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# "FINAL DESIGN REPORT FOR INTERMEDIATE LOAD MODULES FOR TEST AND EVALUATION"

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FLAT-PLATE SOLAR ARRAY PROJECT

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"The JPL Flat-Plate Solar Array Project is sponsored by the U.S. Department of Energy and forms part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays. This work was performed for the Jet Propulsion Laboratory, California Institute of Technology by agreement between NASA and DOE".

ABSTRACT

Applied Solar Energy Corporation built two versions of a 36 cell stainless steel solar module. The first version was built as a commercial module for marine applications and was purchased for evlauation by JPL. Design deficiencies were identified as a result of the evaluation.

This report describes the second version that was built and the improvements that resulted from design changes. Assembly problems, electrical performance, and qualification test results are provided.

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## 1.0 SUMMARY AND INTRODUCTION

Contract No.956350 specified construction of 10 solar cell modules which were designated as JPL Group II Modules, ASEC PN 60-3085, for evaluation per JPL Document 5101-161, "Design and Test Specification for Intermediate Load Modules -1981". The Group II Modules were fabricated and delivered to JPL on March 31, 1983. These modules were a redesign of ASEC's commercial module, PN60-3079, 10 of which were previously evaluated at JPL under the Block V parameters and designated as Group I Modules.

The Group I Modules consisted of a 36 cell laminate with stainless steel foil back to which four stainless steel side angles were attached with polysulfide. A junction box was mounted on the rear of the panel and utilized preformed silicone rubber seals. A plastic feed through connector was used on the junction box and was of the plug and lock ring style. While undergoing evaluation at JPL, these modules experienced dielectric, hot spot and connector continuity problems. The Group II Module was designed to address these problems and furthered the concept of producing a high reliability module for use in adverse climates.

## 2.0 MODULE DESCRIPTION

The Group II Module is a 36 cell module which measures 31.04" L x 13.33" W x 2.04" D (78.8cm x 33.8cm x 5.2cm) and weighs 13 lbs. (5.9kg). Reference Figure 1. It is designed with all exterior metal parts to be made of stainless steel with AISI Type 316 being used on the pan/chassis, junction box, and hold down angles.

The cell string with electric taps (for by-pass diodes) is encapsulated in PVB by lamination. Tempered glass forms the superstrate for the laminate and a polyvinyl fluoride-polyester sandwich serves as the backing. Non-woven glass fiber was placed between the backing and PVB. The laminate is assembled into the pan/chassis with GE RTV 615 silicone rubber and an edge seal is formed by caulking with Tremco "Proglaze" silicone rubber and capping with metal angles which are riveted to the pan/chassis. Reference Figure 2.

A junction box is mounted to the rear of the pan/chassis over threaded studs which are pressed into the pan. Reference Figure 3. Seals to the junction box are made with butyl rubber. The junction box provides the means to make environmentally protected electrical connections between the laminate, diodes, and feed-through receptacle connector mounted to the junction box. The junction box is potted with GE RTV 615 silicone rubber.

The receptacle connector (Brad Harrison Co. "Mini-Change" connector, PN 490XX) has three pins and associated color coded pigtail wires for the internal attachment. Two of the pins are used for connection to the module's electric circuit while the third pin is electrically connected to the pan/chassis to form a ground connection. The connector's rubber is molded in a configuration which provides polarization.

Electrical connection is then made to the module by attaching a female plug-lock-ring connector (Brad Harrison connector PN40901SS) to the male receptacle connector. The plug is molded to a 16 AWG three wire SO cord rated to 90°C. The wires are color coded black (positive), white (negative) and green (ground) and match the coloring of the receptacle's pigtail wires. Ground for the panel is thus effected through the wiring harness.

Three inch (7.62cm) diameter round solar cells measuring .012" (.03cm) thick with a multi-layer antireflective coating were utilized. Reference Figure 4. The cells are made from a base material of 1-3 ohm-cm p-type boron doped silicon. The N on P junction is formed as a shallow junction with diffused phosphorous. The cell's back contact is formed from Al-Ti-Pd-Ag and the front contact and gridlines are Ti-Pd-Ag. The copper mesh used to interconnect the cells is formed from .005" expanded copper mesh with a .001" solder plating.

The 36 cells are soldered in series with electrical taps added to provide for four series blocks with a diode across each series block. This provdes by-pass diode protection for each of the nine cell segments. Reference Figure 1.

## 3.0 RATIONALE FOR DESIGN CHANGES

### 3.1 Group I - Module Deficiencies

Two specific deficiencies were identified on the Group I modules when subjected to Block V test conditions: 1) Electrical and material failure from hot-spot stressing and 2) Electrical degradation from corrosion of the out-put connector pins. Exposure to hot cycles caused undesirable yellowing of the PVB, primarily in the area of the active circuit feed-through at the junction box location. Hot cycles also caused the resistance to ground to drop to 6 megohms.

The problems incurred in the hot-spot tests are explained by the intense heat produced with one cell reverse biased on a 36 cell string with no series blocks nor diode protection. The corrosion of the connector pins is attributed to both a deficiency of the connector design which did not produce a hermetic seal and a faulty preformed gasket design for mounting of the J-Box. The lack of a hermetic seal on the J-box allowed moisture to enter it which could contribute to the pin corrosion from inside the J-Box. The lack of a hermetic seal on the J-box also explains the heavy PVB yellowing at the point where the module circuit leads into the J-box, since air (and moisture) would be available to contribute to oxidation.

### 3.2 Group II - Improvements

Hot-spot protection was provided by creating circuitry with four series blocks and a by-pass diode across each series block. The plastic connector was replaced with a water tight-connector which was constructed of close fitting neoprene surfaces. Instead of a silicone preformed gasket, the Group II junction box was sealed to the module with butyl rubber. The J-box was also potted with silicone rubber to discourage both moisture condensation and air access which could cause PVB oxidation. Generous dimensions were used between electrically active components and module grounding surfaces in an effort to maximize resistance to ground during hot cycles.

## 4.0 MATERIAL PROBLEMS

Original design approval was granted by JPL via Technical Data Memorandum No. 1, dated January 26, 1983.

The design specified a receptacle connector with pigtail wires color coded red (for positive), black (for negative), and green (for ground). Connectors with black, white and green wires were received. These connectors were manufactured under a rush order and the manufacturer stated that replacement connectors would have required a minimum of two months for delivery. JPL was notified and it was jointly agreed between ASEC and JPL to utilize the connectors. A drawing change was made to reflect the change in color code to black (positive), white (negative), and green (ground).When the first module was completed with one of these connectors it was discovered that the stainless steel connector had a high leakage current. Ten of the stainless steel receptacles were tested and leakage current ranged from 42 to 64uA at 3000 VDC. Analysis of the problem and inquiry calls to the manufacturer led to the finding that there were differences in the rubber content between the original receptacle connector (sample) evaluated at ASEC and those which were delivered for module production. The original sample was measured to have .6uA to 1.3uA at 3000VDC, the range stemming from where the test leads were connected to the metal shell and wires.

The high leakage current on the receptacle connectors was unacceptable as it would have prevented the modules from passing isolation tests. Again, the proper replacement parts would have required at least two months for delivery and caused a significant delay in fulfillment of the contract. The manufacturer was contacted and it was determined that die cast zinc receptacles were available with rubber made by the same process as the original sample evaluated at ASEC.

The die cast zinc receptacles were ordered and were tested for leakage current at ASEC. They were found to have low leakage currents like the original sample, .6uA-1.3uA.

Discussion between ASEC and the JPL technical manager for this contract determined that it would be in the best interest of contract fulfillment to utilize the zinc connectors in lieu of the stainless steel ones. This would eliminate at least a two month delay in obtaining stainless steel connectors with low leakage current. Although the zinc connectors were not anticipated to have the same corrosion resistance as the stainless steel ones, it was felt that the zinc would suffice to permit evaluation of the module. It was agreed not to change the module design to specify the use of zinc connectors, as stainless steel is clearly the preferred material.

There was also a problem with vendors supplying glass to the size specified. In the first shipment, all glass sheets were oversized, some as much as .035" over the maximum allowed. The second shipment from a different vendor was an improvement, with some sheets falling within specification and some sheets measuring .015" over the maximum design dimension. It was jointly agreed upon that the oversize glass would not affect module integrity and would only make assemby slightly more difficult. Production proceeded with the oversize glass with no changes made to the module design.

JPL TDM No. 2 dated April 15, 1983 granted written approval for production of the module with the connector and glass variances.

## 5.0 ASSEMBLY PROBLEMS

During assembly module components were easily fitted together with one exception. The task of laying the laminate in the pan/chassis over the uncured GE RTV615 silicone rubber was more difficult than anticipated. The viscosity is 4,000 cps and with support under the pan of the pan/chassis, considerable pressure was required on top of the laminate to extrude excess silicone rubber from underneath the laminate.

Although not a particularly difficult task, cleaning the cured silicone rubber out of the grove between the glass edges and the pan was rather time consuming. This was done to provide for a "deep" silicone rubber section when the groove was back-filled with Tremco Proglaze silicone rubber sealant.

## 6.0 MODULE ELECTRICAL PERFORMANCE - RELATED DATA (REFERENCE TABLES)

Module Packing Efficiency:

$$EFF = \frac{\text{Total Cell Area}}{\text{Total Module Area}} = \frac{35 \text{ Cells} \times 45.6\text{cm}^2}{33.8\text{cm} \times 7.8.8\text{cm}} = 61.6\%$$

Performance At Peak Power Conditions (100mW/$cm^2$, AM1.5, 25°C Cell Temp)

Use Average Data Supplied By JPL:

Pp = 23.42W

Vmp = 17.82V

Imp = 1.31A

Voc = 21.71V

Isc = 1.42A

FF = 76.0

Mod. Eff. = 8.8

Encap. Cell Eff. = 14.3

## 7.0 QUALIFICATION TESTS CONDITIONS AND RESULTS

### 7.1 Electrical

Ground Continuity - This test calls for verification that all exposed metal parts are electrically common. All modules passed.

Electrical Isolation - Modules are subjected to 3000Vdc between the active circuit and module ground and at the same time the leakage current is observed. Acceptable leakage current is specified as not exceeding 50uA. This test is performed initially and at completion of the other qualification tests. All modules passed.

## 7.2 Hot-Spot Endurance

One module has individual cells subjected to reverse bias conditions for a period of 100 hours. Parameters for the test are based on cell characteristics and number of cells per series block protected with a diode. Results from the test were acceptable with the formation of small air bubbles and cell grid discoloration noted.

## 7.3 Environmental Tests

Thermal Cycle - This test exposes modules to temperatures between -40°C to +90°C for a total of 200 cycles. All modules subjected to these conditions experienced the formation of small bubbles throughout the module between cells and on the surfaces of some of the cells. One module was analyzed and the source of the bubbles was attributed to air dissolved (entrapped) in the PVB during autoclaving. When the modules were heated during thermal cycling, the air expanded to form the gas bubbles.

A cell in one of the modules cracked during thermal cycling, resulting in that module's power being reduced by 30%. It is the diode circuitry that prevented the loss from being greater than 30%.

On two modules, resistance to ground was noted as dropping to 10 megohms at hot ends of cycles.

Humidity - Freezing Cycle - This test is similar to the thermal cycle test with the addition of 85% R.H. Problems with the formation of air bubbles throughout the module were again noted during this test. Also, the zinc connectors experienced rather severe corrosion as a direct result of the humidity environment.

Mechanical Loading - In this test modules are supported at their design support points while uniform loads are applied with a diaphram. The complete test involves 10,000 cycles. This test was successfully passed.

Twisted Mounting Surface - Modules in this test are subjected to a twisting of their frames, the amount specified at .25 inches per linear foot. All modules passed.

## 8.0 CONCLUSIONS AND RECOMMENDATIONS

The design changes incorporated into the Group II Modules corrected the deficiencies identified in the Group I Modules. Hot spot stress was minimized by limiting cell reverse bias through the use of by-pass diodes. The new connector and revised method for sealing the J-box eliminated connector electrical problems. Improved J-box seals and/or potting of the J-box eliminated PVB yellowing at the circuit-junction box interface.

Resistance to ground during hot cycles was improved from 6 megohms (Group I Modules) to [illegible] megohms. This represented only a marginal improvement.

The entrapment of air during the lamination process was undetected during module manufacturing and appeared during thermal cycling. Any future production of a laminate for this module by autoclave lamination would require process verification controls. The cracked cell may have been eliminated if all connections had been made to cells with the copper mesh in lieu of the solid copper busing ribbon. Exterior corrosion problems with the zinc connector were anticipated; production modules would be produced with stainless steel only.

For moderate volume production of this specialized module there are three options which could reduce the labor time: 1) less visious two part silicone rubbers are available which would make the task of assembling the laminate into the pan an easier one, 2) the time spent on assembling the diodes to the terminal board and wiring to the terminals could be significantly reduced by utilizing a printed circuit board, and 3) instead of cleaning the silicone rubber out of the groove between the glass edge and the pan it could be neatly trimmed. Then a one part sealant such as silicone or butyl rubber could be formed over the groove and the side angles installed. The integrity of this sealant method would need to be verified.

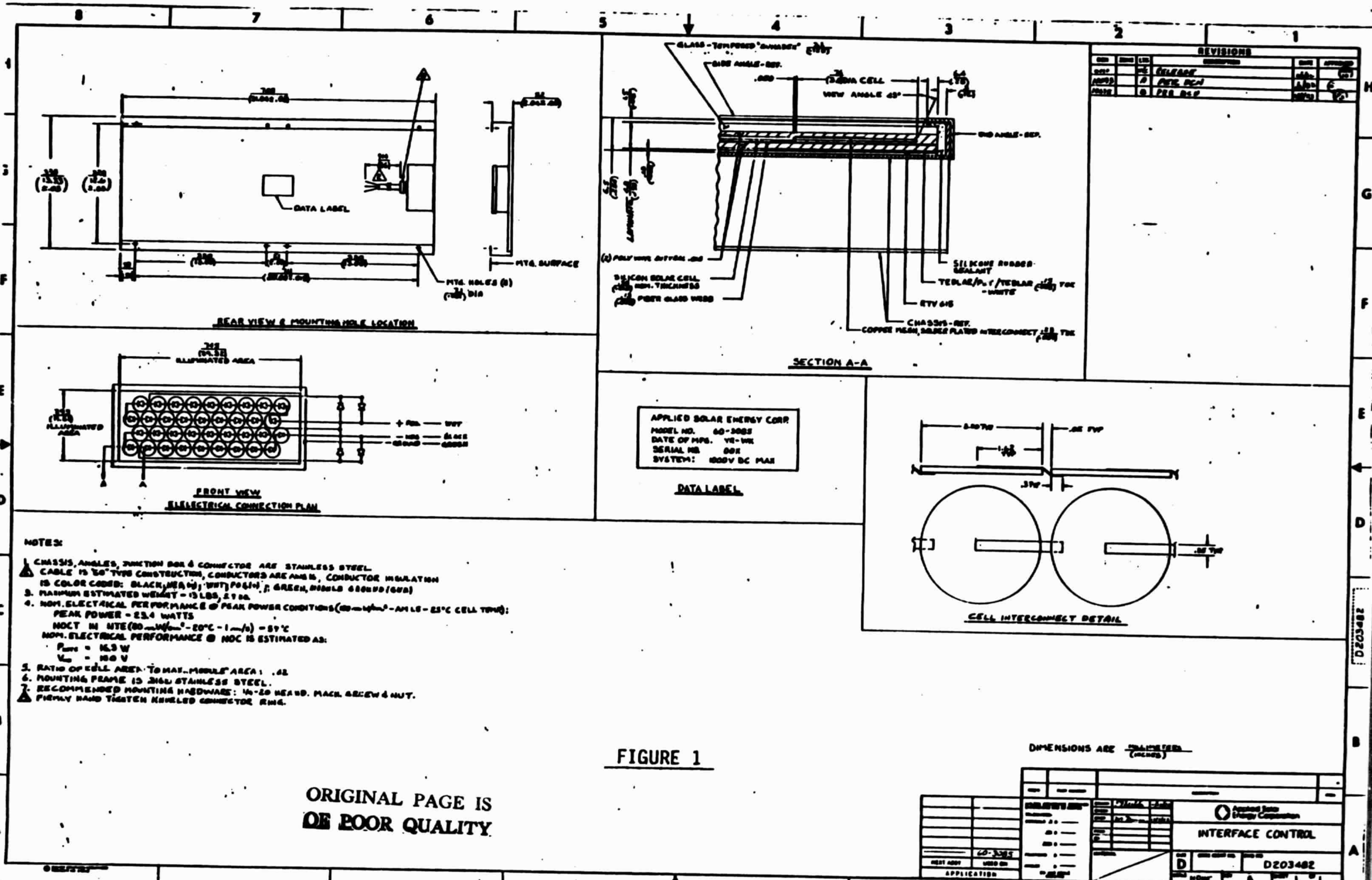
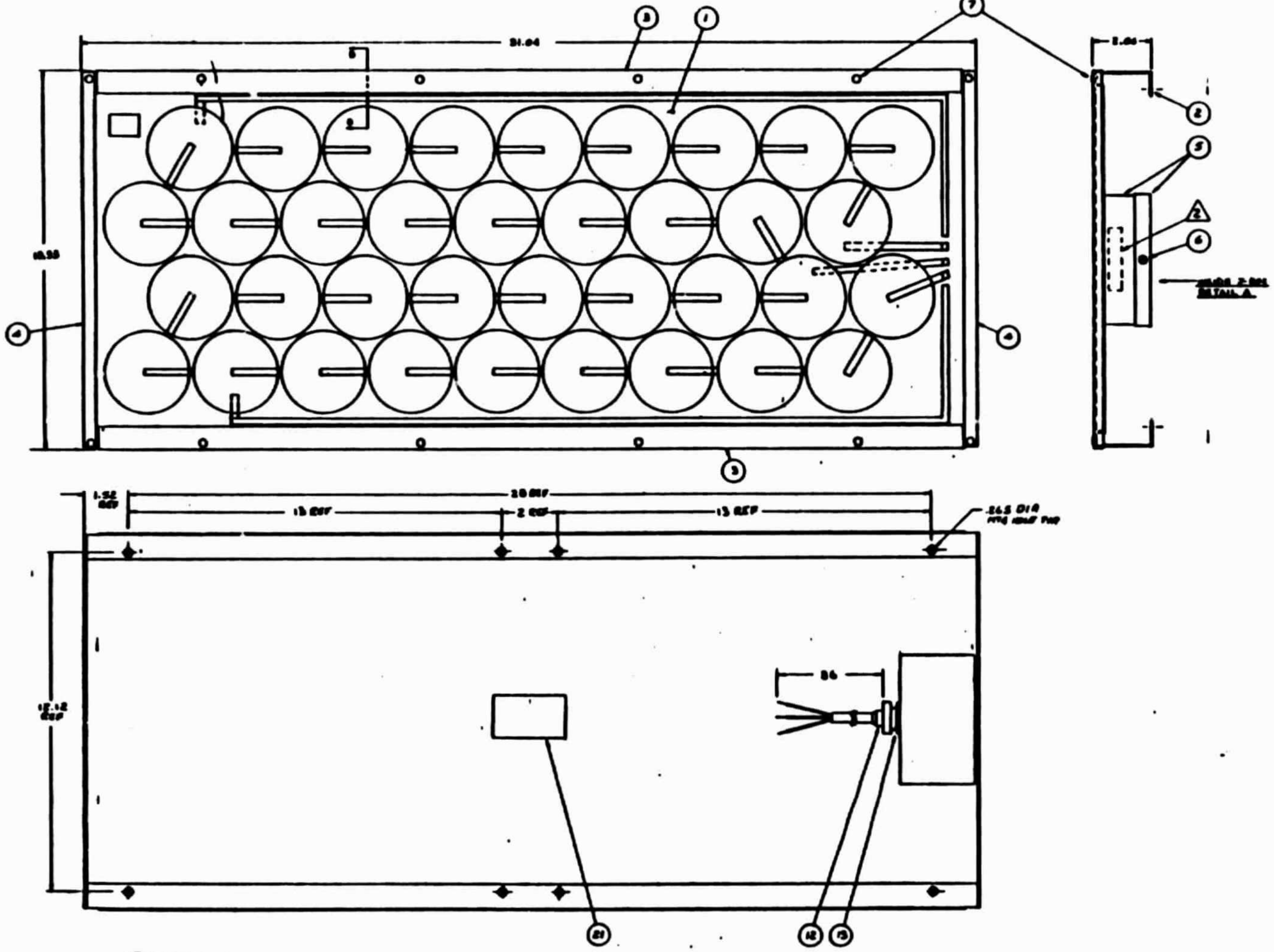

REVISIONS
RELEASE
PER ECN
PER ECN
GLASS - TEMPERED "SUNADEX"
SIDE ANGLE - REF.
CELL
VIEW ANGLE 45°
END ANGLE - REF.
SILICONE RUBBER SEALANT
TEDLAR/P.E.T./TEDLAR -WHITE
RTV 615
CHASSIS - REF.
COPPER MESH, SOLDER PLATED INTERCONNECT
SILICON SOLAR CELL
FIBER GLASS WEBB
SECTION A-A
DATA LABEL
MTG. HOLES (8)
MTG. SURFACE
REAR VIEW & MOUNTING HOLE LOCATION
ILLUMINATED AREA
+ POS. — WHT
— NEG — BLACK
— GROUND — GREEN
FRONT VIEW
ELELECTRICAL CONNECTION PLAN
APPLIED SOLAR ENERGY CORP.
MODEL NO. 60-3085
DATE OF MFG. YR-WK
SERIAL NO. 00X
SYSTEM: 1000V DC MAX
DATA LABEL
CELL INTERCONNECT DETAIL
NOTES:
1. CHASSIS, ANGLES, JUNCTION BOX & CONNECTOR ARE STAINLESS STEEL.
2. CABLE IS "SO" TYPE CONSTRUCTION, CONDUCTORS ARE AWG 16, CONDUCTOR INSULATION IS COLOR CODED: BLACK, NEG (-); WHT, POS (+); GREEN, MODULE GROUND (GND)
3. MAXIMUM ESTIMATED WEIGHT - 13 LBS,
4. NOM. ELECTRICAL PERFORMANCE @ PEAK POWER CONDITIONS (AM 1.5 - 25°C CELL TEMP):
PEAK POWER - 23.4 WATTS
NOCT IN NTE - 20°C - 57°C
NOM. ELECTRICAL PERFORMANCE @ NOC IS ESTIMATED AS:
P = 16.3 W
V = 100 V
5. RATIO OF CELL AREA TO MAX. MODULE AREA: .42
6. MOUNTING FRAME IS STAINLESS STEEL.
7. RECOMMENDED MOUNTING HARDWARE: 1/4-20 HEAD. MACH. SCREW & NUT.
8. FIRMLY HAND TIGHTEN KNURLED CONNECTOR RING.
DIMENSIONS ARE MILLIMETERS (INCHES)
INTERFACE CONTROL
D
D203482
60-3085
APPLICATION

FIGURE 1

TABLE 1

PERFORMANCE AT PEAK POWER CONDITIONS

| MODULE NO. | Pmax (W) | Vmp (V) | Imp (A) | Voc (V) | Isc (A) | FF | Mod. Eff. | Encap Cell Eff. |
|---|---|---|---|---|---|---|---|---|
| 003 | 23.61 | 17.66 | 1.34 | 21.69 | 1.42 | 75.9 | 8.86 | 14.38 |
| 004 | 23.17 | 17.77 | 1.30 | 21.76 | 1.42 | 74.8 | 8.70 | 14.11 |
| 005 | 23.78 | 17.71 | 1.34 | 21.84 | 1.44 | 75.5 | 8.93 | 14.49 |
| 006 | 23.46 | 18.03 | 1.30 | 21.73 | 1.41 | 76.5 | 8.81 | 14.29 |
| 007 | 23.40 | 18.15 | 1.29 | 21.71 | 1.42 | 75.9 | 8.79 | 14.25 |
| 008 | 23.91 | 17.56 | 1.36 | 21.73 | 1.45 | 75.8 | 8.98 | 14.57 |
| 009 | 23.89 | 18.06 | 1.32 | 21.70 | 1.44 | 76.3 | 8.97 | 14.55 |
| 012 | 23.15 | 17.80 | 1.30 | 21.63 | 1.39 | 77.0 | 8.69 | 14.10 |
| 013 | 22.71 | 17.61 | 1.29 | 21.63 | 1.39 | 75.6 | 8.53 | 13.83 |
| 014 | 23.16 | 17.80 | 1.30 | 21.70 | 1.39 | 76.7 | 8.70 | 14.10 |
| AVERAGE | 23.42 | 17.82 | 1.31 | 21.71 | 1.42 | 76.0 | 8.80 | 14.27 |




| | | | | |
|---|---|---|---|---|
| | 7 | | HEX NUT 4-40 CRES | 27 |
| | A.R. | | ADHESIVE TAPE, MYLAR .5" WIDE [illegible] | 26 |
| | A.R. | | FLUX, 485HF - CODAR | 25 |
| 410-0010 | A.R. | | SOLDER SN60 | 24 |
| | 3 | | SOLDER LUG, VINYL INSULATED, [illegible] | 23 |
| | 1 | | LOCK NUT, [illegible] | 22 |
| | 1 | A203[illegible] | DATA LABEL | 21 |
| 309-0043 | A.R. | | SILICON SEALANT - TREMCO PROGLAZE | 20 |
| | A.R. | | BUTYL POLYISOBUTYLENE SEALANT, PTI | 19 |
| | A.R. | | PRIMER [illegible] GEN ELECTRIC | 18 |
| | A.R. | | PRIMER [illegible] GEN ELECTRIC | 17 |
| | A.R. | | RTV 615 GEN ELECTRIC | 16 |
| | A.R. | | WIRE, AWG 14 TYPE C | 15 |
| | 4 | — | DIODE, RECTIFIER, 6 AMP, MOTOROLA [illegible] | 14 |
| | 1 | B203[illegible] | RECEPTACLE, CONNECTOR, [illegible] | 13 |
| | 1 | — | PLUG, CONNECTOR, [illegible] CRES, [illegible] | 12 |
| | 7 | — | SOLDER TERMINAL, 1500-[illegible], CAMBION | 11 |
| | 1 | A203407 | TERMINAL BOARD | 10 |
| | 4 | — | STANDOFF [illegible] | 9 |
| | 10 | — | HEX NUT [illegible] CRES | 8 |
| | 12 | — | POP RIVET, [illegible] | 7 |
| | 2 | — | NO. [illegible] SHEET METAL SCREW, CRES | 6 |
| | 1 | C203[illegible] | JUNCTION BOX & COVER | 5 |
| | 2 | B203[illegible] | END ANGLE | 4 |
| | 2 | B203[illegible] | SIDE ANGLE | 3 |
| | 1 | D203[illegible] | PAN CHASSIS | 2 |
| | 1 | D203[illegible] | LAMINATE ASSEMBLY | 1 |

REVISIONS

SOLAR MODULE ASSEMBLY
36 CELL

D 805655

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FIGURE 2, PART 1

NOTES
1. ALL DETAIL & SECTION VIEWS ARE ON SHEET 2.
2. MARK POLARITY LEGEND WITH BLACK EPOXY INK ON OUTSIDE OF J BOX: "BLACK, NEG(-); WHT, POS(+); GREEN, GND"

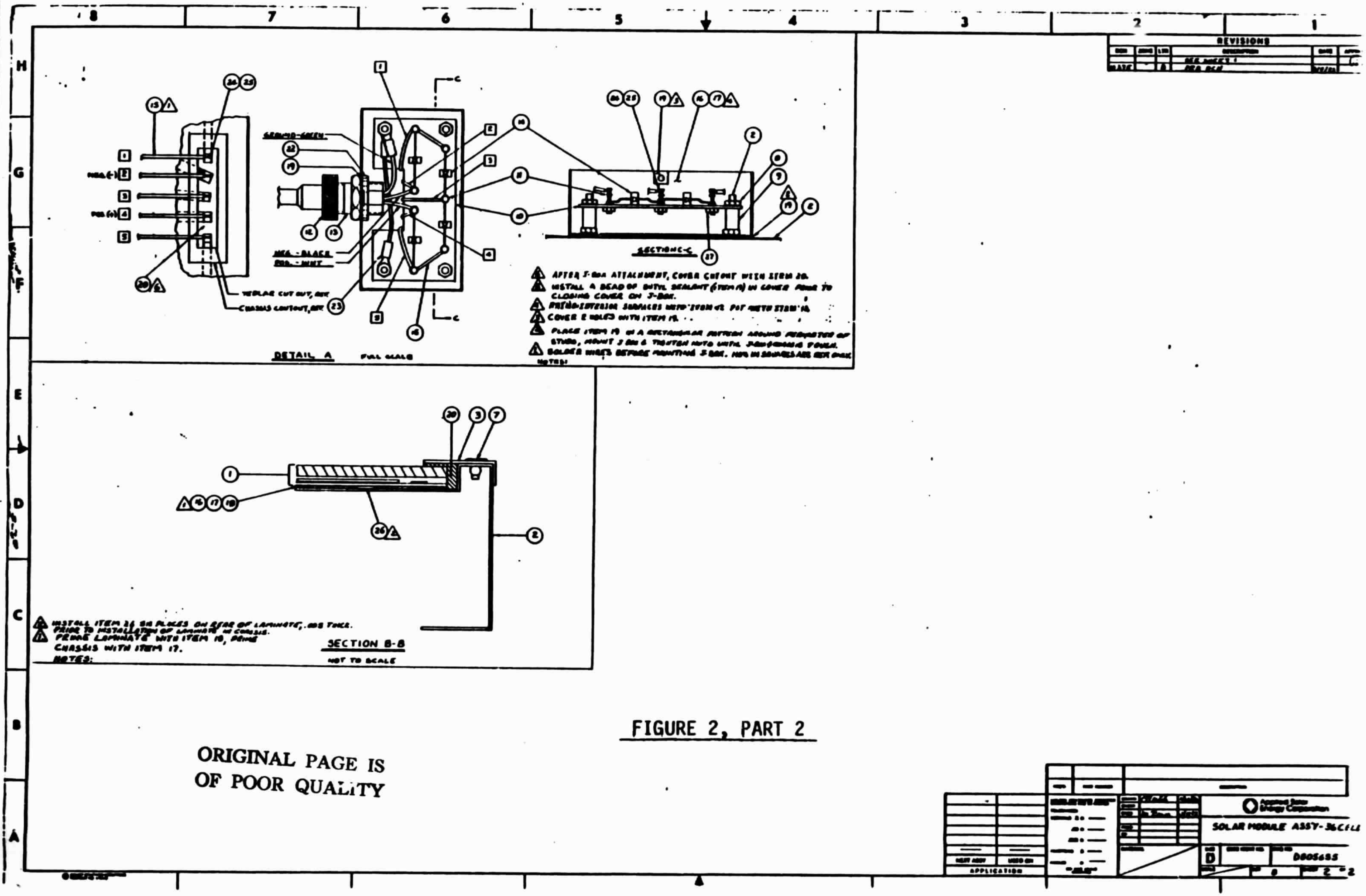


FIGURE 2, PART 2

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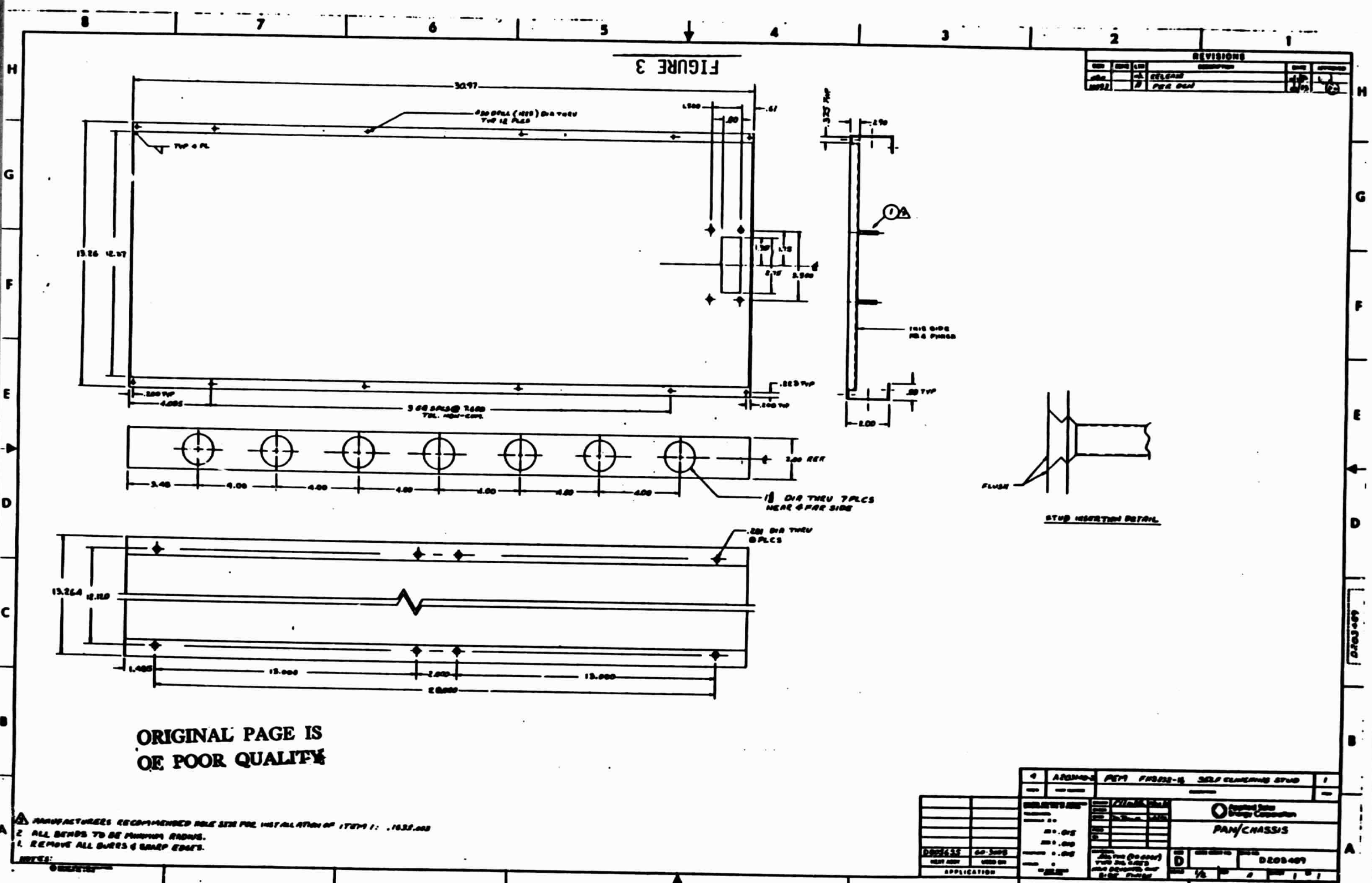


FIGURE 3

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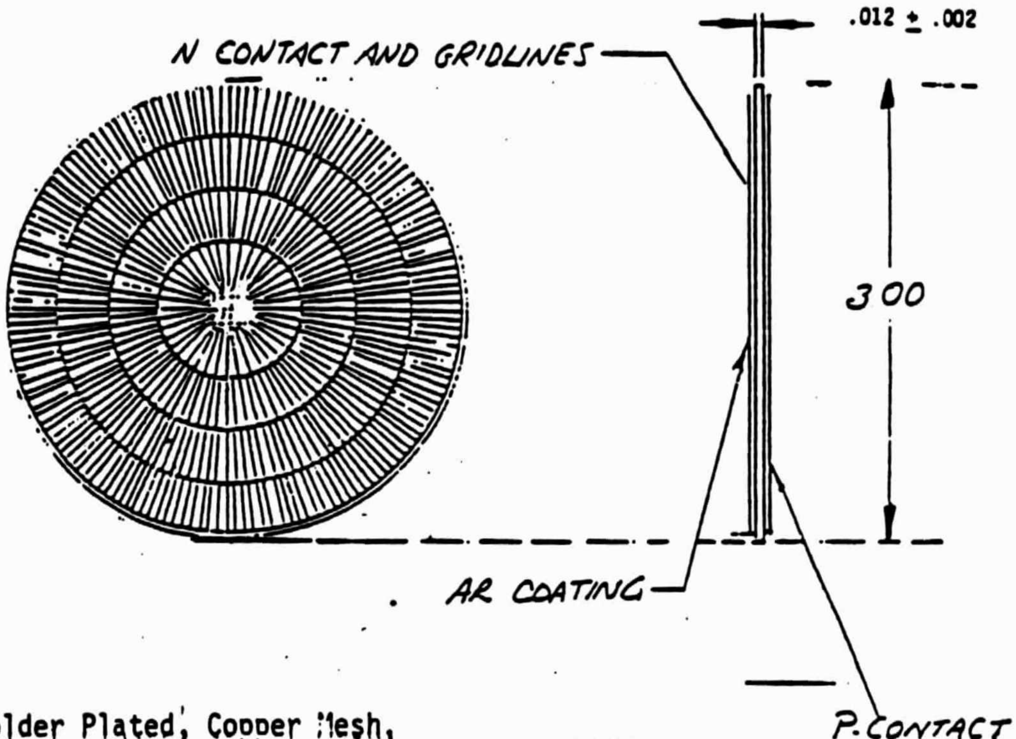
| APPLICATION | | REVISIONS | | | | |
|---|---|---|---|---|---|---|
| Next Assy | Used On | LTR | DCN | Description | Date | Approved |
| C203177 | 60-3085 | N/C | 7531 | Release | 12-22-80 | ASEC 18 |
| D202874 | D202866 | A | 7564 | See DCN 7564 | 1-8-82 | ASEC 18 |
| | | B | 8421 | See DCN 8421 | 9-2-81 | ASEC 18 |
| | | C | 10030 | SEE DCN | 12/8/82 | ASEC 18 |
| | | D | 10377 | SEE DCN | 3/20/82 | |
| | | | | | | |




7.0 Interconnects-Solder Plated, Copper Mesh,
6.0 Junction-N on P Type, Shallow Junction, Phosphorous Diffused.
5.0 Base Material-P-Type, Boron Doped, Single Crystal silicon, 1-3 ohm - cm.

4.0 AR COATING TO BE MLAR

3.0 BACK CONTACT-METALS ARE ALUMINUM TITANIUM-PALLADIUM -SILVER

2.0 FRONT CONTACT - METALS ARE TITANIUM - PALLADIUM-SILVER

1.0 N-CONTACT OF .25 DIAMETER IS AT CENTER OF CELL

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Applied Solar Energy Corporation

unless otherwise specified dimensions are in inches

tolerances

decimals .x ±
.xx ± .010
.xxx ±
fractions ±
angles ±
do not scale drawing

| | |
|---|---|
| Drawn | BREDY 12-12-80 |
| Check | |
| Engr | |
| | |
| Prod | |
| QA | |

# 3" TERR. CELL

Material: SILICON SOLAR TERR CELL

| size | code ident no. | dwg no. |
|---|---|---|
| A | | A202884 |

scale NONE rev D sheet of

shop Graphics/accupress
Reorder No. A4800

FIGURE 4