Specification for the Toroidal Field Bank Modules Capacitor Charge/Discharge Power Supply (CCDPS) for FLARE

March 11, 2016

Contents

List of Tables

List of Figures

1 Specifications for Toroidal Field (TF) bank modules

1.1 Description

Bank schematic is shown in Fig. 1. Starting on the left side of the figure, the module is charged by connecting both positive and negative supply lines. A power supply protection circuit is shown (although the components are distributed between the charge supply rack and the capacitor modules – please refer to the Charge Specification for details). A bleed resistor is connected in parallel with each capacitor and is used to slowly drain bank charge in case of failure of all other dumps (i.e. if left alone overnight the bank will passively discharge below the NFPA 70E safe approach threshold of 50 V). Before each shot, the dump load relays are opened. Then the charging relays are closed and the charging supply charges the caps. When the set-point is reached, the charging switches are opened. The capacitors are then discharged through the inductive and resistive load of the coil, and crowbarred with a delay corresponding to peak current. For TF, it is required that the crowbar fire at anytime from peak current to 50% current, so an ignitron is used to accomplish this. Following a shot, the dump switch is closed to ensure the capacitors are fully discharged. After the bank has dumped, the ground switch is closed to connect cap terminals to ground. Capacitor fuses are thin wires designed to blow during an over-current event. They will be used on each cap and will connect the capacitor to the busbar. Each of the components will be described in the following sections.

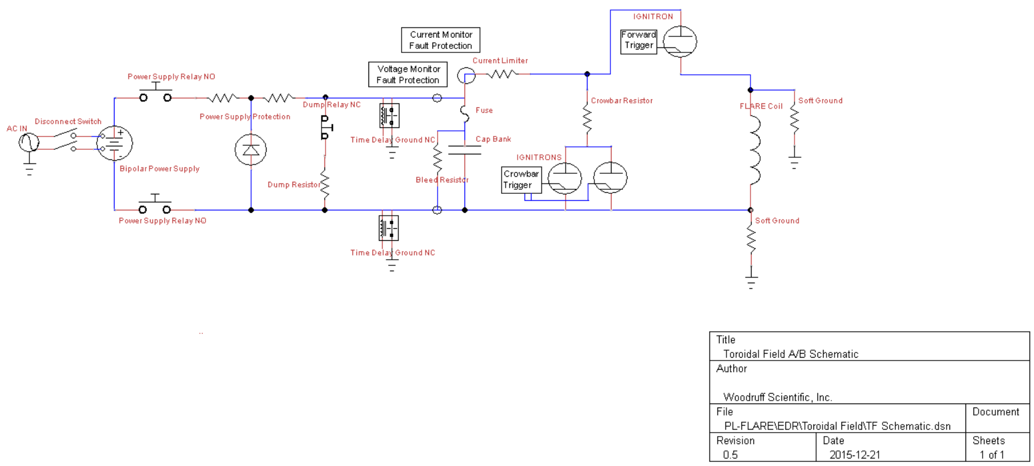

Figure 1: Toroidal Field Circuit Schematic

The TF bank modules are designed to energize the TF-A and TF-B coil sets, providing a current pulse per Fig. 8, meeting the specifications in Table 1. The power supply system shall be designed for a minimum of 10 years design life and a minimum of 100,000 full power shots with regular maintenance.

	TF-A	TF-B
# Sub-Coils	4	4
V (Volts)	20000	20000
Imax (A)	250000	250000
Day 1	0	0
Peak I (kA)	250	250
trise (ms)	< 0.08	< 0.08
tcrowbar	Peak - 50%	Peak-50%
Swing Imin	70%	70%

Table 1: Target parameters for TF bank

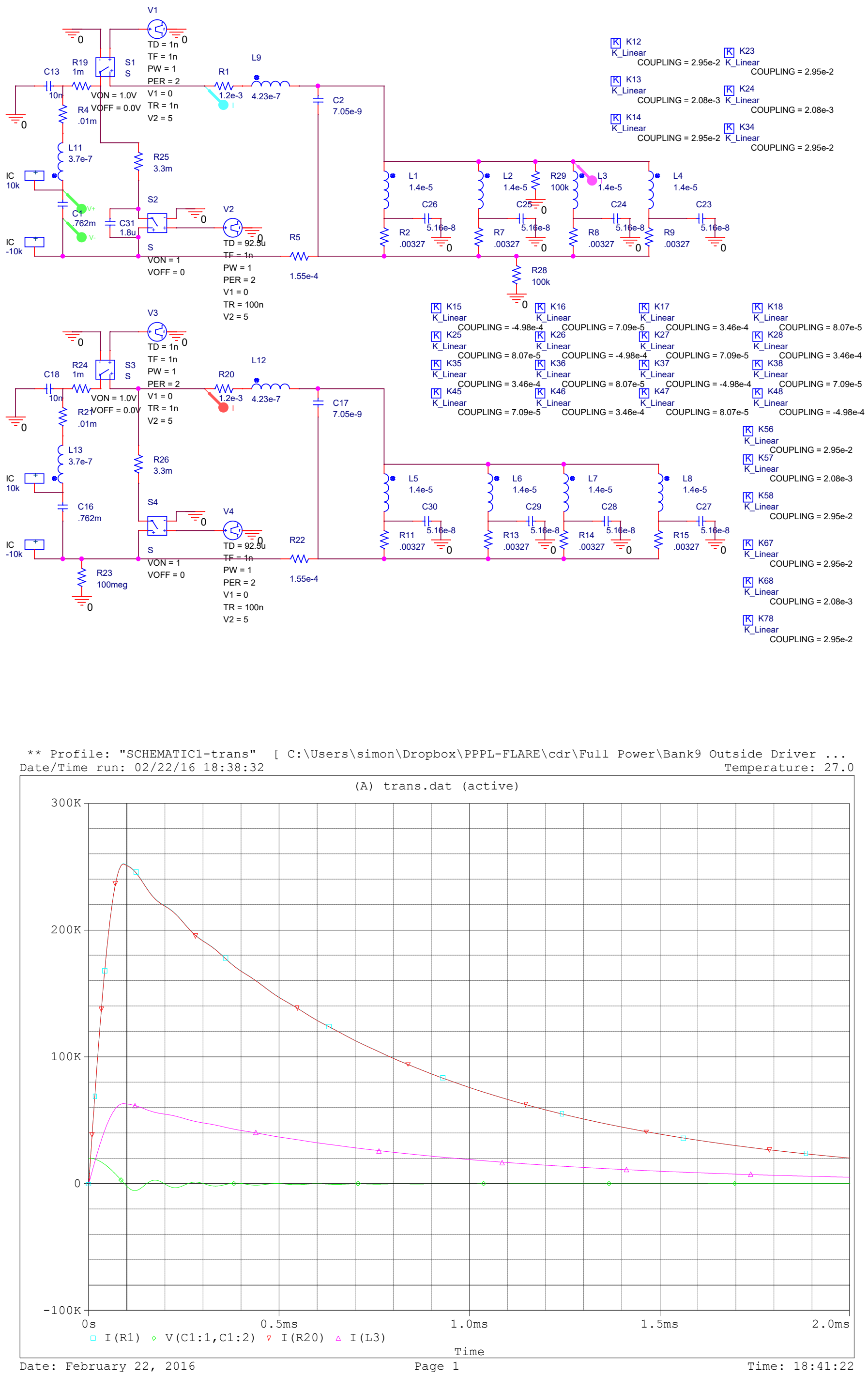

Figure 2: PSpice Schematic and Analysis

1.2 Full Assembly: module

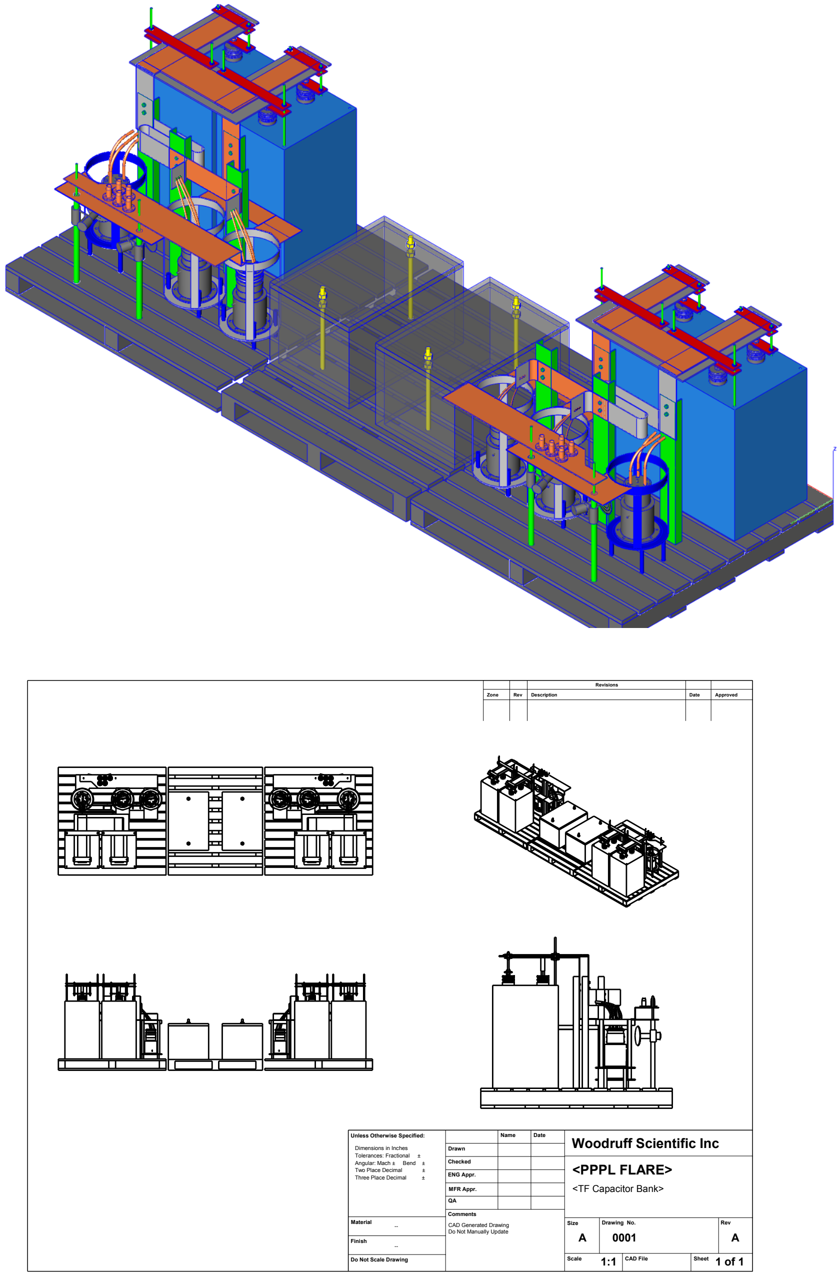

Figure 3: Engineering design point for bank module

Fig. 3 shows the full bank assembly (comprising TF-A and TF-B modules) mounted on two 36 inch square steel pallets, with a third pallet for dumps. The full assembly will have a footprint no smaller than 48sqft with a maximum of 160sqft for egress and maintenance (2 feet on each side), and will be engineered as 2 modules (on 3 pallets) that can be transported and installed onsite with only a small number of connections (connections for 110V power, high voltage and trigger lines (see more details below and connection table below)). The TF Bank and all related components will be mounted on 3 36"x 36" standard pallets, total height under 50 inches, total weight per pallet of 1200lbs. Assembly instructions will be provided.

1.3 Capacitors

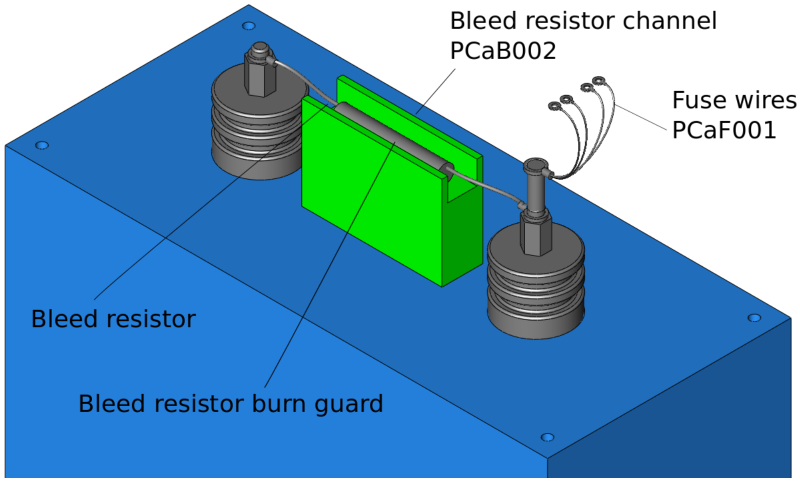

Figure 4: Capacitor detail

The capacitors are expected to see reversal voltages during the experimental shots. The voltage reversal on the caps will be specified to be 80%. Each capacitor unit should be individually fused and self-protected. Energy dumping resistor(s) shall be specified for safe dissipation of stored energy (see below). The dissipation time should be limited to the shorter of the relevant industrial standards or the experimental needs. The TF bank will use 4 NL400-20KV Capacitors, by Richardson Electronics. They have a rated capacitance of 400uF and a rated voltage of 20kVDC. They are rated for 80% discharge voltage reversal. The capacitors are expected to survive at least 500,000 full power shots without failure, per cap manufacturer specification see appendix for the Richardson specification. In parallel with each capacitor is a bleed resistor. These are a redundant dump mechanism for the stored energy. These resistors are sized to discharge the bank to below 50 volts over 12 hours. The bleed resistors are a passive "last resort" safing mechanism in case of failure of the water dump or loss of buswork connections, allowing the operator to leave the bank overnight to dissipate its stored energy. The bleed resistor shown in Fig. 4 is a 30kV 40W 40MΩ Ohmite MOX-H (see spec in appendix). Shown also in Fig. 4 are the fuse wires, which are 4 14AWG bare copper wires soldered into ring terminals. Burn guard will be mounted to the cap with double-sided adhesive tape (e.g. 3M Command Strips).

1.4 Forward Switch

Wherever practical and appropriate, PPPL prefers the following ignitron to be used. Ignitron model NL8900, by Richardson Electronics (see apendix). For the this bank, the forward switch will be such an ignitron. The ignitrons are expected to see reverse voltage and pulse currents. Life time of the ignitron contact shall not be significantly shortened or the minimum design life of the equipment should be maintained. The ignitrons are expected to survive a minimum of 10,000 full power shots without failure. The anode of the ignitron requires heating. This design will utilize a 500W infrared heater mounted close to the anode. The ignitron requires water cooling, provided by 1/4" NPT hose connected to a water chiller (see spec in appendix). Ignitrons are connected to the bus bar using 3 copper braids terminated with ring terminals and bolted with 1/4-20 bolts (see machining drawings for details).

1.5 Crowbar Switch

The crowbar switch on the TF bank is the Ignitron model NL8900, by Richardson Electronics (see appendix). Two will be used in parallel in the crowbar circuit. This Ignitron uses the IG5F2-10 Ignitron Driver, also by Richardson Electronics. After the forward switch is fired, the crowbar will be fired after a delay corresponding to peak current. The anode of the Ignitron requires heating. This design will utilize a 500W infared heater

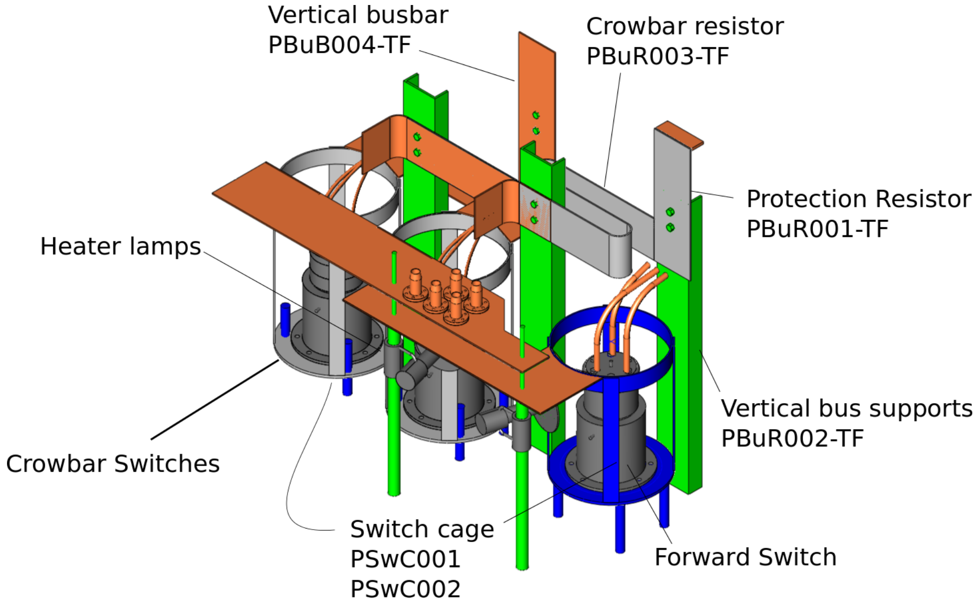

Figure 5: Forward and crowbar switches

mounted close to the anode. The ignitron requires water cooling, provided by 1/4" NPT hose connected to a water chiller. Ignitrons are connected to the bus bar using 3 copper braids terminated with ring terminals and bolted with 1/4-20 bolts (see machining drawings for details).

1.6 Buswork

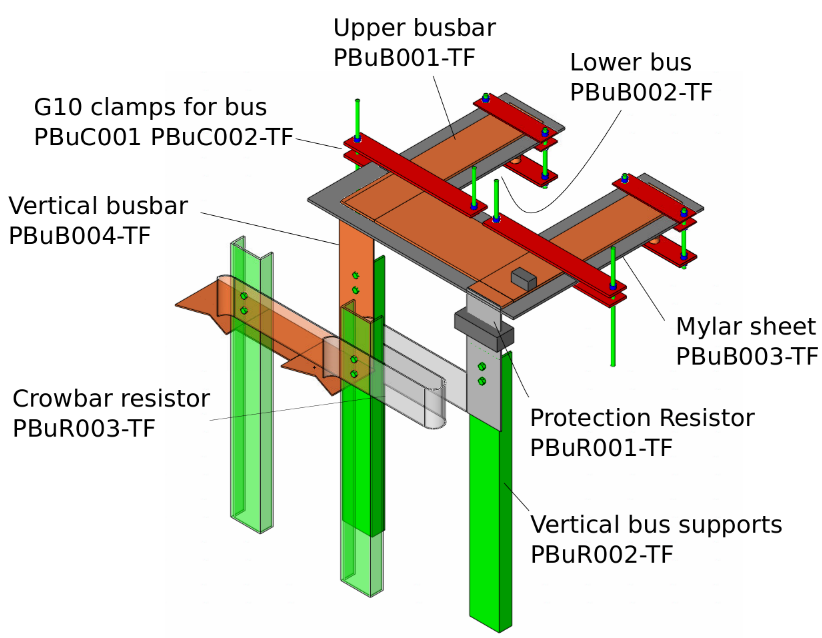

Figure 6: Buswork detail

Buswork consists of busbars connected to the caps by use of brass adapters that are secured by 1/4-20 bolts and have knife-edges that will bite into the copper busbars (see detailed call-out in Fig. 6. A larger bus is used to interconnect all the smaller capacitor buses which then feeds into the current limiting stainless steel resistor. Outgoing and return busbars are isolated from each other by use of multiple layers of mylar sheet, with sufficient overhang to meet the 2E+1 stand-off requirement. A 1mOhm overcurrent protection resistor is provided in case of short failure, clamping the maximum current to tolerable thresholds for the caps. The power supply should be properly insulated based on design. The rule of thumb to be followed is 2E+1, where E is the maximum system voltage. All bus work should be taken into consideration so that the inductance does not limit the system performance.

1.7 Charging

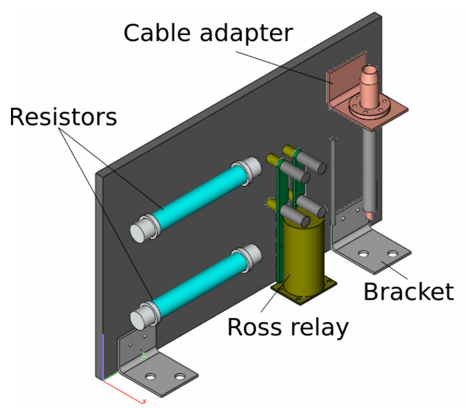

Figure 7: Charging switch and connection detail.

The charging supply will consist of two Spellman SLM10*1200. The charge supplies are wired in series to create a ±10kV bipolar output. The two output lines each include a series resistor to improve regulation and limit output current under fault conditions. The lines are then split to run a cable to each capacitor module. At the capacitor module, the charge cable is connected across a diode that protects the charge supply in the event of a bank pre-fire (when the charge supply is connected to the bank). The diode prevents any bank reversal during pre-fire from imposing a reverse voltage at the charge supply. After the diode is a resistor that limits the charge current for the bank (and limits the protection diode current under reversal). The final connection to the capacitor buswork is made via a normally-open DPST Ross relay (E40-2PNO) which is only connected for charging, and is disconnected immediately prior to programmed discharge. Please refer to the separate specification for the charging supplies (treated as a separate sub-assembly) for circuit schematics and details of the switching needs. Charging cable is terminated at the bank with a custom connector, see Fig. 7.

1.8 Dump

Each capacitor module includes a resistor sized to dissipate the full-charge energy of the bank. The resistor material is an aqueous solution of copper sulfate with brass electrodes in a polycarbonate reservoir. The electrolyte concentration is tuned to discharge the bank to below 50 volts (the NFPA 70E safety threshold) within 30 seconds. This dump rate was chosen based upon a conservative estimate of the time required from removal of the Kirk key at the operator station to entry of the bank enclosure. The dump sizing is also designed to allow several sequential full-energy dumps at 3 minute intervals, but in this operation mode the resistor temperature shall be monitored remotely by the operator to ensure the temperature does not exceed 60°C (as per ASTM C1055) and that the water level is maintained. The normally-closed dump relay on each module (Ross E40-NC) will be energized only during charge, and will be de-energized to engage the dump upon removal of the Kirk key or at any emergency stop or interlock break. A temperature sensor is located on the outside lower section of each dump.

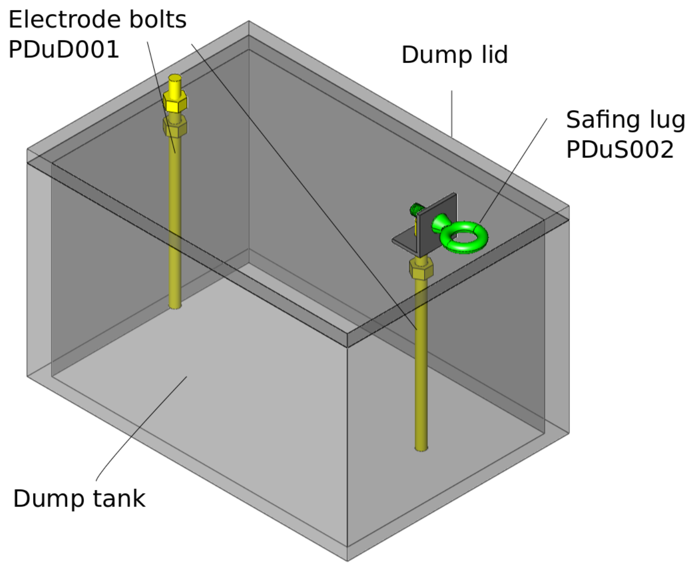

Figure 8: Dump detail for the TF bank module.

1.9 Harnessing

The harnessing sub-assembly comprises all of the interconnecting power cables from the CCDPS to the FLARE machine. The cabling will be triax of suitable current rating (see e.g. Dielectric Sciences specification in the Appendix). 7 cables will connect to the cable header located close to the switches and between the dumps. Cable trays will be used to route cables from the capacitor banks to the device.

1.10 Polarity switching

The TF coil currents have been requested to have the ability to frequently and easily invert the direction of coil current. The CCDPS is fixed in its output polarity such that the cable center conductor is at positive voltage, the middle conductor layer carries the current return at negative voltage, and the outer shield of the cable provides an electrostatic ground. A concept has been developed to invert the current driven in the coil using a particular arrangement of busswork connections, as shown in Figure 9. Ideal placement of this switch would be at the coil interface to the experiment vessel. In the figure, one may consider the busswork at left to come from the cable header where cables from the CCDPS attach, and the busswork at right feeds to the coil interface. The blocks shown at center link the top bus at left to the rear bus at right, and the bottom at left to the front at right (top to rear, bottom to front). Coil polarity can be inverted simply by moving the bars to the other side horizontally (top to front, bottom to rear). Alternating sheets of mylar sheet insulation from the two sides must be interleaved between the connecting blocks to prevent arc flashover. Further engineering details cannot be defined until the coil header design is provided.

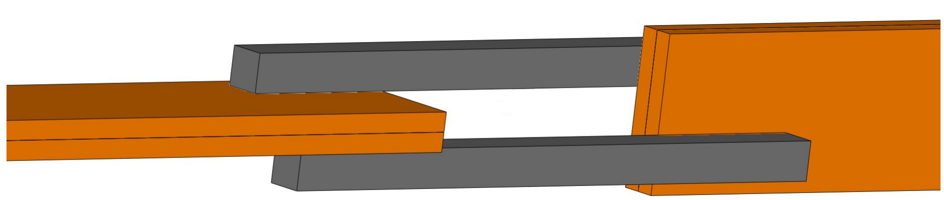

Figure 9: Concept for a simple, low inductance polarity switch. The blocks shown at center link the busswork at left to the busswork at right; moving the blocks to the unoccupied spaces (opposite sides of the busswork) effects a polarity switch. Insulation between the busswork is not shown.

1.11 Diagnostics

Diagnostics must be provided to measure the forward current in the bus leading to the forward switch (see gray block on safety resistor in Fig. 6 for placement), the voltage of the bank module using a voltage divider, and the temperature of the over-current protection resistor, the temperature in the dump resistor and the temperature at the anode of the ignitrons. Each of these diagnostic measurements must be transmitted along a fiber-optic connection to the DAQ. Please see separate DAQ specifications for further information.

1.12 Safety

Monitoring (analog and digital voltage monitoring) will be required. A voltage divider at the bank will be used to monitor the charging voltage on the control computer (see specification for DAQ), and provide a signal for a panel-mounted analog indicator at the entry to the enclosure.

The TF bank module will be housed in a bay that separated it from other bank modules. Each side of the bank module may be separated by a 1/4 inch steel blast shield. The enclosure will be interlocked and procedures will be present to disable the bank before personnel access.

1.13 Cooling requirements

Ignitron switches in the TF module require a connection to a water coolant supply to provide a minimum of 10 degrees of relative temperature difference between anode and cathode. Water coolant is provided by connection of 1/4" NPT fittings on the base of the ignitron to a water chiller. See detailed specifications in the appendix.

1.14 Connection schematics

The connection schematic shows all of the connections that need to be made to the bank modules, power and control systems. From the left of Fig. 10, 208 and 110 power is fed to the bank enclosures via a Kirk key controlled isolation switch. This same switch can be energized by an Emergency Stop (E-stop) button located in the control room (this E-stop is digitized by both the FLARE control DAQ and the CCDPS control DAQ). If energized, the switch will drop all power to the enclosure, thereby killing power to the HV dump (normally closed) and charge (normally open) relays, and dumping bank energy into the cap dumps. The 110 and 208 power is delivered to the charging supply rack (located on it's own separate pallet), and 110 is also delivered to an isolation transformer mounted on the bank module pallet. Connections to the load are made by multiple triax cables (described above). Water is connected to the ignitron switches along 1/4" tubes from a shared chiller unit. The charge, dump ground relays are controlled by individual fiber-optic-enabled switches, with pulse signals sent from the CCDPS DAQ rack (Schematic shown in Fig. 11). Temperature sensor data are transmitted by fiber-optics from the pallet to the DAQ after conversion of voltage to frequency, then reconverting at the DAQ. A BNC connection is made from the current sensor integrator to the DAQ fast data acquisition (sampling at at least 1MHz). Timing synchronization is provided by the FLARE control DAQ. Switch firing is controlled here by the FLARE control computer and DAQ, by transmission of fire signal by fiber-optic connection. CCDPS DAQ requires 110V as input. CCDPS control computer requires 110V as input.

- Electrical input requirements: 208V three phase, 110V, less than 50 Amps (total for all banks at full charge is 100A)
- Load requirements: as specified in [1]
- Cooling requirements: chiller for ignitrons (see specification attached)
- Environmental requirements: dust free, see below
- Control signals needed as inputs: ESTOP and triggers (see Fig. 10)
- Control signals as outputs: none.

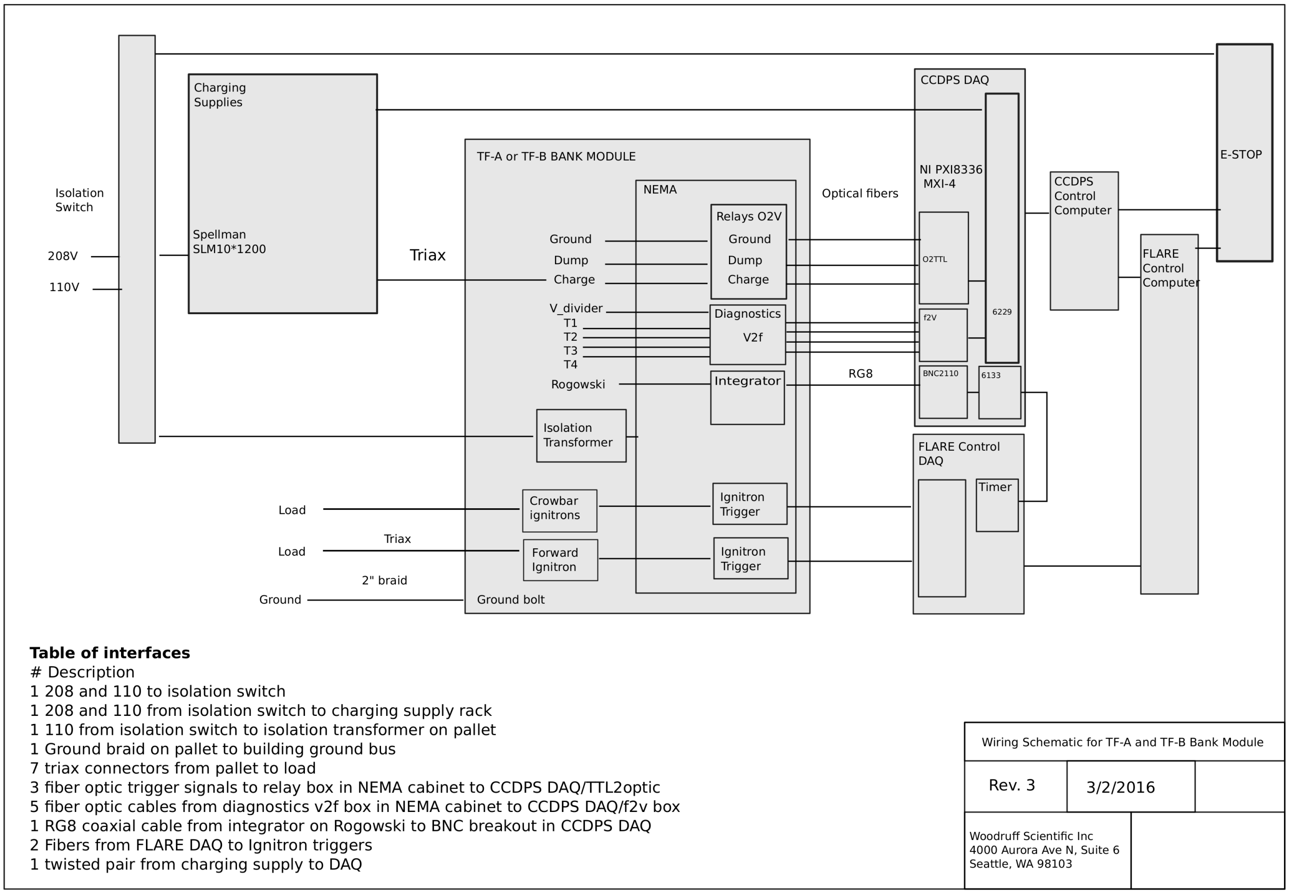

Figure 10: Connections between CCDPS sub-assemblies.

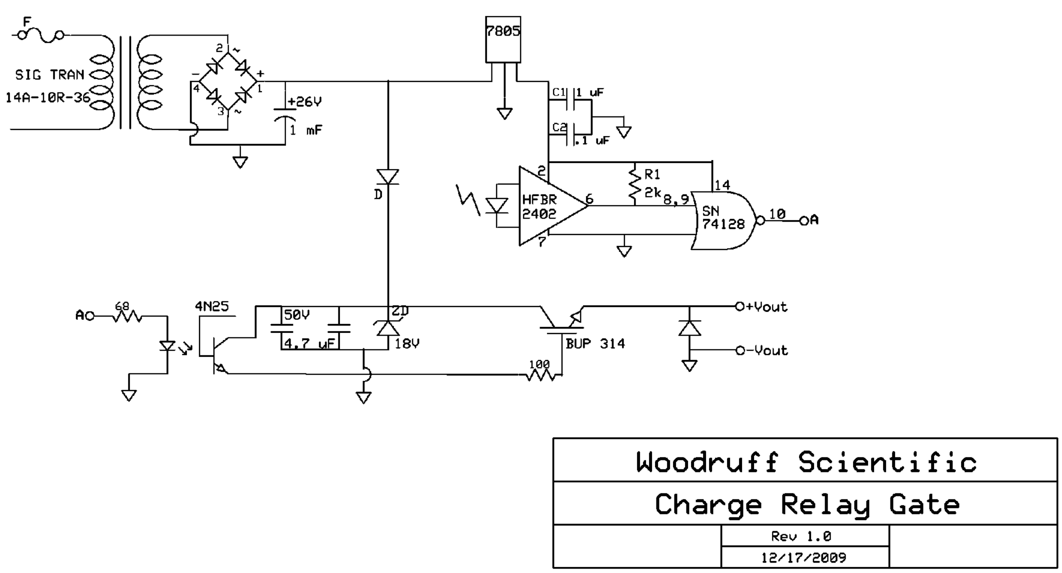

Figure 11: Schematic for charge, dump and ground relay control.

1.15 Environmental requirements

The entire CCDPS is specified to operate at room temperature, and will tolerate seasonal variations in humidity without the need for any special AC, other than cooling lines to the ignitrons. Ideally the banks will be placed in a dust-controlled environment (fans with filters, preferably with drywall to the ceiling), with minimal traffic to the enclosure.

2 References

References

[1] Statement of Work for Design of Capacitor Charge/Discharge Power Supply (CCDPS) for FLARE FLARE-CCDPS-150828, Revision 0, Sept. 9th 2015

3 Appendices

3.1 Engineering Drawings and vendor specs

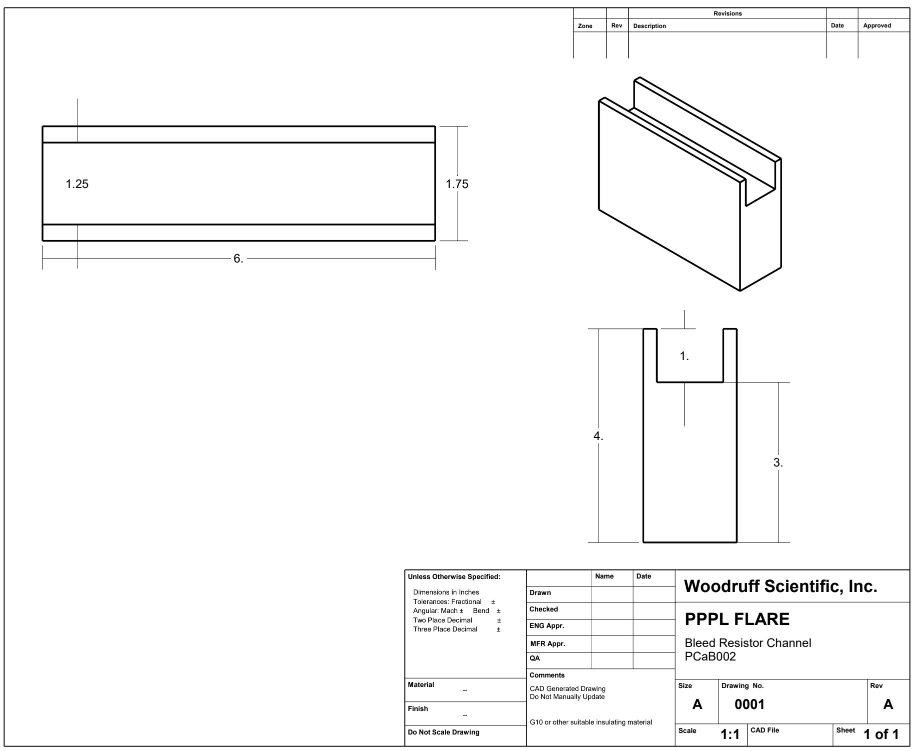

Figure 12: TF Bleed Resistor Channel

	OH	EF	TF	PF
H	8.125	8.125	6.25	6.75
W	10.875	10.875	15	15

Table 2: Bus Clamp Dimensions by Bank (inches)

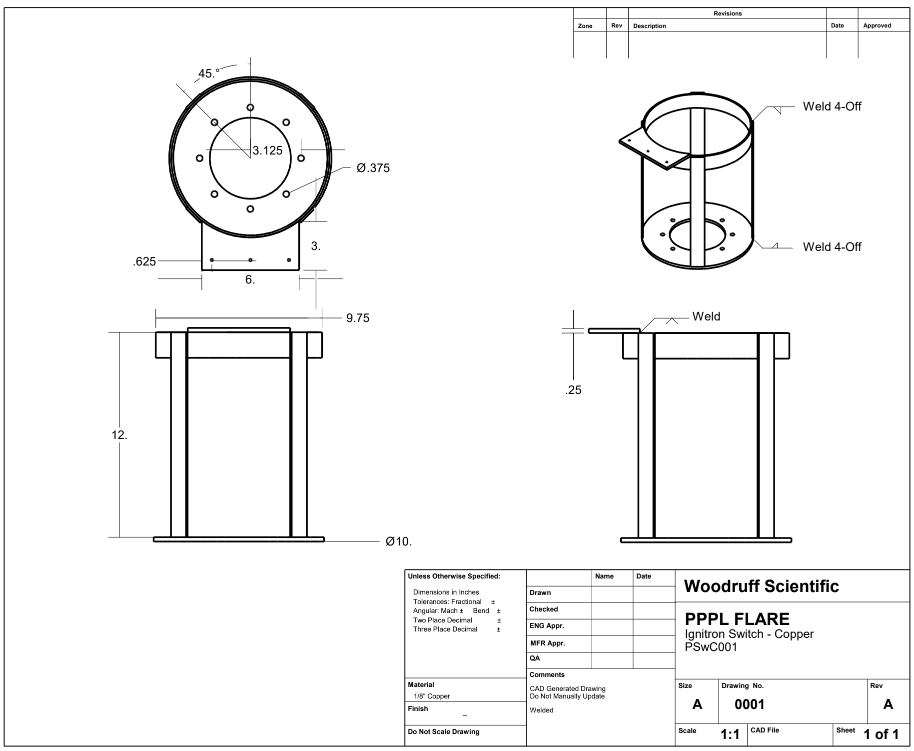

Figure 13: Ignitron Cage - Copper

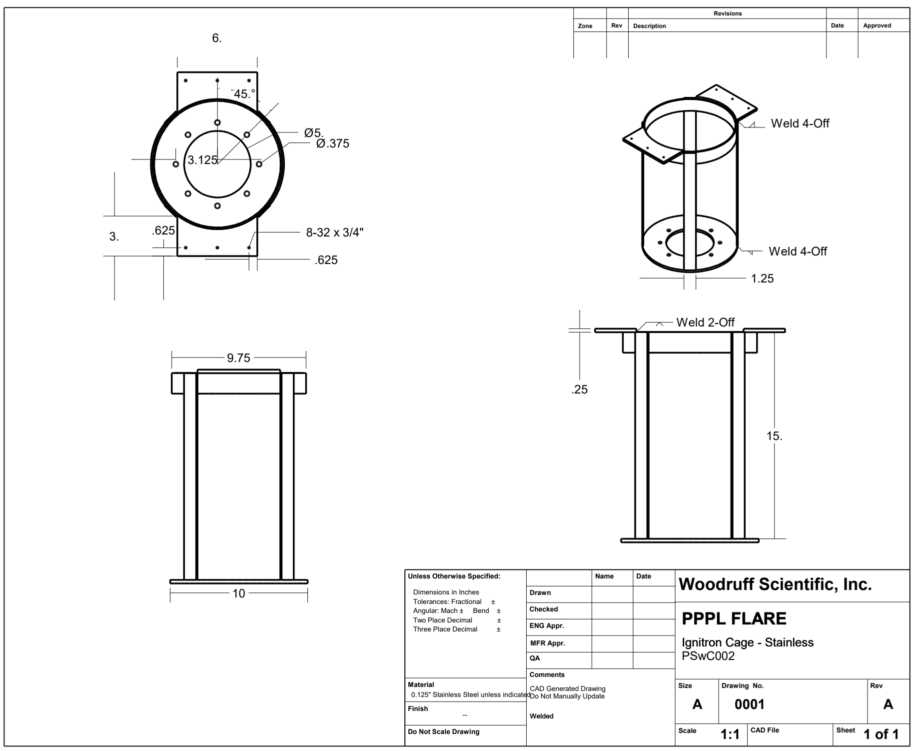

Figure 14: Ignitron Cage - Stainless

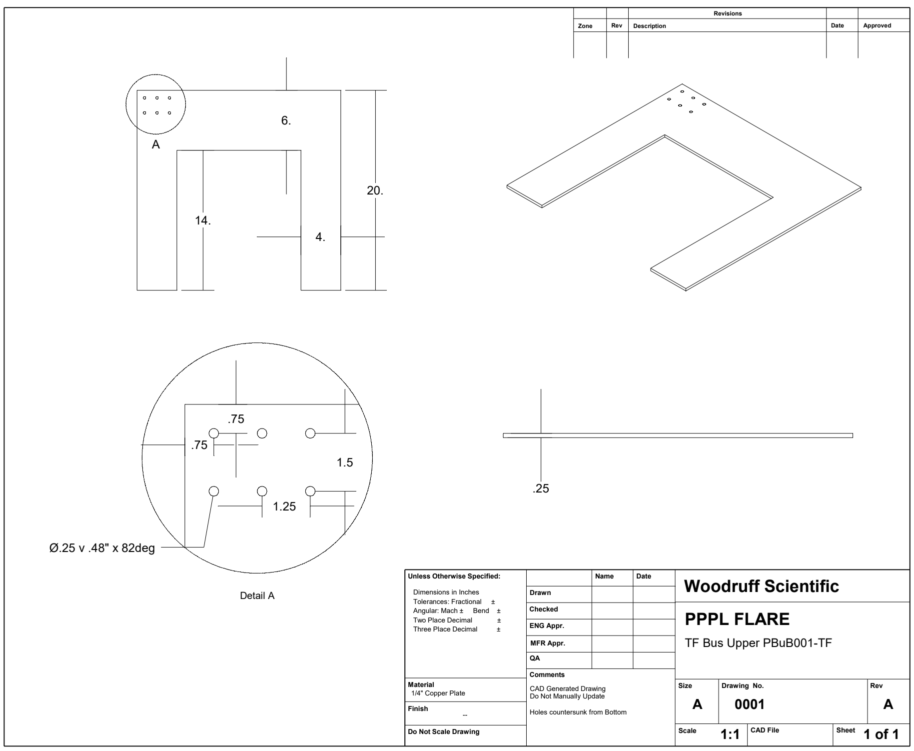

Figure 15: TF Bus Upper

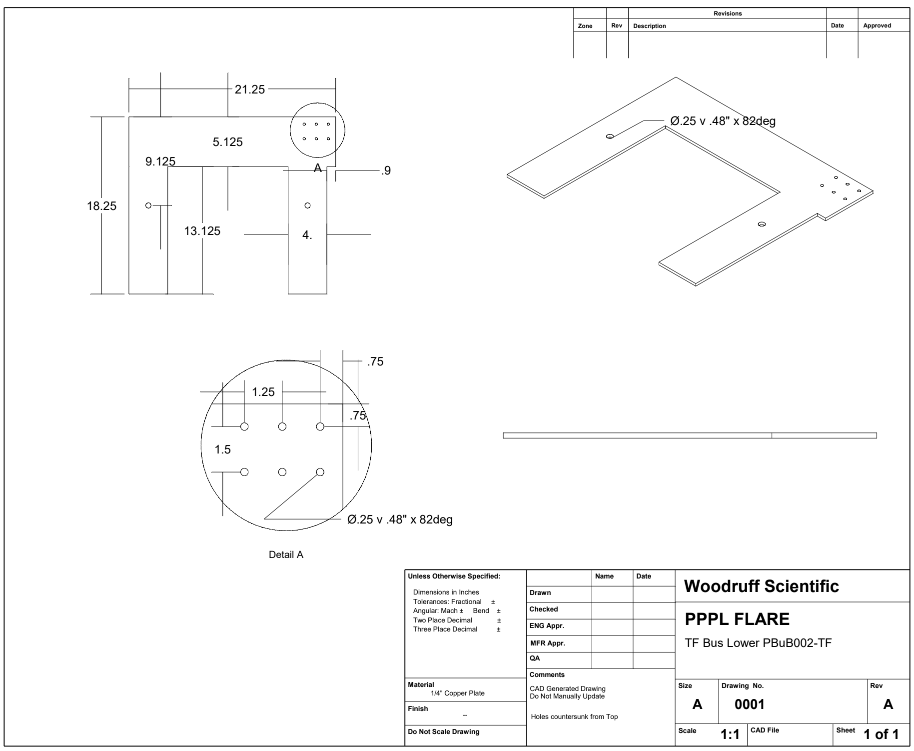

Figure 16: TF Bus Lower

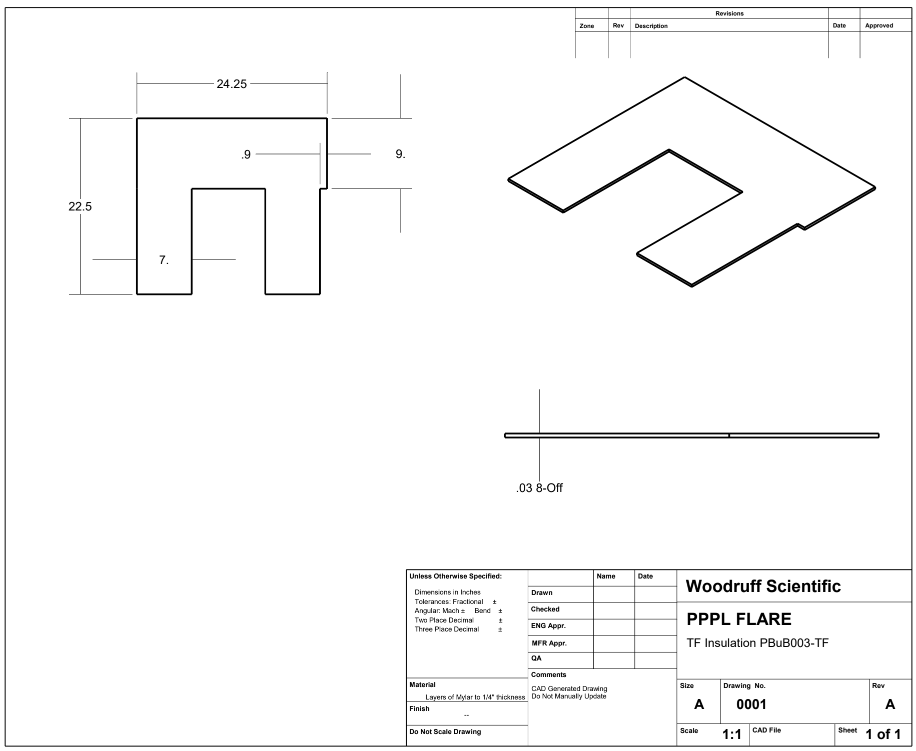

Figure 17: TF Bus Insulation

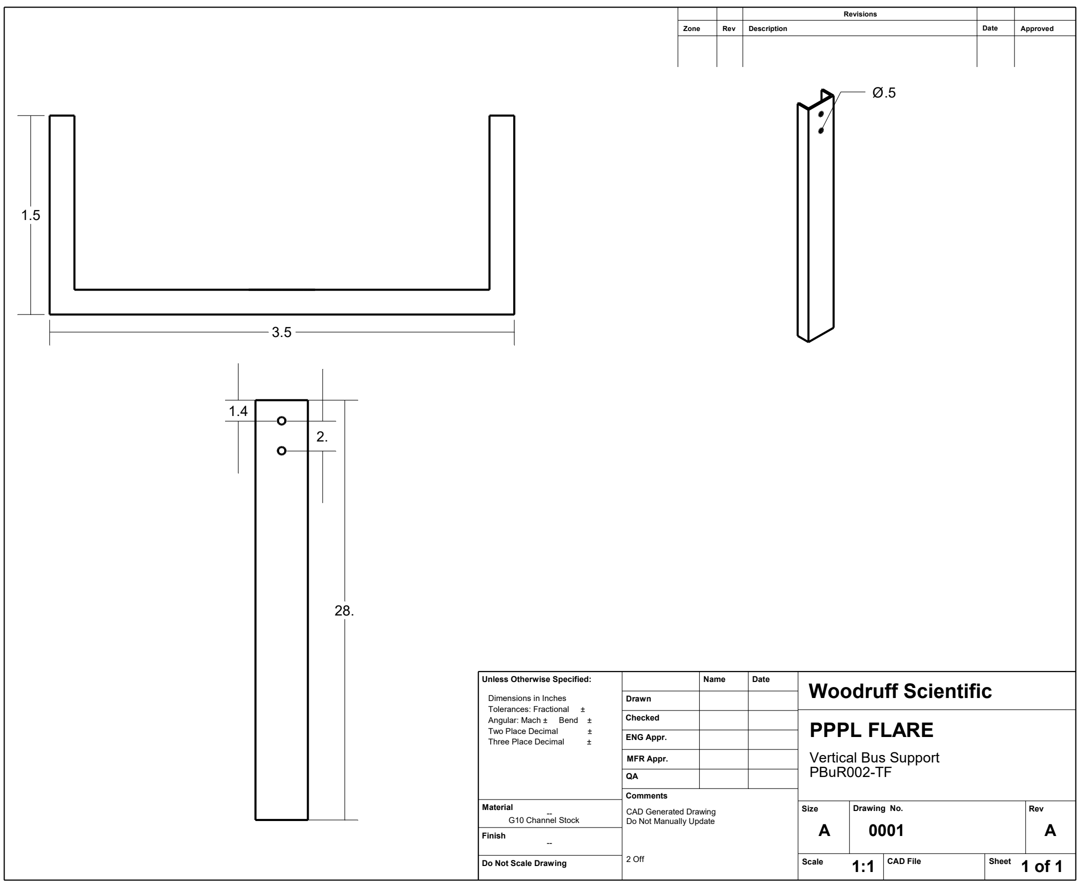

Figure 18: TF Bus Vertical Support - 2 Off

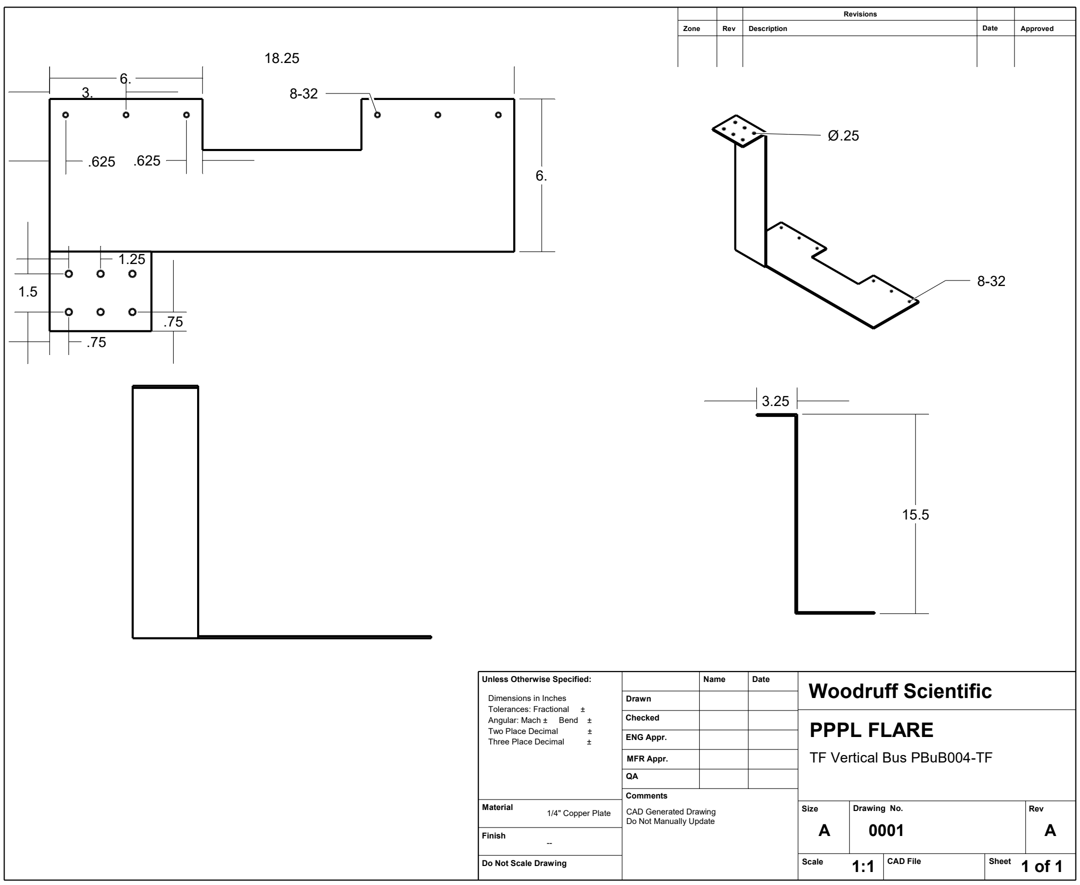

Figure 19: TF Bus Vertical

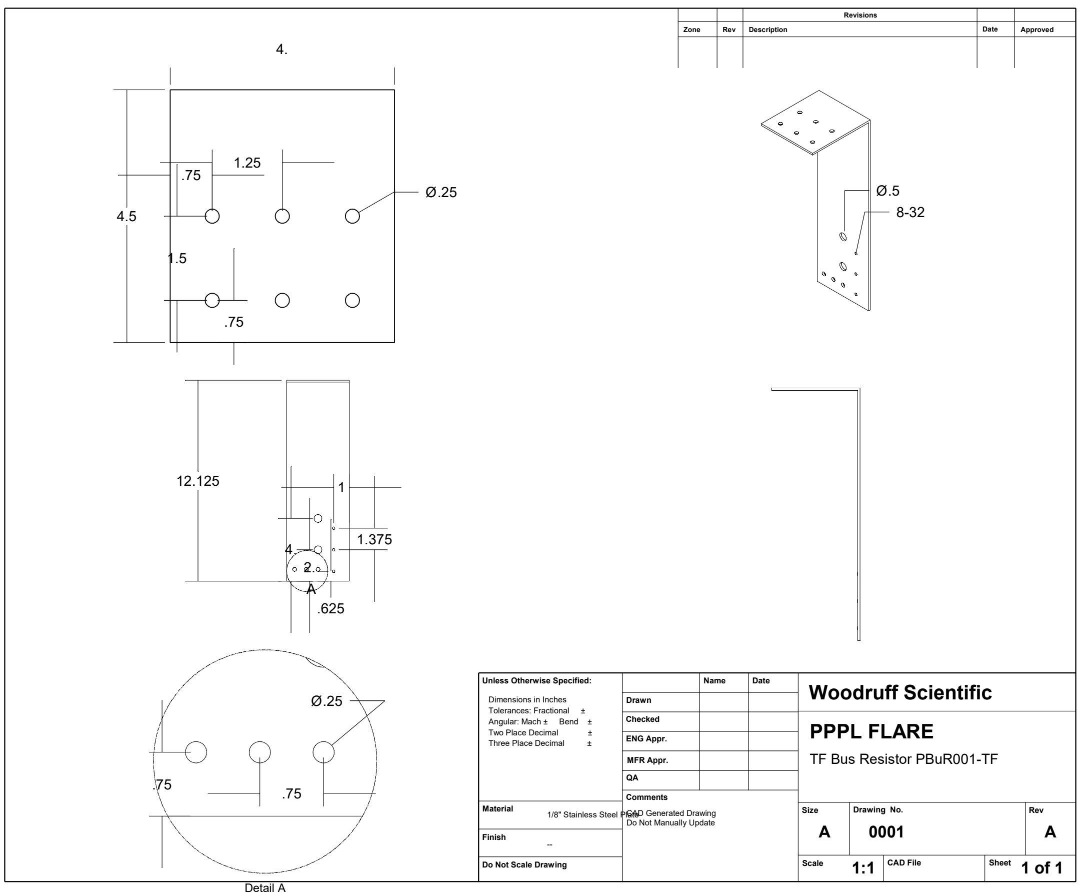

Figure 20: TF Bus Resistor

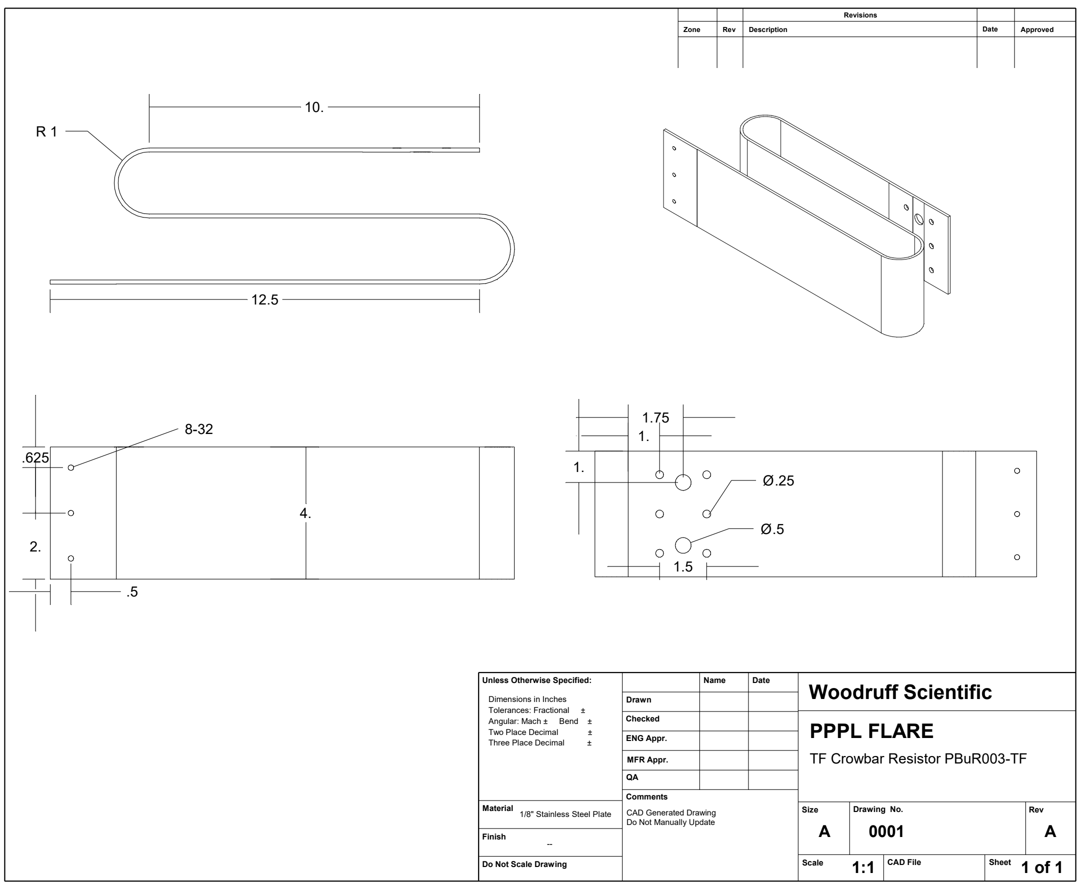

Figure 21: TF Bus Crowbar Resistor

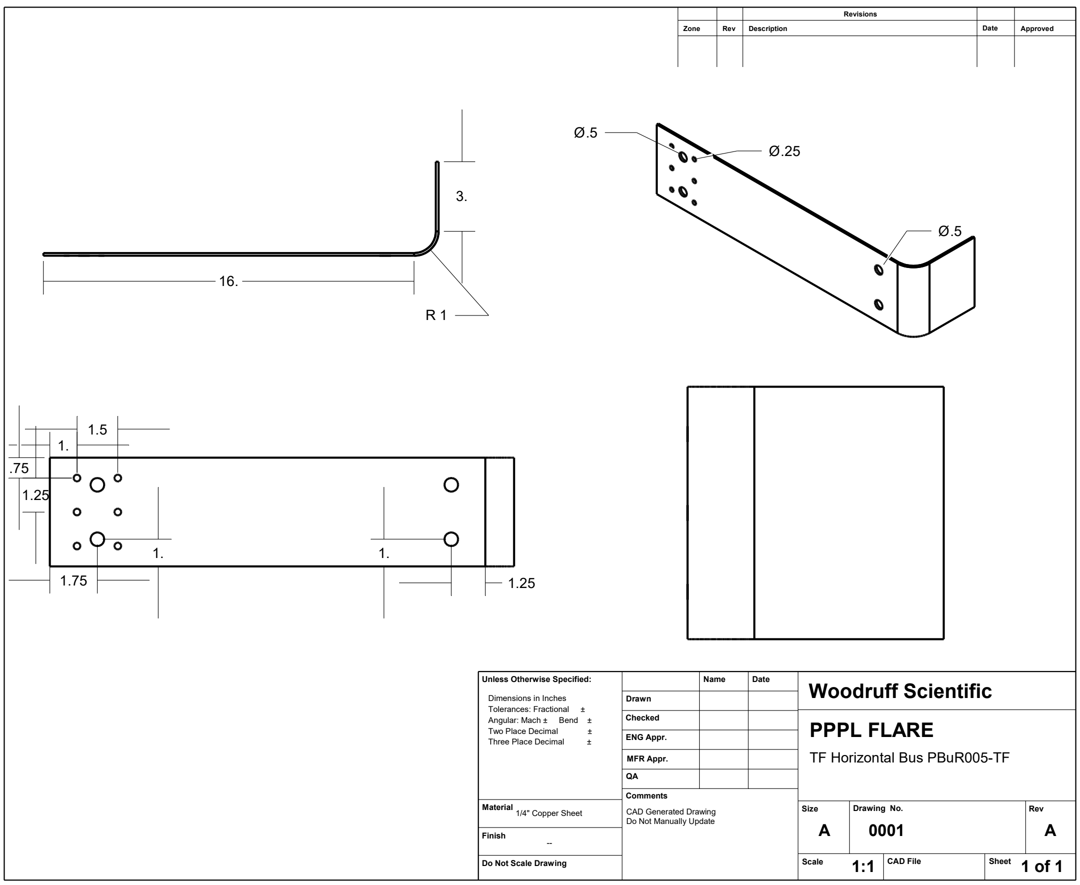

Figure 22: TF Bus Horizontal

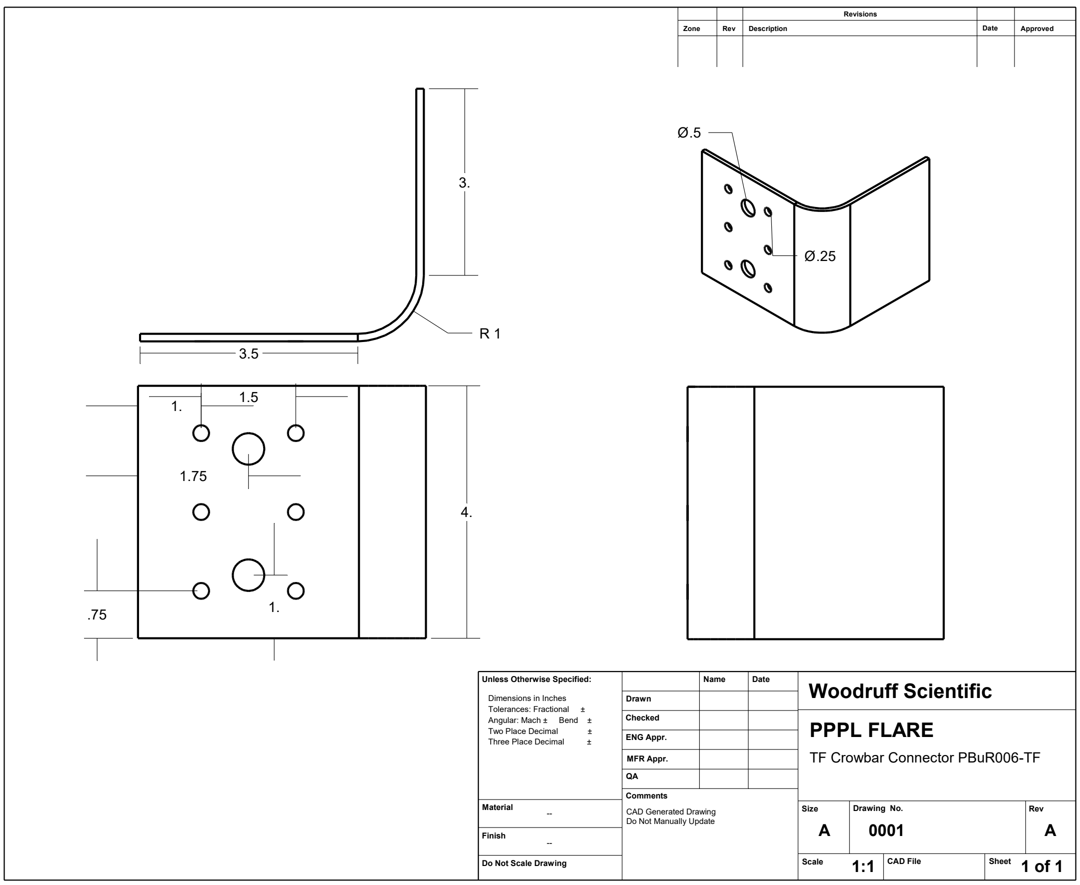

Figure 23: TF Bus Crowbar Connector

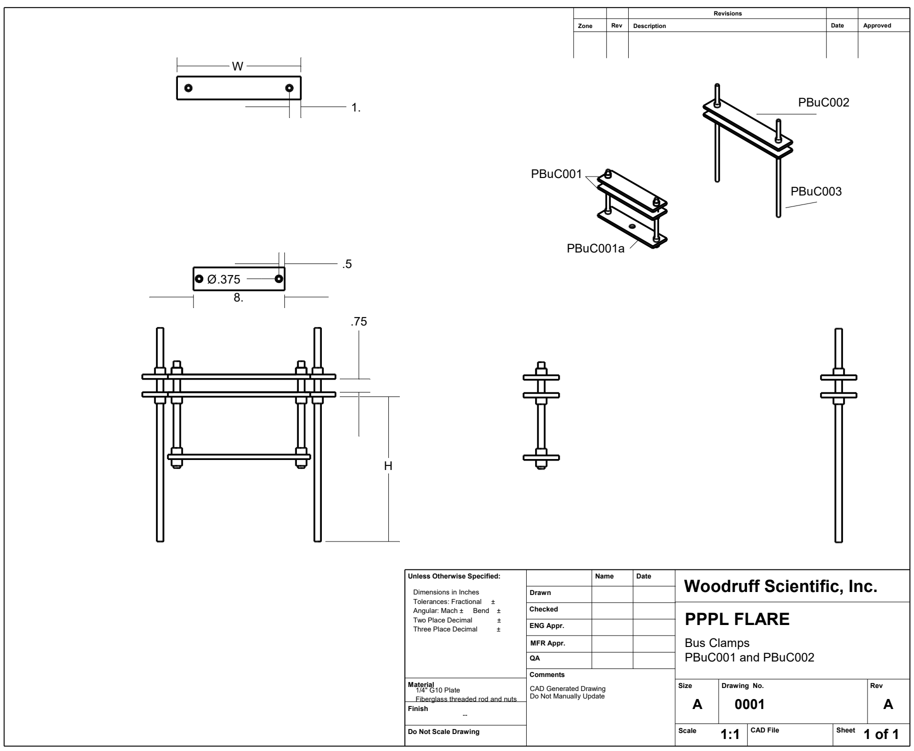

Figure 24: TF Bus Clamps

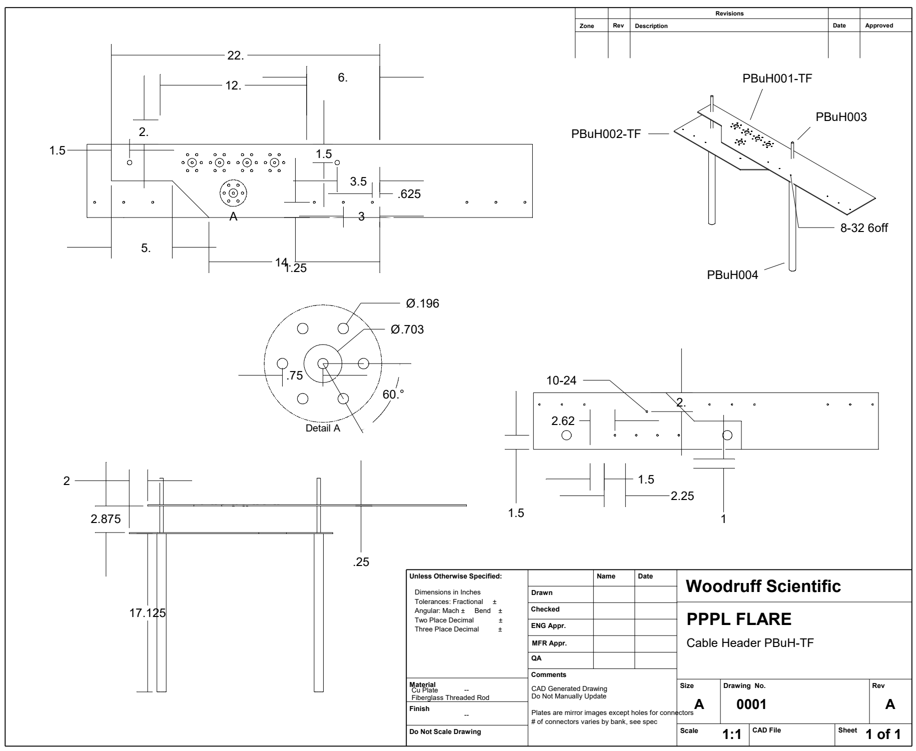

Figure 25: TF Cable Header

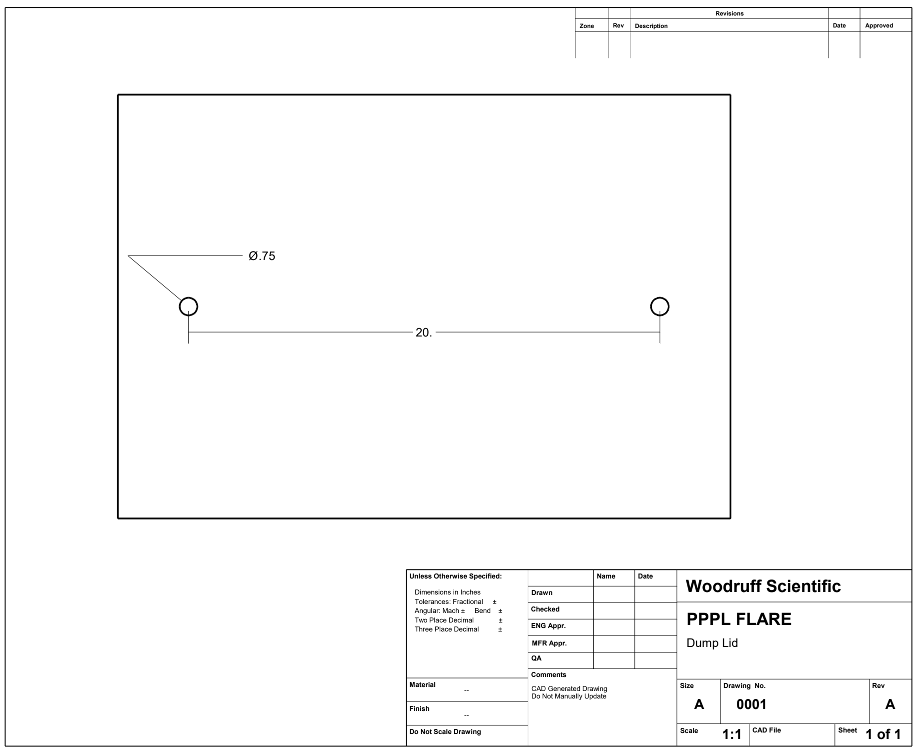

Figure 26: Dump Lid

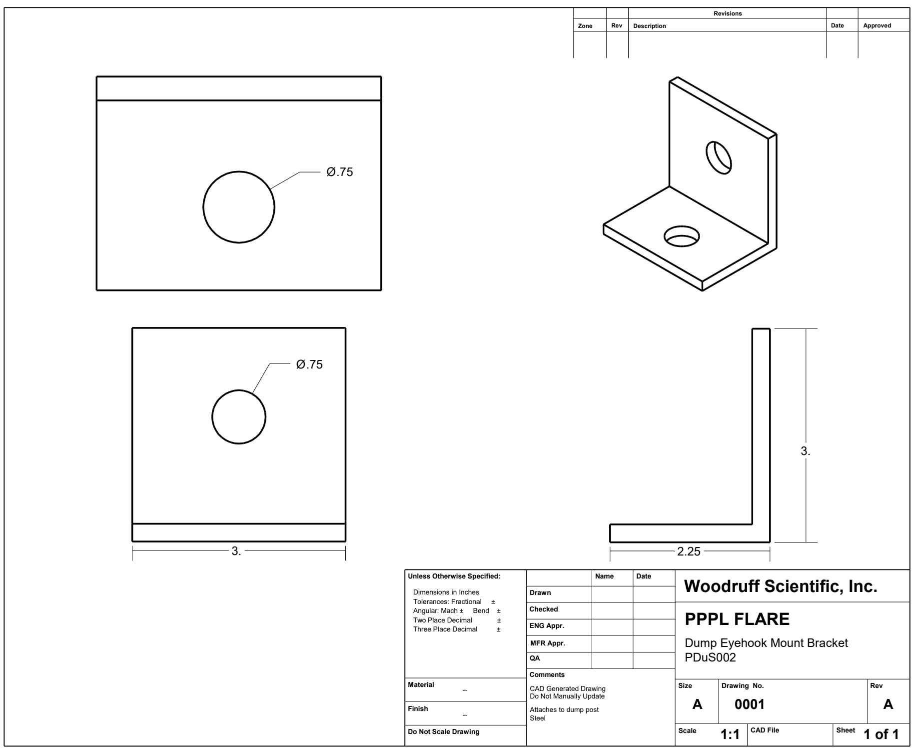

Figure 27: Dump Stick Eyehook Bracket

HDCT 20kV 400 µF Pulse Capacitor

Type		HDCT
Rated voltage	U_{NDC}	20kVDC
Rated capacitance	C_N	400µF
Capacitance tolerance		±5.0%
Rated Discharge Current	I_p	125kA
Max Discharge Current (system fault)	Î	163kA
Rated Discharge Voltage Reversal	%	80%
Self inductance	L_S	<200 nH
Int. series resistance	R_S	< 8mΩ
Loss factor	tanδ	$< 1.0 \times 10^{-3}$ / 100 Hz
Life Expectancy (90 % survival)		500,000 discharges
Operating temperature	Θmin/ max	-40°C / +70 °C
Technology		Metalized Polypropylene film, dry type, SH
Dimensions(mm^3)		418×390×655

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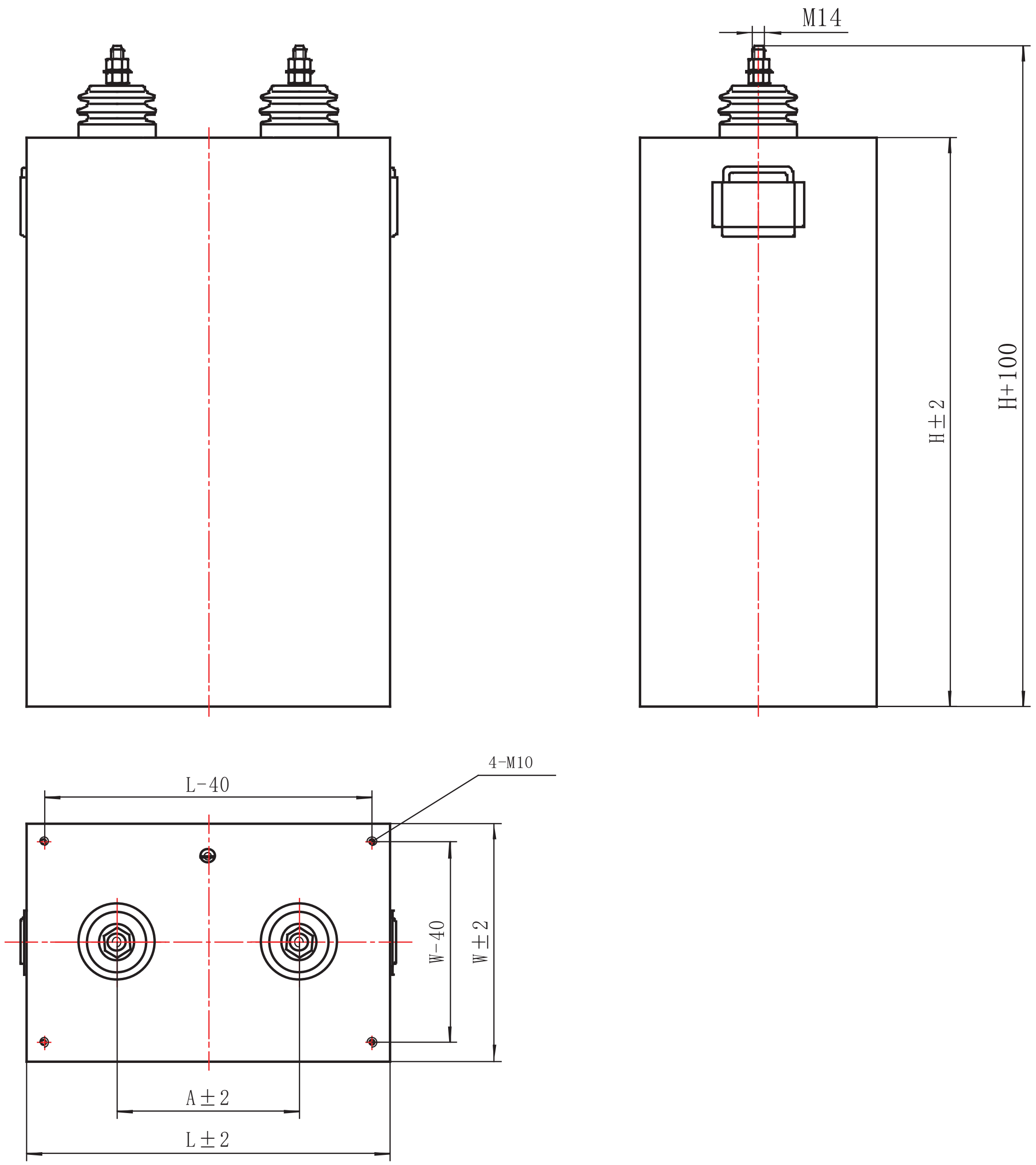
1.630.208.2200 (International)

NL400-20KVDC

HIGH DENSITY CHARGE TRANSFER CAPACITOR



Specification	L（mm）	W（mm）	H（mm）	A（mm）
20kV 400 μF	418	390	655	220

NL8900

IGNITRON

The NL8900 is a convection cooled ignitron for use as a high energy switch in capacitor discharge circuits. The NL8900 is capable of handling peak voltages of 35 kV and peak currents up to 300 kA.

GENERAL DATA

Electrical:

Cathode Spot Starting Ignitor
Number of Electrodes
Anode -- 1
Cathode -- 1
Ignitors -- 2
Inductance (approximate) -------------------------- 200 nh

Mechanical:

Envelope -- Stainless Steel
Anode Material-- Stainless Steel
Mounting Position ---------------------------------- Axis Vertical, Anode Up
Net Weight --- 24 lb (10.9 kg)
Diameter -- 7.25"
Seated Height (Nominal) --------------------------- 10.75"

Ignitor Ratings:

Voltage	MIN	MAX	
Open Circuit (Ignitor +)	1000	35000	V
Inverse (Ignitor -)	------	5	V
Current, Short Circuit	500	2000	A
Length of Firing Pulse, 1/2 Sine Wave	5	10	µs

Thermal:

Type of Cooling ------------------------------------- Liquid
Inlet Water Temperature (MIN) ------------------- 10 °C
Inlet Water Temperature (MAX) ------------------- 30 °C
Water Flow (At MAX Current)---------------------- 3.0 GPM
Cathode Temperature (MAX) ---------------------- 35 °C
Anode Header Temperature (MAX) -------------- 55 °C
Ambient Temperature -------------------------------- 10 to 30 °C
Anode to Cathode Temperature ------------------- (Note 1)

July 09, Rev A

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Maximum Ratings

	Damped Discharge	Ringing Discharge	
Peak Anode Voltage			
Forward	35,000	35,000	V
Inverse	35,000	35,000	V
Critical Anode Starting Voltage (MIN)	100	100	V
Anode Current			
Peak	300,000	300,000	A
Rate of Rise of Current	(Note 2)	(Note 2)	
Discharge (Rep Rate) Typical	2	2	Per Minute
Total Charge (Per Minute)	250	250	Coulombs
Ionization Time	0.5	0.5	µs
Voltage Reversal	None	100	%

WARNING! USING SIMULTANEOUS MAXIMUM RATINGS WILL SEVERELY DETERIORATE IGNITRON LIFE!

Notes:

1) To prevent mercury condensation on the anode and anode seals, the anode header temperature should be 10°C higher than the cathode temperature at all times. Before operation, elevate the temperature of the anode area, with respect to the cathode, long enough to remove any mercury from the top portion of the ignitron.

2) Rate of rise depends upon the external circuitry.

Tube Life Considerations

The method used to determine the life expectancy of an ignitron varies according to the application and it is necessary to consider the various types separately. It must be understood that the ratings specified are absolute limits. It is the responsibility of the equipment designer to ensure that the specified limits cannot be exceeded under the worse possible conditions of component tolerance, voltage fluctuation, and load variation.

A general rule of thumb: To obtain longer life, the ignitron must be operated at lower levels. Typically, life may be increased 10X if either the voltage or current is halved.

Ignitrons are robust high current switching devices. The current ratings may be exceeded to some extent without destroying the ignitron but with the consequence of reduced life.

IGNITOR

The ignitor is a small rod of semiconducting material with a pointed end that is partially immersed into the cathode pool. When a suitable current pulse is passed through the ignitor-mercury junction (with the ignitor being positive with respect to the cathode pool) forms a cathode spot on the surface of the mercury and free electrons are emitted. If the anode is sufficiently positive with the cathode at this time, an arc will form between the cathode and anode. Once the arc is initiated, the ignitor has no further control and the ignitron continues to conduct until the voltage across the ignitron falls below the ionization potential of the mercury vapor.

In capacitor discharge circuits the ignitron has to pass a very high current and the conditions are naturally harmful to the ignitron. The mercury pool and the ignitor itself will become contaminated and the best life will be obtained if a high energy pulse is applied to the ignitor. Under these conditions a pulse from a separate excitation circuit containing a 1uf capacitor charged from 1500V to 3000V will provide 1 to 4.5 Joules of energy to the ignitor. Richardson Electronics endorses National Electronics Ignitrons using these parameters. Considering the wide range of ignitors available across the range of ignitrons produced, Richardson Electronics recommends that an ignitor pulse providing 4 to 7 Joules is optimal.

MOUNTING

The performance and life of the ignitron is greatly improved if it is operated in a field free space. Magnetic fields tend to force the arc toward the tube sidewall and aggravate sidewall arcing. Metal vapor produced by sidewall arcing is one of the major contributors to ignitor wetting. We recommend a coaxial type mounting to minimize field effects. See Page 5 for details.

INSTALLATION INFORMATION

RECOMMENDED CONDITIONING BEFORE INITIAL USE - The ignitron is in high voltage operating condition before leaving the factory. Shipping tends to redistribute mercury throughout the ignitron making certain conditioning steps desirable before installation.

Heat Conditioning - Before applying voltage, heat anode stud to 100-125^{0}C (keeping cathode near room temperature) for two hours minimum. This drives mercury away from anode and anode seal area.

Voltage Conditioning (after Heat Conditioning) - Apply 110% of operating voltage (preferably DCV) or up to 110% of rated maximum voltage across ignitron (anode positive and ignitor not connected) with a series combination of a 1 to 4 uf capacitor and a 1 ohm resistor in parallel with the ignitron. NATIONAL will replace any ignitron that will not hold off minimum voltage at initial test when caused by a manufacturing defect. Additional conditioning at higher voltages is recommended to stabilize the ignitron after shipping. Slowly increase voltage above minimum. Breakdown may occur but the ignitron will attain a Hi-Pot Stabilization Voltage of approximately 125% of operating voltage, or up to 125% of rated maximum voltage.

NOTE: The time required for conditioning to Hi-Pot Stabilization Voltage can be reduced by using a variable ac voltage source connected directly across the ignitron (ignitor not connected). Slowly increase the voltage; limit the current to 30 milliamperes maximum.

RECOMMENDED PRACTICE AFTER INITIAL USE - Mercury condensed in the anode and anode seal area greatly decreases the ignitron's voltage hold-off ability. Heat conditioning before initial use complements proper mercury distribution before the ignitron is first placed in operation. Once in operation, maintain a thermal gradient so that the anode area is at least 10°C greater than the cathode. This is also true during any cooling period. The anode and anode area must not cool faster than the cathode.

The ignitor becomes susceptible to damage by movement of mercury after use in a capacitor discharge or crowbar application. For maximum life, we recommend that an ignitron not be moved until end-of-life once it has been placed in service.

LIFE AND WARRANTY

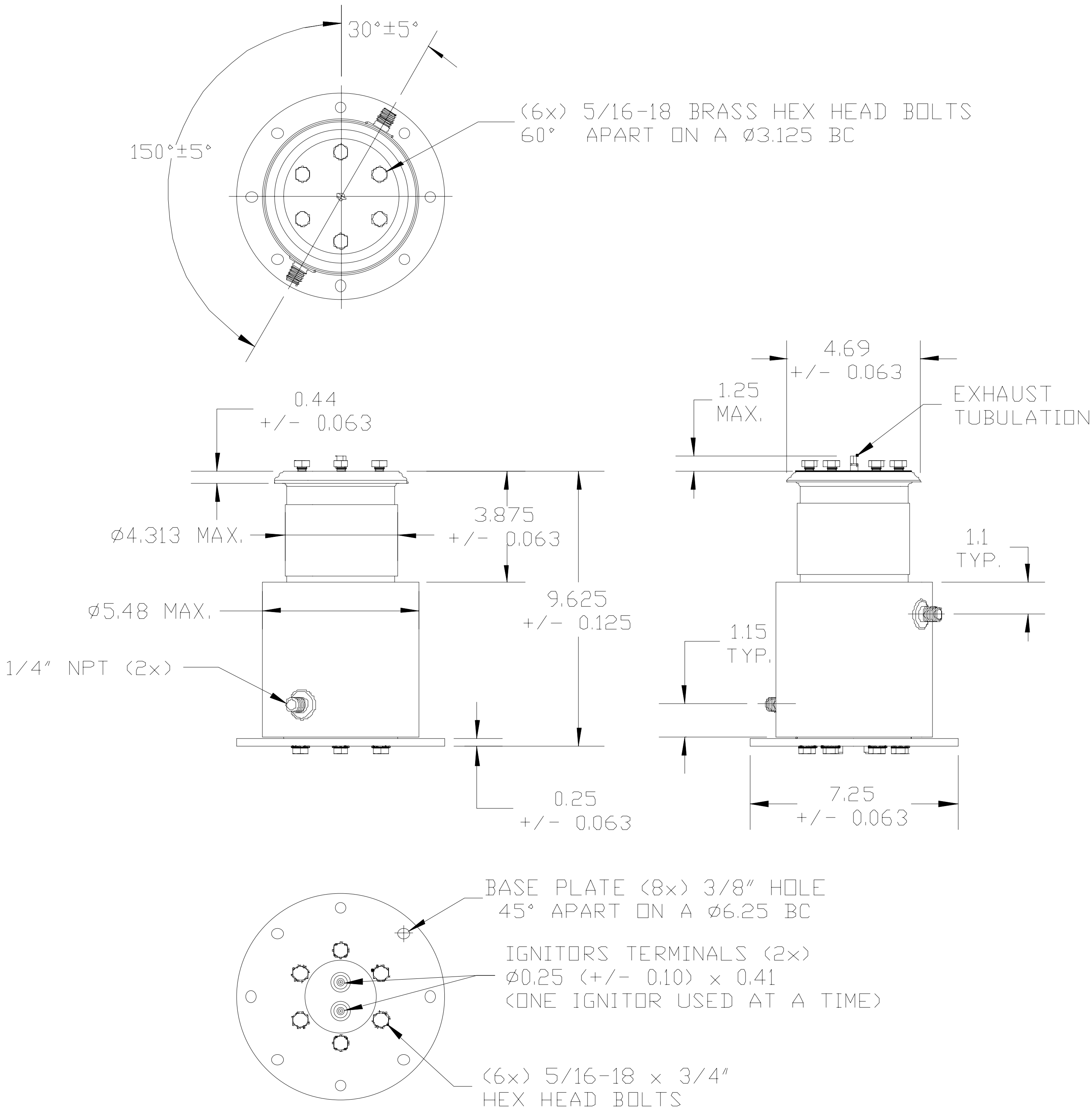
Richardson Electronics, Ltd. warrants the tube types listed above to be free from defects of design, material, and workmanship when received and, after receiving Recommended Conditioning Before Initial Use, to operate satisfactorily when first installed and, if used within ratings, to give a minimum of 1000 operations. No adjustment will be made if the tube is not placed in service within six months after date of shipment by manufacturer. This warranty expires 12 months after date of shipment by manufacturer.

National High Voltage Switching Ignitrons have an expected life of many times the warranted number of operations in most applications. Operating within the recommended ratings and following the *Recommended Practices After Initial Use* will greatly increase the life or operations obtained.

AVAILABLE ACCESSORIES

Part Number	Description
1K958-Series	Ignitor Tulip Clip/Cable Assembly (Various options available, check with your local Richardson representative for details.)
IG5F2-10	Ignitor Trigger Module (Works on all National Ignitrons.)

OUTLINE DRAWING



NOTE: The mounting flange attached to the bottom of the tube can be modified in most cases for compatibility with the users socket. In all cases coaxial returns "squirrel cages" are recommended. The anode contact must NOT be ridged with respect to the cathode and the flexible anode connection MUST absorb all buss bar movement.

NATIONAL ELECTRONICS

IG5F2-10
Ignitron Driver Manual

Serial Number ______________________

Test V open ______________________

Test I short w/protection: ______________________

Test I short w/o protection: ______________________

Life Test Start ______________________

Life Test Finish ______________________

Richardson Electronics

Engineered Solutions

Phone 800-348-5580
FAX 630-208-2553

1. General

The IG5F2-10 Ignitron driver is designed to meet the specifications for triggering all ignitrons. It also provides a trigger isolation capability of 25 kV. It's specifications are:

Stored Energy:	4 Joule at 1.0 Hz.; 3 J at 2 Hz.
Open Circuit Voltage:	1.80 kV at 1.0 Hz.
Current:	370 A output into typical ignitron ignitor (1 Hz.)
AC Input Voltage:	100 - 125 VAC input or 200 - 250 VAC input using internal slide switch. Failure to set the unit properly when using the higher voltage will destroy the unit.
Input Pulse:	5 V TTL if fiber optic transmitter accessory board is used Note that most 5 - 10 mA sources will drive this with 3 m cable.
Input Pulse Duration:	3 - 100 usec
Output Voltage Isolation:	25 kV to the input voltage
Fuse:	1/4 A internal
Supplied Fiber:	10 m. standard HP Versatile Fiber Type
Trigger Delay:	1200 ns. Typical
Status Indicators:	TRIG TEST (See figures for TRIG TEST output characteristics) PS STATUS
Storage Temperature:	-20 C - 45 C
Operating Temperature	5C - 40 C

2.0 Installation

Connect a versatile fiber trigger signal to the input fiber optic. The BNC/fiber adapter may be used to supply the trigger to the unit by applying a 5 - 15 V pulse to the BNC. TTL signals which meet typical TTL requirements will trigger the unit (5 V, 5 mA).

Connect the output marked "Ignitor" to the Ignitor pin, and connect the output marked "Cathode" to the cathode. These connections should be secure and capable of conducting 400 A pulsed.

Open the unit and check the internal switch to assure that the power is set to the type of power line you plan to use. **If the internal power switch is not set correctly the unit may fail.** The factory setting is always for 220 VAC. Connect the input power (220 VAC nominal or 110 VAC nominal) to the AC receptacle once the settings of both switches are assured. If a powered trigger module has been supplied, check the settings of that unit before use.

Pulse the unit. Check the connections without HV applied to the ignitron to make sure that the contacts are not arcing. The unit will make an audible "ticking" noise when triggered.

3.0 Mounting

A template for mounting the unit is appended. Studs used are Metric system M8.

4.0 Applications

The IG5-F is an ignitron driver supplied with the capability for isolation of the output. For circuits where the cathode is floating, such as series ignitron applications, the circuit can derive power from the external circuit:

Circuit A Recomended Wherever Possible

In circuit A, the cathode of the ignitron is grounded. If this circuit can be used, cooling of the ignitron jacket is simplified, along with triggering and monitoring. The unit power is connected to line voltage, the fiber is inserted into the driver, and the unit triggers with each light pulse. The input power ground should be grounded (IEC plug and chassis ground).

Circuit B Lower Value Biases

In circuit B, the cathode of the ignitron is at some potential up to 25 kV from ground. If this circuit can be used, heating of the anode insulator is simplified, along with triggering and monitoring. The unit power is connected to line voltage, the fiber is inserted into the driver, and the unit triggers with each light pulse. An MOV of appropriate voltage connected from either of the line voltages (preferably neutral if such exists) to the preferred earth ground may be desirable. No voltage can exceed 25 kV relative to ground. The input power ground should be grounded (IEC plug and chassis ground).

Circuit C Floating Ignitron Powered by AC

In circuit C the circuit derives it's power from AC voltage, but neither the cathode or anode is grounded. The voltage difference betweeen the cathode/ignitor and anode must not excede 25 kV including during transients. No voltage can exceed 25 kV relative to ground.

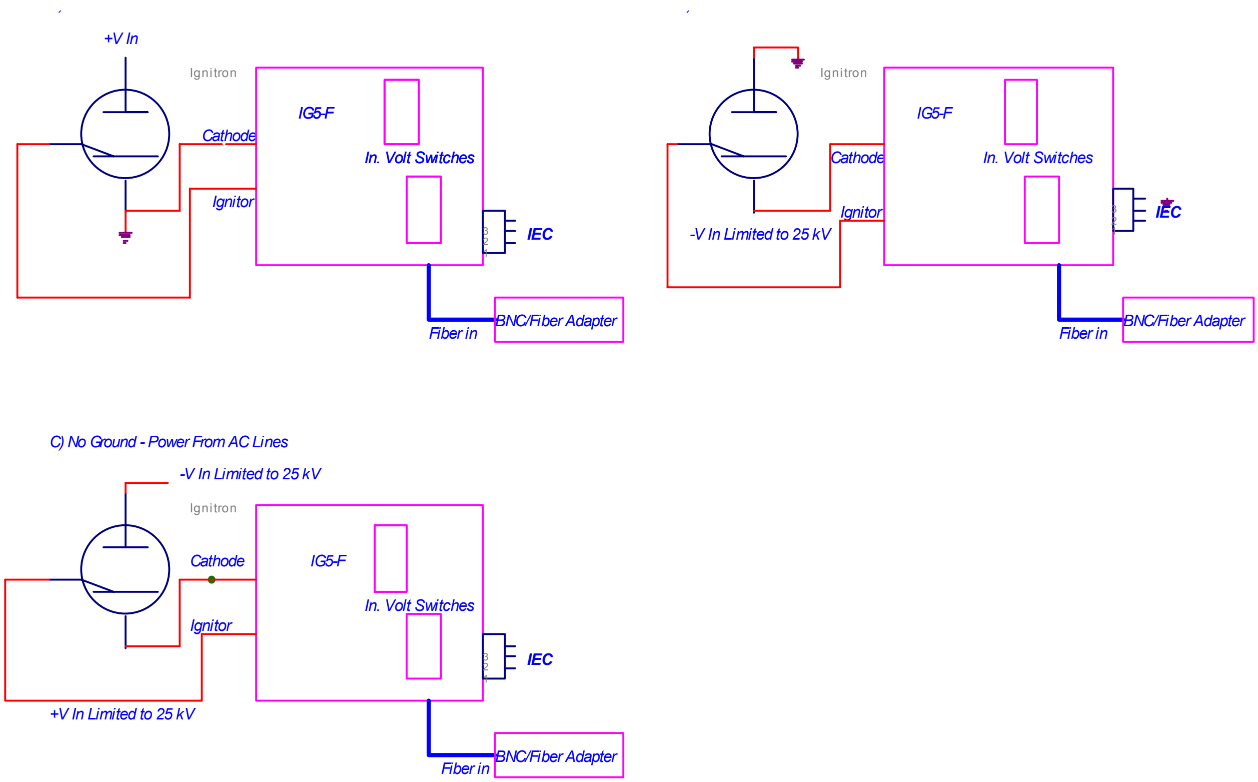


Figure 1 Application scenarios. The metal box should always be grounded.

5.0 Mounting

All parts are mounted to the enclosure. In order to mount the box, drill holes as described in the appended print, or use the template supplied.

6.0 Grounding

The box is designed for grounded operation. If floating operation is neccessary, the signal source and power source must be floated to the same potential. The difference between the power voltage and the box voltage should not exceed 700 V peak.

7.0 Power Supply Voltage Monitor

The monitor labeled PS Status has an output when the power supply driving the SCR is “ready”. This will fail to light if the 600 V internal power supply or SCR fails.

Figure of TRIG TEST output characteristic

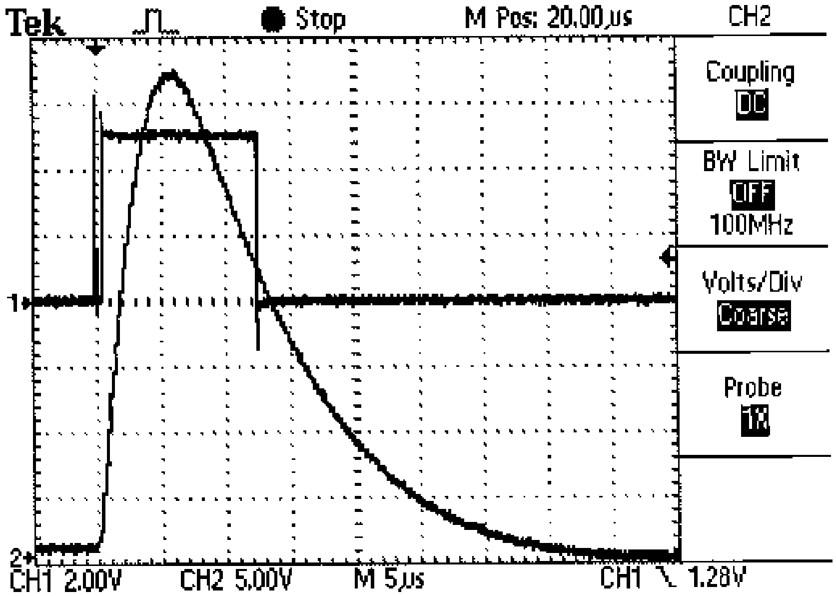


Fig. 2 Short Circuit Monitor and Current.

Figure 2 shows the current in the output along with the monitor output for the case where the ignitron ignitor fires immediately. The montor is on for 10 - 15 microseconds and it's main pulse starts within 2 microseconds of trigger initiation. This corresponds to nominally good performance.

Figure 3 shows the open circuit/open ignitor case. A pulse after saturation of the transformer, delayed by approximately 5 microseconds. In most situations, the pulse should appear in 4 microseconds or less time after initition of the pulse from the fiber.

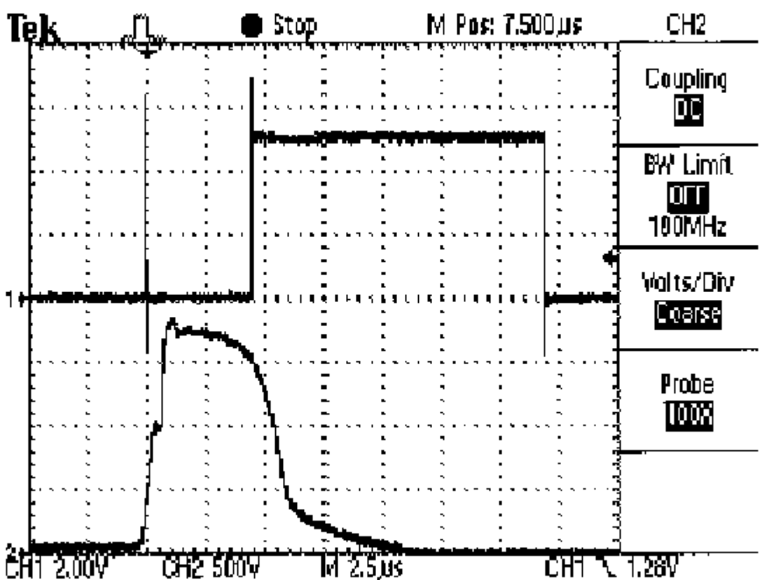


Fig. 3 monitor and open circuit voltage

SPECIFICATIONS IG5F2-10

The IG5F2-10 Ignitron driver is designed to meet the specifications for triggering all ignitrons. It also provides a trigger isolation capability of 25 kV. It's specifications are:

Stored Energy:	4 Joule at 1.0 Hz.; 3 J at 2 Hz.
Open Circuit Voltage:	1.80 kV at 1.0 Hz.
Current:	370 A output into typical ignitron ignitor (1 Hz.)
AC Input Voltage:	100 - 125 VAC input or 200 - 250 VAC input using internal slide switch. Failure to set the unit properly when using the higher voltage will destroy the unit.
Input Pulse:	5 V TTL if fiber optic transmitter accessory board is used Note that most 10 mA sources will drive this with 3 m cable. Longer cables will require more current
Input Pulse Duration:	3 - 100 usec
Output Voltage Isolation:	25 kV to the input voltage
Fuse:	1/8 A internal - 220 VAC; 1/4A internal 110 VAC
Supplied Fiber:	10 m. standard HP Versatile Fiber Type
Trigger Delay:	1200 ns. Typical
Status Indicators:	TRIG TEST (See figures for TRIG TEST output characteristics) PS STATUS

NOTES:

IG-5-F-T2 Ignitron/Thyratron Driver Multiple Trigger Output Accessory

The IG-5-F-T4 is a 2 output trigger driver for North Star Ignitron and Thyratron drivers. It consists of a BNC high impedance input, a pulse amplifier, and 4 trigger output channels. The specifications are:

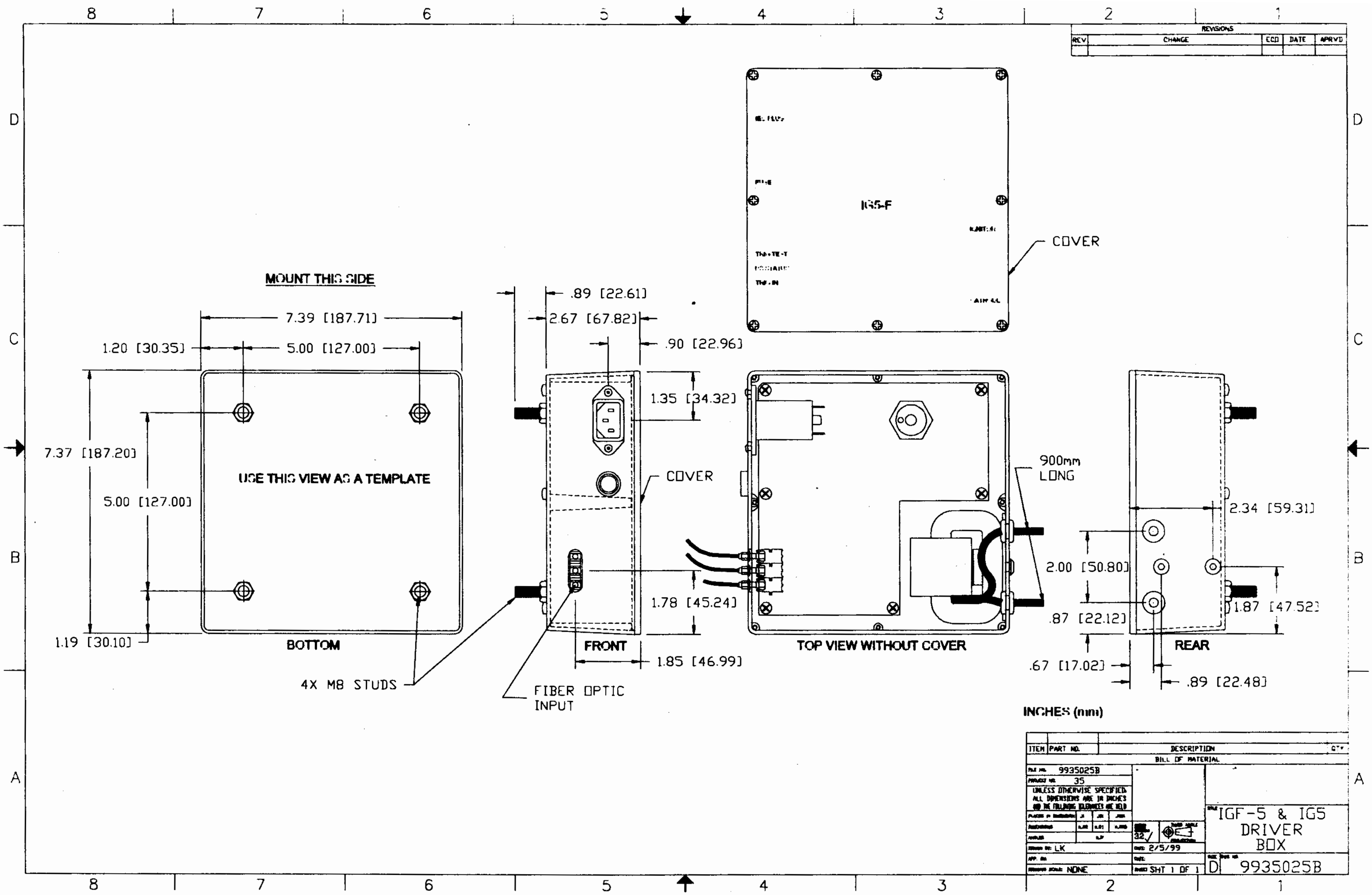
Power Supply Input Voltage:	100 - 260 V
(Note: Power Supply is CE marked)	
Input Power Connection	Standard IEC320 as used on most computers
Input Voltage:	2.4 V "on" 0.8 V "off"
Input Voltage:	15 V max
Input Current:	10 uA
Input Pulse Duration:	100 ns. Minimum
Output Pulse Power	5 dbm
Output Power Risetime Max.	85 ns.
Output Pulse Duration	Input pulse duration- 30 ns. min
Output Delay Time	75 ns. typical
Output Power Peak Wavelength	650 nm.

Output Fiber Specification

Type:	Plastic
Diameter	1 mm
Brand	Hewlett Packard
Part Number	HP 3510 Simplex or HP 3610 Duplex
Notes on cable:	**Do not bend Fiber Optic Cable with a radius of curvature of less than 4 cm.** The light signal drops significantly for tight bends.

Application

The unit is designed to simultaneously trigger multiple ignitrons or thyratrons. The unit should be connected to a TTL or higher input voltage (15 V Max.). It produces an output pulse of the same duration.



MOUNT THIS SIDE
7.39 [187.71]
1.20 [30.35]
5.00 [127.00]
7.37 [187.20]
5.00 [127.00]
1.19 [30.10]
USE THIS VIEW AS A TEMPLATE
BOTTOM
4X M8 STUDS
.89 [22.61]
2.67 [67.82]
.90 [22.96]
1.35 [34.32]
COVER
1.78 [45.24]
FRONT
1.85 [46.99]
FIBER OPTIC INPUT
IGS-F
COVER
TOP VIEW WITHOUT COVER
900mm LONG
2.34 [59.31]
2.00 [50.80]
.87 [22.12]
1.87 [47.52]
.67 [17.02]
.89 [22.48]
REAR
INCHES (mm)
REVISIONS
REV
CHANGE
ECO
DATE
APRVD
ITEM
PART NO.
DESCRIPTION
QTY
BILL OF MATERIAL
9935025B
35
UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN INCHES
LK
2/5/99
NONE
SHT 1 OF 1
IGF-5 & IGS DRIVER BOX
D
9935025B

1200W

300W-600W

- ***Compact & Lightweight***
- ***Models from 1kV-70kV, 300W, 600W AND 1200W***
- ***Universal Input, Power Factor Corrected***
- ***Low Cost Modular Design***
- ***Standard Digital Interfaces: USB, Ethernet and RS-232***
- ***CE Compliant, UL Recognized***

www.spellmanhv.com/manuals/SLM

Spellman's SLM Series of high voltage modules are designed for OEM applications up to 70kV at 1200 watts. Its universal input, small package size and choice of three standard digital interfaces simplifies integrating the SLM into your system design. Models are available in either positive or negative polarity. The SLM is fully arc and short protected. Excellent regulation specifications are provided along with outstanding stability performance.

TYPICAL APPLICATIONS

Capacitor Charging
HiPot Testing
CRT Testing
Electrostatics
E Beam Systems
CW Lasers

FIRMWARE CONFIGURATIONS

STANDARD BASED FEATURES

AOL	Adjustable Overload Trip
AT	Arc Trip
NAD	No Arc Detect
NSS	No Slow Start
PSS	Programmable Slow Start
RFR	Remote Fault Reset
RMI	Remote Mode Indicators
ROV	Remote Overvoltage Adjust

SPECIFICATIONS

Input Voltage:
Power factor corrected input, ≥0.98
90-264Vac, 47-63 Hertz, for 300 watt units
180-264Vac, 47-63 Hertz for 600 and 1200 watt units

Output Voltage:
11 models—1kV to 70kV

Output Polarity:
Negative or positive, specify at time of order

Local Indicators:
Arc, HV On, Temp Error, OVP, I Mode
Power On, OC, Reg Error

Power:
3 power ranges available—300, 600 and 1200 watts.
Other power levels available on special order.

Voltage Regulation:
≤0.01% of rated output voltage over specified input voltage range
≤0.01% of rated output voltage for a full load change

Current Regulation:
≤0.01% of rated output current over specified input voltage range
≤0.01% of rated output current for a ±100μA for a full voltage change

Ripple:
≤0.2% rms of maximum rated voltage, measured with a 10 foot long HV cable

Stability:
≤50ppm/hr after a 2 hour warm up

Temperature Coefficient:
≤100ppm per degree C

Environmental:
Temperature Range:
Operating: 0˚C to 40˚C
Storage: -40˚C to 85˚C
Humidity:
20% to 85% RH, non-condensing.

Control Interface

Local Interface:
Potentiometers are provided to adjust voltage and current.

Remote Interface: USB, Ethernet and RS-232 are standard, implemented with 12 bits of resolution.
All digital monitors have an accuracy specification of 2%.

Control Software: A VB GUI will be provided for RS-232/USB, the Ethernet interface will have an embedded applet for control.

HV Control Enable/Interlock:
A dry contact, hardware based interlock is provided for remote mode. In local mode this I/O is the enable.

Monitor Signals:
Voltage and current monitor signals are scaled 0-10Vdc equals 0-100% of full scale, accuracy is 1%.

Cooling:
Forced air

Dimensions:
300/600 watts:
4.75˝ H X 6˝ W X 12˝ D (120.65mm x 152.4mm x 304.8mm)
1200 watts:
4.75˝ H X 12˝ W X 12˝ D (120.65mm x 304.8mm x 304.8mm)

Weight:
300/600 watts: 14 pounds (6.35kg)
1200 watts: 26 pounds (11.8kg)

Input Line Connector:
IEC320 cord set with integrated EMI filter

Output Cable:
A detachable 10' (3.3m) long shielded HV cable is provided

Regulatory Approvals:
Compliant to 204/108/EC, the EMC Directive and 2006/95/EC, the Low Voltage Directive. UL/CUL recognized, File 227588. RoHS compliant.

SLM SELECTION TABLE- 300W

300 Watt		
kV	mA	Model
1	300	SLM1*300
3	100	SLM3*300
5	60	SLM5*300
10	30	SLM10*300
15	20	SLM15*300
20	15	SLM20*300
30	10	SLM30*300
40	7.5	SLM40*300
50	6	SLM50*300
60	5	SLM60*300
70	4.28	SLM70*300

*Specify "P" for positive polarity or "N" for negative polarity

SLM SELECTION TABLE- 600W

600 Watt		
kV	mA	Model
1	600	SLM1*600
3	200	SLM3*600
5	120	SLM5*600
10	60	SLM10*600
15	40	SLM15*600
20	30	SLM20*600
30	20	SLM30*600
40	15	SLM40*600
50	12	SLM50*600
60	10	SLM60*600
70	8.56	SLM70*600

*Specify "P" for positive polarity or "N" for negative polarity

SLM SELECTION TABLE- 1200W

1200 Watt		
kV	mA	Model
1	1200	SLM1*1200
3	400	SLM3*1200
5	240	SLM5*1200
10	120	SLM10*1200
15	80	SLM15*1200
20	60	SLM20*1200
30	40	SLM30*1200
40	30	SLM40*1200
50	24	SLM50*1200
60	20	SLM60*1200
70	17.14	SLM70*1200

*Specify "P" for positive polarity or "N" for negative polarity

SLM ANALOG INTERFACE— J2 15 PIN MALE D CONNECTOR

PIN	SIGNAL	SIGNAL PARAMETERS
1	Power Supply Fault	Open Collector, 35V @ 10mA Maximum
2	Current Program In	0 to 10V=0 to 100% Rated Output, Zin=10MΩ
3	Voltage Program In	0 to 10V=0 to 100% Rated Output, Zin=10MΩ
4	NC	No Connection
5	Local Voltage Prog.	Multi-turn front panel potentiometer
6	NC	No Connection
7	Local Current Prog.	Multi-turn front panel potentiometer
8	Voltage Monitor	0 to 10V=0 to 100% Rated Output, Zout =4.99k, 1%
9	Signal Ground	Ground
10	Current Monitor	0 to 10V=0 to 100% Rated Output, Zout =4.99k, 1%
11	HV Enable Input	Connect to Pin 12 to HV Enable Supply
12	HV Enable Output	+15V @ Open, ≤15mA @ Closed
13	NC	No Connection
14	HV On Output Signal	Open Collector, 35V @10mA Maximum
15	Spare	No Connection

RS-232 DIGITAL INTERFACE— J3 9 PIN FEMALE D CONNECTOR

PIN	SIGNAL	SIGNAL PARAMETERS
1	NC	No Connection
2	TX out	Transmit Data
3	RX in	Receive Data
4	NC	No Connection
5	SGND	Ground
6	NC	No Connection
7	NC	No Connection
8	NC	No Connection
9	NC	No Connection

USB DIGITAL INTERFACE— J4 4 PIN USB "B" CONNECTOR

PIN	SIGNAL	SIGNAL PARAMETERS
1	VBUS	+5 Vdc
2	D-	Data -
3	D+	Data +
4	GND	Ground

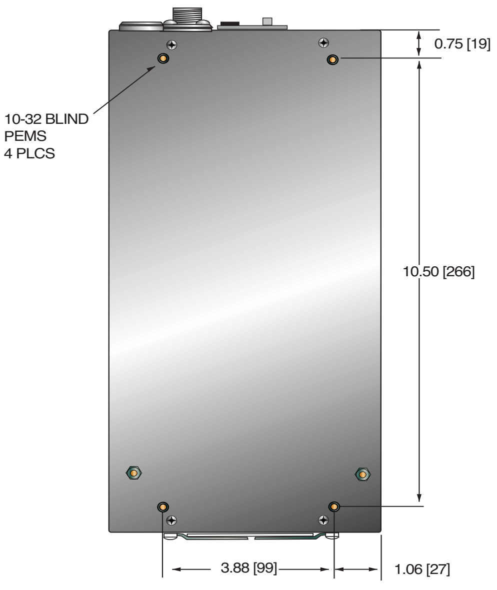
ETHERNET DIGITAL INTERFACE— J5 8 PIN RJ45 CONNECTOR

PIN	SIGNAL	SIGNAL PARAMETERS
1	TX+	Transmit Data +
2	TX-	Transmit Data -
3	RX+	Receive Data +
4	NC	No Connection
5	NC	No Connection
6	RX-	Receive Data -
7	NC	No Connection
8	NC	No Connection

DIMENSIONS: in.[mm]

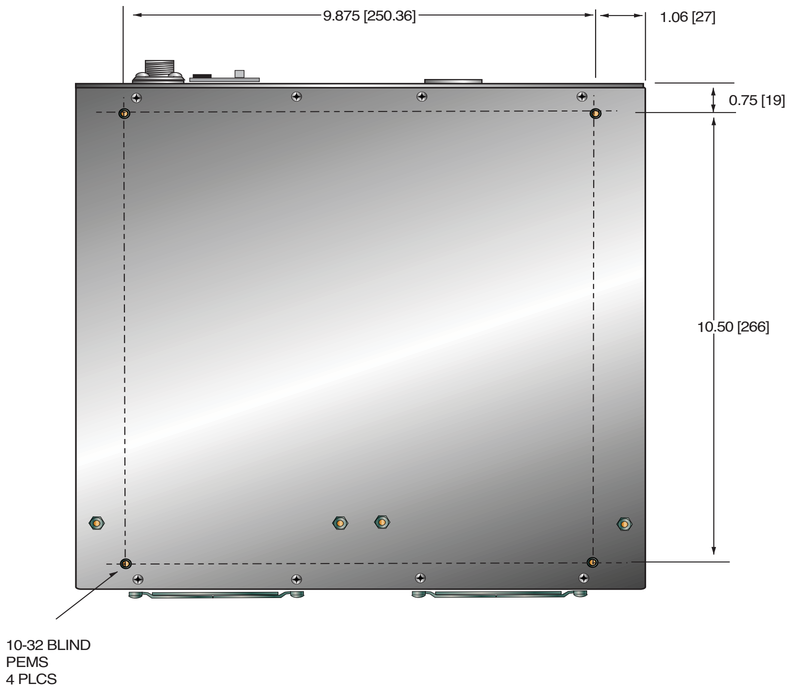
300/600 Watt

BOTTOM VIEW

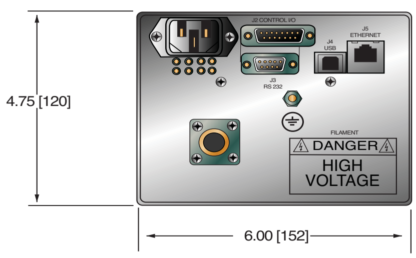


1200 Watt

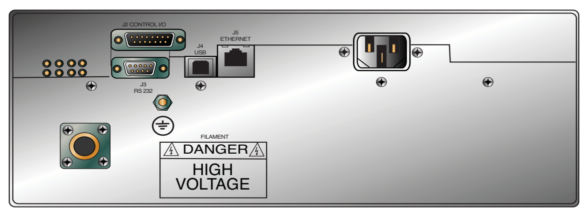
BOTTOM VIEW



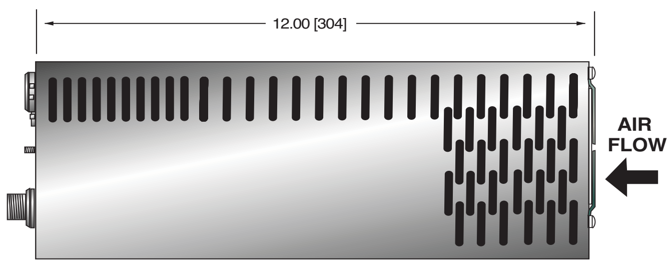
FRONT VIEW



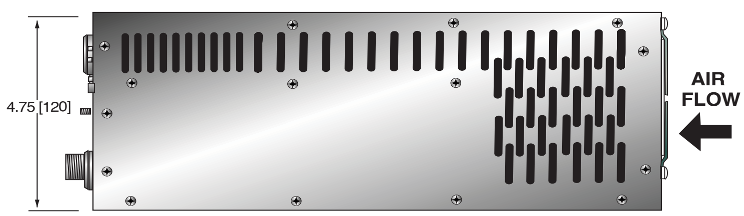
FRONT VIEW



SIDE VIEW



SIDE VIEW



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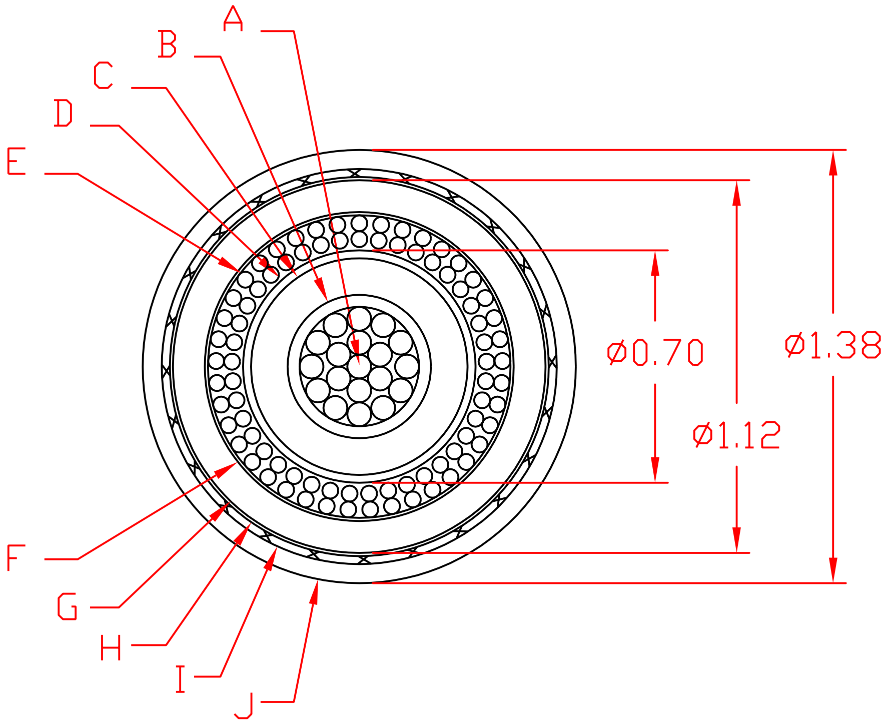
e-mail: sales@spellmanhv.com
www.spellmanhv.com

Spellman High Voltage is an ISO 9001:2008 and ISO 14001:2004 registered company

DWG NO. SK160114 REV 1



LEGEND

A. #00 (19 X BARE COPPER COMPACTED), NOMINAL ø 0.376

B. SEMICONDUCTING EPR, ø 0.42

C. INSULATING EPR – ø 0.115 WALL TO ø0.65

D. SEMICONDUCTING EPR, ø 0.70

E. OUTER CONDUCTOR, DOUBLE LAYER, 12 INCH LAY
RHL INNER 41 x #18 AWG (19 x 30AWG T.C.)
LHL OUTER 41 x #18 AWG (19 x 30AWG T.C.)

F. SEMICON TAPE, 2" WIDE, 0.005 THK

G. INSULATING LDHMW POLYETHYLENE 0.100 WALL.

H. SEMICON TAPE, 2" WIDE, 0.005 THK

I. BRAID, #28 AWG T.C., 6 ENDS, 24 CARRIER, 70% COVERAGE.

J. JACKET, PVC, BLACK, 0.06 WALL.

REVISIONS			
REV	ECO NUMBER	APPD	DATE

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCE ON
DECIMALS .XX ±.01 .XXX ±.005
ANGLES ±
CONCENTRICITY .005 TIR
REMOVE BURRS & SHARP EDGES
ALL MACHINE SURFACES 125√

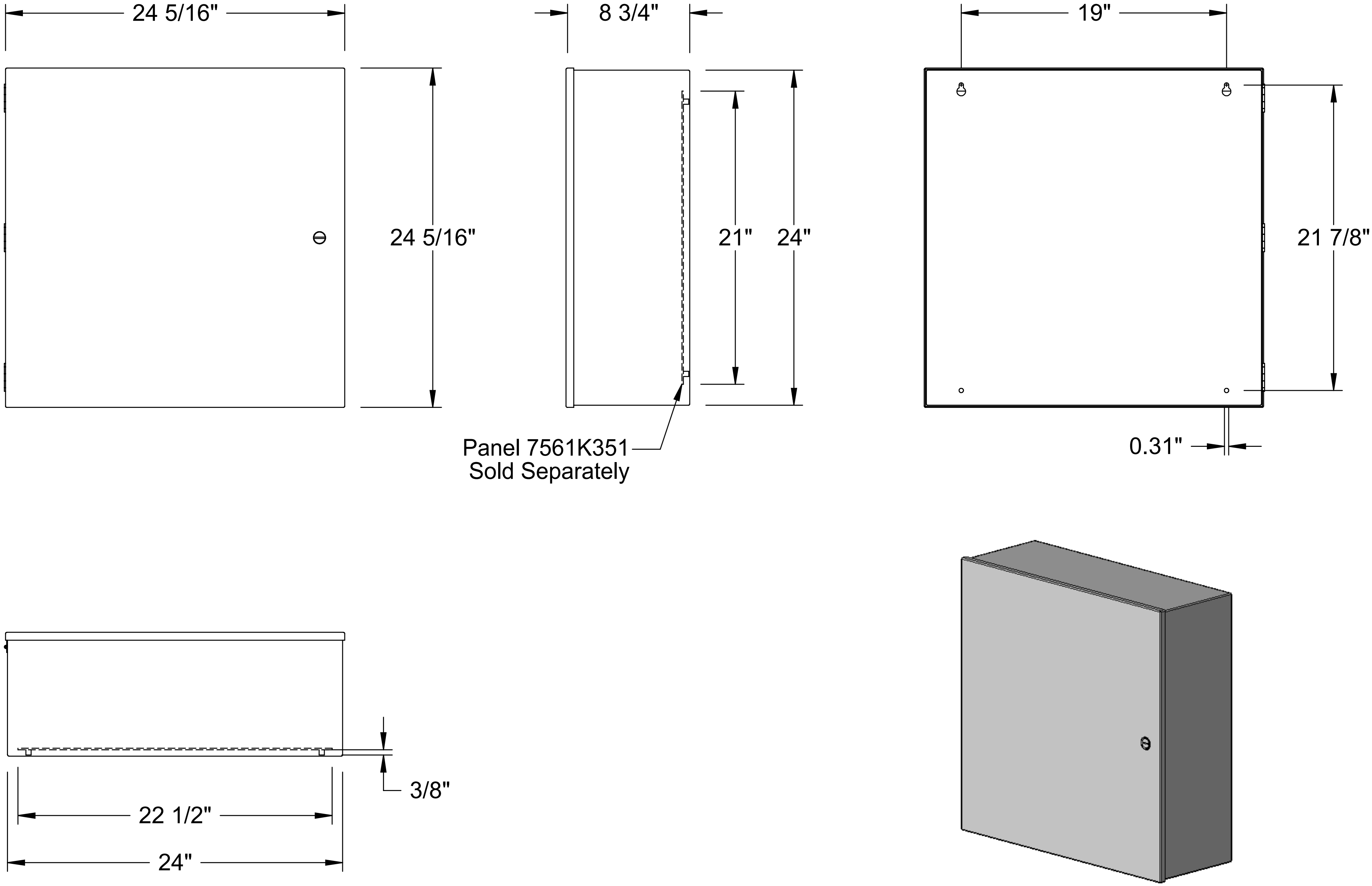
DRAWN D. ABDULKY	DATE 14JAN16
CHECKED	DATE
APPROVED	DATE
MATERIAL	
FINISH	

DIELECTRIC SCIENCES,INC
CHELMSFORD, MASSACHUSETTS 01824

HV CABLE

SIZE	FSCM NO.	DWG NO.	REV
A	50509	SK160114	1

SCALE SHEET OF



14-ga Steel (0.0747")
Approximate Internal Dimension: Ht. 23", Wd. 23", Dp. 8 1/8"

McMASTER-CARR® CAD	PART NUMBER	7561K64
http://www.mcmaster.com © 2014 McMaster-Carr Supply Company	Indoor Steel Enclosure	
Information in this drawing is provided for reference only.		