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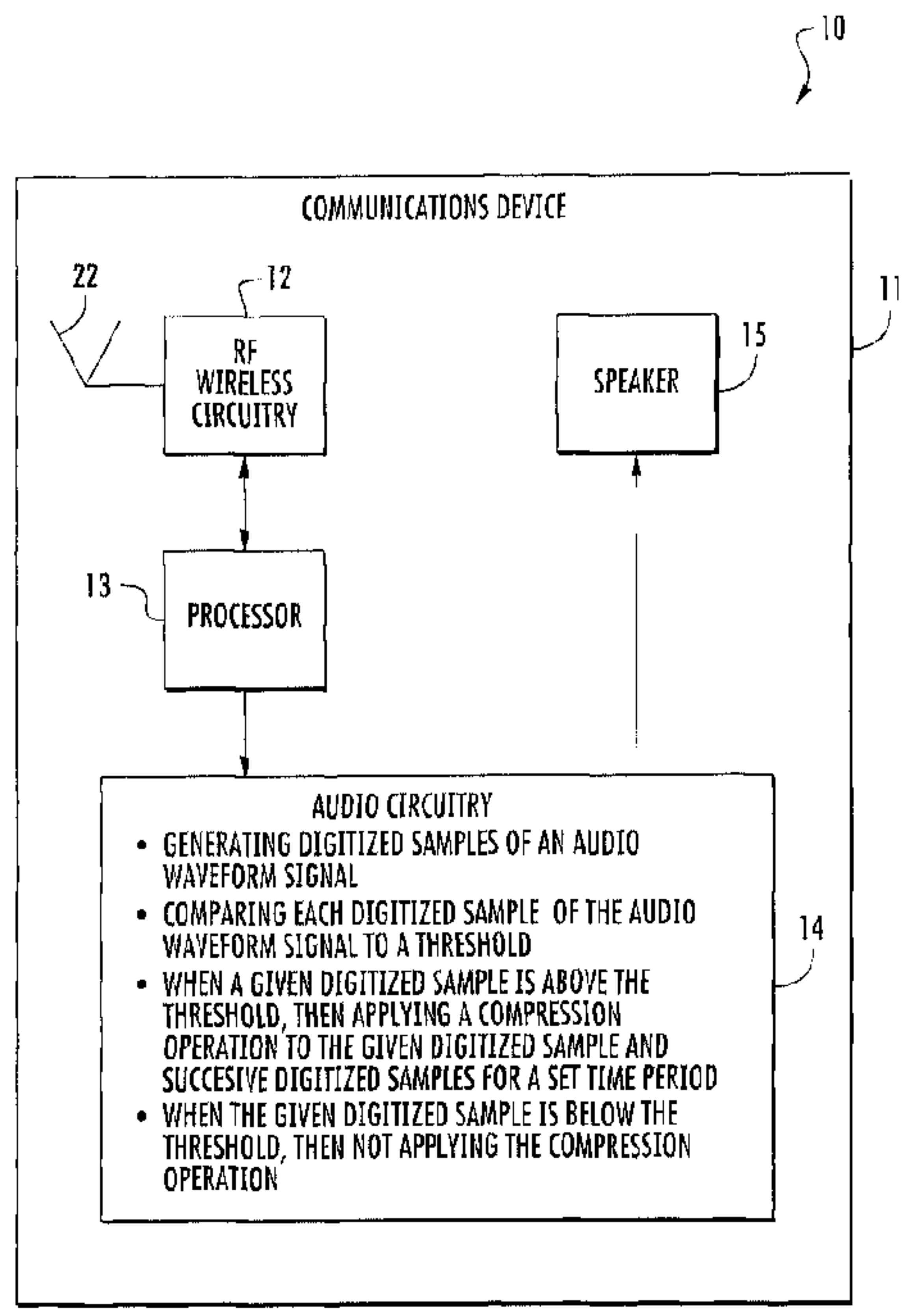
(54) Titre : APPAREIL ELECTRONIQUE A SEUIL FONDE SUR LA COMPRESSION ET APPAREILS ET METHODES ASSOCIES
(54) Title: ELECTRONIC DEVICE WITH THRESHOLD BASED COMPRESSION AND RELATED DEVICES AND METHODS



(57) Abrégé/Abstract:
An electronic device may include a speaker, and audio circuitry coupled to the speaker. The audio circuitry may generate digitized samples of an audio waveform signal, and compare each digitized sample of the audio waveform signal to a threshold. The audio circuitry may when a given digitized sample is above the threshold, then apply a compression operation to the given digitized sample and successive digitized samples for a set time period, and when the given digitized sample is below the threshold and not within the set time period, then not apply the compression operation.

Abstract of the Disclosure

An electronic device may include a speaker, and audio circuitry coupled to the speaker. The audio circuitry may generate digitized samples of an audio waveform signal, and compare each digitized sample of the audio waveform signal to a threshold. The audio circuitry may when a given digitized sample is above the threshold, then apply a compression operation to the given digitized sample and successive digitized samples for a set time period, and when the given digitized sample is below the threshold and not within the set time period, then not apply the compression operation.

ELECTRONIC DEVICE WITH THRESHOLD BASED COMPRESSION AND RELATED DEVICES AND METHODS

Technical Field

[0001] The present disclosure relates to the field of electronic devices, and, more particularly, to electronic devices with speakers and related methods.

Background

[0002] Wireless communications devices are an integral part of society and permeate daily life. The typical wireless communications device includes an antenna, a transceiver coupled to the antenna, and an audio output/input device. The transceiver and the antenna cooperate to transmit and receive communications signals. A typical wireless communications device includes a power amplifier for amplifying low amplitude signals for output via an audio output device, such as a speaker, for example.

[0003] In the typical wireless communications device, the audio performance of the speaker can be limited. This is generally due to the low power amplifier and the size of the speaker. Indeed, in mobile applications, these restraints on design are quite pronounced. Also, a voice based audio output signal may be difficult to process due to its high peak-to-average ratio. Because of this, the typical mobile wireless communications device may provide audio output with significant distortion, which is undesirable.

[0004] An approach to this issue is to compress the audio output signal before outputting via the speaker. In short, the compression reduces the level of the loudest signals in the audio output signal. Two facets of the audio output signal that can be regulated are the peak levels of the signal and the dynamic range of the signal.

[0005] In particular, some approaches use a fixed compression algorithm. These compression algorithms have a fixed gain where higher voltages have less gain than lower voltages. Also, the gain does not vary over time in these approaches. Other approaches use dynamic compression algorithms. These dynamic algorithms include an attack time, i.e. a time needed to attenuate the audio output signal, and a release time, i.e. a time needed to return the audio output signal to original form.

[0006] For example, U.S. Patent No. 8,750,525 to Martz et al., also assigned to the present application's assignee, discloses a dynamic compression algorithm approach. Nevertheless, dynamic algorithm approaches typically cannot guarantee a peak limit and may be difficult to tune, thereby giving each device a different sound or tonality.

[0007] Also, U.S. Patent No. 8,983,092 to Thormundsson et al. discloses another approach. This approach includes a dynamic range compressor/peak limiter comprising a look-ahead buffer and an analysis engine. The look-ahead buffer holds a window of samples of a signal. The analysis engine selects a gain envelope function on the basis of the samples by selecting the Pth sample in the buffer whenever that sample exceeds a given threshold.

Summary

[0008] Generally speaking, an electronic device may comprise a speaker, and audio circuitry coupled to the speaker. The audio circuitry may be configured to generate digitized samples of an audio waveform signal, compare each digitized sample of the audio waveform signal to a threshold, and when a given digitized sample is above the threshold, then apply a compression operation to the given digitized sample and successive digitized samples for a set time period, and

when the given digitized sample is below the threshold and not within the set time period, then not apply the compression operation. Advantageously, the audio circuitry may provide a high fidelity signal to the speaker.

[0009] Additionally, the audio circuitry may be configured to compare each digitized sample in the successive digitized samples to an additional threshold less than the threshold, and when a digitized sample exceeds the additional threshold, then reset the set time period. The electronic device may further include wireless circuitry configured to generate the audio waveform signal for input to the audio circuitry. The audio circuitry may comprise a compression block, a digital-to-analog converter (DAC), a power amplifier coupled downstream from the DAC, and a switch configured to selectively pass the audio waveform signal to the DAC, either directly or through the compression block.

[0010] In some embodiments, the compression block may be configured to reduce a crest factor of the audio waveform signal as an input voltage of the audio waveform signal increases. The compression block may be configured to perform a fixed curve compression operation. The fixed curve compression operation may be based upon a peak voltage of the speaker and a peak level of the audio waveform signal. The compression block may be configured to apply the compression operation to each and every successive digitized sample after the given digitized sample and for the set time period.

[0011] Another aspect is directed to a communications device comprising a portable housing, RF wireless circuitry carried by the portable housing and configured to generate an audio waveform signal, a speaker carried by the portable housing, and audio circuitry carried by the portable housing, and coupled to the speaker and the RF wireless circuitry. The audio circuitry may be configured to generate digitized samples of the audio waveform signal, and compare each digitized sample of the audio waveform signal to a threshold. The audio circuitry may be configured to when a given digitized sample is above the threshold, then apply a compression operation to the given digitized sample and successive digitized samples for a set time period, and when the given digitized sample is below the threshold and not within the set time period, then not apply the compression operation.

[0012] Yet another aspect is directed to a method for operating an electronic device comprising a speaker, and audio circuitry coupled to the speaker. The method may include operating the audio circuitry to generate digitized samples of an audio waveform signal, and operating the audio circuitry to compare each digitized sample of the audio waveform signal to a threshold. The method may include operating the audio circuitry to when a given digitized sample is above the threshold, then apply a compression operation to the given digitized sample and successive digitized samples for a set time period, and when the given digitized sample is below the threshold and not within the set time period, then not apply the compression operation.

Brief Description of the Drawings

[0013] FIG. 1 is a schematic diagram of a communications device, according to the present disclosure.

[0014] FIG. 2 is an example embodiment of the audio circuitry, the speaker, and the processor from the communications device of FIG. 1.

[0015] FIG. 3 is a diagram of an example compression curve for the compression block of FIG. 3.

[0016] FIG. 4 is a diagram of example input and output waveforms in the communications device of FIG. 1.

Detailed Description

[0017] The present disclosure will now be described more fully hereinafter with reference to the accompanying drawings, in which several embodiments of the invention are shown. This present disclosure may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the present disclosure to those skilled in the art. Like numbers refer to like elements throughout.

[0018] Referring initially to FIGS. 1-2, a communications device **10** according to the present disclosure is now described. The communications device **10** illustratively includes a portable housing **11**, an antenna (e.g. whip style antenna) **22**, and RF wireless circuitry **12** carried by the portable housing, coupled to the antenna, and configured to generate an audio waveform signal. For example, the portable housing **11** may have a handheld "walkie-talkie" form factor. In particular, the RF wireless circuitry **12** is configured to receive a transmitted RF signal via the antenna **22**. As will be appreciated, the RF wireless circuitry **12** may include a receiver path for receiving, filtering, demodulating, and decoding the received RF signal. In some embodiments, the received RF signal comprises a Project 25 (P25/APCO-25) waveform, but other waveforms may be used in other embodiments.

[0019] The communications device **10** illustratively includes a processor **13** coupled to the RF wireless circuitry **12** and configured to manipulate a digital version of the received RF signal. The digital version of the received RF signal includes the audio waveform signal, for example, voice data.

[0020] The communications device **10** illustratively includes a speaker **15** carried by the portable housing **11**, and audio circuitry **14** carried by the portable housing, and coupled to the speaker and the RF wireless circuitry **12** and processor **13**. In cooperation with the processor **13**, the audio circuitry **14** is configured to generate digitized samples of the audio waveform signal at a set sampling frequency.

[0021] The audio circuitry **14** illustratively includes a peak detection block **16** operating based upon a threshold **24**, and a volume parameter **23**. The threshold **24** represents a voltage threshold in the audio waveform signal that would potentially damage the speaker **15**. The volume parameter **23** represents a user selected output level for the speaker **15**, i.e. directly controlling amplifier gain. Additionally, the audio circuitry **14** illustratively includes a compression block **17**, a DAC **28**, a power amplifier **29** coupled downstream from the DAC, and a switch **18** coupled between the processor **13** and the DAC/compression block. For example, the compression block **17** may operate based upon a mu(μ)-law, A-law, square root, or RAPP Model (as disclosed in C. Rapp, "Effects of HPA-Nonlinearity on a 4-DPSK/OFDM Signal for a Digital Sound Broadcasting System", Proceedings of the Second European Conference on Satellite Communications, Liège, Belgium, October 22-24, 1991, pp. 179-184) companding algorithm. Moreover, although the compression block **17** is discussed as a compression block, it should be appreciated that this block may comprise a companding block set to compress, but capable of expansion also.

[0022] The peak detection block **16** is configured to compare each digitized sample of the audio waveform signal to the threshold **24**. The peak detection block **16** is configured to when a given digitized sample is above the threshold **24**, then apply a compression operation to the given digitized sample and successive digitized samples for a set time period. In particular, the peak detection block **16** controls the switch **18**

and directs the audio waveform signal to the compression block **17**.

[0023] In some embodiments, the compression block **17** may be configured to apply the compression operation to each and every successive digitized sample after the given digitized sample and for the set time period. The set time period may comprise up to 2 seconds of samples (the number of samples depending on the sampling rate).

[0024] Also, the compression block **17** is configured to apply the compression operation to all samples for the set time period regardless of whether they exceed the threshold. In other words, the given digitized sample being above the threshold **24** starts a timer (countdown from or count up to the set time period), during which all passing samples are compressed. This is contrast to the windowed approach of the '092 patent to Thormundsson et al. Also, the timer is reset every time a new sample passes that exceeds the threshold. Because of this, the compression block **17** commonly applies the compression operation for periods longer than the set time period.

[0025] In some embodiments, the peak detection block **16** is configured to operate based upon one or more thresholds. In particular, once the given sample exceeds the threshold, each successive digitized sample after the given digitized sample and for the set time period would be compared to a second threshold (a hysteresis protection threshold), which would less than the threshold (i.e. first threshold). As will be appreciated, this will enhance the sensitivity of applying the compression operation via the compression block **17**. In other words, in these embodiments, the audio circuitry **14** is configured to compare each digitized sample in the successive digitized samples to an additional threshold less than the threshold, and when a digitized sample exceeds the additional threshold, then reset the set time period.

[0026] The peak detection block **16** is configured to when the given digitized sample is below the threshold **24** and not within the set time period (i.e. the set time period running from a last sample that exceeded the threshold), then not apply the compression operation. In particular, the peak detection block **16** controls the switch **18** and directs the audio waveform signal (unadulterated/undistorted) directly to the DAC **28**. In other words, the switch **18** is configured to selectively pass the audio waveform signal to the DAC **28**, either directly or through the compression block **17**.

[0027] In some embodiments, the communications device **10** has no *a priori* knowledge of the information on the content (digital, analog, etc.) of the audio waveform signal. In other words, the communications device **10** does not know the expected peak value of the audio waveform signal, or the peak-to-average ratio (crest factor), the root mean squared (RMS) value of the signal, or even if it was an analog frequency modulated (FM) signal or a digital, vocoder compressed signal. Indeed, the communications device **10** has knowledge only of the peak and average limits of the speaker **15**, which the threshold **24** is based upon. This is contrast to the approach of the '092 patent to Thormundsson et al., which includes the look-ahead buffer.

[0028] Also, although the illustrated embodiment is depicted in the context of a communications device **10**, it should be appreciated that the disclosed audio circuitry **14** and associated teachings may be applied to other applications. For example, the audio circuitry **14** may be applied to portable battery powered speakers, intercom stations, voice over Internet devices, etc.

[0029] Yet another aspect is directed to a method for operating an electronic device comprising a speaker **15**, and audio circuitry **14** coupled to the speaker. The method may include operating the audio circuitry **14** to generate digitized samples of an audio waveform signal, and operating the audio circuitry to compare each digitized sample of the audio waveform signal to a threshold **24**. The method may include operating the audio circuitry **14** to when a given digitized sample is above the threshold **24**, then apply a compression operation to the given digitized sample and successive digitized samples for a set time period, and when the given digitized sample is below the threshold, then not apply the compression operation.

[0030] Referring now additionally to FIGS. 3-4, in some embodiments, the compression block **17** may be configured to reduce a crest factor of the audio waveform signal as an input voltage of the audio waveform signal increases. Advantageously, this provides the user with audio output having a greater "punch" as the user increases the volume parameter **23** (by exponentially increasing the compression).

[0031] Also, as shown in diagram **20**, the compression block **17** may be configured to perform a fixed curve compression operation. In particular, the compression curve **21** and the fixed curve compression operation may be based upon a peak voltage of the speaker **15** and a peak level of the audio waveform signal. The x-axis of the compression curve **21** is set based upon a peak level from the peak detection block **16**, and the y-axis is set based upon the peak speaker voltage threshold, i.e. the threshold **24**.

[0032] In another embodiment of the use of the compression curve, the x-axis of the compression curve **21** is set based upon the peak level from the peak detection block **16**, and the y-axis is set based upon the peak speaker voltage threshold, i.e. the threshold **24** divided by a constant. This constant acts as a compression dial for increasing the compression. For example, in one embodiment, the constant has the value 10. In this secondary embodiment of the use of the compression curve, the resulting output would be much less than the peak speaker voltage threshold - at its maximum, it would be less by a factor of that constant (the value 10, for example). So, in this secondary embodiment, the output of the compression block would be multiplied by the constant.

[0033] As the user increases the volume parameter **23**, the compression block **17** increases the compression to prevent distortion or damage to the speaker **15**. In other words, the independent variable in the gain function of the compression curve **21** is input voltage, not time as in some prior approaches.

[0034] Also, when the compression operation is applied, the entire gain curve is applied - to reduce the crest factor of audio waveform signal, and so all of the audio at every part of the digital range is affected by the gain. As shown in diagram **25**, the audio circuitry **14** may compress the audio waveform signal **26** and provide an output waveform **27** with minimal distortion.

[0035] In typical approaches, high crest factor audio waveforms were poorly reproduced via the speaker. As discussed above, this is largely due to the poor performance characteristics of the speaker. The communications device **10** provides an approach to this problem by selectively compressing the audio waveform signal **26**, causing minimal distortion yet without damaging the speaker **15**. Advantageously, the audio circuitry **14** of the communications device **10** does not provide a readily perceptible sound or tonality to the user.

[0036] Also, typical approaches that use a dynamic compression algorithm may not guarantee keeping the peak limit intact. These approaches typically employ an additional hard limiter downstream of the compression block. The audio circuitry **14** may reduce unnecessary circuitry and power usage with the compression block **17**. Also, the communications device **10** advantageously may provide pure (i.e. perfect fidelity), undistorted audio when compression is unnecessary.

[0037] In short, the communications device **10** uses a fixed compression curve, but selectively applies it. For example, if the volume parameter **23** has a settable range of 1-20, the audio circuitry **14** provides no compression between the range of 1-15, minimal compression at 16, and progressively more compression between the range of 17-20 (20 having the most compression).

[0038] Moreover, the communications device **10** has a static compression, and this helpfully may eliminate many integration and test steps (dynamic compression is more complex than static compression) during design and manufacture, which decreases time to market and reduces test and verification costs. The communications device **10** may provide the user with variability in that the user selects the volume parameter **23** level and the acceptable level of distortion (compression always adds distortion).

[0039] Many modifications and other embodiments of the present disclosure will come to the mind of one skilled in the art having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is understood that the present disclosure is not to be limited to the specific embodiments disclosed, and that modifications and embodiments are intended to be included within the scope of the appended claims.

CLAIMS

1. An electronic device comprising: a speaker; and audio circuitry coupled to said speaker and configured to generate digitized samples of an audio waveform signal, compare each digitized sample of the audio waveform signal to a threshold, said threshold based upon peak and average limits of the speaker, and when a given digitized sample is above the threshold, then apply a compression operation to the given digitized sample and each and every successive digitized sample after the given digitized sample and for a set time period, and when the given digitized sample is below the threshold and not within a respective set time period for a prior digitized sample exceeding the threshold, then not apply the compression operation.

2. The electronic device of claim 1 wherein said audio circuitry is configured to compare each digitized sample in successive digitized samples of the set time period to an additional threshold less than the threshold, and when a digitized sample exceeds the additional threshold, then reset the set time period.

3. The electronic device of claim 1 further comprising wireless circuitry configured to generate the audio waveform signal for input to said audio circuitry.

4. The electronic device of claim 1 wherein said audio circuitry comprises: a compression block; a digital-to-analog converter (DAC); a power amplifier coupled downstream from said DAC; and a switch configured to selectively pass the audio waveform signal to said DAC, either directly or through said compression block.

5. The electronic device of claim 4 wherein said compression block is configured to reduce a crest factor of the audio

waveform signal as an input voltage of the audio waveform signal increases.

6. The electronic device of claim 4 wherein said compression block is configured to perform a fixed curve compression operation.

7. The electronic device of claim 6 wherein the fixed curve compression operation is based upon a peak voltage of said speaker and a peak level of the audio waveform signal.

8. A communications device comprising: a portable housing; radio frequency (RF) wireless circuitry carried by said portable housing and configured to generate an audio waveform signal; a speaker carried by said portable housing; and audio circuitry carried by said portable housing, coupled to said speaker and said RF wireless circuitry, and configured to generate digitized samples of the audio waveform signal, compare each digitized sample of the audio waveform signal to a threshold, said threshold based upon peak and average limits of the speaker, and when a given digitized sample is above the threshold, then apply a compression operation to the given digitized sample and each and every successive digitized sample after the given digitized sample and for a set time period, and when the given digitized sample is below the threshold and not within a respective set time period for a prior digitized sample exceeding the threshold, then not apply the compression operation.

9. The communications device of claim 8 wherein said audio circuitry is configured to compare each digitized sample in successive digitized samples of the set time period to an additional threshold less than the threshold, and when a digitized sample exceeds the additional threshold, then reset the set time period.

10. The communications device of claim 8 wherein said audio circuitry comprises: a compression block; a digital-to-analog

converter (DAC); a power amplifier coupled downstream from said DAC; and a switch configured to selectively pass the audio waveform signal to said DAC, either directly or through said compression block.

11. The communications device of claim 10 wherein said compression block is configured to reduce a crest factor of the audio waveform signal as an input voltage of the audio waveform signal increases.

12. The communications device of claim 10 wherein said compression block is configured to perform a fixed curve compression operation.

13. The communications device of claim 12 wherein the fixed curve compression operation is based upon a peak voltage of said speaker and a peak level of the audio waveform signal.

14. A method for operating an electronic device comprising a speaker, and audio circuitry coupled to the speaker, the method comprising: operating the audio circuitry to generate digitized samples of an audio waveform signal; operating the audio circuitry to compare each digitized sample of the audio waveform signal to a threshold, said threshold based upon peak and average limits of the speaker; and operating the audio circuitry to when a given digitized sample is above the threshold, then apply a compression operation to the given digitized sample and each and every successive digitized sample after the given digitized sample and for a set time period, and when the given digitized sample is below the threshold and not within a respective set time period for a prior digitized sample exceeding the threshold, then not apply the compression operation.

15. The method of claim 14 further comprising operating the audio circuitry to compare each digitized sample in successive digitized samples of the set time period to an additional threshold less than the threshold, and when a digitized sample

exceeds the additional threshold, then reset the set time period.

16. The method of claim 14 further comprising operating wireless circuitry to generate the audio waveform signal for input to the audio circuitry.

17. The method of claim 14 wherein the audio circuitry comprises: a compression block; a digital-to-analog converter (DAC); a power amplifier coupled downstream from the DAC; and a switch to selectively pass the audio waveform signal to the DAC, either directly or through the compression block.

18. The method of claim 17 further comprising operating the compression block to reduce a crest factor of the audio waveform signal as an input voltage of the audio waveform signal increases.

19. The method of claim 17 further comprising operating the compression block to perform a fixed curve compression operation.

20. The method of claim 19 wherein the fixed curve compression operation is based upon a peak voltage of the speaker and a peak level of the audio waveform signal.

21. The method of claim 19 wherein the fixed curve compression operation uses an output voltage lower than a peak voltage allowed by the speaker, defining a ratio of the output voltage to the peak voltage allowed by the speaker; and wherein all output voltages, after compression, are then digitally amplified by an inverse of the ratio.

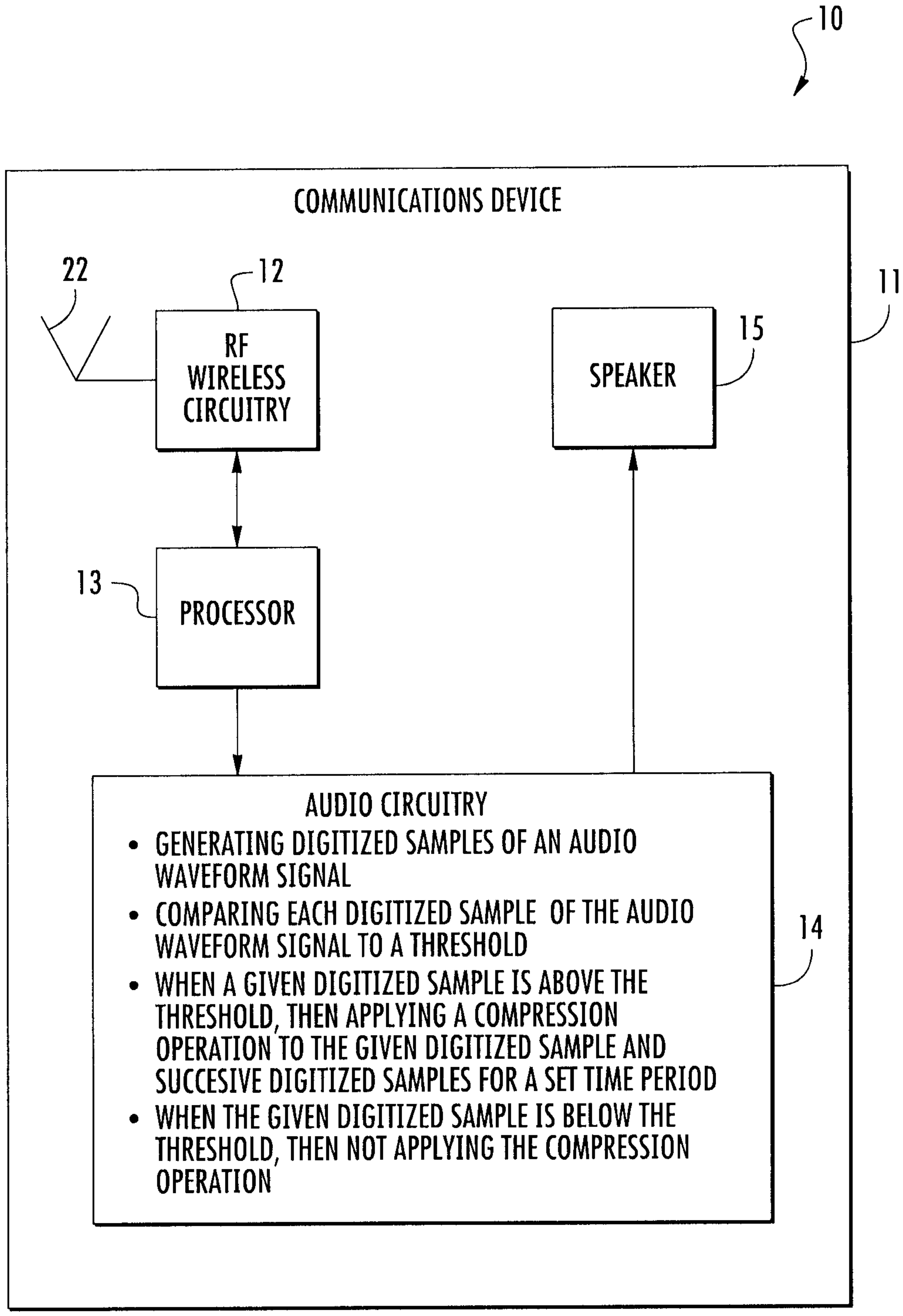

10
COMMUNICATIONS DEVICE
22
12
RF
WIRELESS
CIRCUITRY
11
SPEAKER
15
13
PROCESSOR
AUDIO CIRCUITRY
• GENERATING DIGITIZED SAMPLES OF AN AUDIO WAVEFORM SIGNAL
• COMPARING EACH DIGITIZED SAMPLE OF THE AUDIO WAVEFORM SIGNAL TO A THRESHOLD
• WHEN A GIVEN DIGITIZED SAMPLE IS ABOVE THE THRESHOLD, THEN APPLYING A COMPRESSION OPERATION TO THE GIVEN DIGITIZED SAMPLE AND SUCCESIVE DIGITIZED SAMPLES FOR A SET TIME PERIOD
• WHEN THE GIVEN DIGITIZED SAMPLE IS BELOW THE THRESHOLD, THEN NOT APPLYING THE COMPRESSION OPERATION
14

FIG. 1

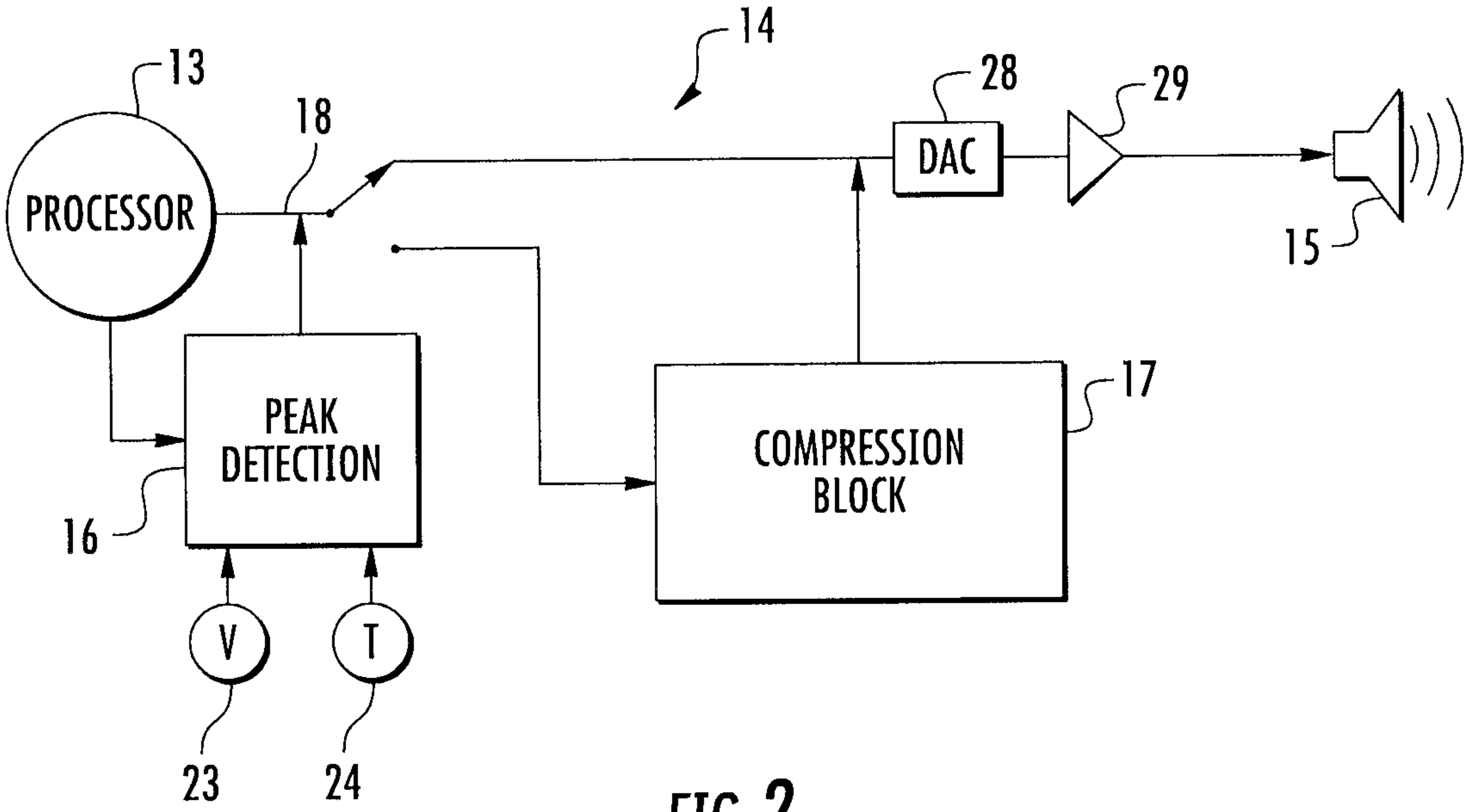
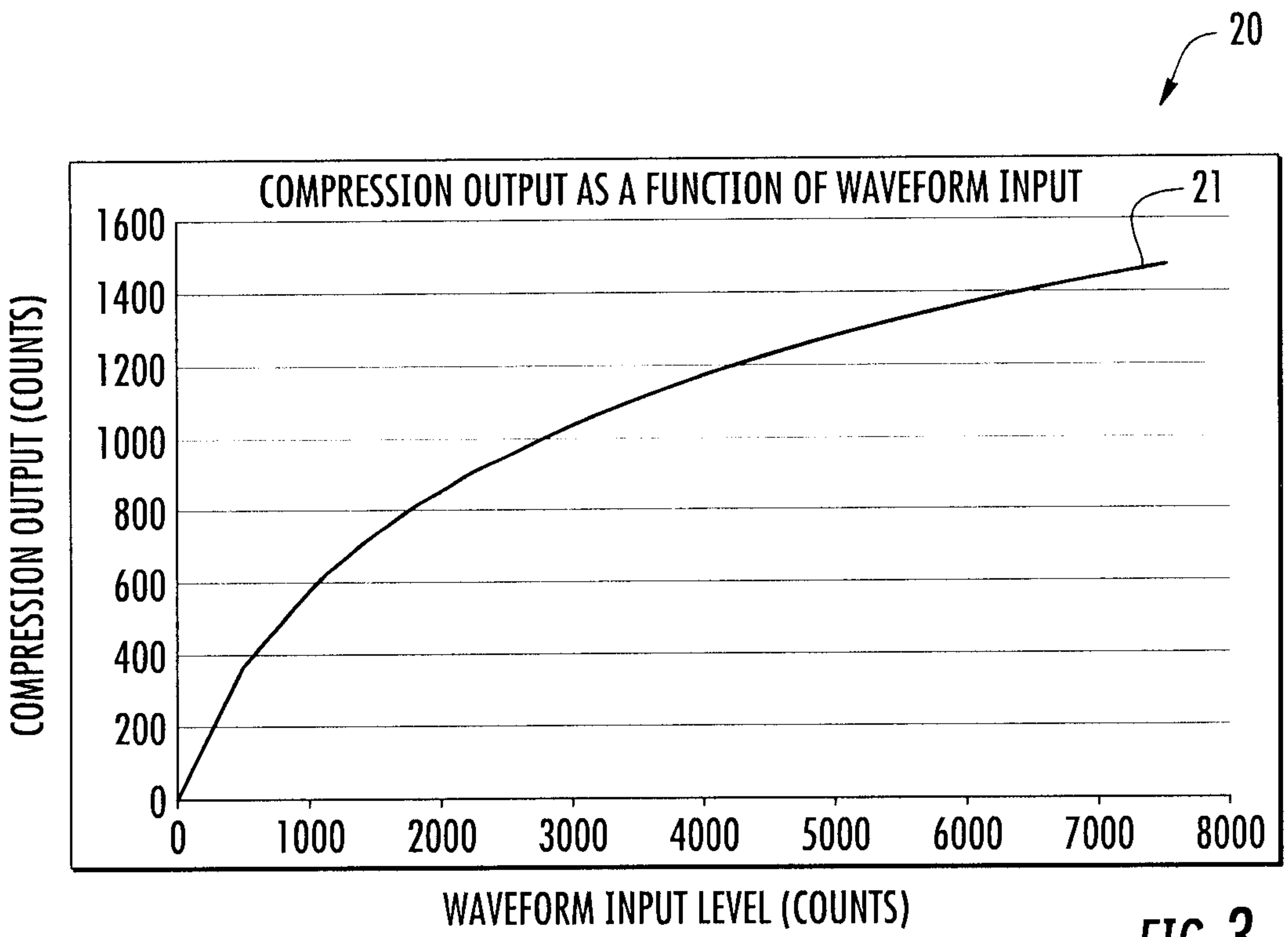

14
13
18
28
29
PROCESSOR
DAC
15
PEAK
DETECTION
COMPRESSION
BLOCK
17
16
V
T
23
24

FIG. 2


20
COMPRESSION OUTPUT AS A FUNCTION OF WAVEFORM INPUT
21
COMPRESSION OUTPUT (COUNTS)
1600
1400
1200
1000
800
600
400
200
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0
1000
2000
3000
4000
5000
6000
7000
8000
WAVEFORM INPUT LEVEL (COUNTS)

FIG. 3

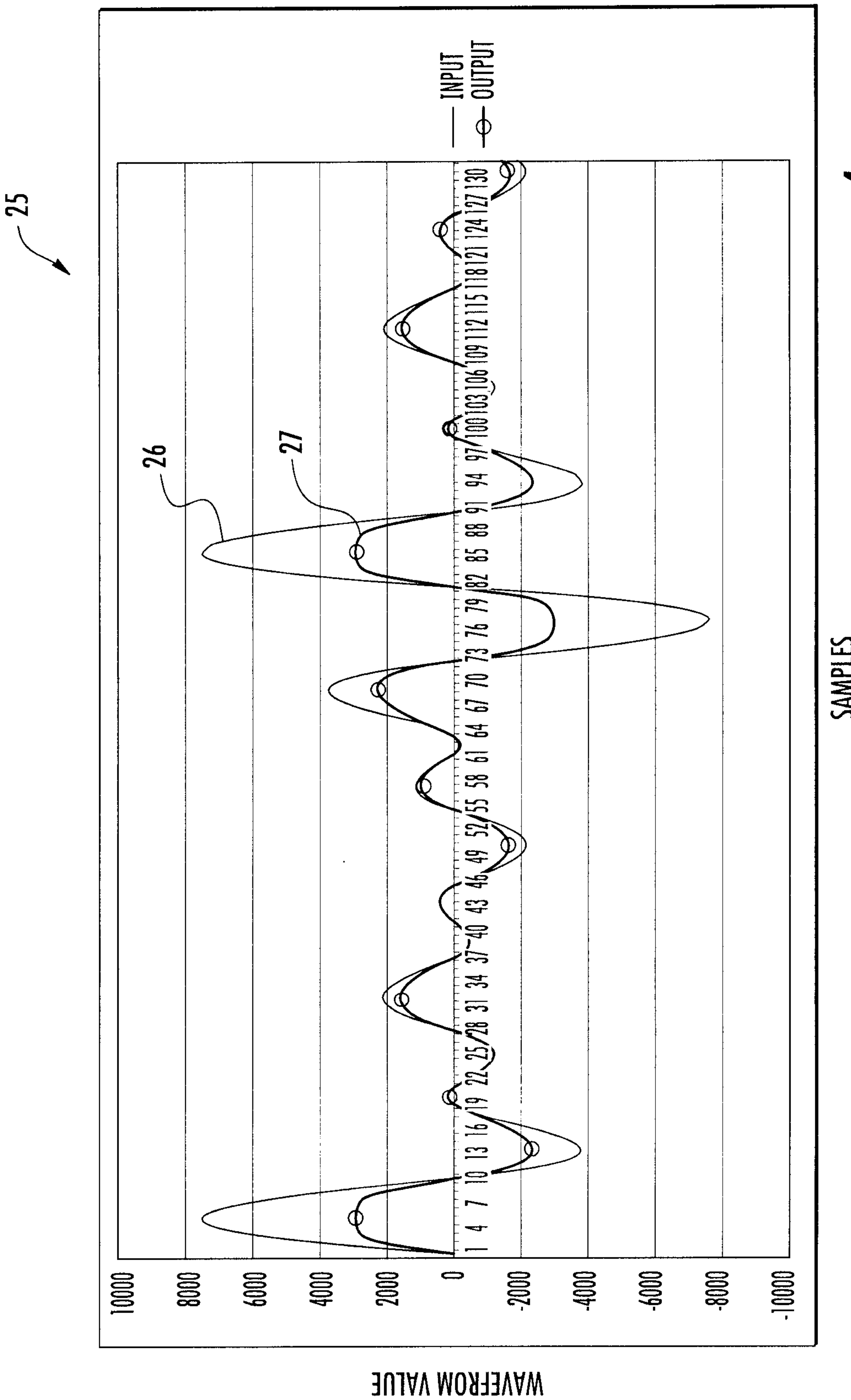
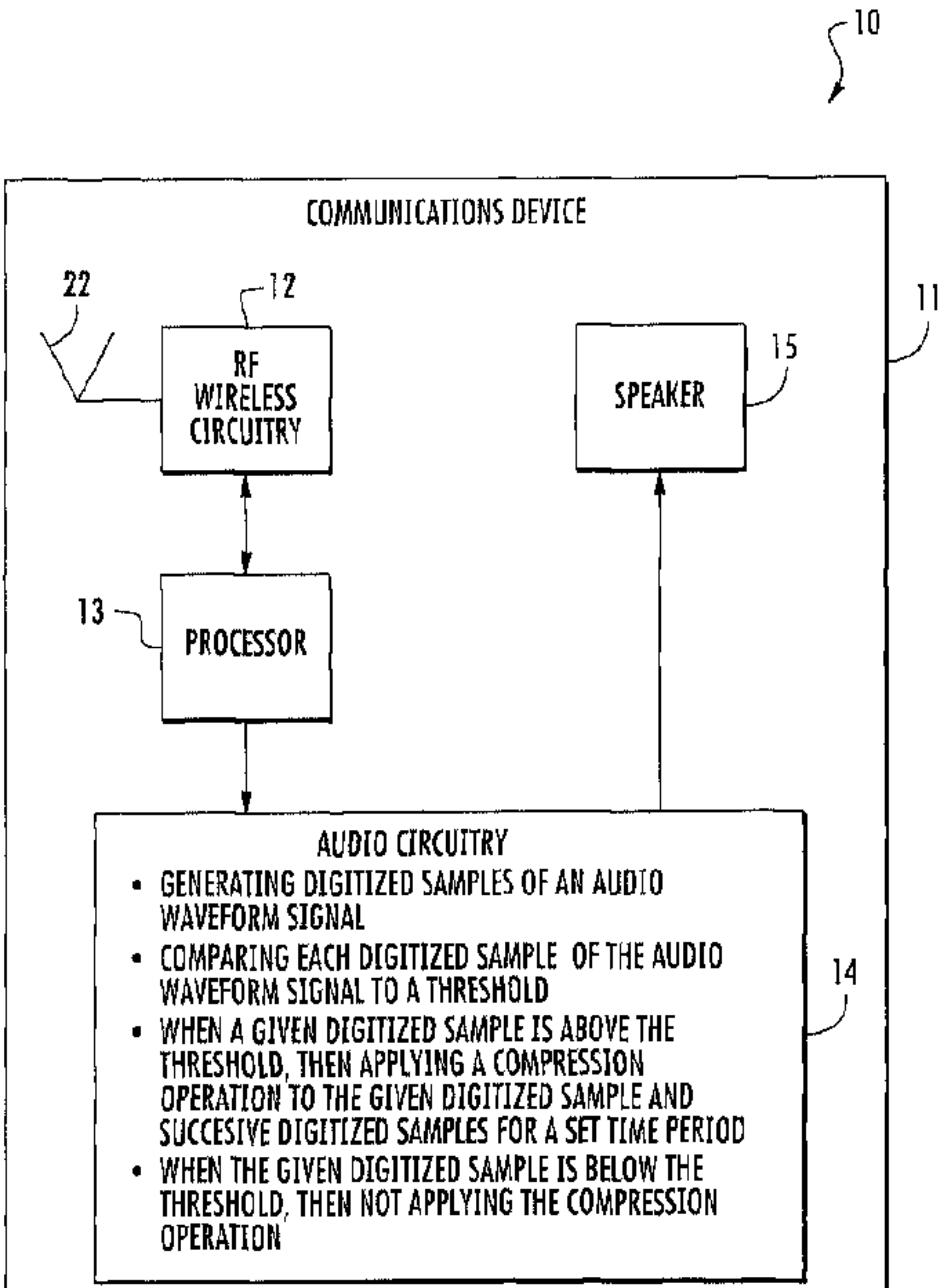

25
26
27
INPUT
OUTPUT
10000
8000
6000
4000
2000
0
-2000
-4000
-6000
-8000
-10000
1 4 7 10 13 16 19 22 25 28 31 34 37 40 43 46 49 52 55 58 61 64 67 70 73 76 79 82 85 88 91 94 97 100 103 106 109 112 115 118 121 124 127 130
SAMPLES
WAVEFROM VALUE

FIG. 4


10
COMMUNICATIONS DEVICE
22
12
11
RF WIRELESS CIRCUITRY
SPEAKER
15
13
PROCESSOR
AUDIO CIRCUITRY
• GENERATING DIGITIZED SAMPLES OF AN AUDIO WAVEFORM SIGNAL
• COMPARING EACH DIGITIZED SAMPLE OF THE AUDIO WAVEFORM SIGNAL TO A THRESHOLD
• WHEN A GIVEN DIGITIZED SAMPLE IS ABOVE THE THRESHOLD, THEN APPLYING A COMPRESSION OPERATION TO THE GIVEN DIGITIZED SAMPLE AND SUCCESIVE DIGITIZED SAMPLES FOR A SET TIME PERIOD
• WHEN THE GIVEN DIGITIZED SAMPLE IS BELOW THE THRESHOLD, THEN NOT APPLYING THE COMPRESSION OPERATION
14