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Rhee

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(54) **UNEQUAL ERROR PROTECTION REED-MULLER CODE GENERATOR AND DECODER**

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(58) **Field of Search** 714/780, 755

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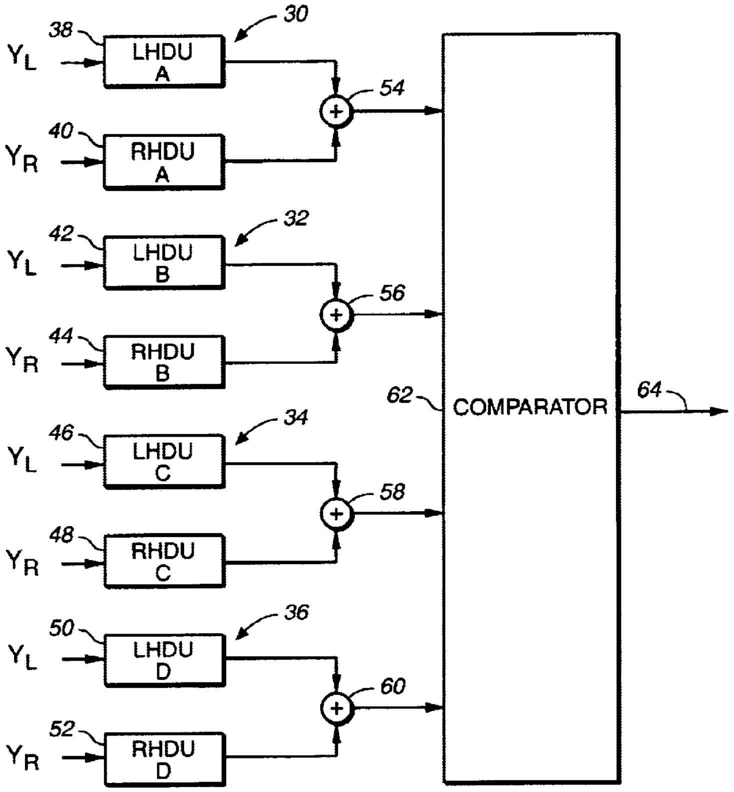
(57) **ABSTRACT**

An unequal error protection Reed-Muller code and method for designing a generator matrix and decoder. A conventional RM code is concatenated with the combination of itself and a subcode of itself. The new generator matrix is decomposed to include empty submatrices. The resulting generator matrix allows parallel decoding of separate portions of the received code word vectors.

20 Claims, 2 Drawing Sheets



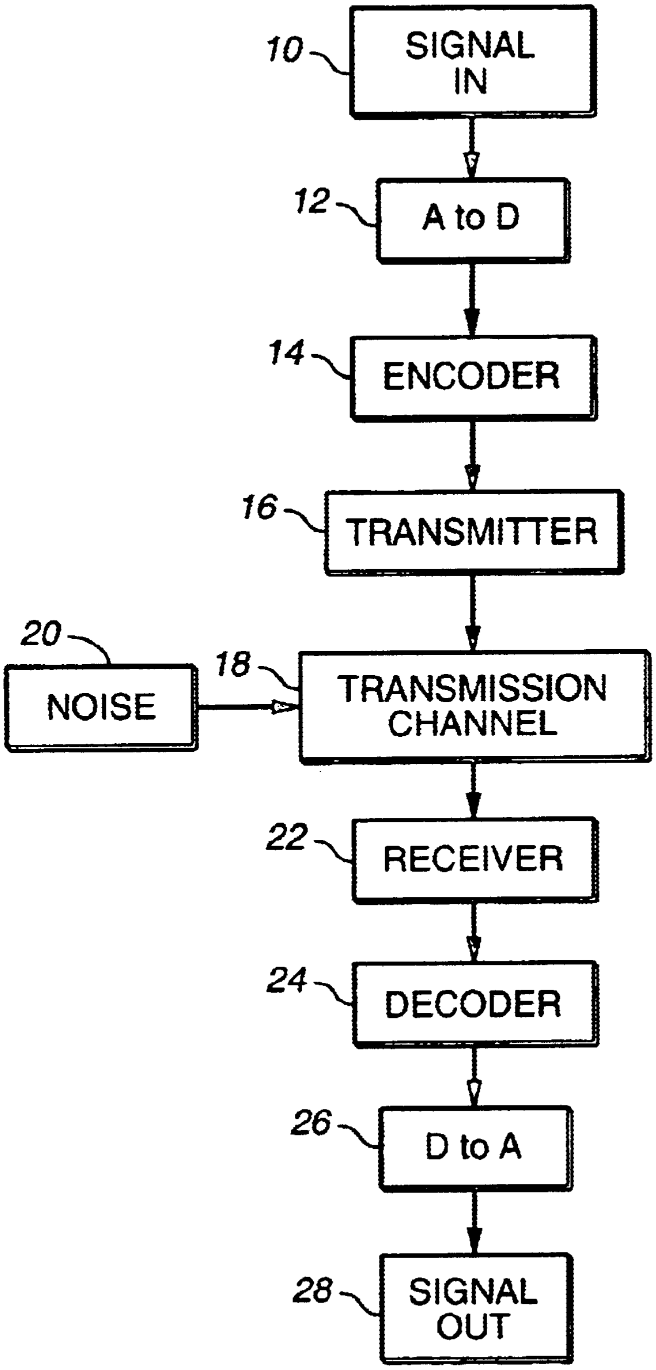

10
SIGNAL IN
12
A to D
14
ENCODER
16
TRANSMITTER
20
NOISE
18
TRANSMISSION CHANNEL
22
RECEIVER
24
DECODER
26
D to A
28
SIGNAL OUT

FIG._1

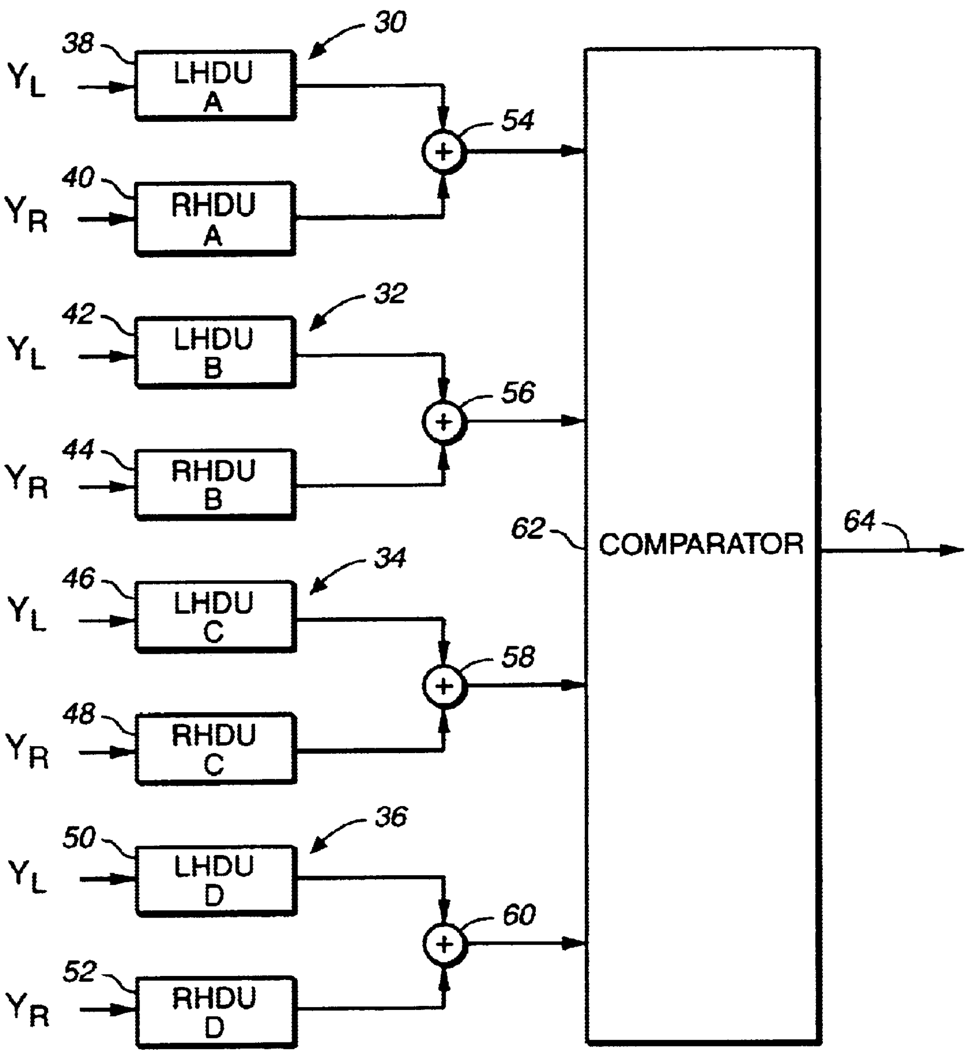

30
38
Y_L
LHDU A
54
40
Y_R
RHDU A
32
42
Y_L
LHDU B
56
44
Y_R
RHDU B
62
COMPARATOR
64
34
46
Y_L
LHDU C
58
48
Y_R
RHDU C
36
50
Y_L
LHDU D
60
52
Y_R
RHDU D

FIG._2

UNEQUAL ERROR PROTECTION REED-MULLER CODE GENERATOR AND DECODER

BACKGROUND OF THE INVENTION

The present invention relates to unequal error protection block codes and more particularly to a generator matrix for an unequal error protection Reed-Muller code and a decoder for such code.

Error protection codes are well known in systems which transmit information from one point to another or which record data on a storage medium for later playback. For example, pictures taken by a space probe must be transmitted back to Earth over long distances and with low power. The signals are therefore subject to interference by noise sources which cause the signal received on Earth to be different from the transmitted signal. By proper encoding of the signal before transmission, it is possible to reconstruct the original signal from the corrupted signal actually received. In similar fashion, information written onto a storage medium such as a compact disk is subject to errors in the writing process, errors caused by damage and wear to the disk and errors in the reading process. These errors are like noise sources in a transmission channel. But, by encoding the information before writing it to the storage medium, a certain level of errors can be corrected when the information is read from the disk.

Information to be error protected is typically digitized and transmitted or stored as a series of binary digits, bits, represented as ones and zeros. Each unit or word of data is usually represented by a fixed series of bits, e.g. eight or sixteen bits. Error codes generally add bits to the length of the data words to form code words which are transmitted or stored. For example, a repetition code may transmit or store a single "1" as four "1"s, which forms a 4,1 code (four bit codeword representing one bit of data). A decoder which receives a four bit word containing three "1"'s and one "0" would assume that one error occurred and four "1"s were transmitted and would decode the received code word as a single data bit of "1".

Coding increases the reliability of transmitted data. But, coding increases the bandwidth needed to transmit a given amount of data. Stated differently, coding reduces the amount of data which can be transmitted with a given bandwidth. Much effort has been made to design codes which most efficiently use available bandwidth and achieve the best level of error protection.

In real systems, all data does not need the same level of error protection. For example, in error protecting voice or music, it is more important to ptotect the most significant bits than the least significant bits. In some forms of video compression, images are broken into blocks which are represented by a number of parameters, one of which is the scale factor which applies to all other bits in the block. Any error in the scale factor causes an error in all other bits in the block. Thus, it is more important to protect the scale bits than the other bits. In such cases, unequal error protection codes can be used to optimize the coding system by using relatively more bandwidth to protect the more important bits and relatively less to protect less important bits.

The Reed-Muller codes are known to be efficient error protecting codes. However, when signals are encoded with a standard Reed-Muller generator matrix and decoded using standard algebraic decoding, the bit error rate for all bits is the same. It would be desirable to have a generator matrix

for using Reed-Muller code to encode data with unequal error protection and a decoder which efficiently decodes the signals while maintaining the unequal error protection.

SUMMARY OF THE INVENTION

In accordance with the present invention, an unequal error protecting code is constructed by concatenating an original code with the sum of itself and a subcode of the original code. The resulting generator matrix provides unequal error protection. By proper decomposition, the generator matrix is simplified to a form which facilitates a simple decoding algorithm in which received code words are split into a plurality of parts which are decoded in parallel.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of a signal transmission system with error protection coding.

FIG. **2** is a block diagram of a signal decoder according to the present invention.

DETAILED DESCRIPTION OF EMBODIMENTS

FIG. **1** illustrates a typical data transmission system in which the present invention is useful. Block **10** represents an input signal, for example a voice, music or picture signal which normally originates as an analog signal. For instance, the input signal may be the output of a microphone in a cellular telephone. At block **12**, the analog signal from block **10** is converted from analog to digital form. For example, an audio signal may be sampled and each sample may be represented by an eight or sixteen bit digital word. The digital signal from block **12** is coupled to an encoder **14** which provides forward error protection by converting each digital data word into a digital code word. The code words are then coupled to a transmitter **16** which may transmit the code words as radio frequency signals. The transmitted signals pass through a transmission channel **18**, which may be the atmosphere of the Earth. Block **20** represents sources of noise or errors which cause the transmitted code words to be corrupted to some extent. At block **22**, the transmitted signal plus noise are received and provided as a digital output to a decoder **24**. The decoder **24** performs several functions. It detects errors in the received signal and, within certain limits, corrects the errors to identify the code word which was actually transmitted. When the proper codeword has been identified, it is mapped to the data word which would generate the code word in encoder **14**. The digital data word is then coupled to a digital to analog converter **26** which may provide an analog output signal which is a good reproduction of the input signal from block **10**.

As noted above, the system of FIG. **1** may also represent a system which records and plays back an audio or video signal. The transmitter **16** may be a system for writing, or burning, data onto a CD or a DVD. The receiver **22** may be a CD or DVD player which reads the recorded information from the CD or DVD. The transmission channel may be the CD or DVD itself. The noise **20** is from errors in the writing process, reading process, and from scratches on the surface of the CD or DVD caused by improper handling.

In similar fashion, the transmission channel may be digital subscriber lines and/or long distance backbone telephone systems or the Internet. In the case of the Internet, the transmitter and receiver may be personal computer systems. Any such systems can be affected by noise sources and therefore can benefit from use of error protection coding. Such systems typically can optimize the tradeoff of bandwidth and error protection by use of unequal error protection codes.

The present invention provides a new method for designing an unequal error protecting code generator for encoder **14**. It also provides a method for designing a corresponding decoder **24** which provides fast parallel decoding and maintains the unequal error protection. To clarify this disclosure of the present invention, only the case of binary codes and relatively short data and code words are considered.

The basic process for encoding a digital data word d into a block code word C is by use of a generator matrix G, according to the equation:

$$[d][G]=[C]$$

The data word d is represented by a vector having a length k. The generator matrix G has k rows and n columns. The code words C have a length of n. As a starting point for the embodiment which is described in this disclosure, assume k is four and n is eight. The resulting generator equation then has the form:

$$[x\ x\ x\ x]\begin{bmatrix} x & x & x & x & x & x & x & x \\ x & x & x & x & x & x & x & x \\ x & x & x & x & x & x & x & x \\ x & x & x & x & x & x & x & x \end{bmatrix} = [x\ x\ x\ x\ x\ x\ x\ x]$$

In this embodiment each "x" represents a digital one or zero. The code, C, is the complete set of all code words which are generated by multiplying every possible data word, d, by the generator matrix, G. Since the data word in this embodiment has four bits, it has sixteen possible values. There are therefore sixteen code words in the code, C, out of the 256 possible eight-bit digital vectors.

In one embodiment of the present invention, a Reed-Muller block code generator matrix, G, which produces the code C is used as the starting point for designing an improved generator matrix. Any binary block code, C, has subcodes, one of which is represented here as C_1. A subcode may be generated by any linear combination of the rows of the original matrix G, which combination forms a subcode generator matrix G_1. The subcode C_1 has a number of rows k_1 which is less than k. In the present embodiment, we will pick k_1 to be two. As a result, the subcode generator matrix G_1 can encode only two data bits and the subcode C_1 includes only four code words. The generator matrix G_1 has the same number of columns as G and produces code words having a length of eight in this embodiment.

In the present invention, a new unequal error protection code C_2 is generated by concatenating the original code C generated by matrix G with the sum of the same code and the subcode C_1 generated by matrix G_1. This process is represented by the equation:

$$C_2 = |U|U+V|$$

where U is a code word of C and V is a codeword of C_1. The new generator matrix G_2 for code C_2, is represented by the equation;

$$[G_2] = \begin{bmatrix} G & G \\ 0 & G_1 \end{bmatrix}$$

The generator matrix G_2 has more rows and more columns than matrix G. The additional rows are provided by G_1, which for this embodiment has two rows. G_2 therefore has six rows and can encode a data word of six bits. The matrix G_2 has sixteen columns and therefore generates code words which are sixteen bits long. In this embodiment, there are 64 code words in code C_2, one for each of the possible six bit data words.

Since C_1 is a subcode of C, we have the following coset decomposition of C:

$$C=C_1+[C/C_1]$$

where $[C/C_1]$ denotes the sets of representatives of the cosets of C_1 in C. The generator matrix for the $[C/C_1]$ coset code is represented as G_3. The dimension, i.e. number of rows, of G_3 is k_3 which is equal to k minus k_1. Therefore, the generator matrix G for code C may be represented as:

$$[G] = \begin{bmatrix} G_3 \\ G_1 \end{bmatrix}$$

The generator matrix G_2 for code C_2 may therefore be rewritten as:

$$[G_2] = \begin{bmatrix} G_3 & G_3 \\ G_1 & G_1 \\ 0 & G_1 \end{bmatrix}$$

The linear operation of subtraction of one row from another does not change the nature of a code generator matrix. Therefore, by subtracting the last two rows of G_2 from the middle two rows of G_2, the matrix G_2 may also be rewritten as:

$$[G_2] = \begin{bmatrix} G_3 & G_3 \\ G_1 & 0 \\ 0 & G_1 \end{bmatrix}$$

In the present embodiment, each of the submatrices G_3 and G_1 have two rows and generator matrix G_2 has a total of six rows. The generator matrix G_2, is therefore designed to encode six bit words instead of the original four-bit data word d. The data vector d_2 for our new code C_2 is six bits long, four corresponding to the original code C and two corresponding to the subcode C_1. The data word d_2 can be divided into three parts for further explanation of the present invention as follows:

$$[d_2]=[d_a|d_b|d_c]$$

The new code C_2 is generated according to the following equation:

$$[d_a|d_b|d_c]\times \begin{bmatrix} G_3 & G_3 \\ G_1 & 0 \\ 0 & G_1 \end{bmatrix} = [C\,|\,C+C_1] = [C_2]$$

From this equation, several things can be seen. The lengths of data bits d_a, d_b, and d_c are k_3, k_1, and k_1 respectively. Data bits d_a affect both halves of the code words C_2 and should therefore have increased error protection. Data bits d_a and d_b generate the left half of the code words C_2. Data bits d_a and d_c generate the right half of the code words C_2. The decomposition of the generator matrix G_2 to include the two zero or empty submatrices provides

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