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[54] **ARRANGEMENT, A SYSTEM, A CIRCUIT AND A METHOD FOR ENHANCING A STEREO IMAGE**

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[52] **U.S. Cl.** **381/1**; 381/10

[58] **Field of Search** 381/1, 22, 10, 381/11, 2, 17, 18, 13

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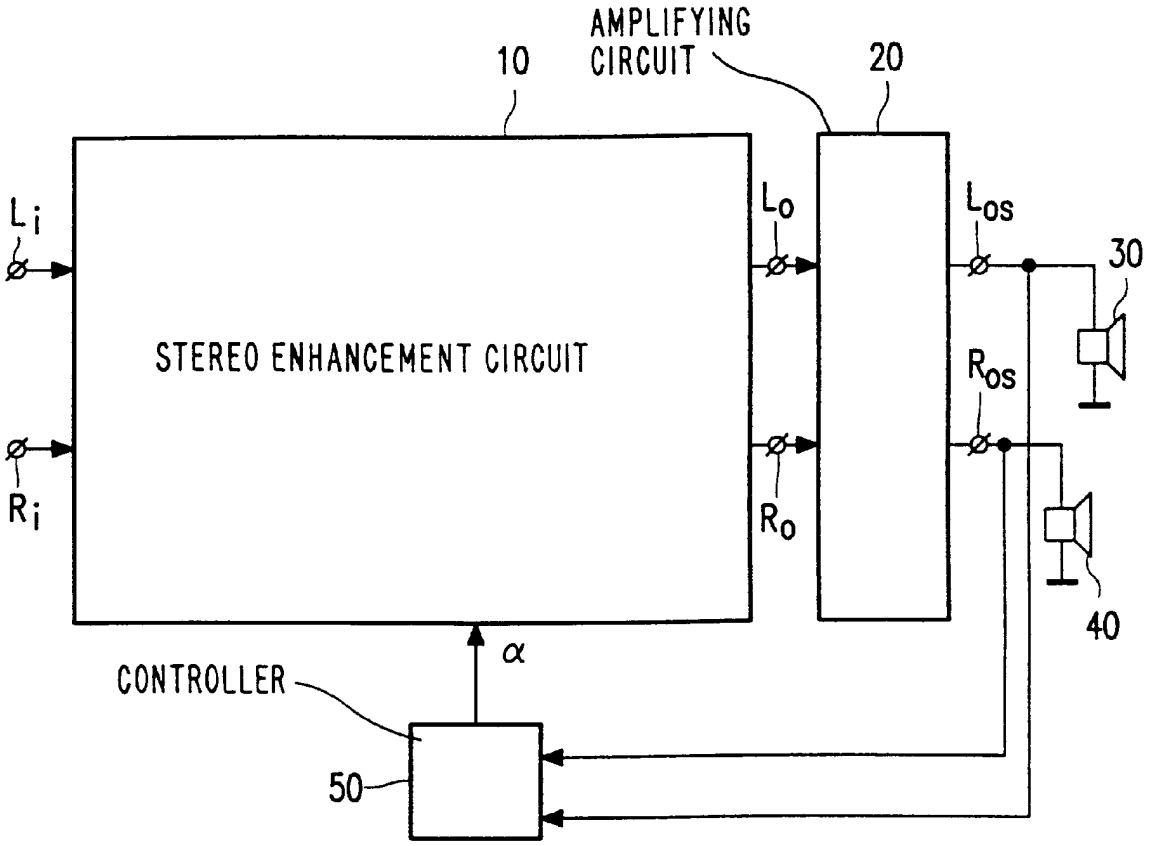
[57] **ABSTRACT**

A stereophonic audio signal processing arrangement for variably enhancing a stereo image, wherein the stereo image enhancement is reduced at high signal levels so as to reduce distortion. The arrangement is used in a stereophonic audio reproduction system for enhancing the stereo image, which system may be part of an audio-visual reproduction system.

9 Claims, 3 Drawing Sheets



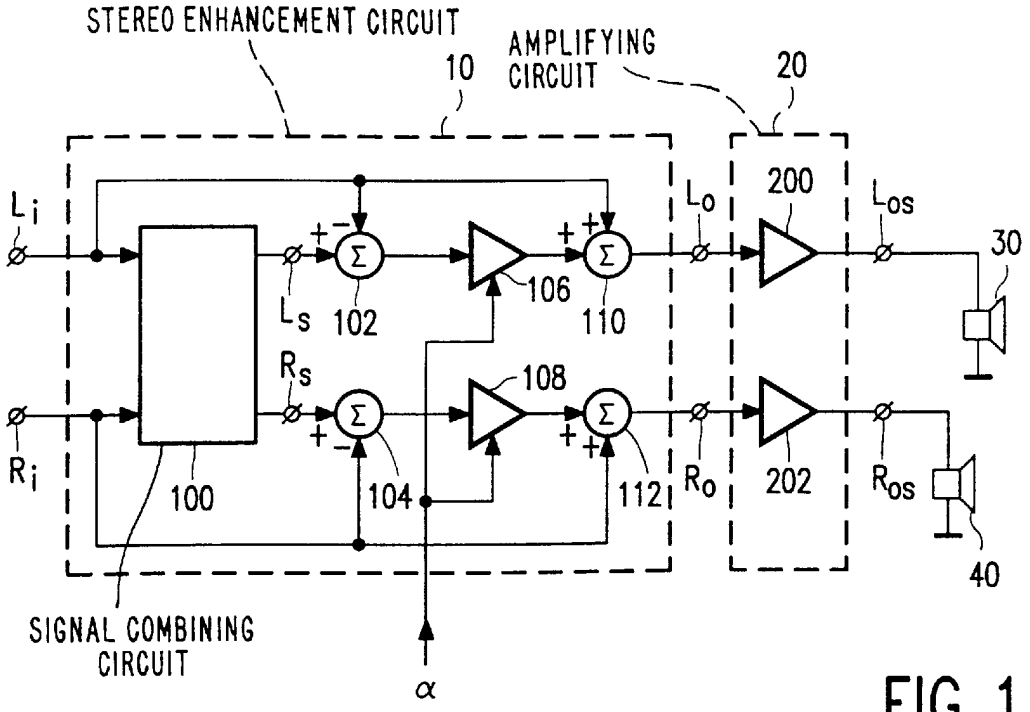


FIG. 1
PRIOR ART

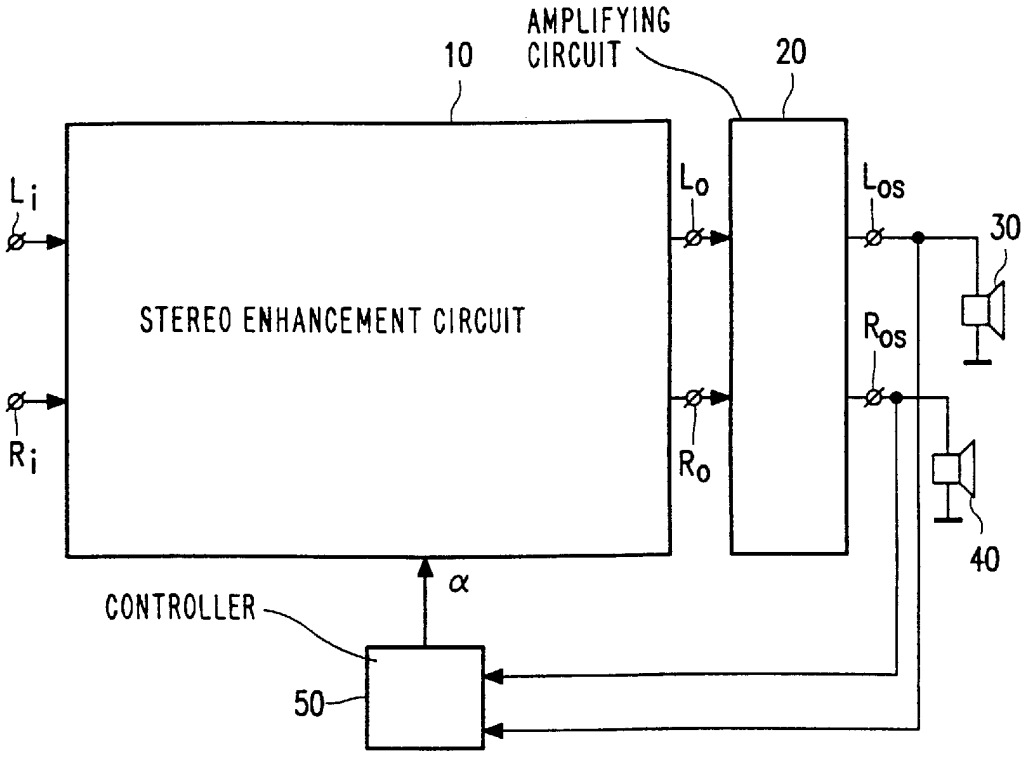


FIG. 2

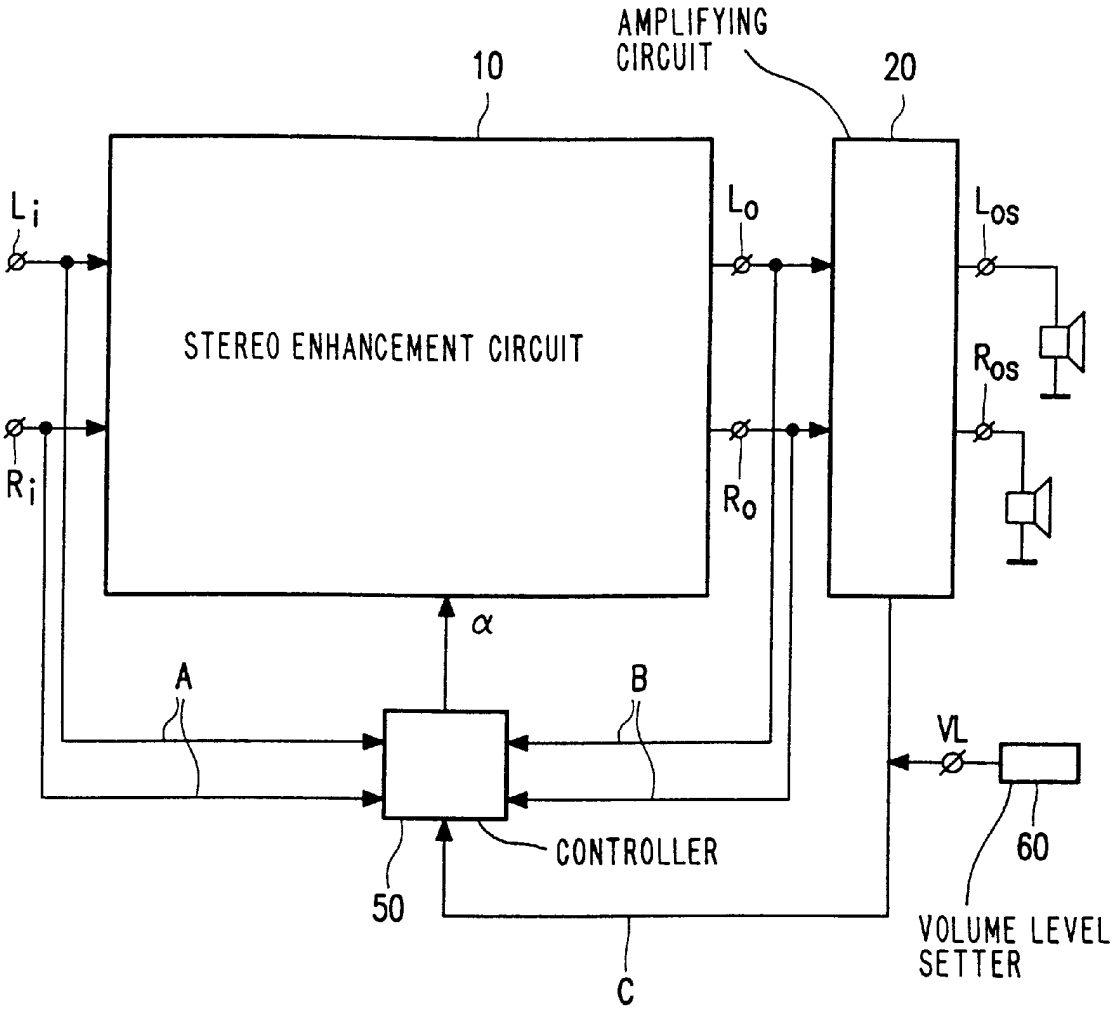

AMPLIFYING CIRCUIT
10
20
L_i
R_i
STEREO ENHANCEMENT CIRCUIT
L_o
R_o
L_{os}
R_{os}
α
A
B
VL
CONTROLLER
50
60
VOLUME LEVEL SETTER
C

FIG. 3

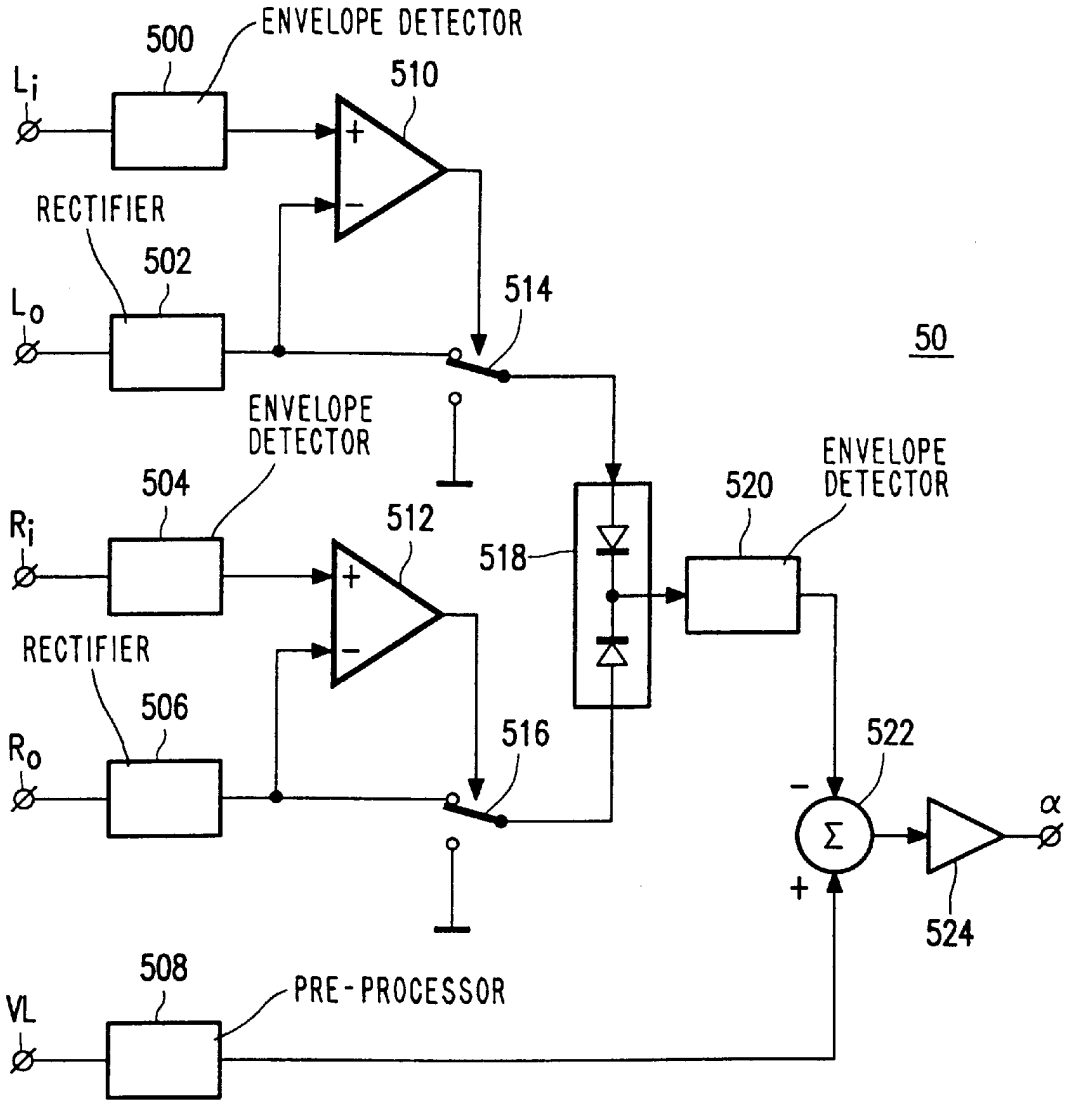

ENVELOPE DETECTOR
500
510
L_i
RECTIFIER
502
L_o
514
50
ENVELOPE DETECTOR
504
512
R_i
518
520
ENVELOPE DETECTOR
RECTIFIER
506
R_o
516
522
α
524
508
PRE-PROCESSOR
VL

FIG. 4

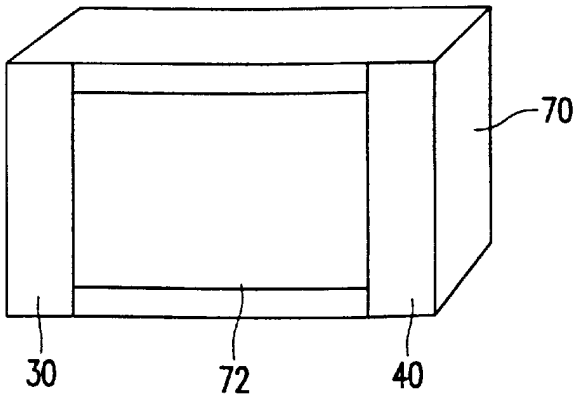

70
30
72
40

FIG. 5

ARRANGEMENT, A SYSTEM, A CIRCUIT AND A METHOD FOR ENHANCING A STEREO IMAGE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to a stereophonic audio signal processing arrangement comprising:

signal processing means, including a stereo enhancement circuit for processing a stereo input signal,

signal amplifying means for amplifying a stereo output signal supplied by the signal processing means,

said stereo enhancement circuit comprising:

first means having a first and a second input for receiving a left channel and a right channel signal of the stereo input signal and a first and a second output for supplying a left channel and a right channel signal of a stereo signal having an enhanced stereo image, and

second means for controllably combining the stereo input signal and the stereo output signal of the first means for varying the stereo image enhancement.

The invention further relates to a stereophonic audio reproduction system including such a stereophonic audio signal processing arrangement, and left channel and right channel loudspeakers for reproducing the amplified stereo signal supplied by the signal amplifying means.

The invention also relates to an audio-visual reproduction system including such a stereophonic audio reproduction system, a cabinet in which a picture display screen and the left channel and right channel loudspeakers are installed.

The invention relates to a stereo enhancement circuit.

The invention also relates to a method for enhancing a stereo image of a stereo input signal, comprising the steps of:

generating a stereo output signal having an enhanced stereo image from the stereo input signal, and

controllably combining the stereo input signal and the stereo output signal to provide a processed stereo output signal.

2. Description of the Related Art

Such an arrangement, such systems and such a circuit are known from the European Patent Application EP-A 664661, corresponding to U.S. patent application Ser. No. 08/371,187, filed Jan. 1, 1995, now U.S. Pat. No. 5,742,687. In the known arrangement the enhanced stereo signal can be mixed with the input stereo signal, for example, in a ratio $(1-\alpha):\alpha$. By varying a between 0 and 1, the amount of stereo image enhancement can be varied from conventional, or normal, stereo to fully enhanced stereo. A drawback of the known stereo image enhancement is that the amplitude of the enhanced stereo signal can be more than 10 dB larger than the amplitude of the normal, unenhanced, stereo signal, even though the loudness of the resulting acoustical signals is perceived as substantially the same. At high signal levels, this larger amplitude of the enhanced stereo signal may give rise to distortion in an amplifier following the arrangement.

SUMMARY OF THE INVENTION

An object of the present invention is to provide an arrangement which produces less distortion than the known arrangement.

An arrangement according to the invention is characterized in that the stereo enhancement circuit comprises control means coupled to the second means for controlling the combining of the stereo signals so as to reduce the stereo image enhancement at high signal levels. The invention is based on the recognition that a reduction of the stereo image enhancement of the stereo signal usually results in a reduction of the amplitude of each of the left channel and right channel signals of the enhanced stereo signal. By reducing the stereo image enhancement at high signal levels, distortion can be significantly reduced, as now the amplifier will receive signals with a reduced amplitude compared to signals having the full stereo image enhancement.

An embodiment of the invention is characterized in that the arrangement comprises volume level setting means supplying a signal representative of a volume level to the amplifying means for setting the volume level, and to the control means for controlling the combining as a function of the set volume level. The actual or set volume level of the arrangement can be used as an indication that high signal levels can be expected. By reducing the stereo image enhancement at high volume levels, i.e., as a function of the set volume level, a simple implementation of the control means is achieved without the need for measuring the actual signal levels.

A further embodiment of the invention is characterized in that the control means comprises means for comparing the signal level of the amplified stereo output signal with a reference level, and for supplying a control signal to the second means for reducing the stereo image enhancement when the signal level exceeds the reference level. By measuring the actual output signals of the amplifying means, it is possible to accurately determine if distortion is present, e.g., when the signal level exceeds a level above which the amplification becomes non-linear. This level is represented by the threshold.

A further embodiment of the invention is characterized in that the control means comprises means for comparing the signal level of the stereo output signal of the second means with a reference level, and for supplying a control signal to the second means for reducing the stereo image enhancement when the signal level exceeds the reference level. An alternative to measuring the signal level of the output signals of the amplifying means is to measure the signal level of the output signals of the second means which are to be supplied to the amplifying means. Now the control means does not need to process signals having a large amplitude resulting from the amplification by the amplifying means.

A further embodiment of the invention is characterized in that the reference level is a function of the set volume level. Headroom is the amount of extra amplification that a signal may undergo before being distorted by the amplifying means. The set volume level gives an indication of how much headroom the amplifier still has. As the volume control is normally located behind the stereo enhancement circuit, the set volume level can serve as the reference level, indicating when the stereo image enhancement should be reduced in order to avoid distortion.

A further embodiment of the invention is characterized in that the control signal is only generated if at least one of the left channel and right channel output signals of the second means exceeds the associated left channel or right channel input signal of the first means. By using this measure, the stereo image enhancement reduction only takes place if it can have a positive effect. If the output signals of the second means do not exceed the input signals of the first means, then a reduction of the stereo image enhancement will have no positive effect on distortion and the reduction should not be done at all in order to avoid any possibly detrimental effects of such a reduction.

BRIEF DESCRIPTION OF THE DRAWINGS

The above object and features of the present invention will be more apparent from the following description of the preferred embodiments with reference to the drawings, wherein:

FIG. **1** shows an embodiment of a known stereophonic audio reproduction system;

FIG. **2** shows a first embodiment of a stereophonic audio reproduction system according to the invention;

FIG. **3** shows a second embodiment of a stereophonic audio reproduction system according to the invention;

FIG. **4** shows an embodiment of control means for use in the present invention; and

FIG. **5** shows an embodiment for an audio-visual reproduction system in the form of, for example, a television set or a so-called multimedia audio-visual system. In the figures, identical parts are provided with the same reference numbers.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. **1** shows an embodiment of a known stereophonic audio reproduction system. The stereophonic audio reproduction system comprises a stereophonic processing arrangement including a stereo enhancement circuit **10** for processing a left channel and right channel input signals Ri and Li into left channel and right channel output signals Lo and Ro, respectively, and amplifying means **20** for amplifying and supplying the left channel and right channel output signals Lo and Ro to respective left channel and right channel loudspeakers **30** and **40**. Such a system is, in principle, known from EP-A 664661. The stereo enhancement circuit **10** comprises first means **100**, having a first input for receiving the left channel input signal Li, a second input for receiving the right channel input signal Ri, a first output for providing a left channel signal Ls, and a second output for providing a right channel signal Rs. The left and right channel signals Ls and Rs have an enhanced stereo image as compared to the signals Li and Ri. For a more detailed description of the first means **100**, reference is made to EP-A 664 661. The stereo enhancement circuit **10** further comprises second means for controllably combining the left channel signals Li and Ls and the right channel signals Ri and Rs. The second means comprises:

first and second subtractors **102** and **104** for providing the subtracted pairs of signals Li-Ls, and Ri-Rs, respectively, to respective controllable attenuators **106** and **108**, each having a controllable gain equal to α, wherein $0 \leqq \alpha \leqq 1$, and third and fourth adders **110** and **112** for adding the output signal of the first and second controllable attenuators **106** and **108** to signals Li and Ri, thereby providing the left channel and right channel output signals Lo and Ro. In this way the output signals Lo and Ro are formed according to the formulas:

$$Lo=\alpha*Ls+(1-\alpha)*Li$$

$$Ro=\alpha*Rs+(1-\alpha)*Ri.$$

By varying parameter α between 0 and 1 the stereo effect in the output signal formed by left channel and right channel signals Lo and Ro can be varied between a normal, i.e., conventional, stereo image for $\alpha=0$, to a fully enhanced stereo image for $\alpha=1$. The second means can be implemented in other ways as well, for example, by providing separate controllable attenuators for each of the signals Li, Ri, Ls and Rs, having respective controllable gains of $(1-\alpha)$, $(1-\alpha)$, α and α, and adding the resulting pairs of attenuated signals Li, Ls, and Ri, Rs.

For a <>0, the amplitude of each of the resulting signals Lo and Ro can be larger than the original signals Li and Ri. This difference may be as high as 12 dB or more. This is due to the fact that the stereo image enhancement is achieved by adding a significant amount of negative cross-talk to the left and right channels. When reproduced by loudspeakers, a part of these signals is acoustically cancelled as a result. The extra 12 dB gain is necessary to achieve substantially the same sound level as for normal stereo. This means that for reproduction of stereo signals having an enhanced stereo image, the amplifying means which amplifies such signals as well as the loudspeakers that reproduce these signals should have a larger dynamic range than required for normal stereo signals.

FIG. **2** shows a first embodiment of a stereophonic audio reproduction system according to the invention. FIG. **2** differs from FIG. **1** in that control means **50** have been added, the control means **50** receiving, as input signals, the left channel and right channel output signals Los and Ros of the amplifying means **20**, and supplying a control signal representing α to the signal enhancement circuit **10** for controlling the stereo image enhancement. The control means **50** are used for controlling the combining of the stereo signals so as to reduce the stereo image enhancement at high signal levels. When either signal Los or Ros exceeds a threshold value, the control signal α supplied by the control means **50** is reduced accordingly. This threshold value is the value of the output signal above which the amplification of the amplifying means **20** becomes non-linear. An advantage of this embodiment is that the control signal α is directly derived from the signals undergoing distortion.

FIG. **3** shows a second embodiment of a stereophonic audio reproduction system according to the invention. FIG. **3** differs from FIG. **2** in that volume level setting means **60** are added, and in that the control means **50** now receive three groups A, B and C, of input signals, instead of one group of signals. Group A comprises the left channel and right channel input signals Li and Ri, group B comprises the left channel and right channel output signals Lo and Ro of the signal enhancement circuit **10**, and group C comprises a signal VL representative of the volume level setting. The volume level setting means **60** supplies a signal VL representative of the volume level setting to the amplifying means **20** for setting the volume level. For this purpose, the amplifiers of the amplifying means **20** each have a controllable gain, the gain being controlled by said signal VL. The groups A, B and C can be used separately or in combination with each other for generating the control signal α. When only the group A and group C signals are used, the control means **50** calculates from the set volume level, the maximum level of an input signal applied to the amplifying means above which maximum level or threshold, the amplification becomes non-linear. This threshold value is reduced by 12 dB to take into account the extra signal level needed for reproducing the enhanced stereo signals. If the level of the input signal exceeds this maximum level or threshold, then the control means **50** reduce α accordingly. When only the group B and group C signals are used, the control means **50** differs only from the control means **50** used for group A and group C signals in that it is no longer necessary to deduct the 12 dB from the maximum level as now the output signals of the stereo enhancement circuit **10** are used instead of its input signals. If the volume level adjustment is made before

the stereo enhancement circuit **10**, the signal VL need not be used as the maximum level or threshold can now have a fixed value. In this case, the group C signal can be dispensed with. The correction, or reduction, of a need only be of the amount required to avoid this distortion. For example, when a reduction of signal level of only 6 dB is needed, α need only be reduced to 0.5. It is also possible to use only the group C signal, i.e., the signal VL representative of the set volume level. This results in a very simple solution for the control means **50** as no signal measurements take place. α will now be reduced if the set volume level is so high that an input signal having a maximum allowed signal level will undergo distortion. Of course, the 12 dB extra margin is taken into account here as well. However, this means that a may be reduced even if no distortion takes place, i.e., if the actual signal level remains below the threshold.

FIG. **4** shows an embodiment of control means for use in the present invention. The control means **50** is an improvement on the control means **50** discussed in connection with FIG. **3**. In the control means **50** of FIG. **4**, all three groups A, B and C are used for generating the control signal α. The control means **50** comprises first to fifth preprocessing means **500**, **502**, **504**, **506** and **508**, first and second comparators **510** and **512**, first and second controlled switches **514** and **516**, adding means **518**, envelope detector **520**, subtracting means **522** and amplifying means **524**. The first comparator **510**, together with the first and second preprocessing means **500** and **502** and the first controlled switch **514**, act as a selective peak detector to pass on to the adding means **518** only those peaks in the Lo signal which exceed the envelope of the Li signal. For this purpose, the signal Li is applied to the positive input of the first comparator **510** via preprocessing means **500**, in this case an envelope detector. The signal Lo is applied to both the controllable switch **514** and the negative input of the comparator **510** via preprocessing means **502**, in this case, a rectifier. When peaks in the rectified signal of Lo exceed the envelope of signal Li, the first comparator **510** activates the controlled switch **514** and the rectified signal Lo will be passed on to the adding means **518**. A similar processing of the signals Ri and Ro is performed by the second comparator **512**, together with the third and fourth preprocessing means **504** and **506** and the second controlled switch **516**. In this example, the preprocessing means **504** comprises an envelope detector and the preprocessing means **506** comprises a rectifier. In the adding means **518**, the larger of the two signals applied to the adding means **518** is passed on to an envelope detector **520**. The output signal of envelope detector **520** is then subtracted, in subtracting means **522**, from the output signal of pre-processing means **508** which receives the signal VL, which is, in its turn, representative of the set volume level. The signal resulting from the subtraction is then amplified by amplifying means **524** and is the control signal α to be supplied to the stereo enhancement circuit **10** of FIG. **3**. The signal derived from signal VL is a threshold above which the amplification in the amplifying means **20** becomes non-linear. This signal may be derived from VL as follows. At a given volume level setting, it is determined, experimentally or theoretically, at what amplitude an input signal supplied to the amplifying means **20** will be amplified non-linearly. This results in a threshold which may not be exceeded by input signals at that given volume level setting. At a new (different) volume level setting, this threshold can be recalculated using the difference between the given volume level setting and the new volume level setting. Thus, when the new volume level setting is 6 dB lower, the threshold should be increased, correspondingly, by 6 dB. In this way, the peak values of the signals Lo and Ro reduce the value of α when these peak values exceed the threshold. The use of the selective peak detectors ensure that α is only reduced when it will have an effect, i.e., when the signals Lo and Ro have larger amplitudes than the signals Li and Ri. If this were not done, α would be reduced even when it does not have any positive effect on distortion reduction. It may even be so that for some input signals, a reduction of α can result in an increase of the output signal level. This depends on the phase difference between the left and right channel input signals. This effect could result in an unstable feedback loop, but is avoided when the selective peak detectors as described previously are used. These selective peak detectors may also be used advantageously in the control means **50** of FIG. **2** for prohibiting the reduction of α when no beneficial effect can be expected from this reduction. The preprocessing means **500**, **502**, **504** and **506** may also comprise other processing than the mentioned rectification or envelope detection, for example, an averaging or peak detection, etc. The envelope detector **520** may also be replaced by other processing, such as peak detection, averaging, etc. The amplifying means **524** is used for providing sufficient loop gain in the feedback loop for controlling α. By this feedback, the time constants of the envelope detectors are apparently reduced. However, when the feedback loop is open, i.e., when controlled switches **514** and **516** are not activated to pass signals Lo and Ro, respectively, the time constants appear at their normal value. This may result in a long settling time of the system. Therefore, it may be desirable to decrease the time constants of the envelope detectors when the feedback loop is open, in particular, the time constant of the envelope detector **520**. Other methods for deriving α may also be used. For example, the signals Los and Ros may also be used in any combination with the groups A, B and/or C signals for deriving the control signal α therefrom. The control signal α may undergo additional smoothing by incorporating a low-pass filter (not shown) following the amplifier **524** of FIG. **4**. In the embodiment of FIG. **3**, the control signal α will usually be generated a little late, due to the feedback nature of the generation of the control signal α. If desired, this may be compensated by inserting delays before the amplifier **20**. The invention may also be used to increase α by increasing α such that the output signal reaches the level above which the amplification of the amplifier **20** becomes non-linear. In this way, the Incredible Sound effect may be maximized.

FIG. **5** shows an embodiment for an audio-visual reproduction system in the form of, for example, a television set or a so-called multimedia audio-visual system. The audio-visual reproduction system comprises a cabinet **70** which accommodates a picture display screen **72** for displaying video pictures. To the left of the picture display screen **72** the left channel loudspeaker **30** is positioned. The right channel loudspeaker **40** is positioned to the right of the picture display screen **72**. The left channel loudspeaker **30** and the right channel loudspeaker **40** are controlled by the stereophonic audio signal processing arrangement shown in FIG. **2** or **3**.

What is claimed is:

1. A stereophonic audio signal processing arrangement comprising:

signal processing means, including a stereo enhancement circuit, for processing a stereo input signal; and

signal amplifying means for amplifying a stereo output signal supplied by the signal processing means,

said stereo enhancement circuit comprising:

first means having a first and a second input for receiving a left channel and a right channel signal of

the stereo input signal, and a first and a second output for supplying a left channel and a right channel signal of a stereo output signal having an enhanced stereo image; and

second means for controllably combining the stereo input signal and the stereo output signal of the first means for varying the stereo image enhancement,

characterized in that the stereo enhancement circuit further comprises control means coupled to the second means for controlling the combining of the stereo input and output signals so as to reduce the stereo image enhancement at high signal levels; and

volume level setting means for supplying a signal representative of a volume level to the amplifying means for setting the volume level, and to the control means for controlling the combining as a function of the set volume level.

2. The arrangement as claimed in claim **1**, characterized in that the control means comprises means for comparing a signal level of the stereo output signal having been amplified in said amplifying means with a reference level, and for supplying a control signal to the second means for reducing the stereo image enhancement when the signal level exceeds the reference level.

3. The arrangement as claimed in claim **1**, characterized in that the control means comprises means for comparing a signal level of the stereo output signal of the second means with a reference level, and for supplying a control signal to the second means for reducing the stereo image enhancement when the signal level exceeds the reference level.

4. The arrangement as claimed in claim **2**, characterized in that the reference level is a function of the set volume level.

5. The arrangement as claimed in claim **1**, characterized in that the control signal is only generated if at least one of the left channel and right channel output signals of the second means exceeds the respective left channel or right channel input signal of the first means.

6. A stereophonic audio reproduction system including a stereophonic audio signal processing arrangement comprising:

signal processing means, including a stereo enhancement circuit, for processing a stereo input signal; and

signal amplifying means for amplifying a stereo output signal supplied by the signal processing means,

said stereo enhancement circuit comprising:

first means having a first and a second input for receiving a left channel and a right channel signal of the stereo input signal, and a first and a second output for supplying a left channel and a right channel signal of a stereo output signal having an enhanced stereo image; and

second means for controllably combining the stereo input signal and the stereo output signal of the first means for varying the stereo image enhancement,

wherein the stereo enhancement circuit further comprises control means coupled to the second means for controlling the combining of the stereo input and output signals so as to reduce the stereo image enhancement at high signal levels, and volume level setting means for supplying a signal representative of a volume level to the amplifying means for setting the volume level, and to the control means for controlling the combining as a function of the set volume level,

said stereophonic audio reproduction system further including left channel and right channel loudspeakers for reproducing the amplified stereo signal supplied by the signal amplifying means.

7. An audio-visual reproduction system including the stereophonic audio reproduction system of claim **6**, said audio visual reproduction system further including a cabinet in which a picture display screen and the left channel and right channel loudspeakers are installed.

8. A stereo enhancement circuit comprising:

first means having a first and a second input for receiving a left channel and a right channel signal of the stereo input signal, and a first and a second output for supplying a left channel and a right channel signal of a stereo signal having an enhanced stereo image; and

second means for controllably combining the stereo input signal and the stereo output signal of the first means for varying the stereo image enhancement,

characterized in that the stereo enhancement circuit further comprises:

control means coupled to the second means for controlling the combining of the stereo signals so as to reduce the stereo image enhancement at high signal levels; and

volume level setting means for supplying a signal representative of a volume level to the amplifying means for setting the volume level, and to the control means for controlling the combining as a function of the set volume level.

9. A method for enhancing a stereo image of a stereo input signal, comprising the steps:

generating a stereo output signal having an enhanced stereo image from the stereo input signal; and

controllably combining the stereo input signal and the stereo output signal to provide a processed stereo output signal, characterized in that the combining is controlled so as to reduce the stereo image enhancement at high signal levels, and the combining is controlled as a function of a set volume level.

* * * * *