An information transmission method with error correction for data symbols, an error correcting decoding method for such data symbols, an apparatus for information transmission for use with the method, a device for information decoding for use with the method, and an apparatus for use with such device.

The invention relates to an information transmission method with error correction, said method comprising the steps of:

a. Reed-Solomon encoding a succession of first numbers of data symbols to produce a sequence of first code words each comprising a second number of symbols composed of the first number of data symbols and a first series of parity symbols;

b. interleaving the symbols of successive first code words by means of respective different delay times over as many first code words as there are symbols in a first code word to produce symbol-interleaved first code words;

c. Reed-Solomon encoding the symbol-interleaved first code words to produce a sequence of second code words each comprising a third number of code symbols composed of the second number of symbols and a second series of parity symbols;

d. modulating said code symbols of said second code words into information symbols for introduction into a medium for later decoding;

An encoding method according to the above is known from British Patent 2 076 569. Likewise, a modulating method according to the above is known from British Patent 2 083 322. These two patents relate to the so-called "Compact Disc", which is an optically readable record for high quality audio data. This same system, with modified values for the constraining parameters, such as Hamming-distances, interleaving pattern, frame format, channel bit run lengths, and with modified technology may find wider use than the "Compact Disc" alone. In this respect the medium may be a master "Compact Disc", a replicated copy thereof, a digital audio tape, a broadcast transmission line, or other.

It has been found that the "Compact Disc" storage medium or other media referred to hereabove are also suitable for the inexpensive storage of digital data that do not directly relate to audio data. Examples of such other data are character data, display data or program data. In this way, it will be possible to realize a playback apparatus

for reproducing visual information such as charts or graphics, pictorial illustration by still pictures, or a video game apparatus. Another useful application would be the distribution of software for personal or business computers. In both instances the addition of a video display unit would widen the application range of such "Compact Disc" or other storage system. Moreover, it is well-known that software must be frequently updated and the "Compact Disc" is of a conveniently reproducible and shippable format. It is envisaged that some applications could diverge from the audio system constraints. For example, the constant linear velocity of an audio system may be interchanged for a constant angular velocity of a data processing system. The former would be chosen for maximum storage density, the latter would allow for easier random access features. The data storage capacity of the "Compact Disc" is about 500 Mbyts which is much larger than the capacity of a magnetic floppy disk. The above advantages and uses could also apply to other transmission media or systems. Now, in the "Compact Disc" system a user word or audio sample of 16 bits is divided into two user symbols: the more significant eight bits and the less signficiant eight bits. The interleave, de-interleave, encoding and decoding using the Reed-Solomon codes are all carried out on a byte unit bases. Therefore, the same error correction processing can be executed both with respect to digital audio signals and digital data. If for audio information the error correction capability would sometimes be insufficient, a final remedy would be interpolation of missing samples between neighbours or some other error "concealment" algorithm. However, there is not sufficient correlation between successive program data or the like, and in such cases interpolation would be little useful.

According to the invention an information transmission method as set forth in the pre-amble is characterised in that said data symbols are generated by

e. Reed-Solomon encoding a finite number of first groups of user symbols to produce respective extended first groups each composed of the symbols of the relevant first group and a first sub-series of parity symbols,

f. forming symbols of different extended first groups into as many second groups of unique symbols as there are symbols in an extended first group, each second group including a first sub-series of

parity symbols,

g. Reed-Solomon encoding the second groups of symbols to produce extended second groups each composed of the symbols of the relevant second group and a second sub-series of parity symbols, the symbols of the extended second groups being said data symbols and being arranged in sectors each corresponding to a unit of organisation of a data format to which the information transmission method is applied.

The invention thus provides a further error protection code as an overlay on the existing Reed-Solomon codes.

In carrying out the invention all processing is done on symbols of relatively short lengths. The data symbol, which typically consists of eight bits, is easy to handle. Processing a longer symbol, e.g. sixteen bits would be a lot more complicated.

Therefore, preferably, said user symbols are obtained from user words which are each divided into a more significant user symbol and a less significant user symbol, said sectors are organised in two planes in that a first plane of a sector comprises data symbols in respect of the more significant user symbols of the sector and the second plane of said sector comprises data symbols in respect of the less significant user symbols of said sector, and steps (e), (f) and (g) are performed separately in each of said two planes. In this way, user symbols are distributed in more significant "planes" and less significant "planes". It has been found that this procedure allows for correction of so-called burst errors on the medium of an increased maximum length, as simulations have proved.

Preferably, each sub-series consists of two parity symbols. Even with this very limited amount of redundancy included in every sub-series, a good performance results. It should be noted that the complications of error correction quickly increase with the length of each sub-series.

Preferably, an additional multi-symbol error detection quantity is included within a sector of data symbols. In this way, failure of the error protection is signalled in a very reliable way.

Preferably, said error detection quantity is a CRC check quantity. CRC algorithms have proved both reliable and elementary.

The invention also relates to an error correcting decoding method for data symbols according to the above, to an apparatus for

information transmission for use with the method, to a device for information decoding and to an apparatus containing such a device, as have been recited in further Claims.

Brief description of the Figures:

The invention will be furthermore explained, by way of example, with reference to the accompanying Figures, wherein:-

Figure 1 shows the data format on a compact optical disc;

Figure 2 shows a general set-up of a decoder;

Figure 3 shows the format of a notional information unit for explaining the (de)coding organization;

Figure 3a shows a different version of the organization;

Figure 4 is a schematic diagram showing an arrangement of one sector on a byte unit basis;

Figure 5 is a schematic diagram showing an arrangement of one sector on a word unit basis;

Figures 6 and 7 are schematic diagrams which are used to explain the interleave relationship within one sector;

Figure 8 is a block diagram of an apparatus comprising a decoder;

Figure 9 is a diagram of the format of the reproduced data; and

Figure 10 is a block diagram of an error correcting decoder.

Description of the data format:

By way of example, hereinafter, first the data format is described as used on a so-called "Compact Disc". It should be noted that the invention could well be used with other values of the format parameters. Notably, the number of bits within a symbol, the numbers of symbols in a sector or in a frame, or the numbers of parity symbols added in successive encoding stages could be different.

In Figure 1, a frame 100 comprises 588 recorded or channel bits. Each frame starts with a synchronization pattern FS of 24 bits. The synchronization pattern, and also all subsequent information symbols DB are followed by a respective group RB of three so-called merging bits (shaded) which are added to diminish the DC-component of the recorded

signal. The information symbol 0 is a control symbol comprising user bits of subcoding signal data. This subcoding signal data may be used to control the playback of a disc, to display content-related information, e.g. timing and addresses on a video display, or for other useful purposes. Symbols numbered 1-12 and 17-28 are assigned for audio data. Symbols numbered 13-16 and 29-32 are assigned for parity symbols. Each of these information symbols consists of fourteen recorded or channel bits and during modulation are formed from code symbols which during demodulation must be reformed again. For brevity, the (de)modulation process is not considered further.

Overall description of the decoder:

Figure 2 shows a decoder for use with the invention according to the format of Figure 1. The encoder to a large extent will be symmetric with the decoder and therefore, will not be elaborated to the same detail as the decoder. The information symbols arrive on input 130 in a bit-serial manner. In demodulator 132, first a series-parallel conversion takes place. Next each 14-bit information symbol is translated into an 8-bit code symbol. The 8-bit code symbol is outputted on interconnection 134. Under certain circumstances additional flag information may be outputted on interconnection 134 to signal whether the conversion was impossible or doubtful. The merging bits may, or may not be taken into account for determining the flag information. Generally, the synchronization of the various modules is not taken into account here. The control symbol may be demodulated in a similar way as the other symbols. A branch-off 136 is present for forwarding the control symbol to a control mechanism not shown.

Next, block 144 represents a multiplexer with a single input 134 and thirty-two parallel outputs. This parallellism may be executed in the time domain, e.g. in that successive incoming code symbols are stored on successive locations of a processing RAM. Multiplexing is done on the basis of symbols, so that each output of block 144 receives one symbol. Blocks such as block 146 delay the symbols received for one frame interval. A frame has been disclosed with respect to Figure 1. Elements such as 148 are invertors for bitwise inverting parity symbols. Element 150 is a decoder for decoding and, if applicable, correcting a received group (code word) of 32 symbols by means of the second Reed-Solomon code. Thus, on the output of decoder 150 for each group of

32 symbols received, a group (code word) of 28 symbols is outputted. If required, each symbol may be provided with its own reliability flag or flags. The blocks 152 which are denoted by reference numerals 1 to 27 introduce respective delays to introduce a de-interleaving effect. The numeral in the block indicates the delay expressed in a number of frame intervals. A "1" indicates four such intervals, a "2" eight intervals, etcetera. Each symbol of a group of 28 symbols outputted together by decoder 150 is therefore assigned to a respective newly formed group of 28 symbols. Thus, any burst error in the medium has its effect spread over a large time interval, causing in general each newly formed group to contain only a few errors.

Element 154 is a decoder for executing decoding, and if applicable, correcting a received group of 28 symbols, by means of the first Reed-Solomon code. Thus, on the output of decoder 154 for each group of 28 symbols received there is a group of 24 data symbols outputted. If required, each such symbol outputted is again provided with its own reliability flag or flags. The blocks 156 which are denoted by reference numerals 2 introduce respective delays to introduce a descrambling effect. The numeral 2 indicates that the delay is over two frame intervals. Furthermore, also within a frame a certain sequential re-ordering of the symbols is effected as shown by the crossing lines. In an audio application, this descrambling ensures better possibilities for concealing the effects stemming from uncorrectable symbols. In that case, an odd-numbered symbol and its even-numbered successor together constitute a 16-bit audio sample. After D/A conversion, a missing analog sample may be reconstituted by means of some interpolating algorithm between correct neighbouring samples.

Block 158 represents a memory for the resulting corrected user symbols, together with associated flag information. These symbols are stored until a so-called sector is present. Finally, element 160 is a decoder for decoding, and if possible correcting, the information of a sector. The corrected user symbols are now presented in conventional manner to a user device not shown.

Figure 3 shows the combined content of 98 successive frames received at input 130 in Figure 2 wherein each frame covers one line in the Figure. Due to the combined effect of delay elements 146, 152, 156 this does not correspond to the actual contents of a sector to be discussed with respect to later Figures. The merging bits are not shown

as it is supposed that demodulation has taken place. Column 102 shows the 98 successive synchronization patterns FS. The second column 104 DB(0) shows the subcode content of the control symbol 0 of each frame. The third column 106 represents the content of data symbols 1-12, 17-28 of each frame. The fourth column 108 represents the content of the eight parity symbols RR with each frame. In an audio system, the 24 data symbols of each frame represent six stereophonic samples of 2 x 16 bits each. In the 0th and 1st frames the control symbol 0 (column 104) forms a synchronization patterns SYNC PAT, which has a predetermined format. This is used to produce synchronization on the level or a sector.

According to the "Compact Disc" format, the P-channel subcoding signal data (the combined first bits of successive control symbols 0 of the 2nd through to the 97th frame) constitute a flag to discriminate between a music program and a pause. The flag has a low level during a music program, a high level during a pause, and switches at a 2Hz frequency in the lead-out section. Therefore, it is possible to select specific music by counting this signal data. The Q-channel enables further control of this type. When the Q-channel information is stored in a microcomputer provided in the disc player it is possible to step from one music program to another to provide a certain random access feature at an accuracy of 1/75 of a second. The channels R..W may contain digitally coded speech as additional information to the audio signal.

In the Q-channel, the first two bits are used for the synchronization in SYNCPAT. The next four bits are used as control bits. The following four bits are used as address bits. The following 72 bits are used as data bits. These may include a track number code TNR and an index code X. Both codes may vary from decimal 00 to decimal 99. Further the data includes a time indication code giving the duration of a music program and a pause, and a time indication code giving the absolute running time from the front end of the program area of the "Compact Disc". These time indication codes give minutes, second and sectors each in two decimal digits. One second is divided into 75 sectors. To access the compact disc on the basis of a unit which is shorter than a music program such as in digital data, the above-mentioned absolute time code is used as an address. Finally, the last sixteen bits of the Q-channel are available for an error detection code by means of a CRC-check.

In the present embodiment, when the digital data is recorded by the information symbols DB, the format of the subcoding signal data in channels P, Q is the same as in the "Compact Disc" system. After the decoding by the first and second Reed-Solomon codes, and the descrambling in elements 156 is applicable, the data (column 106 in Figure 3) is grouped into a sector. The length of a sector corresponds to the user symbols of 98 frames, which is 2352 bytes. Figure 3a shows the function of the respective elements of a sector. A sector in the first place comprises a sector synchronization signal of 12 bytes (110). Next there is a header information 112 of 4 bytes, Next there are 2048 data bytes 114. Next, there is an error-detection code EDC 116 of four bytes. This code is based on the CRC principle and must not be confused with the 16-bit CRC code in the Q-channel of Figure 3. Next there is a space 118 of eight bytes for later extension of functions. Next, there are 172 P-parity bytes (120) and 104 Q-parity bytes (122) of the third Reed-Solomon code. The total information of one sector can be fetched together in decoder 160.

Figure 4 shows the more detailed arrangement of one sector In Figure 4, the left channel and right channel correspond to the sample data in the left and right channels of the stereophonic audio data. In each channel., one word consists of 16 bits and L denotes the least significant bit and M indicates the most significant bit. As mentioned above, in case of stereophonic audio data, the data of (6 x 2 x 2 = 24 bytes) has been recorded in the interval which is specified by the frame sync signal. Therefore, when digital data is recorded in the same signal format (Figure 1) as stereophonic audio data, one sector (2352 bytes) is recorded in the 0th to 97th frames as they are numbered according to the subcoding signal content. Thus, the digital data of a sector has a length corresponding to the interval between two successive 0th frame synchronization patterns (SYNC PAT). There is no interleaving between different sectors.

The first byte of the digital data of a sector has the bits all "0"; the following ten bytes have the bits all "1"; the twelfth byte has the bits all "0". This 12-byte interval is a sector sync signal indicating the head of a sector. After the sector sync signal, there are headers regarding minutes MIN, seconds SEC, sector SECT, and mode MOD each of one byte.

These headers are the address of one sector and 75 sectors correspond to one second similarly to the subcode content of the frames. The mode data indicate the kind of data of a sector. In Figure 4, D0001 to D2336 represent the byte numbers of a sector excluding the sector sync signal and headers. D0001 to D2048 are for the user data; D2049 to D2052 are for the error detection code; D2053 to D2060 are for a space; D2061 to D2232 are for the P-parity; and D2233 to D2336 are for the Q-parity.

Figure 5 shows an arrangement of one sector expressed on a word unit basis. In Figure 5, W0000 and W0001 are for the headers; W0002 to W1025 are for the user data; W1026 and W1027 are for the error detection code; W1028 to W1031 are for a space; W1032 to W1117 are for the P-parity; and W1118 to W1169 are for the Q-parity. The error detection code covers the header and user data (W0000 - W1027) and also the twelve synchronization bytes. The error correction code covers the header and user data (W0000 - W1027) and also the P-parity and Q-parity itself and also the CRC bits and the space 118 (but not the synchronication bytes).

A CRC-code which is used as the error detection code has, for example, the following generating polynomial g(x).

$g(x) = (x^{16} + x^{15} + x^2 + 1)(x^{16} + x^2 + x + 1)$. The CRC-code is a binary code with symbols from Galois-field GF(2). This error detection code is used to check the final reliability after the execution of the error correction. This check may be executed both with respect to the decoding with the cross-interleaved Reed-Solomon codes and with the sector-based pseudo-product-Reed-Solomon code. The CRC code would thus signal a failed correction, to a user device.

Each word W0000 - W1169 of a sector is divided into two bytes, the more significant byte and the less significant byte. The more significant 1170 bytes are grouped into a first data plane, while the less significant 1170 bytes are grouped into a second data plane. The sector-wise error correction processing is executed for each of these data planes separately. The coding processing for the respective data planes is, however, identical.

Figure 6 is a diagram for explaining the encoding regarding either data plane. The data plane consists of 1032 bytes comprising the header and user data and the CRC and space data and these 1032 bytes are notionally arranged like a matrix of (24 x 43) bytes. For convenience, the bytes are identified by the word number of the associated

word. These sector-wise organized bytes are encoded into a further set of two Reed-Solomon codes. The matrix-type depiction in this Figure shows the interleaved organization of the two latter codes in different directions in the matrix.

Now the following Reed-Solomon code is used according to the columns of Figure 6. This code has a code word length of 26 symbols and a so-called dimension of 24 symbols. The associated P-parity symbols are shown in rows 24, 25 (P PAR) at the lower end of the Figure. The associated Galois-field $GF(2^8)$ may be generated by the primitive polynomial $P(x) = x^8 + x^4 + x^3 + x^2 + 1$.
The associated primitive element a = (00000010), the latter bit being the least significant. The generator for the code is given by the product $(x-a^0)(x-a^1)$. The parity check matrix HP for this code is as follows:

$$HP = \begin{bmatrix} 1 & 1 & 1 & \ldots\ldots 1 & 1 \\ a^{25} & a^{24} & a^{23} & \ldots\ldots a^1 & 1 \end{bmatrix}$$

Assuming that the P-series after decoding is $\underline{VP}$, the parity symbols $P0_{NP} = D(43 \times 24 + NP)$ and $P1_{NP} = (43 \times 25 + NP)$ (NP = 0, 1, 2, ..., 41, 42) will satisfy the following equation.

$$\underline{HP} \times \underline{VP} = \underline{0}$$

where,

$$VP = \begin{bmatrix} D(43 \times 0 + NP) \\ D(43 \times 1 + NP) \\ D(43 \times 2 + NP) \\ \\ D(43 \times MP + NP) \\ \\ D(43 \times 24 + NP) \\ D(43 \times 25 + NP) \end{bmatrix} \qquad \text{(Here NP = 0 .. 42, MP = 0 .. 25)}$$

As an example, when N = 0, one reproduced P-parity is generated upon [D0000, D0043, D0086, D0129, D0172, ..., D0946, D0989, D1032 (= P0), D1075 (=P1)] that are located in the first column.

A further Reed-Solomon code is used according to the diagonal direction as given by the arrow Q_{SEC} in Figure 6. This code has a code word length of 45 bytes or symbols and a dimension of 43 symbols. The associated Q-parity symbols are shown in the two rows QPAR at the lower

end of the Figure. In this case, there are 26 x 2 parity symbols (as many pairs as there are user symbols plus P-parity symbols in any column). The polynomial P(x) is the same, the parity check matrix is:

$$HP = \begin{vmatrix} 1 & 1 & 1 & \ldots\ldots 1 & 1 \\ a^{44} & a^{43} & a^{42} & \ldots\ldots a^{1} & 1 \end{vmatrix}$$

When the reproduced Q-series is VQ, the parity symbols X0 = D(43 x 26 9NQ) and Q1 = D(44 x 26 + NQ) satisfy the following equation: HP x VQ = 0, where

$$VQ = \begin{bmatrix} D(44 \times 0 + 43 \times NQ) \\ D(44 \times 1 + 43 \times NQ) \\ D(44 \times 2 + 43 \times NQ) \\ \\ D(44 \times MQ + 43 \times NQ) \\ \\ D(44 \times 40 + 43 \times NQ) \\ D(44 \times 41 + 43 \times NQ) \\ D(44 \times 42 + 43 \times NQ) \\ D(44 \times 26 + NQ) \\ D(44 \times 26 + NQ) \end{bmatrix}$$

The ranges are:
NQ 0...25
MQ 0...42

When it is assumed that (NQ = 0, 1, 2, 3, ..., 24, 25) and (MQ = 0, 1, 2, 3, ..., 41, 42), and if there is the relation of (44 x MQ + 43 x NQ) $\geq$ 1117, (44 x MQ + 43 x NQ) will be calculated as (44 x M + 43 x N - 1118).

Figure 7 corresponds closely to Figure 6. Here, with respect to Figure 6, the column for M = 1 has been rotated upward by one position, for M = 2 by two positions, etcetera. The Q-parity symbols have been shown in two additional columns. In this way, the rows in Figure 7 each constitute their own Q-series. Again, each column forms a (now rotated) P-series, except for the Q0, Q1 columns. Therefore, Figure 7 shows the arrangement of a quasi product code using a (26, 24) Reed-Solomon code in the vertical direction and a (45, 43) Reed-Solomon code in the horizontal direction.

Since these two Reed-Solomon codes each have two parity symbols, even when no error flag exists, up to one symbol error can be corrected in each code sequence. When the error location is known by an error flag, up to two symbol errors can be corrected. This error flag may be produced by the decoding of the first and second Reed-Solomon

codes. Now, by alternately performing the decoding of the Reed-Solomon code in the vertical direction (referred to as the P-decoding) in Figure 7 and the decoding of the Reed-Solomon code in the horizontal direction (referred to as the Q-decoding), for example, by performing (P-decoding; Q-decoding; P-decoding; Q-decoding) all error patterns can be corrected that have at most two flagged error symbols with respect to any of the P-series or Q-series or which, by initial processing, can be reduced thereto. The simplest pattern which cannot be corrected has three P-series with three error symbols each, which error symbols also occur three by three in only three Q-series. Additional errors would make the situation worse, of course.

The encoding is executed for the two data planes (containing the more significant and less significant bytes, respectively) in exactly the same way. The encoding acts upon the 1118 words of the header and user data and CRC-check bits and space bits of one sector.

The respective data planes after encoding are synthesized and the sector sync signal is added so that the arrangement of one sector shown in Figures 4, 7 is obtained. This sector is supplied to the encoder in place of audio data, for the CIRC-encoding of the "Compact Disc"; furthermore it is modulated into the channel data as shown in Figure 1. This channel data is supplied to the cutting machine for the digital disc. Secondary copies may be made by a conventional replicating process.

Figure 8 shows one embodiment of a decoding apparatus according to the invention. Herein, digital disc 1 has the digital signal recorded according to a spiral track. The disc 1 is rotated by spindle motor 2, which is speed-controlled by spindle servo circuit 3. An optical head 4 comprises: a laser generator for read out; a beam splitter; an optical system; and a photo sensitive element to receive the laster beam reflected by the disc 1. The optical head 4 can be moved in radial direction by a motor 5. Motor 5 is driven by a drive circuit 6. In addition, the optical head 4 can be moved in a direction perpendicular to the surface of disc 1 and in a direction parallel therewith. Focus servo circuit 7 and tracking servo circuit 8 are provided for controlling the correct focussing and tracking of optical head 4. Furthermore, optical head 4 is equipped with a known focus error and radial error detecting element.

The output signal of the optical head 4 is supplied to RF-

amplifier 9. The output signal of the RF-amplifier 9 is supplied to a clock extracting circuit 10. The outputs (data and clock) of the clock extracting circuit 10 are supplied to a frame sync detecting circuit 11. The digital signal recorded on the disc 1 is modulated in known manner. A digital demodulator 12 performs the demodulation. The bit clock outputted from the clock extracting circuit 10 and the frame sync signal detected by the frame sync detecting circuit 11 are supplied to the digital demodulator 12 and the spindle servo circuit 3.

The subcoding signal is separated by the digital demodulator 12 and this subcoding signal is supplied to a system controller 14 through a buffer memory 13. The system controller 14 is equipped with a CPU and controls the rotating operation of the disc 1, drive 6 and, the read out operation of the optical head 4. Control commands are supplied through an interface 20 described later to the system controller 14. Controller 14 controls read out of the desired digital signal from the disc 1 while using the subcoding signal.

The main digital data outputted from the digital demodulator 12 is supplied through a RAM controller 15 to a RAM 16 and an error correcting circuit 17. The removal of the time base variation and error correction are executed by the RAM controller 15, RAM 16 and error correcting circuit 17, so that the main digital data is outputted. The output of the RAM controller 15 is supplied to a demultiplexer 18. The demultiplexer 18 is controlled in dependence on whether the disc 1 carries audio data without the third Reed-Solomon code, or has this additional sector-wise code. In other systems the audio channel may be omitted and no multiplexer would be required. The multiplexer 18 is controlled by system controller 14. The control mode may be executed on the basis of the information in the subcoding signal. The latter discrimination information is due signalled to RAM 16. In case of digital data storage the additional error correction can be undertaken (as far as necessary). Data converter 19 receives the digital data and also the reproduced subcoding signal. The reproduced data is parallel-to-serial converted by data converter 19. Also, the subcoding signal is supplied from buffer 13 to data converter 19. Figure 9 shows an example of a word format of the serial signal which is outputted from the data converter 19. Herein one word consists of 32 bits in which the first four bits are for preamble, the next four bits are auxiliary bits of data and the next 20 bits are for data. The digital data of the

user word are inserted with the least significant bit first. Four control bits are added. Bit V is a flag indicating the validity of the word. Bit U is a bit of the subcoding signal, so that all bits of the subcode signal are transmitted in series. Bit C is a channel discrimination bit. Bit P is a parity bit. This word format is defined in consideration of the audio data and is supplied to an interface 20 at the next stage and is converted to the data format for a standard computer. In addition, data for system controller 14 is supplied from microcomputer system 21 through interface 20. The microcomputer system provides the read out address and drive control signals such as the start signal.

An interpolator 22 is connected to the output path of the demultiplexer 18 which is selected when the disc to be played back is for the stereophonic audio signals thereby allowing the error data which could not be error corrected to be interpolated. The audio signals are divided into the signals in the left and right channels by the interpolator 22. The data in the respective channels are converted to the analog signals by D/A converters 23L and 23R and outputted through low-pass filters 24L and 24R.

The time base variation of the subcoding signal may be removed by the buffer memory 13, similarly to the time base corrections with respect to the digital signal in the main channel by the RAM controller 15 and RAM 16. The RAM controller 15 forms the write clock synchronized with the reproduction signal from the detected frame sync signal. The digital signal is written into the RAM 16 in response to this write clock. When the digital signal is read out from the RAM 16, the read clock is formed from the output of a crystal oscillator. Thus, write-in and read-out of the subcoding signal for buffer memory 13 is controlled. Consequently, the subcoding signal read out from the buffer memory 13 includes no time base variation.

In one embodiment of the invention, upon playback of the disc for the storage of digital data, the read command for a predetermined address is first given by the microcomputer system 21. This address is the code itself for the display of the absolute time in the Q-channel. This address is supplied to the system controller 14 through the interface 20. The system controller 14 controls the drive circuit 6, for moving the optical head 4 nearly to the desired read out location while checking the subcoding signal reproduced by the optical head 4.

Then, the reproduction is started from the location which lies a few sectors earlier to prevent malfunction so that the accessing does not end without reproducing the intended subcoding signal because an error were included in the subcoding signal. The desired sector is caught either by the method whereby the reproduced subcoding signal coincides with the designated address or whereby the frame sync signal is counted by starting the reproduction from a near location of the correct subcoding signal.

Figure 10 shows an example of the error correcting circuit when the disc for the storage of digital data is played back. The error correcting circuit is used for both audio discs and for discs for the storage of digital data. The decoder for the CIRC code is not shown. Reproduced data (excluding the sector sync signal) of one SECTOR are stored in the RAM 16 after the data are decoded by the CIRC code. An error flag indicating presence or absence of an error is added to each symbol.

Each symbol is read out from the RAM 16 together with the error flag and is supplied through a data bus 31 to a P-decoder 32 for every P-series of 26 symbols. The P-decoder 32 performs the decoding using the (26, 24) Reed-Solomon code. The symbols after this decoding are written in the RAM 16. The error flag of a symbol of which the error was corrected by the P-decoder 32 is reset. After completion of the P-decoding with respect to one sector, the data read out from the RAM 16 is supplied through the data bus 31 to a Q-decoder 33.

The de-interleave is performed due to the address control of the RAM 16, and in the Q-decoder 33 the (45, 43) Reed-Solomon code is decoded. The error flag of a symbol of which the error was corrected, is reset . Next, the P-decoding is again performed and thereafter the Q-decoding is carried out again. In this way, after the P-decoding and Q-decoding were alternately performed twice each, the reproduced digital data after the error correction from the RAM 16 is supplied to a CRC checker 34, where the error detection is performed. The result of the error detection is supplied to an output gate 35. In the output gate 35 the error flag may inhibit the outputting of erroneous data. In other embodiments, a lower number or a higher number of P and/or Q decoding operations may be performed; for example, if no errors are detected in the beginning, the P and Q-decoding are skipped.

The error detection result can be also used for the error

correction in the P-decoder 32 and Q-decoder 33. Upon error correction, the P-decoder 32 and Q-decoder 33 use the error flag which was generated in the decoding of the CIRC code. Now, when the CIRC flag mechanism indicates that an error exists, but the CRC check indicates a correct situation, further decoding of the third Reed-Solomon code is terminated.

CLAIMS:

1. An information transmission method with error correction, said method comprising the steps of:

a. Reed-Solomon encoding a succession of first numbers of data symbols to produce a sequence of first code words each comprising a second number of symbols composed of the first number of data symbols and a first series of parity symbols;

b. interleaving the symbols of successive first code words by means of respective different delay times over as many first code words as there are symbols in a first code word to produce symbol-interleaved first code words;

c. Reed-Solomon encoding the symbol-interleaved first code words to produce a sequence of second code words each comprising a third number of code symbols composed of the second number of symbols and a second series of parity symbols;

d. modulating said code symbols of said second code words into information symbols for introduction into a medium for later decoding;

characterised in that said data symbols are generated by

e. Reed-Solomon encoding a finite number of first groups of user symbols to produce respective extended first groups each composed of the symbols of the relevant first group and a first sub-series of parity symbols,

f. forming symbols of different extended first groups into as many second groups of unique symbols as there are symbols in an extended first group, each second group including a first sub-series of parity symbols,

g. Reed-Solomon encoding the second groups of symbols to produce extended second groups each composed of the symbols of the relevant second group and a second sub-series of parity symbols, the symbols of the extended second groups being said data symbols and being arranged in sectors each corresponding to a unit of organisation of a data format to which the information transmission method is applied.

2. A method as claimed in Claim 1, characterised in that said user symbols are obtained from user words which are each divided into a more significant user symbol and a less significant user symbol, in that said sectors are organized in two planes in that a first plane of a sector comprises data symbols in respect of the more significant user symbols of the sector and the second plane of said sector comprises data symbols in respect of the less significant user symbols of said sector, and in that said steps (e), (f) and (g) are performed separately in each of said two planes.

3. A method as claimed in Claim 1 or Claim 2, characterised in that each sub-series consists of two parity symbols.

4. A method as claimed in any one of Claims 1 to 3, characterised in that there is included within a sector of data symbols a multi-symbol error detection quantity.

5. A method as claimed in Claim 4, characterised in that said error detection quantity is a CRC check quantity.

6. A method as claimed in any one of Claims 1 to 5, characterised in that there is included within a sector of data symbols a multi-symbol header which is an address for the sector.

7. A method as claimed in any one of Claims 1 to 6, characterised in that there is included within a sector of data symbols a mode symbol which indicates the kind of data of a sector.

8. A decoding method for user symbols that have been encoded according to the method of Claim 1, said method comprising the steps of:

(i) - receiving from a medium a sequence of information symbols and therefrom by demodulation forming a succession of said second code words composed of code symbols;

(ii) - decoding, and if applicable correcting, the code symbols of each second code word to form the associated said first codeword having a smaller number of (interleaved) symbols;

(iii) - de-interleaving the symbols of the first code words by means of respective different delay times over as many

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first code words as there are symbols therein to restore the original first code words;

(iv) - decoding, and if applicable correcting, the symbols of the restored first code words to restore the original data symbols;

(v) - arranging said data symbols into sectors comprising said extended second groups of symbols containing said first and second sub-series of parity symbols and decoding, with correction if applicable, the symbols of these extended second groups and the symbols of said extended first groups of symbols to restore the original user symbols.

9. A method as claimed in Claim 8, characterised in that said user symbols are pair-wise combined into user words, in that each user word consists of a more significant user symbol and a less significant user symbol, in that said sectors are organized in two planes in that a first plane of a sector comprises the more significant user symbols of the sector, and the second plane comprises the less significant user symbols of the sector, and in that decoding as set forth in step (v) is performed separately in each of said two planes.

10. A method as claimed in Claim 8 or Claim 9, characterised in that said first and second sub-series each consist of two symbols and in that with respect to at least one of said extended first and second groups of symbols at least one symbol in a group is rendered correctable by the associated sub-series.

11. A method as claimed in any one of Claims 8 to 10, characterised in that an additional multi-symbol error detection quantity is included within a sector of data symbols, and in that upon decoding an insufficient error protection resulting from the overall decoding, as detectable by said error detection quantity, is signalled to a user device.

12. An apparatus for information transmission with error correction according to the method claimed in Claim 1, said apparatus comprising;

- input distributing means for receiving user words and

distributing any received user word into two multi-bit user symbols of mutually equal lengths;

- a first Reed-Solomon encoder fed by said input distributing means for receiving a succession of first numbers of data symbols generated from said user symbols and having first matrix multiplication means for adding to each first number an associated first series of parity symbols to produce a sequence of first code words;
- interleaving means fed by said first Reed-Solomon encoder and containing delay means for imparting respective different delay times to interleave the symbols of successive first code words over as many first code words as there are symbols in a first code word to produce symbol-interleaved first codes words;
- a second Reed-Solomon encoder fed by said interleaving means for receiving successive symbol-interleaved first code words and having second matrix multiplication means for adding to each received code word an associated second series of parity symbols to produce a sequence of second code words composed of code symbols;
- modulating means fed by said second Reed-Solomon encoder for modulating said code symbols of said second code words into information symbols for introduction into a medium for later decoding;

characterised in that said apparatus furthermore comprises a third Reed-Solomon encoder provided with sequencing means for sequentially presenting the user symbols of a sector as mutually exclusive first groups of the user symbols to third matrix multiplication means for generating associated first sub-series of parity symbols, and furthermore, for sequentially presenting mutually exclusive second groups of the user symbols and associated first sub-series of parity symbols to said third matrix multiplication means for generating associated second sub-series of parity symbols, and in that all symbols of any first group are contained in mutually unique second groups and vice versa.

13. An apparatus as claimed in Claim 12, characterised in that said input distributing means have a first output for outputting a more significant user symbol of a user word, and a second output for outputting a less significant user symbol of a user word, in that said first and second outputs are connected to said third Reed-Solomon encoder for sector-wise entering said more significant user symbols therein to said third matrix multiplication means for multiplication thereby as separate from any less significant symbol in the same sector, and vice versa, thereby organising said sector into two separate planes of more significant symbols and less significant symbols, respectively.

14. An apparatus as claimed in Claim 12, or Claim 13, characterised in that said third Reed-Solomon encoder is provided with a generator for an additional multi-symbol error detection quantity to be contained with a sector of data symbols.

15. An apparatus as claimed in Claim 14, characterised in that said generator is a CRC generator.

16. A device for information decoding with error correction according to the method claimed in Claim 8, said device comprising:

- input means connectable to a medium for therefrom receiving a sequence of information symbols and containing demodulating means for demodulating each information symbol into a code symbol to form said succession of said second code words composed of code symbols;
- second decoding means fed by said input means for receiving the code symbols of each second code word and having fourth matrix multiplication means for generating in respect of each second code word an associated first syndrome symbol group for decoding, and if applicable correcting, the associated second codeword to output a first code word having a smaller number of symbols than said second code word;
- de-interleaving means fed by said second decoding means and containing delay means for imparting respective different delay times to de-interleave the symbols of the received first code words and distribute them over as many first code words

as there are symbols therein to restore said original first code words;

- first decoding means fed by said de-interleaving means for receiving the symbols of said original first code words and having fifth matrix multiplication means for generating in respect of each first code word an associated second syndrome symbol group for decoding, and if applicable correcting, the associated first code word to output the original data symbols;

characterised in that third decoding means are provided, fed by said first decoding means and comprising matrix multiplication means for generating further syndrome symbols for decoding, and if applicable correcting, a sector of data words to output user symbols on an output means, said third decoding means being presented with the user symbols of a sector as mutually exclusive first groups of the user symbols and first sub-series of parity symbols and mutually exclusive second groups of the user symbols and first and second sub-series of parity symbols, and said third decoding means being separately operative for each of said first and second groups.

17. A device as claimed in Claim 16, characterised in that said output means comprise unifying means for reconstituting a user word from a more significant user symbol and less significant user symbol, and in that said sectors are organised into two planes, a first plane of a sector being decoded exclusively to more significant user symbols, and the second plane of a sector being decoded exclusively to less significant user symbols, and in that said third decoding means is separately operative in each of said two planes.

18. A device as claimed in Claim 16 or 17, characterised in that each first and second sub-series consist of two symbols and in that with respect to at least one first or second group said third decoding means is operative for rendering correctable at least one symbol by means of the associated sub-series.

19. A device as claimed in any one of Claims 16 to 18,

characterised in that an additional checker is provided for checking a multi-symbol error detection quantity within a sector, and in that an output of said checker is connected to a user device output for communicating an insufficient correction signalization.

20. A device as claimed in Claim 19, characterised in that said checker is a CRC checker.

21. An apparatus containing a device as claimed in any one of Claims 16 to 20, characterised in that it furthermore contains holding means for holding a storage medium, interrogating means for interrogating said storage medium, drive means for driving said medium along said interrogation means, and interface means for interfacing an output of said interrogation means to an input of said device.

22. An information transmission method with error correction, substantially as hereinbefore described with reference to the accompanying drawings.

23. An error correcting decoding method substantially as hereinbefore described with reference to the accompanying drawings.

24. An apparatus for information transmission with error correction, constructed and arranged to operate substantially as hereinbefore described with reference to and as shown in Figures 1 to 7 of the accompanying drawings.

25. A device for information decoding with error correction, constructed and arranged to operate substantially as hereinbefore described with reference to and as shown in Figures 2 and 8 to 10 of the accompanying drawings.

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