P210562SG-CT/JB

Description

Protective Mechanism for a Wireless Charging Receiver System

The invention relates to an electronic device, in particular a hearing instrument, having a rechargeable battery and a receiver circuit for wirelessly receiving energy for charging the battery. The invention also relates to an inductive charging system comprising the electronic device and the charger for wirelessly charging the battery.

Generally, a hearing instrument is an electronic device being designed to support the hearing of person wearing it (which person is called the user or wearer of the hearing instrument). In particular, the invention relates to a hearing aid, i.e., a hearing instrument that is specifically configured to at least partially compensate a hearing impairment of a hearing-impaired user. Other types of hearing instruments are designed to support the hearing of normal hearing users, i.e., to improve speech perception in complex acoustic situations. Furthermore, the term hearing instrument, as used herein, may relate to a device for streaming an audio signal such as speech or music, e.g. a headset, headphone, ear buds, etc.

Hearing instruments are most often designed to be worn in or at the ear of the user, e.g., as a Behind-The-Ear (BTE) or In-The-Ear (ITE) instrument. With respect to its internal structure, a hearing instrument normally comprises an (acousto-electric) input transducer, a signal processor and an output transducer. During operation of the hearing instrument, the input transducer captures a sound signal from an environment of the hearing instrument and converts it into an input audio signal (i.e., an electric signal transporting a sound information). In the signal processor, the captured sound signal (i.e., input audio signal) is processed, in particular amplified dependent on sound frequency, to support the hearing of the user, in particular to compensate a hearing-impairment of the user, to suppress ambient noise, etc. The signal processor outputs a processed audio signal (also

called processed sound signal) to the output transducer. Most often, the output transducer is an electro-acoustic transducer (also called “receiver”) that converts the processed sound signal into a processed air-borne sound, which is emitted into the ear canal of the user. Alternatively, the output transducer may be an electro-mechanical transducer that converts the processed sound signal into a structure-borne sound (vibrations) that is transmitted, e.g., to the cranial bone of the user**.** Furthermore, besides classical hearing instruments as described before, there are implanted hearing instruments such as cochlear implants, and hearing instruments the output transducers of which output the processed sound signal by directly stimulating the auditory nerve of the user.

Wireless charging of hearing instruments has been proven viable using near-field magnetic or electromagnetic coupling between transmitter and receiver coils, located in the charger and the hearing instrument, respectively.

Normally, in known inductive charging systems, a one-step charging current is applied to the electronic device at the initial charging state. The term “one-step charging current” describes a charging current that changes abruptly (step-like) from zero to a final value as shown in Fig 1 (solid line) when the charging input is provided with enough power. To ensure that the device can be charged in all situations, the charger has to pump a sufficiently high power to generate a strong magnetic field for the receiver coil to induce a high voltage and high power to the receiver system. This phenomenon usually happens to a wireless charging device that has an unpredictable coupling between the receiver coil and the transmitter coil. However, the utilization of a one-step charging current can lead to a high overshoot voltage and overshoot current at the charging input (Fig. 1, dashed line).

Both overvoltage and overcurrent at the receiver system can cause damage to the receiver system, e.g. over-heating the receiver system, destroying components of the charging control system, damaging or destroying the battery, etc. Overvoltage situations often occur at the charging input of the electronic device, when the induced voltage of the receiver coil is high due to high transmitted power from the

charger. In contrast, overcurrent situations usually happen in the circuit near to the battery. Notably, overcurrent situations have been observed to occur both during charging, when a charging current is flowing into the battery, and during discharging, when a current is flowing from battery. The first case, i.e. an overcurrent situation during charging, may be caused by a short circuit at the battery. The latter case, i.e. an overcurrent situation during discharging (e.g. when the electronic device is operating or even when it is switched out) may be caused by the occurrence of a short circuit in a consuming unit of the electronic device or in the charging circuitry. Thus, especially in view of overcurrent situations, the problem to be solved is not limited to the charging state but more generally refers to the battery current which is the current flowing into the battery (during charging) or from the battery (during discharging). In the charging state, the battery current corresponds to charging current.

In known inductive charging systems, often a fixed coupling factor between charger and the electronic device is assumed. Based on this assumption, in order to avoid overvoltage or overcurrent at the charging input of the electronic device, the charger predicts a minimum amount of power to be transmitted that is just sufficient for charging. However, even if said predicted minimum amount of power is transmitted, still charging failures resulting in battery damage or destruction may occur, due to variations of the real coupling factor.

Another problem of known electronic devices, in particular hearing instruments, is that the battery of such devices is sometimes destroyed during assembly or shipping, even before the electronic device is put into operation. These failures are caused by high leakage currents of the battery leaking energy and unpredictable short circuits that happen during assembly of the electronic device or during shipping.

It is, thus, an object of the invention to avoid at least some of the above-mentioned problems.

According to the invention, the above object is met by an electronic device (also referred to as the receiver system) having the features of claim 1. It is also met by an inductive charging system having the features of claim 10. Preferred embodiments of the invention are described in the dependent claims and the subsequent description.

This invention introduces a wireless charging receiver architecture with at least one protection function.

In a preferred embodiment, a gradual or multi-step ramping feature is introduced which forces the charging current to increase slowly at the onset (i.e. in an initial charging phase). Said ramping feature acts as fault prevention mechanism to the receiver system to stabilize the charging and maintain a communication between the charger and the electronic device. The (gradually or multi-step-wise increasing) ramping charging current can be realised, e.g., by controlling a current regulator with a ramping signal from a ramping unit.

In further preferred embodiments, overvoltage protection and/or overcurrent protection are introduced as fault mitigation mechanisms to the receiver system. According to a preferred solution, an overvoltage protection circuit is realised by having a Zener diode in parallel to the charging input. According to another preferred solution, an overcurrent protection circuit is brought out by having a current detection unit and an electronic switch, e.g. a bidirectional transistor. Said bidirectional transistor is realized, e.g., by two field effect transistors (such as MOSFETS) being connected in series with opposite polarity (cf. Fig. 4).

Preferably, the method shall be used in a magnetic resonance (MR) charging system. Herein, the charger creates a magnetic or electric-magnetic field, the frequency of which corresponds to a resonance frequency of the receiver circuit.

Subsequently, embodiments of the present invention will be described with reference to the accompanying drawings in which

Fig. 1 is a schematic diagram of a one-step charging current as is normally applied to an electronic device of a known inductive charging system, by a charger of said system,

Fig. 2 is a schematic block diagram showing an electronic device, in particular a hearing instrument, according to the invention, said electronic device comprising a battery coil module, an electric power management circuit, and a consuming unit, said battery coil module comprising a receiver circuit with a receiver coil for producing a charging current, and battery circuit containing a rechargeable battery (also referred to as “secondary battery”),

Fig. 3 is a schematic block diagram showing an embodiment of the battery coil module of the electronic device of Fig. 2,

Fig. 4 is a schematic block diagram showing an embodiment of an overvoltage protection unit of the electronic device of Fig. 2, said overvoltage protection unit being connected between said battery coil module (more precisely the receiver circuit of said battery coil module) and said electric power management circuit,

Fig. 5 is a schematic block diagram showing an embodiment of overcurrent protection unit of the electronic device of Fig. 2, said overcurrent protection unit being connected between said battery coil module (more precisely the battery of said battery coil module) and said electric power management circuit, and

Fig. 6 is a schematic diagram over time a ramped (i.e. gradually or multi-step-wise increasing) charging current as is produced by a ramping module of the power management circuit of the electronic device of Fig. 2.

Like reference numerals indicate like parts, structures and elements unless otherwise indicated.

Fig. 1, as described before, shows a one-step charging current as is normally applied to an electronic device of a known inductive charging system, by a charger of said system. As can be seen from the figure, the level of the charging current abruptly changes from zero to a final value (solid line) when the charging input is provided with enough power. However, the inductivity of the receipt circuit of the electronic device may lead to an overvoltage situation. The level of charging current may significantly overshoot the final value (see dashed line in Fig. 1) which may damage or destroy the battery or other circuitry of the electronic device.

Fig. 2 shows the functional block diagram of an electronic device according to the invention, which electronic device, in the shown example, is a hearing instrument 2. Preferably, the hearing instrument 2 is a BTE or ITE hearing aid provided and designed to support the hearing of a hearing-impaired user.

Together with a charger (not shown), the hearing instrument 2 forms an inductive charging system. In the inductive charging system, the charger is wirelessly coupled to the hearing instrument 2 to transfer energy to the hearing instrument 2, thereby charging a rechargeable battery 4 of the hearing instrument 2.

The hearing instrument 2 comprises a consuming unit 6 consuming electric energy in an operational state of the hearing instrument 2. In the case of the hearing instrument 2, the consuming unit 6 comprises, e.g., a digital signal processor, a receiver, at least one microphone, etc.

The hearing instrument 2 further comprises a battery coil module 8 and an electric power management circuit (also referred to as “power management module” or PMM 10). Preferably, the consuming unit 6 (or at least a part thereof) and the PMM 10 are integrated on a motherboard 12, as shown in Fig. 2.

The battery coil module 8 combines a receiver circuit 14 and a battery circuit 16, which may be integrated on a flexible printed circuit board or PCB 18 as shown in Fig. 2 and 3. Thus, the battery coil module 8 contains an energy receiver mechanism and an energy storage mechanism.

As the most prominent part of the receiver circuit 14, the battery coil module 8 comprises a receiver coil 20. In the example of Fig. 2, the receiver circuit 14 further comprises a resonance circuit 22 and a rectifier circuit (rectifier 24).

As the most prominent part of the battery circuit 16, the battery coil module 8 comprises the rechargeable battery 4 (which is also referred to as the “secondary battery”). In the example of Fig. 2, the battery circuit 16 further comprises a battery supply line 26 electrically connecting the battery 4 with the PMM 10.

In the example of Fig. 2, the battery coil module 8 further comprises a temperature sensor which, here, is realized by a thermistor 28. Different from the Fig. 2, the battery supply line 26 and the thermistor 28 may be integrated on the PCB 18 as shown in Fig. 3.

A first functionality of the battery coil module 8 (more precisely of the receiver circuit 14) is to capture magnetic or electro-magnetic energy by magnetic or electromagnetic coupling of the receiver coil 20 and a transmitter coil (not shown) of the charger and to convert said magnetic or electro-magnetic energy into electric energy, when the receiver coil 20 is immersed to a magnetic or electro-magnetic field of the transmitter coil.

A second first functionality of the battery coil module 8 (more precisely of the battery circuit 16) is to store electric energy received by the receiver circuit 14 and to provide this energy by acting as source for supplying power to the hearing instrument 2, in particular to the consuming unit 6, in an operational state of the hearing instrument 2.

A third functionality of the battery coil module 8 (more precisely of the thermistor 28) is to sense the temperature of the battery 4, in order to recognize an imminent over-heating of the battery 4.

The rectifier 24 comprises a Schottky diode 30 to convert the AC energy produced by the receiver coil 20 into DC energy (i.e. a DC charging current). The Schottky diode 30 is connected in series to the receiver coil 20 as shown in Fig. 3. In addition, the Schottky diode 30 has a voltage clamping feature that limits the output voltage of the battery coil module 8 (i.e. the voltage of the charging current) to its breakdown voltage. The Schottky diode 30, thus, acts as a means for preventing or reducing an overvoltage situation of the charging current, more precisely as an overvoltage protection unit 44' that limits a voltage of the charging current to a predefined maximum voltage value.

The basic functionality of the PMM 10 is to control the charging current and to monitor the voltage of the battery 4. Preferably, the PMM 10 furthermore transforms the voltage of the battery 4 and outputs the transformed voltage to the consuming unit 6. The PMM 10 can be realised in the form of a discrete component circuit or as an integrated circuit.

An output of the battery coil module 8 is connected to a charging input terminal of PMM 10. Within the PMM 10, the charging input terminal connects to a charging unit 32. Further to the charging unit 32, the PMM 10 comprises a ramping unit 34, a temperature monitoring unit 36, battery voltage monitoring unit 38, a transformation unit 40 and a communication module 42. By the ramping unit 34, optionally in interaction with the charging unit 32, the charging current is manipulated (as will be subsequently described in more detail). The output of the charging unit 32 is connected to a transformation unit 40 and a charging/discharging input terminal.

A charging control (not explicitly shown) of the hearing instrument 2 changes to a charging state when the voltage of the charging current in the PMM 10 exceeds a predefined threshold value. The charging control changes to a discharging state

when said voltage falls below the threshold value. In an operation state of the hearing instrument 2, the PMM 10 provides output power with a constant voltage (Vout) to the consuming unit 6.

The temperature monitoring unit 36 converts the resistance of the thermistor 28 to a voltage signal to monitor the temperature of the battery 4.
The communication module 42 communicates with the charger in order to control the charging process, in particular the power delivered by the charger. The communication may be unidirectional, where a communication signal may be transferred from the hearing instrument 2 to the charger system, e.g. by load modulation of the charging current. Alternatively, the communication between the hearing instrument 2 and the charger may be bidirectional, e.g. using near field magnetic inductance (NFMI) or Bluetooth Low Energy (BLE) technology.

The battery voltage monitor unit 38 is used to monitor the battery voltage and send a control signal to the charging unit 32 to change the charging mode if required.

In addition to the Schottky diode 30 described above, the hearing instrument 2 comprises several further means for preventing or reducing an overcurrent or overvoltage situation of the charging current.

On the one hand, an overvoltage protection unit 44 shown in Fig. 4 is arranged on the motherboard 12. Similar to the Schottky diode 30, the overvoltage protection unit 44 clamps the voltage of the charging current when it exceeds a predefined maximum voltage value. In other words, the overvoltage protection unit 44 limits the voltage of the charging current to the predefined maximum voltage value. According to Figs. 2 and 4, the overvoltage protection unit 44 is connected between the battery coil module 8 (more precisely the receiver circuit 14) and the PMM 10. In the example shown in Fig. 4, the overvoltage protection unit 44 comprises a Zener diode 46 that is connected between an output terminal of the rectifier 24 and ground. The Zener diode 46 has a voltage clamping feature limiting the voltage of the charging current to its so-called Zener voltage. The Zener diode

46 starts to operate by clamping the charging input voltage to the Zener voltage when the given charging input voltage exceeds the Zener voltage.

On the other hand, an overcurrent protection circuit 48 is arranged on the motherboard 12. The overcurrent protection circuit 48, an embodiment which is shown in Fig. 5, is a bridge component placed in between the PMM 10 and the battery 4. The overcurrent protection circuit 48 comprises a current sensor 50 and an electronic switch which, here, is realised by a bidirectional MOSFET 52. The current sensor 50 detects the battery current by measuring the voltage over a detect resistor 54 and disrupts the battery current by turning-off the bidirectional MOSFET 52, if the detected battery current level exceeds a predefined maximum current value. Alternatively, the consuming unit 6 can control the current detection unit and give a command to trigger the cut-off current flow for the hearing instrument 2 to have a long-term storage (shutdown mode). The long-term storage was described in more details in the prior patent application DE 10 2021 205 635.0 of the present applicant, the entire content of which is incorporated herein by reference. In an embodiment of the invention, the overcurrent protection circuit 48 is activated during charging only, in which case the overcurrent protection circuit 48 is specifically implemented to limit the charging current flowing to the battery. However, in preferred embodiments of the invention, the overcurrent protection circuit 48 is activated during discharging also. In the latter case, the overcurrent protection circuit 48 is used to limit the battery current in general.

A second means for preventing an overcurrent (i.e. a second overcurrent protection circuit 48') is realised by a fuse, in particular a resettable fuse 56, that is connected in the battery supply line 26, cf. Fig. 3.

A further means for preventing or reducing an overcurrent or overvoltage situation of the charging current is realised by the PMM 10 and, more specifically, by the ramping unit 34 thereof. At the onset of the charging current, i.e. in the initial charging phase when the charging current starts to flow, the ramping module 34 forces the level of the ramping current to slowly increase in a gradual (continuous, in particular linear) manner (see dashed line in Fig. 6) or in a multi-set-wise

manner (step-wise ramping, see solid line in Fig. 6). The slow increase of the charging current is called a ramp. The ramping unit 34 forms the ramp, e.g., by providing a time-dependent resistance to the charging current. Thus, the ramping unit 34 avoids a one-step increase of the charging current. The ramping unit 34 may be designed as a hardware circuitry made of discrete electronic components or as an integrated circuit. Alternatively, the ramping unit 34 may be designed as a software component that shapes the charging current by controlling hardware circuitry, e.g. a current regulator, in the charging unit 32. The ramped charging current stops increasing and stays at a constant current value once the charging current reaches a pre-set value.

Key aspects of the introduced protective mechanism to the inventive wireless charging receiver system are the means for preventing or reducing an overcurrent or overvoltage situation of the charging current described in the fore-going. Preferably, these means are provided in a combination of ramping of the charging current at onset, overvoltage protection, and overcurrent protection as shown in the example of Figs. 2 to 6. However, compatible with the invention, any of these means can be provided alone, i.e. in absence of the other of said means, or in any sub-combination.

The ramping unit 34 is the fault prevention mechanism to the receiver system that can overcome and reduce the high overshoot voltage and overshoot current to the charging input at the initial charging state. The overvoltage protection unit 44 and the overcurrent protection unit 48 are the fault mitigation mechanisms for the receiver system. Adding the overvoltage protection unit 44 can limit the voltage and prevent overshoot voltage to occur at the charging input in the initial charging state. Adding the overcurrent protection unit 48 between the charging unit 32 and the battery 4 can also avoid a high current and damage to both the PMM 10 and battery 4.

By ramping the charging current, the increase of the charging current can be limited and slowed down. At the moment the hearing instrument 2 is placed on the charger, the whole charging system changes from a no-load condition to a loaded

condition, wherein the ramping feature prevents the occurrence of high overshoot voltage and overshoot current at the charging input.

Furthermore, the ramping of the charging current reduces the risk of a disrupted communication between the charger and the hearing instrument 2 if said communication is effected by load modulation of the charging current. A disrupted communication could otherwise occur as a consequence of signal distortion caused by overshooting voltage or by cutting-off the over-shooting charging current by overvoltage protection and/or overcurrent protection. Using a ramped charging current at the initial charging state, the charger only requires to transmit a low power at the initial state that is sufficient to maintain the load modulation communication between the receiver system and the charger. Once the communication is established, the charging current is ramped up while, simultaneously, the charging stability and communication stability is maintained. Since the communication is stable, the charger can precisely track the power required for the receiver system to charge the battery 4 and gradually increase the transmitted power in accordance with the increasing charging current in the hearing instrument 2.

The Schottky diode 30 is used as the primary overvoltage protection and the Zener diode 46 placed in parallel to the charging input is used as the secondary overvoltage protection. As the Zener diode 46 is the secondary protection unit to the charging input, the selection of voltage rating and power rating for the Zener diode 46 has to be higher than for the Schottky diode 30. The voltage rating of the Zener diode 46 must be lower than the maximum voltage rating of the PMM 10 charging input terminal. Overall, both the Schottky diode 30 (as a part of the rectifier 24 of the battery coil module 8) and the Zener diode 46 (as the overvoltage protection unit 44 to the charging input terminal) can effectively prevent the induced voltage at the receiver coil 20 from exceeding the voltage limit of the charging input at the PMM 10 and, thus, avoid possible damage of the PMM 10.

The overcurrent protection unit 48 connected between the charging/discharging input terminal of the PMM 10 and the battery 4 has the feature of cutting-off current flow when the current exceeds the current rating. This overcurrent feature can avoid damage of the PMM 10 and the battery 4 in an overcurrent situation.

Each of the protective mechanism according to the invention has its own protection feature to the receiver system. The Schottky diode 30 and Zener diode 46, acting as overvoltage protection, can avoid the occurrence of high overshoot voltage to the charging input terminal of the PMM 10 that can be applied to the wireless charging. The current detection unit and bidirectional MOSFET 52, acting as overcurrent protection, can stop the high current flow in and out from the battery 4. Notably, this feature can also be provided in galvanic charging systems in which the charging current is transmitted from the charger to the device to be charged via contacting conductors.

All the protective mechanisms described in the fore-going can be applied, in combination or alone, to any electronic device having a rechargeable battery. With the combination of ramping the charging current and overvoltage protection, a common initial transmitted power at the charger can be realized for different receiver systems with different coupling between the charger and receiver system. The combination of overvoltage protection and overcurrent protection in the receiver system allows for save charging in different battery conditions such as a deeply discharged batteries, fully charged batteries, and normal battery conditions.

It will be appreciated by persons skilled in the art that numerous variations and/or modifications may be made to the invention as shown in the specific examples without departing from the spirit and scope of the invention as broadly described in the claims. The present examples are, therefore, to be considered in all aspects as illustrative and not restrictive. In particular, any of the disclosed embodiments of the invention may be varied by including one or more of the variations disclosed above with reference to another of the disclosed embodiments of the invention.

List of Reference Numerals

2	hearing instrument
4	battery
6	consuming unit
8	battery coil module
10	power management module (PMM)
12	motherboard
14	receiver circuit
16	battery circuit
18	flexible printed circuit board (PCB)
20	receiver coil
22	resonance circuit
24	rectifier
26	battery supply line
28	thermistor
30	Schottky diode
32	charging unit
34	ramping unit
36	temperature monitoring unit
38	battery voltage monitoring unit
40	transformation unit
42	communication module
44, 44’	overvoltage protection unit
46	Zener diode
48, 48’	overcurrent protection circuit
50	current sensor
52	bidirectional MOSFET
54	detect resistor
56	fuse

Claims

1. Electronic device (2), in particular hearing instrument, comprising:
   - a consuming unit (6) consuming electric energy in an operational state of the electronic device (2),
   - a rechargeable battery (4) operable to supply the consuming unit (6) with electrical energy in the operational state of the electronic device (2),
   - an electric receiver circuit (14) including a receiver coil (20), the receiver coil (20) being operable to receive a magnetic or electromagnetic field in a charging state of the electronic device (2), and to produce an electric charging current for charging the battery (4),
   - an electric power management circuit (10) operable to control the charging current fed to the battery (4), and
   - at least one means (34, 44, 44', 48, 48') for preventing or reducing an overcurrent or overvoltage situation of the charging current.

2. Electronic device (2) according to claim 1,
   wherein the at least one means (34, 44, 44', 48, 48') for preventing or reducing an overcurrent or overvoltage situation of the charging current comprises a ramping unit (34), optionally being a part or function of the power management circuit (10), said ramping unit (34) being operable to limit an onset of the charging current to a gradual or multi-step-wise increasing ramp, thus avoiding a one-step increase of the charging current.

3. Electronic device (2) according to claim 1 or 2,
   wherein the at least one means (34, 44, 44', 48, 48') for preventing or reducing an overcurrent or overvoltage situation of the charging current comprises at least one overvoltage protection unit (44, 44') being operable to limit a voltage of the charging current to predefined maximum voltage value or to disrupt the charging current, if the voltage of the charging current exceeds the predefined maximum voltage value.

4. Electronic device (2) according to claim 3,
wherein the at least one overvoltage protection unit (44) includes a Zener diode (46) being connected between a DC output of the receiving circuit (14) and ground.

5. Electronic device (2) according to claim 3 or 4,
wherein the receiver circuit (14) includes a rectifier (24) being connected between the receiver coil (20) and the power management circuit (10), and wherein the rectifier (24) includes a Schottky diode (30) for rectifying the charging current, wherein the Schottky diode (30) has a voltage clamping feature that limits the voltage of the rectified charging current to said predefined maximum voltage value, the Schottky diode (30), thus, being said at least one overvoltage protection unit (44').

6. Electronic device (2) according to one of claim 1 to 5,
wherein the at least one means for preventing or reducing an overcurrent or overvoltage situation of the charging current comprises at least one overcurrent protection unit (48, 48') being operable to limit a current level of a charging current or, more generally, a battery current to a predefined maximum current value or to disrupt the charging current or battery current, respectively, if the current level of the charging current or the battery current, respectively, exceeds the predefined maximum current value.

7. Electronic device (2) according to claim 6,
wherein the at least one overcurrent protection unit (48') includes a fuse, in particular a resettable fuse (56), being connected between the battery (4) and the power management circuit (10).

8. Electronic device (2) according to claim 6 or 7,
wherein the at least one overcurrent protection unit (48) includes at least one electronic switch (52) connected between the battery (4) and the power management circuit (10), and a current sensor (50) operable to detect the current level of the charging current or the battery current, respectively, and

to turn off the at least one electronic switch (52) if the current level of the charging current or the battery current, respectively, exceeds the predefined maximum current value.

9. Electronic device (2) according to claim 8,
wherein said least one electronic switch (52) comprises a bidirectional transistor, in particular a bidirectional field effect transistor.

10. Inductive charging system comprising an electronic device (2) according to any one of claims 1 to 9, and a charger for wirelessly charging the battery (4) of the electronic device (2).