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(54) Title: AMBIENT NOISE-BASED ADAPTATION OF SECONDARY PATH ADAPTIVE RESPONSE IN NOISE-CANCELING PERSONAL AUDIO DEVICES

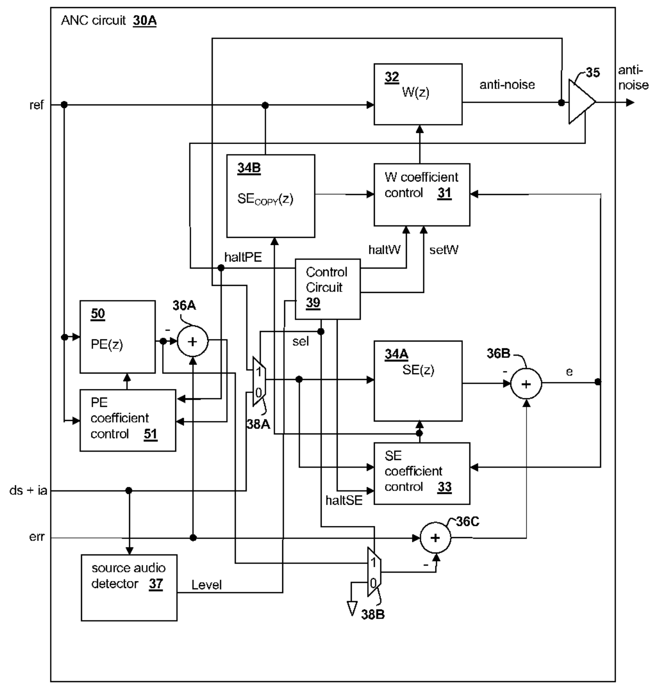

Fig. 3

(57) Abstract: An adaptive noise canceler adapts a secondary path modeling response using ambient noise, rather than using another noise source or source audio as a training source. Anti-noise generated from a reference microphone signal using a first adaptive filter is used as the training signal for training the secondary path response. Ambient noise at the error microphone is removed from an error microphone signal, so that only anti-noise remains. A primary path modeling adaptive filter is used to modify the reference microphone signal to generate a source of ambient noise that is correlated with the ambient noise present at the error microphone, which is then subtracted from the error microphone signal to generate the error signal. The primary path modeling adaptive filter is previously adapted by minimizing components of the error microphone signal appearing in an output of the primary path adaptive filter while the anti-noise signal is muted.

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AMBIENT NOISE-BASED ADAPTATION OF SECONDARY PATH ADAPTIVE RESPONSE IN NOISE-CANCELING PERSONAL AUDIO DEVICES

FIELD OF THE INVENTION

[0001] The present invention relates generally to personal audio devices such as headphones that include adaptive noise cancellation (ANC), and, more specifically, to architectural features of an ANC system in which a secondary path estimating response is trained using ambient noise.

BACKGROUND OF THE INVENTION

[0002] Wireless telephones, such as mobile/cellular telephones, cordless telephones, and other consumer audio devices, such as MP3 players, are in widespread use. Performance of such devices with respect to intelligibility can be improved by providing noise canceling using a reference microphone to measure ambient acoustic events and then using signal processing to insert an anti-noise signal into the output of the device to cancel the ambient acoustic events.

[0003] Noise canceling operation can be improved by measuring the transducer output of a device at the transducer to determine the effectiveness of the noise canceling using an error microphone. The measured output of the transducer is ideally the source audio, e.g., downlink audio in a telephone and/or playback audio in either a dedicated audio player or a telephone, since the noise canceling signal(s) are ideally canceled by the ambient noise at the location of the transducer. To remove the source audio from the error microphone signal, the secondary path from the transducer through the error microphone can be estimated and used to filter the source audio to the correct phase and amplitude for subtraction from the error microphone signal. However, when source audio is absent, the secondary path estimate cannot typically be updated. In particular, at the beginning of a telephone conversation, the secondary path estimate may be incorrect and there is no source audio available for training the secondary path estimate until downlink speech commences.

[0004] Therefore, it would be desirable to provide a personal audio device, including wireless telephones, that provides noise cancellation using a secondary path estimate to measure the output of the transducer and that can adapt the secondary path estimate independent of whether source audio of sufficient amplitude is present.

DISCLOSURE OF THE INVENTION

[0005] The above-stated objective of providing a personal audio device providing noise cancelling including a secondary path estimate that can be adapted whether or not source audio has been present, is accomplished in a personal audio device, a method of operation, and an integrated circuit.

[0006] The personal audio device includes a housing, with a transducer mounted on the housing for reproducing an audio signal that includes both source audio for plackback to a listener and an anti-noise signal for countering the effects of ambient audio sounds in an acoustic output of the transducer. An error microphone is mounted on the housing to provide an error microphone signal indicative of the transducer output and the ambient audio sounds. The personal audio device further includes an adaptive noise-canceling (ANC) processing circuit within the housing for adaptively generating an anti-noise signal from the error microphone signal such that the anti-noise signal causes substantial cancellation of the ambient audio sounds. The processing circuit controls adaptation of a secondary path adaptive filter for compensating for the electro-acoustical path from the output of the processing circuit through the transducer, wherein the processing circuit removes source audio as shaped by the secondary path response from the error microphone signal to provide an error signal. The processing circuit provides ambient noise to the secondary path adaptive filter's coefficient control circuit as a training signal for adapting the secondary path response. The ambient noise provided to the coefficient control circuit may be the anti-noise signal generated from the reference microphone signal, and the ambient noise present at the error microphone removed from the error microphone signal using a primary path modeling adaptive filter to generate an error signal that contains only the components of the error microphone signal due to the anti-noise reproduced by the transducer. The response of the primary path modeling adaptive filter is earlier adapted using the error microphone signal and the reference microphone signal, so that components of the error microphone signal appearing in an output of the primary path adaptive filter are minimized.

[0007] The foregoing and other objectives, features, and advantages of the invention will be apparent from the following, more particular, description of the preferred embodiment of the invention, as illustrated in the accompanying drawings.

DISCLOSURE OF THE DRAWINGS

[0008] Figure 1 is an illustration of an exemplary wireless telephone **10.**

[0009] Figure 2 is a block diagram of circuits within wireless telephone **10.**

[0010] Figure 3 is a block diagram depicting signal processing circuits and functional blocks of various exemplary ANC circuits that can be used to implement ANC circuit **30** of CODEC integrated circuit **20** of Figure 2.

[0011] Figure 4 is a timing diagram illustrating operation of ANC circuit **30**.

[0012] Figure 5 is a block diagram depicting signal processing circuits and functional blocks within CODEC integrated circuit **20**

BEST MODE FOR CARRYING OUT THE INVENTION

[0013] The present disclosure reveals noise canceling techniques and circuits that can be implemented in a personal audio device, such as a wireless telephone. The personal audio device includes an adaptive noise canceling (ANC) circuit that measures the ambient acoustic environment and generates a signal that is injected into the speaker (or other transducer) output to cancel ambient acoustic events. A reference microphone is provided to measure the ambient acoustic environment, and an error microphone is included to measure the ambient audio and transducer output at the transducer, thus giving an indication of the effectiveness of the noise cancelation. A secondary path estimating adaptive filter is used to remove the playback audio from the error microphone signal, in order to generate an error signal. However, depending on the presence (and level) of the audio signal reproduced by the personal audio device, e.g., downlink audio during a telephone conversation or playback audio from a media file/connection, the secondary path adaptive filter may not be able to continue to adapt to estimate the secondary path response. Further, at the beginning of a telephone conversation, not only may downlink audio be absent, but any previous secondary path model may be inaccurate due to a different position of the wireless telephone with respect to the user’s ear. The techniques disclosed herein use ambient noise to provide enough energy for the secondary path estimating adaptive filter to continue to adapt, in a manner that is unobtrusive to the user. The anti-noise signal may be provided to the secondary path adaptive filter, in order to provide a training signal for adapting the secondary path response estimate. The error microphone signal is corrected to remove components due to ambient noise present at the error microphone, leaving only components due to the anti-noise signal. The components due to ambient noise are removed using a primary path response modeling adaptive filter that has been previously adapted to model the primary path response.

[0014] Figure 1 shows an exemplary wireless telephone **10** in proximity to a human ear **5**. Illustrated wireless telephone **10** is an example of a device in which techniques illustrated herein may be employed, but it is understood that not all of the elements or configurations embodied in illustrated wireless telephone **10**, or in the circuits depicted in subsequent illustrations, are required. Wireless telephone **10** includes a transducer such as a speaker **SPKR** that reproduces distant speech received by wireless telephone **10**, along with other local audio events such as ringtones, stored audio program material, near-end speech, sources from web-pages or other network communications received by wireless telephone **10** and audio indications such as battery low and other system event notifications. A near speech microphone **NS** is provided to capture near-end speech, which is transmitted from wireless telephone **10** to the other conversation participant(s).

[0015] Wireless telephone **10** includes adaptive noise canceling (ANC) circuits and features that inject an anti-noise signal into speaker **SPKR** to improve intelligibility of the distant speech and other audio reproduced by speaker **SPKR**. A reference microphone **R** is provided for measuring the ambient acoustic environment and is positioned away from the typical position of a user's mouth, so that the near-end speech is minimized in the signal produced by reference microphone **R**. A third microphone, error microphone **E**, is provided in order to further improve the ANC operation by providing a measure of the ambient audio combined with the audio reproduced by speaker **SPKR** close to ear **5**, when wireless telephone **10** is in close proximity to ear **5**. An exemplary circuit **14** within wireless telephone **10** includes an audio CODEC integrated circuit **20** that receives the signals from reference microphone **R**, near speech microphone **NS**, and error microphone **E** and interfaces with other integrated circuits such as an RF integrated circuit **12** containing the wireless telephone transceiver. In other implementations, the circuits and techniques disclosed herein may be incorporated in a single integrated circuit that contains control circuits and other functionality for implementing the entirety of the personal audio device, such as an MP3 player-on-a-chip integrated circuit.

[0016] In general, the ANC techniques disclosed herein measure ambient acoustic events (as opposed to the output of speaker **SPKR** and/or the near-end speech) impinging on reference microphone **R**, and also measure the same ambient acoustic events impinging on error microphone **E**. The ANC processing circuits of illustrated wireless telephone **10** adapt an anti-noise signal generated from the output of reference microphone **R** to have a characteristic that minimizes the amplitude of the ambient acoustic events present at error microphone **E**. Since acoustic path P(z) extends from reference microphone **R** to error microphone **E**, the ANC circuits are essentially estimating acoustic path P(z) combined with removing effects of an electro-acoustic path S(z). Electro-acoustic path S(z) represents the response of the audio output circuits of CODEC IC **20** and the acoustic/electric transfer function of speaker **SPKR** including the coupling between speaker **SPKR** and error microphone **E** in the particular acoustic environment. Path S(z) is affected by the proximity and structure of ear **5** and other physical objects and human head structures that may be in proximity to wireless telephone **10**, when wireless telephone **10** is not firmly pressed to ear **5**. While the illustrated wireless telephone **10** includes a two microphone ANC system with a third near speech microphone **NS**, other systems that do not include separate error and reference microphones can implement the above-described techniques. Alternatively, near speech microphone **NS** can be used to perform the function of the reference microphone **R** in the above-described system. Finally, in personal audio devices designed only for audio playback, near speech microphone **NS** will generally not be included, and the near speech signal paths in the circuits described in further detail below can be omitted.

[0017] Referring now to **Figure 2**, circuits within wireless telephone **10** are shown in a block diagram. CODEC integrated circuit **20** includes an analog-to-digital converter (ADC) **21A** for receiving the reference microphone signal and generating a digital representation **ref** of the reference microphone signal, an ADC **21B** for receiving the error microphone signal and generating a digital representation **err** of the error microphone signal, and an ADC **21C** for receiving the near speech microphone signal and generating a digital representation of near speech microphone signal **ns**. CODEC IC **20** generates an output for driving speaker **SPKR** from an amplifier **A1**, which amplifies the output of a digital-to-analog converter (DAC) **23** that receives the output of a combiner **26A**. Another combiner **26B** combines audio signals **ia** from internal audio sources **24** and downlink speech **ds** received from a radio frequency (RF) integrated circuit **22** to form source audio signal (ds+ia), which is provided to combiner **26A** and to an ANC circuit **30**. Combiner **26A** combines source audio signal (ds+ia) with the anti-noise signal provided from ANC circuit **30** and a portion of near speech signal **ns**. Near speech signal **ns** is also provided to RF integrated circuit **22** and is transmitted as uplink speech to the service provider via an antenna **ANT**. Anti-noise signal **anti-noise** by convention has the same polarity as the noise in reference microphone signal **ref** and is therefore subtracted by combiner **26A**.

[0018] Figure 3 shows one example of details of an ANC circuit **30A** that can be used to implement ANC circuit **30** of Figure 2. A pair of selectors **38A-38B** are controlled by a control signal **sel** provided from a control circuit **39**. Selectors **38A-38B** select between two operating modes: a normal mode, selected when control signal **sel** is de-asserted (**sel** = 0) and an ambient noise-based SE training mode selected when control signal **sel** is asserted (**sel** = 1). The ambient noise is selectively provided to train response SE(z) when control signal **sel** is asserted (**sel** = 1). In the normal operating mode (**sel** = 0), an adaptive filter **32** receives reference microphone signal **ref** and under ideal circumstances, adapts its transfer function W(z) to be P(z)/S(z) to generate the anti-noise signal **anti-noise**, which is provided to an output combiner that combines the anti-noise signal with the audio to be reproduced by the transducer, as exemplified by combiner **26A** of Figure 2. The coefficients of adaptive filter **32** are controlled by a W coefficient control block **31** that uses a correlation of two signals to determine the response of adaptive filter **32**, which generally minimizes the error, in a least-mean squares sense, between those components of reference microphone signal **ref** present in error microphone signal **err**. The signals processed by W coefficient control block **31** are the reference microphone signal **ref** as shaped by a copy of an estimate of the response of path S(z) provided by a filter **34B** and another signal that includes error microphone signal **err**. By transforming reference microphone signal **ref** with a copy of the estimate of the response of path S(z), response $SE_{COPY}(z)$, and minimizing error microphone signal **err** after removing components of error microphone signal **err** due to playback of source audio, adaptive filter **32** adapts to the desired response of P(z)/S(z). In addition to error microphone signal **err**, the other signal processed along with the output of filter **34B** by W coefficient control block **31** includes an inverted amount of the source audio including downlink audio signal **ds** and internal audio **ia** that has been processed by filter response SE(z), of which response $SE_{COPY}(z)$ is a copy. By injecting an inverted amount of source audio, adaptive filter **32** is prevented from adapting to the relatively large amount of source audio present in error microphone signal **err** and by transforming the inverted copy of downlink audio signal **ds** and internal audio **ia** with the estimate of the response of path S(z), the source audio that is removed from error microphone signal **err** before processing should match the expected version of downlink audio signal **ds**, and internal audio **ia** reproduced at error microphone signal **err**, since the electrical and acoustical path of S(z) is the path taken by downlink audio signal **ds** and internal audio **ia** to arrive at error microphone **E**. Filter **34B** is not an adaptive filter, per se, but has an adjustable response that is tuned to match the response of a secondary path adaptive filter **34A**, so that the response of filter **34B** tracks the adapting of secondary path adaptive filter **34A**.

[0019] To implement the above, secondary path adaptive filter **34A** has coefficients controlled by a SE coefficient control block **33**, which processes the source audio (ds+ia) and error microphone signal **err** after removal, by a combiner **36B**, of the above-described filtered downlink audio signal

ds and internal audio **ia**, that has been filtered by secondary path adaptive filter **34A** to represent the expected source audio delivered to error microphone **E**. Secondary path adaptive filter **34A** is thereby adapted to generate an error signal **e** from downlink audio signal **ds** and internal audio **ia**, that when subtracted from error microphone signal **err**, contains the content of error microphone signal **err** that is not due to source audio (ds+ia). However, if downlink audio signal **ds** and internal audio **ia** are both absent, e.g., at the beginning of a telephone call, or have very low amplitude, SE coefficient control block **33** will not have sufficient input to estimate acoustic path S(z). Therefore, in ANC circuit **30A**, when source audio has not been present, the secondary path estimate is updated by using the ambient noise-based SE training mode mentioned above, which uses ambient noise measured by reference microphone **R** as a training signal for updating response SE(z) of secondary path adaptive filter **34A**.

[0020] When SE coefficient control **33** needs to be updated, e.g., at the start of a telephone conversation, and a source audio detector **37** indicates that source audio (ds+ia) has insufficient amplitude for training the secondary path response SE(z), control circuit **39** asserts control signal **sel** to select the ambient noise-based training mode. In order to provide a copy of the ambient noise training signal referenced at the location of error microphone **E**, an adaptive filter **50** is used to model acoustic path P(z). During an initial training phase with ANC turned off, which is accomplished by de-activating (muting) a controllable amplifier stage **35** in response to de-assertion of a control signal **haltPE**, adaptive filter models path P(z) by filtering reference microphone signal **ref** with adaptive filter **50** and subtracting the output of adaptive filter **50** from error microphone signal **err** using a combiner **36A**. Control signal **haltSE** is also asserted to prevent adaptation of secondary path response SE(z) during adaptation of the primary path response PE(z) of adaptive filter **50**. The output of combiner **36A** is compared with reference microphone signal **err** in a PE coefficient control block **51** which is generally a least-mean-squared (LMS) control block, which causes adaptive filter **50** to adapt primary path response

PE(z) to match acoustic path P(z). After primary path response PE(z) is adapted, control signal **haltPE** is asserted, causing PE coefficient control block to maintain primary path response PE(z) at its current value. Subsequently, adaptive filter **50** filters reference microphone signal **ref** to provide an output that is representative of the ambient noise component of error microphone signal **err**. Control signal **setW** is also set to cause coefficient control block **31** to set the response of adaptive filter **32** to a predetermined response for generating the ambient noise training signal, generally a response that should provide some noise cancelling effect while response SE(z) of adaptive filter **34** is being trained, since the ambient noise training signal will be audible as the anti-noise signal **anti-noise** while secondary path adaptive filter **32** is being adapted. A combiner **36C** is used in the ambient noise-based SE training mode (**sel** = 1) to subtract the output of adaptive filter **50** from error microphone signal **err**. Combiner **36C** thus effectively removes the ambient noise component from error microphone signal **err**, so that error signal **e** will contain only a component due to anti-noise signal **anti-noise**, since source audio (ds+ia) is absent or very low in amplitude. During this time, anti-noise signal **anti-noise** is provided to the input of adaptive filter **34A** via selector **38A** and control signal **haltSE** is de-asserted so that SE coefficient control block **33** is allowed to update coefficients to train response SE(z). Once response SE(z) is adapted, control signal **sel** is de-asserted and control signals **haltW** and **setW** are also de-asserted to allow response W(z) to adapt by updating coefficient control block **31**.

[0021] Referring now to **Figure 4**, a sequence for training SE both with and without source audio (ds + ia) is shown, as can be performed within ANC circuit **30A** of Figure 3. At time $\mathbf{t_1}$, signal **level** is low, indicating that insufficient source audio (ds + ia) is present for adapting response SE(z). Between times $\mathbf{t_1}$ and $\mathbf{t_2}$, control signal haltPE is de-asserted, which causes primary path response PE(z) of adaptive filter **50** to model path P(z). Next, between times $\mathbf{t_2}$ and $\mathbf{t_3}$, control signal SetW is asserted to set response W(z) to a predetermined value. Once adaptive filter **50** has adapted at time $\mathbf{t_2}$, control signal **haltPE** is asserted to maintain the response of adaptive filter **50** at its current value, and control signal **haltSE** is de-asserted to allow response SE(z) to adapt. Control signal **SetW** remains asserted to provide a predetermined response for adaptive filter **32** while adaptive filter **34A** is adapting. During the interval between times $\mathbf{t_2}$ and $\mathbf{t_3}$, secondary path adaptive filter **34A** trains its response to the ambient noise received by reference microphone signal **R** transformed by response W(z), which has been set to a predetermined response (or a bypass flat response) in response to assertion of control signal **setW**. As in the normal mode, the output of secondary path adaptive filter **34A** is subtracted from error microphone signal **err** to provide an input to SE coefficient control **33** and response SE(z) adapts to model S(z), just as when downlink audio is available. At time $\mathbf{t_3}$, control signals **setW** and **haltW** are de-asserted, to permit response W(z) of adaptive filter **32** to adapt. At time $\mathbf{t_4}$, another training of response SE(z) is commenced, which could be due to another call being initiated, a detected change in the response of SE(z), a change in ear pressure, instability, etc. Signal **level** is in an asserted state, indicating that sufficient source audio (ds + ia) is present, and so the cycle from times $\mathbf{t_1}$ and $\mathbf{t_3}$ is not repeated, but rather, response SE(z) will be training in the normal operating mode using source audio (ds + ia). Between times $\mathbf{t_4}$ and $\mathbf{t_5}$, control signal **haltSE** is de-asserted and control signal **haltW** is asserted, permitting response SE(z) of adaptive filter **34A** to adapt, and then between times $\mathbf{t_5}$ and $\mathbf{t_6}$, control signal **haltSE** is asserted and control signal **haltW** is de-asserted, permitting response W(z) of adaptive filter **32** to adapt. However, in the normal operating mode, adapting of adaptive filter **34A** and adaptive filter **32** can be carried out simultaneously or in any other suitable manner.

[0022] Referring now to **Figure 5**, a block diagram of an ANC system is shown for implementing ANC techniques as depicted in Figure 3, and having a processing circuit **40** as may be implemented within CODEC integrated circuit **20** of Figure 2. Processing circuit **40** includes a processor core **42** coupled to a memory **44** in which are stored program instructions comprising a computer-program product that may implement some or all of the above-described ANC techniques, as well as other signal processing. Optionally, a dedicated digital signal processing (DSP) logic **46** may be provided to implement a portion of, or alternatively all of, the ANC signal processing provided by processing circuit **40**. Processing circuit **40** also includes ADCs **21A-21C**, for receiving inputs from reference microphone **R**, error microphone **E** and near speech microphone **NS**, respectively. DAC **23** and amplifier **A1** are also provided by processing circuit **40** for providing the transducer output signal, including anti-noise as described above.

[0023] While the invention has been particularly shown and described with reference to the preferred embodiments thereof, it will be understood by those skilled in the art that the foregoing, as well as other changes in form and details may be made therein without departing from the spirit and scope of the invention.

CLAIMS

WHAT IS CLAIMED:

1. A personal audio device, comprising:

a personal audio device housing;

a transducer mounted on the housing for reproducing an audio signal including both source audio for playback to a listener and an anti-noise signal for countering the effects of ambient audio sounds in an acoustic output of the transducer;

a reference microphone mounted on the housing for providing a reference microphone signal indicative of the ambient audio sounds;

an error microphone mounted on the housing in proximity to the transducer for providing an error microphone signal indicative of the acoustic output of the transducer and the ambient audio sounds at the transducer; and

a processing circuit that generates the anti-noise signal from the reference signal by adapting a first adaptive filter to reduce the presence of the ambient audio sounds heard by the listener in conformity with an error signal and the reference microphone signal, wherein the processing circuit implements a secondary path adaptive filter having a secondary path response controlled by a secondary path coefficient control circuit in conformity with the error signal, wherein the secondary path adaptive filter shapes the source audio with the secondary path response, wherein the processing circuit removes the source audio as shaped by the secondary path response from the error microphone signal to provide the error signal, wherein the processing circuit provides an ambient noise training signal generated from the reference microphone signal to the secondary path adaptive filter to adapt the secondary path response.

2. The personal audio device of Claim 1, wherein the processing circuit detects an amplitude of the source audio, and selectively provides the ambient noise training signal to the secondary path adaptive filter in response to detecting that the amplitude of the source audio is below a threshold value.

3. The personal audio device of Claim 1, wherein the processing circuit sets a response of the first adaptive filter to a predetermined response to generate the ambient noise training signal from the reference microphone signal.

4. The personal audio device of Claim 1, wherein the processing circuit further implements a primary path modeling adaptive filter having a primary path response, and wherein the processing circuit applies the primary path response to the reference microphone signal and subtracts a result of applying the primary path response to the reference microphone signal from the error microphone signal to generate the error signal.

5. The personal audio device of Claim 4, wherein the processing circuit sequences adaptation of the secondary path response and the primary path response so that the primary path response is adapted while the secondary path response is held at a fixed value, and then the secondary path response is adapted after the primary path response has adapted.

6. The personal audio device of Claim 5, wherein the processing circuit mutes the anti-noise signal while the primary path response is adapted.

7. The personal audio device of Claim 6, wherein the processing circuit sets a response of the first adaptive filter to a predetermined response while the ambient noise training signal is provided to the secondary path adaptive filter and the secondary path response is adapted.

8. The personal audio device of Claim 7, wherein the processing circuit adapts the response of the first adaptive filter after the secondary path response is adapted.

9. A method of countering effects of ambient audio sounds by a personal audio device, the method comprising:

adaptively generating an anti-noise signal from a reference microphone signal by adapting a first adaptive filter to reduce the presence of the ambient audio sounds heard by the listener in conformity with an error signal and a reference microphone signal;

combining the anti-noise signal with source audio;

providing a result of the combining to a transducer;

measuring an acoustic output of the transducer and the ambient audio sounds with an error microphone;

implementing a secondary path adaptive filter having a secondary path response controlled by a secondary path coefficient control circuit in conformity with the error signal;

shaping the source audio with the secondary path response;

removing the source audio as shaped by the secondary path response from the error microphone signal to provide the error signal;

generating an ambient noise training signal from the reference microphone signal; and

selectively providing the ambient noise training signal to the secondary path adaptive filter to adapt the secondary path response.

10. The method of Claim 9, further comprising detecting an amplitude of the source audio, and wherein the selectively providing the ambient noise training to the secondary path adaptive filter provides the ambient noise training signal to the secondary path adaptive filter in response to detecting that the amplitude of the source audio is below a threshold value.

11. The method of Claim 9, further comprising setting a response of the first adaptive filter to a predetermined response to generate the ambient noise training signal.

12. The method of Claim 9, further comprising:

modeling a primary path response with a primary path modeling adaptive filter;

applying the primary path response to the reference microphone signal; and

subtracting a result of the applying the primary path response to the reference microphone signal from the error microphone signal to generate the error signal.

13. The method of Claim 12, further comprising sequencing adaptation of the secondary path response and the primary path response so that the primary path response is adapted while the secondary path response is held at a fixed value, and then the secondary path response is adapted after the primary path response has adapted.

14. The method of Claim 13, further comprising muting the anti-noise signal while the primary path response is adapted.

15. The method of Claim 14, further comprising setting a response of the first adaptive filter to a predetermined response while the ambient noise training signal is provided to the secondary path adaptive filter and the secondary path response is adapted.

16. The method of Claim 15, wherein the adaptively generating adapts the response of the first adaptive filter after the secondary path response is adapted.

17. An integrated circuit for implementing at least a portion of a personal audio device, comprising:

an output for providing an output signal to an output transducer including both source audio for playback to a listener and an anti-noise signal for countering the effects of ambient audio sounds in an acoustic output of the transducer;

a reference microphone input for receiving a reference microphone signal indicative of the ambient audio sounds;

an error microphone input for receiving an error microphone signal indicative of the acoustic output of the transducer and the ambient audio sounds at the transducer;

a noise source for providing a noise signal; and

a processing circuit that generates the anti-noise signal from the reference signal by adapting a first adaptive filter to reduce the presence of the ambient audio sounds heard by the listener in conformity with an error signal and the reference microphone signal, wherein the processing circuit implements a secondary path adaptive filter having a secondary path response controlled by a secondary path coefficient control circuit in conformity with the error signal, wherein the secondary path adaptive filter shapes the source audio with the secondary path response, wherein the processing circuit removes the source audio as shaped by the secondary path response from the error microphone signal to provide the error signal, wherein the processing circuit provides an ambient noise training signal generated from the reference microphone signal to the secondary path adaptive filter to adapt the secondary path response.

18. The integrated circuit of Claim 17, wherein the processing circuit detects an amplitude of the source audio, and selectively provides the ambient noise training signal to the secondary path adaptive filter in response to detecting that the amplitude of the source audio is below a threshold value.

19. The integrated circuit of Claim 17, wherein the processing circuit sets a response of the first adaptive filter to a predetermined response to generate the ambient noise training signal from the reference microphone signal.

20. The integrated circuit of Claim 17, wherein the processing circuit further implements a primary path modeling adaptive filter having a primary path response, and wherein the processing circuit applies the primary path response to the reference microphone signal and subtracts a result of applying the primary path response to the reference microphone signal from the error microphone signal to generate the error signal.

21. The integrated circuit of Claim 20, wherein the processing circuit sequences adaptation of the secondary path response and the primary path response so that the primary path response is adapted while the secondary path response is held at a fixed value, and then the secondary path response is adapted after the primary path response has adapted.

22. The integrated circuit of Claim 21, wherein the processing circuit mutes the anti-noise signal while the primary path response is adapted.

23. The integrated circuit of Claim 22, wherein the processing circuit sets a response of the first adaptive filter to a predetermined response while the ambient noise training signal is provided to the secondary path adaptive filter and the secondary path response is adapted.

24. The integrated circuit of Claim 23, wherein the processing circuit adapts the response of the first adaptive filter after the secondary path response is adapted.

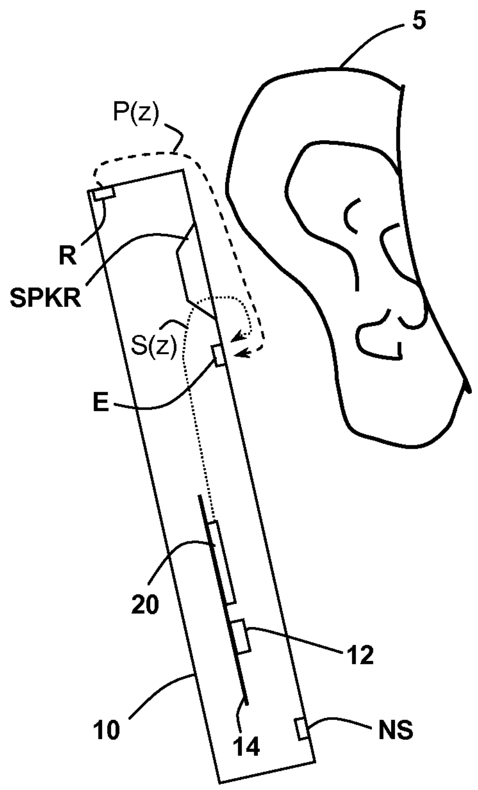


Fig. 1

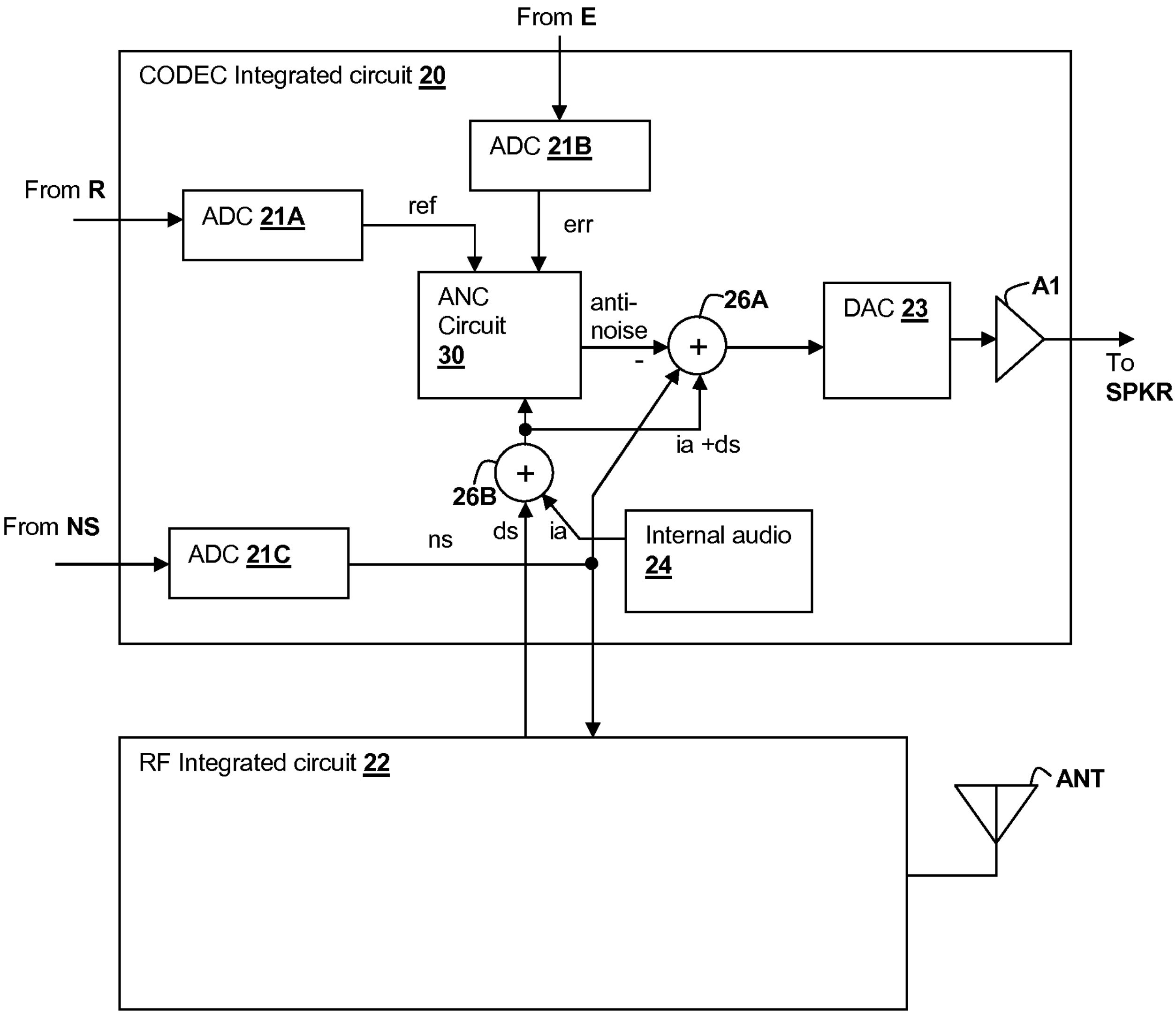
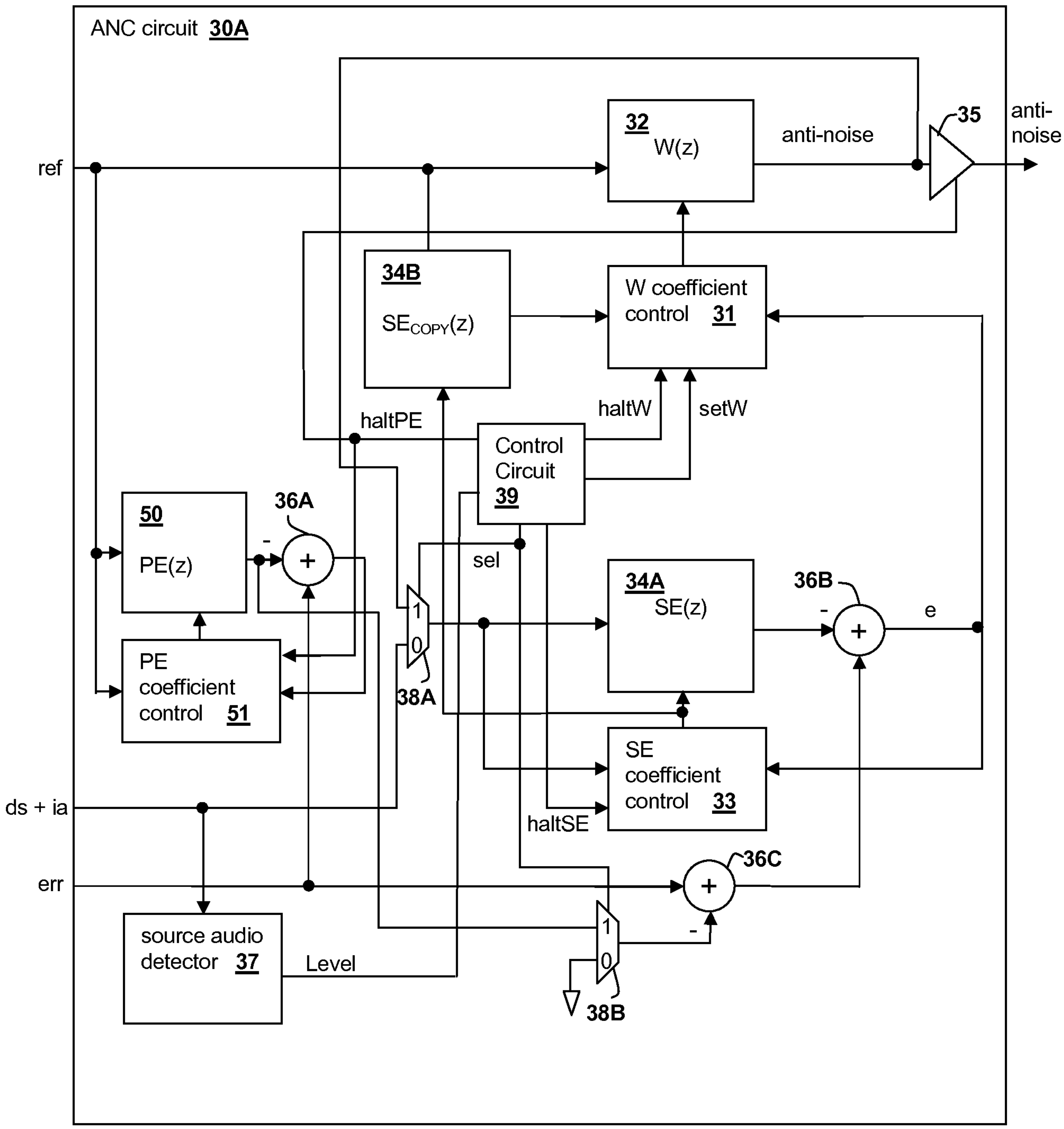

From E
CODEC Integrated circuit 20
ADC 21B
From R
ADC 21A
ref
err
ANC Circuit 30
anti-noise
-
26A
+
DAC 23
A1
To SPKR
ia +ds
+
26B
From NS
ADC 21C
ns
ds
ia
Internal audio 24
RF Integrated circuit 22
ANT

Fig. 2



ANC circuit 30A
32
W(z)
anti-noise
35
anti-noise
ref
34B
SE_COPY(z)
W coefficient control 31
haltPE
haltW
setW
Control Circuit 39
50
PE(z)
36A
sel
34A
SE(z)
36B
e
1
0
38A
PE coefficient control 51
SE coefficient control 33
ds + ia
haltSE
36C
err
source audio detector 37
Level
1
0
38B

Fig. 3

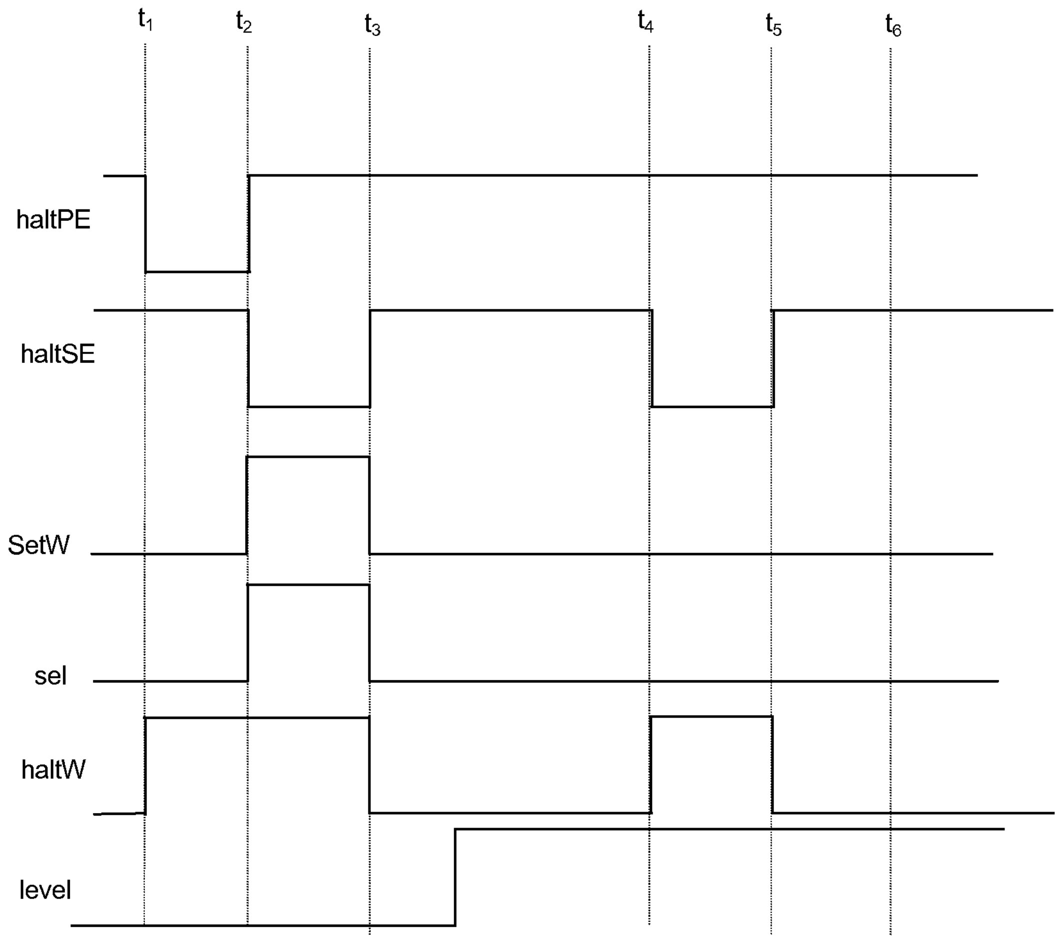


Fig. 4

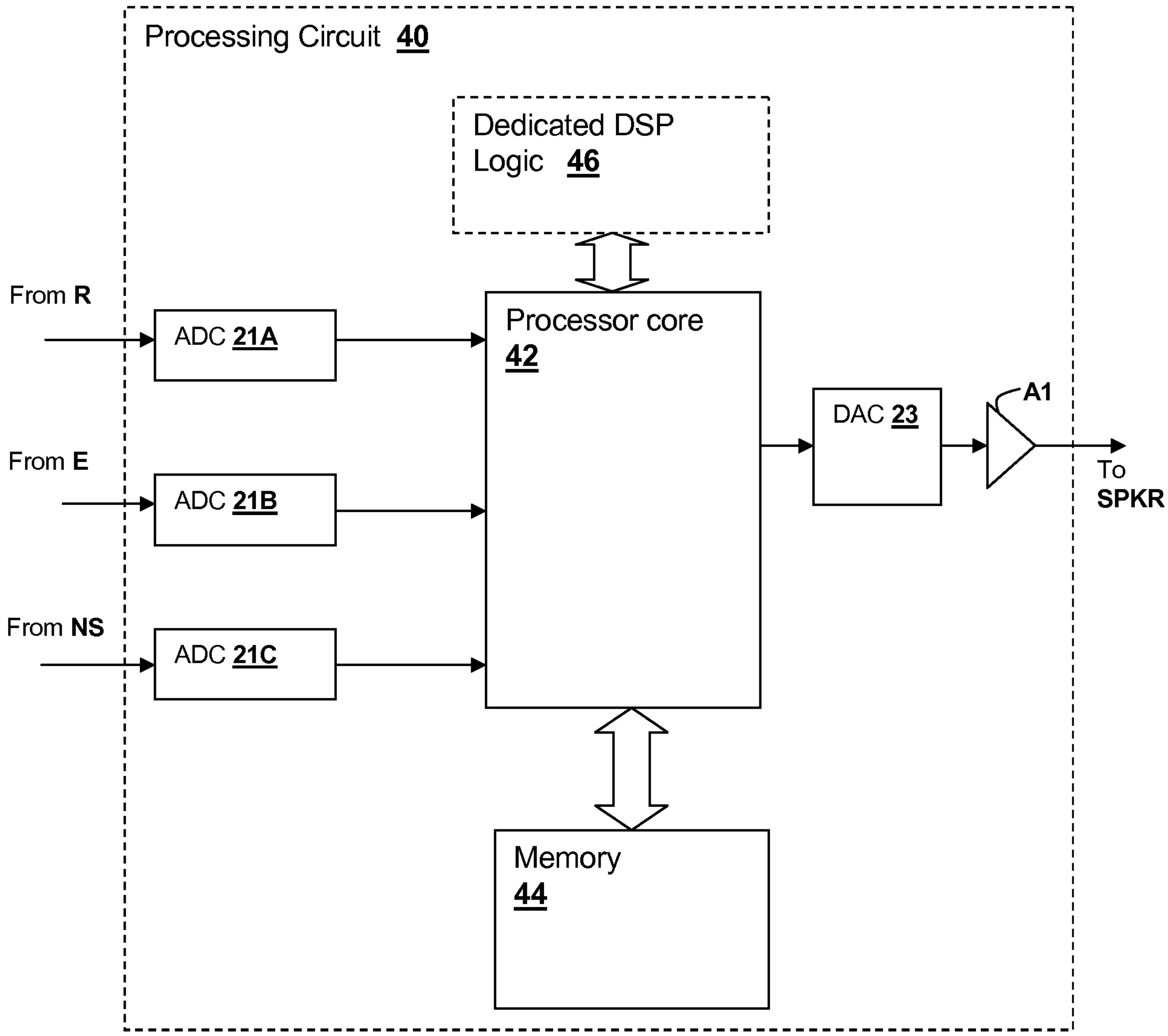

Processing Circuit 40
Dedicated DSP Logic 46
From R
ADC 21A
Processor core 42
A1
DAC 23
From E
ADC 21B
To SPKR
From NS
ADC 21C
Memory 44

Fig. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2014/017962

A. CLASSIFICATION OF SUBJECT MATTER
INV. G10K11/178
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)
G10K

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 A	US 2012/140943 A1 (HENDRIX JON D [US] ET AL) 7 June 2012 (2012-06-07) paragraphs [0008] - [0010], [0023] - [0027]; claims 49-60; figure 3; table 1 -----	1,3,9, 11,17,19 2,4-8, 10, 12-16, 18,20-24
Y	US 2012/308027 A1 (KWATRA NITIN [US]) 6 December 2012 (2012-12-06) paragraphs [0008] - [0009], [0015], [0020] - [0022]; claims 1, 9, 17; figure 3 -----	1,2,9, 10,17,18
Y A	WO 03/015074 A1 (UNIV NANYANG [SG]; ZHANG MING [SG]; LAN HUI [SG]; SER WEE [SG]) 20 February 2003 (2003-02-20) page 3, line 5 - page 8, line 26; figures 1, 3, 4 -----	1,2,9, 10,17,18 4-8, 12-16, 20-24

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

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"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
30 May 2014	10/06/2014

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	Joder, Cyril

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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.
A	JIN ET AL: "A simultaneous equation method-based online secondary path modeling algorithm for active noise control", JOURNAL OF SOUND & VIBRATION, LONDON, GB, vol. 303, no. 3-5, 25 April 2007 (2007-04-25), pages 455-474, XP022046548, ISSN: 0022-460X, DOI: 10.1016/J.JSV.2006.11.039 page 456, line 5 - page 457, line 14; figure 3 -----	4,12,20

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2014/017962

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