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(54) **Title**: CHANNEL CODING USING CODES WITH LOW CORRELATION FOR NON-COHERENT RECEIVERS

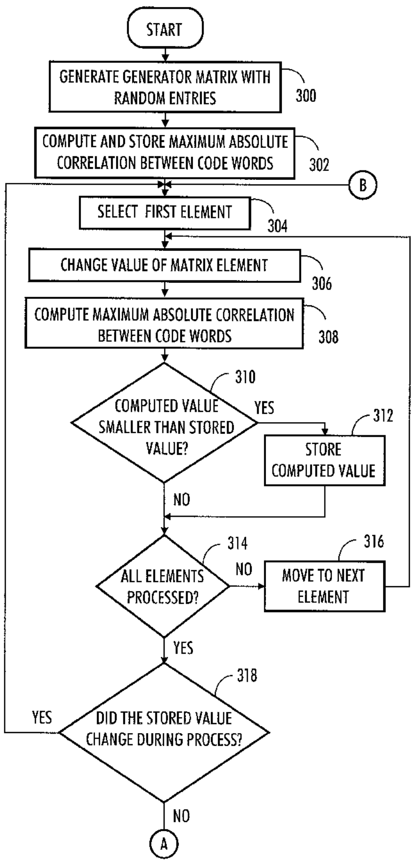

FIG. 3

(57) Abstract: According to an embodiment of the present invention, an apparatus is configured to encode a signal comprising data bits with a channel code defined by a k x n generator matrix whose elements are defined by minimizing the absolute value of the maximum correlation between the code words generated by the generator matrix, where n is an integer depicting the length of a codeword and k is an integer depicting the number of data bits to be coded using each code word of the code; modulate the encoded signal with a phase- or amplitude-based modulation; and transmit the encoded signal.

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CHANNEL CODING USING CODES WITH LOW CORRELATION FOR NON-COHERENT RECEIVERS

FIELD OF THE INVENTION

The exemplary embodiments of this invention relate generally to data transmission and channel coding.

BACKGROUND ART

The following description of background art may include insights, discoveries, understandings, or disclosures, or associations together with disclosures not known to the relevant art prior to the present invention but provided by the invention. Some such contributions of the invention may be specifically pointed out below, whereas other such contributions of the invention will be apparent from their context.

In data links, the transmission path used for transmitting signals is known to cause interference on telecommunication. This occurs regardless of the physical form of the transmission path, i.e., whether the path is a radio link, an optical fibre, or a copper cable. Another main cause for errors in communication is thermal noise.

In order to diminish the effects of thermal noise and interference caused by the transmission path, a digital signal is encoded so that the connection could be made more reliable. In such a case, the errors in the signal to be transmitted caused by the interference and thermal noise can be detected and also corrected without retransmission, depending on the encoding method used.

SUMMARY

The following presents a simplified summary of the invention in order to provide a basic understanding of some aspects of the invention. This summary is not an extensive overview of the invention. It is not intended to identify key/critical elements of the invention or to delineate the scope of the invention. Its sole purpose is to present some concepts of the invention in a simplified form as a prelude to the more detailed description that is presented later.

An aspect of the invention relates to an apparatus, comprising a processor configured to generate a k x n generator matrix for a code by minimizing the absolute value of the maximum correlation between the code words generated by the generator matrix, where n is an integer depicting the length of a codeword and k is an integer depicting the number of data bits to be coded using each code word of the code.

The apparatus may be configured to generate a k x n generator matrix with random entries of 0 and 1; compute and store the maximum absolute correlation between code words generated by the matrix; perform the following three steps a), b) and c) for each element of the generator matrix: a) change the value of an element of the matrix; b) compute the maximum absolute correlation between code words generated by the matrix; c) compare the computed value to the stored value and if the computed value is smaller, store the computed value.

An aspect of the invention relates to an apparatus configured to encode a signal comprising data bits with a channel code defined by a k x n generator matrix whose elements are defined by minimizing the absolute value of the maximum correlation between the code words generated by the generator matrix, where n is an integer depicting the length of a codeword and k is an integer depicting the number of data bits to be coded using each code word of the code; modulate the encoded signal with a phase- or amplitude-based modulation; and transmit the encoded signal.

An aspect of the invention relates to an apparatus comprising means for encoding a signal comprising data bits with a channel code defined by a k x n generator matrix whose elements are defined by minimizing the absolute value of the maximum correlation between the code words generated by the generator matrix, where n is an integer depicting the length of a codeword and k is an integer depicting the number of data bits to be coded using each code word of the code; means for modulating the encoded signal with a phase- or amplitude-based modulation; and means for transmitting the encoded signal.

An aspect of the invention relates to a method comprising performing the following acts by an electronic data processing system: generating a k x n generator matrix for a code by minimizing the absolute value of the maximum correlation between the code words generated by the generator matrix, where n is an integer depicting the length of a codeword and k is an integer depicting the number of data bits to be coded using each code word of the code.

A further aspect of the invention relates to an apparatus comprising at least one demodulator demodulating a phase- or amplitude-modulated signal, at least one decoder calculating correlations between the received codeword and the known code words, at least one calculator determining the absolute value of the correlation result obtained by a decoder, and a selector for deciding the received code word.

A further aspect of the invention relates to an apparatus comprising means for demodulating a phase- or amplitude-modulated signal, means for calculating correlations between the received codeword and the known code words, means for determining the absolute value of the correlation result obtained by a decoder, and means for deciding the received code word.

A further aspect of the invention relates to an article of manufacture comprising a computer readable medium and embodying program instructions executable by a computer operably coupled to a memory which, when executed by the computer, carry out the functions of: generating a k x n generator matrix for a code by minimizing the absolute value of the maximum correlation between the code words generated by the generator matrix, where n is an integer depicting the length of a codeword and k is an integer depicting the number of data bits to be coded using each code word of the code.

A still further aspect of the invention relates to a computer program comprising program code means adapted to perform any of steps of the method according to any embodiment of the invention when the program is run on a computer or a processor.

Although the various aspects, embodiments, and features of the invention are recited independently, it should be appreciated that all combinations of the various aspects, embodiments, and features of the invention are possible and within the scope of the present invention as claimed.

BRIEF DESCRIPTION OF THE DRAWINGS

In the following the invention will be described in greater detail by means of exemplary embodiments with reference to the attached drawings, in which

Figure 1 shows a simplified block diagram illustrating exemplary system architecture

Figure 2 illustrates an example of an apparatus according to an embodiment of the invention;

Figures 3 and 4 are flowcharts illustrating exemplary embodiments of the invention;

Figure 5 illustrates an example of an apparatus according to an embodiment of the invention;

Figures 6A, 6B, and 6C illustrate further examples of an apparatus according to an embodiment of the invention;

Figure 7 is a flowchart illustrating an exemplary embodiment of the invention; and

Figure 8 illustrates the bit error rates of different codes.

DETAILED DESCRIPTION OF SOME EMBODIMENTS

Exemplary embodiments of the present invention will now be described in greater detail hereinafter with reference to the accompanying drawings in which some but not all embodiments of the invention are shown. Indeed, the invention may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will satisfy applicable legal requirements. Although the specification may refer to “an”, “one”, or “some” embodiment(s) in several locations, this does not necessarily mean that each such reference is to the same embodiment(s), or that the feature only applies to a single embodiment. Single features of different embodiments may also be combined to provide other embodiments. Like reference numerals refer to like elements throughout.

Embodiments of present invention are applicable to any user terminal, server, corresponding component, and/or to any communication system or any combination of different communication systems. The communication system may be a wireless communication system or a communication system utilizing both fixed networks and wireless networks. The protocols used and the specifications of communication systems, servers and user terminals, especially in wireless communication, develop rapidly. Such development may require extra changes to an embodiment. Therefore, all words and expressions should be interpreted broadly and are intended to illustrate, not to restrict, the embodiment.

In the following, different embodiments will be described using, as an example of a system architecture to which the embodiments may be applied, an architecture based on the third-generation wireless communication system UMTS (Universal Mobile Telecommunication System) without restricting the embodiment to such an architecture, however.

A general architecture of a communication system is illustrated in Figure 1. Figure 1 is a simplified system architecture only showing some elements and functional entities, all being logical units whose implementation may differ from what is shown. The connections shown in Figure 1 are logical connections; the actual physical connections may be different. It is apparent to a person skilled in the art that the systems also comprise other functions and structures. It should be appreciated that the functions, structures, elements, and protocols used in or for group communication are irrelevant to the actual invention. Therefore, they need not to be discussed in more detail here.

Figure 1 shows two base stations or Node Bs 100 and 102. Base stations 100 and 102 are connected via an interface Iub to a radio network controller 104. The radio network controller and base stations form a radio access network (RAN).

The communication network may further comprise a core network which may be divided into a circuit-switched part 106 and a packet-switched part 108. The radio network controller 104 may be connected to the circuit-switched part 106 of the core network via an interface Iu-CS and the packet-switched part 108 via an interface Iu-PS.

Figure 1 shows user equipment 110 communicating 112 with the base station 100. The user equipment refers to a portable computing device. Such computing devices include wireless mobile communication devices operating with or without a subscriber identification module (SIM), including, but not limited to, the following types of devices: mobile phone, smartphone, personal digital assistant (PDA), handset, laptop computer.

Figure 1 only illustrates a simplified example. In practice, the network may include more base stations and radio network controllers, and more cells may be formed by the base stations. The networks of two or more operators may overlap, the sizes and form of the cells may vary from that depicted in Figure 1, etc.

It should be appreciated that the base stations or node Bs may also be connectable to core network elements directly (not shown in the Figure). Depending on the system, the counterpart on the core network side can be a mobile services switching centre (MSC), a media gateway (MGW), or a serving GPRS (general packet radio service) support node (SGSN), home node B gateway (HNB-GW), mobility management entity and enhanced packet core gateway (MME/EPC-GW), etc. A direct communication between different node Bs over the air interface is also possible by implementing a relay node concept, wherein a relay node may be considered as a special node B having wireless backhauls or, e.g., X2 and S1 interfaces relayed over the air interface by another node B. The communication system is also able to communicate with other networks, such as a public switched telephone network.

The embodiments are not, however, restricted to the network given above as an example, but a person skilled in the art may apply the solution to other communication networks provided with the necessary properties.

In this application, embodiments will be described in conjunction with cellular communications systems. However, it should be understood that the embodiments may be utilized in several kinds of systems, both wired and wireless.

The communication between the user equipment 110 and the base station 100 may be a traffic channel connection or a control channel connection. In many systems, coherent detection is utilised in receivers. In coherent detection, the carrier phase of the received signal must be detected at the receiver. In non-coherent detection, phase information is not required. However, due to better performance, coherent detection is widely used although the receiver complexity is greater.

A reference signal or pilot symbols are typically needed to facilitate coherent reception. When the number of information bits in the information block to be transmitted is large, the use of the reference signal provides good performance. However, if the number of information bits is small, the reference signal may cause large overhead, thus degrading the performance.

Prior to modulation, the signal to be transmitted is coded using a given channel code. Generally, codes are designed by maximizing the minimum distance between the code words of the code. The distance is called Hamming distance.

In an embodiment, the channel code is designed by minimizing the maximum correlation between the code words of the code. When a generator matrix of a code is designed using the above criteria, the code words of the matrix have a low absolute correlation. This way the signal may be received with a non-coherent receiver and a reference signal is not needed.

Figure 2 is a block diagram of an apparatus according to an embodiment of the invention. Although the apparatus has been depicted as one entity, different modules and memory may be implemented in one or more physical or logical entities. The apparatus is configured to generate a channel code. The apparatus comprises a controller or a processor 200. Generally the processor is a central processing unit, but the processor may be an additional operation processor. The processor may comprise a computer processor, application-specific integrated circuit (ASIC), field-programmable gate array (FPGA), and/or other hardware components that have been programmed in such a way as to carry out one or more functions of an embodiment. The apparatus further comprises one or more data storages or memories 202 connected to the controller for storing software and data at least temporarily. In an embodiment, the memory is integrated in the processor. In addition, the apparatus may comprise an input/output interface or module 204.

The processor 200 may be configured to generate a generator matrix for a channel code. The matrix may be a k x n generator matrix where n is an integer depicting the length of a codeword and k is an integer depicting the number of data bits to be coded using each code word of the code. The processor may be configured to generate the matrix by minimizing the absolute value of the maximum correlation between the code words of the generator matrix.

Figure 3 is a flowchart illustrating an embodiment of the invention.

In step 300, the processor 200 generates a k x n generator matrix with random entries of 0 and 1. Here n is an integer depicting the length of a codeword and k is an integer depicting the number of data bits to be coded using each code word of the code.

In step 302, the processor computes the correlations between the code words of the matrix and determines the maximum absolute correlation between code words. The processor further stores the maximum absolute value into the memory 202. The computation of the correlations is performed as known in the art.

In step 304, the processor selects the first element of the matrix.

In step 306, the processor changes the value of the element. For example, if the value is 0, it is changed into 1 and vice versa.

In step 308, the processor computes the correlations between the code words of the matrix and determines the maximum absolute correlation between code words.

In step 310, the computed value is compared with the value stored in the memory 202. If the computed value is smaller, the computed value is stored in the memory 202 in step 312.

The process continues in step 314, where the processor checks if all elements have been processed. If this is not the case, the next element is selected in step 316 and the process continues in step 306.

If all elements have been processed, the process continues in step 318 where it is checked whether the stored value was changed during the above process. If not, the process continues according to the flowchart of Figure 4 starting at point A.

If the stored value was changed, the process continues in step 304, where the first element is reselected. The above process is repeated until the stored value is no longer improved by changing one element at a time.

Figure 4 is a flowchart illustrating an embodiment of the invention.

In step 400, the processor increases the number of elements to be changed at a time. For example, if the process started according to the flowchart of Figure 3 and entered step 400, the number of elements is increased to two elements.

In step 402, the processor selects the first elements of the matrix. For example, if the number of elements to be changed at a time is two, the processor selects the first two successive elements.

In step 404, the processor changes the values of the elements. For example, if the value of an element is 0, it is changed into 1 and vice versa.

In step 406, the processor computes the correlations between the code words of the matrix and determines the maximum absolute correlation between code words.

In step 408, the computed value is compared with the value stored in the memory 202. If the computed value is smaller, the computed value is stored in the memory 202 in step 410.

The process continues in step 412, where the processor checks if all elements have been processed. If this is not the case, the next elements are selected in step 414 and the process continues in step 404.

If all elements have been processed, the process continues in step 416 where it is checked whether the stored value was changed during the above process. If yes, the process continues according to the flowchart of Figure 3 starting at point B where the first element is reselected. The process is repeated until the stored value is no longer improved by changing one element at a time.

If the stored value was not changed, the process continues in step 400, where the number of elements to be changed at a time is increased.

Figure 5 illustrates an example of an apparatus according to an embodiment of the invention. Although the apparatus has been depicted as one entity, different modules and memory may be implemented in one or more physical or logical entities. The apparatus may be a base station or user equipment or any other device of a communication system capable for required operations and processes.

The input to the apparatus is a signal 500 to be transmitted. The signal may comprise data bits or data symbols. The signal 500 is taken to an encoder 502 configured to encode the signal with a channel code defined by a k x n generator matrix whose elements are defined by minimizing the absolute value of the maximum correlation between the code words generated by the generator matrix, where n is an integer depicting the length of a codeword and k is an integer depicting the number of data bits to be coded using each code word of the code.

In an embodiment, the output of the encoder 502 may be defined as

$\mathbf{v} = \mathbf{G}^T\mathbf{u}$ (mod 2),

where $\mathbf{v}$ is the code word of length n, $\mathbf{G}$ is the generator matrix of the code, and $\mathbf{u}$ is the information word to be coded which is of length k.

The encoded signal 504 is taken to a modulator 506 configured to modulate the encoded signal with a phase- or amplitude-based modulation. The modulation method used may be BPSK, QPSK, QAM or the like.

The modulated signal 508 is taken to a radio frequency transmitter 510 which is configured to transmit the signal. The transmitter comprises an interface 512 connected to an antenna (not shown).

Figure 6A illustrates another example of an apparatus according to an embodiment of the invention. Although the apparatus has been depicted as one entity, different modules and memory may be implemented in one or more physical or logical entities. The apparatus may be a base station or user equipment or any other device of a communication system capable for the required operations and processes.

The input to the apparatus is a received phase- or amplitude-modulated signal 600. The signal may have been received with an antenna. The signal is taken to a radio frequency unit 602 which converts the signal to intermediate or base band. The converted signal 604 is taken to a decoder 610 which decodes the signal. In an embodiment, the decoder is a maximum likelihood decoder. The decoder may be configured to calculate a correlation of the received signal with each of the possible code words used in the system and to select the maximum correlation value. As the received signal does not comprise a pilot signal or reference signal, the phase of the received signal is not known. The apparatus comprises a calculator 614 for determining the absolute value of the output signal 612 of the decoder. The apparatus further comprises a selector 616 which decides the received code word 618.

Figures 6B and 6C illustrate other examples of an apparatus according to another embodiment of the invention. The apparatus of Figure 6B utilizes receiver diversity. In this example, the receiver utilizes four antenna branches.

In Fig 6B, the input to the apparatus is a received phase- or amplitude-modulated signal 600. In this example, the signal may have been received with four antennas. The signal is taken to four branches 620, 622, 624, 626, each comprising a radio frequency unit, a decoder, and a calculator for determining the absolute value of the output signal of the decoder. Each decoder may be configured to calculate a correlation of the received signal with each of the possible code words used in the system and to select the maximum correlation value. As the received signal does not comprise a pilot signal or reference signal, the phase of the received signal is not known. The calculator of each branch determines the absolute value of the output signal of the decoder.

The apparatus further comprises a selector 628 which combines the outputs of the calculators of the branches 620, 622, 624, 266 and decides the received code word 618 by selecting the code word with the largest amplitude at the input of the selector 628.

Fig. 6C illustrates an embodiment, where the receiver comprises two branches 630, 632 utilizing antenna diversity. Each branch comprises a radio frequency unit, a decoder, and a calculator for determining the absolute value of the output signal of the decoder. The receiver further comprises two branches 634, 636 utilizing frequency hopping diversity. The branches comprise a common radio frequency unit 638. Each branch further comprises a decoder and a calculator for determining the absolute value of the output signal of the decoder. Otherwise the receiver of Figure 6C is similar to the receiver of Figure 6B.

Figure 7 illustrates a method according to an embodiment.

In step 700, a signal comprising data bits is encoded with a channel code defined by a k x n generator matrix whose elements are defined by minimizing the absolute value of the maximum correlation between the code words generated by the generator matrix, where n is an integer depicting the length of a codeword and k is an integer depicting the number of data bits to be coded using each code word of the code.

In step 702, the encoded signal is modulated with a phase or amplitude based modulation.

In step 704, the encoded signal is transmitted.

Figure 8 illustrates the performance of the code designed according to the principles described above. The figure shows the coded bit error rate of two different codes 800, 802 as a function of Eb/No.

Let us assume that the number of information bits to be transmitted is 5. This is called the dimension of a code. The performance of a prior-art code is denoted with reference number 800. The prior-art code is a Reed-Muller (16,5) code which is a conventional channel code having the following generator matrix:

$$\mathbf{G} = \begin{matrix} 1&1&1&1&1&1&1&1&1&1&1&1&1&1&1&1 \\ 0&1&0&1&0&1&0&1&0&1&0&1&0&1&0&1 \\ 0&0&1&1&0&0&1&1&0&0&1&1&0&0&1&1 \\ 0&0&0&0&1&1&1&1&0&0&0&0&1&1&1&1 \\ 0&0&0&0&0&0&0&0&1&1&1&1&1&1&1&1 \end{matrix}$$

Reed-Muller codes are well known for their good performance with small dimensions. A small k means that the portion the reference signal takes of the total transmission energy is large if optimal performance is to be achieved in terms of E_b/N_0.

The code words generated by this code do not meet the criterion of low absolute correlation between all code words, though this is a very good code for a coherent receiver. Note that a coherent receiver is needed and pilot bits have to be used for carrier phase estimation. The optimal number of pilot bits is 12 for four receive antennas. Therefore altogether 28 bits are transmitted.

The performance of a code designed using the method described above is denoted with 802 in Figure 8. The code is of the form (28,5) as the code does not need any pilot or reference symbols. It thus requires a non-coherent receiver, for example the receiver of Figures 6A or 6B. The generator matrix of the code used in the simulation of Figure 8 is as follows:

$$\mathbf{G} = \begin{matrix} 1&0&1&0&1&1&0&1&0&1&0&0&1&0&1&1&1&0&0&1&0&1&0&1&1&0&0&0 \\ 0&1&1&0&0&1&0&0&0&1&0&0&0&1&1&0&0&0&1&1&1&1&1&0&0&0&1&0 \\ 0&0&0&0&1&0&1&0&1&1&1&0&1&1&1&1&0&0&1&1&0&0&1&0&1&1&0&0 \\ 0&1&1&1&0&0&1&0&0&0&0&0&1&1&1&0&1&1&1&1&1&1&0&1&1&1&0&0 \\ 0&0&1&1&1&0&0&1&1&0&0&0&0&1&1&0&1&0&0&0&1&0&0&0&1&1&1&1 \end{matrix}$$

Note that the number of transmitted bits is the same for both the Reed-Muller RM (16,5) code and the proposed code, since pilot bits are needed for the Reed-Muller code.

Figure 8 shows the performance of the Reed-Muller (16,5) code 800 with 12 pilot bits for channel estimation and the performance 802 of the proposed (28,5) code. The results show that the proposed code has superior performance in comparison with the Reed-Muller code.

The techniques described herein may be implemented by various means. Thus, an apparatus implementing one or more functions described with an embodiment comprises not only prior art means, but also means for implementing the one or more functions of a corresponding apparatus described with an embodiment and it may comprise separate means for each separate function, or means may be configured to perform two or more functions. For example, these techniques may be implemented in hardware (one or more apparatuses), firmware (one or more apparatuses), software (one or more modules), or combinations thereof. For firmware or software, implementation can be through modules (e.g., procedures, functions, and so on) that perform the functions described herein. The software codes may be stored in any suitable, processor/computer-readable data storage medium (or media) or memory unit(s) or article(s) of manufacture and executed by one or more processors/computers. The data storage medium or the memory unit may be implemented within the processor/computer or external to the processor/computer, in which case it can be communicatively coupled to the processor/computer via various means as is known in the art.

User equipment may refer to any user communication device. The term “user equipment” as used herein may refer to any device having a communication capability, such as a wireless mobile terminal, a PDA, a smart phone, a personal computer (PC), a laptop computer, or a desktop computer. For example, the wireless communication terminal may be an UMTS or GSM/EDGE smart mobile terminal having the S60 operating system from Nokia Corporation. Thus, the application capabilities of the device according to various embodiments of the invention may include native S60 applications available in the terminal, or subsequently installed applications.

The steps/points, signaling messages and related functions described above in the figures are in no absolute chronological order, and some of the steps/points may be performed simultaneously or in an order differing from the given one. Other functions can also be executed between the steps/points or within the steps/points and other signaling messages sent between the illustrated messages. Some of the steps/points can also be left out or replaced by a corresponding step/point or part of the step/point.

In an embodiment, at least some of the above described functions may be implemented with software. The software may be stored on a storage circuitry that is configured to store programming such as an executable code or instructions, electronic data, databases, or other digital information, and may include processor-usable media. Processor-usable media may be embodied in any computer program product or article of manufacture which can contain, store, or maintain programming, data or digital information for use by or in connection with an instruction execution system including processing circuitry.

For example, exemplary processor-usable media may include any one of physical media such as electronic, magnetic, optical, electromagnetic, infrared or semiconductor media. Some more specific examples of processor-usable media include, but are not limited to, a portable magnetic computer diskette, such as a floppy diskette, zip disk, hard drive, random-access memory, read only memory, flash memory, cache memory, or other configurations capable of storing programming, data, or other digital information.

An article of manufacture may comprise a computer readable medium and embody program instructions executable by a computer operably coupled to a memory which, when executed by the computer, carry out the functions of generating a k x n generator matrix for a code by minimizing the absolute value of the maximum correlation between the code words generated by the generator matrix, where n is an integer depicting the length of a codeword and k is an integer depicting the number of data bits to be coded using each code word of the code.

It will be obvious to a person skilled in the art that, as technology advances, the inventive concept can be implemented in various ways. The invention and its embodiments are not limited to the examples described above but may vary within the scope of the claims.

CLAIMS

1. A method comprising performing the following acts by an electronic data processing system:

generating a k x n generator matrix for a code by minimizing the absolute value of the maximum correlation between the code words generated by the generator matrix, where n is an integer depicting the length of a codeword and k is an integer depicting the number of data bits to be coded using each code word of the code.

2. A method according to claim 1, comprising:

generating a k x n generator matrix with random entries of 0 and 1;

computing and storing the maximum absolute correlation between code words generated by the matrix;

performing the following three steps a), b) and c) for each element of the generator matrix:

a) changing the value of an element of the matrix;

b) computing the maximum absolute correlation between code words generated by the matrix;

c) comparing the computed value to the stored value and if the computed value is smaller, storing the computed value.

3. A method according to claim 2, comprising:

checking if the stored value was changed when performing the steps a), b) and c) for each element of the generator matrix, and if so, performing the steps again for each element of the generator matrix, otherwise performing the steps a), b), c) for each successive element group comprising two elements and changing the values of an element group in step b) instead of a single element.

4. A method according to claim 3, comprising:

checking if the stored value was changed when performing the steps a), b) and c) for each element group of the generator matrix, and if so, performing the steps again for each group of the generator matrix, otherwise increasing the number of elements in each group by one and performing the steps a), b), c) for each successive element group and changing the values of an element group in step b) instead of a single element.

5. A method comprising:

encoding a signal comprising data bits with a channel code defined by a k x n generator matrix whose elements are defined by minimizing the absolute value of the maximum correlation between the code words generated by the generator matrix, where n is an integer depicting the length of a codeword and k is an integer depicting the number of data bits to be coded using each code word of the code;

modulating the encoded signal with a phase- or amplitude-based modulation; and

transmitting the encoded signal.

6. An apparatus, comprising a processor configured to:

generate a k x n generator matrix for a code by minimizing the absolute value of the maximum correlation between the code words generated by the generator matrix, where n is an integer depicting the length of a codeword and k is an integer depicting the number of data bits to be coded using each code word of the code.

7. The apparatus of claim 6 configured to:

generate a k x n generator matrix with random entries of 0 and 1;

compute and store the maximum absolute correlation between code words generated by the matrix;

perform the following three steps a), b) and c) for each element of the generator matrix:

a) change the value of an element of the matrix;

b) compute the maximum absolute correlation between code words generated by the matrix;

c) compare the computed value to the stored value and if the computed value is smaller, store the computed value.

8. An apparatus configured to:

encode a signal comprising data bits with a channel code defined by a k x n generator matrix whose elements are defined by minimizing the absolute value of the maximum correlation between the code words generated by the generator matrix, where n is an integer depicting the length of a codeword and k is an integer depicting the number of data bits to be coded using each code word of the code;

modulate the encoded signal with a phase- or amplitude-based modulation; and

transmit the encoded signal.

9. An apparatus comprising:

means for encoding a signal comprising data bits with a channel code defined by a k x n generator matrix whose elements are defined by minimizing the absolute value of the maximum correlation between the code words generated by the generator matrix, where n is an integer depicting the length of a codeword and k is an integer depicting the number of data bits to be coded using each code word of the code;

means for modulating the encoded signal with a phase- or amplitude-based modulation; and

means for transmitting the encoded signal.

10. An apparatus comprising

at least one demodulator demodulating a phase- or amplitude-modulated signal,

at least one decoder calculating correlations between the received codeword and the known code words,

at least one calculator determining the absolute value of the correlation result obtained by a decoder, and

a selector for deciding the received code word.

11. The apparatus of claim 9 comprising interfaces with one or more antennas.

12. An apparatus comprising

means for demodulating a phase- or amplitude-modulated signal,

means for calculating correlations between the received codeword and the known code words,

means for determining the absolute value of the correlation result obtained by a decoder, and means for deciding the received code word.

13. An article of manufacture comprising a computer readable medium and embodying program instructions executable by a computer operably coupled to a memory which, when executed by the computer, carry out the functions of:

generating a k x n generator matrix for a code by minimizing the absolute value of the maximum correlation between the code words generated by the generator matrix, where n is an integer depicting the length of a codeword and k is an integer depicting the number of data bits to be coded using each code word of the code.

14. A computer program comprising program code means adapted to perform any of the steps of claims 1 to 5 when the program is run on a computer or a processor.

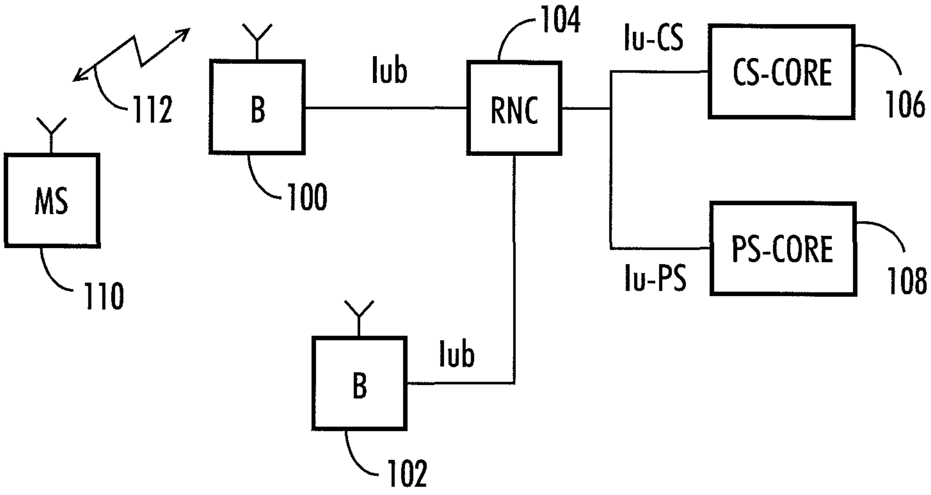
104
Iu-CS
CS-CORE
106
112
B
Iub
RNC
MS
100
PS-CORE
108
Iu-PS
110
Iub
B
102

FIG. 1

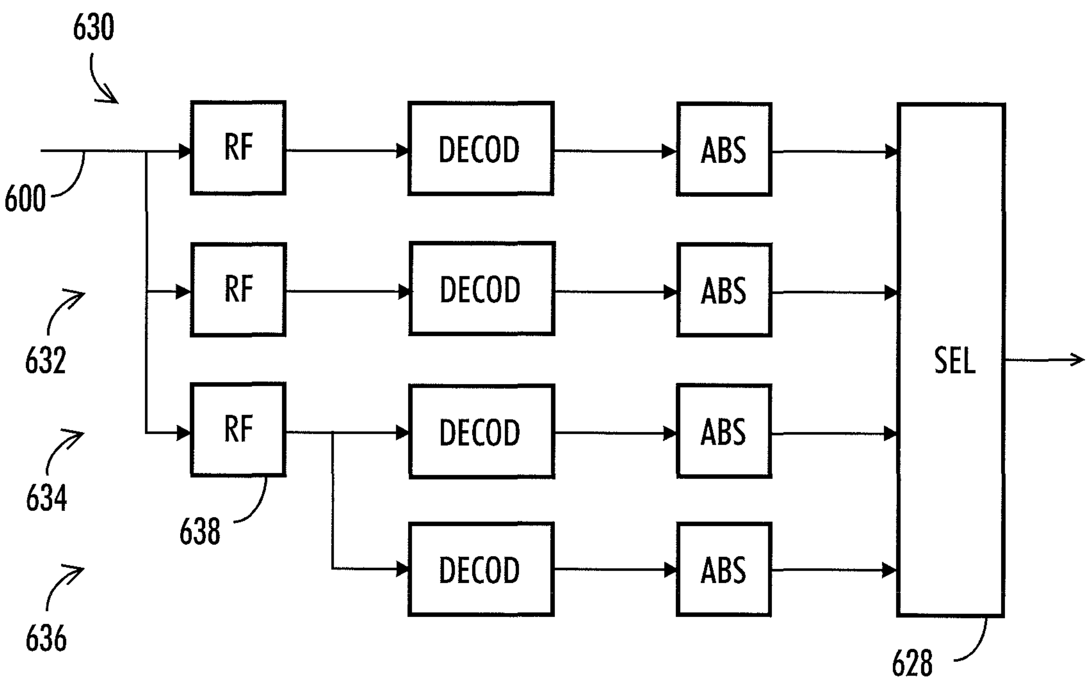
630
RF
DECOD
ABS
600
RF
DECOD
ABS
632
SEL
RF
DECOD
ABS
634
638
DECOD
ABS
636
628

FIG. 6C

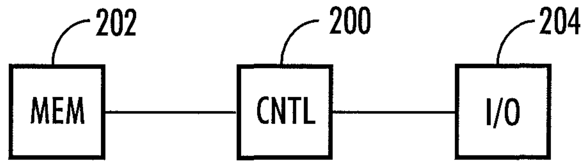

FIG. 2

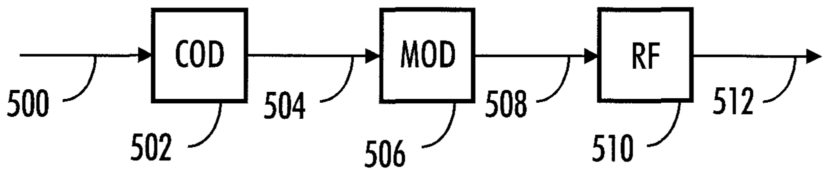

FIG. 5

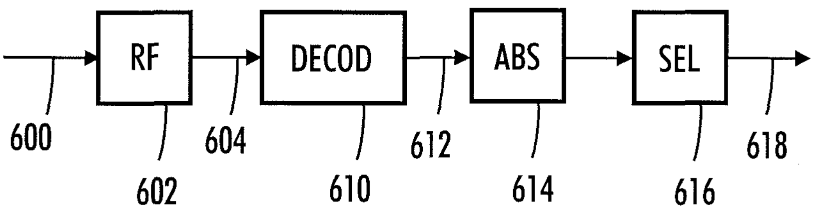

FIG. 6A

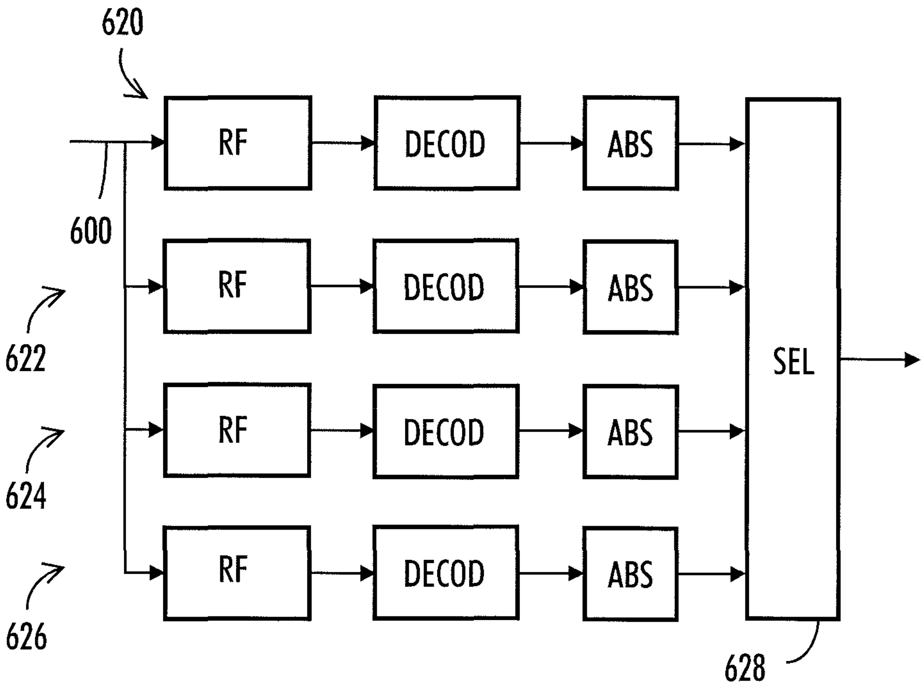

FIG. 6B

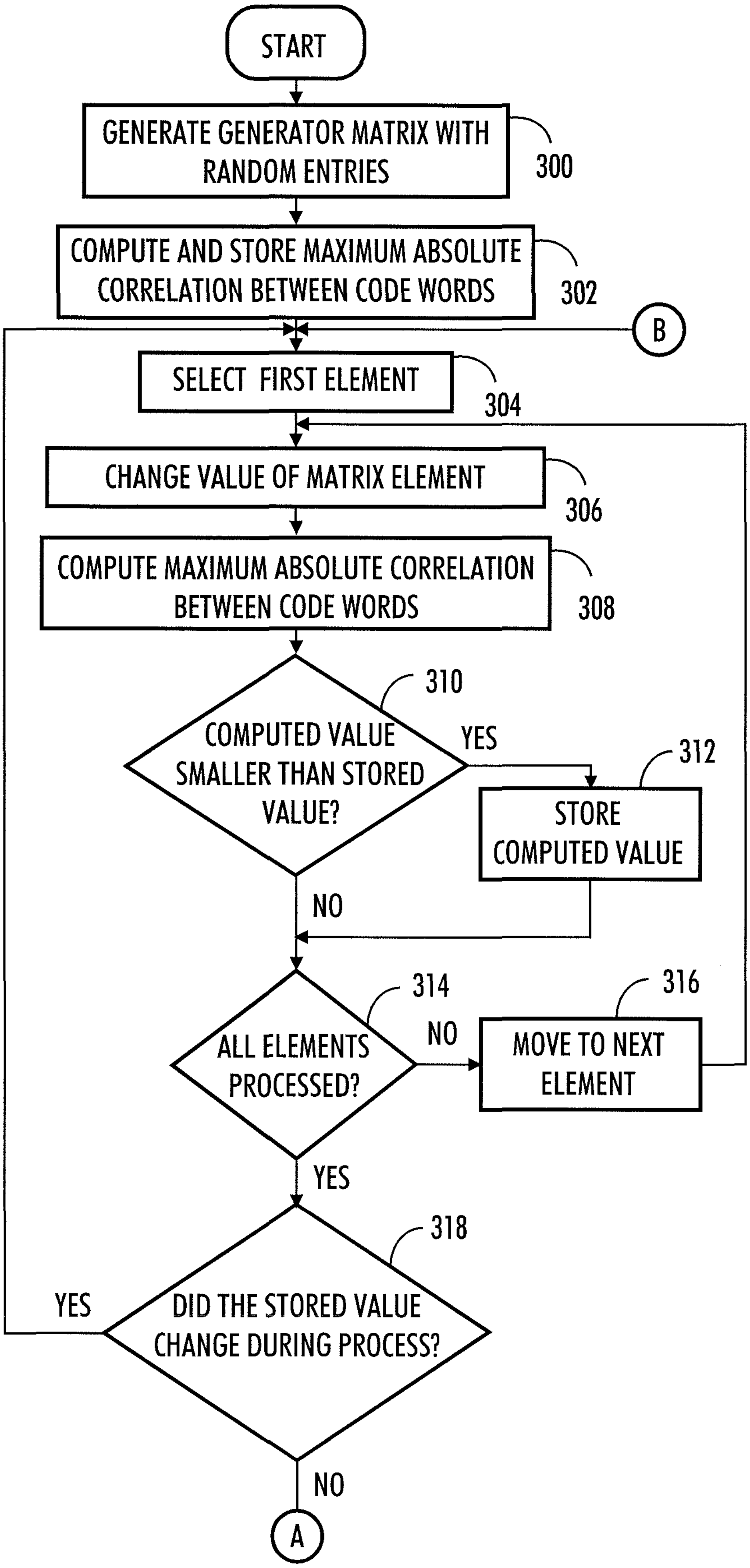
START
GENERATE GENERATOR MATRIX WITH RANDOM ENTRIES
300
COMPUTE AND STORE MAXIMUM ABSOLUTE CORRELATION BETWEEN CODE WORDS
302
B
SELECT FIRST ELEMENT
304
CHANGE VALUE OF MATRIX ELEMENT
306
COMPUTE MAXIMUM ABSOLUTE CORRELATION BETWEEN CODE WORDS
308
310
COMPUTED VALUE SMALLER THAN STORED VALUE?
YES
312
STORE COMPUTED VALUE
NO
314
316
ALL ELEMENTS PROCESSED?
NO
MOVE TO NEXT ELEMENT
YES
318
YES
DID THE STORED VALUE CHANGE DURING PROCESS?
NO
A

FIG. 3

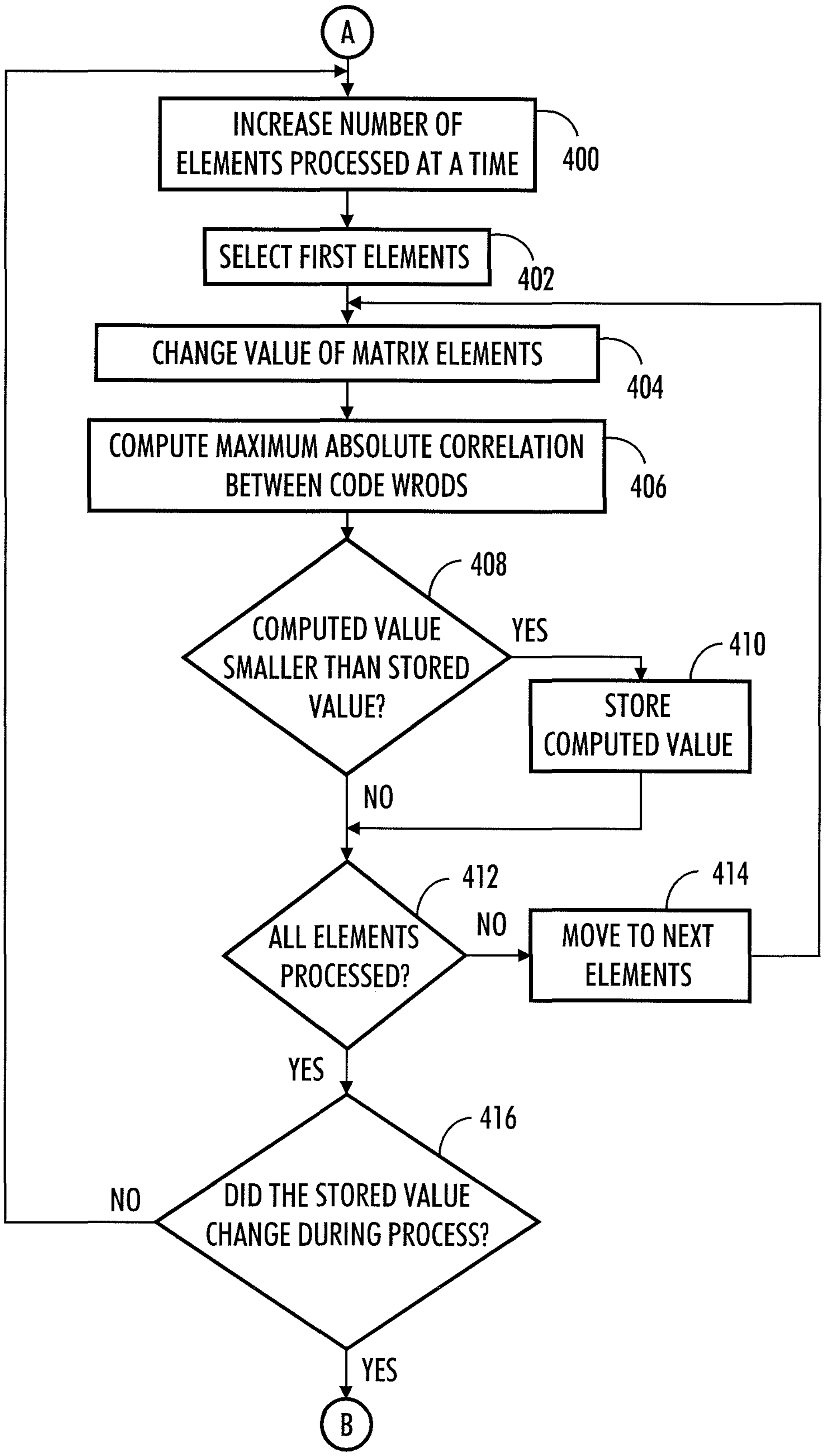
A
INCREASE NUMBER OF ELEMENTS PROCESSED AT A TIME
400
SELECT FIRST ELEMENTS
402
CHANGE VALUE OF MATRIX ELEMENTS
404
COMPUTE MAXIMUM ABSOLUTE CORRELATION BETWEEN CODE WRODS
406
408
COMPUTED VALUE SMALLER THAN STORED VALUE?
YES
410
STORE COMPUTED VALUE
NO
412
ALL ELEMENTS PROCESSED?
NO
414
MOVE TO NEXT ELEMENTS
YES
416
DID THE STORED VALUE CHANGE DURING PROCESS?
NO
YES
B

FIG. 4

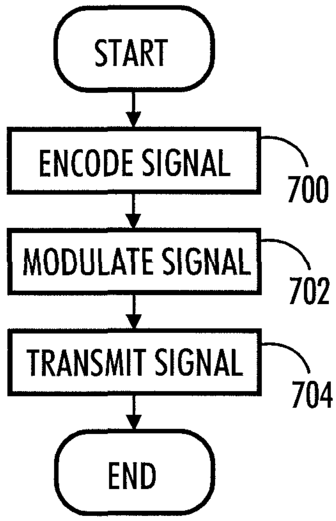
START
ENCODE SIGNAL
700
MODULATE SIGNAL
702
TRANSMIT SIGNAL
704
END

FIG. 7

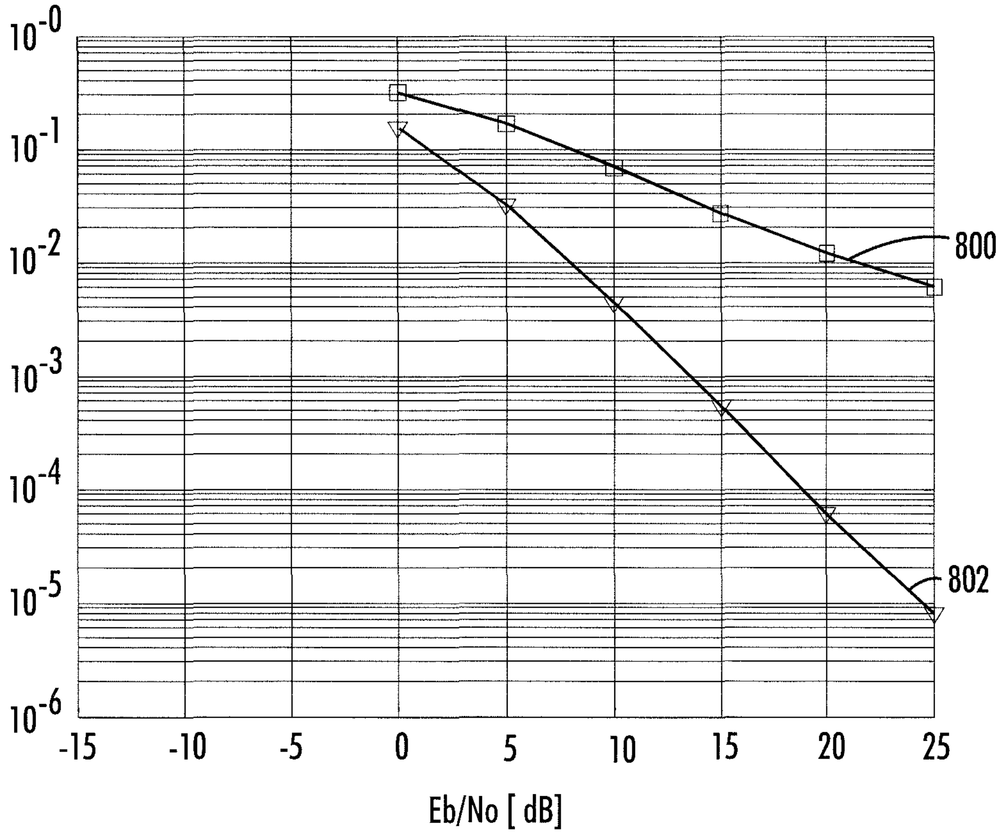
10^{-0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
800
802
-15 -10 -5 0 5 10 15 20 25
Eb/No [dB]

FIG. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2009/051558

A. CLASSIFICATION OF SUBJECT MATTER
INV. H03M13/03 H04W28/00 H04L1/00

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)
H03M H04W H04L

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

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

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PAPADIMITRIOU P. D. ET AL.: "On binary code design for the non-coherent block fading channel" PROC., IEEE GLOBAL TELECOMMUNICATIONS CONFERENCE, GLOBECOM 2003, SAN FRANCISCO, CA, vol. 3, 1 December 2003 (2003-12-01), pages 1603-1607, XP010677564 ISBN: 978-0-7803-7974-9 the whole document	1-14

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 July 2009	23/07/2009

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Offer, Elke

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2009/051558

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PAPADIMITRIOU P D ET AL: "Block code design based on metric-spectrum" PROC., IEEE GLOBAL TELECOMMUNICATIONS CONFERENCE, GLOBECOM '04, DALLAS, TEXAS, US, vol. 1, 29 November 2004 (2004-11-29), - 3 December 2004 (2004-12-03) pages 15-20, XP010757485 ISBN: 978-0-7803-8794-2 page 15 - page 17	1-14
X	ROSS ET AL: "Coded signal design for a transmitterscanned sonar" JOURNAL OF SOUND & VIBRATION, LONDON, GB, vol. 29, no. 2, 22 July 1973 (1973-07-22), pages 227-255, XP025888874 ISSN: 0022-460X [retrieved on 1973-07-22] page 230 - page 233	1-14
X	WO 2008/098221 A1 (QUALCOMM INC [US]; KIM BYOUNG-HOON [US]; MALLADI DURGA PRASAD [US]; DO) 14 August 2008 (2008-08-14)	1-4,6-7, 13-14
A	paragraph [0061] - paragraph [0092] claims 1-63	5,8-12
X	US 2005/083199 A1 (HALL DAVID J [US] ET AL) 21 April 2005 (2005-04-21)	1-4,6-7, 13-14
A	paragraph [0072] - paragraph [0083] claims 1-25	5,8-12
A	CHUNG C.-D. ET AL: "Diversity Coding Technique For Differential Phase Modulation In A Correlated Rayleigh Fading Channel" PROC., IEEE 11TH INTERNAT. SYMPOSIUM ON PERSONAL, INDOOR AND MOBILE RADIO COMMUNICATIONS, PIMRC 2000, vol. 1, 18 September 2000 (2000-09-18), - 21 September 2000 (2000-09-21) pages 232-236, XP010520637 ISBN: 978-0-7803-6463-9 page 232 - page 234	1-14
A	BORGMANN M. AND BÖLCSKEI H.: "Noncoherent Space-Frequency Coded MIMO-OFDM" IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS, IEEE SERVICE CENTER, PISCATAWAY, US, vol. 23, no. 9, 1 September 2005 (2005-09-01), pages 1799-1810, XP011138715 ISSN: 0733-8716 the whole document	1-14

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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2009/051558

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	NURIYEV R ET AL: "Capacity-approaching code design for the noncoherent AWGN channel" PROC., IEEE GLOBAL TELECOMMUNICATIONS CONFERENCE, GLOBECOM 2003, SAN FRANCISCO, CA, vol. 3, 1 December 2003 (2003-12-01), - 5 December 2003 (2003-12-05) pages 1598-1602, XP010677563 ISBN: 978-0-7803-7974-9 the whole document -----	1-14

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2009/051558

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2008098221 A1	14-08-2008	US 2009016459 A1	15-01-2009
US 2005083199 A1	21-04-2005	NONE	