REVISIONS

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**THE UNIVERSITY OF WISCONSIN**

ANTARCTIC ASTRONOMY AND ASTROPHYSICS RESEARCH INSTITUTE

**MADISON, WISCONSIN**

**TITLE**

# ICECUBE
# PMT BASE 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 Base 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 Base High Voltage Power Supply.

## 1.3 Responsibility and Records

Physics/Engineering is responsible for writing and updating these requirements to ensure they are correct, complete and current. Changes to this document shall be via Engineering Change Notices (ECN's) to be approved prior to incorporation according to the IceCube Configuration Management Plan, [TBD document]. Quality Assurance is responsible for ensuring this document and changes to it are properly reviewed, approved and maintained.

## 1.4 Item's Function in the IceCube System

The PMT (Photomultiplier Tube) High Voltage (HV) Board is a modular printed circuit board (PCB) power supply that creates and supplies approximately 2000 volts anode bias to the PMT inside each Digital Optical Module (DOM). The PMT HV Board also supplies multiple bias high voltages to the PMT dynodes. This high voltage provides acceleration and focusing of electrons inside the PMT that flow in response to impinging photons from a nearby photonic event. This electron flow is the sole detection mechanism for the IceCube system. There are 4800 Digital Optical Modules in the IceCube system, each containing a PMT HV Board. The Digital Optical Modules are deployed into deep Antarctic ice 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 Board Dimensional and Component Placement Requirements, PSL 5549B020 Rev ?, Physical Sciences Lab, University of Wisconsin - Madison

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

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

{Interface Requirements, Document No. 9000-xxxx}

{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}

{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

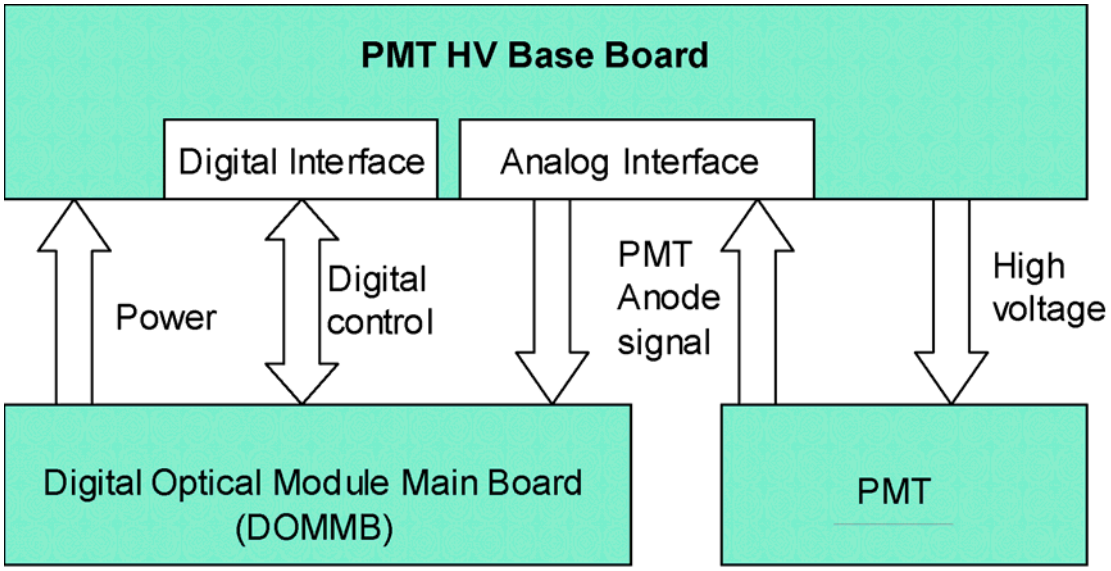
The PMT (Photomultiplier Tube) High Voltage (HV) Board is a modular printed circuit board (PCB) high voltage power supply mounted inside a Digital Optical Module (DOM).

#### 3.1.2 Functional Description

The PMT (Photomultiplier Tube) High Voltage (HV) Board is a power supply that creates and supplies approximately 2000 volts DC anode bias to the PMT inside each Digital Optical Module (DOM). The PMT HV Board 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 High Voltage Board also provides functional monitoring ports for diagnostic voltage measurements and an output circuit for extraction of the PMT analog signal from the PMT anode.

#### 3.1.3 Functional Block Diagram

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




### 3.1.4 Functional External Interfaces

The PMT High Voltage Board has six 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 PMT HV Board by attachment to the PMT pins

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 High Voltage Board 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 High Voltage Board 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 High Voltage Board 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 High Voltage Board 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 High Voltage Board 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 HV Board 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 HV Board 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 HV Board 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 HV Board 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 HV Board 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 HV Board 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 Ground

The low noise analog signal ground shall be referenced by the voltage multiplier, dynode resistive divider, and regulator feedback circuitry.

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

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 regulator and switching circuitry used for HV generation.

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

{enter the traceability answer}

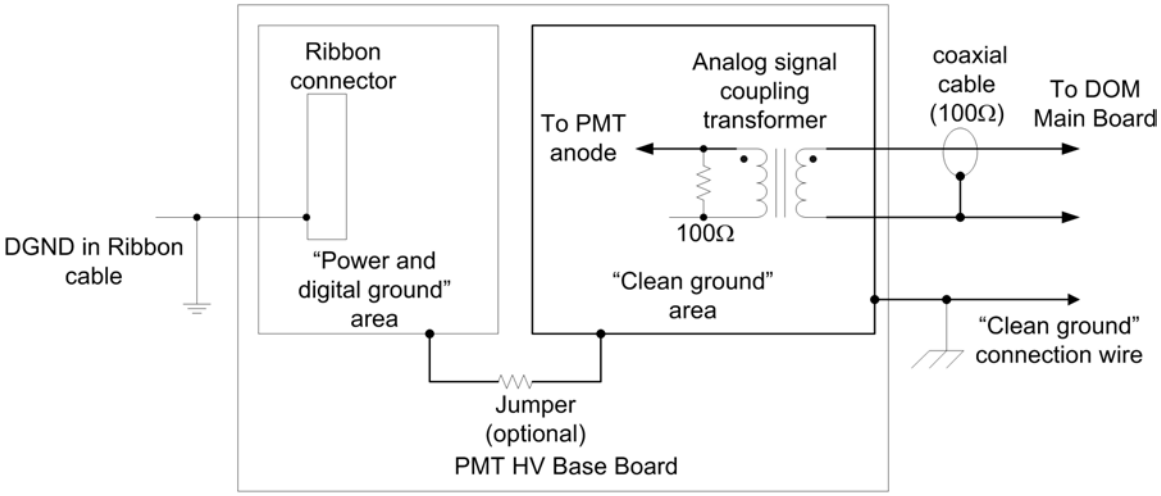
VERIFICATION METHOD:

Inspection

##### 3.2.2.5.3 Split Power/Digital and Analog Grounds

###### 3.2.2.5.3.1 Isolated Grounds Configuration

The PMT HV Board shall have two isolated ground planes, a power/digital ground plane and an analog signal ground plane as illustrated in the figure below.




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

{enter the traceability answer}

VERIFICATION METHOD:

Inspection

### 3.2.2.5.3.2 Isolation Resistance

The two ground planes defined above shall have a minimum isolation resistance of 10 MΩ.

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

{enter the traceability answer}

VERIFICATION METHOD:

Test

### 3.2.2.5.3.3 Stray Capacitance

The stray capacitance between the two ground planes shall be less than 50 pF.

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

{enter the traceability answer}

VERIFICATION METHOD:

Test

### 3.2.2.5.3.4 Noise Tuning Grounds Interconnect Jumper

The PMT HV Board shall have solder pads for a solderable noise tuning jumper (a zero-ohm resistor) between the two ground planes.

- The PMT HV Board shall be delivered without the jumper installed.

- The installation of the optional noise tuning jumper during production at the next higher level of assembly shall be as determined using criteria set by IceCube Engineering.

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

{enter the traceability answer}

VERIFICATION METHOD:

Inspection

#### 3.2.2.5.3.5 Soldering Pad for Clean Analog Ground

The PMT HV Board shall have a wire soldering pad for the purpose of attaching a 20 AWG (0.52 $mm^2$ conductor area) stranded wire for the "clean analog ground" connection 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

### 3.2.2.5.4 RF Grounds

The PMT HV Board 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}

## 3.2.2.6 PMT Cathode

### 3.2.2.6.1 PMT Cathode Potential

The PMT HV Board 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 HV Board shall provide a ground reference for the PMT cathode by direct connection of the cathode to the PMT HV 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 HV Board shall output a voltage that is adjustable over a minimum range of 1000 to 2000 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 2048 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 HV Board 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 HV Board 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 HV Board 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 HV Board shall output the voltages to be applied across the PMT successive dynode stages according to the values specified in the table in paragraph 3.2.2.4.3. Voltage values are expressed in terms of a factor to be multiplied by the voltage across Dynode 1 and Dynode 2 (Dy1-Dy2).

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}

#### 3.2.2.11.2 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 First Dynode (Dy1) Factory Default Voltage

The first dynode (Dy1) voltage shall be set to an initial factory default value of 600 VDC ***[TBR DESIGN ESTIMATE***] ± ***[TBD]*** Volts DC.

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}

### 3.2.2.11.4 First Dynode (Dy1) Field Voltage Adjustment

There shall be a provision for changing the factory default voltage value for dynode (Dy1) in the field after factory delivery to a value in the range of 600 to 800 VDC ***[TBR DESIGN ESTIMATE]***. Acceptable methods include installing or removing resistors or jumpers.

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}

### 3.2.2.11.5 PMT Focus Voltages

The PMT HV Board 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 1 and Dynode 2 (Dy1-Dy2).

| Dynode Interval | Voltage Relative to Dy1 - Dy2 |
|---|---|
| Dy2 - Dy3 | 1.25 |
| Dy3 - Dy4 | 0.83 |
| Dy4 - Dy5 | 0.42 |
| Dy5 - Dy6 | 0.25 |
| Dy6 - Dy7 | 0.30 |
| Dy7 - Dy8 | 0.38 |
| Dy8 - Dy9 | 0.55 |
| Dy9 - Dy10 | 0.75 |
| Dy10 - P | 0.60 |
| Dy1 - F1 | 0.15 |
| Dy1 - F2 | 0 |

| | |
|---|---|
| Dy1 - F3 | 0.15 |

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: F1 and Dy1 are at the same potential.

Table Note 4: F2 and F3 are at the same potential.

Table Note 5: All voltages are measured relative to analog 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 on 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

The PMT HV Board shall be circular with a maximum diameter of 100 mm. The maximum height of the PMT HV 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 5549C021 Rev G, Physical Sciences Lab, University of Wisconsin - Madison

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

{enter one of the above methods}

### 3.2.4.2 Shape

The overall shape of the printed circuit board of the PMT HV 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?)

{enter the traceability answer}

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

{enter one of the above methods}

### 3.2.4.3 Weight

The PMT HV Board 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 HV Board shall receive all of its electric power from the DOM Main Board via conductors in the DOM Main Board interface cable.

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 ON/OFF

##### 3.2.5.2.1.1 High Voltage ON/OFF Control

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

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 ON/OFF Signal Logic Level

The PMT HV Board signal logic level assignment for the High Voltage ON/OFF control shall be as shown in the table below.

| Logic Level | Meaning |
|---|---|
| 0 | OFF |
| 1 | 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 Grounding Wire Interface to the DOM Main Board

There shall be a 20 AWG (0.52 $mm^2$ conductor area) insulated stranded wire connecting the PMT HV Board "clean analog ground" solder pad 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

#### 3.2.5.3.2 PMT Output Voltage

The PMT HV Board shall employ a coaxial toroidal transformer coupled output to deliver the PMT signal pulses 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 HV 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?)

{enter the traceability answer}

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 HV 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

#### 3.2.5.4.5.1 Board Digital Identification Number

The PMT HV 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 HV 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 - PMT HV Board to DOM Main Board

The PMT HV 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 – PMT HV Board to DOM Main Board

Each signal, ground and power in the PMT HV 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 - PMT HV Board to DOM Main Board

The PMT HV 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 PMT HV Board to DOM Main Board Cable Type

The PMT HV Board 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 No. 5549B020. PMT HV Board dimensional and component placement requirements. The figure identifies suggested locations for the ribbon cable connector, the coaxial cable attachment, and the clean ground wire attachment. The PCB material thickness is for reference only. (5549020B_f.pdf) ***[TBR]***

REQUIREMENT'S SOURCE:

PMT HV Board 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 No. 5549C021 Rev G, PMT HV Base Board Component Envelope Definition. ***[TBR]***

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 Summary of PMT HV Board Interface Cables

The following interface table summarizes the electrical connections between the PMT HV Board and the DOM Main Board.

| Connection method | Explanation | Section |
|---|---|---|
| Plated-thru mounting holes | The board is physically mounted to the PMT by soldering the pins to these holes, which also makes electrical connections. | |
| Coaxial<br><br>RG-180B/U or equivalent | Connection between the secondary of the anode signal coupling transformer and the DOM main board. The board shall be delivered with one end of the coaxial cable attached to it. The other end of the coaxial cable requires an SMB ***[TBR]*** type connector. | |
| IDC Ribbon cable | Digital signals<br><br>DC power<br><br>Power & digital ground<br><br>A male ***[TBR]*** connector is required on board. | |
| 0.52 mm2 (20 AWG) stranded wire | "Clean analog ground" connection.<br><br>The board shall provide a 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}

#### 3.2.5.9.4 Pin Outs

##### 3.2.5.9.4.1 Ribbon Cable Connector Pin Assignments

Pin assignments for the ribbon cable between the PMT HV Board and the DOM Main Board are shown in the below table. For increased reliability each signal, ground and power conductor in the PMT HV Board 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 | |

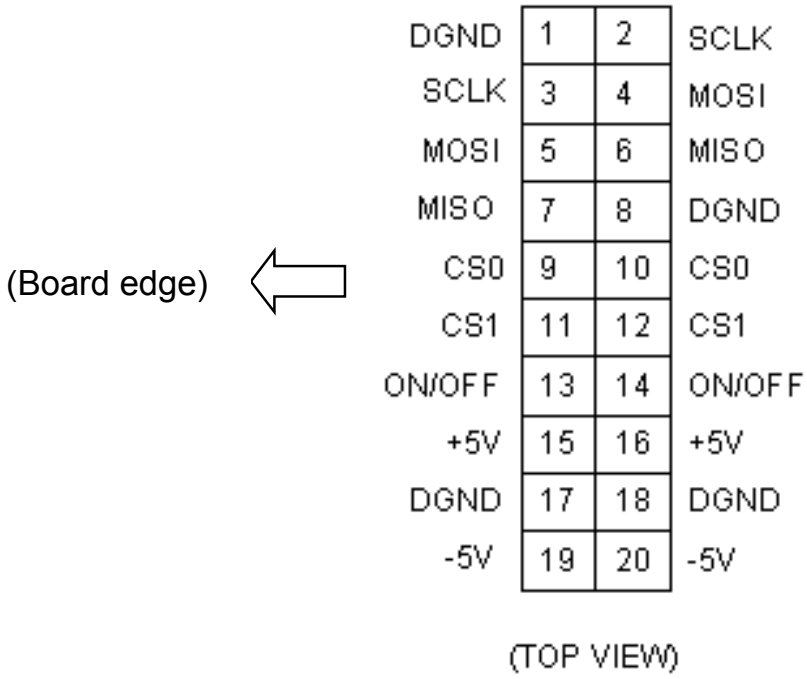
REQUIREMENT'S SOURCE: (What source did this requirement come from? Or, what is its justification?)

{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 HV 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 PMT HV 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 PMT HV Board Mounting to PMT

The PMT HV Board shall provide for plated through soldering holes and solder pads in a pattern that matches the PMT pin pattern that will allow the PMT HV 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 PMT HV 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 HV Board 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 HV Board 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 HV Board 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 HV Board 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 HV Board 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 HV Board 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 HV Board 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 HV Board 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 transformer shall consist of a coaxial cable wound around a toroidal magnetic core.

- The center conductor and the shielding conductor of the coaxial winding shall provide the primary winding and the secondary winding of the transformer, respectively.
- The primary conductor and the secondary conductor accessible at one end of the coaxial winding shall be designated as the "dotted side" of the terminals.
- See the figure below.

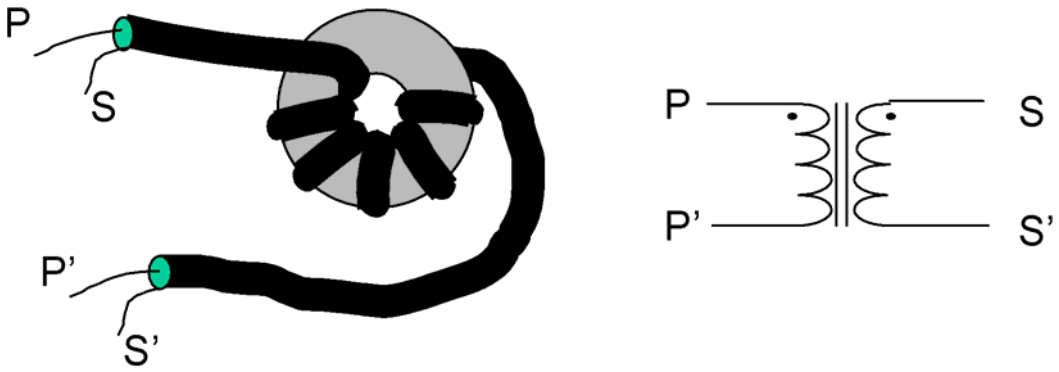



Figure: Anode signal coupling transformer signal definition (Illustration purpose only. See text for correct winding requirements).

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 Coaxial Wound Toroid

The transformer shall consist of a coaxial cable wound nineteen (19) times around a toroidal magnetic core.

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 Coaxial Cable Type

The said coaxial cable shall be RG-178/U or RG-178B/U with a Teflon inner dielectric and a Teflon outer jacket (Alpha Wire Company (www.alphawire.com) P/N 9178B 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}

#### 3.3.2.1.2.3 Toroidal Core Type

The said 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 coaxial 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 coaxial 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 PMT HV Board

The PMT HV 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 SMB ***[TBR]*** 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 SMB ***[TBR]*** 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 PMT HV Board Layout

##### 3.3.6.1.1 Definition

The "bottom side" of the PMT HV 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 PMT HV 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.)
- "Clean ground" connection wire pad

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

- Components for adjusting the first dynode voltage
- Damping resistors
- Solder pads for the optional jumper

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

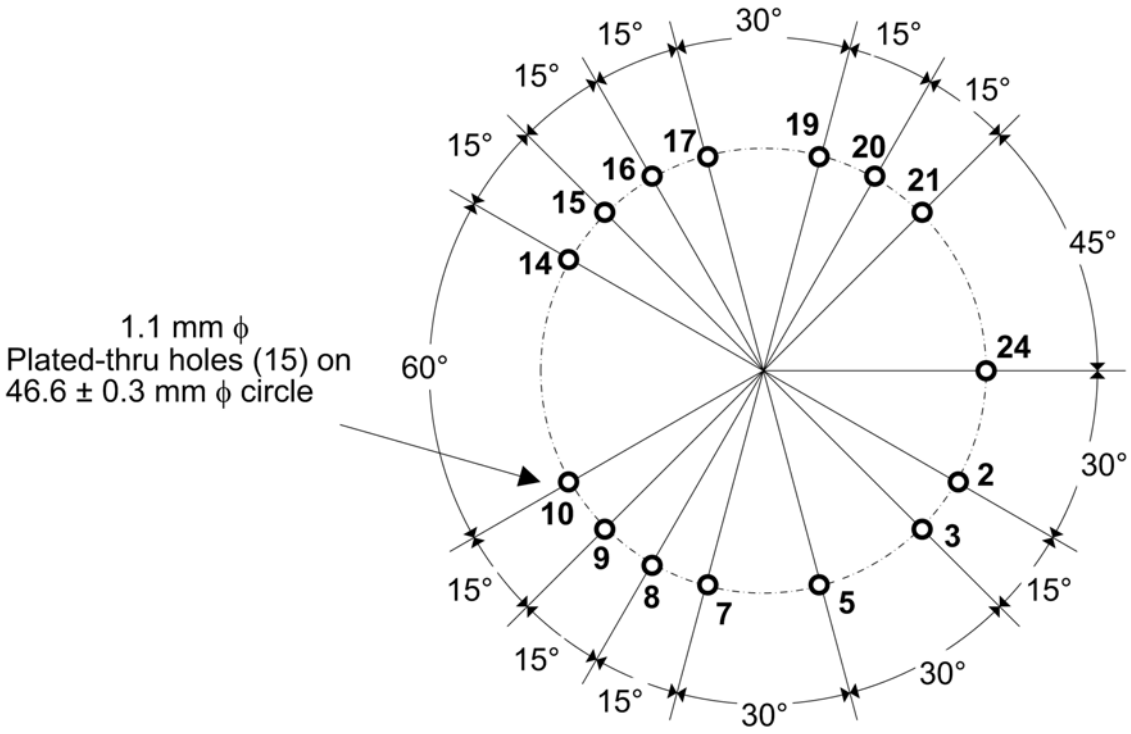



Figure: Plated-thru PMT mounting hole locations viewed from the top-side of the PMT HV Board. The numerical labels associated with the holes mark the corresponding PMT pin number whose signal assignments are defined in the pin assignment table.

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

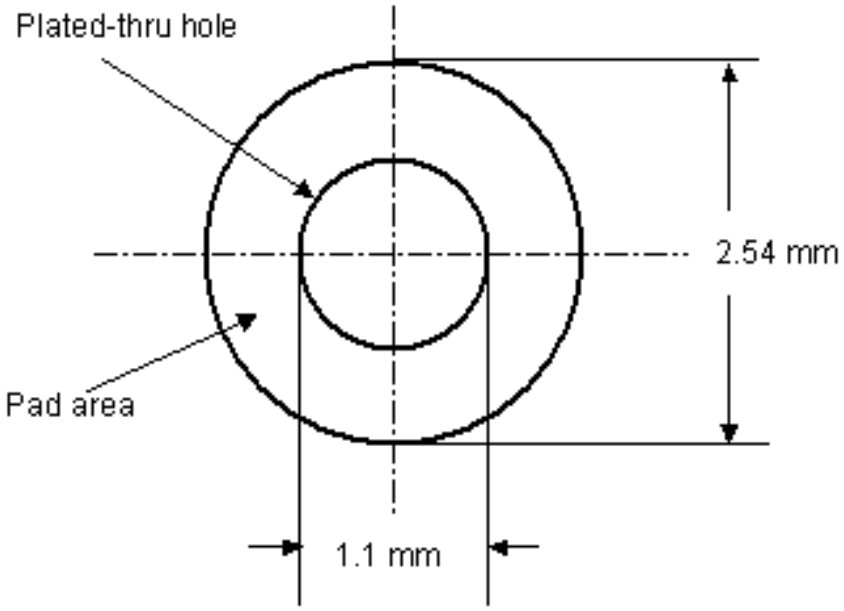



Figure: Solder Pad Specification

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

### 4.1 Responsibility

### 4.2 Special Tests and Examinations

### 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 HV Board 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

FOR AUTHORS ONLY

THIS PAGE (A WORD "SECTION") IS TO BE DELETED PRIOR TO RELEASING ANY DOCUMENT CREATED USING THIS TEMPLATE.

THIS PAGE IS A TOOL FOR THE CONVIENENCE OF AUTHORS USING THIS TEMPLATE TO COMPOSE INDIVIDUAL REQUIREMENTS STATEMENTS.

THE FOLLOWING SET OF THREE PARAGRAPHS, OR ANY PORTION, IS FOR THE AUTHOR TO BUILD THE DETAIL STRUCTURE FOR EACH SPECIFIC REQUIREMENT IN THE TEMPLATE. THIS IS DONE BY DOING A "COPY AND PASTE" OF THE BELOW INTO EACH NUMBERED PARAGRAPH IN THIS TEMPLATE.

THE BELOW PARAGRAPHS ARE ALREADY APPROPRIATELY STYLED.

The {item name} shall …….

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}

VERIFICATION RESOURCES: (location, facilities, equipment, fixtures, software, training, people)

{list the most important needed resources, even if not yet specifically identified}