High Average Current and High Voltage Reliable and Stable Power Supplies for High Current Electron Beam Sources

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Outline

- Brief One Pager on Facilities at InnoSys
- SBIR Topic Background and Need
- Phase II Technical Approach (Brief discussion) including Background/Need
- Specs for the High Average Current and High Voltage Reliable and Stable Power Supplies (**HAC HV RSPS**)
- Some of the Protections for the High Average Current and High Voltage Reliable and Stable Power Supplies
- An Example Result
- Commercialization
- Summary
- Acknowledgements and Questions

Brief Discussion about Some of the Facilities at InnoSys

- InnoSys has a 36,500 square foot facility dedicated to development and manufacturing that houses Class 1000 and Class 100 cleanrooms and other microfabrication areas and has a full complement of processing and fabrication equipment capable of fabricating optoelectronics , microelectronics , MEMS, and bulk and surface micromachining structures, devices, and systems as well as extensive AM/3D-Printing Capability and DC to RF (up to >120 GHz) and optical from 200 nm to >2400 nm. InnoSys has a machine shop, brazing and vacuum exhaust and bake out chambers
- InnoSys also has a full SMT Auto Mask Aligner, Pick and Place and Multi-Zone Oven Assembly Line.

HAC HV RSPS for High Current Electron Beam Sources Background and Need

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- There are needs for high average current and high voltage reliable and stable power supplies for high current electron beam sources for scientific experiments and explorations at USA national facilities and labs as well as other domestic and global applications and uses.
- For example, There is a need for very high voltage power supplies (HVPSs) that can be used for high voltage DC electron guns for accelerator applications. In particular, there are needs for developing a family of high average current and high voltage (e.g.,~200-750kV @ 10-120mA) reliable and stable power supplies for electron beam sources and photoinjectors
- National Labs such as Jefferson Lab, operate DC HVPSs connected to photoemission electron guns. One of these power supplies powers the CEBAF polarized electron beam accelerator for nuclear physics experiments.
- To address this need, we are investigating and implementing low noise, fast switching, highly efficient power supplies to replace existing power supplies with these state of the art switching power supplies with additional capabilities, features and functions. These switching power supply replacements must be flexible, intelligent and robust enough to meet current and expected future performance standards at National Labs and elsewhere.

HAC HV RSPS for High Current Electron Beam Sources Background and Need

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- InnoSys has continued to perform fundamental R&D on cost effective, high average current (>20 mA) and high voltage (>200kV and up-to-and-beyond 500kV – e.g. 600 and 750kV) reliable and stable power supplies for high current electron-beam-sources.
- In particular, our focus is on high-power, cost-effective and affordable, highly reliable and stable DC HVPSs for high current-electron-beam-sources.
- The prototypes will be implemented for testing in nuclear physics accelerator facilities.
- The Prototypes will turn into a family of Commercialized Products.

HAC HV RSPS for High Current Electron Beam Sources Background and Need

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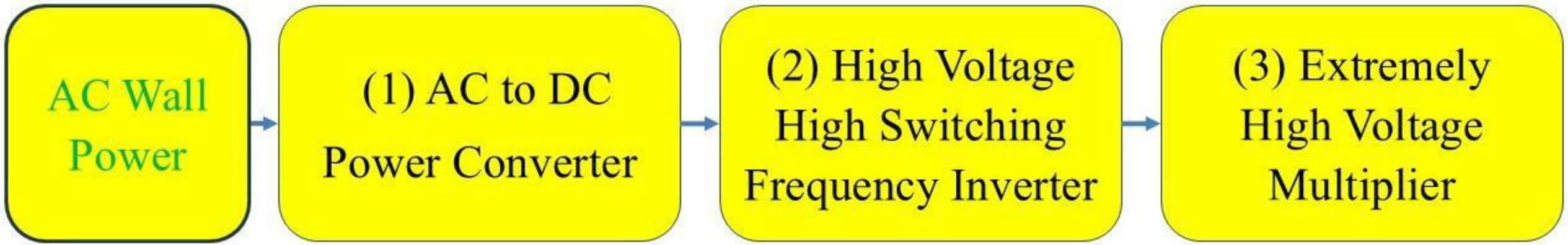
- These high average current and high voltage reliable and stable power supplies for high current electron beam sources power supplies will be modular in design allowing the power supply boards, if needed, to be stacked in both series and parallel to achieve the desired high voltage and current required for a given application. In addition, redundancy can be designed and built in to allow in the field switching if desired.
- We have been designing the AC front end to run off of 120 or 208 VAC 50/60 Hz for up to 6 kW DC output and 208 VAC to 480 VAC three phase for greater than 6kW DC.
- We are designing using modules that will be up to -300 kV and then move up to -600 kV and finally up to -750 kV.
- Note, due to the need to have the anode at ground potential, the actual applied voltage is applied to the cathode of the photoinjector gun is negative with respect to ground. The anode is grounded and the cathode is typically at a negative potential of 200kV or more negative and, in Phase II, up to negative 600 kV (-600 kV) and negative 750kV (-750 kV) for JLab. We have been and will continue to implement comprehensive and complete protections including, but not limited to, over voltage, over current, short circuit protection, over temperature protection, arc detection and protection, etc. We also will need to design these power supplies to relatively slowly ramp up in voltage and have extremely stable output voltage due to the ultra-sensitive nature and easily damaged nature of the photocathodes that these power supplies will be used for.
- We are also designing for soft start and fault shutdown sequencing.

A Simple Block Diagram of a HAC HV RSPS



- ➢ Can use Cockcroft-Walton (C-W) for a while then it starts to poop out.
- ➢ We have developed both a hybrid approach and a different approach for the multiplication.

A Focus Area for the Phase II and HAC HV RSPS – The Choice of Ambient

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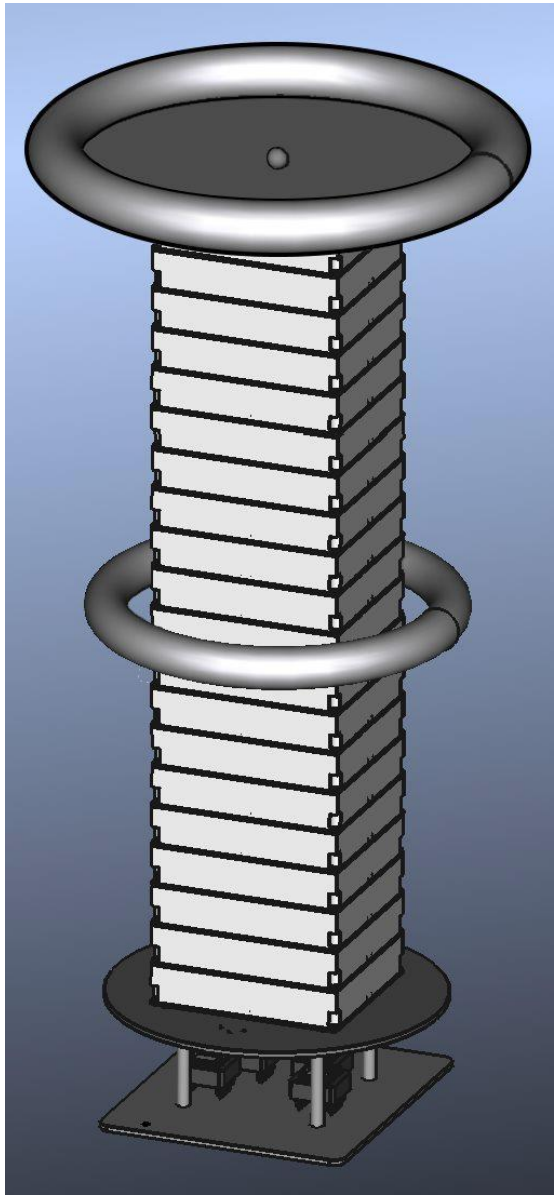
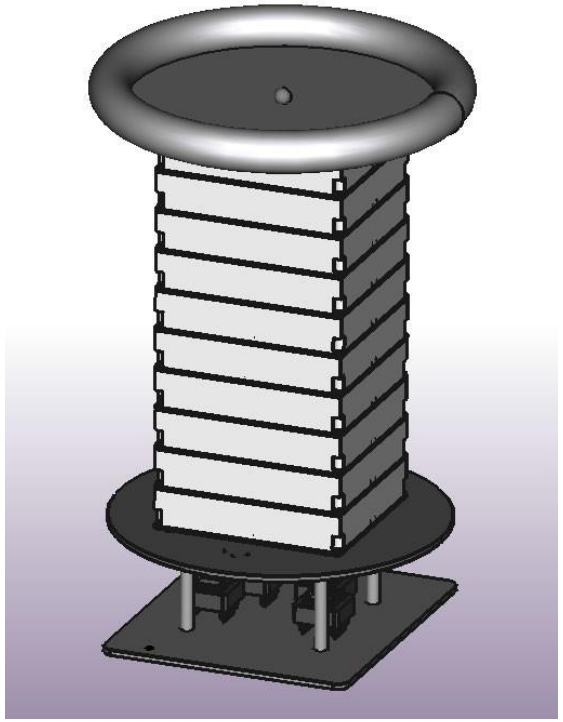
- One of the major problems/issues with high voltage and extremely high voltage are arcs
- Arcs can range from being less than a nuisance to being fatal
- Elimination of Arcs or the possibility of Arcs is a major consideration.
- Often the high/extremely high voltage power supply is immersed in a media.
- Common medias are oils and gases.
- A common gas used in high voltage is sulfur hexafluoride (SF_6).
- We continue to see if it is possible to not use pressurized SF6 gas environment.
- We continue to further investigate and work on functionally acceptable replacements for SF_6
- SF_6 is considered one of the worst, if not the worst and most potent, greenhouse gases.
- We have been looking into air or nitrogen, solid dielectrics instead of SF_6.
- We continue to investigate and look in to this possibility.
- We also continue the approach of using solid dielectric materials to prevent arcing and allow the high voltages needed to be achieved.

A CAD rendering of the Multiplier Stack for the HAC HV RSPS



Twice the Multiplication on the left than below



More Stacks More Multiplication Basically, Multiplication is linear in the number of Stacks until it isn't.

An Example of an InnoSys Product that the form factor for the HAC HV RSPS Control Unit is based on

Actual Photo

InnoSys V- W-Band Travelling Wave Tube Amplifier (TWTA)

An example Data Sheet for an InnoSys TWTA

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SSVD™ V-Band TWTA
105 Watt CW

SVCW-66.5-4-105-24

Feature Highlights:

- *105 Watt CW*
- *63.75-67.5 GHz*
- *Waveguide Input and Output (WR-15)*
- *100% Duty Cycle (CW)*
- *Weight: <30 lbs*
- *Air Cooled*

RF Performance (Typical)

Frequency: 63.75 to 67.5 GHz
RF Output Power: 105 W
RF Input Power: 0.5 W
Small Signal Gain: 24.2 dB

Electrical Characteristics

Duty: CW
Filament Voltage: 5.5 Vdc
Filament Current: 1 Adc
Focus Electrode Voltage: -25 Vdc
Beam On: 0 to -30 Vdc
Beam Off: -750 to -1000 Vdc
Anode Voltage: 0 to -3000 Vdc
Anode Current: 10 mA Max
Cathode Voltage: 16.8 kVdc
Cathode Current: 100 mAdc Max
Body Current: 2 mAdc Max
Collector Voltage 1: 10 kVdc
Collector Voltage 2: 14 kVdc
Collector Voltage 3: 16.5 kVdc
Collector Efficiency: 96.5%
Power Consumption: ~60 Watts
Filament Warm-up Time: 3 Minutes Max

Mechanical Characteristics

Dimensions: 13.0" L x 17.0" W x 5.25" H
Weight: <30 lbs
RF Input Connector: WR-15
RF Output Connector: WR-15

Overview

The InnoSys SVCW-66.5-4-105-24 V-Band traveling wave tube amplifier (TWTA) is a compact and user-friendly broad bandwidth amplifier (63.75-67.5 GHz). InnoSys 105 Watt CW V-Band TWTA comes in a standard 3U rack-mount case and requires only a 24 VDC supply. The user simply connects their RF input signal, connects to the RF output, and turns the unit on. The TWT employs periodic permanent magnet (PPM) focusing, a high-efficiency multistage depressed collector (MDC), and uses RF waveguides for both input and output power delivery. The compact and highly-efficient design of the TWT unit allows for air cooling and relatively light weight compared to other similar power amplifiers.

Company Information

InnoSys focuses on and has been developing and manufacturing TWTs for more than a decade. InnoSys manufactures SSVD™ TWTs from starting materials to finished packages at its Salt Lake City, Utah facility. In addition to vacuum electronic manufacturing and testing capabilities, InnoSys has unique capability in semiconductor and solid-state microelectronics, including class 100 and 1000 cleanrooms, supporting among others microfabrication and micro-electro- mechanical system (MEMS) processes.

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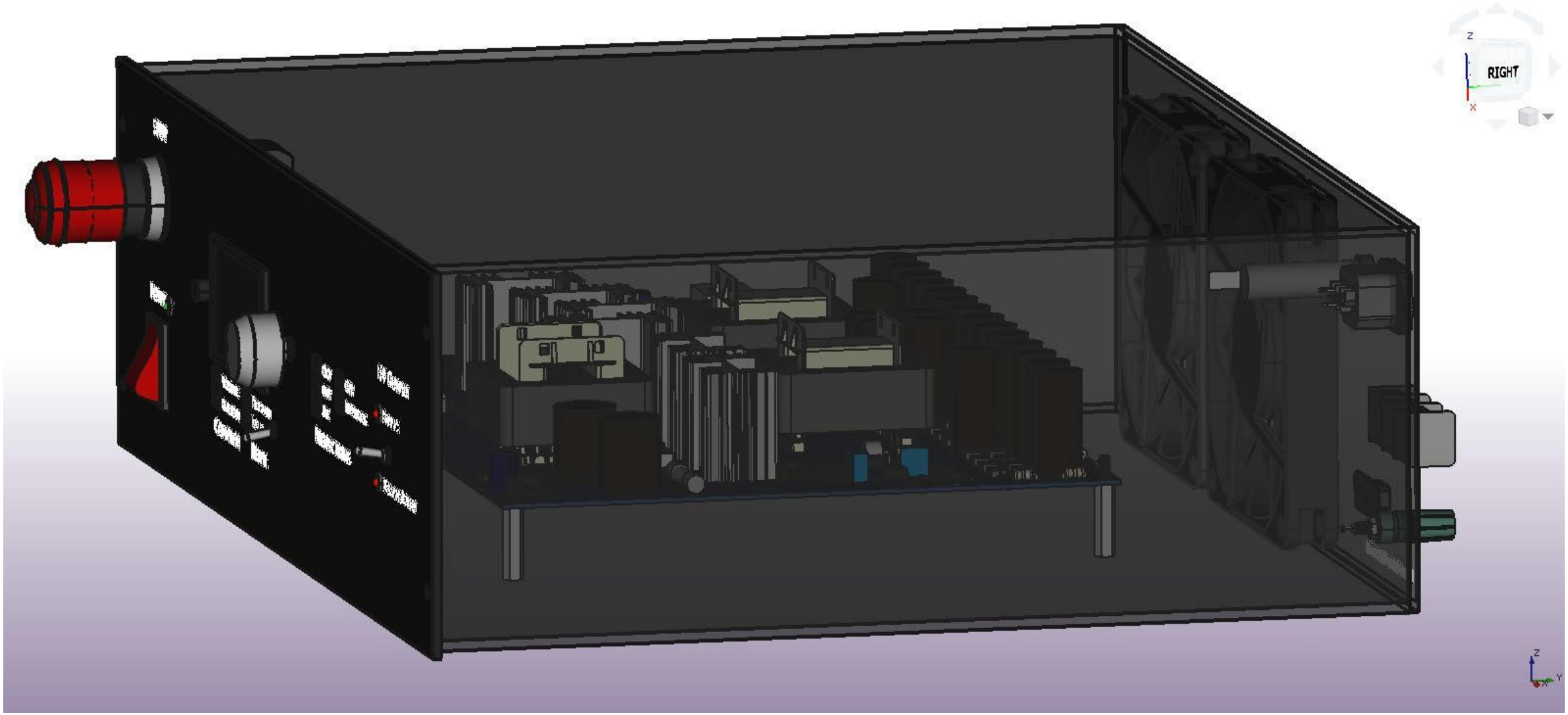
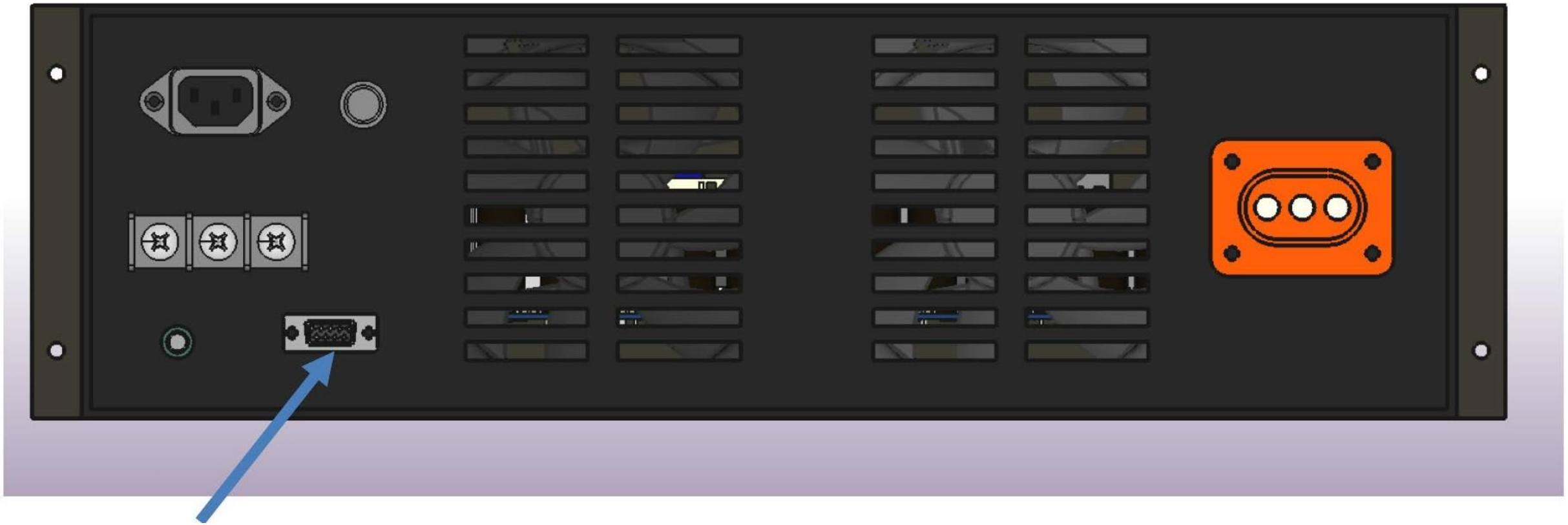
A CAD rendering of the front view of InnoSys' V- and W-Band TWTAs

A CAD rendering of the front view of the HAC HV RSPS Control Unit

A CAD rendering of the side/front view of the HAC HV RSPS Control Unit with Inverter Inside



A CAD rendering of the rear view of the HAC HV RSPS **Control Unit**



Interlock, remote control and monitor signals (in general, customized for specific customer end use.

Specs for the HAC HV RSPSs

The Phase II specs for the high voltage power supplies are:

- 500kV and up to 750kV at 10mA (7.5 kW) with a target of 0.1% ripple using SF_6 for the HV stack.

And

- 600kV at 120mA (72+ kW) at 0.1% ripple.

Some of the Protections for the HAC HV RSPS

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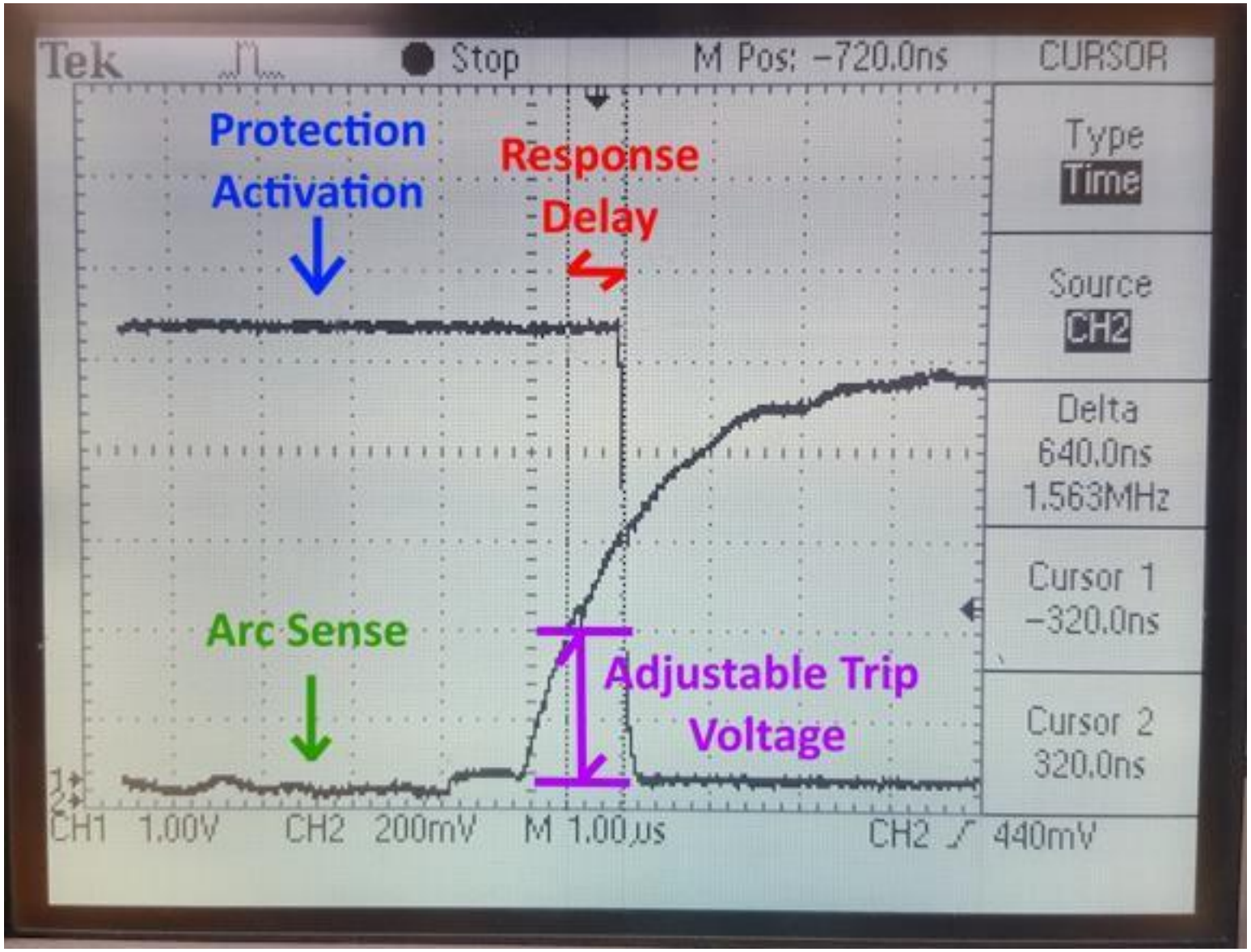
- The InnoSys power supplies have a number of protection and safety features and safeguards incorporated into the power supply which enable the protection of the power supply, itself, the HAC HV RSPS, the system environment that the HAC HV RSPS is in and, most importantly, humans who are interacting with, among other things, the high voltage and high power being used to generate and produce high power RF microwave energy.
- The power supplies are fully short circuit protected, over voltage, under voltage, over current, over temperature protected and arc protected.
- The protections have been incorporated to detect issues with the performance of the photocathode guns and head off issues.
- Sequencing of the power supply and conditioning of the photocathode are very important.
- The power supplies support both analog and digital monitoring and control. A number of options are available.

Some of the Protections for the HAC HV RSPS



Some of t e Protections for the HAC HV RSPS

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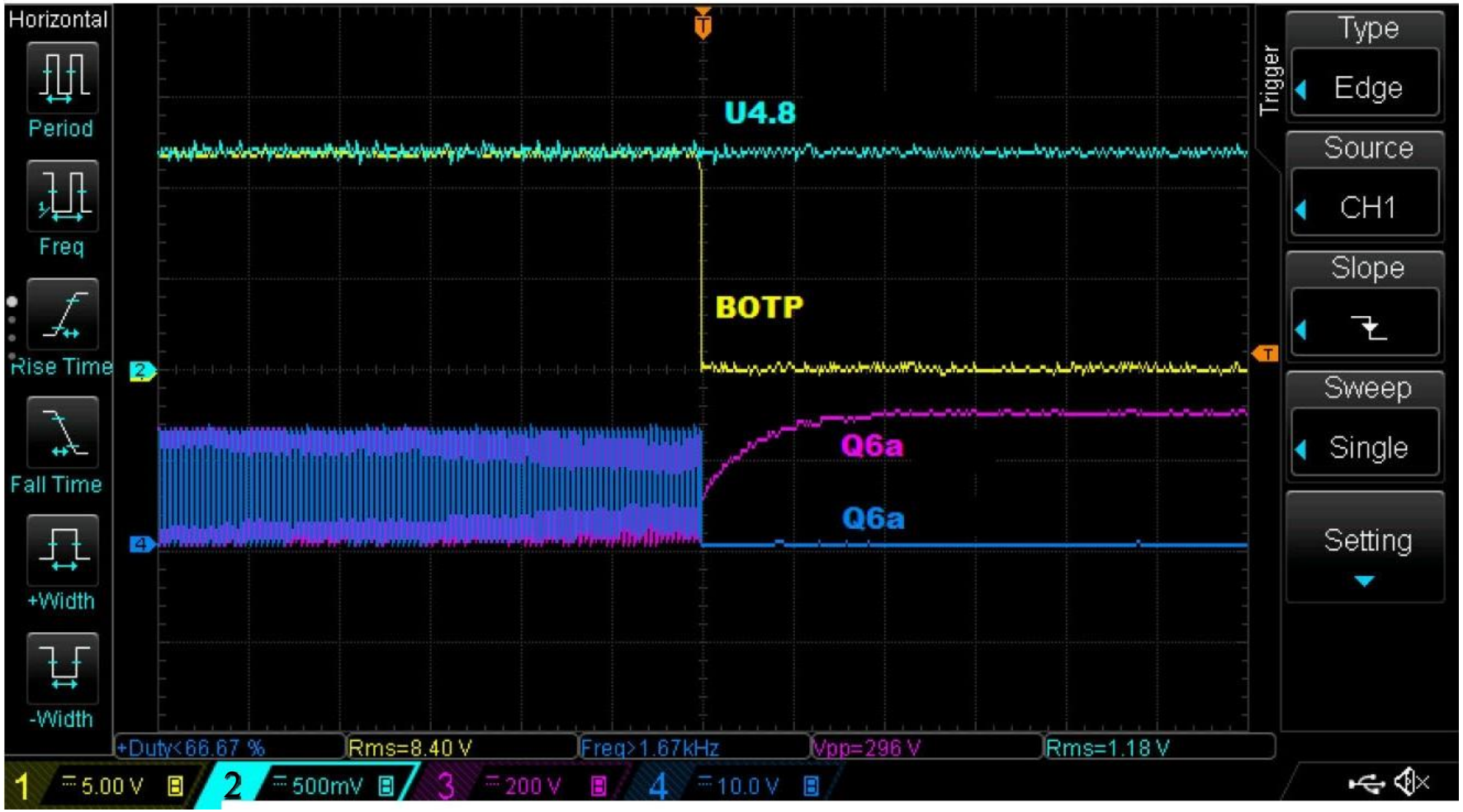

Overtemperature protection (OTP) tripping which turns off the gate to the main switching circuits which, in response, turns off the output voltage of the extremely high voltage power supply. Time base is 10 milliseconds (ms) per division.

Some of t e Protecf ons fi r the HAC HV RSPS

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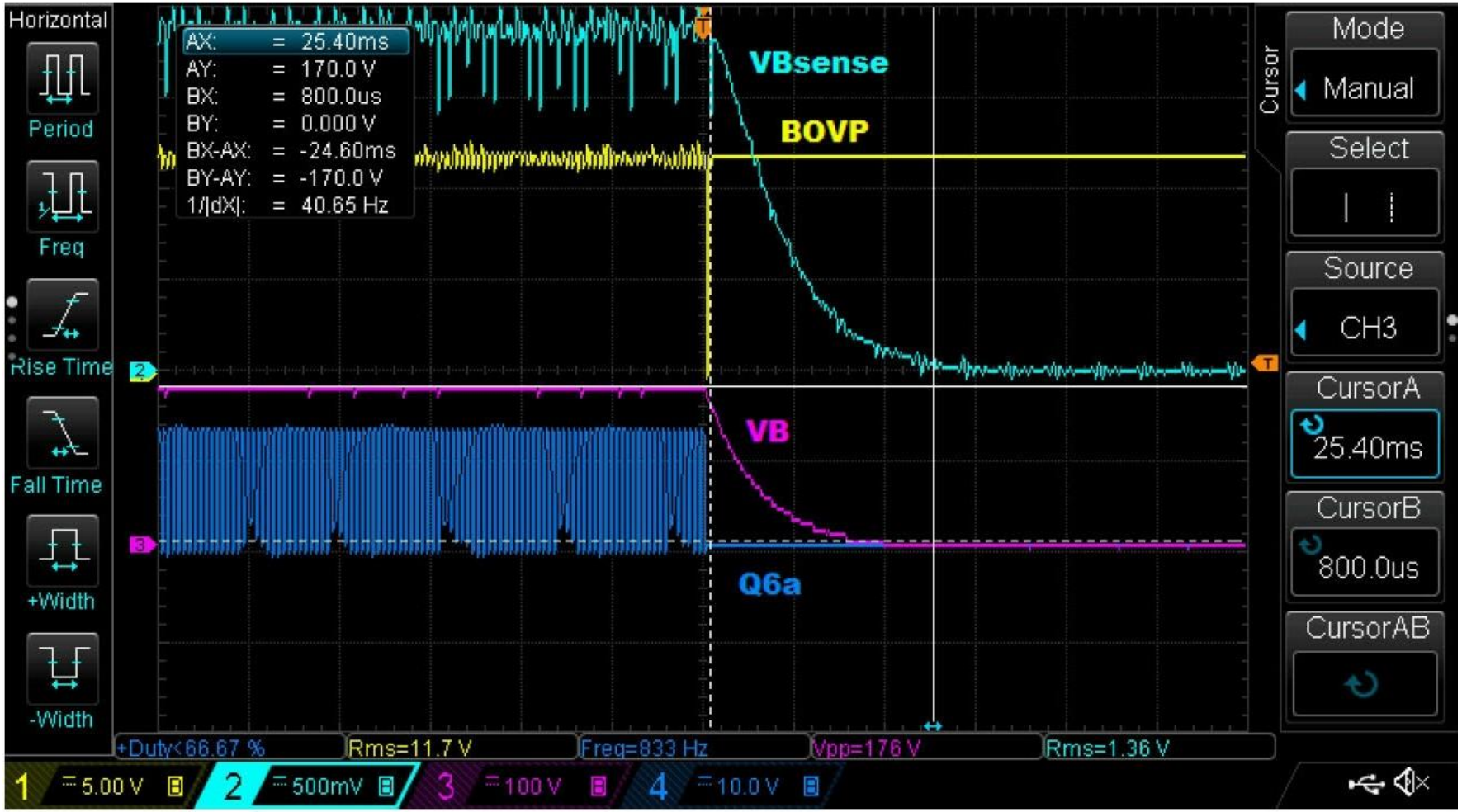

The waveforms over voltage protection (OVP) testing including the tripping and subsequent shutdown of the main switching circuits that drives the rest of the power supply Time base is 10 milliseconds (ms) per division.

Some of t e Protecf ons for the HAC HV RSPS

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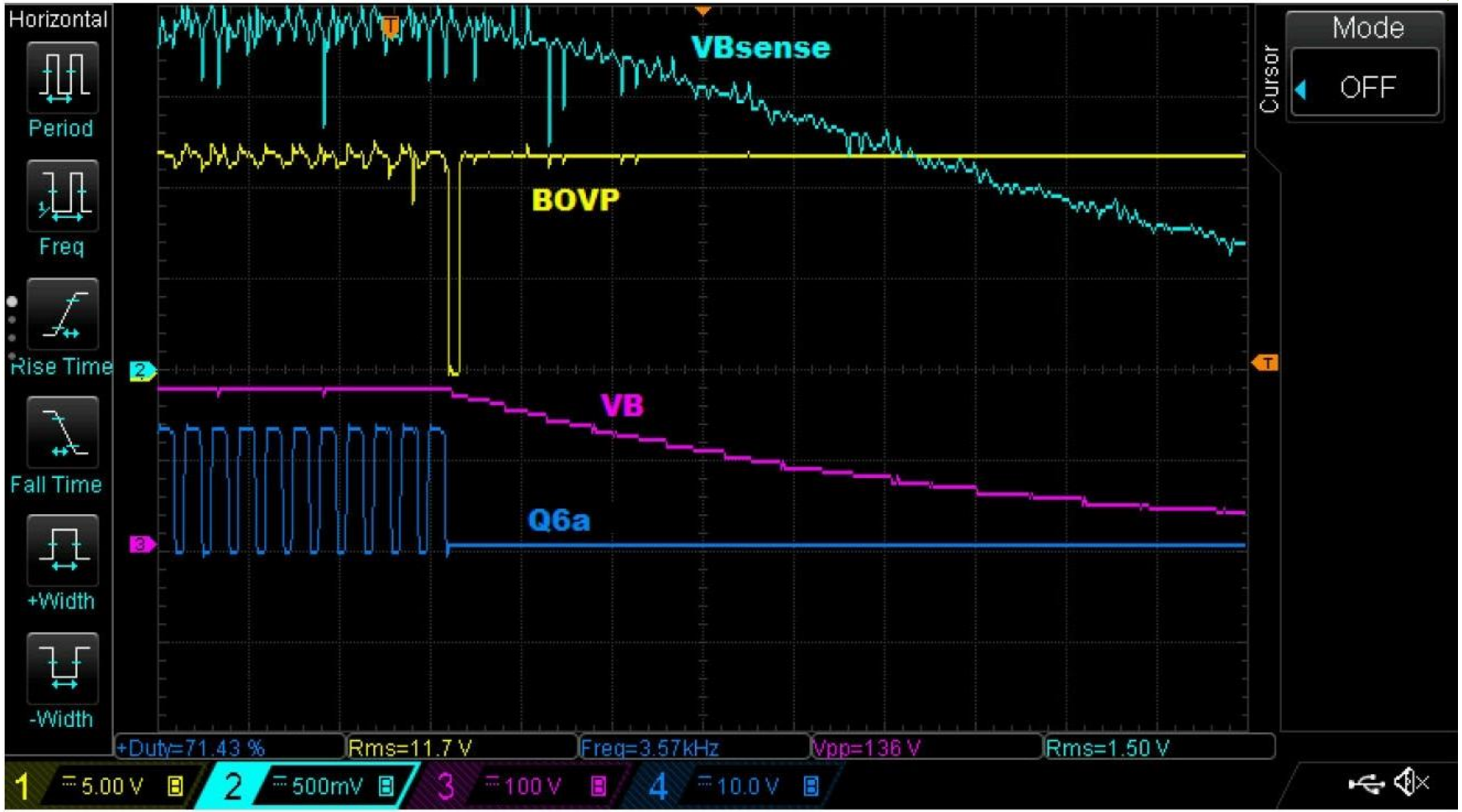
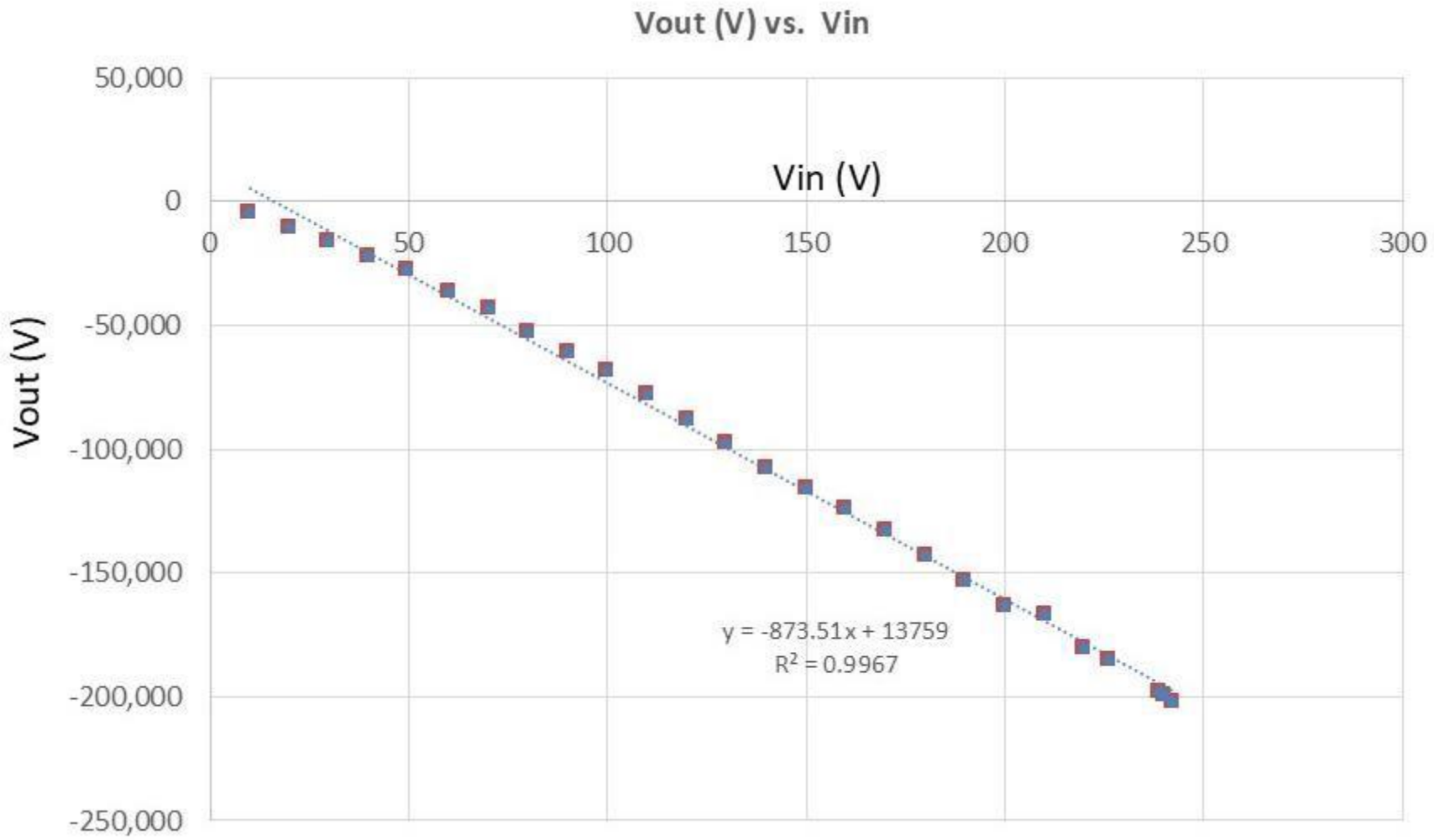


Expanded (i.e., zoomed in 10 times) waveforms shown in previous slide for OVP testing including the tripping and subsequent shutdown of the main switching circuit that drives the rest of power supply Time base is 1 ms/division.

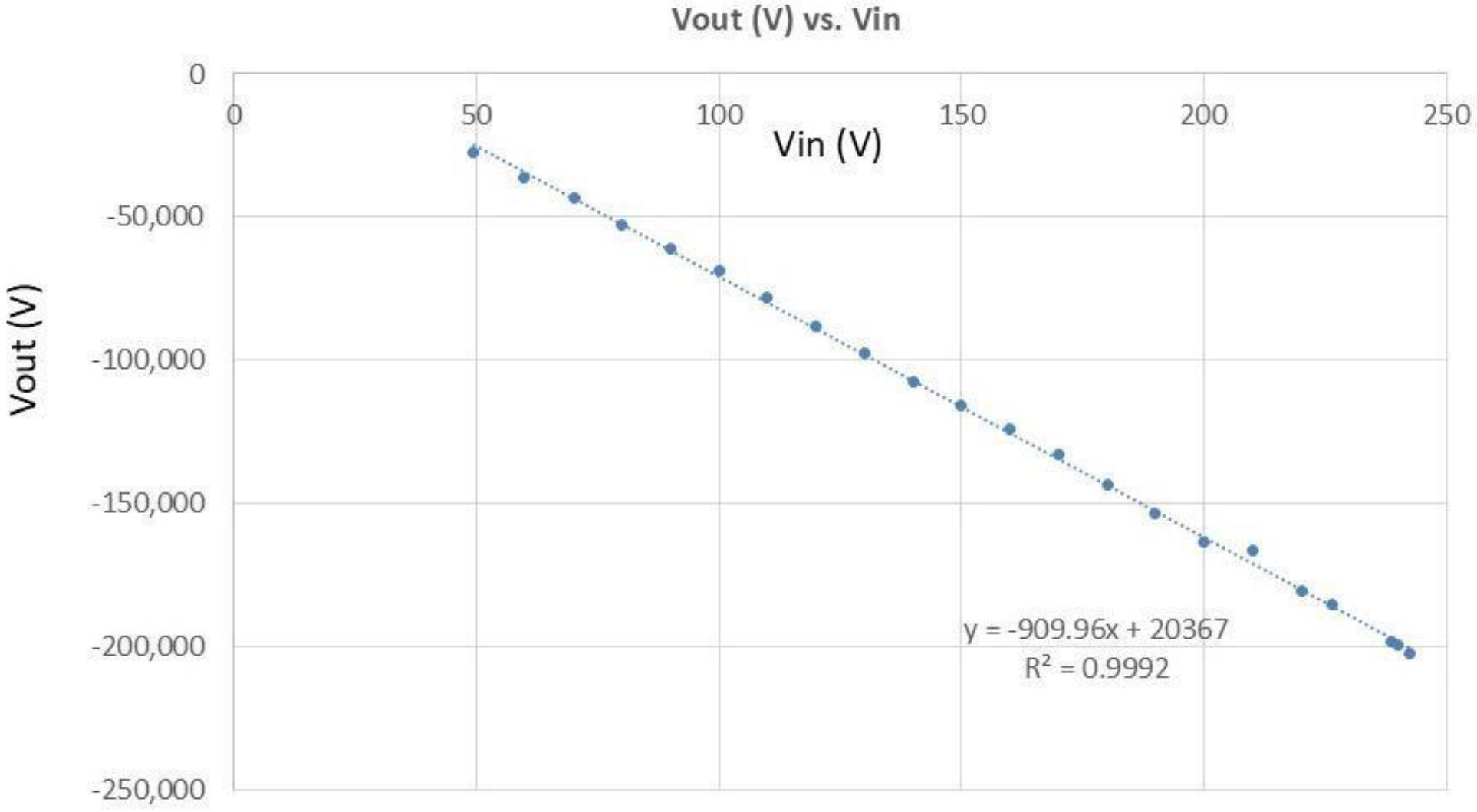
An Example Result



An Example Result (dropped first few points)

Note: Highly linear behavior

Also Note: The inverter stage has gain too.



Some Electrical Considerations of the HAC HV RSPS

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➢These HAC HV RSPS Power Supplies can accept different AC input voltages and phases depending on the output power.

➢ For example:

120 VAC 50/60 Hz Single Phase;

208 VAC 50/60 Hz Single and Three Phase;

240 VAC 50/60 Hz Single and Three Phase;

480 VAC 50/60 Hz, Three Phase, etc. All of these options power factor corrected.

➢Other customized features and functions can be at and powered at Cathode potential.

➢The current limit can be varied from 0 to 100% in either constant current or constant voltage mode.

Commercialization

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- We have been working on customer discovery, differentiators, value proposition and, early adopters, customer acquisition and the costs of customer acquisition.
- Our commercialization goal/objective is to implement and commercialize a family of extremely stable and reliable high average current and high voltage DC power supplies for accelerator applications and other commercial and industrial applications.
- We engaged in preliminary customer discovery, developing beachhead, differentiations.
- We continue to conduct relevant customer discovery interviews.
- As with many others, we are also considering targeting fusion in addition to the accelerator and related markets.

Summary

- We have been researching and developing extremely high voltage/current power supplies for nuclear physics and other applications.
- We have been focusing on arc elimination (or as close as we can come to that) as we increase the high voltage towards -600 kV and -750 kV, respectively.
- We have successfully built several prototypes up to 400 kV of the HAC HV RSPS power supplies at lower currents.
- The power supplies work at full power (and also at lower powers) for air cooled HAC HV RSPS.
- We have implemented extensive safety, protection and safeguards.
- We have designed for 0 to 100% full scale control set points for both the HAC HV RSPS voltage and current output (including current limit).
- We are designing, developing and will continue to implement a module approach for higher voltage and power with focus and attention minimizing arc events.
- We appreciate your questions, input and feedback – Thank you.

Thank you for your time and attention today

Acknowledgements and Grateful Appreciation to
Dr. Michelle Shinn and the DOE NP Program

Questions?