# High Fidelity Battery Measurements

There are many battery chemistries available and they are not all created equal. The discharge profiles and the impedances can be dramatically different. Some battery chemistries are more accepting of high current discharge while others are more suitable for long term “standby” applications. Improper application can result in severe damage to the batteries or the electronics connected to them.

While many engineers consider the first order approximation of a battery to be either a zero impedance source or an infinite capacitor, neither is true. Many batteries are “wound” devices, exhibiting both inductive and capacitive elements. In addition, the battery series resistance is often frequency dependent

Using a combination of Picotest and Omicron-Lab products, we can easily perform the following battery measurements as shown in Figure 1.

**Testing Steps**

- Extract the polynomial approximated discharge curve
- Scan up to 20 batteries, individual cells or temperature (using DMM Scanner Card)
- Measure the battery impedance from 1Hz – 40MHz
- Measure the battery dynamic transient domain response
- Create and perform discharge profiles using the Picotest G5100 Arbitrary Waveform Generator
- Converting an oscilloscope measurement to a Picotest G5100 Arbitrary Waveform Generator


**Equipment Used**

- Picotest M3500A 6.5 Digit DMM/Acquisition Unit
- Omicron-Lab Bode-100 Vector/Network/Impedance Analyzer
- Picotest J2111A Solid State Current Injector
- Agilent DSO60104A High Speed Digital Storage Oscilloscope (DSO)
- Picotest G5100A Arbitrary Waveform Generator

**Figure 1 – Battery used for testing the 9.6V, 700mAh Ni-Cd and the other is a 3.7V 110mA Li-Po battery**

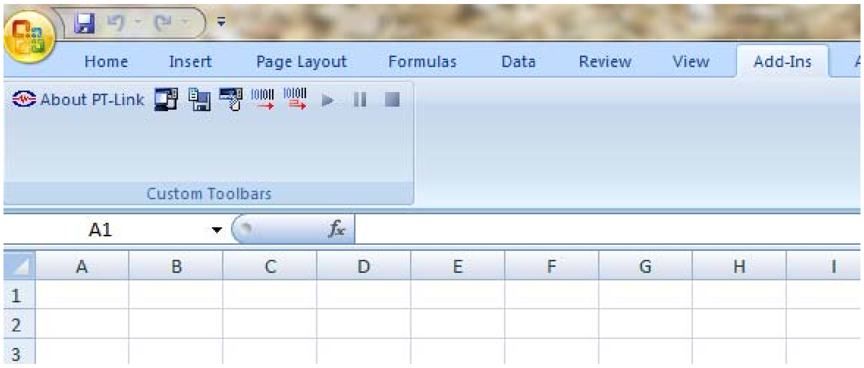
In this application example, two readily available hobby batteries are used to demonstrate the battery measurements. One battery is a 9.6V, 700mAh Ni-Cd and the other is a 3.7V 110mA Li-Po battery.

**Figure 1 – Three types of step load responses**

### *Discharge Profile*

The M3500A 6.5 Digit DMM is not only one of the highest stability meters available, but combined with an optional 10 channel or 20 Channel scanner card, the meter also serves as a data acquisition unit.

The M3500 has the ability to operate directly inside EXCEL, with user defined sample rate and also total recording time.  The number of measurements is only limited by EXCEL.



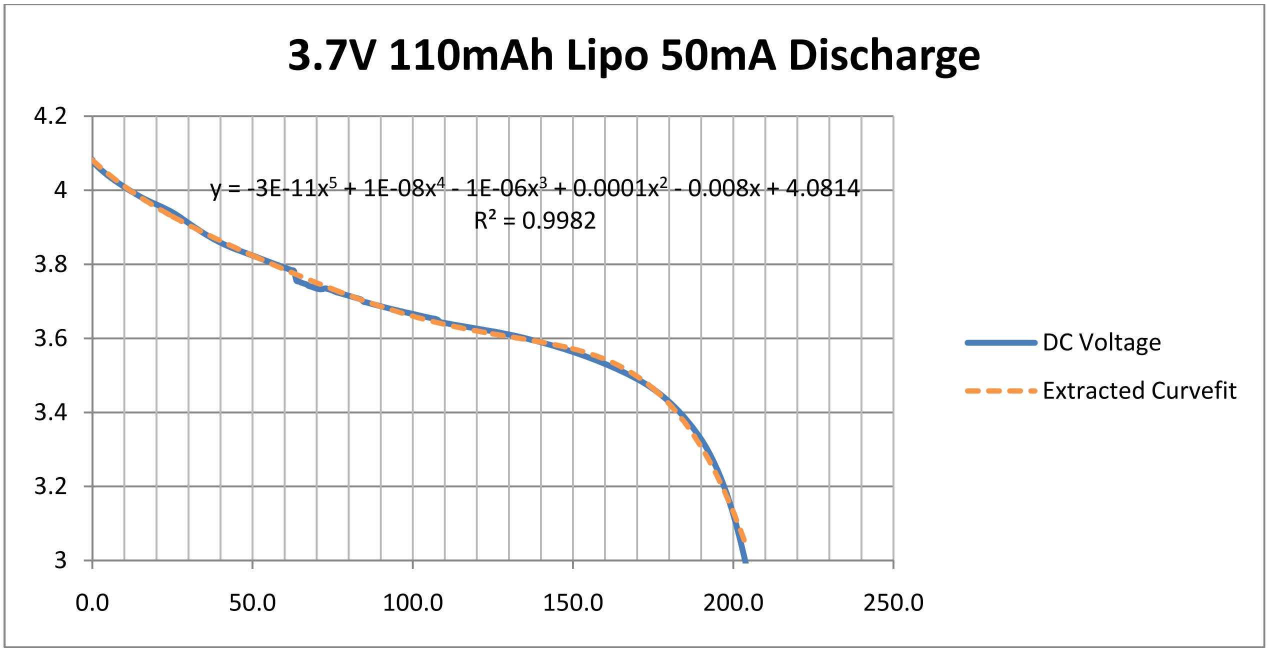
PT-Link Allows the M3500A functions to be directly accessed in EXCEL

| Time | DC Voltage |
|---|---|
| 21:30:18.000 | 10.0267256 |
| 21:31:18.000 | 9.98231488 |
| 21:32:18.000 | 9.95211968 |
| 21:33:18.000 | 9.92569728 |
| 21:34:18.000 | 9.90567296 |
| 21:35:18.000 | 9.88570112 |

| | |
|---|---|
| **Start Time** | 2010/7/29 21:29:18 |
| **Interval** | 00:01:00.000 |
| **Stop Time** | 2010/7/30 21:29:18 |
| **Samples Completed** | 647 |
| **Last Point on Chart** | 647 |

*Discharge Profile Curvefit*

The M3500A PT-Link software also automatically generates a graph of the recorded data



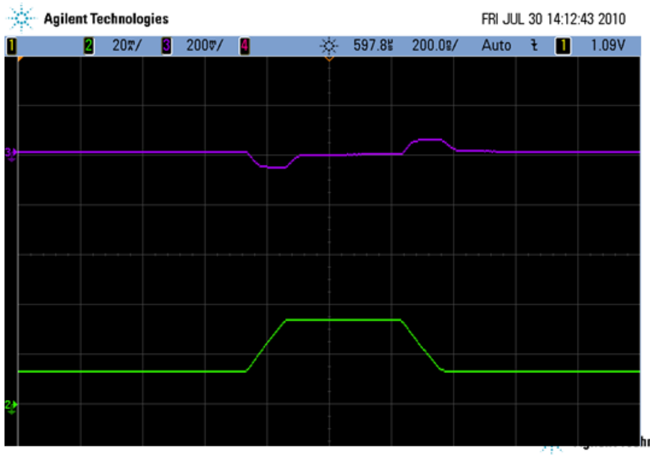

3.7V 110mAhr Li-Po Battery (E-Flite) Voltage vs Discharge Time (in Minutes)

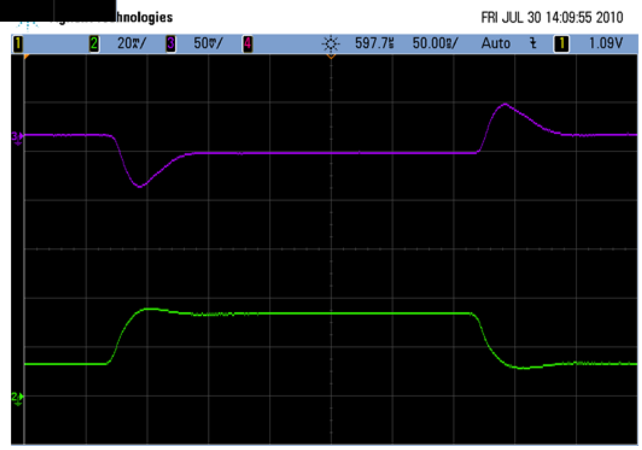
Once in EXCEL, the curvefit can be directly extracted using the EXCEL trendline function. This discharge curve shows the battery voltage in 30 second increments for a duration of approximately 200 minutes. The polynomial curvefit and the regression coefficient, automatically determined within EXCEL, can be added to the graph and all EXCEL graph formatting tools can be applied.

*Battery Dynamic Transient Domain Measurement*

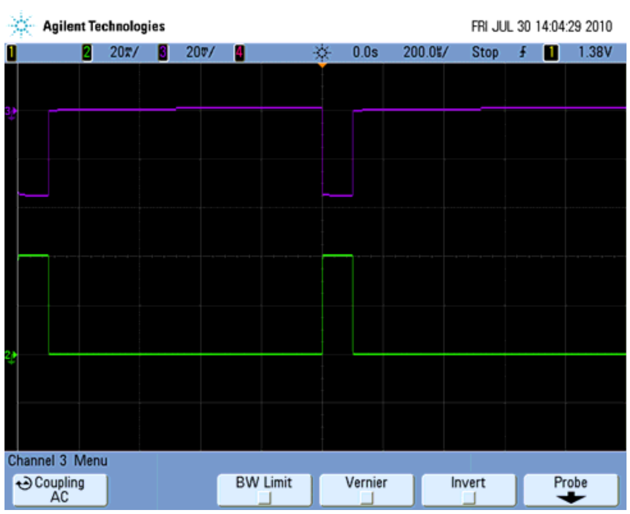
The current injector, which we also used as a load, can be modulated by either the Picotest G5100A Arbitrary Waveform Generator or the Omicron-Lab Bode-100 Network/Impedance Analyzer, allowing the battery impedance to be measured in either the time domain (transient measurement) or in the frequency domain. The current injector has a usable bandwidth of DC-40MHz, which is much faster than an electronic load, allowing the high frequency parasitic effects to be portrayed.

Using the PICOTEST G5100A to control all aspects of the current waveform, the battery current was pulsed approximately 20mA and the battery voltage was viewed using an Agilent DS060104A 1GHz Digital Storage Oscilloscope (DSO). The current injector has a typical rise time of 20nS. Comparing the 20nS risetime with a 100nS rise time reveals the significance of the injector speed.




3.7V 110mAhr LiPo Battery (E-Flite) 20mA current pulse 20nSec vs 100nSec

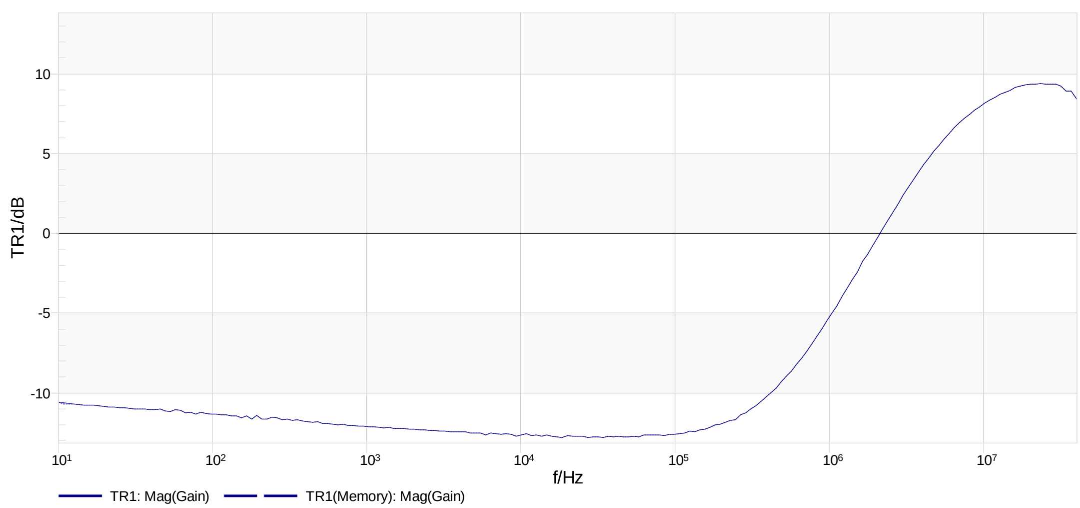



Measured at lower speed, the second order parasitic effects are not evident (though they can still damage our circuits)

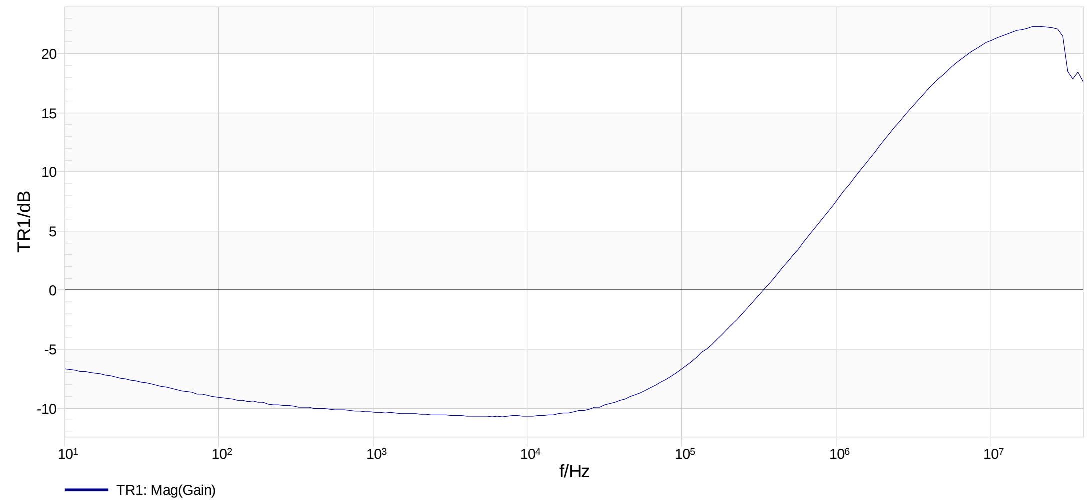
9.6V 700mAh Nicad Transient showing 40mA step with 20nS edge and higher resistance than the Li-Po Battery

*Battery Impedance*

The current injector includes a selectable 25mA internal offset current so that it can be directly connected to the Network Impedance Analyzer. The current injector provides a high fidelity, 50 Ohm current monitor signal allowing a direct coax connection of the current signal to the Analyzer. Channel 2 of the Analyzer measures the battery voltage, so that the resulting division (Gain) is the battery impedance. Depending on the connection from the battery to the current injector and the impedance of the battery, a differential probe maybe advisable to eliminate the cable effects of this interface.



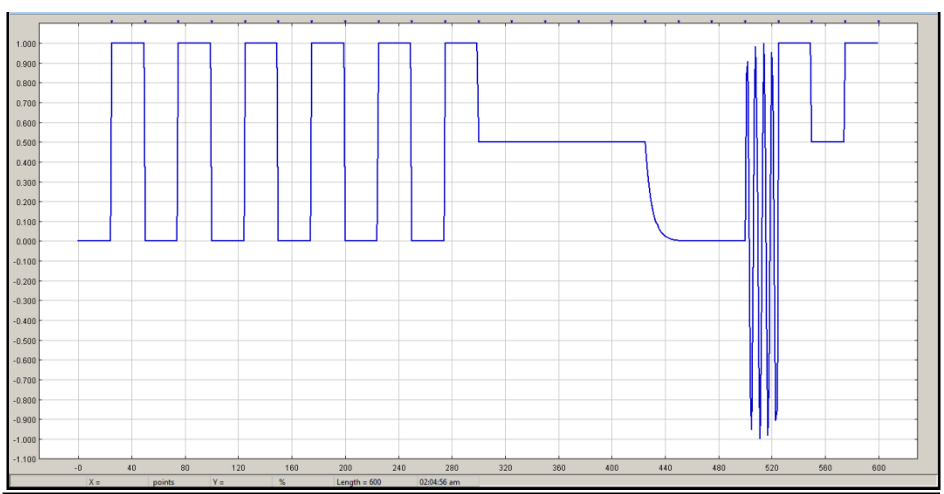
3.7V 110mAhr LiPo Battery (E-Flite) Impedance at 25mA operating current (Full Charge)




9.6V 700mAhr Ni-Cd Battery Impedance at 25mA operating current (Full Charge). Note the much higher resistance, despite the much larger battery size, of the Ni-Cd chemistry

From these measurements we can see that the impedance is frequency dependent, even at lower frequencies that are well below the resonance. We can also observe the inductance and capacitance of the battery.

Finally, the Arbitrary Waveform Generator can be used to simulate a load profile for either the discharge curve or the impedance. The Picotest WavePatt software was used to generate the following load profile, using predefined segments. The PICOTEST G5100A can also import a measured waveform from some oscilloscopes, save it as an AWG file, and then use this measured load profile to control the current injector.

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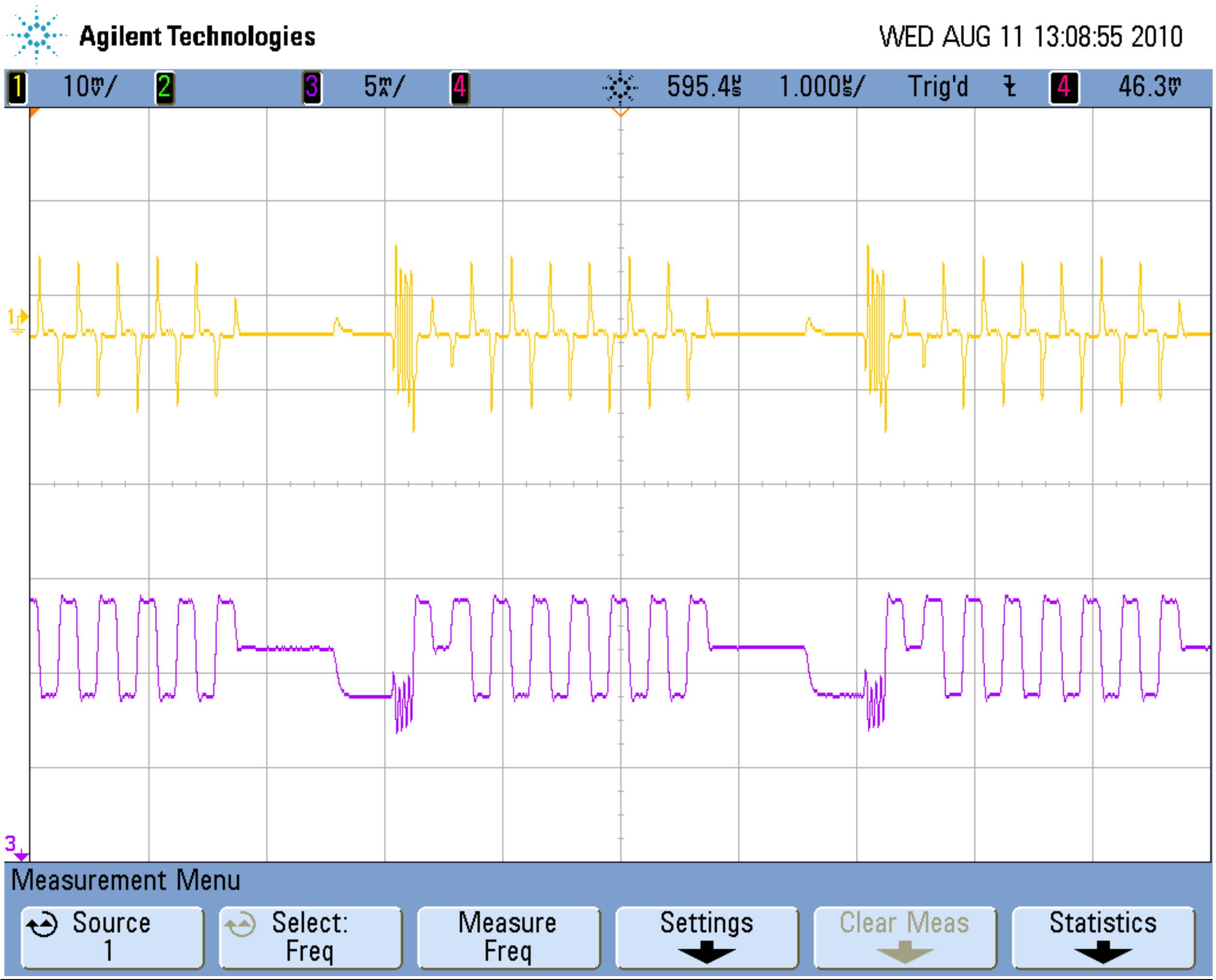


We don't need to get to work on this

*Conclusion*

The combination of the Picotest J2111A Solid State Current Injector, the Picotest G5100A AWG and the Omicron-Lab Bode-100 allowed us to measure potentially damaging effects of battery parasitic elements which would not be seen with lower fidelity equipment.

We successfully measured and curve-fitted the battery discharge profile and measured both the dynamic transient impedance and the frequency domain impedance. These parasitic elements can be incorporated into simulation models to properly reflect the potential effects.

We also demonstrated the combination of the AWG and the Picotest Solid State Current Injector to simulate the performance of a particular load profile.

## About the Authors

*Steve Sandler is the founder and chief engineer of AEi Systems, where he leads development of high-fidelity simulation models for all types of simulators as well as the design and analysis of both power and RF systems. Sandler has over 30 years of* *experience in engineering and is a recognized author, educator and entrepreneur in the areas of power, RF and instrumentation.*

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