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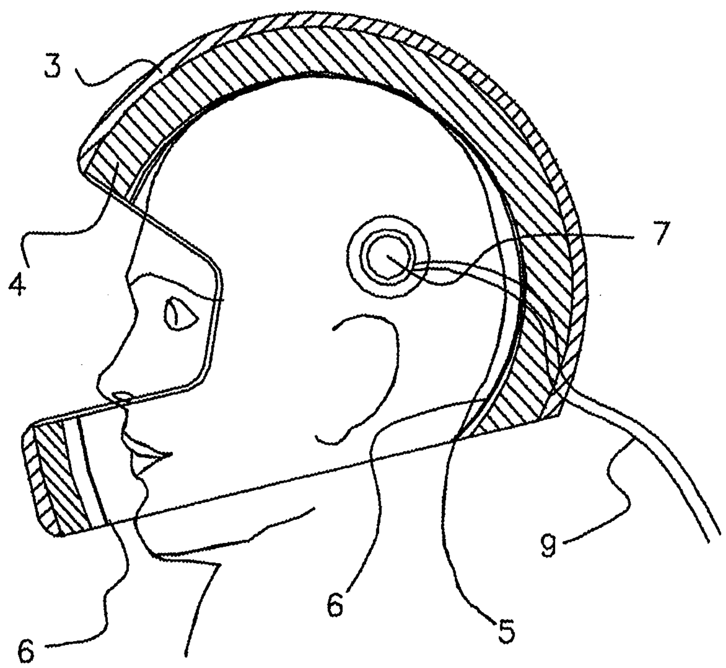
(54) Title: HEADWEAR



(57) Abstract

The invention relates to a helmet (1) or headphones (21) with a rigid structure (3, 23) in which bending waves at sound frequencies pass when excited by a transducer (7). The ridig structure (3, 23) may be acoustically coupled to the wearer's head. The rigid structure (3, 23) may form a modal resonator in which modes are distributed over a frequency range of interest.

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TITLE: HEADWEAR

DESCRIPTION

The invention relates to headwear, more particularly, but not exclusively, safety headwear, e.g. so-called 'hard hats', crash helmets and the like, but also headwear in the nature of headphones.

It is well known that users of protective or safety headwear can experience communications and other problems, particularly in noisy environments.

It is known to provide communication to a full-face protective crash helmet by an externally mounted source speaker. Such a speaker has to work hard, a) to compete with the background noise of its working environment, and b) to transmit through an acoustic barrier, namely the helmet.

As materials have become lighter in weight, stiffer full-head and ear covering helmets have evolved. This has lead to engineering solutions to provide the user with communication. Improvements in headphone and earphone technology have allowed the source to be placed inside the helmet. For example a small speaker is usually placed behind the cloth inner lining of a crash helmet and embedded into the padding of the helmet. The bicycle helmet of US 5,736,808 uses this approach. This overcomes the problems associated with an external speaker source thus providing a good acoustic solution. However, comfort problems arise from having a rigid disc pressed against the ear and the risk of injury to the head increases from side impacts to the helmet.

An earphone inserted into the lobe of the ear provides a good solution but again such earphones are generally uncomfortable and need to be held in place, e.g. with adhesive tape to stop them from becoming dislodged in use. Custom-moulded earplugs with internally mounted speaker are also available. They facilitate communication and also defend against background noise.

An alternative is to use bone conduction to supply sound. In this case, a transducer is fixed to a user's head to be acoustically coupled to the user's skull. Sound is then transmitted from the transducer through the skull and directly to the cochlea. The eardrum is not involved in this sound transmission route.

However, all of these prior art approaches have some disadvantages; for example, wearing comfort, safety, performance, in particular in noisy environments the sound volume often has to be turned up to make the sound intelligible. Such high volume sounds can be dangerous and can cause hearing loss over a long period. A number of police motorcyclists have had hearing problems, resulting in claims to compensation from their employers.

As helmet construction materials there are two general types, namely

1) thermo-injected plastic, such as ABS (polycrylo-nitrite-butadiene-styrene) or polycarbonate, and
2) reinforced resin material such as fibre reinforced plastic.

Fibre reinforced plastics range from glass fibre, Kevlar, carbon fibre to super fibre, each offering a unique strength relative to its specific gravity.

It is an object of the invention to provide headwear having improved sound reproduction.

According to the invention, there is provided headwear comprising a rigid structure shaped to span the head of a wearer and capable of transmitting bending waves at sound frequencies, and a bending wave transducer attached to the rigid structure for transmitting bending sound waves into the rigid structure so that the headwear reproduces sound that can be heard by the wearer of the headwear.

The rigid structure needs to be sufficiently rigid to transmit bending waves. However, it need not be absolutely rigid. In particular, in some embodiments (such as the headphone described below) the rigid structure needs to be able to flex sufficiently to be able to put the headwear on and take it off.

The headwear may further comprise an acoustic coupler on the inside of the rigid structure for mechanically coupling the rigid structure to wearer's head over some or all of the portion covering the skull. The acoustic coupling to the skull allows sound waves to be mechanically transmitted without passing through air. If correctly clamped to the head the acoustic coupler may mechanically transmit sound energy throughout the audible frequency range of 20Hz to 20kHz. A smaller range of frequencies may well be acceptable particularly if the mechanically transmitted sound is only required to provide an output at lower and mid- frequencies.

The mechanically coupled sound can couple direct to the cochlea of the wearer of the helmet without passing through the eardrum. Such sound is perceived as if it were conventional sound pressure waves transmitted through air to the ear.

Some direct shaking of the head through the rigid band may give rise to useful perceived sensations, especially below 30Hz. This may be useful in virtual reality applications.

The transducer is also known as an exciter, since it excites the rigid structure.

The headwear may operate over a suitable sound frequency range depending on the application. For example, a subjective bandwidth from 30 to 10000Hz or better may be provided by the headwear.

The headwear according to the invention may use either or both bone conduction through the coupler and conventional transmission through the air into the wearer's ears. In embodiments, the coupling to the skull can be particularly good at low- and mid- frequencies and the direct air-carried acoustic path to the ear from headshell sound radiation becomes more effective at higher frequencies. By combining the two approaches the headwear can demonstrate improved sound reproduction.

The practices taught in International application WO97/09842 may be employed. This may involve direct excitation of distributed resonant bending waves in the rigid structure of the headwear.

The thickness, shape and/or materials may be selected to optimise the distribution of the resonant modes in frequency, and over the area of the rigid structure, so as to improve the loudspeaker qualities of the headwear.

The acoustic coupler may be integral with the rigid structure; indeed, if the rigid structure is correctly shaped the rigid structure may constitute the acoustic coupler.

However, it is generally more convenient to provide a separate acoustic coupler, which may comprise a plurality of discrete members attached to the inside of the rigid structure, or a member shaped to be in contact with the wearer's head over at least half of the upper surface of the wearer's head.

The rigid structure may be the rigid head shell of a safety helmet. The technology described above is particularly suitable for helmets with an inner shock-absorbent material which is coupled to the head and which constitutes the acoustic coupler. The protective capability of the safety helmet can be maintained while clear sound can be heard by the wearer of the helmet.

Excitation of the shell, compared to the use of small inefficient conventional coherent speakers may offer improved power and intelligibility for similar electrical power and cost.

The helmet may have a soft inner lining inside the inner shock absorbent material. This soft material may tend to decouple the rigid head shell from the wearer of the helmet, especially at higher frequencies, but good coupling may still be obtained at lower frequencies, and even up to frequencies as high as around 8 kHz.

The transducer may be mounted either inside or outside the helmet, although an internal mounting makes it less likely that the transducer will be damaged in normal use. The transducer may positioned away from the wearer's ears, e.g. around towards the rear of the headwear, which will pose less risk during side-of-the-head impact. Such positioning may also reduce cavity resonances in the vicinity of the transducer. Positioning away from the ears is possible since the shell is excited over an area greater than the immediate vicinity of the exciter itself.

Since the materials used for helmet construction are typically in rigid, lightweight, monolithic skin formats, the present invention proposes the use of direct excitation of this structure to facilitate audio communication to the wearer. This may reduce many of the problems associated with existing communications technology in safety helmets and the like.

For single channel applications, the range of possible transducer locations is the majority of the rigid structure's surface, distributing bending waves over the surface. However, tests have shown that the helmet can be easier to drive when the transducer is mounted on the lower portion of the rigid structure.

The headwear may comprise two bending wave transducers attached to the rigid structure for transmitting bending waves into the rigid structure to cause it to act as a loudspeaker. This can increase the power and/or allow stereo and/or a further information channel.

The invention may be applied to a number of forms of safety helmet, such as closed and open face vehicle helmets; flight helmets (military and civilian); construction site safety hats; military ground troop helmets, etc.

The invention may also be applied to a traditional building site/surveyor's safety hat which is supported on an internal harness, providing isolation from the head to the hard shell of the hat. This type of hat will radiate some sound externally and also radiate internally through the air to the ear of the wearer.

A further application of the invention is in the field of helmets carrying displays. Such helmets may be used either for virtual reality applications or for head-up displays. Tests have shown that helmets according to the invention can provide both good intelligibility and a beneficially spacious "out of head" effect - this adds greater realism to stereo and games soundtracks.

For all types of headwear, some sound may radiate outside the helmet as well as internally. The sound radiated outwards is a possible cause of annoyance, and may also reduce the possibility of confidentiality. If external radiation of sound is unwanted the headwear may further comprise an outer layer of sound absorbing material outside the rigid structure.

The invention may also be applied to non-helmet applications such as a new type of hi-fi headphones, the rigid structure comprising a band for spanning the top of the wearer's head between the wearer's ears. The band could be constructed from a composite and may cover each ear.

The band could be energised by one or more exciters, the region around the or each exciter may be constructed as a distributed mode panel. The panels can be small distributed mode loudspeakers using the technology described in WO97/09842, wherein the rigid band can provide for additional coupling to the head.

The rigid band may be coupled to the head through pads mounted on the band providing mechanical conduction to the outside of the head, and hence through to the skull to allow bone conduction. The coupling to the skull appears to increase the perceived low frequency response of the headwear over and above the response provided by the two distributed mode panels: small distributed mode loudspeakers have, in general, poor low frequency performance.

The resonant excitation of the band may provide additional mechanical energy in the audio range to the sound provided from the distributed mode panel.

Exciters may be mounted on the rigid band or the panels to excite both band and panels, or alternatively separate exciters may be used for the band and the DM panels.

The bending waves in the band need not necessarily be resonant standing waves. It may be possible to use travelling waves, especially if the band is appropriately partially terminated.

Exciters may be mounted between the DM panel and the rigid band so that one side of the exciter engages the rigid band and the other side the DM panel. The exciter combination may be designed for a wider frequency range than would otherwise be possible, the band supplementing the low frequencies by skull conduction.

The invention is diagrammatically illustrated, by way of example, in the accompanying drawings, in which:-

Figure 1 shows a crash helmet, the shell of which is excited to act as a resonant panel loudspeaker by an exciter placed at the ear of the external surface of the shell, and

Figure 2 shows a detail of an alternative mounting of the exciter,

Figure 3 shows a headphone embodiment of the invention,

Figure 4 shows the helmet and various transducer positions used in testing the helmet,

Figure 5 shows the mechanical impedance of the helmet as a function of frequency at the positions identified in Figure 4,

Figure 6 shows the modal vibration of the helmet at various frequencies,

Figure 7 shows the sound radiated outside the helmet,

Figure 8 shows the acoustic radiation inside the helmet,

Figure 9 shows the pure acoustic response of a test helmet,

Figure 10 shows the subjective response of the test helmet,

Figure 11 shows the acoustic response of the test helmet on a dummy with and without earphones, and

Figure 12 shows the total subjective response compared to the acoustic response measured by a dummy.

Headwear in the form of a helmet 1 is formed from an outer shell 3, a rigid structure, a firm polystyrene crash absorbing material 4 and a compressible soft foam cushion layer 5. The foam liner is about 1cm thick when not compressed but when worn, the foam liner 5 is compressed tightly against the head of the wearer through a fabric skin 6 and forms with the firm crash absorbing material 4 an acoustical coupler mechanically coupling the outer shell to the head of the wearer.

An bending wave transducer 7 is mounted on the outside of the helmet on the left side; a further transducer is mounted on the right side (not shown). Connections 9 connect the exciters to a radio, CD player or other sound source.

Figure 2 shows an alternative mounting of the transducer 7. The foam liner 5 defines a hole 11 and the transducer 7 is mounted internally of the outer shell in the hole 11.

An embodiment in the form of stereo headphones 21 is shown in Figure 3. A rigid band 23 is rigidly coupled to distributed mode loudspeaker panels 27 positioned to be arranged next to the ears of a wearer when the headphone is worn. Pads 25 form an acoustic coupler for coupling the rigid band 23 to the head of the wearer.

Preliminary trials were made on a full-faced Shoei motorcycle helmet. Firstly, a single exciter was coupled to the rear of the helmet in its lower portion near the neck. A familiar test CD was subjectively listened to from outside the helmet and from inside when wearing the helmet. From outside the helmet, the sound level and quality was very low, sounding similar to a medium-sized pair of headphones at a metre. Inside the helmet excellent results were heard; the sound coupled efficiently to the ear. The sound was loud, high-quality and of full audio bandwidth. An initial tendency to exciter resonance at 50Hz mainly due to the head being directly coupled through the exciter's BL to the magnet mass, was capable of correction by means of a first order approach of grounding the exciter magnet.

In the second test, two exciters were mounted, one over each ear. This gave good results, the sound being focused but spacious with excellent clarity.

The mechanical impedance of a Shoei helmet was then measured for the variety of transducer positions shown in Figure 4. The results are shown in Figure 5. As can be seen, the graphs show a reduction of mechanical impedance as frequency increases. This is due to the wave length size relative to the curvature of the helmet. As the wavelengths reduce, the effective stiffness due to the curvature of the helmet seen by the wave is less.

The most difficult position to drive the helmet is position 6 where the mechanical impedance stays relatively flat hovering around the 800 mark until 1kHz. Then the impedance drops in a similar manner as the other positions. The acoustically optimum drive points are towards the bottom of the hat. The flattest parts of the hat are relatively easy to drive.

The modal behaviour of the helmet tested has also been tested. The vibration caused by bending waves has been measured at a number of frequencies, and is shown in Figure 6.

The sound radiated outside the helmet increases with frequency, as shown in Figure 7.

However the sound radiation inside the helmet is better, and very different. The padding on the inside of the helmet consists of 37mm thick expanded polystyrene and a layer of soft foam, and effectively blocks the high frequency acoustic radiation. This can be seen from Figure 8, which shows sound pressure levels measured by a microphone placed inside the helmet. As can be seen, the sound radiation inside the helmet does not show ideal bandwidth. However, the tests shown in Figure 8 simply use a microphone inside the helmet, and so they omit any bone conduction.

To counter this difficulty, several tests were carried out to try and quantify the overall subjective or perceived response of the helmet user. To do this a series of hearing threshold measurements were undertaken. The tests provided an insight into the mechanisms responsible for the complete subjective result.

The helmet used had a rigid outer shell, lightweight semirigid polystyrene inner and a softer foam lining. The foam lining was about 1cm thick when uncompressed but this reduced significantly when the helmet was worn. Initially a helmet was provided with a transducer at the lower rear (position 4). The helmet was placed on a KU100 dummy head and the frequency response was mapped using pure tones at octave frequencies. This gives the pure air-carried acoustic transmission into the artificial head. This, after applying the appropriate correction, can be assumed to be the response on the eardrum at the threshold of hearing, as shown in Figure 9.

A series of threshold measurements were undertaken in order to gain insight into the total subjective response (air-carried and bone-carried). This involved placing the helmet onto a human subject's head and then submitting them to a series of pure tones. Each tone was ramped up in level until subject's hearing threshold was reached. The results form the full curve in Figure 10.

The test was repeated with the subject wearing high attenuation earplugs to isolate the air-carried acoustic signal from the eardrum. The results can be seen as the dotted curve in Figure 10.

With the earplugs firmly in place, relatively high levels of isolation from ambient noise was achieved but the background noise was obviously not ideal for the test without plugs. The wearing of the helmet provided some added attenuation. Although the tests carried out here will obviously contain masking errors from background noise, these tests do provide an indication of the transmission mechanisms responsible for the different parts of the audio spectrum.

Because the subjective response for the ears plugged (dotted line) is at a similar levels to the air-carried acoustic result (full line), there is little doubt of the extent of mechanical coupling into the Cochlea. If there was no mechanical coupling, the response with earplugs would be similar to the acoustic response but approximately 30dB lower. To show this, pink noise was used to stimulate the helmet and the KU100 dummy was used to measure the pure acoustic transmission with and without the ear plugs present. This result can be seen in Figure 11. As can be seen, without bone conduction the earplugs make a substantial difference to the sound level.

The results from two human subjects (full and dashed lines) and from the KU100 dummy (dotted line) can be seen in Figure 12. It can be noted that the perceived response has a much broader bandwidth than the dummy result.

A technique known as A-weighting corrects for the acoustic transfer function of the outer middle and inner ear. This was applied to the acoustic measurement to allow for a fair and direct comparison of the acoustic measurement and subjective measurement. However, since a large percentage of the perceived sounds is a result of conductive sound (thus bypassing the outer and middle ear) this correction curve may be inaccurate. In the opinion of the inventor the response shown in Figure 12 underestimates the loudness of the bass, especially at the exciter resonance (at 63Hz).

The reason for the perceived high frequency response of the headwear is not known. The air-carried acoustic measurement with the dummy head and the preliminary measurements using a Cleo microphone show a high attenuation at high frequencies, breaking at 3kHz and rolling off at 12dB/Octave (15dB down at 7kHz). So this shows that there is little internal acoustic transmission/output at high frequency. A number of careful checks were made, but the good high frequency response could still not be accounted for by transmission through the eardrum. The obvious assumption was that the high frequencies were coupling mechanically via the cochlea.

However, tests have shown that this is not the case and that mechanical conduction through the helmet at high frequencies is worse than that of the acoustic coupling. Indeed, the soft foam lining will tend to decouple the rigid shell from the skull at higher frequencies. Moreover it can be seen from Figure 10 and 12 that high frequencies can efficiently be identified. When listening to test CD's frequencies up to 14 kHz are perceived.

Thus, the test helmets according to the invention give a much better subjective high frequency response than expected, for reasons unknown.

Benefits of the vehicular type helmet include excellent coupling to the ear inside the helmet through structure-borne sound. If required, this method of coupling allows acoustic background noise to be isolated whilst still permitting communication through the skull/helmet. Poor radiation outside the helmet into the ambient is advantageous.

Conventional bone conduction has been developed for point excitation and depends on the applied force and position of excitation (forehead/mastoid etc). In contrast, the headwear according to the invention tested involves a global coupling with a small force being applied all over the head.

CLAIMS

1. Headwear (1,21) comprising

a rigid structure (3,23) shaped to span the head of a wearer and capable of transmitting bending waves at sound frequencies, and

a bending wave transducer (7) attached to the rigid structure for exciting bending sound waves in the rigid structure so that the headwear reproduces sound that can be heard by the wearer of the headwear.

2. Headwear according to claim 1 further comprising an acoustic coupler (5,25) on the inside of the rigid structure for acoustically coupling the rigid structure to the top of the wearer's head and hence to the wearer's skull.

3. Headwear according to claim 2 wherein the acoustic coupler (5) is shaped to be in contact with the wearer's head over at least half of the upper surface of the wearer's head.

4. Headwear according to claim 2 or 3 wherein the acoustic coupler (25) comprises a plurality of discrete members attached to the inside of the rigid structure (23) for contacting the wearer's head.

5. Headwear according to any preceding claim wherein the rigid structure (3) is the rigid head shell of a safety helmet.

6. Headwear according to claim 5 when appendant to any of claims 2 to 4, wherein the acoustic coupler (5) is inner shock absorbent material on the inside of the rigid

head shell (3) of the safety helmet.

7. Headwear according to any preceding claim wherein the transducer (7) is mounted on the rear of the rigid structure (3,23) away from the wearer's ears.

8. Headwear according to any preceding claim wherein the transducer (7) is mounted on the lower portion of the rigid structure (3,23).

9. Headwear according to any of claims 1 to 4 wherein the rigid structure (23) comprises a band for spanning the top of the wearer's head between the wearer's ears.

10. Headwear according to claim 9 wherein the rigid structure (23) further comprises panels (27) positioned to be adjacent the ears of a wearer.

11. Headwear according to any preceding claims comprising two bending wave transducers (7) attached to the rigid structure for transmitting bending waves into the rigid structure.

12. Headwear according to any preceding claim further comprising an outer layer of sound absorbing material outside the rigid structure.

13. Headwear according to any preceding claim further comprising a visual display.

Figure 1.

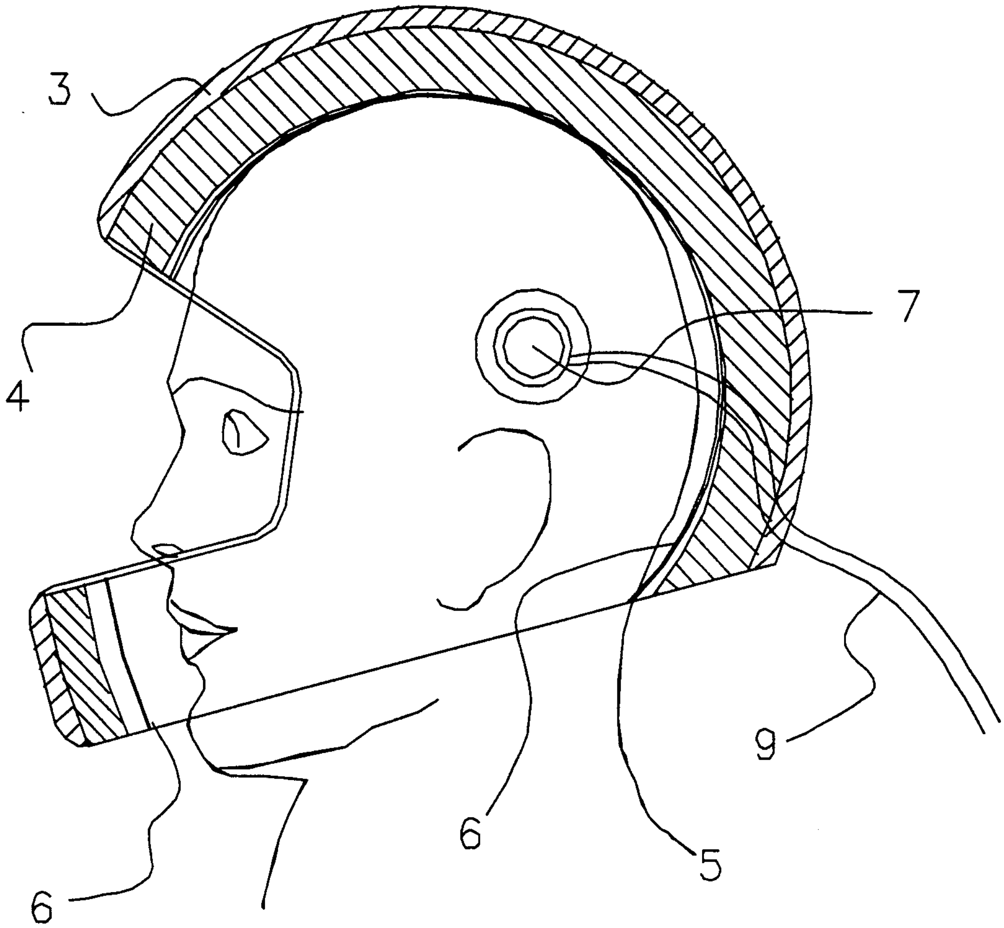
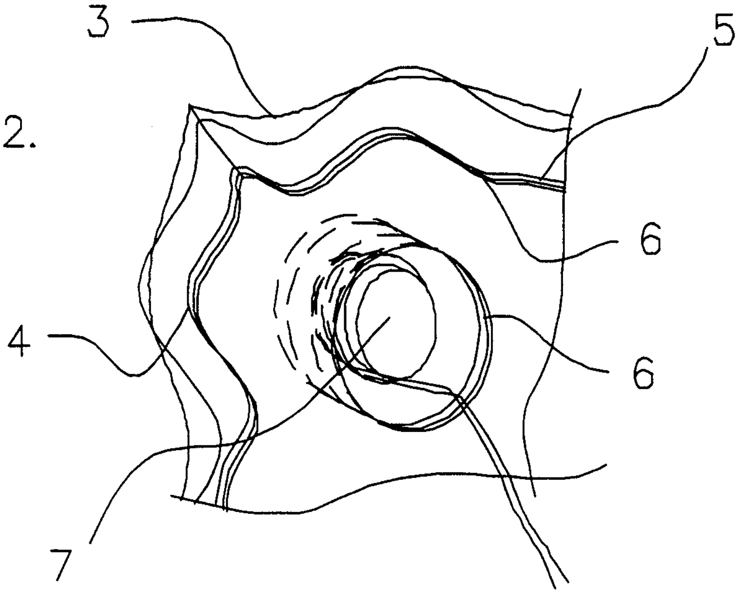


Figure 2.



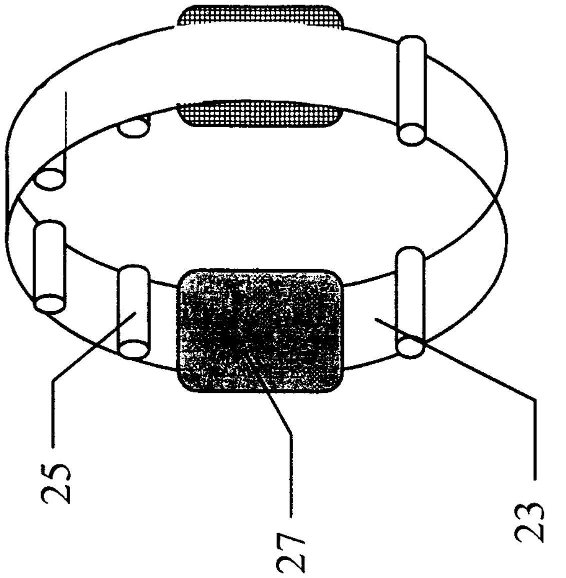

25
27
23

FIG.3

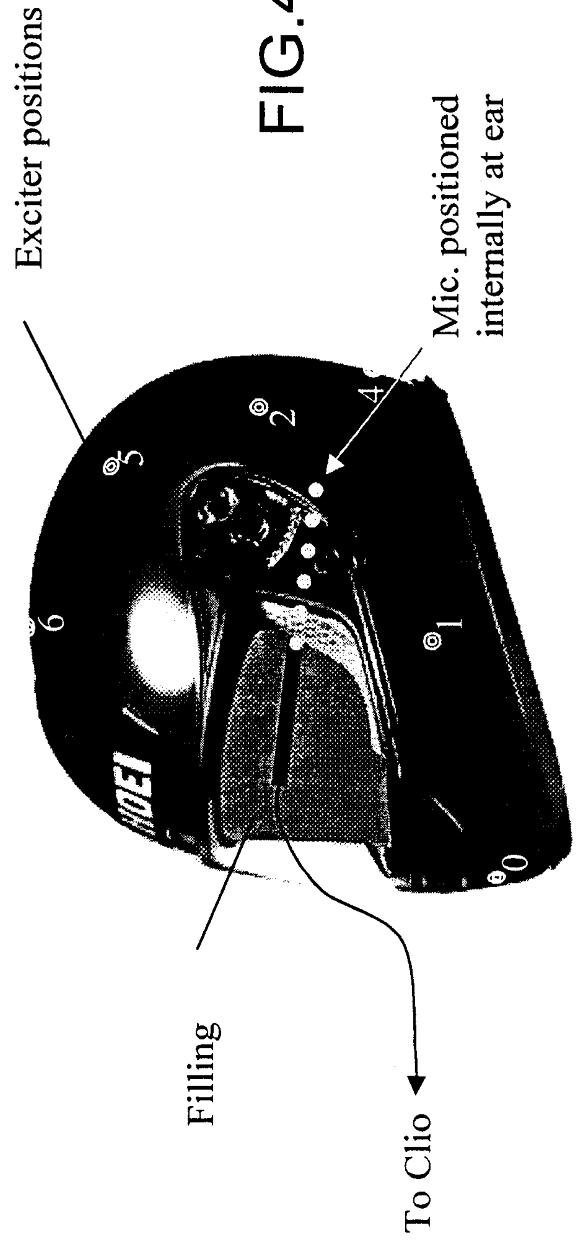
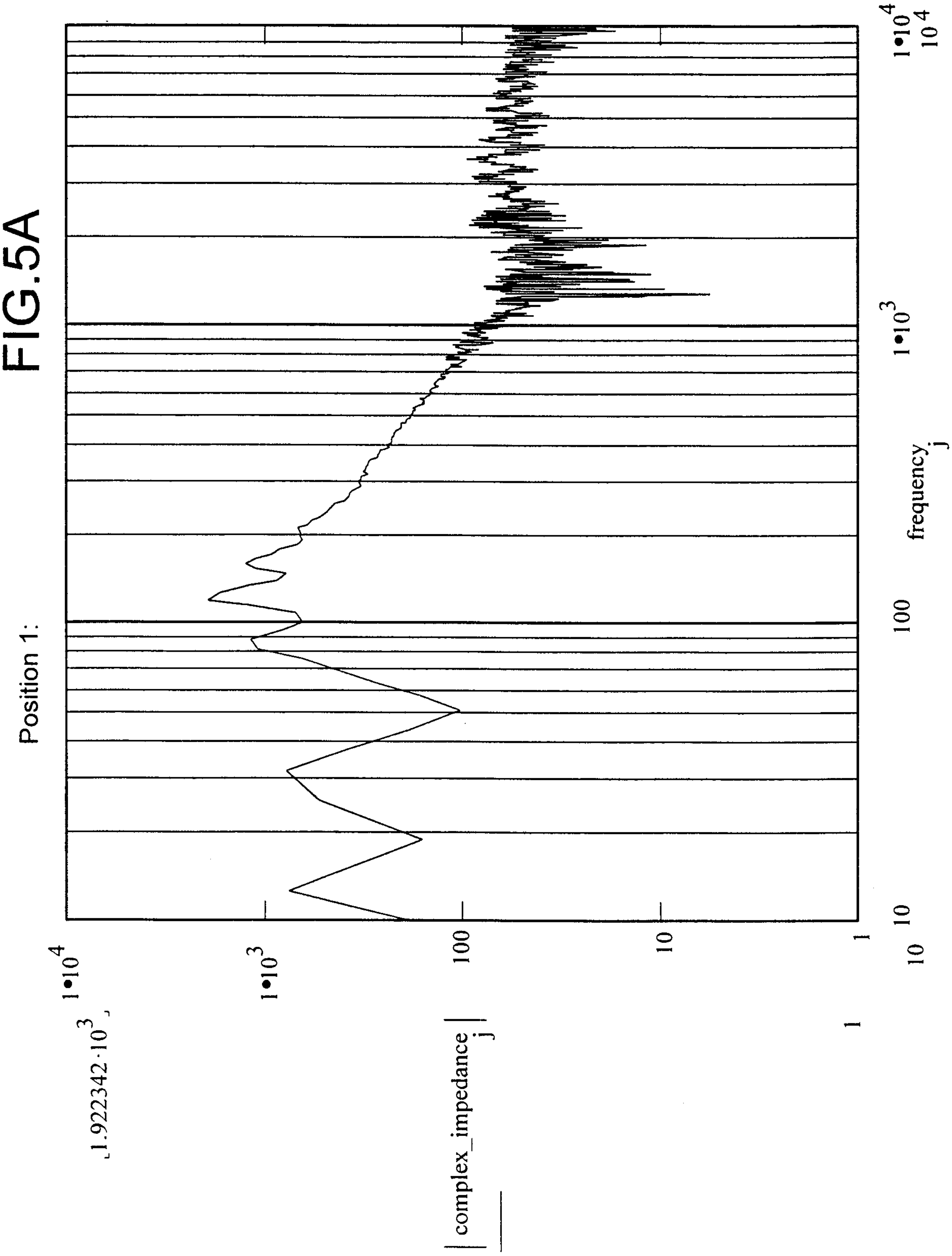

Exciter positions
Mic. positioned
internally at ear
Filling
To Clio
5
2
4
6
1
0

FIG.4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1•10^4
1•10^3
100
10
1
10
10
100
1•10^3
1•10^4
10^4
frequency_j
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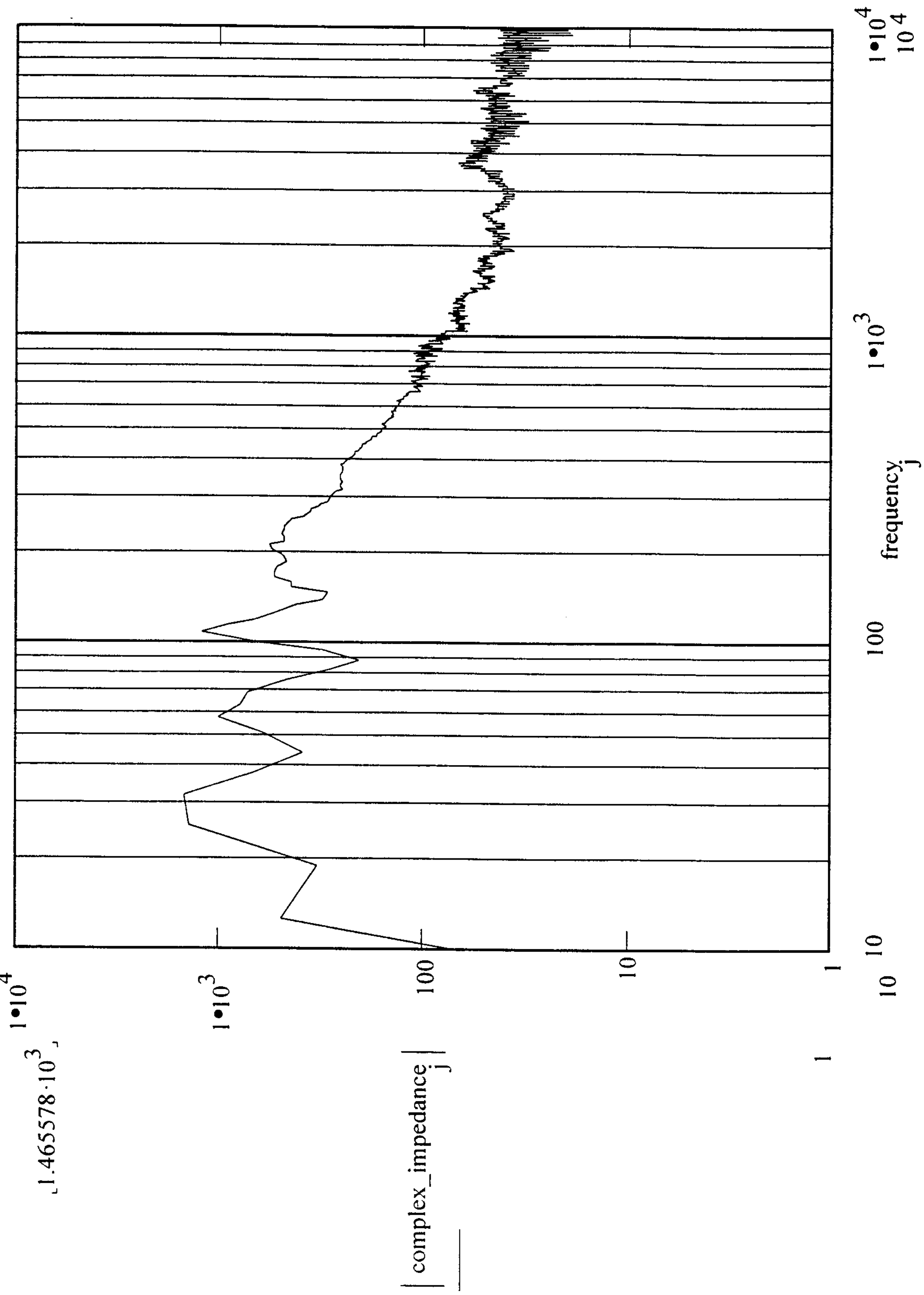
|complex_impedance_j|
1

FIG.5A

FIG.5B

Position 2:



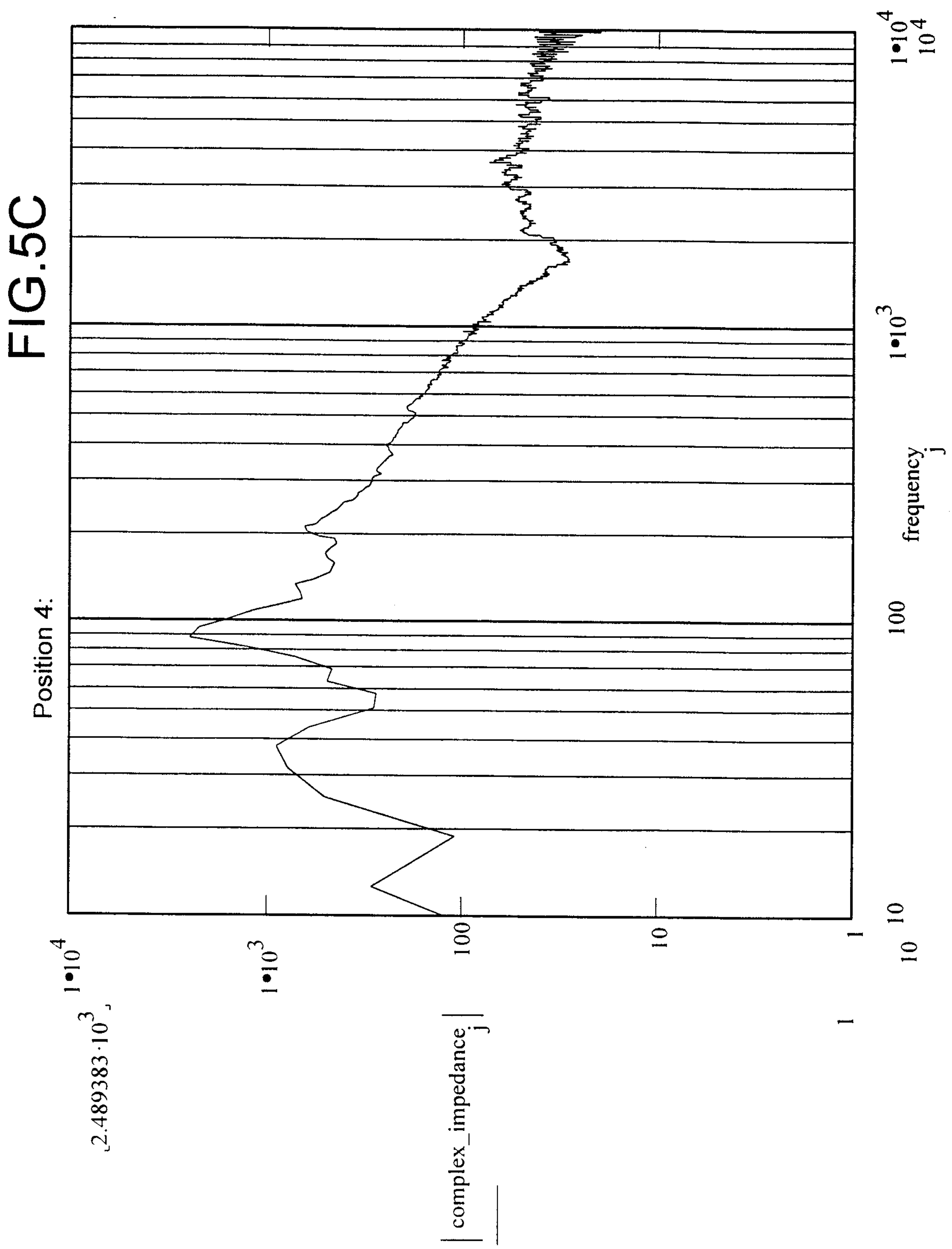

Position 4:
2.489383·10^3
1•10^4
1•10^3
100
10
1
|complex_impedance_j|
10
100
1•10^3
1•10^4
frequency_j
10^4

FIG.5C

FIG.5D

Position 5:

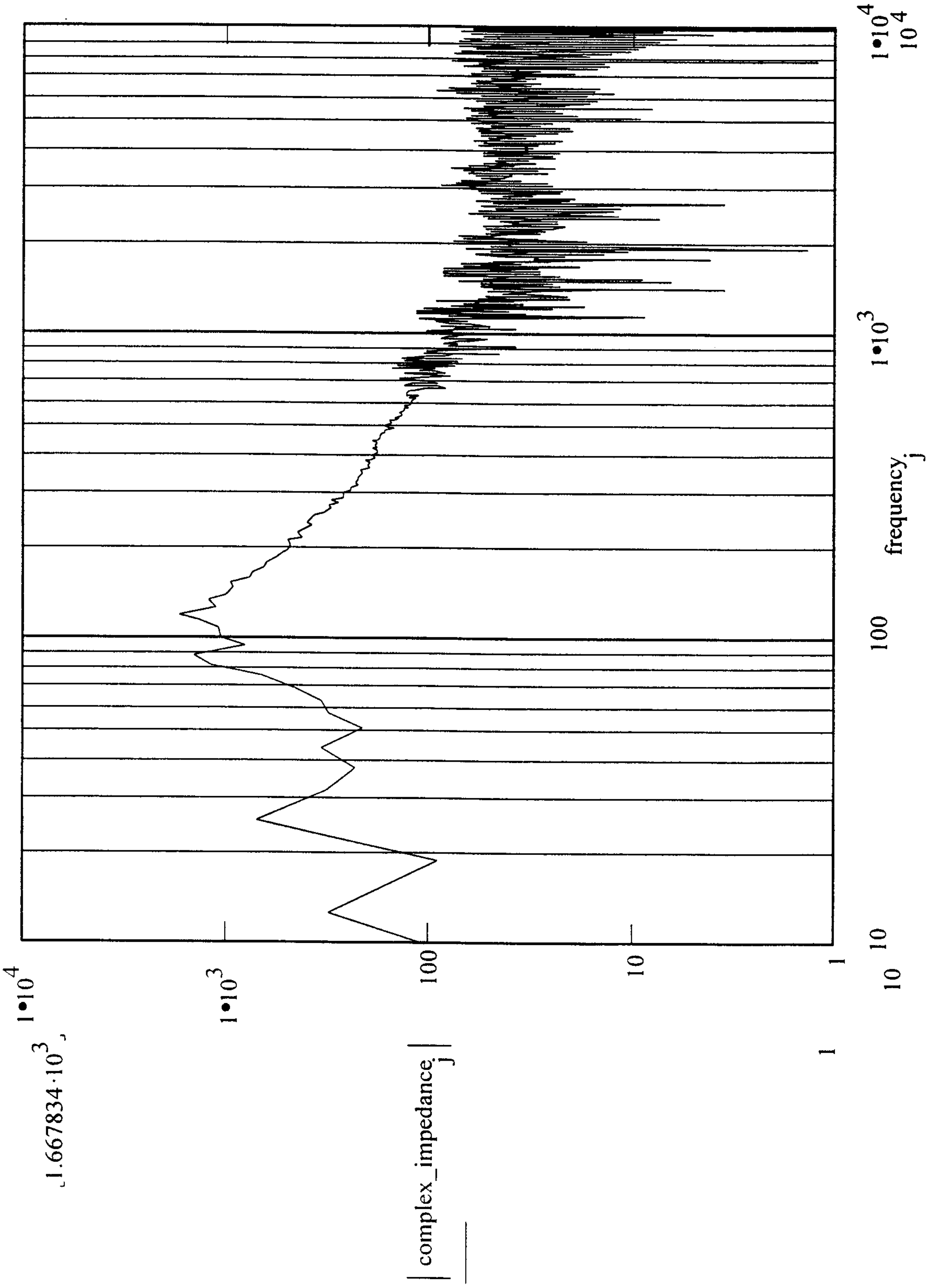
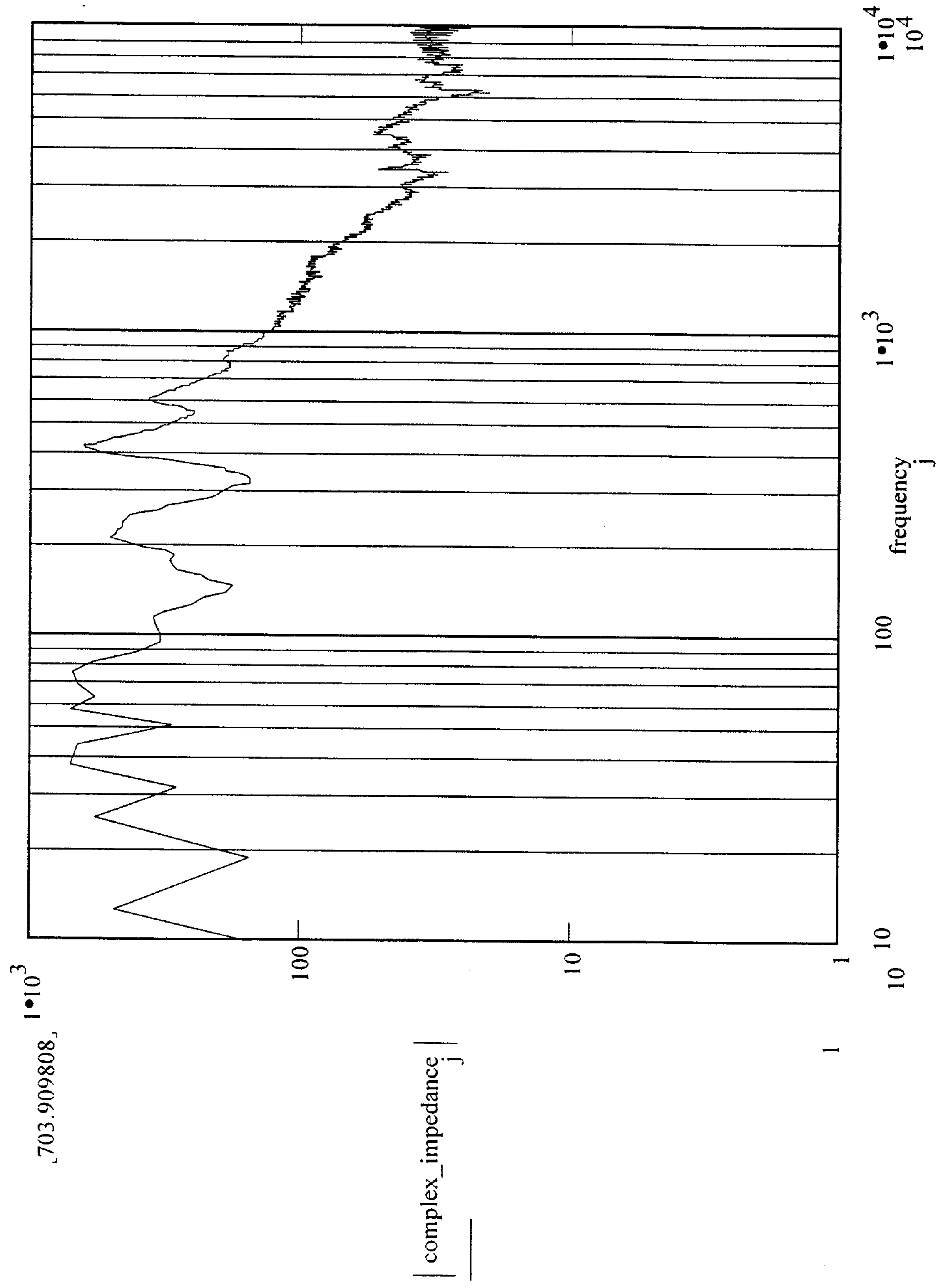


FIG.5E

Position 6:



250Hz

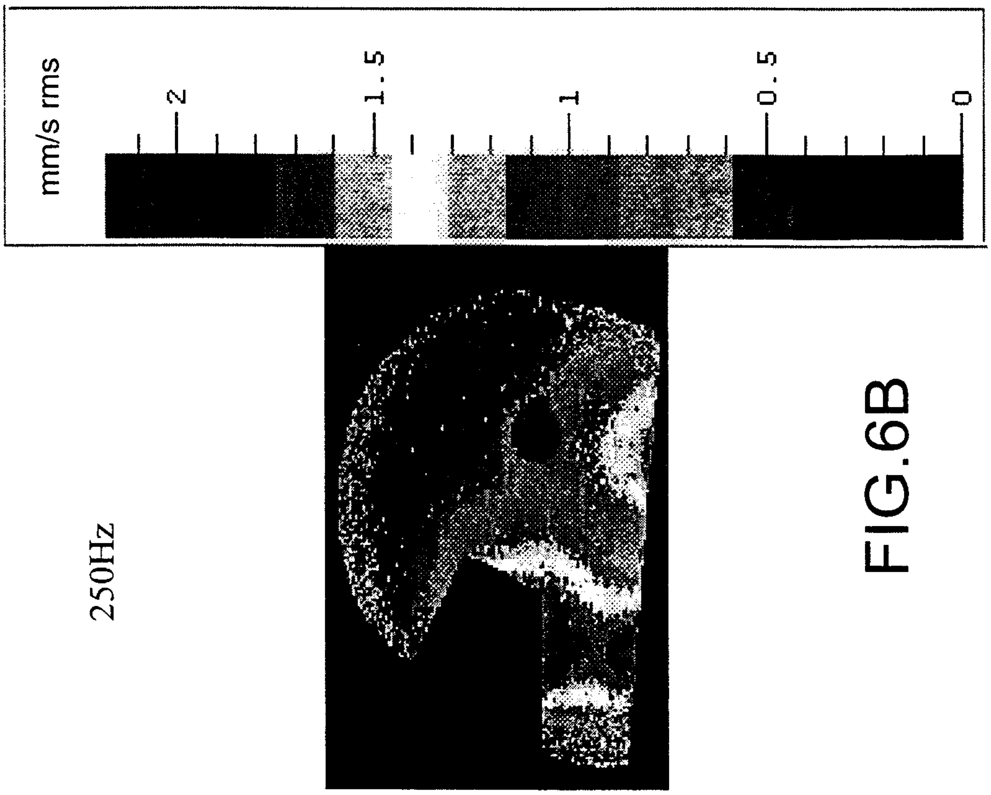


FIG.6B

125Hz

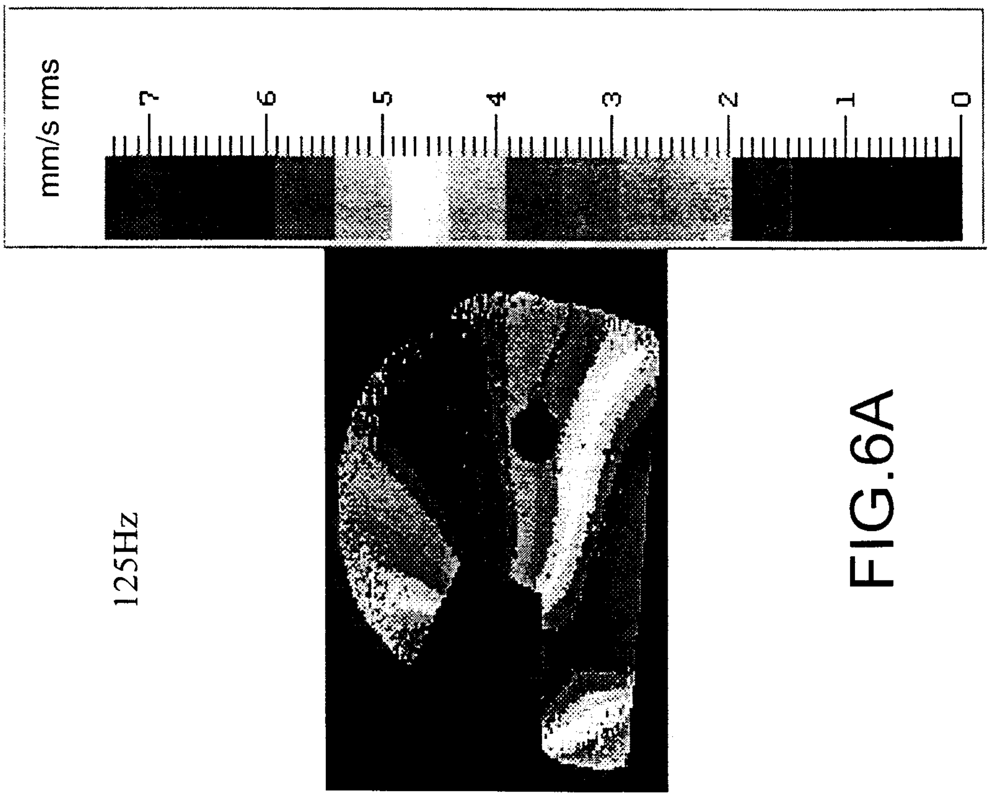
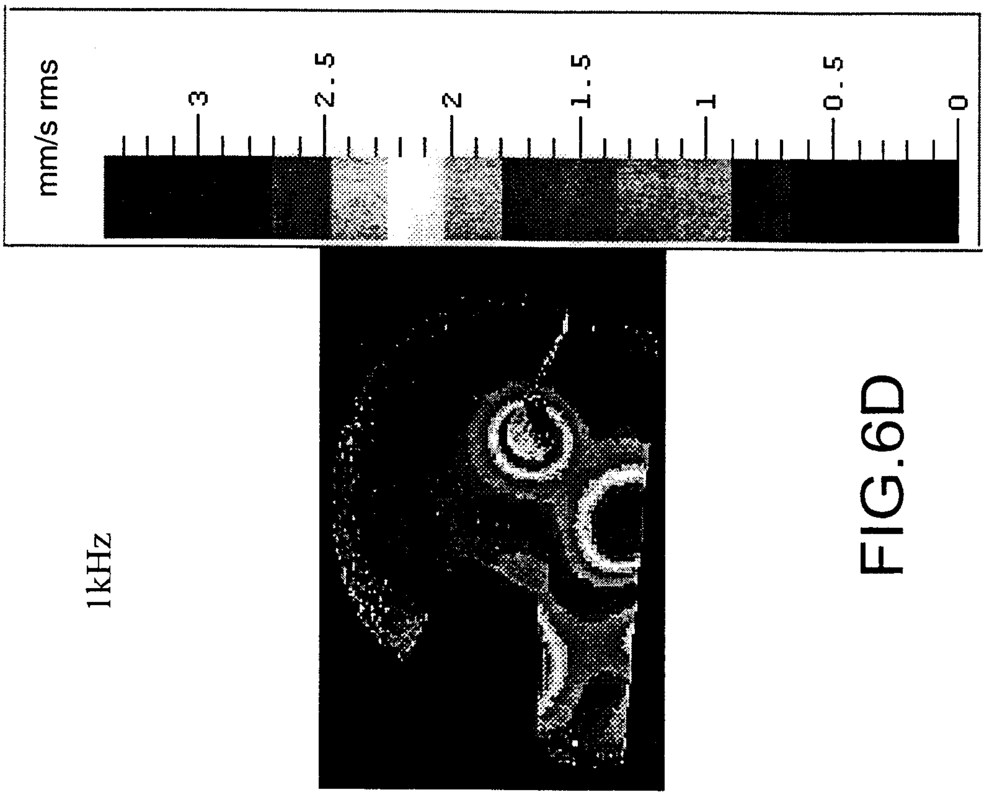
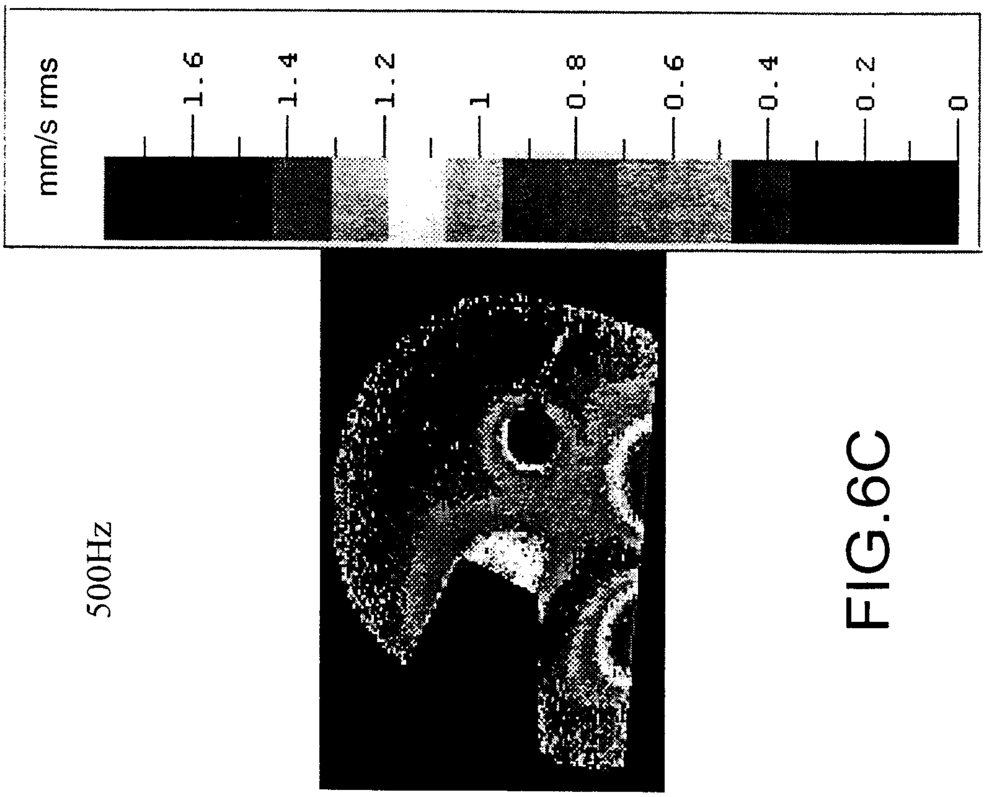


FIG.6A



1kHz

FIG.6D



500Hz

FIG.6C

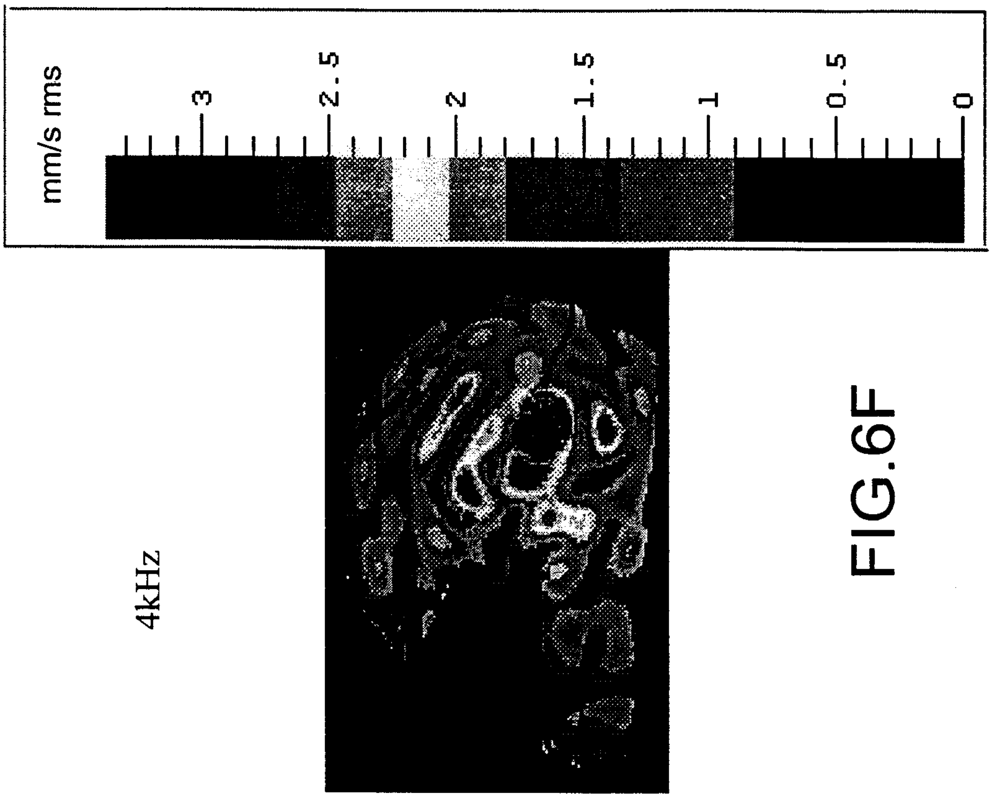


FIG.6F

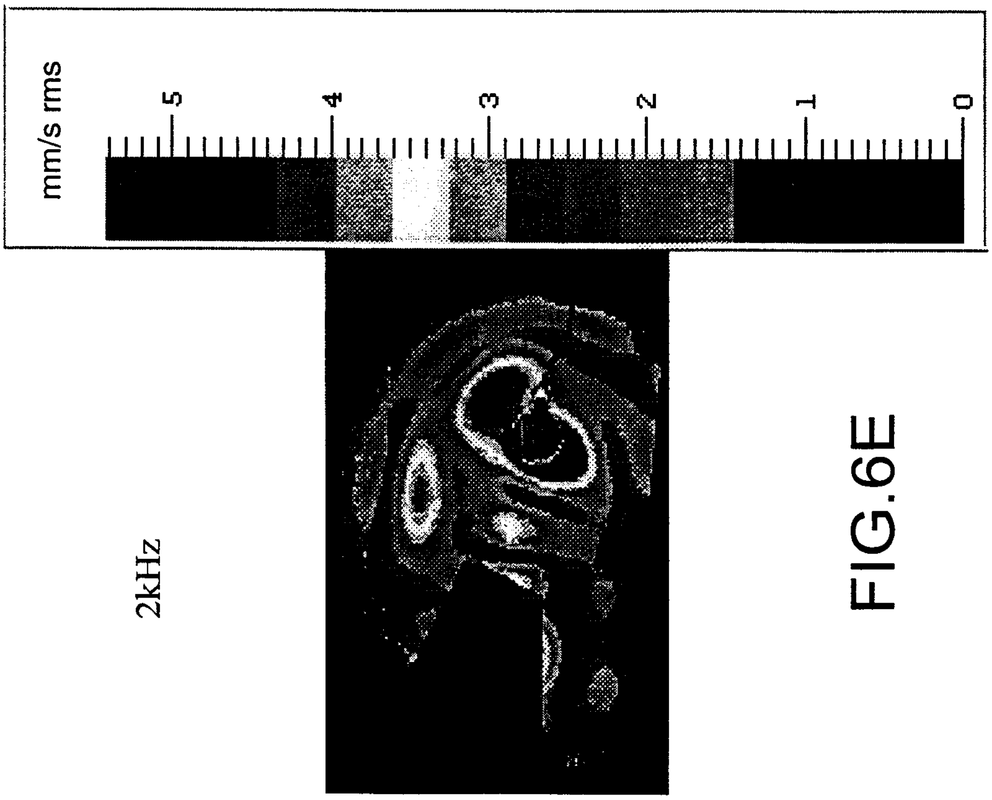


FIG.6E

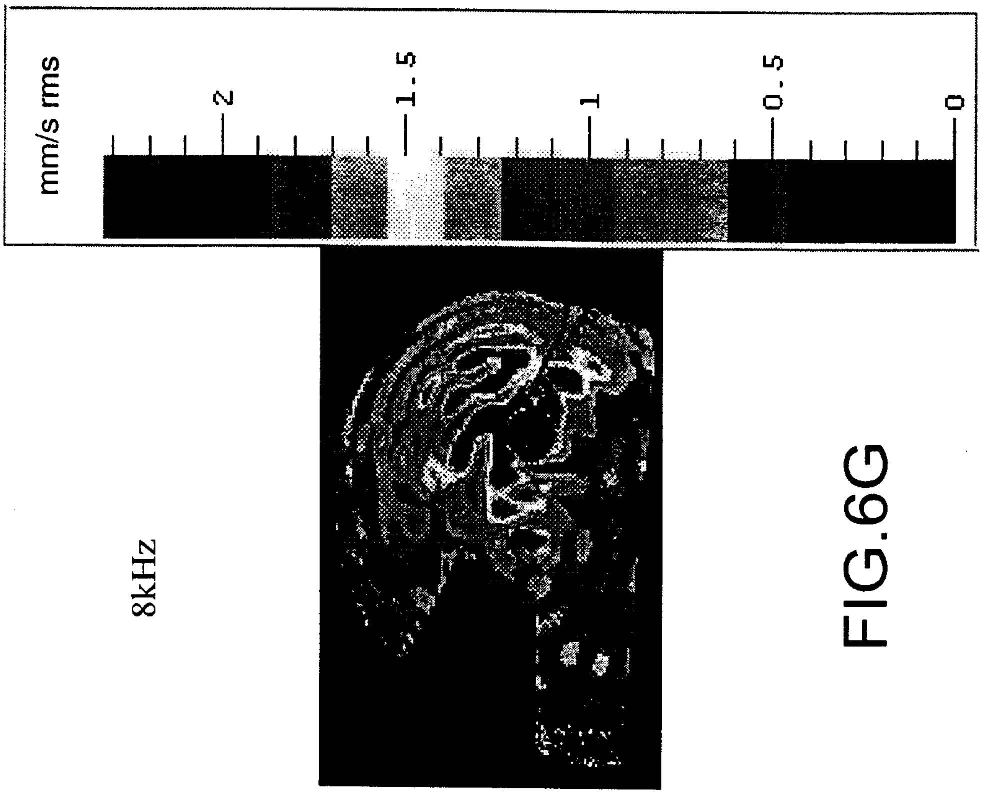


FIG.6G

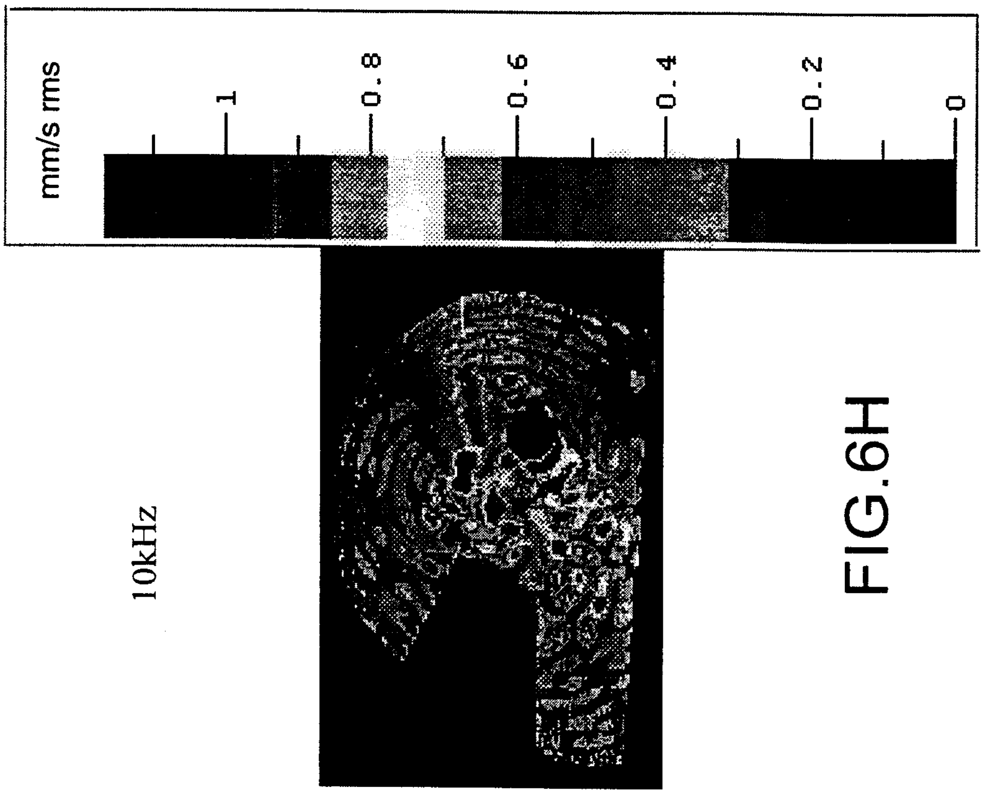


FIG.6H

FIG.7

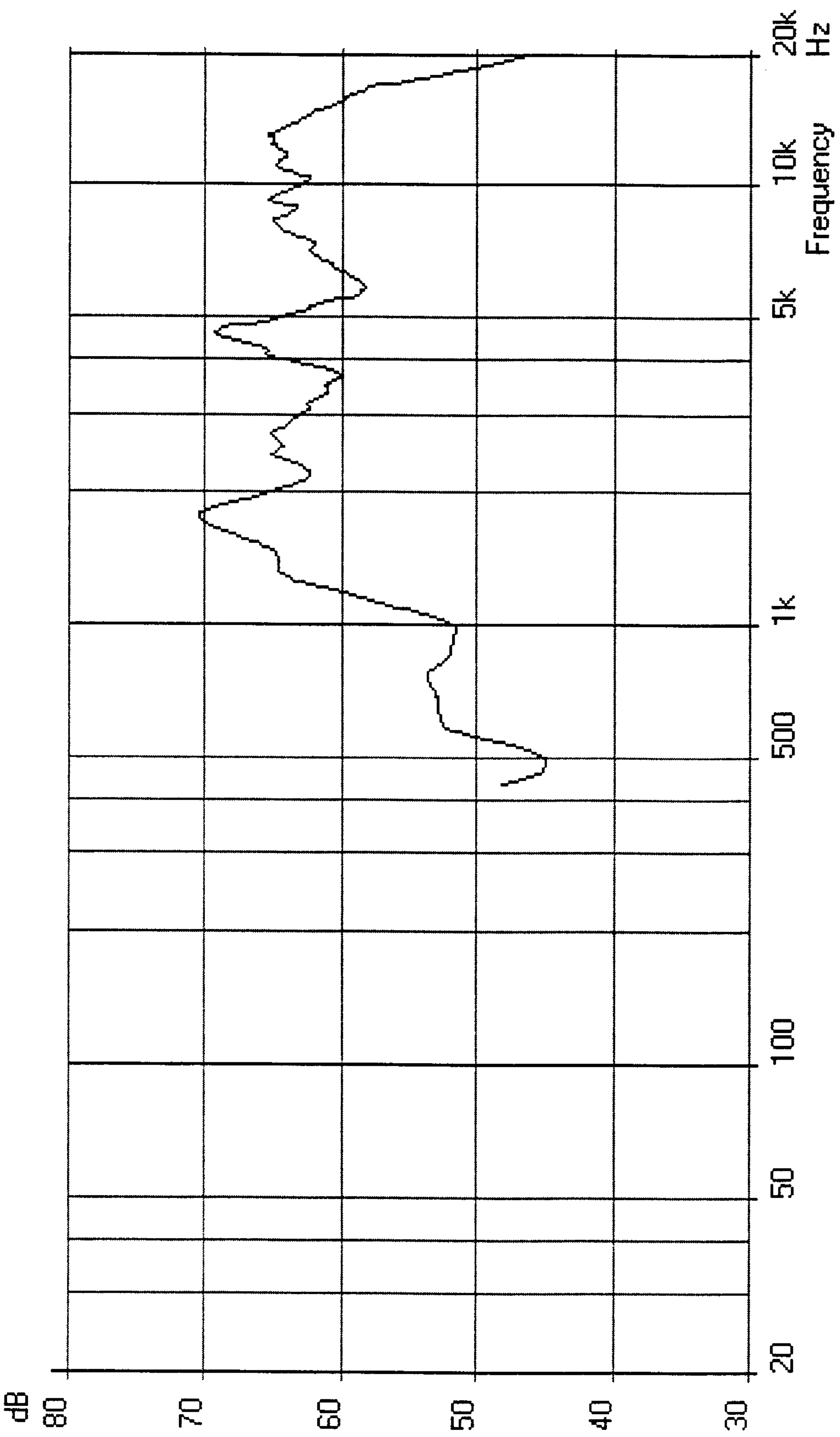


FIG.8

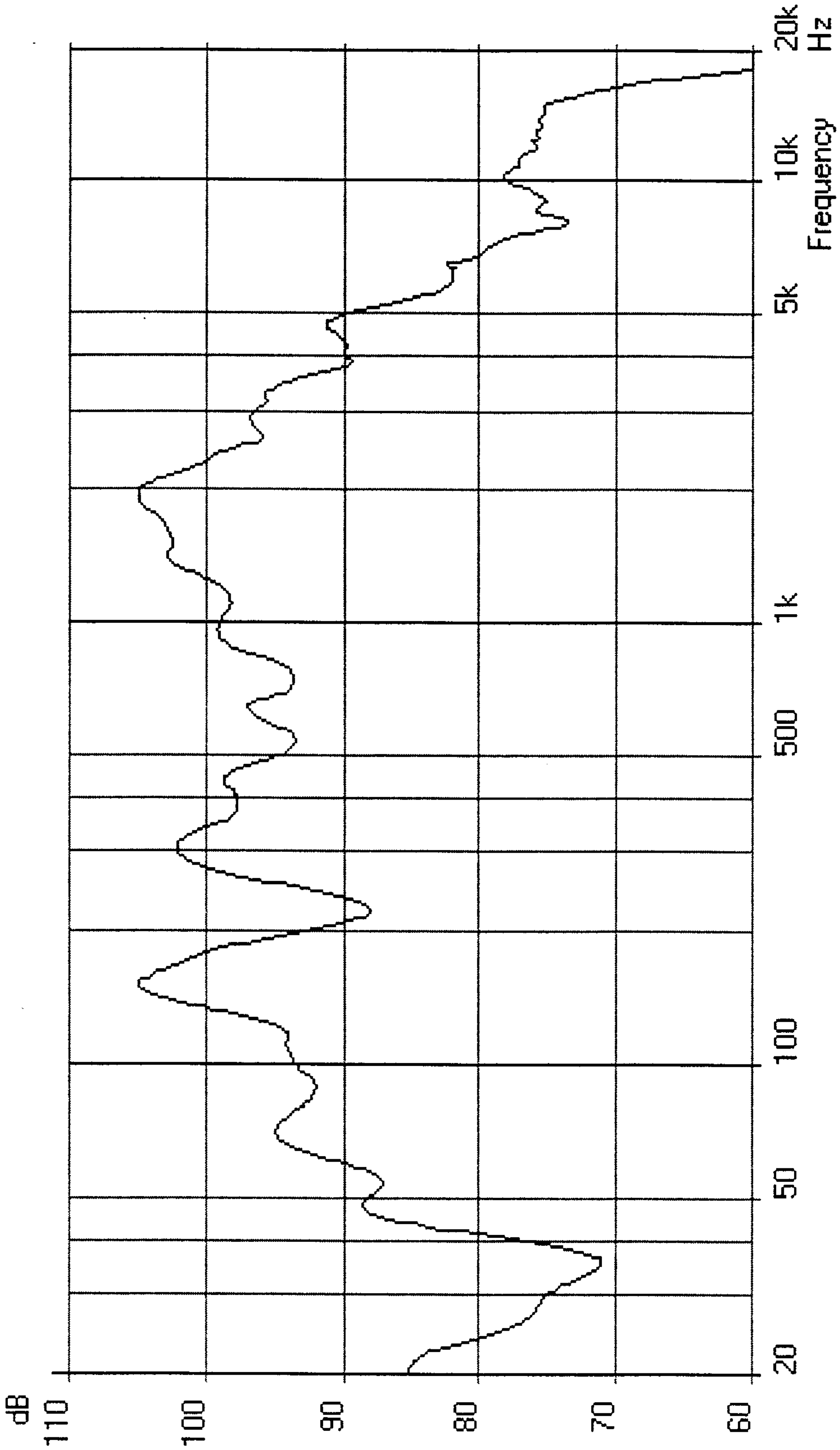


FIG.9

KU100 Pure Acoustic Response

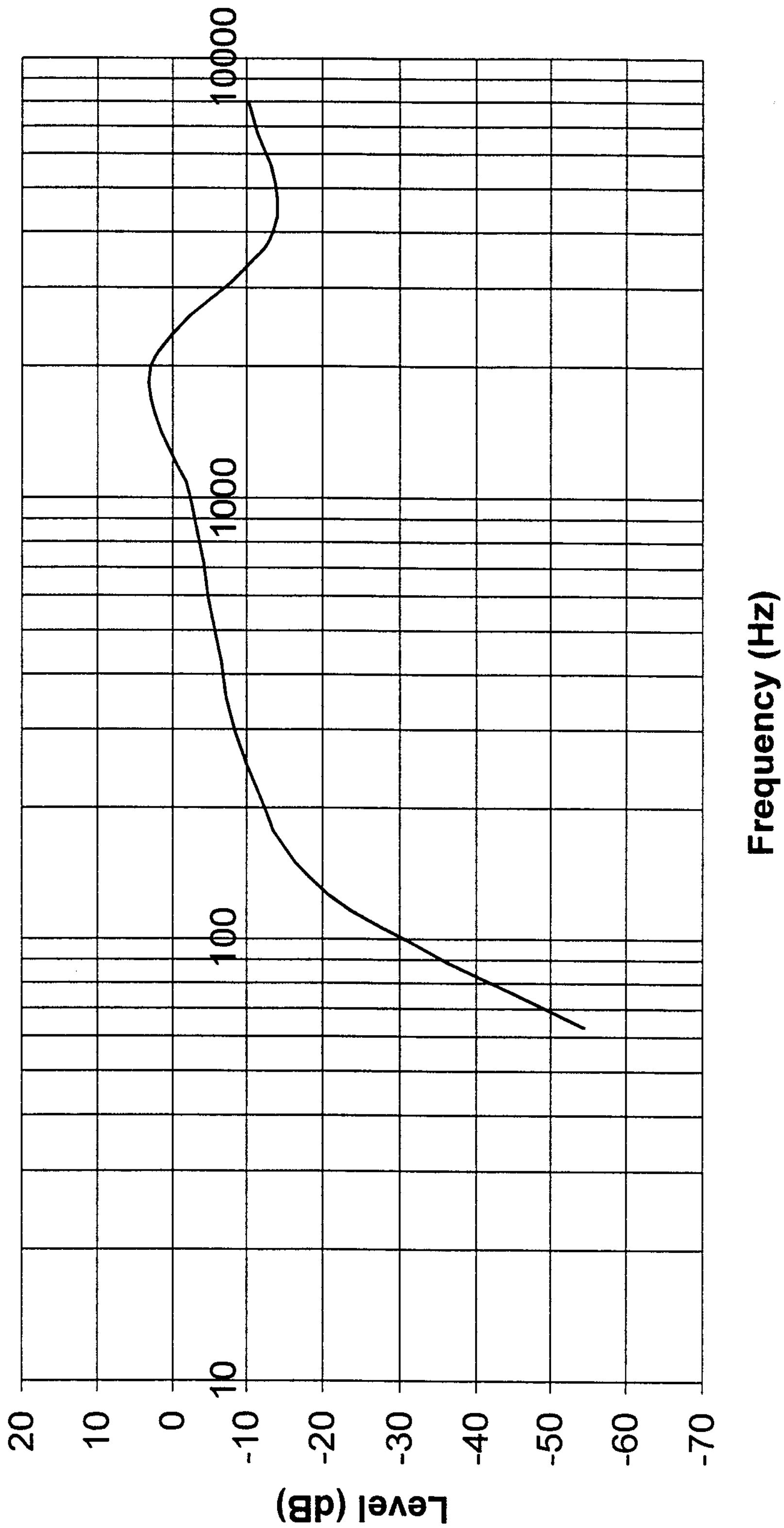


FIG.10

Subjective Response of Subject 2

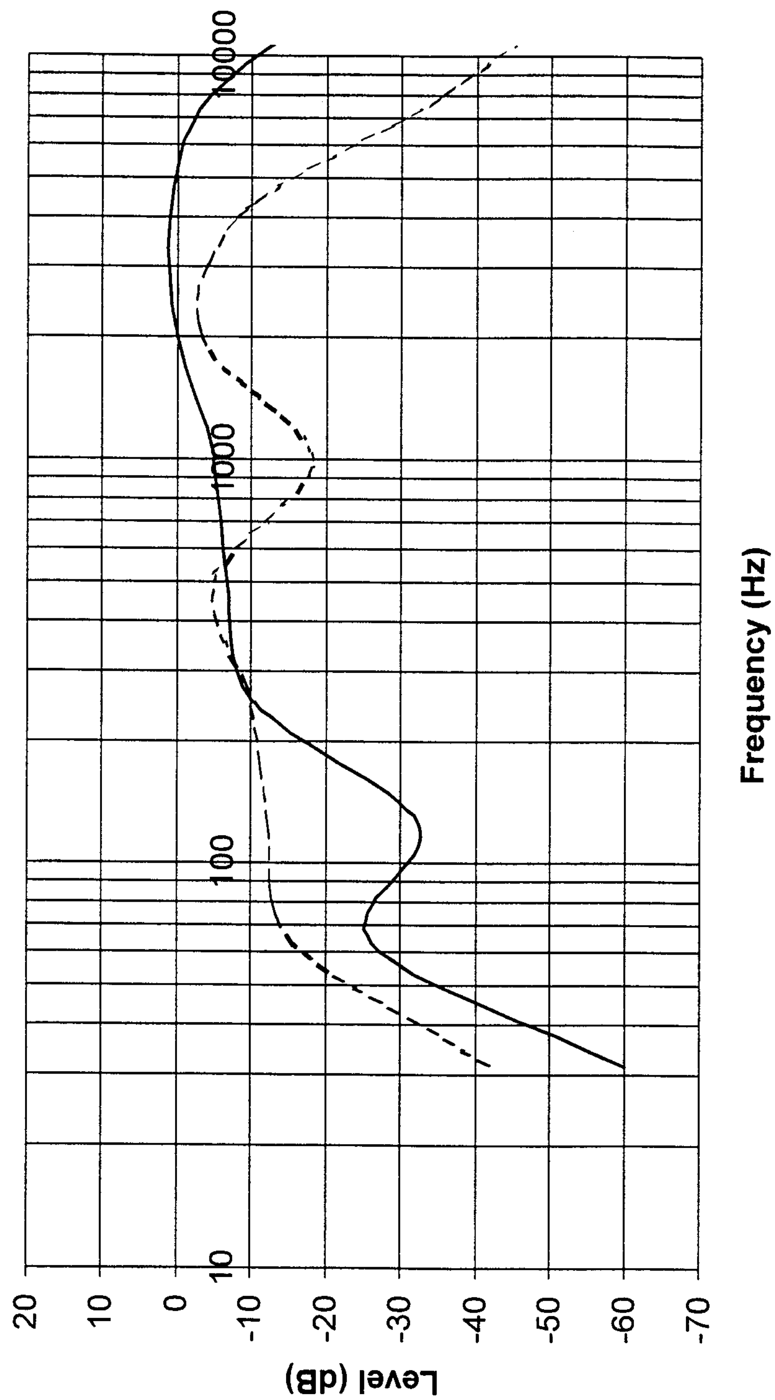


FIG.11

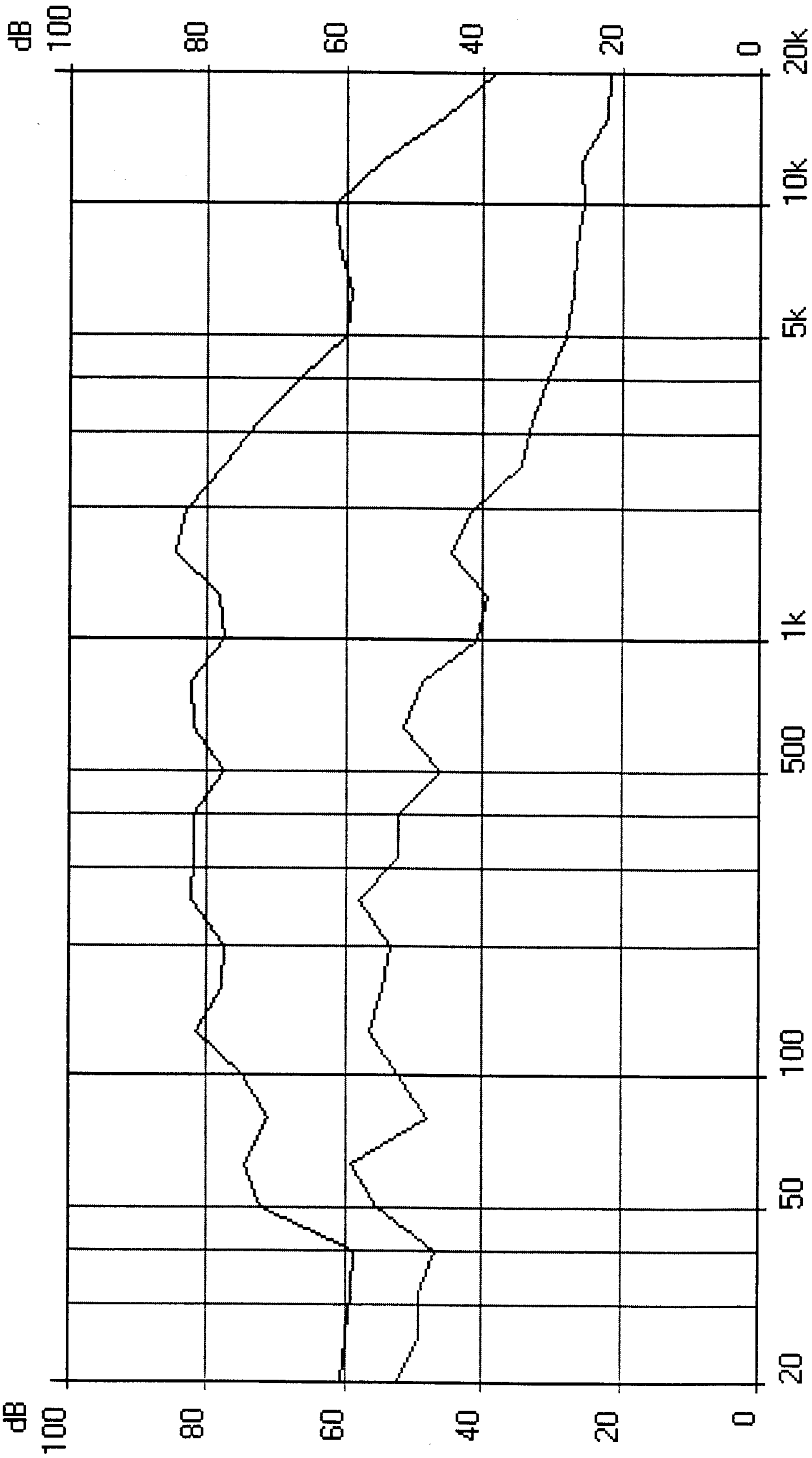
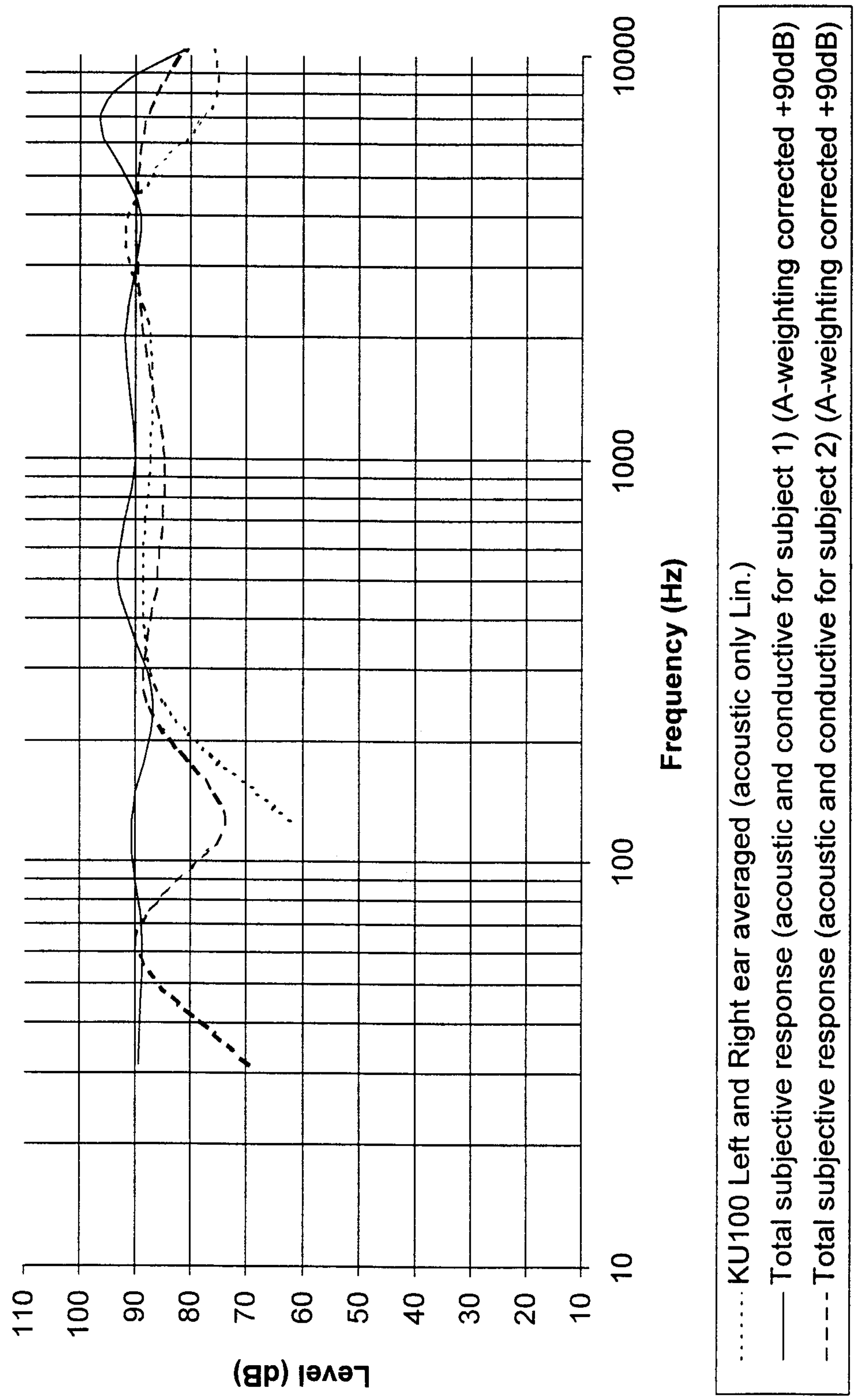


FIG.12

Total Perceived Response



INTERNATIONAL SEARCH REPORT

Intern ial Application No
PCT/GB 99/01985

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 A42B3/30

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 7 A42B

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 practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 152 553 A (M. E. WHITE) 1 May 1979 (1979-05-01) abstract column 1, line 63 -column 2, line 18 column 2, line 65 -column 3, line 38 column 5, line 34 - line 42 column 5, line 59 -column 6, line 17 column 6, line 51 -column 7, line 27 column 7, line 37 -column 8, line 7 figures	1-3,5-8, 12
A		4
Y	---	13
Y	US 5 537 092 A (Y. SUZUKI ET AL.) 16 July 1996 (1996-07-16) abstract; figures ---	13
	-/--	

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

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
13 October 1999	22/10/1999

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

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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.
X	GB 2 295 291 A (P. BURDEN) 22 May 1996 (1996-05-22) the whole document	1,3,5,9
A		2,4,6-8, 10-12

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Form PCT/ISA/210 (continuation of second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

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Intern: al Application No

PCT/GB 99/01985

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US 5537092	A	16-07-1996	JP	5273493 A	22-10-1993
GB 2295291	A	22-05-1996	NONE		