# Battery Ohmic Measurement Methods Revisited

Modern Circuit Analysis Techniques Prove Efficacy of Impedance Measurements

By Joe Rocci & Walt Wilczewski
Phoenix Broadband Technologies

**Overview:**

"Ohmic Measurements" have become a mainstay of modern battery-plant maintenance practices. The basic method consists of instrumentation which forces a known current through a cell and measures the cell's voltage response to the current. In an ideal cell with infinite current producing capability, the terminal voltage would be invariant to the forcing current. In the real world, cells have current producing limitations which can be analyzed as spurious internal resistances and capacitance. An increase in a cell's equivalent internal resistance is well known to correlate directly to a corresponding decrease in the cell's amp/hour capacity. Since steady declines in amp/hour capacity are a leading indicator of the approaching end of the cell's life-cycle, accurate ohmic measurements made by portable instrumentation or fixed monitoring systems can be a very valuable component of a pro-active battery maintenance program.

**Background:**

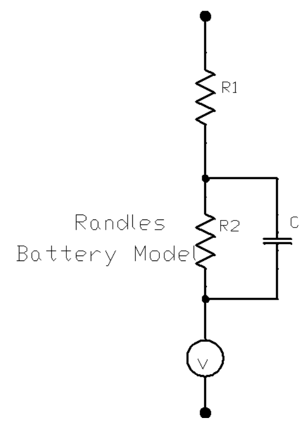
There are several common forms of ohmic measurements. A full-load test made with a load-bank and computerized logging software is universally accepted as the "gold standard". However, load-bank testing is expensive, intrusive, leaves the cells in a discharged state, and subtracts from the cells' limited lifetime number of discharge cycles.

Portable instruments of several forms are available for measuring battery condition. The most basic instrument is the inexpensive portable load tester of the type used by most auto repair garages. These devices produce a discharge DC current of 25-100 amps for several seconds, displaying the cell voltage on a meter during the discharge process. Although inexpensive, these instruments require heavy-duty clamp-on connections to the battery terminals which are difficult to obtain in many dense battery-plants, and they discharge the cell significantly during the testing process. Some manufacturers have developed expensive (>$5,000) portable instruments with extendable probes to contact the cell terminals, and which use short-duration pulses of moderate DC load current to characterize the cell's condition and report the "internal resistance". Another type of expensive portable instrument excites the cell with a low-level, low frequency AC current and analyzes the resulting AC voltage change in a complex vector voltmeter" to extract just the resistive component of the cell's complex resistive-capacitive internal properties. This measurement is commonly called "conductance" testing, and has gained widespread acceptance. Yet other measurement instruments excite the cell with a known low-level AC current, measure the resulting AC voltage variation on the cell's terminals, and display the result as the cell's composite "impedance". This latter measurement technique can be implemented very cost-effectively, leading to availability of cost-effective remote monitoring systems, but the efficacy of the implementation is very dependent of the AC testing methodology.

The remainder of this paper will explain the internal resistance-capacitance properties of a lead-acid cell, the factors which influence the accuracy of AC measurements, invalid objections to AC measurements made by manufacturers of expensive DC-based instrumentation, and an accurate comparison of DC and AC test methods using modern circuit-analysis software.

**The Cell Equivalent Circuit**

A battery cell exhibits performance properties that allow it to be characterized and analyzed by an equivalent circuit of components. The most commonly used cell model is the "Randles" model shown at the right.




In this model, a perfect DC voltage source is combined with some spurious resistances and capacitance which make the cell's performance non-perfect. V1 is a perfect voltage source, typically 2.1VDC per cell. R2 is a component of the cell's total internal resistance due to the non-ideal electrochemical process. R1 is a component of the cell's internal resistance due to the metallic straps and connections inside the cell. C is an equivalent capacitance that represents the cell's voltage inertia responding to changes in DC load current. In a typical lead-acid cell, R2 is about 45% of the total resistance and R1 is 55% of the total. The value of C is typically 1.5F (farad) per 100 amp/hours of cell capacity. As might be expected, The values of R2 and C change directly with aging of the cell's amp/hour capacity, while R2 remains relatively constant unless the internal metallic connections deteriorate.

**AC vs. DC Measurements**

There has been some controversy about the affect that C has on measurements made using AC techniques. The claims, made primarily by Alber (a manufacturer of test systems using DC techniques), are that AC measurement of changes in the R2 component are masked by the very large value of C that shunts it. Alber has published a paper (*"Ohmic Measurements: The History and the Facts"; http://alber.com/Docs/AlberPaperFINAL2003.pdf , delivered at BattCon, March 2003*) that presents a comparison of DC and AC test methods, along with a mathematical analysis of their assertions. Phoenix Broadband has re-visited this comparison using modern circuit analysis software. Our analysis results indicate that the arguments against AC test methods made by Alber are without basis, including the following deficiencies in their analysis:

- Numerous basic arithmetic errors
- A overly simplistic mathematical circuit analysis
- Invalid assumptions about competitive test methods
- Failure to account for basic properties of battery physics

The results of the Alber calculations are summarized in the following chart, which shows the R1 and R2 measurement errors at two different measurement frequencies, 60Hz and 200Hz:

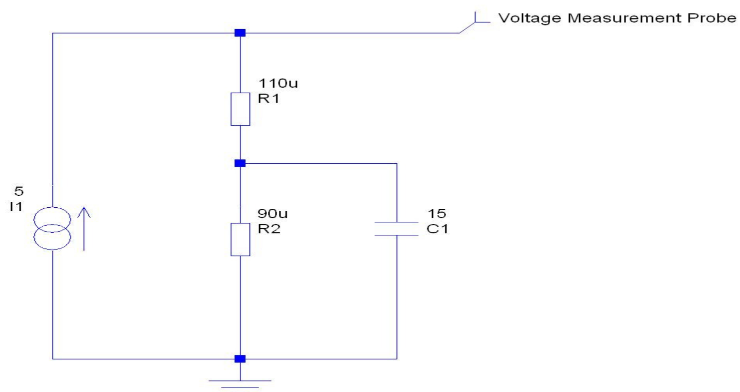
| Test Freq. | Cell Failure | $R_{Tot} = R_1 + R_2$ (μΩ) | % change $R_{Tot}$ from baseline | $X_C$ (μΩ) | $Z_{Tot}$ (μΩ) | % change $Z_{Tot}$ from baseline |
|---|---|---|---|---|---|---|
| | | | | | | |
| 60 | None | 200 | 0 | 177 | 185 | 0 |
| 60 | $R_2$ > 140 | 250 | 25% | 177 | 208 | 12% |
| 60 | $R_1$ >160 | 250 | 25% 870×415 | 177 | 234 | 26.5% |
| 60 | $R_2$ >190 | 300 | 50% | 177 | 220 | 19% |
| | | | | | | |
| 200 | None | 200 | 0 | 53 | 139 | 0 |
| 200 | $R_2$ >140 | 250 | 25% | 53 | 135 | -2.2% |
| 200 | $R_1$ >160 | 250 | 25% | 53 | 187 | 35% |
| 200 | $R_2$ >190 | 300 | 50% | 53 | 133 | -4% |

The first type of flaw in the Alber analysis are arithmetic errors. The values highlighted in red differ from results obtained from Alber's own formulas by as much as 10%.

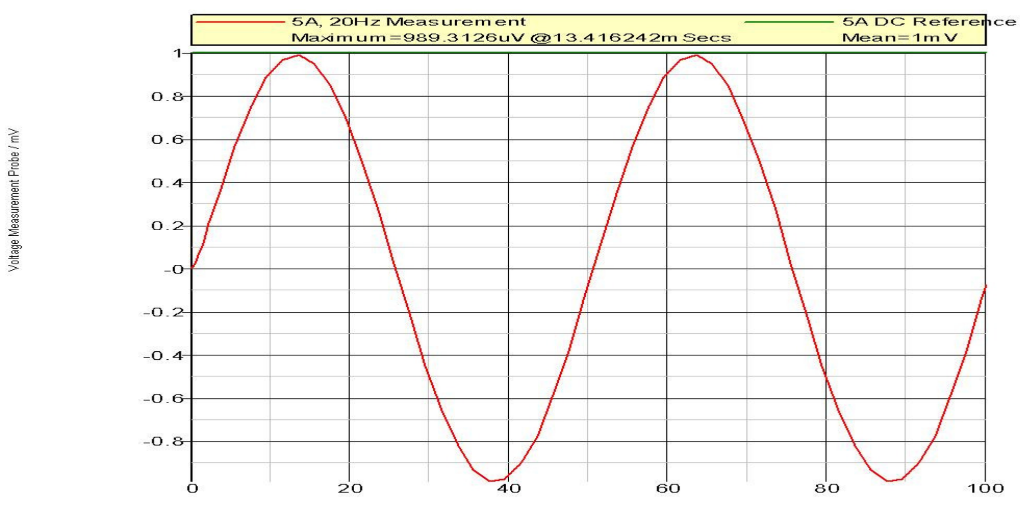
The second flaw in the analysis is the assumption that C is invariant, even as R2 changes. Basic battery physics, confirmed by leading battery manufacturers, teaches that C will vary inversely with R2, in near direct proportion to cell capacity (amp/hours). Thus, when cell deterioration causes an increase in R2, it is accompanied by a decrease in C and greatly reducing the "masking" effect of C.

The third flaw in the Alber argument concerns competitive test methods. Well designed, modern AC ohmic measurement equipment employs test signals in the 20Hz range, so the reactance of capacitor C isn't nearly as significant as it is at 200Hz, or even 60Hz, as analyzed in the Alber document.

The final, and most telling rebuttal of the Albert criticisms of AC testing are revealed by using a modern computer circuit analysis program to gain accurate insight of the facts. The charts below were made with SPICE, a universally accepted circuit analysis program with over 40 years deployment and refinement. The battery circuit was modeled using the Randels model and the internal parameters in the Alber document. The exciting test current was modeled as a 5amp current source at various frequencies from DC to 200Hz. A voltage test probe was connected to the battery terminals to indicate the measured voltage produced by the test current. Any test current could be assumed without affecting the accuracy analysis.

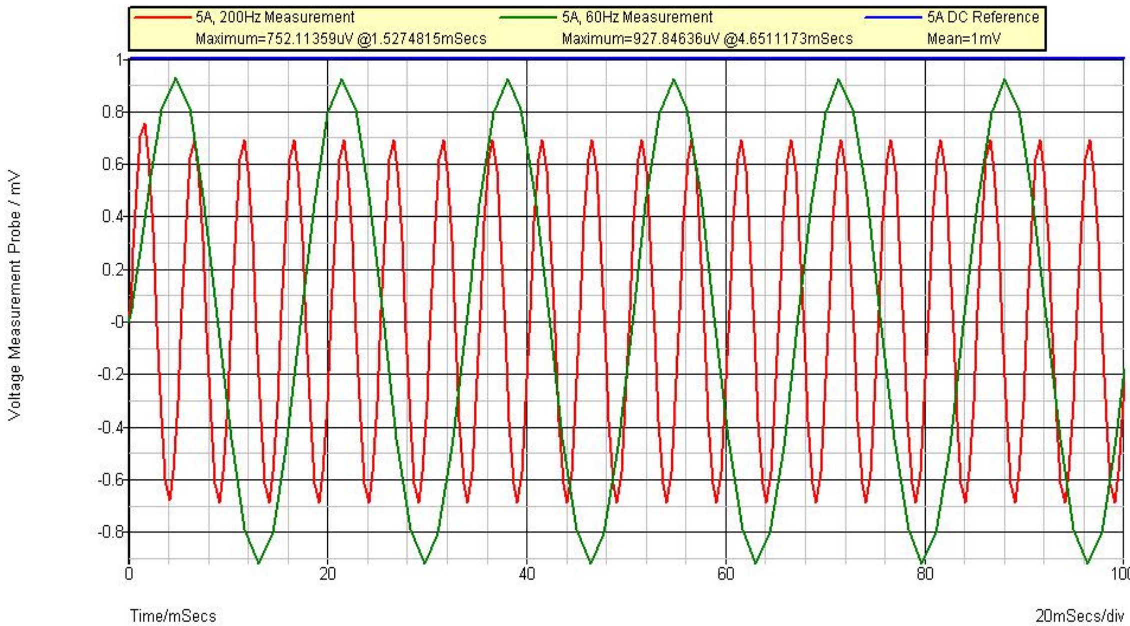



The plot below shows a plot of the measurement with a DC current source, superimposed with a plot of the measurement with a 20Hz AC current source.:



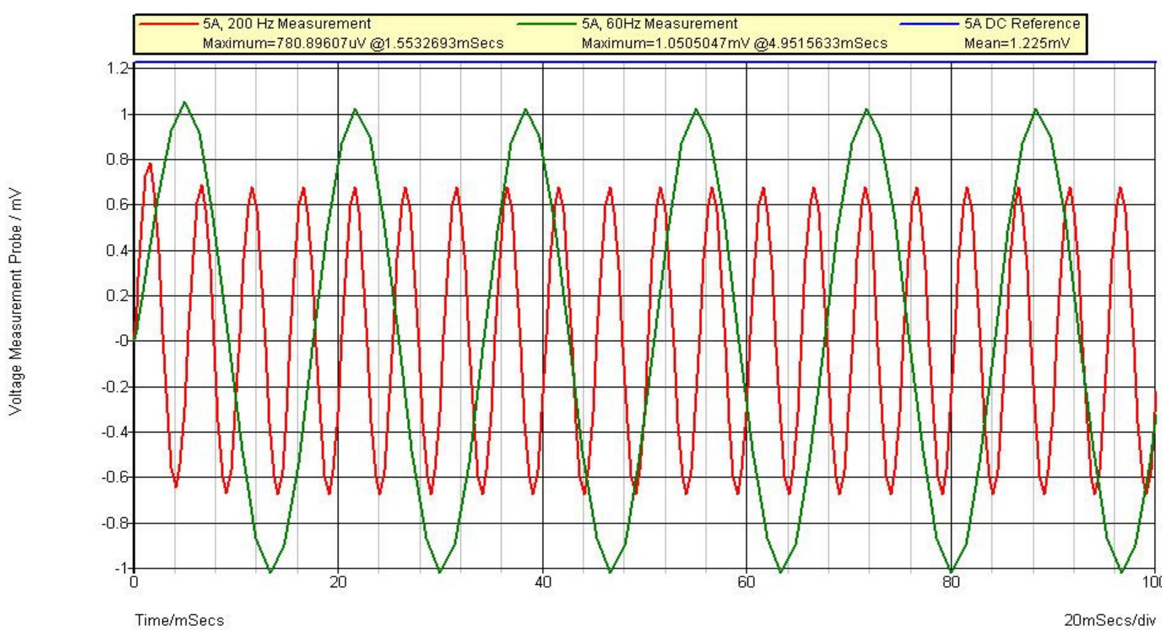

The legend indicates the mean value of the DC test signal and the peak value of the AC signal. The errors, about 0.1% are not discernable.

The plot below is the same test, run with AC test signals of 60Hz and 200Hz:



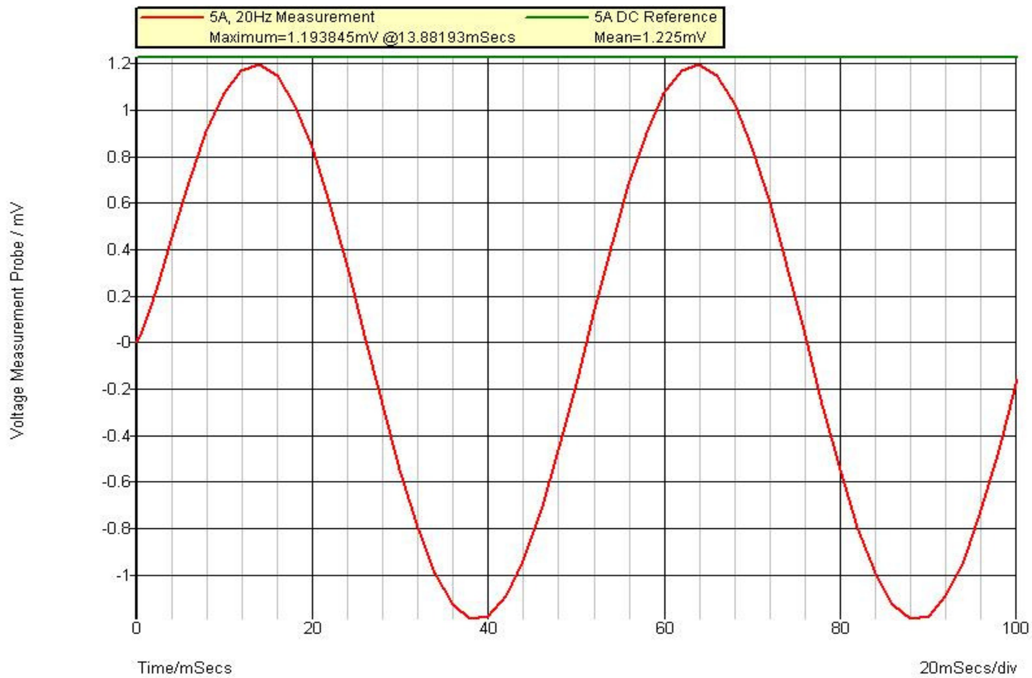

From the legends, we can see that the 60Hz error is about 1%, while the 200Hz error is about 25%.

The chart below, run at 60Hz and 200Hz, shows the measured result of changing R2 by 50%:




The measurement error at 60Hz is about 14%, while the error at 200Hz is about 35%

This final chart shows the same analysis as above, except that it was run with a test frequency of 20 Hz.




The measurement error at 20Hz is about 2.5%. Phoenix Broadband's PowerAgent Battery Monitoring System uses a digitally synthesized sinusoidal test frequency of 20Hz, together with hardware bandpass filtering and synchronous sampling digital signal processing for outstanding performance in high noise environments.

**Conclusions:**

AC test techniques to measure battery cell ohmic properties can be every bit as accurate as DC techniques. The accuracy of the measurements is a function of the test frequency employed, but this only becomes a significant factor with test frequencies well above 60

Hz.