



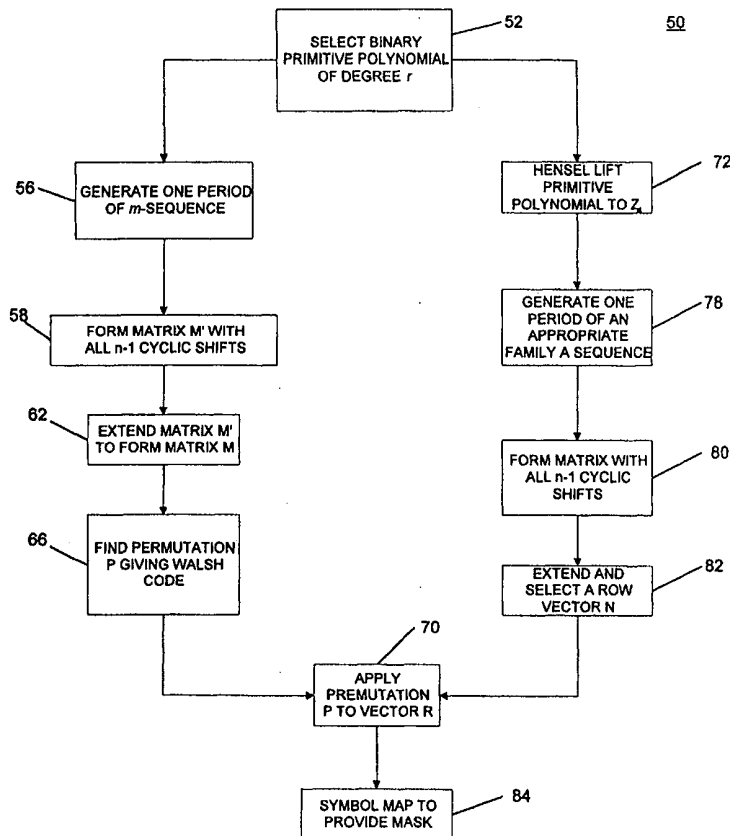
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(54) Title: A METHOD AND APPARATUS FOR THE REFLECTION AND TRANSMISSION OF QUASI ORTHOGONAL VECTORS

(57) Abstract

A transmission method in a communications system has an orthogonal vector and a quasi orthogonal masking function (104) for obtaining a quasi orthogonal vector from the orthogonal vector. Message signals are transmitted according to the quasi orthogonal vector. The method includes receiving the quasi orthogonal masking function (104) and permuting the quasi orthogonal masking function (104) to provide a further quasi orthogonal masking function (104). The further quasi orthogonal masking function is applied to the orthogonal vector to provide a further quasi orthogonal vector. The further quasi orthogonal vector is applied to the message signal to provide an encoded message signal for transmitting the encoded message signal within the communications system.



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A METHOD AND APPARATUS FOR THE REFLECTION AND TRANSMISSION OF QUASI ORTHOGONAL VECTORS

5

BACKGROUND OF THE INVENTION

I. Field of the Invention

This invention relates to the field of communications systems and, in particular, to the transmission of spread coded message signals within communications systems.

II. Description of the Prior Art

It is well known in the art of communications to mix message signals to be transmitted with spreading code vectors. This permits the message signals to be combined, transmitted, and separated from each other after transmission. The most useful feature of a set of code vectors suitable for this purpose is that the spreading code vectors are mutually orthogonal. This permits a theoretical interference of zero between the message signals. The code vectors most commonly used for this purpose are Walsh code vectors.

The total number of binary code vectors having a length n is 2^n . However, of the total number of binary vectors 2^n within the total vector space, only n are mutually orthogonal. For example, when $n = 8$ there are 256 different binary vectors. Only 8 of the 256 vectors are mutually orthogonal. Therefore, in a system wherein $n = 8$ usually only 8 message signals can be combined and separated in this manner and only 8 users can be supported simultaneously. Likewise, if $n = 128$ then 128 users can be supported simultaneously. Some of the vectors can be idle some of the time, thereby permitting more than n users to be serviced. However, the size of the code vectors still places a limitation on the size of the communications system.

A set W of code vectors w meeting the orthogonality requirement for a theoretical interference of zero can be represented as follows:

$$w_1 = [w_{1,1} \ w_{1,2} \ \dots \ w_{1,n}]$$

$$w_2 = [w_{2,1} \ w_{2,2} \ \dots \ w_{2,n}]$$

5 \vdots

$$w_n = [w_{n,1} \ w_{n,2} \ \dots \ w_{n,n}]$$

wherein each vector w_i is a column vector using a 0/1 alphabet or, equivalently, a -1/+1 alphabet. Hereinbelow, a set of code vectors using the 0/1 alphabet is expressed as $W_{b,n}$ and a set using the -1/+1 alphabet is

10 expressed as W_n .

Since all vectors w in the set W are orthogonal to each other, the dot product of any two vectors in the set must be zero. This can be represented as:

$$(w_x, w_y) = 0$$

15 where x and y can have any values between 1 and n , $x \neq y$ and (w_x, w_y) is equal to:

$$\sum_{i=1}^n w_{x,i} w_{y,i}$$

Equivalently, the above can be expressed as the following matrix product:

$$w_x^T w_y = 0$$

20 Also:

$$w_x^T w_x = n$$

Representing the i th data symbol to be transmitted as d_i and the total number of transmit signals as k , the total transmission signal S transmitted by a base station to a mobile station is:

$$S = \sum_{i=1}^k d_i w_i$$

25 The mobile station receives the total transmission signal S and tries to eliminate all message signals except its own.

In order to eliminate the other messages the mobile station can multiply signal S by the transpose of its own Walsh code vector. An example wherein $i = 1$ is as follows:

30 $w_1^T S = w_1^T \sum_{i=1}^k d_i w_i$

$$= w_1^T \left(d_1 w_1 + \sum_{i=2}^k d_i w_i \right)$$

wherein the first term on the right side represents the wanted signal. The second term in the right side represents the interference from all of the remaining message signals mixed with their individual Walsh codes.

5 Solving this equation yields:

$$w_1^T S = nd_1 + 0 .$$

Thus, the separation of the transmitted message signals at the receiver depends on a zero correlation between the wanted signal and all of the other message signals.

10 In order to utilize communications systems as effectively as possible it is desirable to simultaneously transmit and separate as many message signals as possible. However, it is only possible to mix n message signals and separate them with zero interference because only n orthogonal vectors are available, as previously described. To overcome this limitation it is
 15 known to use quasi orthogonal functions. Quasi orthogonal vectors are vectors that are in addition to the n orthogonal vectors. Quasi orthogonal vectors have been selected from the remaining code vectors in the total binary 2^n vector space in order to provide as little interference as possible. Specifically, quasi orthogonal vectors are selected to provide a level of
 20 interference that is within acceptable limits, even though the level of interference is not zero.

In order to select quasi orthogonal vectors a computer search can be performed within the total 2^n vector space for binary (+1/-1 alphabet) masks. The masks can be applied to the orthogonal vectors to form a new set of
 25 vectors that are quasi orthogonal vectors. Applying a total of M masks to a set of Walsh code vectors w_n , the number of quasi orthogonal functions produced is: $(M + 1) n$. Applying a mask m to a code vector $w \in W_n$ includes a component by component multiplication of the mask m and the orthogonal code vector w to give the new code vector:

30 $w_m = w \bullet m$

The interference resulting from the use of the new code vectors can be tested and the code vectors that provide the lowest correlation can be selected to provide a set of quasi orthogonal vectors. A plurality of such masking functions can be found in order to provide a plurality of sets of quasi orthogonal vectors from a single set of orthogonal vectors. In order to permit message signals mixed with the quasi orthogonal vectors found by the computer search to be separated from each other, the quasi orthogonal vectors should be mutually orthogonal with respect to each other. There is a non-zero correlation between at least one code vector in the orthogonal set and one vector in the quasi orthogonal set.

Representing the quasi orthogonal vectors as v it can be shown that:

$$\frac{1}{n} \sum_{j=1}^n ((v, w_j)^2) = \frac{1}{n}$$

The goal in picking quasi orthogonal vectors v is to pick the vectors such that

$$\max_{1 \leq i \leq n} \{ |(v, w_i)| \}$$

is as small as possible.

Since their correlation is a useful measure of the amount of separation between vectors, the normalized correlation between two code vectors \underline{x} and \underline{y} can be defined as:

$$(\underline{x}, \underline{y}) = \frac{1}{n} \sum_{i=1}^n x_i y_i^*$$

The correlation between two orthogonal vectors is zero. A lower absolute value of correlation results in better separation between message signals mixed with the orthogonal vectors and the ones mixed with quasi orthogonal vectors. Better signal separation results in lower interference between the signals at the time of decoding.

The mean square correlation between orthogonal vectors and their corresponding quasi orthogonal vectors where n is a power of two is $1/n$. The lower bound on the absolute value of correlation can be shown to have the value, $1/\sqrt{n}$. This quantity is referred to as the Holtzman lower bound. Masks have been found that meet the lower bound for cases wherein n is an even power of two. However, in cases where n is an odd power of two

this bound has not been met with an equality. The lowest correlation found in the latter case is $\sqrt{2} / \sqrt{n}$. Therefore, the interference of the best quasi orthogonal vectors found in the odd power of two case using the computer search technique is $\sqrt{2}$ times the theoretical limit.

5 Thus it desirable to find additional quasi orthogonal vectors having lower correlation with the orthogonal vectors for the case wherein n is an odd power of two, in order to expand the capacity of communications systems while maintaining acceptably low amounts of interference.

10 SUMMARY OF THE INVENTION

A transmission method in a communications system has an orthogonal vector and a quasi orthogonal masking function for obtaining a quasi orthogonal vector from the orthogonal vector. Message signals are transmitted according to the quasi orthogonal vector. The method includes receiving the quasi orthogonal masking function and permuting the quasi orthogonal masking function to provide a further quasi orthogonal masking function. The further quasi orthogonal masking function is applied to the orthogonal vector to provide a further quasi orthogonal vector. The further quasi orthogonal vector is applied to the message signal to provide an encoded message signal for transmitting the encoded message signal within the communications system.

25 BRIEF DESCRIPTION OF THE DRAWINGS

The features, objects, and advantages of the present invention will become more apparent from the detailed description set forth below when taken in conjunction with the drawings in which like reference characters identify corresponding elements throughout and wherein:

30 Fig. 1 shows a block diagram representation of a permutation matrix algorithm suitable for use in the method of the present invention;

Fig. 2 shows a block diagram representation of the quasi orthogonal mask generation algorithm of the present invention;

Fig. 3 shows a block diagram representation of a method for mapping vectors that is suitable for use in the method of the present invention;

5 Fig. 4 is a block diagram representation of the quasi orthogonal mask generation algorithm of the present invention in a form suitable for use in the binary case;

Fig. 5 is a more detailed representation of a matrix generation step of one embodiment of the mask generation algorithm of Fig. 4;

10 Fig. 6 is a more detailed representation of the matrix generation step in another embodiment of the mask generation algorithm of Fig. 4.; and

Fig. 7 is a flow chart representation of a permutation that can be performed upon the quasi orthogonal vectors of the present invention.

15 DETAILED DESCRIPTION OF THE INVENTION

In the signal transmission method of the present invention, masks m are constructed and applied to orthogonal code vectors in order to provide quasi orthogonal code vectors, wherein the masks are four phase or
20 quaternary phase shift keying (QSPK) masks. Thus the masks m have an alphabet of four elements, $\{\pm 1, \pm j\}$, rather than two elements, where $j = \sqrt{-1}$ is the imaginary root of unity. It will be understood that the signal transmission method of the present invention can require two masks m when transmitting a message signal. One of the two masks can be used for
25 the in phase (I) channel and one can be used for the out of phase (Q) channel.

In order to practice the transmission method of the present invention, the new masks m can be generated using linear feedback shift registers (LFSR). A 2^k -ary LFSR sequence $s[t]$ is a sequence having symbols
30 $\{0, 1, \dots, 2^k-1\}$ where k is limited to the value 1 in the binary case and two in the quaternary case. The sequence satisfies a linear recurrence relationship of the form:

$$\sum_{i=0}^r c_i s(t+i) = 0 \pmod{2^k}, \forall t > 0$$

where $r \geq 1$ is the degree of the recursion. The coefficients c_i belong to the set $\{0, 1, \dots, 2^k-1\}$ and $c_r \neq 0$. This type of sequence $s[t]$ has a characteristic polynomial:

$$5 \quad c(x) = \sum_{i=0}^r c_i x^i$$

When $k = 1$, the sequence $s[t]$ is periodic with a period that is less than or equal to 2^r-1 . If the period of the sequence $s[t]$ reaches the maximum value 2^r-1 , the characteristic polynomial of $s[t]$ is defined as a primitive polynomial and the sequence $s[t]$ is an m -sequence. Sequences of this type
 10 are taught in S. W. Golomb, "Shift Register Sequences," Holden Day, San Francisco, CA, 1967.

A code matrix C' includes one period of an m - sequence and one period of each of its cyclic shifts. Thus, the size of the code matrix C' is 2^r-1 . The code matrix C' can be extended by appending a zero bit to each code
 15 word in matrix C' . The zero is appended at the same bit location of each code word. The inclusion of an all zero vector in this manner forms the code matrix C from the code matrix C' . The code matrix C has a length 2^r and a size 2^r . In one embodiment the code matrix C can be columnwise and rowwise permuted to create the Walsh code $W_{b,2^r}$ of size 2^r . However, it is
 20 sufficient to obtain permutation matrix P such that the set of row vectors of the matrix product CP are the same as the set of row vectors of $W_{b,2^r}$.

Referring now to Fig. 1, there is shown permutation matrix algorithm
 10 which is suitable for use in the present invention. In permutation matrix algorithm 10 a submatrix W of matrix $W_{b,2^r}$ is formed as shown in block 12.
 25 The submatrix W includes r rows having indices $1, 2, 4, \dots, 2^{r-1}$. Note that the indexing of $W_{b,2^r}$ is zero based and ranges from 0 to 2^r-1 . Matrix W therefore has r rows and 2^r columns. Every column of matrix W is distinct from all of the other columns.

A submatrix M of code matrix C is then formed as shown in block 14 of permutation matrix algorithm 10. Submatrix M has r rows and 2^r columns. In order to form submatrix M an intermediate submatrix M' having r rows and $2^r - 1$ columns is formed. Submatrix M' is formed by adding a column containing all zeros to submatrix M . The first row of submatrix M' can be any cyclic shift of the m - sequence used in constructing code C . The $r-1$ rows of submatrix M' following the first row are successive shifts by one time unit in each case beginning with the first row. Every column of submatrix M is distinct.

A permutation matrix P such that $MP = W$ is then determined as set forth in block 16 of permutation matrix algorithm 10. Permutation matrix P is the required output of algorithm 10. Because submatrices M and W have the same set of distinct columns the determination of P in this manner is straightforward. In an alternate embodiment of the invention permutation matrix P can be determined using a matrix computation technique. It will be understood by those skilled in the art that the rows of the matrix CP are the same as the rows of $W_{b,2^r}$.

When $k = 2$, and sequences therefore have a quaternary alphabet, a sequence known as Family A can be determined. The Family A sequence is taught, for example, in S. Boztas, P. V. Kumar, R. Hammons, "4-Phase Sequences with Near-Optimum Correlation Properties," IEEE Transactions on Information Theory, IT-38 No. 3 (May 1992), pp 1101-1113. In order to obtain a Family A sequence, let $c(y)$ be a binary primitive polynomial of degree r . A polynomial $g(x)$ having coefficients in the set $\{0, 1, 2, 3\}$ can be lifted from the polynomial $c(x)$ as follows:

$$g(x^2) = (-1)^r c(x)c(-x) \pmod{4}$$

Such a lift of the binary polynomial $c(x)$ to the quaternary polynomial $g(x)$ is a special case of the Hensel lift of polynomials. For example, see B, R, MacDonald, "Finite Rings with Identity," Marcel Dekker, Inc., New York, 1974. The LFSR sequence with the characteristic polynomial $g(x)$ is defined to be a Family A sequence. The sequence has a period $2^r - 1$.

Referring now to Fig. 2, there is shown quasi orthogonal mask generation algorithm 50. Quasi orthogonal mask generation algorithm 50 can be used to construct four-phase masks for forming quasi orthogonal vectors of length 2^r . In mask generation algorithm 50 a binary primitive
5 polynomial $c(x)$ of degree r is provided as shown in block 52. Using primitive polynomial $c(x)$ as its characteristic polynomial, a period of an m -sequence is constructed as shown in block 56.

Matrix M' having dimensions $(2^r-1) \times (2^r-1)$ is constructed as shown in block 58. The rows of matrix M' each contain a period of the m -sequence of
10 block 56 along with all of its cyclic shifts. Matrix M' is then extended to form matrix M as shown in block 62. The extension of matrix M' is performed by adding an all zero column and an all zero row to matrix M' . The dimensions of matrix M are therefore $2^r \times 2^r$. For convenience, the first column of matrix M can be the all zero column. As set forth in block 66 a
15 permutation P is found which column permutes the matrix M to contain the same row vectors as those contained in $W_{b,2^r}$. The permutation matrix method taught hereinabove, or any other method known to those skilled in the art, can be used to perform the operations of block 66.

A Hensel lift is then performed on the primitive polynomial $c(x)$
20 obtained in block 62 of mask generation algorithm 50 to provide the polynomial $g(x)$ as described hereinabove. The Hensel lift operation is shown in block 72. One period of the Family A sequences with the polynomial $g(x)$ as its characteristic polynomial is generated as shown in block 78. A sequence of the Family A sequences is selected. The selected
25 sequence can be any one of the Family A sequences having at least one symbol equal to one or three.

A vector N' of length (2^r-1) is constructed. The vector N' consists of a period of the Family A sequence selected according to block 78. A vector N of length 2^r is formed by appending a zero bit at the first bit location to vector
30 N' . As shown in block 70 the vector N is then column permuted using the permute P found in block 66. The resulting permuted code word can be

Thus, the maximum absolute correlation is $\frac{1}{8}\sqrt{2} = \frac{1}{\sqrt{n}}$ and the theoretical lower bound on the correlation set forth hereinabove is met with equality. Furthermore, the method of quasi orthogonal mask generation algorithm 50 can be generalized to all powers of two to yield the optimal quasi orthogonal vectors for each power of two. Table II sets forth the correlations and the number of masks provided according to the method of the present invention for several powers of two.

Length	Maximum Absolute Correlation With Walsh code	Correlation With Spectrum	Number Of Available Masks
32	0.177	$\left\{ \pm \frac{1}{8} \pm \frac{j}{8} \right\}$	31
64	0.125	$\left\{ \pm \frac{1}{8}, \pm \frac{j}{8} \right\}$	63
128	0.0833	$\left\{ \pm \frac{1}{16} \pm \frac{j}{16} \right\}$	127
256	0.0625	$\left\{ \pm \frac{1}{16}, \pm \frac{j}{16} \right\}$	255
512	0.0442	$\left\{ \pm \frac{1}{32} \pm \frac{j}{32} \right\}$	511

Table II

In addition to the four phase case described herein, the present invention provides for the construction and transmission of binary quasi orthogonal code vectors using masking functions obtained using the present invention. When the length of a masking function in the binary case is an even power of two the method of the present invention provides quasi orthogonal functions having the optimal correlation with the Walsh code. When the length of the masking function is an odd power of two, the correlation between any pair of sets is as least as good as the known results using binary alphabets.

It will be recalled that in a 2^k -ary linear feedback shift register $s[t]$ is a sequence with symbols $\{0, 1, \dots, 2^k-1\}$ that satisfies the relationship set forth hereinabove. Such a sequence $s[t]$ has a characteristic polynomial $c(x)$ that is defined as also set forth hereinabove. The method for forming binary quasi orthogonal vectors is restricted to the case corresponding to $k = 1$.

When $k = 1$ the sequence $s[t]$ is periodic with a period less than or equal to $2^r - 1$. If the period of the sequence $s[t]$ reaches the maximum value $2^r - 1$ the characteristic polynomial of $s[t]$ can be defined as a binary primitive polynomial. In this case the sequence $s[t]$ is defined as an m -sequence.

5 A code matrix C' can be defined to consist of one period of an m -sequence $m1$ with characteristic polynomial $c(x)$ and one period of all of the cyclic shifts of the m -sequence $m1$. Thus the size of the code matrix C' is $2^r - 1$. The code matrix C' can be extended by appending a zero bit to each code word within matrix C' at the same bit location of each code word. In the
10 preferred embodiment, the appended zero bits can be placed at the first bit location of each code word within matrix C .

When the all zeros vector is applied to code matrix C' in this manner, code matrix C is formed. Code matrix C has a size of $2^r \times 2^r$. Code matrix C can be columnwise and rowwise permuted to form the Walsh code $W_{b,2^r}$ and
15 a record of the permutation operations required to form $W_{b,2^r}$ can be made. However, in the method of the present invention the permutation matrix P can be applied to form the product CP and obtain the same vectors as the set of row vectors of $W_{b,2^r}$.

Referring now to Fig. 4, there is shown binary quasi orthogonal mask
20 generation algorithm 120. Binary quasi orthogonal mask generation algorithm 120 can be used to construct two phase masks for forming quasi orthogonal vectors of length 2^r . In mask generation algorithm 120 a binary primitive polynomial $c(x)$ of degree r is provided as shown in block 122. Using primitive polynomial $c(x)$ as its characteristic polynomial, a period of
25 an m -sequence is constructed as shown in block 126.

Matrix M' having dimensions $(2^r - 1) \times (2^r - 1)$ is constructed as shown in block 128. The rows of matrix M' each contain a period of the m -sequence of block 126 along with all of the cyclic shifts of the m -sequence. Matrix M' is then extended to form matrix M as shown in block 132. The
30 extension of matrix M' is performed by adding an all zero column and an all

zero row to the matrix M' . The dimensions of matrix M are therefore $2^r \times 2^r$. In the preferred embodiment, the first column of the matrix M can be the all zero column. As set forth in block 136 a permutation P is found that column permutes the matrix M to contain the same row vectors as those
 5 contained in $W_{b,2^r}$ and a record of the required permutation operations can be made.

The permutation matrix method taught hereinabove, or any other method known to those skilled in the art, can be used to perform the operations of block 136. A code matrix C_G or a code matrix C_K is then formed
 10 as shown in block 142 of binary quasi orthogonal mask generation algorithm 120. The code matrix C_G is formed in cases where the degree of the primitive polynomial r is odd and the code matrix C_K is formed when r is even.

Referring now to Fig. 5, there is shown a more detailed representation of block 142 in the case where r is odd. A sequence $m2$ that forms a
 15 preferred pair with the m - sequence $m1$ is obtained as shown in block 160. A preferred pair of m -sequences is a pair of m -sequences having a period $2^m - 1$. The preferred pair has the preferred three-valued cross correlation function $\{-1 \pm 2^{\frac{m+1}{2}}, -1\}$ when m is odd. The construction of preferred pairs of m -sequences is taught, for example, by D. Sarwate and M. Pursley,
 20 "Crosscorrelation Properties of Pseudorandom and Related Sequences," Proceedings of the IEEE, pp. 593-620, May 1980. The sequence $m2$ has a period $2^r - 1$.

The code matrix C'_G is then formed from the sequence $m2$ as shown in block 168. It is a matrix having one period of each of the m -sequence $m2$
 25 and all of its distinct cyclic shifts. The number of rows in matrix C'_G is $2^r - 1$ and the number of columns is $2^r - 1$. The code matrix C_G is formed from the code matrix C'_G by extending the matrix C'_G as shown in block 172. The extension of the matrix C'_G can be performed by appending a zero bit at the same bit location of each code word in the matrix C'_G . The bit location used
 30 for appending the zero can be the first bit location in the preferred

embodiment. The number of rows in code matrix C_G is 2^r-1 and the number of columns is 2^r .

Referring now to Fig. 6, there is shown a more detailed representation of block 142 of binary quasi orthogonal mask generation algorithm 120 in the case wherein the degree of the primitive polynomial r is even. In block 5 180 of Fig. 6 a code matrix C is obtained as previously described. The code matrix C is then decimated by a factor of $1 + 2^{r/2}$. The sequence $m3$ is the m -sequence obtained from the m -sequence $m1$ by decimating the sequence $m1$ by a factor $1 + 2^{r/2}$. The sequence $m3$ has a period of $2^{r/2}-1$.

10 In the decimation process of block 184 predetermined columns of C are selected and the remaining columns are not selected as follows. Let C_0 be the all zeros column of C . If C_i is the i th column of code matrix C and $C_{K,i}$ is the i th column of code matrix C formed by decimating the code matrix C then:

$$\begin{aligned}
 C_{K,1} &= C_1 \\
 C_{K,2} &= C_{1+2^{r/2}} \\
 15 \quad C_{K,3} &= C_{2(1+2^{r/2})} \\
 C_{K,j} &= C_{(j-1)(1+2^{r/2})} \\
 &\cdot \\
 &\cdot \\
 &\cdot \\
 C_{K,2^{r/2}} &= C_{(2^{r/2}-1)(1+2^{r/2})}
 \end{aligned}$$

20 This decimation operation is an operation $C_K, 2^{r/2-1}$, that is known in the art.

A code matrix C_K' is formed as shown in block 188. The formation of the matrix C_K' is begun by inserting one period of length $2^{r/2}-1$ of the $m3$ sequence and all its distinct cyclic shifts. This forms the first $2^{r/2}-1$ columns of code matrix C_K' . The first $2^{r/2}-1$ columns are then repeated $2^{r/2}+1$ times as shown in block 192. A code matrix C_K can then be obtained by appending a zero bit at the first location of each code word in the preferred embodiment within the matrix C_K' as shown in block 200. The size of the code matrix C_K

can be $2^{r/2} - 1$ wherein the size is understood to indicate the number of row vectors.

Thus, using the method of the present invention it is possible to construct quasi orthogonal functions for all powers of two in the binary case wherein $k = 1$. Additionally, the method of the present invention can provide many more masking functions than were available in the prior art. The number of masking functions obtained using binary quasi orthogonal mask generation algorithm 120 for some exemplary values of length n are set forth in Table III along with the maximum absolute correlation with the Walsh code and the correlation spectrum.

Length	Maximum Absolute Correlation With Walsh code	Correlation Spectrum	Number Of Available Masks
32	0.25	$\{0, \pm \frac{1}{4}\}$	31
64	0.125	$\{\pm \frac{1}{8}\}$	7
128	0.125	$\{0, \pm \frac{1}{8}\}$	127
256	0.0625	$\{\pm \frac{1}{16}\}$	15
512	0.0625	$\{0, \pm \frac{1}{16}\}$	511

Table III

Returning now to Fig. 4, execution of binary mask generation algorithm 120 proceeds from block 142, which is described in more detail in Figs. 5 and 6. In block 148 of mask generation algorithm 120 a row vector \underline{f} of either code matrix C_C or code matrix C_K is selected. The permutation P determined herein is then applied to the row vector \underline{f} as shown in block 140. As set forth in block 154, and previously described herein, a mask can be provided according to the permutation. The mask can be applied to orthogonal vectors to provide quasi orthogonal vectors.

A lower bound on the minimum correlation between a quasi orthogonal function set and the set of Walsh codes is known as previously

described . Furthermore, the minimum correlation has been attained for all code lengths that are a power of two as also described above. Additionally, the constructions of the four phase symbols, the constellation alphabet, is known in the set $\{+l, -l, +j, -j\}$. However, the masking functions obtained are not necessarily optimized for some specific cases, such as some higher data rate cases. For example, in the so called fat-pipe environment where data rates are increased by giving the user two Walsh codes of length $n/2$ rather than the original Walsh code of length n some of the masking functions are not optimum. In this case the correlation of some subblocks of the quasi orthogonal functions with the corresponding shorter length Walsh code can be suboptimal. Thus, further permuting steps are set forth that can be applied to the masking functions obtained above. With appropriate permutations, new masking functions can be obtained that are optimal in the case where the user is given two $n/2$ codes.

Let n be the length of any code vector in a Walsh code wherein n is an integer power of two. A vector $v = (v_1, \dots, v_n)$ is a unit vector if:

$$\frac{1}{n} \sum_{i=1}^n v_i^2 = 1$$

The maximum absolute correlation satisfies the following lower bound:

$$\max \left\{ \left| \left(\underline{v}, \underline{w}_i \right) \right| : \underline{w}_i \in W_n \right\} \geq \frac{1}{\sqrt{n}}$$

where W_n is the Walsh code of length n and the vector v has symbols that are complex roots of unity. Four phase masks that meet the above bound with equality have been obtained, thus proving the sharpness of the above bound.

For any two non-negative integers $i, k, 0 \leq i < k \leq n$, let $v_{i,k} = [v_i, v_{i+1}, \dots, v_k]$. Furthermore, let $n_1 \leq n$, be an integer power of two and let j be a positive integer such that $j \cdot n_1 \leq n$. The objective is to obtain the mask \underline{v} of length n such that, for every such integer n_1, j , the following is satisfied:

$$\max \left\{ \left| \left(\underline{v}_{(j-1)n_1+1:jn_1}, \underline{w}_i \right) \right| : \underline{w}_i \in W_{n_1} \right\} = \frac{1}{\sqrt{n_1}}$$

Referring now to Fig 7, there is shown mask generation algorithm 220, the masking functions obtained above can be further permuted in to

preserve their optimal correlation with the Walsh code of same length. For example, any permutation within the automorphism group of the first order Reed-Muller codes of the same length can be applied to the masking function that leaves the correlation with the Walsh code of same length
5 unchanged. These permutations can also be applied systematically to obtain permuted masking functions optimal for fat pipe transmission in the sense of the latter equation.

Consider a segment referred to as block b having a length L chips as shown in block 224. The length of L is an integer power of two. Obtain a
10 reflection block b_R of block b as shown in block 228. The block b its first chip at chip location k . The block b_R is a reflection of the block b about an integer point, where $L \leq x < n$, if the block b_R has length L chips, and the first chip of b_R is at the chip location $x+k$. While any kind of permutation known to those skilled in the art can be used one very useful permutation is one that
15 leaves the correlation with the Walsh code of same length unchanged. This permutation is obtained by swapping subblocks of length L chips, where L is an integer power of 2, by their reflections w.r.t. around the center point as shown in block 232. It will be understood that reflections around other points can also be used.

20 In one embodiment of the invention a complex quasi orthogonal function mask of a required length is constructed using the methods taught herein. For optimization in the shorter Walsh code case, subblocks of length two can be optimized. Procedures for performing this optimization include swapping symbols as previously described. Subblocks of length two
25 obtained previously are swapped to provide subblocks of length four. The subblocks with length four are obtained to provide optimal correlation with the corresponding Walsh code of length four. This process is continued recursively, so that at step $k+1$, sub-blocks of length 2^k with optimal correlation with the Walsh code of length 2^k are obtained as shown in block
30 236. Up to $\log_2 n$ steps can be required in order to obtain the fatpipe optimal quasi orthogonal functions.

Using these steps, it is thus possible to obtain fat-pipe optimal quasi orthogonal functions. These steps were carried out on two examples to

provide masking functions of length 128. The following are the two resulting quasi orthogonal function's which are fat-pipe optimal. In this improvement the correlation of every subblock of the quasi orthogonal function with the corresponding shorter length Walsh code is optimal. Two examples of optimal masking functions of length 128 are provided in Table IV. The correlation results for a number of values of n are shown in Table V.

[1j1-j1j-1j1j1-j-1-j1-j1j1-j1j-1j-1-j-1j1j-1j1j1-j-1-j1-j1j1-j 1j-1j1j1-j-1-j1-j-1-j-1j-1-j-1j1j-1j1j1-j1j-1j-1-j-1j1j-1j1j1-j- 1-j1-j1j1-j1j-1j-1-j-1j1j-1-j-1-j1j1-j-1-j-1j-1-j-1-j-1-j-1j]
[1jj-1-j11j-1-j-j1-j11j-j1-1-j1j-j1-j1-1-j-1-jj-1j11-j-1jj1-j-1 -1j-1jj11-jj1-j-11-j1-jj1j1j-1j-j11j1jj-1j-1-1-j1jj-11j-j1-j1 -1-j1j-j1j-11j1-j-j-1-j-1-1j-1jj1-j-1-1jj1-1j-1j-j-1j1-1j1-jj1]

Table IV

10

QOF Length	Walsh Code Length					
	256	128	64	32	16	8
256	0.0625	0.0883	0.125	0.177	0.25	0.35
128		0.0883	0.125	0.177	0.25	0.35
64			0.125	0.177	0.25	0.35
32				0.177	0.25	0.35

Table V

The previous description of the preferred embodiments is provided to enable any person skilled in the art to make or use the present invention. The various modifications to these embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments without the use of the inventive faculty. Thus, the present invention is not intended to be limited to the embodiments shown herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein. Furthermore, it will be understood that the permutation method set forth herein is not limited to use in forming two phase and four phase quasi orthogonal

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vectors. Rather, it can be used as part of any method or apparatus for forming any kind of encoded message signal for any kind of signal transmitted within a communications system.

CLAIMS

1. A transmission method in a communications system having
2 an orthogonal vector and a quasi orthogonal masking function
 for obtaining a quasi orthogonal vector from the orthogonal
4 vector and transmitting message signals according to the quasi
 orthogonal vector, comprising the steps of:
6 (a) receiving the quasi orthogonal masking function;
 (b) permuting the quasi orthogonal masking function
8 to provide a further quasi orthogonal masking function;
 (c) applying the further quasi orthogonal masking
10 function to the orthogonal vector to provide a further
 quasi orthogonal vector; and
12 (d) applying the further quasi orthogonal vector to the
 message signal to provide an encoded message signal for
14 transmitting the encoded message signal within the
 communications system.

2. The transmission method of claim 1, wherein step (b)
2 comprises reflecting the quasi orthogonal masking function.

3. The transmission method of claim 2, comprising the step of
2 determining a first block within the quasi orthogonal masking
 function.

4. The transmission method of claim 3, wherein the first block
2 has a length equal to an integer power of two.

5. The transmission method of claim 3, comprising the step of
2 determining a second block within the quasi orthogonal
 masking function.

6. The transmission method of claim 5, comprising the step of changing the
2 position of at least one of the first and second blocks within the quasi
orthogonal masking function.
7. The transmission method of claim 6, comprising the step of swapping
2 the positions of the first and second blocks within the quasi orthogonal
masking function.
8. The transmission method of claim 7, wherein the first and
2 second blocks have an initial size, comprising the steps of;
- 4 (a) determining the correlation with the orthogonal
vector of the quasi orthogonal vector obtained with the
further quasi orthogonal masking function;
 - 6 (b) determining further blocks having a length larger
than the initial length according to the correlation; and
 - 8 (c) swapping the positions of the further blocks
within the quasi orthogonal masking function.
9. The transmission method of claim 8, comprising the step of
2 recursively swapping bigger blocks to optimize the correlation.
10. The transmission method of claim 8, comprising the step of
2 determining the first and second blocks according to their
positions relative to a predetermined point within the quasi
4 orthogonal masking function.
11. The transmission method of claim 10, wherein the length of
2 the quasi orthogonal masking function is n and the
predetermined point is located at $n/2$.
12. The transmission method of claim 1, wherein the quasi
2 orthogonal vector and the further quasi orthogonal have the
same correlation with the orthogonal vector.

13. The transmission method of claim 1, comprising the steps of;
2 (a) determining a segment having a length L ;
(b) determining a block having a first chip at location k ;
4 (c) forming a block b_R that us a reflection of block b having
a first chip at location $x+k$ where $L \leq x < n$.
14. The transmission method of claim 7, comprising the step of forming
2 a first vector matrix using a first series of cyclic shifts of a sequence having a
characteristic polynomial wherein the characteristic polynomial of the
4 sequence is a primitive polynomial.
15. The transmission method of claim 14, comprising the step of
2 forming a second vector matrix using a second series of cyclic
shifts.
16. The transmission method of claim 15, comprising the steps of:
2 (a) permuting the first vector matrix to provide the
orthogonal vector;
4 (b) determining the permuting operations; and
(c) applying the determined permuting operations to the
6 second matrix to provide the further quasi orthogonal
code vector.
17. The transmission method of claim 14, wherein the primitive
2 polynomial has a *degree* r that is odd and the sequence is an
 m -sequence, comprising the step of obtaining a preferred m -
4 sequence $m1$.
18. The transmission method of claim 17, wherein a matrix C_G is
2 obtained and decimated to form the sequence $m2$.

19. The transmission method of claim 18, wherein the decimation
2 has a decimation factor of $1+2^{r/2}$.
20. The transmission method of claim 18, wherein the sequence
2 m_2 has a period $2^{r/2}-1$.
21. The transmission method of claim 14, wherein r is even
2 comprising the step of forming a matrix C'_k including the
sequence m_2 .
22. The transmission method of claim 21, comprising the steps of
2 including a plurality of repetitions of the sequence m_2 within
the matrix C'_k and extending the matrix C'_k to form the second
4 vector matrix.
23. The transmission method of claim 7, wherein the quasi
2 orthogonal vector is a binary vector.
24. The transmission method of claim 7, wherein the quasi
2 orthogonal vector is a four phase vector.
25. The transmission method of claim 24, comprising the step of
2 determining a permutation matrix P such that $MP=W$.
26. The transmission method of claim 25, wherein r is odd and
2 the sequence is an m -sequence comprising the step of obtaining
a preferred m -sequence m_1 .
27. The transmission method of claim 26, comprising the step of
2 obtaining a sequence m_2 that forms a preferred pair with the
 m -sequence m_1 by extending sequence m_1 .

28. The transmission method of claim 27, comprising the step of
2 forming a matrix C'_k including a plurality of repetitions of the
sequence m_2 .
29. The transmission method of claim 14, wherein:
2 (a) the characteristic polynomial is a binary polynomial; and
4 (b) the method further comprises the step of lifting the binary
polynomial to a quaternary polynomial.
30. The transmission method of claim 29, comprising the step of
2 forming a sequence having the quaternary polynomial as its
characteristic polynomial whereby the sequence thus formed is
4 a Family A sequence.
31. The transmission method of claim 30, comprising the step of
2 forming a second matrix according to the Family A sequence.
32. A communications system having an orthogonal vector and a
2 quasi orthogonal masking function for obtaining a quasi
orthogonal vector from the orthogonal vector and transmitting
4 message signals according to the quasi orthogonal vector,
comprising:
6 (a) a further quasi orthogonal masking function
provided by permuting the quasi orthogonal masking
8 function;
10 (b) a further quasi orthogonal vector provided by
applying the further quasi orthogonal masking function
to the orthogonal vector; and
12 (c) an encoded message signal for transmitting the
encoded message signal within the communications
14 system provided by applying the further quasi
orthogonal vector to the message signal.

33. A communications system having an orthogonal vector and a
2 quasi orthogonal masking function for obtaining a quasi
orthogonal vector from the orthogonal vector and transmitting
4 message signals according to the quasi orthogonal vector,
comprising the steps of:

6 (a) means for receiving the quasi orthogonal masking
function;

8 (b) means for permuting the quasi orthogonal
masking function to provide a further quasi orthogonal
10 masking function;

12 (c) means for applying the further quasi orthogonal
masking function to the orthogonal vector to provide a
further quasi orthogonal vector; and

14 (d) applying the further quasi orthogonal vector to
the message signal to provide an encoded message signal
16 for transmitting the encoded message signal within the
communications system.

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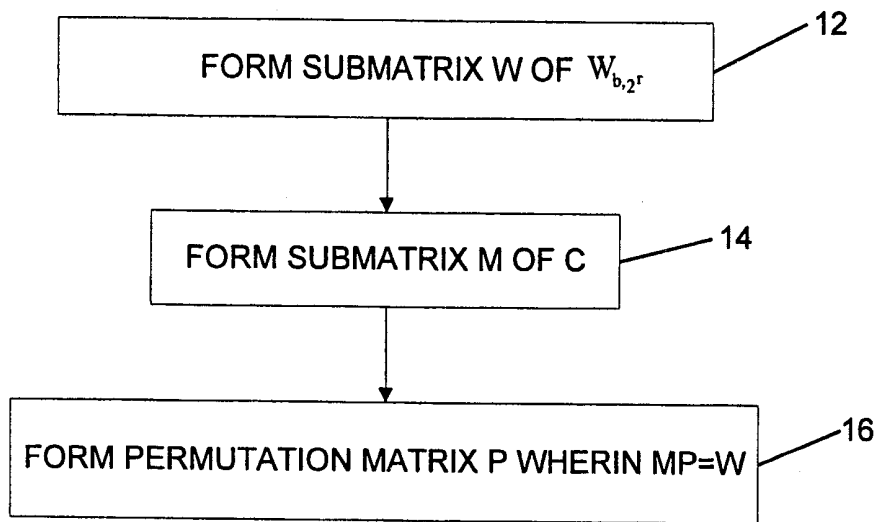


FIG. 1

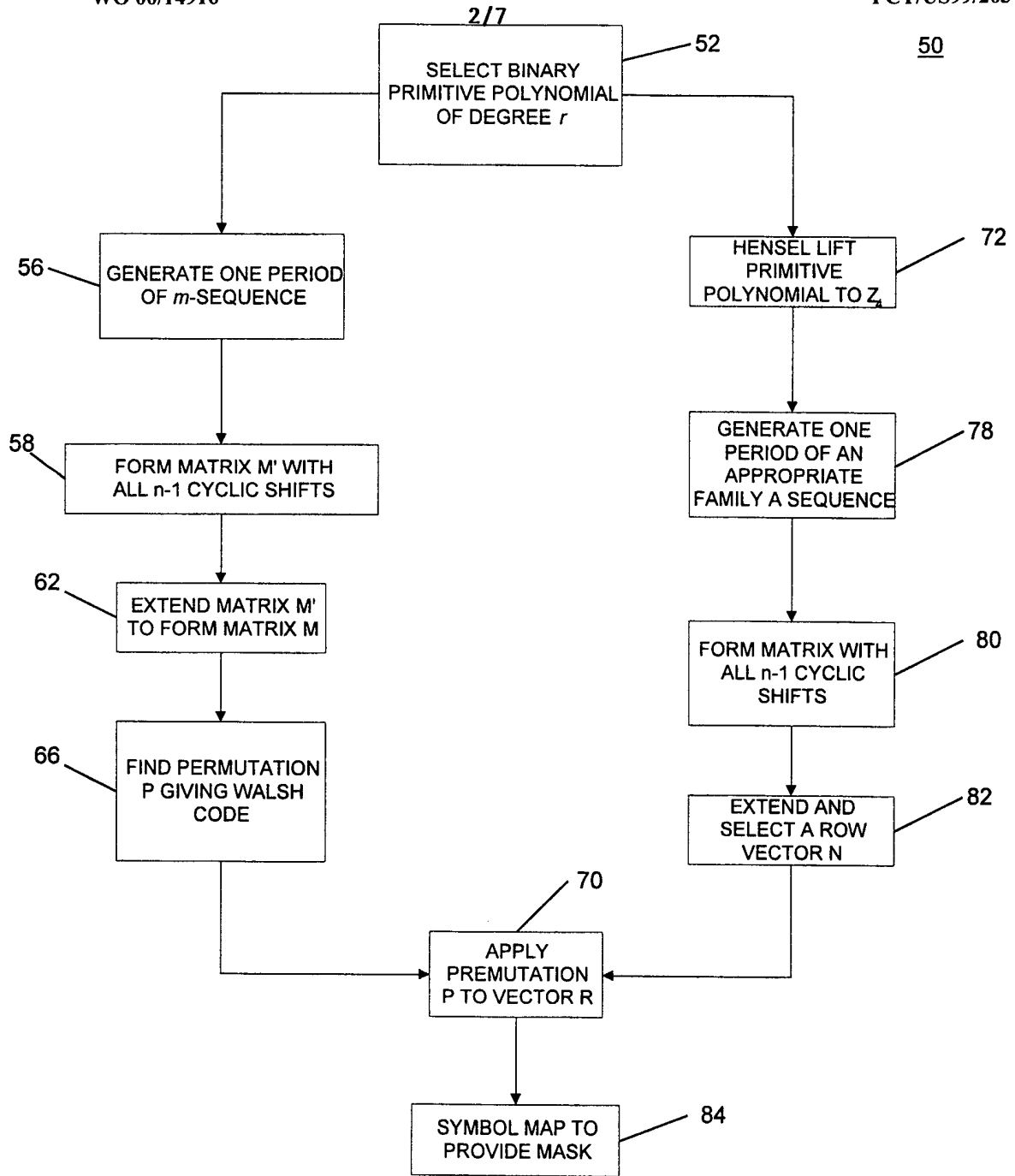


FIG. 2

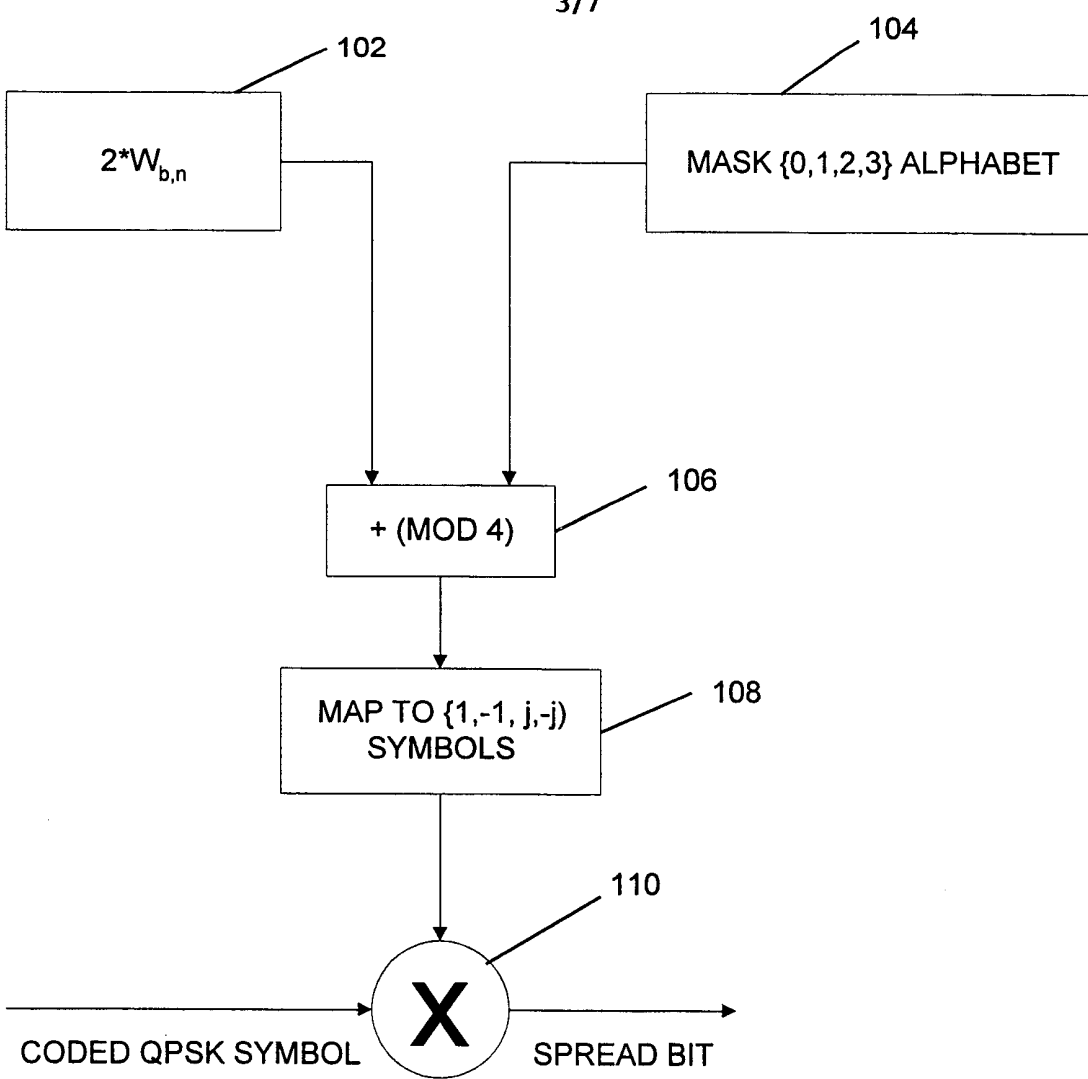


FIG. 3

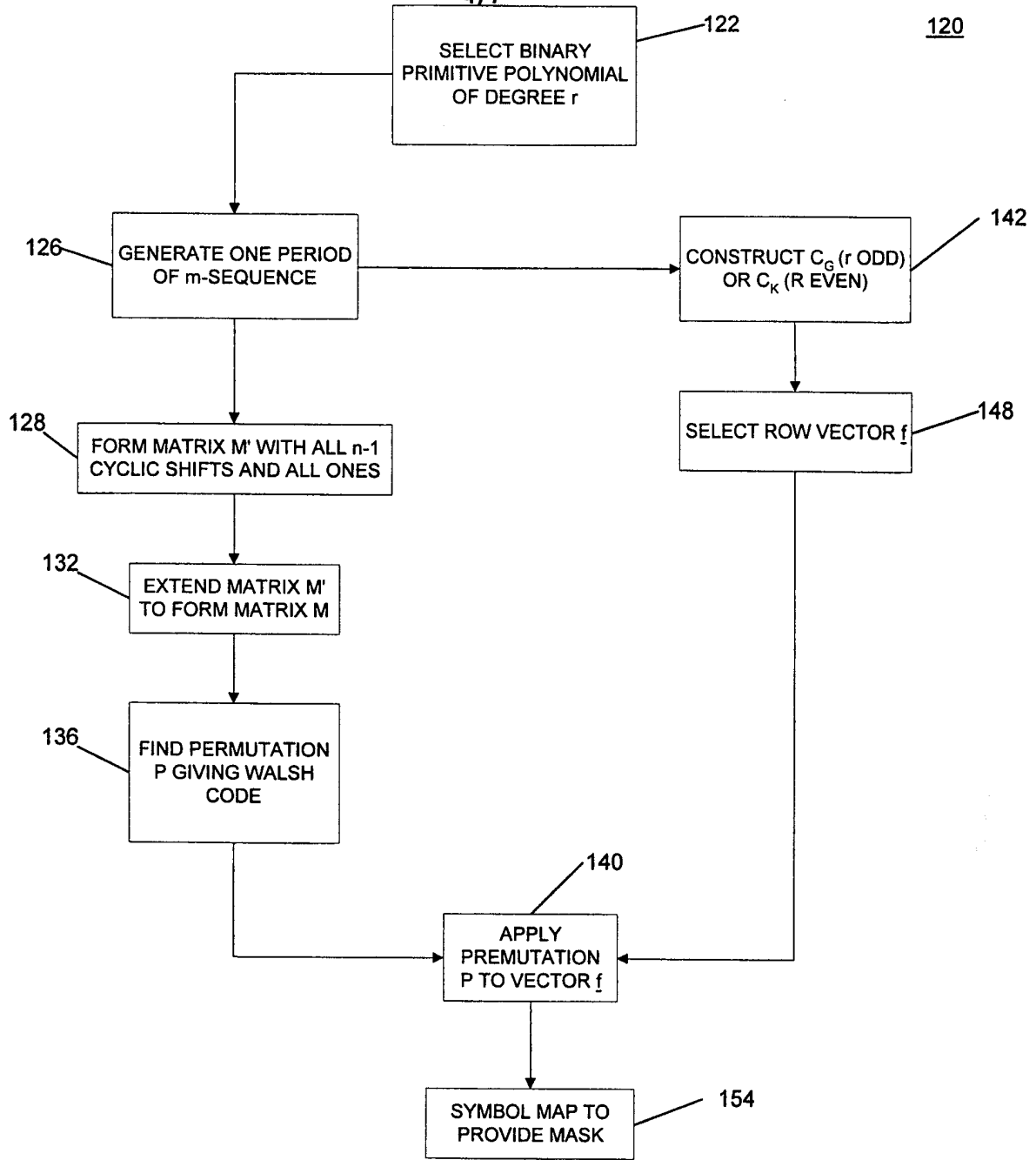


FIG. 4

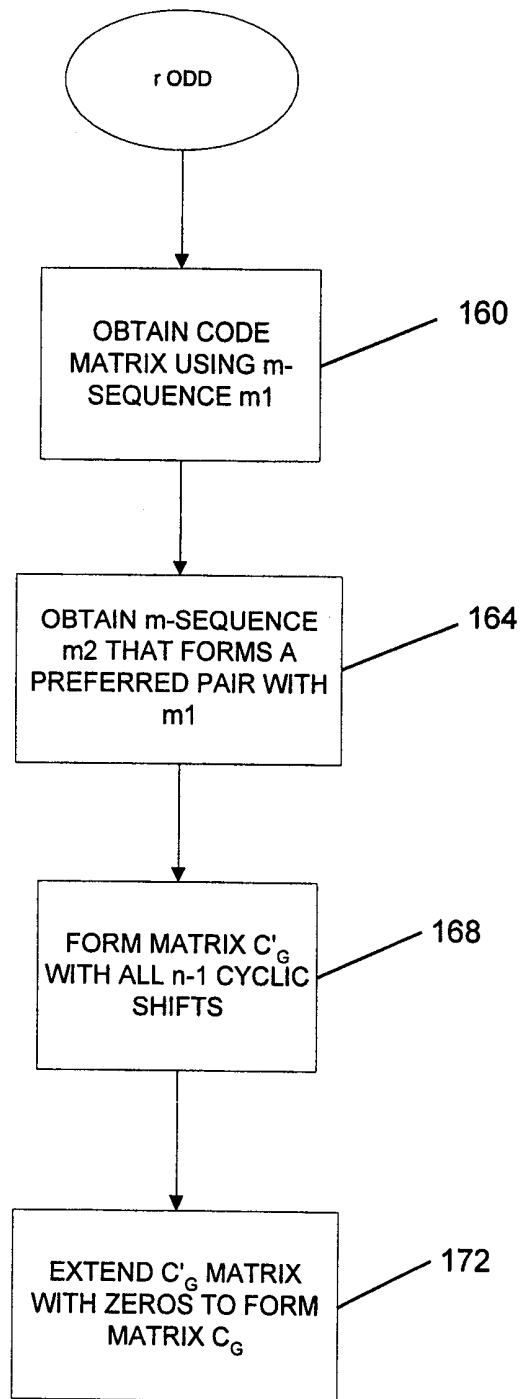


FIG. 5

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142

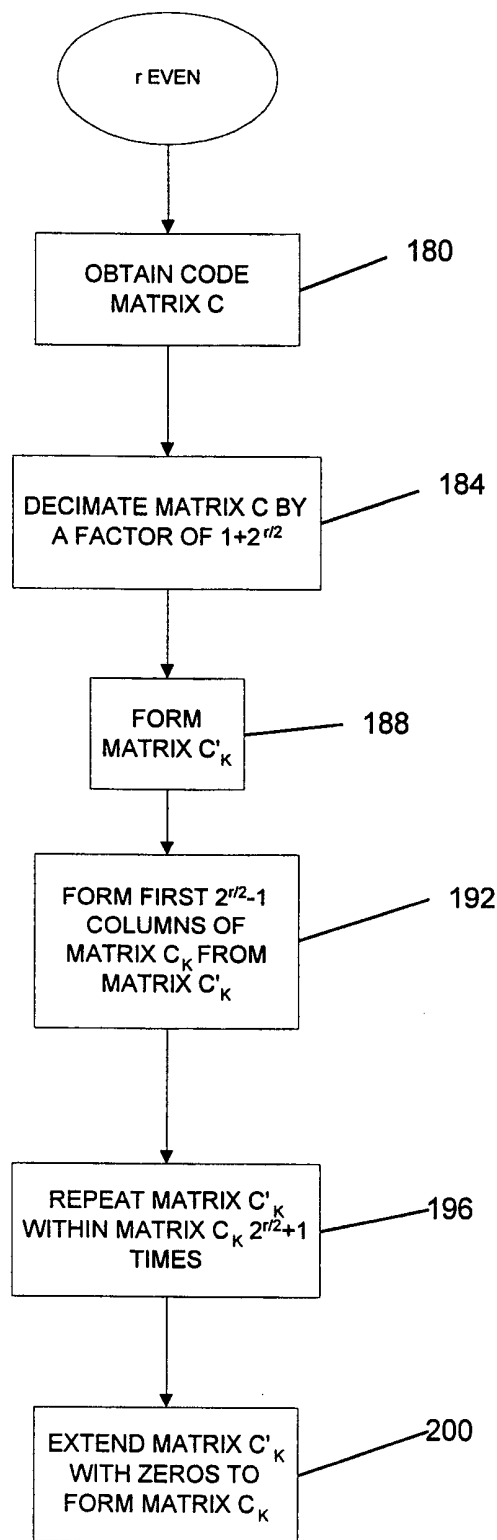


FIG. 6

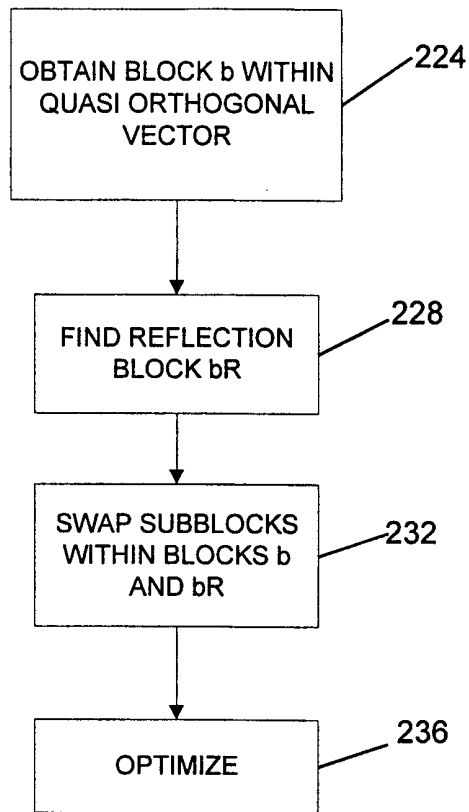


FIG. 7

INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 99/20340

A. CLASSIFICATION OF SUBJECT MATTER
 IPC 7 H04J13/02 H04J11/00

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 H04J

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 96 05668 A (ERICSSON GE MOBILE INC) 22 February 1996 (1996-02-22) abstract page 4, line 12 -page 6, line 2 page 10, line 4 -page 12, line 28	1, 32, 33
A	US 5 535 239 A (JOU YU-CHEUN ET AL) 9 July 1996 (1996-07-09) abstract column 13, line 22 -column 14, line 22 -/-	1, 32, 33

Further documents are listed in the continuation of box C.

Patent family members are listed in annex.

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Date of the actual completion of the International search

8 February 2000

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INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 99/20340

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<p>GOLOMB S W: "SHIFT-REGISTER SEQUENCES AND SPREAD-SPECTRUM COMMUNICATIONS" PROCEEDINGS OF IEEE 3RD INTERNATIONAL SYMPOSIUM ON SPREAD SPECTRUM TECHNIQUES AND APPLICATIONS (ISSSTA'94), vol. 1, 4 - 6 July 1994, pages 14-15, XP002123602 OULU, FINLAND the whole document</p>	1, 32, 33
A	<p>SARWATE D V ET AL: "CROSSCORRELATION PROPERTIES OF PSEUDORANDOM AND RELATED SEQUENCES" PROCEEDINGS OF THE IEEE, vol. 68, no. 5, May 1980 (1980-05), pages 593-619, XP000857081 USA cited in the application abstract</p>	1, 32, 33

INTERNATIONAL SEARCH REPORT

Information on patent family members

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