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(54) **METHOD AND APPARATUS FOR MEASURING A PARAMETER OF A VEHICLE ELECTRICAL SYSTEM**

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See application file for complete search history.

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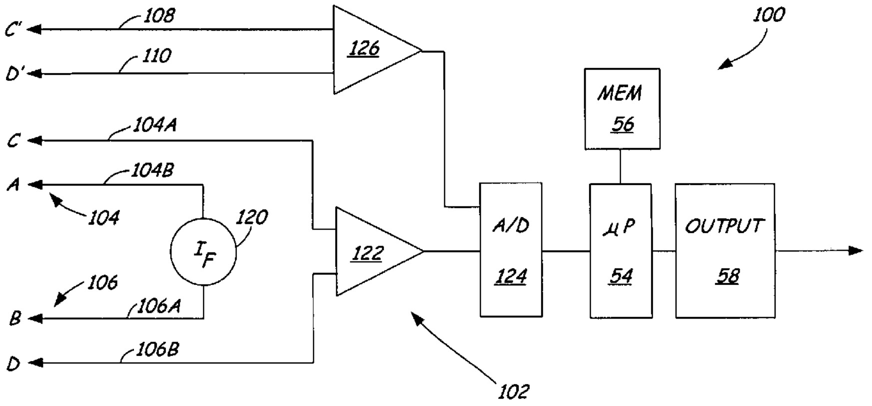
(57) **ABSTRACT**

An apparatus for measuring electrical parameters for an electrical system measures a first and second parameters of the electrical system between connections to the electrical system. A processor determines a third electrical parameter of the electrical system as a function of the first parameter and the second parameter.

24 Claims, 3 Drawing Sheets



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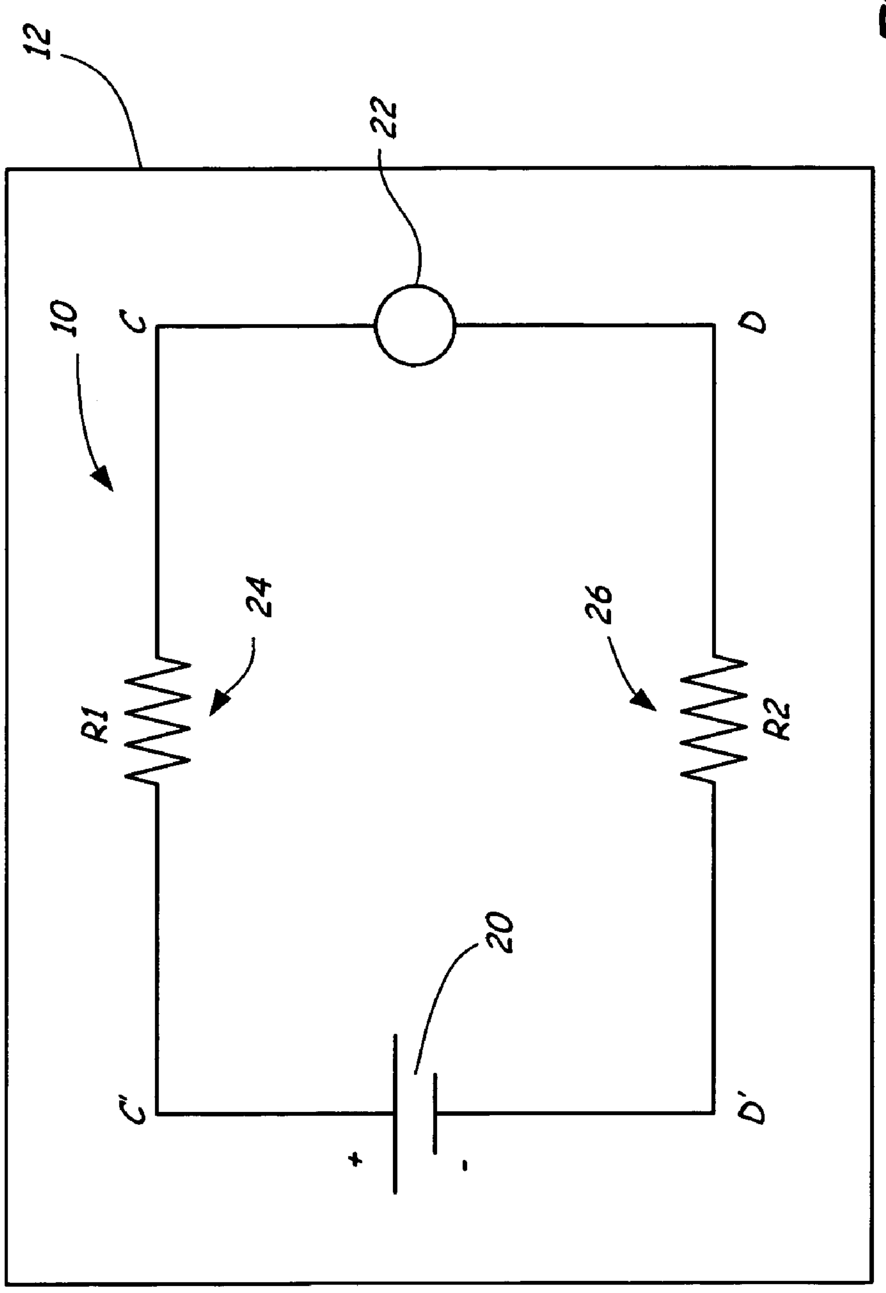
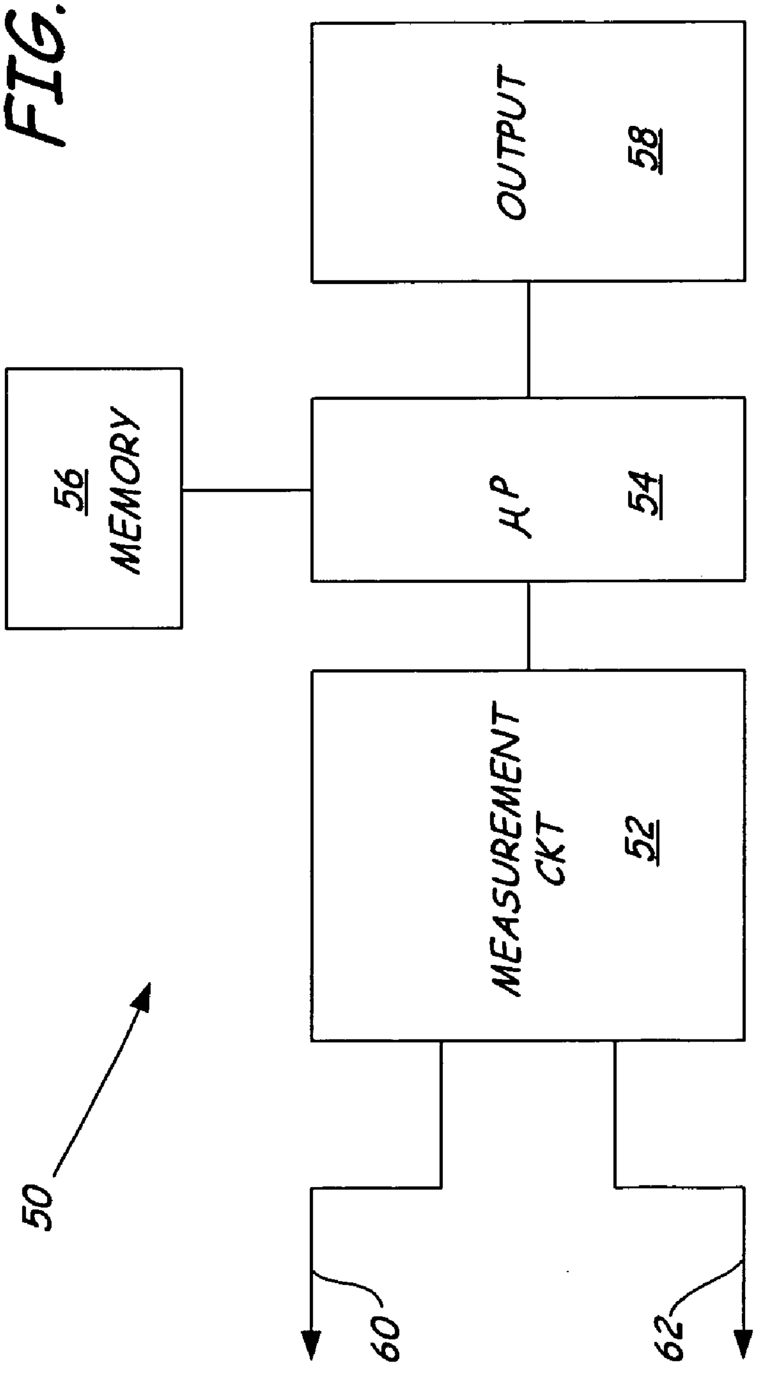


FIG. 1

FIG. 2



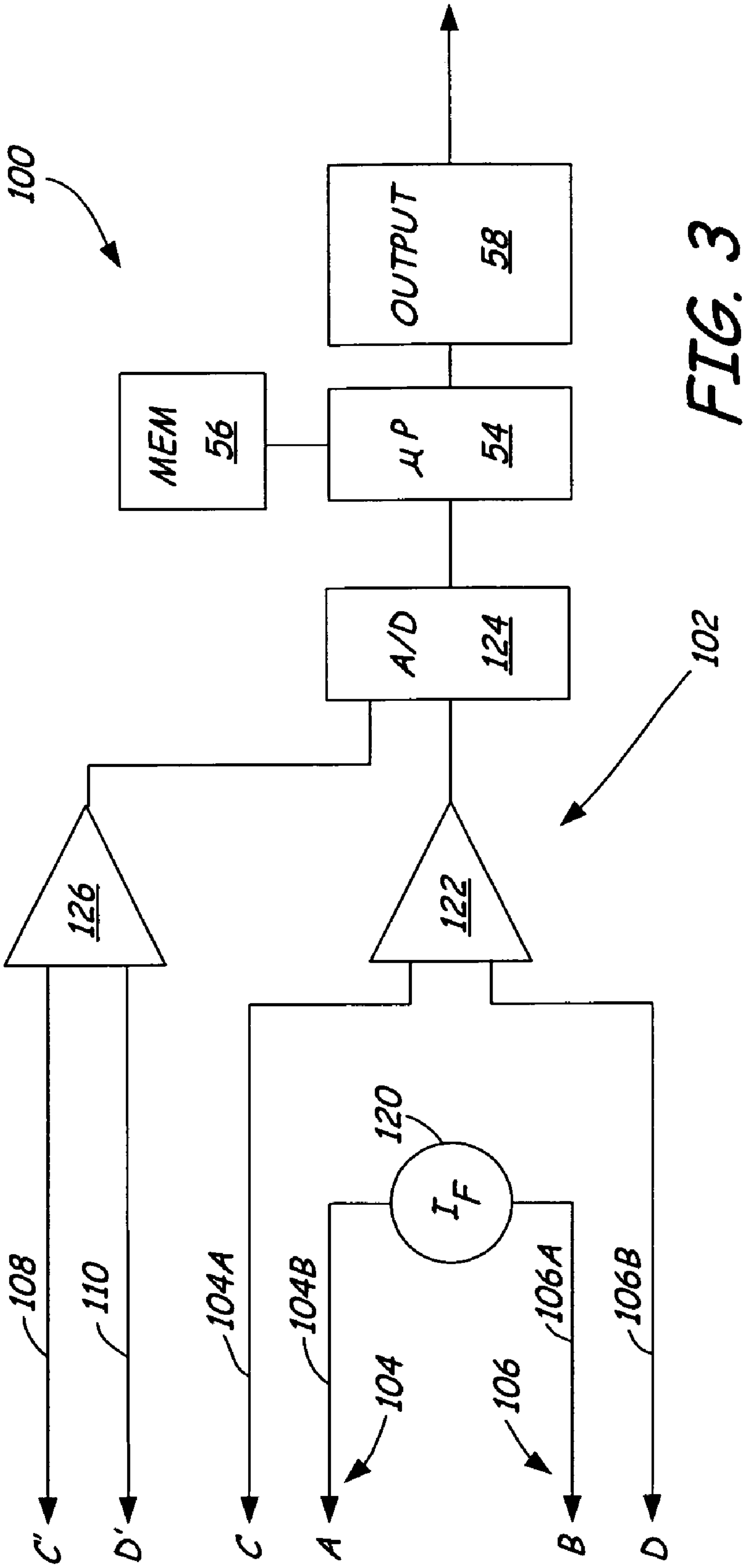

100
OUTPUT
58
MEM
56
μP
54
A/D
124
102
126
122
120
I_F
108
110
104A
104B
106A
106B
104
106
C'
D'
C
A
B
D

FIG. 3

METHOD AND APPARATUS FOR MEASURING A PARAMETER OF A VEHICLE ELECTRICAL SYSTEM

BACKGROUND OF THE INVENTION

The present invention relates to the measurement of electrical parameters of a vehicle electrical system. More specifically, the present invention relates to measuring an electrical parameter of an electrical system of a vehicle through the use of multiple measurements.

Electrical systems, such as those which are used in automotive vehicles, consist of a number of discreet components or systems which are interconnected. Techniques for measuring and utilizing parameters, such as dynamic parameters, of electrical systems are shown and disclosed 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. 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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. 5,914,605, issued Jun. 22, 1999, entitled ELECTRONIC BATTERY TESTER; U.S. Pat. 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No. 10/263,473, filed Oct. 2, 2002, entitled ELECTRONIC BATTERY TESTER WITH RELATIVE TEST OUTPUT; U.S. Ser. No. 60/415,796, filed Oct. 3, 2002, entitled QUERY BASED ELECTRONIC BATTERY TESTER; U.S. Ser. No. 10/271,342, filed Oct. 15, 2002, entitled IN-VEHICLE BATTERY MONITOR; U.S. Ser. No. 10/270,777, filed Oct. 15, 2002, entitled PROGRAMMABLE CURRENT EXCITER FOR MEASURING AC IMMITTANCE OF CELLS AND BATTERIES; U.S. Ser. No. 10/310,515, filed Dec. 5, 2002, entitled BATTERY TEST MODULE; U.S. Ser. No. 10/310,490, filed Dec. 5, 2002, entitled ELECTRONIC BATTERY TESTER; U.S. Ser. No. 10/310,385, filed Dec. 5, 2002, entitled BATTERY TEST MODULE, U.S. Ser. No. 60/437,255, filed Dec. 31, 2002, entitled REMAINING TIME PREDICTIONS, U.S. Ser. No. 60/437,224, filed Dec. 31, 2002, entitled DISCHARGE VOLTAGE PREDICTIONS, U.S. Ser. No. 10/349,053, filed Jan. 22, 2003, entitled APPARATUS AND METHOD FOR PROTECTING A BATTERY FROM OVERDISCHARGE, U.S. Ser. No. 10/388,855, filed Mar. 14, 2003, entitled ELECTRONIC BATTERY TESTER WITH BATTERY FAILURE TEMPERATURE DETERMINATION, U.S. Ser. No. 10/396,550, filed Mar. 25, 2003, entitled ELECTRONIC BATTERY TESTER, U.S. Ser. No. 60/467,872, filed May 5, 2003, entitled METHOD FOR DETERMINING BATTERY STATE OF CHARGE, U.S. Ser. No. 60/477,082, filed Jun. 9, 2003, entitled ALTERNATOR TESTER, U.S. Ser. No. 10/460,749, filed Jun. 12, 2003, entitled MODULAR BATTERY TESTER FOR SCAN TOOL, 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. 10/601,608, filed Jun. 23, 2003, entitled CABLE FOR ELECTRONIC BATTERY TESTER, U.S. Ser. No. 10/601,432, filed Jun. 23, 2003, entitled BATTERY TESTER CABLE WITH MEMORY; U.S. Ser. No. 60/490,153, filed Jul. 25, 2003, entitled SHUNT CONNECTION TO A PCB FOR AN ENERGY MANAGEMENT SYSTEM EMPLOYED IN AN AUTOMOTIVE VEHICLE, which are incorporated herein in their entirety.

There is an ongoing need to measure parameters of electrical systems of vehicles and heavy equipment. Such measurements can be used to diagnose operation, failure or impending failure of components or subsystems of electrical systems. For example, in electrical systems used in vehicles, measurement of electrical parameters of such systems can be used to diagnose operation of system or indicate that maintenance is required before ultimate failure.

One particular measurement is the resistance of cabling used in large equipment such as heavy trucks. For example, one such cable or set of cables connects the battery of vehicle to the starter motor. The starter motor has a relatively large current draw and even a relatively small cable resistance can have a significant impact on operation of the starter motor.

Because the cable resistance is relatively small it typically cannot be measured using a standard ohm meter or other techniques which are normally used to measure resistance. One technique which has been used to measure the cable resistance is to run a very large current through the cable and measure the voltage drop. However, this is cumbersome and requires components capable of handling the large current.

SUMMARY OF THE INVENTION

An apparatus for measuring electrical parameters for an electrical system includes measurement circuitry which is configured to measure a first parameter of the electrical system between a first connection to the electrical system and a second connection to the electrical system. The measurement circuitry is further configured to measure a second parameter of the electrical system between a third connection to the electrical system and the second connection to the electrical system. A processor determines a third electrical parameter of the electrical system as a function of the first parameter and the second parameter. A method can also be employed.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a simplified diagram of an electrical system of a vehicle.

FIG. **2** is a diagram showing test equipment for determining the resistance of cables of the electrical system shown in FIG. **1**.

FIG. **3** shows another example embodiment of test equipment for determining cable resistance.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. **1** is a diagram of an electrical system **10** of large equipment **12** such as a heavy truck. Electrical system **10** includes a battery **20**, a high current load **22** and cables **24** and **26**. Cables **24** and **26** have resistances R_1 and R_2, respectively and connect load **22** to battery **20**. FIG. **1** also shows connection points C, D and C', D'. Connections C and D are across load **22** and connections C' and D' are cross battery **20**.

As discussed in the Background section, the resistances R_1 and R_2 of cables **24** and **26** can have a significant impact on the amount of power which can be delivered to load **22**. Even if the resistance values are relatively small, because a relatively large current passes through cables **24** and **26**, the resultant voltage drop can significantly reduce the voltage at points C and D and therefore the amount of power (or voltage) which can be delivered to load **22**. In industrial equipment, it is often desirable to measure the resistance R_1 and R_2 of cables **24** and **26**, respectively, in order to identify a cable with a resistance which is too high. One technique which has been used to measure the resistance of the cables is to pass a large current through the cable and measure the resulting voltage drop across the cable. However, this is a cumbersome test and requires electrical test equipment which is capable of handling the large current draw. The present invention provides an apparatus and technique for measuring the resistance of a cable in a configuration similar to that shown in FIG. **1**.

FIG. **2** is a simplified block diagram of one example embodiment of electrical test equipment **50** for measuring electrical parameters of the electrical system **10** shown in FIG. **1**. Test equipment **50** includes measurement circuitry **52**, microprocessor **54**, memory **56** and output **58**. Measurement circuitry **52** is configured to couple to electrical system **10** of FIG. **1** through electrical connections **60** and **62**. Measurements obtained by measurement circuitry **52** are used by microprocessor **54** in accordance with program instructions contained in memory **56**. Based upon the measurements, an output is provided through output **58**, for example, to a user or to other equipment. Connectors **60** and **62** are configured to couple to points C, D and C', D' in order to measure parameters of system **10**. Any number of connectors may be used and the invention is not limited to the two illustrated in FIG. **2**.

In one aspect of the present invention, test equipment **50** measures a parameter P(C,D') between points C and D' and a parameter P(C',D') between points C' and D'. These measurements are used to determine the resistance of R_1 in accordance with the formula:

$$R_1=F[P(C,D'),P(C',D')] \quad \text{EQ. 1}$$

Further, a third measurement can be taken to obtain a parameter P(C',D) between points C' and D in FIG. **1**. With this additional parameter, the resistance of R_2 can be determined as:

$$R_2=F[P(C',D),P(C',D')] \quad \text{EQ. 2}$$

Microprocessor **54** can determine the actual values of R_1 and R_2, or can make some other determination related to R_1 and R_2, for example a pass/fail determination, a relative determination, a gradient based determination, etc. Microprocessor **54** provides an output through output **58** based upon the determination related to R_1 and R_2. The output can be a visual output, audible output, or the like, to an operator. In another example, the output is suitable for receipt by other circuitry.

FIG. **3** is a simplified diagram showing another example embodiment of circuitry in accordance with the present invention. In FIG. **3**, test equipment **100** includes a microprocessor **54**, memory **56** and output **58**, similar to the configuration discussed with respect to FIG. **2**. Additionally, measurement circuitry **102** is provided for coupling to the C,D and C',D' connections shown in FIG. **1**. More specifically, Kelvin connections **104** and **106** are provided and are identified as A, B, C and D with connections **104**B, **106**A, **104**A and **106**B, respectively. Kelvin connection **104** is configured to couple to location C shown in FIG. **1**. Kelvin connection **106** is configured to couple to location D shown in FIG. **1**. An additional pair of connections **108** and **110** are configured to couple to locations C' and D' shown in FIG. **1**. A forcing function **120** couples to connections **104**B and **106**A (A and B) and is configured to apply a time varying signal therebetween. The signal can be any type of time varying signal including a periodic signal and may have any type of waveform at a desired frequency or multiple frequencies. Further, in some embodiments, measurements are taken using different forcing functions at differing frequencies or waveforms. The forcing function can be an active signal which is injected through the A/B connection, or can be a passive signal in which a signal is drawn from points A/B through selective application of a resistance, etc.

An amplifier **122** couples to connections **104**A and **106**B (C and D) and provides an output to an analog to digital converter **124**. Connections **108** and **110** (C' and D') couple to an amplifier **126** which provides an output to analog to digital converter **124**. Note that this configuration is for explanation only and other configurations can be implemented in accordance with the present invention including different amplifier configurations, different analog to digital converter configurations, etc. Further, the forcing function **120** can be an active forcing function in which a signal is actively applied or can be a passive forcing function in which a signal is applied passively through a resistance or the like which is selectively applied to draw current from battery **20** shown in FIG. **1**. The circuitry can be implemented in analog or digital circuitry, or their combination. Circuitry in accordance with techniques set forth in the Background section can be implemented, or other measurement techniques can be used.

Using the configuration set forth in FIG. **3**, Kelvin connections **104** and **106** can be applied to points C and D identified in FIG. **1**. Additional connections **108** and **110** can be applied to points C' and D' shown in FIG. **1**. Using this configuration, the parameters measured in accordance with FIGS. **1** and **2** can be dynamic parameters which are functions of the applied forcing function **120**. In another example embodiment, a single pair of Kelvin connections is used in which the connections are moved between various positions C, D, C' and D' shown in FIG. **1** and the resistance R_1 and R_2 of the cables **24** and **26** are determined.

Using the circuitry set forth in FIG. **3**, conductance values between the various connections shown in FIG. **1** can be obtained. Using these conductance values, the resistances R_1 and R_2 can be determined using the following equations:

$$R_1=(K_1/G_{CD'})-(K_2/G_{C'D'}) \quad \text{EQ. 3}$$

$$R_2=(K_3/G_{C'D})-(K_4/G_{C'D'}) \quad \text{EQ. 4}$$

Where $G_{CD'}$ is the conductance measured between points C and D', $G_{C'D}$ is the conductance measured between points C' and D' and $G_{C'D}$ is the conductance measured between points C' and D. The values K_1, K_2, K_3 and K_4 are constants and can be, in some examples, the same value, for example unity. The conductance values can be either direct conductance values or can be conductance values converted to a cold cranking amps (CCA) scale. When CCA values are measured, the values of R_1 and R_2 can be determined using the formula:

$$R_1=(3.125/CCA\_CD')-(3.125/CCA\_C'D') \quad \text{EQ. 5}$$

$$R_2=(3.125/CCA\_C'D)-(3.125/CCA\_C'D') \quad \text{EQ. 6}$$

The value of 3.125 can be adjusted based upon the particular CCA scale employed.

The load **22** can be any type of load including loads which draw high current levels, for example, a starter motor, a magnetic switch, a ground connection, wiring harness, a terminal which may be susceptible to corrosion, a connection through a bolt which may have inappropriate torque or otherwise provide a poor connection, trailer wiring, etc. In one example output, a particular voltage drop is provided for a particular current draw through the cabling. For example, the output can comprise an indication that there is a 0.5 volt drop through the cable under a 500 amp current. Such a parameter can also be used, for example, in a pass/fail test, i.e., if the voltage drop is more than a particular threshold at a given current level, a failure indication can be provided as an output. In one embodiment, the measured parameters comprise dynamic conductance. However, any dynamic parameter can be used in accordance with the present invention including dynamic resistance, reactance, impedance, conductance, susceptance, and/or admittance, including any combination of these parameters.

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. The measurements can be taken using multiple connections to the electrical system or by moving a single pair of connections to various positions on the electrical system. An output can be provided to instruct the operator where to place the connections.

What is claimed is:

1. A method for determining cable resistance of wiring of an electrical system of a vehicle which includes a battery, a load, and a first cable connecting a first side of the battery to a first side of the load, and a second cable connecting a second side of the battery to a second side of the load, comprising:

coupling a first Kelvin connector to the first side of the load of the vehicle, the first Kelvin connector having a first connector and a second connector;

coupling a second Kelvin connector to the second side of the load of the vehicle, the second Kelvin connector having a third connector and a fourth connector;

coupling a first voltage sensor connector to the first side of the battery of the vehicle;

coupling a second voltage sensor connector to the second side of the battery of the vehicle;

applying a forcing function between the first connector of the first Kelvin connector and the third connector of the second Kelvin connector;

measuring a first parameter of the electrical system between the second connector of the first Kelvin connector and the second voltage sensor connector in response to the applied forcing function;

measuring a second parameter of the electrical system between the first voltage sensor connector and the second voltage sensor connector in response to the applied forcing function;

measuring a third parameter of the electrical system between the fourth connector of the second Kelvin connector and the second voltage sensor connector in response to the applied forcing function;

measuring a fourth parameter of the electrical system between the first voltage sensor connector and the second voltage sensor connector in response to the applied forcing function;

determining the cable resistance of the first cable as a function of the first parameter and the second parameter; and

determining the cable resistance of the second cable as a function of the third parameter and the fourth parameter.

2. The method of claim **1** wherein the first and second parameters comprise dynamic parameters.

3. The method of claim **1** wherein the forcing function comprises a time varying signal.

4. The method of claim **1** wherein the forcing function comprises an active forcing function.

5. The method of claim **1** wherein the forcing function comprises a passive forcing function.

6. The method of claim **1** wherein the cable resistance is determined in accordance with the equation:

$$R_1=F[P(C,D'), P(C',D')]$$

Where C, C' and D' are points on the electrical system.

7. The method of claim **1** wherein the first and second parameters are indicative of a cold cranking amps (CCA) measurement.

8. The method of claim **1** including providing an output related to the first and second cable resistances.

9. The method of claim **8** wherein the output is provided to an operator.

10. The method of claim **8** wherein the output is provided to electrical circuitry.

11. The method of claim **8** wherein the output comprises a pass/fail output.

12. The method of claim **8** wherein the output is indicative of a voltage drop for a particular current through the electrical system.

13. An apparatus for determining cable resistance of wiring of an electrical system of a vehicle which includes a battery, a load, and a first cable connecting a first side of the battery to a first side of the load, and a second cable connecting a second side of the battery to a second side of the load, comprising:

a first Kelvin connector to couple the first side of the load, the first Kelvin connector having a first connector and a second connector;

a second Kelvin connector to couple the second side of the load, the second Kelvin connector having a third connector and a fourth connector;

a first voltage sensor connector to couple the first side of the battery;

a second voltage sensor connector to couple to the second side of the battery; and

measurement circuitry configured to measure a first parameter of the electrical system between the second connector of the first Kelvin connector and the second voltage sensor connector in response to the applied forcing function, measure a second parameter of the electrical system between the first voltage sensor connector and the second voltage sensor connector in response to the applied forcing function, measure a third parameter of the electrical system between the fourth connector of the second Kelvin connector and the second voltage sensor connector in response to the applied forcing function, measure a fourth parameter of the electrical system between the first voltage sensor connector and the second voltage sensor connector in response to the applied forcing function, and responsively determine the cable resistance of the first cable as a function of the first parameter and the second parameter, and determine the cable resistance of the second cable as a function of the third parameter and the fourth parameter.

14. The apparatus of claim **13** wherein the first and second parameters comprise dynamic parameters.

15. The apparatus of claim **13** wherein the forcing function comprises a time varying signal.

16. The apparatus of claim **13** wherein the forcing function comprises an active forcing function.

17. The apparatus of claim **13** wherein the forcing function comprises a passive forcing function.

18. The apparatus of claim **13** wherein the cable resistance is determined in accordance with the equation:

$$R_1=F[P(C,D'), P(C',D')]$$

Where C, C' and D' are points on the electrical system.

19. The apparatus of claim **13** wherein the first and second parameters are indicative of a cold cranking amps (CCA) measurement.

20. The apparatus of claim **3** including an output configured to provide an output related to the cable resistance.

21. The apparatus of claim **20** wherein the output comprises an output to an operator.

22. The apparatus of claim **20** wherein the output comprises an output to electrical circuitry.

23. The apparatus of claim **20** wherein the output comprises a pass/fail output.

24. The apparatus of claim **20** wherein the output is indicative of a voltage drop for a particular current through the electrical system.

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