



US006323650B1

(12) **United States Patent**
Bertness et al.

(10) **Patent No.:** **US 6,323,650 B1**
(45) **Date of Patent:** **Nov. 27, 2001**

- (54) **ELECTRONIC BATTERY TESTER**
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- (*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.
- (21) Appl. No.: **09/544,696**
- (22) Filed: **Apr. 7, 2000**

Related U.S. Application Data

- (60) Provisional application No. 60/128,366, filed on Apr. 8, 1999.
- (51) **Int. Cl.**⁷ **G01N 77/416**
- (52) **U.S. Cl.** **324/426; 702/63**
- (58) **Field of Search** **320/426; 702/63**

References Cited

U.S. PATENT DOCUMENTS

- 2,514,745 7/1950 Dalzell 171/95
- 3,356,936 12/1967 Smith 324/29.5
- 3,562,634 2/1971 Latner 31/4

(List continued on next page.)

FOREIGN PATENT DOCUMENTS

- 0 022 450 A1 1/1981 (EP) .
- 29 26 716 B1 1/1981 (DE) .
- 0 637 754 A1 2/1995 (EP) .
- 0 772 056 A1 5/1997 (EP) .
- 2 749 397 12/1997 (FR) .
- 2 088 159 A 6/1982 (GB) .

- 59-17892 1/1984 (JP) .
- 59-17893 1/1984 (JP) .
- 59-17894 1/1984 (JP) .
- 59017894 1/1984 (JP) .
- 59215674 12/1984 (JP) .
- 60225078 11/1985 (JP) .
- 62-180284 8/1987 (JP) .
- 63027776 2/1988 (JP) .
- 03274479 12/1991 (JP) .
- 03282276 12/1991 (JP) .
- 4-8636 1/1992 (JP) .
- 04131779 5/1992 (JP) .
- 04372536 12/1992 (JP) .
- 5216550 8/1993 (JP) .
- 7-128414 5/1995 (JP) .
- WO 93/22666 11/1993 (WO) .
- WO 98/58270 12/1998 (WO) .

OTHER PUBLICATIONS

- "Electrochemical Impedence Spectroscopy in Battery Development and Testing", *Batteries International*, Apr. 1997, pp. 59 and 62-63.
- "Battery Impedence", by E. Willihnganz et al., *Electrical Engineering*, Sep. 1959, pp. 922-925.
- "Determining The End of Battery Life", by S. DeBardelaben, *IEEE*, 1986, pp. 365-368.

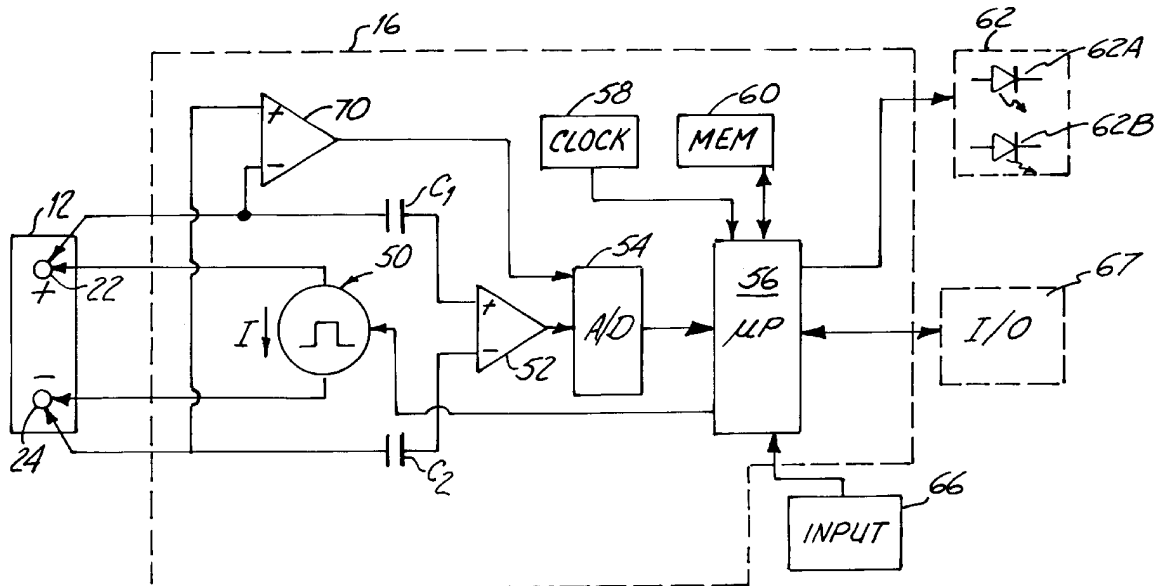
(List continued on next page.)

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(57) **ABSTRACT**

An electronic battery tester includes a calibration interface. A microprocessor is configured to calibrate the battery tester by coupling to a calibrator through the calibration interface.

40 Claims, 3 Drawing Sheets



U.S. PATENT DOCUMENTS							
3,593,099	7/1971	Scholl	320/13	4,931,738	6/1990	MacIntyre et al.	324/435
3,607,673	9/1971	Seyl	204/1	4,937,528	6/1990	Palanisamy	324/430
3,676,770	7/1972	Sharaf et al.	324/29.5	4,947,124	8/1990	Hauser	324/430
3,729,989	5/1973	Little	73/133	4,956,597	9/1990	Heavvvvey et al.	320/14
3,753,094	8/1973	Furuishi et al.	324/29.5	4,968,941	11/1990	Rogers	324/428
3,808,522	4/1974	Sharaf	324/29.5	4,968,942	11/1990	Palanisamy .	
3,811,089	5/1974	Strezelewicz	324/170	5,004,979	4/1991	Marino et al.	324/160
3,873,911	3/1975	Champlin	324/29.5	5,032,825	7/1991	Xuznicki	340/636
3,876,931	4/1975	Godshalk	324/29.5	5,047,722	9/1991	Wurst et al.	324/430
3,886,443	5/1975	Miyakawa et al.	324/29.5	5,087,881	2/1992	Peacock	324/378
3,889,248	6/1975	Ritter	340/249	5,126,675	6/1992	Yang	324/435
3,906,329	9/1975	Bader	320/44	5,140,269	8/1992	Champlin	324/433
3,909,709	9/1975	Champlin	324/29.5	5,144,218	9/1992	Bosscha	320/44
3,936,744	2/1976	Perlmutter	324/158	5,144,248	9/1992	Alexandres et al.	324/428
3,946,299	3/1976	Christianson et al.	320/43	5,160,881	11/1992	Schramm et al.	322/7
3,947,757	3/1976	Grube et al.	324/28	5,170,124	12/1992	Blair et al.	324/434
3,969,667	7/1976	McWilliams	324/29.5	5,179,335	1/1993	Nor	320/21
3,979,664	9/1976	Harris	324/17	5,204,611	4/1993	Nor et al.	320/21
3,984,762	10/1976	Dowgiallo, Jr.	324/29.5	5,214,370	5/1993	Harm et al.	320/35
3,984,768	10/1976	Staples	324/62	5,214,385	5/1993	Gabriel et al.	324/434
3,989,544	11/1976	Santo	429/65	5,241,275	8/1993	Fang	324/430
4,008,619	2/1977	Alcaide et al.	73/398	5,254,952	10/1993	Salley et al.	324/429
4,053,824	10/1977	Dupuis et al.	324/29.5	5,266,880	11/1993	Newland	320/14
4,070,624	1/1978	Taylor	327/158	5,281,919	1/1994	Palanisamy	324/427
4,086,531	4/1978	Bernier	324/158	5,281,920	1/1994	Wurst	324/430
4,112,351	9/1978	Back et al.	324/16	5,295,078	3/1994	Stich et al.	364/483
4,114,083	9/1978	Benham et al.	320/39	5,298,797	3/1994	Redl	307/246
4,126,874	11/1978	Suzuki et al.	354/60	5,300,874	4/1994	Shimamoto et al.	320/15
4,178,546	12/1979	Hulls et al.	324/158	5,302,902	4/1994	Groehl	324/434
4,193,025	3/1980	Frailing et al.	324/427	5,315,287	5/1994	Sol	340/455
4,207,611	6/1980	Gordon	364/580	5,321,626	6/1994	Palladino	364/483
4,217,645	8/1980	Barry et al.	364/483	5,331,268	7/1994	Patino et al.	320/20
4,315,204	2/1982	Sievers et al.	322/28	5,336,993	8/1994	Thomas et al.	324/158.1
4,316,185	2/1982	Watrous et al.	340/636	5,338,515	8/1994	Dalla Betta et al.	422/95
4,322,685	3/1982	Frailing et al.	324/429	5,339,018	8/1994	Brokaw	320/35
4,363,407	12/1982	Barkler et al.	209/3.3	5,343,380	8/1994	Champlin	363/46
4,369,407	1/1983	Korbell	324/416	5,347,163	9/1994	Yoshimura	307/66
4,379,990	4/1983	Sievers et al.	322/99	5,352,968	10/1994	Reni et al.	320/35
4,390,828	6/1983	Converse et al.	320/32	5,365,160	11/1994	Leppo et al.	320/22
4,392,101	7/1983	Saar et al.	320/20	5,365,453	11/1994	Startup et al.	364/481
4,396,880	8/1983	Windebank	320/21	5,381,096	1/1995	Hirzel	324/427
4,408,157	10/1983	Beaubien	324/62	5,412,323	5/1995	Kato et al.	324/429
4,412,169	10/1983	Dell'Orto	320/64	5,426,371	6/1995	Salley et al.	324/429
4,423,378	12/1983	Marino et al.	324/427	5,426,416	6/1995	Jefferies et al.	340/664
4,423,379	12/1983	Jacobs et al.	324/429	5,432,426	7/1995	Yoshida	320/20
4,424,491	1/1984	Bobbett et al.	324/433	5,434,495	7/1995	Toko	320/44
4,459,548	7/1984	Lentz et al.	324/158	5,442,274	8/1995	Tamai	320/23
4,514,694	4/1985	Finger	324/429	5,449,996	9/1995	Matsumoto et al.	320/20
4,520,353	5/1985	McAuliffe	340/636	5,449,997	9/1995	Gilmore et al.	320/39
4,633,418	12/1986	Bishop	364/554	5,451,881	9/1995	Finger	324/433
4,659,977	4/1987	Kissel et al.	320/64	5,457,377	10/1995	Jonsson	320/5
4,667,279	5/1987	Maier	363/46	5,469,043	11/1995	Cherng et al.	320/31
4,678,998	7/1987	Muramatsu	324/427	5,485,090	1/1996	Stephens	324/433
4,679,000	7/1987	Clark	324/428	5,488,300	1/1996	Jamieson	324/432
4,697,134	9/1987	Burkum et al.	320/48	5,519,383	5/1996	De La Rosa	340/636
4,707,795	11/1987	Alber et al.	364/550	5,528,148	6/1996	Rogers	324/426
4,709,202	11/1987	Koenck et al.	320/43	5,537,967	7/1996	Tashiro et al.	123/792.1
4,710,861	12/1987	Kanner	363/46	5,546,317	8/1996	Andrieu	364/481
4,719,428	1/1988	Liebermann	324/436	5,548,273	8/1996	Nicol et al.	340/439
4,743,855	5/1988	Randin et al.	324/430	5,550,485	8/1996	Falk	324/772
4,745,349	5/1988	Palanisamy et al.	320/22	5,561,380	10/1996	Sway-Tin et al.	324/509
4,816,768	3/1989	Champlin	324/428	5,562,501	10/1996	Kinoshita et al.	439/852
4,820,966	4/1989	Fridman	320/32	5,572,136	11/1996	Champlin	324/426
4,825,170	4/1989	Champlin	324/436	5,574,355	11/1996	McShane et al.	320/39
4,849,700	7/1989	Morioka et al.	324/427	5,583,416	12/1996	Klang	320/22
4,876,495	10/1989	Palanisamy et al. .		5,585,728	12/1996	Champlin	324/427
4,881,038	11/1989	Champlin	324/426	5,589,757	12/1996	Klang	320/22
4,912,416	3/1990	Champlin	324/430	5,592,093	1/1997	Klingbiel	324/426
4,913,116	4/1990	Katogi et al.	123/425	5,596,260	1/1997	Moravec et al.	320/30
4,929,931	5/1990	McCuen	340/636	5,598,098	1/1997	Champlin	324/430
				5,602,462	2/1997	Stich et al.	323/258

5,606,242	2/1997	Hull et al.	320/48	6,114,834	9/2000	Parise	320/109
5,621,298	4/1997	Harvey	320/5	6,137,269	10/2000	Champlin	320/150
5,642,031	6/1997	Brotto	320/21	6,150,793	11/2000	Lesesky et al.	320/104
5,650,937	7/1997	Bounaga	364/483	6,163,156	12/2000	Bertness	324/426
5,652,501	7/1997	McClure et al.	320/17	6,172,483	1/2001	Champlin	320/134
5,656,920	8/1997	Cherng et al.	320/31	6,172,505	1/2001	Bertness	324/430
5,675,234	10/1997	Greene	320/15	OTHER PUBLICATIONS			
5,677,077	10/1997	Faulk	429/90	"A Look at the Impedence of a Cell", by S. Debardelaben, <i>IEEE</i> , 1988, pp. 394–397.			
5,699,050	12/1997	Kanazawa	340/636	"The Impedence of Electrical Storage Cells", by N.A. Hampson et al., <i>Journal of Applied Electrochemistry</i> , 1980, pp. 3–11.			
5,701,089	12/1997	Perkins	327/772	"A Package for Impedance/Admittance Data Analysis", by B. Boukamp, <i>Solid State Ionics</i> , 1986, pp. 136–140.			
5,705,929	1/1998	Caravello et al.	324/430	"Precision of Impedence Spectroscopy Estimates of Bulk, Reaction Rate, and Diffusion Parameters", by J. Macdonald et al., <i>J. Electroanal. Chem.</i> , 1991, pp. 1–11.			
5,710,503	1/1998	Sideris et al.	320/6	Internal Resistance: Harbinger of Capacity Loss in Starved Electrolyte Sealed Lead Acid Batteries, by Vaccaro, F. J. et al., <i>AT&T Bell Laboratories</i> , 1987 <i>IEEE</i> , Ch. 2477, pp. 128,131.			
5,717,336	2/1998	Basell et al.	324/430	IEEE Recommended Practice For Maintenance, Testings, and Replacement of Large Lead Storage Batteries for Generating Stations and Substations, <i>The Institute of Electrical and Electronics Engineers, Inc., ANSI/IEEE Std. 450–1987</i> , Mar. 9, 1987, pp. 7–15.			
5,717,937	2/1998	Fritz	395/750.01	"Field and Laboratory Studies to Assess the State of Health of Valve-Regulated Lead Acid Batteries: Part I Conductors/Capacity Correlation Studies", by D. Feder et al., <i>IEEE</i> , Aug. 1992, pp. 218–233.			
5,747,909	5/1998	Syverson et al.	310/156	"Battery Impedance", by E. Willihnganz et al., <i>Electrical Engineering</i> , Sep. 1959, pp. 922–925.			
5,757,192	5/1998	McShane et al.	324/427	"JIS Japanese Industrial Standard—Lead Acid Batteries for Automobiles", <i>Japanese Standards Association UDC</i> , 621.355.2:629.113.006, Nov. 1995.			
5,760,587	6/1998	Harvey	324/434	"Performance of Dry Cells", by C. Hambuechen, Preprint of <i>Am. Electrochem. Soc.</i> , Apr. 18–20, 1912, paper No. 19, pp. 1–5.			
5,773,978	6/1998	Becker	324/430	"A Bridge for Measuring Storage Battery Resistance", by E. Willihncanz, <i>The Electrochemical Society</i> , preprint 79–20, Apr. 1941, pp. 253–258.			
5,789,899	8/1998	van Phuoc et al.	320/30				
5,793,359	8/1998	Ushikubo	345/169				
5,808,469	9/1998	Kopera	324/434				
5,821,756	10/1998	McShane et al.	324/430				
5,825,174	10/1998	Parker	324/106				
5,831,435	11/1998	Troy	324/426				
5,862,515	1/1999	Kobayashi et al.	702/63				
5,872,443	2/1999	Williamson	320/21				
5,895,440	4/1999	Proctor et al.	702/63				
5,914,605	6/1999	Bertness	324/430				
5,929,609	7/1999	Joy et al.	322/25				
5,939,855	8/1999	Proctor et al.	320/104				
5,939,861	8/1999	Joko et al.	320/122				
5,945,829	8/1999	Bertness	324/430				
5,969,625	10/1999	Russo	340/636				
6,002,238	12/1999	Champlin	320/134				
6,008,652	12/1999	Theofanopoulos et al.	324/434				
6,009,369	12/1999	Boisvert et al.	701/99				
6,031,354	2/2000	Wiley et al.	320/116				
6,037,751	3/2000	Klang	320/160				
6,037,777	3/2000	Champlin	324/430				
6,051,976	4/2000	Bertness	324/426				
6,072,299	6/2000	Kurie et al.	320/112				
6,072,300	6/2000	Tsuji	320/116				
6,081,098	6/2000	Bertness et al.	320/134				
6,091,245	7/2000	Bertness	324/426				
6,094,033	7/2000	Ding et al.	320/132				
6,104,167	8/2000	Bertness et al.	320/132				

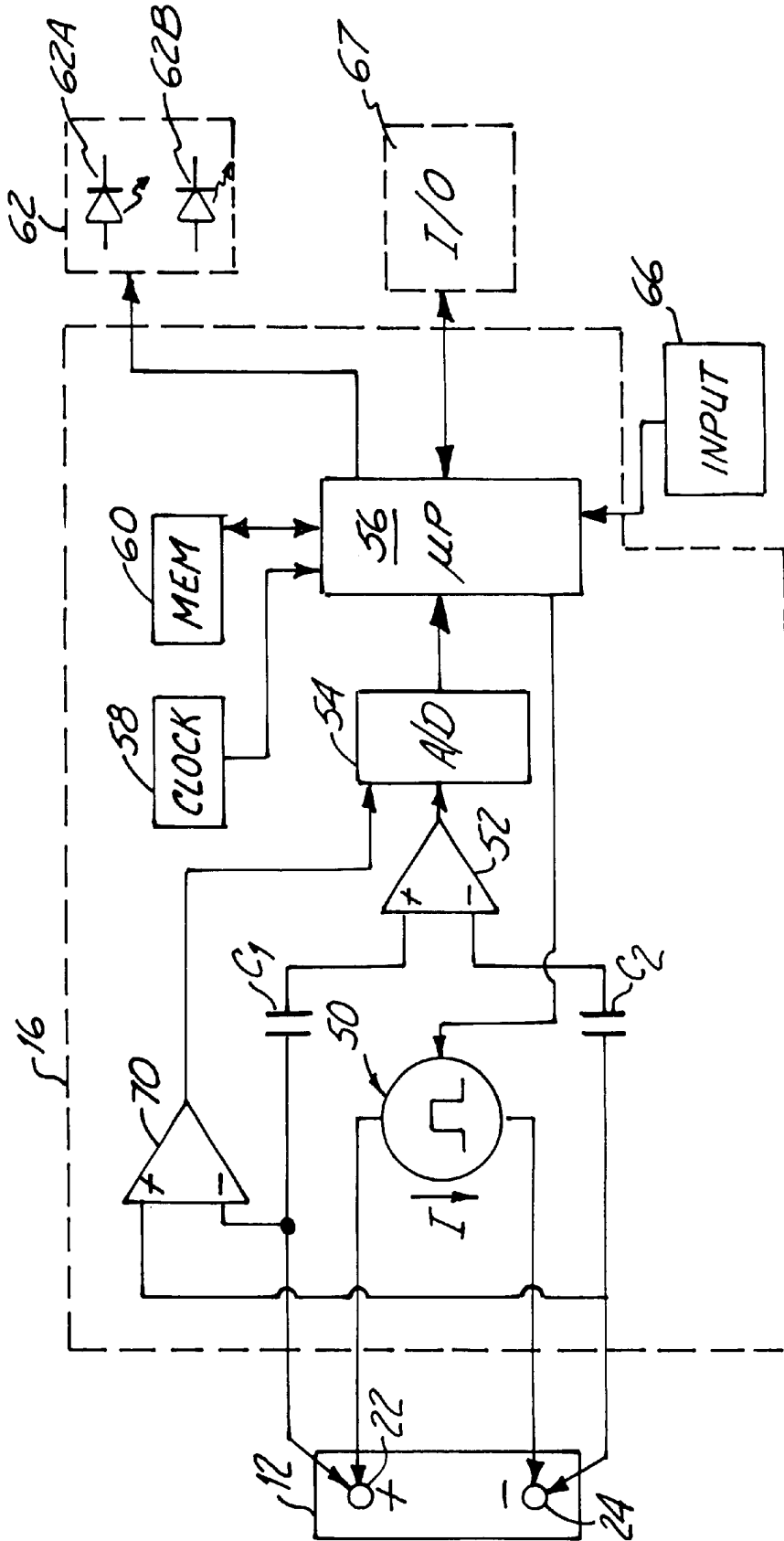
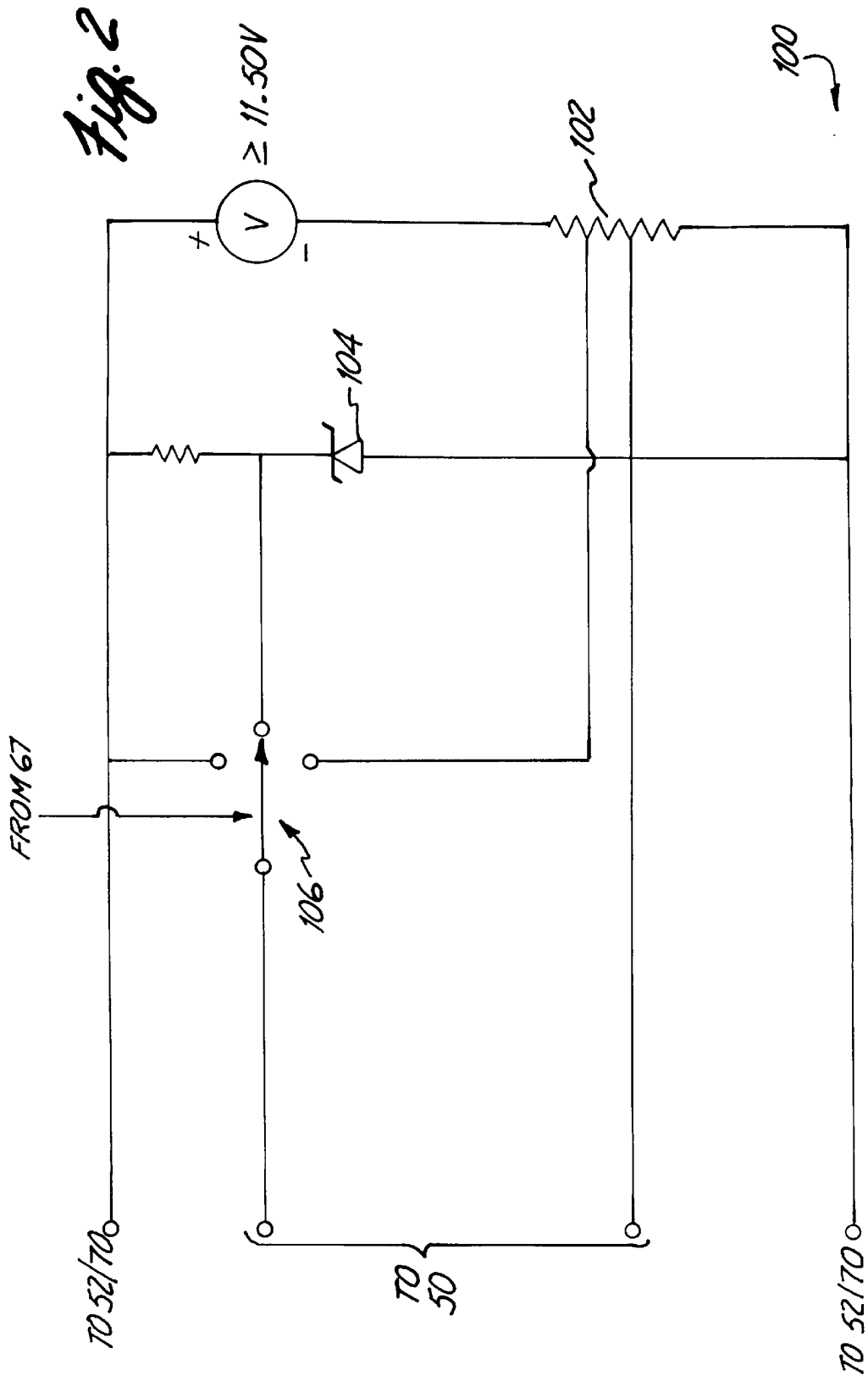


Fig. 1



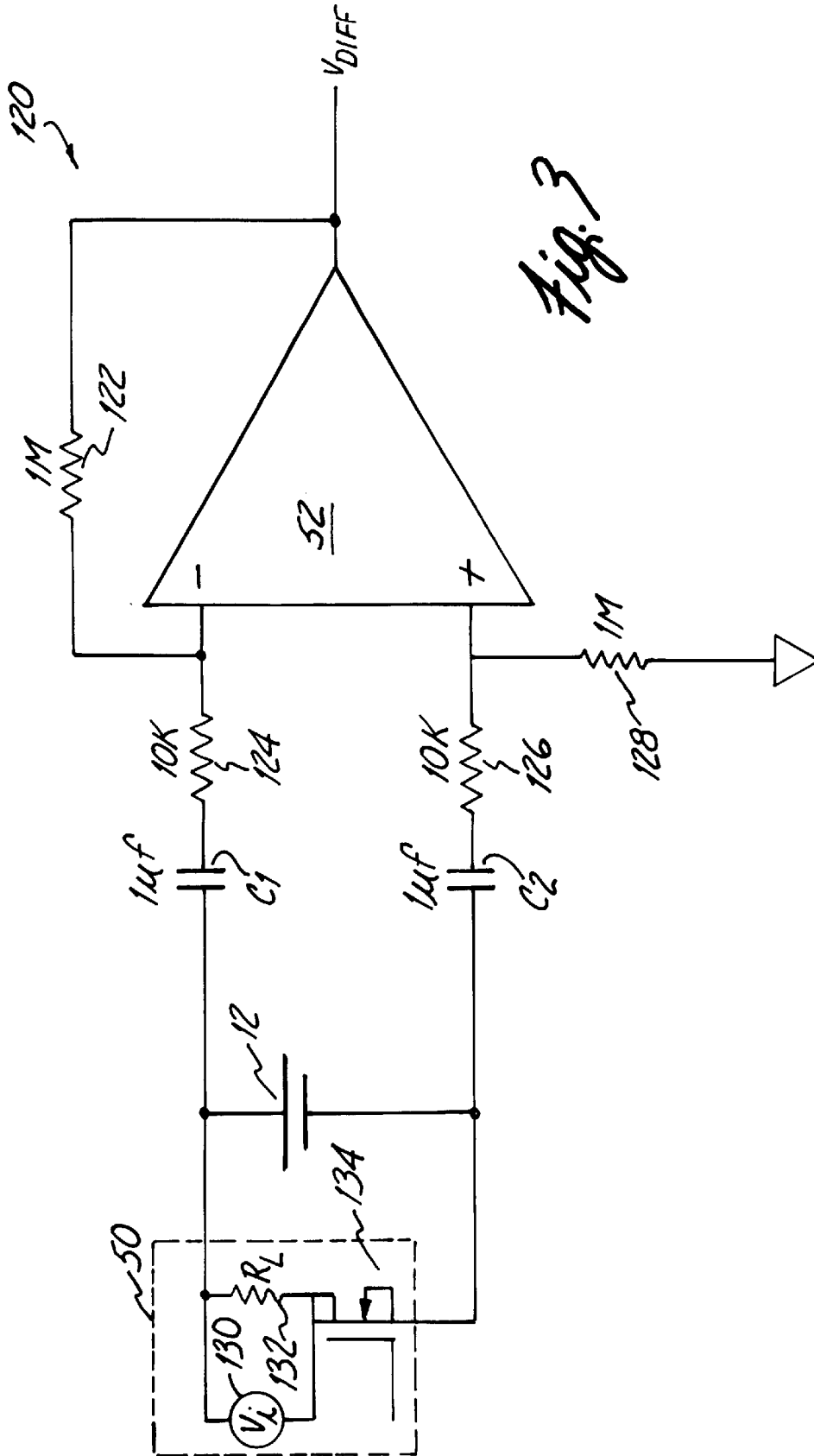


Fig. 3

ELECTRONIC BATTERY TESTER**BACKGROUND OF THE INVENTION**

The present invention claims priority to Provisional Application Serial No. 60/128,366, filed Apr. 8, 1999 and entitled ELECTRONIC BATTERY TESTER.

The present invention relates to testing of storage batteries. More specifically, the present invention relates to electronic battery testers of the type used to test the condition of storage batteries.

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 and Midtronics, Inc. of Burr Ridge, Ill. 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 and Midtronics, Inc. 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;

U.S. Pat. No. 5,140,269, issued Aug. 18, 1992, to Champlin, entitled ELECTRONIC TESTER FOR ASSESSING BATTERY/CELL CAPACITY; U.S. Pat. No. 5,343,380, issued Aug. 30, 1994, entitled METHOD AND APPARATUS FOR SUPPRESSING TIME VARYING SIGNALS IN BATTERIES UNDERGOING CHARGING OR DISCHARGING; U.S. Pat. No. 5,572,136, issued Nov. 5, 1996, entitled ELECTRONIC BATTERY TESTER WITH AUTOMATIC COMPENSATION FOR LOW STATE-OF-CHARGE; U.S. Pat. No. 5,574,355, issued Nov. 12, 1996, entitled METHOD AND APPARATUS FOR DETECTION AND CONTROL OF THERMAL RUNAWAY IN A BATTERY UNDER CHARGE; U.S. Pat. No. 5,585,728, issued Dec. 17, 1996, entitled ELECTRONIC BATTERY TESTER WITH AUTOMATIC COMPENSATION FOR LOW STATE-OF-CHARGE; U.S. Pat. No. 5,592,093, issued Jan. 7, 1997, entitled ELECTRONIC BATTERY TESTING DEVICE LOOSE TERMINAL CONNECTION DETECTION VIA A COMPARISON CIRCUIT; U.S. Pat. No. 5,598,098, issued Jan. 28, 1997, entitled ELECTRONIC BATTERY TESTER WITH VERY HIGH NOISE IMMUNITY; U.S. Pat. No. 5,757,192, issued May 26, 1998, entitled METHOD AND APPARATUS FOR DETECTING A BAD CELL IN A STORAGE BATTERY; U.S. Pat. No. 5,821,756, issued Oct. 13, 1998, entitled ELECTRONIC BATTERY TESTER WITH TAILORED COMPENSATION FOR LOW STATE-OF-CHARGE; U.S. Pat. No. 5,831,435, issued Nov. 3, 1998, entitled BATTERY TESTER FOR JIS STANDARD; U.S. Pat. No. 5,914,605, issued Jun. 22, 1999, entitled ELECTRONIC BATTERY TESTER; U.S. Pat. No. 5,945,829, issued Aug. 31, 1999, entitled MIDPOINT BATTERY MONITORING; and U.S. Pat. No. 6,002,238, issued Dec. 14, 1999, entitled METHOD AND APPARATUS FOR MEASURING COMPLEX IMPEDANCE OF CELLS AND BATTERIES.

Most accurate electronic battery testers have required very accurate and relatively expensive test and interface circuitry. The circuitry must be able to be accurately calibrated to a standard, and maintain that calibration in the harsh environment often associate with automotive battery testing. The user interface associated with such devices has also been relatively complex and expensive. Such devices have required a significant capital investment and, because of this investment, have often not been attractive to individual consumers. Further, the expense associated with such battery testers has reduced the number of testers which are typically available in commercial settings.

SUMMARY OF THE INVENTION

An electronic battery tester includes a calibration interface. A microprocessor is configured to calibrate the battery tester by coupling to a calibrator through the calibration interface.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a simplified schematic diagram showing an electronic battery tester in accordance with the present invention.

FIG. 2 is a simplified block diagram of a test fixture in accordance with one aspect of the invention for use with the battery tester of FIG. 1.

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FIG. 3 is a simplified electrical schematic diagram of an amplifier in the tester of FIG. 1.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention provides an inexpensive electronic battery tester which delivers accurate results and is easy to use. Aspects of the invention will be apparent in the following disclosure.

FIG. 1 is a simplified block diagram of electronic battery tester 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. Battery 12 is a storage battery having a plurality of individual cells, typically six, and a voltage of 12.6 volts.

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, visual output 62 and analog-to-digital converter 54. Microprocessor 56 is also capable of receiving an input from input device 66. Further, an input/output (I/O) port 67 is provided.

In operation, current source 50 is controlled by microprocessor 56 and provides a current 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

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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 dynamic conductance of battery 12 using the following equation:

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

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 . This can then be converted in to cold cranking amps (CCA) and/or compared to a rating of battery 12 stored in memory 60.

One aspect of the present invention includes the reduction in the number of expensive components which are used in the battery tester 16. For example, some prior art battery testers have required a user input through which an operator enters a rating or reference for the particular battery being tested. However, in one embodiment, the present invention uses a fixed reference which is chosen to approximate the capacity of most batteries being tested. For example, a value of approximately 500 CCA may be used as an approximation and stored in memory 60. Although this reduces accuracy of the tester, the tester is still capable of providing satisfactory results for many applications. For example, if a battery is measured as being marginal, the operator can proceed with a battery test using a tester having a separate input. The particular general reference standard which is used in the present invention can be selected for a specific use for the tester. For example, if the tester is intended for use with automotive batteries one standard may be used and if the tester is intended for use with golf carts, for example, another standard may be stored in memory 60 during manufacture. In another embodiment, the rating is entered through input 66 by an operator.

In another aspect of the present invention, indicator 62 comprises two LEDs 62A and 62B. For example, LED 62A can be a red LED and LED 62B can be a green LED. If microprocessor 56 turns both LEDs 62A and 62B on, this indicator that the testing process is under way. A single green LED 62B indicates a good battery while a single red LED 62A indicates a bad battery. A flashing green LED 62B indicates a good battery with a low charge. Flashing red and green LEDs 62A,B indicate the battery should be recharged and retested. In another aspect, the tester 16 can be used as a charging tester by measuring the voltage across the battery 12 during operation of the engine of the vehicle which contains the battery. The tester can be switched between a battery test mode and a charging test mode through user input 66 which comprises a switch, for example. In this aspect of the invention, a green light indicates a normal charging voltage, a red light indicates a low charging voltage and a flashing red light indicates a high charging voltage. Of course, other combinations of light colors, sequences or flashing rates can be used to convey information.

In one aspect, memory 60 includes a non-volatile memory such as a flash memory which can store information when circuitry 16 is not receiving power. In performing a battery test, microprocessor can compare a measured value of a

dynamic parameter of the battery, such as conductance, to a rated value to obtain a relative value. The rated value can be stored in memory **60**. The units of the rating such as CCA, DIN, SAE, JIS or others, can be selected by a user and semi-permanently stored in the flash memory. Any type of non-volatile memory which can be written to and can be used. A rating can be selected through user input **66**. For example, a first button can be used to increment a rating displayed on indicator **62** and a second button can be used to decrement the rating. The value of the increments and decrements can be stored in the flash memory. Programming of the flash memory can be through a special operating mode. For example, if a certain sequence of inputs are provided or pressed on input **66** during operation or during power up of the device, microprocessor **56** can enter a flash memory programming mode. In such a mode, the rating standard or the increment/decrement value can be entered and stored into the flash memory. Typically, circuitry **16** is powered using power derived from battery **12**. In such an embodiment, values in the flash memory will be maintained even when the device is disconnected from battery **12**.

Microprocessor **56** can also capture and store voltages measured by amplifier **70**. For example, microprocessor **56** can take a number of samples using the analog to digital converter **54** and store a high sample value and a low sample value. These values can subsequently be retrieved using input **66** and displayed through indicator **62**. This information is particularly useful to diagnose problems associated with the starter motor of the vehicle. For example, a relatively low voltage value can indicate a impending failure. Similarly, a high value during which the starter motor is not operating can indicate that the starter motor is burned out is failing to receive power.

In one aspect, indicator **62** includes an LED array configured to provide a numerical output. Such an output can provide, for example, a voltage measurement. Further, in one embodiment, an operator is able to enter the rating of a battery, such as a CCA rating, by pushing buttons in user input **66** which allow the operator to scroll through a series of CCA ratings which are displayed on the LED array of indicator **62**. CCA can be stored in increments of 5 or 10, for example, and the operator can scroll through the increments until the battery rating is reached. A test can then be initiated by pressing another button in input **66**.

The battery tester **16** of the present invention is also capable of performing an automated calibration. Typically, this calibration is performed during manufacture, during which time the tester **16** is coupled to a calibrated test fixture. FIG. **2** is a simplified diagram of a test fixture or calibrator **100** for use with tester **16** of FIG. **1**. In the simplified schematic diagram illustrated in FIG. **2**, calibrator **100** includes a calibration resistance or shunt **102** and a calibration voltage generated by zener diode **104** of 10.00 volts. A switch **106** is connected as shown in FIG. **2** and coupled to tester I/O **67**. During operation, microprocessor **56** and tester **16** controls switch **106** to switch between a conductance (CCA) calibration mode and a voltage calibration mode. To calibrate conductance, switch **106** is moved into position to couple to resistance **102**. Tester **16** performs a test upon this calibration resistance **102**. The difference between the measured value and the actual value is stored in

memory **60** and is used to offset subsequent tests. Similarly, to perform a voltage calibration switch **106** is connected to voltage source **104** such that all test connections to tester **16** are connected across voltage source **104**. Again, the measured value is compared to the actual value of source **104** and the offset is stored in memory **60** and used to correct subsequent calibrations. In a third position, switch **106** couples to the other terminal to allow measurement of the voltage source. After the calibration sequence, a second calibration sequence is performed. If errors still exist, or if the errors are outside of an acceptable window, the tester is rejected. Further I/O **67** can couple to a computer (not shown) whereby microprocessor **56** in tester can provide detailed diagnostic information such as specific calibration values or measurement errors for use in performing diagnostics on tester **16**.

Calibrator **200** can have other configurations and the embodiment of FIG. **2** is simply one example. The switch can be formed by a relay transistor or other selectable switch and can comprise multiple switches to achieve the desired functionality. The calibrator can also include a microprocessor to perform more complex calibration steps.

FIG. **3** illustrates a simplified amplifier **120** in accordance with another aspect of the invention. Amplifier **120** includes differential amplifier **52** coupled with resistors **122**, **124**, **126** and **128** as shown. Further, current source **50** is illustrated in FIG. **3** including a measured voltage V_I **130** across a load resistance **132** which is switched by transistor **134**. The amplifier is configured to have a gain of 100 and the transistor **134** switches at a frequency of 100 Hz. Thus, the CCA of the battery **12** is proportional to the conductance of the battery (G_{BATT}) which equals V_I/V_{DIFF} , where V_I is the voltage across load resistance **132** and V_{DIFF} is the differential voltage output from amplifier **52**. In one preferred embodiment, amplifier **52** comprises a LM324 operational amplifier (OPAMP).

The present invention may be implemented using any appropriate technique. For simplicity, a single technique has been illustrated herein. However, other techniques may be used including implementation in all analog circuitry. Additionally, by using appropriate techniques, the battery resistance and a reference resistance (the reciprocal of conductance) may be employed in the invention. Various reference values may be stored in memory and be selected for various testing criteria such as based upon a measured temperature or the measured battery voltage. Although circuitry **16** has been illustrated in which source **50** is a current source and amplifier **52** measures a voltage signal, those skilled in the art will recognize that the circuitry may be modified by using a voltage signal source and detecting the result in current flowing through the battery. A value related to this current level is digitized and provided to the microprocessor. Battery conductance and relative conductance are calculated as appropriate. Further, the voltage or current signals may be pulsed, square waves, sign waves or any other appropriate signal controlled by microprocessor **56** or by an oscillator such as clock **58**. The terms "inject" or "apply" is used herein to describe the applying of voltage or current either with active circuitry or by applying a load to the battery. Further, "time varying" includes step signal inputs, pulse signals, periodic signals, etc.

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 battery tester for testing a storage battery, comprising:

- a first pair of connectors configured to couple to a positive terminal of the battery;
- a second pair of connectors configured to couple to a negative terminal of the battery, the first and second pairs of connectors forming a Kelvin connection with the battery;
- a memory;
- a calibration interface configured to provide a calibrator control output to a calibrator;
- a microprocessor configured to test the battery through the Kelvin connection based upon a calibration value stored in the memory, the microprocessor further configured to communicate with the calibrator through the calibration interface to initiate a self calibration, measure a calibrated value of the calibrator through the Kelvin connection and store the measured calibrator value in memory as the calibration value.

2. The electronic battery tester of claim 1 wherein the calibration interface is configured to provide a first calibrator control output to initiate a resistance calibration and a second calibrator control output to initiate a voltage calibration.

3. The electronic battery tester of claim 1 including a visual output configured to display a result of the battery test, the visual output including a LED and wherein a first test result is indicated with the LED on and a second test result is indicated with the LED off.

4. The electronic battery tester of claim 1 wherein the battery test is further a function of a fixed reference value stored in the memory.

5. The electronic battery tester of claim 1 wherein the battery test is further a function of a selectable reference value.

6. The electronic battery tester of claim 5 wherein the reference value is selected by scrolling through a plurality of reference values.

7. The electronic battery tester of claim 5 wherein the reference value is selected in accordance with an increment value stored in the memory.

8. The electronic battery tester of claim 7 wherein the memory comprises a non-volatile memory.

9. The electronic battery tester of claim 8 wherein the increment value is selectively stored in the non-volatile memory.

10. The electronic battery tester of claim 9 wherein the increment value is stored by placing the microprocessor in a programming mode.

11. The electronic battery tester of claim 11 wherein a programming mode is entered during power-up of the microprocessor.

12. The electronic battery tester of claim 5 wherein the reference value is in accordance with a selectable standard.

13. The electronic battery tester of claim 12 wherein the standard is stored in memory.

14. The electronic battery tester of claim 13 wherein the memory comprises a non-volatile memory.

15. The electronic battery tester of claim 13 wherein the standard is stored by placing the microprocessor in a programming mode.

16. The electronic battery tester of claim 15 wherein the programming mode is entered during power-up of the microprocessor.

17. The electronic battery tester of claim 1 wherein the calibration output is configured to drive a switch in the calibrator.

18. The electronic battery tester of claim 2 wherein the microprocessor calibration values from resistance and voltage measurements are stored in the memory.

19. An electronic battery tester for testing a storage battery, comprising:

- a first pair of connectors configured to couple to a positive terminal of the battery;
- a second pair of connectors configured to couple to a negative terminal of the battery, the first and second pairs of connectors forming a Kelvin connection with the battery;
- a memory;
- a microprocessor configured to test the battery through the Kelvin connection based upon an industry standard battery rating; and
- a user input configured to select an industry standard rating system for the battery rating and store the selected rating system in the memory.

20. The electronic battery tester of claim 19 including a calibration interface configured to couple to a calibrator to initiate measurement of a calibrated value of the calibrator through the Kelvin connection.

21. The electronic battery tester of claim 19 including a visual output configured to display a result of the battery test, the visual output including a LED and wherein a first test result is indicated with the LED on and a second test result is indicated with the LED off.

22. The electronic battery tester of claim 19 wherein the battery test is a function of a fixed reference value stored in the memory.

23. The electronic battery tester of claim 19 wherein the battery test is further a function of a selectable reference value.

24. The electronic battery tester of claim 23 wherein the reference value is selected by scrolling through a plurality of reference values.

25. The electronic battery tester of claim 24 wherein the reference value is selected in accordance with an increment value stored in a non-volatile memory.

26. The electronic battery tester of claim 19 wherein the memory comprises a non-volatile memory.

27. The electronic battery tester of claim 26 wherein the standard rating system is stored by placing the microprocessor in a programming mode.

28. The electronic battery tester of claim 14 wherein the programming mode is entered during power-up of the microprocessor.

29. An electronic battery tester for testing a storage battery, comprising:

- a first pair of connectors configured to couple to a positive terminal of the battery;

a second pair of connectors configured to couple to a negative terminal of the battery, the first and second pairs of connectors forming a Kelvin connection with the battery;

a memory;

a microprocessor configured to test the battery through the Kelvin connection based upon a battery rating; and

a user input configured to select an increment or decrement value for use in entering the battery rating and store the value in the memory.

30. The electronic battery tester of claim 29 includes a calibration interface to couple to a calibrator.

31. The electronic battery tester of claim 29 including a visual output configured to display a result of the battery test, the visual output including a LED and wherein a first test result is indicated with the LED on and a second test result is indicated with the LED off.

32. The electronic battery tester of claim 29 wherein the battery rating is selected by scrolling through a plurality of reference values.

33. The electronic battery tester of claim 29 wherein the reference value is selected in accordance with an increment value stored in the memory.

34. The electronic battery tester of claim 29 wherein the memory comprises a non-volatile memory.

35. The electronic battery tester of claim 29 wherein the increment or decrement value is stored in memory by placing the microprocessor in a programming mode.

36. The electronic battery tester of claim 35 wherein the programming mode is entered during power-up of the microprocessor.

37. The electronic battery tester of claim 29 wherein the battery rating is in accordance with a selectable standard.

38. The electronic battery tester of claim 37 wherein the standard is stored in memory.

39. The electronic battery tester of claim 38 wherein the standard is stored by placing the microprocessor in a programming mode.

40. A battery tester calibrator, comprising:

a control input configured to receive a control input from an electronic battery tester;

a Kelvin connection coupling configured to couple to a Kelvin connection of the battery tester;

a voltage reference;

a resistance reference;

at least one switch configured to selectively couple the voltage and resistance references to the Kelvin connection coupling in respective first and second relay positions in response to the control input.

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