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PHOTOVOLTAIC STAND-ALONE MODULAR SYSTEMS PHASE II FINAL REPORT

George J. Naff
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Long Beach, California 90810-0399

July, 1983

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Lewis Research Center
Under Contract DEN 3-207

for
U.S. DEPARTMENT OF ENERGY
Conservation and Renewable Energy
Division of Photovoltaic Energy Technology

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The Photovoltaic Stand-Alone Modular System engineering model construction was conducted by the Hughes Aircraft Company, Long Beach, California, for the NASA Lewis Research Center, Cleveland, Ohio.

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ABSTRACT

This report covers the final hardware and system qualification phase of a two part stand-alone photovoltaic (PV) system development. Phase one, reported previously, included the analysis of methodologies, conduct of trade-off studies and the evolvement of viable conceptual design alternatives and preliminary designs culminating in the final design of an autonomous system capable of being deployed in stand-alone power increments up to 15 kilowatts peak. Emphasis was placed upon the achievement of optimally low balance-of-system (BOS) costs as well as cost-effective modular expandability over the spectrum of desired power ratings. The final configurations were also required to be capable of being effectively deployed and operationally survivable, on a world-wide basis.

The final design, approved for the Phase Two engineering model construction and qualification, incorporated modular, power blocks capable of expanding incrementally from 320 watts to twenty kilowatts (pk). The basic power unit (PU) was nominally rated 1.28 kWp.

The controls units, power collection buses and main lugs, electrical protection subsystems, power switching, and load management circuits are housed in a common control enclosure. Photovoltaic modules are electrically connected in a horizontal daisy-chain method via Amp Solarlok plugs mating with compatible connectors installed on the back side of each photovoltaic module. A pair of channel rails accomodate the mounting of the modules into a frameless panel support structure. Foundations are of a unique planter (tub-like) configuration to allow for world-wide deployment without restriction as to types of soil. One battery string capable of supplying approximately 240 ampere hours nominal of carryover power is specified for each basic power unit. Load prioritization and shedding circuits are included to protect critical loads and selectively shed and defer lower priority or non-critical power demands.

The baseline system, operating at approximately 2 1/2 PUs (3.2 kW pk.) has been installed and deployed at Hughes, Long Beach since January 1983. Qualification was successfully complete in March 1983; since that time the demonstration system has logged approximately 3000 hours of continuous operation under load without major incident.

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1.0 SUMMARY

1.1 OVERALL OBJECTIVE OF CONTRACT DEN3-207

The primary objective of Contract DEN3-207 was to develop a family of modular stand-alone photovoltaic power systems that covered the range in power level from 1 kWp to 15 kWp. Products within this family were required to be easily adaptable to different environments and applications, and were to be both reliable and cost effective. Additionally, true commonality in hardware was to be exploited, and recurrent engineering charges associated with field deployment were to be minimized. Assurance of compatibility with large production runs, and ready BOS element availability were also underlying program goals.

A second objective was to compile, evaluate, and determine the economic and technical status of available, and potentially available, technology options associated with the BOS for stand-alone PV power systems. The secondary objective not only directly supported the primary but additionally contributed to the definition and implementation of the BOS cost reduction plan. The power systems considered in this contract were PV stand-alone (no utility grid backup) DC systems utilizing flat plate silicon solar cell modules. The study was expanded to include modular systems of fractional kilowatt power levels with ratings from 1/4 PU (approximately 320 watts peaks) to 16 PU (2048 kWp).

Both the primary and the secondary objectives of the contract were considered satisfied by the sequential execution of Phase I, the initial analytical and design phase, and the stand-alone system breadboarding, engineering model construction, and evaluation, the subject of this Phase II final report.

1.2 IMPLEMENTATION OF OBJECTIVE

Under Phase I design study the system was configured for world-wide application within a general environmental temperature range of -15°C to +40°C in good to moderate solar insolation environments. The central thrust of the design was directed toward sun-belt (moderate temperature/equatorial) applications requiring reliable power from the photovoltaic energy source. Basic BOS elements designed or specified were the photovoltaic module/panel support structures, the battery protection and charge controls, lightning and fault protection, load management, instrumentation and diagnostics, electrical and mechanical installation, and checkout and operation. Economic analyses and cost trade- off studies of the BOS elements were an integral part of the design and parts selection process.

Go-ahead was given on Phase II shortly after completion of Phase I and approval of the surviving final design. The general approach for the conduct of the Phase II work was outlined under the Phase II (Option) "Modular System Development & Evaluation", Page 17 of Exhibit A, Contract DEN3-207. It was stipulated therein that Hughes would build and evaluate the modular system designed and approved in Phase I of the contract. A breadboard model of the critical electronic elements were to be first constructed. Breadboarding and developmental testing was principally directed toward the electronic circuits and control subsystems; other BOS elements of greater design maturity, or those not requiring experimentation were specified and directly incorporated in the final engineering model. An example of a high maturity item was the C&D industrial battery; another BOS subsystem not requiring developmental testing was the array structure and foundation. The solar cell modules purchased were in production and commercially available within the cost and performance goals. These PV modules additionally had to meet the Jet Propulsion Laboratory's LSA Project electrical and mechanical performance specifications for Block IV modules (JPL Document No. 5101-83).

The multipurpose modular PV power system was implemented within the baseline requirements outlined above. Breadboarding and developmental testing was undertaken only on the circuits comprising the battery C/R (Charger/Regulator), the L/M (Load Management) functions, and the master systems control and protection elements. The engineering model was assembled both from proven circuits and circuit board and controls evolved out of the breadboard verification successful test and evaluation was accomplished on this final system hardware configuration. The economic analyses required by contract were developed from the final design as constructed and proof-tested.

1.3 CONCLUSIONS

The results of the program are considered successful; all program goals were met. Competitive, cost effective designs have been evolved for the major BOS systems; these designs have been mechanized as prototype field hardware and qualified under stand-alone field conditions.

The manufactured hardware, purchased equipment, and sub-systems involve "off-the-shelf" technology resulting in readily available hardware. With the possible exception of the lead-calcium battery, the subsystem will have a life expectancy of at least twenty years. The battery does however represent the "top-of-the line" insofar as quality industrial electrochemical storage devices are concerned. The C/R and L/M circuit boards are of best industrial quality, able to withstand, without incident, the rigors of the tropical, coastal, or equatorial desert environment. Both the logic and the master control boards employ circuit and semiconductors qualified to stress levels equivalent to military specifications; hermatic relays are exclusively used in both control and power applications. The selected photovoltaic modules (15 Vdc nominal) are standard 2 ft x 4 ft devices delivering approximately 67 watts under standard conditions. The system-as-a-whole can be readily upgraded as the specific power output of PV modules increases. The conservative rating of the Power Controller can presently accommodate a significant increase in power level with virtually no retrofit or modifications.

The inclusion of a load management capability was an essential requirement of DEN3-207. Both a means of determining the energy remaining in storage and one of selectively shedding less critical loads in the event of an anticipated energy shortfall were required. Phase I analysis indicated that battery SOC (State-of-Charge) offered the best present alternative for assessment of energy remaining during the discharge cycle. We extensively reviewed and analyzed options known to us for sensing battery SOC. One approach, that of a GO/NO-GO cell specific gravity sensor was selected as the candidate, and incorporated into the engineering model design. The production of this candidate devices had an extensive listing of acceptable performance in electromotive service similar to that encounted in electric vehicles. In stationary fixed installation service the trip point below the selected gravity threshold unfortunately proved to be erratic and the present design of the method appears in question. With a modest additional developmental engineering effort, however, a dependable, and precise design configuration should result. These less than optimal results experienced to date should by no means signal the abandonment of this potentially viable solution.

2.0 INTRODUCTION

Terrestrial photovoltaics (PV) is an renewable energy technology evolving at a substantial rate. Early proponents recognized that the contribution of this soft energy generation could be significant in providing power to remote, isolated sites throughout the world. A number of developmental, analytical, and demonstration projects were undertaken by the Department of Energy's (DOE) National Photovoltaic Program. The broad goals of these projects were to prove the design, productivity and reliability of stand-alone systems, capable of economically meeting the power needs of remote, isolated locations, principally in emerging nations. It became apparent that stand-alone PV power would ultimately need both greater flexibility and lower cost to realistically meet the diverse power needs. Therefore, the NASA Lewis Research Center established a contract with Hughes to investigate and verify solutions to the above stated goals.

As several private and national efforts were under way to improve the performance and reduce the costs of photovoltaic cells and modules, the NASA effort concentrated on the Balance of Systems (BOS); only those attributes associated with the physical aspects, voltage/current ratings, and wiring topologies of the PV module were addressed as part of the BOS. The contract was segregated into two phases; phase one convered the analytical investigations and design optimization of a modular stand-alone PV system in the range of one to fifteen kilowatts peak. Phase II, the subject of this report, covered BOS hardware verification.

During the Phase I design study it was recognized that site-to-site differences must involve standardized equipment complements not requiring major design alternations. However, Hughes was not able to identify a unique, simplistic solution to the design of an optimally cost-effective stand-alone photovoltaic power system capable of satisfying all site specific variations. The final system design was therefore selected to satisfy the "majority" of potential worldwide installation requirements; deployments in extreme environments, such as North Alaska, would require modifications to the basic system design to accommodate unusual site specific requirements.

Hughes found the characterization of the BOS to be reasonably straightforward. In some arreas, however, such as the system regulation and control, the achievement of optimal designs involved the selection of BOS options which involved innovativeness, technical judgement, and cost trade-off analyses. In many instances several options appeared to be equally attractive.

This Phase II final report sets forth the activities and results in fabricating, testing, and verifying the hardware of the final design prepared under Phase I . Except for essential developmental upgrading involving refining circuit characteristics, the apparatus has been "built to print" from the Phase I documentation package. A generalized block diagram of the engineering model is depicted in Figure 2.0-1.

2.1 SCOPE OF PRESENT WORK

The DEN3-207 contract covers the development of a family of modular stand-alone photovoltaic power system. Power ratings were from less than 1 kWp to nominal maximum outputs of 15 kWp. These modularly expandable systems featured a high degree of hardware commonality as a means of eliminating recurrent design and development costs and for reducing production costs by facilitating large production runs. Both the initial BOS element costs and the lifetime costs of energy producted by these systems were considered. The scope of work of this contract included two sequential phases; Phase I, design of the modular system, and Phase II, construction and evaluation of the selected the modular final design developed under Phase I. Phase I, previously reported, was executed in several sequential tasks, conducted within well-defined developmental and analytical milestones. These tasks included:

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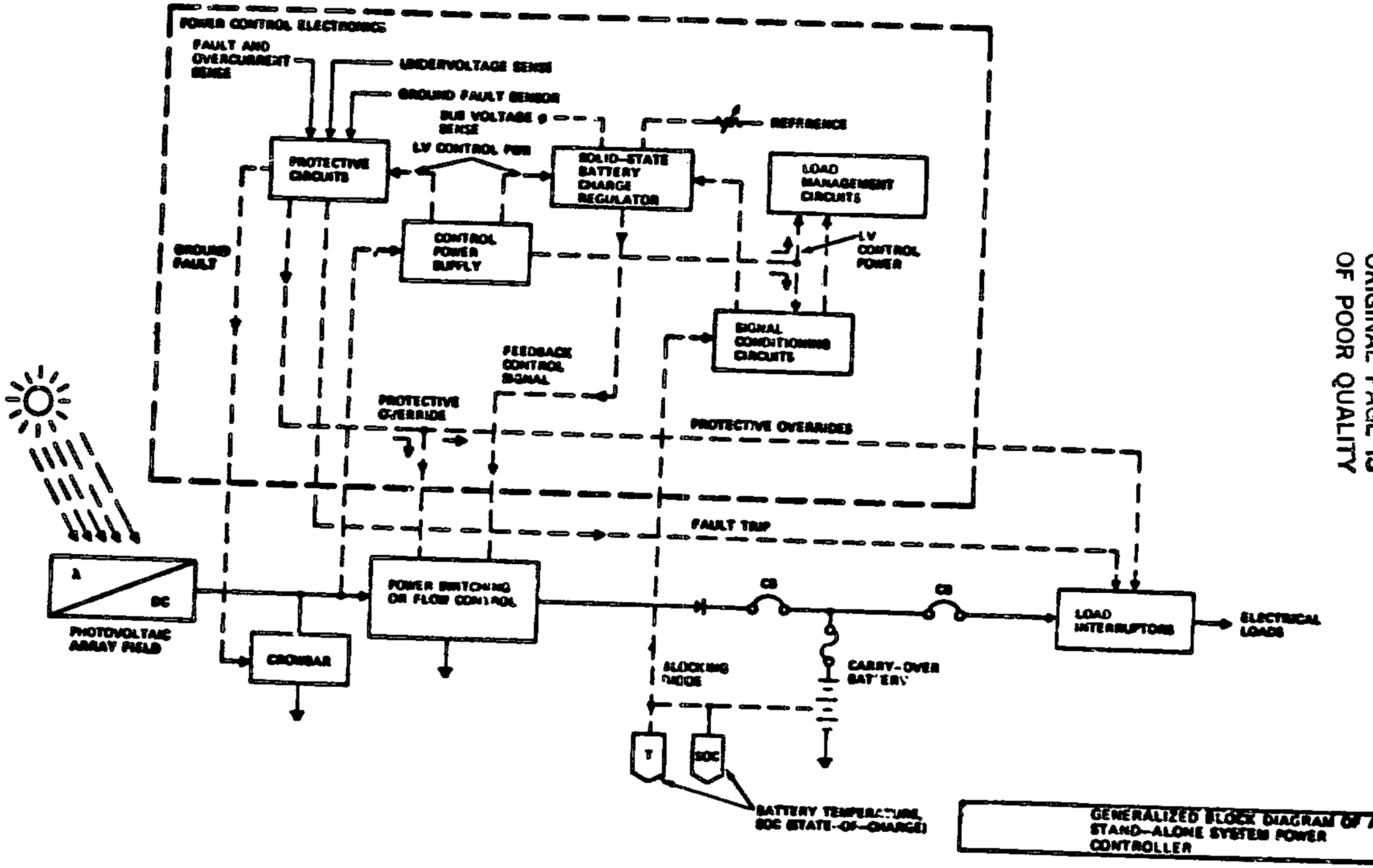

GENERALIZED BLOCK DIAGRAM OF A STAND-ALONE SYSTEM POWER CONTROLLER

Figure 2.0-1

a) analyzing and evaluating BOS elements ad costs; b) conceptual designs of alternative system approaches; c) preliminary system design options; and d) a final system design, review and documentation. Phase II, the hardware fabrication and qualification effort is the subject of this final report. Subject report includes: developmental breadboarding,design retrofit, fabircation, assembly of the engineering model, test and evaluation, and reporting.

2.2 RELEVANCE OF THE MATERIAL REPORTED TO THE GENERAL FIELD

The stand-alone designs developed, fabricated and evaluated under this project and the applications data accrued should be of direct interest to a group/ agency seeking a cost effective solution for supplying stand-alone village or remote power by dispersed terrestrial photovoltaic generators. Remote power applications dictate that photovoltaic power system exhibit high operational reliability and survivability. These designs, universally deployable with a minimum of site-specific engineering, should satisfy such objectives.

3.0 THE BREADBOARD MODEL

3.1 PROGRAM REQUIREMENTS

Baseline contract DEN3-207 criteria cites the possible need for laboratory experimentation and breadboarding of criteria electronic circuits. It also anticipated the probabilty of design refinements and iterations prior to freezing the configuration of the engineering model. Circumstances indeed proved that this step in verifying the functional adequacy of the solid state circuits and logic was required. Breadboarding of the critical circuits revealed several potential disparities that were readily corrected prior to committment to printed circuitry. The control elements involved included the load management circuits, the charger-regulator controls, and to a lessor degree, the master display and power control circuits board. Specific circuit changes incorporated in the the revised schematics are included under the respective summaries for each element breadboarded.

Because only the conceptual approach of the load management functions and the interactions with the charger-regulator and control circuits was available for reporting on at the completion of Phase I, the rationale, logic and developmental design details will be extended more explicitly in this Phase II Final Report.

3.2 BOS ELEMENTS

The stand-alone PV power system is functionally configured as depicted in the block diagram, Figure 3.2-1 following. The major subsystems, including the photovoltaic modules, that were fabricated and/or procured directly for the engineering model are identified in the subsequent discussions. The control electronics and logic were principally those BOS elements subjected to the intervening breadboarding step.

3.2.1 Photovoltaic Modules

The Phase I selection of 2 ft x 4 ft PV modules delivering approximately 67 watts peak at 4.4 Adc remained unaltered for the engineering model.

3.2.2 3KCPSA-5 Battery Strings

Two series strings of 20 each 3KCPSA-5 batteries manufactured by C & D were procured directly for the engineering model. These three cell batteries (289AH, 100 hr. rate at 77°F) are precisely as configured during the Phase I final report.

3.3 POWER CONTROLLER DEVELOPMENT

3.3.1 Design Commonality of C/R and L/M Control Circuits

The multilevel charger regulator (C/R) control circuits and the load management (L/M) decisional circuits utilize a common printed circuit board. The change of a few divider resistor values and serse inputs, the deletion of the temperature compensation function, and the addition of the DELTAR SOC sense inputs convert a C/R board to L/M control board. In the load management function the inputs to each of four dual state comparators are dedicated respectively to each of four DELTAR sensor outputs corresponding to 20

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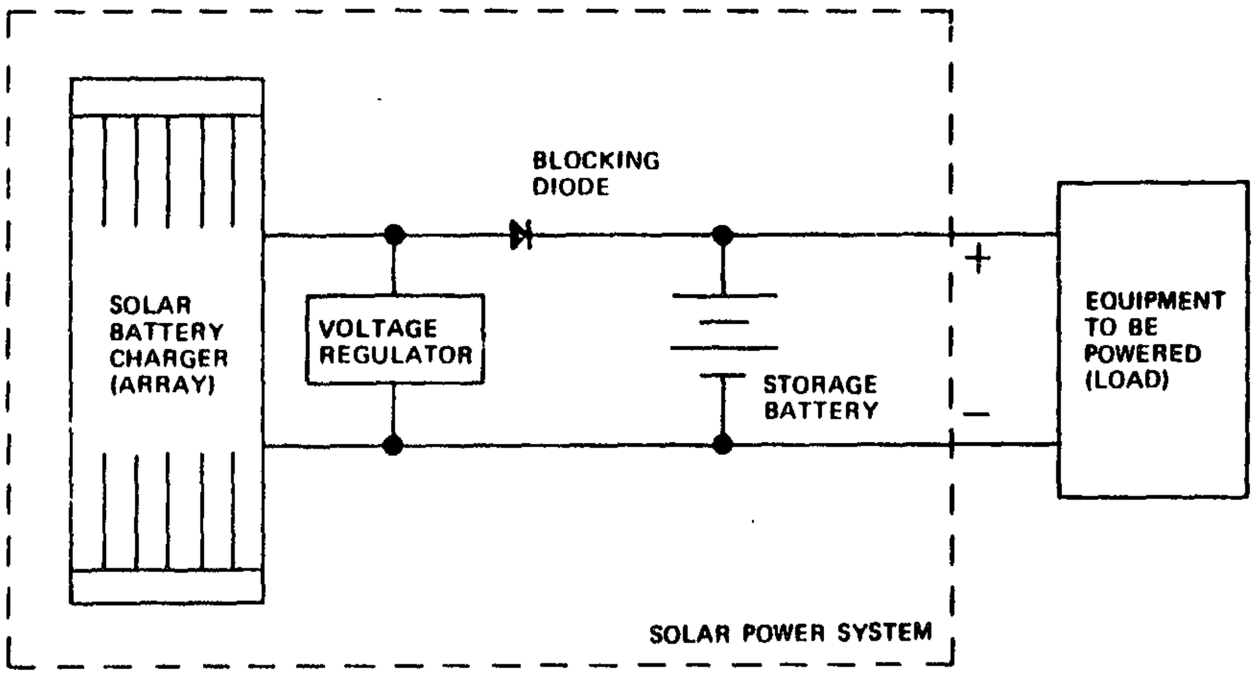

Typical System Block Diagram

Figure 3.2-1

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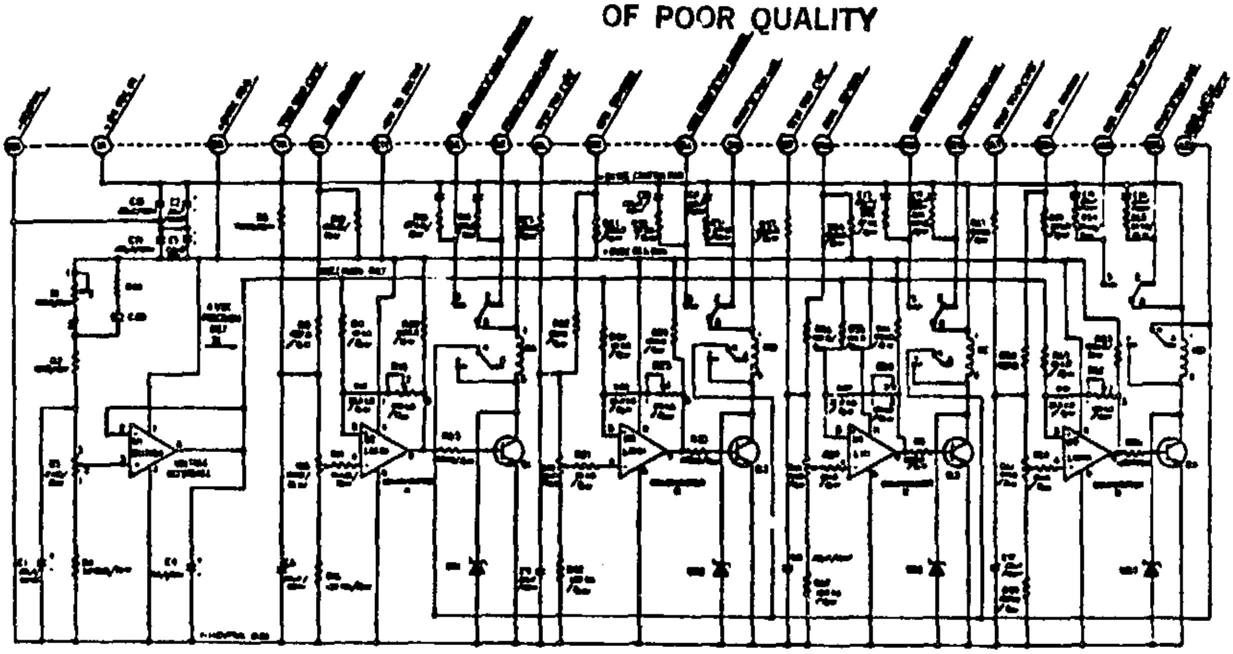
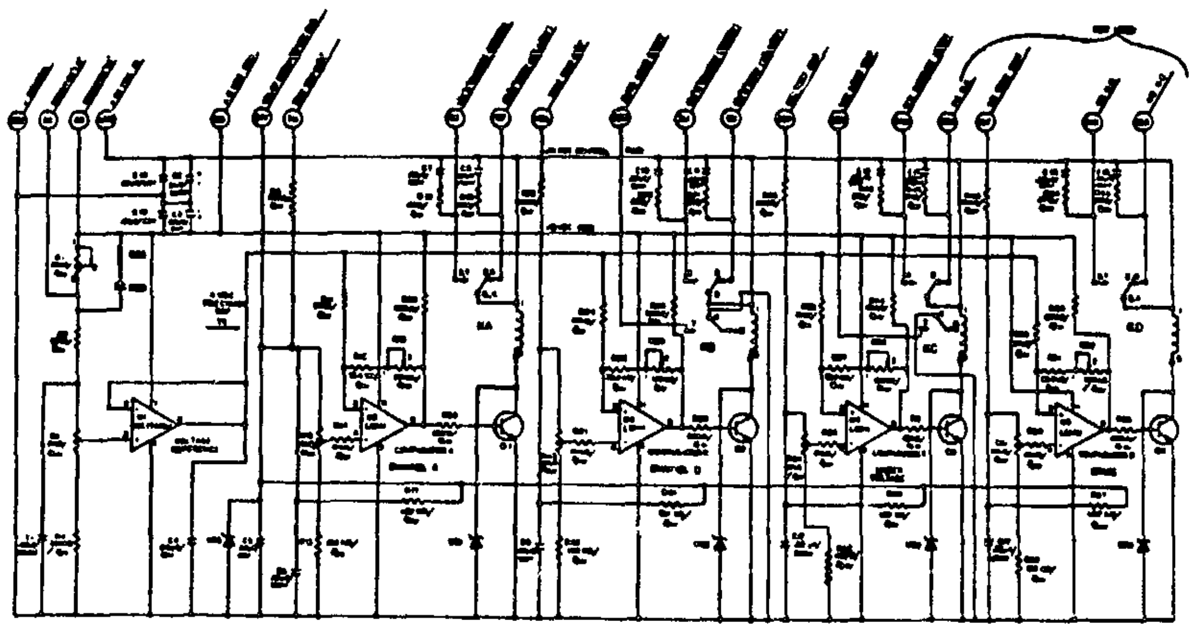


LOAD/MANAGEMENT CONFIGURATION-01



CHARGE/REGULATOR CONFIGURATION - 02

Figure 3.3.1-1

percent, 40 percent, 60 percent and 80 percent state-of-charge. In the multilevel regulator configuration, two comparators perform the dual channel regulation function; a third comparator is used for undervoltage trip. The fourth channel is presently uncommitted and available as a spare. Figure 3.3.1-1 is the schematic of this common plug-in element with both configurations shown. In the common circuit, the comparator IC outputs to a bipolar drive transistor, which in turn energizes a hermatically sealed, "one-half crystal-can" relay. These channel output relays can energize up to eight Mercury displacement contactors installed in the series "OFF-ON" charge regulating circuit.

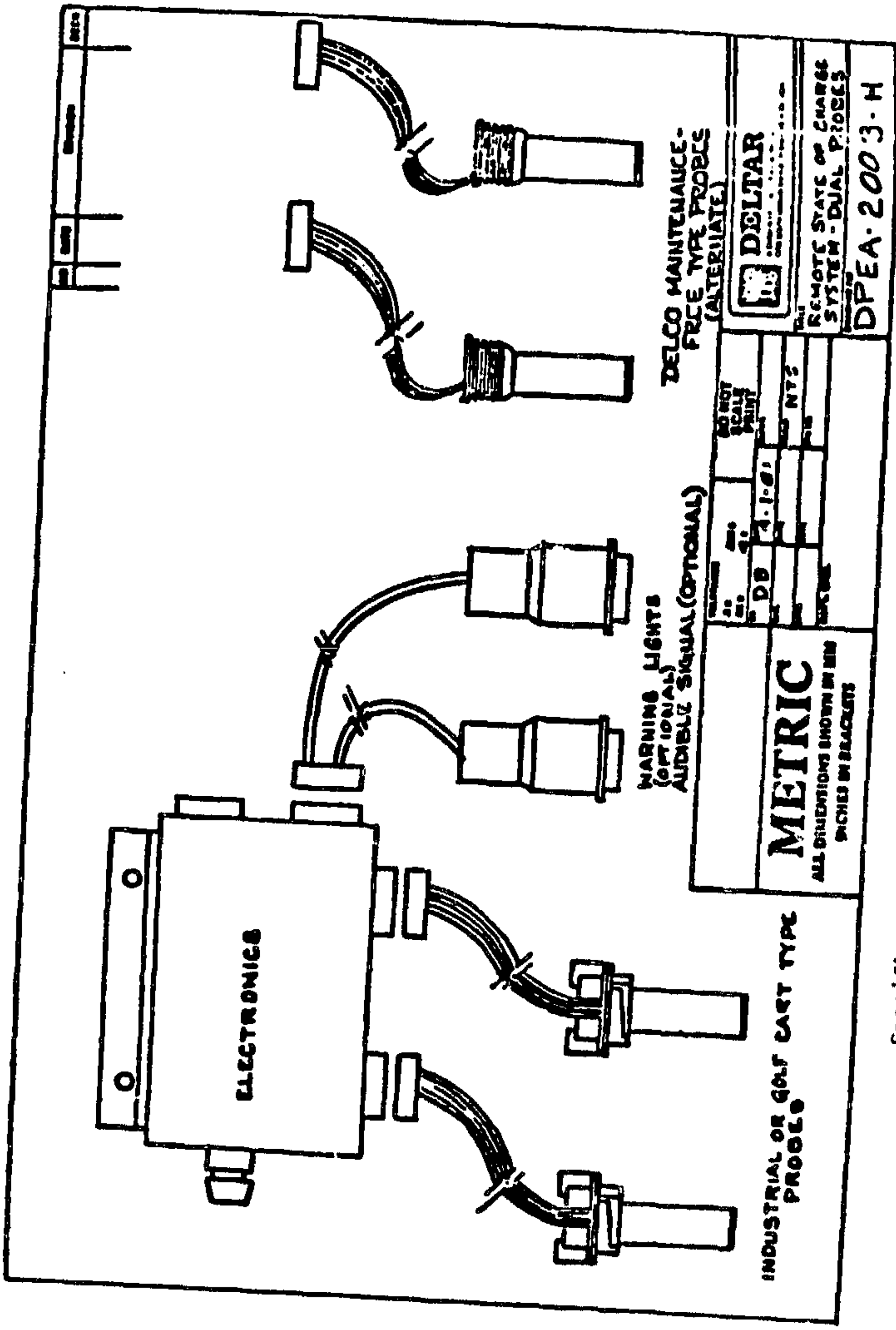
In the L/M configuration, each of the four comparator output relays energizes the corresponsing contactor assigned to that particular prioritized load bus. Each comparator is in turn actuated by an output level change in the DELTAR specific gravity sensor for that channel. Figure 3.3.1-2 is a specification control drawing of the DELTAR sensor assembly.

3.3.2 The Charger-Regulator (C/R) Board Function

In the charger-regulator configuration Channel "A" and Channel "B" comparators are both used for battery charge regulation through the mechanization of the Hughes multilevel series "OFF-ON" control system. This scheme, described in Para 3.5.9 of the DEN3-207 Phase I report, is herein included as Appendix "A". In the multilevel control scheme, the array field is compartmentalized; two subfield positive buses are summed at the inputs of the Power Switching Modules (PSM) controlling the power developed by one half of the PV branches.

Figures 3.3.2-1,-2, and -3 are simplified schematics of each comparator and the unique relay configurations for each individual function.

Figure 3.3.2-4 shows the load latch logic, load reset logic, and the undervoltage protection function. In the event the battery discharges below 1.80-1.85 volts per cell, the inverting input of the comparator goes low, raising the output level to the "Hi" state, and subsequently energizing the control relay, Kc. This subsequently opens the normally closed contacts and interdicts coil power to the load management contactors, thus shedding all loads. The UV trip is employed as a emergency (or contingency) back-up to the four channel prioritized load management function. In the event of a DELTAR sensor malfunction, or a failure elesewhere in the load shedding circuits, the UV trip can prevent full battery depletion.



Specification Control Drawing - Deltar Sensor Assembly

Figure 3.3.1-2

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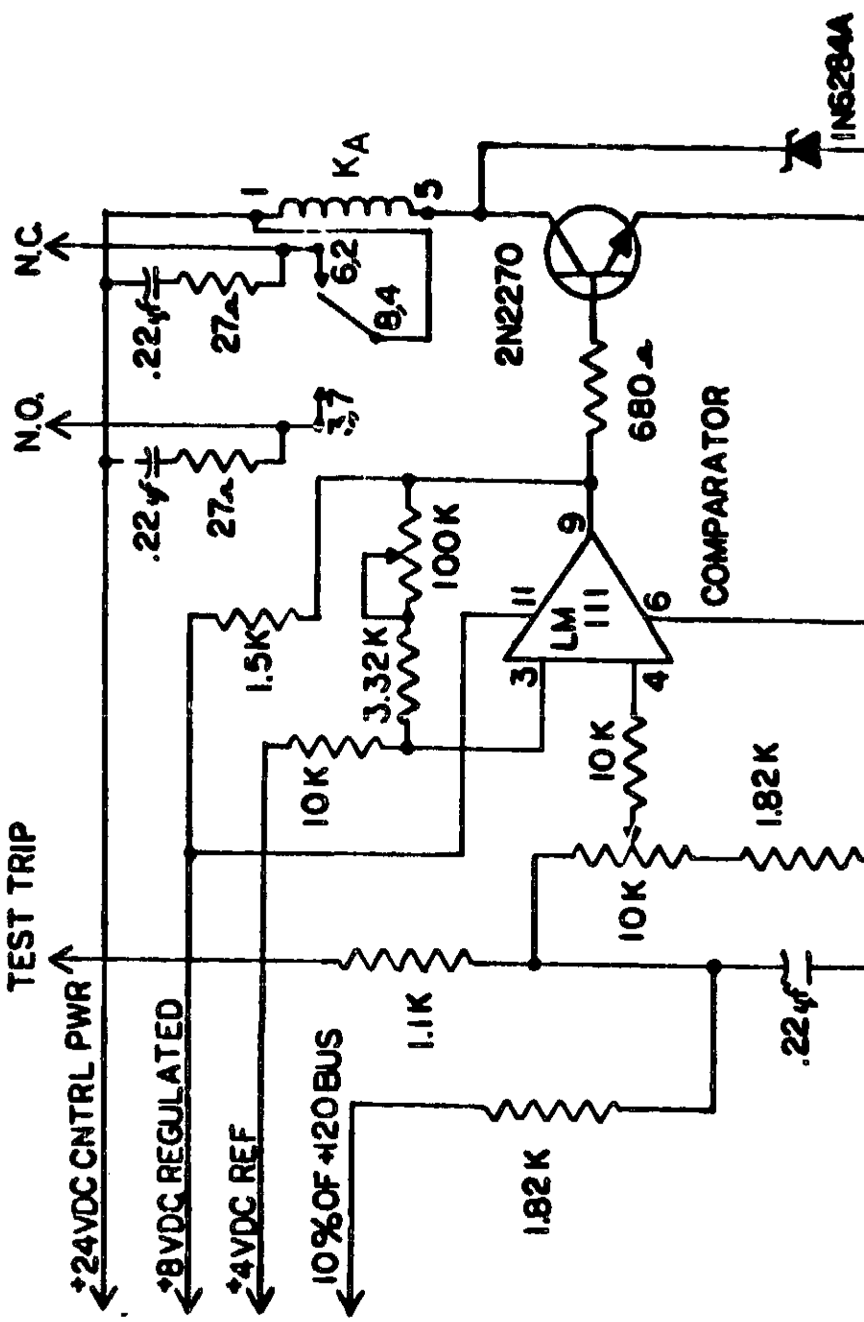
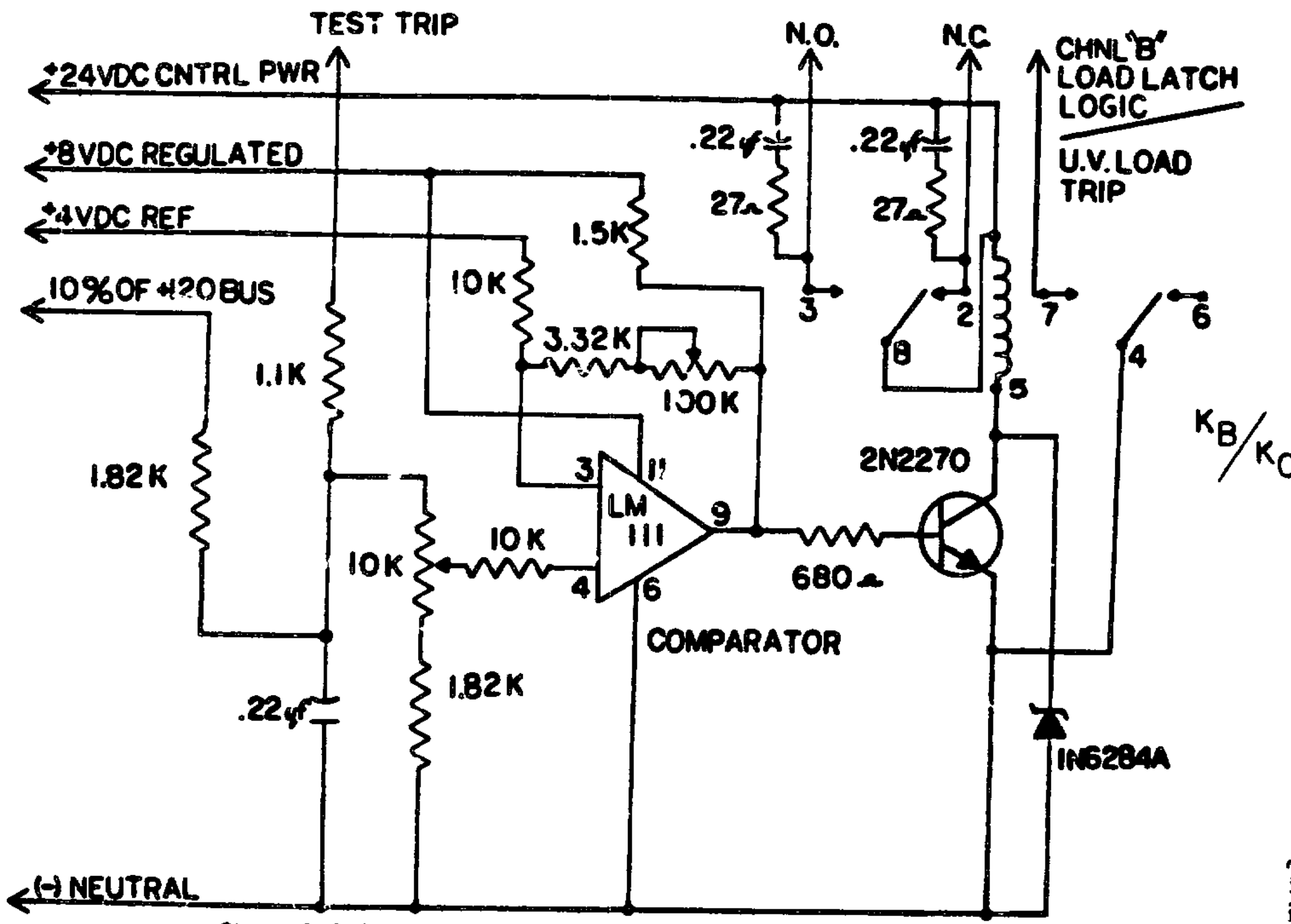


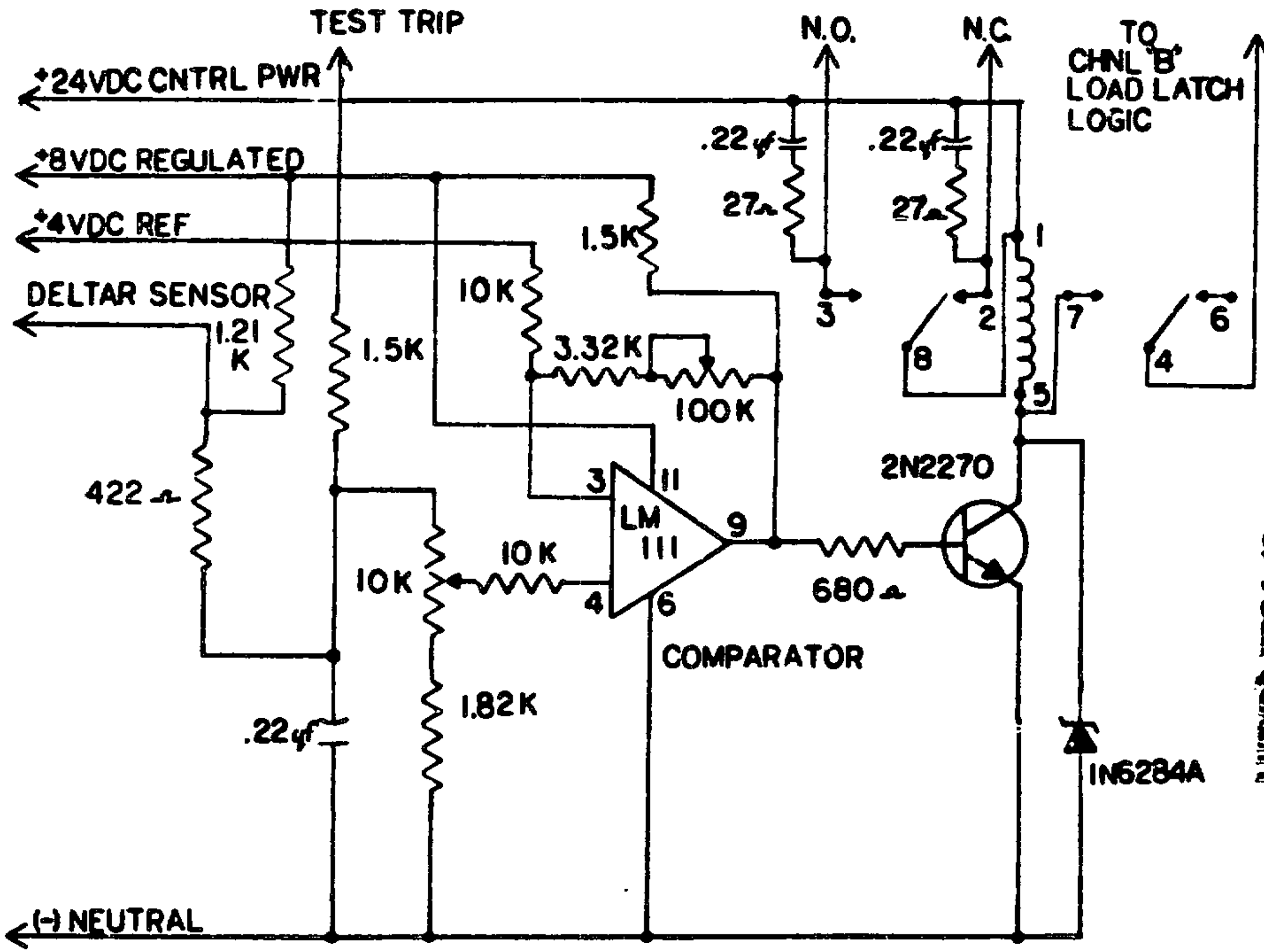
Channel "A" Configuration

Figure 3.3.2-1



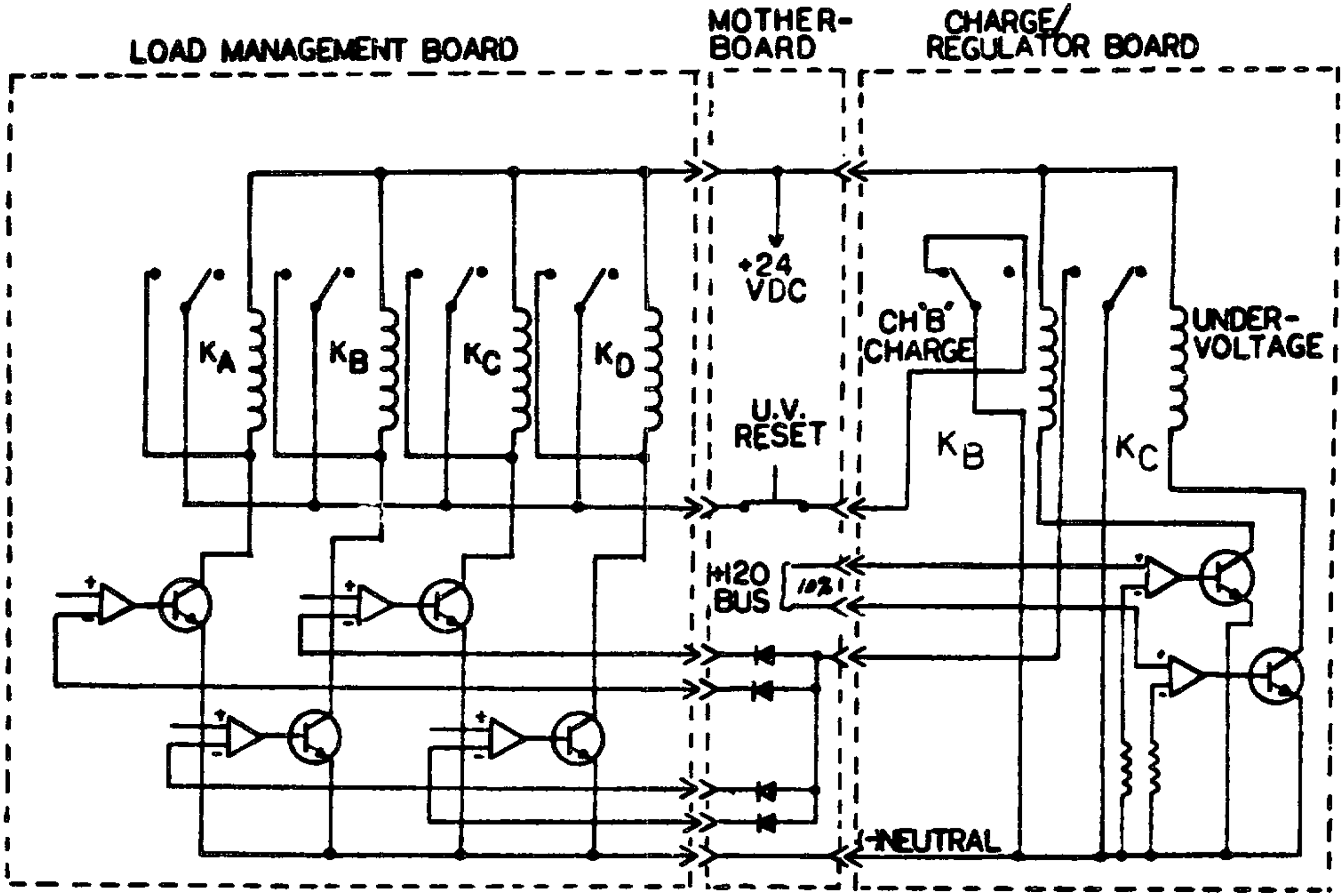
Channel "B" and Undervoltage Circuit Configuration

Figure 3.3.2-2



Load Management Configuration

Figure 3.3.2-3

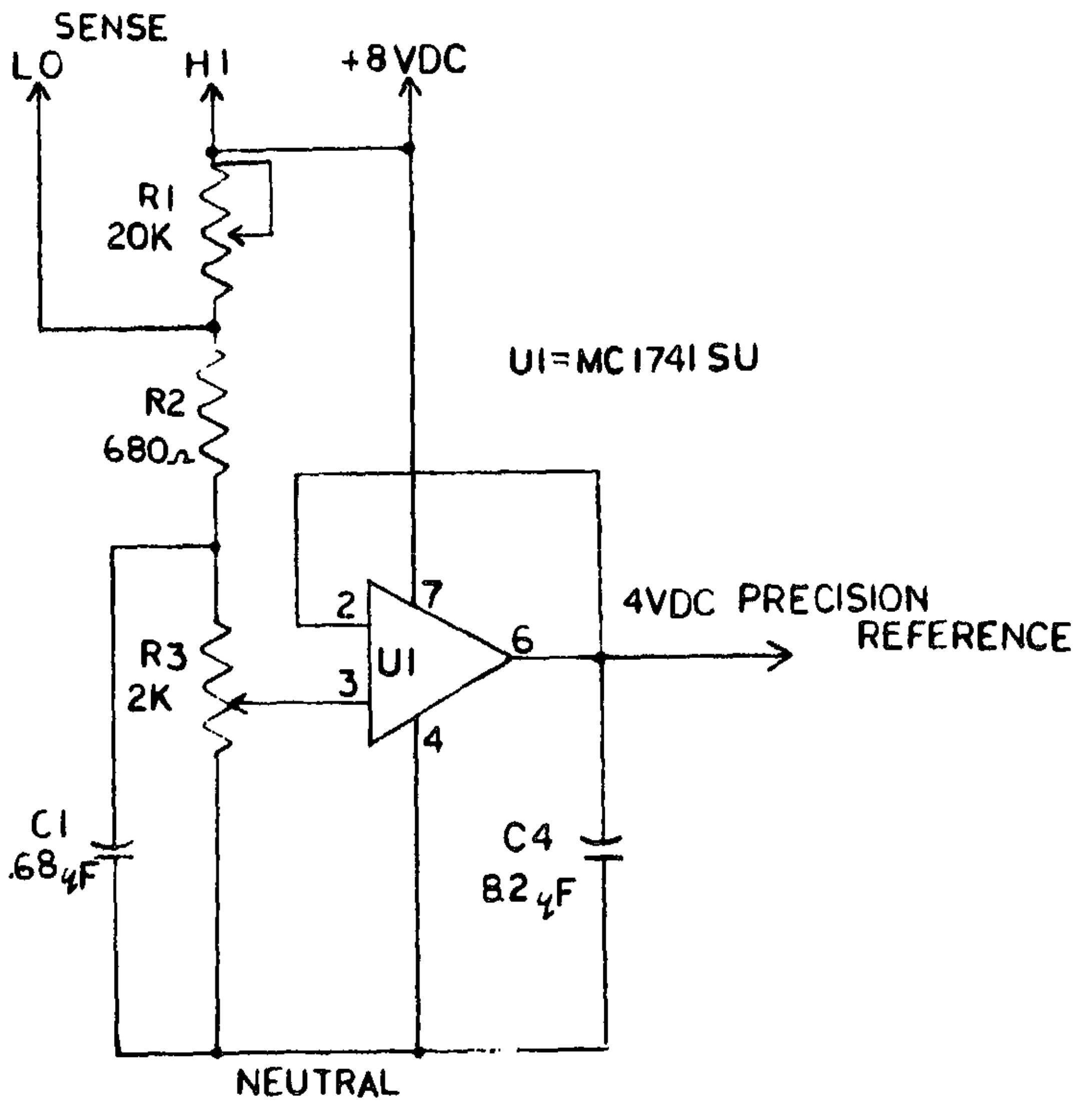


Load Control Relay Latch/Unlatch Logic

Figure 3.3.2-4

The charge control comparators, in concert with the power switching assemblies, form a closed-loop regulator. Stability is assured by the charging time constant of the battery, and smooth hysterisis control. In protective functions typical of the UV trip circuit the response may not be unconditionally stable; some combination of parameters may produce regenerative trips, for example, a trip may result from an inordinarily heavy load on a partially depleted battery. The load current will discharge the battery to below the preset 1.80-1.85 Vpc (volts per cell) level, causing the comparator to change state. The battery, under the condition resulting from release of loads, would quickly recover to perhaps 1.95 VPC. If the hysterisis setting is such that the comparator resets below this level, a change of state back to the original will result. A potentially disruptive cycling could thus result. A hysterisis setting of 25%, a relatively large value, lengthens the regeneration period; the amount of positive feedback would however be excessive and detrimental to precise and positive comparator triggering. The power remedial action was to reconfigure the comparator/relay drive as a latch. This bistable configuration was obtained by using the second uncommitted relay contact set to bypass the drive transistor to neutral (electronics common). Figure 3.3.2-4 shows the latching circuitry of the L/M Board. With a transition to "Hi" on the output of the IC, the relay will remain latched, irrespective of the state of the comparator. The relay can then be released only by the manual or automatic opening of the switch, or alternatively the set of contacts, in the latch line. The utility of this latching mode, as well as the availability of the additional contact set is further described in the discussion of the load managment breadboard.

Referring to Figure 3.3.2-5, an MC 1741 SU operational amplifier is configured as a voltage follower. In this negative feedback configuration the output voltage is a precise replication of the potential appearing between the positive input and neutral. The actual reference potential is established by potentiometer R-3, which when adjusted to center position at a 25°C ambient temperature, yields a midpoint voltage of 4.0 Vdc. This is accomplished by first making the value of the parallel combination of R_{NL} the external "sensistor" and R_1 a 100 kilohm potentiometer, in series with the padding resistor R_2, approximately equal to R_4.



OP AMP Precision Reference
Figure 3.3.2-5

The Texas Instruments Sensitor R_{NL} is a silicon resistor with a positive temperature coefficient of resistivity of about 0.79% per degree centigrade. Approximately 0.25% per °C correction is required to perform the float voltage compensation previously described. Application of the full temperature coefficient of the sensistor without "dilution" with linear resistors would result in overcompensation. During first article design the values of R_1 and R_2 were selected to yield approximately the required compensation when R1 and R_3 were centered. All resistors and potentiometers, except the Silicon R_{NL}, are precision 1% metal film devices with a $\pm$ 50 ppm temperature coefficient. For subsequent systems adjustment of R_1 establishes the actual precentage compensation; R_3 then permits resetting of the absolute magnitude of the reference level.

The sensistor probe is hermatically sealed in a copper reference block which in turn is affixed to the negative battery terminal.

Only minor changes were made in the transition from the hand wired experimental breadboards to the printed circuits of the engineering model. These changes were as follows:

a) Increase of R_1 to 100 kilohms
b) Deletion of series diode clamps around R_1
c) Substition of 2.2 mf/35V tantalum capicator. for the diode clamps.
d) Increase in thermal conductivity and mass of reference copper block.

The charging control algorithm for lead acid batteries is temperature dependent. The float voltage for lead calcium cells must decrease from the 25°C value at 6 millivolts per °C per cell to assure battery survivability at high temperature. Correspondingly, the float potential must linearly increase at this same rate below 25°C to ensure full recharge. At 25°C (77°F) a float potential of 2.45 Vpc has been recommended by the manufacturer for batteries using 1.300 specific gravity electrolyte. For 60 cell complement, the charging bus must therefore be set for a float voltage of 147 Vdc. This voltage should be decreased 300 millivolts for each degree centigrade rise.

This programmed decrease at higher temperatures precludes overcharging, water-loss, and subsequent cell damage. As the temperature decreases the electrolyte resistivity increases. As the result of this decreasing battery activity, a higher float voltage must be employed to assure complete energy replenishment. If the control algorithm is not implemented for low temperature, the cells will simply not recharge.

3.3.3 Load Management Board Function

The load prioritization control function was mechanized by modifying the configuration of the standard (universal) printed circuit board by changing specific jumpers and components. The actual printed circuitry is designed to accomodate either the L/M and the C/R versions; the differences are only in few assembly and wiring details with but one variation occuring in the reference circuit, the Pin (3) non-inverting input. In the C/R configuration, the reference level inversely tracks the temperature coefficient of battery float voltage. In the L/M board, Pin (3), the comparators is preset and adjusted for 4.0 Vdc. Similarly, the variable sense input in the C/R is a voltage divider whose top point is sampled at Pin (4), the inverting input. Just prior to a transistion, the positive potential on Pin (4) is only slightly less than that on the Pin (3) reference. In the L/M application however, the inverting input remains high, i.e., +5 Vdc, until the Deltar sensor had changed states from "Hi" to "Low" as the result of falling below the transition value as the result of charge depletion. The basic comparator circuits, and component values established for the breadboard however, remain unaltered through the transition to the final printed circuits.

One singular improvement was the selective conversion of the analog comparator function to one of the amplitude sensitive latching type. This breadboard change required utilization of the unused contact set on each of the trip relays K_A-K_D driven respectively by the associated comparators. As described earlier Pin (4) (-) remains "High" as long as the Deltar ball is interdicting the LED produced light beam falling upon the phototransistor. When the ball becomes negatively buoyant relative to the electrolyte specific gravity as the result of acid depletion, the ball sinks. The latch circuit ensure that a comparator transition always occurs at the precise moment the ball sinks.

3.3.4 The Mother Board

The mother board performs the following:

a) Serves as main internal electrical intertie for all control, display and logic functions.

b) Routes and distributes all control and sense signals including both automatic and manual commands, to the proper control and/or decisional circuit.

c) Provides protected DC power to the various control and logic circuits.

Breadboarding and test prior to commitment to artwork and printed circuit board fabrication resulted in the following design refinements.

- Inclusion of automatic reset lines for L/M channel latches
- Extension of automatic crowbar function to include load disconnect
- Deletion of manual disconnect crowbarring control mode
- Relocation of protective DC/DC converter fuses

The leading particulars of each of the above circuits modifications are described in the paragraphs following.

3.3.4.1 Inclusion of Automatic Reset Lines for L/M Channel Latches

Deltar probe jitter during the "High" to "Low" output transition required that the comparator/relay threshold sense circuits be configured as voltage sensitive latches. For L/M channels "A", "B", "C", and "D" each respective state change triggered by a sinking or non-buoyant float results in a latch-up in the "load disconnect" state. Initially the latch would ensure that the particular load contactor would be held open until the circuit were later broken by manually energizing the UV Reset pushbutton. Conceptually this mechanization approach proved to be unacceptable since it would require manual intervention before the affected load could be restored. The circuit was therefore modified to reflect the final configuration depicted on Figure 3.3.2-4.

Refering to Figure 3.3.2-4 the reset function for any/all of the four load control channels were shifted to Channel "B" of the multilevel battery charge regulator. In the multilevel charging scheme the PV array is partitioned into separate current generating elements typically consisting of an equal number of contributing parallel branch circuits. As the battery approaches full charge one of the contributing segments is automatically switched off , thus tapering the final charge. In the engineering model, the float cycle point on the segment controlled by Channel "B" is set for 2.35 Vpc to at 77°F. When the battery recharges to this float voltage, the Channel "B" comparator trips, thus deenergizing the normally open relay, interdicting this portion of the PV charging current. A committed contact in the Channel "B" charging relay is used to mechanize the reset function. At nightime or during any other periods when battery charging current is not present and the bus voltage is perforce low, the control relays revert to "On-charge" state, closing the charging contactor. Energizing the charging relay subsequently closes the second set of normally open contacts on the Channel "B" charging relay, thus holding the latch for any of the L/M control relays (K_A, K_B, K_C, K_D on the L/M Board) that have latched and held the load contactor open due to a load shedding command. This latch will hold through the next period of insolation during which the battery is recharged. With recharging, the battery energy is continuously replenished. The "On-Charge" voltage will rise to the preset trip point, in this case 2.35 Vpc, producing a comparator transition, which in turn deenergizes the relay thus breaking the affected L/M channel latch. This control logic accrues several advantages:

a) The restoration of service to a previously disconnncted load becomes automatic, thus not requiring manual intervention.

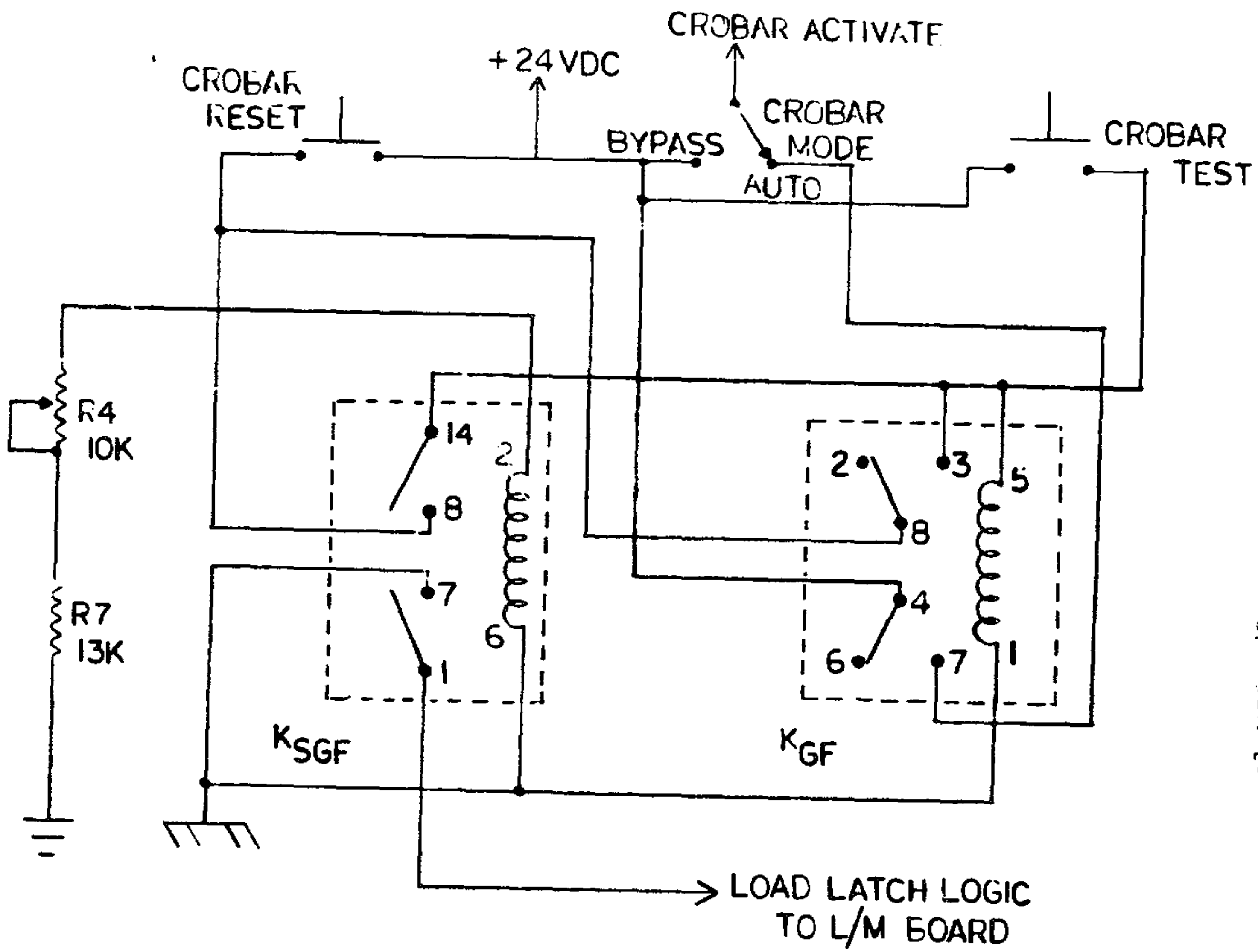
b) Load pick-up is delayed until the battery state-of-charge replenishment is at some safe predetermined point within the subsequent recharge cycle.

c) Except by manual override, a load cannot later be reconnected to a battery whose state-of-charge has not been sufficiently restored to support that load for a prescribed future period.

Repatching of existing circuit interfaces would permit expanison of this control function to selectively perform several other load management tasks. For example, the fourth comparator on the C/R board might be dedicated to the most critical load channel. The algorithm here might defer automatic pickup of this most essential load (for example the radio transmitter or the medical refrigerator) only for a minimum recharge period, perhaps only until the battery had reached 2.20 - 2.35 Vpc. Similarly the fourth channel C/R comparator, set at 2.45 Vpc, could be employed to interlock with the lowest priority "D" channel latch. In this case, the deferrable, non-essential loads, for example those involved in community recreational/social functions might not be picked up until the battery were fully recharged during the next insolation period. This modest degree of additional decisional capability may be of future operational value.

3.3.4.2 <u>Extension of Automatic Crowbar Function to Load Disconnect</u>

Fault current flowing from the isolated conductor to ground, if above 12 milliamperes DC, will energize the ground fault detection circuit. The ground fault is most serious if errant personnel are involved; the ground fault relay (GFR) in turn will activate the crowbar. In this emergency mode battery charging is terminated. If the crowbar closure goes undetected all subsequent power demands will be supplied by the battery until the crowbar is released. It is immaterial whether the crowbar activation occurs during the daytime or nighttime period. Extended battery discharge without replenishment will invariably result in total load shedding and near-depletion of the battery. This will of course finally call attention to the required crowbar reset action; in the meanwhile, without immediate annuniciation, energy available from the system would be temporaily and undersirably lost. In the interests of system performance and safety the crowbarring function has been extended to include simultaneous shedding of all loads. These circuits have been incorporated into the motherboard design. See Figure 3.3.4.2-1 for Ground Fault Logic.



GROUND FAULT LOGIC
Figure 3.3.4.2-1

3.3.4.3 Deletion of the Manual Disconnect Crowbar Control Mode

The inclusion of a manually selectable disconnect mode has proven valuable in connection with the checkout of the other control functions. To inhibit crowbar activitation in this mode via front panel switching may not be desirable for the reasons of increased operating risk and non-essentiality. For example if the mode selection switch is advertantly left in the "Disconnect" position, ground fault detection and protective response will not be present. The fact that the GFR is reset, and the array can charge the battery, amply verified that the crowbar is open. This change has likewise been incorporated in the mother board PC design.

3.3.4.4 Relocation of Protective DC/DC Converter Fuses

Subject fuses were revised and shifted from the 120 Vdc input lines to the 24 Vdc output lines. The fuses now fully protect the redundant DC/DC converters from control overloads and short circuits. In this original configuration the transformation impedance of the DC/DC prevented potentially damaging overloads from safely initiating fuse melting and clearing.

3.3.5 Deltar Sensors and Conditioning Electronics

The Deltar specific gravity sensing technique was extensively evaluated during the Phase I BOS analysis. At that time concern was expressed that some automation problems might be expected. This has proven to be the case. It was also concluded at that time that the methodology was both sound and applicable; if properly mechanized the approach should yield both a reliable and direct assessment of battery SOC. Using a directly proportioinal parameter is always a more desirable approach. Given initial electrolyte conditions, once temperature corrections are made, a direct proportionality exists between specific gravity and battery SOC.

The potential problem of stratification had surfaced early in developmental evaluation. The possibility of a small "closed cycle: electrolytic lift pump was considered. The electrolyte of the individual pilot cells would be properly stirred, or circulated and the opto-electronic transition would take place at a specific grav.ty representative of the entire cell. Early experiments indicated that this somewhat cumbersome auxiliary might not be required. It appeared that the relating long charge-discharge cycles provided an opportunity for the electrolyte to reach equilibrium concentration without supplemental mechanical agitation.

Another shortcoming of the Deltar sensor design quickly overshadowed the stratification problem. Even without the circulating pump assistance, the concentration equilibrium appeared manageable by calibration of the specific gravity. This more serious problem, that of failure to respond to the actual specific gravity transition is summarized below.

This problem possibly of a more unmanageable nature, might be characterized as "hang-up", or failure of the ball to sink at the transition point. As the electrolyte slowly depletes due to discharge, each Deltar ball sensor drops as it assumes a negative buoyancy point . Each of the four sensors include a ball fabricated to become negatively buoyant at a particular specific gravity correspondong to 80%, 60%, 40% and 2-% pf charge remaining. This methodology, neither new nor noval, has been in industrial use for perhaps four decades.

In one particular test the system was exercized through some thirty short charge/discharge cycles. It was observed that the transition dependability was low in some 30% of the discharge events. The ball:

- o did not immediately make the transition unaided, or
- o went from "float-to-sink" some point later, as indicated later by independent hydrometer measurements.
- o did not exhibt a constant delay period for delayed transitions.

The problem appears related to "stiction" (static-friction) or surface tension, and is <u>not</u> one of transition accuaracy or uncertainty. The desired transition could be forced by sharply rapping the battery case. The surface tension against air for a 1.300 specific gravity solution of H_2SO_4 in water is comparatively high in the range 60-65 dynes per centimeter. The diameter of the DELTAR ball is about 3mm; it is estimated to weigh approximately 15 milligrams. A potentially serious succeptibility to "stiction" appears probable. In electromotive applications the cells are always subject to severe vibrational and shock stresses. In fact batteries used in forklifts, steelmill auxiliaries and the like, may incorporate special internal supports to prevent plate deformation. In these high stress applications, the opto-electronic as well as the visual "green-eye" indicators operate satisfactorily.

The unsuitability of the present Deltar design for these stationary PV applications was communicated to the manufacturer. One dual assembly exhibiting this problem was returned to him for evaluation. No definitive results have to date been forthcoming; likewise no "quick fixes" or inuitive solutions of the short-term type are expected.

Hughes however yet considers the specific gravity control methodology to be one of high potential utility and direct applicability to the load management strategy advanced in this study. The failure of a particular electro-mechanical sensor to yield the required results (perhaps in an incompatible application) should not vitiate the promise of the overall approach. Hughes is of the opinion that the problems of stratification and "stiction" might be expeditiously solved by directing an investigation along the following:

- o Design a miniature floating element of the same general form-factor as a conventional hydrometer float. This type of float gives a proportional rather than a OFF-ON response.

- o For C&D batteries, use the lift pump access port.

- o Investigate the use of various types of transducers (optic-electronic, magnetic and linear variable differential transformer for coversion of float level changes to an electrical analog signal.

None of the above criteria appear to impose insurmountable technical problems. Battelle (Switzerland) has recently announced the development of a state-of-charge monitor based upon change of electrolyte refractive index with its acid concentraction. A synopsis of this methodology is included as Appendix C.

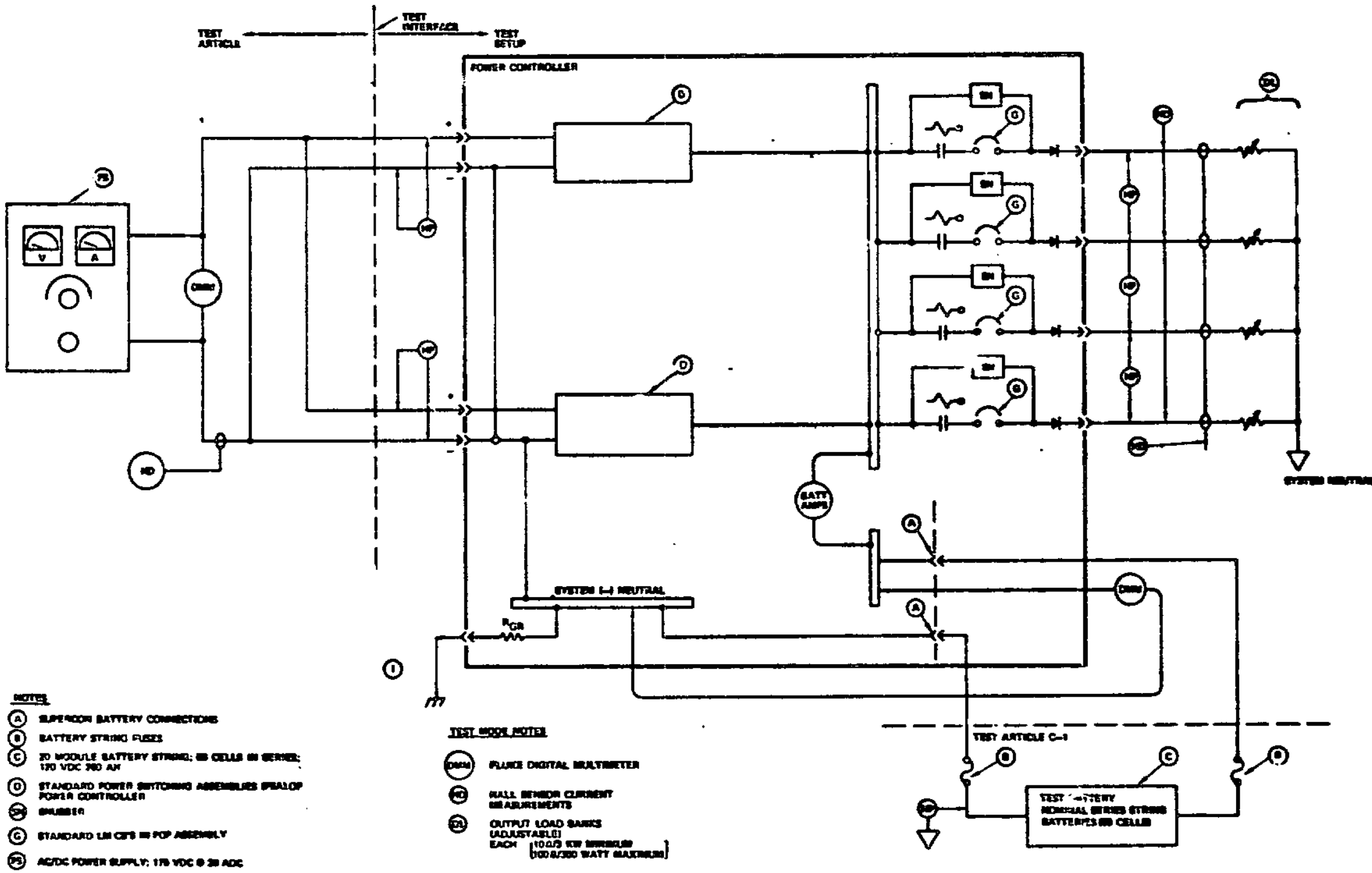
3.4 DEVELOPMENTAL TEST & EVALUATION

During the breadboarding phase, the circuit refinements described under 3.3 preceeding were implemented and subject to testing. Circuit changes were first made on the handwired modules; after proof testing, the changes were incorporated into the engineering model schematics and thence to the printed circuit boards themselves.

The engineering model of the complete stand alone system was brought on line in the protected test and evaluation area adjacent to the Hughes, Long Beach Plant.

Initial testing was accomplished with the engineering model versions of all BOS subsystems except the electronic boards within the Power Controller. During later testing, but prior to the conduct of Acceptance Tests, the actual printed circuit boards were retrofitted in the model. At the conclusion of systems upgrading and verification, with the possible exception of the DELTAR sensors, all BOS subsystems and assemblies were performing within specifications.

During breadboarding and final debugging it was essential that the control system be synthetically tested under power in the laboratory. An 180 Vdc/30 Adc voltage regulated, current limited, phase back power supply was employed to simulate the array output; a 10 module/60 cell DELCO 2000 battery string provided laboratory electrical storage in lieu of the larger C&D complement of the array. Several dummy loads to 2.5 kW @ 120 Vdc nominal were additionally employed. A block diagram of the test set-up is shown in Figure 3.4-1. A special calibration fixture was devised for the purpose of establishing the control parameters and performing the final calibration and temperature compensation.



Laboratory Test Set-Up

Figure 3.4-1

3.5 DEVELOPMENTAL RESULTS

Overall results of developmental breadboarding were satisfactory. Changes of the UV comparator to a latched circuit produced the required stability. Minor chages on the TC reference circuit reduced the numbers of circuit elements and resulted in simpler calibration procedure. The latch and associated voltage sensitive reset circuits (implemented in the L/M and the C/R boards respectively) resulted in more intelligent control logic, improved automaticity and expanded flexibility. Expansion of emergency crowbarring to include automatic load disconnect was an essential change that should improve power availability. Testing and performance verfication proceeded smoothly from bench and laboratory testing to full system testing in the field. By the time the system was readied for final commissioning tests all breadboard circuits had been retrofitted with the printed circuit board versions; the system was performing as the full engineering model.

4.0 THE ENGINEERING MODEL

4.1 REQUIREMENTS

Under Phase II of the contract Hughes was required to build and evaluate the modular system designed and approved in Phase I of the contract. The engineering model described herein was constructed for the purpose of demonstrating the form, fit and performance of the modular concept and incorporation control system design verification results of developmental breadboarding. This engineering model conforms to the approved design, as upgraded by the developmental effort.

Detailed designs and drawings developed under Phase I permitted the construction, installation, operation, and maintenance of a baseline system. This documentation included:

(a) Electrical block, schematic, and wiring diagrams of the baseline system.

(b) Engineering design drawings in agreement with MIL-STD DOD-D-1000B level 2.

(c) Physical layout and installation of the modular system.

(d) Instrumentation incorporated in the operational system.

(e) Parts list with part sources, model number and rated values.

(f) A detailed Acceptance Test Procedure, including installation and checkout.

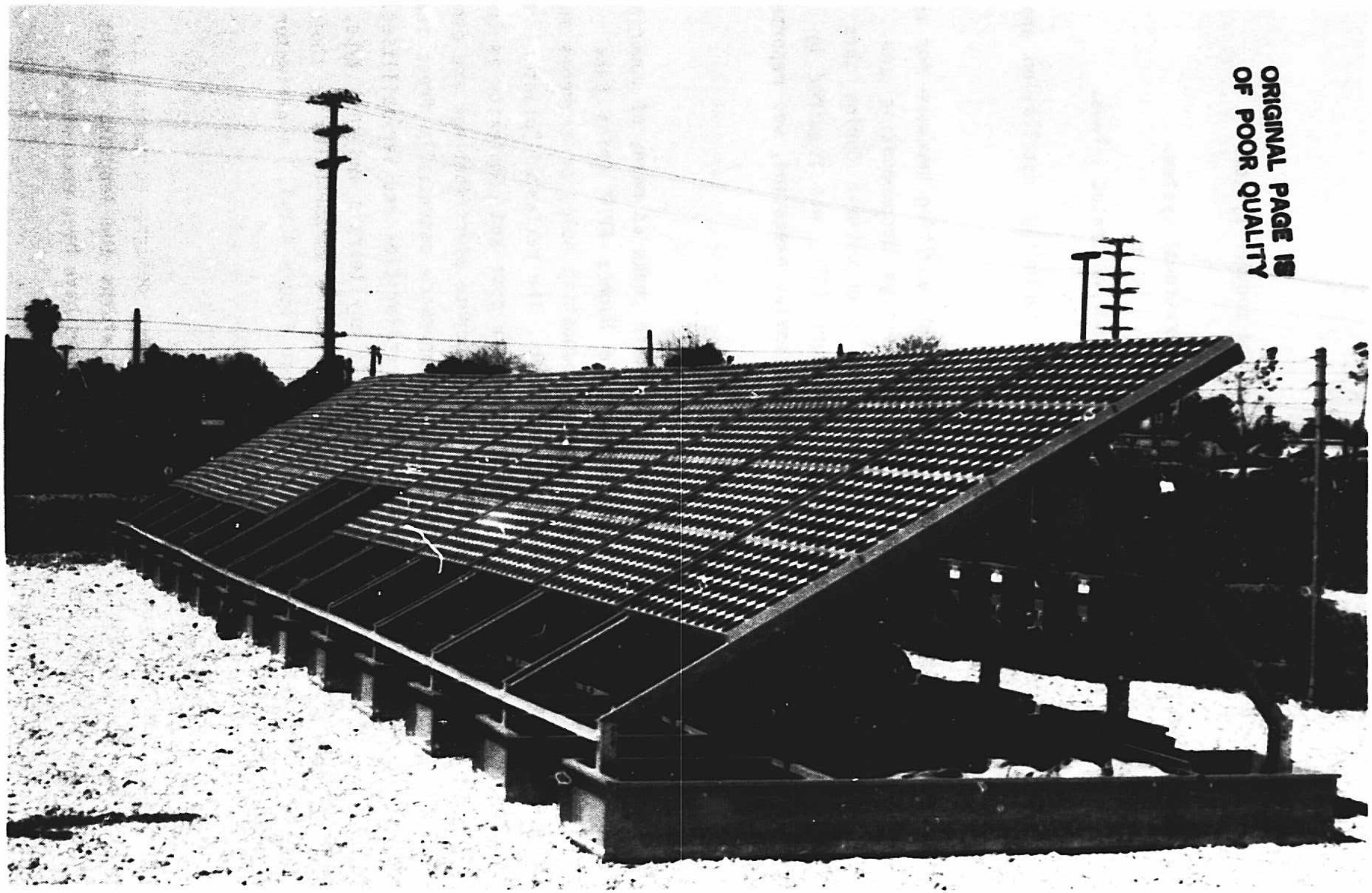
The manufacturing test and assembly processes and resulting hardware for the engineering model comply with the approved design documentation and specifications; no significant departure from plan occured during this particular phase. An Acceptance Test Procedure (ATP) was required by contract. This procedure, as well as its successful execution, was reported separately.

4.2 SITE PREPARATION & INSTALLATION

Remote systems are frequently located on mountain peaks as means of powering communication gear and other apparatus. The Hughes FPUP China Lake installations are a good example. Digging foundation holes or trenches in rocky or dense soil/aggregrate can be expensive. The ballasted "planter" was developed for this application. The installation cost and complexity is low as compared to designs requiring excavation, concrete piers/footings and other anchoring techniques. The ballasted planter approach essentially frees the photovoltaic system installer from terrain peculiarities and variabilities. The system is readily installable on virtually any terrain and soil type, except steeply sloped monolithic rock, which require anchor-bolts or their equivalent. The engineering model is shown in Figure 4.2-1. A perimeter fence, not necessaily typical is also shown.

4.3 ARRAY STRUCTURES AND FOUNDATIONS

The modular frameless panel is a straightforward design, economical to manufacture, and adaptable to various module widths and lengths. Field experience has shown that no installation problems have been encountered.



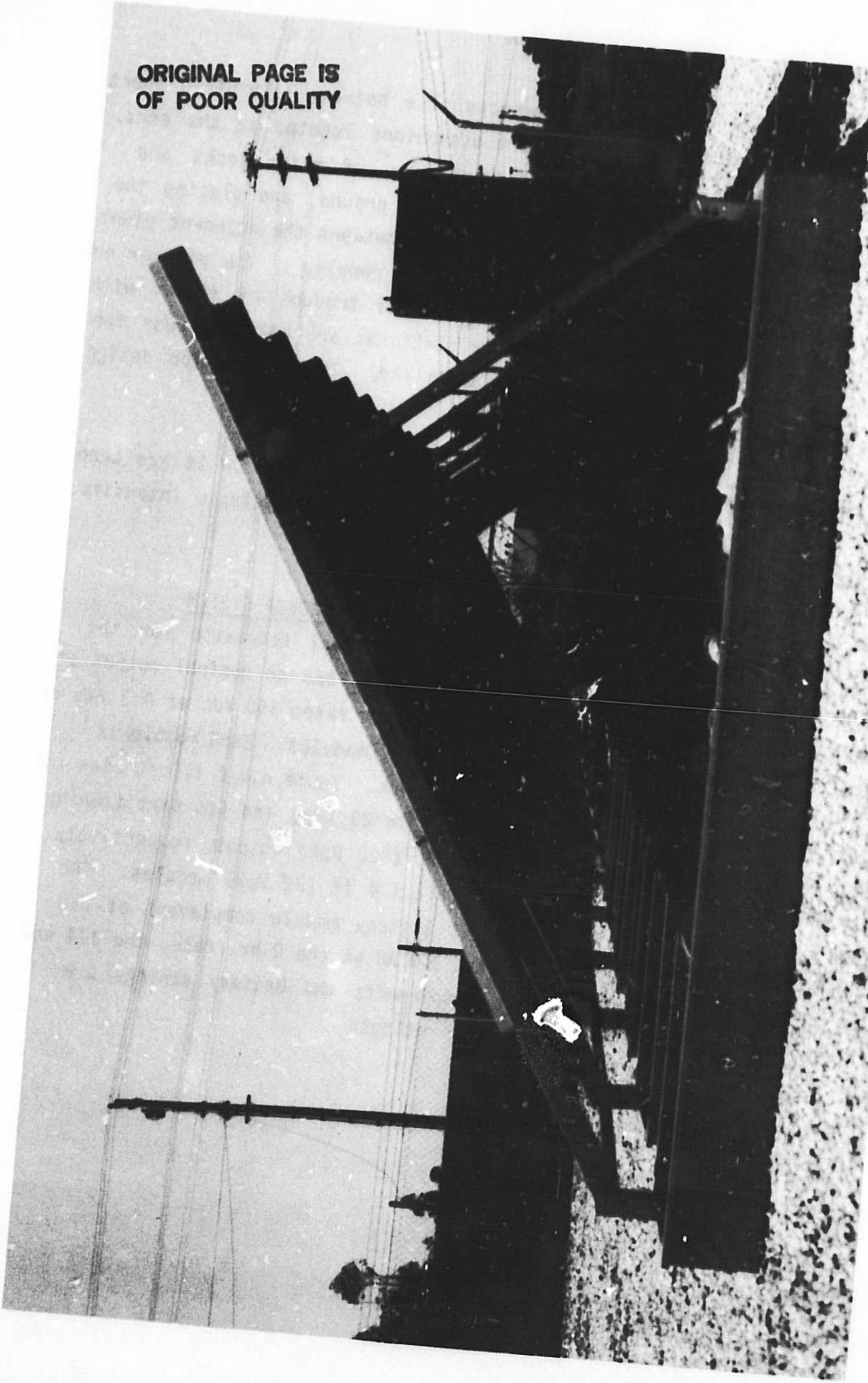
Engineering Model
Figure 4.2-1

The planter shown in Figure 4.3-1, consists of a hot-dip galvanized sheet metal trough weldment with panel support stanchions located at the ends. Installation involves clearing the selected area of major rocks and vegetation, rough shovel grading of the planter ground, and placing the planters thereon. Spacer rods are then fastened between the adjacent planter stanchions to ensure easy acceptance of the array panels. The planter end closures are then bolted into place. The planter troughs are filled with nearby rocks, dirt or sand bags. Battery platforms are bolted across the planter's top flanges and the batteries installed. This foundation design appears to have almost universal site acceptability.

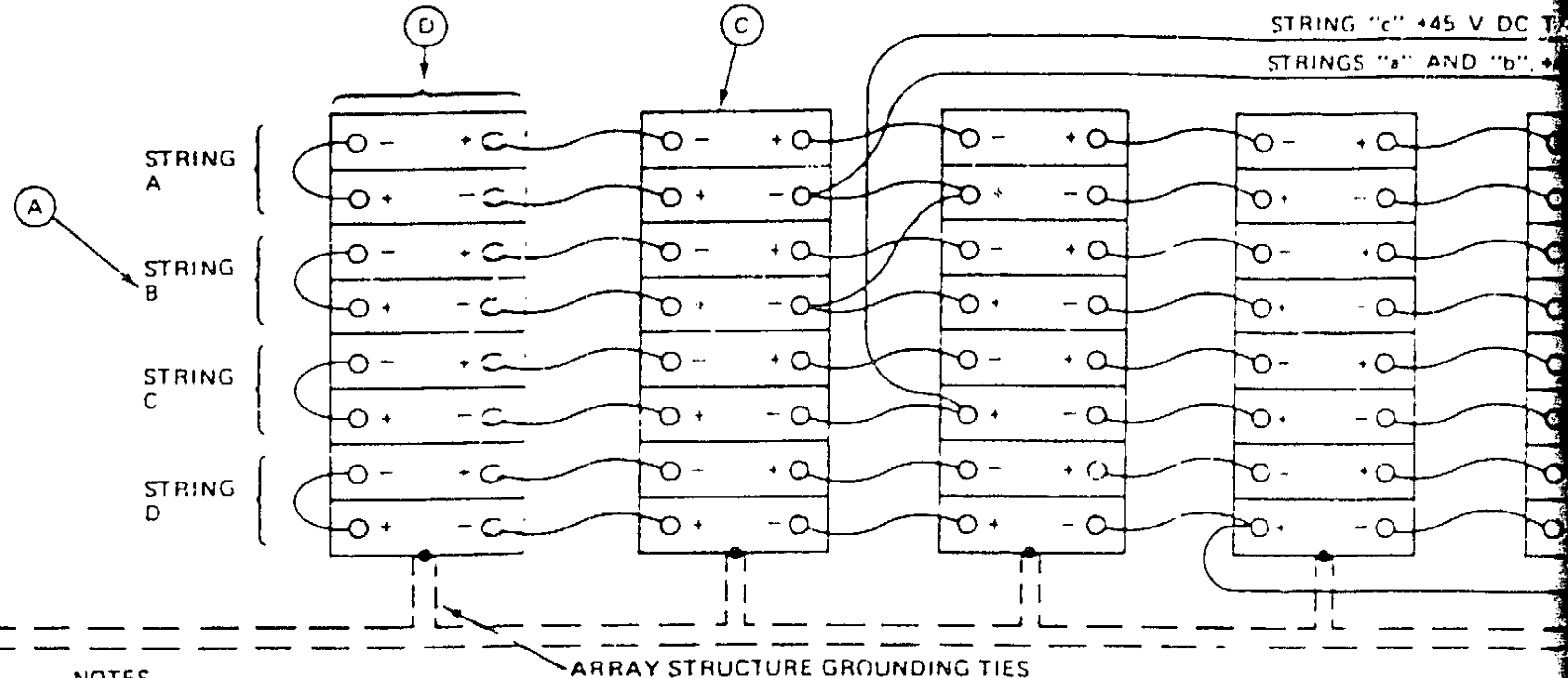
The installation shown has been installed for about 8 months. It has been exposed to a winter of almost continuous storms, one of cyclonic intensity. It has survived without incident.

4.4 ELECTRICAL CONFIGURATION OF THE STAND-ALONE PV POWER SYSTEM

Figure 4.4-1 following is the generalized electrical schematic for the baseline one Power Unit (PU) system. The baseline has an nominal output of 1.28 kWp consisting of two parallel branches, each rated 150 Vdc at 4.3 Adc or 640 Wpk. Each branch is a series string of 10 PV modules. Each module is 2 ft x 4 ft in size, delivering a nominal 64 Wpk. Table 4.4-2 illustrates the modular expansion of the array field (16 PU to 20 kWp) and its partitioning into a 1/2 PU (640 Wpk) output and a 1/4 PU (320 Wpk) output, respectively. The 1/4 PU rating requires the use of 1 ft x 4 ft (32 Wpk) modules. The baseline battery string is a 60 cell/20 battery module complement of C&D 3KCPS5A-3 cell packages, each cell rated 260 AH at the 8 hr. rate; the 1/4 and 1/2 PU ratings also use this basic complement; the battery strings are proportionally replicated for the higher ratings.



Metal Trough-Planters
Figure 4.3-1



NOTES

(A) EACH 640 WATT BRANCH C/C TWO STRINGS IN PARALLEL

(B) EACH 320 WATT STRING C/C TEN SERIES 1 FT x 4 FT PV MODULES ARRANGED IN A FOLDED HORIZONTAL DAISY CHAIN CONFIGURATION

(C) 40 EACH 1 FT x 4 FT MODULES ARE USED IN A BASELINE 1 PU (1.28 KWP) ARRAY FIELD MODULES ARE RATED 15 V DC AT 2.13 A DC (32 WP)

(D) EACH 4 FT x 8 FT PANEL HOUSES 8 EACH 1 FT x 4 FT MODULES AND GENERATES 256 WP. IT IS NOT AN ELECTRICAL ENTITY.

(E) INTERCONNECTIVE CABLE RUN LENGTHS BECOME SIGNIFICANT ONLY ABOVE 2 PU

SYMBOLS

UV — UNDERVOLTAGE DISPLAY (LED)

F — FAULT TRIP DISPLAY (LED)

S — STATUS DISPLAY (LED)

I — CURRENT READOUT

V — VOLTAGE READOUT

CR–1 — BLOCKING DIODE

I — CURRENT SENSE

V — VOLTAGE SENSE

K_1 — CROWBAR

K_2 — ARRAY DISCONNECT

K_3

GFR

T

SG

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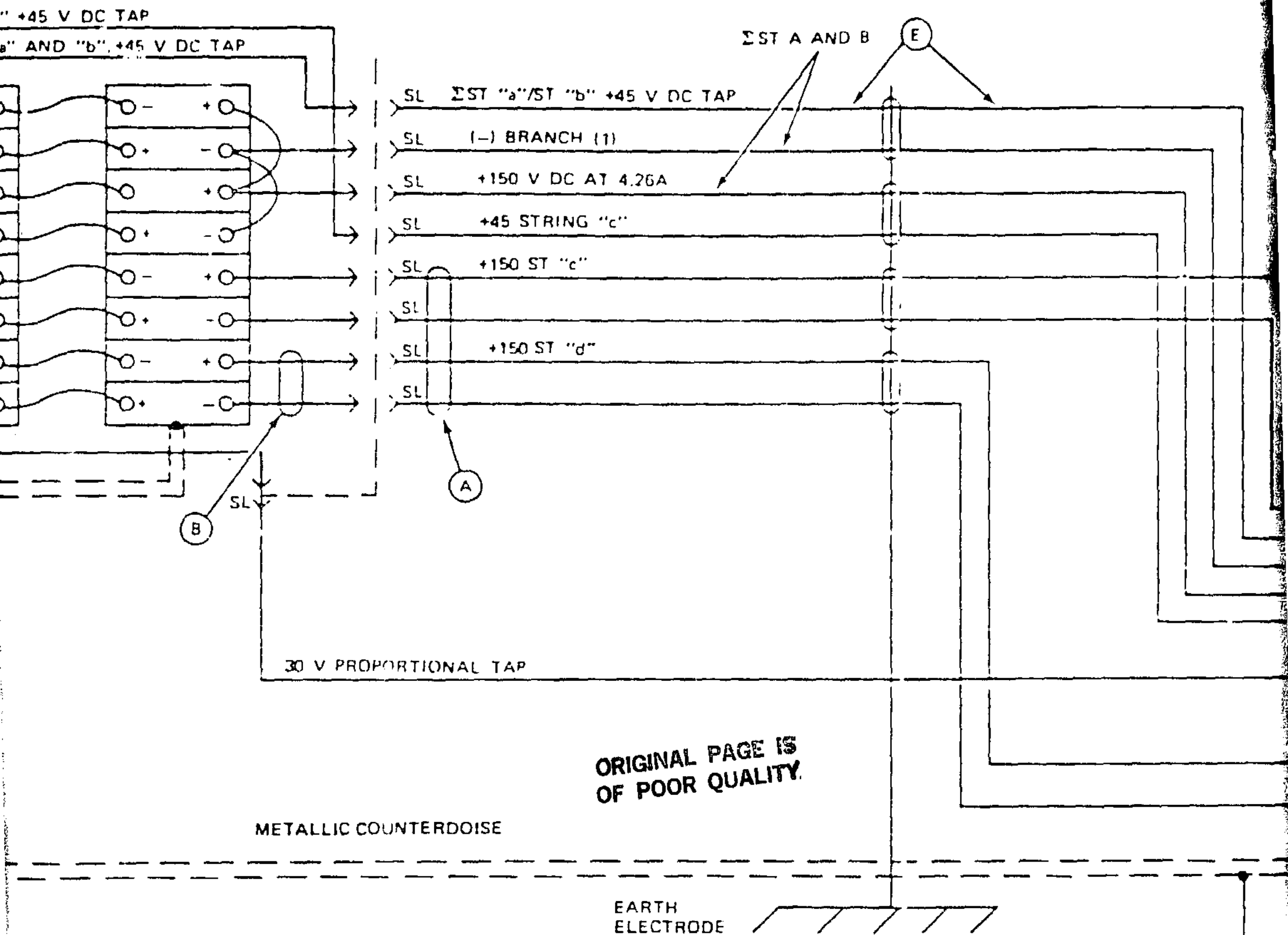

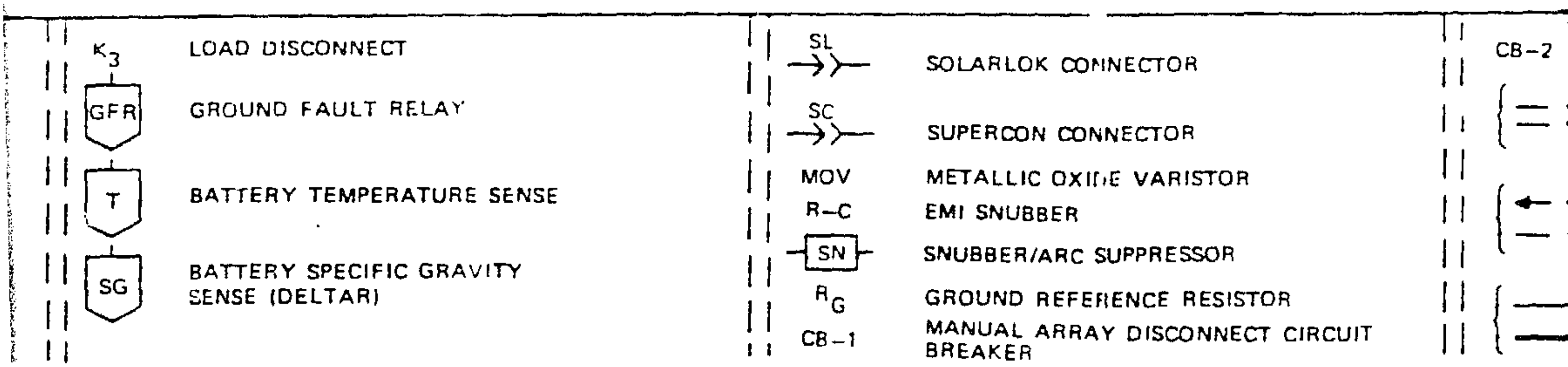

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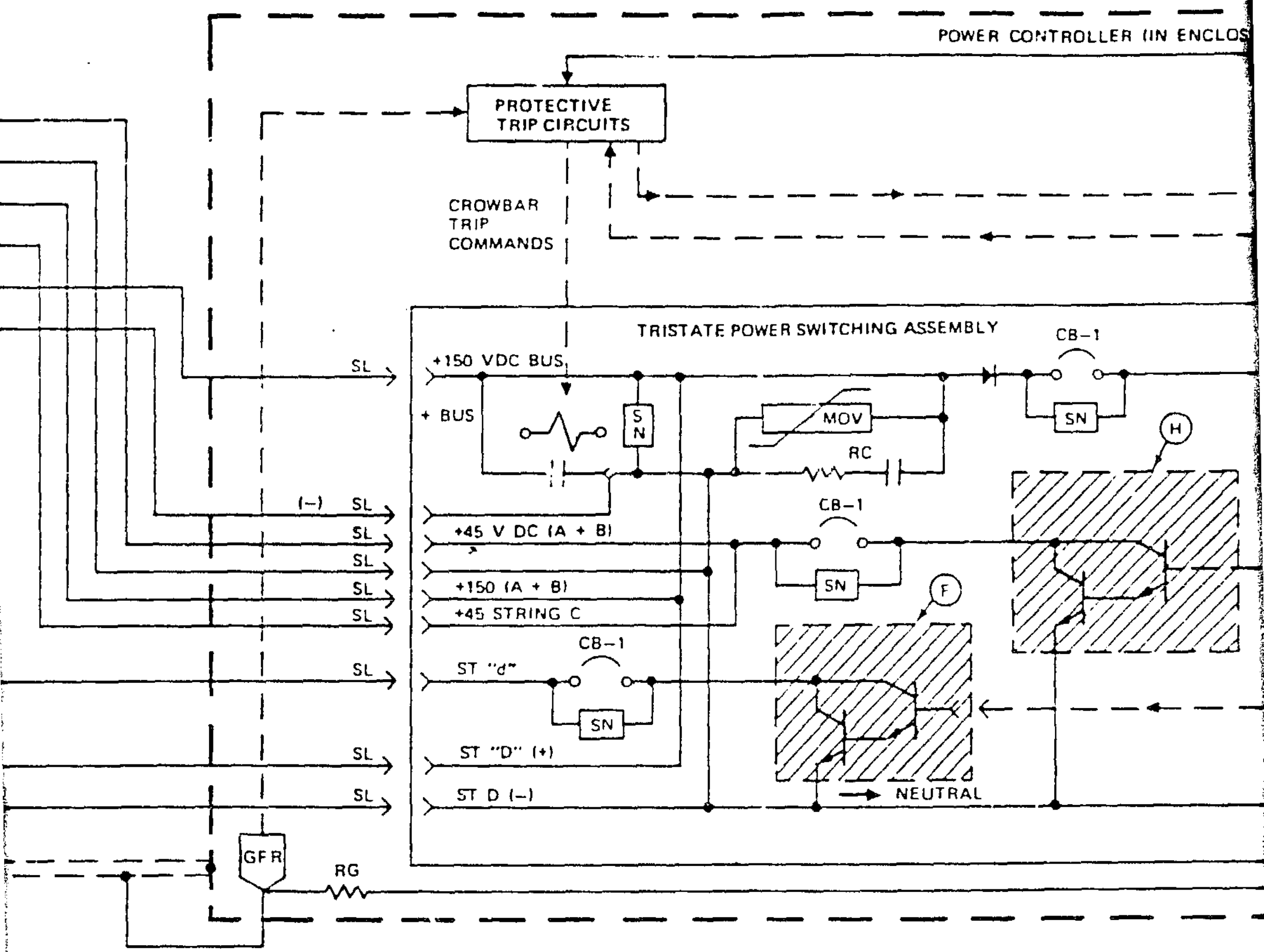
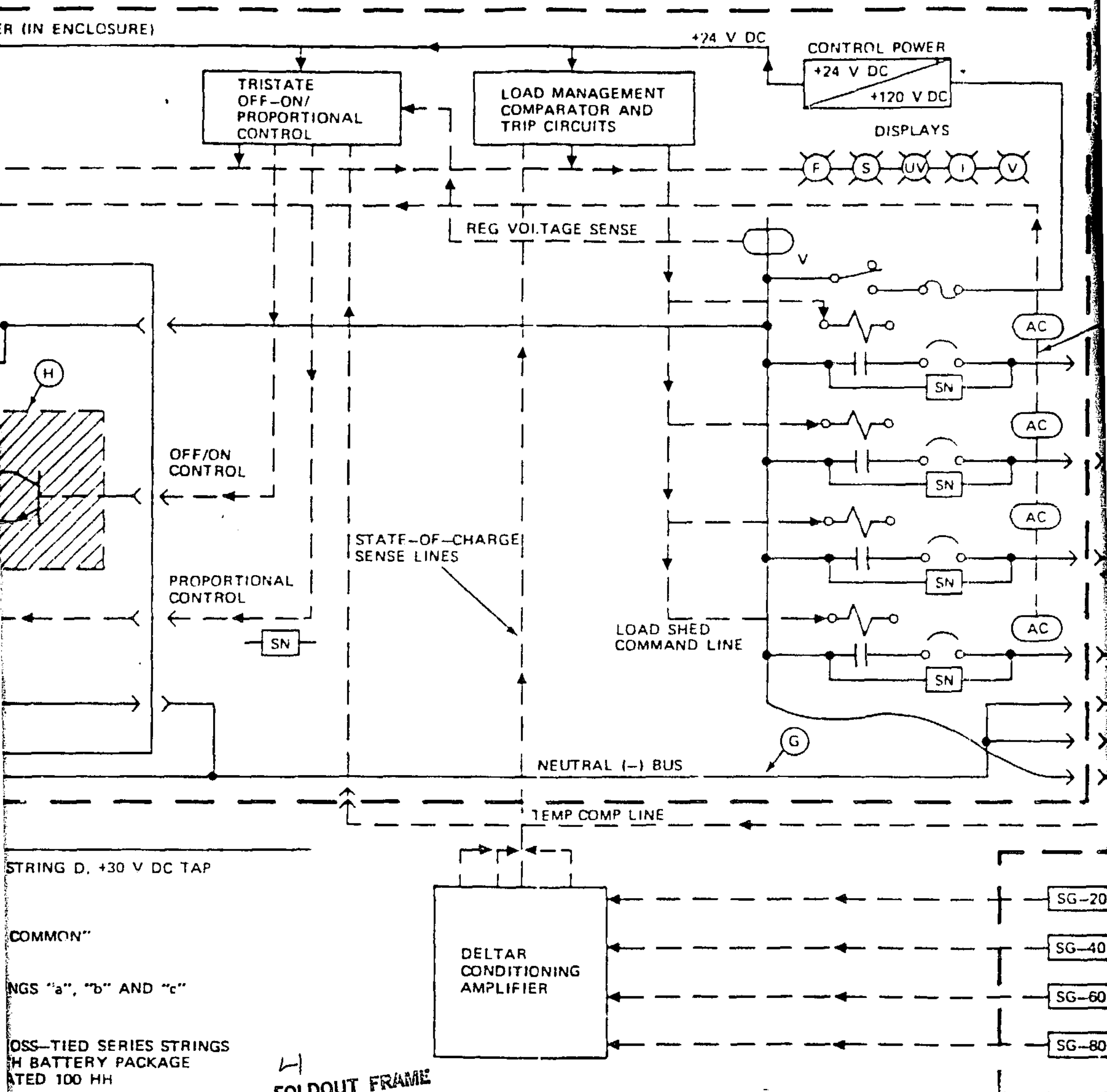


CB-2	MANUAL LOAD BREAK CIRCUIT BREAKER
	EARTHING CONNECTIONS SHOWN IN DOUBLE LINES
	CONTROL, COMMAND AND SENSE SIGNALS SHOWN AS DOTTED LINES WITH ARROW INDICATING SIGNAL FLOW
	POWER FLOW/CIRCUITS SHOWN WITH SOLID LINES (HI AMP HEAVIER)

F	PROPORTIONAL SHUNT DARLINGTON BST, STRING D, +30 (~ 2.13 A DC MAX)
G	NEUTRAL (–) BUS IS ALSO "ELECTRONICS COMMON"
H	OFF/ON SHUNT DARLINGTON SWITCH STRINGS "a", "b" A 45 V DC TAP
I	BATTERY CONSISTS OF TWO PARALLEL CROSS–TIED SER OF 10 EACH DELCO 20–00 BATTERIES. EACH BATTERY P CONTAINING SIX SERIES 2 VOLT–CELLS RATED 100 HH



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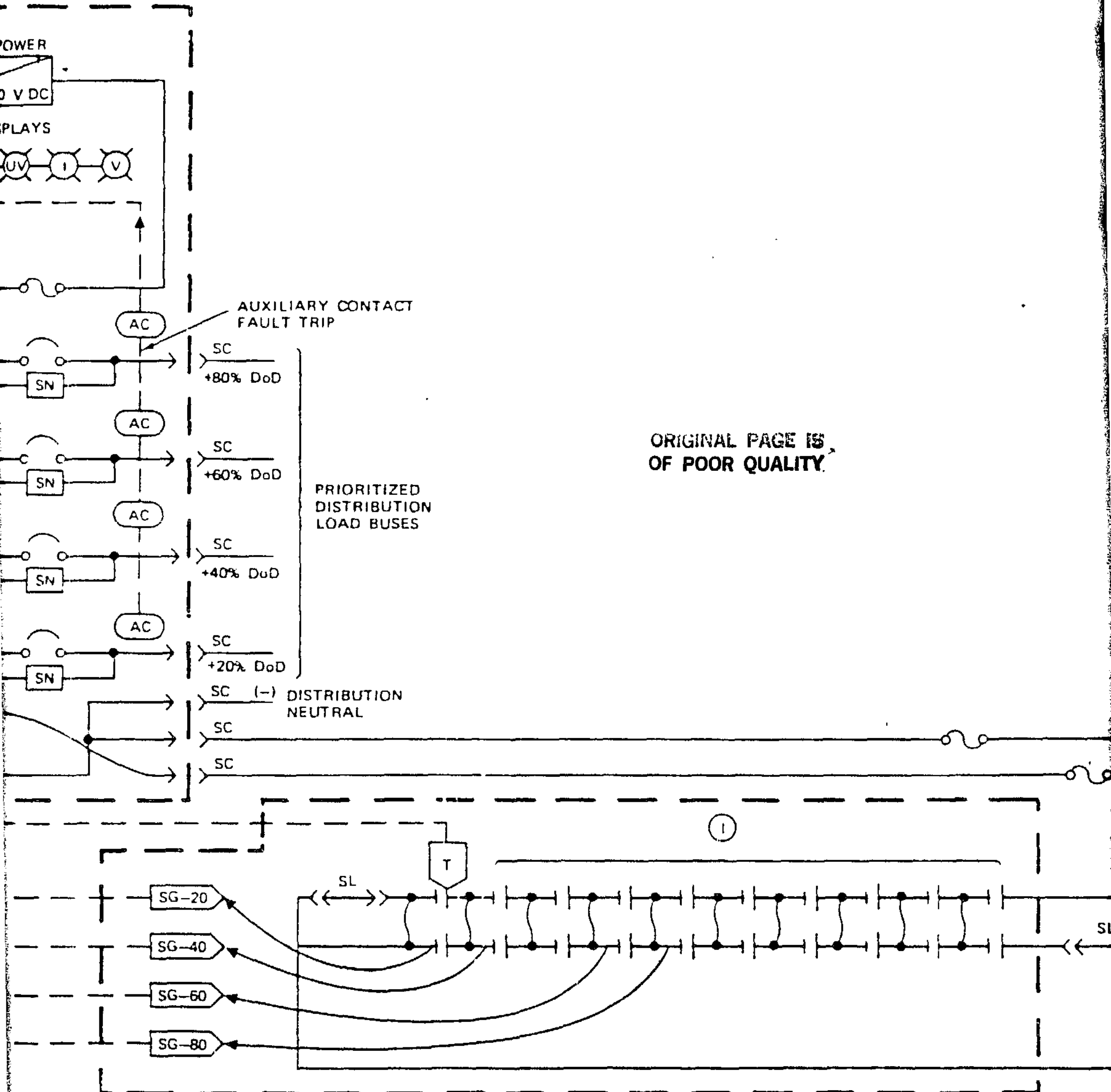

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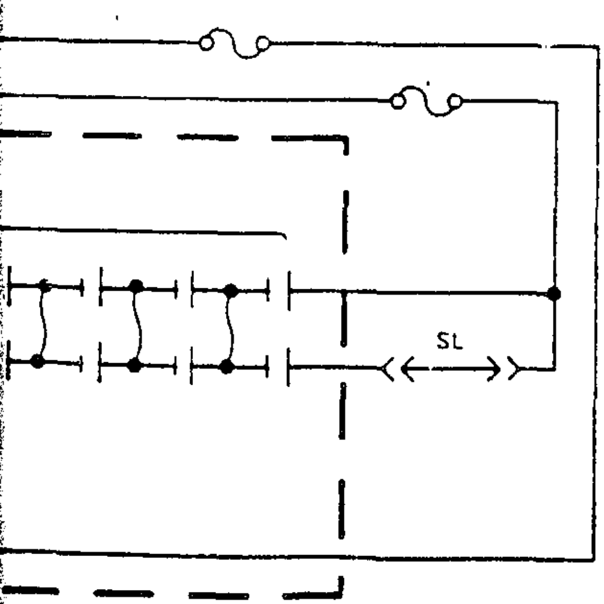

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BASELINE I PU SYSTEM

Generalized Electrical Schematic

Figure 4.4-1

Table 4.4-2

Power Rating Structure

Power Unit (PU)	Peak Power from Array W*	Peak Array Current at 150 Vdc A	Basic PV Module Size (ft) and power W	Array Power Branch Increments PU	Basic Battery String Complement	Basic Power Controller Capacity (PU)
1/4	320	2.1	1 x 4 (32W)	1/2	1 ea.	4
1/2	640	4.3	2 x 4 (64W)	1	1 ea.	4
1 **	1,280	8.5	2 x 4 (64W)	2	2 ea.	4
2	2,560	17	2 x 4 (64W)	4	4 ea.	4
4	3,120	34	2 x 4 (64W)	8	8 ea.	4
8	10,249	68.3	2 x 4 (64W)	16	16 ea.	8
16	20,480	1,36.3	2 x 4 (64W)	32	32 ea.	8 (2 ea.)

* At 1000 Watts/M^2 insolation; Air mass = 1.5; $T_{ambient}$ = 25°C

** Baseline Rating

Within the overall electrical system, the array field wiring and cabling provides the electrical power interface between the power generating array elements, the series module branches, and the power controller. Except for the fractional power unit ratings, the horizontal folded daisy chain wired string of 10 series, 15 volt/64 Wpk modules will be employed. For the extended higher power ratings, above 8 PU, transition from the intermodule wiring to the radial branch cabling can be accomplished in several ways. The following wiring options become available when the site geometry forces the deployed systems to be deployed out in multiple East-West oriented rows:

(1) Aerial/burial cable, with North-South overhead ductway.
(2) Rigid metallic/non-metallic conduit, for special protection of power cables; IMC; or alternatively protected surface runs, also with aerial/burial cable.

Figure 4.4-3 is the specification control drawing for the Solarlok devices; Figure 4.4-4 is that of the "Supercon" connectors used in array battery and load terminations within the Power Controller. The branch currents are routed directly to the Power Controller. Radial collection is employed throughout. A two string summing junction can be used directly at the termination of two subranch loops in the event the smaller 1 ft x 4 ft modules are deployed in a 320 Wp series string. Figure 4.4-5 is a photograph of the backplane of the engineering model.

4.5 PHOTOVOLTAIC MODULES

The basic photovoltaic modular building block is the 2 ft x 4 ft solar cell module described in Hughes Procurement Specification SEP-11396 (Appendix B). The module was produced by Photowatt International Inc. of Tempe, Arizona. A photograph of a typical panel is given in Figure 4.5-1.

The module specification defines the electrical performance parameters, tests, and mechanical design of the module. The specification basically conforms to JPL's Block IV solar cell design and test specification (No. 5101-83).

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ADL [illegible]
ADV. DEV. LAB., LARGO, FL. 33540

AMP® SOLARLOK®

CONNECTOR SYSTEM

INSTRUCTION SHEET
IS 7405-211-1

Published 1-5-81

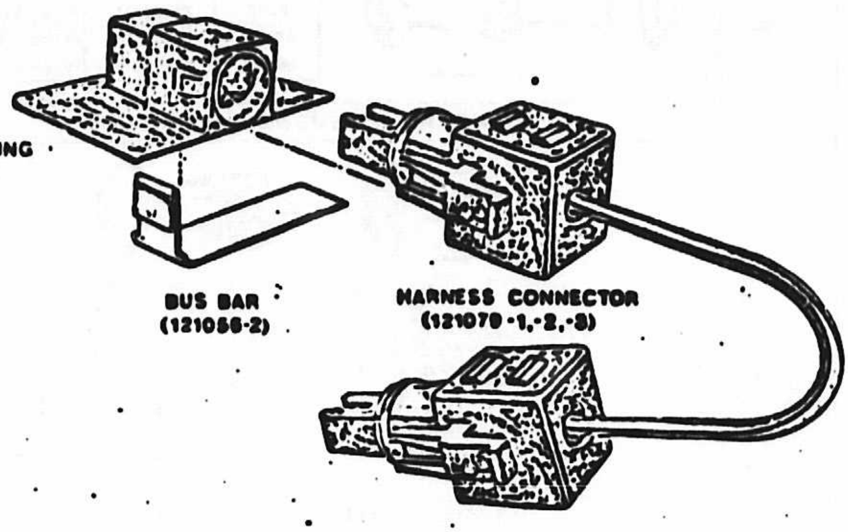


FIGURE-1

1.1 Descrition

AMP SOLARLOK® Connector was primarily designed and introduced to the Solar Energy Industry in 1979. The Connector system is packaged and initially available as a complete kit as shown in Figure-1.

1.2 Each kit consists of a one tab Bus Bar, Bus Bar Housing and Harness Connector with 18" wire length. The basic kit is available under AMP part number 121055-1.

1.3 Other kits will be available with variations in type and length of wire, 2 tab Bus Bars and assorted quantities of Bus Bar Housings and Harness Connectors to accommodate customer requirements.

2.1 Read the following instructions for specific information in regard to the AMP SOLARLOK® Connector installation for a typical module.

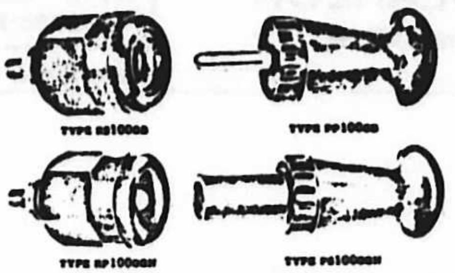
® TRADEMARK OF AMP INCORPORATED

Specification Control Drawing for Solarlok Connectors

Figure 4.4-3

PRICES SHOWN AT BACK OF THIS SECTION. ALL ITEMS ON THIS PAGE NORMALLY IN MINARIK STOCK.

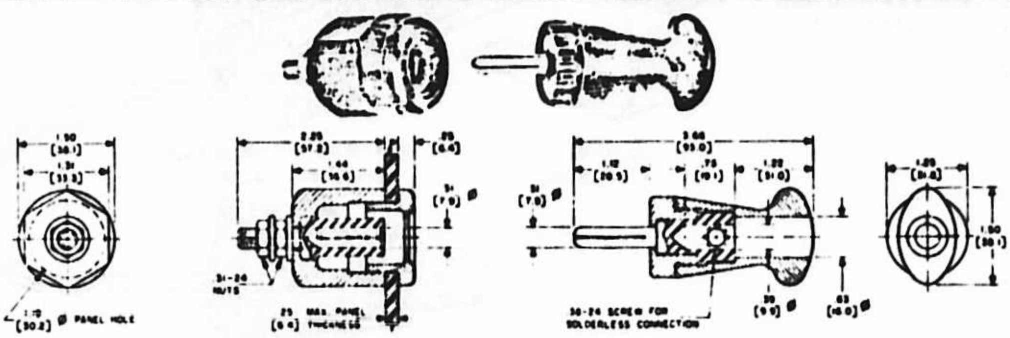
100 AMPERE SUPERCON®



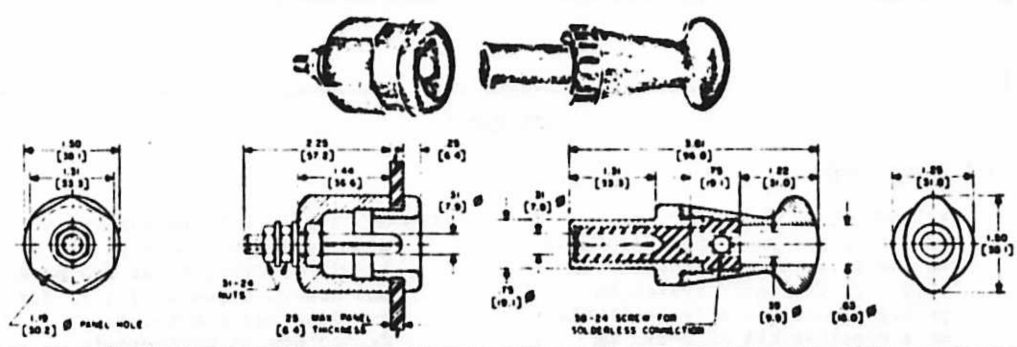
CATALOG NUMBER

COLOR	SOCKET RECEPTACLE	PIN PLUG	PIN RECEPTACLE	SOCKET PLUG
BLACK	RS100GB	PP100GB	RP100GB	PS100GB
YELLOW	RS100GY	PP100GY	RP100GY	PS100GY
RED	RS100GR	PP100GR	RE100GR	PS100GR
BLUE	RS100GBL	PP100GBL	RP100GBL	PS100GBL
GREEN	RS100GGN	PP100GGN	RP100GGN	PS100GGN
WHITE	RS100GWT	PP100GWT	RP100GWT	PS100GWT

100 AMPERE TYPES RS and PP DIMENSIONS



100 AMPERE TYPES RP and PS DIMENSIONS



SAFETY WARNINGS

INSTALLATION:— It is the responsibility of the equipment manufacturer or individual installing the apparatus to take diligent care when installing equipment. The National Electrical Code (NEC), sound local electrical and safety codes, and when applicable, the Occupational Safety and Health Act (OSHA) should be followed when installing the apparatus to reduce hazards to persons and property.

USE:— The chance of electric shocks, fire or explosion can be reduced by giving proper consideration to the use of grounding, thermal and over-current protection, type of enclosure and good maintenance procedures.

Minarik Electric Company
Masters of Control

SCD for Supercon Connectors

Figure 4.4-4

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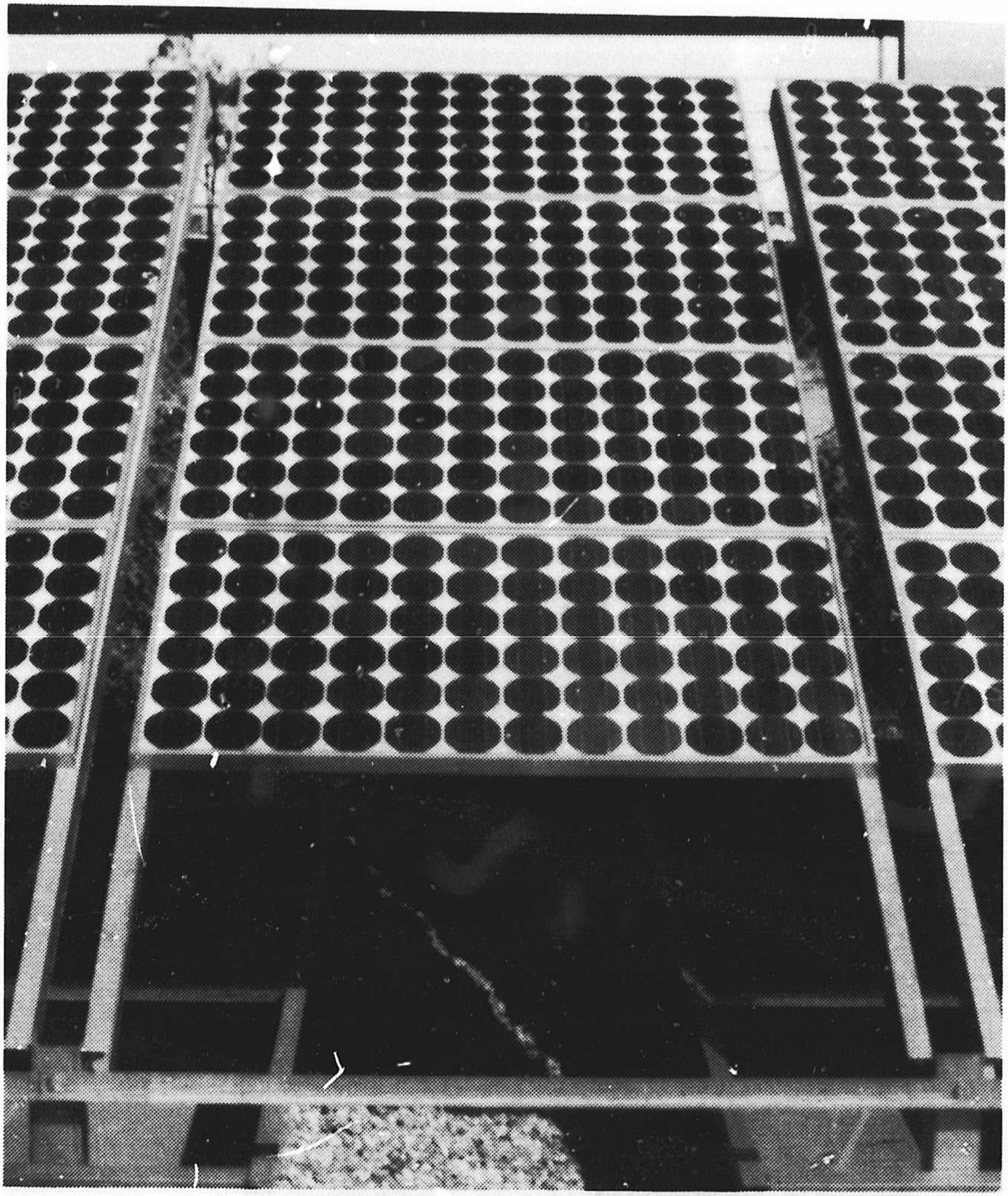
Photograph of Engineering Model Back Plane

Figure 4.4-5



Typical PV Panel
Figure 4.5-1

The procurement specification SEP 11396 (Appendix B) defines all quality assurance provisions and acceptance testing to ensure that the requirements will be met. Photowatt's module inspection system plan is covered by SEP-11396.

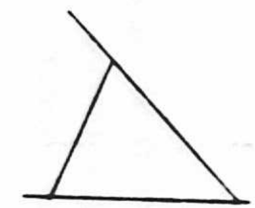
The module specification requires that the module design be capable of withstanding the following Block IV environmental tests:

Thermal cycle
Humidity cycle
Mechanical loading
Twisted-Mounting Surface
Hail impact

Photowatt letter, March 28, 1983 (Appendix D) certifies that the design met the environmental requirements as demonstrated through previous Block IV testing.

All 50 modules were subjected to acceptance testing. Each module was visibly inspected for any non-conforming or damaged front surfaces, frames, solar cells, interconnects, solder joints, laminates, terminals, diodes and dimensional variations. Electrically, each module's performance was determined by obtaining a current-voltage (I-V) curve of the module by means of a pulsed xenon solar simulator. All I-V curves were corrected to standard conditions of AM 1.5 1000 W/M^2, 28°C. Appendix E contains a summary of each module's serial number and performance. The average output for the 50 module lot was 66.17 watts. Based on the performance summary, the modules were electrically matched into circuits each containing ten series connected modules. The location of each module by serial number in the array is shown in Figure 4.5-2 the Module Matching Plan.

5201	5198	5183	4969	5184	4741	4229	5399	4975	5330	5202	5197	4974
5488	5203	4915	4976	5117	4090	4228	4758	4966	5329	5478	3512	5049
4707	4968	4981	3631	5271	4973	4711	5484	5081	5116	4714	4740	5047
4130*	5114	4980	3993	5480			4712	3987	4782	5115	4967	5205



* MODULE SERIAL NUMBER

Module Matching Plan

Figure 4.5-2

In addition to electrical performance testing, each module was subjected to a 3000 Vdc electrical insulation test and a diode verification test. All acceptance test data were submitted to Hughes for review and approval.

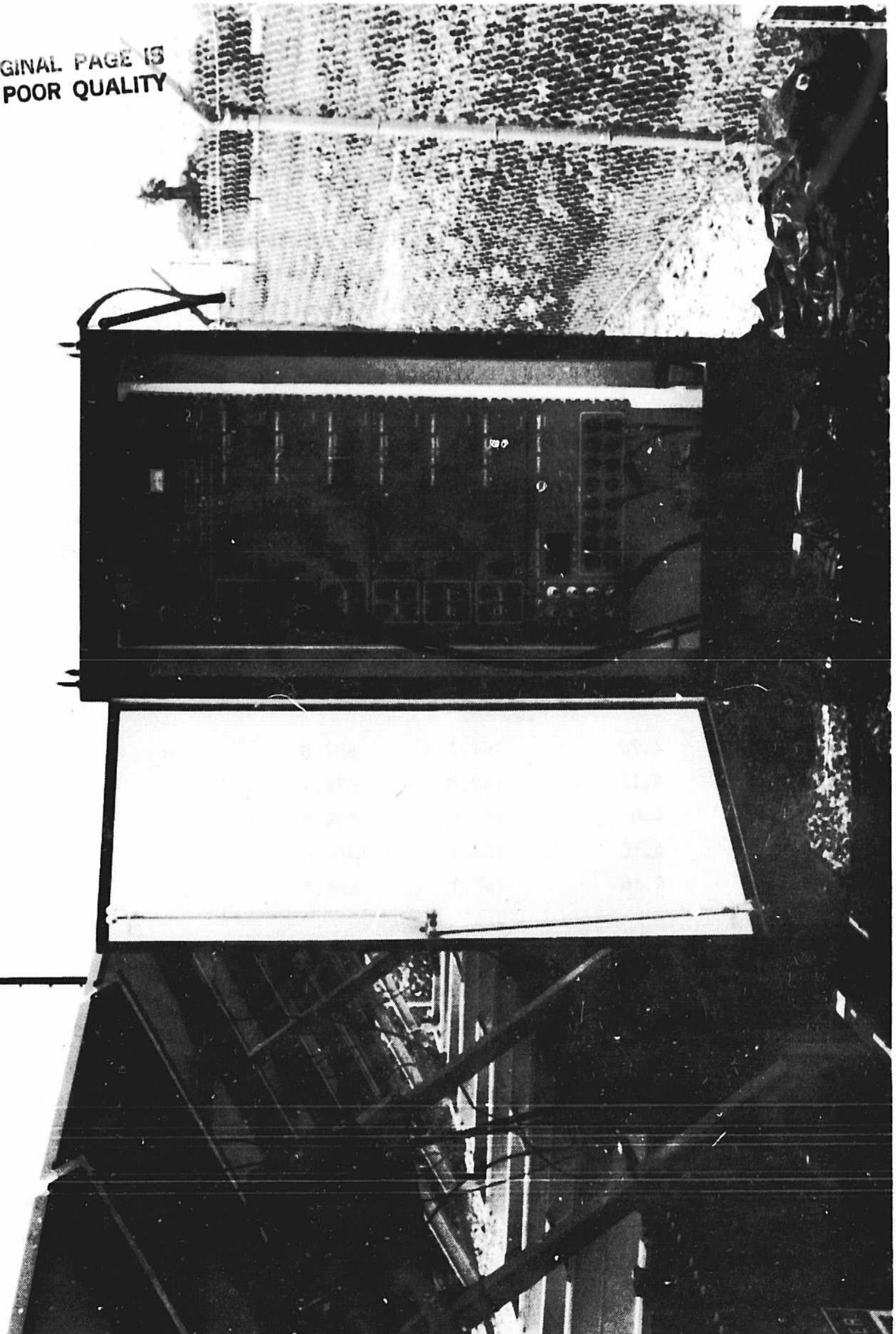
A sample of two production modules was selected at random for inspection and performance verification by Hughes. I-V curves were obtained for each module under natural sunlight conditions. The data was corrected to standard conditions of AM 1.5, 1000 W/M^2, 28 °C. The performance of these modules agreed with Photwatt's acceptance test data within $\pm$ 2%.

Each solar array string of 10 series connected modules was electrically performance tested on February 14, 1983. Although there were thin, high clouds the array strings all appeared to be functioning properly. When corrected to AM 1.5 1000 W/M^2 , 28°C the following performance parameters were obtained.

String	I_{mp} (Amps)	V_{mp} (Volts)	P_{mp} (Watts)
Upper West	4.20	164.1	689.0
Lower West	4.16	162.5	676.1
Center	4.06	157.5	639.8
Upper East	4.16	165.1	686.8
Lower East	4.16	162.1	674.4

4.6 POWER CONTROLLER

The Power Controller (PC) is the collection, conditioning and distribution center for all system DC power. One basic Power Controller is furnished; this baseline configuration is used in all ratings through 8 PU. Power Switching Modules (PSM) are progressively added with increasing power ratings. Figure 4.6-1 is a photograph baseline 8 PU cabinet. Figure 4.6-2 is the cabinet and controller interface wiring diagram. The Power Controller also houses the Power Control Panel (PCP) and the Power Output Panel (POP). These panels and the associated hardware assemblies are also common for all systems. The Power Controller also accomodates all of the SOLARLOK male receptacles that



Power Controller
Figure 4.6-1

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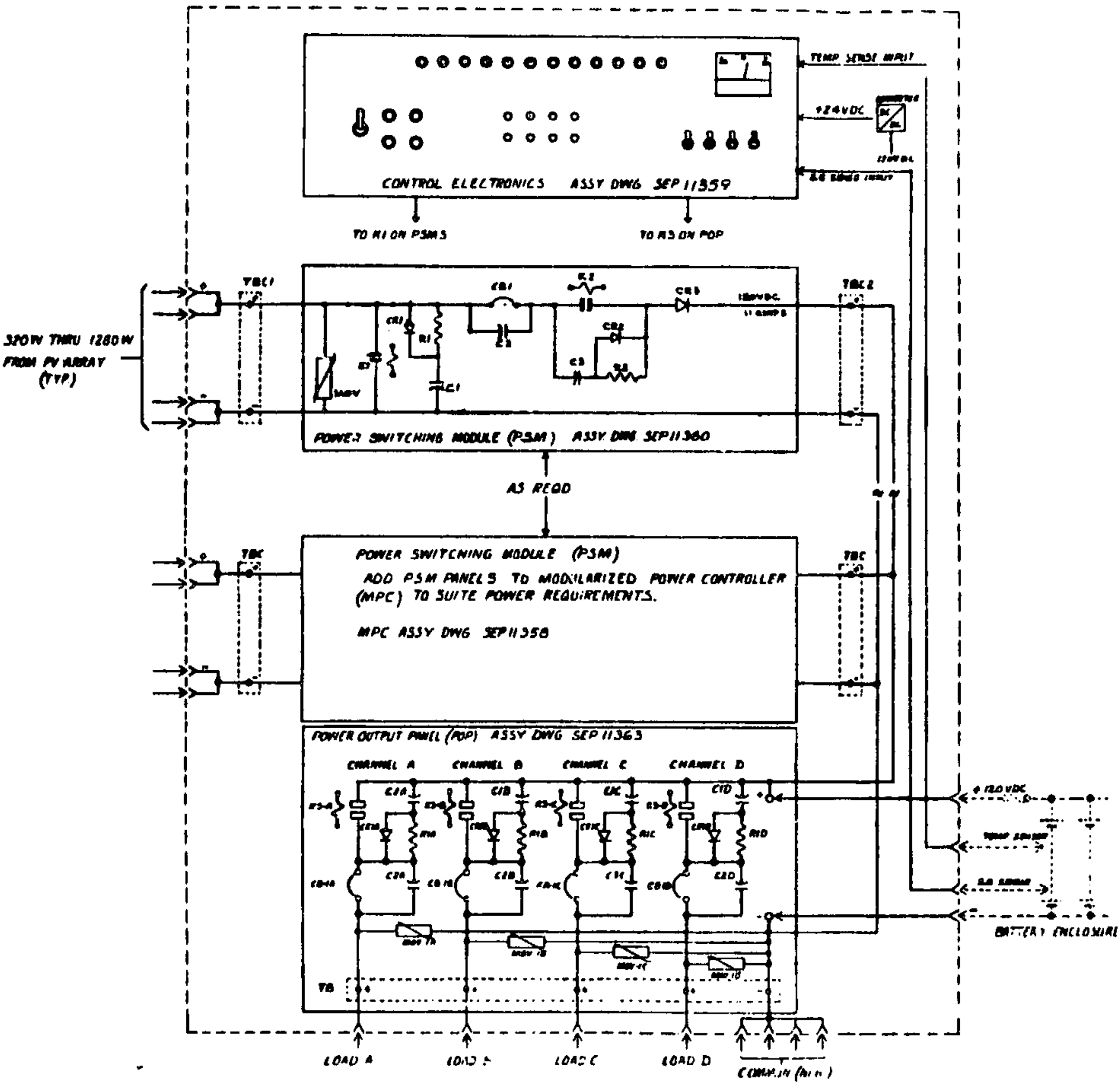


Power Controller Cabinet Wiring Diagram
Figure 4.6-2

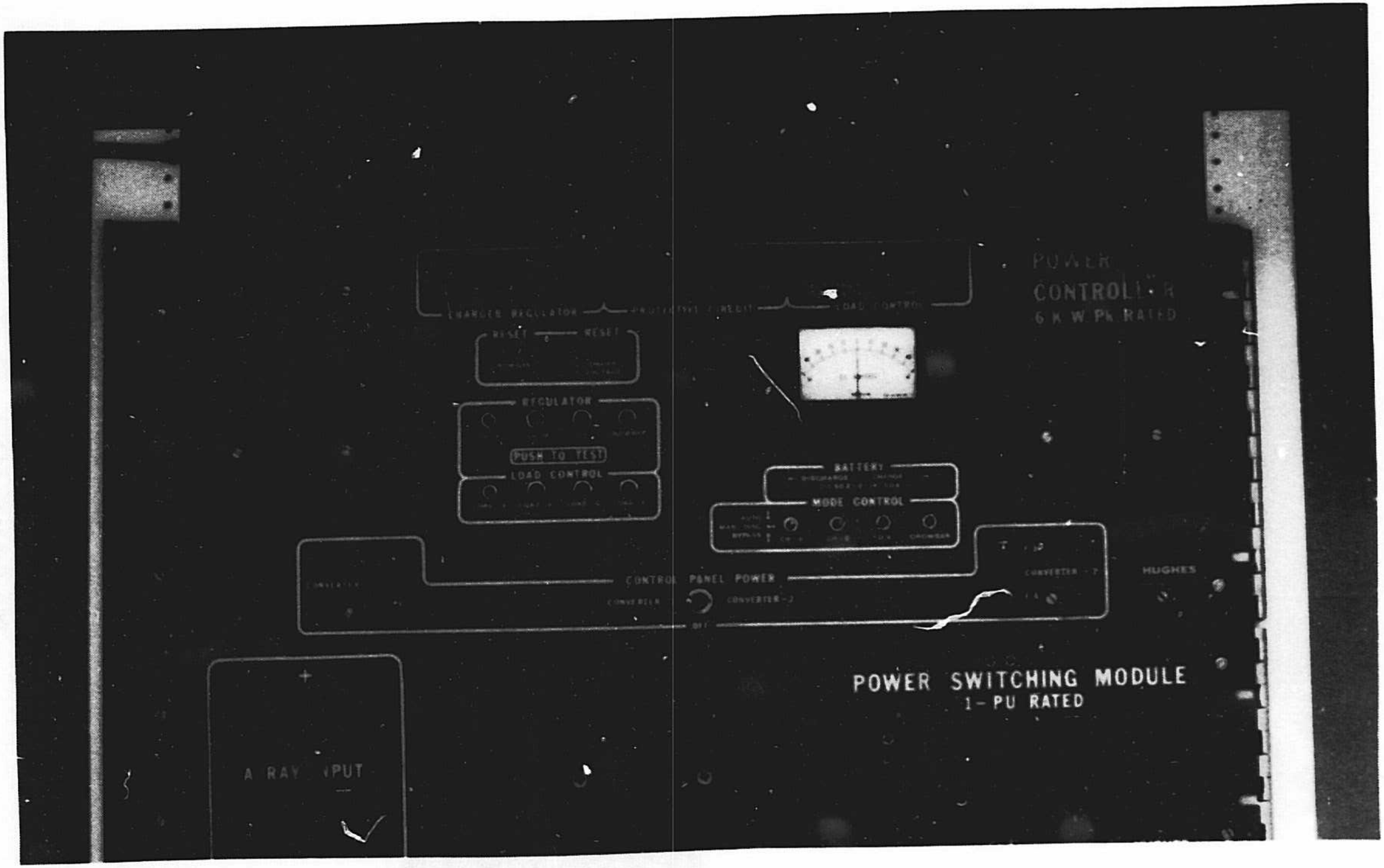
interface with the PV array branch collection circuits as well as the "Supercon" load connectors outputting from the distribution circuit breakers. The PC cabinet also houses the high current summing bus or main lugs sized for maximum system power rating. The battery strings are connected by "Supercon" connectors to these main lugs.

4.6.1 Power Control Panel (PCP)

The PCP houses all of the master electronic controls for the power systems. It includes the following:

1) The Two Channel Charger (Multi-Level) Regulator printed circuit board.
2) The Load Management printed board.
3) Summary system status displays and indicators and the zero centered battery current meter.
4) The ground fault relay.
5) The control system motherboard, electrically interfacing the power control subsystems, the electronic sensing and decisional circuits, the manual/automatic control, and the displays and indicators.
6) Manual override controls and mode selectors.
7) All pilot relays required to energize the main contactors.
8) The dual redundant DC/DC converters, supplying 24 Vdc control power.
9) System protective logic and control elements.
10) Interfaces with the Deltar SOC sensors.

Figure 4.6.1-1 is a photograph of the PCP front panel and Figure 4.6.1-2 shows the interior physical arrangement of the several PCP subassemblies. Figure 4.6.1-3 is a schematic of the motherboard; Figure 4.6.1-4 is a photograph showing the physical layout of the major elements. A low cost DC/DC converter is employed to efficiently obtain low voltage control power without dissipation in the dropping power resistor. Two converters are redundantly employed in the cold standby/manual switchover mode. A DC/DC converter is included as Figure 4.6.1-5.



Front Panel of Power Control Panel

Figure 4.6.1-1

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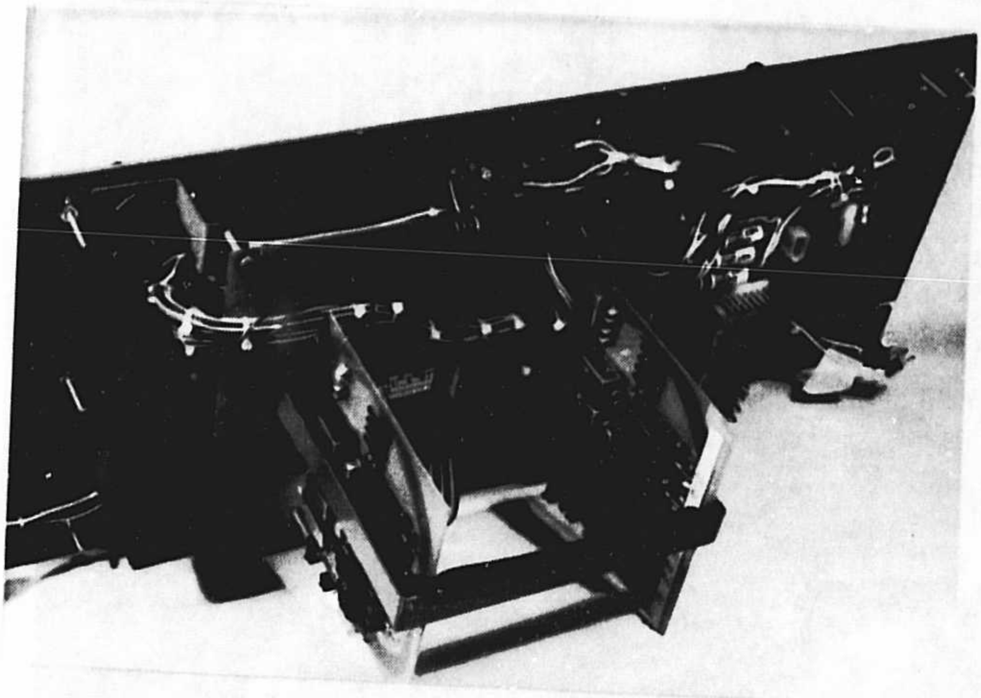
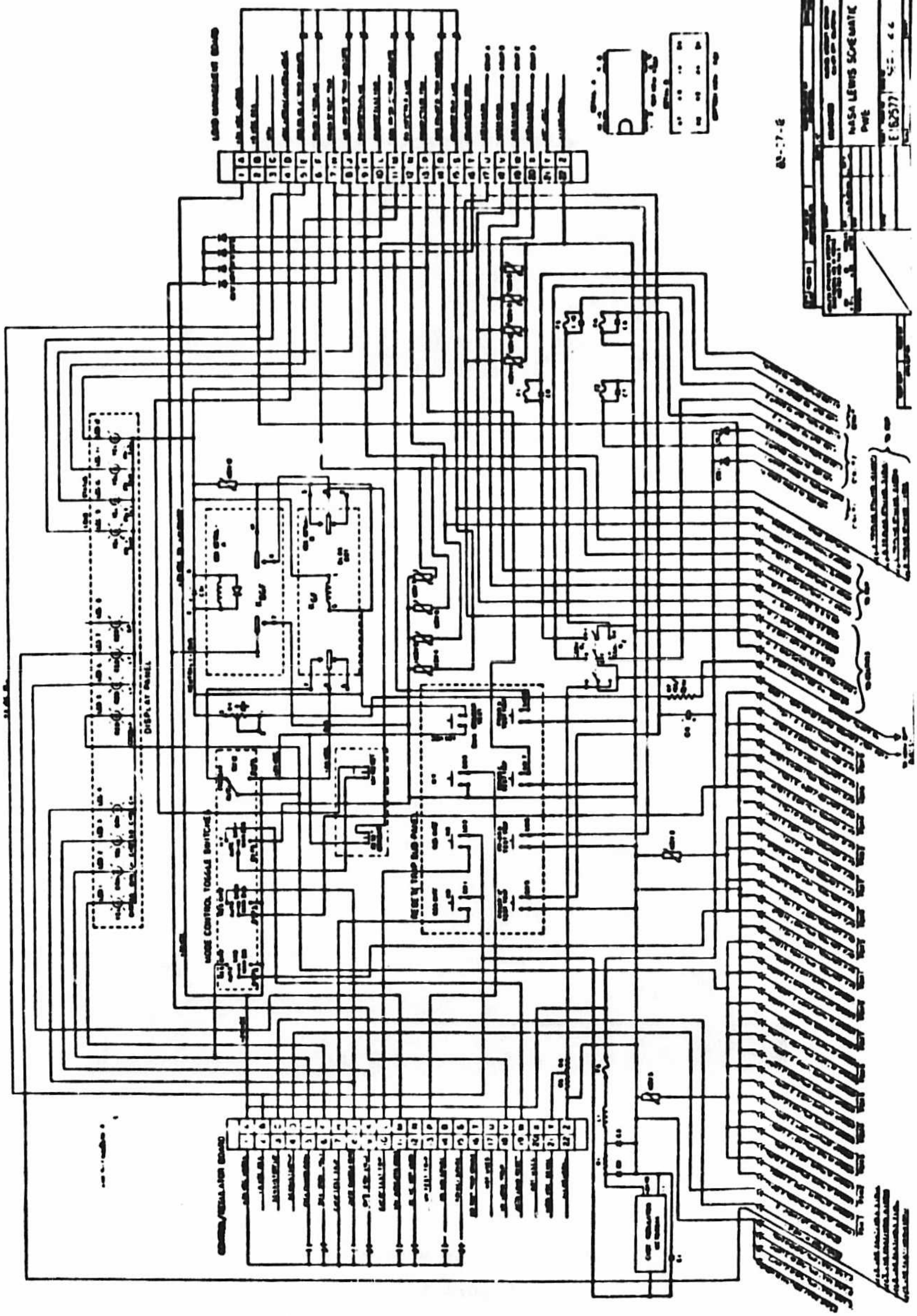


PCP Subassemblies

Figure 4.6.1-2



Schematic of Motherboard
Figure 4.6.1-3

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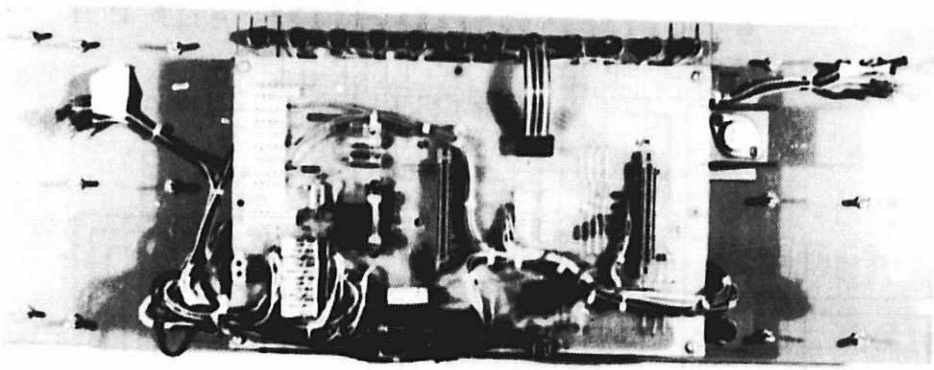
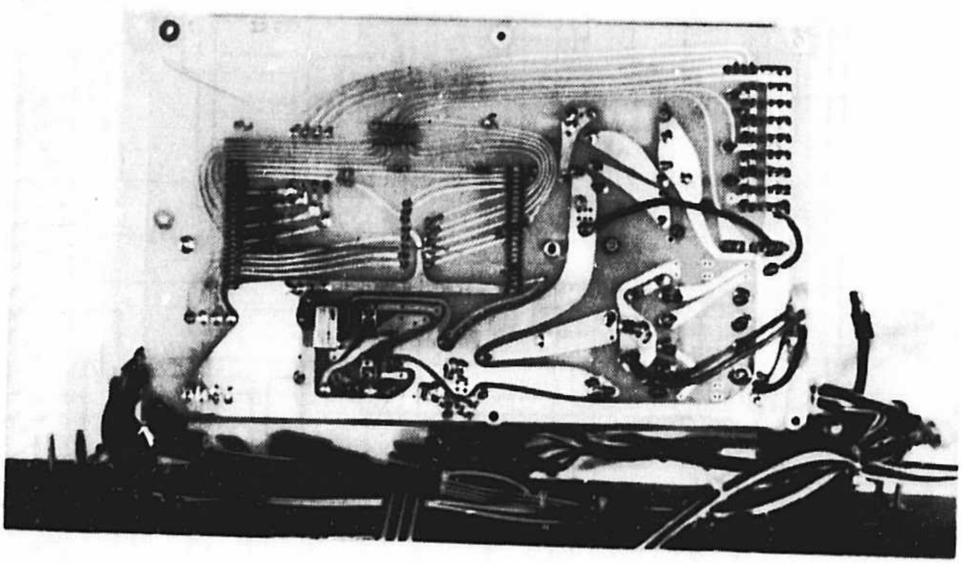




Photograoh of Motherboard
Figure 4.6-6

BIKOR CORPORATION

DC-DC UNREGULATED POWER CONVERTERS

• High Efficiency (90% Typ. & Fl.) ■ Isolated Input/Output ■ 0.5% Maximum Ripple ■ Submodular Construction

11 TO 14 VDC INPUT

Output @ 12 VDC Input Voltage (VDC)	Output @ 12 VDC Input Current (Amps)	Model No.	Case Size	Price (1-24)
12	4.0	DDU 1201	A	152.00
	7.0	DDU 1202	B	189.00
	12.0	DDU 1203	D	275.00
24	2.0	DDU 1204	A	152.00
	3.5	DDU 1205	B	189.00
	6.0	DDU 1206	D	275.00
48	1.0	DDU 1207	A	152.00
	1.8	DDU 1208	B	189.00
	3.0	DDU 1209	D	275.00
110	0.5	DDU 1210	A	152.00
	0.8	DDU 1211	B	189.00
	1.5	DDU 1212	D	275.00

22 TO 30 VDC INPUT

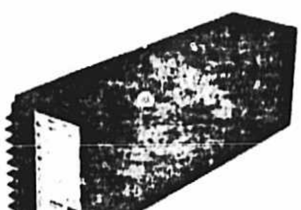
Output @ 24 VDC Input Voltage (VDC)	Output @ 24 VDC Input Current (Amps)	Model No.	Case Size	Price (1-24)
12	4.0	DDU 2401	A	152.00
	7.0	DDU 2402	B	189.00
	15.0	DDU 2403	D	275.00
24	2.0	DDU 2404	A	152.00
	3.5	DDU 2405	B	189.00
	8.0	DDU 2406	D	275.00
48	1.0	DDU 2407	A	152.00
	1.8	DDU 2408	B	189.00
	4.0	DDU 2409	D	275.00
110	0.5	DDU 2410	A	152.00
	0.8	DDU 2411	B	189.00
	2.0	DDU 2412	D	275.00

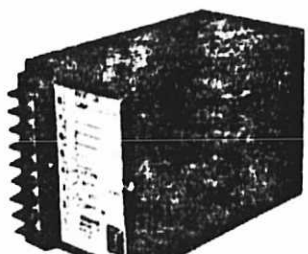
44 TO 56 VDC INPUT

Output @ 48 VDC Input Voltage (VDC)	Output @ 48 VDC Input Current (Amps)	Model No.	Case Size	Price (1-24)
12	4.0	DDU 4801	A	152.00
	7.0	DDU 4802	B	189.00
	15.0	DDU 4803	D	275.00
24	2.0	DDU 4804	A	152.00
	3.5	DCU 4805	B	189.00
	8.0	DDU 4806	D	275.00
48	1.0	DDU 4807	A	152.00
	1.8	DDU 4808	B	189.00
	4.0	DDU 4809	D	275.00
110	0.5	DDU 4810	A	152.00
	0.8	DDU 4811	B	189.00
	2.0	DDU 4812	D	275.00

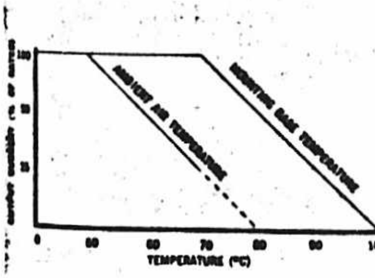
105 TO 140 VDC INPUT

Output @ 110 VDC Input Voltage (VDC)	Output @ 110 VDC Input Current (Amps)	Model No.	Case Size	Price (1-24)
12	4.0	DDU 11001	A	152.00
	7.0	DDU 11002	B	189.00
	15.0	DDU 11003	D	275.00
24	2.0	DDU 11004	A	152.00
	3.5	DDU 11005	B	189.00
	8.0	DDU 11006	D	275.00
48	1.0	DDU 11007	A	152.00
	1.8	DDU 11008	B	189.00
	4.0	DDU 11009	D	275.00
110	0.5	DDU 11010	A	152.00
	0.8	DDU 11011	B	189.00
	2.0	DDU 11012	D	275.00

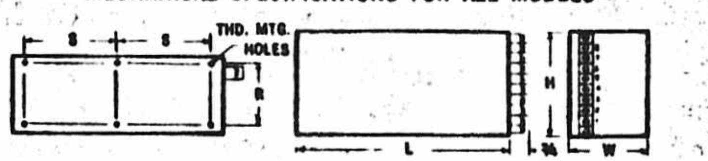




TEMPERATURE RATINGS FOR ALL MODELS



MECHANICAL SPECIFICATIONS FOR ALL MODELS



Case	L	W	H	R	S	Number of Mounting Holes / Thread Size	Weight (Typ.)
A	5¾ (14.61)	3 (7.62)	4 (10.16)	2.4 (6.10)	5 (12.70)	4 / #6-32 THD.	1¼ (.57)
B	8 (20.32)	3 (7.62)	4 (10.16)	2.4 (6.10)	3.5 (8.89)	6 / #6-32 THD.	1¾ (.79)
C	12 (30.48)	3 (7.62)	4 (10.16)	2.4 (6.10)	5.5 (13.97)	6 / #6-32 THD.	2½ (1.13)
D	10 (25.40)	4 (10.16)	4⅝ (11.75)	3 (7.62)	4.5 (11.43)	6 / #10-32 THD.	3½ (1.59)
E	15 (38.10)	4 (10.16)	4⅝ (11.75)	3 (7.62)	4.5 (11.43)	8 / #10-32 THD.	4¼ (1.93)
G	15 (38.10)	6 (15.24)	4⅝ (11.75)	5 (12.7)	4.5 (11.43)	8 / #10-32 THD.	6 (2.72)

NOTE: Sizes, Inches (CM); Weight, Pounds (KG)

SCD for DC/DC Converter

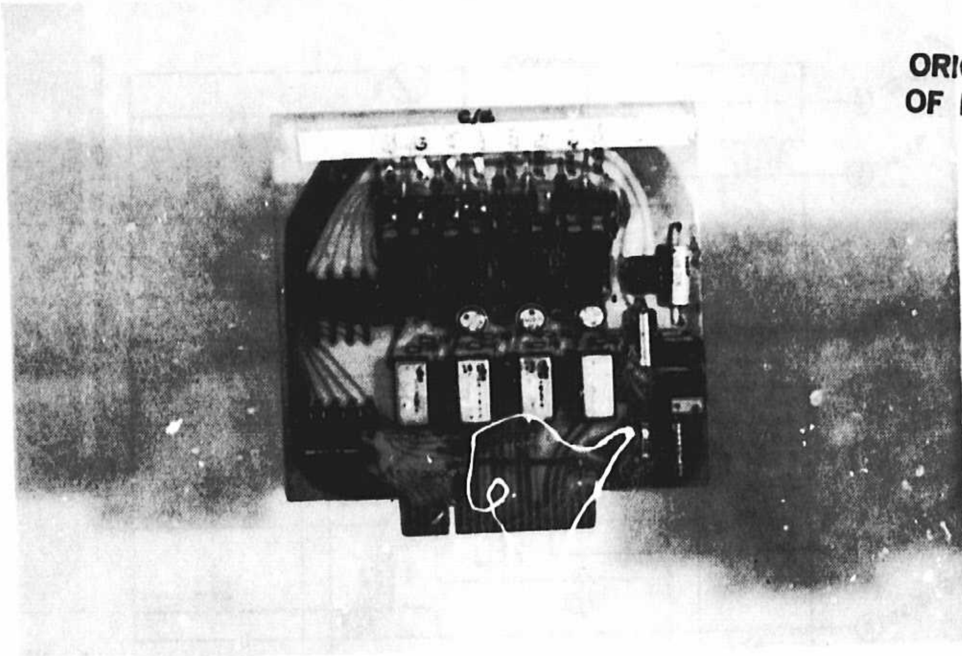
Figure 4.6.1-5

4.6.2 Universal Control Board Printed Circuit

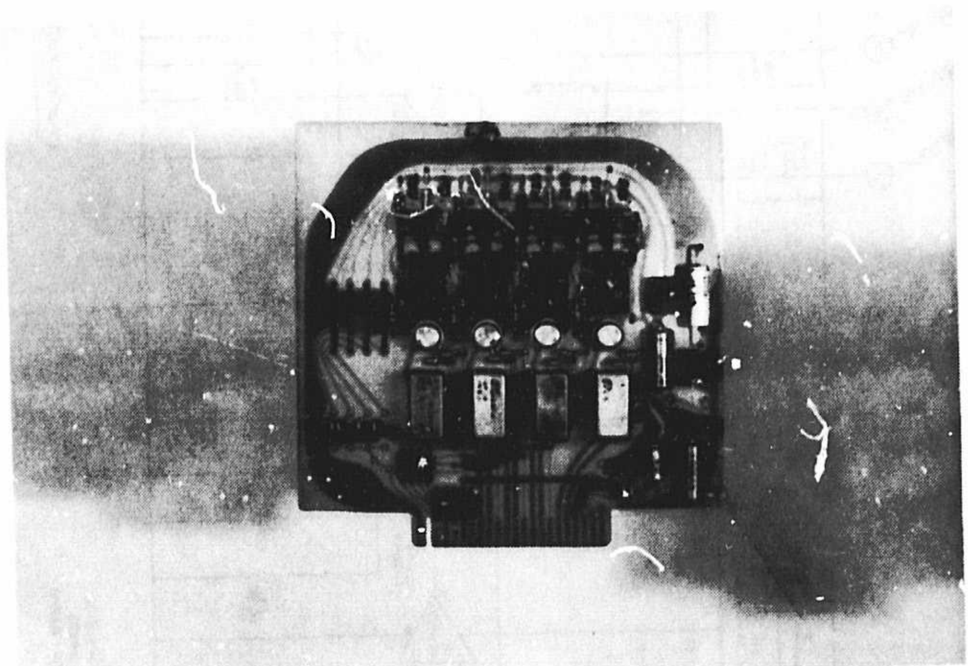
The multilevel charge-regulator control circuits and the load management decisional circuits utilize a common printed circuit board. The change of a limited number of divider resistor values and sense inputs, plus the deletion of the temperature compensation function and the addition of the DELTAR sense inputs convert a charge regulator board to L/M control board . In the load management function the inputs to each of four dual state comparators are dedicated respectively to each of four Deltar sensor outputs corresponding to 20 percent, 40 percent, 60 percent and 80 percent state of charge. In the multilevel regulator configuration, two comparators are dedicated to the dual channel regulation and the third to undervoltage trip. The fourth channel is presently uncommitted and available as a spare. Figures 4.6.2-1 and 4.6.2-2 are photos of the C/R and L/M boards respectively; Figure 4.6.2-3 and 4.6.2-4 are of the schematics of the boards. In the standard circuit the comparator IC outputs to a bipolar drive transistor which in turn operates a one-half crystal can hermetic relay. The charge regulation channel output relays can energize up to eight series switching Mercury contactors. In the L/M configuration, each of the four comparator output relays energizes the corresponding contactor in that particular prioritized load bus. Upon occurance of a Deltar sense transition, the comparator, upon dropout, latches in response to a change in level in the DELTAR specified gravity sensor assigned to that particular channel.

4.6.3 Power Switching Module

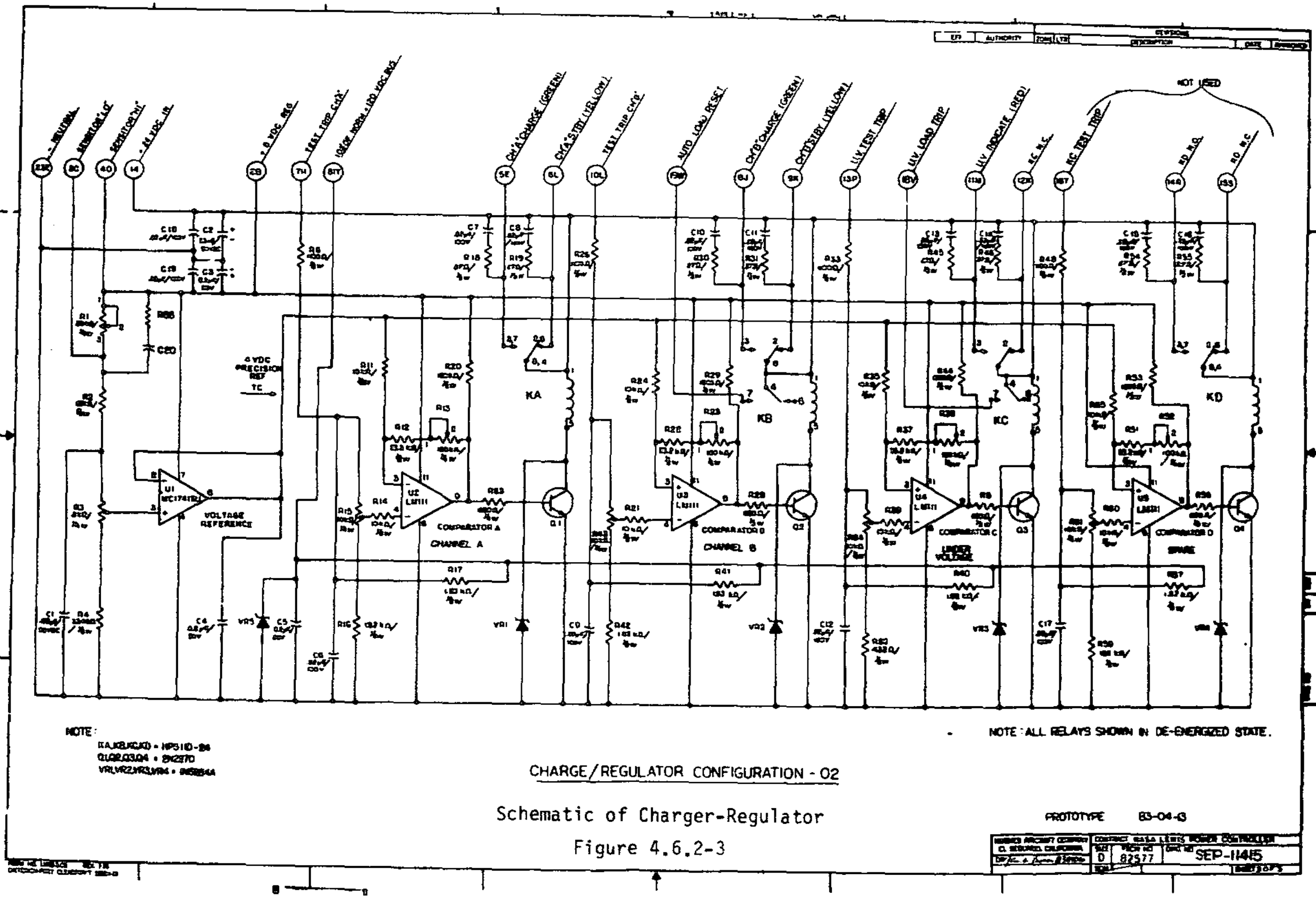
The Power Switching Module (PSM) consolidates all input power switching elements for each 1 PU (1.28 kWp) increment on a single panel. Figure 4.6.3-1 is the photo layout of a single PSM panel; Figure 4.6.3-2 depicts the parts layout and the intraconnective wiring. The PSM accepts the output of contributing branches, delivering the power to to the summing (battery) bus. It includes the following control/protective switchgear: Figure 4.6.3-3



Photograph of Charge-Regulator Board
Figure 4.6.2-1

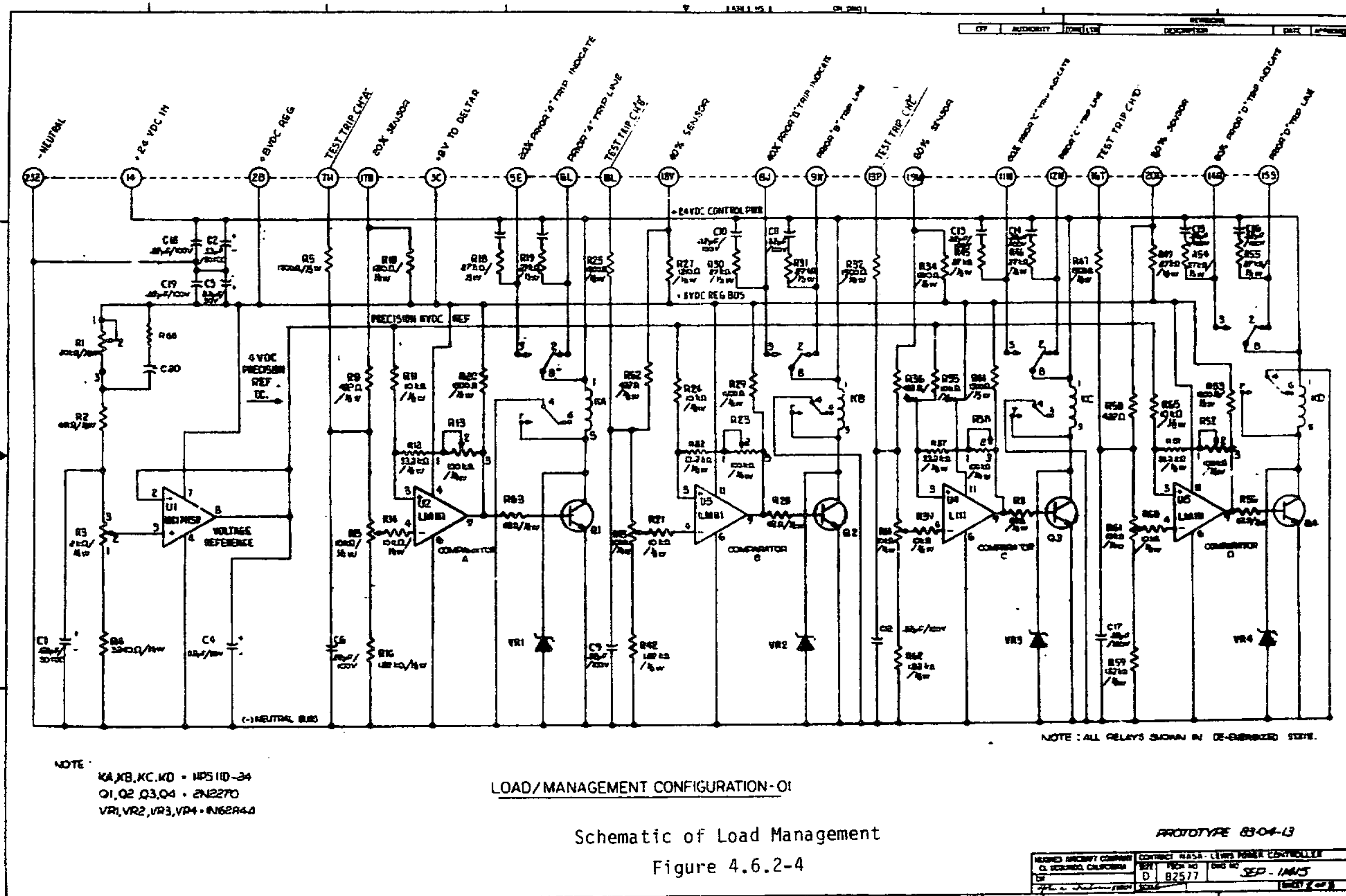


Photograph of Load Management Board
Figure 4.6.2-2



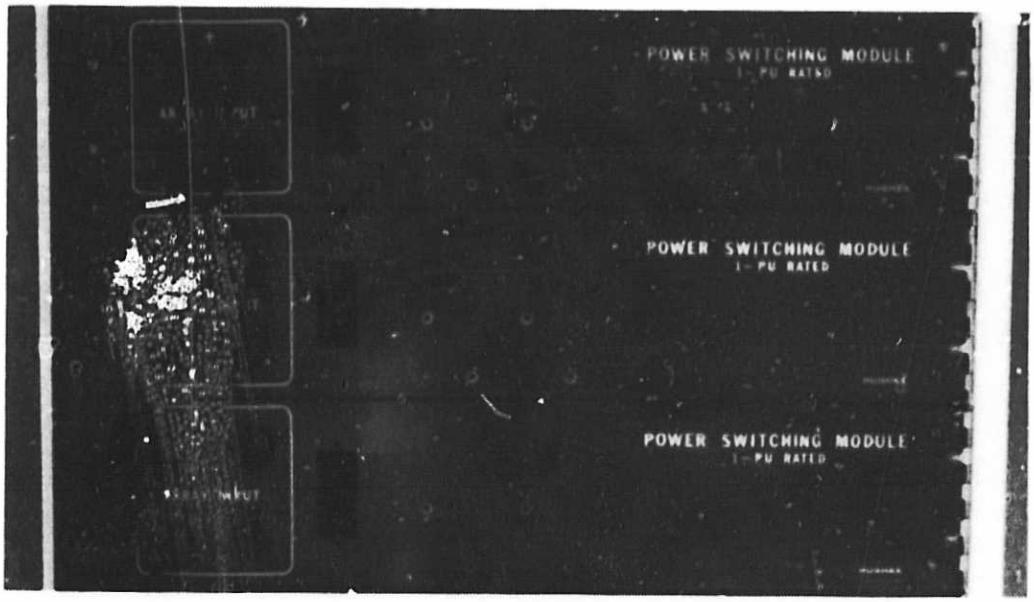
Schematic of Charger-Regulator

Figure 4.6.2-3



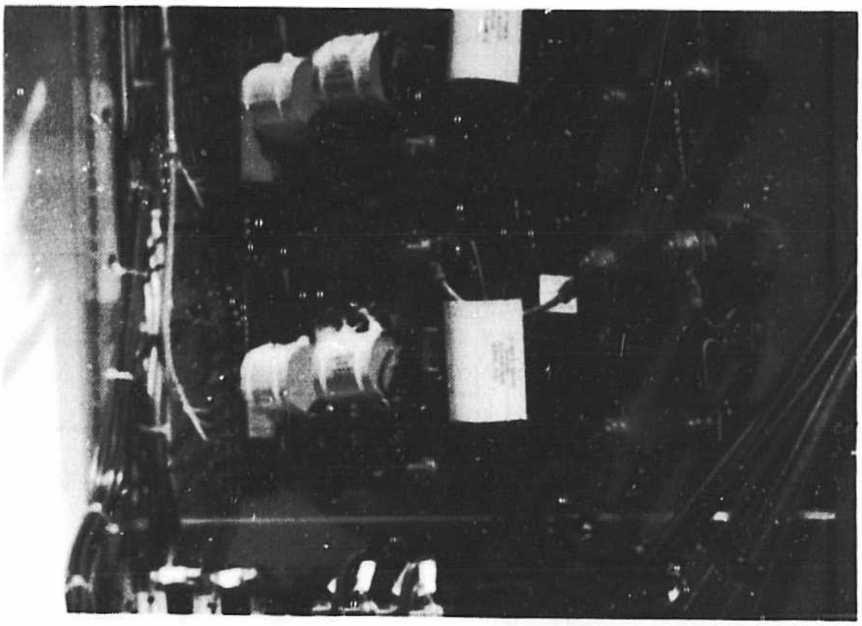
Schematic of Load Management

Figure 4.6.2-4



Power Switching Module Panels

Figure 4.6.3-2



Power Switching Module Layouts and Wirings

Figure 4.6.3-2

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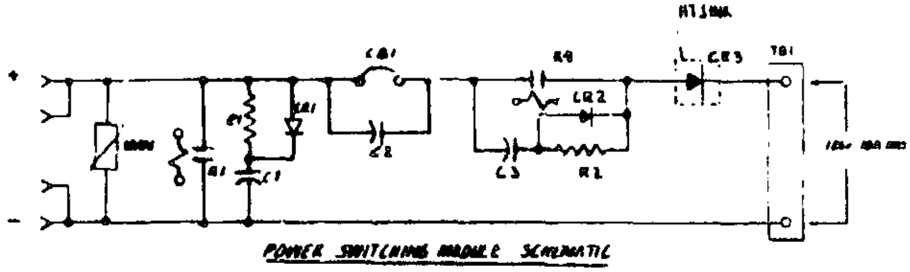
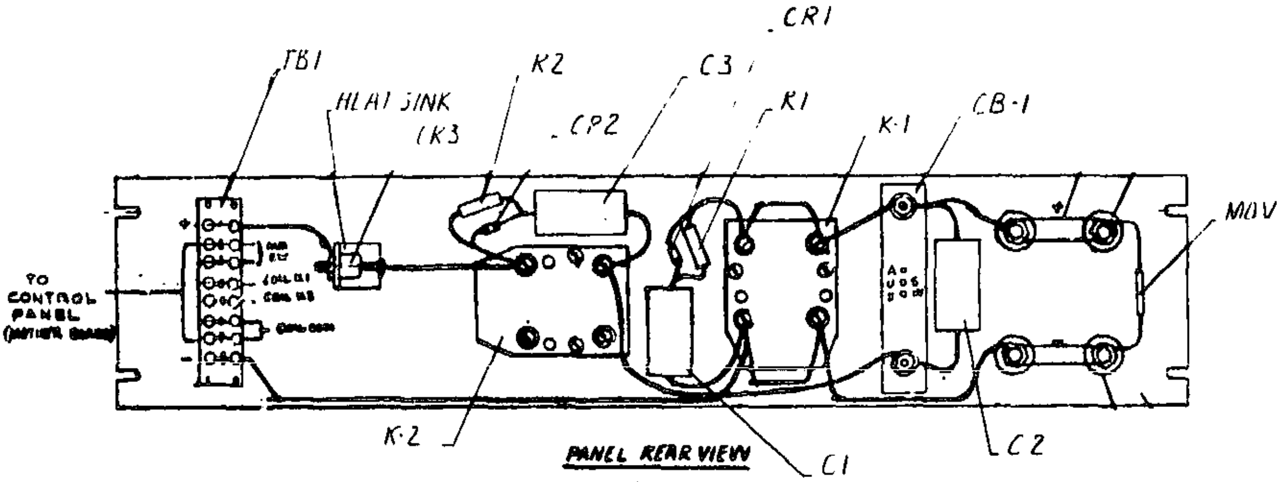




Power Switching Module Wiring Diagram

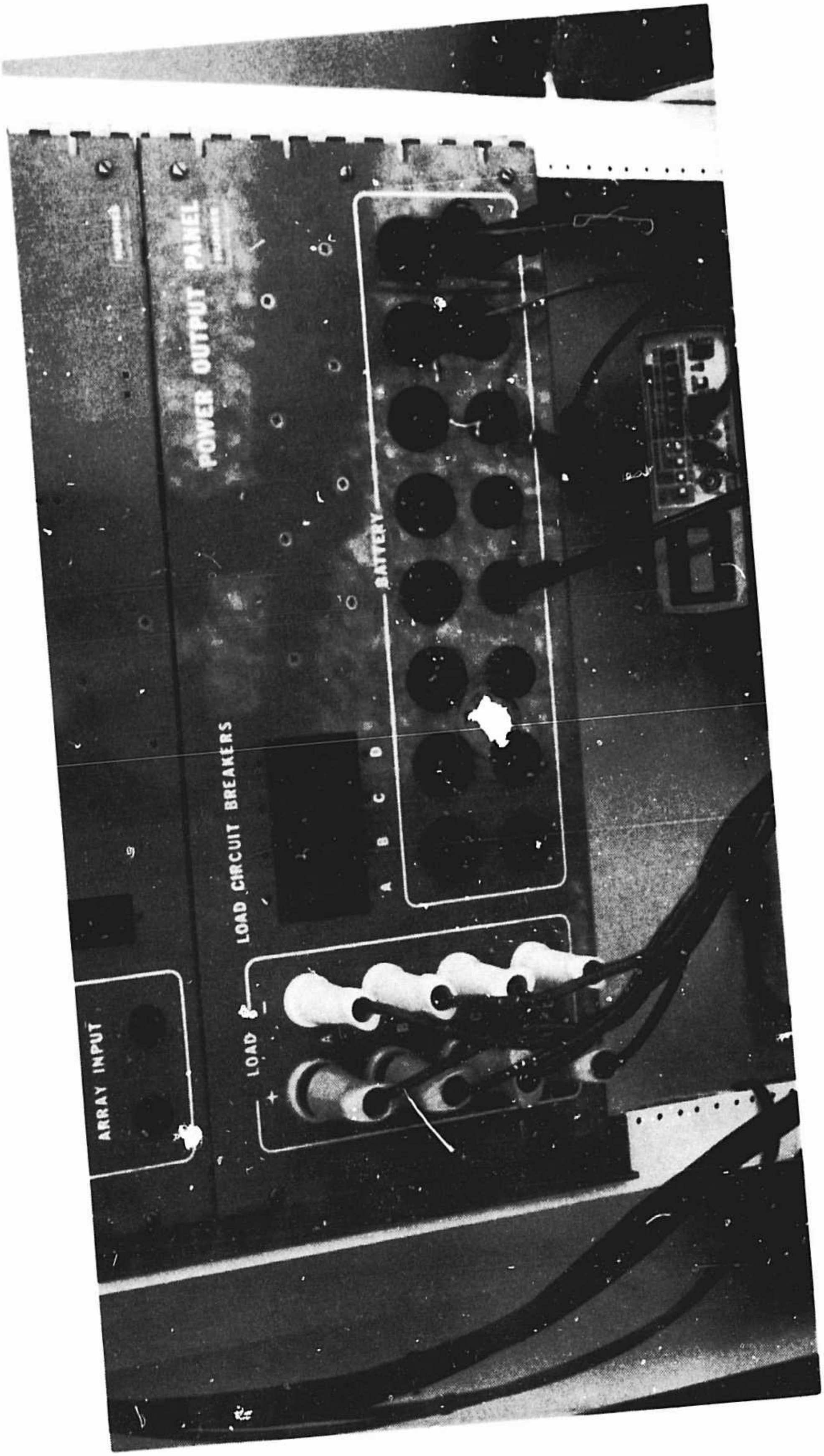
Figure 4.6.3-3

1) An input circuit breaker for manually connecting/disconnecting the particular array branch involved.
2) A crowbar contactor, part of system protection.
3) A series power relay of the hermetic mercury displacement type, protected by a snubber, performing the dual function of the power pass element in the feedback control loop and "overvoltage shutdown."

The blocking diode, CR-1, precludes back current flow from the main power bus to the array in the event of a faulted array element. The power snubber circuits used with the hermetic contactors result in virtually arcless power interruption, thus ensuring MCBF (means-cycles-before-failure) in excess of several million cycles. Metal Oxide Varistors are across the PSM input hold voltage surges to safe dielectric levels. Up to eight power switching modules may be installed in the power controller cabinet, thus accomodating ratings up to 8 PU, 10.24 kWp. The main bus circuits are rated at 135% continuous overload; the layout of the main lugs and interconnective control and power harnesses are depicted in the photograph. By using 2 each 8 PU controllers in tandem, a 16 PU rating is achieved.

4.6.4 Power Output Panel

The Power Output Panel (POP) is depicted in two figures, the front panel photograph and layout, Figure 4.6.4-1, and the interior photograph and wiring interconnection drawings, Figure 4.6.4-2. the POP incorporates the output contactors that control the power flow to the four prioritized load outputs. It also includes the four back-up low voltage circuit breakers that provide manual load break and automatic fault trip. Each output panel will handle up to four circuit breakers and contactors with an aggregate 105 Amps continuous rating at 50 Vdc.



Power Output Panel
Figure 4.6.4-1

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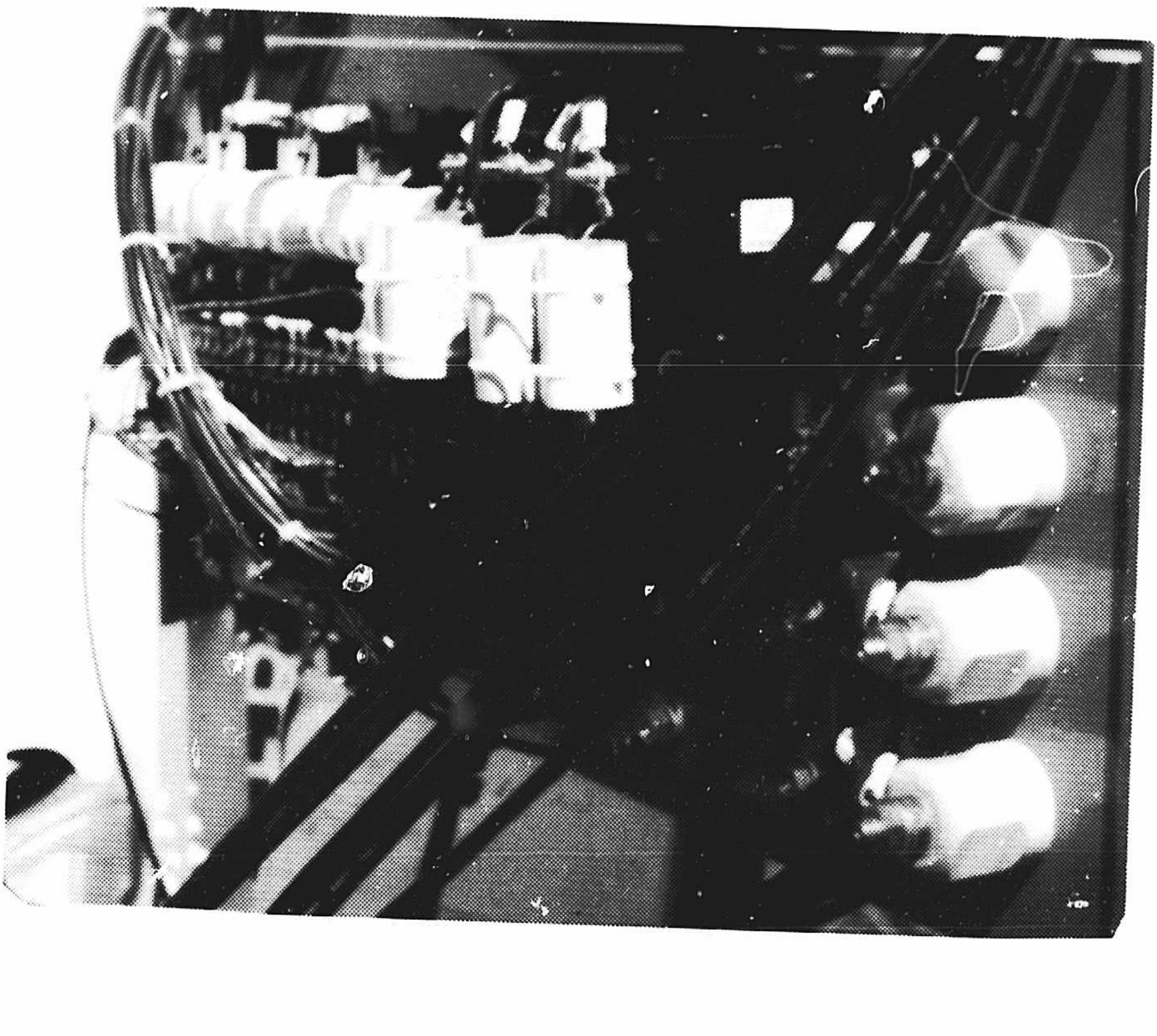

Power Output Panel Layout and Wiring
Figure 4.6.4-2

The POP circuit breakers, as well as the array series disconnects are DC breakers with auxiliary contacts. Their continuous carry and fault trip ratings are coordinated with battery fusing and vary with system rating. For the baseline 1 PU, the circuit breakers have been selected for 15 amperes continuous carry and an NEMA inverse time trip characteristic 01 (1 sec/700 percent continuous). The four hermetic mercury displacement contactors, each in series with a circuit breaker, are dedicated to that particular prioritized distribution feeder. The panel also includes the master control relay that interdicts the holding current on each of the four prioritized bus contactor coils in the event of sensing a catastrophic battery undervoltage, nominally less than 1.80 VPC at 25°C. The panel also includes the main lugs for the load output and battery input. The load buses and the battery interfaces use Supercon connectors, however they are not interchangeable.

4.7 THE LEAD CALCIUM BATTERY

The Lead-Calcium Battery, the C&D 3KCPSA-5, selected for this application represents the best, off-the-shelf product, consistent with reliability performance, life cycle cost, and field handling requirements. Figure 4.7-1 the Specification Control Drawing, fully characterizes this battery. Figure 4.7-2 summarizes pertinent installation and maintenance data. The baseline 1 PU battery consists of twenty of these 3 cell batteries in series, giving a nominal 120 Vdc bus voltage. A photograph of the two identical 60 cell battery strings for the engineering model is shown in Figure 4.7-3

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NORMAL AND COLD CLIMATE APPLICATION DATA

For Average Annual Temperatures less than 90°F (32°C)

Type	AH Capacity					Dimensions						Weight		Max. AH
	8 Hr.	100 Hr.	500 Hr.			Length		Width		Height				
	77°F (25°C)	77°F (25°C)	77°F (25°C)	32°F (0°C)	0°F (-18°C)	in.	mm	in.	mm	in.	mm	lbs.	kg.	to 0°F FP*
PSA-3	31	42	50	45	36	3.58	91	7.38	187	10.31	262	18.4	8.3	50
3 DCPSA-3	31	42	50	45	36	5.28	134	7.38	187	10.31	262	27.7	12.6	50
2 DCPSA-5	62	73	75	68	65	3.58	91	7.38	187	10.31	262	22.6	10.3	67
3 DCPSA-5	62	73	75	68	65	5.28	134	7.38	187	10.31	262	33.6	15.2	67
2 DCPSA-7	94	128	150	134	109	6.38	162	7.38	187	10.31	262	36.9	16.7	139
3 DCPSA-7	94	128	150	134	109	9.47	241	7.38	187	10.31	262	54.3	24.6	139
2 DCPSA-9	125	140	145	129	105	6.38	162	7.38	187	10.31	262	40.8	18.5	128
3 DCPSA-9	125	140	145	129	105	9.47	241	7.38	187	10.31	262	61.2	27.8	128
DCPSA-11	156	212	250	224	182	6.38	162	7.38	187	10.75	273	37	16.8	250
DCPSA-13	188	255	300	268	218	6.38	162	7.38	187	10.75	273	39	17.7	286
DCPSA-15	219	300	310	276	225	6.38	162	7.38	187	10.75	273	41	18.6	274
DCPSA-17	250	286	295	264	216	6.38	162	7.38	187	10.75	273	42	19.1	261
2 KCPSA-5	225	289	340	306	249	5.59	142	10.44	265	18.25	464	88	39.9	304
3 KCPSA-5	225	289	340	306	249	8.53	217	10.44	265	18.25	464	131	59.4	304
KCPSA-7	337	358	400	336	293	3.62	92	10.44	265	18.25	464	58	26.3	357
KCPSA-9	450	509	525	471	384	4.62	117	10.44	265	18.25	464	79	35.8	467
KCPSA-11	562	625	645	579	471	5.59	142	10.44	265	18.25	464	96	43.5	574
KCPSA-13	675	747	770	690	561	6.59	167	10.44	265	18.25	464	113	51.3	684
KCPSA-15	787	1023	1055	851	774	8.53	217	10.44	265	18.25	464	139	63.0	843
KCPSA-17	900	992	1023	891	725	8.53	217	10.44	265	18.25	464	146	66.2	909
4 LCPSA-5	420	518	535	479	390	10.14	258	14.12	359	22.62	575	276	125.2	474
4 LCPSA-7	630	795	820	734	597	15.00	381	14.12	359	22.62	575	391	177.4	727
LCPSA-11	1050	1402	1650	1476	1202	7.62	194	14.12	359	22.62	575	188	85.3	1577
LCPSA-13	1260	1649	1700	1521	1238	7.62	194	14.12	359	22.62	575	205	93.0	1508
LCPSA-15	1470	1571	1620	1451	1182	7.62	194	14.12	359	22.62	575	222	100.7	1439
LCPSA-17	1680	1867	1925	1723	1403	8.62	219	14.12	359	22.62	575	254	115.2	1707
LCPSA-19	1890	2308	2380	2132	1735	10.62	270	14.12	359	22.62	575	294	133.4	2113
LCPSA-21	2100	2231	2300	2061	1678	10.62	270	14.12	359	22.62	575	310	140.6	2042
LCPSA-23	2310	2880	2970	2658	2163	13.19	335	14.12	359	22.62	575	353	160.1	2364
LCPSA-25	2520	2803	2890	2589	2107	13.19	335	14.12	359	22.62	575	370	167.8	2565

Recommended Charge Voltage — 2.45 to 2.49 volts per cell @ 77°F (25°C)
Specific Gravity at 77°F (25°C) — Full Charge — 1.300
Specific Gravity at 77°F (25°C) — 100% Discharge — 1.130 @ 500 Hour Rate
Specific Gravity at 32°F (0°C) — 100% Discharge — 1.180 @ 500 Hour Rate
*Electrolyte will not freeze if these values are not exceeded.

BATTERIES
3043 WALTON ROAD, PLYMOUTH MEETING, PA 19462
an Eltra company

BATTERIES OF CANAD
190 CONNIE CRESCENT, UNIT 15, CONCORD, ONTARIO L4K 1B6
an Eltra company

5M/580

Specification for 3 KCPSA-5 Battery

Figure 4.7-1

CONDENSED INSTRUCTIONS FOR STANDBY BATTERY SERVICE, FULL FLOAT OPERATION

CAUTION:

WET BATTERIES must be placed on charge within 3 months if lead-antimony or 6 months if lead-calcium from time of shipment from factory.

DRY-CHARGED BATTERIES must be properly activated and charged within 12 months. See RS-864 or pages 13 & 14 in Section 12-860.

WARNING:

Electrolyte is an acid and can cause severe burns. Always wear protective clothing such as a rubber apron, safety goggles and rubber gloves when working around batteries.

1. RECEIVING - If packing material shows evidence of physical damage or spillage of electrolyte make notation on bill of lading before signing. Check electrolyte level in each cell. It should be between low and high level lines. If more than ½" of plate surface has been exposed to air, the cell has suffered permanent damage and should be replaced.

2. INSTALLATION - Locate battery in a cool clean dry place so no cells are affected by radiators, heaters, or pipes. Arrange cells on rack so they can be connected positive to negative throughout. Connections between cells must be clean, dry, free of acid and coated with NO-OX-ID grease before bolting together. SEE SECTION 3.3 to 3.11 of "Installation and Operating Instructions", Section 12-800.

3. CONNECTING BATTERY TO CHARGER - Only direct current (dc) is used for charging. Connect battery positive terminal to charger positive terminal and battery negative terminal to charger negative terminal.

4. WATERING - Add approved or distilled water after charging and as required to keep electrolyte level between high and low level lines on container.

5. CLEANING - Keep outside of cells clean and dry by wiping with a water damp cloth as required and dry. Neutralize any acid on covers or connectors with a cloth moistened with a solution of baking soda and water, then wipe off all traces of soda. NEVER USE ANY SOLVENTS, CLEANING COMPOUNDS, OILS, WAXES OR POLISHES ON PLASTIC CONTAINERS OR COVERS SINCE SUCH MATERIALS MAY ATTACK THE PLASTIC AND CAUSE IT TO CRAZE OR CRACK. DO NOT USE ANTI-CORROSION AEROSOL SPRAYS ON CONNECTIONS.

PURPOSE AND METHODS OF CHARGING (REFER TO TABLES I & II)

INITIAL CHARGE -

A **Lead-Antimony Types (1.210 nominal specific gravity)** - Give initial charge not later than 3 months after battery has been shipped and at highest voltage permitted by connected load. Table I shows various suggested voltages and corresponding time.

B **Lead-Calcium Types** (Check nominal specific gravity shown on nameplate on top of cells before proceeding.) Charge at highest voltage per cell permitted by connected load (equalize value if possible) until voltage of lowest cell stops rising and then continue for an additional 24 hours. If lead-calcium cells are to be floated at the recommended voltage they will automatically receive their initial charge at this voltage, providing they have not been on open circuit for more than six months. If on open circuit longer than six months they should be given an extended equalizing charge. Contact your local C & D representative or the C & D Technical Services Department for more information.

FLOAT CHARGING - Float batteries continuously after the Initial Charge from a voltage-regulated dc supply bus at the values in Tables I and II.

(Use recommended float voltage value unless other circuit components make it necessary to use the minimum float voltage values.) Check panel voltmeter against a known standard annually and calibrate if necessary.

EQUALIZING CHARGES - Compensate for irregularities in floating. Equalize charges are also required if cells reach critical voltages listed in Table II. Raise bus voltage to values shown in Tables I & II. Continue charge at these elevated values until lowest cell reads within 0.05 volts of the average of the cells in the lead calcium battery. Lead-antimony cells are equalized regularly at intervals of one to three months and are charged at equalize potential for 8 to 24 hours.

FINISH RATES - Normal finish rates are 5A/100 AH of the 8 Hour Capacity or 6A/100 AH of the 3 Hour Capacity. Finish rate currents are utilized in constant current charging for initial charging of dry charged cells and special remedial charging techniques. Float and equalize currents are considerably lower current values.

TABLE I - LEAD-ANTIMONY CELLS

CHARGE VOLTAGE PER CELL (VPC) (1.210 SPECIFIC GRAVITY)			
INITIAL		FLOAT	EQUALIZE
VPC	HOURS	VPC	VPC
2.39	40	2.15 to 2.17	2.33 for 8 to 24 hrs.
2.36	60		
2.33	110		
2.30	160		
2.24	210		

TABLE II - LEAD-CALCIUM CELLS

CHARGE VOLTAGE PER CELL (VPC)				
SP. GR. OF CELLS	FLOAT VPC		INITIAL/EQUALIZE (VPC)	
	MIN.	NOMINAL	CRITICAL CELL VOLT.	NOM. VPC
1.210	2.17	2.20-2.26	2.13	2.33-2.38
1.225	2.19	2.22-2.27	2.16	2.36-2.40
1.250	2.20	2.25-2.30	2.18	2.38-2.43
1.275	2.23	2.29-2.34	2.20	2.40-2.46
1.300	2.27	2.33-2.38	2.23	2.45-2.50

Installation and Maintenance Data

Figure 4.7-2

BATTERY STRINGS
Figure 4.7-3

5.0 MODULAR SYSTEM ASSEMBLY, TESTING AND EVALUATION

5.1 OVERVIEW

Shortly following approval to proceed on Phase II, Hughes was required to develop and submit a fabrication work plan for approval by the NASA Project Manager. The plan included the proposed work schedule and fabrication activity sequence, as well as planned procurement, inspection and quality assurance coverage. It also included the rationale for the number of modules and configuration needed to demonstrate the adapability of the modular system to cover the range of power from 1 kWp to 16 kWp; fabrication of at 16 kWp was not required as long as assurance could be given that "scaled-down" testing would demonstrate modular expansion.

To the above end, a mutually acceptable PV array and BOS subsystem configuration was developed; the engineering model, now having completed long-term evaluation (6 months)at Hughes, Long Beach, comprises the above approved hardware complement. This configuration, described in Section 4.0 preceeding included:

- o 2-60 cell/20 module, 3KCPSA-5 Battery Strings
- o 5 each 640 watt, 150 Vdc PV module strings, each consisting of 10 series, 2 ft x 4 ft, 15 Vdc modules (2-1/2 PU)
- o Power Controller with 6 power switching modules

Hughes was additionally required to submit a detailed test plan for approval by the NASA Project Manager. The test plan cover testing subsystems, the breadboard model and the engineering model. The test plan was designed to evaluate electronic and control circuitry components and to verify the functional adequacy of the modular system over the entire power range; the plan also covered evaluation of the mechanical suitability of the system for add-on, field utilization transportation, installation by unskilled personnel, repairability and servicing. The tests were also designed to detect deficiencies in design, materials and components, and to identify the key causes of the deficiencies.

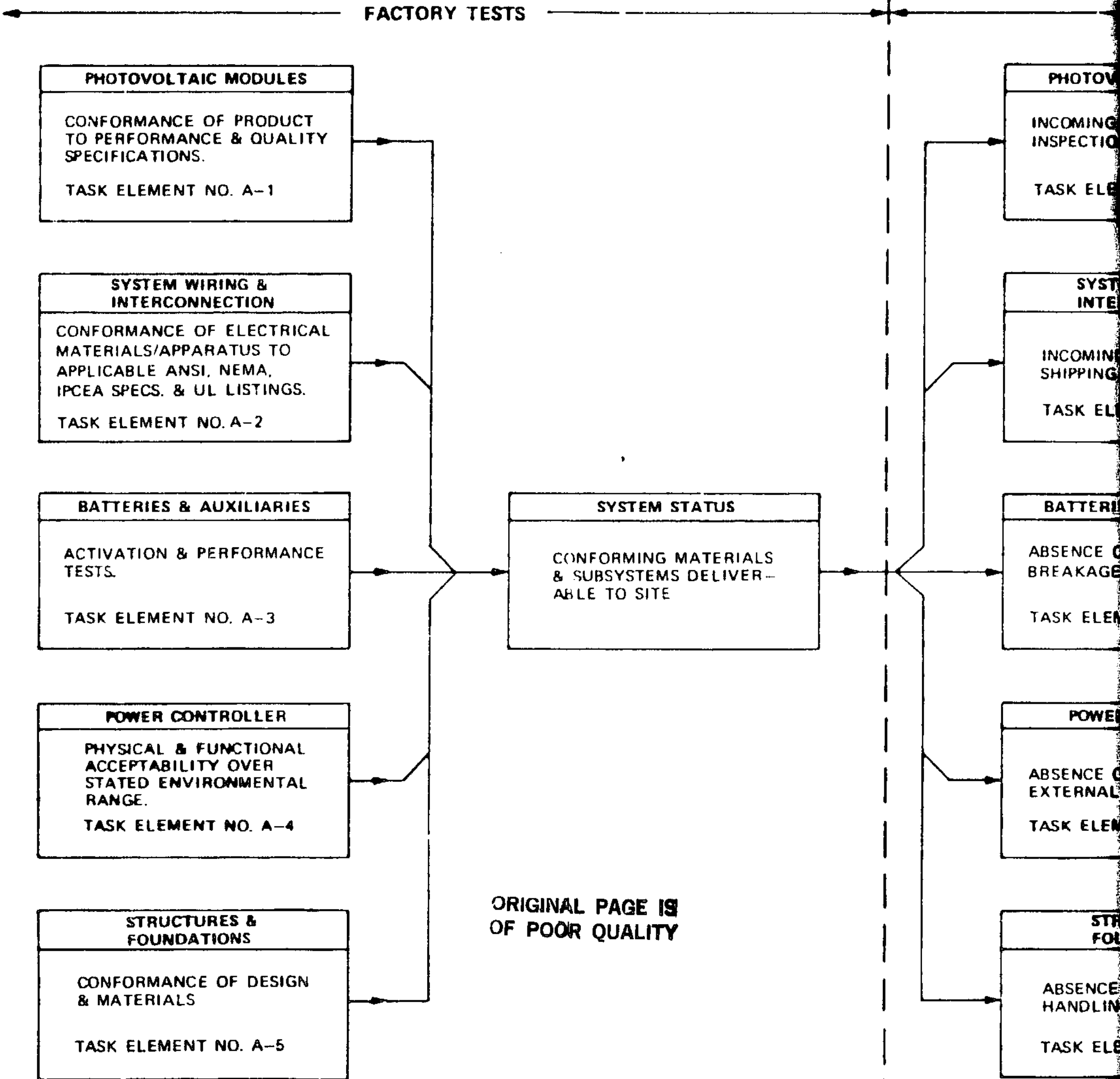
The functional performance criteria imposed during testing upon the breadboard vis-a-vis the engineering model were identical. Breadboard testing was however specifically directed and limited to control elements and circuitry particularly requiring verification through test. Further testing of all BOS elements whose performance acceptability could be anticipated with complete certainty was deferred until the conduct of the full acceptance testing on the Engineering Model.

5.2 ACCEPTANCE TEST PLAN

An Acceptance Test Plan (ATP) for the engineering model was developed and submitted to the NASA Project Manager. In consanance with the requirements of subject contract DEN3-207, the test plan addressed the following topics:

(1) Procedures for testing each component and subsystem and the basis for evaluation of results.
(2) Procedures for testing the complete system and the basis for evaluation of results.
(3) Environmental test conditions satisfying the criteria developed during Phase I.
(4) Identification of data to be recorded and the results to be derived from the data.
(5) A list of test instrumentation and their characterictics.
(6) Drawings and schematics of test fixtures and test configurations.
(7) Description of location where testing will be performed.
(8) Procedures for correction of deficiencies uncovered during testing.
(9) Test program schedule and duration of individual tests.

Figure 5.2-1 "The ATP Flow Chart for the Stand-Alone PV Power System" traces the audit of the BOS element and system performance from factory testing, through commissioning and into long term monitoring activities. The complete ATP including the actual test records, was submitted to NASA on June 17, 1983 and is not included herein as a part of this final report.



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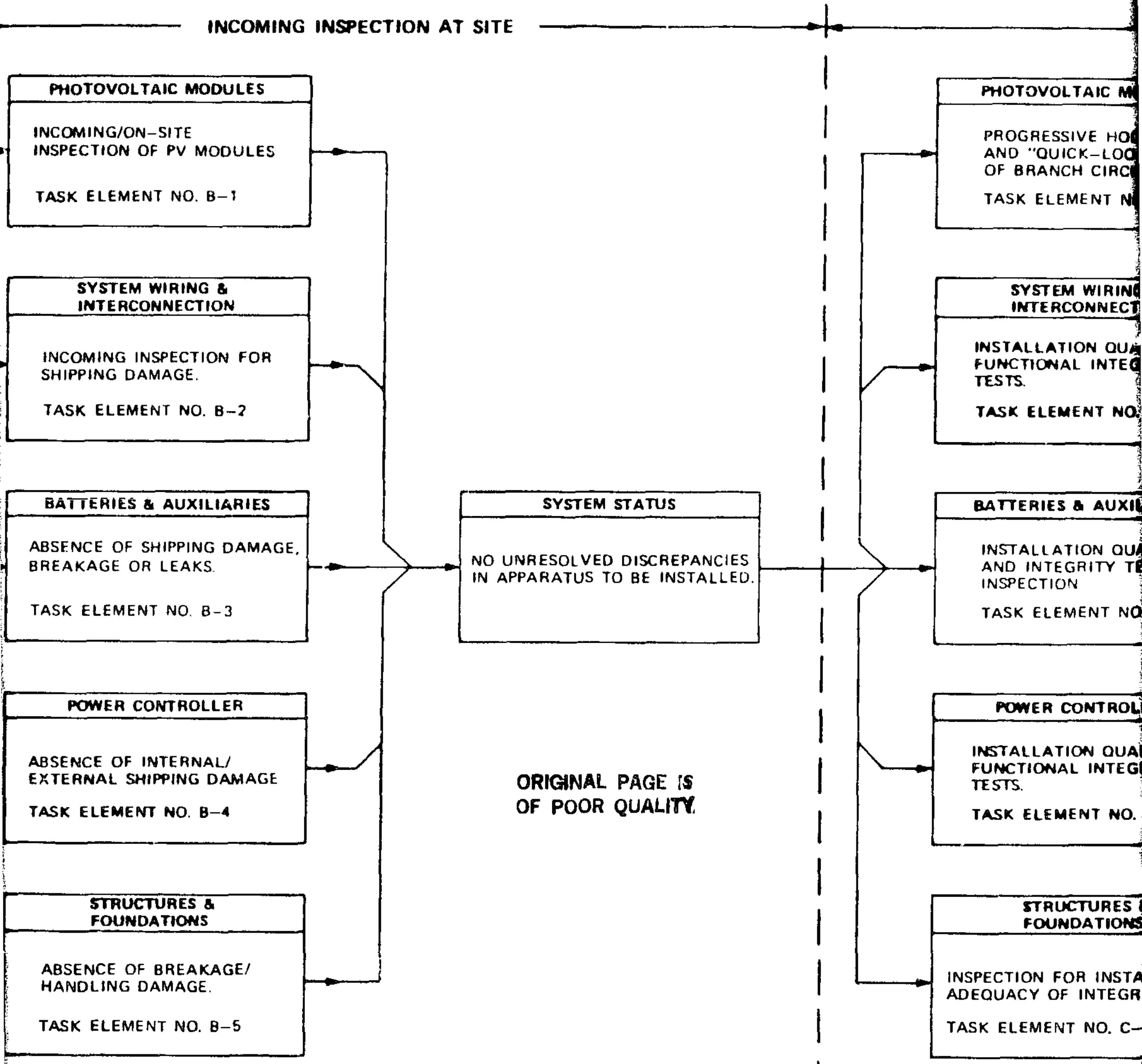
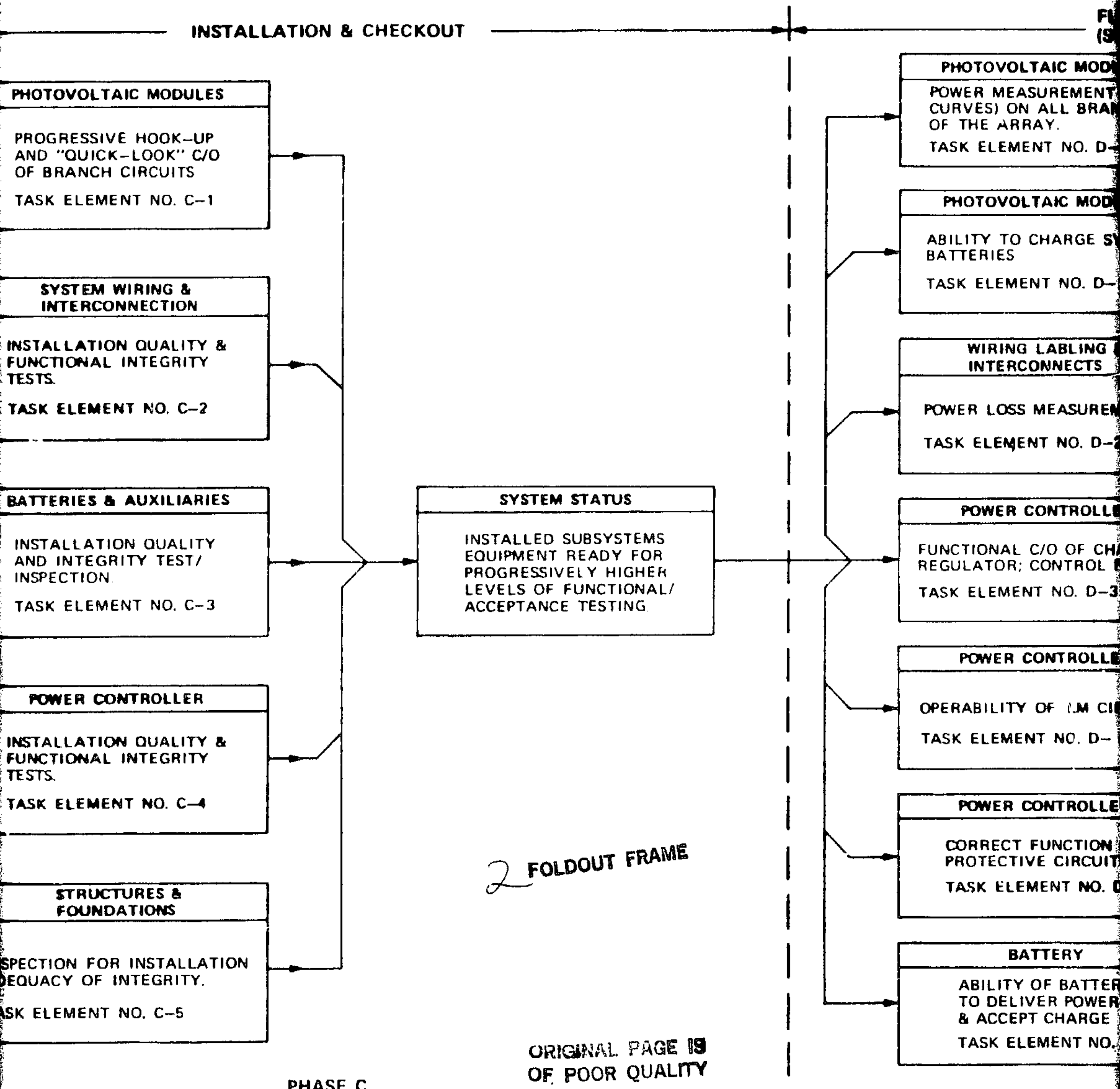
PHASE A

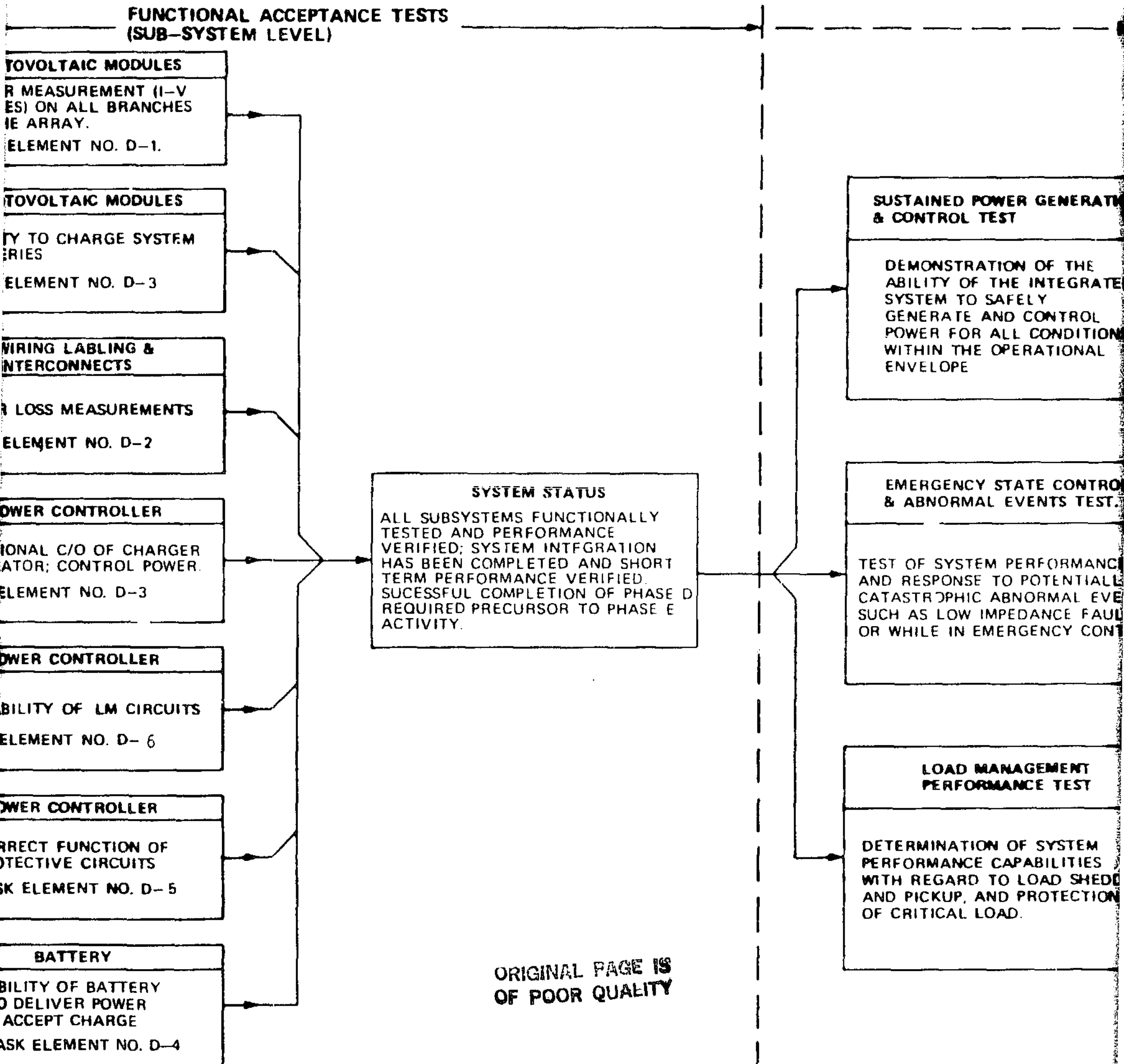
FOLDOUT FRAME



PHASE B

2 FOLDOUT FRAME


INSTALLATION & CHECKOUT
PHOTOVOLTAIC MODULES
PROGRESSIVE HOOK-UP AND "QUICK-LOOK" C/O OF BRANCH CIRCUITS
TASK ELEMENT NO. C-1
SYSTEM WIRING & INTERCONNECTION
INSTALLATION QUALITY & FUNCTIONAL INTEGRITY TESTS.
TASK ELEMENT NO. C-2
BATTERIES & AUXILIARIES
INSTALLATION QUALITY AND INTEGRITY TEST/ INSPECTION
TASK ELEMENT NO. C-3
POWER CONTROLLER
INSTALLATION QUALITY & FUNCTIONAL INTEGRITY TESTS.
TASK ELEMENT NO. C-4
STRUCTURES & FOUNDATIONS
SPECTION FOR INSTALLATION DEQUACY OF INTEGRITY.
SK ELEMENT NO. C-5
SYSTEM STATUS
INSTALLED SUBSYSTEMS EQUIPMENT READY FOR PROGRESSIVELY HIGHER LEVELS OF FUNCTIONAL/ ACCEPTANCE TESTING.
PHOTOVOLTAIC MOD
POWER MEASUREMENT CURVES) ON ALL BRA OF THE ARRAY.
TASK ELEMENT NO. D-
PHOTOVOLTAIC MOD
ABILITY TO CHARGE S BATTERIES
TASK ELEMENT NO. D-
WIRING LABLING INTERCONNECTS
POWER LOSS MEASURE
TASK ELEMENT NO. D-
POWER CONTROLL
FUNCTIONAL C/O OF CH REGULATOR; CONTROL
TASK ELEMENT NO. D-3
POWER CONTROLL
OPERABILITY OF
TASK ELEMENT NO. D-
POWER CONTROLLE
CORRECT FUNCTION PROTECTIVE CIRCUIT
TASK ELEMENT NO.
BATTERY
ABILITY OF BATTER TO DELIVER POWER & ACCEPT CHARGE
TASK ELEMENT NO.
PHASE C



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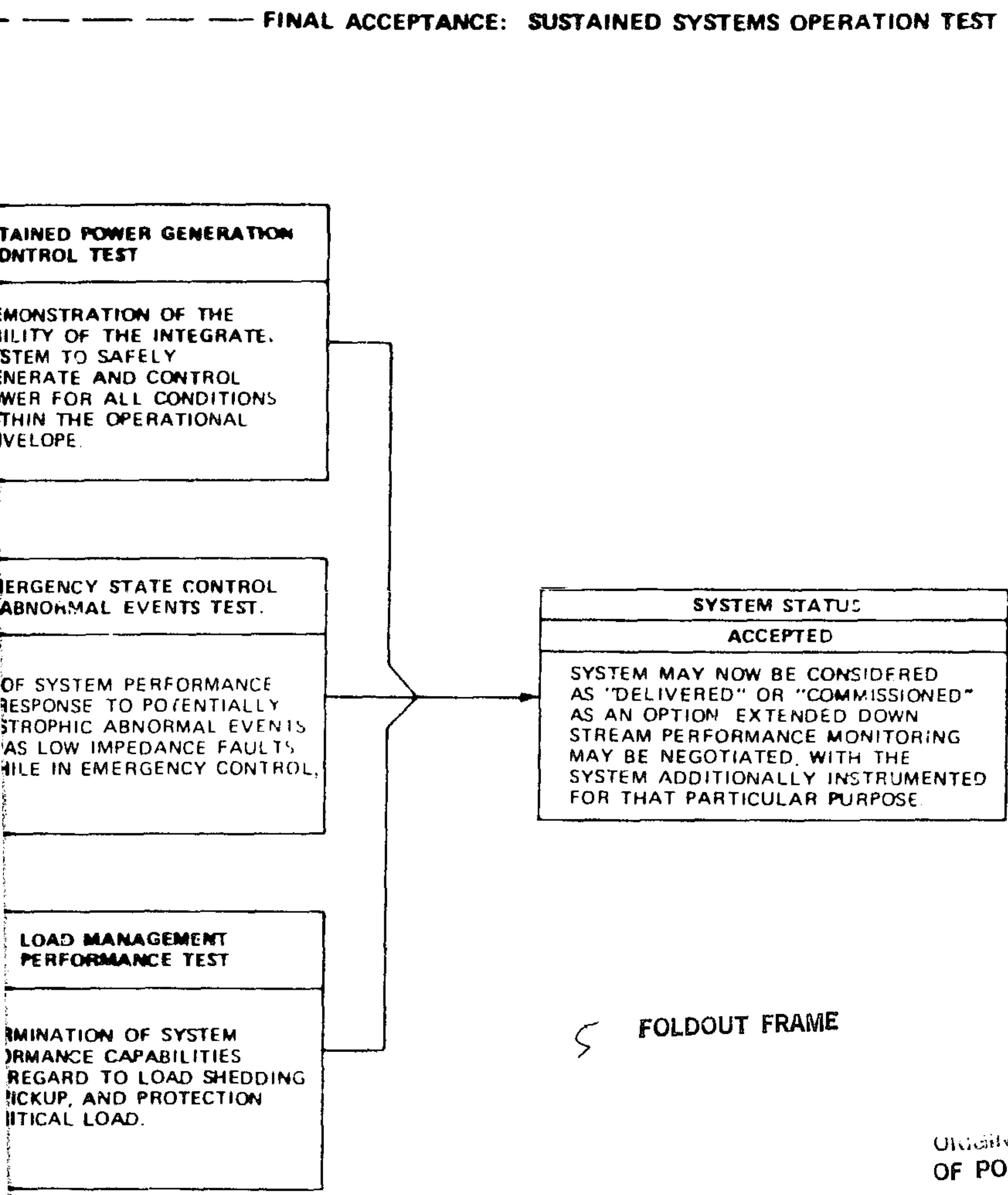

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PHASE E

Figure 5.2-1 Acceptance Test Plan (ATP) Flow Chart

5.3 SUMMARY OF TEST OPERATIONS

5.3.1 TEST HIGHLIGHTS

The final engineering model tests at Hughes, Long Beach were conducted in compliance with the approved plan under field conditions similar to a wide variety of actual field installations. The period of installation, pre-testing, formal testing and post test monitoring to date, encompassed a span from Dec. 1982 to July 1983. During that period the following environmental advertisities have been successfully survived, without untoward incident.

- .. Excessive wind driven rainfall to 2-3 inches per 24 hour period.
- .. Cyclone force winds -- to 90 mph gusts.
- .. Extended periods of high humidity, condensation during and between storms.
- .. Reasonably large diurnal temperature variations.

In addition to natural stresses the system was exercised extensively, operating under substantial continuous load as well as cyclic loads for several months.

6.0 ECONOMIC ANALYSIS

During the Phase I Design Study, economic analyses were carried out as an integral part of the Life Cost analyses. A computerized cost breakdown structure was generated to assist in the selection and optimization of the various system design options. The final design selected and developed under this Phase II effort was in part chosen on the basis of its lower overall projected twenty year Life Cycle Costs. These Life Cycle Costs were generated under the assumptions of a mature photovoltaic industry in which the systems produced were part of a dedicated factory whose annual output was in the range of one to ten megawatts.

Because the 2-1/2 PU power system fabricated under this Phase II effort was in essence a "one-of-a-kind" engineering model and included several developmental tasks, it is not practical to compare these BOS costs with the final design Life Cycle Costs generated under Phase I efforts. For example, the Life Cycle Costs of the battery subsystem require multiple battery replacements and period maintenance over the twenty year life, while to demonstrate the performance and modular capabilities of the engineering model, less than one battery string per PU is employed on a one time basis.

Detailed cost records were maintained of the material, assembly labor, and installation elements. A listing of the major material items and subcontract procurements are shown in Table 6.0-1. As the efficiencies of photovoltaic modules are continually improving and will vary among various module suppliers, these BOS elements costs are summarized in terms of dollars per square meter of photovoltaic array (PV modules). The 2-1/2 PU engineering model consists of 50 photovoltaic modules, each 2 ft x 4 ft in size; the total array field being 37.16 square meters. The table following lists the actual costs per square meter for this engineering model.

ACTUAL COSTS FOR 2-1/2 PU PV SYSTEM	$\$/M^2$
Array structures and foundations	90.90
Installation and wiring	27.29
Array and power wiring	9.26
Power controller and electrical protection and safety	448.98
Battery subsystem	285.58
Perimeter security (Hughes furnished)	Not applicable
	Total $\$862.01/M^2$

*Note: $ at price level to customer.

The costs shown above include the Hughes labor employed in the assembly, installation and field wiring of the 2-1/2 PU system. Care was taken to exclude any costs associated with the engineering breadboarding and developmental testing of the critical electronic control circuits. Even so, an examination of these costs reflect generally higher than anticipated. The primary reason stems from this engineering model is a "one-of-a-kind" program and the purchased parts and fabricated subassemblies cost substantially more than the same items had they been procurred in larger quantities; no price breaks could be obtained on small quantity purchases. Also, as this was the first manufactured article of the final design, much greater attention was paid to the BOS elements that would have occured if this were one of many factory fabricated, installed projects.

Because this was an "engineering" project rather than a "production factory" project, engineering personnel performed tasks that would normally have been delegated to lower paid, semi-skilled labor. These included such tasks as quality assurance and control, site installation supervision, vendor liaison, and electrical test and check-out.

Installation of Support Structures

The simplicity of the structures and foundations allowed for easy assembly and installation. The organized approach of laying out the ballast planters, the stanchion and planter covers and allocating appropriate hardware to each, then assembling the structures in sequence, allowed the assembly to be completed with relative ease and speed. Although, the assembly initially required two persons for the planter layout and assembly; assembly of the array stuctures required only one person. This task was completed without incident.

Installation of the Batteries

To lift the batteries with a strap and place them on the battery platform required two persons. A more than normal level of care is required because of the dangers of tipping, dropping or damaging these potentially corrosive devices.

Array and Power Wiring

The PV array wiring was completed with extreme ease and speed using the Solarlok connectors. The connectors used on the engineering model were the non-polarized type. The new polarized, Solarlok connectors will prevent polarity mismatch. The battery connections and the power wiring from the array and batteries to the Fower Controller offered no problems.

Power Controller and Electrical Protection and Safety

The NEMA 4 enslosure was fabricated by a local vendor to Hughes specifications. The enclosure was sized to handle eight PSMs. Surveillance Systems of Costa Mesa, CA built one PCP, six PCMs, and one POP panel. Surveillance Systems also fabricated the motherboard and the C/R and L/M boards, wired up the subassemblies and installed them into the enclosure. The PCP, PCMs and POP were fabricated in a model shop manner.

Perimeter Security

The engineering model was erected within a fenced off site on Hughes property and therefore perimeter security costs were avoided.

Operation and Maintenance

Because of the developmental nature of this engineering model, operation and maintenance costs were not collected.

Conclusions

The engineer model is the first article and as such incured costs that would not have been incured from a "factory" model. The experience gained from this system is primarly the efficient manner in which it can be installed. Material costs depend largely on quantity for cost breaks. The engineering model has experienced a variety of local weather conditions and has held up very well. The engineering model has met or exceed the design requirements.

Material and Subcontract Procurement

Table 6.0-1

Item Description	Vendor	Price
PV Modules	Photowatt International Tempe, AZ	$33,111
Structures & Foundations	Pico Metal Los Angeles, CA	3,378
Power Controller Enclosure	Metal Cabinets & Fixtures Anaheim, CA	1,667
Power Controller	Surveillance Systems Inc. Costa Mesa, CA	7,904
Array Wiring & Connectors	Amp Inc. Lango, FL	334
Batteries (C&D)	Manmac Santa Ana, CA	10,612
Misc. Materials	Various	7,113
	TOTAL	$64,129

APPENDIX A

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Multilevel Series Control (OFF-ON) Description

This control scheme, a variation of the series OFF/ON regulator, and the Tri-State control are is depicted in Figure 3.5-8. Tri-state control features leading to improved battery life are retained without the attendant complexity of two different control modes.

The performance of each channel is identical to that of the single channel series contactor system except that the trip float voltage limits are set at slightly different values for each of the two channels.

The 2.45 VPC maximum (volts per cell) at 25°C is typically recommended by the manufacturer as a float voltage for the 1300 specific gravity lead calcium cells. Channel (1) typically controlling 50 percent of the array power is set to trip at, 2.5 VPC. Channel (2) is set to trip at a slightly lower value, about 2.45 VPC. At some point in the recharge cycle, the 2.45 VPC Channel 2 limit would be reached. For a 150 volts, 1 power unit system nominal charging current would be about nine amperes. An OFF-TRIP of Channel 2 would therefore result in a 50 percent charge current reduction. The final charge regime on the battery has now been tapered to about 4.5 amperes. When the cell potential reaches 2.50 VPC @ 25 C, the Channel 1 regulator OFF-TRIPS, terminating charging current completely.

As the battery discharges, the first trip point reached would be 2.45 VPC. Charging resumes; the battery potential would continue to decline if a net negative energy balance (Power out > Power in) existed. When the 2.35 VPC level is reached, the other contributing subarray would be connected. Thereinafter, the cycle is repeated.

The advantages of multilevel OFF-ON series control are:

(a) As in the case of the Hughes tri-state design, the charging current is reduced to a minimum rate consistent with load and PV power input. Battery heating is reduced, and battery life should be extended from both cyclic and thermal considerations.

(b) Only a small heat sink is required for the string blocking diodes (800mW/amp); no cabinet ventilation is required.

(c) Multilevel regulation requires only replication of the standard EM (electromechanical) OFF-ON control and partitioning of parallel array elements.

(d) Quasi-proportional control is approached if the number of array power increments and steps are increased, and additional control channels are employed.

(e) This method is also compatible with summing and regulating the outputs of hybrid Renewable Energy System sources on a battery bus. This cannot be done with shunt regulation.

(f) Overvoltage protection, manual override and shutdown can be done with the same multilevel control contactors.

APPENDIX B

HUGHES HUGHES AIRCRAFT COMPANY	TITLE PRODUCT SPECIFICATION SOLAR CELL MODULE MODULAR STAND-ALONE SYSTEM	NUMBER SEP 11396 CODE IDENT NO 82577	REV C TOTAL PAGES 12

REVISIONS

EFF	AUTHORITY	LTR	DESCRIPTION	DATE	APPROVED
		A	Fig 1.0, is: 51 ± 13 (2.0 ± 0.5) was: 51^{+00}_{-13} $(2.0^{+0.0}_{-0.5})$	5/26/82	
	DCN #419754	B	Revised per DCN #419754	6-17-82	
	DCN #390198	C	Revised per DCN #390198	6-22-82	

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APPROVALS

	DATE		DATE
	1/14/82		
John Castle	5/21/82		
	5/14/82		

PRODUCT SPECIFICATION

SOLAR CELL MODULE

MODULAR STAND-ALONE SYSTEM

1.0 Scope

This specification defines the requirements for the design and construction of photovoltaic solar cell modules (herein referred to as the module) to be used for terrestrial applications.

1.1 Design Requirements

The module shall be designed to meet all requirements specified herein. Designated tests shall be successfully completed demonstrating the ability of the module to meet all performance requirements of this specification.

1.2 Deviations and Changes

Deviations from or changes to this specification shall not be allowed without written authorization from Hughes.

2.0 Applicable Documents

2.1 Government Documents

The following documents, of the exact issue shown or of the current issue when no date is shown, form a part of this specification to the extent specified herein. In the event of conflict between the documents referenced herein and the contents of this specification, the detail contents of this specification shall be considered as binding.

JPL 5101-83, Block IV Solar Cell Module Design and Test Specificiation for Residential Applications (November 1, 1978).

JPL #5101-138, 1982 Technical Readiness Module, Design and Test Specification - Intermediate Load Applications - (January 15, 1980).

3.0 Requirements

3.1 Functional Description

The module specified herein shall be used to convert solar energy to electrical energy in terrestrial applications.

3.2 Performance

The photovoltaic module shall provide the required power output when subjected to the specified test conditions.

3.2.1 Power Output

Configuration	Power Output	
	Minimum Lot Average	Module Minimum
-1	33 Watts (2.04 amps)	31.5 Watts (1.94 amps)
-2	66 Watts (4.07 amps)	63 Watts (3.89 amps)

3.2.2 Test Conditions

Solar intensity	-	1000 W/m^2, AM 1.5
Cell temperature	-	28° C minimum
Test voltage	-	16.2 volts minimum

3.3 Design

3.3.1 Electrical Design

All module circuitry, including output terminations shall be insulated from the electrically conductive external surfaces. Leakage current shall not exceed 50 microamps when a potential of 3000 VDC is applied between the external conductive surface and the output terminals.

3.3.1.2 Electrical Interface

Each terminal on the module shall be equipped with an AMP SOLARLOK connector bus bar housing No. 121044-1. The polarity of each socket shall be clearly marked in a permanent and legible manner. Positive and negative terminals shall be located at opposite ends of the module.

3.3.1.3 Bypass Diode

Each module shall have at least 3 encapsulated bypass diodes. Each diode shall be connected in parallel across no more than 12 series connected solar cells. The forward direct current capacity of the diodes shall be greater than 1.1 times the module short circuit current and derated for a temperature of 75° C. The peak inverse voltage rating of the diode shall be not less than 1000 volts. The diode shall be designed and mounted so that heat generated from diode forward current operation shall not damage the module.

3.3.1.4 Reliability and Redundancy

The module shall meet or exceed the reliability and redundancy requirements of Section II, Part B, Paragraph 4 of the referenced JPL Specification 5101-83.

3.3.2 Mechanical Design

3.3.2.1 Geometry

Overall dimensions and hole locations shall conform to Figure 1.

3.3.2.2 Optical Surface

The illuminated optical surface of the module shall be tempered low iron glass and shall conform to the requirements of Section II, Part C, paragraph 3 of the referenced JPL Specification 5101-83.

3.3.2.3 Interchangeability

All modules shall be physically interchangeable.

3.3.2.4 Defects

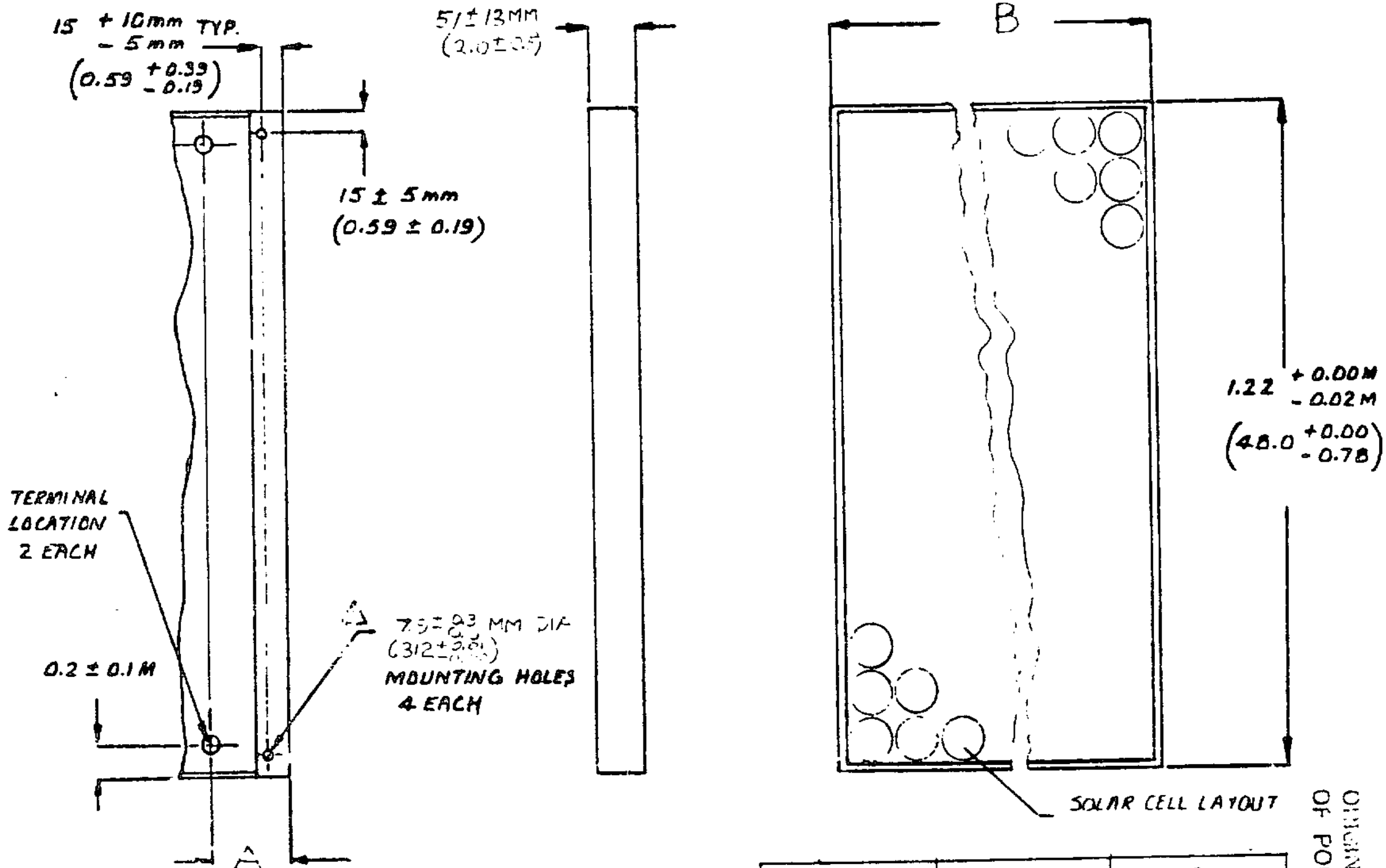
3.3.2.4.1 Rejections

Modules with the following defects shall not be accepted:

a) Cracked or broken front surface
b) Cracked or broken frame
c) Cracked or broken solar cells
d) Cracked or broken interconnects
e) Cells with unsoldered solder joints
f) Laminate voids greater than 1/4 inch diameter and 1 square inch total area per module
g) Loose or broken terminals
h) Broken diodes or diode connections

3.3.2.4.2 Allowable Cosmetic Defects

At the discretion of Hughes, selected cosmetic defects which do not affect form, fit, function or reliability may be permitted.



NOTES:

1. MOUNTING HOLES MUST BE LOCATED IN MODULE SIDE FRAME MEMBERS ONLY.
2. DIMENSIONS IN PARENTHESES IN INCHES.

DIMENSION	-1	-2
A	0.15 ± 0.07M (6 ± 3)	0.3 ± 0.2M (12 ± 8)
B	$0.30^{+0.00M}_{-0.02M}$ ($12.0^{+0.00}_{-0.75}$)	$0.61^{+0.00M}_{-0.04M}$ ($24^{+0.00}_{-1.50}$)

FIGURE 1.0 MODULE STANDARD DIMENSIONS

3.4 Operational Life

The module shall be designed for an operational life of at least 20 years.

3.5 Environment

As a minimum the module design shall be capable of withstanding exposure to the environmental tests defined in Section V of reference JPL Specification 5101-83. The module shall also be capable of meeting the requirements of the Hot Spot Endurance Test of Section II, Part B, paragraph 5 of the JPL Specification 5101-138.

3.6 Identification

Each module shall be legibly identified with the following:

a) Seller part number
b) Serial number
c) Current at test voltage
d) Month and year of manufacture

4.0 Quality Assurance Provisions

4.1 General

The product covered by this specification shall be subject to inspection and testing by both the seller and Hughes in accordance with the quality assurance provisions of this section.

4.1.1 Interface Control Drawing (ICD)

Prior to the manufacturing of modules for this Hughes program, the vendor shall generate an "Interface Control Drawing" (ICD). This drawing shall identify the configuration, dimensions, parts and materials used in module fabrication. This ICD shall be submitted to Hughes for approval prior to module fabrication. Any changes thereafter to the ICD shall be submitted for approval to Hughes prior to intended implementation of such changes.

4.2 Requirement Verification

4.2.1 Test and/or Inspection

Requirements specified in Section 3 of this specification and listed in 4.2.3 (Requirements/Specification Matrix) shall be verified by the applicable paragraphs of Section 4.

4.2.2 Certification

Requirements specified in Section 3 of this specification not verified by inspection or test shall be satisfied by a submittal to Hughes of documentation showing evidence of conformance in the form of data and/or test reports.

4.2.3 Requirements/Verficiation Matrix

Requirements	Title	Verification Method Paragraph No.
3.2	Performance	4.4.2
3.3.1.1	Electrical Voltage Insulation	4.4.3
3.3.1.2	Electrical Interface	4.4.1
3.3.1.3	Bypass Diodes	4.2.2
3.3.1.4	Reliability and Redundancy	4.2.2
3.3.2.1	Moisture Protection	4.2.2
3.3.2.2	Geometry	4.4.1
3.3.2.3	Optical Surface	4.4.2
3.3.2.4	Interchangability	4.2.2
3.3.2.5.1 (a-g)	Rejections	4.4.1
3.3.2.5.1 (h)	Broken Diodes or Diode Connections	4.4.1/4.4.4
3.4	Operational Life	4.2.2
3.5	Environment	4.2.2
3.6	Identification	4.4.1

4.3 Inspection and Test Methods

4.3.1 Hughes Source Inspection

The Hughes Aircraft Company, may, at its option, provide inspection to monitor the seller's quality control procedures. The completed hardware may be source inspected by Hughes to assure that the product conforms to all the requirements specified on the applicable drawings and specifications.

4.3.2 Test Location

Unless otherwise specified in the contract, acceptance tests shall be performed by the seller at the seller's plant. If the use of outside test facilities is required, such use shall be subject to prior approval by Hughes. Hughes shall have the right to witness, inspect and review all acceptance tests.

4.3.3 Test Conditions

Unless otherwise specified herein, all tests shall be performed at the following nominal ambient conditions:

a)	Temperature	+25 degrees ± 5 degrees C
b)	Relative humidity	No greater than 50%

4.3.4 Test Equipment

4.3.4.1 Test Equipment Accuracy

All meters, scales, thermometers and similar measuring equipment used in conducting tests specified herein shall be accurate within one percent of full-scale value except temperature which shall be accurate within ± 1°C. Full-scale deflection of meters shall not be more than twice the maximum value of the item being measured.

4.3.4.2 Test Equipment Calibration

All test apparatus shall be calibrated at proper intervals and records of such calibration shall be available for Hughes inspection. Hughes may examine the seller's test equipment and determine that they are of the proper type and range to make measurements of the required accuracy and are in calibration.

4.3.4.3 Solar Simulator

The solar simulator shall be capable of simulating air mass 1.5 spectral conditions and a solar radiation intensity of 1000 W/m^2. The solar simulator intensity shall be calibrated and verified using a Hughes approved standard solar cell which is traceable to a JPL calibrated standard. The simulator may be either a constant xenon light source or pulsed xenon type.

4.4 Acceptance Tests

4.4.1 Examination

Each module shall be visually inspected for compliance to the following paragraphs: 3.3.1.2, 3.3.2.2, 3.3.2.5, 3.6, and the ICD (4.1.1).

4.4.2 Electrical Performance

The seller shall test each module under the test conditions specified in paragraph 3.2.2 to verify the output requirement of paragraph 3.2.1 The solar simulator used for this test must comply with paragraph 4.3.4.3.

A full current-voltage (I-V) characteristic curve is required for each module. If a pulsed xenon type simulator is utilized, a minimum of 5 data points along the I-V curve is required including short circuit current, current at rated voltage and open circuit voltage.

4.4.3 Electrical Voltage Insulation Test

Each module shall be subjected to a "Hi-Pot" test conducted with the output terminations shortcircuited. The leads from a suitable dc voltage power supply shall be connected with the positive lead on the terminals and the negative lead on the module frame. Voltage shall be applied at a rate not to exceed 500 V/sec up to the test voltage of 3000 Vdc, and then held at this test voltage for at least 1 minute. The module shall be observed during the test and there shall be no signs of arcing or flashover. Leakage current shall be monitored during the test and shall not exceed 50 microamps.

4.4.4 Diode Verification Test

A diode verification test shall be performed on each module to insure that none of the bypass diodes or their associated connections have open or short circuits. The procedure for this shall be submitted to Hughes by the Seller for approval prior to performance of this test.

4.4.5 Hughes Electrical Performance Tests

Upon preparation for shipment of each lot of modules Hughes will randomly select one module for each 25 modules in the lot. These selected modules will be retested by Hughes in accordance with paragraph 4.4.2. If the Hughes average values of power at the test voltage for the sampled modules vary from the vendors values by more than 2%, acceptance of the shipping lot shall be withheld pending further testing and investigation.

4.5 Rejection and Retest - Production Modules

4.5.1 Rejected Modules

Rejected modules shall not be resubmitted for acceptance without furnishing full details concerning the rejection, the measures taken to overcome the defects, and the prevention of their future occurence. Each rejected module shall be identified by a serialized rejection tag. This rejection tag shall not be removed until rework requirements have been complied with.

4.5.2 Defective Modules

Notwithstanding the warranty of individual modules, if, after receipt by Hughes, a significant number of modules prove defective, such as to indicate a vendor manufacturing problem, the entire lot may be rejected.

4.5.3 Retest

Any unilateral changes from Paragraph 4.1.1 by the supplier in manufacturing techniques, processes, materials, quality control levels, or type of manufacturing equipment shall be cause for rejection of subsequent modules.

4.6 Test Records

Records shall be kept of all tests and of all applicable manufacturing data, and these records shall be made available to Hughes. All physical markings, defects and other visual characteristics shall be noted and recorded as a portion of the test record. The I-V curve for each module shall be delivered to Hughes.

5.0 Preparation for Delivery

5.1 Packaging

5.1.1 The Seller shall package the modules into shipping containers which adequately protect the modules from shipping damage.

5.1.2 Module containers shall be assembled onto and tied down to a pallet for shipping and storage.

5.2 Marking

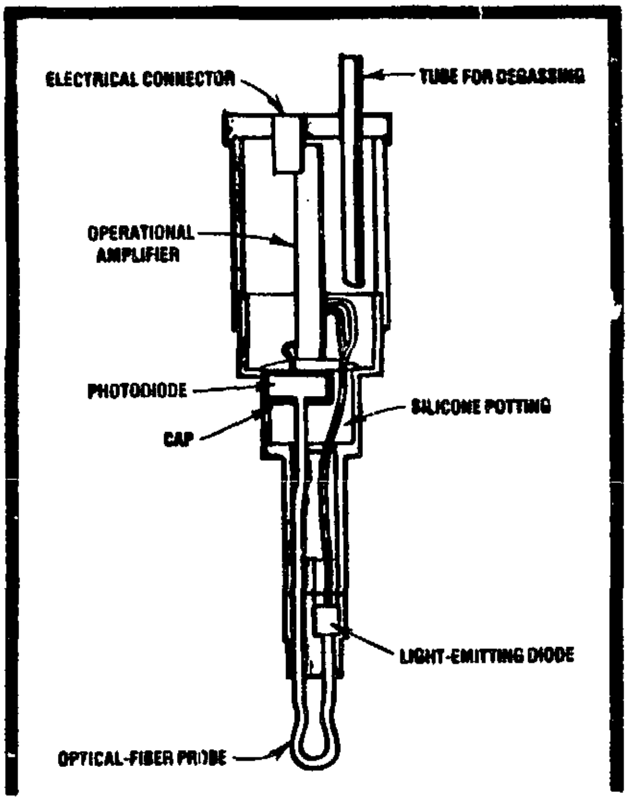
Each module shipping container shall be legibly identified with the following:

a) Hughes part number (specification number).
b) Seller's part number, serial number(s) and quantity of modules.
c) Lot number if applicable.
d) Month and year of manufacture.

6.0 Warranty

The contractor shall warrant that the solar cell modules offered will be free from defects in material, workmanship, and performance for a period of not less than two years after acceptance by Hughes Aircraft Company. During the warranty period all modules found to have defects not caused by misuse or accident through fault or negligence by Hughes or end user must be replaced at Seller's expense.

APPENDIX C



Bent optical fibers sense battery charge

■ The level of charge in a lead-acid battery is monitored with a fiber-optic probe that serves as a refractometer. Mounted in the cap of an automotive battery, the probe tip consists of a polystyrene fiber connected between a light-emitting diode and a photodiode. A refractive capability is provided by several alternating bends in the fiber, which enable light propagated in the coating around the fiber core to leak into the surrounding fluid. Changes in the density of sulphuric acid correspond to variations in the refractive index of the battery fluid, thereby modulating the amplitude of light reaching the photodiode. A small operational amplifier incorporated in the device amplifies the signal that subsequently is relayed to a display. A similar version of the probe can be used to sense the concentration of antifreeze in water, reports Battelle Memorial Institute, Geneva, Switzerland.

MACHINE DESIGN

APPENDIX D

PHOTOWATT
INTERNATIONAL, INC.

ELECTRICITY FROM THE SUN

SYSTEMS GROUP

2414 WEST 14th STREET, TEMPE, ARIZONA 85281
(602) 894-9564/TWX 910-950-0142

RECEIVED
APR 05 1983
SSD SUBCONTRACTING

28 March 1983

Mike Keeling
Chief Engineer
Photowatt International, Inc.
2414 West 14th Street
Tempe, AZ 85281

Helen Lopez
Subcontract Administrator
Hughes Aircraft Company
Support Systems
P.O. Box 9399
Long Beach, CA 90810

Dear Helen:

In response to Section 4.2.2 of the Hughes Product Specification No. SEP 11396 Rev. C, the following letter is submitted adressing each requirement in sequential order. All responses are referenced in respect to photovoltaic modules shipped to Hughes' purchase order No. 05-234838-DT5.

3.1 Functional Description

Photovoltaic modules are designed and manufactured by Photowatt for the expressed purpose of converting solar irradiance to electrical energy.

3.2 - 3.2.2 Performance, Power Output, Test Conditions

All Photowatt solar modules have undergone 100% testing and comply with the power output requirements of Section 3.2.1. at the test conditions of Section 3.2.2; excepting the AM 1.5 filtering stipulation. This filtering requirement was determined unnecessary through the use of a JPL standard reference cell constructed of Photowatt cell material having the same spectral response as those assembled in production modules. Since the reference cell has been calibrated at one sun, AM 1.5 by the JPL, the spectral distribution of the test light source has no effect upon the module output referenced to the calibrated cell.

Records of individual module output power compliance have been submitted to Hughes.

3.3.1 Electrical Design

All modules underwent 100% capacitive leakage testing at an

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applied voltage of 3000V without failure (i.e., without leakage current exceeding 50 microamps).

3.3.1.2 Electrical Interface

Each module was constructed with 2 Amp-Solarlok bus bar housings No. 121044-1, with legible, permanently attached polarity markers. Positive and negative terminals were located at opposite ends of the module.

3.3.1.3 Bypass Diodes

Each module shipped to this order was manufactured with 3 encapsulated diodes connected across 12 series cells. These diodes are rated at 1000V reverse breakdown as shown in the attached Varo Semiconductor specification sheet. Photowatt conducted tests upon diodes in sample EVA laminates exposed to a 75.8 C ambient with an applied forward current of 4.88 A (1.1 times module short-circuit current). The maximum junction temperature recorded was 105.4 C, well below the minimum temperature of 200 C at which EVA degradation begins to occur; as defined in the DuPont Co. Technical Guide for Elvax 150 resin. This junction temperature is also below the maximum diode operating temperature of 150 C specified by Varo. No damaged was observed in the laminate pottant.

3.3.1.4 Reliability and Redundancy

As required in the JPL specification 5101-83, Section 2, Part B, Paragraph 4, all modules utilized redundant triple cell interconnection ribbons to insure reliability. A 2 series by 36 parallel cell interconnection configuration was used to provide the specified output power characteristics. Integral bypass diodes were utilized to provide protection against module damage and power loss resulting from "hot-spot" heating of a shaded or damaged cell.

Tests conducted by Photowatt, as outlined in the latter half of paragraph 4 mentioned above, for single cell open-circuit conditions, reveal that cell heating is eliminated through the use of internal bypass diodes. In the event a single cell is damaged or shaded, (simulated by open-circuiting a cell), the remaining cells of the affected parallel string begin operating in the reverse bias mode; thus forward biasing the protective diode.

The reverse current which would normally cause heating in the damaged cell is carried by the diode at its forward voltage drop of .8 volts. Because of this voltage drop, the remaining affected parallel strings are forced to operate virtually at

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ELECTRICITY FROM THE SUN

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short-circuit condition and power dissipation in these cells is held at a safe minimum. Power dissipation in the diode will not exceed 3.5 watts at module short-circuit current. Diode temperatures associated with this power dissipation are below the safe maximum pottant thermal operation limit as discussed previously.

3.3.2.1 & .3 Geometry & Interchangeability

All module dimensions and hole locations comply with the specifications illustrated in Fig. 1.0 of SEP 11396 Rev. C. Because of this compliance, all modules are physically interchangeable.

3.3.2.2 Optical Surface

The illuminated optical surface of each module is constructed of tempered, low iron glass. Photowatt takes exception to the requirement that the exposed surface be smooth. Photowatt has produced modules to this order with a stippled glass surface exposed. This configuration provides significantly improved module power output due to a zero-depth concentration effect.

3.3.2.4.1 Rejections

All Photowatt modules supplied under this order comply with the rejection criteria of this specification excepting No. 3.2.4.1 (c). Some configurations of broken or cracked solar cells are acceptable in accordance with the JPL Block 5 inspection criteria upon which the Photowatt Inspection System Plan is based. A copy of this document has been enclosed with this letter.

3.3.2.4.2 Allowable Cosmetic Defects

The acceptance of modules having cosmetic defects not affecting form, fit, function or reliability has been left to the discretion of Hughes Corp.

3.4 Operational Life

In accordance with JPL Block 5 module design and test specifications, 5101-161, all Photowatt modules have been designed for a minimum operational life of 20 years.

3.5 Environment

While the MU6010 has not been subjected to the environmental exposure testing of section V of 5101-83, a similar Photowatt

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module, the ML1961, has successfully completed all the JPL Block IV environmental tests. Documentation for these test results is enclosed. The ML1961 is a 46 by 16.28 inch PVB-encapsulated module and contains 72, 3 inch solar cells in a 12 series by 6 parallel configuration.

While the ML1961 does not use EVA as its encapsulant material, accelerated environmental tests conducted at Photowatt, as well as tests performed by Springborn Laboratories, indicate that the performance of EVA should be equal or superior to that of PVB. EVA-encapsulated Photowatt modules are at present undergoing the Block V environmental test sequence at the JPL.

In order to estimate the hot spot endurance of its various module configurations, Photowatt has developed a computer simulation program which can calculate worst-case cell temperature for a given set of environmental characteristics (irradiance level, cell shading, module temperature) and electrical characteristics (cell Isc, Voc, shunt resistance, series resistance, number of series and parallel cells per module or diode). This program has been verified by means of actual environmental testing and yeilds an accurate estimate of worst-case hot spot cell heating.

This program was used to determine compliance with the requirements of section II.B.5 of JPL 5101-138. Of the four conditions listed in this section, condition (a), shadowing of any section of any cell within the module, yields the worst-case cell heating. Condition (b), a straight-line crack through the cell in any direction, results in a reduction in cell output current equivalent to that obtained by cell shading. Condition (c), opening any single interconnect, results only in a minor increase in cell string series resistance since two additional interconnects are still available to carry current. No significant cell heating occurs in this condition. Condition (d), short-circuiting a cell, forces the cells in that string to operate slightly nearer their Voc point. This reduces current flow through this string and increases current flow through the adjacent parallel string. There is still a net power production for the 24 cell block protected by the bypass diode and no significant cell heating occurs.

Simulations were performed to calculate the worst-case cell heating in a 24 cell block (12 series by 2 parallel cells) protected by a bypass diode in the ML6010 module. Nominal values for cell Voc and Isc at standard test conditions were used. A shunt resistance value of 46.2 ohms was assumed, representing the worst-case cell shunt resistance measured among several test modules. The simulations assumed that the module was forced to operate at its short-circuit condition. Two tests were run, one at the module NOCT of 47 C, and one at the estimated module worst-case temperature of 70 C.

In both cases the presence of the bypass diode in the system

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significantly reduced cell temperature. For a module temperature of 47 C, worst-case condition occurred with a cell shading of 29% and a maximum cell temperature of 93.2 C was calculated. For the case of a 70 C module temperature, the cell temperature was 108.7 C with 30% shading.

The 94.2 C cell temperature represents the worst-case condition to be expected in the hot spot endurance test referenced in section II.B.5 of 5101-138. The 108.7 C temperature represents a condition significantly worse than that tested in 5101-138 and is representative of the most extreme condition ever to be expected in the field. Both values are well below the 200 C temperature where significant degradation begins to occur in the EVA encapsulant material.

3.6 Identification

Each MU6010 module shipped to this order is identified by means of a metallized label containing information on the Photowatt part number, serial number, nominal module voltage and power, the maximum recommended system voltage, and the date of manufacture. While current at test voltage is not explicitly stated on the label, nominal current at test voltage can be readily obtained by dividing module nominal power by nominal voltage.

We hope this response will fulfill your requirements for additional information on the MU6010 module.

Sincerely,

M C Keeling

Mike Keeling
Chief Engineer

TECHNICAL DIRECTION MEMORANDUM

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr / Pasadena Calif 91103

TO (NAME OF CONTRACTOR)	CONTRACT NO.
Sensor Technology, Inc. - ATTN: Mike Keeling	955410
(ADDRESS OF CONTRACTOR)	TDM NO.
Photowatt International, Inc., 2414 W. 14th St., Tempe, AZ 85281	23

THIS TDM IS ISSUED PURSUANT TO THE CONTRACT ARTICLE ENTITLED "AUTHORITY OF JPL REPRESENTATIVES."

PURPOSE

☐ APPROVAL ☐ DISAPPROVAL ☒ CLARIFICATION ☐ RECOMMENDATION

THE CONTRACTOR IS DIRECTED AS FOLLOWS:

Subject: Qualification Tests

The Contractor is informed of satisfactory completion of the Qualification Tests.

Enclosed herewith, is a copy of the test data, entitled "Summary, Results of Environmental Tests of Solar Modules at JPL", dated 06/09/82.

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THE DIRECTIONS GIVEN HEREIN ARE WITHIN THE SCOPE OF THE ABOVE NUMBERED CONTRACT, AND SHALL NOT CONSTITUTE A BASIS FOR ANY CHANGE IN ANY OF THE CONTRACT PROVISIONS OR REQUIREMENTS RELATING TO QUANTITY, QUALITY, FEE, FIXED PRICE, DELIVERY OR PERFORMANCE SCHEDULE, OR ANY OTHER TERMS OF THE CONTRACT, NOR SHALL SUCH DIRECTIONS CONSTITUTE ANY CHANGE IN THE INSTITUTE'S OBLIGATION TO YOU UNDER ANY LIMITATION OF COST OR LIMITATION OF FUNDS PROVISION IN THE CONTRACT. BY YOUR ACCEPTANCE OF THIS TECHNICAL DIRECTION MEMORANDUM, YOU AGREE THAT NO CLAIMS FOR CHANGE OR ADJUSTMENT IN ANY OF THE TERMS OR PROVISIONS OF THE ABOVE NUMBERED CONTRACT WILL BE BASED UPON THE DIRECTIONS GIVEN HEREIN.

IF YOU TAKE EXCEPTION TO ANYTHING CONTAINED IN THIS MEMORDANDUM, DO NOT PROCEED WITH THE DIRECTIONS, AND NOTIFY THE JPL AUTHORIZED REPRESENTATIVE WHOSE SIGNATURE APPEARS BELOW OF SUCH FACT AS SOON AS POSSIBLE, BUT IN ANY EVENT, NO LATER THAN THREE (3) DAYS FROM THE DATE THIS MEMORANDUM IS RECEIVED.

SIGNED	THE CONTRACTOR ACCEPTS THIS TECHNICAL DIRECTION MEMORANDUM WITHOUT EXCEPTION. SIGNED
Melvin I. Smokler — 6/10/82	M C Keeling — 6/11/82
AUTHORIZED REPRESENTATIVE — DATE	AUTHORIZED REPRESENTATIVE — DATE
Melvin I. Smokler	Michael C Keeling Jr
PRINT NAME	PRINT NAME
Technical Manager	Chief Eng
TITLE	TITLE
JET PROPULSION LABORATORY	CONTRACTOR

COPY DESIGNATION: WHITE - CONTRACTOR COPY CANARY - CONTRACTOR ACKNOWLEDGMENT COPY PINK ORIGINATOR COPY GOLDENROD NEGOTIATOR COPY

JPL 2084 S R 10/80

FSA MODULE TEST SUMMARY

TEST SPEC 5101-151,162 (100mW/sq cm)

TEST/DURATION
HF=HUMIDITY FREEZE/CYCLES
HS=HOT SPOT/CYCLES
HL=HAIL/SIZE/INCHES
M=MECH INTEGRITY/CYCLES
S/A=MOUNTED IN SUBARRAY
T=TEMPERATURE/CYCLES

ID NUMBER
LETTERS= MFGER/BLOCK/USE
NUMBER= VENDOR SERIAL NO.

COMMENTS
COEF=TEMP COEFFICIENT
DELAM=DELAMINATION
DSCN=DISCOLORATION
ENCAP=ENCAPSULATION
INTCON=INTERCONNECTOR

DPMC=DELTA PMAX OF CONTROL MODULE
I=IDENTIFIER/J=JPL, V=VENDOR
P/FR=FAILURE REPORT NO.
SAT=TESTED SATISFACTORY
SBSTR=SUBSTRATE

ELECTRICAL
IMP=CURRENT AT PM,28DEG C,100mW/sqcm
ISC=SHORT CKT CURRENT,28DEG C,A
P=POWER AT RATING V,NUCT

PM=POWER MAX,28DEG C CURVE
VOC=OPEN CKT VOLTAGE 28DEG C,V
VMP=VOLTAGE AT PM,V

DELTA,PCT=DIFFERENCE PERCENT
FF=FILL FACTOR,PM/ISC X VOC
FLASH DATE=DATE OF ELEC TEST

VENDOR PHOTOWATT INTER.
NU09 D20-10-1961

PROCUREMENT
BLOCK IV

RATING VOLTAGE
5.0V 54 DEG C

STATUS AS OF
02/19/82

ID NUMBER	LINE	TEST DURATION	JPL PM,W	DELTA PM,PCT	FLASH DATE	I	P NUCT	DELTA P,PCT	ISC	VOC	IMP	VMP	FF	P/FR
VS4J-2032	1	INITIAL	38.20		08/12/81				7.204	7.05	6.600	5.80	.75	
VS4J-2032	2	S/A-26-8	33.63		10/19/81		BASE.							
VS4J-2032	3	T-50	38.32	-0.8	11/03/81		SATISFACTORY.							
VS4J-2032	4	H-5	38.50	-0.3	11/23/81		SATISFACTORY.							
VS4J-2032	5	M-10K	38.60	-0.1	01/11/82		SATISFACTORY.							
VS4J-2032	6	TWIST	39.25	+1.6	02/04/82		SATISFACTORY.							
VS4J-2032	7	HL-.75	38.64	0.0	02/18/82		SATISFACTORY.							
VS4J-2032	8	HI-POT			02/15/82									
VS4J-2033	1	INITIAL	39.62		08/12/81				7.495	7.10	6.950	5.74	.74	
VS4J-2033	2	S/A-26-8	39.52		10/19/81		BASE.							
VS4J-2033	3	T-50	39.14	-1.0	11/03/81		SATISFACTORY.							
VS4J-2033	4	H-5	39.39	-0.3	11/23/81		SATISFACTORY.							
VS4J-2033	5	H-10K	39.67	+0.4	01/11/82		INTERMITTENT OPEN DURING TEST, 1 PR.OF TERMINALS ONLY.							2802
VS4J-2033	6	TWIST	40.14	+1.6	02/04/82		SATISFACTORY.							
VS4J-2033	7	HL-.75	39.71	+0.5	02/18/82		SATISFACTORY.							
VS4J-2033	8	HI-POT			02/15/82		SATISFACTORY.							
VS4C-2034	1	INITIAL	38.08		08/10/81				7.328	7.05	6.600	5.77	.74	
VS4C-2034	2		38.08		10/19/81		BASE. CONTROL MODULE.							
VS4C-2034	3		37.30	-2.0	11/03/81		CONTROL MODULE.							
VS4C-2034	4	RECHECK	37.87	-0.6	11/03/81		CONTROL MODULE.							
VS4C-2034	5		37.86	-0.6	11/13/81		CONTROL MODULE.							
VS4C-2034	6		37.86	-0.6	11/20/81		CONTROL MODULE.							
VS4C-2034	7		37.96	-0.3	11/23/81		CONTROL MODULE.							
VS4C-2034	8		38.03	-0.1	12/09/81		CONTROL MODULE.							
VS4C-2034	9		38.01	-0.2	12/14/81		CONTROL MODULE.							
VS4C-2034	10		37.34	+0.7	12/29/81		CONTROL MODULE.							
VS4C-2034	11		37.55	-1.4	01/11/82		CONTROL MODULE.							
VS4C-2034	12	RECHECK	37.94	-0.4	01/11/82		CONTROL MODULE.							
VS4C-2034	13		38.93	+2.2	01/25/82		CONTROL MODULE.							
VS4C-2034	14		38.40	+0.8	02/04/82		CONTROL MODULE.							
VS4C-2034	15		37.87	-0.7	02/17/82		CONTROL MODULE.							
VS4C-2034	16		37.65	-1.1	02/18/82		CONTROL MODULE.							

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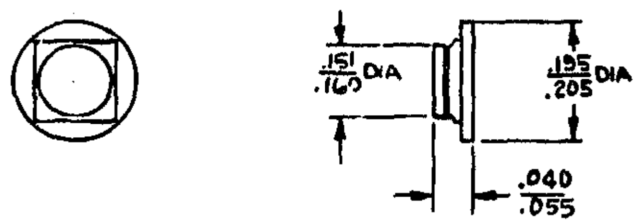
VS4J 35	1	INITIAL	36.95		08/10/81		7.188	7.03	6.370	5.80	.73	
VS4J-..35	2	S/A-30-2	36.62		10/19/81	BASE.						
VS4J-2035	3	T-50	36.18	-1.2	11/04/81	SATISFA..ORY.						
VS4J-2035	4	H-5	36.19	-1.2	11/23/81	SATISFACTORY.						
VS4J-2035	5	H-10K	36.60	+0.2	12/29/81	SATISFACTORY.						
VS4J-2035	6	TWIST	37.26	+1.7	02/04/82	SATISFACTORY.						
VS4J-2035	7	HL-.75	36.93	+0.8	02/18/82	SATISFACTORY.						
VS4J-2035	8	HI-POT			02/15/82	SATISFACTORY.						
VS4J-2036	1	INITIAL	38.73		08/10/81		7.514	7.05	6.880	5.63	.73	
VS4J-2036	2	S/A-30-2	39.17		10/19/81	BASE.						
VS4J-2036	3	T-50	38.97	-0.5	11/04/81	SATISFACTORY.						
VS4J-2036	4	H-5	38.53	-1.6	11/23/81	SATISFACTORY.						
VS4J-2036	5	H-10K	39.31	+0.4	12/29/81	SATISFACTORY.						
VS4J-2036	6	TWIST	39.69	+1.3	02/04/82	SATISFACTORY.						
VS4J-2036	7	HL-.75	39.32	+0.4	02/18/82	SATISFACTORY.						
VS4J-2036	8	HI-POT			02/15/82	SATISFACTORY.						
VS4J-2037	1	INITIAL	37.12		08/10/81		7.214	7.07	6.400	5.80	.73	
VS4J-2037	2	S/A-26-8	37.05		10/19/81	BASE.						
VS4J-2037	3	T-50	36.47	-1.6	11/03/81	SATISFACTORY.						
VS4J-2037	4	H-5	37.05	0.0	11/23/81	SATISFACTORY.						
VS4J-2037	5	H-10K	38.21	+3.1	01/25/82	SATISFACTORY.						
VS4J-2037	6	TWIST	37.85	+2.2	02/04/82	SATISFACTORY.						
VS4J-2037	7	HL-.75	37.15	+0.3	02/18/82	SATISFACTORY.						
VS4J-2037	8	HI-POT			02/15/82							
S/A-26-8	1	INITIAL	113.28		10/19/81		7.395	20.98	6.670	16.98		S/A-26-8-2032,2033,2037
S/A-26-8	2	T-50	114.43	+1.0	11/03/81							
S/A-26-8	3	H-5	116.02	+2.4	11/23/81							
S/A-30-2	1	INITIAL	72.85		10/19/81		7.331	13.92	6.610	11.01		S/A-30-2 IS 2035,2036
S/A-30-2	2	T-50	73.89	+1.4	11/04/81							
S/A-30-2	3	H-5	75.46	+3.6	11/23/81							
S/A-30-2	4	H-10K	75.02	+3.0	12/29/81							

DOUBLE-DISCED GLASS PASSIVATED CHIP



NOTE: Discs are nickle plated copper

GCC 130 SERIES

MAXIMUM RATINGS (At $T_A = 25°C$ unless otherwise noted)	SYMBOL	GCC130- 200	400	600	800	1000	UNITS
Peak Repetitive Reverse Voltage	V_{RRM}	200	400	600	800	1000	Volts
RMS Reverse Voltage	$V_{R(RMS)}$	140	280	420	560	700	Volts
Maximum Reverse Current @ Rated V_{RRM}@T_J=25°C	I_{RM}	10					UA
Maximum Reverse Current @ Rated V_{RRM}@T_J=125°C	I_{RM}	2					mA
Maximum Instantaneous Forward Voltage @ 30amps	V_f	1.4					Volt
Junction Operating & Storage Temperature	T_J, T_{STG}	-50 to + 150					°C

ELECTRICAL CHARACTERISTICS (At $T_A = 25°C$ unless otherwise noted)	SYMBOL		UNITS
With adequate assembly, the following typical operational properties are obtainable:			
Peak Surge Current, 1/2 cycle at 60Hz	I_{FSM}	300	Amps
Avg. Rectified Forward Current (Resistance Load)	I_o	15	Amps

VARO

VARO SEMICONDUCTOR, INC. P.O. BOX 676, 1000 NORTH SHILOH, GARLAND, TEXAS 75040 (214) 271-8511 TWX 910-860-5178

APPENDIX E

HUGHES
HUGHES AIRCRAFT COMPANY

INTERDEPARTMENTAL CORRESPONDENCE

TO: G.J. Naff
ORG:

CC: SEPS
H.A. Lopez

DATE: 16 February 1983
REF. SEPS/16

SUBJECT: NASA Lewis Stand-Alone Array String Test Results

FROM: D.B. Cohen
ORG. C1-43-00

BLDG. A1 MAIL STA. 4C843
LOC. LB PHONE 3490

Each solar array string of 10 series connected modules was electrically performance tested on February 14, 1983. Although there were thin, high clouds the array strings all appeared to be functioning properly. When corrected to AM 1.5, 1000 W/M^2, 28°C the following performances were obtained:

STRING	Imp (Amps)	Vmp (Volts)	Pmp (Watts)
Upper West	4.20	164.1	689.0
Lower West	4.16	162.5	676.1
Center	4.06	157.5	639.8
Upper East	4.16	165.1	686.8
Lower East	4.16	162.1	674.4

D.B. Cohen

/ymh

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NASA
~~SANDIA~~ MODULE TEST DATA
IN ASCENDING ORDER

DEAN COCHRAN
1-21-83

ORDER	TEST ITEM NO	POWER	S/N
1	14	63.34	4741
2	35	63.50	4229
3	—	63.50	5399
4	23	63.66	4090
5	3	63.82	4228
6	9	63.84	4758
7	25	63.99	4973
8	4	64.00	4711
9	—	64.15	5484
10	5	64.80	4713
11	18	65.28	5081
12	16	65.28	5116
13	28	65.28	4714
14	15	65.40	4740
15	27	65.44	5042
16	1	65.61	3987
17	6	65.61	4782
18	7	65.77	5115
19	32	65.77	4967
20	38	65.93	5205
21	39	65.93	5271
22	44	66.09	3631
23	21	66.25	4981
24	19	66.40	4968
25	17	66.42	4707
26	—	66.42	5480
27	22	66.42	3993
28	30	66.42	4980
29	50	66.58	5114
30	2	66.58	4130
31	11	66.74	4975
32	43	66.74	5330
33	40	66.90	5202
34	10	66.90	5197
35	12	67.06	4974
36	29	67.06	4966
37	—	67.06	5329
38	—	67.06	5478
39	45	67.55	3512
40	37	67.55	5049
41	31	67.55	5184
42	21	67.72	4969
43	8	67.87	5153
44	42	67.87	5195
45	36	67.87	5201
46	13	67.88	5117
47	26	65.02	4976
48	20	68.04	4915
49	41	68.04	5203
50	—	68.52	5488