Application Note

High-current Pulses for Battery Research

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Introduction

There are many different ways of testing batteries and battery materials to determine their characteristics. Traditional methods include long-term cycling to determine cycle life and capacity fade, electrochemical impedance spectroscopy (EIS) to internal resistance, capacitance and other characteristics, potentiostatic (and galvanostatic) intermittent titration techniques (PITT/GITT) for diffusion rates, leakage rates, and self-discharge. There are many others but these form the basis for a large number of tests.

Recently, there has been an interest in rapid, higher current pulsing of batteries. This is different than what you get when you test using an Urban Drive Cycle where you have a series of pulses to simulate start/stop driving during a normal car ride. These pulses are on the order of 100 µs to 100s of ms and can be used to stress a battery in ways that normal DC charging/discharging can't.

Gamry Instruments equipment has long been able to do these types of rapid, high-current pulses. One such example is the Reference 3000 potentiostat/galvanostat and Reference 30k Booster. Together, these two pieces of equipment let you pulse up to 30A on the order of 10s of microseconds. Now, just because our equipment can handle these types of demands doesn't mean your cell can. This application note is meant to show that our equipment can handle these demanding applications. It is up to you then to take it one step further and see if your cell can respond to these types of pulses.

Fig. 1. Reference™ 3000 (left) with Reference™ 30k Booster (right), with Test and Cal cell (green).

As a cell, we used our 30k Test and Cal cell. The 30k Test and Cal cell printed circuit board was carefully designed for:

- True four-terminal sensing on both the Test and Calibration sides of the Cell
- Minimal inductance in the current-carrying connections
- Minimal mutual inductance between the current-carrying and sensing circuits.

Gamry Instruments uses the Calibration side of the cell to galvanostatically measure impedance spectra at frequencies up to 300 kHz with less than 2° of phase error.

This Application Note shows results of our own research into the characteristics of our equipment.

Experimental

The tests were run on a Reference 3000 and Reference 30k Booster. A Gamry Reference 30k Test and Cal cell was connected to the booster in all tests. The cell connections used the standard cables supplied with the system: a 1 m current-carrying cable and a 1.5 m sense cable.

Most of the testing was done on the calibration side of the Test and Cal cell. This side is a 200 mΩ resistor with a 2.5 A fast-blow fuse in the counter electrode lead. The fuse protects the 1 W resistor from damage caused by excessive current flow. The resistance of a sample fuse was measured to be 34 mΩ. Fast current pulses larger than the 2.5 A fuse rating will not blow the fuse if the pulses are short enough.

The Test side of the Test and Cal Cell is a 3 mΩ four-terminal resistor. It does not require a fuse because it can safely pass 30 A currents.

Many tests were performed at different CA (control amplifier) speed settings. The faster the CA speed is, the better time-resolution is achieved, but at the cost of stability in the amplifier. For a review of potentiostat design, see our Fundamentals of a Potentiostat Application Note.

Some of the tests required the additional use of a Tektronix 2024C digital oscilloscope in order to show CA response. This was achieved using the by attaching the oscilloscope to the E or I monitor BNCs on the rear of the potentiostat.

Results

2 A Pulses on 200 mΩ Cell, Using the Framework™ Software

Fig. 2 below shows 2 A current steps lasting 200 µs each. Connections were made through the Reference 30k Booster, with the Reference 3000's 3 A full-scale range.

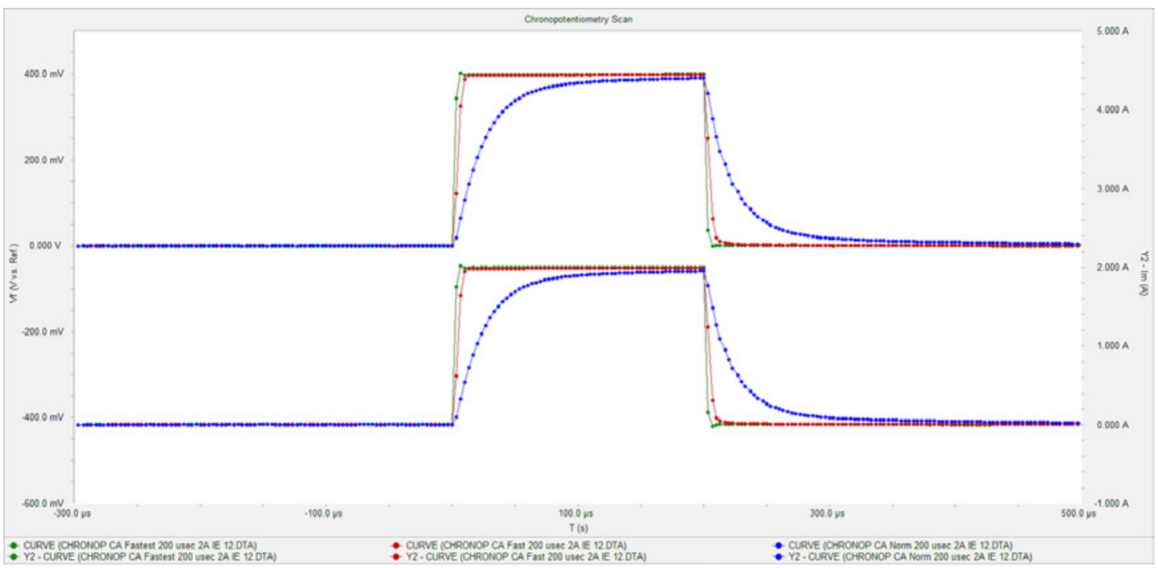

Fig. 2. The cell voltage is the upper trace, and cell current is the lower. Colors correspond to different control-amplifier speeds (CA speeds): green are CA speed **fastest**, (red) are CA speed **fast**, (blue) are CA speed **norm**.

Note the symmetry between the rising and falling waveforms. Charge lost from one edge of the pulse is recovered on the other edge.

Oscilloscope Data on 200 mΩ Taken from the E Monitor BNC

A BNC cable was connected between the Reference 3000 rear panel E Monitor output and the input of the oscilloscope.

Fig. 3 shows the voltage-versus-time curve of a 200 µs, 2 A pulse on the Calibration-side resistor. The graph was recorded in CA speed **fast**.

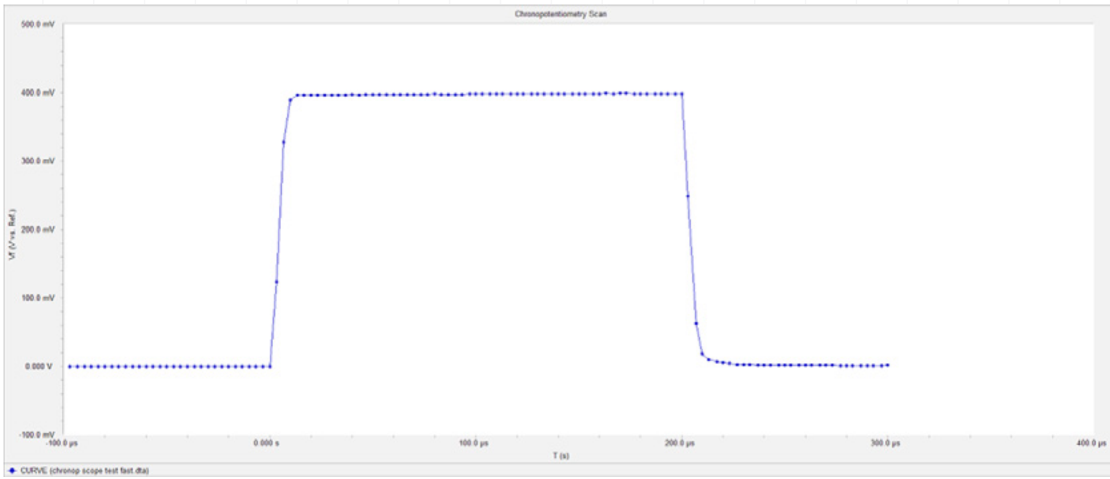

Fig. 3 Data recorded through the E Monitor connector.

The oscilloscope-screen capture (Fig. 4) shows a very similar waveform.

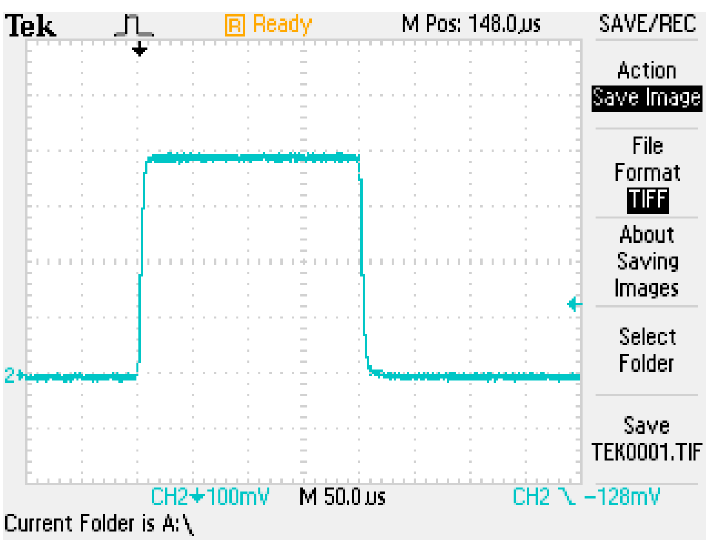

Fig. 4. Data recorded to oscilloscope under same conditions as Fig. 5.

Reference 3000 Booster Current Pulses on 200 mΩ

Here (**Fig. 5**) Gamry Instruments tested a range of current pulses. The smallest current of 2 A did not require the 30k Booster. The larger currents (4 A through 12 A) included the Booster. The curves show no evidence of slew-rate limiting.

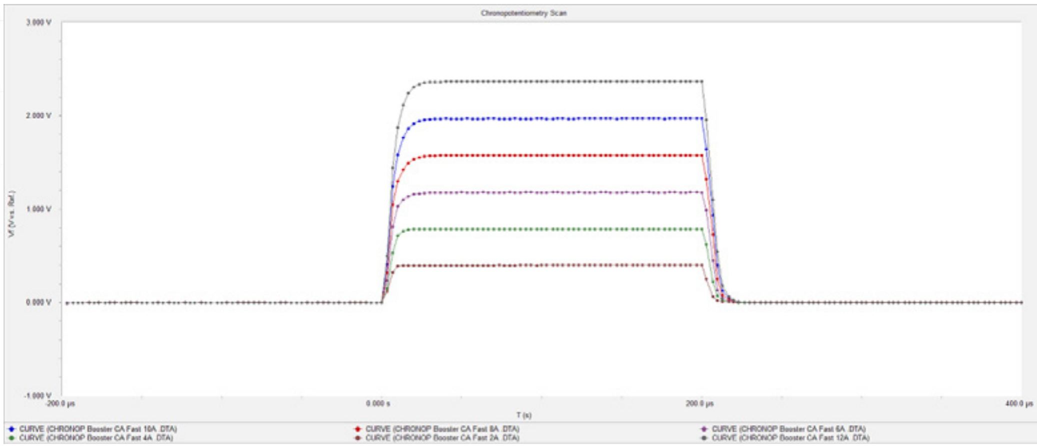

Fig. 5. Data from a range of currents. The lowest current (2 A) used no 30k Booster; the higher currents (4–12 A) added the Booster.

Fig. 6 shows the effect of CA speed on 8 A pulses. The blue curve was recorded with CA speed **fast** and red curve was recorded with CA speed **fastest**.

The red curve has a squarer response but ringing is seen on both the rising and falling edges.

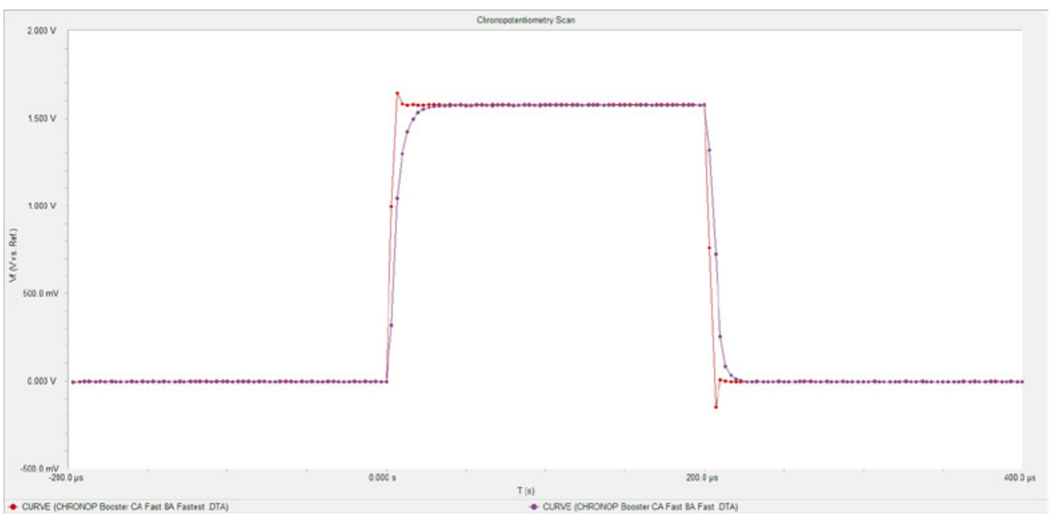

Fig. 6. Data at 8 A, using the CA speed **fast** (blue) and CA speed **fastest** (red).

The next curve (**Fig. 7**) shows 4 A and 8 A pulses in CA speed **fastest**. There is still no evidence of slew- rate limitations.

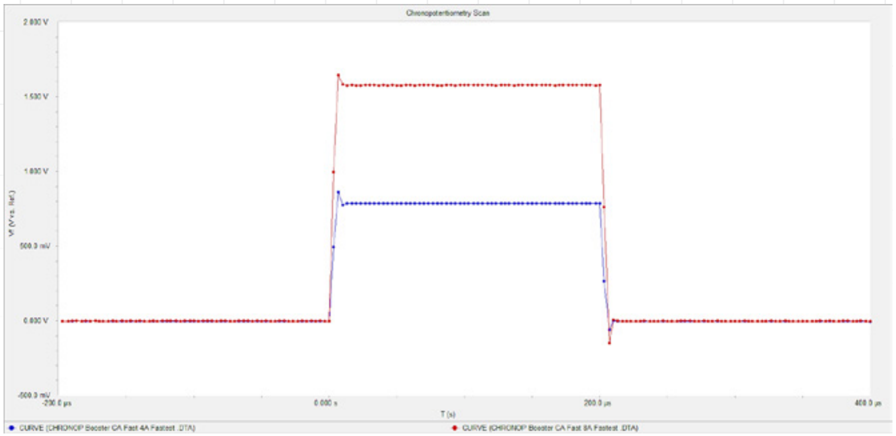

Fig. 7. Data using the CA speed **fastest** , comparing signal responses at 4 A (blue) and 8 A (red).

Results on a 3 mΩ Cell

The connections were switched to the Test side of the Test and Cal Cell. This side is a 3 mΩ, 4 W resistor. At 30 A, its power dissipation is only 2.7 W, so it is safe from misconnection and oscillation.

Fig. 8 shows 2 A pulses on this cell. Such current pulses always are applied with the Reference 3000. Voltage is on the top set of traces and current is on the bottom set. The trace colors correspond to CA speeds: green is **fastest**, red is **fast**, and blue is **norm**.

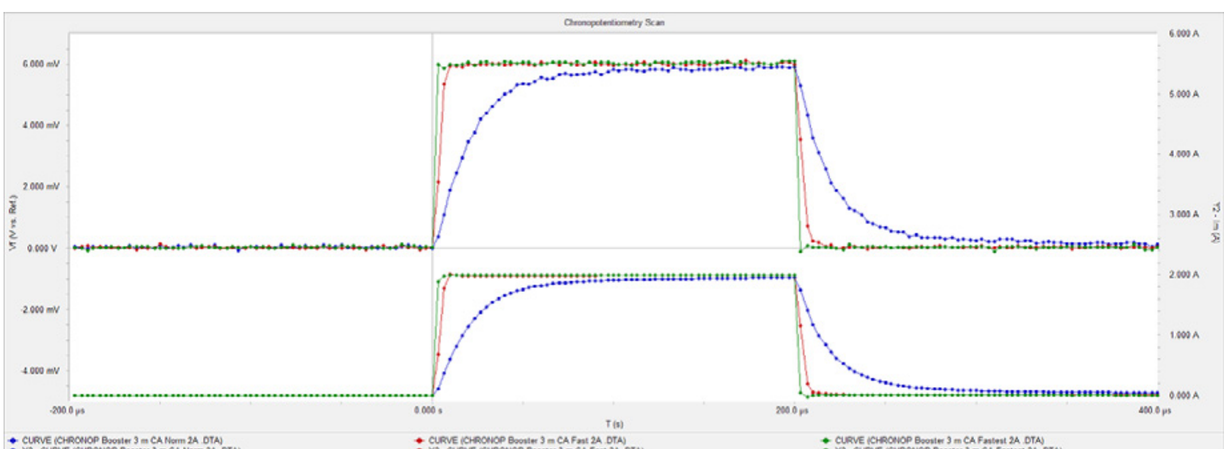

Fig. 8. Data on the Test side of the Test and Cal cell, from 2 A pulses, at CA speeds of **norm** (blue), **fast** (red) and **fastest** (green).

There is a slight indication of ringing in the fastest CA speed.

The next graph (**Fig. 9**) shows 4 A pulses on the Test side resistor at the different CA speeds. The trace placement and colors are the same as the plot above.

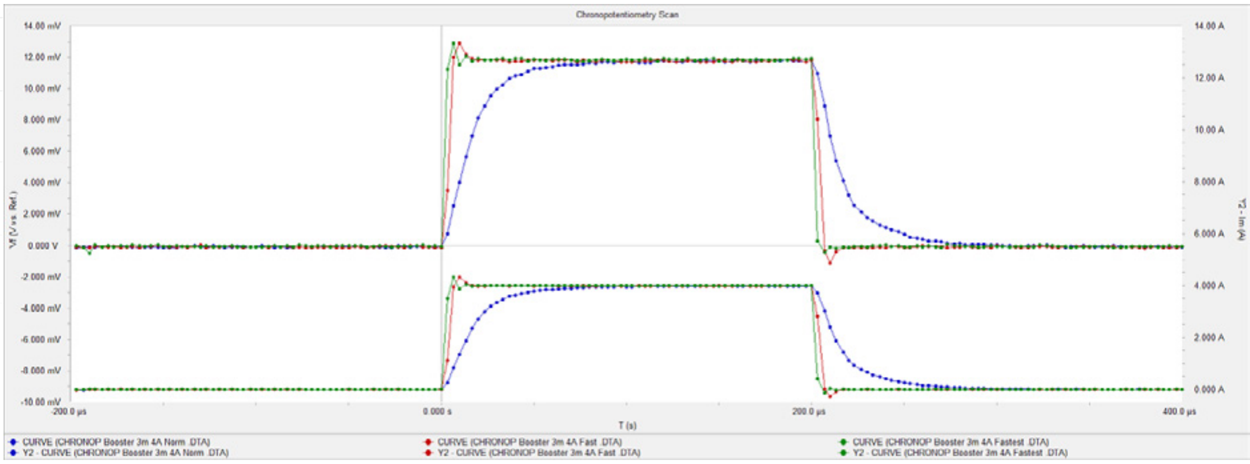

Fig. 9. Data on the Test side of the Test and Cal cell, from 4 A pulses, at CA speeds of **Norm** (blue), **fast** (red) and **fastest** (green). Top: Voltage; bottom: Current.

Both **fastest** and **fast** CA speeds show ringing in **Fig. 9**. The oscilloscope capture in Fig. 10 shows the **E Monitor** waveform for CA speed **fastest** and a 4 A pulse. Ringing is also visible here.

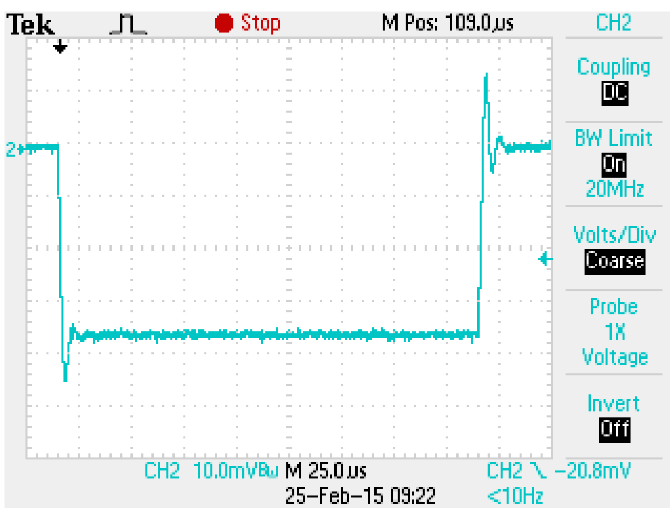

Fig. 10. Oscilloscope data on the Test side of the Test and Cal cell, from 4 A pulses, at the CA speed of **fastest**.

50 μs Current Pulses

Fig. 11 shows 50 μs 2 A and 4 A current pulses into the 200 mΩ Calibrate side of the Test and Calibrate cell. The green trace is a 4 A pulse in CA speed **Fastest**, the red trace is a 4 A pulse with CA speed **fast**, and the blue trace is a 2 A pulse at CA speed **Fast**.

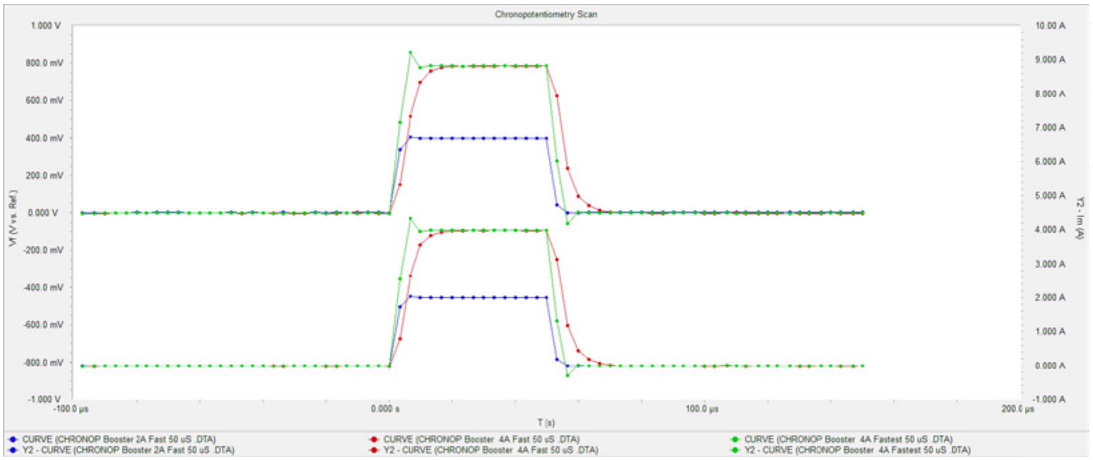

Fig. 11. Data on the Calibrate side of the Test and Cal cell, from 50 μs pulses, at 2 A (blue), 4 A **fast** (red) and 4A **fastest** (green). Top: Voltage; bottom: current.

Summary

Gamry's Reference 3000 and Reference 30k Booster can accurately and reliably generate current pulses as short as the high tens of microseconds.

As to which is the optimal CA speed setting, Gamry Instruments recommends that users run a preliminary test that measures the rise time on a typical cell prior to running a set of experiments.

Galvanostats generally become more stable when cells are capacitive. This effect was not measured in this application note.

Approximate rise times τ are shown in the Table below:

Instrument	Cell	τ for Fastest	τ for Fast	τ for Norm
Reference 3000	200 mΩ	$\tau < 6$ µs ringing	$\tau \approx 10$ µs	$\tau \approx 29$ µs
	3 mΩ	$\tau < 6$ µs ringing	$\tau \approx 7$ µs	$\tau \approx 23$ µs
30k Booster	200 mΩ	$\tau < 5$ µs ringing	$\tau \approx 7$ µs	$\tau \approx 17$ µs
	3 mΩ	$\tau < 2$ µs ringing	$\tau \approx 6$ µs	$\tau \approx 22$ µs

Additional Resources

If you need additional information, please visit our website for our online resources and support.

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A compilation of technical support information by hardware and software.

Software Updates
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