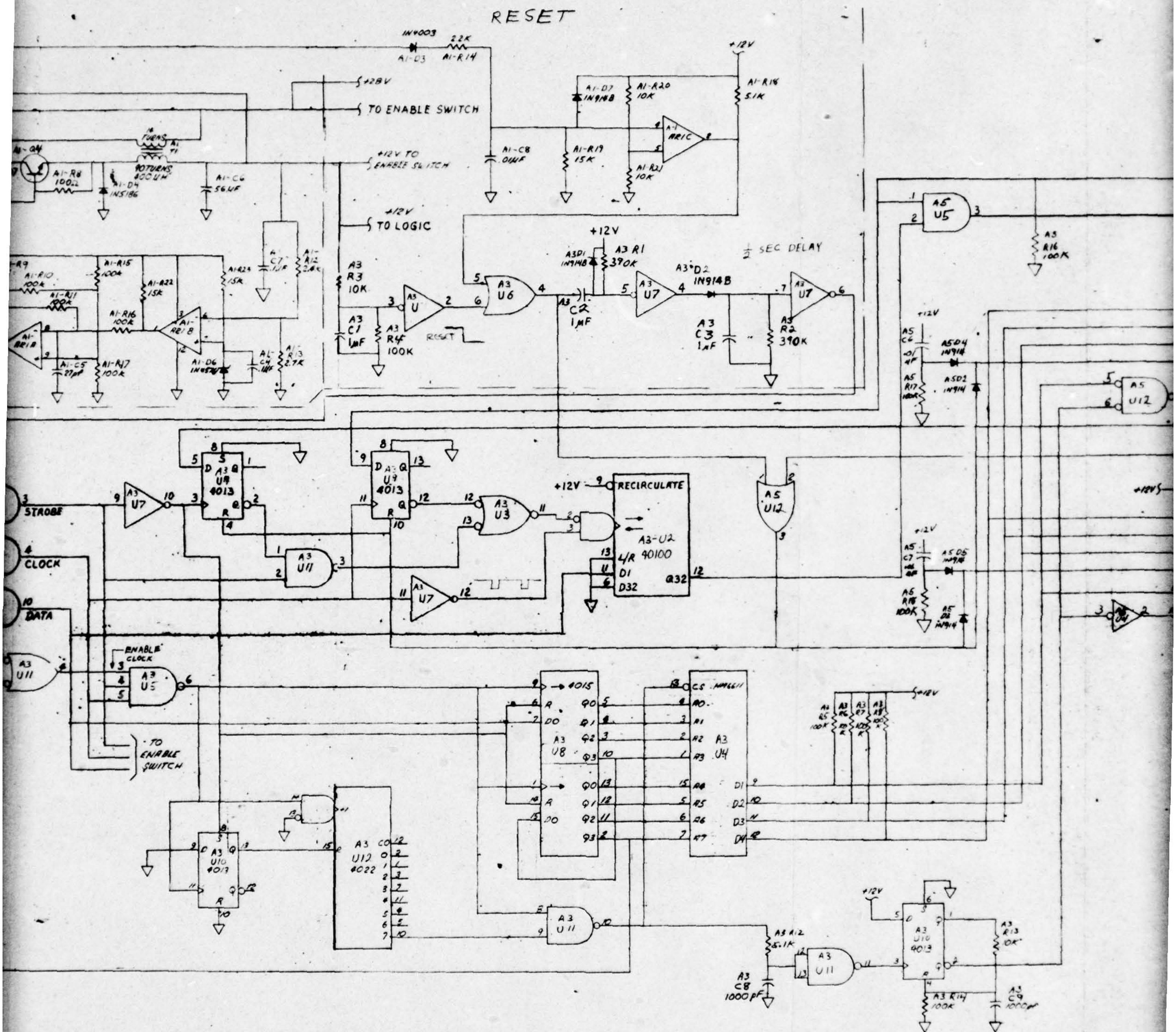
Appendix A

E/OD Logic Diagram Schematic



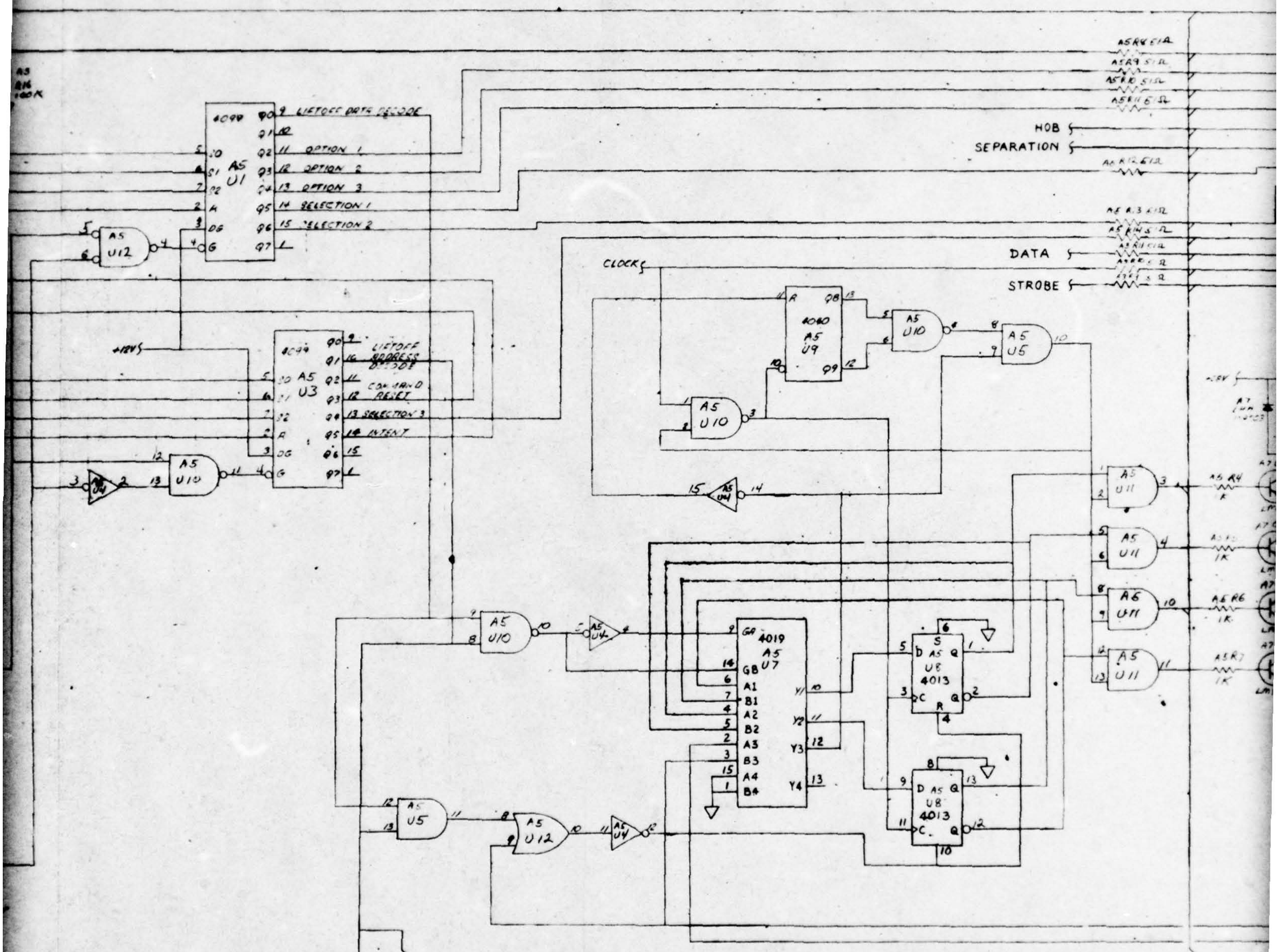
POWER CONDITIONING
COMMON INPUT
J1
+28V 8
+28V 9
+28V 10
WARHEAD ID 19
WARHEAD ID 20
WARHEAD ID 21
REFERENCE 11
REFERENCE 12
REFERENCE 13
STROBE 15
STROBE 16
CLOCK 3
CLOCK 4
DATA 2
DATA 1
DATA ECHO 17
SEPARATION 7
HOB 22
TO CHAN B
+28V
TO ENABLE SWITCH
HIGH CURRENT REF
LOGIC REF
A1-Q2 2N5885
A1 Q3 2N2905A
A1 Q1 3N86
A1-D1 1N914B
A1-R5 5.1K
A3-D53 1N4003
A3-D52 1N4003
+12V FROM CHAN. B
STROBE
CLOCK
DATA
A3 U3
A3 U7
A3 U11
TO CHAN 1 ENABLE SWITCH
TO CHAN 2 ENABLE SWITCH
A4 U1

1

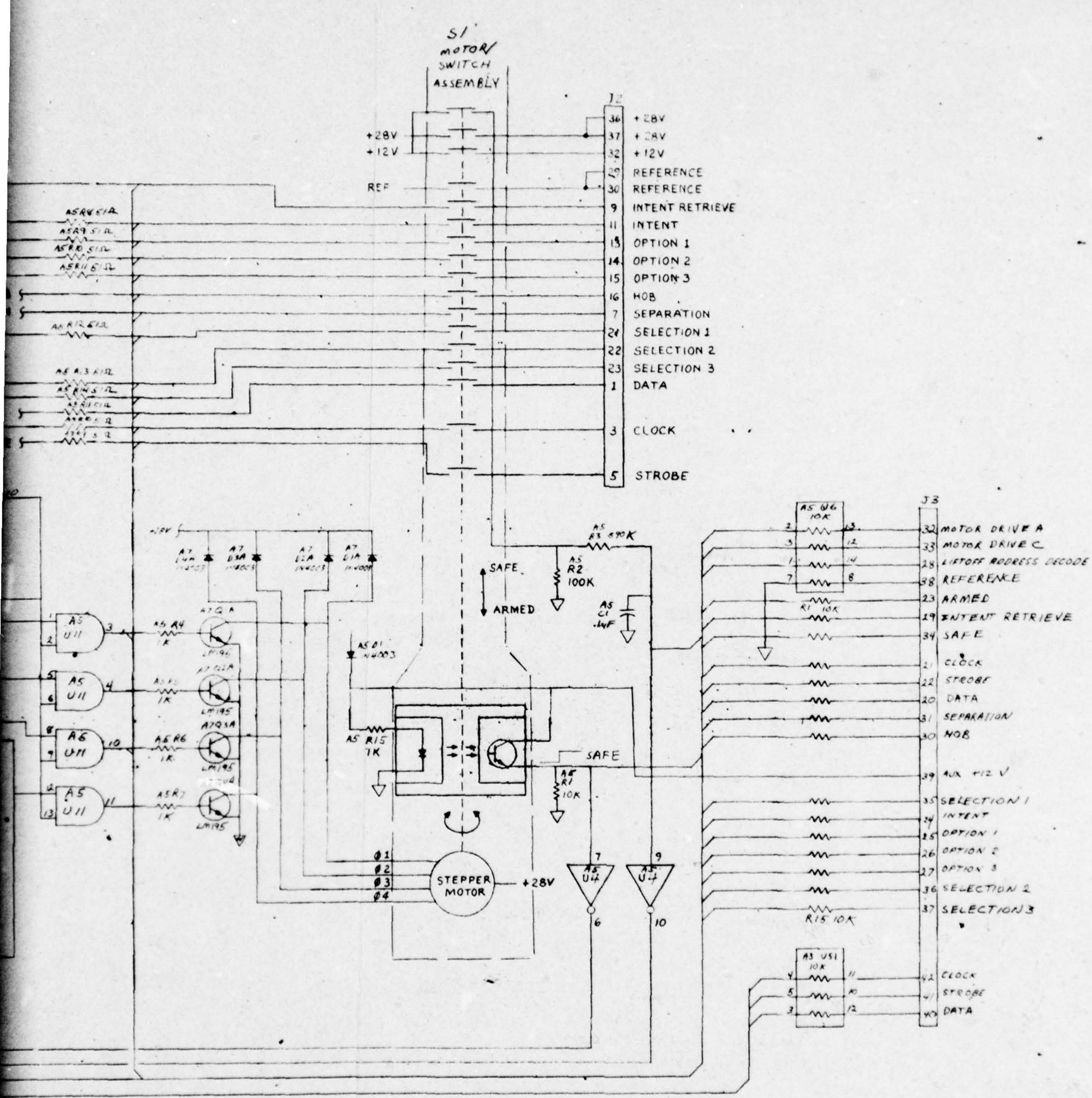


DECODE AND MEMORY

γ



MOTOR DRIVER



E/OD Logic Diagram Schematic

Appendix B

Statement of Work W/S 1360

REVISIONS

REV OR ED	DESCRIPTION	DATE	APPROVED
1	Initial Release	4/6/77	RFN
2	Change Milestone Dates and Para. IV	4/14/77	RFN
3	Change Para. III, IV, VI, VII, VIII, IX, XII Change Appendix A: Safety and Reliability, Para. b, Functional Requirements and Environmental Requirements	5/5/77	RFN
4	Update schedule, eliminate packing requirements; Change Appendix A Functional Requirements - Gear Ratio, Reset Time	6/20/77	RFN

INDEX SHEET

REVISION OR EDITION																				
	4	2	3	4	-															
	3	2	3	3	2															
	2	1	2	2	1															
	1	1	1	1	1															
SHEET	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

Appendix B Iss: 1 44 pages

Including Appendix A Iss: 3 16 pages

☐ PROCEDURES

☐ PROCESS

☐ OTHER

APPROVALS	SIGNATURES	DATE
Engineer	[signature]	6 APR 77
Engineer	[signature]	April 6-77
Proj. Engr.	[signature]	April 6, 1977
Q.A.	[signature]	April 6, 77
Program Office	[signature]	Apr 6 77

LOCKHEED ELECTRONICS COMPANY, INC.
PLAINFIELD, NEW JERSEY

STATEMENT OF WORK FOR
ENABLE SWITCH ASSEMBLY FOR E/OD

SIZE	DRAWING NUMBER
A	W/S 1360

CODE IDENT 87557 SHEET 1 OF 4

FORM LEC 103

STATEMENT OF WORK

ENABLE SWITCH ASSEMBLY FOR E/OD

I. OBJECTIVE

The contractor shall provide design, manufacturing, and test effort to develop an Enable Switch Assembly to meet the total requirements as stated in Appendices A and B, including the revised power loss reset features and power contact requirements as described herein.

II. APPLICABLE DOCUMENTS

The following documents form a part of this Statement of Work. Where conflicts arise between documents, Appendix A will take precedence. Exceptions to these documents must be approved in writing by LEC.

SPECIFICATIONS

Appendix A - Switch, Enable: Requirements of

PROPOSAL

Appendix B - Switch, Enable: Design Proposal for (ref. RFQ DAAA21-76-Q-0528, E/OD-P2)

III. DESIGN

The contractor shall design the Enable Switch to meet the requirement as set forth in the E/OD Specifications in Appendix A, and as proposed by Applied Resources Corp. in response to Solicitation RFQ DAAA21-76-Q-0528 given in Appendix B, with the following changes:

1. A power loss reset feature to mechanically return the Enable Switch Assembly to the "Safe" position upon loss of power will be incorporated. The reset feature will accumulate energy derived from the Enable Switch Assembly stepper motor to return the switch and drive mechanism to the "Safe" (Start) position via a spring if power loss occurs before the switch is committed to the arm position [within 10° (mechanical) of full switch closure on geneva]. This reset feature will be deactivated and the energy derived from the stepper motor dissipated from the spring when the Enable Switch is committed to the "enabled" position. The reset feature will be restored to its initial condition when either power loss occurs prior to "enabled" commit or when command reset returns the switch to its "safe" position. (Command reset, which is a powered reset, occurs when reset is required after the switch is committed to the "enabled" position.) The power loss reset feature will not be a one shot device.

2. As a design goal, Applied Resources Corp. shall try to incorporate the following desirable feature: Arrangement of power signal contacts to provide closure of power contacts prior to closure of signal contacts. If feasible, power contacts will close 10° (mechanical) prior to signal contacts.

3. Although no environmental tests are included in the Phase I effort, the En. Sw. Assy. will be designed to meet the environmental requirements set forth in Appendix A. The paragraphs of the environmental requirements in Appendix A marked "for info only" are not included in the En. Sw. Assy. "design to meet" environmental requirements.

IV. DRAWINGS AND SPECIFICATIONS

The contractor shall provide a Technical Data Package containing drawings and lists on contractor format, identified by contractor document numbers and federal supply code identification number. The data package shall, as a minimum, consist of: details; subassemblies; assembly drawings; and parts lists required to manufacture and test an En. Sw. Assy. including associated test equipment. Copies shall be submitted to LEC, as required, for review and evaluation. Delivery of the data package shall consist of the original drawings of the entire TDP. The drawings must reflect the "as delivered" configuration of the En. Sw. Assy. Traceability of change activity must be provided within the drawings and lists for changes made subsequent to the prelminary design review with LEC. Acceptance Test Procedures will be generated by the contractor and included as part of this effort. (MIL-D-1000 Category E Form 3 should be used only as a guide in the generation of the TDP.)

V. DESIGN REVIEWS

Design reviews will be held with LEC during the design and development portion of the program. A final design review will be held prior to delivery of the Technical Data Package and prior to delivery of prototype hardware.

VI. MANUFACTURING

a. The contractor shall manufacture two (2) En. Sw. Assemblies to be provided to LEC to the requirements set forth in this Work Statement and attached Appendices.

b. The contractor shall design and fabricate the necessary items of special test equipment to perform contractor acceptance tests required under Paragraph VII. Written approval shall be obtained from LEC for this equipment.

VII. TESTING

1. The contractor shall conduct preliminary evaluation tests as required during the En. Sw. Assy. development to assure compliance with the requirements of this document and the Acceptance Test Procedure.

2. The contractor shall conduct "acceptance" tests to procedures and test equipment approved by LEC prior to delivery of the En. Sw. Assy's., including a functional bench test to demonstrate fulfillment of Appendix A requirements.

3. No environmental tests are included in the Phase I effort.

VIII. SCHEDULE

The following milestones shall apply:

1.	Initial design and analyses	7 June 1977
2.	Preliminary Design Review and Technical Data Package	13 June 1977
3.	Final Design Review	5 July 1977
4.	Deliver test equipment documentation and Acceptance Test Procedures for approval	11 July 1977
5.	Deliver two (2) Enable Switch Assemblies	6 September 1977
6.	Deliver Enable Switch Assembly Technical Data Package (engineering sketch format) including test equipment drawings and acceptance test procedures.	8 August 1977

IX. APPROVALS

The following approvals shall be obtained by the contractor:

1. All Enable Switch Assembly preliminary drawings shall be reviewed by LEC Engineering prior to fabrication of the two (2) assemblies.

2. Enable Switch Assembly Technical Data Package shall be approved by LEC prior to acceptance.

3. Test plans, equipment, and procedures shall be approved by LEC prior to initiation of tests on the two (2) assemblies.

X. QUALITY ASSURANCE

1. The contractor shall prepare and submit, to LEC for approval, a Quality Program Plan in accordance with MIL-Q-9858A. Detailed quality planning for the items being procured shall also be provided. The contractor shall comply with the approved plan throughout the duration of the contract.

2. The Enable Switch Assemblies (2) will be subjected to functional bench testing as part of the acceptance testing.

APPENDIX A

ENABLE SWITCH ASSEMBLY REQUIREMENTS

The Enable Option Device (E/OD) acts as the key interface subassembly between other adaption kit subassemblies and the Pershing II Missile. The E/OD is a dual channel device. The E/OD contains two multi-deck rotary switches, each independently driven by a four phase stepper motor through a gear drive. The switch, motor, and drive constitute an Enable Switch Assembly.

The following paragraphs provide the design requirements for an Enable Switch Assembly (En. Sw. Assy.).

PHYSICAL REQUIREMENTS

The envelope shown in Figure 1 represents the configuration which is to be used as a baseline. The final configuration shall be coordinated and approved by LEC. The Enable Switch Assemblies will be designed to provide an interlocking configuration of two assemblies as shown in Figure 2.

The weight of the assembly must be minimized. A design limit of .550 pounds maximum for each Enable Switch Assembly must not be exceeded.

DURABILITY REQUIREMENTS

The En. Sw. Assy. shall be designed for a minimum stockpile life of twenty (20) years during which, except for short periods, it will be either in an RF/weather sealed container or an interior part of the unsealed assembled missile.

The En. Sw. Assy. must be capable of being functioned at least 100 cycles after completion of all acceptance testing without degradation.

RESET AND STATUS VERIFICATION

For test and evaluation, the switch decks (referred to as the Enable Switch) should be electrically resettable. This reset capability must be accomplished without degrading reliability or safety.

There shall be the following means of visually verifying the position of the En. Sw. Assys. to assure that they are in either the safe or the enabled position:

a. When indicating an unarmed condition, the indication shall show the marking "SAFE" in a green background.

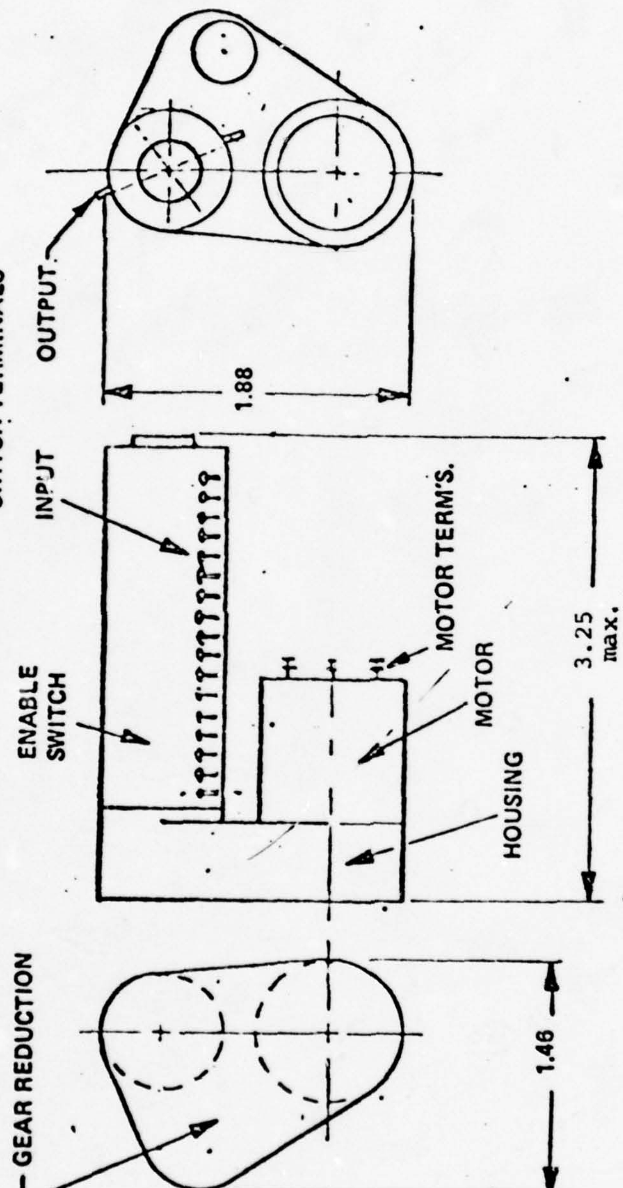


Figure 1. Enable Switch Assembly

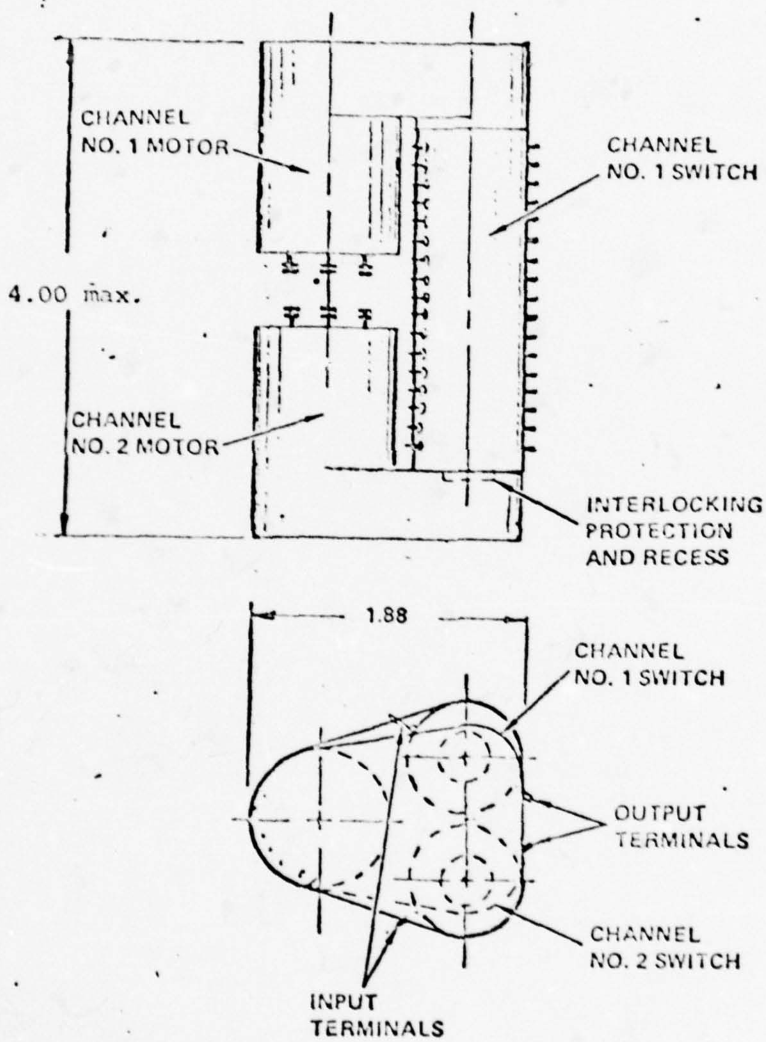


Figure 2. Enable Switch Interlocking Design

e. Insulation Resistance. When tested in accordance with Method 302 of MIL-STD-202, the minimum insulation resistance of the Enable Switch shall be 50 megohms. The following details shall apply:

(1) Insulation resistance shall be measured between each input connector pin and case.

(2) Insulation resistance shall be measured between each output connector pin and case.

(3) Test Condition B (500V DC ±10%) of MIL-STD-202 applies.

TESTABILITY

There shall be no "one shot" (i.e., explosive switches) devices employed in this subassembly. The En. Sw. Assy. must be completely testable without replacing hardware or refurbishing prior to retest.

FUNCTIONAL REQUIREMENTS

When "Lift-Off" is received, the E/OD logic shall decode this signal and shall then cause the En. Sw. Assy. to transfer from the safe to the enable position. The electronics will drive a four phase stepper motor which, in turn, shall control the contact position of the Enable Switch.

The E/OD will contain two En. Sw. Assys. each made up of 17 sets of normally open contacts and a four phase stepper motor which controls the contact position. Functional contact designations will be coordinated between LEC and the subcontractor.

The lift-off signal represents actual motion of the missile as it leaves the launcher. The motor must drive the Enable Switches from the Safe to the Enable position in less than two seconds but shall require at least one second; i.e., contact transfer will actually occur in flight.

The motor shall complete at least 80% of its total motion before the contacts begin to move from the Safe position. Only during the last 15% of motor motion do the contacts actually become enabled.

The timing requirements will be met using a 90 degree per step motor with an input to output ratio to be defined and fixed within a range of 44:1 to 56:1 and the E/OD electronics master clock for timing at 122Hz.

The driving motor shall require less than one ampere per phase at 28V DC for driving power (on a two out of four drive sequence, each motor may draw up to two amperes per pulse). Pulse duration will be 8.192 msecs.

Should power to the Enable Switch Assembly drive be lost before the switch contacts are committed to the "enable" (closed) position, the LEC electronics shall electrically disconnect power from the enable switch motor drive, and the contacts and the drive shall automatically reset to the safe position without reapplication of power required. The time to reset the entire Enable Switch Assembly in and by itself, while all connections are open-circuited except for connections required for bench test monitoring purposes is one second as a goal. The time to open all switch contacts will be 250msec maximum. This feature is in addition to a command reset feature which will use the stepper motor and gear drive in conjunction with the LEC electronics to reset the switch assembly after the contacts are committed to the "enable" position.

There shall be some mechanical means of holding the switch in the safe and the enable position (such as a detent).

All switch contacts shall be open when the Enable Switch is in its "safe" (Start) position.

In addition to meeting the other requirements herein, the contacts shall be capable of carrying 7.5 amperes steady state and shall be capable of switching a 28V DC, 5 ampere resistive load.

The Enable Switch Assembly will provide a feedback signal to the E/OD electronics indicating the "safe" (start) position of the entire assembly.

The Enable Switch will provide a separate switch deck for use in monitoring closure of all switch contacts.

ENVIRONMENTAL REQUIREMENTS

The environmental requirements are covered in three distinct categories: normal; extraordinary; and abnormal. During and/or after the normal environments, the Enable Switch Assembly must function properly. The extraordinary environments are system requirements to which the system will be exposed and the Enable Switch Assembly experience indirectly when assembled into the system. Following exposure to the extraordinary environments, the system is expected to operate properly and, therefore, also the Enable Switch Assembly. The extraordinary environments are also listed below only for information and possible future coordination with the contractor. Abnormal environments are covered in Paragraph "c" below. These environmental requirements are included herein as "design to meet" requirements in that no actual environmental testing is included in this phase of development.

a. Normal Environments - The normal environments encountered during storage and operations, conducted prior to missile launch, may be experienced intermittently over a period of 20 years. At any time during this period the En. Sw. Assy. (ESA) shall operate properly after experiencing the environments of storage and operations and while experiencing the normal in-flight environments. Proper operation is to be evaluated based on meeting the reliability requirements specified for the ESA. Each of the normal environments to be considered in the design are defined below. Appropriate design analysis which presents evidence that materials used are not susceptible to the effects of the environments, evidence of adequacy of sealing, and inclusion of design features and manufacturing controls to preclude detrimental responses when exposed to the environments shall be considered in determination of whether a particular test is required to be conducted in subsequent phases.

(1) High Temperature - Prolonged exposure at 52°C (125°F) will be experienced during storage with daily excursions above 52°C (125°F) during which no more than 4 continuous hours will be above 68°C (155°F) and the air temperature extreme of 71°C (160°F) will not exceed an hour in duration. Solar radiation will not be present and air movement will be negligible. Procedure II, Method 501.1, MIL-STD-810 may be used to evaluate susceptibility to the high temperature storage environment except that the basic 12 hour cycle is to be 6 hours at 52°C (125°F), rise to 68°C (155°F) in 1 hour, hold at 68°C (155°F) 1 additional hour, rise to 71°C (160°F) in 1/2 hour, hold at 71°C (160°F) 1 additional hour, lower to 68°C (155°F), in 1/2 hour, hold at 68°C (155°F) 1 additional hour, lower to 52°C (125°F) in 1 hour, and operate at the end of the last cycle only and while at 52°C (125°F). During missile flight, the temperature will increase with a sequence such that the highest temperature sequence will be:

O_f (sec)	T_c (^oF)	T_R (^oF)	T_m (^oF)
0	125	125	125
50	135	140	135
100	193	225	175
200	200	225	185
450	191	210	180
470	203	225	185
490	285	340	225

O_f = time after start of flight

T_c = compartment air temp.

T_R = radiation heat sink temp.

T_m = mounting surface temp.

In-flight condition test to be based on heat transfer studies.

(2) Low Temperature - A minimum ambient air temperature of -34°C (-30°F) may be experienced during storage for periods of up to six hours daily without solar radiation and with negligible air movement. The lowest ambient air temperature which will be experienced during pre-flight operations will be -32°C (-25°F) for periods of up to six hours daily. Missile firings will start at a compartment air temperature of -32°C (-25°F) minimum followed by aerodynamics heating to produce a worst case low temperature time sequence which has not been determined. Procedure I, Method 502.1 MIL-STD-810 may be used to evaluate susceptibility to the low temperature environment except that a -34°C (-30°F) storage temperature and a -32°C (-25°F) operating temperature apply. Operation at -32°C (-25°F) will be considered adequate to demonstrate low temperature in-flight operation.

(3) Temperature Shock - Ambient air temperature changes of up to 105°C (190°F) between the limits of 71°C and -34°C (160°F and -30°F) may be experienced in pre-flight operations. Compartment air temperature increases of up to 56°C (100°F) between the limits of -32°C and 141°C (-25°F and 285°F) may be experienced in flight. Procedure I, Method 503.1, MIL-STD-810 may be used to evaluate susceptibility to temperature shock during pre-flight operations except that a one minute transfer time, a low temperature of -34°C (-30°F), a period of 1 hr. max. at high temperature, and operation only after exposure while at ambient temperature apply. The in-flight temperature shock susceptibility may be evaluated using Procedure I, Method 503.1, MIL-STD-810 except that 4 cycles of Step 3 then Step 4 with the item functioned at the completion of transfer during step 4 shall apply with the following internal chamber temperature: Cycle 1; step 3 @ -25°F and step 4 @ +75°F, Cycle 2; step 3 @ 60°F and step 4 @ 160°F, Cycle 3; step 3 @

125°F and step 4 @ 225°F and Cycle 4, step 3 @ 185°F and step 4 @ +285°F.

(4) Humidity - The highest humidity which will be experienced is characterized by a 100 percent relative humidity for temperatures below 29°C (85°F), a dew point of 29°C (85°F) at temperatures above 29°C (85°F) up to 35°C (95°F) and a linear decrease in grains of moisture per pound of dry air versus degrees of temperature increase between 35°C (85°F) at 75 percent relative humidity and 52°C (125°F) at zero percent relative humidity. Procedure V, Method 507.1, MIL-STD-810 may be used to evaluate the susceptibility to moisture except that the drying temperature is to be 52°C (125°F), conditioning temperature and humidity are to be 29°C (85°F) and 75%, step 4 chamber temperature and humidity 98 to be 51.5°C (125°F), and 30% min. by the end of step 4 and maintained in step 5, and the temperature and humidity are to be 29°C (85°F) and 95% minimum in steps 7 and 8. Operation is required only after exposure.

(5) Low Pressure - The most adverse low pressure environment which may be experienced during storage or pre-launch operations will be in air transportation involving descent from a 40,000 ft altitude (air pressure = 2.47 psia), at a maximum rate of 5,000 ft. per minute. During missile flight the compartment pressure will decrease from 17 psia to 2.5×10^{-9} at a rate of 0.5 psia/sec. and subsequently increase to 17 psia. at a rate of 1.5psi/sec. Procedure I, Method 500.1, MIL-STD-810 may be used to evaluate susceptibility to pre-launch low pressure except for no operation in step 2 where 40,000 ft. altitude (5" hg) and 5,000 fpm pressure change applies.

(6) Fungus - The fungi such as given below may be encountered during storage and pre-flight operations. Its growth shall be withstood. Procedure I, Method 508.1, MIL-STD-810 may be used to evaluate the susceptibility to fungi growth except that the fungi to be used are to be as given below:

Group	Fungi	ATCC No.
I	Chaetomium globsum	6205
	Myrothecium verrucaria	9095
II	Memnoniella echinata	9597
	Aspergillus niger	6275
III	Aspergillus flavus	10836
	Aspergillus terreus	10690
IV	Penicillium citrinum	9849
	Penicillium ochrochloron	9112

(7) Salt Spray - Salt spray as typical of coastal regions may be encountered with a maximum fallout rate of 2.8 gm/m^2 - yr. Procedure I, Method 509.1, MIL-STD-81C may be used to evaluate susceptibility to salt spray except that no operation is required at the end of the drying period.

(8) Sand and Dust - The tabulated data given below defines the sand and dust particle sizes, wind speeds and concentrations which will be encountered in pre-flight operations. Procedure I, Method 510.1, MIL-STD-810 may be used to evaluate susceptibility to this environment except two separate test conditions as given below are to be evaluated.

Condition 1 (Sand)		Condition 2 (Dust)		
Air Velocity (knots)	Particle Size (mm)	Air Velocity (knots)	Particle Size (mm)	Concentration In Air Stream (gr/cc)
30	0.1 to 1.0 dia range 0.15 to 0.3 Predominate Dia's.	35	0.0001 to 0.01 Dia Range	6×10^{-9}*

(9) Accoustics - The maximum levels of accoustical noise which may be encountered will be: 40-10,000 Hz @123db steady state, during pre-flight operations; 40-10,000 Hz @160db steady state, during in-flight operation (both referred to 0.0002 dynes/cm^2. Procedure I, Method 512.2, MIL-STD-810 may be used to evaluate susceptibility to accoustical noise using a 123db steady state, 40-10,000 Hz sound pressure level when the ESA is unoperating and a 160db steady state, 40-10,000 Hz sound pressure level when the ESA is operating. Exposure time is 8 minutes at each sound pressure level.

*Although not recommended as a test condition it is noted that sand or dust stirred up by aircraft or other vehicles may produce heavier concentrations.

(10) Chemical - Contact with various chemicals may be experienced many times during the life of the ESA during storage and pre-flight operations. The chemical agents are: (a) Ozone concentrations up to 325 micrograms per cubic meter; (b) J.P. series Kerosene; (c) gasoline; (d) diesel fuel; (e) Hydraulic fluids; (f) lubricants; (g) all standard cleaning fluids; (h) fresh water with or without antifreeze; (i) salt-water; and the following fire fighting agents:

Sodium bicarbonate, with or without sulfuric acid if used to create pressure to expel water.

Aircraft Film - Forming - Form (AFFF)

Carbon dioxide

Freon P301 which is non-corrosive to metals and alloys.

(11) Acceleration - Procedure II, Method 513.2, MIL-STD-810 may be used to evaluate susceptibility when the exposure level is determined from the following definition of the acceleration environment which may be encountered. Operation is required during this environment. ESA mounting surface facing sideward and its c.g. located 11 inches from ground launched missile centerline with any side closest to the centerline and 22 inches forward or aft of the reentry vehicle c.g.; angular accelerations of 100 radians per second^2 in roll and 35 radians per second^2 in pitch and yaw; 12g maximum for the forward acceleration (occurring during the first 60 to 75 seconds after lift-off) with a simultaneous radial vector of 0 to 3 g due to angular accelerations; and either a max. 40 g rearward acceleration with a simultaneous max. 20 g radial vector or a max. rearward acceleration of 20 g with a simultaneous max. 40 g radial vector required. (Radial vectors due to angular accelerations.) The high rearward acceleration will occur during the last 30 seconds of the in-flight operations.

(12) Vibration - The most adverse transportation vibration after which operation is required and which can be encountered over the temperature range of +52°C (125°F) to -32°C (-25°F) has been characterized as a sinusoidal input as below:

Axis perpendicular to Mounting Surface	Other 2 axes
2-3.4 Hz at 5 inches DA	2-3.1 Hz at 10 inches DA
3.4-15 Hz at 3 g's	3.1-10 Hz at 5 g's
15-500 Hz at 2.5 g's	10-500 Hz at 2.5 g's

The most adverse in-flight vibration during which operation is required has been characterized by the following power spectral density definitions of random vibration:

(a) A 2 minute exposure to the following levels at 8.9 composite G-RMS while at any temperature appropriate to the first 100 seconds after lift-off.

20-100 Hz at + 6db/Oct

100-1000 Hz at 0.05 g^2/Hz

1000-3000 Hz at - 6db/Oct

(b) A 1 minute exposure to the following levels at 17.9 Composite G-RMS while at any temperature appropriate to the last 10 seconds of missile flight.

20-100 Hz at + 6db/Oct

100-1000 Hz at 0.2 g^2/Hz

1000-3000 Hz at - 3db/Oct

Procedure X, and Part 2 of Procedure VII, Method 514.2, MIL-STD-810 may be used respectively to evaluate the susceptibility to the above sinusoidal and random vibration inputs except that tests are to be at ambient, +52°C (125°F) and -32°C (-25°F) for sinusoidal and at -32°C (-25°F), ambient, and an elevated temperature to be determined from the data given for high temperature operation. Tests at each temperature to be in each of three mutually perpendicular axes for random and for sinusoidal.

(13) Shock - The most adverse shock environment which may be encountered during pre-flight operations has been characterized as a 20 g's, 60 millisecond, 1/2 Sine wave pulse in each of three mutually perpendicular axes. The most adverse shock environment which may be encountered during the first 60 to 75 seconds after lift-off has been characterized as a 20 g's, 6 millisecond, 1/2 sine wave pulse. Within about three seconds after the 60 to 75 second boost period a shock characterized by the following shock response spectrum will be experienced in each of three mutually perpendicular axes:

50 - 600 Hz @ + 9db/Oct

600 - 2,500 Hz @ 450 g's

2,500 - 10,000 Hz @ - 3db/Oct

0.3 Damping

Procedure I, Method 516.2, MIL-STD-810 may be used to evaluate susceptibility to the 1/2 sine wave shocks. Operation is required after the 60 millisecond 1/2 sine pulse and during the 6 millisecond 1/2 sine pulse and shock response spectrum.

b. Extra Ordinary Environments.

FOR INFO ONLY (1) Electromagnetic Radiation - The E/OD, as a part of higher assemblies in or out of shipping and storage containers, will experience electromagnetic fields and must function properly after exposure. Maximum field levels are:

Frequency Range (Hz)	Electric Field Avg (V/M)	Electric Field Peak (V/M)	Polarization
$200 \times 10^3 - 10 \times 10^6$	100	200	Vertical
$200 \times 10^3 - 10 \times 10^6$	10	20	Horizontal
$10 \times 10^6 - 100 \times 10^6$	100	200	Vertical & Horizontal
$100 \times 10^6 - 17 \times 10^9$	200	4000	Vertical & Horizontal

(2) Lightning - The E/OD may encounter typical lightning strokes at a 20 meter distance or extreme lightning strokes at a 200 meter distance. A typical lightning stroke is defined by a 20,000 ampere peak current and a maximum time rate of change of 20,000 amperes per microsecond. An extreme lightning stroke is defined by a 200,000 ampere peak current and a maximum time rate of change of 100,000 amperes per microsecond. The maximum fields are:

(a) Magnetic Field Gradient - 150 ampere turns per meter peak with a 10-200 microsecond pulse width at 50% of peak value.

(b) Rate of Change of Magnetic Field Gradient - 150 ampere turns per meter per microsecond peak with a 0.2-10 microsecond pulse width at 50% of peak value.

FOR INFO ONLY (c) Electric Field Gradient - 60,000 volts per meter peak with 0.2-10 microsecond pulse width at 50% of peak value.

FOR INFO ONLY (3) Static Charge - The system shall operate properly after a 500 picofarad capacitance charged to 30,000 volts of either polarity with respect to case is discharged through a 5000 ohm resistance. The E/OD will be unoperated during the discharge. When shipped by aircraft, the E/OD, in its repair parts container or as part of the AK, or Warhead Section in shipping and storage containers grounded to the aircraft, may build up a maximum voltage with respect to earth surface and discharge to earth after which it shall operate properly. The discharge voltage and current are:

Volts	Microamperes
-200,000	50
+60,000	1.5

(4) Nuclear - The nuclear environment is classified and is available under separate cover.

c. Abnormal Environments: The ESA, when a part of the E/OD, complete Warhead Section, or missile may experience abnormal environments during which the warhead section need not operate but must remain safe. In order to provide assurance that this requirement is met, selected components of the adaption kit are required to be fail-safe under the abnormal environments singly or in credible combinations.

No testing to abnormal environments will be required of the contractor. A definition of each abnormal environment to be considered follows:

FOR INFO ONLY (1) Fire: A hydrocarbon fire up to 1850°F (black body radiation source).

(2) Impact/Shock:

FOR INFO ONLY (a) Transportation:

Aircraft - maximum	1000 ft/sec.
Helicopter -	200 ft/sec.
Rail -	147 ft/sec.
Truck -	110 ft/sec.

(b) Handling: 9 foot drop which is equivalent to 24 ft/sec.

FOR INFO ONLY (3) Immersion: Salt water or fresh water up to 32,000 foot depth.

FOR INFO ONLY (4) Crush: Crush levels are: Static up to 40,000 lbs; Dynamic equal to static of 80,000 lbs. Static may follow initial dynamic loading.

(5) Tumbling: 2 revolutions per second.

FOR INFO ONLY (6) Lightning: The following describes the environment on the ballistic case of the missile or on the container.

(a) Single Pulse Parameters.

Peak Current - 2,000 to 200,000 amperes with 50 percent of pulses having peak values greater than 20,000 amperes.

Time to Peak - 0.2 to 15 microseconds with 50 percent of pulses having times greater than 2.0 microseconds.

Rate of Current Rise - (10 to 90 percent peak current). 40,000 to 100,000 amperes per microsecond with 50 percent of the pulses having rates greater than 20,000 amperes per microsecond.

Time to Half Value on Decay Side of Peak - 10 to 200 microseconds with 50 percent of the pulses having decay times greater than 50 microseconds.

Time for current decay to 1,000 amperes - 60 to 800 amperes with 50 percent of the pulses having decay times greater than 200 microseconds.

Amplitude of Continuing Current* - 30 to 700 amperes with 50 percent of the continuing currents having amplitudes greater than 140 amperes.

Duration of Continuing Current* - 50 to 500 milliseconds with 50 percent of the continuing currents having durations greater than 160 milliseconds.

(b) Total Flash Parameters.

Number of Pulses - 1 to 12 with 50 percent of the flashes containing greater than 2 pulses.

Interval between pulses - 10 to 500 milliseconds with 50 percent having intervals greater.

Total flash duration - 0.03 to 1.0 seconds with 50 percent of flashes having durations greater than 0.2.

Charge Transfer - 1 to 300 coulombs with 50 percent of flashes transferring greater than 15 coulombs of charge.

Action ($\int i^2 dt$) - 3×10^2 to 3×10^6 amp^2 sec. with 50 percent of flashes having greater than 3×10^4 amp^2 sec.

*The continuing current is not present in all flashes. It may appear between the pulses or following the last pulse.

FOR INFO ONLY (c) Cloud/Earth System Recycle Time after a Discharge. Typically 20 seconds.

FOR INFO ONLY (7) Electromagnetic Radiation: In addition to the extraordinary electromagnetic radiation environment, an abnormal environment exists. The abnormal levels are defined in classified supplement "PERSHING II Adaption Kit Nuclear and Electromagnetic Environments".

DESIGN PROPOSAL FOR ENABLE SWITCH ASSEMBLY

(ABSTRACTED FROM E/OD PROPOSAL NO. 26-6321-5000 18 OCTOBER 1976)

3.4 ENABLE SWITCH ASSEMBLY (SOW - F.1IV6, 7, 14, and 15)

3.4.1 Design Philosophy and General Features

The Enable Switch modules to be supplied by Applied Resources Corporation are compact, rugged assemblies designed to enhance the specific requirements of the Enable Option Device. Three elements, the enable switch proper, the motor and its associated gear train, and the housing assembly form a unified design meeting and, in some cases, exceeding the specification requirements. These three functional entities join together as shown in figure 3-9.

Each channel of the E/OD is equipped with an independent enable switch/drive module. These interlock when assembled into the E/OD, contributing to the high packaging density. Figure 3-10 illustrates this packaging technique.

The enable switches, motor and associated drive components are a unique assembly designed with the primary objective of providing reliable function under normal and extraordinary environments, and which will behave predictably and remain safe during the abnormal environments specified in the RFQs Scope of Work.

The design is straightforward, modularized where such an approach aids in meeting the primary objective, and characterized by ease of assembly and inspection. Alignments, tolerance accumulations, and assembly techniques are an integral part of the design effort since its inception. The considerations and constraints imposed by produceability and the requirements for cost economics were used at each stage of the design effort.

Practical demonstration of the design concepts and production techniques contemplated is essential to confirm the validity

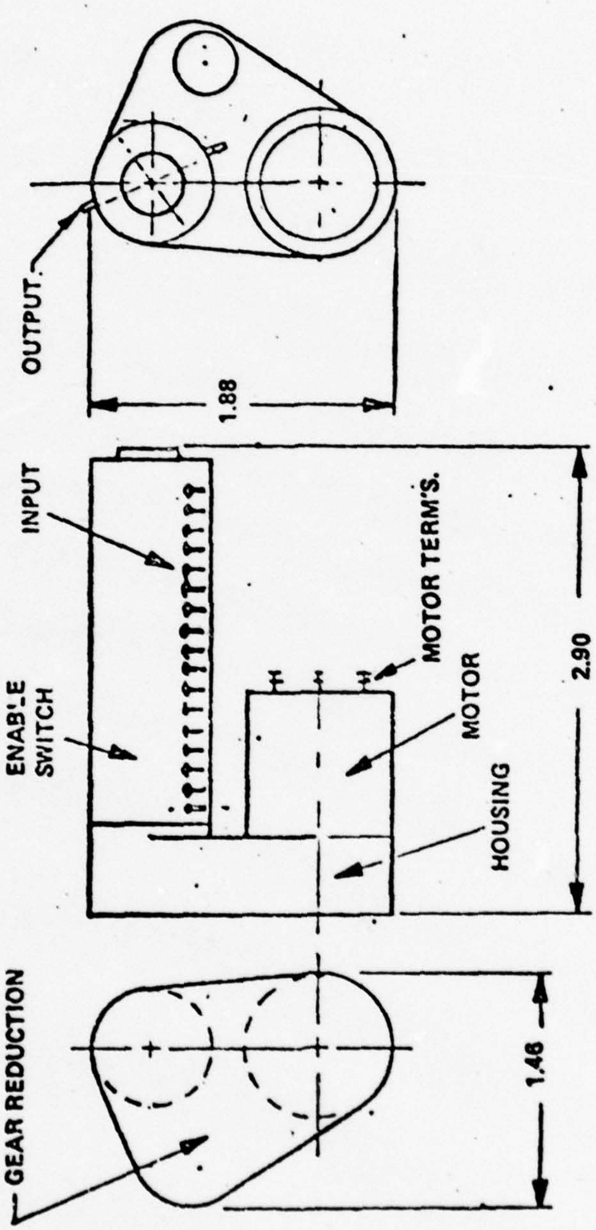


Figure 3-9. Enable Switch Assembly

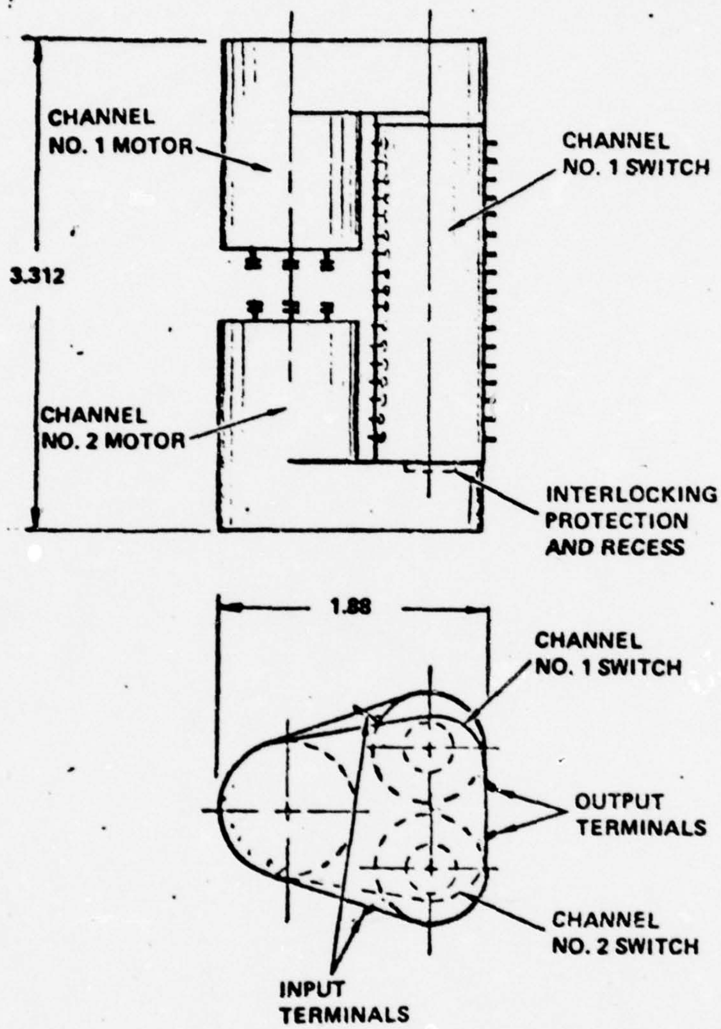


Figure 3-10. Enable Switch Interlocking Design

of the approaches taken. Each element in the design has been reduced to operating hardware to determine feasibility and verify its specific characteristics. Interrelation of these elements has been demonstrated through construction of a completely operational model incorporating all required features. This model is shown in figure 3-11.

In the quest for a design to meet the rigorous specifications and provide for manufacturability, emphasis has been placed on two production techniques which have been amply demonstrated in flight qualified missile hardware designed and produced by ARC. These techniques are hermetic ceramic-to-metal brazing and precision TIG welding.

Extensive ceramic-to-metal brazing is employed in every M42E1 Lance selector swich ARC has produced as well as on our Pershing M21A1 motor operated switch. Approximately 275,000 hermetic ceramic-to-metal brazes were used in these programs as part of the 6000 switches supplied. Similar hermetic constructions are employed on all our flight qualified hardware for the NASA Shuttle Orbiter and switch components for the Pershing ARS/SLA. These applications all employ extensive hermetic TIG welding, comprising more than 1.4 miles of hermetic welds. Army field experience with these components confirms the high integral reliability associated with these techniques.

The enable switches proposed feature a configuration in which more than 85% of the volume is solid, ceramic or metal. The spacing between rotor and stator is only .010 in. contributing to the high packaging density which approaches a completely solid mass. No materials other than ceramic or metal are located in the switch module. No wiring, cabling, or solder is employed in the switch module. No lubricants are used in

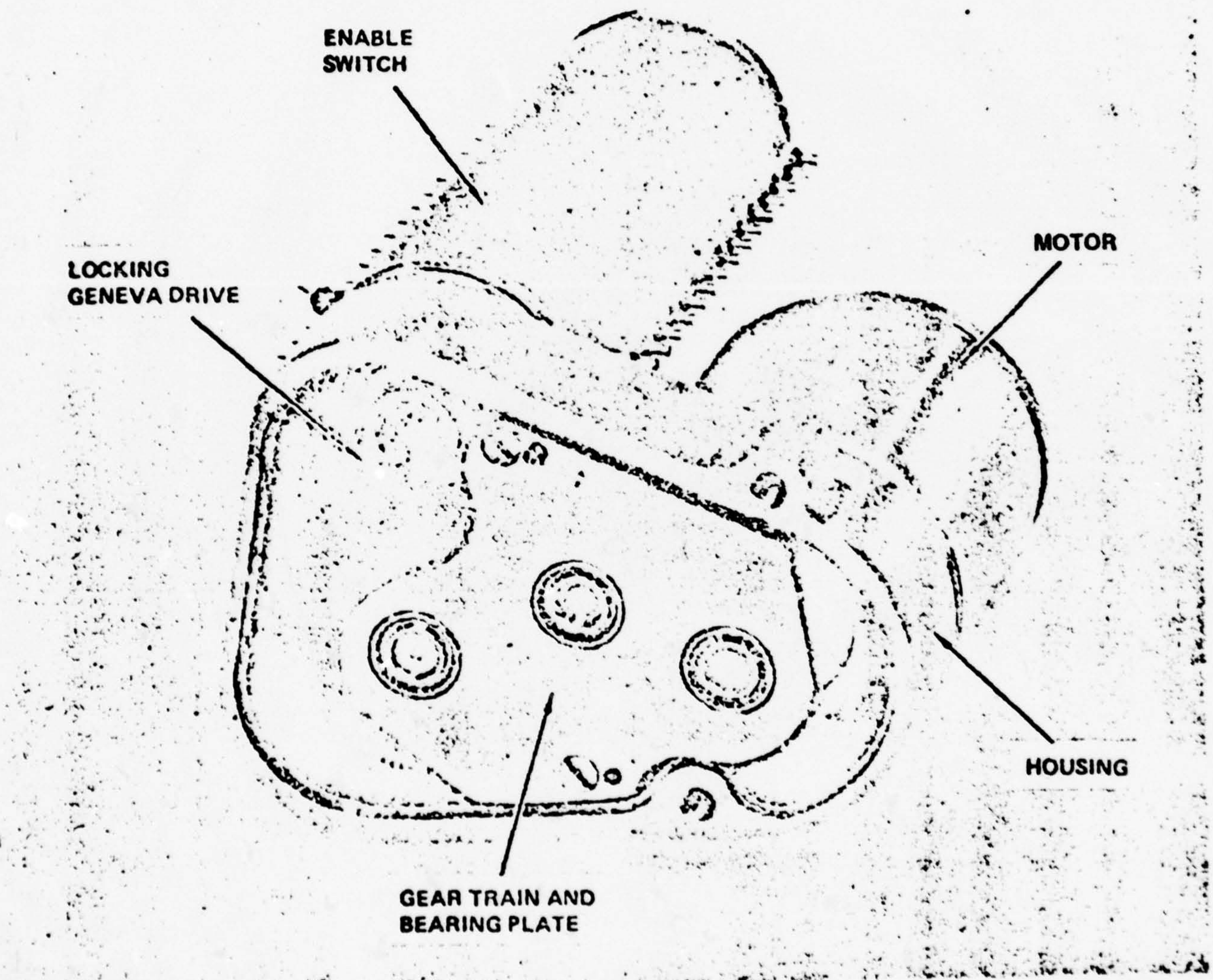


Figure 3-11. Enable Switch Operational Model

the switch module, either on the switch contacts or shaft bearings. All insulation is inorganic. Input and output circuits are isolated on opposite sides of the switch module and the ceramic rotor is a physical dielectric barrier between them. Contact interface forces are high, contributing to reliable operation under the influence of environmentally induced forces, yet rotational torque requirements are minimal. These high contact forces augment the switch capability to handle the range of high currents as well as the logic level signals to be transmitted. The position of the rotor is positively locked in either the Safe or Enabled position. No movement of the rotor may take place except for the fraction of a second in which deliberate circuit transfer is desired. Special switch circuits, physically isolated from the output terminals are provided for positive electricl indication of switch position. Visual indication of switch position is also provided (see figure 3-12).

Weight is minimized, partially through use of a miniturized high energy efficiency stepper motor. The motor and associated gearing provide the required 80% of total motion prior to initiation of the shaft rotation phase. Confirmation of reset is achieved by sensing unique relationships in the gear train. Rotor locking and gear train detenting is provided.

These features are provided in a high strength, minimum size, hermetic welded enclosure, protected from the deteriorating influences of external environment.

In the following detailed technical discussion, each major element, the enable switch, motor and gear train, and enclosure are treated separately. When appropriate, however, the discussion focuses on those areas where they interact to create the final functional entity.

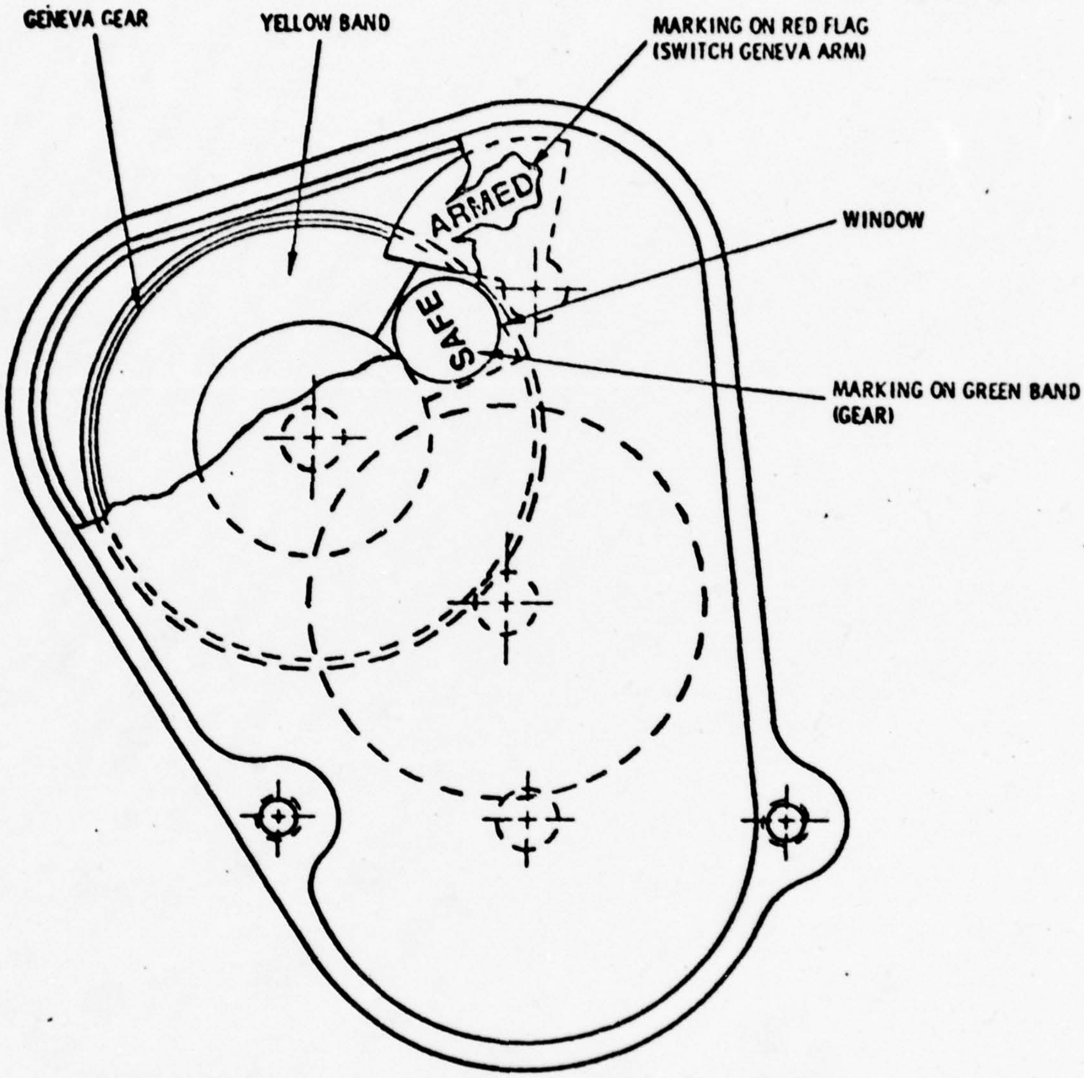


Figure 3-12. Enable Switch Position Visual Indicator

3.4.2 Design Configurations

3.4.2.1 Stator and Contact Arrangement

a) Detail Elements. - Each circuit to be accommodated by the Enable Switch has its input and output connection on diametrically opposite sides of a heavy wall-machined stainless steel tube. Each contact pin is a plated single solid member of Kovar per ASTMF15. This is a readily cold worked material which can be formed easily to the desired hemispherical shape to assure proper contact interface. Each pin serves as an external connection point as well as an internal interface to the switching mechanism. These pins are isolated from the stator module by a ceramic insulator. The assembly of the pins, ceramic insulation, and tube is performed in a single, fixtured brazing operation assuring repeatable accurate positioning as shown in figure 3-13.

Each contact pin (figure 3-13) is a single solid metallic member formed of Kovar per ASTMF15. The end which projects outward to provide the external connection point is configured to suit the specific termination and interfacing requirements of the electronics portion of the E/OD and connection to J2. The E/OD output leads to J2 are designed to be welded directly to the enable switch output circuit terminals to augument the safety of the output lines. The selected Kovar material is amenable to welding and has a melting point of 2640°F, safely above the specification maximum stress of 1850°F.

The pillar ceramic insulator (figure 3-13) is formed from 94/96% alumina selected for flexural strength, nominally 50-53,000 psi, and compressive strength, in excess of 300,000 psi. The ceramic insulator is prepared for assembly by application of molv-manganese metallization to the inside diameter of the insulator, as well as the outside major diameter. This

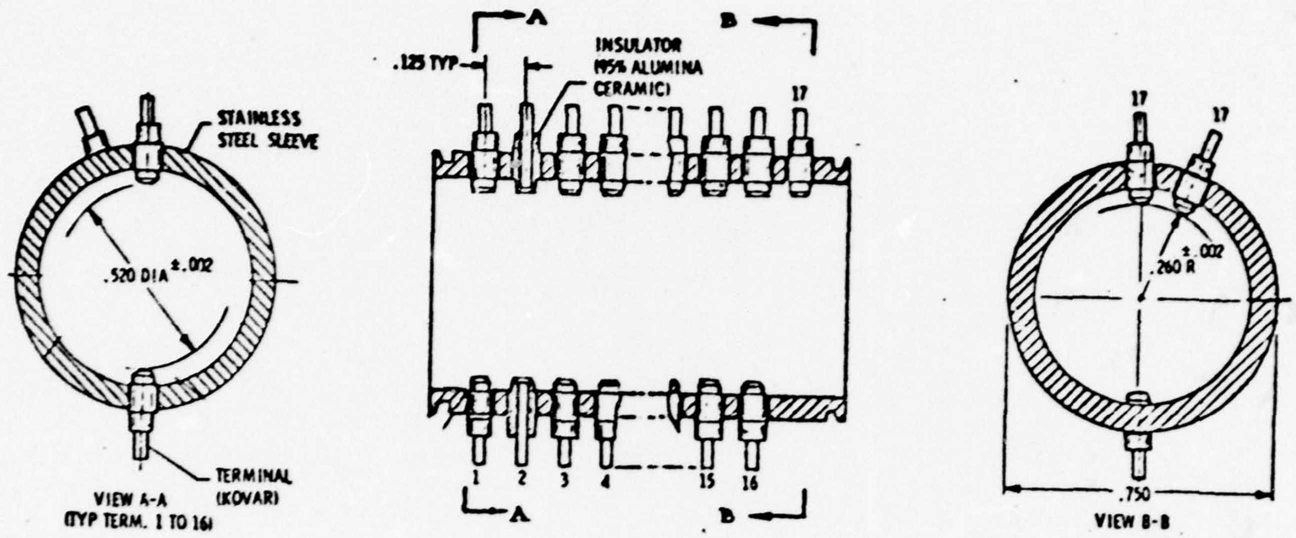


Figure 3-13. Enable Switch Station Module

3.4.2 Design Configurations

3.4.2.1 Stator and Contact Arrangement

a) Detail Elements. - Each circuit to be accommodated by the Enable Switch has its input and output connection on diametrically opposite sides of a heavy wall-machined stainless steel tube. Each contact pin is a plated single solid member of Kovar per ASTMF15. This is a readily cold worked material which can be formed easily to the desired hemispherical shape to assure proper contact interface. Each pin serves as an external connection point as well as an internal interface to the switching mechanism. These pins are isolated from the stator module by a ceramic insulator. The assembly of the pins, ceramic insulation, and tube is performed in a single, fixtured brazing operation assuring repeatable accurate positioning as shown in figure 3-13.

Each contact pin (figure 3-13) is a single solid metallic member formed of Kovar per ASTMF15. The end which projects outward to provide the external connection point is configured to suit the specific termination and interfacing requirements of the electronics portion of the E/OD and connection to J2. The E/OD output leads to J2 are designed to be welded directly to the enable switch output circuit terminals to augument the safety of the output lines. The selected Kovar material is amenable to welding and has a melting point of 2640°F, safely above the specification maximum stress of 1850°F.

The pillar ceramic insulator (figure 3-13) is formed from 94/96% alumina selected for flexural strength, nominally 50-53,000 psi, and compressive strength, in excess of 300,000 psi. The ceramic insulator is prepared for assembly by application of molv-manganese metallization to the inside diameter of the insulator, as well as the outside major diameter. This metallization is fired into the body of the ceramic at 2775°F, at which temperature it enters into and forms part of the intergranular structure of the ceramic. These metallized surfaces are then nickel plated and copper flashed to facilitate the subsequent brazing operation.

The stator proper, the third element making up the stator module is a tube machined from 17-4 PH stainless steel. Type 17-4 PH is characterized by high strength and amenability to brazing and welding - two processes to which the stator will be exposed. The characteristics of 17-4 PH may be further augmented by heat treatment, and following the brazing operations described later, the completed stator module is brought to 900°F to maximize the alloy's characteristics. The stator will be configured as shown in figure 3-13.

The stator tube ends have machined surfaces matching bearing retainers and end caps. These outside diameters are configured with a weld prep to facilitate the later welding of these parts.

b) Stator Assembly. - The contact/terminal insulator, and a stator previously described, are joined together to form a single entity. This is achieved by the simultaneous brazing of these parts using copper preform material. The individual elements are fixtured in their proper position using oxidized stainless steel fixtures or machined carbon blocks. The brazing operation takes place at about 2015°F. The appearance of a section of a typical assembly is illustrated in figure 3-13. The enable switch is provided with an additional or 17th deck within the confines of the sealed tube. Two circuits in this deck provide monitoring signals to the electronics portion of the E/OD. This monitoring deck is singular in design since all of its terminals are located on the input side of the switch.

3.4.2.2 Rotor and Wiper Module

a) Detail Elements. - A rotor module consists of two parts, the rotor proper and the wiper. The ceramic rotor serves the multiple functions of a retainer for the wiper, an element of dielectric bulk, contributing to the maximum material concept on which the switch is based, and also provide for alignment and driving of the other rotors which together form the rotor assembly.

The rotor is fabricated of the same 94/96% alumina composition used for the terminal pillar insulator and displays the same high strength dielectric and physical characteristics. Each rotor is provided with two 0.060 diameter through holes which are used for alignment purposes and through which ceramic rods are placed during assembly. The other salient feature is the special shape of each rotor segment, which carries a recess on its rear surface and a projection on the front surface. This male and female configuration couples in assembly of the rotor modules. The mating features provide tightly toleranced, controlled minimal clearance for the metal wiper spring to lie between them. The wipers are thereby positively restrained and the philosphy of maximum material content is satisifed. Figure 3-14 illustrates a typical rotor.

The monitoring deck incorporates a rotor which provides the same features except that the interfacial relationship of the two sets of contacts are on the input side of the switch. The monitor deck rotor differs from the conventional by inclusion of a drive slot feature which serves as a coupling link to the input shaft.

The wiper is a specially configured strip of molybdenum having high tensile strength, excellent spring properties, formability, wear, and abrasion resistance qualities. It is

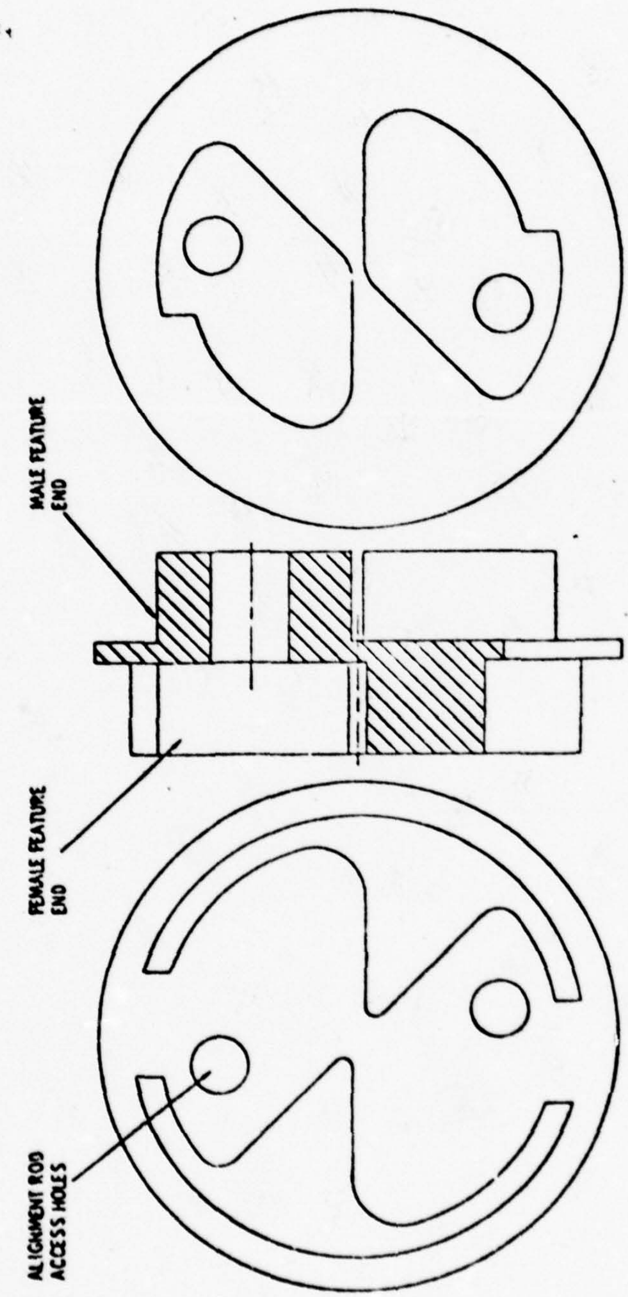


Figure 3-14. Enable Switch Rotor (Typical)

highly fatigue resistant and has a melting point of 2620°C, well above the SOW temperature tolerance limit of 1850°F.

The wiper is formed as illustrated in figure 3-15. The monitoring deck wiper is formed as illustrated in figure 3-16.

b) Rotor Assembly. - A rotor module assembly is prepared for subsequent operations simply by lightly depressing the ends of the wiper enabling the wipers to be inserted into the rotor recess. This is illustrated in figure 3-15 for the standard decks and figure 3-16 for the monitoring deck. In these figures, the view shows mating of the male and female features and alignment with the stator.

A special support rotor is intentionally lacking a wiper assembly. Its function is to terminate the assembly of wipers by acting as a retainer for the wiper located in the final switching module and as a shaft protruding into the end plate bearing.

The rotor module assemblies are joined to create the full rotor assembly. Alignment of modules is assured by the two .060 diameter ceramic rods inserted into the corresponding holes in each rotor and permanently secured in place by a ceramic bonding compound, Eccoceram Type CS. When cured, the Eccoceram has the strength and other properties of a typical ceramic and and an operating range of -90°F to +2000°F. An application of this material is also made on the opposing flat faces of adjacent rotors. After curing, the full rotor assembly is a homogenous unitary ceramic structure. The use of ceramic rods facilitates proper alignment of rotor parts and minimizes the internal metal structure while retaining the maximum material concept.

Detail part and fixturing design of the rotor assembly takes into consideration variability in contact alignment and

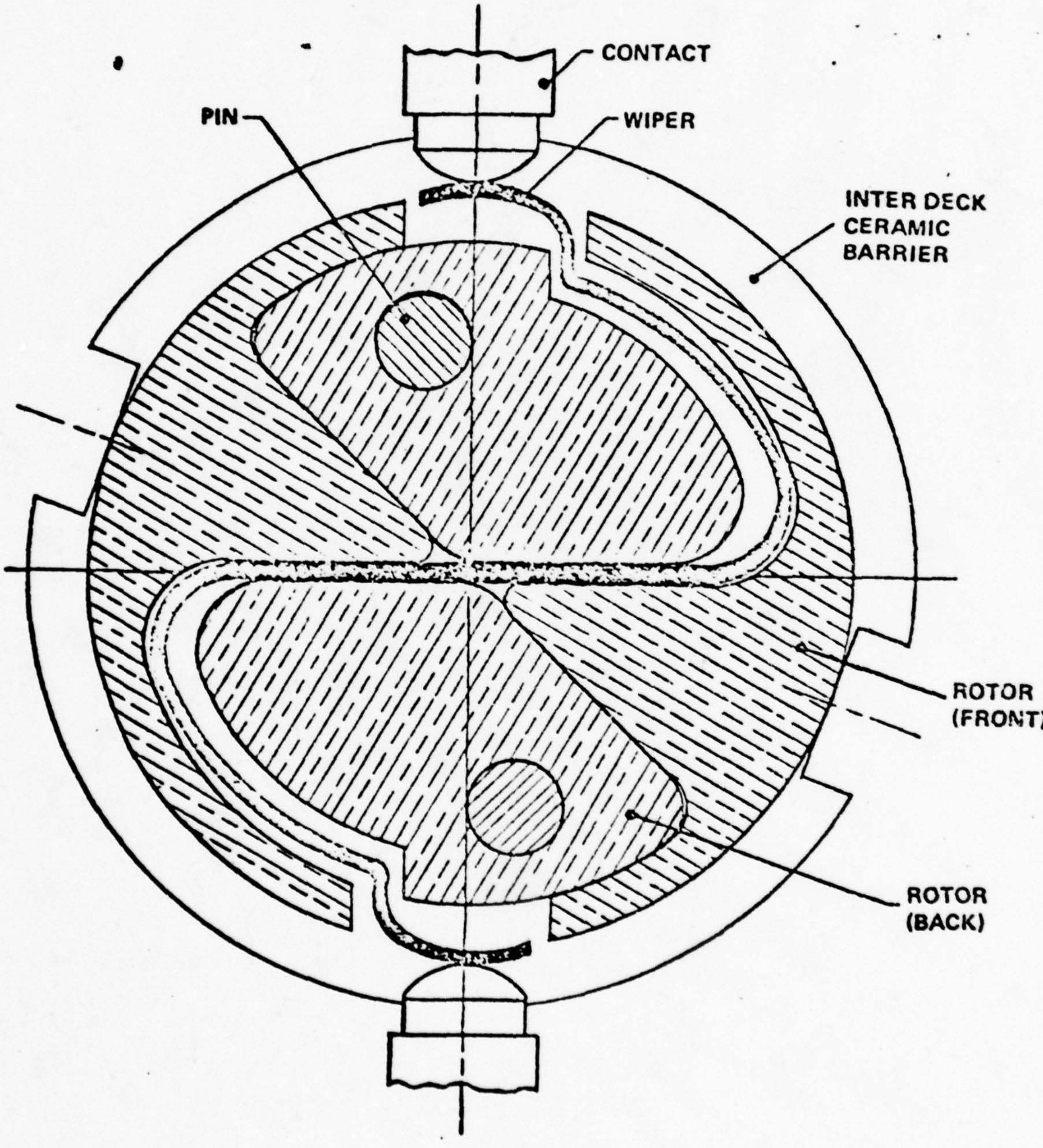


Figure 3-15. Enable Switch Rotor Assembly

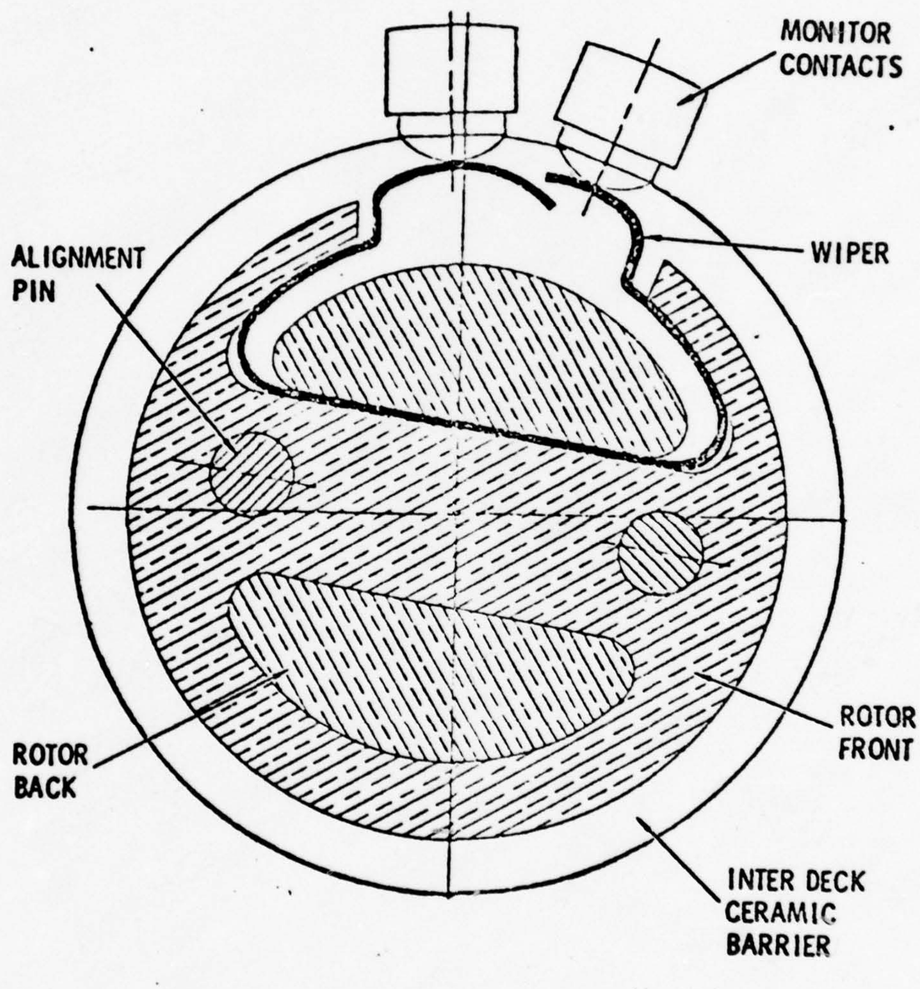


Figure 3-16. Enable Switch Wiper Assembly (Monitoring Deck)

contact pressure. These parameters will be measured prior to and following fabrication of the modularized rotor assemblies. The design allows an axial alignment variation of .020 in. between the rotor and stator. The fixturing and inspection will check this feature to .005 in., thereby providing a large measure of safety.

In final assembly, the driving shaft is locked into position to the rotor assembly using .060 pins. Centrality is maintained since the end of the rotor assembly fits into a bore at the end of the driving shaft. Figure 3-17 shows this completed configuration.

c) Structural Components. - The design presented in this proposal incorporates two other structural members which complement the strength of the completed assembly and terminate it. These members are the front and rear end supports.

The end supports captivate and centralize the rotors and serve as a structural member in the event of adverse mechanical environments. Heat treatment of the 17-4 PH stainless steel to condition 900H is used in this application to maximize the materials strength. These discs are .750 in. diameter and .100 in. thick. The end support employed at the shaft end is machined to accommodate input ball bearings. The rear support disc accommodates the rear shaft ball bearing assembly.

Both supports are machined with weld preps on their faces to facilitate final assembly.

The completed enable switch is illustrated in figure 3-17.

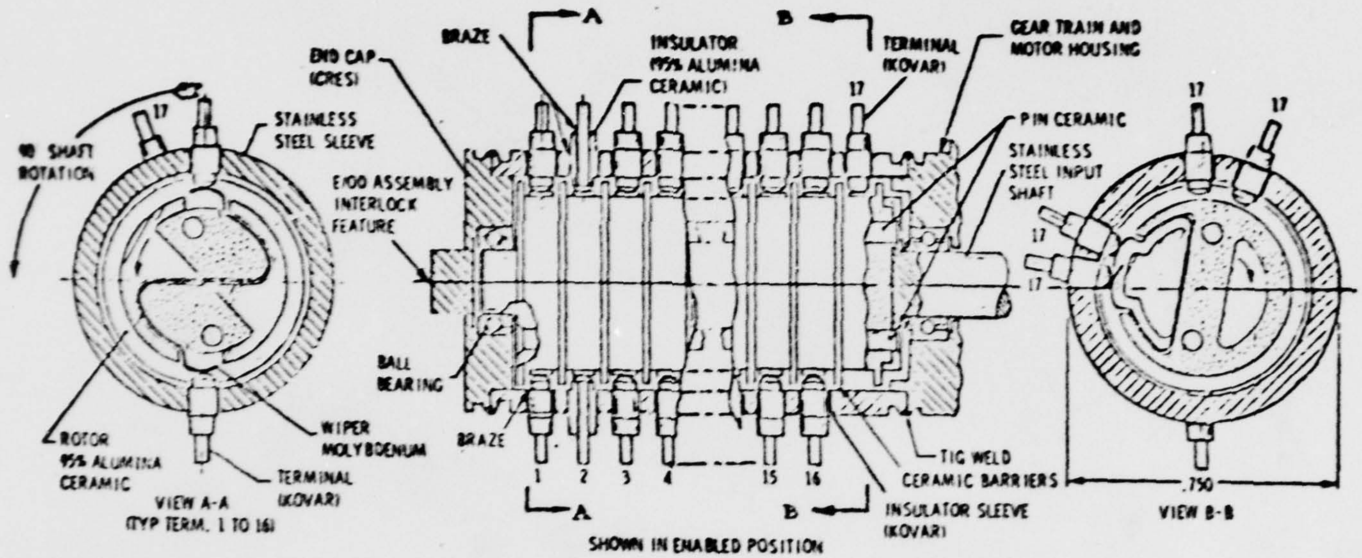


Figure 3-17. Enable Switch Stator and Rotor Assembly

A photograph of the operational model incorporating these features is shown as figure 3-18.

3.4.2.3 Motor, Gear Train and Housing. - The motor, drive and housing perform complimentary functions in achievement of the performance requirements. Among the functions served are:

- Timing and control of switch position through motor and gears.
- Feedback to electronics portion to establish consistent reference position for operation and reset.
- Outgas and backfill system for enhancement of long term reliability.
- Provisions for mounting each of the enable switch/motor modules (and alignment features providing for their interlocking).

Figure 3-19 is a photograph of these parts as incorporated in the operational model.

The action of the gear train is to transfer to the enable switch through the action of a generator mechanism. This mechanism is not only useful in establishing proper timing of the switch transfer but contributes greatly to safety by providing a positive lock-up preventing switch motion from either Safe or Enable position except when transition is specifically intended.

a) Design Considerations. - Considerable effort has been directed toward minimizing the weight and volume of the enable switch assembly while maintaining reliability, resistance to adverse environments, and guaranteed first operation success after exposure to any and all environments.

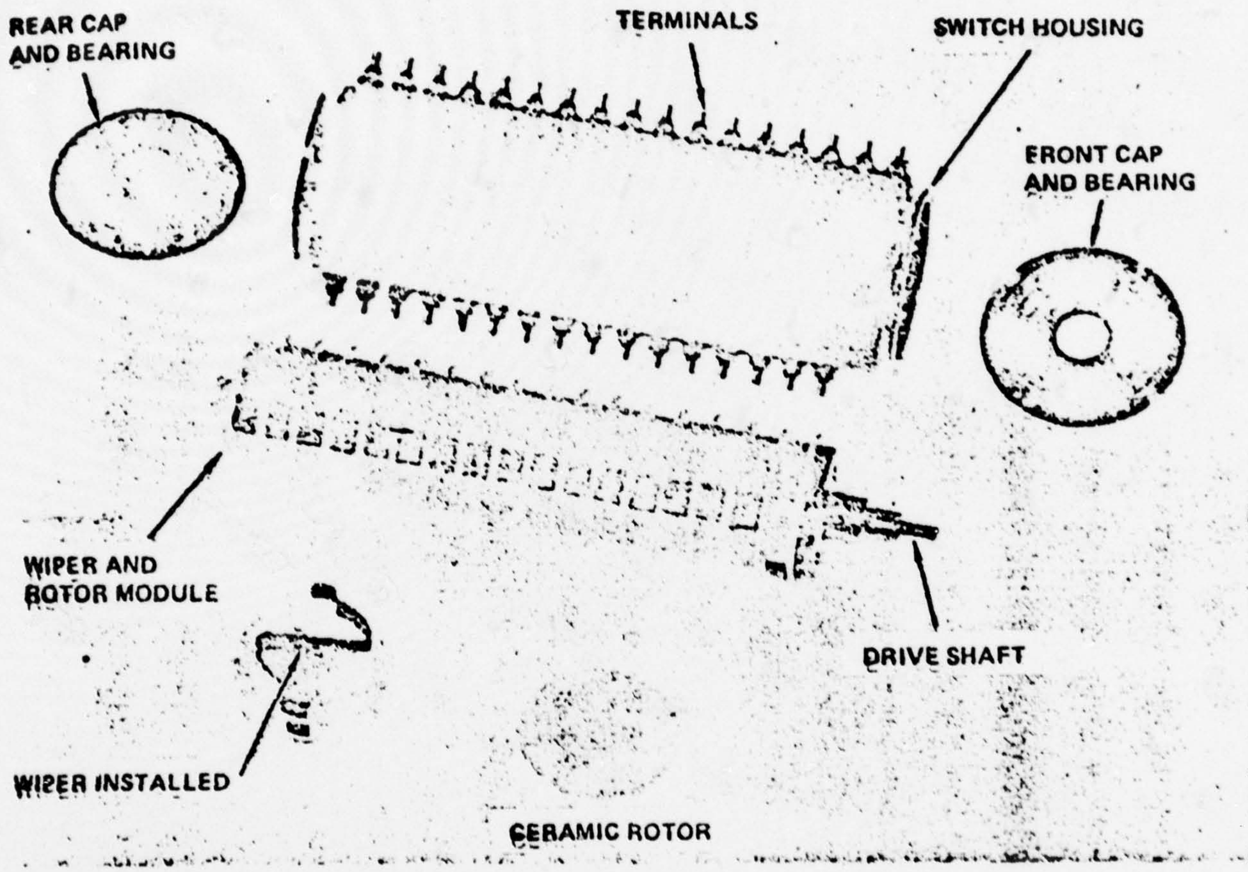


Figure 3-18. Enable Switch Stator and Rotor Components

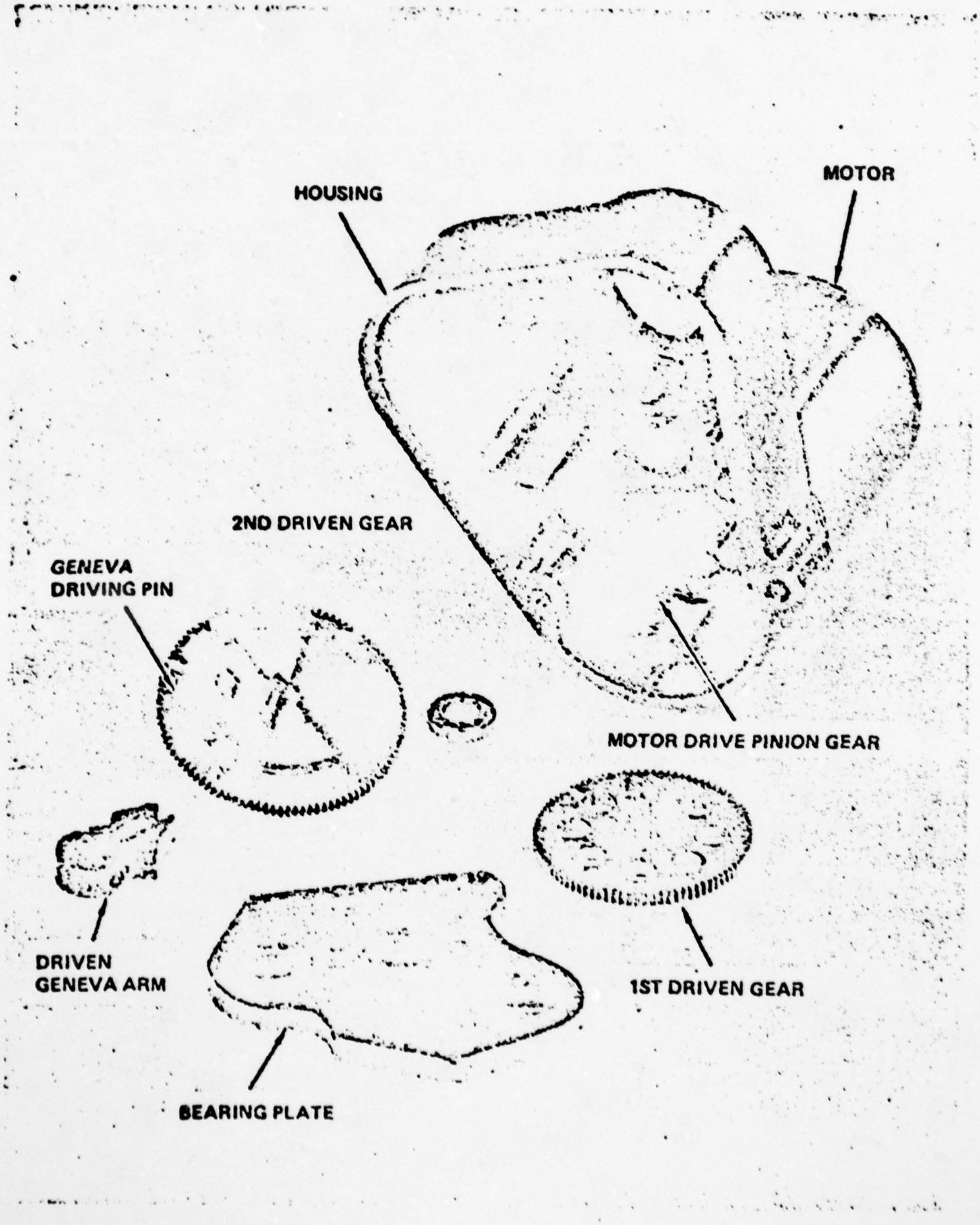


Figure 3-19. Enable Switch Motor Gear Train and Housing Components

The stepper motor is typical. From an originally specified motor with a volume of 2.39 cu. in. and a weight of 7.3 oz., successive refinements reduced the volume to .48 cu. in. and the weight to 1.7 oz. This was achieved by changing the motor to a high efficiency, 4-phase permanent magnet type.

Measurements of torque requirements for a switch deck assembly established 1 oz-in. as the design basis. For the 17 wipers, therefore, a base value of 17 oz-in. is required. The tabulation below is based on a conservative need to supply 20 oz-in. of torques, incorporating an 18% built-in safety factor.

Required	Cumulative Torque Required (oz-in.)
Torque required at switch	20
(Gain) loss through geneva ratio	*
Loss through (2) gear passes at 5% each = 10%	22
Loss in torque (copper vs. Δt at 115°C = 1/3)	30
Gear train detent @ 10 oz-in.	40
Available	
Motor output	1.2
Times gear ratio of 43.8:1	
	52.56

Worst case safety margin $\frac{52.56}{40} - 1 = 31\%$

*The action of the geneva mechanism is not linear as regards velocity or power gain or loss. Available torque is greatest at the beginning and end of the geneva stroke. It is at these precise points representing (1) the start of rotation of the rotor mass and (2) the engagement of the wipers to the contacts that maximum power is desired. In the reset mode, this maximum torque is available to (2) disengage the contacts and (1) start accelerating the return of the rotor mass to the safe position.

The advantages represented by this additional factor is not reflected in the 1/3 safety margin and represents yet an additional safety margin.

b) Motor. - This design incorporates a four phase, 90°, stepper motor driven two phases at a time. Each phase has an ambient temperature resistance of 31.5Ω and draws .89 amp. To achieve the required driving torque and timing in the smallest envelope with lightest weight, a permanent magnet construction unit is employed. Initial designs used a 15° variable reluctance type stepper but optimization of given parameters led us to the current configuration.

c) Special Environments. - Considerable investigation was made of the potential susceptibility of the permanent magnet structure to demagnetize under the influence of the extraordinary and abnormal EM and radiation fields and the potential influence of lightning strokes. Inquire at university research centers, private industry R&D Labs, Government installation including RADC and White Sands, and at Sandia give assurance that when mounted the motor will not be adversely affected. Magnetic material currently used is Alnico 9. The use of samarium cobalt or other rare earth metals would further enhance magnetic properties margin. The motor itself is installed within a shielded enclosure whose electromagnetic and electrostatic shielding characteristics may be varied as desired, affording additional isolation from the environment. Current missile systems exposed to comparable potential environments employ permanent magnet structures. Typical components employing these structures are designated MC2911 and MC2936. Classified material describing these components and their environments is available.

d) Timing and Gear Train. - The master clock delivers timing pulses at 122.07 pps. These pulses supply power to the motor in sequenced fashion. To conform to specification, the interval from turn on motor operation to switch transition from Safe to Enable must take place between 1 and 2 seconds. Based on a nominal value of 1-1/2 seconds the following events transpire (see figure 3-20).

The stepper motor is fitted with a 13-tooth pinion gear which couples the motor to a series arrangement of two additional gears. The ratios of these two gears is 6.923 to 1 and 6.333 to 1 rendering an overall ratio of 43.84 to 1. Since the pulse rate of 122.07 pps is equivalent to a time of 8.192 ms per pulse, the nominal operate time of 1.55 seconds requires the motion of the motor for 190 steps of the 90° stepper.

e) Internal Feedback and Monitoring. - The design is provided with three sources of data used for internal monitoring of the motor/switch status. Two of these independent inputs arise from the monitoring deck in the switch proper and indicate whether the switch is in the safe or enabled condition. The third input is generated by an opto-electrical sensor consisting of an LED and phototransistor. These devices are configured on either side of the final gear and geneva mechanism. These three signals interface directly with the electronics portion which makes use of the fact that there is a singular position for this group that represents the starting point for operation of the device - the point to which reset and initialized conditions are homed.

f) Gear Drive, Geneva Drive and Bearing Plate. - Each of the gears is located in precise alignment and rigidly centralized through bored supports in the base of the housing and gear plate. Each gear spindle is supported in close tolerance bearings to preserve the original alignments. These bearings are designed to operate as dry elements, without lubrication. This feature promotes the longevity of the enable switches by eliminating a potential source of outgassing

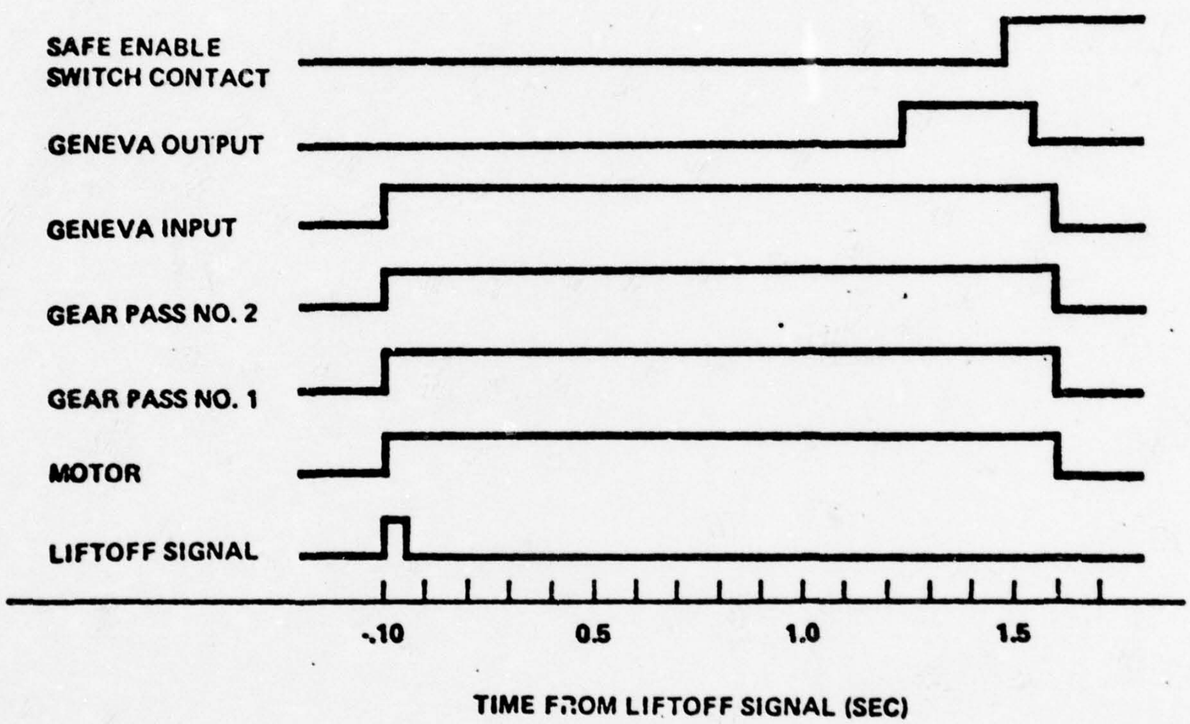


Figure 3-20. Enable Switch Gear Train Timing Diagram

contamination. The gears are of stainless steel and the final gear is fitted with a welded in place stainless steel polished pin which serves as a drive for the geneva arm, which is an integral part of the switch shaft. During the final 20% of motor operation, this pin engages the slot in the driven portion of the geneva and by its action rotates the integrally connected switch shaft, rotor, and wipers to the enable position. Total motion of the switch shaft occurs in approximately 300 ms. Only during the last 90 ms does contact/wiper engagement occur.

The driven portion of the geneva mechanism is fitted with a concave face aligned with a diameter feature of the final driving gear. This positive interrelation establishes a true locking mechanism which prevents any rotation of the driven portion of the geneva (and the integrally connected rotor shaft) except for the moment of transition when rotation of the shaft is desired. Following this interval, the locking feature again comes into play, locking the switch in the enabled position. Thus the enable switch is positively locked in both the safe and enable positions.

3.4.2.4 Structural Enclosures. - All operating elements of the enable switch/motor drive are mounted on or in a precision housing which serves as the unifying member of the structural and hermetic systems. All exposed interfaces of the housing are provided by welded seals. No gasket, O ring or soldered interfaces exist to compromise this essential barrier against deterioration with time. Major elements include:

- Housing and bearing plate
- Cover, outgas and backfill system, and sight window
- Motor, enclosure, and enable switch attachment

Figure 3-21 displays many of these features in the operational model. All major elements of the structure are constructed of stainless steel and weight calculations are based on this material. Weight reduction can be accomplished through substitution of titanium in many of these applications without degradation of technical requirements. Based on the actual operational model using finalized materials, each Enable Switch/Drive module weighs 7.82 ozs. Table 3-3 details this analysis.

a) Housing and Bearing Plate. - The housing is precision machined from 321 stainless steel with a typical wall thickness of .075 in. The interior is bored to accept the lower surface of all gear spindles and their bearings. The exterior is configured to accept the welded-in-place enable switch module and motor sleeve. The opposite exterior surface accepts the welded-in-place cover. The housing adjacent to the cover is also provided with mounting bosses for attachment of this enable switch module to the case of the E/OD.

Photo-optical sensors are incorporated within the housing cavity and they operate as previously noted in connection with the establishment of the reset position. Terminals for these circuits are brought out from the housing proper to keep this control and monitor circuitry isolated from the motor power leads which is the object of their control.

The bearing plate, .075 in. thick, is also stainless steel and is bored to accept the bearings supporting the canti levered end of the gears. It is pinned to the housing to maintain alignments between gear support points. The bearing plate also serves as a mounting surface for portions of the photo optic sensor system. Rigidity and strength of the heavy wall housing assembly is enhanced by inclusion of this substantial plate.

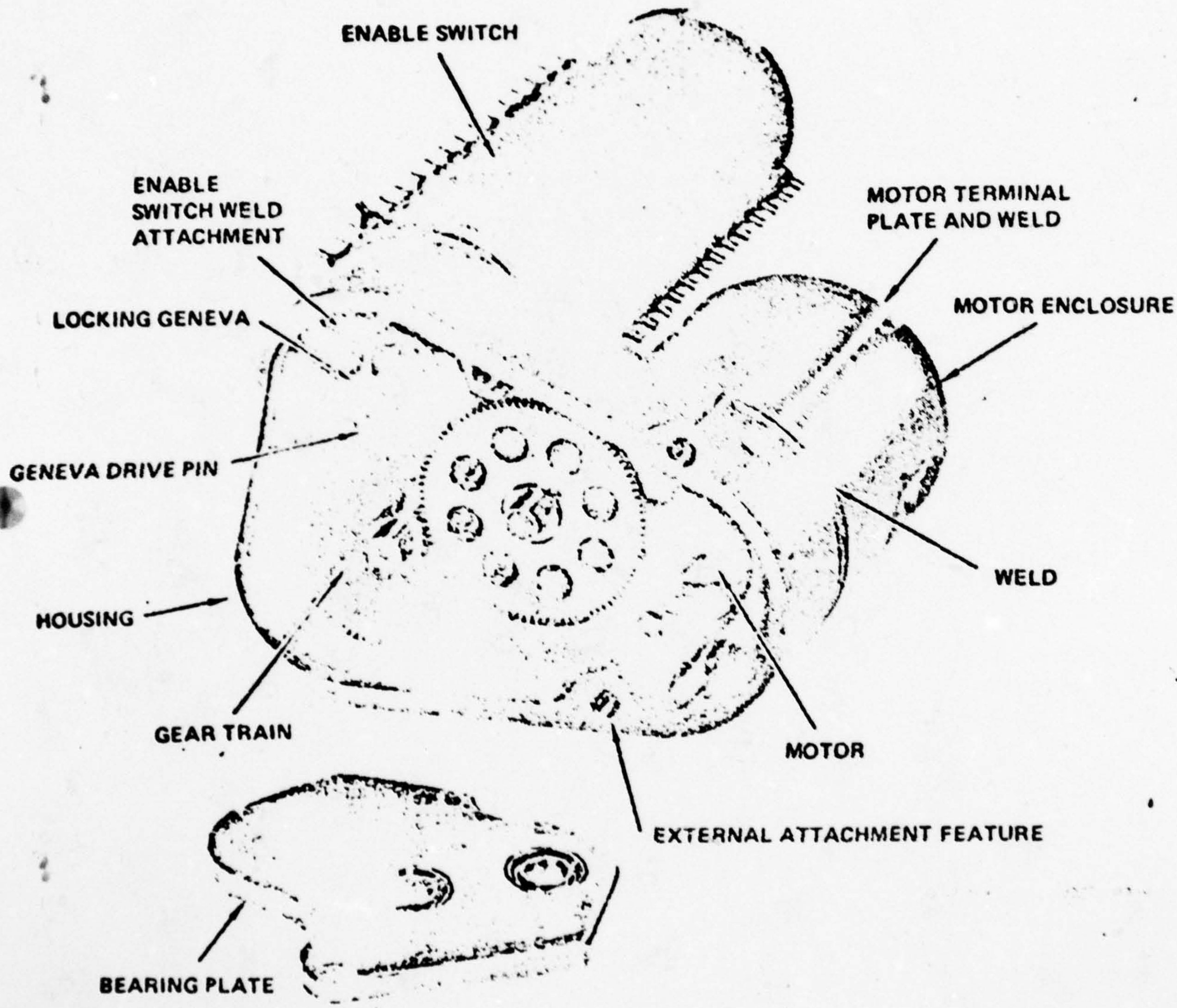


Figure 3-21. Enable Switch Operational Model (Bearing Plate Removed)

b) Cover, Outgas and Backfill System and Sight Window. - The cover is a contoured plate of 321 stainless steel configured to form a weld preparation relationship with a prepared recess in the housing. At final assembly the cover is TIG welded to form a hermetic closure of the gear box cavity and the enable switch module and motor attached to it. Two additional functional elements are fabricated for inclusion in the cover plate.

The sight window a sapphire-to-metal seal, provides a 30-in. diameter viewing area, permitting a direct view from the exterior of the cover to the color band indicators and flag associated with the final gear and driven geneva element, as previously described. The cover is mounted directly against the E/OD external surface and viewing is unimpaired from the exterior of the E/OD.

To permit the sight glass to withstand the full stress imposed by the 1850°F desired safety level, conventional sealing glasses must be eliminated from the design. These conventional glasses, typically Corning #7052, are able to withstand temperatures up to about 1400°F. Some quartz glass seals are designed for use above 1400°F but the general application for these seals is a design where the quartz itself is exposed to a local hot spot with a cooler surrounding area. Since quartz does not bond effectively to metal, the seal is of a configuration known as a graded seal. In this method, the quartz is bonded to successively lower temperature glasses, ending at the metal junction with a conventional sealing glass such as the #7052. In application where the entire structure will be exposed to high temperatures, the seal would only be as strong as its weak link - the 1400°F rating of the #7052 glass.

The sapphire - originally a single crystal boule - is sliced, ground and polished to the requisite dimensions. In a manner similar to the metallization of ceramic and its subsequent bonding to metal, the surfaces of the sapphire to be bonded are metallized with moly-manganese with a 2% tantalum addition, a moly-manganese and sillicate coating or moly-manganese yttrium mixture. These materials are fired into the surface of the sapphire at 1500°C (2732°F) and enter into the sapphire lattice. Subsequent plating over this metallized surface renders it compatible with the brazing process - forming an integrally bonded seal. The brazing is accomplished at 1100°C (2012°F), well above the maximum temperature environment of 1850°F. The metallized sapphire is brazed into a surrounding sleeve, itself welded to a prepared hole in the cover.

Outgassing and back filling with an inert gas is a multi-step operation facilitated by the unique design of the system. Three basic parts are involved in this subsystem. The outgas block or housing is permanently welded to the cover and is a cylinder with the outer end open to the environment and inner end sealed at the interior except for a small opening. An outgas tube assembly consists of a brass cylinder with surrounding O ring and a central hollow copper tube. Extending from the base of the outgas cylinder - and not interfering with gas flow through the tube - is a pointed prod similar in shape to a needle style stab igniter. In operation the switch/motor assembly is heated in an oven to facilitate moisture elimination from the interior and simultaneously a vacuum is drawn on the end of the copper tube. The O ring seals the OD of the tube assembly to the ID of the outgas block. This O ring functions only during this transient outgas period. Upon completion of the thermal vacuum outgas cycle, the unit is flushed and backfilled to a positive pressure utilizing a dry backfill gas containing 90% nitrogen, and 10% helium. The copper tube is sealed using a conventional cold pressure weld close to the brass cylinder. A seal plug is then welded in place at the formerly open end of the outgas block, creating a permanently welded joint at the outgas area. The stab igniter form at the base of the outgas assembly is forced into the former gas passage hole in the outgas block to seal the O ring and any potential outgassing over time or high temperature from entering the atmosphere of the housing, switches or motor. This technique and its variations to meet particular equipment needs has been used in over 6000 missile qualified flight rated switches.

c) Motor, Enclosure and Enable Switch Attachment. - The motor is configured as a straight cylinder approximately .875 diameter with a nominal .500 inch reduced diameter-projection on the shaft end. This projection is concentric to the motor shaft and therefore the location of the motor in the housing - and relation of the motor shaft to the gear train - is mediated through this concentric feature. Four tapped holes for attachment to the housing are located on the front face of the motor. Internally, the motor consists of a series of coils arranged in a four phase sequence with a central longitudinal cavity. Within this cavity the rotor proper is fitted. The rotor is a permanent magnet structure utilizing Alnico 9 material. Each end of the rotor is held in dry lubricated bearings to control location and free play. The end of the rotor extends beyond the motor as the output shaft and is externally configured as a 13-tooth gear to interface with the balance of the gear train. The motor is cased in a stainless steel shell with stainless steel front and rear caps. Although the motor construction is enclosed, the motor is not hermetically sealed as manufactured. For

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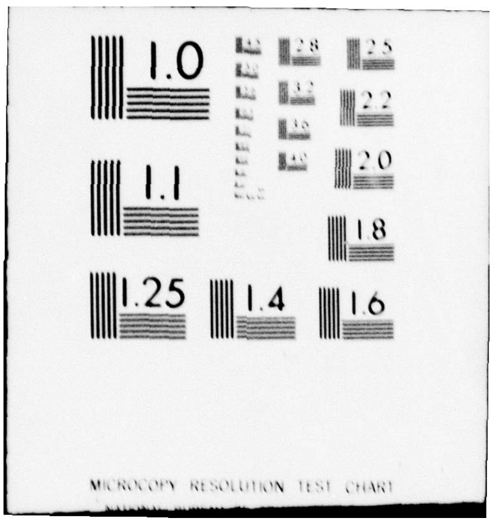
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motor hermeticuity an enclosing stainless steel sleeve is welded to the rear of the housing and extends beyond the end of the motor. The end of this sleeve is welded to a stainless steel cover carrying a high temperature resistant ceramic to metal brazed header to which the motor leads are directly connected. Motor leads are therefore physically isolated from any of the power circuits feeding the input or output of the enable switch module. The sleeve and cover described form a hermetic seal around the motor.

The motor is mechanically coupled to the enclosing sleeve by a stepped metal ring between the rear of the motor and ID of the sleeve. The cover previously described is designed to hold the ring in place. The object of this ring is to reduce the resonant frequency of the motor/sleeve system and to eliminate the otherwise cantilevered length of the motor by coupling together the motor and its enclosure.

3.4.2.5 Packaging into the E/OD. - The enable switch module is in itself hermetic and its front cap is provided with a weld prep allowing direct TIG welding to a prepared bore in the rear of the housing. The enable module extends approximately 2.4 inches from the rear of the housing. It is desirable to reduce the effects of cantilevering. For the switch this is accomplished by providing the rear of the switch with a reduced diameter extension which plugs into a mating recess on the rear of the housing of the other E/OD channel of the enable switch/motor assembly. The two assemblies are therefore tied together so as to more nearly approximate a single body under the various induced mechanical stresses. The E/OD packaging places the motors in a colinear arrangement and therefore the motor enclosures may be fitted into a junction sleeve at the time of packaging into the

E/OD to provide additional strength, reduction in resonant frequency, and further reduction in contilevered influence. Provisions for passage of lead attachment to the respective motor header terminals are provided.

3.4.3 Specific Comments To Statement of Work Paragraphs

F.1-IV-4. Durability. - Demonstration of stockpile life is subjected to simulation testing as described in the development testing portion of this proposal. Specific features have been incorporated in the design of the enable switch/motor drive modules from the outset which in the past have contributed to stockpile longevity and stability of operating characteristics. These include:

a) Environmental Isolation of Critical Components. - In the enable switch/drive module this is accomplished by creation of a completely hermetic assembly. Each exterior interface is welded or brazed. No solder seals - with attendant flux joint or cold solder joint potential problem area - is employed. Compression or resilient seals are eliminated. Even glass to metal seals have been removed from the design due to their susceptibility to crazing and subsequent increase in hermetic leak rate following lead attachment, and the tendency of internal striae to deteriorate with the passage of time.

b) Control of Internal Atmosphere. - Hermetic construction as described will avail little if the contained internal environment is not conducive to extended life. An extended outgas cycle incorporating both temperature and vacuum applications serves to remove moisture and outgassing vapors from the switch/drive interior. Moisture removal lessens greatly the possibility of any chemical reaction between or within any contained portion of the system and outgas component removal prevents redeposition or sublimation and reformation of any film on surfaces intended to subsequently mate as current carrying parts. Additionally, these outgas components are frequently corrosive and deposition on surfaces between isolated electrical circuits may incur degradation of insulation resistance and dielectric withstanding properties.

Following the outgas procedures, the module is backfilled with a 90% nitrogen, 10% helium mixture. Dew point of the fill gas is held to -80°F or better. A positive pressure of 3-5 is maintained to discourage any residual outgassing and to maintain minimum water vapor conditions.

Outgassing is best controlled by elimination of all materials susceptible to this phenomenon. To this end all organics have been eliminated from the interior of the module with the exception of the polyimide motor winding insulation and the potting compound used in connection with the windings. This amounts to a total weight of 50 mg of low volatile materials. All other materials are non volatile. All liquid lubricants have been eliminated throughout the module. Where adviseable - as in the motor bearings - deposited and fired dry lube systems are employed. Photo-optical components within the enclosure are themselves hermetically sealed and their lead insulation to the exterior will consist of ceramic sleeve and head insulators.

All functional current interfaces - the wipers and contact buttons-are additionally protected by gold electroplated surfaces to preserve their surface condition and the platings relative ductility will permit sufficient surface deformation when contact is established thereby assuring that proper contact is made.

The wiper springs themselves are stressed to a level of 65% of conservative design limit when installed in the rotors, therefore no degradation of wiper spring pressure will occur over the stockpile life.

The hermetic enclosure and the brazed and welded joints are expected to establish a leak rate not exceeding 1×10^{-9} atm-cc/sec and because of these constructional features will remain constant over the stockpile life.

F.1-IV-5. Cycle Life. - The actual operating life of the enable switch/drive module is expended in very small units of time and operation. One hundred cycles of operation is equivalent to no more than 3-1/3 minutes of enabling operation and 3-1/3 minutes of reset functioning. Cycles of enable and reset are anticipated to occur with some time interval between them. Based on 100 operations in 20 years, there are months between operations therefore no continuous operation is anticipated. Even with continuous operation, the motor is rated at 1000 hours at a duty cycle of 25%.

Switching configurations of this generic design are capable of a minimum of 10,000 operations.

Liberal applications of bearings at all points of rotation contributes to minimized wear and maintenance of alignments.

Gear teeth are .060 in. thick and are stressed to no more than 50% of their conservative load driving capability.

F.1-IV-6. Reset Capability. - The enable switch/drive module provides the sets of electrical signals which interact with the electronics portion of the E/OD providing information and feedback utilized in reset action. The switch and drive portions provide independent sources of data. The switch is provided with a deck whose terminals are physically isolated from the output terminals. This deck is electrically configured as two single pole switches and conduct signals, one when the enable switch is in the safe, the other when the switch is in the enabled position. These signals interface with the electronics portion of the E/OD so as to indicate, safe, enabled, or if both signals are absent, a transiting state.

For proper timing for 1-2 second operating time, the geneva driving pin on the last gear should be located at a particular ratation from the point of entry into the geneva slot at the time of lift off signal. Reset or initial position setting on missile power on requires the pin to be brought back to this location. This is achieved by the photo-optical system consisting of a LED and a phototransistor. These are located on opposite sides of the geneva slot disc and the gear containing the geneva drive pin. At a unique relative position, these four elements, the sighting holes in the two gears, the LED, and the phototransistor are in line. The state change in the phototransistor at this time signals reset and is operated upon by the electronics as described in that exposition.

F.1-IV-7. Visual Status. - The unique relationships that prevail in the geneva related parts serve double duty in the visual status system. When in the armed position, a red flag, an integral part of the driven geneva and a positive indicator of switch shaft position, is brought in front of a hermatically sealed viewing window, a part of the cover of the enable switch/drive module. In any position but armed, the flag is withdrawn and the view through the window is of the final driving gear. High visibility green and yellow bands are located on the face of this gear and indicate the status of the module as safe or in an intermediate position. Nomenclature Safe or Armed is superimposed on the band and flag, in accordance with specification requirements. The window in the cover is directly adjacent to a viewing port in the outer enclosure of the E/OD permitting direct sighting of the internal elements. This arrangement is illustrated in figure 3-12.

F.i-IV-9. Single Point Failure Degradation. - All of the design effort has been based on a primary requirement for safety. The following features are included in consideration of this element.

a) Isolation of inputs and outputs to the enable switch is achieved by their separation of 180°. The output leads run directly to the output connector and may be welded to the switches output terminals. Input leads are positioned and dimensioned so that in event of their breakage they cannot physically reach the output terminals or output connectors. Output leads are similarly restricted.

b) Each switch input and output terminal is located within a ceramic feed through insulator penetrating the shell. These elements are all hi-temperature brazed in place resulting in a highly stress-resistant construction. Shouldered design of the switch housing and insulator/terminal prevents inward travel of the terminal into the switching chamber. Physical deformation of terminals causes grounding to case and not interconnection of critical circuits.

c) The internal design of the switch is based on maximum material considerations, greatly limiting freedom of passage of any loose material within the switch chamber while maximizing internal strengths and resistance to crushing forces.

d) Each wiper is encased in interlocking ceramic rotors, which also serve as barriers completely isolating all but the tip intended for actual contact interface. These tips are located perpendicular to the location of the contacts except during actual arming of the switch.

e) Monitoring circuits are active at all times and feedback indicative of abnormal shaft position initiates reset.

f) The rotor shaft is locked in position - either safe or armed-at all times except during the fractions of a second required for circuit transfer. This is a simple and direct locking system and not a detent dependent on springs for holding force.

g) Motor power terminals are physically isolated from the enable switch input or output leads and from the output connector to preclude inadvertent transfer of power to the E/OD output.

h) Photo-optical component leads used to control motor operation for reset status are isolated from all other leads to preclude motor power and control circuit interconnection.

i) All components and elements are inherently corrosion and fungus resistant.

F.1-IV-11. Electrical Requirements.

a) Circuit Transfer Mechanism. - All circuits appearing on the output connector, J2, are isolated from the input source by the 16-circuit enable switch. One enable switch is associated with each of the output channels. Input to output isolation as verified on the feasibility model constructed to prove this design is in excess of 50,000 megohms at 500 V, several orders of magnitude greater than specification requirements.

b) Contact Resistance. - Maintenance of contact resistance characteristics is dependent primarily on proper interface materials and maintenance of an inert atmosphere. Gold plating on wiper and contacts provides good interfaces for the digital and power circuits to be handled and the metal-to-metal or ceramic brazing and welding assure long term hermetic capabilities.

Measurement of circuit resistance on the operational feasibility model confirmed values less than 15 milliohms. Less than 5 milliohms is a function of contact interface resistance - the balance is a fixed value arising from the wiper material, chosen for excellent retention of mechanical properties under elevated temperature exposure, and high contact pressures required for proper operation during and after shock and vibration.

c) Contact Chatter. - Direct force of wipers against contact surfaces for most switch designs of this type is 40-50 grams. In consideration of the environmental requirements and the necessity for assuring reliable first time contact after long stockpile, this design has established a nominal level of 125 gm for direct contact force. This high force coupled with the low mass of the wiper assures that reliable contact will be maintained at all times during passage through the environmental spectrum. The worst case condition is expected when the module is subjected to the 450 g shock wave. Since the wiper approximates 0.1 gm, a 3:1 safety margin has been calculated at this worst case.

The current design and the feasibility model are based on a single, full-width wiper surface. If desirable, the wiper ends can be unsymetrically bifurcated so as to provide two wiping surfaces at each contact face, each with a different natural frequency. Our design is based on circuit interruptions of less than 10 microseconds as contrasted with a specification permitting 50 microseconds maximum.

d) Preferential Breakdown Path. - Input and output lines are connected directly to their respective terminals. These terminals are mounted in ceramic insulators located in the grounded stainless steel housings. An air gap of approximately .050 in. is maintained between each terminal and the case on both the interior and exterior of the shell. The spacing provided will provide a conservative breakdown of approximately 1000 V. Beyond that voltage, breakdown may occur, probably on the exterior surface since the interior will be slightly pressurized over nominal ambient pressure and the backfill gas is a very dry (-80°F. dew point) mixture of 90% nitrogen and 10% helium. The 10% concentration in the fill gas of the lower breakdown voltage (helium) is not sufficient to substantially alter the nitrogen characteristics of the interior atmosphere.

The breakdown path to the shell may be augmented if necessary by post forming a needle point feature on the exterior shank of each terminal.

Available breakdown paths between input and output terminals - as contrasted to breakdowns to case - are very much longer, typically 1/4 inch when the enable switch is in the safe position, and the intervening material between conductive elements is ceramic. To assure safety the shortest breakdown path, therefore, is terminals to grounded shell and not terminal to terminal.

e) Insulation Resistance. Measurements on the operational feasibility model show insulation resistance to be in excess of 50,000 megohms at 500 volts for tests between shell and either input or output terminals. Measurements between input and output terminals are in excess of 100,000 megohms. All these readings are far in excess of the specification level of 50 megohms. Operational life is not expected to significantly reduce these results since the design is such that any residue derived from the arc upon switching will deposit away from each of the terminal insulators (maintaining a clear insulating surface), and the splatter is directed towards adjacent insulators but is shielded from them by the interposing of a ceramic barrier carried as a projection on the outer diameter of the rotors.

f) Overvoltages. - Components subject to overvoltage in the enable switch/drive module includes the LED and the motor. Both of these are protected by virtue of features in the electronics portion, as described there.

F.1-IV-12. Testability. No time sensitive or one-shot components are incorporated in the enable switch/drive module. All parts singly and in combination are designed to withstand thousands of test cycles, far in excess of specification requirements. No hardware replacement or refurbishing is required prior to retest or placement in operational status.

F.1-IV-14. Functional Requirements. The two enable switch/drive module which are incorporated in the E/OD are functionally independent of each other. Each contains 16 normally open circuits plus monitoring circuits. Each switch is operated to the Enable or Safe position by an independent four phase stepper motor.

1) Operating Time. - The master clock generating 122.07 timing pulses per second is used in this design to control the operation of the integral stepper motor, prime mover of the system. The action of the motor is transferred through a two stage gear train and the switch is activated by a geneva driving pin on the final gear acting against a geneva slot, an integral part of the switch rotor.

The motor is fitted with a 13-tooth pinion which engages a 90-tooth mating configuration on the first gear for a step down of 1:6.923. The spindle of this gear carries 15 teeth and is mated to a second gear with a 95 tooth interface. The cumulative ratio therefore is nominally 1:43.84.

The stepper motor rotates 90° with each input of driving power. As seen at the end of the gear train, each step is reduced to 2.053° of rotation of the geneva pin. For a pin rotation of 390° , at which time all circuits will be enabled, 190 steps of the motor are required. At a time interval for each step of 8.192 ms $\frac{1}{122.07}$, the 190 steps are accomplished in 1.556 seconds, a value approximately centered on the 1-2 seconds specification operating band.

2) 80% Timing Factor. For a 390° geneva pin operation, 80% of non-engaged operation requires that 312° rotation be traveled by the pin prior to engagement in the geneva slot. Actual value in this design is 312°, satisfying this requirement. Only during the last 15° of switch shaft rotation does contact become established. This 15° does not occur until the driving pin has traveled 376°, 94% of its operation.

3) Motor Concept. - The system employed in this design uses a four phase stepper motor driven two phases at a time. Current per phase is less than one ampere. Reduction in weight and size has been made possible by modifying the original concept of a 15° stepper to 90° motion and correspondingly adjusting the gear ratios for timing and requisite output torque. Master clock pulses are used for control of timing.

4) Power Interruption. - Loss of power in excess of 100 microseconds is sensed by the electronics portion of the E/OD. Monitoring circuits in the enable switch inform the electronics section if the enable switch has been armed. These two information inputs are acted upon by the electronics portion of the E/OD to generate a reset signal, when required.

5) Output Terminals. - Enable switch output terminals are located in a single plane on each shell and are positioned to directly face the output connector. The two switch modules are installed one above the other so that both sets of output leads have short direct paths to the connector.

6) Input Wiring. Input terminals are located 180° away from the output terminals and therefore both sets of inputs are isolated from the output circuits. Input leads - even if broken loose - cannot reach the output terminals.

7) Output Connections. All leads to the J2 output connector are run directly to the output terminals of the enable switch and must pass through the enable switch contacts to complete a circuit.

8) Positional Safety. - The enable switch shaft is locked in a fixed position at both the safe and enabled conditions by the geometric lockups between a concave and convex interlocking feature on the geneva driving gear and driven gear. No motion of the switch shaft is possible except at the desired moment of switching.

9) Motor Power. - Each phase of the stepper motor draws less than 0.9 ampere. Driven two phases at a time, the total consumption per motor is less than 2 amperes.

10) Switching Capacity. - Current carrying capacity has been tested simulating the wiper and contact arrangement. The interface was subjected to a current in excess of 20 amperes for two hours. A temperature rise of less than $140^{\circ}F$ was measured under these overstress conditions.

The high temperature materials used for contact interfaces and the rapidity of switching action contribute to the current breaking capacity of the switch. Current breaking characteristics may be augmented, if desirable, by inclusion of brazed in-place sintered tungsten contact tips on the wiper and fixed contact. Tungsten configured interfaces of this general design have been qualified for 15 ampere breaking capacity - even under thermal vacuum conditions.

11) Switch Closure. - Connections are direct from the J2 output connector to the enable switch terminals. The switch internal contact surfaces are plated and configured to establish effective continuity for both the digital signal level and power level signals to be transferred. Sensing of the armed position via the monitoring deck occurs after the point of contact establishment on the 16 functional circuits, assuring that all functional circuits are made prior to motor turn off.