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EP 0018334 A1 **WO 92/06552 A1** **US 4714912 A**

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(54) Transmitting data over a power cable utilizing a magnetically saturable core reactor

(57) The present invention impresses the data on the power signal by utilizing a saturable core reactor. The saturable core reactor uses two cores. Each core has both load windings 23, 25 and control windings 27, 29. The control windings 27, 29 are selectively energized to alter an electrical characteristic of the current passing through the load windings. The saturable core reactor is designed with cores made of a highly magnetically permeable material so that the cores are easily saturated. The cyclical saturation of the cores achieved by the load current, and the selective saturation of the cores achieved by selectively applying a D.C. control current, results in "deformations" being selectively formed at the zero crossings of the load current waveform. These "deformations" can be selectively formed on the power signal to represent a binary data stream. Once the series of "deformations" is impressed onto the power signal, the "deformations" are communicated from one point on the power cable to another point on the power cable together with the power signal. The "deformations" are then read and transformed into a binary data stream. Thus, the power cable is converted from a mere power cable to a power cable capable of transmitting both power and data simultaneously. The invention is useful for the transmission of data regarding temperature, pressure, pump operation in an oil or gas wellbore over a power cable to the surface. Construction of the core with the load and control windings thereon is also described (Figs. 5A, 5D not shown).

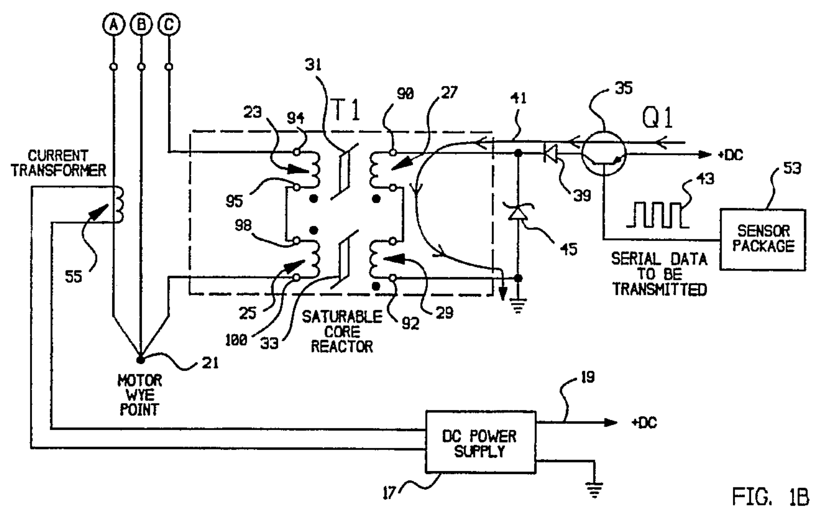

FIG. 1B

GB 2 290 686 A

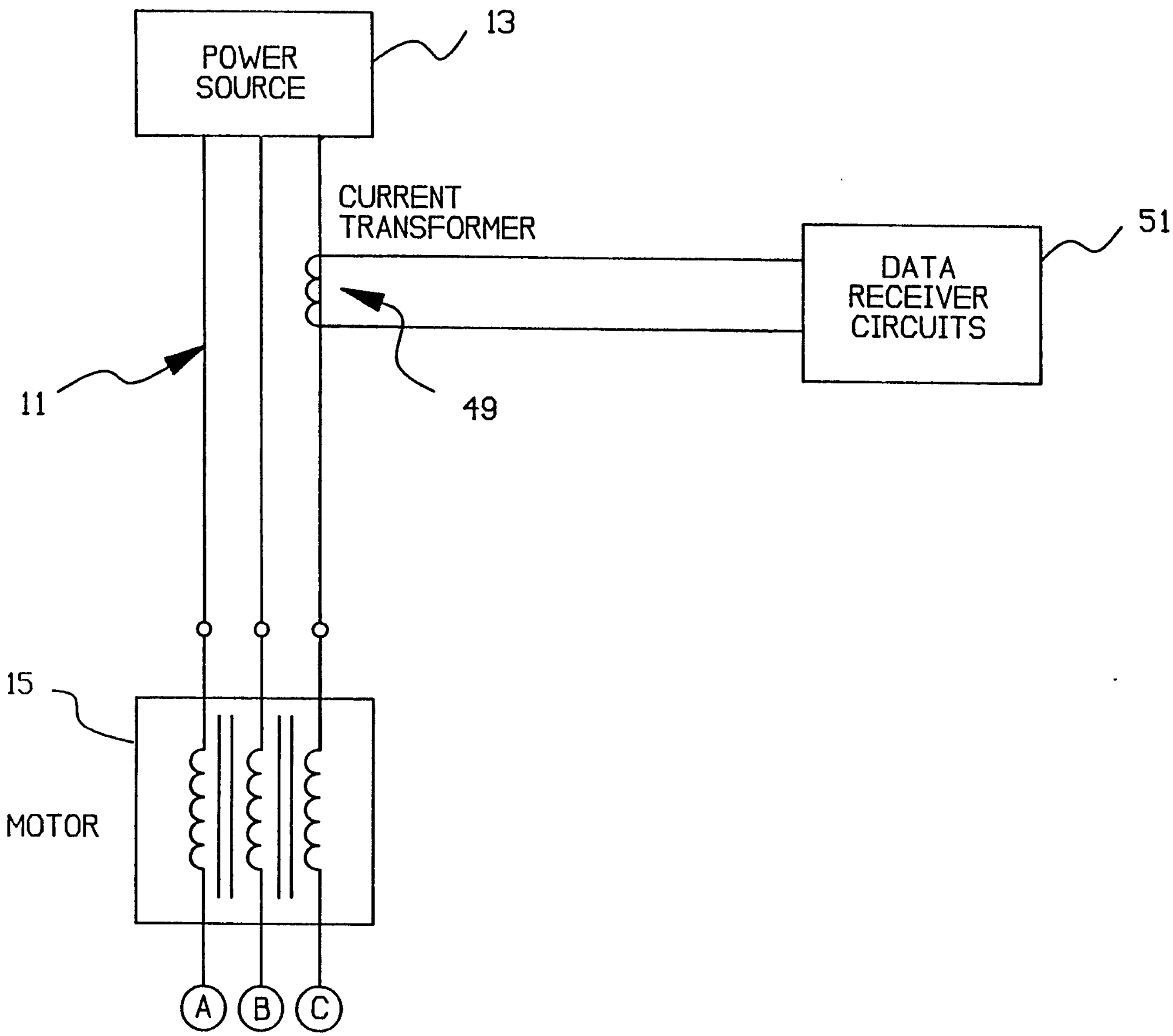
POWER SOURCE
13
CURRENT TRANSFORMER
DATA RECEIVER CIRCUITS
51
11
49
15
MOTOR
A
B
C

FIG. 1A

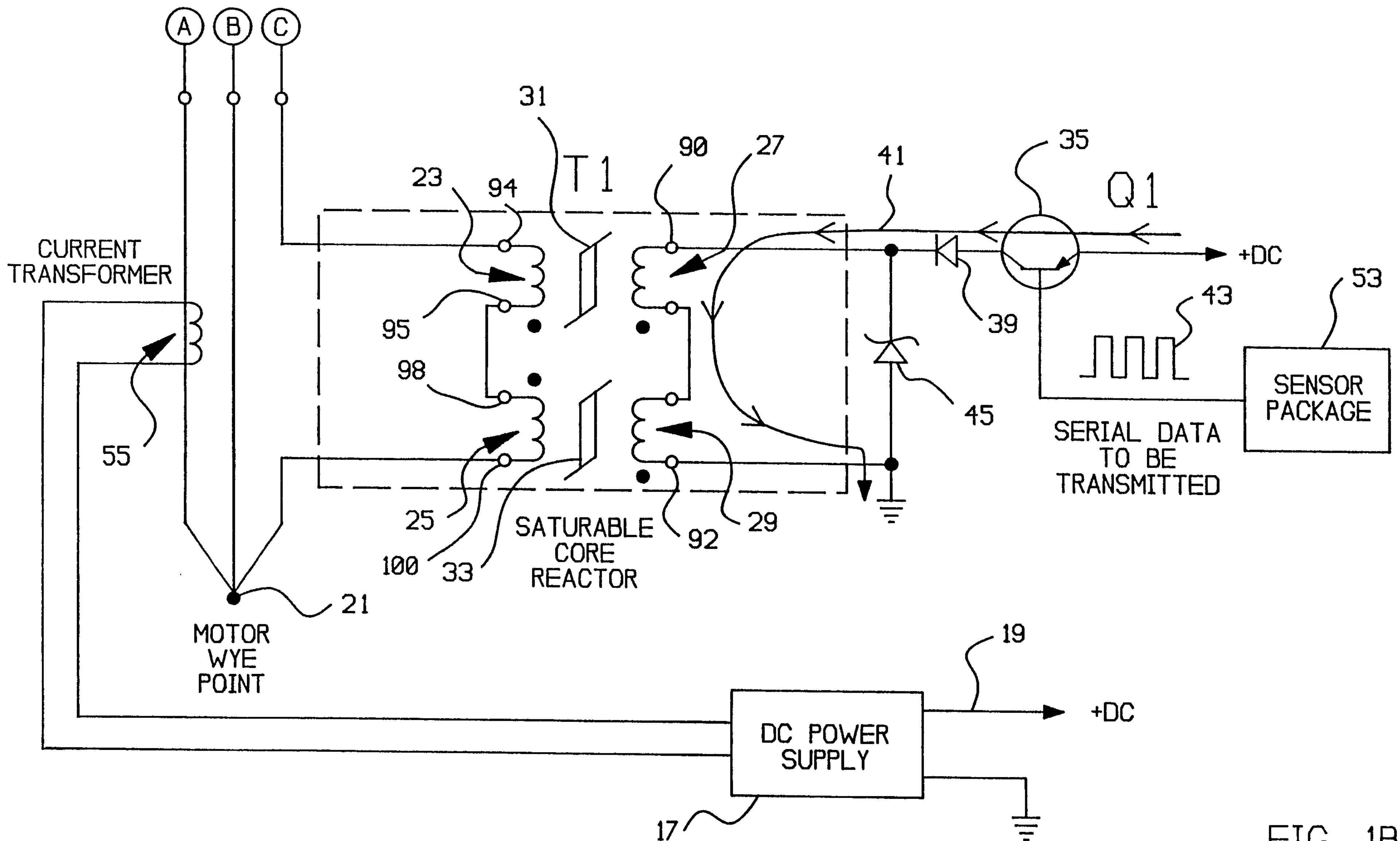
A
B
C
CURRENT TRANSFORMER
55
MOTOR WYE POINT
21
23
94
31
T1
90
27
41
35
Q1
+DC
95
98
25
100
33
SATURABLE CORE REACTOR
92
29
39
45
43
53
SENSOR PACKAGE
SERIAL DATA TO BE TRANSMITTED
19
+DC
DC POWER SUPPLY
17

FIG. 1B

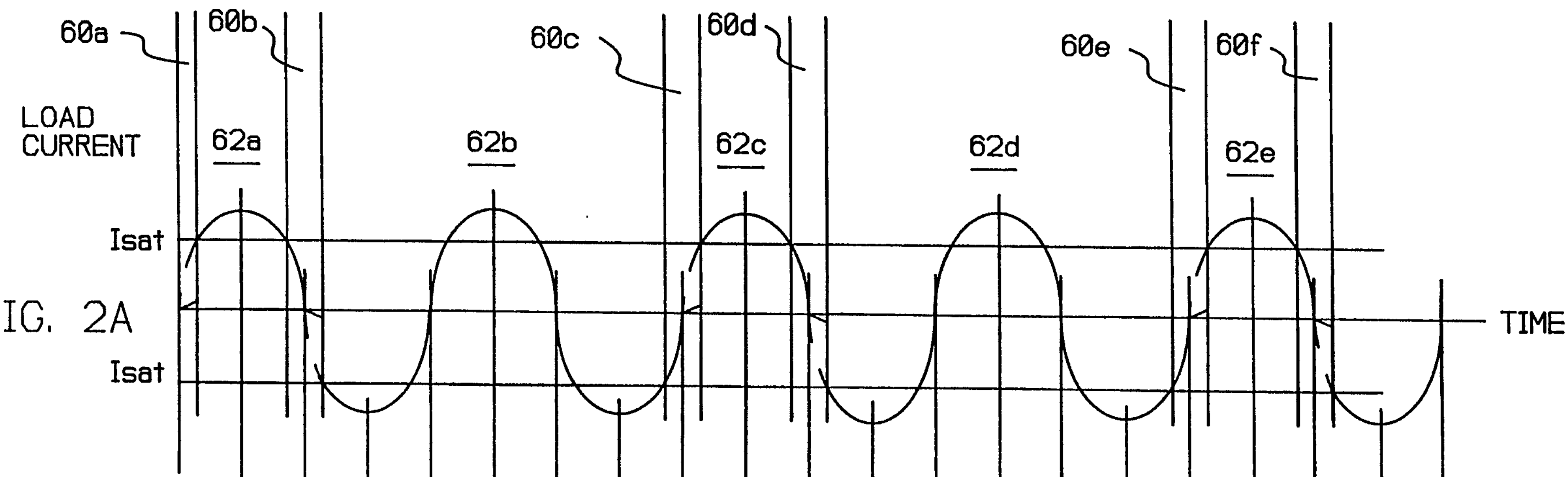
60a
60b
60c
60d
60e
60f
LOAD CURRENT
62a
62b
62c
62d
62e
Isat
Isat
TIME

FIG. 2A

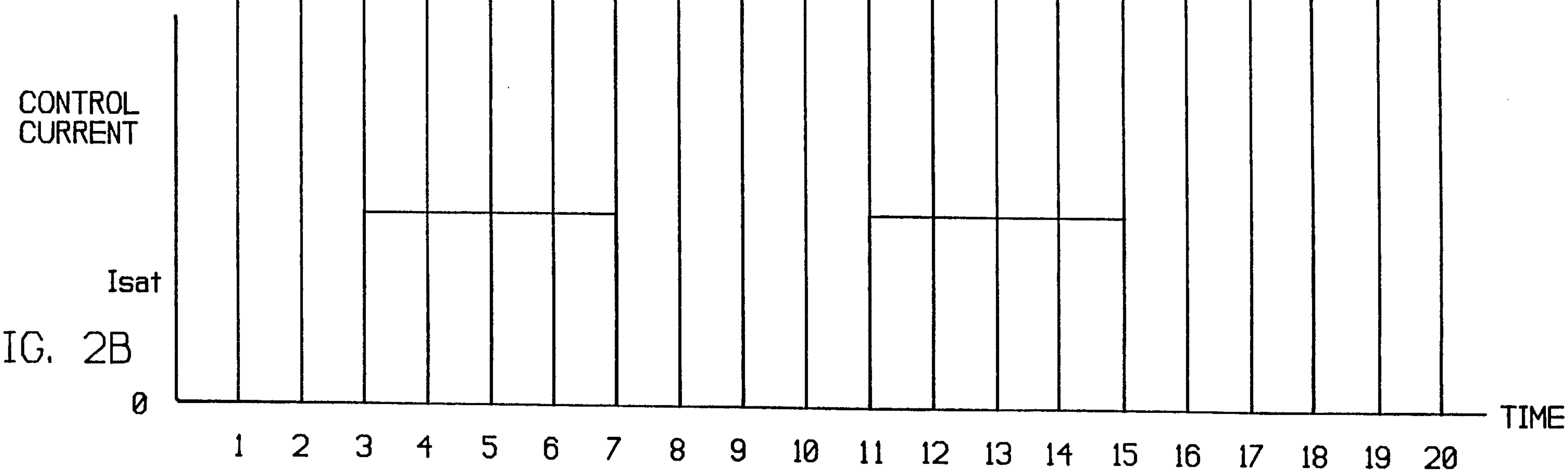
CONTROL CURRENT
Isat
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
TIME

FIG. 2B

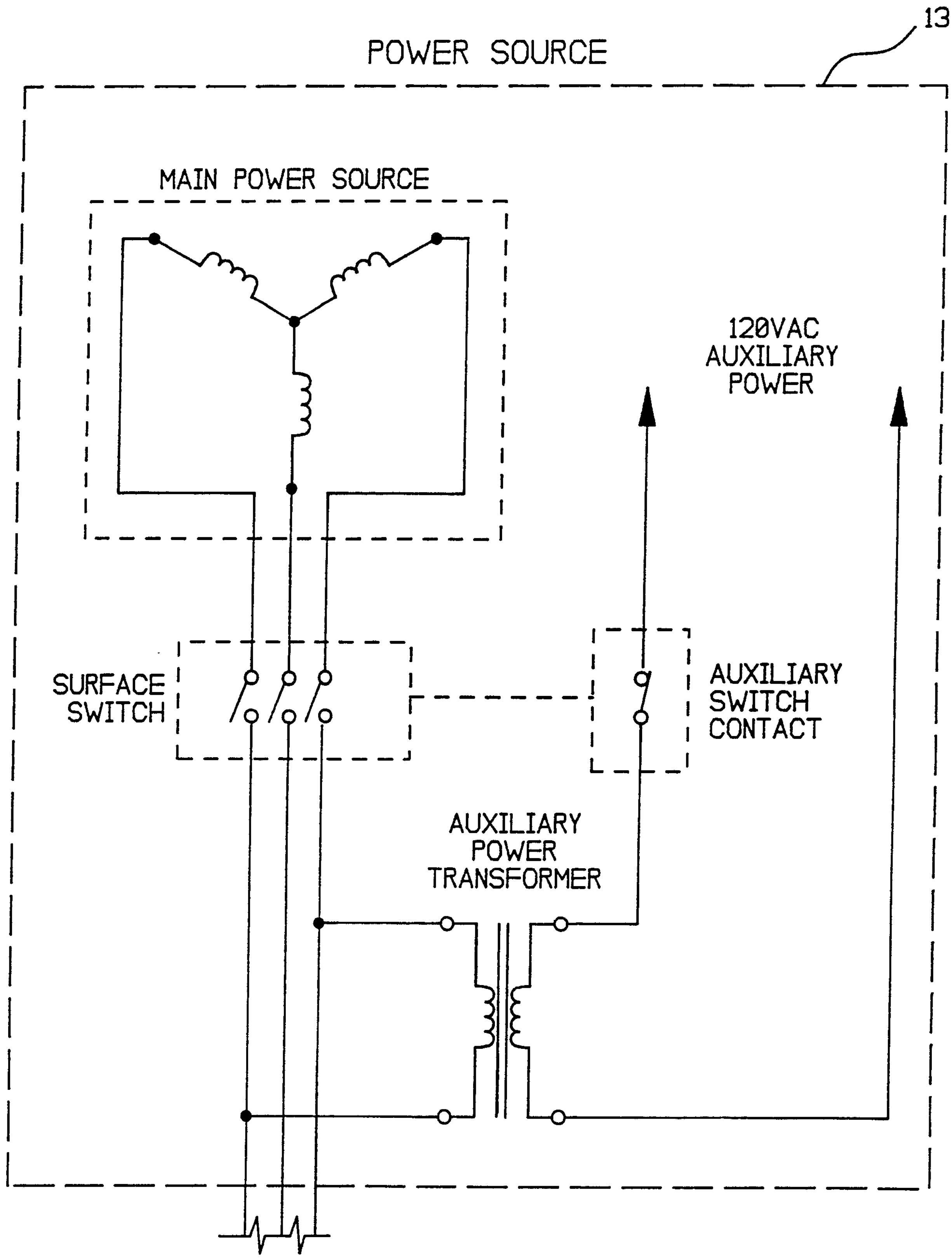
13
POWER SOURCE
MAIN POWER SOURCE
120VAC
AUXILIARY
POWER
SURFACE
SWITCH
AUXILIARY
SWITCH
CONTACT
AUXILIARY
POWER
TRANSFORMER

FIG. 3

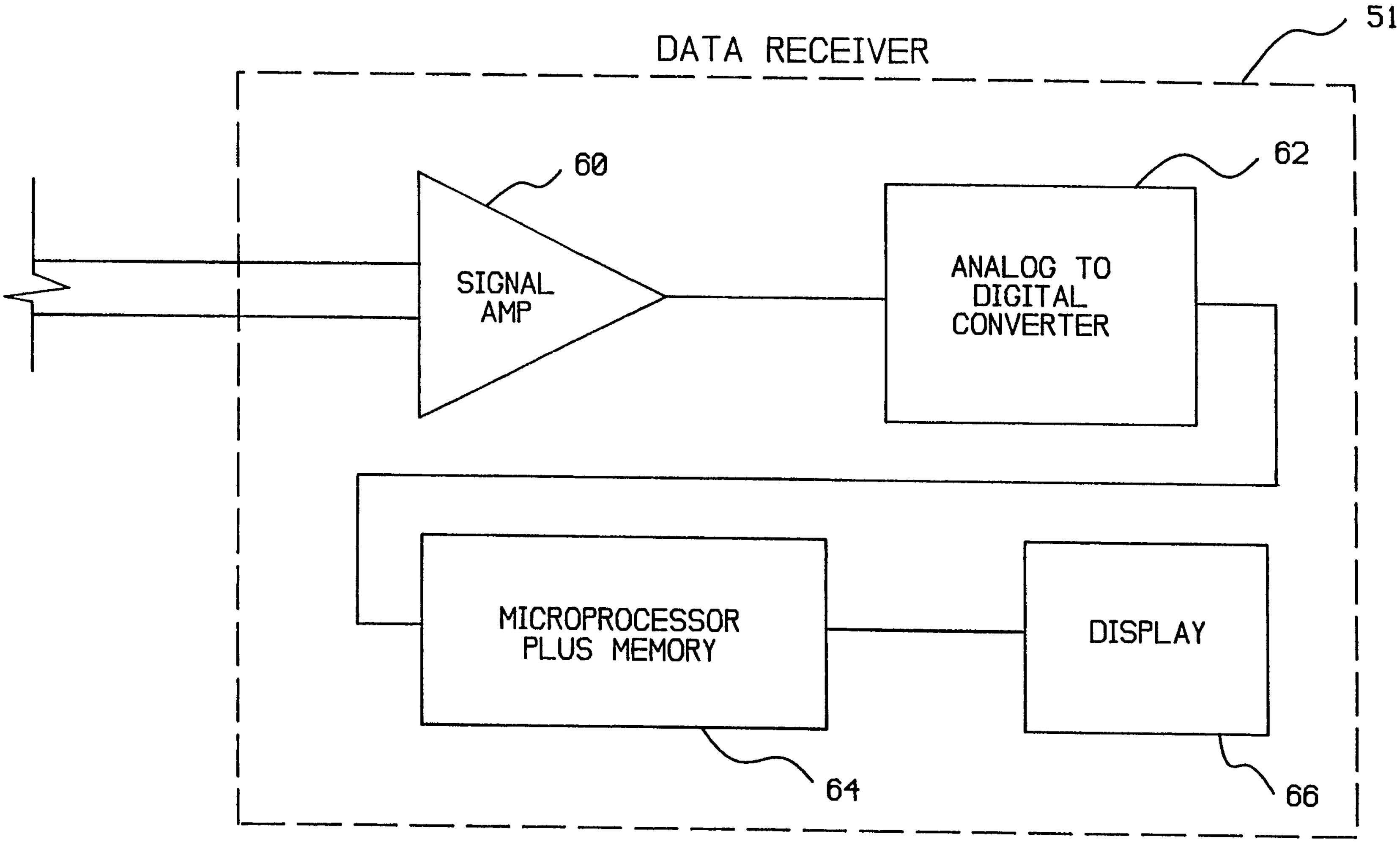
DATA RECEIVER
51
60
SIGNAL AMP
62
ANALOG TO DIGITAL CONVERTER
MICROPROCESSOR PLUS MEMORY
64
DISPLAY
66

FIG. 4

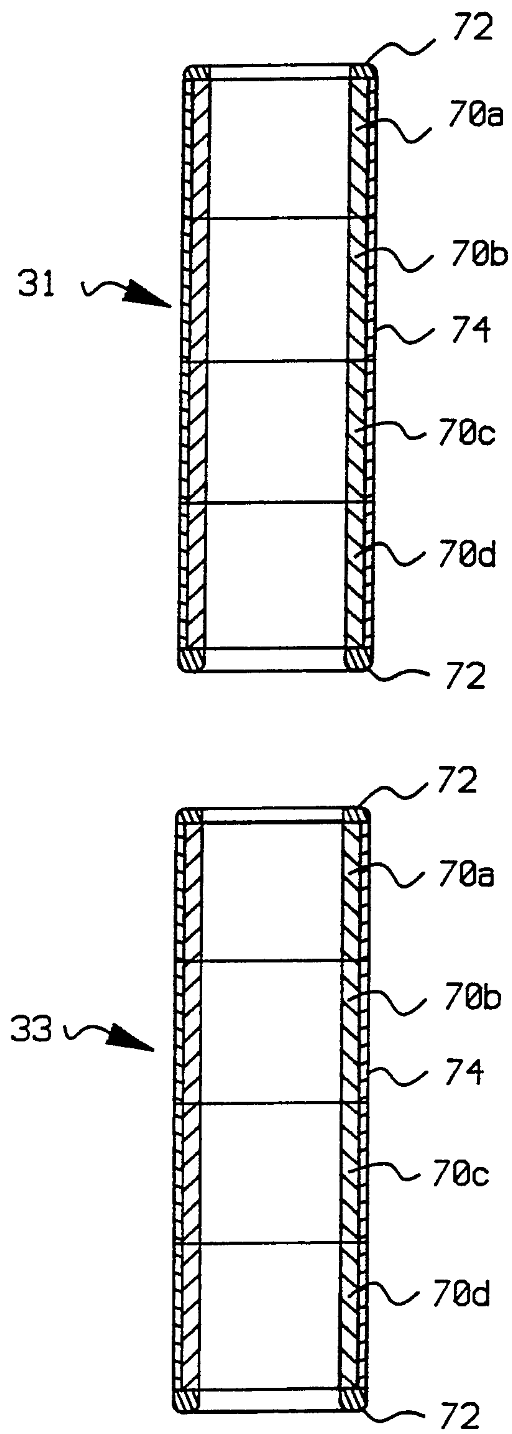
72
70a
70b
31
74
70c
70d
72
72
70a
70b
33
74
70c
70d
72

FIG. 5A

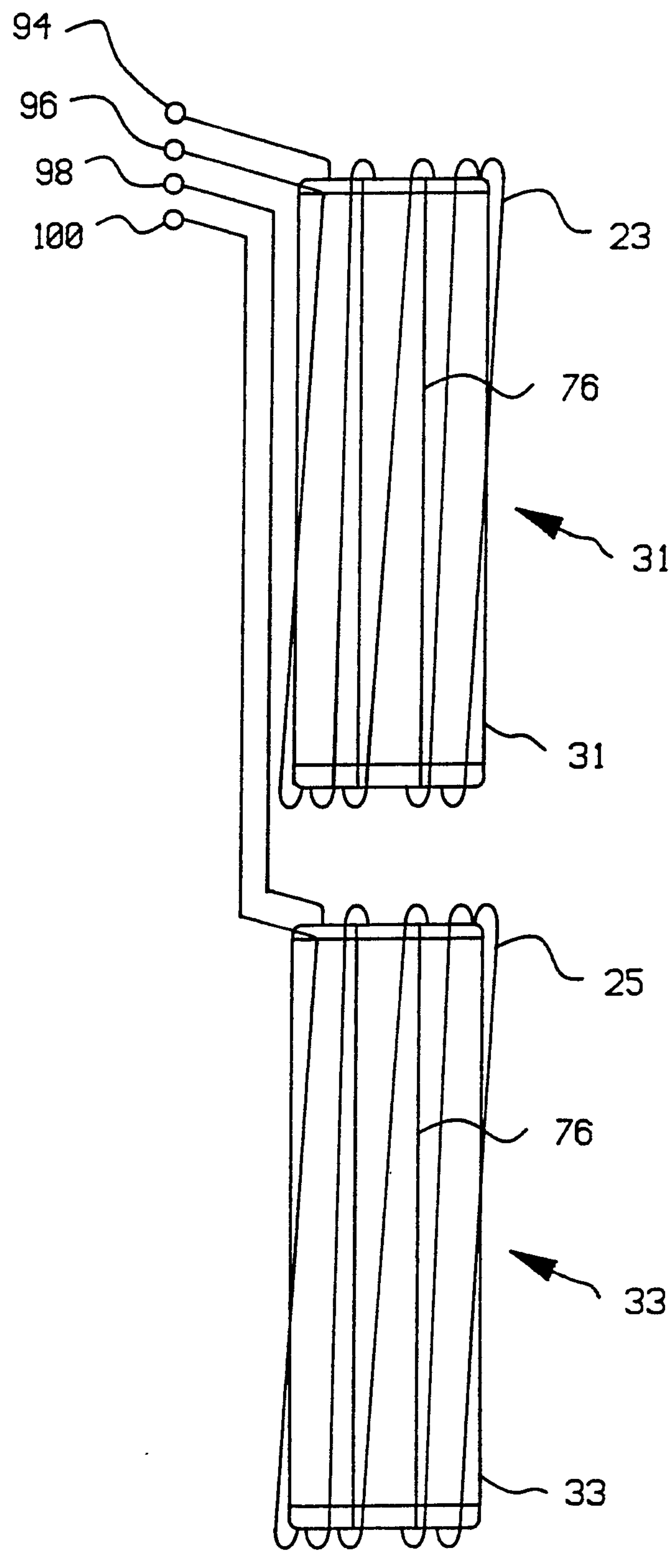
94
96
98
100
23
76
31
31
25
76
33
33

FIG. 5B

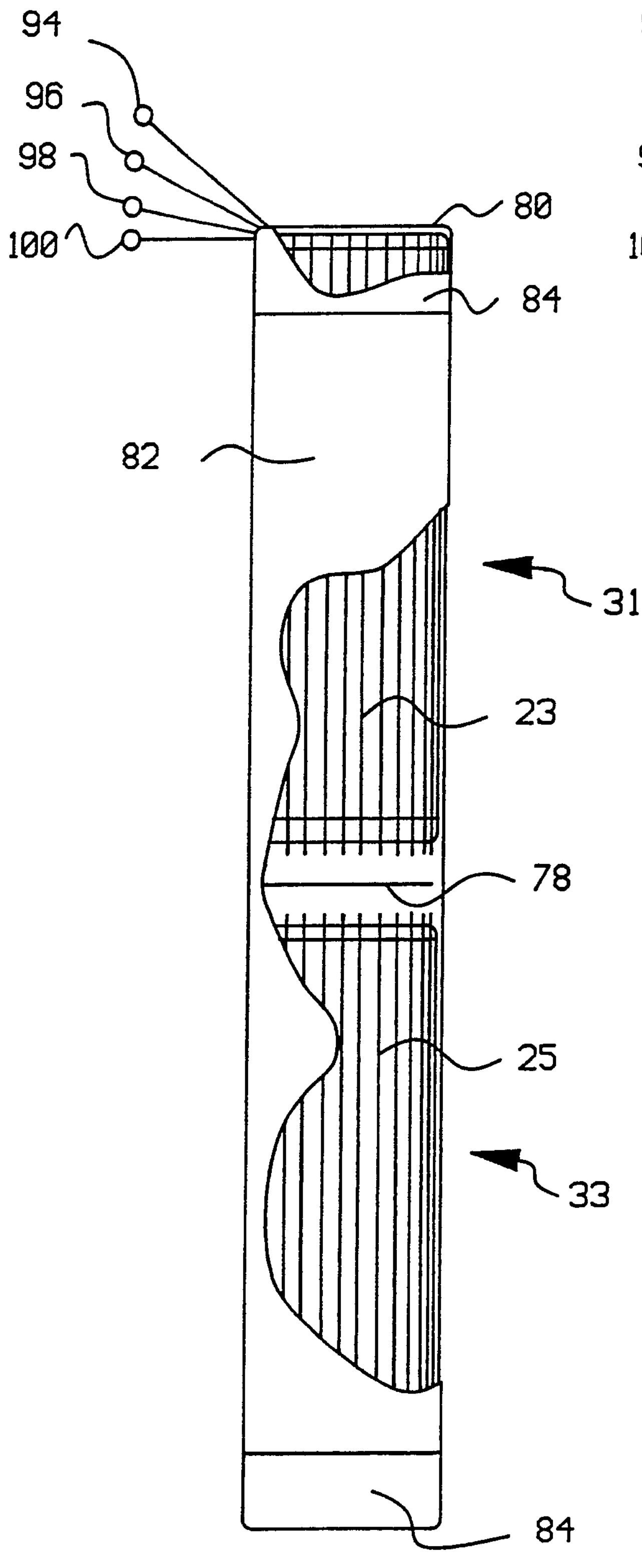

FIG. 5C

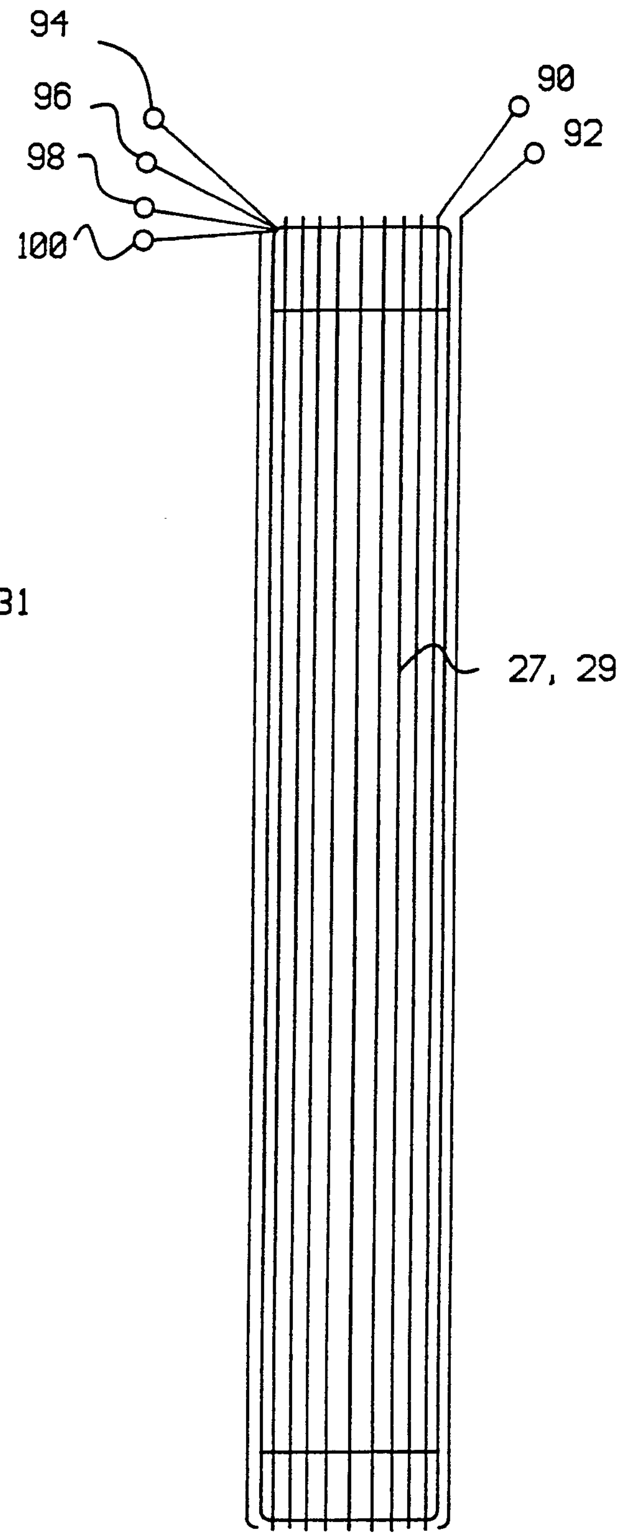

FIG. 5D

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METHOD AND APPARATUS FOR TRANSMITTING DATA OVER A POWER CABLE UTILIZING A MAGNETICALLY SATURABLE CORE REACTOR

Field of the Invention:

The present invention relates in general to the transmission of data over a power cable, and in particular relates to the transmission of data in a wellbore over a power cable.

Description of the Prior Art:

The economical transmission of data within a producing oil and gas wellbore has been one long recognized goal in the oil and gas industry. This is particularly true since data gathered from locations deep within the subterranean wellbore can be utilized to (a) optimize production of oil and gas from the wellbore, and (b) monitor the operation of remotely located subsurface equipment such as submersible pumps to prolong the service life of the equipment and avoid damaging the equipment or the wellbore by being unable to identify impending failures.

Since a producing oil and gas wellbore typically extends several thousand feet downward from the surface, with a fixed radial dimension, the utilization of a dedicated hardwire for the transmission of data accumulated in a subterranean location is not practical from an engineering viewpoint. Typically, a cable is however provided to energize wellbore components such as submersible pumps. The lack of clearance for an additional cable, as well as the associated cost of a dedicated data cable, has resulted in numerous attempts in the prior art to superimpose a data signal upon the power cable for the power consuming subterranean device. Unfortunately, many of the solutions offered by the prior art involve the utilization of delicate electronic components which are not likely to withstand prolonged exposure to the high temperature, high pressure wellbore environments, nor the corrosive fluids and gases which are frequently present within wellbores. One additional problem with prior art solutions is that the superimposition of the data stream onto the power signal results in an inefficient power distribution which may damage the subterranean power consuming device.

There exists a great need for a data transmission system which can be used in a wellbore under the hostile conditions encountered therein, but which does not unnecessarily interfere with the distribution of power to the subterranean power consuming devices.

SUMMARY OF THE INVENTION

The present invention allows a power cable to supply power, while at the same time serving as a databus for transmitting data between two locations. In the oil and gas industry, it is often necessary to transmit data from a remote wellbore location to the surface. Although this can be achieved by using a cable dedicated to data transmission, it would be highly advantageous to be able to transmit data over an existing power cable which is already suspended from the surface down to the remote location.

When transmitting data over a power cable, it is important to avoid significant alteration of the power signal. Significant alteration of the power signal will result in poor power transfer and poor power distribution which can cause malfunctioning of the equipment being powered. Thus, the present invention only alters the power signal at points near the zero crossing of an alternating current power signal. Since very little power is being transmitted at such points, such alteration results only in minimal alteration of the power being transmitted by the power cable.

The present invention is directed to a data transmission apparatus for transmitting data over power cable which supplies alternating electric current to an electrical-power-consuming component. The data transmission apparatus includes at least one alternating-electrical-current-modifying circuit component. Each of these includes an alternating electrical current input, and an alternating electrical current output. A control circuit is provided for selectively communicating a data signal to the at least one alternating-electrical-current-modifying circuit component, for modifying the alternating electrical current as it passes through the at least one alternating-electrical-current-modifying circuit component. Data is then transmitted to a remote location through the power cable through alteration of at least one electrical characteristic of the alternating electrical current in a predefined manner by switching action of the control circuit in response to a data signal. More particularly, in accordance with a preferred embodiment of the present invention, the alternating electrical current is altered in at least one zero-crossing region in a predefined manner by the switching action of the control circuit. This minimizes the disruption of power transfer to the electrical-power-consuming component.

More particularly, the present invention impresses the data on the power signal by utilizing a saturable core reactor. The saturable core reactor uses two cores. Each core has both load windings and control windings. The control windings are selectively energized to alter an electrical characteristic of the current passing through the load windings. The saturable core reactor is designed with cores made of a highly magnetically permeable material so that the cores are easily saturated. The cyclical saturation of the cores achieved by the load current, and the selective saturation of the cores achieved by selectively applying a control current, results in "deformations" being selectively formed at the zero crossings of the load current waveform. These "deformations" can be selectively formed on the power signal to represent a binary data stream. Once the series of "deformations" is impressed onto the power signal, the "deformations" are communicated from one point on the power cable to another point on the power cable together with the power signal. The "deformations" are then read and transformed into a binary data stream. Thus, the power cable is converted from a mere power cable to a power cable capable of transmitting both power and data simultaneously.

A significant advantage of the present invention is that it allows data transmission over a cable which is also being used to carry electrical power. The present invention allows simultaneous data and power transmission, thereby eliminating the need of a separate means of transmitting the data.

Another significant advantage of the present invention is that the transmission equipment is relatively uncomplicated and durable, which is especially important for use in extremely hostile environments within which remotely located wellbore equipment (such as pumps) is expected to perform for prolonged time periods.

Additional objects, features, and advantages will be apparent in the written description which follows.

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features believed characteristic of the invention are set forth in the appended claims. The invention itself, however, as well as a preferred mode of use, further objects and advantages thereof, will best be understood by reference to the following detailed description of an illustrative embodiment when read in conjunction with the accompanying drawings, wherein:

Figures 1A and **1B** together provide a schematic and block diagram representation of the circuit components of an embodiment of the present invention.

Figures 2A and 2B are timing diagrams in which Figure 2A is a graph of load current versus time and Figure 2B is a graph of control current versus time, both shown over the same period of time.

Figure 3 is a schematic of the power source;

Figure 4 is a block diagram of the data receiver circuit;

Figure 5A is a cross sectional view of the two saturable cores taken along a vertical section through the middle of the core;

Figure 5B is a view of the two cores with the load windings shown wound around each core;

Figure 5C is a view of the cores of Figure 5B assembled and ready to accept the control windings; and

Figure 5D is a view of the control windings wound around the two cores of Figure 5C.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is best understood in the context of the following illustrative embodiment. Figures 1A and 1B together provide a schematic and block diagram representation of the circuit components of an embodiment of the present invention. As is shown, a power source 13 is located at the earth's surface. A three-phase power cable 11 extends from the power source 13 to a remote wellbore location to supply power to a submersible pump motor such as motor 15. A current transformer 55 is magnetically coupled to one of the wires which come together at motor WYE point 21, and serves to provide an input for DC power supply 17. DC power supply 17 provides as an output a regulated DC current level 19 which operates to power the remaining subsurface circuit components.

A number of inductive windings are provided about two saturable magnetic cores. As shown, windings 23, 25, 27, and 29 are provided, with windings 23 and 27 disposed about saturable core 31, while windings 25 and 29 are disposed about saturable core 33. Windings 23 and 25 are load windings and are connected to one of the legs of the three-phase power cable 11. Windings 27 and 29 are control windings and are connected to the control circuit and the sensor package 53. (It should be noted that although the control windings are referred herein as being two separate sets of windings 27 and 29, the preferred embodiment, as will be described later, actually uses only one winding disposed about both cores. Having two windings 27 and 29 one around each core, or one winding around both cores gives the same results).

Cores 31 and 33 are formed of a magnetically permeable material. In the preferred embodiment of the present invention, cores 31 and 33 are formed of at least fifty percent nickel, which allows for easy saturation of the cores.

Conventional reactors are normally designed so that the AC current passing through the windings results in fluxes in the core that have a peak value which just fails to saturate the core. Such reactors offer a high resistance (or impedance) to the alternating current passing through the load windings. This is due to the core being in an unsaturated condition. In an unsaturated condition, current will lag behind voltage by 90 degrees.

However, if a core is operated in a saturated condition, the effective resistance at the load windings would approach zero. The saturable core reactor used in the present invention differs from ordinary reactors in that it is designed so that the AC current passing through the load windings results in fluxes in the cores that easily saturate the cores. Such a design results in the cores being saturated for the majority of each power cycle, thereby offering low resistance at the load windings for the majority of each power cycle.

The cores in a saturable core reactor can be saturated in either of two ways. The first way is to design the reactors so that portions of each half cycle of the alternating current through the load windings are sufficient to bring the cores into saturation. This saturation method causes the cores to cycle between a saturated state and an unsaturated state, thus causing the resistance to alternating current of the load windings to cycle between a very high level and a very level close to zero. The other method of bringing the cores into saturation is to apply a direct current to the control windings which is itself sufficient to saturate the cores. As long as such direct current is being applied, the cores remain saturated, and the effective resistance to the alternating current in the load windings remains close to zero.

The present invention uses a combination of the above two methods of saturating cores 31 and 33. Firstly, cores 31 and 33 are designed so that they are very easily saturated, thus allowing the load current passing through load windings 23 and 25 to maintain cores 31 and 33 in saturation for a majority of each current cycle. Secondly, control windings 27 and 29 are provided to allow selective application of direct current to the cores sufficient to selectively saturate cores 31 and 33.

In the preferred embodiment, switching transistor 35 is a PNP transistor with a base input, a collector input and an emitter input. The switching transistor functions merely as a switch in this embodiment. The application of a current to the base closes the switch allows current to flow between the emitter and the collector. With specific reference now to the specific circuit components, application of a binary pulse train (such as binary data stream 43) to the base of switching transistor 35 will allow current to flow in the direction of arrows 41. More specifically, switching transistor 35 is switched from the off-condition (open-condition) to the on-condition (closed-condition) to allow DC current 19 to cause current flow from the emitter to the collector of switching transistor 35, through diode 39, through control windings 27 and 29, and eventually to ground. Diodes 39 and 45 are provided merely to protect the circuitry from certain types of damage, and are not central to the concepts of the invention.

Figures 2A and 2B show graphs of the load current and control current, respectively, versus a given period of time. Reference to these Figures and to Figure 1 will aid in understanding the following description of the operation of the invention.

During the period from T=0 to T=3, no control current is allowed to flow through control windings 27 and 29. Following the load current curve from T=0, the load current begins at zero. If the load current were not passing through load windings 23 and 25, the load current would rise sinusoidally as shown by the sinusoidal dotted line of Figure 2A. However, the load current is passing through load windings 23 and 25, which are wound around unsaturated cores 31 and 33. Since cores 31 and 33 are unsaturated, the resistance to the alternating current is very high. The load current therefore lags the voltage by nearly a full 90 degrees, and is depicted by the solid line on the load current graph of Figure 2A as being very close to zero, thus creating a "deformation" in the load current waveform.

As time progresses, the amplitude of the alternating current increases above a saturation threshold (I_{sat}) and the cores reach a state of saturation. When the cores saturate, the resistance in the load windings 23 and 25 becomes very small. As the resistance in the load windings essentially disappears, the load current returns in phase with the voltage and is depicted by the solid line in Figure 2A as jumping up to its normal sinusoidal waveform. As long as the load current remains sufficiently high to maintain the cores in saturation, the load current follows its normal sinusoidal waveform. At T=1, the load current peaks and then begins to decrease. At some point between T=1 and T=2, the amplitude of the alternating current drops below the saturation threshold (I_{sat}) and the cores become unsaturated, and the load current again lags behind the voltage by 90^0 and is shown in Figure 2A as returning to around zero.

At T=2, if the load current were not passing through load windings 23 and 25, it would begin to increase in the negative direction along the sinusoidal dotted line of Figure 2A. However, since it is passing through load windings 23 and 25, and cores 31 and 33 are now unsaturated, the resistance in the load windings is high, and the load current will thus remain near zero, or, as stated above, lag behind the voltage by 90^0, and thus create a "deformation" in the load current waveform. Between T=2 and T=3, the cores will once again saturate, and the load current will return in phase with the voltage and jump down along the solid line, and resume its normal sinusoidal waveform.

As just described, the saturable cores going into and out of saturation due to the sinusoidal waveform of the load current result in "deformations" being formed in the load current waveform at around the zero crossings.

At T=3, the control current is allowed to flow through control windings 27 and 29. This control current is sufficient, in and by itself, to maintain the cores in saturation. Since the cores are being maintained in saturation by the control current, the resistance in the load windings remains very low even as the load current passes through the zero crossings at T=4 and T=6. As a result of the control current maintaining the cores in saturation, the sinusoidal waveform of the load current from T=3 to T=7 is unaltered.

At T=7, the control current is turned off and no longer allowed to flow through control windings 27 and 29. Therefore, as the load current approaches the zero crossings at T=8 and T=10, the cores will become unsaturated, and the load current will again lag the voltage by 90^0, thus dropping to near zero around those zero crossings and creating a "deformation" in the sinusoidal waveform.

Reference numerals 60a-60f indicate the time periods during which cores 31 and 33 are unsaturated. Reference numerals 62a-62e indicate the time periods during which cores 31 and 33 are saturated.

As illustrated in Figures 2A and 2B, by selectively applying a control current through control windings 27 and 29, it is possible to selectively prevent "deformations" from being formed at the zero crossings of the load current waveform.

If the control current through control windings 27 and 29 is selectively applied to represent the binary data stream 43, then the "deformations" created in the load current waveform will be representative of the binary data stream 43. These "deformations" can then be read at the surface and converted into a binary data stream identical to binary data stream 43.

In accordance with the present invention, remotely located sensing instruments in sensor package 53 monitor a variety of conditions, such as temperature, pressure, and the performance of subsurface equipment, such as motor 15. The output of the sensors in the sensor package 53 is digitized and multiplexed, and provided as a binary data stream 43. The data stream 43 actuates the transistor switch 35 to allow the selective passage of current 41 through control windings 27 and 29 which are disposed about cores 31 and 33.

In the preferred embodiment of the present invention, the ratio of control windings to load windings is ten to one, thus allowing relatively small changes in the control windings to produce correspondingly large changes in the output of the load windings. It is also important to note that load windings 23 and 25 are connected in series, but out of phase, so that the impact of the passage of current therethrough results in a cancellation effect, so as to practically eliminate any undesirable AC current transfer from the load windings 23 and 25 to the control windings 27 and 29.

Once the data has been impressed onto the power signal travelling through power cable 11, the data must be read at the surface. Current transformer 49 is magnetically coupled to the leg of the three-phase power cable 11 onto which the data was impressed. The current transformer 49 is connected to data receiving circuits 51. Data receiving circuits 51 use well-known digital or analog techniques to analyze the current waveform and detect "deformations" in the signal at around the zero crossing. Any number of techniques can be used with the end result being the detection of the "deformations" in the power signal. The presence or absence of "deformations" in the signal is used to represent the "1"'s or "0"'s of the serial data being transmitted.

Figure 4 shows a block diagram of a circuit that could be used to detect the "deformations" at the zero crossing. A signal amplifier 60 amplifies the signal being received from current transformer 49. An analog to digital converter 62 then converts the analog signal into a digital signal which is fed into a microprocessor and memory unit 64. The microprocessor 64 processes the signal, and with the help of software, samples and analyzes the signal to detect "deformations" in the signal. The microprocessor 64 then converts the absence and presence of "deformations" into a data stream that corresponds to data stream 43 and that can be displayed through display 66.

Figure 3 shows a schematic of a power source that could be used in the present invention. Any adequate three-phase power source can be used. One feature shown in Figure 3 is the presence of an auxiliary power source which can be connected in any one of several ways so as to provide auxiliary power in the event that the main power source should fail.

Although saturable core reactors can take on many forms, Figures 5A-5D illustrate one embodiment of a saturable core reactor. The exact size and other design parameters of a saturable core reactor for use in the present invention must be such that the passage of alternating current through load windings 23 and 25 easily saturate the cores so that the cores remain in saturation for the majority of the alternating current waveform. The shorter amount of time the cores remain unsaturated, the smaller the "deformations" will be, and the less the load current waveform is deformed. The less the load current is deformed, the fewer negative effects will be felt by motor 15. However, the smaller the "deformations" are, the harder it is to detect them reliably. Therefore, a balance must be achieved that will result in a waveform that is not altered enough to seriously effect the operation of motor 15, but that is altered enough to allow reliable detection of the "deformations" by data receiver circuits 51. This balance will in large part be based on the particular application for which the present invention is being used.

If the present invention is to be used in an oilfield industry application, where the power cable 11 is being used to power a 60 ampere motor 15, and the sensor package 53 is being used to measure such data as pressure and other downhole information, the construction and dimensions of the saturable core reactor discussed below have been found to work well.

The cores shown in Figure 5A are made up by four sections 70a, 70b, 70c, and 70d. Each cylindrical section 70 is made by winding a 2.25 inch wide strip, made of 50 percent iron and 50 percent nickel, to form a cylinder having an outer diameter of 2.75 inches, an inner diameter of 2 inches, and a height of 2.25 inches. Four sections 70 are then stacked end-to-end to form each core 31 and 33. Cores 31 and 33 are each 9 inches long. The four sections 70 are held together by taping each section 70 to the adjacent sections 70. An aluminum tube 74 is then placed around the four sections, and end washers 72 are placed at each end of tube 74. The tube 74, end washers 72, and sections 70 are kept together with a strip of tape 76 (shown in Figure 5B).

Referring now to Figure 5B, load windings 23 are wound around core 31, and load windings 25 are wound around core 33. Load windings 23 and 25 are made of rectangular copper wire that is 0.128 inches by 0.408 inches. The rectangular copper wire used for the load windings is wound around the cores as shown in Figure 5B. Load windings 23 form 12 turns around core 31, and load windings 25 form 12 turns around core 33. Referring now to Figure 5C, once the load windings 23 and 25 are wound around cores 31 and 33, cores 31 and 33 are placed end-to-end with a washer 78 made of insulation paper separating the ends of the cores 31 and 33. A washer 80 made of insulation paper (only one is visible in Figure 5C) is also placed at the exterior end of each core. A cylindrical insulation paper outer tube 82 is placed around the cores 31 and 33 and control windings 23 and 25. A cylindrical insulation paper inner tube (not shown in Figure 5C) is also placed in the cylindrical space inside cores 31 and 33 and windings 23 and 25. Tape 84 is then used to hold the inner and outer tubes, and the washers 80 in place around cores 31 and 33 and control windings 23 and 25.

Referring now to Figure 5D, control windings 27 and 29 are wound around the cores 31 and 33. Control windings 27 and 29 have been referred to as being two separate windings, one on core 31 and one on core 33. However, in the preferred embodiment, control windings 27 and 29 are just one single winding extending around both cores 31 and 33, as shown in Figure 5D. Having one single winding around both cores, or one winding around each core makes no difference since the two structures are equivalent. The control windings 27 and 29 form 120 turns around cores 31 and 33. The control windings 27 and 29 are made of #12AWG copper wire.

While the invention has been shown in only one of its forms, it is not thus limited but is susceptible to various changes and modifications without departing from the spirit thereof.

What is claimed is:

1. A data transmission apparatus for transmitting data over a power cable which supplies alternating electrical current to an electrical-power-consuming component, comprising:

(a) at least one alternating-electrical-current-modifying circuit component, each including:

(1) an alternating electrical current input;

(2) an alternating electrical current output;

(b) a control circuit for selectively communicating a data signal to said at least one alternating-electrical-current-modifying circuit component for modifying said alternating electrical current as it passes through said at least one alternating-electrical-current-modifying current component;

(c) wherein data is transmitted to a remote location through said power cable through alteration of at least one electrical characteristic of said alternating electrical current in a predefined manner by switching action of said control circuit in response to said data signal.

2. A data transmission apparatus according to claim 1, wherein data is transmitted to a remote location through alteration of said alternating electrical current in at least one zero-crossing region in a predefined manner by switching action of said control circuit.

3. A data transmission apparatus according to claim 1, wherein data is transmitted to a remote location through and alteration of said alternating electrical current in a manner which minimizes disruption of power transfer to said electrical-power-consuming component.

4. A data transmission apparatus according to claim 1, wherein data is transmitted to a remote location through the development of current waveform

discontinuities in said alternating electrical current in at least one zero-crossing region in a predefined manner by switching action of said control circuit.

5. A data transmission apparatus according to claim 4, wherein said current waveform discontinuities identify a binary data stream.

6. A data transmission apparatus according to claim 4, further comprising:

means located at said remote location, for identifying said current waveform discontinuities.

7. A data transmission apparatus for transmitting data over a power cable which supplies alternating electrical current to an electrical-power-consuming component, comprising:

(a) at least one reactive circuit component, each including:

(1) a highly magnetically-permeable core defining a magnetic flux pathway;

(2) load windings wound about a portion of said highly magnetically-permeable core for receiving at least a portion of said alternating electrical current from said power cable;

(3) control windings wound about a portion of said highly magnetically-permeable core;

(b) a control circuit for selectively communicating a data signal to said control windings;

(c) said data transmission apparatus being operable in a plurality of modes of operation, including:

(1) a saturated mode of operation wherein said highly magnetically-permeable core is in a magnetically saturated condition and provides a low impedance to alternating current flow; and

(2) an unsaturated mode of operation wherein said highly magnetically-permeable core is in magnetically unsaturated condition and provides a high impedance to alternating current flow;

(d) wherein data is transmitted to a remote location through said power cable through alteration of at least one electrical characteristic of said alternating electrical current in a predefined manner by switching between said saturated mode of operation and said unsaturated mode of operation in response to said data signal.

8. A data transmission apparatus according to Claim 7, wherein said at least one electrical characteristic utilized to transmit data to a remote location comprises a deformation of said alternating electric current at selected waveform zero-crossings.

9. A data transmission apparatus according to Claim 7, including two reactive circuit components coupled in series but out of phase to minimize power transfer from said load windings to said control windings.

10. A data transmission apparatus according to Claim 7, wherein said alternating electrical current comprises a multi-phase power signal, and wherein said load winding of said at least one reactive circuit component communicates with at least one leg of said multi-phase power signal.

11. A data transmission apparatus according to Claim 7, further comprising:

a receiver member remotely located from said at least one reactive circuit component for identifying alterations of said at least one electrical characteristic of said alternating electrical current and reconstructing said data signal.

12. A data transmission apparatus according to Claim 7, wherein said control circuit includes a switch member responsive to said data signal for selectively applying a direct current to said control windings to switch said data transmission apparatus to a saturated mode of operation.

13. A data transmission apparatus according to Claim 7, wherein said highly magnetically-permeable core is adapted to switch to said saturated mode of operation at a saturation current which is intermediate zero current and a peak current for said alternating electrical current so that passage of said alternating electrical current through said load windings switches said data transmission apparatus between said saturated mode of operation and said unsaturated mode of operation.

14. A data transmission apparatus for transmitting data over a power cable which supplies alternating electrical current to an electrical-power-consuming component, comprising:

(a) at least one reactive circuit component, each including:

(1) a highly magnetically-permeable core defining a magnetic flux pathway;

(2) load windings wound about a portion of said highly magnetically-permeable core for receiving at least a portion of said alternating electrical current from said power cable;

(3) control windings wound about a portion of said highly magnetically-permeable core;

(b) a control circuit for selectively communicating a data signal to said control windings;

(c) said data transmission apparatus being operable in a plurality of modes of operation, including:

(1) a saturated mode of operation wherein said highly magnetically-permeable core is in a magnetically saturated condition and provides a low impedance to alternating current flow; and

(2) an unsaturated mode of operation wherein said highly magnetically-permeable core is in magnetically unsaturated condition and provides a high impedance to alternating current flow;

(d) wherein said alternating electrical current passing through said load windings switches said data transmission apparatus (a) to a saturated mode of operation at high amplitude current levels and (b) to an unsaturated mode of operation at low amplitude current levels, causing distortion at zero crossings of said alternating electrical current;

(e) wherein said control signal which is selectively supplied to said control windings is sufficient to maintain said data transmission apparatus in a saturated mode of operation at high current levels but not at low current levels;

(f) wherein data is transmitted to a remote location through said power cable through distortion of said alternating electrical current in a predefined manner by switching between said saturated mode of operation and said unsaturated mode of operation in response to said data signal.

15. A data transmission apparatus according to Claim 14, including two reactive circuit components coupled in series but out of phase to minimize power transfer from said load windings to said control windings.

16. A data transmission apparatus according to Claim 14, wherein said alternating electrical current comprises a multi-phase power signal, and wherein said load winding of said at least one reactive circuit component communicates with at least one leg of said multi-phase power signal.

17. A data transmission apparatus according to Claim 14, further comprising:

a receiver member remotely located from said at least one reactive circuit component for identifying distortions of said alternating electrical current and reconstructing said data signal.

18. A data transmission apparatus according to Claim 14, wherein said control circuit includes a switch member responsive to said data signal for selectively applying a direct current to said control windings to switch said data transmission apparatus to a saturated mode of operation.

19. A data transmission apparatus according to Claim 14, wherein said highly magnetically-permeable core is adapted to switch to said saturated mode of operation at a saturation current which is intermediate zero current and a peak current for said alternating electrical current so that passage of said alternating electrical current through said load windings switches said data transmission apparatus between said saturated mode of operation and said unsaturated mode of operation.

20. A method of transmitting data over a power cable which supplies alternating electrical current to an electrical-power-consuming component, comprising the method steps of:

(a) providing at least one reactive circuit component, each including:

(1) a highly magnetically-permeable core defining a magnetic flux pathway;

(2) load windings wound about a portion of said highly magnetically-permeable core for receiving at least a portion of said alternating electrical current from said power cable;

(3) control windings wound about a portion of said highly magnetically-permeable core;

(b) providing a control circuit for selectively communicating a data signal to said control windings;

(c) switching said data transmission apparatus between the following plurality of modes in response to said data signal:

(1) a saturated mode of operation wherein said highly magnetically-permeable core is in a magnetically saturated condition and provides a low impedance to alternating current flow; and

(2) an unsaturated mode of operation wherein said highly magnetically-permeable core is in magnetically unsaturated condition and provides a high impedance to alternating current flow;

(d) wherein data is transmitted to a remote location through said power cable through alteration of at least one electrical characteristic of said alternating electrical current in a predefined manner by switching between said saturated mode of operation and said unsaturated mode of operation in response to said data signal.

21. A data transmission apparatus for transmitting data over a power cable substantially as herein described with reference to the accompanying drawings.

22. A method of transmitting data over a power cable substantially as herein described with reference to the accompanying drawings.

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Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.N): H4R: RTSR, RTSU, RTC

Int Cl (Ed.6): H04B-003/54

Other: Online: WPI, JAPIO, INSPEC, EDOC

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	GB2197568 A	PITTWAY (see especially figures 1 and 4	1 - 6
X	GB2159377 A	COMMUNICATIONS (see especially figures 1 and 3)	1 - 6
X	GB1500891	GENERAL (see especially figure 5)	1 - 6
X	WO92/06552 A1	MOTOROLA (see especially figures 1,3,5	1 - 6
X	EP0018334 A1	HANDELSBOLAGET (see especially figure 1)	1
X	US4714912	GENERAL (see especially figures 1 to 3)	1 - 8

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