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## HEARING AID AND A METHOD OF COMPENSATING MAGNETIC DISTORTION

The present invention relates to hearing aids. The invention further relates to a method of countering electromagnetic radiation from hearing aids. More particularly, the invention relates to circuits for the power supply of a hearing aid. The invention, still more particularly, relates to a hearing aid that is partly powered by a capacitor having a large capacitance.

As used in this context, a hearing aid is understood as generally comprising an input transducer for transforming an acoustic input signal into a first electrical signal, a signal processor for generating of a second electrical signal based on the first electrical signal, an output transducer for conversion of the second signal into sound, and a battery for supplying energy to the signal processor.

Typically, a hearing aid has a housing holding the input and the output transducer, the battery and the signal processor. The housing is adapted to be worn, i.e. behind the ear, in the ear, or in the ear canal, and the output of the output transducer is led to the eardrum in a way that is well-known in the art of hearing aids. The processor will generally be adapted for processing the electric signal in order that the resulting acoustic output signal compensates a hearing deficiency of a user.

A hearing aid may comprise a telecoil, i.e. an antenna for picking up an electromagnetic signal, that may be processed and fed to the output transducer in order to provide an acoustic signal.

Most hearing aids are powered by a replaceable battery. Metal-air cells, such as zinc-air cells, are commonly used to power hearing aids because of their stable output voltage during their operating period. Metal-air cells use air to activate the cell. They are activated when air, in particular oxygen, is allowed to enter the cell. Prior to use, the battery is sealed with a pull-tab that covers one or more small openings that allow air to reach an air-cathode assembly within the cell. To activate the battery, the pull-tab is removed and air is allowed into the battery. The battery is then inserted into the hearing aid. The open-circuit voltage of a fresh zinc-air cell is typically 1.4 Volt. During use, the output voltage of the battery decreases slowly with time until the end of the battery life where the output voltage drops more rapidly. The life or operating period of the battery is the period within which the battery output voltage is greater than the minimum operating voltage of the circuit, the battery supplies. It is measured in ampere hours. In an analogue hearing aid, the minimum operating voltage is typically 0.9 Volt.

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Prior art hearing aids may have a battery alarm circuit that alerts the user when the output voltage of the battery falls below a certain threshold voltage. Thus, the threshold in an analogue hearing aid is typically 0.9 Volt.

DE 197 12 236 C1 discloses a hearing aid with telecoil, provided with a compensation coil for compensating magnetic interference.

DE 198 54 201 C2 discloses a hearing aid with telecoil, provided with a compensation coil for compensating magnetic interference.

The emergence of hearing aids with digital circuitry, e.g. digital signal processors, has increased the demands on batteries used to power hearing aids. For example, the digital circuitry does not operate at a supply voltage below 1.1 Volt. Also the current needed to supply the digital circuitry increases rapidly as a function of increasing output volume of the hearing aid, and transient currents drawn by the digital circuitry tend to be larger and of shorter rise and fall times than transient currents drawn by analogue circuitry. This means that users of digital hearing aids experience a shortened battery life and in some cases even an extremely shortened battery life. The transient currents induce electromagnetic fields, which, although tiny, may induce noise problems inside the electric components of the hearing aid.

It is an object of an embodiment of the present invention to provide a hearing aid having an electronic circuit with the capability of drawing only low transient currents with slow rise and fall times, in order that a battery powering the hearing aid exhibits an extended service life. It is a further object of an embodiment of the invention to reduce electromagnetic radiation from a hearing aid. It is a still a further object of an embodiment of the invention to counter noise problems inside a hearing aid.

In a first aspect, the invention provides a hearing aid comprising a housing, an input transducer for transforming an acoustic input signal into a first electrical signal, a signal processor means for compensating a hearing deficiency by generation of a second electrical signal based on the first electrical signal, an output transducer for conversion of the second signal into sound, an energy source for supplying energy to at least the signal processor and at least one capacitor characterized in that the at least one capacitor is coupled in parallel with the energy source for supply of transient currents drawn by the signal processor, and that the at least one capacitor comprises a super capacitor with a capacitance.

The signal processor may be a digital signal processor.

- 30 The capacitance of the at least one capacitor is preferably greater than 1 mF, more preferred greater than 4 mF, even more preferred greater than 10 mF, most preferred greater than 20 mF.

Preferably, the energy source is a metal-air battery, such as a zinc-air battery.

The at least one capacitor may comprise a fast super capacitor, e.g. an electrochemical double layer capacitor with a highly conductive polymeric, proton conductive electrolyte of the type disclosed in Technical Information, Bestcap a new dimension in "fast" supercapacitors, Scot

- 5 Tripp, AVX Ltd, Fleet, UK.

The terminals of the at least one capacitor are preferably connected across the battery terminals of the hearing aid.

- In another embodiment, the terminals of the at least one capacitor are connected to the signal processor in such a way that the distance between the terminals and the power supply terminals  
10 of the signal processor is substantially minimized.

- Still other objects of the present invention will become apparent to those skilled in the art from the following description wherein the invention will be explained in greater detail. By way of example, there is shown and described a preferred embodiment of this invention. As will be realized, the invention is capable of other different embodiments, and its several details are  
25 capable of modification in various, obvious aspects, all without departing from the scope of the invention. Accordingly, the drawings and descriptions will be regarded as illustrative in nature and not as restrictive. In the drawings:

Fig. 1 shows a plot of output voltage as a function of ampere-hours for two batteries loaded by a continuous current,

- Fig. 2 shows a plot of output voltage as a function of ampere-hours for two batteries loaded by a continuous current with superposed current pulses,
- Fig. 3 shows a plot of the current drawn by a digital hearing aid amplifying speech, and a plot of the resulting battery output voltage,
- 5 Fig. 4 is a schematic diagram of a hearing aid according to the present invention,
- Fig. 5 shows a plot of the current drawn by a digital hearing aid according to the present invention amplifying speech, and a plot of the resulting battery output voltage,
- Fig. 6 shows a plot of the current drawn by a digital hearing aid according to the present invention amplifying speech, and a plot of the resulting battery output voltage,
- 10 Fig. 7 is a schematic diagram of a hearing aid according to the present invention, comprising a telecoil,
- Fig. 8 shows a plot of second harmonic distortion in a telecoil signal as a function of rotational position of three different zinc-air batteries,
- Fig. 9 shows a vertical section in a battery for use in the hearing aid,
- 15 Fig. 10 shows a schematic diagram of a hearing aid according to the prior art, and
- Fig. 11 shows a schematic diagram of a hearing aid according to an embodiment of the invention
- Fig. 1 shows a plot of output voltage 1, 2 as a function of ampere-hours for two batteries from different battery manufacturers loaded by a continuous current of 3.0 mA. The operating period  
20 of the battery is said to expire when the battery output voltage falls below 1.1 volt. It is seen that the battery with the highest initial output voltage 1 also has the shortest operating period. A short drop 3 in output voltage 2 at the start of operation of the other battery is also noted.
- Fig. 2 shows a plot of output voltage 1, 2 as a function of ampere-hours for two batteries from the same battery manufacturers as Fig. 1, however, loaded with a current regimen consisting of  
25 a continuous current of 3.0 mA superposed with 12 mA current pulses with 100 ms duration. The period between pulses is one hour. This loading regimen has been designed to imitate the power consumption of a digital hearing aid in order to create a realistic battery test.

It is noted that for both batteries, the output voltages 1, 2 have dropped while the operating period of the battery with the highest output voltage 1 remained unchanged and the operating period of the other battery decreased to the same value. It is also noted that the short drop 3 in output voltage 2 at the start of operation of the other battery has become deeper and that the  
5 battery output voltage 2 falls below 1.1 volt during the drop 3. Thus, a hearing aid user using this battery under these circumstances would experience an extremely short operating period of 1-2 hours.

Fig. 3 shows a plot of the current 4 drawn by a prior art digital hearing aid amplifying speech, and a plot of the resulting battery output voltage 5. The speech signal is the artificial speech  
10 signal from the ICRA noise CD developed by the International Colloquium of Rehabilitative Audiology. It should be noted that the battery output voltage falls below 1.1 volt whereby the battery alarm is triggered forcing or urging the hearing aid user to replace the battery.

The voltage drops and corresponding lack of ability of the battery to supply the required current pulse also creates distortion of the output signal of the signal processor.

15 Fig. 4 shows a schematic diagram of a hearing aid 10 with a capacitor 12 connected in parallel with the battery 14 according to the present invention. The hearing aid 10 comprises a microphone 16 constituting the input transducer for reception of sound from the environment and generation of a corresponding electronic signal. The microphone 16 may be of a directional type, e.g. the input transducer may comprise more than one microphone, wherein several input  
20 signals are combined into a single signal. The electronic signal is fed to a digital signal processor 20 via an A/D converter 18. If appropriate, the A/D converter 18 may be preceded by a preamplifier (not shown). The digital signal processor 20 processes the signal according to a desired frequency characteristic and compressor function to provide an output signal suitable for compensating the hearing impairment of the user. The output signal is fed to an output  
25 transducer 24 through a sigma-delta converter 22. The output transducer 24 converts the output signal to an acoustic output signal. The capacitance of the capacitor 12 is 5 mF.

Fig. 5 corresponds to Fig. 3 and shows a plot of the current 4 drawn by a digital hearing aid according to the present invention during amplification of ICRA artificial speech, and of the resulting battery output voltage 5. Comparing with Fig. 3, it is seen that the battery output  
30 voltage 5 is smoothened and that the voltage no longer drops below 1.1 volt. Thus, with a hearing aid according to the present invention, the operating period of the battery has been prolonged compared to prior art digital hearing aids. Further, the smaller variations in voltage lead to less distortion of the output signal of the signal processor.

Fig. 6 shows another plot corresponding to the plot shown in Fig. 5, wherein the capacitance is 20 mF. It is seen that voltage 5 variations decrease further.

Fig. 7 is a schematic diagram of a hearing aid 10 according to the present invention, comprising a pick-up coil, namely telecoil 26. The microphone 16 and the telecoil 26 are connected to a mixer stage 28 and the output of the mixer stage 28 is connected to the A/D converter 18. In a hearing aid 10 with a telecoil 26, the inclusion of a capacitor 12, such as a supercapacitor 12, for energy supply has a further effect. The currents drawn by the hearing aid circuitry 18, 20, 22, mainly for feeding the output transducer, creates a magnetic field in the surroundings.

For reason of the technology of the output power stage, i.e. the sigma-delta converter, these currents are generally distorted as compared to the current fed to the output transducer, notably including second and higher harmonics of the output current. The magnetic field due to this current is picked up by the telecoil 26 and distorts the telecoil signal. Second harmonic distortion may amount to 30 %.

In some prior art hearing aids this has been compensated by adding a compensating current path to the power supply current loop so that the generated magnetic field is lowered. However, the compensating current path is designed under the assumption of a specific power supply current loop geometry. The inventors have found that this assumption may not hold.

Reference is here made to Fig. 9 for an explanation of some structural details of a zinc-air battery, which influence the current loop geometry. The battery 14, as shown in the section in Fig. 9, generally comprises a lid 33, a can 32, a separator 40 and a powder filling 34. The lid 33, which provides the negative terminal, has the shape of a cup turned upside down. The can 32, which provides the positive terminal, has the shape of a slightly larger cup, which encloses a sleeve portion of the lid. The lid 33 and the can 32 have contact surfaces accessible for spring-biased contact buttons 36 of the hearing aid for conducting electric current. The separator 40 provides a seal and an electric insulation in the gap between respective sleeve portions of the lid and the can.

The powder filling 34 leaves a void 35 inside the battery. The void is required for allowing expansion of the powder filling expected due to the chemical process taking place during discharge. The void may comprise e.g. 14 % of the enclosed volume. The void allows shifting around of the filling, e.g. due to mechanical influences or due to chemical reactions; therefore the position of the filling is not precisely known and it may vary over time.

However, the void does affect the path of the current through the powder filling inside the cell, as indicated by the dotted line 37. Due to the design of the cell and due to shifting around and changing of the properties of the filling over time, the geometry of the current path may change. As the magnetic field is related to the area of the current loop, the magnetic field  
5 generated will change accordingly. As the telecoil picks up magnetic signals, distorted signals induced by the load current drawn from the battery will be picked up by the telecoil.

Reference is now made to Fig. 8 for some measurements showing such variations. Thus, Fig. 8 shows a plot of second harmonic distortion in the telecoil signal as a function of rotational position of three different zinc-air batteries. It is seen that the amount of distortion is different  
10 for different batteries and for different orientations of batteries. Therefore, it is generally not possible to eliminate the distortion through magnetic compensation.

Reference is made to Fig. 10 for an explanation of a prior art method of compensating distortion. Fig. 10 shows a schematic diagram of a hearing aid, comprising microphone 16, telecoil 26, processing unit 30, output transducer 24 and battery 14. In this figure, for clarity,  
15 components such as input converter, signal processor and output converter have generally just been represented by the processing unit 30. This hearing aid has been provided with a compensation coil 31, carrying the supply current to the processing unit and coupling magnetically to the telecoil 26. This compensation coil 31 is adapted and oriented such as to offset as closely as possible all the magnetic influence on the telecoil caused by the remaining  
20 part of the loop of supply current 38.

However, the inventors have discovered that the strength of the magnetic field and the variability in the geometry of the current path inside the battery makes complete compensation impossible.

Reference is now made to Fig. 11 for a description of a hearing aid according to an  
25 embodiment of the invention. This hearing aid is basically similar to that of Fig. 10 except for the inclusion of a capacitor 12. The capacitor 12 is connected by suitable connectors to the processing unit 30, in order that these components together form a capacitor current loop 39. Thus current through the processing unit 30 will be the sum of the currents flowing in the battery current loop 38 and in the capacitor current loop 39.

30 According to the invention, the capacitor 12 is arranged and connected to the processing unit in such a way that the distance between the capacitor terminals and the power supply terminals of the signal processor is substantially minimized. The capacitor may be arranged closer to the

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processing unit than is the case with the battery, since the battery requires a dedicated compartment, accessible from the outside for permitting replacement and provided with spring loaded contact buttons. Reducing the distance between the capacitor terminals and the power supply terminals of the processing unit reduces the area of the current loop and thus the magnetic field generated.

According to the invention, the capacitor is a fast super capacitor. One example of a suitable capacitor is an electrochemical double layer capacitor with a highly conductive polymeric, proton conductive electrolyte of the type disclosed in Technical Information, "Bestcap a new dimension in fast supercapacitors", Scot Tripp, AVX Ltd, Fleet, UK. This capacitor exhibits an internal impedance of about 100 milliohms. Other examples of suitable capacitors are Murata 100 microfarad X7R and Murata 100 microfarad GRM55FR from Murata Manufacturing Co., Ltd., Kyoto, Japan. These capacitor have impedances as low as 2,6 milliohms.

As the battery has an internal impedance of e.g. 6 ohms, transients of current drawn by the processing unit will be split between the capacitor and the battery with the battery providing only about 2 % of the total current. Thus the creation of disturbing magnetic fields by transients in the battery current loop have been cut by almost two orders of magnitude.

Even more important is the fact that the capacitor is a stable and predictable unit not subject to variations in the geometry of the current path. Thus it is possible to match the compensation coil to precisely offset any magnetic influence onto the telecoil due to currents in the capacitor current path.

This avoids unwanted variation due to battery type, battery manufacturing process, and rotational position of the battery.

## CLAIMS

1. A hearing aid comprising a housing, an input transducer for transforming an acoustic input signal into a first electrical signal, a signal processor means for compensating a hearing deficiency by generation of a second electrical signal based on the first electrical signal, an output transducer for conversion of the second signal into sound, an energy source for supplying energy to at least the signal processor, and at least one capacitor characterized in that the at least one capacitor is coupled in parallel with the energy source for supply of transient currents drawn by the signal processor, and that the at least one capacitor comprises a super capacitor with a capacitance.
2. A hearing aid according to claim 1, wherein the signal processor is a digital signal processor.
3. A hearing aid according to claim 1 or 2, wherein the energy source is a metal-air battery.
4. A hearing aid according to any of the preceding claims, wherein the energy source is a zinc-air battery.
5. A hearing aid according to any of the preceding claims, wherein the capacitance of the at least one capacitor is greater than 1 mF.
6. A hearing aid according to any of the preceding claims, wherein the capacitance of the at least one capacitor is greater than 4 mF.
7. A hearing aid according to any of the preceding claims, wherein the capacitance of the at least one capacitor is greater than 10 mF.
8. A hearing aid according to any of the preceding claims, wherein the capacitance of the at least one capacitor is greater than 20 mF.

9. A hearing aid according to any of the preceding claims, wherein the at least one capacitor is an electrochemical double layer capacitor with a conductive polymeric, proton conductive electrolyte.
10. A hearing aid according to any of the preceding claims, wherein the terminals of the at least one capacitor is connected to the signal processor in such a way that the distance between the capacitor terminals and the power supply terminals of the signal processor is minimised.
11. A hearing aid according to claim 10, further comprising a telecoil.
12. A hearing aid according to claim 11, comprising means for adding a compensation current to lower the generated magnetic field.
13. A hearing aid according to claim 11, comprising a mixer for mixing the first signal with the signal from the telecoil, and means for feeding the mixer output signal to the signal processor means.