

High-current Pulses for Battery Research

Introduction

For those interested in determining the characteristics of batteries, especially by discharging them to see their changes in impedance, Gamry Instruments offers the Reference™ 3000 potentiostat plus our 30k Booster. This combination of instruments is useful for running stress tests on batteries, by applying rapid, high-current pulses singly or repeatedly.



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.

Most data were recorded using our signature Framework™ software. Some of the tests required use of a Tektronix 2024C digital oscilloscope instead.

Results

2A 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.

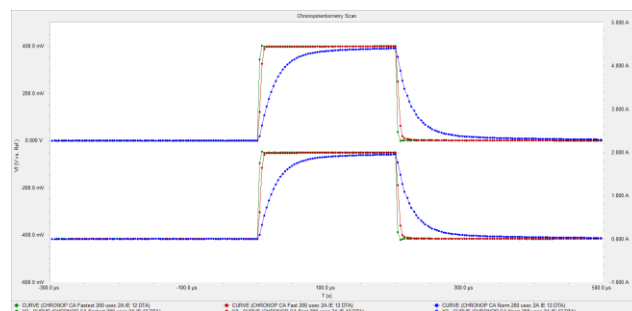


Fig. 2. The cell voltage is the upper trace, and cell current is the lower. Colors correspond to different control-amplifier speeds (CA Speeds): green are CA Speed **Fastest**, red are CA Speed **Fast**, and blue are CA Speed **Norm**.

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 m Ω 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 μ s, 2 A pulse on the Calibration-side resistor. The graph was recorded in CA Speed **Fast**.

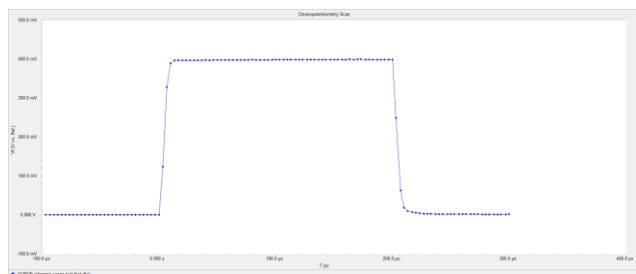


Fig. 3 Data recorded through the E Monitor connector.

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

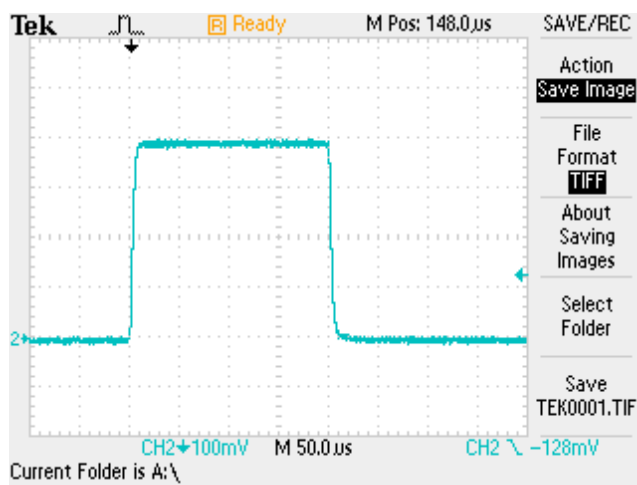


Fig. 4. Data recorded to oscilloscope under same conditions as Fig. 5.

Reference 3000 Booster Current Pulses on 200 m Ω

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.

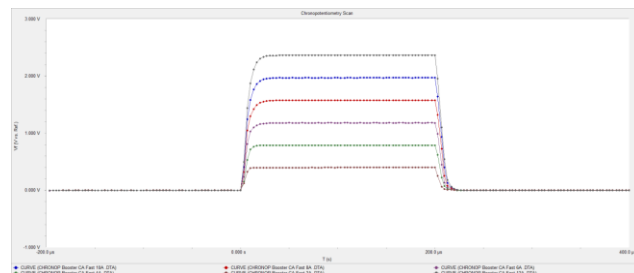


Fig. 5. Data from a range of currents. The lowest current (2 A) used no 30k Booster; the higher currents (4–12 A) added the Booster.

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.

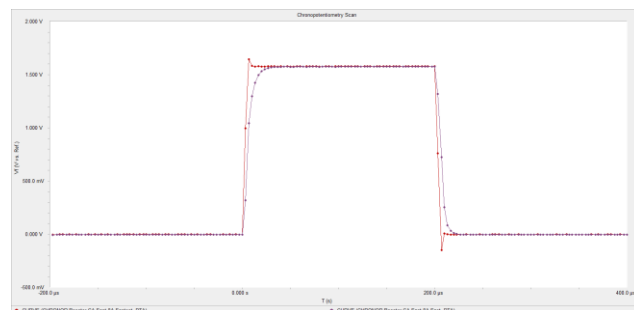


Fig. 6. Data at 8 A, using the CA Speed **Fast** (blue) and CA Speed **Fastest** (red).

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.

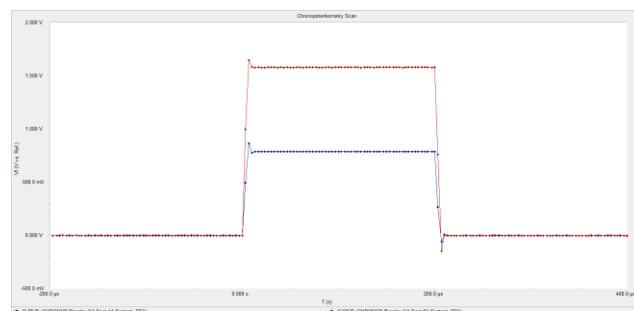


Fig. 7. Data using the CA Speed **Fastest** , comparing signal responses at 4 A (blue) and 8 A (red).

Results on a 3 m Ω Cell

The connections were switched to the Test side of the Test and Cal Cell. This side is a 3 m Ω , 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**.

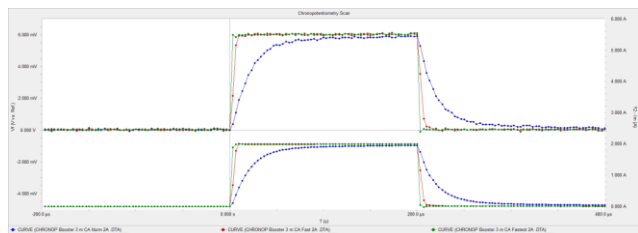


Fig. 8. Data on the Test side of the Test and Cal cell, from 2 A pulses, at CA speeds of **Norm** (blue), **Fast** (red) and **Fastest** (green).

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.

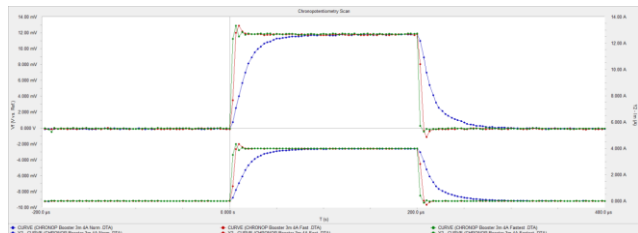


Fig. 9. Data on the Test side of the Test and Cal cell, from 4 A pulses, at CA speeds of **Norm** (blue), **Fast** (red) and **Fastest** (green). Top: Voltage; bottom: Current.

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.

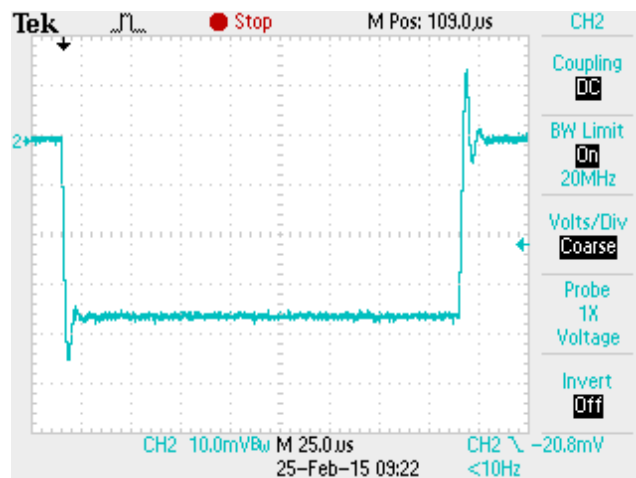


Fig. 10. Oscilloscope data on the Test side of the Test and Cal cell, from 4 A pulses, at the CA speed of **Fastest**.

50 μ s Current Pulses

Fig. 11 shows 50 μ s 2 A and 4 A current pulses into the 200 m Ω 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**.

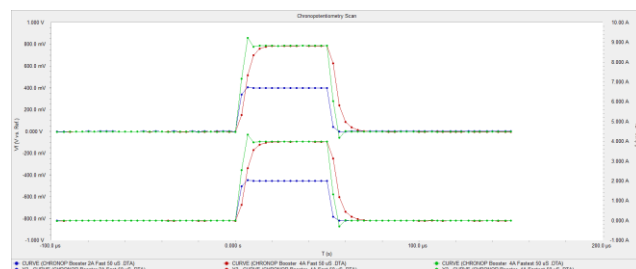


Fig. 11. Data on the Calibrate side of the Test and Cal cell, from 50 μ s pulses, at 2 A (blue), 4 A **Fast** (red) and 4A **Fastest** (green). Top: Voltage; bottom: current.

The charge lost in the slow rising edge is recovered in the slow falling edge.

30 A pulses

Gamry Instruments's equipment even allows you to pulse with 30 A current, as Fig. 12 reveals.

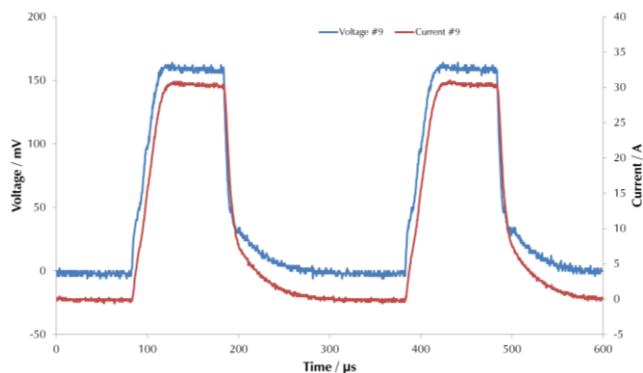


Fig. 12. 30 A pulses using the Reference 3000 and 30k Booster. Red trace is current; blue trace is voltage.

Summary

Gamry's Reference 3000 and Reference 30k Booster can accurately and reliably generate current pulses as short as the high tens of microseconds. Approximate rise times τ are shown in the Table below:

Instrument	Cell	τ for Fastest	τ for Fast	τ for Norm
Reference 3000	200 m Ω	$\tau < 6 \mu\text{s}$ ringing	$\tau \approx 10 \mu\text{s}$	$\tau \approx 29 \mu\text{s}$
	3 m Ω	$\tau < 6 \mu\text{s}$ ringing	$\tau \approx 7 \mu\text{s}$	$\tau \approx 23 \mu\text{s}$
30k Booster	200 m Ω	$\tau < 5 \mu\text{s}$ ringing	$\tau \approx 7 \mu\text{s}$	$\tau \approx 17 \mu\text{s}$
	3 m Ω	$\tau < 2 \mu\text{s}$ ringing	$\tau \approx 6 \mu\text{s}$	$\tau \approx 22 \mu\text{s}$

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.

Rev. 1.1 10/5/2017 © Copyright 2017 Gamry Instruments, Inc.



734 Louis Drive • Warminster, PA 18974 • Tel. 215 682-9330 • Fax 215 682-9331 • www.gamry.com • info@gamry.com