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MICHAEL W. DOBBINS
CLERK, U.S. DISTRICT COURT

IN THE UNITED STATES DISTRICT COURT
FOR THE NORTHERN DISTRICT OF ILLINOIS
EASTERN DIVISION

MIDTRONICS, INC.	)	
	)	
Plaintiff,	)	
	)	No. 04 C 2865
vs.	)	Judge Zagel / Magistrate Judge Ashman
	)	
ACTRON MANUFACTURING COMPANY, INC.,	)	**JURY DEMANDED**
	)	
	)	
Defendant.	)	

DOCKETED
JUN 1 0 2004

AMENDED COMPLAINT FOR PATENT INFRINGEMENT

Midtronics, Inc., plaintiff herein, by its attorneys, for its complaint against Actron Manufacturing Company, Inc., states as follows:

The Parties

1. Plaintiff Midtronics, Inc. ("Midtronics") is a corporation of the State of Illinois and has its principal place of business in Willowbrook, Illinois.

2. Defendant Actron Manufacturing Company ("Actron") is a corporation of the State of Ohio having its principal offices in Cleveland, Ohio. Actron does business in this judicial district directly or through established distribution channels.

Jurisdiction and Venue

3. This is an action for patent infringement that arises under the patent laws of the United States, Title 35 U.S.C. § 1 et seq. This Court has subject matter jurisdiction under 28 U.S.C. §§ 1331 and 1338(a).

4. Venue is proper in this district under 28 U.S.C. §§ 1391(c) and 1400(b).

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The Patents in Suit

5. On April 18, 2000, United States Patent No. 6,051,976 ("the '976 Patent") was duly and legally issued to Kevin I. Bertness. The '976 Patent is entitled "METHOD AND APPARATUS FOR AUDITING A BATTERY TEST." A copy of the '976 Patent is attached hereto as Exhibit A.

6. The '976 Patent is assigned to plaintiff Midtronics.

7. On October 13, 1998, United States Patent No. 5,821,756 ("the 756 Patent") was duly and legally issued to Stephen J. McShane et al. The '756 Patent is entitled "ELECTRONIC BATTERY TESTER WITH TAILORED COMPENSATION FOR LOW STATE OF CHARGE." A copy of the '756 Patent is attached hereto as Exhibit B.

8. The '756 Patent is assigned to plaintiff Midtronics.

COUNT I

9. Midtronics restates and realleges the allegations in paragraphs 1-8 and incorporates them by reference.

10. Actron has manufactured, used, offered for sale or sold, in the United States, electronic battery testing devices, including Actron's KM8680 product or other products utilizing similar technology, that infringe, either literally or under the doctrine of equivalents, one or more claims of the '976 Patent, either directly, contributorily, by inducement or otherwise, in violation of 35 U.S.C. § 271.

11. Actron has had notice of the '976 Patent prior to the filing of this Complaint.

12. The infringement of the '976 Patent by Actron has injured and damages Midtronics. The injury to Midtronics is irreparable and will continue unless and until Actron is enjoined from further infringement.

COUNT II

13. Midtronics restates and realleges the allegations in paragraphs 1-8 and incorporates them by reference.

14. Actron has manufactured, used, offered for sale or sold, in the United States, electronic battery testing devices, including Actron's KM8680 product or other products utilizing similar technology, that infringe, either literally or under the doctrine of equivalents, one or more claims of the '756 Patent, either directly, contributorily, by inducement or otherwise, in violation of 35 U.S.C. § 271.

15. Actron has had notice of the '756 Patent prior to the filing of this Complaint.

16. The infringement of the '756 Patent by Actron has injured and damages Midtronics. The injury to Midtronics is irreparable and will continue unless and until Actron is enjoined from further infringement.

JURY DEMAND

17. Midtronics demands a trial by jury on all issues so triable in this Complaint.

PRAYER FOR RELIEF

WHEREFORE, Midtronics prays for judgment as follows:

A. That United States Patent No. 6,051,976 be judged valid, enforceable, and infringed by Actron and that defendant's infringement is judged to be willful;

B. That United States Patent No. 5,821,756 be judged valid, enforceable, and infringed by Actron and that defendant's infringement is judged to be willful;

C. That Actron be ordered to account and pay to Midtronics the damages to which Midtronics is entitled as a consequence of the infringement;

D. That such damages be trebled for the willful, deliberate and intentional infringement of the '976 and '756 Patents, as alleged herein;

E. That plaintiff Midtronics be awarded prejudgment interest and its costs, disbursements, and attorneys' fees here in accordance with Title 35 U.S.C. § 285;

F. That the Court permanently enjoin Actron, its subsidiaries, parent, divisions, agents, servants, and employees, and all persons or entities acting in concert with Actron, from making, using, selling, importing, offering for sale, or distributing the KM8680 product and any other devices that are found to infringe and from contributing to and inducing infringement of the '976 and '756 Patents and for all further and proper injunctive relief; and

G. That Midtronics be awarded other and further relief as this Court may deem just and proper under the circumstances.

Respectfully submitted,

Dated: June 4, 2004

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Attorneys for Plaintiff
MIDTRONICS, INC.

US006051976A

United States Patent [19]

Bertness

[11] **Patent Number: 6,051,976**

[45] **Date of Patent: *Apr. 18, 2000**

[54] METHOD AND APPARATUS FOR AUDITING A BATTERY TEST

[75] Inventor: **Kevin I. Bertness**, Batavia, Ill.

[73] Assignee: **Midtronics, Inc.**, Burr Ridge, Ill.

[*] Notice: This patent issued on a continued prosecution application filed under 37 CFR 1.53(d), and is subject to the twenty year patent term provisions of 35 U.S.C. 154(a)(2).

[21] Appl. No.: **08/681,730**

[22] Filed: **Jul. 29, 1996**

[51] **Int. Cl.**^{7} **G01R 27/26**

[52] **U.S. Cl.** **324/426**; 340/636

[58] **Field of Search** 324/426, 427, 324/429, 433; 340/636

[56] **References Cited**

U.S. PATENT DOCUMENTS

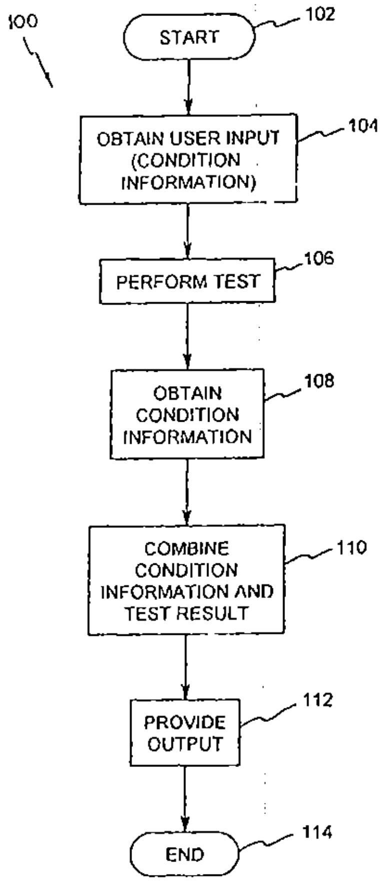
3,873,911	3/1975	Champlin	324/29.5
3,909,708	9/1975	Champlin	324/29.5
4,423,378	12/1983	Marino et al.	324/427
4,514,694	4/1985	Finger	324/429
4,816,768	3/1989	Champlin	324/428
4,820,966	4/1989	Fridman	324/434
4,825,170	4/1989	Champlin	324/436
4,881,038	11/1989	Champlin	324/426
4,912,416	3/1990	Champlin	324/430
5,032,825	7/1991	Kuznicki	340/825.44
5,140,269	8/1992	Champlin	324/433
5,144,248	9/1992	Alexandres et al.	324/428
5,426,371	6/1995	Salley et al.	324/429
5,528,148	6/1996	Rogers	324/426
5,606,242	2/1997	Hull et al.	324/426

Primary Examiner—Maura Regan
Attorney, Agent, or Firm—Westman, Champlin & Kelly, P.A.

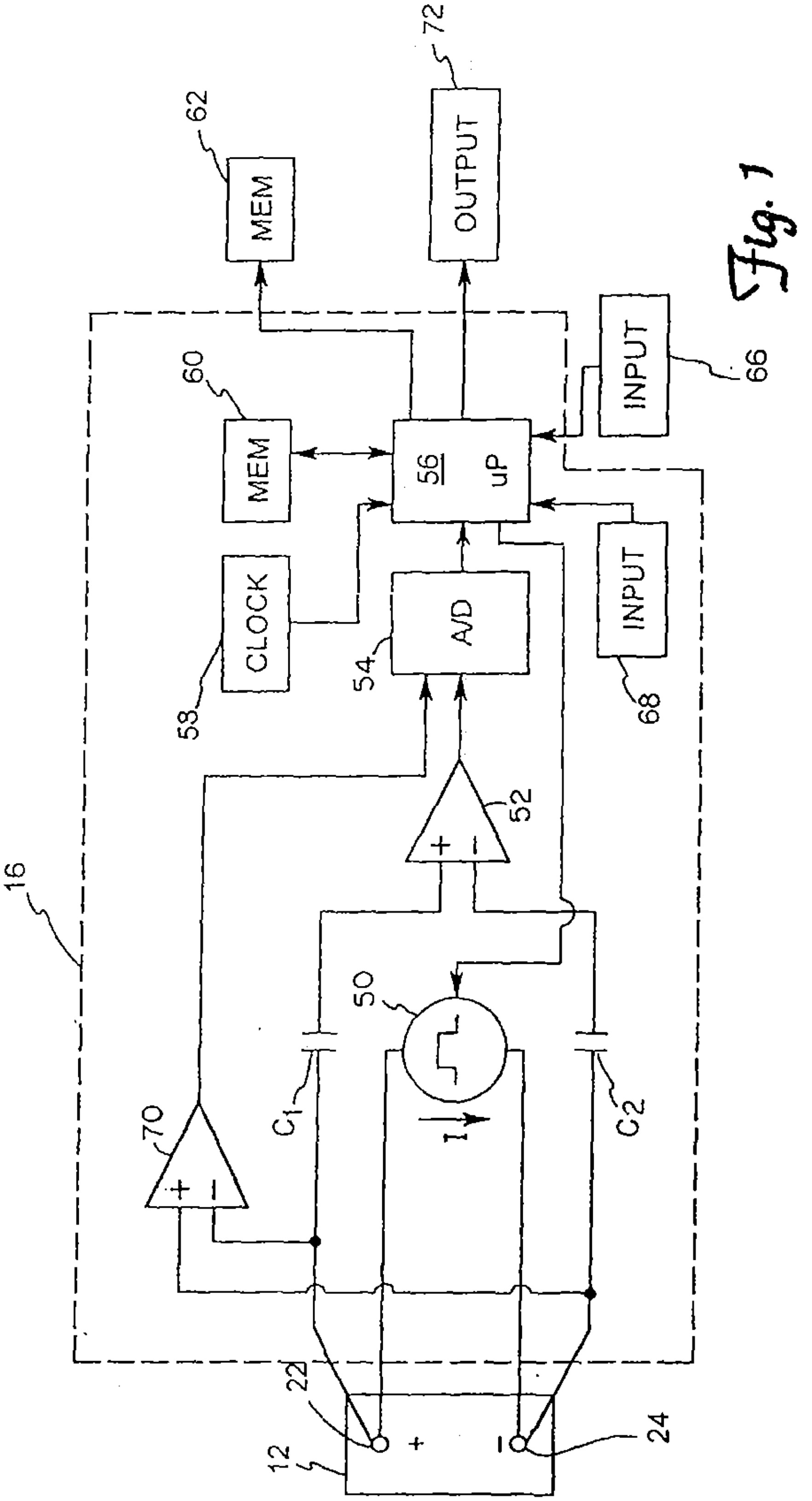
[57] **ABSTRACT**

A method and apparatus for auditing condition of a storage battery performs a battery test on the storage battery to obtain a test result. Test condition information is obtained related to conditions of the battery test. The battery test result and the test condition information is combined into a code. The code may be subsequently used to determine conditions during the battery test which lead to the particular test result.

54 Claims, 2 Drawing Sheets



PENGAD-Bayonne, N. J.
EXHIBIT
A


72
OUTPUT
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MEM
56
uP
INPUT
66
INPUT
68
CLOCK
58
A/D
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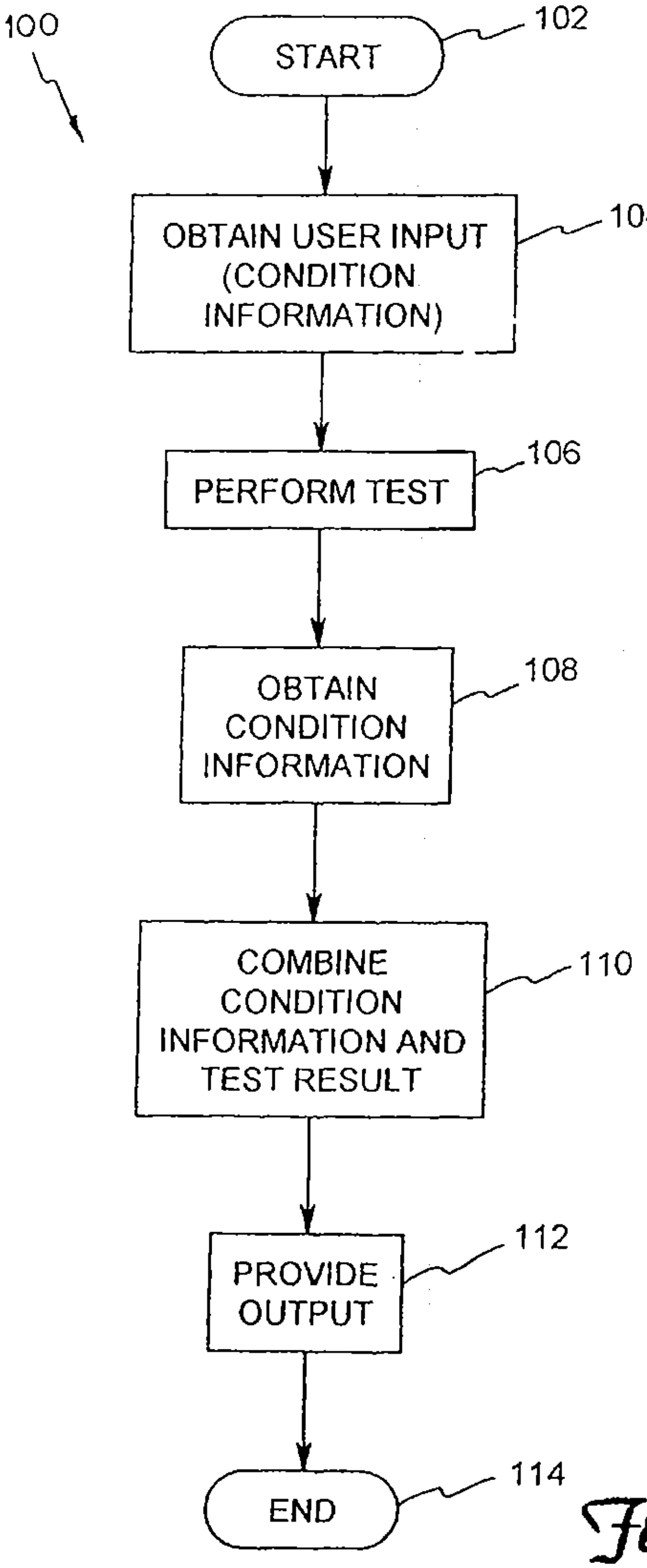
+
-
C1
C2
22
24
12
+
-

Fig. 1



100
START
102
OBTAIN USER INPUT (CONDITION INFORMATION)
104
PERFORM TEST
106
OBTAIN CONDITION INFORMATION
108
COMBINE CONDITION INFORMATION AND TEST RESULT
110
PROVIDE OUTPUT
112
END
114

Fig. 2

METHOD AND APPARATUS FOR AUDITING A BATTERY TEST

BACKGROUND OF THE INVENTION

The present invention relates to testing storage batteries. More specifically, the present invention relates to generating a code related to a battery test.

Storage batteries, such as lead acid storage batteries of the type used in the automotive industry, have existed for many years. However, understanding the nature of such storage batteries, how such storage batteries operate and how to accurately test such batteries has been an ongoing endeavor and has proved quite difficult. Storage batteries consist of a plurality of individual storage cells electrically connected in series. Typically each cell has a voltage potential of about 2.1 volts. By connecting the cells in series, the voltages of the individual cells are added in a cumulative manner. For example, in a typical automotive storage battery, six storage cells are used to provide a total voltage when the battery is fully charged of 12.6 volts.

There has been a long history of attempts to accurately test the condition of storage batteries. A simple test is to measure the voltage of the battery. If the voltage is below a certain threshold, the battery is determined to be bad. However, this test is inconvenient because it requires the battery to be charged prior to performing the test. If the battery is discharged, the voltage will be low and a good battery may be incorrectly tested as bad. Furthermore, such a test does not give any indication of how much energy is stored in the battery. Another technique for testing a battery is referred as a load test. In a load test, the battery is discharged using a known load. As the battery is discharged, the voltage across the battery is monitored and used to determine the condition of the battery. This technique requires that the battery be sufficiently charged in order that it can supply current to the load.

More recently, a technique has been pioneered by Dr. Keith S. Champlin for testing storage batteries by measuring the conductance of the batteries. This technique is described in a number of United States patents obtained by Dr. Champlin, for example, U.S. Pat. No. 3,873,911, issued Mar. 25, 1975, to Champlin, entitled ELECTRONIC BATTERY TESTING DEVICE; U.S. Pat. No. 3,909,708, issued Sep. 30, 1975, to Champlin, entitled ELECTRONIC BATTERY TESTING DEVICE; U.S. Pat. No. 4,816,768, issued Mar. 28, 1989, to Champlin, entitled ELECTRONIC BATTERY TESTING DEVICE; U.S. Pat. No. 4,825,170, issued Apr. 25, 1989, to Champlin, entitled ELECTRONIC BATTERY TESTING DEVICE WITH AUTOMATIC VOLTAGE SCALING; U.S. Pat. No. 4,881,038, issued Nov. 14, 1989, to Champlin, entitled ELECTRONIC BATTERY TESTING DEVICE WITH AUTOMATIC VOLTAGE SCALING TO DETERMINE DYNAMIC CONDUCTANCE; U.S. Pat. No. 4,912,416, issued Mar. 27, 1990, to Champlin, entitled ELECTRONIC BATTERY TESTING DEVICE WITH STATE-OF-CHARGE COMPENSATION; and U.S. Pat. No. 5,140,269, issued Aug. 18, 1992, to Champlin, entitled ELECTRONIC TESTER FOR ASSESSING BATTERY/CELL CAPACITY.

As battery test results have become more accurate, and the repeatability of those results has increased, we have recognized a new problem. Specifically, if a subsequent battery test is performed at a later time and perhaps at a different location and under different conditions, there is no adequate way to compare the results of the two tests. It is impossible to determine if differences in test results are due to improper use of the test equipment, inaccurately recorded test results or even falsification of the test results. For example, this problem can be particularly vexing to battery manufactures, battery distributors, and automobile companies who offer warranties with their batteries. Further, the precise conditions of the test and test results would be useful in determining the cause of the failure and reducing the likelihood of failure in new batteries by identifying and correcting defects.

SUMMARY OF THE INVENTION

The present invention offers solutions to problems associated with the aforementioned problems. The present invention provides a method and apparatus for auditing a battery test. In the method, a battery test is performed on a storage battery to obtain a test result. Test condition information is obtained regarding conditions related to the battery test. The test result and the test condition information is combined into a code and the code is stored or output for future reference.

Similarly, the apparatus includes battery test circuitry for performing a battery test on the storage battery and providing a test result. Input circuitry receives test condition information which is related to conditions of the battery test. Calculation circuitry coupled to the battery test circuitry and the input circuitry combines the battery test result and the test condition information and responsively provides a code output.

In various embodiments of the invention, the code output can be used to subsequently analyze the battery test in view of the test conditions.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a simplified schematic diagram showing battery monitoring and auditing circuitry in accordance with the present invention.

FIG. 2 is a simplified block diagram shown the steps of a method in accordance with the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention provides a new and useful technique for monitoring and auditing a battery test of a storage battery, such as a lead acid storage battery. The present invention is for use with any battery tester or testing technique and those discussed herein are strictly as examples. The present invention provides a method and apparatus for combining the result of a battery test with information related to conditions of the battery test into a code which can be subsequently accessed. As described herein, the present invention is useful in subsequent analysis of batteries which failed the battery test and may be used to monitor batteries returned on warranty, to monitor operator performance and can be used in detecting and identifying a faulty design of a storage battery.

FIG. 1 is a simplified block diagram of battery monitoring circuitry **16** in accordance with the present invention. Apparatus **16** is shown coupled to battery **12** which includes a positive battery terminal **22** and a negative battery terminal **24**.

Circuitry **16** operates in accordance with one embodiment of the present invention and determines the conductance (G_{BAT}) of battery **12** and the voltage potential (V_{BAT}) between terminals **22** and **24** of battery **12**. Circuitry **16** includes current source **50**, differential amplifier **52**, analog-to-digital converter 54 and microprocessor 56. Amplifier 52 is capacitively coupled to battery 12 through capacitors C_1 and C_2. Amplifier 52 has an output connected to an input of analog-to-digital converter 54. Microprocessor 56 is connected to system clock 58, memory 60, memory 62 and analog-to-digital converter 54. Microprocessor 56 is also capable of receiving an input from input devices 66 and 68. Microprocessor 56 also connects to output device 72.

In operation, current source 50 is controlled by microprocessor 56 and provides a current I in the direction shown by the arrow in FIG. 1. In one embodiment, this is a square wave or a pulse. Differential amplifier 52 is connected to terminals 22 and 24 of battery 12 through capacitors C_1 and C_2, respectively, and provides an output related to the voltage potential difference between terminals 22 and 24. In a preferred embodiment, amplifier 52 has a high input impedance. Circuitry 16 includes differential amplifier 70 having inverting and noninverting inputs connected to terminals 24 and 22, respectively. Amplifier 70 is connected to measure the open circuit potential voltage (V_{BAT}) of battery 12 between terminals 22 and 24. The output of amplifier 70 is provided to analog-to-digital converter 54 such that the voltage across terminals 22 and 24 can be measured by microprocessor 56.

Circuitry 16 is connected to battery 12 through a four-point connection technique known as a Kelvin connection. This Kelvin connection allows current I to be injected into battery 12 through a first pair of terminals while the voltage V across the terminals 22 and 24 is measured by a second pair of connections. Because very little current flows through amplifier 52, the voltage drop across the inputs to amplifier 52 is substantially identical to the voltage drop across terminals 22 and 24 of battery 12. The output of differential amplifier 52 is converted to a digital format and is provided to microprocessor 56. Microprocessor 56 operates at a frequency determined by system clock 58 and in accordance with programming instructions stored in memory 60.

Microprocessor 56 determines the conductance of battery 12 by applying a current pulse I using current source 50. The microprocessor determines the change in battery voltage due to the current pulse I using amplifier 52 and analog-to-digital converter 54. The value of current I generated by current source 50 is known and is stored in memory 60. In one embodiment, current I is obtained by applying a load to battery 12. Microprocessor 56 calculates the conductance of battery 12 using the following equation:

$$\text{Conductance} = G_{BAT} = \frac{\Delta I}{\Delta V} \qquad \text{Equation 1}$$

where ΔI is the change in current flowing through battery 12 due to current source 50 and ΔV is the change in battery voltage due to applied current ΔI.

Based upon the battery conductance G_{BAT} and the battery voltage, the battery tester 16 determines the condition of battery 12. For example, if the battery conductance G_{BAT} is lower than a predetermined threshold for a particular battery at a particular voltage, microprocessor 56 determines that battery 12 has failed the battery test. For example, as explained in the Champlin patents, the tester can compare the measured CCA (Cold Cranking Amp) with the rated CCA for that particular battery. Microprocessor 56 uses information input from input device 66 provided by, for example, an operator. This information may consist of the particular type of battery, location, time, the name of the operator etc. Additional information relating to the conditions of the battery test is received by microprocessor 56 from input device 68. Input device 68 may comprise one or more sensors, for example, or other elements which provide information such as ambient or battery temperature, time, date, humidity, barometric pressure, noise amplitude or characteristics of noise in the battery or in the test result, or any other information or data which may be sensed or otherwise recovered which relates to the conditions of the test, how the battery test was performed, or intermediate results obtained in conducting the test. Additional test condition information is provided by microprocessor 56. Such additional test condition information may include the values of G_{BAT} and battery voltage, the various inputs provided to battery tester 16 by the operator which may include, for example, type of battery, estimated ambient or battery temperature, type of vehicle (i.e., such as provided through the Vehicle Identification Number (VIN) code for the vehicle) or the particular sequence of steps taken by the operator in conducting the test. In accordance with the present invention, microprocessor 56 uses some, or all, of the various battery test condition information and combines such test condition information with the test result to generate a code. This code is provided to output device 72 which may comprise, for example, a display or a printer. In another embodiment, the code is stored in memory 62 for subsequent use. As used herein, input circuitry refers to any circuitry used to obtain the test condition information and may include inputs 66 and 68, memory 60, etc.

The code of the present invention may be generated through any appropriate technique. Two examples follow.

For example, the display 72 will indicate:

"TEST CODE: A0XXXX1YYYY2222Z".

Where the information is encoded as follows:

A: Alphanumeric code representing geographic territory
0: 0=no temperature compensation used in conditioning the test. 1=temperature compensation used in conditioning the test.
XXXX: Entered battery rating in coded CCA (Cold Cranking Amps) (0=A, 1=B, 2=C, etc.) I.E. "0625 CCA" displayed as AGCF
1: Result of battery test:
  0=Good—Return to Service
  1=Good—Recharge & Return to Service
  2=Recharge & Retest
  3=Bad battery
  4=Bad cell battery
YYYY: Measured coded battery voltage without decimal point (0=A, 1=B, etc.) I.E. "12.65 Volts" displayed as BCGF
2222: Actual CCA measured by tester.
Z: Alphanumeric code representing state of charge.

An example using eight characters follows. A pseudo base 26 number, represented by two alpha characters, is used to represent certain values in this test code.

For example, to convert the coded number "CZ", look up the alpha characters in the following table:

A = 0	B = 1	C = 2	D = 3	E = 4	F = 45
G = 6	H = 7	I = 8	J = 9	K = 10	L = 11
M = 12	N = 13	O = 14	P = 15	Q = 16	R = 17
S = 18	T = 19	U = 20	V = 21	W = 22	X = 23
Y = 24	Z = 25				

Take the first letter, "C", and multiply its value by 26. Then add the value of the second letter "Z": {"C"×26}+"Z".

$$(2)\times(26)=52. \qquad \text{Equation 2}$$

$$52+25=77. \qquad \text{Equation 3}$$

The coded number is 77.

The display 72 will indicate "TEST CODE: XX0YY1ZZ", for example.

The information is encoded as follows:

XX: Entered coded battery rating in 5 CCA increments. For example, 360 CCA would be represented as 72, 650 CCA as 130, etc. CCA will be rounded to the nearest 5 CCA value. The coded CCA is then represented using the Pseudo Base 26 scheme listed above. 360 CCA=72 coded=CU. 650 CCA=130=FA.

0: Result code:

0=Good—Return to Service

1=Good—Recharge & Return to Service

2=Recharge & Retest

3=Bad battery

4=Bad cell battery

5=Good—Return to Service (temperature compensated during test)

6=Good—Recharge & Return to Service (temperature compensated during test)

7=Recharge & Retest (temperature compensated during test)

8=Bad battery (temperature compensated)

9=Bad cell battery (temperature compensated)

YY: Measured coded voltage in 50 mVolt increments. For example, 10.00 volts would be represented as 200, 12.75 volts as 255, etc. Voltage will be rounded to the nearest 50 mVolt value. The coded voltage is then represented using the Pseudo Base 26 scheme listed above. 10.00 volts=200 coded=HS. 12.75 volts=255=JV.

1: Numeric code representing state of charge. The state of charge of the battery is indicated by a single numeric character. "0" represents that SOC is not applicable, such as in Replace Battery or Recharge and Retest. "5" represents 100% state of charge. "1"–"4" are divided in equal steps between a selected lower percentage and 100% relative conductance.

ZZ: Actual measured battery cranking power in 5 CCA increments. For example, 360 CCA would be represented as 72, 650 CCA as 130, etc. CCA will be rounded to the nearest 5 CCA value. The coded CCA is then represented using the Pseudo Base 26 scheme listed above. 360 CCA=72 coded=CU. 650 CCA=130=FA.

FIG. 2 is a simplified block diagram showing steps in accordance with the method of the present invention. FIG. 2 shows flow chart 100 which initiates operation at start block (or step) 102. At block 104, user input is obtained. For example, user input is obtained through input device 66 and may constitute instructions for performing a battery test, the rated cold cranking amps (CCA) for the batter under test, estimated temperature during the test for temperature compensation during the test or any other user input related to the test or test environment. This information is provided to microprocessor 56 and is stored in memory 60 for use during the test. Additional information may relate to a particular vehicle in which the battery in installed which may be obtained, for example, using the VIN code for the vehicle. Further, the make, model and manufacturer of the battery 12 may be provided. Other such information includes battery specific information, such as a serial number, digital signature for tracking and identifying the battery, make, model, and date of manufacture of the battery, etc. Such information

may be manually input or, for example, read from a bar code carried on the battery.

At block 106, microprocessor 56 performs the battery test using the techniques described above. However, it will be understood that those techniques are merely examples and the battery test may be any battery test including a simple voltage measurement test, a load test, resistance, conductance, impedance, admittance, or other parameter test, battery capacity or state of charge test, digital hygrometer test in which the specific gravity of the battery acid is measured, complex charging and discharging tests which are known in the art, etc. It will be understood that in various embodiments of the present invention, the particular test may be selected from any available or yet to be discovered battery test.

At block 108, microprocessor 56 obtains any additional condition information which may be used in accordance with the invention. As explained above, the information may be any information related to the test such as actual ambient or battery temperature sensed by device 68, various intermediate test results which were obtained in performing the test at step 106, various battery parameters such as surface charge, voltage, conductance, resistance, float current, noise amplitude, noise frequency or other noise characteristics, etc. At step 110, microprocessor 56 combines the condition information obtained at step 108 with the test results obtained at step 106 into a string of information. The information may be of any form and is not limited to the character code described above. The information may be digitally encoded into a series of data bytes. However, in one preferred embodiment, an alpha numeric code is preferred. This combination of information is referred to herein as a code. At block 112, this code is output using an appropriate technique. For example, the code can be output on output device 72 which may be a display, printer, label printer, bar code printer, modem or other data transmission means, etc. In another variation on the invention, the step 112 provides the output to memory 62 for subsequent use. For example, a plurality of codes may be collected in memory for subsequent output or analysis. At block 114, the procedure ends.

One advantage of the present invention is that it is particularly useful in ensuring compliance with the warranty return policies of manufacturers. For example, if, upon identifying a faulty battery, the operator marks the battery 12 with the code provided on output device 72, for example, by marking directly on the battery or applying a sticker to the battery when the battery is returned, the manufacturer will have information regarding the test which resulted in the return of the battery. In one preferred embodiment, the code is encrypted or otherwise difficult to duplicate whereby the code cannot be falsified. Thus, the manufacturer may then perform a subsequent test on the battery and compare the subsequent test result with the result obtained which lead to the warranty return. This will make it very difficult for the unscrupulous individual to return a battery under a warranty policy where the battery is not faulty. Furthermore, the invention provides additional traceability of the batteries which are being returned to the manufacturer in that the particular code may contain geographic and location information used to identify the particular test location and operator which lead to the failed test. Further still, if the battery is in a new car and is being returned to the automobile manufacturer, the manufacturer can retrieve information regarding the vehicle such as through the VIN code of the vehicle.

The present invention provides a convenient technique for a manufacturer to collect information regarding batteries which fail battery tests. Such information can be used in improving future batteries or identifying faults in existing batteries. For example, the code can contain information regarding the various intermediate steps or measurements which are obtained in providing the battery test. This could be, for example, battery recovery voltage, voltage after a first test, voltage after a second test, surface charge voltage, voltage or current in response to an applied load or signal, temperature compensation input, noise amplitude or other noise characteristics, float current, etc.

The present invention may be used with standby batteries such as those used to power remote telephone switching locations, computer facilities, power company facilities, pumping stations, etc. It will be understood by those skilled in the art that the present invention is not limited to automotive storage batteries.

In one embodiment of the invention, the code is in an encrypted format to thereby reduce the likelihood of code falsification. In the two examples described above, the code is encrypted in that it is difficult for a user who is unfamiliar with the particular coding technique to discover the precise technique being used and generate valid codes which contain falsified information. A further embodiment of the invention includes providing a stronger encryption algorithm which may be as simple as an offset or transposition cipher or a more complex technique such as a public key encryption technique. Such a technique can also be used to apply a digital signature to the code containing, for example, information about the particular battery tester being used.

Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention. For example, one may use other input mechanisms to obtain test condition information or employ other battery tests than those explicitly described. Further, the code may be generated using any appropriate technique.

What is claimed is:

1. A method of monitoring a condition of a storage battery, comprising:

connecting a battery test device to the storage battery;

obtaining test condition information related to the battery;

obtaining raw battery test data by performing a step in a battery test on the storage battery with the battery test device;

digitizing the raw test data with the battery test device;

determining, using a microprocessor in the battery test device, the condition of the battery as a function of the digitized raw test data and the test condition information;

providing a visual output indicative of the condition of the battery;

digitally combining the test condition information, the digitized raw test data and the condition of the battery to form an audit code, the audit code having properties such that the digitized raw test data and the condition of the battery are subsequently recovered from the audit code and the battery test subsequently audited through comparing the raw test data to the condition of the battery to identify user falsification of the battery test; and

outputting the audit code.

2. The method of claim 1 wherein the raw test data includes battery conductance.

3. The method of claim 1 wherein the test condition information includes temperature information.

4. The method of claim 1 wherein the test condition information includes rated battery Cold Cranking Amps (CCA).

5. The method of claim 1 wherein the test condition information is related to a vehicle which contains the battery.

6. The method of claim 1 wherein the test condition information includes information related to the battery.

7. The method of claim 1 wherein the raw test data includes battery voltage.

8. The method of claim 1 wherein the step of obtaining the raw battery test data includes applying an electrical load to the battery.

9. The method of claim 1 wherein the audit code comprises an alpha numeric code.

10. The method of claim 1 including the step of placing the audit code onto the battery following the step of outputting the audit code.

11. The method of claim 1 including subsequently auditing the battery test based upon the audit code.

12. The method of claim 11 wherein the step of subsequently auditing comprises:

extracting the raw test data, the test condition information and the battery condition from the battery;

calculating on the battery condition as a function of the extracted raw test data and the extracted test condition information; and

comparing the extracted battery condition with the calculated battery condition.

13. An apparatus for performing a battery test on a storage battery to determine the condition of the storage battery, comprising:

battery test circuitry obtaining raw test data for the battery;

an analog to digital converter providing digitized raw test data;

input circuitry adapted to receive test condition information related to a test condition of the storage battery;

a microprocessor determining the battery condition of the storage battery as a function of the digitized raw test data and the test condition information, wherein the microprocessor includes calculation circuitry for providing an audit code which is a combination of the battery condition, the digitized raw test data, and the test condition information, the audit code having properties such that the battery condition, the digitized raw test data, and the test condition information is subsequently recovered from the audit code and the battery test subsequently audited through comparing the raw test data to the condition of the battery to identify user falsification of the battery test; and

output circuitry outputting the final battery test result and separately outputting the audit code.

14. The apparatus of claim 13 wherein the battery test circuitry includes circuitry determining battery conductance.

15. The apparatus of claim 13 wherein the battery test circuitry includes circuitry applying an electrical load to the battery.

16. The apparatus of claim 13 wherein the raw test data comprises battery voltage.

17. The apparatus of claim 13 wherein test condition information includes information related to battery temperature.

18. The apparatus of claim 13 wherein test condition information includes information related to geographic location.

19. The apparatus of claim 13 wherein test condition information includes information related to a vehicle containing the battery.

20. The apparatus of claim 13 wherein test condition information includes information related to the battery.

21. The apparatus of claim 13 wherein the input circuitry includes a manual input for receiving an input from a user.

22. The apparatus of claim 20 wherein information related to the battery comprises rated battery Cold Cranking Amps (CCA).

23. The method of claim 1 wherein the test condition information comprises battery type.

24. The method of claim 1 wherein the test condition information comprises geographic location.

25. The method of claim 1 wherein the test condition information comprises time information.

26. The method of claim 1 wherein the test condition information comprises the name of the operator.

27. The method of claim 1 wherein the test condition information comprises the VIN code of a vehicle which contains the battery.

28. The method of claim 1 wherein the test condition information comprises battery specific information.

29. The method of claim 1 wherein the test condition information comprises battery serial number.

30. The method of claim 1 wherein the test condition information comprises battery model.

31. The method of claim 1 wherein the test condition information comprises date of manufacture of the battery.

32. The method of claim 1 wherein the test condition information comprises a digital signature.

33. The method of claim 1 wherein the step of outputting comprises printing an audit code.

34. The method of claim 1 wherein the step of printing the audit code comprises printing a label.

35. The method of claim 1 wherein the step of printing the audit code comprises printing a bar code.

36. The method of claim 1 wherein the step of outputting comprises transmitting the audit code data.

37. The method of claim 1 wherein the step of transmitting the audit code data comprises transmitting data through a modem.

38. The method of claim 1 wherein the step of determining the condition of the battery comprises determining battery capacity.

39. The method of claim 1 wherein the step of determining the condition of the battery comprises determining state of charge.

40. The method of claim 1 wherein the step of obtaining raw battery test data comprises performing a resistance test.

41. The method of claim 1 wherein the step of obtaining raw battery test data comprises an impedance test.

42. The apparatus of claim 20 wherein the information related to the battery comprises battery type.

43. The apparatus of claim 20 wherein the information related to the battery comprises battery serial number.

44. The apparatus of claim 20 wherein the information related to the battery comprises battery model.

45. The apparatus of claim 20 wherein the information related to the battery comprises date of the manufacture of the battery.

46. The apparatus of claim 19 wherein the information related to the vehicle comprises the vehicle VIN code.

47. The apparatus of claim 13 wherein the test condition information includes geographic location.

48. The apparatus of claim 13 wherein the test condition information includes time information.

49. The apparatus of claim 13 wherein the test condition information includes the name of the operator.

50. The apparatus of claim 13 wherein the test condition information includes a digital signature.

51. The apparatus of claim 13 wherein the output circuitry comprises a printer output.

52. The apparatus of claim 13 wherein the output circuitry comprises a data transmission circuit.

53. The apparatus of claim 5 wherein the data transmission circuit comprises a modem.

54. The apparatus of claim 13 wherein the battery test circuitry includes a circuitry determining battery impedance.

* * * * *

US005821756A

United States Patent [19]

McShane et al.

[11] **Patent Number: 5,821,756**

[45] **Date of Patent: Oct. 13, 1998**

[54] ELECTRONIC BATTERY TESTER WITH TAILORED COMPENSATION FOR LOW STATE-OF CHARGE

[75] Inventors: **Stephen J. McShane**, Oak Brook; **Kevin I. Bertness**, Batavia, both of Ill.; **Keith S. Champlin**, Minneapolis, Minn.

[73] Assignee: **Midtronics, Inc.**, Burr Ridge, Ill.

[21] Appl. No.: **721,618**

[22] Filed: **Sep. 26, 1996**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 496,467, Jun. 29, 1995, Pat. No. 5,585,728, which is a continuation of Ser. No. 292,925, Aug. 18, 1994, abandoned, which is a continuation of Ser. No. 877,646, May 1, 1992, abandoned.

[51] **Int. Cl.**^{6} **G01N 27/416**; G01R 31/36

[52] **U.S. Cl.** **324/430**; 324/427; 324/429

[58] **Field of Search** 324/426, 427, 324/429, 430; 320/106, 162; 340/636

[56] References Cited

U.S. PATENT DOCUMENTS

3,873,911	3/1975	Champlin	324/430
3,886,443	5/1975	Miyakawa et al.	324/426
3,909,708	9/1975	Champlin	324/431
3,946,299	3/1976	Christianson et al.	320/43
3,969,667	7/1976	McWilliams	324/427
4,193,025	3/1980	Frailing et al.	324/427
4,423,378	12/1983	Marino et al.	324/427
4,697,134	9/1987	Burkum et al.	320/48
4,719,428	1/1988	Liebermann	324/436
4,816,768	3/1989	Champlin	324/428
4,825,170	4/1989	Champlin	324/436
4,881,038	11/1989	Champlin	324/426
4,912,416	3/1990	Champlin	324/430
4,929,931	5/1990	McCuen	340/636
4,968,941	11/1990	Rogers	324/428
5,032,825	7/1991	Kuznicki	340/636
5,047,722	9/1991	Wurst et al.	324/430
5,140,269	8/1992	Champlin	324/433
5,343,380	8/1994	Champlin	363/46
5,434,495	7/1995	Toko	324/427 X
5,485,090	1/1996	Stephens	324/433

OTHER PUBLICATIONS

Debardelaben, Sheldon, Determining the End of Battery Life, New York Telephone Company, 1986 IEEE, Ch. 2328, pp. 365–368. (month unavailable).

Vaccaro, F.J. and Casson, P., Internal Resistance: Harbinger of Capacity Loss in Starved Electrolyte Sealed Lead Acid Batteries, AT&T Bell Laboratories, 1987 IEEE, Ch. 2477, pp. 128,131. (month unavailable).

IEEE Recommended Practice for Maintenance, Testings and Replacement of Large Lead Storage Batteries for Generating Stations and Substations, The Institute of Electrical and Electronics Engineers, Inc., ANSI/IEEE Std. 450–1987, Mar. 9, 1987, pp. 7–15.

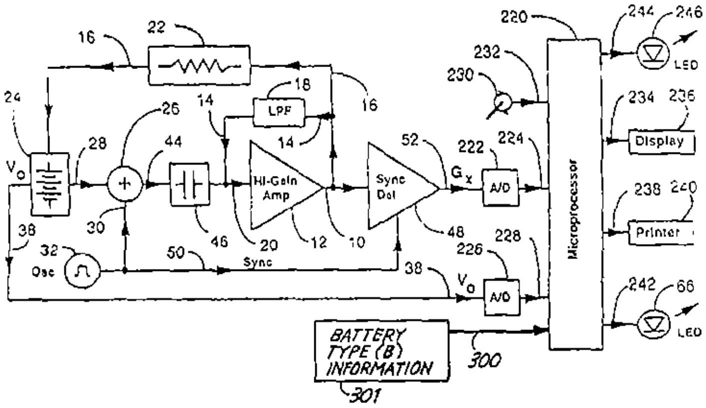
Primary Examiner—Glenn W. Brown

Attorney, Agent, or Firm—Westman, Champlin & Kelly, P.A.

[57] ABSTRACT

Various embodiments of an improved electronic device for testing or monitoring storage batteries that may be only partially charged are disclosed. The device determines the battery's small-signal dynamic conductance in order to provide either a proportional numerical readout, displayed in appropriate battery measuring units, or a corresponding qualitative assessment of the battery's relative condition based upon its dynamic conductance and electrical rating. The device also determines the battery's terminal voltage in an essentially unloaded condition and utilizes this information to automatically correct the measured dynamic conductance. The automatic correction is performed by the electronic device using information or functions which are tailored for the particular type of battery being tested. By virtue of this automatic correction, the quantitative or qualitative information displayed to the user conforms with that of a fully-charged battery even though the battery may, in actual fact, be only partially charged. If the battery's state-of-charge is too low for an accurate assessment to be made, no information is displayed. Instead, an indication is made to the user that the battery must be recharged before testing.

12 Claims, 7 Drawing Sheets



EXHIBIT

B

PENGAD-Bayonne, N. J.

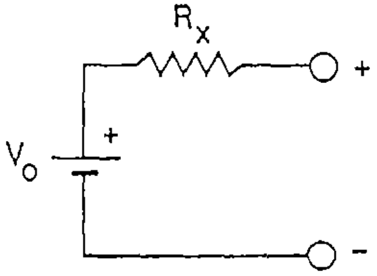

R_X
+
+
V_O
-

Fig. 1

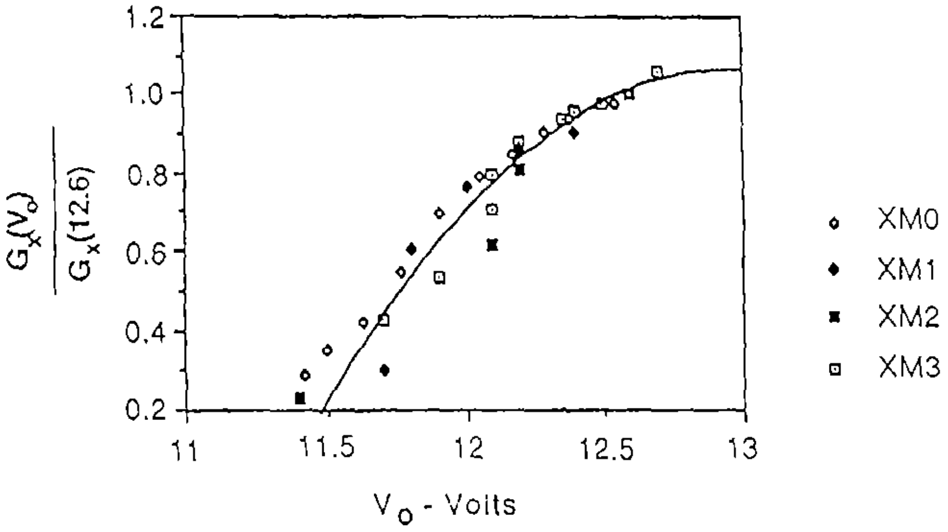
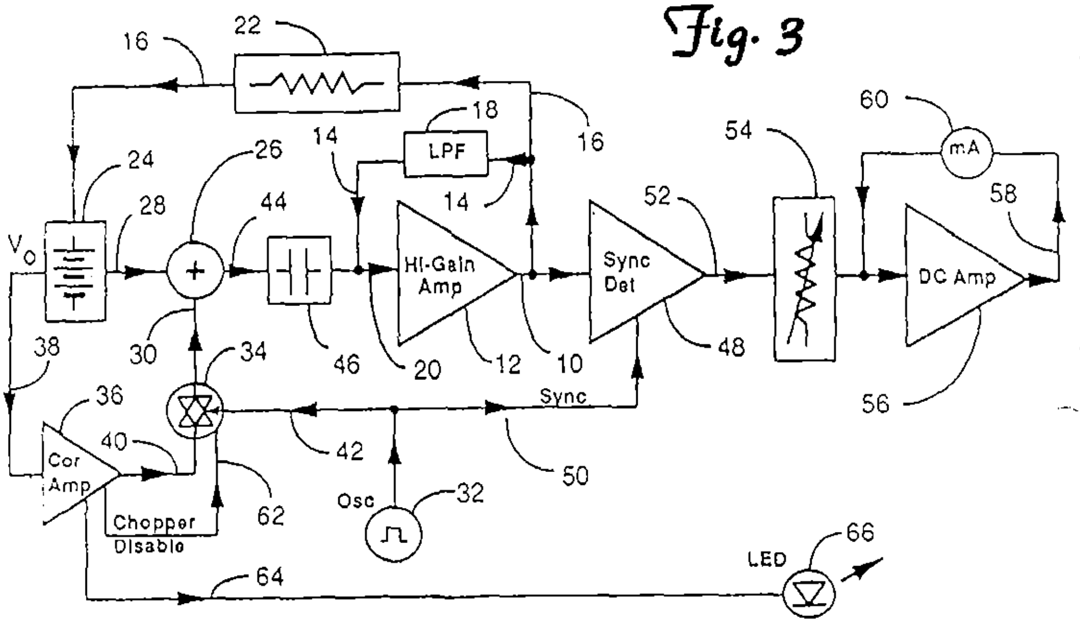

1.2
1.0
0.8
0.6
0.4
0.2
11
11.5
12
12.5
13
V_O - Volts
$\frac{G_X(V_O)}{G_X(12.6)}$
◇ XM0
◆ XM1
✱ XM2
▫ XM3

Fig. 2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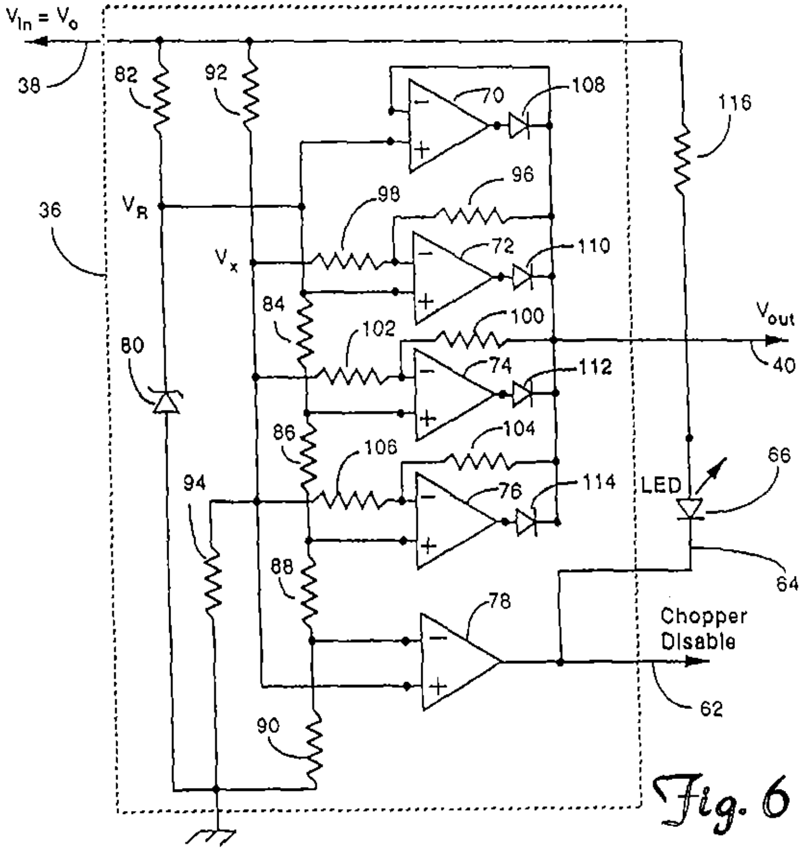
22
18
LPF
14
16
60
mA
54
24
26
28
44
14
52
58
Vo
Hi-Gain Amp
Sync Det
DC Amp
38
30
34
46
20
12
10
48
56
36
Cor Amp
40
42
Sync
50
62
Chopper Disable
Osc
32
66
LED
64

Fig. 3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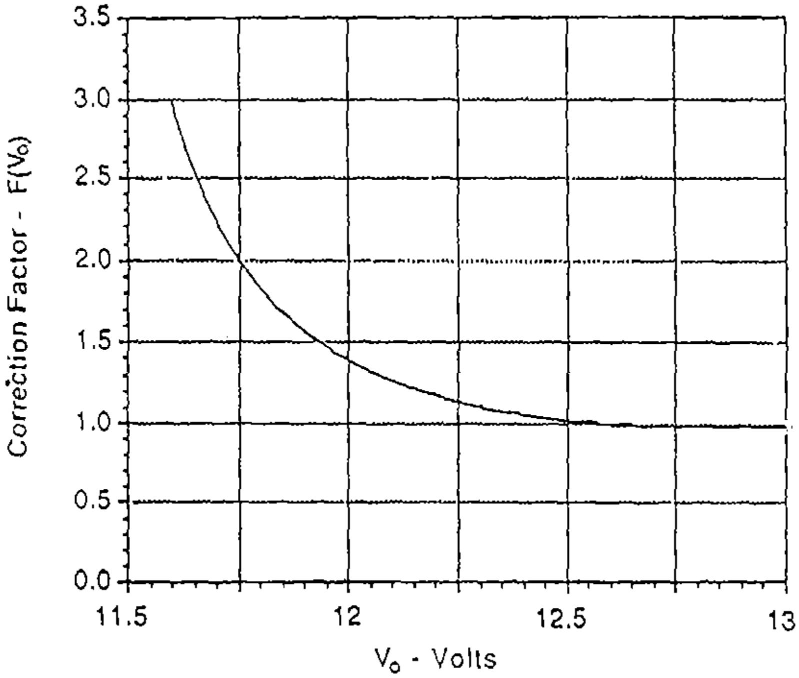
82
92
70
108
116
36
VR
98
96
Vx
72
110
84
102
100
Vout
40
80
74
112
86
106
104
66
94
76
114
LED
64
88
78
Chopper Disable
62
90

Fig. 6


3.5
3.0
2.5
2.0
1.5
1.0
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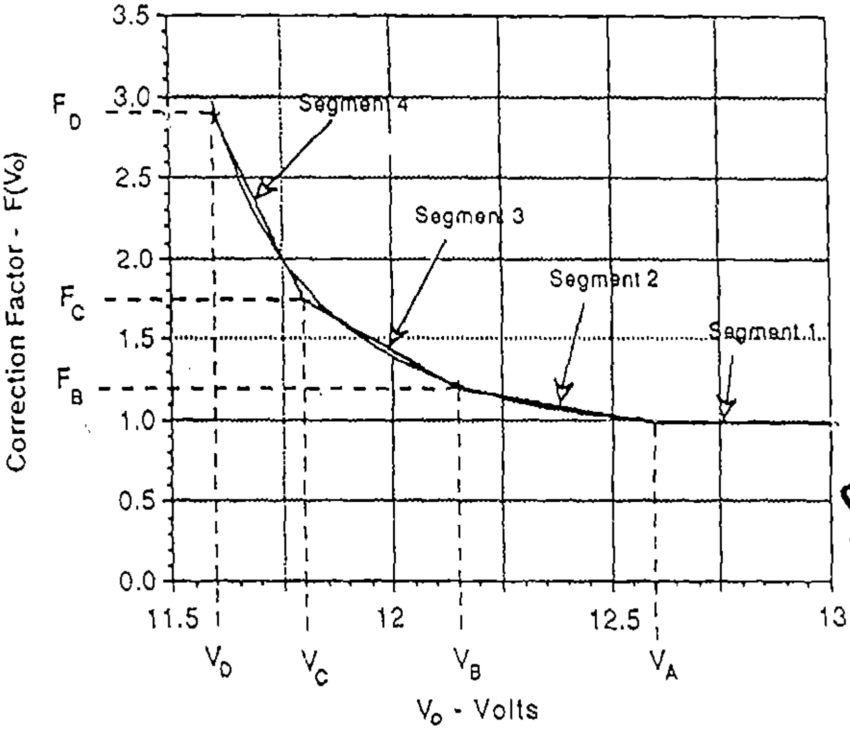
0.0
Correction Factor - $F(V_o)$
11.5
12
12.5
13
V_o - Volts

Fig 4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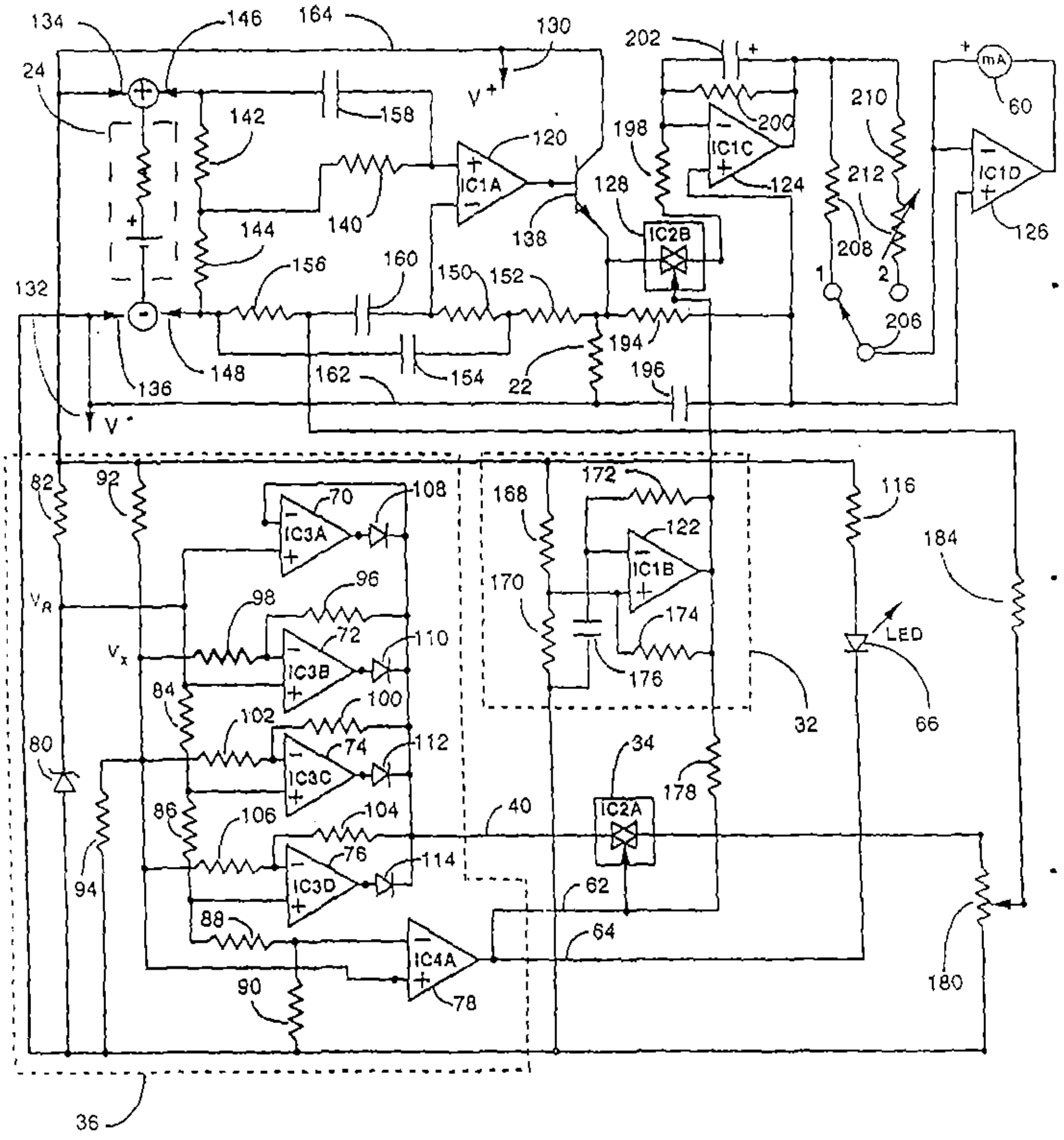
3.0
2.5
2.0
1.5
1.0
0.5
0.0
F_D
F_C
F_B
Correction Factor - $F(V_o)$
Segment 4
Segment 3
Segment 2
Segment 1
11.5
12
12.5
13
V_D
V_C
V_B
V_A
V_o - Volts

Fig 5


134
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202
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V+
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IC1C
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IC1D
126
144
140
138
128
IC2B
208
1
2
156
160
150
152
132
194
206
136
148
162
154
22
196
V-
82
92
70
IC3A
108
168
172
122
IC1B
116
184
V_R
98
96
170
174
LED
V_x
72
IC3B
110
176
84
102
100
32
66
74
IC3C
112
80
34
178
IC2A
86
106
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IC3D
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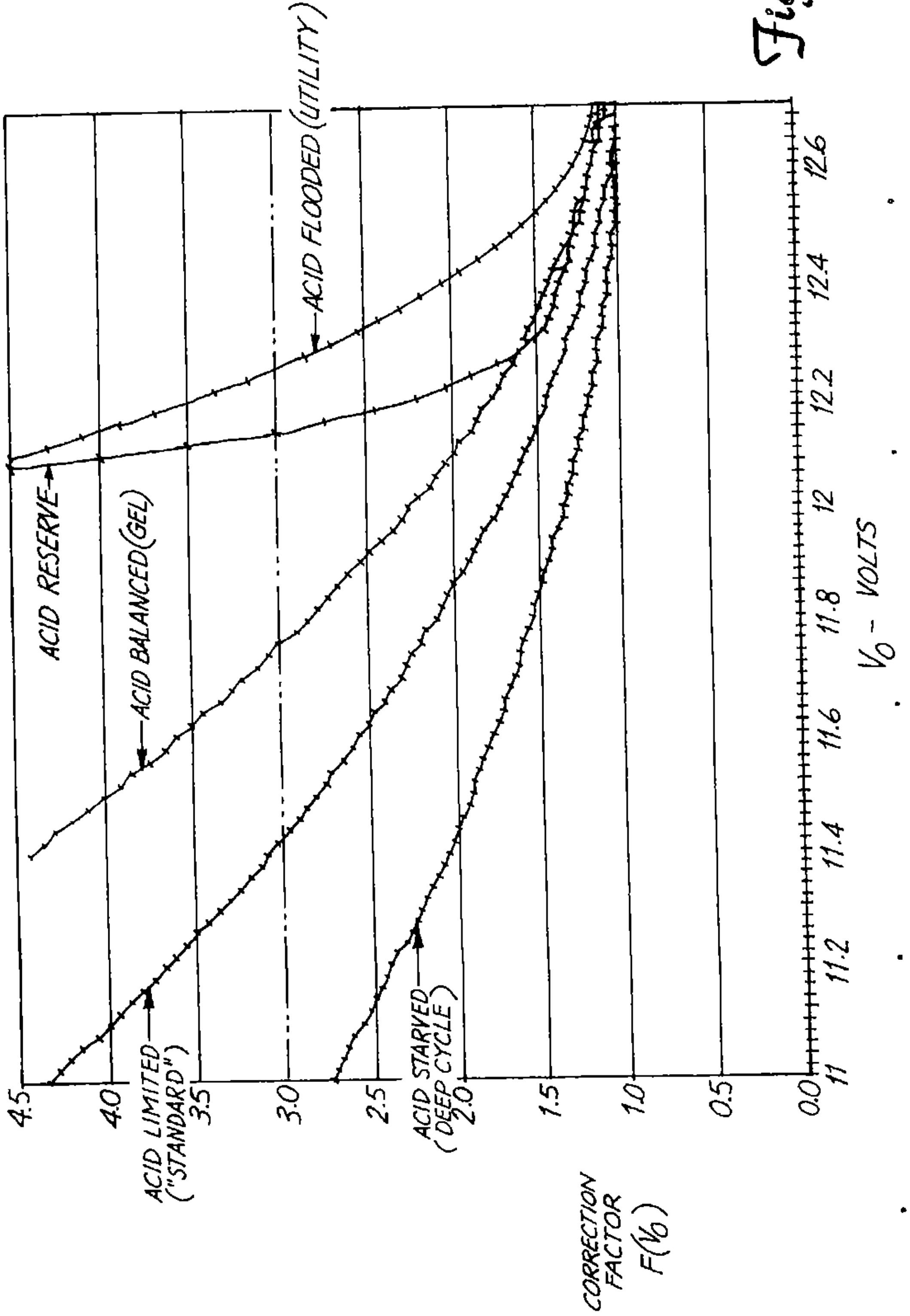
94
62
88
IC4A
64
180
90
78
36

Fig. 7

Fig. 8


ACID FLOODED (UTILITY)
ACID RESERVE
ACID BALANCED (GEL)
ACID LIMITED ("STANDARD")
ACID STARVED (DEEP CYCLE)
CORRECTION FACTOR $F(V_0)$
V_0 - VOLTS
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
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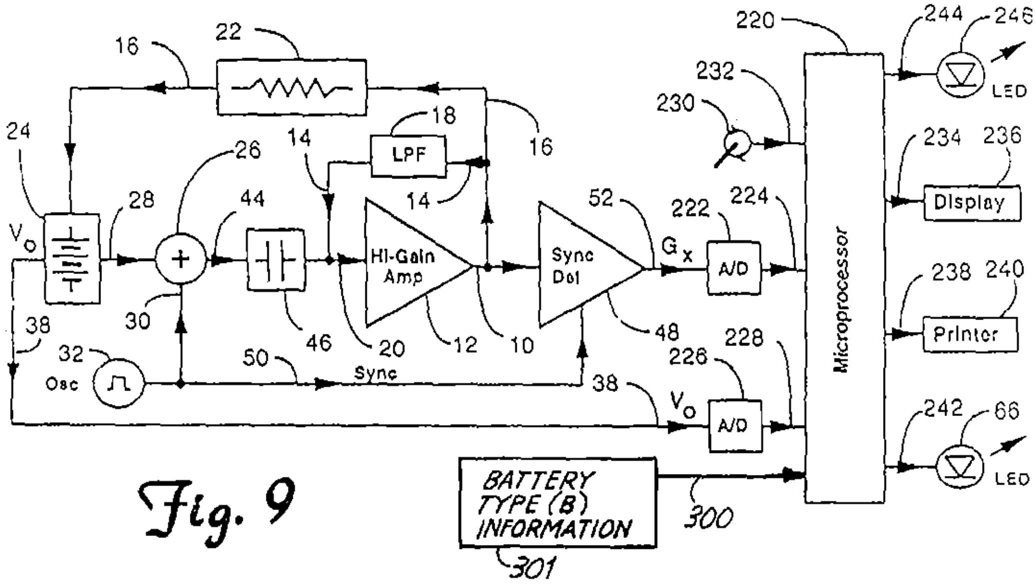
0.0
11
11.2
11.4
11.6
11.8
12
12.2
12.4
12.6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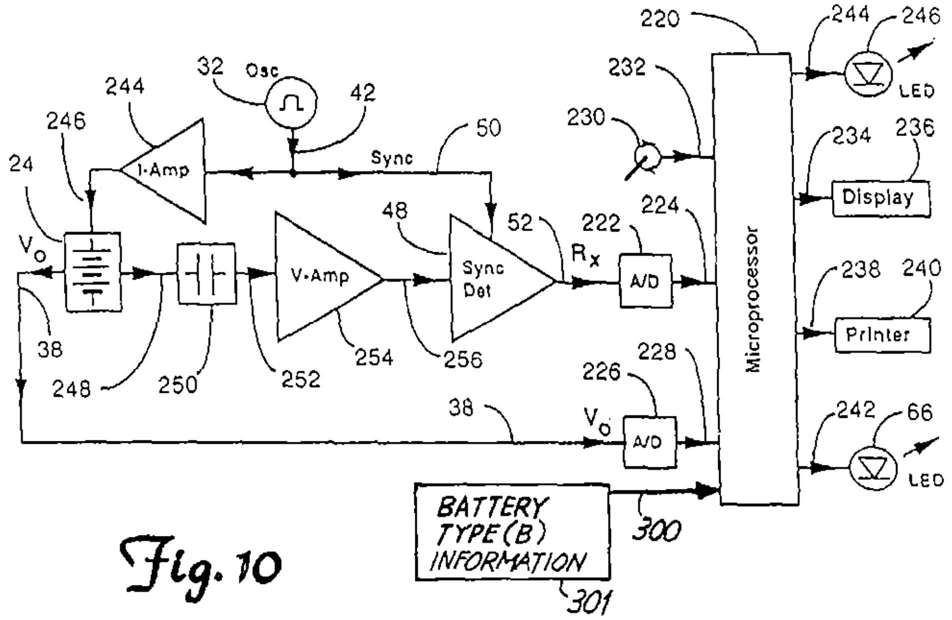
222
224
Display
Vo
Hi-Gain Amp
Sync Det
Gx
A/D
Microprocessor
38
30
46
20
12
10
48
238
240
Printer
32
Osc
50
Sync
226
228
38
Vo
A/D
242
66
LED
BATTERY TYPE (B) INFORMATION
300
301

Fig. 9


220
244
246
32
Osc
42
232
LED
244
246
I-Amp
50
Sync
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234
236
24
Display
48
52
222
224
Vo
V-Amp
Sync Det
Rx
A/D
Microprocessor
238
240
Printer
38
248
250
252
254
256
226
228
38
Vo
A/D
242
66
LED
BATTERY TYPE (B) INFORMATION
300
301

Fig. 10

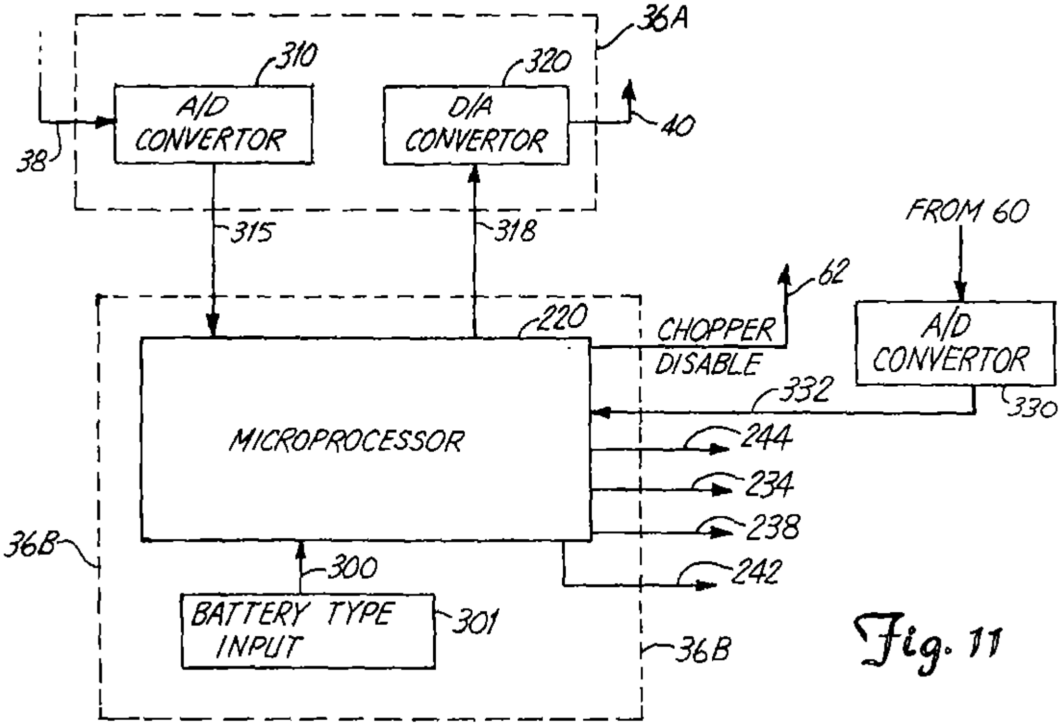
36A
310
A/D CONVERTOR
320
D/A CONVERTOR
40
38
315
318
FROM 60
62
220
CHOPPER DISABLE
A/D CONVERTOR
332
330
MICROPROCESSOR
244
234
238
242
36B
300
BATTERY TYPE INPUT
301
36B

Fig. 11

ELECTRONIC BATTERY TESTER WITH TAILORED COMPENSATION FOR LOW STATE-OF CHARGE

BACKGROUND OF THE INVENTION

This application is a Continuation-In-Part of patent application entitled ELECTRONIC BATTERY TESTER WITH AUTOMATIC COMPENSATION FOR LOW STATE-OF-CHARGE, United States patent application Ser. No. 08/496,467, filed Jun. 29, 1995, now U.S. Pat. No. 5,585,728, which is a file wrapper continuation of Ser. No. 08/292,925, filed on Aug. 18, 1994, now abandoned, which is a file wrapper continuation of Ser. No. 07/877,646, filed May 1, 1992, now abandoned.

This invention relates to an electronic measuring or monitoring device for assessing the ability of a storage battery to deliver power to a Load. More specifically, it relates to improved apparatus of the type disclosed previously in U.S. Pat. Nos. 3,873,911, 3,909,708, 4,816,768, 4,825,170, 4,881,038, and 4,912,416 issued to Keith S. Champlin.

Storage batteries are employed in many applications requiring electrical energy to be retained for later use. Most commonly, they are employed in motor vehicles utilizing internal combustion engines. In such applications, energy stored by "charging" the battery during engine operation is later used to power lights, radio, and other electrical apparatus when the engine is stopped. The most severe demand upon the battery of a motor vehicle is usually made by the starter motor. Failure to supply the starter motor with sufficient power to crank the engine, particularly in cold weather, is often the first indication of battery deterioration. Clearly, a simple measurement that accurately assesses a battery's ability to supply cranking power is of considerable value.

Prior to the introduction of the dynamic conductance testing method disclosed in the six U.S. patents enumerated above, the method most generally available for assessing a battery's ability to supply cranking power was the standard load test. This test subjects a battery to a heavy dc current having a predetermined value dictated by the battery's rating. After a prescribed time interval, the battery's voltage under load is observed. The battery is then considered to have "passed" or "failed" the load test according to whether its voltage under load is greater, or less, than a particular value.

Although the standard load test has been widely used for many years, it has several serious disadvantages. These include:

1. The test draws a large current and therefore requires apparatus that is heavy and cumbersome.
2. Considerable "sparking" can occur if the test apparatus is connected or disconnected under load conditions. Such "sparking" in the presence of battery gasses can cause an explosion with the potential for serious injury to the user.
3. A standard load test leaves the battery in a significantly reduced state-of-charge and therefore less capable of cranking the engine than before the test was performed.
4. The battery's terminal voltage decreases with time during performance of the load test. Accordingly, test results are generally imprecise and often dependent upon the skill of the operator.
5. Load test results are not repeatable since the test itself temporarily polarizes the battery. Such test-induced polarization significantly alters the initial conditions of any subsequently-performed tests.

A practical alternative to the standard load test is taught in the six U.S. Patents enumerated above. These documents disclose electronic apparatus for accurately assessing a battery's condition by means of small-signal ac measurements of its dynamic conductance. They teach that a battery's dynamic conductance is directly proportional to its dynamic power—the maximum power that the battery can deliver to a load. Dynamic conductance is therefore a direct measure of a battery's ability to supply cranking power.

In comparison with the load test method of battery appraisal, the dynamic conductance testing method has many advantages. For example, dynamic conductance testing utilizes electronic apparatus that is small and lightweight, draws very little current, produces virtually no sparking when connected or disconnected, does not significantly discharge or polarize the battery, and yields accurate, highly reproducible, test results. Virtually millions of battery measurements performed over the years have fully corroborated these teachings and have proven the validity of this alternative testing method.

One disadvantage, however, of the dynamic conductance testing method has been the fact that test results are somewhat dependent upon the battery's state-of-charge. Accordingly, the methods and apparatus disclosed in the first five of the six U.S. patents cited above have generally required that the battery be essentially fully charged to be tested. Since many batteries are, in fact, fairly discharged when they are returned for replacement under warranty, or when they are otherwise suspected of being faulty, it has been frequently necessary to recharge a battery before testing it. Such recharging is costly and time-consuming. Clearly, a simple method for performing accurate dynamic conductance tests on batteries "as is"—batteries that may be only partially charged—would be of considerable benefit.

Great progress toward solving this problem has been engendered by the methods and apparatus disclosed in the sixth U.S. patent cited above; U.S. Pat. No. 4,912,416. As is well known to those skilled in the art, a battery's state-of-charge is directly related to its open-circuit (unloaded) terminal voltage. By utilizing this fact, along with extensive experimental data, an empirical relationship was established between a battery's state-of charge, as reflected by its open-circuit voltage, and its relative dynamic conductance, normalized with respect to its fully-charged value. This empirical relationship was first disclosed in U.S. Pat. No. 4,912,416. Further, apparatus disclosed therein utilized this empirical relationship, along with measurements of open-circuit voltage, to appropriately correct dynamic conductance readings—thus yielding battery assessments that were essentially independent of the battery's state-of-charge.

However, the measuring apparatus disclosed in U.S. Pat. No. 4,912,416 utilized an inconvenient two-step testing procedure requiring intermediate interaction by the user. The battery's open-circuit voltage was first measured. Next, using the results of the voltage measurement, the user adjusted a variable attenuator to an appropriate setting. Finally, the dynamic conductance was measured. By virtue of the previously adjusted variable attenuator, the quantitative or qualitative dynamic conductance information ultimately displayed to the user conformed with that of a fully-charged battery even though the battery may, in actual fact, have been only partially charged when tested. The state-of-charge problem was thus solved in principle by the methods and apparatus taught in U.S. Pat. No. 4,912,416.

Measuring apparatuses and methods which compensate a battery's relative conductance based upon the teaching of

U.S. Pat. No. 4,912,416 work extremely well for "standard" (i.e., "acid-limited") battery types—batteries for which the relationship between the state-of-charge and the relative dynamic conductance closely follows the empirical relationship disclosed in U.S. Pat. No. 4,912,416. However, this "standard" empirical relationship does not work as well for compensating the relative dynamic conductance of batteries constructed differently, for which the "standard" empirical relationship may not be as accurate. For example, a battery designed for use in warmer climates may have a lower plate count for its size as compared to a more expensive battery which has more plates per acid volume. The higher plate count battery ("acid-starved") will typically provide power down to a much lower voltage than will the lower plate count ("acid-flooded") battery. Thus, a "standard" charge compensation curve will tend to overcompensate the battery with the high plate count and undercompensate the battery with the low plate count.

It is therefore quite apparent that an improved apparatus which provides automatic state-of-charge correction for a wide variety of battery types would be highly advantageous. Just such an improved electronic battery testing apparatus, providing for automatic correction for low state-of-charge for a wide variety of battery types, is disclosed herein below.

SUMMARY OF THE INVENTION

Various embodiments of an improved electronic device for testing or monitoring storage batteries that may be only partially charged are disclosed. The device determines the battery's small-signal dynamic conductance in order to provide either a proportional numerical readout, displayed in appropriate battery measuring units, or a corresponding qualitative assessment of the battery's relative condition based upon its dynamic conductance and electrical rating. The device also determines the battery's terminal voltage in an essentially unloaded condition and utilizes this information to automatically correct the measured dynamic conductance. The automatic correction is performed by the electronic device using information or functions which are tailored for the particular type of battery being tested. By virtue of this automatic correction, the quantitative or qualitative information displayed to the user conforms with that of a fully-charged battery even though the battery may, in actual fact, be only partially charged. If the battery's state-of-charge is too low for an accurate assessment to be made, no information is displayed. Instead, an indication is made to the user that the battery must be recharged before testing.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 depicts the Thevenin's equivalent circuit of a lead-acid storage battery comprising its open-circuit voltage, V_o, and its internal resistance, R_x, connected in series.

FIG. 2 is an empirical plot of normalized dynamic conductance, G_x, versus open-circuit voltage, V_o, showing the correlation with measurements performed upon four different "standard" (acid-limited) lead-acid storage batteries having differing electrical ratings and fabricated by different manufacturers.

FIG. 3 is a simplified block diagram of an improved electronic battery testing/monitoring device employing automatic compensation for low state-of-charge in accordance with a first embodiment of the present invention.

FIG. 4 is a graphical plot of the state-of-charge correction factor obtained by taking the reciprocal of the "standard" empirical normalized dynamic conductance curve of FIG. 2.

FIG. 5 is a plot of a four-segment piecewise-linear approximation to the correction factor curve of FIG. 4 implemented by the correction amplifier circuit disclosed in FIG. 6.

FIG. 6 is a schematic diagram of a dc correction amplifier embodiment which implements the four-segment piecewise-linear transfer function disclosed in FIG. 5.

FIG. 7 is a complete schematic diagram of an improved electronic battery testing/monitoring device with automatic compensation for low state-of-charge configured for testing/monitoring "standard" 12-volt automotive batteries.

FIG. 8 is a graphical plot similar to FIG. 4 but illustrating state-of-charge correction factors for five different types of batteries.

FIG. 9 is a simplified block diagram of an embodiment of an improved electronic battery testing/monitoring device which provides battery type specific automatic compensation for low state-of-charge.

FIG. 10 is a simplified block diagram of another embodiment of an improved electronic battery testing/monitoring device which provides battery type specific automatic compensation for low state-of-charge.

FIG. 11 is a simplified block diagram illustrating one embodiment of the correction amplifier of the device shown in FIG. 3 which can be used to implement the multiple charge compensation curve approach of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring first to FIG. 1, the Thevenin's equivalent circuit of a lead-acid storage battery is shown. In this equivalent representation, the battery is described by its open-circuit voltage, V_o, and its internal resistance, R_x, connected in series.

As has been fully disclosed in the first five of the six U. S. Patents cited above, a conventional dynamic conductance battery test of a fully-charged battery traditionally ignores the open-circuit voltage, V_o. Instead, the electronic test apparatus directly measures the battery's dynamic conductance $G_x = 1/R_x$. The testing/monitoring device then provides the operator with either a numerical readout displayed in proportional battery measuring units (such as "Cold Cranking Amps", "Ampere-Hours", or "Watts") or else with a qualitative display ("Pass/Fail") based upon comparing the measured value of G_x with a corresponding reference value determined from the battery's electrical rating and temperature.

Although the open-circuit voltage, V_o, has not been normally used in dynamic conductance testing of fully-charged batteries, it has been previously used to determine state-of-charge. As is well known to those skilled in the art, a battery's state-of-charge is directly related to its open-circuit (unloaded) terminal voltage. For example, with "standard" (acid-limited) automotive-type lead-acid batteries having nominal voltage of 12 volts, the open-circuit voltage is known to vary from about 11.4 volts, for batteries that are virtually totally discharged, to about 12.6 volts, for batteries that are nearly fully charged.

FIG. 2 shows the observed relationship between normalized dynamic conductance and open-circuit voltage appropriate to "standard" (acid-limited) automotive-type lead-acid storage batteries. This information was disclosed previously in U. S. Pat. No. 4,912,416. FIG. 2 displays an empirical graph of relative dynamic conductance, normalized with respect to the fully-charged value, $G_x(V_o)/G_x(12.6)$, plotted as a function of open-circuit voltage, V_o. The solid curve plotted in FIG. 2 is described by a second-order polynomial equation having coefficients adjusted to best fit the experimental data. The appropriately adjusted polynomial equation is:

$$\frac{G_x(V_x)}{G_x(12.6)} = -\{78.1963\} + \{12.3939\}V_o - \{0.4848\}v_o^2 \qquad \text{Eq. 1}$$

FIG. 2 also discloses normalized experimental points which represent actual measurements obtained from four different "standard"-type (acid-limited) batteries possessing different electrical ratings and fabricated by different manufacturers. Batteries XM0, XM1, and XM3 are six-cell batteries having nominal voltages of 12 volts. Battery XM2 is actually a three-cell, 6-volt battery. Open-circuit voltage measurements of battery XM2 were multiplied by a factor of two in order to plot XM2 data points on the same graph as the other three batteries. One sees that the normalized measurements obtained from all four batteries agree quite closely with the empirical relation described by Equation (1). The fact that the same empirical relation shows strong correlation with experimental data obtained from both 6-volt and 12-volt batteries indicates that the empirical state-of-charge correction disclosed in FIG. 2 is quite universal and is actually a fundamental property of a single cell.

Referring now to FIG. 3, a simplified block diagram of a first embodiment of an improved electronic battery testing/monitoring device with automatic compensation for low state-of-charge is disclosed. Except for specific details having to do with the circuitry for automatic compensation for low state-of-charge, the explanation of the operation of the block diagram of FIG. 3 is identical with that of the corresponding block diagram referred to as FIG. 1 in U.S. Pat. No. 4,816,768.

Accordingly, signals representative of the signal at output **10** of high-gain amplifier cascade **12** are fed back to input **20** of high-gain amplifier cascade **12** by means of two feedback paths; internal feedback path **14** and external feedback path **16**. Internal feedback path **14** includes low pass filter (LPF) **18** and feeds a signal directly back to input **20** of high-gain amplifier cascade **12**. The purpose of internal feedback path **14** and low pass filter **18** is to provide large dc feedback but relatively little ac feedback in order to define the operating point of high-gain amplifier cascade **12** and ensure its dc stability without appreciably reducing its ac voltage gain. External feedback path **16** contains resistive network **22** and feeds a signal current back to the battery undergoing test **24**. Summation circuitry **26** combines the resulting signal voltage **28** developed thereby across battery **24** with a 100 Hz periodic square-wave signal voltage **30**.

In the embodiment disclosed in FIG. 3, the periodic square-wave signal voltage **30** is formed by the action oscillator **32**, chopper switch **34**, and dc correction amplifier (Cor Amp) **36**. The oscillation frequency of oscillator **32** may, for example, be 100 Hz. The voltage applied to input **38** of dc correction amplifier **36** is the dc terminal voltage of battery **24**. By virtue of the fact that the electronic apparatus disclosed in FIG. 3 draws very little load current from the battery, this terminal voltage is essentially the battery's open-circuit (unloaded) terminal voltage V_o. Signal output **40** of dc correction amplifier **36** is a dc voltage derived from V_o —having a voltage level that is inversely related to V_o—and hence inversely related to the state-of-charge of battery **24**. This derived dc voltage **40** is repetitively interrupted by chopping switch **34** whose control input **42** is activated by the output of oscillator **32**. The chopped dc voltage thus comprises a periodic square-wave signal voltage **30** having a voltage amplitude chat is inversely related to V_o, and hence inversely related to the state-of-charge of battery **24**. This signal voltage **30** is presented to summation circuitry **26** along with the signal voltage **28** developed across battery **24**. The resulting composite signal voltage **44** at the output of summation circuitry **26** is then capacitively coupled to input **20** of high-gain amplifier cascade **12** by means of capacitive coupling network **46**.

As has been fully explained in U.S. Pat. No. 4,816,768, the voltage at out-put **10** of high-gain amplifier cascade **12** comprises a constant dc bias component along with an ac signal component that is proportional to the dynamic conductance G_x of the battery undergoing test **24** as well as to the level of the square-wave signal voltage **30**. The constant dc bias component is ignored while the variable ac signal component is detected and accurately converted to a dc signal voltage by synchronous detector **48**, synchronized to oscillator **32** by means of synchronizing path **50**.

The dc signal voltage at output **52** of synchronous detector **48** passes through adjustable resistive network **54** to the input of dc-coupled operational amplifier **56**. Feedback path **58** of operational amplifier **56** contains dc milliammeter **60**. Accordingly, the reading of dc milliammeter **60** is proportional to the dc signal voltage level at the output **52** of synchronous detector **48**, and hence to the dynamic conductance G_x of battery **24**. In addition, the constant of proportionality relating the milliammeter reading to G_x is determined by the value assumed by adjustable resistive network **54** as well as by the level of the signal voltage at **30**—and hence by the battery's state-of-charge as exemplified by its unloaded dc terminal voltage V_o.

By utilizing an appropriate fixed resistance value in resistive network **54** and then calibrating milliammeter **60** in battery measuring unit numbers that are proportional to the battery's dynamic conductance, the embodiment disclosed in FIG. 3 will emulate the direct reading battery tester disclosed in U.S. Pat. 3,873,911. In addition, as is fully taught in U.S. Pat. No. 4,816,768, the resistance value of resistive network **54** which brings the reading of dc milliammeter **60** to a particular fixed value is directly proportional to the dynamic conductance of battery **24**. Hence, by calibrating resistive network **54** in traditional battery rating units, and then designating "pass" and "fail" regions on the face of milliammeter **60**, the embodiment disclosed in FIG. 3 will also emulate the "pass-fail" battery testing device disclosed in U.S. Pat. No. 3,909,708. Furthermore, one can employ a switch to select either a fixed-valued resistive network **54** or an adjustable-valued network **54** and can arrange both a number scale and "pass-fail" regions on the face of milliammeter **60**. One can therefore realize both a direct-reading battery tester and a "pass-fail" battery tester with a single device.

For either emulation, the amplitude of the detected signal at the output **52** of synchronous detector **48** is directly proportional to the amplitude of the square-wave signal **30** at the output of chopper switch **34**. Hence, both the level of the numerical quantity displayed during direct-reading operation as well as the relative qualitative assessment provided in "pass-fail" operation are influenced by the battery's "state-of-charge", as exemplified by its unloaded terminal voltage V_o. In order for this displayed information to be independent of the battery's state-of-charge, one must require V_{out}, the dc output voltage at **40** of dc correction amplifier **36**, to be proportional to the reciprocal of $G_x(V_o)$. Under these conditions, V_{out} can be written as:

$$V_{out}(V_o)-V_{out}(12.6)\times F(V_o) \qquad \text{Eq. 2}$$

where:

$$F(V_o) = \frac{G_x(12.6)}{G_x(V_o)} \qquad \text{Eq. 3}$$

is an appropriate state-of-charge "correction factor" imposed by correction amplifier **36**. Rearranging Equation 2 leads to:

$$F(V_o) = \frac{V_{out}(V_o)}{V_{out}(12.6)} \qquad \text{Eq. 4}$$

which shows that $F(V_o)$ may be simply regarded as the dc output voltage of amplifier **36** normalized with respect to the corresponding dc output voltage obtained with a fully-charged battery; i.e., a battery for which V_o=12.6 volts.

In addition to providing a dc signal output **40**, the dc correction amplifier **36** also provides a "Chopper Disable" output **62** and an LED output **64**. These two additional outputs become activated whenever the battery's terminal voltage V_o, and hence its state-of-charge, is too small for an accurate dynamic conductance test to be made. Under these special conditions, chopper switch **34** becomes disabled so that no qualitative or quantitative information is displayed to the user. Instead, LED **66** lights to indicate to the user that the battery must be recharged before it can be tested.

FIG. **4** displays a graphical plot of the state-of-charge correction factor $F(V_o)$ obtained by taking the reciprocal of the empirical $\{G_x(V_o)/G_x(12.6)\}$ curve disclosed in FIG. **2**. A four-segment piecewise-linear approximation to this empirical curve is disclosed in FIG. **5**. The parameters which specify the four breakpoints of this piecewise-linear approximation are listed in Table I.

TABLE I

Piecewise-Linear Approximation Parameters

Breakpoint	V_o(Volts)	Correction Factor - F
A	12.60	1.00
B	12.15	1.21
C	11.80	1.78
D	11.60	2.91

The piecewise-linear input-output relationship of FIG. **5** is implemented by the transfer function of the dc correction amplifier circuit embodiment disclosed in FIG. **6**. Referring now to FIG. **6**, the dc correction amplifier contained generally in block **36** comprises the interconnection of four operational amplifiers, **70**, **72**, **74**, and **76** along with comparator **78**. Circuit input lead **38** connects to the positive terminal of the battery **24** under test, while the negative battery terminal is grounded. By virtue of the fact that very little current is drawn from battery **24**, the circuit's input voltage at **38**, V_{in}, measured with respect to ground, is essentially equal to the battery's open-circuit terminal voltage V_o.

Within the dc correction amplifier circuit disclosed in FIG. **6**, a constant reference voltage V_R is established by means of voltage reference diode **80** receiving operating current through series resistor **82**. Reference voltage V_R may, for example, be 2.5 volts. V_R is further operated on by a voltage divider chain comprising resistors **84**, **86**, **88**, and **90**. Accordingly, the voltage level applied to the noninverting inputs of operational amplifiers **70** and **72** is V_R, while increasingly smaller fractions of reference voltage V_R are applied to the noninverting inputs of operational amplifiers **74** and **76** and to the inverting input of comparator **78**, respectively. In addition to these fixed voltage levels, a variable voltage V_x, that is proportional to battery voltage V_o, is derived from V_{in} by means of voltage divider resistors **92** and **94**. This variable voltage is applied directly to the noninverting input of comparator **78** and to the inverting inputs of operational amplifiers **72**, **74**, and **76** through resistors **98**, **102**, and **106**, respectively.

The outputs of the four operational amplifiers, **70**, **72**, **74**, and **76**, are connected to a common output bus, V_{out}, through the four diodes, **108**, **110**, **112**, and **114**, respectively. Because of the operation of these four diodes, only one of the operational amplifiers will be active at any one given time—the amplifier having the largest (most positive) output voltage. That operational amplifier alone will be connected to the output bus and will thus be controlling the output voltage V_{out}. The other three operational amplifiers, those having smaller output voltages, will be disconnected from the output bus by virtue of their having reverse-biased diodes in their output circuits.

Operational amplifier **70** has its inverting input connected directly to the output bus and is therefore configured as a unity-gain voltage-follower amplifying the reference voltage V_R. Operational amplifiers **72**, **74**, and **76** utilize feedback resistors and are configured as inverting amplifiers; each amplifying the variable voltage V_x; and each providing a negative incremental voltage gain given, respectively, by the appropriate resistance ratio {R(96)/R(98)}, {R(100)/R(102)}, or {R(104)/R(106)}.

The circuit of FIG. **6** functions as follows: For $V_{in}>V_A$= 12.6 volts, the output voltage of operational amplifier **70** will be larger than the output voltages of the other three operational amplifiers. Accordingly, the output bus will be controlled by the unity-gain voltage-follower amplifier **70** so that $V_{out}=V_R$. This region of constant output-voltage is represented by segment **1** in the piecewise-linear transfer function displayed in FIG. **5**.

When V_{in} has decreased to V_A=12.6 volts, V_x will have become sufficiently less than V_R that the output of inverting amplifier **72** will equal that of amplifier **70**. Thus, for $V_{in}<V_A$, diode **108** will be reverse biased while diode **110** will be forward biased, and amplifier **72** will control the output bus. Due to the amplification of inverting amplifier **72**, further decreases in V_{in} will cause V_{out} to increase with incremental gain or "slope" of −{(R96)/R(98)}. This region of amplification, which continues unitil $V_{in}=V_B$, is represented by segment **2** in FIG. **5**.

When V_{in} has decreased to V_B, V_X will have decreased sufficiently that the output of inverting amplifier **74** will exceed that of amplifier **72**. Diode **110** will therefore be reverse biased while diode **112** will be forward biased, and amplifier **74** will now control the output bus. Due to the amplification of inverting amplifier **74**, further decreases in V_{in} will cause V_{out} to increase with the larger incremental gain or "slope" of −{R(100)/R(102)}. This region of amplification continues until $V_{in}=V_c$ and is represented by segment **3** in FIG. **5**.

When V_{in} has decreased to V_c, V_x will have decreased sufficiently that the output of inverting amplifier **76** will exceed that of amplifier **74**. Diode **112** will therefore be reverse biased while diode **114** will be forward biased. Thus, amplifier **76** will now control the output bus. Due to the amplifying action of inverting amplifier **76**, any further decreases in V_{in} will cause V_{out} to increase with the still larger incremental gain or "slope" −{R(104)/R(106)}. This region of largest amplification is represented by segment **4** in FIG. **5**.

Finally, for $V_{in}<V_D$, the derived voltage V_x will be less than the tapped-down reference voltage existing at the point of interconnection of resistors **88** and **90**. Under these special conditions, the noninverting input of comparator **78**

will be at a lower potential than the inverting input thus causing comparator **78**'s output to be in a "low" state. As a consequence, LED **66** will be lit to provide an indication to the user that the battery must be recharged before it can be tested. In addition, output line **62** will be in a "low" state, thus disabling chopper switch **34** and preventing any qualitative or quantitative dynamic conductance information from being conveyed to the user.

FIG. 7 discloses a complete schematic diagram of a first embodiment of an improved electronic battery testing/monitoring device with automatic state-of-charge compensation configured or testing/monitoring 12-volt batteries in accordance with the present invention. Operational amplifiers **120**, **122**, **124**, and **126** comprise four elements of a quad operational amplifier integrated circuit, ICI. Bilateral analog switches **34** and **128** comprise two elements of a quad CMOS bilateral switch integrated circuit, IC2. Operational amplifiers **70**, **72**, **74**, and **76** comprise four elements of a quad operational amplifier integrated circuit, IC3. Comparator **78** comprises one element of a quad comparator integrated circuit IC4. All four integrated circuits, ICl, IC2, IC3, and IC4 are powered by means of common power connections, V^+ 130 and V^- 132, connected to the battery undergoing test **24** through battery contacts **134** and **136**, respectively.

High-gain amplifier cascade **12** of FIG. **3** comprises operational amplifier **120** and npn transistor **138** connected as an emitter follower. Resistor **140** conducts a dc bias voltage to the noninverting (+) input of operational amplifier **120** from voltage divider resistors **142** and **144** which are connected to battery **24** through battery contacts **146** and **148**. The output voltage of high-gain amplifier cascade **12** is established across external-path feedback resistor **22**. An internal feedback path comprising resistors **150** and **152** conducts the dc voltage at the common connection between the emitter of npn transistor **138** and resistor **22** to the inverting (−) input of operational amplifier **120**. Resistors **150** and **152** along with capacitor **154** comprise low-pass filter **18** of FIG. **3**.

The ac signal voltage developed across battery **24** is sensed at battery contacts **146** and **148** and added in series to an input signal voltage component established across viewing resistor **156**. The resultant composite ac signal voltage is coupled to the differential input of operational amplifier **120** by means of a capacitive coupling network comprising capacitors **158** and **160**. A feedback current that is proportional to the voltage established across resistor **22** passes through battery **24** by means of external feedback path conductors **162** and **164** along with battery contacts **134** and **136**.

An ac square-wave input signal voltage is established across viewing resistor **156** and is formed by the action of oscillator **32**, chopper switch **34**, and correction amplifier **36**. Oscillator **32**, which generates a 100 Hz square-wave synchronizing signal, is a conventional a stable multivibrator comprising operational amplifier **122** along with resistors **168**, **170**, **172**, **174**, and capacitor **176**. The synchronizing output signal of oscillator **32** is conducted to the control input of chopper switch **34** through resistor **178**. Accordingly, chopper switch **34** turns on and off periodically at a 100 Hz rate. The signal terminals of chopper switch **118** interconnect the dc signal output **40** of correction amplifier **36** with the input lead of trimmer potentiometer **180** used for initial calibration adjustment. The signal voltage across trimmer potentiometer **180** therefore comprises a 100 Hz square wave having amplitude proportional to the dc output voltage of correction amplifier **36**. A signal current proportional to the signal output voltage of trimmer potentiometer **180** passes through injection resistor **184** and is injected into viewing resistor **156** thereby developing a 100 Hz signal voltage across viewing resistor **156**.

By virtue of the action of correction amplifier **36** described with reference to FIG. **6**, the signal voltage across viewing resistor **156** will contain an automatic correction for the state-of-charge of the battery undergoing test. If, however, the battery's state-of-charge is too low for an accurate battery assessment to be made, the correction amplifier's output lines **62** and **64** will be in logic low states. These output lines will, in turn, pull the control input of chopper switch **34** low and pull the cathode of LED **66** low. As a result, chopper switch **34** will be disabled so that no ac signal will be injected into viewing resistor **156**, and LED **66** will light to indicate to the user that the battery must be recharged before a dynamic conductance test can be performed.

Analog switch **128** along with operational amplifier **124**, which is connected as an integrator, comprise synchronous detector **48** of FIG. **3**. Resistor **194** and bypass capacitor **196** comprise a low-pass filter which biases the noninverting input of operational amplifier **124** to the voltage level of the dc bias component developed across feedback resistor **22**. A signal current derived from the total voltage at the common connection between resistor **22** and transistor **138** passes through resistor **198** and analog switch **128** to the inverting input of operational amplifier **124**. This signal current is periodically interrupted at the oscillator frequency by virtue of the control input of analog switch **128** being connected to the synchronizing output of oscillator **32**. Resistor **200** provides negative dc feedback to operational amplifier **124**. Integration capacitor **202** serves to smooth the detected voltage signal outputted by operational amplifier **124**.

The noninverting input of operational amplifier **126** is biased to the dc level of the noninverting input of operational amplifier **124** while the inverting input of operational amplifier **126** is connected to SPDT selector switch **206**. Accordingly, a dc current proportional to the detected signal voltage at the output of operational amplifier **124** passes through milliammeter **60** to the output of operational amplifier **116** by way of one of the two paths selected by selector switch **206**. With switch **206** in position **1**, the meter current passes through fixed resistor **208**. Under these conditions, the disclosed invention emulates a direct reading battery testing device providing a quantitative output displayed in battery measuring units that are proportional to the dynamic conductance of battery **24**. With switch **206** in position **2**, the meter current passes through fixed resistor **210** and variable resistor **212**. Under these conditions the disclosed invention emulates a qualitative, "pass-fail", battery testing device having a manually adjusted battery rating scale that is linearly related to the setting of variable resistance **212**, and a rating offset that is determined by the value of fixed resistor **210**.

The improved battery testing/monitoring device embodiment having automatic compensation for low state-of-charge disclosed in FIG. **7** is operated as follows: The operator simply connects the device to the battery undergoing test and selects one of the two positions of selector switch **206**. If position **1** is selected, meter **60** will display the battery's quantitative condition in appropriate battery measuring units—with the displayed quantitative results having been automatically adjusted to conform with those of a fully-charged battery. If switch **206** is in position **2**, and variable resistance **212** has been set in accordance with the battery's rating, meter **60** will display the battery's qualitative ("pass/fail") condition. Again, the displayed results will have been automatically adjusted to conform with those of a fully-charged battery. With either selection, if the battery's state-of-charge is too low for an accurate assessment to be made, no information will be displayed to the user. Instead, an LED will light to indicate to the user that the battery must be recharged before testing.

Table II contains a listing of component types and values for the first embodiment of an improved electronic battery testing/monitoring device with automatic compensation for low state-of-charge disclosed in FIG. 7.

TABLE II

Component Types and Values for Circuit of FIG. 7

REFERENCE NUMBER	COMPONENT
Semiconductor Devices	
120, 122, 124, 126	IC1 - LM324N
34, 128	IC2 - CD4066B
70, 72, 74, 76	IC3 - LM324N
78	IC4 - LM339
80	IC5 - LM336-2.5
138	TIP31C Power Transistor
108, 110, 112, 114	1N4148 Diodes
66	T-1 ¾ LED
Resistors - Ohms (¼-W unless specified)	
22	22Ω - 5 Watts
82	4.7K
84	5.36K
86	6.19K
88	6.04K
90	200K
92	2.25K
94	576
96, 100, 104	1.00M
98	174K
102	49.9K
106	13.7K
116, 142, 144	1.0K
156, 210	100
208	470
212	500 Variable
180	10K Trimpot
184	470K
140, 200	47K
178, 194, 198	100K
172	150K
174	270K
150, 152, 168, 170	1 Meg
Capacitors - Mfd	
176	0.022
154, 158, 160, 196	0.47
202	1.0
Meter	
204	1 mA dc milliammeter
Switch	
206	SPDT

Frequently, modern batteries are designed for specific cost targets and specific applications. For example, a low cost battery which may be used in warmer climates may have a lower plate count (less active material surface area) for its size as compared to a colder climate battery which costs more and has a higher plate count (more plates per acid volume). The low plate count battery may consume all plate surface area by the time the battery discharges to a voltage of only about 12.4 volts, while the battery with a relatively higher plate count will be able to provide power at much lower voltages. A wide variety of different battery types are

available, using different technologies and construction techniques. The various battery types have different relationships between the battery's open circuit voltage and its relative dynamic conductance. Therefore, using a single "standard" state-of-charge correction factor curve for all battery types can tend to overcompensate some batteries, while undercompensating other batteries.

In order to improve the accuracy of the state-of-charge correction of the present invention, a potentially infinite number of different state-of-charge correction factor curves, corresponding to different battery types, can be used. Like the single correction factor curve approach, the multiple correction factor curve approach of the present invention uses empirical data to establish the correction factor curves in the manner described above. From a practical standpoint, it has been observed that a relatively limited number of correction factor curves can be used by establishing categories of battery types which tend to respond in the same manner. The exact number of curves can be varied to increase the accuracy of the correction.

FIG. 8 is a graphical plot, similar to FIG. 4, illustrating state-of-charge correction factor curves for five different types of batteries. These five battery types, ordered from the largest to the smallest ratio of plate area to acid volume, are designated:

Acid Starved ("Deep Cycle")
Acid Limited ("Standard")
Acid Balanced
Acid Reserve
Acid Flooded ("Utility")

The five curves of FIG. 8 were each determined empirically from experimental data in the same manner as is described above with reference to the single "standard" curve of FIG. 4. Similar to the approximation discussed above with reference to FIG. 5, each of the correction factor curves illustrated in FIG. 8 can be described using segmented piecewise-linear approximations for implementation by the electronic testing devices of the present invention.

The invention provides for the use of one of the standard curves illustrated in FIG. 8, or for the use of one of an infinite variety of curves, as is required to best represent the battery being tested. Theoretically, every battery type or style in existence can be accurately correlated to a specific correction factor curve, so long as the specific battery type can be identified by a stock number or by other identifying codes or designations.

In some embodiments of the present invention, in addition to a compensation factor curve being chosen which most closely represents the characteristic performance of the battery being tested, a threshold voltage for the battery being tested is also selected. Recall that the threshold voltage is the open circuit voltage, for a particular battery type, below which an indication should be given that the battery must be charged before testing can be continued. A wide variety of correction factor functions or look-up tables and threshold voltages can be programmed into a microprocessor in the testing equipment. The particular battery type (B) is identified to the battery tester. By utilizing the particular correction factor function and threshold voltage most closely correlated to the specific battery type being tested, the "fully-charged" dynamic conductance can be more accurately determined and a more accurate indication of the condition of the battery can be given.

FIG. 9 discloses a simplified block diagram of another embodiment of an improved electronic battery testing/monitoring device with automatic compensation for low state-of-charge. This embodiment eliminates the correction amplifier **36** and chopper switch **34** of the first embodiment disclosed in block diagram form in FIG. 3. Instead, it contains a microprocessor represented generally by block **220** of FIG. 9. Further, this embodiment allows the automatic state-of-charge compensation to be tailored for the specific battery type. Microprocessor block **220** includes all of the usual elements which comprise a microprocessor system such as the requisite logic elements, a clock oscillator, a random access memory, a firmware program contained in read-only memory, and, of course, the processor itself. The memory and other components can be integrated with the microprocessor, or they can be distinct external components coupled the microprocessor for operation therewith. With the embodiment of FIG. 9, the appropriate correction for low state-of-charge is performed by microprocessor block **220** under the control of the firmware program contained therein.

Microprocessor block **220** is programmed with functional representations of multiple state-of-charge correction factor curves, such as those illustrated in FIG. **8**, for a number of different battery types (B). Alternatively, microprocessor block **220** can be programmed with look-up table data representative of multiple state-of-charge correction factor curves. Further, voltage threshold values, below which the battery must be recharged prior to testing, are programmed into microprocessor block **220**. The voltage threshold values and the state-of-charge correction factor functions, curves, or look-up tables can be stored for example, in the ROM or RAM associated with microprocessor block **220**. Alternatively, this data can be programmed into EEPROM type memory devices. Further, this data can be updated or altered using a keyboard, a modem communication link with another system, and/or with any other type of suitable input device.

Battery type information is provided to microprocessor block **220** at input **300** using input device **301**. Input device **301** can be a keypad entry device, a barcode reader, a menu driven terminal or any other type of input device adapted for supplying battery type information about the battery being tested to microprocessor block **220**. Battery type related information B can include battery manufacturer serial numbers, model information, manufacturer data, battery ratings in cold cranking amps (CCA), vehicle identification numbers or any other information or format which can be used to inform microprocessor block **220** of the particular type, class, group or characteristics of the battery being tested. With battery type information provided to microprocessor block **220** at input **300**, microprocessor block **220** can tailor the state-of-charge correction by selecting an appropriate correction factor function and threshold voltage which most closely correlate to the battery type of the particular battery being tested.

A description of operation of most of the elements of FIG. 9 parallels the description of operation of the embodiment disclosed in FIG. 3. Signals representative of the signal at output **10** of high-gain amplifier cascade **12** are fed back to input **20** of high-gain amplifier cascade **12** by means of two feedback paths; internal feedback path **14** and external feedback path **16**. Internal feedback path **14** includes low pass filter (LPF) **18** and feeds a signal voltage directly back to input **20** of high-gain amplifier cascade **12**. External feedback path **16** contains resistive network **22** and feeds a signal current back to the battery undergoing test **24**. Summation circuitry **26** combines the resulting signal voltage **28** developed thereby across battery **24** with a periodic square-wave signal voltage **30**.

In the embodiment of FIG. 9, signal voltage **30** simply comprises the constant output signal of oscillator **32**. The oscillation frequency of oscillator **32** may, for example, be 100 Hz. This periodic signal voltage is presented to summation circuitry **26** along with the signal voltage **28** developed across battery **24**, the resulting composite signal voltage **44** at the output of summation circuitry **26** is then capacitively coupled to input **20** of high-gain amplifier cascade **12** by means of capacitive coupling network **46**. Accordingly, the voltage at output **10** of high-gain amplifier cascade **12** comprises a constant dc bias component along with an ac signal component that is proportional to the dynamic conductance G_x of the battery undergoing test **24**. The constant dc bias component is ignored while the variable ac signal component is detected and accurately converted to a dc signal voltage by synchronous detector **48**, synchronized to the oscillator by means of synchronizing path **50**.

The dc signal level at output **52** of synchronous detector **50** is proportional to the battery's dynamic conductance G_x. This analog voltage is converted to a corresponding digital representation of G_x by analog to digital (A/D) converter **222** and then inputted to microprocessor block **220** through input port **224**. In addition, the battery's unloaded voltage V_o is connected via dc path **38** to the input of analog to digital converter **226**. A corresponding digital representation of V_o at the output of A/D converter **226** is thereby inputted to microprocessor block **220** through input port **228**.

By programmed algorithmic techniques that are well-known to those skilled in the art, the microprocessor's firmware program utilizes the digital representation of V_o to correct the digital representation of G_x for the battery's state-of-charge. This can be done, for example, by inputting V_o to a "look-up table" whose output is the corresponding correction factor F, and then multiplying G_x by the resulting factor F to obtain the corrected conductance value, G_x (12.6). Alternatively, the appropriate value of G_x (12.6) could be calculated directly by numerically evaluating the reciprocal of the empirical relationship disclosed in Equation 1. In either case, in preferred embodiments, the microprocessor uses the battery type information from input device **301** provided at input **300** to tailor the state-of-charge correction by selecting the appropriate correction factor function and threshold voltage which most closely correlate to the battery type.

In order to emulate a quantitative-type electronic battery tester, a numerical value proportional to G_x (12.6) is outputted and displayed on a digital display such as **236** interfaced through output port **234**, or printed by a printer such as **240** interfaced to microprocessor **220** through output port **238**. In addition, whenever V_o is less than a predetermined minimum value determined as a function of the particular type of battery being tested, the firmware program suppresses the numerical display and instead provides an indication to the user that the battery must be recharged before testing. This special information can, for example, be displayed by digital display **236**, printed by printer **240**, or conveyed to the user by an LED **66** interfaced to microprocessor **220** through output port **242**.

For emulation of a qualitative ("pass/fail") electronic battery tester, the battery's rating is first inputted to microprocessor **220** through an input device such as a shaft encoder **230** interfaced to microprocessor **220** through input port **232**. A dial associated with shaft encoder **230** is calibrated in battery rating units such as cold cranking amperes or ampere-hours. By programmed algorithmic techniques that are well-known to those skilled in the art, the microprocessor's firmware program then directs microprocessor block **220** to compare the dynamic conductance corrected for state-of-charge, G_x (12.6), with a reference value appropriate to the inputted battery rating and to output the resulting pass/fail information to the user. This qualitative output information can, for example, be displayed by digital display **236**, printed by printer **240**, or conveyed to the user by an LED **246** interfaced to microprocessor **220** through output port **244**. Again, if V_o is less than a predetermined minimum value, the displayed information is suppressed and the user is informed that the battery must be recharged before testing. This special information can, for example, be displayed by digital display **236**, printed by printer **240**, or conveyed to the user by LED **66**.

FIG. **10** discloses a simplified block diagram of another embodiment of an improved electronic battery testing/monitoring device with battery-type specific automatic compensation for low state-of-charge. Like the embodiment disclosed in FIG. **9**, this embodiment employs a microprocessor block **220** to implement the appropriate correction for low state-of-charge. It differs from the embodiment of FIG. **9**, however, in that the hardware inputs a digital representation of the battery's dynamic resistance R_x to microprocessor **220** which then utilizes its firmware program to calculate the reciprocal quantity, the battery's dynamic conductance $G_x=1/R_x$, as well as to correct for the battery's state-of-charge.

The hardware disclosed in FIG. **10** functions as follows: Oscillator **32** generates a periodic square-wave signal **42** which is inputted directly to current amplifier **244**. The oscillation frequency of oscillator **32** may, for example, be 100 Hz. The output of current amplifier **244**, a periodic signal current **246**, then passes through battery **24**. By virtue of the fact that the output resistance of current amplifier **244** is much larger than the battery's dynamic resistance R_x, the amplitude of signal current **246** will be virtually independent of R_x. Accordingly, the resultant ac signal voltage **248** appearing across the battery's terminals will be directly proportional to the battery's dynamic resistance R_x. Capacitive coupling network **250** couples the ac signal voltage **248** to input **252** of voltage amplifier **254**. This coupling network suppresses the battery's dc terminal voltage but permits amplification of the ac signal voltage by voltage amplifier **254**. The output voltage **256** of voltage amplifier **254** provides the input to synchronous detector **48** which is synchronized to oscillator **32** by means of synchronizing path **50**. Accordingly, a dc signal voltage **52** appears at the output of synchronous detector **48** that is directly proportional to the battery's dynamic resistance R_x.

The analog voltage **52** is converted to a corresponding digital representation of R_x by analog to digital (A/D) converter **222** and then inputted to microprocessor block **220** through input port **224**. In addition, the battery's unloaded voltage V_o is connected via dc path **33** to the input of analog to digital converter **226**. A corresponding digital representation of V_o at the output of A/D converter **226** is thereupon inputted to microprocessor block **220** through input port **228**.

As was the case with the battery tester of FIG. **9**, battery-type information is provided to the microprocessor at input **300** using input device **301**. Microprocessor block **220** then uses this information to select one of a number of conversion functions or look-up tables to be used in the state-of-charge correction step. By programmed algorithmic techniques that are well-known to those skilled in the art, the microprocessor's firmware program directs microprocessor block **220** to invert the digital representation of R_x to obtain a digital representation of the battery's dynamic conductance G_x. It then utilizes the digital representation of V_o to correct the digital representation of G_x for the battery's state-of-charge. This can be done, for example, by inputting V_o to a "look-up table" whose output is the corresponding correction factor F, and then multiplying G_x by the resulting factor F to obtain the corrected conductance value, $G_x(12.6)$; or by computing $G_x(12.6)$ directly from is the reciprocal of the empirical relationship disclosed in Equation 1. Alternatively, a corrected value of R_x, $R_x(12.6)$, can be computed first and then algorithmically inverted to obtain $G_x(12.6)$.

In order to emulate a quantitative-type electronic battery tester, a numerical result proportional to $G_x(12.6)$ is outputted and displayed on a digital display such as **236** interfaced through output port **234**, or printed by a printer such as **240** interfaced to microprocessor **220** through output port **238**. In addition, whenever V_o is less than a predetermined minimum value, preferably specific to the particular type of battery being tested, the firmware program suppresses the numerical display and instead provides an indication to the user that the battery must be recharged before testing. This information can, for example, be displayed by digital display **236**, printed by printer **240**, or conveyed to the user by an LED **66** interfaced to microprocessor **220** through output port **242**.

For emulation of a qualitative ("pass/fail") type of electronic battery tester, the battery's rating is inputted to microprocessor **220** through an input device such as a shaft encoder **230** interfaced to microprocessor **220** through input port **232**. A dial associated with shaft encoder **230** is calibrated in battery rating units such as cold cranking amperes or ampere-hours. By programmed algorithmic techniques that are well-known to those skilled in the art, the microprocessor's firmware program directs microprocessor block **220** to compare the computed quantity, $G_x(12.6)$, with a reference quantity appropriate to the inputted battery rating to determine whether the battery passes or fails. For a computed quantity larger than the reference quantity, the battery passes. Otherwise it fails. Alternatively, a comparison can be made between the computed quantity $R_x(12.6)$ and a corresponding reference quantity appropriate to the inputted battery rating to determine whether the battery passes or fails. For a computed quantity less than the reference quantity, the battery passes. Otherwise it fails. In either case, this qualitative information is outputted and displayed by digital display **236**, printed by printer **240**, or conveyed to the user by an LED **246** interfaced to microprocessor **220** through output port **244**. Again, if V_o is less than a predetermined minimum value, the display of qualitative information is suppressed and the user is informed that the battery must be recharged before testing. This special information can, for example, be displayed by digital display **236**, printed by printer **240**, or conveyed to the riser by LED **66**.

The improved electronic battery testing device of the present invention, as illustrated in FIGS. **9** and **10**, can also be implemented using an analog circuit such as the one illustrated in FIG. **3**. FIG. **11** shows portions of one possible implementation of correction amplifier **36** from the electronic testing device illustrated in FIG. **3**. As shown in FIG. **11**, correction amplifier **36** is, for ease of illustration, divided into sections **36A** and **36B**. The DC terminal or open circuit voltage V_o is applied to section **36A** of the correction amplifier at input **38**. Analog-to-digital converter **310** of correction amplifier section **36A** converts open circuit voltage V_o to a digitally represented value and provides this digital value to microprocessor block **220** at input **315**.

Microprocessor block **220** of correction amplifier section **36**B uses battery type information obtained at input **300** from input device **301** to select which of a variety of state-of-charge correction factor curves, functions or look-up tables best correlates to the particular type of battery being tested. Microprocessor block **220** then provides a digital signal at output **318** which is representative of a DC voltage, derived from open circuit voltage V_o having a voltage level that is inversely related to V_o—and hence is inversely related to the state-of-charge of the battery being tested or monitored. Digital-to-analog converter **320** then converts the derived voltage into analog signal **40**. Portions **36**A and **36**B of the correction amplifier illustrated in FIG. **11** can be used as correction amplifier **36** in the device shown in FIG. **3** to provide battery-type specific compensation.

Additionally, microprocessor block **220** shown in FIG. **11** can be used to form a variety of other functions. For example, chopper disable signal **62** from correction amplifier **36** can also be provided as an output of microprocessor block **220**. Further, from FIG. **3**, the output of DC milliammeter **60** can be provided to analog-to digital converter **330** for conversion to a digital signal which is supplied at input **332** to microprocessor block **220**. Thus, the output reading of DC milliammeter **60**, which is proportional to the corrected dynamic conductance of the battery, can be provided to microprocessor **220**. Hence, microprocessor **220** can use this information to provide outputs **244, 234, 238** and or **242** of the type shown in FIGS. **9** and **10**. Thus, LEDs, displays and or printers can be controlled by microprocessor block **220** to display the results of the battery test.

Additionally, it is possible to implement the multiple state-of-charge correction factor curve approach of the present invention with limited or no use of a microprocessor. For example, each of multiple correction amplifiers **36** of the type illustrated in FIG. **6** can be separately tailored for use with different battery types to implement a corresponding state-of-charge correction factor curve. Then, a microprocessor, a manually controlled switch, or other control devices can be used to switch the appropriate correction amplifier into the circuit. In the alternative, a single correction amplifier of the type illustrated in FIG. **6** can be used with selectable components to achieve various piece-wise-linear curves, depending on the battery type being tested.

Although three specific modes for carrying out the invention hereof have been described, it should be understood that many modifications and variations can be made without departing from what is regarded to be the scope and subject matter of the invention. For example, the invention may comprise a single, self-contained, instrument that is temporarily connected to the battery to test the battery on-site. Alternatively, the device may comprise a monitoring device that is semi-permanently connected to the battery to provide continuous monitoring of the battery's condition at a remote location. In this latter case, the device will probably be separated into two parts—one part connected to the battery and located at the battery's site; the other part containing the remote display and located at the remote location. The division between the two parts can be made somewhat arbitrarily. Further, the device can measure either the dynamic conductance of a battery, or the dynamic resistance of the battery. Therefore, as used herein, the term "dynamic battery parameter" is intended to refer to either the dynamic conductance or the dynamic resistance of a battery. We contend that all such divisions, modifications, and variations fall within the scope of the invention disclosed herein and are therefore intended to be covered by the appended claims.

Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention.

What is claimed is:

1. An electronic device for monitoring or testing a battery having one of a plurality of battery types associated therewith, comprising:
   - input circuitry for receiving information related to the type of the battery;
   - dynamic battery parameter determining circuitry for determining an intermediate dynamic parameter of the battery;
   - open circuit voltage sense circuitry coupled to the battery for sensing an open circuit voltage of the battery;
   - correction circuitry coupled to the dynamic battery parameter determining circuitry, to the open circuit voltage sense circuitry and to the input circuitry which adjusts the determined intermediate dynamic parameter based upon the battery type information and upon a value of the open circuit voltage of the battery;
   - output circuitry coupled to the correction circuitry for providing test results indicative of the condition of the battery, wherein the test results are provided as a function of the adjusted intermediate parameter.

2. The electronic device of claim **1** wherein the test results comprise qualitative results in conformance with the adjusted intermediate dynamic parameter relative to a reference dynamic parameter value.

3. The electronic device of claim **1** wherein the correction circuitry comprises a microprocessor and wherein digital representations of the open circuit voltage and the intermediate dynamic parameter are both inputted to the microprocessor and combined algorithmically to adjust the intermediate dynamic parameter.

4. The electronic device of claim **1** wherein the output circuitry provides a special indication when the open circuit voltage is less than a predetermined value and suppresses the test results when the open-circuit voltage is less than the predetermined value.

5. The electronic device of claim **1** wherein the dynamic battery parameter determining circuitry comprises:
   - a time varying current source coupled to the battery for providing a current therethrough;
   - voltage response sense circuitry for sensing a response voltage between two terminals of the battery developed in response to the current flowing therethrough; and
   - detection circuitry coupled to the sense circuitry for determining the intermediate dynamic parameter of the battery based upon the current and the sensed response voltage.

6. The electronic device of claim **5** wherein the time varying current source comprises a load.

7. The electronic device of claim **1** wherein the dynamic battery parameter determining circuitry comprises:
   - a time varying voltage source for applying a time varying voltage between two terminals of the battery;
   - current response sense circuitry for sensing a current flowing through the battery developed in response to the time varying voltage applied thereto;
   - detection circuitry coupled to the sense circuitry for determining the intermediate dynamic parameter of the battery based upon the time varying voltage and the sensed response current.

8. The electronic device of claim 7 wherein the current response sense circuitry senses current flowing through a load.

9. The electronic device of claim 1 wherein the intermediate parameter of the battery is a dynamic conductance of the battery, and wherein the correction circuitry adjusts the dynamic conductance in inverse correspondence with the value of the open circuit voltage of the battery.

10. The electronic device of claim 9 wherein the test results comprise numbers proportional to the adjusted intermediate dynamic conductance.

11. The electronic device of claim 1 wherein the intermediate dynamic parameter of the battery is a dynamic resistance of the battery, and wherein the correction circuitry adjusts the dynamic resistance in direct correspondence with the value of the open circuit voltage of the battery.

12. The electronic device of claim 11 wherein the test results comprise numbers inversely proportional to the adjusted intermediate dynamic resistance.

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