REVISIONS

LTR.	ECN	DESCRIPTION	DATE	APPROVED
-	NA	Original release		

SHEET REVISION STATUS

SHEET	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
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ANTARCTIC ASTRONOMY AND ASTROPHYSICS RESEARCH INSTITUTE

THE UNIVERSITY OF WISCONSIN - MADISON, WISCONSIN

TITLE

IceCube
DOM PMT High Voltage Power Supply Generator
Source Control Drawing – Procurement Document

ORIGINATOR	DATE	ENGINEER	DATE	CHECKER	DATE
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FIGURES

TABLES

1 INTRODUCTION

1.1 Purpose

This IceCube Specification or Source Control Drawing (SCD) specifies the performance, fabrication, verification, and production acceptance requirements for the High Voltage Generator used on the IceCube PMT Modular High Voltage Power Supply.

1.2 Scope

This Source Control Drawing shall be applicable to the procurement, integration, verification, validation, logistics, field deployment, and disposal of the High Voltage Generator.

1.3 Responsibility and Records

1.3.1 Document Responsibility

The IceCube Project of the Antarctic Astronomy and Astrophysics Research Institute (AAARI) at the University of Wisconsin – Madison (UW) is responsible for writing and updating these requirements to ensure they are correct, complete and current. UW AAARI 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 associated verification and qualification records shall be maintained as follows:

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

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

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

1.4 Item's Function in the IceCube System

The IceCube Neutrino Observatory System at the South Pole requires high voltage for one Photomultiplier Tube (PMT) in each of its Digital Optical Module (DOM) sensors. The High Voltage (HV) Generator is the source of this high voltage. The HV Generator is a component of the PMT High Voltage Control Board, which is one of two subassemblies of the PMT Modular High Voltage (HV) Power Supply. The adjustable output PMT HV Power Supply creates and supplies approximately 2000 volts maximum anode bias and multiple dynode bias voltages to the PMT inside each DOM sensor. The PMT HV Base Board distributes these multiple high voltages to individual PMT electrodes for 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. Adjustable high voltage is provided to the PMT HV Base Board from the HV Generator in accordance with digital control commands received by the PMT HV Control Board. Commanded values of high voltage adjust the PMT for different photon sensitivities. There are 5120 Digital Optical Modules in the IceCube system, each containing a HV Generator in 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 controlled Design Item only to the extent they are invoked by specific requirements herein.

a. PMT Modular High Voltage Power Supply Engineering Requirements Document, University of Wisconsin-Madison, 9400-0016-ERD.

b. PMT High Voltage Control Board Specification Control Drawing, University of Wisconsin-Madison, 9400-0027-SCD.

2.1 Order of Precedence

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

b. 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 High Voltage Generator is a low-power, high-reliability, printed-circuit-board-mounted, modular 2000 VDC high voltage power supply. It is packaged in a metal case shield that minimizes EMI / RFI radiation. High voltage is delivered externally via a captive cable.

3.1.2 Functional Description

The High Voltage Generator produces high voltage in the programmable range of 0 to 2050 volts from a low noise internal quasi-sine wave oscillator driving an isolated transformer. It is programmable via an analog input voltage compatible with a DAC. A voltage monitor produces an analog output voltage proportional to the generated high voltage that is compatible with an ADC. It uses a single +5 VDC input power with provisions for an enable/disable logic input signal for turning off the high voltage output without turning off the power supply.

3.1.3 Functional Block Diagram

The following block diagram (Figure 1) illustrates the functional relationships of the HV Generator at its interfaces:

3.1.4 Functional External Interfaces

The HV Generator has 10 external functional interfaces:

- **a.** +5 VDC primary input voltage
- **b.** 0 to 2050 VDC output voltage
- **c.** Analog voltage input for programmable output
- **d.** Analog voltage monitor output of high voltage
- **e.** ENABLE/DISABLE logic control of output voltage
- **f.** Input power and logic signal ground return
- **g.** Output power ground return
- **h.** Metal case EMI/RFI shielding
- **i.** Metal case ground

j. Mechanical mounting via structural solder pins

These interfaces are illustrated in Figure 1.

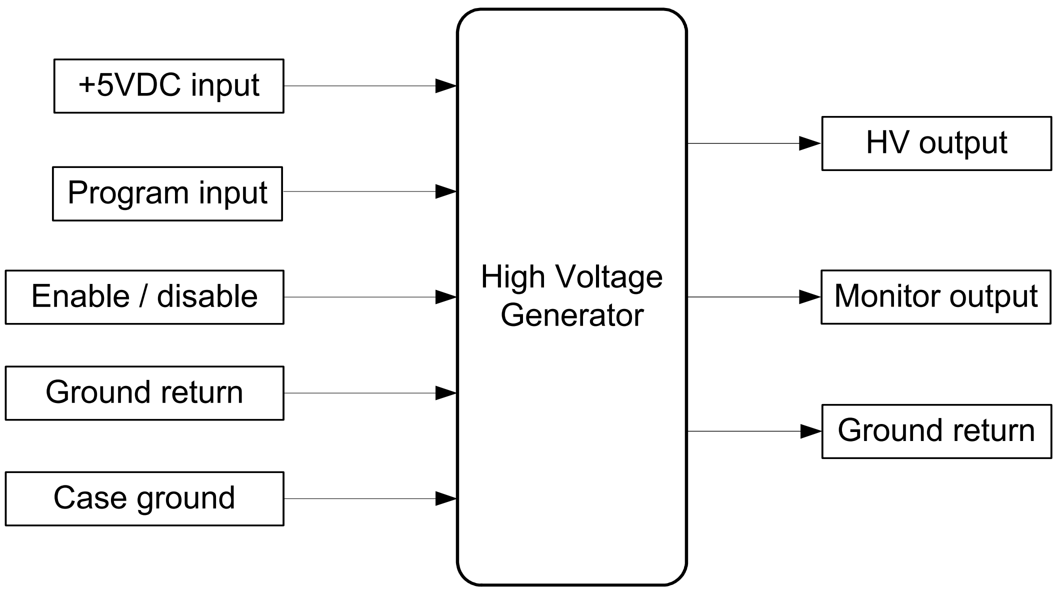

Figure 1: Functional Block Diagram

3.2 Performance Requirements

3.2.1 Functional Requirements

3.2.1.1 High Voltage Generation

The HV Generator shall generate an adjustable high voltage output.

3.2.1.2 Programmable Output

The HV Generator shall provide an analog input for programming the output high voltage from 0 to 100% of the maximum voltage output.

3.2.1.3 High Voltage Monitor

The HV Generator shall provide a signal-level analog voltage proportional to the output high voltage value.

3.2.1.4 High Voltage Output Disable

The HV Generator shall provide a logic level input for enabling and disabling the high voltage output without turning off the HV Generator.

3.2.1.5 EMI / RFI Radiation Control

The HV Generator shall incorporate design practices to minimize the emission of electromagnetic energy to its exterior that may interfere with and/or degrade the performance of the Digital Optical Module and should be tested according to emission test standards (EN55011 (Industrial, Scientific, or Medical), or equivalent).

3.2.2 Electrical Requirements

3.2.2.1 Input Power

3.2.2.1.1 Voltage Power Source

The HV Generator shall receive a power input voltage of +5 VDC ±5%.

3.2.2.1.2 Input Current

The HV Generator input current for the +5 Volt power shall not exceed 60 mA.

3.2.2.1.3 Operating Power

The total input power to the HV Generator shall not exceed 300 mW.

3.2.2.1.4 Standby Power

a. The standby power consumed by the HV Generator while producing the minimum high voltage value shall not exceed 25mW.

b. The standby power consumed by the HV Generator while its high voltage output is disabled should not exceed 50 mW.

3.2.2.1.5 In-rush Current

The maximum in-rush current allowed to enter the HV Generator input power pin should be 2 amps.

3.2.2.1.6 Over-Voltage Protection

The voltage (+5 VDC) input pin of the HV Generator shall withstand an over-voltage of up to 15V.

3.2.2.2 Internal Grounds

Each ground for input power, output voltages, analog signals, logic commands, and the shielded metal enclosure shall be electrically tied together inside the HV Generator.

3.2.2.3 High Voltage Output Toggling

3.2.2.3.1 Functional Definition

High voltage output toggling shall be accomplished by applying a logic signal to the HV_DISABLE pin on the HV Generator, as shown in Table 1.

Table 1 HV_DISABLE Logic Definition.

Logic level	High Voltage output
“1”	Disabled
“0”	Enabled

3.2.2.3.2 HV_DISABLE Usage Requirements

a. The HV_DISABLE pin input shall be in logic “0” while the input power is off or within 0.5 sec. after the power is turned on.

b. The logic level of HV_DISABLE should not change more than once per second.

3.2.2.3.3 Logic Level Standard

The HV_DISABLE signal shall be compatible with the LVTTL signal standard, as defined in *JESD8-B, “Interface Standard for Nominal 3V/3.3V Supply Digital Integrated Circuits”, JEDEC Solid State Technology Association, September 1999*.

3.2.2.4 High Voltage Output Quality

This subsection shall be applicable to the performance of the HV Generator after one hour of warm-up.

3.2.2.4.1 Current Sourcing Capability

The HV Generator high voltage output shall be capable of sourcing a minimum of 30µA of steady state current.

3.2.2.4.2 Output Voltage Stability

a. The HV Generator high voltage output shall not deviate from the programmed value by more than 200 ppm over any eight-hour period.

b. The HV Generator high voltage output shall not change from the programmed value at a rate any faster than 200 ppm per hour.

3.2.2.4.3 Output Voltage Ripple (Noise)

The HV Generator high voltage output ripple voltage shall typically be 2mV but shall not exceed 5mV when measured at the component level (that is, before integration onto the HV Control board) using a resistive load of 130 MΩ ± 5 %.

3.2.2.4.4 Line Regulation

The line regulation of the HV Generator shall be 0.1% or better. Interpretation: the maximum deviation of the high voltage output attributable to the maximum supply voltage fluctuation of 5% shall be less than 0.1 %.

3.2.2.5 HV Adjustment

3.2.2.5.1 Output Voltage Programming Range

The HV Generator high voltage output shall be adjustable over the range of 0 to 2047 VDC, when measured using a resistive load of 130 MΩ ± 5 %, by the programmable input control voltage in the range of 0.000 to 2.047 VDC.

3.2.2.5.2 Output Voltage Programming Current

The programming input of the HV Generator shall not draw more than 100µA.

3.2.2.5.3 Output Voltage Programming Linearity

The output voltage programming linearity shall not exceed 0.5% from 20% to 100% of the programmable range measured using a resistive high-voltage load of 130 MΩ ± 5%.

3.2.2.6 High Voltage Monitoring

3.2.2.6.1 Monitoring Voltage Output

The HV Generator shall monitor the high voltage output and provide a corresponding continuous analog voltage output where 0 VDC represents 0 VDC output and 2.047 VDC output represents 2047 VDC high voltage output.

3.2.2.6.2 Monitoring Current Output

The HV Generator monitoring voltage output shall be able to source up to 1 mA of current at all monitoring output voltages.

3.2.2.6.3 Voltage Monitoring Linearity

The HV Generator high voltage output being monitored and the corresponding monitoring voltage output should have a linear relationship in the specified programmable voltage range with a linearity error of less than 0.5% with a resistive high-voltage load of 130 MΩ ± 5%.

3.2.2.6.4 Voltage Monitoring Accuracy

The HV Generator monitoring voltage output should represent the scaled high voltage output value within ±1 % of the true value from 20% to 100% of the programmable voltage output range.

3.2.3 Mass Properties Requirements

3.2.3.1 Size

The HV Generator shall meet the dimensions shown in Figure 2.

3.2.3.2 Shape

Figure 2 illustrates the overall shape of the HV Generator.

3.2.3.3 Weight

The HV Generator weight (including the HV output cable) shall not exceed 80 grams.

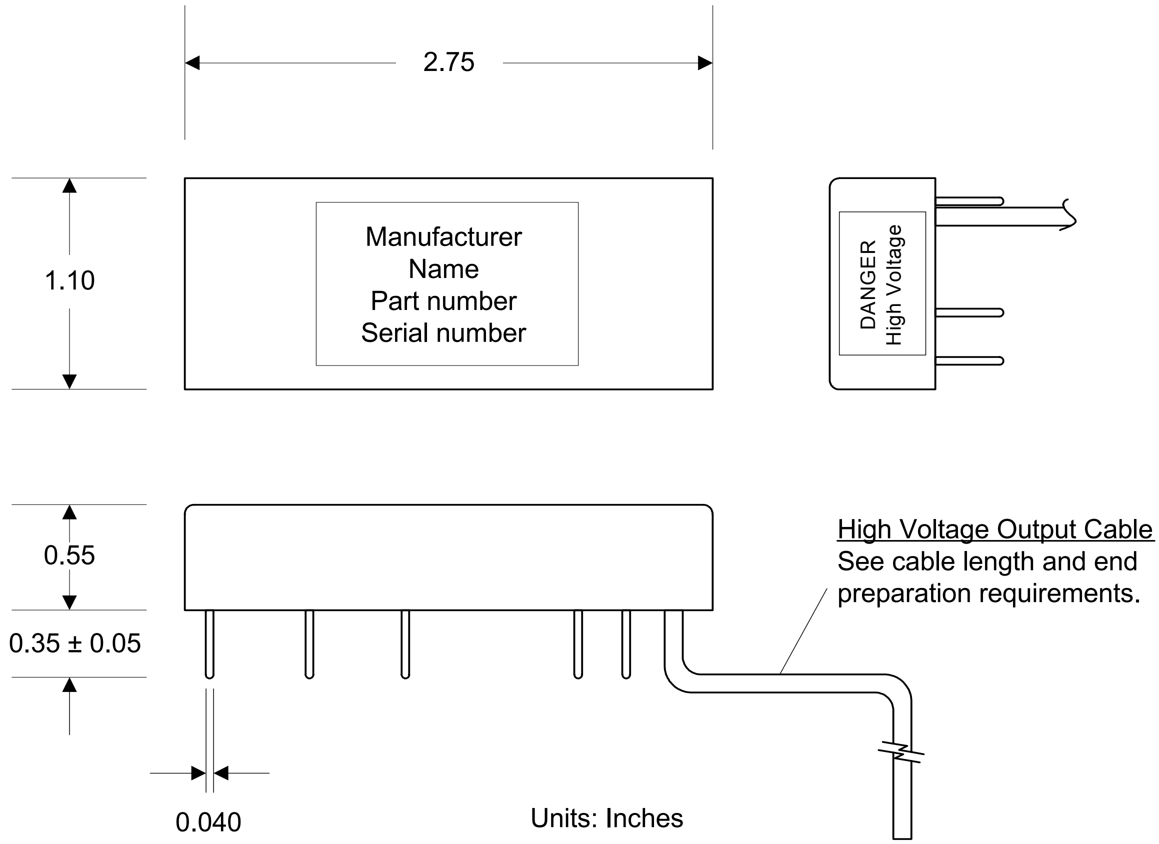

Figure 2 High Voltage Generator Outline Drawing (See also Figure 4)

3.2.4 External Interface Requirements

3.2.4.1 External Grounding

3.2.4.1.1 Discrete Signal Ground

Discrete (logic) signals will be referenced to the Ground pin on the HV Generator.

3.2.4.1.2 Analog Signal Ground

Analog signals will be referenced to the Case Ground pin on the HV Generator.

3.2.4.1.3 Primary Power Ground

Primary power will be referenced to the Ground pin on the HV Generator.

3.2.4.1.4 Safety Ground

Safety grounding will be referenced to the Case Ground on the HV Generator.

3.2.4.2 Voltage, Current, Power, and Timing Requirements

See 3.2.2 Electrical Requirements.

3.2.4.3 High Voltage Output Connection

3.2.4.3.1 HV Cable Interface Medium

The high voltage output cable or wires shall consist of a coaxial medium, specified in Table 2.

3.2.4.3.2 HV Cable Termination

a. The high voltage cable shall be electrically and mechanically terminated inside the High Voltage Generator.

b. The center conductor and the shield of the HV cable shall be connected to the high voltage output and ground, respectively.

3.2.4.3.3 HV Cable Connection Mechanical Integrity

The high voltage cable or wires should not degrade when the cable or wires are pulled with a maximum of 5 Kg of force in any direction from HV Generator.

3.2.4.3.4 HV Cable Length

The high voltage output cable or wires shall have a length of 10.5 ± 0.5 inches measured from the bottom surface of the HV Generator to the end of the inner insulation.

3.2.4.3.5 HV Cable Voltage Rating

The high voltage output cable or wires shall provide 5000 V DC voltage rating over all the operational environments specified herein.

3.2.4.3.6 HV Cable Construction

See Table 2.

3.2.4.3.7 HV Cable Minimum Bending Radius

See Table 2.

Table 2 High Voltage Output Coaxial Cable Specification

Construction		
Component	Material	Nominal diameter (inches)
Center conductor	22 AWG (7/30—7 strands of 30 AWG wire) tin-plated copper.	0.030
Insulation	Extruded modified fluorinated ethylene propylene (FEP)	0.064
Shield	40 AWG tin-plated copper braid with 85% minimum coverage.	0.077
Outer jacket	Extruded fluorinated ethylene propylene (FEP)	0.094
Physical Properties		
Operating temperature	-65 °C to +150 °C	
Maximum operating voltage	5kV DC	
Dielectric withstanding voltage	10kV DC	
Minimum bending radius	10X jacket OD (0.94 inches)	
Miscellaneous		
Identification	No marking on cable is required.	
Incoming Test	All cable to be used shall be tested at incoming	

3.2.4.3.8 HV Cable Pigtail Wire-Prep

a. The high voltage cable shall be stripped and tinned as shown in Figure 3.

b. The end of both the center conductor and the shield shall be tinned with solder in order to protect those ends and facilitate subsequent handling.

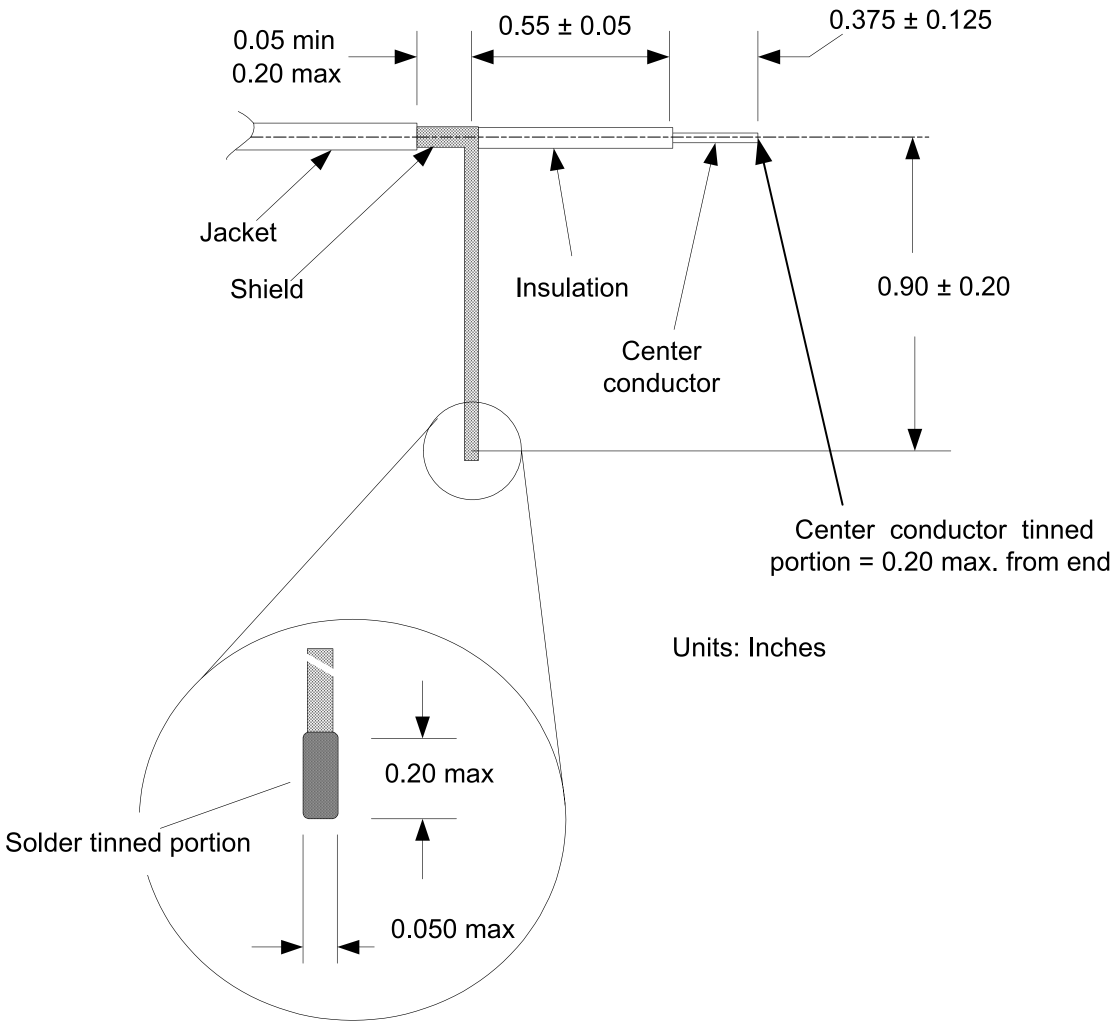

Figure 3: High Voltage Output Cable End Preparation Requirements.

3.2.4.4 Connectors

None applicable.

3.2.4.5 PCB Mounting Pins

3.2.4.5.1 Pinouts

The High Voltage Generator shall have pin numbers and names as shown in Table 3.

Table 3 HV Generator Pin Assignments

Pin #	Functional Name	Input	Output
1	Programming	X	
2	Ground	X	X
3	Ground	X	X
4	+ 5VDC Power	X	
5	Voltage Monitor		X
6	HV Disable	X	
7	No Connection		
8	No Connection		

3.2.4.5.2 Mounting Hole Pattern

Figure 4 gives the dimensions for locations of the pins (1-8), plus the location where the HV output cable exits the HV Generator (9), as viewed from the bottom side of the HV Generator.

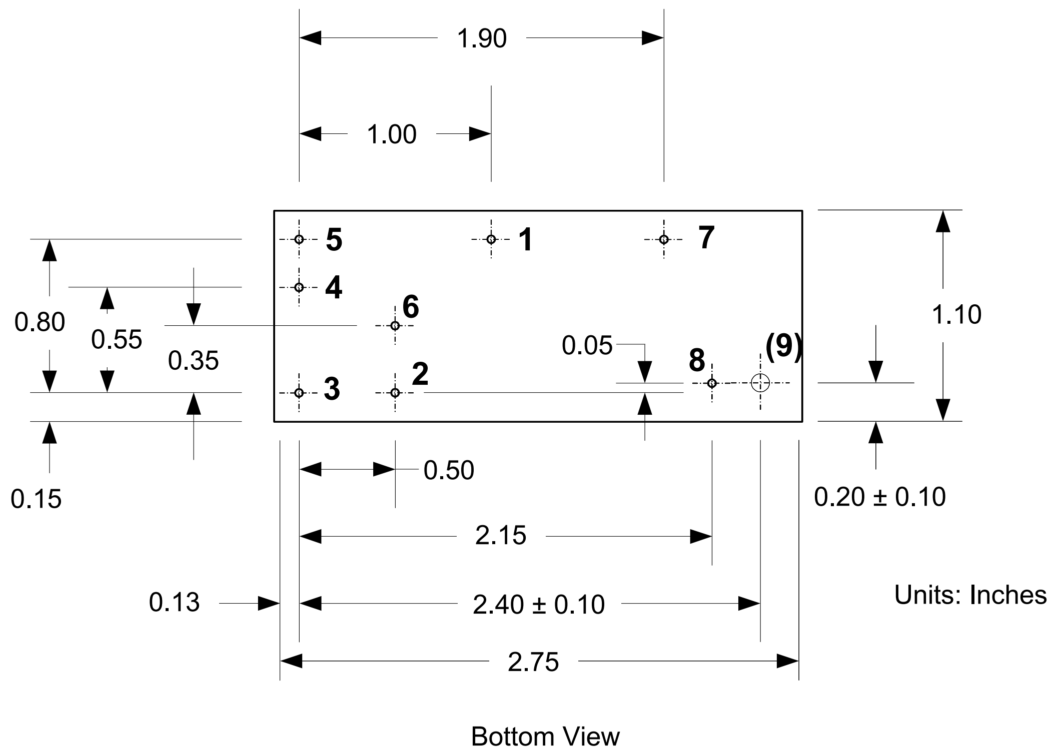

Figure 4: Mounting pattern of the HV Generator. The pin numbers are labeled in boldface. The label (9) refers to the high-voltage output coaxial cable.

3.2.5 Environmental Requirements

3.2.5.1 Temperature

3.2.5.1.1 Operating Temperature

After thermal stabilization, the HV Generator shall meet all performance requirements when operating over an ambient temperature range of −55°C to +50°C.

3.2.5.1.2 Storage Temperature

The HV Generator shall meet all performance requirements after storage in an ambient temperature range of −55°C to +70°C.

3.2.5.1.3 Cold-Start Temperature

The HV Generator should be capable of cold starting after a 48 hours' non-operating storage at −55°C.

3.2.5.2 Environmental Stress and Screening

The HV Generator shall pass through Environmental Stress and Screening (ESS) Test for stress conditioning and trapping of early life failures.

- **a.** Units exhibiting statistical anomalies during the ESS, but otherwise within specifications, shall fail this test.
- **b.** Test duration shall be 96 hours at minimum.
- **c.** Units under test shall be temperature-stressed early in the cycle by soaking at 70 °C before cooling down to –55 °C in no less than 2.5 hours.
- **d.** Functional tests shall be conducted after soaking for a minimum of 5 hours at 45 °C and –40 °C; and after soaking for a minimum of 2 hours at 70 °C and –55 °C.
- **e.** Supplier shall document the ESS test plan.
- **f.** Test data and pertinent record shall be captured on-line and shall be available for a minimum of 15 years henceforth.

3.2.5.3 Vibration

The packaged generators shall be shippable by all means of common carrier.

3.3 Design and Construction Requirements

3.3.1 Electrical and Electronic Parts

a. To the extent practical, all electrical and electronic components used for the PMT High Voltage Generator shall meet the lowest operating temperature of –55°C, as specified by the component manufacturer, where "practical" means such components are readily available from standard sources.

b. All the PCB material, conformal coating, wires, insulators, and solder shall be considered as electrical components and be subject to this requirement.

c. The vendor of the High Voltage Generator shall supply IceCube with a complete list of components in use that do not meet the –55°C or lower operating temperature.

d. Components critical to output stability and precision shall be tested prior to being received into stock or kitting.

3.3.2 Soldering

The connector pins shall be solderable per MIL-STD-202G, Method 208H, Test Method 3, Soldering Iron Test Method.

3.3.3 Reliability

The High Voltage Generators shall have a Mean Time To Critical Failure (MTTCF) of greater then 1×10^6 hours as predicted in accordance with the Parts Stress Analysis method of MIL-HDBK-217F (N1/2).

3.3.4 Workmanship

a. The components shall be free from physical or electrical defects upon receipt at the purchaser's facility.

b. Labeling on a component shall be undamaged and legible upon receipt.

3.4 Quality Requirements

3.4.1 Certificate of Conformance

All shipments of the High Voltage generator shall have a Certificate of Conformance (C of C), indicating that all units meet the specifications as defined in this document.

3.4.2 Environmental Stress Screening

All units shall pass the ESS test as described in section 3.2.5.2 of this document.

3.4.3 Functional Tests

3.4.3.1 Timing of tests during the manufacturing process

All units shall pass a functional test that is executed 3 times during the manufacturing process. This test shall be done prior to potting, immediately after potting, and after ESS testing is complete.

3.4.3.2 Test requirements

a. The parameters measured in the functional test suite shall at minimum include the following:
   - Drop-off voltage under full load
   - Output voltage over the input voltage range (3.2.2.1), as a function of Programming voltage and the logic state of HV Disable.
   - Line regulation
   - Input current
   - Output current
   - Programming linearity
   - Programming input current
   - Voltage monitor accuracy
   - Monitor output current

b. Unit serial numbers, job numbers, operator I.D., date and time stamps, and parameter results of the unit under test shall be captured by the database. (No manual entry)

c. Factory guard-bands shall be set by Test Engineering in charge.

3.4.4 Visual Inspection

Units should be visually inspected prior to shipment and should be free of the following visual defects:

a. Voids in the potting material.

b. Corrosion of the steel cover and connecting pins

c. Contaminate materials which may degrade the lifetime of the HV Generator.

3.5 Safety Requirements

a. The unit shall be designed and manufactured such that the housing does not allow contact with the high voltage components of the unit.

b. Ground and high voltage output leads shall be clearly identifiable.

c. A "DANGER: High Voltage" label shall be affixed to each unit.

4 PREPARATION FOR DELIVERY

4.1 Identification Nameplates and Marking

All units shall be clearly marked. See Figure 2.

4.1.1 Part and Serial Numbers

Each unit must be individually serial numbered.

4.2 Acceptance Inspection and Tests

See Quality Requirements section

4.3 Shipping

Component shall be packaged in ESD protective packaging and shipped by common carrier. The mode of shipping shall not introduce additional risk of unanticipated accidental damage to the component.