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[54] **MONO-STEREO CONVERSION DEVICE, AN AUDIO REPRODUCTION SYSTEM USING SUCH A DEVICE AND A MONO-STEREO CONVERSION METHOD**

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[30] **Foreign Application Priority Data**

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[51] **Int. Cl.**[7] **H04R 5/00**

[52] **U.S. Cl.** **381/17**; 381/306

[58] **Field of Search** 381/1, 17, 18, 381/19, 22, 23, 300, 306, 307

[56] **References Cited**

FOREIGN PATENT DOCUMENTS

0190198 11/1983 Japan 381/17

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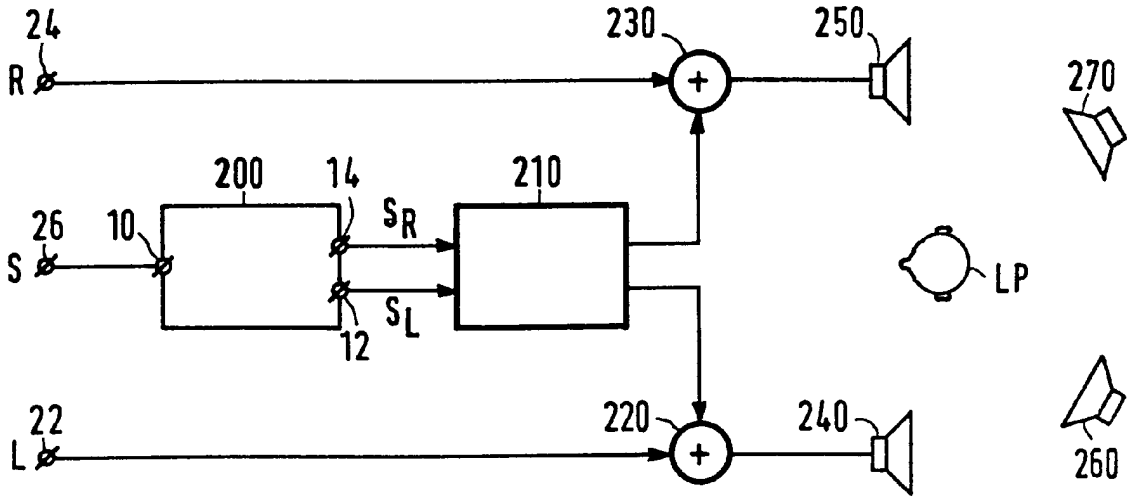
Attorney, Agent, or Firm—Edward W. Goodman

[57] **ABSTRACT**

The invention provides a method and a device for converting a monaural signal into a stereo signal by selectively allocating frequency bands of the input signal to left or right outputs. In this way, some instruments will be present only in the left output and others only in the right output.

8 Claims, 2 Drawing Sheets



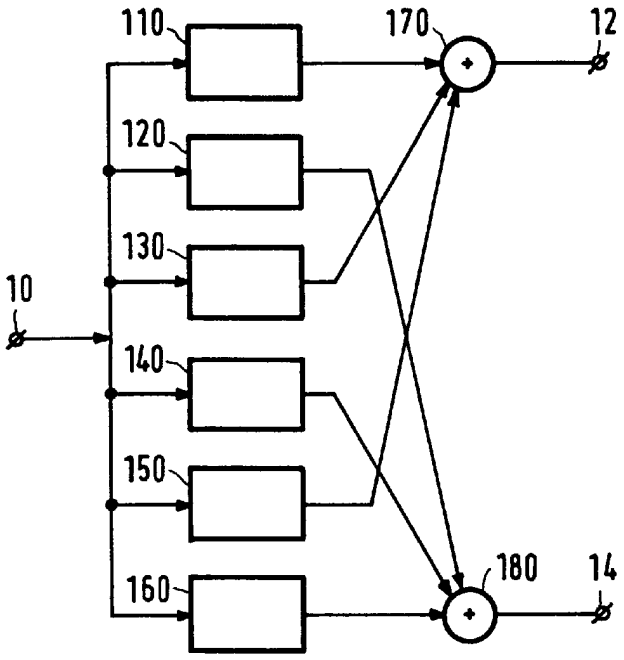


FIG.1

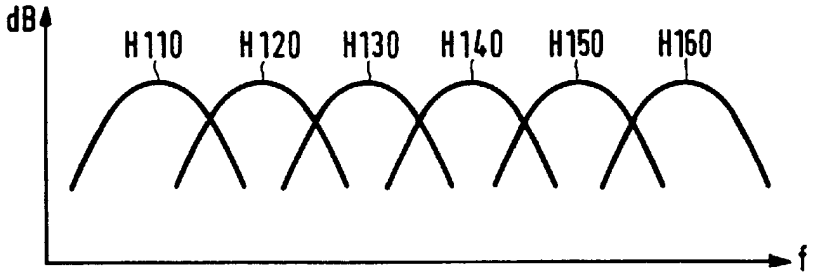


FIG.2

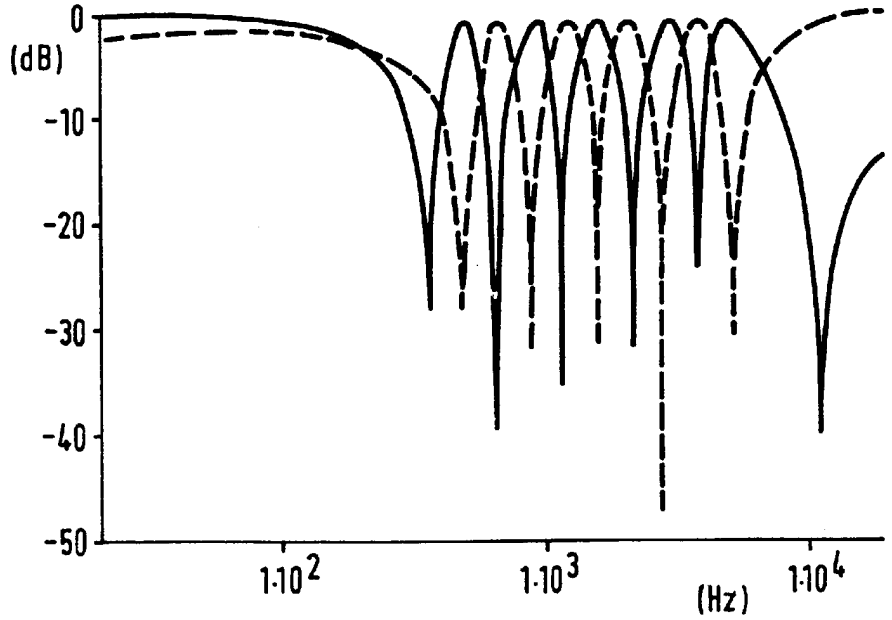


FIG.3

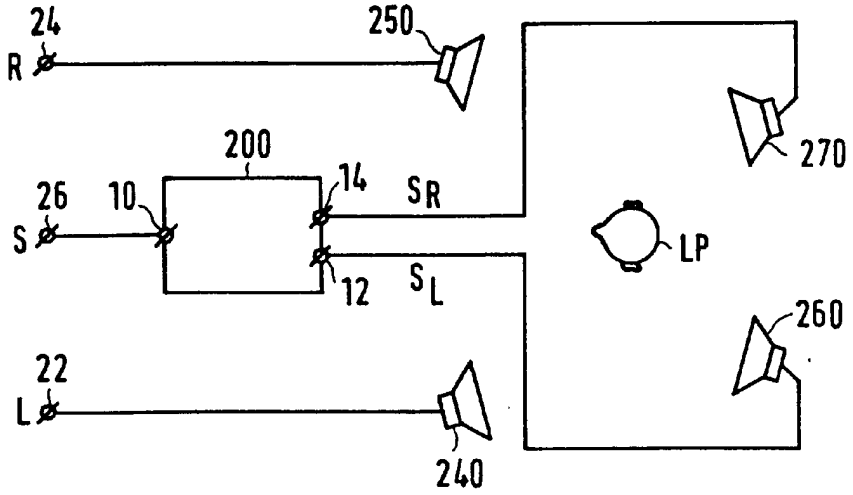


FIG.4

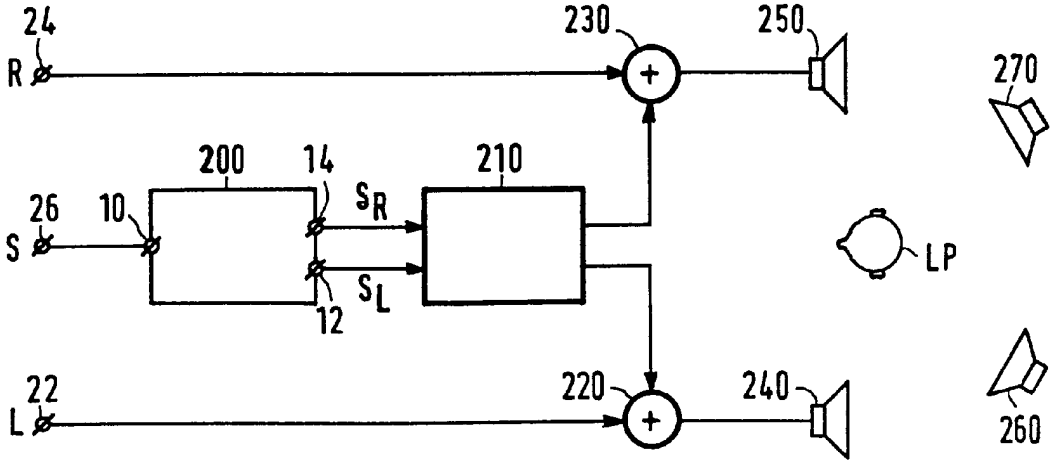


FIG.5

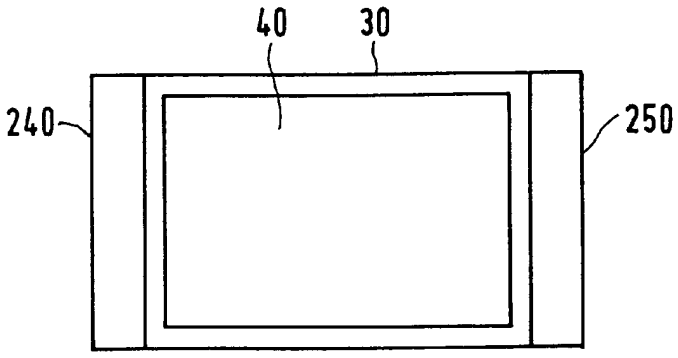


FIG.6

MONO-STEREO CONVERSION DEVICE, AN AUDIO REPRODUCTION SYSTEM USING SUCH A DEVICE AND A MONO-STEREO CONVERSION METHOD

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to a device comprising an input for receiving an input signal, a first output for supplying a left channel output signal, and a second output for supplying a right channel output signal.

The invention also relates to an audio reproduction system comprising an audio signal processing circuit including a left channel input, a right channel input, a surround channel input, a left channel output and a right channel output, left channel and right channel loudspeakers coupled to the left channel and right channel outputs, respectively, the circuit comprising the aforementioned device, having the input coupled to the surround channel input, the circuit further comprising localizing means having first and second inputs coupled to the first and second outputs of the device, respectively, for localizing output signals of the device at virtual sound sources located away from the left channel and right channel loudspeakers.

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

The invention also relates to a method for processing an input signal into a left channel and a right channel output signal.

2. Description of the Related Art

Present-day audio sets are arranged for reproducing stereo signals. However, not all signal sources are able to provide stereo signals. For instance, some television or radio stations do not broadcast stereo audio signals. This results in a distinct audible difference in the reproduction of monaural signals with respect to stereo signals. It is known to provide some kind of mono to stereo conversion in order to provide the illusion to a listener that a stereo signal is reproduced. However, the illusion of stereo generated with these devices is usually rather limited or results in a coloring of the sound due to the use of phase shifts and/or delays.

SUMMARY OF THE INVENTION

An object of the invention is to provide a device for reproducing a monaural signal as stereo signals with an improved stereo illusion.

A device according to the invention is characterized in that the device comprises means for dividing a predetermined frequency range of the first signal into a plurality of adjacent frequency bands, supplying a first selection of frequency bands to the first output and supplying a second selection of frequency bands to the second output, the first and second selections being substantially disjunct, a sum of the first and second selections covering the predetermined frequency range.

The invention is based on the recognition that the spectral content of a musical instrument is mainly present in only a limited frequency band. Different instruments may thus be present in different frequency bands of the audio signal. By dividing the spectrum of the audio signal into a plurality of adjacent frequency bands and by passing non-identical or substantially disjunct selections of the frequency bands to respective left and right outputs, the musical instruments present in the audio signal are then located in either the left or the right output signal. In this way, an improved illusion of stereo is created.

An embodiment according to the invention is characterized in that the means are arranged for alternately supplying consecutive frequency bands to the first and second outputs, respectively. In this way, a more or less balanced distribution of frequency bands is realized, resulting in a pleasant quasi-stereo image.

An embodiment according to the invention is characterized in that the center frequency of a frequency band is substantially twice the center frequency of a lower numbered adjacent frequency band. By selecting the center frequencies of adjacent frequency bands to differ by a factor of two, it is possible to achieve an adequate separation of musical instruments.

A further embodiment according to the invention is characterized in that the means are arranged for supplying frequencies lower than a lower limit of the predetermined frequency range to both first and second outputs.

Low frequencies are less easy to localize in the sound field and therefore it is not necessary to divide these low frequencies into separate frequency bands. In a preferred embodiment, the lower limit is in the order of 400 Hz.

Another embodiment according to the invention is characterized in that the means are arranged for supplying frequencies higher than an upper limit of the predetermined frequency range to both first and second outputs. Similar to the situation for low frequencies, there is no need to provide filtering for high frequencies, as, due to the short wavelength, a small movement of the head will already result in a difference between sounds perceived by the left and the right ear of a listener and localizing cues provided by placing these frequencies in either left or right channel output signal are not useful.

Utilization of the device according to the invention is especially advantageous in the reproduction of surround sound. Surround sound usually comprises a front left channel, a front right channel and a rear surround channel. By using the device according to the invention in audio reproduction systems suitable for surround sound reproduction, for converting the single rear surround channel into two stereo-like rear surround channels, the illusion of surround sound is greatly enhanced.

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 a mono-stereo conversion device according to the invention,

FIG. **2** shows a diagram of the amplitude-vs-frequency transfer curves of the bandpass filters used in the device according to the invention;

FIG. **3** shows a diagram of alternative amplitude-vs-frequency transfer curves from the input to the outputs of the device according to the invention;

FIG. **4** shows a diagram of a first embodiment of an audio reproduction system comprising a device in accordance with the invention;

FIG. **5** shows a diagram of a second embodiment of an audio reproduction system;

FIG. **6** shows an embodiment for an audio-visual reproduction system in the form of, for example, a television set.

In the figures, identical parts are provided with the same reference numbers.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In a lot of countries, audio signals are broadcast as stereo signals including a left channel and a right channel signal. Present-day receivers, both for radio and television receivers, are arranged for reproducing stereo signals. However, not all broadcasts are in stereo. In these situations, it is desirable to derive from these monaural broadcasts in some way stereo audio signals. Often devices are used which include delays or phase shifters to obtain an illusion of stereo. A drawback is that these devices often color the audio signal, i.e., some frequencies appear to be accentuated more than others.

The present invention provides a device for converting a monaural signal into a left channel and a right channel stereo, which uses a different approach for creating an illusion of stereo. By dividing the spectrum of the monaural signal into adjacent frequency bands and creating two new signals from two disjunct selections of these bands a quasi-stereo sound is obtained.

FIG. **1** shows a mono-stereo conversion device according to the invention. The device comprises a plurality of bandpass filters **110** . . . **160**, having their inputs coupled to input **10** for receiving an input signal. Outputs of bandpass filters **110**, **130** and **150** are coupled to a first adder **170**, which supplies the added output signals of the bandpass filters **110**, **130** and **150** to the first output **12** for providing a left channel output signal. Outputs of bandpass filters **120**, **140**, and **160** are supplied to a second adder **180**, which supplies the added output signals of these bandpass filters to the second output **14** for providing a right channel output signal. The transfer characteristics of the bandpass filters **110** . . . **160** are preferably chosen such that when the output signals of all the bandpass filters **110** . . . **160** are added, the resulting transfer function would show a substantially flat curve over most of the audio frequency range.

FIG. **2** shows a diagram of the amplitude-vs-frequency transfer curves of the bandpass filters used in the device according to the invention. H**110**, H**120**, H**130**, H**140**, H**150** and H**160** are the amplitude-versus-frequency transfer curves of bandpass filters **110**, **120**, **130**, **140**, **150** and **160**, respectively. Preferably the center frequencies of adjacent bandpass filters differ by a factor of **2**. This means that the center frequency of bandpass filter **140** is twice the centre frequency of bandpass filter **130**, which is in its turn, twice the center frequency of bandpass filter **120**. For example, the center frequency of bandpass filter **110** is around 150 Hz, the center frequency of bandpass filter **120** is 300 Hz, etc. Preferably the bandwidth of each bandpass filter is around **1** octave wide.

The invention is based on the recognition that the spectral content of most instruments is mainly present in a limited frequency range. This means that a quasi stereo image can be obtained by passing a first part of the spectrum to the left output **12**, which first part may contain a guitar, and a second part of the spectrum of the input signal to the right output **14**, this second part may contain for example, a base guitar or other low-frequency instruments. Thus, by dividing the spectrum of the input signal into adjacent frequency bands and distributing these bands between the left output and the right output, a stereo image is realized at the left and right outputs, **12** and **14**. Thus, at the left or first output a first selection of frequency bands is present, and at the right or second output, a second selection of frequency bands is present. These first and second selections should not be identical, although some frequency bands may be present in both outputs. In fact, the first and second selections may be disjunct. However, the sum of the first and second selections should cover the frequency range of the input signal, at least for a predetermined part of it. Due to the fact that no extra phase shifts or delays are used to obtain the mono-stereo conversion, there is hardly any coloring of the sound field due to this mono-stereo conversion. This is an advantageous feature.

FIG. **3** shows a diagram of alternative amplitude-vs-frequency transfer curves from the input to the outputs of the device according to the invention. The solid curve, for example, shows the transfer curve from the input **10** to the first output **12** and the dashed curve shows the transfer curve from the input **10** to the second output **14**. In a predetermined frequency range from around 400 Hz to approximately 10 kHz, it is clear to see that certain frequency bands are passed on only to the first output **12** and others only to the second output **14**. Peaks in one curve coincide with dips in the other curve. The allocation of frequency bands to the first or second output may be done on an alternating basis: the first band is passed to the first output, the second band to the second output, the third band to the first output, etc. In this way, the structure resembles a comb-like filter structure.

For frequencies below a 400 Hz lower limit of the predetermined frequency range, no such selection is needed as it is very difficult for a listener to locate the direction of these low-frequency signal components. Therefore these low-frequency components may be present at both first and second outputs **12** and **14**, as they do not contribute to the stereo image. For frequencies above a 10 kHz upper limit of the predetermined frequency range, a small movement of the head may already result in different perception of direction of the signal. For Dolby surround signals, the upper limit may even be at 5–7 kHz as the frequency range of the surround signal is already restricted to this upper limit. This means that those high frequencies also do not need to be part of the selections and they may be present in both outputs if so desired, as they also do not contribute significantly to the stereo image. This means, in fact, that, for example, filter **110** can be implemented as a low-pass filter and, for example, filter **160** as a high-pass filter. The curves of FIG. **3** were realized using 6 second-order digital filters.

FIG. **4** shows a diagram of a first embodiment of an audio reproduction system comprising a device in accordance with the invention. The audio reproduction system is suitable for multi-channel audio signal reproduction and comprises, for this purpose, a first input **22** for receiving a left channel input signal L, a second input **24** for receiving a right channel input signal R and a third input **26** for receiving a third input signal, for example, a surround input signal S. These three input signals may be supplied by, for example a Dolby ProLogic decoder or other surround sound decoders. The first input **22** is coupled to a front left channel loudspeaker **240**. The second input **24** is coupled to a front right channel loudspeaker **250**. The third input **26** is coupled to input **10** of the conversion device **200**, which is the device according to the invention, for example, as shown in FIG. **1**. The first output **12** of the device is coupled to a rear left channel loudspeaker **260** and the second output **14** is coupled to a rear right channel loudspeaker **270**. The mono-stereo conversion device **200** converts the monaural surround input signal S into a left channel surround signal S**1** and a right channel surround signal Sr. The left and right channel

surround signals are then reproduced by loudspeakers **260** and **270** arranged behind or next to a listening position LP. By converting the monaural surround signal S into stereo surround signals **S1** and Sr the surround sound image is increased. In this embodiment, localization means are arranged for localizing the signals **S1** and Sr away from the loudspeakers **240** and **250**. These localization means are implemented by the extra loudspeakers **260** and **270** arranged behind the listening position.

FIG. **5** shows a diagram of a second embodiment of an audio reproduction system. FIG. **5** differs from FIG. **4** in that:

- rear loudspeakers **260** and **270** are deleted,
- localizing means **210** are provided for localizing the left and right surround signals **S1** and Sr at predetermined speaker angles when reproduced through front loudspeakers **240** and **250**,
- first adding means **220** is provided for adding the left channel input signal L and the localized left channel surround signal **S1** and supplying the sum to the left channel loudspeaker **240**,
- second adding means **230** for adding the right channel input signal R and the localized right channel surround signal Sr and supplying the sum to the left channel loudspeaker **240**.

Now the localization means comprises the first and second adding means **220** and **230**, localizing means **210** and in fact the front loudspeakers **240** and **250**. The localizing means **210** are arranged for localizing surround signals **S1** and Sr at virtual speaker positions **260** and **270** as indicated in FIG. **5**. This is done using head-related transfer functions, which is a well-known technique for localizing signals as coming from phantom sources located away from the actual loudspeakers and will therefore not be discussed in detail. Other localizing means may also be used, such as stereo enhancement circuits as known from European Patent Application EP-A 664661. In general, by using the localizing means **210** in this way, it is possible to use only front loudspeakers, and still achieve a surround sound field. This also applies to true **4**-channel surround sound systems, wherein the surround sound is built up from a front left channel, a front right channel, a rear left surround channel and a rear right surround channel. For **3**-channel surround systems, the mono-stereo conversion provides a more spatial or increased surround effect. An advantage of the use the device **200** according to the invention is that it does not color the sound. This makes it especially suitable for use in combination with localizing means **210**. In these embodiments, no attention is given to the possible presence of a front center channel in a surround sound system, as this is not part of the present invention.

FIG. **6** shows an embodiment for an audio-visual reproduction system in the form of, for example, a television set. The audio-visual reproduction system comprises a cabinet **30** which accommodates a picture display screen **40** for displaying visual images. To the left of the picture display screen **40** the left loudspeaker **240** is positioned. The right channel loudspeaker **250** is arranged to the right of the picture display screen. The loud-speakers **240** and **250** are controlled by the audio signal reproduction arrangement of FIG. **5**. In this way, a compact set-up is realized for an audio-visual reproduction system, while still achieving the improved surround sound field.

It will be evident that the device of FIG. **1** can also be used in conventional stereo television sets or audio sets for converting monaural audio signals into stereo audio signals. Furthermore, it is possible to use the device in combination with stereo enhancement circuits as, for example, known from EP-A 664 661.

It will be further evident that the filters may be implemented analog or digital. The order of the filters may be chosen at will, although second-order filter have proven to perform satisfactorily. The number of filters used may also be determined freely and is not restricted to the number of six filters as shown in FIG. **1**.

The invention can be used not only in television sets, but also in multi-media sets, sound cards for computer systems, portable audio equipment, etc.

What is claimed is:

1. An audio reproduction system comprising an audio signal processing circuit including a left channel input, a right channel input, a surround channel input, a left channel output and a right channel output, left channel and right channel loudspeakers coupled to the left channel and right channel outputs, respectively, the audio signal processing circuit comprising a device having an input for receiving an input signal, a first output for supplying a left channel output signal, and a second output for supplying a right channel output signal, characterized in that the device comprises:

means for dividing a predetermined frequency range of the input signal into a plurality of adjacent frequency bands; and

means for supplying a first selection of said frequency bands to the first output, and for supplying a second selection of said frequency bands to the second output, the first and second selections being substantially disjunct, a sum of the first and second selections covering the predetermined frequency range, the input of said device being coupled to the surround channel input, the audio signal processing circuit further comprising localization means having first and second inputs coupled to the first and second outputs of the device, respectively, for localizing output signals of the device at virtual sound sources located away from the left channel and right channel loudspeakers.

2. The audio reproduction system as claimed in claim **1**, characterized in that the supplying means alternately supplies consecutive frequency bands to the first and second outputs, respectively.

3. The audio reproduction system as claimed in claim **1**, characterized in that the center frequency of a frequency band is substantially twice the center frequency of a lower numbered adjacent frequency band.

4. The audio reproduction system as claimed in claim **1**, characterized in that the supplying means supplies frequencies lower than a lower limit of the predetermined frequency range to both of said first and second outputs.

5. The audio reproduction system as claimed in claim **4**, characterized in that lower limit is in the order of 400 Hz.

6. The audio reproduction system as claimed in claim **1**, characterized in that the supplying means supplies frequencies higher than an upper limit of the predetermined frequency range to both of said first and second outputs.

7. The audio reproduction system as claimed in claim **6**, characterized in that the upper limit is in the order of 10 kHz.

8. An audio/visual reproduction system including the audio reproduction system as claimed in claim **1**, and a cabinet in which a picture display screen and the left channel and right channel loudspeakers are installed.

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