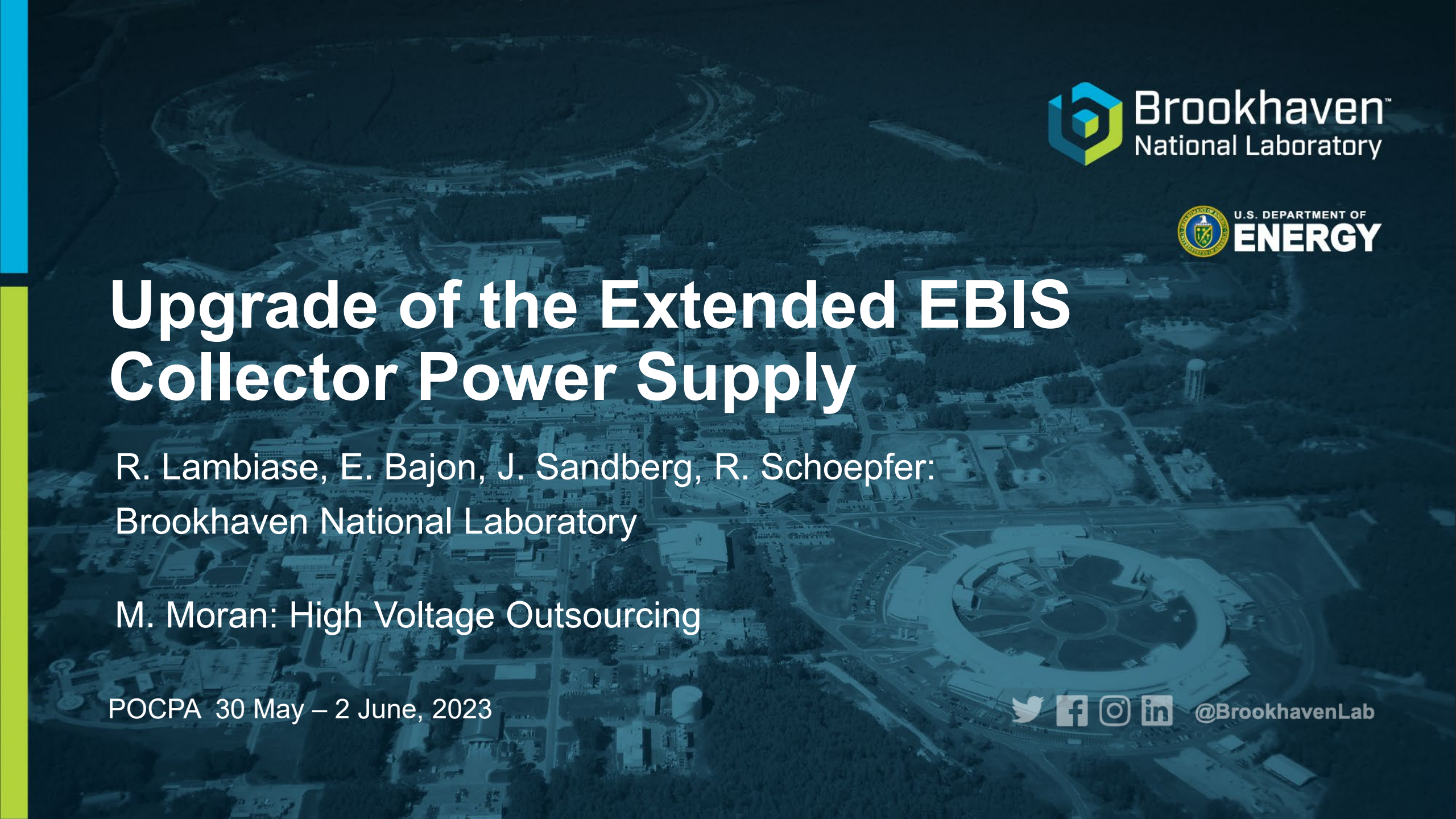

Upgrade of the Extended EBIS Collector Power Supply

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The BNL EBIS

The RHIC EBIS is used to provide ions, of various species, with the desired charge state. To use an example, one of the external ion sources can produce a gold ion with a +1 charge. Those ions are transported though the combiner into the EBIS superconducting solenoid which is to the left of this diagram.

The ions are trapped in the solenoid by its magnetic field and drift tubes on both end, the gold ions interact with an electron beam. The longer the ions are left in the solenoid, the higher the charge state. To get to the desired state of +32 takes about 30 ms.

When the desired charge state is reached, the ions are released from the trap in a short pulse. Just prior to this extraction of ions from the trap, the EBIS platform is pulsed up to ≤ 100 kV to get the proper RFQ input energy. It then goes through the LEBT a RFQ accelerator, and a Linac. It continues down a beam line for injection into the booster ring.

The new Extended EBIS will add a second superconducting solenoid. It will improve ion intensity and have other performance enhancements.

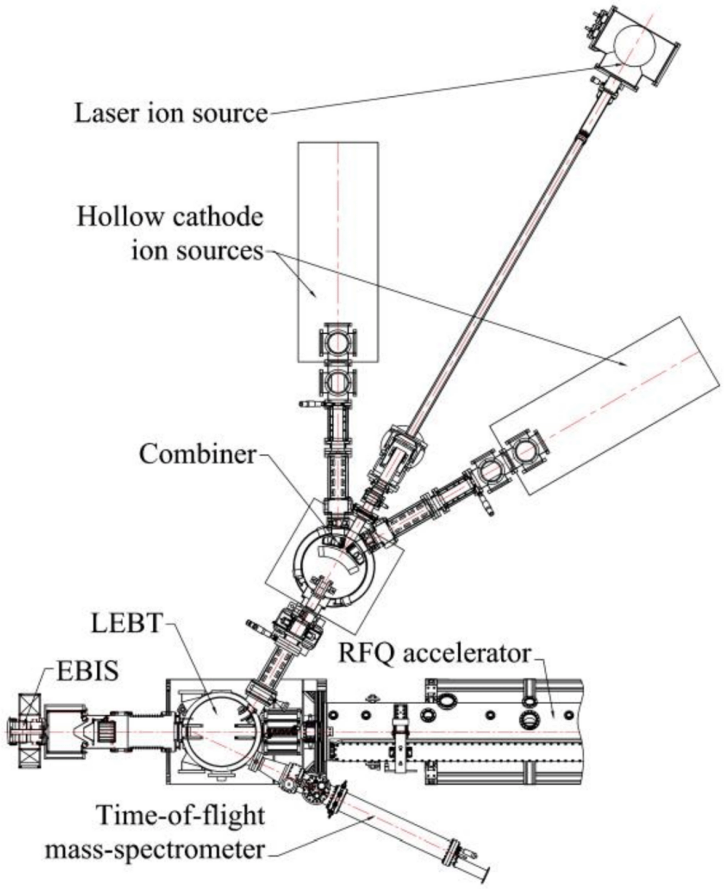


Fig 1. External Ion Sources of the RHIC EBIS

Ref: Reliable operation of the Brookhaven EBIS for highly charged ion production for RHIC and NSRL, E. Beebe et al.

The EBIS Collector PS – In The Beginning ~ 2009

The EBIS required a collector power supply (CPS) of up to 15kV at 15A. It was a very simple system.

- The DC power part was an OCEM RF anode power supply. A supply of this design was already in use at BNL, so there would be not development costs or risks. It is a simple rectifier with filtering and an ignitron crowbar.
- The CPS sits on a platform, which is pulsed to about 80kV, so a step – up isolation transformer was designed by Stangenes.
- To vary the output of the CPS, an off-the-shelf GE Inductrol was used. An Inductrol is a variable transformer, which acts similar to a Variac, but the Inductrol voltage is varied by moving a rotor instead of sliding brushes as with a Variac.

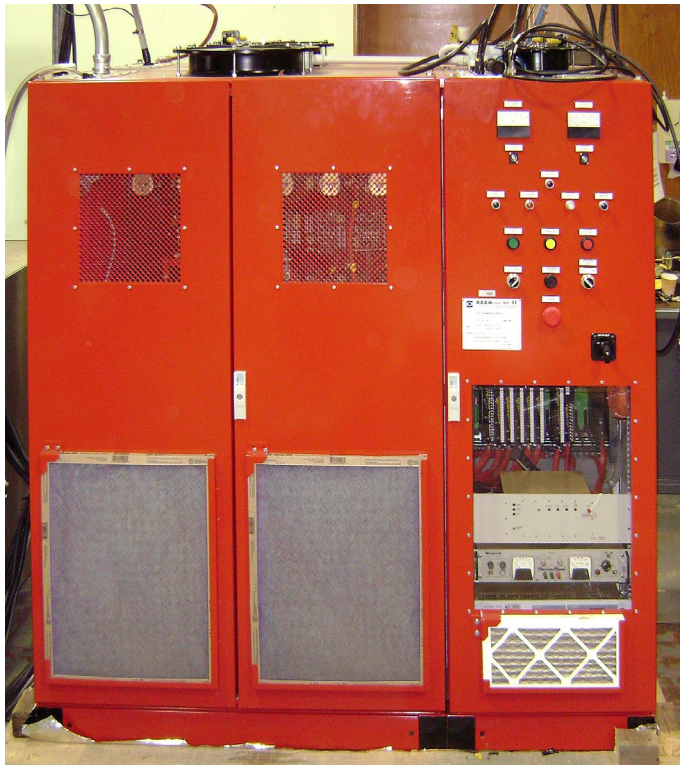


Fig 2. Anode Power Supply

Fig 3. Inductrol

Improving Regulation ~ 2011

It's also worth mentioning that the original power supply used an ignitron as a crowbar. These are mercury filled switches and are capable of carrying massive currents, which makes them well suited as a crowbar. These are obsolete now. The toxicity of the mercury helped with this obsolescence.

There was a desire to improve the regulation, and we had a tetrode on hand. This was used as a pass regulator and worked well.

This is the configuration that has been used up to this day. It does have some limitations:

- The anode voltage means the maximum output voltage is lowered
- While the tetrode is fast, it cannot make large scale voltage changes quickly. That still required the mechanical adjustment of the Ignitron.

Fig 4. Ignitron

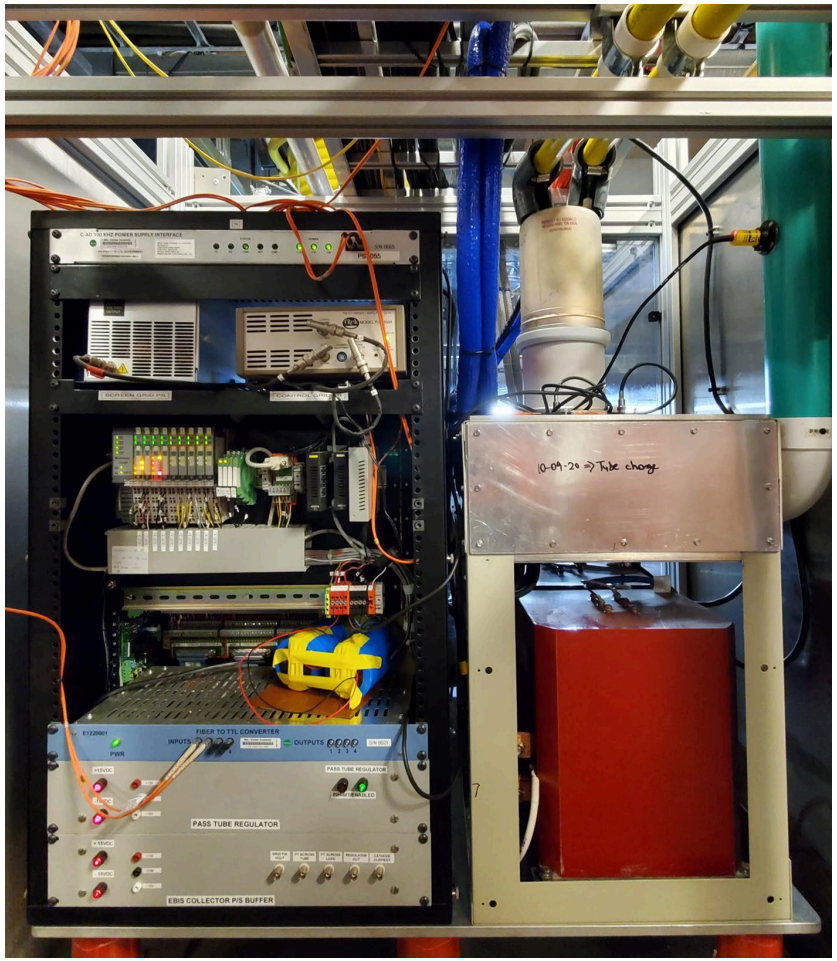


Fig 5. Tetrode

Motivation for a New Collector Power Supply ~ 2023

There were two categories driving the need for a new CPS. The first category is the availability of parts, both now and 25 years from now. The second category was to improve performance.

For availability of parts:

- The Inductrol – Once in very common use in tall buildings to boost voltage, these devices are now extinct.
- The Ignitron – Also once in very common use, but now also nearly extinct. In addition, they create an environmental hazard.
- The Transformer – While not extinct, the isolation transform for the current CPS is unique as a 700V to 13kV step up isolation device. We use two other transformers in our lab at the same power and isolation level, but 480V to 480V isolation. It is an advantage to have a new CPS use the same 480V to 480V isolation transformer.

For improved performance:

- Full Output Voltage – The new supply will have the full capability of 15kV at 15A. This gives more options for the EBIS operating points.
- Pulse to Pulse Voltage Changes – The EBIS facility is designed to change species in one second. This is because it has several users – the RHIC blue ring, the RHIC yellow ring, and the NASA Space Radiation Laboratory (NSRL).
- Changes in Voltage Within a Species – It is sometimes desirable to have a small slope in amplitude during a pulse train of a specific species.
- Operation Recovery After a Fault – In the original CPS, recovery is many minutes, due to the mechanical response time of the Inductrol. The new CPS recovers quickly.

The Collector Power Supply Overview

At an overview level, the new and old supplies are similar, with some differences:

- The CPS has two parts – the power supply itself, which is pulsed to 80kV, and a ground potential cabinet for controls. Communication between these two parts is by fiber.
- The new CPS uses a 480-480VAC isolation transformer, as opposed to the present 700-13kVAC unit.
- The new CPS is controlled by a BNL power supply interface, as opposed to the present Inductrol.
- The new CPS controls energy to an arc with current limiting and a Behlke switch, as opposed to the present ignitron.

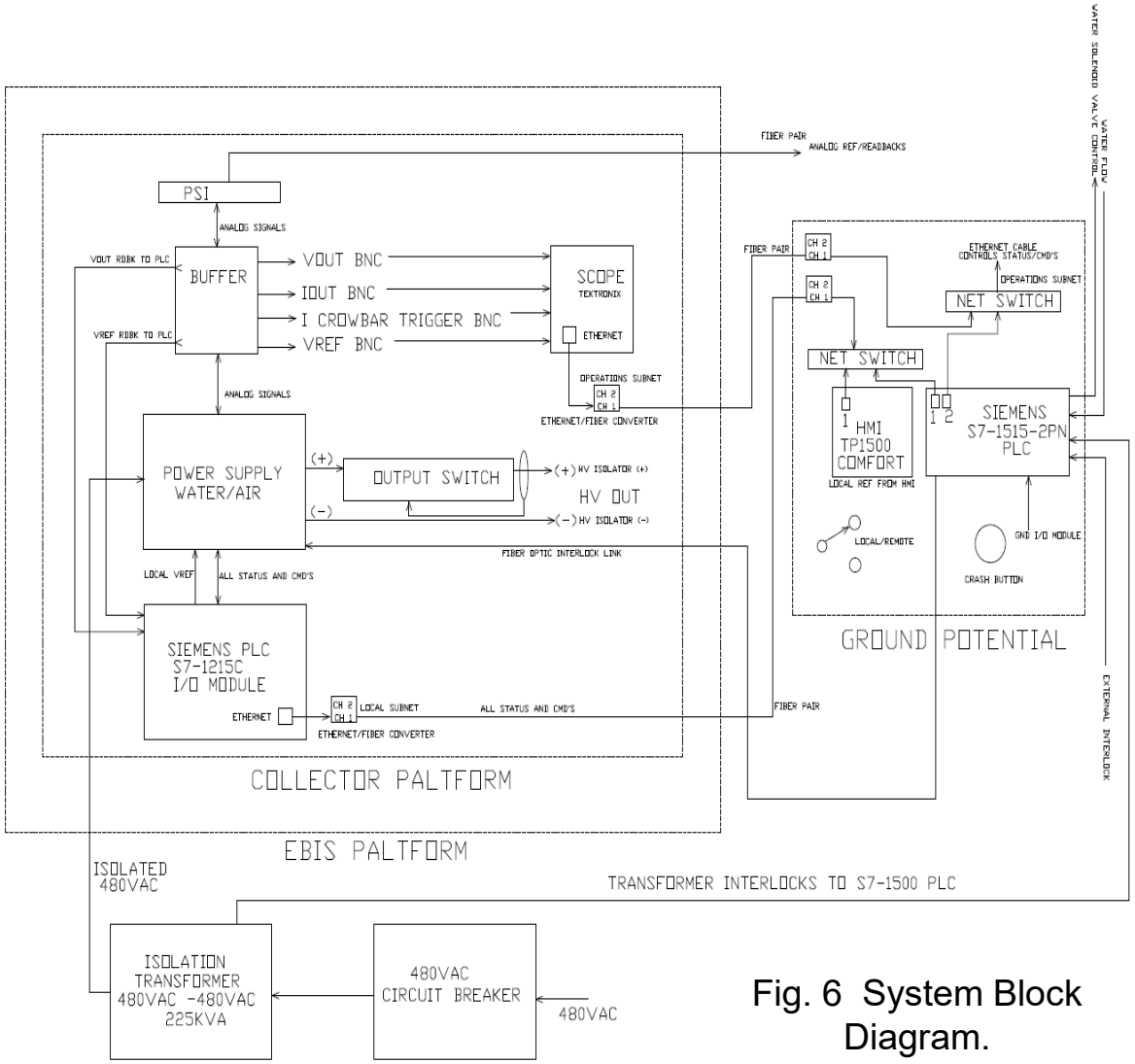


Fig. 6 System Block Diagram.

The Power Modules

The basic building block of the CPS is the power module. Each power module will supply 15kV at a nominal 0.5A. It can provide up to 1.0A to recover from a step load current.

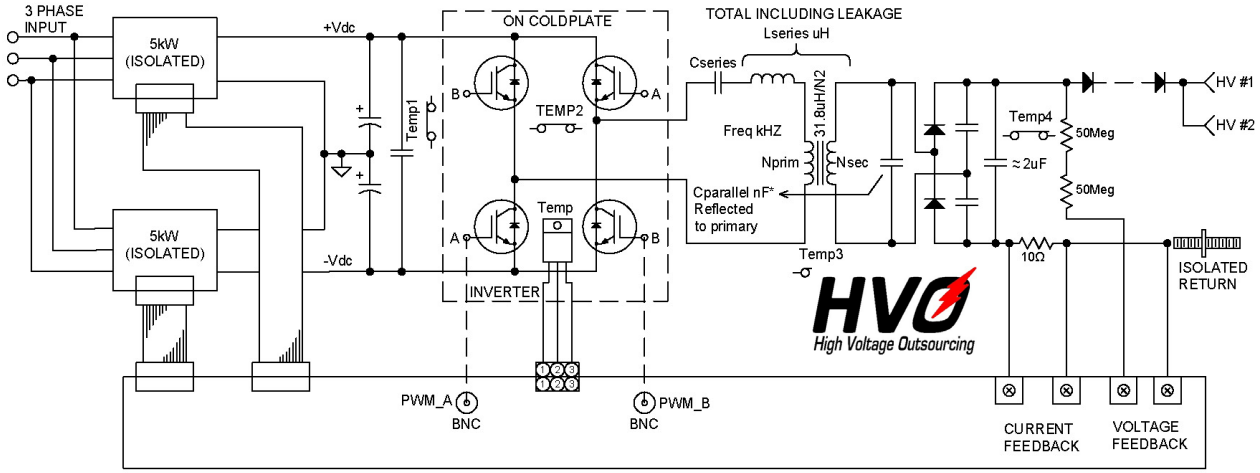
The CPS can contain up to 30 of these modules in parallel to reach the rated 15kV at 15A. This unit was purchased with 20 modules to reach 15kV at 10A. We can upgrade at a later time to the full 30 modules.

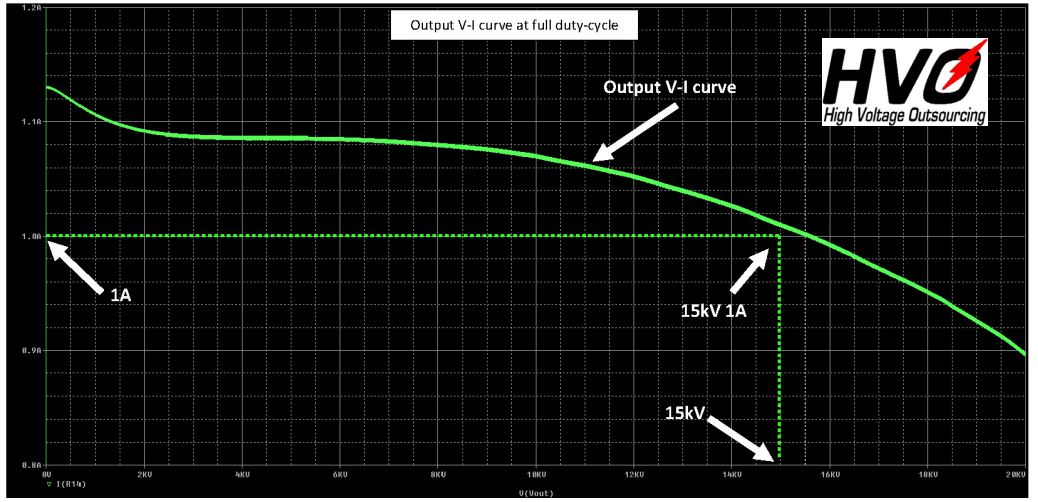
The power module uses COTS power supplies as a power bus. This is followed by a pulse width modulated resonant converter. The output impedance of this type of converter helps with the paralleling of the modules.

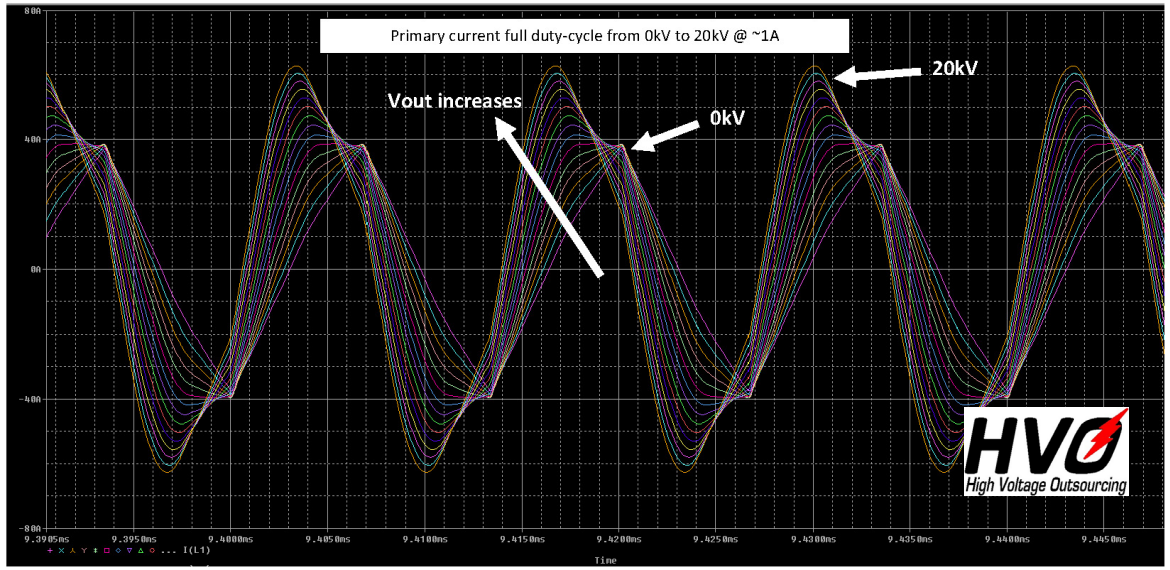
Some details of this converter are shown on the next slide. That slide has been provided by Mariano Moran of High Voltage Outsourcing (HVO),

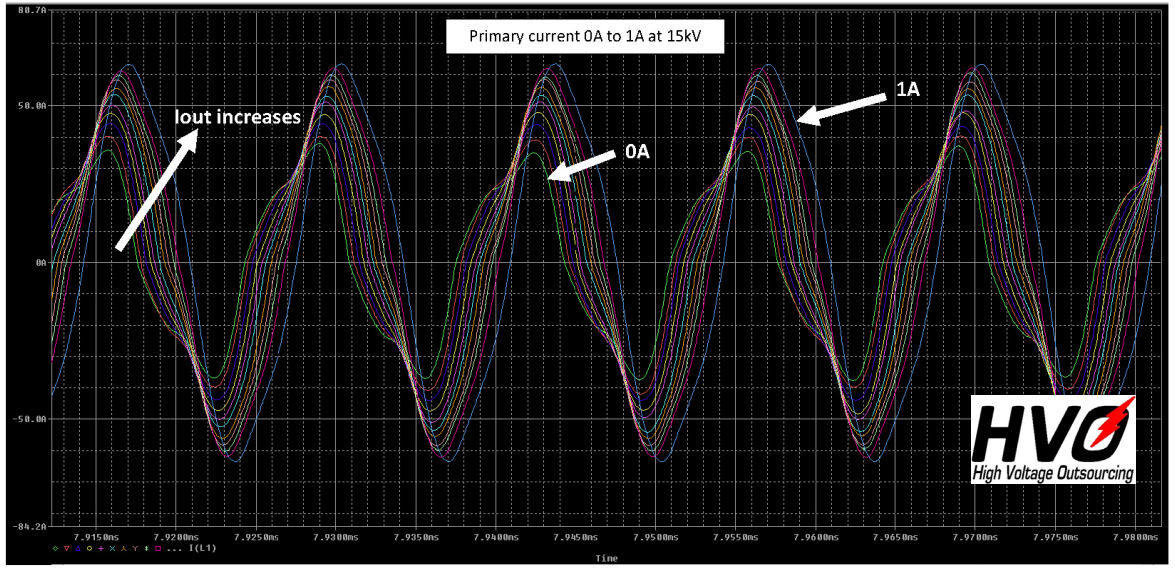
Fig. 7 EEBIS CPS at Cathode Potential

Power Module Details









Other Important Features of the New CPS

There are other important features of the new CPS. I'll describe some of them and then show test data. Other acceptance tests included the standard stability, ripple, and heat run.

- Limiting Energy to an Arc: The EBIS has different users that require different species of ions. The two colliding rings of RHIC may have different species. Also, ions are provided to the NASA Space Radiation Laboratory. The other EBIS components were able to make a large change in parameters within one second. But the present is too slow. The new CPS can change this quickly, but requires a switched pre-load to remove energy when the EBIS beam current is off.

  In the present design this is done with an ignitron, which is an obsolete device.

- Response to a Step in Load Current: When the EBIS beam turns on it presents a step load current. The droop due to this step is to be less than 150V.

  In the current power supply, this function is performed by a power tetrode. This is another device to put in the power supply museum.

- Pre-load: The EBIS has different users that require different species of ions. The two colliding rings of RHIC may have different species. Also, ions are provided to the NASA Space Radiation Laboratory. The other EBIS components were able to make a large change in parameters within one second. But the present is too slow. The new CPS can change this quickly, using a switched pre-load to remove stored energy.

  This function does not exist in the current power supply.

Transient Response and Ripple

For this test, a very fast 10A (full load) step was applied to the output, which was set to 15kV. From this we can see:

- The maximum dip in voltage is 200V
- The voltage recovers to within 100V in slightly more than 600µs.
- The ripple voltage at full load current is seen to be about 35V peak – peak.

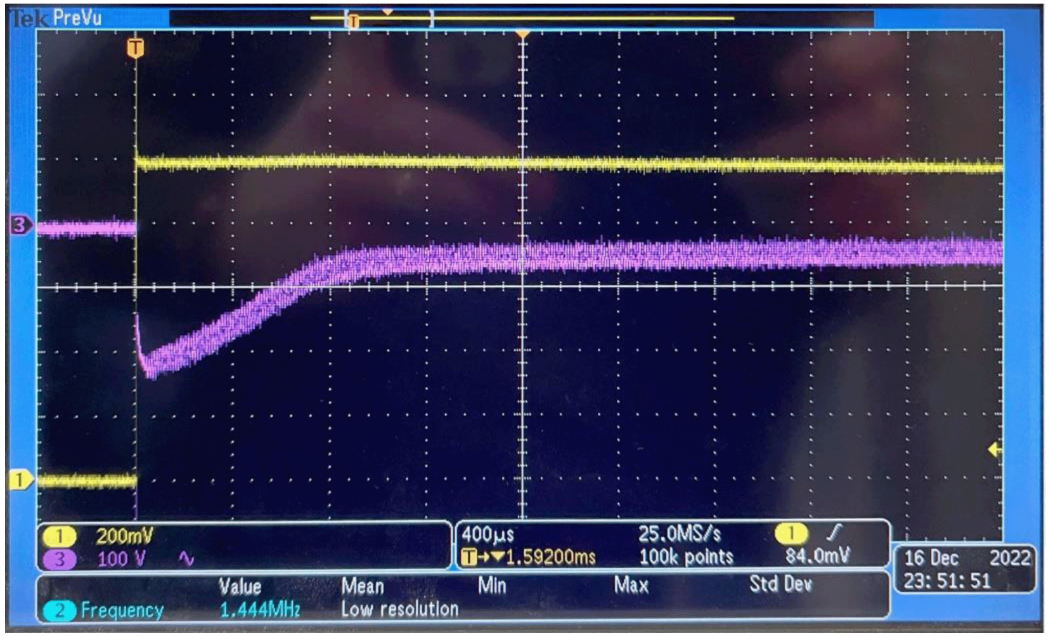


Fig. 9 Transient Response and Ripple

Yellow: Output current, 2A per division, DC coupled.
Purple: Output voltage, 100V per division, AC coupled.
Time: 400µs per division

Limiting Energy in an Arc

The energy in an arc is limited by a combination of a current limiting circuit and an output Behlke switch.

- Test conditions: The PS is set to 15kV. The output is shorted through a series network with a cable inductance of 30μHy and negligible resistance (braid on a shorting stick).
- There are two parts to the current spike – the energy stored in the cable between the PS and the test load (which cannot be controlled) and the energy provided by the PS (which is controlled).
- We expect a vacuum arc to have a voltage of 50V to 100V. This current waveform into a constant 100V arc will absorb 287mJ, which is also acceptable.

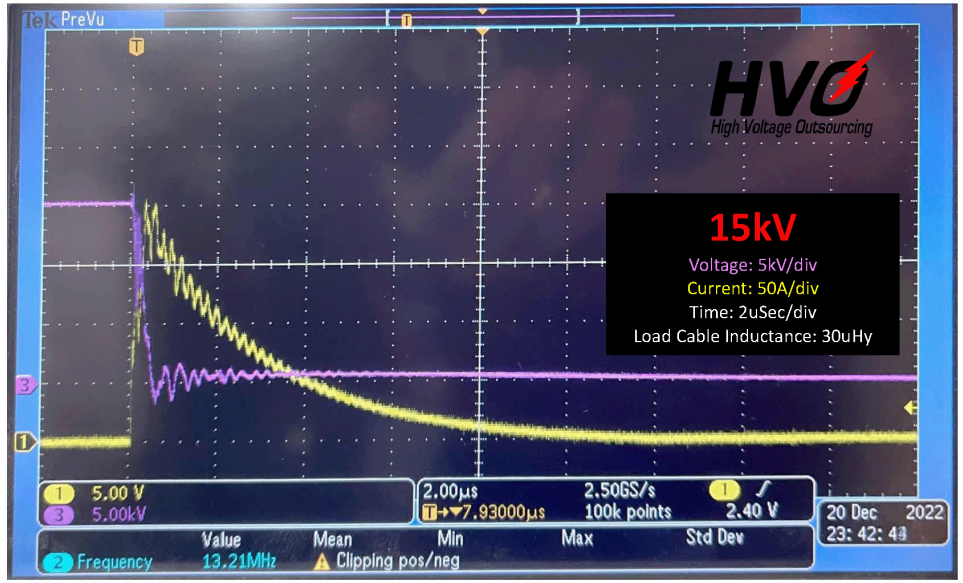


Fig. 10 Current in Arc

Yellow: Output current, 50A per division, DC coupled.
Purple: Output voltage, 5kV per division, DC coupled.
Time: 2μs per division

Preload to Reduce Voltage Between Species

A feature of this new power supply is that it enables a different collector voltage for different species of ions. Between species, there is no beam current and the power supply can only source current. To effect this change, a pre-load is switched in, when needed, absorbing energy from the capacitor bank and lowering the voltage. This transition is to take place in one second. The wave shape of this transition is unimportant, as the EBIS beam is off.

- Test conditions: There is no load on the PS, and the ouput is initially set to 14kV. A set point change is made to 8kV for a 6kV transition.
- Results: The transition is made to a 150V band in less than one second.
- The rise is much faster, since the power supply can easily supply current to charge the capacitor bank.

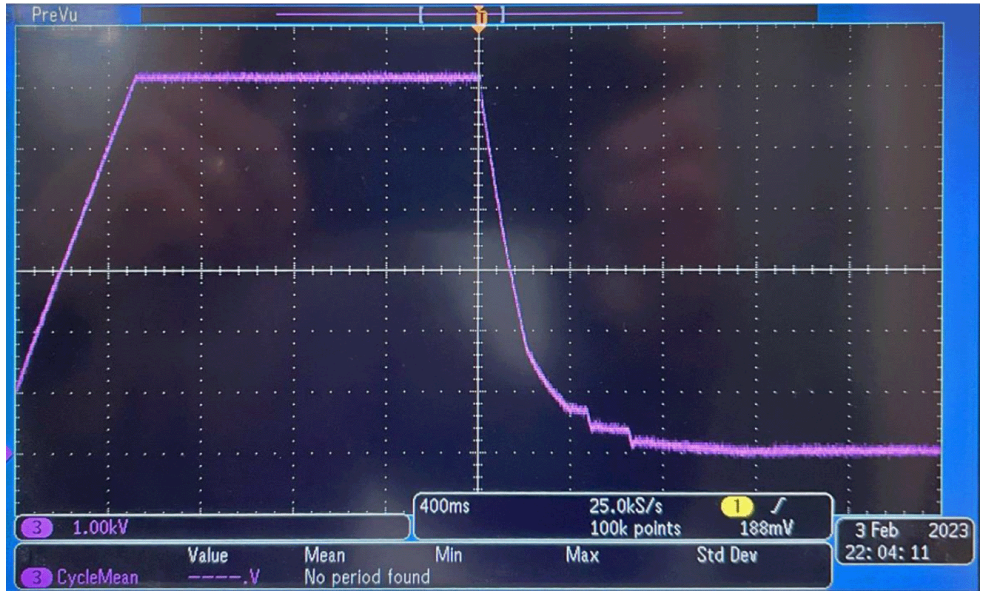


Fig. 11 Voltage Pre-Load

Purple: Output Voltage, 1kV per division, DC coupled, offset by 8kV.
Time: 400ms per division

Current Status

The new Extended EBIS (EEBS) Collector Power Supply (CPS) has been delivered to BNL.

At BNL, we have an operational EBIS, which supplies ions to the RHIC and NSRL, and a R&D EBIS, used for R&D. Until we have enough shut down time to remove the existing CPS, it will be installed, tested, and used to operate the R&D EBIS.

Once we have the opportunity to install the new CPS in the operational EBIS, the R&D EBIS will be operated with the original CPS.

Thank you for your attention.