INVENTION DISCLOSURE

Invention: A highly sensitive vacuum ion pump current measurement device for monitoring ultra-high vacuum.

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Problem the invention is designed to solve:
It can be a difficult and expensive task to monitor vacuum below 1x10^-9 Torr (i.e., the pressure regime of the CEBAF photoinjector and other vacuum systems common worldwide). Vacuum gauges designed to operate at this pressure range, such as extractor gauges and residual gas analyzers, cost thousands of dollars. At Jefferson Lab, where vacuum systems can be very large (i.e., the length of the 10 m photoinjector accelerator beamline), it is cost prohibitive to install enough gauges to accurately monitor the vacuum quality throughout the entire system.

Besides expense, these vacuum gauges suffer other drawbacks. The gauges contain hot filaments that produce gas within the vacuum system. It is counterproductive to use a vacuum gauge that degrades vacuum quality when in use. The gauges also produce light, which can generate unwanted photoemission from photocathodes within the polarized electron sources at the CEBAF photoinjector.

Ion pumps are common vacuum pumps used extensively throughout the Jefferson Lab accelerator and at other government and commercial institutions. Ion pumps contain metal plates that are biased at high voltage. Gas within the vacuum chamber is ionized as it passes between the ion-pump plates (i.e., electrons are stripped from the gas atoms and molecules). Once ionized, the gas atoms and molecules embed themselves within the metal plates of the ion pump. In this manner, the gas within the vacuum chamber is pumped away.

The ionized gas that becomes embedded within the plates of the ion pump constitutes an electrical current. This electrical current provides a measure of the vacuum quality within the vacuum chamber. At high pressure, ion pumps produce a relatively large electrical current (milliAmperes) that is easily measured. At lower pressure, ion pumps produce less current. At extremely low pressure, often referred to as "ultra high vacuum", it can be difficult to measure the small electrical current that is produced by an ion pump.

The manufacturers of ion pumps provide a measurement of the electrical current produced by an ion pump. Unfortunately, this value is limited to ~ 1x10^-6 Amperes, which corresponds to ~ 1x10^-9 Torr vacuum pressure. At Jefferson Lab and other institutions, many vacuum systems operate below this value.

This Invention Disclosure describes a device that can be used with standard, unmodified ion pumps to monitor ultra high vacuum pressure below 1x10^-9 Torr. Specifically, this Invention Disclosure describes an electrical circuit that enhances ones ability to monitor the electrical current produced by an ion pump from typical commercial limit of ~ 1x10^-6 Amperes to ~ 0.001x10^-6 Amperes, a factor of 1000 improvement. With this device, it will be possible to extensively and inexpensively monitor the vacuum pressure at many locations throughout the CEBAF photoinjector without introducing additional vacuum components and gauges. We will obtain information about vacuum conditions in regions of the accelerator that are presently not outfitted with adequate pressure monitoring diagnostics.

This device should find widespread application outside Jefferson Lab, at institutions both commercial and government-funded. Considerable money savings will be enjoyed because expensive pressure monitoring equipment may no longer be needed for many vacuum applications. Enhanced ion pump current monitoring will suffice.

Description of invention:

The invention has been evaluated in 3 different configurations. At the time of the initial invention disclosure, the first configuration was described and testing was underway on the newer designs. The second and third configurations have proven to have greater accuracy and flexibility than the first.

The first version was a battery powered "floating" circuit that is inserted in series with the 5000V ion pump power supply cable. The circuit measured the ion pump current and digitized this signal. This information was reported over an infrared data link to instrumentation at ground potential. The circuit contained a 14bit ADC and was capable of measuring ion pump current as low as ~ 10 nanoA, or 0.01x10^-6 Amperes, a factor of ~ 100 improvement over current measurement capability of commercial ion pump manufacturers. Battery life was ~ 6 months. This version of the design has been terminated.

The second design incorporates its own high voltage supply and thus eliminates the need to use the vendor supplied high voltage power supply. From here on, the system is referred to as a UHV (ultra-high vacuum) ion pump supply. The measurement is now performed at ground potential which eliminates the need for batteries. The design has manual range selection over 5 decades of measurement from 0-10nA to 0 to 100uA. The unit provides a front panel indication of the current measurement and an analog output of 0 to 10 volts for the decade selected. This design allows current measurements to < 1 nanoAmp (.001e-6 Amperes) with picoAmp resolution. This is a factor of 1000 improvement over the commercial ion pump supplies. Because this design uses a high efficiency DC-DC converter for the high voltage power supply, a car battery can be used to sustain an ion pump for up to several weeks. This was demonstrated in 2003 when Hurricane Isabel interrupted power to Jefferson Lab for several days. Nine injector ion pumps were maintained by a single car battery for the entire outage. All other lab UPS systems expired within hours.

The third design builds on the capabilities of the second. The manual range selection has been replaced by a microprocessor controlled auto-ranging circuit. The microprocessor provides serial communication with an external computer as well as a large variety of options that were not available in the second design. Such options could include the following:

- Time stamping of the data with day, date, and time.
- On-board data-logging capability.

- Trend reporting capability.
- Derivative alarm.
- Remotely settable alarm setpoints.
- Digital filtering of data.
- Direct cabled or wireless interface to the World Wide Web (internet or intranet).
- Ability to self-diagnose the system and page or email an individual if a problem is noted.

Operation of Invention:

The third design is described in detail below as it has the greatest capabilities of all designs to date:

Figure 1 shows the basic structure of current flow in the system. A floating high voltage source is applied to an ion pump. As ions are pumped, electrons are drawn from the high voltage plate. Any electron current that flows in the pump must also flow back into the high voltage supply. A sensitive current measuring circuit is employed to read this current flow. The voltage produced at the output of this circuit is proportional to current.

Figure 2 shows an expansion of the basic system. The high voltage is provided by a high efficiency high voltage DC-DC converter. The value of the feedback resistor can be changed by closing a relay for a specific range. The output of the circuit is available as an analog level and is fed to the microprocessor shown in Figure 3.

Figure 3 shows the microprocessor. The microprocessor gets the analog level from the Figure 2 op-amp and digitizes it. The software is programmed to allow the microprocessor to make an intelligent decision as to which range resistor should be activated and will scale up or down as the current through the ion pump changes. The microprocessor writes to a liquid crystal display (LCD) to give a front panel indication of the measured current. Software can be modified as required to provide additional functionality as previously mentioned. The addition of a Real time clock counter (RTCC) circuit and memory would provide the provisions of time stamping, datalogging and trend reporting. A version of this circuit can be built that writes all information to a common memory card like those used in a modern digital camera. The microprocessor in this example provides the information to a computer over the serial interface. The software programming and interface type can be changed to provide RS-232, 422, 485, CAN bus, USB, or even direct Ethernet protocols or Web server.

By proper selection of circuit components and DC-DC converter, the system can be built to provide a moderate safety margin over existing high voltage systems. All commercial ion pump power supplies known to the inventor produce a lethal high voltage at the output of the supply. The invention described here is designed to provide the same voltage, but at a limited current that is non-lethal when energized. It is not the author’s intent to call the system safe because outside factors such as cable length and system capacitance could produce a lethal charge. If the circuit enclosure is redesigned for direct attachment to an ion pump without the use of an intermediate high voltage cable, a non-lethal status could be claimed.

Figures 4&5 represent real data collected from a commercial supply and the invention described herein. Figures 6 & 7 show photos of the invention.

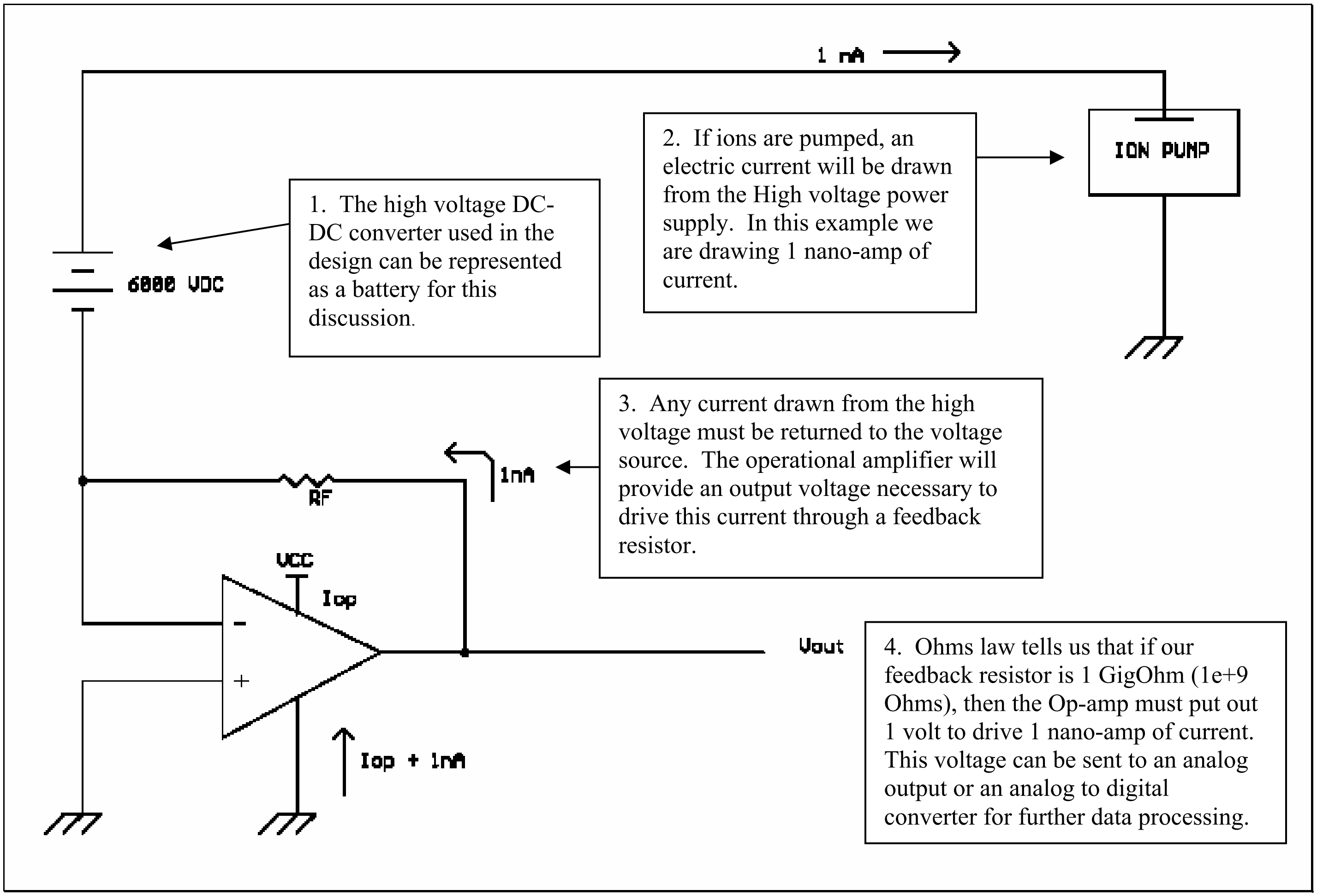

Figure 1. System Basic design.

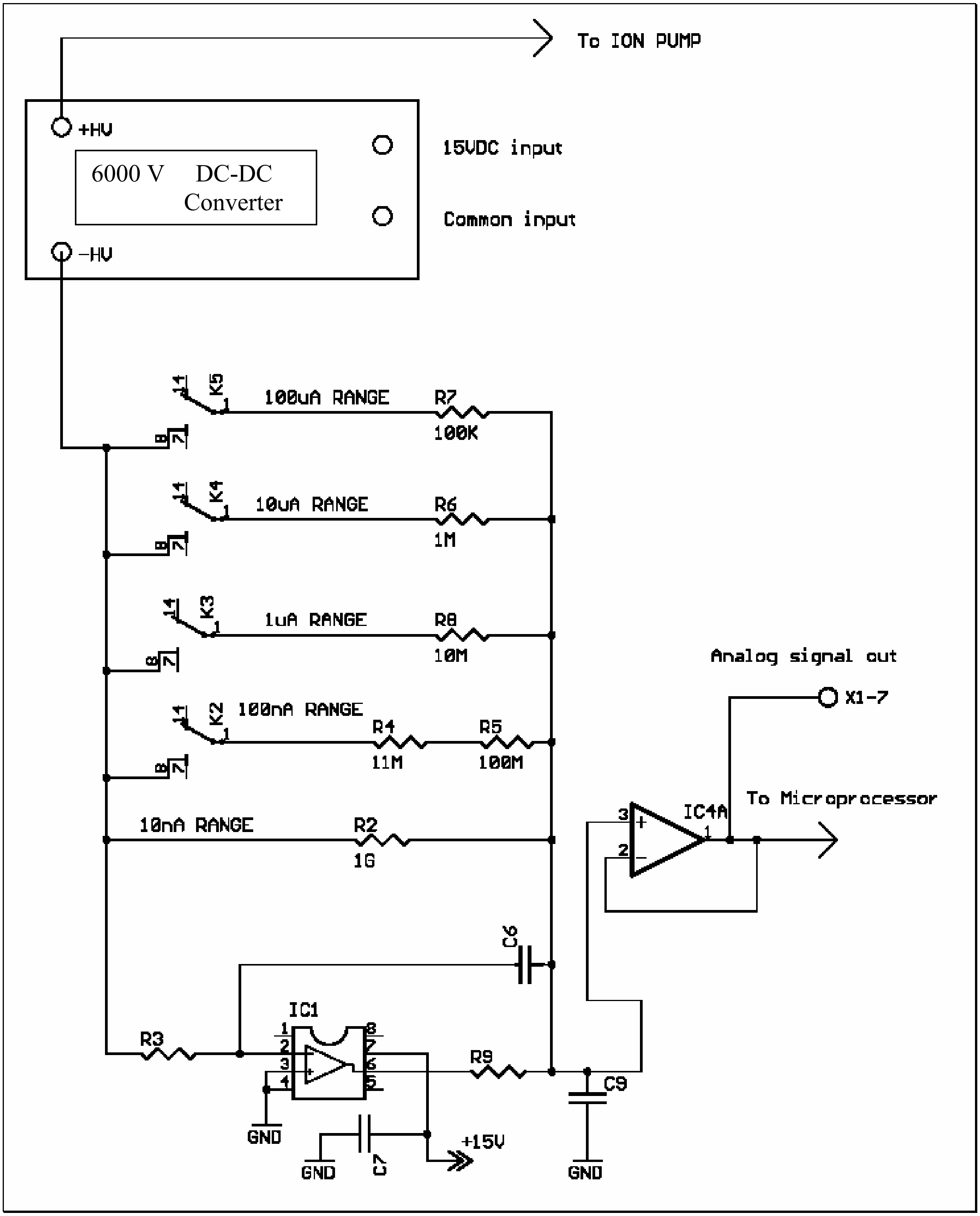

Figure 2. More detailed description of circuit.

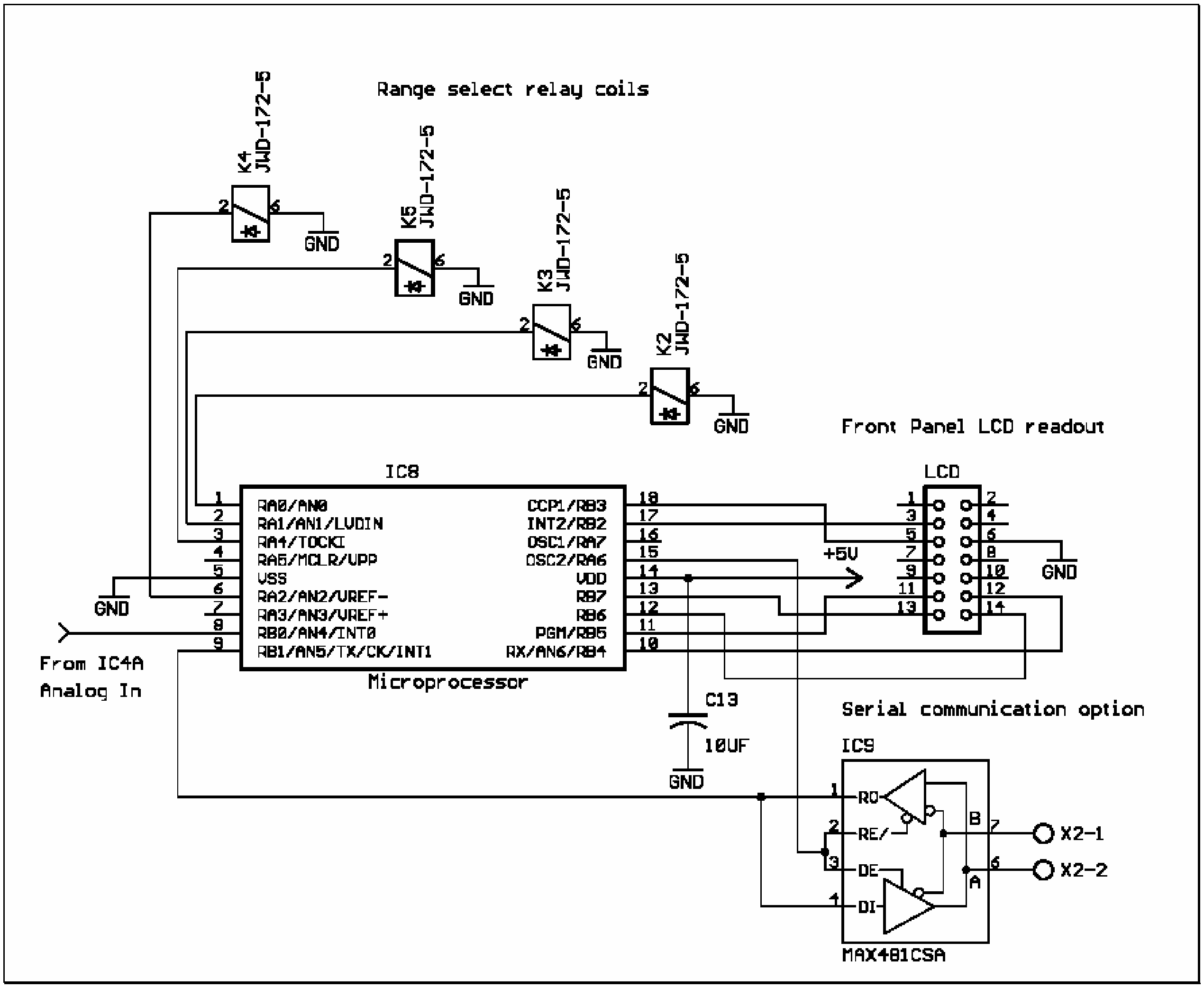

Figure 3. Microprocessor section.

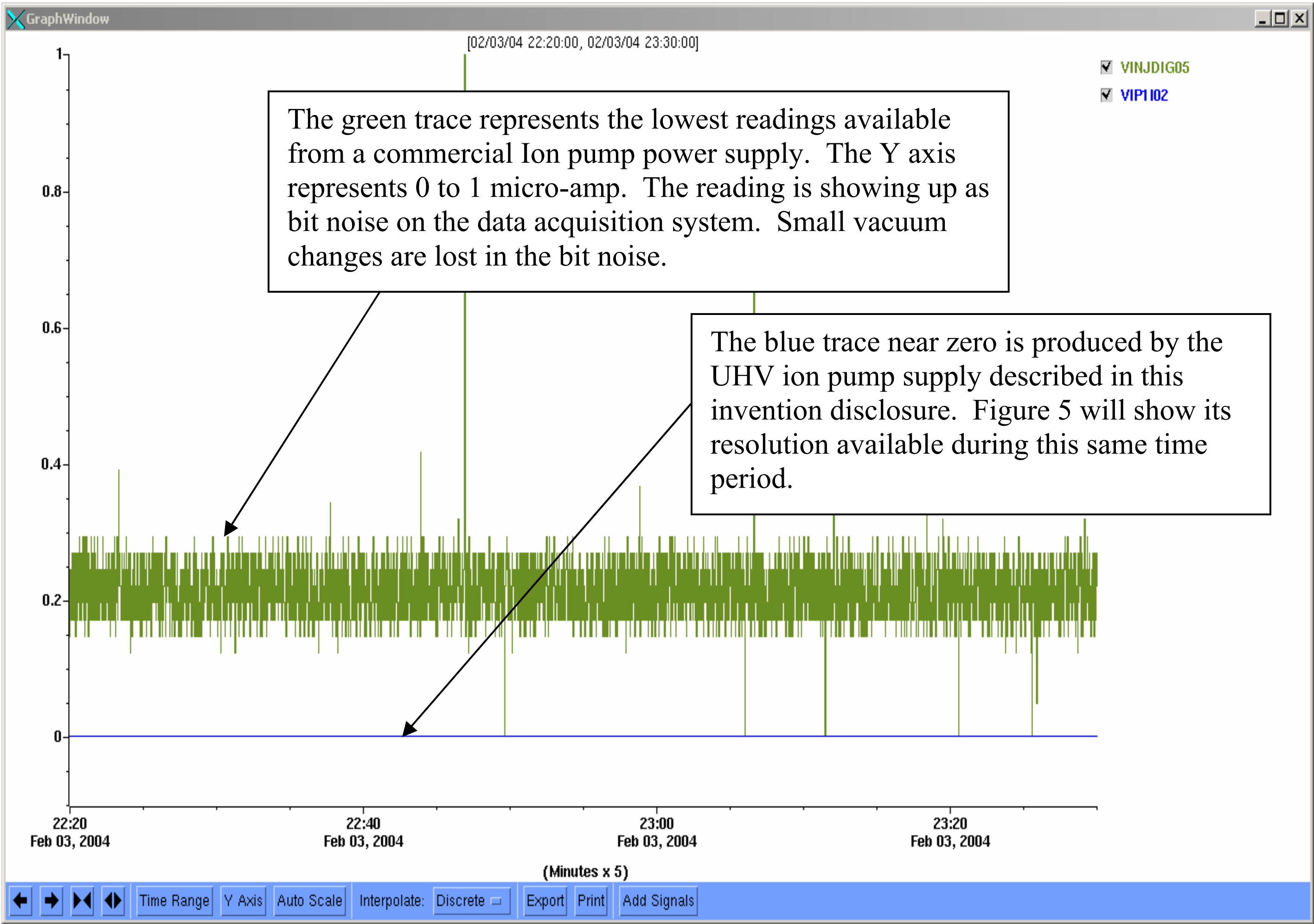
GraphWindow
[02/03/04 22:20:00, 02/03/04 23:30:00]
VINJDIG05
VIP1I02
The green trace represents the lowest readings available from a commercial Ion pump power supply. The Y axis represents 0 to 1 micro-amp. The reading is showing up as bit noise on the data acquisition system. Small vacuum changes are lost in the bit noise.
The blue trace near zero is produced by the UHV ion pump supply described in this invention disclosure. Figure 5 will show its resolution available during this same time period.
1
0.8
0.6
0.4
0.2
0
22:20 Feb 03, 2004
22:40 Feb 03, 2004
23:00 Feb 03, 2004
23:20 Feb 03, 2004
(Minutes x 5)
Time Range
Y Axis
Auto Scale
Interpolate:
Discrete
Export
Print
Add Signals

FIGURE 4.

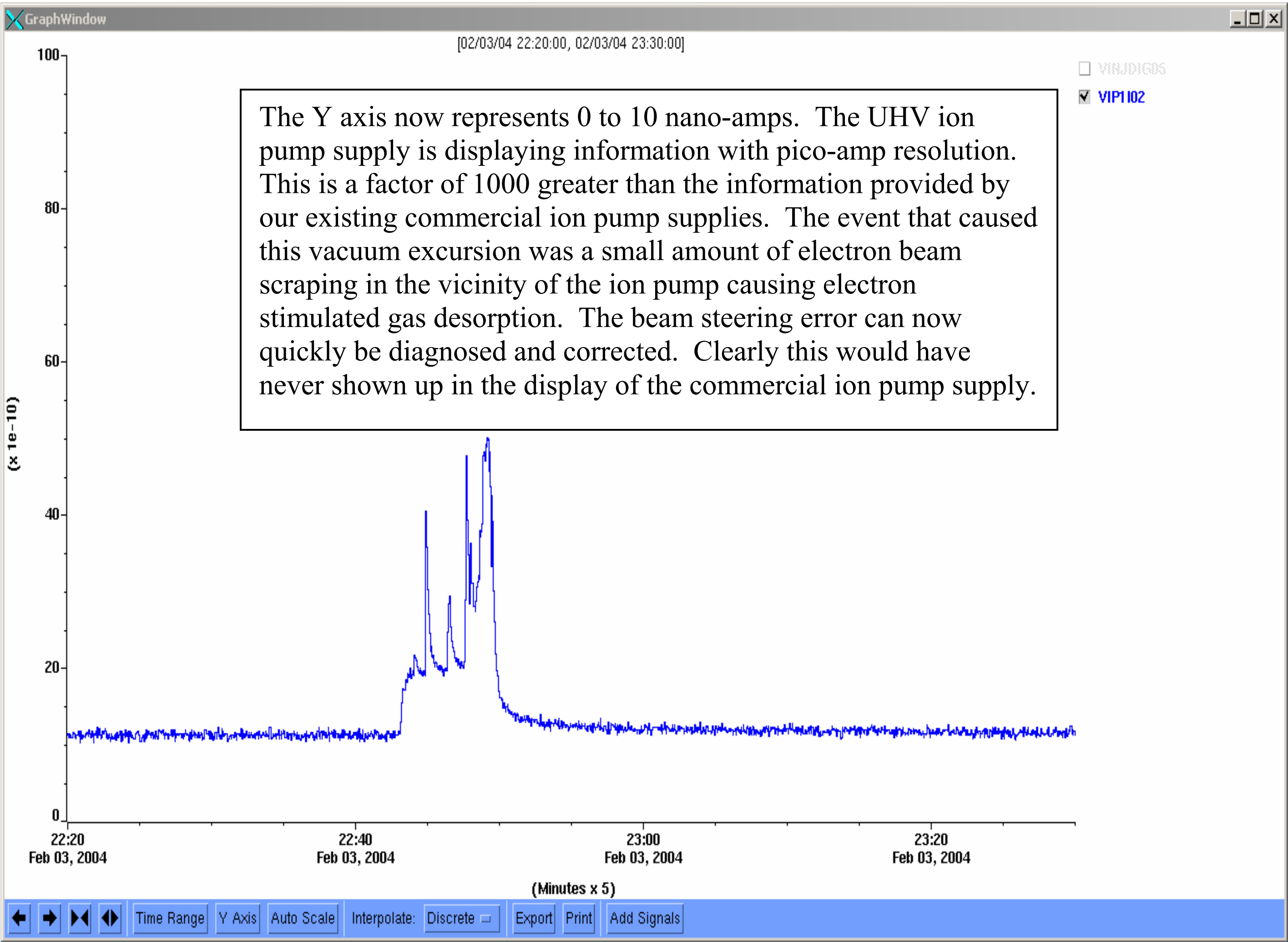
GraphWindow
[02/03/04 22:20:00, 02/03/04 23:30:00]
The Y axis now represents 0 to 10 nano-amps. The UHV ion pump supply is displaying information with pico-amp resolution. This is a factor of 1000 greater than the information provided by our existing commercial ion pump supplies. The event that caused this vacuum excursion was a small amount of electron beam scraping in the vicinity of the ion pump causing electron stimulated gas desorption. The beam steering error can now quickly be diagnosed and corrected. Clearly this would have never shown up in the display of the commercial ion pump supply.
VIP1I02
(x 1e-10)
100
80
60
40
20
0
22:20 Feb 03, 2004
22:40 Feb 03, 2004
23:00 Feb 03, 2004
23:20 Feb 03, 2004
(Minutes x 5)
Time Range
Y Axis
Auto Scale
Interpolate:
Discrete
Export
Print
Add Signals

FIGURE 5

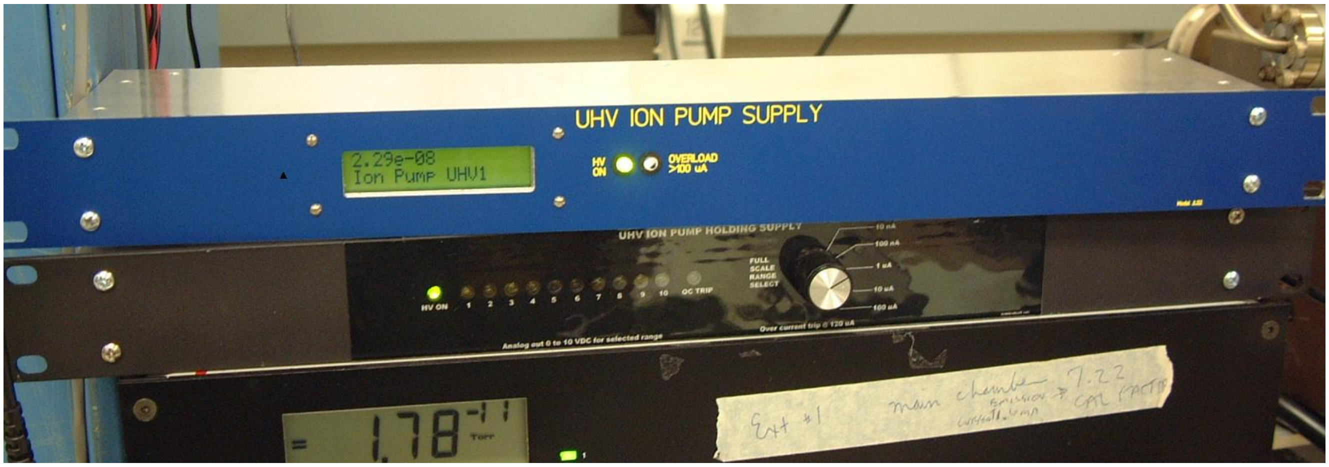

Figure 6. Third (latest) design on top. Second design with manual range select immediately below it.

Figure 7. Nine supplies installed in 19" rack. All communicating over a single RS-485 network with the lab data acquisition system.

Features of the invention that are believed to be novel:

- Resolution of the current monitoring of vacuum ion pumps is substantially higher than all commercially available ion pump power supplies. See figures 4&5.
- Time stamp option to allow built in data-logging and trend reporting.
- Memory card option
- 12vdc car battery backup could run a pump for weeks.
- Low component cost compared to commercially available systems.
- Safety factor consideration. Non-lethal status is achievable.
- Derivative alarm option
- Web interface option
- Self diagnostics option

Please use black ink:

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Witnessed and understood by: Date:	Witnessed and understood by: Date: