

*Made to Measure*

# SEC Series

## Single Electrode Voltage and Current Clamp Amplifiers



**SEC-05X**



**SEC-10LX**

npi SEC amplifiers are versatile intracellular recording systems. They are the fastest and most accurate single electrode current- and voltage-clamp amplifiers available. SEC devices are suitable for recordings with high resistance microelectrodes, and for tight-seal perforated patch or whole-cell recording techniques with patch pipettes. SEC systems can be used for extracellular recordings as well. They also allow artifact-free simultaneous recordings from two cells (double-cell VC technique) or intracellular recordings during voltammetry experiments.

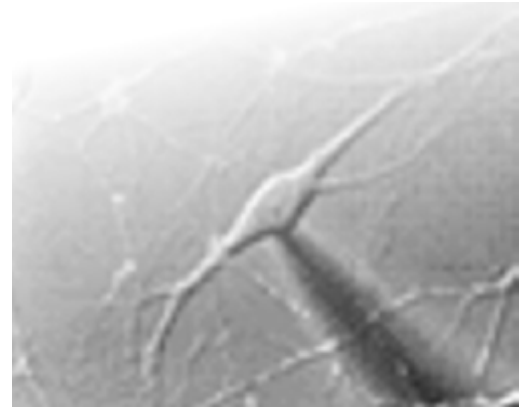
The SEC amplifiers fully compensate the recording microelectrode. This is a significant improvement over other time-sharing amplifiers, and makes possible single electrode recordings with the same accuracy and speed of response as with the standard two electrode voltage clamp approach. Moreover, the time-sharing principle of SEC amplifiers completely eliminates series resistance errors.

All amplifiers include at least four modes of operation, many automatic functions, protection circuits, versatile I/O signal conditioning units, and digitally controlled operation. Furthermore, a lot of accessories and additional options are available. All of these features make these amplifiers the ideal research instruments for all electrophysiological investigations that utilize intracellular microelectrodes.



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## Features:



- ⇒ four modes of operation by default
  - ⇒ Bridge mode (BR)
  - ⇒ Current Clamp mode (CC)
  - ⇒ Voltage Clamp mode (VC)
  - ⇒ Electrode resistance test mode ( $R_{EL}$ )
- ⇒ three additional modes optional
  - ⇒ **Voltage Clamp controlled Current Clamp mode (VCcCC)**  
Allows Current Clamp experiments at controlled resting potentials
  - ⇒ **Dynamic Hybrid Clamp mode (DHC)**  
Allows precise measurement of conductances after action potentials
  - ⇒ Linear (unswitched) mode (LIN), **optional with series resistance compensation**
    - x1: Allows low-noise recordings of small currents, and approaching the cell and seal formation in VC mode
    - x10: Provides 10 times more current in CC and 10 times more voltage in VC mode for non-invasive (juxtacellular) filling of cells
- ⇒ complete compensation of electrode artifacts allowing high (> 30 kHz) switching frequencies
- ⇒ no series resistance errors
- ⇒ perfect for recording also from coupled cells with two synchronized SEC amplifiers (SEC-SYNC)
- ⇒ recordings with sharp microelectrodes or patch pipettes
- ⇒ perfect for **Dynamic Clamp** recordings
- ⇒ true current clamp in switched and bridge mode
- ⇒ fast switched voltage clamp with proportional-integral (PI) controller
- ⇒ versatile and configurable penetration unit
- ⇒ BESSEL filters for current and voltage (16 corner frequencies)
- ⇒ monitors for filters and current output sensitivity

### References:

- Books:** Polder, H.R., M. Weskamp, K. Linz and R. Meyer (2005). Voltage-Clamp and Patch-Clamp Techniques. (2005) Chapter 3.4, in: Dhein, St.; Mohr, FW; Delmar, M. (eds.) Practical Methods in Cardiovascular Research, Springer, Berlin Heidelberg New York.
- Lalley, P. M., Moschovakis, A. K. and Windhorst, U. (1999). Electrical Activity of Individual Neurons in Situ: Extra- and Intracellular Recording, in: U. Windhorst and H. Johansson (eds.) Modern Techniques in Neuroscience Research, Springer, Berlin, New York
- Theory:** Polder, H.R. and D. Swandulla (2001). The use of control theory for the design of voltage clamp systems: A simple and standardized procedure for evaluating system parameters, J. Neurosci. Meth., 109: 97-109.
- VCcCC:** Sutor, B., Ch. Grimm and H.R. Polder (2003). Voltage-Clamp controlled Current-Clamp Recordings, Pflügers Arch. 446, 133-141.
- DHC:** Dietrich, D. et al. (2002). Improved hybrid clamp: resolution of tail currents following single action potentials. J.Neurosci.Meth. 116, 55-63.
- SEC-SYNC:** Müller, A., M. Lauen, R. Berkels, S. Dhein, H.R. Polder and W. Klaus (1999). Switched single electrode amplifiers allow precise measurement of gap junction conductance, Am. J. Physiol. (Cell) 276, C980-88.
- Hartveit, E. & Veruki, M. L. (2010). Accurate measurement of junctional conductance between electrically coupled cells with dual whole-cell voltage-clamp under conditions of high series resistance. J Neurosci.Methods. 187, 13-25.
- Juxtacellular filling:** Both M, Böhner F, von Bohlen, Halbach O, und Draguhn A. (2008.) Propagation of specific network patterns through the mouse hippocampus. Hippocampus. May 2008, DOI: 10.1002/hipo.20446.



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SEC-03M module for EPMS-07 system



SEC low-noise headstage with electrode holder



SEC standard headstage with electrode holder and adapter



SEC headstage for extracellular recording



SEC mini headstage set



SEC passive cell model



## Technical Data

### MODES of OPERATION

$R_{el}$ : Electrode resistance test  
 BR: Bridge mode  
 CC: Current Clamp mode  
 VC: Voltage Clamp Mode  
 DHC: Dynamic Hybrid Clamp mode (option)  
 VCcCC: Voltage Clamp controlled Current Clamp mode (option)  
 LIN: Linear mode (x1 and x10)  
 LIN: Linear mode with series resistance compensation  
 Mode selection:  
 rotary switch with six positions (SEC 05X)  
 four pushbuttons (SEC 10LX)  
 rotary switch with five positions (SEC 03M)  
 Linear mode with switch

### HEADSTAGES

**Standard** headstage(SH), **low-noise** headstages(HSP)  
 operation voltage:  $\pm 15$  V  
 size: 100x40x25mm, HSP: 77x37x20mm  
 headstage enclosure connected to ground  
 electrode connector: gold plated SMB (SH)  
 BNC connector (HSP), both with driven shield  
 ground: 2.6 mm connector or headstage enclosure  
 input resistance:  $> 10^{13}$  Ohms  
 current range (continuous mode):  
 150 nA (SH); 15 nA into 100 MOhms (HSP)  
 CC control: Coarse control for cap. comp.  
 holding bar (SH): diameter 8 mm, length 10 cm  
 mounting plate (HSP headstage) 60x50 mm  
**EXT** headstage: 1 mm connectors,  
 differential high impedance input, gain of ten  
 cap. comp. for the non-inverting input  
 high pass filter with six corner frequencies  
 (1; 3; 10; 30; 100; 300 Hz)

### BANDWIDTH AND SPEED OF RESPONSE

Full power bandwidth ( $R_e=0$ ):  $> 100$  kHz  
 rise time (10-90%,  $R_e = 100$  MOhms)  $< 30 \mu s$   
 rise time (10-90%,  $R_e = 5$  MOhms)  $< 8 \mu s$   
 Electrode artifact decay (switched modes  
 10 nA signal)  $< 1 \mu s$  ( $R_e = 5$  MOhms)  
 $< 1.5 \mu s$  ( $R_e = 100$  MOhms)  
 cap. comp. tuned with no overshoot

### ELECTRODE RESISTANCE TEST

10 mV/MOhm, obtained by application of square  
 current pulses  $\pm 1$  nA, display XXX MOhm

### OSCILLATION SHUT-OFF

Turns off current injection and cap. comp. function  
 indicated by red/green LED,  
 disabled / off / reset switch  
 threshold set with linear control (0-1200 mV).  
 SEC-03: no oscillation shut-off

### Optional accessories:

**SEC-GIA:** gating unit for SEC-05X  
**SEC-MOD:** passive cell model  
**SEC-MODA:** active cell model  
**SEC-EH-SET:** electrode holder set (1 with port, 1 without port, 1 BNC holding bar)  
**SEC-PRS:** remote switch for penetration  
**Headstages:** SEC-HSP extra low-noise recording  
 SEC-EXT extracellular recording  
 SEC-HSD differential recording  
 SEC-MINI-SE *in-vivo* recording

### CELL PENETRATION

Overcompensation of cap. comp.,  
 timer controlled, with remote switch  
 connected via BNC connector.  
 Application of DC pulses, variable frequency and  
 amplitude, timer controlled, with remote switch  
 connected via BNC connector (SEC-10LX).  
 Application of max. continuous DC current, BUZZ,  
 with push button or remote switch connected via  
 BNC connector (SEC-05X).  
 No cell penetration unit (SEC-03M)  
 (modular penetration unit available)

### SWITCHED MODES PARAMETERS

Switching frequency: linear control  
 1.5 to  $> 50$  kHz; display: XX.XX kHz.  
 duty cycles: 1/2, 1/4, 1/8  
 selected by toggle switch.  
 SEC-03M: fixed 1/4 duty cycle

### CURRENT RANGE vs. DUTY CYCLE

1/8 - 15 nA; 1/4 - 30 nA, 1/2 - 60 nA  
 (standard headstage)  
 1/8 - 1.5 nA; 1/4 - 3 nA, 1/2 - 6 nA  
 (low noise headstage)

### SWITCHED MODE OUTPUTS

Electrode potential: max.  $\pm 15$  V,  
 output impedance 250 Ohms.  
 switching frequency: TTL (5 V),  
 output impedance 250 Ohms.

### CURRENT OUTPUT

Sensitivity: 0.1...10 V/nA in 1-2-5 steps  
 with lowpass Bessel filter  
 output impedance 250 Ohms  
 sensitivity monitor: 1...7 V, 1V/switch position  
 output impedance 250 Ohms  
 current display: X.XX nA  
 SEC-03M: fix 0.1V/nA

### POTENTIAL OUTPUT

Sensitivity x10 mV, with lowpass Bessel filter  
 output impedance 250 Ohms  
 potential display: XXX mV

### AUDIO MONITOR

Pitch correlated with potential signal

### OUTPUT FILTERS

SEC-05X: two-pole (standard version) or  
 four-pole lowpass Bessel filters (SEC-05X-BF) with  
 16 corner frequencies, 20 Hz - 20 kHz  
 frequency monitor: -8...+7 V, 1 V/switch position  
 output impedance 250 Ohms.  
 SEC-10LX: four-pole lowpass Bessel filter with  
 16 corner frequencies, 20 Hz - 20 kHz  
 output impedance 250 Ohms.  
 SEC-03M: unfiltered or 5 kHz, internally adjustable

### CURRENT CLAMP

Inputs: 1 nA/V, 0.1 nA/V with ON/OFF switches  
 SEC-03M: 1 nA/V  
 input resistance  $> 100$  kOhms  
 hold: X.XX nA ten-turn digital control, -/0/+ switch  
 max. 10 nA.  
 Gated input (SEC-10LX systems only): X.XX nA  
 with +/0/- switch, TTL input (HI  $> 2.5$  V, input  
 resistance 10 kOhm).  
 BRIDGE balance: XXX MOhms with  
 ten-turn digital control.  
 noise (BRIDGE MODE): 400  $\mu V$  pp / pA pp  
 with 100 MOhms resistance at 10 kHz bandwidth  
 (internal four-pole Bessel filters)

### VOLTAGE CLAMP

Inputs:  $\pm 10$  mV or  $\pm 40$  mV  
 SEC-03M:  $\pm 10$  mV  
 input resistance  $> 100$  kOhms  
 hold: XXX mV, ten-turn digital control  
 with +/0/- switch, max. 1000 mV  
 rise time limit: 0-2 ms (SEC-05 / SEC-10 only)  
 gain: 100 nA/V - 10  $\mu A/V$  ten-turn linear control  
 noise (filters set to 10 kHz, SEC-05 / SEC-10)  
 Potential output:  $< 400 \mu V$  pp  
 current output:  $< 400$  pA pp

### SPEED of RESPONSE (VC Mode)

1 % settling time:  $< 80 \mu s$  for 10 mV step  
 $< 800 \mu s$  for 50 mV step applied to cell model  
 ( $R_e = 100$  MOhms,  $R_m = 50$  MOhms,  $C_m = 470$  pF  
 duty cycle = 1/4, switching frequency = 30 kHz  
 standard headstage)  
 $< 400 \mu s$  with 1/2 duty cycle.

### DIMENSIONS

SEC-05X / SEC-10LX systems:  
 19" (483 mm) wide  
 14" (355 mm) deep  
 5.25" (132.5 mm) high,  
 SEC-03M (two slots):  
 24 HP (121 mm) x 3U (128 mm) x 7 inch (175 mm)

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