REVISIONS

LTR.	ECN	DESCRIPTION	DATE	APPROVED
-	NA	Original release	yy/mm/dd	

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THE UNIVERSITY OF WISCONSIN

ANTARCTIC ASTRONOMY AND ASTROPHYSICS RESEARCH INSTITUTE

MADISON, WISCONSIN

TITLE

ICECUBE
PMT MODULAR HIGH VOLTAGE POWER SUPPLY REQUIREMENTS DOCUMENT

ORIGINATOR	DATE	ENGINEER	DATE	CHECKER	DATE
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Table of Contents

1 INTRODUCTION

1.1 Purpose

This IceCube Engineering Requirements Document (ERD) specifies the functional, constraint, and verification requirements for the PMT Modular High Voltage Power Supply Configuration Item (CI) including the source traceability (justification) for each requirement.

1.2 Scope

This requirements document shall be applicable to the design, development, integration, verification, production, logistics, field deployment and disposal of the PMT Modular High Voltage Power Supply.

1.3 Responsibility and Records

1.3.1 Document Responsibility

Physics/Engineering is responsible for writing and updating these requirements to ensure they are correct, complete and current. Quality Assurance is responsible for ensuring this document and changes to it are properly reviewed, approved and maintained.

1.3.2 Document and Verification Records

Records of this document and CI verification records shall be maintained as follows:

a. The approved and signed original of this document shall be maintained per 9000-0004, Document Management Process.

b. Changes to this document shall be via Engineering Change Notices (ECN's) as described in 9000-0004, Document Management Process.

c. Verification records shall be maintained as described in Section 4 of this document in compliance with 9000-0003, IceCube Quality Plan.

1.4 Item's Function in the IceCube System

The PMT (Photomultiplier Tube) Modular High Voltage (HV) Power Supply is an adjustable modular two-printed circuit board (PCB) power supply that creates and supplies approximately 2000 volts maximum anode bias and multiple dynode bias voltages to the PMT inside each Digital Optical Module (DOM). These multiple high voltages provide acceleration and focusing of electrons inside the PMT that flow in response to impinging photons from a nearby photonic event. This PMT electron flow is the critical sole detection mechanism for the IceCube system. By digital control a range of high voltages can be commanded that adjust the PMT for different photon sensitivities. There are 5120 Digital Optical Modules in the IceCube system, each containing a PMT Modular HV Power Supply. The IceCube system has 4800 DOMs deployed over a kilometer deep in the Antarctic ice with 320 additional DOMs installed on the ice surface, all used for scientific research.

2 APPLICABLE DOCUMENTS

The following documents of the exact issue shown are applicable requirements for this Configuration Item only to the extent they are invoked by specific requirements herein.

2.1 Government Requirements

{National Science Foundation, xxxxxxxx}

{Occupational Safety and Health Administration, xxxxxxxx}

{Federal Communications Commission, xxxxxxxx}

{Federal Aviation Administration, xxxxxxxx}

{Customs – import/export}

{Hazardous materials storage and handling}

{International Trafficking in Arms Regulation (ITAR)}

{Standard government test methods}

{Regulations for packing and shipping to Antarctica}

{Etc.}

2.2 University Policy Requirements

{Personnel and equipment safety}

{Test equipment calibration}

{Hazardous material storage and handling}

{Protecting intellectual property}

{Etc.}

2.3 Industry Requirements

{ASTM, ASME, EIA, NEC, ANSI, IEEE, JDEC, NFPA}

{Building codes}

{Standard on printed wiring board design}

{Standard test methods}

{Standard for soldering}

{Packing and shipping containers for commercial shipping}

{Etc.}

2.4 Certifications and Approvals

{Underwriters Laboratory, xxxxxxxx}

{European Union CE Marking, EC Directive xx/xx/EEC}

{Etc.}

2.5 Project Requirements

PMT HV Base Board Dimensional and Component Placement Requirements, PSL 5549B020 ***[TBR]*** Rev ?, ***[TBD]*** Physical Sciences Lab, University of Wisconsin – Madison ***[To be updated using 5549020B_f_nk1.pdf]***

Component Envelope Drawing, PSL 5549C021 Rev G, ***[TBR]*** Physical Sciences Lab, University of Wisconsin – Madison ***[To be updated using 5549021C_g_nk1.pdf]***

{Top level IceCube System specification, Document No. 9000-xxxx}

{Interface Requirements, Document No. 9000-xxxx}

PMT HV Base Board—DOMMB Interface Document (9000-0006 11/13/2002—To be updated)

{Etc.}

2.6 Reference Documents

{Reports or analyses from associated, similar or prior projects}

{Textbooks, symposia proceedings, or other associated references of record}

{White papers relating to the CI specified in this document}

Hamamatsu PMT Datasheet (R7081-02, Ver.4, July 2003)

{Etc.}

2.7 Order of Precedence

Conflicts within this document shall be resolved as directed by the IceCube System Engineer in collaboration with the Project Lead responsible for this Configuration Item.

In the event of a conflict between this document and any other documents, this document shall govern. An annotation of the nature of the conflict shall be placed in this document.

Conflicts between other documents as they relate to or impact this document shall be resolved as directed by the IceCube Project Manager in collaboration with the IceCube System Engineer.

3 REQUIREMENTS

3.1 Item Identification

3.1.1 Definition

The PMT (Photomultiplier Tube) Modular High Voltage (HV) Power Supply is a modular two-printed circuit board (PCB) 2000 volt high voltage power supply with a digitally

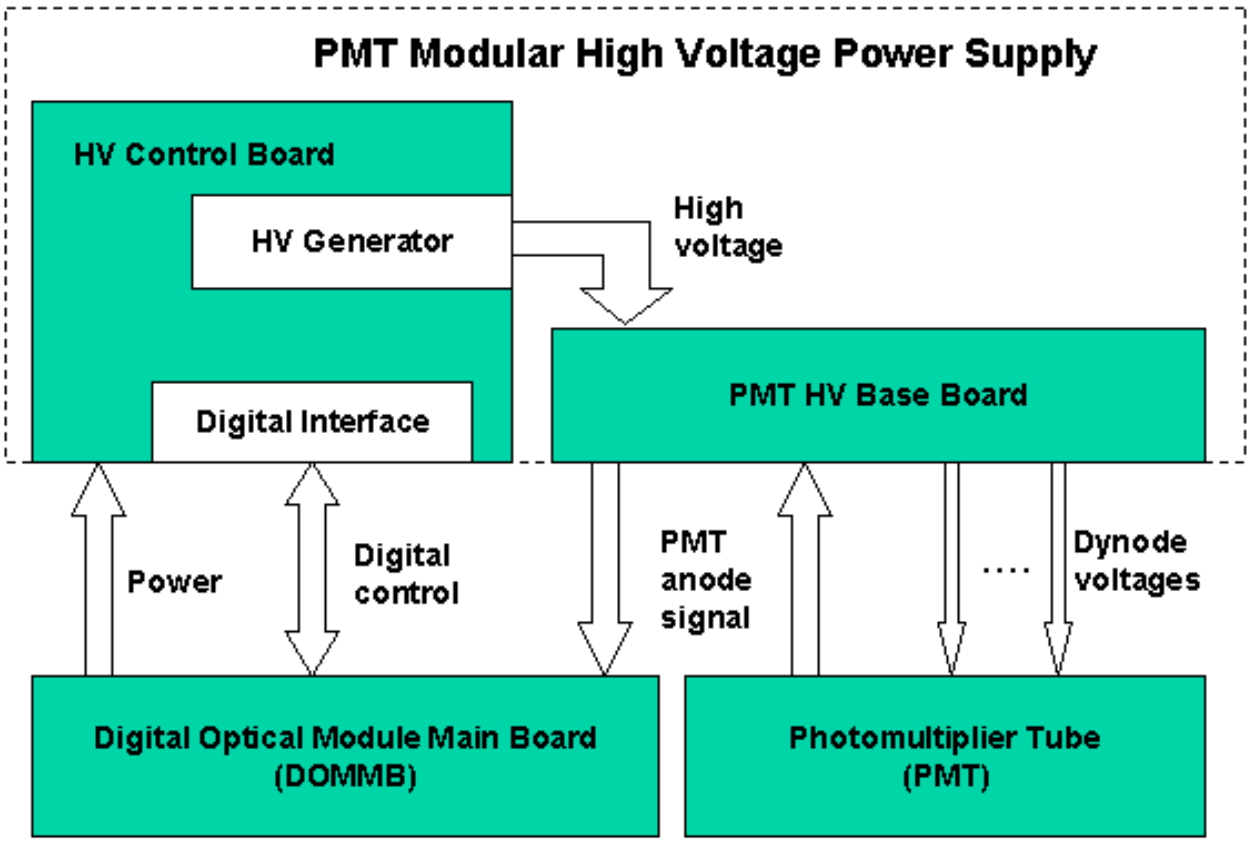
controlled and adjustable output, mounted inside a Digital Optical Module (DOM). The Power Supply consists of the High Voltage Control Board and the High Voltage Base Board.

3.1.2 Functional Description

The PMT (Photomultiplier Tube) Modular High Voltage (HV) Power Supply is an adjustable power supply that creates and supplies approximately 2000 volts DC anode bias to the PMT inside each Digital Optical Module (DOM). The PMT Modular HV Power Supply also supplies multiple DC bias high voltages to the PMT dynodes and focusing electrodes. The high voltages provide energy for e-fields inside the PMT that control the flow of electrons in response to impinging photons from a nearby photonic event. The PMT Modular HV Power Supply also provides functional monitoring for diagnostic voltage measurements and a transformer coupled circuit for extracting the analog output signal from the PMT anode.

3.1.3 Functional Block Diagram

The following block diagram illustrates the functional relationships of the PMT Modular High Voltage Power Supply with the DOM Main Board and the PMT in the IceCube system.



3.1.4 Functional External Interfaces

The PMT Modular High Voltage Power Supply has seven external functional interfaces:

1. Power input from the DOM Main Board
2. Bidirectional digital command, control, and monitoring to and from the DOM Main Board
3. Analog anode signal input from the PMT
4. PMT analog anode signal output to the DOM Main Board
5. High voltage outputs to the PMT's anode, dynodes, and focusing electrodes
6. Structural mounting of the HV Base Board by attachment to the PMT pins
7. Structural mounting of the HV Control Board by attachment to the Flasher Board

These interfaces are illustrated in the figure.

3.2 Performance Requirements

3.2.1 Functional Requirements

3.2.1.1 High Voltage Generation

The PMT Modular High Voltage Power Supply shall generate a series of high voltages for the individual dynodes, focusing electrodes and the anode of the PMT, using the power provided by the DOM Main Board.

REQUIREMENT'S SOURCE:

Preliminary Design Document (PDD), Section 7.2, Digital Optical Module

VERIFICATION METHOD:

Inspection

3.2.1.2 PMT Signal Output

The PMT Modular High Voltage Power Supply shall transfer the anode signal pulses from the PMT to the DOM Main Board through a coaxial cable.

REQUIREMENT'S SOURCE:

Coaxial cable is a straightforward way of implementing an impedance-controlled transmission line that transfers the PMT pulses with high fidelity.

VERIFICATION METHOD:

Inspection

3.2.1.3 Command Response

The PMT Modular High Voltage Power Supply shall respond to the digital control commands issued by the DOM Main Board for High Voltage on/off and for the adjustment of the high voltages.

REQUIREMENT'S SOURCE:

Preliminary Design Document (PDD), Section 7.2, Figure 65

VERIFICATION METHOD:

Test

3.2.1.4 High Voltage Readings Output

The PMT Modular High Voltage Power Supply shall provide a digital reading output of the values of the high voltage to the DOM Main Board upon request.

REQUIREMENT'S SOURCE:

Document review (http://icecube.wisc.edu/internal/requirements/pmt_hv_base_erd/) and the subsequent telephone conference with ***[TBA]*** on October 3, 2002.

VERIFICATION METHOD:

Test

3.2.1.5 Board Identification Output

The PMT Modular High Voltage Power Supply shall provide digital board identification information output to the DOM Main Board upon request.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer here}

VERIFICATION METHOD:

Test

3.2.2 Electrical Requirements

3.2.2.1 Input Voltage

3.2.2.1.1 +5 Volts DC

The PMT Modular High Voltage Power Supply shall receive a power input voltage of +5 VDC ±5%.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer here}

VERIFICATION METHOD:

Test

3.2.2.1.2 –5 Volts DC

The PMT Modular High Voltage Power Supply shall receive a power input voltage of -5 VDC ±5%.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer here}

VERIFICATION METHOD:

Test

3.2.2.2 Input Current

3.2.2.2.1 +5 Volts Input Current

The PMT Modular High Voltage Power Supply input current for +5 Volt power shall not exceed ***[TBD]*** mA.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer here}

VERIFICATION METHOD:

Test

3.2.2.2.2 –5 Volts Input Current

The PMT Modular High Voltage Power Supply input current for -5 Volt power shall not exceed ***[TBD]*** mA.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer here}

VERIFICATION METHOD:

Test

3.2.2.3 Input Power

The total input power to the PMT Modular High Voltage Power Supply shall not exceed 300 mW.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer here}

VERIFICATION METHOD:

Test

3.2.2.4 Internal Power Distribution

The PMT Modular High Voltage Power Supply shall …

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer here}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.2.2.5 Internal Grounds

3.2.2.5.1 Analog Grounds

3.2.2.5.1.1 HV Control Board Analog Ground

The low noise analog signal ground on the HV Control Board shall be referenced by and connected to the negative (low side) input power pin and metal case of the high voltage generator, the negative (low side) input power pin(s) of the DAC and ADC and Reference, with a single point connection to the DOM Main Board interface connector pin(s) designated as DGND.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Inspection

3.2.2.5.1.2 HV Base Board Analog Ground

The low noise analog signal ground on the HV Base Board shall be referenced by and connected to the PMT cathode, the HV negative line from the HV generator on the HV Control Board, and the ground end of all grounded capacitors and resistors.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Inspection

3.2.2.5.2 Power and Digital Grounds

3.2.2.5.2.1 HV Control Board Power and Digital Ground

Power and digital grounds shall be as one on the PCB and connected to the DOM Main Board interface connector pin(s) designated as DGND; and, referenced by the digital control and monitor circuitry including the ADC and the DAC; and, referenced by the negative (low side) input power pin and metal case of the HV generator.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Inspection

3.2.2.5.2.2 HV Base Board Power and Digital Ground

Power ground shall be referenced by and connected to the PMT cathode, the HV negative conductor from the HV generator on the HV Control Board, and the ground end of all grounded capacitors and resistors. (With no digital circuitry, there is no digital ground.)

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Inspection

3.2.2.5.3 RF Grounds

The PMT Modular High Voltage Power Supply high voltage generator metal case shall be connected to an RF ground plane area on the HV Control Board (which will be the same conductor as the negative power to the high voltage generator).

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer here}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.2.2.6 PMT Cathode

3.2.2.6.1 PMT Cathode Potential

The PMT Modular High Voltage Power Supply shall provide a low impedance zero voltage for the PMT cathode.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer here}

VERIFICATION METHOD:

Inspection

3.2.2.6.2 PMT Cathode Ground Reference

The PMT Modular High Voltage Power Supply shall provide a ground reference for the PMT cathode by direct connection of the cathode to the HV Base Board analog ground.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer here}

VERIFICATION METHOD:

Inspection

3.2.2.7 PMT Anode High Voltage Generation

3.2.2.7.1 Adjustable Voltage Range

The PMT Modular High Voltage Power Supply shall output a voltage that is adjustable over a minimum range of 1000 to 2048 Volts DC to be applied to the PMT anode.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer here}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.2.2.7.2 Minimum Adjustment Voltage

The low end of the adjustable anode voltage range shall not be less than 800 VDC.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer here}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.2.2.7.3 Maximum Adjustment Voltage

The high end of the adjustable anode voltage range shall not exceed 2100 VDC.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer here}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.2.2.7.4 Voltage Adjustment DAC Resolution

The DAC used for digitally setting the anode voltage shall have a 12-bit resolution.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer here}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.2.2.7.5 Voltage Adjustment Linearity

The digital command code value and the corresponding analog anode voltage value shall have a linear relationship in the voltage range specified in 3.2.2.4.1.1 with a slope of 0.5 Volts ± ***[TBD]*** Volts per bit.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer here}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.2.2.8 High Voltage Quality

3.2.2.8.1 Voltage Stability

The drift rate for the voltage across Dy1 and anode shall be less than 4 V/week during in-ice operation. (i.e. The maximum excursion over any given 1 week period shall be less than 4V.)

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer here}

VERIFICATION METHOD:

Test

3.2.2.8.2 Anode Voltage Ripple (Noise)

The ripple voltage observed at the output of the secondary of the anode signal-coupling transformer shall not exceed 0.5mVpp when the output is terminated with a 100 Ω resistor.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Test

3.2.2.9 Anode Voltage Monitoring

3.2.2.9.1 Voltage Monitoring Output

There shall be a provision for monitoring the anode voltage using an ADC and transmitting its value to the DOM Main Board as a digital code.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Inspection

3.2.2.9.2 Voltage Monitoring ADC Resolution

The ADC used for monitoring the anode voltage shall have a 12-bit resolution.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

Inspection

3.2.2.9.3 Voltage Monitoring Linearity

The monitored anode voltage and the corresponding digital value shall have a linear relationship in the voltage range specified in 3.2.2.4.1.1 with a slope of 0.5 V ± ***[TBD]*** Volts per bit.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.2.2.10 Anode Current Sourcing Capability

3.2.2.10.1 Current Sourcing at Minimum Operating Temperature

The PMT Modular High Voltage Power Supply shall provide a DC anode current sourcing capability of a minimum of 12 nA, at the minimum operating temperature specified herein, as determined by the output anode voltage changing less than 10V as the current is varied from zero to the specified minimum current.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

(Relates to In-Ice noise rate)

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.2.2.10.2 Current Sourcing at Maximum Operating Temperature

The PMT Modular High Voltage Power Supply shall provide a DC anode current sourcing capability of a minimum of 240 nA, at the maximum operating temperature specified herein, as determined by the output anode voltage changing less than 10V as the current is varied from zero to the specified minimum current.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

(Relates to room-temperature noise rate)

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.2.2.10.3 Pulsed Current Sourcing

The PMT Modular High Voltage Power Supply shall provide an anode current sourcing capability of a minimum of 100 mA for a single 1 μsec square-pulse, at the minimum operating temperature specified herein, as determined by the output anode voltage changing less than 10V when the current is changed from zero to the specified pulse current during the pulse time.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer here}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.2.2.11 PMT Dynode and Focus Voltages

3.2.2.11.1 Dynode Chain Voltage Distribution

The PMT Modular High Voltage Power Supply shall output the voltages to be applied across the PMT successive dynode stages according to the values specified in Table ***[TBD]*** , Dynode Chain Voltage Distribution. Voltage values are expressed in terms of a factor to be multiplied by the voltage across Dynode 5 and Dynode 6 (Dy5-Dy6).

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

Hamamatsu tentative datasheet ver. 4, July 2003, Photomultiplier Tube R7091-02 for ICECUBE Experiment, Table 2.

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.2.2.11.2 Voltage Source Impedance

The electrical source impedance of the voltage sources for the individual dynodes must be less than [TBD] ohms in order to meet the anode current sourcing capability in paragraph [TBD].

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer here}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.2.2.11.3 PMT Focus Voltages

The PMT Modular High Voltage Power Supply shall output the voltages to be applied to the PMT focusing electrodes, denoted as F1, F2 and F3, as determined by the factor specified in the following table, multiplied by the voltage across Dynode 5 and Dynode 6 (Dy5-Dy6).

Dynode Interval	**Voltage Relative to Dy5 – Dy6** **Tolerance = *[TBD]* %**
K - Dy1	16.80
Dy1 - Dy2	4.00

Dy2 - Dy3	5.00
Dy3 - Dy4	3.33
Dy4 - Dy5	1.67
Dy5 - Dy6	1.00 (Reference)
Dy6 - Dy7	1.20
Dy7 - Dy8	1.50
Dy8 - Dy9	2.20
Dy9 - Dy10	3.00
Dy10 - P	2.40
Dy1 - F1	0.60
Dy1 - F2	0.00
Dy1 - F3	0.60

Table Title - Dynode Chain Voltage Distribution

Table Note 1: "Dyn" denotes the n-th dynode or Dynode n.

Table Note 2: "Fn" denotes the n-th focusing electrode or Electrode n.

Table Note 3: Dy1 and F2 are at the same potential.

Table Note 4: F1 and F3 are at the same potential.

Table Note 5: All voltages are differentially measured relative to a node pair, not to ground.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.2.2.12 Dynode Damping Resistors

3.2.2.12.1 HV Damping Resistors

A resistor that is designed to minimize corona from its body in its mounting location shall be placed in series with each of the last dynodes (Dy8, Dy9 and Dy10) and their corresponding high-voltage sources.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.2.2.12.2 Resistor Value

Each damping resistor shall have a value of 100Ω ± 5%, rated at a minimum of 1/16 Watts.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.2.2.12.3 Resistor Accessibility

The damping resistors shall be mounted at locations accessible without the need for removal or relocation of any parts to allow the shunting or replacement of the resistors after the PMT HV Base Board has been mounted onto the PMT.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.2.3 Mechanical Requirements

3.2.3.1 Force Inputs

3.2.3.1.1 Linear

3.2.3.1.2 Rotational

3.2.3.2 Force Outputs

3.2.3.2.1 Linear

3.2.3.2.2 Rotational

3.2.3.3 Loading

3.2.3.3.1 Structural Load

3.2.3.3.2 Tensile Strength

3.2.3.3.3 Compressive Strength

3.2.3.3.4 Elasticity

3.2.3.3.5 Compressibility

3.2.3.4 Thermal Transfer

3.2.4 Mass Properties Requirements

3.2.4.1 Size

3.2.4.1.1 HV Base Board Size

The PMT Modular High Voltage Power Supply HV Base Board shall be circular with a maximum diameter of 100 mm. The maximum height of the HV Base Board including all solder leads and component part heights shall not exceed ***[TBD]*** mm. The height (and volume) constraints shall apply to the mated pieces of the ribbon connectors.

REQUIREMENT'S SOURCE:

Component Envelope Drawing, PSL 5549021C_g_nk1.pdf, Physical Sciences Lab, University of Wisconsin - Madison

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.2.4.1.2 HV Control Board Size

The PMT Modular High Voltage Power Supply HV Control Board shall be

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.2.4.2 Shape

3.2.4.2.1 HV Base Board Shape

The overall shape of the printed circuit board of the PMT Modular High Voltage Power Supply HV Base Board shall be circular. A greater diameter or a deviation from the circular outline for accommodation of special components such as connectors and cable harnesses

shall be permitted provided that there is sufficient clearance between such components and the interior surface of the pressure sphere of the Digital Optical Module.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

The circular board distributes the weight evenly on the PMT, which is more desirable than an uneven distribution. Also, the DOM enclosure is spherical and the maximum allowable shape of the board tends to be circular due to the volume constraint.

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.2.4.2.2 HV Control Board Shape

The PMT Modular High Voltage Power Supply HV Control Board shape shall be

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.2.4.3 Weight

The PMT Modular High Voltage Power Supply weight shall not exceed ***[TBD]*** grams.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.2.4.4 Center of Gravity

3.2.4.5 Momentum

3.2.5 External Interface Requirements

3.2.5.1 Electric Power

The PMT Modular High Voltage Power Supply shall receive all of its electric power from the DOM Main Board via conductors in the DOM Main Board interface cable to the HV Control Board.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.2.5.2 Discrete Signals

3.2.5.2.1 High Voltage Power Supply ON/OFF

3.2.5.2.1.1 High Voltage Power Supply ON/OFF Control

The PMT Modular High Voltage Power Supply shall support Power ON/OFF control of the HV Power Supply by the DOM Main Board through a discrete signal wire in the DOM Main Board interface cable to the HV Control Board.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Test

3.2.5.2.1.2 High Voltage Power Supply ON/OFF Signal Logic Level

The PMT Modular High Voltage Power Supply input signal logic level assignment for power ON/OFF control to the HV Control Board shall be as shown in the table below.

Logic Level	Meaning
0	POWER OFF
1	POWER ON

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.2.5.3 Analog Signals

3.2.5.3.1 RF Grounding Wire Interface for HV Control and HV Base Boards

There shall be provisions on the HV Control Board and the HV Base Board for connecting a 9 mm flat insulated braided wire between the HV Control Board ground foil and the HV Base Board ground foil.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Inspection

3.2.5.3.2 PMT Output Voltage

The PMT Modular High Voltage Power Supply shall employ a toroidal transformer coupling to output the analog PMT signal pulses from the HV Base Board to the DOM Main Board.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Inspection

3.2.5.4 Digital Signals

3.2.5.4.1 Digital Signal Definitions

3.2.5.4.1.1 CMOS Standard

The digital signals (logic levels and voltages) between the PMT Modular High Voltage Power Supply HV Control Board and the DOM Main Board shall comply with the 3.3V CMOS signal standard, ***[TBD standard document reference in Section 2].***

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

All the digital interface on the DOMMB side is implemented in a CPLD that employs a 3.3V logic, hence this requirement.

VERIFICATION METHOD:

Inspection

3.2.5.4.2 High Voltage Control

3.2.5.4.2.1 HV Adjustment Digital Command Code

The digital command code for setting the anode voltage shall be in 12-bit unsigned straight binary with the digital value 000(hex) representing 0 Volts DC.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer here}

VERIFICATION METHOD:

Inspection

3.2.5.4.2.2 HV Monitoring Digital Output Code

The digital output code for monitoring the anode voltage shall be in 12-bit unsigned straight binary with the digital value 000(hex) representing 0 Volts DC.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Inspection

3.2.5.4.3 Chip Select

3.2.5.4.3.1 Chip Select Signals (CS0, CS1)

The two chip-select signals, CS0 and CS1, shall be used in combination to select one of the following three digital devices residing on the PMT Modular High Voltage Power Supply HV Control Board:

DAC - Digital-to-analog converter

ADC - Analog-to-digital converter

IDENT - Board identification device

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Inspection

3.2.5.4.3.2 Chip Selection Codes

The logic level chip selection codes for CS0 and CS1 shall be as follows:

CS0	CS1	Function
1	1	IDENT
0	1	DAC
1	0	ADC
0	0	(not allowed)

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Test

3.2.5.4.4 MOSI, MISO, and SCLK Signals

3.2.5.4.4.1 DAC Signals

DAC shall use MOSI and SCLK for data and serial clock, respectively.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Inspection

3.2.5.4.4.2 ADC Signals

ADC shall use MISO and SCLK for data and serial clock, respectively.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Inspection

3.2.5.4.4.3 IDENT Signals

IDENT shall use MISO.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Inspection

3.2.5.4.5 Board Digital Identification *[TBR]*

3.2.5.4.5.1 Board Digital Identification Number

The PMT Modular High Voltage Power Supply HV Control Board shall provide a unique digital board identification number (board ID) upon request from the DOM Main Board.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Test

3.2.5.4.5.2 Board Identification Protocol

The PMT Modular High Voltage Power Supply HV Control Board digital board ID device shall comply with the Dallas 1-Wire protocol to communicate with the DOM Main Board serving as the bus master.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Test

3.2.5.5 RF Signals

3.2.5.6 Fiber Optic Signals

3.2.5.7 External Grounding

3.2.5.7.1 Discrete Signal Grounding

3.2.5.7.2 Analog Signal Grounding

3.2.5.7.3 Digital Signal Grounding

3.2.5.7.4 RF Signal Grounding

3.2.5.7.5 Secondary Power Grounding

3.2.5.7.6 Primary Power Grounding

3.2.5.7.7 High Energy Grounding

3.2.5.7.8 Safety Grounding

3.2.5.8 Test and Maintenance

3.2.5.8.1 Test Points

Voltage measurement test points shall be provided for use in the factory and field for measuring the anode voltage and first dynode voltage without the need for removal or relocation of any parts for access to the test points.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

Demonstration

3.2.5.8.2 Access (Doors, Panels, etc.)

3.2.5.9 Interconnections

3.2.5.9.1 Cables and Harnesses

3.2.5.9.1.1 Cable Interface – HV Control Board to DOM Main Board

The PMT Modular High Voltage Power Supply HV Control Board shall have electrical connections with the DOM Main Board through a single multiconductor cable for power, ground, and digital signal connections.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Inspection

3.2.5.9.1.2 Signal Duplication – HV Control Board to DOM Main Board

Each signal, ground and power in the PMT Modular High Voltage Power Supply HV Control Board to DOM Main Board cable shall have two conductors allocated to it.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.2.5.9.1.3 Cable Type – HV Control Board to DOM Main Board

The PMT Modular High Voltage Power Supply HV Control Board to DOM Main Board cable shall be a 1mm-pitch flat IDC ribbon cable with 28 AWG [0.2mm] ***[TBR]*** conductors.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.2.5.9.2 Connectors

3.2.5.9.2.1 HV Control Board to DOM Main Board Connector Type

The PMT Modular High Voltage Power Supply ribbon connector shall have a 2mm-pitch male connector, Samtec STMM-110-02-S-D. ***[TBA DESIGN ESTIMATE]***.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Inspection

3.2.5.9.2.2 Connector Locations

See PSL Drawing 5549B020_f_nk1.pdf. PMT Modular High Voltage Power Supply dimensional and component placement requirements. The figure identifies suggested locations for the coaxial cable attachment. The PCB material thickness is for reference only.

REQUIREMENT'S SOURCE:

PMT Modular High Voltage Power Supply Dimensional and Component Placement Requirements, PSL 5549B020 Rev ?, Physical Sciences Lab, University of Wisconsin - Madison

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.2.5.9.2.3 Other Connector Locations

Other connector locations shall be as shown in PSL Drawing ***[TBD]***

REQUIREMENT'S SOURCE:

Component Envelope Drawing, PSL 5549C021 Rev G, Physical Sciences Lab, University of Wisconsin - Madison

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.2.5.9.3 Modular HV Power Supply and DOM Main Board Interface Cables

The following interface table summarizes the electrical connections between the PMT Modular High Voltage Power Supply and the DOM Main Board.

Connection method	Explanation	Section
Plated-thru mounting holes	The HV Base Board is physically mounted to the PMT by inserting and soldering the pins in these holes, which also makes electrical connections.	
Coaxial RG-180B/U or equivalent	Connection between the secondary of the anode signal coupling transformer and the DOM main board. The board shall be manufactured with one end of the coaxial cable attached to it. The other end of the coaxial cable shall have a SMB ***[TBR]*** type connector attached.	
IDC Ribbon cable	Digital signals DC power Power & digital ground A male ***[TBR]*** connector is required on board.	
9 mm flat braided wire	RF noise reduction low-Z connection. Each board shall provide a grounding wire pad on its analog ground plane.	

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.2.5.9.4 Pin Outs

3.2.5.9.4.1 Ribbon Cable Connector Pin Assignments

Pin assignments for the ribbon cable between the PMT Modular High Voltage Power Supply and the DOM Main Board are shown in the below table. For increased reliability each signal, ground and power conductor in the PMT Modular High Voltage Power Supply to DOM Main Board cable shall have a minimum of two redundant pins allocated as shown.

Pin #	Signal Name	Description
01	DGND	Digital and power ground
02	SCLK	Serial clock
03	SCLK	
04	MOSI	Master-out-slave-in
05	MOSI	
06	MISO	Master-in-slave-out
07	MISO	
08	DGND	
09	CS0	Chip-select bit 0
10	CS0	
11	CS1	Chip-select bit1
12	CS1	
13	ON/OFF	Board enable/disable
14	ON/OFF	
15	+5V	Main power (+)
16	+5V	
17	DGND	
18	DGND	

19	-5V	Main power (-)
20	-5V	

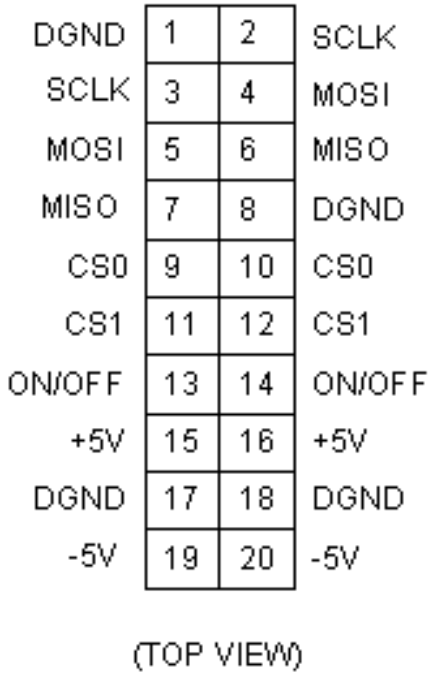
REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Inspection

3.2.5.9.4.2 Board Connector Physical Pin Layout



REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Inspection

3.2.5.9.4.3 PMT Pin Assignment

The PMT Modular High Voltage Power Supply HV Base Board shall electrically mate and function with the PMT using the pin assignments shown in the table below.

Pin #	Signal name	Description
01	NC	No connection
02	Dy1	Dynode #1
03	F3	Focus #3
04	NC	No connection
05	Dy3	Dynode #3
06	NC	No connection
07	Dy5	Dynode #5
08	Dy7	Dynode #7
09	Dy9	Dynode #9
10	P	Anode
11	NC	No connection
12	NC	No connection
13	NC	No connection
14	Dy10	Dynode #10
15	Dy8	Dynode #8
16	Dy6	Dynode #6
17	Dy4	Dynode #4
18	NC	No connection
19	Dy2	Dynode #2
20	F1	Focus #1
21	F2	Focus #2
22	NC	No connection
23	NC	No connection
24	K	Cathode

Figure: PMT Pin Assignment

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.2.5.10 Grasping/Mounting Points

3.2.5.10.1 Production

3.2.5.10.1.1 PMT Collar Positioning Pins Clearance

The HV Base Board shall provide for component clearance areas on the PWB to accommodate the three positioning pins on the PMT collar used to position the PWB with respect to the PMT base.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Inspection

3.2.5.10.1.2 HV Base Board Mounting to PMT

The HV Base Board shall provide for plated through soldering holes and solder pads in a pattern that matches the PMT pin pattern that will allow the HV Base Board to be securely soldered to the PMT pins to provide a structural mounting that will survive the physical environmental requirements specified herein.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Test

3.2.5.10.2 Shipping Transport

3.2.5.10.3 Installation

3.2.5.11 Human

3.2.5.12 Solar

3.2.5.13 Thermal

3.2.5.14 Optical

3.2.5.15 Photonic

3.2.5.16 Hydraulic

3.2.5.17 Pneumatic

3.2.6 Environmental Requirements

3.2.6.1 Temperature

3.2.6.1.1 Operating Temperature

The HV Base Board shall meet all performance requirements when operating over an ambient temperature range of –40 °C to +27 °C.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Test

3.2.6.1.2 Non-Operating Temperature

The PMT Modular High Voltage Power Supply shall withstand a non-operating temperature range of ***[TBD]*** °C to [***TBD]*** °C for a period up to ***[TBD]*** months without any degradation in performance.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Test

3.2.6.1.3 Storage/Transport Temperature

The PMT Modular High Voltage Power Supply shall withstand a storage and transport temperature range of –55 °C to +45 °C for a period of ***[TBD]*** months without any degradation in performance.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Test

3.2.6.2 Thermal Shock

3.2.6.2.1 Operating Thermal Shock

3.2.6.2.2 Non-Operating Thermal Shock

3.2.6.2.3 Storage/Transport Thermal Shock

3.2.6.3 Pressure

3.2.6.3.1 Operating Pressure

The PMT Modular High Voltage Power Supply shall meet all performance requirements while operating at 1 atmosphere in air or while operating inside a pressure vessel with a sustained internal ***[TBD gas]*** atmospheric pressure of 40,000 Pa to 100,000 Pa.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.2.6.3.2 Non-Operating Pressure

The PMT Modular High Voltage Power Supply shall withstand a non-operating atmospheric pressure in air or in ***[TBD gas]*** of ***[TBD]*** Pa to ***[TBD]*** Pa for a period up to ***[TBD]*** months without any degradation in performance.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.2.6.3.3 Storage/Transport Pressure

The PMT Modular High Voltage Power Supply shall withstand a storage and transport atmospheric pressure in air or in ***[TBD gas]*** of ***[TBD]*** Pa to ***[TBD]*** Pa for a period up to ***[TBD]*** months without any degradation in performance.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.2.6.4 Vibration

3.2.6.4.1 Operating Vibration

3.2.6.4.2 Non-Operating Vibration

3.2.6.4.3 Storage/Transport Vibration

3.2.6.5 Mechanical Shock

3.2.6.5.1 Operating Mechanical Shock

3.2.6.5.2 Non-Operating Mechanical Shock

3.2.6.5.3 Storage/Transport Mechanical Shock

3.2.6.6 Acoustic Vibration

3.2.6.6.1 Operating Acoustic Vibration

3.2.6.6.2 Non-Operating Acoustic Vibration

3.2.6.6.3 Storage/Transport Acoustic Vibration

3.2.6.7 Electromagnetic Interference/Compatibility

3.2.6.7.1 Conducted Energy

3.2.6.7.2 Susceptible to Conducted Energy

3.2.6.7.3 Radiated Energy

3.2.6.7.4 Susceptible to Radiated Energy

3.2.6.8 Electrostatic Discharge

3.2.6.9 Lightning and EMP

3.2.6.10 Sand and Dust

3.2.6.11 Humidity

3.2.6.12 Radioactivity

3.2.7 Built-in Test Diagnostics

3.2.8 Flexibility and Expansion

3.2.9 Portability

3.2.10 Transportability

3.2.11 Storage

3.3 Design and Construction Requirements (parts, materials, and processes)

3.3.1 Electrical Parts (wire, connectors, solder, insulation, switches, batteries, etc.)

To the extent practical, all electrical components used for the PMT Modular High Voltage Power Supply shall meet the lowest operating temperature of –55°C, as specified by the component manufacturer. "Practical" means that this requirement applies to all PCB material; conformal coating; and any electrical components that are readily available for the operating temperature of –55°C or lower.

The vendor of the PMT Modular High Voltage Power Supply shall supply IceCube with a list of electrical components used that do not meet the –55°C or lower operating temperature.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Inspection

3.3.2 Electronic Parts (resistors, capacitors, inductors, semiconductors, tubes, etc.)

To the extent practical, all electronic components used for the PMT HV Base board shall meet the lowest operating temperature of –55°C, as specified by the component manufacturer. "Practical" means that this requirement applies to all resistors, capacitors and diodes and any other electronic components that are readily available for the operating temperature of –55°C or lower.

The vendor of the PMT Modular High Voltage Power Supply shall supply IceCube with a list of electronic components used that do not meet the –55°C or lower operating temperature.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.3.2.1 PMT Signal Output Transformer

3.3.2.1.1 Transformer Signal Definition

The PMT signal output interface on the HV Base Board shall consist of a closely wound bifilar toroidal transformer whose two wires shall be designated P for primary and S for secondary with dot phase polarities as designated in Figure ***[TBD]*** below.

See the figure below. ***[TBR]***

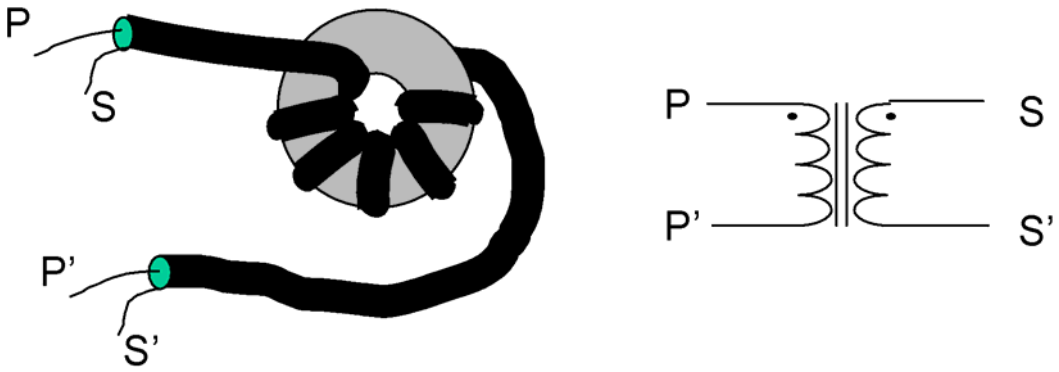


Figure: Anode signal coupling transformer signal definition (Illustration purpose only. See text for correct winding requirements).

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Test

3.3.2.1.2 Transformer Construction

3.3.2.1.2.1 Bifilar Wound Toroid

The transformer shall consist of a bifilar wound ferrite toroid of ***[TBD]*** turns.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Inspection

3.3.2.1.2.2 Transformer Wire Type

The wire type used for both primary and secondary windings shall be [18 or 20 AWG] ***[TBR]*** high voltage type silicone insulated stranded wire with a minimum continuous operating voltage rating of [5 or 10 kV] [TBR].

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.3.2.1.2.3 Toroidal Core Type

The transformer toroidal magnetic core shall be Magnetics Model ZH-42206-TC (www.mag-inc.com) ***[TBR]*** or equivalent.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.3.2.1.2.4 Winding Retention

There shall be a means to hold the windings in place (such as a plastic plug pressed into the toroidal center, or a "belly-band" around the transformer)..

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Inspection

3.3.2.1.3 Primary Side Requirements

3.3.2.1.3.1 Primary Resistor Termination

The primary side of the bifilar transformer shall be terminated with a 100Ω resister across the primary terminals ("back termination").

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Inspection

3.3.2.1.3.2 PMT Anode Primary Termination

The "dotted" side of the primary terminal shall connect to the PMT anode terminal.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Inspection

3.3.2.1.3.3 PMT Anode High Voltage Primary Termination

The "un-dotted" side of the primary terminal shall connect to the source of the PMT anode high-voltage.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Inspection

3.3.2.1.4 Secondary Side Requirements

3.3.2.1.4.1 Coaxial Output Secondary Interface

The secondary side of the bifilar transformer shall be connected to the DOM Main Board using a coaxial medium.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Inspection

3.3.2.1.4.2 Output Coax Type

The output coax type shall be RG-180B/U or a similar coaxial cable with a nominal characteristic impedance of 95Ω.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Test

3.3.2.1.4.3 Output Coax Secondary Connections

The center conductor and the shield conductor of the said coaxial cable shall connect to the "dotted" side and the "un-dotted" side of the secondary terminal of the transformer, respectively.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Inspection

3.3.2.1.5 Coaxial Cable Installation

3.3.2.1.5.1 Coax Cable Delivery With High Voltage Base Board

The PMT Modular High Voltage Power Supply HV Base Board shall be delivered with the coaxial cable specified in 3.3.1.3.4.2 already installed.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Inspection

3.3.2.1.5.2 Soldered Coax Connections

Electrical connections of the coaxial cable shall be accomplished by direct soldering.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Inspection

3.3.2.1.5.3 Electrical Connections Mechanical Integrity

The coaxial electrical connections shall not degrade when the cable is pulled with a maximum of 5kg of force in any direction.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Test

3.3.2.1.5.4 Length of Coax Cable

The length of the coaxial cable shall be 20 ±1cm. ***[TBR]***

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.3.2.1.5.5 Coax Cable Free End Connector

The end of the said coaxial cable not attached to the PCB shall have a right-angle, crimp-type ***[TBD]*** connector.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.3.2.1.5.6 Coax Connector Type

The above ***[TBD]*** connector shall be Applied Engineering Products (AEP) 2715-1521-004, gold plated coax crimp type; or, Sealectro 51-128-9511.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD:

Inspection

3.3.3 Mechanical Parts (structures, fasteners, holders, containers, valves, etc.)

3.3.4 Coatings, Platings, Corrosion Prevention

3.3.5 Adhesives and Sealants

3.3.6 Printed Circuit Boards

3.3.6.1 HV Base Board Layout

3.3.6.1.1 Definition

The "bottom side" of the HV Base Board shall refer to the side of the PCB from which the PMT leads are inserted. The "top side" of the PMT HV Base board shall refer to the side opposite to the bottom side. The terms "top view" and "bottom view" shall refer to the views from the top side and the bottom side of the PMT HV Base board, respectively.

Note: The "ice top view" is a view of the Digital Optical Module components in ice seen from the ice top. For the purpose of the HV Base Board, the "ice top view" and the "top view" are synonymous.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.3.6.1.2 Component Placement

The components may be placed on either the top side or the bottom side of the PCB within the constraints of the component envelope, except for the following items

- Anode signal coupling transformer (Bottom side)
- Coaxial cable for the anode signal connection
- Ribbon cable connector (Top side.)
- RF grounding connection wire pad

The following items shall be installed at locations where IceCube engineers can easily access for modification after the HV Base Board has been mounted on the PMT:

- Damping resistors
- RF grounding connection wire pad

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.3.6.1.3 Excluded Area

No PWB components shall be mounted in the areas so specified in ***[TBD]*** figure.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.3.6.1.4 Minimum Trace Spacing Requirements

In compliance with the circuit board trace layout rules specified in ***[TBD]*** the following conditions shall be met for both DC voltages and AC peak voltages:

- For voltage difference greater than 100 V and less than 300 V, the minimum trace spacing shall be ***[TBD]*** mm.
- For voltage difference greater than 300 V and less than 500 V, the minimum trace spacing shall be ***[TBD]*** mm.
- For voltage difference greater than 500 V, the minimum trace spacing shall be ***[TBD]*** mm plus ***[TBD]*** mm per every volt exceeding 500 V.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.3.6.1.5 Plated-thru Holes

The HV Base Board shall have plated-thru holes.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.3.6.1.6 Hole Pattern

The HV Base Board shall have a hole pattern as specified in the figure below to provide mechanical mating with the pins on the PMT.

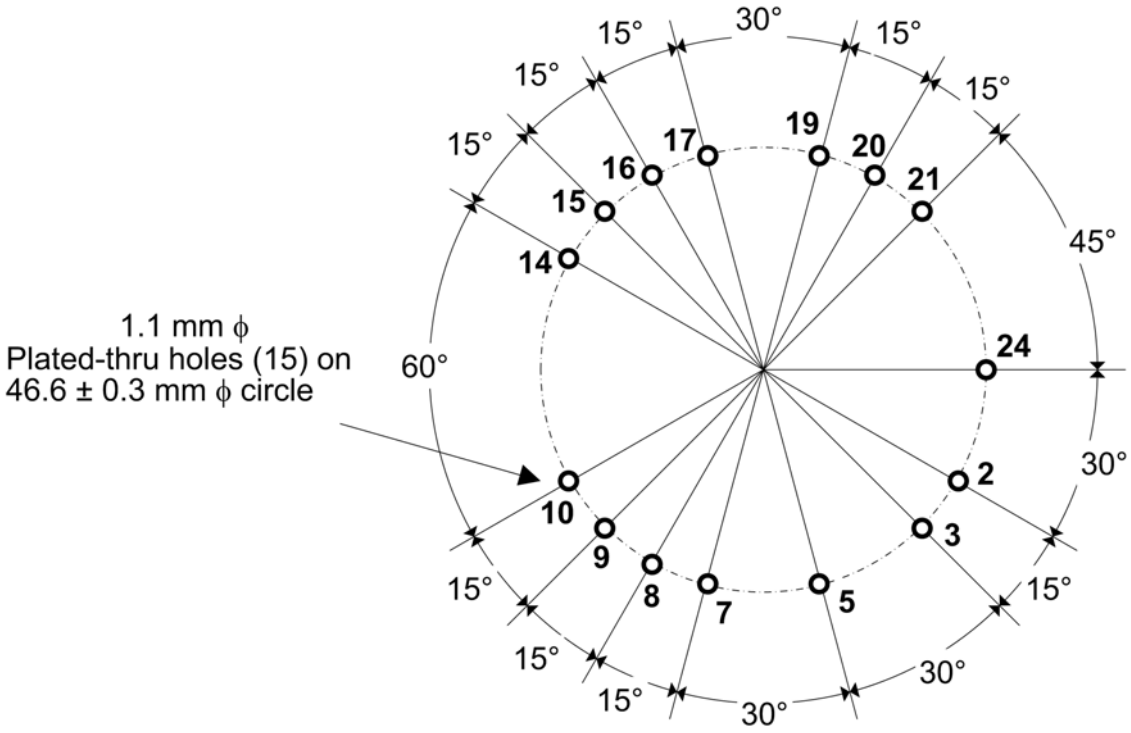


Figure: Plated-thru PMT mounting hole locations viewed from the top-side of the HV Base Board. The numerical labels associated with the holes mark the corresponding PMT pin number whose signal assignments are defined in the pin assignment table.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.3.6.1.7 Annular Ring

Each of the HV Base Board plated-thru holes shall have top and bottom annular ring soldering pads as specified in the below figure.

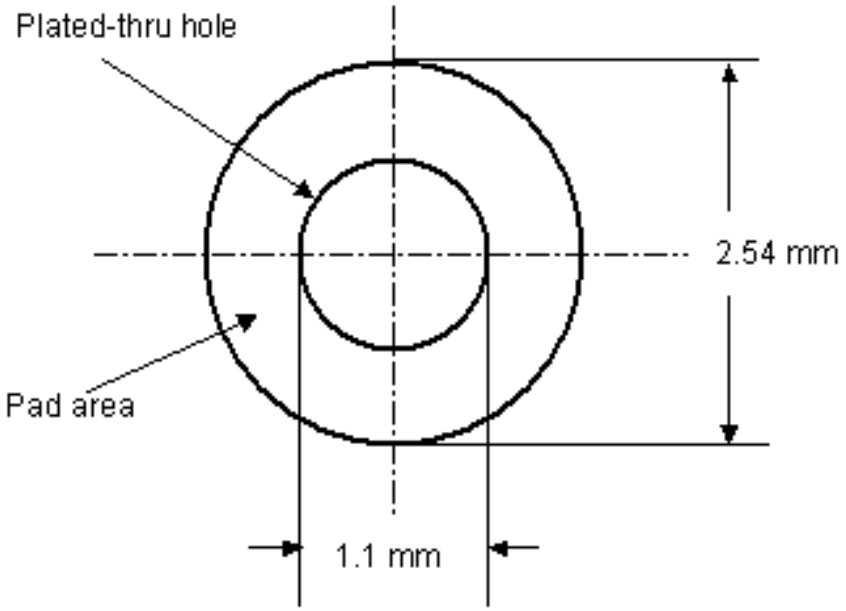


Figure: Solder Pad Specification

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.3.6.2 Manual Soldering Compatibility

The PCB shall be compatible with the increased temperature during the manual soldering of the PMT pins at the solder pads specified in ***[TBD]***.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.3.6.3 Solder Mask

A solder mask shall be applied to both the top and bottom sides of the Printed Circuit Board (PCB) with masked clearance including, but not limited to, the following items:

All solder pads

Through holes for component pins and leads

Test points

Designated clear solder pad areas for jumpers, changeable calibration resistors, etc.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.3.6.4 Silk Screen Marking

Silk screen markings shall include, but not be limited to, the following items:

- Supplier identifier
- IceCube Project identifier
- Part number and revision number
- Component reference designators
- Connector reference designators with pin 1 and the highest pin number marked
- Test points
- PMT pin numbers

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.3.6.5 Conformal Coating

[TBD]

REQUIREMENT'S SOURCE:

DOM production meeting at DESY-Zeuthen, Germany, May 2003.

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.3.7 Soldering

The Printed Circuit Board design shall be compatible with the increased temperature during the manual soldering of the PMT pins at the solder pads specified in paragraph [x.x.x.x].

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

3.3.8 Welding

3.3.9 Machining

3.3.10 Restricted Parts, Materials and Processes

3.3.10.1 Beryllium

3.3.10.2 Cadmium

3.3.10.3 CFC

3.3.10.4 Lead

3.3.10.5 Mercury

3.3.11 Reliability

3.3.12 Maintainability

3.3.13 Interchangeability

3.3.14 Manufacturability

3.3.15 Workmanship

3.3.16 Human Engineering

3.4 Quality Requirements

3.5 Safety Requirements

3.5.1 Personnel

3.5.2 Equipment

3.5.3 Environment

3.6 Special Test Equipment

3.6.1 Engineering

4.3 Requirement vs. Verification Cross Reference with Section 3

5 PREPARATION FOR DELIVERY

5.1 Identification Nameplates and Marking

5.1.1 Part and Serial Numbers

The PMT Modular High Voltage Power Supply shall be indelibly marked with part number, revision, serial number and manufacture date code.

REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{enter the traceability answer}

VERIFICATION METHOD: ☐ Test ☐ Analysis ☐ Inspection ☐ Demonstration ☐ Similarity

{enter one of the above methods}

5.1.2 Nameplate

5.1.3 Cable and Connector ID Tags

5.2 Acceptance Inspection and Tests

5.3 Packaging

5.4 Recording Sensors

5.5 Crating

5.6 Labeling

5.7 Shipping

6 DEFINITIONS

6.1 IceCube Acronyms

ADC	Analog-to-Digital Converter
ATWD	Analog Transient Waveform Digitizer
AWG	American Wire Gauge
cm	Centimeter
CMOS	Complementary Metal Oxide Semiconductor
CS0	Chip-select bit 1
CS1	Chip-select bit 0
DAC	Digital-to-Analog Converter
DAQ	Data Acquisition System
DC	Direct Current
DOM	Digital Optical Module
DOMMB	Digital Optical Module Main Board
EM	Electromagnetic
EMC	Electromagnetic Compatibility
ERD	Engineering Requirements Document
HV	High Voltage
Hz	Hertz
ID	Inside Diameter
IDC	Insulation Displacement Connector
IPC	Institute for Interconnecting and Packaging Electronic Circuits
k	Kilo (103
kg	Kilogram
LED	Light-Emitting Diode

MKS	Meter-kilogram-second
M	Mega (106)
m	Meter
mA	Milliampere
MOSI	Master-Out-Slave-In
MISO	Master-In-Slave-Out
mV	Millivolt
mW	Milliwatt
n	Nano (10-9)
OD	Outside Diameter
OM	Optical Module
Pa	Pascal
PCB	Printed Circuit Board
PE	Photoelectron
pF	Pico Farad
PMT	Photomultiplier Tube
P/N	Part Number
PSL	Physical Sciences Laboratory, University of Wisconsin-Madison
P/V ratio	Peak-to-valley ratio
s, sec	Second
SCLK	Serial Clock
SI	Système International d'Unités
SMB	Sub-Miniature B
SPE	Single Photoelectron
TBD	To Be Determined

TBR	To Be Reviewed
UL	Underwriters Laboratory
V	Volt
VDC	Volt DC
W	Watt

6.2 IceCube Glossary

Anode	A PMT dynode, the last in the multiplier chain and typically larger than the preceding dynodes, that collects the final charge pulse.
Cathode	The active surface of the photomultiplier from which photoelectrons are initially liberated.
Zero	The temperature, in degrees Celsius, at which water changes state from a liquid into a solid.

7 APPENDIX