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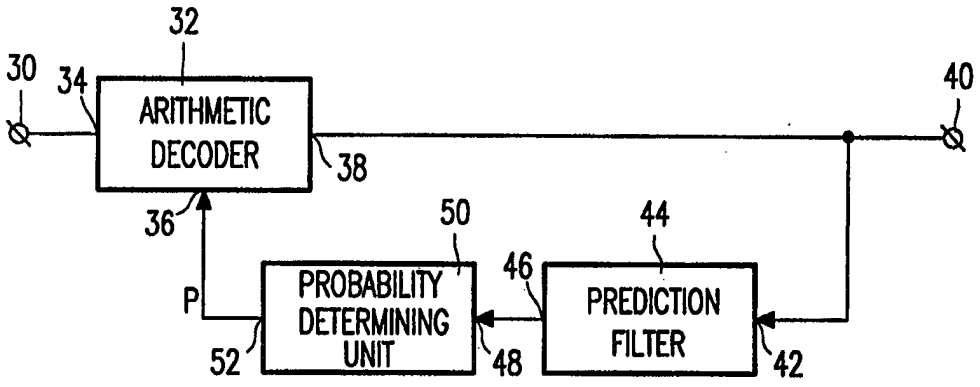

(57) Abstract

A data compression apparatus is disclosed for data compressing an information signal, which is in n–level form, n being larger than 2. The data compression apparatus comprises an input terminal (1) for receiving the n–level information signal, an entropy coder, such as an arithmetic coder (4) having an input (2) for receiving an input signal, which is adapted to carry out a lossless encoding step on the input signal, so as to obtain a data compressed output signal at an output (6). The apparatus further comprises a prediction filter (12) for carrying out a prediction step on the n–level information signal so as to obtain a prediction signal and a probability signal determining unit (18) for generating the probability signal in response to said prediction signal. An output terminal (8) is available for supplying said data compressed output signal further, a data expansion apparatus is disclosed.

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Data compression and expansion of an n-level information signal.

The invention relates to a data compression apparatus for data compressing an n-level information signal, to a data compression method, a transmitter comprising the data compression apparatus, a record carrier having the data compressed audio signal recorded on it in a track of said record carrier, to a data expansion apparatus for data expanding a data compressed n-level information signal, to a data expansion method, and to a receiver comprising the data expansion apparatus.

Oversampling delta-sigma data converters are applied for high-quality analog-to-digital conversion. Usually, these converters are designed such as to produce a binary, two level digital output signal, also referred to as bitstream or DSD signal. Although it is also possible to design delta-sigma data converters that produce output signals with more than two levels, such converters were not used in practice because of distortion products and noise caused by non-linearities in such multi-level converters.

Recently, however, a converter was described for generating a 3-level information signal. Reference is made in this respect to the AES preprint 4443, 'A 120 dB dynamic range, 96 kHz, stereo 24-bit analog-to-digital converter', by K. Leung et al 102nd AES convention (Munich, Germany). The 3-level information signal is available as an internal representation in the converter.

The invention aims at providing an apparatus for enabling a data compression step on the 3-level, more specifically, an n-level information signal, and aims at providing an apparatus for enabling a data expansion step on the data compressed n-level information signal so as to regain a replica of the n-level information signal.

The data compression apparatus in accordance with the invention for data compressing an information signal, which is in n-level form, n being larger than 2, comprises

- input means for receiving the n-level information signal,
- lossless coding means having an input for receiving an input signal, for carrying out a lossless

encoding step on the input signal, so as to obtain a data compressed output signal at an output, said lossless encoding means comprising an entropy encoder for carrying out the lossless encoding step on the input signal in response to a probability signal,

- prediction means for carrying out a prediction step on the n-level information signal so as to obtain a prediction signal,
- probability signal determining means for generating the probability signal in response to said prediction signal,
- output means for supplying said data compressed output signal.

The data expansion apparatus in accordance with the invention for data expanding a data compressed input signal so as to obtain an information signal, which is in n-level form, n being larger than 2, comprises

- input means for receiving the data compressed input signal,
- lossless decoding means having an input for receiving the data compressed input signal, for carrying out a lossless decoding step on the data compressed input signal, so as to obtain a data expanded output signal at an output, said lossless decoding means comprising an entropy decoder for carrying out the lossless decoding step on the data compressed input signal in response to a probability signal,
- output means for supplying said information signal,
- prediction means for carrying out a prediction step on the information signal so as to obtain a prediction signal,
- probability signal determining means for generating the probability signal in response to said prediction signal.

By this, a more efficient storage or transmission of the n-level information signal can be achieved.

These and other aspects of the invention will be apparent from and elucidated further with reference to the embodiments described in the following figure description, in which

figure 1 shows an embodiment of the data compression apparatus,

figure 2 shows an embodiment of a corresponding data expansion apparatus,

figure 3 shows a second embodiment of the data compression apparatus,

figure 4 shows an embodiment of the corresponding data expansion apparatus,

figure 5 shows a data compression apparatus incorporated in a transmitter, which is in the form of as a recording apparatus, and

figure 6 shows a data expansion apparatus incorporated in a receiver, which is in the form of a reproduction apparatus.

Figure 1 shows an embodiment of the data compression apparatus, comprising an input terminal 1 for receiving the n-level information signal. In the present example, n-level information signal has been obtained from converting an audio signal using a delta-sigma modulator. The input terminal 1 is coupled to an input 2 of an entropy encoder which is in the present case in the form of an arithmetic coder 4. An output 6 of the arithmetic coder is coupled to an output terminal 8 of the compression apparatus.

The input terminal 1 is further coupled to an input 10 of a prediction filter , which has an output 14 coupled to an input 16 of a probability determining unit 18. The output 20 of the probability unit 18 is coupled to a control input 22 of the arithmetic coder 4.

The arithmetic coder 4 encodes the signal applied to its input 4 into a data compressed information signal in response to probability values p supplied to its control input 22 and supplies the data compressed information signal to its output 6. The probability determining unit 18 determines a probability value indicating the probability that a symbol in the n-value information signal supplied to the input terminal 1 has a predetermined level. In the case of a three valued information signal, those levels (or values) can be -1, 0 or +1. This probability value, denoted p in figure 1, is supplied to the arithmetic coder 4 so as to enable the data compression of the n-level information signal in the arithmetic coder 4. The determining unit 18 determines the probability values p from the output signal of the prediction filter 12. The arithmetic coder 4 can data compress the n-level information signal on a frame-by-frame basis.

The functioning of the apparatus of figure 1 is as follows. The prediction filter 12 realizes a prediction filtering on the n-level information so as to obtain a multi value output signal.

Various embodiments of the prediction filter unit 12 and the probability determining unit 18 are possible. In a first embodiment, the prediction filter unit 12 and the probability determining unit 18 are fixed (static) units, in the sense that their behaviour does not change in time. In a second embodiment, the filter unit 12 is adaptive, so that it can adapt itself to a changing input signal characteristic, so as to obtain the best prediction result. The probability unit 18 can again be fixed. In a third embodiment, the prediction filter unit 12 can be fixed and the probability determining unit 18 can be adaptive. This adaptivity will be explained later. In

a fourth embodiment, both units 12 and 18 are adaptive.

The multi value output signal supplied by the prediction filter unit 12 can have a plurality of levels within a range of eg. +3 and -3. Further, for each of a plurality of subintervals in the value range of the multi level output signal, it is determined what the probability is that the symbol in the level in the n-level information signal is a '+1', '0' or '-1', assuming a 3-level information signal, as explained above. This could have been realized in advance, or in real time, during the data compression itself, eg. by counting the number of '+1's, '0's and '-1's occurring in the n-level information signal during a specific time interval, when the multi level output signal of the prediction filter 12 falls in one of such ranges. For each symbol supplied to the coder 4, the probability determining unit 18 supplies the three probabilities for '+1", '0'and '-1'that correspond to the subinterval in which the multi level output signal for that symbol is located. The data compressed n-level information signal is supplied by the arithmetic coder 14 to the output terminal 8, eg. for transmission via a transmission medium or a record carrier.

Figure 2 shows a corresponding data expansion apparatus for decoding the data compressed n-level information signal, received via an input terminal 30. The data expansion apparatus of figure 2 comprises an entropy decoder 32, which receives the data compressed n-level information signal via an input 34. In the present example, the entropy decoder 32 is in the form of an arithmetic decoder that carries out an arithmetic decoding step on the data compressed n-level information signal, under the influence of a probability signal p, supplied to a control input 36 so as to generate a replica of the original n-level information signal which is supplied to an output 38. The output 38 of the decoder 32 is coupled to an output terminal 40 as well as to an input 42 of a prediction filter 44, which has an output 46 coupled to an input 48 of a probability determining unit 50. The probability determining unit 50 has an output 52 which is coupled to the control input 36 of the decoder 32.

The data expansion apparatus of figure 2 is complementary to the data compression apparatus of figure 1, in the sense that, if the prediction filter 12 and the unit 18 are both fixed, the prediction filter 44 and the unit 50 are fixed, that if the prediction filter 12 is adaptive also the filter 44 is adaptive, and that if the unit 18 is adaptive, the unit 50 is also adaptive.

When the filters 12 and 44 are adapted, it is required to transmit side information from the compression apparatus to the expansion apparatus. Such side information then include the filter coefficients. When, the units 18 and 50 are adaptive, it is also required to transmit side information to the expansion apparatus, such side information comprising information concerning the conversion of the multi-level information signal supplied by the filter 44 into the probabilities

p generated in response thereto by the unit 50.

The entropy encoder used in the embodiment of figure 1 is adapted to encode the n-level information signal using a probability signal in order to obtain the data compressed information signal, which is a binary signal. One such entropy encoder is the arithmetic coder described above. One other type of such entropy coder is, as an example, the well known finite state coder. The entropy decoder used in the embodiment of figure 2 is adapted to decode the data compressed information signal using a probability signal in order to obtain a replica of the n-level information signal. One such entropy decoder is the arithmetic decoder described above. One other type of such entropy decoder is, as an example, the well known finite state decoder.

Figure 3 shows another embodiment of the data compression apparatus. The data compression apparatus shows much resemblance with the data compression apparatus of figure 1, but further comprises a quantizer 60 having an input 62 coupled to the output 14 of the prediction filter 12 and an output 64 coupled to a first input 66 of a signal combination unit 70. The signal combination unit 70 has a second input 68 coupled to the input terminal 1 and an output 72 which is coupled to the input 2 of the arithmetic coder 4.

The functioning of the apparatus of figure 3 is as follows. The quantizer 60 is adapted to quantize the multi value prediction signal generated by the prediction filter 12 into an n-level output signal which is a predicted version of the n-level information signal supplied to the input 1. The signal combination unit 70 combines the n-level information signal applied to its input 68 and the predicted version of the n-level information signal supplied to its input 66 in a subtractive way so as to obtain a residual information signal, which is supplied to its output 72. The advantage of generating a residual information signal, is that, by combining the n-level information signal and the predicted n-level information signal, the probability of occurrence of symbols with zero level in the residual information signal is significantly increased. This can simplify the subsequent data compression in the arithmetic coder 4.

The probability determining unit 18 now generates a probability value indicating the probability that a value of the residual information signal supplied by the combination unit 70 has a predetermined value, such as '+1'. This probability value, denoted p in figure 3, is supplied to the arithmetic coder 14 so as to enable the data compression of the n-level information signal in the arithmetic coder 14. The determining unit 18 determines the probability values again from the output signal of the prediction filter 12.

It should be noted that the probability values p for data compressing the residual information signal are obtained from the prediction signal generated by the prediction filter 12, which has a relation with the n-level information signal, and not from a signal that has a relation

with the residual information signal. This has an advantage, in that a higher compression ratio can be obtained with the arithmetic coder 14. The arithmetic coder 14 can data compress the residual information signal on a frame-by-frame basis.

The functioning of the apparatus of figure 3 is as follows. As stated above, both the filter 12 and the unit 18 can be static, or one or both of the filter 12 and the unit 18 can be adaptive. The prediction filter 12 again realizes a prediction filtering on the n-level information signal so as to obtain the multi value output signal. The multi value output signal lies again within a range of eg. +3 and -3. The quantizer 60 receives the multi value output signal and generates a predicted version of the n-level information signal therefrom, eg. by allocating a value of '+1' if the multi value output signal is eg. larger than +1, by allocating a value '-1' if the multi value prediction signal is smaller than -1 and by allocating a value '0', if the multi value prediction signal lies between -1 and +1.

The residual information signal can have values '-2', '-1', '0', '+1" and "+2'. For each of a plurality of subintervals in the value range of the multi value output signal, it is determined what the probability is that the corresponding value of the residual signal is eg. '+1'. In the adaptive embodiment of the unit 18, this can be realized by counting the number of '+2's, '+1's, '0's, '-1's and '-2's occurring in the residual information signal during a specific time interval, when the multi value output signal falls in one of such ranges. The probabilities thus obtained for the various values in the multi value output signal are subsequently supplied as the probability signal p to the arithmetic coder 14. The data compressed residual information signal is supplied by the arithmetic coder 14 to the output terminal 8, for transmission via a transmission medium or for recording.

Figure 4 shows a corresponding data processing apparatus for decoding the data compressed signal, received via the transmission or recording medium. The data processing apparatus of figure 4 shows a large resemblance with the data expansion apparatus of figure 2, with the difference that that apparatus of figure 4 further comprises a quantizer 80 and a signal combination unit 90. The quantizer has an input 82 coupled to the output 46 of the prediction filter 44, and an output 84 which is coupled to a first input 86 of the signal combination unit 90. The signal combination unit 90 has a second input 88 which is coupled to the output 38 of the decoder 32. The output 92 of the signal combination unit 92 is coupled to the output terminal 40 and to the input 42 of the prediction filter.

The decoder 32 receives the data compressed residual information signal via its input 34. The decoder 32 carries out an arithmetic decoding step on the data compressed residual information signal under the influence of the probability signal p, supplied to the control input

36 so as to generate a replica of original residual information signal which is supplied to its output 38. The replica is supplied to the input 88 of the signal combination unit 90. The signal combination unit 90 further receives a predicted version of the n-level information signal via its input 86 and generates a replica of the original n-level information signal at its output 92 in response thereto.

The functioning of the prediction filter 44 and the quantizer 80 can be identical to the functioning of the prediction filter 12 and the quantizer 60 in figure 3. When the filters 12 and 44 are adaptive, side information will be transmitted concerning the filter coefficients in the filter 44. When the units 18 and 50 are adaptive, the side information will also include information concerning the conversion of the multi value output signal into the probabilities p.

The entropy encoder used in the embodiment of figure 3 is adapted to encode the residual information signal using a probability signal in order to obtain the data compressed residual information signal. One of such entropy encoder is the arithmetic coder described above. One other type of such entropy coder is, as an example, the well known finite state coder. The entropy decoder used in the embodiment of figure 4 is adapted to decode the data compressed residual information signal using a probability signal in order to obtain a replica of the residual information signal. One of such entropy decoder is the arithmetic decoder described above. One other type of such entropy decoder is, as an example, the well known finite state decoder.

Figure 5 shows an embodiment of a transmission apparatus which is in the form of a recording apparatus. The recording apparatus comprises the data compression apparatus shown in figure 1 or 3. The recording apparatus further comprises a write unit 106 for writing the data compressed n-level information signal in a track on the record carrier 108. In the present example, the record carrier 108 is a magnetic record carrier, so that the write unit 106 comprises at least one magnetic head 110 for writing the data compressed n-level information signal in the record carrier 108. The record carrier may however be an optical record carrier, such as a CD disk or a DVD disk.

Transmission via a transmission medium, such as a radio frequency link or a record carrier, generally requires an error correction encoding and a channel encoding carried out on the data compressed information signal to be transmitted. Figure 5 shows such signal processing steps. The recording arrangement of figure 5 therefore comprises an error correction encoder 102, well known in the art, and a channel encoder 104, also well known in the art.

Figure 6 shows the data expansion apparatus of figure 2 or 4 incorporated in a receiver apparatus, which is in the form of a reproduction apparatus. The reproducing apparatus further comprises a read unit 112 for reading the data compressed n-level information signal from a

track on the record carrier 108. In the present example, the record carrier 108 is a magnetic record carrier, so that the read unit 112 comprises at least one magnetic head 114 for reading the data compressed n-level information signal from the record carrier 108. The record carrier may however be an optical record carrier, such as a CD disk or a DVD disk.

As has been explained above, transmission via a transmission medium, such as a radio frequency link or a record carrier, generally requires an error correction encoding and a channel encoding carried out on the data compressed n-level information signal to be transmitted, so that a corresponding channel decoding and error correction can be carried out upon reception. Figure 6 shows the signal processing steps of channel decoding and error correction carried out on the received signal, received by the reading means 112. The reproducing arrangement of figure 6 therefore comprise a channel decoder 116, well known in the art, and an error correction unit 118, also well known in the art, so as to obtain a replica of the data compressed n-level information signal.

Whilst the invention has been described with reference to preferred embodiments thereof, it is to be understood that these are not limitative examples. Thus, various modifications may become apparent to those skilled in the art, without departing from the scope of the invention, as defined by the claims.

Further, the invention lies in each and every novel feature or combination of features.

CLAIMS

1. Data compression apparatus for data compressing an information signal, which is in n-level form, n being larger than 2, the data compression apparatus comprising

- input means for receiving the n-level information signal,

- lossless coding means having an input for receiving an input signal, for carrying out a lossless encoding step on the input signal, so as to obtain a data compressed output signal at an output, said lossless encoding means comprising an entropy encoder for carrying out the lossless encoding step on the input signal in response to a probability signal,

- prediction means for carrying out a prediction step on the n-level information signal so as to obtain a prediction signal,

- probability signal determining means for generating the probability signal in response to said prediction signal,

- output means for supplying said data compressed output signal.

2. Data compression apparatus as claimed in claim 1, wherein the prediction means comprises a prediction filter for carrying out a prediction filtering operation on the n-level information signal so as to obtain a multi value prediction signal and wherein said probability signal determining means is adapted to generate the probability signal in response to said multi value prediction signal.

3. Data compression apparatus as claimed in claim 1 or 2, wherein the apparatus further comprises quantizing means and signal combination means, the quantizing means being adapted to quantize the multi value prediction signal so as to obtain a predicted version of the n-level information signal, the signal combination means being adapted to combine the n-level information signal and the predicted version of the n-level information signal so as to obtain a residual information signal so as to supply the residual information signal to said entropy encoder for data compression.

4. Data compression apparatus as claimed in claim 1, wherein the entropy encoder is in the form of an arithmetic coder.

5. Data compression method of data compressing an information signal, which is in n-level form, n being larger than 2, the data compression method comprising the steps of

- receiving the n-level information signal,

- carrying out a lossless encoding step on an input signal, so as to obtain a data compressed output signal, said lossless encoding step comprising an entropy encoding step for carrying out the lossless encoding step on the input signal in response to a probability signal,
- carrying out a prediction step on the n-level information signal so as to obtain a prediction signal,
- generating the probability signal in response to said prediction signal,
- supplying said data compressed output signal.

6. Data expansion apparatus for data expanding a data compressed input signal so as to obtain an information signal, which is in n-level form, n being larger than 2, the data expansion apparatus comprising

- input means for receiving the data compressed input signal,
- lossless decoding means having an input for receiving the data compressed input signal, for carrying out a lossless decoding step on the data compressed input signal, so as to obtain a data expanded output signal at an output, said lossless decoding means comprising an entropy decoder for carrying out the lossless decoding step on the data compressed input signal in response to a probability signal,
- output means for supplying said information signal,
- prediction means for carrying out a prediction step on the information signal so as to obtain a prediction signal,
- probability signal determining means for generating the probability signal in response to said prediction signal.

7. Data expansion apparatus as claimed in claim 6, wherein the prediction means comprises a prediction filter for carrying out a prediction filtering operation on the n-level information signal so as to obtain a multi value prediction signal and wherein said probability signal determining means is adapted to generate the probability signal in response to said multi value prediction signal.

8. Data expansion apparatus as claimed in claim 6 or 7, wherein the apparatus further comprises quantizing means and signal combination means, the quantizing means being adapted to quantize the multi value prediction signal so as to obtain a predicted version of the n-level information signal, the signal combination means being adapted to combine the output signal of the entropy decoder and the predicted version of the n-level information signal so as to obtain said information signal.

9. Data expansion apparatus as claimed in claim 6, wherein the entropy decoder is in the form of an arithmetic decoder.

10. Data expansion method for data expanding a data compressed input signal so as to obtain an information signal, which is in n-level form, n being larger than 2, the data expansion method comprising the steps of

- receiving the data compressed input signal,
- carrying out a lossless decoding step on the data compressed input signal, so as to obtain a data expanded output signal at an output, said lossless decoding step comprising an entropy decoding step on the data compressed input signal in response to a probability signal,
- supplying said information signal,
- carrying out a prediction step on the information signal so as to obtain a prediction signal, - generating the probability signal in response to said prediction signal.

11. Transmitter for transmitting an n-level information signal via a transmission medium, comprising the data compression apparatus as claimed in anyone of the claims 1 to 5, further comprising error correction encoding means and/or channel encoding means for error correction encoding and/or channel encoding the output signal of the entropy encoder, and transmission means for applying the error correction encoded and/or channel encoded output signal of the entropy encoder to the transmission medium.

12. Transmitter as claimed in claim 11, wherein the transmitter is in the form of an apparatus for recording the n-level information signal on a record carrier and the transmission means is in the form of writing means for writing the error correction encoded and/or channel encoded output signal of the entropy encoder on the record carrier.

13. Transmitter as claimed in claim 12, wherein the record carrier is an optical or a magnetic record carrier.

14. Record carrier obtained with the transmitter as claimed i claim 12, provided with the error correction encoded and/or channel encoded output signal of the entropy encoder.

15. Receiver for receiving an n-level information signal via a transmission medium, comprising the data expansion apparatus as claimed in anyone of the claims 6 to 10, the receiver further comprising receiving means for retrieving a channel encoded and/or error correction encoded transmission signal from the transmission, channel decoding means and/or error correction means for channel decoding and/or error correcting the channel encoded and/or error correction encoded transmission signal so as to obtain said input signal for the entropy decoder.

16. Receiver as claimed in claim 15, wherein the receiver is in the form of an apparatus for reading the n-level information signal from a record carrier and the receiving means is in the form of reading means for reading the error correction encoded and/or channel encoded transmission signal from the record carrier.

17. Transmitter as claimed in claim 16, wherein the record carrier is an optical or a magnetic record carrier.

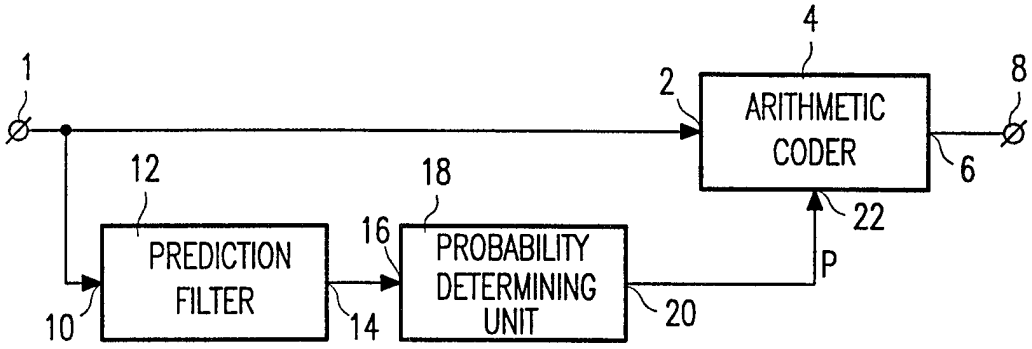

FIG. 1

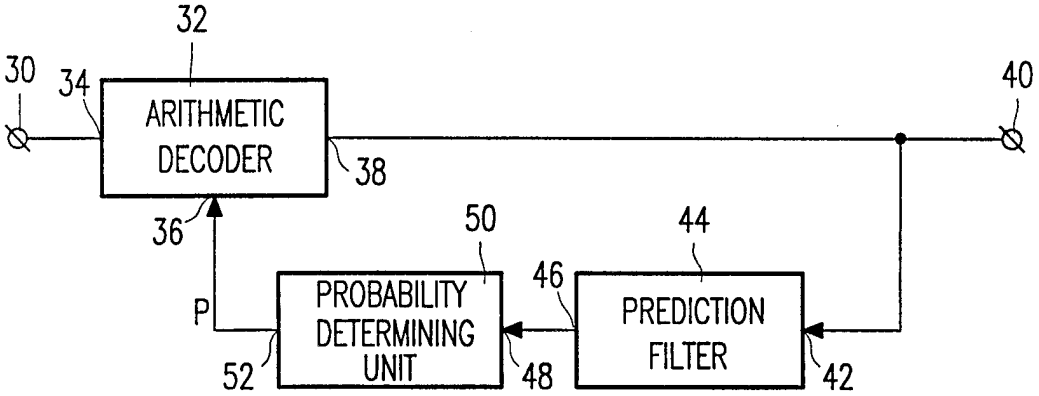

FIG. 2

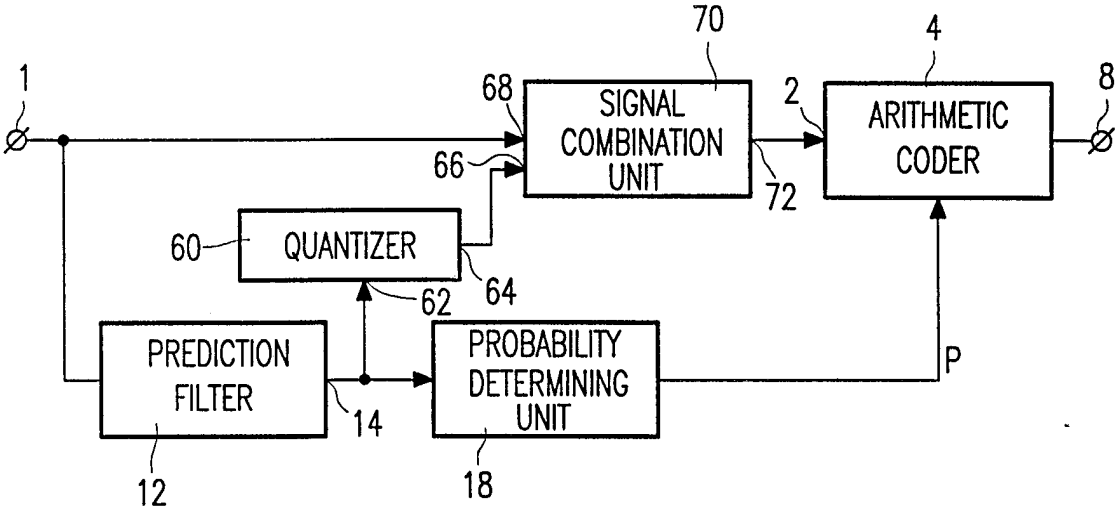

FIG. 3

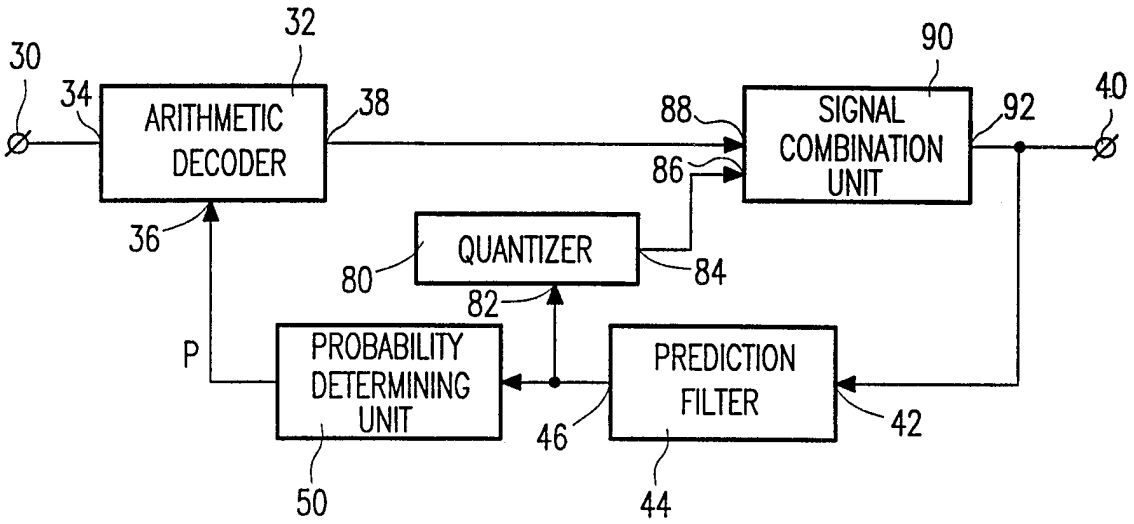

FIG. 4

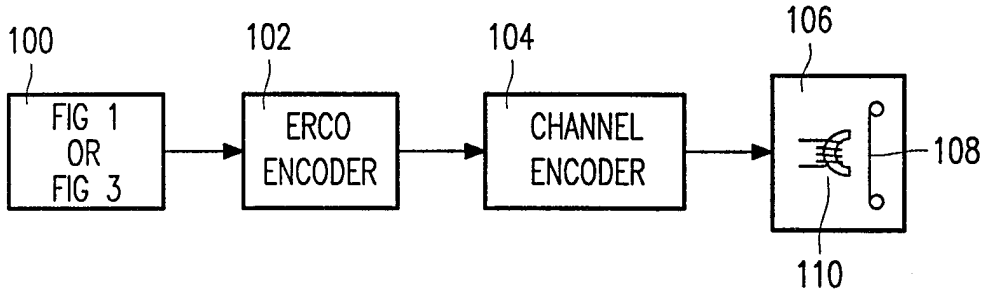

FIG. 5

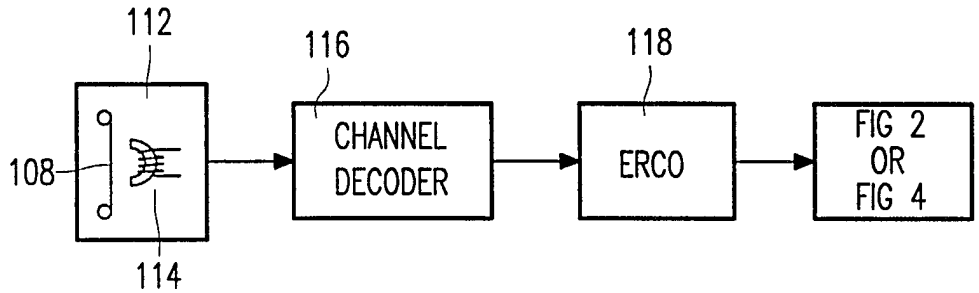

FIG. 6