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GB 2280571 A **GB 2270819 A**

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(54) Multicarrier communication system and method for peak power control

(57) A communication device (60) for simultaneously transmitting independent information (76, 78) on multiple channels encodes information (75) for each of the multiple channels with a coding scheme to produce channel encoded information. A mask vector (72), derived from a code redundancy in the coding scheme, encodes (68) the channel encoded information (75) to transpose the channel encoded information into codewords having Hamming distance properties identical to those of the channel encoded information (75). Modulation of each codeword for each channel in a modulator (70) then produces a composite signal envelope (78), having a peak-to-mean envelope power ratio (PMEPR) reduced relative to a PMEPR for correspondingly modulated channel encoded information.

The OFDM transmission is via radio or fibre-optic technology.

Application is to Digital Audio Broadcasting (DAB) and Broadband Wireless Local Area Networks (LANs).

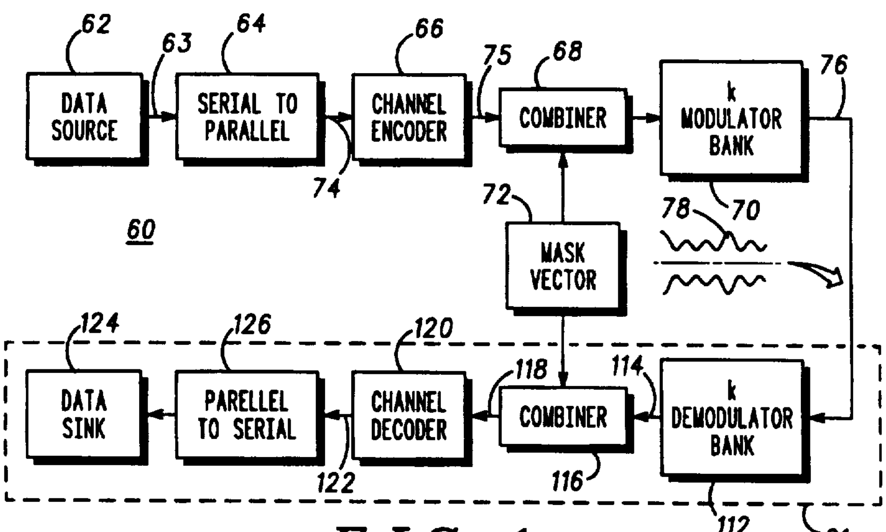

FIG.4

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

This print incorporates corrections made under Section 117(1) of the Patents Act 1977.

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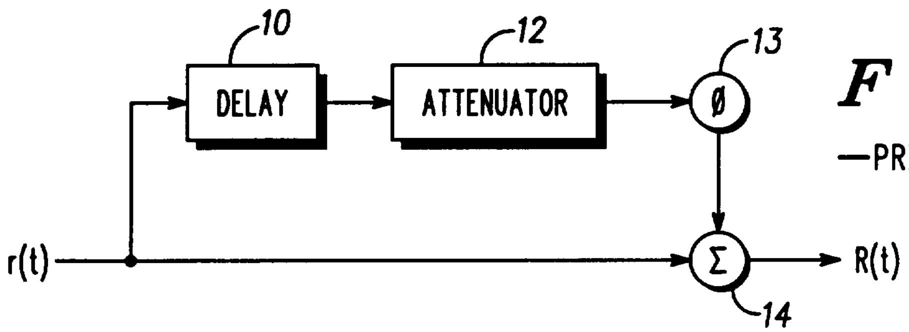

FIG.1

—PRIOR ART—

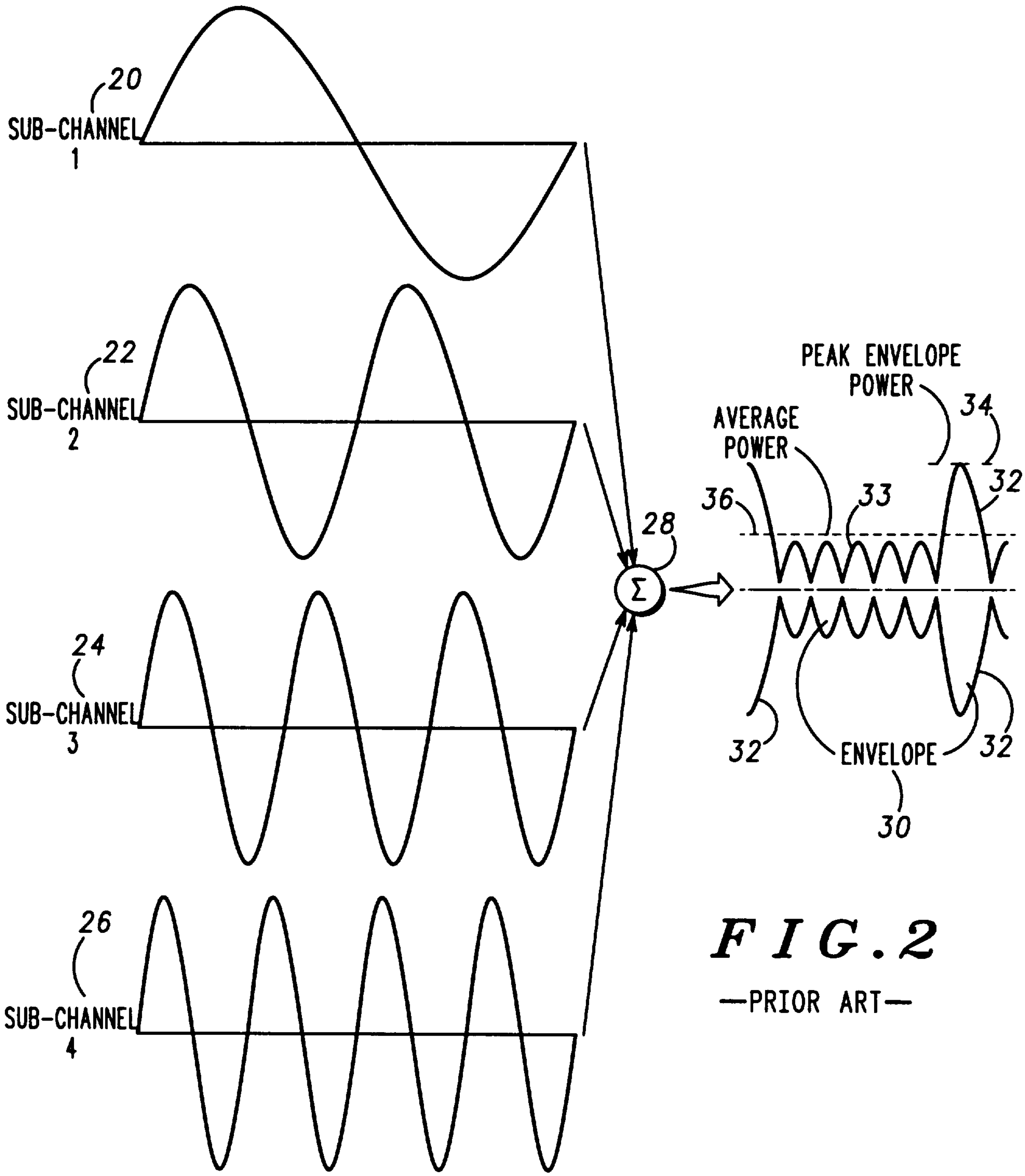

FIG.2

—PRIOR ART—

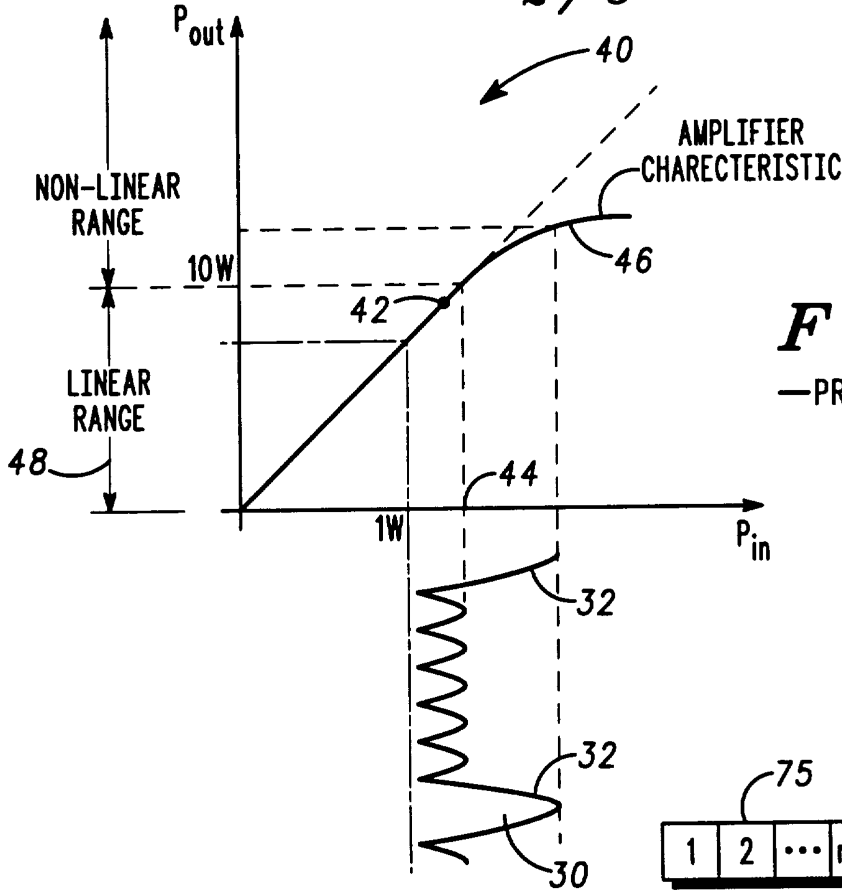

FIG.3
—PRIOR ART—

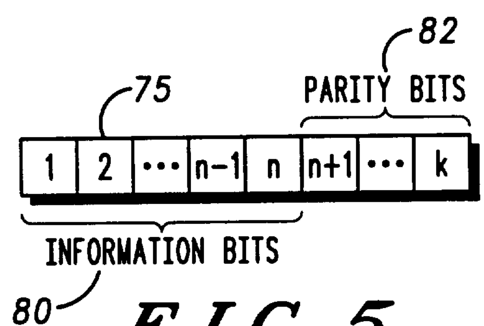

FIG.5

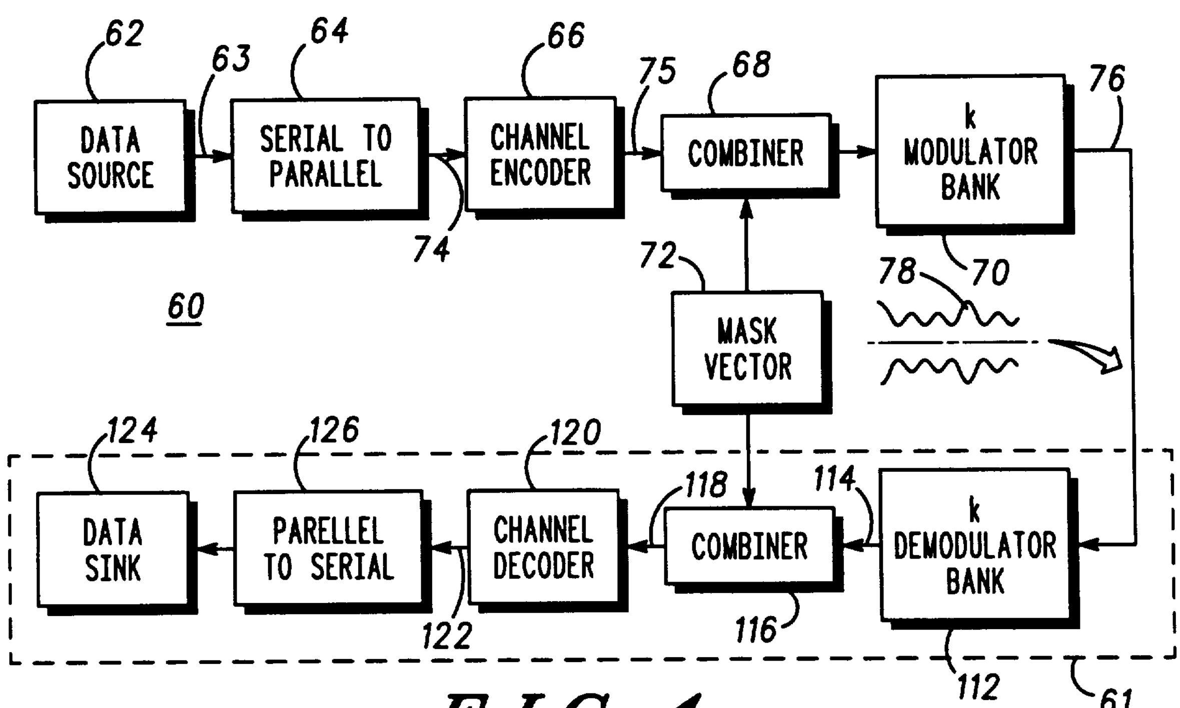

FIG.4

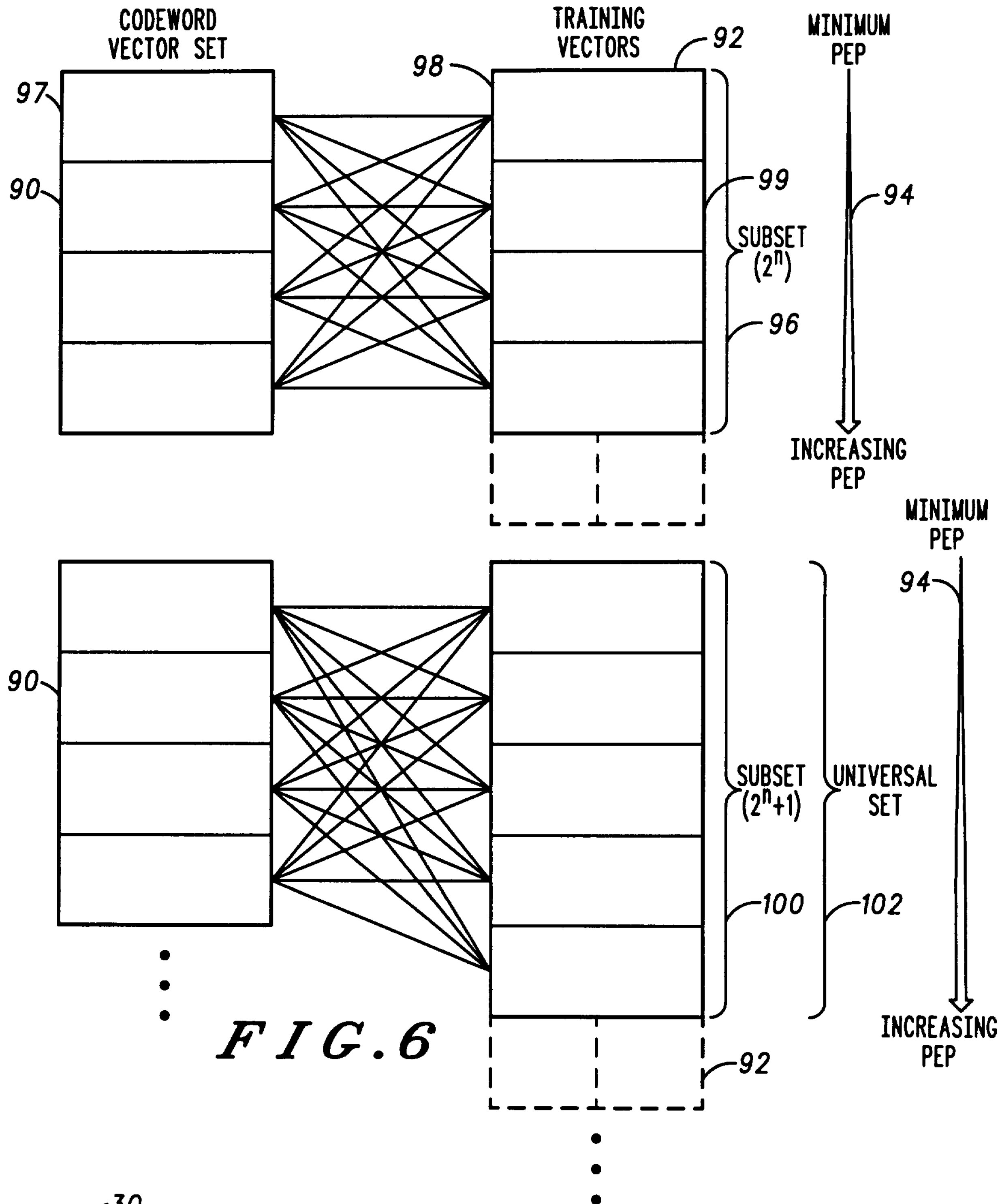
CODEWORD VECTOR SET
TRAINING VECTORS
MINIMUM PEP
97
90
98
92
99
94
SUBSET (2^n)
96
INCREASING PEP
MINIMUM PEP
94
90
SUBSET (2^n+1)
UNIVERSAL SET
100
102
INCREASING PEP
92

FIG.6

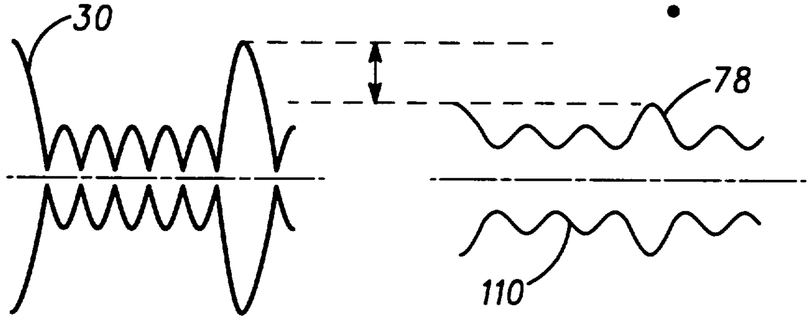
30
78
110

FIG.7

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MULTICARRIER COMMUNICATION SYSTEM AND METHOD FOR PEAK POWER CONTROL

Background of the Invention

This invention relates, in general, to multicarrier communication systems, such as an Orthogonal Frequency Division Multiplexed (OFDM) communication system, and is particularly applicable to a mechanism for controlling the peak-to-mean envelope power ratio (PMEPR) for transmissions in such systems.

Summary of the Prior Art

Multicarrier transmission schemes, such as OFDM, have been proposed for many different types of communication system, including Digital Audio Broadcasting (DAB) and Broadband Wireless Local Area Networks (LANs). The advantage of such schemes is that unlimited transmission rates are theoretically possible in highly time dispersive channels that arise from a summation of multiple-delayed, phase-shifted paths for a signal, and which therefore display a distorted characteristic. Unfortunately, the composite signal envelope produced by OFDM exhibits a high PMEPR (which term is also commonly referred to as “the crest factor”). Moreover, in order to mitigate against the effects of distortion and spectral spreading (e.g. adjacent channel splatter) in multicarrier systems, a linear (and consequently inefficient) transmit amplifier is required for amplification of this composite signal envelope.

In addition to the foregoing disadvantages, the average power of a multicarrier signal (for a specified Peak Envelope Power (PEP) limit) is considerably lower than that for a constant envelope, single carrier signal (such as a Gaussian Minimum Shift-Keyed (GMSK) signal used in cellular communication systems, for example). Consequently, the selection of a multicarrier transmission scheme for a system does not currently utilise the available power range to a maximum extent.

As such, there is a desire to reduce the PMEPR of multicarrier transmission schemes in order to obtain the inherent advantages associated with the use of multicarrier signals in the limited frequency spectrum available to communication systems, generally.

Summary of the Invention

According to a first aspect of the present invention there is provided a communication device for simultaneously transmitting independent information on multiple channels, the communication device comprising: first encoding means for encoding the information for each of the multiple channels with a coding scheme to produce channel encoded information for error control; second encoding means for encoding the channel encoded information for each of the multiple channels with a mask vector derived from a code redundancy in the coding scheme, whereby the mask vector transposes the channel encoded information into codewords having Hamming distance properties identical to those of the channel encoded information; and modulation means for modulating each codeword for each channel to produce a composite signal envelope having a peak-to-mean envelope power ratio (PMEPR) reduced relative to a PMEPR for correspondingly modulated channel encoded information.

In a preferred embodiment, the mask is a function of the channel encoded information and a training vector which is obtained from an associative map having a ranking in ascending order of peak envelope power.

In another aspect of the present invention there is provided a method of simultaneously transmitting independent information on multiple channels comprising the steps of: for encoding the information for each of the multiple channels with a coding scheme to produce channel encoded information; encoding the channel encoded information for each of the multiple channels with a mask vector derived from a code redundancy in the coding scheme, whereby the mask vector transposes the channel encoded information into codewords having Hamming distance properties identical to those of the channel encoded information; and modulating each codeword for each channel to produce a composite signal envelope having a peak-to-mean envelope power ratio (PMEPR) reduced relative to a PMEPR for correspondingly modulated channel encoded information.

The present invention advantageously provides a mechanism which can achieve significant improvements in PMEPR by encoding the transmitted sequence in such a way as to avoid excessive PEPs.

Exemplary embodiments of the present invention will now be described with reference to the accompanying drawings.

Brief Description of the Drawings

FIG. 1 is a physical representation of the mechanism by which a prior art time dispersive channel is formed.

FIG. 2 is a waveform diagram illustrating the formulation of a time domain signal of a prior art multicarrier system.

FIG. 3 shows an operating characteristic and quiescent point of a typical linear amplifier for the time domain signal of the multicarrier system of FIG. 2.

FIG. 4 is a block diagram of a multicarrier transceiver in accordance with a preferred embodiment of the present invention.

FIG. 5 represents a codeword vector generated in the multicarrier transceiver of FIG. 4.

FIG. 6 illustrates a process (in accordance with a preferred embodiment of the present invention) by which a mask vector is calculated for use in the multicarrier transceiver of FIG. 4.

FIG. 7. is a graphical representation contrasting a time domain representation of a waveform utilised by the multicarrier transceiver of FIG. 4 with the time domain signal of the multicarrier system of FIG. 2.

Detailed Description of a Preferred Embodiment

Referring to FIG. 1, there is shown a physical representation of the mechanism by which a prior art time dispersive channel is formed.

Explicitly, a data signal r(t) is subjected to a multiplicity of paths (only two of which are shown), one of which contains a time delay 10, an attenuator 12 and a phase offset 13. At a later point, the multiplicity of alternate paths are combined (as represented by summation block 14) to obtain a distorted signal R(t). As will be understood, as the bandwidth for the data signal r(t) increases, the period of the time delay effects the signal to a greater extent, and so limits the use of an available bandwidth.

FIG. 2 is a waveform diagram illustrating the formulation of a time domain signal of a prior art multicarrier system. Indeed, FIG. 2 is representative of an OFDM scheme in which the effects of the time delay are mitigated against by distributing data (not shown) amongst a plurality of frequency channels 20-26 (four channels in this particular instance). Typically, a frequency relationship exists between the frequency of a first channel (channel 1) and the other channels in the scheme, i.e. channel 2 is twice the frequency of channel 1, while channel 3 has thrice the frequency of channel 1 (and so on). Distribution of data in this fashion has the effect that each channel is less susceptible to the inherent delay spread, as will be understood. Superposition of individual signals from each channel (occurring in summation block 28) therefore produces a composite envelope 30 having power spikes 32 separated by a relatively low (but oscillating) signal profile 33. However, the power spikes 32 have a peak envelope power (PEP) 34 substantially greater in value than an average power level 34 for the entire composite envelope 30.

Turning now to FIG. 3, an operating characteristic 40 and quiescent point 42 of a typical linear amplifier (not shown) for the time domain signal of the multicarrier system of FIG. 2 is shown. As will be appreciated, a linear amplifier provides a limited, linear gain between an input signal and an output signal. At a certain input power (P_{in}) threshold 44, non-linearities 46 in the amplification occur. In order to optimise the use of the linear amplifier in, for example, communications systems requiring linear transmitters (or the like), an input signal (in this case the time domain representation of the composite envelope 30) is positioned about the quiescent point 42. More particularly, the composite envelope 30 is arranged such that its average power level 36 provides (when taking into account the gain of the amplifier) a desired output level, and whereby a majority of the signal envelope 30 is within a linear range 48 of the amplifier. Unfortunately, the PEP 34 of power spikes 32 exceeds the linear range of operation of the amplifier with the effect that information contained thereon is distorted by the non-linearity 46 of the amplifier. More crucially though, standards bodies, such as ETSI (the European Technical Standards Institute) may require operational compliance to specified a maximum transmit power output level, say 10 watts. Therefore, to accommodate the relatively high (but relatively infrequent) PEPs of the power spikes 32, the input signal (composite envelope 30) requires the re-positioning of the quiescent point 42 to a lower level, whereby the amplification of the average transmit power is reduced and the range of the transmitter (in which the linear amplifier is used) diminished accordingly.

Although FIG. 4 is a block diagram of a multicarrier transceiver 60 constructed in accordance with a preferred embodiment of the present invention, it will be appreciated that the present invention is not limited to bi-directional communication devices, and that a multicarrier transmitter can be considered as a physically separate device from a multicarrier receiver (which may principally comprise a combination of the circuitry shown enclosed within the broken outline 62 and a mask vector; the function of which will be described subsequently).

The multicarrier transmitter comprises a data source 62 for generating a stream of data 63, a serial-to-parallel converter 64, a channel encoder 66, a combiner 68, a bank of k identical modulators 70 and a mask vector 72 (stored in a memory). In the preferred embodiment, the data source utilises a non-return to zero (NRZ) data format and therefore generates logical ±1s. The serial-to-parallel converter 64 is responsive to the data stream 63 and converts the data stream 63 into parallel data words 74, which in turn are input into the channel encoder 66 for block encoding. Codeword vectors 75 that are output from the channel encoder 66 are weighted by the mask vector 72 in the combiner 68, and then an output from the combiner 68 is applied to the bank of k identical modulators 70 to produce, ultimately, an output signal 76 having a composite envelope 78 suitable for transmission. Each modulator in the bank of k modulators 70 is assigned to a particular channel frequency, while a spacing between channels is orthogonal, i.e. there is no interference between channels (carriers). Operational control of the multicarrier transmitter (transceiver or receiver) is performed by a microprocessor (not shown), as will be readily understood.

Referring briefly to FIG. 5, a format for the codeword vectors 75 is shown. Each codeword vector 75 comprises k bits that are attributed as n information bits 80 and k-n parity check bits 82, with the length of the codeword vector 75 defining the number of channels (carriers) and hence the number of modulators used in the multicarrier transmission. The codeword vectors 75 and the mask vector 72 are of identical length, namely k bits. The k-n parity bits are provided by the channel encoding process.

The composite envelope 78 of the multicarrier signal can be expressed mathematically as:

$$u(t) = \sqrt{r(t)r^*(t)}$$

in which

$$r(t) = \sum_{i=0}^{N} s_i(t)e^{j(2\pi f_i(t) + \phi_i(t))}$$

and $r^*(t)$ is the complex conjugate; $s_i(t)$ is the parallel data of the ith carrier; f_i is the frequency of the ith carrier; and $\phi_i(t)$ is a phase function of the ith carrier.

As will be appreciated, linearity is essential in block coding schemes, such as those contemplated in the context of the present invention. Indeed, since the codeword vector 75 is linear, an all-zero logic sequence (in this case a succession of logical "-1s" in the codeword vector 75) produces the largest possible PEP for an OFDM system. In order to avoid this PEP (and the problems associated with its periodic appearance), the preferred embodiment of the present invention combines respective bits of the codeword vector 75 (through a multiplication function in the case of NRZ, or a modulo 2 addition for data schemes employing logical "0s") with corresponding bits in the mask vector 72 prior to modulation, and therefore provides pre-processing of the data to produce a reduced PMEPR in the output signal 76 .

More particularly, it has been recognised that since the number of information bits 80 in the codeword vector 75 is fixed (by the robustness offered by the parity bits of the code selected for the system, e.g. a Golay code compared against a Hamming code), the number of possible codeword vectors 75 is finite, namely $2^{(k-n)}$. However, the number of combinations for the mask vectors is 2^k, which number of combinations is usually very much greater. The mask vector 72 is therefore selected so as not to coincide with any of the possible codeword vectors 75, and its addition does not resemble the all-zero case in the modulation domain. Indeed, the present invention makes use of the code redundancy provided by the inclusion of parity check bits in the coding scheme, i.e. the additional words that are generated by the inclusion of at least one parity check bit and which do not form a valid codeword vector are used for the mask vector.

Although many techniques exist to determine the similarities between two vectors (e.g. correlation), the concept of minimising Euclidean distance d_{ij} between two vectors is used by the preferred embodiment of the present invention to assess selection of the mask vector 72. As will be appreciated, Euclidean distance is defined by:

$$d_{ij} = || p_i - c_j ||$$

where: d_{ij} is a scalar value; and c_j is a codeword vector 75. Therefore, given a codeword vector c_j, its nearest neighbour is the p_i vector for which the Euclidean distance is minimum. Indeed, the structure of the mask vector 72 is determined by an amount of similarity between individual phase offset vectors.

FIG. 6 illustrates a process (in accordance with a preferred embodiment of the present invention) by which the mask vector 72 (a solitary data word of length k bits) is determined for use in the multicarrier transceiver of FIG. 4. Specifically, all possible 2^k codewords p_i are generated and respective bits of these codewords p_i are modulated by an appropriate modulator from the bank of k modulators 70 to obtain PEP values for each of the possible 2^k p_i codewords. Block codewords 90 corresponding to all possible codes of the codeword vectors 75 are disregarded, and the remaining $(2^k - 2^{(k-n)})$ p_i codewords 92 tabulated to produce an associative map that is ranked in order of PEP magnitude 94. From this ranked order of the remaining p_i codewords 92 (where p_i denotes a k-by-1 vector in k-dimensional Euclidean space), a subset 96 of the k-n lowest p_i codewords is initially selected. This subset 96 of the k-n lowest p_i codewords represents an initial subset of training vectors that potentially possess the exact same Hamming distance properties (but with a reduced PMEPR for the composite envelope 78) as the k-n codeword vectors 75 generated by the channel encoder 66.

In order to assess the similarity between the set of block codewords 90 and subset 96 of k-n lowest p_i codewords, each block codeword (vector) is modified by a test mask vector that satisfies the equation:

$$w = p_i * c_j$$

where i and j are indices; and w is a test mask vector. More particularly, if we consider (for exemplary purposes) a set of block codewords 90 consisting of four alternative codes, then the initial subset of training vectors 96 is arranged to contain four training vectors (having the four lowest PEP values). A first member 97 of the set of block codewords is mathematically combined (multiplied, in the preferred embodiment) with a first member 98 of the subset of training vectors to generate a first test mask vector. The first test mask vector is then systematically applied to each of the four block codewords (vector) in an attempt to obtain zero values for Euclidean distance between all block codewords and all members of the initial subset 96 of training vectors, according to the equation:

$$d_{ij} = || \ p_i - wcj \ ||$$

However, in the event that any non-zero Euclidean distance is recorded, the first test mask vector must be rejected, and a second test mask vector calculated from, perhaps, the same block codeword used to calculate the first test mask vector in combination with a different training vector from the subset 96 having the next lowest PEP value. The second test mask vector is then systematically applied to each of the four block codewords (vector) in an attempt to obtain a zero value for Euclidean distance between all block codewords and all members of the initial subset of training vectors 96. Again, if a non-zero Euclidean distance is recorded, the second test mask vector is rejected and another (new) test mask vector generated. Clearly, with four block codes and the initial subset of training vectors 96, sixteen possible test mask vectors may be systematically generated and applied in the hope of finding zero Euclidean distance (and hence a direct mapping) between all the block codes and all the training vectors. However, it may be that none of the sixteen possible test mask vectors produce a direct mapping and so it is necessary to increase the number of training vectors and therefore to generate a larger subset 100 containing (k-n+1) training vectors. It is preferable that the larger subset is simply increased by the addition of the training vector having the next lowest PEP in the rank order. The search for the test mask vector that provides an all zero Euclidean distance result is then resumed with this enlarged subset 100. If necessary, the number of training vectors is again increased such that the size of the subset of training vectors approaches the size of universal set 102 of $(2^k - 2^{(k-n)})$ possible training vectors. The mappings shown in FIG. 6 illustrate how the test mask vectors are derived and how they are applied to determine the mask vector 72.

The optimum mask vector, w*, which corresponds to the minimum PMEPR, is not necessarily given by the m^{th} training vector which has the minimum PEP in an initially selected subset, but rather by a training vector that belongs to the universal set. If the initial training subset, or the increments in the size of the training subset are large, it is possible that a local minimum may be selected for w; resulting in sub-optimum PMEPR performance. However, if the size of the initial training subset is $2^{(k-n)}$ vectors, and the increments in the size of the training set are relatively small with increasing minimum PEP, a single minimum will be ensured (where w=w*). Consequently, the selection process for the mask vector satisfies the following rule:

IF [the Euclidean distance is zero for all codewords] THEN
[accept w as the optimum weight vector]
ELSE [increase the size of the training set]
END

It will now be appreciated that the test vector is therefore constant for any group of calculations and is not modified until a non-zero Euclidean distance is noted. This is necessary for two reasons: firstly, the distance properties of the block code must be maintained for all the possible block codewords 90; and secondly, only one classification (mapping) of the c_j

codeword vectors to the p_i training vectors is required. Therefore, the test vector that linearly maps the set of codeword vectors to the set of minimum PEP training vectors having identical distance properties represents a desired transposition and is therefore nominated as the mask vector 72 for the system. Indeed, use of the mask vector ensures that the worst-case all-zero codeword is never transmitted because of a pointwise multiplication. Moreover, in the preferred embodiment, the value of the mask vector 72 is determined when the minimum distance for classification is zero.

FIG. 7. is a graphical representation contrasting a time domain representation of a waveform utilised by the multicarrier transceiver of FIG. 4 with the time domain signal of the multicarrier system of FIG. 2. In contrast with the prior art time domain envelope 30, application of the mask vector 72 to each codeword vector 75 for each channel has the effect of reducing the PMEPR and increasing the average power transmitted in the envelope 110. The new composite envelope 78 has reduced PEP spikes that are separated by a region having a new signal profile 110 that perturbates less vigorously than that of the prior art composite envelope 30.

Use of the coding scheme of the present invention advantageously permits the use of linear amplifiers in a more efficient manner, since the PEP value of the composite signal envelope is reduced and the peak-to-peak variation in power of the composite envelope is corresponding reduced. These reductions in the power profile of the envelope provide the ability to operate the amplifier at a quiescent point towards its non-linear range, and do not require clipping of the amplifier. Furthermore, there is an increase in a transmitting range for a transmitter utilising the present invention, since the average power in the composite envelope is increased. Also, use of the coding scheme of the present invention does not degrade spectral efficiency because the mask vector is derived from coding redundancy and is part of the modulation. Therefore, no additional information bearing sub-carrier channels are required.

In addition, the segmentation of broadband data and its transmission over multiple, narrow-band carriers (channels) eliminates the need for high speed equalisers in communication systems.

Referring again to FIG. 4, there is shown a multicarrier receiver 62 according to the preferred embodiment of the present invention. The multicarrier receiver is arranged to receive a multicarrier signal 76 having a composite envelope 78. The received signal 76 is applied to a bank of k identical demodulators 112, with each demodulator in the bank of k demodulators 112 assigned to a particular channel frequency. The mask vector 72 (used for transmission) is applied, in combiner 116, to signals 114 emanating from the bank of k demodulators 112 in order to decode the signals 114 into a signal format 118 suitable for channel decoding in channel decoder 120. Channel decoded signals 122 from the channel decoder 120 are ultimately provided to a data sink 124, such as a visual display or audio circuitry, in a parallel or serial format. In the latter instance, a parallel-to-serial converter 126 is positioned between the channel decoder 120 and the data sink 124. Operational control of the multicarrier receiver 62 is performed by a microprocessor (not shown), as will be readily understood.

In an alternative embodiment of the receiver 62 of the present invention, the combiner 116 may be omitted provided that there is synchronisation via a packet header (which is analogous to a midamble synchronisation sequence transmitted in a time-slot of GSM, for example), The presence of this synchronisation can be used to remove channel phase offset (or rotation) introduced to the information signal 78 by the mask vector 72, as will be understood. More explicitly, a synchronisation sequence that is therefore necessarily utilised in the demodulator 112 is predetermined such that the mask vector 72 appears as part of the time dispersive channel (shown in FIG. 1), with the result that the synchronisation and the effect of the mask vector are removed during demodulation. Consequently, no additional processing is required in the receiver, and migration to the coding scheme offered by the present invention would not involve re-design of current receivers.

It will, of course, be understood that the above description has been given by way of example only and that modifications in detail may be made within the scope of the invention. For example, although the above description discusses the invention in the general context of a radio transmission, it will be appreciated that the multicarrier system may utilise fibre-optic technology as a communication resource for the multiple information carriers. Additionally, although the training vectors of the preferred embodiment are arranged in rank order by PEP magnitude 94, it is considered that the function of modulation provided to the channel coding by this ranking is supplemental to the advantages and benefits derived by the coding of individual channels of the multicarrier system with a mask vector derived from the inherent coding redundancy. As such, it is possible that the mask vector may not be optimised to produce a composite envelope with the lowest possible PMEPR, although the composite envelope will have an improved PMEPR.

Claims

1. A communication device for simultaneously transmitting independent information on multiple channels, the communication device comprising:

first encoding means for encoding the information for each of the multiple channels with a coding scheme to produce channel encoded information;

second encoding means for encoding the channel encoded information for each of the multiple channels with a mask vector derived from a code redundancy in the coding scheme, whereby the mask vector transposes the channel encoded information into codewords having euclidean distance properties corresponding to those of the channel encoded information; and

modulation means for modulating each codeword for each channel to produce a composite signal envelope having a peak-to-mean envelope power ratio (PMEPR) reduced relative to a PMEPR for correspondingly modulated channel encoded information.

2. The communication device of claim 1, wherein the mask is a function of the channel encoded information and a training vector which is obtained from an associative map having a ranking in ascending order of peak envelope power.

3. The communication device of claim 1 or 2, wherein the mask vector transposes the channel encoded information such that a minimum Euclidean distance between channel encoded information for each channel and its respective codeword is obtained.

4. The communication device of claim 3, wherein the Euclidean distance is zero.

5. The communication device of any preceding claim, wherein the communication device is a radio communication device.

6. A method of simultaneously transmitting independent information on multiple channels comprising the steps of:

for encoding the information for each of the multiple channels with a coding scheme to produce channel encoded information;

encoding the channel encoded information for each of the multiple channels with a mask vector derived from a code redundancy in the coding scheme, whereby the mask vector transposes the channel encoded information into codewords having Euclidean distance properties identical to those of the channel encoded information; and

modulating each codeword for each channel to produce a composite signal envelope having a peak-to-mean envelope power ratio (PMEPR) reduced relative to a PMEPR for correspondingly modulated channel encoded information.

7. The method of claim 1, wherein the mask is a function of the channel encoded information and a training vector which is obtained from an associative map having a ranking in ascending order of peak envelope power.

8. A communication device for simultaneously transmitting independent information on multiple channels substantially as hereinbefore described with reference to FIGs. 4, 5 and 6 of the accompanying drawings.

9. A method of simultaneously transmitting independent information on multiple channels substantially as hereinbefore described with reference to FIGs. 4, 5 and 6 of the accompanying drawings.

10. A method of calculating a mask vector for use in the communication device of any one of claims 1 to 5, the method substantially as hereinbefore described with reference to FIGs. 4, 5 and 6 of the accompanying drawings.

The Patent Office

15

Application No: GB 9600930.3
Claims searched: 1-10

Examiner: Keith Williams
Date of search: 1 April 1996

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): H4M (MFX); H4P (PAL, PAQ, PDT, PDX, PEP, PRR, PRV)

Int Cl (Ed.6): H04H 1/00; H04J 11/00; H04L 5/06, 12/28, 23/02

Other: online WPI, INSPEC

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
A	GB 2280571 A B B C - see abstract	1,6
A	GB 2270819 A B B C - see abstract (equivalent to WO 94/06231)	1,6

X Document indicating lack of novelty or inventive step
Y Document indicating lack of inventive step if combined with one or more other documents of same category.
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E Patent document published on or after, but with priority date earlier than, the filing date of this application.