# EC301 Manual

October 2, 2014

# Contents

# 1 General information

## 1.1 Safety and preparation for use

### Warning

**Dangerous voltages, capable of causing injury or death, are present in this instrument. Use extreme caution whenever the instrument covers are removed. Do not remove the covers while the unit is plugged into a live outlet.**

**Line fuse**
Verify that the correct line fuse(s) are installed before connecting the line cord. Fuse size is 3AB/3AG "slo-blo" ($\phi$6.3 × 32 mm). For 100 V/120 V, use a single 3 A fuse; for 220 V/240 V, use two 1.5 A fuses.

**Line cord**
The EC301 has a detachable, three-wire power cord for connection to the power source and to a protective ground. The exposed metal parts of the instrument are connected to the outlet ground to protect against electrical shock. Always use an outlet which has a properly connected protective ground.

**Service**
Do not attempt to service or adjust this instrument unless another person, capable of providing first aid or resuscitation, is present.

Do not install substitute parts or perform any unauthorized modification to this instrument. Contact the factory for instructions on how to return the instrument for authorized service and adjustment.

## 1.2 Symbols you may find on SRS products

| Symbol | Description |
|---|---|
| ∼ | Alternating current |
| ⚡ | Caution - risk of electric shock |
| ⏊ | Frame or chassis terminal |
| ⚠ | Caution - refer to accompanying documents |
| ⏚ | Earth (ground) terminal |
| 🔋 | Battery |
| ⏛ | Fuse |
| \| | On (supply) |
| ○ | Off (supply) |

## 1.3 Specifications

### Voltage and current measurement accuracy

- Voltage measurement accuracy

  ±0.2% of reading ($V_{RE} - V_{WE\ SENSE}$) ± 5mV

- Current measurement accuracy, 1 A range

  ±0.5% of reading ($I_{WE}$) ± 0.2% of range

- Current measurement accuracy, other ranges

  ±0.2% of reading ($I_{WE}$) ± 0.2% of range

- Power amplifier
  - Compliance voltage

    $\geq \pm$30V full compliance
  - Maximum output current

    $\geq \pm$1A
  - Slew rate (power amplifier in isolation)

    $\geq$ 10V/$\mu$s
  - Output short-circuit protected

### Potentiostat mode

- Applied potential accuracy:

| Potential versus reference within | Accuracy |
|---|---|
| ±5V | ±0.2% of setting ± 5mV |
| ±10V | ±0.5% of setting ± 5mV |
| ±15V | ±1% of setting ± 5mV |

- Applied potential resolution:

| Mode | Resolution |
|---|---|
| General (potential set with thumbwheel or remote interface) | 500$\mu$V |
| Performing an automatic scan (CV or LSV) | 200$\mu$V |

- Noise and ripple

  $< 20\mu\mathrm{V}_{\mathrm{rms}}$ (1Hz → 10kHz)

- Applied E range

  ±15V versus reference (|CE| <30V versus signal ground)

### Galvanostat mode

- Applied current accuracy:

  ±0.5% of setting ±0.2% of current range, 1 A range

  ±0.2% of setting ±0.2% of current range, all other ranges

### ZRA mode

- Voltage offset

  `CE sense` and `WE sense` electrodes held within 5 mV of each other

- Output current

  1 A range: −1 A min, +1 A max

  All other ranges: −2× full scale min, +2× full scale max

**General control loop**

- Bandwidth control

  Bandwidth limits: 10Hz, 100Hz, 1kHz, 10kHz, 100kHz, >1MHz (10kΩ resistive load, < 100$\mu$A output current)

- Compliance limiting

  Voltage limit accuracy

| Cell current ($I_{\mathrm{CE}}$) | Accuracy |
|---|---|
| ≤10mA | ±250 mV |
| ≤1A | ±1V |

### IR compensation

- Current interrupt

| | |
|---|---|
| Switching time (on → off) | $< 5\mu$s (1 kΩ resistive load) |
| Interrupt time | $100\mu$s → 1s |
| Interrupt frequency | 0.1 Hz → 300 Hz |

- Positive feedback

Range

| $I_{\text{range}}$ | $R_{\text{u}}$ |
|---|---|
| 1 A | 0 → 3 Ω |
| 100 mA | 0 → 30 Ω |
| 10 mA | 0 → 300 Ω |
| 1 mA | 0 → 3 kΩ |
| 100 $\mu$A | 0 → 30 kΩ |
| 10 $\mu$A | 0 → 300 kΩ |
| 1 $\mu$A | 0 → 3 MΩ |
| 100 nA | 0 → 30 MΩ |
| 10 nA | 0 → 300 MΩ |
| 1 nA | 0 → 3 GΩ |

| | |
|---|---|
| Resolution | 1 mΩ for 1A range<br>1 MΩ for 1nA range |

**General system**

- Remote interfaces

  LAN (10/100 base-T Ethernet)

  GPIB (IEEE-488)

- Dimensions (W × H × D)
  - Main box

    17 × 18.5 × 5.25 inches
  - External box

    3.25 × 4.75 × 2.5 inches
  - Umbilical

    36 inches
  - Weight
  - Power

- RTD measurement
  - Temperature sensor

    User supplied 100Ω Pt RTD, $\alpha = 0.00385\ \Omega/\Omega/{}^\circ\mathrm{C}$
  - Range

    $-100\,^\circ\mathrm{C}$ to $+200\,^\circ\mathrm{C}$
  - Resistance measurement accuracy

    $\pm 0.3\,\Omega$

**Front panel connectors**

- External input

  ±15V analog input in potentiostat mode, ±2V in galvanostat mode

  Input impedance: 10kΩ ∥ 50pF

- Rotating electrode output BNC

  0→10V analog output

  Accuracy: ±1% of setting ±5mV

  Output impedance: 10Ω

  10mA max output current

- Voltage (E) output BNC

  ±15V analog output

  Accuracy: ±0.2% of $V_{RE} - V_{WE\ Sense} \pm 5\,mV$

  Output impedance: 50Ω

  10mA max output current

- Current (I) output BNC

  ±2V analog input

  Accuracy: $I_{WE}$ within ±0.5% of $(V_{BNC} \times I_{range}) \pm 0.2\% \times I_{range}$, 1 A range

  Accuracy: $I_{WE}$ within ±0.2% of $(V_{BNC} \times I_{range}) \pm 0.2\% \times I_{range}$, other ranges

  Output impedance: 50Ω

  10mA max output current

### Rear panel connectors

- Timebase input BNC

  Frequency: 10MHz

  Level: 1Vpp (nominal)

- TTL measurement synchronization BNCs

  Current interrupt and scan synchronization outputs, scan trigger input

- Program E/I output BNC

  ±15V analog output

  Accuracy: ±0.2% of total program voltage (internal sources + external input) ± 5 mV

  Output impedance: 10Ω

  10mA max output current

- Auxiliary ADC input BNCs

  Three ±10V analog to digital inputs

  input impedance: 100kΩ

  1mV resolution

- Signal / floating ground banana jacks

  Signal ground ohmically connected to chassis ground

  Floating ground can float ±8 V relative to signal ground

  Signal/floating ground isolation: 10 MΩ

- RTD input

  5-pin connector for Pt RTD temperature probe

- Raw E output BNC

  ±15V analog output

  Accuracy: ±0.2% of $V_{RE} - V_{WE\ SENSE} \pm 5$mV

  Output impedance: 50Ω

  10mA max output current

- Raw I output BNC

  ±2V analog input

  Accuracy: $I_{WE}$ within ±0.2% of $(V_{BNC} \times I_{range}) \pm 0.2\% \times I_{range}$, 1 A range

  Accuracy: $I_{WE}$ within ±0.2% of $(V_{BNC} \times I_{range}) \pm 0.2\% \times I_{range}$, other ranges

  Output impedance: 50Ω

  10mA max output current

- CE/3 output BNC

  ±10V analog output

  Accuracy: ±1% of $V_{CE}/3 \pm 10$mV

  Output impedance: 50Ω

  10mA max output current

- Synchronous ADC input
  Sampled synchronously with E and I ADCs
  ±10V analog to digital input
  input impedance: 100kΩ
  16-bit resolution
- Ethernet interface
- IEEE 488 interface
- Chassis ground
- Power entry module

**Differential electrometer**

- Input impedance

  $> 1\text{T}\Omega \parallel 20\text{pF}$

- Input bias current

  $< 20$pA

- Common-mode rejection ratio (CMRR)

  | Bandwidth | CMRR (dB) |
  |---|---|
  | 10 kHz | 80 (90 typ.) |
  | 100 kHz | 60 (70 typ.) |

- Bandwidth

  $> 10$MHz

**Cell current input (WE)**

- Ranges

  10 decades – 1A to 1nA

- Frequency response

## 1.4 Serial number and firmware revision

- Serial number

  If you need to contact Stanford Research Systems, please have the serial number of your unit available. The 5-digit serial number is printed on a label affixed to the rear panel. the unit is powered on. The serial number can also be displayed on the front panel after the unit is powered on by pressing the `[DISPLAY]` key.

- Firmware revision

  The firmware revision code is shown on the front panel when the unit is powered on.

# 2 EC301 basics

## 2.1 Software

The EC301 is intended to operate with the *SRSLab* Windows software package. *SRSLab* can be downloaded from the SRS web site, `www.thinkSRS.com`. Complete instructions for *SRSLab*, in the form of documentation videos, are also available on the website.

## 2.2 Functional block diagram

Figure 1 illustrates the major signal paths in the EC301.

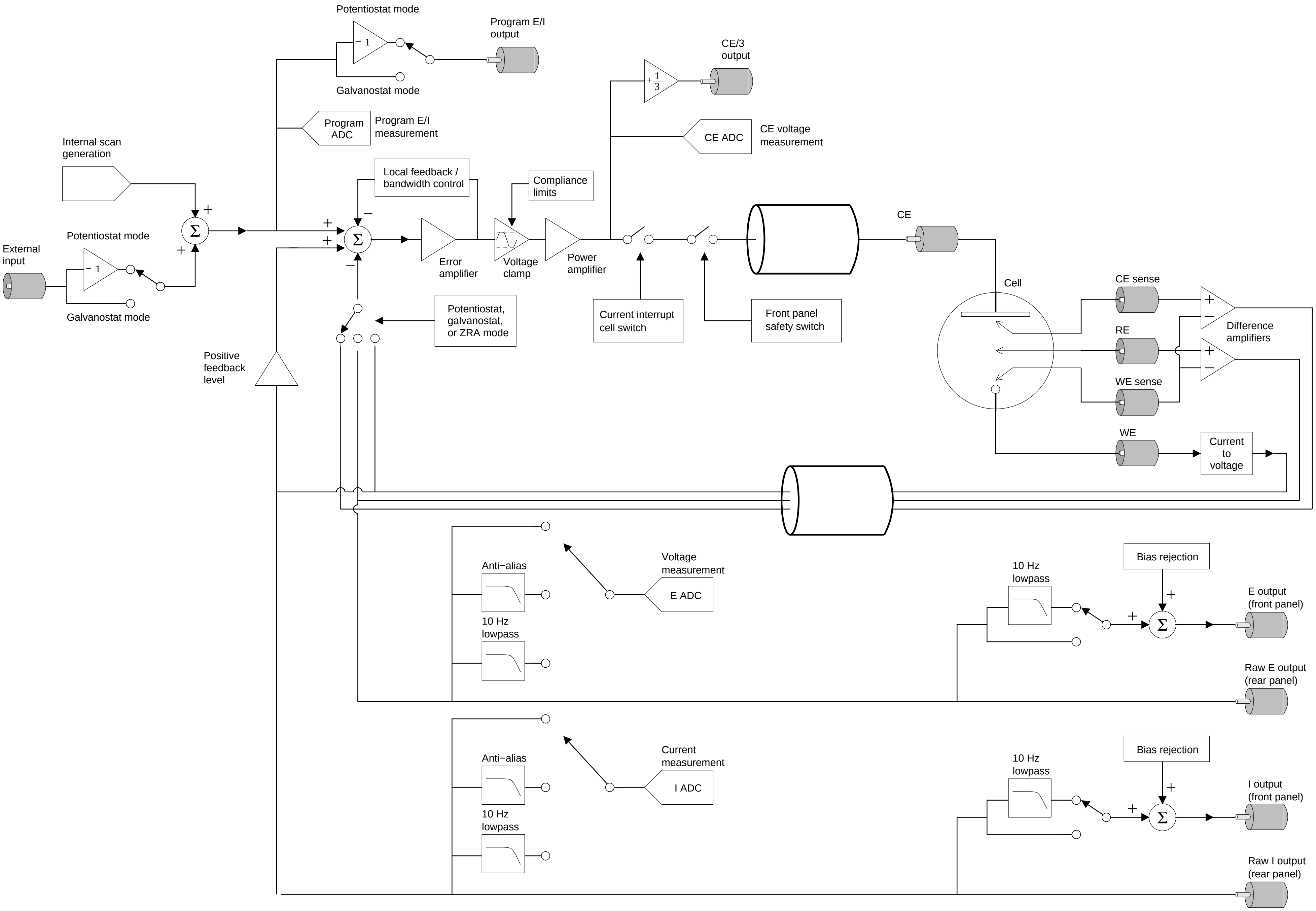


Figure 1: EC301 block diagram.

## 2.3 Polarity convention

The relative polarity of voltages and currents handled by the EC301 follows the American polarity convention. As illustrated in Fig. 2, this convention calls for cathodic (reducing) currents to be taken as positive. Voltages are programmed taking RE as the reference potential, so asking for +1V with the external input or the front panel will move the WE potential +1V above RE. We invert the polarity of the front and rear panel `VOLTAGE` outputs relative to the front panel display in order to accommodate frequency response analyzers (FRAs).

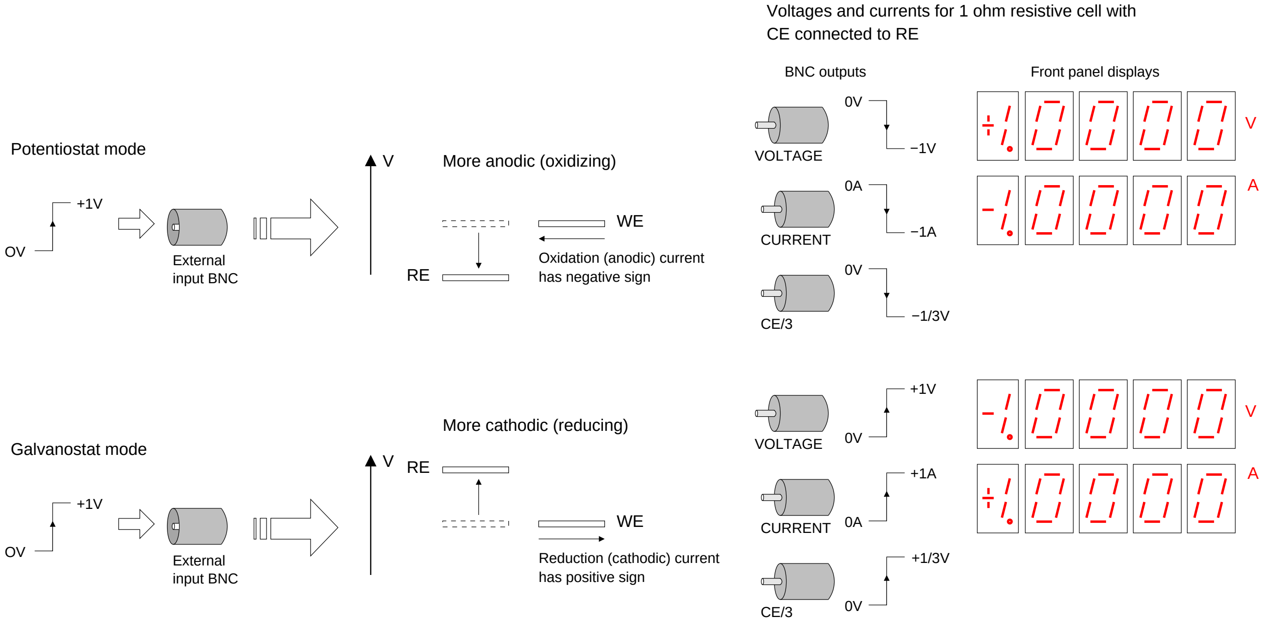


Figure 2: The EC301 uses the American polarity convention when applying voltages and currents.

## 2.4 Connecting the EC19 to the EC301

Before you do any electrochemical measurements with the EC301, you must first connect the EC19.

### 2.4.1 Necessary Items

In order to connect an EC19 to an EC301, you will need a flat blade screwdriver, and the umbilical cable. All items except the flat bladed screwdriver were provided in your EC301 shipment. Each item is pictured in Fig. 3.

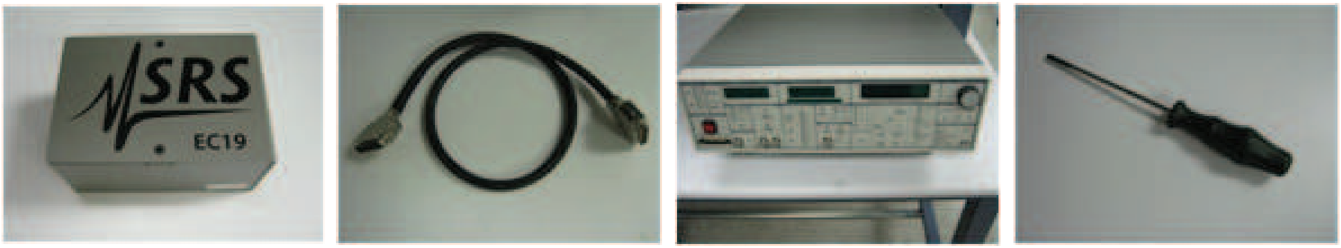


Figure 3: From left to right: EC19, umbilical cable, EC301, flat blade screwdriver.

### 2.4.2 Steps

1. Identify the connection points on the EC19. There are two jack screws on the rear panel of the unit, shown in Fig. 4.

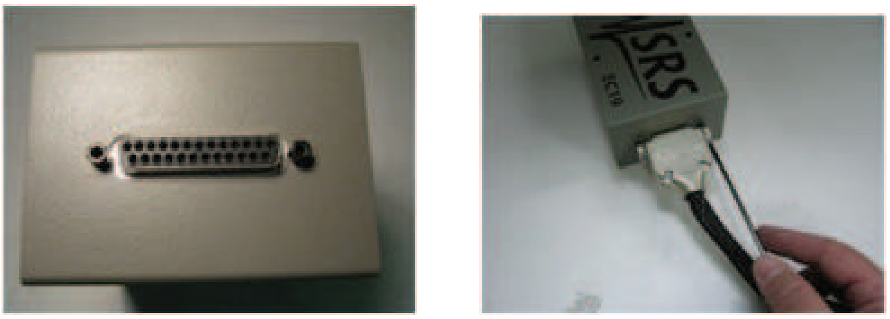


Figure 4: EC19 rear panel connector. Securing the umbilical cable.

2. Screw the umbilical cable screws into the jack screws of the EC19 as shown in Fig. 4.
3. Identify the connection points on the EC301. There are two jack screws on the front panel of the unit, shown in Fig. 5.

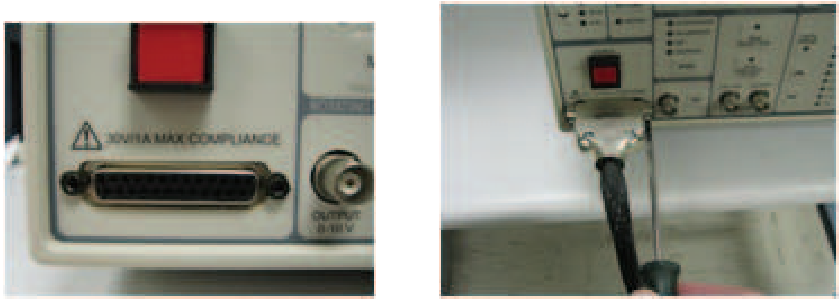


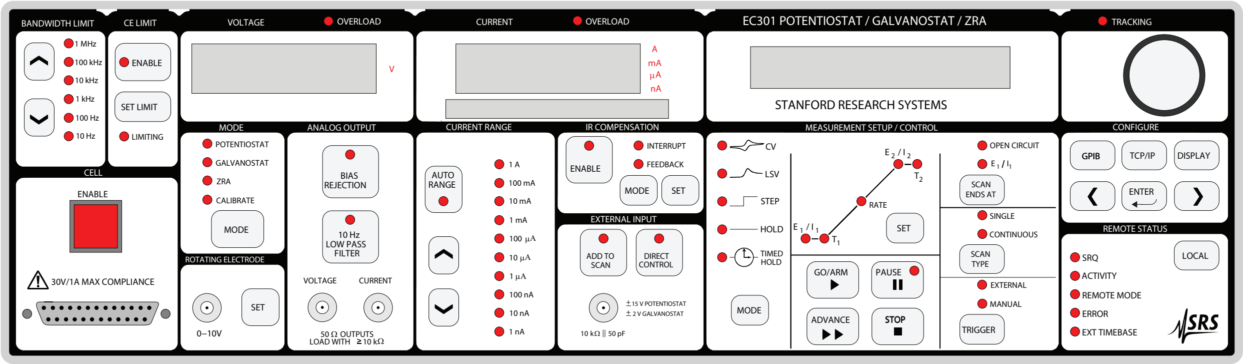
Figure 5: Front panel umbilical connector on EC301. Securing the umbilical cable to the EC301.

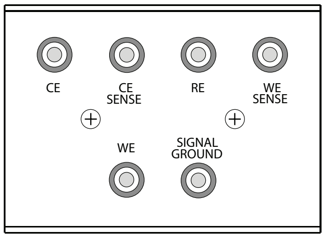
4. Screw the umbilical cable screws into the jack screws of the EC301 as shown in Fig. 5.
5. Power up the EC301 (switch is on rear panel). If you get any front panel errors about the EC19, turn off the EC301. Check the umbilical connection on both ends and power up the EC301 again. If errors persist, contact SRS.

# 3 Operation

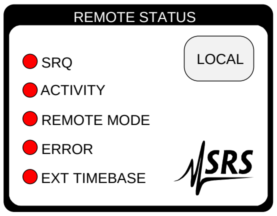
This manual will refer to a key with brackets such as [Key].

## 3.1 Front panel



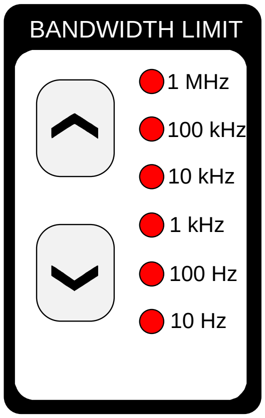


### 3.1.1 Power-on reset



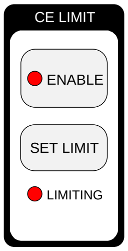
To restore the instrument to its factory-default settings from the front panel, hold down the `[LOCAL]` key while the power is turned on.

### 3.1.2 Bandwidth limit



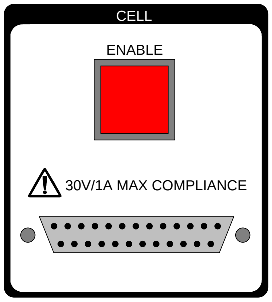
Use the [∧] and [∨] keys to increase or decrease the control bandwidth.

### 3.1.3 CE limit



The counter electrode (CE) voltage relative to ground can be limited to protect sensitive cells. Using the `[ENABLE]` key to enter the limiting mode allows reducing the maximum CE voltage from ±500mV to ±30 V. This maximum is adjusted by pressing the `[SET LIMIT]` key and turning the knob. The tracking light will indicate that the CE limit follows the knob movement.

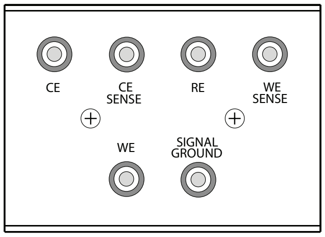
### 3.1.4 Cell



The external electrometer should be connected to the main box using this DB-25 connector. The umbilical should be securely fastened to this connector using the jack screws on either side.

Use the `[ENABLE]` switch to manually disconnect the CE from the power amplifier whenever you must come in contact with the cell electrodes. This switch is illuminated when the CE is connected to the control circuitry. When this switch is “in,” the instrument connects or disconnects the CE as needed. When “out,” the CE is always disconnected and the switch is dark.

### 3.1.5 External electrometer



The external electrometer face contains the counter electrode (CE) output, three electrometer inputs, the working electrode (WE) current input, and a grounded binding post. See section 4 for illustrations of how these inputs and outputs are used in different instrument modes.

CE (counter electrode) output: This is the output of the EC301's control amplifier. It can source or sink 1A into a -30V to +30V range.

CE SENSE input: This electrometer input is used with WE SENSE in ZRA mode to monitor the voltage between two typically identical electrodes. As shown in figure 12, it is named for usually being connected to the CE output.

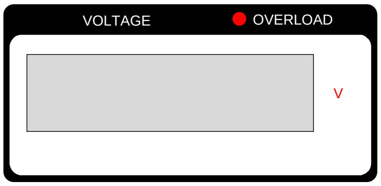
RE (reference electrode) input: As illustrated in figure 1, this electrometer input is used with WE SENSE to monitor cell potentials.

WE SENSE input: As illustrated in figure 1, this electrometer input is used with both the RE and CE SENSE electrodes to monitor cell potentials.

WE input: This input connects to a shunt resistor used to measure current flowing in the working electrode. The input resistance here will vary with the current range setting.

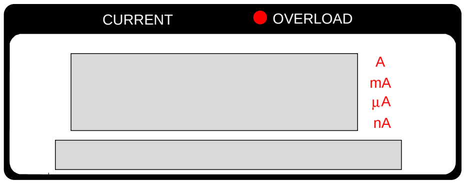
SIGNAL GROUND: This can be connected to a Faraday cage to isolate sensitive cells from electrical noise.

### 3.1.6 Voltage



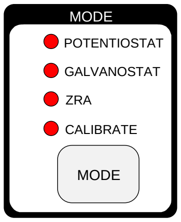
This display shows the results of the internal $V_{\mathrm{WE\ SENSE}} - V_{\mathrm{RE}}$ measurement. The OVERLOAD light indicates when the cell potential exceeds ±15 V relative to signal ground. Measurement accuracy will degrade from specifications outside of this range.

### 3.1.7 Current



This display shows the results of the internal cell current measurement. The OVERLOAD light indicates when current exceeds $\pm 2 \times I_{\mathrm{range}}$ or 1A, where $I_{\mathrm{range}}$ is the current range in use. Measurement accuracy will degrade from specifications during overloads.

### 3.1.8 Mode



Use the [MODE] key to cycle the EC301 through its various operating modes.

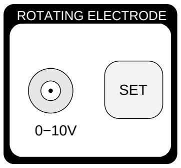
POTENTIOSTAT: control potential and measure current. In this mode, the EC301 controls the potential of the working relative to the reference electrode. The counter electrode is driven to whatever potential is necessary (within the ±30 V or the user-imposed compliance limits) to hold $V_{\mathrm{WE\ SENSE}} - V_{\mathrm{RE}}$ at the control (program) voltage.

GALVANOSTAT: control current and measure potential. In this mode, the EC301 controls cell current flowing through the working electrode. The counter electrode is driven to whatever potential is necessary to hold this current at the programmed value.

ZRA (Zero-resistance ammeter): hold two electrodes at the same potential. In this mode, the EC301 holds the counter and working electrodes at the same potential while current flows between them. Current flow with no potential drop implies no resistance – hence the name of the mode. The relative potential is sensed with the WE SENSE and CE SENSE connections, and the counter electrode is driven to hold this potential at zero.

CALIBRATE: This function is reserved for use by the factory.

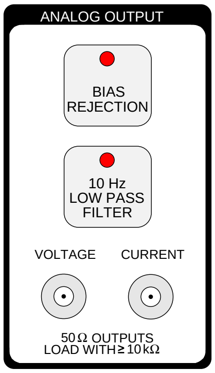
### 3.1.9 Rotating electrode



This DC voltage output can be used with an external control unit to control the speed of rotating working electrodes. Use the [SET] key to adjust the output voltage within 0 → 10V.

This output can source a maximum of 10 mA. The input impedance of the external control unit must be larger than 1 kΩ to achieve the maximum 10 V output.

### 3.1.10 Analog output



This section contains the `VOLTAGE` and `CURRENT` analog outputs as well as the `[BIAS REJECTION]` and `[10 Hz LOWPASS FILTER]` controls for modifying the outputs.

`VOLTAGE` output ($E_{\text{BNC}}$): This output is the potential of the reference electrode with respect to the working electrode, optionally subjected to a 10 Hz lowpass filter and/or bias rejection. The ±15 V output range is the same as the maximum polarization range.

`CURRENT` output ($I_{\text{BNC}}$): This output is proportional to current flowing in the working electrode ($I_{\text{WE}}$), optionally subjected to a 10 Hz lowpass filter and/or bias rejection. The output voltage is given by

$$I_{\text{BNC}} = 1\text{V} \times \frac{I_{\text{WE}}}{I_{\text{range}}}$$

where $I_{\text{range}}$ is the current range in use (1 mA, 10 mA, etc.). As described in section 2.3, $I_{\text{BNC}}$ becomes more positive when current flows into the working electrode (cathodic current).

The polarity at the `VOLTAGE` BNC output ($E_{\text{BNC}}$) is opposite that reported on the front panel displays. The voltage is thus $E_{\text{BNC}} = \text{V}_{\text{RE}} - \text{V}_{\text{WE SENSE}}$. We invert the polarity here to correct the sign of the cell impedance $Z_{\text{cell}}$ calculated with

$$Z_{\text{cell}} = \frac{E_{\text{BNC}}}{I_{\text{range}} \times I_{\text{BNC}}}$$

where $I_{\text{range}}$ is the current range in use and $I_{\text{BNC}}$ is the voltage at the `CURRENT` BNC output. See figure 2 for an illustration of BNC versus display polarities.

`[BIAS REJECTION]`: Bias rejection attempts to subtract off the DC component of the analog output voltages. This can be useful when making AC response measurements in the presence of a DC hold. Removing the DC component of a signal can allow the use of more sensitive input ranges on external equipment like frequency response analyzers.

When `[BIAS REJECTION]` is pushed, the EC301 will immediately average $\text{V}_{\text{RE}} - \text{V}_{\text{WE SENSE}}$ and $I_{\text{WE}}$ over a 1s window. It will then subtract those average values from all subsequent front panel $E_{\text{BNC}}$ and $I_{\text{BNC}}$ outputs. The averages will not update until bias rejection is turned off and then back on. Note that the `RAW E` and `RAW I` outputs on the rear panel always provide the $\text{V}_{\text{RE}} - \text{V}_{\text{WE SENSE}}$ and $I_{\text{WE}}$ measurements with no filtering or bias rejection.

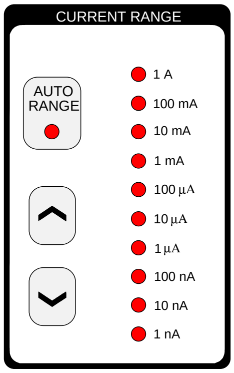
Bias rejection affects both analog outputs simultaneously when engaged from the front panel, but can be limited to either output when set up using the remote interface. The individual rejection levels can also be set arbitrarily instead of being automatically detected. See section 7.3.8 on page 75 for the appropriate remote commands.

Neither changing the current range nor enabling autoranging is allowed while bias rejection is active.

`[10 Hz LOW PASS FILTER]`: Use this key to simultaneously filter both the `VOLTAGE` and `CURRENT` analog outputs. The front panel filter has a 6 dB/octave rolloff with a -3 dB frequency of 10 Hz.

You can customize filter settings using the `lpfili` and `lpfile` commands described in section 7.3.8. These commands allow filtering a single output instead of both. Note that the `[10 Hz LOW PASS FILTER]` key will light whenever filtering is applied to either output.

### 3.1.11 Current range

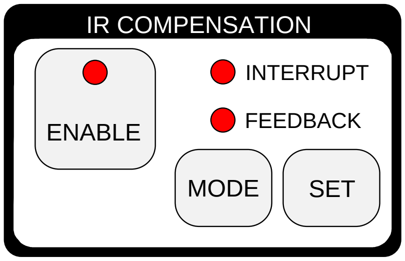


Use the [∧] and [∨] keys to select a current range. A cell current ($I_{\mathrm{WE}}$) equal to the selected current range ($I_{\mathrm{WE}} = I_{\mathrm{range}}$) gives 1 V at the `CURRENT` output BNC ($I_{\mathrm{BNC}} = 1$ V). Likewise, 1 V applied to the `EXTERNAL INPUT` BNC in galvanostat mode will generate a controlled current of $I_{\mathrm{range}}$.

Currents exceeding $\pm 2\times I_{\mathrm{range}}$ or ±1 A will generate an overload condition. While the EC301 can accept currents $\leq \pm 1$ A in any range without damage, measurement accuracy is degraded during overloads.

Use the `[AUTO RANGE]` key to toggle automatic selection of $I_{\mathrm{range}}$ based on the measured cell current. Note that auto-ranging is not allowed in galvanostat mode.

### 3.1.12 IR compensation



IR compensation involves adding an "extra" voltage to the control (program) voltage to compensate for drops between `RE` and `WE`. Use the `[MODE]` key to toggle between two ways of generating this voltage: positive feedback and current interrupt. Compensation will not be applied until the `[ENABLE]` key is pressed.

`INTERRUPT` mode: Figure 6 illustrates the parameters used for current interrupt when engaged from the front panel. In this mode, the `CE` is periodically disconnected from the control electronics to interrupt the cell current. This removes any IR drop between the reference and working electrodes, causing $|V_{\mathrm{WE\ SENSE}} - V_{\mathrm{RE}}|$ to drop by $\Delta V_{\mathrm{ir}}$. The EC301 then takes two samples of $|V_{\mathrm{WE\ SENSE}} - V_{\mathrm{RE}}|$ to measure this drop – one after interruption, and one after control is restored. This value, along with the percent correction factor, is used to calculate the boost potential $\Delta V_{\mathrm{b}}$ added to the program voltage.

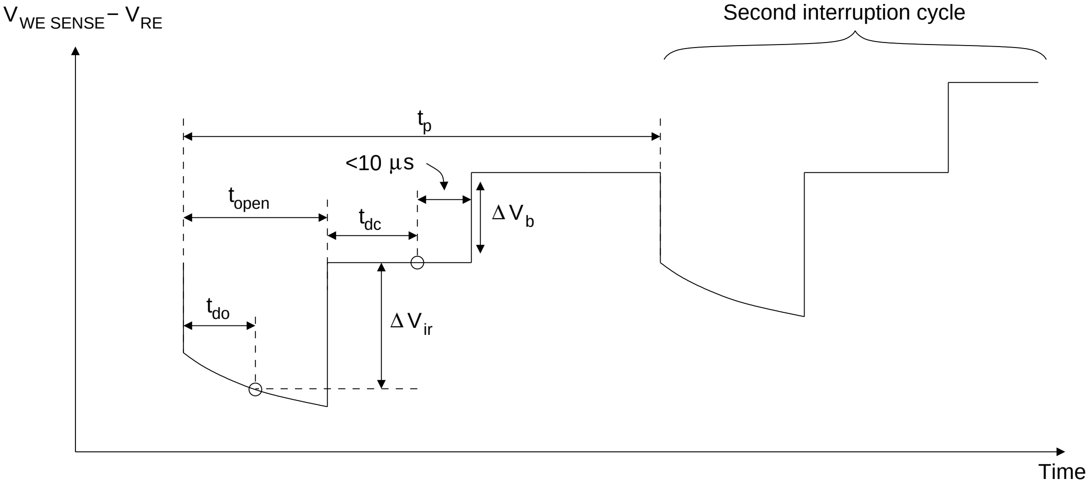


Figure 6: Cell potentials during current interrupt IR compensation. Default values for the various parameters are shown in table 1.

Use the `[SET]` key in `INTERRUPT` mode to adjust the percent correction factor – the only parameter than can be set from the front panel. The other parameters shown in figure 6 are set to the default values shown in table 1.

| Parameter | Default value | Remote command |
|---|---|---|
| $t_{\mathrm{p}}$ | 100 ms (10 Hz) | `ciperd` (see page 72) |
| $t_{\mathrm{open}}$ | 200$\mu$s | `ciopen` (see page 71) |
| $t_{\mathrm{do}}$ | 120$\mu$s | `cidlay` (see page 72) |
| $t_{\mathrm{dc}}$ | 200$\mu$s | |

Table 1: Default values for current interrupt parameters. These values are used when current interrupt is engaged using the front panel.

The current interrupt parameters can be adjusted away from their default values using the remote interface. See section 7.4.3 on page 119 for an example.

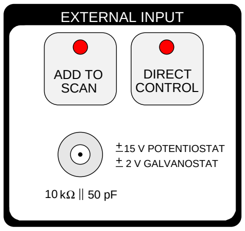
`FEEDBACK` mode: Positive feedback IR compensation adds a boost voltage $I_{\mathrm{WE}} \times R_{\mathrm{u}}$ to the program voltage, where $R_{\mathrm{u}}$ is the uncompensated resistance parameter.

Use the `[SET]` key in `FEEDBACK` mode to adjust $R_{\mathrm{u}}$. The allowed ranges for $R_{\mathrm{u}}$ in each current range are shown in table 2.

| $I_{\mathrm{range}}$ | $R_{\mathrm{u}}$ |
|---|---|
| 1 A | $0 \to 3\ \Omega$ |
| 100 mA | $0 \to 30\ \Omega$ |
| 10 mA | $0 \to 300\ \Omega$ |
| 1 mA | $0 \to 3\ \mathrm{k}\Omega$ |
| 100 $\mu$A | $0 \to 30\ \mathrm{k}\Omega$ |
| 10 $\mu$A | $0 \to 300\ \mathrm{k}\Omega$ |
| 1 $\mu$A | $0 \to 3\ \mathrm{M}\Omega$ |
| 100 nA | $0 \to 30\ \mathrm{M}\Omega$ |
| 10 nA | $0 \to 300\ \mathrm{M}\Omega$ |
| 1 nA | $0 \to 3\ \mathrm{G}\Omega$ |

Table 2: Allowed $R_{\mathrm{u}}$ ranges for each current range.

### 3.1.13 External input



The EC301 can take its control voltage directly from the external analog input, allowing its use with function generators and frequency response analyzers. These control voltages can be used by themselves or added to internally-generated scans.

In potentiostat mode, voltages applied at the external input will be applied to the cell according to the American Polarity Convention described in section 2.3. This input has unity gain: +1 V applied at the input will change $(V_{\mathrm{WE\ SENSE}} - V_{\mathrm{RE}})$ by +1 V. The input thus accepts the full ±15 V allowed polarization range.

In galvanostat mode, controlled current is given by

$$I_{\mathrm{WE}} = I_{\mathrm{range}} \left( \frac{V_{\mathrm{ext}} + V_{\mathrm{prog}}}{1V} \right)$$

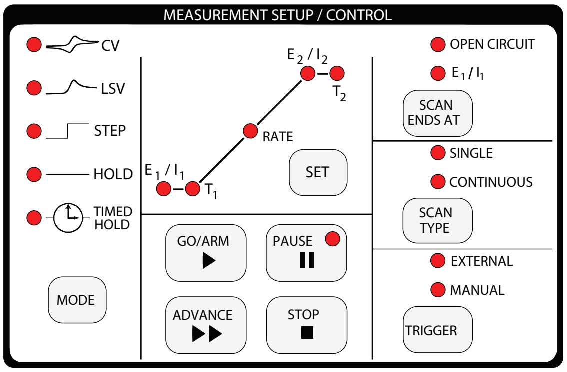
where $V_{\mathrm{ext}}$ is the voltage applied at the external input and $V_{\mathrm{prog}}$ is the internally-generated program voltage. Currents greater than $2 \times I_{\mathrm{range}}$ or 1 A will generate overloads, so the external input's range in this mode is ±2 V for $I_{\mathrm{range}} < 1$ A, and ±1 V for $I_{\mathrm{range}} = 1$ A. The polarity is again taken from the American Polarity Convention described in section 2.3.

Use the `[ADD TO SCAN]` key to toggle adding the external input voltage to internally-generated scans or holds. This key leaves engaging the control loop (lighting the `CELL` button) up to the scan controls.

Use the `[DIRECT CONTROL]` key if potentials or currents to be applied to the cell come only from the external input. If the cell is enabled (via the `CELL` button), `[DIRECT CONTROL]` engages or disengages the control loop, taking control voltages or currents solely from the external input.

The external input is ignored (taken as 0 V) if both the `[ADD TO SCAN]` and `[DIRECT CONTROL]` lights are dark.

### 3.1.14 Measurement setup/control

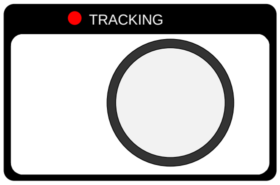


A variety of automatic scans and holds can be programmed from the EC301's front panel. Once the scan type is selected, you will be prompted for a set of necessary parameters. When [GO/ARM] is pressed with a MANUAL trigger setting, the EC301 will engage control, apply the scan, and remove control as required by the scan end condition.

Use the [MODE] key to select a scan type. These types are described in section 5 on page 50.

Use the [TRIGGER] key to select the action of [GO/ARM]. In MANUAL mode, the programmed scan will begin when [GO/ARM] is pressed. In EXTERNAL mode, pressing [GO/ARM] will "arm" the EC301 – preparing it to scan with the next rising or falling edge received at the rear panel SCAN TRIGGER input. This allows the scan to be triggered by other experimental events. See section 3.2.6 on page 34 for more information about the SCAN TRIGGER input.

### 3.1.15 Knob

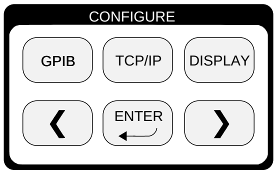


Use the knob to enter numbers via the character display. The knob is velocity-sensitive, so experiment with different rotation speeds to set large numbers.

The TRACKING indicator will light when turning the knob will immediately affect cell conditions. For example, if a hold has been engaged from the front panel (control loop is engaged – big red CELL button is lit) and the [SET] key is pressed to adjust $E_1/I_1$, TRACKING will light to indicate that cell polarization is moving with the knob. This allows manually adjusting polarization while observing other cell characteristics – "thumb-wheel scanning."

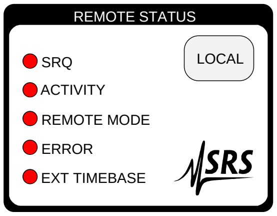
Most parameters can be "locked in" by re-pushing the same key used to set them. For example, pushing [SET] once to adjust the $E_1$ of a hold will allow will allow $E_1$ to be freely changed with the knob. Pushing [SET] again will lock the value in and disable the knob. The value will also be locked in if a [SET] key from another section is pressed. In general, moving on to another setting will lock the previous one.

### 3.1.16 Configure



Use this section to configure the remote interface (LAN, GPIB) and to cycle through the various display modes.

### 3.1.17 Remote status



The indicators in this section describe the status of the remote (GPIB or LAN) interface and the external timebase.

SRQ: This indicator is on whenever a service request (SRQ) is generated by the EC301. It will stay on until the status register (INSR, MESR, or *ESR) causing the SRQ is cleared. See figure 29 on page 99 for a description of how status bit values are promoted to cause SRQs.

ACTIVITY: This indicator flashes when there is activity on the remote interface.

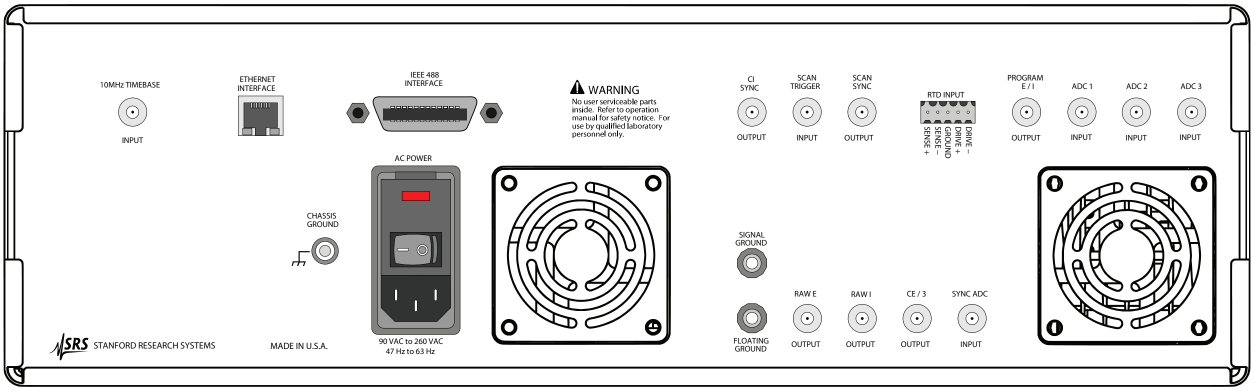
REMOTE MODE: This indicator is on when the front panel is locked out by the remote interface. No front panel adjustments may be made until the [LOCAL] key is pressed.

ERROR: This indicator flashes when there is a remote interface error such as an illegal command or an out of range parameter.

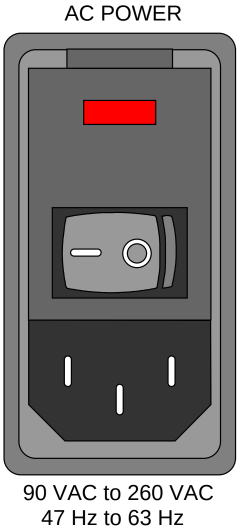
EXT TIMEBASE: The EC301 can accept an external 10 MHz timing signal to improve the accuracy and stability of automatic scans. This indicator will light when such a timing signal is detected.

[LOCAL]: The remote command LOCKFP can lock out the front panel keyboard. Use the [LOCAL] key to exit this mode and enable the front panel keys.

## 3.2 Rear panel

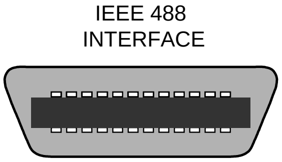


### 3.2.1 Power entry



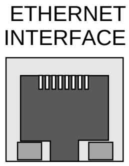
The power entry module is used to fuse the AC line voltage input and to block high frequency noise from entering or exiting the instrument.

### 3.2.2 GPIB interface



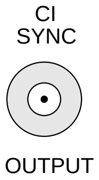
The 24 pin GPIB connector allows a computer to control the EC301 via the GPIB (IEEE-488) instrument bus. The GPIB address is set with the front panel [GPIB] key.

### 3.2.3 Ethernet interface



There are two LEDs on the RJ-45 ethernet connector. The green LED lights only when the system is transmitting. The yellow LED lights whenever it sees any packet on the wire. This includes packets not destined for the EC301.

### 3.2.4 Current interrupt synchronization



This digital output allows triggering an oscilloscope or other data acquisition at the beginning of current interruption. This output will be brought low before just before interruption begins and returned high after it ends. The timing diagram is shown in figure 7.

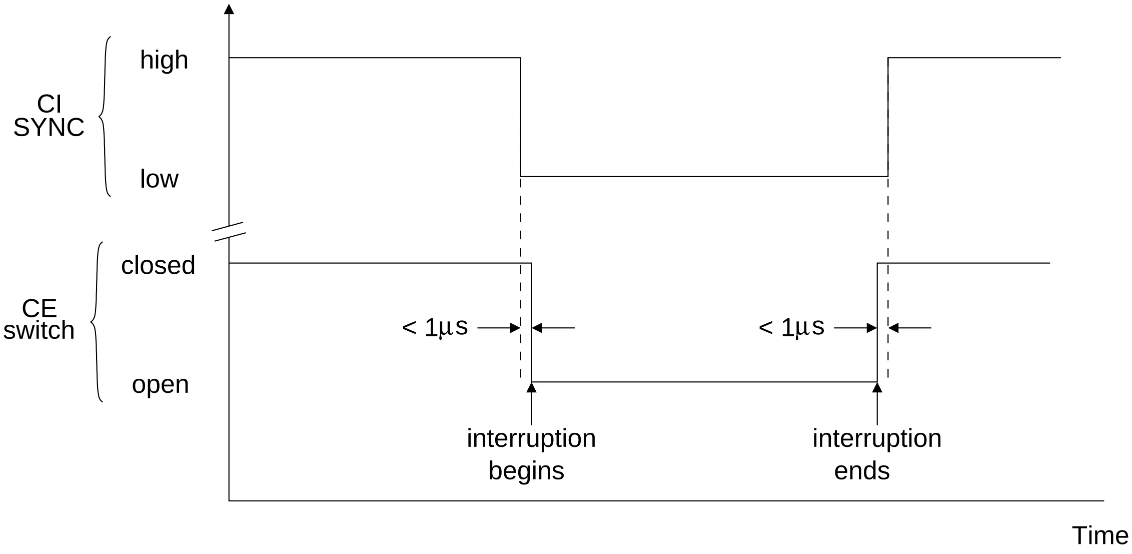
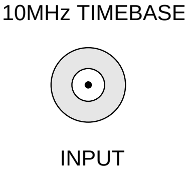


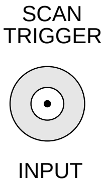
Figure 7: Timing diagram for the `CI SYNC` digital output.

### 3.2.5 Timebase synchronization input

This BNC can accept a 10 MHz reference signal from an external source to improve the stability of the internal clock. The external source should be greater than 1V peak-to-peak and should be within ±2 ppm of 10 MHz.

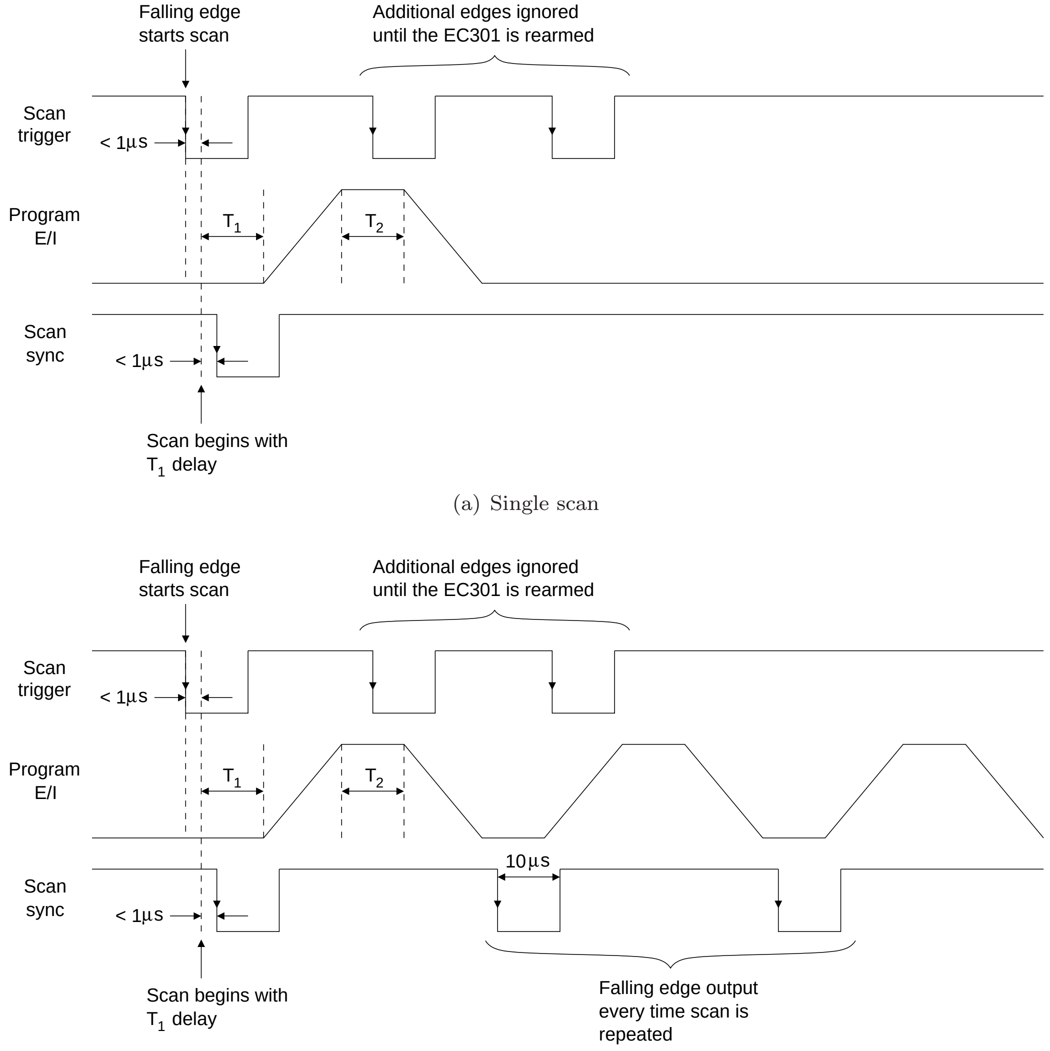


### 3.2.6 Scan trigger input



This input allows starting an automatic scan with external equipment. As illustrated in figure 8, an falling edge here will begin the scan within 1$\mu$s.

The EC301 must be "armed" from the front panel or the remote interface to use this input. See section 3.1.14 on page 29 to set this condition from the front panel. See the `trgarm` command described on page 73 to arm with the remote interface.


Falling edge starts scan
Additional edges ignored until the EC301 is rearmed
Scan trigger
< 1µs
Program E/I
T1
T2
Scan sync
< 1µs
Scan begins with T1 delay
Falling edge starts scan
Additional edges ignored until the EC301 is rearmed
Scan trigger
< 1µs
Program E/I
T1
T2
10µs
Scan sync
< 1µs
Scan begins with T1 delay
Falling edge output every time scan is repeated

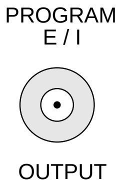
(a) Single scan

(b) Continuous scan

Figure 8: Timing diagrams for the `SCAN TRIGGER` input and the `SCAN SYNC` output using falling edge trigger polarity.

Why do these scans have flat "tops?" Figure 8 illustrates both CV and LSV scans triggered by the rear panel scan trigger input. Since the `OPEN CIRCUIT` end condition isn't allowed for this trigger mode, LSV scans must track back to their initial state after $T_2$ – making them look like CV scans with flat tops. The two scans would look identical for $T_2 = 0$.

### 3.2.7 Program $E/I$ output

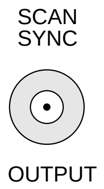


This output is a copy of the input to the EC301's control circuitry. As illustrated in figure 1, it is the sum of the external input and the internal scan voltages.

When used with current interrupt IR compensation, this output provides the "corrected" potential applied to the working electrode. It can be used to plot IR-compensated data on xy plotters and displays.

This output will reflect the input to the EC301's control circuitry even when the control loop is open. For example, starting a +1V hold from the front panel (without any external input voltage) will move `PROGRAM E/I` to −1V. Stopping the hold won't change this output – it will remain at −1V until a new scan is configured and run. Note that the polarity for this output is consistent with the front-panel `VOLTAGE` output described in section 2.3 on page 19.

### 3.2.8 Scan synchronization output



This output allows triggering an oscilloscope or synchronizing other data acquisition using with the start of a scan. As illustrated in figure 9, this output is brought low immediately before the scan begins and before every scan repetition during continuous scans. The output is held low for 10 $\mu$s before returning high, which limits the rate to roughly 50 kHz. The EC301 can not reliably send trigger pulses for repetition rates faster than this.

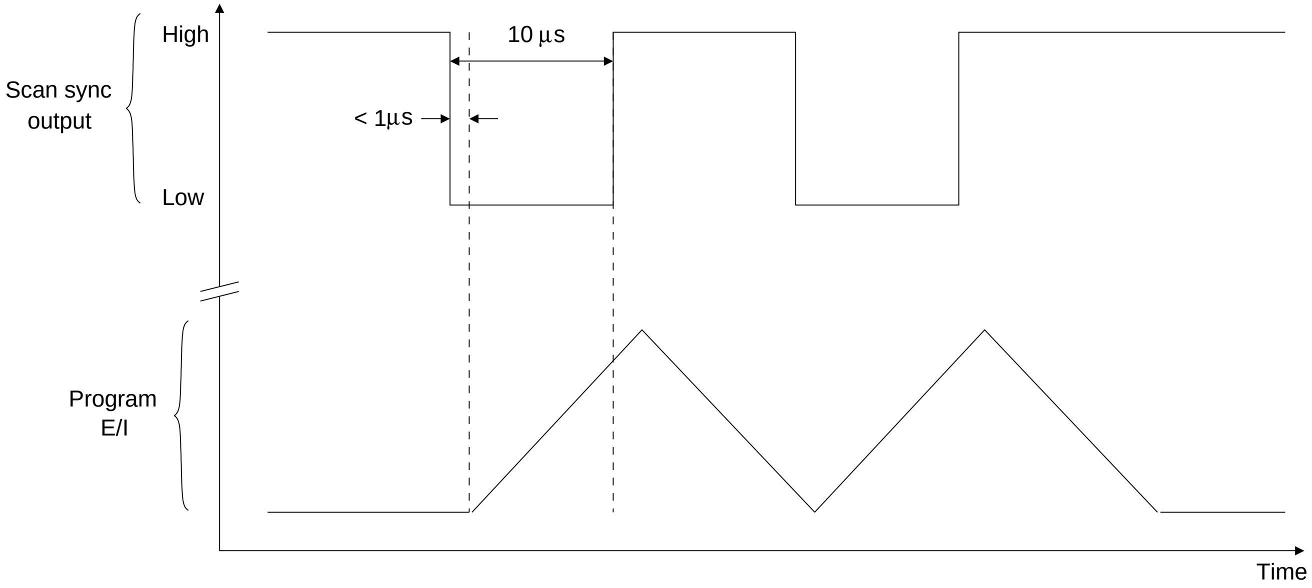
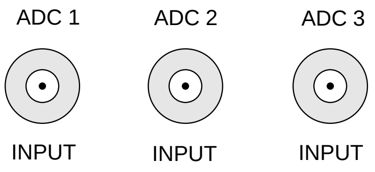


Figure 9: The SCAN SYNC output is brought low at the beginning of a scan and held there for 10 $\mu$s.

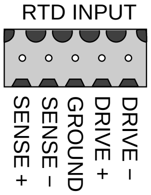
### 3.2.9 Auxiliary ADC inputs (1-3)



These ±10 V inputs allow monitoring analog signals like flow rate, pH, or temperature along with $E$ and $I$ data. Using the remote interface, data from these inputs can be synchronized with $E$ and $I$ collection to within 1 ms. Use the synchronous ADC input described in section 3.2.14 on page 43 for tighter timing requirements.

Use the `getaux?` command described on page 80 to acquire data from these BNCs using the remote interface

### 3.2.10 Resistance temperature detector (RTD) input



The EC301 can accept standard 100Ω Pt RTD probes for logging experimental temperatures. The probe temperature is determined with a 4-wire measurement of the probe resistance. As illustrated in figure 10, commercial 4-wire RTDs normally have two wires of the same color connected to one end of the resistive sensor, and two wires of a different color connected to the opposite end. One of each pair carries the drive current used in the measurement, and the other is used to sense the voltage induced by this current. The "drive" and "sense" leads are interchangeable.

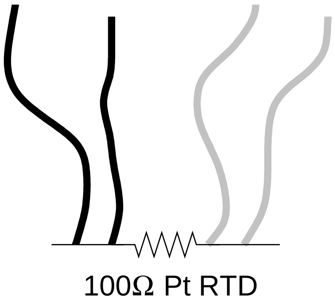


Figure 10: Commercial 4-wire RTD probes have two wires with the same color attached to each end.

These 4-wire sensors are connected to the EC301 in one of two electrically-identical ways illustrated in figure 11. Notice that the signs of the `DRIVE` and `SENSE` inputs match for the same color of wire. Any other wire configuration will give no temperature reading when the probe is connected.

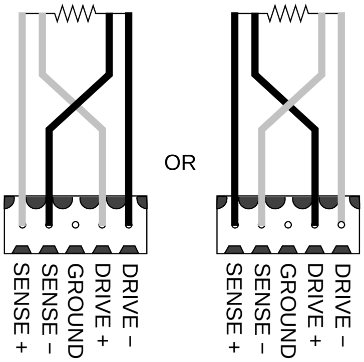
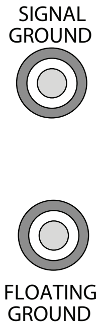


Figure 11: 4-wire probes can be connected to the EC301 in one of these two ways.

RTD sensor wires are connected to the RTD input using 5-pin Weidmuller plugs (Weidmuller part number 169045). These plugs use a tension clamp to hold the wires in place. To install the wires:

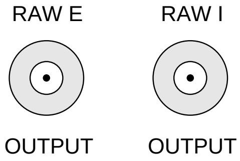
1. Hold the plug in front of you with the five small holes on top and the five larger holes on the bottom.
2. In each hole is a metal clip. Place a small screwdriver into one of the small holes and firmly push it in to the small gap above the clip. The screwdriver should go in about half an inch. The thickness of the screwdriver shaft pushes the clip down toward the larger hole.
3. The larger hole should open up. Place a stripped wire into the hole and remove the screwdriver.

### 3.2.11 Grounding posts



**These grounding posts should be connected together unless the cell's working electrode is intrinsically grounded.** Disconnecting these isolates the CE-to-WE current path from earth ground, allowing measurements with grounded working electrodes. See section 4.2 for more information on this situation.

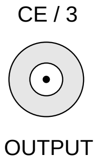
### 3.2.12 Raw analog outputs



These outputs carry the same signals as their counterparts on the front panel, but without any bias rejection or filtering. See section 3.1.10 for a better description of the $E$ and $I$ output voltages. The same polarity convention applies to both the front and rear panel outputs.

The output resistance of these sources is 50Ω – the same as for those on the front panel. The input resistance of whatever these outputs are connected to should exceed 10kΩ to keep loading errors below 1%.

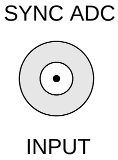
### 3.2.13 CE monitor



This output provides the counter electrode (CE) voltage relative to floating ground divided by 3. If signal and floating grounds are connected together, this output will span ±10 V as the CE spans ±30 V. As with the raw $E$ and $I$ outputs, this signal is not affected by bias rejection or filter settings.

The output resistance of this source is 50Ω. The input resistance of whatever this is connected to should exceed 10kΩ to keep loading errors below 1%.

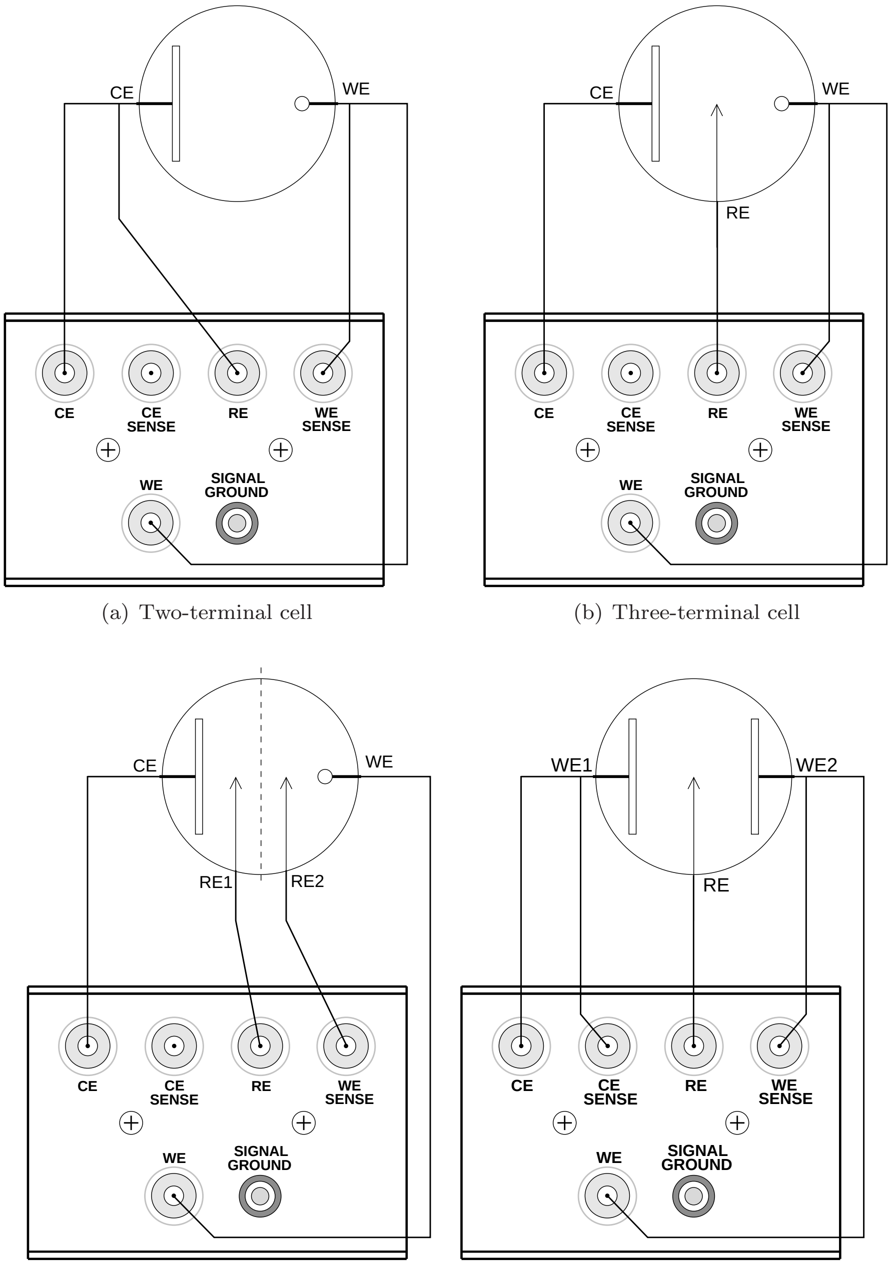
### 3.2.14 Synchronous ADC input



This ±10 V analog input allows sampling external signals simultaneously with the $E$ and $I$ measurements. The EC301 has separate ADCs devoted to the $E$, $I$, and synchronous ADC measurements. All three ADCs share the same sample control signal to ensure simultaneous measurements.

# 4 Making cell connections

Figures 12a, b, and c illustrate how the EC301 should be used with cell configurations in potentiostat and galvanostat modes. Figure 12d illustrates typical cell connections during an experiment using ZRA mode.



(a) Two-terminal cell

(b) Three-terminal cell

(c) Four-terminal cell

(d) ZRA mode

Figure 12: Making cell connections

Probing electrode voltages with a standard oscilloscope probe can cause problems with grounding and noise. See appendix A for more details.

## 4.1 Floating operation

The EC301 was designed with floating operation in mind. Users may operate on a Working Electrode (WE) that is intrinsically grounded, or they may wish to strap the Counter Electrode (CE) to earth ground for safety reasons. The EC301 will accommodate those measurements, but there are some configuration adjustments that must be made.

### 4.1.1 Overview

For floating operation, remove the factory-installed shorting bar that ties the “signal ground” and the “floating ground” together (see Fig. 13). Pull the bar away from the instrument to remove it.

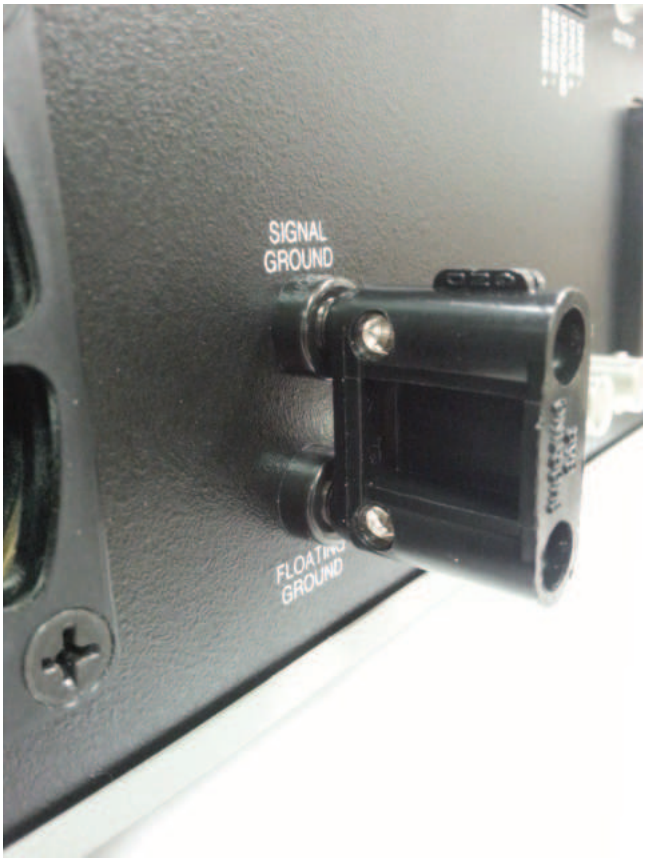


Figure 13: EC301 grounding bar (installed).

The signal ground is an internal reference which is maintained at close to chassis ground potential. The floating ground is a separate reference that is free to reach a potential difference up to ±8 volts from signal ground. In the event the potential between signal and floating grounds exceeds this limit, the instrument will not be damaged. In this case, the CE limit will be activated and the potential across the cell will not be well-controlled.

The EC301 grounding scheme leaves all the connectors on the chassis unaffected by floating operation. Instruments such as oscilloscopes and frequency response analyzers often tie other instruments' chassis to earth ground once a BNC cable is attached between them. This is permissible even when the EC301 is floating, because the BNC shells are tied to chassis ground and not floating ground. This enables EIS (electrochemical impedance spectroscopy) even on working electrodes that must float.

Floating operation necessitates some trade-offs in performance. The EC301 specifications only apply when the signal and floating grounds are connected on the rear panel by the supplied shorting bar (i.e. when the instrument is *not* floating).

### 4.1.2 Grounded Working Electrode

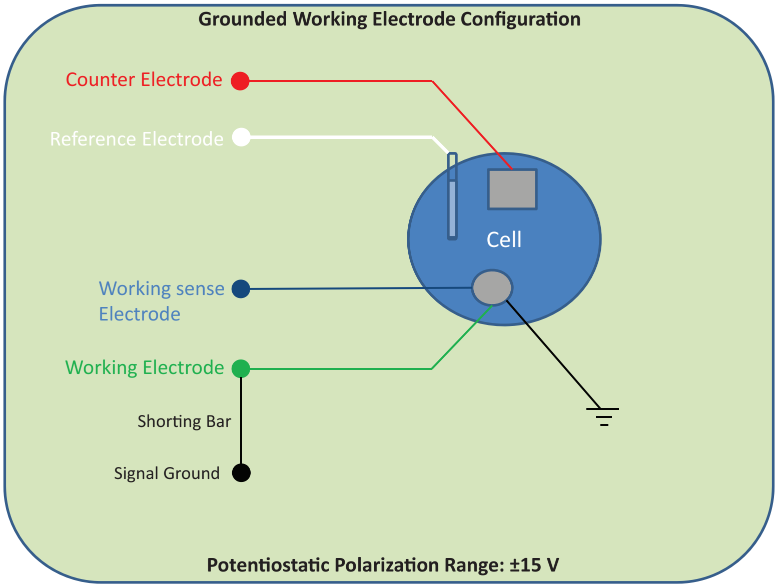


Figure 14: Grounded working electrode configuration.

Once you have removed the shorting bar from the rear panel of the instrument (see Overview, above), install it between the two banana jacks on the EC19 labeled "WE" and "SIGNAL GROUND" (see Fig. 15). The shorting bar provides a low impedance path between the intrinsic ground at the cell and the EC301 internal reference ground, improving noise performance and adding stability to the current meter.

Make the rest of the connections from the EC19 to the cell as normal. Under these conditions, the full ±15 V potentiostatic polarization range is available.

### 4.1.3 Grounded Counter Electrode

Once you have removed the shorting bar from the rear panel of the instrument (see Overview, above), you are ready to begin measurements in this configuration. You may achieve somewhat improved noise performance by attaching a jumper between CE and signal ground.

When you tie the CE to Earth ground, be aware that the full potentiostatic polarization range is not available. In this configuration, the potentiostatic set point dictates the potential between signal and floating ground. The maximum polarization range under these conditions is ±8 V.

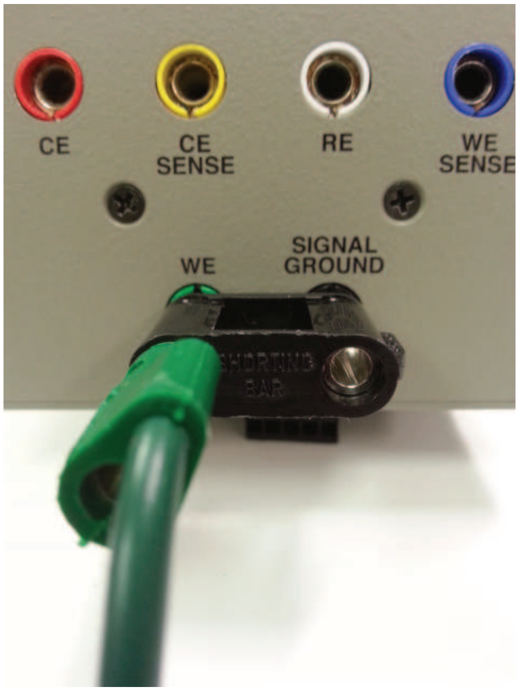


Figure 15: Grounding WE at the EC19.

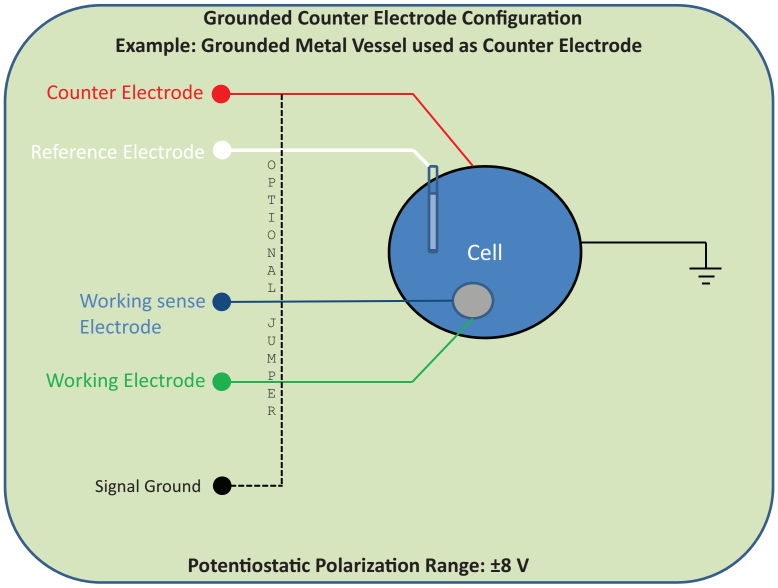

Grounded Counter Electrode Configuration
Example: Grounded Metal Vessel used as Counter Electrode
Counter Electrode
Reference Electrode
OPTIONAL JUMPER
Cell
Working sense Electrode
Working Electrode
Signal Ground
Potentiostatic Polarization Range: ±8 V

Figure 16: Grounded counter electrode configuration.

## 4.2 Working with grounded electrodes

Grounded electrodes are those inextricably connected to earth ground. Figure 17 illustrates cathodic protection of a buried pipeline, in which the counter and working electrodes are necessarily buried in and thus connected to earth. Figure 18a illustrates the proper current circuit in this situation: out of the power amplifier, through the CE and WE electrodes, through the WE shunt resistor, and back to the power amplifier through floating ground. If, however, the floating and signal ground binding posts described in section 3.2.11 are left connected, current can bypass the WE entirely. Figure 18b shows current flowing out of the CE and being returned to the power amplifier through earth ground, which has a low-resistance connection to signal ground. The rear panel signal and floating grounds should thus be disconnected when making measurements with grounded electrodes.

**The rear panel ground banana jacks should only be disconnected when necessary. Reconnect them when using isolated cells to improve frequency response.**

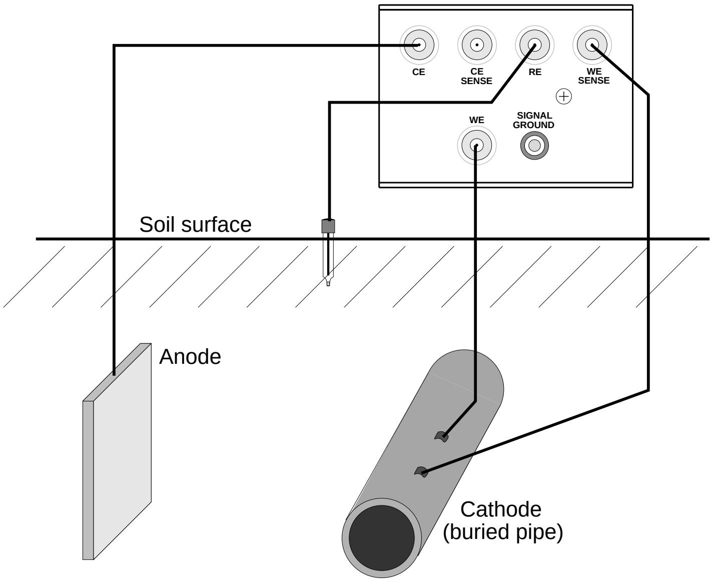
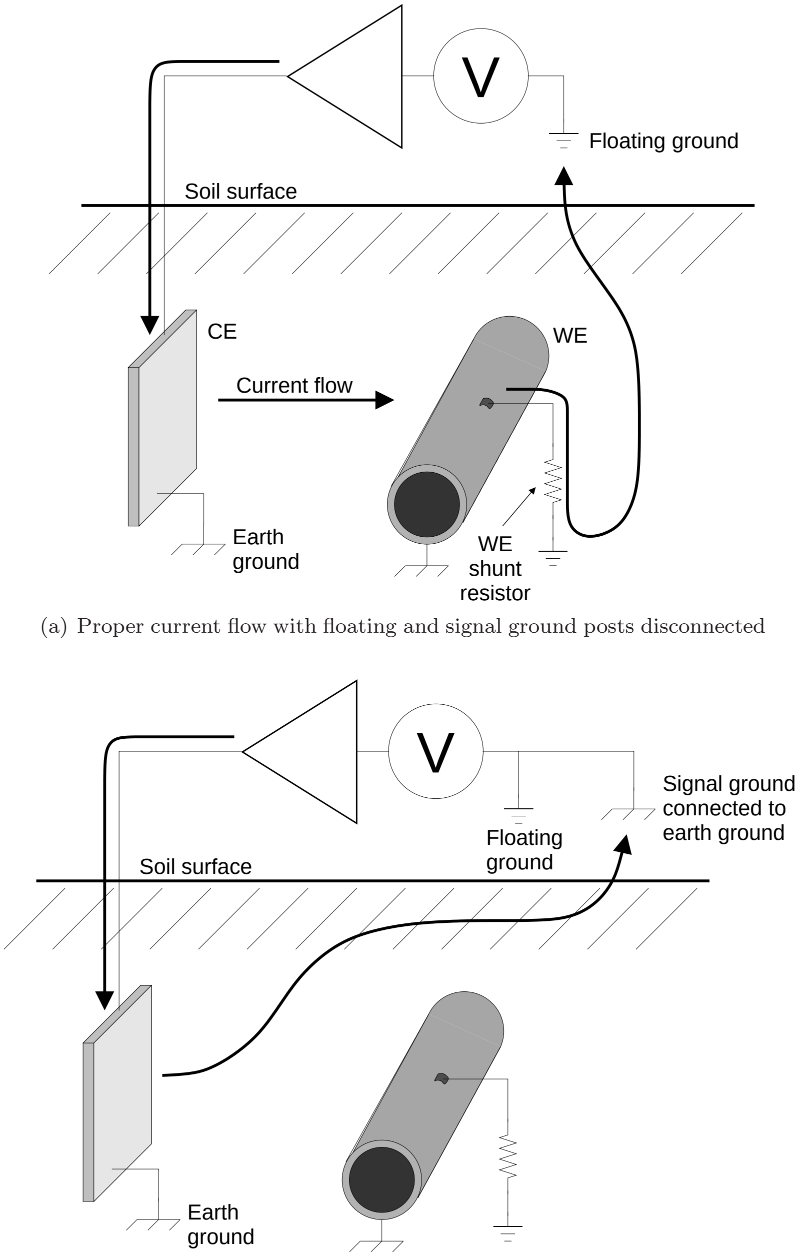


Figure 17: Buried and inextricably grounded electrodes used in cathodic protection.



(a) Proper current flow with floating and signal ground posts disconnected

(b) One of many undesired current flow paths with floating and signal ground posts connected

Figure 18: Disconnecting the signal and floating ground terminals on the EC301 allows current to flow in circuits including earth ground.

# 5 Performing scans using the front panel

## 5.1 Setting scan parameters – potentiostat mode

### 5.1.1 Cyclic voltammetry (CV)

Figure 19 illustrates the parameters needed to specify a CV scan. The procedure is as follows:

1. Use the `[MODE]` key to select `CV`.

2. Cycle through the required parameters using `[SET]`, adjusting values using the knob. Times are adjusted using the knob for individual fields, and the arrow keys described in section 3.1.16 on page 30 to move between the fields shown below.

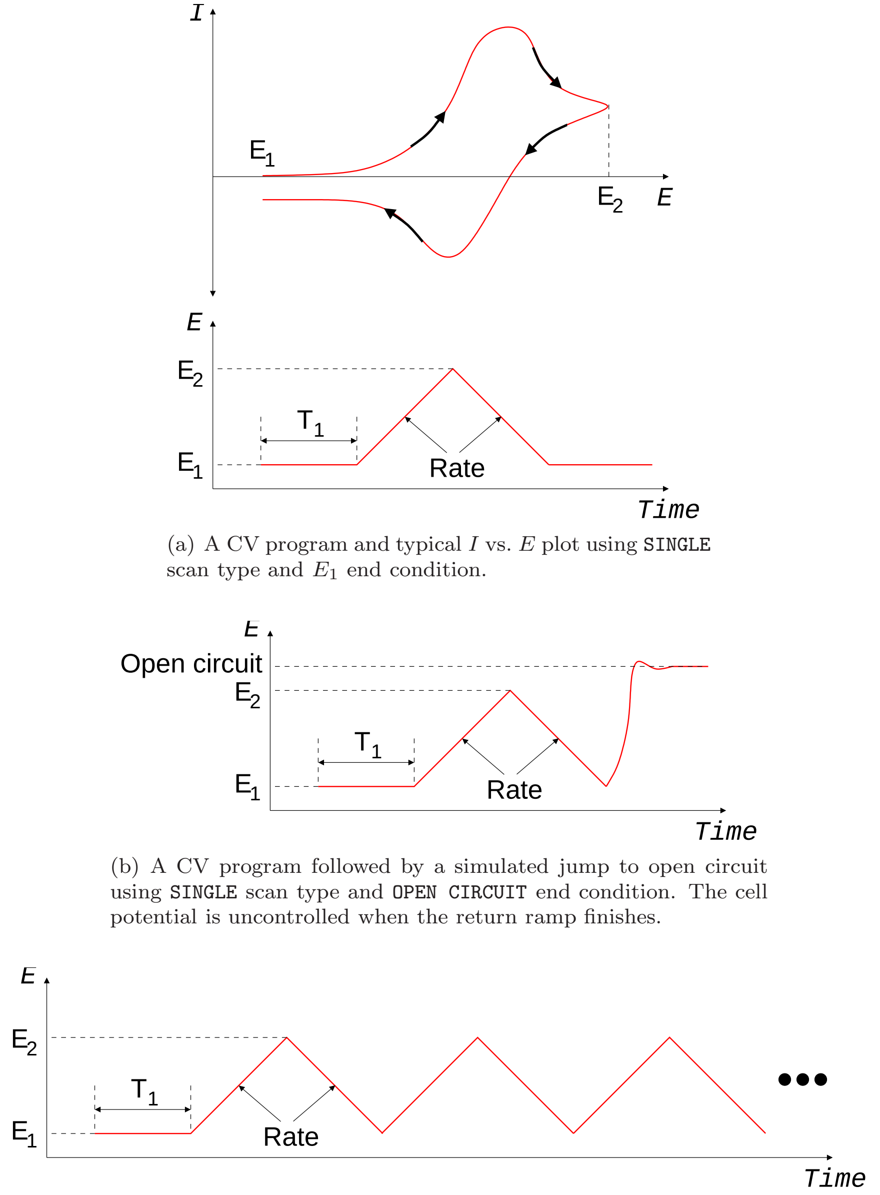
   $$\underbrace{00}_{\text{hours}} : \underbrace{00}_{\text{minutes}} : \underbrace{00}_{\text{seconds}} : \underbrace{0000}_{\text{seconds}/10^4}$$

   The maximum hold time for a CV is 99:59:59.9999 (100 $\mu$s short of 100 hours). The setability is in 100 $\mu$s steps.

3. Choose the scan end condition. Figure 19(a) illustrates the cell potential for the $E_1$ end condition, while 19(b) shows it for `OPEN CIRCUIT`.

4. Choose `SINGLE` or `CONTINUOUS` scanning. Single scans, illustrated in figures 19(a) and (b), go to the end scan condition after reaching $E_1$ on the return ramp. Continuous scans, illustrated in figure 19(c), immediately turn around to repeat the forward ramp and then the entire triangle-shaped waveform.

5. Choose the trigger mode. `MANUAL` allows the `[GO/ARM]` key to trigger the scan, while `EXTERNAL` mode requires the rear panel scan trigger input. See section 5.4 on page 61 for a better description of scan triggers in general, and section 3.2.6 on page 34 for a description of the rear panel scan trigger.



(a) A CV program and typical $I$ vs. $E$ plot using `SINGLE` scan type and $E_1$ end condition.

(b) A CV program followed by a simulated jump to open circuit using `SINGLE` scan type and `OPEN CIRCUIT` end condition. The cell potential is uncontrolled when the return ramp finishes.

(c) A CV program using `CONTINUOUS` scan type. The triangle-shaped program continues indefinitely.

Figure 19: Parameters used to set up a cyclic voltammogram (CV).

### 5.1.2 Linear sweep voltammetry (LSV)

Figure 20 illustrates the parameters needed to specify a LSV scan. The procedure is as follows:

1. Use the `[MODE]` key to select `LSV`.

2. Cycle through the required parameters using `[SET]`, adjusting values using the knob. Times are adjusted using the knob for individual fields, and the arrow keys described in section 3.1.16 on page 30 to move between the fields shown below.

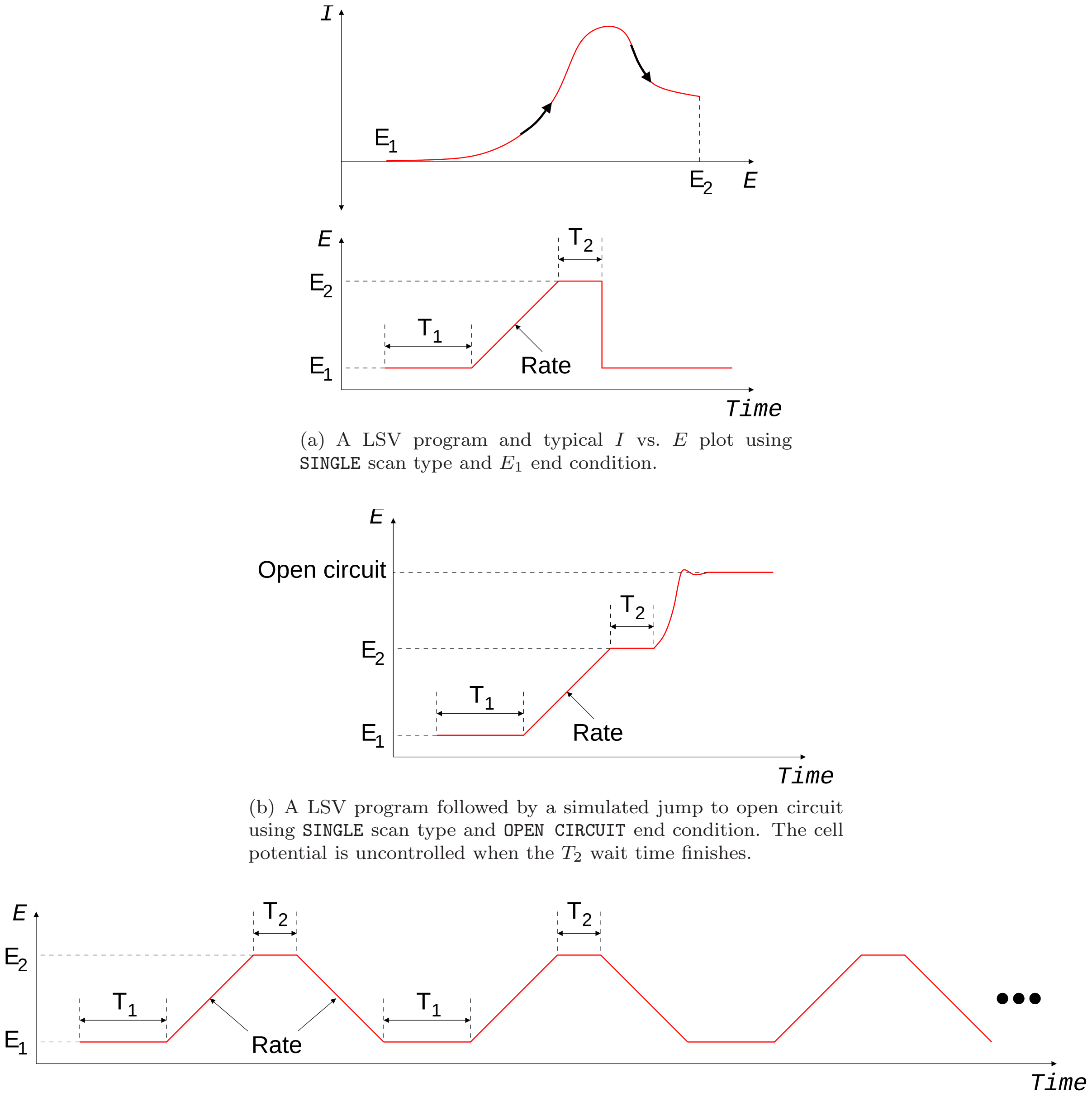
   $$\underbrace{00}_{\text{hours}} : \underbrace{00}_{\text{minutes}} : \underbrace{00}_{\text{seconds}} : \underbrace{0000}_{\text{seconds}/10^4}$$

   The maximum hold time for a LSV is 99:59:59.9999 (100 $\mu$s short of 100 hours). The setability is in 100 $\mu$s steps.

3. Choose the scan end condition. Figure 20(a) illustrates the cell potential for the $E_1$ end condition, while 20(b) shows it for `OPEN CIRCUIT`. If the end condition is `OPEN CIRCUIT`, the cell potential will be free to drift after the $T_2$ wait time. If the condition is $E_1$, the potential will immediately return to $E_1$.

4. Choose `SINGLE` or `CONTINUOUS` scanning. Single scans, illustrated in figures 20(a) and (b), go to the end scan condition after the $T_2$ wait time. Continuous scans, illustrated in figure 20(c), track back to $E_1$ after the $T_2$ wait time with the same rate used for the forward ramp. They then repeat the entire program indefinitely.

5. Choose the trigger mode. `MANUAL` allows the `[GO/ARM]` key to trigger the scan, while `EXTERNAL` mode requires the rear panel scan trigger input. See section 5.4 on page 61 for a better description of scan triggers in general, and section 3.2.6 on page 34 for a description of the rear panel scan trigger.



(a) A LSV program and typical $I$ vs. $E$ plot using `SINGLE` scan type and $E_1$ end condition.

(b) A LSV program followed by a simulated jump to open circuit using `SINGLE` scan type and `OPEN CIRCUIT` end condition. The cell potential is uncontrolled when the $T_2$ wait time finishes.

(c) A LSV program using `CONTINUOUS` scan type. The trapezoid-shaped program continues indefinitely.

Figure 20: Parameters used to set up a linear sweep voltammogram (LSV).

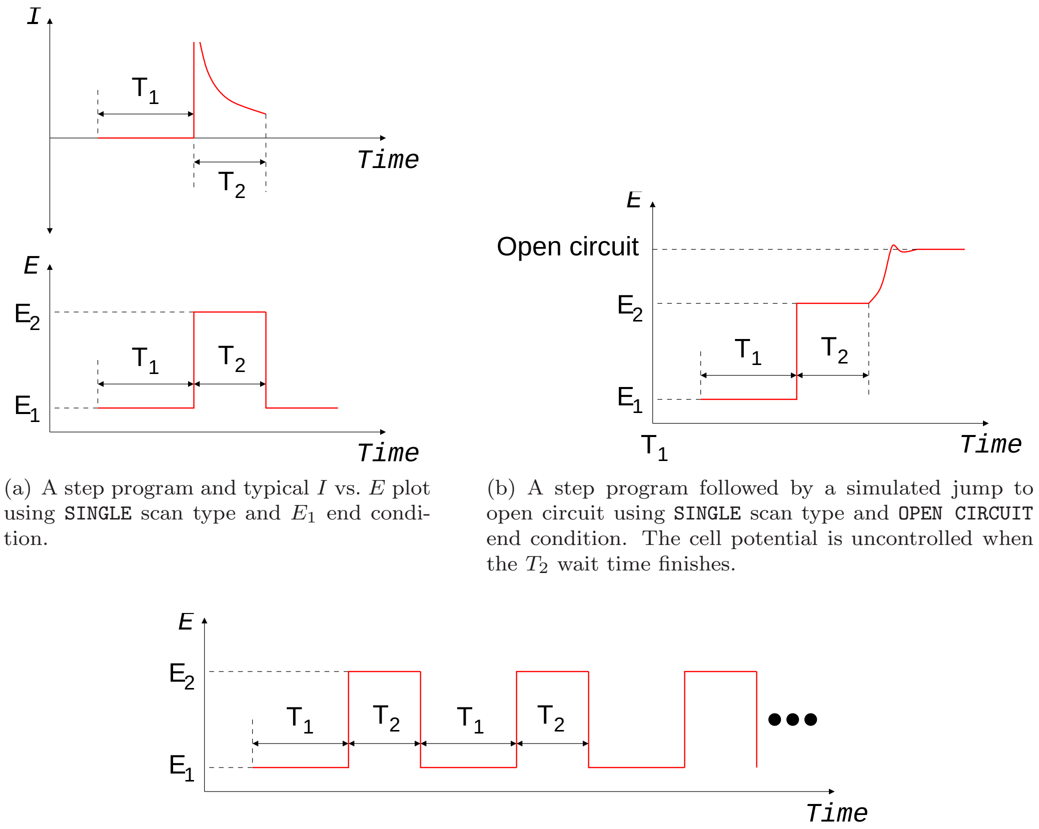
### 5.1.3 Steps

Figure 21 illustrates the parameters needed to specify a step scan. The procedure is as follows:

1. Use the `[MODE]` key to select `STEP`.
2. Cycle through the required parameters using `[SET]`, adjusting values using the knob. Times are adjusted using the knob for individual fields, and the arrow keys described in section 3.1.16 on page 30 to move between the fields shown below. Note that the setability is in $4\mu$s steps.

   $$\underbrace{00}_{\text{minutes}} : \underbrace{00}_{\text{seconds}} : \underbrace{000}_{\text{milliseconds}} : \underbrace{000}_{\mu\text{seconds}}$$

   The maximum delay time is 01:07.108 860 ($2^{24} - 1$ counts × $4\,\mu$s/count).
3. Setability is $4\,\mu$s.
4. Choose the scan end condition. Figure 21(a) illustrates the cell potential for the $E_1$ end condition, while 21(b) shows it for `OPEN CIRCUIT`. If the end condition is `OPEN CIRCUIT`, the cell potential will be free to drift after the $T_2$ wait time. If the condition is $E_1$, the potential will immediately return to $E_1$.
5. Choose `SINGLE` or `CONTINUOUS` scanning. Single scans, illustrated in figures 21(a) and (b), go to the end scan condition after the $T_2$ wait time. Continuous scans, illustrated in figure 21(c), step back to $E_1$ after the $T_2$ wait time and repeat the entire step program indefinitely.
6. Choose the trigger mode. `MANUAL` allows the `[GO/ARM]` key to trigger the scan, while `EXTERNAL` mode requires the rear panel scan trigger input. See section 5.4 on page 61 for a better description of scan triggers in general, and section 3.2.6 on page 34 for a description of the rear panel scan trigger.



(a) A step program and typical $I$ vs. $E$ plot using SINGLE scan type and $E_1$ end condition.

(b) A step program followed by a simulated jump to open circuit using SINGLE scan type and OPEN CIRCUIT end condition. The cell potential is uncontrolled when the $T_2$ wait time finishes.

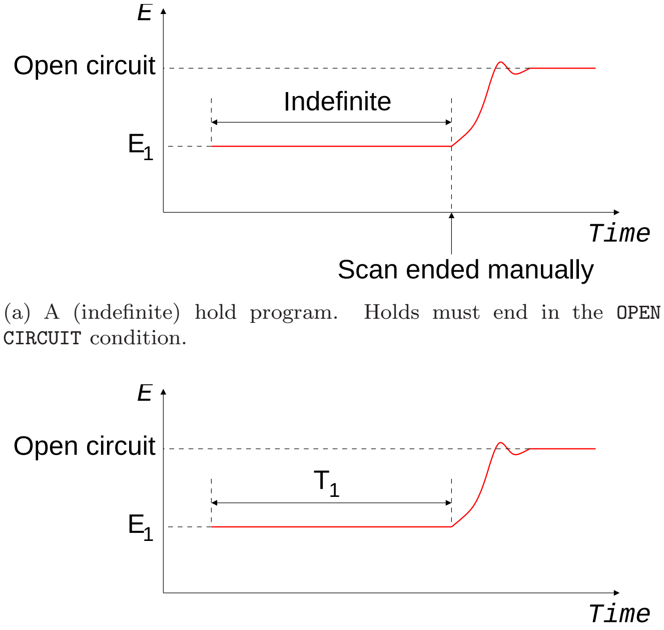
(c) A step program using CONTINUOUS scan type. The rectangle-shaped program continues indefinitely.

Figure 21: Parameters used to set up a step scan.

### 5.1.4 Holds

Figure 22 illustrates the parameters needed to specify holds or timed holds. These scans must end in the `OPEN CIRCUIT` condition, and the scan type can only be `SINGLE`. Only `MANUAL` trigger mode is allowed. The remaining setup procedure is as follows:

1. Use the `[MODE]` key to select `HOLD` or `TIMED HOLD`.
2. Set the $E_1$ and $T_1$ parameters using `[SET]` and the knob.
3. Choose the trigger mode. `MANUAL` allows the `[GO/ARM]` key or the remote interface to start the hold. See section 5.4 on page 61 for a better description of scan triggers. `EXTERNAL` mode is not allowed.



(a) A (indefinite) hold program. Holds must end in the `OPEN CIRCUIT` condition.

(b) A timed hold program. Control is automatically released after the $T_1$ hold time.

Figure 22: Parameters used to set up a regular and timed hold.

## 5.2 Setting scan parameters – galvanostat mode

### 5.2.1 Cyclic current ramp

Figure 23 illustrates the parameters needed to specify a cyclic current ramp scan. The procedure is as follows:

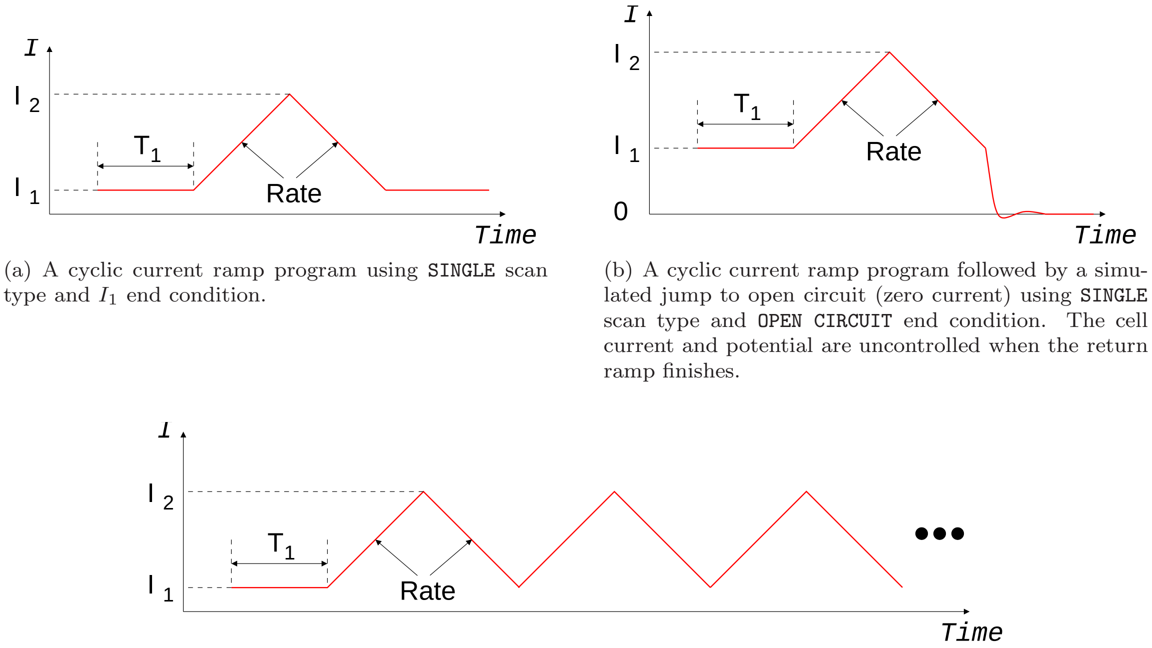
1. Use the [MODE] key to select CV. While this scan mode is named for its use in potentiostat mode, it will set up a cyclic current ramp in galvanostat mode.

2. Cycle through the required parameters using [SET], and adjust values using the knob.

3. Choose the scan end condition. Figure 23(a) illustrates the cell current for the $I_1$ end condition, while 23(b) shows it for OPEN CIRCUIT.

4. Choose SINGLE or CONTINUOUS scanning. Single scans, illustrated in figures 23(a) and (b), go to the end scan condition after reaching $I_1$ on the return ramp. Continuous scans, illustrated in figure 23(c), immediately turn around to repeat the forward ramp and then the entire triangle-shaped waveform.

5. Choose the trigger mode. MANUAL allows the [GO/ARM] key to trigger the scan, while EXTERNAL mode requires the rear panel scan trigger input. See section 5.4 on page 61 for a better description of scan triggers in general, and section 3.2.6 on page 34 for a description of the rear panel scan trigger.



(a) A cyclic current ramp program using SINGLE scan type and $I_1$ end condition.

(b) A cyclic current ramp program followed by a simulated jump to open circuit (zero current) using SINGLE scan type and OPEN CIRCUIT end condition. The cell current and potential are uncontrolled when the return ramp finishes.

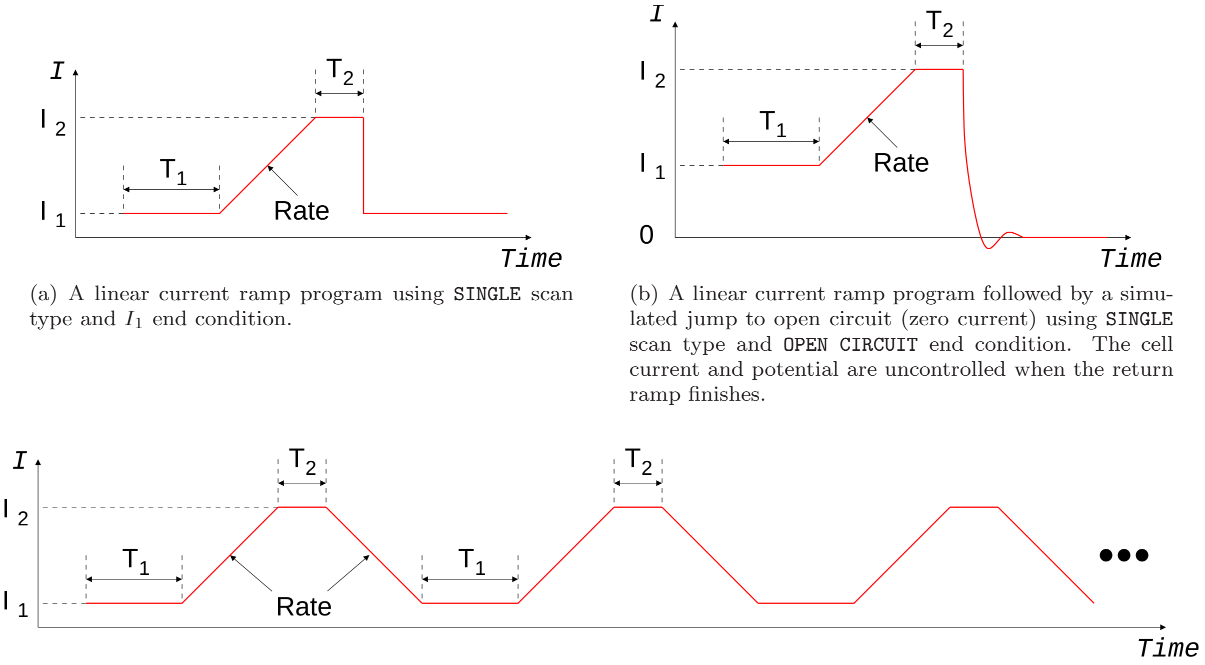
(c) A cyclic current ramp program using CONTINUOUS scan type. The triangle-shaped program continues indefinitely.

Figure 23: Parameters used to set up a cyclic current ramp scan.

### 5.2.2 Linear current ramp

Figure 24 illustrates the parameters needed to specify a linear current ramp scan. The procedure is as follows:

1. Use the `[MODE]` key to select `LSV`. While this scan mode is named for its use in potentiostat mode, it will set up a linear current ramp in galvanostat mode.
2. Cycle through the required parameters using `[SET]`, and adjust values using the knob.
3. Choose the scan end condition. Figure 24(a) illustrates the cell potential for the $I_1$ end condition, while 24(b) shows it for `OPEN CIRCUIT`.
4. Choose `SINGLE` or `CONTINUOUS` scanning. Single scans, illustrated in figures 24(a) and (b), go to the end scan condition after the $T_2$ wait time. Continuous scans, illustrated in figure 24(c), track back to $I_1$ after the $T_2$ wait time with the same rate used for the forward ramp. They then repeat the entire program indefinitely.
5. Choose the trigger mode. `MANUAL` allows the `[GO/ARM]` key to trigger the scan, while `EXTERNAL` mode requires the rear panel scan trigger input. See section 5.4 on page 61 for a better description of scan triggers in general, and section 3.2.6 on page 34 for a description of the rear panel scan trigger.



(a) A linear current ramp program using `SINGLE` scan type and $I_1$ end condition.

(b) A linear current ramp program followed by a simulated jump to open circuit (zero current) using `SINGLE` scan type and `OPEN CIRCUIT` end condition. The cell current and potential are uncontrolled when the return ramp finishes.

(c) A linear current ramp program using `CONTINUOUS` scan type. The triangle-shaped program continues indefinitely.

Figure 24: Parameters used to set up a linear current ramp scan.

### 5.2.3 Current step

Figure 25 illustrates the parameters needed to specify a current step scan. The procedure is as follows:

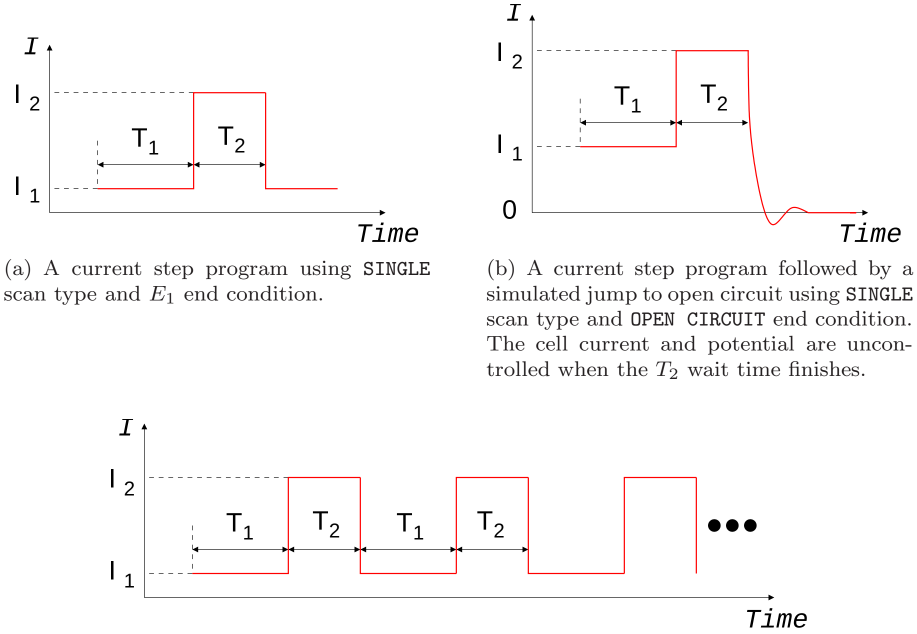
1. Use the `[MODE]` key to select `STEP`.

2. Cycle through the required parameters using `[SET]`, and adjust values using the knob.

3. Choose the scan end condition. Figure 25(a) illustrates the cell potential for the $I_1$ end condition, while 25(b) shows it for `OPEN CIRCUIT`. If the end condition is `OPEN CIRCUIT`, the cell potential will be free to drift after the $T_2$ wait time. If the condition is $I_1$, the potential will immediately return to $I_1$.

4. Choose `SINGLE` or `CONTINUOUS` scanning. Single scans, illustrated in figures 25(a) and (b), go to the end scan condition after the $T_2$ wait time. Continuous scans, illustrated in figure 25(c), step back to $I_1$ after the $T_2$ wait time and repeat the entire step program indefinitely.

5. Choose the trigger mode. `MANUAL` allows the `[GO/ARM]` key to trigger the scan, while `EXTERNAL` mode requires the rear panel scan trigger input. See section 5.4 on page 61 for a better description of scan triggers in general, and section 3.2.6 on page 34 for a description of the rear panel scan trigger.



(a) A current step program using `SINGLE` scan type and $E_1$ end condition.

(b) A current step program followed by a simulated jump to open circuit using `SINGLE` scan type and `OPEN CIRCUIT` end condition. The cell current and potential are uncontrolled when the $T_2$ wait time finishes.

(c) A current step program using `CONTINUOUS` scan type. The rectangle-shaped program continues indefinitely.

Figure 25: Parameters used to set up a step scan.

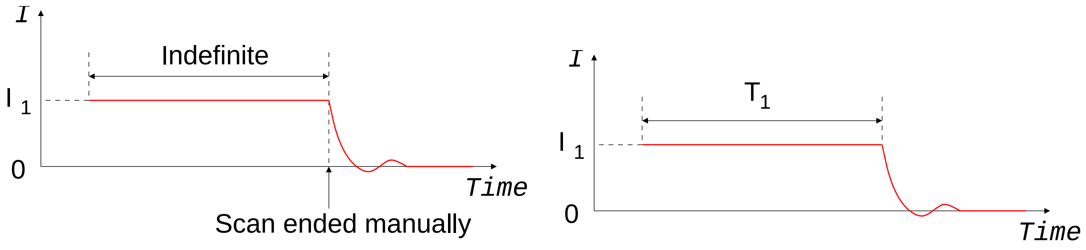
### 5.2.4 Current hold

Figure 26 illustrates the parameters needed to specify current holds or timed holds. These scans must end in the `OPEN CIRCUIT` (zero current) condition, and the scan type can only be `SINGLE`. Only `MANUAL` trigger mode is allowed. The remaining setup procedure is as follows:

1. Use the `[MODE]` key to select `HOLD` or `TIMED HOLD`.

2. Set the $I_1$ and $T_1$ parameters using `[SET]` and the knob.

3. Choose the trigger mode. `MANUAL` allows the `[GO/ARM]` key or the remote interface to start the hold. See section 5.4 on page 61 for a better description of scan triggers. `EXTERNAL` mode is not allowed.

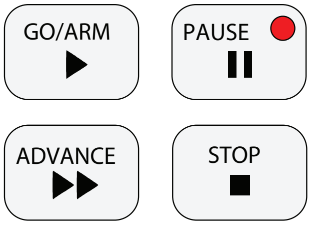


(a) A (indefinite) current hold program. Holds must end in the `OPEN CIRCUIT` (zero current) condition.

(b) A timed current hold program. Control is automatically released after the $T_1$ hold time.

Figure 26: Parameters used to set up a regular and timed current hold.

## 5.3 Basic scan controls



Once a scan is configured, the [GO/ARM], [PAUSE], [ADVANCE], and [STOP] keys control how it will execute.

Pressing the [GO/ARM] key is one way to send a scan trigger described in section 5.4. This will begin a scan in MANUAL trigger mode, or arm the instrument in EXTERNAL mode.

The [PAUSE] key freezes the scan wherever it happens to be. Pressing it again will resume the scan.

The [ADVANCE] key increments the scan stage. For example, pressing this during the forward ramp of a CV scan will start the return ramp. Pressing this during the return ramp will skip to the end scan condition.

The [STOP] key terminates the scan and releases cell control. This does **not** simply take the scan to the scan end condition – control is always released. Use the [ADVANCE] key instead to skip to the end of a scan.

## 5.4 Triggering scans

A configured scan will start once the EC301 receives a scan trigger. This can come from the front panel [GO/ARM] button, the rear panel scan trigger input, or the remote interface.

### 5.4.1 Triggering a scan from the front panel

As described in section 3.1.14 on page 29, the front panel [GO/ARM] key will start a scan if the trigger mode is set to MANUAL. Pressing this in the EXTERNAL trigger mode will "arm" the instrument – control will engage but scanning will wait for the scan trigger input.

The [GO/ARM] key will try to engage cell control to begin a scan in both trigger modes – lighting the [ENABLE] switch. Make sure to allow this by pressing this switch to the "on" position.

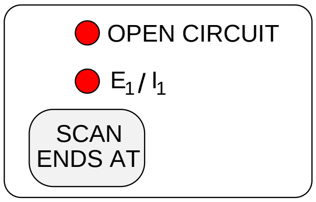
### 5.4.2 Triggering a scan with the scan trigger input

As described in section 3.2.6 on page 34, the rear panel scan trigger input allows fine control over when the scan begins. This can help to synchronize external data acquisition during fast scans.

### 5.4.3 Triggering a scan from the remote interface

The scan trigger remote commands are described in section 7.3.6 on page 73.

## 5.5 Setting the end of scan condition



The EC301 can either retain or release control of a cell at the end of a scan. Retaining control may reduce drift in cell characteristics between scans, while releasing control may reduce stress on the cell. Select OPEN CIRCUIT to release control, or $E_1/I_1$ to retain control at the $E_1$ or $I_1$ setting.

Only `OPEN CIRCUIT` is allowed as an end condition for `HOLD` or `TIMED HOLD` scan modes.

# 6 Using the EC301 with a frequency response analyzer (FRA)

The EC301 can be used with an FRA to perform electrochemical impedance spectroscopy (EIS) measurements. The FRA supplies the stimulus for these measurements via the external input, and measures the cell response via the E and I outputs. Figure 27 shows the EC301 used with the Stanford Research Systems SR780 for this purpose.

For best results, especially at high frequency, SRS recommends using the rear panel outputs for EIS measurements.

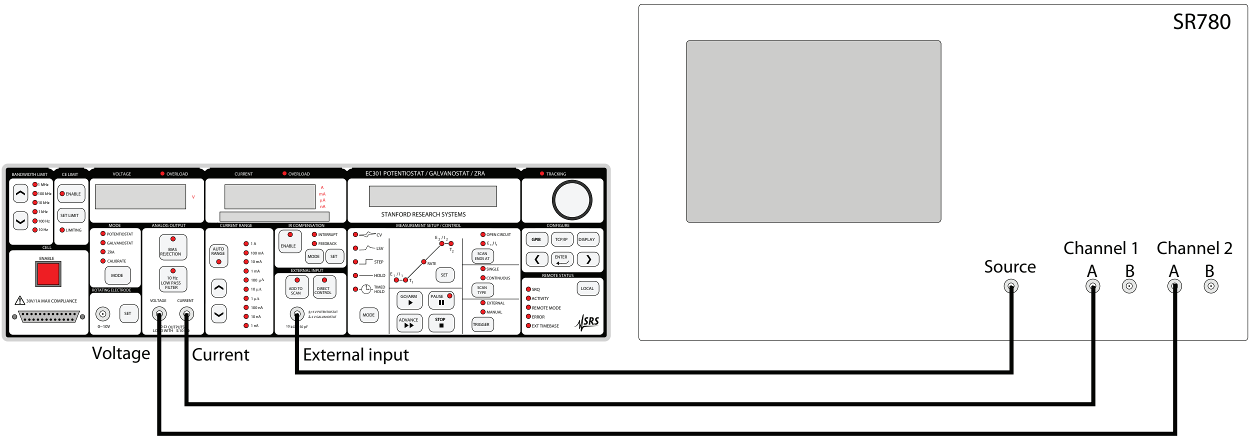


Figure 27: Using the EC301 with the SR780 for impedance spectroscopy

Using the setup shown in figure 27, the SR780 supplies the stimulus for swept-sine or FFT-based measurements via the external input BNC. It then can calculate the complex cell frequency response as

$$\text{Response} = \frac{\text{FFT2}}{\text{FFT1}} \tag{1}$$

for FFT-based measurements or as

$$\text{Response} = \frac{\text{spectrum2}}{\text{spectrum1}} \tag{2}$$

using the swept-sine mode. The cell impedance $Z_{\text{cell}}$ can be calculated from this using

$$Z_{\text{cell}} = \frac{\text{spectrum2}}{I_{\text{fs}} \times \text{spectrum1}} \tag{3}$$

where $I_{\text{fs}}$ is the current range (10mA, 100$\mu$A, etc).

# 7 Remote programming

The EC301 may be remotely programmed via either the GPIB or ethernet interfaces.

When using the ethernet interface, be advised that some "personal firewall" systems will terminate idle connections.

## 7.1 Command syntax

Communication with the EC301 is done with ASCII characters. Commands may be in either UPPER or lower case and may contain any number of embedded space characters. For example, the commands

```
ECMODE 1
ECMODE     1
ecmode   1
```

will all put the instrument in galvanostat mode.

Multiple commands may be sent on one command line by separating them with semicolons (;). The individually-sent commands

```
ecmode 1
clbwth 4
irange 1
```

can be sent simultaneously with

```
ecmode 1;clbwth 4;irange 1
```

following which the EC301 will buffer and then execute the command string from left to right.

## 7.2 Argument formats

Table 3 summarizes the number formats expected for each argument designator.

| Argument designators | Format | Good examples | Unrecognized |
|---|---|---|---|
| `i,j,k` | integer | `-1200,0,1,5,+6` | `-1.2e3,0x5` |
| `x,y,z` | real number | `-1.34,0.0,3.14159` | |

Table 3: Number formats expected for each argument designator.

Numbers written in scientific notation will not be recognized as allowed arguments.

## 7.3 Detailed command list

### 7.3.1 Firmware and hardware revisions

fpgarv?

**Name:** `fpgarv?` – Query the FPGA revision number.
**Description:** The instrument's FPGA revision number is important for firmware upgrades.

### 7.3.2 Program E/I setup (with external input)

setvol(?){i}

**Name:** `setvol(?)` – Set or query DC bias voltage.
**Description:** This command provides an easy way to control a DC voltage without setting up a scan.

| Parameter | Units | Range |
|---|---|---|
| `i` | mV | $-15000, -14999, -14998, \cdots, +15000$ |

For example, the sequence

```
ecmode 0
ceenab 1
setvol 1000
setvol?
1000
```

will set up a program voltage of 1V in potentiostat mode. The `setvol?` query command will return a value in the same format as the setting. This command is not allowed in galvanostat mode, zra mode, or if the unit is in direct control mode.

`setcur(?){x}`

**Name:** `setcur(?)` – Set or query DC bias for the current program in galvanostat mode.
**Description:** This command provides an easy way to control a DC current without setting up a scan.

| Parameter | Units | Range |
|---|---|---|
| x | fraction of range | −2 → +2 |

For example, the sequence

```
ecmode 1
ceenab 1
irange 4
setcur 0.543
setcur?
5.43e-4
```

will set up a program current of 0.543mA in galvanostat mode. The argument to `setcur` is the signed floating-point fraction of the current range. Since `irange 4` chooses the 1mA range, an argument of 0.543 sets a control current of $0.543 \times 1\text{mA} = 543\mu\text{A}$. The `setvol?` query command will return the actual setpoint in A instead of the fraction of full scale. This command is not allowed in potentiostat or zra mode.

`addscn(?){i}`

**Name:** `addscn(?)` – Set or query the external input's "add to scan" mode.
**Description:** This command enables or disables the external input without affecting the state of the control loop.

| i | Setting |
|---|---|
| 0 | Voltage at external input ignored |
| 1 | Voltage at external input added to scan or hold |

This is useful for adding a waveform from an external source to a ramp generated by the EC301. For example, a sine wave could be added to a ramp for AC voltammetry. Changing the `addscn` state will turn the external waveform on or off without affecting the EC301's waveform. If −1V is applied to the external input, the sequence

```
ecmode 0
setvol +1000
ceenab 1
addscn 1
```

will result in 0V over the cell.

`dcntrl(?){i}`

**Name:** `dcntrl(?)` – Set or query the external input's "direct control" mode.
**Description:** This command enables or disables the external input while engaging and disengaging cell control.

| i | Setting |
|---|---|
| 0 | Voltage at external input ignored |
| 1 | Voltage at external input applied to cell |

This is useful when you have an external source for your entire stimulus and you don't want to use the internal sources. Sending `dcntrl 1` works like pushing `[DIRECT CONTROL]` on the front panel – the control loop will close with the control voltage taken from the external input BNC. However, sending `dcntrl 0` will only open the control loop if the external input has been put in charge with `dcntrl 1` – not if an internally-generated scan or hold is running.

This command will generate an error if an internally-generated scan or hold is already running. Make sure all control has been released before sending `dcntrl 1`.

`progrm?`

**Name:** `progrm?` – Read the program E/I voltage.
**Description:** This command queries the total voltage program input to the control loop.

| Parameter | Units | Range |
|---|---|---|
| x | V | $-15.000 \rightarrow +15.000$ |

The program input is the sum of voltages from the external input BNC and from internal sources. This command is useful during current interrupt IR compensation, as the values returned should represent the cell voltage with any IR drop removed. Returned values are formatted as floating-point volts. For example, the sequence

```
ecmode 0
setvol 123
progrm?
+0.123
```

calls for +123mV to be applied to the cell in potentiostat mode. If there is no external input voltage, the return value of `progrm?` will be `+0.123`.

### 7.3.3 Control loop commands

ecmode(?){i}

**Name:** `ecmode(?)` – Set or query the control loop mode.
**Description:** The control loop can take its feedback from one of three sources, resulting in the three modes described below.

| i | Mode |
|---|---|
| 0 | Potentiostat |
| 1 | Galvanostat |
| 2 | Zero-resistance ammeter (ZRA) |

clbwth(?){i}

**Name:** `clbwth(?)` – Set or query the control bandwidth.
**Description:** Set or query the control loop bandwidth.

| i | Control loop bandwidth |
|---|---|
| 0 | 1 MHz |
| 1 | 100 kHz |
| 2 | 10 kHz |
| 3 | 1 kHz |
| 4 | 100 Hz |
| 5 | 10 Hz |

celimt(?){i}

**Name:** `celimt(?)` – Enables or disables CE voltage limiting mode.
**Description:** Sending this command is identical to using the front panel `[ENABLE]` key in the `CE LIMIT` group. See the description in section 3.1.3 on page 22 for more information.

| i | Setting |
|---|---|
| 0 | Disable – full ±30V compliance |
| 1 | Enable – CE voltage limit set with front panel or `celimv` command. |

celimv(?){i}

**Name:** `celimv(?)` – Set the CE voltage clamp limits.
**Description:** The CE limits are symmetric about `SIGNAL GROUND`. For example, the command `celimv 1000` will limit the CE voltage to ±1V of `SIGNAL GROUND`.

| Parameter | Units | Range |
|---|---|---|
| x | mV | $500, 501, 502, \cdots, 30000$ |

**Name:** `limitg?` – Query if the CE Limit is active.

`limitg?`

**Description:** `limitg?` returns 1 if the CE limit is active, 0 if the limit is inactive. Use the `celimt` command to enable or disable the CE limiting.

### 7.3.4 Cell switch

**Name:** `ceenab(?)` – Set or query the CE switch position.
**Description:** Enable or disable the cell. The red “enable” switch on the front panel will illuminate if the cell is enabled and the switch is pushed in.

`ceenab(?){i}`

| i | Cell connection |
|---|---|
| 0 | Disabled |
| 1 | Enabled |

---

**Name:** `cellon?` – Query the cell connection.
**Description:** This query-only command returns the state of the cell connection. As shown in figure 1 on page 18, this connection is made only if both the current interrupt cell switch and the front panel safety switch are closed. Since the safety switch lights up only when both of these are closed, this query tells you whether or not this light is on.

`cellon?{i}`

| i | Cell connection |
|---|---|
| 0 | Disconnected – Either the current interrupt cell switch or the front panel safty switch is open (safety switch red light is off). |
| 1 | Connected – Both the current interrupt cell switch and the front panel safety switch are closed (safety switch red light is on). |

### 7.3.5 IR compensation

`irenab(?){i}`

**Name:** `irenab(?)` – Enable or disable IR compensation.
**Description:** Enable or disable either mode of IR compensation. This corresponds to pushing the front panel `[ENABLE]` key described in section 3.1.12 on page 27.

| i | Setting |
|---|---|
| 0 | Disable IR compensation |
| 1 | Enable IR compensation |

---

`irtype(?){i}`

**Name:** `irtype(?)` – Set or query the IR compensation mode.
**Description:** Set or query the IR compensation mode. This corresponds to pushing the front panel `[MODE]` key described in section 3.1.12 on page 27.

| i | Setting |
|---|---|
| 0 | Current interrupt |
| 1 | Positive feedback |

---

`pfback(?){x}`

**Name:** `pfback(?)` – Set the positive feedback amount.
**Description:** No description.

| Parameter | Units | Range |
|---|---|---|
| x | none | 0 → fff |

---

`ciopen(?){i}`

**Name:** `ciopen(?)` – Set or query the CE switch open time for current interrupt.
**Description:** This command sets or queries the “interruption” time for current interrupt IR compensation. The resolution is 100$\mu$s. This corresponds to the $t_{open}$ delay shown in figure 6 on page 27.

| Parameter | Units | Range |
|---|---|---|
| i | $\mu$s | $100, 200, 300, \cdots, 1 \times 10^6 (1\text{s})$ |

The interruption time must be shorter than the time between interrupts. Be sure to set a valid value for `ciperd` after setting `ciopen`.

`ciperd(?){i}`

**Name:** `ciperd(?)` – Set or query the interruption frequency for current interrupt.
**Description:** This command sets or queries the $t_p$ period described in figure 6 on page 27. This is the time between interrupt cycles, set with 1ms resolution.

| Parameter | Units | Range |
|---|---|---|
| i | ms | $1, 2, 3, \cdots, 10000$ |

⛔ The time between interrupt cycles ($t_p$) must be longer than the interruption time ($t_{\text{open}}$). Be sure to set a valid value for `ciopen` (described on the preceding page) after setting `ciperd` (described on the current page).

`cicorr(?){i}`

**Name:** `cicorr(?)` – Set or query the correction percentage used for current interrupt IR compensation.
**Description:** As described in section 3.1.12 on page 27, a fraction of $\Delta V_{\text{ir}}$ is added to the program voltage after current interruptions. Sending `cicorr 0` will make $\Delta V_{\text{b}} = 0$, and sending `cicorr 100` will make $\Delta V_{\text{b}} = \Delta V_{\text{ir}}$.

| Parameter | Units | Range |
|---|---|---|
| i | % | $0, 1, 2, \cdots, 200$ |

`cidlay(?){i}{j}`

**Name:** `cidlay(?)` – Set or query the voltage sampling times used during current interrupt IR compensation.
**Description:** This command sets the $t_{do}$ and $t_{dc}$ sample delays described in figure 6 on page 27. Both sample delays are entered in integer $\mu$s.

| i | Delay | Units | j |
|---|---|---|---|
| 0 | $t_{do}$ (open delay) | $\mu$s | 0,1,2,$\cdots$,$1 \times 10^6$(1s) |
| 1 | $t_{dc}$ (closed delay) | | |

### 7.3.6 Scan trigger commands

`trgarm(?){i}`

**Name:** `trgarm(?)` – Set or query the scan trigger arm condition.
**Description:** The instrument must be armed before a scan can be started with an external trigger. The armed instrument will wait for a trigger edge before scanning. This command will set or query this waiting (armed) state. See section 3.1.14 on page 29 for more information about the external trigger setting. See section 3.2.6 on page 34 for more information about the rear panel scan trigger input.

| i | Mode |
|---|---|
| 0 | Unarmed |
| 1 | Armed – waiting for external scan trigger |

---

`scntrg?`

**Name:** `scntrg(?)` – Query the scan trigger state (are we scanning?).
**Description:** This command will tell you if the instrument is running an automatic scan.

| Return value | Mode |
|---|---|
| 0 | Not triggered |
| 1 | Triggered (scanning) |

---

`stsync(?){i}`

**Name:** `stsync(?)` – Set or query whether software triggered scans are synchronized with the power line cycle.
**Description:** If the argument to STSYNC is 1, a remote command software-triggered scan (i.e. not triggered from the front panel) will not begin until the power line cycle measuring circuit detects a zero crossing. This allows the user to synchronize a fast cyclic voltammogram to occur at the same point in a power line cycle each time such a trigger is issued. The default is *not* to gate with the power line cycle, and begin the scan immediately.

| i | Mode |
|---|---|
| 0 | No power line synchronization |
| 1 | Software triggered scans aligned to power line cycle |

### 7.3.7 Rotating working electrode commands

**Name:** `rotate(?)` – Set or query the rotator output voltage.
**Description:** No description.

`rotate(?){x}`

| Parameter | Units | Range |
|---|---|---|
| `x` | mV | 0 → 10000 |

### 7.3.8 Analog output commands

**Name:** `brenab` – Set or query the use of bias rejection.
**Description:** The EC301 uses bias rejection to remove DC voltages from the front panel VOLTAGE and CURRENT outputs.

| i | Mode |
|---|---|
| 0 | Bias rejection disabled |
| 1 | Automatic bias rejection |

Sending `brenab 1` begins automatic bias rejection by triggering a measurement of the front panel VOLTAGE and CURRENT signals. This is a simple detection of the constant component (bias) of these signals. Once this bias is detected, the EC301 attempts to null (reject) it by adding constant voltages to the BNC outputs.

Custom bias rejection amounts can be entered with the `bireje` command, described on page 75, and the `bireji` command, described on page 76. Note that you can only use these commands after sending `brenab 1` to turn bias rejection on.

brenab(?){i}

**Example:**

```
setvol 1000  Programs a +1V controlled voltage in potentiostat mode.
ceenab 1  Closes the cell switch to engage control.
brenab 1  Begins automatic bias rejection
brenab?  Is bias rejection enabled?
1  Yes, it is.
bireje?  What is the nulling voltage applied to VOLTAGE ?
-998  Automatically applied value in mV.
bireje -1000  Send a custom nulling value for the VOLTAGE output.
bireje?  What is the nulling voltage applied to VOLTAGE ?
-1000
bireji?  What is the nulling voltage applied to CURRENT ?
-0.87  Automatically applied value in V – 1V is full scale current.
brenab 0  Turn off bias rejection.
bireje 1000  Trying to set a custom nulling voltage...
remote command error  ...returns an error since rejection has been turned off.
```

**Name:** `bireje(?)` – Set or query the amount of E bias rejection.
**Description:** Sets or queries the amount of bias rejection applied to the front panel VOLTAGE output. Accepts an argument in fixed point millivolts. The `brenab` command described on page 75 must be sent before this command can be used.

bireje(?){x}

| Parameter | Units | Range |
|---|---|---|
| x | V | −15000 → +15000 |

**Name:** `bireji(?)` – Set or query the amount of I bias rejection.

`bireji(?){x}`

**Description:** Sets or queries the amount of bias rejection applied to the front panel CURRENT output. The `brenab` command described on page 75 must be sent before this command can be used. The argument is in floating point, and indicates what fraction of full scale current will be rejected.

| Parameter | Units | Range |
|---|---|---|
| x | fraction of full scale | −2.000 → +2.000 |

---

**Name:** `lpfile(?)` – Set or query the front panel *E* low pass filter status.
**Description:** No description.

`lpfile(?){i}`

| i | Setting |
|---|---|
| 0 | No filter |
| 1 | 10Hz lowpass |

---

**Name:** `lpfili(?)` – Set or query the front panel *I* low pass filter status.
**Description:** No description.

`lpfili(?){i}`

| i | Setting |
|---|---|
| 0 | No filter |
| 1 | 10Hz lowpass |

---

### 7.3.9 Voltage ($E$) measurement setup

**Name:** `eadcrg(?)` – Set or query the full-scale range of the internal $E$ measurement.
**Description:** The instrument defaults to a ±15V measurement range. This can be reduced to increase measurement resolution.

`eadcrg(?){i}`

| i | Setting |
|---|---|
| 0 | ±2 V |
| 1 | ±5 V |
| 2 | ±15 V |

---

**Name:** `eadcfl(?)` – Set or query the low pass filter in front of the $E$ ADC.
**Description:** No description.

`eadcfl(?){i}`

| i | Setting |
|---|---|
| 0 | No filter |
| 1 | 10Hz lowpass |
| 2 | 10kHz lowpass (anti-alias) |

### 7.3.10 Current ($I$) measurement setup

**Name:** `irange(?)` – Set or query the current range.
**Description:** No description.

`irange(?){i}`

| i | Current range |
|---|---|
| 1 | 1A |
| 2 | 100mA |
| 3 | 10mA |
| 4 | 1mA |
| 5 | 100$\mu$A |
| 6 | 10$\mu$A |
| 7 | 1$\mu$A |
| 8 | 100nA |
| 9 | 10nA |
| 10 | 1nA |

⛔ You cannot do `irange` if you are autoranging.

---

**Name:** `iadcfl(?)` – Set or query the low pass filter in front of the $I$ ADC.
**Description:** No description.

`iadcfl(?){i}`

| i | Setting |
|---|---|
| 0 | 10Hz lowpass |
| 1 | No filter |
| 2 | 10kHz lowpass (anti-alias) |

---

**Name:** `irnaut(?)` – Set or query the I autoranging mode.
**Description:** The current measurement circuit can automatically change ranges when the measured current is at the extreme end of a range.

| i | Autoranging |
|---|---|
| 0 | Off |
| 1 | On |

`irnaut(?){i}`

Autoranging of the I/V converter is disallowed if any of these conditions are true:

- Galvanostat mode is in use.
- Positive feedback IR compensation is in use.
- Bias rejection is in use.

### 7.3.11 Reading single measurement results

`vlevel?`

**Name:** `vlevel?` – return an *E* measurement.
**Description:** This query only command takes no arguments and returns a floating point number in volts. For example, if ($V_{\text{WE SENSE}} - V_{\text{RE}}$) happens to be -1.543V, the sequence

```
vlevel?
-1.543
```

will return that value.

---

`ilevel?`

**Name:** `ilevel?` – return an *I* measurement.
**Description:** This query only command takes no arguments and returns a floating point number in amps. For example, if $I_{\text{WE}}$ happens to be -1.543mA, the sequence

```
ilevel?
-1.543e-3
```

will return that value.

---

`getaux?{i}`

**Name:** `getaux?` – Get voltages from the rear panel auxiliary input BNCs.
**Description:** This query-only command returns voltage measurements made with the rear panel auxiliary input BNCs described on page 38.

| i | Voltage returned |
|---|---|
| 1 | Auxiliary input 1 |
| 2 | Auxiliary input 2 |
| 3 | Auxiliary input 3 |
| 4 | Comma delimited values from all three channels |

**Example:**

```
getaux? 1  Query the voltage at auxiliary input BNC 1
1.723993  Volts
```

---

**Name:** `avgexp(?)` – Set or query the running average length.
**Description:** Sets or queries the number of data points averaged to make a measurement result. The averaged number is $2^i$.

| Parameter | Range |
|---|---|
| `i` | 0,1,2,$\cdots$,8 |

For example, the sequence

```
avgexp 4
```

`avgexp(?){i}`

will make every measurement returned over the remote interface an average of $2^4 = 16$ internal measurements.

Sending **`avgexp`** clears the instruments's existing averaged data memory. New measurement results won't be accurate until the memory is allowed to refil, which takes ∼30ms. Please wait at least 30ms after sending **`avgexp`** to ensure that measurement results are accurate.

### 7.3.12 Streaming data

`getbda{i}`

**Name:** `getbda` – Start or stop binary data streaming.
**Description:** This command is intended for users writing their own data acquisition software. See figure 28 on page 83 for an overview of data packets used for streaming.

| i | Action |
|---|---|
| 0 | Stop streaming data |
| 1 | Start streaming data |

---

`polbda?`

**Name:** `polbda?` – Get a single packet of binary data.
**Description:** This command is intended for users writing their own data acquisition software. See figure 28 on page 83 for an overview of data packets used for streaming. While the `getbda?` command (page 82) tells the instrument to start streaming an indefinite number of data packets, `polbda` asks for just one. This is useful for “polling” data acquisition, in which the host PC sends `polbda?` over and over again to collect data.

---

`getbdp?{i}`

**Name:** `getbdp?` – Query the binary data streaming protocol.
**Description:** This query-only command is used by host software to interpret streaming binary data. This manual documents protocol 2.

---

Binary data streams in from the EC301 least significant bit (LSB) first, and that may cause some confusion with binary → hexadecimal converters that operate byte-by-byte. For example, if the EC301 wants to send `0xdeadbeef`, it will send

MSB, arrives last → `11011110101011011011111011101111` ← LSB, arrives first

...and the byte-by-byte hexadecimal conversion will make this `0xefbeadde`. You have to reverse the byte order inside each streamed word to recover the correct value.

---

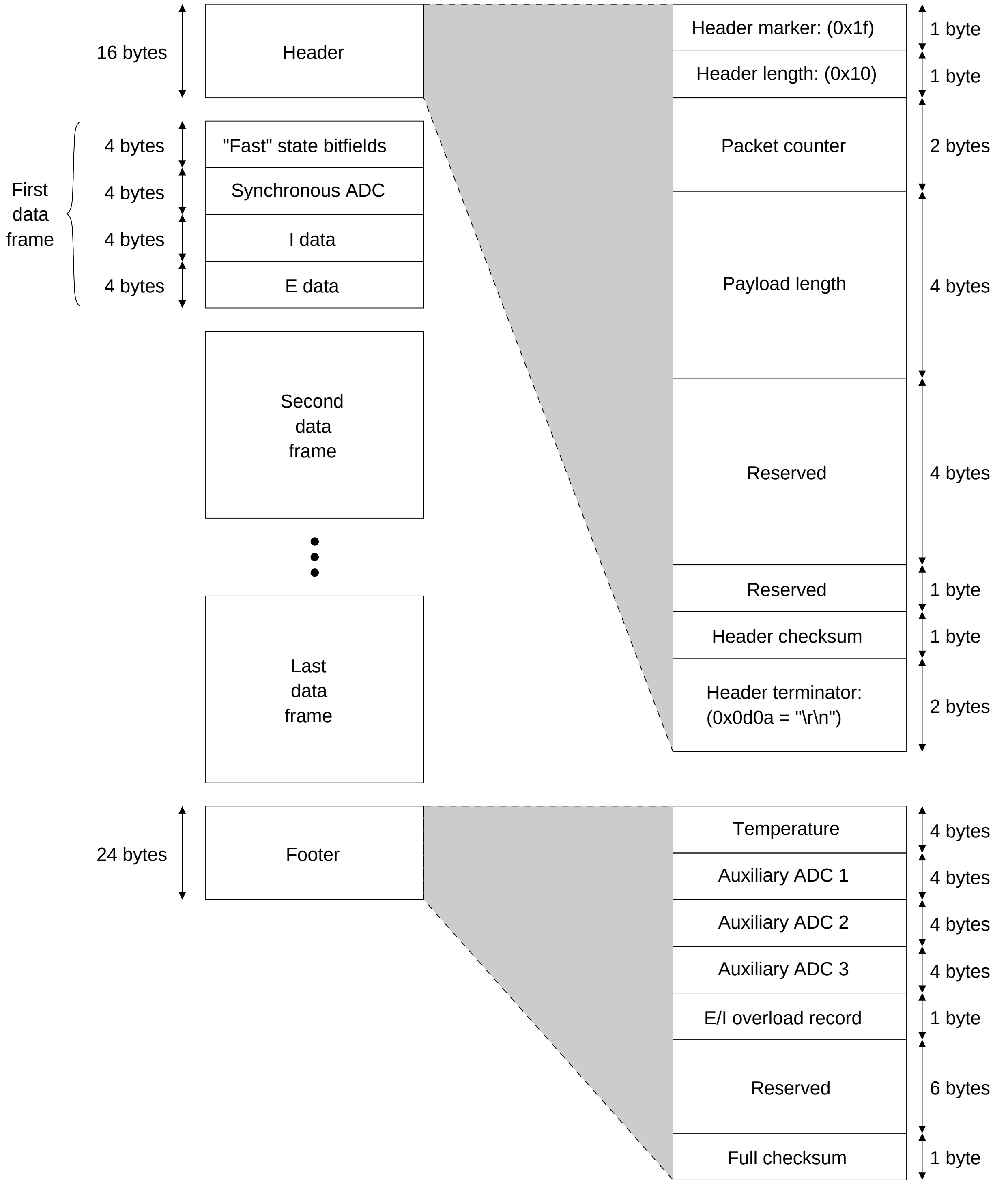


Figure 28: Basic construction of the data packet used for streaming data. The four bytes of "fast" instrument state in each data frame are described in table 4 on page 84. The E/I overload record byte in the footer is described in table 5 on page 85.

| Bit | Quantity | Values |
|---|---|---|
| 0 | Cell switch position | 0 On (closed)<br>1 Off (open) |
| 1 | Internal use | Internal use |
| 2 | Power line synchronization toggle | Toggle after each zero crossing |
| 3 | Compliance limiting status | 0 Not limiting<br>1 Limiting |
| 4:7 | Current ($I$) range | 1 1A<br>2 100mA<br>3 10mA<br>4 1mA<br>5 100$\mu$A<br>6 10$\mu$A<br>7 1$\mu$A<br>8 100nA<br>9 10nA<br>10 1nA |
| 8:10 | Voltage ($E$) range | 3 2V<br>5 5V<br>6 15V |
| 11 | Ramp waveform generator status | 0 Idle<br>1 Running |
| 12 | Ramp waveform synchronization toggle | Toggle after ramps begin and repeat |
| 13:14 | Internal use | Internal use |
| 15:18 | Data averaging window width | N $2^N$ points wide |
| 19 | Pulse waveform generator status | 0 Idle<br>1 Running |
| 20 | Pulse waveform edge toggle | Toggle after each edge |
| 21 | Pulse waveform synchronization toggle | Toggle after pulse waveforms begin and repeat |
| 22 | Arbitrary waveform generator status | 0 Idle<br>1 Running |
| 23 | Arbitrary waveform synchronization toggle | Toggle after arbitrary waveforms begin and repeat |
| 24:31 | Internal use | Internal use |

Table 4: “Fast” instrument state bitfields built into each data frame.

| Bit | Quantity | Values |
|---|---|---|
| 0:1 | Reserved | Reserved |
| 2 | E overload record | 0 No overloads detected during the last packet.<br>1 One or more overloads detected during the last packet. |
| 3 | I overload record | 0 No overloads detected during the last packet.<br>1 One or more overloads detected during the last packet. |
| 4:7 | Reserved | Reserved |

Table 5: Bit positions in the E/I overload record byte.

### 7.3.13 Remote interface commands

`*IDN?`

**Name:** `*IDN?` – return the EC301's device identification string.
**Description:** This query only command takes no arguments and returns the device identification string.

---

`*RST`

**Name:** `*RST` – Reset the EC301 to its default configuration.
**Description:** This command sets all modes and settings to their default configurations and values.

---

`*TST?`

**Name:** `*TST?` – return the Power-on Self Test (POST) results.
**Description:** This command has no description.

---

`*OPC(?)`

**Name:** `*OPC(?)` – Operation complete.
**Description:** This command is implemented for compatibility with the IEEE-488 standard. The original intent was for `*OPC?` queries to indicate when a long process was complete. The EC301 executes commands as it receives them though, and so the `*OPC?` query will be always be processed after the long process finishes. These queries will thus always return 1, indicating that all previous operations are complete.

This command can still be used to indicate when the instrument is ready to process new commands. In this example,

```
*OPC?
Long process finishes...
1
```

waiting for the 1 to be returned would indicate completion of all commands. The non-query version of the command simply sets the `*OPC` bit in the Standard Event Status Register when the long process finishes. See the `*ESR` documentation on page 90 for a description of this register.

---

`*WAI`

**Name:** `*WAI` – Wait to continue.
**Description:** This command is implemented for compatibility with the IEEE-488 standard. The original intent was for `*WAI` to prevent the instrument from executing commands until it completed all pending operations.

---

`verbmd(?){i}`

**Name:** `verbmd(?)` – Set or query the instrument's verbosity.
**Description:** This command sets or queries the instrument's verbosity using the mapping below. In terse mode, the instrument will issue no unsolicited output – such as error messages. This mode suits automated equipment that can not handle unexpected inputs. In verbose mode, the instrument will issue warning and error messages as needed.

| i | Mode |
|---|---|
| 0 | Terse mode |
| 1 | Verbose mode |

`lockfp(?){i}`

**Name:** `lockfp(?)` – Set or query front panel lockout.
**Description:** The front panel keypad can be disabled to prevent inadvertent adjustments.

| i | Mode |
|---|---|
| 0 | Front panel unlocked – normal operation |
| 1 | Front panel disabled |

All buttons except `[LOCAL]` will be disabled after sending `lockfp 1`. Pressing `[LOCAL]` will unlock the front panel and reset `lockfp` to 0.

`ifcclr`

**Name:** `ifcclr` – Reset the remote interface.
**Description:** This command clears the remote interface's transmit and receive queues. If the instrument's reply to a query isn't read before another query is issued, an error occurrs and new reads are forbidden. Sending `ifcclr` when this happens will clear this condition, allowing new queries to be sent and their replys to be read.

The `REF` bit in the instrument status register described on page 92 is set when multiple queries are sent without a read. Sending `ifcclr` will not clear this bit – it should be cleared with a normal `INSR?` query.

`macadr?`

**Name:** `macadr?` – return the EC301's Media Access Control (MAC) address.
**Description:** This query only command takes no arguments and returns the MAC address.

`vfdmsg{i}{string}`

**Name:** `vfdmsg` – Display a string on the character display.
**Description:** This set-only command prints the input string argument to either the first or second line of the front panel vacuum fluorescent character display. The string must be less than 24 characters long, and may not contain any spaces, tabs, or other whitespace characters.

| i | Display line |
|---|---|
| 0 | Top line |
| 1 | Bottom line |

For example, the command

```
vfdmsg 0 string_to_display
```

will print `STRING_TO_DISPLAY` on the top line of the character display.

---

`nulcmd(?){i}`

**Name:** `nulcmd` – Do absolutely nothing.
**Description:** This command is useful for testing the remote interface without doing any harm. Sending the `nulcmd?` query will always return 0.

**Example:**

```
nulcmd?  Does nothing but write 0 to the transmit queue.
0
```

### 7.3.14 Timebase commands

exttmb?{i}

**Name:** exttmb – Query the timebase.
**Description:** This query-only command returns the state of the sampling timebase.

| i | Timebase setting |
|---|---|
| 0 | Internally generated (no external timebase present) |
| 1 | Externally generated (external timebase automatically selected when present) |
| 2 | Internally generated (external timebase present, but disabled via the **autotb** command described on this page). |

---

autotb{i}

**Name:** autotb – Turn automatic timebase selection on or off.
**Description:** This set-only command turns automatic timebase selection on or off. Use the exttmb? query described above to query the timebase selection state.

| i | Setting |
|---|---|
| 0 | Manual mode – timebase generated internally even though an external timebase is present. |
| 1 | Automatic mode – timebase generated internally by default, but accepted from external source if present. |

### 7.3.15 Status reporting commands

*ESR?{i}

**Name:** *ESR? – Query the Standard Event Status register.
**Description:** This command returns values from the Standard Event Status register. Sending *ESR? will return the entire register value in decimal format, while sending *ESR? i will only return bit i. Reading the register will also clear it. Sending *ESR? will clear the entire register, while sending *ESR? i will only clear bit i. Table 6 below lists the conditions corresponding to the register bits. Use the *ESE register described on the following page to enable these bits to set a bit in the Status Byte. See figure 29 on page 99 for an overview of status bit promotion.

| Bit | Name | Set when... |
|---|---|---|
| 0 | OPC | The *OPC command has completed. |
| 1 | Unused | |
| 2 | QYE | Query error – data has been lost instead of transmitted. |
| 3 | DDE | Device specific error – an error was encountered while executing a remote command. |
| 4 | EXE | Execution error – a remote command could not be executed due to an argument or state problem. |
| 5 | CME | Command error – an invalid remote command was received. |
| 6 | URQ | User request – front panel activity was attempted regardless of local/remote status. |
| 7 | PON | The unit has turned on. |

Table 6: The Standard Event Status register bits.

The Standard Event Status register is defined by the IEEE-488.2 (1987) standard, and is used primarily to report errors in commands received over the remote interface. These bits remain set until read, cleared by the *CLS command, or until the unit is turned on with *PSC enabled.

**Example:**

```
*ESR?  Returns the Standard Event Status register value (0→255)
*ESR? 5  Returns 0 if bit 5 (CME) is cleared, or 1 if it is set.
```

`*ESE(?){i}{,j}`

**Name:** `*ESE(?)` – set or query bits in the Standard Event Enable register.
**Description:** The `*ESE i` command sets the Standard Event Enable register to the decimal value `i` (0 → 255). The `*ESE i,j` command sets bit `i` (0 → 7) to `j` (0 or 1). As shown in figure 29, bits enabled in the *ESR register via the *ESE register set the ESB bit in the status byte.

The `*ESE?` query returns the value (0 → 255) of the Standard Event Enable Register. The `*ESE? i` command queries the value (0 or 1) of bit `i` (0 → 7).

When the instrument sets a bit in the Standard Event Status Register (*ESR, described on the previous page), and the corresponding bit is set in the Standard Event Enable Register (this one) by the user, bit 5 (ESB) of the Status Byte (*STB, described on page 96) is set. This causes a SRQ if bit 5 in the Status Byte is set.

**Example:**

```
*ESE?  Returns the register value in decimal format
*ESE? 2  Returns 0 if bit 2 is cleared, or 1 if it is set
*ESE 48  Sets the register value to 48 (bits 4 and 5 set)
*ESE 7,0  Clears bit 7
```

INSR?{i}

**Name:** `INSR?` – Query the Instrument Status Register.
**Description:** This command returns values from the Instrument Status Register. Sending `INSR?` will return the entire register value in decimal format, while sending `INSR? i` will only return bit `i`. Reading the register will also clear it. Sending `ISNR?` will clear the entire register, while sending `INSR? i` will only clear bit `i`. Table 7 lists the conditions corresponding to the register bits. See figure 29 on page 99 to see an overview of all status registers.

| Bit | Name | Set when... |
|---|---|---|
| 0 | `STF` | Selftest Failure – the selftest has failed. |
| 1 | `KPE` | Keypress Event – a key was pressed on the front panel in local mode. |
| 2 | `KRO` | Knob Rotation – a parameter was changed by rotating the knob in local mode. |
| 3 | `RES` | Remote Set – a remote set command (not a query) was issued |
| 4 | `CRC` | Current Range Change – there was a change in the current (I) range. |
| 5-11 | | Internal use. |
| 12 | `ETA` | External Timebase Acquired – achieved lock to 10MHz timebase. |
| 13 | `ETL` | External Timebase Lost – lost lock to 10MHz timebase. |
| 14 | `ERR` | An error has been posted that can be queried with `errlst?`. |
| 15 | `REF` | Query Refused - a previous query has not been completely read. Perform read or send `ifcclr` |

Table 7: The Instrument Status register bits.

**Example:**

```
INSR?  Returns the Instrument Status register value (0→65535)
INSR? 4  Returns 0 if bit 4 (CRC) is cleared, or 1 if it is set.
```

**Name:** `INSE(?)` – set or query bits in the Instrument Status Enable Register.
**Description:** The `INSE i` command sets the Instrument Status Enable register to the decimal value `i` (0 → 65535). The `INSE i,j` command sets bit `i` (0 → 15) to `j` (0 or 1). As shown in figure 29 on page 99, bits enabled in the INSR register (defined on the preceding page) via the INSE register (this one) set the INSW bit in the status byte.

The `INSE?` query returns the value of the Instrument Status Enable register. The `INSE? i` command queries only bit `i`.

`INSE(?){i}{,j}`

When the instrument sets a bit in the Instrument Status Register, and the corresponding bit is set in the Instrument Status Enable register by the user, bit 1 (INSW) of the Status Byte is set. This causes a SRQ if bit 0 in the Status Byte Enable register is set.

**Example:**

```
INSE?  Returns the register value in decimal format
INSE? 2  Returns 0 if bit 2 is cleared, or 1 if it is set
INSE 16  Sets the register value to 16 (bit 4 set)
INSE 4,0  Clears bit 4
```

MESR?{i}

**Name:** MESR? – Query the Measurement Status register.
**Description:** This command returns values from the Measurement Status register. Sending MESR? will return the entire register value in decimal format, while sending MESR? i will only return bit i. Reading the register will also clear it. Sending MESR? will clear the entire register, while sending MESR? i will only clear bit i. Table 8 lists the conditions corresponding to the register bits.

| Bit | Name | Set when... |
|---|---|---|
| 0 | CEL | CE limit – The CE voltage limit (either ±30V or the user-defined limit) was reached. |
| 1 | EOL | E overload – the E measurement exceeded ±15V. |
| 2 | IOL | I overload – the I measurement exceeded 200% of a range or 1A. |
| 3 | A01 | Auxiliary ADC channel 1 overload – the BNC input exceeded ±10V. |
| 4 | A02 | Auxiliary ADC channel 2 overload – the BNC input exceeded ±10V. |
| 5 | A03 | Auxiliary ADC channel 3 overload – the BNC input exceeded ±10V. |
| 6 | NRH | No remote amplifier (EC19) detected |
| 7 | CIL | CE limit – The CE current limit (±1A) was reached. |

Table 8: The Measurement Status register bits.

**Example:**

```
MESR?  Returns the Instrument Status register value (0→65535)
MESR? 4  Returns 0 if bit 4 (CRC) is cleared, or 1 if it is set.
```

**Name:** `MESE(?)` – set or query bits in the Measurement Status Enable Register.
**Description:** The `MESE i` command sets the Measurement Status Enable register to the decimal value `i` (0 → 65535). The `MESE i,j` command sets bit `i` (0 → 15) to `j` (0 or 1). As shown in figure 29 on page 99, bits enabled in the MESR register (defined on the preceding page) via the MESE register (this one) set the MESW bit in the status byte.

The `MESE?` query returns the value of the Measurement Status Enable Register. The `MESE? i` command queries only bit `i`.

`MESE(?){i}{,j}`

When the instrument sets a bit in the Measurement Status Register, and the corresponding bit is set in the Measurement Status Enable register by the user, bit 1 (MESW) of the Status Byte is set. This causes a SRQ if bit 1 in the Status Byte Enable register is set.

**Example:**

```
MESE?  Returns the register value in decimal format
MESE? 2  Returns 0 if bit 2 is cleared, or 1 if it is set
MESE 48  Sets the register value to 48 (bits 4 and 5 set)
MESE 7,0  Clears bit 7
```

*STB?{i}

**Name:** `*STB?` – Query Status Byte values.
**Description:** This command returns values from the Status Byte register. Sending `*STB?` will return the entire register value in decimal format, while sending `*STB? i` will only return bit `i`. Reading this register will not clear it – it must be cleared by reading the registers that feed it. See figure 29 on page 99 for a description of how status bit values are promoted to this register. Table 9 lists the conditions corresponding to the register bits.

| Bit | Name | Set when... |
|---|---|---|
| 0 | INSW | An unmasked bit in the Instrument Status Register (described on page 92) has been set. |
| 1 | MESW | An unmasked bit in the Measurement Status Register (described on page 94) has been set. |
| 2 | | Not used. |
| 3 | | Not used. |
| 4 | MAV | There is a message available in the GPIB queue. |
| 5 | ESB | An unmasked bit in the Standard Event Status Register (described on page 90) has been set. |
| 6 | SRQ | Service request. See the `*SRE` command described on the next page for more information. |
| 7 | IFC | Set when the remote interface's receive queue is full. |

Table 9: The Status Byte Register bits.

*SRE(?){i}{,j}

**Name:** `*SRE(?)` – set or query bits in the Status Byte Enable register.
**Description:** The `*SRE i` command sets the Status Byte Enable register to the decimal value `i` (0 → 255). The `*SRE i,j` command sets bit `i` (0 → 7) to `j` (0 or 1). As shown in figure 29 on page 99, bits enabled in the *STB register via the *SRE register set the SRQ bit.

The `*SRE?` query returns the value (0 → 255) of the Standard Event Enable Register. The `*SRE? i` command queries the value (0 or 1) of bit `i` (0 → 7).

When the instrument sets a bit in the Status Byte register, and the corresponding bit is set in the Status Byte Enable register by the user, bit 6 (SRQ) of the Status Byte is set. The front panel SRQ light described in section 3.1.17 on page 31 will also light up. This can be used as a general purpose indicator for a condition described by the status bits. The example below describes using SRQ to indicate an overload at the rear panel auxiliary ADC input BNC.

**Example:**

```
*SRE 2  Unmask the MESR status bits only
MESE 8  Unmask the “Aux 1 overload” status bit from MESR
Apply more than 10V to the rear panel Aux 1 BNC to cause a SRQ
*STB?  See that bit 6 (SRQ) of the status byte has been set
Remove the overload on Aux 1
MESR?  Query the MESR register to clear the “Aux 1 overload” bit
*STB?  See that bit 6 (SRQ) has also been cleared in the status byte
```

*CLS

**Name:** `*CLS` – clear all status registers.
**Description:** This command clears all the status registers (INSR, MESR, and *ESR). It will also terminate all scans in progress.

errmsg?{i}

**Name:** `errmsg?` – Return the front panel's most recent error code or message.
**Description:** This query-only command returns errors that have been displayed on the front panel character display. Since these errors disappear after a short time, this command provides a way to always get the most recent error message.

The error codes returned with `i` = 0 are unique to `errmsg?` – the front panel errors. They can not be decoded using `errdcd?`. See the `errlst?` and `errdcd?` commands on pages 98 and 98 for more information about error reporting.

| i | Error report returned |
|---|---|
| 0 | Most recent error code |
| 1 | Most recent error message |
| 2 | Verbose form of most recent error message |

**Name:** `errlst?` – Return the most recent system-level error code.
**Description:** This query-only command returns the code corresponding to the most recent system-level error. While the `errmsg?` command described on page 97 deals with error messages visible on the front panel, this query deals with errors output via the remote interface. Error codes are decoded with the `errdcd?` query described on this page.

These errors are cleared by either a front panel button press or a set command.

`errlst?`

**Example:**

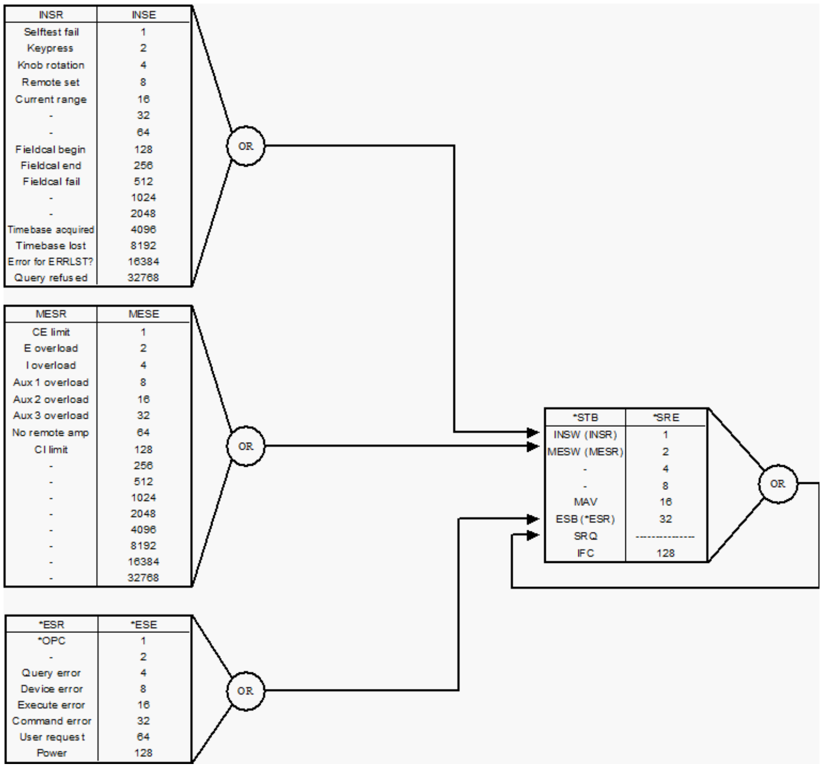
```
badcmd  badcmd isn't a known command
errlst?  Query the most recent error
114  The error code is 114
errdcd? 114  Let's see what error code 114 is
Bad remote command  Yes, that makes sense
irange 5  Use a set command to clear the error
errlst?
0  The error has been cleared
```

---

**Name:** `errdcd?` – Decode the error code from `errlst?`.

`errdcd?{i}`

**Description:** This query-only command returns the description of the error code reported by `errlst?`. See the `errlst?` query description on the current page for more information.



| INSR | INSE |
|---|---|
| Selftest fail | 1 |
| Keypress | 2 |
| Knob rotation | 4 |
| Remote set | 8 |
| Current range | 16 |
| - | 32 |
| - | 64 |
| Fieldcal begin | 128 |
| Fieldcal end | 256 |
| Fieldcal fail | 512 |
| - | 1024 |
| - | 2048 |
| Timebase acquired | 4096 |
| Timebase lost | 8192 |
| Error for ERRLST? | 16384 |
| Query refused | 32768 |

| MESR | MESE |
|---|---|
| CE limit | 1 |
| E overload | 2 |
| I overload | 4 |
| Aux 1 overload | 8 |
| Aux 2 overload | 16 |
| Aux 3 overload | 32 |
| No remote amp | 64 |
| CI limit | 128 |
| - | 256 |
| - | 512 |
| - | 1024 |
| - | 2048 |
| - | 4096 |
| - | 8192 |
| - | 16384 |
| - | 32768 |

| *ESR | *ESE |
|---|---|
| *OPC | 1 |
| - | 2 |
| Query error | 4 |
| Device error | 8 |
| Execute error | 16 |
| Command error | 32 |
| User request | 64 |
| Power | 128 |

| *STB | *SRE |
|---|---|
| INSW (INSR) | 1 |
| MESW (MESR) | 2 |
| - | 4 |
| - | 8 |
| MAV | 16 |
| ESB (*ESR) | 32 |
| SRQ | -------------- |
| IFC | 128 |

Figure 29: The status bit promotion diagram. Enabling bits in the INSR, MESR, and *ESR status registers allows them to set bits in the *STB. Enable these bits with the INSE, MESE, and *ESE registers. Properly configuring status bit promotion allows quick status byte (*STB) queries to indicate problems.

### 7.3.16 Pulsed waveform generation commands

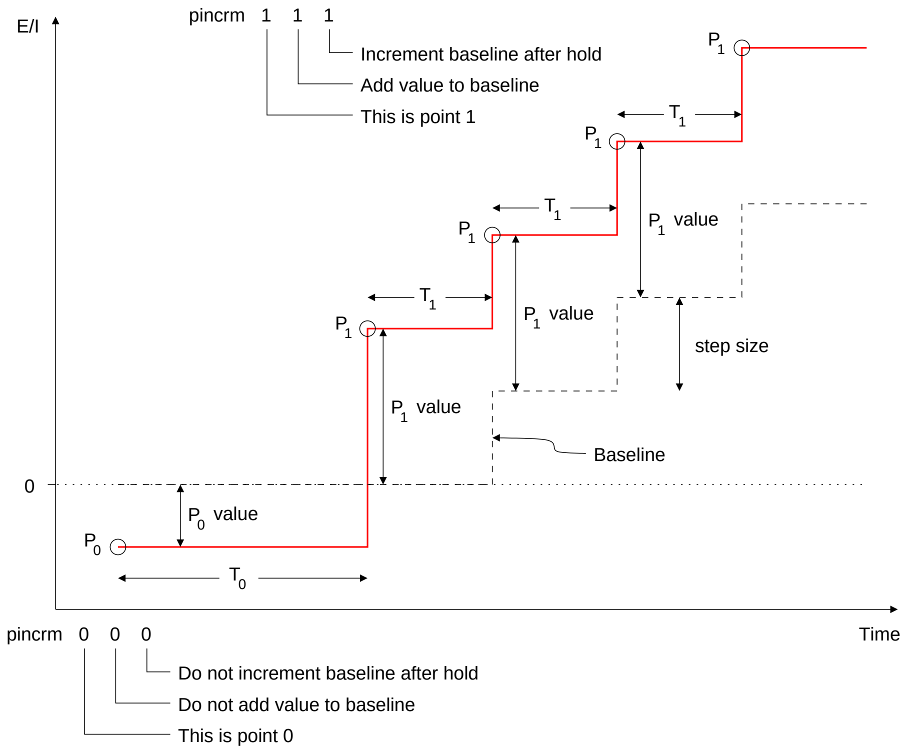


Figure 30: A very basic waveform illustrating the pulsed waveform construction parameters.

**Name:** `ppoint(?)` – Set or query the number of pulse waveform points.
**Description:** Pulsed waveforms may be specified with up to six control points, with the number of points given by `i` + 1. The waveform generator must be told how many points it will be using.

| Parameter | Allowed values |
|---|---|
| i | 1,2,3,4,5, . . . , 15 |

`ppoint(?){i}`

Figure 30 illustrates a waveform with only two control points. The first point, $P_0$, allows the cell to be held at a constant potential or current before the repetitive part of the waveform is applied. Subsequent points are then output until the `ppoint` value is reached. The waveform then loops back to output point $P_1$.

For example, the command

```
ppoint 1
```

will tell the waveform generator to make room for the minimum number of two control points.

**Name:** `psteps(?)` – Set or query the pulsed waveform step size.
**Description:** This is the current or potential increment applied to the pulsed waveform baseline.

`psteps(?){x}`

| Parameter | Mode | Units | Range |
|---|---|---|---|
| `x` | Potentiostat | mV | $-15000, -14999, -14998, \cdots, +15000$ |
|  | Galvanostat | $\frac{I_{\text{range}}}{1000}$ | $-2000, -1999, -1998, \cdots, +2000$[1]<br>[1] $-1000 \rightarrow +1000$ for 1A range |

This step size takes mV values in potentiostat mode, and milli-fractions of the full scale current ($I_{\text{range}}$) in galvanostat mode. As illustrated in figure 30, the baseline is incremented after a control point is applied with its increment bit set (`pincrm x x 1`).

For example, the command

```
psteps 50
```

sets the step size to 50mV.

---

**Name:** `pdatap(?)` – Set or query the pulse data waveform control point values.
**Description:** Each of the possible six control points used to specify a pulsed waveform needs a voltage or current "value."

| Parameter | Range |
|---|---|
| `i` | $0, 1, 2, \cdots, 5$ |

`pdatap(?){i}{x}`

| Parameter | Mode | Units | Range |
|---|---|---|---|
| `x` | Potentiostat | mV | $-15000, -14999, -14998, \cdots, +15000$ |
|  | Galvanostat | $\frac{I_{\text{range}}}{1000}$ | $-2000, -1999, -1998, \cdots, +2000$[1]<br>[1] $-1000 \rightarrow +1000$ for 1A range |

The `i` parameter chooses the control point to set or query. The point values take mV values in potentiostat mode, and milli-fractions of the full scale current ($I_{\text{range}}$) in galvanostat mode. As illustrated in figure 31, these values can be added to the baseline to form the finished waveform.

For example, the command

```
pdatap 0 1000
```

sets the value of $P_0$ to 1V in potentiostat mode, or $I_{\text{range}}$ in galvanostat mode.

**Name:** `pholdt(?)` – Set or query the pulse data waveform control point hold times.
**Description:** Each of the possible six control points used to specify a pulsed waveform needs a hold time.

| Parameter | Range |
|---|---|
| `i` | $0, 1, 2, \cdots, 5$ |

`pholdt(?){i}{x}`

| Parameter | Units | Range |
|---|---|---|
| `x` | $4\mu$s | $1, 2, 3, \cdots, 16777215$ $(2^{24} - 1)$ |

The `i` parameter chooses the control point to set or query. Figure 31 shows hold times $T_0$ and $T_1$ for points $P_0$ and $P_1$.

For example, the command

```
pholdt 0 2000
```

sets the $T_0$ hold time to 8ms.

**Name:** `pincrm(?)` – Configure how a pulsed waveform point interacts with the baseline.
**Description:** Each control point in the pulsed waveform can either add its value to the baseline or to 0V/0A to form the finished waveform. The points (all except $P_0$) can also instruct the baseline to increment when their hold times have expired.

| Parameter | Range |
|---|---|
| `i` | $1, 2, 3, 4, 5$ |

| j | Mode |
|---|---|
| 0 | Do not add this point's value to the baseline |
| 1 | Add this point's value to the baseline |

| k | Mode |
|---|---|
| 0 | Increment baseline after the point's hold has expired |
| 1 | Leave baseline unchanged after this point |

`pincrm(?){i}{j}{k}` The `i` parameter chooses the control point to set or query. The `j` parameter selects whether or not the selected control point's value (set with `pdatap`) will add to the baseline in the final waveform. The `k` parameter selects whether or not the baseline should be incremented after the point's hold has ended.

For example, the $P_1$ point shown in figure 30 is configured with the command

```
pincrm 1 1 1
```

to have its value added to the baseline, and for the baseline to increment after the $T_1$ hold has expired.

The first $P_0$ point in a pulsed waveform definition is unique. It allows a non-repeating hold to be applied to the cell before a pulsed waveform train is applied. `pincrm` bits set for this point will be ignored, and queries will always return `0 0 0` `plimit(?){x}`

**Name:** `plimit(?)` – Set or query the number of steps in a pulsed waveform.
**Description:** This command sets the number of steps the baseline will make in a pulsed waveform.

| Parameter | Range |
|---|---|
| x | $1, 2, 3, \cdots, 1048575$ ($2^{20} - 1$) |

For example, the waveform shown in figure 30 shows four steps. The command

```
plimit 4
```

would make the pulsed waveform either stop or turn around depending on the `plendm` command.

---

`plendm(?){i}`

**Name:** `plendm(?)` – Set or query the pulsed waveform end mode.
**Description:** The pulsed waveform can either run in one direction and stop, or continuously scan between two endpoints.

| i | Mode |
|---|---|
| 0 | Baseline increment reverses every `plimit` steps |
| 1 | Baseline will increment `plimit` steps and stop |

---

`plinit`

**Name:** `plinit` – Initialize the pulsed waveform.
**Description:** This command must be sent before a pulsed waveform can be output. See the example pulsed waveform example in section 7.4.1 on page 117 for more information.

---

`pprogm?`

**Name:** `pprogm?` – Verify the pulse program has no missing points.
**Description:** This query must be sent before beginning a pulse waveform with the `pstart` command. It verifies that there are no missing data points for the pulse program. If one or more points are missing, pprogm? returns an error code (see table below).
If no points are missing, `pprogm?` returns zero.
The `pprogm?` error code is a bit field defined as follows:

| $n$ | $2^n$ | Issue |
|---|---|---|
| 0 | 1 | One or more unique points has no data |
| 1 | 2 | reserved |
| 2 | 4 | reserved |
| 3 | 8 | reserved |
| 4 | 16 | reserved |
| 5 | 32 | reserved |
| 6 | 64 | reserved |
| 7 | 128 | reserved |

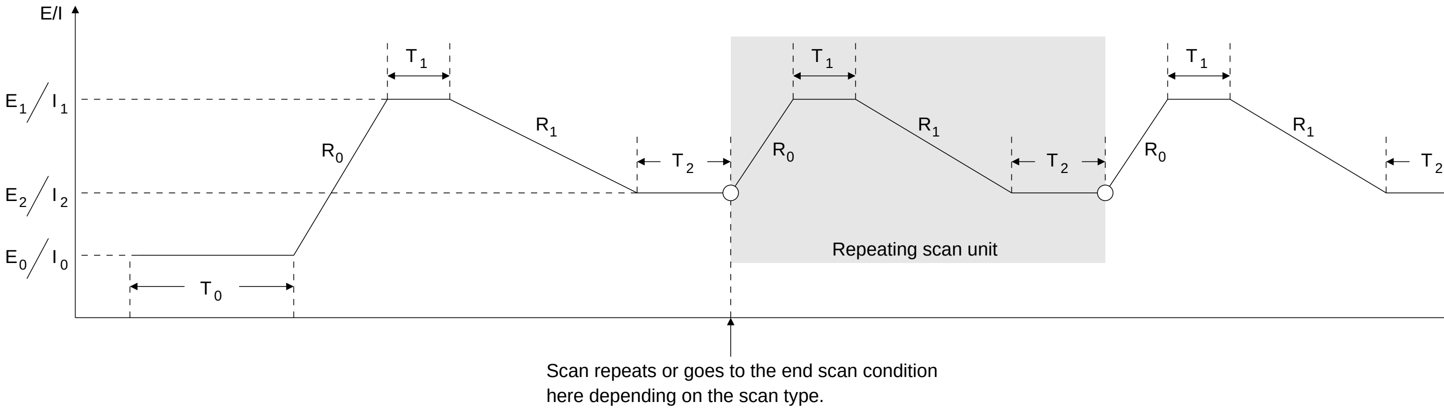
pstart

**Name:** `pstart` – Start the pulsed waveform.
**Description:** Sending this command will close the control loop and run the programmed pulsed waveform.

plstop

**Name:** `plstop` – Stop the pulsed waveform.
**Description:** This command halts the pulsed waveform, leaving the control loop closed.

### 7.3.17 Ramp generation commands



Scan repeats or goes to the end scan condition here depending on the scan type.

Figure 31: Parameters needed for the ramp generation commands.

**Name:** `ramppt(?)` – Set an $E$ or $I$ vertex point for the ramp.
**Description:** As illustrated in figure 31, there are three $E/I$ vertex points needed to define a ramp waveform.

| i | Vertex point |
|---|---|
| 0 | $E_0/I_0$ |
| 1 | $E_1/I_1$ |
| 2 | $E_2/I_2$ |

`ramppt(?){i}{x}`

| Parameter | Mode | Units | Range |
|---|---|---|---|
| x | Potentiostat | mV | $-15000, -14999, -14998, \cdots, +15000$ |
| | Galvanostat | $\frac{I_{\text{range}}}{1000}$ | $-2000, -1999, -1998, \cdots, +2000$[1]<br>[1] $-1000 \rightarrow +1000$ for 1A range |

These vertex points take mV values in potentiostat mode, and milli-fractions of the full scale current ($I_{\text{range}}$) in galvanostat mode.

For example, the command

```
ramppt 0 -500
```

sets the first ramp vertex to -500mV (potentiostat mode) or 500 thousandths of $I_{\text{range}}$ (galvanostat mode). The command

```
ramppt? 0
-500
```

will return the value loaded into index 0.

**Name:** `ramprt(?)` – Set or query a ramp rate for the ramp waveform.
**Description:** As illustrated in figure 31, there are two ramp rates needed to define a ramp waveform.

| i | Ramp rate |
|---|---|
| 0 | $R_0$ |
| 1 | $R_1$ |

| Parameter | Mode | Units | Range |
|---|---|---|---|
| x | Potentiostat | $100\mu$V/s | $1, 2, 3, \cdots, 1 \times 10^8$ |
| | Galvanostat | $\frac{I_{\text{range}}}{1000 \cdot \text{s}}$ | $1, 2, 3, \cdots, 2000$ |

`ramprt(?){i}{x}`

These rates take multiples of $100\mu$V/s in potentiostat mode, and milli-fractions of the full scale current ($I_{\text{range}}$) per second in galvanostat mode. They are always entered as positive numbers. The actual scan direction (sign of the rate) will be determined by the relative magnitudes of the vertices set with `ramppt`.

Maximum current on the 1 A range is 1 A, but it is fine to scan at 2 A/s. There is no special restriction for scan rate on the 1 A range.
For example, the command

```
ramprt 0 1000
```

sets the $R_0$ ramp rate to 100mV/s (potentiostat mode) or $\frac{I_{\text{range}}}{10 \cdot \text{s}}$ in galvanostat mode. The command

```
ramprt? 0
1000
```

will return the value loaded into index 0.

**Name:** `rampdt(?)` – Set or query a delay time for the ramp.
**Description:** As illustrated in figure 31, there are three delay times needed to define a ramp waveform.

| i | Delay time |
|---|---|
| 0 | $T_0$ |
| 1 | $T_1$ |
| 2 | $T_2$ |

`rampdt(?){i}{x}`

| Parameter | Units | Range |
|---|---|---|
| x | 100$\mu$s | $0, 1, 2, \cdots, 4294967295$ $(2^{32} - 1)$ |

For example, the command

```
rampdt 0 10000
```

will set $T_0$ to 1s. The command

```
rampdt? 0
10000
```

returns the value loaded into index 0.

`ramprs`

**Name:** `ramprs` – Reset the ramp program.
**Description:** This command clears the previous ramp program. It must be sent before a new ramp waveform is programmed. Sending `ramprs` will stop any running ramp waveforms. Use `rampst` instead to simply stop the waveform without clearing the program.

ramppg?

**Name:** `ramppg?`{x} – Verify the ramp program parameters for ramp type {x}.

**Description:** This query must be sent before beginning a ramp with the `rampst` command. It verifies that the parameters necessary for the given ramp type {x} are specified. If one or more of the parameters are missing, `ramppg?`{x} returns an error code (see table below). If no parameters are missing, `ramppg?`{x} returns zero.
`ramppg?`{x} has the following valid argument range for {x}:

| {x} | Check parameters for this waveform type |
|---|---|
| 0 | Cyclic Voltammetry |
| 1 | Linear Sweep Voltammetry |
| 2 | Infinite Hold |
| 3 | Timed Hold |
| 4 | Arm Linear Sweep Voltammetry |

The `ramppg?`{x} error code is a bit field defined as follows:

| $n$ | $2^n$ | Missing parameter |
|---|---|---|
| 0 | 1 | T1 |
| 1 | 2 | T2 |
| 2 | 4 | P1 |
| 3 | 8 | P2 |
| 4 | 16 | P3 |
| 5 | 32 | R1 |
| 6 | 64 | R2 |
| 7 | 128 | reserved |

rampst{i}

**Name:** `rampst` – Start a ramp or hold.
**Description:** Sending this command will close the control loop (if necessary) and run the programmed ramp waveform. Use `rampst 4` or `rampst 5` for scans triggered with the rear panel `SCAN TRIGGER` input.

| i | Mode |
|---|---|
| 0 | Begin a CV ramp |
| 1 | Begin an LSV ramp |
| 2 | Begin an infinite hold |
| 3 | Begin a timed hold |
| 4 | Arm in preparation for a CV ramp |
| 5 | Arm in preparation for an LSV ramp |

rampen{x}

**Name:** `rampen` – End the ramp in progress.
**Description:** This command will end a running ramp waveform without clearing the program.

---

rampcy(?){x}

**Name:** `rampcy(?)` – Set or query the number of ramp cycles.
**Description:** The "repeating scan unit" illustrated in figure 31 can be repeated a few times or forever. Use this command to set a finite number of repeats after disabling single scanning with `scantp 0`.

| Parameter | Range |
|---|---|
| x | $1, 2, 3, \cdots, 254$ |

Note that sending `rampcy 1` will still set the $E_2/I_2$ vertex twice, since the repeating scan unit will be run once. Send `scantp 1` to set the single scan type for just one scan.

---

scantp(?){i}

**Name:** `scantp(?)` – Set or query the scan type.
**Description:** This command enables or disables single scanning.

| i | Mode |
|---|---|
| 0 | Continuous scanning |
| 1 | Single scan |

A single scan sets the end scan condition after waiting the first $T_2$ delay shown in figure 31. If this is disabled, the scan will continue and repeat the "repeating scan unit." The number of repetitions is infinite by default, but can be made finite by sending a value for `rampcy`.

---

scanem(?){i}

**Name:** `scanem(?)` – Set or query the scan end condition.
**Description:** Single scans can either return the cell to open-circuit or to the $E_0/I_0$ vertex shown in figure 31.

| i | Scan end condition |
|---|---|
| 0 | Open circuit |
| 1 | Hold at $E_0/I_0$ |

### 7.3.18 Arbitrary waveform generation commands

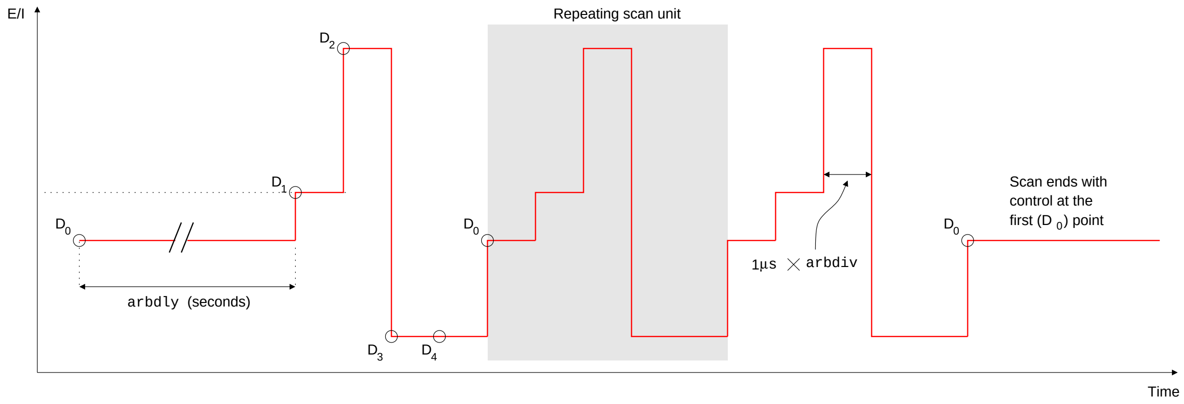


Figure 32: Illustration of an arbitrary waveform with five arbset points and three repetition cycles. The time between ARBSET points is always 1$\mu$s × arbdiv. Repeat points to get longer hold times.

arbrst

**Name:** arbrst – Reset the arbitrary waveform generator.
**Description:** The arbitrary waveform generator should be reset before a new waveform is programmed. This reset disables the generator and sets the default conditions listed in table 10.

| Parameter | Set with... | Default value | Notes |
|---|---|---|---|
| Waveform type | arbtyp | Undefined | A waveform type must be chosen with arbtyp before points can be entered with arbset. |
| Number of points | arbpts | 0 | |
| Start delay | arbdly | 0 | |
| Clock divider | arbdiv | 1 | |
| Number of cycles | arbcyc | 1 | |
| End condition | arbend | $E_1/I_1$ | By default, the instrument will loop back to hold the first point in the waveform when the scan ends. |
| Scan trigger | arbrun | Internal | By default, triggering via the SCAN TRIGGER input is disabled. |

Table 10: Arbitrary waveform generator parameters after issuing the arbrst command.

arbpts?

**Name:** `arbpts?` – Query the number of points in the arbitrary waveform.
**Description:** This query-only command returns the number of points that have been set via the **`arbset`** command. It may be used to verify that all **`arbset`** commands were processed properly.

| Returned parameter | Values |
|---|---|
| Programmed points | 0,1,2,···,1599 |

arbdly(?){i}

**Name:** `arbdly(?)` – Set or query the hold time for the first arbitrary waveform point.
**Description:** The EC301 can hold the first point in an arbitrary waveform to let a cell settle. This command sets the "extra" time that the point should be held relative to the following points.

| Parameter | Units | Range |
|---|---|---|
| `i` | seconds | $0, 1, 2, \cdots, 1023$ |

arbdiv(?){i}

**Name:** `arbdiv(?)` – Set or query the playback rate divider for the arbitrary waveform generator.
**Description:** The default playback rate for arbitrary waveform points is 1 megasample per second. This command allows reducing that rate by a factor of `i`.

| Parameter | Units | Range |
|---|---|---|
| `i` | None | $1, 2, 3, \cdots, 1024$ |

For example, the sequence

```
arbdiv 1000
arbdiv?
1000
```

will set the playback rate to $\frac{1\text{Msps}}{1000}$ = 1ksps, or 1000 points per second.

arbend(?){i}

**Name:** `arbend(?)` – Set or query the end condition for arbitrary waveform scans.
**Description:** Arbitrary waveform scans can end by either maintaining control at the first point of the waveform, or by releasing control (open circuit).

| i | Mode |
|---|---|
| 0 | Control is maintained at the first waveform point (default) |
| 1 | Control is released (open circuit) |

**Name:** `arbcyc(?)` – Set or query the number of repetitions for arbitrary waveform scans.
**Description:** Arbitrary waveform scans can be set to repeat either a finite or infinite number of times.

`arbcyc(?){i}`

| i | Mode |
|---|---|
| 0 | Repeat an infinite number of times. The user can end the infinite loop by sending `arbrun 0`. |
| $1, 2, 3, \cdots, 1024$ | Repeat `i` number of times. The scan will end in the condition set by `arbend`. |

**Name:** `arbset?` – Set an arbitrary waveform datum.
**Description:** This command programs arbitrary waveform data on a point-by-point basis. Each point is specified by an index (`i`) and a datum (`j`). Waveform points are played beginning with `i`=0, and up to 16,000 points can define the waveform.

The datum type is set by `arbtyp`. Potentiostatic datum types have units of mV, while galvanostatic types have milli-$I_{\text{range}}$ units. For example, if the datum type is 5 – corresponding to galvanostat mode in the 1mA range – the datum will have units of $\mu$A.

`arbset?{i}{j}`

| Parameter | Range |
|---|---|
| `i` | $0, 1, 2, \cdots, 1599$ |

| Parameter | Type | Range | Units |
|---|---|---|---|
| `j` | Potentiostat | $-15000, -14999, -14998, \cdots, +15000$ | mV |
| | Galvanostat (1 A range) | $-1000, -999, -998, \cdots, +1000$ | $\frac{I_{\text{range}}}{1000}$ |
| | Galvanostat (all others) | $-2000, -1999, -1998, \cdots, +2000$ | $\frac{I_{\text{range}}}{1000}$ |

Each `arbset?` produces an error code reply from the EC301. If the reply to `arbset?` is non-zero, it signifies an error. Every `arbset?` must be followed by reading the error code reply from the EC301

**Name:** `arbget` – Query the value of the arbitrary waveform at index {i}.

`arbget?{i}`

**Description:** To determine what value is programmed at any index, use `arbget?` If no value is programmed at the given index {i}, `arbget?` returns an error code, 31.

---

**Name:** `arbtyp(?)` – Set or query the arbitrary waveform type.

`arbtyp(?){i}`

**Description:** The user must set the arbitrary waveform type with `arbtype` before entering data points with `arbset`. The `arbtype` command argument defines the legal range of `arbset` arguments. This waveform type can only be defined once. This prevents mixing control point data types in memory. This also means that the `arbrst` command must be sent between `arbtyp` commands.

| i | Scan type | Range |
|---|---|---|
| 0 | Potentiostatic | ±15V |
| 1 | Galvanostatic | 1A |
| 2 | | 100mA |
| 3 | | 10mA |
| 4 | | 1mA |
| 5 | | 100$\mu$A |
| 6 | | 10$\mu$A |
| 7 | | 1$\mu$A |
| 8 | | 100nA |
| 9 | | 10nA |
| 10 | | 1nA |

Notice that there is a scan type for each current range. Arbitrary waveform points for galvanostat scan types are simply fractions of the full scale current, so there must be a way to define this current. After setting a galvanostatic scan type, sending `arbrun 1` or `arbrun 2` will force the instrument into the range defined by the scan type.

---

**Name:** `arbrun` – Begin, end, or arm arbitrary waveform playback.
**Description:** This set-only command allows for either internal or external triggering of arbitrary waveform scans.

`arbrun{i}`

| i | Instruction |
|---|---|
| 0 | Stop waveform playback and open the control loop. This will also disarm the scan to ignore `SCAN TRIGGER` inputs. |
| 1 | Start waveform playback automatically. This will engage the control loop in whichever mode/range combination specified with `arbtyp`. |
| 2 | Arm waveform playback. This will engage the control loop in whichever mode/range combination specified with `arbtype`, but playback will not begin until a falling edge is received at the rear panel `SCAN TRIGGER` input. |

Only one scan type (ramp, pulse, hold, or arbitrary) can be "armed" at any one time. The most recent scan type to be armed will be run when a trigger is received at `SCAN TRIGGER` .

### 7.3.19 Reading temperature measurements

**Name:** `getrtd?` – get temperature reading.
**Description:** This query-only command returns the RTD probe measurement in ℃.

`getrtd?`

**Example:**

```
getrtd?
52.75  Degrees Celsius
```

---

**Name:** `rtdohm?` – get the RTD probe resistance.
**Description:** This query-only command returns the RTD probe resistance in ohms.

`rtdohm?`

**Example:**

```
rtdohm?
50.35  Ohms
```

## 7.4 Programming examples

### 7.4.1 Normal pulse

As described by Bard and Faulkner [1], the normal pulse voltammetry waveform involves a base potential and a series of increasing steps. The following command sequence produces the waveform shown in figure 33. *Slanted text* following a command is only used to clarify the example, and would be rejected by the EC301.

```
PLINIT  Initialize the waveform generator
PPOINT 2  The waveform will have 3 control points
PSTEPS 200  Baseline potential will increment in +200mV steps
PLIMIT 4  Baseline will increment 4 times
PDATAP 0 100  The zeroth point is at +100mV
PHOLDT 0 500000  The zeroth point is held for 2s
PDATAP 1 400  The first point amplitude is +400mV
PHOLDT 1 62500  The first point is held for 250ms
PINCRM 1 1 1  The first point is added to the baseline
PDATAP 2 100  The second point amplitude is +100mV
PHOLDT 2 250000  The second point is held for 1s
PINCRM 2 0 0  The second point is not added to the baseline, and is the last point
PLENDM 1  Set the scan to end after the set number of increments
PPROGM?  Load the pulse program, verify parameters
PSTART  Start the scan
```

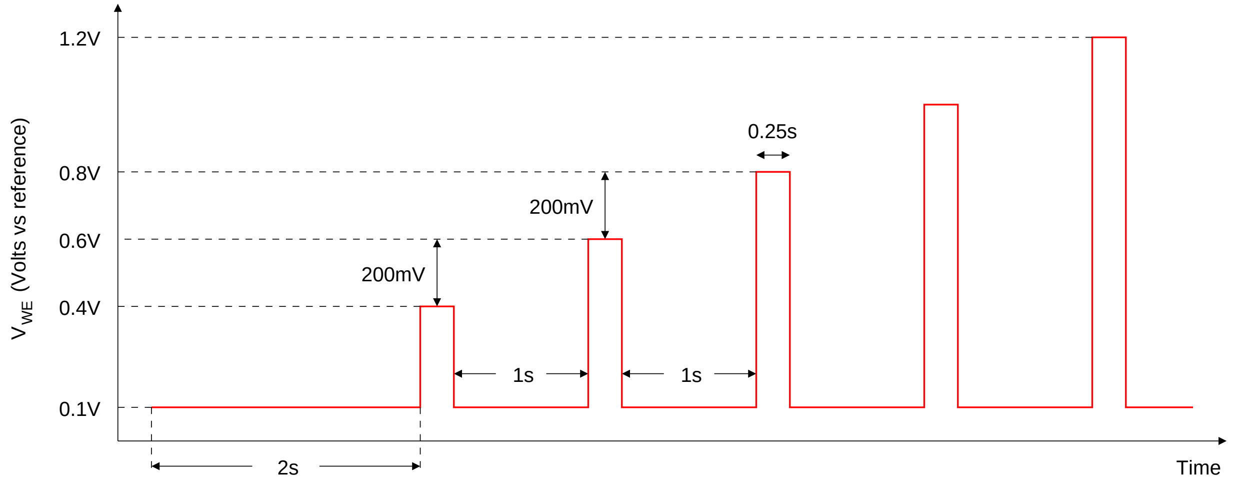


Figure 33: Sample normal pulse waveform.

### 7.4.2 Cyclic voltammetry

The cyclic voltammetry waveform includes a hold and a ramp reversed at a switching potential. The following command sequence produces the waveform shown in figure 34. Refer to figure 31 on page 106 for definitions of the potential, delay, and rate point indexes.

```
RAMPRS  Initialize the ramp generator
SCANTP 1  Set single (not continuous) scan type
SCANEM 1  Set the scan endpoint to E0
RAMPPT 0 100  Set the E0 point at +100mV
RAMPDT 0 60000  Set the T0 delay time to 6s
RAMPRT 0 2000  Set the R0 ramp rate to 0.2V/s
RAMPPT 1 500  Set the E1 point at +500mV
RAMPDT 1 0  No delay at the E1 point
RAMPRT 1 2000  Set the R1 ramp rate to 0.2V/s
RAMPPT 2 100  Set the E2 point at +100mV
RAMPPG? 0  Load the ramp program, verify parameters
RAMPST 0  Start the scan
```

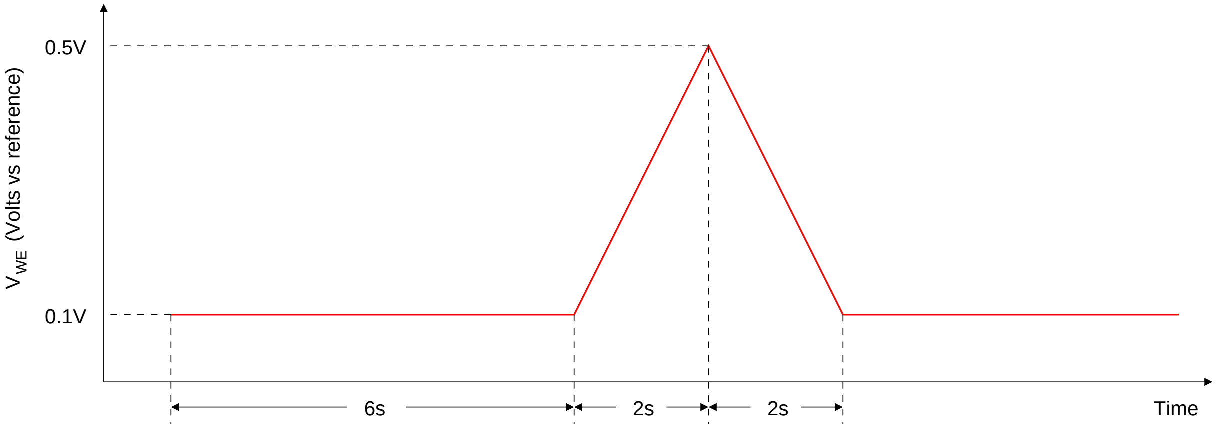


Figure 34: Sample cyclic voltammetry waveform.

### 7.4.3 Current interrupt IR compensation

This example doesn't completely set up IR compensation, but it illustrates the use of the remote commands described in section 7.3.5 on page 71. Figure 35 below illustrates interruption of current through a resistor with no actual correction applied. The commands below set up the timing parameters and start interruption.

```
IRTYPE 0  Set current interrupt mode
CIOPEN 3000  Set the interruption time to 3ms
CIPERD 10  Set the interruption period to 10ms
CICORR 0  Set the correction amount in percent
CIDLAY 0 100  Set the “open” voltage sampling delay to 100µs
CIDLAY 1 100  Set the “closed” voltage sampling delay to 100µs
IRENAB 1  Turn current interrupt on
```

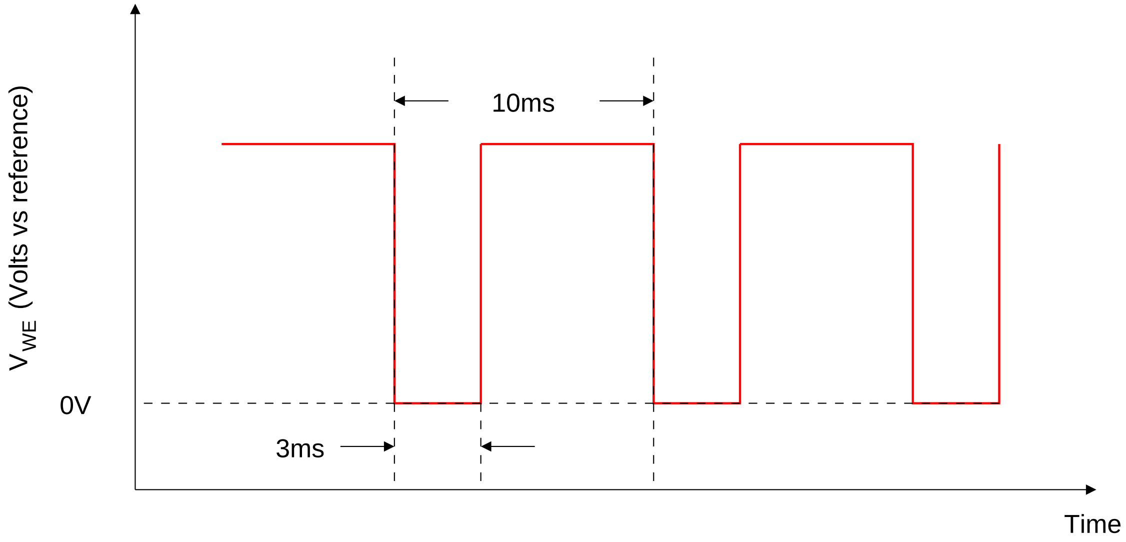


Figure 35: Sample current interruption waveform.

### 7.4.4 Arbitrary waveform

The following command sequence produces the waveform shown in figure 36. This arbitrary waveform example includes five `ARBSET?` points and three cycles. The scan ends with the system in control at the first data point.

`ARBRST` *Reset the arbitrary waveform interface*

`ARBTYP 1` *Waveform data type will be potentiostatic*

`ARBDLY 1` *Hold $D_0$ for one second, then play $D_1$*

`ARBCYC 3` *Cycle the waveform three times*

`ARBEND 0` *Maintain control at $D_0$ when finished*

`ARBDIV 1000` *Play points back at 1MHz/1000 (1ms sample time)*

`ARBSET? 0 100` *Set the $D_0$ point at +100mV.*

`0` *EC301 responds "0"*

`ARBSET? 1 200` *Set the $D_1$ point at +200mV.*

`0` *EC301 responds "0"*

`ARBSET? 2 500` *Set the $D_2$ point at +500mV.*

`0` *EC301 responds "0"*

`ARBSET? 3 -100` *Set the $D_3$ point at −100mV.*

`0` *EC301 responds "0"*

`ARBSET? 4 -100` *Set the $D_4$ point at −100mV.*

`0` *EC301 responds "0"*

`arbrun 1` *Start the scan*

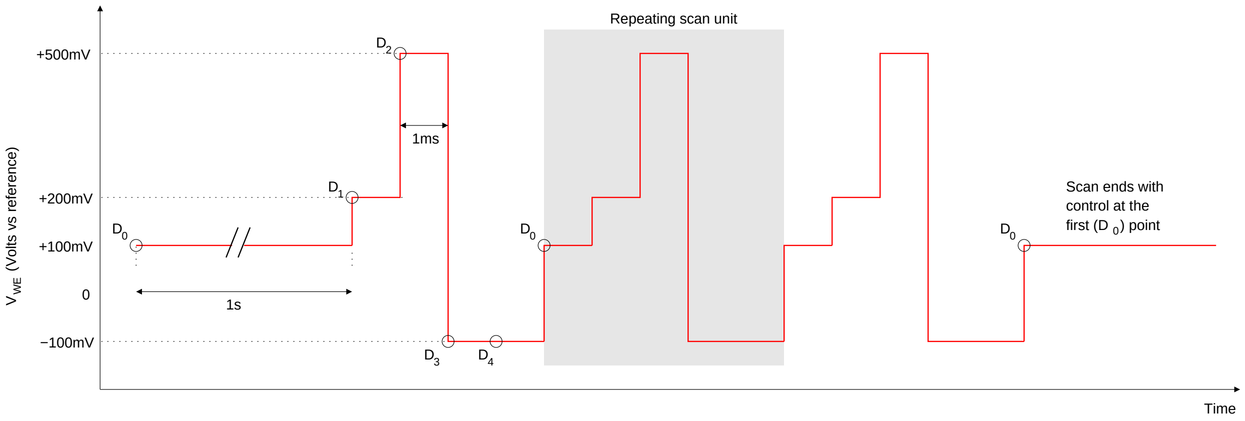


Figure 36: Arbitrary waveform example. Points are played back at the 1MHz/`arbdiv`, rate, so use repeated values to get longer hold times. Waveforms can have 1600 programmed points.

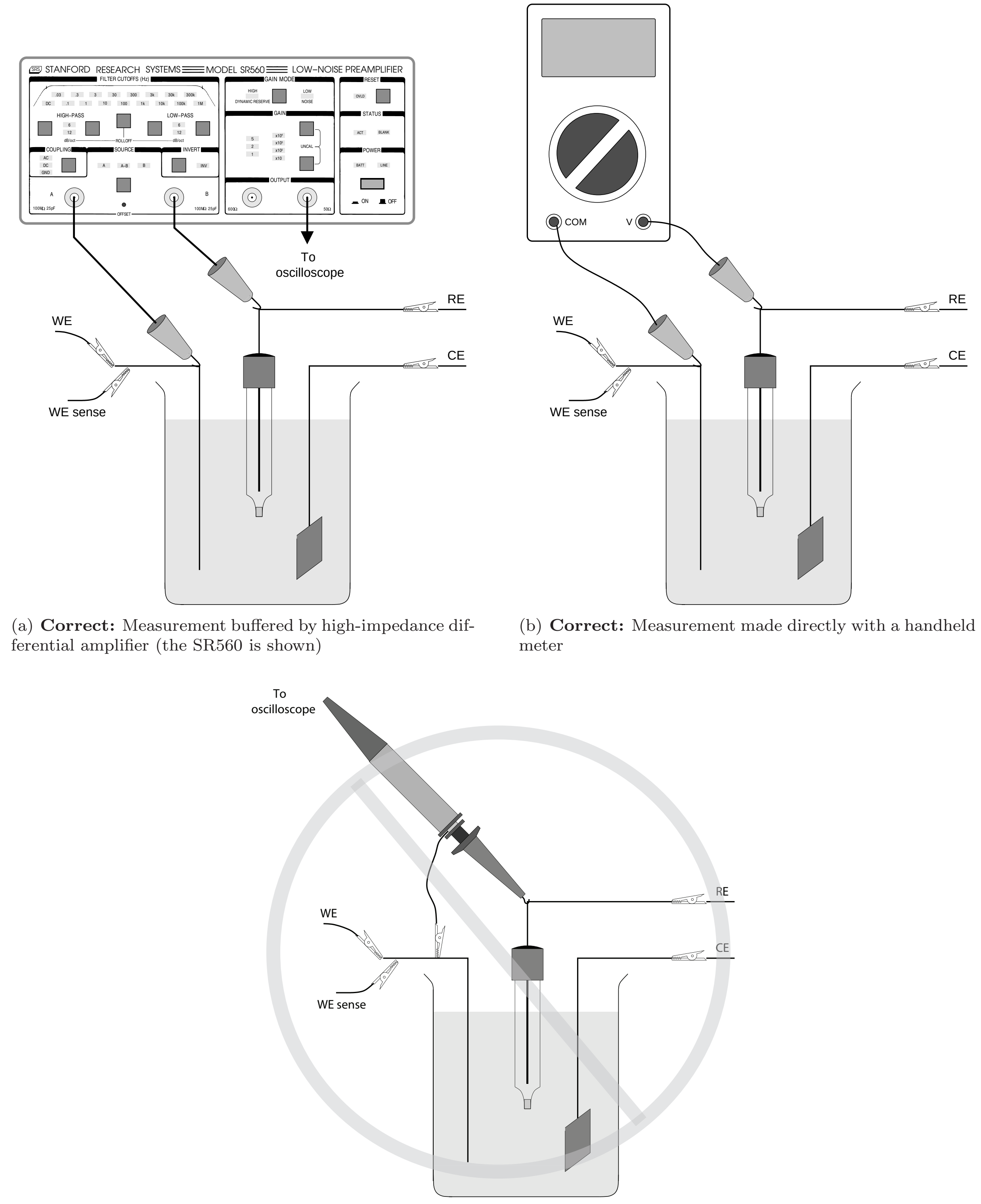
# References

[1] A. J. Bard and L. R. Faulkner, *Electrochemical Methods: Fundamentals and Applications*. John Wiley and Sons, 1980.

# A Measuring cell voltages at the cell

The EC301's WE connection must not be connected to an external instrument's ground when measuring cell voltages. Doing so would divert cell current from the WE to the external ground and thus invalidate current measurements. Figure 37 illustrates good and bad ways of making these measurements. Figure 37a shows a high-impedance differential preamplifier used to buffer the desired voltage before sending it to an oscilloscope. Figure 37b shows a handheld meter used to make the measurement directly. Figure 37c shows the ground "pigtail" of an oscilloscope probe incorrectly connected to the WE electrode – diverting cell current away from the EC301's measurement electronics and possibly destabilizing the cell.

The methods shown in figures 37a and 37b are correct because both probes in each case are floating – not connected to ground. The method shown in 37c is incorrect because the oscilloscope probe pigtail does not float.



(a) **Correct:** Measurement buffered by high-impedance differential amplifier (the SR560 is shown)

(b) **Correct:** Measurement made directly with a handheld meter

(c) **Incorrect:** Connecting the ground pigtail of an oscilloscope probe to WE

Figure 37: Correct and incorrect ways to make cell voltage measurements with external instruments.

# B Pinouts

## B.1 Cell interface (25 pins)

| Pin | Signal |
|---|---|
| 1 | Counter electrode (CE) |
| 2 | Serial data to external box (MOSI) |
| 3 | Serial data clock |
| 4 | Shift register output enable |
| 5 | Main voltmeter (`RE - WE SENSE`) output |
| 6 | ZRA voltmeter (`CE SENSE - WE SENSE`) output |
| 7 | -20V referenced to signal ground |
| 8 | -12V referenced to signal ground |
| 9 | `WE` connection to internal shunt resistors |
| 10 | Output from external shunt resistor buffers |
| 11 | +12V referenced to floating ground |
| 12 | Ground return for relay actuator current in external box |
| 13 | Signal ground |
| 14 | Serial data from external box (MISO) |
| 15 | Chip select for eeprom in external box |
| 16 | Calibrated current source from external box |
| 17 | Signal ground |
| 18 | Signal ground |
| 19 | +20V referenced to signal ground |
| 20 | +12V referenced to signal ground |
| 21 | +5V referenced to signal ground |
| 22 | Floating ground |
| 23 | Signal ground |
| 24 | -12V referenced to floating ground |
| 25 | Chassis ground |

Table 11: Pinout for the front panel cell umbilical (DB25) connector

## B.2 RTD interface (5 pins)

| Pin | Signal |
|---|---|
| 1 | High-side voltage sense (SENSE+) |
| 2 | Low-side voltage sense (SENSE-) |
| 3 | Signal ground (GROUND) |
| 4 | Current source (DRIVE+) |
| 5 | Current sink (DRIVE-) |

Table 12: Pinout for the rear panel RTD connector (numbered left to right)

# C Major symbols and abbreviations

| Symbol | Meaning | Usual units |
|---|---|---|
| $E$ | Potential of an electrode versus a reference | V |

## Alphabetical command index