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(54) Title: AMPLIFIER CIRCUITRY FOR A COMBINED AC/DC SIGNAL OF AN ELECTROCHEMICAL SENSING ELECTRODE

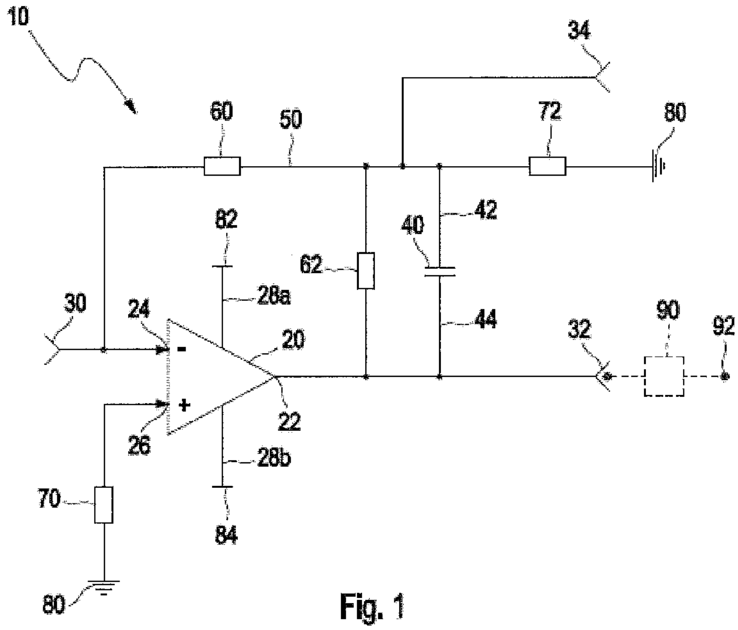

Fig. 1

(57) Abstract: The invention relates to an amplifier circuitry for a combined AC/DC signal of an electrochemical sensing electrode. The circuitry comprises an amplifier element as well as an in¬ put terminal for connection to the sensing electrode. The amplifier circuitry further comprises a DC output terminal as well as an AC output terminal. The amplifier circuitry provides a low pass transmission characteristic between the input terminal and the DC output terminal. The inventive amplifier circuitry allows to simultaneously process and amplify a DC and an AC component of the sensing signal, in particular with individual gains for these components. In addition, the invention relates to a potentiostat comprising the inventive amplifier circuitry as well as a sensor system comprising the potentiostat as well as the electrochemical sensing electrode

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Amplifier Circuitry for a Combined AC/DC Signal of an Electrochemical Sensing Electrode

Field of the Invention

The invention relates to electronically measuring electrochemical properties of liquid, in particular for measuring analytes in a liquid.

Prior Art

It is known that the presence of an analyte in a liquid can be assessed by measuring electrical properties. Accordingly, potentiostats are known, which comprise a working electrode as well as a counter electrode the resistance between which is measured by applying a current and measuring the resulting voltage occurring between these electrodes. Further, a reference electrode is used which is located between the working electrode and the counter electrode in order to measure a potential within the electric field implied by the working electrode and the counter electrode.

As described in US 5,682,884 A, a sensor system that detects a current representative of a compound in a liquid mixture features a two-electrode strip adapted for releasable attachment to signal readout circuitry. An active electrode, positioned to contact the liquid mixture and the first conductor, comprises a deposit of an enzyme capable of catalyzing a reaction involving the compound and an electron mediator, capable of transferring electrons between the enzyme-catalyzed reaction and the first conductor. A reference electrode is positioned to contact the mixture and the second conductor. The system includes circuitry adapted to provide an electrical signal representative of the current.

Such measurements as well as an apparatus therefore are described in US 6,645,368 B1, in which the biosensor is excited by an AC signal (for measuring an AC impedance) as well as by a DC signal. In order to assess the resulting measurement signals, an input stage of an amplifier is switched in order to measure the result of the AC excitation or the result of the DC excitation. The measurement signal of the DC excitation significantly differs from the measurement signal of the AC excitation, the amplifier has to be adjusted accordingly.

Firstly, switching an input stage imposes significant effort as regards the switching elements in the input stage and secondly, this switching imposes additional noise thereby reducing the precision of the measurement. Thirdly, the delay of alternating measurements does not allow simultaneous DC and AC measurements and, additionally, leads to faulty signals during the switching process, wherein incorrect switching processes bear a risk to damage the input stage of the amplifier.

It is therefore an object of the invention to provide an approach to solve at least one of these problems inherent to the prior art.

Disclosure of the Invention

This problem is solved by an amplifier circuitry, a potentiostat as well as a sensor system according to the features of claims 1, 10 and 11. Preferred embodiments of the invention, which can be realized separately or in combination are given by the claims depending thereon. According to the invention, an amplifier circuitry is provided having two output terminals with distinct gains and distinct frequency characteristics as regards the transmission function. In this way, a measured combined AC/DC signal can be processed and amplified as a whole. Any clipping or saturation effects are obviated since the distinct frequency characteristics and in particular the low pass characteristic of for a DC output terminal of the amplifier circuitry allows to mutually adapt distinct signal strengths of the AC component and the DC component.

The measurements of the AC component and the DC component of the combined AC/DC signal are processed simultaneously by the inventive circuitry obviating any switching processes for distinct magnitudes of the AC and the DC component. In addition, any signal processing stage prior to the amplifier circuitry can be obviated. The electrode signal of the sensing electrode can be input directly into the inventive circuitry. This reduces noise and simplifies the circuitry.

Whereas the switching process of the prior art for measuring either the DC or the AC component can be seen as a time multiplex (involving switching and the resulting disadvantages mentioned above), the present invention can be seen as a frequency multiplexed measurement which distinguishes signal components by their frequency. The invention uses a low pass transmission characteristic in order to distinguish the DC component from the combined AC/DC signal. Since the DC component has a lower magnitude, this separation by using a low pass transmission characteristic allows to assess the magnitude of the DC signal without or with reduced interference by the AC component (clipping or saturation) within the amplification process.

The inventive amplifier circuitry comprises two output terminals, an AC output terminal and a DC output terminal. Further, the amplifier circuitry comprises an input terminal for the combined AC/DC signal and in particular for connecting the sensing electrode to the amplifier circuitry. The separated measurement is enabled by attenuating the AC component from the DC output terminal, wherein this attenuating function is provided by the low pass transmission characteristic with respect to the DC output terminal. In the context of the invention, attenuating comprises to lower the signal strength of the pertaining signal component to a positive value or to zero.

The separation realized by the amplifier circuitry provides distinct gains for the AC component and for the DC component. One single amplifier component can be used for providing both, the DC component and the AC component and the respective output terminals. The distinct gains for the AC component and the DC component are used to at least partly compensate the difference of the signal strengths of the components, which enables to process both signals with one circuitry, in particular with an amplifier element amplifying both components simultaneously. By providing these distinct gains for the AC component and the DC component, the output of the signal components can be separated, however, using one common circuitry which processes both components in a combined AC/DC signal. The distinct gains mutually adapt the distinct signal strengths of the AC and DC components and, in particular, lower the signal strengths of the stronger signal. The stronger signal, in particular the AC component, is amplified with a lower gain as compared to the weaker signal, in particular the DC component. This in particular relates to the DC terminal.

By using the inventive separation based on frequency separation, any switching can be obviated which would be necessary when separating the components for providing distinct gains using a switching circuitry as proposed by the prior art. Further, no additional noise or clipping occurs, even if the signal strengths of the AC and the DC component significantly differ from each other.

Therefore, an amplifier circuitry is provided for a combined AC/DC signal of an electrochemical sensing electrode, in particular the working electrode of a sensor assembly of a potentiostat. As already mentioned, the AC/DC signal comprises two components, the AC component and the DC component. The signal magnitude of the DC component is significantly lower than the magnitude of the AC component. The combined AC/DC signal can be provided as voltage or, more preferably, as an electrical current. The inventive amplifier circuitry is adapted to be connected to a working electrode of a potentiostat at the ground terminal or, alternatively, can be provided at the counter electrode of a potentiostat. The amplifier circuitry comprises an amplifier element, preferably a semiconductor amplifier element, in particular in form of an integrated circuit. Advantageously, an operational amplifier is used, for example a low noise and/or low supply voltage operational amplifier. The amplifier element has a gain bandwidth of at least 50 kHz, 100 kHz, 500 kHz or 1 MHz.

The amplifier circuitry further comprises an input terminal adapted to receive an input signal being based on the combined signal. The input terminal of the amplifier circuitry (or an input of an amplifier element of the amplifier circuitry) can be directly connected to the electrochemical sensing electrode, or additional electrical components like a resistor can be provided which are connected between the input terminal (or the input of the amplifier element) and the electrochemical sensing electrode, or the respective electrode ports adapted to be directly connected with the sensing electrode. In a particular embodiment, the input terminal of the amplifier circuitry is directly connected to an input of the amplifier element; an alternative comprises a resistor of less than 1 kOhm, preferably less than 10 Ohm, connected input of the amplifier element. In particular, no signal processing stage like an amplification stage is connected between electrode and input terminal (or input of the amplifier element). A serial resistor between electrode and input terminal (or input of the amplifier element) as given above is not regarded as signal processing stage since its function lies in a current limitation only. However, in particular if used for amplifying a glucose sensor signal, the electrode is directly connected to the input terminal (and to an input of the amplifier element). The input terminal may comprise a plug contact, in particular for receiving a corresponding plug contact element of the electrochemical sensing electrode.

The amplifier circuitry further comprises a DC output terminal connected to the amplifier element, in particular to an output of the amplifier element. The DC output terminal can be directly connected to the amplifier element or can be directed to the amplifier element via output circuitry, for example comprising a resistor connected in series to the amplifier element, in particular to the output of the amplifier element. The amplifier element is connected to provide a DC component of the combined signal to the DC output terminal. Such a connection can be provided as given above by a direct or indirect connection between the DC output terminal and an output of the amplifier element. A capacitor can be connected in parallel to the DC output terminal or to the output of the amplifier element and ground. Further, an inductivity can be provided connected in series downstream the output of the amplifier element or upstream the DC output terminal. Such a capacitor or inductivity can be utilized for smoothing, i.e. for removing residual AC signals from the DC component. In addition, other output low pass filters instead or in combination with such a capacitor or inductivity can be used, in particular active or passive filters of a degree N, N preferably being at least 1, preferably 4 or more. Such an output low pass filter is described further below.

According to the invention, the amplifier circuitry further comprises an AC output terminal connected to the amplifier element. The AC output terminal provides a signal corresponding to the DC component of the combined AC/DC signal. The amplifier element is connected to provide the AC component of the combined signal to the AC output terminal. In particular, the amplifier element is connected to provide an AC component corresponding to the AC component of the AC/DC signal. Further, the amplifier circuitry provides a low pass transmission characteristic between the input terminal and the DC output terminal. At the DC output terminal, a DC component is provided corresponding to the DC component of the AC/DC signal. Since the DC component at the DC output terminal and the AC component at the AC output terminal reflect or correspond to the respective components within the AC/DC signal at the input terminal, the same terminology is used.

The low pass transmission characteristic is provided by the connection of the amplifier element within the amplifier circuitry. In particular, auxiliary electric or electronic elements being part of the inventive amplifier circuitry are connected to the amplifier element in order to provide the low pass transmission characteristic between the input and the DC output terminal. The auxiliary components connected to the amplifier element can be regarded as frequency selective circuitry which provides the low pass transmission characteristic. The frequency selective circuitry comprises at least one frequency selective component, e.g. a capacitor or an inductivity. The low pass transmission characteristic attenuates the AC signal component. In particular, the low pass transmission characteristic provides a higher attenuation for the AC component in comparison to the DC component or provides a lower gain for the AC component in comparison to the DC component. In this way, the invention allows to separate the DC component from the AC component.

Therefore, according to an embodiment of the invention, the amplifier circuitry further comprises a frequency selective circuitry connected to the amplifier element. This enables the amplifier circuitry to provide the low pass transmission characteristic between the input terminal and the DC output terminal. The frequency selective circuitry and the amplifier, and in particular their interconnection, provide the low pass characteristic.

The amplifier element is connected to provide the DC component of the combined signal to the DC output terminal with a first gain. Further, the amplifier is connected to provide the AC component of the combined signal to the AC output terminal with a second gain. The second gain is distinct from the first gain. In particular, the second gain is lower than the first gain. This allows to adapt the distinct magnitudes of the AC and the DC component to each other. This, in turn, allows to simultaneously amplify both components by one common single amplifier element.

Advantageously, the amplifier circuitry is adapted to provide the AC component also to the DC output terminal. This allows for simple realizations of the amplifier circuitry. The AC component is provided to the DC output terminal with a gain (which can be denoted as crosstalk gain) distinct to and preferably lower than the gain (i.e. the first gain) for the DC component provided to the DC terminal. As an effect, the AC component is also present at the DC output terminal, however, with an adapted gain or strength. In particular, the crosstalk gain reduces the differences between the AC and the DC component appearing at the DC output terminal. In consequence, the DC component at the DC output terminal can easily be separated for from the AC component at the DC output terminal for further evaluation purposes, e.g. by an output low pass filter. The output low pass filter blocks high frequency components. Since the AC component is provided with a lower gain at the DC output terminal in comparison the DC component at the DC output terminal, further signal processing is simplified and in particular, the risk of clipping the AC component or of neglecting the DC component with regard to the AC component during further signal processing is excluded.

Since the DC component in the combined AC/DC signal at the input terminal of the amplifier of the amplifier circuitry is lower than the magnitude of the AC component of the signal at the input terminal, the second gain is lower than the first gain in order to at least partly compensate these distinct magnitudes. In a particular embodiment, the ratio between the first and the second gain corresponds approximately to the ratio of the magnitude of the AC component versus the magnitude of the DC component at the input terminal, wherein the magnitudes of the AC and the DC components at the input terminal are magnitudes typically occurring at the combined AC/DC signal at normal operation and as given by the design of the sensing device for which the amplifier circuitry is used. According to a particular embodiment, the ratio between the first gain and the second gain is greater than 1 and preferably at least 2, at least 10 at least 20, or at least 100 or 200. The first gain refers to frequencies below a transition frequency of the low pass transmission characteristic and preferably to signals with a frequency below 1 Hz or preferably 0.1 Hz. The features of the second gain also apply to the crosstalk gain as described above.

According to a further embodiment of the invention, the frequency selective circuitry is provided by a capacitor connected in series in a feedback loop. The feedback loop is connected to the amplifier element and, in particular, forms auxiliary elements connected to the amplifier element. The feedback loop connects an output of the amplifier element and an inverting input of the amplifier element. In this regard, the amplifier element is advantageously an operational amplifier with an inverting input and, preferably, a non-inverting input. The feedback loop defines the behavior of the amplifier element. The feedback loop together with the amplifier element provides an active low pass filter of order 1. Further, the feedback loop is connected to the amplifier element providing the amplifier element as inverting amplifier. In general, also other frequency selective circuitry can be provided within the feedback loop as long as the feedback loop and its connection to the amplifier element provides the low pass transmission characteristic.

According to a particular embodiment, the amplifier circuitry comprises a T-type attenuator circuit. At least a part of the components of the T-type attenuator circuit are part of the feedback loop. A serial feedback transistor, e.g. a serial feedback transistor as described further below and a feedback loop pull-down resistor, e.g. a serial feedback transistor as described further below, are connected in series and form the serial branches of the T-type attenuator circuit. A capacitor (or, in general, a frequency selective component as described herein) is connected in parallel and forms the parallel branch of the T-type attenuator circuit. The serial branch of the T-type attenuator circuit provided by the serial feedback resistor and the parallel branch are serially connected within the feedback loop. The serial branch of the T-type attenuator circuit provided by the feedback pull-down resistor connects the feedback loop to a reference potential (e.g. ground) and can be regarded as forming a part of the feedback loop. The T-type attenuator circuit can be regarded as a form of a frequency selective circuitry to which the amplifier element is connected.

The DC output terminal is preferably connected to the feedback loop, in particular downstream the frequency selective circuitry as seen from an output of the amplifier element to which the frequency selective circuitry is connected. According to an embodiment of the invention, the inverting input of the amplifier element is connected to the input terminal, preferably in a direct way. The output of the amplifier element is connected to the DC output terminal, also preferably in a direct way. Alternatively, these connections can comprise a resistor connected in series. The AC output terminal is connected to a port of the capacitor opposite to a port of the capacitor connected to the output of the amplifier element. In general, the AC output terminal is connected to a port of the frequency selective circuitry downstream the frequency selective circuitry as seen from the output terminal. According to a corresponding aspect of the invention, the AC output terminal is connected to the feedback loop at the point of the feedback loop which does not correspond to one of the ends of the feedback loop. In an embodiment comprising a T-type attenuator circuit within the feedback loop, the DC output terminal is connected to the connection of both serial branch. In other words, the DC output terminal is connected to the junction of (at least one of) the serial branches and the parallel branch.

Further, with respect to components of the feedback loop, in another embodiment, the feedback loop further comprises a serial feedback resistor. The serial feedback resistor is connected between the inverting input and the frequency selective circuitry, in particular the capacitor representing or pertaining to the frequency selective circuitry. The serial connection of the serial feedback resistor and the frequency selective circuitry (preferably the capacitor) close the feedback loop between the inverting input and the output of the amplifier element. Additionally or alternatively, a parallel resistor is connected in parallel to the frequency selective circuitry, in particular the capacitor. Further, the parallel resistor is connected in series to the serial feedback resistor. The AC output terminal is provided by or connected to the connection between the frequency selective circuitry and the serial feedback resistor.

In particular, the gain for the DC output terminal is proportional to the serial connection of the parallel resistor and the serial feedback resistor, ie. proportional to the sum of these resistors, for the DC component within the combined AC/DC signal. For the DC component, the frequency selective circuitry, in particular a capacitor, can be regarded as open loop and can be neglected. For the AC component within the combined AC/DC signal, the frequency selective circuitry, in particular a capacitor can be regarded as short circuit bypassing the parallel resistor. For the AC component, the gain for the DC output terminal is proportional to the serial feedback resistor while the parallel resistor is short-circuited by the frequency selective circuitry, in particular by the capacitor. The factor by which the second gain is lower than the first gain is proportional to the ratio of the serial feedback resistor and the sum of the serial feedback resistor and the parallel resistor. Thus, this factor representing the low pass transmission characteristic can be easily set on a desired value by choosing the parallel resistor and/or the proportion of the parallel resistor with regard to the serial feedback transistor. A gain transition frequency denoting the limit frequency separating the DC component from the AC component can be selected by selecting the frequency selective circuitry, in particular the capacitor, with regard to the parallel resistor and/or the serial feedback resistor.

In a particular realization of the invention, the feedback loop connecting the inverting input and the output of the amplifier element consists of a serial feedback resistor in series to a parallel connection of the frequency selective circuitry (for example the capacitor) and the parallel resistor. In this realization, the parallel resistor as well as the capacitor are connected to the output of the amplifier element and the serial feedback resistor is connected to the inverting input of the amplifier element. Generally, the frequency selective circuitry can be provided by one single element, for example a capacitor, or by a plurality of components, e.g. a T-type attenuator circuit (in particular an asymmetric T-type attenuator circuit as regards the values of the serial branches) or a corresponding Π -type attenuator circuit. The frequency selective circuit has a negative reactance.

According to a further aspect of the invention concerning the connection of the amplifier element, the amplifier element further comprises a non-inverting input. An input pull-down resistor connects the non-inverting input to a reference potential, in particular to a mass potential or a ground potential of the amplifier circuitry. The non-inverting input and the inverting input are complementary to each other. The amplifier element comprising the inverting input and the non-inverting input amplifies the voltage difference between the non-inverting input and the inverting input according to an internal gain of the amplifier element.

Further, the amplifier circuitry comprises a feedback loop pull-down resistor which is connected to the feedback loop and the reference potential, in particular to the mass potential or to ground potential. The feedback loop pull-down resistor connects the reference potential as given above and the port of the frequency selective circuitry, preferably a capacitor, opposite to the port of the frequency selective circuitry or capacitor connected to the output of the amplifier element. In other words, the feedback loop pull-down resistor connects the reference potential with a connection connecting the frequency selective circuitry and the serial feedback resistor within the feedback loop. In another view, the feedback loop pull-down resistor is connected between the AC output terminal of the amplifier circuitry and a reference potential of the amplifier circuitry, in particular mass potential or ground potential. As given above, the serial feedback resistor can form a serial branch of a T-type attenuator circuit, in particular a left branch or an input branch thereof.

In further embodiments, the low pass transmission characteristic is provided with a certain low pass transition frequency. Accordingly, the low pass transmission characteristic has a transition frequency of less than 100 Hz, preferably less than 10 Hz and most preferably less than 5 Hz. In further embodiments, the transition frequency is less than 2 Hz or less than 1 Hz. The low pass transmission characteristic is preferably of order 1 or can be of higher order. According to the low pass transmission characteristic, the frequency specific gain is a function of the frequency, wherein this function is a strictly decreasing function. For increasing frequencies, the gain or attenuation of the low pass transmission characteristic approximates a constant value (i.e. a limit). The constant value can be a value greater than zero or approximately zero, in particular in case that the serial feedback resistor is very low.

According to a further aspect of the invention, an output low pass filter is connected downstream the DC output terminal. This allows to further suppress undesired residual AC signals within the amplified DC component at the DC output terminal. The output low pass filter provides a filtered output terminal at which an additionally filtered DC component is provided. The output low pass filter has a low pass filter characteristic of degree 4 or higher. Alternatively, the output low pass filter has a low pass filter characteristic of lower degree, i.e. degree 2 or 1. The degree of the filter characteristic can depend on the particular application of the inventive amplifier circuitry. In particular, the amplifier circuitry is provided with an output low pass filter, in case that the constant value mentioned above with regard to the low pass transmission characteristic is greater than zero.

A particular aspect of the inventive amplifier circuitry is the form of the input signal and the output signal. Preferably, the amplifier element is connected as current amplifier, wherein the combined AC/DC signal at the input terminal is provided as a current. The signals at the output terminals are provided as voltages. Further, the feedback loop provides a current feedback. The amplifier circuitry is adapted for a current as at the input signal, particularly received by the input terminal. Further, the amplifier circuitry is adapted for providing voltages as the AC and DC components as output, preferably at the AC and DC output terminal, respectively. The connection of the amplifier element and the input terminal are connected to provide a low input impedance for the input terminal. Such a low input impedance for the input terminal can be provided by a low resistance of the input pull-down resistor. Further, this low input impedance is provided by the feedback loop which results in the effect that the output potential follows the potential of the inverting input. In this regard, the feedback loop urges the inverted input to follow the non-inverted input, which, in turn, is connected to a reference potential (for example ground) via a low resistance input pull-down resistor. In particular, the amplifier element is connected within the amplifier circuitry as an amplifier amplifying an input current as combined AC/DC signal. Preferably, the amplifier element is connected within the amplifier circuitry as current feedback operational amplifier, in particular as current-to-voltage converter, and amplifies the combined AC/DC signal into voltages as AC and DC components. The amplifier element is connected within the amplifier circuitry as transimpedance amplifier. The amplifier circuitry itself can be provided as transimpedance amplifier and in particular as current feedback operational amplifier or current-to-voltage converter.

Both pull-down resistors or one of the pull-down resistors is provided with a low resistance, for example less than 10 kOhm, less than 1 kOhm or less than 500 Ohm. The serial feedback resistor and/or the parallel resistor are provided with substantially higher resistance values, in particular at least 50 kOhm, 100 kOhm or more. Typically, the serial feedback resistor and/or the parallel resistor each have a resistance which is higher than the resistance of the pull-down resistors by a factor of at least 500, 800, 1000 or 2000.

The frequency selective circuitry is preferably provided with a time constant greater than 10 ms, 50 ms, 100 ms and preferably more than 0.5 or 1 second.

The invention is further provided by a potentiostat comprising the inventive amplifier circuitry. Further, the potentiostat comprises a driving circuitry and a signal generator. The signal generator is adapted to provide a driving signal comprising a DC component and an AC component. The signal generator is connected to an input of the driving circuitry, preferably to a non-inverting input of the driving circuitry. The driving signal is used to excite electrodes of a sensor electrode arrangement. In particular, the driving signal, after being processed by the driving circuitry, is provided at a counter electrode terminal and a working electrode terminal of the potentiostat. At these terminals, a counter electrode and a working electrode can be connected, wherein these electrodes are part of the sensor electrode arrangement. The inventive amplifier circuitry, as a part of the potentiostat, can be provided at the counter electrode terminal and more preferably at the working electrode terminal. In particular, the input terminal of the inventive amplifier circuitry is the working electrode terminal. In another, modified embodiment, the input terminal of the amplifier circuitry is the counter electrode terminal, wherein the connection of the amplifier circuitry within the amplifier circuit is adapted to this modification.

In addition, the invention is provided by a sensor system for electrochemically measuring analyte in a liquid. This sensor system comprises the potentiostat as given above as well as a electrochemical sensing electrode for the attachment of which the amplifier circuitry is adapted to. The electrochemical sensing electrode of the sensor system is provided as a working electrode of the sensor electrode arrangement connectable to the potentiostat. Further, the electrochemical sensing electrode is electrically connected to the input terminal of the amplifier circuitry. Advantageously, the sensor system comprises the potentiostat as well as the sensor electrode arrangement.

Such a sensor system comprises components for exciting the sensor, i.e. the driving circuitry, as well as components for measuring the results in form of the amplifier circuitry. Further, the sensor system comprises components for applying the driving signal to a liquid which is to be measured.

According to a particular embodiment of the inventive sensor system, the sensor electrode arrangement further comprises a counter electrode electrically connected to an output of the driving circuitry. The counter electrode carries the driving signal. Advantageously, the sensor electrode arrangement further comprises a reference electrode. The reference electrode is connected to an inverting input of the driving circuitry.

According to a preferred application, the electrochemical sensing electrode and in particular the sensor electrode arrangement are provided for glucose level measurement in blood. The electrochemical sensing electrode and in particular the sensor electrode arrangement can be provided as implantable components, in particular for subcutaneous or intracutaneous application.

The DC component is used to measure a voltage reflecting a blood glucose level. The AC component is used to measure an impedance reflecting an operational status of the sensor electrode arrangement, in particular in order to assess whether the sensor system is operating within normal parameters.

Brief Description of the Drawings:

Further details or features of the invention are given by the following description of preferred embodiments, in particular in connection with the dependent claims. The respective features can be realized independently or as a combination of at least two features. The invention is not delimited by the given embodiments. The embodiments are schematically drawn in the figures. Identical reference signs in the respective figures relate to the same or functionally corresponding elements.

Figure 1 shows an exemplary embodiment of the inventive amplifier circuitry,

Figure 2 shows an inventive sensor system comprising a potentiostat as well as the amplifier circuitry according to the invention,

Figure 3a shows an equivalent circuit of the inventive amplifier circuitry in case of a frequency of 0 Hz and

Figure 3b shows an equivalent circuit of the inventive amplifier circuitry in case of an infinite frequency.

Embodiments of the Invention

Figure 1 shows an embodiment of the inventive amplifier circuitry 10. The amplifier circuitry comprises an amplifier element 20 in form of an operational amplifier. Further, the amplifier circuitry 10 comprises an input terminal 30 adapted to be connected to an electrochemical sensing electrode (not shown). Further, a DC output terminal 32 is provided as well as an AC output terminal 34. The operational amplifier 20 comprises an inverting input 24 connected to the input terminal 30, a non-inverting input 26 as well as an output 22 connected to the DC output terminal 32. Further, the operational amplifier comprises supply voltage terminals 28a and 28b connected to potentials 82 and 84 of a voltage supply. The amplifier circuitry 10 shown in Figure 1 further comprises a feedback loop 50 which comprises a capacitor 40 providing a frequency selective circuitry (or at least a part thereof), a parallel resistor 62 and a serial feedback resistor 60. The parallel resistor 62 is connected in parallel to the capacitor 40. The serial feedback resistor 60 is connected in series to the capacitor 40 and the parallel resistor 62. Further, the serial feedback resistor 60 is connected to the inverting input 24. The capacitor 40 comprises a port 44 which is connected to the output 22 of the operational amplifier 20 as well as a port 42 opposite thereof. The port 42 opposite to the port 44 connected to the output 22 of the operational amplifier 20 is connected to the serial feedback resistor 60.

The amplifier circuitry further comprises an input pull-down resistor 70 which connects the non-inverting input 26 of the operational amplifier 20 to a reference potential 80, which is identical to ground. The voltage supply potentials 82 and 84 of the operational amplifier 20 are symmetrical to the reference potential 80. Further, a feedback loop pull-down resistor 72 is provided, which connects port 42 of capacitor 40 to the reference potential 80, i.e. to ground. An AC output terminal 34 of the amplifier circuitry 10 is provided, which is connected to the port 42 of capacitor 40, i.e. connected to the port 42 opposite to the port 44 of the capacitor 40, which is connected to the output 22 of the operational amplifier 20. Further, it can be seen from Figure 1 that the feedback loop pull-down resistor 72 is connected between the AC output terminal 34 and the reference potential 80. In addition, the serial feedback resistor 60 is connected to the reference potential 80 via the feedback loop pull-down resistor 72.

Capacitor 40, in particular in combination with the parallel resistor 62, can be regarded as a high pass connecting the output port 22 of the operational amplifier 20 to ground 80 via the feedback loop pull-down resistor 72 for high frequency components. According to this, as shown in Figure 3b, in case of a combined AC/DC signal at the input terminal 30 with an infinite frequency, the capacitor 40 has no ohmic resistivity, so that the current flows only through the bypass 40b and will bypass the parallel resistor 62. Therefore, the value of the AC component at the AC output terminal 34 is equal to the DC component at the DC output terminal 32 and both can be considered as the inverted input current times ohmic resistivity of the feedback resistor 60. Otherwise, for low frequency components, the influence of capacitor 40 can be neglected. For example the equivalent circuit in case of a DC signal at the input terminal 30 with a frequency of 0 Hz is shown in Figure 3a. In this case the capacitor 40 has an infinite ohmic resistivity, so that the current flows only through the parallel resistor 62. Therefore, the equivalent circuit will be without the capacitor 40a and the value of the DC component at the DC output terminal 32 can be considered as the inverted input current times the ohmic resistivity of the feedback resistor 60 times the ohmic resistivity of the parallel resistor 62 divided by the ohmic resistivity of the feedback loop pull-down resistor 72. The value of the AC component at the AC output terminal 34 can be considered as the inverted input current times the ohmic resistivity of the feedback resistor 60.

Since capacitor 40 corresponds to a (nearly) open circuit for the DC component, the DC output terminal 32 is provided with a high gain for low frequency components, i.e. for DC components. For high frequency components, i.e. for the AC component, the impedance of capacitor 40 becomes very small and the connection of the capacitor 40 and the parallel resistor 62 becomes negligible compared to the serial feedback resistor 60. This determines a gain for the AC component lower than the gain for the DC component.

Further, the serial feedback resistor 60 can be regarded as a left serial branch or input branch of a T-type attenuator circuit. Further, the feedback loop pull-down resistor 72 can be regarded as a right serial branch or output branch of the T-type attenuator circuit. In addition, the capacitor 40, and preferably the combination of the capacitor 40 and the parallel resistor, can be regarded as parallel branch of the T-type attenuator circuit. The T-type attenuator circuit or at least the input branch and the parallel branch forms the feedback loop. The right branch connects the feedback loop with a reference potential 80 (i.e. ground). The right branch drains AC signal components within the feedback loop to ground.

The circuitry shown in figure 1 is adapted to receive a current as the combined AC/DC signal at the input terminal 30 and to provide voltages as AC and DC components at the AC and DC output terminals 32 and 34. The circuitry shown in figure 1 is a current-feedback operational amplifier.

In the current example, serial feedback loop resistor 60 is 100 kOhm, parallel resistor 62 is 100 kOhm, the input pull-down resistor 70 is 100 Ohm and the feedback loop pull-down resistor 72 is 300 Ohm. As can be seen, the values of the pull-down resistors are significantly smaller than the resistor values of the resistors 60 and 62 within the feedback loop. This individually applies to each of the pull-down resistors. The capacitor 40 is 1 µF. In particular, the time coefficient for the parallel resistor 62 parallel to the capacitor 40 is $2\pi * 0.1$ s.

Of course, the values can significantly differ from the example given in Figure 1. However, the values of the pull-down resistors are smaller than the values of the resistors 60 and 62 within the feedback loop by a factor of more than 200, more than 300 or more than 500, preferably about 1000. The input pull-down resistor 70 defines the input impedance for the input terminal 30. Further, the values of the resistors 60 and 62 and the value of the feedback loop pull-down resistor 72 define the transmission characteristic for the AC output terminal 34 and the DC output terminal 32 with respect to the input terminal 30. In particular, the transmission characteristic is defined by the capacitor 40 and in particular by the parallel combination of capacitor 40 and parallel resistor 62. In particular, the transition frequency of the low pass transmission characteristic is defined by the relationship of the values of capacitor 40 and the value of the parallel resistor 62 as well as the value of feedback loop pull-down resistor 72.

In a modified embodiment based on the embodiment shown in Figure 1, an output low pass filter 90 is provided which provides a filtered output terminal 92. The optional output low pass filter is connected in series between its filtered output terminal and the DC output terminal 32. In an exemplified embodiment, the output low pass filter is a low pass filter of order 4. The output low pass filter can be an active or a passive filter.

In Figure 2, a typical application of the inventive amplifier circuitry is shown, wherein Figure 2 shows a sensor system for electrically measuring analyte in a liquid 200. The sensor system comprises a potentiostat 210 being provided with driving circuitry 220 and a signal generator 230. The signal generator 230 is adapted to provide a driving signal which comprises both, a DC component as well as an AC component, to a sensor electrode arrangement of the sensor system. The signal generator 230 is connected between a reference potential 280, in particular ground, and a non-inverting input of the operational amplifier providing the driving circuitry 220. A plurality of electrodes provided by the sensor electrode arrangement and being part of the sensor system is connected to the potentiostat 210. The plurality of electrodes of the sensor system comprises a counter electrode 132 connected to an output of the driving circuitry 220 of the potentiostat, a reference electrode 134 connected to the inverting input of the driving circuitry 220 of the potentiostat 210 as well as a working electrode 130. The reference electrode 134 is encompassed by the working electrode 130, in which the concentration of an analyte 200 is measured. The working electrode 130 is depicted in form of a receptacle. However, the presentation of the liquid and the electrodes is only symbolically.

The working electrode 130 is connected to the input port 30 of the inventive amplifier circuitry 10. Further, the amplifier circuitry 10 is connected to a reference potential 80, in particular, ground. The reference potential 280 to which the signal generator 230 is connected, is identical to the reference potential 80 to which the inventive amplifier circuitry is connected to.

Reference Signs

10	amplifier circuitry
20, 220	amplifier element
22	output of the operational amplifier
24, 26	inverting/non-inverting input of the operational amplifier
28a, 28b	supply voltage terminals of the operational amplifier
30	input terminal
32	DC output terminal
34	AC output terminal
40	frequency selective circuitry, capacitor
40a	capacitor at a frequency of 0 Hz
40b	capacitor at an infinite frequency, bypass
42, 44	ports of the capacitor
50	feedback loop
60	serial feedback resistor
62	parallel resistor
70	input pull-down resistor
72	feedback loop pull-down resistor
80, 280	reference potential
82, 84	supply voltage potentials
90	output low pass filter
92	filtered output terminal
130	working electrode
132	counter electrode
134	reference electrode
200	liquid
210	potentiostat
220	driving circuitry
230	signal generator

Claims

1. Amplifier circuitry (10) for a combined AC/DC signal of an electrochemical sensing electrode (130), the amplifier circuitry comprising:
an amplifier element (20);
an input terminal (30) adapted to receive an input signal being based on the combined signal, the input terminal (30) being connected to the amplifier element (20);
a DC output terminal (32) connected to the amplifier element (20), wherein the amplifier element is connected to provide a DC component of the combined signal to the DC output terminal (32),
characterized in that
the amplifier circuitry (10) further comprises an AC output terminal (34) connected to the amplifier element (20), wherein the amplifier element (20) is connected to provide an AC component of the combined signal to the AC output terminal (34), wherein the amplifier circuitry (10) provides a low pass transmission characteristic between the input terminal (30) and the DC output terminal (32).

2. Amplifier circuitry according to claim 1, further comprising a frequency selective circuitry (40) connected to the amplifier element (20), the frequency selective circuitry and the amplifier element (20) providing the low pass characteristic, wherein the amplifier element is connected to provide the DC component (32) of the combined signal to the DC output terminal (32) with a first gain and the amplifier element is connected to provide the AC component of the combined signal to the AC output terminal (34) with a second gain distinct to and in particular lower than the first gain and/or wherein the amplifier element is connected to provide the AC component of the combined signal to the DC output terminal (32) with a crosstalk gain distinct to and preferably lower than the first gain.

3. Amplifier circuitry according to claim 1 or 2, wherein the frequency selective circuitry (40) is provided by a capacitor connected in series in a feedback loop (50), the feedback loop (50) connecting an output (22) of the amplifier element (20) and an inverting input (24) of the amplifier element.

4. Amplifier circuitry according to claim 3, wherein the inverting input (24) of the amplifier element is connected to the input terminal (30), wherein the output (22) of the amplifier element is connected to the DC output terminal (32), and wherein the AC output terminal (34) is connected to a port (44) of the capacitor opposite to a port (42) of the capacitor connected to the output (22) of the amplifier element.

5. Amplifier circuitry according to any of claims 3 or 4, wherein the feedback loop further comprises a serial feedback resistor (60) connected between the inverting input (24) and the frequency selection circuitry (40) and wherein a parallel resistor (62) is connected in parallel to the frequency selective circuitry (40) and in series to the serial feedback resistor (60).

6. Amplifier circuitry according to any of claims 3 - 5, wherein the amplifier element further comprises a non-inverting input (26), wherein an input pull-down resistor (70) connects the non-inverting input to a reference potential (80), in particular to a mass potential of the amplifier circuitry and wherein the amplifier circuitry further comprises a feedback loop pull-down resistor (72), which connects the reference potential (80), in particular the mass potential, and the port (42) of the capacitor (40) opposite to the port (44) of the capacitor connected to the output (22) of the amplifier element (20).

7. Amplifier circuitry according to any of claims 1 - 6, wherein the low pass transmission characteristic has a transition frequency of less than 100 Hz, preferably less than 10 Hz and most preferably less than 5 Hz.

8. Amplifier circuitry according to any of claims 1 - 7, wherein an output low pass filter (90) is connected downstream the DC output terminal (32), wherein the output low pass filter (90) provides a filtered output terminal (32) and wherein the output low pass filter has a low pass filter characteristic of degree 4 or higher.

9. Amplifier circuitry according to any of claims 1 - 8, wherein the amplifier element (20) and the input terminal (30) are connected and provide a low input impedance for the input terminal, and wherein the amplifier circuitry (10) is adapted for a current as the input signal and is adapted for providing voltages as the AC and DC components as output.

10. Potentiostat (210) comprising the amplifier circuitry (10) according to any of claims 1 - 9 as well as driving circuitry (220) and a signal generator (230) adapted to provide a driving signal comprising a DC component and an AC component.

11. Sensor system for electrochemically measuring analyte in a liquid (200), comprising the potentiostat (210) according to claim 10 as well as the electrochemical sensing electrode, which is provided as a working electrode (130) of the potentiostat (210) and is electrically connected to the input terminal (30) of the amplifier circuitry (10).

12. Sensor system of claim 11, further comprising a sensor electrode arrangement comprising the working electrode and a counter electrode (132) electrically connected to an output of the driving circuitry (220) carrying a driving signal, the sensor electrode

arrangement preferably further comprising a reference electrode (134) connected to an inverting input of the driving circuitry.

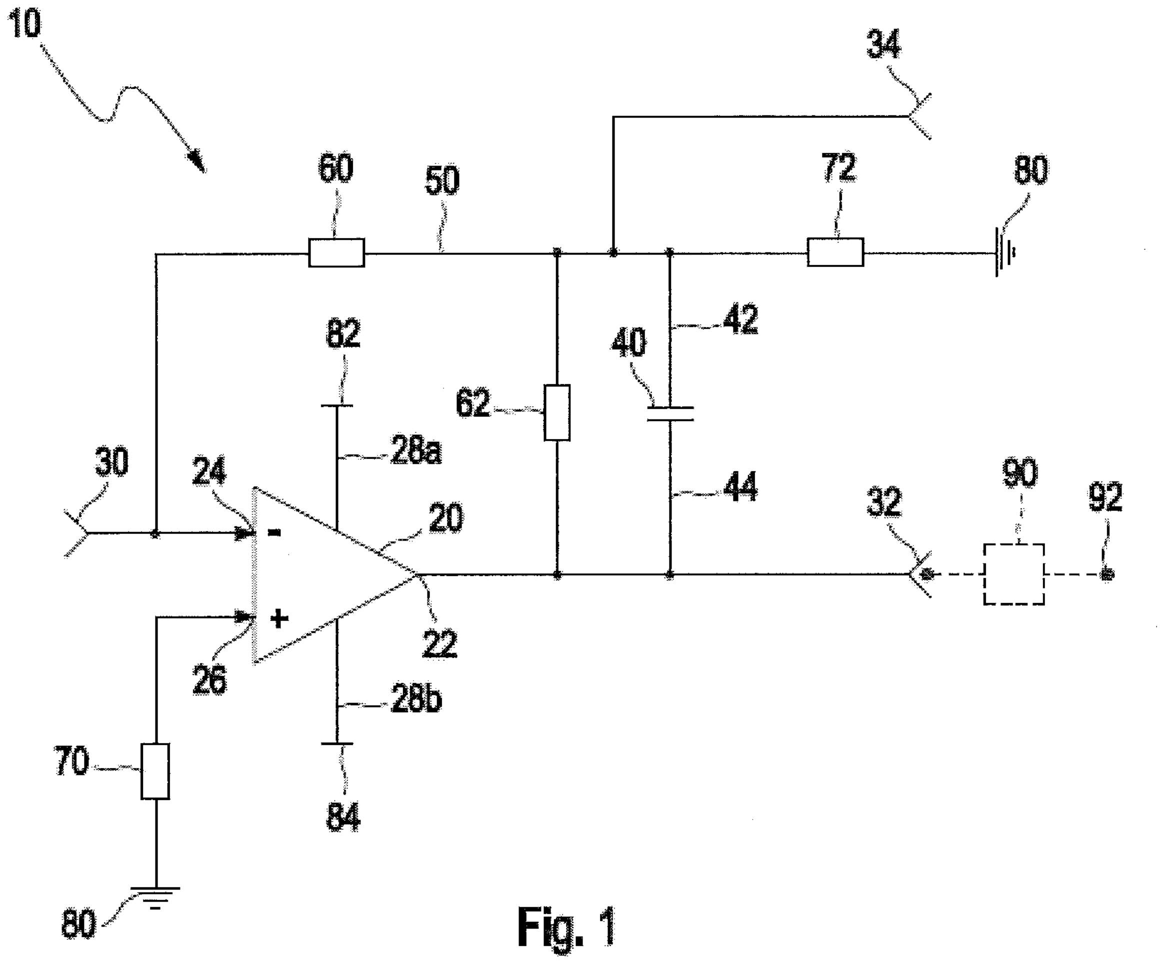
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Fig. 1

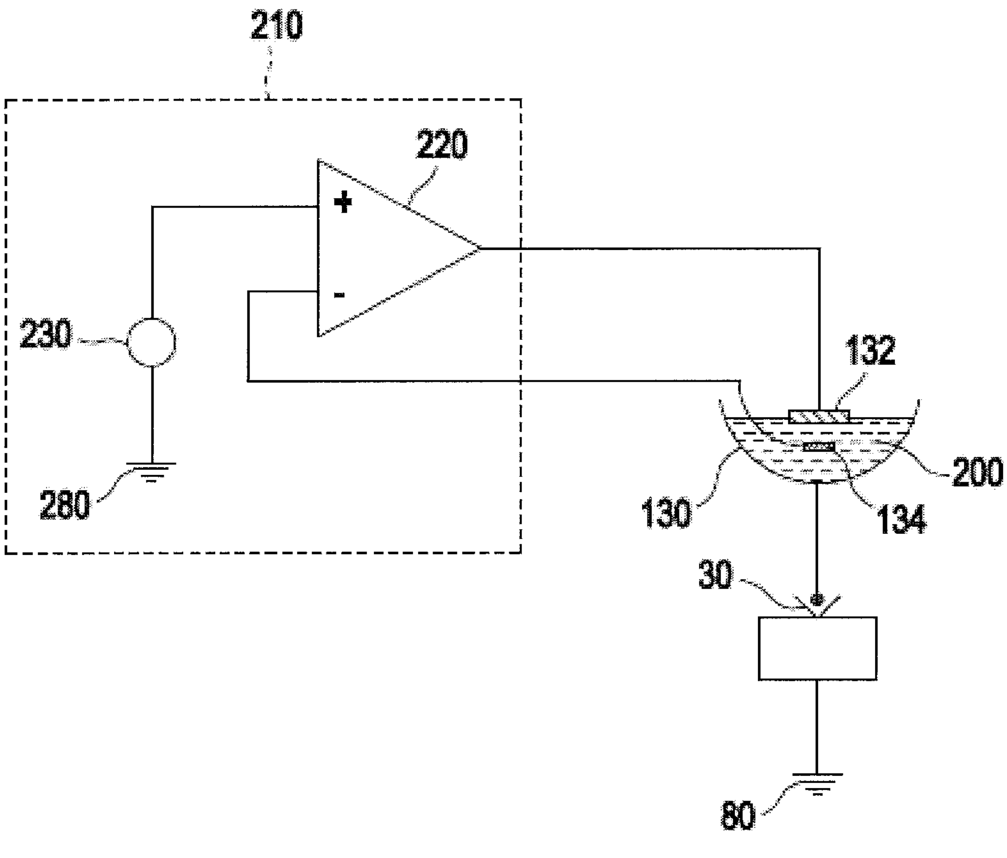
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Fig. 2

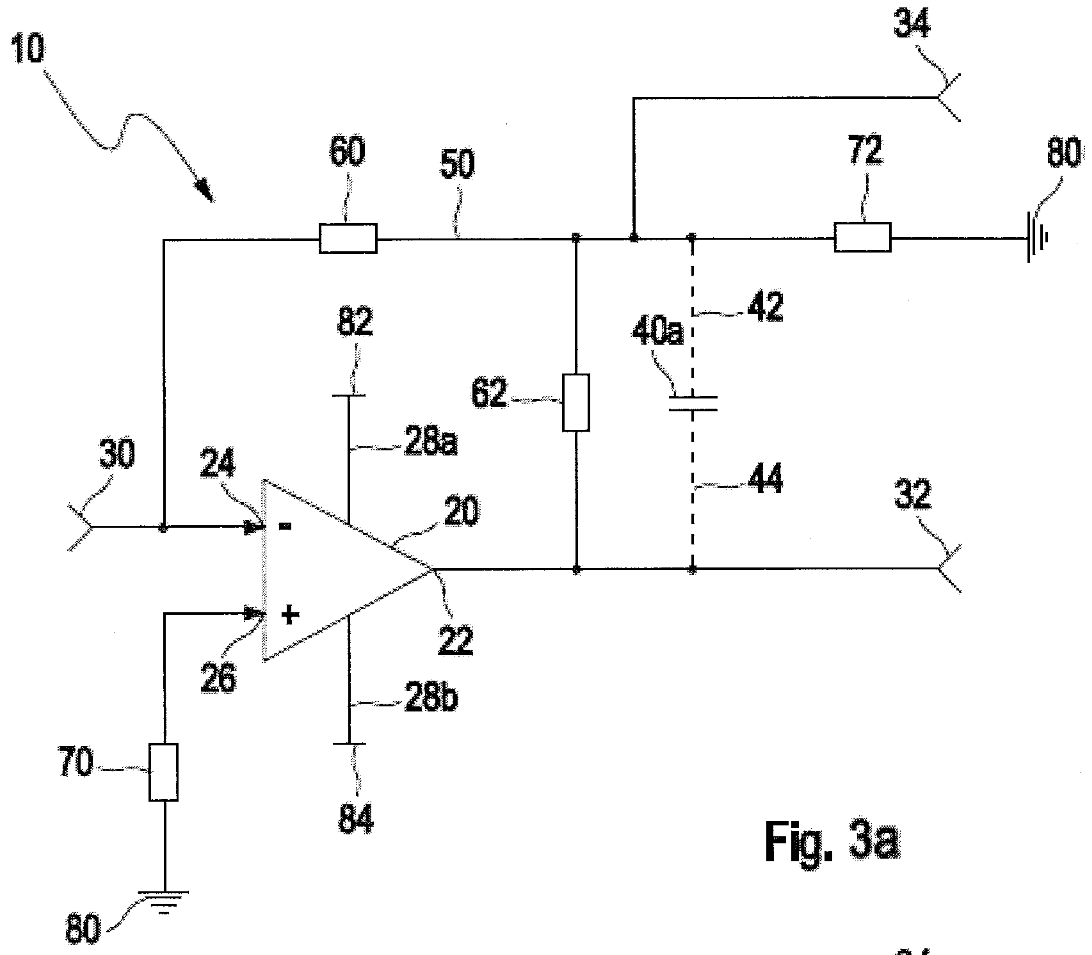
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Fig. 3a

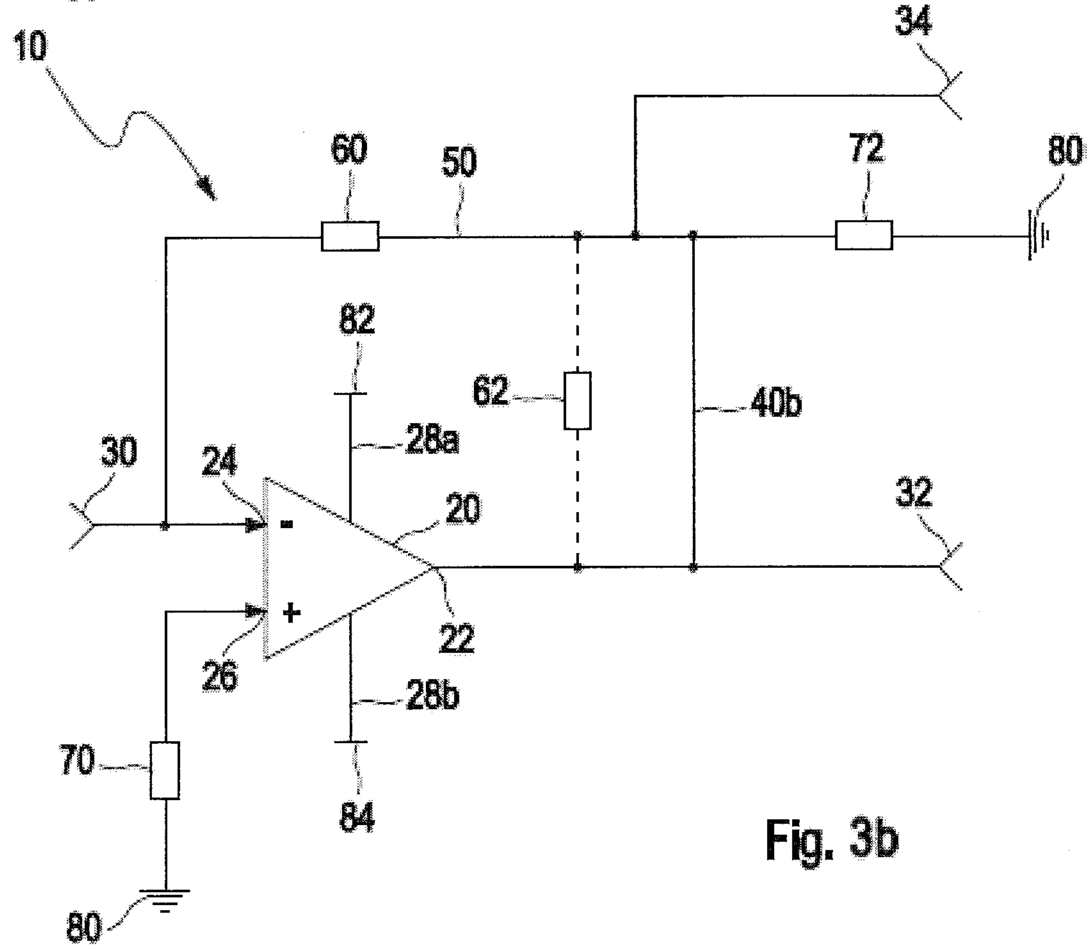
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Fig. 3b

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2013/050710

A. CLASSIFICATION OF SUBJECT MATTER
INV. H03F3/00 G01N27/327
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H03F G01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

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Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 682 884 A (HILL HUGH ALLEN OLIVER [GB] ET AL) 4 November 1997 (1997-11-04) column 11, line 16 - column 12, line 15; figure 12 -----	1-4,7-9
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	-/--	

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 June 2013	26/06/2013

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Kurzbauer, Werner

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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