

**Device and method for improving stereophonic or  
pseudo-stereophonic audio signals**

The invention relates to audio signals and  
apparatuses or methods for the generation,  
5 transmission, conversion and reproduction thereof.

It is general knowledge that audio signals  
which are emitted via two or more loudspeakers provide  
the listener with a spatial impression, provided that  
they show different amplitudes, frequencies, time or  
10 phase differences or are reverberated appropriately.

Methods are also known for converting a mono  
signal into two different audio signals which give the  
impression of a stereo signal. These solutions to this  
problem are used particularly in order to convert  
15 monophonic audio signals into audio signals which are  
suggestive of a real or fictitious spatiality to the  
ear. When a pair of different, partially correlated  
audio signals is generated from a mono signal, this is  
referred to as "pseudo-stereophony".

20 EP0825800 (Thomson Brandt GmbH) proposes the  
formation of different kinds of signals from a mono  
input signal by means of filtering, which signals are  
used - for example by using a method proposed by  
Lauridsen based on amplitude and time difference  
25 corrections, depending on the recording situation - to  
generate virtual single-band stereo signals separately,  
these subsequently being combined to form two output  
signals.

EP2124486 and EP1850639 describe, by way of  
30 example, a method for methodically evaluating the angle  
of incidence for the sound event that is to be mapped,  
said angle of incidence being enclosed by the main axis

of the microphone and the directional axis for the sound source, this being achieved by applying time differences and amplitude corrections which are functionally dependent on the original recording situation (which may be interpolated by using the system). The content of EP2124486 and of EP1850639 is hereby introduced as a reference.

US5173944 (Begault Durand) applies HRTFs (Head Related Transfer Functions) which correlate with 90, 120, 240 and 270 degrees azimuth, respectively, to the varyingly delayed but uniformly amplified monophonic input signal, the signals formed in turn being finally superimposed on the original mono signal. In this case, the amplitude correction and the time difference corrections are chosen independently of the recording situation.

Some pseudo-stereophonic signals show increased "phasiness", that is to say distinctly perceptible time differences between both channels. Frequently, the degree of correlation between both channels also is too low (lack of compatibility) or too high (undesirable convergence towards a mono sound). Pseudo-stereophonic, but also stereophonic, signals may therefore show deficiencies due to lacking or excessive decorrelations between the emitted signals.

It is therefore an aim of the invention to solve this problem and to align stereophonic (including pseudo-stereophonic) signals or, conversely, to differentiate them to a greater extent.

It is another aim to improve, to generate, to transmit, to convert or to reproduce stereophonic and pseudo-stereophonic audio signals.

#### Disclosure of the Invention

The invention is used to solve these problems inter alia by means of the ostensibly not purposeful downstream connection of a panoramic potentiometer in an apparatus for pseudo-stereo conversion.

5           Panoramic potentiometers (also called pan pots or panoramic controllers) are known per se and are used for intensity stereophonic signals, that is to say for stereo signals which differ exclusively in terms of their levels but not in terms of time or phase  
10 differences or different frequency spectra. The circuit principle of a known panoramic potentiometer is shown in FIGURE 1. The device has an input 101 and two outputs 202, 203 which are connected to the buses 204, 205 for the group channels L (left audio channel) and R  
15 (right audio channel). In the center position (M), both buses receive the same level; in the side positions to the left (L) and to the right (R), the signal is routed only to the left bus or to the right bus, respectively. In the intermediate positions, a panoramic  
20 potentiometer produces level differences which correspond to the different positions of the phantom source on the sound stage.

Figure 2 shows the attenuation curve for the left channel and the right channel of a panoramic  
25 potentiometer without an extended stereo width range, and corresponding mapping angles. In the center position, the attenuation in each channel is 3 dB, the acoustic convolution thereby producing the same perception of level as would be with only one channel  
30 in the L or R position.

Panoramic potentiometers, as they represent voltage dividers, are able, for instance, to distribute the left channel in a different, selectable ratio to the resulting left output and to the resulting right  
35 output (these outputs are also called buses) or in the

same way to distribute the right channel in a different, selectable ratio to the same left output and to the same right output (the same buses). Therefore, in the case of intensity stereophonic signals, the mapping width can be narrowed and the direction of such signals can be shifted.

In the case of pseudo-stereophonic signals, which make use of time or phase differences, different frequency spectra or reverberation (and also in the case of stereo signals of such kind in general), such narrowing of the mapping width or shifting of the mapping direction are not possible by using a panoramic potentiometer. Application of panoramic potentiometers to such signals is therefore fundamentally disregarded intendedly.

In line with the invention, however, it has been unexpectedly - and contrary to experience to date - found that the previously unknown downstream connection of a panoramic potentiometer downstream to a circuit for pseudo-stereo conversion affords unexpected advantages. Although such downstream connection cannot result in the aforementioned narrowing of the mapping width or in the shifting of the mapping direction of the stereo signals obtained, the degree of correlation between the left signal and the right signal can be increased or else lowered in this way by using such a panoramic potentiometer.

In one preferred embodiment, a respective panoramic potentiometer is connected downstream to the left output and to the right output of the circuit for obtaining a pseudo-stereophonic signal. In this case, the buses of both panoramic potentiometers are preferably used collectively and preferably identically.

In this arrangement, each panoramic potentiometer has an input and two outputs. The input of a first panoramic potentiometer is connected to a first output of the circuit, and the input of a second panoramic potentiometer is connected to a second output of this circuit. The first output of the first panoramic potentiometer is connected to the first output of the second panoramic potentiometer. The second output of the first panoramic potentiometer is connected to the second output of the second panoramic potentiometer.

Alternatively and equivalently, rather than using panoramic potentiometers, the degree of correlation can also be adjusted by using a first circuit for pseudo-stereo conversion having an MS matrix and an amplifier, connected upstream to the MS matrix, for amplifying an input signal for the MS matrix, this being achieved without a panoramic potentiometer. Equivalent adjustment of the degree of correlation can therefore be implemented with fewer components.

Alternatively and equivalently, rather than using a panoramic potentiometer, the degree of correlation can also be varied by using a second circuit, this being achieved with a modified MS matrix which contains an adder and a subtractor in order to add or subtract, respectively, input signals (M, S), which are respectively amplified by predetermined factors, in order to generate signals which are identical to the bus signals from the panoramic potentiometers. Equivalent adjustment of the degree of correlation can therefore be implemented with even fewer components.

The invention can also be applied to apparatuses or methods which generate signals which are

reproduced by more than two loudspeakers (for example surround sound systems belonging to the prior art).

#### Brief Description of the Figures

5 Various embodiments of the present invention are described by way of example below, with reference being made to the following drawings:

- FIGURE 1 shows the circuit principle of a known panoramic potentiometer.
- 10 - FIGURE 2 shows the attenuation curve of the left channel and of the right channel of a panoramic potentiometer without an extended stereo width range, and corresponding mapping angles.
- 15 - FIGURE 3 shows a first embodiment of the invention, in which, respectively, the left channel L' and the right channel R' resulting from the MS matrixing are each fed to a panoramic potentiometer for collective buses L and R.
- 20 - FIGURE 4 shows a second embodiment of the invention.
- FIGURE 5 shows a third embodiment of the invention.
- 25 - FIGURE 6 shows a fourth embodiment of the invention with a circuit which is equivalent to FIGURE 3 having a slightly modified MS matrix, which renders direct downstream connection of panoramic potentiometers superfluous.

5 - FIGURE 7 shows a circuit which is equivalent to FIGURE 3 or FIGURE 6, provided that the relation  $\lambda = \rho$  is true for the inversely proportional attenuations  $\lambda$  and  $\rho$  of the panoramic potentiometers shown in FIGURE 3.

- FIGURE 8 shows an enhanced circuit based on FIGURE 7 for normalizing the level of the output signals from the MS matrix.

10 - FIGURE 9 shows an example of a circuit which, as an enhancement to FIGURE 8, maps given signals  $x(t)$ ,  $y(t)$  as the sum of the transfer functions  $f^*[x(t)] = [x(t)/\sqrt{2}] * (-1 + i)$  and  $g^*[y(t)] = [y(t)/\sqrt{2}] * (1 + i)$  on the complex number plane.

15 - FIGURE 10 shows the example of a circuit which, as an enhancement to FIGURE 9, stipulates the mapping width of a stereo signal.

20 - FIGURE 11 shows an example of an input circuit for an already existing stereo signal  $L^\circ$ ,  $R^\circ$  prior to transfer to a circuit as shown in FIGURE 12 (for determining the localization of the signal) which maps  $L^\circ$ , that is to say  $l(t)$ , and  $R^\circ$ , that is to say  $r(t)$ , as the sum of the transfer functions  $f^*[l(t)] = [l(t)/\sqrt{2}] * (-1 + i)$  and  $g^*[r(t)] = [r(t)/\sqrt{2}] * (1 + i)$  on the complex number plane.

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30 - FIGURE 12 shows a circuit for determining the localization of the signal, the inputs of which circuit may be connected to the outputs in FIGURE 10 or to the outputs in FIGURE 11.

Detailed description of various embodiments of  
the subject matter of the invention

Figures 3 to 5 show various embodiments of a circuit according to the invention in which a  
5 respective panoramic potentiometer 311 and 312, 411 and 412, 511 and 512 is connected directly downstream to a pseudo-conversion circuit 309, 409 and 509, respectively. In each example shown here, the pseudo-conversion circuit 309, 409 or 509 comprises a  
10 circuit having an MS matrix 310, 410 or 510, as described in EP2124486 and likewise in EP1850639.

This panoramic potentiometer 311 and 312, 411 and 412, 511 and 512 can be used to increase or lower the degree of correlation of the resulting buses L 304,  
15 404, 504 and R 305, 405, 505. Accordingly, the left channel L' 302, 402, 502 and the right channel R' 303, 403, 503 resulting from the MS matrixing are fed to a respective panoramic potentiometer for collectively used buses L and R.

20 If the attenuation  $\lambda$  for the left input signal L' for the panoramic potentiometer 311, 411 or 511 and the attenuation  $\rho$  for the right input signal R' for the panoramic potentiometer 312, 412, 512 with a stereo signal 302 and 303, 402 and 403, 502 and 503 resulting  
25 from an apparatus 309, 409 or 509 is limited to the range between 0 and 3 dB, the inversely proportional relations

$$1 \geq \lambda \geq 0$$

30 and

$$1 \geq \rho \geq 0$$

may be introduced (where 1 corresponds to the value 0 dB and 0 corresponds to the value 3 dB).

5  $\lambda$  and  $\rho$  therefore correspond to the inversely proportional attenuations of the panoramic potentiometers shown in FIGURE 3 to FIGURE 5, limited to the range between 0 and 3 dB.

Therefore, the following relations are obtained for the resulting stereo signals (buses) L and R (304 and 305, 404 and 405, 504 and 505) and, respectively, 10 the output signals L'' 313, 413, 513 and R'' 314, 414, 514 from the panoramic potentiometer 311, 411, 511 and the output signals L''' 315, 415, 515 and R''' 316, 416, 516 from the panoramic potentiometer 312, 412, 15 512:

$$(1) \quad L = L'' + L''' = \frac{1}{2} * L' (1 + \lambda) + \frac{1}{2} * R' (1 - \rho)$$

and

$$(2) \quad R = R'' + R''' = \frac{1}{2} * L' (1 - \lambda) + \frac{1}{2} * R' (1 + \rho)$$

20 Figure 6 shows a further embodiment with a circuit equivalent to FIGURE 3 having a slightly modified MS matrix, which renders direct downstream connection of panoramic potentiometers superfluous. Taking account of the equivalences of the MS matrixing

$$25 \quad L' = (M + S) * 1/\sqrt{2}$$

and

$$R' = (M - S) * 1/\sqrt{2},$$

the following relations are obtained:

$$(1) \quad L = [M (2 + \lambda - \rho) + S (\lambda + \rho)] * 1/2\sqrt{2}$$

$$(2) \quad R = [M (2 - \lambda + \rho) - S (\lambda + \rho)] * 1/2\sqrt{2}$$

This allows the signals on the buses L and R to  
 5 be also derived directly from the input signals M and S  
 for the MS matrixing circuit.

If  $\lambda = \rho$  (the same attenuation in the left  
 channel and in the right channel), the following  
 relations are true:

$$10 \quad (3) \quad L = (M + \lambda * S) * 1/\sqrt{2}$$

$$(4) \quad R = (M - \lambda * S) * 1/\sqrt{2}$$

i.e. the variation in the amplitude of the  
 15 signal S is equivalent to the downstream connection of  
 a respective panoramic potentiometer for identical  
 attenuation in the left channel and in the right  
 channel. Under these assumptions, the output signals L  
 and R correspond to the bus signals L and R in FIGURE  
 20 3.

Therefore, a circuit or a method is obtained  
 showing the form in FIGURE 6, for example (trivial  
 modifications being possible), which forms a composite  
 signal from the M signal, amplified by the factor  $(2 +$   
 25  $\lambda - \rho)$ , and the S signal, amplified by the factor  $(\lambda +$   
 $\rho)$ , and also a difference signal which is compiled from  
 the M signal, amplified by the factor  $(2 - \lambda + \rho)$ ,  
 minus the S signal, amplified by the factor  $(\lambda + \rho)$ ,  
 with correction by the factor  $1/2\sqrt{2}$  needing to be  
 30 performed overall in order to obtain signals L and R  
 equivalent to formulae (1) and (2).

FIGURE 7 shows a circuit equivalent to FIGURE 3 and FIGURE 6, provided that the relationship  $\lambda = \rho$  is true for the inversely proportional attenuations  $\lambda$  and  $\rho$  of the panoramic potentiometers shown in FIGURE 3.

5 This circuit should not be confused with the arrangement known from intensity stereophony (MS microphone technique) for altering the recording or opening angle (which does not take place here!).

In this case, it is assumed that uniform  
 10 attenuation for proposed panoramic potentiometers or modified MS matrix, as just illustrated, is frequently sufficient for aligning or differentiating stereo signals. When  $\lambda = \rho$ , the apparatus just illustrated is then simplified on the basis of the above formulae (3)  
 15 and (4) according to:

$$(3) \quad L = (M + \lambda * S) * 1/\sqrt{2}$$

$$(4) \quad R = (M - \lambda * S) * 1/\sqrt{2}$$

20

which is equivalent to simple amplitude correction of the S signal (717).

Such amplitude correction for the S signal has been known to date only for the classical MS microphone  
 25 technique and in the ideal range results in the alteration of the recording or opening angle in that case, which does not take place here. A transfer of the same action principle is not possible (and an application of the MS microphone technique to the  
 30 present circuit is accordingly not obvious).

In FIGURE 7, the S signal is therefore additionally amplified by the factor  $\lambda$  ( $1 \geq \lambda \geq 0$ ) prior to finally passing through the MS matrix. The resulting stereo signal is equivalent to the bus  
 5 signals 304 and 305 in FIGURE 3, 404 and 405 in FIGURE 4 and 504 and 505 in FIGURE 5 for uniform attenuation and to the output signal L and R in FIGURE 6, provided that  $\lambda = \rho$  is true in that case.

In practice, this circuit or method can be used  
 10 to exactly stipulate the degree of correlation, i.e. there is a direct functional relationship between the attenuation  $\lambda$  and the degree of correlation  $r$ , for which ideally

$$0.2 \leq r \leq 0.7$$

15

is true. For  $\lambda$ , a series of experiments has found

$$0.07 \leq \lambda \leq 0.46$$

to be favorable for most applications.

20 In particular, artifacts (such as disturbing time differences, phase shifts, or the like) can be eliminated without difficulty by using this apparatus or method, whether manually or automatically (algorithmically).

25 On the basis of the equivalence of downstream panoramic potentiometers with uniform attenuation and amplitude correction of the S signal by the factor  $\lambda$  ( $1 \geq \lambda \geq 0$ ) prior to final MS matrixing, it is therefore possible to achieve convincing pseudo-stereophony  
 30 which, on the basis of the original mono signal, grants the listener a comprehensive, albeit extremely simple,

post processing option, while fundamentally maintaining the compatibility and avoiding disturbing artifacts.

This apparatus can be used in telephony, for example, in the area of professional post processing of audio signals or else in the area of high quality electronic consumer goods, the aim of which is extremely simple but efficient handling.

#### Narrowing or expanding of the mapping width

For this application, the additional use of compression algorithms or data reduction methods which are part of the prior art or the consideration of characteristic features, such as the minima or maxima for the pseudo-stereophonic signals obtained, is recommended in order to speed up evaluation thereof in accordance with the invention.

Of particular interest (for example for reproducing stereophonic signals in automobiles) is the subsequent narrowing or expanding of the mapping width of the stereo signal obtained by using the specific variation of the degree of correlation  $r$  of the resulting stereo signal or, respectively, the attenuations  $\lambda$  or else  $\rho$  (for forming the resulting stereo signal). The previously determined parameters  $f$  (or, respectively,  $n$ ) which describe the directional pattern of the signal that is to be rendered stereophonic, the angle  $\phi$  - to be ascertained manually or by metrology - enclosed by the main axis and the sound source, the fictitious left opening angle  $\alpha$  and the fictitious right opening angle  $\beta$  can be retained in this case, and it makes sense that now only final amplitude correction is necessary, for example as per

the logic element 120 in FIGURE 8, provided that this narrowing or expanding of the mapping width is performed manually.

5            If this is intended to be automated, series of psychoacoustic experiments show that a constant mapping width for stereophonic output signals  $x(t)$ ,  $y(t)$  or complex transfer functions thereof

10    (5)    $f^*[x(t)] = [x(t)/\sqrt{2}] * (-1 + i)$

          (6)    $g^*[y(t)] = [y(t)/\sqrt{2}] * (1 + i)$

is essentially dependent on the criterion

15

$$(7) \quad 0 \leq S^* - \varepsilon \leq \max |\operatorname{Re} \{f^*[x(t)] + g^*[y(t)]\}| \leq S^* + \varepsilon \leq 1$$

and also on the criterion

20

$$(8) \quad 0 \leq U^* - \kappa \leq \int_{-T}^T |f^*[x(t)] + g^*[y(t)]| dt \leq U^* + \kappa$$

25    (where  $S^*$  and  $\varepsilon$  or, respectively,  $U^*$  and  $\kappa$  need to be stipulated differently for telephone signals, for example, than for music recordings). Accordingly, it is now necessary to determine only suitable function values  $x(t)$ ,  $y(t)$  which are dependent on the degree of  
30    correlation  $r$  of the resulting stereo signal or, respectively, on the attenuations  $\lambda$  or else  $\rho$  (for the formation of the resulting stereo signal) or on a logic element 120 in FIGURE 8, in accordance with an

iterative operating principle which is based on feedback.

The arrangement according to the invention can  
 5 accordingly be enhanced as follows within the context of an arrangement, for instance, of the form shown in FIGURES 8 to 10:

An output signal resulting from an arrangement as shown  
 10 in FIGURES 1 to 7 is in this case amplified uniformly by a factor  $\rho^*$  (amplifiers 118, 119 in FIGURE 8) such that the maximum of both signals has a level of exactly 0 dB (normalization on the unit circle of the complex number plane). By way of example, this is achieved by  
 15 the downstream connection of a logic element 120 which varies or corrects the gain factor  $\rho^*$  of the amplifiers 118 and 119 via the feedback loops 121 and 122 until the maximum level for the left channel and for the right channel is 0 dB.

20

In a further step, the resulting signals  $x(t)$  (123) and  $y(t)$  (124) are now fed to a matrix in which, following respective amplification by the factor  $1/\sqrt{2}$  (amplifiers 229, 230 in FIGURE 9), they are split into a respective  
 25 identical real and imaginary part, with the real part formed from the signal  $x(t)$ , amplified by means of 229, additionally passing through the amplifier 231 with the gain factor -1. Therefore, the transfer functions

30 (5)  $f^*[x(t)] = [x(t) / \sqrt{2}] * (-1 + i)$

and

$$(6) \quad g^*[y(t)] = [y(t) / \sqrt{2}] * (1 + i)$$

are obtained.

- 5 The respective real and imaginary parts are now summed and therefore produce the real part and the imaginary part of the sum of the transfer functions  $f^*[x(t)] + g^*[y(t)]$ .
- 10 An arrangement, for example based on the logic element 640 in FIGURE 10, now needs to be connected downstream, which arrangement checks, for a limit value  $S^*$  - suitably selected by the user with respect to the mapping width of the stereo signal that is to be
- 15 achieved - or a suitably selected deviation  $\varepsilon$  - both defined by the inequality (7) - whether the condition

$$(7) \quad 0 \leq S^* - \varepsilon \leq \max_1 |\operatorname{Re} \{ f^*[x(t)] + g^*[y(t)] \}| \leq S^* + \varepsilon \leq 1$$

- 20 is met. If this is not the case, a feedback loop 641 is used to determine a new optimized value for the degree of correlation  $r$  or, respectively, the attenuations  $\lambda$  or else  $\rho$  (for the formation of the resulting stereo
- 25 signal), and the previous steps just described, as illustrated in FIGURES 8 to 10, are performed until the above condition (7) is met.

- The input signals for the logic element 640 are now
- 30 transferred to an arrangement, for example based on the logic element 642 in FIGURE 10. Such arrangement finally analyzes the relief of the function  $f^*[x(t)] +$

$g^*[y(t)]$  for the purpose of optimizing the function values in terms of the mapping width of the stereo signal that is to be achieved, the user being able to suitably select the limit value  $U^*$  and the deviation  $\kappa$ ,  
 5 both defined by the inequality (8), with respect to the mapping width of the stereo signal that is to be achieved. Overall, the condition

$$(8) \quad 0 \leq U^* - \kappa \leq \int |f^*[x(t)] + g^*[y(t)]| dt \leq U^* + \kappa$$

10

must be met. If this is not the case, a feedback loop  
 643 is used to determine a new optimized value for the degree of correlation  $r$  or, respectively, for the attenuations  $\lambda$  or else  $\rho$  (for the formation of the  
 15 resulting stereo signal), and the previous steps just described, as illustrated in FIGURES 8 to 10, are performed until the relief of the function  $f^*[x(t)] +$   
 $g^*[y(t)]$  satisfies the desired optimization of the function values with respect to the mapping width  
 20 taking account of the limit value  $U^*$  and the deviation  $\kappa$ , both suitably chosen by the user.

In terms of the mapping width - determined by the degree of correlation  $r$  or, respectively, the  
 25 attenuations  $\lambda$  or else  $\rho$  (for the formation of the resulting stereo signal) - the signals  $x(t)$  (123) and  $y(t)$  (124) therefore correspond to the specifications by the user and represent the output signals  $L^{**}$  and  $R^{**}$  from the arrangement which has just been described.

30 The present considerations remain valid as an entity even if a different reference system than the unit circle of the imaginary plane is chosen. By way of example, instead of normalizing function values, it is

also possible to normalize the axis length in order to reduce the computing time accordingly.

#### Stipulation of the mapping direction

Occasionally, it is also important to mirror  
 5 the stereophonic mapping obtained about the main axis  
 of the directional pattern on which the stereophonic  
 processing is based, since, for instance,  
 mirror-inverted mapping in relation to the main axis  
 occurs. This can be achieved manually by swapping the  
 10 left channel and the right channel.

If an already existing stereo signal  $L^\circ$ ,  $R^\circ$  is  
 to be mapped by the present system, the correct mapping  
 direction can also be ascertained automatically on  
 behalf of the phantom sources generated by means of the  
 15 illustrated pseudo-stereophonic methodology, by way of  
 example, as is shown in FIGURE 12 (which is directly  
 connected downstream with FIGURE 10, whereas FIGURE 11  
 may likewise be added to FIGURE 12 for determining the  
 sum of the complex transfer functions  $f^*(l(t_i)) +$   
 20  $g^*(r(t_i))$  for the already existing stereo signal  $L^\circ$ ,  
 $R^\circ$ ; cf. the explanations relating to FIGURE 9). In this  
 case, at suitably chosen times  $t_i$  (for which not all of  
 the subsequently cited correlating function values of  
 the transfer functions  $f^*(x(t_i)) + g^*(y(t_i))$  or,  
 25 respectively,  $f^*(l(t_i)) + g^*(r(t_i))$  may be equal to zero  
 for at least one case), the already ascertained  
 transfer function  $f^*(x(t_i)) + g^*(y(t_i))$  as shown in  
 FIGURE 9 is compared with the transfer function  
 $f^*(l(t_i)) + g^*(r(t_i))$  of the left signal  $l(t)$  and the  
 30 right signal  $r(t)$  of the original stereo signal  $L^\circ$ ,  $R^\circ$ .  
 If these transfer functions range in the same quadrant  
 or in the diagonally opposite quadrant of the complex  
 number plane, the total number  $m$  of function values  
 from the cited transfer functions which are located in  
 35 the same quadrant or in the diagonally opposite

quadrant of the complex number plane is increased by 1 in each case.

An empirically (or statistically ascertained) stipulatable number  $b$ , which should be less than or equal to the number of correlating function values of the transfer functions  $f^*(x(t_i)) + g^*(y(t_i))$  and  $f^*(l(t_i)) + g^*(r(t_i))$  unequal to zero, now stipulates the number of necessary matches. Below this number, the left channel  $x(t)$  and the right channel  $y(t)$  of the stereo signal resulting, for example, from an arrangement as shown in FIGURES 8-10 are swapped.

If an originally stereophonic signal is to be encoded into a mono signal plus the function  $f$  describing the directional pattern (or, respectively, the simplifying parameter  $n$  of said function) and likewise the parameters  $\phi$ ,  $\alpha$ ,  $\beta$ ,  $\lambda$  or  $\rho$  (for example for the purpose of data compression) (for an exemplary output 640a which may be enhanced by the parameter  $z$ , see below), it makes sense to jointly encode the information regarding whether the resulting left channel and the resulting right channel need to be swapped (for example expressed by the parameter  $z$ , which takes the value 0 or 1).

With slight modifications, similar circuits to the circuits shown in FIGURES 11 and 12 can be constructed which can be connected directly downstream with FIGURE 3 or 4 or 5 or 6 or 7 or else can be used at another location within the electrical circuit or algorithm.

Obtaining stable FM stereo signals by using the present invention, being an example for the evaluation of an existing stereo signal which can be reproduced by two or more loudspeakers.

The invention is also of particular importance in connection with the obtaining of stable FM stereo signals under bad reception conditions (for example in automobiles). In this case, it is possible to achieve

5 stable stereophony by simply using the main channel signal  $(L + R)$  as an input signal, which is the sum of the left channel and the right channel of the original stereo signal. The complete or incomplete subchannel signal  $(L - R)$ , which is the result of subtracting the

10 right channel from the left channel of the original stereo signal, can also be used in this case in order to form a useable S signal or in order to determine or optimize the parameters  $f$  (or, respectively,  $n$ ), which describe the directional pattern of the signal that is

15 to be rendered stereophonic as well as the angle  $\varphi$  that is to be ascertained manually or by metrology and is enclosed by the main axis and the sound source, the fictitious left opening angle  $\alpha$ , the fictitious right opening angle  $\beta$ , the attenuations  $\lambda$  or else  $\rho$  for the

20 formation of the resulting stereo signal or, resulting therefrom, the gain factor  $\rho^*$  for normalizing the left channel and the right channel, resulting from the MS matrixing (for example ascertained in the similar fashion to the logic element 120 as shown in FIGURE 8)

25 or from another arrangement according to the invention, on the unit circle (in this case 1 corresponds to the maximum level of 0 dB which has been normalized by using  $\rho^*$ , where  $x(t)$  is the left output signal resulting from this normalization and  $y(t)$  is the right

30 output signal resulting from this normalization) or the degree of correlation  $r$  of the resulting stereo signal or the parameter  $a$ , for example defined by the inequality (9) or else (9a) below, for defining the

admissible range of values for the sum of the transfer functions of the resulting output signals (for example the cited complex transfer functions

$$(5) f^*[x(t)] = [x(t)/\sqrt{2}] * (-1 + i)$$

5 and

$$(6) g^*[y(t)] = [y(t)/\sqrt{2}] * (1 + i)$$

where, for  $0 \leq a \leq 1$ , for example, the following is true:

$$(9) |\operatorname{Re}\{f^*[x(t)] + g^*[y(t)]\}| \leq |a * \cos \arg\{f^*[x(t)] +$$

$$10 \quad g^*[y(t)]\}|$$

and

$$(10) |\operatorname{Im}\{f^*[x(t)] + g^*[y(t)]\}| \leq |\sin \arg\{f^*[x(t)] +$$

$$g^*[y(t)]\}|)$$

or else in general

$$15 \quad (9a) \operatorname{Re}^2\{f^*[x(t)] + g^*[y(t)]\} * 1/a^2 + \operatorname{Im}^2\{f^*[x(t)] + g^*[y(t)]\} \leq 1,$$

or the limit value  $R^*$ , defined by inequality (11) or else (11a) below, or the deviation  $\Delta$ , likewise defined by inequality (11) or else (11a) below, for stipulating  
 20 or maximizing the absolute value of the function values of the sum of these transfer functions (where, for this stipulation or maximization and for the time interval  $[-T, T]$  or, respectively, the total number of possible

output signals  $x_j(t)$ ,  $y_j(t)$ , the following is true, for example:

$$\begin{aligned}
 & (11) \quad 0 \leq R^* - \Delta \leq \int_{-T}^T |f^*[x(t)] + g^*[y(t)]| dt \\
 & \leq \max_{\{f^*[x_j(t)], g^*[y_j(t)]\} \in \Phi} \int_{-T}^T |f^*[x_j(t)] + g^*[y_j(t)]| dt \\
 & \leq R^* + \Delta \\
 & \leq \int_{-T}^T |a * \cos \arg\{f^*[x(t)] + g^*[y(t)]\} + i * \sin \arg\{f^*[x(t)] + g^*[y(t)]\}| dt)
 \end{aligned}$$

or else

$$\begin{aligned}
 & (11a) \quad 0 \leq R^* - \Delta \leq \int_{-T}^T |f^*[x(t)] + g^*[y(t)]| dt \\
 & \leq \max_{\{f^*[x_j(t)], g^*[y_j(t)]\} \in \Phi} \int_{-T}^T |f^*[x_j(t)] + g^*[y_j(t)]| dt \\
 & \leq R^* + \Delta
 \end{aligned}$$

$$\leq \int_{-T}^T a * \{1 / \sqrt{[1 - (1 - a^2) * \sin^2 \arg \{f^*[x(t)] + g^*[y(t)]\}]} dt\}$$

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or the limit value  $S^*$  defined above or the deviation  $\varepsilon$  defined above (for which, by way of example, it must be true that

$$(7) \quad 0 \leq S^* - \varepsilon \leq \max |\operatorname{Re} \{f^*[x(t)] + g^*[y(t)]\}| \leq S^* + \varepsilon \leq 1)$$

or the limit value  $U^*$  defined above or the deviation  $\kappa$  defined above (for which, by way of example, it must be true that

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$$(8) \quad 0 \leq U^* - \kappa \leq \int_{-T}^T \|f^*[x(t)] + g^*[y(t)]\| dt \leq U^* + \kappa,$$

20 all for determining the mapping width of the stereo signal to be achieved, or the mapping direction of the reproduced sound sources in accordance with the arrangement described above. In any case, the result is stereophonic mapping which is constant in respect of  
25 the FM signal.

In particular, the use of compression algorithms or data reduction methods which belong to the prior art or the evaluation of characteristic features, such as the minima or maxima, is also

recommended in this case in order to speed up the evaluation of stereophonic or pseudo-stereophonic signals according to the criteria described above.

### Patent Claims

1. An apparatus for transforming a monophonic input signal into pseudo-stereophonic signals with a variable degree of correlation between the left signal and the right signal, comprising either:

a first circuit (309, 409, 509) having an MS matrix for pseudo-stereo conversion and having a first panoramic potentiometer (311; 411; 511) and a second panoramic potentiometer (312; 412; 512), wherein the MS matrix transforms an MS signal into an LR signal, wherein each panoramic potentiometer forms two bus signals, wherein each panoramic potentiometer has an input (302; 303), a first output (313; 315) and a second output (314; 316), wherein the input (302) of the first panoramic potentiometer (311) is connected downstream to a first output (L') of the MS matrix, wherein the input (303) of a second panoramic potentiometer (312) is connected to a second output (R') of the MS matrix, wherein the first output (313) of the first panoramic potentiometer (311) is connected to the first output (315) of the second panoramic potentiometer (312), and wherein the second output (314) of the first panoramic potentiometer (311) is connected to the second output (316) of the second panoramic potentiometer (312);

or:

a second circuit (309, 409, 509) for pseudo-stereo conversion having an MS matrix which transforms an MS signal into an LR signal and an amplifier (717), connected upstream to one input of the MS matrix, for amplifying the one input signal for the MS matrix with a gain smaller than one; or:

a third circuit having a modified MS matrix which transforms an MS Signal into an LR Signal and which comprises summation means for forming a composite signal from a first input signal (M), amplified by the factor  $(2 + \lambda - \rho)$ , and a second input signal (S), amplified by the factor  $(\lambda + \rho)$  and comprises a differentiation means for forming a difference signal from the first input signal (M), amplified by the

factor  $(2 - \lambda + \rho)$ , minus the second input signal (S), amplified by the factor  $(\lambda + \rho)$ .

2. The apparatus as claimed in claim 1, in which the first output (313) of the first panoramic potentiometer (311) is summed up with the first output (315) of the second panoramic potentiometer (312) to a first output signal of the first circuit, and the second output (314) of the first panoramic potentiometer (311) is summed up with the second output (316) of the second panoramic potentiometer (312) to a second output of the first circuit.

3. The apparatus as claimed in claim 1, in which both panoramic potentiometers comprise buses (313-314; 315-316; 413-414; 415-416; 513-514; 515-516), wherein both buses can be used only collectively and identically.

4. The apparatus as claimed in claim 1, in which the amplifier (717) of the second circuit is arranged upstream from the input of the MS matrix for the S signal.

5. The apparatus as claimed in claim 1, characterized by:

(a) means for the final signal formation on a left bus L from a left output signal  $L'$ , the latter signal multiplied by the factor  $\frac{1}{2} * (1 + \lambda)$  (where  $\lambda$  is inversely proportionally the attenuation for said left output signal  $L'$  from the MS matrix, 1 (corresponds to 0 dB)  $\geq \lambda \geq 0$  (corresponds to 3 dB)), added to the right output signal  $R'$  from the MS matrix, the latter signal multiplied by the factor  $\frac{1}{2} * (1 - \rho)$  (where  $\rho$  is inversely proportionally the attenuation for said right output signal  $R'$  from the MS matrix, 1 (corresponds to 0 dB)  $\geq \rho \geq 0$  (corresponds to 3 dB)), and

(b) means for the final signal formation on a right bus R from the left output signal  $L'$  cited in (a), the latter signal multiplied by the factor  $\frac{1}{2} * (1 - \lambda)$ , added to the right

output signal  $R'$  from the MS matrix, cited in (a), the latter signal multiplied by the factor  $\frac{1}{2} * (1 + \rho)$ .

6. The apparatus as claimed in claim 1, in which the attenuations  $\lambda$  and  $\rho$  are identical.

7. The apparatus as claimed in one of claims 1 to 6, having normalization means for normalizing the level of the maximum of the resulting left channel and of the resulting right channel, or, equivalently, for normalizing the axis length of the reference system for  $\langle x(t), y(t) \rangle$ .

8. The apparatus as claimed in one of claims 1 to 7, characterized by means for additionally stipulating the mapping width of the resulting pseudo-stereophonic signal by using the possible variation of the degree of correlation  $r$  thereof or of an attenuation  $\lambda$  or of an attenuation  $\rho$ .

9. The apparatus as claimed in one of claims 1 to 8 having means for additionally ascertaining or stipulating the mapping direction of a stereo signal.

10. The apparatus as claimed in one of claims 1 to 9 having means for additionally evaluating an existing stereo signal which can be reproduced by two or more loudspeakers.

11. The apparatus as claimed in one of claims 1 to 10, having means for compression or data reduction or other selective evaluation of audio signals.

12. The apparatus as claimed in one of claims 1 to 11, characterized by one or more converters for converting the obtained stereophonic output signals into stereo signals which are intended for reproduction by more than two loudspeakers.

13. The use of the apparatus as claimed in one of claims 1 to 12 for obtaining pseudo-stereophonic signals on the basis of FM stereo signals.

14. A method for transforming a monophonic input signal into pseudo-stereophonic signals with a variable degree of correlation between the left signal and the right signal, comprising:

Transforming an MS signal to an LR signal using an MS matrix, and

adjusting the degree of correlation between the left signal and the right signal output from the MS matrix by using:

- a first panoramic potentiometer (311; 411; 511) and a second panoramic potentiometer (312; 412; 512), wherein each panoramic potentiometer forms two bus signals, wherein each panoramic potentiometer has an input (302; 303), a first output (313; 315) and a second output (314; 316), wherein the input (302) of the first panoramic potentiometer (311) is connected downstream to a first output (L') of the MS matrix, wherein the input (303) of a second panoramic potentiometer (312) is connected to a second output (R') of the MS matrix, wherein the first output (313) of the first panoramic potentiometer (311) is connected to the first output (315) of the second panoramic potentiometer (312), and wherein the second output (314) of the first panoramic potentiometer (311) is connected to the second output (316) of the second panoramic potentiometer (312); or

-by using an amplifier (717), connected upstream to one input of the MS matrix, for amplifying the one input signal for the MS matrix by a gain smaller than one; or

-by using a modified MS matrix which comprises summation means for forming a composite signal from a first input signal (M), amplified by the factor  $(2 + \lambda - \rho)$ , and a second input signal (S), amplified by the factor  $(\lambda + \rho)$  and comprises a differentiation means for forming a difference signal from the first input signal (M), amplified by the factor  $(2 - \lambda + \rho)$ , minus the second input signal (S), amplified by the factor  $(\lambda + \rho)$ .

15. The method as claimed in claim 14, in which the first output (313) of the first panoramic potentiometer (311)

is summed up with the first output (315) of the second panoramic potentiometer (312), and the second output (314) of the first panoramic potentiometer (311) is summed up with the second output (316) of the second panoramic potentiometer (312).

16. The method as claimed in claim 14, wherein both buses are used collectively and identically.

17. The method as claimed in claim 14, in which the amplifier (717) of the second circuit is arranged upstream from the input of the MS matrix for the S signal.

18. The method as claimed in claim 14, characterized by (a) the final signal formation on a left bus L from a left output signal L', the latter signal multiplied by the factor  $\frac{1}{2} * (1 + \lambda)$  (where  $\lambda$  is inversely proportionally the attenuation for said left output signal L' from the MS matrix, 1 (corresponds to 0 dB)  $\geq \lambda \geq 0$  (corresponds to 3 dB)), added to the right output signal R' from the MS matrix, the latter signal multiplied by the factor  $\frac{1}{2} * (1 - \rho)$  (where  $\rho$  is inversely proportionally the attenuation for said right output signal R' from the MS matrix, 1 (corresponds to 0 dB)  $\geq \rho \geq 0$  (corresponds to 3 dB)), and

(b) the final signal formation on a right bus R from the left output signal L' cited in (a), the latter signal multiplied by the factor  $\frac{1}{2} * (1 - \lambda)$ , added to the right output signal R' from the MS matrix, cited in (a), the latter signal multiplied by the factor  $\frac{1}{2} * (1 + \rho)$ .

19. The method as claimed in claim 14, in which the attenuations  $\lambda$  and  $\rho$  are identical.

20. The method as claimed in one of claims 14 to 19, in which the level of the maximum of the resulting left channel and of the resulting right channel is normalized or,

equivalently, the axis length of the reference system for  $\langle x(t), y(t) \rangle$  is normalized.

21. The method as claimed in one of claims 14 to 20, characterized by the additional stipulation of the mapping width of the resulting pseudo-stereophonic signal by using the possible variation of the degree of correlation  $r$  thereof or of an attenuation  $\lambda$  or of an attenuation  $\rho$ .

22. The method as claimed in one of claims 14 to 21, characterized by the additional ascertainment or stipulation of the mapping direction of an existing stereo signal.

23. The method as claimed in one of claims 14 to 22, characterized by the additional evaluation of an existing stereo signal which can be reproduced by two or more loudspeakers.

24. The method as claimed in one of claims 14 to 23, characterized by the additional application of compression methods or data reduction methods or other selective evaluation methods to audio signals.

25. The method as claimed in one of claims 14 to 24, characterized by conversion of the obtained stereophonic output signals into stereo signals which are reproduced by more than two loudspeakers.

26. The method as claimed in one of claims 14 to 25, characterized by application thereof to FM stereo signals.