Electronic Instruments for the Life Sciences

OPERATING INSTRUCTIONS AND SYSTEM DESCRIPTION FOR THE

MVCS / MVCC Series

IONTOPHORESIS MODULES FOR EPMS-07 SYSTEMS

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About this Manual

Available Modules

MVCS-01	one channel without headstage, R_{EL} test and CAPACITY COMPENSATION
MVCS-02	two channels without headstage, R_{EL} test and CAPACITY COMPENSATION
MVCS-C-01	one channel with headstage, R_{EL} test and CAPACITY COMPENSATION
MVCS-C-02	two channels with headstage, R_{EL} test and CAPACITY COMPENSATION
MVCC-02	balance module for up to four channels.

This manual describes the MVCS-02 / MVCC-02 systems. The only difference between MVCS-01 and MVCS-02 systems are the number of channels. Therefore the MVCS-01 systems are not mentioned separately.

The manual should help you setup and use the MVCS-02 / MVCC-02 system correctly and to perform accurate experiments. With MVCS-02 the iontophoresis is performed and MVCC-02 is the balance module for the iontophoresis system used to compensate for the iontophoretic current (see also chapter 4.2). Unless otherwise noted, functions and settings that apply to MVCS-02 also apply to MVCC-02.

Generally, two different versions of the MVCS-02 / MVCC-02 system are available:

- System **without** headstage, R_{EL} test and CAPACITY COMPENSATION (MVCS-02 / MVCC-02 versions)
- System **with** headstage, R_{EL} test and CAPACITY COMPENSATION (MVCS-**C**-02 / MVCC- **C**-02 versions)

Note: In this manual, the slow MVCS-02 / MVCC-02 version is referred as MVCS / MVCC, whereas the fast MVCS-**C**-02 / MVCC- **C**-02 version is referred as MVCS-C / MVCC-C.

If you are not familiar with the use of instruments for iontophoretic application of substances, please read the manual completely. The experienced user should read at least chapters 1, 5, and 5.2.

Important: Please read chapter 1 carefully! It contains general information about safety regulations and how to handle highly sensitive electronic instruments.

Signs and conventions

In this manual names of all elements of the front panel are written in capital letters as they appear on the front panel.
System components that are shipped in the standard configuration are marked with ✓, optional components with ➪. In some chapters the user is guided step by step through a certain procedure. These steps are marked with ❑.
Important information, hints and special precautions are highlighted in gray.

Abbreviations

I_{EL} current at electrode
R_{EL} electrode resistance
V_{EL} voltage at electrode

1. Safety Regulations

<u>VERY IMPORTANT</u>: Instruments and components supplied by npi electronic are NOT intended for clinical use or medical purposes (e.g. for diagnosis or treatment of humans) or for any other life-supporting system. npi electronic disclaims any warranties for such purpose. Equipment supplied by npi electronic must be operated only by selected, trained and adequately instructed personnel. For details please consult the GENERAL TERMS OF DELIVERY AND CONDITIONS OF BUSINESS of npi electronic, D-71732 Tamm, Germany.

1) GENERAL: This system is designed for use in scientific laboratories and must be operated by trained staff only. General safety regulations for operating electrical devices should be followed.

2) AC MAINS CONNECTION: While working with the npi systems, always adhere to the appropriate safety measures for handling electronic devices. Before using any device, please read manuals and instructions carefully.
   The device is to be operated only at 115/230 Volt 60/50 Hz AC. Please check for appropriate line voltage before connecting any system to mains.
   Always use a three-wire line cord and a mains power-plug with a protection contact connected to ground (protective earth).
   Before opening the cabinet, unplug the instrument.
   Unplug the instrument when replacing the fuse or changing line voltage. Replace fuse only with an appropriate specified type.

3) STATIC ELECTRICITY: Electronic equipment is sensitive to static discharges. Some devices such as sensor inputs are equipped with very sensitive FET amplifiers, which can be damaged by electrostatic charge and must therefore be handled with care. Electrostatic discharge can be avoided by touching a grounded metal surface when changing or adjusting sensors. **Always turn power off when adding or removing modules, connecting or disconnecting sensors, headstages or other components from the instrument or 19” cabinet.**

4) TEMPERATURE DRIFT / WARM-UP TIME: All analog electronic systems are sensitive to temperature changes. Therefore, all electronic instruments containing analog circuits should be used only in a warmed-up condition (i.e. after internal temperature has reached steady-state values). In most cases a warm-up period of 20-30 minutes is sufficient.

5) HANDLING: Please protect the device from moisture, heat, radiation and corrosive chemicals.

6) CURRENT INJECTION HIGH VOLTAGE HEADSTAGE: The current injection headstages have an output compliance of ±45 V up to ±225 V. In addition, some headstages are equipped with a driven shield electrode connector (marked "Driven Shield" on the headstage enclosure). After turning on the instrument do not touch the interior contact or the shield of the electrode plug or of the cable that is connected to this plug. **In addition, it is extremely important that the instrument is turned off when changing or adjusting the electrode.**

2. EPMS-07 Modular Plug-In System

2.1. Components of the EPMS-H-07 Housing

The following items are shipped with the EPMS-H-07 housing:

- ✓ EPMS-H-07 cabinet
- ✓ Power cord
- ✓ Fuse 2 A / 1 A, slow
- ✓ Front covers

2.2. General System Description / Operation

The npi – EPMS-H-07 is a modular system for processing of bioelectrical signals in electrophysiology (see Figure 1). The system is housed in a 19” rackmount cabinet (3U) containing a low voltage and a high voltage power supply and has room for up to 7 plug-in units. The plug-in units are connected to power by a bus at the rear panel.

The plug-in units must be kept in position by four screws (M 2,5 x 10). The screws are important not only for mechanical stability but also for proper electrical connection to the system housing. Free area must be protected with covers.

In order to avoid induction of electromagnetic noise the power supply unit, the power-switch and the fuse are located at the rear of the housing.

Figure 1: Example of a measurement system located in an EPMS housing with two channel iontophoresis and balance module (MVCS-02, MVCC-02), bridge amplifier module (BRAMP-01R) and an extracellular amplifier module (EXT-01C)

2.3. System Grounding

The 19" cabinet is grounded by the power cable through the ground pin of the mains connector (= protective earth). In order to avoid ground loops the internal ground is isolated from the protective earth. The internal ground is used on the BNC connectors or GROUND plugs of the modules that are inserted into the EPMS-H-07 housing. The internal ground and mains ground (= protective earth) can be connected by a wire using the ground plugs on the rear panel of the instrument. It is not possible to predict whether measurements will be less or more noisy with the internal ground and mains ground connected. We recommend that you try both arrangements to determine the best configuration.

2.4. Technical Data

- 19” rackmount cabinet, 3U high (1U=1 3/4” = 44.45 mm), for up to 7 plug-in units
- Power supply: 115/230 Volts AC, 60/50 Hz, fuse 2 A / 1 A slow, 45-60 W

3. MVCS / MVCC Components

The following items are shipped with a MVCS / MVCC system:

- ✓ MVCS / MVCC amplifier module
- ✓ Headstage (MVCS-C / MVCC-C systems only)
- ✓ GND connector for headstage (2.6 mm, MVCS-C / MVCC-C systems only)
- ✓ Electrode cables (MVCS / MVCC systems only)
- ✓ User manual

Optional accessories:

- ➪ Electrode holder
- ➪ Electrode adapter with BNC- and SMB connector

4. System Description

4.1. MVCS Iontophoresis Module

MVCS-02 systems are high-voltage current sources for iontophoresis or other applications, where constant currents in the nano- or microampere range are needed. Standard MVCS-02 systems have an output compliance of ±45 V and can generate currents up to 450 nA into 100 MΩ while high-voltage MVCS-02 systems work with up to ±225 V generating currents up to 2.25 µA into 100 MΩ.

Generally, two different versions of the MVCS-02 system are available:

- System **without** headstage, R_{EL} test and CAPACITY COMPENSATION (MVCS-02 versions)
- Systems **with** headstage, R_{EL} test and CAPACITY COMPENSATION (MVCS-**C**-02 versions)

Note: In this manual the slow MVCS-02 version is referred as MVCS whereas the fast MVCS-**C**-02 version is referred as MVCS-C.

The operating and display elements of these instruments facilitate the application of drugs in physiological, pharmacological and biochemical studies. All systems allow very fast drug applications in the millisecond range, and even the sub-millisecond range, if equipped with the fast capacitance compensation option. Therefore, these systems can be used to simulate synaptic events (Behrends et al., 2002; Renger et al., 2001; Cottrell et al., 2000; Liu et al., 1999).

The MVCS systems are available as 19” instruments or as modules for the EPMS-07 modular system. The systems described here, are EPMS-07 modules. The MVCS-01 has one channel for current injection while the MVCS-02 consists of two independent injection channels. Each

injection channel has digital ten-turn potentiometer for EJECT or RETAINING currents and CAPACITY COMPENSATION. Each injection channel also has a digital display, over range LEDs and two switches for selection of the operating mode. The MVCC has the same controls, but no potentiometer for adjusting current.

In fast systems with CAPACITY COMPENSATION (MVCS-C / MVCC-C), the injecting electrodes are connected via small SUBCLIC or BNC shielded connectors that are mounted to a small headstage avoiding artifacts caused by long cables.
Systems for slow, long lasting applications, in the second or minute range (MVCS / MVCC), need no headstages. In this case the electrodes are connected by special connectors at the front panel with shielded cables.

For EJECT or RETAIN currents modes of operation include manual activation and automatic control by digital TTL signals (HI = EJECT, LO = RETAIN). An automated electrode resistance test mode (MVCS-C / MVCC-C) is also available.

4.2. MVCC-02 Balance Module

To avoid artifacts caused by iontophoretic drug application, the MVCS-02 systems can be operated with the balance module MVCC-02. The balance (compensation) signal (inverted sum of current output signals divided by 10), generated by the MVCC module, is applied to a separate compensation electrode, if the OPERATE mode is selected for the injection channel(s) and COMPENSATE mode is selected for the compensation channel. The MVCC module can compensate iontophoretic current for up to four injection channels.

4.3. Fast Capacitance Compensation

The MVCS-C / MVCC-C iontophoresis instruments have been designed for high-speed application of drugs in electrophysiological experiments. In addition to the standard features of the slow MVCS / MVCC devices each channel has a capacity compensation circuit and an R_{EL} test unit (see chapter 4.4). The capacity compensation circuit is operated by the control marked CAP. COMP.

The correct tuning of the capacity compensation is very important if high speed operation with high resistance microelectrodes is required. Uncompensated stray capacitances are charged from the iontophoretic current that is supplied by the instrument. Uncompensated stray capacitance therefore slows application. The tuning procedure is described in chapter 8.1.

The CAPACITY COMPENSATION control is based on the well-known conventional compensation: stray capacitances around the electrode are compensated by passing amounts of the electrode signal through a small capacitor. The circuit is set so that overshoots are avoided as far as possible.

Caution: Just lik3 any feedback circuit, this circuit can cause overshoots or oscillations if it is overcompensated.

4.4. Electrode Resistance Test

MVCS-C / MVCC-C systems are equipped with an automatic electrode resistance test facility. By switching the V_{EL}, I_{EL}, R_{EL} switch to R_{EL}, the value of the electrode resistance is shown on the digital display in MΩ, whether current is applied or not. This means that changes in electrode resistance caused by high currents (”rectification” effects) can be monitored directly. The electrode resistance test uses current pulses of ±10 nA to measure the electrode resistance. These pulses are monitored at the current OUTPUT BNC and the voltage response can be seen on the V_{EL}/10 BNC. In this way, changes of electrode resistance can be recorded with a chart recorder or computer based data acquisition system. In addition, the electrode resistance test mode can be used to tune the fast capacity compensation (see chapter 8.1).

Important: The CAPACITY COMPENSATION unit must be tuned properly. Otherwise the electrode resistance display may be inaccurate.

5. Description of the Front Panel

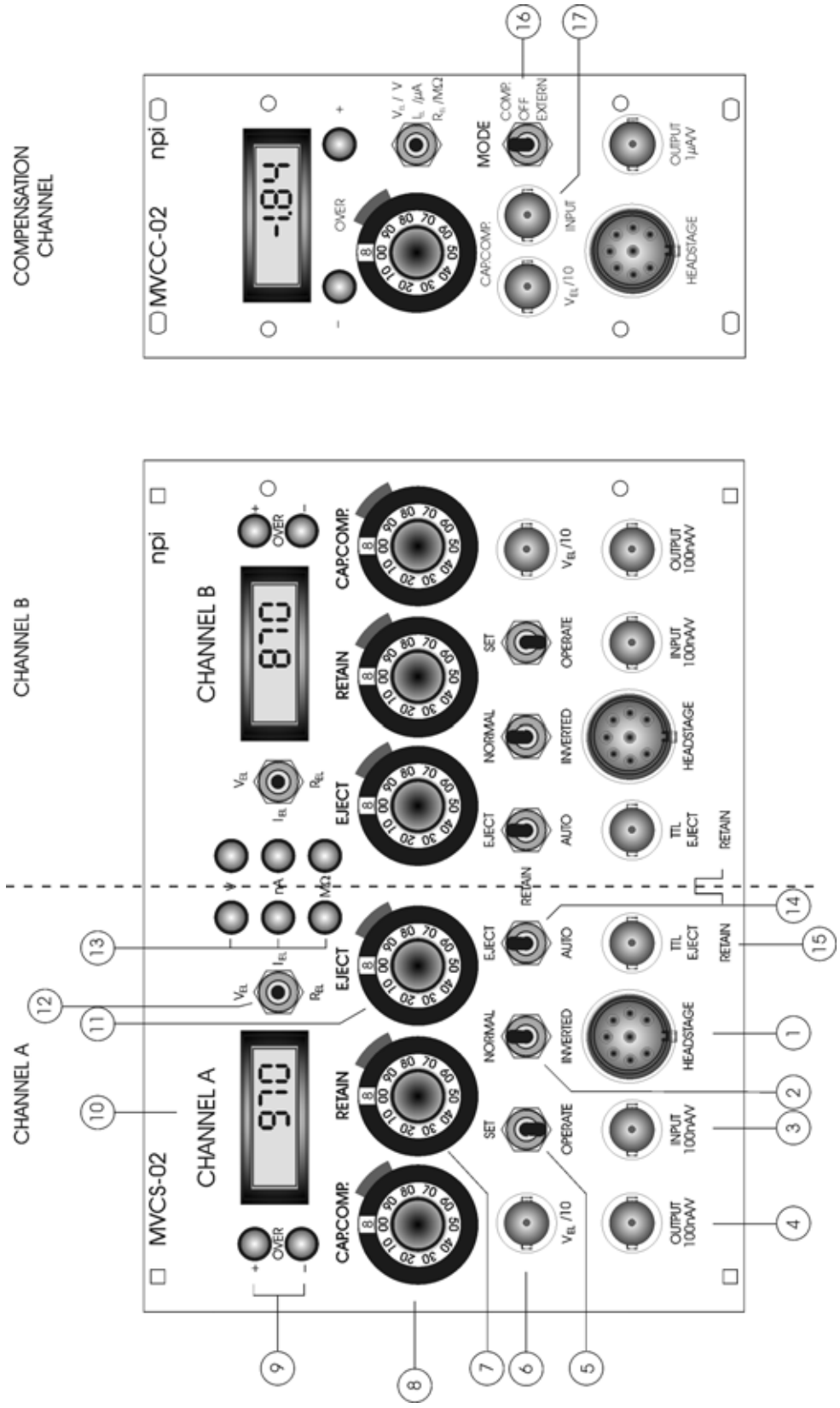

Figure 2: MVCS-C-02 / MVCC-C front panel view (the numbers are related to those in the text below)

5.1. Front Panel Elements

In the following description of the front panel elements, each element has a number that is related to that in Figure 2. The number is followed by the name (in uppercase letters) written on the front panel and the type of the element (in lowercase letters). Then, a short description of the element is given.

The front panel of the MVCS-C-02 can be divided into two functional units:
CHANNEL A and CHANNEL B.
The MVCC-C module serves for balancing the iontophoretic current for up to four injection channels.

Most of the elements are identical for each channel (with identical functions and labels) and therefore, are numbered and described only once (e.g. #**1**, HEADSTAGE connector that is also present for CHANNEL B and the MVCC).

Figure 2 shows the MCVS-C-02 / MVCC-C (fast systems) with capacity compensation and the automatic electrode resistance test facility. These two features are not present in the MVCS-02 / MVCC (slow systems). In slow systems the CAP. COMP. potentiometer is not installed and the function of R_{EL} is somewhat different (see below).

(**1**) HEADSTAGE connector

8 pole connector for the HEADSTAGE (MVCS-C systems) or for the cable directly connected to the injecting electrode (MVCS systems).

(**2**) NORMAL / INVERTED switch

Switch to set polarity of EJECT and RETAIN current: NORMAL = EJECT positive, RETAIN = negative.

(**3**, **17**) INPUT connectors

BNC connectors for an auxiliary INPUT. These BNCs are directly connected to the output current source and are not isolated from ground.

Calibration for channels A and B: 100 nA / V
Calibration for the MVCC (**17**): 1 µA / V

Note: The MVCC can be used as an additional injection channel by linking an external waveform to this connector and setting switch (**16**) to EXTERN.

(**4**) OUTPUT 100nA/V connector

BNC connector monitoring the EJECT or RETAIN current.
Calibration for channels A and B: 100 nA / V
Calibration for the MVCC: 1 µA / V.
(The OUTPUT is not isolated from system ground.)

(**5**) SET / OPERATE switch

Two position switch to set the mode of operation. In SET position the electrode outputs are connected to an internally grounded load and no compensation signal is generated. Thus, the SET position is used to preset the desired values at the EJECT / RETAIN controls on a well defined basis. In the OPERATE position, the current preset at the EJECT / RETAIN controls will flow through the electrode and a compensation signal is generated at the MVCC.

(**6**) $V_{EL}/10$ connector

BNC connector monitoring the electrode potential divided by 10. Normally used to monitor the electrode resistance (scaling: 1 mV / MΩ, see also chapters 4.4 and 8.1).

(**7**) RETAIN potentiometer

Ten-turn control to set the RETAIN current, range 0-100 nA.

(**8**) CAP.COMP. potentiometer

Ten-turn control to set amount of compensation of electrode stray capacitance (see also chapter 8.1).

(**9**) + – OVER LEDS

LEDs indicating that the current source is out of linear range or that the electrode voltage / current is 10% below the maximum output voltage / current.

(**10**) CHANNEL A display

3 1/2 digit display for the electrode potential in V (XXX.X V), the electrode current in nA (XXXX nA for channels A and B, XX.XX µA for MVCC) or the electrode resistance in MΩ (XXXX MΩ, i.e. 0100 correspond to 100 MΩ), selected by toggle switch (**12**). For the correct value of the electrode resistance display it is necessary to adjust the capacity compensation accurately (see chapter 8.1).

(**11**) EJECT potentiometer

Ten-turn control to set the EJECT current, range 0-1 µA.

(**12**) V_{EL}, I_{EL}, R_{EL} switch

3 position toggle switch to set the mode of display CHANNEL A (**10**).
Position V_{EL}: the electrode potential is displayed. Position I_{EL}: the current flowing through the electrode is displayed. Position R_{EL}: the electrode resistance is displayed.

Important: The R_{EL} mode is an option that is only implemented in MVCS-C / MVCC-C (fast) systems. In MVCS / MVCC (slow) systems, the R_{EL} position of the switch has the same function as the I_{EL} position (middle position).

(**13**) V / nA / MΩ LEDs

LEDs indicating the unit of the reading of the DISPLAY (**10**).

(**14**) EJECT / RETAIN / AUTO switch

Switch to select the mode of operation. EJECT: the EJECT current set with (**11**) is applied to the electrode. RETAIN: the RETAIN current set with (**7**) is applied to the electrode. AUTO: Operation controlled by a TTL pulse at (**15**).

Remember: Current is applied to the electrode only if switch (**5**) is set to OPERATE.

(**15**) TTL connector

Optically isolated BNC connector for external control in the AUTO mode (see also **14**). LO = RETAIN, HI = EJECT.

MVCC-C Only

(**16**) MODE switch, (**17**) INPUT connector

Switch to select the operation mode of the MVCC-C.

COMP.:	The inverted sum of all injection channels is applied to the electrode.
OFF:	No current is applied to the electrode.
EXTERN:	The output current source is connected directly to INPUT BNC (**17**). In this mode the MVCC can be used as an additional injection channel. If e.g. 1 V is connected at (**17**), an injection current of 1 µA is applied to the electrode connected to the MVCC.

5.2. MVCC-02 Balance Module

The front panel of the “slow” MVCC-02 is different from the “fast” MVCC-C-02 module.

Figure 3: MVCC-02 module

(**1**) GND connector

Banana jack providing system ground.

(**2**) OUTPUT 1µA/V connector

BNC connector providing the monitor of the compensation (balance) current (compensation OUTPUT). Calibration: 1 µA / V, i.e. 1 V means that a compensation current of 1 µA flows.

(**3**) INPUT COMPENSATION 1µA/V connector

BNC connector for connecting a second compensation (balance) source. Suppose one has two iontophoresis systems, system 1 and system 2. The compensation OUTPUT of the system 2 (without compensation electrode) can be fed into the COMPENSATION INPUT of system 1 (with compensation electrode). With switch (**5**) in COMP. position (both systems) the current flowing through the compensation electrode connected to system 1 is then the sum of both COMPENSATION channels. Thus, the current of all injection electrodes are balanced with only one compensation electrode.

(**4**) EXT. INPUT connector

BNC connector for a signal from an external device, e.g. a function generator (see #5, MODE switch below).

(**5**) MODE switch

Switch to select the operation mode of the MVCC.

COMP.:	The inverted sum of all injection channels is applied to the electrode.
OFF:	No current is applied to the electrode.
EXTERN:	The output current source is connected directly to EXT. INPUT BNC (**4**). In this mode the MVCC can be used as an additional injection channel. If e.g. 1 V is connected at (**4**), an injection current of 1 µA is applied to the electrode connected to the MVCC.

6. Headstage (MVCS-C / MVCC-C Systems)

The headstage is housed in a small box that can be mounted directly onto a micromanipulator. It is connected to the main amplifier by means of a shielded flexible cable and a multi-pole connector.

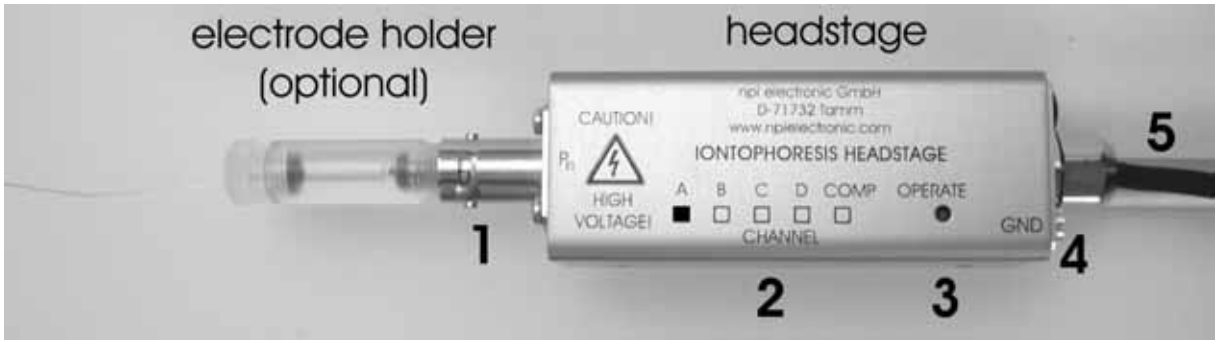

Figure 4: MVCS-C-02C headstage

1 P_{EL}: BNC connector for the electrode holder, grounded shield
2 CHANNEL indicator: marker show for which CHANNEL the headstage is configured, in the example shown for CHANNEL A (see also hint below)
3 holding bar and headstage cable to amplifier
4 GND: ground connector
5 OPERATE LED: indicates that injection takes place

GND (GROUND) connector

The bath (or reference) of the recording chamber is connected to GND. This is the ”lowest” signal level in the recording system, i.e. all signals are related to this signal. This connector must be connected to the ground signal of the recording amplifier / chamber.

P_{EL}

In order to avoid disturbances on the recording amplifier, the microelectrode holder is connected via a BNC connector with a grounded shield.

***Caution*:** The current injection headstages have an output compliance of ±45 V up to ±150 V. In addition, all headstages are equipped with very sensitive FET amplifiers that can be damaged with electrostatic charge and must therefore be handled with care (see also chapter 1.

Very Important: Always turn power off when connecting or disconnecting headstages from the 19" cabinet. For changing electrodes it is sufficient to switch the respective channel to SET mode.

Also very important: Each headstage is adjusted for a specific channel and instrument. They are labeled A and B for the EJECT channels, and C for the COMPENSATION channel. Please **do not exchange headstages** for a respective instrument or between different MVCS instruments.

Hint: If one channel is not used the haedstage can be left unconnected, but then the display for this channel will show anything and may change. So, we recommend to connect the headstage even if it is not used and set channel to SET mode using switch #**5**, Figure 2).

Systems for slow, long lasting applications (in the second or minute range) need no headstages (MVCS systems). In these systems the electrodes are connected from special connectors on the front panel with shielded cables:
Pin 2: white/blue wire = ground
Pin 5: yellow/red wire = electrode

7. Setting up the Iontophoresis System

The following steps should help you set up the iontophoresis system correctly. Always adhere to the appropriate safety measures (see chapter 1).
Usually the module(s) are shipped mounted in an EPMS-H-07 housing. If a single module is delivered the user has to mount the module in the EPMS-H-07 housing. This is done by performing the basic installation steps.

① **Basic installation**

- ❑ Turn off the EPMS-07 system.
- ❑ Remove front covers from the EPMS-07 housing.
- ❑ Plug in the MVCS / MVCC and fasten the iontophoresis / balance module with four screws. The screws are important not only for mechanical stability but also for proper electrical connection to the EPMS-07 housing.

After installation, MVCS / MVCS-C / MVCC-C / MVCC are attached to the setup by assembling the electrical connections.

② **Electrical connections**

❑ Turn POWER off.

❑ MVCS / MVCC: Connect your injection electrodes to the special connectors with shielded cables at the front panel of the MVCS module. Connect your compensation electrode to the special connector with shielded cables at the front panel of the MVCC module.
Pin 2: white/blue wire = ground
Pin 5: yellow/red wire = electrode

MVCS-C / MVCC-C: Connect the headstages to the HEADSTAGE connectors (#**1**, Figure 2) at the front panel of the respective module.

❑ If the recording chamber is not grounded, connect GND of the headstage (MVCS-C).

Note: System ground is isolated from mains ground. The 19" cabinet (EPMS-H-07 housing) is connected to mains ground (see also chapter 2), headstage enclosures are connected to the internal system ground.

❑ MVCS-C / MVCC-C: Connect the $V_{EL}/10$ connectors and the current OUTPUT (#**4**, Figure 2) to an oscilloscope or to a data acquisition system.

- ❑ If you intend to control the MVCS / MVCS-C system externally (e.g. by a computer) connect the gating waveform to TTL (#**15**, Figure 2), the stimulus waveform to INPUT (#**3**, Figure 2) and the current OUTPUT (#**4**, Figure 2) to the analog input of the data acquisition system.

8. Operation

MVCS / MVCS-C / MVCC / MVCC-C systems are modules for the npi EPMS-07 system.

Important: These modules require an EPMS-07 housing with high voltage power supply!! Users of systems delivered before April 2002 will recognize a built-in high voltage power supply by the fact that the EPMS-07 housing is 354 mm deep (instead of 245 mm with low voltage power supply). Systems delivered after September 2006 have a yellow warning label above the respective channels.
Additionally, each channel has a mark (A, B, C, D, COMPENSATION) and the related headstages are labeled accordingly. Please use headstage A for channel A, headstage B for channel B and so on, because each headstage is dedicated to a particular channel.

Each system is composed of one (MVCS-01 / MVCS-C-01) or two independent injection channels (MVCS-02 / MVCS-C-02) marked A and B. MVCC / MVCC-C systems serve as compensation (balance) channels and can compensate iontophoretic current for up to four injection channels.

Each channel has an auxiliary analog input and an output which monitors the current flowing through the electrode. Each channel is equipped with a digital display and two overload LEDs.

All numbered items refer to Figure 2, page 11, in the following discussion.

The systems can be operated manually by means of a toggle switch on the front panel (#**14**) or by an external digital pulse (TTL) connected to #**15**.

- ❑ Turn CAP.COMP. (#**8**) for all channels to less than 1 to avoid oscillations.
- ❑ Turn POWER on.
- ❑ Set the operation mode of all channels to SET using switch #**5** to disable current output.
- ❑ Set the EJECT and/or RETAIN current amplitude to the desired values using #**11** and #**7**.
- ❑ MVCS-C: First, compensate the stray capacitances of the electrodes (see chapter 8.1) and second, check the electrode resistances by switching #**12** to R_{EL}.

Important: The values of the ELECTRODE RESISTANCE are accurate only if the capacitances of the electrodes are compensated properly.

- ❑ Put the injection- and compensation electrodes to the desired positions.
- ❑ Start iontophoresis either manually by setting switch #**14** to EJECT and switch #**5** to OPERATE or remotely by setting switch #**14** to AUTO and applying a TTL pulse to #**15**.

8.1. Capacity Compensation Tuning Procedure (MVCS-C / MVCC-C Systems)

The tuning of the capacity compensation controls is performed with the help of the electrode potential monitor BNC marked $V_{EL}/10$ (#**6**) and square pulses applied to the electrode. This pulse can originate from the built-in ELECTRODE RESISTANCE TEST circuit or from an external signal source. The pulses generated internally by the ELECTRODE RESISTANCE test unit have an amplitude of ±10 nA.

The following tuning procedure is described for the MVCS-C channels A or B only. The tuning of the capacity compensation for the MVCC-C module is done analogue.

The tuning must be performed with the electrode in the bath immersed to the maximal depth required during the experiment. Square pulses (positive and negative) of a few nA and 0.1-10 ms duration are applied to one of the INPUT BNCs (#**3**) or by activating the ELECTRODE RESISTANCE test unit (#**12**). The signals from the $V_{EL}/10$ and CURRENT OUTPUT BNCs (#**4**) are monitored on an oscilloscope.

The CAP.COMP. control (#**8**) is turned on clockwise until the signal at the $V_{EL}/10$ BNC is as square as possible. The highest speed is obtained with a small overshoot (theoretically 4.3 %).

The CAPACITY COMPENSATION is based on the well-known conventional compensation: stray capacitances around the electrode are compensated by passing amounts of the electrode signal through a small capacitor. The circuit is designed to minimize oscillations.

***Caution*:** Just as in any feedback circuit, this circuit can cause overshoots or oscillations, if it is overcompensated.

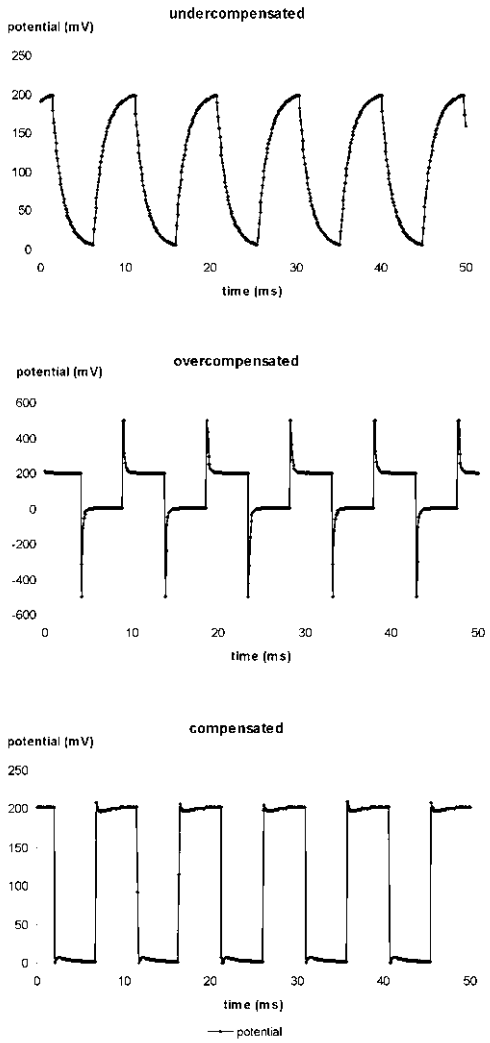

Figure 5: Capacity compensation of the electrode

9. Literature

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Fast capacity compensation / Simulation of synaptic events

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10. Technical Data

Electrode output:	floating current source, output impedance $>10^{12}$ Ω
Maximum current:	450 nA [1.5 µA] into 100 MΩ load
Display:	current: XXXX nA, balance: XX.XX µA, voltage: XXX.X V, R_{el}: XXXX MΩ, displayed value is set by a three position toggle switch, separate displays for each channel
Over LEDs:	activated 10% below maximum current / voltage
Eject:	adjustable by ten-turn control
Minimum pulse duration:	50 µs
Retain:	adjustable by ten-turn control, maximum 100 nA
Capacity compensation:	adjustable by ten-turn control, range 0-30 pF
Output current polarity:	selected by INVERTED/NORMAL toggle switch
Modes of operation:	set by two toggle switches EJECT/RETAIN/AUTO switch enables manual or TTL controlled operation SET/OPERATE switch connects automatically electrode outputs to ground (SET position)
TTL input (AUTO mode):	LO = RETAIN, HI = EJECT, isolated, R_{in} >5 kΩ
Analog input:	sensitivity 100 nA / V, R_{in} > 100 kΩ, range ±10 V
Current monitor:	sensitivity 100 nA / V, R_{out} = 250 Ω, not isolated
Voltage monitor:	V_{EL} / 10, R_{out} = 250 Ω, not isolated
Electrode resistance test:	1 mV / MΩ at voltage monitor V_{EL} / 10
MVCC output:	inverted sum of all injection currents (up to four channels) sensitivity 1 µA / V

Output connector pins and cable colors: (for systems without headstage)	Pin 2: white/blue wire = ground Pin 5: yellow/red wire = electrode

Dimensions

MVCS-01:	Front panel:	18 HP (91.1 mm) x 3U (128.5 mm)
	Housing:	7” (175 mm) deep
MVCS-02:	Front panel:	36 HP (182.5 mm) x 3U (128.5 mm)
	Housing:	7” (175 mm) deep
MVCC-02:	Front panel:	12 HP (60.75 mm) x 3U (128.5 mm)
	Housing:	7” (175 mm) deep

Headstage size: approx. 65x25x25 mm