EC301 Manual — Preliminary

April 23, 2013

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 "slo-blo" line fuse is installed before connecting the line cord. For 100V/120V, use a 3 Amp fuse. For 220V/240V, use a 1.5 Amp fuse.

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 factor for instructions on how to return the instrument for authorized service and adjustment.

1.2 Specifications

Voltage and current measurement accuracy

- Voltage measurement accuracy
  $\pm 0.2\%$ of reading ($V_{RE} - V_{WE\ SENSE}$) $\pm$ 5mV
- Current measurement accuracy, 1 A range
  $\pm 0.5\%$ of reading (I_{WE}) $\pm$ 0.2% of range
- Current measurement accuracy, other ranges
  $\pm 0.2\%$ of reading (I_{WE}) $\pm$ 0.2% of range
- Power amplifier (specifications for power amplifier in isolation)
  - Compliance voltage
    $\geq \pm 30$V full compliance
  - Maximum output current
    $\geq \pm 1$A
  - Slew rate
    ≥ 10V/μs
  - 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)	500μV
Performing an automatic scan (CV or LSV)	200μV

- Automatic scan limits:

Parameter	Min	Max
Rate	0.1mV/s	10kV/s
Delay	1ms	1hr
Span	10mV	30V

- Noise and ripple

  $< 20\mu V_{rms}$ (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

- Automatic scan limits:

	Min	Max
Rate	1pA/s	2A/s
Delay	1ms	1hr
Span	10pA	2A

ZRA mode

- Voltage offset

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

General control loop

- Bandwidth control

  Bandwidth limits: 10Hz, 100Hz, 1kHz, 10kHz, 100kHz, >1MHz (10kΩ resistive load, < 100μA output current)

- Compliance limiting

  Voltage limit accuracy:

Cell current (I_{CE})	Accuracy
≤10mA	±250 mV
≤1A	±1V

IR compensation

- Current interrupt

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

- Positive feedback

Range

I_{range}	R_{u}
1 A	0 → 3 Ω
100 mA	0 → 30 Ω
10 mA	0 → 300 Ω
1 mA	0 → 3 kΩ
100 μA	0 → 30 kΩ
10 μA	0 → 300 kΩ
1 μA	0 → 3 MΩ
100 nA	0 → 30 MΩ
10 nA	0 → 300 MΩ
1 nA	0 → 3 GΩ

Resolution: 1mΩ for 1A range
100kΩ for 1nA range

General system

- 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
- Temperature measurement
  - Accuracy
    ±1℃, −100℃ to +200℃
  - Reproducibility
    0.2℃
  - Temperature sensor
    User supplied 100Ω Pt RTD, $\alpha = 0.00385$ Ω/Ω/℃

Front panel connectors

- External input

  $\pm$15V analog input in potentiostat mode, $\pm$2V in galvanostat mode

  Input impedance: 10kΩ $\|$ 50pF

- Rotating electrode output BNC

  0$\rightarrow$10V analog output

  Accuracy: $\pm$1% of setting $\pm$5mV

  Output impedance: 10Ω

  10mA max output current

- Voltage (E) output BNC

  $\pm$15V analog output

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

  Output impedance: 50Ω

  10mA max output current

- Current (I) output BNC

  $\pm$2V analog input

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

  Accuracy: I_{WE} within $\pm$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 binding posts
  Signal ground ohmically connected to chassis ground
  Floating ground can float ±10V relative to signal ground
  Signal/floating ground isolation: 1MΩ
- RTD input
  5-pin connector for Pt RTD temperature probe
- Raw E output BNC
  ±15V analog output
  Accuracy: ±0.2% of $V_{RE} - V_{WE\ SENSE} \pm 5mV$
  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 $V_{CE}/3 \pm 10mV$
  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

  1mV resolution

Differential electrometer

- Input impedance

  $> 1T\Omega \parallel 20pF$

- Input bias current

  $< 20pA$

- Common-mode rejection ratio (CMRR)

Bandwidth	CMRR (dB)
10 kHz	80
100 kHz	60
1 MHz	40

- Bandwidth

  $> 10MHz$

Cell current input (WE)

- Ranges

  10 decades – 1A to 1nA

- Frequency response

1.3 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 serial number is also displayed on the front panel when the unit is powered on.

- Firmware revision

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

2 EC301 basics

2.1 Functional block diagram

Figure 1 illustrates the major signal paths in the EC301.

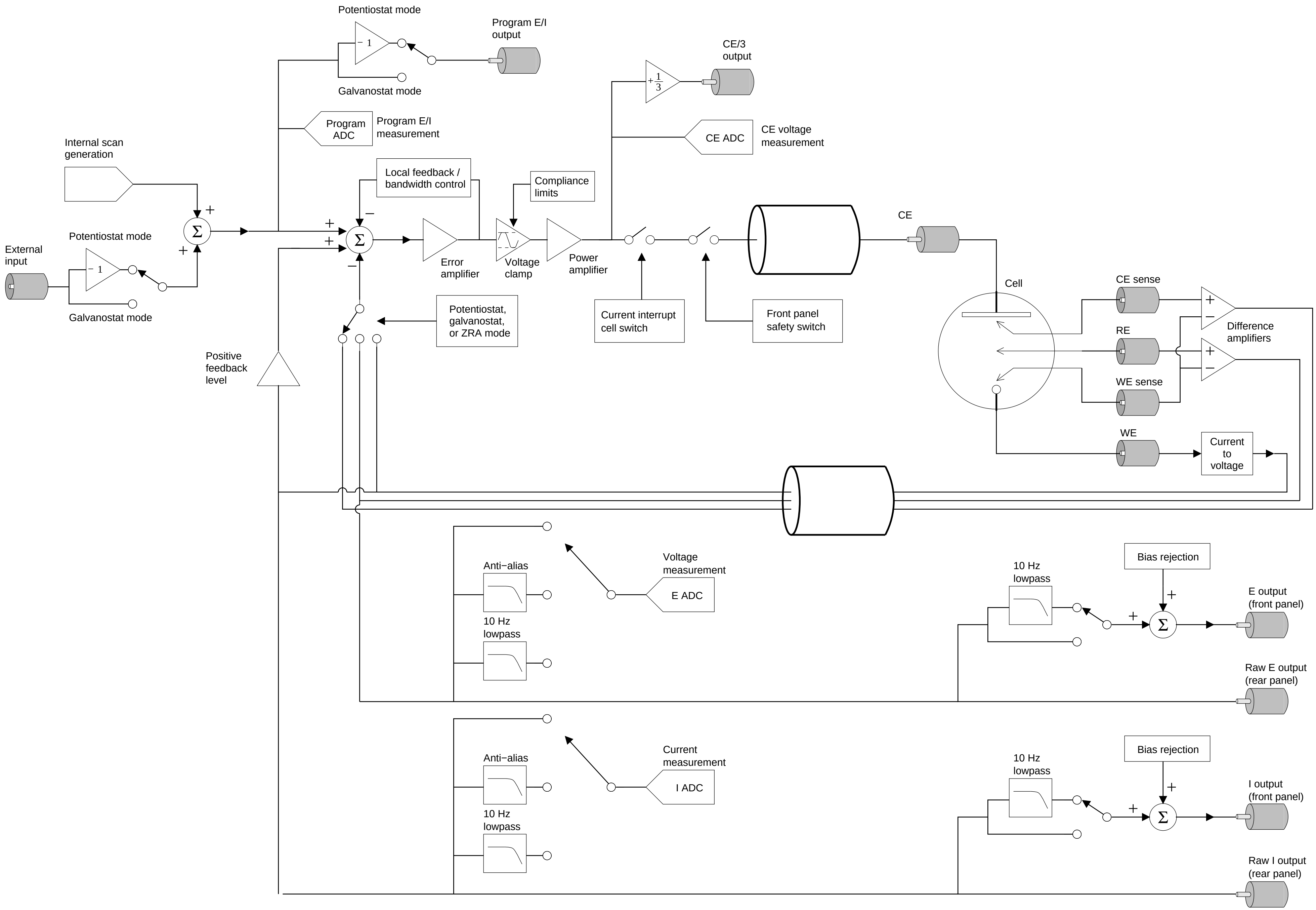


Figure 1: EC301 block diagram.

2.2 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).

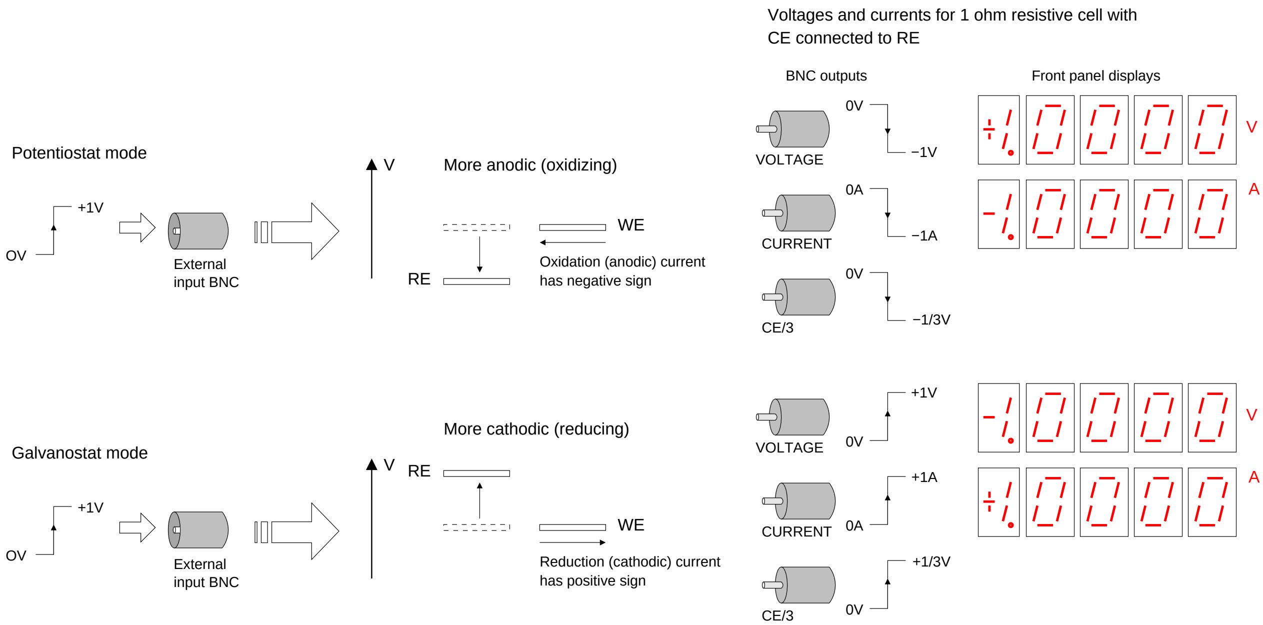
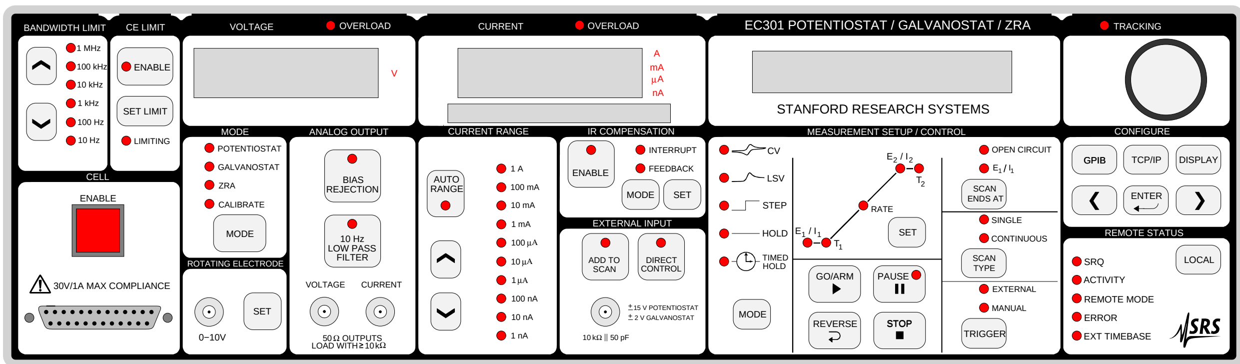


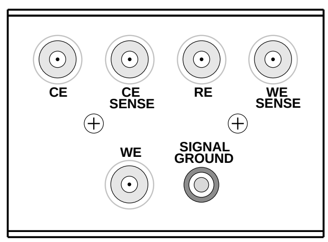
Figure 2: The EC301 uses the American polarity convention when applying voltages and currents.

3 Operation

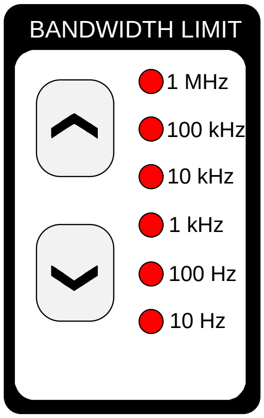
This manual will refer to a key with brackets such as [Key].

3.1 Front panel



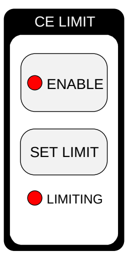


3.1.1 Bandwidth limit



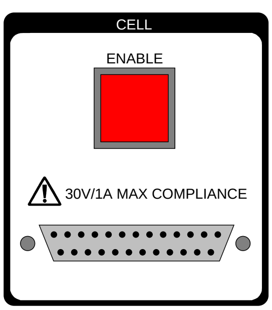
Use the [∧] and [∨] keys to increase or decrease the control bandwidth.

3.1.2 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.

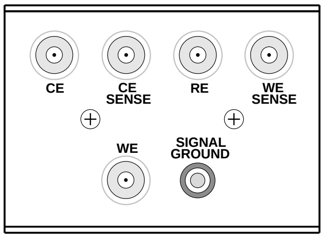
3.1.3 Cell



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.

3.1.4 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 10, it is named for usually being connected to the CE output.

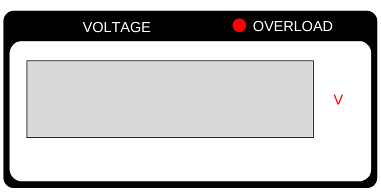
RE (reference electrode) input: As illustrated in figure 1, this electrometer input is used with WE SENSE to monitor cell potentials.

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.

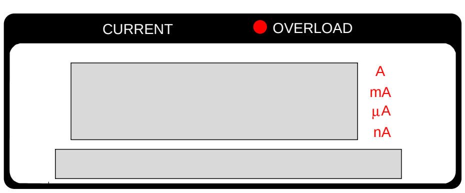
SIGNAL GROUND: This can be connected to a Faraday cage to isolate sensitive cells from electrical noise.

3.1.5 Voltage



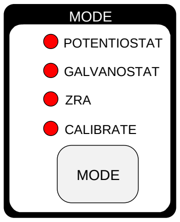
This display shows the results of the internal $V_{\mathrm{WE\ SENSE}} - V_{\mathrm{RE}}$ measurement. The OVERLOAD light indicates when the cell potential exceeds ±15 V relative to signal ground. Measurement accuracy will degrade from specifications outside of this range.

3.1.6 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_{range} is the current range in use. Measurement accuracy will degrade from specifications during overloads.

3.1.7 Mode



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

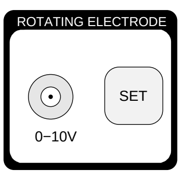
`POTENTIOSTAT`: control potential and measure current. In this mode, the EC301 controls the potential of the working relative to the reference electrode. The counter electrode is driven to whatever potential is necessary (within the ±30 V or the user-imposed compliance limits) to hold $V_{WE\ SENSE} - V_{RE}$ 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`: perform a self-calibration. This mode is for the EC301 to make measurements of its own electrical characteristics and apply trims for calibration. All cell and BNC connections should be removed prior to initiating the calibration procedure.

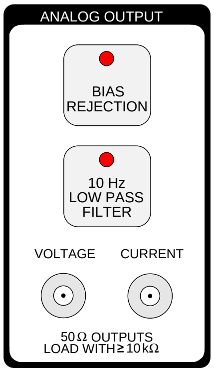
3.1.8 Rotating electrode



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.

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

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

where I_{range} is the current range in use (1 mA, 10 mA, etc.). As described in section 2.2, I_{BNC} becomes more positive when current flows into the working electrode (cathodic current).

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

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

where I_{range} is the current range in use and I_{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 $\mathrm{V}_{\mathrm{RE}} - \mathrm{V}_{\mathrm{WE\,SENSE}}$ and I_{WE} over a 1s window. It will then subtract those average values from all subsequent front panel E_{BNC} and I_{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 $\mathrm{V}_{\mathrm{RE}} - \mathrm{V}_{\mathrm{WE\,SENSE}}$ and I_{WE} measurements with no filtering or bias rejection.

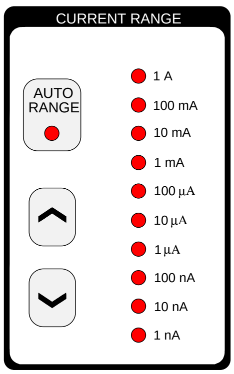
Bias rejection affects both analog outputs simultaneously when engaged from the front panel, but can be limited to either output when set up using the remote interface. The individual rejection levels can also be set arbitrarily instead of being automatically detected. See section 7.3.8 on page 68 for 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.

3.1.10 Current range

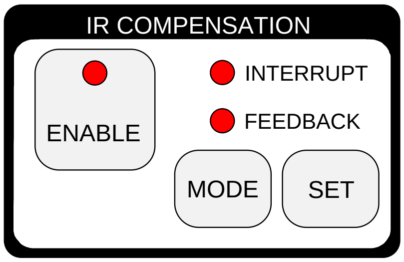


Use the [∧] and [∨] keys to select a current range. A cell current (I_{WE}) equal to the selected current range ($I_{\mathrm{WE}} = I_{\mathrm{range}}$) gives 1 V at the CURRENT output BNC ($I_{\mathrm{BNC}} = 1$ V). Likewise, 1 V applied to the EXTERNAL INPUT BNC in galvanostat mode will generate a controlled current of I_{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_{range} based on the measured cell current. Note that auto-ranging is not allowed in galvanostat mode.

3.1.11 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 3 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 ΔV_{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 ΔV_{b} added to the program voltage.

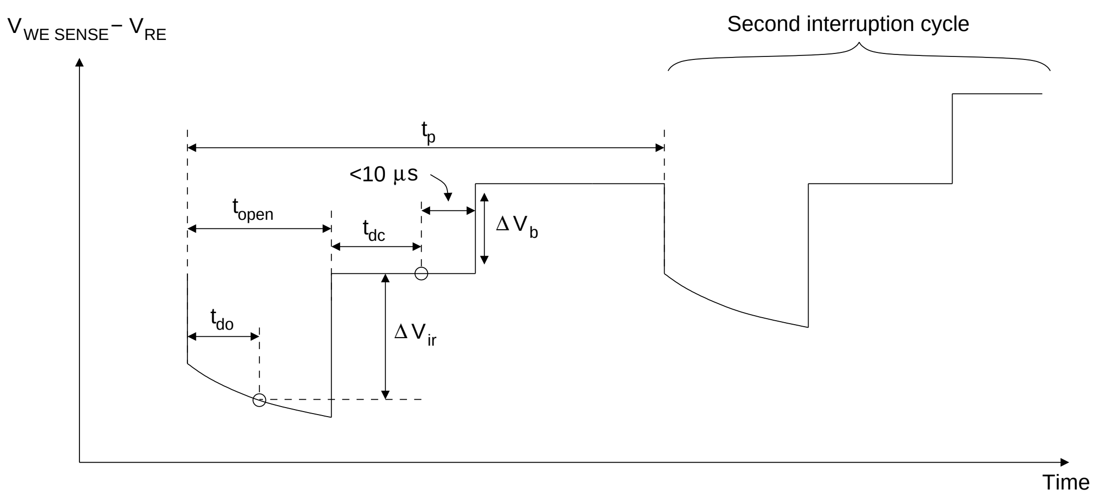


Figure 3: Cell potentials during current interrupt IR compensation. Default values for the various parameters are shown in table 1.

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 3 are set to the default values shown in table 1.

<table>
<tr><th>Parameter</th><th>Default value</th><th>Remote command</th></tr>
<tr><td>t_{p}</td><td>100 ms (10 Hz)</td><td><code>ciperd</code> (see page 65)</td></tr>
<tr><td>t_{open}</td><td>200μs</td><td><code>ciopen</code> (see page 64)</td></tr>
<tr><td>t_{do}</td><td>120μs</td><td rowspan="2"><code>cidlay</code> (see page 65)</td></tr>
<tr><td>t_{dc}</td><td>200μs</td></tr>
</table>

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 109 for an example.

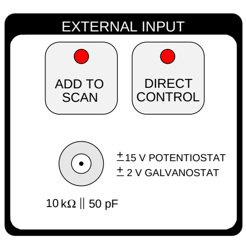
`FEEDBACK` mode: Positive feedback IR compensation adds a boost voltage $I_{\mathrm{WE}} \times R_{\mathrm{u}}$ to the program voltage, where R_{u} is the uncompensated resistance parameter.

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

I_{range}	R_{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 μA	$0 \to 30\ \mathrm{k}\Omega$
10 μA	$0 \to 300\ \mathrm{k}\Omega$
1 μA	$0 \to 3\ \mathrm{M}\Omega$
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_{u} ranges for each current range.

3.1.12 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 2.2. 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

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

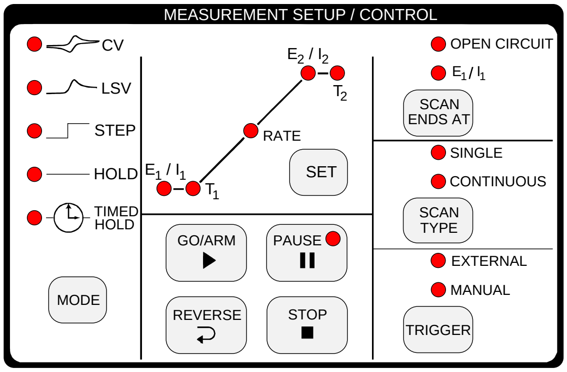
where V_{ext} is the voltage applied at the external input and V_{prog} is the internally-generated program voltage. Currents greater than $2 \times I_{\mathrm{range}}$ or 1 A will generate overloads, so the external input's range in this mode is ±2 V for $I_{\mathrm{range}} < 1$ A, and ±1 V for $I_{\mathrm{range}} = 1$ A. The polarity is again taken from the American Polarity Convention described in section 2.2.

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.

3.1.13 Measurement setup/control

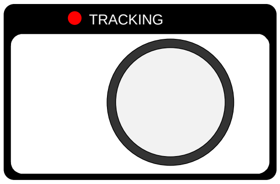


A variety of automatic scans and holds can be programmed from the EC301's front panel. Once the scan type is selected, you will be prompted for a set of necessary parameters. When `[GO/ARM]` is pressed with a `MANUAL` trigger setting, the EC301 will engage control, apply the scan, and remove control 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 44.

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 31 for more information about the `SCAN TRIGGER` input.

3.1.14 Knob

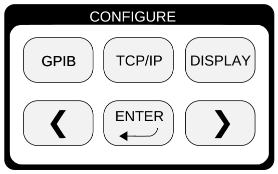


Use the knob to enter numbers via the character display. The knob is velocity-sensitive, so experiment with different rotation speeds to set large numbers.

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."

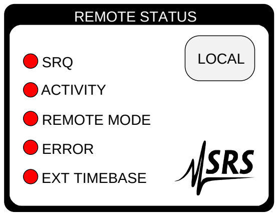
Most parameters can be "locked in" by re-pushing the same key used to set them. For example, pushing `[SET]` once to adjust the E_1 of a hold will allow will allow E_1 to be freely changed with the knob. Pushing `[SET]` again will lock the value in and disable the knob. The value will also be locked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

3.1.15 Configure



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

3.1.16 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 23 on page 91 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.

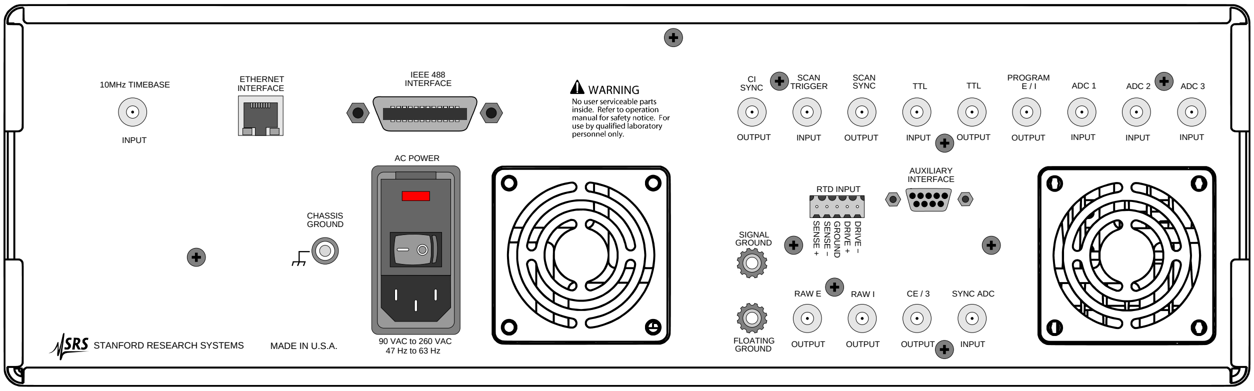
`REMOTE MODE`: This indicator is on when the front panel is locked out by the remote interface. No front panel adjustments may be made.

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

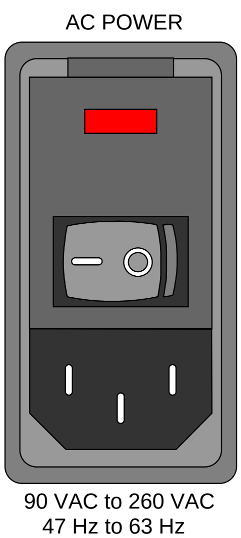
`EXT TIMEBASE`: The EC301 can accept an external 10 MHz timing signal to improve the accuracy and stability of automatic scans. This indicator will light when such a timing signal is detected.

`[LOCAL]`: The EC301 will ignore all keypad input or knob adjustment when in remote mode. Use the `[LOCAL]` key to exit this mode and enable the front panel keys.

3.2 Rear panel

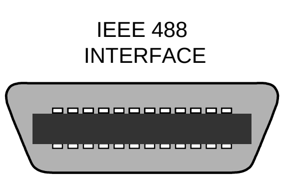


3.2.1 Power entry



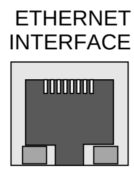
The power entry module is used to fuse the AC line voltage input and to block high frequency noise from entering or exiting the instrument.

3.2.2 GPIB interface



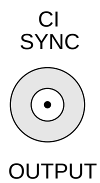
The 24 pin GPIB connector allows a computer to control the EC301 via the GPIB (IEEE-488) instrument bus. The GPIB address is set with the front panel [GPIB] key.

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 4.

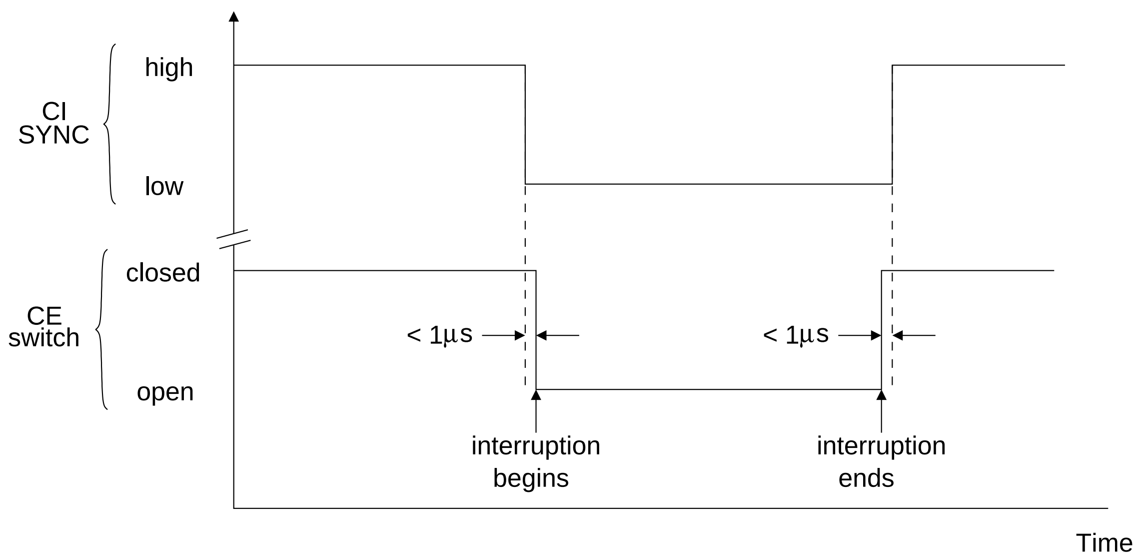
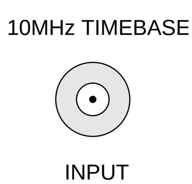


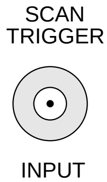
Figure 4: Timing diagram for the `CI SYNC` digital output.

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.

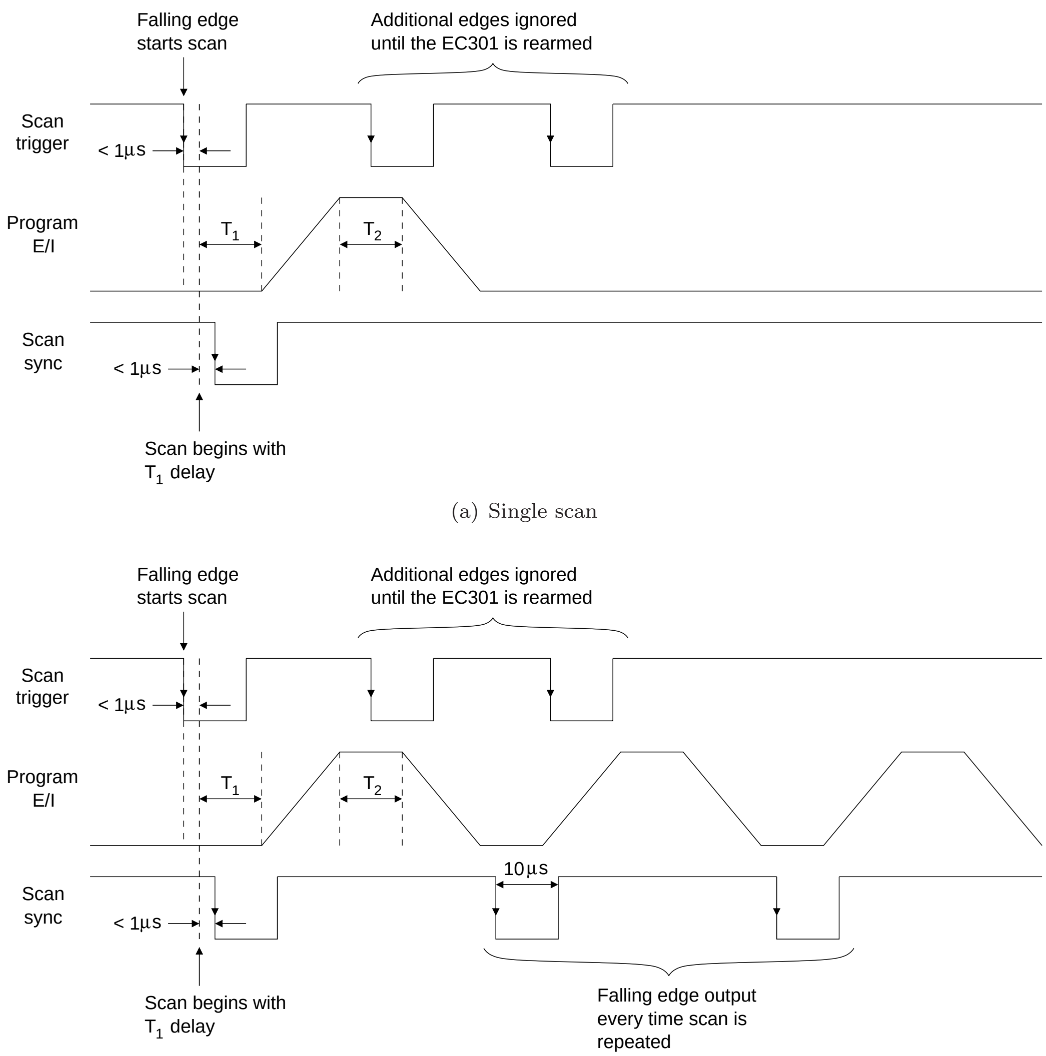


3.2.6 Scan trigger input



This input allows starting an automatic scan with external equipment. As illustrated in figure 5, an falling edge here will begin the scan within 1μs.

The EC301 must be “armed” from the front panel or the remote interface to use this input. See section 3.1.13 on page 26 to set this condition from the front panel. See the `trgarm` command described on page 66 to arm with the remote interface.



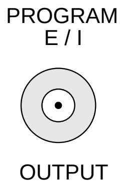
(a) Single scan

(b) Continuous scan

Figure 5: 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 5 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

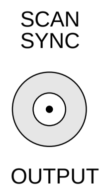


This output is a copy of the input to the EC301's control circuitry. As illustrated in figure 1, it is the sum of the external input and the internal scan voltages.

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 2.2 on page 17.

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 6, 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 μs 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.

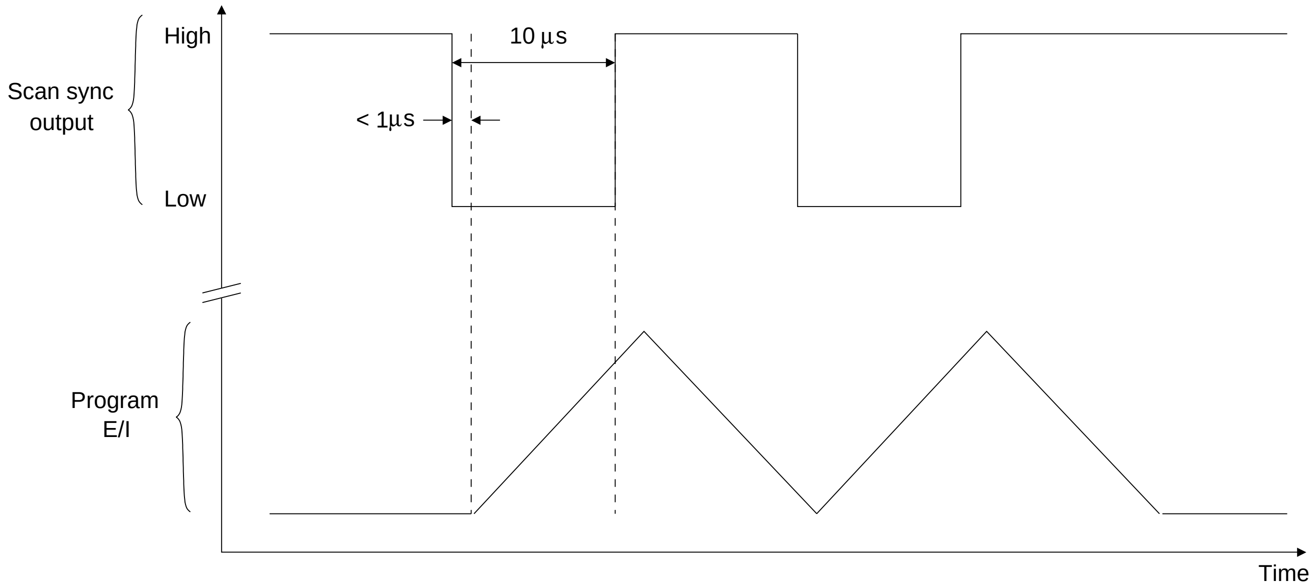
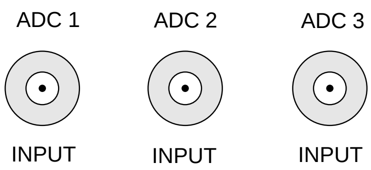


Figure 6: The `SCAN SYNC` output is brought low at the beginning of a scan and held there for 10 μs.

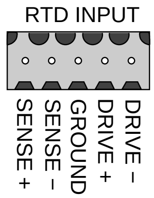
3.2.9 Auxiliary ADC inputs (1-3)



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 40 for tighter timing requirements.

Use the `getaux?` command described on page 72 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 7, 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.

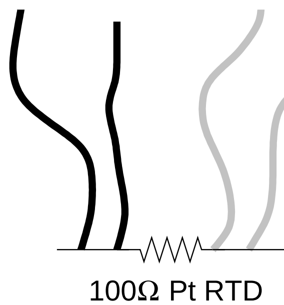


Figure 7: Commercial 4-wire RTD probes have two wires with the same color attached to each end.

These 4-wire sensors are connected to the EC301 in one of two electrically-identical ways illustrated in figure 8. 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.

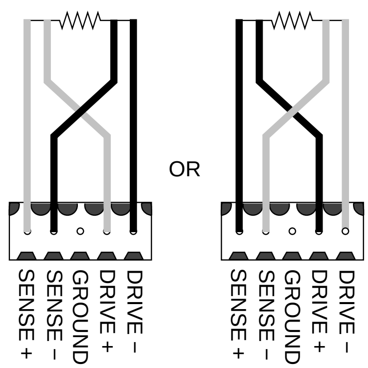
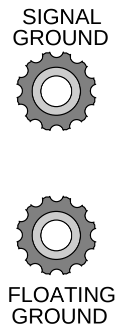


Figure 8: 4-wire probes can be connected to the EC301 in one of these two ways.

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 4.1 for more information on this situation.

Figure 9 illustrates the relationship between the rear panel ground connections. All front and rear panel BNC shields are tied to signal ground, which is always close to the chassis ground connection to earth.

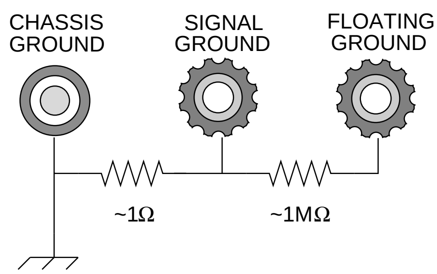
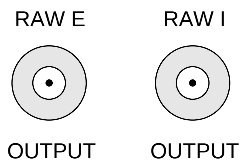


Figure 9: Electrical relationships between the rear-panel grounding posts.

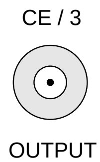
3.2.12 Raw analog outputs



These outputs carry the same signals as their counterparts on the front panel, but without any bias rejection or filtering. See section 3.1.9 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%.

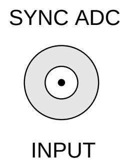
3.2.13 CE monitor



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%.

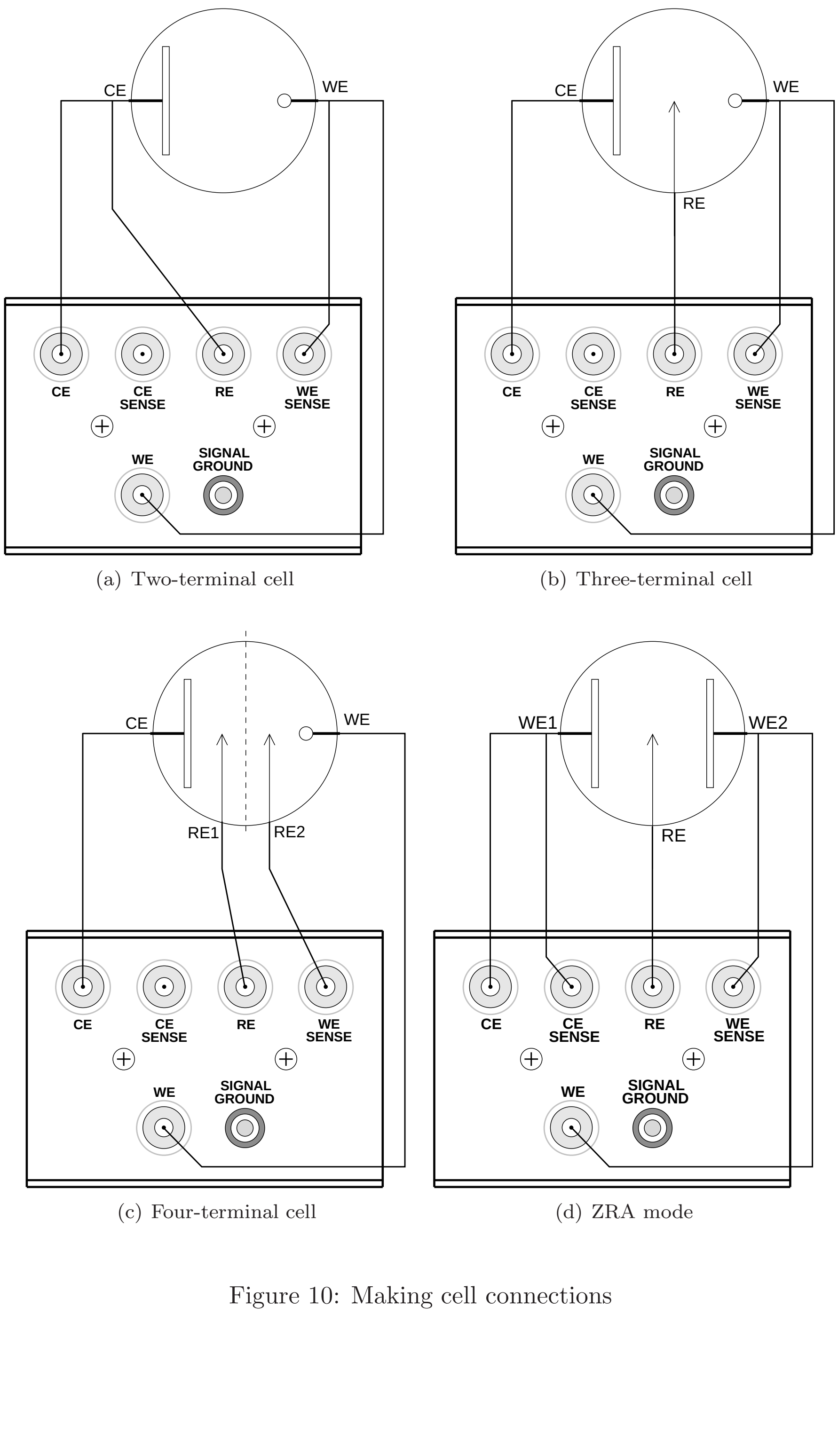
3.2.14 Synchronous ADC input



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 10a, b, and c illustrate how the EC301 should be used with cell configurations in potentiostat and galvanostat modes. Figure 10d 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 10: 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 Working with grounded electrodes

Grounded electrodes are those inextricably connected to earth ground. Figure 11 illustrates cathodic protection of a buried pipeline, in which the counter and working electrodes are necessarily buried in and thus connected to earth. Figure 12a 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 12b 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 binding posts should only be disconnected when using grounded electrodes. Reconnect them when using isolated cells to improve frequency response.

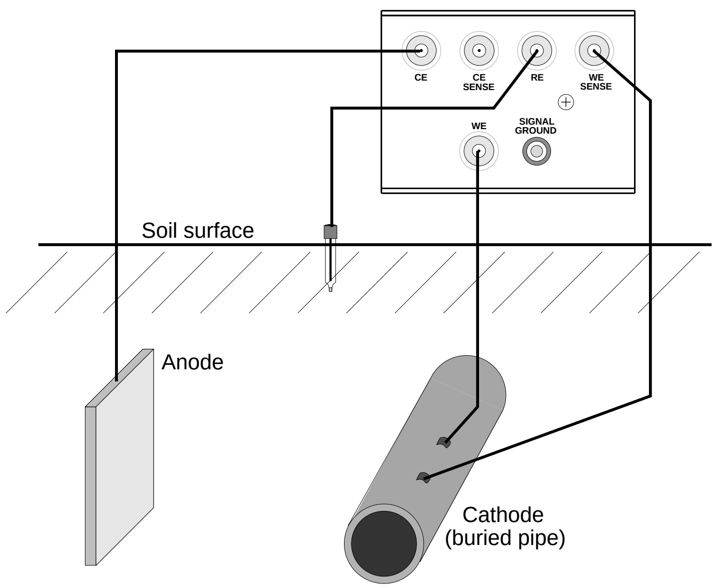
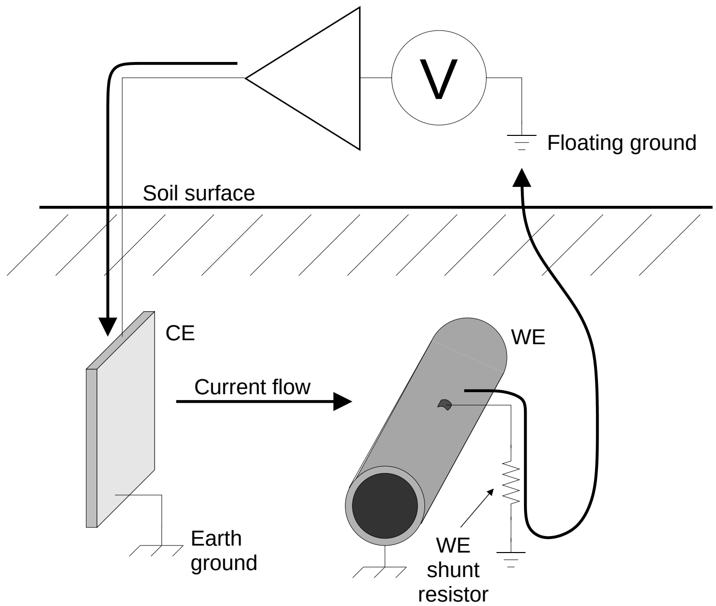
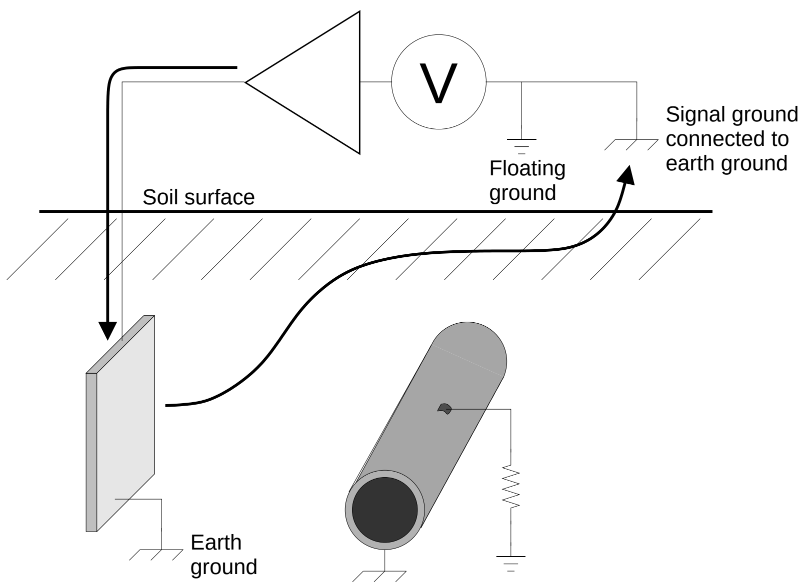


Figure 11: Buried and inextricably grounded electrodes used in cathodic protection.



(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 12: 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

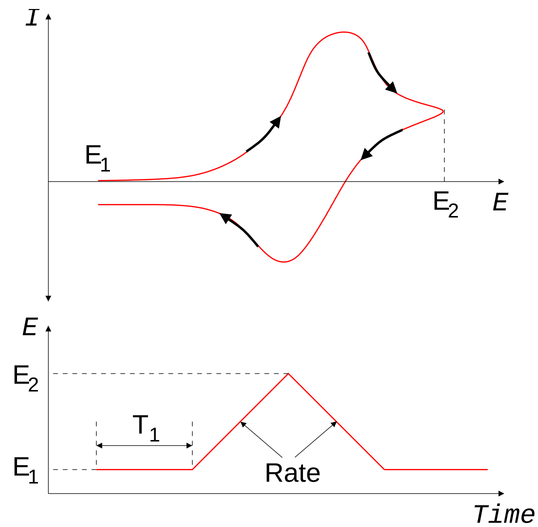
5.1.1 Cyclic voltammetry (CV)

Figure 13 illustrates the parameters needed to specify a CV scan. The procedure is as follows:

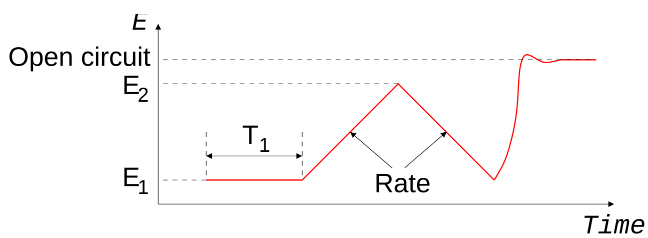
1. Use the `[MODE]` key to select `CV`.
2. Cycle through the required parameters using `[SET]`, adjusting values using the knob. Times are adjusted using the knob for individual fields, and the arrow keys described in section 3.1.15 on page 27 to move between the fields shown below.

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

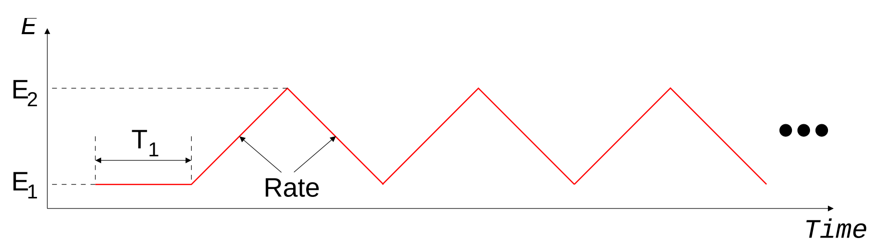
3. Choose the scan end condition. Figure 13(a) illustrates the cell potential for the E_1 end condition, while 13(b) shows it for `OPEN CIRCUIT`.
4. Choose `SINGLE` or `CONTINUOUS` scanning. Single scans, illustrated in figures 13(a) and (b), go to the end scan condition after reaching E_1 on the return ramp. Continuous scans, illustrated in figure 13(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 55 for a better description of scan triggers in general, and section 3.2.6 on page 31 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 13: Parameters used to set up a cyclic voltammogram (CV).

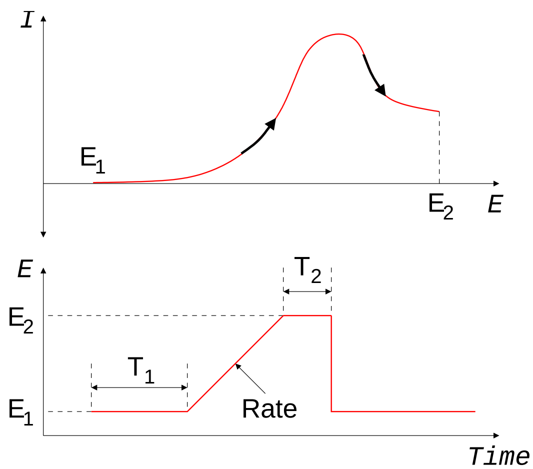
5.1.2 Linear sweep voltammetry (LSV)

Figure 14 illustrates the parameters needed to specify a LSV scan. The procedure is as follows:

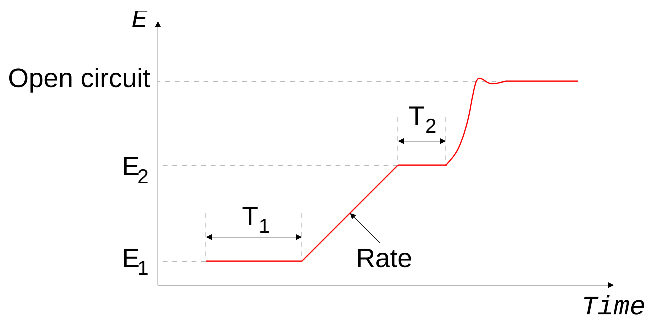
1. Use the [MODE] key to select LSV.
2. Cycle through the required parameters using [SET], adjusting values using the knob. Times are adjusted using the knob for individual fields, and the arrow keys described in section 3.1.15 on page 27 to move between the fields shown below.

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

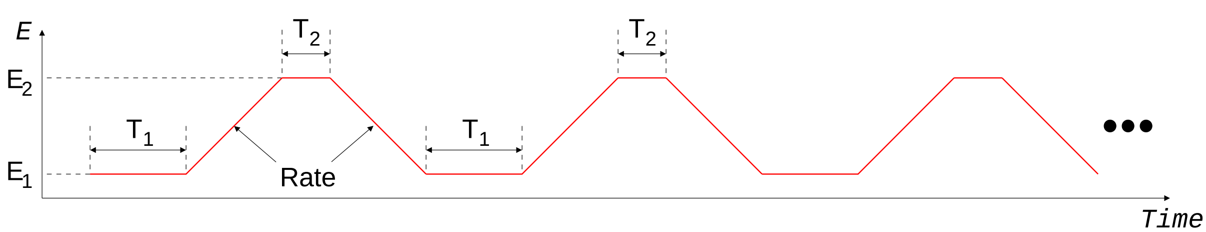
3. Choose the scan end condition. Figure 14(a) illustrates the cell potential for the E_1 end condition, while 14(b) shows it for OPEN CIRCUIT. If the end condition is OPEN CIRCUIT, the cell potential will be free to drift after the T_2 wait time. If the condition is E_1, the potential will immediately return to E_1.
4. Choose SINGLE or CONTINUOUS scanning. Single scans, illustrated in figures 14(a) and (b), go to the end scan condition after the T_2 wait time. Continuous scans, illustrated in figure 14(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 55 for a better description of scan triggers in general, and section 3.2.6 on page 31 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 14: Parameters used to set up a linear sweep voltammogram (LSV).

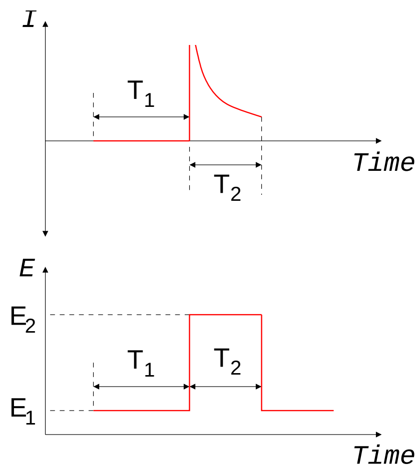
5.1.3 Steps

Figure 15 illustrates the parameters needed to specify a step scan. The procedure is as follows:

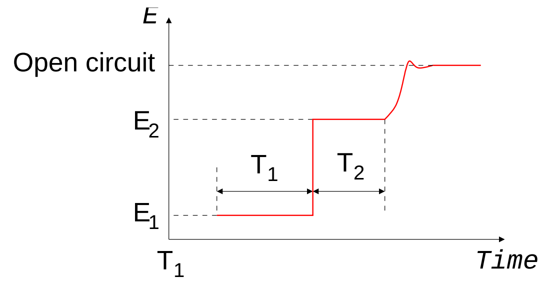
1. Use the [MODE] key to select STEP.
2. Cycle through the required parameters using [SET], adjusting values using the knob. Times are adjusted using the knob for individual fields, and the arrow keys described in section 3.1.15 on page 27 to move between the fields shown below. Note that we have 4μs resolution, so the μs field will change in 4μs steps.

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

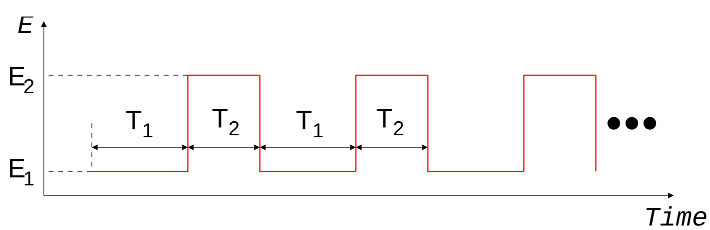
3. Choose the scan end condition. Figure 15(a) illustrates the cell potential for the E_1 end condition, while 15(b) shows it for OPEN CIRCUIT. If the end condition is OPEN CIRCUIT, the cell potential will be free to drift after the T_2 wait time. If the condition is E_1, the potential will immediately return to E_1.
4. Choose SINGLE or CONTINUOUS scanning. Single scans, illustrated in figures 15(a) and (b), go to the end scan condition after the T_2 wait time. Continuous scans, illustrated in figure 15(c), step back to E_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 55 for a better description of scan triggers in general, and section 3.2.6 on page 31 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.



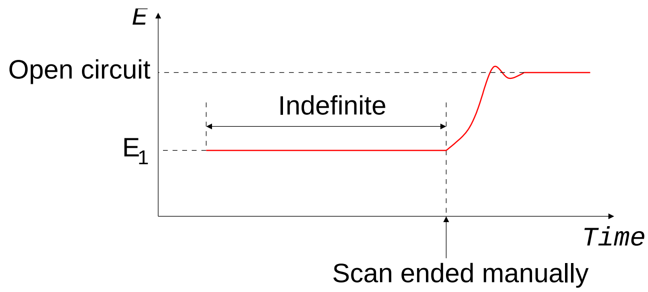
(c) A step program using `CONTINUOUS` scan type. The rectangle-shaped program continues indefinitely.

Figure 15: Parameters used to set up a step scan.

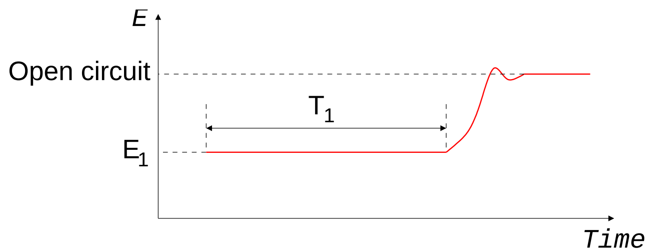
5.1.4 Holds

Figure 16 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 55 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.

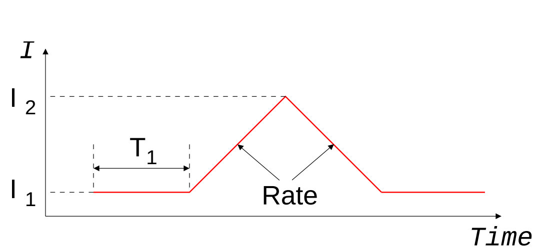
Figure 16: Parameters used to set up a regular and timed hold.

5.2 Setting scan parameters – galvanostat mode

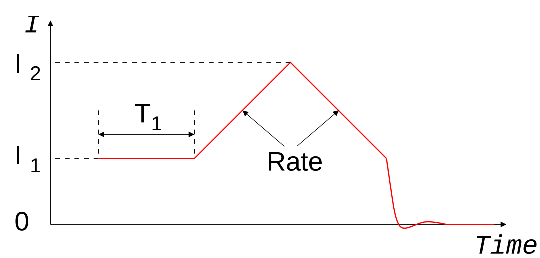
5.2.1 Cyclic current ramp

Figure 17 illustrates the parameters needed to specify a cyclic current ramp scan. The procedure is as follows:

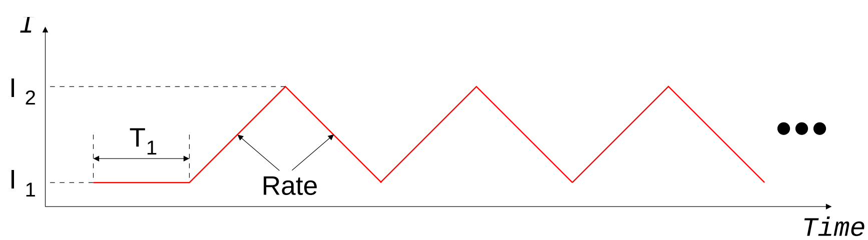
1. Use the `[MODE]` key to select `CV`. While this scan mode is named for its use in potentiostat mode, it will set up a cyclic current ramp in galvanostat mode.
2. Cycle through the required parameters using `[SET]`, and adjust values using the knob.
3. Choose the scan end condition. Figure 17(a) illustrates the cell current for the I_1 end condition, while 17(b) shows it for `OPEN CIRCUIT`.
4. Choose `SINGLE` or `CONTINUOUS` scanning. Single scans, illustrated in figures 17(a) and (b), go to the end scan condition after reaching I_1 on the return ramp. Continuous scans, illustrated in figure 17(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 55 for a better description of scan triggers in general, and section 3.2.6 on page 31 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 17: Parameters used to set up a cyclic current ramp scan.

5.2.2 Linear current ramp

Figure 18 illustrates the parameters needed to specify a linear current ramp scan. The procedure is as follows:

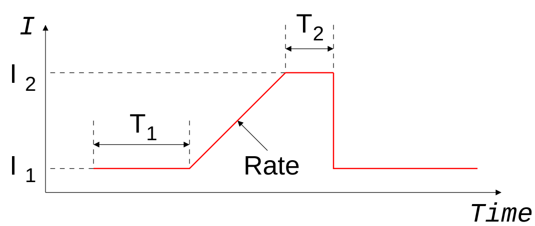
1. Use the [MODE] key to select LSV. While this scan mode is named for its use in potentiostat mode, it will set up a linear current ramp in galvanostat mode.

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

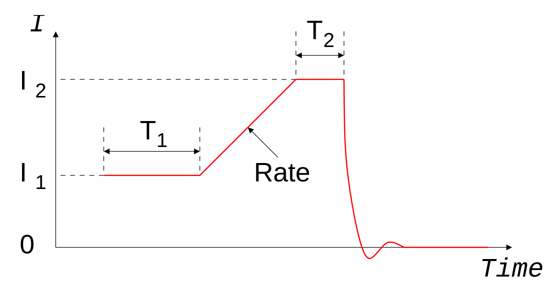
3. Choose the scan end condition. Figure 18(a) illustrates the cell potential for the I_1 end condition, while 18(b) shows it for OPEN CIRCUIT.

4. Choose SINGLE or CONTINUOUS scanning. Single scans, illustrated in figures 18(a) and (b), go to the end scan condition after the T_2 wait time. Continuous scans, illustrated in figure 18(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.

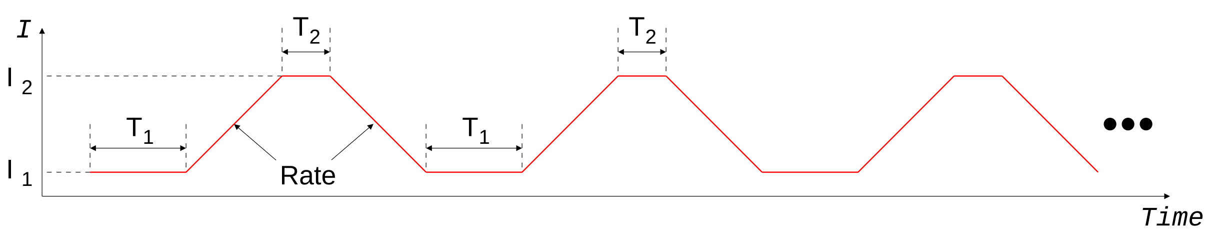
5. Choose the trigger mode. MANUAL allows the [GO/ARM] key to trigger the scan, while EXTERNAL mode requires the rear panel scan trigger input. See section 5.4 on page 55 for a better description of scan triggers in general, and section 3.2.6 on page 31 for a description of the rear panel scan trigger.



(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.



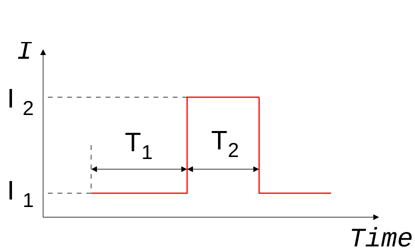
(c) A linear current ramp program using CONTINUOUS scan type. The triangle-shaped program continues indefinitely.

Figure 18: Parameters used to set up a linear current ramp scan.

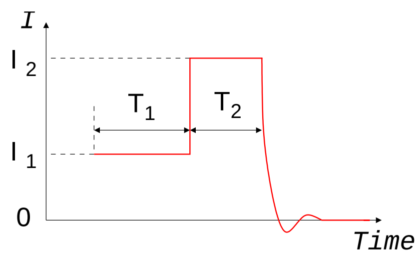
5.2.3 Current step

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

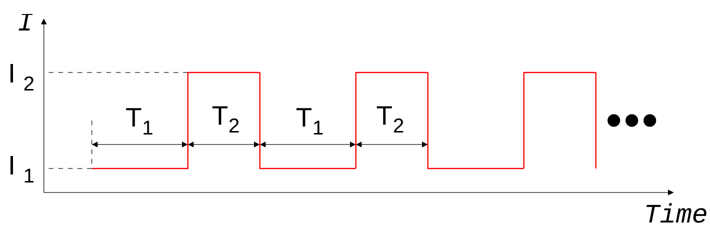
1. Use the [MODE] key to select STEP.
2. Cycle through the required parameters using [SET], and adjust values using the knob.
3. Choose the scan end condition. Figure 19(a) illustrates the cell potential for the I_1 end condition, while 19(b) shows it for OPEN CIRCUIT. If the end condition is OPEN CIRCUIT, 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 19(a) and (b), go to the end scan condition after the T_2 wait time. Continuous scans, illustrated in figure 19(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 55 for a better description of scan triggers in general, and section 3.2.6 on page 31 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.



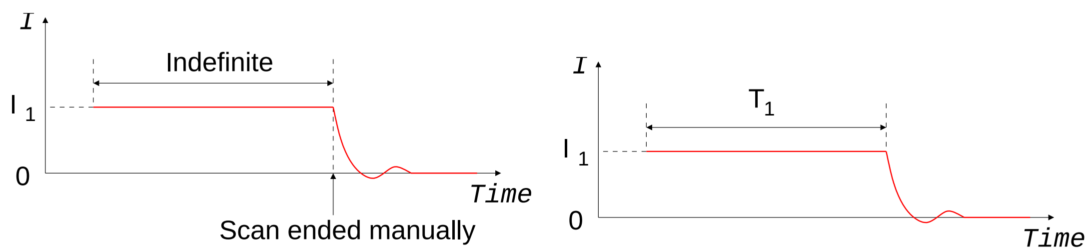
(c) A current step program using CONTINUOUS scan type. The rectangle-shaped program continues indefinitely.

Figure 19: Parameters used to set up a step scan.

5.2.4 Current hold

Figure 20 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 55 for a better description of scan triggers. EXTERNAL mode is not allowed.

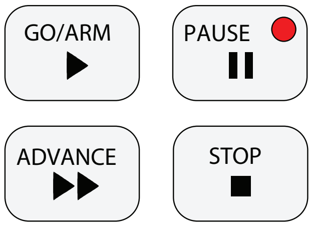


(a) A (indefinite) current hold program. Holds must end in the OPEN CIRCUIT (zero current) condition.

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

Figure 20: 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 3.1.13 on page 26, 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.

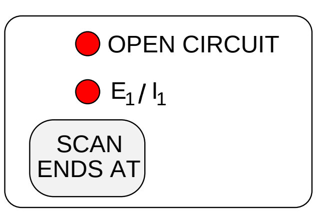
5.4.2 Triggering a scan with the scan trigger input

As described in section 3.2.6 on page 31, 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 66.

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 21 shows the EC301 used with the Stanford Research Systems SR780 for this purpose.

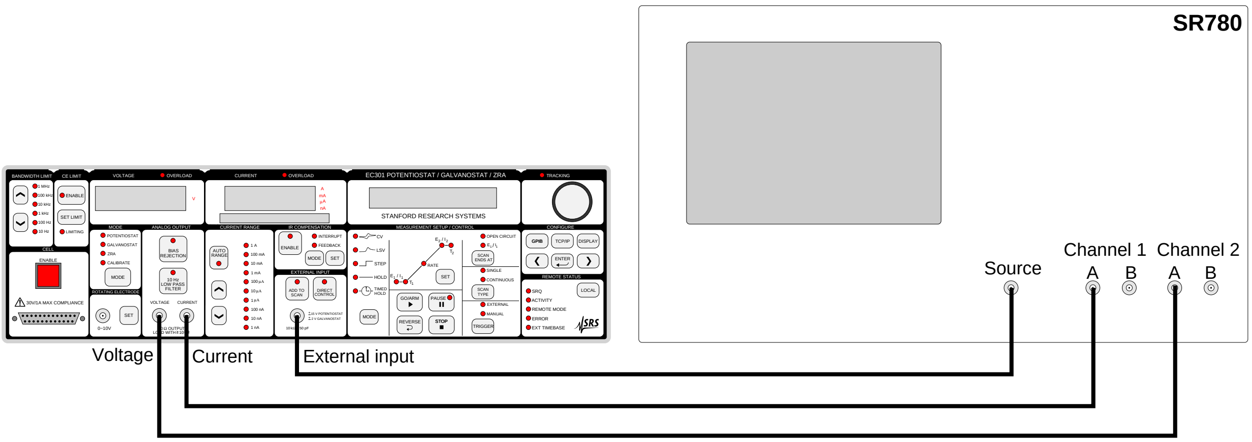


Figure 21: Using the EC301 with the SR780 for impedance spectroscopy

Using the setup shown in figure 21, 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_{cell} can be calculated from this using

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

where I_{fs} is the current range (10mA, 100μA, etc).

7 Remote programming

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

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 or zra mode.

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	$-2 \rightarrow +2$

setcur(?){x}

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.

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

addscn(?){i}

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.

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

`dcntrl(?){i}`

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`.

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	$-15.000 \rightarrow +15.000$

`progrm?`

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 3.1.2 on page 19 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	$500, 501, 502, \cdots, 30000$

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 16, 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 3.1.11 on page 24.

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 3.1.11 on page 24.

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	$0 \to$ 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 100μs. This corresponds to the t_{open} delay shown in figure 3 on page 24.

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

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 3 on page 24. 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_{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 3.1.11 on page 24, a fraction of ΔV_{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 3 on page 24. Both sample delays are entered in integer μs.

i	Delay	Units	j
0	t_{do} (open delay)	μs	0,1,2,$\cdots$,1×10^6(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 3.1.13 on page 26 for more information about the external trigger setting. See section 3.2.6 on page 31 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)

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	$0 \rightarrow 10000$

7.3.8 Analog output commands

brenab(?){i}

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 68, and the `bireji` command, described on page 69. Note that you can only use these commands after sending `brenab 1` to turn bias rejection on.

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.*

---

bireje(?){x}

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 floating point Volts. The `brenab` command described on page 68 must be sent before this command can be used.

Parameter	Units	Range
x	V	$-15 \rightarrow +15$

`bireji(?){x}`

Name: `bireji` – Set or query the amount of I bias rejection.
Description: Sets or queries the amount of bias rejection applied to the front panel `CURRENT` output. The `brenab` command described on page 68 must be sent before this command can be used.

Parameter	Units	Range
x	fraction of full scale	$-2 \rightarrow +2$

`lpfile(?){i}`

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

i	Setting
0	No filter
1	10Hz lowpass

`lpfili(?){i}`

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

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

`irange(?){i}`

Name: `irange` – Set or query the current range.
Description: No description.

i	Current range
1	1A
2	100mA
3	10mA
4	1mA
5	100μA
6	10μA
7	1μA
8	100nA
9	10nA
10	1nA

`iadcfl(?){i}`

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

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

`irnaut(?){i}`

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

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 ($V_{\mathrm{WE\ SENSE}} - V_{\mathrm{RE}}$) 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_{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 35.

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
```

`avgexp(?){i}`

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
```

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 22 on page 75 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 22 on page 75 for an overview of data packets used for streaming. While the `getbda?` command (page 74) 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.

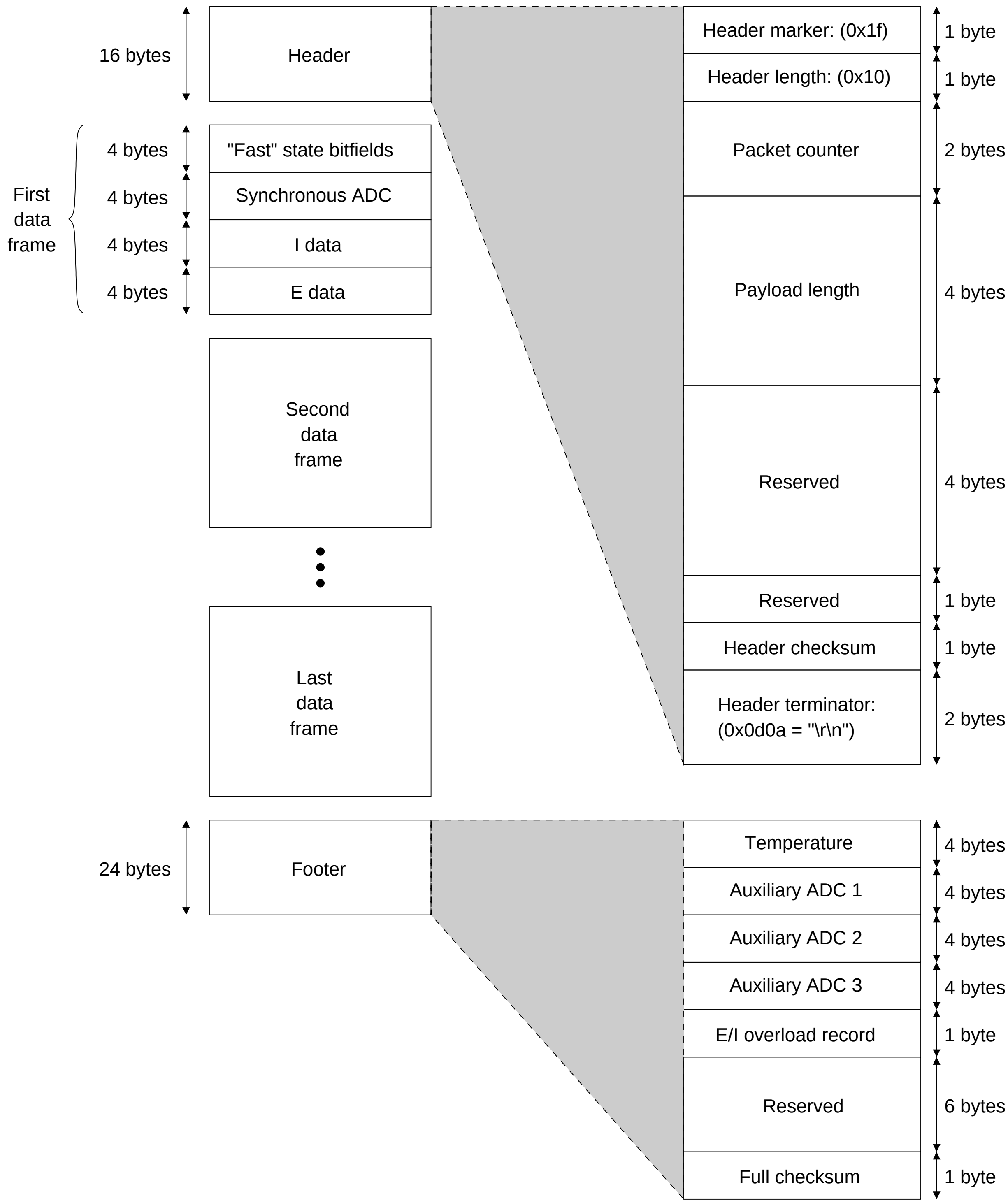


Figure 22: Basic construction of the data packet used for streaming data. The four bytes of "fast" instrument state in each data frame are described in table 4 on page 76. The E/I overload record byte in the footer is described in table 5 on page 77.

Bit	Quantity	Values
0	Cell switch position	0 On (closed) 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 1 Limiting
4:7	Current (I) range	1 1A 2 100mA 3 10mA 4 1mA 5 100μA 6 10μA 7 1μA 8 100nA 9 10nA 10 1nA
8:10	Voltage (E) range	3 2V 5 5V 6 15V
11	Ramp waveform generator status	0 Idle 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 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 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. 1 One or more overloads detected during the last packet.
3	I overload record	0 No overloads detected during the last packet. 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 82 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 84 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

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

`exttmb?{i}`

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).

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.

`autotb{i}`

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

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 23 on page 91 for an overview of status bit promotion.

*ESR?{i}

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` ($0 \rightarrow 255$). The `*ESE i,j` command sets bit `i` ($0 \rightarrow 7$) to `j` (0 or 1). As shown in figure 23, bits enabled in the *ESR register via the *ESE register set the ESB bit in the status byte.

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

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 88) 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 23 on page 91 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.
5-6		Internal use.
7	FCB	Field Calibration Began – field calibration was started.
8	FCE	Field Calibration Ended – field calibration ended.
9	FCF	Field Calibration Failure – there was a failure during field calibration.
10-11		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 23 on page 91, 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	AO1	Auxiliary ADC channel 1 overload – the BNC input exceeded ±10V.
4	AO2	Auxiliary ADC channel 2 overload – the BNC input exceeded ±10V.
5	AO3	Auxiliary ADC channel 3 overload – the BNC input exceeded ±10V.
6	NRH	No remote amplifier (buddy box) 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` ($0 \rightarrow 65535$). The `MESE i,j` command sets bit `i` ($0 \rightarrow 15$) to `j` (0 or 1). As shown in figure 23 on page 91, 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 23 on page 91 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 84) has been set.
1	MESW	An unmasked bit in the Measurement Status Register (described on page 86) 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 82) 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 23 on page 91, 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 3.1.16 on page 28 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 90 and 90 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 89 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.

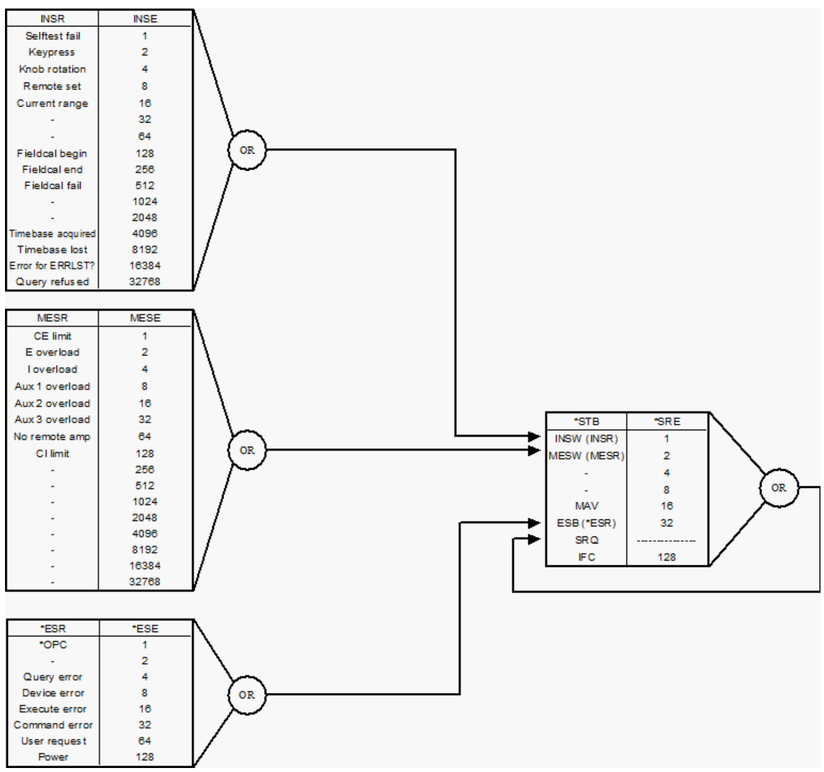


Figure 23: The status bit promotion diagram. Enabling bits in the INSR, MESR, and *ESR status registers allows them to set bits in the *STB. Enable these bits with the INSE, MESE, and *ESE registers. Properly configuring status bit promotion allows quick status byte (*STB) queries to indicate problems.

7.3.16 Pulsed waveform generation commands

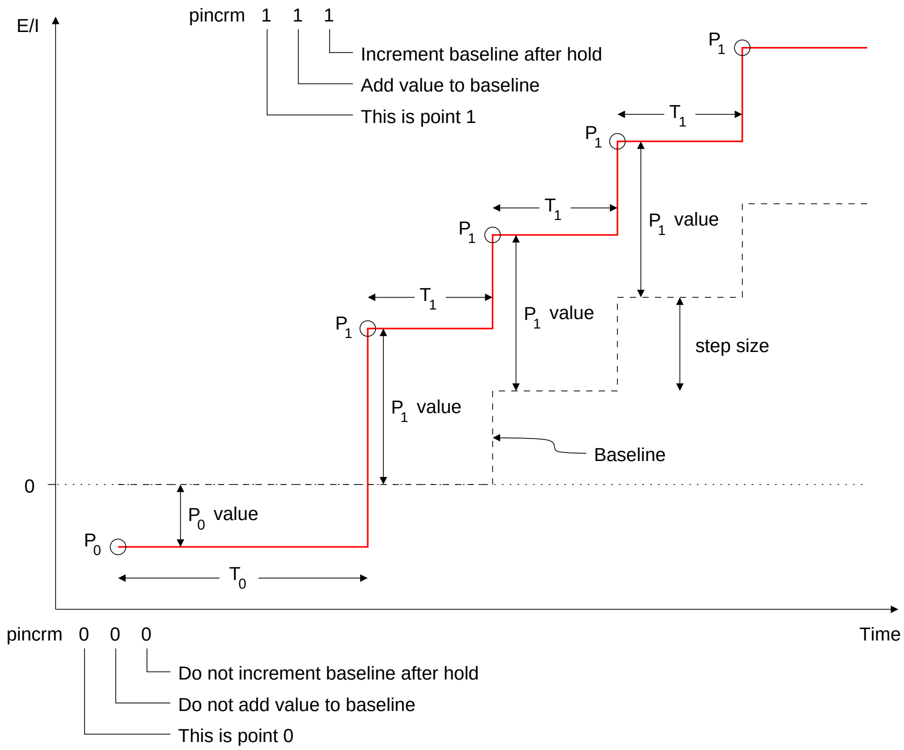


Figure 24: A very basic waveform illustrating the pulsed waveform construction parameters.

ppoint(?){i}

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

Figure 24 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	$\frac{I_{\mathrm{range}}}{1000}$	$-2000, -1999, -1998, \cdots, +2000$[1]

[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_{range}) in galvanostat mode. As illustrated in figure 24, 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."

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

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

Parameter	Mode	Units	Range
`x`	Potentiostat	mV	$-15000, -14999, -14998, \cdots, +15000$
	Galvanostat	$\frac{I_{\mathrm{range}}}{1000}$	$-2000, -1999, -1998, \cdots, +2000$[1]

[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_{range}) in galvanostat mode. As illustrated in figure 25, 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_{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`	4μs	$1, 2, 3, \cdots, 16777215$ $(2^{24} - 1)$

The `i` parameter chooses the control point to set or query. Figure 25 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 24 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 24 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 107 for more information.

preset

Name: `preset` – Reset the pulsed waveform.
Description: This command clears any pulsed waveform configuration variables. It should be sent before defining a new waveform.

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

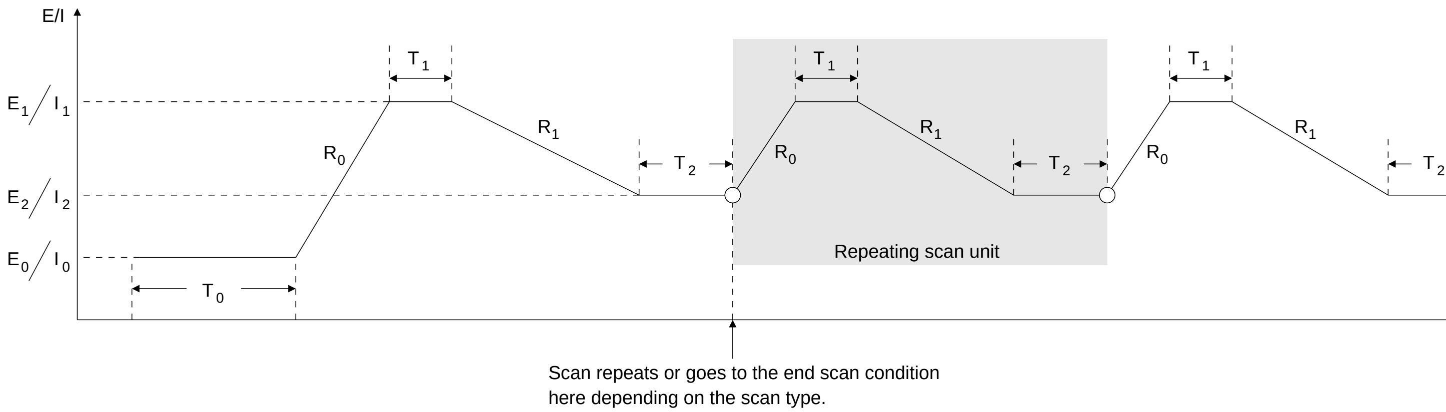


Figure 25: Parameters needed for the ramp generation commands.

Name: `rampppt` – Set an E or I vertex point for the ramp.
Description: As illustrated in figure 25, 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] [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_{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_{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 25, 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	100μV/s	$1, 2, 3, \cdots, 1 \times 10^8$
	Galvanostat	$\frac{I_{\text{range}}}{1000 \cdot \text{s}}$	$1, 2, 3, \cdots, 2000$[1] [1] 1 → 1000 for 1A range

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

These rates take multiples of 100μV/s in potentiostat mode, and milli-fractions of the full scale current (I_{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`.

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 25, 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	100μs	$0, 1, 2, \cdots, 4294967295$ ($2^{32} - 1$)

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.

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.

`rampst{i}`

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 25 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 25. 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 25.

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

7.3.18 Arbitrary waveform generation commands

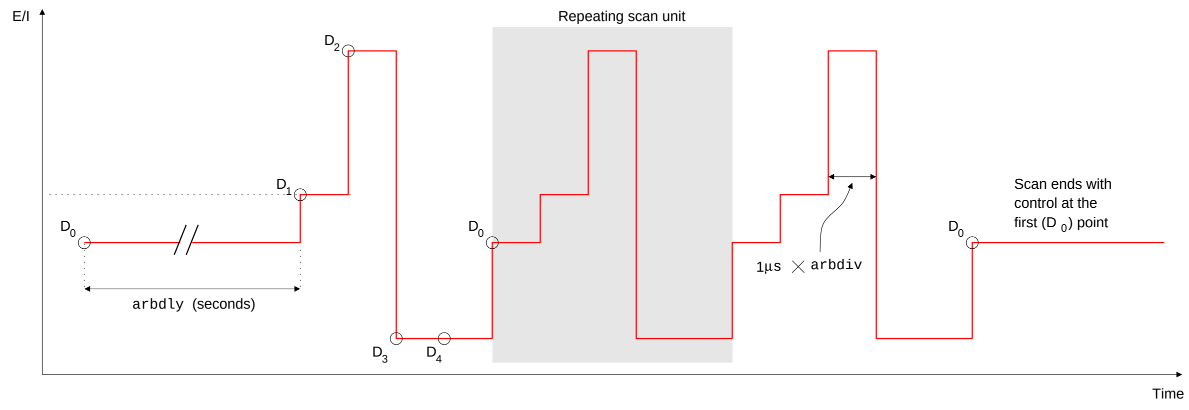


Figure 26: Illustration of an arbitrary waveform with five `arbdat` points and three repetition cycles. The time between `ARBDAT` points is always $1\mu s \times$ `arbdiv`. Repeat points to get longer hold times.

`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 `arbdat`.
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 `arbdat` command. It may be used to verify that all `arbdat` commands were processed properly.

Returned parameter	Values
Programmed points	$0,1,2,\cdots,1599$

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 $\frac{\text{1Msps}}{1000} = \text{1ksps}$, 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)

arbcyc(?){i}

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.

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`.

arbtyp(?){i}

Name: `arbtyp` – Set or query the arbitrary waveform type.
Description: The user must set the arbitrary waveform type with `arbtype` before entering data points with `arbdat`. The `arbtype` command argument defines the legal range of `arbdat` arguments. This waveform type can only change from 0 to another type – never from a nonzero to a nonzero type. 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	Undefined	None
1	Potentiostatic	±15V
2	Galvanostatic	1A
3		100mA
4		10mA
5		1mA
6		100μA
7		10μA
8		1μA
9		100nA
10		10nA
11		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` .

Name: `arbdat` – Set or query 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 1600 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_{range} units. For example, if the datum type is 5 – corresponding to galvanostat mode in the 1mA range – the datum will have units of μA.

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

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

Parameter	Type	Range	Units
`j`	Potentiostat	$-15000, -14999, -14998, \cdots, +15000$	mV
	Galvanostat	$-1000, -999, -998, \cdots, +1000$	$\frac{I_{\text{range}}}{1000}$

7.3.19 Reading temperature measurements

getrtd?

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

Example:

```
getrtd?
52.75  Degrees Celsius
```

---

rtdohm?

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

Example:

```
rtdohm?
50.35  Ohms
```

7.3.20 Managing instrument calibration

`calres`

Name: `calres` – Restore backup calibration.
Description: No description.

`calrev`

Name: `calrev` – Revert to factory calibration.
Description: This command sets the instrument's calibration constants to those measured at SRS.

`caldcd?{i}`

Name: `caldcd?` – Return the name of a calibration step given its system error code.
Description: This query-only command translates system error codes into calibration stage names.

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 27. *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
pstart  Start the scan
```

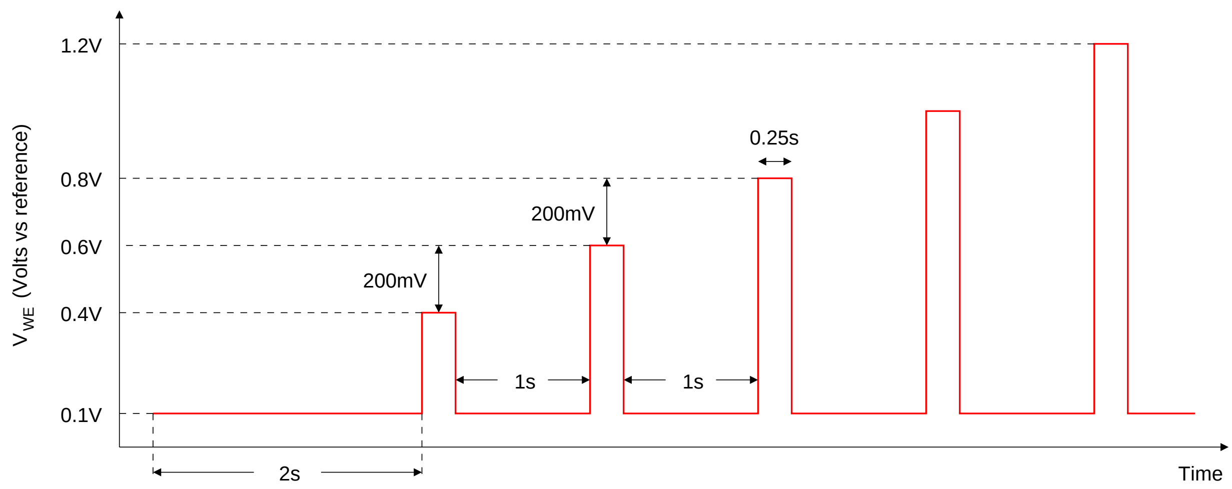


Figure 27: Sample normal pulse waveform.

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 28. Refer to figure 25 on page 97 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
rampppt 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
rampppt 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
rampppt 2 100  Set the E2 point at +100mV
rampst 0  Start the scan
```

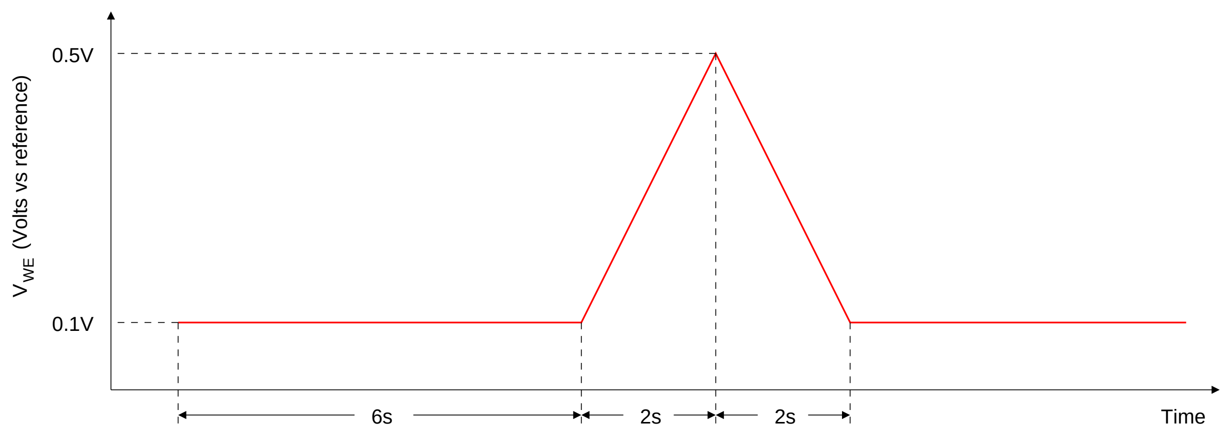


Figure 28: Sample cyclic voltammetry waveform.

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 64. Figure 29 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
```

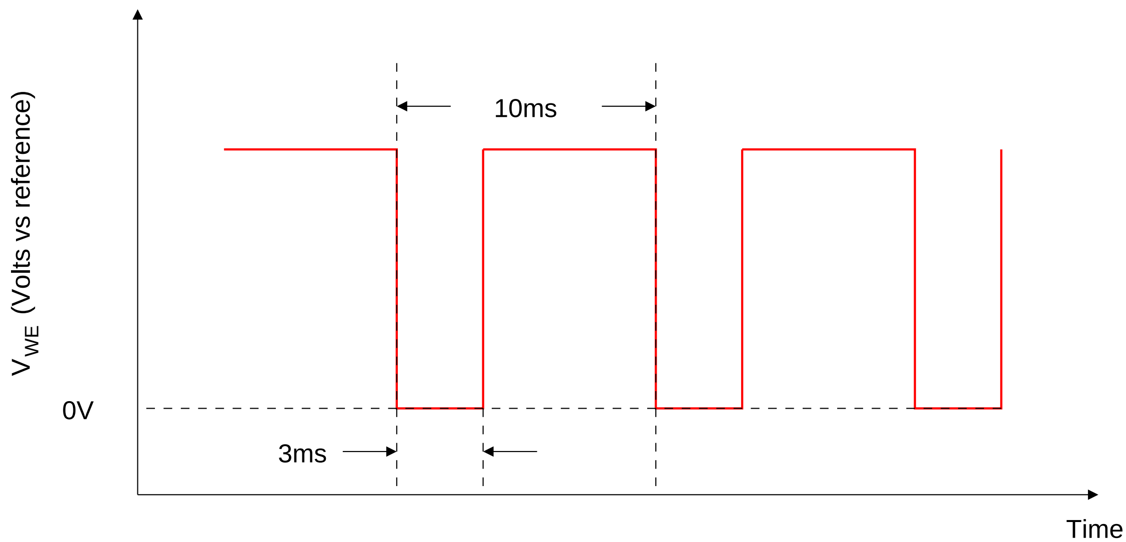


Figure 29: Sample current interruption waveform.

7.4.4 Arbitrary waveform

The following command sequence produces the waveform shown in figure 30. This arbitrary waveform example includes five `arbdat` 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)*
`arbdat 0 100`	*Set the* D_0 *point at +100mV*
`arbdat 1 200`	*Set the* D_1 *point at +200mV*
`arbdat 2 500`	*Set the* D_2 *point at +500mV*
`arbdat 3 -100`	*Set the* D_3 *point at −100mV*
`arbdat 4 -100`	*Set the* D_4 *point at −100mV*
`arbrun 1`	*Start the scan*

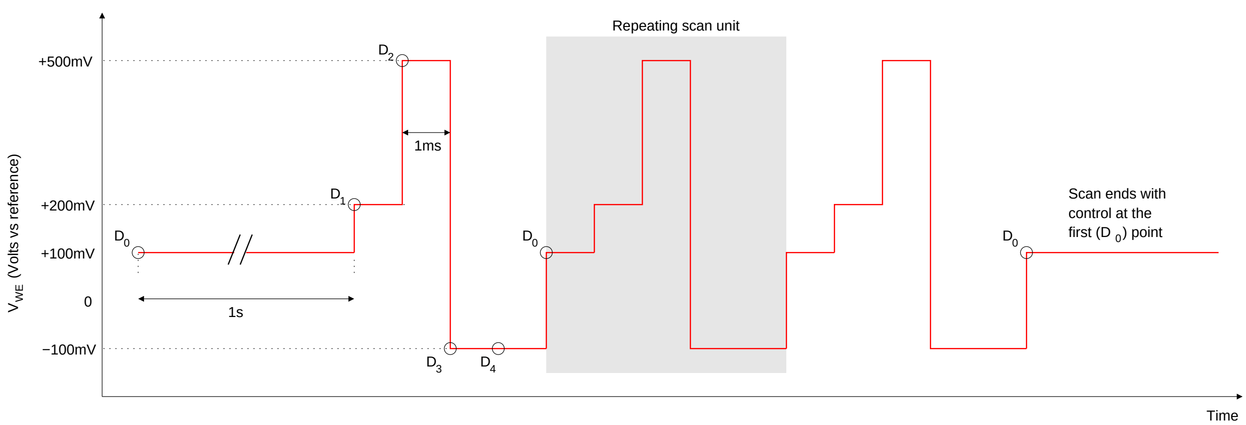


Figure 30: Arbitrary waveform example. Points are played back at the 1MHz/`arbdiv`, rate, so use repeated values to get longer hold times. Waveforms can have 1600 programmed points.

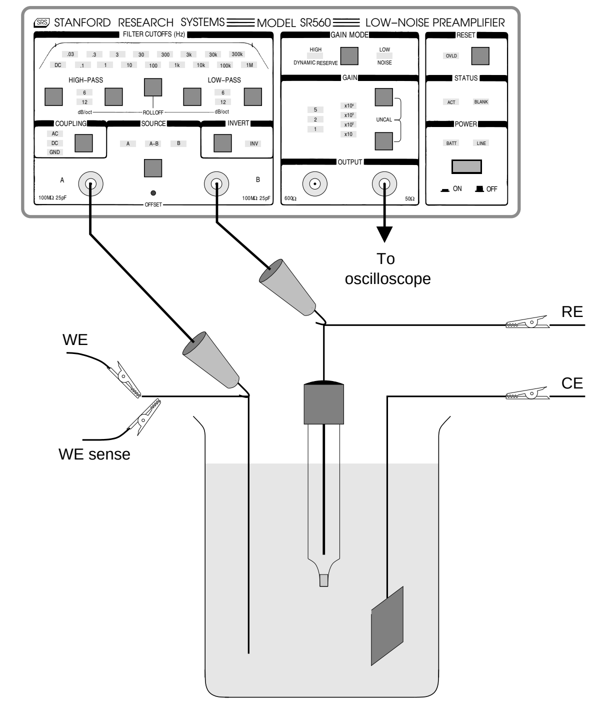
References

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

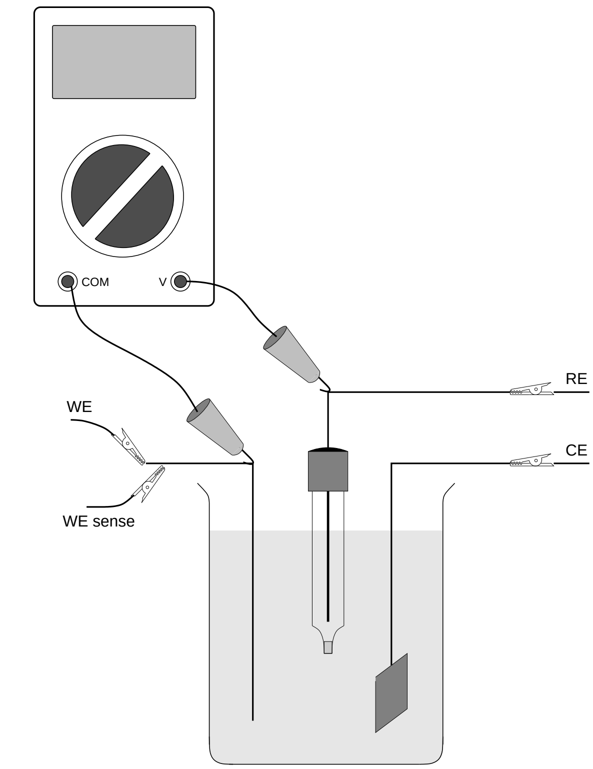
A Measuring cell voltages at the cell

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 31 illustrates good and bad ways of making these measurements. Figure 31a shows a high-impedance differential preamplifier used to buffer the desired voltage before sending it to an oscilloscope. Figure 31b shows a handheld meter used to make the measurement directly. Figure 31c 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.

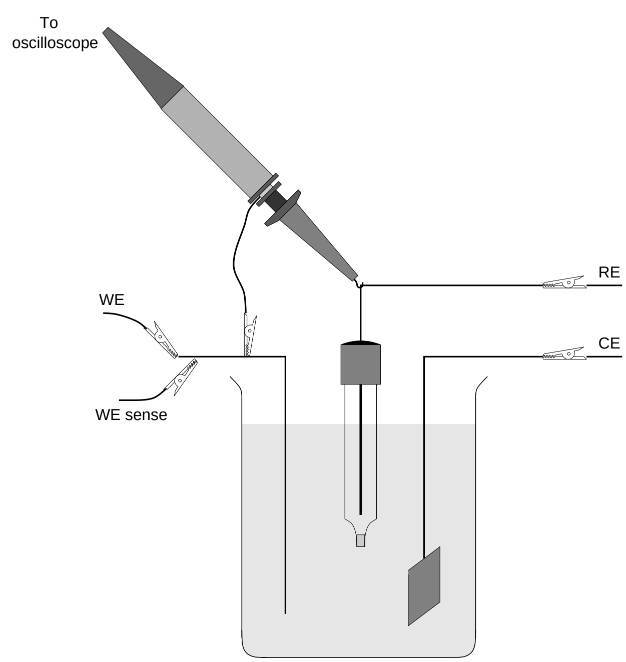
The methods shown in figures 31a and 31b are correct because both probes in each case are floating – not connected to ground. The method shown in 31c is incorrect because the oscilloscope probe pigtail does not float.



(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 31: 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	Not connected
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	Not connected

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