

# Model 2302/2302-PJ/2306/2306-PJ/ 2306-VS Battery/Charger Simulator

## Quick Results Guide

2306-903-01 Rev. D / May 2019



2306-903-01D

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Model 2302/2302-PJ/2306/2306-PJ/2306-VS  
Battery/Charger Simulator  
Quick Results Guide

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The following safety precautions should be observed before using this product and any associated instrumentation. Although some instruments and accessories would normally be used with nonhazardous voltages, there are situations where hazardous conditions may be present.

This product is intended for use by personnel who recognize shock hazards and are familiar with the safety precautions required to avoid possible injury. Read and follow all installation, operation, and maintenance information carefully before using the product. Refer to the user documentation for complete product specifications.

If the product is used in a manner not specified, the protection provided by the product warranty may be impaired.

The types of product users are:

**Responsible body** is the individual or group responsible for the use and maintenance of equipment, for ensuring that the equipment is operated within its specifications and operating limits, and for ensuring that operators are adequately trained.

**Operators** use the product for its intended function. They must be trained in electrical safety procedures and proper use of the instrument. They must be protected from electric shock and contact with hazardous live circuits.

**Maintenance personnel** perform routine procedures on the product to keep it operating properly, for example, setting the line voltage or replacing consumable materials. Maintenance procedures are described in the user documentation. The procedures explicitly state if the operator may perform them. Otherwise, they should be performed only by service personnel.

**Service personnel** are trained to work on live circuits, perform safe installations, and repair products. Only properly trained service personnel may perform installation and service procedures.

Keithley Instruments products are designed for use with electrical signals that are measurement, control, and data I/O connections, with low transient overvoltages, and must not be directly connected to mains voltage or to voltage sources with high transient overvoltages. Measurement Category II (as referenced in IEC 60664) connections require protection for high transient overvoltages often associated with local AC mains connections. Certain Keithley Instruments measuring instruments may be connected to mains. These instruments will be marked as category II or higher.

Unless explicitly allowed in the specifications, operating manual, and instrument labels, do not connect any instrument to mains.

Exercise extreme caution when a shock hazard is present. Lethal voltage may be present on cable connector jacks or test fixtures. The American National Standards Institute (ANSI) states that a shock hazard exists when voltage levels greater than 30 V RMS, 42.4 V peak, or 60 VDC are present. A good safety practice is to expect that hazardous voltage is present in any unknown circuit before measuring.

Operators of this product must be protected from electric shock at all times. The responsible body must ensure that operators are prevented access and/or insulated from every connection point. In some cases, connections must be exposed to potential human contact. Product operators in these circumstances must be trained to protect themselves from the risk of electric shock. If the circuit is capable of operating at or above 1000 V, no conductive part of the circuit may be exposed.

Do not connect switching cards directly to unlimited power circuits. They are intended to be used with impedance-limited sources. NEVER connect switching cards directly to AC mains. When connecting sources to switching cards, install protective devices to limit fault current and voltage to the card.

Before operating an instrument, ensure that the line cord is connected to a properly-grounded power receptacle. Inspect the connecting cables, test leads, and jumpers for possible wear, cracks, or breaks before each use.

When installing equipment where access to the main power cord is restricted, such as rack mounting, a separate main input power disconnect device must be provided in close proximity to the equipment and within easy reach of the operator.

For maximum safety, do not touch the product, test cables, or any other instruments while power is applied to the circuit under test. ALWAYS remove power from the entire test system and discharge any capacitors before: connecting or disconnecting cables or jumpers, installing or removing switching cards, or making internal changes, such as installing or removing jumpers.

Do not touch any object that could provide a current path to the common side of the circuit under test or power line (earth) ground. Always make measurements with dry hands while standing on a dry, insulated surface capable of withstanding the voltage being measured.

For safety, instruments and accessories must be used in accordance with the operating instructions. If the instruments or accessories are used in a manner not specified in the operating instructions, the protection provided by the equipment may be impaired.

Do not exceed the maximum signal levels of the instruments and accessories. Maximum signal levels are defined in the specifications and operating information and shown on the instrument panels, test fixture panels, and switching cards.

When fuses are used in a product, replace with the same type and rating for continued protection against fire hazard.

Chassis connections must only be used as shield connections for measuring circuits, NOT as protective earth (safety ground) connections.

If you are using a test fixture, keep the lid closed while power is applied to the device under test. Safe operation requires the use of a lid interlock.

If a  screw is present, connect it to protective earth (safety ground) using the wire recommended in the user documentation.

The  symbol on an instrument means caution, risk of hazard. The user must refer to the operating instructions located in the user documentation in all cases where the symbol is marked on the instrument.

The  symbol on an instrument means warning, risk of electric shock. Use standard safety precautions to avoid personal contact with these voltages.

The  symbol on an instrument shows that the surface may be hot. Avoid personal contact to prevent burns.

The  symbol indicates a connection terminal to the equipment frame.

If this  symbol is on a product, it indicates that mercury is present in the display lamp. Please note that the lamp must be properly disposed of according to federal, state, and local laws.

The **WARNING** heading in the user documentation explains dangers that might result in personal injury or death. Always read the associated information very carefully before performing the indicated procedure.

The **CAUTION** heading in the user documentation explains hazards that could damage the instrument. Such damage may invalidate the warranty.

The **CAUTION** heading with the  symbol in the user documentation explains hazards that could result in moderate or minor injury or damage the instrument. Always read the associated information very carefully before performing the indicated procedure. Damage to the instrument may invalidate the warranty.

Instrumentation and accessories shall not be connected to humans.

Before performing any maintenance, disconnect the line cord and all test cables.

To maintain protection from electric shock and fire, replacement components in mains circuits — including the power transformer, test leads, and input jacks — must be purchased from Keithley Instruments. Standard fuses with applicable national safety approvals may be used if the rating and type are the same. The detachable mains power cord provided with the instrument may only be replaced with a similarly rated power cord. Other components that are not safety-related may be purchased from other suppliers as long as they are equivalent to the original component (note that selected parts should be purchased only through Keithley Instruments to maintain accuracy and functionality of the product). If you are unsure about the applicability of a replacement component, call a Keithley Instruments office for information.

Unless otherwise noted in product-specific literature, Keithley Instruments instruments are designed to operate indoors only, in the following environment: Altitude at or below 2,000 m (6,562 ft); temperature 0 °C to 50 °C (32 °F to 122 °F); and pollution degree 1 or 2.

To clean an instrument, use a cloth dampened with deionized water or mild, water-based cleaner. Clean the exterior of the instrument only. Do not apply cleaner directly to the instrument or allow liquids to enter or spill on the instrument. Products that consist of a circuit board with no case or chassis (e.g., a data acquisition board for installation into a computer) should never require cleaning if handled according to instructions. If the board becomes contaminated and operation is affected, the board should be returned to the factory for proper cleaning/servicing.

Safety precaution revision as of June 2017.



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# Model 2306

## Quick Results Guide

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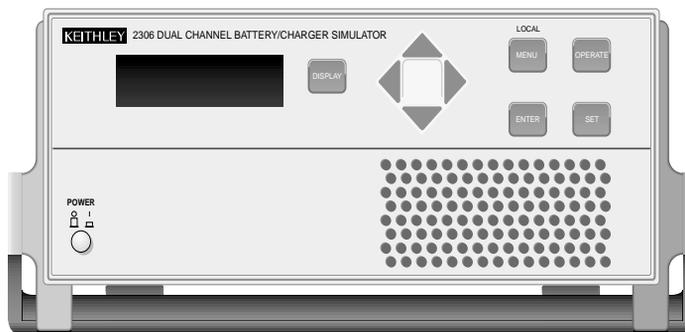
**NOTE** This quick results guide provides information on four different models of battery or battery/charger simulators (Models 2302, 2302-PJ, 2306, and 2306-PJ). In this guide, references to Model 2306 apply to all of the simulators unless otherwise noted. Likewise, references to specific models (for example, Model 2306 and 2306-PJ, or Model 2306-PJ and 2302-PJ) refer only to the models listed. Since the Model 2302 and 2302-PJ are single channel battery simulators, functions related to the second channel (i.e., the charger channel) are not available for these models. Therefore:

- battery and charger channel features contained in this manual apply for the Model 2306 and 2306-PJ
- only battery channel features contained in this manual apply for the Model 2302 and 2302-PJ

Refer to Appendix F of Instruction Manual (2306-901-01) for specific Model 2302 and 2302-PJ information.

Information contained in this guide applies to all power supply channels (unless otherwise noted). In this manual, channel 1 refers to the battery channel while channel 2 refers to the charger channel (2306 and 2306-PJ features only).

**Figure 1**  
Model 2306 front panel



**NOTE** For additional information on any feature discussed in this guide (including programming examples) refer to the Instruction Manual (part number 2306-901-00).

# Introduction

This guide is designed to familiarize users of the Keithley Model 2306 Dual Channel Battery/Charger Simulator and Model 2302 Single Channel Battery Simulator with the basic operating features available from the instrument's front panel and also the GPIB bus. The sequence of operating instructions reflects the order in which the instrument would be configured for a typical application. For each operating mode, an example set of bus commands is provided. While the SCPI command strings are generic, the exact programming syntax will depend on the test program language.

## Performance features

The battery channel, the single output channel of the Model 2302 and channel #1 on the Model 2306, has several enhanced performance features:

1. The transient response, defined by the voltage recovery time and voltage drop when subjected to a 1000% load change, is faster. For exact specifications, refer to Appendix A in the Model 2306 Instruction Manual.
2. Three current trigger ranges for pulsed current and long integration operation as opposed to a single range on the charger channel, channel #2 (5A). Available trigger ranges for the 5A current range: 100mA, 1A, and 5A. Available trigger ranges for the 500mA current range (Model 2306-PJ and 2302-PJ): 10mA, 100mA, and 500mA.
3. Variable output impedance on channel #1 ( $0\Omega$  to  $1.00\Omega$  in  $0.01\Omega$  steps). Channel #2 has fixed output impedance.

## Proper connection of the supply to the DUT

**WARNING** When installing a unit into a test system, make sure the external power sources do not apply voltage to the power supply in excess of its maximum limits (see specifications). Failure to do so could result in personal injury or death.

**WARNING** The power cord supplied with the Model 2306 contains a separate ground for use with grounded outlets. When proper connections are made, instrument chassis is connected to power line ground through the ground wire in the power cord. Failure to use a grounded outlet may result in personal injury or death due to electric shock.

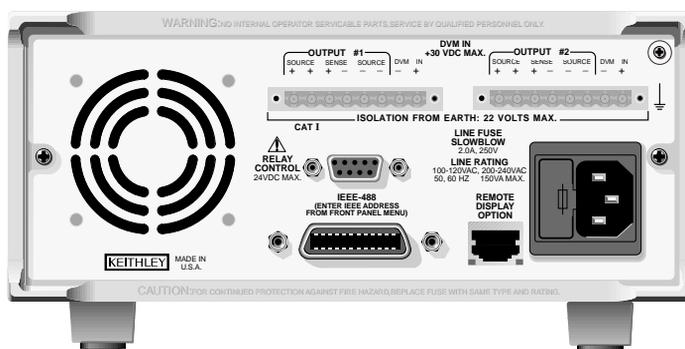
**WARNING** To prevent any human contact with a live conductor, connections to the DUT must be fully insulated and the final connections to the DUT must only use safety-rated safety jack socket connectors that do not allow bodily contact.

**NOTE** On some sensitive or easily damaged devices under test (DUTs), the instrument power-up sequence can apply transient signals to the DUT that may affect or damage it. When testing this type of DUT, do not make final connections to it until the instrument has completed its power-up sequence and is in a known operating state.

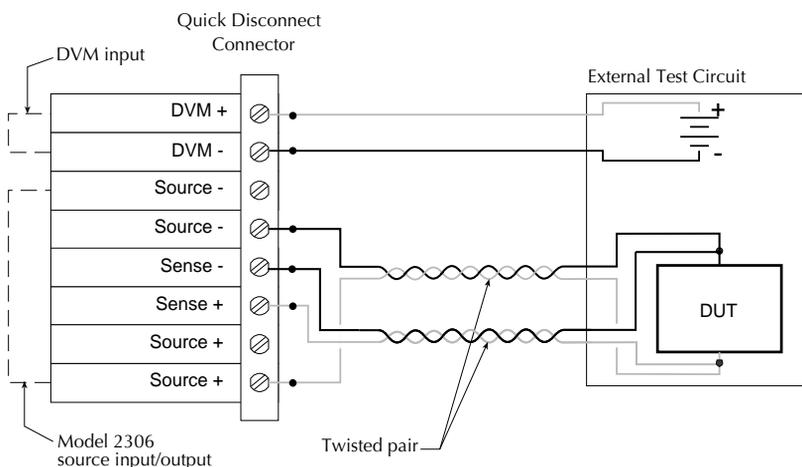
**NOTE** On some sensitive or easily damaged devices under test (DUTs), the instrument power-down sequence can apply transient signals to the DUT that may affect or damage it. When testing this type of DUT, disconnect it from the instrument before turning the instrument off.

Figure 2 shows a rear panel view of the Model 2306 detailing the connector sockets for the battery channel “OUTPUT #1” and the charger channel “OUTPUT #2.” The Model 2306 does not have an internal local sense connection. Therefore, the operator must connect the DUT to the supply in either a remote or local sense configuration as illustrated. For a 4-wire remote sense application, the sense inputs to the supply must be connected at load as close to the inputs of the load as possible through twisted pair leads as shown in Figure 3.

**Figure 2**  
Rear panel view of Model 2306



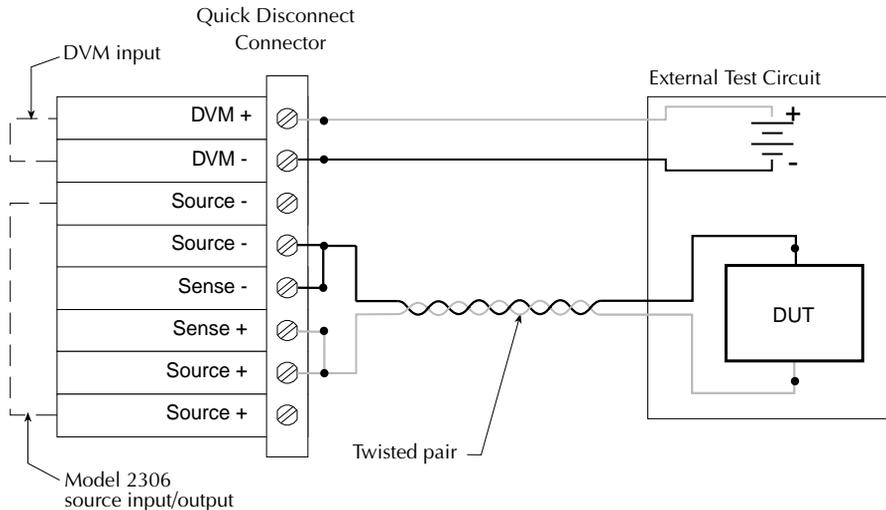
**Figure 3**  
4-wire remote sense connection of the DUT to the output



**NOTE** DO NOT jumper the sense inputs and supply outputs at the rear of the supply.  
DO NOT pass the source and sense leads together in the same twisted pair.

Failure to connect the sense leads in this fashion will **severely** compromise the performance of Model 2306 with dynamic loads. Figure 4 illustrates the proper connection of the supply to the DUT using a 2-wire local sense configuration.

**Figure 4**  
2-wire local sense connection of the DUT to the output



## Front panel operation

### Menu controls

- Press the MENU key to activate the main menu.
- Use the UP and DOWN keys to scroll through the primary menu items.
- Changing channels (Model 2306 only): When the main menu is displayed, use the ◀/▶ keys to change the active channel (each press of the ◀/▶ keys will toggle between channel #1 and channel #2).

**NOTE** *If a channel number is not shown, the LEFT and RIGHT key presses will be ignored. Also the LEFT and RIGHT key presses will be ignored if a sub-menu only exists on the battery channel (not on the charger channel).*

## Setting the output voltage, current range, and current limit

Output voltage can be set from 0 to 15V. For the Model 2306 and 2302, there are two ranges for current, 5A and 5mA. For the Model 2306-PJ and 2302-PJ, there are also two ranges for current, 5A and 500mA. Current range is checked or changed from the CURRENT RANGE item of the MENU.

1. Press the SET key to select the Output Settings Mode. A blinking cursor appears in the voltage field of the display.
2. Use the ◀, ▶, ▲, and ▼ keys to key in the desired output voltage value and press SET. The blinking cursor moves to the current field of the display.
3. Use the ◀, ▶, ▲, and ▼ keys to key in the desired current limit and press SET to exit from the output settings mode.
4. CURRENT RANGE #1/#2 can be checked or changed from the menu (which is accessed by pressing the MENU key). The “#1” (battery channel active) or “#2” (charger channel active) will appear on the top line of the display.

**NOTE** *The active channel may be toggled in any of the main menu items by using the ◀/▶ keys. The ◀/▶ keys will not change the active channel in the sub-menu items.*

## Turning supply output ON/OFF

The OPERATE key is used to control the output of the power supply. This key toggles the output between on and off. While in one of the display modes, output ON or OFF is displayed in the upper right corner of the display. The key is active in any front panel menu or display mode. In menus, the on/off state of operate is not displayed.

## Actual V and I mode

Measured output voltages and currents are displayed with the actual V and I display mode selected. This display mode is selected as follows:

**NOTE** *To display measured readings if the instrument is in the settings mode, press the SET key until the blinking stops (the measured readings can then be displayed). To determine if the instrument is in the settings mode, check for a blinking cursor in a digit of the voltage or current field (if present, the instrument is in the setting mode).*

1. Press the DISPLAY key to access the display menu. DISPLAY TYPE #1 (battery channel active) or DISPLAY TYPE #2 (charger channel active) will appear on the top line of the display. Toggle the active channel if necessary.
2. Press the ▲ / ▼ keys until “ACTUAL V AND I” is displayed.
3. Press ENTER. Voltage readings are located on the top line of the display and current readings are located on the bottom line.

## NPLC rate

The integration (reading) rate of the instrument is specified as a parameter based on the number of power-line cycles (NPLC), where 1 PLC for 60Hz line frequency is 16.67msec. In general, the fastest integration time (0.01 PLC) results in increased reading noise. The slowest integration time (10 PLC) provides the best common-mode and normal-mode rejection. In between settings are a compromise between speed and noise. The NPLC RATE #1/#2 item of the menu is also used to set the reading rate for DVM measurements.

**NOTE** *NPLC RATE is not used to set the integration rate for pulse current and long integration measurements. These measurements are covered in the paragraphs titled “Pulse current mode” on page 9 and “Long integration mode” on page 16.*

## Average readings

The average reading count (1 to 10) specifies the number of measurement conversions to average for each reading. For example, with a reading count of 5, each displayed reading will be the average of five measurement conversions. The AVER READINGS #1/#2 menu items are also used to set the average reading count for DVM measurements.

**NOTE** *AVER READINGS is not used to set the average reading count for pulse current and long integration measurements. Refer to applicable sections of this guide for information on setting the average reading count for pulse current and long integration measurements.*

## Programming examples: outputting and reading back V and I

The following command sequences demonstrate how to output voltage and current, and read back (measure) the actual voltage and current:

### Battery channel (#1)

Command	Description
VOLT 5	‘ Set output voltage to 5V.
SENS:CURR:RANG:AUTO ON	‘ Enable auto range for current.
CURR 750e-3	‘ Set current limit to 750mA.
CURR:TYPE TRIP	‘ Select Trip mode for current limit.
SENS:FUNC ‘VOLT’	‘ Select the voltage measurement function.
SENS:NPLC 2	‘ Set integration rate to 2 PLC.
SENS:AVER 5	‘ Set average reading count to 5.
OUTP ON	‘ Turn on the power supply output.
READ?	‘ Trigger 5 voltage measurement conversions and return the average of those 5 conversions. The average reading is displayed on the front panel.
SENS:FUNC ‘CURR’	‘ Select current measurement function.
READ?	‘ Trigger 5 current measurement conversions and return the average of those 5 conversions. The average of the 5 readings is displayed on the front panel.

**Charger channel (#2)**

Command	Description
SOUR2:VOLT 5	‘ Set output voltage to 5V.
SENS2:CURRE:RANG:AUTO ON	‘ Enable auto range for current.
SOUR2:CURRE 750e-3	‘ Set current limit to 750mA.
SOUR2:CURRE:TYPE LIM	‘ Select LIM mode for current limit.
SENS2:FUNC ‘VOLT’	‘ Select the voltage measurement function.
SENS2:NPLC 4	‘ Set integration rate to 4 PLC.
SENS2:AVER 4	‘ Set average reading count to 4.
OUTP2 ON	‘ Turn on the power supply output.
READ2?	‘ Trigger 4 voltage measurement conversion and return the average of those 4 conversions.
SENS2:FUNC ‘CURR’	‘ Select current measurement function.
READ2:ARR?	‘ Trigger 4 current measurement conversions and return all 4 conversions. The average of the 4 readings is displayed on the front panel.

**DVM input mode**

The DVM input display mode must be selected in order to measure voltage applied to DVM input of the power supply. This display mode is selected as follows:

1. Press the DISPLAY key to access the display menu. DISPLAY TYPE #1 (battery channel active) or DISPLAY TYPE #2 (charger channel active) will appear on the top line of the display. Toggle the active channel, if necessary, by using the left or right arrow keys.
2. Press the ▲ / ▼ key until “DVM INPUT” is displayed.
3. Press ENTER.

## Programming examples: making voltage measurements with the DVM

The following command sequence demonstrates how to measure voltage applied to the DVM input of the power supply:

### Battery channel (#1)

Command	Description
SENS:FUNC 'DVM'	' Select the DVM input function.
SENS:NPLC 6	' Set integration rate to 6 PLC.
SENS:AVER 10	' Set average reading count to 10.
READ:ARR?	' Trigger and return 10 readings. The average of the 10 readings is displayed on the front panel.

### Charger channel (#2)

Command	Description
SENS2:FUNC 'DVM'	' Select the DVM input function.
SENS2:NPLC 3	' Set integration rate to 3 PLC.
SENS2:AVER 8	' Set average reading count to 8.
READ2:ARR?	' Trigger and return 8 readings. The average of the 8 readings is displayed on the front panel.

## Pulse current mode

### Description

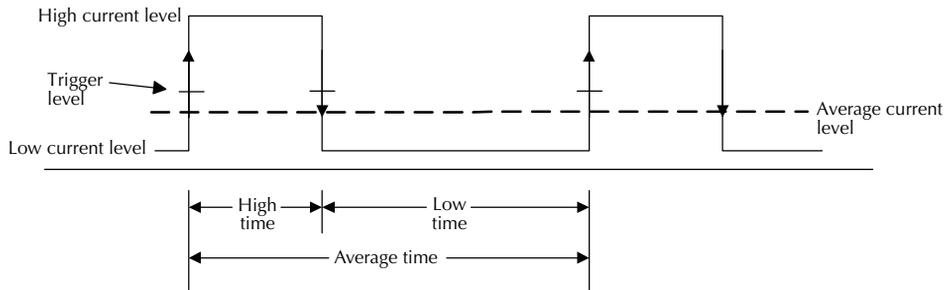
The Model 2306 can perform pulsed current measurements for dynamic loads. The built-in measurements include:

1. Peak measured current - measures the peak (high) current of the pulse train.
2. Idle measured current - measures the idle (low) current of the pulse train.
3. Average transmitted current - measures the average current of the pulse train.

The high measurement is triggered on the rising edge of the pulse (Figure 5) and an integration is performed for the time specified for the high measurement. The falling edge of the pulse triggers the low measurement, and an integration is performed for the time specified for the low measurement. An average measurement is triggered on the rising edge, and covers both the high and low periods of the pulse as specified by the average measurement time setting. The Model 2306 computes one measurement parameter, high, low, or average, at a time. The desired measurement mode on the front panel is selected with the up and down arrow keys.

The pulse measurement period  $T$  can be selected manually or be automatically set by the Model 2306. First, the user must specify a trigger level that serves as a threshold to initiate integration process, i.e., at  $t = 0$ . Once the trigger level is selected, the output is turned on and the pulsed load is operational, the 2306 can be prompted to automatically determine the high time, low time, and average time in pulsed current mode according to Figure 5. These parameters may also be set manually from the front panel or over the GPIB bus.

**Figure 5**  
*Pulsed waveform*



**NOTE** *The pulsed waveform in Figure 5 shows trigger level and the high, low, and average times set by the Model 2306 using the auto-time feature.*



## Front panel operation for performing pulse current measurements

All of the following settings are available in sub-menus of PULSE CURRENT #1/#2 main menu item. Scroll through the main menu and when PULSE CURRENT #1/#2 is displayed, press “ENTER” to access the sub-menus.

### Turn on the output

Press the OPERATE key after setting the appropriate voltage and current limits for the DUT.

### Select CURRENT RANGE

For Models 2306-PJ and 2302-PJ, select 500mA or 5A. For Models 2306 and 2302, the 5A range is automatically selected.

### Set trigger level and range

#### “TRIG LEVEL RANGE” and “TRIGGER LEVEL” sub-menus

Battery Channel (#1) — On the 5A current range, the trigger level can be set for either the 5A, 1A, or 100mA range.

Trigger level ranges: 5A range: 0–5A in 5mA steps  
1A range: 0–1A in 1mA steps  
100mA range: 0–100mA in 0.1mA steps

#### “TRIG LEV mA RANGE” and “TRIG LEVEL mA” sub-menus

Battery Channel (#1) (Models 2306-PJ and 2302-PJ) — On the 500mA current range, the trigger level can be set for either the 500mA, 100mA, or the 10mA range.

Trigger level ranges: 500mA range: 0–500mA in 0.5mA steps  
100mA range: 0–100mA in 0.1mA steps  
10mA range: 0–10mA in 0.1mA steps

To change the range for the trigger level setting, place the blinking cursor on the “A” at the far right end of line two of the display, and press the UP or DOWN key. After keying in the trigger level (in amps), press ENTER to update the displayed range for that trigger level setting only.

Charger Channel (#2) — Set the trigger level from 0 to 5A in 5mA steps.

Same as battery channel but settings for one range only 5A range: 0–5A in 5mA steps.

If the trigger level is incorrect or the DUT is not functioning properly, the “PULSE CURR TRIG NOT DETECTED” message will be displayed. (See note No Pulses Detected message on page 14.)

### Integration time (manual setting) “AVERAGE TIME”, “LOW TIME”, and “HIGH TIME” sub-menus

The values for HIGH, LOW, and AVERAGE time may be changed in 33.3333  $\mu$ sec intervals with the UP and DOWN keys. Range of values is 33.3333 $\mu$ sec to 833.33msec.

**Integration time (auto time setting) “AUTO TIME” sub-menu**

Press ENTER when “ACQUIRE TIMES” appears on the display. If the correct trigger level is selected in the previous step and the DUT is operating, the Model 2306 will automatically determine the HIGH, LOW, and AVERAGE times. If the trigger level is incorrect or the DUT is not functioning properly, the message “PULSE CURR TRIG NOT DETECTED” will be displayed. (See note No Pulses Detected message on page 14.)

**Trigger delay (if necessary) channel #1 and channel #2:**

The trigger level is changed in the TRIGGER LEVEL sub-menu by pressing the UP or DOWN key.

Range is 0 – 0.100sec in 10 $\mu$ sec increments.

**NOTE** *The high, low, or average integration times can be set either manually or automatically. When a pulse is detected, there is a 15 $\mu$ sec trigger latency before the integration time begins. An additional user trigger delay can be set to allow the leading edge pulse overshoot to settle. Regardless of the user trigger delay setting, the internal trigger delay is always present.*

**Average readings count (if necessary) Channel #1 and Channel #2:**

The AVERAGE READINGS sub-menu of the PULSE CURRENT #1/#2 menu item is used to set the average readings count for pulse current measurements. This count specifies the number of measurements (integrations) to average for each reading. Range is 1–100.

**Pulse current display mode**

Pulse current measurements are displayed with the pulse current display mode selected. This display mode is selected as follows:

**NOTE** *To display measured readings if the instrument is in the settings mode, press the SET key until the blinking stops (the measured readings can then be displayed). To determine if the instrument is in the settings mode, check for a blinking cursor in a digit of the voltage or current field (if present, the instrument is in the settings mode).*

1. Press the DISPLAY key to access the display menu.
2. If the desired active display is not selected, use the LEFT and RIGHT keys to toggle the active display. The top line of the display will show which output channel is active.
3. Press the UP or DOWN key until “PULSE CURRENT” is displayed, and press ENTER.
4. Use the UP or DOWN key to display the desired pulse measurement; high, low, or average.

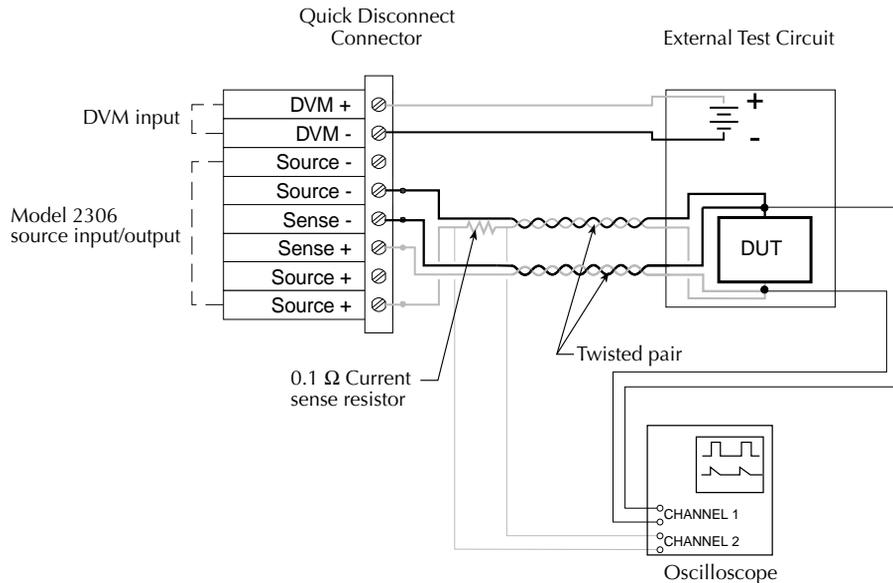
**NOTE** *No Pulses Detected message*

If no pulses are detected, current will not be measured (i.e., -----A), and the “NO PULSE” message will be displayed. The “NO PULSE” message is displayed with dashes or the last valid pulse reading. Dashes are shown if the pulse-current measurement settings are not appropriate for detecting pulses. The last valid pulse is shown if the pulse disappears while taking readings and no change in pulse settings was made.

Pulses are not detected with the output OFF. With the output ON, pulses will not be detected if the trigger level is too low or too high. Adjust the trigger level as necessary and toggle back to the display mode until pulse measurements are displayed.

**NOTE** If possible, the user should always use an oscilloscope to determine the timing and transient characteristics of a DUT. The waveform information is very useful in setting up the Model 2306, reducing setup time, and achieving maximum performance and productivity. The voltage and current characteristics of the DUT can be determined with a two-channel oscilloscope, a 0.1 ohm resistor used as a current sense resistor, and a voltage probe at the DUT as shown in Figure 7.

**Figure 7**  
Circuit — determining the dynamic voltage and current characteristics of a DUT



**NOTE** Figure 7 contains a simple circuit for determining the dynamic voltage and current characteristics of the DUT using a 2-channel oscilloscope, a 0.1 ohm resistor used as a current sense resistor, and a voltage probe at the DUT.

## Programming examples: pulse current measurements

The following command sequence will return the average of 10 peak pulse current measurements:

### Battery channel (#1)

Command	Description
SENS:RANG 5	‘ Select 5A range.
VOLT 15	‘ Set output voltage to 15V.
CURR 0.75	‘ Set current limit to 750mA.
OUTP ON	‘ Turn output on.
SENS:PCUR:SYNC ON	‘ Enable trigger synchronization.
SENS:PCUR:AVER 10	‘ Set average count to 10.
SENS:PCUR:SYNC:TLEV:RANG 0.5	‘ Select the 1A trigger level range.
SENS:PCUR:SYNC:TLEV:ONE 0.1	‘ Set trigger level to 100mA for 1A trigger level range.
SENS:PCUR:TIME:AUTO	‘ Set integration times automatically.
SENS:PCUR:SYNC:DEL 50e-3	‘ Set trigger delay to 50msec.
SENS:FUNC “PCUR”	‘ Select pulse current function.
SENS:PCUR:MODE HIGH	‘ Configure to measure peak pulse.
READ?	‘ Trigger 10 measurement conversions and return the average of those 10 conversions. The average of the 10 conversions is displayed on the front panel. Each of the 10 conversion syncs to the rising edge.

**Charger channel (#2)**

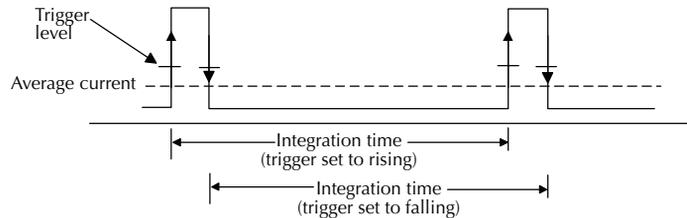
Command	Description
SENS2:RANG 5	‘ Select 5A range.
SOUR2:VOLT 15	‘ Set output voltage to 15V.
SOUR2:CURR 0.75	‘ Set current limit to 750mA.
OUTP2 ON	‘ Turn output on.
SENS2:PCUR:SYNC ON	‘ Enable trigger synchronization.
SENS2:PCUR:AVER 10	‘ Set average count to 10.
SENS2:PCUR:SYNC:TLEV 0.1	‘ Set trigger level to 100mA.
SENS2:PCUR:TIME:AUTO	‘ Set integration times automatically.
SENS2:PCUR:SYNC:DEL 50e-3	‘ Set trigger delay to 50msec.
SENS2:FUNC “PCUR”	‘ Select pulse current function.
SENS2:PCUR:MODE HIGH	‘ Configure to measure peak pulse (trigger on).
READ2	‘ Trigger 10 measurement conversions and return the average of those 10 conversions. The average of the 10 conversions is displayed on the front panel. Each of the ten conversion syncs to the rising edge.

## Long integration mode

In the long integration mode, a current measurement results from a continuous integration of the dynamic current for a period ranging from approximately 850ms to 60sec set in 1msec increments. The Model 2306 can determine the integration time automatically or the user can set the integration time manually from the front panel. A pulse edge can be used to trigger the start of the measurement as shown in Figure 8. Select **RISING** to use a rising pulse edge to start the measurement. Select **FALLING** to use a falling pulse edge to start the measurement. A third option is available if you do not want measurements controlled by pulse edges. With **NEITHER** selected, measurements will start as soon as the long integration function is selected. Note that a pulse has to be detected before a **RISING** or **FALLING** pulse edge can trigger a long integration measurement (see Trigger Level and Range on page 17). To average over several pulse periods, the user must enter the sum of the pulse periods as the integration time.

The GPIB commands **TIMEOUT**, **SEARCH**, **DETECT**, and **FAST** are available exclusively in the long integration mode to optimize measurement speed. For the relevance and use of these commands regarding a particular measurement application, refer to the Model 2306 Instruction Manual, Section 4, Long Integration Measurements.

**Figure 8**  
Pulsed waveform



**NOTE** The pulse waveform contained in Figure 8 shows trigger level and the integration time used by the Model 2306 for pulse current measurements.

## Front panel operation for performing long integration measurements

All of the following settings are available in sub-menus of the LONG INTEGRAT #1/#2 main menu item. Scroll through the main menu and when LONG INTEGRAT #1/#2 is displayed press “ENTER” to access the sub-menus.

### Turn on the output

Press the OPERATE key after setting the appropriate voltage and current limits for the DUT.

### Select CURRENT RANGE

For Models 2306-PJ and 2302-PJ, select 500mA or 5A. For Models 2306 and 2302, the 5A range is automatically selected.

### Set trigger level and range

#### “TRIG LEVEL RANGE” and “TRIGGER LEVEL” sub-menus

Battery Channel (#1) — On the 5A current range, the trigger level can be set for either the 5A, 1A, or 100mA range.

Trigger level ranges: 5A range: 0–5A in 5mA steps  
 1A range: 0–1A in 1mA steps  
 100mA range: 0–100mA in 0.1 mA steps

#### “TRIG LEV mA RANGE” and “TRIG LEVEL mA” sub-menus

Battery Channel (#1) (Models 2306-PJ and 2302-PJ) — On the 500mA current range, the trigger level can be set for either the 500mA, 100mA, or the 10mA range.

Trigger level ranges: 500mA range: 0–500mA in 0.5mA steps  
 100mA range: 0–100mA in 0.1mA steps  
 10mA range: 0–10mA in 0.1mA steps

To change the range for the trigger level setting, place the blinking cursor on the “A” at the far right end of line two of the display, and press the UP or DOWN key. After keying in the trigger level (in amps), press ENTER to update the displayed range for that trigger level setting only.

Charger Channel (#2) — Set the trigger level from 0 to 5A in 5mA steps.

**NOTE** *This is the same as battery channel but settings are for only one range, the 5A range: 0–5A in 5mA steps.*

If the trigger level is incorrect or the DUT is not functioning properly, the message “LONG INT TRIG NOT DETECTED” will be displayed. (See the LONG INT TRIG NOT DETECTED note on page 19.)

### **Trigger edge – “TRIGGER EDGE” sub-menus**

Toggle between the RISING, FALLING, and NEITHER settings with the UP and DOWN keys. With NEITHER selected, measurements will start as soon as the long integration function is selected.

### **Timeout – “TIMEOUT” sub-menu**

When the TIMEOUT value is reached, NO PULSE is displayed (top line of the front panel display). The value for TIMEOUT should be set to a value greater than the long integration time for a long integration reading.

### **Manually setting long integration time (“INTEGRATION TIME” sub-menu)**

The value for LINT INT TIME for channel #1 or channel #2 can be specified in 0.850 sec to 60 sec (i.e. @ 60Hz) with the UP and DOWN keys.

### **Automatically setting long integration time (“AUTO TIME” sub-menu)**

Press ENTER when “LINT AUTOTIME #1, #2”, “ACQUIRE TIMES” appears on the display. If the correct trigger level is selected in the previous step and the DUT is operating, the Model 2306 will automatically determine the INTEGRATION times. If the trigger level is incorrect or the DUT is not functioning properly, the message “LONG INT TRIG NOT DETECTED” will be displayed. (See the LONG INT TRIG NOT DETECTED note on page 19.)

### **Long integration display mode**

Long integration measurements are displayed with the long integration display mode selected. This display mode is selected as follows:

**NOTE** *To display measured readings if the instrument is in the settings mode, press the SET key until the blinking stops (the measured readings can then be displayed). To determine if the instrument is in the settings mode, check for a blinking cursor in a digit of the voltage or current field (if present, the instrument is in the setting mode).*

1. Press the DISPLAY key to access the display menu.
2. If the desired active display is not selected, use the LEFT and RIGHT keys to toggle the active display. The top line of the display will show which output channel is active.

3. Press the UP or DOWN key until “LONG INTEGRATION” is displayed and press ENTER.
4. To stop taking long integration readings, press any front panel key. As long as the instrument remains in the long integration display state, the measurement process can be resumed by pressing the UP or DOWN key.

**NOTE** *LONG INT TRIG NOT DETECTED message*

*This message may take a few seconds to appear. With the trigger edge set to NEITHER, this message may appear if level setting causes no rising edge detection. A valid trigger level is not required if the trigger edge is set to NEITHER. For the battery channel (#1), this message will only appear if the range of the trigger level setting matches the selected trigger level range. For the charger channel #2, the trigger level range setting is not user selectable.*

**NOTE** *If you select AUTO TIME to set the integration time, the pulse timeout message “LONG INT TRIG NOT DETECTED” will display if the output is OFF. This message indicates that the integration time has not been updated. To update the integration time, select AUTO TIME after the output is turned ON.*

## Programming examples: long integration measurements

The following command sequence will trigger and return one long integration measurement:

### Battery channel (#1)

Command	Description
SENS:RANG 5	‘ Select 5A range.
VOLT 15	‘ Set output voltage to 15V.
CURR 0.75	‘ Set current limit to 750mA.
OUTP ON	‘ Turn output on.
SENS:LINT:TLEV:RANG 0.5	‘ Select 1A trigger level range.
SENS:LINT:TEDG RISING	‘ Select rising trigger edge to initiate measurement.
SENS:LINT:TLEV:ONE 0.1	‘ Set trigger level to 100mA for 1A trigger level range.
SENS:LINT:TIME:AUTO	‘ Set integration time automatically for single pulse.
SENS:FUNC “LINT”	‘ Select long integration function.
READ?	‘ Trigger and return one reading and reading shown on display.

**Charger channel (#2)**

Command	Description
SENS2:RANG 5	‘ Select 5A range.
SOUR2:VOLT 15	‘ Set output voltage to 15V.
SOUR2:CURR 0.75	‘ Set current limit to 750mA.
OUTP2 ON	‘ Turn output on.
SENS2:LINT:TEDG RISING	‘ Select rising trigger edge to initiate measurement.
SENS2:LINT:TLEV 0.1	‘ Set trigger level to 100mA.
SENS2:LINT:TIME:AUTO	‘ Set integration time automatically for single pulse.
SENS2:FUNC “LINT”	‘ Select long integration function.
READ2?	‘ Trigger and return one reading and reading shown on display.

## Advanced features

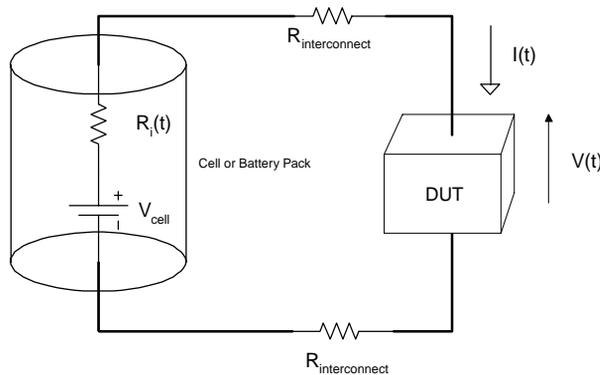
### Simulating battery impedance

The electronic resistance of batteries varies according to a variety of factors such as chemistry, cell construction, number of charge/discharge cycles, temperature, and depth of discharge. If a battery is used as a source in a circuit with a dynamic load, changes in the voltage across the load will be produced proportional to the electronic resistance of the battery and other sources of resistance in the circuit. If the peak load current is high enough or the electronic resistance of the battery and the resistance between the source and the DUT is large, the voltage drop compromises the performance of the device.

This phenomenon occurs in TDMA and GSM cellular handsets where the magnitude of the “ON/OFF” current during transmission varies by as much as a factor of 20. In the absence of any filtering capacitance between the battery and the RF power amplifier, the handset will shut off if the supply voltage is below the operating threshold for periods as short as several microseconds.

Figure 9 shows a simple schematic of a battery. This battery is represented by an ideal voltage source,  $V_{\text{cell}}$ , with internal impedance,  $R_i(t)$ , and is connected to a DUT with interconnects having resistance  $R_{\text{interconnect}}$ .

**Figure 9**  
Battery schematic



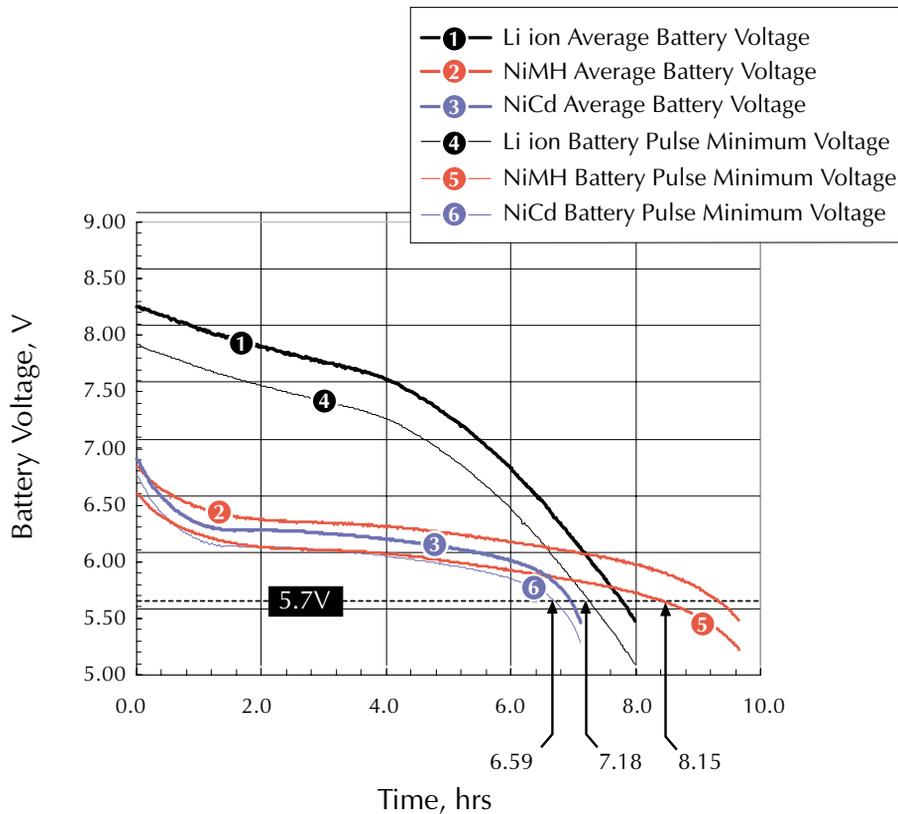
If  $R_{\text{interconnect}}$  is small compared to  $R_i(t)$  and if  $R_i(t)$  is relatively constant during the length of the pulse,  $R_i(t) \sim R_i$ , then the voltage across the DUT may be expressed as:

$$V(t) = V_i - I(t)R_i$$

where  $I(t)$  is the time varying current through the battery.

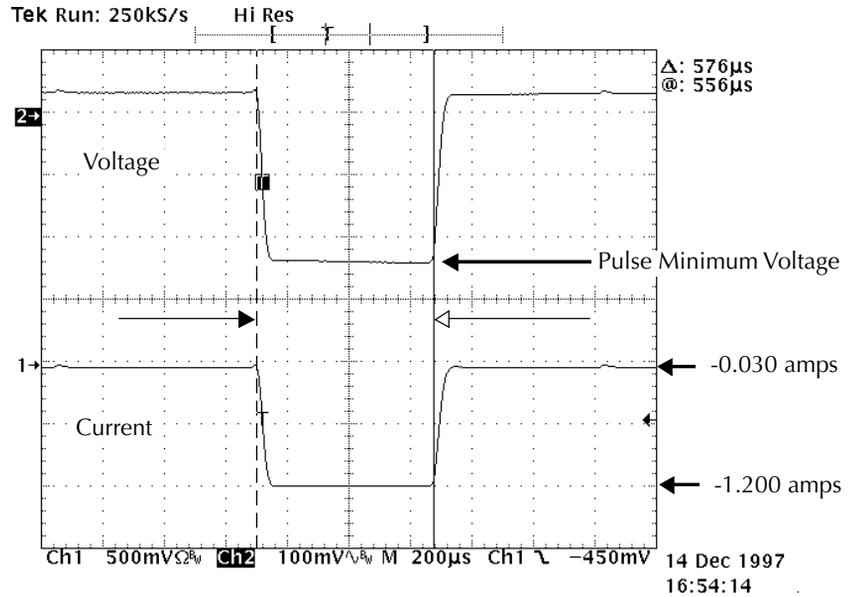
Figure 10 shows the actual performance of typical Li ion, NiMH, and NiCd handset battery packs with a dynamic load, shown in Figure 11, simulating a GSM handset during transmission. The pulse minimum voltage is the voltage at the battery terminals during the transmit, or high current portion, of the data frame. The average battery voltage is the voltage across the terminals measured with a  $6\frac{1}{2}$  digit DMM at approximately 50 readings per second. The figure shows the pulse minimum voltage reaches the shutdown threshold of 5.7V before the average battery voltage. The difference between the pulse minimum and average battery voltage also varies as a function of the electronic resistance with time. Figure 12 shows the variations for specific battery packs and ranges between 200 and 500mV. The results of these measurements prove that the impedance of the battery must be considered when evaluating handset performance, especially near the end of life for the battery pack.

**Figure 10**  
Actual battery pack terminal voltage during GSM phone simulation



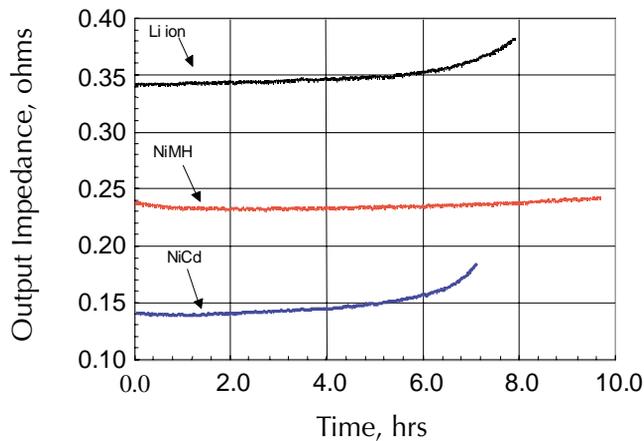
**NOTE** Figure 10 shows the average and minimum battery pack terminal voltage during a load pulse from a dynamic load simulating a GSM phone.

**Figure 11**  
 Simulated GSM phone current profile



**NOTE** The simulated GSM phone current profile contained in Figure 11 shows a standby current of 0.030A, a transmit current of 1.2A, and the pulse minimum voltage during the transmit frame.

**Figure 12**  
*Electronic resistance of NiCd, NiMH, and Li ion battery packs*



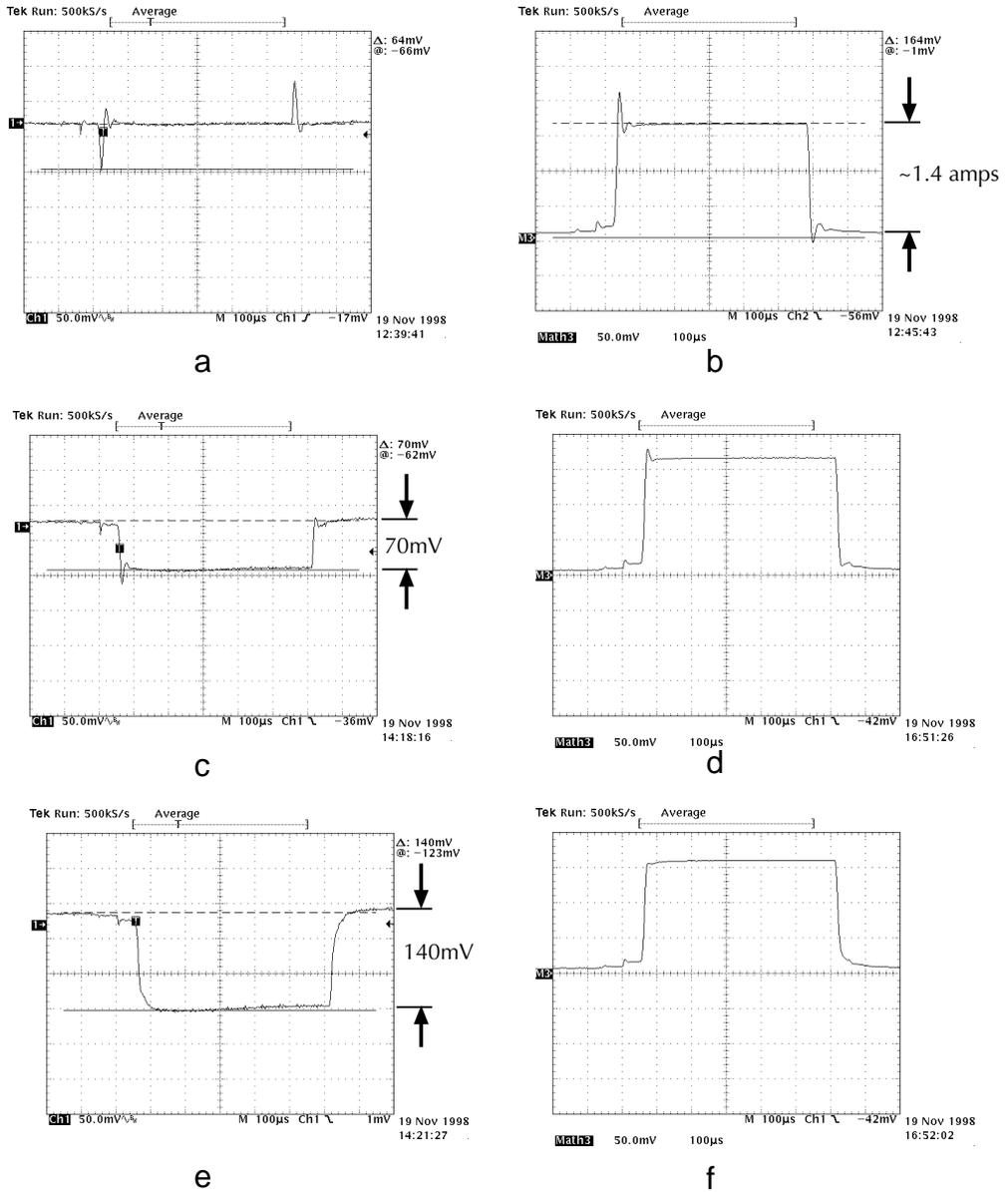
**NOTE** *Figure 12 shows electronic resistance for battery packs during a simulated GSM phone pulsed discharge from full charge to 5.5 volts.*

### **Variable output impedance control on channel #1**

Channel #1 of the Model 2306 has a variable output impedance control that can be used to simulate the impedance of a battery pack. The output impedance may be set from 0.00 ohms (default condition) to 1.00 ohms in 0.01 ohm increments from the front panel or over the GPIB bus.

Figure 13 shows the output voltage and current response of channel #1 with a GSM phone for output impedance values of 0.00, 0.05, and 0.10 ohms. The voltage drop, 70mV in **c** and 140mV in **e**, is approximately equal to the dynamic load current, 1.4A, multiplied by the output impedance, **c** (0.05 ohms) and **e** (0.10 ohms).

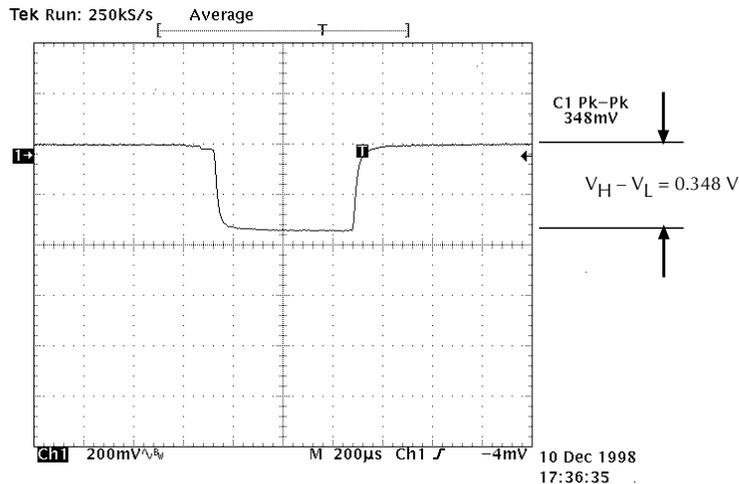
**Figure 13**  
Effect of variable output impedance control



**NOTE** Figure 13 contains the effect of the variable output impedance control of the Model 2306 on the current and voltage performance of a GSM handset.

Two methods are used to determine the impedance value of the cell or battery pack. The first method uses data from the battery manufacturer or another source and is simply entered into the Model 2306 from the front panel or over the GPIB bus. The second method involves a simple series of measurements as follows.

**Figure 14**  
*Voltage drop sample (with supplied Li ion battery pack)*



**NOTE** *Figure 14 shows the voltage drop during the transmit portion of the pulse with the supplied Li ion battery pack. See Figure 15 for the comparative illustration using the Model 2306.*

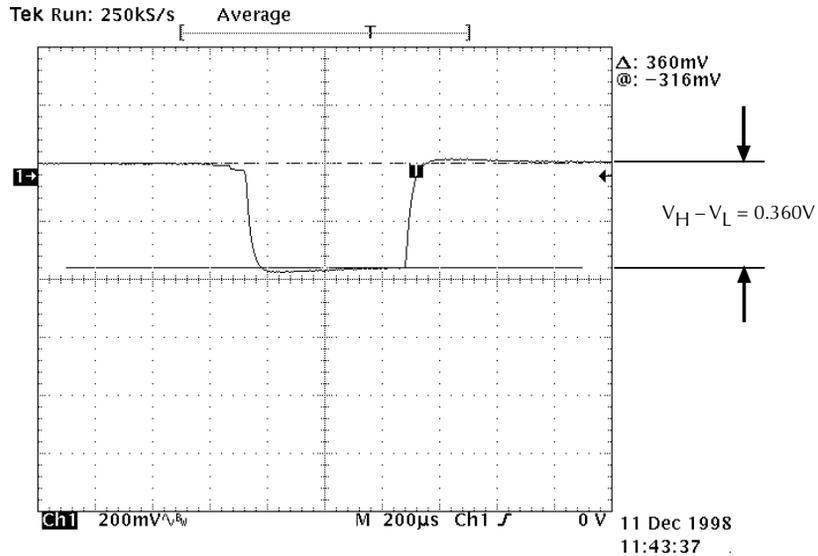
Figure 14 shows the transient voltage response at the battery terminals with the handset battery. Using Figure 14, the voltage drop during the transmit portion of the pulse of a GSM phone with the supplied Li ion battery is 0.348V. Using the pulse current mode of the battery channel the measured current during the transmit portion of the data frame is  $I_H = 1.536\text{A}$  and the idle portion of the data frame is  $I_L = 0.082\text{A}$ . To estimate  $R_i$  from the measured voltage, we use

$$R_i \cong \frac{V_H - V_L}{I_H - I_L} = \frac{0.348\text{V}}{1.454\text{A}} = 0.239\Omega :$$

Using this value for the output impedance setting in the battery channel, the voltage drop across the output terminals, as shown in Figure 15, is 0.360V. This value is in agreement, to within 3%, with the results obtained with the battery included with the handset.

**Figure 15**

*Voltage drop sample (with Model 2306 and output impedance set at 0.24Ω)*



**NOTE** *Figure 15 shows the voltage drop during the transmit portion of the pulse of a GSM phone using the Model 2306 battery channel with output impedance set to 0.24Ω. See Figure 14 for actual Li ion battery results.*

## Variable output bandwidth

Testing the performance of the battery charger circuitry in a handset does not require the high bandwidth performance in channel #1 or channel #2 of the Model 2306. Since a charger circuit is a voltage regulated circuit, it resembles a high capacitance load to the output of the Model 2306. For this type of application, the LOW bandwidth output mode provides increased stability and eliminates oscillations that may occur. The LOW bandwidth output mode is selectable from the front panel or over the GPIB bus of the Model 2306.

### Front panel operation for output bandwidth

The following settings are available in main menu under OUT BANDWIDTH #1,#2. Use the UP or DOWN keys to set the desired output bandwidth, either HIGH or LOW.

#### GPIB commands

Command	Description
:OUTPut:BANDwidth HIGH or LOW	‘ Bandwidth when the output state is ON and current range is set to 5A. When output is OFF, the bandwidth is LOW. When current range is 5mA, bandwidth is LOW.
:OUTPut2:BANDwidth HIGH or LOW	‘ Same as above, but for output channel #2.

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