

(10) **Patent No.:** US 8,493,022 B2
(45) **Date of Patent:** Jul. 23, 2013

- (51) **Int. Cl.**
H02J 7/00 (2006.01)
H01M 10/48 (2006.01)

- (52) **U.S. Cl.**
USPC **320/104**; 320/116; 320/139; 340/636.1;
340/636.21

- (58) **Field of Classification Search**
USPC 320/104
See application file for complete search history.

- (56)
- References Cited**

- U.S. PATENT DOCUMENTS

- | | | | | |
|-----------|---|--------|-------------|---------|
| 85,553 | A | 1/1869 | Adams | 33/472 |
| 2,000,665 | A | 5/1935 | Neal | 439/440 |

- (Continued)

US 2010/0262404 A1 Oct. 14, 2010

Related U.S. Application Data

- (60) Continuation of application No. 11/511,872, filed on Aug. 29, 2006, now Pat. No. 7,705,602, and a continuation-in-part of application No. 10/200,041, filed on Jul. 19, 2002, now Pat. No. 7,126,341, which is a continuation-in-part of application No. 10/046,659, filed on Oct. 29, 2001, now Pat. No. 6,909,287, which is a division of application No. 09/564,740, filed on May 4, 2000, now Pat. No. 6,331,762, said application No. 10/046,659 is a continuation-in-part of application No. 09/575,627, filed on May 22, 2000, now Pat. No. 6,313,608, which is a continuation-in-part of application No. 08/962,754, filed on Nov. 3, 1997, now Pat. No. 6,081,098, said application No. 10/200,041 is a continuation-in-part of application No. 09/816,768, filed on Mar. 23, 2001, now Pat. No. 6,586,941.

- FOREIGN PATENT DOCUMENTS

DE	29 26 716 B1	1/1981
DE	196 38 324	9/1996

(Continued)

OTHER PUBLICATIONS

“Electrochemical Impedance Spectroscopy in Battery Development and Testing”, *Batteries International*, Apr. 1997, pp. 59 and 62-63.

(Continued)

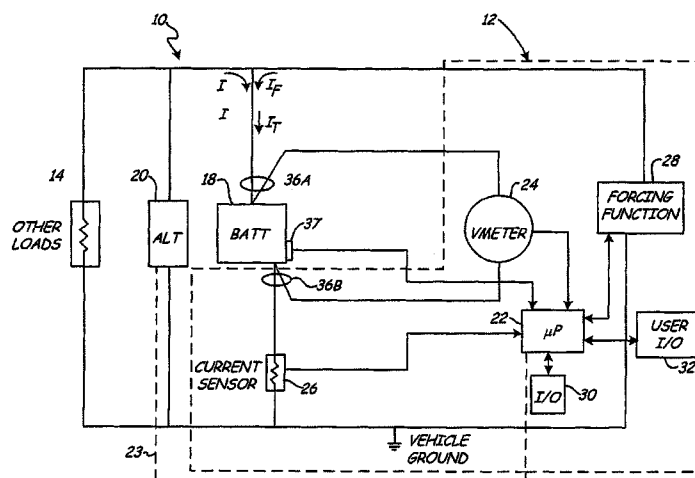
Primary Examiner — Yalkew Fantu

- (74) *Attorney, Agent, or Firm* — Westman, Champlin & Kelly, P.A.

- (57) **ABSTRACT**

An automotive vehicle electrical system diagnostic apparatus includes first and second electrical connections configured to electrically couple to an electrical system of an automotive vehicle which includes a battery. Digital samples are obtained during operation of the vehicle which are related to the system. The digital samples are stored in memory.

24 Claims, 13 Drawing Sheets



US 8,493,022 B2

Page 2

U.S. PATENT DOCUMENTS

2,417,940 A	3/1947	Lehman	200/61.25	4,441,359 A	4/1984	Ezoe	73/116.06
2,514,745 A	7/1950	Dalzell	324/115	4,459,548 A	7/1984	Lentz et al.	324/472
2,727,221 A	12/1955	Springg	340/447	4,514,694 A	4/1985	Finger	324/429
3,178,686 A	4/1965	Mills	340/447	4,520,353 A	5/1985	McAuliffe	340/636.16
3,223,969 A	12/1965	Alexander	340/447	4,521,498 A	6/1985	Juergens	429/59
3,267,452 A	8/1966	Wolf	340/249	4,564,798 A	1/1986	Young	320/103
3,356,936 A	12/1967	Smith	324/429	4,620,767 A	11/1986	Woolf	439/217
3,562,634 A	2/1971	Latner	324/427	4,633,418 A	12/1986	Bishop	702/63
3,593,099 A	7/1971	Scholl	320/127	4,637,359 A	1/1987	Cook	123/179
3,607,673 A	9/1971	Seyl	324/425	4,659,977 A	4/1987	Kissel et al.	320/150
3,652,341 A	3/1972	Halsall et al.	29/623.2	4,663,580 A	5/1987	Wortman	320/153
3,676,770 A	7/1972	Sharaf et al.	324/430	4,665,370 A	5/1987	Holland	324/429
3,729,989 A	5/1973	Little	73/862.192	4,667,143 A	5/1987	Cooper et al.	320/153
3,750,011 A	7/1973	Kreps	324/430	4,667,279 A	5/1987	Maier	363/46
3,753,094 A	8/1973	Furuishi et al.	324/430	4,678,998 A	7/1987	Muramatsu	324/427
3,776,177 A	12/1973	Bryant et al.	116/311	4,679,000 A	7/1987	Clark	324/428
3,796,124 A	3/1974	Crosa	411/521	4,680,528 A	7/1987	Mikami et al.	320/165
3,808,522 A	4/1974	Sharaf	324/430	4,686,442 A	8/1987	Radomski	320/123
3,811,089 A	5/1974	Strzelewicz	324/170	4,697,134 A	9/1987	Burkum et al.	320/134
3,816,805 A	6/1974	Terry	320/123	4,707,795 A	11/1987	Alber et al.	702/63
3,850,490 A	11/1974	Zehr	439/822	4,709,202 A	11/1987	Koenck et al.	320/112
3,873,911 A	3/1975	Champlin	324/430	4,710,861 A	12/1987	Kanner	363/46
3,876,931 A	4/1975	Godshalk	324/429	4,719,428 A	1/1988	Liebermann	324/436
3,886,426 A	5/1975	Daggett	320/117	4,723,656 A	2/1988	Kiernan et al.	206/705
3,886,443 A	5/1975	Miyakawa et al.	324/426	4,743,855 A	5/1988	Randin et al.	324/430
3,889,248 A	6/1975	Ritter	340/636.11	4,745,349 A	5/1988	Palanisamy et al.	320/125
3,906,329 A	9/1975	Bader	320/134	4,773,011 A	9/1988	VanHoose	701/30
3,909,708 A	9/1975	Champlin	324/431	4,781,629 A	11/1988	Mize	439/822
3,936,744 A	2/1976	Perlmutter	324/772	4,816,768 A	3/1989	Champlin	324/428
3,946,299 A	3/1976	Christianson et al.	320/430	4,820,966 A	4/1989	Fridman	320/116
3,947,757 A	3/1976	Grube et al.	324/416	4,825,170 A	4/1989	Champlin	324/436
3,969,667 A	7/1976	McWilliams	324/427	4,847,547 A	7/1989	Eng, Jr. et al.	320/153
3,979,664 A	9/1976	Harris	324/397	4,849,700 A	7/1989	Morioka et al.	324/427
3,984,762 A	10/1976	Dowgiallo, Jr.	324/430	4,874,679 A	10/1989	Miyagawa	429/91
3,984,768 A	10/1976	Staples	324/712	4,876,495 A	10/1989	Palanisamy et al.	320/106
3,989,544 A	11/1976	Santo	429/65	4,881,038 A	11/1989	Champlin	324/426
3,997,830 A	12/1976	Newell et al.	320/102	4,885,523 A	12/1989	Koenck	230/131
4,008,619 A	2/1977	Alcaide et al.	73/724	4,888,716 A	12/1989	Ueno	702/63
4,023,882 A	5/1977	Pettersson	439/426	4,901,007 A	2/1990	Sworm	324/110
4,024,953 A	5/1977	Nailor, III	206/344	4,907,176 A	3/1990	Bahnick et al.	364/551.01
4,047,091 A	9/1977	Hutchines et al.	363/59	4,912,416 A	3/1990	Champlin	324/430
4,053,824 A	10/1977	Dupuis et al.	324/434	4,913,116 A	4/1990	Katogi et al.	123/406.32
4,056,764 A	11/1977	Endo et al.	320/101	4,926,330 A	5/1990	Abe et al.	701/33
4,057,313 A	11/1977	Polizzano	439/219	4,929,931 A	5/1990	McCuen	340/636.15
4,070,624 A	1/1978	Taylor	324/772	4,931,738 A	6/1990	MacIntyre et al.	324/435
4,086,531 A	4/1978	Bernier	324/772	4,932,905 A	6/1990	Richards	439/822
4,106,025 A	8/1978	Katz	343/715	4,933,845 A	6/1990	Hayes	710/104
4,112,351 A	9/1978	Back et al.	324/380	4,934,957 A	6/1990	Bellusci	439/504
4,114,083 A	9/1978	Benham et al.	340/636.13	4,937,528 A	6/1990	Palanisamy	324/430
4,126,874 A	11/1978	Suzuki et al.	396/301	4,947,124 A	8/1990	Hauser	324/430
4,160,916 A	7/1979	Papasideris	307/10.6	4,949,046 A	8/1990	Seyfang	324/427
4,178,546 A	12/1979	Hulls et al.	324/772	4,956,597 A	9/1990	Heavey et al.	320/129
4,193,025 A	3/1980	Frailing et al.	324/427	4,965,738 A	10/1990	Bauer et al.	320/136
4,207,611 A	6/1980	Gordon	701/33	4,968,941 A	11/1990	Rogers	324/428
4,217,645 A	8/1980	Barry et al.	702/63	4,968,942 A	11/1990	Palanisamy	324/430
4,280,457 A	7/1981	Bloxham	123/198 R	4,969,834 A	11/1990	Johnson	439/141
4,297,639 A	10/1981	Branham	324/429	4,983,086 A	1/1991	Hatrock	411/259
4,307,342 A	12/1981	Peterson	324/767	5,004,979 A	4/1991	Marino et al.	324/160
4,315,204 A	2/1982	Sievers et al.	322/28	5,030,916 A	7/1991	Bokitch	324/503
4,316,185 A	2/1982	Watrous et al.	340/636.11	5,032,825 A	7/1991	Kuznicki	340/636.15
4,322,685 A	3/1982	Frailing et al.	324/429	5,034,893 A	7/1991	Fisher	1/99
4,351,405 A	9/1982	Fields et al.	180/65.2	5,037,778 A	8/1991	Stark et al.	228/121
4,352,067 A	9/1982	Ottone	324/434	5,047,722 A	9/1991	Wurst et al.	324/430
4,360,780 A	11/1982	Skutch, Jr.	324/437	5,081,565 A	1/1992	Nabha et al.	362/465
4,361,809 A	11/1982	Bil et al.	324/426	5,087,881 A	2/1992	Peacock	324/378
4,363,407 A	12/1982	Buckler et al.	209/3.3	5,095,223 A	3/1992	Thomas	307/110
4,369,407 A	1/1983	Korbell	324/416	5,108,320 A	4/1992	Kimber	439/883
4,379,989 A	4/1983	Kurz et al.	320/165	5,109,213 A	4/1992	Williams	340/447
4,379,990 A	4/1983	Sievers et al.	322/99	5,126,675 A	6/1992	Yang	324/435
4,385,269 A	5/1983	Aspinwall et al.	320/129	5,130,658 A	7/1992	Bohmer	324/435
4,390,828 A	6/1983	Converse et al.	320/153	5,140,269 A	8/1992	Champlin	324/433
4,392,101 A	7/1983	Saar et al.	320/156	5,144,218 A	9/1992	Bosscha	320/139
4,396,880 A	8/1983	Windebank	320/156	5,144,248 A	9/1992	Alexandres et al.	324/428
4,408,157 A	10/1983	Beaubien	324/712	5,159,272 A	10/1992	Rao et al.	324/429
4,412,169 A	10/1983	Dell'Orto	320/123	5,160,881 A	11/1992	Schramm et al.	322/7
4,423,378 A	12/1983	Marino et al.	324/427	5,168,208 A	12/1992	Schultz et al.	322/25
4,423,379 A	12/1983	Jacobs et al.	324/429	5,170,124 A	12/1992	Blair et al.	324/434
4,424,491 A	1/1984	Bobbett et al.	324/433	5,179,335 A	1/1993	Nor	320/159
				5,187,382 A	2/1993	Kondo	307/10.1

5,194,799 A	3/1993	Tomantschger	320/103	5,596,260 A	1/1997	Moravec et al.	320/135
5,204,611 A	4/1993	Nor et al.	320/145	5,596,261 A	1/1997	Suyama	320/152
5,214,370 A	5/1993	Harm et al.	320/152	5,598,098 A	1/1997	Champlin	324/430
5,214,385 A	5/1993	Gabriel et al.	324/434	5,602,462 A	2/1997	Stich et al.	323/258
5,241,275 A	8/1993	Fang	324/430	5,606,242 A	2/1997	Hull et al.	320/106
5,254,952 A	10/1993	Salley et al.	324/429	5,614,788 A	3/1997	Mullins et al.	315/82
5,266,880 A	11/1993	Newland	320/125	5,621,298 A	4/1997	Harvey	320/134
5,278,759 A	1/1994	Berra et al.	701/1	5,631,536 A	5/1997	Tseng	320/15
5,281,919 A	1/1994	Palanisamy	324/427	5,633,985 A	5/1997	Severson et al.	704/267
5,281,920 A	1/1994	Wurst	324/430	5,637,978 A	6/1997	Kellett et al.	320/104
5,295,078 A	3/1994	Stich et al.	700/297	5,642,031 A	6/1997	Brotto	320/156
5,298,797 A	3/1994	Redl	327/387	5,644,212 A	7/1997	Takahashi	320/134
5,300,874 A	4/1994	Shimamoto et al.	320/106	5,650,937 A	7/1997	Bounaga	702/65
5,302,902 A	4/1994	Groehl	324/434	5,652,501 A	7/1997	McClure et al.	340/636.15
5,313,152 A	5/1994	Wozniak et al.	320/118	5,653,659 A	8/1997	Kunibe et al.	477/111
5,315,287 A	5/1994	Sol	340/455	5,654,623 A	8/1997	Shiga et al.	320/106
5,321,626 A	6/1994	Palladino	702/63	5,656,920 A	8/1997	Cherng et al.	324/431
5,321,627 A	6/1994	Reher	702/63	5,661,368 A	8/1997	Deol et al.	315/82
5,323,337 A	6/1994	Wilson et al.	702/73	5,666,040 A	9/1997	Bourbeau	320/118
5,325,041 A	6/1994	Briggs	320/149	5,675,234 A	10/1997	Greene	340/636.11
5,331,268 A	7/1994	Patino et al.	320/158	5,677,077 A	10/1997	Faulk	429/90
5,332,927 A	7/1994	Paul et al.	307/66	5,684,678 A	11/1997	Barrett	363/17
5,336,993 A	8/1994	Thomas et al.	324/158.1	5,691,621 A	11/1997	Phuoc et al.	320/134
5,338,515 A	8/1994	Dalla Betta et al.	422/95	5,699,050 A	12/1997	Kanazawa	340/636.13
5,339,018 A	8/1994	Brokaw	320/147	5,701,089 A	12/1997	Perkins	324/772
5,343,380 A	8/1994	Champlin	363/46	5,705,929 A	1/1998	Caravello et al.	324/430
5,347,163 A	9/1994	Yoshimura	307/66	5,707,015 A	1/1998	Guthrie	241/120
5,352,968 A	10/1994	Reni et al.	320/136	5,710,503 A	1/1998	Sideris et al.	320/116
5,357,519 A	10/1994	Martin et al.	371/15.1	5,711,648 A	1/1998	Hammerslag	414/800
5,365,160 A	11/1994	Leppo et al.	320/160	5,712,795 A	1/1998	Layman et al.	700/297
5,365,453 A	11/1994	Startup et al.	702/36	5,717,336 A	2/1998	Basell et al.	324/430
5,369,364 A	11/1994	Renirie et al.	324/430	5,717,937 A	2/1998	Fritz	713/300
5,381,096 A	1/1995	Hirzel	324/427	5,721,688 A	2/1998	Bramwell	324/426
5,387,871 A	2/1995	Tsai	324/429	5,732,074 A	3/1998	Spaur et al.	370/313
5,402,007 A	3/1995	Center et al.	290/40 B	5,739,667 A	4/1998	Matsuda et al.	320/128
5,410,754 A	4/1995	Klotzbach et al.	370/466	5,744,962 A	4/1998	Alber et al.	324/426
5,412,308 A	5/1995	Brown	323/267	5,745,044 A	4/1998	Hyatt, Jr. et al.	340/5.23
5,412,323 A	5/1995	Kato et al.	324/429	5,747,189 A	5/1998	Perkins	429/91
5,425,041 A	6/1995	Seko et al.	372/45.01	5,747,909 A	5/1998	Syversen et al.	310/156.56
5,426,371 A	6/1995	Salley et al.	324/429	5,747,967 A	5/1998	Muljadi et al.	320/148
5,426,416 A	6/1995	Jefferies et al.	340/664	5,754,417 A	5/1998	Nicollini	363/60
5,430,645 A	7/1995	Keller	364/424.01	5,757,192 A	5/1998	McShane et al.	324/427
5,432,025 A	7/1995	Cox	29/65	5,760,587 A	6/1998	Harvey	324/434
5,432,426 A	7/1995	Yoshida	320/160	5,772,468 A	6/1998	Kowalski et al.	439/506
5,434,495 A	7/1995	Toko	320/135	5,773,962 A	6/1998	Nor	20/134
5,435,185 A	7/1995	Eagan	73/587	5,773,978 A	6/1998	Becker	324/430
5,442,274 A	8/1995	Tamai	320/146	5,778,326 A	7/1998	Moroto et al.	701/22
5,445,026 A	8/1995	Eagan	73/591	5,780,974 A	7/1998	Pabla et al.	315/82
5,449,996 A	9/1995	Matsumoto et al.	320/148	5,780,980 A	7/1998	Naito	318/139
5,449,997 A	9/1995	Gilmore et al.	320/148	5,789,899 A	8/1998	van Phuoc et al.	320/112
5,451,881 A	9/1995	Finger	324/433	5,793,359 A	8/1998	Ushikubo	345/169
5,453,027 A	9/1995	Buell et al.	439/433	5,796,239 A	8/1998	van Phuoc et al.	320/107
5,457,377 A	10/1995	Jonsson	324/430	5,808,469 A	9/1998	Kopera	324/434
5,459,660 A	10/1995	Berra	701/33	5,811,979 A	9/1998	Rhein	324/718
5,469,043 A	11/1995	Cherng et al.	320/161	5,818,201 A	10/1998	Stockstad et al.	320/119
5,485,090 A	1/1996	Stephens	324/433	5,818,234 A	10/1998	McKinnon	324/433
5,488,300 A	1/1996	Jamieson	324/432	5,820,407 A	10/1998	Morse et al.	439/504
5,504,674 A	4/1996	Chen et al.	705/4	5,821,756 A	10/1998	McShane et al.	324/430
5,508,599 A	4/1996	Koenck	320/138	5,821,757 A	10/1998	Alvarez et al.	324/434
5,519,383 A	5/1996	De La Rosa	340/636.15	5,825,174 A	10/1998	Parker	324/106
5,528,148 A	6/1996	Rogers	320/137	5,831,435 A	11/1998	Troy	324/426
5,537,967 A	7/1996	Tashiro et al.	123/192.1	5,832,396 A	11/1998	Moroto et al.	701/22
5,541,489 A	7/1996	Dunstan	320/134	5,850,113 A	12/1998	Weimer et al.	307/125
5,546,317 A	8/1996	Andrieu	702/63	5,862,515 A	1/1999	Kobayashi et al.	702/63
5,548,273 A	8/1996	Nicol et al.	340/439	5,865,638 A	2/1999	Trafton	439/288
5,550,485 A	8/1996	Falk	324/772	5,869,951 A	2/1999	Takahashi	320/104
5,561,380 A	10/1996	Sway-Tin et al.	324/509	5,871,858 A	2/1999	Thomsen et al.	429/7
5,562,501 A	10/1996	Kinoshita et al.	439/852	5,872,443 A	2/1999	Williamson	320/160
5,563,496 A	10/1996	McClure	320/128	5,872,453 A	2/1999	Shimoyama et al.	324/431
5,572,136 A	11/1996	Champlin	324/426	5,883,306 A	3/1999	Hwang	73/146.8
5,573,611 A	11/1996	Koch et al.	152/152.1	5,895,440 A	4/1999	Proctor et al.	702/63
5,574,355 A	11/1996	McShane et al.	320/161	5,903,154 A	5/1999	Zhang et al.	324/437
5,578,915 A	11/1996	Crouch, Jr. et al.	324/428	5,903,716 A	5/1999	Kimber et al.	395/114
5,583,416 A	12/1996	Klang	320/160	5,912,534 A	6/1999	Benedict	315/82
5,585,416 A	12/1996	Audett et al.	522/35	5,914,605 A	6/1999	Bertness	324/430
5,585,728 A	12/1996	Champlin	324/427	5,927,938 A	7/1999	Hammerslag	414/809
5,589,757 A	12/1996	Klang	320/160	5,929,609 A	7/1999	Joy et al.	322/25
5,592,093 A	1/1997	Klingbiel	324/426	5,939,855 A	8/1999	Proctor et al.	320/104
5,592,094 A	1/1997	Ichikawa	324/427	5,939,861 A	8/1999	Joko et al.	320/122

5,945,829 A	8/1999	Bertness	324/430	6,254,438 B1	7/2001	Gaunt	439/755
5,946,605 A	8/1999	Takahisa et al.	455/68	6,259,170 B1	7/2001	Limoge et al.	307/10.8
5,950,144 A	9/1999	Hall et al.	702/108	6,259,254 B1	7/2001	Klang	324/427
5,951,229 A	9/1999	Hammerslag	414/398	6,262,563 B1	7/2001	Champlin	320/134
5,953,322 A	9/1999	Kimball	370/328	6,263,268 B1	7/2001	Nathanson	701/29
5,955,951 A	9/1999	Wischerop et al.	340/572.8	6,271,643 B1	8/2001	Becker et al.	320/112
5,961,561 A	10/1999	Wakefield, II	701/29	6,271,748 B1	8/2001	Derbyshire et al.	340/442
5,961,604 A	10/1999	Anderson et al.	709/229	6,275,008 B1	8/2001	Arai et al.	320/132
5,969,625 A	10/1999	Russo	340/636.19	6,285,191 B1	9/2001	Gollomp et al.	324/427
5,973,598 A	10/1999	Beigel	340/572.1	6,294,896 B1	9/2001	Champlin	320/134
5,978,805 A	11/1999	Carson	707/10	6,294,897 B1	9/2001	Champlin	320/153
5,982,138 A	11/1999	Krieger	320/105	6,304,087 B1	10/2001	Bertness	324/426
5,990,664 A	11/1999	Rahman	320/136	6,307,349 B1	10/2001	Koenck et al.	320/112
6,002,238 A	12/1999	Champlin	320/134	6,310,481 B2	10/2001	Bertness	324/430
6,005,489 A	12/1999	Siegle et al.	340/825.69	6,313,607 B1	11/2001	Champlin	320/132
6,005,759 A	12/1999	Hart et al.	361/66	6,313,608 B1	11/2001	Varghese et al.	320/132
6,008,652 A	12/1999	Theofanopoulos et al.	324/434	6,316,914 B1	11/2001	Bertness	320/134
6,009,369 A	12/1999	Boisvert et al.	701/99	6,320,351 B1	11/2001	Ng et al.	320/104
6,016,047 A	1/2000	Notten et al.	320/137	6,323,650 B1	11/2001	Bertness et al.	324/426
6,031,354 A	2/2000	Wiley et al.	320/116	6,324,042 B1	11/2001	Andrews	361/93.2
6,031,368 A	2/2000	Klippel et al.	324/133	6,329,793 B1	12/2001	Bertness et al.	320/132
6,037,745 A	3/2000	Koike et al.	320/104	6,331,762 B1	12/2001	Bertness	320/134
6,037,749 A	3/2000	Parsonage	320/132	6,332,113 B1	12/2001	Bertness	702/63
6,037,751 A	3/2000	Klang	320/160	6,346,795 B2	2/2002	Haraguchi et al.	320/136
6,037,777 A	3/2000	Champlin	324/430	6,347,958 B1	2/2002	Tsai	439/488
6,037,778 A	3/2000	Makhija	320/433	6,351,102 B1	2/2002	Troy	320/139
6,046,514 A	4/2000	Rouillard et al.	307/77	6,356,042 B1	3/2002	Kahlon et al.	318/138
6,051,976 A	4/2000	Bertness	324/426	6,356,083 B1	3/2002	Ying	324/426
6,055,468 A	4/2000	Kaman et al.	701/29	6,359,441 B1	3/2002	Bertness	324/426
6,061,638 A	5/2000	Joyce	702/63	6,359,442 B1	3/2002	Henningson et al.	324/426
6,064,372 A	5/2000	Kahkoska	345/173	6,363,303 B1	3/2002	Bertness	701/29
6,072,299 A	6/2000	Kurle et al.	320/112	RE37,677 E	4/2002	Irie	315/83
6,072,300 A	6/2000	Tsuji	320/116	6,377,031 B1	4/2002	Karuppana et al.	323/220
6,075,339 A	6/2000	Reipur et al.	320/110	6,384,608 B1	5/2002	Namaky	324/430
6,081,098 A	6/2000	Bertness et al.	320/134	6,388,448 B1	5/2002	Cervas	324/426
6,081,109 A	6/2000	Seymour et al.	324/127	6,392,414 B2	5/2002	Bertness	324/429
6,087,815 A	7/2000	Pfeifer et al.	323/282	6,396,278 B1	5/2002	Makhija	324/402
6,091,238 A	7/2000	McDermott	324/207.2	6,407,554 B1	6/2002	Godau et al.	324/503
6,091,245 A	7/2000	Bertness	324/426	6,411,098 B1	6/2002	Laletin	324/436
6,094,033 A	7/2000	Ding et al.	320/132	6,417,669 B1	7/2002	Champlin	324/426
6,097,193 A	8/2000	Bramwell	324/429	6,420,852 B1	7/2002	Sato	320/134
6,100,670 A	8/2000	Levesque	320/150	6,424,157 B1	7/2002	Gollomp et al.	324/430
6,100,815 A	8/2000	Pailthorp	324/754.07	6,424,158 B2 *	7/2002	Klang	324/433
6,104,167 A	8/2000	Bertness et al.	320/132	6,437,957 B1	8/2002	Karuppana et al.	361/78
6,113,262 A	9/2000	Purola et al.	374/45	6,441,585 B1	8/2002	Bertness	320/132
6,114,834 A	9/2000	Parise	320/109	6,445,158 B1	9/2002	Bertness et al.	320/104
6,136,914 A	10/2000	Hergenrother et al.	524/495	6,449,726 B1	9/2002	Smith	713/340
6,137,269 A	10/2000	Champlin	320/150	6,456,036 B1	9/2002	Thandiwe	320/106
6,140,797 A	10/2000	Dunn	320/105	6,456,045 B1	9/2002	Troy et al.	320/139
6,144,185 A	11/2000	Dougherty et al.	320/132	6,465,908 B1	10/2002	Karuppana et al.	307/31
6,147,598 A	11/2000	Murphy et al.	340/426.19	6,466,025 B1	10/2002	Klang	324/429
6,150,793 A	11/2000	Lesesky et al.	320/104	6,466,026 B1	10/2002	Champlin	324/430
6,158,000 A	12/2000	Collins	713/1	6,469,511 B1	10/2002	Vonderhaar et al.	324/425
6,161,640 A	12/2000	Yamaguchi	180/65.8	6,477,478 B1	11/2002	Jones et al.	702/102
6,163,156 A	12/2000	Bertness	324/426	6,495,990 B2	12/2002	Champlin	320/132
6,164,063 A	12/2000	Mendler	60/274	6,497,209 B1	12/2002	Karuppana et al.	123/179.3
6,167,349 A	12/2000	Alvarez	702/63	6,500,025 B1	12/2002	Moenkhaus et al.	439/502
6,172,483 B1	1/2001	Champlin	320/134	6,505,507 B1	1/2003	Imao	73/146.5
6,172,505 B1	1/2001	Bertness	324/430	6,507,196 B2	1/2003	Thomsen et al.	324/436
6,177,737 B1	1/2001	Palfev et al.	307/64	6,526,361 B1	2/2003	Jones et al.	702/63
6,181,545 B1	1/2001	Amatucci et al.	361/502	6,529,723 B1	3/2003	Bentley	455/405
6,184,656 B1	2/2001	Karunasiri et al.	320/119	6,531,848 B1	3/2003	Chitsazan et al.	320/153
6,191,557 B1	2/2001	Gray et al.	320/132	6,532,425 B1	3/2003	Boost et al.	702/63
6,202,739 B1	3/2001	Pal et al.	165/104.33	6,534,992 B2	3/2003	Meissner et al.	324/426
6,211,651 B1	4/2001	Nemoto	320/133	6,534,993 B2	3/2003	Bertness	324/433
6,215,275 B1	4/2001	Bean	320/106	6,536,536 B1	3/2003	Gass et al.	173/2
6,218,805 B1 *	4/2001	Melcher	320/105	6,544,078 B2	4/2003	Palmisano et al.	439/762
6,218,936 B1	4/2001	Imao	340/447	6,545,599 B2	4/2003	Derbyshire et al.	340/442
6,222,342 B1	4/2001	Eggert et al.	320/105	6,556,019 B2	4/2003	Bertness	324/426
6,222,369 B1	4/2001	Champlin	324/430	6,566,883 B1	5/2003	Vonderhaar et al.	324/426
D442,503 S	5/2001	Lundbeck et al.	D10/77	6,570,385 B1	5/2003	Roberts et al.	324/378
6,225,808 B1	5/2001	Varghese et al.	324/426	6,577,107 B2	6/2003	Kechmire	320/139
6,236,186 B1	5/2001	Helton et al.	320/106	6,586,941 B2	7/2003	Bertness et al.	324/426
6,236,332 B1	5/2001	Conkright et al.	340/3.1	6,597,150 B1	7/2003	Bertness et al.	320/104
6,236,949 B1	5/2001	Hart	702/64	6,599,243 B2	7/2003	Woltermann et al.	600/300
6,238,253 B1	5/2001	Qualls	439/759	6,600,815 B1	7/2003	Walding	379/93.07
6,242,887 B1	6/2001	Burke	320/104	6,611,740 B2	8/2003	Lowrey et al.	701/29
6,249,124 B1	6/2001	Bertness	324/426	6,614,349 B1	9/2003	Proctor et al.	340/572.1
6,250,973 B1	6/2001	Lowery et al.	439/763	6,618,644 B2	9/2003	Bean	700/231

6,621,272 B2	9/2003	Champlin	324/426	7,208,914 B2	4/2007	Klang	320/132
6,623,314 B1	9/2003	Cox et al.	439/759	7,209,850 B2	4/2007	Brott et al.	324/426
6,624,635 B1	9/2003	Lui	324/426	7,209,860 B2	4/2007	Tsars et al.	702/183
6,628,011 B2	9/2003	Droppo et al.	307/43	7,212,887 B2	5/2007	Shah et al.	700/276
6,629,054 B2	9/2003	Makhija et al.	702/113	7,219,023 B2	5/2007	Banke et al.	702/58
6,633,165 B2	10/2003	Bertness	324/426	7,233,128 B2	6/2007	Brost et al.	320/132
6,635,974 B1	10/2003	Karuppana et al.	307/140	7,235,977 B2	6/2007	Koran et al.	324/426
6,667,624 B1	12/2003	Raichle et al.	324/522	7,246,015 B2	7/2007	Bertness et al.	702/63
6,679,212 B2	1/2004	Kelling	123/179.28	7,272,519 B2	9/2007	Lesesky et al.	702/63
6,686,542 B2	2/2004	Zhang	174/74	7,287,001 B1	10/2007	Falls et al.	705/22
6,696,819 B2	2/2004	Bertness	320/134	7,295,936 B2	11/2007	Bertness et al.	702/63
6,707,303 B2	3/2004	Bertness et al.	324/426	7,319,304 B2	1/2008	Veloo et al.	320/134
6,736,941 B2	5/2004	Oku et al.	203/68	7,339,477 B2	3/2008	Puzio et al.	340/572.1
6,737,831 B2	5/2004	Champlin	320/132	7,363,175 B2	4/2008	Bertness et al.	702/63
6,738,697 B2	5/2004	Breed	701/29	7,398,176 B2	7/2008	Bertness	702/140
6,740,990 B2	5/2004	Tozuka et al.	307/9.1	7,408,358 B2	8/2008	Knopf	324/426
6,744,149 B1	6/2004	Karuppana et al.	307/31	7,425,833 B2	9/2008	Bertness et al.	324/426
6,745,153 B2	6/2004	White et al.	702/184	7,446,536 B2	11/2008	Bertness	324/426
6,759,849 B2	7/2004	Bertness	324/426	7,453,238 B2	11/2008	Melichar	320/132
6,771,073 B2	8/2004	Henningson et al.	324/426	7,479,763 B2	1/2009	Bertness	320/134
6,777,945 B2	8/2004	Roberts et al.	324/426	7,498,767 B2	3/2009	Brown et al.	320/107
6,781,382 B2	8/2004	Johnson	324/426	7,501,795 B2	3/2009	Bertness et al.	320/134
6,784,635 B2	8/2004	Larson	320/104	7,505,856 B2	3/2009	Restaino et al.	702/63
6,784,637 B2	8/2004	Raichle et al.	320/107	7,545,146 B2	6/2009	Klang et al.	324/426
6,788,025 B2	9/2004	Bertness et al.	320/104	7,557,586 B1	7/2009	Vonderhaar et al.	324/437
6,795,782 B2 *	9/2004	Bertness et al.	702/63	7,590,476 B2	9/2009	Shumate	701/31.6
6,796,841 B1	9/2004	Cheng et al.	439/620.3	7,592,776 B2	9/2009	Tsukamoto et al.	320/136
6,805,090 B2	10/2004	Bertness et al.	123/198	7,595,643 B2	9/2009	Klang	324/426
6,806,716 B2	10/2004	Bertness et al.	324/426	7,598,699 B2	10/2009	Restaino et al.	320/105
6,825,669 B2	11/2004	Raichle et al.	324/426	7,598,743 B2	10/2009	Bertness	324/426
6,842,707 B2	1/2005	Raichle et al.	702/62	7,598,744 B2	10/2009	Bertness et al.	324/426
6,845,279 B1	1/2005	Gilmore et al.	700/115	7,619,417 B2	11/2009	Klang	324/427
6,850,037 B2	2/2005	Bertness	320/132	7,642,786 B2	1/2010	Philbrook	324/426
6,856,162 B1	2/2005	Greatorex et al.	324/764.01	7,642,787 B2	1/2010	Bertness et al.	324/426
6,856,972 B1	2/2005	Yun et al.	705/36 R	7,656,162 B2	2/2010	Vonderhaar et al.	324/426
6,871,151 B2	3/2005	Bertness	702/63	7,657,386 B2	2/2010	Thibedeau et al.	702/63
6,885,195 B2	4/2005	Bertness	324/426	7,667,437 B2	2/2010	Johnson et al.	320/150
6,888,468 B2	5/2005	Bertness	340/636.15	7,679,325 B2	3/2010	Seo	20/116
6,891,378 B2	5/2005	Bertness et al.	324/426	7,684,908 B1	3/2010	Ogilvie et al.	701/29.6
6,904,796 B2	6/2005	Pacsai et al.	73/146.8	7,688,074 B2	3/2010	Cox et al.	324/426
6,906,522 B2	6/2005	Bertness et al.	324/426	7,698,179 B2	4/2010	Leung et al.	705/28
6,906,523 B2	6/2005	Bertness et al.	324/426	7,705,602 B2	4/2010	Bertness	324/426
6,906,624 B2	6/2005	McClelland et al.	340/442	7,706,991 B2	4/2010	Bertness et al.	702/63
6,909,287 B2	6/2005	Bertness	324/427	7,710,119 B2	5/2010	Bertness	324/426
6,909,356 B2	6/2005	Brown et al.	340/3.2	7,723,993 B2	5/2010	Klang	324/431
6,913,483 B2	7/2005	Restaino et al.	439/504	7,728,556 B2	6/2010	Yano et al.	320/134
6,914,413 B2	7/2005	Bertness et al.	320/104	7,728,597 B2	6/2010	Bertness	324/426
6,919,725 B2	7/2005	Bertness et al.	324/433	7,751,953 B2	7/2010	Namaky	701/33.2
6,930,485 B2	8/2005	Bertness et al.	324/426	7,772,850 B2	8/2010	Bertness	324/426
6,933,727 B2	8/2005	Bertness et al.	324/426	7,774,151 B2	8/2010	Bertness	702/63
6,941,234 B2	9/2005	Bertness et al.	702/63	7,777,612 B2	8/2010	Sampson et al.	340/426.1
6,967,484 B2	11/2005	Bertness	324/426	7,791,348 B2	9/2010	Brown et al.	324/426
6,972,662 B1	12/2005	Ohkawa et al.	340/10.1	7,808,375 B2	10/2010	Bertness et al.	340/455
6,993,421 B2	1/2006	Pillar et al.	701/29.4	7,848,857 B2	12/2010	Nasr et al.	701/22
6,998,847 B2	2/2006	Bertness et al.	324/426	7,883,002 B2	2/2011	Jin et al.	235/376
7,003,410 B2	2/2006	Bertness et al.	702/63	7,924,015 B2	4/2011	Bertness	324/427
7,003,411 B2	2/2006	Bertness	702/63	7,940,053 B2	5/2011	Brown et al.	324/426
7,012,433 B2	3/2006	Smith et al.	324/426	2001/0035737 A1	11/2001	Nakanishi et al.	320/122
7,015,674 B2	3/2006	Vonderhaar	320/103	2002/0004694 A1	1/2002	McLeod	701/29
7,029,338 B1	4/2006	Orange et al.	439/755	2002/0010558 A1 *	1/2002	Bertness et al.	702/63
7,034,541 B2	4/2006	Bertness et al.	324/426	2002/0021135 A1	2/2002	Li et al.	324/677
7,039,533 B2	5/2006	Bertness et al.	702/63	2002/0030495 A1	3/2002	Kechmire	324/427
7,058,525 B2	6/2006	Bertness et al.	702/63	2002/0041175 A1	4/2002	Lauper et al.	320/106
7,081,755 B2	7/2006	Klang et al.	324/426	2002/0044050 A1	4/2002	Derbyshire et al.	340/442
7,089,127 B2	8/2006	Thibedeau et al.	702/63	2002/0050163 A1	5/2002	Makhija et al.	73/116
7,098,666 B2	8/2006	Patino	324/433	2002/0074398 A1	6/2002	Lancos et al.	235/382
7,102,556 B2	9/2006	White	341/141	2002/0118111 A1	8/2002	Brown et al.	340/573.1
7,106,070 B2	9/2006	Bertness et al.	324/538	2002/0121901 A1	9/2002	Hoffman	324/426
7,116,109 B2	10/2006	Klang	324/426	2002/0171428 A1	11/2002	Bertness	702/63
7,119,686 B2	10/2006	Bertness et al.	340/572.1	2002/0176010 A1	11/2002	Wallach et al.	348/362
7,120,488 B2	10/2006	Nova et al.	600/2	2003/0009270 A1	1/2003	Breed	701/29
7,126,341 B2	10/2006	Bertness et al.	324/426	2003/0025481 A1	2/2003	Bertness	324/427
7,129,706 B2	10/2006	Kalley	324/426	2003/0036909 A1	2/2003	Kato	704/275
7,154,276 B2	12/2006	Bertness	324/503	2003/0040873 A1	2/2003	Lesesky et al.	702/57
7,177,925 B2	2/2007	Carcido et al.	709/223	2003/0078743 A1	4/2003	Bertness et al.	702/63
7,182,147 B2	2/2007	Cutler et al.	173/1	2003/0088375 A1	5/2003	Bertness et al.	702/63
7,184,905 B2	2/2007	Stefan	702/63	2003/0124417 A1	7/2003	Bertness et al.	429/90
7,198,510 B2	4/2007	Bertness	439/500	2003/0128036 A1	7/2003	Henningson et al.	324/426
7,200,424 B2	4/2007	Tischer et al.	455/567	2003/0137277 A1	7/2003	Mori et al.	320/132

2003/0169018	A1	9/2003	Berels et al.	320/132
2003/0169019	A1	9/2003	Oosaki	320/132
2003/0184262	A1	10/2003	Makhija	320/156
2003/0184306	A1	10/2003	Bertness et al.	324/426
2003/0187556	A1	10/2003	Suzuki	701/29
2003/0194672	A1	10/2003	Roberts et al.	431/196
2003/0197512	A1	10/2003	Miller et al.	324/426
2003/0212311	A1	11/2003	Nova et al.	600/300
2003/0214395	A1	11/2003	Flowerday et al.	340/445
2004/0000590	A1	1/2004	Raichle et al.	235/462.01
2004/0000891	A1	1/2004	Raichle et al.	320/107
2004/0000893	A1	1/2004	Raichle et al.	320/135
2004/0000913	A1	1/2004	Raichle et al.	324/426
2004/0000915	A1	1/2004	Raichle et al.	324/522
2004/0002824	A1	1/2004	Raichle et al.	702/63
2004/0002825	A1	1/2004	Raichle et al.	702/63
2004/0002836	A1	1/2004	Raichle et al.	702/188
2004/0032264	A1	2/2004	Schoch	324/426
2004/0044452	A1	3/2004	Bauer et al.	703/33
2004/0049361	A1	3/2004	Hamdan et al.	702/115
2004/0051533	A1	3/2004	Namaky	324/426
2004/0051534	A1	3/2004	Kobayashi et al.	324/429
2004/0054503	A1	3/2004	Namaky	702/183
2004/0113588	A1	6/2004	Mikuriya et al.	320/128
2004/0145342	A1	7/2004	Lyon	320/108
2004/0164706	A1	8/2004	Osborne	320/116
2004/0178185	A1	9/2004	Yoshikawa et al.	219/270
2004/0199343	A1	10/2004	Cardinal et al.	702/63
2004/0207367	A1	10/2004	Taniguchi et al.	320/149
2004/0227523	A1	11/2004	Namaky	324/537
2004/0239332	A1	12/2004	Mackel et al.	324/426
2004/0251876	A1	12/2004	Bertness et al.	320/136
2005/0007068	A1	1/2005	Johnson et al.	320/110
2005/0017726	A1	1/2005	Koran et al.	324/433
2005/0021294	A1	1/2005	Trsar et al.	702/183
2005/0025299	A1	2/2005	Tischer et al.	379/199
2005/0043868	A1	2/2005	Mitcham	701/29
2005/0057256	A1	3/2005	Bertness	324/426
2005/0073314	A1	4/2005	Bertness et al.	324/433
2005/0102073	A1	5/2005	Ingram	701/29
2005/0128083	A1	6/2005	Puzio et al.	340/572.1
2005/0159847	A1	7/2005	Shah et al.	700/276
2005/0162172	A1	7/2005	Bertness	324/426
2005/0168226	A1	8/2005	Quint et al.	324/426
2005/0173142	A1	8/2005	Cutler et al.	173/181
2005/0182536	A1	8/2005	Doyle et al.	701/29
2005/0218902	A1*	10/2005	Restaino et al.	324/433
2005/0254106	A9	11/2005	Silverbrook et al.	324/433
2005/0256617	A1	11/2005	Cawthorne et al.	701/22
2005/0258241	A1	11/2005	McNutt et al.	235/385
2006/0012330	A1	1/2006	Okumura et al.	320/103
2006/0030980	A1	2/2006	St. Denis	701/29
2006/0089767	A1	4/2006	Sowa	701/29
2006/0095230	A1	5/2006	Grier et al.	702/183
2006/0161313	A1	7/2006	Rogers et al.	701/1
2006/0161390	A1	7/2006	Namaky et al.	702/183
2006/0217914	A1	9/2006	Bertness	702/113
2006/0282323	A1	12/2006	Walker et al.	705/14
2007/0024460	A1	2/2007	Clark	340/663
2007/0026916	A1	2/2007	Juds et al.	463/1
2007/0159177	A1	7/2007	Bertness et al.	324/426
2007/0194791	A1	8/2007	Huang	324/430
2007/0259256	A1	11/2007	Le Canut et al.	429/90
2008/0036421	A1	2/2008	Seo et al.	320/132
2008/0059014	A1	3/2008	Nasr et al.	701/22
2008/0094068	A1	4/2008	Scott	324/426
2008/0169818	A1	7/2008	Lesesky et al.	324/426
2008/0303528	A1	12/2008	Kim	324/430
2008/0303529	A1	12/2008	Nakamura et al.	324/433
2009/0006476	A1	1/2009	Andreasen et al.	707/104.1
2009/0146800	A1	6/2009	Grimlund et al.	340/505
2009/0198372	A1	8/2009	Hammerslag	700/226
2009/0247020	A1	10/2009	Gathuman et al.	439/759
2009/0276115	A1	11/2009	Chen	701/32
2010/0145780	A1	6/2010	Nishikawa et al.	705/14.11
2010/0314950	A1	12/2010	Rutkowski et al.	307/125
2011/0004427	A1	1/2011	Gorbald et al.	702/63

FOREIGN PATENT DOCUMENTS

DE	10 2008 036 595	A1	2/2010
EP	0 022 450	A1	1/1981
EP	0 476 405	A1	9/1991
EP	0 637 754	A1	2/1995
EP	0 772 056	A1	5/1997
EP	0 982 159	A2	3/2000
EP	1 810 869	A1	11/2004
EP	1 807 710	B1	7/2007
FR	2 749 397		12/1997
GB	2 029 586		3/1980
GB	2 088 159	A	6/1982
GB	2 246 916	A	10/1990
GB	2 275 783	A	7/1994
GB	2 367 235	A	10/2003
JP	59-17892		1/1984
JP	59-17893		1/1984
JP	59017894		1/1984
JP	59215674		12/1984
JP	60225078		11/1985
JP	62-18028		8/1987
JP	63027776		2/1988
JP	03274479		12/1991
JP	03282276		12/1991
JP	4-8636		1/1992
JP	04095788		3/1992
JP	4131779		5/1992
JP	04372536		12/1992
JP	05211724	A	8/1993
JP	5216550		8/1993
JP	7-128414		5/1995
JP	09061505		3/1997
JP	10056744		2/1998
JP	10232273		9/1998
JP	11103503	A	4/1999
JP	11-150809		6/1999
RU	2089015	C1	8/1997
WO	WO 93/22666		11/1993
WO	WO 94/05069		3/1994
WO	WO 99/23738		3/1994
WO	WO 96/01456		1/1996
WO	WO 96/06747		3/1996
WO	WO 96/28846		9/1996
WO	WO 97/01103		1/1997
WO	WO 97/44652		11/1997
WO	WO 98/04910		2/1998
WO	WO 98/21132		5/1998
WO	WO 98/58270		12/1998
WO	WO 99/56121		11/1999
WO	WO 00/16083		3/2000
WO	WO 00/62049		10/2000
WO	WO 00/67359		11/2000
WO	WO 01/59443		2/2001
WO	WO 01/16614		3/2001
WO	WO 01/16615		3/2001
WO	WO 01/51947		7/2001
WO	03/047064	A3	6/2003
WO	WO 03/076960	A1	9/2003
WO	WO 2004/047215	A1	6/2004

OTHER PUBLICATIONS

- "Battery Impedance", 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.
- "A Look at the Impedance of a Cell", by S. DeBardelaben, *IEEE*, 1988, pp. 394-397.
- "The Impedance of Electrical Storage Cells", by N.A. Hampson et al., *Journal of Applied Electrochemistry*, 1980, pp. 3-11.
- "A Package for Impedance/Admittance Data Analysis", by B. Boukamp, *Solid State Ionics*, 1986, pp. 136-140.
- "Precision of Impedance Spectroscopy Estimates of Bulk, Reaction Rate, and Diffusion Parameters", by J. Macdonald et al., *J. Electroanal. Chem.*, 1991, pp. 1-11.
- Internal Resistance: Harbinger of Capacity Loss in Starved Electrolyte Sealed Lead Acid Batteries, by Vaccaro, F.J. et al., *AT&T Bell Laboratories*, 1987 IEEE, Ch. 2477, pp. 128,131.

- 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.
- "Field and Laboratory Studies to Assess the State of Health of Valve-Regulated Lead Acid Batteries: Part I Conductance/Capacity Correlation Studies", by D. Feder et al., *IEEE*, Aug. 1992, pp. 218-233.
- "JIS Japanese Industrial Standard—Lead Acid Batteries for Automobiles", *Japanese Standards Association UDC*, 621.355.2:629.113.006, Nov. 1995.
- "Performance of Dry Cells", by C. Hambuechen, Preprint of *Am. Electrochem. Soc.*, Apr. 18-20, 1912, paper No. 198, pp. 1-5.
- "A Bridge for Measuring Storage Battery Resistance", by E. Willihncanz, *The Electrochemical Society*, preprint 79-20, Apr. 1941, pp. 253-258.
- National Semiconductor Corporations, "High Q Notch Filter", Mar. 1969, Linear Brief 5, Mar. 1969.
- Burr-Brown Corporation, "Design a 60 Hz Notch Filter with the UAF42", Jan. 1994, AB-071, 1994.
- National Semiconductor Corporation, "LMF90—4th-Order Elliptic Notch Filter", Dec. 1994, RRD-B30M115, Dec. 1994.
- "Alligator Clips with Wire Penetrators" *J.S. Popper, Inc.* product information, downloaded from <http://www.jspopper.com/>, prior to Oct. 1, 2002.
- "#12: LM78S40 Simple Switcher DC to DC Converter", *ITM e-Catalog*, downloaded from <http://www.pcbcafe.com>, prior to Oct. 1, 2002.
- "Simple DC-DC Converts Allows Use of Single Battery", *Electronic Express*, downloaded from http://www.elexp.com/t_dc-dc.htm, prior to Oct. 1, 2002.
- "DC-DC Converter Basics", *Power Designers*, downloaded from http://www.powederdesigners.com/InforWeb.design_center/articles/DC-DC/converter.shtm, prior to Oct. 1, 2002.
- "Improved Impedance Spectroscopy Technique for Status Determination of Production Li/SO₂ Batteries" Terrill Atwater et al., pp. 10-113, (1992).
- "Programming Training Course, 62-000 Series Smart Engine Analyzer", Testproducts Division, Kalamazoo, Michigan, pp. 1-207, (1984).
- "Operators Manual, Modular Computer Analyzer Model MCA 3000", Sun Electric Corporation, Crystal Lake, Illinois, pp. 1-1-14-13, (1991).
- Supplementary European Search Report Communication for Appl. No. 99917402.2; Sep. 7, 2004.
- "Dynamic modelling of lead/acid batteries using impedance spectroscopy for parameter identification", *Journal of Power Sources*, pp. 69-84, (1997).
- "A review of impedance measurements for determination of the state-of-charge or state-of-health of secondary batteries", *Journal of Power Sources*, pp. 59-69, (1998).
- "Results of Discrete Frequency Immittance Spectroscopy (DFIS) Measurements of Lead Acid Batteries", by K.S. Champlin et al., *Proceedings of 23rd International Teleco Conference (INTELEC)*, published Oct. 2001, IEE, pp. 433-440.
- "Examination Report" from the UK Patent Office for App. No. 0417678.1; Jan. 24, 2005.
- Wikipedia Online Encyclopedia, Inductance, 2005, <http://en.wikipedia.org/wiki/inductance>, pp. 1-5, mutual Inductance, pp. 3,4.
- "Professional BCS System Analyzer Battery-Charger-Starting", pp. 2-8, (2001).
- Young Illustrated Encyclopedia Dictionary of Electronics, 1981, Parker Publishing Company, Inc., pp. 318-319.
- Office Action from U.S. Appl. No. 11/352,945; dated Jan. 5, 2007.
- Office Action from U.S. Appl. No. 11/146,608 dated May 13, 2008.
- Office Action from U.S. Appl. No. 11/063,247 dated Apr. 11, 2008.
- "DSP Applications in Hybrid Electric Vehicle Powertrain", Miller et al., *Proceedings of the American Control Conference*, Sand Diego, CA, Jun. 1999; 2 ppg.
- "Notification of Transmittal of the International Search Report and the Written Opinion of the International Searching Authority, or the Declaration" for PCT/US2008/008702 filed Jul. 2008; 15 pages.
- "Notification Concerning Availability of the Publication of the International Application" for PCT/US2008/008702, filed Jul. 17, 2008; 24 pages.
- "First Notice Informing the Applicant of the Communication of the International Application (To Designated Offices which do not apply the 30 Month Time Limit Under Article 22(1))" for PCT/US2008/008702 filed Jul. 17, 2008; one page.
- "Notification of the Recording of a Change" for PCT/US2008/008702 filed Jul. 17, 2008; one page.
- USPTO Office Action from related U.S. Appl. No. 09/564,740, mailing date Mar. 28, 2001.
- USPTO Office Action from related U.S. Appl. No. 09/816,768, mailing date May 3, 2002.
- USPTO Office Action from related U.S. Appl. No. 12/962,754, mailing date Aug. 17, 1999.
- USPTO Office Action from related U.S. Appl. No. 08/962,754, mailing date Apr. 15, 1999.
- USPTO Office Action from related U.S. Appl. No. 10/046,659, mailing date Jun. 18, 2003.
- USPTO Office Action from related U.S. Appl. No. 10/200,041, mailing date May 16, 2005.
- USPTO Office Action from related U.S. Appl. No. 10/200,041, mailing date Oct. 4, 2005.
- USPTO Office Action from related U.S. Appl. No. 10/200,041, mailing date Feb. 27, 2006.
- USPTO Office Action from related U.S. Appl. No. 11/511,872, mailing date May 14, 2009.
- German Office Action along with its translation from corresponding German application Serial No. 10332625.1-53, dated Aug. 18, 2010.
- "Notification of Transmittal of The International Search Report or the Declaration", PCT/US03/41561; Search Report completed Apr. 13, 2004, mailed May 6, 2004.
- "Notification of Transmittal of The International Search Report or the Declaration", PCT/US03/27696, filed Sep. 4, 2003 and mailed Apr. 15, 2004.
- "Search Report Under Section 17" for Great Britain Application No. GB0421447.4, date of search Jan. 27, 2005, date of document Jan. 28, 2005.
- "Notification of Transmittal of The International Search Report or the Declaration", PCT/US02/29461, filed Sep. 17, 2002 and mailed Jan. 3, 2003.
- "Notification of Transmittal of The International Search Report or the Declaration", PCT/US03/07546, filed Mar. 13, 2003 and mailed Jul. 4, 2001.
- "Notification of Transmittal of The International Search Report or the Declaration", PCT/US03/06577, filed Mar. 5, 2003 and mailed Jul. 24, 2003.
- "Notification of Transmittal of The International Search Report or the Declaration", PCT/US03/07837, filed Mar. 14, 2003 and mailed Jul. 4, 2003.
- Notification of Transmittal of the International Search Report for PCT/US03/30707, filed Sep. 30, 2003 and mailed Nov. 24, 2004.
- "A Microprocessor-Based Control System for a Near-Term Electric Vehicle", Bimal K. Bose; *IEEE Transactions on Industry Applications*, vol. IA-17, No. 6, Nov./Dec. 1981; 0093-9994/81/1100-0626\$00.75 © 1981 IEEE, 6 pages.
- Search Report and Written Opinion from PCT Application No. PCT/US2011/026608, dated Aug. 29, 2011, 9 pages.
- Notification of Transmittal of the International Search Report and the Written Opinion of the International Searching Authority, or the Declaration for PCT/US2011/038279 filed May 27, 2011, date of mailing Sep. 16, 2011, 12 pages.
- U.S. Appl. No. 60/387,912, filed Jun. 13, 2002 which is related to U.S. Patent No. 7,089,127.
- "Conductance Testing Compared to Traditional Methods of Evaluating the Capacity of Valve-Regulated Lead-Acid Batteries and Predicting State-of-Health", by D. Feder et al., May 1992, pp. 1-8; (13 total pgs.).
- Notification of Transmittal of the International Search Report and Written Opinion from PCT/US2011/039043, dated Jul. 26, 2012.
- Notification of Transmittal of the International Search Report and Written Opinion from PCT/US2011/053886, dated Jul. 27, 2012.
- Communication from GB1216105.5, dated Sep. 21, 2012.

"A Fundamentally New Approach to Battery Performance Analysis Using DFRA™/DTIS™ Technology", by K. Champlin et al., Sep. 2000, 8 pgs; (12 total pgs.).

"Battery State of Health Monitoring, Combining Conductance Technology With Other Measurement Parameters for Real-Time Battery Performance Analysis", by D. Cox et al., Mar. 2000, 6 pgs; (10 total pgs.).

Examination Report under section 18(3) for corresponding Great Britain Application No. GB1000773.0, dated Feb. 6, 2012, 2 pages.

"Field and Laboratory Studies to Assess the State of Health of Valve-Regulated Lead Acid Batteries: Part I-Conductance/Capacity Correlation Studies", by D. Feder et al., Oct. 1992, pp. 1-15; (19 total pgs.).

"Field Application of Conductance Measurements Use to Ascertain Cell/Battery and Inter-Cell Connection State-of-Health in Electric Power Utility Applications", by M. Hlavac et al., Apr. 1993, pp. 1-14; (19 total pgs.).

"Conductance Testing of Standby Batteries in Signaling and Communications Applications for the Purpose of Evaluating Battery State-of-Health", by S. McShane, Apr. 1993, pp. 1-9; (14 total pgs.).

"Conductance Monitoring of Recombination Lead Acid Batteries", by B. Jones, May 1993, pp. 1-6; (11 total pgs.).

"Evaluating the State-of-Health of Lead Acid Flooded and Valve-Regulated Batteries: A Comparison of Conductance Testing vs. Traditional Methods", by M. Hlavac et al., Jun. 1993, pp. 1-15; (20 total pgs.).

"Updated State of Conductance/Capacity Correlation Studies to Determine the State-of-Health of Automotive SLI and Standby Lead Acid Batteries", by D. Feder et al., Sep. 1993, pp. 1-17; (22 total pgs.).

"Field and Laboratory Studies to Access the State-of-Health of Valve-Regulated Lead-Acid Battery Technologies Using Conductance Testing Part II—Further Conductance/Capacity Correlation Studies", by M. Hlavac et al., Sep. 1993, pp. 1-9; (14 total pgs.).

"Field Experience for Testing VRLA Batteries by Measuring Conductance", by M.W. Kniveton, May 1996, pp. 1-4; (9 total pgs.).

"Reducing the Cost of Maintaining VRLA Batteries in Telecom Applications", by M.W. Kniveton, Sep. 1994, pp. 1-5; (10 total pgs.).

"Analysis and Interpretation of Conductance Measurements used to Access the State-of-Health of Valve Regulated Lead Acid Batteries Part III: Analytical Techniques", by M. Hlavac, Nov. 1994, 9 pgs; (13 total pgs.).

"Testing 24 Volt Aircraft Batteries Using Midtronics Conductance Technology", by M. Hlavac et al., Jan. 1995, 9 pgs; (13 total pgs.).

"VRLA Battery Monitoring Using Conductance Technology Part IV: On-Line State-of-Health Monitoring and Thermal Runaway Detection/Prevention", by M. Hlavac et al., Oct. 1995, 9 pgs; (13 total pgs.).

"VRLA Battery Conductance Monitoring Part V: Strategies for VRLA Battery Testing and Monitoring in Telecom Operating Environments", by M. Hlavac et al., Oct. 1996, 9 pgs; (13 total pgs.).

"Midpoint Conductance Technology Used in Telecommunication Stationary Standby Battery Applications Part VI: Considerations for Deployment of Midpoint Conductance in Telecommunications Power Applications", by M. Troy et al., Oct. 1997, 9 pgs; (13 total pgs.).

"Impedance/Conductance Measurements as an Aid to Determining Replacement Strategies", M. Kniveton, Sep. 1998, pp. 297-301; (9 total pgs.).

* cited by examiner

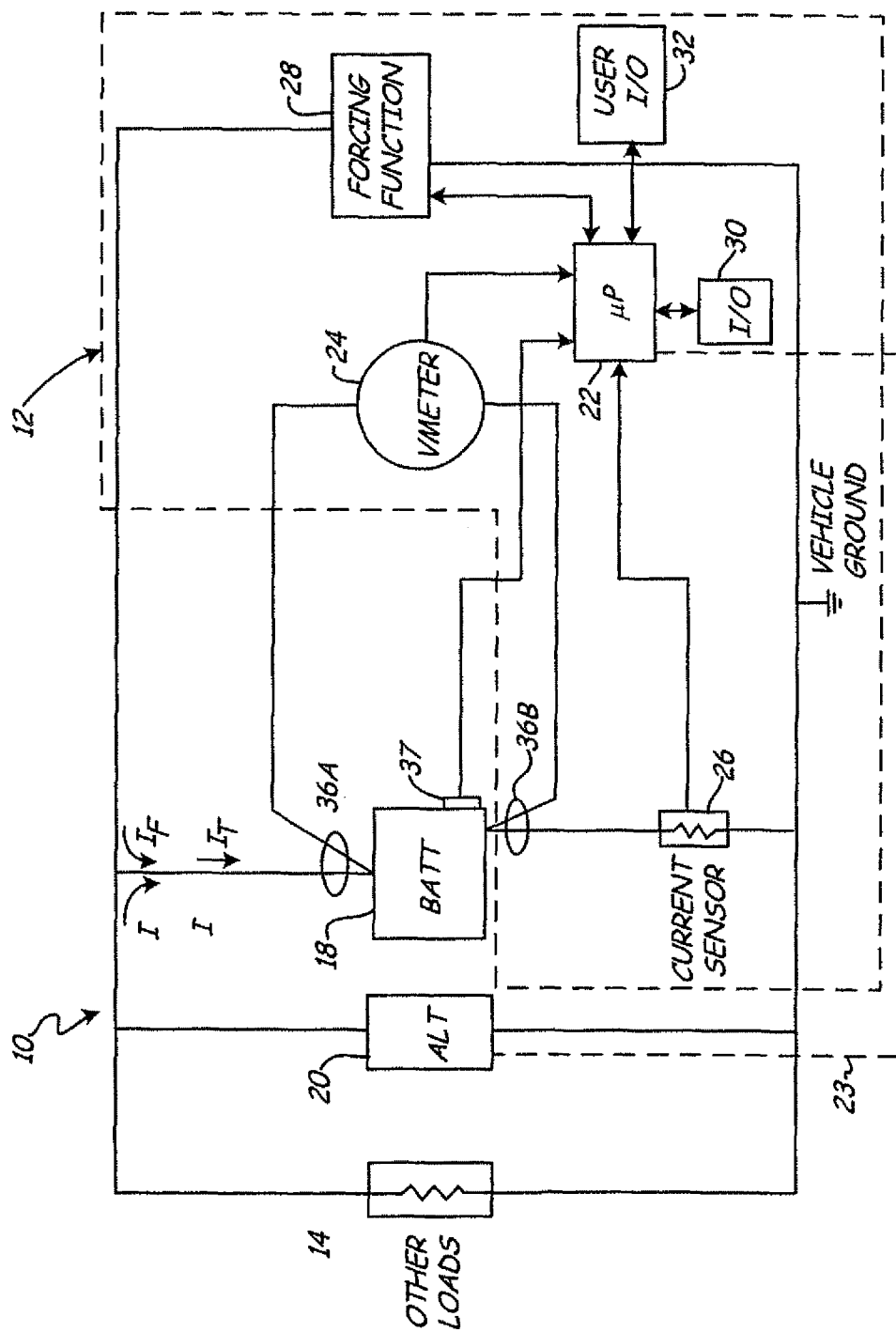


Fig. 1

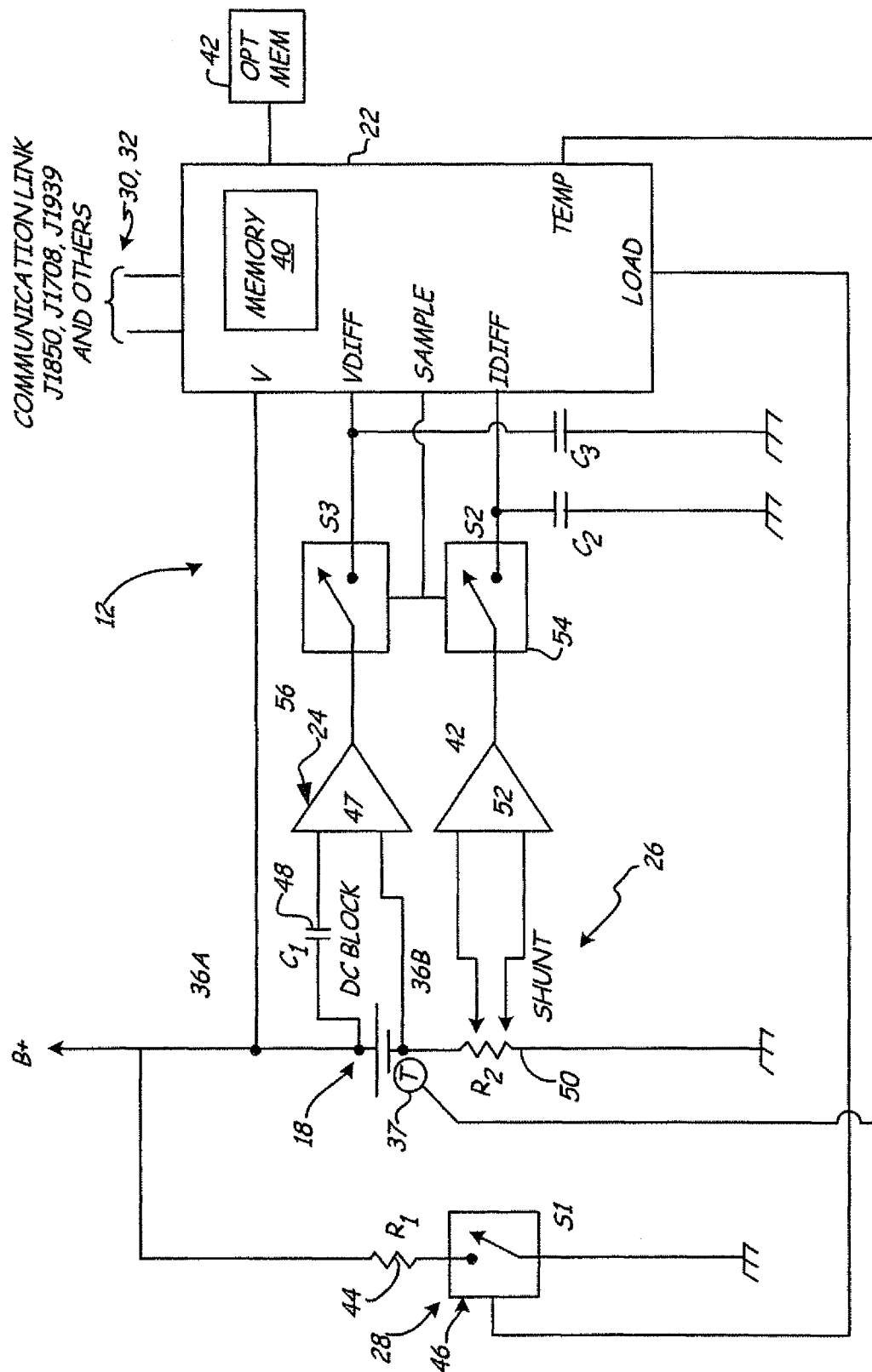
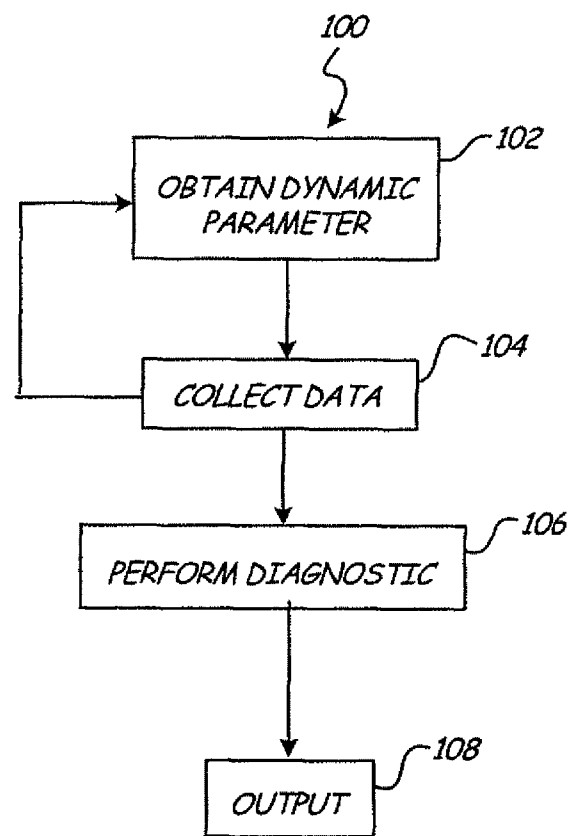
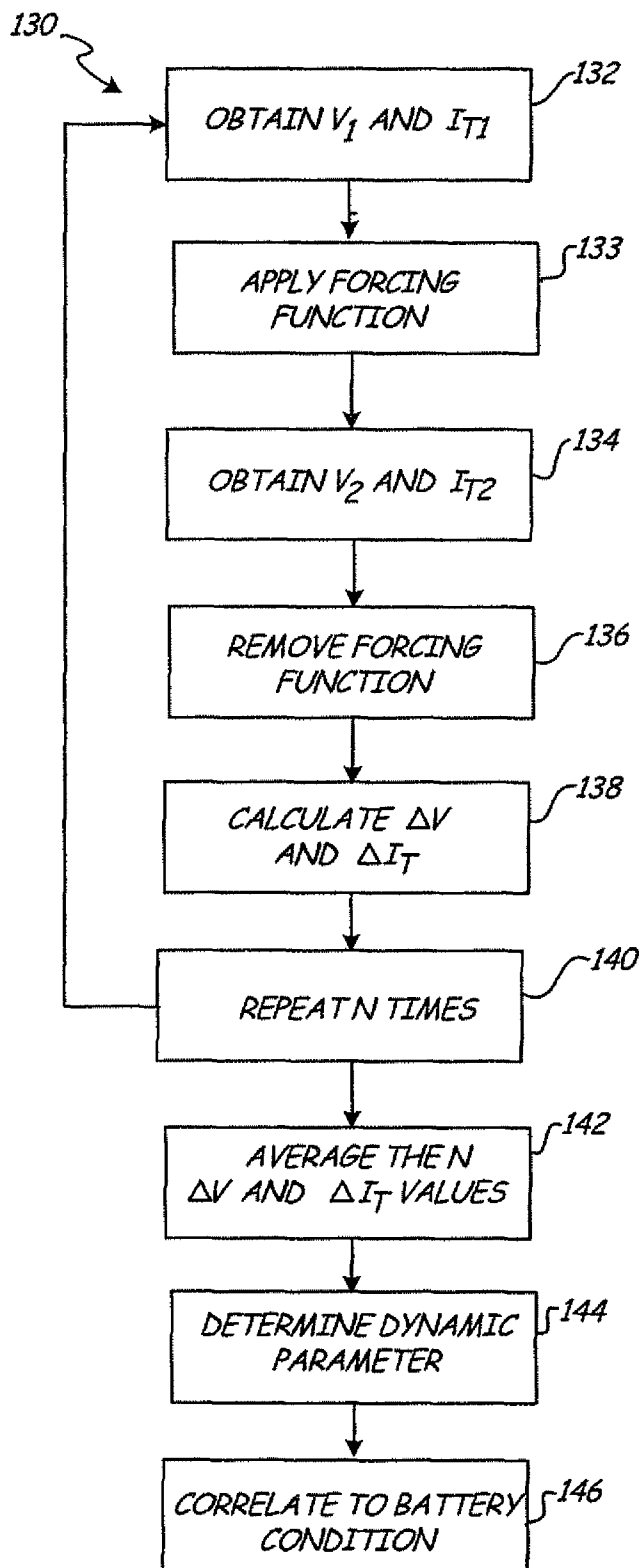
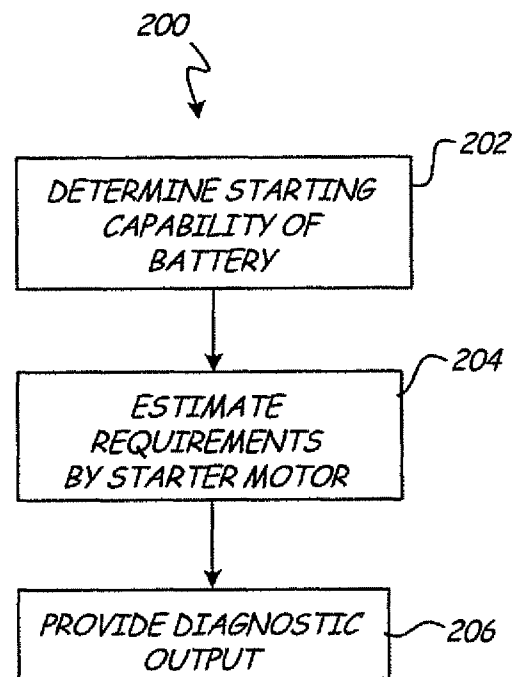
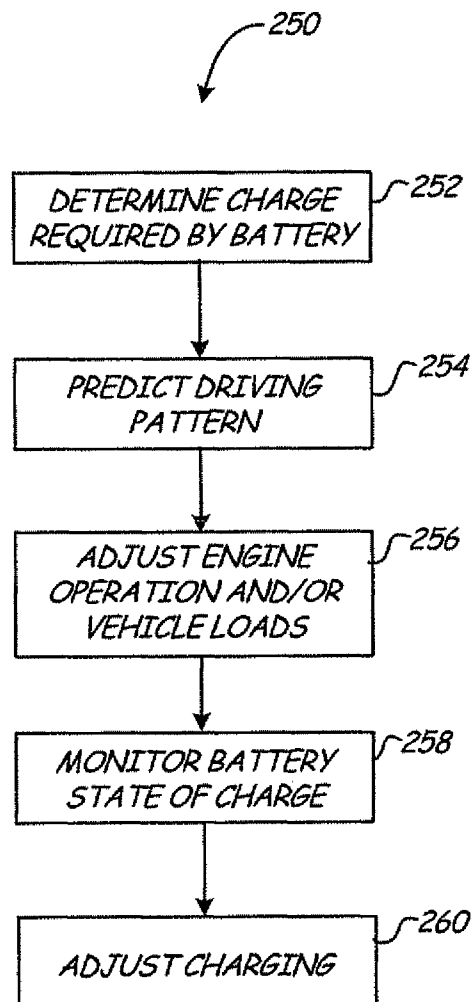


Fig. 2

**Fig. 3**

**Fig. 4**

**Fig. 5**

*Fig. 6*

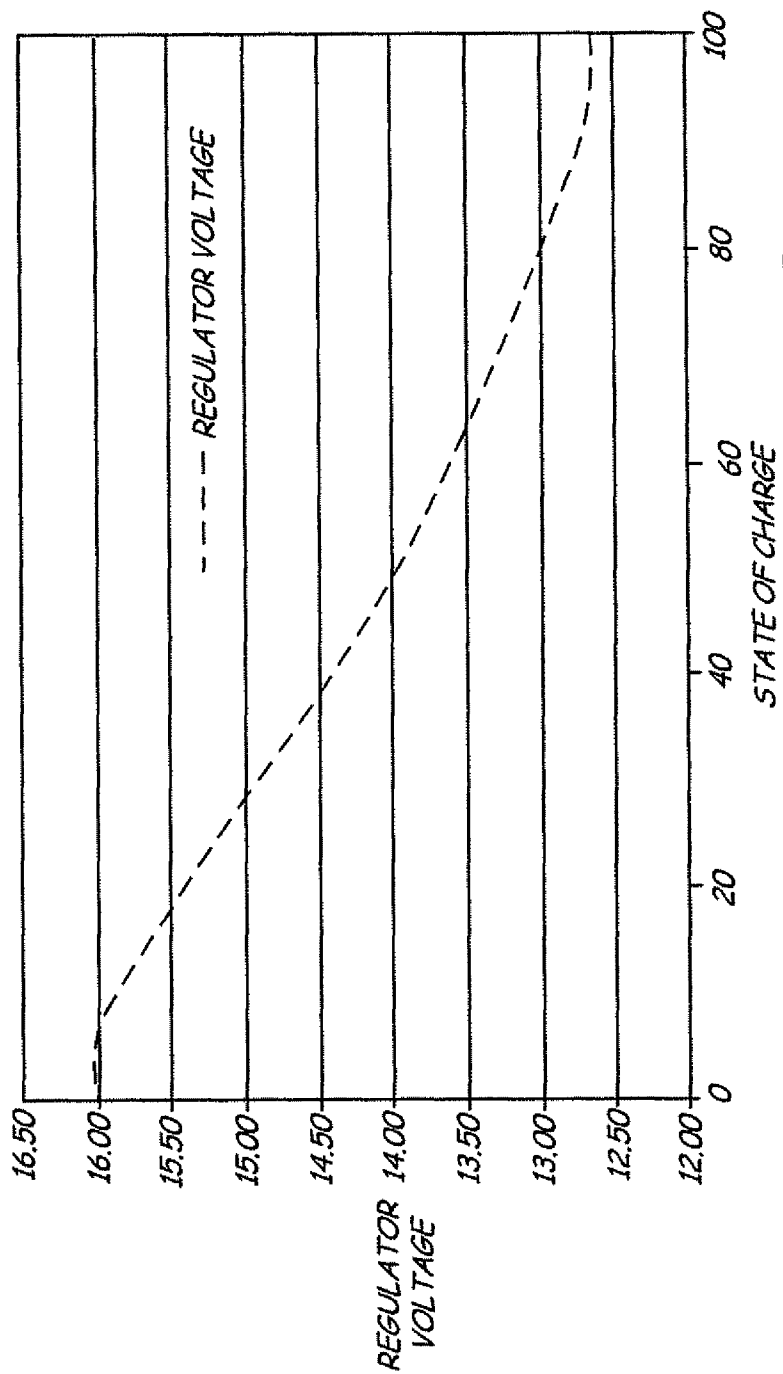


Fig. 7

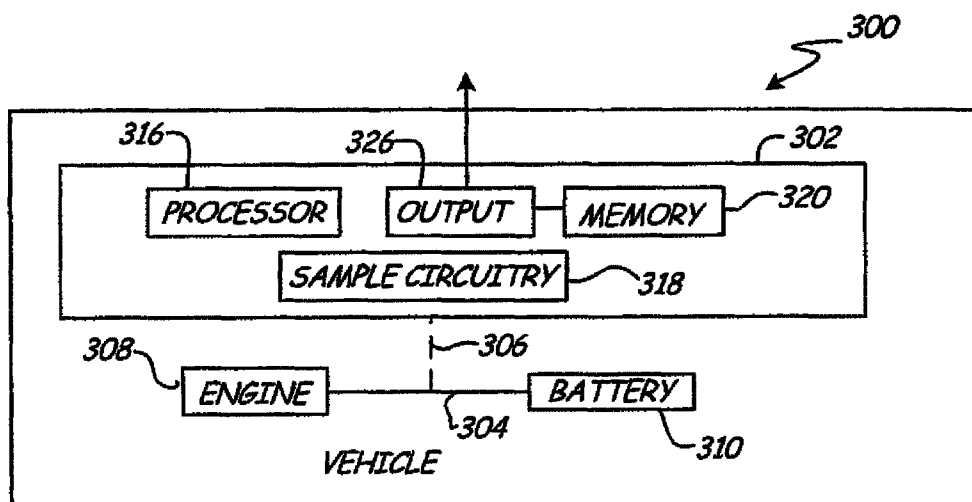


Fig. 8

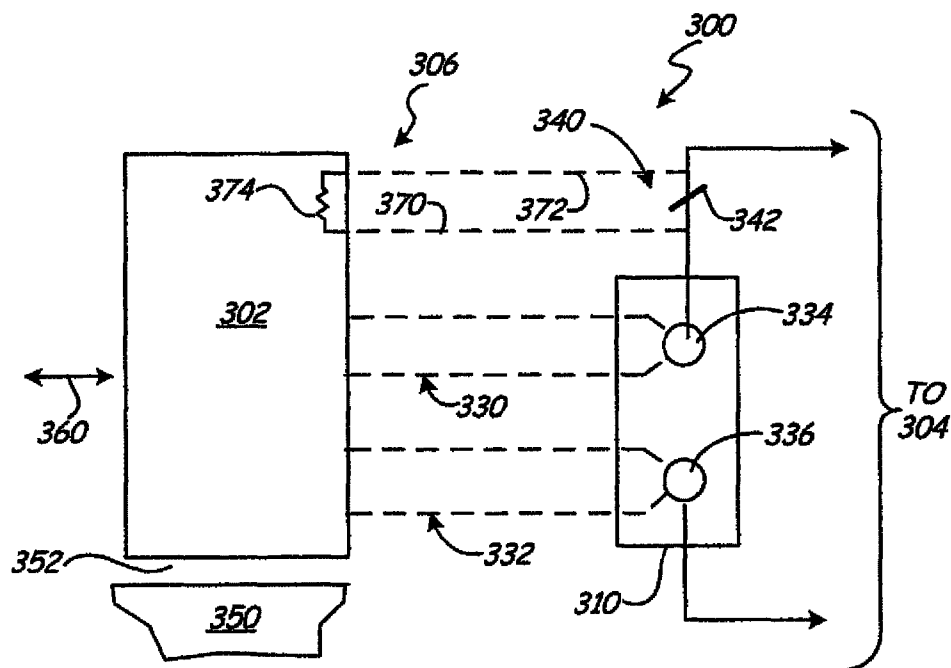


Fig. 9

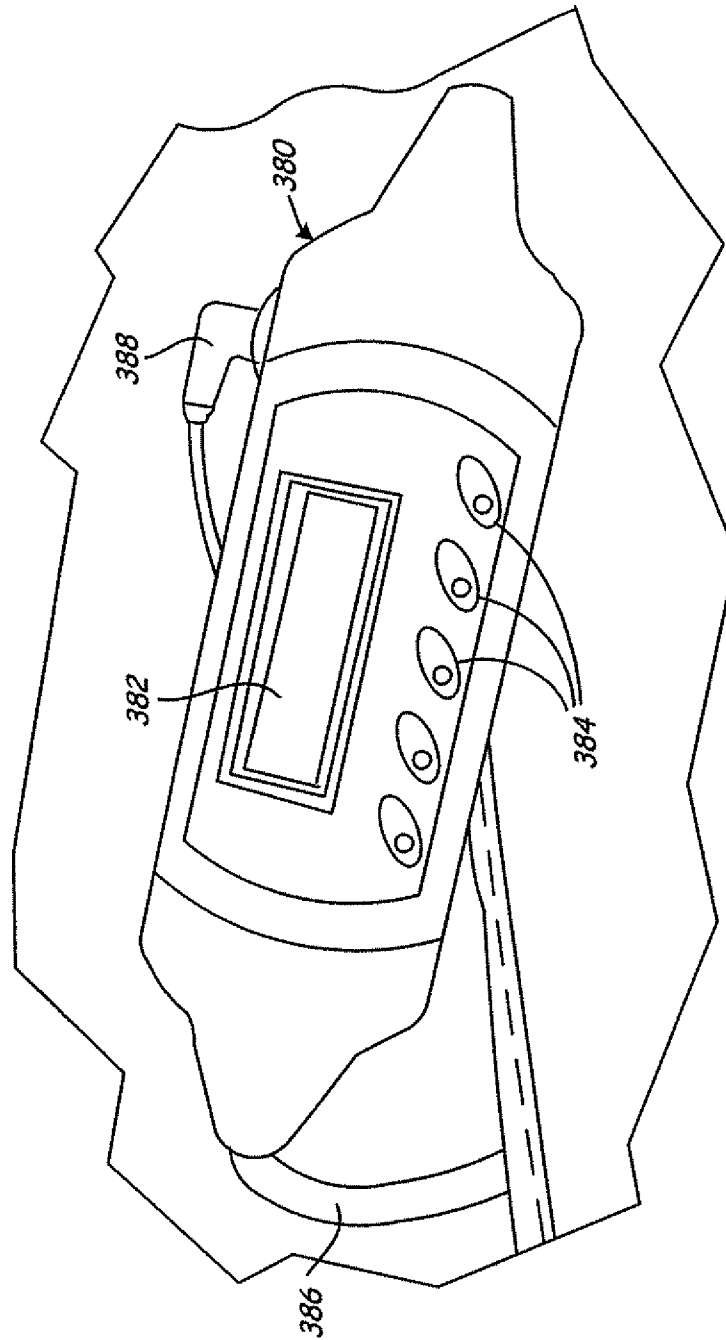


Fig. 10

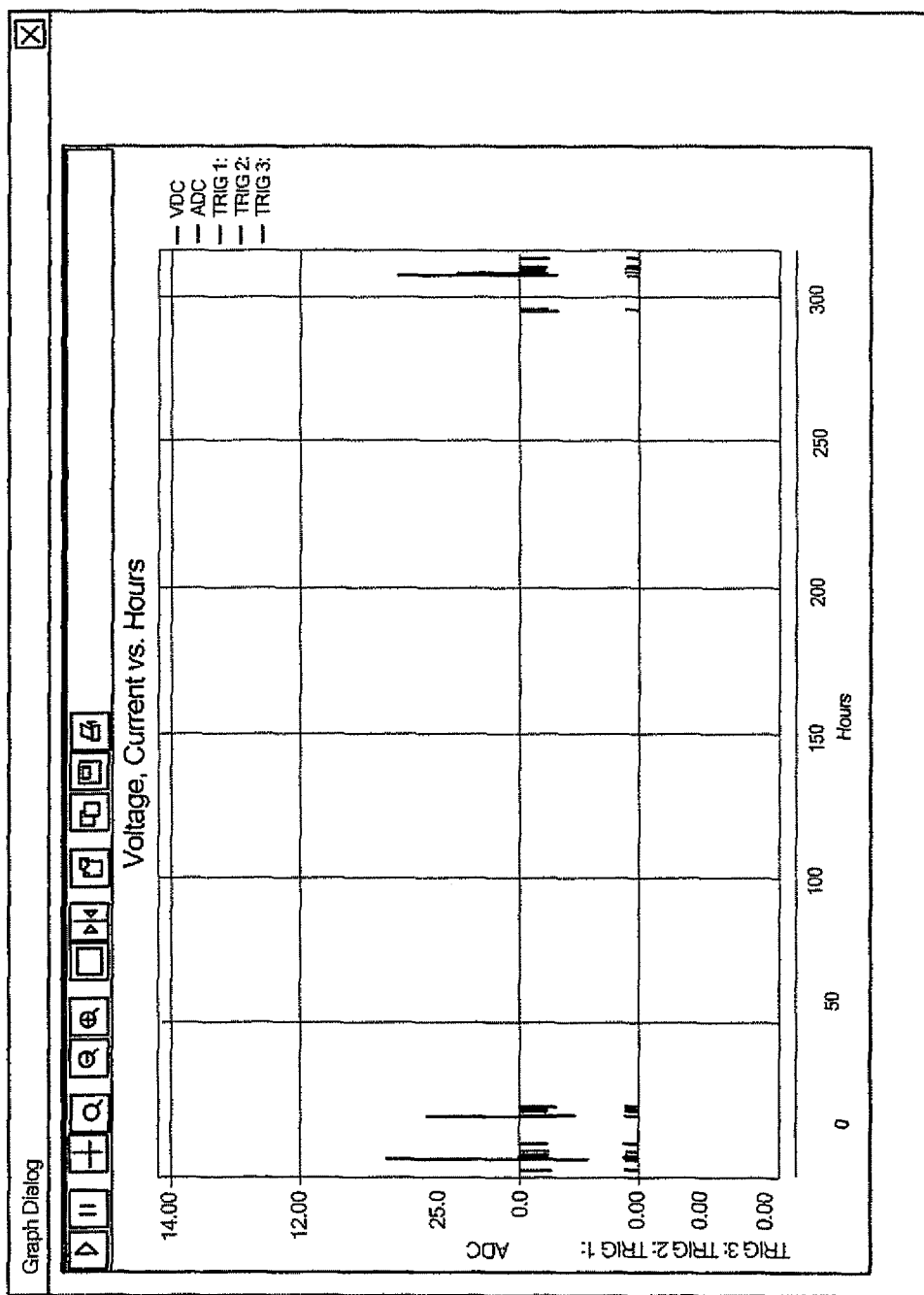


Fig. 11

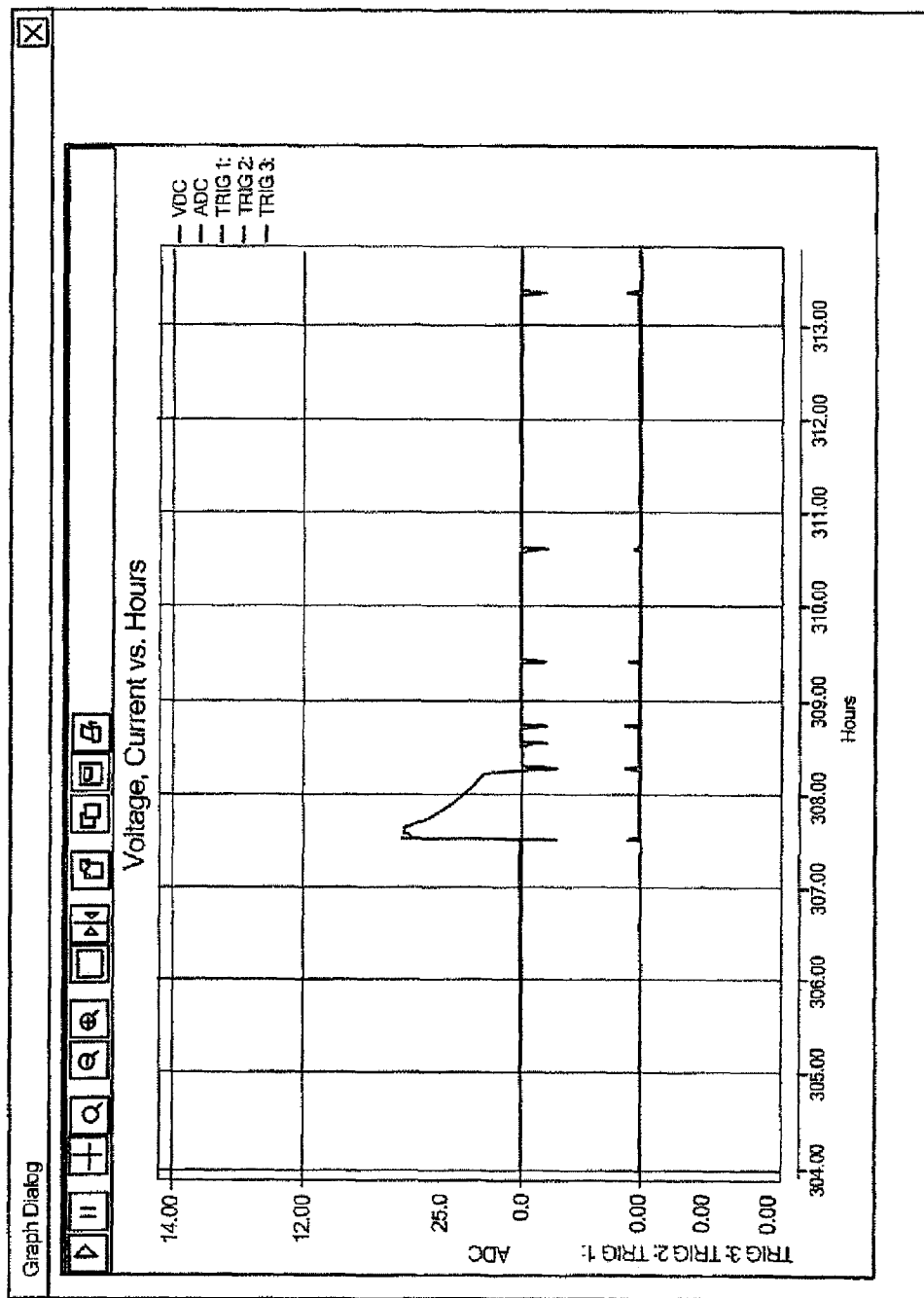


Fig. 12

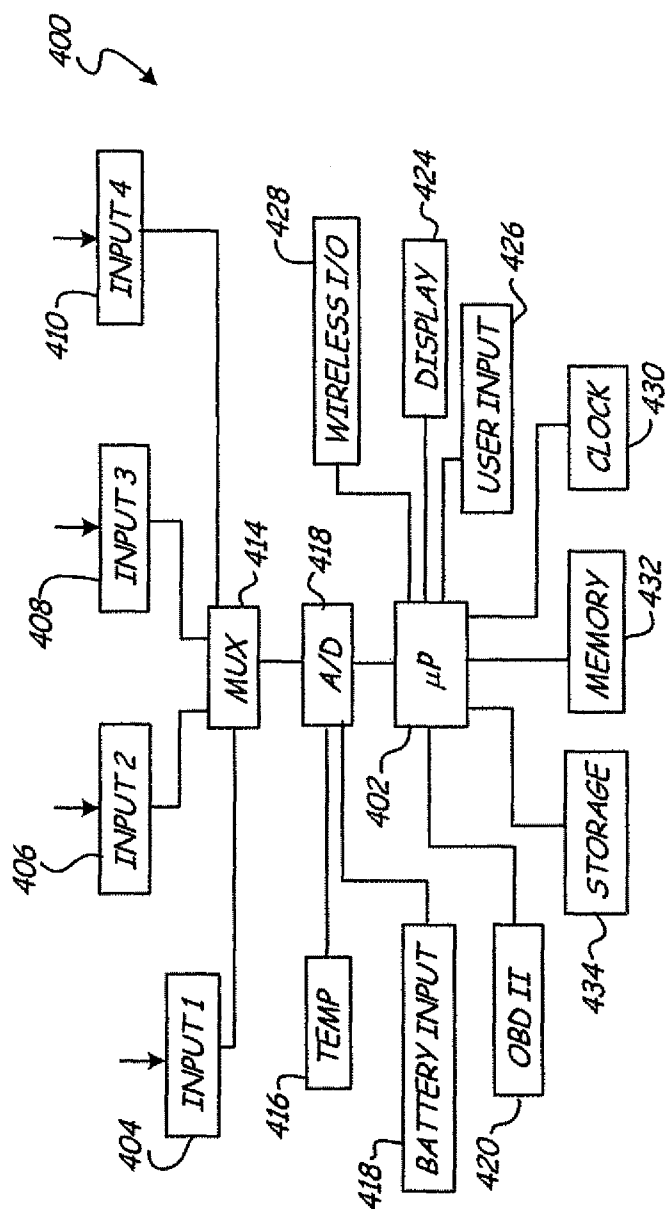
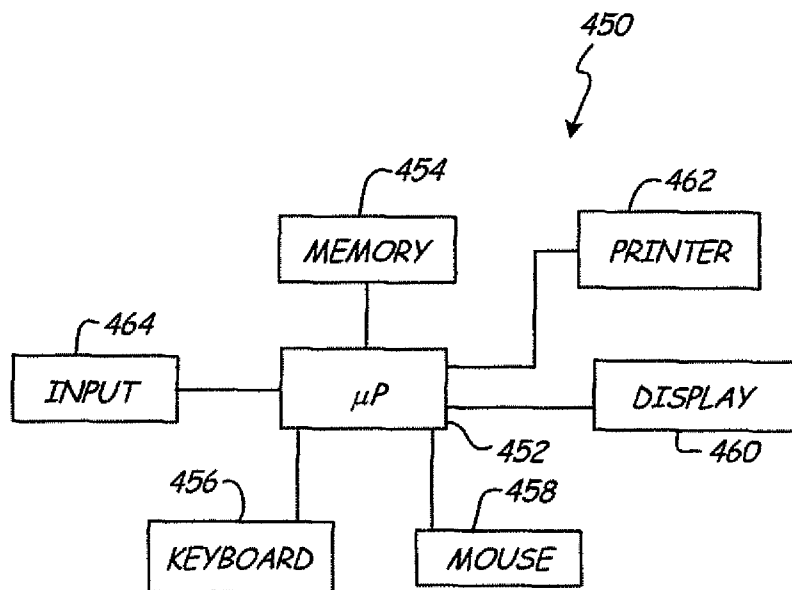


Fig. 13

*Fig. 14*

1

**AUTOMOTIVE VEHICLE ELECTRICAL
SYSTEM DIAGNOSTIC DEVICE****CROSS-REFERENCE TO RELATED
APPLICATION**

The present application is a Continuation of U.S. Ser. No. 11/511,872, filed Aug. 29, 2006, which is based on and claims the benefit of U.S. provisional patent application Ser. No. 60/731,887, filed Oct. 31, 2005, and also the benefit of U.S. provisional patent application Ser. No. 60/712,322, filed Aug. 29, 2005, application Ser. No. 11/511,872 is also a Continuation-In-Part of 10/200,041, filed Jul. 19, 2002, now U.S. Pat. No. 7,126,341 which is a Continuation-In-Part 10/046,659, filed Oct. 29, 2001, now U.S. Pat. No. 6,909,287, which is a Divisional of 09/564,740, filed May 4, 2000, now U.S. Pat. No. 6,331,762, which claims the benefit of 60/132,622, filed May 5, 1999, and 60/165,208, filed Nov. 12, 1999, and 60/175,762, filed Jan. 12, 2000, said application Ser. No. 10/046,659 is also a Continuation-In-Part 09/575,627, filed May 22, 2000, now U.S. Pat. No. 6,313,608, which is a Continuation-In-Part 08/962,754, filed Nov. 3, 1997, now U.S. Pat. No. 6,081,098, said application Ser. No. 10/200,041 is also a Continuation-In-Part 09/816,768, filed Mar. 23, 2001, now U.S. Pat. No. 6,586,941, which claims the benefit of 60/192,222, filed Mar. 27, 2000, the contents of which are hereby incorporated by reference in their entirety.

BACKGROUND OF THE INVENTION

The present invention relates to storage batteries and automotive vehicle electrical systems. More particularly, the present invention relates to testing storage batteries and automotive vehicle electrical systems.

Storage batteries are used in automotive vehicles containing internal combustion engines, including hybrid vehicles, as well as in electric vehicles. The storage batteries and electrical systems of such automotive vehicles can fail completely or decay with time. It is desirable to identify an impending failure or diagnose the cause of an existing failure. Further, failures or symptoms related to such failures, can be intermittent and difficult to identify.

Typical diagnostic and troubleshooting techniques related to storage batteries and vehicle electrical systems are performed while the vehicle is located in a shop, test facility or otherwise not under normal operation. Further, intermittent symptoms may not occur during such testing.

Various testing techniques for storage batteries, vehicle electrical systems and related devices are shown and described in 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;

2

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 DEVICE; 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. 5,585,416, issued Dec. 10, 1996, entitled APPARATUS AND METHOD FOR STEP-CHARGING BATTERIES TO OPTIMIZE CHARGE ACCEPTANCE; 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. 5,589,757, issued Dec. 31, 1996, entitled APPARATUS AND METHOD FOR STEP-CHARGING BATTERIES TO OPTIMIZE CHARGE ACCEPTANCE; 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. 5,656,920, issued Aug. 12, 1997, entitled METHOD FOR OPTIMIZING THE CHARGING LEAD-ACID BATTERIES AND AN INTERACTIVE CHARGER; 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. 5,871,858, issued Feb. 16, 1999, entitled ANTI-THEFT BATTERY; 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; U.S. Pat. No. 6,002,238, issued Dec. 14, 1999, entitled METHOD AND APPARATUS FOR MEASURING COMPLEX IMPEDANCE OF CELLS AND BATTERIES; U.S. Pat. No. 6,037,751, issued Mar. 14, 2000, entitled APPARATUS FOR CHARGING BATTERIES; U.S. Pat. No. 6,037,777, issued Mar. 14, 2000, entitled METHOD AND APPARATUS FOR DETERMINING BATTERY PROPERTIES FROM COMPLEX IMPEDANCE/ADMITTANCE; U.S. Pat. No. 6,051,976, issued Apr. 18, 2000, entitled METHOD AND APPARATUS FOR AUDITING A BATTERY TEST; U.S. Pat. No. 6,081,098, issued Jun. 27, 2000, entitled METHOD AND APPARATUS FOR CHARGING A BATTERY; U.S. Pat. No. 6,091,245, issued Jul. 18, 2000, entitled METHOD AND APPARATUS FOR AUDITING A BATTERY TEST; U.S. Pat. No. 6,104,167, issued Aug. 15, 2000, entitled METHOD AND APPARATUS FOR CHARGING A BATTERY; U.S. Pat. No. 6,137,269, issued Oct. 24, 2000, entitled METHOD AND APPARATUS FOR ELECTRONICALLY EVALUATING THE INTERNAL TEMPERATURE OF AN ELECTROCHEMICAL CELL OR BATTERY; U.S. Pat. No. 6,163,156, issued Dec. 19, 2000, entitled ELECTRICAL CONNECTION FOR ELECTRONIC BATTERY TESTER; U.S. Pat. No. 6,172,483, issued Jan. 9, 2001, entitled METHOD AND APPARATUS FOR MEASURING COMPLEX IMPEDANCE OF CELLS AND BATTERIES; U.S. Pat. No. 6,172,505, issued Jan. 9, 2001, entitled ELECTRONIC BATTERY TESTER; U.S. Pat. No. 6,222,369, issued Apr. 24, 2001, entitled METHOD AND APPARATUS FOR DETERMINING BATTERY PROPERTIES FROM COMPLEX IMPEDANCE/ADMITTANCE.

TANCE; U.S. Pat. No. 6,225,808, issued May 1, 2001, entitled TEST COUNTER FOR ELECTRONIC BATTERY TESTER; U.S. Pat. No. 6,249,124, issued Jun. 19, 2001, entitled ELECTRONIC BATTERY TESTER WITH INTERNAL BATTERY; U.S. Pat. No. 6,259,254, issued Jul. 10, 2001, entitled APPARATUS AND METHOD FOR CARRYING OUT DIAGNOSTIC TESTS ON BATTERIES AND FOR RAPIDLY CHARGING BATTERIES; U.S. Pat. No. 6,262,563, issued Jul. 17, 2001, entitled METHOD AND APPARATUS FOR MEASURING COMPLEX ADMITTANCE OF CELLS AND BATTERIES; U.S. Pat. No. 6,294,896, issued Sep. 25, 2001, entitled METHOD AND APPARATUS FOR MEASURING COMPLEX SELF-IMMITTANCE OF A GENERAL ELECTRICAL ELEMENT; U.S. Pat. No. 6,294,897, issued Sep. 25, 2001, entitled METHOD AND APPARATUS FOR ELECTRONICALLY EVALUATING THE INTERNAL TEMPERATURE OF AN ELECTROCHEMICAL CELL OR BATTERY; U.S. Pat. No. 6,304,087, issued Oct. 16, 2001, entitled APPARATUS FOR CALIBRATING ELECTRONIC BATTERY TESTER; U.S. Pat. No. 6,310,481, issued Oct. 30, 2001, entitled ELECTRONIC BATTERY TESTER; U.S. Pat. No. 6,313,607, issued Nov. 6, 2001, entitled METHOD AND APPARATUS FOR EVALUATING STORED CHARGE IN AN ELECTROCHEMICAL CELL OR BATTERY; U.S. Pat. No. 6,313,608, issued Nov. 6, 2001, entitled METHOD AND APPARATUS FOR CHARGING A BATTERY; U.S. Pat. No. 6,316,914, issued Nov. 13, 2001, entitled TESTING PARALLEL STRINGS OF STORAGE BATTERIES; U.S. Pat. No. 6,323,650, issued Nov. 27, 2001, entitled ELECTRONIC BATTERY TESTER; U.S. Pat. No. 6,329,793, issued Dec. 11, 2001, entitled METHOD AND APPARATUS FOR CHARGING A BATTERY; U.S. Pat. No. 6,331,762, issued Dec. 18, 2001, entitled ENERGY MANAGEMENT SYSTEM FOR AUTOMOTIVE VEHICLE; U.S. Pat. No. 6,332,113, issued Dec. 18, 2001, entitled ELECTRONIC BATTERY TESTER; U.S. Pat. No. 6,351,102, issued Feb. 26, 2002, entitled AUTOMOTIVE BATTERY CHARGING SYSTEM TESTER; U.S. Pat. No. 6,359,441, issued Mar. 19, 2002, entitled ELECTRONIC BATTERY TESTER; U.S. Pat. No. 6,363,303, issued Mar. 26, 2002, entitled ALTERNATOR DIAGNOSTIC SYSTEM; U.S. Pat. No. 6,377,031, issued Apr. 23, 2002, entitled INTELLIGENT SWITCH FOR POWER MANAGEMENT; U.S. Pat. No. 6,392,414, issued May 21, 2002, entitled ELECTRONIC BATTERY TESTER; U.S. Pat. No. 6,417,669, issued Jul. 9, 2002, entitled SUPPRESSING INTERFERENCE IN AC MEASUREMENTS OF CELLS, BATTERIES AND OTHER ELECTRICAL ELEMENTS; U.S. Pat. No. 6,424,158, issued Jul. 23, 2002, entitled APPARATUS AND METHOD FOR CARRYING OUT DIAGNOSTIC TESTS ON BATTERIES AND FOR RAPIDLY CHARGING BATTERIES; U.S. Pat. No. 6,441,585, issued Aug. 17, 2002, entitled APPARATUS AND METHOD FOR TESTING RECHARGEABLE ENERGY STORAGE BATTERIES; U.S. Pat. No. 6,437,957, issued Aug. 20, 2002, entitled SYSTEM AND METHOD FOR PROVIDING SURGE, SHORT, AND REVERSE POLARITY CONNECTION PROTECTION; U.S. Pat. No. 6,445,158, issued Sep. 3, 2002, entitled VEHICLE ELECTRICAL SYSTEM TESTER WITH ENCODED OUTPUT; U.S. Pat. No. 6,456,045, issued Sep. 24, 2002, entitled INTEGRATED CONDUCTANCE AND LOAD TEST BASED ELECTRONIC BATTERY TESTER; U.S. Pat. No. 6,466,025, issued Oct. 15, 2002, entitled ALTERNATOR TESTER; U.S. Pat. No. 6,465,908, issued Oct. 15, 2002, entitled INTELLIGENT POWER MANAGEMENT SYSTEM; U.S. Pat. No. 6,466,026, issued Oct. 15, 2002, entitled PROGRAM-

MABLE CURRENT EXCITER FOR MEASURING AC IMMITTANCE OF CELLS AND BATTERIES; U.S. Pat. No. 6,469,511, issued Nov. 22, 2002, entitled BATTERY CLAMP WITH EMBEDDED ENVIRONMENT SENSOR; U.S. Pat. No. 6,495,990, issued Dec. 17, 2002, entitled METHOD AND APPARATUS FOR EVALUATING STORED CHARGE IN AN ELECTROCHEMICAL CELL OR BATTERY; U.S. Pat. No. 6,497,209, issued Dec. 24, 2002, entitled SYSTEM AND METHOD FOR PROTECTING A CRANKING SUBSYSTEM; U.S. Pat. No. 6,507,196, issued Jan. 14, 2003, entitled BATTERY HAVING DISCHARGE STATE INDICATION; U.S. Pat. No. 6,534,993, issued Mar. 18, 2003, entitled ELECTRONIC BATTERY TESTER; U.S. Pat. No. 6,544,078, issued Apr. 8, 2003, entitled BATTERY CLAMP WITH INTEGRATED CURRENT SENSOR; U.S. Pat. No. 6,556,019, issued Apr. 29, 2003, entitled ELECTRONIC BATTERY TESTER; U.S. Pat. No. 6,566,883, issued May 20, 2003, entitled ELECTRONIC BATTERY TESTER; U.S. Pat. No. 6,586,941, issued Jul. 1, 2003, entitled BATTERY TESTER WITH DATABUS; U.S. Pat. No. 6,597,150, issued Jul. 22, 2003, entitled METHOD OF DISTRIBUTING JUMP-START BOOSTER PACKS; U.S. Pat. No. 6,621,272, issued Sep. 16, 2003, entitled PROGRAMMABLE CURRENT EXCITER FOR MEASURING AC IMMITTANCE OF CELLS AND BATTERIES; U.S. Pat. No. 6,623,314, issued Sep. 23, 2003, entitled KELVIN CLAMP FOR ELECTRICALLY COUPLING TO A BATTERY CONTACT; U.S. Pat. No. 6,633,165, issued Oct. 14, 2003, entitled IN-VEHICLE BATTERY MONITOR; U.S. Pat. No. 6,635,974, issued Oct. 21, 2003, entitled SELF-LEARNING POWER MANAGEMENT SYSTEM AND METHOD; U.S. Pat. No. 6,707,303, issued Mar. 16, 2004, entitled ELECTRONIC BATTERY TESTER; U.S. Pat. No. 6,737,831, issued May 18, 2004, entitled METHOD AND APPARATUS USING A CIRCUIT MODEL TO EVALUATE CELL/BATTERY PARAMETERS; U.S. Pat. No. 6,744,149, issued Jun. 1, 2004, entitled SYSTEM AND METHOD FOR PROVIDING STEP-DOWN POWER CONVERSION USING AN INTELLIGENT SWITCH; U.S. Pat. No. 6,759,849, issued Jul. 6, 2004, entitled BATTERY TESTER CONFIGURED TO RECEIVE A REMOVABLE DIGITAL MODULE; U.S. Pat. No. 6,781,382, issued Aug. 24, 2004, entitled ELECTRONIC BATTERY TESTER; U.S. Pat. No. 6,788,025, filed Sep. 7, 2004, entitled BATTERY CHARGER WITH BOOSTER PACK; U.S. Pat. No. 6,795,782, issued Sep. 21, 2004, entitled BATTERY TEST MODULE; U.S. Pat. No. 6,805,090, filed Oct. 19, 2004, entitled CHARGE CONTROL SYSTEM FOR A VEHICLE BATTERY; U.S. Pat. No. 6,806,716, filed Oct. 19, 2004, entitled ELECTRONIC BATTERY TESTER; U.S. Pat. No. 6,850,037, filed Feb. 1, 2005, entitled IN-VEHICLE BATTERY MONITORING; U.S. Pat. No. 6,850,037, issued Feb. 1, 2005, entitled IN-VEHICLE BATTERY MONITOR; U.S. Pat. No. 6,871,151, issued Mar. 22, 2005, entitled ELECTRONIC BATTERY TESTER WITH NETWORK COMMUNICATION; U.S. Pat. No. 6,885,195, issued Apr. 26, 2005, entitled METHOD AND APPARATUS FOR AUDITING A BATTERY TEST; U.S. Pat. No. 6,888,468, issued May 3, 2005, entitled APPARATUS AND METHOD FOR PROTECTING A BATTERY FROM OVERDISCHARGE; U.S. Pat. No. 6,891,378, issued May 10, 2005, entitled ELECTRONIC BATTERY TESTER; U.S. Pat. No. 6,906,522, issued Jun. 14, 2005, entitled BATTERY TESTER WITH BATTERY REPLACEMENT OUTPUT; U.S. Pat. No. 6,906,523, issued Jun. 14, 2005, entitled METHOD AND APPARATUS FOR TESTING CELLS AND BATTERIES EMBEDDED IN SERIES/PARALLEL SYSTEMS; U.S.

Pat. No. 6,909,287, issued Jun. 21, 2005, entitled ENERGY MANAGEMENT SYSTEM WITH AUTOMOTIVE VEHICLE; U.S. Pat. No. 6,914,413, issued Jul. 5, 2005, entitled ALTERNATOR TESTER WITH ENCODED OUTPUT; U.S. Pat. No. 6,913,483, issued Jul. 5, 2005, entitled CABLE FOR ELECTRONIC BATTERY TESTER; U.S. Pat. No. 6,930,485, issued Aug. 16, 2005, entitled ELECTRONIC BATTERY TESTER WITH BATTERY FAILURE TEMPERATURE DETERMINATION; U.S. Pat. No. 6,933,727, issued Aug. 23, 2005, entitled ELECTRONIC BATTERY TESTER CABLE, U.S. Pat. No. 6,941,234, filed Sep. 6, 2005, entitled QUERY BASED ELECTRONIC BATTERY TESTER; U.S. Pat. No. 6,967,484, issued Nov. 22, 2005, entitled MODULAR BATTERY TESTER FOR SCAN TOOL; U.S. Pat. No. 6,998,847, issued Feb. 14, 2006, entitled ELECTRONIC BATTERY TESTER WITH DATA BUS FOR REMOVABLE MODULE, U.S. Pat. No. 7,003,410, issued Feb. 21, 2006, entitled ELECTRONIC BATTERY TESTER WITH RELATIVE TEST OUTPUT, U.S. Pat. No. 7,003,411, issued Feb. 21, 2006, entitled ELECTRONIC BATTERY TESTER WITH NETWORK COMMUNICATION, U.S. Pat. No. 7,012,433, ISSUED Mar. 14, 2006, entitled BATTERY TESTER UPGRADE USING SOFTWARE KEY, U.S. Pat. No. 7,015,674, issued Mar. 21, 2006, entitled BOOSTER PACK WITH STORAGE CAPACITOR, U.S. Pat. No. 7,034,541, issued Apr. 25, 2006, entitled QUERY BASED ELECTRONIC BATTERY TESTER, U.S. Pat. No. 7,039,533, issued May 2, 2006, entitled BATTERY TESTER MODULE, U.S. Pat. No. 7,058,525, issued Jun. 6, 2006, entitled BATTERY TESTER MODULE, U.S. Pat. No. 7,081,755, issued Jul. 25, 2006, entitled BATTERY TEST CAPABLE OF PREDICTING A DISCHARGE VOLTAGE/DISCHARGE CURRENT OF A BATTERY; U.S. Ser. No. 09/780,146, filed Feb. 9, 2001, entitled STORAGE BATTERY WITH INTEGRAL BATTERY TESTER; U.S. Ser. No. 09/756,638, filed Jan. 8, 2001, entitled METHOD AND APPARATUS FOR DETERMINING BATTERY PROPERTIES FROM COMPLEX IMPEDANCE/ADMITTANCE; U.S. Ser. No. 09/862,783, filed May 21, 2001, entitled METHOD AND APPARATUS FOR TESTING CELLS AND BATTERIES EMBEDDED IN SERIES/PARALLEL SYSTEMS; U.S. Ser. No. 09/880,473, filed Jun. 13, 2001, entitled BATTERY TEST MODULE; U.S. Ser. No. 09/993,468, filed Nov. 14, 2001, entitled KELVIN CONNECTOR FOR A BATTERY POST; U.S. Ser. No. 10/042,451, filed Jan. 8, 2002, entitled BATTERY CHARGE CONTROL DEVICE; U.S. Ser. No. 10/109,734, filed Mar. 28, 2002, entitled APPARATUS AND METHOD FOR COUNTERACTING SELF DISCHARGE IN A STORAGE BATTERY; U.S. Ser. No. 10/112,998, filed Mar. 29, 2002, entitled BATTERY TESTER WITH BATTERY REPLACEMENT OUTPUT; U.S. Ser. No. 10/200,041, filed Jul. 19, 2002, entitled AUTOMOTIVE VEHICLE ELECTRICAL SYSTEM DIAGNOSTIC DEVICE; U.S. Ser. No. 10/263,473, filed Oct. 2, 2002, entitled ELECTRONIC BATTERY TESTER WITH RELATIVE TEST OUTPUT; U.S. Ser. No. 10/310,385, filed Dec. 5, 2002, entitled BATTERY TEST MODULE; U.S. Ser. No. 10/462,323, filed Jun. 16, 2003, entitled ELECTRONIC BATTERY TESTER HAVING A USER INTERFACE TO CONFIGURE A PRINTER; U.S. Ser. No. 10/653,342, filed Sep. 2, 2003, entitled ELECTRONIC BATTERY TESTER CONFIGURED TO PREDICT A LOAD TEST RESULT; U.S. Ser. No. 10/656,526, filed Sep. 5, 2003, entitled METHOD AND APPARATUS FOR MEASURING A PARAMETER OF A VEHICLE ELECTRICAL SYSTEM; U.S. Ser. No. 10/441,271, filed May 19, 2003, entitled ELECTRONIC BATTERY TESTER; U.S. Ser. No. 09/653,

963, filed Sep. 1, 2000, entitled SYSTEM AND METHOD FOR CONTROLLING POWER GENERATION AND STORAGE; U.S. Ser. No. 10/174,110, filed Jun. 18, 2002, entitled DAYTIME RUNNING LIGHT CONTROL USING AN INTELLIGENT POWER MANAGEMENT SYSTEM; U.S. Ser. No. 10/258,441, filed Apr. 9, 2003, entitled CURRENT MEASURING CIRCUIT SUITED FOR BATTERIES; U.S. Ser. No. 10/705,020, filed Nov. 11, 2003, entitled APPARATUS AND METHOD FOR SIMULATING A BATTERY TESTER WITH A FIXED RESISTANCE LOAD; U.S. Ser. No. 10/681,666, filed Oct. 8, 2003, entitled ELECTRONIC BATTERY TESTER WITH PROBE LIGHT; U.S. Ser. No. 10/748,792, filed Dec. 30, 2003, entitled APPARATUS AND METHOD FOR PREDICTING THE REMAINING DISCHARGE TIME OF A BATTERY; U.S. Ser. No. 10/783,682, filed Feb. 20, 2004, entitled REPLACEABLE CLAMP FOR ELECTRONIC BATTERY TESTER; U.S. Ser. No. 10/791,141, filed Mar. 2, 2004, entitled METHOD AND APPARATUS FOR AUDITING A BATTERY TEST; U.S. Ser. No. 10/823,140, filed Apr. 13, 2004, entitled THEFT PREVENTION DEVICE FOR AUTOMOTIVE VEHICLE SERVICE CENTERS; U.S. Ser. No. 10/864,904, filed Jun. 9, 2004, entitled ALTERNATOR TESTER; U.S. Ser. No. 10/867,385, filed Jun. 14, 2004, entitled ENERGY MANAGEMENT SYSTEM FOR AUTOMOTIVE VEHICLE; U.S. Ser. No. 10/896,835, filed Jul. 22, 2004, entitled BROAD-BAND LOW-INDUCTANCE CABLES FOR MAKING KELVIN CONNECTIONS TO ELECTROCHEMICAL CELLS AND BATTERIES; U.S. Ser. No. 10/896,834, filed Jul. 22, 2004, entitled ELECTRONIC BATTERY TESTER; U.S. Ser. No. 10/897,801, filed Jul. 23, 2004, entitled SHUNT CONNECTION TO A PCB FOR AN ENERGY MANAGEMENT SYSTEM EMPLOYED IN AN AUTOMOTIVE VEHICLE; U.S. Ser. No. 10/958,821, filed Oct. 5, 2004, entitled IN-VEHICLE BATTERY MONITOR; U.S. Ser. No. 10/958,812, filed Oct. 5, 2004, entitled SCAN TOOL FOR ELECTRONIC BATTERY TESTER; U.S. Ser. No. 11/008,456, filed Dec. 9, 2004, entitled APPARATUS AND METHOD FOR PREDICTING BATTERY CAPACITY AND FITNESS FOR SERVICE FROM A BATTERY DYNAMIC PARAMETER AND A RECOVERY VOLTAGE DIFFERENTIAL, U.S. Ser. No. 60/587,232, filed Dec. 14, 2004, entitled CELLTRON ULTRA, U.S. Ser. No. 11/018,785, filed Dec. 21, 2004, entitled WIRELESS BATTERY MONITOR; U.S. Ser. No. 60/653,537, filed Feb. 16, 2005, entitled CUSTOMER MANAGED WARRANTY CODE; U.S. Ser. No. 11/063,247, filed Feb. 22, 2005, entitled ELECTRONIC BATTERY TESTER OR CHARGER WITH DATABUS CONNECTION; U.S. Ser. No. 60/665,070, filed Mar. 24, 2005, entitled OHMMETER PROTECTION CIRCUIT; U.S. Ser. No. 11/141,234, filed May 31, 2005, entitled BATTERY TESTER CAPABLE OF IDENTIFYING FAULTY BATTERY POST ADAPTERS; U.S. Ser. No. 11/143,828, filed Jun. 2, 2005, entitled BATTERY TEST MODULE; U.S. Ser. No. 11/146,608, filed Jun. 7, 2005, entitled SCAN TOOL FOR ELECTRONIC BATTERY TESTER; U.S. Ser. No. 60,694,199, filed Jun. 27, 2005, entitled GEL BATTERY CONDUCTANCE COMPENSATION; U.S. Ser. No. 11/178,550, filed Jul. 11, 2005, entitled WIRELESS BATTERY TESTER/CHARGER; U.S. Ser. No. 60/705,389, filed Aug. 4, 2005, entitled PORTABLE TOOL THEFT PREVENTION SYSTEM, U.S. Ser. No. 11/207,419, filed Aug. 19, 2005, entitled SYSTEM FOR AUTOMATICALLY GATHERING BATTERY INFORMATION FOR USE DURING BATTERY TESTER/CHARGING, U.S. Ser. No. 60/712,322, filed Aug. 29, 2005, entitled AUTOMOTIVE VEHICLE ELECTRICAL SYSTEM

7

DIAGNOSTIC DEVICE, U.S. Ser. No. 60/713,169, filed Aug. 31, 2005, entitled LOAD TESTER SIMULATION WITH DISCHARGE COMPENSATION, U.S. Ser. No. 60/731,881, filed Oct. 31, 2005, entitled PLUG-IN FEATURES FOR BATTERY TESTERS; U.S. Ser. No. 60/731,887, filed Oct. 31, 2005, entitled AUTOMOTIVE VEHICLE ELECTRICAL SYSTEM DIAGNOSTIC DEVICE; U.S. Ser. No. 11/304,004, filed Dec. 14, 2005, entitled BATTERY TESTER THAT CALCULATES ITS OWN REFERENCE VALUES; U.S. Ser. No. 60/751,853, filed Dec. 20, 2005, entitled BATTERY MONITORING SYSTEM; U.S. Ser. No. 11/304,004, filed Dec. 14, 2005, entitled BATTERY TESTER WITH CALCULATES ITS OWN REFERENCE VALUES; U.S. Ser. No. 60/751,853, filed Dec. 20, 2005, entitled BATTERY MONITORING SYSTEM; U.S. Ser. No. 11/352,945, filed Feb. 13, 2006, entitled BATTERY TESTERS WITH SECONDARY FUNCTIONALITY; U.S. Ser. No. 11/356,299, filed Feb. 16, 2006, entitled CENTRALLY MONITORED SALES OF STORAGE BATTERIES; U.S. Ser. No. 11/356,436, filed Feb. 16, 2006, entitled ELECTRONIC BATTERY TESTER WITH RELATIVE TEST OUTPUT; U.S. Ser. No. 11/356,443, filed Feb. 16, 2006, entitled ELECTRONIC BATTERY TESTER WITH NETWORK COMMUNICATION; U.S. Ser. No. 11/410,263, filed Apr. 24, 2006, entitled QUERY BASED ELECTRONIC BATTERY TESTER; which are incorporated herein in their entirety.

SUMMARY OF THE INVENTION

An automotive vehicle electrical system diagnostic apparatus includes a first electrical connection configured to electrically couple to a first terminal of a battery of an automotive vehicle and a second electrical connection configured to electrically couple to electrical wiring of the automotive vehicle. The first and second electrical connections are configured to connect with the battery and the electrical system of the automotive vehicle. Digital sample circuitry is coupled to the connections and is configured to provide a plurality of digital samples during operation of the vehicle which are related to the electrical system and/or storage battery. A memory is configured to store the plurality of digital samples. A method is also provided along with techniques to subsequently analyze the collected samples.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a simplified block diagram showing a battery monitor in a vehicle in accordance with one embodiment of the present invention.

FIG. 2 is a more detailed schematic diagram showing the battery monitor of FIG. 1.

FIG. 3 is a simplified block diagram showing steps in performing diagnostics in accordance with one aspect of the present invention.

FIG. 4 is a simplified block diagram showing steps in collecting data for use with the present invention.

FIG. 5 is a simplified block diagram which illustrates performing diagnostics on a starter motor of the vehicle of FIG. 1.

FIG. 6 is a simplified block diagram showing steps related to adjusting the charging profile for charging the battery of the vehicle of FIG. 1.

FIG. 7 is a graph which illustrates one sample curve of regulator voltage output versus state of charge for the battery of FIG. 1.

8

FIG. 8 is a simplified block diagram of a vehicle including a diagnostic device temporarily coupled to the electrical system of the vehicle.

FIG. 9 is a diagram showing the connection of the diagnostic device of FIG. 8 to the vehicle electrical system.

FIG. 10 is a view of an example data logger in accordance with the invention.

FIGS. 11 and 12 are graphs showing the display of logged data on a PC.

FIG. 13 is a block diagram showing a diagnostic device in accordance with one aspect of the invention.

FIG. 14 is a simplified block diagram of a personal computer system used for displaying or analyzing data logged from an automotive vehicle.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention includes an apparatus and method for testing a battery and/or electrical system of an automotive vehicle using a diagnostic device which is temporarily coupled to the electrical system of the vehicle. While the device is coupled to the vehicle, the vehicle can be driven such that data can be collected while the vehicle undergoes normal operation. The diagnostic device is removed from the vehicle after the testing period and during normal operation. Data collected by the diagnostic device while testing can then be observed or otherwise analyzed in order to identify failures or symptoms of failures in the electrical system and/or battery of the vehicle.

FIG. 1 is a simplified block diagram showing an automotive vehicle 10 which includes a battery monitor 12 in accordance with one embodiment of the present invention. Vehicle 10 includes vehicle loads 14 which are shown schematically as an electrical resistance. A battery 18 is coupled to the vehicle load 14 and to an alternator 20. Alternator 20 couples to an engine of the vehicle 10 and is used to charge battery 18 and provide power to loads 14 during operation.

In general, automotive vehicles include electrical systems which can be powered when the engine of the vehicle operates a generator, or alternator. However, when the engine is not running, a battery in the vehicle is typically used to power the system. Thus, the standard generator system in a vehicle serves two purposes. The generator is used to supply power to the vehicle loads, such as lights, computers, radios, defrosters and other electrical accessories. Further, the generator is used to recharge the battery such that the battery can be used to start the vehicle and such that the battery may power the electrical accessories when the engine is not running. Some vehicles do not include internal combustion engines and are completely operated by electrical power.

A standard generator system typically consists of a three phase AC alternator coupled to the engine by a belt or a shaft, rectification diodes and a voltage regulator. These components may exist separately or be part of an integral unit and are typically, somewhat inaccurately, referred to as an "alternator". The voltage regulator is configured such that a constant voltage is supplied by the charging system, regardless of the current being drawn by the electrical system. The actual load applied to the generator system varies depending upon the number of accessories that are activated and the current required to recharge the battery. Typical values for the voltage regulator output are between 13.5 and 15.5 volts, depending upon the vehicle manufacturer and particular battery chemistry. Further, the voltage on a specific vehicle can also be compensated for ambient temperature.

This prior art approach has a number of drawbacks. The output voltage of the generator must be selected to be high enough to rapidly charge the battery under any condition and regardless of the state of charge of the battery. Electrical loads on the vehicle are designed to operate at 12.6 volts, the voltage provided by the battery when the engine is switched off. However, these electrical loads must also operate at the higher voltage supplied when the generator system is on. This higher voltage which is impressed upon the electrical system causes higher I^2R (resistive) losses in the loads due to the increased voltage level. This wastes energy and causes the components to heat. This results in reduced life of the electrical circuitry, higher operating temperatures and wasted energy which must ultimately come from the primary fuel source used to operate the engine.

The high voltage across the battery is necessary when the battery's state of charge is low in order to rapidly recharge the battery. However, when the battery's state of charge is within an acceptable range (which occurs most of the time at normal driving speeds), the high voltage across the battery results in high I^2R (resistive heating) losses within the battery resulting in waste of energy, heating of the battery causing premature battery failure, gassing of the battery also resulting in premature failure and heating of electrical components causing premature component failure.

One aspect of the present invention includes the recognition of the aforementioned problems associated with prior art battery charging techniques. In one aspect of the present invention, a battery charging system controller is provided which monitors the condition of the battery under charge and controls the charging system in response to the condition of the battery. With such general aspects of the invention, the particular implementation of the battery monitor and charge control can be selected as appropriate.

In the embodiment illustrated in FIG. 1, battery monitor 12 includes a microprocessor 22 coupled to a voltage sensor 24, a current sensor 26 and a forcing function 28. Microprocessor 22 may also include one or more inputs and outputs illustrated as I/O 30 adapted to couple to an external databus or to an internal databus associated with the vehicle 10. Further, a user input/output (I/O) 32 is provided for providing interaction with a vehicle operator. In one embodiment, microprocessor 22 is coupled to alternator 20 to provide a control output 23 to alternator 20 in response to inputs, alone or in various functional combinations, from current sensor 26, voltage sensor 24 and forcing function 28. In one embodiment, the control output 23 is configured to control alternator 20 such that a nominal voltage output from alternator 20 is 12.6 volts, typical of the nominal open-circuit voltage of the battery 18. Further, microprocessor 22 can raise the output voltage from alternator 20 in accordance with an inverse relationship to the state of charge of battery 18. This can be configured such that alternator 20 only charges battery 18 when necessary, and only charges battery 18 as much as is necessary. This charging technique can increase battery life, lower component temperature of loads 14, increase the lifespan of loads 14 and save fuel. This configuration provides a feedback mechanism in which the state of charge of battery 18 is used to control the charging of battery 18. The battery monitor 12 is easily installed in a vehicle electrical system. A single shunt current sensor 26 must be inserted in one of the primary battery cables and a control line provided to allow control of alternator 20. The control can be by simply adjusting the voltage supplied to a voltage regulator of alternator 20 to thereby control charging of battery 18. The battery monitor 12 can be a separate, self-sufficient and self-contained monitor which operates

without requiring interaction with other components of the vehicle, except in some embodiment, alternator 20.

FIG. 1 also illustrates a Kelvin connection formed by connections 36A and 36B to battery 18. With such a Kelvin connection, two couplings are provided to the positive and negative terminals of battery 18. This allows one of the electrical connections on each side of the battery to carry large amounts of current while the other pair of connections can be used to obtain accurate voltage readings. Because substantially no current is flowing through the voltage sensor 24, there will be little voltage drop through the electrical connection between sensor 24 and battery 18 thereby providing more accurate voltage measurements. In various embodiments, the forcing function 28 can be located physically proximate battery 18 or be connected directly to battery 18. In other embodiments, the forcing function 28 is located anywhere within the electrical system of vehicle 10. In one aspect, the present invention includes an in-vehicle battery monitor 12 which couples to battery 18 through a Kelvin connection and further may optionally include a current sensor 26 and may be capable of monitoring battery condition while the engine of vehicle 12 is operated, loads 14 are turned on and/or alternator 20 is providing a charge signal output to charge battery 18. In one particular embodiment, the combination of the Kelvin connection formed by connections 36A and 36B along with a separate current sensor 26 connected in series with the electrical system of the vehicle 10 is provided and allows monitoring of the condition of battery 18 during operation of vehicle 10. The use of an current sensor 26 is used to provide a monitor of the total current I_T flowing through battery 18.

In operation, microprocessor 22 is capable of measuring a dynamic parameter of battery 18. As used herein, a dynamic parameter includes any parameter of battery 18 which is measured as a function of a signal having an AC or transient component. Examples of dynamic parameters include dynamic resistance, conductance, admittance, impedance or their combinations. In various aspects of the invention, this measurement can be correlated, either alone or in combination with other measurements or inputs received by microprocessor 22, to the condition or status of battery 18. This correlation can be through testing of various batteries and may be through the use of a lookup table or a functional relationship such as a characterization curve. The relationship can also be adjusted based upon battery construction, type, size or other parameters of battery 18. Examples of various testing techniques are described in the following references which are incorporated herein by reference 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

11

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 RUN-AWAY 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; U.S. Pat. No. 6,002,238, issued Dec. 14, 1999, entitled METHOD AND APPARATUS FOR MEASURING COMPLEX IMPEDANCE OF CELLS AND BATTERIES; U.S. Pat. No. 6,037,777, issued Mar. 14, 2000, entitled METHOD AND APPARATUS FOR DETERMINING BATTERY PROPERTIES FROM COMPLEX IMPEDANCE/ADMITTANCE; and U.S. Pat. No. 6,051,976, issued Apr. 18, 2000, entitled METHOD AND APPARATUS FOR AUDITING A BATTERY TEST.

In the specific embodiment illustrated in FIG. 1, the forcing function is a function which applies a signal having an AC or transient component to battery 18. The forcing function can be through the application of a load which provides a desired forcing function in which current is drawn from battery 18, or can be through active circuitry in which a current is injected into battery 18. This results in a current labeled I_F in FIG. 1. The total current, I_T through battery 18 is due to both the forcing function current I_F and the current flowing through loads 14, I_L . Current sensor 26 is positioned to sense the total current I_T . One example battery dynamic parameter, the dynamic conductance (or reciprocally the battery resistance) can be calculated as:

$$\Delta G = V = \Delta I_T / \Delta V \quad \text{EQ. 1}$$

where ΔV is the change in voltage measured across the battery 18 by voltage sensor 24 and ΔI_T is the change in total current measured flowing through battery 18 using current sensor 26. Note that Equation 1 uses current and voltage differences. In one embodiment, the change in voltage and change in current are measured over a period of 12.5 seconds and at a rate of 50 msec to thereby provide a total of 20 readings for ΔV and ΔI_T every second. The forcing function 28 is provided in order to ensure that the current through battery 18 changes with time. However, in one embodiment, changes in I_T due to loads 14 or the output from alternator 20 can be used alone such that $\Delta I_T = \Delta I_L$ and the forcing function 28 is not required.

In one embodiment, the voltage and current sensors provide synchronized operation, within one microsecond, and are substantially immune to measurement errors due to network propagation delays or signal line inductance. Further-

12

more, microprocessor 22 can detect a failure of the voltage regulator and alternator 20 if the voltage output exceeds or drops below predetermined threshold levels. This information can be provided to an operator through user interface 32, for example, a "service regulator soon" indication.

A temperature sensor 37 is provided which can be coupled directly to one of the terminals of the battery 18 for measuring battery temperature. The temperature sensor 37 can be used in determining the condition of the battery, as battery condition is a function of temperature and can be used in estimating the amount of power which will be required to start the engine of the vehicle. Any type of temperature sensor can be used, for example, a thermistor, thermocouple, RID, semiconductor or other temperature sensor.

In one embodiment, current sensor 26 comprises a resistance shunt of 250 μ ohms and current through the shunt is determined by measuring the voltage drop across the shunt. However, other types of current measurement techniques can also be used such as Hall Effect sensors or through an inductance probe. The change of voltage across the battery and the resultant change in current through the battery is sampled using, for example, one or more analog to digital converters. This information can be correlated to determine the total capacity, such as the total Cold Cranking Amp (CCA) capacity of the battery.

Note that during the measurement cycle, vehicle loads 14 may be applied unexpectedly causing noise to be present in the measurements. One technique which might be considered to reduce the noise is to discard those samples which are outside of a predetermined or adjustable window or are outside of the dynamic range of the analog to digital converter. However, quite unexpectedly it has been found that the accuracy of measurements can be increased by increasing the dynamic range of the analog to digital converters, at the expense of the accuracy of the samples obtained from the converter. By averaging all of the samples, even those which are statistically large or small relative to other samples, the present invention is capable of providing accurate voltage and current measurements even in a noisy environment. By averaging samples, and providing sufficient dynamic range for the analog to digital converter, no samples will be discarded and errors in the measurements will tend to cancel against other errors.

In general, the present invention uses the direct relationship between the dynamic conductance of the battery and the condition of the battery. For example, if a battery drops more than 15% below its rated capacity, microprocessor 22 can provide an output which indicates that the battery 18 should be replaced. Further, the conductance can be used to determine the charge level of the battery. Such a measurement can be augmented to improve accuracy by monitoring the total current flowing into battery 18, or out of battery 18, using current sensor 26. The voltage across the battery 18 can also be used to determine the charge used in the determination of charge level. In general, the state of charge can be determined as a function of various combinations either alone or together of battery state of health, temperature, charge balance (charge going into and out of the battery), charging efficiency and initial conditions such as the battery construction, manufacture, plate configuration or other conditions of the battery. The functional relationship can be determined by characterizing multiple batteries or through the use of artificial intelligence techniques such as neural networks.

FIG. 2 is a more detailed schematic diagram of battery monitor 12. FIG. 2 shows microprocessor 22 which includes a memory 40. FIG. 2 illustrates I/O 32 with which can be, for specific examples, a communication link in accordance with

13

various standards such as J1850, J1708, J1939, etc. Memory 40 is shown as an internal memory. However, external memory or an optional external memory 42 can also be provided. In general, memory is provided for storing programming functions, ratings, variables, etc. Microprocessor 22 can be a microcontroller or any type of digital circuitry and is not limited specifically to a microprocessor. FIG. 2 illustrates forcing function 28 in greater detail and includes a resistance R_1 44 and a switch S_1 46 controlled by microprocessor 22. Switch 46 can be, for example, a field effect transistor. Voltage sensor 24 is shown as including a differential amplifier 47 coupled to battery 18 through a DC blocking capacitor C_1 48. Shunt 26 is illustrated as a resistance R_2 50 and a differential amplifier 52. Switches S_2 54 and S_3 56 are positioned to selectively couple amplifiers 52 and 47, respectively, to microprocessor 22 and are actuated by a sample control line to provide data samples to microprocessor 22. An analog to digital converter can be an integral part of microprocessor 22 or it can be a separate component to digitize the outputs from amplifiers 47 and 52. Capacitors C_2 and C_3 provide sample and hold circuits.

Forcing function 28 can be formed by resistance as illustrated in FIG. 2, or by a current sink or through an existing load of the vehicle. Switch S_1 46 can be an FET, or biopolar transistor or can be a mechanical or existing switch in the automotive vehicle. Although shunt 26 is illustrated with a shunt resistance, other types of current sensors such as Hall effect sensors or cable resistance based sensors can be used. Other types of DC blocking techniques can be used to replace capacitance C_1 48 such as a DC coupled amplifier.

FIG. 3 is a simplified block diagram 100 showing diagnostic steps performed by microprocessor 28 in accordance with the invention. At blocks 102 and 104, the dynamic parameter(s) for the battery 18 are obtained and at block 104 data is collected. The type of data collected at block 104 can be any type of data used in determining the condition of the battery. For example, the data can be values used for ΔV and ΔI_T , information related to the type of battery, etc. This information can be stored in memory 40 for subsequent retrieval by microprocessor 22. The data can be collected over any time period and during any type of engine or battery operation. At block 106, microprocessor 22 performs diagnostics based upon the data stored in memory 40. If a battery fault or impending fault is detected, an output can be provided at block 108 such as providing a "service battery soon" indication on the dash of the vehicle 10.

Various aspects of the invention include the particular diagnostics performed by diagnostic block 106. The diagnostics can be simple diagnostics such as a simple if-then rule in which the collected data is compared to various thresholds to provide the diagnostic output. Absolute values of the data can be used for this comparison or various statistical operations can be performed on the data for use in the comparison. For example, averages or standard deviation of the data can be compared to a threshold. The threshold levels can be determined through testing of the vehicle and entered into memory 40 during manufacture. Preferably, when battery 18 is replaced, the thresholds are updated accordingly.

In more advanced embodiments of the diagnostic block 106, microprocessor 22 can perform diagnostics using fuzzy logic, neural networks or artificial intelligence techniques. Neural networks can advantageously be used as they do not require that the battery, alternator and vehicle loads be modeled. Instead, neural networks are capable of learning what "normal" data collected at step 104 should be, and can provide an indication when a pattern of the data is drifting outside of normal operation. Further, the neural network can be

14

"trained" to recognize potential sources of the failure and provide an expected time until the system completely fails. These diagnostic techniques can be selected and implemented such that the operator is warned of an impending failure, prior to the complete failure of the battery 18 or alternator 20.

FIG. 4 is a block diagram 130 showing example steps in accordance with data collection and calculation of a dynamic parameter in accordance with the present invention. Of course, as should be pointed out with respect to all of the flow charts set forth herein, those skilled in the art will recognize that the particular functions of the blocks and the order in which the blocks are executed can be easily rearranged and the invention is not limited to the specific embodiments set forth herein.

In block diagram 130, at block 132 microprocessor 22 obtains an initial voltage V_1 across battery 18 using voltage sensor 24 and an initial current I_{T1} through battery 18 using current sensor 26. Next, the forcing function 28 is applied to battery 18 at step 133. At block 134, microprocessor 22 obtains values V_2 and I_{T2} with the forcing function applied, and at step 136 the forcing function is removed. Values for ΔV and ΔI_T are calculated at step 138. In one example embodiment, the forcing function is applied for a duration of 100 μ Sec 20 times every second. N values are obtained at block 140. In one example, N is equal to 256. At block 142, the average of ΔV and I_{T2} for the N samples is calculated and a dynamic parameter for the battery 18 is determined at block 144. This dynamic parameter can be correlated to a condition of the battery at block 146 and displayed on user I/O 32, output through I/O 30 or used to control alternator 20 through alternator control 23.

In one aspect of the invention, the battery monitor performs a state of charge measurement, in real time and regardless of battery polarization, and automatically corrects for the state of health of the battery and the battery temperature. In general, state of health can be determined as a function of the battery conductance and the open circuit voltage across battery 18. For example, the state of health can be determined as:

$$SOH = k_1(G/RATING) * f(V_{OC}) - k_2 \quad \text{EQ. 2}$$

where k_1 and k_2 are constants which are related to the type of battery, G is the measured conductance of the battery, rating is a rating for the battery and $f(V_{OC})$ is a relationship between the state of charge and the open circuit voltage of the battery as set forth in the aforementioned Champlin and Midtrons, Inc. patents. The state of health will range between 0 and 100%. Using the state of health determined by Equation 2, the state of charge (from 0 to 100%) can be determined in accordance with Equation 3:

$$SOC_{t_2} = 100 * \frac{\left[\int_{t_1}^{t_2} i dt \int_{t_1}^{t_2} e(T) dt \int_{t_1}^{t_2} e(i) dt \right]}{(SOH)(AMP-HOURCAPACITY)} + SOC_{t_1} \quad \text{EQ. 3}$$

where t_1 is the time at which the state of charge is known (i.e., from the period of overcharge, for example), t_2 is the present time, i is the current (amps) in or out of the battery at time t, T is the battery temperature, $e(T)$ is the charge acceptance efficiency at temperature T, and $e(i)$ is the charge acceptance efficiency at current i. Of course, Equations 2 and 3 are simply examples of state of health and state of charge measurements and other techniques can be used in accordance with the invention.

15

Using the battery state of charge and the battery state of health, battery monitor **12** can predict the starting capabilities of a starter motor of vehicle **10**. For example, by comparing the amount of current measured by current sensor **26** which has been previously been required to start the engine of vehicle **10** for a particular temperature, microprocessor **22** can determine if the current state of charge of the battery for the current state of health at the current temperature will be sufficient to provide enough current to start the engine. The performance and any degradation in the starter motor can also be taken into account by microprocessor **22**. For example, if the amount of current required to start the engine has been increasing with time, microprocessor **22** can extrapolate and predict what amount of current will be required to start the engine in the future. FIG. **5** is a simplified block diagram **200** which illustrates steps performed by a microprocessor **22** in diagnosing the starting capability of battery **18**. At block **202**, microprocessor **22** determines the starting capability of battery **18**. For example, the starting capability can be an estimation or measurement of the amount of current which battery **18** can supply over a short duration. At block **204**, microprocessor **22** estimates the starting requirements of the starting motor of the engine of vehicle **10**. For example, the past requirements of the starter motor can be recalled from memory **40** and any trend can be used to predict what will be required for starting the engine. Other inputs can also be used in this determination such as the current temperature. At block **206**, a starter diagnostic output is provided. For example, if it appears that the battery will have difficulty in operating the starter motor for a sufficient duration to start the motor of the vehicle, vehicle loads **14** can be selectively switched off by microprocessor **22** through I/O **30**. Additionally, a warning can be provided to an operator through user I/O **32** of an impending problem, prior to its actual occurrence, such that the battery **18** can be replaced.

In another aspect of the invention, microprocessor **22** can be adapt or alter the performance of the engine and/or loads **14** based upon a number of different parameters in order to provide optimal charging to battery **18**. For example, microprocessor **22** can interface to a data bus of a microprocessor of the vehicle **10** through I/O **30** to control engine operation. Alternatively, microprocessor **22** can be the same microprocessor used to control vehicle operation. The microprocessor **22** can adjust the idle speed of the engine, shift points of the transmission and the load placed on the electrical system by some of the loads **14** to increase or decrease the rate of battery charging based upon the expected driving patterns of an operator. For example, if the microprocessor has observed that the vehicle is normally operated for a short duration, the microprocessor **22** can increase the idle speed of the engine and attempt to reduce loads placed on battery **18** to increase the charging rate of battery **18**. Further, microprocessor **22** can alter the shift points of the transmission to cause the engine to operate at a high (or lower) speed than normal. The prediction of engine operation can also be based upon time of day and the day of the week such that repeated driving patterns can be accounted for, for example, commuting to work. Further, in vehicles where it is possible to recognize the operator of the vehicle, such as through the seat position memory in a power seat of the vehicle, microprocessor **22** can alter the charging pattern based upon the driving characteristics of a specific driver.

FIG. **6** is a simplified block diagram flowchart **250** showing steps performed by microprocessor **22** in adjusting engine speed or loads to control the charge in battery **18**. Block **252**, microprocessor **22** determines the charge required by battery **18** to become fully charged, this determination can be based

16

upon a measurement of the current charge level of battery and a determination of the maximum amount of charge that battery **18** can hold, for example, as a function of the state of health of battery **18**. At block **254**, microprocessor **22** predicts the expected driving pattern for the upcoming engine use. At block **256**, microprocessor **22** adjusts the engine operation and/or vehicle loads **14** in order to optimize the charging of the battery **18** based upon the charge required as determined at step **252** and the driving pattern predicted at step **254**. During engine operation, microprocessor **22** continues to monitor the battery state of charge at block **258** and adjusts the charging accordingly at block **260**. Once battery **18** has been fully charged, the microprocessor **22** can reduce the charging rate as appropriate.

If the drive cycle is, or has tendency to be, insufficient to charge the battery **18**, microprocessor **22** can provide an output to an operator through user I/O **32** to indicate that either the vehicle must be driven for an extended period of time or an alternative charging method be used to charge battery **18**. An indication can also be provided as to a prediction regarding how many further such drive cycles can be supported by the battery **18** before it will have insufficient remaining charge to start the vehicle.

As discussed above, in one aspect of the present invention, the output from the alternator **20** is adjusted based upon the state of charge and/or the state of health determination(s). FIG. **7** is a graph showing the regulator voltage output from alternator **20** as a function of the state of charge of battery **18**. As illustrated in FIG. **7**, microprocessor **22** reduces the voltage output from alternator **20** as the state of charge of battery **18** increases to 100% charge. The particular profile can be adjusted to a specific battery, alternator and/or engine configuration or to the driving characteristics of an operator. Such a system can significantly reduce or eliminate overcharging of battery **10** and the generation of excessive heat. Further, such a technique can be used to reduce or eliminate the undercharging of battery **10**. Additionally, by adjusting the voltage based upon the state of charge, battery **18** and system component life will increase. For example, vehicle loads **14** will be exposed to over voltages for a reduced amount of time. This also allows the various systems components to be optimized for particular charging requirements or voltage levels. In general, the output of the alternator **20** can be reduced and the battery capacity required for a particular vehicle can be reduced because battery charge will be more efficiently maintained. This can reduce overall vehicle weight and improve vehicle mileage. Further still, IR (current-resistance) type losses in the electrical system and overcharging will be reduced thereby reducing the load on the vehicle engine and improving efficiency of the vehicle. In general, this technique will improve vehicle reliability by reducing heat due to excessive IR losses, increasing battery life, providing early detection of impending battery failure and insuring proper vehicle operation even with after market batteries which are used to replace the original battery.

If such a system is implemented when the vehicle is originally manufactured, monitor **12** allows battery management over the entire life of the vehicle. This can be both during assembly and delivery of the vehicle as well as during the lifespan of actual vehicle operation. Additionally, one aspect includes a storage battery **18** with rating information carried in a computer storage device such as a digital memory within a housing of the battery. This data can be communicated to monitor **12** through I/O **30**. In one aspect, the electrical connections to the battery are also used as a data communication bus such that monitor **12** can communicate with the storage

17

device in battery 18. The storage device can also be used to store the history, such as the charging and usage history, of battery 18.

Battery monitor 12 can monitor and diagnose operation of alternator 20. For example, a typical alternator provides a multiphase output. By monitoring the data points collected and stored in memory 40, microprocessor 22 can observe the loss of one or more phases in the alternator's output. Similarly, the failure of a rectifying diode in alternator 20 can be detected by microprocessor 22 by observing an asymmetrical ripple pattern. Microprocessor 22 can provide an output to an operator through user I/O 32 such as a "service alternator soon" output. This information can also be communicated to the vehicle microprocessor through I/O 30.

I/O 30 is shown in schematic form and can be any type of input or output and represents, in some embodiments, multiple input(s) and output(s). Various examples of inputs and outputs include a connection to a databus of the vehicle, a connection to a databus adapted to couple to a diagnostic device such as that provided in service equipment, a connection to a remote vehicle monitoring system, such as one that is capable of coupling through a cellular phone connection of the vehicle. In such an embodiment, the vehicle is capable of recording and reporting information to a remote service such as an emergency assistance service or a service provided to monitor the operation of the vehicle and suggest that maintenance be provided. Various types of inputs and outputs can be provided through direct connections or through non-physical connections such as radio frequency or infrared communication techniques. The particular form of the data and standard used for the inputs and outputs can be selected as proprietary or industry standards. Microprocessor 22 can also be capable of providing advanced reporting and control functions through the use of standardized interfaces such as are available through HTML, XML, or various known or proposed alternatives. In such an embodiment, information collected by microprocessor 22 can be viewed through a "web page" interface provided by a browser. Such an embodiment is advantageous because it can provide a user input/output such as user I/O 32 in a standardized form such that it can be viewed or controlled through many types of standardized devices. In such an embodiment, information can be reported to, or the monitor 12 can be controlled, from a remote location. Additionally, if the vehicle 10 includes a browser type interface which may become commonly available in vehicles, the microprocessor 22 can be controlled and communicate through the vehicle's browser. In one aspect, vehicle monitor includes an IP (Internet Protocol) address such that it is capable of communicating in accordance with the Internet Protocol. When coupled to, for example, a cellular telephone connection of the vehicle, the battery monitor 12 is capable of being monitored and controlled from a remote location coupled through the Internet. However, as mentioned above, such an interface also provides a simple technique for interfacing the monitor 12 with a local computer in the vehicle and displaying information from the monitor 12 for use or control by an operator.

Through the use of the data collected by microprocessor 22 and memory 40, microprocessor 22 is also capable of detecting the imminent failure of the starter motor of the vehicle. For example, by monitoring the voltage drop through the system during starting, microprocessor 22 can determine the average time to start the engine and the average and peak currents required during starting. Changes in these, or other, measurement values can indicate a degrading starter motor.

18

Upon detection of an impending failure, a "service starter motor soon" indication can be provided to an operator through user interface 32.

Microprocessor 22 can provide an indication that the battery 18 has insufficient capacity or substandard performance and alert an operator accordingly. For example, upon power up, such as that which occurs when battery 18 is replaced, microprocessor 22 can measure the capacity of the battery 18 and provide an indication to the operator if the capacity is less than a threshold level determined by the vehicle manufacturer and stored in the memory of the vehicle computer system.

Microprocessor 22 can generate an audit code (or a warranty code) in response to the various tests and data collected. Such codes are described in U.S. Pat. No. 6,051,976, issued Apr. 18, 2000, entitled METHOD AND APPARATUS FOR AUDITING A BATTERY TEST which is assigned to the present assignee and is incorporated herein by reference. In such an embodiment, microprocessor 22 encodes data collected or obtained during its operation. For example, raw data related to a battery test can be obtained and/or the ultimate result of the battery test and subsequently encoded by microprocessor 22. The encoding can be a simple transposition cipher in which the locations and values of various bytes of information are rearranged. Such a code can be designed to prevent falsification of data which can occur where unscrupulous individuals are attempting to submit a falsified warranty claim for a failed component to a manufacturer. This coding technique allows the manufacturer to verify information when a warranty is submitted. Additionally, the information can be used to track operator error and assist in identification and isolation of component failure in order to redesign the components and reduce such failures.

In another aspect, microprocessor 22 is capable of automatically calibrating the measurements obtained from voltage sensor 24 and current sensor 26. Using this aspect of the invention, microprocessor 22 can perform automatic or periodic calibrations to maintain accuracy over the lifespan of the vehicle. Automatic calibration can be provided by selectively switching in calibrated elements having known temperature and time drift characteristics, and using the measured data to correct for instrumentation gains and offsets. For example, a known resistance or voltage source can be selectively coupled to amplifiers 47 or 52. Any offset values from these known values can be stored in memory 40 and used by microprocessor 22 to compensate for errors in measurements.

With the present invention, any polarization of the battery 18 such as that which can result from charging or starting operations, does not produce errors in the measurements performed by microprocessor 22. Specifically, any such errors are eliminated by use of a real-time state of charge algorithm that is independent of the real time battery terminal voltage.

When the engine of vehicle 10 is not operating, microprocessor 22 can enter a sleep mode to reduce current draw and the resultant discharge of battery 18. If desired, microprocessor 22 can periodically "wake up" to perform tests or monitor some aspect of the electrical system of vehicle 10.

A loose or corroded connection to battery 18 can be detected by microprocessor 22 by observing a sudden increase in the resistance across battery 18. An error can be provided to an operator through user interface 32 to alert the operator of the degraded connection.

Microprocessor 22 can also perform diagnostics on the electrical system of vehicle 12 when the engine is not operating. For example, microprocessor 22 can monitor the current being drawn by loads 14 when the engine is not running using current sensor 26. For example, microprocessor 22 can compare the rate of current draw, over a selectable sample

period with a threshold stored in memory 40. If the measured rate exceeds the threshold, there may be a fault in the electrical system of the vehicle. Similarly, a small but constant current drain can also indicate a fault which could lead to the discharge of battery 18. Microprocessor 22 can provide an indication to the user through user interface 32 that excessive current draw has occurred while the engine is off. Such current draw can lead to rapid discharge of battery 18 and prevent starting.

Current sensor 26 can also be used by microprocessor 22 to monitor the current flowing into and out of battery 18. The summation of this current, taken over a time period (i.e., integration) can provide an indication that the battery is not receiving sufficient charge, or can provide an indication of the total charge received by battery 18. This information can be displayed to an operator through user I/O 32. Additionally, the information can be provided on I/O 30. If the information indicates that the battery 18 is not receiving sufficient charge, steps can be taken as discussed above, to increase the charging rate of battery 18.

In one embodiment, microprocessor 22 stores information in memory 40 related to the model number, and/or serial number, capacity or other information related to battery 18. In such an embodiment, battery monitor 12 can be a physical part of battery 18 such that battery specific information can be programmed into memory during manufacture. The battery monitor 12 can provide an output to an operator through a display or other type of output device which is physically located on the battery 18. Additionally, the display or user I/O 32 can be located within the vehicle. Input/output 30 can be configured to couple to the databus of the vehicle. For example, the battery 18 can include a data plug adapted to plug into the databus of the vehicle such that monitor 12 can exchange information through the databus. Microprocessor 22 can then report this information to the databus of the vehicle using input/output 30. This allows the microprocessor of the vehicle the ability to perform advanced diagnostics and monitoring as the specific battery type is known.

FIG. 8 is a block diagram of a vehicle 300 including a diagnostic device 302 in accordance with another aspect of the invention. Device 302 operates using the battery testing principles, such as those set forth above or others. Device 302 couples to the electrical system 304 of vehicle 300 through a connection 306. Electrical system 304 is shown as coupling vehicle engine 308 to a storage battery 310.

In accordance with this aspect of the present invention, diagnostic device 302 is configured to temporarily couple to electrical system 304 through temporary connection 306. As discussed herein, connection 306 can be a Kelvin connection and/or an inline connection in which diagnostic device 302 is optionally coupled electrically in series or in parallel, or a combination of both, with electrical system 304. Diagnostic device 302 includes a processor 316, sample circuitry 318 and memory 320. Sample circuitry 318 collects data samples through connection 306. Information related to the data samples, which may include the data samples themselves, time stamps, data generated as a function of the data samples, etc., is stored in memory 320. Processor 316 controls operation of diagnostic device 302.

Diagnostic device 302 is used to perform in situ testing of battery 310 and vehicle electrical system 304. Device 302 is temporarily coupled to electrical system 304 through connection 306. While device 302 is temporarily coupled to electrical system 304, the vehicle 300 can be operated in a normal manner, or under any condition as desired, such that data is collected and stored in memory 320 through the actual use and operation of the vehicle 300. This can be very useful to a

technician in tracking down intermittent problems, or the source of a component failure or degradation. Additionally, this provides a useful research tool for understanding the nature and operation of the vehicle electrical system 304 and battery 310 along with the interaction between battery 310 and the alternator and charging system provided by engine 308. Connection 306 can include an electrical connection to a databus of the vehicle 300 such that data carried on the bus is also stored in memory 320. Such data can provide useful information for subsequent analysis such as the operating parameters of the engine, state of various sensors, engine speed, etc.

Once the in situ testing is complete, device 302 can be removed from the vehicle 300 by disconnecting connection 306. While coupled to vehicle 300 or after removal from vehicle 300, data stored in memory 320 can be recovered from diagnostic device 302 through output 326.

FIG. 9 is a simplified diagram which illustrates connection 306 in greater detail. Connection 306 may include Kelvin connections 330 and 332 configured to couple to terminals 334 and 336, respectively, of battery 310. An inline series connections 340 is also shown. If series connection 340 is used, a break 342 must be provided in the connection between battery 310 and electrical system 304. In various aspects, diagnostic device 302 uses Kelvin connections 330 and 332 or inline series connection 340 alone. In another embodiment, both Kelvin connections 330 and 332 are used along with inline series connections 340.

Inline connection 340 includes first electrical connection 370 and second electrical connection 372 connected in series between battery 310 and vehicle electrical system 304. A low resistance path 374 is provided between connections 370 and 372. The electrical current flowing through the low resistance path 374 can be measured using any appropriate technique and the data stored in inline connection 340 or otherwise used to perform diagnostics.

Physically, diagnostic device 302 can be mounted to, for example, a fixed member 350 of vehicle 300 by a mount 352. For example, mount 352 can be a clamp or some other attachment mechanism including a magnet which issued to secure device 302 to the chassis, engine or some other fixed component of vehicle 300. The Kelvin connections 330 and 332 can be provided through clamps. Depending on the duration of the test or the physical vibrations or other shocks which the vehicle may undergo during operation, the connections 330 and 332 can be through clamps or some other more permanent attachment technique. The clamps can be, for example, spring loaded or screwed together. The inline series connection 340 can be achieved by removing a connection to battery 310. The removed connection is then electrically coupled to diagnostic device 302 and another connection is provided to terminal 334 of battery 310 by a battery clamp coupled to device 302. In one embodiment, series connection 340 does not require a break in the electrical system and is achieved using an induction clamp, hall effect sensor, etc.

Diagnostic device 302 collects data related to a dynamic parameter of battery 310. A forcing function is applied to battery 310 which may include an active or passive signal source in device 302 and can also include signals injected into battery 310 by electrical system 304 of vehicle 300. The sampling rate should be sufficiently fast to ensure enough data is collected to diagnose the battery 310. Data compression techniques can be used when samples are stored.

An input/output connection 360 is provided to diagnostic device 302. The input/output connection 360 can be used to initiate the data collection. In one embodiment, diagnostic device 302 only collects data when the vehicle is operating,

which is determined by communication with the databus of the vehicle, or by monitoring the voltage and/or current applied to battery 310 or by some other means.

One type of data which can be collected and stored in the memory are voltage measurements measured across the battery 310. In one embodiment, the connections 330 and 332 illustrated in FIG. 9 are not Kelvin connections and are single wire connections to terminals 334 and 336, respectively. Additional data can be collected such that particular events observed in electrical system 304 and/or battery 310 can be correlated with the operation of the vehicle, for example, as monitored using the databus of the vehicle. In one embodiment, diagnostic device 302 analyzes the collected data and provides an output to an operator which can be used to identify a particular fault with battery 310 or electrical system 308. As discussed above, in another aspect the collected data can be downloaded to a computer or database for subsequent analysis.

In one embodiment, the memory 300 does not contain individual samples and instead contains the result of a diagnostic test. This result is then later retrieved by an operator directly or through a remote computer system.

As discussed above, the present invention provides a technique for monitoring current and/or voltage of a battery of a vehicle during operation of the vehicle. In such a configuration, the monitoring can be fowled using single connections, or using Kelvin connections. When configured to monitor current, the device is connected in series with the battery on either the positive or negative side of the battery. The series connection is between the battery and the electrical system of the vehicle. Voltage can be monitored by connecting to the other side of the battery. Additionally, a temperature sensor can be included to monitor temperature at a selected location, for example, in the device, or at another location or locations in the vehicle. As the data is collected, it is stored in a memory for future retrieval. Such a configuration can be particularly useful on cars using advanced electrical systems which electronically control many aspects of operation of the vehicle. In such systems, it can be particularly difficult to diagnose which components or components of the complex electrical system is the source of a failure.

In one specific example, when a customer notices a problem with a vehicle, the customer can bring the vehicle to a service center. At the service center, a device in accordance with the present invention can be coupled to the electrical system of the vehicle. The customer then leaves the service center and continues normal operation of the vehicle for a desired period of time. The logged data can provide an indication of the source of the failure. For example, the failure may be related to a component or subsystem of the electrical system which is not powering down properly or coming on at random times. The logged data can provide an indication of an occurrence of such a failure. Many subsystems of the electrical system of a vehicle have unique current and/or voltage signatures so that it is possible to identify which subsystem is operating by simply comparing the logged data with the known voltage signatures for the various subsystems of the vehicle. The device preferably operates using relatively low power so as not to alter the test environment. Further, the logged data can be stored using any appropriate type of memory including, for example, a removable memory card. In another example, the data is stored in fixed memory within the device and later downloaded to a computer. The transfer of the logged data from the device can be through any appropriate technique including networking databus techniques including both a wireless and wired communication techniques.

Preferably, the apparatus in accordance with the present invention is capable of measuring relatively small currents, for example less than 10 mA, as well as large currents, for example, upwards of 100 amps which may be drawn by a starter motor of a vehicle.

In one configuration, the apparatus of the present invention includes a display and/or user inputs for viewing and/or controlling the device. The display can be used to monitor the data in real time by an operator. Additionally, a clock can be included so that the data is time stamped when it is stored in the memory. The clock can be set with an external reference for correlation with the actual time of an event. Data in the memory or memory card can be formatted, written to, closed, or appended to as desired. The data can be collected and written to the memory at fixed intervals, for example at a set or settable period such as every 30 seconds. In another configuration, the data can be written at times in accordance with a rule set, for example only when the engine is running, only when the engine is off, only when experiencing particular temperature ranges, etc. The interval at which the data is logged can also be adjusted for particular times during operation of the vehicle. For example, increased data logging can be provided during a particular period, such as when the vehicle is starting, accelerating, etc.

The data can be downloaded into any appropriate device such as a PC or an automotive diagnostic tool, battery tester, etc. In one configuration, the device is capable of transmitting the data over an internal databus of the vehicle. In such a configuration, the logged data can be read using, for example, a scan tool.

A PC can be configured to read the data and format it as desired. For example, the data can be provided in a graphical format of a measured value versus time. More advanced displays can be provided including zoom functions, scrolling, autoranging or overlapping. Software within the PC can set trigger points that will highlight specific events that a technician may be trying to identify. For example, a trigger point could be set to monitor a discharge threshold of between 5 and 6 amps if the technician is trying to identify whether the climate computer of the vehicle is turning on in an inappropriate manner. The PC software can be built specifically for a particular manufacturer or car model with preprogrammed triggers for various systems. The software can display which subsystem within the vehicle is responsible for a particular set of logged data. The graph or other display output can then autorange to a particular area and highlight, for example with a particular color, the various subsystems.

In various embodiments of the present invention, additional voltage and/or current sensor channels can be used. For example, one or more auxiliary current channels with various resolutions can be provided to further pinpoint diagnostics. Similarly, one or more additional voltage sensing circuits can be provided for reading and logging additional voltages at any desired resolution. The voltage and current sensors can also be used to detect a threshold to trigger logging or other activity, for example, if a branch of a circuit is turned on or off.

The apparatus of the present invention can mount at any location. For example, the device can be electrically connected or spliced into an existing wire, or can be coupled into the electrical system at the fuse block or other location. This allows individual circuits to be isolated and their data logged.

The particular type of voltage and current sensors can be in accordance with any technique. Currents can be sensed using shunt techniques or non-invasive techniques such as a using Hall effect sensor or the like.

23

FIG. 10 is a view of an example diagnostic device or data logger 380 in accordance with the invention. Device 380 includes display 382, user inputs 384, in-line connection 386, and a channel input 388.

FIGS. 11 and 12 are graphs showing the display of logged data on a PC.

In various aspects, the present invention includes one or more current monitoring channels which are able to monitor branch circuits to record and analyze data. Similarly, one or more secondary voltage monitoring channels can also be used so that branch circuit voltages can be recorded and analyzed. In one configuration, a circular buffer is used which allows "pretriggering" of data capture. In such a configuration, when a trigger event occurs, the data from before the trigger event is stored into the memory card. Similarly, data during or following the triggered event can also be stored. The trigger event can be assigned to a change in voltage or current on any of the monitoring channels. Triggers can be received a remote device, either through a wired or wireless connection, or that a customer or technician can activate when an anomaly is observed. In more advanced configurations, the triggers can be based upon rules, for example through Boolean or algebraic combination of events.

An interface can be provided that connects the vehicle onboard databus (OBDII) connector to the device. Data from the vehicle bus can be recorded and monitored for activity. Triggers can be based on this activity. An RF interface can also be provided and used to wirelessly connect to a wireless OBDII interface. This reduces installation complexity and can be used to interface to a wireless trigger button provided to a customer or a technician. The wireless connection can also be used to download or upload data or software. Similarly, the wireless connection can be used to interface to a display readout in the cockpit of the vehicle or at another location to assist a technician while testing the vehicle. In some configurations, the device can enter a reduced power state (i.e. a sleep mode) to reduce current drain to a minimum for long term problem analysis. A trigger can be used to wake electronics of the device up at desired intervals. An auxiliary battery can be connected to the device to reduce the current drain on the vehicle under test to zero if it is desirable to eliminate a current draw from the vehicle to operate the device. Software on a PC used to review the stored data can be configured to support one or more data streams. In such a configuration, a technician can connect a data recorder to a faulty vehicle and another data recorder to a known, good vehicle. Then, for example, both vehicles can be operated in a similar manner and the collected data from the two vehicles compared.

In one configuration, a sensor used to collect data comprises a temperature sensor. As discussed above, one or more auxiliary channels can be used to capture and record data such as voltages or currents of circuitry in the electrical system for more comprehensive diagnosis. There may be triggers based upon these additional channels. The triggers can cause data to begin being recorded, or can be used to change the time between samples of stored data. For example, during normal operation data can be collected at one speed, but upon the occurrence of a trigger, the rate at which data is stored can be increased (i.e., the time between data samples decreased). Example triggers include starting of a vehicle, opening of a door, etc.

In one configuration, the device is configured to operate in three general modes. In a run mode, data can be received through any of the various inputs which may be available including sensors, wireless data, etc., and transmitted as described, for example through a wireless data transmission.

24

In this configuration, the device uses a relatively large amount of power and it is preferable that the device only enter this mode while the vehicle is running so as not to drain the battery. In a lower power mode which can be used when the vehicle is off, various circuitry is shut down to conserve power. For example, RF communication circuitry can be powered down, etc. However, triggers can still be available to capture data or to change the frequency which data is stored into memory. For a deep sleep mode, the testing device can be configured to detect lack of activity for an extended period of time, for example 24-48 hours. When such a period of inactivity is detected, the device can go into a deep sleep and only collect data at a very slow rate, for example once every minute.

The triggers used to trigger data collection, or changes in the rate of data collection, can be any appropriate trigger mechanisms. For example, triggers can be activated through wired or wireless connections including wire to wireless pushbuttons, set to respond to a particular voltage or current, signature observed on any channels, based upon some combination of events detected through a rule, based upon time, etc. In one configuration, data can be continually collected at a high speed, for example once every 50 msec, and written to a large circular buffer. When a trigger occurs, the device can loop back a selected period, depending on the size of the buffer, and record that data into a more permanent memory. Data following the trigger can also be recorded. The software used to graphically show the data can be configured to address the variable time scale.

In one configuration, the test device includes a real time clock that records data to the memory card so that anomalies observed in the data can be correlated to user feedback or to other real time occurrences. Preferably, a battery back up is provided for the real time clock.

Current monitoring channels can be configured to operate bi-directionally such that the current sensor can be connected to the electrical system without regard to polarity. The channels can be fused and equipped with quick connect clips to make tapping into the vehicle circuits easier.

Auxiliary sensor channels, for example voltage channels, can also record on/off information, or absolute voltages, so that, for example, IR drops in the vehicle can be observed. The auxiliary voltage and current channels can be color keyed to match the corresponding graph data on a computer display.

In one configuration, a user input is provided having buttons that are configured to operate with a stylus or the like so that they cannot be accidentally bumped causing the logging data to stop or the device to be reconfigured. If an internal memory is used, for example a SD card, a key such as stylus or the like can also be required to remove the memory to prevent accidental removal.

An output can be provided, for example a display (i.e., an LCD display) on the unit so that it can be used as a real time volt meter, amp meter, or as a general service tool. For example, the input channels can be configured to accurately read over a wide current range, for example as low as 10 mA and as high as 1000 amps, while being capable of receiving impulses an spikes greatly in excess of these levels.

The tester can be equipped with interchangeable couplings, for coupling to different types of vehicles. For example, one type of vehicle may require a ring terminal to connect to a battery while another type may require a connection to a battery post. A serial port can be included to provide wired connectivity to the onboard databus of the vehicle (OBD2) for use in recording vehicle bus activity. The serial port can also be used to spool data to another device such as a portable computer, laptop, printer, other serial

device. A wireless communication port (for example a Zigbee port in accordance with IEEE 802.15.4) can be provided to interface to a wireless connection such as a wireless OBDII connection to capture vehicle data, update software, download data, receive trigger events from a vehicle operator, or to display real time data on a receiving device, for example another testing device, PDA, computer, etc. for drive time analysis. The trigger can be actuated by the vehicle operator, for example when an anomaly is observed (for example, a navigation system error). The operator can then trigger the device to record the event. Subsequently, a technician can examine the logged data looking for the trigger and identify possible events leading up to the problem.

The data stored in the device, for example stored in the memory card, can be easily transferred by email or other transfer techniques, so that a remotely located technical expert can analysis data collected by a less experienced technician. When a vehicle arrives at a dealership or service center, a technician can quickly install the device and park the vehicle at a remote location while performing several hours of service work on other vehicles. When the technician then begins servicing the vehicle, a data log has been created to help the technician to begin the analysis. This is similar to arriving for a medical examination with a doctor. Prior to meeting with the doctor, a nurse or other medical technician collects initial data for use by the doctor performing the diagnosis.

The definitions of triggers and operating modes can be controlled through a configuration file located, for example, on the memory card. This configuration file can be set up using a PC or other interface. If during operation, the device does not find a configuration file, the device can use the last available configuration file. The configuration files can be further enhanced with information related to the particular vehicle diagnosed.

Physically, the device can be designed to handle rugged conditions. For example, a soft case can be used to prevent automotive fluids from damages the device if it is installed under the hood. An external battery connection can be made available if it is desired that the device be capable of drawing no current from the vehicle under test. Although the current drawn by the device is very small, especially in the low power and deep sleep modes, the current draw can still become significant for a vehicle undergoing long periods of non-use. The tester can be used in any type of service station or the like including, for example, battery manufacturer automotive test fleets, vehicle OEMs, studying state of charge loss during logistics, etc.

In accordance with aspects of the present invention, all or some of the memory in the device is removable. The removable memory can be in accordance with standard format such as compact flash, MMC, secure digital, USB flash, etc. In such a configuration, the device can be left in the vehicle to record data to a new memory card while the removed card is viewed or otherwise analyzed. The cards with data can be downloaded onto a personal computer, PDA, or other device.

FIG. 13 is a simplified block diagram of diagnostic device 400 which illustrates aspects of the present invention. Device 400 includes a microprocessor 402 which couples to input channels 404, 406, 408 and 410 which are configured to receive desired inputs. For example, these inputs can be voltage levels, current levels, AC or DC signals, etc. These inputs can be used for recording data, as simple triggers to trigger the recording of data, or other purposes. The inputs 404 through 410 coupled to the microprocessor 402 through an analog to digital converter 412 and multiplexor 414. In another example embodiment, multiplexor 414 is not required and

each input couples to its own analog to digital converter. Microprocessor 402 also receives temperature information from temperature sensor 416, battery input data through battery input 418, and data from the onboard data bus of a vehicle through OBDII connector 420. The battery input can be sensed through a serial, parallel or combination connection including Kelvin connections as discussed above, and used to measure static or dynamic parameters. Other inputs and outputs to microprocessor 402 are provided through display 424, user input 426 and wireless I/O connection 428. Microprocessor 402 operates in accordance with a clock 430 which can also be used for providing a time information. A memory 432 can store data and/or program instructions. A storage device 434 is shown which can be used to store or log data. Storage device 434 can comprise, for example, a removable storage device such as a SD card. The temperature sensor 416 can be located within device 400. In such a configuration, if the device 400 is coupled to the vehicle battery, or near the vehicle battery, the temperature measured by temperature sensor 416 will approximate the temperature of the battery.

The device 400 can operate with some or all of the techniques discussed above. In one mode of operation, microprocessor 402 takes data samples at a fixed interval, for example every 30 seconds, and stores the data on storage device 434. The logged data can comprise some or all of the various data inputs to microprocessor 402. In a sleep mode, the microprocessor 402 can be configured to "wake up" at a fixed interval, for example, every 5 minutes, and store certain information on storage device 434 such as battery voltage, battery current and temperature. In a trigger mode for operation, the microprocessor can continuously record data for a fixed interval at a fixed rate for a desired period. The triggers can be input to the device using the user input 426, the wireless I/O connection 428 or through the removable storage device 434. The triggers can be configured to be boolean in nature such that multiple events can occur to trigger data logging.

FIG. 14 is a simplified diagram of a PC system 450 which can be used for analyzing or displaying data collected using the techniques discussed above. PC 450 includes a microprocessor 452 which couples to a memory 454. User input/output is provided through a keyboard 456 and a mouse 458. Microprocessor 452 can display data on display 460 in print data on printer 462 and input 464 is provided for receiving data collected as discussed above. The PC 450 is configured to format data collected from the vehicle. The data can be filtered as desired and viewed using any appropriate technique, for example, using the views shown in FIGS. 11 and 12.

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. A system for measuring a condition of a battery coupled to an electrical system of a vehicle, the system comprising:
 - first and second electrical connections to the battery;
 - a forcing function source configured to apply a forcing function to the battery;
 - a voltage sensor configured to measure a voltage of the battery;
 - a current sensor configured to measure current flowing between the battery and the electrical system of the vehicle; and
 - measurement circuitry configured to:
 - determine a charge capacity of the battery by measuring a dynamic parameter of the battery based upon a change in the voltage and a change in the current in response of the battery to the applied forcing function,

27

- the dynamic parameter comprising at least one of dynamic resistance, dynamic conductance, dynamic admittance, and dynamic impedance,
determine a charge level of the battery as a function of total measured current flowing between the battery and the electrical system of the vehicle which is indicative of the total charge stored by the battery and the charge capacity of the battery.
2. The system of claim 1 wherein the forcing function source comprises an electrical component of the vehicle.
 3. The system of claim 1 wherein the forcing function source comprises an active source.
 4. The system of claim 1 wherein the forcing function source comprises a passive source.
 5. The system of claim 1 wherein the voltage sensor and the current sensor obtain voltage and current measurements which are synchronized.
 6. The system of claim 1 wherein the measurement circuitry collects a plurality of voltage and current measurements and determines charge level of the battery based upon an average value of the voltage and current measurements.
 7. The system of claim 1 including a temperature sensor and wherein the measurement circuitry further determines a charge level of the battery as a function of temperature.
 8. The system of claim 1 wherein the current sensor comprises a resistance shunt.
 9. The system of claim 1 wherein the current sensor comprises a Hall Effect sensor.
 10. The system of claim 1 wherein the measurement circuitry determines a charge level of the battery based upon a plurality of voltages measurements and a plurality of current measurements which include noise.
 11. The system of claim 1 wherein the measurement circuitry determines a charge level of the battery based upon information stored in a memory.
 12. The system of claim 11 wherein the information stored in the memory comprises information related to battery type.
 13. The system of claim 1 including an output configured to provide a "service battery soon" indication.
 14. A method for measuring a condition of a battery coupled to an electrical system in a vehicle, comprising:
 - applying a forcing function to the battery from a forcing function source;
 - measuring voltage of the battery;

28

- measuring current flowing between the battery and the electrical system of the vehicle;
identifying an electrical response of the battery to the applied forcing function; and
determining a dynamic parameter of the battery based upon a change in the measured voltage and a change in the measured current in response to the applied forcing function, the dynamic parameter indicative of battery capacity, the dynamic parameter comprising at least one of dynamic resistance, dynamic conductance, dynamic admittance, and dynamic impedance;
determining a charge level of the battery as a function of measured total current flowing between the battery and the electrical system of the vehicle which is indicative of the total charge stored in the battery and the charge capacity of the battery.
15. The method of claim 14 wherein the forcing function source comprises an electrical component of the vehicle.
 16. The method of claim 14 wherein the forcing function source comprises an active source.
 17. The method of claim 14 wherein the forcing function source comprises a passive source.
 18. The method of claim 14 wherein the steps of sensing the voltage and sensing current sensor are synchronized.
 19. The method of claim 14 wherein determining includes collecting a plurality of voltage and current measurements and calculating an average value of the voltage and current measurements to determine charge level of the battery.
 20. The method of claim 14 including measuring a temperature and wherein determining a charge level of the battery is further a function of temperature.
 21. The method of claim 14 wherein determining a charge level of the battery is based upon obtaining a plurality of voltages measurements and a plurality of current measurements which include noise.
 22. The method of claim 14 wherein the determining a charge level of the battery is based upon information stored in a memory.
 23. The method of claim 22 wherein the information comprises information related to battery type.
 24. The method of claim 14 including providing "service battery soon" indication on an output.

* * * * *