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(54) **Feedback active noise control system with a long secondary path**

(57) A feedback ANC system is disclosed that comprises a microphone (1) and a loudspeaker (2) arranged in a distance from each other; the microphone being acoustically coupled to the loudspeaker via a secondary path (3) and the loudspeaker being electrically coupled

to the microphone via an ANC filter (6). The distance between the microphone and the loudspeaker is larger than a value that is determined by the speed of sound divided by 20 times an upper critical frequency of the ANC system.

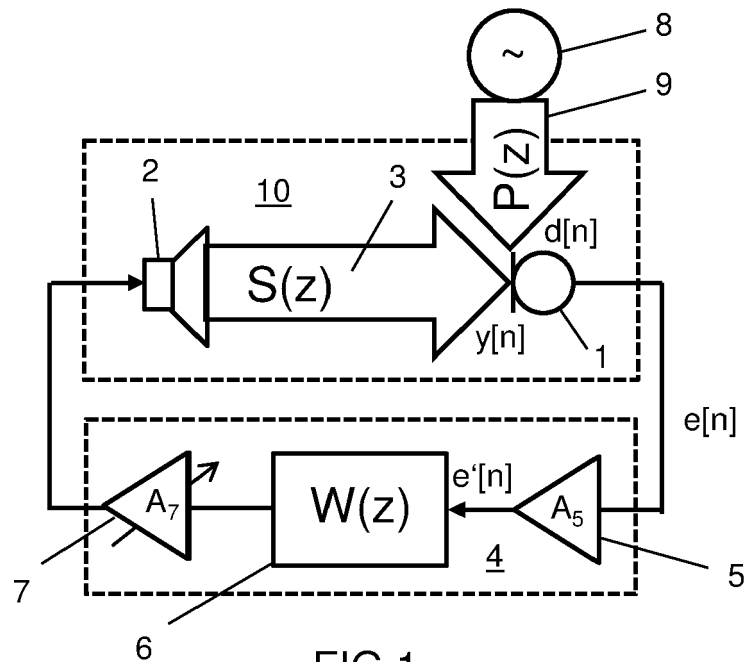


FIG 1

Description

BACKGROUND

[0001] The invention relates to a feedback ANC system having a long secondary path and, in particular, to a feedback ANC system applicable in vehicle cabins.

[0002] In active noise control (ANC) systems of the feedback type, a microphone is acoustically coupled to a loudspeaker via a secondary path and the loudspeaker is electrically coupled to the microphone via an electrical ANC filter. The ANC filter filters the signal from the microphone such that the signal that it provides to the loudspeaker and that is radiated by the loudspeaker to the microphone via the secondary path cancels the noise signal in the vicinity of the microphone. The degree of noise cancellation depends on the quality and stability of the secondary path and the ANC filter. Feedback ANC systems are commonly used in arrangements in which the microphone is arranged relatively close (< 0.34 m) to the loudspeaker as, for instance, in ANC headphones and, thus, in connection with very short secondary paths. Furthermore, feedback ANC systems are often implemented in analog circuitry and/or as non-adaptive fixed filters so that subsequent adaption to different modes of operation is difficult or even impossible. For instance, vehicle cabins are relatively large rooms with long distances (≥ 0.34 m) between loudspeaker and microphone. Furthermore, different modes of operation with widely varying secondary paths are determined by different passengers, a different number of passengers, open doors and open windows etc.

[0003] Feedback ANC systems are not considered suitable for applications in large rooms and are therefore not suitable for automotive applications. Common automotive ANC systems are feedforward systems, such as the so-called engine order compensation (EOC) system or the road noise compensation (RNC) system, that use dedicated non-acoustic sensors and operate in a very limited frequency range. However, feedback ANC systems in general are less complex, require less circuitry, operate in a broader frequency range and exhibit a better performance.

[0004] There is a need to provide an improved large room feedback ANC system in particular for use in vehicle cabins.

SUMMARY

[0005] A feedback ANC system is disclosed herein that comprises a microphone and a loudspeaker arranged in a distance from each other. The microphone is acoustically coupled to the loudspeaker via a secondary path and the loudspeaker is electrically coupled to the microphone via an ANC filter. The distance between the microphone and the loudspeaker is larger than a value that is determined by the speed of sound divided by 20 times an upper critical frequency of the ANC system.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] Various specific embodiments are described in more detail below based on the exemplary embodiments shown in the figures of the drawings. Unless stated otherwise, similar or identical components are labeled in all of the figures with the same reference numbers.

FIG. 1 is a block diagram illustrating the principles of signal processing in a feedback ANC system.

FIG. 2 is a schematic diagram of a vehicle cabin in which the active noise reduction system of FIG. 1 may be applied.

FIG. 3 is a diagram depicting simulation results of the system shown in FIGS. 1 and 2.

FIG. 4 is a diagram depicting measurements of the attenuation over frequency of the system shown in FIGS. 1 and 2 when the ANC system is active and inactive.

FIG. 5 is a schematic diagram illustrating a multi-channel ANC system.

FIG. 6 is a block diagram of a general feedback type active noise reduction system in which a useful signal is supplied to the loudspeaker and microphone signal paths.

FIG. 7 is a block diagram of the active noise reduction system of FIG. 6, in which the useful signal is supplied via a spectrum shaping filter to the loudspeaker path.

FIG. 8 is a block diagram of the active noise reduction system of FIG. 6, in which the useful signal is supplied via a spectrum shaping filter to the microphone path.

DETAILED DESCRIPTION

[0007] Reference is now made to FIG. 1, which is a block diagram illustrating the principles of signal processing in a feedback ANC system. In the ANC system of FIG. 1, an error microphone 1 is acoustically coupled to a loudspeaker 2 via a secondary path 3 and the loudspeaker 2 is electrically coupled to the microphone 1 via a feedback signal path 4 including a microphone pre-amplifier 5, a subsequent ANC filter 6 with a transfer function $W(z)$ and a subsequent loudspeaker driver amplifier 7 whose amplification A_7 is adjustable or controllable. The microphone 1 and the loudspeaker 2 are arranged in a room, e.g., a vehicle cabin 10. The term "loudspeaker" as used herein means any type of transducer that converts electrical signals it receives into acoustic signals that it radiates. Accordingly, the term "microphone" as used herein means any type of transducer that converts acoustic signals it receives into electrical signals that it provides.

[0008] The microphone 1 receives an acoustic signal that is composed of an acoustic output signal $y(t)$ and an acoustic disturbance signal $d(t)$. Output signal $y(t)$ is the output signal of the loudspeaker 2 filtered with a transfer function $S(z)$ of the secondary path 3 and disturbance signal $d(t)$ is the output signal of a noise source 8 filtered with a transfer function $P(z)$ of a primary path 9. From this received acoustic signal $y(t)-d(t)$ the microphone 1 generates an electrical error signal $e(t)$ which is amplified by the microphone pre-amplifier 5 and then supplied as amplified error signal $e'(t) = A_5 e(t)$ to the subsequent ANC filter 6. For the sake of simplicity, the amplification A_5 of microphone pre-amplifier 5 is assumed to be equal to 1 in the considerations below so that $e'(t) = e(t)$, but may have any other appropriate value if required. The ANC system shown in FIG. 1 can be described by the following differential equations in the spectral domain based on the various signals in the time domain, in which $D(z)$, $E(z)$ and $Y(z)$ are the spectral representations of the signals $d(t)$, $e(t)$ and $y(t)$ in the time domain:

$$E(z) = D(z) - Y(z),$$

$$Y(z) = E(z) \cdot W(z) \cdot S(z).$$

[0009] The use of feedback ANC systems in vehicles is widely discussed, e.g., by Stephen Elliott, "Signal Processing", Academic Press, London, 2001, paragraphs 6.5.2 and 6.10. His findings include, inter alia, the following:

(a) Feedback ANC systems are not capable of distinguishing between wanted signals such as acoustic warning signals, music and speech, and unwanted signals such as noise.

(b) The maximum attenuation in feedback ANC systems is much more sensitive to the plant delay T of the systems than it is in feedforward ANC systems. Therefore, the plant delay of feedback ANC systems should be kept below 1 millisecond ($\tau < 1$ ms) because above 5 millisecond ($\tau > 5$ ms) the achievable attenuation is almost zero (see Elliot, "Signal Processing", Academic Press, London, 2001, figure 6.18 in paragraph 6.5.2). At $\tau \approx 1.5$ ms feedback and feedforward systems exhibit similar performances.

(c) The plant delay τ is composed of the delay times of the ANC filter, analog-to-digital converter, digital-to-analog converter, digital signal processor, loudspeaker, microphone and secondary path; the (acoustic) secondary path has a length d (distance between loudspeaker and microphone) provides as acoustic plant delay τ_a the relevant contribution to the plant delay τ in which $\tau_a / d \approx 3$ [ms/m] with a speed of sound 343 m/s at a temperature of 20°C.

(d) Thus, plant delays $\tau < 1$ ms can only be achieved in case of distances $d < 0.33$ m, which is the distance between loudspeaker and microphone. According to Elliot's findings feedback ANC systems cannot be used in vehicle cabins if the distance between loudspeaker and microphone is more than 0.4 m. Most common vehicle cabins require, however, a distance of more than 0.4 m.

(e) A further finding by Stephen Elliott in "A Review of Active Noise and Vibration Control in Road Vehicles", 2008, is, that even if meeting all the requirements outlined above, the maximum critical frequency f_{UL} of the frequency range under noise control is approximately $1/10$ of the acoustic aliasing frequency $f_{ACAI} = c/2d$, in which c is the speed of sound (343 m/s at a temperature of 20 °C) and d is the distance between loudspeaker and microphone. The so-called "zone of silence", which is an area around the microphone with a noise attenuation of more than 6 dB, has, according to Elliott, a radius r , in which

$$r \sim \lambda/10 \text{ and } \lambda = c/f_{UL} = 20 \cdot d.$$

[0010] FIG. 2 shows a vehicle cabin 10 in which the active noise reduction system of FIG. 1 may be applied. In the vehicle cabin 10, e.g., the interior of a Mercedes W211, the microphone 1 is mounted in the left front portion 11 of the cabin 10, close to a driver's head. The loudspeaker 2, e.g., a subwoofer, is mounted on the rear shelf 12 of the cabin 10. The distance d between the microphone 1 and the loudspeaker 2 is approximately 3 m.

[0011] Simulations have been conducted on the basis of the arrangement of FIG. 2, the results of which are shown in FIG. 3. FIG. 3 depicts (a) the magnitude frequency response, (b) the phase frequency response, (c) the sensitivity function and (d) the complementary sensitivity function. The magnitude frequency response is the magnitude in dB over frequency in Hz. The phase frequency response is the phase in degree over frequency in Hz. The sensitivity function $N(z)$, which is the disturbance signal to error signal ratio, can be described as:

$$N(z) = D(z)/E(z) = 1/(1 + W(z) \cdot S(z)) = 1/(1 + H_{OL}(z)),$$

in which $H_{OL}(z) = W(z) \cdot S(z)$ is the transfer function of the open loop of the feedback ANC system.

[0012] The differentiation equation of a complementary sensitivity function $T(z)$, which is the disturbance signal $d(t)$ to output signal $y(t)$ ratio, is accordingly:

$$T(z) = D(z)/Y(z) = H_{OL}(z)/(1 + H_{OL}(z)).$$

[0013] Both the sensitivity and the complementary functions are depicted in FIG. 3 c and d as magnitude in dB over frequency in Hz.

[0014] From the Bode diagram (magnitude and phase over frequency) 13 of the secondary path in an open loop $H_{OL}(z)$ as shown in FIGS. 3a and b it can be seen that there is an at least theoretical possibility of extending the range of sufficient attenuation up to frequencies of about 100 Hz. Due to the shape of the secondary path, however, it turned out that a sufficient attenuation can only be reached in a range up to 50 Hz which is, nevertheless, about 10 times higher than expected according to Elliott's observations. In the arrangement described above with reference to FIGS. 1 and 2, an analog, non-adaptive ANC filter may be used that comprises one boost and one cut equalizing filter with the following dimensioning:

$$f_{CEQ1} = 44 \text{ Hz}, G_{EQ1} = 21.4 \text{ dB}, Q_{EQ1} = 4.04,$$

$$f_{CEQ2} = 82 \text{ Hz}, G_{EQ2} = -3.6 \text{ dB}, Q_{EQ2} = 6.05,$$

$$LG = 1.9 \text{ dB},$$

[0015] in which f_{CEQ1} , f_{CEQ2} are the corner frequencies, G_{EQ1} , G_{EQ2} are the maximum/ minimum gain, Q_{EQ1} , Q_{EQ2} are the quality factors, and LG is the loop gain. FIGS 3c and 3d illustrate the corresponding sensitivity function 17 and the complementary sensitivity function 19, each in connection with the error margin 18.

[0016] Referring now to FIG. 4, graphs 20 and 21 depict measurements of the attenuation A [dB] over frequency f [Hz] of the system shown in FIGS. 1 and 2 when the ANC system is not active (20) and when it is active (21). It can readily be seen from graph 25 that a maximum attenuation of approximately 8 dB is reached in exact the spectral range identified in the simulations and that the ANC filter used exhibits the so-called "Waterbed Effect" which describes an increase in attenuation in a certain spectral range typical for ANC systems but which may be considered too large in the present case and, thus, may render the system instable under certain conditions.

[0017] For an increase in stability, in particular in view of a possible maximum change in the secondary path behavior, e.g., by opening all doors, the loop gain LP may be decreased by, e.g., up to 3 dB. This particular situation is depicted in FIG. 4 by graph 22 which represents a system with low-pass filtering and inactive ANC and by graph 23 which represents a system with low-pass filtering and active ANC; the difference of graphs 22 and 23 being about 6 dB and represented by graph 24. Furthermore, graphs 20 and 21 show that there is no attenuation by the ANC system at higher frequencies.

[0018] As can be seen and in contrast to the prevailing opinion, the system disclosed herein allows for distances between the microphone and the loudspeaker larger than a value that is determined by the speed of sound divided by 20 times an upper critical frequency. A satisfactory performance may be even achieved, e.g., for distances between the microphone and the loudspeaker that are smaller than or equal to a value that is determined by the speed of sound divided by 2 times an upper critical frequency.

$$d > c/(20f_{UL})$$

and, for instance,

$$d \leq c/(2f_{UL}).$$

[0019] FIG. 5 shows a multi-zone ANC system with four zones of silent FL, FR, RL and RR that correspond to driver/passenger positions front left, front right, rear left and rear right. At each position one of microphones 1_{fl} , 1_{fr} , 1_{rl} , 1_{rr} and one of loudspeakers 2_{fl} , 2_{fr} , 2_{rl} , 2_{rr} are arranged in a distance d_{fl} , d_{fr} , d_{rl} , $d_{rr} > 0.3$ m from each other. Each one of microphones 1_{fl} , 1_{fr} , 1_{rl} , 1_{rr} is connected to a corresponding one of loudspeakers 2_{fl} , 2_{fr} , 2_{rl} , 2_{rr} via one of ANC filters 6_{fl} , 6_{fr} , 6_{rl} , 6_{rr} which are operated independently of each other.

[0020] Further investigations have proven that, by applying dedicated circuit structures, the feedback ANC systems described herein are capable of distinguishing between wanted signals, i.e., useful signals such as acoustic warning signals, music and speech, and unwanted signals such as noise. Exemplary circuit structures with specific input paths for the useful signals are described below with reference to FIGS. 6, 7 and 8.

[0021] FIG. 6 is a block diagram illustrating a general feedback type active noise reduction system in which the useful signal is supplied to both the loudspeaker path and the microphone path. For the sake of simplicity, the primary path 9 is omitted below, notwithstanding that noise (disturbing signal $d[n]$) is still present. In particular, the system of FIG. 6 is based on the system of FIG. 1, however with an additional subtractor 26 that subtracts the useful signal $x[n]$ from the microphone output signal $y[n]$ to form the ANC filter input signal, i.e., error signal $e[n]$ and with a subtractor 27 that subtracts the useful signal $x[n]$ from the output signal $u[n]$ of ANC filter 6.

[0022] The differential equations describing the system illustrated in FIG. 3 are as follows:

$$Y(z) = S(z) \cdot V(z) = S(z) \cdot (U(z) - X(z))$$

$$U(z) = W(z) \cdot E(z) = W(z) \cdot (Y(z) - X(z))$$

[0023] The useful signal transfer characteristic $M(z)$ in the system of FIG. 6 is thus

$$M(z) = (S(z) - W(z) \cdot S(z)) / (1 - W(z) \cdot S(z))$$

$$\lim_{(W(z) \cdot S(z) \rightarrow 1)} M(z) \Rightarrow M(z) \rightarrow \infty$$

$$\lim[(W(z) \cdot S(z)) \rightarrow 0] M(z) \Rightarrow M(z) \rightarrow S(z)$$

5

$$\lim[(W(z) \cdot S(z)) \rightarrow \pm\infty] M(z) \Rightarrow M(z) \rightarrow 1.$$

10 **[0024]** It can be seen from the above equations that the useful signal transfer characteristic $M(z)$ approaches $S(z)$ when the open loop transfer characteristic $(W(z) \cdot S(z))$ approaches 0. Like the system of FIG. 1, the system of FIG. 6 depends on the transfer characteristic $S(z)$ of the secondary path 3 and its fluctuations due to aging, temperature, change of listener etc.

15 **[0025]** In FIG. 7, a system is shown that is based on the system of FIG. 6 and that additionally includes an equalizing filter 28 connected upstream of the subtractor 27 in order to filter the useful signal $x[n]$ with the inverse secondary path transfer function $1/S(z)$. The differential equations describing the system illustrated in FIG. 7 are as follows:

$$Y(z) = S(z) \cdot V(z) = S(z) \cdot (U(z) - X(z)/S(z))$$

20

$$U(z) = W(z) \cdot E(z) = W(z) \cdot (Y(z) - X(z))$$

25 **[0026]** The useful signal transfer characteristic $M(z)$ in the system of FIG. 7 is thus

$$M(z) = (1 - W(z) \cdot S(z)) / (1 - W(z) \cdot S(z)) = 1$$

30

35 **[0027]** As can be seen from the above equations, the microphone output signal $y[n]$ is identical to the useful signal $x[n]$, which means that signal $x[n]$ is not altered by the system if the characteristic of the equalizing filter is exactly the inverse of the secondary path transfer characteristic $S(z)$. Since the secondary path transfer function $S(z)$ in a car is generally not minimum-phase, as can be seen, e.g., from the phase frequency response shown FIGS. 3a and 3b, only approximations of its inverse exist. The probably simplest way is to take the minimum-phase version of $S(z)$, since this can be inverted. Other, more sophisticated but more complex solutions exist as well, that are able to, at least partly, invert the complex transfer function $S(z)$, thus also taking into account, at least partly, its phase characteristic during the inversion process.

40 **[0028]** This configuration acts as an ideal linearizer, i.e. it compensates for any deteriorations of the useful signal resulting from its transfer from the loudspeaker 2 to the microphone, representing ideally the listener's ear. It therefore compensates for, or linearizes, the disturbing influence of the secondary path $S(z)$ to the useful signal $x[n]$, such that the useful signal arrives at the microphone (listener) as provided by the source, without any negative effect caused by the acoustical properties of the vehicle cabin, i.e., $y[z] = x[z]$. As such, with the help of such a linearizing filter, it is possible to make a poorly designed sound resemble like an acoustically perfectly adjusted, i.e. linear one.

45 **[0029]** In FIG. 8, a system is shown that is based on the system of FIG. 3 and that additionally includes an equalizing filter 28 connected upstream of the subtractor 26 in order to filter the useful signal $x[n]$ with the secondary path transfer function $S(z)$.

[0030] The differential equations describing the system illustrated in FIG. 8 are as follows:

50

$$Y(z) = S(z) \cdot V(z) = S(z) \cdot (U(z) - X(z))$$

55

$$U(z) = W(z) \cdot E(z) = W(z) \cdot (Y(z) - S(z) \cdot X(z))$$

[0031] The useful signal transfer characteristic $M(z)$ in the system of FIG. 8 is thus

$$M(z) = S(z) \cdot (1 + W(z) \cdot S(z)) / (1 + W(z) \cdot S(z)) = S(z)$$

[0032] As can be seen, the useful signal transfer characteristic $M(z)$ is identical with the secondary path transfer characteristic $S(z)$ when the ANC system is active. When the ANC system is inactive, the useful signal transfer characteristic $M(z)$ is also identical with the secondary path transfer characteristic $S(z)$. Thus, the aural impression of the useful signal for a listener at a location close to the microphone 1 is the same regardless of whether noise reduction is active or not.

[0033] This is the most likely way of considering a useful-signal in terms of an automobile environment, since there the useful-signal is mostly music, which should not be disturbed by an algorithm like the feedback ANC system specified here. Furthermore, the thereby needed replica of the secondary path $S(z)$, can, without any problems, be realized in a complex form e.g. as a FIR filter, which, on the other hand, can be made adaptive very easily, e.g. by utilizing one of the multiple forms of the LMS/RLS algorithms. Hence it is shown that, despite the previously mentioned findings of Elliott et al. it is possible to guide a useful signal through a feedback ANC system.

[0034] The ANC filter 6 and the equalizing filters 28 and 29 may be fixed filters with constant transfer characteristics or adaptive filters with controllable transfer characteristics. In the drawings, the adaptive structure of a filter per se is indicated by an arrow underlying the respective block and the optionality of the adaptive structure is indicated by a broken line.

[0035] Although various examples of realizing the invention have been disclosed, it will be apparent to those skilled in the art that various changes and modifications can be made which will achieve some of the advantages of the invention without departing from the spirit and scope of the invention. It will be obvious to those reasonably skilled in the art that other components performing the same functions may be suitably substituted. Such modifications to the inventive concept are intended to be covered by the appended claims.

Claims

1. A feedback ANC system comprising a microphone and a loudspeaker arranged in a distance of each other; in which the microphone is acoustically coupled to the loudspeaker via a secondary path; the loudspeaker being electrically coupled to the microphone via an ANC filter; and the distance between the microphone and the loudspeaker is larger than a value that is determined by the speed of sound divided by 20 times an upper critical frequency of the ANC system.
2. The system of claim 1, in which the distance between the microphone and the loudspeaker is smaller than or equal to a value that is determined by the speed of sound divided by 2 times an upper critical frequency.
3. The system of claim 2, in which the distance between loudspeaker and microphone is more than 0.34 meter or more than 0.5 meter or more than 1 meter.
4. The system of one of claims 1-3, in which the ANC filter is an analog filter.
5. The system of one of claims 1-4, in which the ANC filter is a non-adaptive filter.
6. The system of one of claims 1-5, further comprising $n \geq 1$ additional microphones and n loudspeakers, each of the loudspeakers being arranged in a distance larger than a value that is determined by the speed of sound divided by 20 times an upper critical frequency.
7. The system of claim 6, in which the distance between each microphone and each loudspeaker is smaller than or equal to a value that is determined by the speed of sound divided by 2 times an upper critical frequency.
8. The system of claim 5 or 6, further comprising n additional ANC filters; each additional ANC filter being connected between one of the additional microphones and one of the additional loudspeakers.
9. The system of one of claims 1-8, further comprising a first subtractor that is connected downstream of the microphone and a first useful-signal path, in which the ANC filter is connected downstream of the first subtractor; and

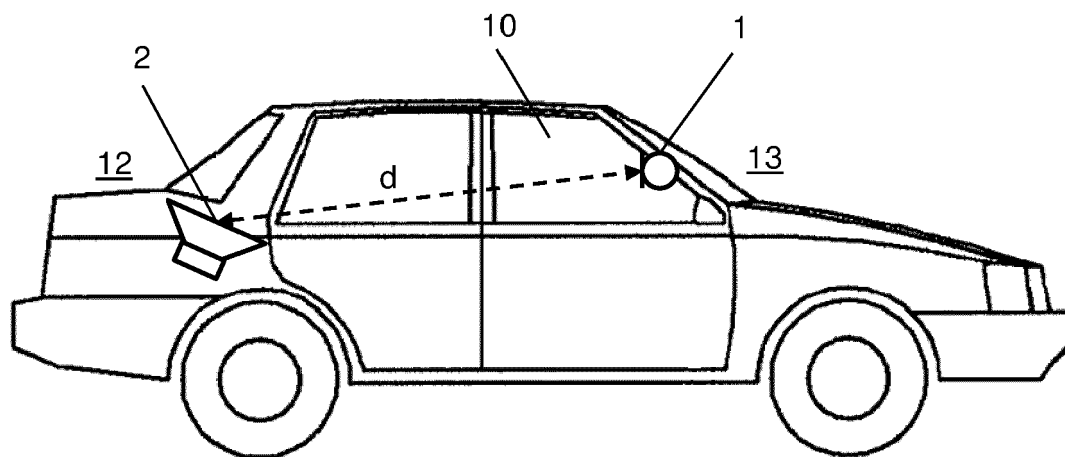
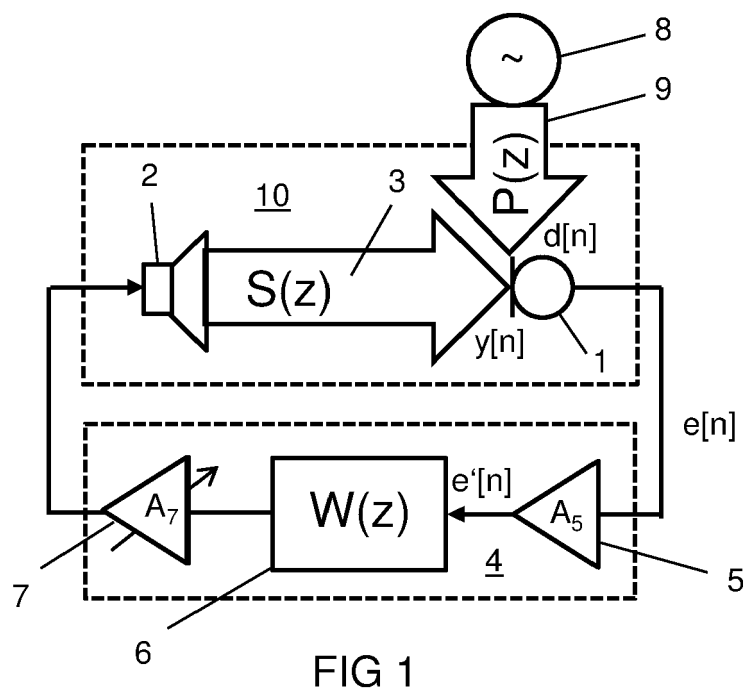
a second subtractor that is connected upstream of the loudspeaker and to the ANC filter and a second useful-signal path; in which both useful-signal paths are supplied with a useful signal to be reproduced.

5 **10.** The system of claim 9, in which at least one of the useful-signal paths comprises at least one spectrum shaping filter.

11. The system of claim 9 or 10, in which the secondary path has a secondary path transfer characteristic and at least one of the spectrum shaping filters has a transfer characteristic that models the secondary path transfer characteristic or linearizes a microphone signal output by the microphone with regard to the useful signal.

10 **12.** The system of one of claims 9-11, in which the first useful-signal path comprises a first spectrum shaping filter that has a transfer characteristic that is equal to the secondary path transfer characteristic.

13. The system of one of claims 9-12, in which the second useful-signal path comprises a second spectrum shaping filter that has a transfer characteristic that is equal to the inverse secondary path transfer characteristic.



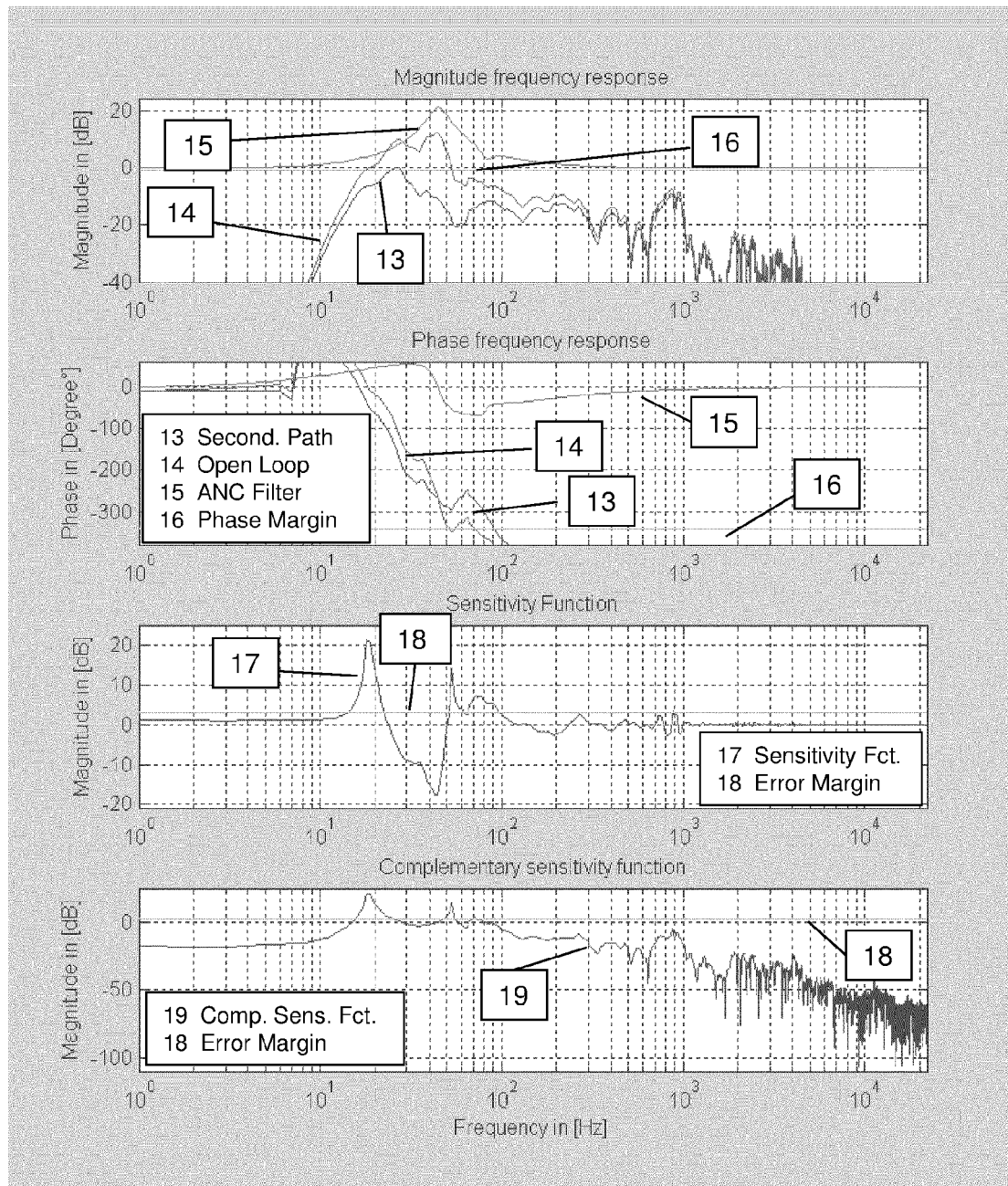


FIG 3

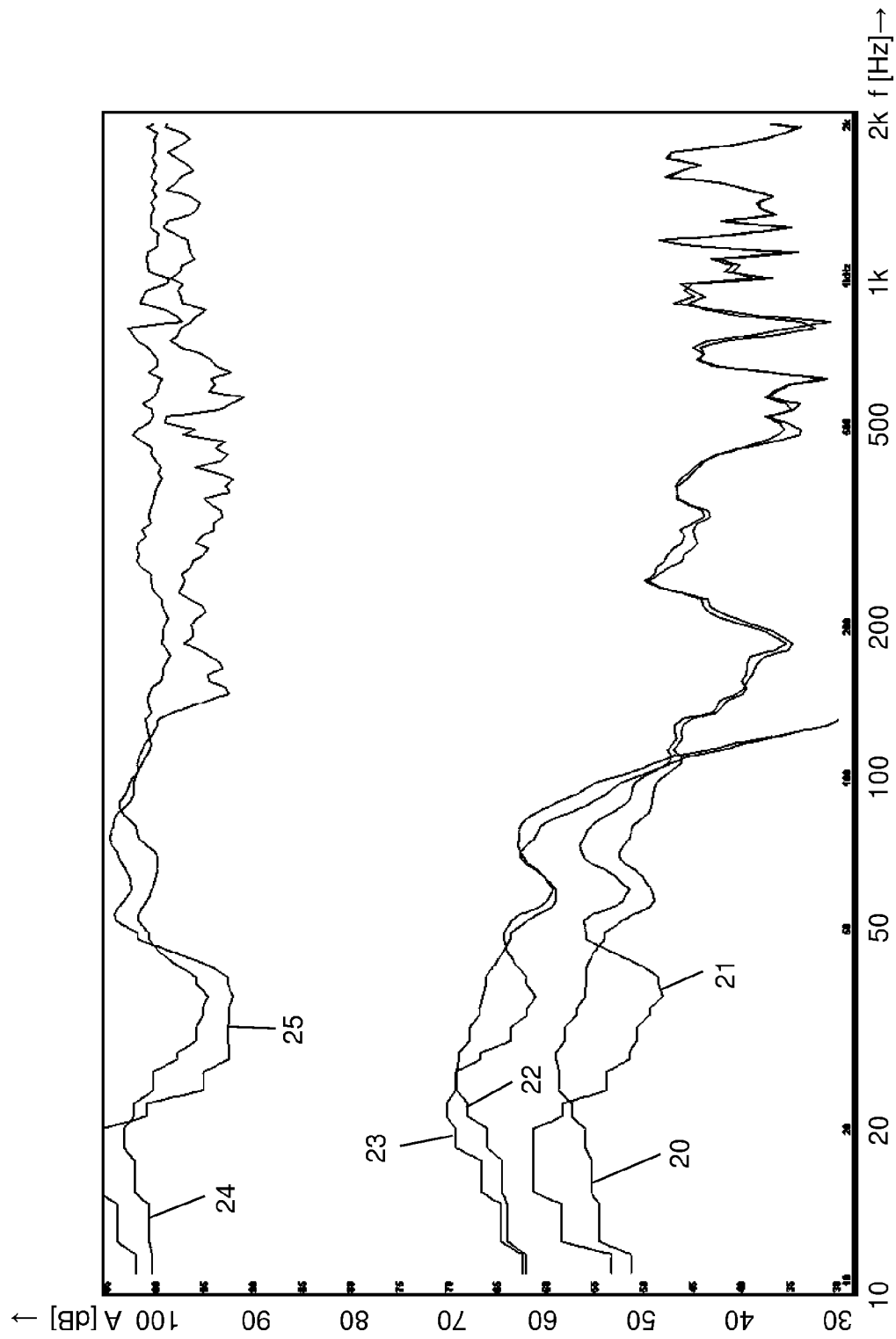


FIG 4

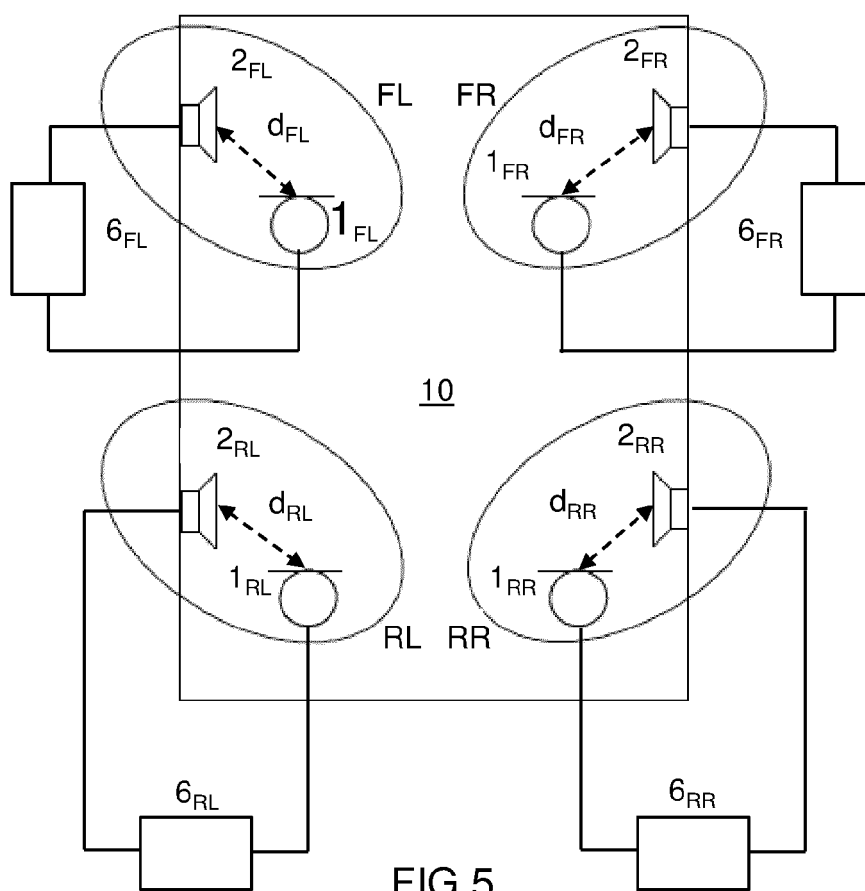


FIG 5

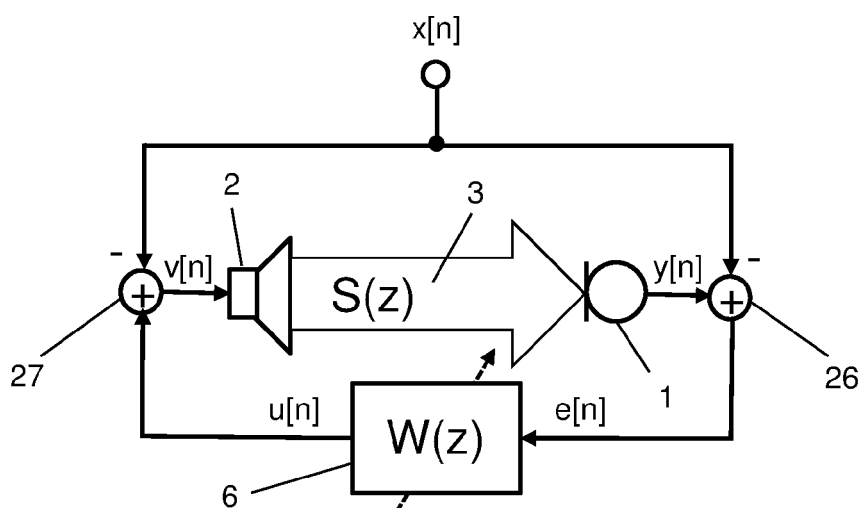


FIG 6

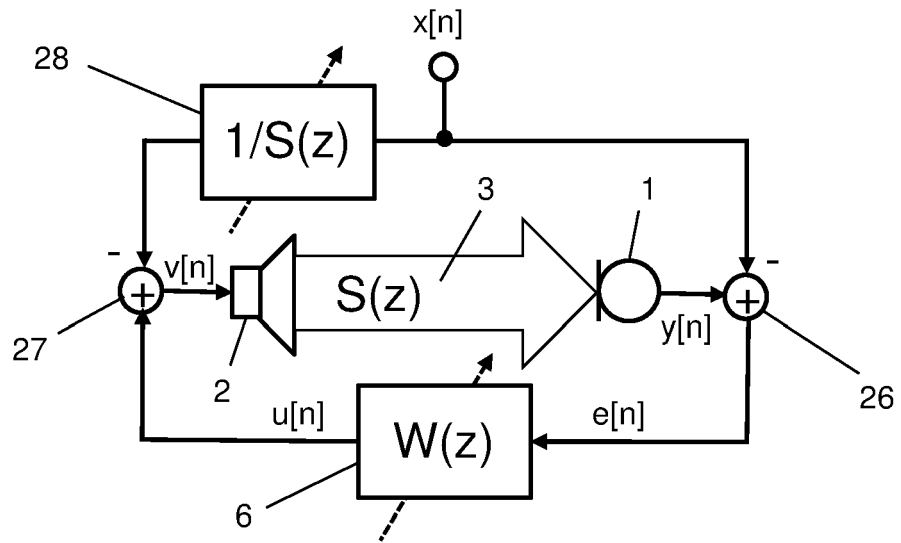


FIG 7

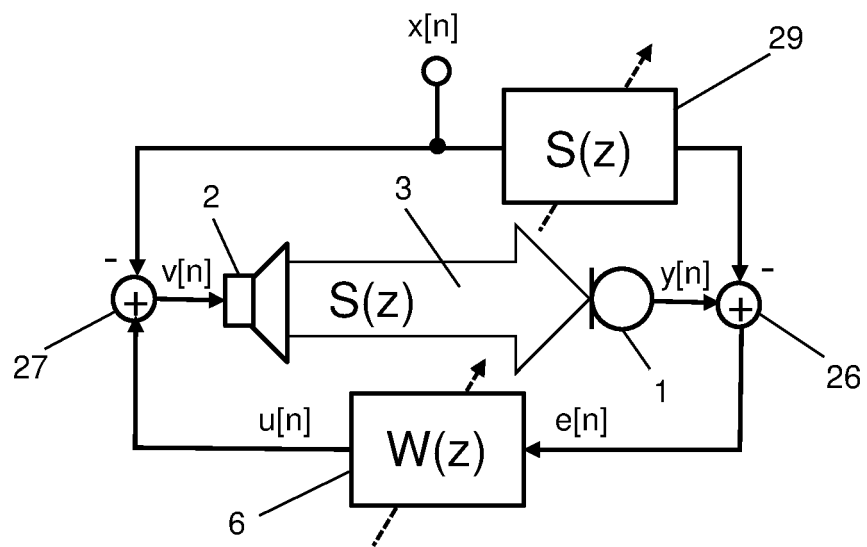


FIG 8



EUROPEAN SEARCH REPORT

Application Number
EP 12 15 5561

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	JP 60 183900 A (MAZDA MOTOR) 19 September 1985 (1985-09-19) * abstract; figures 1,4A,4B * * page 661 *	1-5 6-13	INV. G10K11/178
X	US 2008/240456 A1 (SAKAMOTO KOSUKE [JP] ET AL) 2 October 2008 (2008-10-02) * abstract; figures 2,3,5,11 * * paragraphs [0047], [0048], [0057], [0058], [0061], [0062] *	1-3 4,5	
X,D	S. J. Elliott: "A Review of Active Noise and Vibration Control in Road Vehicles", ISVR Technical Memorandum No 981, 1 December 2008 (2008-12-01), pages 1-25, XP55032773, Retrieved from the Internet: URL:http://eprints.soton.ac.uk/65371/1/Pub10974.pdf [retrieved on 2012-07-13] * the whole document *	1,2	
A	US 2005/207585 A1 (CHRISTOPH MARKUS [DE]) 22 September 2005 (2005-09-22) * abstract; figure 1 * * paragraphs [0004], [0005], [0102], [0103], [0105], [0119] *	1	
Y	US 5 953 428 A (SILVERBERG MICHAEL H [US] ET AL) 14 September 1999 (1999-09-14) * abstract; figures 1,2 * * column 1, lines 40-65 * * column 2, lines 42-64 * * column 3, lines 41-47 *	6-8	
The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 5 October 2012	Examiner de Jong, Frank
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

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EPO FORM 1503 03 82 (P04C01)



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EP 12 15 5561

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
Y	JP 11 305784 A (MATSUSHITA ELECTRIC IND CO LTD) 5 November 1999 (1999-11-05) * abstract; figure 5 * * paragraphs [0019], [0024], [0053] - [0062] *	9-12	
Y	US 2010/124337 A1 (WERTZ DUANE [US] ET AL) 20 May 2010 (2010-05-20) * paragraphs [0044] - [0052], [0060], [0066]; figures 4-7 * * abstract; figures 2,4 *	6-13	
A	US 2009/220098 A1 (CHRISTOPH MARKUS [DE]) 3 September 2009 (2009-09-03) * abstract; figures 2,3 * * paragraphs [0019] - [0023] *	6-8	
			TECHNICAL FIELDS SEARCHED (IPC)
The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 5 October 2012	Examiner de Jong, Frank
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

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CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing claims for which payment was due.

☐ Only part of the claims have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due and for those claims for which claims fees have been paid, namely claim(s):

☐ No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due.

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

see sheet B

☒ All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.

☐ As all searchable claims could be searched without effort justifying an additional fee, the Search Division did not invite payment of any additional fee.

☐ Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid, namely claims:

☐ None of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims, namely claims:

☐ The present supplementary European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims (Rule 164 (1) EPC).



**LACK OF UNITY OF INVENTION
SHEET B**

Application Number
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The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

1. claims: 1-5

Feedback ANC system wherein the acoustic aliasing frequency is kept below the upper critical frequency

2. claims: 6-8

Feedback ANC system wherein a plurality of control zones exist

3. claims: 9-13

Feedback ANC system wherein a useful signal can be introduced into the cabin without cancelation

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

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This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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05-10-2012

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
JP 60183900	A	19-09-1985	NONE	

US 2008240456	A1	02-10-2008	JP 2008247221 A	16-10-2008
			US 2008240456 A1	02-10-2008

US 2005207585	A1	22-09-2005	AT 402468 T	15-08-2008
			EP 1577879 A1	21-09-2005
			US 2005207585 A1	22-09-2005

US 5953428	A	14-09-1999	EP 0805432 A2	05-11-1997
			US 5953428 A	14-09-1999

JP 11305784	A	05-11-1999	NONE	

US 2010124337	A1	20-05-2010	CN 101877808 A	03-11-2010
			EP 2239729 A2	13-10-2010
			JP 2010244053 A	28-10-2010
			US 2010124337 A1	20-05-2010

US 2009220098	A1	03-09-2009	AT 518381 T	15-08-2011
			EP 2043383 A1	01-04-2009
			EP 2043384 A1	01-04-2009
			EP 2051543 A1	22-04-2009
			EP 2282555 A2	09-02-2011
			US 2009086990 A1	02-04-2009
			US 2009086995 A1	02-04-2009
			US 2009220098 A1	03-09-2009

EPO FORM P0458

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

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Non-patent literature cited in the description

- **STEPHEN ELLIOTT.** Signal Processing. Academic Press, London, 2001 **[0009]**
- **ELLIOT.** Signal Processing. Academic Press, London, 2001 **[0009]**
- **STEPHEN ELLIOTT.** A Review of Active Noise and Vibration Control in Road Vehicles, 2008 **[0009]**