

Automotive “Smart” Battery with State of Health Conductance Testing and Monitoring Technology (onGUARD[®])

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ABSTRACT

This paper will detail the development and validation of the world's first integrated smart automotive lead-acid battery tester. As today's automobiles add more electronic and electrical systems to the vehicle the need for reliable battery power is more important than ever. The need to determine the battery's functional life span has demanded a product to reliably test the battery's state of health (SOH).

After two years of development backed up by over 17 years experience in testing lead acid batteries, onGUARD[™] delivers the ability to accurately test and predict the batteries life expectancy.

The paper details the elements behind the smart tester technology and its ability to measure the battery's voltage, temperature and conductance to accurately diagnose the health of the battery. A background of conductance testing technology and its approach to measuring the health of a battery by measuring the internal resistance of the battery is included. The benefits of conductance as a safe and accurate alternative to load testing in determining the Cold Cranking Amps of a battery are included.

The mechanical configuration of onGUARD will be described, as it presently is available in two platforms. One platform is fully integrated into the battery, designed for a specific manufacturer's battery. A second is an external sensor module, which can be applied to any lead acid battery in the 300 to 1500 CCA range. The integrated onGUARD model is designed to fit inside a battery lid connected internally to the battery's posts. The onGUARD unit can be programmed to specifically test a particular battery after a battery characterization has been established, and this process will be explained. The aftermarket onGUARD unit is a universal model to be attached to the outside case of the battery. The customer interface process of pushing and holding a pushbutton on the onGUARD unit perform measurements, and a display of test results as shown by a simple series of LEDs (A pattern of green, yellow and

red LEDs indicate the batteries state of health) will be included.

A full-production lead-acid SLI automotive battery will launch in October 2002 in Japan featuring an integrated onGUARD conductance test module with SOH and voltage state of charge (SOC) diagnostics. This paper provides some technical details of that platform, and as onGUARD has application in automotive, marine and battery backup power systems, a brief mention of potential benefits from the integration of additional technologies is also presented.

INTRODUCTION

Automotive battery diagnostics historically have derived from discharge testing or load testing measurements. A fixed current discharge is timed and a voltage threshold is set and the resulting timed-discharge test is interpreted for battery capacity. Over the past 15 years, a simpler, quicker and safer technology has emerged as an OEM standard for battery diagnostics and testing. Conductance technology, or Ohmic testing, debuted as a service tool in 1994 With FORD MOTOR CO. and today every major global automotive OEM utilizes conductance testing technology for battery diagnostics in production, distribution, dealer service, and/or warranty programs.

Conductance testing technology research is featured in over ten years of technical papers and presentations. In 1992, Atlas Testing Laboratory correlated conductance tests on over 400 field battery samples. The batteries were deconstructed to chemically and physically verify the conductance testing results, and the correlation for battery “failures” as diagnosed with conductance testing was 97%.¹ Midtronics presently holds 66 patents in the area of battery conductance testing, with another 30 patents pending.

Introduction of conductance testing technology into the battery itself effectively creates a revolutionary “smart” lead-acid battery with simple, quick, safe and accurate on-board diagnostics.

MAIN SECTION

CONDUCTANCE TECHNOLOGY

To summarize previous SAE technical papersⁱⁱ a battery’s measured conductance correlates linearly with its ability to deliver current. As conductance declines over time or due to other faults, so does a battery’s ability to meet its specified capacity and supply energy. A major benefit to utilizing conductance is the ability to calculate a battery’s capacity without performing an extensive discharge or load test.

Conductance measurements are created by the insertion of a low level AC signal, which is inherently passive and does not cycle or age the battery, as displayed in Figure 1, where:

1. A low voltage A/C Signal is Impressed across the battery terminals (VAC)
2. The A/C Current (IAC) Response is measured
3. Conductance (G) is calculated using Ohm’s Law: $G = IAC/VAC$

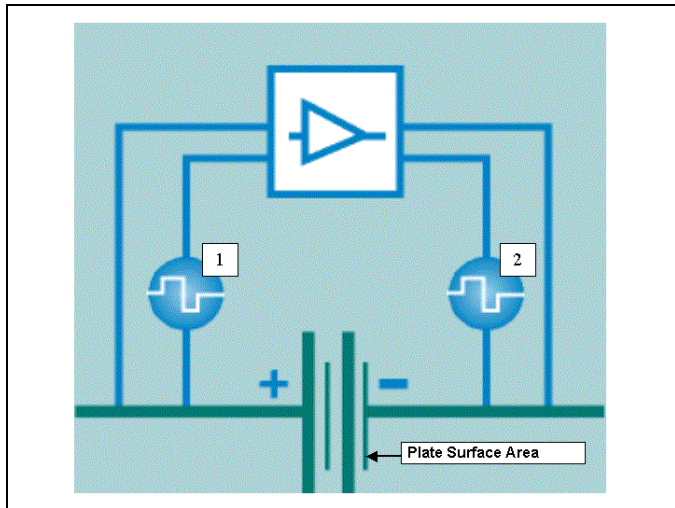


Figure 1: Basic Conductance Measurement Circuit

In the automotive industry, conductance is measured in CCA (cold crank amperes) from a scale of approximately 100 to 2000 CCA, where CCA is also convertible to DIN, EIn, JIS and other country’s standards or benchmarks.

Figures 2 and 3 show the relationship of resistance and conductance with regards to discharge voltage. In Figure 2, note that the measured increase in battery resistance is linear with the decrease in discharge voltage, where in Figure 3 the relationship is converse, but equally as correlative.

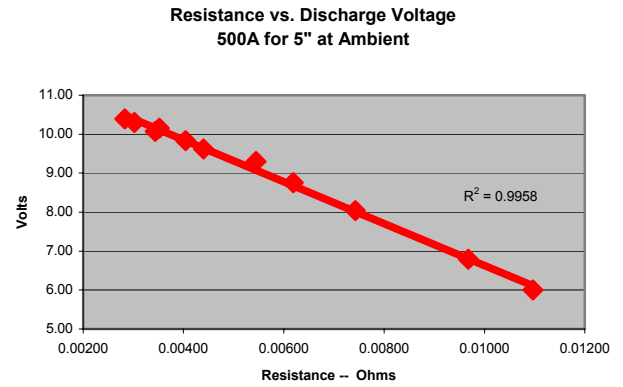


Figure 2: Resistance vs. Discharge Voltage

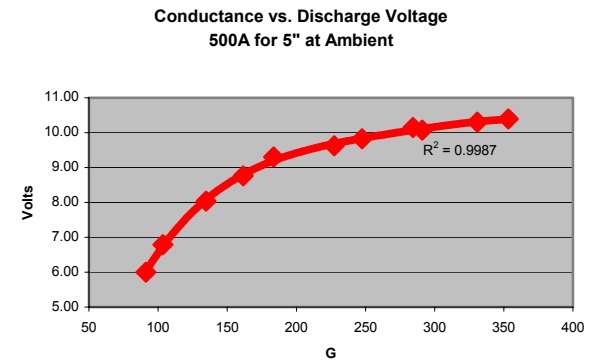


Figure 3: Conductance vs. Discharge Voltage

Also note that voltage by itself is NOT an adequate measure of battery capacity or battery SOH. As Figure 4 indicates, the battery capacity has very little correlation to its open circuit voltage.

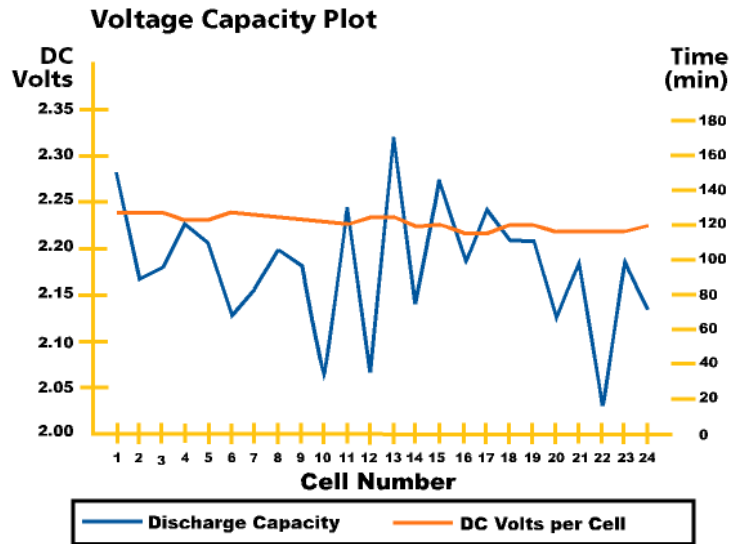


Figure 4: Battery Voltage versus Capacity Lead-acid flooded battery. DC voltage per cell. Discharge time in minutes

However, as Figure 5 indicates, conductance measurements have a very high correlation.

Conductance / Capacity Plot

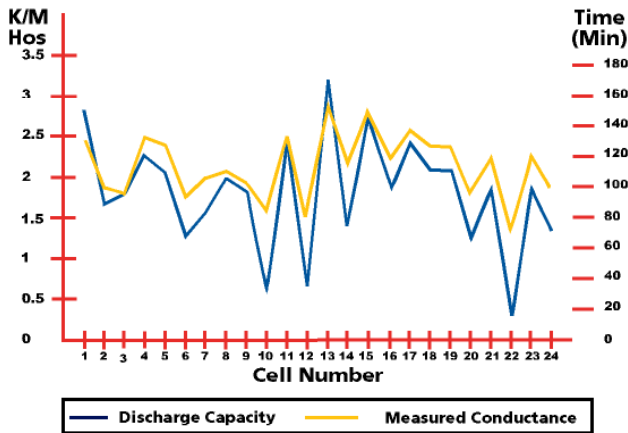


Figure 5: Battery Conductance versus Capacity Lead-acid flooded battery. Conductance in Siemens/Mhos. Discharge time in minutes.

Additionally, Figure 6 displays SOH measurements compared to the actual deliverable cranking power of a military application battery. The chart represents the relationship between the dynamically measured CCA and the SOH calculation as it relates to the vehicle-cranking requirement.



Figure 6: Cranking Capacity (CCA) versus SOH Diagnostic Calculations Lead-acid flooded Military Battery (270 RC minutes), 795 CCA minimum required

Besides being just as accurate as previous load or discharge techniques, conductance testing has several advantages in its simplicity, speed, safety and cost. However, conductance technology utilized in the onGUARD platform has testing limitations associated with electrical system noise and surface charging. For advancements in these areas for continuous in-vehicle monitoring, please refer to SAE papers 2001-01-2715 and 2002-01-3259.

SMART BATTERY TECHNOLOGY

Together, conductance and voltage measurements provide the foundation for onGUARD’s “smart” automotive lead-acid battery. By utilizing a voltage measurement, discharged batteries can easily be identified. Many batteries that are discarded and replaced are actually only discharged.

Surveys of scrapped and discarded automotive batteries from multiple automotive OEMs utilizing conductance technology have shown a minimum 20% and up to 50% of battery “failures” are not actually failed or faulty, only discharged. Thus, for the automotive OEM, unnecessary battery returns and replacements could be reduced by up to 50% with an onGUARD battery monitoring system.

VOLTAGE

As displayed above, conductance and voltage levels are directly related to one another. As the voltage of the battery decreases the conductance of the battery will decrease as well. Because of this relationship, it is important to characterize a battery’s conductance measurement at numerous voltage levels before determining a battery’s SOH. If a battery’s conductance measurement is low it may not necessarily mean the battery has a diminished capacity or health. A low conductance measurement coupled with a low voltage sometimes implies a weak battery that may need to be replaced, or it could be that the battery simply needs to be recharged. onGUARD thus takes into account both the voltage and conductance measurements in calculating the battery’s state of health.

Once onGUARD determines that the battery is adequately charged, it applies a conductance measurement to determine the relative SOH of the battery. The conductance measurement along with the voltage measurement performed and interpreted by onGUARD’s microprocessor (plus temperature, discussed below) are used in onGUARD’s analysis algorithm to calculate battery’s state of health. The conductance measurement of the battery under test is compared to the battery’s rating or design. Normally, these ratings are printed on the battery casing or label in CCA, CA, DIN, JIS, or other ratings.

TEMPERATURE

However, temperature is also important in determining the SOH of a battery. Lowering temperatures will lower the measured conductance of a battery, and increasing temperatures will result in higher conductance measurements. The effects of colder temperatures increase the resistivity of the electrolyte. This is the main reason why a battery is able to supply less cranking current at lower temperatures. Figure 7 displays typical effects of temperature on measured conductance for a SLI (starting-lighting-ignition) lead-acid battery

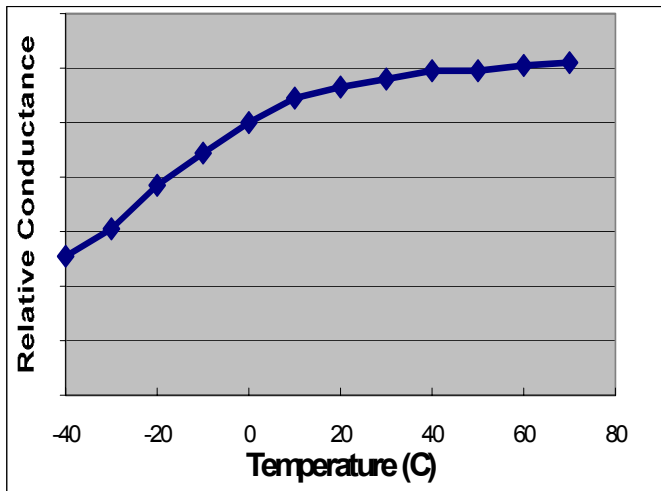


Figure 7: Conductance Measurements at Varying Temperatures Lead-acid flooded automotive battery; 12.71V – 525 CCA at 25 degrees C.

As Figure 7 demonstrates, the measured conductance starts to decline rapidly as the temperature falls below 10°C, while the effects of temperatures above 25°C on the battery’s conductance is less dramatic.

By using a temperature sensor mounted near the battery post in conjunction with a temperature compensation algorithm in onGUARD’s microprocessor, onGUARD can avoid incorrectly diagnosing a cold battery as a failed battery. Low conductance measurements due to lower temperatures are accounted for in the diagnostic algorithm.

SOH ALGORITHM & BATTERY CHARACTERIZATION

In order to establish the thresholds for good or bad, it is necessary to understand the design and performance of a new, healthy battery.

The conductance, voltage and temperature measurements must be developed in accord with the particular battery type and/or application. The process “characterizes” the onGUARD unit for analyzing a battery in a given application. “Characterizing” a battery involves recording the batteries conductance, voltage and/or temperature measurements for known good (healthy) and bad (failed) batteries of the same make and model. Usually 10 samples of healthy and failing batteries are required to do a proper characterization. For the onGUARD smart battery, it is important to characterize a specific model or type, as each battery has particular characteristics for conductance and voltage correlation. (For SOH and SOC monitoring independent of battery design, again refer to SAE papers 2001-01-2715 and 2002-01-3259.) Once battery characterization is complete a SOH algorithm can be developed and transferred into software for onGUARD’s microprocessor. Where previous conductance technology was created to test across the entire industry

of battery types, sizes and capacities, this process makes onGUARD the most accurate battery conductance tester, since it is designed specifically to the battery type in which it will be installed.

MECHANICAL CONFIGURATION

Once an algorithm is established, it must be utilized within the onGUARD design to provide a simple, clear, and unmistakable analysis to the customer; is the battery healthy, is it in a critical or warning area, or does it need to be replaced?

This can be accomplished in a number of different ways through inexpensive, off-the-shelf communication technology, which is simplified into two separate platforms:

1. Battery integrated (onGUARD NT)
2. External module (XT)

The NT integrated unit involves designing onGUARD for a specific battery design, mechanically incorporating the electronics design and packaging with the battery’s casing and lid. A production version of onGUARD NT, complete in potted housing and ready for assembly into the battery casing, is shown in Figure 8.

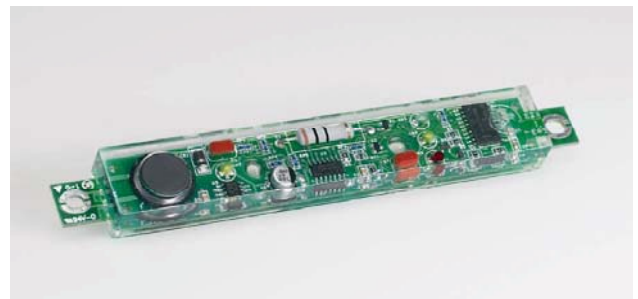


Figure 8: Production version of onGUARD NT

This design also utilizes conductance characteristics obtained through several patented designs for connecting the onGUARD NT circuitry to the battery’s positive and negative terminals. Special post extensions have been designed into the battery’s terminals resulting in a solid and vibration-resistant thorough connection between the post and onGUARD printed circuit board. The connection from the circuit board to the post extension is secured after the circuit board is soldered to the post extension.

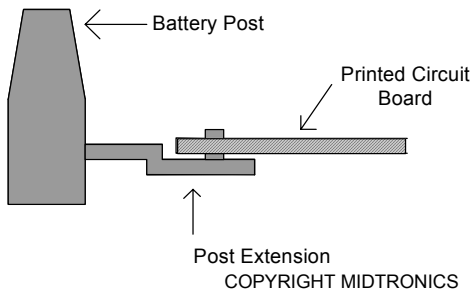


Figure 9: Kelvin-style connection for onGUARD

Figure 9 demonstrates the patented electrical connection required to ensure accurate SOH measurements.

A four-wire Kelvin connection is made between the post extensions and onGUARD's voltage and conductance circuitry. The Kelvin connection is necessary to isolate the voltage and the current sensing circuits used in the conductance measurement process. Various Kelvin connections are used in all of Midtronics conductance testers as well as in many resistance meters that measure very small resistance values (under 1.0 ohm).

FUNCTIONAL SPECIFICATION

onGUARD NT functions according to the following block diagram:

CUSTOMER INTERFACE

To activate the onGUARD NT, the end user is required to push and hold a small pushbutton to start the test. The time it takes to come to a SOH decision is approximately 3 seconds. Once onGUARD NT has made a decision on the conductance of the battery it will light LEDs arranged to indicate relative SOH according to the application requirements. For instance, the LEDs can be arranged in a "stop light" configuration. A green led indicates a healthy battery, yellow a decline in health, and red an unhealthy battery, indicating that the user should replace the battery. Along with the 3 SOH LEDs, this design also has a low voltage yellow LED. Illumination of this LED indicates the battery's voltage is below a preset low-voltage threshold and the battery should be recharged.

A sample display is shown in Figure 11, and Figure 12 is a picture of a production onGUARD battery, with sample graphics, as viewed from the top.



Figure 10: Sample graphics for onGUARD NT

Figure 11: Production onGUARD NT battery with sample graphics and onGUARD NT circuitry shown (view from the top)

Additional LED, LCD and other display designs and patterns are easily configurable according to the application and market requirements.

EXTERNAL, NON-INTEGRATED SOLUTIONS

onGUARD can also be designed as an external unit (XT), for post-battery manufacture installation and utilization. This allows the same voltage and SOH testing benefits as the integrated unit, without the mechanical issues of altering the battery casing and design. It also allows additional flexibility in display interfaces, memory storage and wired and wireless communication of data. The XT unit is also designed to be connected to the battery posts with a Kelvin connection. The unit is then mounted to either the top or side of the battery or in a nearby location off battery.

onGUARD XT intended use is on a large variety of batteries with different conductance ratings. Because of this variability the decision making algorithm must be generalized for any number of batteries. onGUARD accomplishes this by a built in relative conductance calibration feature. Once the unit is connected to a fully charged new battery the user can simply press and hold the activation button for a few seconds. During this period onGUARD XT calculates the battery's measurements and saves the result in onGUARD's flash memory. All tests performed on this battery will then compare its conductance measurement against the

original, or benchmark, measurement and will make a SOH decision based on the new measurement relative to the old measurement. The unit can be reset to a new or different battery through the same process.

The XT unit has the same options for test button(s), a series of LED indicators for both SOH and voltage. The unit can be incorporated into various housings or can utilize existing housings or encapsulations in the vehicle applications.

POTENTIAL INTEGRATION AND APPLICATIONS

Besides being a stand alone battery tester onGUARD has the potential for being a smart sensor used in an vehicle diagnostic systems. onGUARD has the capability to be remotely activated from inside the passenger compartment and its output can be displayed via a stand-alone warning light indicator or incorporated in a vehicle voltmeter gauge. The new "battery meter" could utilize an analog or a digital read out. onGUARD could also be prompted by an automobile's engine computer and communicate the results via network communication using J1939, J1708 or LIN bus standards.

onGUARD can also be used to track a battery's voltage and SOH throughout its life by incorporating a data collection system using deep memory storage. The data can later be recalled to verify if the starter and charging system are working properly with the battery. Battery manufacturers and suppliers can also use the data to gather information about the application environment and requirements that their batteries endure. The onGUARD can store battery identification information to track the battery throughout its service life, and provide history to enable cost management systems and save resource expenses throughout the distribution and service systems.

A secondary diagnostic reader tool can also be utilized to view the output of the onGUARD unit. The diagnostic readers have LCD display and/or printer paper readouts that would numerically show the conductance, voltage and temperature of the battery. The information from onGUARD could be transmitted by wire or by an infrared led to the reader. A diagnostic tool could also be used to reprogram and calibrate the onGUARD should the vehicle or battery application ever need to be updated.

CONCLUSION

The modern vehicle is highly dependent on its electrical system for operation and operator pleasure. Output of consistent power from the battery is critical to maintain the vehicle. Battery questions and issues continue to cause major service problems and continuous wasted costs in nearly every vehicle application worldwide. Monitoring the battery's ability to deliver power throughout its life using state of health diagnostics, like those available through onGUARD technology, is essential to guarantee satisfactory vehicle operation for the present and emerging electrical systems. applications for fuel economy, emissions, safety, comfort and convenience and drive operation are ensured whenever and wherever required.

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