(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) **World Intellectual Property Organization**
International Bureau

(43) **International Publication Date**
14 November 2013 (14.11.2013)

WIPO | PCT

(10) **International Publication Number**
WO 2013/169454 A4

(51) **International Patent Classification**: *G10K 11/178* (2006.01)

(21) **International Application Number**: PCT/US2013/037051

(22) **International Filing Date**: 18 April 2013 (18.04.2013)

(25) **Filing Language**: English

(26) **Publication Language**: English

(30) **Priority Data**:
61/645,265 10 May 2012 (10.05.2012) US
13/787,906 7 March 2013 (07.03.2013) US

(71) **Applicant**: **CIRRUS LOGIC, INC.** [US/US]; 800 W 6th St., Austin, TX 78701 (US).

(72) **Inventors**: **ALDERSON, Jeffrey**; 7205 Twilight Mesa Dr, Austin, TX 78735 (US). **HENDRIX, Jon, D.**; 1351 Thompson Ranch Rd, Wimberly, TX 78676 (US). **LU, Yang**; 6636 William Cannon Dr Apt 1313, Austin, TX 78738 (US).

(74) **Agent**: **HARRIS, Andrew, Mitchell**; Mitch Harris, Attorney at Law, LLC, P.O. Box 7998, Athens, GA 30604 (US).

(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

[Continued on next page]

(54) **Title**: ERROR-SIGNAL CONTENT CONTROLLED ADAPTATION OF SECONDARY AND LEAKAGE PATH MODELS IN NOISE-CANCELING PERSONAL AUDIO DEVICES

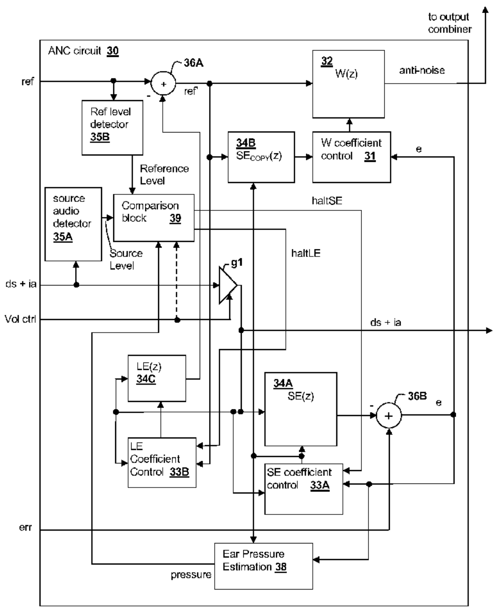

Fig. 3

(57) **Abstract**: A personal audio device, such as a wireless telephone, generates an anti-noise signal from a microphone signal and injects the anti-noise signal into the speaker or other transducer output to cause cancellation of ambient audio sounds. The microphone measures the ambient environment, but also contains a component due to the transducer acoustic output. An adaptive filter is used to estimate the electro-acoustical path from the noise-canceling circuit through the transducer to the at least one microphone so that source audio can be removed from the microphone signal. A determination of the relative amount of the ambient sounds present in the microphone signal versus the amount of the transducer output of the source audio present in the microphone signal is made to determine whether to update the adaptive response.

WO 2013/169454 A4

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Published:

— *with international search report (Art. 21(3))*

— *with amended claims (Art. 19(1))*

(88) Date of publication of the international search report: 27 March 2014

Date of publication of the amended claims: 10 July 2014

AMENDED CLAIMS

received by the International Bureau on 11 April 2014 (11.04.14).

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;

at least one microphone mounted on the housing for providing at least one microphone signal indicative of the ambient audio sounds and that contains a component due to the acoustic output of the transducer; and

a processing circuit that generates the anti-noise signal to reduce the presence of the ambient audio sounds heard by the listener, wherein the processing circuit implements an adaptive filter having a response that shapes the source audio and a combiner that removes the source audio from the at least one microphone signal to provide a corrected microphone signal, wherein the processing circuit determines a relative magnitude of a source audio component of the acoustic output of the transducer present in the at least one microphone signal and the ambient audio sounds present in the at least one microphone signal, wherein the processing circuit determines a degree of coupling between the transducer and an ear of the listener and adjusts the determined relative magnitude of the source audio component of the acoustic output of the transducer present in the error signal and the ambient audio sounds present in the error signal in conformity with the determined degree of coupling, and wherein the processing circuit takes action to prevent improper adaptation of the adaptive filter in response to determining that the relative magnitude of the source audio component of the acoustic output of the transducer present in the at least one microphone signal to the ambient audio sounds present in the at least one microphone signal indicates that the adaptive filter may not adapt properly.

2. The personal audio device of Claim 1, wherein the at least one microphone signal includes an error microphone signal provided by an error microphone mounted on the housing proximate to the transducer, wherein the adaptive filter is a secondary path adaptive filter that adapts to model a response of a secondary path taken by the source audio through the transducer and into the error microphone signal , and wherein an output of the secondary path adaptive filter is combined with the error microphone signal to generate an error signal indicative of the source audio component of the acoustic output of the transducer.

3.The personal audio device of Claim 2, wherein the at least one microphone signal includes a reference microphone signal provided by a reference microphone mounted on the housing for measuring the ambient audio sounds, and further comprising a leakage path adaptive filter that adapts to model a response of a leakage path taken by the source audio through the transducer and into the reference microphone signal , and wherein an output of the leakage path adaptive filter is combined with the reference microphone signal to generate a leakage-corrected reference microphone signal from which the anti-noise signal is generated.

4.The personal audio device of Claim 1, wherein the at least one microphone signal includes a reference microphone signal provided by a reference microphone mounted on the housing for measuring the ambient audio sounds, wherein the adaptive filter is a leakage path adaptive filter that adapts to model a response of a leakage path taken by the source audio through the transducer and into the reference microphone signal, and wherein an output of the leakage path adaptive filter is combined with the reference microphone signal to generate a leakage-corrected reference microphone signal from which the anti-noise signal is generated.

5. The personal audio device of Claim 2, wherein the processing circuit computes a ratio of a first magnitude of the source audio component of the acoustic output of the transducer present in the error signal relative to a second magnitude of the ambient audio sounds present in the error signal and compares the ratio to a threshold, wherein the processing circuit further halts adaptation of the secondary path adaptive filter in response to determining that the ratio is less than the threshold.

6. The personal audio device of Claim 1, wherein the processing circuit detects a magnitude of the source audio and uses the magnitude of the source audio to determine the magnitude of the source audio component of the acoustic output of the transducer present in the error signal.

7. The personal audio device of Claim 1, wherein the processing circuit uses a volume control setting applied as gain to the source audio to determine the magnitude of the source audio component of the acoustic output of the transducer present in the error signal.

8. The personal audio device of Claim 1, wherein the processing circuit detects a magnitude of the ambient sounds using the at least one microphone, and wherein the processing circuit uses the magnitude of the ambient audio sounds to determine the magnitude of the ambient audio sounds present in the error signal.

9. The personal audio device of Claim 8, wherein the processing circuit detects the magnitude of the ambient sounds by determining a wideband root-mean-square amplitude of at least one microphone signal generated by the at least one microphone.

10. The personal audio device of Claim 8, wherein the processing circuit detects the magnitude of the ambient sounds by determining a root-mean-square amplitude of at least one microphone signal generated by the at least one microphone in one or more predetermined frequency bands.

11. The personal audio device of Claim 8, wherein the processing circuit detects a magnitude of the source audio and compares the magnitude of the source audio to a magnitude of at least one microphone signal generated by the at least one microphone to determine the relative magnitude of the source audio component of the acoustic output of the transducer present in the error signal and the ambient audio sounds present in the error signal.

12. The personal audio device of Claim 11, wherein the processing circuit adjusts the comparing of the magnitude of the source audio to the magnitude of the at least one microphone signal by adjusting the magnitude of the at least one microphone signal that is compared to the magnitude of the at least one microphone signal in conformity with the determined degree of coupling.

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

adaptively generating an anti-noise signal to reduce the presence of the ambient audio sounds heard by the listener;

combining the anti-noise signal with source audio;

providing a result of the combining to a transducer;

measuring the ambient audio sounds and an acoustic output of the transducer with at least one microphone;

implementing an adaptive filter having a response that shapes the source audio and a combiner that removes the source audio from at least one microphone signal to provide a corrected microphone signal to the at least one microphone;

determining a relative magnitude of a source audio component of the acoustic output of the transducer present in the at least one microphone signal and the ambient audio sounds present in the at least one microphone signal;

determining a degree of coupling between the transducer and an ear of the listener and adjusting the determined relative magnitude of the source audio component of the acoustic output of the transducer present in an error signal and the ambient audio sounds present in the error signal in conformity with the determined degree of coupling; and

taking action to prevent improper adaptation of the adaptive filter in response to determining that the relative magnitude of the source audio component of the acoustic output of the transducer present in the at least one microphone signal to the ambient audio sounds present in the at least one microphone signal indicates that the adaptive filter may not adapt properly.

15. The method of Claim 14, wherein the at least one microphone signal includes an error microphone signal provided by an error microphone mounted on the housing proximate to the transducer, wherein the adaptive filter is a secondary path adaptive filter that adapts to model a response of a secondary path taken by the source audio through the transducer and into the error microphone signal, and wherein the method further comprises combining an output of the secondary path adaptive filter with the error microphone signal to generate an error signal indicative of the source audio component of the acoustic output of the transducer.

16. The method of Claim 15, wherein the at least one microphone signal further includes a reference microphone signal provided by a reference microphone mounted on the housing for measuring the ambient audio sounds, and wherein the method further comprising:

generating a leakage correction signal using a leakage path adaptive filter that adapts to model a response of a leakage path taken by the source audio through the transducer and into the reference microphone signal; and

combining the leakage correction signal with the reference microphone signal to generate a reference signal from which the anti-noise signal is generated.

17. The method of Claim 14, wherein the at least one microphone signal includes a reference microphone signal provided by a reference microphone mounted on the housing for measuring the ambient audio sounds, and wherein the method further comprising:

generating a leakage correction signal using a leakage path adaptive filter that adapts to model a response of a leakage path taken by the source audio through the transducer and into the reference microphone signal; and

combining the leakage correction signal with the reference microphone signal to generate a reference signal from which the anti-noise signal is generated.

18. The method of Claim 15, wherein the determining comprises computing a ratio of a first magnitude of the source audio component of the acoustic output of the transducer present in the error signal relative to a second magnitude of the ambient audio sounds present in the error signal and comparing the ratio to a threshold, and wherein the taking action comprises halting adaptation of the secondary path adaptive filter in response to determining that the ratio is less than the threshold.

19. The method of Claim 14, further comprising detecting a magnitude of the source audio, wherein the determining uses the detected magnitude of the source audio to determine the magnitude of the source audio component of acoustic output of the transducer present in the error signal.

20. The method of Claim 14, wherein the determining uses a volume control setting applied as gain to the source audio to determine the magnitude of the source audio component of the acoustic output of the transducer present in the error signal.

21. The method of Claim 14, further comprising detecting a magnitude of the ambient sounds using the at least one microphone, and wherein the determining uses the magnitude of the ambient audio sounds to determine the magnitude of the ambient audio sounds present in the error signal.

22. The method of Claim 21, wherein the detecting detects the magnitude of the ambient sounds by determining a wideband root-mean-square amplitude of at least one microphone signal generated by the at least one microphone.

23. The method of Claim 21, wherein the detecting detects the magnitude of the ambient sounds by determining a root-mean-square amplitude of at least one microphone signal generated by the at least one microphone in one or more predetermined frequency bands.

24. The method of Claim 21, wherein the detecting detects a magnitude of the source audio and compares the magnitude of the source audio to a magnitude of at least one microphone signal generated by the at least one microphone to determine the relative magnitude of the source audio component of the acoustic output of the transducer present in the error signal and the ambient audio sounds present in the error signal.

25. The method of Claim 24, further comprising adjusting the comparing of the magnitude of the source audio to a magnitude of the at least one microphone signal by adjusting the magnitude of the at least one microphone signal that is compared to the magnitude of the at least one microphone signal in conformity with the determined degree of coupling.

27. 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;

at least one microphone input for receiving at least one microphone signal indicative of the ambient audio sounds and that contains a component due to the acoustic output of the transducer; and

a processing circuit that adaptively generates the anti-noise signal to reduce the presence of the ambient audio sounds heard by the listener, wherein the processing circuit implements an adaptive filter having a response that shapes the source audio and a combiner that removes the source audio from the at least one microphone signal to provide a corrected microphone signal, wherein the processing circuit determines a relative magnitude of a source audio component of the acoustic output of the transducer present in the at least one microphone signal and the ambient audio sounds present in the at least one microphone signal, wherein the processing circuit determines a degree of coupling between the transducer and an ear of the listener and adjusts the determined relative magnitude of the source audio component of the acoustic output of the transducer present in the error signal and the ambient audio sounds present in the error signal in conformity with the determined degree of coupling,_and wherein the processing circuit takes action to prevent improper adaptation of the adaptive filter in response to determining that the relative magnitude of the source audio component of the acoustic output of the transducer present in the at least one microphone signal to the ambient audio sounds present in the at least one microphone signal indicates that the adaptive filter may not adapt properly.

28. The integrated circuit of Claim 27, wherein the at least one microphone signal includes an error microphone signal indicative of the ambient audio sounds and the acoustic output of the transducer, wherein the adaptive filter is a secondary path adaptive filter that adapts to model a response of a secondary path taken by the source audio through the transducer and into the error microphone signal, and wherein an output of the secondary path adaptive filter is combined with the error microphone signal to generate an error signal indicative of the source audio component of the acoustic output of the transducer.

29. The integrated circuit of Claim 28, wherein the at least one microphone signal includes a reference microphone signal indicative of the ambient audio sounds, and further comprising a leakage path adaptive filter that adapts to model a response of a leakage path taken by the source audio through the transducer and into the reference microphone signal, and wherein an output of the leakage path adaptive filter is combined with the reference microphone signal to generate a leakage-corrected reference microphone signal from which the anti-noise signal is generated.

30. The integrated circuit of Claim 27, wherein the at least one microphone signal includes a reference microphone signal indicative of the ambient audio sounds, wherein the adaptive filter is a leakage path adaptive filter that adapts to model a response of a leakage path taken by the source audio through the transducer and into the reference microphone signal, and wherein an output of the leakage path adaptive filter is combined with the reference microphone signal to generate a reference signal from which the anti-noise signal is generated.

31. The integrated circuit of Claim 28, wherein the processing circuit computes a ratio of a first magnitude of the source audio component of the acoustic output of the transducer present in the error signal relative to a second magnitude of the ambient audio sounds present in the error signal and compares the ratio to a threshold, wherein the processing circuit further halts adaptation of the secondary path adaptive filter in response to determining that the ratio is less than the threshold.

32. The integrated circuit of Claim 27, wherein the processing circuit detects a magnitude of the source audio and uses the magnitude of the source audio to determine the magnitude of the source audio component of the acoustic output of the transducer present in the error signal.

33. The integrated circuit of Claim 27, wherein the processing circuit uses a volume control setting applied as gain to the source audio to determine the magnitude of the source audio component of the acoustic output of the transducer present in the error signal.

34. The integrated circuit of Claim 27, wherein the processing circuit detects a magnitude of the ambient sounds using the at least one microphone, and wherein the processing circuit uses the magnitude of the ambient audio sounds to determine the magnitude of the ambient audio sounds present in the error signal.

35. The integrated circuit of Claim 34, wherein the processing circuit detects the magnitude of the ambient sounds by determining a wideband root-mean-square amplitude of the at least one microphone signal.

36. The integrated circuit of Claim 34, wherein the processing circuit detects the magnitude of the ambient sounds by determining a root-mean-square amplitude of the at least one microphone signal in one or more predetermined frequency bands.

37. The integrated circuit of Claim 34, wherein the processing circuit detects a magnitude of the source audio and compares the magnitude of the source audio to a magnitude of the at least one microphone signal to determine the relative magnitude of the source audio component of the acoustic output of the transducer present in the error signal and the ambient audio sounds present in the error signal.

38. The integrated circuit of Claim 37, wherein the processing circuit adjusts the comparing of the magnitude of the source audio to the magnitude of the at least one microphone signal by adjusting the magnitude of the at least one microphone signal that is compared to the magnitude of the at least one microphone signal in conformity with the determined degree of coupling.