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(54) **Title**: BONE CONDUCTION TRANSDUCER WITH IMPROVED HIGH FREQUENCY RESPONSE

(57) **Abstract**: A bone conduction transducer comprising a first seismic mass and a second mass connected to each other by a first spring suspension, and where the first mass and the first spring suspension creates a first mechanical resonance f_1 in the low frequency range, and that a second mechanical resonance f_2 is created in the high frequency range by interaction between the second mass and a second spring compliance that is introduced between the second mass and the skull.

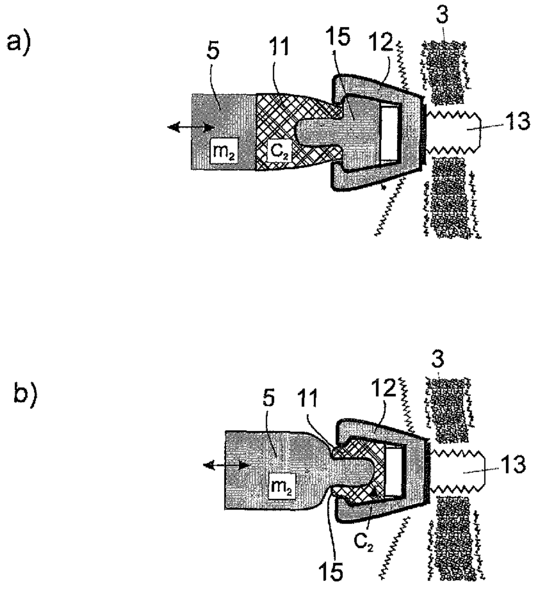

Figure 6

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TITLE

Bone conduction transducer with improved high frequency response

DESCRIPTION

Technical field

The present invention relates to vibration generating transducers for bone conduction hearing devices.

Background of the invention

Bone conduction hearing devices are used by patients who can not use conventional air conduction hearing aids e.g., due to chronic middle ear disease or a congenital/acquired deformity.

A traditional low cost bone conduction hearing device consists of a bone conduction transducer enclosed in a plastic housing which is pressed with a constant pressure of 3-5 Newton against the skin over the bone behind the ear. Microphone, amplifier, and power source are placed in their own housing at a suitable site and at a secure distance from the transducer to avoid feedback problems. The most essential drawbacks of this type of bone conduction hearing devices are that it is uncomfortable to wear due to the constant pressure and that the soft skin over the bone deteriorate the transmission of vibrations to the bone.

Since the beginning of the 1980's there is a second type bone conduction device - the bone anchored hearing aid (BAHA) - where the bone conduction transducer is connected directly to the bone via a skin penetrating and bone anchored implant of titanium, cf e.g., SE8107161, SE9404188 or Tjellström et al. 2001. In this way a bone conduction hearing device is obtained which provides higher amplification, improved wearing comfort, and where all parts can be enclosed in the same housing.
In the future there may be a third generation of bone conduction hearing devices where the transducer is supposed to be implanted completely and thereby skin and soft tissue can remain intact. Signal and necessary energy can in this case be transferred through intact

skin by means of inductive coupling, as described by Håkansson et al. 2008. At more severe hearing damages where the energy demand is large the energy can be transferred by means of skin penetrating (percutaneous) electric connection device, cf e.g., SE9704752. The advantages implanting the whole transducer into the temporal bone compared with a transducer being externally situated are, besides the pure medical ones, that an increased sensitivity is obtained, the size of the externally placed unit becomes smaller and stability margins are improved.

It is of course of utmost importance that all bone conduction transducers in general and implantable ones in particular are efficient and keep current consumption low and that the sensitivity i.e. output force over the whole frequency range is high enough.

To achieve sufficiently high low frequency sensitivity conventional transducers are designed to have a first resonance created from the interaction between the counterweight mass and the suspension compliance (elasticity). Both the mass and the compliance are also needed from inherent reasons i.e. the suspension compliance is needed to prevent air gaps from collapsing and the counter weight mass is needed to induce the forces created in the airgap to the load. This low frequency resonance is typically placed somewhere between 200-1000 Hz and gives the transducer a low frequency sensitivity boost. However, it is well known that bone conduction devices suffer from a limited maximum output at high frequencies, especially if compared with air conduction devices. To improve the sensitivity of bone conduction transducers in the high frequency area is the major objective behind the present invention.

The present innovation is also applicable to other applications than bone conduction hearing aids such as transducers for bone conduction communication systems, audiometric and vibration testing devices.

Prior art

A cross-section of conventional variable reluctance type bone conduction transducers are shown in Fig. 1a and 1b (State of the Art). The transducer in Fig 1a is of the balanced type whereas the transducer in Fig 1b is of the unbalanced type. For a more detailed description of the balanced design see for example 10/237,391 and Håkansson 2003.

Both types of transducers are supposed to be connected to a patient (Z_{load}) either via a bone anchored implant and a coupling of some sort or via a casing, capsulating the transducer, which in turn is in contact with the bone tissue. Normally in direct bone conduction applications one assumes that the load impedance i.e. the skull impedance is much higher than the transducers mechanical output impedance i.e. the load do not significantly affect the transducers force generating performance.

The counter weight with total mass m1 is engaging electromagnetically with the driving side of the transducer having a total driving mass m2. One or more suspension springs with total compliance C1 is needed to maintain stable airgaps, formed in between m1 and m2, in which the dynamic forces are created by the electromagnetic circuits (only symbolically depicted in Fig. 1a and 1b).

The primary task of the mass m_l is to act as a counter weight for the dynamic forces generated in the airgaps and to create a low frequency resonance to boost the low frequency sensitivity. The resonance frequency f_l relates approximately to Equ. 1.

$$f_1 \cong \frac{1}{2\pi\sqrt{C_1 m_1}}\ Hz \qquad \text{Equ. 1}$$

As shown in Figure 1 the mass of the coil (S2) is included in the driving mass m2 for the balanced design whereas the coil (S1) is included in the counter weight mass m1 for the unbalanced design. The resonance frequency may, in accordance with Equ. 1, be lowered by either increasing the total weight of the counter weight mass m1 or increasing the compliance of the total spring suspensions C1.

Summary of the present invention

The present innovation comprise of a new design to improve the high frequency performance of bone conduction transducers. The new design is based on that a compliant member is introduced between the driving mass of the transducer and the load thereby creating a resonance between that compliance and the driving mass in the high frequency region. This resonance will improve the response in that frequency region.

Description of the figures

Figure 1a, b: Prior art - cross-section of (a) balanced and (b) unbalanced conventional variable reluctance transducer.

Figure 2: Cross-section of a preferred embodiment of the invention with the second suspension compliance permanently in place.

Figure 3a, b, c: Electro-mechanical lumped parameter models of (a) prior art and (b) present innovation and (c) a modification of present innovation.

Figure 4: Frequency responses of Prior art (P) and present innovation (solid line).

Figure 5a, b: Cross-section of a preferred embodiment of the present invention using a snap arrangement (a) engaging internally or (b) engaging externally to a skin penetrating abutment.

Figure 6a, b: Cross-section of a preferred embodiment of the present invention for attachment of the external transducer using a coupling engaging to an adaptor fitted into a skin penetrating abutment where the compliant material could be placed either (a) on transducer side or (b) interiorly of the abutment.

Figure 7a, b, c: Cross-section of a preferred embodiment of the present invention for a attachment of external transducer by a bayonet coupling (a) where the compliant material are on the transducer side (b) or interiorly the abutment (c).

DETAILED DESCRIPTION

A first embodiment according to the present invention is shown in Fig. 2. In this embodiment the transducer (1) is capsulated in a housing (2) of biocompatible material for implantation in the skull bone (3). In this example a balanced design (Fig 1a) is used but also an unbalanced design (Fig 1b) could used. The counter weight unit consisting of soft iron material and magnets with total mass m1 (4) is engaging with driving side unit consisting of soft iron material and including the coil with total mass m2 (5) forming small air gaps (6) in between. In order to maintain stable and balanced airgaps there is needed a first spring suspension arrangement (7) with total compliance C1 that in one end is attached to the seismic mass unit (4) and in the other end is attached to the driving side unit (5). The suspension spring arrangement (7) can typically be made of one or more blade springs and they may have damping material attached (not shown) to give the resonance peak an appropriate shape. The mass m1 of counter weight unit (4) and the compliance C1 of the first suspension spring form a low frequency resonance f1 according to Equ. 1. This low frequency resonance is designed to boost the low frequencies in the range from 200 to 1000 Hz.

In a conventional transducer the driving mass unit (5) is directly attached to the housing (2) whereas in this invention a second suspension arrangement (8) with total compliance C2 is placed in between the driving mass unit (5) and the housing (2). The housing (2) is directly attached to the skull bone (3) either directly or via a bone anchored coupling (not shown). Hence the mass m2 and the compliance C2 form a second resonance frequency according to Equ 2. This resonance is designed to boost the high frequencies in the range approximately from 1k to 7 k Hz

$$f_2 \cong \frac{1}{2\pi\sqrt{C_2 m_2}} \, Hz \qquad \text{Equ. 2}$$

The second suspension (8) may have some damping material (9) attached between the spring and the housing as shown in Figure 2 or directly on the spring surface (not shown).

In Figures 3a, b, and c electro-mechanical analogue lumped parameter networks of the transducer designs are shown. There are some more parameters in Figure 3 not described above such as the electrical input impedance Ze, the electro-magnetic conversion factor g, the damping of the first suspension spring R1, the damping of the second suspension spring R2 and the mechanical load impedance Z_{load}. The load impedance Z_{load} is the mechanical impedance of the skull which has been described in more detail by Håkansson et al. 1986. The conventional (prior art) model is shown in Figure 3a and the model of the new invention is shown in Figure 3b where the second suspension compliance C2 is added. If desired some damping R2 can be added. Generally the values m2, C2 and R2 are chosen to give a desired resonance frequency f_2 and an appropriate shape of the frequency response in the high frequency region but considering that other parameters have some influence as well. It should also be noted that appropriate damping of C2 can be achieved by the damping R1 only as R1 and R2 are in series, see Figure 3a and b. The damping of resonances f_1 and f_2 can also be introduced electronically as described in SE 0302489-0 instead of using R1 and/or R2. In Figure 3c it is also shown that an additional mass m3 can be introduced between the mechanical load and the second compliance C2 to take into account the mass of the housing or just to increase the impedance of the load to avoid interaction between the load Z_{load} and the resonance network m2 and C2.

In Figure 4 the graphs show the prior art frequency response (dashed line) and the frequency response of the present innovation (solid line). It is obvious that the present innovation can give a high frequency boost shown by the cross hatched area by up to 20 dB at the resonance frequency f_2 which here is designed to be approx. 3 kHz. In this example the improvement in sensitivity starts already slightly above 1 kHz and ends below 5kHz. This frequency range from 1-5 kHz is very important for speech understanding. Improving the performance of the transducer in this frequency range is main purpose with the present innovation.

In Figure 5a, b it is shown one embodiment of the present innovation where a snap coupling is modified to create a second resonance frequency f_2. In Figure 5a the snap male unit (10) constitute the second compliant member (11) with compliance C2 that is attached to the driving mass unit (5) of the transducer. Here the compliant member (11) is snapped into the female part formed by the skin penetrating abutment (12) that is firmly attached to the bone anchored titanium screw (13). In Figure 5b the snap parts are reversed i.e. the female part (14) constitute the second compliant member C2 (11) and is in one end attached to the driving mass unit (5) of the transducer and in the other snapped onto the outer portion of the skin penetrating abutment (12). It should be noted that the snap coupling used in the present BAHA (SE 9404188-6) is designed so that the inherent compliance that exist in any coupling is so stiff that the resonance occurs in a frequency range above the useful range of frequencies for hearing impaired which was deemed to be around 10 kHz. In this way potential feedback problems could be avoided and it was also thought to expand the frequency range of the device. Therefore, if the snap coupling for a BAHA is worn out and the resonance was decreased to around 8k Hz it should be replaced according to the instructions as it often then was also insufficiently attached and unintentionally was released from the implant.

In Figure 6a, b other embodiments of the present innovation are shown. In Figure 6a an adapter unit (15) is rigidly attached to the interior part of the skin penetrating abutment (12). The driving mass unit (5) of the transducer with the compliant member (11) on top is snapped or pressed onto the adapter unit (15). In Figure 6b the coupling units are reversed i.e. the adapter unit constitute the compliant member (11) and the driving mass unit (5) of the transducer is snapped or coupled to it.

In Figure 7a,b,c, the coupling between the driving mass unit (5) and the skin penetrating abutment is similar to in Figure 5a,b but here the coupling is using a bayonet principle instead of a snapping principle. In Figure 7a it is shown that the driving mass unit (5) of the transducer with the compliant member (11) on top constituting the bayonet male unit (16) is positioned into the adapter unit (15) in a slot or female part of bayonet coupling (17) then, as shown in Figure 7b by the arrow, the coupling action is achieved by a turning motion by preferably 90 degrees. As shown in Figure 7c the compliant member (11) can constitute the adapter unit 15 and hence the driving mass unit (5) is formed to constitute the male bayonet part (16).

It is evident from the embodiments of Fig. 2, 3, 5, 6, 7 each individually or in combination that there are a number of different possibilities to introduce the compliant member C2 in between the driving mass unit 5 and the mechanical load Z_{load}. Even if the specific solutions are different the technical effect i.e. enhancing the high frequency response applies to all embodiments. This is further strengthened by that the electro-mechanical analogue models in Figure 3 apply to all possible embodiments under this innovation.

In spite of the fact that all embodiments have been presented to describe the invention it is evident that the one skilled in the art may modify, add or reduce details without diverging from the scope and basics of the present invention as defined in the following claims.

REFERENCE NUMBERS

1 Transducer
2 Housing
3 Skull bone
4 Counter weight unit m1
5 Driving mass unit m2
6 Air gaps
7 First suspension spring arrangement C1
8 Second suspension spring arrangement C2
9 Damping material R2
10 Male snap unit
11 Seconed compliant member C2, R2
12 Skin penetrating abutment
13 Bone anchored screw
14 Female snap unit
15 Adapter unit
16 Bayonet male part
17 Slot in adapter unit – female part

REFERENCES

Håkansson, B. Carlsson, P. and Tjellström, A., 1986. The mechanical point impedance of the human head, with and without skin penetration. Journal of the Acoustic Society of America, 80(4), 1065-1075.

Tjellström, A., Håkansson, B. and Granström, G. (2001). The bone-anchored hearing aids – Current status in adults and children, Otolaryngologic Clinics of North America, Vol. 34, No 2, pp 337 – 364.

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Håkansson, B.; Eeg-Olofsson, M.; Reinfeldt, S.; Stenfelt, S.; Granström, G. (2008). Percutaneous Versus Transcutaneous Bone Conduction Implant System: A Feasibility Study on a Cadaver Head, Otology & Neurotology: Volume 29(8). pp 1132-1139.

CLAIMS

1. A bone conduction transducer comprising a first seismic mass m_1 and a second mass m_2 connected to each other by a first spring suspension with compliance C1, where the coil and magnetic circuits are integrated into the two masses and are generating dynamic forces in the air gaps formed between the first and second masses when a current is supplied to the coil, and where the first mass m_1 and the first spring suspension C1 creates a first mechanical resonance f_1 in the low frequency range,

characterized in

that a second mechanical resonance f_2 is created in the high frequency range by interaction between the second mass m_2 and a second spring compliance C2 that is introduced between the second mass m2 and the load Z_{load}.

2. Device according to claim 1,

characterized in that the second mechanical resonance f_2 has its maximum sensitivity in the range between 1 and 7 kHz.

3. Device according to claims 2,

characterized in that the second spring suspension C2 has a damping arrangement integrated.

4. Device according to claim 2 or 3,

characterized in that the second spring suspension C2 is attached to the skull via a biocompatible housing of an implanted transducer with mass m3.

5. Device according to claim 4,

characterized in that the second suspension spring C2 is formed by a blade spring attached to the second mass m_2 in one end and attached to the housing in its other end.

6. Device according to claims 2 or 3,

characterized in that the second suspension spring C2 is integrated in the coupling arrangement between the transducer and the a bone anchored implant system.

7. Device according to claim 6,
characterized in that the attachment of the second mass m_2 of the transducer to the bone anchored implant system is provided by a snap coupling where the male or female unit constitute the second suspension spring C2 which is made of a material that inherently has the proper compliance and damping to create the second resonance f_2.

8. Device according to claim 6,
characterized in that the attachment of the second mass m_2 of the transducer to the bone anchored implant system is provided by a bayonet coupling where the male or female unit constitute the second suspension spring C2 which is made of a material that inherently has the proper compliance and damping to create the second resonance f_2.

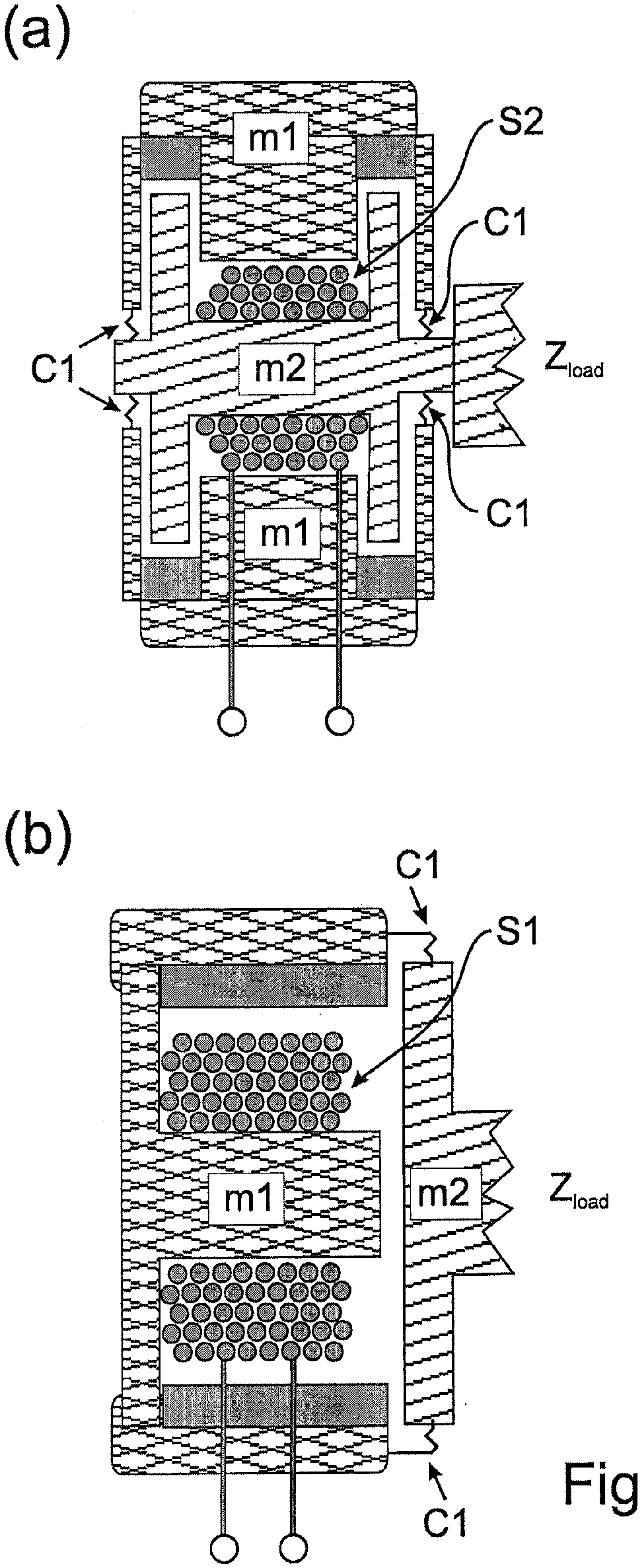

Figure 1

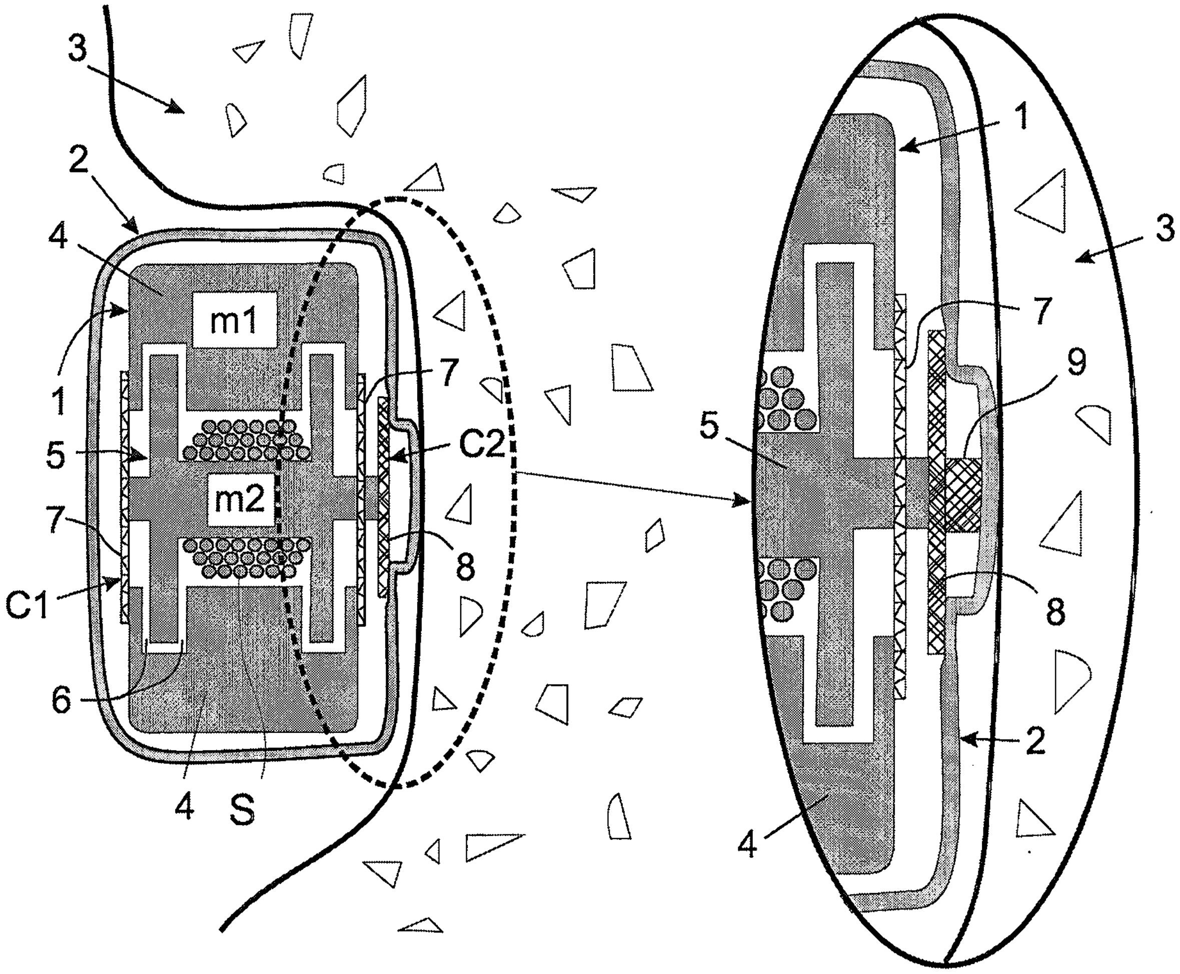

Figure 2

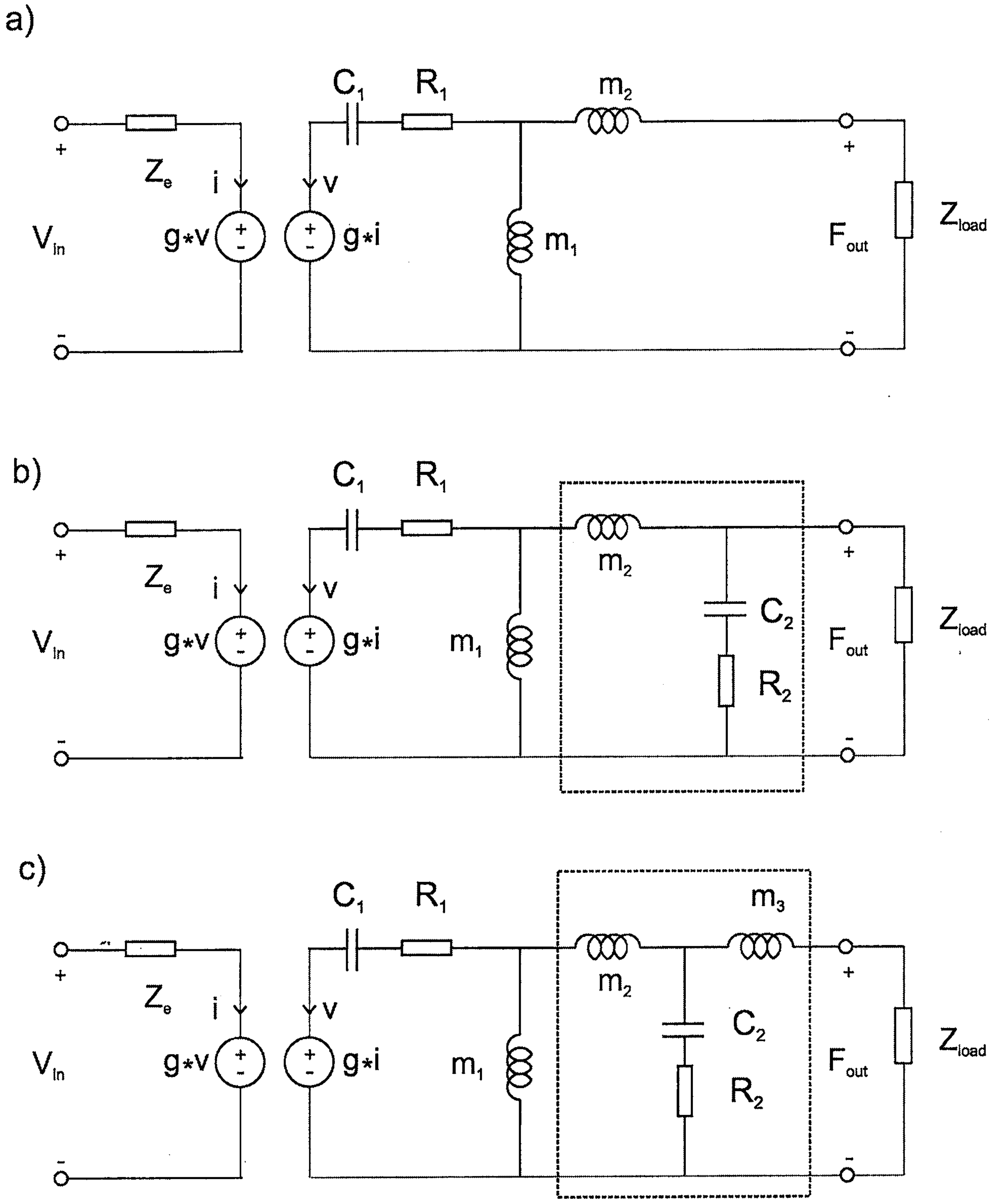
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Figure 3

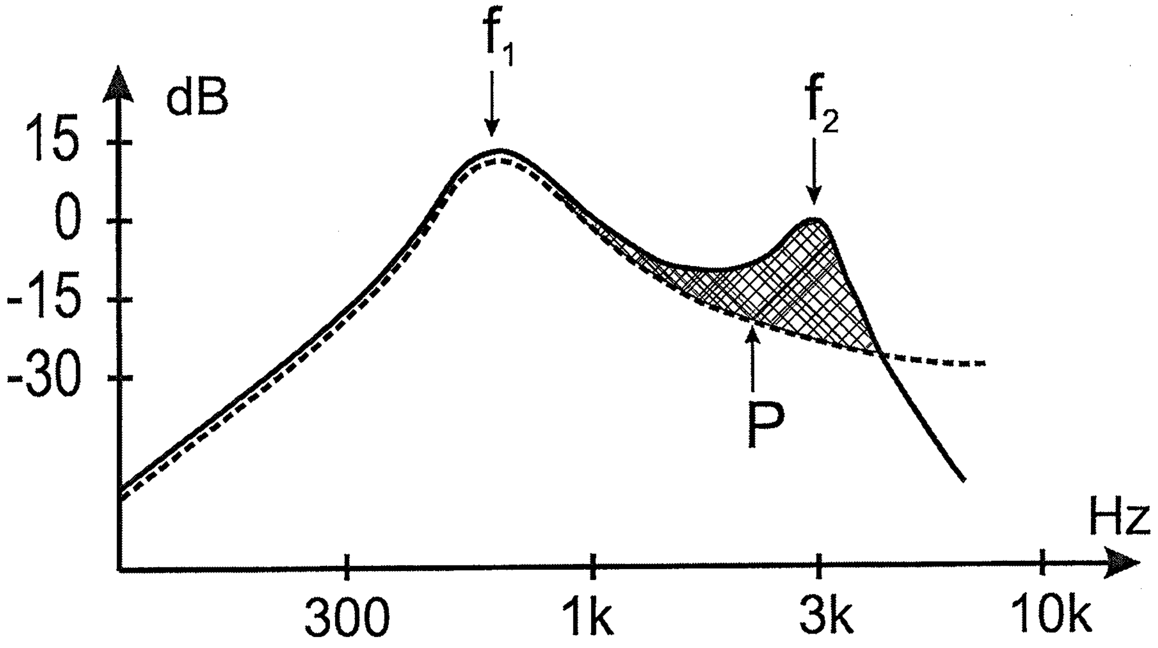

Figure 4

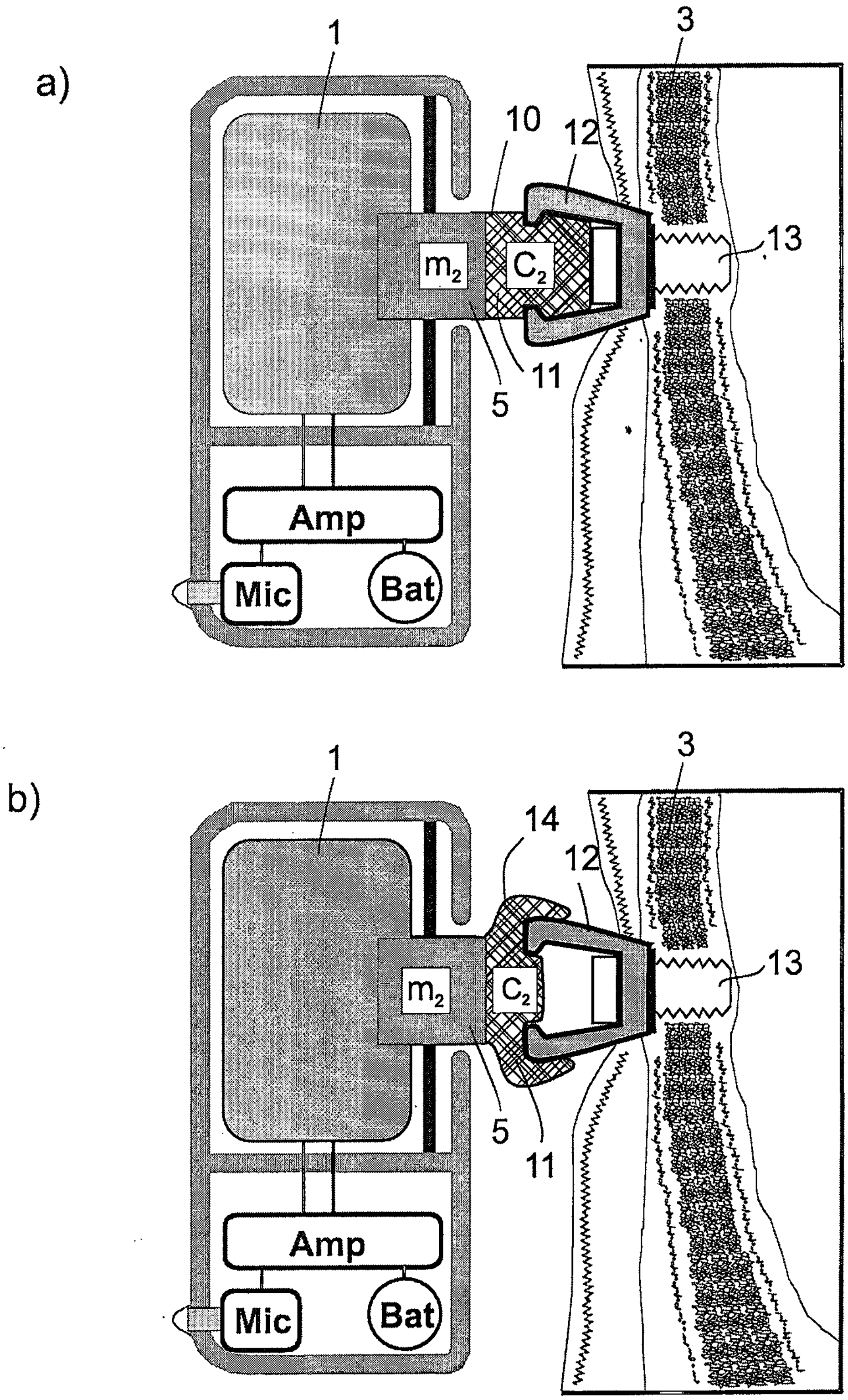
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Figure 5

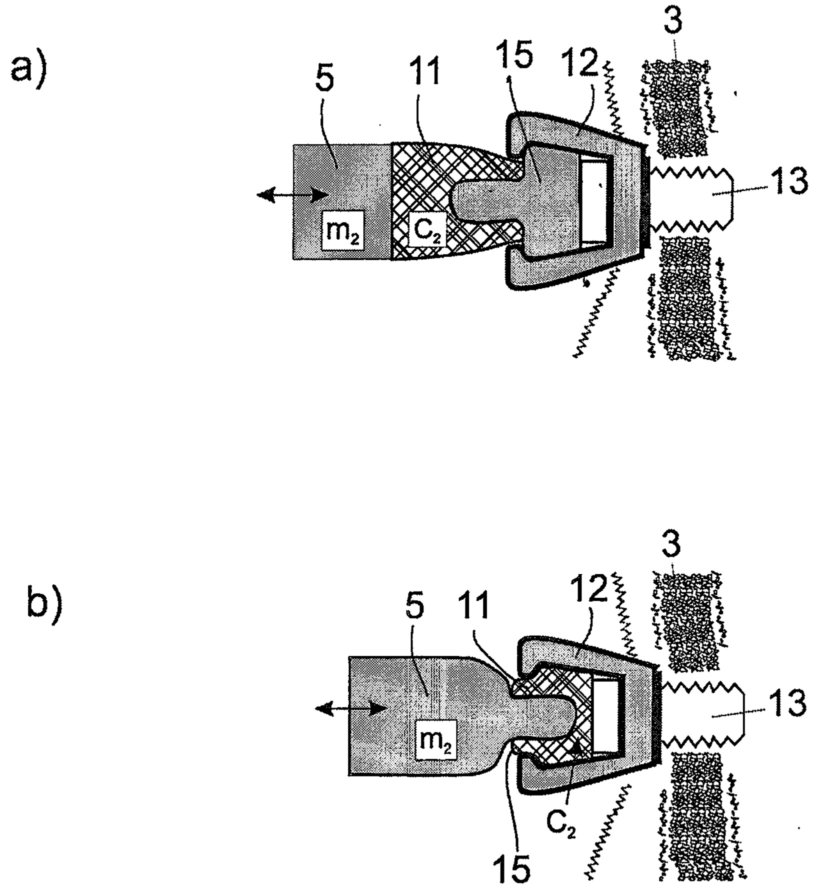

Figure 6

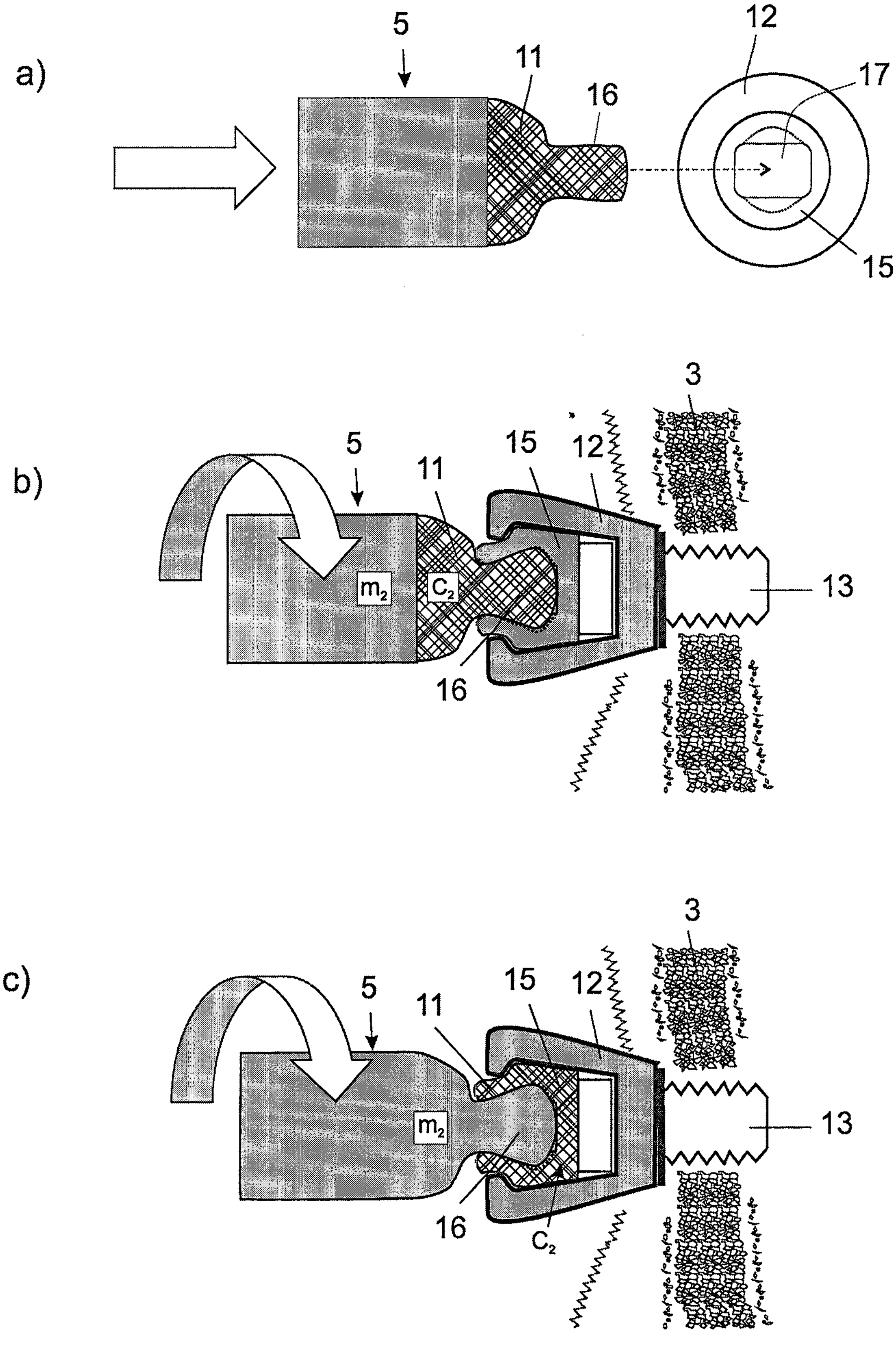

Figure 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE2010/000066

A. CLASSIFICATION OF SUBJECT MATTER

IPC: see extra sheet
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)

IPC: H04R

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

SE,DK,FI,NO classes as above

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

EPO-INTERNAL, WPI DATA, PAJ, COMPENDEX, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 20040097785 A1 (C. SCHMID ET AL), 20 May 2004 (20.05.2004), figures 1-2, abstract, paragraphs (0002), (0009), (0011), (0015)-(0016), (0028)-(0030), (0037)-(0046) --	1-8
A	US 20050101830 A1 (J.R. EASTER ET AL), 12 May 2005 (12.05.2005), abstract, paragraphs (0006)-(0013), (0018)-(0019), (0046), (0055), (0058), (0066)-(0068) --	1-8
A	WO 03001846 A1 (P & B RESEARCH AB), 3 January 2003 (03.01.2003), abstract --	1-8

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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	WO 03096744 A1 (OSSEOFON AB), 20 November 2003 (20.11.2003), abstract -- --------	1-8

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International application No.
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H04R 25/00 (2006.01)
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