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innovative measurement systems

MVP

fast UHV protection system

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Introduction

In many large ultra high vacuum systems, for example accelerators, accumulator rings or beam tubes, thin windows to the high pressure side are needed to minimise interaction with the extracted particles. So the risk of window rupture emerges, leading to severe damage of vacuum equipment like sensors and pumps.
To limit those risks a very fast shutter* which seals the beam tube, driven by fast vacuum sensors and control electronics was developed to close a beamline with a diameter of 150mm within 10ms. This corresponds to a shockwave propagation in vacuum of about 6m. In addition a fast vacuum breakdown detection system had to be developed, with a time from shockwave hitting the detector to valve trigger of less than 1ms.
It can also be used as an upgrade for systems with standard security valves (closing times 50 to 100ms) to improve the overall reaction time of the system.

The newly developed vacuum protection system **"mesytec MVP"** permanently monitors vacuum conditions and reacts within 100us when the pressure raises above 10^{-2} mbar.
The mesytec MVP system consists of the following components:

- The fast RIVA sparc detector for vacuum monitoring. It is made of ceramics and stainless steel and is bakable for UHV use.
- The central NIM-module MVP-2 which monitors and supplies two RIVA sensors and triggers and supplies two security valves. For larger systems, several modules can be chained.
- The valve frontend electronics is situated near the pyro pills and is triggered by the central module. It starts the ignition of the explosive pills.

A schematic setup is shown below:

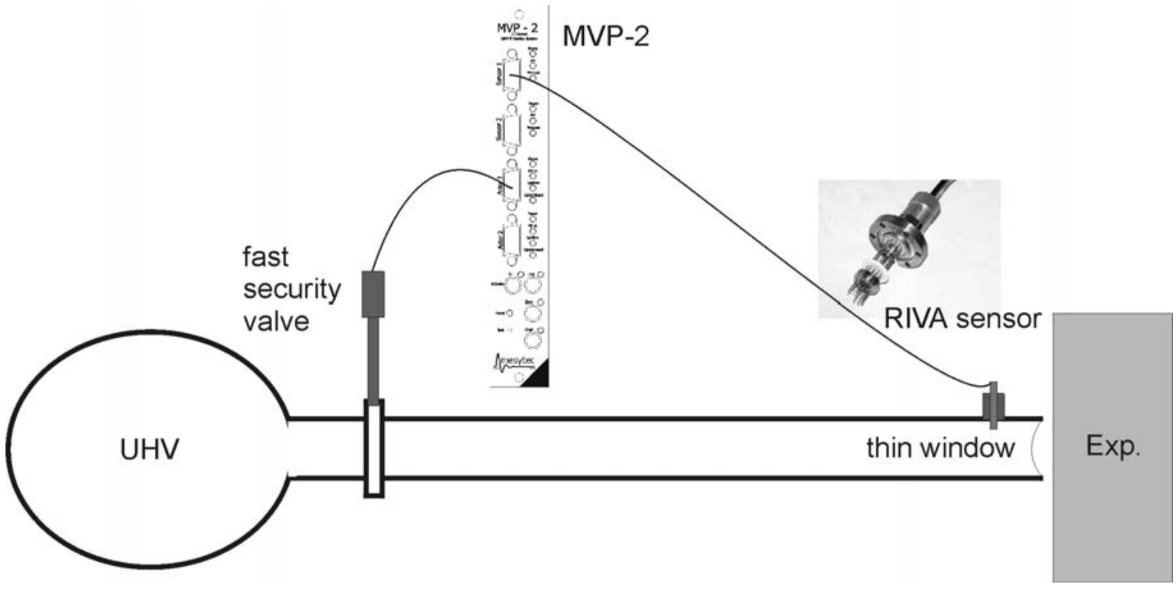

Fig. 1: The MVP components and their interaction

*(valve mechanics by Ingenieurbüro Schott in collaboration with Forschungszentrum Jülich)

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Central Controling Module MVP-2

mesytec MVP is a fast protection system for large UHV vacuum systems. It consists of the fast RIVA sparc detector which is bakable for UHV-use, a central NIM-module and a valve frontend electronics. The breakdown of a vacuum window can be detected within 100µs. It is especially developed for a fast valve (closing time: some ms) driven by up to two pyro pills.

MVP-2: Central module, 1/12 wide NIM module

- **sensor1 and 2 input**: (SubD9) input of 2 RIVA sensors
  control LEDs:
  sensor power supply ok
  high voltage applied to sensor
  vacuum detected, sensor ready

- **actor 1 and 2 outputs:** (SubD9) supplies two Valves
  control LEDs:
  power supply ok
  pill1 and pill2 ok
  ignition command was sent
  valve opened, closed, undefined

- **activate input**: TTL, system activation from remote controller. For Test purpose: can be always activated by internal jumper.

- **activate output**: TTL, system sets this line high when at least one detector is ok and detects vacuum. Each detector which is not in vacuum or signals an error is inactivated until all of its signals are ok.

- **/error output**: TTL, if any problem occurs (detector not in vacuum at activation, pill or power not ok) the /error output gets low. The activation works anyway.

- **chain modules input/output**: to include more than 2 sensors or more than 2 Valves in the system, up to 5 modules can be connected. An ignition state is transmitted to all connected modules which are activated. TTL output, if used, terminate line at one end with 50Ohm.

- Future option: On the rear side of the module: **RS232-readout and remote control.**

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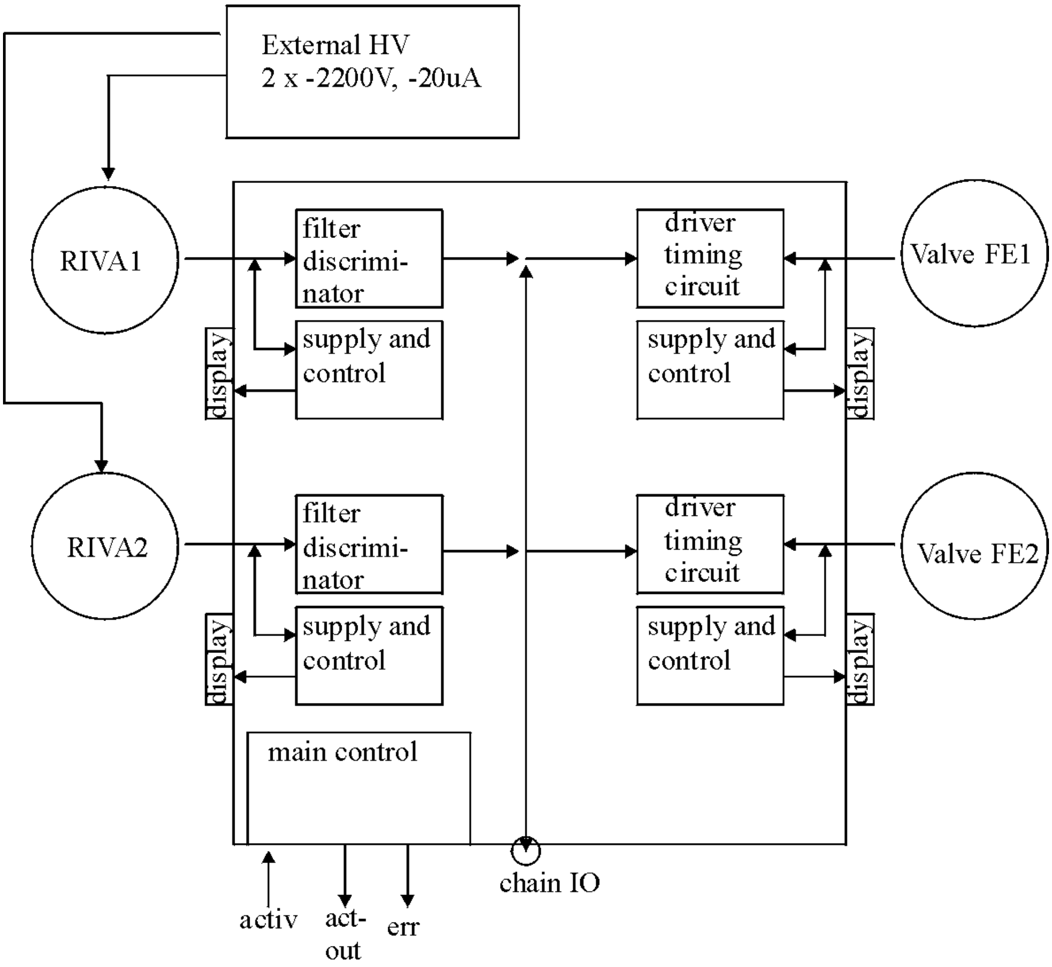
Schematic



RIVA Detector Frontend Electronics

- The detector includes a frontend electronics which mainly amplifies the detector signals.
- The power supply and the signals are handled by the central module "MVP-2" through a SubD9 connector.
- Additionally the detector high voltage of 2kV- 0.5µA must be supplied by a standard HV-module through an SHV-connector.

Valve Frontend Electronics

The Valve includes a frontend electronics which does the following things:

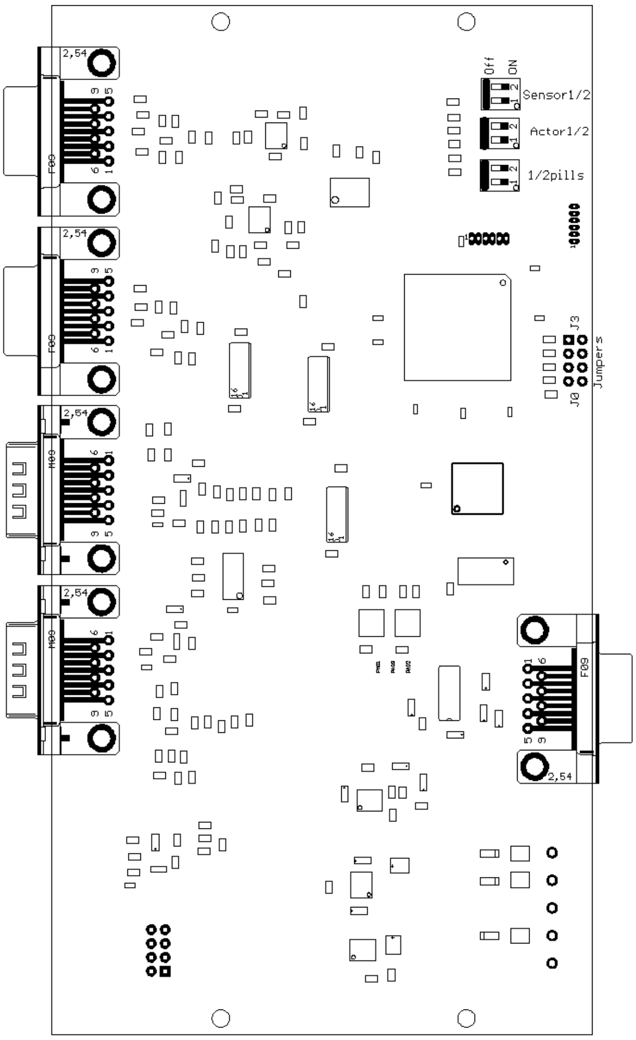
- fast discharge of capacitors to one or two ignition pills
- handles valve open and close signals
- controls pill resistance continuously
- outputs open/close signals and ignition pulse for test ignition measurements
- the power supply and signals are supplied by the "MVP-2" by a SubD9 connector.

Design Philosophy

The system is designed the way that no external handling like disconnecting or connecting of plugs, power failure, failure of any component will cause an activation of the Valves.
On the other hand, any real detection of vacuum failure at any detector will cause a valve activation for all valves, even if valve errors are detected.
If an error occurs, the error output goes high.

All the electronics and a detector will be supplied for system test end of 2003.
The high voltage supply is not included in the mesytec MVP system.

Internal jumper settings



<- Dipswitches: set sensor 1, 2 or both active
<- Dipswitches: set actor 1,2 or both active
<- Dipswitches: set resistor control for pill 2 in actors if two pills per actor are used

<- jumpers 3..0 (top..bottom)
jumper 2,3: not used
jumper 1: if jumpered: ignition only at fastly rising pressure. Not jumpered: ignition also at slowly rising pressure.
jumper 0: if jumpered the activation is always on. No external activation signal needed

Power consumption MVP-2:

+24V 20mA
+6V 200mA
-6V 50mA

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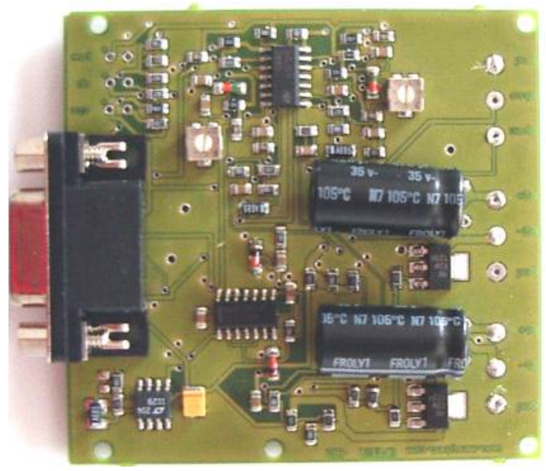
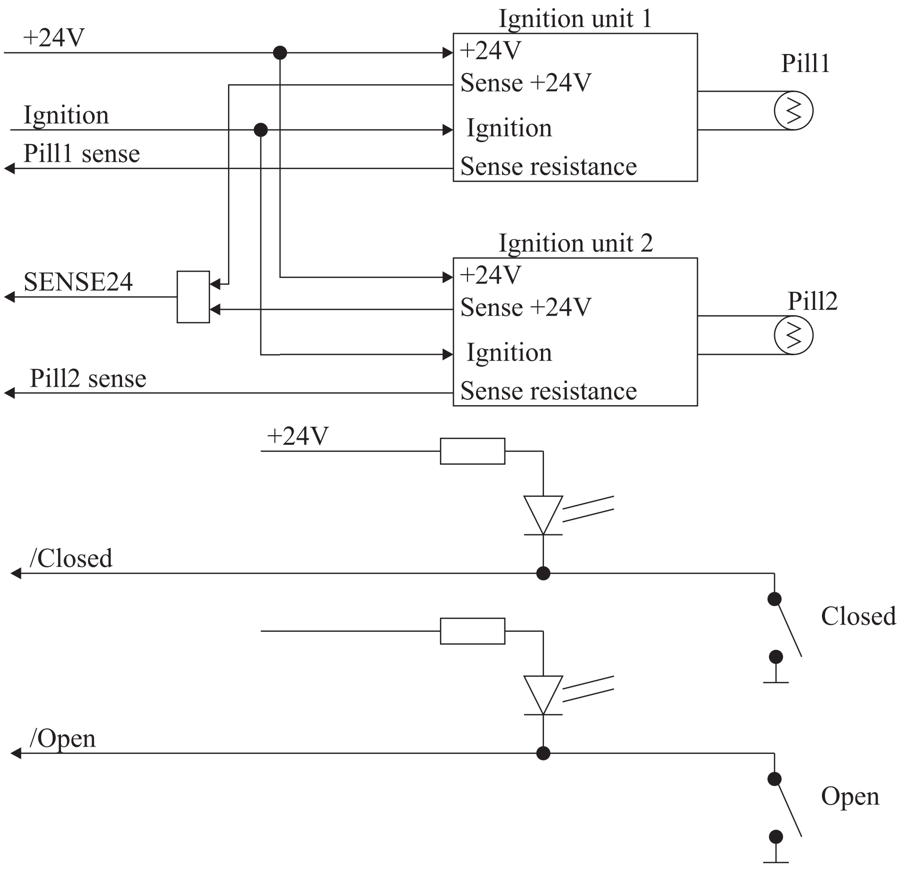
Pyro Valve Frontend

Features:



- Delivers ignition current simultaneously for two pyro pills with approx. 2Ω.
- 24V ignition voltage.
- 100mJ in 100us into 2 Ω.
- TTL ignition pulse (into 50 Ω)
- Continuous Survey of:
  - resistance of both pills
  - of ignition voltage
- Output of open/closed switches

Schematics:



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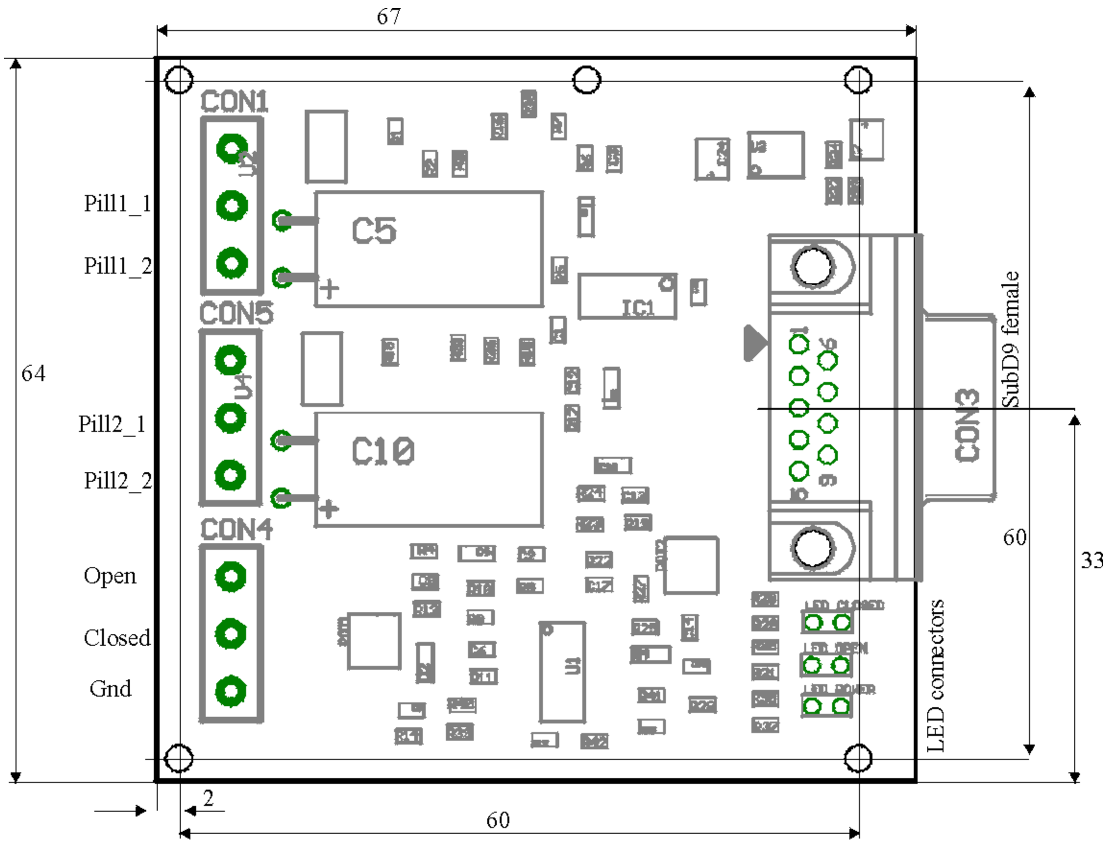
Outputs and dimensions



Ignition outputs, connect pills between PillX_1 and PillX_2. Must be ground free. Short circuit can destroy the driver.

Pill1_1: ignition output 1 for pill1
Pill1_2: ignition output 2 for pill1
Pill2_1: ignition output 1 for pill2
Pill2_2: ignition output 2 for pill2

Connect **valve switches** "closed" and "open" to the "Closed" and "Open" inputs. Connect ground to valve switch ground.

LEDs will show:
Power LED: +24V power applied
Closed LED: switch "Closed" closed to gnd
Open LED: switch "Open" closed to gnd

SubD9 connector:
1,2 : gnd
3 : sense 24V
4 : /Closed (internally: +2.2kOhm to +24V. Outputs 0V when switch is closed)
5 : Pill2 resistance: +5V -> short circuit, 6V -> Pill has 2Ohm, +20V ->Pill not connected
6 : Pill1 resistance: +5V -> short circuit, 6V -> Pill has 2Ohm, +20V ->Pill not connected
7 : Power input +24V, 50mA
8 : ignition input: min 3V into 50Ohm, Pulse length > 10us
9 : /Open (internally: +2.2kOhm to +24V. Outputs 0V when switch is closed)

RIVA sensor

The RIVA (Rapid Interruption of VAcuum) detector is responsible for a fast detection of UHV-breakdown. As shown in the tests below, RIVA may reach response times equal or below 100 μs at a pressure range from 10^{-2} to 10^{3} mbar. This leaves enough time for closing the fast security valve.

Fig. 2: The RIVA sensor with plug and analog electronics

Function principle

The main function principle of the RIVA sensor is the detection of gap discharge depending on the gas pressure it is exposed to.
Gap discharge as described by Paschen in 1889 occurs at a gas filled gap in an electric field. Molecules can become ionised in high electrical fields around an anode. The electron is absorbed at the anode and the ion is accelerated towards the cathode. On the way to the cathode it can – depending on gas pressure – ionise other molecules, finally leading to an avalanche of ions reaching the cathode. This can be measured as a charge pulse, or even a permanent current if conditions are suitable. This is called the "breakdown" of the gap. The breakdown characteristics are a nonlinear function of the product of gas density and gap length as shown in Fig. 3.

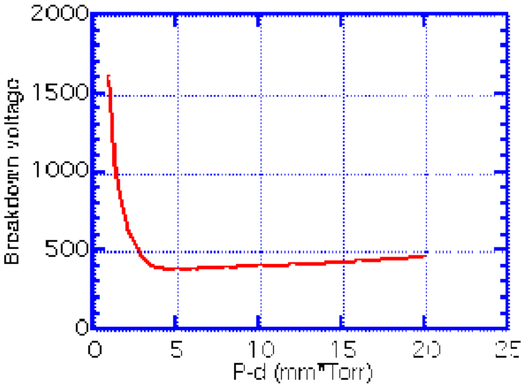


Fig. 3: Breakdown voltage against product of gas density and gap distance

Given a fixed gap distance, the breakdown voltage for gap discharge drops quickly to a minimum with rising gas densitiy, increasing slowly again for further rising pressure.
Below a certain pressure, there's no gap discharge. This characteristic behaviour can be used for detection of a vacuum breakdown by measuring the corresponding charge pulses at the cathode.
Creating the first ion is due to field ionisation. The high local fields needed for field ionisation can be achieved by chosing a proper design for the anode. Sharp needles generate high fields at their tips. Thus, designing the gap geometry like shown in Fig. 4 improves the performance of the detector.

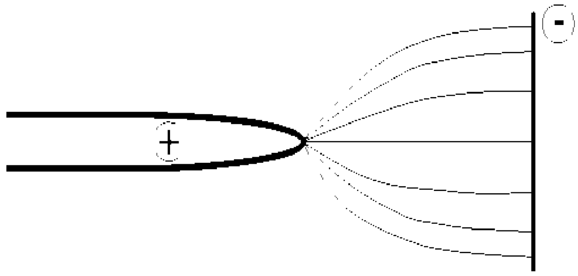


Fig. 4: Field lines in the vicinity of a needle anode opposite to a flat cathode.

Finally, grouping various needle anodes with different gap distances in opposition to a cylindric cathode gives optimal conditions for gap discharge reaching over a broad range of gas densitiy (pressure).

Mechanical design

The RIVA sensor has to be suitable for UHV-applications. It consists only of materials like stainless steel and ceramics, therefore it can be heated up to 250 °C.
A robust design based on a CF40 UHV high voltage feedthrough provides highest reliability at a minimum of maintenance.

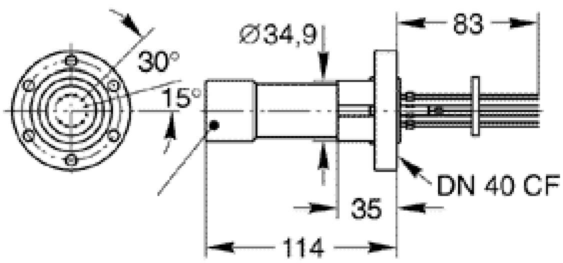


Fig. 5: Sketch of RIVAs mechanical design, together with the connector including analog electronics.

A stainless steel ring keeps the needle electrodes - pointing from various directions and with different gap lengths onto the cathode pin – very precisely at their position. The different gap distances enable a broader pressure range to be monitored, as mentioned above.
The tips of the needle anodes are optimized to a radius of only a few microns. Sharper tips would result in lower voltage needed but would also increase the risk of severe damage in single discharges.

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The detector bias voltage can be applied by a standard HV module connected by an SHV connector.

Fig. 6: Needle anodes placed in different distances to a cylindric kathode.

Test measurements of RIVA sensor

The time behaviour and the pressure dependence of the RIVA sensor was tested in a standard vacuum setup shown in Fig. 7.

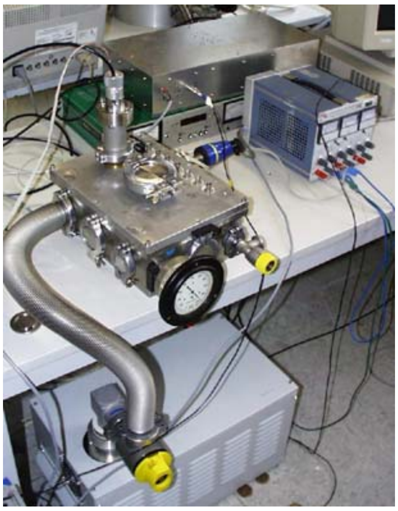

Fig. 7: Test setup with RIVA sensor mounted on the vacuum vessel in center, HV switch in background

The time response was measured in the inverse process – meaning that pressure was held constant while the high voltage was turned on and off with a fast HV switch. This allows for a very precisely determined response time in order of some μs as well as frequently repeated measurements for reliable statistics. As there is no fundamental difference in ion kinematics, this method is equal to the normal use of the detector.

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What should be mentioned is that the influence of the shockwave passing the sensor might show some significant effect. This can be avoided by mounting the sensor outside the direct path the shockwave propagates. Final conclusions will be drawn from a realistic test with a rapidly destroyed window.

Measurements gave the following results:

- Operation is recommended at U = 2200 V (0.5µA)
- There is no gap discharge below 10^{-2} mbar
- Signal risetimes for 10^{-2} mbar < p < 10 mbar are expected to be less than 20µs
- A maximum risetime of <= 1 ms occurs at 10 mbar < p < 200 mbar
- For 200 mbar < p < 1000 mbar, risetime is again expected to be < 100 µs.

This gives good evidence that the sensor will have a reaction time of less than 100 µs in case of a window breakdown in a UHV system.
Samples of the measured curves are shown in Fig. 8, 9

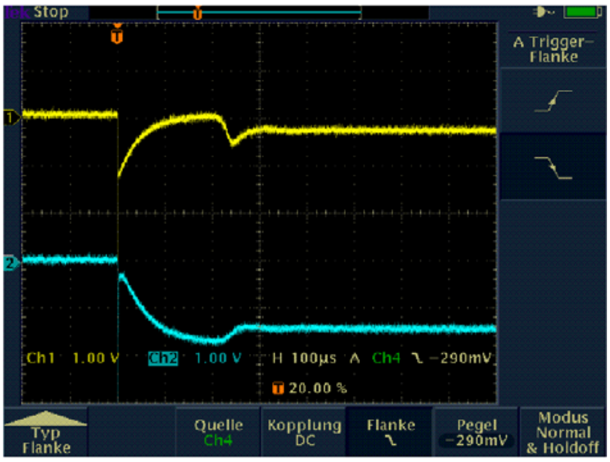

Fig. 8: Output of the RIVA sensor (upper) and voltage at the gap (lower), using 2200 V and a gas pressure of 1x10^{-2} mbar (minimum detectable pressure). Trigger time T indicates HV switched on.

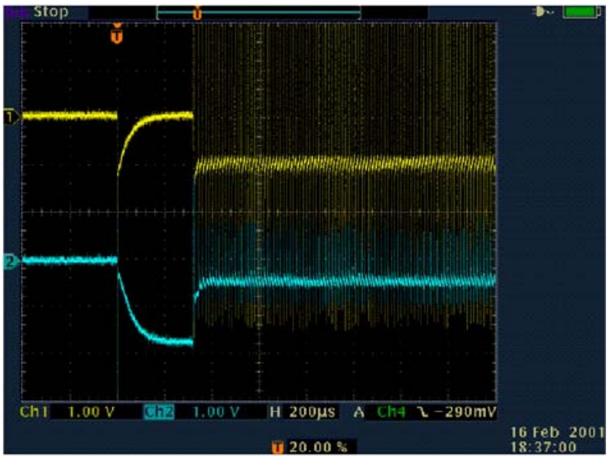

Fig. 9: Output of the RIVA sensor (upper) and voltage at the gap (lower), using 2200 V and a gas pressure of 100 mbar.

System test

For system test a fast change of vacuum had to be simulated. So a pyro pill was situated in vacuum 15 cm away from the sensor in a 90 degree geometry to avoid burning residuals of the pill hitting the detector. When igniting the pill the burning time is known to be about 500 to 700µs. In our vacuum setup the start pressure of 10^{-3} mb rised to 2mb after ignition. The ignition trigger for the vacuum break pill (first blue curve) and the response of the vacuum detection electronics (second green curve) was measured together with the sensor signals. The red curve shows the sensor current through the sparc gap. The lower pink curve shows the high voltage of 2200 volts at the sparc gap, which breaks down when current flows. The detection electronics monitors the current and sends the ignition signal when the current goes below a threshold for at least 40us. From experiment we could see a total reaction time of about 550µs. Most of this time is probably due to the pill heating and burnig time. From earlier experiments we estimate the detector reaction time to be below 100µs.
From a second experiment with 65cm distance between pill and sensor we could derive a shockwave velocity of 550m/s.
Experiments in high fields will be performed in 2003 at Forschungszentrum Jülich.

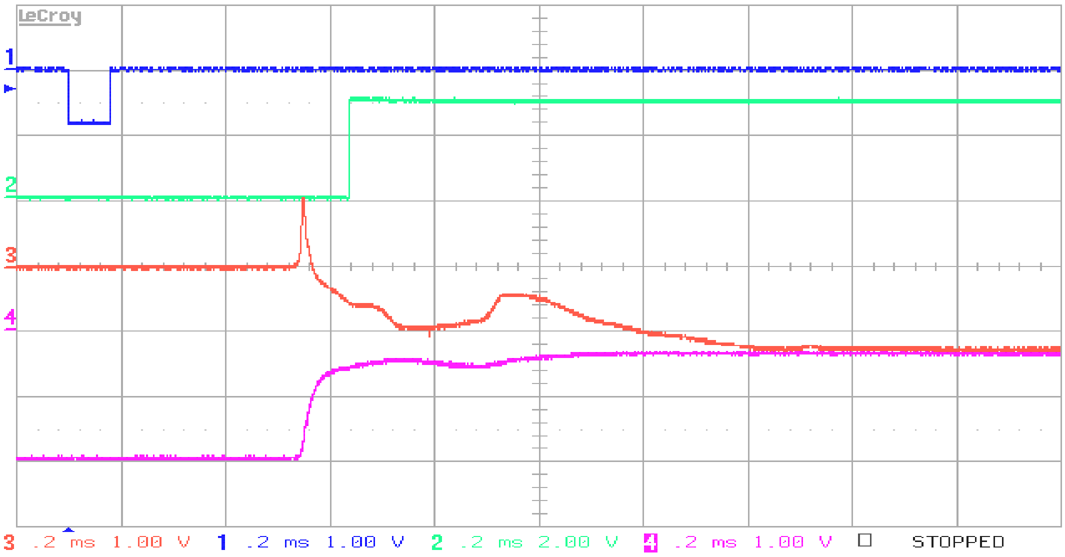

Fig. 10: Pill sensor distance 15cm: total time 550µs.

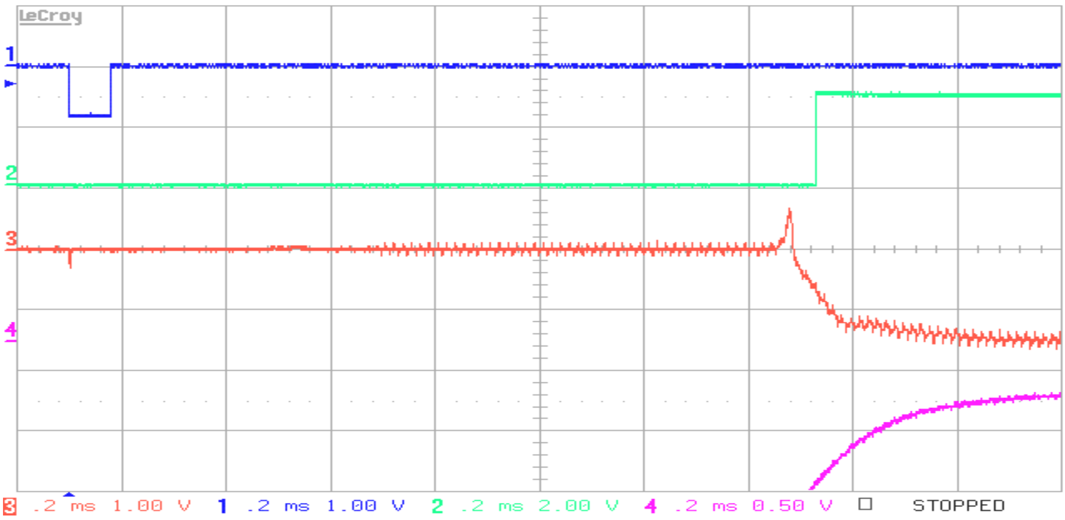

Fig. 11: Pill-sensor distance 65 cm : total time 1450µs.

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