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(54) **CONDITION MONITORING APPARATUS FOR TRACK CIRCUITS AND METHOD**

ZUSTANDSÜBERWACHUNGSVORRICHTUNG FÜR GLEISSTROMKREISE UND VERFAHREN

APPAREIL DE SUIVI DE CONDITION POUR CIRCUITS DE VOIE ET PROCEDE

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## Description

**[0001]** This invention relates to the field of condition monitoring. More specifically it relates to the condition monitoring of railway infrastructure such as track circuits.

**[0002]** A track circuit is an electrical circuit which includes a length of running rails and permits the detection of the presence of a train. A track circuit may also be used to communicate commands, instructions, or indications between the wayside and the train. Track circuits provide information on the location of the trains, and this information may be used to command train speeds and is used to operate signalling so that the trains operate safely.

**[0003]** As background information the operation of a number of track circuits will be described with reference to the accompanying drawings, throughout which like parts are referred to by like references, and in which:

Figure 1 schematically illustrates a basic DC track circuit;
Figure 2 schematically illustrates a basic AC track circuit;
Figure 3 schematically illustrates an untuned audio frequency AC track circuit;
Figure 4 schematically illustrates a tuned audio frequency AC track circuit;
Figure 5 schematically illustrates a simplified TI style 21 track circuit employing end-fed topology; and
Figure 6 schematically illustrates a simplified TI style 21 track circuit employing centre-fed configuration
In all track circuits an electrical signal of some kind is impressed between the running rails, and the presence of a train is detected by the electrical connection that the wheels and axle ("wheel set") of the train make between the two running rails.

**[0004]** Figure 1 schematically illustrates a basic DC track circuit. In DC track circuits the electrical signal is a direct current. The signal source 10, in this case a battery, is connected at one end of the track circuit while a receiver 12 is connected to the other end to detect the electrical signal. The receiver 12 is normally a relay. When no train is present on the track the relay is energised by the current flowing through the track circuit. In jointed tracks the tracks are isolated into sections by use of insulated joints 14 in the running rails 16. The insulated joints 14 provide electrical insulation between a given track circuit and the abutting tracks which form part of adjacent track circuits. When a train enters a track section the wheel set 18 of the train causes a short circuit and the relay in that section de-energises.

**[0005]** In this way it is possible to determine which section of track the train is occupying. In the case where the railway uses a conductor rail to provide DC traction and both running rails 16 are used for the return current then the railway cannot be isolated against DC. In this case the railway needs to be isolated against the flow of track current between abutting track circuits by using AC transmitters and receivers.

**[0006]** Figure 2 schematically illustrates a basic AC track circuit. An AC source 20 is coupled to the rails 16 by a transformer and capacitor (not shown) at one end of the track circuit whilst the receiver 12 (a relay) is connected to the other end. The rails 16 still have insulated joints 14 but a pair of centre tapped impedance bonds 22 connect the rails 16 either side of the insulated joints 14. The centre taps of each one of the pair of the impedance bonds 22 are joined together. The purpose of the impedance bonds 22 is to maintain continuity for the return of the DC traction current shared equally in the two running rails 16. The impedance bonds 22 do this while still maintaining a high impedance at the signalling frequencies between the two rails 16 and between adjacent track circuits.

**[0007]** The introduction of continuously welded rails 16 over long distances means that an AC track signalling system must be adopted. The track, however, still needs to be divided into sections and this is done by providing short circuits (rail shunts) rather than series breaks.

**[0008]** Figure 3 schematically illustrates an untuned audio frequency AC track circuit employing an "end-fed" topology. The rails 16 have a self-inductance of 1mH/km, therefore a source 26 operating at audio frequencies (e.g., 1kHz) is provided that can operate without being short circuited. It is now possible to locate the AC source 26 and a receiver 28 across the track so that neither will be shunted. The track circuit illustrated in figure 3 comprises a first rail shunt 24, a second rail shunt 25 and a pair of running rails 16 connecting the first 24 and second 25 rail shunts together. The length of track (zone D1) between the AC source 26 and first rail shunt 24 and the length of track (zone D2) between the receiver 28 and second rail shunt 25 are both 100 m long. These distances are sufficiently large so that the AC source 26 and receiver 28 are not short circuited. Therefore, with no wheel set 18 present anywhere on the rails 16 between the source 26 and the receiver 28 (zone D3), the signal transmitted by the source 26 will be picked up by the receiver 28 and the track relay 30 will be energised. When a wheel set 18 (not shown in Figure 3) enters zone D3 the received signal will be attenuated and the track relay will drop.

**[0009]** The audio frequency AC track circuit illustrated in Figure 3 is termed 'end fed' because the transmitter is at one end of the track circuited section and the receiver is at the other end. Audio frequency track circuits can also have a 'centre-fed' topology. In this topology the transmitter is situated at the centre of the track circuited section with two receivers located at respective ends of the section.

**[0010]** A problem with untuned track circuits is that there will always be sections of track (dead zones), i.e. zones D1

and D2, where the presence of a wheel set 18 cannot be detected. The solution to this problem requires a tuned AC track circuit.

**[0011]** Figure 4 schematically illustrates a tuned audio frequency AC track circuit. The track is divided into sections by shunts 32 formed by an inductor L and a capacitor C in series. The shunts are frequency selective such that the short circuit corresponds to a particular spot frequency. By using two different frequencies, F1 and F2, along the track in the sequence F1-F2-F1-F2 etc. it is possible to divide the track into overlapping sections. In this way train detection can be achieved over the entire track distance without any dead zones. A proprietary track circuit that adopts this method is the TI style 21 track circuit. The TI style 21 track circuit is widely used on British railways.

**[0012]** Railways normally consist of one or more pairs of carriageways; designated up road(s) and a down road(s). The TI21 track circuit divides the roads into pairs of operating frequencies, alternating every section. The frequencies or channels used in the TI21 track circuit are allocated the letters and designations as set out in table 1. "Track Section 1" and "Track Section 2", referred to in the table, are adjacent sections of track. The "Road Condition", referred to in the table, specifies the direction of travel ("up" or "down") of a train on a particular railway and whether the train is a stopping service ("slow") or non-stopping service ("fast"). The terms "fast" and "slow" are only generalisations and need not necessarily define line speeds in all cases.

**Table 1 TI21 track circuit channel designations**

| Track Section 1 | Track Section 2 | Road Designation |
|---|---|---|
| A: 1699 Hz | B: 2296 Hz | Down Slow |
| C: 1996 Hz | D: 2593 Hz | Up Slow |
| E: 1549 Hz | F: 2146 Hz | Down Fast |
| G: 1848 Hz | H: 2445 Hz | Up Fast |

**[0013]** The frequencies listed in table 1 are the centre frequencies of a frequency modulated signal. The signal deviates by $\pm$ 17 Hz at a rate of 4.8 Hz.

**[0014]** Figure 5 schematically illustrates a simplified TI21 track circuit employing an end-fed topology where a single transmitter feeds one section to a single receiver at the opposite end. The track circuit comprises a first tuned zone 33 between points X1 and X2, a kilometre section of track between points X2 and X3, and a second tuned zone 35 between points X3 and X4. A transmitter TxA, located in the first tuned zone 33 provides a source of audio frequency AC energy at frequency A into the running rails 16 at point X2. A shunt 34, comprising an inductor LA in series with a capacitor CA, is located at point X1. The shunt prevents current with a frequency A from travelling leftwards beyond point X1. The energy from the transmitter TxA is picked up by a receiver RxA at position X3 in second tuned zone 35.

**[0015]** A tuning capacitor CpA is connected in parallel to the receiver RxA. The capacitor CpA tunes the two lengths of rail in the second tuned zone 35 to frequency A. The shunt 34 at position X4 shunts the rails 16 at frequency A. The operation of the circuits in the two tuned zones 33, 35 is to select frequency A and convey it to the receiver RxA. This receiver RxA has additional bandpass filtering to enhance the rejection of frequencies from adjacent track circuits. The tuned zone operating at frequency B operates in the same way, with equivalent components that are tuned to frequency B.

**[0016]** The tuned elements (apart from the rails) are contained in a unit called a "Track Tuning Unit" (TTU). In the end-fed configuration shown in figure 5 the two TTUs are located at the ends of the tuned zones 33 and 35. The TTU's would contain LA, CA and CpB, and LB, CB and CpA.

**[0017]** Figure 6 schematically illustrates a simplified TI21 track circuit employing a centre-fed topology. In this example of the TI21 track circuit a transmitter 99 (and its accompanying TTU) is situated at the centre of the track circuit with two receivers (and TTUs) 101, 106 located at the respective ends of the track circuit.

**[0018]** In further configurations the T121 track circuit employs tuned zones that comprise multiple transmitters and receivers, for example, utilising a tuned zone with two transmitters and a tuned zone with two receivers. A feature of the TI 21 track circuits is that the self inductance of the rails 16 is one of the tuned elements in a tuned zone. The circuit that makes up a tuned track zone comprises a 20 m length of track and two TTUs

**[0019]** A track circuit may fail for one of several reasons. Typical causes of failure include:

1) drift in the frequencies of the transmitter oscillators;
2) drift in the receiver bandpass filtering;
3) drift in one or more tuned component values in one or more TTUs causing a drift in the tuned frequency of one or more TTUs;
4) modulation deviation or modulation rate drifting out of specification;
5) transmitter output reduced in amplitude;

6) poor ballast condition (for example the ballast may become conductive when wet or contaminated) and degraded capacitor compensation (if used) *;
7) excess DC return imbalance in the two running rails 16;
8) excess harmonic content of traction current ripple interfering with the receiver signal;
9) poor TTU tail connections to the running rails 16, creating excess series resistance;
10) other causes of change in the tuned zone characteristic, for example extreme environmental effects or intrusion of unwanted ferrous material between the running rails 16 in the tuned zones; and
11) broken or degraded running rails.
(* Capacitor compensation is a technique used to raise the ballast impedance by resonating the track section self inductance with a shunt parallel tuning capacitor.)

**[0020]** The failure of track circuits has severe consequences in terms of train delays and disruption to the rail network, In the United Kingdom those responsible for the rail infrastructure are fined a set amount of money per passenger for each minute of delay caused by signalling failures. The fines amount to several million pounds per annum. The failure of track circuits presents a big problem both in terms of lost time and inconvenience to rail users, and in lost money to the rail industry.

**[0021]** EP-A-958986 discloses a monitoring system which consists essentially in the fact that operating characteristic variables of a track release signalling system such as the feed voltage and the signal voltages and, if appropriate, the phase angle of the voltage measured values in the quiescent state (of the signalling system) are fed to a separate monitoring device, independently of the signalling system, the operating characteristic variables being measured and evaluated as a function of time. In an embodiment, the track release signalling system contains at least one motor track relay and the track has insulated rail sections. Signal voltages are tapped off at the insulated rail sections. The signal voltages and phase angles of signal voltages are measured and monitored. In one embodiment they are compared with know operating parameters.

**[0022]** According to an aspect of the present invention there is provided an apparatus for monitoring the condition of an alternating current track circuit comprising: a sensor for sensing a current in the track circuit when arranged in proximity to, but not contacting, the track circuit; an analogue to digital converter operable to convert the sensed current to a digital signal; and a processor operable to receive the digital signal from the analogue to digital converter and to perform signal processing on the digital signal, said signal processing providing a parameter indicative of the condition of the track circuit.

**[0023]** According to an aspect of the present invention there is provided a system for monitoring the condition of an alternating current track circuit comprising: a plurality of sensing modules; and a communication link between the modules, wherein each sensing module comprises the apparatus as set forth in the aforementioned aspect of the invention.

**[0024]** According to another aspect of the present invention there is provided a method for monitoring the condition of an alternating current track circuit comprising the steps:

sensing a current flowing in the track circuit without contacting the track circuit; converting the sensed track current to a digital signal; and processing the digital signal to provide a parameter indicative of the condition of the track circuit.

**[0025]** In so far as aspects of the invention described above are implemented as methods, it will be appreciated that computer software for carrying out those methods are also aspects of the present invention.

**[0026]** Embodiments of the invention which provide particular benefit relate to the apparatus and methods for monitoring alternating current track circuits, wherein the alternating current track circuit is operable with an alternating current which oscillates at audio frequencies.

**[0027]** The use of a non-contacting monitoring system allows the system to be deployed on an operational track without the vigorous safety testing and approval that would otherwise be necessary.

**[0028]** A non-contacting monitoring system provides further advantages including the provision of portable apparatus thereby allowing the optimum position of the apparatus, for a particular mode of operation of the apparatus, to be readily found. The apparatus may be easily moved to be adjacent to various parts of the track circuit depending on the fault or potential fault being investigated. A suitably designed apparatus can make measurements up to several metres from the track circuit thereby allowing personnel to have access to the monitoring apparatus without exposing the personnel to the risk of moving rolling stock.

**[0029]** A non-contacting apparatus measuring the track current would not affect the track current and therefore would not invalidate the results obtained by the apparatus.

**[0030]** Further respective aspects and features of the invention are defined in the appended claims. Combinations of features from the dependent claims may be combined with features of the independent claims as appropriate and not merely as explicitly set out in the claims.

**[0031]** Embodiments of the invention will now be described with reference to the accompanying drawings, throughout which like parts are referred to by like references, and in which:

Figure 7 schematically illustrates an arrangement of a sensor and a processing module in relation to a track circuit;
Figure 8 schematically illustrates a processing module;
Figures 9A and B schematically illustrate coils;
Figure 10 schematically illustrates a printed circuit board;
Figure 11 schematically illustrates a sensor circuit;
Figure 12 is a graph illustrating the frequency response of a coil with a load resistance of 10 kΩ;
Figure 13 is a graph illustrating the frequency response of a coil with a load resistance of 1 kΩ;
Figure 14 is a graph of the voltage across the rail terminals of a tuned track unit as a function of frequency;
Figure 15 is a graphical representation of the current flowing through a correctly functioning tuned track unit as function of frequency;
Figure 16 is a graphical representation of the current flowing through a faulty tuned track unit as function of frequency;
Figure 17 is a chart illustrating a spectrum of a sensor signal measured adjacent to a tuned zone when no train is present in the tuned zone;
Figure 18 is a chart illustrating a spectrum of a sensor signal measured adjacent to a tuned zone when a train is approaching the tuned zone, shunting the track circuited section stimulated by frequency A;
Figure 19 is a chart illustrating the detailed spectrum of a sensor signal measured at specific frequency;
Figure 20 schematically illustrates an arrangement of a sensor and a track side computer in relation to a railway;
Figure 21 is a schematic block diagram of the sensor and computer of Figure 20;
Figure 22 schematically illustrates a monitoring system configured in a star geometry;
Figure 23 schematically illustrates a monitoring system configured in a ring geometry;
Figure 24 schematically illustrates a monitoring system configured in a spur geometry; and
Figure 25 schematically illustrates portable equipment according to the invention.

**[0032]** Figure 7 is a schematic illustration of the arrangement of a sensor unit 90 and a processing module 50 in relation to an end-fed track circuit 100. The track circuit 100 comprises a tuned zone as described above having a transmitter 26 and a receiver 28. The sensor is housed separately from the processing module 50 in a separate sensing unit 90 which is placed between the rails 16 of the track circuit 100. Alternatively, the sensor unit 90 may also be placed to one side of the railway 102. The signals from the sensor unit 90 are fed via a conduit 92 to the processing module 50. Preferably, the conduit is constructed from reinforced and electrically insulating material.

**[0033]** An example of the sensor is a magnetic field sensor which senses the magnetic field produced by the current circulating in the track circuit. Preferably, the sensor comprises a helical coil. Preferably the sensor responds to the rate of change of the magnetic field to eliminate the effects of static magnetic fields. The sensor unit 90 is in proximity to, but not in contact with, the track circuit.

**[0034]** The processing module 50 preferably performs a spectral analysis of the signal produced by the sensor to produces a parameter or parameters indicative of the condition of the track circuit. Alternatively, the processing module may analyse the time envelope of the detected non-static magnetic field.

Processing module

**[0035]** Figure 8 is a schematic illustration of the processing module 50. The processing module 50 has an input port 52 to receive an electrical sensor signal from the sensing unit 90. In an alternative arrangement the sensing unit 90 may be housed in the processing module 50. The sensing unit 90 monitors the electrical current flowing through a track circuit. The sensing unit 90 can be arranged to monitor the current flowing through the rails 16 or the current flowing through other parts of the track circuit.

**[0036]** Preferably, the signal from the sensing unit 90 is passed through isolation electronics 54 so that the remaining components in the processing module 50 are protected from excessive current surges impressed upon the sensor signal an dto reject any source of common mode interference. The isolation electronics 54, which may utilise optical or transformer coupling, may be of a proprietary type or may be purpose built for the processing module 50.

**[0037]** An amplifier 56 is connected to the isolation electronics 54 to receive the sensor signal. The amplifier 56 amplifies the sensor signal so that the sensor signal is at an amplitude appropriate for further processing in the processing module 50.

**[0038]** An analogue to digital converter (ADC) 58 is connected to the amplifier to receive the amplified sensor signal and convert it to a digital signal: The digital signal is then optionally passed through a digital filter 60 to remove low frequency noise in the sensor signal. It may also be appropriate to use an analogue filter to condition the sensor signal before it enters the ADC 58 to further enhance interference rejection and eliminate aliasing.

**[0039]** A microprocessor 64 is connected to the digital filter 60 so that signal processing is performed on the filtered digital signal. The microprocessor 64 is connected to a memory unit 66 so that the processed signal and parameters derived from the processed signal may be stored. The memory unit 66 may be a random access memory (RAM), for

example a non-volatile RAM such as a battery maintained RAM.

**[0040]** The processed signal from the microprocessor 64 may be outputted to a second amplifier 68 for driving a serial communications link.

**[0041]** The second amplifier 68 amplifies the processed signal so that the processed signal is at a level appropriate for further processing by a communications microprocessor 70 which may be optionally located remote from the main processing module 50. The communications microprocessor 70 receives the signal from the amplifier and/or the parameters derived from the processed signal and provides them to a communication port 72.

**[0042]** The communication port 72 may be connected to a communication network 104. The communication network 104 may be an Integrated Services Digital Network (ISDN), the Internet, a cellular telephone system (e.g., a Global System for Mobile Communications (GSM system)), a telemetry system or a local area network (LAN), for example Ethernet. When the communication network 104 is a LAN it is preferable that the LAN is dedicated to the monitoring system and implemented using optical fibres. The communication network 104 is connected to remote analysis system 105. The remote analysis system 105 provides for further processing and/or analysis of the sensor signal. The communication port 72 can, alternatively or additionally, be lined to a computer, data logger or digital storage device/medium 103 to allow the data to be downloaded from the microprocessor 64 or the memory unit 66.

**[0043]** Instead of the microprocessors 64, 70 in the processing module 50 there may be a data logger 62. Alternatively, the processing module 50 has both microprocessors 64, 70 and a data logger 62. The data logger 62 is preferably connected to the digital filter 60 to store the filtered digital sensor signal. The data logger 62, can also connect to the ADC input depending on the purpose of the monitoring: in this instance the data logger can be based upon a digital computer using an analogue to digital converter, a sound card, a random access memory or a digital tape recorder to capture the data. If the sensor signal comprises signals in the audio frequency range then a sound card or a digital audio tape recorder may be particularly appropriate for use as the data logger 62. The data logger 62 has a port 63 to allow data stored in the data logger 62 to be accessed.

**[0044]** Data may be fed from the data logger port 63 or from an analogue port 631 to a digital audio tape recorder. An example of a digital audio tape recorder is a Sony TCD-D8 DAT recorder.

Sensing Unit

**[0045]** The sensing unit 90 comprises a sensor circuit that includes a non-contact sensor that is responsive to the current in the track circuit. Preferably the sensor is a helical coil that responds to the rate of change of the magnetic field. The use of such a sensor means that the sensor can operate without physical contact to the track circuit.

**[0046]** The use of a non-contacting sensor allows a track circuit monitoring system to be deployed on or adjacent to an operational track without the vigorous safety testing and approval that would otherwise be necessary.

**[0047]** A non-contacting sensor provides further advantages including the provision of portable apparatus which will allow the optimum position of the apparatus to be readily found, the optimum position being different for the different configurations (end-fed, centre-fed etc.) of the track circuit. The apparatus, in a portable implementation, may be easily moved to be adjacent to various parts of the track circuit depending on the fault or potential fault being investigated. The apparatus can make measurements up to several metres from the track circuit thereby allowing personnel to have access to the monitoring apparatus without exposing the personnel to the risk of moving rolling stock.

**[0048]** The non-contacting sensor measuring the track current is designed so that it does not affect the track current.

**[0049]** Preferably, the sensor is a coil of metallic material. Preferentially the metallic material is substantially non-ferrous so that the coil will not influence the electrical performance of the components of the track circuit. An illustrative material for the coil is copper or an alloy in which copper is the major component.

**[0050]** An example of the sensor is an air-cored coil. Another example of the sensor is a coil in which the core of the coil contains material, for example material chosen for its specific electromagnetic properties (e.g., permittivity or permeability). In one example, the sensor is a coil that is part of a printed circuit board (PCB). An example of a printed circuit board coil 78 is shown in figure 9A. The PCB coil 78 may have numerous configurations, the PCB coil 78 shown in figure 9, by way of example only, covers an area with a length (L) of 89 mm, a width (W) of 81 mm, with the track that makes up the coil having width (t) of 0.254 mm and the coil having 70 turns with the distances between the turns being 0.254 mm.

**[0051]** Another example of the coil is a wire wound coil 781 having an air-core, or having a core 782 chosen for its specific electromagnetic properties; see (Figure 9B).

**[0052]** Figure 10 schematically illustrates a printed circuit board 76 having a coil 78 and various electronic components of the processing module 50. The coil 78 is a printed circuit on the board 76. A printed circuit board coil 78 can be manufactured integrally on a circuit board along with the various signal condition monitoring electronics 50 including the microprocessors 64 and 70. A printed circuit board coil 78 can be manufactured with a thickness comparable with the thickness of a printed circuit board (a typical printed circuit having, for example, a thickness of about 1.5 mm). The printed circuit board 76 will take up little space and can be housed in a small container which can be easily deployed adjacent to a track circuit or between the running rails 16. It will be easy to change the position of the printed circuit board 76,

and therefore the position of the coil 78, to provide the best pick-up of the magnetic field radiated by the track circuit. A printed circuit board coil 78 can be easily manufactured to follow a geometry chosen by a designer to suit a particular application. Figures 9A and 10 show a PCB coil 78 in one such configuration. Of course, the PCB coil is not limited to the configuration illustrated.

**[0053]** A PCB coil may be less sensitive to magnetic fields than a wire wound coil. A PCB coil is preferable when the sensing unit 90 is allowed to be positioned between the rails. However, that may not be allowed due to safety concerns in the installation of the sensor. A wire wound coil 781 (Figure 9B) can be more sensitive and is preferably used in a sensing unit 90 for use adjacent to, but spaced from, the track.

**[0054]** Figure 11 is a schematic illustration of a circuit that is equivalent to the sensor circuit. A resistor R and an inductor L placed in series represent the resistance and inductance of the sensing coil. An illustrative value of resistance of the resistor R is 250 Ohms. The inductor L can take any inductance value in the range 1-500 mH; an illustrative value of inductance is 500 mH. Preferably the inductor has a fixed inductance. Placed in series with the coil is a tuning capacitor Ct. Preferably the capacitor Ct has a fixed capacitance in the range 4.7 nF-3.3 μF. An illustrative capacitance is 10 nF, however when distributed parasitics are taken into account the effective capacitance of the circuit is closer to 11 μF. The sensor circuit is designed to be in low resonance (having a low Q factor). Preferably the Q factor is in the range 0.5 - 5.

**[0055]** Placed in series with the coil and parallel to the capacitor Ct is a damping resistor Rload. Rload represents the resistance of the monitoring electronics plus the resistance of an additional resistor, the value of which is chosen to give Rload a particular value. Preferably the resistor Rload has a resistance in the range 1-10 kΩ, an illustrative value of resistance is 10 kΩ.

**[0056]** Figures 12 and 13 graphically illustrate the frequency response (pick up response) of the track circuit for two different values of load resistance. It can be seen from figures 12 and 13 that the full width at half maximum (FWHM) of the frequency response depends strongly on the damping resistor Rload; the larger the value of the resistor the smaller the FWHM of the coil pickup response. The value of Rload is chosen to achieve a desired Q factor.

**[0057]** The electromotive force induced in the coil 78 (Figure 9) by a magnetic field is proportional to the product of the cross-sectional area of the coil that intersects the radiated magnetic field (the collection area) with the rate of change of the flux density of that magnetic field. Preferentially, the coil is orientated relative to the track circuit so as to maximise the collection area.

**[0058]** The skilled man will appreciate that the processing circuit 50 can be modified in many ways and that there will be many circuits that will be substantially equivalent to the circuit 50 schematically illustrated in figure 8.

**[0059]** The sensor can be used to monitor currents throughout the track circuit. The running rails 16 are an integral part of the track circuit and it may be convenient to position the sensor adjacent to the running rails 16. The use of the sensor in this way can provide not only information on the integrity of the track circuit but can also provide information on the relative levels of traction current flowing in the running rail ( to which it is adjacent) by responding to the ripple component.

**[0060]** The sensor may be placed between the running rails 16 (an area known in the rail industry as the "four-foot" although the techniques and apparatus described in this application are not limited to any particular gauge of railway). If a section of railway comprises more than one road then the placing of the sensor in the four foot of one particular road will cause the sensor to pick up substantially only frequencies present in the track circuit of that particular road. The sensor may be placed in the centre of the four-foot since this position provides the most stable and predictable magnetic flux density for a given current flowing in the track circuit.

**[0061]** However, useful results can be provided by positioning the sensor outside the four-foot. A suitably designed sensor can monitor track currents when placed on the wayside up to several metres from the railway. Placing the sensor outside the four-foot may be preferable on safety grounds.

**[0062]** Preferentially the sensor is positioned towards the centre of a tuned zone because it is often the condition of the tuned zone that determines the operability of the associated track circuits either side of the tuned zone. Siting the sensor outside of the tuned zone towards the centre of the track circuited section may also offer more useful data with regard to ballast condition.

Digital Signal Processing

**[0063]** In one example, the digital signal produced by the ADC 58 from the sensor signal undergoes digital signal processing. The digital signal processing is now described in relation to a TI style 21 track circuit, however, the skilled person will appreciate that similar digital processing can be applied to the sensor signal from any AC track circuit. In accordance with preferred embodiments of the invention a digital signal processor (for example as provided by the microprocessor 64) performs a frequency analysis (e.g., a Fourier transform of the sensor signal) to determine the spectrum of the sensor signal. The frequency information in the digital signal provides a rich source of information on the condition of the track circuit.

**[0064]** Figure 14 is a graph of the voltage across the terminals of track tuning units (TTUs) of a tuned zone as a function

of frequency about a frequency, B = 2296 Hz. The frequency of 2296 Hz is one of the standard operating frequencies used in the operation of TI style 21 track circuits. Four plots (plots I, II, III and IV) are illustrated in figure 14. Plots I and II are respectively for measurements taken on a TTUs in which there is no fault. Plots III and IV correspond respectively to plots I and II but in which there is a tail connection fault in the TTU connected to the receiver. The connection fault was simulated by adding a 0.5 Ohm resistor to the tail connection. The ratio of the voltage across one TTU to the adjacent TTU, at a particular frequency, is called the "rejection ratio".

**[0065]** It can be seen from figure 14 that the rejection ratio in the TTU without the fault is:

0.45/8 ~ 1:18

The rejection ratio in the TTU with the tail connection fault is:

3.1/4.6 ~ 1:1.5

The rejection ratio provides an indication of the overall condition of tuning of all components within the tuned zone.

**[0066]** The tail connection fault is also apparent from an analysis of the current circulating in the tuned zone as will now be described with reference to Figures 15 and 16.

**[0067]** Figure 15 is a graphical representation of the current flowing in the TTU when there is no fault in the TTU. Figure 16 is a graphical representation of the current flowing in the TTU when the 0.5 Ohm tail connection fault is present. Two spectral components are clearly visible in each figure, these respectively correspond to frequencies A and B at which adjacent TTUs operate. It can be seen that the spectral component at frequency A drops from a magnitude of 4.7 Amps when the unit is fault free to a magnitude of 0.6 Amps when the fault is present.

**[0068]** It can also be seen that the spectral component at frequency B drops from a magnitude of 16 Amps when the unit is fault free to a magnitude of 7 Amps when the fault is present.

**[0069]** A special fault condition, not necessarily indicative of a fault to that of the tuned zone being monitored, is exposed if one spectral component drops in amplitude in the presence of the neighbouring component remaining constant.

**[0070]** The microprocessor 64 can be programmed to process the digital sensor signal so that an output is given that corresponds to that of poor rejection ratio or to the magnitude of the current at one or more pre-determined frequencies. The microprocessor 64 can be programmed to give a warning when the estimated rejection ratio or the magnitude of a current indicates a failure of the track circuit. Preferably the microprocessor 64 will be programmed so that a warning can be given when a fault has been predicted in either the near, medium or distant future. The microprocessor 64 may also process the digital sensor signal by performing a spectral analysis on the sensor signal.

**[0071]** Figure 17 shows a spectrum of the digital sensor signal obtained by operating the sensor outside of the four-foot, line side within the vicinity of two closely positioned tuned zones in up and down roads. The spectrum illustrated in Figure 17 shows frequency components that match the pre-set TI-21 frequencies A, B, C and D, and was recorded when there was no train present in either track sections or tuned zones. Figure 18 illustrates a spectrum recorded when a train enters the channel A track section. It can be readily seen that the amplitude of the signal at frequency A drops by several decibels when a train enters the section and short circuits the track circuit.

**[0072]** Figure 19 illustrates a detailed spectrum centred about frequency A. The detailed spectrum clearly shows a central peak with upper and lower side lobes on which a modulation frequency is imposed. Table 2 compares the frequency of these features with the frequencies specified for that of TI 21 channel A.

**Table 2 A comparison of parameters measured by the processing module with theoretical values**

| Parameter | Specified | Measured |
|---|---|---|
| Upper lobe frequency (Hz) | 1716 | 1715.1 |
| Lower lobe frequency (Hz) | 1682 | 1684.6 |
| Calculated Median (Hz) | 1699 | 1699.9 |
| Positive deviation (Hz) | +17 | +15.3 |
| Negative deviation (Hz) | -17 | -15.3 |
| Modulation Rate | 4.8 | 4.6 |

**[0073]** It can be seen that the measured values are close to the specified values and the results imply that the track circuit is healthy.

**[0074]** Other techniques for analysing the digital sensor signal include the use of Bessel functions. The following

parameters are illustrative of the information that can be obtained from a spectrum parameter measured is one or more of:

(i) a frequency shift of one or more frequency features;
(ii) the amplitude of frequency at one or more frequencies;
(iii) the integrated intensity of one or more frequency features over a frequency range;
(iv) the change in shape of the frequency profile of one or more frequency features;
(v) the ratio of the amplitude of two frequency values;
(vi) a warble between two or more frequency values;
(vii) the presence of a frequency modulation characteristic;
(viii) the current versus time profile measured in a particular frequency range;
(ix) the presence of an amplitude modulation characteristic.

**[0075]** Relationships between parameters of the sensor signal and conditions of the track circuit can be determined by field trials.

**[0076]** The following correlations are illustrative of what can be achieved:

a) drift in frequencies of the transmitter oscillations, drift of modulation deviation and modulation rate, and reduced transmitter output (in one or both sidebands) can be detected by monitoring the signal produced at the transmitter frequency;
b) drift in tuned component values in the TTUs, changes in the tuned zone characteristics (e.g., due to unwanted ferrous material in the four-foot), degraded ballast and capacitor compensation (if used) of a track circuit, and poor tail connections to the running rails 16 can be detected by monitoring spectral signal amplitudes; and
c) reduction in amplitude of the transmitter frequency in the TTU in one or more sidebands can be detected by using a combination of absolute and ratiometric measurements of the intensity of specific frequency peaks.

**[0077]** The microprocessor 64 operates on one or more algorithms. In one example of the invention the algorithm on which the microprocessor 64 operates is set to sample the sensor signal at predetermined intervals, for example, hourly, daily, or weekly according to the condition being monitored. In this way it is possible to track a drift in a particular frequency or set of frequencies and to sound a warning if the drift is greater than a pre-set value. The same would also be true when looking at the magnitude of particular frequency features. The microprocessor 64 may be provided with a library of spectra each of which corresponds to a fingerprint of a particular failure mode. The microprocessor 64 may be set up to compare the frequency spectrum of the sensor signal with the spectra held in the library so that an early warning may be given of an impending failure in the track circuit.

Time Domain

**[0078]** In another example of the invention, the microprocessor 64 can be arranged to digitally process the sensor signal so as to monitor the current flowing in the track circuit in the time domain. In a healthy track circuit, the current at a given frequency will follow a substantially sinusoidal short-term time profile since the transmitter is a harmonic rich alternating current source stimulating a high Q tuned circuit. For example, a time profile that follows a truncated sine wave or an otherwise distorted waveform may indicate a fault in the track circuit. Monitoring the current in the time domain over a longer period will consolidate the findings of poor tuning. For example if the envelope of the audio carrier is observed to modulate substantially in amplitude in sympathy with the rate of frequency modulation, this would indicate that the frequency modulation of the transmitter was not centred on or close to the natural frequency of the tuned zone.

**[0079]** In one example, the time variation of the envelope 64 of the detected signal is analysed.

**[0080]** In another example, an individual TI21 frequency component is extracted and the characteristic of the amplitude modulation thereof is analysed. That provides an indication of the condition of the tuned zone and/or more TTUs.

Analogue Processor

**[0081]** In yet another example, in which the time-varying envelope of the detected signal is analysed, analogue signal processing may be used instead of digital signal processing.

**[0082]** In a further example of the invention the microprocessor 64 is an intelligent processor that can be trained to recognise faults. More preferably the condition monitoring units are connected to form a network. A neural network may be formed by incorporating in each monitoring unit one or more simple processors ("neurons"), each neuron possibly having a small amount of local memory. The neurons are connected by unidirectional communication channels ("connections"), which carry numeric data. The neurons can, for example be elementary non-linear signal processors (in the limit they are simple threshold discriminators). Each neuron is preprogrammed and continuously active. The units operate

only on their local data and on the inputs they receive via the connections. The neural network has a "training" rule whereby the weights of connections are adjusted on the basis of presented patterns. In other words, the neural networks will "learn" from examples and exhibit a structural capability for generalisation. A neural network will be advantageous to the present application by providing a monitoring system that can learn about the behaviour and failure modes of track circuits.

**[0083]** The examples given above of the type of processing that can be made is not exhaustive.

**[0084]** It would be particularly advantageous if a potential failure in a track circuit were to be predicted before it were to happen. In this way it would be possible to remedy the fault or potential failure before a failure of the track circuit occurs. It will be seen that such an early warning system would be of immense benefit to passenger safety. The cost of a delay due to a track circuit failure is very high due to heavy fines from the rail industry regulators. The repair of track circuits, before critical failures occur, would provide large financial savings to those responsible for the track infrastructure.

Modifications and Alternatives

**[0085]** A number of modifications can be envisaged for the monitoring system described above.

**[0086]** Figures 20 and 21 schematically illustrate an alternative arrangement for the sensor and the processing electronics. In this configuration the signal condition monitoring electronics comprising, for example, the isolation electronics, amplifiers, ADC 58 and electronic filters, may be housed together with the sensor in a sensing/condition monitoring module 94. The sensing/condition monitoring module 94 can be situated between the rails 16 or to the side of the railway 102. A signal is then fed from the sensing/processing module 94, via a conduit, to a site computer 96, laptop computer or purpose built processor. The site computer 96, laptop computer or processor comprise, for example, an interface card 961 for receiving the signal from the sensing/condition monitoring module 94, control software 962 to perform signal processing on the signal received from the sensing/condition monitoring module 94, data storage unit 963 and a data link 964. The data storage unit 963 is used for storing the signal from the sensing/processing module 94 or for storing the signal after it has been processed by the control software. The data link 964 provides access to the stored data via a network 104 by a remote system 105 so that the data may be further analyse. Alternatively, the data link is accessed by a zip drive, digital tape recorder or other similar device 98 so that the data can be stored on a portable medium, the portable medium then being taken away so that the data stored on it can undergo further analysis by the remote analysis system 105.

**[0087]** Figures 22 to 24 schematically illustrate a monitoring system in which a plurality of monitoring modules 50 and/or sensing/condition monitoring modules 94 are connected by a communication network 104 to the remote analysis system 105. The modules 50, 94 may be connected to the remote analysis system 105 according to a number of different geometries: Figure 22 illustrates a star geometry; Figure 23 illustrates a ring geometry; and Figure 24 illustrates a spur geometry. The configuration of the monitoring system deployed on a railway network is likely to involve a combination of these geometries.

**[0088]** An alternative to using a metallic coil as a sensor is the use of a fibre optic magnetic field sensor. A fibre optic sensor comprising one or more coils of optical fibre is placed adjacent to the rails. The use of a fibre optic sensor would require a light source and photoelectric cell for converting the optical signal from the optical sensor into an electrical signal.

Software/Firmware

**[0089]** The control software can be stored on a portable medium, for example but not limited to, a magnetic disc, an optical disc such as a CD or a digital tape. Preferably, the control software is stored as firmware or placed in a read only memory that is present in the computer 60, laptop computer, processor or in the modules 50, 94. The computer, laptop computer, processor or the modules 50, 94 can be linked to a central computer to download data or to receive new or replacement software from the central computer. The central computer may also provide updated parameters, frequency ranges and warning limits etc. on which the software will operate.

Portable Equipment

**[0090]** In another example of the invention, portable equipment is provided comprising sensor unit 90 preferably comprising a wire-wound coil 78 as the magnetic field sensor and a signal processor 50 which may include a data logger and/or a signal analyser which produces an indication of a fault. The signal analyser may be a frequency spectrum analyser as described above. Alternatively, it may analyse the time varying envelope of the detected signal using a digital signal processor or an analogue processor as described above. The portable equipment may include a display 106 for displaying the results of the signal analysis.

## Claims

**1.** An apparatus for monitoring the condition of an alternating current track circuit (100) comprising:

a sensor (90) for sensing the alternating current of the alternating current track circuit when arranged in proximity to, but not contacting, the track circuit;
an analogue to digital converter (58) operable to convert the sensed current to a digital signal; and
a processor (50) operable to receive the digital signal from the analogue to digital converter and to perform signal processing on the digital signal, said signal processing providing a parameter indicative of the condition of the track circuit.

**2.** An apparatus according to claim 1 wherein the sensor (90) is arranged in proximity to, but not contacting, the track circuit (100), for sensing the alternating current in the alternating current track circuit.

**3.** The apparatus according to claim 1 or 2, further comprising a data store (103) arranged to store the digital signal.

**4.** The apparatus according to claims 1, 2 or 3, wherein the processor (50) is arranged to perform a spectral analysis of the sensed track current and the parameter is derived from the spectral analysis.

**5.** The apparatus according to any one of claims 1 to 4, wherein the processor (50) is arranged to indicate a trend in the parameter to indicate the onset of failure of the track circuit.

**6.** The apparatus of any one of claims 1 to 5, wherein the processor (50) is arranged to perform an analysis of the time-varying envelope of the sensed track current,

**7.** The apparatus according to any one of claims 1 to 6, wherein the parameter measured is one or more of:

(i) a frequency shift of one or more frequency features;
(ii) the amplitude of frequency at one or more frequencies;
(iii) the integrated intensity of one or more frequency features over a frequency range;
(iv) the change in shape of the frequency profile of one or more frequency features;
(v) the ratio of the amplitude of two frequency values;
(vi) a warble between two or more frequency values;
(vii) the presence of a frequency modulation characteristic;
(viii) the current versus time profile measured in a particular frequency range;
(ix) the presence of an amplitude modulation characteristic.

**8.** The apparatus according to any one of claims 1 to 6, wherein the condition of the track circuit monitored is one or more of:

(i) drift in one or more of the frequencies of the oscillators or oscillator in a transmitter connected to the track tuning unit (TTU) of the track circuit;
(ii) drift in one or more tuned component values in one or more TTUs causing a drift in the tuned frequency of one or more TTUs;
(iii) change in the modulation deviation and modulation rate of the oscillator or oscillators in the transmitter or transmitters connected to the rails via TTUs;
(iv) reduction in amplitude in one or more sidebands of the output of a transmitter or transmitters connected to the rails via TTUs;
(v) degraded ballast condition and capacitor compensation, if used, of a track circuit;
(vi) DC return imbalance in the two running rails affecting the performance of the track circuit;
(vii) harmonic content of the traction current ripple interfering with the receiver signal of the TTU;
(viii) unwanted ferrous material in a tuned zone of the track circuit;
(ix) faulty TTU tail connections to the running rails of the track circuit; and
(x) physical condition of the running rails of the track circuit.

**9.** The apparatus according to any one of claims 1 to 6, wherein the condition indicated by the processor is one or more of:

drift in one or more of the frequencies of the transmitter oscillator(s) connected to a track tuning unit (TTU) of

the track circuit;
change in the modulation deviation and modulation rate of the transmitter; and
a reduction in amplitude of the transmitter in one or more sidebands as it would appear at the rails from the TTU output;

wherein the parameter used to indicate the condition is the frequency or intensity of the transmitter output as it would appear at the rails from the TTU output.

**10.** The apparatus according to claim 9, wherein the parameter is derived from the spectrum of the transmitter frequency which has been resolved into its spectral components.

**11.** The apparatus according to claim 9 or 10, wherein the frequency or intensity of the transmitter frequency is compared to a specified reference frequency.

**12.** The apparatus according to any one of claims 1 to 6, wherein the condition indicated by the processor is one or more of:

(i) drift in one or more of the tuned component values in one or more of the track tuning units (TTUs) of the track circuit;
(ii) degraded ballast condition and/or capacitor compensation, if used, of the track circuit;
(iii) unwanted ferrous material in a tuned zone of the track circuit; and
(iv) condition of TTU tail connections to the running rails of the track circuit.

**13.** The apparatus according to any one of claims 1 to 6, wherein the condition indicated by the processor is a reduction in amplitude of the transmitter output in one or more sidebands as it would appear at the rails of the TTU output.

**14.** The apparatus according to any preceding claim, wherein the sensor is a fibre optic magnetic field detector.

**15.** The apparatus according to any one of claims 1 to 13, wherein the sensor is a coil (78, 781, 782).

**16.** The apparatus according to claim 15, wherein the coil (78) is a wire-wound coil.

**17.** The apparatus according to claim 16, wherein the coil (78) is printed on a printed circuit board.

**18.** The apparatus according to any preceding claim, further comprising a communication processor (70) for providing the digital signal to a communication system.

**19.** Apparatus according to any preceding claims which is portable.

**20.** A system for monitoring the condition of a plurality of alternating current track circuits of a railway, comprising:

a plurality of sensing modules (94, 96); and
a communication network (104) linked to the modules,
wherein each sensing module comprises the apparatus as set forth in claim 18.

**21.** The system according to claim 20 wherein the processors in the plurality of sensing modules are arranged to form one or more neural networks.

**22.** The system according to claim 20 or 21, further comprising:

a command computer;
wherein the communications network links one or more of the modules to the command computer.

**23.** The system, according to claim 22, wherein the command computer is arranged to supply data to one more of the plurality of sensing modules.

**24.** A method of monitoring the condition of an alternating current track circuit comprising the steps:

sensing the alternating current flowing in the alternating current track circuit without contacting the track circuit;

converting the sensed track current to a digital signal; and
processing the digital signal to provide a parameter indicative of the condition of the track circuit.

**25.** The method according to claim 24, wherein the said processing performs a spectral analysis of the digital signal and the parameter is derived from the spectral analysis.

**26.** The method according to claim 24, wherein said processing performs an analysis of the time-varying envelope of the sensed track current.

**27.** The method according to claim 24, 25 or 26 wherein the said processing indicates a trend in the parameter to indicate the onset of failure of the track circuit.

**28.** The method according to claim 24, 25, 26 or 27, wherein the parameter measured is one or more of:

(i) a frequency shift of one or more frequency features;
(ii) the amplitude of frequency at one or more frequencies;
(iii) the integrated intensity of one or more frequency features over a frequency range;
(iv) the change in shape of the frequency profile of one or more frequency features;
(v) the ratio of the amplitude of two frequency values;
(vi) a warble between two or more frequency values;
(vii) the presence of a frequency modulation characteristic;
(viii) the current versus time profile measured in a particular frequency range;
(ix) the presence of an amplitude modulation characteristic.

**29.** The method according to claim 24, 25, 26 or 27, wherein the condition of the track circuit monitored is one or more of:

(i) drift in one or more of the frequencies of the oscillator or oscillators in a transmitter or transmitters connecting to a track circuit using track tuning unit (TTU) of the track circuit;
(ii) drift in one or more tuned component values in one or more TTUs causing a drift in the tuned frequency of one or more TTUs ;
(iii) change in the modulation deviation and modulation rate of the oscillator(s) of the transmitter(s) connecting to the rails via TTU(s);
(iv) reduction in amplitude of the transmitter frequency in one or more sidebands as would be observed at the TTU output;
(v) degraded ballast condition and capacitor compensation, if used, of a track circuit;
(vi) DC return imbalance in the two running rails of the track circuit effecting the performance of the track circuit;
(vii) harmonic content of the traction current ripple that could potentially interfere with the receiver signal;
(viii) unwanted ferrous material in a tuned zone of the track circuit;
(ix) faulty TTU tail connections to the running rails of the track circuit; and
(x) physical condition of the running rails of the track circuit.

**30.** The method according to claim 24,25,26 or 27, wherein the signal processing indicates one or more of:

(i) drift in one or more of the frequencies of the oscillator or oscillators in a transmitter or transmitters connecting to a track circuit using track tuning unit (TTU) of the track circuit;
(ii) change in the modulation deviation and modulation rate of the oscillator(s) of the transmitter(s) connecting to the rails via TTU(s); and
(iii) reduction in amplitude of the transmitter frequency in one or more sidebands as would be observed at the TTU output;

wherein the parameter used to indicate the condition is the frequency or intensity of the transmitter output of a TTU.

**31.** The method according to claim 30, wherein the parameter is derived from the spectrum of the transmitter frequency which has been resolved into its spectral components.

**32.** The method according to claim 30 or 31, wherein the frequency or intensity of the transmitter frequency is compared to a specified reference frequency.

**33.** The method according to claim 24 or 25, wherein the signal processing indicates one or more of:

(i) drift in one or more tuned component values in one or more TTUs causing a drift in the tuned frequency of one or more TTUs ;
(ii) degraded ballast condition and capacitor compensation, if used, of a track circuit;
(iii) unwanted material in a tuned zone of the track circuit; and
(iv) condition of TTU tail connections to the running rails of the track circuit.

**34.** The method according to claim 24 or 25, wherein the condition is a reduction in amplitude of the transmitter frequency in one or more sidebands driving the TTU, and the parameters used to indicate the condition is the amplitude of the transmitter frequency as monitored in the current flowing in the tuned zone.

**35.** The method according to any one of claims 24 to 34, further comprising the step of storing the digital signal.

**36.** The method according to any one of claims 24 to 35, further comprising providing the digital signal to a communications system.

**Patentansprüche**

**1.** Vorrichtung zum Überwachen des Zustands eines Wechselstrom-Gleisstromkreises (100), umfassend:

einen Sensor (90) zum Messen des Wechselstroms des Wechselstrom-Gleisstromkreises, wobei dieser nahe dem Gleisstromkreis, ohne diesen zu berühren, angeordnet ist;
ein Analog-Digital-Wandler (58), der dazu dient, den gemessenen Strom in ein digitales Signal zu wandeln, und einen Prozessor (50), der dazu dient, das digitale Signal vom Analog-Digital-Wandler zu empfangen und das digitale Signal zu verarbeiten, wobei diese Signalverarbeitung einen Parameter liefert, der den Zustand des Gleisstromkreises angibt.

**2.** Vorrichtung nach Anspruch 1, wobei der Sensor (90) in der Nähe des Gleisstromkreises (100), ohne diesen zu berühren, angeordnet ist, um den Wechselstrom im Wechselstrom-Gleisstromkreis zu messen.

**3.** Vorrichtung nach Anspruch 1 oder 2, ferner umfassend einen zum Speichern des digitalen Signals ausgelegten Datenspeicher (103).

**4.** Vorrichtung nach einem der Ansprüche 1 bis 3, wobei der Prozessor (50) dazu ausgelegt ist, eine Spektralanalyse des gemessenen Gleisstroms durchzuführen, und der Parameter aus der Spektralanalyse abgeleitet wird.

**5.** Vorrichtung nach einem der Ansprüche 1 bis 4, wobei der Prozessor (50) dazu ausgelegt ist, einen Trend in dem Parameter anzugeben, um das Einsetzen eines Versagens des Gleisstromkreises anzugeben.

**6.** Vorrichtung nach einem der Ansprüche 1 bis 5, wobei der Prozessor (50) dazu ausgelegt ist, eine Analyse der zeitabhängigen Hülle des gemessenen Gleisstroms durchzuführen.

**7.** Vorrichtung nach einem der Ansprüche 1 bis 6, wobei der oder die gemessenen Parameter einer oder mehrere der folgenden sind:

(i) eine Frequenzverschiebung eines oder mehrerer Frequenzmerkmale;
(ii) die Frequenzamplitude bei einer oder mehreren Frequenzen;
(iii) die integrierte Intensität eines oder mehrerer Frequenzmerkmale über einen Frequenzbereich;
(iv) die Veränderung der Form des Frequenzprofils einer oder mehrerer Frequenzmerkmale;
(v) das Amplitudenverhältnis zweier Frequenzwerte;
(vi) ein Wobbeln zwischen zwei oder mehreren Frequenzwerten;
(vii) das Vorliegen einer Frequenzmodulationscharakteristik;
(viii) das in einem bestimmten Frequenzbereich gemessene Profil des Stroms gegen die Zeit;
(ix) das Vorliegen einer Amplitudenmodulationscharakteristik.

**8.** Vorrichtung nach einem der Ansprüche 1 bis 6, wobei der Zustand des überwachten Gleisstromkreises einer oder

mehrere der folgenden sind:

(i) Abdriften bei einer oder mehreren der Frequenzen des Oszillators oder der Oszillatoren in einer mit der Gleisstrom-Abstimmeinheit (TTU) des Gleisstromkreises verbundenen Übertragungseinrichtung;
(ii) Abdriften bei einer oder mehreren abgestimmten Komponentenwerte in einer oder mehreren TTUs, wodurch ein Abdriften bei der abgestimmten Frequenz einer oder mehrerer TTUs bewirkt wird;
(iii) Änderung in der Modulationsabweichung und Modulationsrate des Oszillators oder der Oszillatoren in der Übertragungseinrichtung oder den Übertragungseinrichtungen, die über die TTUs mit den Gleisen verbunden sind;
(iv) Verringerung der Amplitude in einem oder mehreren Seitenbänden der Ausgabe einer oder mehrerer Übertragungseinrichtungen, die über die TTUs mit den Gleisen verbunden sind;
(v) verschlechterter Gleisbettzustand und Kondensatorausgleich, falls verwendet, eines Gleisstromkreises;
(vi) Ungleichgewicht im Gleichstromrücklauf in den zwei Laufgleisen, das die Leistungsfähigkeit des Gleisstromkreises beeinträchtigt;
(vii) harmonischer Anteil der Bahnstromwelligkeit, die sich mit dem Empfangssignal der TTU überlagert;
(viii) unerwünschtes eisenhaltiges Material in einer abgestimmten Zone des Gleisstromkreises;
(ix) fehlerhafte TTU-Endverbindungen mit den Laufgleisen des Gleichstromkreises; und
(x) physikalischer Zustand der Laufgleise des Gleisstromkreises.

**9.** Vorrichtung nach einem der Ansprüche 1 bis 6, wobei der vom Prozessor angegebene Zustand einer oder mehrere der folgenden sind:

Abdriften bei einer oder mehreren der Frequenzen des oder der Übertragungsoszillatoren, die mit einer Gleisstrom-Abstimmeinheit (TTU) des Gleisstromkreises verbunden sind;
Änderung in der Modulationsabweichung und der Modulationsrate der Übertragungseinrichtung und
eine Verringerung in der Amplitude der Übertragungseinrichtung in einem oder mehreren Seitenbändern, wie sie an den Gleisen aus der TTU-Ausgabe heraus erscheinen würden;
wobei der zur Angabe des Zustands verwendete Parameter die Frequenz oder Intensität der Ausgabe der Übertragungseinrichtung ist, wie sie bei den Gleisen aus der TTU-Ausgabe heraus erscheinen würde.

**10.** Vorrichtung nach Anspruch 9, wobei der Parameter aus dem Spektrum der Übertragungsfrequenz abgeleitet wird, die in ihre Spektralkomponenten aufgelöst worden ist.

**11.** Vorrichtung nach Anspruch 9 oder 10, wobei die Frequenz oder Intensität der Übertragungsfrequenz mit einer vorgegebenen Bezugsfrequenz verglichen wird.

**12.** Vorrichtung nach einem der Ansprüche 1 bis 6, wobei der vom Prozessor angegebene Zustand einer oder mehrere der folgenden sind:

(i) Abdriften bei einem oder mehreren der abgestimmten Komponentenwerte in einer oder mehreren der Gleichstrom-Abstimmeinheiten (TTUs) des Gleisstromkreises;
(ii) verschlechterter Gleisbettzustand und/oder Kondensatorausgleich, falls verwendet, des Gleisstromkreises;
(iii) unerwünschtes eisenhaltiges Material in einer abgestimmten Zone des Gleisstromkreises; und
(iv) Zustand der TTU-Endverbindungen mit den Laufgleisen des Gleisstromkreises.

**13.** Vorrichtung nach einem der Ansprüche 1 bis 6, wobei der vom Prozessor angegebene Zustand eine Verringerung in der Amplitude der Ausgabe der Übertragungseinrichtung in einem oder mehreren Seitenbändern ist, wie sie bei den Gleisen aus der TTU-Ausgabe heraus erscheinen würde.

**14.** Vorrichtung nach einem der vorhergehenden Ansprüche, wobei der Sensor ein Glasfasermagnetfelddetektor ist.

**15.** Vorrichtung nach einem der Ansprüche 1 bis 13, wobei der Sensor eine Spule (78, 781, 782) ist.

**16.** Vorrichtung nach Anspruch 15, wobei die Spule (78) eine drahtgewickelte Spule ist.

**17.** Vorrichtung nach Anspruch 16, wobei die Spule (78) auf eine gedruckte Leiterplatte gedruckt ist.

**18.** Vorrichtung nach einem der vorhergehenden Ansprüche, ferner umfassend einen Kommunikationsprozessor (70)

zum Weitergeben des digitalen Signals an ein Kommunikationssystem.

**19.** Vorrichtung nach einem der vorhergehenden Ansprüche, die tragbar ist.

**20.** System zum Überwachen des Zustands mehrerer Wechselstrom-Gleisstromkreise eines Bahngleises, umfassend:

mehrere Sensormodule (94, 96); und
ein mit den Modulen verbundenes Kommunikationsnetzwerk (104),
wobei jedes Sensormodul die Vorrichtung nach Anspruch 18 umfasst.

**21.** System nach Anspruch 20, wobei die Prozessoren in den mehreren Sensormodulen so eingerichtet sind, dass sie ein oder mehrere neuronale Netze bilden.

**22.** System nach Anspruch 20 oder 21, ferner umfassend:

einen Steuercomputer;
wobei das Kommunikationsnetzwerk eines oder mehrere der Module mit dem Steuercomputer verbindet.

**23.** System nach Anspruch 22, wobei der Steuercomputer dazu ausgelegt ist, eines oder mehrere der mehreren Sensormodule mit Daten zu versorgen.

**24.** Verfahren zum Überwachen des Zustands eines Wechselstrom-Gleisstromkreises, umfassend die folgenden Schritte:

Messen des im Wechselstrom-Gleisstromkreis fließenden Wechselstroms, ohne den Gleisstromkreis zu berühren;
Wandeln des gemessenen Gleisstroms in ein digitales Signal und
Verarbeiten des digitalen Signals, um einen Parameter bereitzustellen, der den Zustand des Gleisstromkreises angibt.

**25.** Verfahren nach Anspruch 24, wobei beim besagten Verarbeiten eine Spektralanalyse des digitalen Signals ausgeführt wird und der Parameter aus der Spektralanalyse abgeleitet wird.

**26.** Verfahren nach Anspruch 24, wobei beim besagten Verarbeiten eine Analyse der zeitabhängigen Hülle des gemessenen Gleisstroms ausgeführt wird.

**27.** Verfahren nach einem der Ansprüche 24 bis 26, wobei beim besagten Verarbeiten ein Trend im Parameter angegeben wird, um das Einsetzen eines Versagens des Gleisstromkreises anzugeben.

**28.** Verfahren nach einem der Ansprüche 24 bis 27, wobei der gemessene Parameter einer oder mehrere der folgenden sind:

(i) eine Frequenzverschiebung eines oder mehrerer Frequenzmerkmale;
(ii) die Frequenzamplitude bei einer oder mehreren Frequenzen;
(iii) die integrierte Integrität eines oder mehrerer Frequenzmerkmale über einen Frequenzbereich;
(iv) die Veränderung der Form des Frequenzprofils einer oder mehrerer Frequenzmerkmale;
(v) das Amplitudenverhältnis zweier Frequenzwerte;
(vi) ein Wobbeln zwischen zwei oder mehreren Frequenzwerten;
(vii) das Vorliegen einer Frequenzmodulationscharakteristik;
(viii) das in einem bestimmten Frequenzbereich gemessene Profil des Stroms gegen die Zeit;
(ix) das Vorliegen einer Amplitudenmodulationscharakteristik.

**29.** Verfahren nach einem der Ansprüche 24 bis 27, wobei der Zustand des überwachten Gleisstromkreises einer oder mehrere der folgenden sind:

(i) Abdriften bei einer oder mehreren Frequenzen des Oszillators oder der Oszillatoren in einer oder mehreren Übertragungseinrichtungen, die mittels einer Gleisstrom-Abstimmeinheit (TTU) des Gleisstromkreises mit einem Gleisstromkreis verbunden sind;

(ii) Abdriften bei einem oder mehreren abgestimmten Komponentenwerten in einer oder mehreren TTUs, wodurch ein Abdriften in der abgestimmten Frequenz einer oder mehrerer TTUs bewirkt wird;
(iii) Änderung der Modulationsabweichung und Modulationsrate des oder der Oszillatoren der einen oder mehreren Übertragungseinrichtungen, die über die eine oder mehreren TTUs mit den Gleisen verbunden sind;
(iv) Verringerung der Amplitude der Übertragungsfrequenz in einem oder mehreren Seitenbändern, wie sie an der TTU-Ausgabe beobachtet würde;
(v) verschlechterter Gleisbettzustand und Kondensatorausgleich, falls verwendet, eines Gleisstromkreises;
(vi) Ungleichgewicht im Gleichstromrücklauf in den zwei Laufgleisen des Gleisstromkreises, das die Leistungsfähigkeit des Gleisstromkreises beeinträchtigt;
(vii) harmonischer Anteil der Bahnstromwelligkeit, der sich möglicherweise mit dem Empfangssignal überlagern könnte;
(viii) unerwünschtes eisenhaltiges Material in einer abgestimmten Zone des Gleisstromkreises;
(ix) fehlerhafte TTU-Endverbindungen der Laufkreise des Gleisstromkreises; und
(x) physikalischer Zustand der Laufgleise des Gleisstromkreises.

**30.** Verfahren nach einem der Ansprüche 24 bis 27, wobei die Signalverarbeitung eines oder mehrere der folgenden angibt:

(i) Abdriften bei einer oder mehreren der Frequenzen des Oszillators oder der Oszillatoren in einer oder mehreren Übertragungseinrichtungen, die mittels einer Gleisstrom-Abstimmeinheit (TTU) des Gleisstromkreises mit einem Gleisstromkreis verbunden sind;
(ii) Änderung der Modulationsabweichung und Modulationsrate des oder der Oszillatoren der einen oder mehreren Übertragungseinrichtungen, die über die eine oder mehreren TTUs mit den Gleisen verbunden sind; und
(iii) Verringerung der Amplitude der Übertragungsfrequenz in einem oder mehreren Seitenbändern, wie sie an der TTU-Ausgabe beobachtet würde;

wobei der zur Angabe des Zustands verwendete Parameter die Frequenz oder Intensität der Ausgabe der Übertragungseinrichtung einer TTU ist.

**31.** Verfahren nach Anspruch 30, wobei der Parameter aus dem Spektrum der Übertragungsfrequenz abgeleitet wird, das in seine Spektralkomponenten aufgelöst worden ist.

**32.** Verfahren nach Anspruch 30 oder 31, wobei die Frequenz oder Intensität der Übertragungsfrequenz mit einer vorgegebenen Bezugsfrequenz verglichen wird.

**33.** Verfahren nach Anspruch 24 oder 25, wobei die Signalverarbeitung eines oder mehrere der folgenden angibt:

(i) Abdriften bei einem oder mehreren abgestimmten Komponentenwerten in einer oder mehreren TTUs, wodurch ein Abdriften in der abgestimmten Frequenz einer oder mehrerer TTUs bewirkt wird;
(ii) verschlechterter Gleisbettzustand und Kondensatorausgleich, falls verwendet, eines Gleisstromkreises;
(iii) unerwünschtes Material in einer abgestimmten Zone des Gleisstromkreises; und
(iv) Zustand der TTU-Endverbindungen mit den Laufgleisen des Gleisstromkreises.

**34.** Verfahren nach Anspruch 24 oder 25, wobei der Zustand eine Verringerung der Amplitude der Übertragungsfrequenz in einem oder mehreren Seitenbändern, die die TTU antreibt, ist und der zur Zustandsangabe verwendete Parameter die Amplitude der Übertragungsfrequenz ist, wie sie in dem in der abgestimmten Zone fließenden Strom überwacht wird.

**35.** Verfahren nach einem der Ansprüche 24 bis 34, ferner umfassend das Speichern des digitalen Signals.

**36.** Verfahren nach einem der Ansprüche 24 bis 35, ferner umfassend das Weitergeben des digitalen Signals an ein Kommunikationssystem.

## Revendications

**1.** Appareil pour contrôler l'état d'un circuit de voie (100) à courant alternatif comportant :

un capteur (90) destiné à capter le courant alternatif du circuit de voie à courant alternatif lorsqu'il est agencé à proximité du circuit de voie, mais sans contact avec lui ;
un convertisseur analogique-numérique (58) pouvant être mis en oeuvre pour convertir le courant capté en un signal numérique ; et
un processeur (50) pouvant être mis en oeuvre pour recevoir le signal numérique provenant du convertisseur analogique-numérique et pour exécuter un traitement de signal sur le signal numérique, ledit traitement de signal produisant un paramètre indicatif de l'état du circuit de voie.

**2.** Appareil selon la revendication 1, dans lequel le capteur (90) est agencé à proximité du circuit de voie (100), mais sans contact avec celui-ci, pour capter le courant alternatif dans le circuit de voie à courant alternatif.

**3.** Appareil selon la revendication 1 ou 2, comportant en outre une mémoire (103) de données agencée pour stocker le signal numérique.

**4.** Appareil selon les revendications 1, 2 ou 3, dans lequel le processeur (50) est agencé pour exécuter une analyse spectrale du courant de voie capté et le paramètre est dérivé de l'analyse spectrale.

**5.** Appareil selon l'une quelconque des revendications 1 à 4, dans lequel le processeur (50) est agencé pour indiquer une tendance du paramètre à indiquer le commencement d'une défaillance du circuit de voie.

**6.** Appareil selon l'une quelconque des revendications 1 à 5, dans lequel le processeur (50) est agencé de façon à effectuer une analyse de l'enveloppe variant en fonction du temps du courant de voie capté.

**7.** Appareil selon l'une quelconque des revendications 1 à 6, dans lequel le paramètre mesuré est l'un de :

(i) un décalage de fréquence d'une ou plusieurs caractéristiques de fréquence ;
(ii) l'amplitude de fréquence à une ou plusieurs fréquences ;
(iii) l'intensité intégrée d'une ou plusieurs caractéristiques de fréquence sur une plage de fréquence ;
(iv) la variation de la forme du profil de fréquence d'une ou plusieurs caractéristiques de fréquence ;
(v) le rapport des amplitudes de deux valeurs de fréquence ;
(vi) une vobulation entre deux ou plus de deux valeurs de fréquence ;
(vii) la présence d'une caractéristique de modulation de fréquence ;
(viii) le profil du courant en fonction du temps mesuré dans une plage de fréquence particulière ;
(ix) la présence d'une caractéristique de modulation d'amplitude.

**8.** Appareil selon l'une quelconque des revendications 1 à 6, dans lequel l'état du circuit de voie contrôlé est un ou plusieurs de :

(i) une dérive d'une ou plusieurs des fréquences des oscillateurs ou d'un oscillateur dans un émetteur connecté à l'unité d'accord de voie (TTU) du circuit de voie ;
(ii) une dérive d'une ou plusieurs valeurs de composantes accordées dans une ou plusieurs unités TTU provoquant une dérive de la fréquence accordée d'une ou plusieurs unités TTU ;
(iii) une variation de l'écart de modulation et du taux de modulation de l'oscillateur ou des oscillateurs dans l'émetteur ou dans les émetteurs connectés aux rails par l'intermédiaire des unités TTU ;
(iv) une réduction de l'amplitude dans une ou plusieurs bandes latérales du signal de sortie d'un émetteur ou d'émetteurs connectés aux rails par l'intermédiaire d'unités TTU ;
(v) un état dégradé du ballast et une compensation de condensateur, si utilisé, d'un circuit de voie ;
(vi) un déséquilibre du retour de courant continu dans les deux rails de roulement, affectant la performance du circuit de voie ;
(vii) une teneur en harmonique de l'ondulation du courant de traction interférant avec le signal du récepteur de l'unité TTU ;
(viii) une matière ferreuse non voulue dans une zone accordée du circuit de voie ;
(ix) des connexions de queue défectueuses des unités TTU sur les rails de roulement du circuit de voie ; et
(x) un état physique des rails de roulement du circuit de voie.

**9.** Appareil selon l'une quelconque des revendications 1 à 6, dans lequel l'état indiqué par le processeur est un ou plusieurs de :

une dérive d'une ou plusieurs des fréquences de l'oscillateur ou des oscillateurs d'émetteurs connectés à l'unité d'accord de voie (TTU) du circuit de voie ;
une variation de l'écart de modulation et du taux de modulation de l'émetteur ; et
une réduction de l'amplitude de l'émetteur dans une ou plusieurs bandes latérales telle qu'elle apparaîtrait aux rails à partir de la sortie de l'unité TTU ;
dans lequel le paramètre utilisé pour indiquer l'état est la fréquence ou l'intensité du signal de sortie de l'émetteur telle qu'elle apparaîtrait aux rails à partir de la sortie de l'unité TTU.

**10.** Appareil selon la revendication 9, dans lequel le paramètre est dérivé du spectre de la fréquence de l'émetteur qui a été résolue en ses composantes spectrales.

**11.** Appareil selon la revendication 9 ou 10, dans lequel la fréquence ou l'intensité de la fréquence de l'émetteur est comparée à une fréquence de référence spécifiée.

**12.** Appareil selon l'une quelconque des revendications 1 à 6, dans lequel l'état indiqué par le processeur est un ou plusieurs de :

(i) une dérive d'une ou plusieurs des valeurs de composante accordées dans une ou plusieurs des unités d'accord de voie (TTU) du circuit de voie ;
(ii) un état dégradé du ballast et/ou une compensation de condensateur, si utilisé, du circuit de voie ;
(iii) une matière ferreuse non voulue dans une zone accordée du circuit de voie ; et
(iv) l'état de connexions de queue d'unités TTU sur les rails de roulement du circuit de voie.

**13.** Appareil selon l'une quelconque des revendications 1 à 6, dans lequel l'état indiqué par le processeur est une réduction de l'amplitude du signal de sortie de l'émetteur, dans une ou plusieurs bandes latérales, telle qu'elle apparaîtrait aux rails de la sortie de l'unité TTU.

**14.** Appareil selon l'une quelconque des revendications précédentes, dans lequel le capteur est un détecteur de champ magnétique à fibre optique.

**15.** Appareil selon l'une quelconque des revendications 1 à 13, dans lequel le capteur est une bobine (78, 781, 782).

**16.** Appareil selon la revendication 15, dans lequel la bobine (78) est une bobine à fil enroulé.

**17.** Appareil selon la revendication 16, dans lequel la bobine (78) est imprimée sur une plaquette à circuit imprimé.

**18.** Appareil selon l'une quelconque des revendications précédentes, comportant en outre un processeur (70) de communication pour fournir le signal numérique à un système de communication.

**19.** Appareil selon l'une quelconque des revendications précédentes, qui est portable.

**20.** Système pour contrôler l'état de plusieurs circuits de voie à courant alternatif d'une voie ferrée, comportant :

plusieurs modules de détection (94, 96) ; et
un réseau de communication (104) relié aux modules,
dans lequel chaque module de détection comporte l'appareil selon la revendication 18.

**21.** Système selon la revendication 20, dans lequel les processeurs dans les multiples modules de détection sont agencés de façon à former un ou plusieurs réseaux neuronaux.

**22.** Système selon la revendication 20 ou 21, comportant en outre :

un ordinateur de commande ;
dans lequel le réseau de communications relie un ou plusieurs des modules à l'ordinateur de commande.

**23.** Système selon la revendication 22, dans lequel l'ordinateur de commande est agencé de façon à fournir des données à un de plus des multiples modules de détection.

**24.** Procédé de contrôle de l'état d'un circuit de voie à courant alternatif, comprenant les étapes qui consistent :

à capter le courant alternatif circulant dans le circuit de voie à courant alternatif sans contact avec le circuit de voie ;
à convertir le courant de voie capté en un signal numérique ; et
à traiter le signal numérique pour fournir un paramètre indicatif de l'état du circuit de voie.

**25.** Procédé selon la revendication 24, dans lequel ledit traitement exécute une analyse spectrale du signal numérique et le paramètre est dérivé de l'analyse spectrale.

**26.** Procédé selon la revendication 24, dans lequel ledit traitement effectue une analyse de l'enveloppe variant en fonction du temps du courant de voie capté.

**27.** Procédé selon la revendication 24, 25 ou 26, dans lequel ledit traitement indique une tendance du paramètre à indiquer le commencement d'une défaillance du circuit de voie.

**28.** Procédé selon la revendication 24, 25, 26 ou 27, dans lequel le paramètre mesuré est un ou plusieurs de :

(i) un décalage de fréquence d'une ou plusieurs caractéristiques de fréquence ;
(ii) l'amplitude de la fréquence à une ou plusieurs fréquences ;
(iii) l'intensité intégrée d'une ou plusieurs caractéristiques de fréquence sur une plage de fréquence ;
(iv) la variation de la forme du profil de fréquence d'une ou plusieurs caractéristiques de fréquence ;
(v) le rapport des amplitudes de deux valeurs de fréquence ;
(vi) une vobulation entre deux ou plus de deux valeurs de fréquence ;
(vii) la présence d'une caractéristique de modulation de fréquence ;
(viii) le profil du courant en fonction du temps mesuré dans une plage de fréquence particulière ;
(ix) la présence d'une caractéristique de modulation d'amplitude.

**29.** Procédé selon la revendication 24, 25, 26 ou 27, dans lequel l'état du circuit de voie contrôlé est un ou plusieurs de :

(i) une dérive d'une ou plusieurs des fréquences de l'oscillateur ou des oscillateurs dans un émetteur ou des émetteurs se connectant à un circuit de voie utilisant une unité d'accord de voie (TTU) du circuit de voie ;
(ii) une dérive d'une ou plusieurs valeurs de composantes accordées dans une ou plusieurs unités TTU provoquant une dérive de la fréquence accordée d'une ou plusieurs unités TTU ;
(iii) une variation de l'écart de modulation et du taux de modulation de l'oscillateur ou des oscillateurs de l'émetteur ou des émetteurs se connectant aux rails par l'intermédiaire d'unités TTU ;
(iv) une réduction de l'amplitude de la fréquence d'émetteurs dans une ou plusieurs bandes latérales telle qu'elle serait observée à la sortie de l'unité TTU ;
(v) un état dégradé du ballast et une compensation de condensateur, s'il est utilisé, d'un circuit de voie ;
(vi) un déséquilibre du retour de courant continu dans les deux rails de roulement du circuit de voie, affectant la performance du circuit de voie ;
(vii) une teneur en harmonique de l'ondulation du courant de traction qui pourrait potentiellement interférer avec le signal du récepteur ;
(viii) une matière ferreuse non voulue dans une zone accordée du circuit de voie ;
(ix) des connexions de queue défectueuses des unités TTU sur les rails de roulement du circuit de voie ; et
(x) un état physique des rails de roulement du circuit de voie.

**30.** Procédé selon la revendication 24, 25, 26 ou 27, dans lequel le traitement du signal indique un ou plusieurs de :

(i) une dérive d'une ou plusieurs des fréquences de l'oscillateur ou des oscillateurs dans un émetteur ou des émetteurs se connectant à un circuit de voie utilisant une unité d'accord de voie (TTU) du circuit de voie ;
(ii) une variation de l'écart de modulation et du taux de modulation de l'oscillateur ou des oscillateurs de l'émetteur ou des émetteurs se connectant aux rails par l'intermédiaire d'unités TTU ; et
(iii) une réduction de l'amplitude de la fréquence d'émetteur dans une ou plusieurs bandes latérales telle qu'elle serait observée à la sortie de l'unité TTU ;

dans lequel le paramètre utilisé pour indiquer l'état est la fréquence ou l'intensité du signal de sortie d'émetteur d'une unité TTU.

**31.** Procédé selon la revendication 30, dans lequel le paramètre est dérivé du spectre de la fréquence d'émetteur qui a été résolue en ses composantes spectrales.

**32.** Procédé selon la revendication 30 ou 31, dans lequel la fréquence ou l'intensité de la fréquence de l'émetteur est comparée à une fréquence de référence spécifiée.

**33.** Procédé selon la revendication 24 ou 25, dans lequel le traitement du signal indique un ou plusieurs de :

(i) une dérive d'une ou plusieurs valeurs de composantes accordées dans une ou plusieurs unités TTU provoquant une dérive de la fréquence accordée d'une ou plusieurs unités TTU ;
(ii) un état dégradé du ballast et une compensation de condensateur, s'il est utilisé, d'un circuit de voie ;
(iii) une matière non voulue dans une zone accordée du circuit de voie ; et
(iv) un état des connexions de queue d'unités TTU sur les rails de roulement du circuit de voie.

**34.** Procédé selon la revendication 24 ou 25, dans lequel l'état est une réduction de l'amplitude de la fréquence d'émetteur dans une ou plusieurs bandes latérales attaquant l'unité TTU, et les paramètres utilisés pour indiquer l'état sont l'amplitude de la fréquence d'émetteur telle que contrôlée dans le circuit circulant dans la zone accordée.

**35.** Procédé selon l'une quelconque des revendications 24 à 34, comprenant en outre l'étape de stockage du signal numérique.

**36.** Procédé selon l'une quelconque des revendications 24 à 35, comprenant en outre la fourniture du signal numérique à un système de communications.

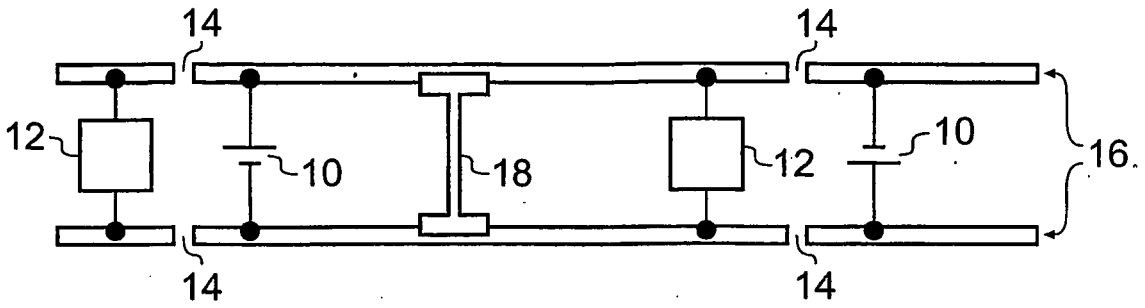


Fig. 1

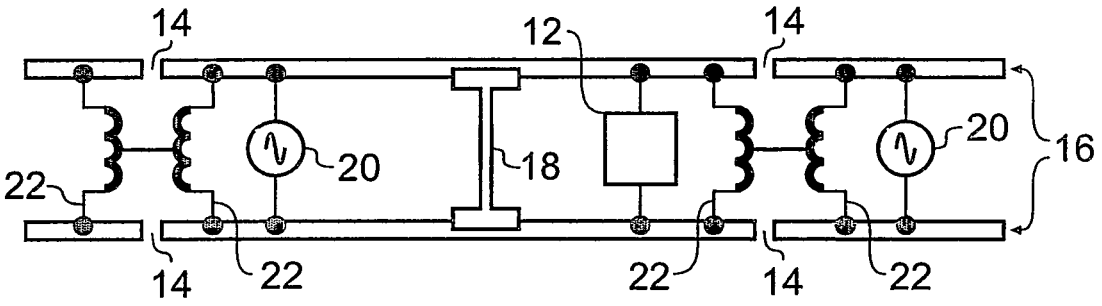


Fig. 2

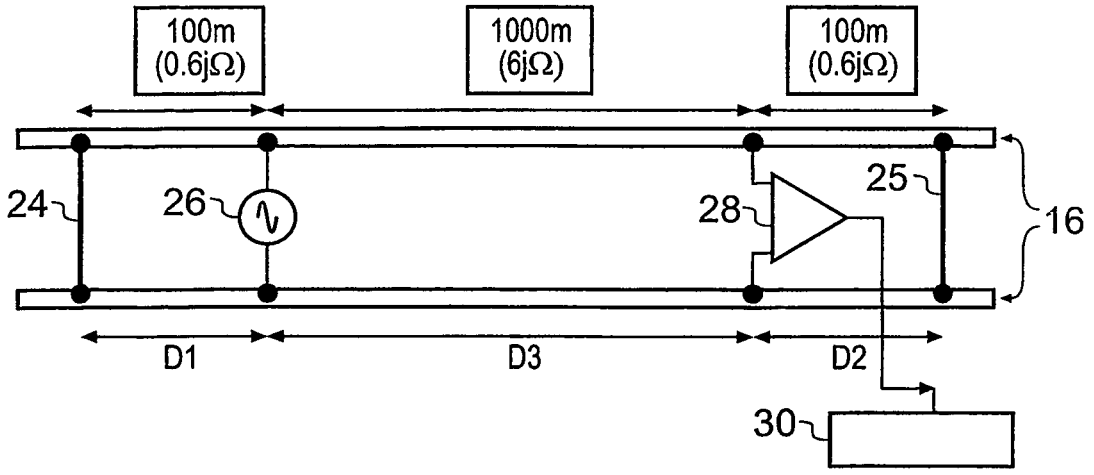


Fig. 3

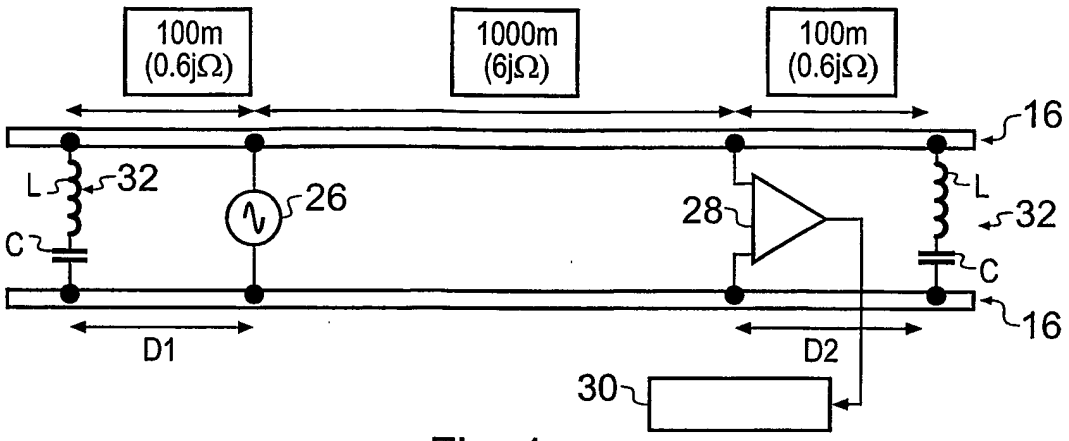


Fig. 4

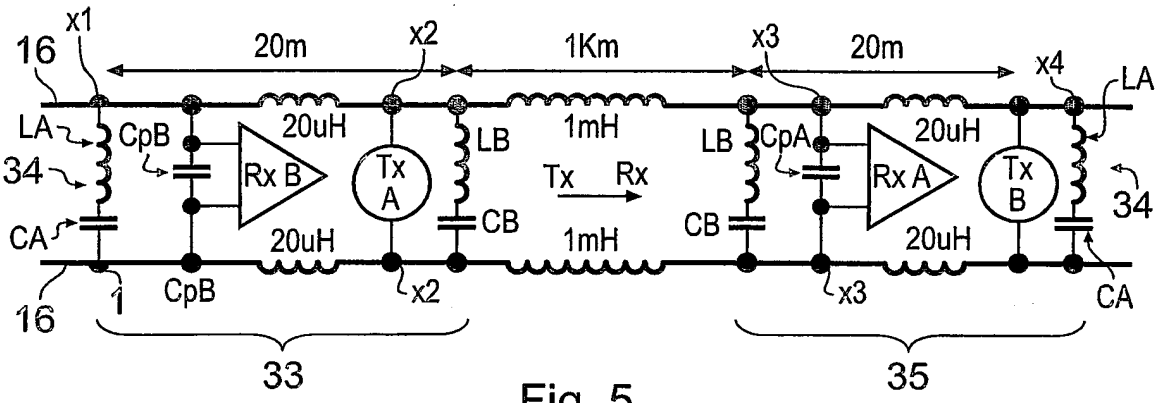


Fig. 5

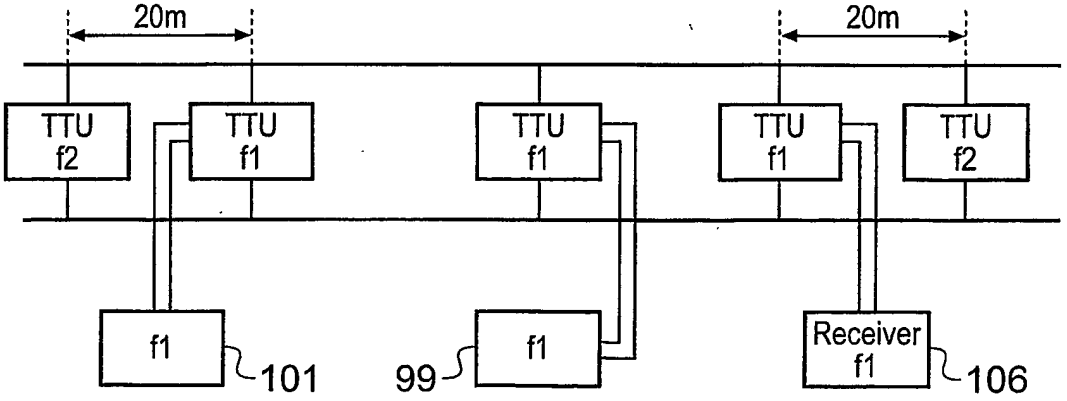


Fig. 6

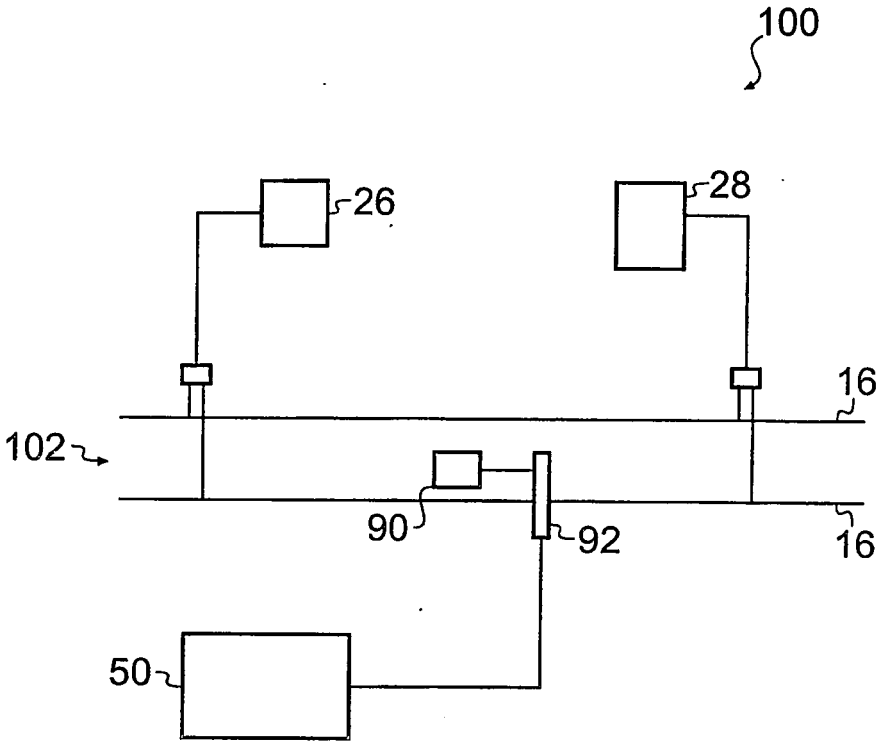


Fig. 7

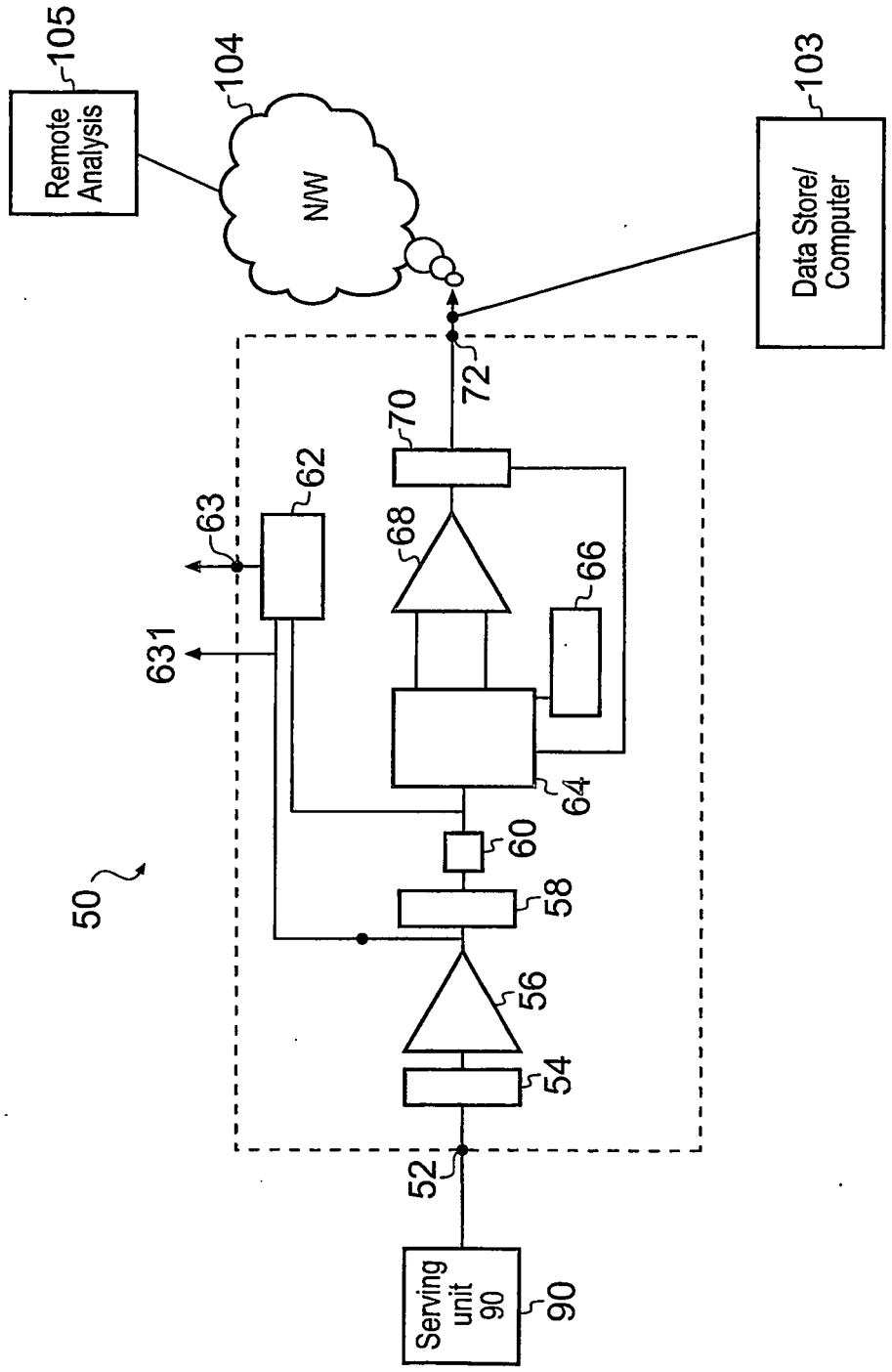
105
Remote Analysis
104
N/W
103
Data Store/ Computer
72
70
62
63
68
66
631
64
60
50
58
56
54
52
Serving unit 90
90

Fig. 8

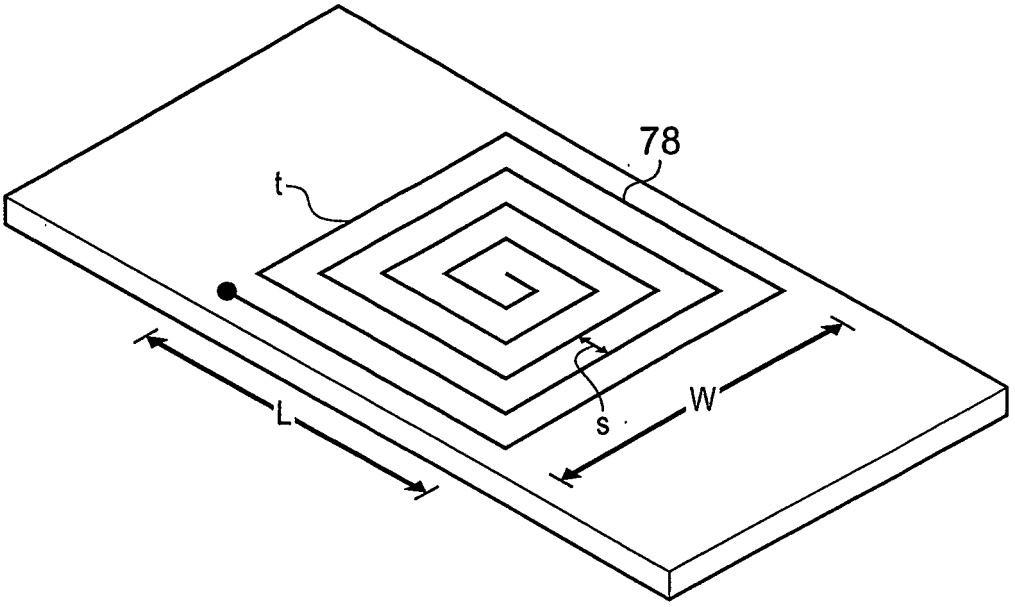


Fig. 9A

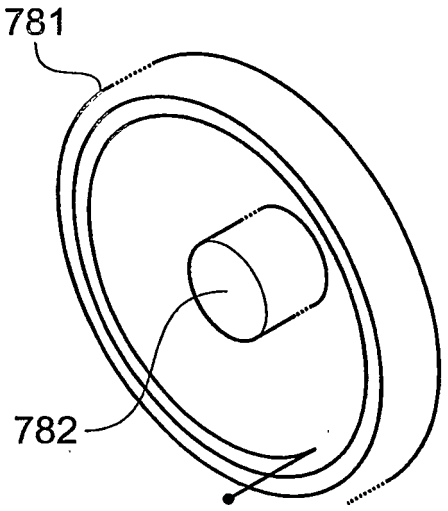


Fig. 9B

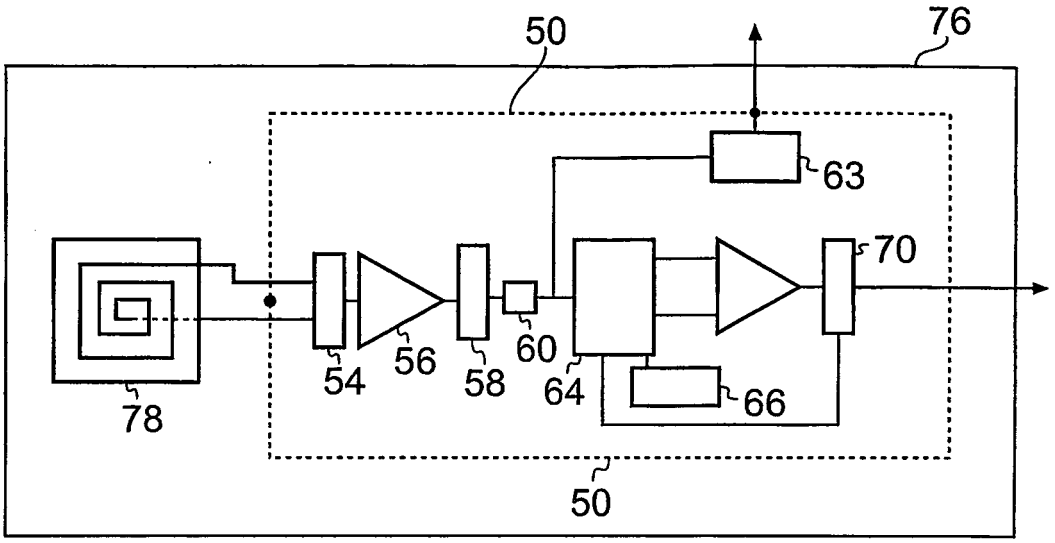
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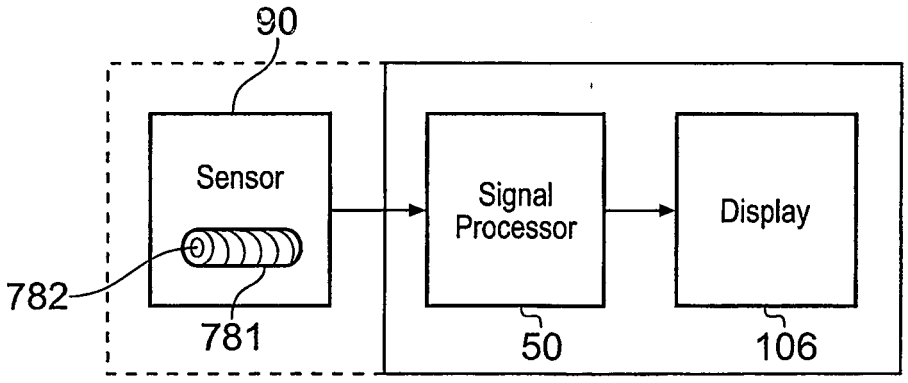
Fig. 10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Sensor
782
781
Signal Processor
Display
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106

Fig. 25

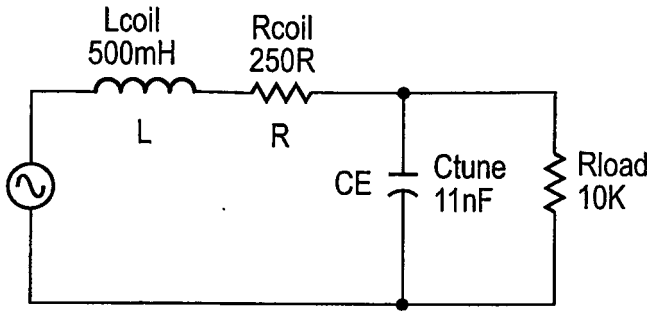


Fig. 11

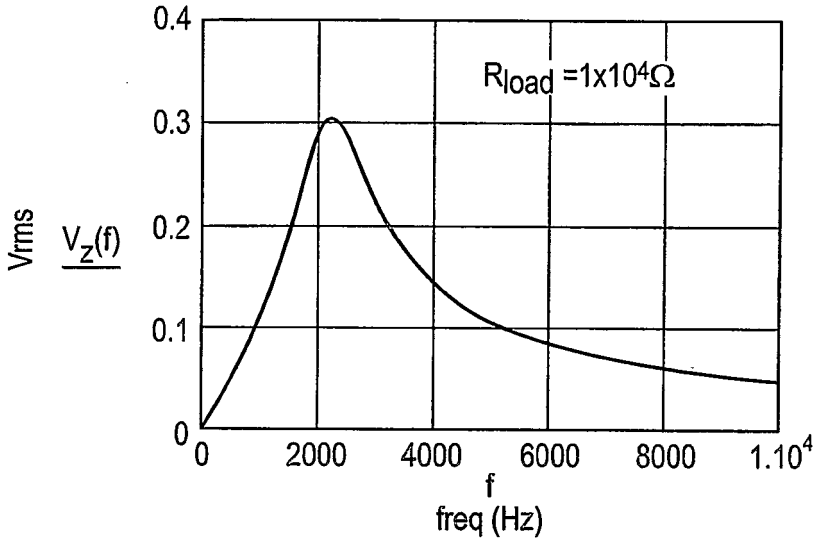


Fig. 12

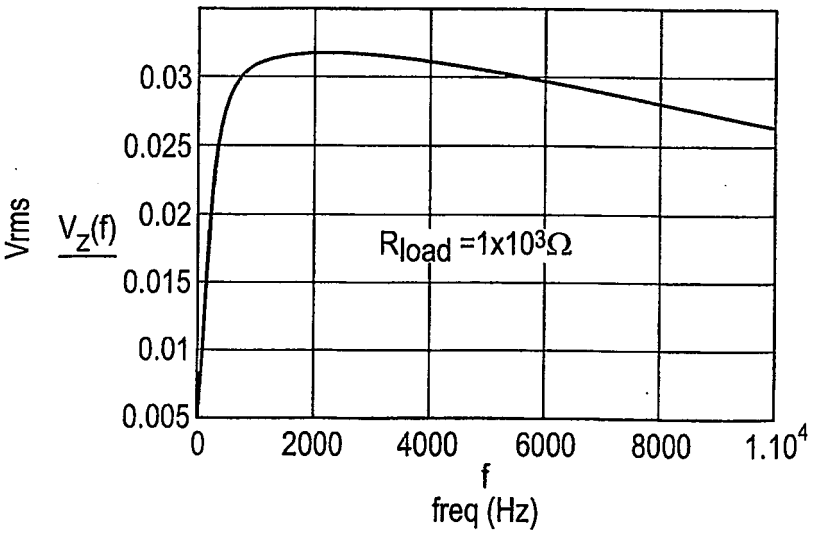


Fig. 13

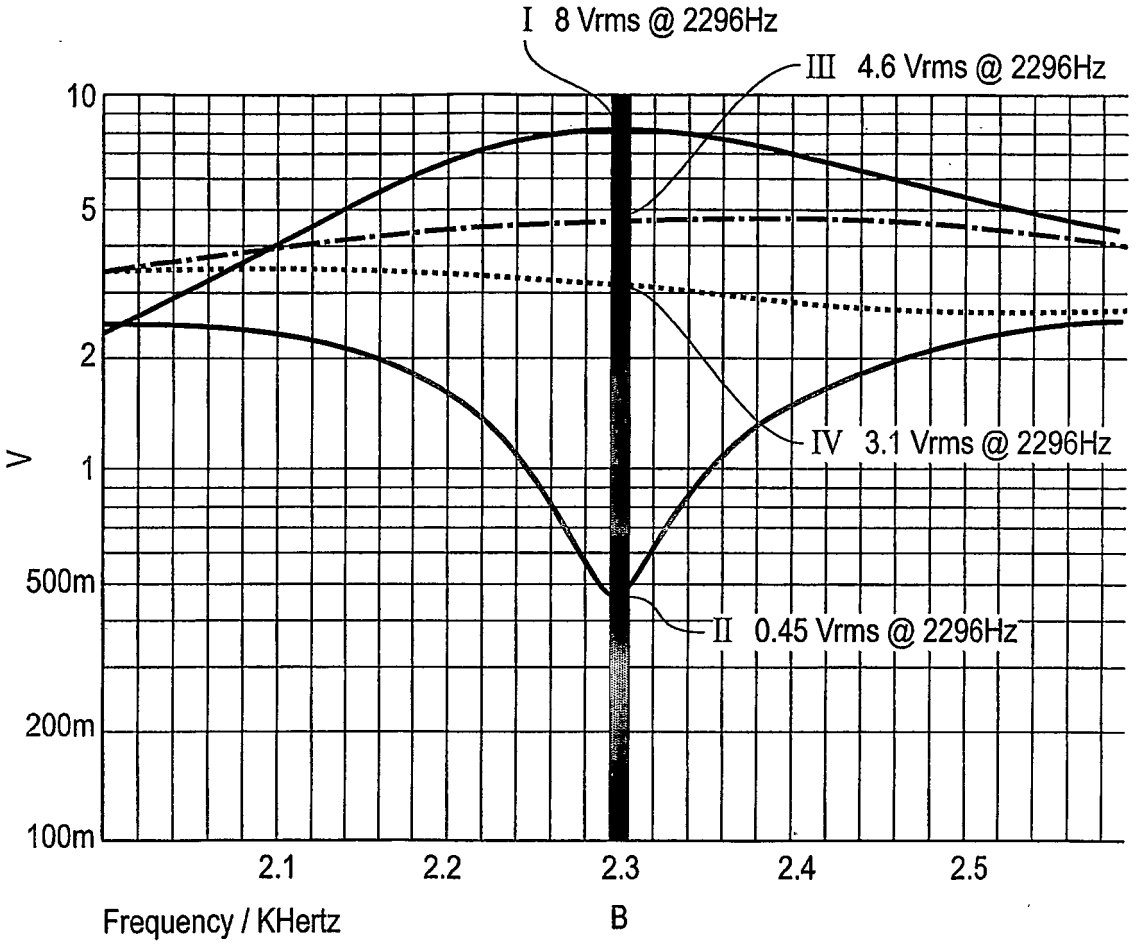
I 8 Vrms @ 2296Hz
III 4.6 Vrms @ 2296Hz
IV 3.1 Vrms @ 2296Hz
II 0.45 Vrms @ 2296Hz
10
5
2
1
500m
200m
100m
V
2.1
2.2
2.3
2.4
2.5
Frequency / KHertz
B

Fig. 14

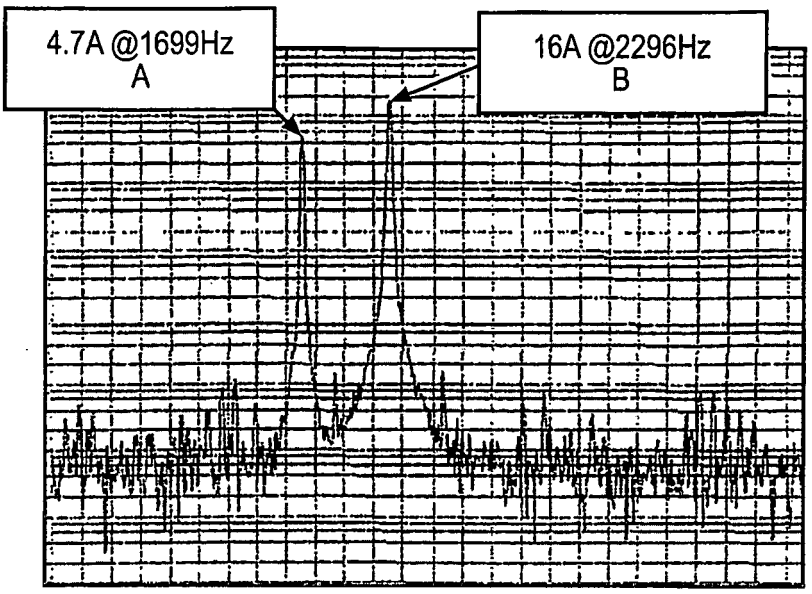


Fig. 15

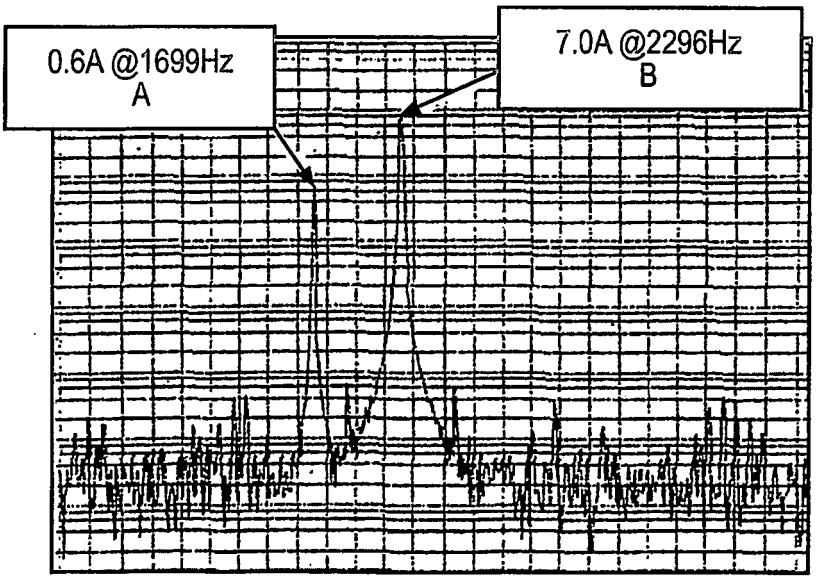


Fig. 16

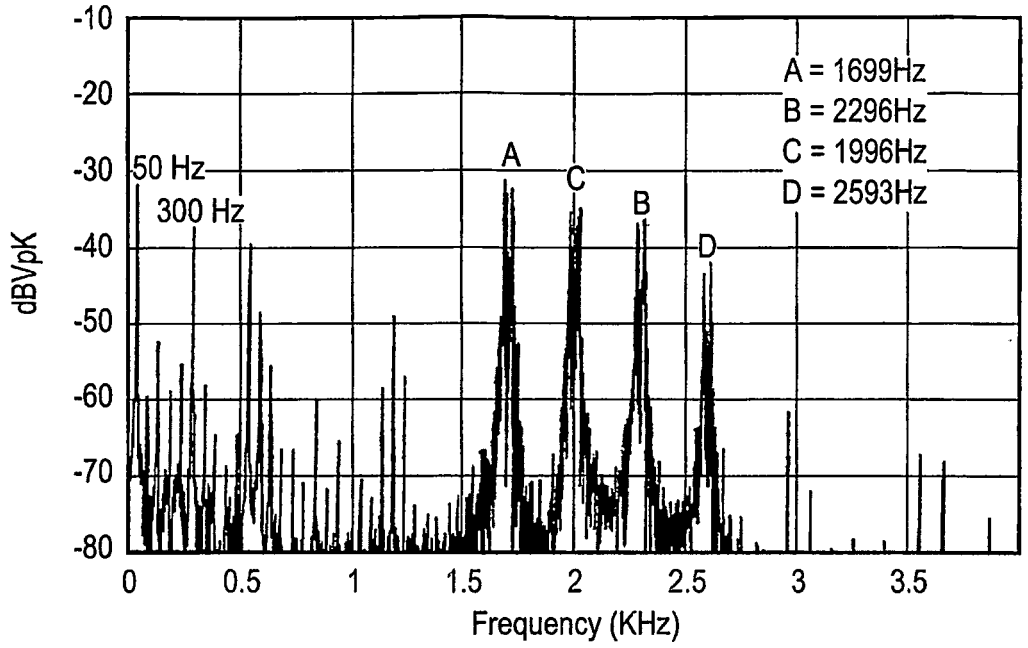
-10
-20
-30
-40
-50
-60
-70
-80
dBVpK
50 Hz
300 Hz
A
C
B
D
A = 1699Hz
B = 2296Hz
C = 1996Hz
D = 2593Hz
0
0.5
1
1.5
2
2.5
3
3.5
Frequency (KHz)

Fig. 17

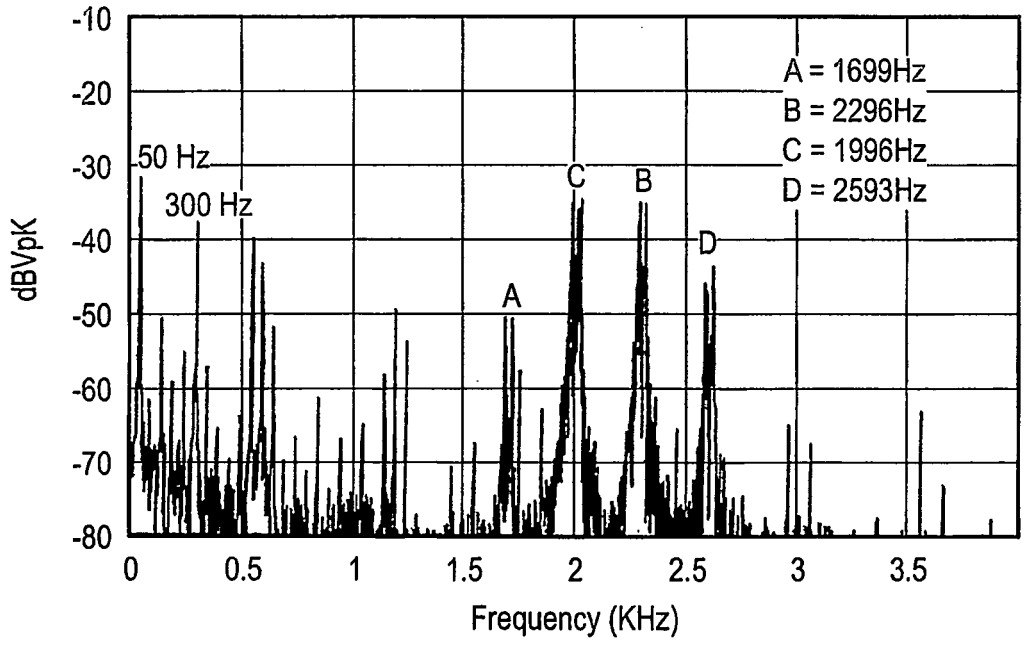
-10
-20
-30
-40
-50
-60
-70
-80
dBVpK
50 Hz
300 Hz
A
C
B
D
A = 1699Hz
B = 2296Hz
C = 1996Hz
D = 2593Hz
0
0.5
1
1.5
2
2.5
3
3.5
Frequency (KHz)

Fig. 18

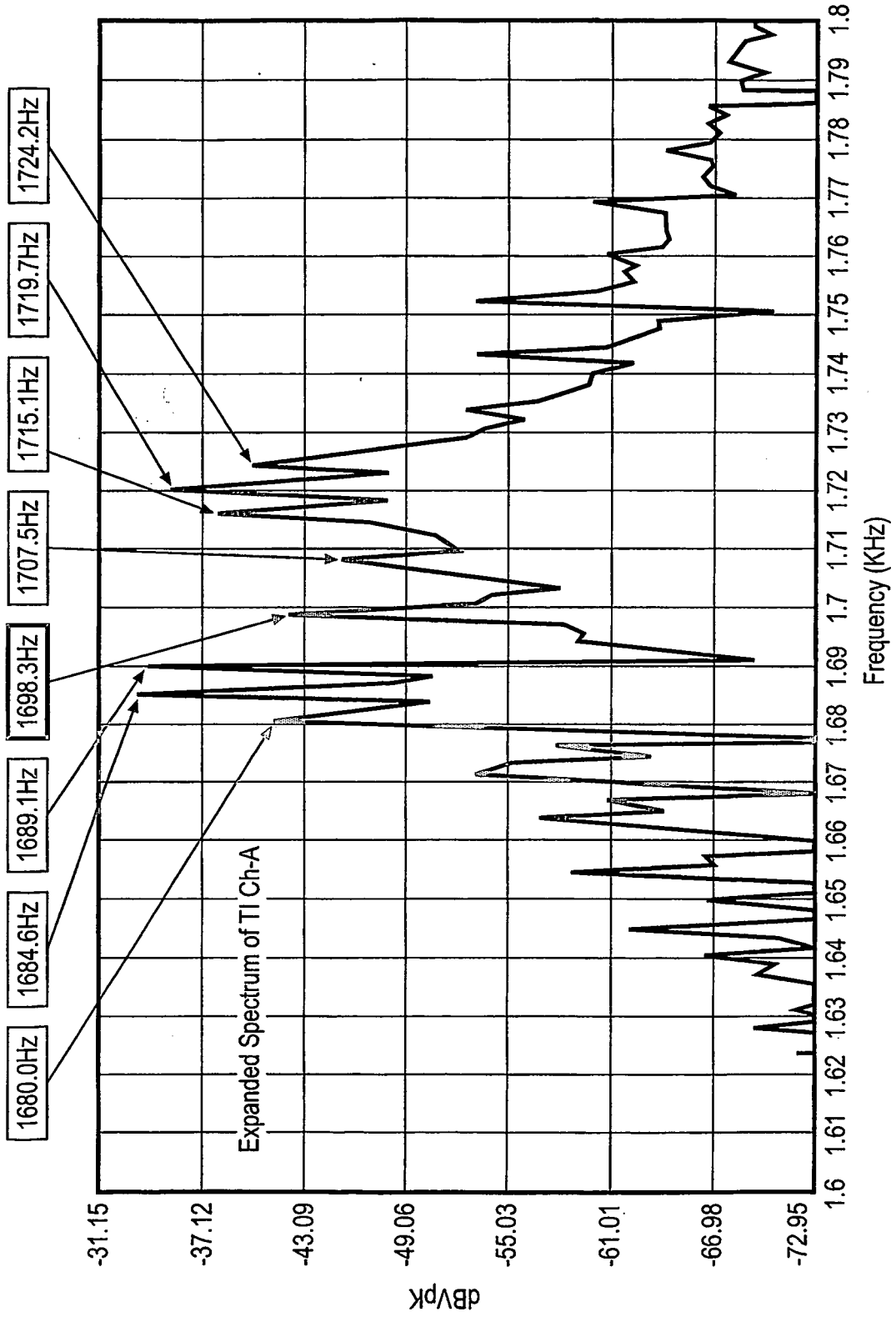
1724.2Hz
1719.7Hz
1715.1Hz
1707.5Hz
1698.3Hz
1689.1Hz
1684.6Hz
1680.0Hz
Expanded Spectrum of TI Ch-A
dBVpk
-31.15
-37.12
-43.09
-49.06
-55.03
-61.01
-66.98
-72.95
1.6
1.61
1.62
1.63
1.64
1.65
1.66
1.67
1.68
1.69
1.7
1.71
1.72
1.73
1.74
1.75
1.76
1.77
1.78
1.79
1.8
Frequency (KHz)

Fig. 19

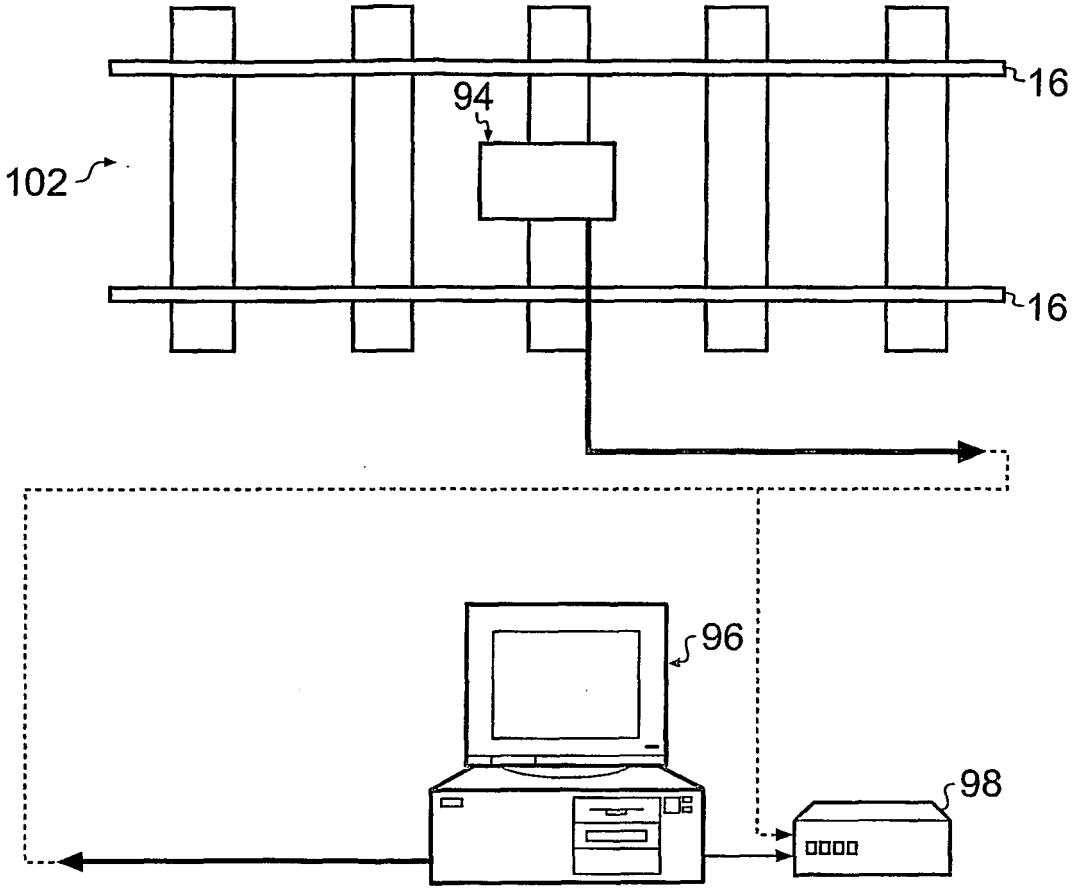


Fig. 20

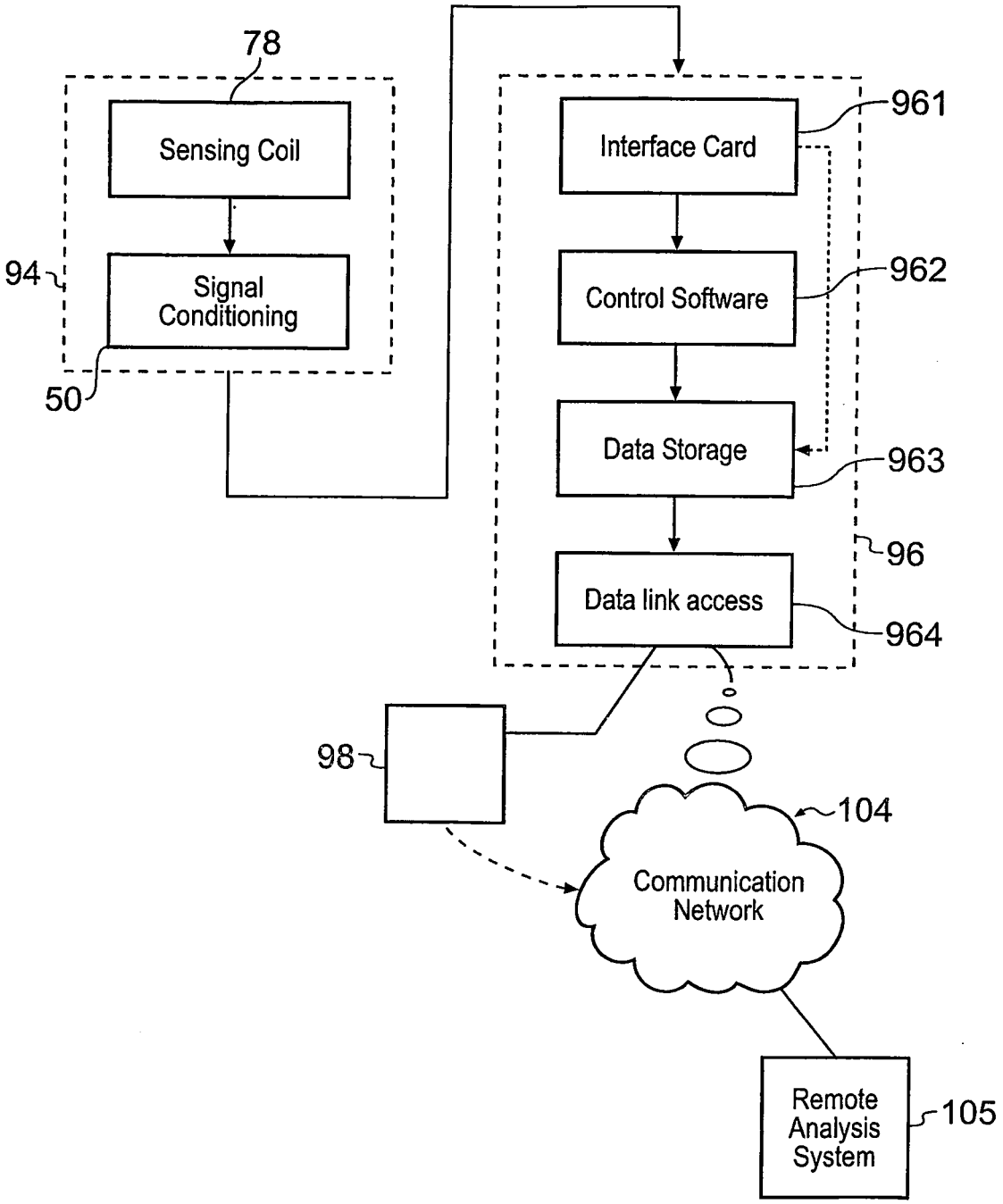
78
Sensing Coil
94
Signal Conditioning
50
961
Interface Card
962
Control Software
963
Data Storage
96
964
Data link access
98
104
Communication Network
Remote Analysis System
105

Fig. 21

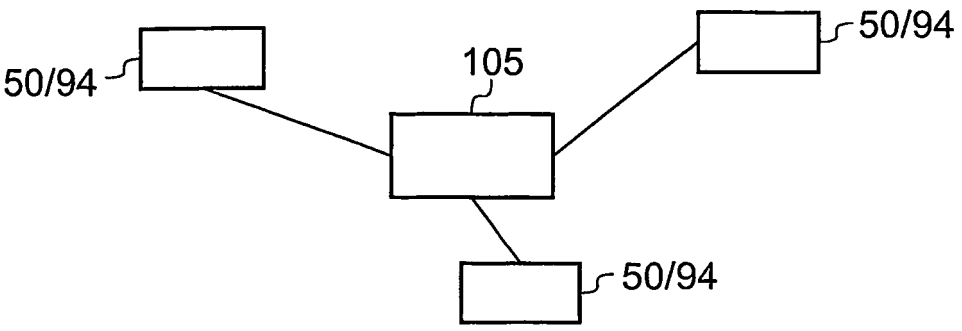


Fig. 22

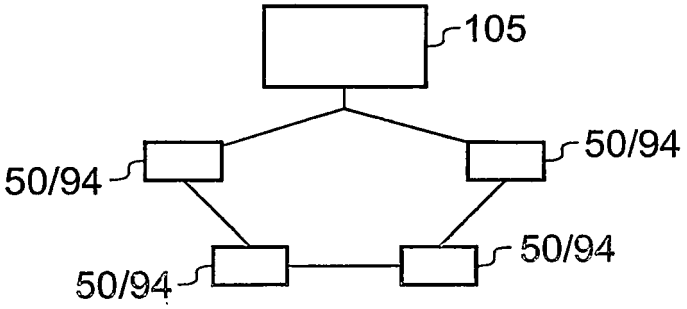


Fig. 23

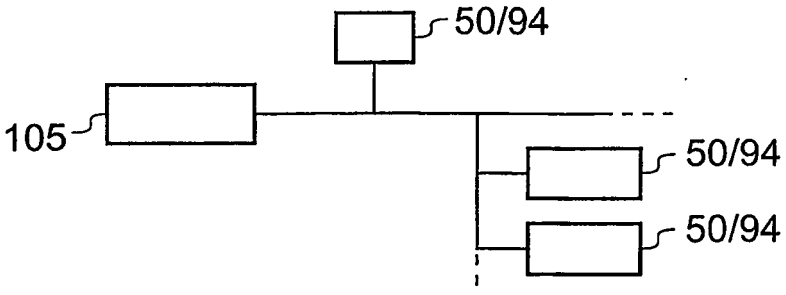


Fig. 24

## REFERENCES CITED IN THE DESCRIPTION

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### Patent documents cited in the description


- EP 958986 A **[0021]**