

**Apparatus for Encoding or Decoding an Encoded Multichannel Signal Using a
Filling Signal Generated by a Broad Band Filter**

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Description

The present invention is related to audio processing and, particularly, to multichannel audio processing within an apparatus or method for decoding an encoded multichannel signal.

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The state of the art codec for parametric coding of stereo signals at low bitrates is the MPEG codec xHE-AAC. It features a fully parametric stereo coding mode based on a mono downmix and stereo parameters inter-channel level difference (ILD) and inter-channel coherence (ICC), which are estimated in subbands. The output is synthesized from the mono downmix by matrixing in each subband the subband downmix signal and a decorrelated version of that subband downmix signal, which is obtained by applying subband filters within the QMF filterbank.

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There are some drawbacks related to xHE-AAC for coding speech items. The filters by which the synthetic second signal is generated produce a very reverberant version of the input signal, which requires a ducker. Therefore, the processing heavily smears the spectral shape of the input signal over time. This works well for many signal types but for speech signals, where the spectral envelope changes rapidly, this causes unnatural coloration and audible artifacts, such as *double talk* or *ghost voice*. Furthermore, the filters depend on the temporal resolution of the underlying QMF filter bank, which changes with the sampling rate. Therefore, the output signal is not consistent for different sampling rates.

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Apart from this, the 3GPP codec AMR-WB+ features a semi-parametric stereo mode supporting bitrates from 7 to 48kbit/s. It is based on a mid/side transform of left and right input channel. In low frequency range, the side signal s is predicted by the mid signal m to obtain a balance gain and m and the prediction residual are both encoded and transmitted, alongside with the prediction coefficient, to the decoder. In mid-frequency range, only the downmix signal m is coded and the missing signal s is predicted from m using a low order FIR filter,

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which is calculated at the encoder. This is combined with a bandwidth extension for both channels. The codec generally yields a more natural sound than xHE-AAC for speech, but faces several problems. The procedure of predicting s by m by a low order FIR filter does not work very well if the input channels are only weakly correlated, as is e.g. the case for echoic speech signals or double talk. Also, the codec is unable to handle out-of-phase signals, which can lead to substantial loss in quality, and one observes that the stereo image of the decoded output is usually very compressed. Furthermore, the method is not fully parametric and hence not efficient in terms of bitrate.

Generally, a fully parametric method may result in audio quality degradations due the fact that any signal portions lost due to parametric encoding are not reconstructed on the decoder-side.

On the hand, waveform-preserving procedures such as mid/side coding or so do not allow substantial bitrates savings as can be obtained from parametric multichannel coders.

It is an object of the present invention to provide an improved concept for decoding an encoded multichannel signal.

This object is achieved by an apparatus for decoding an encoded multichannel signal, a method of decoding an encoded multichannel signal of claim 37, a computer program of claim 38, and audio signal decorrelator of claim 39, a method of decorrelating an audio input signal of claim 49 or a computer program of claim 50.

The present invention is based on the finding that a mixed approach is useful for decoding an encoded multi-channel signal. This mixed approach relies on using a filling signal generated by a decorrelation filter, and this filling signal is then used by a multi-channel processor such as a parametric or other multi-channel processor to generate the decoded multi-channel signal. Particularly, the decorrelation filter is a broad band filter and the multi-channel processor is configured to apply a narrow band processing to the spectral representation. Thus, the filling signal is preferably generated in the time domain by an allpass filter procedure, for example, and the multichannel processing takes place in the spectral domain using the spectral representation of the decoded base channel and, additionally, using a spectral

representation of the filling signal generated from the filling signal calculated in the time domain.

Thus, the advantages of frequency domain multi-channel processing on the one
5 hand and time domain decorrelation on the other hand are combined in a useful way to obtain a decoded multi-channel signal having a high audio quality. Nevertheless, the bitrate for transmitting the encoded multi-channel signal is kept as low as possible due to the fact that the encoded multi-channel signal is typically not a waveform-preserving encoding format but, for example, a parametric multi-channel
10 coding format. Hence, for generating the filling signal, only decoder-available data such as the decoded base channel is used and, in certain embodiments, additional stereo parameters such as a gain parameter or a prediction parameter or, alternatively, ILD, ICC or any other stereo parameters known in the art.

15 Subsequently, several preferred embodiments are discussed. The most efficient way to code stereo signals is to use parametric methods such as Binaural Cue Coding or Parametric Stereo. They aim at reconstructing the spatial impression from a mono downmix by restoring several spatial cues in subbands and as such are based on psychoacoustics. There is another way of looking at parametric methods: one simply
20 tries to parametrically model one channel by another, trying to exploit inter channel redundancy. This way, one may recover part of the secondary channel from the primary channel but one is usually left with a residual component. Omitting this component usually leads to an unstable stereo image of the decoded output. Therefore, it is necessary to fill in a suitable replacement for such residual components.
25 Since such a replacement is *blind*, it is safest to take such parts from a second signal that has similar temporal and spectral properties as the downmix signal.

Hence, embodiments of the present invention is particularly useful in the context of parametric audio coder and, particularly, parametric audio decoder where replacements
30 for missing residual parts are extracted from an artificial signal generated by a decorrelation filter on the decoder-side.

Further embodiments relate to procedures for generating the artificial signal. Embodiments relate to methods of generating an artificial second channel from
35 which replacements for missing residual parts are extracted and its use in a fully parametric stereo coder, called enhanced Stereo Filling. The signal is more

suitable for coding speech signals than the xHE-AAC signal, since its spectral shape is temporally closer to the input signal. It is generated in time domain by applying a special filter structure, and therefore independent of the filter bank in which the stereo upmix is performed. It can hence be used in different upmix
5 procedures. It could, for instance, be used in xHE-AAC to replace the artificial signals after transforming to QMF domain, which would improve the performance for speech, as well as in the midrange of AMR-WB+ to stand in for the residual in the mid/side prediction, which would improve the performance for weakly correlated input channels and improve the stereo image. This is of special interest
10 for codecs featuring different stereo modes (such as time domain and frequency domain stereo processing).

In preferred embodiments, the decorrelation filter comprises at least one allpass filter cell, the at least one allpass filter cell comprising two Schroeder allpass filter cells
15 nested into a third Schroeder allpass filter, and/or the allpass filter comprises at least one allpass filter cell, the allpass filter cell comprising two cascaded Schroeder allpass filters, wherein an input into the first cascaded Schroeder allpass filter and an output from the cascaded second Schroeder allpass filter are connected, in the direction of the signal flow, before a delay stage of the third Schroeder allpass filter.

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In a further embodiment, several such allpass filter cells comprising of three nested Schroeder allpass filters are cascaded in order to obtain a specifically useful allpass filter that has a good impulse response for the purpose of stereo or multi-channel decoding.

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It is to be emphasized here that, although several aspects of the present invention are discussed with respect to stereo decoding generating, from a mono base channel, a left upmix channel and a right upmix channel, the present invention is also applicable for multi-channel decoding, where a signal of, for example, four
30 channels is encoded using two base channels, wherein the first two upmix channels are generated from the first base channel and the third and the fourth upmix channel are generated from the second base channel. In other alternatives, the present invention is also useful to generate, from a single base channel, three or more upmix channels always using preferably the same filling signal. In all such procedures,
35 however, the filling signal is generated in a broad band manner, i.e., preferably in the

time domain, and the multi-channel processing for generating, from the decoded base channel, the two or more upmix channels is done in the frequency domain.

The decorrelation filter preferably operates fully in the time domain. However, other
5 hybrid approaches are useful as well, where, for example, the decorrelation is performed by decorrelating a low band portion on the one hand and a high band portion on the other hand while, for example, the multi-channel processing is performed in a much higher spectral resolution. Thus, exemplarily, the spectral resolution of the multi-channel processing can, for example, be as high as
10 processing each DFT or FFT line individually, and parametric data is given for several bands, where each band, for example, comprises two, three, or many more DFT/FFT/MDCT lines, and the filtering of the decoded base channel to obtain the filling signal is done broad band like i.e., in the time domain or semi-broad band like, for example, within a low band and a high band or, probably within three different
15 bands. Thus, in any case, the spectral resolution of the stereo processing that is typically performed for individual lines or subband signals is the highest spectral resolution. Typically, the stereo parameters generated in an encoder and transmitted and used by preferred decoder have a medium spectral resolution. Thus, the parameters are given for bands, the bands can have varying bandwidths, but each
20 band at least comprises two or more lines or subband signals generated and used by the multi-channel processors. And, the spectral resolution of the decorrelation filtering is very low and, in the case of time domain filtering extremely low or is medium, in the case of generating different decorrelated signals for different bands, but this medium spectral resolution is still lower than the resolution, in which the
25 parameters for the parametric processing are given.

In a preferred embodiment, the filter characteristic of the decorrelation filter is an allpass filter having a constant magnitude region over the whole interesting spectral range. However, other decorrelation filters that do not have this ideal allpass filter
30 behavior are useful as well as long as, in a preferred embodiment, a region of constant magnitude of the filter characteristic is greater than a spectral granularity of the spectral representation of the decoded base channel and the spectral granularity of the spectral representation of the filling signal.

35 Thus, it is made sure that the spectral granularity of the filling signal or the decoded base channel, on which the multi-channel processing is performed does not

influence the decorrelation filtering, so that a high quality filling signal is generated, preferably adjusted using an energy normalization factor and then used for generating the two or more upmix channels.

5 Furthermore, it is to be noted that the generation of a decorrelated signal such as described with respect to subsequently discussed Figs. 4, 5, or 6 can be used in the context of a multichannel decoder, but can also be used in any other application, where a decorrelated signal is useful such as in any audio signal rendering, any reverberating operation etc.

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Subsequently, preferred embodiments are discussed with respect to the accompanying drawings in which:

15 Fig. 1a illustrates an artificial signal generation when used with an EVS core coder;

Fig. 1b illustrates an artificial signal generation when used with an EVS core coder in accordance with a different embodiment;

20 Fig. 2a illustrates an integration into DFT stereo processing including time domain bandwidth extension upmix;

25 Fig. 2b illustrates an integration into DFT stereo processing including time domain bandwidth extension upmix in accordance with a different embodiment;

Fig. 3 illustrates an integration into a system featuring multiple stereo processing units;

30 Fig. 4 illustrates a basic allpass unit;

Fig. 5 illustrates an allpass filter unit;

Fig. 6 illustrates an impulse response of a preferred allpass filter;

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Fig. 7a illustrates an apparatus for decoding an encoded multi-channel signal;

- Fig. 7b illustrates a preferred implementation of the decorrelation filter;
- Fig. 7c illustrates a combination of a base channel decoder and a spectral
5 converter;
- Fig. 8 illustrates a preferred implementation of the multi-channel processor;
- Fig. 9a illustrates a further implementation of the apparatus for decoding an
10 encoded multi-channel signal using bandwidth extension processing;
- Fig. 9b illustrates preferred embodiments for generating a compressed energy
normalization factor;
- 15 Fig. 10 illustrates an apparatus for decoding an encoded multi-channel signal
in accordance with a further embodiment operating using a channel
transformation in the base channel decoder;
- Fig. 11 illustrates cooperation between a resampler for the base channel
20 decoder and the subsequently connected decorrelation filter;
- Fig. 12 illustrates an exemplary parametric multi-channel encoder useful with
the apparatus for decoding in accordance with the present invention;
- 25 Fig. 13 illustrates a preferred implementation of the apparatus for decoding an
encoded multi-channel signal; and
- Fig. 14 illustrates a further preferred implementation of the multi-channel
30 processor.
- Fig. 7a illustrates a preferred embodiment of an apparatus for decoding an encoded
multichannel signal. The encoded multi-channel signal comprises an encoded base
channel that is input into a base channel decoder 700 for decoding the encoded
base channel to obtain a decoded base channel.

Furthermore, the decoded base channel is input into a decorrelation filter 800 for filtering at least a portion of the decoded base channel to obtain a filling signal.

Both the decoded base channel and the filling signal are input into a multi-channel processor 900 for performing a multi-channel processing using a spectral representation of the decoded base channel and, additionally, a spectral representation of the filling signal. The multi-channel processor outputs the decoded multi-channel signal that comprises, for example, a left upmix channel and a right upmix channel in the context of stereo processing or three or more upmix channels in the case of multi-channel processing covering more than two output channels.

The decorrelation filter 800 is configured as a broad band filter, and the multi-channel processor 900 is configured to apply a narrowband processing to the spectral representation of the decoded base channel and the spectral representation of the filling signal. Importantly, broad band filtering is also done, when the signal to be filtered is downsampled from a higher sampling rate such as downsampled to 16 kHz or 12.8 kHz from a higher sampling rate such as 22 kHz or lower.

Thus, the multi-channel processor operates in a spectral granularity that is significantly higher than a spectral granularity, with which the filling signal is generated. In other words, a filter characteristic of the decorrelation filter is selected so that the region of a constant magnitude of the filter characteristic is greater than a spectral granularity of the spectral representation of the decoded base channel and a spectral granularity of the spectral representation of the filling signal.

Thus, for example, when the spectral granularity of the multi-channel processor is so that, for each spectral line of a, for example, 1024 line DFT spectrum the upmix processing is performed, then the decorrelation filter is defined in such a way that the region of constant magnitude of the filter characteristic of the decorrelation filter has a frequency width that is higher than two or more spectral lines of the DFT spectrum. Typically, the decorrelation filter operates in the time domain, and the used spectral band, for example, from 20 Hz to 20 kHz. Such filters are known to be allpass filters, and it is to be noted here that a perfectly constant magnitude range where the magnitude is perfectly constant can be typically not be obtained by allpass filters, but variations from a constant magnitude by +/- 10% of an average value also are found

to be useful for an allpass filter and, therefore, also represent a "constant magnitude of the filter characteristic".

Fig. 7b illustrates an implementation of the decorrelation filter 800 with a time domain filter stage 802 and the subsequently connected spectral converted 804 generating a spectral representation of the filling signal. The spectral converter 804 is typically implemented as an FFT or a DFT processor, although other time-frequency domain conversion algorithms are useful as well.

Fig. 7c illustrates a preferred implementation of the cooperation between the base channel decoder 700 and a base channel spectral converter 902. Typically, the base channel decoder is configured to operate as a time domain base channel decoder generating a time domain base channel signal while the multi-channel processor 900 operates in the spectral domain. Thus, the multi-channel processor 900 of Fig. 7a has, as an input stage, the base channel spectral converter 902 of Fig. 7c, and the spectral representation of the base channel spectral converter 902 is then forwarded to the multi-channel processor processing elements that are, for example, illustrated in Fig. 8, Fig. 13, Fig. 14, Fig. 9a or Fig. 10. In this context, it is to be outlined that, in general, reference numerals starting from a "7" represent elements that preferably belong to the base channel decoder 700 of Fig. 7a. Elements having a reference numeral starting with a "8" preferably belong to the decorrelation filter 800 of Fig. 7a, and elements with a reference numeral starting with "9" in the figures preferably belong to the multi-channel processor 900 of Fig. 7a. However, it is to be noted here that the separations between the individual elements are only made for describing the present invention, but any actual implementation can have different, typically hardware or alternatively software or mixed hardware/software processing blocks that are separated in a different manner than the logical separation illustrated in Fig. 7a and other figures.

Fig. 4 illustrates a preferred implementation of the filter stage 802 that is indicated as 802'. Particularly, Fig. 4 illustrates a basic allpass unit that can be included in the decorrelation filter alone or together with more such cascaded allpass units as, for example, illustrated in Fig. 5. Fig. 5 illustrates the decorrelation filter 802 with exemplarily five cascaded basic allpass units 502, 504, 506, 508, 510, while each of basic allpass units can be implemented as outlined in Fig. 4. Alternatively, however, the decorrelation filter can include a single basic allpass unit 403 of Fig. 4 and,

therefore, represents an alternative implementation of the decorrelation filter stage 802'.

Preferably, each basic allpass unit comprises two Schroeder allpass filters 401, 402 nested into a third Schroeder allpass filter 403. In this implementation, the allpass filter cell 403 is connected to two cascaded Schroeder allpass filters 401, 402, wherein input into the first cascaded Schroeder allpass filter 401 and an output from the cascaded second Schroeder allpass filter 402 are connected, in the direction of the signal flow, before a delay stage 423 of the third Schroeder allpass filter.

Particularly, the allpass filter illustrated in Fig. 4 comprises: a first adder 411, a second adder 412, a third adder 413, a fourth adder 414, a fifth adder 415 and a sixth adder 416; a first delay stage 421, a second delay stage 422 and a third delay stage 423; a first forward feed 431 with a first forward gain, a first backward feed 441 with a first backward gain, a second forward feed 442 with a second forward gain and a second backward feed 432 with a second backward gain; and a third forward feed 443 with a third forward gain and a third backward feed 433 with a third backward gain.

The connections are illustrated in Fig. 4 are as follows: The input into the first adder 411 represents an input into the allpass filter 802, wherein a second input into the first adder 411 is connected to an output of the third filter delay stage 423 and comprises the third backward feed 433 with a third backward gain. The output of the first adder 411 is connected to an input into the second adder 412 and is connected to an input of the sixth adder 416 via the third forward feed 443 with the third forward gain. The input into the second adder 412 is connected to the first delay stage 421 via a first backward feed 441 with the first backward gain. The output of the second adder 412 is connected to an input of the first delay stage 421 and is connected to an input of the third adder 413 via the first forward feed 431 with the first forward gain. The output of the first delay stage 421 is connected to a further input of the third adder 413. The output of the third adder 413 is connected to an input of the fourth adder 414. The further input into the fourth adder 414 is connected to an output of the second delay stage 422 via the second backward feed 432 with the second backward gain. The output of the fourth adder 414 is connected to an input into the second delay stage 422 and is connected to an input into the fifth adder 415 via the second forward feed 442 with the second forward gain. The output of the second delay stage 421 is connected to a further input into the fifth adder 415. The output of the fifth adder 415 is connected to an input of the third delay stage 423. The

output of the third delay stage 423 is connected to an input into the sixth adder 416. The further input into the sixth adder 416 is connected to an output of the first adder 411 via the third forward feed 443 with the third forward gain. The output of the sixth adder 416 represents an output of the allpass filter 802.

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Preferably, as illustrated in Fig. 8, the multi-channel processor 900 is configured to determine a first upmix channel and a second upmix channel using different weighted combinations of spectral bands of the decoded base channel and corresponding spectral bands of the filling signal. Particularly, the different weighted combinations depend on a prediction factor and/or a gain factor as derived from encoded parametric information included within the encoded multi-channel signal. Furthermore, the weighted combinations preferably depend on an envelope normalization factor or, preferably an energy normalization factor calculated using a spectral band of the decoded base channel and the corresponding spectral band of the filling signal. Thus, the processor 904 of Fig. 8 receives the spectral representation of the decoded base channel and the spectral representation of the filling signal and outputs, preferably in the time domain, a first upmix channel and a second upmix channel, and the prediction factor, the gain factor, and the energy normalization factor are input in a per-band manner and these factors are then used for all spectral lines within a band, but change for a different band, where this data is retrieved from the encoded signal or locally determined in the decoder.

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Particularly, the prediction factor and the gain factor typically represent encoded parameters that are decoded on the decoder side and are then used in the parametric stereo upmixing. Contrary thereto, the energy normalization factor is calculated on the decoder-side typically using a spectral band of the decoded base channel and the spectral band of the filling signal. The same is true for the envelope normalization factor. Preferably, the envelope normalization corresponds to an energy normalization per band.

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Although the present invention is discussed with the specific reference encoder illustrated in Fig. 12 and the specific decoder illustrated in Fig. 13 or Fig. 14, it is, however, to be noted that the generation of a broad band filling signal and the application of the broad band filling signal in multi-channel stereo decoding operating in a narrow band spectral domain can also be applied to any other parametric stereo encoding techniques known in the art. These are parametric stereo encoding known

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from the HE-AAC standard or from the MPEG surround standard or from Binaural Cue Coding (BCC coding) or any other stereo encoding/decoding tools or any other multi-channel encoding/decoding tools.

5 Fig. 9a illustrates a further preferred embodiment of the multi-channel decoder comprising a multi-channel processor stage 904 generating a first upmix channel and a second upmix channel and subsequently connected time domain bandwidth extension elements 908, 910 that perform a time domain bandwidth extension in a guided or unguided manner to the first upmix channel and the second upmix channel
10 individually. Typically, a windower and energy normalization factor calculator 912 is provided to calculate an energy normalization factor to be used by the multi-channel processor 904. In alternative embodiments that are discussed with respect to Fig. 1a or Fig. 1b and Fig. 2a or Fig. 2b, however, the bandwidth extension is performed with the mono or decoded core signal and, only a single stereo processing element 960
15 of Fig. 2a or Fig. 2b is provided for generating, from the high band mono signal, a high band left channel signal and a high band right channel signal that are then added to the low band left channel signal and the low band right channel signal with the use of adders 994a and 994b.

20 This adding illustrated in Fig. 2a or 2b can, for example, be performed in the time domain. Then, block 960 generates a time domain signal. This is the preferred implementation. However, alternatively, the stereo processing 904 in Fig. 2a or 2b and the left channel and right channel signals from block 960 can be generated in the spectral domain and, the adders 994a and 994b are, for example, implemented
25 by a synthesis filter bank so that the low band data from block 904 is input into the low band input of the synthesis filter bank and the high band output of block 960 is input into the high band input of the synthesis filter bank and the output of the synthesis filter bank is the corresponding left channel time domain signal or a right channel time domain signal.

30 Preferably, the windower and factor calculator 912 in Fig. 9a generates and calculates an energy value of the high band signal as, for example, also illustrated at 961 in Fig. 1a or Fig. 1b and uses this energy estimate for generating high band first and second upmix channels as will be discussed later on with respect to equations
35 28 to 31 in a preferred embodiment.

Preferably, the processor 904 for calculating the weighted combination receives, as an input, the energy normalization factor per band. In a preferred embodiment, however, a compression of the energy normalization factor is performed and the different weighted combinations are calculated using the compressed energy normalization factor. Thus, with respect to Fig. 8, the processor 904 receives, instead of the non-compressed energy normalization factor, a compressed energy normalization factor. This procedure is illustrated, with respect to different embodiments, in Fig. 9b. Block 920 receives an energy of the residual or filling signal per time/frequency bin and an energy of the decoded base channel per time and frequency bin, and then calculates an absolute energy normalization factor for a band comprising several such time/frequency bins. Then, in block 921, a compression of the energy normalization factor is performed, and this compression can, for example, be the usage of a logarithm function as, for example, discussed with respect to equation 22 later on.

Based on the compressed energy normalization factor generated by block 921, different procedures for generating the compressed energy normalization factor are given. In the first alternative, a function is applied to the compressed factor as illustrated in 922, and this function is preferably a non-linear function. Then, in block 923 the evaluated factor is expanded to obtain a specific compressed energy normalization factor. Hence, block 922 can, for example, be implemented to the function expression in equation (22) that will be given later on, and block 923 is performed by the "exponent" function within equation (22). However, a different alternative resulting in a similar compressed energy normalization factor is given in block 924 and 925. In block 924 an evaluation factor is determined and, in block 925, the evaluation factor is applied to the energy normalization factor obtained from block 920. Thus, the application of the factor to the energy normalization factor as outlined in block 912 can, for example, be implemented by subsequently illustrated equation 27.

Thus, as for example, illustrated in equation 27 later on, the evaluation factor is determined and this factor is simply a factor that can be multiplied by the energy normalization factor g_{norm} as determined by block 920 without actually performing special function evaluations. Therefore, the calculation of block 925 can also be dispensed with, i.e., the specific calculation of the compressed energy normalization factor is not necessary, as soon as the original non-compressed energy

normalization factor, and the evaluation factor and a further operand within a multiplication such as a spectral value of the filling signal are multiplied together to obtain a normalized filling signal spectral line.

5 Fig. 10 illustrates a further implementation, where the encoded multi-channel signal is not simply a mono signal but comprises an encoded mid signal and an encoded side signal, for example. In such a situation, the base channel decoder 700 not only decodes the encoded mid signal and the encoded side signal or, generally, the encoded first signal and the encoded second signal, but additionally performs a
10 channel transformation 705, for example, in the form of a mid/side transform and inverse mid/side transformation to calculate a primary channel such as L and a secondary channel such as R, or the transformation is a Karhunen Loeve transformation.

15 However, the result of the channel transformation and, particularly, the result of the decoding operation is that the primary channel is a broad band channel while the secondary channel is a narrow band channel. Then, the broad band channel is input into the decorrelation filter 800 and, a high pass filtering is performed in block 930 to generate a decorrelated high pass signal and this decorrelated high pass signal is
20 then added to the narrow band secondary channel in the band combiner 934 to obtain the broad band secondary channel so that, in the end, the broad band primary channel and the broad band secondary channel are output.

Fig. 11 illustrates a further implementation, where a decoded base channel obtained
25 by the base channel decoder 700 in a certain sampling rate associated with the encoded base channel is input into a resampler 710 in order to obtain a resampled base channel that is then used in the multi-channel processor that operates on the resampled channel.

30 Fig. 12 illustrates a preferred implementation of a reference stereo encoding. In block 1200, an inter-channel phase difference IPD is calculated for the first channel such as L and the second channel such as R. this IPD value is then, typically quantized and output for each band in each time frame as encoder output data 1206. Furthermore, the IPD values are used for calculating parametric data for the stereo
35 signal such as a prediction parameter $g_{t,b}$ for each band b in each time frame t and a gain parameter $r_{t,b}$ for each band b in each time frame t .

Furthermore, both first and second channels are also used in a mid/side processor 1203 to calculate, for each band, a mid signal and a side signal.

- 5 Depending on the implementation, only the mid signal M can be forwarded to an encoder 1204, and the side signal is not forwarded to the encoder 1204 so that the output data 1206 only comprises the encoded base channel, the parametric data generated by block 1202 and the IPD information generated by block 1200.
- 10 Subsequently, a preferred embodiment is discussed with respect to a reference encoder, but it is to be noted that any other stereo encoders as discussed before can be used as well.

A REFERENCE STEREO ENCODER

- 15 A DFT based stereo encoder is specified for reference. As usual, time frequency vectors L_t and R_t of the left and right channel are generated by simultaneously applying an analysis window followed by a Discrete Fourier Transform (DFT). The DFT bins are then grouped into subbands $(L_{t,k})_k \in I_b$ resp. $(R_{t,k})_k \in I_b$, where I_b denotes the set of subband indices.

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Calculation of IPDs and Downmixing. For the downmix, a bandwise inter-channel- phase-difference (IPD) is calculated as

$$(1) \quad IPD = \arg(\sum_{k \in I_b} L_{t,k} R_{t,k}^*),$$

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Where z^* denotes the complex conjugate of z . This is used to generate a band-wise mid and side signal

$$(2) \quad M_{t,k} = \frac{e^{-i\beta} L_{t,k} + e^{i(IPD_{t,b} - \beta)} R_{t,k}}{\sqrt{2}}$$

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and

$$(3) \quad S_{t,k} = \frac{e^{-i\beta} L_{t,k} - e^{i(IPD_{t,b} - \beta)} R_{t,k}}{\sqrt{2}}$$

for $k \in I_b$, where β is an absolute phase rotation parameter e.g. given by

$$(4) \quad \beta = \text{atan2} \left(\sin(IPD_{t,b}), \cos(IPD_{t,b}) + 2 \frac{1+g_{t,b}}{1-g_{t,b}} \right).$$

- 5 **Calculation of parameters.** In addition to the band-wise IPDs, two further stereo parameters are extracted. The optimal coefficient for predicting $S_{t,b}$ by $M_{t,b}$, i.e. the number $g_{t,b}$ such that the energy of the remainder

$$(5) \quad p_{t,k} = S_{t,k} - g_{t,b} M_{t,k}$$

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is minimal, and a relative gain factor $r_{t,b}$ which, if applied to the mid signal M_t , equalizes the energy of p_t and M_t in each band, i.e.,

$$(6) \quad r_{t,b} = \sqrt{\frac{\sum_{k \in I_b} |p_{t,k}|^2}{\sum_{k \in I_b} |M_{t,k}|^2}}$$

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The optimal prediction coefficient can be calculated from the energies in the subbands

$$(7) \quad E_{L,t,b} = \sum_{k \in I_b} |L_{t,k}|^2 \quad \text{and} \quad E_{R,t,b} = \sum_{k \in I_b} |R_{t,k}|^2$$

- 20 and the absolute value of the inner product of L_t and R_t

$$(8) \quad X_{L/R,t,b} = \left| \sum_{k \in I_b} L_{t,k} R_{t,k}^* \right|$$

as

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$$(9) \quad g_{t,b} = \frac{E_{L,t,b} - E_{R,t,b}}{E_{L,t,b} + E_{R,t,b} + 2X_{L/R,t,b}}.$$

From this it follows that $g_{t,b}$ lies in $[-1, 1]$. The residual gain can be calculated similarly from the energies and the inner product as

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$$(10) \quad r_{t,b} = \left(\frac{(1-g_{t,b})E_{L,t,b} + (1+g_{t,b})E_{R,t,b} - 2X_{L/R,t,b}}{E_{L,t,b} + E_{R,t,b} + 2X_{L/R,t,b}} \right)^{1/2},$$

which implies

$$(11) \quad 0 \leq r_{t,b} \leq \sqrt{1 - g_{t,b}^2}.$$

- 5 Fig. 13 illustrates a preferred implementation of the decoder-side. In block 700, representing the base channel decoder of Fig. 7a, the encoded base channel M is decoded.

Then, in block 940a, the primary upmix channel such as L is calculated.
 10 Furthermore, in block 940b, the secondary upmix channel is calculated which is, for example, channel R .

Both blocks 940a and 940b are connected to the filling signal generator 800 and receive the parametric data generated by block 1200 in Fig. 12 or 1202 of Fig. 12.

15 Preferably, the parametric data is given in bands having the second spectral resolution and the blocks 940a, 940b operate in high spectral resolution granularity and generate spectral lines with a first spectral resolution that is higher than the second spectral resolution.

20 The output of blocks 940a, 940b are, for example, input into frequency-time converters 961, 962. These converters can be a DFT or any other transform, and typically also comprise a subsequent synthesis window processing and a further overlap-add operation.

25 Additionally, the filling signal generator receives the energy normalization factor and, preferably, the compressed energy normalization factor, and this factor is used for generating a correctly leveled/weighted filling signal spectral line for blocks 940a and 940b.

30 Subsequently, a preferred implementation of blocks 940a, 940b is given. Both blocks comprise the calculation 941a of phase rotation factor, the calculation of a first weight for the spectral line of the decoded base channel as indicated by 942a and 942b. Furthermore, both blocks comprise the calculation 943a and 943b for the
 35 calculation of the second weight for the spectral line of the filling signal.

Furthermore, the filling signal generator 800 receives the energy normalization factor generated by block 945. This block 945 receives the filling signal per band and the base channel signal per band and, then, calculates the same energy normalization factor used for all lines in a band.

Finally, this data is forwarded to the processor 946 for calculating the spectral lines for the first and the second upmix channels. To this end, the processor 946 receives the data from blocks 941a, 941b, 942a, 942b, 943a, 943b and the spectral line for the decoded base channel and the spectral line for the filling signal. The output of block 946 is then a corresponding spectral line for the first and the second upmix channel.

Subsequently, preferred implementations of a decoder are given.

15

Reference Decoder

A DFT based decoder for reference is specified which corresponds to the encoder described above. The time-frequency transform from both the encoder is applied to the decoded downmix yielding time-frequency vectors $\tilde{M}_{t,b}$. Using the dequantized values $\tilde{IPD}_{t,b}$, $\tilde{g}_{t,b}$, and $\tilde{r}_{t,b}$, left and right channel are calculated as

$$(12) \quad \tilde{L}_{t,k} = \frac{e^{i\beta(\tilde{M}_{t,k}(1+\tilde{g}_{t,b})+\tilde{r}_{t,b} g_{norm} \tilde{p}_{t,k})}}{\sqrt{2}}$$

25 and

$$(13) \quad \tilde{R}_{t,k} = \frac{e^{i(\beta-\tilde{IPD}_{t,b})(\tilde{M}_{t,k}(1+\tilde{g}_{t,b})-\tilde{r}_{t,b} g_{norm} \tilde{p}_{t,k})}}{\sqrt{2}}$$

for $k \in I_b$ where $\tilde{p}_{t,k}$ is a substitute for the missing residual $p_{t,k}$ from the encoder, and g_{norm} is the energy normalizing factor

30

$$(14) \quad g_{norm} = \sqrt{\frac{E_{\tilde{M},t,b}}{E_{\tilde{p},t,b}}}$$

which turns the relative residual prediction gain $r_{t,b}$ into an absolute gain. A simple choice for $\tilde{p}_{t,k}$ would be

$$(15) \quad \tilde{p}_{t,k} = \tilde{M}_{t-d_b,k},$$

5

where $d_b >$ denotes a band-wise frame-delay but this has certain drawbacks, namely

- $\tilde{p}_t$ and $\tilde{M}_t$ can have very different spectral and temporal shapes,
- even in the case of matching spectral and temporal envelopes, the use of (15) in (12) and (13) induces a frequency dependent ILD and IPD, which varies only slowly in low to mid frequency range. This causes problems e.g. for tonal items,
- for speech signals, the delay should be chosen small in order to stay below the echo threshold but this causes strong coloration due to comb-filtering.

15

It is therefore better to use time-frequency bins of the artificial signal which is described below.

20 The phase rotation factor β is again calculated as

$$(16) \quad \beta = \text{atan2}\left(\sin(\widetilde{IPD}_{t,b}), \cos(\widetilde{IPD}_{t,b}) + 2 \frac{1+\tilde{g}_{t,b}}{1-\tilde{g}_{t,b}}\right).$$

Synthetic Signal Generation

25

For replacing missing residual parts in the stereo upmix, a second signal is generated from the time-domain input signal $\tilde{m}$, outputting a second signal $\tilde{m}_f$. The design constrain for this filter is to have a short, dense impulse response. This is achieved by applying several stages of basic allpass filters obtained by nesting two Schroeder allpass filter into a third Schroeder filter, i.e.

30

$$(17) \quad B(z) = H((z^{-d_3}S(z))^{-1}),$$

where

35

$$(18) \quad S(z) = \frac{g_1 + z^{-d_1}}{1 - g_1 z^{-d_1}} \frac{g_2 + z^{-d_2}}{1 - g_2 z^{-d_2}}$$

and

$$(19) \quad H(z) = \frac{g_3 + z^{-1}}{1 - g_3 z^{-1}}.$$

5 These elementary allpass filters

$$(20) \quad \frac{g + z^{-d}}{1 - g z^{-d}}$$

have been proposed by Schroeder in the context of artificial reverb generation, where they are applied with both large gains and large delays. Since it is not desirable in
 10 this context to have a reverberant output signal, gains and delays are chosen to be rather small. Similarly to the reverb case, a dense and random-like impulse response is best obtained by choosing delays d_i that are pairwise coprime for all allpass filters.

The filter runs at a fixed sampling rate, regardless of the bandwidth or sampling
 15 rate of the signal that is delivered by the core coder. When used with the EVS coder, this is necessary since the bandwidth may be changed by a bandwidth detector during operation and the fixed sampling rate guarantees a consistent output. The preferred sampling rate for the allpass filter is 32 kHz, the native super wide band sampling rate, since the absence of residual parts above 16kHz
 20 are usually not audible anymore. When used with the EVS coder, the signal is directly constructed from the core, which incorporates several resampling routines as displayed in Figure 1.

A filter that has been found to work well at 32kHz sampling rate is

25

$$(21) \quad F(z) = \prod_{i=1}^5 B_i(z)$$

where B_i are basic allpass filters with gains and delays displayed in Table 1. The impulse response of this filter is depicted in Figure 6. For complexity reasons,
 30 one can also apply such a filter at lower sampling rates and/or reduce the number of basic allpass filter units.

The allpass filter unit also provides the functionality to overwrite parts of the input signal by zeros, which is encoder-controlled. This can for instance be used to delete attacks from the filter input.

5 COMPRESSION OF THE g_{norm} FACTOR

To obtain a smoother output it has been found beneficial to apply a compressor to the energy- adjusting gain g_{norm} which compresses the values towards one. This also compensates a bit for the fact that part of the ambience is typically lost after coding the downmix at lower bitrates.

Such a compressor can be constructed by taking

$$(22) \quad \tilde{g}_{norm} = \exp(f(\log(g_{norm}))),$$

15

where,

$$(23) \quad f(t) = t - \int_0^t c(\tau) d\tau$$

20 and the function c satisfies

$$(24) \quad 0 \leq c(t) \leq 1.$$

The value of c around t then specifies how strongly this region is compressed, where the value 0 corresponds to no compression and the value 1 corresponds to total compression. Furthermore, the compression scheme is symmetric if c is even, i.e., $c(t) = c(-t)$. One example is

$$(25) \quad c(t) = \begin{cases} 1 & -\alpha < t < \alpha, \\ 0 & \text{else,} \end{cases}$$

30

which gives rise to

$$(26) \quad f(t) = t - \max\{\min\{\alpha, t\}, -\alpha\}.$$

35 In this case, (22) can be simplified to

(27)

$$\tilde{g}_{norm} = g_{norm} \min\{\max\{\exp(-\alpha), 1/g_{norm}\}, \exp(\alpha)\},$$

5

and one can save the special function evaluations.

USE IN COMBINATION WITH A TIME DOMAIN STEREO UPMIX OF THE BANDWIDTH
EXTENSION FOR ACELP FRAMES

10

When used with the EVS codec, a low delay audio codec for communication scenarios, it is desirable to perform the stereo upmix of the bandwidth extension in time domain, to safe delay induced by the time domain bandwidth extension (TBE). The stereo bandwidth upmix aims at restoring correct

15 panning in the bandwidth extension range, but does not add a substitute for the missing residual. It is therefore desirable to add the substitute in frequency domain stereo processing, as is depicted in Figure 2.

The notation $\tilde{m}$ for the input signal at the decoder, $\tilde{m}_F$ for the filtered input signal, $\tilde{M}_{t,k}$ for the time-frequency bins of $\tilde{m}$ and $\tilde{p}_{t,k}$ for the time frequency bins of $\tilde{m}_F$ are used.

20

One then faces the problem that $\tilde{M}_{t,k}$ is not known in the bandwidth extension range, hence the energy normalizing factor

25

$$(28) \quad g_{norm} = \sqrt{\frac{\sum_{k \in I_b} |\tilde{M}_{t,k}|^2}{\sum_{k \in I_b} |\tilde{p}_{t,k}|^2}}$$

cannot be computed directly if some of the indices $k \in I_b$ lie in the bandwidth extension range. This problem is solved as follows: let I_{HB} and I_{LB} denote the high band resp.

30 low band indices of the frequency bins. Then an estimate $E_{\tilde{M},HB}$ of $\sum_{k \in I_{HB}} |\tilde{M}_{t,k}|^2$ is obtained by calculating the energy of the windowed high band signal in time domain. Now if $I_{b,LB}$ and $I_{b,HB}$ denote the low band and high band indices in I_b , the indices of band b , then one has

$$(29) \quad \sum_{k \in I_b} |\tilde{M}_{t,k}|^2 = \sum_{k \in I_{b,LB}} |\tilde{M}_{t,k}|^2 + \sum_{k \in I_{b,HB}} |\tilde{M}_{t,k}|^2.$$

Now the summands in the second sum on the right hand side are unknown, but since $\tilde{m}_F$ is obtained from $\tilde{m}$ by an allpass filter, one can assume that the energy of $\tilde{p}_{t,k}$ and $\tilde{m}_{t,k}$ is similarly distributed and therefore one will have

$$(30) \quad \frac{\sum_{k \in I_{b,HB}} |\tilde{p}_{t,k}|^2}{\sum_{k \in I_{HB}} |\tilde{p}_{t,k}|^2} \approx \frac{\sum_{k \in I_{b,HB}} |\tilde{M}_{t,k}|^2}{\sum_{k \in I_{HB}} |\tilde{M}_{t,k}|^2} \approx \frac{\sum_{k \in I_{b,HB}} |\tilde{M}_{t,k}|^2}{E_{\tilde{M},HB}}.$$

Therefore, the second sum on the right hand side of (29) can be estimated as

$$(31) \quad \frac{E_{\tilde{M},HB}}{\sum_{k \in I_{HB}} |\tilde{p}_{t,k}|^2} \sum_{k \in I_{b,HB}} |\tilde{p}_{t,k}|^2.$$

USE WITH CODERS THAT CODE A PRIMARY AND A SECONDARY CHANNEL

The artificial signal is also useful for stereo coders, which code a primary and a secondary channel. In this case, the primary channel serves as input for the allpass filter unit. The filtered output may then be used to substitute residual parts in the stereo processing, possibly after applying a shaping filter to it. In the simplest setting primary and secondary channel could be a transformation of the input channels like a mid/side or KL-transform, and the secondary channel could be limited to a smaller bandwidth. The missing part of the secondary channel could then be replaced by the filtered primary channel after applying a high pass filter.

USE WITH A DECODER THAT IS CAPABLE OF SWITCHING BETWEEN STEREO MODES

A particularly interesting case for the artificial signal is, when the decoder features different stereo processing methods as depicted in Figure 3. The methods may be applied simultaneously (e.g. separated by bandwidth) or exclusively (e.g. frequency domain vs. time domain processing) and connected to a switching decision. Using the same artificial signal in all stereo processing methods smooths discontinuities both in the switching case and the simultaneous case.

BENEFITS AND ADVANTAGES OF PREFERRED EMBODIMENTS

The new method has many benefits and advantages over State of the Art Methods as for instance applied in xHE-AAC.

5 Time domain processing allows for a much higher time resolution as subband processing, which is applied in Parametric Stereo, which makes it possible to design a filter whose impulse response is both dense and fast decaying. This leads to the input signals spectral envelope getting less smeared out over time, or the output signal being less colored and therefore sounding more natural.

10

Better suitability for speech, where the optimal peak region of the filter's impulse response should lie between 20 and 40ms.

15

The filter unit features a resampling functionality for input signals with different sampling rates. This allows for operating the filter at a fixed sampling rate, which is beneficial since it guarantees a similar output at different sampling rates; or smooths discontinuities when switching between signals of different sampling rate. For complexity reasons, the internal sampling rate should be chosen such that the filtered signal covers only the perceptually relevant frequency range.

20

Since the signal is generated at the input of the decoder and not connected to a filter bank, it may be used in different stereo processing units. This helps to smooth discontinuities when switching between different units, or when operating different units on different parts of the signal.

25

It also saves complexity, since no re-initialization is needed when switching between units.

30

The gain compression scheme helps to compensate for loss of ambience due to core coding.

35

The method relating to bandwidth extension of ACELP frames mitigates the lack of missing residual components in a panning based time domain bandwidth extension upmix, which increases stability when switching between processing the high band in DFT domain and in time domain.

The input may be replaced by zeros on a very fine time scale, which is beneficial for handling attacks.

Subsequently, additional details with respect to Fig. 1a or 1b, Fig. 2a or 2b and Fig. 3 are discussed.

Fig. 1a or Fig. 1b illustrates the base channel decoder 700 as comprising a first decoding branch having a low band decoder 721 and a bandwidth extension decoder 720 to generate a first portion of the decoded base channel. Furthermore, the base channel decoder 700 comprises a second decoding branch 722 having a full band decoder to generate a second portion of the decoded base channel.

The switching between both elements is done by a controller 713 illustrated as a switch controlled by a control parameter included in the encoded multi-channel signal for feeding a portion of the encoded base channel either into the first decoding branch comprising block 720, 721 or into the second decoding branch 722. The low band decoder 721 is implemented, for example, as an algebraic code excited linear prediction coder ACELP and the second full band decoder is implemented as a transform coded excitation (TCX) / high quality (HQ) core decoder.

The decoded downmix from blocks 722 or the decoded core signal from block 721 and, additionally, the bandwidth extension signal from block 720 are taken and forwarded to the procedure in Fig. 2a or 2b. Additionally, the subsequently connected decorrelation filter comprises resamplers 810, 811, 812 and, if necessary and where appropriate, delay compensation elements 813, 814. An adder combines the time domain bandwidth extension signal from block 720 and the core signal from block 721 and forwards same to a switch 815 controlled by encoded multi-channel data in the form of a switch controller in order to switch between either the first coding branch or the second coding branch depending on which signal is available.

Furthermore, a switching decision 817 is configured that is, for example, implemented as a transient detector. However, the transient detector does not necessarily have to be an actual detector for detecting a transient by a signal analysis, but the transient detector can also be configured to determine a side information or a specific control parameter in the encoded multi-channel signal indicating a transient in the base channel.

The switching decision 817 sets a switch in order to either feed the signal output from switch 815 into the allpass filter unit 802 or a zero input which results in actually deactivating the filling signal addition in the multi-channel processor for certain very specifically selectable time regions, since the EVS allpass signal generator (APSG) indicated at 1000 in Fig. 1a or 1b operates completely in the time domain. Thus, the zero input can be selected on a sample-wise basis without having any reference to any window lengths reducing the spectral resolution as is required for spectral domain processing.

The device illustrated in Fig. 1a is different from the device illustrated in Fig. 1b in that the resamplers and delay stages are omitted in Fig. 1b, i.e., elements 810, 811, 812, 813, 814 are not required in the Fig. 1b device. Hence, in the Fig. 1b embodiment, the allpass filter units operate at 16 kHz rather than at 32 kHz as in Fig. 1a

Fig. 2a or Fig. 2b illustrates the integration of the allpass signal generator 1000 into the DFT stereo processing including a time domain bandwidth extension upmix. Block 1000 outputs the bandwidth extension signal generated by block 720 to a high band upmixer 960 (TBE upmix – (Time domain) bandwidth extension upmix) for generating a high band left signal and a high band right signal from the mono bandwidth extension signal generated by block 720. Furthermore, a resampler 821 is provided connected before a DFT for the filling signal indicated at 804. Additionally, a DFT 922 for the decoded base channel which is either a (fullband) decoded downmix or the (lowband) decoded core signal is provided.

Depending on the implementation, when the decoded downmix signal from the fullband decoder 722 is available, then block 960 is deactivated, and the stereo processing block 904 already outputs the fullband upmix signals such as a fullband left and right channel.

However, when the decoded core signal is input into DFT block 922, then the block 960 is activated and a left channel signal and a right channel signal are added by adders 994a and 994b. However, the addition of the filling signal is nevertheless performed in the spectral domain indicated by block 904 in accordance with the procedures as, for example, discussed within a preferred embodiment based on the

equations 28 to 31. Thus, in such a situation, the signal output by DFT block 902 corresponding to the low band mid signal does not have any high band data. However, the signal output by block 804, i.e., the filling signal has low band data and high band data.

5

In the stereo processing block, the low band data output by block 904 is generated by the decoded base channel and the filling signal but the high band data output by block 904 only consists of the filling signal and does not have any high band information from the decoded base channel, since the decoded base channel was
10 band limited. The high band information from the decoded base channel is generated by bandwidth extension block 720, is upmixed into a left high band channel and right high band channel by block 960 and is then added by the adders 994a, 994b.

15 The device illustrated in Fig. 2a is different from the device illustrated in Fig. 2b in that the resampler is omitted in Fig. 2b, i.e., element 821 is not required in the Fig. 2b device.

Fig. 3 illustrates preferred implementation of a system having multiple stereo
20 processing units 904a to 904b, 904c as discussed before with respect to the switching between stereo modes. Each stereo processing blocks receives side information and, additionally, a certain primary signal but exactly the same filling signal irrespective of whether a certain time portion of the input signal is processed using the stereo processing algorithm 904a, a stereo processing algorithm 904b or another stereo
25 processing algorithm 904c.

Although some aspects have been described in the context of an apparatus, it is clear that these aspects also represent a description of the corresponding method, where a block or device corresponds to a method step or a feature of a method step. Analogously, aspects
30 described in the context of a method step also represent a description of a corresponding block or item or feature of a corresponding apparatus. Some or all of the method steps may be executed by (or using) a hardware apparatus, like for example, a microprocessor, a programmable computer or an electronic circuit. In some embodiments, one or more of the most important method steps may be executed by such an apparatus.

35

The inventive encoded audio signal can be stored on a digital storage medium or can be transmitted on a transmission medium such as a wireless transmission medium or a wired transmission medium such as the Internet.

- 5 Depending on certain implementation requirements, embodiments of the invention can be implemented in hardware or in software. The implementation can be performed using a non-transitory storage medium or a digital storage medium, for example a floppy disk, a DVD, a Blu-Ray, a CD, a ROM, a PROM, an EPROM, an EEPROM or a FLASH memory, having electronically readable control signals stored thereon, which cooperate (or are
10 capable of cooperating) with a programmable computer system such that the respective method is performed. Therefore, the digital storage medium may be computer readable.

- Some embodiments according to the invention comprise a data carrier having electronically readable control signals, which are capable of cooperating with a
15 programmable computer system, such that one of the methods described herein is performed.

- Generally, embodiments of the present invention can be implemented as a computer program product with a program code, the program code being operative for performing
20 one of the methods when the computer program product runs on a computer. The program code may for example be stored on a machine readable carrier.

- Other embodiments comprise the computer program for performing one of the methods described herein, stored on a machine readable carrier.

- 25 In other words, an embodiment of the inventive method is, therefore, a computer program having a program code for performing one of the methods described herein, when the computer program runs on a computer.

- 30 A further embodiment of the inventive methods is, therefore, a data carrier (or a digital storage medium, or a computer-readable medium) comprising, recorded thereon, the computer program for performing one of the methods described herein. The data carrier, the digital storage medium or the recorded medium are typically tangible and/or non-
35 transitionary.

A further embodiment of the inventive method is, therefore, a data stream or a sequence of signals representing the computer program for performing one of the methods described herein. The data stream or the sequence of signals may for example be configured to be transferred via a data communication connection, for example via the Internet.

A further embodiment comprises a processing means, for example a computer, or a programmable logic device, configured to or adapted to perform one of the methods described herein.

A further embodiment comprises a computer having installed thereon the computer program for performing one of the methods described herein.

A further embodiment according to the invention comprises an apparatus or a system configured to transfer (for example, electronically or optically) a computer program for performing one of the methods described herein to a receiver. The receiver may, for example, be a computer, a mobile device, a memory device or the like. The apparatus or system may, for example, comprise a file server for transferring the computer program to the receiver.

In some embodiments, a programmable logic device (for example a field programmable gate array) may be used to perform some or all of the functionalities of the methods described herein. In some embodiments, a field programmable gate array may cooperate with a microprocessor in order to perform one of the methods described herein. Generally, the methods are preferably performed by any hardware apparatus.

The apparatus described herein may be implemented using a hardware apparatus, or using a computer, or using a combination of a hardware apparatus and a computer.

The apparatus described herein, or any components of the apparatus described herein, may be implemented at least partially in hardware and/or in software.

The methods described herein may be performed using a hardware apparatus, or using a computer, or using a combination of a hardware apparatus and a computer.

The methods described herein, or any components of the apparatus described herein, may be performed at least partially by hardware and/or by software.

The above described embodiments are merely illustrative for the principles of the present invention. It is understood that modifications and variations of the arrangements and the details described herein will be apparent to others skilled in the art. It is the intent, therefore, to be limited only by the scope of the impending patent claims and not by the specific details presented by way of description and explanation of the embodiments herein.

In the foregoing description, it can be seen that various features are grouped together in embodiments for the purpose of streamlining the disclosure. This method of disclosure is not to be interpreted as reflecting an intention that the claimed embodiments require more features than are expressly recited in each claim. Rather, as the following claims reflect, inventive subject matter may lie in less than all features of a single disclosed embodiment. Thus the following claims are hereby incorporated into the Detailed Description, where each claim may stand on its own as a separate embodiment. While each claim may stand on its own as a separate embodiment, it is to be noted that - although a dependent claim may refer in the claims to a specific combination with one or more other claims - other embodiments may also include a combination of the dependent claim with the subject matter of each other dependent claim or a combination of each feature with other dependent or independent claims. Such combinations are proposed herein unless it is stated that a specific combination is not intended. Furthermore, it is intended to include also features of a claim to any other independent claim even if this claim is not directly made dependent to the independent claim.

It is further to be noted that methods disclosed in the specification or in the claims may be implemented by a device having means for performing each of the respective steps of these methods.

Furthermore, in some embodiments a single step may include or may be broken into multiple sub steps. Such sub steps may be included and part of the disclosure of this single step unless explicitly excluded.

Claims

1. Apparatus for decoding an encoded multichannel signal, comprising:
 - 5 a base channel decoder for decoding an encoded base channel to obtain a decoded base channel;
 - a decorrelation filter for filtering at least a portion of the decoded base channel to obtain a filling signal, wherein the decorrelation filter comprises an allpass filter; and
 - 10 a multichannel processor for performing a multichannel processing using a spectral representation of the decoded base channel and a spectral representation of the filling signal,
 - 15 wherein the decorrelation filter is a broad band filter and the multichannel processor is configured to apply a narrow band processing to the spectral representation of the decoded base channel and the spectral representation of the filling signal,
 - 20 wherein the allpass filter comprises at least one allpass filter cell, the at least one allpass filter cell comprising two Schroeder allpass filters nested into a third Schroeder allpass filter, or
 - 25 wherein the allpass filter comprises at least one allpass filter cell, the allpass filter cell comprising a first Schroeder allpass filter and a second Schroeder allpass filter cascaded to the first Schroeder allpass filter, wherein an input into the first Schroeder allpass filter and an output from the second Schroeder allpass filter are connected, in the direction of the signal flow, before a delay stage of a third Schroeder allpass filter.
- 30 2. Apparatus of claim 1,
 - 35 wherein a filter characteristic of the decorrelation filter is selected so that a region of a constant magnitude of the filter characteristic is greater than a spectral granularity of the spectral representation of the decoded base channel and a spectral granularity of the spectral representation of the filling signal.

3. Apparatus of claim 1 or 2, wherein the decorrelation filter comprises:

a filter stage for filtering the decoded base channel to obtain a broad band or time domain filling signal; and

5

a spectral converter for converting the broad band or time domain filling signal into the spectral representation of the filling signal.

4. Apparatus of one of the preceding claims,

10

further comprising a base channel spectral converter for converting the decoded base channel into the spectral representation of the decoded base channel.

- 15 5. Apparatus of one of the preceding claims,

wherein at least one of the first Schroeder allpass filter, the second Schroeder allpass filter, and the third Schroeder allpass filter having a first adder, a delay stage, a second adder, a forward feed with a forward gain and a backward feed with a backward gain.

20

6. Apparatus of claim 1, wherein the allpass filter comprises:

25

a first adder, a second adder, a third adder, a fourth adder, a fifth adder and a sixth adder;

a first delay stage, a second delay stage and a third delay stage;

30

a first forward feed with a first forward gain, a first backward feed with a first backward gain,

a second forward feed with a second forward gain and a second backward feed with a second backward gain; and

35

a third forward feed with a third forward gain and a third backward feed with a third backward gain.

7. Apparatus of claim 6,

5

wherein an input into the first adder represents an input into the allpass filter, wherein a second input into the first adder is connected to an output of the third delay stage and comprises the third backward feed with a third backward gain,

10

wherein an output of the first adder is connected to an input into the second adder and is connected to an input of the sixth adder via the third forward feed with the third forward gain,

15

wherein a further input into the second adder is connected to the first delay stage via a first backward feed with the first backward gain,

20

wherein an output of the second adder is connected to an input of the first delay stage and is connected to an input of the third adder via the first forward feed with the first forward gain,

25

wherein an output of the first delay stage is connected to a further input of the third adder,

wherein an output of the third adder is connected to an input of the fourth adder,

wherein a further input into the fourth adder is connected to an output of the second delay stage via the second backward feed with the second backward gain,

30

wherein an output of the fourth adder is connected to an input into the second delay stage and is connected to an input into the fifth adder via the second forward feed with the second forward gain,

35

wherein an output of the second delay stage is connected to a further input into the fifth adder,

wherein an output of the fifth adder is connected to an input of the third delay stage,

wherein the output of the third delay stage is connected to an input into the sixth adder,

5 wherein a further input into the sixth adder is connected to an output of the first adder via the third forward feed with the third forward gain, and

wherein the output of the sixth adder represents an output of the allpass filter.

10 8. Apparatus of claim 1,

wherein the allpass filter comprises two or more allpass filter cells, wherein delay values of the delays of the allpass filter cells are mutually prime.

15 9. Apparatus of claim 1,

wherein a forward gain and a backward gain of a least one of the first Schroeder allpass filter, the second Schroeder allpass filter, and the third Schroeder allpass filter are equal or different from each other by less than 10 % of a greater gain value
20 of the forward gain and the backward gain.

10. Apparatus of claim 1,

wherein the decorrelation filter comprises two or more allpass filter cells,

25

wherein one of the two or more allpass filter cells has two positive gains and one negative gain and another of the two or more allpass filter cells has one positive gain and two negative gains.

30 11. Apparatus of claim 1,

wherein a delay value of a first delay stage is lower than a delay value of a second delay stage, and wherein the delay value of the second delay stage is lower than a delay value of a third delay stage of an allpass filter cell comprising the first
35 Schroeder allpass filter, the second Schroeder allpass filter, and the third Schroeder allpass filter, or

wherein sum of a delay value of a first delay stage and a delay value of a second delay stage is smaller than a delay value of the third delay stage of an allpass filter cell comprising the first Schroeder allpass filter, the second Schroeder allpass filter, and the third Schroeder allpass filter.

12. Apparatus of claim 1,

wherein the allpass filter comprises at least two allpass filter cells in a cascade, wherein a smallest delay value of an allpass filter later in the cascade is smaller than a highest or second to highest delay value of an allpass filter cell earlier in the cascade.

13. Apparatus of claim 1,

wherein the allpass filter comprises at least two allpass filter cells in a cascade,

wherein each allpass filter cell has a first forward gain or a first backward gain, a second forward gain or a second backward gain, and a third forward gain or a third backward gain, a first delay stage, a second delay stage and a third delay stage,

wherein the values for the gains and the delays are set within a tolerance range of $\pm 20\%$ of values indicated in the following table:

Filter	g_1	d_1	g_2	d_2	g_3	d_3
$B_1(z)$	0.5	2	-0.2	73	0.5	83
$B_2(z)$	-0.4	11	0.2	67	-0.5	97
$B_3(z)$	0.4	19	-0.3	61	0.5	103
$B_4(z)$	-0.4	29	0.3	47	-0.5	109
$B_5(z)$	0.3	37	-0.3	41	0.5	127

wherein $B_1(z)$ is a first allpass filter cell in the cascade,

wherein $B_2(z)$ is a second allpass filter cell in the cascade,

wherein $B_3(z)$ is a third allpass filter cell in the cascade,

wherein $B_4(z)$ is a fourth allpass filter cell in the cascade, and

wherein $B_5(z)$ is a fifth allpass filter cell within the cascade,

5 wherein the cascade comprises only the first allpass filter cell B_1 and the second allpass filter cell B_2 or any other two allpass filter cells of the group of allpass filter cells consisting of B_1 to B_5 , or

10 wherein the cascade comprises three allpass filter cells selected from the group of five allpass filter cells B_1 to B_5 , or

wherein the cascade comprises four allpass filter cells selected from the group of allpass filter cells consisting of B_1 to B_5 , or

15 wherein the cascade comprises all five allpass filter cells B_1 to B_5 ,

20 wherein g_1 represents the first forward gain or backward gain of the allpass filter cell, wherein g_2 represents a second backward gain or forward gain of the allpass filter cell, and wherein g_3 represents the third forward gain or backward gain of the allpass filter cell, wherein d_1 represents a delay of the first delay stage of the allpass filter cell, wherein d_2 represents a delay of the second delay stage of the allpass filter cell, and wherein d_3 represents a delay of a third delay stage of the allpass filter cell, or

25 wherein g_1 represents the second forward gain or backward gain of the allpass filter cell, wherein g_2 represents a first backward gain or forward gain of the allpass filter cell, and wherein g_3 represents the third forward gain or backward gain of the allpass filter cell, wherein d_1 represents a delay of the second delay stage of the allpass filter cell, wherein d_2 represents a delay of the first delay stage of the allpass filter cell, and wherein d_3 represents a delay of a third delay stage of the allpass filter cell.

30 14. Apparatus of one of the preceding claims,

35 wherein the multichannel processor is configured to determine a first upmix channel and a second upmix channel using different weighted combinations of spectral bands of the decoded base channel and a corresponding spectral band of the filling signal, the different weighted combinations depending on a prediction factor and/or a gain factor and/or an envelope or energy normalization factor calculated using a

spectral band of the decoded base channel and a corresponding spectral band of the filling signal.

15. Apparatus of claim 14,

5 wherein the multichannel processor is configured to compress the energy normalization factor and to calculate the different weighted combinations using the compressed energy normalization factor.
- 10 16. Apparatus of claim 15, wherein the energy normalization factor is compressed using:

calculating a logarithm of the energy normalization factor;

subjecting the logarithm to a non-linear function; and

15 calculating an exponentiation result of a result of the non-linear function.
17. Apparatus of claim 16,

20 wherein the non-linear function is defined based on $f(t) = t - \int_0^t c(\tau) d\tau$,

wherein the function c is based on $0 \leq c(t) \leq 1$,

wherein t is a real number, and wherein τ is an integration variable.

25
18. Apparatus of claim 14 or 16,

wherein the multichannel processor is configured to compress the energy normalization factor and to calculate the different weighted combinations using the compressed energy normalization factor and using a non-linear function,

30 wherein the non-linear function is defined based on $f(t) = t - \max\{\min\{a, t\}, -\alpha\}$,

wherein α is a predetermined boundary value, and wherein t is a value between $-\alpha$ and $+\alpha$.

35

19. Apparatus of one of the preceding claims,

wherein the multichannel processor is configured to calculate a low band first upmix channel and a low band second upmix channel, and

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wherein the apparatus further comprises a time domain bandwidth expander for expanding the low band first upmix channel and the low band second upmix channel, or a low band base channel

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wherein the multichannel processor is configured to determine a first upmix channel and a second upmix channel using different weighted combinations of spectral bands of the decoded base channel and the corresponding spectral band of the filling signal, the different weighted combinations depending on an energy normalization factor calculated using an energy of the spectral band of the decoded

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base channel and the spectral band of the filling signal,

wherein the energy normalization factor is calculated using an energy estimate derived from an energy of a windowed high band signal.

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20. Apparatus of claim 19,

wherein the time domain bandwidth expander is configured to use the high band signal without the windowing operation used for the calculation of the energy normalization factor.

25

21. Apparatus of one of the preceding claims,

wherein the base channel decoder is configured to provide a decoded primary base channel and a decoded secondary base channel,

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wherein the decorrelation filter is configured for filtering the decoded primary base channel to obtain the filling signal,

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wherein the multichannel processor is configured for performing a multichannel processing by synthesizing one or more residual parts in the multichannel processing using the filling signal, or

wherein a shaping filter is applied to the filling signal.

22. Apparatus of claim 21,

5

wherein the primary and the secondary base channels are a result of a transformation of original input channels, the transformation being e.g. a mid/side transformation or a Karhunen Loeve transformation, and wherein the decoded secondary base channel is limited to a smaller bandwidth,

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wherein the multichannel processor is configured for high pass filtering the filling signal and for using the high pass filtered filling signal as a secondary channel for a bandwidth not included in the bandwidth limited decoded secondary base channel.

15 23. Apparatus of one of the preceding claims,

wherein the multichannel processor is configured for performing different stereo processing methods and

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wherein the multichannel processor is furthermore configured to perform the different multichannel processing methods simultaneously, for example separated by bandwidth, or exclusively, for example frequency domain versus time domain processing and connected to a switching decision, and

25

wherein the multichannel processor is configured to use the same filling signal in all multichannel processing methods.

24. Apparatus of one of the preceding claims,

30

wherein the decorrelation filter comprises as a time domain filter having an optimal peak region of the time domain filter impulse response between 20 ms and 40 ms.

25. Apparatus of one of the preceding claims,

35

wherein the decorrelation filter is configured for resampling the decoded base channel to a predefined or input-dependent target sampling rate,

wherein the decorrelation filter is configured to filter a resampled decoded base channel using a decorrelation filter stage, and

5 wherein the multichannel processor is configured to convert a decoded base channel for a further time portion to the same sampling rate, so that the multichannel processor operates using spectral representations of the decoded base channel and the filling signal that are based on the same sampling rate irrespective of different sampling rates of the decoded base channel for different time portions, or

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wherein the apparatus is configured to perform a resampling before, or when converting to a frequency domain or subsequent to converting to the frequency domain.

15 26. Apparatus of one of the preceding claims,

further comprising a transient detector for finding a transient in the encoded or decoded base channel,

20

wherein the decorrelation filter is configured for feeding a decorrelation filter stage with noise or zero values in a time portion, in which the transient detector has found transient signal samples, wherein the decorrelation filter is configured for feeding the decorrelation filter stage with samples of the decoded base channel in a further time portion in which the transient detector has not found a transient in the encoded or

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decoded base channel.

27. Apparatus of one of the preceding claims,

wherein the base channel decoder comprises:

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a first decoding branch comprising a low band decoder and a bandwidth extension decoder to generate a first portion of the decoded channel;

a second decoding branch having a full band decoder to generate a second portion of the decoded base channel; and

35

a controller for feeding a portion of the encoded base channel either into the first decoding branch or the second decoding branch in accordance with the control signal.

5 28. Apparatus of one of the preceding claims, wherein the decorrelation filter comprises:

a first resampler for resampling a first portion to a predetermined sampling rate;

10 a second resampler for resampling a second portion to the predetermined sampling rate; and

an allpass filter unit for allpass filtering an allpass filter input signal to obtain the filling signal; and

15 a controller for feeding a resampled first portion or a resampled second portion into the allpass filter unit.

29. Apparatus of claim 28,

20 wherein the controller is configured to feed, in response to the control signal, either the resampled first portion or the resampled second portion or zero data into the allpass filter unit.

25 30. Apparatus of one of the preceding claims, wherein the decorrelation filter comprises:

a time-to-spectral converter for converting the filling signal into a spectral representation comprising spectral lines with a first spectral resolution,

30 wherein the multi-channel processor comprises an time-to-spectral converter for converting the decoded base channel into a spectral representation using spectral lines with the first spectral resolution,

35 wherein the multi-channel processor is configured to generate spectral lines for a first upmix channel or a second upmix channel, the spectral lines having the first spectral resolution, using, for a certain spectral line, a spectral line of the filling signal, a spectral line of the decoded base channel and one or more parameters,

wherein the one or more parameters have associated therewith a second spectral resolution being lower than the first spectral resolution, and

5 wherein the one or more parameters are used to generate a group of spectral lines, the group of spectral lines comprising the certain spectral line and at least one frequency adjacent spectral line.

31. Apparatus of one of the preceding claims, wherein the multi-channel processor is
10 configured to generate a spectral line for the first upmix channel or the second upmix channel using:

a phase rotation factor depending on one or more transmitted parameters;

15 a spectral line of the decoded base channel;

a first weight for the spectral line of the decoded base channel, the first weight depending on a transmitted parameter;

20 a spectral line of the filling signals;

a second weight for the spectral line of the filling signal, the second weight depending on a transmitted parameter; and

25 an energy normalization factor.

32. Apparatus of claim 31,

30 wherein, for the calculating the second upmix channel, a sign of the second weight is different from a sign of the second weight used in calculating the first upmix channel, or

wherein, for calculating the second upmix channel, the phase rotation factor is different from a phase rotation factor used in calculating the first upmix channel, or

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wherein, for calculating the second upmix channel, the first weight is different from the first weight used in calculating the first upmix channel.

- 5 33. Apparatus of one of the preceding claims, wherein the base channel decoder is configured to obtain the decoded base channel with a first bandwidth,

10 wherein the multi-channel processor is configured to generate a spectral representation of a first upmix channel and a second upmix channel, the spectral representation having the first bandwidth and an additional second bandwidth comprising a band above the first bandwidth with respect to frequency,

wherein the first bandwidth is generated using the decoded base channel and the filling signal,

- 15 wherein the second bandwidth is generated using the filling signal without the decoded base channel,

wherein the multi-channel processor is configured to convert the first upmix channel or the second upmix channel into a time domain representation,

20 wherein the multi-channel processor further comprises a time domain bandwidth extension processor for generating a time domain extension signal for the first upmix signal or the second upmix signal or the base channel, the time domain extension signal comprising the second bandwidth; and

25 a combiner for combining the time domain extension signal and the time representation of the first or second upmix channel or of the base channel to obtain a broadband upmix channel.

- 30 34. Apparatus of one claim 33, wherein the multi-channel processor is configured to calculate an energy normalization factor used for calculating the first or the second upmix channel in the second bandwidth

using an energy of the decoded base channel in the first bandwidth,

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using an energy of a windowed version of a time extension signal for the first channel or the second channel or for a bandwidth extended downmix signal, and

using an energy of the filling signal in the second bandwidth.

5

35. Method of decoding an encoded multichannel signal, comprising:

decoding an encoded base channel to obtain a decoded base channel;

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decorrelation filtering at least a portion of the decoded base channel to obtain a filling signal, wherein the decorrelation filter comprises using an allpass filter; and

performing a multichannel processing using a spectral representation of the decoded base channel and a spectral representation of the filling signal,

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wherein the decorrelation filtering is a broad band filtering and the multichannel processing comprises applying a narrow band processing to the spectral representation of the decoded base channel and the spectral representation of the filling signal,

20

wherein the allpass filter comprises at least one allpass filter cell, the at least one allpass filter cell comprising two Schroeder allpass filters nested into a third Schroeder allpass filter, or

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wherein the allpass filter comprises at least one allpass filter cell, the allpass filter cell comprising a first Schroeder allpass filter and a second Schroeder allpass filter cascaded to the first Schroeder allpass filter, wherein an input into the first Schroeder allpass filter and an output from the second Schroeder allpass filter are connected, in the direction of the signal flow, before a delay stage of a third Schroeder allpass filter.

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36. Computer program for performing, when running on the computer or processor, the method of claim 35.

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