OCEAN ENGINEERING DIVISION
UNITED STATES COAST GUARD
WASHINGTON, D.C.

MARCH 2005

SPECIFICATION FOR SOLAR PHOTOVOLTAIC MODULES FOR 12 VOLT DC MARINE AIDS TO NAVIGATION

SPECIFICATION NO. 401C

1. SCOPE.

1.1 General. This specification defines requirements for 12-volt solar photovoltaic (PV) power generating modules. For the purposes of this specification, module (6.1.7) defines the basic power unit. Modules will be installed on remote, unmanned stations and buoys in coastal or river environments to serve as the power supply for marine aids to navigation (AtoN). Long-term reliable operation of the equipment at these locations is essential. Photovoltaic modules will be used to charge lead-acid batteries connected in 12 volt banks of 100 ampere-hour (AH) and larger. Figure 1 shows an informational block diagram with modules, battery bank, and other related AtoN equipment that will make up the solar photovoltaic-powered aid to navigation system. Detailed module requirements are contained in subsequent sections of this specification. A list of definitions of terms used in this specification is included in section 6.1 and noted, when first used, by parentheses, which refer to the applicable paragraph in section 6.1.

1.2 Documentation. The contractor shall furnish the following documentation:

- First Article Test Plan (3.6.1)
- First Article Test Data (3.6.2) (3.5.1.4) (3.5.3.1)
- Report of First Article Testing (3.6.2)

1.3 Equipment Deliverables. The contractor shall fabricate modules in the power categories designated below. Quantities will be specified in procurement documents.

- Ten (10) Watt Module
- Twenty (20) Watt Module
- Forty (40) Watt Module

1.4 Government Testing. As part of the approval procedure the following testing will be furnished at no cost to the contractor.

1.4.1 An Accelerated Life Test (4.6) and an Electrical Isolation Test (4.4.2.3). At the conclusion of the accelerated life test, the electrical isolation test will be conducted. The contractor shall notify the contracting officer thirty (30) calendar days in advance of their intent to submit samples for the Accelerated Life Test (4.6).

1.5 Government Furnished Equipment (GFE). The following equipment will be furnished at no cost to the contractor to aid in the design of the solar modules.

- 5 EA Tamperproof Nuts (NSN: 5310-01-198-8978)

1.6 Precedence. Any ambiguity or conflict between this specification, drawings, and applicable documents shall be resolved by utilizing the following documents in the precedence shown.

a. This specification
b. Engineering drawings
c. Applicable documents

2. APPLICABLE DOCUMENTS.

2.1 Issues of Documents. The following documents form a part of this specification to the extent referenced herein.

2.1.1 Industry Specifications.

ASTM B209-04	-	Standard Specification for Aluminum and Aluminum-Alloy Sheet and Plate
SAE-AMS-5524K (JUN-03)	-	Steel, Corrosion and Heat-Resistant, Sheet, Strip, and Plate
SAE-AMS-QQ-S-763A (FEB-03)	-	Steel, Corrosion Resistant, Bars, Wire, Shapes, and Forgings

2.1.2 Military Specifications.

MIL-DTL-15024F (28-NOV-97)	-	Plates, Tags, and Bands for Identification of Equipment
MIL-PRF-19500M (22-OCT-99)	-	General Specification for Semiconductor Devices

2.1.3 Standards.

J-STD-006A (01-MAY-01)	-	Electronic Grade Solder Alloys and Fluxed and Non-Fluxed Solid Solders for Electronic Soldering Applications
MIL-STD-129P (29-OCT-04)	-	Standard Practice for Military Marking
MIL-STD-810F (05-MAY-03)	-	Environmental Test Methods
MIL-STD-889B (3) (17-MAY-93)	-	Dissimilar Metals

2.1.4 Reference Standards.

ASTM D1603 (10-MAR-01)	-	Carbon Black in Olefin Plastics
ASTM E948-95 (Rev. 2001)	-	Standard Test Method for Electrical Performance of Photovoltaic Cells Using Reference Cells

ASTM G159-98 (Rev. 1998)	-	Standard Tables for Reference Solar Spectral Irradiance at Air Mass 1.5: Direct Normal and Hemispherical for a 37° Tilted Surface
ASTM E1597-99	-	Standard Test Method for Saltwater Pressure Immersion and Temperature Testing of Photovoltaic Modules for Marine Environments
ASTM D3951-98 (Rev. 2004)	-	Standard Practice for Commercial Packaging

2.1.5 Handbooks.

MIL-HDBK-454 (03-NOV-00)	-	Standard General Requirements for Electronic Equipment
DOE Publication JPL Doc#: 5101-162 (1981)	-	Block V Solar Cell Module Design and Test Specifications for Residential Applications
DOE Publication JPL Doc#: 5101-21 (1977)	-	Rejection Criteria for JPL LSSA Modules

2.1.6 Other References.

ANSI/AIM BC 1 (16-AUG-95)	-	Uniform Symbology Specification Code 39

2.2 Drawings. U.S. Coast Guard Civil Engineering Drawings form a part of this specification to the extent specified herein. Latest versions of both drawings can be found here: http://www.uscg.mil/systems/gse/gse2/Drawings2B.htm.

121103 (Rev. G, 1999)	-	Universal Solar Panel Frame
120978 (Rev. E, 1999)	-	Fixed Aids Lantern Stand Assembly and Details

2.3 Sources of Coast Guard Documents. All U.S. Coast Guard publications and documents may be obtained from the Contracting Officer.

3. REQUIREMENTS.

3.1 General. Design and construction of solar PV modules shall be based on a minimum service life of twelve (12) years in the marine environment. Detailed module requirements are contained in subsequent sections and paragraphs of this specification.

3.2 Approval. Modules submitted for approval shall be in conformance with all requirements of this specification.

3.3 Standardization of design. All modules delivered to the Coast Guard of a given watt size shall be electrically and mechanically interchangeable to permit individual modules to be removed and replaced after installation. In the event the contractor wishes to introduce any changes, to correct design deficiencies or selection of marginal parts, etc., the Contracting Officer may require repetition of any or all of the first article tests before the proposed changes are approved. Additionally, any contractor intending to provide modules that are somewhat physically and/or dimensionally non-conforming (that is, does not meet any of the three standard geometric configurations described herein) shall use the mounting adapter (6.1.22) provision (3.5.1.3.1) to ensure interchangeability. The largest acceptable non-conforming module footprint with a proposed mounting adapter attached shall fit inside a square not exceeding 28⅛ inches in length by 28⅛ inches in width. The contractor shall submit adapter design details including drawings/diagrams, materials used, and construction techniques along with a fully constructed sample adapter to the Contracting Officer's Technical Representative for evaluation and approval before proceeding with any pending production contract activity.

3.4 Environmental. Modules will be exposed to a variety of abuses while installed on marine aids to navigation. Among potential abuses are heavy winds, precipitation, extremes of temperature and humidity, salt spray, collision, bird guano, air pollution, and vandalism. Each module shall operate as specified under the following environmental conditions:

3.4.1 Ambient Temperature. From -20° F through 125° F.

3.4.2 Humidity. From 0% through 100% relative humidity.

3.4.3 Salt air and salt water. Each module shall be constructed of materials so as to be resistant to corrosion from continuous exposure to salt air and occasional immersion in salt water.

3.4.4 Shock and Vibration. Each module shall be ruggedly constructed to withstand the shock and vibration incident to service on lighted buoys and fixed AtoN structures.

3.5 Module. For the purposes of this specification, the module is the basic power unit, and all requirements are given on this basis. Modules shall not employ solar collecting techniques such as mirrors, lenses, and other concentrating devices to increase power output.

3.5.1 Design and Construction. Modules will be operated in a marine environment. The exterior of each module shall be free from protrusions and sharp edges that may catch the clothing of or lacerate servicing personnel. The corners of all modules shall be rounded.

3.5.1.1 Dimensions for Standard Module Packages. The contractor shall package modules into any of three standard module packages (6.1.20), as shown in Table 1. The maximum permissible weight for each complete module package shall not exceed 1.0 pound (0.45 kg) per watt of output electrical power including module mounting provisions (including mounting adapters, if used) and potted electrical output cable.

TABLE 1

Module Size (including Borders and Frame)	Length (In inches) ±1/32"	Width (In inches) ±1/32"	Maximum Depth (In inches) Excluding the Junction Box (3.5.1.6)	Maximum Weight (In pounds)
Ten-Watt Module Package	16	16	2	10
Twenty-Watt Module Package	22	22	2	20
Forty-Watt Module Package	28	28	2	40

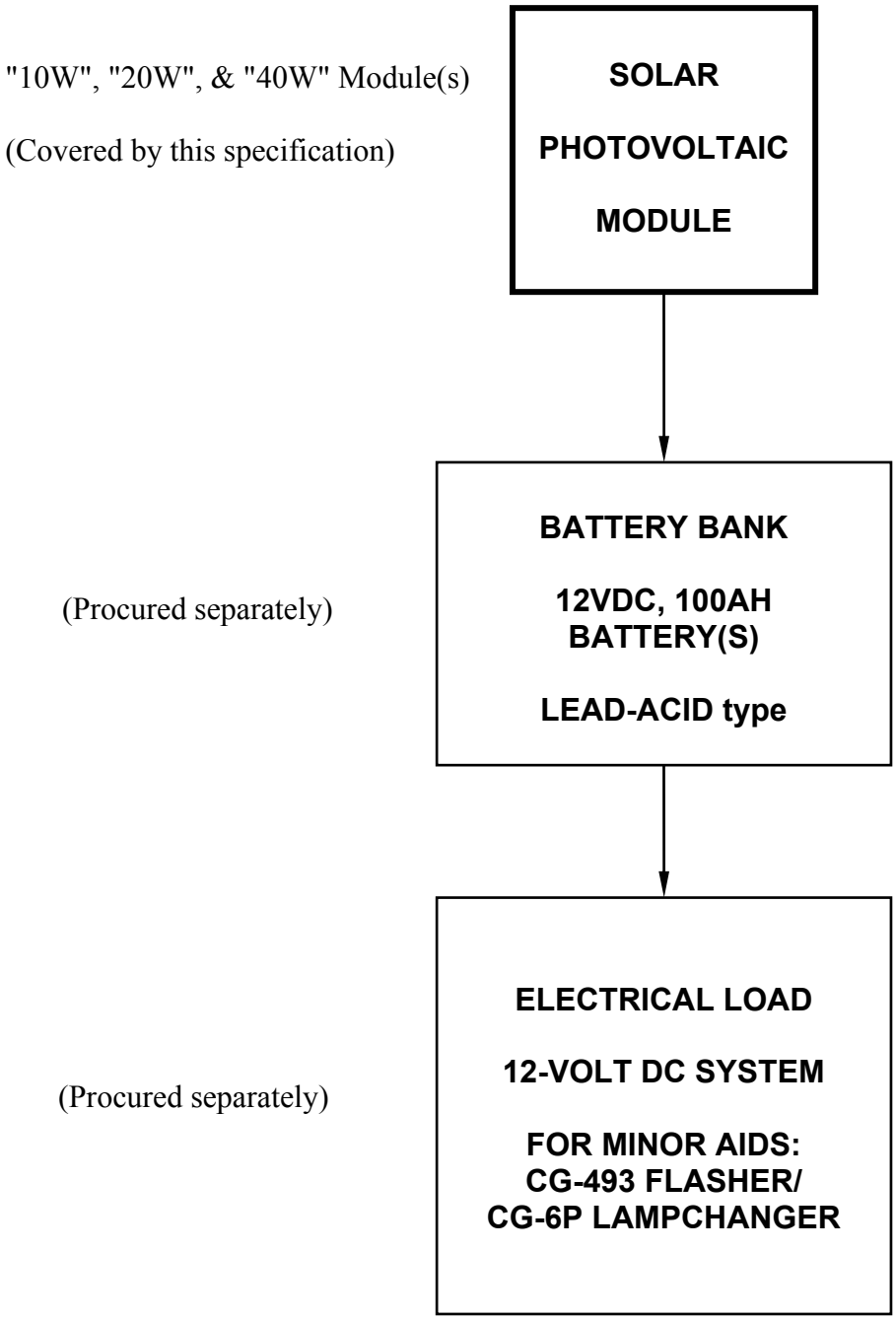
3.5.1.2 Sealing. The modules shall be constructed with a hermetic seal between the upper and lower vapor barriers. A glass cover shall provide the upper vapor barrier. A supporting metal backing plate (substrate, 6.1.16) shall cover the entire underside of the module and form the lower vapor barrier.

3.5.1.2.1 Encapsulation. The encapsulant shall fill all voids in the interior of the module and shall adhere to the front glass and the backing plate. It shall have a water absorption coefficient of less than 0.15% and a dielectric strength greater than 500 volts/mil. The encapsulation system of the module shall incorporate, at minimum, a layer of silicone encapsulant at the edge interface and the junction box interface filling all voids and vapor paths to the interior of the module.

3.5.1.3 Mounting Provisions for Standard Module Packages. Modules shall be fabricated with bolt holes for mounting in accordance with the composite bolt hole spacing patterns shown in Figures 2, 3, and 4. Bolt holes for this mounting arrangement shall be configured as "through holes" to accept the stud-mounted AtoN Bird Springs as described in specification G-SEC-342 (find latest version of the spec here: http://www.uscg.mil/systems/gse/gse2/Specifications.htm) and the tamperproof nuts issued as GFE. These two pieces of hardware will be mounted on top of the module framework. The composite bolt hole spacing patterns will allow for multi-directional mounting capability and interchangeability between the support platforms for fixed and floating AtoN. The module construction shall permit assembly in accordance with all the details contained in the referenced U.S. Coast Guard Civil Engineering Drawings.

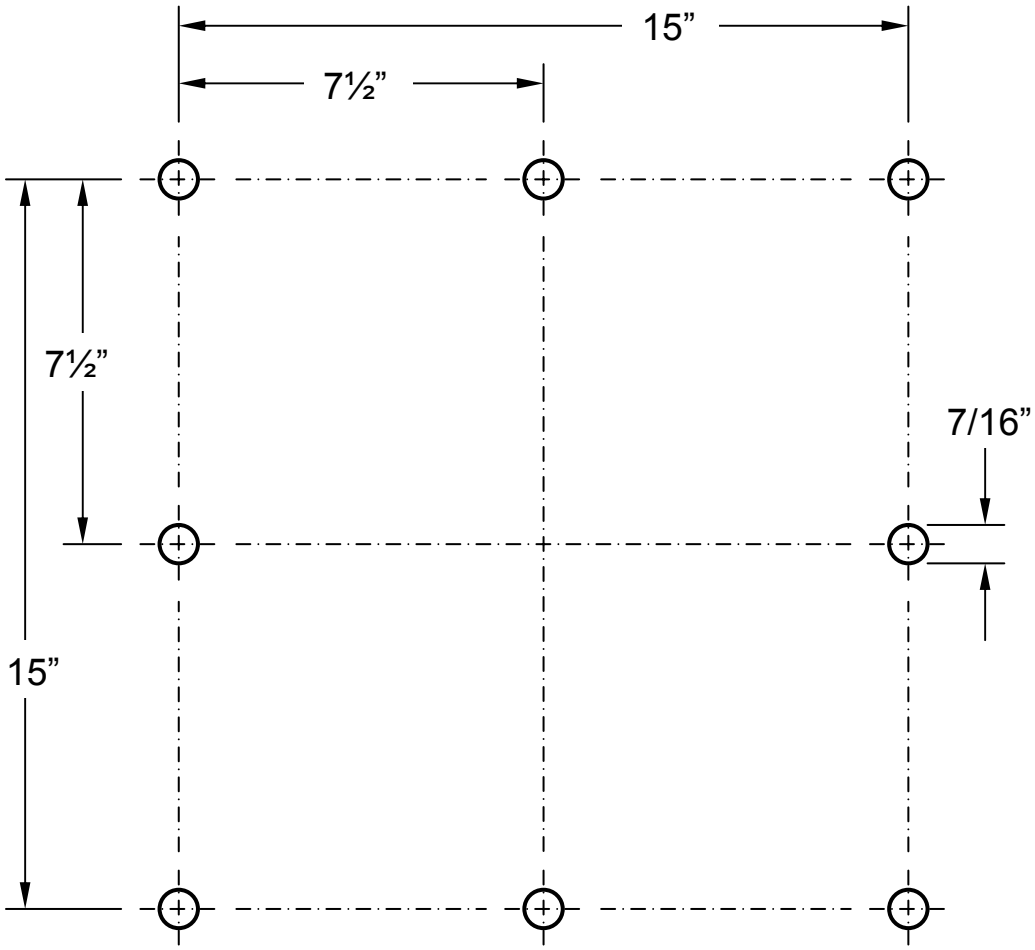
3.5.1.3.1 Mounting Adapter (Optional). The mounting adapter described here is separate from this specification and will be evaluated individually on a case-by-case basis. If, for whatever reason, the contractor cannot or will not produce solar photovoltaic modules to meet all of the

physical and dimensional requirements set forth in section 3.5 to achieve the standard geometric configuration required to ensure product interchangeability but still meets all other requirements in this specification as demonstrated by successfully passing all tests and inspections required in section 4, Quality Assurance Provisions (except those tests and inspections that are precluded by the very physical and/or dimensional differences in question), then the contractor shall provide an adapter plate, frame, or other means of adapting the module to match the standard mounting hole spacing patterns shown in Figures 2, 3, and 4 such that the interchangeability requirement in paragraph 3.3 is satisfied. Please be reminded that the maximum allowable length and width of the module with adapter installed (that is, the footprint of the entire module/adapter assembly) shall be 28⅛ inches (L) by 28⅛ inches (W). Adapter hardware shall be constructed of material suited to withstand the same harsh marine environmental extremes that the modules themselves will be operated in. The adapter shall have a minimum service life of twelve (12) years. The adapter shall hold the module rigidly and securely in place for the duration of its service life in the marine environment. For bidding purposes on competitive production-quantity contracts, a quotation or bid submitted in response to an official RFQ or IFB for Solar Photovoltaic Modules for 12 Volt DC Marine Aids to Navigation shall include the cost of mounting adapters, if used, as an integral part of the modules and shall not be added as a separate contract line item (CLIN). A successful bidder using this provision shall provide one each, previously-approved, mounting adapter with each production module that is offered to the Coast Guard for inspection and acceptance.



SOLAR PHOTOVOLTAIC POWER EQUIPMENT BLOCK DIAGRAM

FIGURE 1

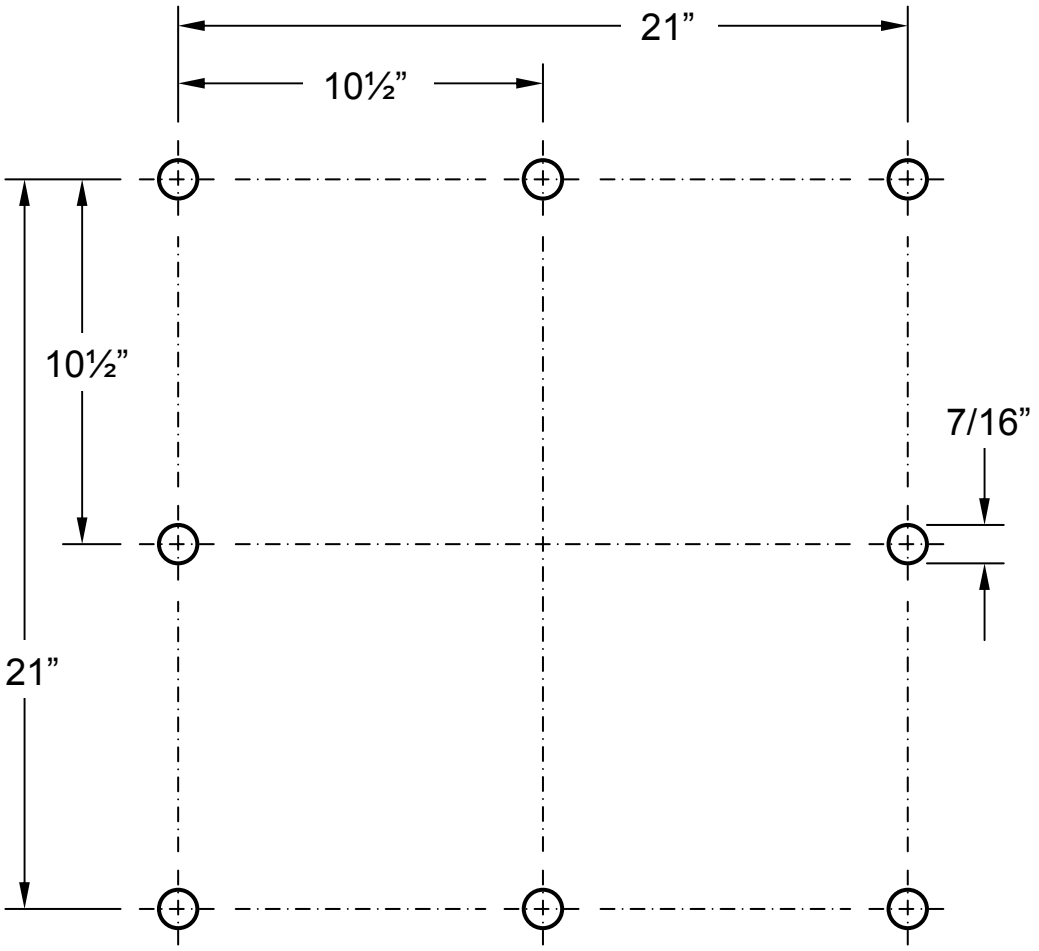


NOTES:

1. All tolerances shall be ±1/32”
2. Bolt hole diameter shall be 7/16”

COMPOSITE BOLT HOLE SPACING PATTERN FOR TEN WATT MODULES

FIGURE 2

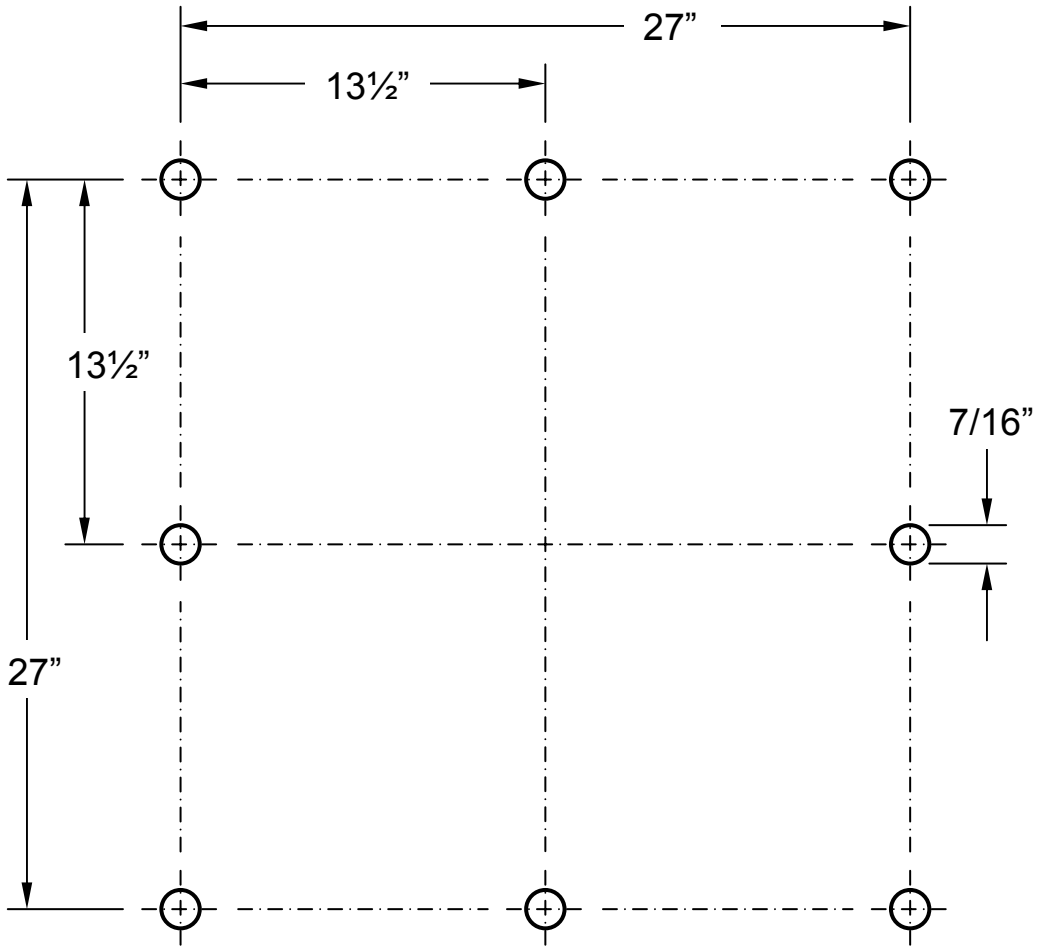


NOTES:

1. All tolerances shall be ±1/32”
2. Bolt hole diameter shall be 7/16”

COMPOSITE BOLT HOLE SPACING PATTERN FOR TWENTY WATT MODULES

FIGURE 3



NOTES:

1. All tolerances shall be ±1/32”
2. Bolt hole diameter shall be 7/16”

COMPOSITE BOLT HOLE SPACING PATTERN FOR FORTY WATT MODULES

FIGURE 4

3.5.1.4 Intercell Connections. Intercell connections (6.1.10) within the module shall be made to allow for thermal expansion and to relieve mechanical stress. Two or more intercell electrical contacts to the collector grid contact area (6.1.12) of one cell and the back contact area (6.1.13) of the next cell shall be provided. These connections shall be designed such that failure of any contact shall not degrade the individual cell electrical output by more than 5% from its output under Standard Test Conditions (STC) (6.1.1). The contractor shall provide certified test data verifying that the method of intercell connections employed meets the above requirement. Interconnection rework (e.g., patching or solder coating) is acceptable only before the circuit element is encapsulated provided rework meets workmanship requirements.

3.5.1.5 Solder. Solder employed in cell connections shall be composition Sn62 type alloy consisting of 62% tin, 36% lead, and 2% silver conforming to J-STD-006. Solder shall cover the entire contact area where the intercell connection overlaps the front cell area (6.1.6) of one cell and the back contact area of the next cell.

3.5.1.6 Electrical Output Connections. Each module shall have a sealed junction box. This box shall not extend more than one and three-quarters inch (1¾") from the back plate of the module. The junction box shall be centered ±1 inch on any side of the module and located four inches ±¼ inch from the edge of the substrate. This junction box shall enclose both the positive and negative output terminal posts. These terminal posts shall penetrate the substrate and the base of the junction box. The junction box shall contain a small removable/replaceable cover for easy access to and replacement of the blocking diode (3.5.2.5) should the need arise. The junction box shall be completely filled with a soft, clear, removable, self-healing, room temperature cure (RT cure), dielectric potting gel leaving no air gaps (Sylgard® 527 dielectric gel or equivalent meets this requirement). The junction box shall be attached in such a manner as to prevent the intrusion of air or moisture between the junction box and the array. The output terminal connection leading from the module terminal posts shall be a hard service cord having a UV stabilized polyvinyl chloride (PVC) jacket with a carbon black content (by weight) of not less than 2.6% ±0.25% and a particle size of 20 as determined in accordance with ASTM-D1603 and two No. 18 minimum AWG stranded copper wire conductors with polyethylene (PE) insulation. The conductors shall be color coded black for the positive module lead and white for the negative module lead. The cord length shall be twelve (12) feet ±4 inches as measured from the point where the cord exits the junction box. The outside diameter of the cord shall not exceed one-quarter inch (¼").

3.5.1.7 Ground Terminal. A ground terminal is not required.

3.5.2 Materials. Materials used in the construction of the photovoltaic modules shall conform to the following requirements.

3.5.2.1 Metals. Metals used in the construction of modules including the mounting framework, which will be exposed to the environment, shall be selected from the following:

a. Aluminum sheet stock shall be type 5086 or type 5052 conforming to ASTM B209.

b. Aluminum plate shall be type 5456 or type 5052 conforming to ASTM B209.

c. Stainless steel shall be type 316 or 316 L conforming to SAE-AMS-5524 or SAE-AMS-QQ-S-763.

When contact between dissimilar metals is required in the construction of the modules, they shall be selected and treated in accordance with MIL-STD-889.

3.5.2.1.1 Backing Plate Thickness. Backing plate thickness shall be a minimum of 0.07375 inch aluminum or 0.0525 inch stainless steel.

3.5.2.2 Glass Cover. Tempered glass, capable of passing the test outlined in paragraph 4.5.2, shall be used as the protective cover for the front (or active surface area) of the module. It shall be selected for high impact and thermal shock resistance. Iron content shall be equal to or less than 0.04% by weight.

3.5.2.3 Cell Material. All the photovoltaic cells shall be made from silicon.

3.5.2.4 Other Materials. With the exception of the service cord, materials used in the module shall be selected from those designated as Group 1 fungus inert materials. A list of these materials is available in Guideline 4 of MIL-HDBK-454.

3.5.2.5 Blocking Diode. A blocking diode integral to the module conforming to MIL-PRF-19500 shall be installed in series with the positive module lead. The anode (+) of the diode shall be connected to the module side and the cathode (-) to the output side of the positive module lead. Each diode shall have a minimum Peak Inverse Voltage (PIV) rating of 50 volts and a minimum current rating of three (3) times the short circuit current of the module in which it is installed. The diode shall be enclosed in the sealed junction box (3.5.1.6) and be completely immersed in the soft removable potting gel.

3.5.3 Electrical Performance. The electrical performance of each module shall conform to the following requirements.

3.5.3.1 Power and Voltage Output. The power and voltage output of each module with the blocking diode installed as measured at the end of the twelve feet (12') long service cord shall conform to the requirements in Table 2.

TABLE 2

Module Size	Power Output @ 13.3 volts under STC		Voc @ STC (6.1.4)	
	Minimum	Maximum	Minimum	Maximum
Ten Watt Module	8.0 watts	13.0 watts	16.6 volts	17.2 volts
Twenty Watt Module	17.0 watts	24.0 watts	16.6 volts	17.2 volts
Forty Watt Module	35.0 watts	50.0 watts	16.6 volts	17.2 volts

A copy of each measured I-V curve shall be identified with the serial number of the module and furnished to the Coast Guard when the article is submitted for acceptance. Module measurements shall be made in accordance with standard ASTM-E948 using a global solar spectrum conforming to standard ASTM-G159.

3.5.3.2 Fill Factor (FF). The fill factor (FF) (6.1.9) of each module as determined at STC shall not be less than 0.70. The fill factor shall be measured and documented on the individual module I-V curve for each module submitted for approval or acceptance.

3.5.3.3 Electrical Isolation. Insulation resistance shall be greater than 25 megohms measured from the shorted module output terminals to the metal frame or substrate.

3.6 Documentation.

3.6.1 First Article Test Plan. The contractor shall submit to the Contracting Officer for approval a detailed test plan for the first article testing specified herein. This test plan shall be submitted to the Contracting Officer not later than thirty (30) days prior to the commencement of testing. At a minimum this plan shall include the following information:

a. A chronological listing of the tests to be performed;
b. Location of test facility;
c. A complete listing of all equipment to be used;
d. Detailed test procedures for the test configuration and pass/fail criteria;
e. All information necessary to fully describe the test; and
f. Test data sheets shall be provided with the test plan and shall be used to record observed performance data.

3.6.2 First Article Test Data and Final Report. Within thirty (30) days of the conclusion of first article testing the contractor shall submit to the Contracting Officer a test report containing all test data and the results of each test. Each test data sheet shall contain a summary of all deficiencies noted and the corrective action taken. It shall also include any recommended changes to the detailed test procedures. At a minimum the test data sheets shall include the following information:

1. Time and date of test;
2. Module and test equipment serial numbers;
3. Name of test being performed. Include references to the requirement and test paragraphs of this specification and reference the applicable test plan paragraph;
4. Pass/fail criteria;
5. Actual measured values;
6. Date and signatures of test personnel; and
7. Appropriate space for the witnessing signature of the Coast Guard Inspector.

This report shall be submitted to the Contracting Officer for review and approval before beginning production.

3.7 Workmanship. Workmanship shall be evaluated in accordance with Guideline 9 of MIL-HDBK-454. In addition, each module shall meet the more stringent requirement of being free from the defects listed in Table 3 of this specification.

3.8 Nametag. Nametags for modules shall be Type E conforming to MIL-DTL-15024. The nametag shall be located under the glass cover. All information contained in the nametag shall be legible to the naked eye from a distance of two feet. The size of the nametag shall be optimized to satisfy legibility requirements and to meet module dimensional constraints. The nametag shall, at a minimum, contain the information listed in Figure 5. The contractor shall place an "XX" in the manufacturer's code field of the nametags of the modules submitted for First Article testing. The contractor shall then obtain the two-letter manufacturer's identification code from the Contracting Officer following successful first article testing and approval. All modules manufactured under a production contract shall have serial numbers that contain a suffix letter "**Y**" where "**Y**" represents a letter issued by the Contracting Officer upon award of contract to identify a specific purchase, as shown in Figure 5.

(Not to scale)

NAMETAG

FIGURE 5

3.9 Identification Plate. An identification plate listing the module as "PROPERTY OF U.S. COAST GUARD" shall be permanently displayed on the module to conspicuously identify the owner of the module to the uninformed. The plate shall be placed in a strategic yet conspicuous location such that a thief would have to dismantle or destroy the module to remove the plate. Possible methods of attachment include permanent attachment to the backing plate or frame, molded into the backing plate or frame, stamped into the backing plate or frame, and incorporated into the nametag (3.8). Any method of identification plate attachment requires approval prior to submission for First Article testing.

4. QUALITY ASSURANCE PROVISIONS.

4.1 Classification of Inspections. The inspection requirements specified herein are classified as follows:

a. First Article Tests - Sections 4.3 through 4.7
b. Production - Section 4.2.2

4.2 Responsibility.

4.2.1 First Article Test Inspection Responsibility. The contractor shall be responsible for the performance of all first article testing with the exception of the Accelerated Life Test (4.6) and a post-Accelerated Life Test Electrical Isolation Test (4.4.2.3), which will be provided by the government. The contractor shall provide space, personnel, and test equipment for the conduct of all other approval inspection requirements. All testing and inspection except those furnished by the government shall be performed at the contractor's plant, or at other facilities acceptable to the Coast Guard. The contractor shall notify the Contracting Officer at least fourteen (14) working days prior to the scheduled commencement of any tests required by this specification.

4.2.2 Production Inspection Responsibility. The contractor shall be responsible for the performance of all production inspections. The contractor shall conform to the production inspection requirements set forth in the Solicitation/Contract. The tests and inspections required by this specification are not intended to supplant any controls, examinations, inspections, or tests normally employed by the contractor to assure product quality. The contractor shall provide space, personnel, and test equipment for the conduct of all production inspection requirements. All testing and inspection shall be performed at the contractor's plant, or at other facilities acceptable to the Coast Guard. The contractor shall notify the Contracting Officer at least fourteen (14) working days prior to the scheduled commencement of any tests required by this specification or according to the provisions set forth in the Solicitation/Contract. The contractor shall not give notification unless the quantity of materials ready for inspection consists of a full lot as defined by the Contract.

4.2.3 Coast Guard Production Inspection. The Coast Guard reserves the rights to observe, verify, or perform the tests and inspections outlined in the paragraphs above.

4.3 First Article Inspection. Upon notification to the Contracting Officer of a desire to submit samples for first article testing, the Contracting Officer will assign quality assurance inspectors and will provide the address to which the contractor's products are to be delivered for accelerated life testing (4.6).

4.3.1 Sample Submission. Samples submitted for first article testing and approval shall be representative of the contractor's proposed normal production. Samples shall consist of two 10 watt modules, two 20 watt modules, and two 40 watt modules.

4.3.2 First Article Test Sequence. All samples submitted shall be subjected to the following tests, in the sequence shown, at the indicated facility:

1. Basic Module Inspection (4.4.1) (contractor's facility)
2. Electrical Performance and Special Tests (4.4.2) (contractor's facility)
3. Environmental Tests (4.5) (contractor's facility)
4. Accelerated Life Test (4.6) (U.S. Coast Guard facility)
5. Electrical Isolation Test (4.4.2.3) (U.S. Coast Guard facility)
6. Electrical Output Test (4.4.2.1) (contractor's facility)
7. Fill Factor Test (4.4.2.2) (contractor's facility)

4.4 Capabilities Inspection. Samples shall be subjected to a series of inspections as defined below:

4.4.1 Basic Module Inspection. Each module shall be visually examined, measured, and weighed to determine conformance to requirements of sections 3.5.1, 3.5.2, 3.7, 3.8, and 3.9 relating to the design, construction, materials, workmanship, nametags, and identification plates.

4.4.2 Electrical Performance and Special Tests.

4.4.2.1 Electrical Output. The electrical output of each module shall be tested as outlined in paragraph 3.5.3.1 using indoor solar simulation measurement procedures specified in ASTM-E948-95.

4.4.2.2 Fill Factor. Using data obtained in paragraph 4.4.2.1 the fill factor (FF) of each module shall be calculated and recorded as noted in paragraph 3.5.3.2.

4.4.2.3 Electrical Isolation. Module output terminals shall be shorted together and connected to the high voltage contact of a megohmeter. The return contact of the megohmeter shall be connected to the module metal frame or backing plate (substrate). The module shall be tested in the non-illuminated state. The insulation resistance shall be measured after a one (1) minute application of +500 VDC. Insulation resistance shall be greater than 25 megohms as measured from the shorted module output terminals to the metal frame or backing plate (substrate) of the module.

4.5 Environmental Tests. All six (6) sample modules shall undergo the following environmental tests.

4.5.1 Twisted Mounting Surface. Modules shall be subjected to a deflection test in accordance with JPL Document #: 5101-162, Section V, Part E.

4.5.2 Impact Resistance. Modules shall be tested for impact resistance according to the following procedure: Module glass cover shall survive one hit in the center of its front surface area using a one inch (1") diameter, 2.36 oz. steel ball dropped from a height of one yard (36.0 inches) above the top surface with the module lying face up supported by blocks on a hard horizontal surface.

4.5.3 Robustness of Termination. The electrical output cable of each module shall be subjected to a force equal to the weight of the unit under test (the module) applied in any direction

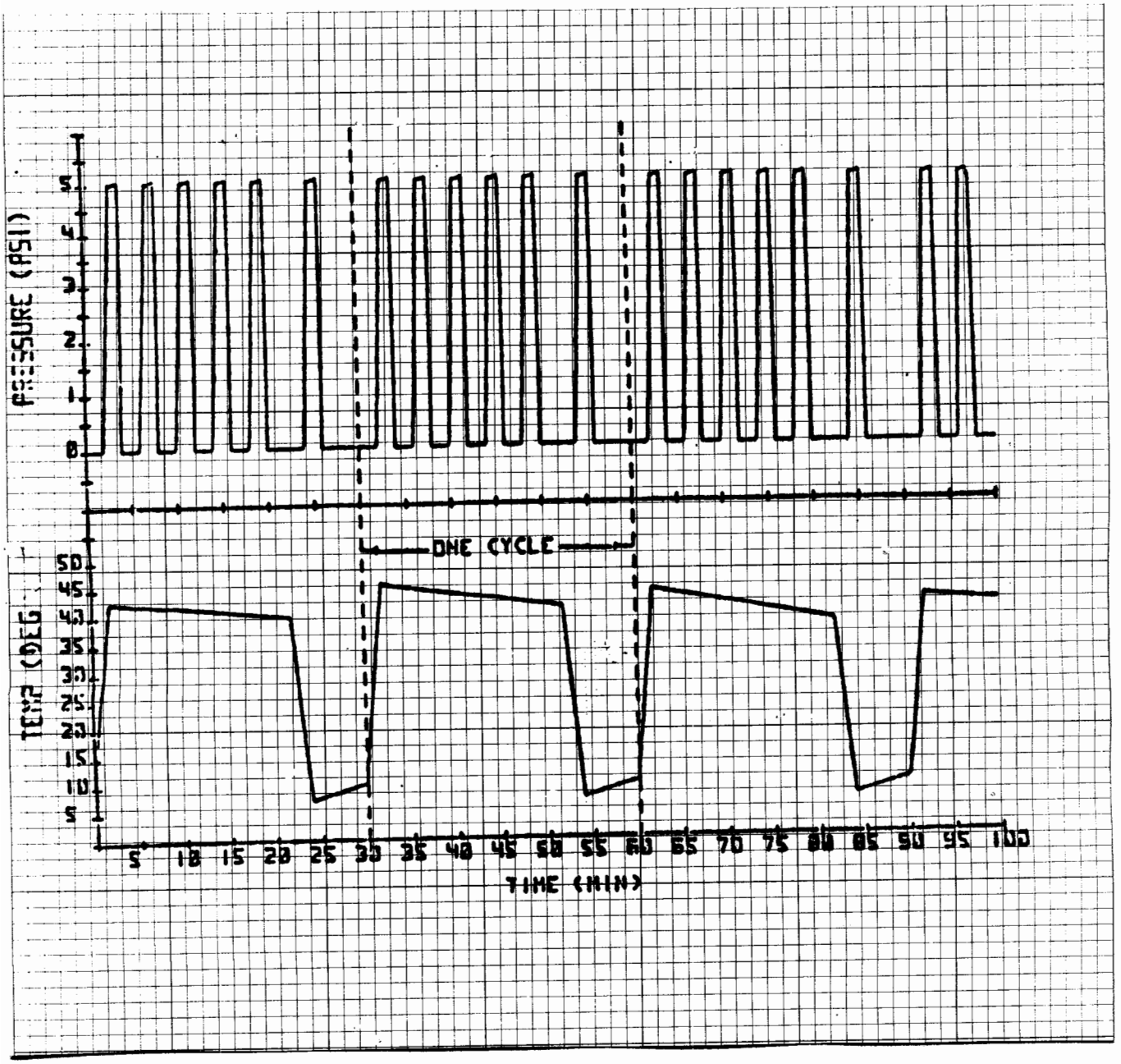
permitted by the module construction for a period of one (1) minute. No damage to the output cable, junction box, or the module shall occur.

4.5.4 Temperature Shock. Modules shall be subjected to thermal shock in accordance with MIL-STD-810, Method 503.1.

4.6 Accelerated Life Test. Modules shall be subjected to an accelerated life test known as the Pressure Immersion Temperature Cycling (PIT) test. This test was developed by the U.S. Coast Guard Research and Development Center to permit rapid and accurate identification of solar photovoltaic modules that would be suitable for use in the marine environment. Additionally, the Coast Guard's PIT test has been approved by the ASTM subcommittee E44.09 for Photovoltaic Electric Power Conversion and published as ASTM E1597. The ASTM document describes the PIT test in greater detail than presented here. During the PIT test, modules are placed in an environmental control chamber and immersed in a salt-water solution. The chamber is then run through a number of pressurization cycles in both hot and cold water. Although ASTM E1597 calls for 500 hot-cold PIT cycles, the Coast Guard has reduced this requirement to 200 cycles for purposes of this specification. The modules are then electrically tested for defects. As illustrated in Figure 6, module temperature may drift slightly outside the limits of the temperature of the immersing water. This is normal and acceptable. Each cycle of PIT testing takes about 30 minutes to accomplish. As stated above, the U.S. Coast Guard will perform 200 hot-cold PIT cycles on the modules submitted for approval. The contractor shall allow three weeks for the performance and completion of this test.

Note: U.S. Coast Guard personnel prior to placing modules into the environmental control chamber will seal the end of the service cord.

4.7 Acceptance/Rejection Criteria. Failure of any sample module to conform to all aspects of the Basic Module Inspection (4.4.1), Electrical Performance and Special Tests (4.4.2), and Environmental Tests (4.5) prior to being subjected to the PIT test shall constitute a failure. Failure of any one (1) of the six (6) module samples to conform to all the requirements of this specification at the conclusion of all testing shall result in rejection of all samples.



Pressure and Temperature Cycling Sequence

FIGURE 6

5. PREPARATION FOR DELIVERY.

5.1 Packaging. Each item is to be individually packaged in accordance with ASTM-D3951 "Standard Practice for Commercial Packaging."

5.2 Marking. Marking shall be in accordance with MIL-STD-129. Required Bar Coding shall be in accordance with ANSI AIM BC1. The National Stock Numbers (NSN) for the three modules are:

- Ten (10) Watt Module ……... 6117-01-145-7152
- Twenty (20) Watt Module …. 6117-01-145-7153
- Forty (40) Watt Module …….6117-01-148-7879

6. NOTES.

6.1 Definitions. The following terms and definitions are used throughout this specification.

6.1.1 Standard Test Conditions (STC). Cell temperature stabilized at 25° C ±2° C at an irradiance level of 1,000 W/m², as measured with a calibrated reference cell at Air Mass 1.5 (AM1.5).

6.1.2 Reference Cell. A calibrated cell made from the same material as the test cell/module.

6.1.3 Short Circuit Current (Isc). The current through a precision load resistor such that the voltage across the cell/module is less than 20 mV per junction.

6.1.4 Open Circuit Voltage (Voc). The voltage across a loaded cell/module and blocking diode with the circuit conducting 10 ±1.0 milliamps.

6.1.5 Watts. A measurement of module output power consisting of the product of module output current multiplied by module output voltage at a specified voltage.

6.1.6 Cell Area. The entire front surface area of the solar cell including the area covered by the grids and contacts.

6.1.7 Module. The smallest independent unit which will produce the required electrical characteristics consisting of solar cells, blocking diode, junction box, and service cord. A solar module is sometimes referred to as a solar array or solar panel.

6.1.8 Module Area. The entire surface area (length times width) of the module including borders and frame.

6.1.9 Fill Factor (FF). The ratio of the maximum power output (Pmax) of the cell/module divided by the product of the open circuit voltage (Voc) and short circuit current (Isc), at STC.

6.1.10 Intercell Connections. The current carrying electrical connections (also referred to as interconnects) attached to the P and N junctions of the solar cells.

6.1.11 Service Band Loops. A type of interconnection made of formed metal ribbon having an out-of-plane expansion loop to allow for thermal stress relief and thermal expansion.

6.1.12 Collector Grid Contact Area. The illuminated area of the solar cell where the contacts are made.

6.1.13 Back Contact Area. The metallic deposit area on the back surface of the solar cell, not illuminated.

6.1.14 Bubble. An interior void in the silicone encapsulant.

6.1.15 Delamination. The partial or complete separation of the materials at their interface, including local interior delamination sometimes called "blisters." This includes adhesive delamination, anti-reflective coating delamination, and contact delamination.

6.1.16 Substrate. The supporting metal backing plate upon which the module assembly rests. The substrate also serves as the lower vapor barrier of the module.

6.1.17 Adhesive Delamination. Separation, or partial separation, of the silicone at the glass protective cover or at the interface between the silicone and the substrate.

6.1.18 Contact Delamination. Separation, or partial separation, of any layers of the electrical contact from the solar cell or from each other.

6.1.19 Foreign Material. Any stray matter such as dust, dirt, lint, adhesive, silicon, solder, water, salt water, salt crystals, etc., which is not a constituent of the module assembly.

6.1.20 Module Packages. The three standard geometric configurations that are compatible with existing mounting hardware. Power rating of each package indicates only relative physical size.

6.1.21 Scratch. A slight injury or mark penetrating a surface that can be felt when a fingernail is dragged across it in a direction perpendicular to the injury's or mark's longest dimension and with the fingernail normal to the injured surface.

6.1.22 Mounting Adapter. Hardware allowing interchangeability of modules that do not meet any of the three standard geometric configurations outlined in this specification.

6.3 Changes from Previous Issue. The margins of this specification are marked with an asterisk to indicate where official changes (additions, modifications, corrections, and deletions) from the previous issues were made, if any. The number of asterisks in the margin corresponds to the change number. New revisions to this specification will incorporate all official changes issued up to the new revision date; and, any future changes to the new revision will once again start with change number 1.

TABLE 3

Basic Module Inspection

Magnification: Inspection shall be performed using 6x magnification. Higher magnification shall be used for evaluation or clarification.

The following defects shall be cause for module rejection. Illustrated examples and further explanation of these type defects may be found in JPL Document #: 5101-21, Rejection Criteria for JPL LSSA Modules.

A. Identification.

- ○ 1. Markings or identification that shows signs of peeling or readily coming off.
- ○ 2. Missing contractual markings or identifications.
- ○ 3. Incorrect markings or identification.
- ○ 4. Illegible markings.

B. Module Mechanical Features.

- ○ 1. Module length, width, or depth out of tolerance.
- ○ 2. Module mounting hole size or location out of tolerance.
- ○ 3. Cracked or damaged structural elements.

C. Solar Cells.

- ○ 1. Cracked or broken solar cells.
- ○ 2. Cells in edge-to-edge contact.
- ○ 3. Cells in edge contact with the metal substrate.
- ○ 4. Overlapping cells.

D. Interconnects and Soldering.

- ○ 1. Collector or interconnect delamination.
- ○ 2. Alligatored contact (silicon fractured under collector).
- ○ 3. Extensive collector dewetting from silicon in the interconnect-to-collector contact area.
- ○ 4. Less than 50% solder fillet on soldered area of the interconnect-to-collector or back contact.
- ○ 5. Fractured, overstressed, or damaged interconnects.
- ○ 6. Solder joints obscured by residual flux.
- ○ 7. Broken or nicked wire strands at solder joints.
- ○ 8. Insulation of wire buried into solder joint.
- ○ 9. Solder joints that lack a solder fillet to all wires or other elements contained within the solder junction.
- ○ 10. Broken or fractured solder joints at output terminals.

- ○ 11. Split, burnt, crushed, or cut insulation on any of the lead wires; except that these defects will be allowed if within two inches from the unconnected end of the output service cord.
- ○ 12. Cut, nicked, or broken wire, or strand of wire; except that these defects will be allowed if within two inches from the unconnected end of the output service cord.
- ○ 13. Interconnect misalignment with less than 50% of interconnect in contact with collector.
- ○ 14. Stress relief loop frozen by solder.
- ○ 15. Wire or other interconnects in or near contact with other conductors, including conductive substrates.
- ○ 16. Folded interconnects.
- ○ 17. Damaged flat or printed circuit paths having less than 75% of current-carrying conductor remaining.
- ○ 18. Interconnect rework after circuit element encapsulation.

E. <u>Encapsulation</u>.

- ○ 1. Encapsulant cracking or splitting.
- ○ 2. Frame seal delamination.
- ○ 3. Holes or bubbles (6.1.14) in the encapsulant, regardless of size, which could serve as a direct moisture ingress path from the outside environment to an internal component.
- ○ 4. Bubbles or delamination (6.1.15) between output terminals or terminals to substrate.
- ○ 5. Uncured or insufficiently cured encapsulant characterized by excessively sticky surfaces and/or streaks of liquid on the surface of the encapsulant.
- ○ 6. Interlayer delamination.
- ○ 7. Air bubbles in uncured encapsulant that move about under finger pressure.
- ○ 8. Delaminations and bubbles.
    a. Delamination and/or bubbles greater than 5 mm across the largest dimension at any location.
    b. A bubble and/or delamination located where it can provide a path from one conductor to another or from a conductor to the metallic frame or substrate.
- ○ 9. Internal conductors, interconnects, or cells within 1.5 mm of the external surface of the encapsulant.
- ○ 10. Cracked or fractured glass or other protective coating.
- ○ 11. Scratches over 5 cm in length in any direction or location on the glass cover.

F. <u>Foreign Material</u>. (6.1.19)

- ○ 1. Any metallic particle (including solder) resting on the cell junction.
- ○ 2. Any metallic particle (including solder) trapped between the interconnect and the cell junction.
- ○ 3. Any metallic particle trapped between an internal conductor, such as an interconnect and a conductive substrate.

○ 4. Dust, dirt, lint, water, salt water, or salt crystals in the interior of the module.

G. <u>Hardware</u>.

○ 1. Loose, missing, damaged, or non-conforming hardware.
○ 2. Encapsulant on external electrical contacts, mounting bosses, or mounting hardware surfaces.

H. <u>Final Test and I-V Data</u>.

○ 1. Data missing, incorrect, or out of specification tolerances.

SOLAR PHOTOVOLTAIC MODULES
FOR 12 VOLT DC MARINE
AIDS TO NAVIGATION

SPECIFICATION NO. 401C

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