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Felder et al.

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(54) **HEADPHONE DRIVER AND METHODS FOR USE THEREWITH**

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(51) **Int. Cl.**
H04R 1/10 (2006.01)

(52) **U.S. Cl.** **381/74**

(58) **Field of Classification Search** 381/74, 381/309, 1, 27, 55
See application file for complete search history.

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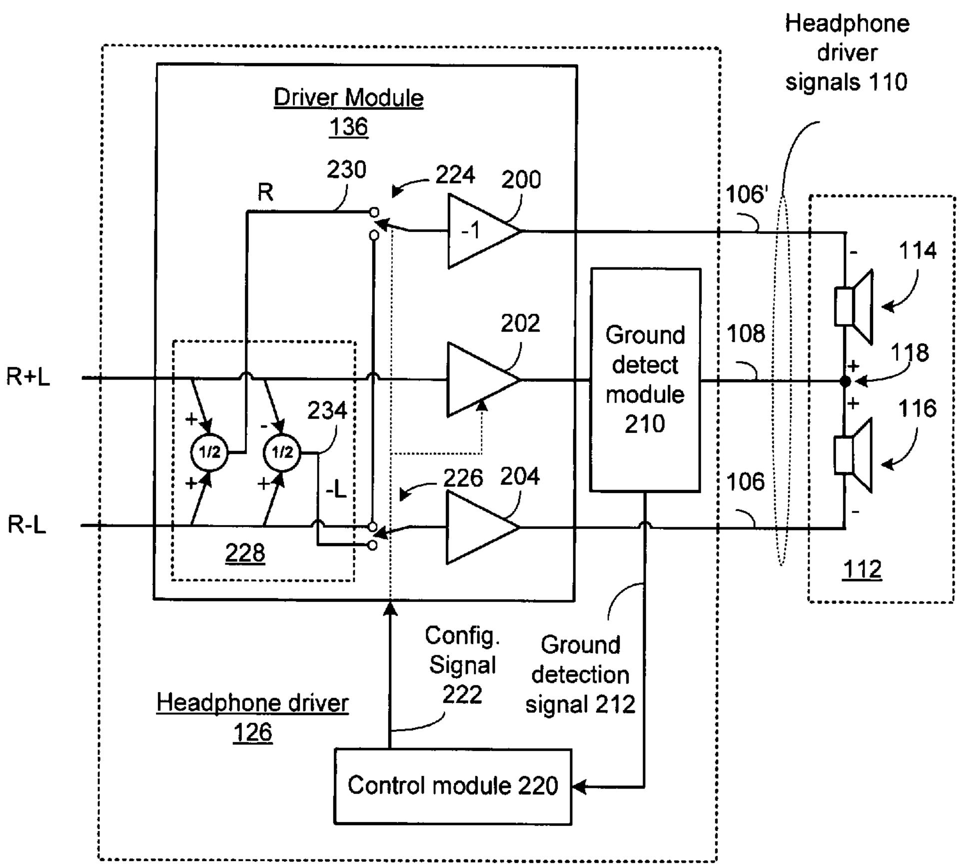
(57) **ABSTRACT**

A headphone driver includes a driver module for generating a plurality of headphone driver signals including a filtered stereo sum signal.

10 Claims, 19 Drawing Sheets



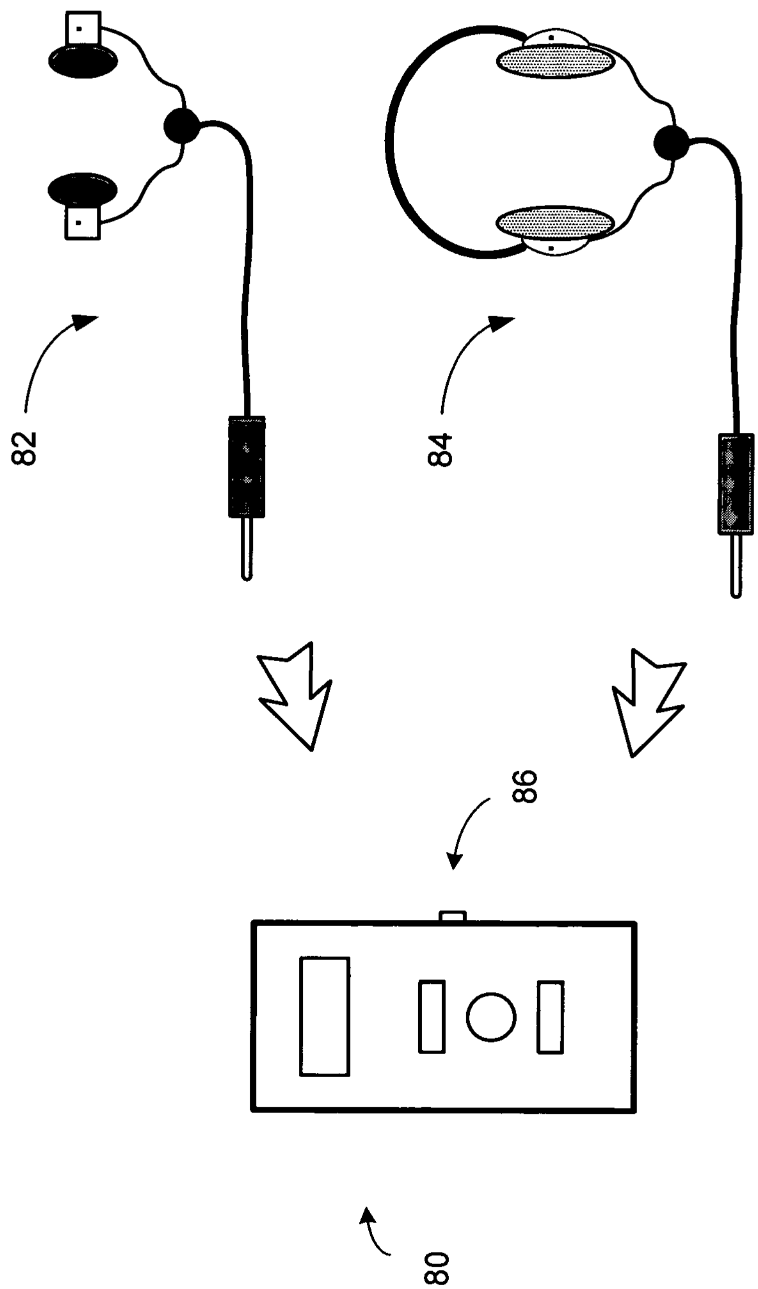


FIG. 1

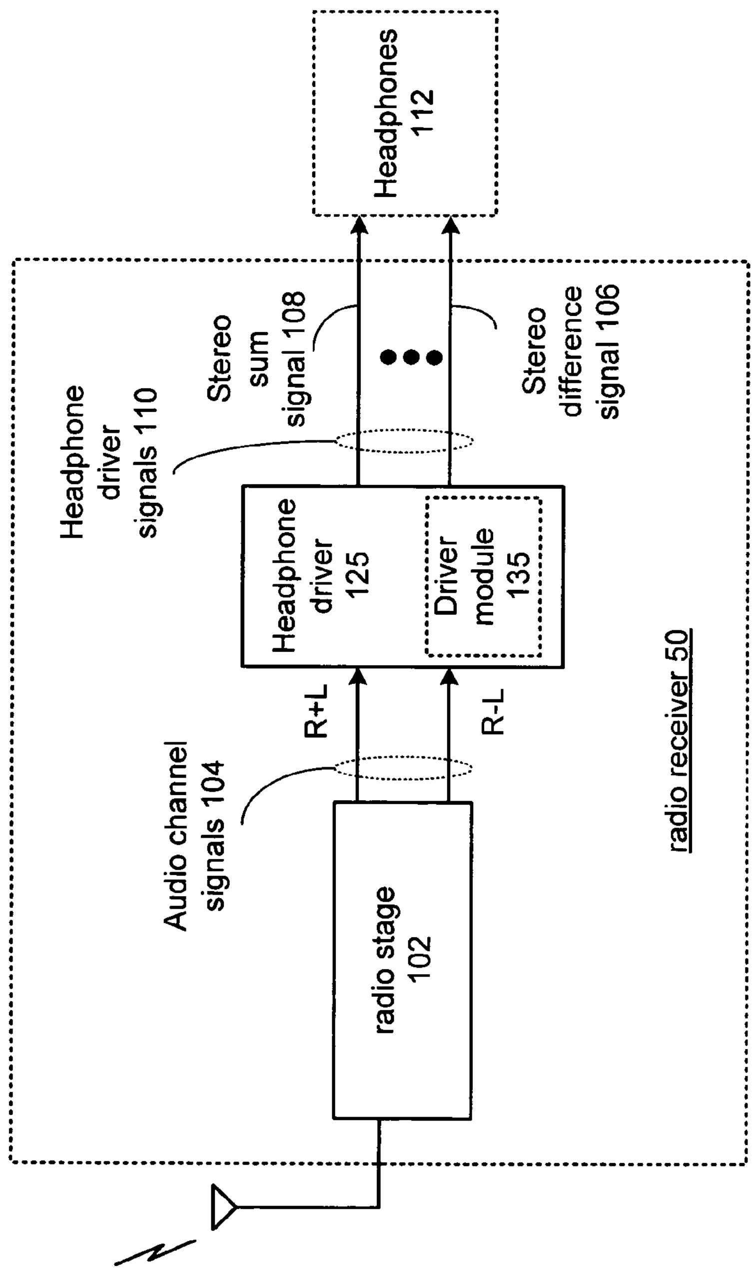

Headphones 112
Headphone driver signals 110
Stereo sum signal 108
Stereo difference signal 106
Headphone driver 125
Driver module 135
R+L
R-L
Audio channel signals 104
radio stage 102
radio receiver 50

FIG. 2

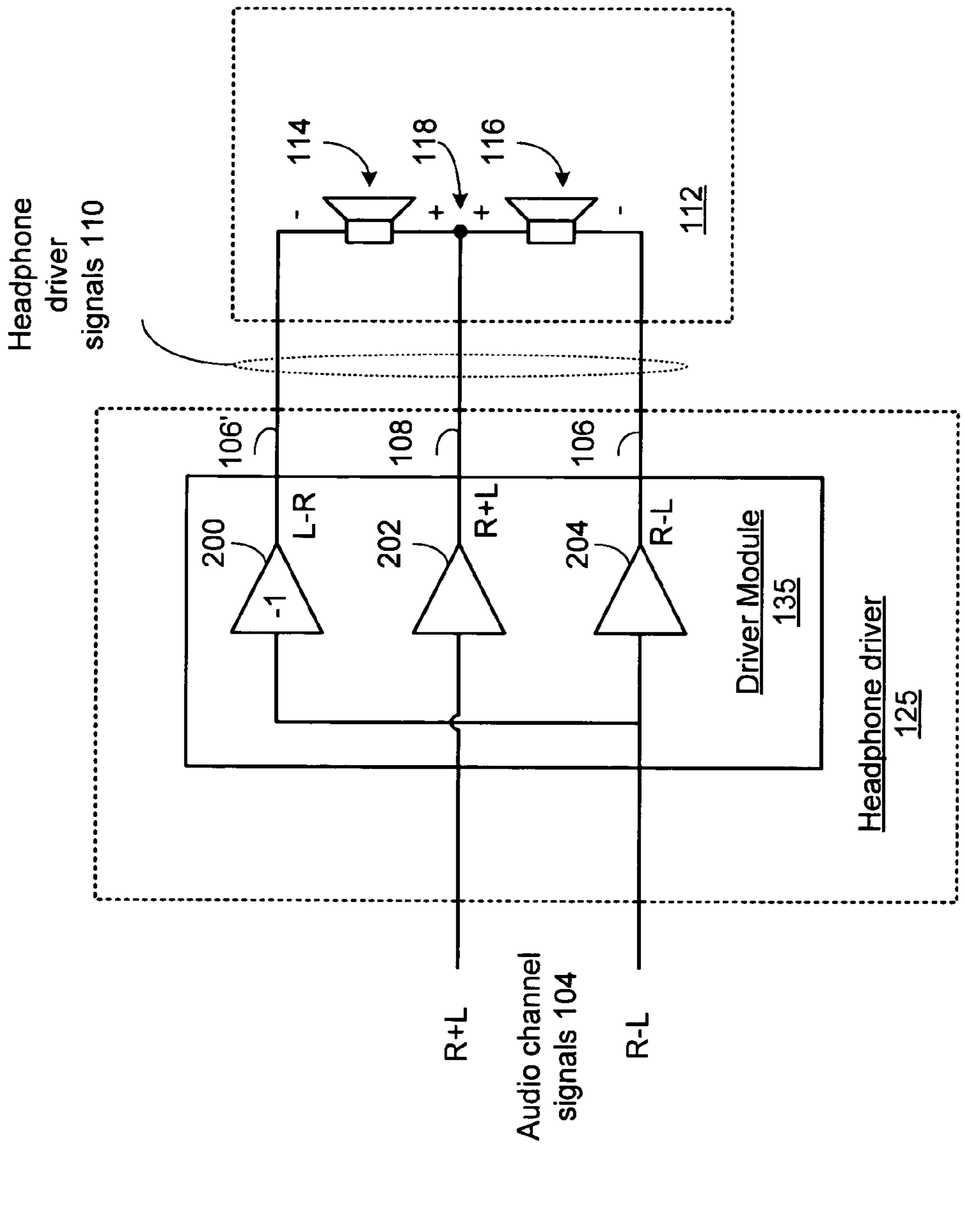

Headphone driver signals 110
114
118
116
112
106'
108
106
L-R
R+L
R-L
200
202
204
-1
Driver Module
135
Headphone driver
125
R+L
Audio channel signals 104
R-L

FIG. 3

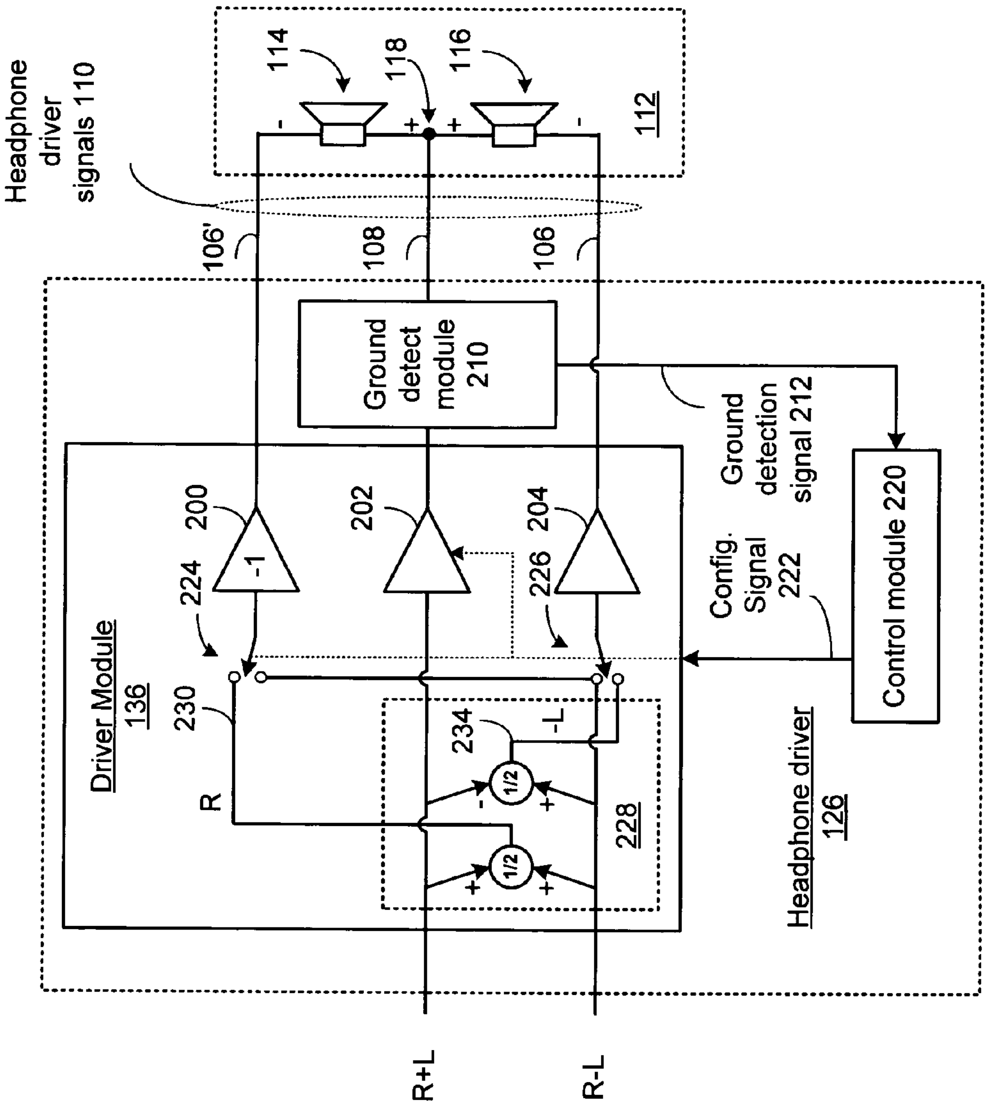

Headphone driver signals 110
114
118
116
112
106'
108
106
Ground detect module 210
Ground detection signal 212
Driver Module 136
200
-1
202
204
224
226
Config. Signal 222
Control module 220
230
R
234
-L
1/2
1/2
228
Headphone driver 126
R+L
R-L

FIG. 4

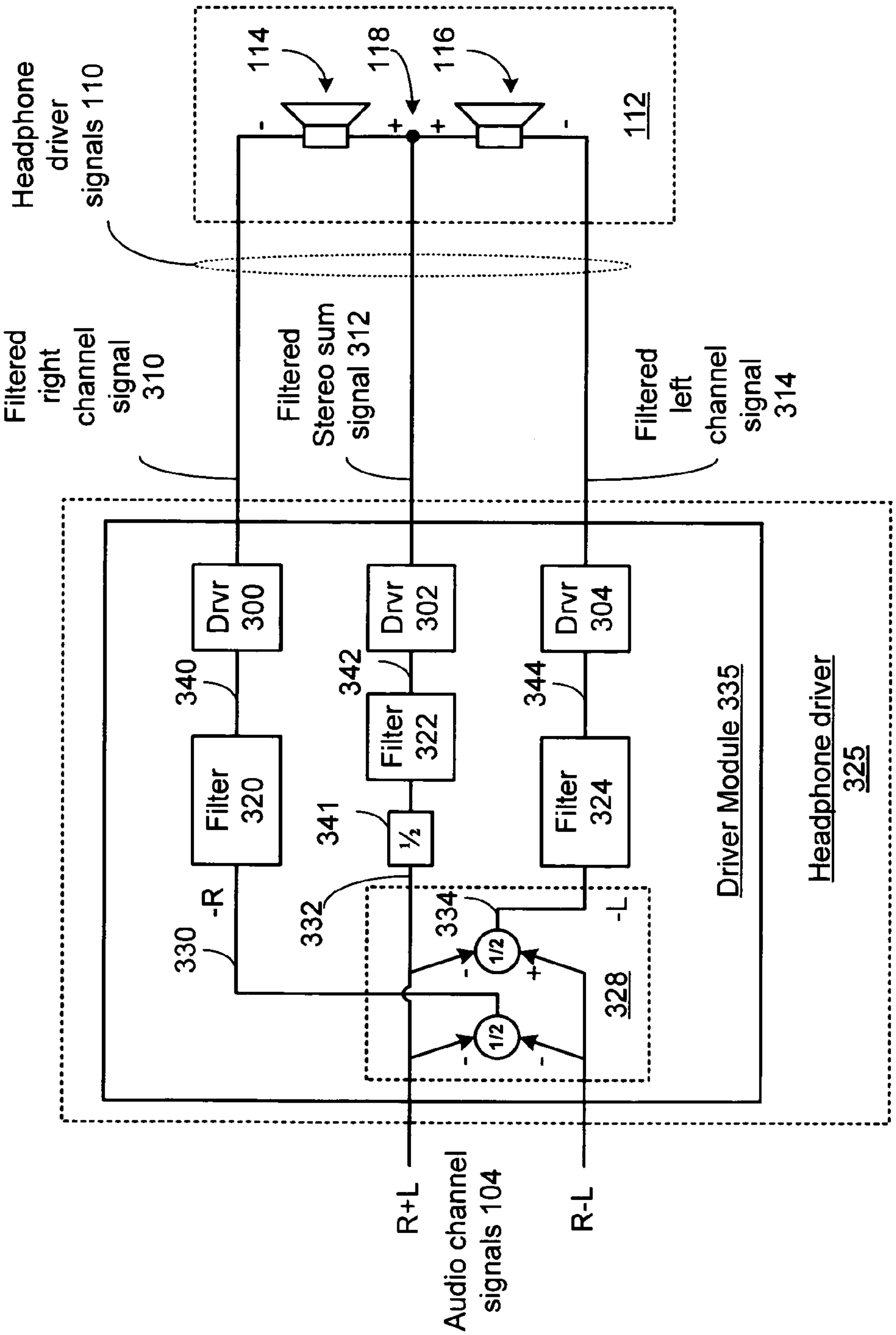
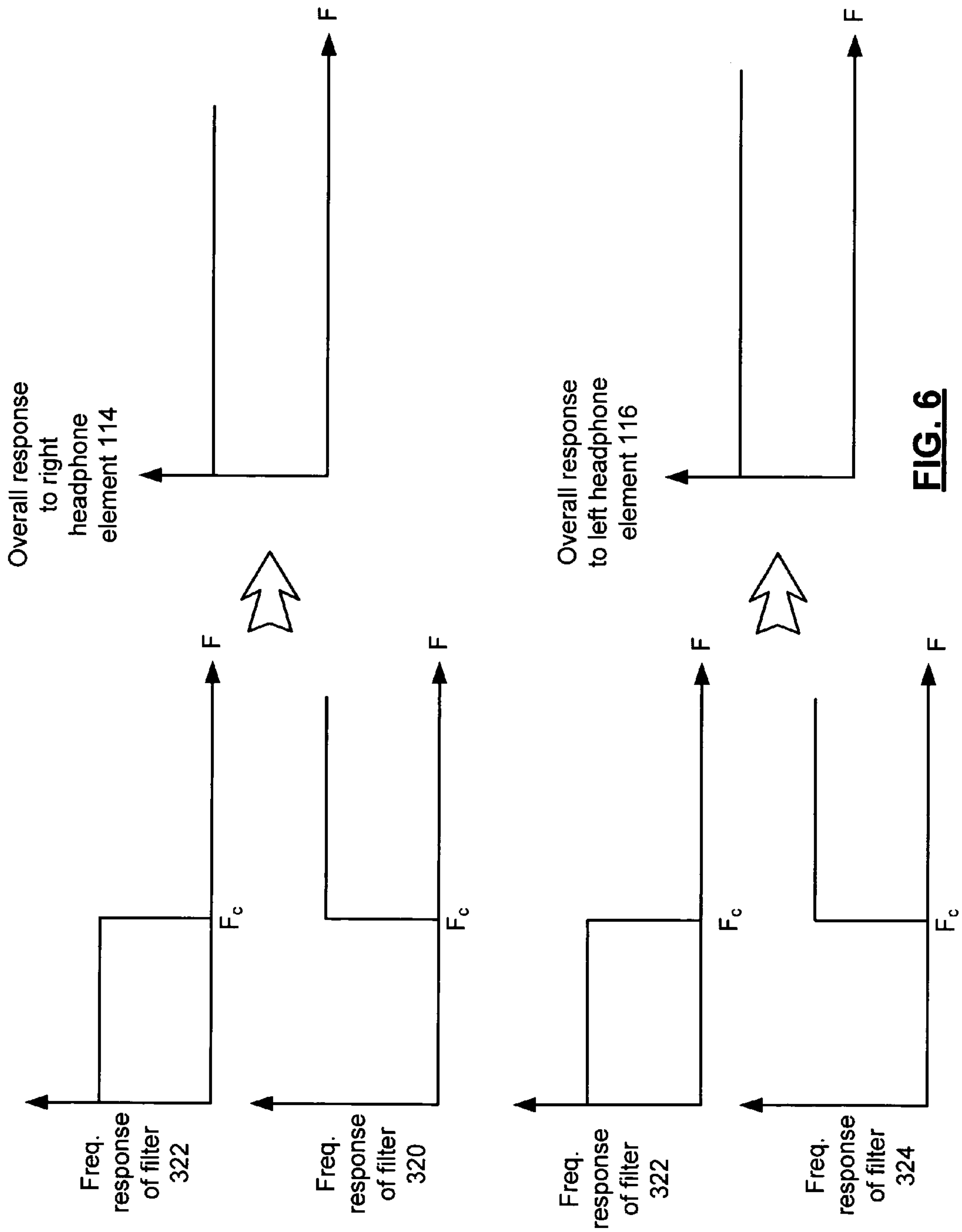

Headphone driver signals 110
114
118
116
112
Filtered right channel signal 310
Filtered Stereo sum signal 312
Filtered left channel signal 314
Drvr 300
Drvr 302
Drvr 304
340
342
344
Filter 320
Filter 322
Filter 324
341
½
-R
330
332
334
1/2
1/2
328
-L
Driver Module 335
Headphone driver 325
R+L
R-L
Audio channel signals 104

FIG. 5



Freq. response of filter 322
F
Fc
Freq. response of filter 320
F
Fc
Overall response to right headphone element 114
F
Freq. response of filter 322
F
Fc
Freq. response of filter 324
F
Fc
Overall response to left headphone element 116
F

FIG. 6

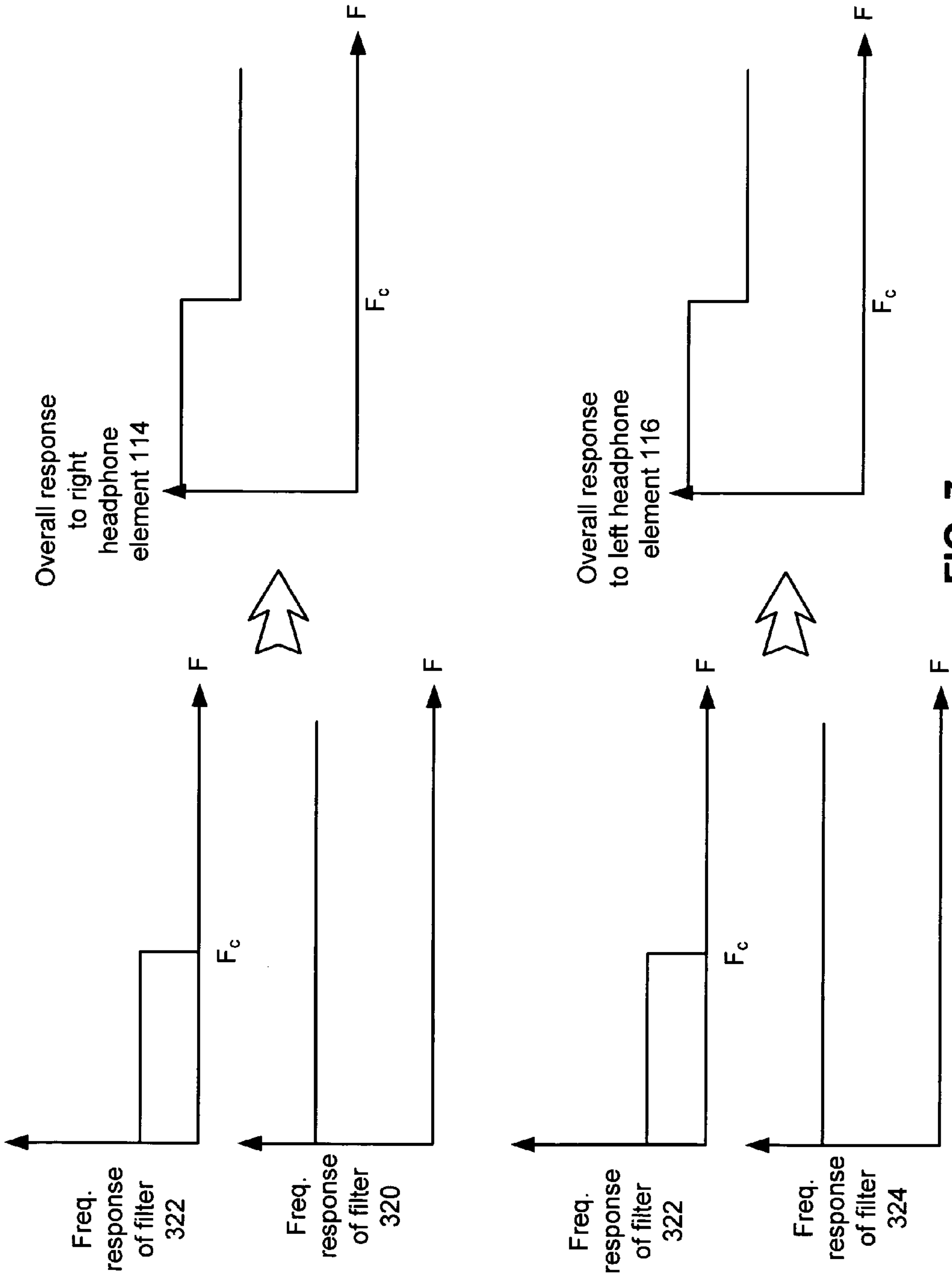

Freq. response of filter 322
F
F_c
Freq. response of filter 320
F
Overall response to right headphone element 114
F_c
F
Freq. response of filter 322
F
F_c
Freq. response of filter 324
F
Overall response to left headphone element 116
F_c
F

FIG. 7

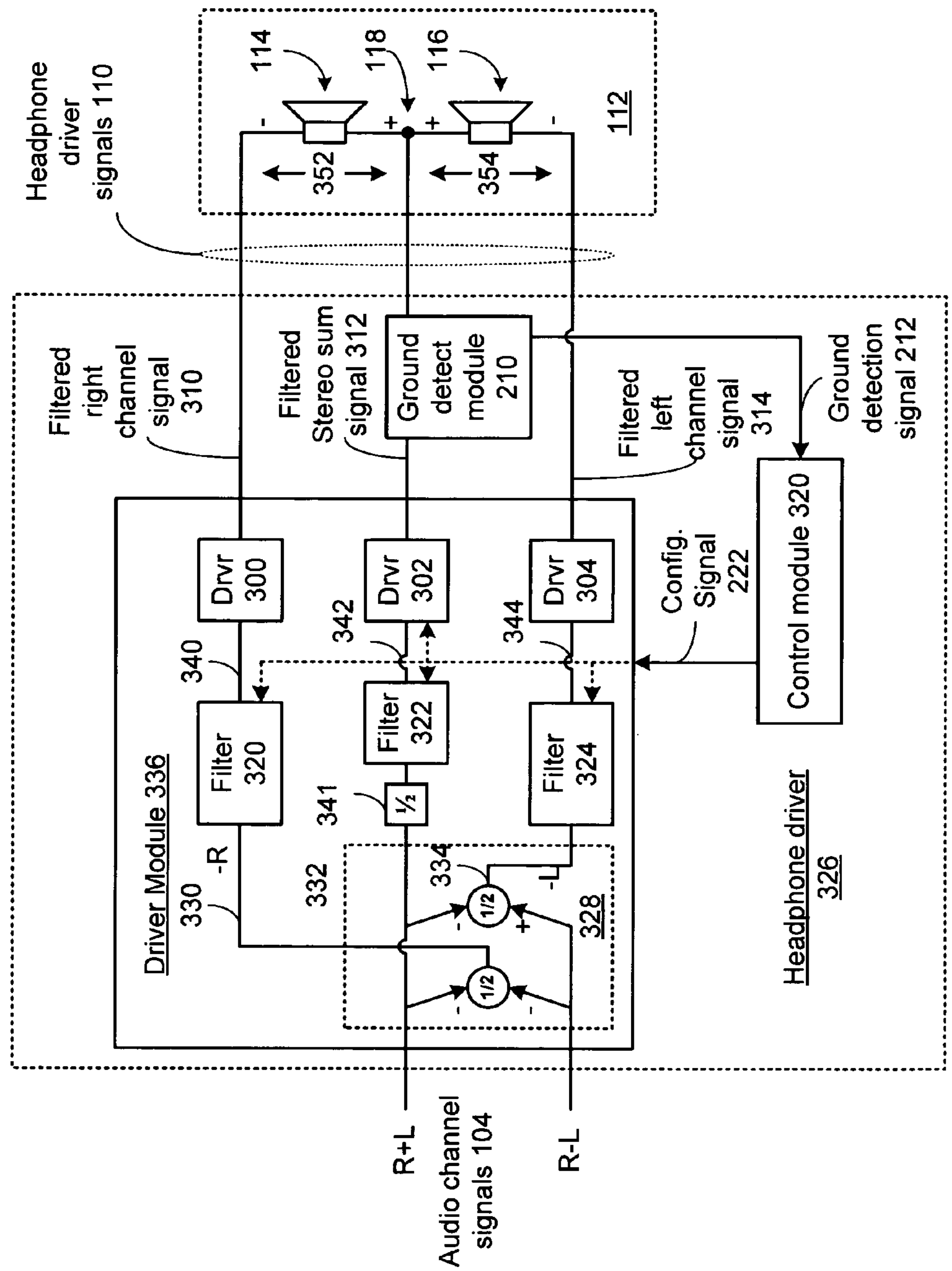

Headphone driver signals 110
114
118
116
112
352
354
Filtered right channel signal 310
Filtered Stereo sum signal 312
Ground detect module 210
Filtered left channel signal 314
Ground detection signal 212
Control module 320
Config. Signal 222
Drvr 300
Drvr 302
Drvr 304
340
342
344
Filter 320
Filter 322
Filter 324
½
341
Driver Module 336
330
-R
332
334
-L
1/2
328
Headphone driver 326
R+L
R-L
Audio channel signals 104

FIG. 8

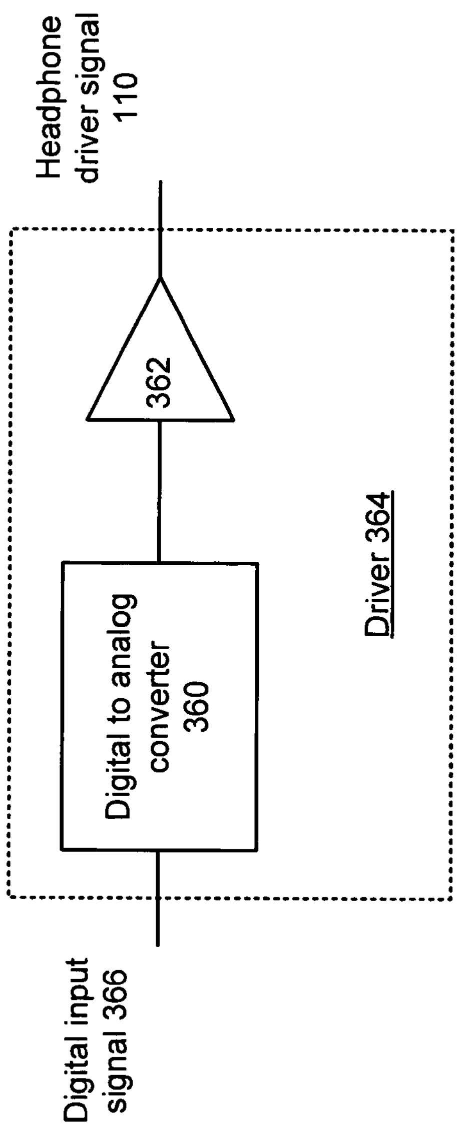

Headphone driver signal 110
362
Digital to analog converter 360
Driver 364
Digital input signal 366

FIG. 9

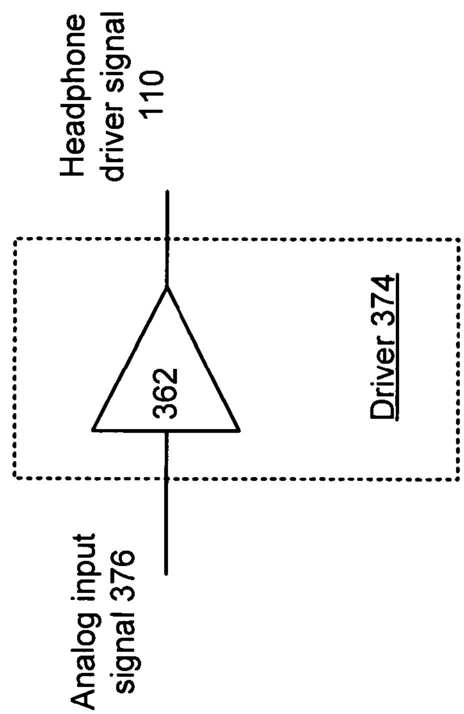

Headphone driver signal 110
362
Driver 374
Analog input signal 376

FIG. 10

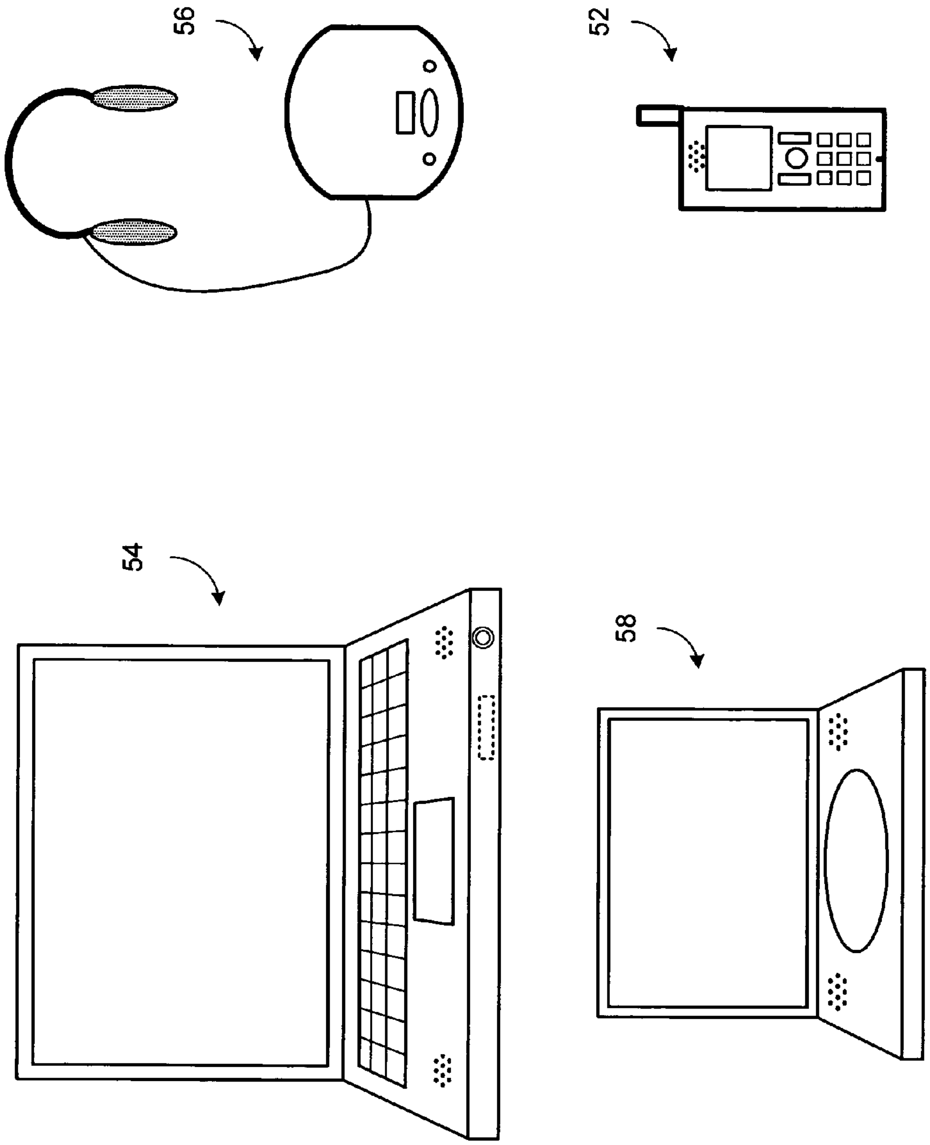


FIG. 11

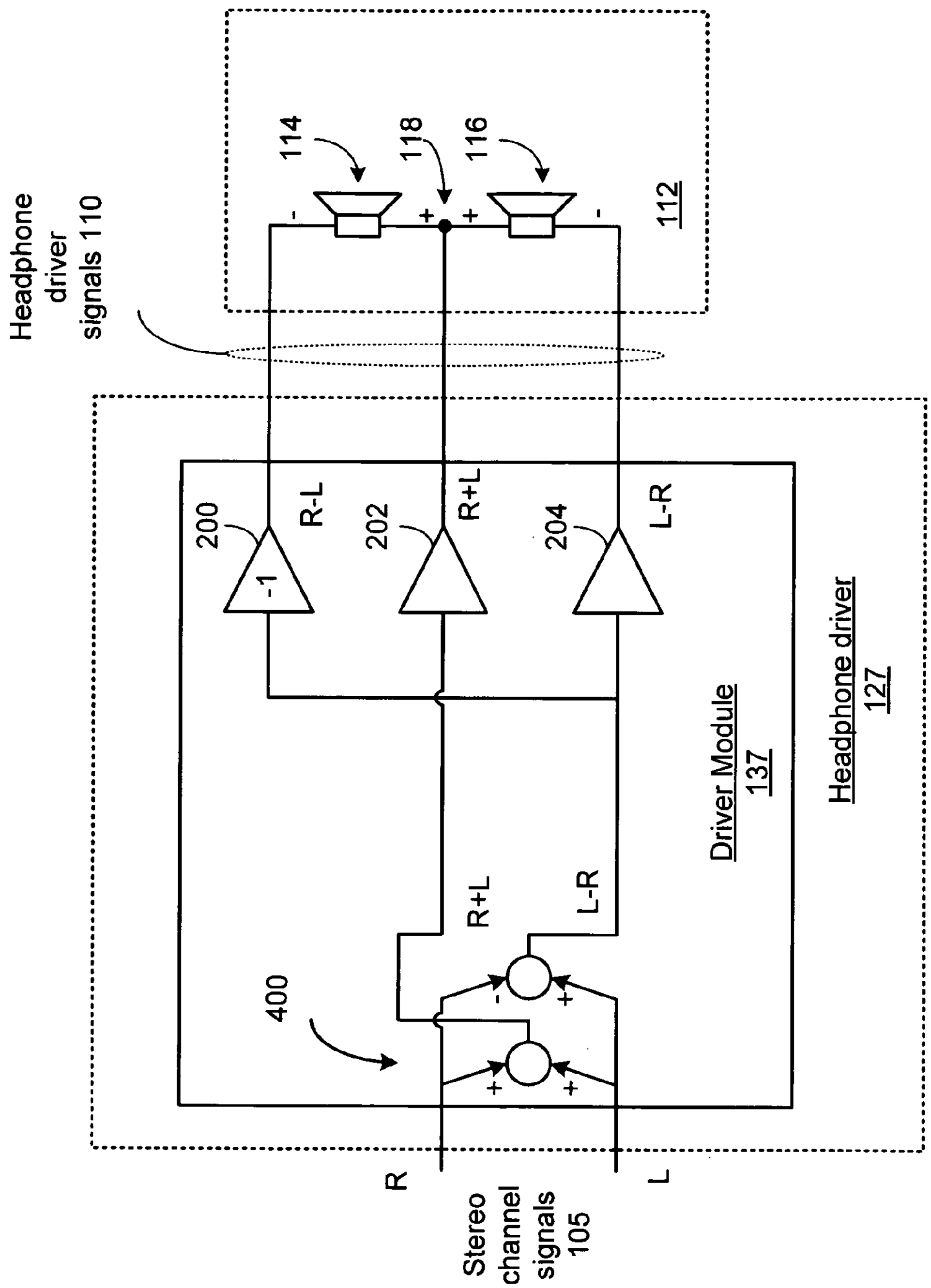

Headphone driver signals 110
114
118
116
112
200
202
204
-1
R-L
R+L
L-R
400
R+L
L-R
Driver Module 137
Headphone driver 127
R
L
Stereo channel signals 105

FIG. 12

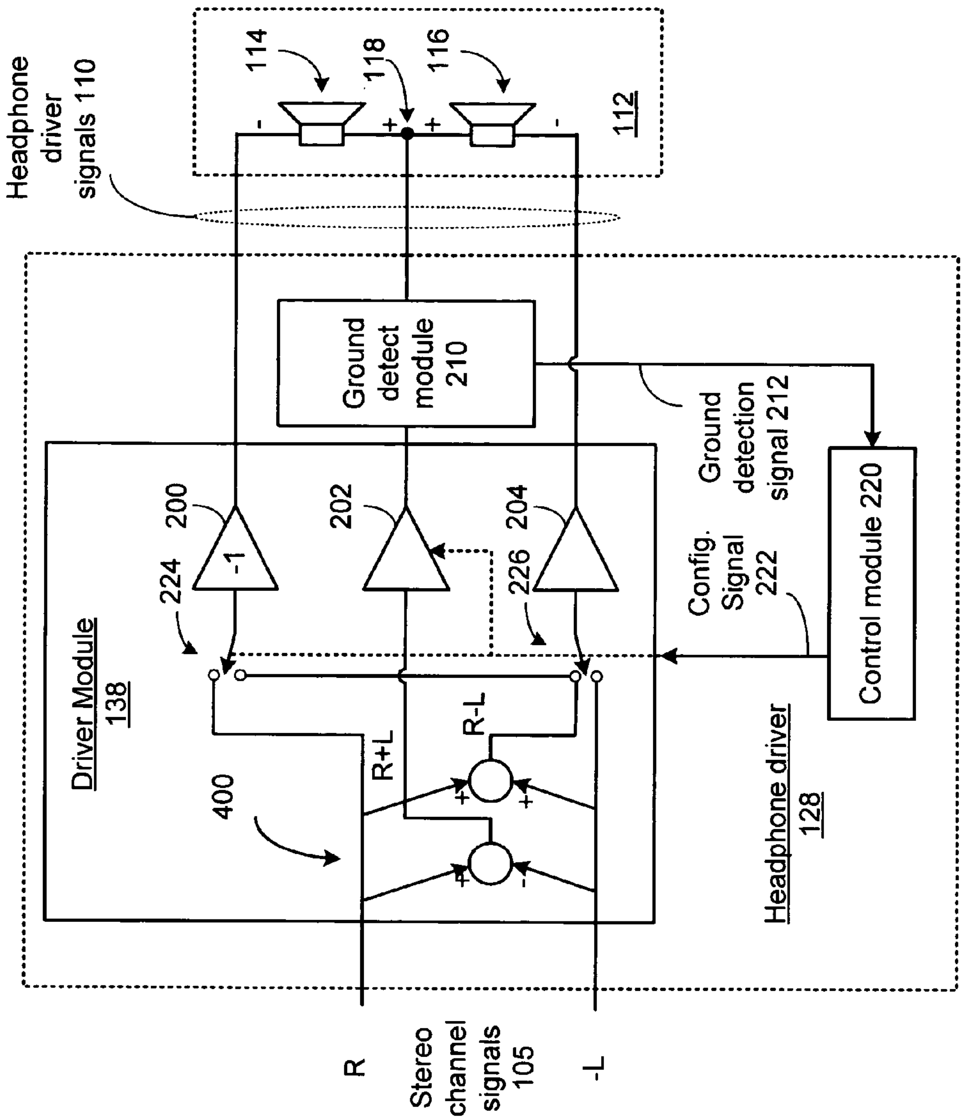

Headphone driver signals 110
114
118
116
112
Ground detect module 210
Ground detection signal 212
200
202
204
-1
224
226
Config. Signal 222
Control module 220
Driver Module 138
R+L
R-L
400
Headphone driver 128
R
Stereo channel signals 105
-L

FIG. 13

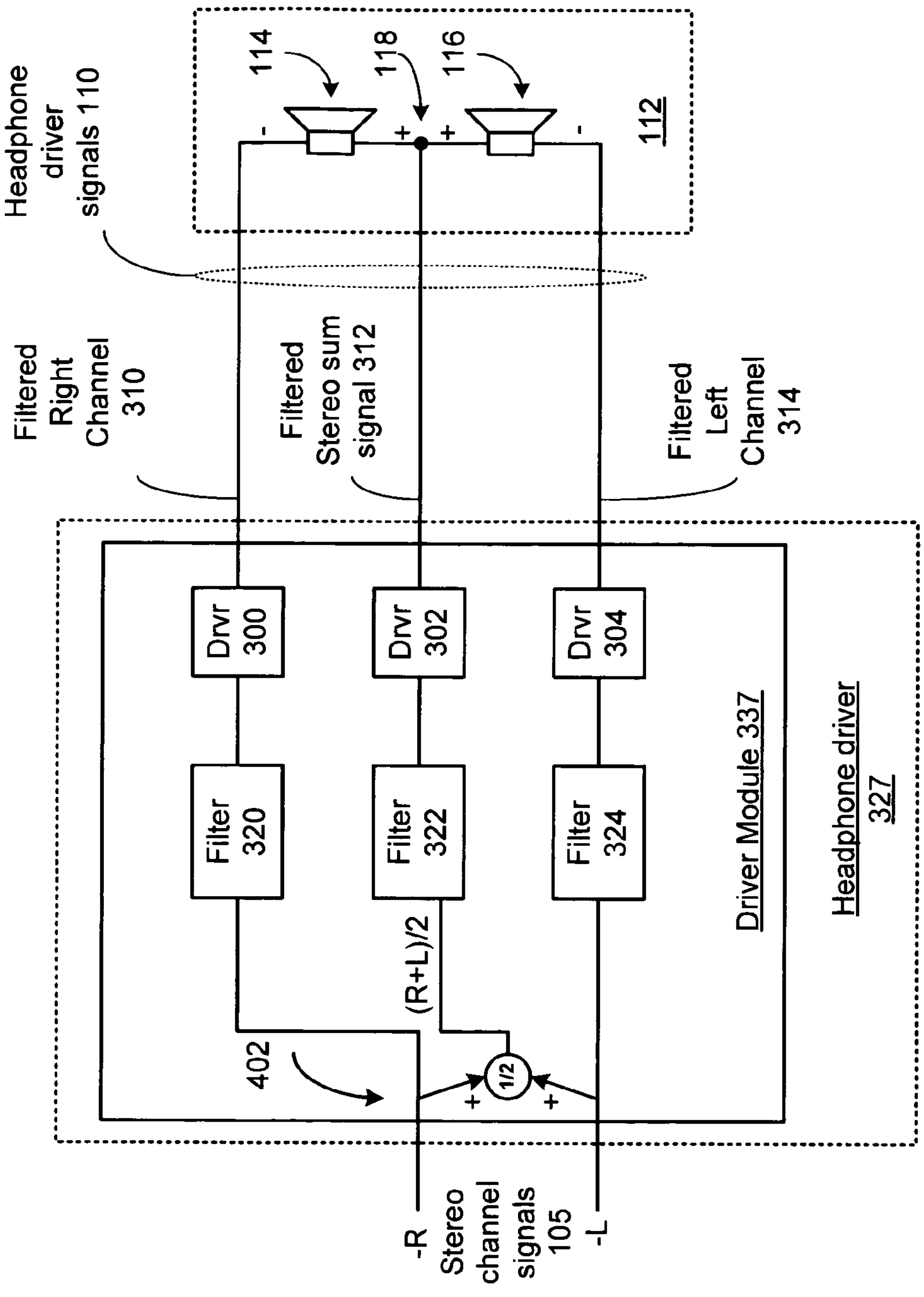

Headphone driver signals 110
114
118
116
112
Filtered Right Channel 310
Filtered Stereo sum signal 312
Filtered Left Channel 314
Drvr 300
Drvr 302
Drvr 304
Filter 320
Filter 322
Filter 324
(R+L)/2
402
1/2
Driver Module 337
Headphone driver 327
-R
Stereo channel signals 105
-L

FIG. 14

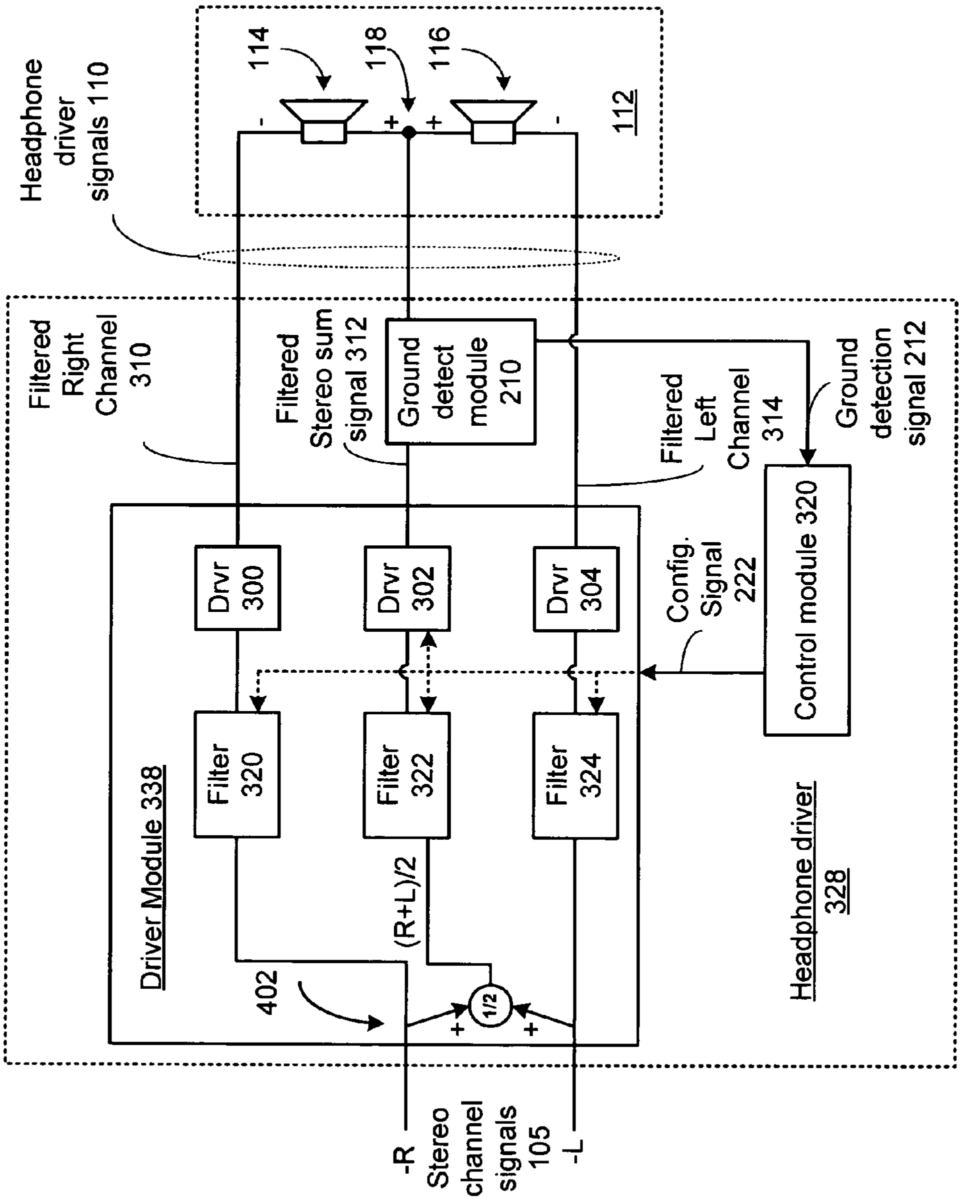

Headphone driver signals 110
114
118
116
112
Filtered Right Channel 310
Filtered Stereo sum signal 312
Ground detect module 210
Filtered Left Channel 314
Ground detection signal 212
Control module 320
Config. Signal 222
Drvr 300
Drvr 302
Drvr 304
Filter 320
Filter 322
Filter 324
(R+L)/2
1/2
402
Driver Module 338
Headphone driver 328
-R
Stereo channel signals 105
-L

FIG. 15

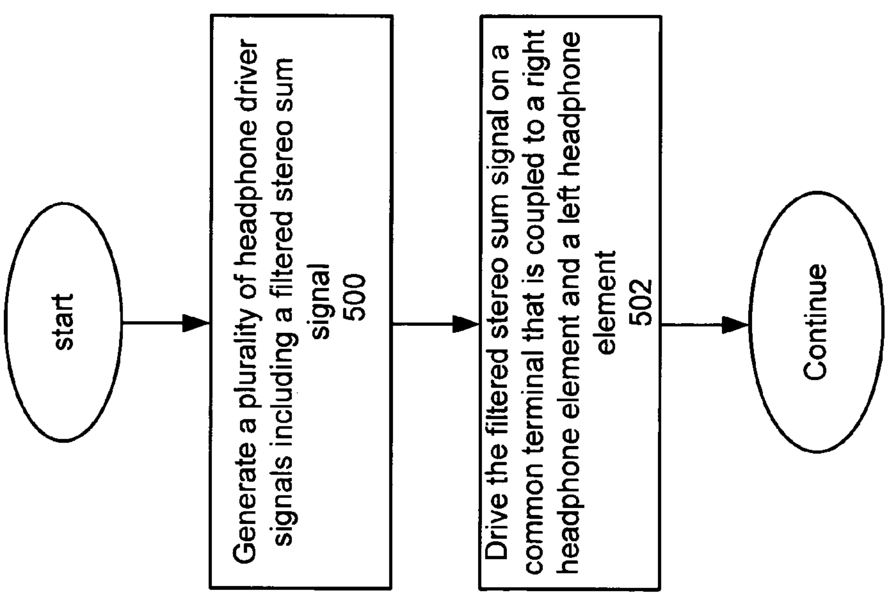

start
Generate a plurality of headphone driver signals including a filtered stereo sum signal
500
Drive the filtered stereo sum signal on a common terminal that is coupled to a right headphone element and a left headphone element
502
Continue

FIG. 16

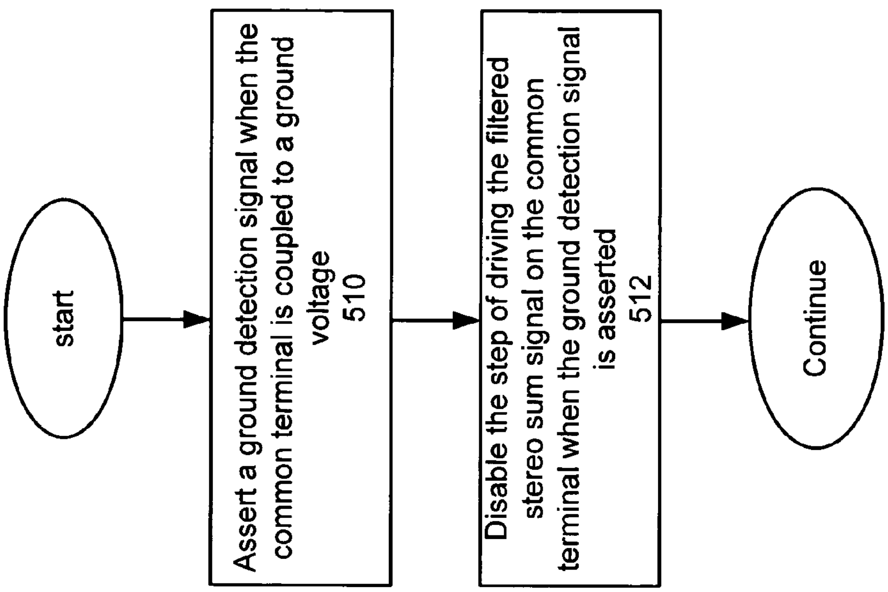

start
Assert a ground detection signal when the common terminal is coupled to a ground voltage
510
Disable the step of driving the filtered stereo sum signal on the common terminal when the ground detection signal is asserted
512
Continue

FIG. 17

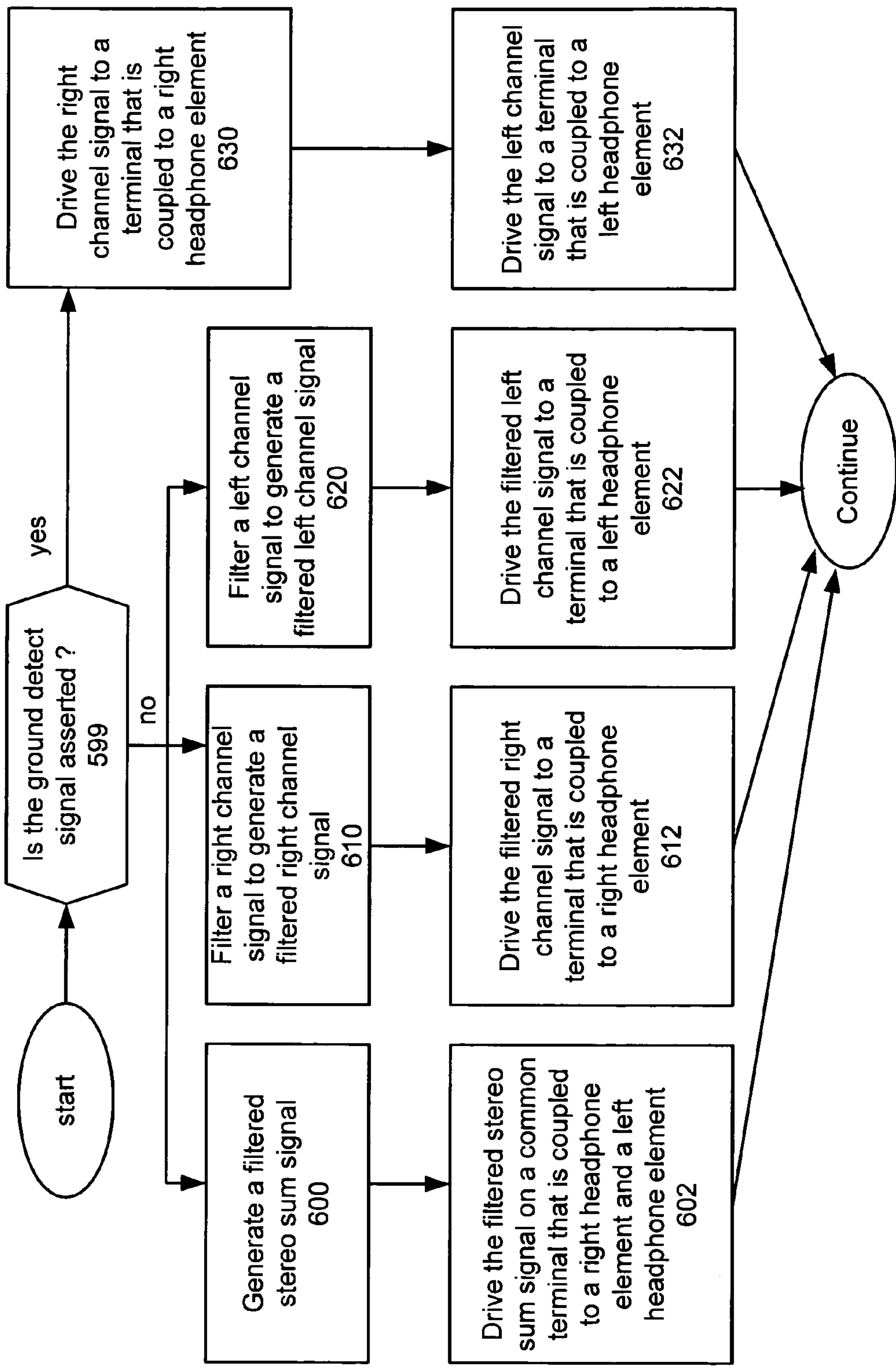

start
Is the ground detect signal asserted ? 599
yes
no
Drive the right channel signal to a terminal that is coupled to a right headphone element 630
Drive the left channel signal to a terminal that is coupled to a left headphone element 632
Filter a left channel signal to generate a filtered left channel signal 620
Drive the filtered left channel signal to a terminal that is coupled to a left headphone element 622
Filter a right channel signal to generate a filtered right channel signal 610
Drive the filtered right channel signal to a terminal that is coupled to a right headphone element 612
Generate a filtered stereo sum signal 600
Drive the filtered stereo sum signal on a common terminal that is coupled to a right headphone element and a left headphone element 602
Continue

FIG. 18

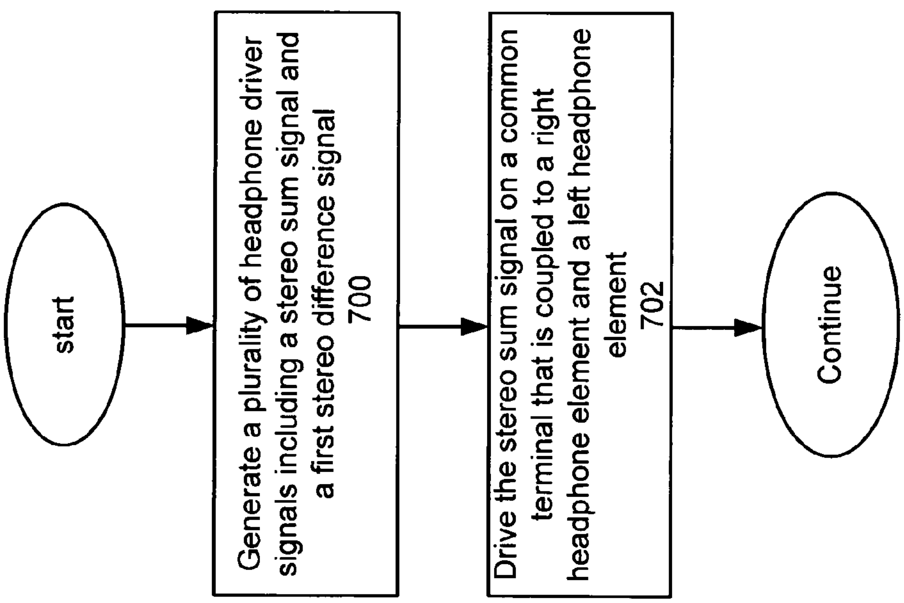

start
Generate a plurality of headphone driver signals including a stereo sum signal and a first stereo difference signal
700
Drive the stereo sum signal on a common terminal that is coupled to a right headphone element and a left headphone element
702
Continue

FIG. 19

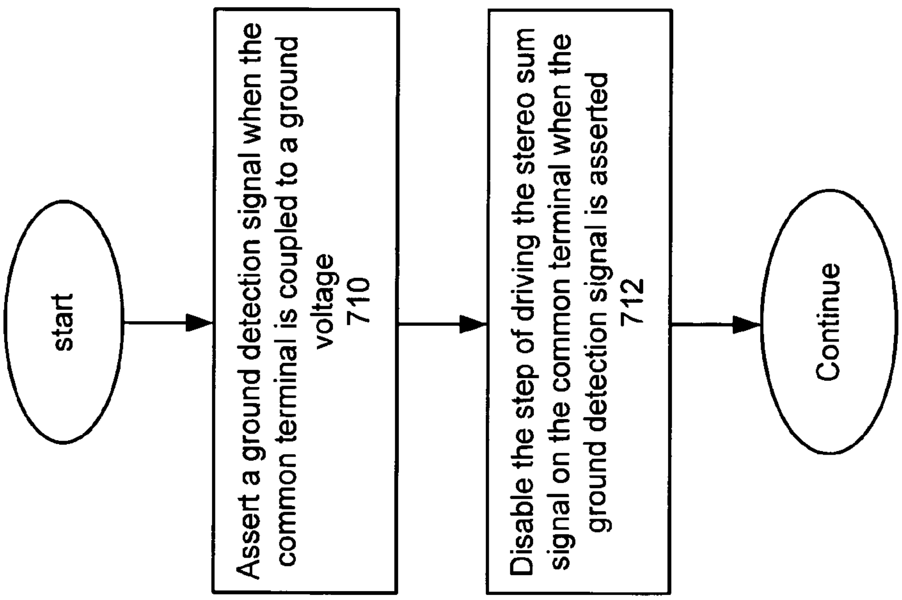

start
Assert a ground detection signal when the common terminal is coupled to a ground voltage
710
Disable the step of driving the stereo sum signal on the common terminal when the ground detection signal is asserted
712
Continue

FIG. 20

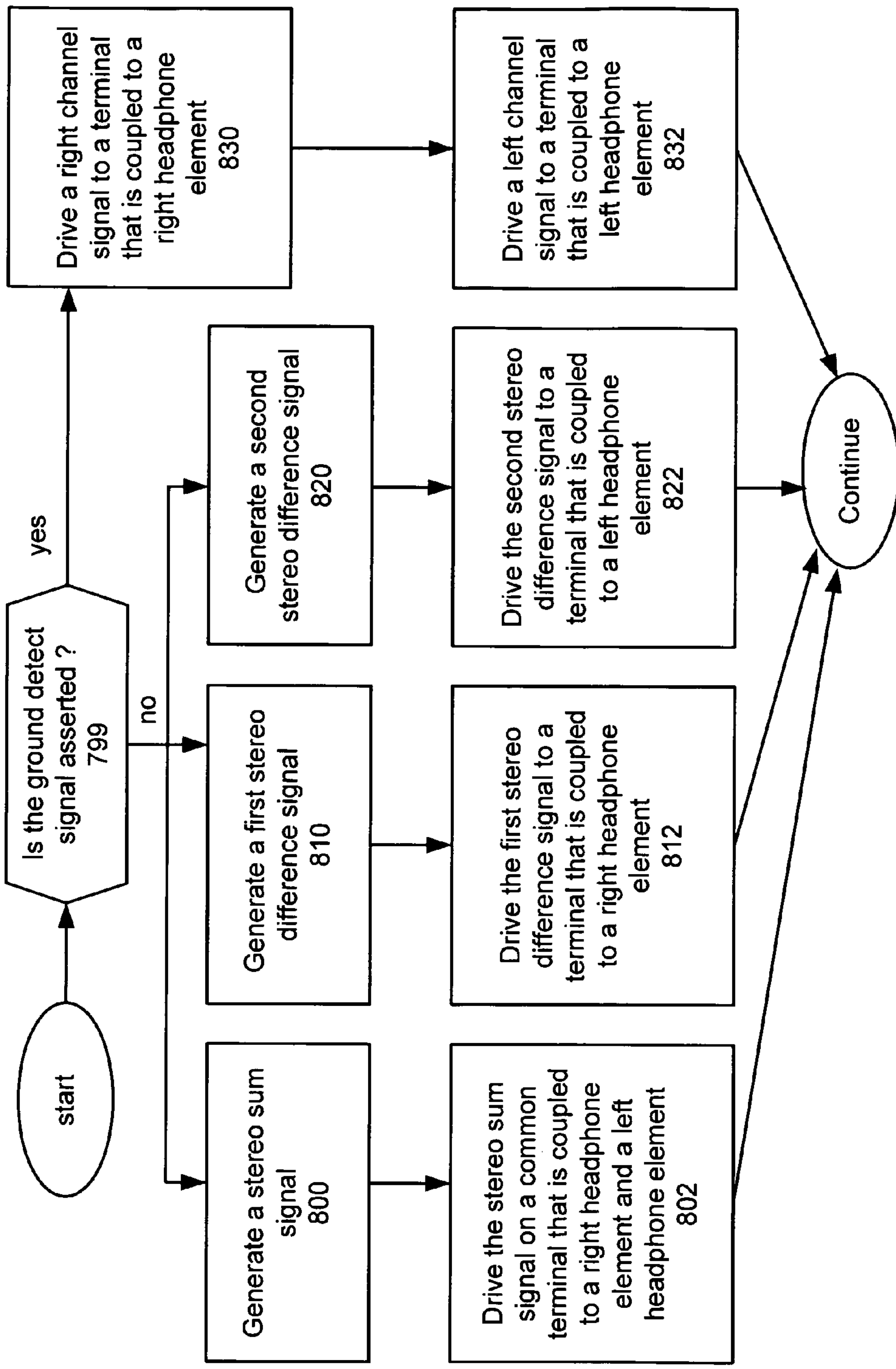

start
Is the ground detect signal asserted ? 799
yes
no
Drive a right channel signal to a terminal that is coupled to a right headphone element 830
Drive a left channel signal to a terminal that is coupled to a left headphone element 832
Generate a stereo sum signal 800
Drive the stereo sum signal on a common terminal that is coupled to a right headphone element and a left headphone element 802
Generate a first stereo difference signal 810
Drive the first stereo difference signal to a terminal that is coupled to a right headphone element 812
Generate a second stereo difference signal 820
Drive the second stereo difference signal to a terminal that is coupled to a left headphone element 822
Continue

FIG. 21

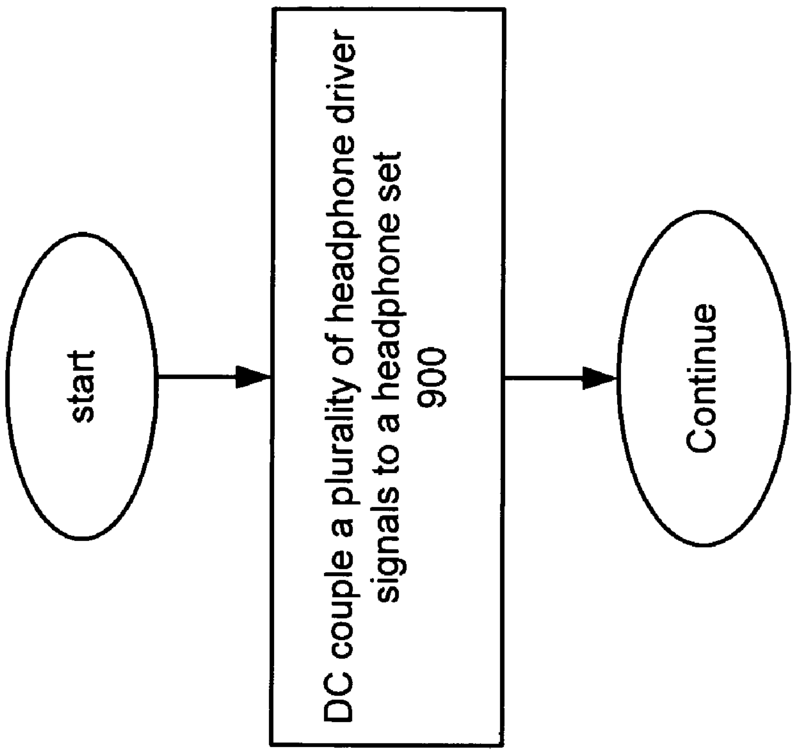

start
DC couple a plurality of headphone driver signals to a headphone set
900
Continue

FIG. 22

HEADPHONE DRIVER AND METHODS FOR USE THEREWITH

TECHNICAL FIELD OF THE INVENTION

The present invention relates to headphone drivers as may be used in radio receivers and other electronic devices that produce an audio output, and related methods.

DESCRIPTION OF RELATED ART

As is known, integrated circuits are used in a wide variety of electronic equipment, including portable, or handheld, devices. Such handheld devices include AM/FM radios, computers, CD players, MP3 players, DVD players, cellular telephones, etc. Each of these handheld devices includes one or more integrated circuits to provide the functionality of the device.

As an example, a handheld FM radio receiver may include multiple integrated circuits to support the reception and processing of broadcast radio signals, in order to produce audio output signals that are delivered to the user through speakers, headphones or the like. In a stereo configuration, right and left channel signals are generated. A typical headphone driver includes right and left channel audio amplifiers that supply the power required to drive headphone elements, earbuds, etc.

It is desirable for a headphone driver to efficiently provide a high output power. The amount of power produced is dependent upon the maximum output swing of these devices. However, the supply voltage or voltages limit the output swing of the headphone driver.

The need exists for a headphone that produces high output power and that can be implemented efficiently on an integrated circuit.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

FIG. **1** presents a pictorial diagram of a handheld audio system in accordance with an embodiment of the present invention.

FIG. **2** presents a schematic block diagram of a radio receiver in accordance with an embodiment of the present invention.

FIG. **3** presents a schematic block diagram of a headphone driver in accordance with an embodiment of the present invention.

FIG. **4** presents a schematic block diagram of a headphone driver in accordance with an embodiment of the present invention.

FIG. **5** presents a schematic block diagram of a headphone driver in accordance with an embodiment of the present invention.

FIG. **6** presents a graphical representation of plurality of frequency responses in accordance with an embodiment of the present invention.

FIG. **7** presents a graphical representation of plurality of frequency responses in accordance with an embodiment of the present invention.

FIG. **8** presents a schematic block diagram of a headphone driver in accordance with an embodiment of the present invention.

FIG. **9** presents a schematic block diagram of a driver in accordance with an embodiment of the present invention.

FIG. **10** presents a schematic block diagram of a driver in accordance with an embodiment of the present invention.

FIG. **11** presents pictorial representations of various electronic devices in accordance with embodiments of the present invention.

FIG. **12** presents a schematic block diagram of a headphone driver in accordance with an embodiment of the present invention.

FIG. **13** presents a schematic block diagram of a headphone driver in accordance with an embodiment of the present invention.

FIG. **14** presents a schematic block diagram of a headphone driver in accordance with an embodiment of the present invention.

FIG. **15** presents a schematic block diagram of a headphone driver in accordance with an embodiment of the present invention.

FIG. **16** presents a flowchart representation of a method in accordance with an embodiment of the present invention.

FIG. **17** presents a flowchart representation of a method in accordance with an embodiment of the present invention.

FIG. **18** presents a flowchart representation of a method in accordance with an embodiment of the present invention.

FIG. **19** presents a flowchart representation of a method in accordance with an embodiment of the present invention.

FIG. **20** presents a flowchart representation of a method in accordance with an embodiment of the present invention.

FIG. **21** presents a flowchart representation of a method in accordance with an embodiment of the present invention.

FIG. **22** presents a flowchart representation of a method in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION INCLUDING THE PRESENTLY PREFERRED EMBODIMENTS

FIG. **1** presents a pictorial diagram of a handheld audio system in accordance with an embodiment of the present invention. In particular, a handheld audio system **80** is shown that receives a radio signal that carries at least one stereo audio channel that includes audio channel signals **104**. Note that the audio channel signals **104** may be digital signals or analog signals. The received radio signal may be an AM radio signal, FM radio signal, satellite radio signal, cable radio signal, that carries at least one stereo audio channel. In operation, the handheld audio system **80** produces an audio output for a user by means of headphones **84**, earbuds **82** or other speaker systems coupled to headphone jack **86**. In addition to producing an audio output from the received radio signal, the handheld audio system **80** can optionally process stored MP3 files, stored WMA files, and/or other stored digital audio files to produce an audio output for the user. Handheld audio system **80** includes a headphone driver coupled to headphone jack **86** that implements one or more of the features and functions in accordance with an embodiment of the present invention as set forth further in conjunction with the remaining figures and the appended claims.

FIG. **2** presents a schematic block diagram of a radio receiver in accordance with an embodiment of the present invention. In particular, radio receiver **50** includes a radio stage **102** that receives and demodulates a received radio signal. In an embodiment of the present invention, the radio signal includes a frequency modulated (FM) stereo broadcast signal that includes a stereo sum signal, the sum of right and left channel signals (R+L), and includes a stereo difference signal, the difference of right and left channel signals (R−L). As used herein stereo sum signal means any signal that includes the sum of two or more audio channel signals, regardless of polarity, and scaling. As used herein stereo difference signal means any signal that includes the difference between two or more audio channel signals, regardless of polarity, and scaling. As used herein, right and left channel signals mean, respectively, any signal that includes predominately one audio channel of a multi-channel audio encoding scheme, regardless of polarity, and scaling. It should be noted throughout this description that the polarities and/or phases of the various signals described herein are referenced with respect to the other signals. The polarities and/or phases of a signal can be modified with a commensurate modification of polarities and/or phases of the other signals present. In addition, while polarity inversions are presented herein at a particular points in a circuit, these polarity inversions can likewise occur at other points along a signal path or be implemented by multiple inversions and/or phase shifts.

In an embodiment of the present invention, radio stage **102** produces audio channel signals **104** that include stereo sum signal (R+L) and stereo difference signal (R−L). Headphone driver **125** includes a driver module **135** for generating a plurality of headphone driver signals **110** that include a stereo sum signal **108** and a stereo difference signal **106**, for driving headphones **112**.

FIG. **3** presents a schematic block diagram of a headphone driver in accordance with an embodiment of the present invention. In particular, an embodiment of headphone driver **125** and driver module **135** are presented. Headphones **112** are stereo headphones that include a right headphone element **114** and a left headphone element **116** that are coupled together at a common terminal **118**. Driver module **135** includes an audio driver **202** for driving the stereo sum signal **108** on common terminal **118**. Driver module **135** also includes an audio driver **200** for driving stereo difference signal **106'** on the negative terminal of right headphone element **114**. Driver module **135** further includes an audio driver **204** for driving stereo difference signal **106** on the negative terminal of left headphone element **116**.

In an embodiment of the present invention, headphone driver signals **110** are direct current (DC) coupled to headphones **112**. This avoids the necessity of providing capacitors for alternative current (AC) coupling of headphone drivers signals **110** to headphones **112** that would require substantial chip space or the use of external components when headphone driver **125** is implemented on an integrated circuit.

In an embodiment of the present invention, the right headphone element **114** and left headphone element **116** have relatively low load impedances, such as 100 Ohms or less. While headphones **112** are described as identified as "headphones" such as headphones **84**, headphones **112** include earbuds, such as earbuds **82**, and any other speakers or audio output devices that are capable of producing an audio output in response to headphone driver signals **110**.

In an embodiment of the present invention, audio channel signals **104** are analog signals and audio drivers **200**, **202**, and **204** are audio power amplifiers that provide the power necessary drive the load impedances of headphones **112**. Audio drivers **200**, **202** and **204** optionally provide a voltage gain for amplifying the magnitude of audio channel signals **104**. Further, audio driver **200** is an inverting amplifier that produces stereo difference signal **106'** with a polarity that is inverted from the polarity of stereo difference signal **106**. In an alternative embodiment of the present invention, audio channel signals **104** can be digital signals and headphone driver **125** or driver module **135** can include a plurality of digital to analog converter modules (not shown) for converting the digital audio channel signals **104** to corresponding analog audio channel signals.

In a stereo environment, driver module **135** can produce up to two times the maximum output swing of a typical driver module having a traditional right and left channel output. In operation, the voltage across right headphone element **114** can be represented by the voltage of stereo sum signal **108** (R+L) minus the voltage of stereo difference signal **106'** (L−R), which equals (2R). Likewise, the voltage across left headphone element **116** can be represented by the voltage of stereo sum signal **108** (R+L) minus the voltage of stereo difference signal **106** (R−L), which equals (2L). This provides a maximum output voltage swing that is twice the swing of a traditional right and left channel driver configuration. In the alternative, the same maximum output voltage swing can be achieved with the audio drivers **200**, **202** and **204** constructed with less voltage swing, when audio signals **104** have substantially independent right and left channel signals. A further advantage of this configuration is that it eliminates the need of radio stage **102** to include a stereo matrix circuit that produces right and left channel signals from the stereo sum and difference signals that result from demodulating an FM stereo broadcast.

FIG. **4** presents a schematic block diagram of a headphone driver in accordance with an alternative embodiment of the present invention. A headphone driver **126** is presented that can be used in implementations of radio receiver **50** in place of headphone driver **125**. Headphone driver **126** includes many similar elements of headphone driver **125** that are referred to by common reference numerals. In addition, headphone driver **126** includes a ground detect module **210**, operatively coupled to the common terminal **118** and audio driver **202**, for asserting a ground detection signal **212** when headphones **112** are used that have common terminal **118** coupled to a ground voltage. Control module **220** is operatively coupled to the driver module **136** for disabling the audio driver **202** when the ground detection signal **212** is asserted. In a further embodiment, control module **220** is further operable to reconfigure the driver module **136** when the ground detection signal **212** is asserted, to have driver module **136** drive headphones **112** with a traditional right channel signal and left channel signal.

In an embodiment of the present invention, ground detect module **210** includes a jack sense module for detecting that headphones have been newly coupled to headphone driver **126**. In response, ground detect module generates a test signal, such an oscillating signal, such as within, slightly above or below the audible frequency range. The ground detect module **212** monitors either the current drawn by common terminal **118** or the resulting voltage at common terminal **118** and compares the result to a voltage or current threshold, indicative of low impedance to ground. In response, ground detect module **210** asserts ground detection signal **212**.

In a further embodiment of the present invention, ground detect module includes a current monitor and comparator for detecting a high current state on the output of audio driver **202** during operation. When the current draw from common terminal **118** exceeds a current threshold for a period that is sustained, beyond a time period corresponding to an acceptable level of clipping, ground detect module asserts ground detect signal **212**. Alternatively, the current output of audio driver **202** can be limited and the voltage output can be compared to a threshold to detect a short to ground.

In an embodiment of the present invention, driver module **136** includes stereo decoder matrix **228** for producing right channel signal **230** and left channel signal **234**. Switches **224** and **226**, are controlled by configuration signal **222** from control module **220**. When the ground detection signal **212** is deasserted, switches **224** and **226** couple audio channel signals **104** to audio drivers **200** and **204**, and audio driver **202** is enabled. When configuration signal **222** is asserted in response to ground detection signal **212**, switches **224** and **226** couple right channel signal **230** and left channel signal **234** to audio drivers **200** and **204** and audio driver **202** is disabled. In the embodiment shown where audio driver **200** is inverting, stereo decoder matrix **228** can generate an inverted right channel signal **230** as shown. In embodiments of the present invention, audio driver **202** can be disabled by being powered down, put into low current class A mode, being disconnected or by being otherwise disabled.

While configuration signal **222** is shown as a single signal, likewise separate signals can be generated to control the reconfiguration of driver module **136**. In an embodiment of the present invention, control module **220** is implemented using a single processing device or a plurality of processing devices. Such a processing device may be a microprocessor, micro-controller, digital signal processor, microcomputer, central processing unit, field programmable gate array, programmable logic device, state machine, logic circuitry, analog circuitry, digital circuitry, and/or any device that manipulates signals (analog and/or digital) based on operational instructions. The memory may be a single memory device or a plurality of memory devices. Such a memory device may be a read-only memory, random access memory, volatile memory, non-volatile memory, static memory, dynamic memory, flash memory, cache memory, and/or any device that stores digital information. Note that when the control module **220** implements one or more of its functions via a state machine, analog circuitry, digital circuitry, and/or logic circuitry, the memory storing the corresponding operational instructions may be embedded within, or external to, the circuitry comprising the state machine, analog circuitry, digital circuitry, and/or logic circuitry. Further the processing device or processing devices that implement the functions of control module **220** may optionally perform functions associated with ground detect module **210**, driver module **136** and or other modules of the electronic device that optionally hosts headphone driver **126**.

FIG. **5** presents a schematic block diagram of a headphone driver in accordance with an alternative embodiment of the present invention. A headphone driver **325** is presented that can be used in implementations of radio receiver **50** in place of headphone driver **125** and/or **126**. Headphone driver **325** includes many similar elements of headphone drivers **125** and **126** that are referred to by common reference numerals. A headphone driver **325** is presented that includes driver module **335** for generating a plurality of headphone driver signals **110** including a filtered stereo sum signal **312**. In an embodiment of the present invention, driver module **335** DC couples the plurality of headphone driver signals **110** to headphones **112**.

In an embodiment of the present invention, driver module **335** includes a stereo matrix decoder **328** that generates an inverted right channel signal **330** and an inverted left channel signal **334** from audio channel signals **104**. Filter **322** filters stereo sum signal **332**, attenuated by 6 dB (a gain of ½) by attenuator **341**, into a filtered sum signal **342** that is input to driver **302**. Driver **302** generates filtered stereo sum signal **312** on common terminal **118**. Filter **320**, filters right channel signal **330** into a filtered right channel signal **340** that is input to driver **300**. Driver **300** generates filtered right channel signal **310** on a terminal that is coupled to a right headphone element **114**. Filter **324**, filters left channel signal **334** into a filtered left channel signal **344** that is input to driver **304**. Driver **304** generates filtered left channel signal **314** on a terminal that is coupled to a left headphone element **116**.

FIG. **6** presents a graphical representation of plurality of frequency responses in accordance with an embodiment of the present invention. In an embodiment of the present invention, filter **322** includes a low-pass filter having a corner frequency F_c. Filter **322** passes the low frequencies, such as the bass portion, of stereo sum signal **332** while attenuating higher frequency components. Filters **320** and **324** are high pass filters with corner frequency F_c. Right headphone element **114** is driven by a voltage potential that is equal to the filtered stereo sum signal **312** minus the filtered right channel signal **310**. At low frequencies, the stereo separation is typically minimal, and the left channel signal is approximately equal to the right channel signal. In this case, the filtered stereo sum signal **312** is approximately equal to a low-pass filtered version of right channel signal **330**. The voltage potential across right headphone **114** is then the sum of high-pass filtered and low-pass filtered versions of the right channel signal with approximately equal amplitudes. The overall frequency response to the right headphone element includes the high frequencies from filter **320** and the low frequencies from filter **322**—forming a full spectrum. Likewise, the overall frequency response to the left headphone element includes the high frequencies from filter **324** and the low frequencies from filter **322**—also forming a full spectrum.

While the frequency responses shown represent ideal filters, other filters may be implemented. In an embodiment of the present invention, filter **322** is a first order low-pass filter having a corner frequency F_c and filters **320** and **324** are both first order high-pass filters and higher orders having corner frequency F_c. However, other filters including other high-pass and low-pass filters such as raised cosine filters, Butterworth filters, either digital or analog, etc., can be implemented within the broad scope of the present invention.

FIG. **7** presents a graphical representation of plurality of frequency responses in accordance with an embodiment of the present invention. While FIG. **6** illustrates flat spectrum frequency response characteristics as described above, other configurations are likewise possible. For instance, using a low-pass filter for filter **322** and all-pass filters for filters **320** and **324** results in a bass boost to right and left headphone elements **114** and **116**. In an embodiment of the present invention, the gain of low-pass filter **322** is adjustable, providing an adjustable bass boost for equalization, user bass control functions and other applications. Other configurations can be used to attenuate the bass, boost the treble portions of the audio spectrum, provide loudness controls, and/or implement Fletcher-Munson equal-loudness contours, etcetera, within the broad scope of the present invention.

FIG. **8** presents a schematic block diagram of a headphone driver in accordance with an alternative embodiment of the present invention. A headphone driver **326** is presented that can be used in implementations of radio receiver **50** in place of headphone drivers **125**, **126**, and **325**. Headphone driver **326** includes many similar elements of headphone driver **125**, **126** and **325** that are referred to by common reference numerals. In particular, headphone driver **326** includes ground detect module **210**, operatively coupled to the common terminal **118** and driver **302**, for asserting a ground detection signal **212** when headphones **112** are used that have common terminal **118** coupled to a ground voltage. Control module **320** is operatively coupled to the driver module **136** for disabling the driver **302** and filter **322** when the ground detection signal **212** is asserted. In a further embodiment, control module **320** is further operable to reconfigure the driver module **336** when the ground detection signal **212** is asserted, to have driver module **336** drive headphones **112** with a traditional right channel signal and left channel signal.

In an embodiment of the present invention, control module **320** is implemented in a manner similar to control module **220**. However, in response to ground detection signal **212** being asserted, control module **320** generates configuration signal **222** that disables filter **322** and/or driver **302**, and that converts filters **320** and **324** into all-pass filters—to the extent that filters **320** and **324** were implemented using other transfer functions. When ground detection signal **212** is asserted, driver **300** produces filtered right channel signal **310** directly from right channel signal **330**. In this mode, filtered right channel signal **310** is all-pass filtered. Further, when ground detection signal **212** is asserted, driver **304** produces filtered left channel signal **314** directly from left channel signal **334**. In this mode, filtered left channel signal **314** is all-pass filtered. It should be noted that any of the all-pass filters disclosed herein can be implemented by disabling or bypass a filter with an alternative transfer function, since an all-pass filter does not alter the frequency characteristics of an input signal.

FIG. **9** presents a schematic block diagram of a driver in accordance with an embodiment of the present invention. Driver **364** is shown that can be used to implement drivers **300**, **302** and/or **304** presented in association with FIGS. **5** and **8**. In particular, driver **364** uses digital to analog converter (DAC) **360** to convert a digital input **366** to an analog input of audio driver **362**. In an embodiment of the present invention, audio driver **362** can be implemented in a similar fashion to audio drivers **200**, **202** and **204**. Driver **362** can be either a single-ended driver or a differential driver.

FIG. **10** presents a schematic block diagram of a driver in accordance with an alternative embodiment of the present invention. Driver **374** is shown that can be used to implement drivers **300**, **302** and/or **304** presented in association with FIGS. **5** and **8**. In particular, audio driver **362** accepts an analog input signal **376** and can be implemented in a similar fashion to audio drivers **200**, **202** and **204**.

FIG. **11** presents pictorial representations of various electronic devices in accordance with embodiments of the present invention. While the prior description has focused on a headphone drivers **125**, **126**, **325** and **326** that are implemented in a radio receiver, such as radio receiver **50**, similar drivers may be implemented on a wide variety of other electronic devices such as computer **54**, CD player **56**, DVD player **58**, wireless telephone **52**, and other devices that employ headphones, earbuds or other audio output devices with two or more channels.

FIG. **12** presents a schematic block diagram of a headphone driver in accordance with an embodiment of the present invention. A headphone driver **127** is presented that can be used in implementations of radio receiver **50**, computer **54**, CD player **56**, DVD player **58**, wireless telephone **52** in place of headphone driver **125**. In particular, headphone driver **127** includes similar elements to headphone driver **125** referred to by common reference numerals. However, headphone driver **127** receives stereo channel signals **105** that include traditional right and left channel signals. Driver module **137** includes stereo matrix encoder **400** for producing the stereo sum and difference signals that are employed.

FIG. **13** presents a schematic block diagram of a headphone driver in accordance with an embodiment of the present invention. A headphone driver **128** is presented that can be used in implementations of radio receiver **50**, computer **54**, CD player **56**, DVD player **58**, wireless telephone **52** in place of headphone driver **126**. In particular, headphone driver **128** includes similar elements to headphone driver **126** referred to by common reference numerals. However, headphone driver **128** receives stereo channel signals **105** that include traditional right and left channel signals. Driver module **138** includes stereo matrix encoder **400** for producing the stereo sum and difference signals that are employed.

FIG. **14** presents a schematic block diagram of a headphone driver in accordance with an embodiment of the present invention. A headphone driver **327** is presented that can be used in implementations of radio receiver **50**, computer **54**, CD player **56**, DVD player **58**, wireless telephone **52** in place of headphone driver **325**. In particular, headphone driver **327** includes similar elements to headphone driver **325** referred to by common reference numerals. However, headphone driver **327** receives stereo channel signals **105** that include traditional right and left channel signals. Driver module **337** includes summing module **402** for producing the stereo sum signal that is employed.

FIG. **15** presents a schematic block diagram of a headphone driver in accordance with an embodiment of the present invention. A headphone driver **328** is presented that can be used in implementations of radio receiver **50**, computer **54**, CD player **56**, DVD player **58**, wireless telephone **52** in place of headphone driver **326**. In particular, headphone driver **328** includes similar elements to headphone driver **326** referred to by common reference numerals. However, headphone driver **328** receives stereo channel signals **105** that include traditional right and left channel signals. Driver module **338** includes summing module **402** for producing the stereo sum signal that is employed.

FIG. **16** presents a flowchart representation of a method in accordance with an embodiment of the present invention. In particular, a method is presented for use in conjunction with one or more of the features and functions presented in association with FIGS. **1-15**. In step **500**, a plurality of headphone driver signals are generated including a filtered stereo sum signal. In step **502**, the filtered stereo sum signal is driven on a common terminal that is coupled to a right headphone element and a left headphone element. In an embodiment of the present invention, step **500** includes low-pass filtering a stereo sum signal.

In an embodiment of the present invention step **500** includes high-pass filtering a right channel signal, and step **502** includes driving the filtered right channel signal to a terminal that is coupled to a right headphone element. In an embodiment of the present invention step **500** includes high-pass filtering a left channel signal, and step **502** includes driving the filtered left channel signal to a terminal that is coupled to a left headphone element.

FIG. **17** presents a flowchart representation of a method in accordance with an embodiment of the present invention. In particular, a method is presented for use in conjunction with the method of FIG. **16**. In step **510**, a ground detection signal is asserted when the common terminal is coupled to a ground voltage. In step **512**, step **502** is disabled when the ground detection signal is asserted. In an embodiment of the present invention, step **500** includes generating a right channel signal and a left channel signal when the ground detection signal is asserted.

FIG. **18** presents a flowchart representation of a method in accordance with an embodiment of the present invention. In particular, a method is presented for use in conjunction with one or more of the features and functions presented in association with FIGS. **1-17**. In step **599**, the method determines if a ground detect signal is asserted. If so, the method executes steps **630** and **632**, and if not, the method executes steps **600**, **602**, **610**, **612**, **620** and **622**.

In step **630** a right channel signal is driven to a terminal that is coupled to a right headphone element. In step **632** a left channel signal is driven to a terminal that is coupled to a left headphone element.

In step **600**, a filtered stereo sum signal is generated. In step **602**, the filtered stereo sum signal is driven on a common terminal that is coupled to a right headphone element and a left headphone element. In an embodiment of the present invention, step **600** includes low-pass filtering a stereo sum signal.

In step **610** a right channel signal is filtered. In step **612**, the filtered right channel signal is driven to a terminal that is coupled to a right headphone element. In step **620** a left channel signal is filtered. In step **622**, the filtered left channel signal is driven to a terminal that is coupled to a left headphone element. The filtering of the right and left channel signal can be high-pass filtering, low-pass filtering or filtering with other transfer functions.

FIG. **19** presents a flowchart representation of a method in accordance with an embodiment of the present invention. In particular, a method is presented for use in conjunction with one or more of the features and functions presented in association with FIGS. **1-15**. In step **700**, a plurality of headphone driver signals are generated including a stereo sum signal and a first stereo difference signal. In step **702**, the stereo sum signal is driven on a common terminal that is coupled to a right headphone element and a left headphone element.

FIG. **20** presents a flowchart representation of a method in accordance with an embodiment of the present invention. In particular, a method is presented for use in conjunction with one or more of the features and functions presented in association with FIG. **19**. In step **710**, a ground detection signal is asserted when the common terminal is coupled to a ground voltage. In step **712**, step **702** is disabled when the ground detection signal is asserted. In an embodiment of the present invention, step **700** includes generating a right channel signal and a left channel signal when the ground detection signal is asserted.

FIG. **21** presents a flowchart representation of a method in accordance with an embodiment of the present invention. In particular, a method is presented for use in conjunction with one or more of the features and functions presented in association with FIGS. **1-15**. In step **799**, the method determines if a ground detect signal is asserted. If so, the method executes steps **830** and **832**, and if not, the method executes steps **800**, **802**, **810**, **812**, **820** and **822**.

In step **830** a right channel signal is driven to a terminal that is coupled to a right headphone element. In step **832** a left channel signal is driven to a terminal that is coupled to a left headphone element.

In step **800**, a stereo sum signal is generated. In step **802**, the stereo sum signal is driven on a common terminal that is coupled to a right headphone element and a left headphone element.

In step **810** a first stereo difference signal is generated. In step **812**, the first stereo difference signal is driven to a terminal that is coupled to a right headphone element. In step **820** a second stereo difference signal is generated. In step **812**, the second stereo difference signal is driven to a terminal that is coupled to a left headphone element. In an embodiment of the present invention, the first stereo difference signal has a polarity that is inverted from a polarity of the second stereo difference signal.

FIG. **22** presents a flowchart representation of a method in accordance with an embodiment of the present invention. In particular, a method is presented for use in conjunction with one or more of the features and functions presented in association with FIGS. **1-21**. In step **900**, the plurality of headphone driver signals are direct current (DC) coupled to a headphone set.

As one of ordinary skill in the art will appreciate, the term "substantially" or "approximately", as may be used herein, provides an industry-accepted tolerance to its corresponding term and/or relativity between items. Such an industry-accepted tolerance ranges from less than one percent to twenty percent and corresponds to, but is not limited to, component values, integrated circuit process variations, temperature variations, rise and fall times, and/or thermal noise. Such relativity between items ranges from a difference of a few percent to magnitude differences. As one of ordinary skill in the art will further appreciate, the term "operably coupled", as may be used herein, includes direct coupling and indirect coupling via another component, element, circuit, or module where, for indirect coupling, the intervening component, element, circuit, or module does not modify the information of a signal but may adjust its current level, voltage level, and/or power level. As one of ordinary skill in the art will also appreciate, inferred coupling (i.e., where one element is coupled to another element by inference) includes direct and indirect coupling between two elements in the same manner as "operably coupled". As one of ordinary skill in the art will further appreciate, the term "compares favorably", as may be used herein, indicates that a comparison between two or more elements, items, signals, etc., provides a desired relationship. For example, when the desired relationship is that signal **1** has a greater magnitude than signal **2**, a favorable comparison may be achieved when the magnitude of signal **1** is greater than that of signal **2** or when the magnitude of signal **2** is less than that of signal **1**.

In preferred embodiments, the various circuit components are implemented using 0.35 micron or smaller CMOS technology. Provided however that other circuit technologies, both integrated or non-integrated, may be used within the broad scope of the present invention. Likewise, various embodiments described herein can also be implemented as software programs running on a computer processor. It should also be noted that the software implementations of the present invention can be stored on a tangible storage medium such as a magnetic or optical disk, read-only memory or random access memory and also be produced as an article of manufacture.

Thus, there has been described herein an apparatus and method, as well as several embodiments including a preferred embodiment, for implementing a headphone driver, and driver module. Various embodiments of the present invention herein-described have features that distinguish the present invention from the prior art.

It will be apparent to those skilled in the art that the disclosed invention may be modified in numerous ways and may assume many embodiments other than the preferred forms specifically set out and described above. Accordingly, it is intended by the appended claims to cover all modifications of the invention which fall within the true spirit and scope of the invention.

What is claimed is:

1. A headphone driver module comprising:

a low-pass filter for providing a filtered stereo sum signal from a stereo sum signal, wherein the low-pass filter has a corner frequency that is within an audio range;

a first audio driver for driving the filtered stereo sum signal on a common terminal that is coupled to a right headphone element and a left headphone element;

a first high-pass filter for providing a filtered right channel signal from a right channel signal;

a second audio driver for driving the filtered right channel signal on a second terminal of the right headphone element;

a second high-pass filter for providing a filtered left channel signal from a left channel signal;

a third audio driver for driving the filtered left channel signal on a second terminal of the left headphone element;

a ground detect module, operatively coupled to the common terminal, for asserting a ground detection signal when the common terminal is coupled to a ground voltage; and

a control module, operatively coupled to the first audio driver, for disabling the first audio driver when the ground detection signal is asserted, wherein the control module disables or bypasses filtering of the first high-pass filter when the ground detection signal is asserted so that the second audio driver drives the right channel signal on the second terminal of the right headphone element, and wherein the control module disables or bypasses filtering of the second high-pass filter when the ground detection signal is asserted so that the third audio driver drives the left channel signal on the second terminal of the left headphone element.

2. The headphone driver module of claim **1** wherein the first high-pass filter has a corner frequency that is within the audio range.

3. The headphone driver module of claim **1** wherein the second high-pass filter has a corner frequency that is within the audio range.

4. The headphone driver module of claim **1** wherein the first, second and third audio drivers provide direct current (DC) coupling to a headphone set.

5. A headphone driver comprising:

a decoder matrix having a first input receiving a stereo sum signal which comprises a sum of a right channel signal and a left channel signal, having a second input receiving a stereo difference signal which comprises a difference of the right channel signal and the left channel signal, having a first output providing the right channel signal and having a second output providing the left channel signal;

a first audio driver which drives the stereo sum signal on a common terminal when a ground detection signal is not asserted, wherein the common terminal is coupled to a first terminal of each of a right headphone element and a left headphone element;

a second audio driver which drives the stereo difference signal on a second terminal of the right headphone element when the ground detection signal is not asserted;

a third audio driver which drives the stereo difference signal on a second terminal of the left headphone element when the ground detection signal is not asserted;

a first switch which selectively provides one of the right channel signal and the stereo difference signal to the second audio driver, wherein the first switch selects the stereo difference signal when the ground detection signal is not asserted;

a second switch which selectively provides one of the left channel signal and the stereo difference signal to the third audio driver, wherein the second switch selects the stereo difference signal when the ground detection signal is not asserted;

a ground detect module, operatively coupled to the common terminal, for asserting the ground detection signal when the common terminal is coupled to a ground voltage;

a control module, operatively coupled to the first, second and third audio drivers, wherein the control module causes the first switch to select the right channel signal to be provided to the second audio driver when the ground detection signal is asserted, wherein the control module causes the second switch to select the left channel signal to be provided to the third audio driver when the ground detection signal is asserted, and wherein the control module disables the first audio driver when the ground detection signal is asserted;

wherein the second audio driver drives the right channel signal on the second terminal of the right headphone element when the ground detection signal is asserted; and

wherein the third audio driver drives the left channel signal on the second terminal of the left headphone element when the ground detection signal is asserted.

6. The headphone driver of claim **5** wherein the first, second and third audio drivers provide direct current (DC) coupling to a headphone set.

7. A method comprising:

filtering a stereo sum signal with a corner frequency within an audio range and providing a filtered stereo sum signal;

driving the filtered stereo sum signal on a common terminal that is coupled to a first terminal of each of a right headphone element and a left headphone element;

high-pass filtering a right channel signal and providing a filtered right channel signal;

driving the filtered right channel signal on a second terminal of the right headphone element;

high-pass filtering a left channel signal and providing a filtered left channel signal;

driving the filtered left channel signal on a second terminal of the left headphone element;

asserting a ground detection signal when the common terminal is coupled to a ground voltage;

disabling the step of driving the filtered stereo sum signal when the ground detection signal is asserted;

disabling or bypassing filtering of the right channel signal when the ground detection signal is asserted so that the right channel signal is provided to the second terminal of the right headphone element; and

disabling or bypassing filtering of the left channel signal when the ground detection signal is asserted so that the left channel signal is provided to the second terminal of the left headphone element.

8. The method of claim **7** wherein the step of high-pass filtering the right channel signal comprises high-pass filtering the right channel signal at a corner frequency within the audio range.

9. The method of claim **7** wherein the step of high-pass filtering the left channel signal comprises high-pass filtering the left channel signal at a corner frequency within the audio range.

10. The method of claim **7** wherein said driving comprises direct current (DC) coupling the signals to a headphone set.

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