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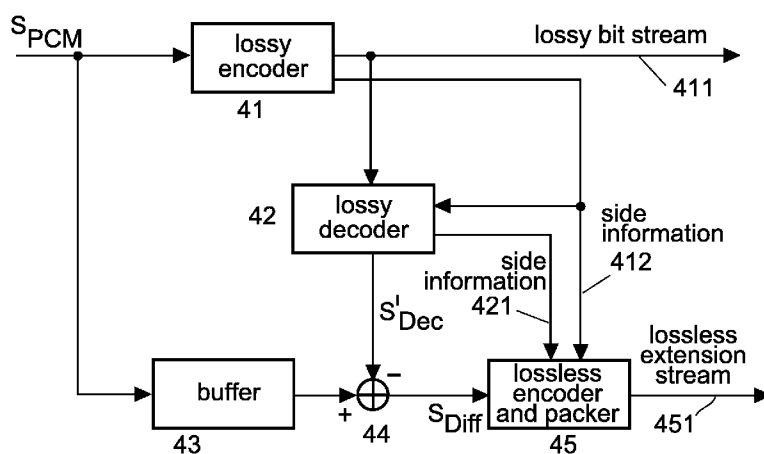
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(54) Title: METHOD AND APPARATUS FOR LOSSLESS ENCODING OF A SOURCE SIGNAL USING A LOSSY ENCODED DATA STREAM AND A LOSSLESS EXTENSION DATA STREAM



(57) Abstract: In lossy based lossless coding a PCM audio signal passes through a lossy encoder (41) to a lossy decoder (42). The lossy encoder provides a lossy bit stream. The difference signal ( $S_{Diff}$ ) between the PCM signal and the lossy decoder output is lossless encoded (52), providing an extension bit stream. The invention facilitates enhancing a lossy perceptual audio encoding/decoding by an extension that enables mathematically exact reproduction of the original waveform using enhanced de-correlation, and provides additional data for reconstructing at decoder site an intermediate-quality audio signal. The lossless extension can be used to extend the widely used mp3 encoding/decoding to lossless encoding/decoding and superior quality mp3 encoding/de-coding.

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**Method and Apparatus for lossless encoding of a source signal using a lossy encoded data stream and a lossless extension data stream**

5 The invention relates to a method and to an apparatus for lossless encoding of a source signal, using a lossy encoded data stream and a lossless extension data stream which together form a lossless encoded data stream for said source signal. Lossy perceptual audio coding data are enhanced by  
10 extension data that enable mathematically exact (lossless) reproduction of the original audio signal waveform.

Background

15

The basic principle of lossless audio coding is depicted in Fig. 1. The digital PCM Audio signal samples are not independent to each other. A signal de-correlation 11 is used to reduce this dependency before entropy coding 12. This process needs to be reversible, to be able to restore the original signal. Known de-correlation techniques are using Linear Predictive Filtering (also known as Linear Predictive Coding LPC), integer filter-banks and lossy based approaches.

25 The basic principle of lossy based lossless coding is depicted in Fig. 2 and Fig. 3. In the encoding part (left side) in Fig. 2, a PCM audio input signal  $S_{PCM}$  passes through a lossy encoder 21 to a lossy decoder 22 and as a lossy bit stream to a lossy decoder 25 in the decoding part  
30 (right side). Lossy encoding and decoding is used to de-correlate the signal. The output signal of decoder 22 is removed from the input signal  $S_{PCM}$  in a subtractor 23, and the resulting difference signal passes through a lossless encoder 24 as an extension bit stream to a lossless decoder  
35 27. The output signals of the decoders 25 and 27 are combined 26 so as to regain the original signal  $S_{PCM}$ .

This basic principle is disclosed for audio coding in EP-B-0756386 and US-B-6498811, and is also discussed in P. Craven, M. Gerzon, "Lossless Coding for Audio Discs", J. Audio Eng. Soc., Vol.44, No.9, September 1996, and in J. Koller, Th. Sporer, K.H. Brandenburg, "Robust Coding of High Quality Audio Signals", AES 103rd Convention, Preprint 4621, August 1997.

In the lossy encoder in Fig. 3, the PCM audio input signal  $S_{PCM}$  passes through an analysis filter bank 31 and a quantisation 32 of sub-band samples to a coding and bit stream packing 33. The quantisation is controlled by a perceptual model calculator 34 that receives signal  $S_{PCM}$  and corresponding information from the analysis filter bank 31.

At decoder side, the encoded lossy bit stream enters a means 35 for de-packing the bit stream, followed by means 36 for decoding the subband samples and by a synthesis filter bank 37 that outputs the decoded lossy PCM signal  $S_{Dec}$ .

Examples for lossy encoding and decoding are described in detail in the standard ISO/IEC 11172-3 (MPEG-1 Audio).

Because a lossy encoder produces an error signal  $S_{Diff}$  that is proportional to the masking thresholds in the frequency domain, the signal is not very well de-correlated and therefore sub-optimum for entropy coding. As a consequence, the following publications focus on a special handling of the error signal  $S_{Diff}$ . The common approach is to apply variations of LPC de-correlation schemes to the error signal  $S_{Diff}$ : WO-A-9953677, US-A-20040044520, WO-A-2005098823. In EP-A-0905918 the amplitude of the error signal  $S_{Diff}$  is used with a feedback loop to the quantisation stage of the lossy encoder part in order to control the quantisation in the lossy encoder and thus to generate a better de-correlation of the error signal  $S_{Diff}$ .

Invention

When providing a lossless coding extension for lossy coding it is desirable to facilitate this in a scalable manner.

5

A problem to be solved by the invention is to provide an improved lossless coding/decoding extension for lossy coding/decoding in a scalable manner, the lossy coding/decoding being based for example on mp3 (MPEG-1 Audio Layer 3). This  
10 problem is solved by the encoding method disclosed in claim 1 and the decoding methods in claims 3 and 5. Apparatuses that utilise these method are disclosed in claims 2, 4 and 6, respectively.

15 The invention facilitates enhancing a lossy perceptual audio encoding/decoding by an extension that enables mathematically exact reproduction (i.e. lossless encoding/decoding) of the original waveform. The lossy based lossless coding makes use of enhanced de-correlation by means of spectral  
20 de-correlation build into the lossy encoder-decoder and additional temporal LPC de-correlation, where the LPC filter parameters need not be transmitted. Advantageously, the inventive lossless extension can be used to extend the widely used mp3 encoding/decoding to lossless  
25 encoding/decoding.

In principle, the inventive encoding method is suited for lossless encoding of a source signal, using a lossy encoded data stream and a lossless extension data stream which together form a lossless encoded data stream for said source  
30 signal, said method including the steps:

- lossy encoding said source signal, wherein said lossy encoding provides said lossy encoded data stream as well as spectral whitening data;
- 35 - correspondingly lossy decoding said lossy encoded data, thereby reconstructing a standard decoded signal and, using

said spectral whitening data, constructing from said standard decoded signal a superior quality decoded signal;

- forming a difference signal between said source signal and said superior quality decoded signal and lossless encoding said difference signal;
- packing said encoded difference signal together with said spectral whitening data to form said lossless extension data stream.

10 In principle the inventive encoding apparatus is suited for lossless encoding of a source signal, using a lossy encoded data stream and a lossless extension data stream which together form a lossless encoded data stream for said source signal, said apparatus including:

- 15 - means being adapted for lossy encoding said source signal, wherein said lossy encoding provides said lossy encoded data stream as well as spectral whitening data;
- means being adapted for correspondingly lossy decoding said lossy encoded data, thereby reconstructing a standard
- 20 decoded signal and, using said spectral whitening data, for constructing from said standard decoded signal a superior quality decoded signal;
- means being adapted for forming a difference signal between said source signal and said superior quality decoded
- 25 signal and for lossless encoding said difference signal and for packing said encoded difference signal together with said spectral whitening data to form said lossless extension data stream.

30 In principle, the inventive decoding method is suited for decoding a lossless encoded source signal data stream, which data stream was derived from a lossy encoded data stream and a lossless extension data stream which together form a lossless encoded data stream for said source signal,

35 wherein said source signal was lossy encoded, said lossy encoding providing said lossy encoded data stream as well as

spectral whitening data,  
and wherein said lossy encoded data were correspondingly  
lossy decoded, thereby reconstructing a standard decoded  
signal and, using said spectral whitening data, a superior  
5 quality decoded signal was constructed from said standard  
decoded signal,  
and wherein a difference signal between said source signal  
and said superior quality decoded signal was formed and  
lossless encoded,  
10 and wherein said lossless encoded difference signal was  
packed together with said spectral whitening data to form  
said lossless extension data stream,  
said method including the steps:  
- de-packing said lossless extension data stream and decod-  
15 ing said lossless encoded difference signal so as to provide  
said difference signal and said spectral whitening data;  
- lossy decoding said lossy encoded data stream, thereby  
reconstructing said standard decoded signal and, using said  
spectral whitening data, reconstructing said superior qual-  
20 ity decoded signal from said standard decoded signal;  
- forming from said decoded lossless encoded difference  
signal and from said superior quality decoded signal a re-  
constructed source signal.

25 In principle the inventive decoding apparatus is suited for  
for decoding a lossless encoded source signal data stream,  
which data stream was derived from a lossy encoded data  
stream and a lossless extension data stream which together  
form a lossless encoded data stream for said source signal,  
30 wherein said source signal was lossy encoded, said lossy en-  
coding providing said lossy encoded data stream as well as  
spectral whitening data,  
and wherein said lossy encoded data were correspondingly  
lossy decoded, thereby reconstructing a standard decoded  
35 signal and, using said spectral whitening data, a superior  
quality decoded signal was constructed from said standard

decoded signal,  
and wherein a difference signal between said source signal  
and said superior quality decoded signal was formed and  
lossless encoded,

5 and wherein said lossless encoded difference signal was  
packed together with said spectral whitening data to form  
said lossless extension data stream,  
said apparatus including:

- 10 - means being adapted for de-packing said lossless extension data stream and for decoding said lossless encoded difference signal so as to provide said difference signal and said spectral whitening data;
- means being adapted for lossy decoding said lossy encoded data stream, thereby reconstructing said standard decoded  
15 signal and, using said spectral whitening data, reconstructing said superior quality decoded signal from said standard decoded signal;
- means being adapted for forming from said decoded lossless encoded difference signal and from said superior quality  
20 decoded signal a reconstructed source signal.

In principle, the further inventive decoding method is  
suited for decoding a lossless encoded source signal data  
stream, which data stream was derived from a lossy encoded  
25 data stream and a lossless extension data stream which together form a lossless encoded data stream for said source signal,  
wherein said source signal was lossy encoded, said lossy encoding providing said lossy encoded data stream as well as  
30 spectral whitening data,  
and wherein said lossy encoded data were correspondingly lossy decoded, thereby reconstructing a standard decoded signal and, using said spectral whitening data, a superior quality decoded signal was constructed from said standard  
35 decoded signal,  
and wherein a difference signal between said source signal

and said superior quality decoded signal was formed and lossless encoded,

and wherein said lossless encoded difference signal was packed together with said spectral whitening data to form

5 said lossless extension data stream,

said method including the steps:

- de-packing said lossless extension data stream so as to provide said spectral whitening data;

- lossy decoding said lossy encoded data stream, thereby  
10 reconstructing said standard decoded signal and, using said spectral whitening data, reconstructing said superior quality decoded signal from said standard decoded signal.

In principle the further inventive decoding apparatus is  
15 suited for decoding a lossless encoded source signal data stream, which data stream was derived from a lossy encoded data stream and a lossless extension data stream which together form a lossless encoded data stream for said source signal,

20 wherein said source signal was lossy encoded, said lossy encoding providing said lossy encoded data stream as well as spectral whitening data,

and wherein said lossy encoded data were correspondingly lossy decoded, thereby reconstructing a standard decoded  
25 signal and, using said spectral whitening data, a superior quality decoded signal was constructed from said standard decoded signal,

and wherein a difference signal between said source signal and said superior quality decoded signal was formed and  
30 lossless encoded,

and wherein said lossless encoded difference signal was packed together with said spectral whitening data to form said lossless extension data stream,

said apparatus including:

- 35 - means being adapted for de-packing said lossless extension data stream so as to provide said spectral whitening



data;

- means being adapted for lossy decoding said lossy encoded data stream, thereby reconstructing said standard decoded signal and, using said spectral whitening data, reconstruct-
- 5 ing said superior quality decoded signal from said standard decoded signal.

Advantageous additional embodiments of the invention are disclosed in the respective dependent claims.

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### Drawings

Exemplary embodiments of the invention are described with

15 reference to the accompanying drawings, which show in:

Fig. 1 known principle of lossless audio signal compression;

Fig. 2 basic block diagram for a known lossy based lossless encoder and decoder;

20 Fig. 3 known principle operation of a lossy encoder and a lossy decoder;

Fig. 4 block diagram for the inventive lossy based lossless encoding;

Fig. 5 block diagram for the inventive lossy based lossless

25 decoding;

Fig. 6 more detailed block diagram for the lossy encoder in Fig. 4;

Fig. 7 example signals:

a) discrete signal spectrum in lossy encoder sub-

30 band domain,

b) error signal following perceptually controlled quantisation,

c) error signal following whitening,

d) spectral noise shaping to adapt to a given LPC

35 filter signal;

Fig. 8 more detailed block diagram for the lossy decoder in

Fig. 5;

Fig. 9 more detailed block diagram for the lossless encoder and packer in Fig. 4;

Fig. 10 LPC de-correlator;

5 Fig. 11 more detailed block diagram for the lossless de-packer and decoder in Fig. 5;

Fig. 12 extension file structure;

Fig. 13 bit stream formatting.

10

### Exemplary embodiments

The invention solves the problem of suboptimum de-correlation of lossy based lossless coding by making use of a modified lossy encoder like encoder 41 shown in Fig. 4. Besides of producing from the original input signal  $S_{PCM}$  a compliant lossy bit stream 411, this encoder generates special spectral whitening data which is sent, besides other information, as side information 412 to a corresponding modified lossy decoder 42 and to a lossless encoder and packer 45 outputting a lossless extension bit stream. The lossy encoder 41 is shown in more detail in Fig. 6. The spectral whitening data are formed as explained in connection with figures 6 and 7. In the modified lossy decoder 42 the lossy bit stream 411 is decoded and the frequency spectrum for the current frame of the input signal is restored whereby the spectral whitening data from signal 412 is added to the spectrum. Thereafter in decoder 42 a synthesis filter bank is applied, and a time domain error signal  $S_{Diff}$  is calculated in a subtractor 44 by subtracting the corresponding decoder 42 output signal  $S'_{Dec}$  from the input signal  $S_{PCM}$  that has been correspondingly delayed by a buffer 43 in order to compensate for the required processing time in encoder 41 and decoder 42. The error signal  $S_{Diff}$  now has a white (i.e. a flat) frequency power spectrum, which is equivalent to having a high de-correlation, and thus is

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suited for efficient entropy coding. Signal  $S_{Diff}$  is fed to a lossless encoder and packer 45 which contains an entropy encoder and includes in its lossless extension stream 451 output lossy encoder side information data 412 provided from encoder 41 and lossy decoder side information data 421 provided by decoder 42.

To increase the lossless coding efficiency, the modified lossy encoder 41 can reduce the amount of whitening data (and thus the related bit rate) in favour of an additional LPC filter placed inside the lossless encoder and packer 45. The LPC filter coefficients are determined using lossy bit stream elements like scale factors or the block spectrum in decoder 42 in the preferred embodiment, and only a very small amount of additional data needs to be transmitted to enable calculation of the filter coefficients at decoder side.

In the lossy based lossless decoding in Fig. 5 the lossy bit stream 411 is decoded in a modified lossy decoder 51 that outputs a (known) lossy encoded and decoded output signal  $S_{Dec}$ , e.g. a decoded mp3 signal, which may be denoted as lossy mode 1.

When receiving the lossless extension stream 451, consistency to match the lossy bit stream 411 and a permission check to allow decoding for different modes can be performed, e.g. in a lossless de-packer and decoder 52. The different modes can be the lossy mode 1, a lossy mode 2 and a lossless mode 3.

If not operating in mode 1 only, received spectral whitening data is de-packed in means 52 and is sent (among other information) as side information 521 to the lossy decoder 51, in which spectral whitening data is added to the restored spectrum and a synthesis filter-bank is applied to create the output signal  $S'_{Dec}$ . In lossy mode 2  $S'_{Dec}$  is the output signal. This is a lossy signal which is superior to signal  $S_{Dec}$  in terms of perceptual quality and is called 'interme-

mediate quality' in the following description. It is not necessary to decode the lossless encoded difference signal  $S_{\text{Diff}}$ .

In lossless mode 3 the lossless extension stream 451 is further de-packed in means 52 and entropy decoding is applied therein, and an optional LPC synthesis can be applied if signalled correspondingly in the lossless extension bit stream 451. In a preferred embodiment the LPC synthesis filter coefficients are determined using corresponding information items from lossy bit stream 411 data elements like scale factors or the spectrum of related lossy coefficient blocks in sub-band domain of the lossy decoder 51, as well as optional helper information items transmitted inside the lossless extension stream 451. The error signal  $S_{\text{Diff}}$  is restored in means 52 and is synchronised to signal  $S'_{\text{Dec}}$ . The error signal  $S_{\text{Diff}}$  and the signal  $S'_{\text{Dec}}$  (i.e. the intermediate quality signal) are combined in an adder 53 so as to regain the mathematically lossless reconstruction of the original signal  $S_{\text{PCM}}$ .

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The lossy decoder 51 operates exactly like lossy decoder 42 in the encoding part in terms of calculation of signal  $S'_{\text{Dec}}$ . Signal  $S'_{\text{Dec}}$  in the decoding part and signal  $S'_{\text{Dec}}$  in the encoding part are mathematically identical, as well as signals  $S_{\text{Diff}}$  in the decoding part and  $S_{\text{Diff}}$  in the encoding part.

25

Advantageously, the lossy decoder implementations 51 and 42 and the optional LPC elements in means 52 and means 45 can be realised platform independent using integer arithmetic.

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The lossy encoder 41 of Fig. 4 is explained in more detail in connection with Fig. 6. The lossy decoder 51 of Fig. 5 is explained in more detail in connection with Fig. 8. By combining lossy encoder 41 and lossy decoder 42 in Fig. 4, simplifications are feasible.

35

*Lossy encoder*

The lossy encoder 41 includes an analysis filter-bank 61 and a perceptual model calculator 64 which both receive the original input signal  $S_{PCM}$ . The output signal of filter bank 61 passes to the first input of a subtractor 65 and through a first quantisation means 62 to the second input of a first subtractor 65 and to an encoding and bit stream packing means 63 that provides the lossy bitstream 411. The analysis filter-bank 61 converts signal  $S_{PCM}$  into the sub-band domain.

An example spectrum of signal 611 is depicted in Fig. 7a, showing the amplitudes  $A$  of the spectrum versus the frequency  $f$ .

Signal 611 is quantised in the first quantiser 62 according to the control of the perceptual model provided by calculator 64. An error signal 651 is calculated by subtracting the quantised sub-band samples 621 from the original sub-band samples 611. Usually the amplitude of this error signal is proportional to the masking thresholds determined in the perceptual model. An example error signal 651 is depicted in Fig. 7b in comparison to signal 611.

The error signal 651 is quantised in a second quantisation means 66 in such a way that a further error signal 681 is calculated within an adaptation control loop formed by a second subtractor 68 and an adaptation controller 67, which further error signal 681 is the difference between signal 651 and the output signal of the second quantiser 66 and approaches a white spectrum, as depicted in Fig. 7c together with signals 611 and 651. The output signal of second quantiser 66 represents spectral whitening data 661 that is sent as part of the side information 412 to lossy decoder 42 and to lossless encoder and packer 45. Adaptation control 67 controls second quantiser 66 and takes care to find the right quantisation and the right bit rate for signal 661. If the bit rate exceeds a pre-determined threshold value and the error spectrum 681 is therefore not estimated 'white',

within side information 412 an escape signal 671 is sent indicating that the lossless encoder and packer 45 shall use additional LPC de-correlation. Adaptation control 67 sets the optimum quantisation step for quantiser 66 to enable a flat noise floor, see signal 681 in Fig. 7c. This control may include a power analysis of signal 651. An iterative process is not necessary.

The second task of adaptation control 67 is to observe an estimation of the bit rate of the entropy encoded signal 661. Signal 661 is later entropy coded in step or stage 93. The bit rate of the entropy coded signal 661 is a main contribution to the overall rate of the 'lossless' bit-stream 451. In case this bit rate estimate exceeds a threshold the escape signal 671 to use additional LPC de-correlation in time domain is sent.

In another embodiment, adaptation control 67 can optimise signal 661 such that signal 681 is no longer white (i.e. it uses different quantisation steps over the frequency bin axis). The noise floor 681 is then formed to match the characteristics of a given LPC de-correlator filter out of a dictionary of different LPC filters. The adaptation control process then becomes iterative in order to find the closest match of signal 681 with lowest costs (i.e. share of bit rate). This embodiment is depicted in Fig. 7d.

#### *Lossy decoder*

The lossy decoder 42 shown in Fig. 8 receives lossy bit stream 411 which is de-packed in a bit stream depacker 81 and is decoded (including inverse quantiser scale factor processing if applicable) in a sub-band sample decoder 82 to create a sub-band sample signal 821 which is identical to signal 621 in the lossy encoder in Fig. 6. Signal 821 is transformed back to the time domain in a synthesis filter bank 83 that restores in each case a block of data values of signal  $S_{Dec}$ . The spectral whitening data 661 (which is re-

ceived from the lossless extension stream following de-  
packing) is added in a combiner 84 to signal 821, in order  
to form a signal 841 that has a quantisation error in the  
sub-band domain which is identical to the quantisation error  
5 of signal 681 in figures 6 and 7c. A synthesis filter bank  
85 transforms signal 841 back to the time domain and re-  
stores in each case a block of data values of signal  $S'_{Dec}$ .  
Because normally either signal  $S_{Dec}$  or signal  $S'_{Dec}$  is out-  
put, a single synthesis filter can be used that is connected  
10 to either signal 821 or signal 841, respectively.

The lossy decoder should be realised in a platform independ-  
ent manner using special integer arithmetic operations. De-  
coding a given bit stream to signal  $S'_{Dec}$  within the loss-  
less decoder at encoding or at decoding side needs to pro-  
15 duce numerically equivalent results on every platform like  
ARM based, Intel Pentium based, or DSP based platforms.

#### *Buffer and synchronisation*

20 Lossy encoding and decoding induces a delay between the sig-  
nals  $S_{PCM}$  and  $S'_{Dec}$  in Fig. 4. When operating the lossless  
encoder in streaming real-time applications the lossy en-  
coder is aware of this delay and will control First-In  
First-Out buffering in buffer 43 to guarantee sample-exact  
25 (i.e. synchronised) operation at subtractor 44 in Fig. 4.  
When operating the lossless encoder for file-to-file opera-  
tions, e.g. converting PCM Audio files to lossless encoded  
files, the buffer 43 can be replaced by using synchronisa-  
tion means as described in US-B-6903664.  
30 In the preferred embodiment the lossy encoder will insert  
information items indicating the coding delay and the origi-  
nal file length into the auxiliary data part of the lossy  
bit stream of the first one or two audio frames as well as  
into the first frame of the lossless extension. The lossy  
35 decoder 42 and 51 will read this information and skip the  
first decoded (zero) samples indicated by the delay informa-

tion.

#### *Lossless encoder and packer*

The lossless encoder and packer 45 of Fig. 4 is shown in more detail in Fig. 9. During regular operation the error signal  $S_{\text{Diff}}$  is highly de-correlated and can be entropy coded in entropy encoder 93, for which coding the preferred embodiment uses a Golomb-Rice coding. Spectral whitening data 661 (from bus 412) is also entropy coded in encoder 93 using a different entropy coding method, e.g. Huffman coding. The packer 94 forms a frame based bit stream using the entropy coded data 931 and additional information items 412 like escape signal 671 from lossy encoder 41, and outputs the lossless extension stream 451. If indicated by lossy encoder 41 with the escape signal 671, the error signal  $S_{\text{Diff}}$  can be further de-correlated using a linear prediction in an LPC de-correlator 91, which is shown in more detail in Fig. 10. LPC de-correlator 91 receives helper information from bus 421. The switching according to escape signal 671 (from bus 412) is performed by switch 92.

#### *LPC de-correlator*

In the LPC de-correlator in Fig. 10, from the input signal  $S_{\text{Diff}}$  a version passed through predictor 102 is subtracted in a subtractor 101. Its output signal is fed to switch 92. Predictor 102 uses a filter that is calculated using a filter determinator 103, the filter coefficients of which are derived from the helper information signal from bus 421. Filter determinator 103 can operate as follows:

#### *Mode 1*

The scale factors of the decoder are transmitted as signal 421 to filter determinator 103. These scale factors  $s_i$  are used to estimate the spectral power of the residual in the transform domain:

$S_{ee}(i) = 2^{-3/8} s_i$ , with  $i = 0, \dots, N_{band}-1$  (number of bins), whereby the step-like power estimate may become smoothed.



These spectral power values are duplicated to form an even sequence  $S'_{ee}(i)$  with  $i = 0, \dots, N_{band} - 1, \dots, 2N_{band} - 1$ . This is done to enable a real-valued inverse FFT sequence. Thereafter the auto-correlation is calculated by  $iFFT(S'_{ee}(i))$ .

5 The Levinson-Durbin algorithm can be used to determine the LPC coefficients.

This procedure can also be used in the lossless decoder. If relevant parts of the higher frequency spectrum are not transmitted inside the lossy encoder bit stream 411, this  
 10 missing information 631 is sent from step/stage 63 in the lossy encoder to packer 94 for transmission, and from de-packer 111 to filter determinator 103.

#### *Mode 2*

A set of LPC filter-coefficients is selected from a directory of LPS filter coefficient sets by adaptation controller  
 15 67. Then signal 631 becomes the directory index for the selected set of coefficients and is passed to packer 94 for transmission.

20

#### *Side Information*

The side information buses 412 and 421 carry data from lossy encoder 41 to lossy decoder 42 and from either one to the lossless encoder and packer 45, and these buses include the  
 25 following data elements:

- encoded spectral whitening data 661 (sent via bus 412 from encoder 41 to decoder 42 and to encoder/packer 45);
- an escape signal 671 to indicate additional LPC de-correlation (sent via bus 412 from encoder 41 to encoder/packer  
 30 45, i.e. indicating that LPC de-correlation and LPC synthesis is active;
- a helper information signal (sent via bus 421 from decoder 42 to encoder/packer 45 or 94, respectively), i.e. scale factors for LPC filter determination;
- 35 - a helper information 631 sent from lossy encoder 41 to encoder packer 45/94, for transmitting missing scale factors

- for high frequency bands or an index to a set of predefined LPC filter coefficients;
- for file-to-file applications, lossy coder delay value and/or original file length value (sent via bus 412 from encoder 41 to decoder 42 and to encoder/packer 45).

#### *Lossy based lossless decoding*

As already described in connection with Fig. 2, the decoding is carried out using a lossy decoder 25 and a lossless decoder 27, the output signals of which are combined to regain the original input signal samples  $S_{PCM}$ . Advantageously, the decoding can be carried out in different modes.

#### *Mode 1*

The decoder can decode any compliant lossy bit stream 411 without a lossless extension stream 451 being present, and provides signal  $S_{Dec}$ . This mode is also active when a lossless extension stream 451 is present but no permission is provided to use another mode. Preferably, the decoder will check the lossless extension stream for a matching permission ID in its rights data-base.

#### *Mode 2*

This intermediate-quality mode is also enabled by a permission check in the decoder when examining the lossless extension stream data. Only the whitening data 661 is de-packed and used by the lossy decoder to provide signal  $S'_{Dec}$ .

#### *Mode 3*

The lossless mode decoding is started following a positive permission check result, and signal  $S_{PCM}$  is output.

The corresponding lossy decoder 51 is depicted in Fig. 8 in more detail. The modes of operation are signalled within side information 521 from the lossless de-packer and decoder 52. Basically, the same details apply as described for the

lossy decoder 42. The encoded lossy bit stream 411 enters a means 81 for de-packing the bit stream, followed by means 82 for decoding the subband samples and by a synthesis filter bank 83 that outputs the decoded lossy PCM signal  $S_{Dec}$ . The  
5 output signal 821 from means 82 is combined in an adder 84 with the corresponding spectral whitening data 661. The combined signal 841 enters a second synthesis filter bank 85 that outputs the decoded lossy PCM signal  $S'_{Dec}$ .

10 *Lossless de-packer and decoder*

Fig. 11 shows the lossless de-packer and decoder 52 in more detail. The lossless de-packer 111 receives the lossless extension stream 451 which is parsed and de-packed. Control information is routed to operation controller 115 in  
15 which in case of file-to-file applications a consistency check can be performed to identify integrity with respect to the lossy bit stream 411. As an option, a reference fingerprint (e.g. CRC data) is extracted from the lossless extension stream 451 and a current fingerprint is calculated over  
20 a certain data block of the lossy bit stream 411. If both finger prints are identical the normal operation proceeds. A permission check may be performed as a next step to identify the allowed mode or modes of operation. Corresponding information items 1151 received from an external database are  
25 used for comparison with permission identifiers of the received bit stream. The current mode is determined and a corresponding signal 1152 is used to send related information to the lossy decoder 51 using the side information channel 521. In special embodiments, means for deciphering an en-  
30 crypted lossless extension stream might also be used.

Following de-packing, the audio extension signal data 1111 is entropy decoded in an entropy decoder 112. The entropy encoded spectral whitening data items are correspondingly entropy decoded, e.g. in encoder 112. The decoded whitening  
35 data 661 is sent to the lossy decoder 51 and the difference signal data  $S_{Diff}$  is sent to the combiner or summation unit

53. If escape information to apply additional LPC synthesis is identified in the bit stream 451 by de-packer 111 and operation controller 115, that controller will use signal 1153 to switch switcher 113 to the LPC synthesis path. The coefficients of LPC synthesis filter 114 are calculated using helper information 1141 which is provided from de-packer 111, or which can be determined from the lossy bit stream scale-factors or from the decoder sub-band signal 841 and additional information transmitted in the lossless extension bit stream 451 like missing scale-factors or spectral power information of high frequency bands not transmitted in lossy bit stream 411, or an index value pointing to a set of pre-defined LPC coefficients.

#### 15 *Side information*

The side information 521 exchanged between lossy decoder 51 and lossless de-packer and decoder 52 includes the following information and data elements:

- a mode indicator signal 1152 (sent to decoder 52);
- 20 - spectral whitening data 661 (sent to decoder 52);
- helper information 1141 from lossy decoder 42 to determine LPC filter coefficients (sent to lossless de-packer and decoder 52);
- lossy coder delay value and/or original file length value
- 25 for file-to-file applications (sent to decoder 52).

#### *Lossless extension bit stream*

The following data elements can be provided within the lossless extension bit stream as header data elements:

- 30 - a fingerprint to unambiguously identify corresponding lossy bit stream. This element is needed especially for two files applications and might be disregarded for container (one file) and streaming applications;
- mode indicators and corresponding DRM information;
- 35 - synchronisation information (lossy coding delay, original file length, file end indicator);

- PCM word size of original signal (16, 20 or 24 bits);
- cue point information enabling a faster addressing of lossless data frames inside the (variable bit rate) stream, consisting of a table of constant frame interval pointers and an frame interval length indicator.

In file-to-file applications these information items need to be provided only once at the beginning of the lossless bit stream. In streaming applications these information items, excluding the cue- point data, need to be sent every N frames.

Frame data elements of the lossless extension bit stream bit stream are:

- a frame boundary indicator to enable frame-synchronous operation for the lossy bit stream;
- coded spectral error (i.e. whitening) data;
- escape information indicating the use of additional LPC synthesis, and LPC helper information;
- the encoded time error signal data.

A lossless extension stream file format is shown in Fig. 12. A file header provides side information to start the process of decoding. Following the header data, data frames of variable length containing data for reconstructing an intermediate-quality audio signal and for reconstructing a lossless-quality audio signal are arranged.

File header data:

- header ID;
- header length;
- fingerprint (e.g. CRC32 data);
- mode indication information block;
- side info: codec delay, original file length, PCM word size, sample rate;
- a cue point table data block: block-length value, interval info in frames, number of table entries, pointer-table.

Frame data:

- sync word (optional) and frame length;
- coded spectral error (i.e. whitening) data: block-length,  
coded data. This is the data required to decode to inter-  
5 mediate quality (mode 2). Decoders operating in mode 2  
will skip the rest of the frame data if such data are pre-  
sent;
- LPC helper information: block length value, LPC mode indi-  
cator, coded data;
- 10 - coded time error signal: block length value, coded data.

*Bit stream formats and rights management*

The lossy bit stream 411 and the lossless extension stream  
451 can be formatted for different storage or streaming ap-  
15 plications, see Fig. 13. The output signals 411 and 451 of  
the lossy based lossless encoding 131 are fed to a bit  
stream formatter 132. The resulting output signal 1322 can  
be a single stream or file or can consist of two streams or  
two files. A rights management processing may be applied by  
20 supplying formatter 132 with corresponding rights management  
data 1321.

At decoding side, a corresponding bit stream de-formatter  
can be used.

Claims

1. Method for lossless encoding of a source signal ( $S_{PCM}$ ),  
using a lossy encoded data stream (411) and a lossless  
5 extension data stream (451) which together form a lossless  
encoded data stream (1322) for said source signal,  
**characterised** by the steps:
  - lossy encoding (41) said source signal, wherein said  
lossy encoding provides said lossy encoded data stream  
10 (411) as well as spectral whitening data (661);
  - correspondingly lossy decoding (42) said lossy encoded  
data, thereby reconstructing a standard decoded signal  
( $S_{DEC}$ ) and, using said spectral whitening data, con-  
structing from said standard decoded signal a superior  
15 quality decoded signal ( $S'_{DEC}$ );
  - forming (43, 44) a difference signal ( $S_{Diff}$ ) between said  
source signal ( $S_{PCM}$ ) and said superior quality decoded  
signal ( $S'_{DEC}$ ) and lossless encoding (45) said difference  
signal;
  - 20 - packing said encoded difference signal together with said  
spectral whitening data (661) to form said lossless ex-  
tension data stream (451).
2. Apparatus for lossless encoding of a source signal  
25 ( $S_{PCM}$ ), using a lossy encoded data stream (411) and a  
lossless extension data stream (451) which together form  
a lossless encoded data stream (1322) for said source  
signal, said apparatus including:
  - means (41) being adapted for lossy encoding said source  
30 signal, wherein said lossy encoding provides said lossy  
encoded data stream (411) as well as spectral whitening  
data (661);
  - means (42) being adapted for correspondingly lossy decod-  
ing said lossy encoded data, thereby reconstructing a  
35 standard decoded signal ( $S_{DEC}$ ) and, using said spectral  
whitening data, for constructing from said standard de-

- coded signal a superior quality decoded signal ( $S'_{Dec}$ );
- means (43, 44, 45) being adapted for forming a difference signal ( $S_{Diff}$ ) between said source signal ( $S_{PCM}$ ) and said superior quality decoded signal ( $S'_{Dec}$ ) and for lossless encoding said difference signal and for packing said encoded difference signal together with said spectral whitening data (661) to form said lossless extension data stream (451).
- 10 3. Method for decoding a lossless encoded source signal ( $S_{PCM}$ ) data stream, which data stream was derived from a lossy encoded data stream (411) and a lossless extension data stream (451) which together form a lossless encoded data stream (1322) for said source signal,
- 15 wherein said source signal was lossy encoded (41), said lossy encoding providing said lossy encoded data stream (411) as well as spectral whitening data (661), and wherein said lossy encoded data were correspondingly lossy decoded (42), thereby reconstructing a standard decoded signal ( $S_{Dec}$ ) and, using said spectral whitening data, a superior quality decoded signal ( $S'_{Dec}$ ) was constructed from said standard decoded signal,
- 20 and wherein a difference signal ( $S_{Diff}$ ) between said source signal ( $S_{PCM}$ ) and said superior quality decoded signal ( $S'_{Dec}$ ) was formed (43, 44) and lossless encoded (45),
- 25 and wherein said lossless encoded difference signal was packed together with said spectral whitening data (661) to form said lossless extension data stream (451),
- 30 said method including the steps:
- de-packing (52) said lossless extension data stream (451) and decoding (52) said lossless encoded difference signal so as to provide said difference signal ( $S_{Diff}$ ) and said spectral whitening data (661);
  - 35 - lossy decoding (51) said lossy encoded data stream (411), thereby reconstructing said standard decoded signal



- (S<sub>Dec</sub>) and, using said spectral whitening data, reconstructing (51) said superior quality decoded signal (S'<sub>Dec</sub>) from said standard decoded signal;
- 5 - forming (53) from said decoded lossless encoded difference signal (S<sub>Diff</sub>) and from said superior quality decoded signal (S'<sub>Dec</sub>) a reconstructed source signal (S<sub>PCM</sub>).
4. Apparatus for decoding a lossless encoded source signal
- 10 (S<sub>PCM</sub>) data stream, which data stream was derived from a lossy encoded data stream (411) and a lossless extension data stream (451) which together form a lossless encoded data stream (1322) for said source signal,
- wherein said source signal was lossy encoded (41), said
- 15 lossy encoding providing said lossy encoded data stream (411) as well as spectral whitening data (661),
- and wherein said lossy encoded data were correspondingly lossy decoded (42), thereby reconstructing a standard decoded signal (S<sub>Dec</sub>) and, using said spectral whitening
- 20 data, a superior quality decoded signal (S'<sub>Dec</sub>) was constructed from said standard decoded signal,
- and wherein a difference signal (S<sub>Diff</sub>) between said source signal (S<sub>PCM</sub>) and said superior quality decoded signal (S'<sub>Dec</sub>) was formed (43, 44) and lossless encoded
- 25 (45),
- and wherein said lossless encoded difference signal was packed together with said spectral whitening data (661) to form said lossless extension data stream (451),
- said apparatus including:
- 30 - means (52) being adapted for de-packing said lossless extension data stream (451) and for decoding said lossless encoded difference signal so as to provide said difference signal (S<sub>Diff</sub>) and said spectral whitening data (661);
- 35 - means (51) being adapted for lossy decoding said lossy encoded data stream (411), thereby reconstructing said

- standard decoded signal ( $S_{Dec}$ ) and, using said spectral whitening data, reconstructing (51) said superior quality decoded signal ( $S'_{Dec}$ ) from said standard decoded signal;
- means (53) being adapted for forming from said decoded
- 5 lossless encoded difference signal ( $S_{Diff}$ ) and from said superior quality decoded signal ( $S'_{Dec}$ ) a reconstructed source signal ( $S_{PCM}$ ).
5. Method for decoding a lossless encoded source signal
- 10 ( $S_{PCM}$ ) data stream, which data stream was derived from a lossy encoded data stream (411) and a lossless extension data stream (451) which together form a lossless encoded data stream (1322) for said source signal,
- wherein said source signal was lossy encoded (41), said
- 15 lossy encoding providing said lossy encoded data stream (411) as well as spectral whitening data (661),
- and wherein said lossy encoded data were correspondingly lossy decoded (42), thereby reconstructing a standard decoded signal ( $S_{Dec}$ ) and, using said spectral whitening
- 20 data, a superior quality decoded signal ( $S'_{Dec}$ ) was constructed from said standard decoded signal,
- and wherein a difference signal ( $S_{Diff}$ ) between said source signal ( $S_{PCM}$ ) and said superior quality decoded signal ( $S'_{Dec}$ ) was formed (43, 44) and lossless encoded
- 25 (45),
- and wherein said lossless encoded difference signal was packed together with said spectral whitening data (661) to form said lossless extension data stream (451),
- said method including the steps:
- 30 - de-packing (52) said lossless extension data stream (451) so as to provide said spectral whitening data (661);
- lossy decoding (51) said lossy encoded data stream (411), thereby reconstructing said standard decoded signal ( $S_{Dec}$ ) and, using said spectral whitening data, recon-
- 35 structing (51) said superior quality decoded signal ( $S'_{Dec}$ ) from said standard decoded signal.

6. Apparatus for decoding a lossless encoded source signal ( $S_{PCM}$ ) data stream, which data stream was derived from a lossy encoded data stream (411) and a lossless extension data stream (451) which together form a lossless encoded data stream (1322) for said source signal, wherein said source signal was lossy encoded (41), said lossy encoding providing said lossy encoded data stream (411) as well as spectral whitening data (661), and wherein said lossy encoded data were correspondingly lossy decoded (42), thereby reconstructing a standard decoded signal ( $S_{DEC}$ ) and, using said spectral whitening data, a superior quality decoded signal ( $S'_{DEC}$ ) was constructed from said standard decoded signal, and wherein a difference signal ( $S_{Diff}$ ) between said source signal ( $S_{PCM}$ ) and said superior quality decoded signal ( $S'_{DEC}$ ) was formed (43, 44) and lossless encoded (45), and wherein said lossless encoded difference signal was packed together with said spectral whitening data (661) to form said lossless extension data stream (451), said apparatus including:
- means (52) being adapted for de-packing said lossless extension data stream (451) so as to provide said spectral whitening data (661);
  - means (51) being adapted for lossy decoding said lossy encoded data stream (411), thereby reconstructing said standard decoded signal ( $S_{DEC}$ ) and, using said spectral whitening data, reconstructing (51) said superior quality decoded signal ( $S'_{DEC}$ ) from said standard decoded signal.
7. Method according to one of claims 1, 3 and 5, or apparatus according to one of claims 2, 4 and 6, wherein said spectral whitening data (661) are or were, respectively, generated by:
- processing said source signal ( $S_{PCM}$ ) in an analysis fil-

ter bank (61) and quantising (62) its output signal and forming (65) the difference signal (651) between the analysis filter bank output signal (611) and the quantisation output signal (621), wherein said quantising is,  
5 or was, controlled by a perceptual model calculator (64);  
- quantising (66) said difference signal (651) thereby controlling (67) this further quantisation such that the difference signal (681) between the input and the output of said further quantisation approaches a white spectrum,  
10 whereby the output signal of said further quantisation forms said spectral whitening data (661).

8. Method or apparatus according to claim 7, wherein:  
- said further quantisation (66) is controlled by an adaptation controller (67) that checks the current bit rate  
15 of said spectral whitening data (661) and, if said current bit rate exceeds a pre-determined threshold value, sets an escape signal (671);  
- said lossless encoding of said difference signal ( $S_{Diff}$ )  
20 uses an entropy encoder (93) the input signal of which passes through an LPC de-correlator if said escape signal is set, and, respectively,  
said lossless decoding of said lossless encoded difference signal ( $S_{Diff}$ ) uses an entropy decoder (112) the  
25 output signal of which passes through an LPC synthesis 114) if said escape signal was set at encoding site.

9. Method according to one of claims 1, 3, 5, 7 and 8, or apparatus according to one of claims 2, 4 and 6 to 8,  
30 wherein said spectral whitening data (661) are or were, respectively, entropy encoded (93) at encoding site and, respectively, are entropy decoded (112) at decoding site.

10. Method or apparatus according to claim 8 or 9, wherein  
35 said LPC de-correlator and said LPC synthesis are an LPC filter, the filter coefficients of which are determined

using information items like scale factors and/or the spectrum of related coefficient blocks in the sub-band domain of said lossy bit stream (411) and/or helper information items.

5

11. Method according to one of claims 1, 3, 5 and 7 to 10, or apparatus according to one of claims 2, 4 and 6 to 10, wherein said lossless extension data stream (451) includes

- 10    - encoded spectral whitening data (661);  
      - an escape signal (671) indicating that LPC de-correlation is active;  
      - a helper information signal;  
      - for file-to-file applications, a lossy coder delay value  
15       and/or an original file length value.

12. Lossless extension bit stream (451) including:

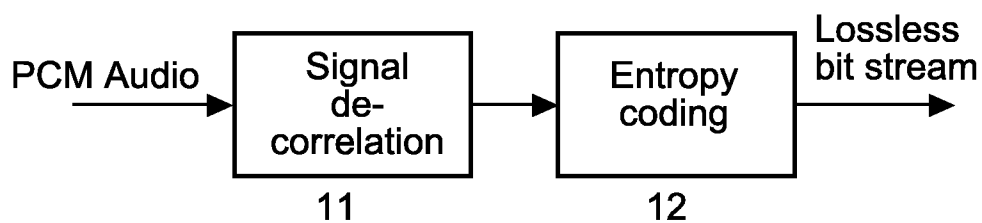
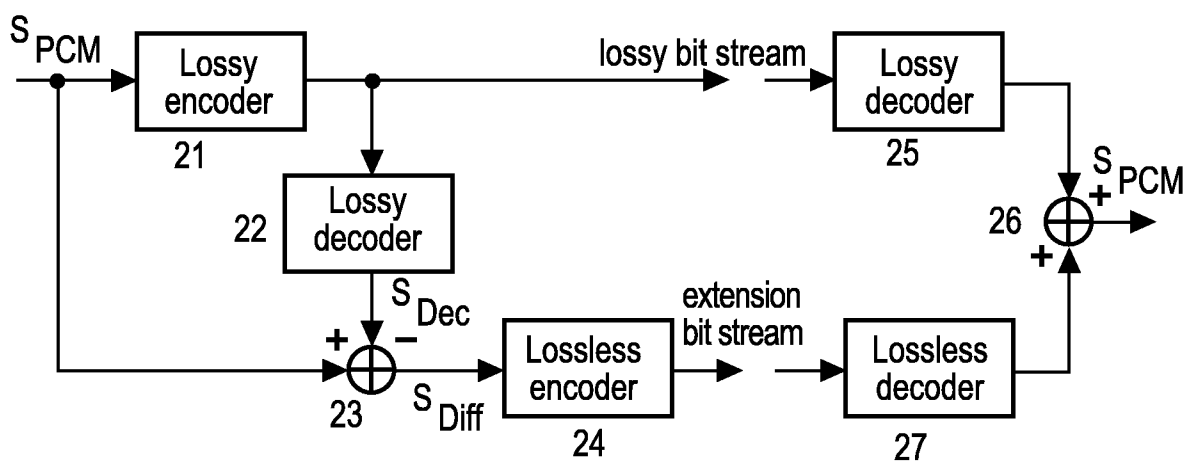
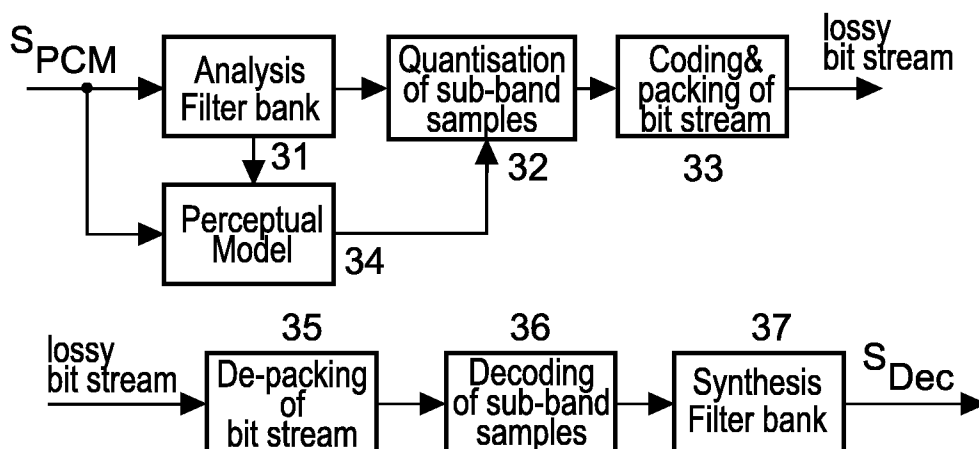
- entropy encoded difference signal ( $S_{Diff}$ ) data;  
      - encoded spectral whitening data (661);  
20    - an escape signal (671) indicating that LPC de-correlation is active;  
      - a helper information signal;  
      - for file-to-file applications, a lossy coder delay value and/or an original file length value,  
25       which data items and signals facilitate carrying out the method according to claims 3 or 5.

13. Lossless encoded bit stream (1322), including lossy encoded signal data (411), e.g. mp3 data, and the data  
30       items and signals and optionally values defined in claim 12.

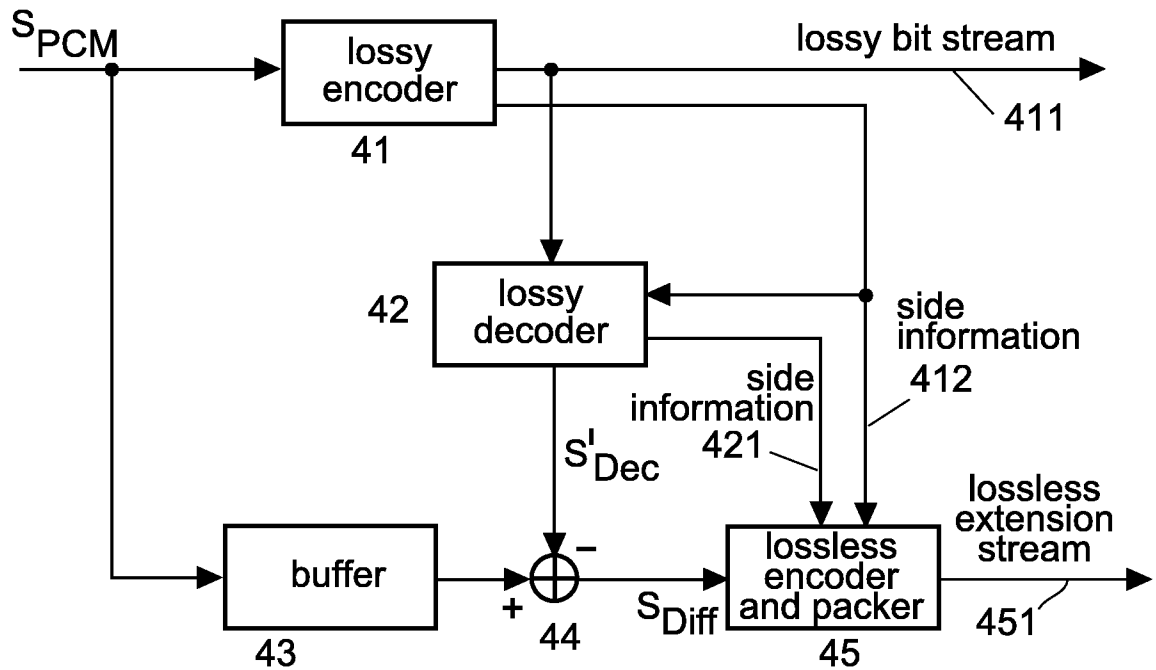
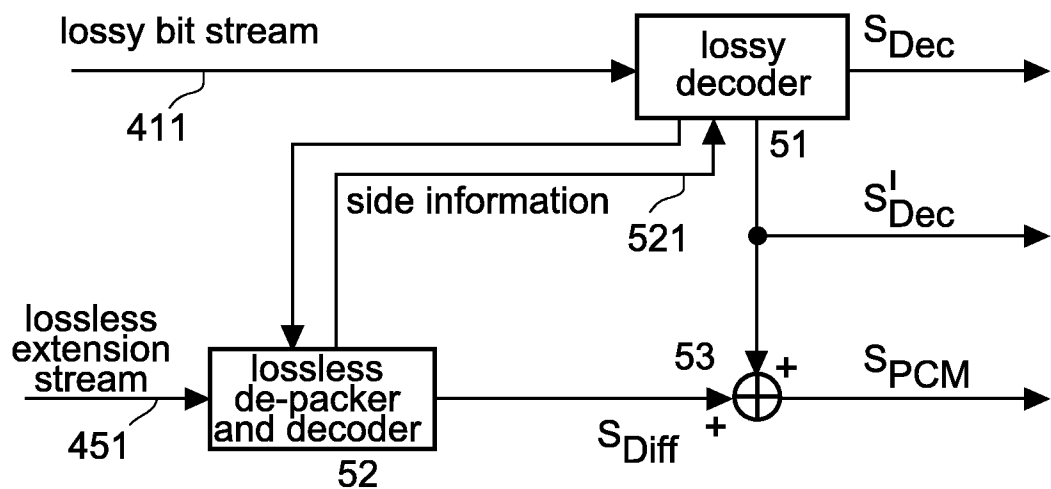
14. Storage medium, for example on optical disc, that contains or stores, or has recorded on it, a digital video  
35       signal encoded according to the method of one of claims 1 and 7 to 11.

15. Storage medium, for example on optical disc, that contains or stores, or has recorded on it, a bit stream according to claim 12 or 13.

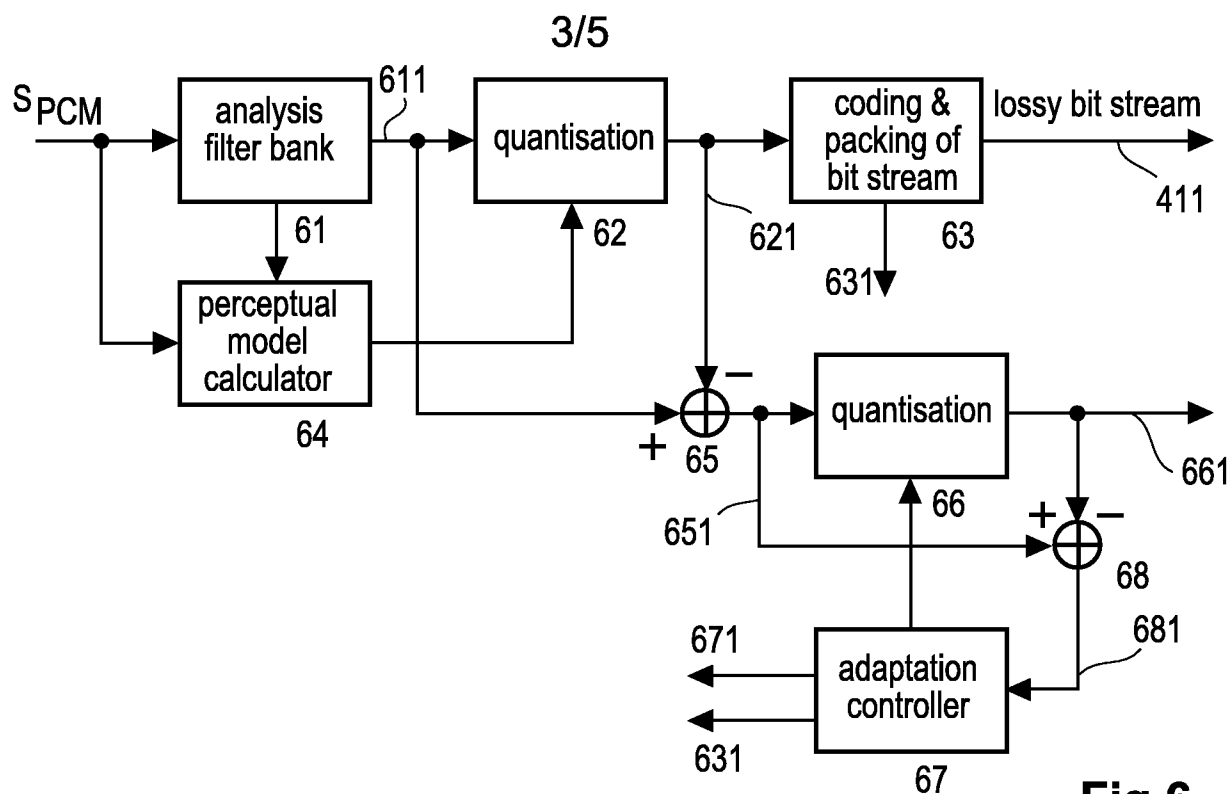
1/5

**Fig.1****Fig.2****Fig.3**

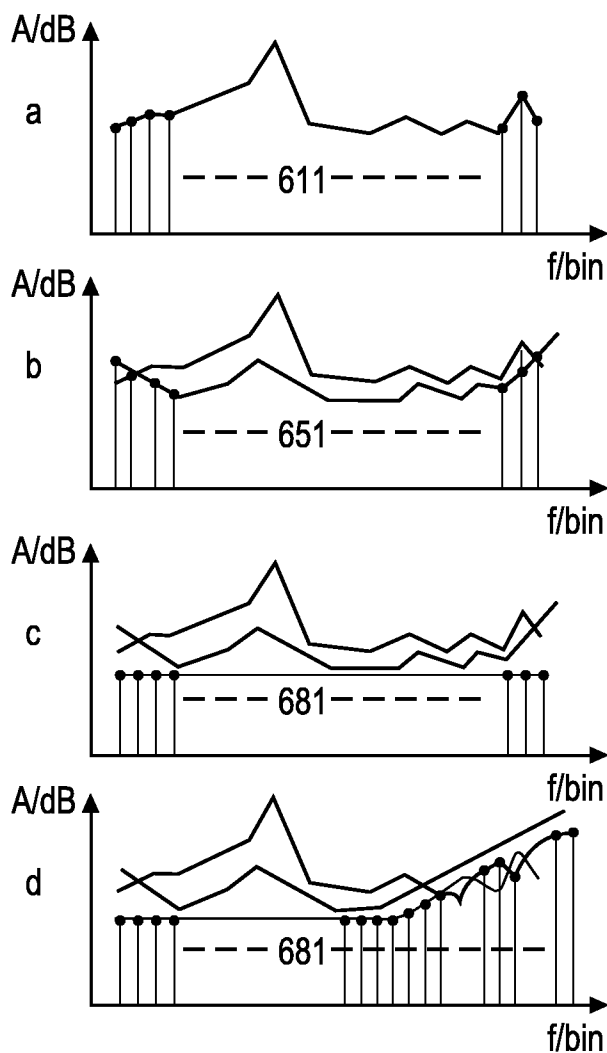
2/5

**Fig.4****Fig.5**





**Fig.6**



**Fig.7**

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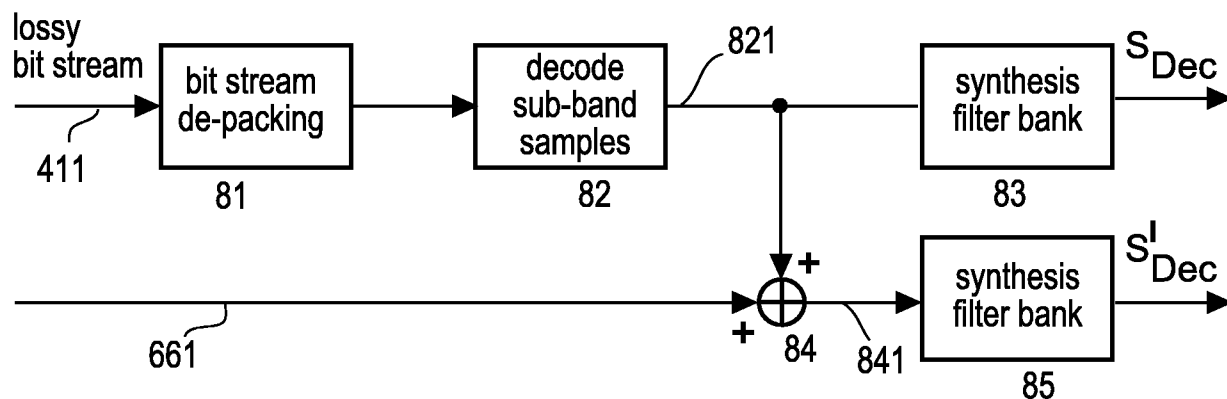


Fig.8

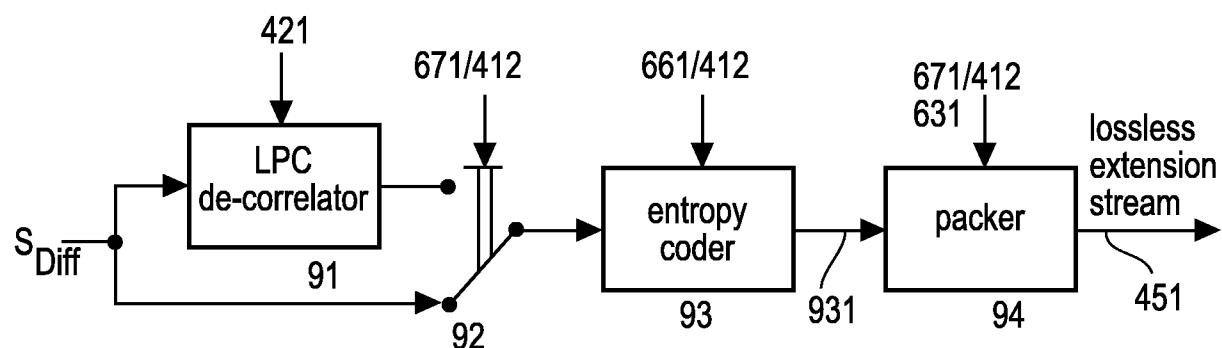


Fig.9

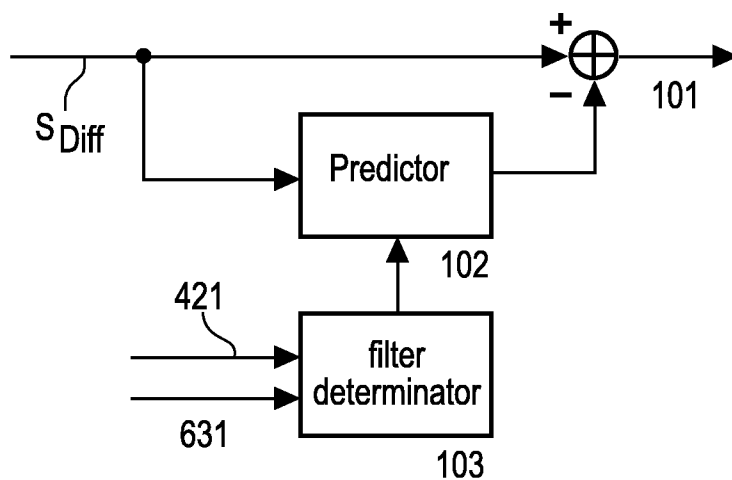
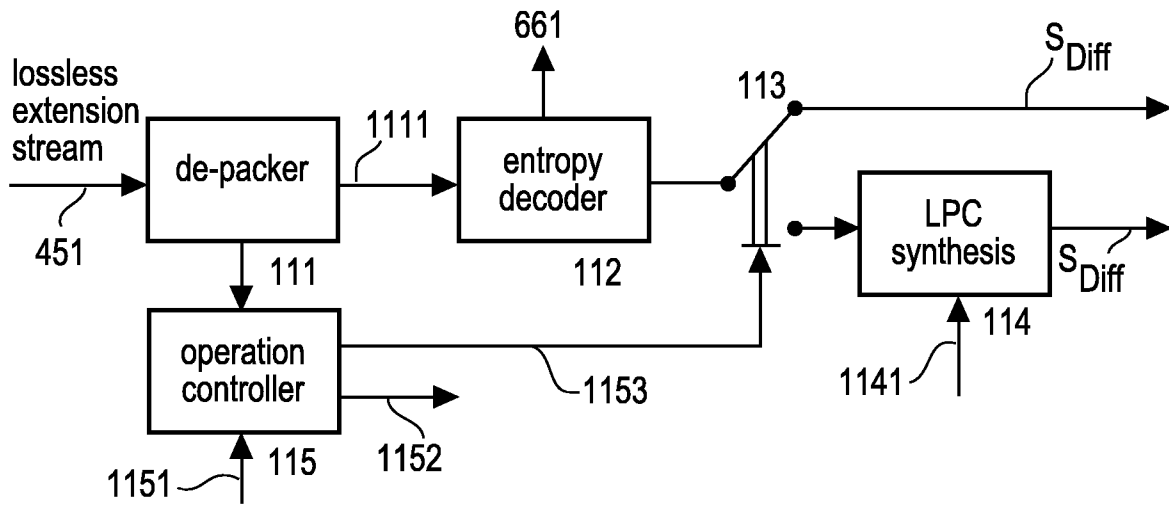
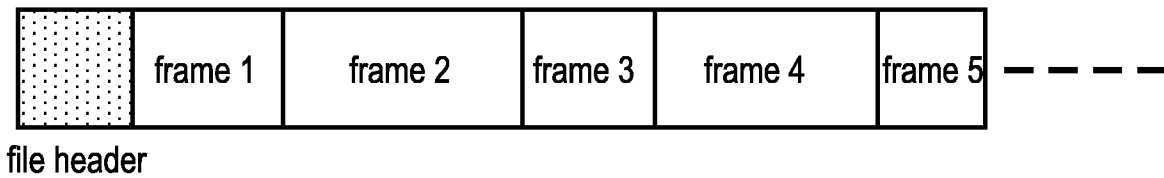
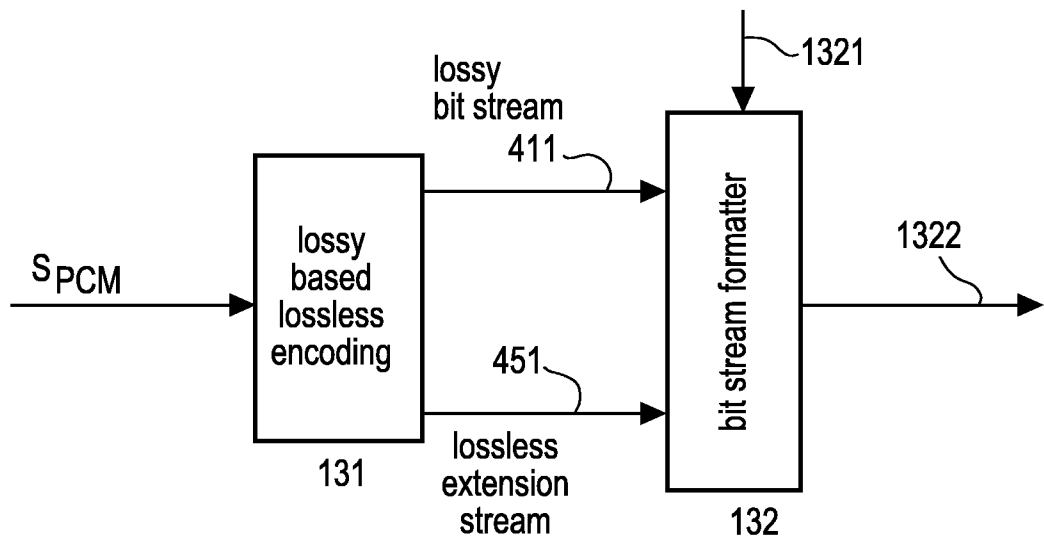


Fig.10

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**Fig.11****Fig.12****Fig.13**

## INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2007/053783

## A. CLASSIFICATION OF SUBJECT MATTER

INV. G10L19/00 G10L19/14

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)  
G10L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, INSPEC

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

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☒ Further documents are listed in the continuation of Box C.☒ See patent family annex.

## \* Special categories of cited documents:

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- \*&\* document member of the same patent family

Date of the actual completion of the international search

19 June 2007

Date of mailing of the international search report

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## INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2007/053783

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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Information on patent family members

International application No

PCT/EP2007/053783

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