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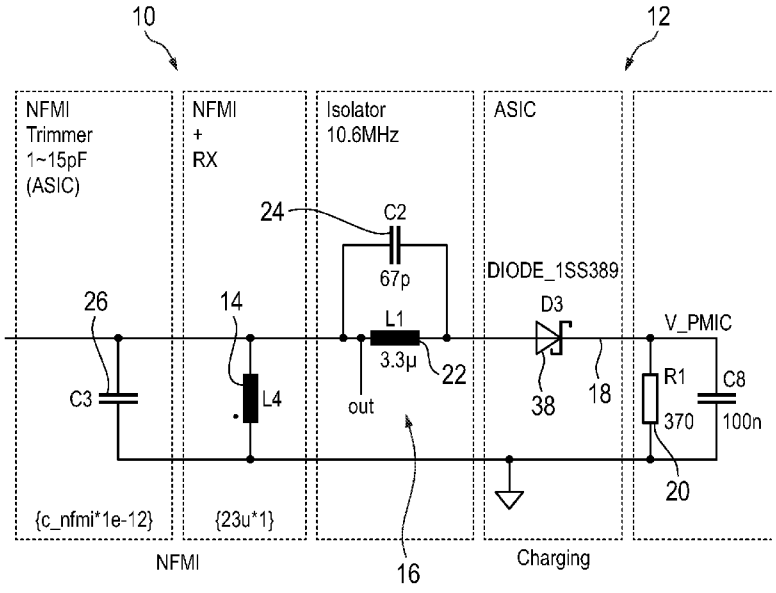


Fig. 2

(57) Abstract: Shared coil topology for communication and charging A wearable device (2) is described, comprising a communication circuit (10), for wireless communication, a charging circuit (12), for wireless charging, a coil (14), which is shared by the communication circuit (10) and the charging circuit (12), a resonance isolator (16), wherein the coil (14) is configured to receive a signal, namely a communication signal at a first frequency (f1) during a communication mode and a charging power signal at a second frequency (f2) during a charging mode, wherein the resonance isolator (16) is configured to isolate the coil (14) from the communication circuit (10) or the charging circuit (12) depending on a frequency (f) of the signal received by the coil (14). Further, a method of operating such a wearable device (2) is described.

WO 2024/054151 A1

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Description

Shared coil topology for communication and charging

The invention concerns a wearable device and a method of operating such. Preferably, the wearable device is a hearing instrument, in particular a hearing aid.

A hearing instrument generally has an input transducer, a signal processing unit and an output transducer. The input transducer is usually a microphone. The output transducer is usually an earphone, which is also referred to as a loudspeaker or receiver. A hearing instrument is regularly assigned to an individual user and is only used by this user. A hearing instrument is used, for example, to care for a hearing-impaired user and to compensate for a hearing loss (hearing aid). The input transducer generates an input signal, which is fed to the signal processing unit. The signal processing unit modifies the input signal and thereby produces an output signal which is thus a modified input signal. To compensate for a hearing loss, the input signal is amplified with a frequency-dependent amplification factor, for example according to an audiogram of the user. The output signal is finally output to the user by means of the output transducer. In a hearing instrument with a microphone and receiver, the microphone generates the input signal from sound signals in the environment and the receiver generates another sound signal from the output signal. The input signal and the output signal are electrical signals, which are therefore also referred to as signals for short. In contrast, the sound signals of the environment and the sound signal that may be emitted by the listener are acoustic signals.

A wearable device may be configured for wireless communication with other devices. Also, a wearable device may be configured for wireless charging. Combination of both such functions is often prevented in wearable devices with very small dimensions, e.g., hearing instruments.

A possible solution for a shared coil concept uses a diplexer approach. An example for a diplexer approach is shown in US 10,974,052 B2, which describes a

medical communication and charging system. The system includes a communication module with a communication transmitter, for sending communication signals, a charging module with an energy charging transmitter, for transmitting charging energy. The system further comprises a receiver for communication signals and energy. The receiver can be switched into a first status for receiving communication signals provided by the communication module and into a second status for receiving energy provided by the charging module.

In general, a diplexer approach can achieve multiple bandwidth frequency activations by separating the total signal into multiple frequencies via multiple bandpass filters in combination with a switch. For example, two bandpass filters are selected for the diplexer approach to achieve two applications, e.g. wireless communication and wireless charging. The higher bandpass filter is used for the wireless communication and the lower bandpass filter is used for the wireless charging. When either of the two is active, the other one will stop functioning immediately. The diplexer approach requires an active switch to change the function of the shared coil. Hence, the diplexer approach requires a detection circuit to determine whether an incoming signal to the coil is a charging power signal or communication signal. Then, the switch is activated according to the incoming signal to switch the device to either a communication mode or a charging mode.

In view of this, it is desirable to provide an alternative shared coil solution for wireless communication and wireless charging which does not require an active switch or detection circuit as mentioned in connection with the diplexer approach.

In general, objectives of the present invention include providing an improved wearable device, in particular hearing aid, and an improved method of operating such. In particular, an alternative to the diplexer approach shall be provided, thereby avoiding the corresponding disadvantages. Further objectives can be derived from the following description.

One or several objectives are solved by the subject matter as claimed in the independent claims directed towards a wearable device and a method for operating a wearable device. Further solutions and preferred embodiments are described in the dependent claims and the following description. As far as steps of the method are implicitly or explicitly described in the following, advantageous embodiments for the wearable device result in said wearable device comprising a control unit, configured to execute one or several of these steps.

The wearable device comprises a communication circuit, for wireless communication, and a charging circuit, for wireless charging of the wearable device. In particular, the wireless communication is a magnetic induction communication. Further, the wearable device comprises a coil, which is shared by the communication circuit and the charging circuit. The coil is configured to receive a signal (communication signal) at a first frequency during a communication mode and a charging power signal at a second frequency during a charging mode. In other words: During operation, the coil is functionally associated with the communication circuit or the charging circuit and is then a receiver coil for the respective circuit. In this way, the very same coil is used for two applications: A first application is a communication application, for which the coil is functionally associated to the communication circuit to receive a communication signal, i.e. a signal comprising data. A second application is a charging application, for which the coil is functionally associated to the charging circuit to receiver a charging power signal, i.e. power for charging the wearable device, preferably of a secondary battery of the wearable device.

The term “functionally associated” is understood to mean, that the coil at a given point of time is used by one of the circuits to realize the corresponding application during the corresponding mode, without necessarily being galvanically separated from the other circuit. In other words: the signal (or part of it) received by the coil is transferred to either the communication circuit or the charging circuit depending on the frequency of the signal, thereby also defining which mode is active.

The charging mode and the communication mode are each a mode of operation of the wearable device. In the charging mode, the wearable device is (wirelessly) connected to a charger and usually not worn or used by the user. The charger may be a receptacle, in which the wearable device is placed for charging. The communication mode, however, is usually active during the intended use of the wearable device. Hence, in the communication mode, the device is usually worn or used by the user. However, the communication mode may also be active at other times and also during charging.

The first frequency preferably is a tuning frequency of the communication circuit, i.e. corresponds to a (communication) frequency which is used for communication. The second frequency preferably is a tuning frequency of the charging circuit, i.e. corresponds to a (charging) frequency used for charging. The first frequency is different from the second frequency, such that communication and charging occur on different frequency channels.

For the sake of simplicity, frequencies are mentioned throughout this application, but this expression is not necessarily restricted to mean a single frequency, but rather may be substituted by “bandwidth” or “frequency range”, in particular around the mentioned frequency, where appropriate.

The wearable device further comprises a resonance isolator. The resonance isolator is configured to isolate the coil from the communication circuit or the charging circuit depending on a frequency of the signal received by the coil, i.e. the received signal. In other words: The resonance isolator functionally associates the coil with either the communication circuit or the charging circuit, depending on the frequency of the received signal. In this way, the wearable device is automatically switched between the communication mode and the charging mode depending on the frequency of the signal received by the coil.

The operation of the resonance isolator depends on the frequency of the received signal at the shared coil. In particular, the resonance isolator has a tuning frequency which defines the resonance isolator’s behavior for a given frequency.

This behavior is different for the first and second frequency. In general, the resonance isolator is preferably configured to associate the coil with one of the circuits and thereby cut off the other circuit when the frequency of the received signal corresponds to a tuning frequency of the resonance isolator. In other words: One of the modes is activated when the frequency of the received signal corresponds to the tuning frequency and the other mode is activated when the frequency of the incoming signal does not correspond to the tuning frequency. Without loss of generality, it is assumed in the following that the communication mode is activated when the frequency of the received signal corresponds to the tuning frequency and the charging mode is activated when the frequency of the incoming signal does not correspond to the tuning frequency. This is also the preferred configuration. Further preferred is an embodiment, in which the resonance isolator's tuning frequency corresponds to either the first frequency or the second frequency. In other words: The resonance isolator is designed such that its tuning frequency matches one of the two application frequencies. This achieves an optimal discrimination between the two frequencies and a particularly selective behavior of the resonance isolator.

In principle, both modes (communication and charging) may also be used at the same time, wherein the resonance isolator then prevents the communication signal from being transmitted to the charging circuit and vice versa the charging power signal being transmitted to the communication circuit. In this way, the resonance isolator also acts like a filter, distributing the various frequency components of the received signal to the respective circuit.

At the core of the present invention is a shared coil concept for both of a wireless communication application and a wireless charging application. This is an ideal concept for future wearable devices (short: device), such as hearing instruments, in particular hearing aids. The wireless charging preferably is an inductive or magnetic charging, preferably also a resonance charging. The wireless charging is used to transfer power and thus energy from a charger separate from the device to a secondary battery of the device. The shared coil concept is a concept according to which both applications, namely wireless charging on the one hand and wireless

communication on the other hand, share the same coil. The shared coil concept advantageously results in lower overall cost and smaller overall design for the wearable device, as this then comprises only a single coil. The latter applies even more so since the coil usually is one of the largest components in a wearable device.

This application then describes an improved shared coil topology for wireless communication and wireless charging with an additional resonance isolator. The solution with the resonance isolator presented here advantageously solves the problems of size and cost constraints in hearing instruments and generally in any wearable devices. This solution also preserves the wireless communication and wireless charging functions in the same device, giving the benefit of using a shared (common) coil for both applications that operate at different frequencies. With the shared coil concept, the overall design of the wearable device can be reduced without the need for a second and separate coil to cater to the wireless charging or communication application.

Preferably, the wearable device is a hearing aid. A hearing aid generally has an input transducer, a signal processing unit and an output transducer. The input transducer is preferably a microphone. The output transducer is preferably an earphone, which is also referred to as a loudspeaker or receiver. A hearing aid is regularly assigned to an individual user and is only used by this user. A hearing aid is used to care for a hearing-impaired user and to compensate for a hearing loss. The input transducer generates an input signal, which is fed to the signal processing unit. The signal processing unit modifies the input signal and thereby produces an output signal which is thus a modified input signal. To compensate for a hearing loss, the input signal is amplified with a frequency-dependent amplification factor, for example according to an audiogram of the user. The output signal is finally output to the user by means of the output transducer. In a hearing aid with a microphone and receiver, the microphone generates the input signal from sound signals in the environment and the receiver generates another sound signal from the output signal. The input signal and the output signal are electrical signals, which are therefore also referred to as signals for short. In contrast, the

sound signals of the environment and the sound signal that may be emitted by the listener are acoustic signals. The communication circuit preferably is an alternate source for the input signal and separate from the input transducer and may also be used parallel to the input transducer.

Aside from hearing aids, the present invention is also applicable to other hearing instruments, such as headphones.

Preferably, the resonance isolator is positioned along (i.e. on) a charging path between the coil and a load. In the charging mode, the coil receives power (i.e. the charging power signal) from a charger and said power is transmitted to the load, which is part of the wearable device. Preferably, the load is a secondary battery or power management circuit connected to a secondary battery or similar. The charging path is part of the charging circuit. Since the resonance isolator is positioned along the charging path, the power also flows through the resonance isolator. In principle, the resonance isolator may alternatively be positioned in an analogous way along a communications path between the coil and a load (e.g. processor for the communication signal) in or behind the communications circuit.

Advantageously, the resonance isolator comprises an inductor and a capacitor in parallel. In other words: The resonance isolator is an oscillating circuit, also LC-resonator or resonance circuit. The resonance isolator has a tuning frequency which is defined by the inductance and capacitance values of the inductor and capacitor, respectively. In particular, the inductor and capacitor are arranged on parallel branches along the charging path. When the received signal has a frequency corresponding to the resonance isolator's tuning frequency, the resonance isolator starts resonating and has a high impedance which will pseudo-isolate both sides of the resonance isolator against each other, at least for this frequency. Preferably, the resonance isolator isolates the shared coil on the one side from the charging circuit or communication circuit on the other side. In other words, the resonance isolator will cut off the connection between the shared coil and one of the circuits when the frequency of a received signal corresponds to the tuning frequency. Other frequencies, however, are permitted through the

resonance isolator, such that the resonance isolator is effectively a frequency selective isolator or gate. While some frequencies (not the tuning frequency) are permitted to pass, other frequencies (the tuning frequency) are blocked.

The resonance isolator can be designed to be entirely passive, in contrast to a diplexer, which comprises one or several active components (detection circuit, switch). Hence, in a suitable embodiment, the resonance isolator is a purely passive circuit. This is understood to mean, that the resonance isolator's function of isolating the coil from one of the circuits depending on frequency (i.e. switching between the two modes) is realized entirely passive, i.e. without active components. As such the resonance circuit is then entirely made from passive components (inductor, capacitor) and, in particular, comprises no active switch. The connection of an inductor and a capacitor in parallel passively isolates the two circuits with different functions (communication and charging), in particular by an appropriate choice of the tuning frequency of the resonance isolator.

Generally, the term "a mode is activated" is understood to mean that a received signal (or part thereof) is routed to the corresponding circuit for suitable processing. Correspondingly, the term "a circuit is cut off" is generally understood to mean that a received signal (or part thereof) is not routed to the particular circuit. In other words: The coil is isolated from the respective circuit, at least with respect to a certain frequency. This has the effect, that the coil is isolated (cut off) from the charging circuit at the first frequency and that the coil is isolated (cut off) from the communication circuit at the second frequency.

Preferably, the resonance isolator has a higher impedance at the first frequency than at the second frequency or vice versa vice (i.e. the resonance isolator has a higher impedance at the second frequency than at the first frequency). In this way, a suitable frequency dependent isolation and hence activation of the respective mode is achieved. Without loss of generality, it is preferred and in the following assumed that the impedance is higher at the first frequency than at the second frequency.

In a particularly suitable embodiment, the resonance isolator acts as a notch filter (bandstop filter), in particular at either the first or the second frequency, preferably at the first frequency, which is assumed in the following without prejudice. Hence, the resonance isolator exclusively blocks the first frequency. In particular, the resonance isolator acts as notch filter to the entire combination of charging circuit and communication circuit, i.e. the entire system. In a preferred embodiment, the resonance isolator simply is a notch filter. The resonance isolator acting as a notch filter advantageously has a response of very low magnitude, e.g. less than -30 dB, for the first frequency (in particular for communication) and of larger magnitude, e.g. 0 dB, at all other frequencies, including the second frequency. In such an embodiment, the resonance isolator's impedance is high at the first frequency compared to a low impedance for all other frequencies, i.e. the impedance is higher at the first frequency than at any other frequency. Hence, any signal, in particular power signal, at the second frequency or at any frequency other than the first frequency is accepted by and permitted through the resonance isolator, while any signal, in particular communication signal, at the first frequency is prohibited to pass through the resonance isolator (cut off). In contrast, a diplexer approach naturally uses two operating frequencies for the two different applications. Said operating frequencies cannot be too close to each another due to the diplexer having the characteristic of two bandpass filters. The two bandpass filters are usually not ideal and their respective cutoff frequency is not sharply defined. Hence, an overlapping of the bandpass filters' bandwidths might occur when the two operating frequencies are too close to each another. This will cause the charging mode to be dominant and the communication to be inoperable due to this. In contrast, the resonance isolator presented here allows two different applications with close operating frequencies to operate, because the resonance isolator approach preferably has a notch filter behavior for the charging application. The charging application's operation is stopped only at one frequency and is operable for the rest of the frequencies. As such, the communication application is only working at said one frequency but it is not operable for the rest of the frequencies.

The coil is connected to both the communication circuit and the charging circuit. For the communication circuit, the coil acts as a signal receiver and is preferably connected to one or several of a tuning capacitor, a power amplifier, a low noise amplifier, two limiting diodes in parallel to the coil for protection, and an analog to digital converter. For the charging circuit, the coil acts as a power receiver and is preferably connected to a rectifier charging circuit, which in a suitable embodiment consists of a diode and a smoothing capacitor.

Per definition, a coil has an inductance behavior, so in a standalone operation, i.e. without connection to any charging or communication circuit, a high impedance can be achieved over a wide range of frequencies according to the selection of a capacitance of tuning capacitor to be combined with the coil. For the communication circuit, a single or several capacitors connected in parallel to the coil preferably act as a corresponding communication tuning capacitor. A lower capacitance value to the communication tuning capacitor results in a larger frequency range and a high impedance for the communication circuit. A suitable communication circuit comprises only a single capacitor, which is then connected to the shared coil. The corresponding first frequency may then be selected from a wide frequency range, e.g. 7 MHz to 25 MHz, when choosing the respective capacitance values for the communication tuning capacitor, e.g. in the range of 15 pF down to 1 pF. For such a communication circuit using a coil connected to a capacitor in parallel, a high impedance indicates a high quality-factor that implies that the ratio of circulating current is high compared to the branch current flowing to any other load, such as the load connected to the charging path. In other words, a high impedance indicates that most of the energy (signal received by the shared coil) is circulating over the coil and the parallel communication tuning capacitor at that frequency as a result of low power loss. Hence, a high impedance at a particular frequency means that a communication is possible at that frequency due to most of the received signal being trapped within the oscillating circuit formed by the shared coil and communication tuning capacitor resulting in a high induced voltage at the coil.

When a wireless charging circuit is introduced to the device using the same coil, said coil is a component that receives magnetic energy from the magnetic field of a charger and converts it to electrical energy in AC form. Preferably, the charging circuit comprises a rectifier circuit configured to convert AC power to DC power. The rectifier circuit is suitably connected between the coil and the already mentioned load (in particular resistive load). The charging circuit now connected to the shared coil, that originally serves the communication circuit as mentioned above, limits the possible frequency range of the communication circuit.

When implementing a shared coil concept as described here, the coil is preferably connected to both the charging circuit, in particular the rectifier circuit, and the communication circuit, in particular the communication tuning capacitor. When selecting the communication tuning capacitor as discussed above, e.g. in the range of 1 pF to 15 pF, the additional charging circuit also connected to the coil, limits the available frequency range of the communication circuit to e.g. 5 MHz to 8 MHz. This also applies even when the communication tuning capacitor uses a low capacitance value such as 1 pF. The phenomenon of the communication circuit's bandwidth being limited to such a narrow range is due to that the diode of the charging circuit is normally not an ideal component and usually has a parasitic capacitance, e.g. in a range of 12 pF to 25 pF. This parasitic capacitance can dominate the communication tuning capacitance. As a result, the shared coil concept for wireless communication and wireless charging will cause the first frequency (communication frequency) to be limited to a small bandwidth. This in turn will result in a limited flexibility with respect to the design of the communication application.

In a preferred embodiment, the resonance isolator has an impedance maximum at the first frequency (tuning frequency of the communication circuit) and acts as a notch filter at said first frequency. Hence, the resonance isolator realizes a pseudo-isolation when the received signal operates at the first frequency, which then matches the tuning frequency of the resonance isolator. The particularly high impedance at the resonance isolator's tuning frequency corresponds to a low energy loss at the tuning frequency and a low branch current along the charging

path to the load. Low energy loss at the tuning frequency also indicates that a high voltage can be induced at the shared coil when the received signal has the same frequency as the tuning frequency of the resonance isolator. As a result, a communication application at a high frequency can be achieved in combination with a charging application by using such a resonance isolator.

The addition of the resonance isolator advantageously creates an additional impedance maximum (i.e. peak or local maximum) for the entire system, i.e. combination of communication circuit, charging circuit, shared coil and resonance isolator, at the tuning frequency of the resonance isolator. In particular, the impedance as a function of frequency now has two local maxima and a notch between these maxima. In comparison to a direct connection of the shared coil to the charging circuit without the resonance isolator an additional frequency is created with respect to the tuning frequency of the resonance isolator and resulting in two peak impedances over the frequencies. With a high impedance at the tuning frequency, the shared coil and the communication tuning capacitor act as a resonance circuit circulating energy with low loss at the tuning frequency. In addition, the branching current to the charging circuit is low. A low branching current to the charging circuit is achieved as the shared coil and the communication circuit are isolated from the charging circuit. Since most of the energy is trapped in the resonance circuit, it induces a high voltage across the shared coil which is sufficient for the communication application to function. As such, the adoption of a resonance isolator allows the communication application to be implemented at a higher or lower frequency, but not limited to the frequency range of e.g. 5 MHz to 8 MHz only as mentioned above. In other words, the resonance isolator acts as a notch filter for the entire system (charging and communication) and especially for the charging application. This allows the communication application to operate only at the tuning frequency of the resonance isolator, while the charging application is operable at all other frequencies.

Summarizing the finding above, the diplexer approach as mentioned requires an active switch to change the coil's association to the circuits and thereby change

the mode of operation and the function of the shared coil. Overall, the diplexer approach requires more components than the resonance isolator approach described here. In particular, an additional detection circuit to actively control the switch are required in the diplexer approach. Such are not required and hence not used in solution presented here with the resonance isolator. A comparison of a diplexer to a preferred embodiment of the resonance isolator is also provided in the following Table 1:

	Diplexer Approach	Resonance Isolator Approach
Operation	Actively controls a switch to change the mode of operation by sensing the incoming signal frequency	Passively isolates two circuits that have different modes of operation which depend on the received signal's frequency
Components	2 series capacitors 1 tuning capacitor 1 switch	1 inductor 1 capacitor
Characteristic	Two bandpass filters for two applications	Notch filter and/or single bandpass filter
Disadvantages	Requires a detection circuit to detect the frequency Two operating frequencies cannot be too close	

Table 1: Comparison of diplexer approach and resonance isolator approach

Preferably, the communication circuit is an NFMI communication circuit, for near field magnetic induction (NFMI) communication. A suitable NFMI communication circuit is an NFC (near-field communication) circuit or telecoil circuit. The resonance isolator approach presented here can be used for various embodiments of the communication and charging circuits, in particular a telecoil communication circuit in combination with wireless charging for which the first and second frequencies are quite close to each other, e.g. both < 500 kHz. Setting the tuning frequency of the resonance isolator to the telecoil frequency (first frequency)

allows sharing the coil between a telecoil communication function and wireless charging function of the wearable device.

In a suitable embodiment, the communication circuit is configured to operate in a frequency range from 10 MHz to 11 MHz, in particular at 10.6 MHz. In other words: the first frequency is in the range from 10 MHz to 11 MHz and preferably 10.6 MHz. In another suitable embodiment, the communication circuit is a telecoil communication circuit, configured to operate in a frequency range from 0 Hz to 40 kHz. In other words: the first frequency is in the range from 0 Hz to 40 kHz.

In a suitable embodiment, the charging circuit is configured to operate in a frequency range from 13 MHz to 14 MHz, in particular at 13.56 MHz. In another suitable embodiment, the charging circuit is configured to operate in a frequency range from 100 kHz to 300 kHz. In other words: The second frequency preferably is in the range from 13 MHz to 14 MHz, most preferably at 13.56 MHz, or in the range from 100 kHz to 300 kHz.

The communication circuit, the charging circuit, the shared coil and the resonance isolator are part of a control unit of the wearable device. The control unit may be implemented completely or partially as an ASIC. The control unit preferably further comprises one or several of the other components mentioned above, in particular the charging path, the load, the inductor, the capacitor, the communication tuning capacitor, the power amplifier, the low noise amplifier, the limiting diode, the analog to digital converter, the rectifier charging circuit, the diode, the smoothing capacitor.

In the following, exemplary and preferred embodiments of the invention are described with reference to a drawing. Said drawing schematically showing:

Fig. 1 a wearable device, here a hearing aid,

Fig. 2 a combination of communication circuit, charging circuit, shared coil and resonance isolator of the wearable device of Fig. 1,

Fig. 3 further components of the wearable device of Fig. 1,

Fig. 4 impedance as function of frequency for a communication circuit only,

Fig. 5 impedance as function of frequency for a communication circuit in combination with a charging circuit,

Fig. 6 impedance as function of frequency for a communication circuit and charging circuit with an additional resonance isolator.

Fig. 1 shows a wearable device 2 (short: device), which in this particular embodiment is a hearing aid. The present invention and the following explanations, however, can also be applied to other wearable devices 2. The wearable device 2 has an input transducer 4, a signal processing unit 6 and an output transducer 8. The wearable device 2 shown here is used to care for a hearing-impaired user and to compensate for a hearing loss. The input transducer 4 generates an input signal, which is fed to the signal processing unit 6, which in turn modifies the input signal and thereby produces an output signal. To compensate for a hearing loss, the input signal is amplified with a frequency-dependent amplification factor. The output signal is finally output to the user by means of the output transducer 8.

The wearable device 2 comprises a communication circuit 10, for wireless communication, and a charging circuit 12, for wireless charging, e.g. as shown in Fig. 2. Further, the wearable device 2 comprises a coil 14, which is shared by the communication circuit 10 and the charging circuit 12. The coil 14 is configured to receive a signal (communication signal) at a first frequency f1 during a communication mode and a charging power signal at a second frequency f2 during a charging mode. In other words: During operation, the coil 14 is functionally associated with the communication circuit 10 or the charging circuit 12 and is then a receiver coil for the respective circuit 10, 12. In this way, the very same coil 14 is used for two applications: A first application is a communication application, for

which the coil 14 is functionally associated to the communication circuit 10 to receive a communication signal, i.e. a signal comprising data. A second application is a charging application, for which the coil 14 is functionally associated to the charging circuit 12 to receiver a charging power signal, i.e. power for charging the wearable device 2, e.g. of a secondary battery of the wearable device 2.

The charging mode and the communication mode are each a mode of operation of the wearable device 2. In the charging mode, the wearable device 2 is (wirelessly) connected to a charger (not shown) and usually not worn or used by the user. The charger may be a receptacle, in which the wearable device 2 is placed for charging. The communication mode, however, is usually active during the intended use of the wearable device 2. Hence, in the communication mode, the device 2 is usually worn or used by the user. However, the communication mode may also be active at other times and also during charging.

In the embodiment shown here, the first frequency f1 is a tuning frequency of the communication circuit 10, i.e. corresponds to a (communication) frequency which is used for communication. The second frequency f2 is a tuning frequency of the charging circuit 12, i.e. corresponds to a (charging) frequency used for charging. The first frequency f1 is different from the second frequency f2, such that communication and charging occur on different frequency channels.

The wearable device 2 further comprises a resonance isolator 16. The resonance isolator 16 is configured to isolate the coil 14 from the communication circuit 10 or the charging circuit 12 depending on a frequency of the signal received by the coil 14, i.e. depending of the frequency of the received signal. In other words: The resonance isolator 16 functionally associates the coil 14 with either the communication circuit 10 or the charging circuit 12, depending on the frequency of the received signal. In this way, the wearable device is automatically switched between the communication mode and the charging mode depending on the frequency of the signal received by the coil 14.

The operation of the resonance isolator 16 depends on the frequency of the received signal at the shared coil 14. The resonance isolator 16 has a tuning frequency ft which defines the resonance isolator's 16 behavior for a given frequency. This behavior is different for the first and second frequency f1, f2. In general, the resonance isolator 16 is configured to associate the coil 14 with one of the circuits 10, 12 and thereby cut off the other circuit 10, 12 when the frequency of the received signal corresponds to the tuning frequency ft. Without loss of generality, it is assumed in the following that the communication mode is activated when the frequency of the received signal corresponds to the tuning frequency ft and the charging mode is activated when the frequency of the incoming signal does not correspond to the tuning frequency ft. Further, the tuning frequency ft as shown here matches one of the two application frequencies f1, f2.

In the exemplary embodiment according to Fig. 2, the resonance isolator 16 is positioned along (i.e. on) a charging path 18 between the coil 14 and a load 20. In the charging mode, the coil 14 receives power from a charger and said power is transmitted to the load 20, which is part of the wearable device 2. The load may be a secondary battery or power management circuit connected to a secondary battery or similar. The charging path 18 is part of the charging circuit 12. Since the resonance isolator 16 is positioned along the charging path 18, the power also flows through the resonance isolator 16. In principle, the resonance isolator 16 may alternatively be positioned in an analogous way along a communications path between the coil 14 and a load in or behind the communications circuit 10.

The resonance isolator 16 as shown here comprises an inductor 22 and a capacitor 24 in parallel. In other words: The resonance isolator 16 is an oscillating circuit, also LC-resonator or resonance circuit. The tuning frequency ft is defined by the inductance and capacitance values of the inductor 22 and capacitor 24, respectively. In Fig. 2 the inductor 22 and capacitor 24 are arranged on parallel branches along the charging path 18. When the received signal has a frequency corresponding to the tuning frequency ft, the resonance isolator 16 starts resonating and has a high impedance i which will pseudo-isolate both sides of the resonance isolator 16 against each other, at least for this frequency. The

resonance isolator 16 will cut off the connection between the shared coil 14 and one of the circuits 10, 12 when the frequency of a received signal corresponds to the tuning frequency ft. Other frequencies, however, are permitted through the resonance isolator 16, such that it is effectively a frequency selective isolator or gate. While some frequencies are permitted to pass, other frequencies are blocked.

The resonance isolator 16 as shown here is a purely passive circuit and as such is entirely made from passive components (inductor 22, capacitor 24) and comprises no active switch. The connection of an inductor 22 and a capacitor 24 in parallel passively isolates the two circuits 10, 12 with different functions (communication and charging) by an appropriate choice of the tuning frequency ft. The resonance isolator 16 as shown here has a higher impedance i at the first frequency f1 than at the second frequency f2 (in the alternative the impedance i is higher at the second frequency f2 than at the first frequency f1). In this way, a suitable frequency dependent isolation and hence activation of the respective mode is achieved. In the embodiment shown here, the resonance isolator 16 then acts as a notch filter (bandstop filter) at the first frequency f1 and its impedance i is high at the first frequency f1 and low for all other frequencies f, including the second frequency f2. In other words: the resonance isolator's 16 gain response is about 0 dB for all frequencies except the first frequency f1, for which the gain is very low, e.g. -100 dB. Hence, the first frequency f1 is exclusively blocked by the resonance isolator 16, while all other frequencies f are permitted to pass through, especially the second frequency f2. This allows two different applications with close operating frequencies f1, f2 to operate. The charging application's operation is stopped only at one frequency (the first frequency f1) and is operable for the rest of the frequencies. As such, the communication application is only working at said one frequency (the first frequency f1) but it is not operable for the rest of the frequencies.

As shown in Fig. 2, the coil 14 is connected to both the communication circuit 10 and the charging circuit 12. For the communication circuit 10, the coil 14 acts as a signal receiver and is connected e.g. as shown in Fig. 3 to a tuning capacitor 26, a

power amplifier 28, a low noise amplifier 30, two limiting diodes 32 in parallel to the coil 14 and an analog to digital converter 34. For the charging circuit 12, the coil 14 acts as a power receiver and is connected e.g. as shown in Fig. 3 to a rectifier charging circuit 36, which consists of a diode 38 and a smoothing capacitor 40. In Fig. 3, the resonance isolator 16 is not explicitly shown.

The components shown in Figs. 2 and 3 are part of a control unit 42 of the wearable device 2.

For the communication circuit 10, a single or several capacitors connected in parallel to the coil 14 act as a corresponding communication tuning capacitor 26. A lower capacitance value to the communication tuning capacitor 26 results in a higher frequency, a larger frequency range (bandwidth) and a high impedance i for the communication circuit 10. In Fig. 2 the communication circuit 10 comprises only a single capacitor 26, which is then connected to the shared coil 14. The corresponding first frequency f1 may then be selected from a wide bandwidth, e.g. 7 MHz to 25 MHz when choosing the respective capacitance values for the communication tuning capacitor 26 in the range of 15 pF down to 1 pF, as shown in Fig. 4. For such a communication circuit 10 a high impedance i indicates a high quality-factor that implies that the ratio of circulating current is high compared to the branch current flowing to any other load, such as the load 20 connected to the charging path 18. Most of the energy is circulating over the coil 14 and the parallel communication tuning capacitor 26 at that frequency as a result of low power loss and a communication is possible at that frequency due to most of the received signal being trapped within the oscillating circuit formed by the shared coil 14 and communication tuning capacitor 26.

When a wireless charging circuit 12 is introduced to the device 2 using the same coil 14, the charging circuit 12 limits the possible frequency range of the communication circuit 10. This is illustrated in Fig. 5 for the above-mentioned case of a communication tuning capacitor 26 in the range of 1 pF to 15 pF and without the resonance isolator 16. As Fig. 5 shows, the additional charging circuit 12 connected to the coil 14, limits the available frequency range of the communication

circuit 12 to 5 MHz to 8 MHz. This also applies even when the communication tuning capacitor 26 uses a low capacitance value such as 1 pF.

In the embodiment shown here, the resonance isolator 16 has an impedance i maximum at the first frequency f1 and acts as a notch filter to the charging circuit 12. This is shown in Fig. 6, illustrating the impedance i as a function of frequency f for the entire combination of both circuits 10, 12, coil 14 and resonance isolator 16. Hence, the resonance isolator 16 realizes a pseudo-isolation when the received signal operates at the first frequency f1, which then matches the tuning frequency ft of the resonance isolator 16. The particularly high impedance i at the tuning frequency ft corresponds to a low energy loss at the tuning frequency ft and a low branch current along the charging path 18 to the load 20. Low energy loss at the tuning frequency ft also indicates that a high voltage can be induced at the shared coil 14 when the received signal has the same frequency as the tuning frequency ft of the resonance isolator 16. As a result, a communication application at a high frequency can be achieved in combination with a charging application by using such a resonance isolator 16.

As is visible in Fig. 6, the addition of the resonance isolator 16 creates an additional impedance i maximum for the entire combination of communication circuit 10, charging circuit 12, shared coil 14 and resonance isolator 16 at the tuning frequency ft. The impedance i as a function of frequency f now has two local maxima and a notch between these maxima. In comparison to a direct connection of the shared coil 14 to the charging circuit 10 without the resonance isolator 16 an additional frequency is created with respect to the tuning frequency ft of the resonance isolator 16, resulting in two peak impedances i over the frequencies f. With a high impedance i at the tuning frequency ft, the shared coil 14 and the communication tuning capacitor 26 act as a resonance circuit circulating energy with low loss at the tuning frequency ft. In addition, the branching current to the charging circuit 18 is low. Since most of the energy is trapped in the resonance circuit 16, it induces a high voltage across the shared coil 14 which is sufficient for the communication application to function. As such, the adoption of a resonance isolator 16 allows the communication application to be

implemented at a higher or lower frequency, but not limited to the frequency range of e.g. 5 MHz to 8 MHz only as mentioned above. In other words, the resonance isolator 16 acts as a notch filter for the charging application. This allows the communication application 10 to operate only at the tuning frequency ft of the resonance isolator 16, while the charging application is operable at all other frequencies f.

The communication circuit 10 shown here is an NFMI communication circuit 10, for near field magnetic induction (NFMI) communication, e.g. an NFC circuit or telecoil circuit. The communication circuit 10 may be configured to operate in a frequency range from 10 MHz to 11 MHz, e.g. at 10.6 MHz as shown here. In another embodiment, the communication circuit 10 is a telecoil communication circuit, configured to operate in a frequency range from 0 Hz to 40 kHz. The charging circuit 12 may be configured to operate in a frequency range from 13 MHz to 14 MHz, e.g. at 13.56 MHz as shown here, or in a frequency range from 100 kHz to 300 kHz.

The features and embodiments described in this application and particularly those described in connection with the figures are not restricted to the specific combinations and values as described and shown herein.

List of reference numerals

2	wearable device
4	input transducer
6	signal processing unit
8	output transducer
10	communication circuit
12	charging circuit
14	coil
16	resonance isolator
18	charging path
20	load
22	inductor (of resonance isolator)
24	capacitor (of resonance isolator)
26	(communication) tuning capacitor
28	power amplifier
30	low noise amplifier
32	limiting diode
34	analog to digital converter
36	rectifier charging circuit
38	diode
40	smoothing capacitor
f	frequency
f1	first frequency
f2	second frequency
i	impedance
ft	tuning frequency

Claims

1. Wearable device (2), comprising:
   - a communication circuit (10), for wireless communication,
   - a charging circuit (12), for wireless charging,
   - a coil (14), which is shared by the communication circuit (10) and the charging circuit (12),
   - a resonance isolator (16),
   - wherein the coil (14) is configured to receive a signal, namely a communication signal at a first frequency (f1) during a communication mode and a charging power signal at a second frequency (f2) during a charging mode,
   - wherein the resonance isolator (16) is configured to isolate the coil (14) from the communication circuit (10) or the charging circuit (12) depending on a frequency (f) of the signal received by the coil (14).

2. Wearable device (2) according to claim 1,
wherein the resonance isolator (16) has a tuning frequency (ft), which corresponds to either the first frequency (f1) or the second frequency (f2).

3. Wearable device (2) according to claim 1 or 2,
wherein the resonance isolator (16) is configured to associate the coil (14) with one of circuits (10, 12) and thereby cut off the other circuit (10, 12) when the frequency (f) of the received signal corresponds to a resonance isolator (16) tuning frequency (FT).

4. Wearable device (2) according to any one of claims 1 to 3,
which is configured such, that
the communication mode is activated when the frequency (f) of the received signal corresponds to a tuning frequency (ft) of the resonance isolator (16) and

the charging mode is activated when the frequency (f) of the received communication signal does not correspond to the tuning frequency (ft).

5. Wearable device (2) according to any one of claims 1 to 4, wherein the resonance isolator (16) has a higher impedance (i) at the first frequency (f1) than at the second frequency (f2).

6. Wearable device (2) according to any one of claims 1 to 5, wherein the resonance isolator (16) acts as a notch filter.

7. Wearable device (2) according to claim 1 or 6, which comprises a load (20), wherein the resonance isolator (16) is positioned along a charging path (18) between the coil (16) and the load (20).

8. Wearable device (2) according to any one of claims 1 to 7, wherein the resonance isolator (16) comprises an inductor (22) and a capacitor (24) in parallel.

9. Wearable device (2) according to any one of claims 1 to 8, wherein the resonance isolator (16) is a purely passive circuit.

10. Wearable device (2) according to any one of claims 1 to 9, wherein the communication circuit (10) is configured to operate in a frequency range from 10 MHz to 11 MHz, in particular at 10.6 MHz.

11. Wearable device (2) according to any one of claims 1 to 9, wherein the communication circuit (10) is a telecoil communication circuit, configured to operate in a frequency range from 0 Hz to 40 kHz.

12. Wearable device (2) according to any one of claims 1 to 11, wherein the charging circuit (12) is configured to operate in a frequency range from 13 MHz to 14 MHz, in particular at 13.56 MHz.

13. Wearable device (2) according to any one of claims 1 to 11, wherein the charging circuit (12) is configured to operate in a frequency range from 100 kHz to 300 kHz.

14. Wearable device (2) according to any one of claims 1 to 13, which is a hearing aid.

15. Method of operating a wearable device (2) according to any one of claims 1 to 14, wherein the wearable device (2) is automatically switched between the communication mode and the charging mode depending on the frequency (f) of the signal received by the coil (14).

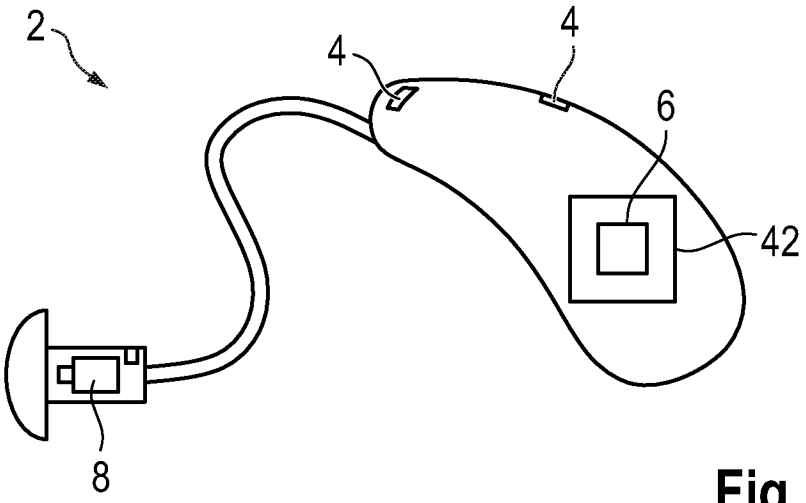

2
4
4
6
42
8

Fig. 1

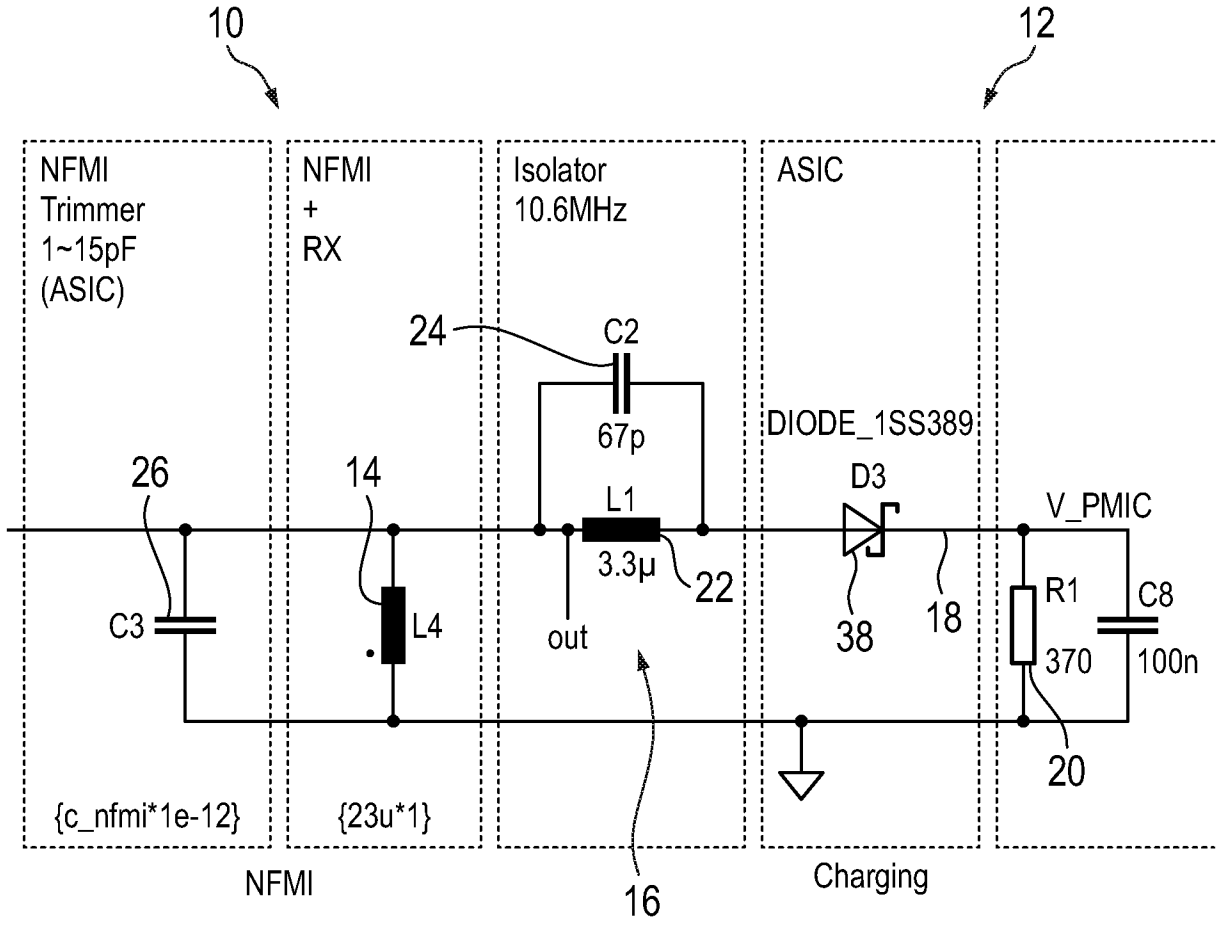

10
12
NFMI
Trimmer
1~15pF
(ASIC)
NFMI
+
RX
Isolator
10.6MHz
ASIC
24
C2
67p
DIODE_1SS389
26
14
L1
D3
V_PMIC
3.3µ
22
C3
L4
out
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NFMI
Charging

Fig. 2

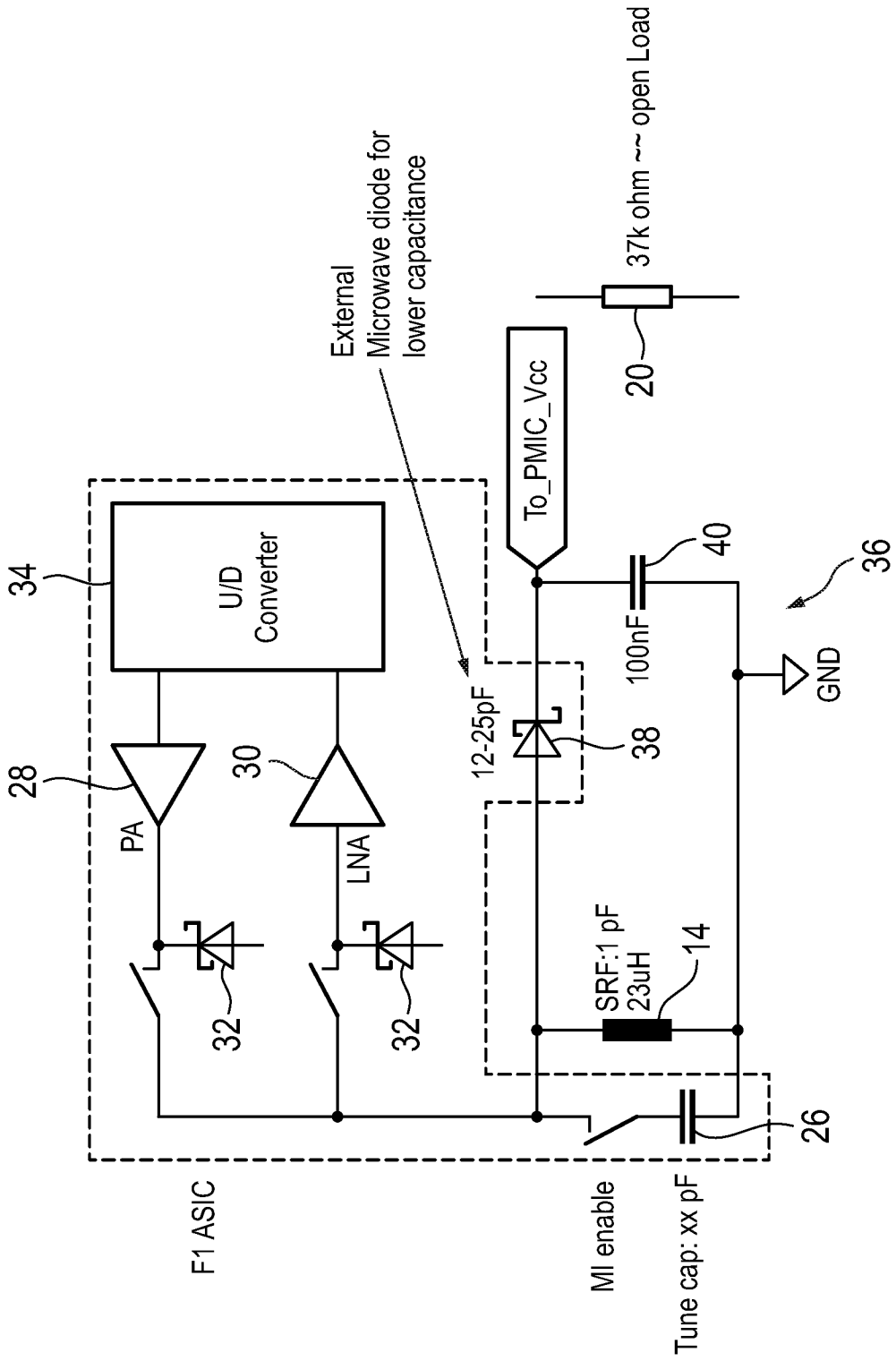

37k ohm ~~ open Load
20
External
Microwave diode for
lower capacitance
To_PMIC_Vcc
34
U/D
Converter
40
36
100nF
GND
12-25pF
38
28
30
PA
LNA
SRF:1 pF
23uH
14
32
32
26
F1 ASIC
MI enable
Tune cap: xx pF

Fig. 3

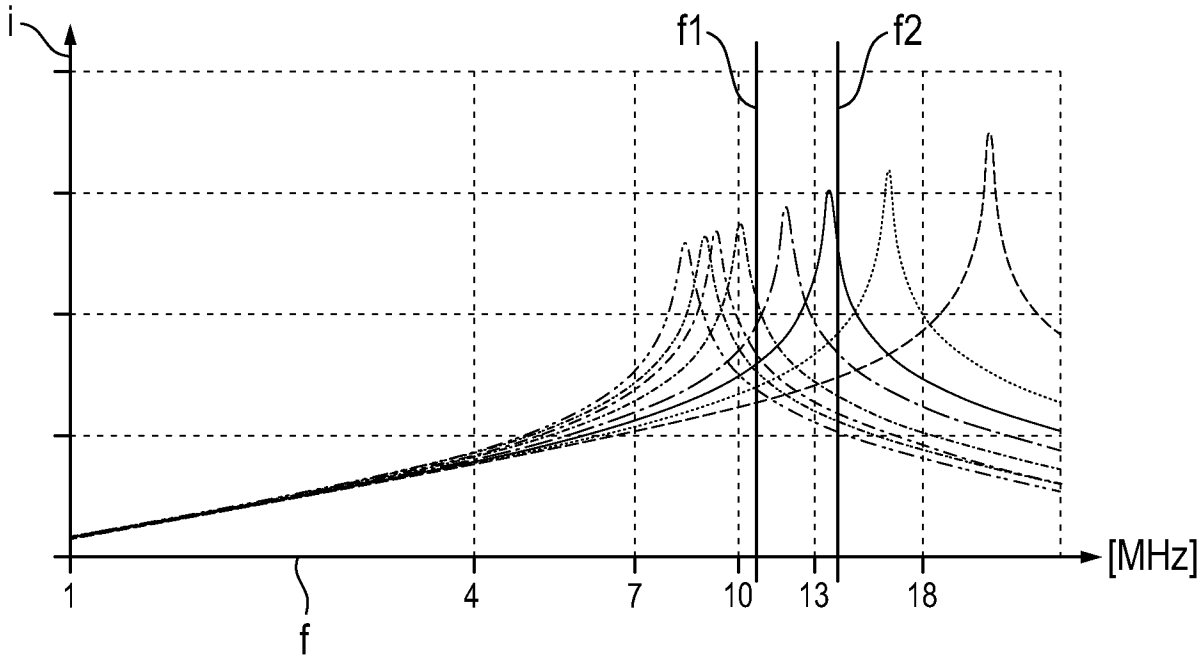


Fig. 4

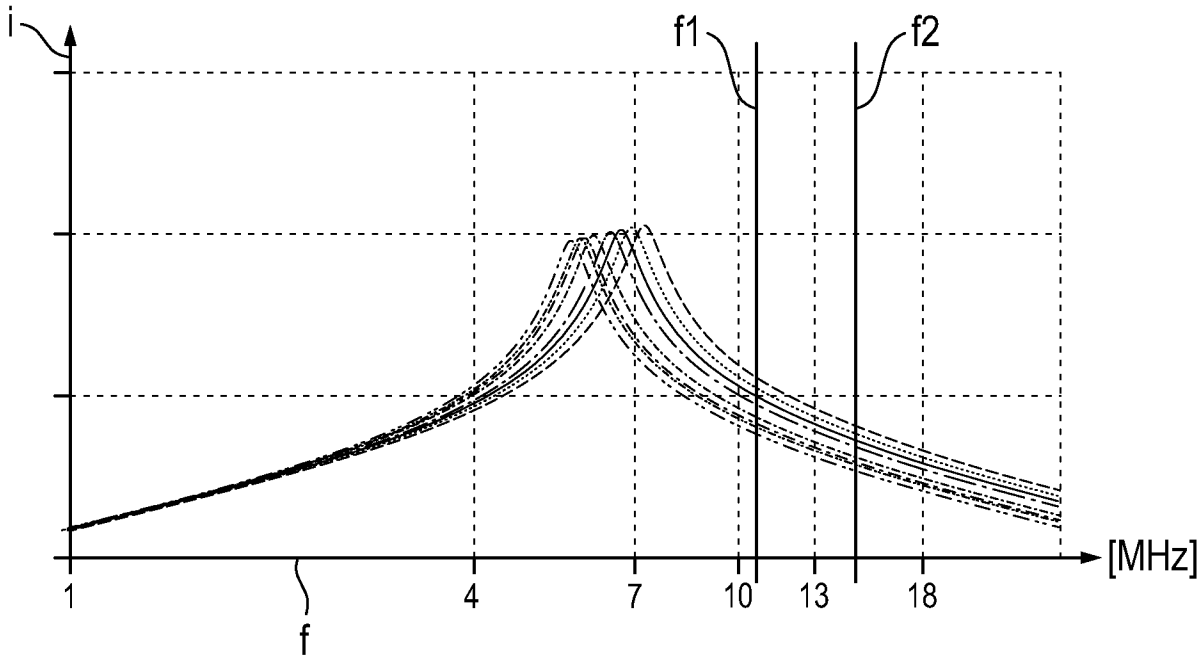


Fig. 5

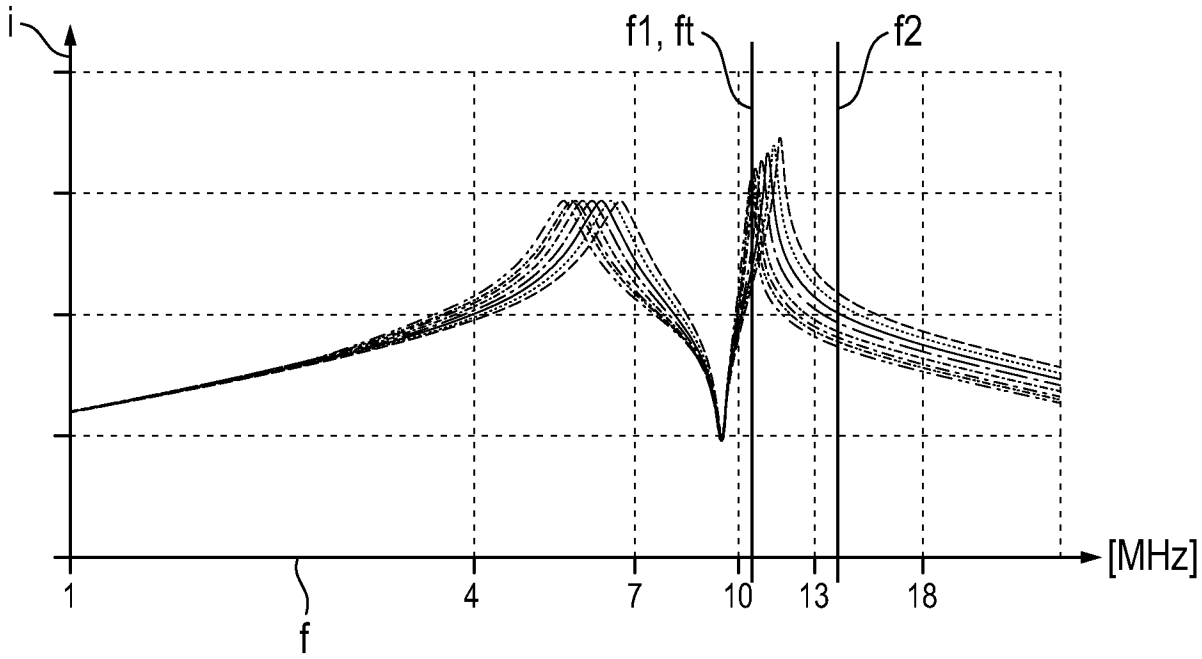


Fig. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/SG2022/050947

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04R25/00 H02J50/10 H04B5/00
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)
H04R H02J H04B

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2015/054345 A1 (MONAT PAVEL [US] ET AL) 26 February 2015 (2015-02-26) paragraphs [0001], [0002], [0057] - [0074]; figures 7-10	1-15
A	EP 3 493 556 A1 (SEMICONDUCTOR COMPONENTS IND LLC [US]) 5 June 2019 (2019-06-05) paragraphs [0028] - [0030]; figures 1-4	1-15
A	CN 203 708 487 U (DONG YONGZHENG; LI PENGSHUAN; LIU XIAOJIE) 9 July 2014 (2014-07-09) abstract; figures 1,2	1-15

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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"P" document published prior to the international filing date but later than the priority date claimed

"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

"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
8 May 2023	16/05/2023

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	Righetti, Marco

Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/SG2022/050947

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2015054345 A1	26-02-2015	CN 105493374 A	13-04-2016
		EP 3022823 A1	25-05-2016
		JP 6382982 B2	29-08-2018
		JP 2016536964 A	24-11-2016
		US 2015054345 A1	26-02-2015
		WO 2015031016 A1	05-03-2015
EP 3493556 A1	05-06-2019	CN 209314105 U	27-08-2019
		DK 3493556 T3	08-03-2021
		EP 3493556 A1	05-06-2019
		US 2019174239 A1	06-06-2019
CN 203708487 U	09-07-2014	NONE	