High-Voltage Bipolar Power Supply / Amplifier with a High-Sensitive Current Sensor, 4 Channels, ±200 V

Version 1.00

User Manual

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Safety Information

- The device may be installed and used by authorized and instructed personnel only. Read this manual carefully before installing and using the device. Always follow the safety notes and warnings in this manual.
- The device is designed for indoor dry laboratory use only. Before powering the device on, the device temperature must accommodate to the ambient temperature to avoid moisture condensation. Take this into account when setting up the device after transporting it.
- Do not operate the device if it is damaged or not functioning properly. Never use damaged cables or accessories.
- Do not open the device case, install replacement parts, or perform modifications to the device. There are no user serviceable parts inside.
- To avoid damage, connect the line cord to a properly wired and grounded receptacle only. Be sure that the mains voltage and the fuse rating match the device specification. Never operate the device during electrical storms.
- Never use corrosive or abrasive cleaning agents or polishes, avoid the usage of organic solvents. If necessary, clean the device with a soft moist cloth. Make sure that the device is completely dry and free from contaminants before powering it on.

! **Warning:** The device produces lethal voltages. Never touch the output terminals even if the device is powered off. The device is equipped with several protection features that eliminate the risk of contact with a high voltage. This protection, however, may fail and unexpected high voltages may be present at the terminals.

! **Warning:** The amplifier is an electronic device that is sensitive to static electricity. While manipulating the amplifier, the ESD (*Electro-Static Discharge*) protection rules must be followed.

! Avoid touching the heatsink of the device if the device is running or has just been turned off. The heatsink temperature may reach up to 50°C, you may suffer burns.

! **Warning:** The device weighs about 7.5 kg. Use an appropriate carrier when transporting and provide a stable support for its operation.

Technical Data

Characteristics

- four-channel high-voltage power supply unit / amplifier for heavy capacitive loads
- DC accuracy, low temperature coefficient of the output voltage
- digital control and monitoring of the output voltages
- monitoring of amplifier supply voltage and heatsink temperature
- high-sensitivity current sensor with large dynamical range
- supply voltage supervising
- interlock loop
- microcontroller-based controller with USB and LAN data interface
- user-friendly graphical interface
- non-volatile memory (FRAM) to permanently store device setting
- 19" case

Output Amplifiers

- four channels
- output voltage: ±200 V
- output current: >20 mA, 23 mA typ.
- signal bandwidth (–3dB): DC..5 kHz typ.
- power bandwidth:
  limited by the output current, >1 kHz w/o any load
- slew rate: >8 V/µs w/o load
- output noise:
  2.5 $mV_{p\text{–}p}$ typ. (DC to 500 kHz)
  200 $\mu V_{p\text{–}p}$ typ. (DC to 10 Hz)
- output accuracy: < 0.2% (0.1% typ.)
- temperature coefficient of the output voltage:
  < 50 ppm/K (25 ppm/K typ.)

Current Sensor

- one channel
- three measurement ranges: 10 nA, 1 µA, 100 µA
- input capacitance: 1 nF
- input offset voltage: 100 µV typ.

- resolution: 16-bit
- sampling rate: 2S/s
- analog signal bandwidth (–3dB): DC..10 Hz typ.
- accuracy: < 0.2% (0.1% typ.)
- temperature coefficient of the measurement circuit: < 100 ppm/K
- measurement noise:
  30 fA_{RMS}, 100 fA_{pp} (range 10 nA, 0 nA input),
  400 fA_{RMS}, 800 fA_{pp} (range 10 nA, 5 nA input),
  4 pA_{RMS}, 8 pA_{pp} (range 1 µA, 0 nA input),
  17 pA_{RMS}, 30 pA_{pp} (range 1 µA, 500 nA input),
  500 pA_{RMS}, 1.5 nA_{pp} (range 100 µA)

Security

- interlock loop: BNC socket, short circuit enables the amplifier
- overcurrent protection: output current limiter
- overtemperature protection:
  temperature sensor at the heatsink, shutdown at 50°C

Monitoring

- output monitoring:
  four 16-bit analog-to-digital converters
  sampling rate: 2S/s
  accuracy: < 0.2% (0.1% typ.)
  overall precision: < 100 mV
  temperature coefficient of the monitoring:
  < 50 ppm/K (25 ppm/K typ.)
- supply voltages
- temperature at the heatsink and the CPU
- interlock loop

Human Interface

- monochrome LCD display 128x64 pixel
  pixel size: 0.5 mm
  pixel color: yellow, background: blue
  background illumination: white LED
- keypad: 5 keys: 4x direction + 1x "enter"

- rotary encoders:
  24 positions per revolution, integrated press button
  one encoder located beneath the LCD for general control,
  4 encoders for direct control of the output voltages
- optional external shutdown button via the interlock loop

Power Supply

- rated voltage: 115/230 V ±10%, 50/60 Hz
- power consumption:
  standby (outputs without load): 15 VA
  maximum (outputs fully loaded): 40 VA
- main fuse: T 2.5 A (115 V), T 1.25 A (230 V),
  size ø5x20 mm, slow acting
- mains connection:
  IEC inlet with EMC filter and integrated fuse holder

Connectors

- data link:
  USB receptacle series B, location: front panel
  LAN receptacle RJ–45, location: rear panel
- output: Amphenol MS3102R14S–6S
  high-voltage panel receptacle with 6 female sockets
  location: rear panel
- current sensor: isolated 50 Ω BNC socket, location: front panel
- interlock loop: 50 Ω BNC socket, location: rear panel
- mains input: IEC inlet, location: rear panel

General

- 3 U 19" plug-in box:
  height: 130.5 mm, width: 428 mm, depth: 280 mm,
  total height of the front panel: 132.6 mm,
  total width of the front panel: 482.6 mm,
  plug-in depth incl. heatsink: 322 mm,
  total depth with heatsink and handles: 365 mm,
  cover and bottom panels, side walls, rear panel: passivated,
  front panel: clear anodized

- heatsink:
  black anodized extruded aluminum profile at the rear panel
  height: 75 mm, width: 300 mm, depth: 40 mm
- operating temperature range: +10..+40°C
- operating humidity: 20% to 80% non-condensing
- weight: 7.5 kg
- cleaning: use moist cloth only, avoid use of organic solvents

Shipment Contents

- high-voltage bipolar power supply HV-AMP200-4DS
- line cord (universal IEC mains lead, length 1.8 m)
- 19"-rack mounting hardware
  (set of 4 screws, caged nuts, and washers)
- control and diagnostic software (available online)
- user manuals (available online)

upon request available:

- customer-specific output cable
- BNC cable for the interlock connection
- special BNC cable for the current sensor
- USB cable
- LAN cable

Description

The high-voltage power supply is a combination of four high-voltage amplifiers and four digital-to-analog converters driven by a controller unit. The device is equipped with several analog-to-digital converters for monitoring the output voltages, the power supplies, and the operation temperature. Further, a high-sensitive current sensor with a large dynamical range is available for monitoring external currents. The device is fit into a metallic 19" plug-in box, the front panel is shown in Figure 2.

The controller unit of the device is described in an individual manual. It controls and monitors the amplifiers and their power supplies. The function is briefly described in this document, for more details please consult its manual.

Device Function

The output voltages are produced by high-voltage amplifiers capable to drive heavy capacitive loads. The maximum output voltage of each output channel is ±200 V, each channel can supply a current of more than 20 mA. The output ground is common for all four channels but is galvanically isolated from the device housing, i.e. from the PE wire. Thus, it can be externally connected to a vacuum chamber or any other reference potential without any risk of ground loop.

Unloaded amplifiers have a power bandwidth of several kHz. Typically, the full voltage transition from –200 V to +200 V or vice versa can be performed within less than 100 µs when considering the 10-to-90% transition. However, the settling time may be as long as several milliseconds, dependent on the required precision. In the practice, the settling time is determined by the amplifier's slew rate that is a result of the limited output current. The output current has to recharge the capacitance at the output, thus, the slew rate is given by the following expression:

$$\mathrm{SR} = \frac{\mathrm{d}U}{\mathrm{d}t} = \frac{I_\mathrm{out}}{C_\mathrm{Load}}.$$

I_out is the amplifier's output current (for the typical value, see the section "Technical Data" and the test protocol of the particular device), C_Load is the capacitance attached to the amplifier output. Usually, the capacitance is given by the bypass capacitors connected to the outputs. In some cases, the bypass capacitors may be installed in the device to simplify the experimental setup, consult the test protocol of the device for details. As an example, with a capacitance of 1 µF and a typical output current of 20 mA, the slew rate is reduced to about 20 mA / 1 µF = 20 V/ms. Thus, the full voltage transition from –200 V to +200 V will require about 20 ms. Note that the settling time required to reach a certain precision at the output is much longer than the time calculated from the voltage difference and the slew rate. In time critical application, you should experimentally check the voltage transitions and obtain the settling time necessary for the precision required by your experiment.

The integrated current sensor can monitor external currents of either polarity. The current sensor has a high sensitivity and a large dynamical range. It can measure currents ranging from less that 1 pA to about 100 µA, thus extending over at least 8 orders of magnitude. This region is subdivided in three measurement ranges (10 nA, 1 µA, and 100 µA), the controller unit selects the suitable range automatically.

The resolution of the most sensitive range is given by the sensor noise of about 30 fA_{RMS}. Note that the measurement noise increases with the input current, this given by several factors. One of them is the shot noise that is a result of the charge quantization, another source is the voltage noise caused by the voltage across the internal measurement resistor that is proportional to the input current. Since the current noise increases approximately with the square root of the input current, it plays the most important role at low input currents. At larger input currents, especially when the measurement range of 100 µA is used, the current noise is not resolvable by the used circuit.

The input signal of the current sensor is attached to the output ground, i.e. usually to the ground of the vacuum setup (see above). The real potential of the input wire is given by the input offset voltage of about 100 µV. The input offset voltage is temperature dependent and may rise to much larger values if the most sensitive range is selected and the internal device temperature exceeds 60°C.

The input sensor capacitance of 1 nF acts as a filter rejecting high-frequency noise that may be picked up by the input wire and/or the attached collector electrode. In most applications, no special screening of the collector electrode is necessary even if they are located in the proximity of other electrodes attached to signals with high amplitudes like multipoles driven by radio-frequency generators.

! **Warning:** Do not apply any external voltage to the input of the current sensor. Although the input is protected against overvoltage, any negative or a positive voltage higher than 0.5 V may lead to a permanent destruction of the device.

The device contains several precise power supply units. The power supply units and the output amplifiers itself are equipped by current limiters to avoid catastrophic damage in case of any failure. The device with its heatsink is designed to withstand a permanent short circuit at all outputs simultaneously.

The user interface is provided via embedded operating system (firmware) running on a microcontroller residing in the amplifier controller unit (for details, see the separate manual of the controller unit). It controls the graphic liquid crystal display (LCD), reads the keypad and the rotary encoders, and serves the USB and/or LAN interfaces. Using the interfaces, the system can be remotely controlled by several online-available utilities or by user software.

The microcontroller monitors the temperature of the heatsink at the rear panel. If the sensor fails or the measured temperature exceeds a certain value, the output voltages are reset to zero to prevent additional heating.

The microcontroller further monitors the interlock loop. If the circuit connected to the interlock connector is not shorted, the output voltages are reset to zero. This measure ensures that in critical situations, no lethal voltage can be present at the outputs. It also prevents discharges if the device is connected to a vacuum setup and the interlock loop is opened at high vacuum pressure.

The amplifiers and the power supplies are linearly operating circuits. The power supplies are equipped with a toroidal transformer; it produces only a weak stray magnetic field. The device does not use any power switching circuits such as switching-mode power supplies or switching amplifiers. Further, the digital circuits work on moderate frequencies and are separated from sensitive analog circuits. Such design leads to a low emission level of electromagnetic radiation and of conducted digital noise in the output signals. As a result, the device should not interfere with even high-sensitive instruments nearby.

The digital-to-analog converters used to control the output voltages are precise converters with a resolution of 16 bits and a low temperature coefficient. The amplifiers use precise feedback resistors with a tolerance of 0.1 % (1000 ppm = 1 ppt) and a low temperature coefficients (< 25 ppm/K). The amplifiers use the auto-zeroing technique to optimize their DC precision. This leads to a substantial reduction of the offset and drift voltages. The AC performance has been optimized to tolerate high capacitive loads while providing a fast response given by the bandwidth of about 5 kHz. The ability to drive heavy capacitive loads enables that the output signals can be bypassed by large capacitors. This is a useful technique to reduce coupling of any high-frequency noise to an electrode from outer sources like a RF generator connected to nearby electrodes.

The monitoring circuits of the output voltages and the high-voltage supplies are based on precise analog-to-digital converters with a resolution of 16 bits. The overall precision calculated from the digital output control to the digital monitoring is better than 100 mV for all possible output voltages. The monitoring circuits of the low-voltage supplies use simple analog-to-digital converters with a resolution of 12 bits. Using the monitored values, the device supervises the line voltage and interrupts the function on voltage drops or on permanent undervoltage.

The USB interface can also be used to rewrite the actual firmware in the controller unit. A new firmware can be easily uploaded by the user by a dedicated PC software utility. The firmware might be an update with bug fixes or functionality enhancements. Upon request, new functions that adapt the device to a particular task can be implemented by the manufacturer.

Embedded safety precautions

The device is equipped with an interlock loop that resets the output voltages to zero if it is opened. The terminals of the interlock loop are located at a BNC socket at the rear panel. If the device drives electrodes in a vacuum chamber, the interlock terminals should be conducted to the control system of the vacuum setup. To prevent discharges, they should be short-connected if the vacuum pressure is sufficiently low. To implement a security push button, the interlock loop can be additionally interrupted by a switch with a breaking contact. If opened, the device will be prevented to produce nonzero voltages at the outputs.

The amplifiers and their power supplies are cooled by a heatsink located at the rear panel of the device. The heatsink is passively cooled, thus the device produces virtually no acoustic noise. The heatsink is large enough to prevent overheating even if all outputs are shorted. To prevent any catastrophic damage, the output voltages are set to zero if the heatsink temperature exceeds the preset level of 50°C (see section "Technical Data").

Beside the temperature, the device monitors all output and supply voltages. In case of any unusual behavior, you may check the measured parameters through the user interface to locate the failure. For more details, consult the manual of the amplifier controller.

Control and Indication Elements

All control elements are located at the front panel of the high-voltage power supply (see Fig. 2).

Using the rocker switch "Power", you can power the device on or off. When powered on, the power switch lights red and the LCD turns on.

For controlling the operation, the device is equipped with a graphic LCD, a set of keys, and several rotary encoders. Consult the section "Human Interface" in the manual of the amplifier controller to learn more about these control and indication elements.

Terminals

The output terminals are located at the connector "Output" at the rear panel. The connector is a robust Amphenol panel receptacle MS3102R14S–6S with six female sockets (for the pin layout, see Fig. 1 and Tab. 1). The connection should be realized by a special set of coaxial cables. Contact the manufacturer for available solutions.

Note that the output terminals are not galvanically connected to the device housing, i.e. to the PE wire. The output ground is defined by the shielding of the output cables and should be connected to the metallic parts of the vacuum chamber in that the attached electrode system is located or to another reference potential.

Fig. 1. The output connector.
The figure shows the look on the male pin contacts of the cable plug.

The connector of the interlock loop is a BNC socket at the rear panel. Although it is isolated from the device housing, there is no galvanic isolation present. The connector has to be shorted to enable the device. Generally, this requires a control by an isolated relay contact. If this is not available, the middle contact of the BNC socket can be shorted to the device housing, i.e. to the PE wire to close the interlock loop.

! **Warning:** Do not apply an external voltage to the interlock input. Although the input is protected against overvoltage, any negative or a positive voltage higher than 5 V may lead to a permanent destruction of the device.

Tab. 1. Pin layout of the output connector.

Pin	Signal	Description
A	Out3	output channel 3
B	Out2	output channel 2
C	Out1	output channel 1
D	Gnd	ground
E	Gnd	ground
F	Out4	output channel 4

For the mains connection, an IEC inlet with an EMC filter and an integrated fuse holder is located at the rear panel. Use a standard line cord with the universal IEC mains lead to connect the device to the mains. To replace the fuses, remove the line cord and open the fuse holder. Insert the new fuses, close the fuse holder, and connect the line cord back to the IEC inlet.

! **Warning:** Note that a fuse never melts without a reason. It may be an extreme voltage spike in the line voltage but also a serious failure of the device. A fuse with a lower rating than specified also often do not survive the startup of the device. Further, the fuses can blow if the voltage selector is wrongly set. In most cases, this leads to a destruction of the device if a substantially higher line voltage was applied than selected. If you replace the fuses and they melt again contact the manufacturer immediately and do not try to replace the fuses again since it strongly indicates a device failure.

Practical usage

The typical output load of the device is an electrode system acting as an electron or ion lens. The output voltages are adjustable in the range of ±200 V. The output current can be as high as 20 mA, thus large enough to drive even electrodes, which collect high electron or ion currents.

The output channels can be grouped into two pairs to provide a differential control. In this case, the device allows to control the mean voltage of the particular output pair and the voltage difference between the outputs. This is useful, for instance, if the attached electrodes form a deflection electrode system. In this case, the mean voltage determines the focusing properties and the differential voltage controls the deflection.

The integrated current sensor is aimed to monitor ion or electron current on a dedicated electrode. It can be a mesh placed in the particle beam or a Faraday cup located in place of a target. The current sensor can measure currents ranging from less that 1 pA to about 100 µA.

The input signal of the current sensor is attached to the device ground, i.e. usually to the ground of the vacuum setup. Note that the real potential of the collector electrode attached to the sensor input may be much higher due to contact potentials. Select proper materials of the electrode and of the wires if these effects play an important role in your application.

Take a special care in selecting a proper connection cable and isolating the input wire and the collector electrode. You should use a high-quality coaxial or triaxial cable to connect the current sensor, the dielectric material should have good isolation properties. The best choice are Teflon™ cables like RG 188. To isolate the input wire and the collector electrode in the vacuum chamber, use also high-quality materials like Teflon™ or ceramics. Be sure that there is no voltage applied on the isolators around the collector electrode. Even high-quality isolators may produce leakage currents in the order of several pA when a voltage is applied on them. Note that a resistance of 1 TΩ (10^{12} Ω) that may be easily produced by a slightly polluted surface generates a leakage current of 1 pA already if a voltage of just 1 V is applied. To eliminate leakage currents, the used isolators should be attached to the collector electrode on one side and to a grounded metallic surface on the other side only.

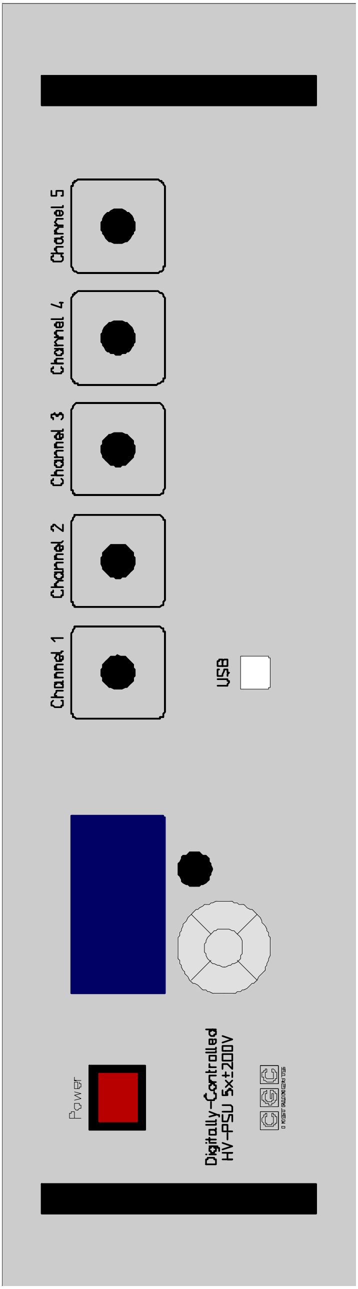

Fig. 2. The front panel of the high-voltage power supply.

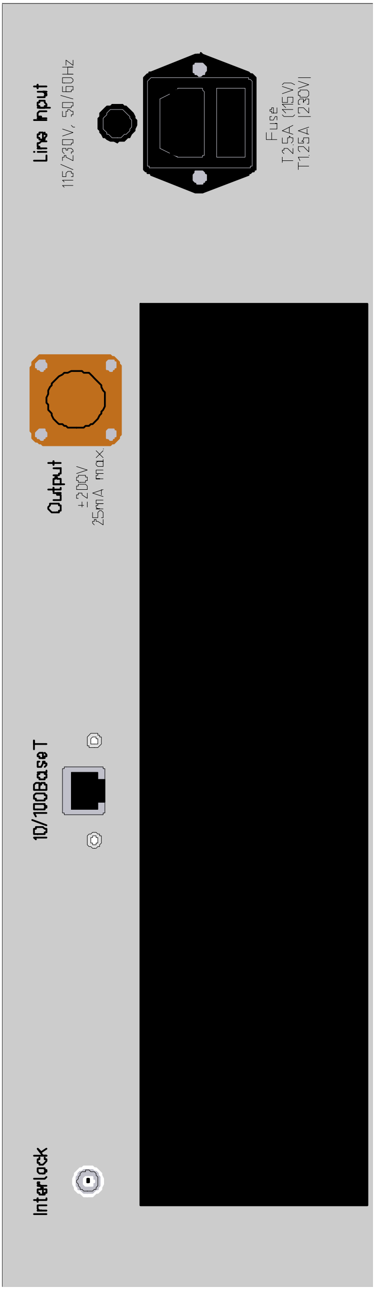

Fig. 3. The rear panel of the high-voltage power supply.

Installation

To install the high-voltage power supply, space for a 3 U plug-in unit (height of about 13 cm) in a 19" rack is required. The rack must offer a free insertion depth of at least 37 cm. Optionally, the device may be installed as a bench-top instrument. Then, it requires a space of at least 48 × 37 × 12 cm³ (W × D × H) on top of a stable table. The device weighs about 7.5 kg, the mounting in the rack or the table support must guarantee mechanical stability under this load. Note that vibrations or mechanical shocks may lead to microphonic effects, thus produce voltage spikes at the device outputs and disturb the function of the current sensor.

The installation area must be kept dry and the temperature and humidity within the range specified in the section "Technical Data". Note that, dependent on the load, the device produces heat during the operation. Avoid exposing the device to direct sun light since this may substantially elevate the device temperature. High device temperature may increase the noise and lower the precision of the output voltages or even lead to a thermal shut-down, if the heatsink approaches the shut-down temperature (see section "Technical Data"). Further, it may increase the noise of the current sensor and its offset voltage (see section "Device Function").

During the operation, only the front panel of the power supply must be accessible. Before installing the device in its final position, you should install the line cord, the interlock connection, the output cable, and optionally the LAN cable. The input of the current sensor is located on the front panel, thus is easily accessible even if the device is inserted in a 19" rack.

The heatsink at the rear panel must not be covered or obstructed during device operation, it must be provided with sufficiently cool air for passive cooling of the device. Take necessary precautions to ensure a sufficient supply of cool air when installing the device in closed racks. Use a vacuum cleaner to remove dust from the heatsink. Note that large dust layers substantially lower the cooling power of the heatsink, thus the device may tend to overheat if the heatsink is extremely dirty.

To power the device, a power mains socket with proper grounding is required. Check the power rating of the mains socket, since the power consumption of the device may peak during the startup at about 1 kVA.

Before powering on the device, check the setting of the voltage selector at the rear panel. Be sure that the setting corresponds to the mains voltage.

! **Warning:** A wrong setting of the voltage selector may lead to a permanent damage of the device.

If already connected, disconnect the load and power on the device by toggling the rocker switch "Power". The power switch will light red and the display will turn on. Follow the instructions in the section "Quick Setup Guide" in the manual of the device controller to take the device in operation.

If you encounter any problem, do not proceed the installation. Read this manual and the manual of the device controller carefully. Contact the manufacturer if you cannot solve the problem by yourself.